Coronagraph Contrast and Efficiency i	Tier       Description         y in the       1       The capability to suppress starlight and receive planet light with a coronagraph to the level needed to detect and spectrally characterize Earth-like exoplanets the habitable zones of Sun-like stars across the wavelength range 1-2 microns.	Current State-of-the-Art           in         JWST NIRSPEc typical performance 1.0×10-4 raw contrast (no wavefront control), after post processing 10-5 at ~2 lambda/D, 3×10-8 > 30 lambda/D           JWST MIRI 1.0×10-4 raw contrast working angle 2 MD (4-5 micron wavelength)           Ground based 1.0×10-5 raw contrast at 8 MD working angle (Gemini Planet Imager wavefront control for atmosphere correction)	TRL       Performance Goals and Objectives         3       R~40 spectroscopy in the infrared between 1 and 1.8 micron wavelengths [TBD] for a direct imaging telescope mission. ~1×10-9 flux ratio at the detector; >30% core throughput, inner working angle ≤ 2 lambda/D at 1.6 micron; 20% bandwidth; obscured/segmented pupil	Scientific, Engineering, and/or Programmatic Benefits This gap is likely to be closed by improvements in coronagraph masks and optics, wavefront sensing and control (deformable mirrors), data post-processing, and integrated models.	<b>Applications and Potential Relevant Astrophysics Missions</b> HWO, or any other coronagraph-based exoplanet direct-imaging mission.	<b>Urgency</b> Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the mid-to-late 2020's.
E Near Ultraviolet Coronagraph Stability	y in the       1       The capability to suppress starlight and receive planet light with a coronagraph to the level needed to detect and spectrally characterize Earth-like exoplanets the habitable zones of Sun-like stars across the wavelength range 200-400 nm.         1       The capability to maintain the deep starlight suppression provided by a coronagraph for a time period long enough to detect light from an exo-Earth.	in None RST CGI demonstrated ~10 <sup>8</sup> contrast in a simulated dynamic environment using LOWFS (which obtained 12 pm focus sensitivity) SIM and non-NASA work has demonstrated nm accuracy and stability with laser metrology Capacitive gap sensors demonstrated at 10 pm 80 dB vibration isolation demonstrated Gaia cold gas microthrusters and LISA pathfinder colloidal microthrusters can reduce vibrations	<ul> <li>2 R~7 spectrophotometry in the near ultraviolet between 200 and 450 micron wavelengths for a direct imaging telescope/mission. ≤ 1×10-10 raw contrast, &gt;20% core throughput, inner working angle ≤ 10 M at 200 nm, 20% bandwidth; obscured/segmented pupil.</li> <li>3 Contrast stability on time scales needed for spectral measurements (possibly as long as days). Achieving this stability requires an integrated approach to the coronagraph and telescope, possibly including wavefront sense/control, metrology and correction of mirror segment phasing, vibration isolation/reduction This stability is likely to require wavefront error stability at the level of 10-100 pm per control step (of order 10 minutes).</li> <li>Sub-gaps that could partially or fully close this gap:         <ul> <li>Tuned Mass Damping</li> <li>Edge Sensor</li> </ul> </li> </ul>	D This gap is likely to be closed by improvements in coronagraph masks and optics, wavefront sensing and control (deformable mirrors), data post-processing, and integrated models. This gap is likely to be closed by a combination of many factors in a coronagraph/observatory system, including active wavefront control at the coronagraph level, thermal control, active and passive ultra-stable structures, and disturbance isolation/ reduction. Integrated modeling for tracability to flight environments is likely to be a key capability to close this gap	HWO, or any other coronagraph-based exoplanet direct-imaging mission. HWO; or any other coronagraph-based exoplanet direct-imaging mission.	Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the mid-to-late 2020's. Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the mid-to-late 2020's.
Cryogenic Readouts for Large-format I IR Detectors C	at Far-       1       Readout schemes including cryogenic multiplexing for arrays of large-format Far-IR detectors need to be developed.	Readout schemes using HEMT or SiGe amplifiers and frequency-multiplexed resonant circuits are in development. A few hundred channels per 1 mW HEMT amplifier have been demonstrated. Low power dissipation at 4 K is required. For TES-based detectors a microwave SQUID multiplexer using frequency division, time division or code division multiplexing is needed. Frequency division multiplexing is well advanced and can meet the needs of a far-IR flagship when scaled to 2000 pixels (resonators) per 4 GHz channel.	<ul> <li>PM-SM-Instrument Bench Metrology</li> <li>Wavefront Sensing for segment phasing &amp; alignment</li> <li>Out-of-Field WFS</li> <li>Low Disturbance Systems: Active &amp; Passive Isolation, Microthrusters, low-disturbance cryo-cooler</li> <li>Control Algorithms</li> <li>Near-term, this scheme should result in 2000 pixels per amplifier channel (enabling), 3000 pixels/channel (enhancing).HEMT amplifiers from Low Noise Factory can achieve 10 dB with 0.38 mW of dissipation at 4 K.</li> </ul>	coverage by ×10-100. Overall mapping speed can increase by factors of thousands. Sensitivity enables measurement of low-surface-brightness debris disks and protogalaxies with an interferometer. This is	Far-IR Probe FIR detector technology is an enabling aspect of all future FIR mission concepts, and is essential for future progress.	Required TRL 6 by mission PDR. Extreme stretch Single tech
Fast, Low-noise, Megapixel X-ray Imag Arrays with Moderate Spectral Resolut P	lution equivalent X-ray position resolution), and moderate spectral resolution (comparable to modern scientific CCDs).	or The Lynx High-Definition Imager Technology Roadmap (https://www.lynxobservatory.com/blog/roadmaps) identifies three candidate technologies, all judged to be TRL 3 for Lynx. Despite technical progess since completion of that roadmap, no sensor technology has yet achieved TRL 4. Current CCDs provide excellent noise performance but frame rates need to be increased and application- and specific readout circuits must be demonstrated. Hybrid and monolithic CMOS silicon active pixel sensors (APS) currently provide high frame rates but hybrid sensors need lower noise and monolithic sensors need thicker depleition layers. Further work is needed on these technologies to meet all requirements simultaneously.	Probe and Great Observatory requirements are nearly identical. The only differences are that the Probe may require somewhat lower frame rates (20 vs 100 frames/s) for full field of view, while the Great Observatory requires higher frames rates in a subfield on axis (10,000 vs 100 fr/s in a sub-field on axis,). Common requirements include: • Large format X-ray detectors with sufficient spatial resolution so as not to compromise the imaging performance of the optics (notionally with 0.5" half power diameter, HPD, requiring ≤ 16 µm pixels for both AXIS-like and Lynx-like missions); • Multi-chip abuttability to build detector surface approximating best focal surface for the mirrors; • Roughly Fano-limited spectral resolution in the 0.2-12 keV energy band, e.g. 70 eV FWHM at 0.3 keV for Lynx-like mission;	high spectral resolution) to be launched in this decade. Raises technical readiness, increases scientific capability, and	This technology can improve science capability at a fixed cost much more rapidly than larger telescope sizes. This development serves Astrophysics almost exclusively (with some impact on planetary and Earth studies). Many synergies exist with similar developments for x-ray microcalorimeters X-Ray Probe X-Ray Flagship In addition to Probe- and Great Observatory-class missions, wide-field time-domain X-ray monitoring missions as recommended by Astro 2020, (p 197) for Missions of Opportunity/SmallSat, Small or Medium Explorers or missions in a dedicated Time-Domain Astrophysics Program, e.g. Joint Astrophysics Nascent Universe Satellite (JANUS) / X-ray Time Domain Explorer (XTiDE) -like, or any other focused X-ray optics, or coded-aperture wide-field X-ray-monitoring, or X-ray-	
High-Bandwidth Cryogenic Readout Technologies for Compact and Large- Format Calorimeter Arrays	1 The signals from energy-resolving, superconducting calorimeters, such as transition-edge sensor (TES) based calorimeters or metallic magnetic calorimeters (MMCs), typically need to be multiplexed cryogenically to reduce thermal loads, wiring complexity, and power consumption. Array sizes of 1,000s–10,000s will lik be required for these calorimeters to be considered for future space astrophysics missions such as HWO and/or x-ray probe/flagship concepts. Cryogenic multiplexers are typically at the same temperature as the detectors, ~ 40-100 mK. Here, the relevant detector time constants range from milliseconds to as sho as a few tens of microseconds. The more compact the cryogenic components of the readout are, the easier they are to magnetically shield. This leads to small	Superconducting calorimeter arrays are typically read out using superconducting quantum interference devices (SQUIDs) and superconducting micro-resonators. Several multiplexed SQUID readout schemes have been developed. The most mature of these techniques is time-division multiplexing (TDM) (TRL-5), which is currently baselined for the X-IFU aboard the upcoming Athena space satellite. But more advanced versions of TDM with potential to enhance their usefulness in reading out larger arrays are under development, that incorporate flip-chip bump-bonded multiplexer chips ( lower TRL). Microwave multiplexing (µMUX) techniques have also been developed, originally for the read-out of microwave kinetic inductance detectors (MKIDs) using superconducting microresonators which have been used to achieve significantly higher multiplexing factors than their TDM counterparts. Similar micro-resonators that incorporate SQUIDs into the resonators have been developed for the read-out of	<ul> <li>Sensor-specific fast, low-noise, low-power readout circuitry;</li> <li>Optical-blocking filters with minimal X-ray absorption above 0.2 keV;</li> <li>Radiation hardness supporting 5-20 years of science operations in their respective orbits (e.g., low-inclincation LEO for Probe, L2 for Great Observatory).</li> </ul> There exists a myriad of potential array sizes and formats, and a similar myriad of different approaches to the multiplexed read-out designs. For example, the Line Emission Mapper (LEM) concept calls for a 13,806-pixel hybrid TES array consisting of single-pixel and 4-pixel hydra geometries, and requires around 4,000 readout elements. Future X-ray flagships of the type developed for the 2020 Decadal Report (Lynx) will likely require significantly more detectors and associated readout elements, with around 100,000 detectors requiring aound 8-thousand read-out elements for the Lynx concept. Even larger arrays may be feasible and enabling of new critical observators over the next decade, there are critical design requirements beyond pixel number and multiplexing factor such as signal slew rate and bandwidth that must also be taken into consideration for the various detector aplications. The readout technology should be sufficiently scalable to read out large-format calorimeter arrays Readout footprint: The size of	t calorimeter arrays for their science output. Although a detector technology has not been baselined for HWO, arrays of energy-resolving calorimeters could enhance/increase the science output due to having a combined imaging/spectroscop at camera. For both x-ray probes and the HWO, developing compact cryogenic readouts with high multiplexing factors provides additional engineering and programmatic benefits. High multiplexing factors and compact architectures would	grating mission (larger than an Explorer but less than than half the cost of a Probe). Any future mission with X-ray optics for imaging and/or gratings for high-resolution spectroscopy. A high-bandwidth, cryogenic readout system that is compact and scalable has applications for a number of potential future space astrophysics missions incorporating cryogenic calorimeters. The most immediate of these missions could be for the X-ray probe, where this technology could be used to read out a calorimeter array of ~ 14k pixels. But although currently considered a back-up, the use of microcalorimeters has high potential for use in the HWO flagship mission. Where this back-up option is realized likely depends on the outcome of studies of the potential impact of cryocoolers on	Although future launch dates are difficult to predict, following the last Decadal Survey there is a strong desire for technologies to reach TRL-6 pror to the their main implemtation phases in order to reduce cost-risk. Thus, the timescal an X-ray Probe to continue to develop is essentially the next 2 years. There is probably ~4-8 years for HWO detector s and read-out, and 8-12 years for the needs of an X-ray flagship mission, unless the order of flagship missions changes
Ρ	and lighter cryogenic detector assemblies, which are less complex to cool, and ultimately cheaper to accomodate.	TESs and MMCs. Even more recently, proof of concept measurements have been performed for readouts based on the nonlinear kinetic inductance effect, bypassing SQUIDs altogether (e.g. KPUP or KICS). Beyond TDM, these technologies have not yet demonstrated the ability to meet all the requirements and technical goals for the needs of future space telescopes.	cryogenic readout elements has historically been significantly larger than the active area of the calorimeters. This is incompatible with the next generation of space astrophysics missions, which typically require higher pixel densities. This would be most easily realized by having the size of the readout cell be comparable to or smaller than the size of the detector cell. An architecture that maximizes array density by combining detector and readout cells would also likely be preferred. Dynamic range: The dynamic range of the readout must be sufficiently high as to not limit the wavelength coverage of the detector system. https://doi.org/10.1109/TASC.2019.2904472 https://doi.org/10.1109/TASC.2023.3256343 https://doi.org/10.1007/s10909-024-03076-3		the stability of the telescope. But if established as feasible, a cryogenic detector is a highly desirable instrument, and attention will return to the TRL and capabilities of the detectors and multiplexed read-out. A future NASA X-ray flagship mission, just like Lynx, is highly likely in need of a more advanced larger, and more capable X-ray microcalorimeter array with over 100k pixels, and with pixel sizes that correspond to sub-arceond angular resolution.	
High-Efficiency X-ray Grating Arrays fo High-Resolution Spectroscopy		Proven technologies (grating spectrometers on Chandra and X-ray Multi-mirror Mission-Newton, XMM-Newton) fall short in efficiency, collecting area, and resolving power, by factors of 5-10. There are two technology candidates with potential to meet strategic spectrometer performance: Off-plane reflection gratings (OPG) and Critical-Angle Transmission (CAT) gratings. High-efficiency blazed (sawtooth groove profile) OPGs have been demonstrated that place > 50% of the incident soft X-ray light into the diffracted orders. Separately, individual laminar groove profile OPGs have demonstrated R > 2200-4500. Recently, a pair of aligned CAT gratings has achieved R ~ 12,000. Over 40% diffraction efficiency has been demonstrated with CAT gratings, but only over a narrow band. Both technologies have been vetted at TRL 4 in 2016, but TRL 4 has been questioned for Lynx performance. Currently no gratings exist that perform at a strategic level, simultaneously providing reasonably large form	https://arxiv.org/abs/2405.15017 https://doi.org/10.1117/12.2313730 https://doi.org/10.1117/1.JATIS.10.2.025008 Demonstrate CAT gratings and OPGs with high efficiency (>45%) and resolving power (> 7500) with size > 50 x 50 mm <sup>2</sup> . CAT grating open area (illuminated by x rays and not blocked by support structures) = 70%. This requires a scalable (many hundreds of gratings), large-area fabrication process for ~ 6 m deep, ~ 40 nm wide grating bars and narrow support structures. OPGs require fabrication processes for modestly blazed grooves (~30-50°) in radial groove patterns that can be replicated onto thin substrates. Alignment into large arrays needs to be demonstrated.	SMBH, and characterizing stellar lifecycles from birth to death. CAT gratings operate at near-normal incidence and are thin, light weight, and alignment insensitive. OPGs are highly efficient and can be mass produced through replication. Hig	X-ray Flagship X-ray Probe and a high spatial and spectral resolution X-ray strategic mission with some of the capabilities of the proposed Lynx. Broadband soft x-ray polarimetry such as REDSoX or GOSoX. Laboratory astrophysics (improved laboratory data on transition energies, electron impact ionization collision strengths, photoexcitation, and ionization).	Years to estimated launch or other schedule driver: <b>7-15</b> Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> Level of difficulty (straightforward, stretch, or major stretch): <b>straightforward/stretch</b>
Р		factor, and the required high diffraction efficiency over the whole grating area and high enough resolving power. References: "X-Ray Performance of Critical-angle Transmission Grating Prototypes for the Arcus Mission", Ralf K. Heilmann et al 2022 ApJ 934 171 "Manufacture and Performance of Blazed Soft X-ray Transmission Gratings for Arcus and Lynx," R. K. Heilmann et al. Proc. SPIE 11822, 1182215 (2021). — "Toward Volume Manufacturing of High- Performance Soft X-ray Critical-Angle Transmission Gratings," R. K. Heilmann et al; Proc. SPIE 11444, 114441H (2020). "Demonstration of Resolving Power <i>N</i> Δλ > 10,000 for a Space-Based X-ray Transmission Grating Spectrometer," R. K. Heilmann et al., Appl. Opt. 58, 1223 (2019). — "Large-format X-Ray Reflection Grating Operated in an Echelle-like Mounting," C. T. deRoo et al., Ap. J. 897, 92 (2020). — " Performance Testing of a Large-Format X-ray Reflection Grating Prototype for a Suborbital Rocket Payload," B. D. Donovan et al., J. Astron. Instrum. 9(3), 2050017 (2020). — Lynx Concept Study Report: https://wwwastro.msfc.nasa.gov/lynx/docs/LynxConceptStudy.pdf. — "Fabrication and Diffraction Efficiency of a Large-format, Replicated X-ray Reflection Grating," D. M. Miles et al., ApJ, 869, 95	3-4	efficiency reduces required mirror aperture and grating array size. Larger gratings lead to reduced fabrication, testing, an assembly cost. The technology is mission enabling for an x-ray probe complementary to ATHENA, and mission enhancing for a high spatial and spectral resolution X-ray strategic mission.		
High-Efficiency, Low-Scatter, High- and Ruling-Density, High- and Low-Blazed- UV Gratings (from HWO START/TAG)	<ul> <li>d-Angle</li> <li>HST-STIS) used multi-channel grating wheels to address the different observing requirements, including:</li> <li>1) High-resolution far-UV and near-UV echelles, with scatter levels and efficiency superior to the echelles used on HST-STIS</li> <li>2) Gratings with aberration-correcting groove shapes that may not be feasible using current recording assemblies. Adapting existing free-form ruling methods (mechanical or lithographic) could expand the parameter space for designing variable-spaced, curved-grooves gratings that provide uniform point spread</li> </ul>	<ul> <li>(2018) "Reflection grating concept for the Lynx X-ray Grating Spectrograph," R. L. McEntaffer, JATIS, 5(2), 021002 (2019).</li> <li>High Resolution (R &gt; 50,000): Mechanically ruled echelle gratings with flight heritage exist (e.g. HST-STIS E140H), but suffer from low efficiency (~20-30%) and prohibitive scatter (~20%). KOH-etched echelle gratings fabricated with electron-beam lithography (EBL) show significantly improved efficiency (&gt;60%) and scatter performance (~1%; Kruczek et al. 2022), but have not been tested comprehesively (resolution, ghosting, etc), nor yet reach the full theoretical performance.</li> <li>Medium/Low Resolution (1000 &lt; R &lt; 50,000): Holographically ruled aberration-correcting gratings have ~ 65% efficiency and excellent scatter properties (I/I_o &lt; 10^-5) and have been used on many flight programs, including HST-COS. The possible grating solutions are limited by the recording wavelengths and assemblies, placing constraints on instrument designs. Electron-beam lithography has been demonstrated to generate custom groove layouts and high ruling densities (~9000 l/mm), opening new parameter space for aberration correction (e.g. Grise et al. 2021). APRA/SAT efforts are on-going to produce blazed UV gratings on curved substrates.</li> </ul>	<ul> <li>3-5 The technical goal should include the development and in-vacuum demonstration of several classes of diffraction gratings:</li> <li>High Resolution: Echelle gratings capable of achieving R ≥ 50,000 with ≥ 80% peak-order groove efficiency and I/I0 &lt; 1e-3 at Δλ = 1 nm post-coating, with supporting simulations predicting the observed performance. This performance should extend through the far ultraviolet (FUV; 100 – 180 nm) bandpass.</li> <li>Medium/Low Resolution: Aberration correcting (curved grooves) solutions on curved substrates demonstrating groove efficiencies ≥ 60% post-coating and I/I0 &lt; 1e-5 at Δλ = 1 nm</li> </ul>	characterization and exoplanet studies. Observations of ionizing radiation escape, CGM emission, and the UV backgroun benefit from ultra-low resolution blazed gratings. These developments are required to realize the promise of MOS for answering the science questions outlined in Table I.1 of the Decadal 2020 report Pathways to Discovery.	Cross-cutting to all branches of NASA SMD and all mission classes, from sub-orbital and Cube/SmallSats to HWO.	Years to estimated launch or other schedule driver: Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6. Level of complexity: Single technology Level of difficulty: Echelles - straightforward, Ultra-low blaze angles - stretch
c	functions over the extended fields of view of a multi⊨object spectrograph. 3) Ultra-low blaze angles (< 2°), for high-efficiency, low-resolution spectroscopy of faint objects. 4) The application of reflective coatings can impact the groove depth and modify the facet shape (changing the apparent blaze angle), altering both the diffraction efficiency and the grating's impact on the instrument. It is necessary to understand and model the impact of coatings on grating performance to best optimize deposion methods. Baseline (Need TRL 5 by MCR, but could accept waiver on readiness depending on remaining work or possibility for servicing)	Ultra-low blaze angles (R < 1000): Shallow blaze angles can be used for low-resolution (R<300) gratings for high sensitivity measurements of the CGM or other diffuse sources. Ion etching is generally limited to 6-8 degree angles, while mechanically and KOH-etched gratings can achieve shallower blazes, but have not been demonstrated to meet performance objectives. APRA/SAT efforts are on- going to produce ultra-low (~ 1 degree) features. UV coatings on gratings: The HST-COS G225M and G285M grating efficiencies were significantly altered by the interactions between the groove profiles and the growth of oxide on the bare aluminum coating over time (Kuznetsov et al. 2004). Advanced UV mirror coatings use high temperatures (eLiF, ALD processes) or chemical interactions (XeLiF, ALD) for which the impact on the grating during to coating is not understood. Gratings have been coated for the SPRITE mission (eLiF) and INFUSE sounding rocket (XeLiF). Grating Characterization: The resolution and sensitivity requirements of HWO medium resolution channels will require precision groove placement and profiles for which sufficient metrology capabilities for tracking ghosting, scatter, and groove errors do not exist. Limited studies have been carried out on individual gratings (e.g. DeRoo et al., 2023). High Resolution: Conventional FUV echelle gratings (e.g. HST-STIS E140H) are not viable for HWO. KOH etched echeles are TRL 5 from a recent SAT	Ultra-low blaze angles: (≤ 2°) gratings demonstrating ≥ 60% groove efficiency and I/I0 < 1e-5 at Δλ = 5 nm post-coating UV Coatings on gratings: Demonstrated compatibility with state-of-the-art FUV coating techniques with < 1% loss in relative diffraction efficiency. Grating Characterization: Specialized vacuum characterization facilities for scatter, resolution, ghosting and efficiency measurements.	An improved understanding of the grating design and fabrication process and how it relates to the final measured efficiency will further provide programmatic benefits in the form of streamlined testing and calibration schedules. This includes the ability to develop targeted grating solutions without the need to test multiple potential samples.		
High-Performance, Sub-Kelvin Coolers	<ul> <li>Prs</li> <li>Optics and detectors for FIR, sub-millimeter, and certain X-ray missions require very low temperatures of operation, typically in the tens of mill-Kelvins. Compact, low-power, lightweight coolers suitable for space-flight are needed to provide this cooling.</li> </ul>	Medium/Low Resolution: Holographic gratings are TRL 6+. EBL etched gratings are TRL 3+ Ultra-low Blaze Angles: TRL 3+ UV Coatings on gratings: TRL 6+, however interactions are not fully understood which may impact final efficiency Existing adiabatic demagnetization refrigerators with low cooling power (0.4 µW) at 50 mK are at TRL 7-9 (Hitomi/SXS) (Shirron, 2015)but high-cooling-power versions (6 µW) are at TRL 4. (Shirron, 2000) rel Low cooling power (<1µW) dilution refrigerators (Colaudin, 1999) and ultra low (<0.1 µW) solid-state cooling approach based on quantum tunneling through normal-insulator-superconductor (NIS) junctions are both at TRL 3. Currently funded technology development is expected to result in a TRL 5 or 6 ADR for use over the temperature range of 10 to 0.050K with high efficiency and cooling power of 6 micro-W at 0.05 K.	A sub-Kelvin cooler operating from a base temperature of ~4 K and cooling to 50 mK with a continuous heat lift of 6 μW at 50 mK is required. To enhance detector sensitivity, cooling to 35 mK with 6 μW of cooling power is enhancing. Features such as compactness, low input power, low vibration, intermediate cooling, and other impact-reducing design aspects are desired.	resolution sensitive X-ray microcalorimetry.	Far-IR Flagship Far-IR Probe This technology is a key enabling technology for any future FIR mission, including OST. Sensors operating near 100 mK are envisioned for future missions for X-ray astrophysics, measurements of the CMB, and FIR imaging and spectroscopy.	Need to demonstrate TRL 6 by mission PDR.
High-Reflectivity Broadband FUV-to-NII Mirror Coatings (from HWO START/TAC	NIR 1 Transformational astrophysics and exoplanet science require high-throughput observations between 100 nm and 2.5 mm. Coatings should achieve the reflectance objectives at all wavelengths for HWO, while niche coatings or variations on formula may have advantages for specific channels of the instruments. Coatings must be environmentally resilient, scalable to meter-class segments, and repeatable to ensure uniform performance across an aperture comprised of several segments.	Currently funded technology development is expected to result in a TRL 5 or 6 ADR for use over the temperature range of 10 to 0.050K with high efficiency and cooling power of 6 micro-W at 0.05 K. (Tuttle, 2017) Further development, extending the low temperature to 35 mK while maintaining the 6µW cooling capability would be enhancing. Dielectric coatings (LiF, AIF3, MgF2, etc) vary in FUV reflectance based on the dielectric thickness. Thinner coatings favor shorter wavelengths, while thicker coatings favor longer FUV wavelengths. There is no difference for NUV/visible wavelengths. Most heritage missions, as well as FUSE, have favored sensitivity at O VI 103.2, 103.8 nm, and therefore thinner coatings that have low reflectance between 140 - 160 nm. Coatings for HWO will likely be tuned to optimize broadband performance. <b>Reflectance at 102 nm</b> : > 50% on eLiF/protected eLiF, and LiF+AI for a thin LiF layer (FUSE). Enhancement of 102 nm reflectance to > 70% may supress longer wavelength FUV reflectance around 140 - 180 nm. Alternative coatings < 40% <b>Reflectance at 103 nm</b> : > 80% on eLiF/protected eLiF, > 75% on protected eLiF, and > 70% on AI+LiF plus XeF2 fluorination (XeLiF), and other LiF-based advanced coatings. Alternative coatings <	3 For a single mirror coating (one thickness): Reflectance at 102 nm: > 60% Reflectance at 103 nm: > 75% Average reflectance for 105 nm - 250 nm: > 80% Average reflectance for 250 nm - 2.5 microns: > 90%	The HWO UV instrument imposes the requirement that the HWO telescope optics be coated in a UV-reflective mirror coating. A stable broadband coating enables access to more spectral and imaging diagnostics than prior generations of instruments. Improved coating reflectivity has cross-cutting benefits for any missions with broadband UVOIR science. Stable coatings that maintain performance in ambient environments can have programmatic benefits by simplifying I&T an	FIR imaging and spectroscopy. Applicable to missions of all classes (balloons, Explorers, Probes, and flagship observatories). High synergy with X-ray missions using microcalorimeters. Cross-cutting to all branches of NASA SMD and all mission classes, from sub-orbital and Cube/SmallSats (platforms that have driven the maturation of advanced coatings) to HWO.	Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6. Level of Complexity: Single Technology (multiple types) Level of Difficulty: Stretch for all requirements and scalability by 2028
c	for technology gaps related to the compatability of FUV-reflective mirror coatings with the broadband HWO observatory.	50% Reflectance at 105 nm: > 80% on eLiF, protected eLiF, XeLiF, ALD-deposited LiF+AI, and other LiF-based advanced coatings. Conventional LiF+AI ~ 73%. Atternative coatings < 50% Reflectance at 110 nm: > 80% on all advanced LiF varieties and advanced AIF3+AI. Reflectance for 115 - 200 nm: > 85% for XeLiF. eLiF at such thickness varies between 68 - 85% in this band, however for thicker coatings is > 80% for only slight losses at 103 nm. Conventional MgF2+AI (as was used on HST) > 85% in this band. Reflectance at > 200 nm: > 85% (aluminum has ~70% reflectance between 700-850 nm) Resiliance: LiF is hygroscopic and a single mirror can degrade by ~ 8-12% reflectance after ~ 1 month in ambient clean room-like conditions (RH ~ 50%). Protection via a thin layer of MgF2 deposited via ALD reduces this degredation to <1%. Some deposition methods appear to reduce this sensitivity without capping (XeLiF), with further testing on-going.	Resiliance (Humidity): Less than 1% degredation of reflectance at 103 nm with 1 month exposure to RH 50%. Resiliance (In space): Less than 1% degredation of reflectance at 103 nm per year under L2 environment conditions (radiation, etc.) Scalability: Deposition process viable for optics > 1m diameter Care and Handling: Procedure for optic cleaning in the event of contamination during I&T/handling	handling procedures.		
High-Resolution, Lightweight X-ray Opt	Inplics 1 Needed is a technology capable of manufacturing an X-ray mirror assembly meeting two requirements simultaneously: (1) angular resolution better than 1 arcs half-power diameter (HPD) for X rays in the 10-200 keV band and better than 0.5 arcsec for 0.1-10 keV X rays; and (2) mass per unit mirror surface area less		The technical objectives are to meet the following performance requirements: 1. Better than 1" HPD angular resolution for 10-200 keV and better than 0.5" HPD for 0.1-10 keV, as measured with full X-ray illumination	This technology will enable next generation X-ray astronomical missions in the 2020s, 2030s, 2040s, and 2050s. In particular it will enale missions like an X-ray flagship and X-ray Probes which will scientifically and observationally complement	X-Ray Probe t X-Ray Flagship	Years to estimated launch or other schedule driver: <b>&lt; 8 years</b> to support a Probe mission as receommended by Astro- 2020. This means that the technology development must be ramped up as soon as possible to enable NASA to start
P High-Throughput, Large-Format Object	<ul> <li>Chandra so that future missions like an X-ray Flagship, which requires up to 20 times more mirror surface area, will also be financially feasible. The development path should include empirical demonstrations, building progressively more substantial sub-assemblies to show the feasibility of a complete process for building a mirror assembly required by missions like an X-ray Flagship or Probe.</li> <li>Based on early UV science concepts, the HWO UV instrument requires spatially multiplexed spectroscopy to select multiple targets over an extended field-of-vie</li> </ul>	<ul> <li>- Mirror mass 951 kg.</li> <li>The Lynx Technology Roadmaps (https://www.lynxobservatory.com/blog/roadmaps) identifies three candidate mirror technologies. As of December 2021, of the three candidate technologies, the silicon meta-shell technology has shown that it is possible to achieve sub-arcsecond image quality with lightweight mirrors (areal density less than 2 kg/m2). (W.W. Zhang, PCOS Annual Technology Report, 2020). The associated mirror alignment and bonding techniques need further development to meet both precision and structural strength requirements. The low TRL is mainly due to a lack of empirical demonstration of "substantial" sub-assemblies. The advancement of TRL is characterized by two parameters: angular resolution or PSF, and the "size" of the sub-assembly relative to the final assembly.</li> <li>W. Objective prisms/grisms are effective at acquiring spectra of multiple objects in an extended field, however there are no known transmissive optics that are effective to 100 nm. Close objects can also</li> </ul>	<ul> <li>2. Less than 3 kg/m<sup>2</sup> mass per unit mirror surface area (though up to 10 kg/m<sup>2</sup> may be acceptable for some applications)</li> <li>3. Scalable up to at least 2 m<sup>2</sup> effective area</li> <li>3. An anticipated HWO UV MOS design covers 2'x<sup>2</sup> with a resolution of 50 mas, with any given spectral element no more than 5x the size of the telescope PSF (~ 250 mas) to maintain spectral resolution for</li> </ul>	JWST, Roman, ATHENA, and many other missions. It will retire the most important technical and programmatic risks of those missions, insuring credible and reliable cost estimates for implementing those missons. HWO includes an UV multi-object spectrograph in the current concept study.	A scalable X-ray mirror technology would be applicable to missions of all sizes, from flagship missions like Lynx, to Probe missions like AXIS, LEM, and HEX-P, to Explorer missions like STAR-X and Arcus, and to sounding rocket experiements like OGRE.	Level of complexity (single tech, system of techs, or system of tech systems): single technologies that can be develope individually and in parallel; then they must be implemented together to make the mirror assembly to form a <b>system of</b> <b>technologies</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>Straightforward to stretch</b> . Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6. MOS enebling technolog
Selection Technologies for Multi-Objec Integral Field Spectroscopy (from HWC START/TAG)	ect and This capability should extend to a variety of bandpasses from the far-UV to near-UV/optical, allowing spectral and spatial resolution of continuum emitting obje without overlapping spectral confusion produced by objective prism/grism surveys.	<ul> <li>overlap, creating spectral confusion, especially for medium resolution, large bandpass systems.</li> <li>Programmable MOS technologies that overcome spatial/spectral confusion:</li> <li>Large format programmable slit aperture arrays (0.1 mm x 0.2 mm pitch) exist in the form of 1st generation microshutter arrays (MSAs) currently operational on JWST/NIRSpec.</li> <li>A 2nd generation MSA with improved performance in proto-type format (128 x 64 shutters) has flown successfully on a the FORTIS sounding rocket 36.312.</li> <li>Large format (736 x 384) and 3rd generation (electrostatic actuation) proto-type format MSA-3G are under development.</li> <li>Digital Micromirror Devices (DMDs) are commercially available reflective slit arrays that have a typical pitches of (13.7 µm)<sup>4</sup>2 and come in a standard package with a 1024 x 768 format. These devices have been deployed in optical spectrographs on the ground with near-UV spaceflight instrumentation in development (SUMO - APRA). Use in the far-UV requires repackaging and/or customized solutions. Demostration of re-coating has been carried out in the FUV to 100 nm, however other properties (contrast, scatter) have not yet been measured in this band.</li> </ul>	extended sources. An IFS would be a smaller FOV and unlikely to meet both the field-of-view and resolution requirements, but could be a strong science enhancement as an additional channel. Form Factor: Miminim 80 mm length/width for a MOS (Assumes element size of 0.1 mm to capture > 98% of the light from a 20 micron rms PSF @ 50 mas resolution, 2' FOV) Fill Factor (Open area ratio within FOV): > 50% Yield: >90% functionality, two-side buttable if Form Factor cannot be met by a single device Targeting: Re-programmable. Actuation timescales < 3 seconds for tracking moving objects. Does not apply to an IFS. Contrast: Sufficient to reduce light leak to at least a factor of 2x less than typical detector backgrounds. For interplanetary Lyman alpha at 1500 R, an element FOV of 150 mas^2, and an effective area of 10,000 cm <sup>2</sup> , the required contrast to reduce stay light to half an MCP background level at L2 of 4e-8/micron is > 20,000. Does not apply to an IFS. Source Multiplexing: Spectroscopic measurement of > 200 objects simultaneously in any grating mode/resolution	High-performance multi-object spectroscopy increases the multiplexing advantage of missions by orders of magnitude. MOS and IFS applications eliminate spectral confusion, enabling efficient spectroscopic mapping of extended sources in the far-UV. An IFS enables efficient mapping of galaxies and nebular regions that is prohibitive for a long-slit or MOS on a competitively-allocated resource. These technologies are required to realize the promise of multiplex spectroscopy for answering the science questions	have driven the maturation of MSAs, DMDs, and IFSs) to HWO.	should demonstrate scalability, contrast, and lifetime. IFS technologies should demonstrate a design and assessment feasability. Level of Complexity: Single Tech Level of Difficulty: Straightforward with development
Integrated Modeling for HWO: Multi-Phy Systems Modeling, Uncertainty	NASA SMD Large Mission Study (LMS) identified Integrated Modeling (IM) as one of 10 critical capabilities for future flagship missions to manage performance		SOTA o Improve the modeling efficiency to reduce the modeling cycle time from the current norm of ~6 months, including parallel multi-processor options, and interoperability for end-to-end sensitivities, control and		Test-as-you-fly is already not possible with JWST and RST, these missions must rely on very detailed and accurate models for predicting performance requirements. All large future astrophysics mission will require some level of IM to design, test	Level of complexity (single tech, system of techs, or system of tech systems): System of Tech Systems
Quantification and Model Validation	margin and verify system performance, since these missions will be too large and complex to be tested end-to-end prior to launch. LMS specifically recommend "new or existing SMD strategic technology program lines fund the development of turnkey, anchored integrated modeling systems and other engineering took reduce analysis timelines, and as early as possible in the life cycle, to ensure the integrity of performance budgets." IM refers to the pipeline of engineering discipline models from observing scenario, thermal, structures, optics, pointing, jitter, wavefront sensing and control, diffraction propagation for starlight suppression, postprocessing to predict the end-to-end static and stability performance of the observatory through the instruments. IM also derives sensitivities to evaluate error budgets and key performance contributors for design consideration, quantifies the uncertainties of th predictions to estimate system margin, and informs the criteria for model validation of flight models and technology testbeds. IM development extends beyond traditional Technology Maturation as it will provide the foundational infrastructure required to support the overall technology and mission development efforts, analogous to facilities for hardware demonstrations.	s to For model validation & fidelity of uncontrolled WFE predictions: TRL 9 for microns WFE TRL 9 for 15nm WFE (JWST) TRL 5-7 expected for 1-5 nm ground , 1nm flight (once Roman completes I&T and flight commissioning) e TRL 5-7 transient time constants (JWST, to be improved by Roman)	design optimization. o Investigate parallel processing capabilities of large model size (>> 10M dofs) and reduced model methodologies o Investigate surrogate modeling techniques to gauge improvements in modeling turnaround time and impact to prediction accuracy. o Identificaty and eliminate of tools that severely limit parallel predicitive multi-physics model execution due to license constraints or other costs, and replace with less restrictive tools. o Identify and adopt shared, platform-independent deployment environment of multi-physics IM codes, that are extensible over the 20-30 year span of the flagship missions. o Investigate how AI/ML can improve the IM and Systems Engineering process. Develop and demonstrate Uncertainty Quantification methods to bound known and unknown probabilistic error forms o Develop an alternative to Monte Carlo techniques to derive MUFs (Model Uncertainty Factors).	oDecrease overall system development time, and hence cost, for program phases/activities. oAllow for more analysis to be performed, affording greater insight into the behavior of complex systems oAllow cross-discipline optimization to target the key performance drivers early in the design and test process oAssure the integrity of the performance budget with validation of testbed sensitivities and systematic quantification of uncertainty for a standardized and credible margin philosophy and improved decision support. oDecrease reliance on over-conservative assumptions and analyzing to unlikely, worst-case scenarios that may drive to unnecessarily conservative design solutions. •Through a robust error budgeting formulation process and comprehensive model validation strategy, improve technology gap assessments, testing goals, testbed infrastructure requirements, and guide tests to mitigate testbed performance	and verify system performance for requirement verification. HWO is the first of the planned astrophysics flagship that will require a robust IM capability for its successful development, by pushing the limits on model accuracy, size and complexity. HWO, X-ray Flagship, Far-IR Flagship	Level of difficulty (straightforward, stretch, or major stretch): stretch
E	disturbance sources and mitigation strategies (e.g., reaction wheels, cryocoolers, vibration isolation), precision of control sensors/actuators (e.g. LOWFS,	Ability to accurately quantify model uncertainty TRL 5-6 for 50nm/5mas stability JWST demonstrated flight performance within predictions + MUFs for Thermal/Thermal Distortion at ~15nm. Jitter was harder to evaluate as cryocooler and reaction wheel of jitter were not studied in depth on orbit, but data suggest predictions were over conservative. Microdynamics and Segment/Wing tilts were not included in pre-launch analyses. WF stability issues due to workmanship of harness rogue paths and MLI tensioning weren't identified on JWST until the OTIS cryo vac tests at JSC. While fortunately none of these affected JWST's ability to meet requirements	o Apply UQ and statistical methods to the process of robust margin estimation. o Demonstrate how UQ can help optimize design options and avoid over-designing by relying on worse-case simulations. Collaborate with other Technology threads on testbed model validation o Formulate Model Validation success criteria commensurate with the modeling discipline's intended use on HWO and demonstrate model validation on technology testbed to within acceptable level of uncertainty. Domains of interest are those affecting oberservatory stability at the pm, mK, mas, 10-12 levels: transient thermal, thermal distortion, structural jitter, vibration isolation or control, line-of-sight pointing and control, system and coronagraph wavefront sensing and control, starlight suppression, speckle post processing. Includes defining the level of allowable uncertainty between test data and mode predictions.	shortfalls •Improvements in predictive accuracy at the required physical scales (picometers, milli-K, etc.) will reduce risk when verification of requirements can only be done by analysis. •Requirements on model formulation, verification and validation, with credibility assessments will minimize model errors and improve the robustness of the performance budgets through the project lifecycle.		
	Telescope sensing & control, DM drifts)  •Emerging techniques in systematic uncertainty quantification, surrogate modeling and AI/ML.  •Standards for model formulation, verification and validation, and for assessing credibility of the predictions.  •Discipline-specific model validation methodology and success criteria that are commensurate with the intended use of the models, level of expected performance, allowable uncertainty and the flight environment.  •Standards for model validation of the testbed system, error budgets and uncertainty quantification, including defining testbed infrastructure and metrology limitations to flight-like performance levels. Ability to guide experimental results through analyses when results don't meet predictions.  •Model validation techniques across multiple physics domain (e.g., thermal, structures, jitter, contrast) with control using precision measurement capabilities •Identification and elimination of tools that severely limit parallel predictive multi-physics model execution due to license constraints or other costs, including	because of a robust margin, the risk remains in future missions. Roman/CGI may provide better opportunities for model validation and uncertainty quantification assuming they are adequate provided engineering time to collect the required flight data. TRL 1 for pm, /sub mK residuals post control, 10-12 contrast stability The other identified IM gaps, such as interoperability, multi-domain sensitivity and optimization, uncertainty quantification methods in general are at low to mid levels of development maturity for HWO. Standard IM practices support modeling cycles on order of 6 months and require large-scale Monte Carlo studies or engineering judgement to define model uncertainty factors. Current models and coronagraph testbeds diverege at a few*1e-10 level. The DOE Sandia tools Dakota/PCMM are being demonstrated on the Mars Sample Return Entry Descent and Landing flight mechanics IM, but these have never been applied to IM for large precision NASA observatories and would be at TRL 2-3 for HWO by NASA flight standards. JWST & Roman/CGI represent the state-of-the-art of Multi-Physics Systems IM for large astrophysics observatories. The authors of this paper are the Systems Modeling leads for these missions and have	o Validate the limits of prediction accuracy capability at the pm-level on testbed models and verify sensitivities and the quantified model uncertainty for robust error budgets. o Demonstrate the practice of over-drive testing to validate models at levels higher than the intended application when there are performance limits in the infrastructure or with the test metrology. Investigate whether there is loss of predictive accuracy to within acceptable uncertainty. o Improve model updating methodologies from test data to improve on model validation outcomes. Investigate cross-discipline model validation and updating techniques (e.g. update thermal distortion mode based on coronagraph or WFE measurements, when there are insufficient local measurements of temperature or thermal distortions ) Develop and define model standards o Define requirements on model formulation, verification and validation, including documented credibility assessment upon delivery of flight models, with the same level of rigor as delivery of flight hardware.	4		
Large-Format, High-Resolution Far-UV 200 nm) Detectors (from HWO START/I	<ul> <li>replacement of tools that are not restrictive.</li> <li>A shared, platform-independent deployment environment of multi-physics IM codes that can be run by developers and users on varied OS versions, and enabling easy deployment to High Performance Computing facilities for execution of massively parallel simulations with no modification of the delivery image. Th ensures computing software environment consistency across all users and execution environments. Modern container-based computing can be implemented t accomplish this. Adoption across a multi-organizational aerospace analysis team is new, as we lag behind modern IT in implementing solutions like this for</li> <li>IV (100-1</li> </ul>	first hand knowledge of existing modeling capabilities and limitations, model validation and uncertainty quantification accomplishments, including JWST flight model validation and IM lessons learned (Levine & Mosier, keynote SPIE 2023). as Bandpass: FUV-optimized MCP detectors are available in open face formats with peak QE of 50% between 100 - 180 nm with alkalai photocathodes, and 40% with GaN. These devices are photon- counting and solar blind, with the HST-COS MCP photocathode (CsI) having QE < 10E-12 at 400 nm. CCD/CMOS devices are available with delta doping and additional coatings to achive > 50-60% QE	o Demonstrate the numerical limits of prediction accuracy capability at the pm-level. Incorporate in models all physics which otherwise are approximated (eg nonlinearities) to gauge range of predictions. Perform model discretization convergence studies. 4 <b>Statement of Needs:</b> At a 2' FOV and assuming 50 mas resolution, this requires > 2400 resolution elements in the cross-dispersion axis. For R = 30,000 at 120 nm and 3x grating modes to cover the 100 - 200 nm bandpass, this requires ~ 8,750 resolution elements in the dispersion direction.	missions across all of NASA SMD, including new borosilicate devices on the SPRITE CubeSat (launch 2025) and Aspera	Cross-cutting to all branches of NASA SMD and all mission classes, from sub-orbital and Cube/SmallSats (where in-family devices have already been demonstrated) to HWO (where additional development is needed to meet all key metrics)	
с		above Ly-alpha (121 nm). Multi-layer filter coatings can be despotisted to CCD/CMOS to change peak QE in tandem with the spectral bandpass, or to reduce red-sensitivity. t Background/Sensitivity: MCPs detctors are photon counting (no read noise) and have dark rates < 0.1-1 counts/s/cm*2. Conventional CCD/CMOS have read noise and require cooling to achieve low background rates. These rates vary depending on the device and electronics/operation. Photon-counting CCD variants exist at various stages of development and capability (e.g. EMCCDs, Skipper CCDs). Resolution: MCP detectors can be digitized to many pixel sizes, but typically have the ability to resolve objects at a separation of <20 microns (cross-stip or Timepix) to 40 microns (cross delay line). Scientific CMOS devices are available with pixel scales spanning ~4-10 µm. CCDs typically have larger pixels at 5-15 microns, which sample most spectrograph systems at near the Nyquist limit of 2-3 nivels	Key performance metrics include: Form Factor (Size): Assuming 25 micron resolution elements, this requires focal plane arrays of at least 60 mm (cross-dispersion axis) x 220 mm (dispersion axis). Longer (dispersion axis) arrays are desireable to fully sample the MOS FOV in the spectral bandpass. Pixel Size/Resolution: ~ 15-25 micron resolution elements (5-8 micron pixels at 3x pixel sampling) Bandpass/Sensitivity: Sensitivity is a function of quantum efficiency (QE) and background noise. For some science cases it is desireable to have higher QE even if it comes at the cost of added noise, while in others it is desireable to have low noise, even at the expense of some efficiency loss. HWO science concepts baseline photon-counting capability for the FUV to maximize detetion potential for low surface- brightness sources. QE (103 nm): > 30% QE (>110 nm): > 40%	Large-format devices can improve field-of-view and/or resolution for future missions.		Level of Complexity: System of Techologies (detectors, electronics) Level of Difficulty: Straightforward
Large-Format, High-Resolution Near-U (200 - 400 nm) Detectors (from HWO	-UV 1 Based on early UV science concepts, the HWO Multi-Object Spectrograph near-UV (NUV) channel requires focal plan arrays capable of < 30 mas detector-limit resolution (< 50 mas instrument limited), and R > 30,000 from 200 - 400 nm.	Form-Factor: Borosilicate glass MCPs can be made in sizes up to 200 mm x 200 mm, and have been tiled on several flight programs (e.g. HST-COS). CCD/CMOS devices are available in many formats, with commercial units as large at 10 cm square. Some devices are readily butt-able on 1-3 sides to gaps < 5 mm to mosaic larger focal planes. TRL of FUV sensitive detectors vary depending on the specific devices and technologies. There exist devices with TRL > 4 that could meet the anticipated requirements of the HWO FUV spectrograph channel. There are no devices that are TRL 6 that could meet all the anticipated requirements, however there are in-family technologies are TRL 6+.  d Bandpass: Commercial NUV-sensitive CCD/CMOS devices routinely achieve > 50-60% QE in the 250 - 400 nm range, with somewhat lower QE at shorter UV wavelengths depending on the method of UV enhancement. Additional coatings or doping can improve this for lambda < 250 nm. Multi-laver filter coatings can be deposited to change peak QE in tandem with the spectral bandpass, or to reduce	Background: Total of all intrinsic sources (read, dark, CIC, etc): < 5e-6 e-/pixel/s Photon Counting Device Rate Limit (Global): > 1 M count/s per device with < 5% Dead Time Photon Counting Device Rate Limit (Local): > 100 counts/s/resolution element Radiation hardness: Tolerant to an L2 radiation environment or a has a viable shielding solution Contamination Mitigation: FUV-sensitive detectors that operate at cold temperatures require strategies for hydrocarbon contamination mitigation (see e.g. HST-WFPC2; Koekemoer et al., 2002)  Statement of Needs: At a 2' FOV and assuming 3 pixel sampling for 50 mas resolution, this requires > 7200 pixels in the cross-dispersion axis. For R = 30,000 from 200 - 400 nm and assuming minimum 3 pixel sampling, this requires ~ 60,000 pixels in the dispersion direction, or up to eight 8k x 8k pixel devices.		Cross-cutting to all branches of NASA SMD and all mission classes, from sub-orbital and Cube/SmallSats (where in-family devices have already been demonstrated) to HWO (where additional development is needed to meet all key metrics)	Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6.
(200 - 400 nm) Detectors (from HWO START/TAG)	This requires high sensitivity detectors with appropriate resolution element size and form factor (or tilability) capable of recording the spectra at such resolution and FOV. The final spectroscopic instrument design may have intrinsic point-spread functions of ~20-40 microns, therefore very small pixels may require sampling the spectra at such resolution and FOV.	Ing Background/Sensitivity: Conventional CCD/CMOS have read noise and require cooling to achieve low background rates. These rates vary depending on the device and electronics. Photon-counting CCD variants exist at various stages of development and capability (e.g. EMCCDs, Skipper CCDs). Sealed MCPs are photon counting and have no read noise. Conventional sealed NUV-sensitive units with a modified Hi-QE UV S20 photocathode have a dark rate ~ 4-5 counts/cm^2/s. Resolution: Scientific CMOS devices are available with pixel scales spanning ~4-10 μm. CCDs typically have larger pixels at 5-15 microns, which sample most spectrograph systems at near the Nyquist limit	pixel sampling, this requires ~ 60,000 pixels in the dispersion direction, or up to eight 8k x 8k pixel devices. Key performance metrics include: Form Factor (Size): 8k x 8k (6-8 cm), buttable on three sides with minimal gaps Pixel Size/Resolution: ~ 5-7 µm pixels to effectively sample a 20 micron PSF. Bandpass/Sensitivity: Sensitivity is a function of quantum efficiency (QE) and background noise. For some science cases it is desireable to have higher QE even if it comes at the cost of added noise, while in others it is desireable to have low noise, or photon-counting capability, even at the expense of some efficiency loss. Therefore, there are two parallel development paths for potential HWO NUV detectors, one for integrating devices (e.g., CCD/CMOS) and one for photon counting devices (e.g., EMCCD/Skipper CCD/MCPs). An ideal detector would have both high DE and low background	the SPARCS CubeSat (launch in 2025) and were used in the CUTE CubeSat (on-orbit since 2021), demonstrating the role of such detectors as enabling for all classes of science mission. Large-format devices can improve field-of-view and/or resolution for future missions. Photon-counting can greatly improve sensitivity of missions for low-brightness observations.	, council development is needed to meet all key metrics)	Level of Complexity: System of Techologies (detectors, electronics, cooling systems) Level of Difficulty: Straightforward
C		Resolution: Scentric CMUS devices are available with pixel scales spanning -4-10 µm. CCDs typically have larger pixels at 5-15 microns, which sample most spectrograph systems at near the Nyquist limit of 2-3 pixels. MCP detectors can be digitized to many pixel sizes, but typically have the ability to resolve objects at a separation of < 20 microns (cross-stip or Timepix readout) to 40 microns (cross delay line readout). Form-factor: CCD/CMOS devices are available in many formats, with commercial units as large at 10 cm square. Some devices are readily butt-able on 1-3 sides to gaps < 5 mm to mosaic larger focal planes. Commercial sealed MCP detectors are currently limited to 50 mm formats with the required spatial resolution, but larger packages (up to 200 mm) are available. Sealed MCP detectors are butt-able to ~ 1 cm gap sizes. TRL of NUV sensitive detectors vary depending on the specific devices and technologies. There exist devices with TRL > 3 that could meet the anticipated requirements of the HWO NUV spectrograph channel. There are no devices that are TRL 6 that could meet all the anticipated requirements, however there are in-family technologies that are TRL 6+.	in others it is desireable to have low noise, or photon-counting capability, even at the expense of some efficiency loss. Therefore, there are two parallel development paths for potential HWO NUV detectors, one for integrating devices (e.g. CCD/CMOS) and one for photon counting devices (e.g. EMCCD/Skipper CCD/MCPs). An ideal detector would have both high QE and low background. Integrating Device QE (200 - 400 nm): > 60% averaged over the bandpass Integrating Device Background: <~1 e- per read, Dark Current: < 1e-3 e-/pixel/s Photon Counting Device QE (200 - 400 nm): > 30% averaged over the bandpass Photon Counting Device Background: Total of all intrinsic sources (read, dark, CIC, etc): < 1e-5 e-/pixel/s Photon Counting Device Rate Limit (Global): > 1 M count/s per device with < 5% Dead Time Photon Counting Device Rate Limit (Local): > 100 counts/s/resolution element			
Low-Stress, Low-Roughness, High-Stat X-ray Reflective Coatings	10-150 keV: < 5 arcsec). The X-ray mirrors used to construct the telescopes will comprise thin, curved substrates (either segmented or full-shell) coated with X- reflective thin films. The thin-film coatings must provide high reflectance over the target energy band, and must maintain or reduce the high-frequency surface		Photon Counting Device Rate Limit (Local): > 100 counts/s/resolution element Radiation hardness: Tolerant to an L2 radiation environment or a has a viable shielding solution Thin-film single-layer and multilayer coatings deposited onto figured, thin-shell substrates that (a) provide high X-ray reflectance over the target bandwidth, (b) have low high-frequency surface roughness (to	High X-ray reflectance and low surface roughness are needed to achieve high telescope collecting area. However, without the development of effective methods to mitigate coating-stress induced substrate deformations, arcsecond telescope resolution (< 5-arcsec) will not be possible using thin-shell mirror substrates. Systematic study of various coating processes, pre-coat surface preparations, and post-coat annealing and correction processes will build a body of knowledge that can be used to optimize coatings and ensure a well understood manufacturing process.	Probe class X-ray mission X-ray Great Observatory Astro2020 enumerated numerous science objectives driving large aperture, high resolution x-ray mirrors. Small or Medium Explorer missions would also benefit from sub-arcsec imaging enabled by this technology.	Years to estimated launch or other schedule driver: <b>5-10 years</b> to launch of Explorer; <b>&lt;10 years</b> to launch of prob X-ray mission; <b>&lt;20 years</b> for Great Observatory. Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>stretch</b>
P Mirror Technologies for High Angular	Image: resolve the solution of	have been performed on mirror coupons, however, systematic studies of methods to stabilize stress in single-layer and multilayer coatings are needed. Advancement to TRL 5 will require demonstration of temporally stable X-ray reflective coatings deposited on thin, curved substrates (segmented or full-shell) with acceptable figure preservation (after compensation), demonstration of preservation (or improvement) of high-frequency substrate surface roughness, and demonstration of acceptable X-ray reflectance, using techniques that are scalable for mass production. For multilayer coating aimed at hard X-ray applications, Pt/C and W/Si are well established, however, as for Ir- based coatings, residual stress to achieve <5" has not been demonstrated. To achieve even higher energies (<80 keV), Ni- based coatings are needed, and these are in the very early stages of development (TRL < 3), primarily focused on achieving the required surface roughness (<0.1 nm), with stress still to be investigated. Monolith: 3.5-m sintered SiC with < 3 µm SFE (Herschel); 2.4-m ULE with ~10 nm SFE (HST); Waterjet cutting is TRL 9 to 14" depth, but TRL 3 to >18" depth. Fused core is TRL 3; slumped fused core is	<ul> <li>3-4</li> <li>4 Large (4-16 m) monolith and multi-segmented mirrors for space that meet SFE &lt; 10 nm ms (wavelength coverage 400-2500 nm); Wavefront stability better than 10 pm ms per wavefront control time step;</li> </ul>		НЖО	Level of difficulty (straightforward, stretch, or major stretch): stretch
Resolution (UV/Vis/Near IR)		TRL 3 (AMTD); 4-m class Zerodur mirrors from single boules are TRL 4. Segmented: (no flight SOA): 6.5 m Be with 25 nm SFE (JWST); Non-NASA: 6 DOF, 1-m class SiC and ULE, < 20 nm SFE, and < 5 nm wavefront stability over 4 hr with thermal control	CTE uniformity characterized at the ppb level for a large monolith; Segmented apertures leverage 6 DOF or higher control authority meter-class segments for wavefront control. Sub-gaps that could partially or fully close this gap: - Stable Mirrors - Stable Structures - Thermal Sensing & Control System - Ground Support Technology: Metrology - Mirror Rigid-Body Actuators - Mirror Baffle Assembly	large primary mirrors enhance planet sensitivity due to reduction in science integration time with greater collecting areas and throughput enabling probing of a larger number of more distant stars' habitable zones and improved spectral resolution.		
Optical Blocking Filters for X-ray Instruments	be able to block optical, UV, and infrared photons from being absorbed by the detector array. They need to be optimized as thin as possible to allow for maximum transmission at low energies, down to 0.2 keV. The method used to attenuate the undesirable photons needs to offer high transmission of the targ		<ul> <li>Wild Rya-body Actuators</li> <li>Miror Baffle Assembly</li> <li>Ground Support Technology: Gravity Sag Offloader</li> <li>UV Coatings: Wavefront Effects</li> <li>Ground Support Technology: Characterization of Thermal Expansion Characterization</li> </ul> Optical blocking filter technology needs to be advanced along both categories of filters. Directly deposited OBFs have, to date, consisted entirely of a thin film of Al deposited on the back surface of a Si sensor. There are complex trade-offs between optical blocking and X-ray transmission for other filter materials, but these have not been fully explored because of the chemical and electrical effects that meta deposition has on the back-surface of pixellated Si sensors. Investigation of direct deposition of thin films of Ti, W, and other materials onto Si sensors needs to be undertaken to truly optimize soft X-ray sensitivity and minimize optical contamination. Alternatively, free-standing filters that can be thin enough to compete with directly deposited filters (50 nm or thinner), with a structure that supports the filter film that is better than 90% transparent also need	I through high X-ray transmission. Having more than an order of magnitude transmission available for the softest X-ray makes more of the collecting area of the X-ray optic available for science. The X-ray optic would have a corresponding order of magnitude more area for some scientific measurements. Measurements include observations of highly redshifted	X-Ray Flagship X-Ray Probe Advances in OBF technology will be applicable to any missions that use detectors on the focal plane that are sensitive to optical photons but that target photons in the EUV to soft X-ray bandpass (50 eV to 2 keV). This would include missions falling under both the X-ray Flagship and Probe designs that have a large effective area optic and an imaging camera on	
р	maximum transmission at low energies, down to 0.2 keV. The method used to attenuate the undesirable photons needs to offer high transmission of the targ photons, good optical photon attenuation, high throughput, and relative immunity to contamination issues.	polyimide, thinner than has so far been developed or demonstrated. The filters also need to be significantly larger (> 6 cm). Thus for the full solution, the TRL is 3, with the principle having been demonstrated experimentally. The waveguide cut-off filter option has been demonstrated for 15 micron holes, but not at small enough holes for this application (~1-2 microns). - Ryu, K. K. et al. Development of CCDs for REXIS on OSIRIS-REx. Proc. SPIE 9144, 914440 (2014). - Bautz, M., et al. Directly-deposited blocking filters for high-performance silicon X-ray detectors. Proc. SPIE 9905, 99054C (2016). - Brinkman, A. C. et al. The Refection Grating Spectrometer on board XMM. in SPIE EUV, X-ray and Gamma Ray Instrumentation for Astronomy 2808, 463–480 (1996). - den Herder, J. et al. The reflection grating spectrometer on board XMM-Newton. Astron. Astrophys. 365, L7–L17 (2001). - Pollock, A. M. T. Status of the RGS Calibration. XMM-Newton Users Group, European Space Astronomy Centre, Villanueva de la Canada, Madrid, Spain (2008). doi:10.1002/hed.21900	Alternatively, free-standing filters that can be thin enough to compete with directly deposited filters (50 nm or thinner), with a structure that supports the filter film that is better than 90% transparent also need to be explored. This structure, with large area films (> 6 cm) supported by fine meshes with as thin as 10 nm of aluminum and 20 nm of polyimide, would have to be strong enough to survive launch vibrational bads and the thermal cycling environment that would be expected in a space mission. Another approach is the use of waveguide cutoff filters that have no films betweena support mesh, with extremely tiny holes (1-2 microns across). The filters would have to have a high X-ray transmission over the 150 eV to 2 keV energy range, while maintaining a good optical attenuation performance. The requirement would be >40 % X-ray transmission above 200 eV and >10% X-ray transmission below 200 eV. The optical attenuation at a thickness of 50 nm should be 10 <sup>-3</sup> . It would also be advantageous to have the ability to control the temperature of the filters so that any contamination that did build-up on them could be removed through heating.	The signal-to-noise performance of the instrument can be optimized by limiting the amount of optical photons that would be able to reach the detectors without affecting target photon energy throughput. Contamination build-up can be controlled by free-standing filters as they can be thermally isolated from the detectors and	the focal plane that would be silicon based. Effective optical blocking filters will allow the signal-to-noise of the detected photons to be maximized by attenuating optical photons, while maximizing effective area with highly X-ray transparent	Years to estimated launch or other schedule driver: <b>5-10 years</b> to launch of Explorer; <b>&lt;10 years</b> to launch of probe X-ray mission; <b>&lt;20 years</b> for Great Observatory. Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>stretch</b>
		<ul> <li>- Chandra X-ray Observatory. HRC Calibration Information. HEX IPI Team, CXC Calibration Team, da Harvard (2014). At http://cxc.harvard.edu/cal/Hrc/detailed_info.html#uvis_trans</li> <li>Free-standing filters are held in-front of the detectors. This removes them from the detector so they can be warm (reducing contamination issues). However, they require a support structure, often have a polyimide structure to support the blocking material, and are thicker than directly deposited filters (&gt;100 nm Al) which all affect instrument effective area. Free-standing filters have been used on Chandra, XMM-Newton, and Hitomi (TRL 9), but filters on highly transmissive frames are at TRL 4 or 5.</li> <li>- McCammon, D. et al. The X-ray quantum calorimeter sounding rocket experiment: Improvements for the next flight. J. Low Temp. Phys. 151, 715–720 (2008).</li> <li>- Takahashi, T. et al. The ASTRO-H Mission. in SPIE Space Telescopes and Instrumentation 7732, 18 (2010).</li> <li>- Koyama, K. et al. X-Ray Imaging Spectrometers (XIS) on Board Suzaku. Publ. Astron. Soc. Japan 59, 23–33 (2007).</li> <li>- Chandra X-ray Center. The Chandra Proposers' Observatory Guide. Chandra Project Science, MSFC Chandra IPI Teams, Version 14.0 (2011). http://cxc.harvard.edu/proposer/POG/html/chap6.html</li> <li>- Gastaldello, F. et al. Status of the EPIC thin and medium filters on-board XMM-Newton after more than 10 years of operation : II - analysis of in-flight data. in Proceedings of the SPIE 8859, 885914 (2013).</li> </ul>				
Scaling and Metrology for Advanced Broadband Mirror Coatings for HWO (fr HWO START/TAG)	(from reflective coatings. To advance any coating to TRL 6+ for HWO, the deposition processes must be scaled to > 1m-class optics with demonstrated uniformity the	(2013). /- Conventional LiF+Al has flight heritage on OAO-3 Copernicus, FUSE, and several sounding rocket platforms, while MgF2+Al has ample heritage, including on HST. Both coatings can be considered TRL- at 9 for basic observatories, however neither is TRL 6 for HWO given the unique requirements of the program. Advanced coatings, primarily LiF+Al based (eLiF, XeLiF, etc see "High Reflectivity Broadband FUV-to-NIR Mirror Coatings" Gap) have also been matured to TRL 5/6 on small programs. The most mature is protected eLiF, which will reach orbit on the SPRITE CubeSat in 2025 and again on the Aspera SmallSat in 2026. Both unprotected and protected eLiF have been used on multiple sounding rockets, while the newer XeLiF will fly on the INFUSE sounding rocket in 2025.	Key Performance Metrics: Scaleability to >1m class optics: Demonstrate a successful demonstration on a mirror larger than 50 cm, and up to 2 m. Develop a facility capable of measuring the reflectance of optics of this size from 100 nm to 2.5 microns. Reflectionce Uniformity: Demonstrate < 1% reflectance variation across the surface for wavelengths > 200 nm (this parameter only applies to wavelengths used for high-contrast imaging).	The HWO UV instrument imposes the requirement that the HWO telescope optics be coated in a UV-reflective mirror coating. It is neccessary to evaluate the coatings in the context of the observatory, including high-contrast imaging systems.	Primarily HWO given the multi-purpose nature of the observatory	Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6. Facilities and metrology capability are essential to the development of a roadmap for maturing UV coatings to TRL 6+, while measurements a needed to effectively model the instruments performance. Level of Complexity: System of Techologies for measurements and metrology
c	This technology gap focuses primarily on the needs of the HWO telescope and compatability with the entire instrument suite. See "High Reflectivity Broadband FUV-to-NIR Mirror Coatings" for technology gaps related to the needs of a UV spectrograph. Facility (an associated facility and/or capability that will need to be developed to support the overall technology development effort)	Scalability to >1m class optics: Conventional MgF2+AI - 2.4m (HST), Conventional LiF+AI - 35 cm (FUSE), 50 cm (sounding rockets), eLiF - 50 cm (sounding rockets), protected eLiF - 16 cm (SISTINE), protected LiF - 18 cm (SPRITE), XeLiF - 2.5 cm (INFUSE grating), ALD deposited coatings - 18 cm (SPRITE) Reflective uniformity over large optics (200 nm - 2.5 microns): No facility to carry out these measurements. Limited measurements have been made on witness samples distributed over the deposition chamber. Models suggest requirements for uniformity variation < 0.1 - 3% (e.g. Krist et al., 2023), however deformable mirrors may be able to reduce this sensitivity. Polarization Aberrations from 200 nm - 2.5 microns: No significant measurements of any coatings, nor facility to carry out these measurements Demonstration of UV-reflective coatings in a high-contrast imaging system: No measurements have been carried out on any dielectic+metalic coating, and there is insufficient data on polarization and uniformity to properly model these systems.	Reflectiance Uniformity: Demonstrate < 1% reflectance variation across the surface for wavelengths > 200 nm (this parameter only applies to wavelengths used for high-contrast imaging). Polarization Aberrations: Measure the complex index of refraction and polarization aberrations (including cross-terms) for various angles of incidence and optic curvature. This data must be made publically available to evaluate any on coating for HWO. Metrology facilities for these measurements do not currently exist. Significant TRL advancement is also possible through direct demonstration of UV-reflective coatings in a HWO high-contrast imaging system.			Level of Difficulty: Stretch for all measurements prior 2028
Segmented-Pupil Coronagraph Contras Efficiency in Visible Band	<b>ast and</b> 1 The capability to suppress starlight and receive planet light with a coronagraph to the level needed to detect and spectrally characterize Earth-like exoplanets the habitable zones of Sun-like stars across the wavelength range 400-1000 nm.	All potential candidate coatings for HWO are TRL 4+ for basic use, with several TRL 6+. No UV-reflective coatings have been evaluated to meet the anticipated requirements of HWO (scalability of process, metrology), therefore all coatings are less than TRL 5. in unobscured pupil: 4×10 <sup>-10</sup> raw contrast at 10% bandwidth, angles of 3-15 <i>N</i> D (Lyot coronagraph demo in HCIT); obscured pupil: 1.6×10 <sup>-9</sup> raw contrast at 10% bandwidth across angles of 3-9 <i>N</i> D (Roman CGI Lab Demos); segmented/unobscured pupil: 4.2×10-8 raw contrast in 10% band 2-13 <i>N</i> D (PAPLC demo in HiCAT)	3 Maximized science yield in imaging and spectroscopy for a direct imaging telescope/mission. Assuming a ~6m space telescope, this implies ≤ 10 <sup>-10</sup> raw contrast, >30% core throughput, inner working angle ≤ 3 ND, outer working angle >= 45 ND [TBD], 20% bandwidth; obscured/segmented pupil For the two distinct cases of monolith and segmented primary mirrors, Sub-gaps that could partially or fully close this gap:	This gap is likely to be closed by improvements in coronagraph masks and optics, wavefront sensing and control (deformable mirrors), data post-processing, and integrated models.	HWO, or any other coronagraph-based exoplanet direct-imaging mission.	Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the mid-to-late 2020's.
E UV Multi-Object Spectrograph Calibrati Technologies (from HWO START/TAG)	establishing wavelength zero-points and flux calibration. A MOS consists of thousands of potential 1D spectral paths, each with a unique wavelength and	Flux Calibration: Standard stars are observed through point-source apertures on a given calibration timescale on HST and prior UV observatories. Such stars can be observed in a grid of MOS elements, which can be interpolated into an effective area map. In addition, GO programs requiring flux accuracy could elect to observe a standard star through specific multiplexing elements for direct	<ul> <li>Small Inner Working Angle Single-mode Coronagraph</li> <li>Starlight Suppression Optics</li> <li>Deformable Mirrors</li> <li>WFSC</li> <li>High-contrast Spectroscopy</li> <li>Computational Throughput on Space-rated processors</li> <li>&lt; 5</li> <li>The technical goal is to illuminate different MOS elements, or a grid of points around or across a MOS, with a traceable calibration source.</li> </ul>	Efficient and accurate calibration maximizes the value of any medium resolution spectroscopic observation. Temporal evolution of wavelength calibrations over an observation are essential for monitoring transient objects and comparing	HWO-specific, with potential value to Explorer-dass missions.	Years to estimated launch or other schedule driver: Per HWO Objectives, TRL 5 is required by the end of 2028, with viable roadmap to TRL 6.
с	effective area solution that may be variable depending on the conditions of the instrument (temperature, etc.) during an observation. Many prior observatories (e.g. HST) have utilized on-board calibration lamps to track the wavelength solution in real-time. There is a significant challenge to accurately interpolating a fix calibration lamp spectrum to any given element of a MOS. Likewise, it is not feasible to flux calibrate every multiplexing element with standard stars on a regula cadance. Baseline (Need TRL 5 by MCR, but could accept waiver on readiness depending on remaining work or possibility for servicing)		Flux Calibration: Onboard light source (or method for diffusing an astrophysical calibration source) and optical system for tracking spectroscopic throughput over time over a large spatial (> 100 x 100 mm) and angular area (> 2' x 2') Wavelength Calibration: Lamp/calibration sources capable of producing stable and narrow (< 0.05 angstrom) FWHM spectral lines from 100 nm through the visible. Quantified lamp stability or traceable reference detectors for monitoring lamp output to < 2% uncertainty. Wavelength Calibration of a MOS: Optical systems/techniques for illumination of individual elements of a MOS array with calibration sources, or a pattern of calibration apertures near the MOS, without interfering with a science observation.	multiple related objects in a given MOS observation.		Level of complexity: System of Technologies Level of difficulty: Stretch
UV Single-Photon Detection Sensitivity E Vis/NIR Single-Photon Detection Sensit		Onboard calibration sources for lambda > 115 nm are TRL 9         Lamp/on-board wavelength calibration sources for lambda < 115 nm are TRL < 5	<ul> <li>3-4 Low-noise ultraviolet (200-400 nm) detectors to characterize exoplanets with an imaging spectrograph. Read Noise: 0 e-; Dark Current: 0 e- /resolution/s; Spurious Count Rate: &lt; 0.05 counts/cm²/s; QE: 75%; Resolution size ≤ 10 mm; Tolerant to space radiation environment over mission lifetime.</li> <li>4 Near IR (roughly 900 nm to 2.5 µm) and visible-band (roughly 400-900nm) extremely low noise detectors for exo-Earth spectral characterization with spectrographs or intrinsic spectral resolution with quantum efficiency, QE&gt;90% across all wavelengths for all modes on the focal plane. The boundary between visible and near-IR is not fixed. Depending on the visible detector that is used, the visible could be</li> </ul>	Enables UV coronagraphy and/or UV spectroscopy with a starshade. N Single-photon counting detectors in the Vis/NIR bands allow characterization of very faint objects, including exo-Earths.	НЖО	Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the late 2020's Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the late 2020's
		EMCCD detectors provide dark current of 7×10-4 e-/px/sec; CIC of 0.01 e-/px/frame; zero effective read noise (in Roman Coronagraph Instrument Photon Counting Mode) after irradiation when cooled to 165.15 K (Roman; Morrisey et al 2023); 4k×4k EMCCD fabricated. Single Photon Sensing and Photon Number Resolving slicon CMOS image sensors are now in commercial production in formats from 1 to 163 Mpixel. They have a dark current <0.002 e-/pix/s at T~230-250 K, 0.2 e- read noise, 90% peak QE at 500 nm with sensitivity from 200 nm – 1100 nm. The read noise is effectively unchanged after irradiation of up to 10 mission lifetimes (50 krad(Si)), and the dark current increase can be brought back to beginning of life levels with modest additional cooling, i.e. ~5 K for a single mission lifetime. Thick, large format, fully depleted, p-channel "Skipper" CCDs successfully count photons using non-destructive readout with ultra-low dark current, although the readout time needs to be reduced for use in space. Multi-Amplifier Sensing CCDs (MAS-CCD) promise shorter readout times. These are entering test now. Small format SiSERO sensors have also demonstrated photon counting capabilities with non-destructive readout at significantly higher speeds than skipper-CCDs, further development and readout optimization of large format SiSERO still needs to be done before use in space.	extended to include an exoplanet H2O vapor feature at 940 nm. NIR Read noise < 0.15 e- rms for photon counting, spurious count rate (dark current+glow) < 0.001 e-/pix/s, Vis band read noise < 0.15 e- rms for photon counting; CIC < 3×1e-3 e-/px/frame; dark current < 1e-4 e-/px/sec, all performance requirements met at end of life (5 year mission requirement; 10 year goal); large ≥ 2k×2k format is the minimum format for a R~50 spectrograph for likely bandwidth and FOV. Spectrally resolving detectors need fewer pixels (≥10k) to achieve imaging and spectroscopy goals, with spectral resolving power R=150 at λ=760 nm and R=200 at λ=1590 nm). Sub-gaps that could partially or fully close this gap: - NIR Low-noise Detector - UV/VIS Low-noise Detector			
E		Near Infrared Megapixel format HgCdTe near-IR arrays are proven, mature flight technology. 2k×2K format devices are TRL9 for JWST and Euclid. Conventional HgCdTe photodiode arrays have read noise ≾ 2 e- rms with multiple nondestructive reads; 4k×4k format (Roman WFI; TRL8); dark current < 0.001 e-/s/pix; very radiation tolerant (JWST), high QE down to 600 nm (JWST & Roman); HgCdTe LmAPDs demonstrated a spurious count rate dominated by ROIC glow at 0.01 e-/frame (Bottom et al 2024 in prep), RN ~ 0.5 e- CDS and 1k×1k format with 15 micron pixels. Spurious count rate and read noise can be traded to some degree. Low Temperature Detectors	- Noiseless Single-photon Detectors for NIR/VIS			
Advanced Cryocoolers		Superconducting photon-counting detectors (SNSPDs): . spectrally-resolving detectors (MKID,TES): 0 read noise/dark current; MKID space radiation tolerance not systematically studied; MKID Exoplanet Camera (MEC) on Subaru is 140x146 format (Walter et al 2020); TESs have sounding rocket heritage, demonstrated radiation hardness/vibe/aging, and demonstrated spectral resolution R=90 in visible (R=3000 in x-ray)	??? The goal is the development of a 4 K cryocooler requiring only one type of refrigerator (therefore only one compressor) that is appropriate in an aerospace environment. This refrigerator should provide 10s of mWs of cooling at 4 K, and should use helium-4 as the working fluid (helium-3 is increasingly expensive). Improved understanding of the real-fluid effects of helium near 4 K—and their impact to 4 K cryocoolers—would greatly benefit the development of this cooler. This refrigerator should also have low vibration levels. Although such an aerospace cryocooler does not currently exist, ground-based laboratory cryocoolers routinely provide cooling at temperatures below 3 K using a single refrigerator that has a reject	Cryocooler development is critical for future astrophysics missions. It is estimated that the MIRI cryocooler aboard the JWS cost \$150 million to develop (much more than originally anticipated). The Athena mission has recently been impacted by the search for and/or development of an appropriate cryocooler (NewAthena update). If a single cryocooler can provide 10s of mWs of cooling at 4.5 K then future aerospace missions will require half the	The following mission concepts are anticipated to launch in the mid 2030s or later and will require 10 mW (or more) of cooling at 4.5 K: Origins Space Telescope, PICO (Probe of Inflation and Cosmic Origins), PRIMA (the Probe far-Infrared Mission for Astroyphysics), Athena (Advanced Telescope for High Energy Astrophysics), and the Lynx X-ray Observatory. This list may not be exhaustive.	Level of complexity (single tech, system of techs, or system of tech systems): System of technologies (refrigerator and
Broadband X-Ray Detectors	reveal enshrouded accreting black holes, or tracing the hottest phases of gas driven outward by this same accretion, with the spatial and spectral resolution needed to isolate critical physical quantities" [1] as one of the three key Priority Areas for the next decade and beyond. In practice this requires X-ray telescope	While silicon detectors have been the workhorse for X-ray observatories, they lack sensitivity to hard X-rays. The 450 µm-thick detectors for ATHENA's WFI [1] – approaching the maximum thickness at which silicon can be fully-depleted – have a cutoff (<50% QE) around 17 keV. Today's SOTA is represented by the CdZnTe detectors flown on NuSTAR [2]; the same detectors have been proposed for HEX-P [3] and still lag silicon in terms of format, energy resolution, and spatial resolution. The energy resolution of CZT is limited by the purity of the crystal growth of the crystals and the ability to cut the crystal from a good region of the CZT [4]. The low-enegy triggering threshold of the CZT is also tied to the crystal purity and to the electronic noise of the readout system. Germanium is an alternative	temperature of 295 K. This suggests that aerospace cryocoolers might benefit from a shift of their operating regimes (frequency, pressure ratio, mean pressure, etc.) towards those used in ground-based laboratory cryocoolers. "Modifications to the MIRI cryocooler design to provide significant lift in the 2K to 4K range" (Petach, Michaelian, and Nguyen, 2019) A future X-ray Probe would benefit from large-format, low-noise detectors with sensitivity spanning both the soft and hard X-ray bands. Key performance parameters include:	number of compressors and half the number of electronics packages for running the compressors. This reduces complexity, cost, and weight. Achievement of these goals will enable X-ray telescopes with wide field of view, excellent spatial resolution, and moderate		Years to estimated launch or other schedule driver: <b>5-10 years</b> (Explorer-class mission), <b>15 years</b> (Probe-class missio Level of complexity (single tech, system of techs, or system of tech systems): <b>Single technology</b>
P	absorbing gas and dust in the young galaxy environs.	<ul> <li>crystal from a good region of the CZT [4]. The low-enegy triggering threshold of the CZT is also tied to the crystal purity and to the electronic noise of the readout system. Germanium is an alternative by detector material, but requires cryogenic temperatures for operation while CZT operates near room temperature. The hard X-ray detectors flown on Hitomi combined a Si detector with CZT by having the Si on top of the CZT detector [4]. A detector that combines the capabilities of silicon detectors (in noise, format, and resolution) with broadband sensitivity would enable simultaneous spectroscopy of time-variable sources at low (&lt;2 keV) and high (&gt; 10 keV) energies, providing new insights into the complex physics of accretion and feedback, and could potentially eliminate the need to perform calibrations between different instruments or observatories.</li> <li>1. N. Meidinger, M. Barbera, V. Emberger and others, "The Wide Field Imager instrument for ATHENA," SPIE Proceedings, vol. 10397, 2017.</li> <li>2. F. Harrison, W. W. Craig, F. E. Chritensen and others, "The Nuclear Spectroscopic Telescope Array (NuSTAR) High-Energy X-ray Mission," The Astrophysical Journal, vol. 770, p. 103, 2013.</li> <li>3. K. Madsen, et al., "The high energy X-ray probe (HEX-P): instrument and mission profile", Frontiers in Astronomy and Space Sciences, vol. 11, id. 1357834</li> <li>4. Kazuhiro Nakazawa, et al, "Hard x-ray imager onboard Hitomi (ASTRO-H)", JATIS, 021410 (2018).</li> </ul>	<ul> <li>technologies or even multiple FPAs optimized for different energy regimes) that fulfills all requirements would substantially reduce the tocal plane mass, power and system complexity.</li> <li>Format: While HEX-P targets [3] 70 kpixel, even larger formats would be preferred. Detectors with four-side abuttability and minimal gap widths will enable wide field of view mosaics of individual detectors.</li> <li>Four-side abuttable detectors also enable a focal plane with the detector surface approximating the best focal surface for the mirror.</li> <li>Spatial Resolution: The HEX-P goal is 5 arcsec (0.3 mm pixel pitch, 20 m focal length).</li> <li>Spectral Resolution: Approaching Fano-limited energy resolution across the entire range of sensitivity.</li> <li>Requisite radiation hardness for a multiyear mission.</li> </ul>			Level of difficulty (straightforward, stretch, or major stretch): <b>Stretch</b>
C C Compact, Integrated Spectrometers for to 1000 μm C C Cryogenic Far-IR to mm-Wave Focal Pl Detectors	(R = λ/Δλ = n/Δn) ~500 with high efficiency in a compact (~10 cm) package that could be arrayed in a focal plane to provide integral-field mapping or multi-obje spectroscopy capability. Si immersion technology can provide increased spectrometric capability (R~1x105) with smaller size (factor of 3) over standard Echelle gratings.	er Multiple compact spectrometers are under development: including compact silicon gratings and grating analogs, as well as superconducting filter banks. These systems are promising, and in some cases are approaching photon-noise limited performance suitable for ground-based observations, but have not yet been demonstrated in a scientific application.	An integrated spectrometer + detector array system would demonstrate 1:1.7 bandwidth (or greater), high efficiency (>50%, including detector absorption), resolving power > 400, and a coupling scheme compatible with a telescope beam e.g., an f/4 Gaussian beam. To enable the observatories with hundreds of spectrometers, a single spectrometer + detector array would be a packaged on a silicon wafer on order tens of square cm in size (i.e., less than one 4" wafer). Goals are to develop feeds and feed-coupling structures that can couple >3:1 total bandwidth. Advanced homs, len-coupled antennas, end-fire antennas, and phased arrays are among the candidate technologies.	combination of large spatial coverage (many to tens of square degrees) and spectral bandwidth (giving redshift, or line-or sight distance) will simultaneously find galaxies and measure their redshifts in large numbers (e.g., on order millions with Origins). This measurement addresses key questions in galaxy evolution and the reionization epoch. This is enabling technology.	Far-IR Probe	Need to demonstrateTRL 6 by mission PDR. Years to estimated launch or other schedule driver: 10 years Level of complexity (single tech, system of techs, or system of tech systems): Systems that are built into the detector.
C Far-IR Imaging Interferometer for High Resolution Spectroscopy C	<b>gh- 2</b> A technology enabling far-infrared (FIR: 50 microns to 500 microns) imaging at a high angular resolution (~0.1" arcsecond) comparable to ALMA and optical systems with AO is needed. High sensitivity at such angular resolution should be achieved at a sub-Kelvin level in brightness temperature or 1- $\sigma$ noise < 10 <sup>-23</sup> W/m <sup>2</sup> in 1-hour. A spectral resolution of ( $\lambda\Delta\lambda$ > 100,000) is also needed for identifying line emission and probe gas dynamics in protoplanetary disks and star-forming regions.	None provided The Herschel Space Observatory is the current SOTA for the FIR spaceborne telescope that has the capability of imaging astronomical objects. With its 3.5-meter primary reflector, the best angular resolutions are 5" at 70 microns and 37 microns at 500 microns. Another SOTA is BETTII, which is the twin telescope in FIR on a high-altitude balloon. The angular resolution of BETTII is as small as 0.5", but, practically, it does not obtain images but measures visibilities. Also, the spectral resolution is <i>N</i> Δλ ~ 100. A full-solution consists of developing a high-speed data communication, high-precision telemetry, and formation flying system that can combine multiple Herschel-like telescopes into a FIR interferometer.	2 Develop a FIR heterodyne interferometric system with multiple interferometric terminals. The critical subsystems to be developed or improved include the following: expand the high-accuracy telemetry system (e.g., GRACE-FO) to be applied to multiple interferometric terminals (number of terminals >4). Expand the high-speed optical communication links from 1-to-1 links to a 1-to-N link for collecting large data from multiple interferometric terminals to either a data-processing satellite or a ground facility. Develop most efficient orbits for formation flying, maintaining the baseline and the uv-coverage required to science in the Astro2020 decadal report.	critical science in the Astro2020 decadal report and NASA Strategic Plan 2018. A direct probe of the gas distribution and the snowline in disks requires higher than 0.1" resolution with high spectral resolution in the crucial tracers for the gas and the snowline, singly deuterated hydrogen molecule (HD at 2.7 & 5.3 THz), and water (H2O at 0.5, 1.1, & 1.6 THz), which are not accessible from the ground. Galaxy evolution and black hole science are also key science topics in Astro2020 and require observations of atomic fine-structure lines at 1 – 2 THz at sub-arcsecond resolution. Closing the technology gap	Far-IR Probe The technology discussed here is directly applicable to the mission technology of a future NASA FIR Flagship or FIR Probe. A FIR Probe has been identified by Astro2020 as one of two priorities for the first Probe-class mission competition. Astro220 has identified FIR as "an area where advances in technology and focused objectives can yield transformative	Level of difficulty (straightforward, stretch, or major stretch): stretch Years to estimated launch or other schedule driver: 10 for the FIR probe, 15 for FIR flagship Level of complexity (single tech, system of techs, or system of tech systems): System of tech systems Level of difficulty (straightforward, stretch, or major stretch): major stretch
Far-IR Spatio-Spectral Interferometry	resolution and R ~ 3000 spectral resolving power. This technique will give the Far-IR Surveyor the measurement capabilities envisaged in the Astrophysics Roadmap. With those capabilities the community will learn how habitable conditions develop in nascent planetary systems and will overcome source confusion measure the spectra of individual high-z galaxies, complementing JWST to understand their formation and evolution. The angular resolution achievable with a	ial This work was the subject of two successfully-defended PhD theses, one by Dr. Roser Juanola-Parramon, and another by Dr. Alexander lacchetta. During Dr. Juanola-Parramon's tenure as a NASA	Additional effort is required to fully characterize the hyperspectral scene projector used in the testbed, as well as minor testbed optical aberrations, and then to close the loop by demonstrating reconstruction of a hyperspectral astronomically realistic scene that matches an independent measure of the "truth" scene to high fidelity, with residual differences explained. All necessary equipment is in place to characterize the scene projector. Testbed optical aberrations will be understood with the aid of an existing, thoroughly tested computational optical system model of the testbed. Finally, experimentation with "single dish" (standard FTS) mode and simulation and experimentation with data acquired with a rotating interferometer, will close the gap and provide enabling technology for a space-based far-IR interferometer.	described here will bring a major step forward to understand key science by matching the angular resolution of FIR observations to those of optical and radio observations. Interferometric baselines in the tens of meters, up to ~100 m, are required to provide the spatial resolution needed to follow up on discoveries made with the Spitzer and Herschel space telescopes, and to provide information complementar to that attainable with ALMA and JWST. The capability to definitively map the distributions of gas, dust, and ice in protoplanetary disks, to find structures (gaps or holes) indicating the presence of young planets, and to learn how the conditions for habitability arise during the planet formation process, is particularly strong motivation for the Far-IR Surveyo Only a space-based far-IR interferometer will have these capabilities.	Far-IR Flagship Far-IR Probe Wide-field spatio-spectral interferometry is the critical path technology for a Far-IR astrophysics mission consistently given high priority by the Far-IR astrophysics community since the 2000 Decadal Survey, and most recently in the NASA Astrophysics Roadmap, Enduring Quests, Daring Visions. The first interferometer will be structurally connected and might resemble the SPIRIT mission concept recommended as a Probe-class mission to the 2010 Decadal Survey	This technology is the pacing item for a space-based far-IR interferometer. The future envisaged in the Astrophysics Roadmap will be delayed until NASA invests to close the gap on wide-field spectral interferometry, so the urgency is great.
c	algorithm development are needed to advance spatio-spectral interferometry to flight-ready status for the Far-IR Surveyor. The gap can be closed in 2 to 3 years of concerted effort, and depends entirely on funding. Nearly all of the required hardware exists in an established testb as does the optical system model. The testbed is currently housed in a world-class facility, which offers the stability of a quiescent space environment. The graduate student and postdoc have moved on to new positions, so new qualified experimentalists will have to be hired. Current SOTA in detector technology is the only other pacing item for a far-IR interferometer, and current investments may yield detectors – TES bolometers o KIDs – that satisfy mission requirements. (The detector requirements and performance goals are relaxed relative to those for OST.) A structurally connected interferometer could enter development in the early 2020s and fly by the end of the decade. Interferometry is perceived to be comple but the engineering challenge is greatly relaxed at long (far-IR) wavelengths. Wavefront sensing and control for JWST, a mature technology, is a harder engineering problem than far-IR spatio-spectral interferometry.	r		Programmatically, as explained in the Astrophysics Roadmap, Enduring Quests, Daring Visions, the far-infrared is the best "training ground" for space-based interferometry, but eventually interferometers will be needed across the entire electromagnetic spectrum.	(https://asd.gstc.nasa.gov/cosmology/spirit/). Later interferometers would rely on the same technology, but could use formation flight to provide long interferometric baselines and correspondingly improved angular resolution (Harwit et al. 2006, see http://adsabs.harvard.edu/abs/2006NewAR50228H). The Astrophysics Roadmap explains the need for space-based interferometers across the electromagnetic spectrum, from far-infrared to X-rays. Potential applications also exist in NASA's Planetary and Earth science programs.	
Heterodyne Far-IR Detector Systems	objects including comets. These arrays require mixers with low noise-temperature and wide intermediate frequency (IF) bandwidth, local oscillators (LOs) that a	n 7-pixel receivers have been developed for flight (SOFIA/upGREAT); arrays of 64 pixels (in development) are approaching TRL ~ 4. LOs above 2 THz are at TRL 4. Heterodyne arrays are used/being developed for infrared observations on platforms including SOFIA and balloons (GUSTO, ASTHROS). The sensitivity is still at the level ×20 QL (quantum limit) above 1 THz. Existing systems have good performance but power requirements far exceed what is available in spacecraft, especially if there are more pixels in arrays than currently employed. Ambient temperature LOs deliver < 100 µW around 1.9THz, cryogenically cooled LOs (SOFIA/upGREAT) have an output power < 2.5 mW at 4.7 THz. TRL details: 3-4, except for the THz amplifiers (1), nearly QL mixers are available at ≤ 0.6 THz.	<ul> <li>1-4</li> <li>*Tunable-bandwidth array receivers for operation at frequencies of 0.5-5 THz. Arrays with 100+ pixels are required to build on the discoveries of Herschel and exploit the sub-millimeter/far-IR region for astronomy. Should include optics, LO beam demultipexers, and accompanying system components;</li> <li>•Mixers with QL sensitivity are required across the entire far-IR range;</li> <li>•For mixers, IF bandwidths of 8 GHz at shorter wavelengths ( &lt; 100 microns) are essential to analyze entire galactic spectrum in one observation;</li> <li>•Sensitive mixers not requiring cooling to 4 K (e.g., based on high critical temperature superconductors) will be essential for application on space platforms, especially with the benefit of increased IF bandwidth;</li> <li>•Above 2 THz, LO sources operating at 100+ K are highly desirable;</li> </ul>	Ability to observe and map spectral lines (such as CII at 1.90 THz or OI at 4.75 THz) to study star formation and galactic chemical evolution. Observations of transitions of water are necessary to probe the early phases of planet formation, and to determine the origin of the Earth's oceans. Development of such systems and associated technology will make imaging observations over 10 faster. They will also significantly benefit laboratory spectroscopy and biomedical imaging. Increasing the pixel count by 1-2 orders of magnitude over existing instruments will dramatically increase imaging efficiency for high spectral resolution observations. Increased instantaneous bandwidth will enable simultaneous observation of multiple lines, further improving efficiency and relative calibration accuracy.	The technologies discussed here are directly applicable to heterodyne instrumentation on a future NASA Far-IR Flagship or a Far-IR Probe. A Far-IR Probe has been identified by Astro2020 as one of two priorities for the first Probe-class mission competition. Astro2020 has identified Far-IR as "an area where advances in technology and focused objectives	Years to estimated launch or other schedule driver: 10 for the Far-IR probe, 15 for Far-IR Flagship. Level of complexity (single tech, system of techs, or system of tech systems): System of techs Level of difficulty (straightforward, stretch, or major stretch): Extreme Stretch
High-Performance Computing for Even Reconstruction	ent 2 On-board reconstruction of particle events in detectors using high-performance computing such as GPUs, FPGAs and other highly parallel computing technolo	gy. The hardware exists and has been demonstrated on a lab bench at several institutions. Current missions (Fermi-LAT) and upcoming missions (COSI) use simple on-board filters to discriminate photon events from particle events for event discrimination, triggering, and event classification. These are usually based on simple FPGA logic or low-power, low-performance computing.	<ul> <li>•Far-IR/THz low-noise amplifiers are sought to mitigate the challenge of achieving QL mixers and also to boost the LO power;</li> <li>•LO sources with output power levels ≥ 10 mW at frequencies &gt; 2 THz are needed in order to pump an entire mixer array with a singe LO;</li> <li>•For digital spectrometers, 8 GHz bandwidth with &gt; 8000 spectral channels, and &lt; 1W power per pixel will be necessary for large arrays used in space missions;</li> <li>•Cryogenic IF amplifiers with reduced power dissipation also needed, e.g. 0.5 mW for 8 GHz bandwidth.</li> </ul>	Full on-board reconstructions of both Compton and Pair events in a particle tracking detector would have significant impact to TDAMM and other strategic missions. It would allow for reconstruction of photon parameters like photon energy and direction while remaining low power (a baseline is the performance of current CPUs). It needs to be able to keep up with expected events rates of tracking detectors in low earth orbit and survive the radiation environment. This technology	missions are highly relavant for the astrophysics division, particularly for TDAMM applications.	Years to estimated launch or other schedule driver: <b>4</b> Level of complexity (single tech, system of techs, or system of tech systems): <b>single tech</b>
C High-Resolution, Direct-Detection Spectrometers for Far-IR Wavelengths High-Throughput Focusing Optics for 0 MeV Photons	these spectrometers need to have many spatial pixels as well.         r 0.1-1       2         The Astro2020 report highlighted several science priorities that require hard X-ray and soft gamma-ray imaging that is beyond current technological capabilities.         Multilayer coatings of dense materials, the current state-of-the-art in X-ray optics, suffer from a precipitous drop in photon reflectivity above 80 keV. The High	n, 10. There are currently no high-TRL direct imaging capabilities at energies >80 keV. There have been promising proof-of-concept demonstrations for different optical designs that could fill this capability gap. Recent studies show a fairly high reflectance (~30%) for grazing incidence mirrors at 600 keV (Brejnholt et al, 2014), on a single test wafer. Other imaging technologies that could serve to fill this capability	Achieve resolution of <1km/s or R>1E5 with <100 spectral elements (goal of 1000). Being able to simultaneously observe in 100 or more spatial positions. Sensitivity: tbd. The Key Peformance Parameters to fill the capability gap are effective area, energy bandpass, and image quality. This technology gap requires optics operating between 80 keV and ~1 MeV with effective areas in excess of ~200 cm^2 within the bandpass and without adding significant energy dispersion. Focusing optics overcome the sensitivity limitations of coded aperture instruments by decoupling effective	studying compact objects, energetic transients, and dark matter annihilation. The continuum cutoff for neutron star and	High-throughput, hard X-ray optics would be relevant for the HEX-P mission concept to enable science investigations beyond 80 keV. These types of optics would be applicable to a follow-on for COSI observations of positron annihilation or	Level of difficulty (straightforward, stretch, or major stretch): <b>straighforward</b> Years to estimated launch or other schedule driver: <b>2-3 years</b> (next MIDEX call), <b>~5 years</b> (hard X-ray Probe)
Ρ	Energy X-ray Probe (HEX-P) concept, originally designed with an operational bandpass up to 200 keV, has been redesigned with a bandpass to 80 keV due the limitations of current hard X-ray optics technology and geometry challenges. In order to address Astro2020 science goals like understanding black hole jet kinematics (B-Q2), the mechanisms powering transients (B-Q2, B-Q3), or detecting the byproducts of the annihilation or decay of dark matter particles (C-Q2), to community needs to develop high-throughput focusing optics for the low-energy portion of the MeV gap at ~ 0.1-1 MeV. Focusing optics in this energy range greatly enhance performance (point-source sensitivity, angular resolution) of future missions over non-focusing imagers (e.g., coded mask aperatures).	- Barrière, N., et al., Laue lens: The challenge of focusing gamma rays, Proc. SPIE, 10566:1056603, Nov. 2017. he - Brejnholt, N.F., et al., Demonstration of multilayer reflective optics at photon energies above 0.6 MeV, Opt. Express,	area and detector size, reducing the impact of background radiation. Hard X-ray/soft gamma-ray optics with angular resolution of < 10 arcminutes would surpass the ≳ 15 arcminute resolution of state-of-the art coded aperatures at >100 keV and enable groundbreaking point-source studies.	energy nonthermal emission associated with these objects. X-ray observations above 100 keV would enable characterization of the kinematics in black hole jets, revealing information on the black hole spin and launch mechanisms of the jets. Such optics would enable a probe of energetic transient sources as they evolve from gamma-ray bursts through soft X-rays. The 80-1000 keV bandpass would encompass the positron direct annihilation line at 511 keV and ortho- positronium continuum, enabling probes of radioactive decay and dark matter annihilation.		Level of difficulty (straightforward, stretch, or major stretch): Stretch
High-Throughput UV Bandpass Standal and Detector-Integrated Filters and Bandpass Selection (from HWO START/TAG)		or Heritage: The high heritage option for far-UV bandpass filters are from HST-WFPC (1/2) and ACS-SBC. These are either long-pass filters that rely on the solar blindness of the detector (ACS-SBC), or UV medium-band (e.g. 122 nm filter on ACS/SBC and WFPC-2). Red-blocking "Woods filters" with low efficiency (<10-15%) and lifetime issues have been employed for solar-blind imaging. Indium filters enable imaging at wavelengths shorter than 120 nm, but are fragle and have poor heritage. <b>Commercial bandpass filters:</b> optical filters are mature and widely available for visible and NUV wavelengths (> 250 nm). Current state of the art UV-transmission filters has efficiencies of <10-20% below 180 nm and < 50% for 180-280 nm. <b>Reflective Coatings:</b> New multi-layer reflective filters are under development that have ~ 50% reflectance at 110 nm and < 10% at 121 nm. When compounded over 2+ reflections, this suppresses the out-of-band to < 1% while maintaining throughput. As the coating can be deposited on powered optics, the losses are only relative to a standard coated mirror. <b>Environmental Sensitivity</b> : As with LiF-based optics, some of the coatings require low humidity to avoid degredation. Degredation results both in a decrease in peak reflectance, but also an increase in out-of-band transmission. Would not be	<ul> <li>Medium (20 nm) and wide (40 nm) bandpass filter sets covering 100-200 nm</li> <li>Work with shaped optics</li> <li>UV Bandpass Filters</li> <li>&gt;80% peak throughput over central 15 nm for medium band filters (120-200 nm)</li> <li>&gt;50% peak throughput over central 15 nm for medium band filters (100-120 nm)</li> <li>&gt;60% peak throughput over central 30 nm for wide band filters (120-200 nm)</li> </ul>	Covering the FUV bandpass is important for measurements of stellar populations, circumgalactic structures, exoplantary aurorae, and other cosmic origins science. However, no standard set of FUV filters that meet the LUMOS reference design have been built, tested, and calibrated (as noted above, the long-pass filter set on HST suffer from red leaks and rely on uncertain filter-differencing techniques to quantify in-band fluxes and do not meet the HWO science requirements		Per HWO Objectives, TRL 5 is required by the end of 2028, with a viable roadmap to TRL 6. Level of complexity (single tech, system of techs, or system of tech systems): single tech, but demonstration requires a vacuum demonstration in a relevant instrument testbed to be developed Level of difficulty (straightforward, stretch, or major stretch): Straightforward to raise the TRL of existing filters, Stretch to develop fully HWO enabling systems by 2028.
c		applied to telescope optics, so may be easier to hold to low RH than other HWO optics. Teams are experimenting with capping layers for resiliance. Photocathode technologies for photoemissive detectors: Demonstrated broad band sensitivity and various long wavelength cutoff profiles. Newer photocathode implementations (GaN, blue Bialkali) have steep cutoffs (0.1%) at ~350nm but are not yet fully developed. Detector Integrated UV bandpass filters: Metal-dielectric photonic bandgap structures integrated directly onto a Si sensor to block visible light; band center, in band throughput and rejection ratios are tunable. Throughtput rejection ratios >10,000:1 demonstrated (UV peak vs. 500 nm). Preliminary humidity testing show stability up to 70 % RH Dichroic filters: Have been designed for the UV, but are limited at current SOTA. For example the dichroic for the FUV/NUV split in the GALEX instrument demonstrated 50/80% channel efficiencies, repectively, and effective bandwidth in each channel (< 50 nm). The SPARCS FUV/NUV dichroic (split at ~200 nm) similarly exhibited 60/90% channel efficiencies and ~60 nm bandwidth (FUV channel). Reflective Coatings: TRL 4; Multilayer reflective coatings have been used extensively in the heliophysics EUV (9 - 50 nm). These coatings use different matierals, but largely high	<1% throughput (system) at 121.6 nm and <0.0001% to 0.01% throughput (system) at >300 nm Stability/Resiliance: Peak throughput dedine <10% (relative) and out-of-band rejection degradation <20% (relative) with exposure to RH<=50% for 12 months Bandpass Splitting (e.g. Dichroics, edge filters): Mid-UV dichroic Split: R (FUV) > 0.8, T (NUV) > 0.9;			
Improving the Calibration of Far-IR Heterodyne Measurements C	2 Relative instrument flux calibration (flux calibration of one spectral line relative to another line in the same spectrum) of about 1% is required for measurements molecular isotopic line ratios in the THz spectral range (~0.5 – 1.3 THz).	heritage ones (LiF, MgF2, etc). Small telescopes have been prototyped and demonstrated in the lab (FLUID), but not flown. Sub-orbital flight program has been proposed. The FLUID optic size is at the scale of the optics used in LUVOIR/LUMOS. Detector Integrated UV bandpass filters: TRL 5 ; baselined for UVEX (2032); SPARCS (2025), and FIREBall-2 (2025) of The HIFI instrument on Herschel represents the current SOTA for FIR space-based heterodyne spectrometers. The relative calibration accuracy was 5-7%, depending on the frequency band, limited by the sideband ratio and optical standing waves. Other factors, such as the overall beam efficiency, influence the absolute flux calibration, but not the relative flux calibration. The full solution consists of developing an instrument, in which multiple lines are downconverted to the same intermediate frequency band, so that they can be observed simultaneously.	1 Increase the RF and IF bandwidth of the current FIR spectrometers to allow simultaneous observations of multiple spectral lines. Improve the characterization and stability of the sideband ratios, instrument standing waves, as well as the thermal environment to eliminate gain variations between different signal paths.	system materials. Such measurements, e.g., those of oxygen isotopic ratios in water, require ~1% relative flux calibration of	The technology discussed here is directly applicable to heterodyne instrumentation on a future NASA FIR Flagship or a f FIR Probe. A FIR Probe has been identified by Astro2020 as one of two priorities for the first Probe-class mission competition. Astro220 have identified FIR as "an area where advances in technology and focused objectives can yield transformative science on a moderate-sized platform."	Years to estimated launch or other schedule driver: 10 for the FIR probe, 15 for FIR flagship Level of complexity (single tech, system of techs, or system of tech systems): System of techs Level of difficulty (straightforward, stretch, or major stretch): Stretch
Large-Format, High-Spectral-Resolutio Small-Pixel X-ray Focal Plane Arrays	some sections of the array corresponding to sub-arcsecond imaging (i.e. < 25 µm pixels), and with resolving powers of 1k to 6k over various energy ranges to	<ul> <li>The Lynx X-ray Microcalorimeter Technology Roadmap (https://www.lynxobservatory.com/blog/roadmaps) identified two candidate detector technologies that remain the most promising for future X-ray flagship mission and remain those with most potential for meeting this gap. Transition-edge sensors (TES) (detectors only) were judged to be at TRL-4 for Lynx, and Magnetic Micro-calorimeters (MMCs)</li> <li>were judged to be TRL 3 for Lynx. Further work is needed on these technologies to reach TRL-5 for such a demonading future mission, with pixel numbers increasing from ~ 2k pixel (0.32 mm in pitch) for NewAthena's X-ray Integral Field Unit instrument, to over 100k pixels for a future X-ray flagship mission</li> <li>S. J. Smith et al., "Toward 100,000-Pixel Microcalorimeter Arrays Using Multi-absorber Transition-Edge Sensors," J Low Temp Phys, vol. 199, no. 1–2, pp. 330–338, Apr. 2020, doi: 10.1007/s10909-020-02362-0.</li> <li>S. J. Smith et al., "Multi-absorber transition-edge sensors for X-ray astronomy", Journal of Astronomical Telescopes, Instruments, and Systems 5(2), 021008 (Apr–Jun 2019), special ed. on The Lynx X-ray ray Observatory. 2019.</li> </ul>	The following reflects the goal of the Lynx concept in 2020. With more time for development, even smaller pixel sizes and even larger arrays in terms of pixel number and field-of-view are possible, enabling even greater observations of extended sources the X-ray Universe. Main Array: Parameter Requirement Technical Requirement Energy Range 0.2-7 keV for 3 eV Field of View ≥ 5 arcmin ≥ 300 ´ 300 pixels ~100k pixels Pixel size ≤ 1 arcsec ´ 1 arcsec ≤ 50 µm ´ 50 µm	based and airborne assets, such as Herschel, SOFIA, or Rosetta.	In addition the X-ray Great Observatory mission, X-ray microcalorimeters could potentially be used on a variety of different future X-ray missions beyond NewAthena. For example, The Light Element Mapper LEM, a proposed Probe. Opportunities might also exist for their use in the Time-Domain Astrophysics Program (larger than an Explorer but less than	of the X-ray Great Observatory prior to its build-up scheduled for the latter half of this decade. It is imperitive to have TRL demonstrations in order for cost estimates to be similar to current estimated grass-roots cost estimates, and be forseen cost-cap of the X-ray Great Observatory. This has been demonstrated very clearly through the review proce the two most recent Decadal Surveys. For these demonstrations, a full cryogenic detector system is needed comprisi a system of technologies that includes a detector, cold readout electronics, and warm readout electronics. This is pri the program of development needed in the latter part of the decade where a flight-like prototype will be needed
Ρ		<ol> <li>S.J. Smith et al., "Multi-absorber transition-edge sensors for X-ray astronomy", Journal of Astronomical Telescopes, Instruments, and Systems 5(2), 021008 (Apr-Jun 2019), special ed. on The Lynx X-ray Observatory, 2019.</li> <li>F. T. Jaeckel et al., "Calibration and Testing of Small High-Resolution Transition Edge Sensor Microcalorimeters With Optical Photons", IEEE Trans. On Appl. Sup. 31(5), 2100305 (2021).</li> <li>A.M. Devasia, S.R. Bandler, K. Ryu, T.R. Stevenson, W. Yoon, "Large-Scale Magnetic Microcalorimeter Arrays for the Lynx X-Ray Microcalorimeter", Volume 209, pages 337-345, (2022).</li> <li>S.R. Bandler, A. Devasia, B. Mates. K. Ryu, T.R. Stevenson, J. Ullom, W. Yoon, "New X-ray Detectors to Provide Unprecedented Vision of the Invisible Universe", NASA SMD Technology Highlight, https://science.nasa.gov/science-research/science-enabling-technology/new-x-ray-detectors-to-provide- unprecedented-vision-of-the-invisible-universe/, August 2023.</li> </ol>	Field of View ≥ 5 arcmin ≥ 300 300 pixels ~100k pixels         Pixel size ≤ 1 arcsec 1 arcsec ≤ 50 µm 50 µm         Energy Resolution 3 eV (FWHM)         Enhanced Main Array:         4       Parameter Requirement Technical Requirement         Energy Range 0.2-7 keV for 3 eV         Field of View ≥1 arcmin 1 arcmin ≥ 120 120 pixels ~14.4k pixels         Pixel size ≤ 0.5 arcsec 10.5 arcsec ≤ 25 µm 25 µm         Energy Resolution ≤ 2 eV (FWHM)			the program of development needed in the latter part of the decade where a flight-like prototype will be needed integrating a flight-like focal plane assembly, cooling system (cryocoolers and ADRs), and cryostat.
Large-Format, Low-Noise and Ultralow	<ul> <li>w- 2 The most important technology for the FIR/submillimeter is large-format detectors that operate with high efficiency (≥ 80%), low noise, and relatively fast time</li> </ul>			Sensitivity reduces observing times from many hours to a few minutes (≈ 100× faster), while array format increases areal	Far-IR Flagship	Need to demonstrate TRL 6 by mission PDR
C Large-Format, Low-Noise and Ultralow Noise Far-IR Direct Detectors Low-Power Readout and Multiplexing for CMB Detectors	constant. Arrays containing thousands of pixels are needed to take full advantage of spectral information content. Arrays containing tens of thousands of pixels are needed to take full advantage of the focal plane available on a large, cryogenic telescope. Detector sensitivity is required to achieve background-limited performance, using direct (incoherent) detectors to avoid quantum-limited sensitivity.	Sensitive (noise-equivalent power ,NEP, of low 10 <sup>-19</sup> W/vHz), fast detectors (TES bolometers, and MKIDs in kilo pixel arrays) are at TRL 3.(Suzuki, 2015), (Baselmans, 2017)	Detector sensitivities with NEP of $\approx$ 3×10 <sup>-20</sup> W/√Hz are needed for spectroscopy (enabling), available in a dose-packed configuration in at least one direction. NEPs of 3x10 <sup>-21</sup> W/√Hz would enable background limited sensitivity(Echternacht, 2018) (enhancing) The detector system should be scalable to enable ~million-pixel total format (10k~50k pixels per sensor) in a large mission. Array size of 1x10 <sup>4</sup> is enabling and 5x10 <sup>4</sup> is enhancing	coverage by ×10-100. Overall mapping speed can increase by factors of thousands. Sensitivity enables measurement of low-surface-brightness debris disks and protogalaxies with an interferometer. This is enabling technology.	Far-IR Probe FIR detector technology is an enabling aspect of all future FIR mission concepts, and is essential for future progress. This technology can improve science capability at a fixed cost much more rapidly than larger telescope sizes. This development serves Astrophysics almost exclusively (with some impact on planetary and Earth studies).	Need to demonstrate TRL 6 by mission PDR Single tech Extreme stretch
	assembly, it will be necessary to multiplex the readout. The readout systems will require broadband and low-noise amplification at cryogenic temperatures, followed by electronics operated at ambient temperatures that process and digitize time-stream data. These systems must operate at powers appropriate for a	frequency-division multiplexing (FDM) where variations in optical loading amplitude modulate within narrow frequency channels, and even RF-multiplexing (RFmux) where optical loading frequency (phase) a modulates in narrow frequency channels. The CMB and far-IR community have similarly demonstrated KID and TKID readout using RF-multiplexing. TDM has demonstrated a multiplexing factor of ~10,	Fast detector time constant (~200 µs) is needed for Fourier-transform spectroscopy. 1. Demonstrate multiplexing with a 100x reduction in cable count, which is a multiplexing factor that includes lines for electronics control (e.g. bias and feedback lines). The added noise from multiplexing must be subdominant to background noise and the detectors' fundamental noise. 2. Demonstrate cryogenic amplification at 100 mK base temperatures.	infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and	CNID MODE, ANAY MODE, FAINK MODE	Years to estimated launch or other schedule driver: <b>10</b> . Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> .
Millimeter-Wave Focal-Plane Arrays fo CMB Polarimetry	<ul> <li>assembly, it will be necessary to multiplex the readout. The readout systems will require broadband and low-noise amplification at cryogenic temperatures, followed by electronics operated at ambient temperatures that process and digitize time-stream data. These systems must operate at powers appropriate for a satellite and must be robust against L2's radiation environment.</li> <li>A CMB Probe requires arrays of detectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, and control of systematic errors at multiple frequencies between ~10 and ~1000 GHz for foreground removal. Architectures must be scalable to large arrays for the requisite sensitivity, which could be achieved with either bolometeric devices (e.g. TESes, TKIDs) or with thermal devices (e.g. KIDs). High multiplexing factors are efficient detector and readout focal-plane packaging are necessary design characteristics. Detector systems must be compatible with the space environment.</li> </ul>	<ul> <li>frequency-division multiplexing (FDM) where variations in optical loading amplitude modulate within narrow frequency channels, and even RF-multiplexing (RFmux) where optical loading frequency (phase) modulates in narrow frequency channels. The CMB and far-IR community have similarly demonstrated KID and TKID readout using RF-multiplexing. TDM has demonstrated a multiplexing factor of ~10, while FDM and RFmux have demonstrated 10-100 level reduction.</li> <li>Cryogenic amplifiers are highly mature, using SQUIDs or HEMT-style amplifiers. TDM readout has also been repeatedly demonstrated with SQUID-like switching operated at ~200mK. Finally, all of these readout schemes have been downsampled, FFTed (as needed) and digitized using FPGA-based electronics systems.</li> <li>Planck demonstrated background-limited performance in space of single bolometers across much of the relevant optical observing bands, although they did not demonstrate optimal radiation hardening. Modern balloon-borne experiments (SPIDER) have demonstrated moderate-sized TES arrays (~1000-5000 detectors) with noise levels approaching space needs, and have made a case that the modern designs are radiation hardened. Modern ground-based CMB experiments have demonstrated arrays with ~10,000 detectors and have shown control of systematics to r~5e-3 levels. These This modern experiments have demonstrated performance over optical bands of 40-300 GHz and stability to ~0.1 Hz.</li> </ul>	<ol> <li>Demonstrate multiplexing with a 100x reduction in cable count, which is a multiplexing factor that includes lines for electronics control (e.g. bias and feedback lines). The added noise from multiplexing must be subdominant to background noise and the detectors' fundamental noise.</li> <li>Demonstrate cryogenic amplification at 100 mK base temperatures.</li> <li>Demonstrate ambient-temperature readout electronics with power-consumption levels compatible with that available for space observatories.</li> <li>Demonstrate both cryogenic amplifier performance and readout electronics in a radiation environment representative of that at L2.</li> <li>Demonstrate radiation hardening for L2 conditions to limit data loss to sub-percent levels, as judged by both total ionizing dose (TID) and single event effects (SEEs)."</li> </ol> The detectors need the following properties: <ul> <li>Background limited in space (0.1-10 aW/rtHz per-detector internal white noise levels; variations are with optical band and loading).</li> <li>Detector/readout time stream bands of 10 mHz - 1 kHz.</li> <li>Demonstrated radiation hardening for L2 conditions to limit dead-time to sub-percent levels.</li> </ul>	TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far- infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays. Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally,	CMB Probe, Far-IR Probe or Flagship.	Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>stretch</b> . Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs.
CMB Polarimetry	assembly, it will be necessary to multiplex the readout. The readout systems will require broadband and low-noise amplification at cryogenic temperatures, followed by electronics operated at ambient temperatures that process and digitize time-stream data. These systems must operate at powers appropriate for a satellite and must be robust against L2's radiation environment.         for       A CMB Probe requires arrays of detectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, and control of systematic errors at multiple frequencies between ~10 and ~1000 GHz for foreground removal. Architectures must be scalable to large arrays for the requisite sensitivity, which could be achieved with either bolometeric devices (e.g. TESes, TKIDs) or with thermal devices (e.g. KIDs). High multiplexing factors are efficient detector and readout focal-plane packaging are necessary design characteristics. Detector systems must be compatible with the space environment. Includes low dielectric exposure to low-energy electrons and robust performance in the presence of cosmic rays. Continued deployment in ground-based and baloon-borne platforms will likely benefit development efforts; however, the performance requirements (see Technical Goals) on detectors for space are much more stringent than those on detectors for ground and balloon experiments, and additional development is mandatory. Finally, there is still a need for radiome style detection chains that would control for low-frequency synchrotron with less stringent base temperature requirements than direct detectors and also offer systematic cross-check against direct detection. This need could be supported by developing high-bandwidth quantum-noise-limited amplifiers; those same amplifiers could also assist readout of KID-style focal planes.	frequency-division multiplexing (FDM) where variations in optical loading amplitude modulate within narrow frequency channels, and even RF-multiplexing (RFmux) where optical loading frequency (phase) modulates in narrow frequency channels. The CMB and far-IR community have similarly demonstrated KID and TKID readout using RF-multiplexing. TDM has demonstrated a multiplexing factor of ~10, while FDM and RFmux have demonstrated 10-100 level reduction. Cryogenic amplifiers are highly mature, using SQUIDs or HEMT-style amplifiers. TDM readout has also been repeatedly demonstrated with SQUID-like switching operated at ~200mK. Finally, all of these readout schemes have been downsampled, FFTed (as needed) and digitzed using FPGA-based electronics systems. Met Planck demonstrated background-limited performance in space of single bolometers across much of the relevant optical lobserving bands, although they did not demonstrate optimal radiation hardening. Modern baloon-borne experiments (SPIDER) have demonstrated moderate-sized TES arrays (~1000-5000 detectors) with noise levels approaching space needs, and have made a case that the modern designs are radiation hardened. Modern ground-based CMB experiments have demonstrated arrays with ~10,000 detectors and have shown control of systematics to r~5e-3 levels. These This modern experiments have demonstrated performance over optical bands of 40-300 GHz and stability to ~0.1 Hz. A note on the TRL level: 3 is a conservative estimate. Even for the extreme goals, the proof of principle is certainly established. Technology has been demonstrated for many cases at a system level (TRL 4), and in a few cases (balloons) in a representative environment (TRL 5); however, these demonstrations are not universal. a	<ul> <li>1. Demonstrate multiplexing with a 100x reduction in cable count, which is a multiplexing factor that includes lines for electronics control (e.g. bias and feedback lines). The added noise from multiplexing must be subdominant to background noise and the detectors' fundamental noise.</li> <li>2. Demonstrate cryogenic amplification at 100 mK base temperatures.</li> <li>3. Demonstrate ambient-temperature readout electronics with power-consumption levels compatible with that available for space observatories.</li> <li>4. Demonstrate both cryogenic amplifier performance and readout electronics in a radiation environment representative of that at L2.</li> <li>5. Demonstrate radiation hardening for L2 conditions to limit data loss to sub-percent levels, as judged by both total ionizing dose (TID) and single event effects (SEEs)."</li> </ul> The detectors need the following properties: <ul> <li>Background limited in space (0.1-10 aWlrHz per-detector internal white noise levels; variations are with optical band and loading).</li> <li>Detector/readout time stream bands of 10 mHz - 1 kHz.</li> <li>Demonstrated radiation hardening for L2 conditions to limit detad-time to sub-percent levels.</li> <li>Spectral response to ~25% bandwidth channels spanning the optical range of 10-1000 GHz.</li> <li>Optical coupling that will match to telescopes with 11.5473 optics.</li> <li>Monoilthic fabrication of sub-arrays efficiently packaged to focal planes with total counts of 10,000-100,000.</li> <li>Must readily integrate into multiplexing that will limit bading on the focal plane to manageable levels (practically, corresponds to a cable count reduction of a factor of ~100).</li> <li>Warm electronics that are compatible with the power and radiation demands of an L2 satellie.</li> <li>A mixture of direct and coherent technologies that will allow for further systematic cross-checks, especially at the low frequency synchrotron monitor channels (40 GHz and bower).<td><ul> <li>TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far-infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays.</li> <li>Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSF's announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead.</li> </ul></td><td>CMB Probe, Far-IR Probe or Flagship.</td><td>Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (straightforward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succ so far. However, investments in the short term are critical and if deferred further, could convert this to a stretch.</td></li></ul>	<ul> <li>TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far-infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays.</li> <li>Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSF's announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead.</li> </ul>	CMB Probe, Far-IR Probe or Flagship.	Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (straightforward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succ so far. However, investments in the short term are critical and if deferred further, could convert this to a stretch.
	<ul> <li>assembly, it will be necessary to multiplex the readout. The readout systems will require broadband and low-noise amplification at cryogenic temperatures, followed by electronics operated at ambient temperatures that process and digitize time-stream data. These systems must operate at powers appropriate for a satellite and must be robust against L2's radiation environment.</li> <li>A CMB Probe requires arrays of detectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, and control of systematic errors at multiple frequencies between ~10 and ~1000 GHz for foreground removal. Architectures must be scalable to large arrays for the requisite sensitivity, which could be achieved with either bobmeteric devices (e.g. TESes, TKIDs) or with thermal devices (e.g. KIDs). High multiplexing factors ar efficient detector and readout focal-plane packaging are necessary design characteristics. Detector systems must be compatible with the space environment. includes low dielectric exposure to low-energy electrons and robust performance in the presence of cosmic rays. Continued deployment in ground-based and baloon-bome platforms will likely benefit development efforts; however, the performance requirements (see Technical Goals) on detectors for ground and baloon experiments, and additional development is mandatory. Finally, there is still a need for radiome style detection chains that would control for low-frequency synchrotron with less stringent base temperature requirements than direct detectors and also offer systematic cross-check against direct detection. This need could be supported by developing high-bandwidth quantum-noise-limited amplifiers; those same amplifiers could also assist readout of KID-style focal planes.</li> <li>A CMB satellite observatory will require telescope optics and other elements in the optical path that differ substantially from those used in optical and near-IR bands. Many of these technologies have been demons</li></ul>	<ul> <li>frequency-division multiplexing (FDM) where variations in optical loading amplitude modulate within narrow frequency channels, and even RF-multiplexing (RFmux) where optical loading frequency (phase) and ublates in narrow frequency channels. The CMB and far-R community have similarly demonstrated NID and TKID readout using RF-multiplexing. TDM has demonstrated a multiplexing factor of ~10, while FDM and RFmux have demonstrated 10-100 level reduction.</li> <li>Cryogenic amplifiers are highly mature, using SQUIDs or HEMT-style amplifiers. TDM readout has also been repeatedly demonstrated with SQUID-like switching operated at ~200mK. Finally, all of these readout schemes have been downsampled. FFTed (as needed) and digitized using FFGA-based electronics systems.</li> <li>Planck demonstrated background-finited performance in space of single bolometers across much of the relevant optical lobserving bands, although they did not demonstrate optimal radiation hardening. Modern baloon-borne experiments (SPIDER) have demonstrated moderate-sized TES arrays (~1000-5000 detectors) with noise levels approaching space needs, and have made a case that the nondern experiments have demonstrated performance over optical bands of 40-300 GHz and slability to ~0.1 Hz.</li> <li>A note on the TRL level: 3 is a conservative estimate. Even for the extreme goals, the proof of principle is certainly established. Technology has been demonstrated for many cases at a system level (TRL 4), and in a few cases (baloons) in a representative environment (TRL 5); however, these demonstrations are not universal.</li> <li>Telescope architectures, thermal filters, AR coatings, and modulators have all been demonstrated in ground-based and suborbital telescopes, but only over a narrow range of optical observing channels (Od 300 GHz). Refractive optical elements include vacuum windows, absorbing filters, half-wave plates, and lenses. Materials for optical elements in the far IR and milmeter-wave include plastics such as poly</li></ul>	<ul> <li>1. Demonstrate multiplexing with a 100x reduction in cable count, which is a multiplexing factor that includes lines for electronics control (e.g. bias and feedback lines). The added noise from multiplexing must be subdominant to background noise and the detectors' fundamental noise.</li> <li>2. Demonstrate cryogenic amplification at 100 mK base temperatures.</li> <li>3. Demonstrate ambient-temperature readout electronics with power-consumption levels compatible with that available for space observatories.</li> <li>4. Demonstrate both cryogenic amplifier performance and readout electronics in a radiation environment representative of that at L2.</li> <li>5. Demonstrate radiation hardening for L2 conditions to limit data loss to sub-percent levels, as judged by both total ionizing dose (TID) and single event effects (SEEs)."</li> </ul> The detectors need the following properties: <ul> <li>Background limited in space (0.1-10 aW/rHz per-detector internal white noise levels; variations are with optical band and loading).</li> <li>Detector/readout time stream bands of 10 mHz - 1 kHz.</li> <li>Demonstrated radiation hardening for L2 conditions to limit dead-time to sub-percent levels.</li> <li>Spectral response to ~25% bandwidth channels spanning the optical range of 10.1000 GHz.</li> <li>Optical coupling that will match to telescopes with f/1.5-4/3 optics.</li> <li>Monolithic fabrication of sub-arrays efficiently packaged to focal planes with total counts of 10,000-100,000.</li> <li>Must readily integrate into multiplexing that will limit bading on the focal plane to manageable levels (practically, corresponds to a cable count reduction of a factor of ~100).</li> <li>Vam electronics that are compatible with the align on the focal plane to manageable levels (practically, corresponds to a cable count reduction of a factor of ~100).</li> <li>Vam electronics that are compatible with the power and radiation demands of an L2 satelife.</li> <li>A m</li></ul>	<ul> <li>TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far-infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays.</li> <li>Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSF's announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead.</li> <li>Detection of B-mode polarization in the CMB or setting a stringent upper limit. Robust rejection of foregrounds. Enabling broadband and polarimetric measurements in the far IR. Overcoming the telescope design and implementation challenge</li> </ul>	CMB Probe, Far-IR Probe or Flagship. CMB Probe, Far-IR Probe or Flagship.	Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>stretch</b> . Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succe so far. However, investments in the short term are critical and if deferred further, could convert this to a stretch.
CMB Polarimetry	<ul> <li>assembly, it will be necessary to multiplex the readout. The readout systems will require broadband and low-noise amplification at cyogenic temperatures, followed by electronics operated at ambient temperatures that process and digitze time-stream data. These systems must operate at powers appropriate for a satelile and must be robust against L2's radiation environment.</li> <li>for A CMB Probe requires arrays of delectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, at control of systematic errors at multiple frequencies between -10 and -1000 CH2 for foreground removal. Architectures must be exable to large arrays for the requires ensibility, which could be achieved with ether bolometind devices (e.g. ECBs, TKDS) or with thermal devices (e.g. KDS). High multiplexing factors are efficient detector and readout tocal-plane packaging are necessary design characteristics. Detector systems must be compatible with the space environment. Includes bw dielectric exposure to bwe-nergy electrons and robust performance in the presence of cosmic rays. Continued deployment in ground-based and baloon experiments, and addional development is mandatory. Finaly, there is still a need for radorm more stringent than those on detectors for ground and baloon experiments, and addional development is mandatory. Finaly, there is still a need for radorm syle detection chars that would control for low-frequency synchrotron with less stringent base temperature requirements than direct detectors and also offer systematic coss-check against direct detection. This need could be supported by developing high-bandwidth quantum-noise-imited amplifiers; those same amplifiers could also assist readout of KID-style focal planes.</li> <li>a ACMB satelite observatory will require telescope optics and other elements in the optical path that differ substantially from those used in optical and near-IR bands. Many of these technologies have been demonstrated in grou</li></ul>	frequency-division multiplexing (FDM) where variations in optical bading amplitude modulate within narrow frequency channels, and even RF-multiplexing (RFmux) where optical bading frequency (phase) and dualates in narrow frequency channels. The CMB and far-IR community have similarly demonstrated KID and TKID readout using RF-multiplexing. TDM has demonstrated a multiplexing factor of -10, while FDM and RFmu have demonstrated 10-100 level reduction. Cryogenic amplifiers are highly mature, using SQUIDs or HEMT-style amplifiers. TDM readout has also been repeatedly demonstrated with SQUID-like switching operated at -200mK. Finally, all of these readout schemes have been downsampled, FFTed (as needed) and digited using FPGA-based electronics systems. Planck demonstrated background-limited performance in space of single bolometers across much of the relevant optical observing bands, although they did not demonstrate optimal radiation hardening. Modern baloon-bome experiments (SPIDER) have demonstrated moderate-sized TES arrays (-1000-S000 detectors) with noise levels approaching space needs, and have made a case that the modern designs are radiation hardened. Modern ground-based CMB experiments have demonstrated arrays with -10,000 detectors and have shown control of systematics to r-5e-3 levels. These filts modern experiments have demonstrated performance over optical bands of 40-300 GHz and stability to -0.1 Hz. A note on the TRL level: 3 is a conservative estimate. Even for the extreme goals, the proof of principle is certainly established. Technology has been demonstrated for many cases at a system level (TRL ter 4), and in a few cases (baloons) in a representative environment (TRL 5); however, these demonstrated in ground-based and suborbial telescopes, but only over a narrow range of optical observing channels (40-300GHz). Refractive optical elements indude vacuum windows, absorbing filters, half-wave plates, and lenses. Materials for optical elements in the far IR and milimeter-wave i	1. Demonstrate multiplexing with a 100x reduction in cable count, which is a multiplexing factor that induces lines for electronics control (e.g. bias and feedback lines). The added noise from multiplexing multiple subdominant to badground noise and the detector's fundamental noise.         3. Demonstrate propertic amplification at 100 mK base temperature.       3. Demonstrate induces and the detector's fundamental noise.         3. Demonstrate bind propertic amplification at 100 mK base temperature.       4. Demonstrate bind propertics.         3. Demonstrate bind propertics.       5. Demonstrate bind propertics.         4. Demonstrate bind propertics.       5. Demonstrate bind propertics.         9. Bedground limited in space (1)-10 a Withtz perdetector internal white noise levels, variations are with optical band and loading).         9. Demonstrate for the strain bind of 10 mK - 1 Hiz.         9. Demonstrate for the strain bind of 10 mK - 1 Hiz.         9. Demonstrate for the strain bind of 10 mK - 1 Hiz.         9. Demonstrate for the strain bind of 10 mK - 1 Hiz.         9. Optical coupling that will mit backing on the focal plane with that outs of 10,000.014.         9. Optical coupling that will mit backing on the focal plane with that outs of 10,000.014.         9. Wondbits fabrication does in the diabet of rule plane to manageable by leb (practically, corresponds to a cable count reduction of a factor of ~100).         9. Wondbits fabrication does that will alw to further systematic cores dhecks, sepacially at the bind reduction of a factor of ~100).         9. Wondbits fabrica	TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far- infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays. Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSFs announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead.	CMB Probe, Far-IR Probe or Flagship. CMB Probe, Far-IR Probe or Flagship.	Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (straightforward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succe so far. However, investments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated launch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer to 2030s. Level of complexity (single tech, system of techs, or system of tech systems): system of techs: telescope + optical components.
P Optical Elements for a CMB Space Miss P	assembly, it will be necessary to multiplex the readout. The readout systems will require "broadband and bu-noise amplification at cryogenic temperatures."         followed by electionics operated at ambient temperatures that process and digites time-stream data. These systems must operate at powers appropriate for isstellate and must be robust against L2's radiation environment.         for       2       A CMB Probe requires arrays of detectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, and control of systematic errors at multiple frequencies between -10 and -1000 GHz for foreground removal. Architectures must be scalable to large arrays for the requires assertive to low-energy electrons and robus performance in the presence of coxin: ros. Continued dephyment is ground-based and baloon-bome platforms will kely benet field evelopment for forst, however, the performance requirements (see Technical Goals) on detectors for space are much used wide better exposure to bow-energy electrons and robus performance in the presence of coxin: ros. Continued dephyment is ground-based and baloon experiments will kely benet field detection. This need could be supported by developing high-bandwidth quantum-noise-imited amplifiers; those same amplifiers could also assist readout of KID-style focal planes.         ission       2       A CMB statilite by-frequency synchrotron ontrols. A fair Regue missi (abc) GH2 by on-orbit a starshade that is stowed in a kunch vehicle fairing to a precise shape, and to maintain that shape precision during all operational evelopments. All of these will need to preserve polarization stales to high levels of fidelity.         ability       2       The capability to deploy on-orbit a starshade that is stowed in a kunch vehicle fairing to a pre	Integrancy-dision multiplexing (FDM) where subtions in optical bading amplitude modulites with namew frequency channels, and even RF-multiplexing. TDM has demonstrated a multiplexing factor of ~10, while FDM and RFmux have demonstrated 10-100 kvel reduction.           Copging amplifies are highly mature, using SQUDS or HEMT-style amplifies. TDM madout has also been repeatedly demonstrated with SQUD-like switching operated at ~200mK. Finally, all of these madout schemes have been downsimped. FFTed (as needed) and glated using FPGA-based electronics system.           Pland: demonstrated badgioun-fined performance in gale of single biometers across much of the relevant optical observing bands, although they did not demonstrate optimal rediation hardening. Which halos no time operations (Meding ground-acade CMB experiments have demonstrated arms with ~100 coll detectors) with noise levels approaching space needs, and have mode a case that the dimade materials arms with ~100 coll detectors and have and as are soft ~100. While FDM endots and have is and across and coll of splanatics to ~5+3 kivels. These that me demonstrated performance were optical bands of 40-300 GHz and stability to ~0.1 Hz.           A note on the TRL keys 1 is a consentate estimate. Even for the externe goals, the proof of principle is certainly establed. Technology has been demonstrated for many cases at a system level (TRL 4), and in a few cases (ballowing) in a representative acuum windows, absorbing filters, balk-wave pilters, and esses. Metricike for optical elevancies windows glates and a system in coll of an administrace window palses and levane segments.           5         fortering to the active stress and the externes and the externes of forter do principle is certainly establed. Technology has been demonstrated for many cases at a system level (TRL 4), and in a few cases (ballowing) in a representati	<ol> <li>Demonstrate mapping with a 100 reduction in cable out, which is a multiplexing factor that includes less for electronics control (e.g. bus and feedback lines). The added noise from multiplexing multi</li></ol>	TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far- Infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays. Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the allowed variety of models of inflation. Excellent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSF's announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead.	CMB Probe, Far-IR Probe or Flagship. A CMB space mission akin to PICO (https://arxiv.org/abs/1902.10541) or similar. Could also be relevant to far-IR missions (probe or flagship). HWO; other future starshade missions	Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (straightforward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been success far. However, investments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated launch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer to 2030s. Level of complexity (single tech, system of techs, or system of tech systems): system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch): straightforward. TRL 6 needed by mission PDR.
CMB Polarimetry         P         Optical Elements for a CMB Space Miss         P         P         Starshade Deployment and Shape Stable         E         Starshade Starlight Suppression and M         Validation         E         Stellar Reflex Motion Sensitivity:	assembly, it will be necessary to multiplex the readout. The readout systems will equire broadehand and bow-noise amplification at cryogenic temporatures.         for       2       A CMB Probe requires arrays of detectors with system noise temperatures near those of the sky (CMB + foregrounds), dual-polarization detection capability, and ontoil of systematic errors at multiple frequences between -10 and -1000 GHz for foreground rerowal. Architectures must be acabable to large arrays of the module cashibity, which cube the achieved with their bobmaried devices (as [CSB. H] multiplesing factors are effected detector and readout focal-plane packaging are necessary de grafts. Tableo are vibrational activity with how the active and with their bobmaried devices (as [CSB. H] multiplesing factors are effected detectors and and trobust performance in the presence of osmic rays. Continued deplyment in ground-based and balon-bone platforms will key beneft development efforts, however, the performance equirements (see Tableoffacial Gash) on detectors for gase are multiplesing factors are stringent than these an detectors for ground and balon experiments, and additional development is mandatory. Finally, there is still are of or radium sight detection chains that would be applied and near the singent than these and eclosis for gase are multiples; factors and as of the supported by developing high-bandwidth quantum-noise-inited are places. These explanes are equiverents, but only over a interdeption and a solution of the subscinetions and as a place and as about the size and a solution (WB explanes). These setting are explained as a predict as an about for bar-frequences (addition and as about the subscinetions) will have be accessed as a data of the subscinetion on a solution are within the apple barbor will require the subscinetion on the size and the subscinetion of the subscinetion on the subscented of the subscinetions and as of the subscinted of	Integrand-Mission multiplesing (FDM) where variations in optical bacing amplitude module within narrow frequency channels, and even FP-multiplexing. TDM has demonstrated a multiplexing factor of -10, where FDM and RFmux have demonstrated 10-100 level reduction.           Optical amplifies are highly malure, using SQUDs or HEMT dyte amplifies. TDM readout has abe been repeatedly demonstrated with SQUD-Re selecting optical additional statemests have been downsampled. FFrate (as needed) and dyted using FPGA-based electronics splanns.           Image: Plant demonstrated Discound-Merted performance is aged of single boometers across much of the relevant optical boexing bands, athough they did not demonstrate optimal radiation hardening: model and sub-othere sparse indicates harder performance is aged of single boometers across much of the relevant optical boexing bands, athough they did not demonstrate optimal radiation hardening: model meapsiminis have demonstrated performance aver optical based. Of Beoperiments have demonstrated arrays with -10,000 detectors and have shown control of systematics to r.5-3 levels. These the model mapser internation of the externe goats, the pool of principle is certainly estableted. Technology has been demonstrated for many cases at a system level (TRL 4), and in a few cases (baborne) in a mpresentative environment (TRL 5); however, these demonstrated in ground-based end/with depend on the relevant optical elevants in the fair IR and mainterevave include plastics such as pophythyne and to find ensites for approximation or an invested is antiver dynames in the distra system invested is antiversed on costing (ARC) through applying null-levers (ML), and in a few cases (baborne) in a mpresentative environment (TRL 5); however, these demonstrated in ground-based and/with depend on the antiversed on costing (ARC) through applying null-levers (ML), and in a few cases state system invest. Applying the state accord wi	<ul> <li>1. Demonstrate ratiobary eth. 100 mcbase from enables on the in a ratiobary data that includes free breaks control (e.g., bias and feedbard line).</li> <li>2. Demonstrate optication and the developer for formational table.</li> <li>3. Demonstrate optication and the developer formation at the optication and table optication and table optication.</li> <li>3. Demonstrate optication and the developer on the break optication and table optication and table optication.</li> <li>4. Demonstrate optication and the optication and table optication and table optication.</li> <li>4. Demonstrate optication and the optication and table optication are set optical band and badreg).</li> <li>4. Demonstrate optication and table optication and table optications are set optical band and badreg).</li> <li>4. Demonstrate optication and table optication and table optications are set optical band.</li> <li>4. Demonstrate optication and table optications are set optical band.</li> <li>4. Determination of the optication optication and table optications are set optical band.</li> <li>4. Determination of table optications are set optical band.</li> <li>4. Determination of table optications are set optical band.</li> <li>4. Determination of table optications are set optical band.</li> <li>4. Determination optication and table optication and table optication and table optication.</li> <li>4. Determination optication and table optication and table optication.</li> <li>4. Determination optication and table optication and table optication.</li> <li>4. Determination optication and table optication optication</li></ul>	TES sensors are used by a wide range of astrophysics and high-energy physics experiments including CMB, X-ray, far- infrared astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment will benefit from readout technology that displates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMIs and cosmic rays. Use in a CMB probe mission, where detection of B-mode polarization in the CMB and hence a gravitational wave background would reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the alkowed variety of models of inflation. Excelent measurements of B-modes due to lensing would afford unique determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DOE 2023 P5 decadal survey gives CMB the highest rating for new projects. NSF's announcement of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based alternatives, and if started soon, will reach the community's science objectives many years ahead. Detection of B-mode polarization in the CMB or setting a stringent upper limit. Robust rejection of foregrounds. Enabling broadband and polarimetric measurements in the far IR. Overcoming the telescope design and implementation challenge now could save significant development time when the mission is selected for a start. The starshade must create contrast levels to better than 10-10 in the image plane with shape tolerances specified by an error budget. The precise positioning and manufacture of the starshade edges minimas the diffraction of news startigh and scatteridiffraction of off-axis Sunght detected at the science focal plane. The starght suppression capabilities of the starshade must be demonstrated on the ground to validate optical modes and the error budget, which are used to pr	CMB Probe, Far-IR Probe or Flagship. A CMB space mission akin to PICO (https://arxiv.org/abs/1902.10541) or similar. Could also be relevant to far-IR missions (probe or flagship). HWO; other future starshade missions	Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (straightforward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been success far. However, investments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated launch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer to 2030s. Level of complexity (single tech, system of techs, or system of tech systems): system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch): straightforward. TRL 6 needed by mission PDR. TRL 6 needed by mission PDR.
P       Optical Elements for a CMB Space Miss         P       Optical Elements for a CMB Space Miss         P       Starshade Deployment and Shape Stab         E       Starshade Starlight Suppression and M         Validation       Stellar Reflex Motion Sensitivity:         Astrometry       Stellar Reflex Motion Sensitivity: Extrem         Precision Radial Velocity       Precision Radial Velocity         E       Warm Readout Electronics for Large-Format Far-IR Detectors	assembly, it will be necessary to multiples the readout, softere will equire broadband and two-roles amplification at cryogenic temperatures. In the broadband temperatures in the process and digities time-stream data. These systems must operate at provers appropriate for setelike and must be robust against L2's radiation environment.           for         2         A CMB Proble requires arrays of detectors with system roads temperatures in tops of the sky (CMB - foreground), dual-potentiation detector appablic, a control of systemic ream at multiple impactness between - 10 and -1000 GHz for foreground in CMB. (ADB, High multiplexing factors array for the top control of systemic reams at multiple padaging are necessary degin dramatication. Detecting temperatures arrays of the detection appading the necessary degin dramatication. Detecting temperatures in the source and actual foreable padaging are necessary degin dramatication. Detecting temperatures are set to appatible with space environment in discontoor the patient detection for your and and babon house, patient for the set op control of systems with by operating to the viewspace systems, and additional development a finance docute for approximation with by stemating to the viewspace in systems that and and to stop temperatures in the operation of the set operation with the stemation of the viewspace systems and additional development approximate that and the operation of the viewspace systems that and and the view operating that the presence of control systems and the control of the systems that and the presence of control systems must be compatible with the stemate and the systems that additional development for the systems that additional development for top temperatures in the operation with the stemate and the systems that additional development for the systems that additional development for the systems that additional development frequence system that the stemperature in the system of	https://doi.org/10.1011/j.com/2014/2014/2014/2014/2014/2014/2014/2014	<ul> <li>Denotative includency of in 100 mcbase for an additional road to come which is a maripleving factor that indices in the indices indices.</li> <li>Demonstrate an indice indices in the indices in the indices indices in a markation environment expresentiate of the indices indices.</li> <li>Demonstrate indices indintices indices indices indices indices indintices indices in</li></ul>	TES sensors are used by a wide range of astophysis and high-energy physis experiments holding CMB. X-ray, far- finance astrophysis, dark matter searches, and neutrinoises doub beat decay. Every experiment wite beach readout technology that dissipates small amounts of heat, requires less electrical power, and is light weight, reliable and nobust against EMs and cosmic rays. Use in a CMB probe mission, where defection of B-mode polarization in the CMB and hence a gravitational wave background work reveal the energy scale of inflation. Stringent upper limits on B-modes would strongly reduce the ablowed variety of modes of inflation. Excellent measurements of B-modes due to lensing would afford unque determination of neutrino masses. These technologies may also benefit future far-IR missions (probe or flagship). Finally, DC 2023 FPG stread survey gives CMB the highest rating for new projects. NE's a noncommernet of not supporting the observations at the South Pole that target inflation science elevates the role for a space mission. For the first time in decades, a CMB space mission is cheaper than the ground-based aternatives, and if started soon, will reach the community's science objectives many years ahead. Detection of B-mode polarization in the CMB or setting a stringent upper limit. Robust rejection of foregrounds. Enabling troadband and polarimetric measurements in the far IR. Overcoming the telescope design and implementation chalenge now could save significant development time when the mission is selected for a start.	CMB Probe, Far-IR Probe or Flagship. CMB Probe, Far-IR Probe or Flagship. A CMB space mission akin to PICO (https://anki.org/abs/1902.10541) or similar. Could also be relevant to far-IR missions (probe or flagship). HWO; other future starshade missions HWO; other future starshade missions HWO HWO	Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> . Level of difficulty (straightforward, stretch, or major stretch): <b>stretch</b> . Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succe so far. However, investments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated launch or other schedule driver: <b>10 years</b> to CMB probe, or for a far-IR probe that might defer to 2030s. Level of complexity (single tech, system of techs, or system of tech systems): <b>system of techs</b> : telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch): <b>straightforward</b> . TRL 6 needed by mission PDR. TRL 6 needed by mission PDR. If a need for a precision astrometry mode in the IR/O/UV Great Observatory is identified, then demonstration of feat and as much risk reduction as possible prior to mission formulation. TRL 6 in the late 2020's. If a need for space-based RV is identified, then need TRL 6 in the late 2020's. If ground-based supporting role is
P   P   Optical Elements for a CMB Space Missi   P   P   P   E   Starshade Deployment and Shape Stab   E   Starshade Starlight Suppression and M   Validation   E   Stellar Reflex Motion Sensitivity:   Astrometry   E   Stellar Reflex Motion Sensitivity: Extrem   Precision Radial Velocity   E   C   Broadband X-ray Polarimeter   P   Charged-Particle-Discriminating X-	asteritik ji u tit a nesissing in nitjes tile exclut. The result of all bis insistential all bis med seements and gipter insistential and russing assignments and gipter insistential and russing assignment and gipter insistential and russing assignment and gipter insistential and russing assignment and assignment and gipter insistential and russing assignment and assignment and assignment assignment and assignment assignment and assignmentand assignmentand assignment and assignment and assignment and ass	<ul> <li>Inspanderen ingeleren (handen). The defendence of the advectory densets, and you PE-nutperior (PE-nutperior) (PE-</li></ul>	<ul> <li>1. Discretismin exploration and the attribute framework in the second provide for the model for the</li></ul>	TS sensors are used by a wider range of astrophysics and high-energy physics experiments including CMS. X-ray, far- findend astrophysics, dark matter exarches, and neutrinoles double bed deay. Every experiment with energit from readout technology that displaces and amounts of heat, requires less electrical power, and is light weight, reliable and obust against EMS and cosmic rays.	CMB Probe, FarsIR Probe or Flagship. CMB Probe, FarsIR Probe or Flagship. A CMB space mission akin to PICO (https://antiv.org/abs/1902.10541) or amler. Could also be relevant to far-IR missions (inclue or flagship). WWC; other future starshade missions WWC; other future starshade missions WWC; other future starshade missions WWC other future starshade missions WWC HWC HWC HWC HWC HWC HWC HWC HWC HWC	Level of complexity (single tech, system of techs, or system of tech systems): system of techs. Level of difficulty (single/toward, stretch, or major stretch): stretch. Years to estimated launch or other schedule driver: 10. Level of complexity: system of techs. Level of difficulty: straightforward because we already have a strategy on how to move forward that has been succ so far. However, investments in the short term are ortical and if deferred further, could convert the to a stretch. Years to estimated launch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer b 2030s. Level of complexity (single tech, system of techs, or system of tech systems): system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch): straightforward. TRL 6 needed by mission PDR. TRL 6 needed by mission PDR. If a need for a precision astrometry mode in the IR/OUV Great Observatory is identified, then demonstration of feat and as much risk reduction as possible prior to mission formulation. TRL 6 in the late 2020s. If a need for space-based RV is identified, then need TRL 6 in the late 2020s. If ground-based supporting role is identified, then capability is needed well alread of launch in early 2030s. Need to demonstrate TRL 6 by mission PDR.
P       CMB Polarimetry         P       Optical Elements for a CMB Space Mission         P       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and M         E       Starshade Starlight Suppression and M         Validation       Stellar Reflex Motion Sensitivity:         E       Stellar Reflex Motion Sensitivity: Extreme         Precision Radial Velocity       Precision Radial Velocity         E       Warm Readout Electronics for Large-         C       Broadband X-ray Polarimeter         P       Charged-Particle-Discriminating X-ray/Gamma-ray Detectors	assembly, in the necessary to induption to record. The redoct system in targets benchow as how-loss and regions motopools inspace to respective system in the operating of the target instruments. The regions must be recurs approximate in the instrument instruments in the process and rights the reduction as the recurs approximate in the instrument instruments. The regions must be subset with reduction instruments in the result against (2 to relation an encomponent instruments). The regions must be subset with reduction in the result against (2 to relation and reduction instruments in the result against (2 to relation and reduction instruments). The regions are not an efficient instrument instrument instrument instruments in the result in the result in reduction in the result is a bandward with the relation instruments in the regions in the result in reduction in the result in reduction in the result is a bandward with the relation of reduction in the result is a result in the result instrument in reduction in the result is a result in the result in reduction in the result is a result in the result in reduction in the result is a result in reduction in the result is a result in reduction in the result is a result in reduction in the result is result in result in reduction in the result is result in result in reduction in the result is result in result in result in reduction in the result is result in re	Tensor of the second s	<ol> <li>Denomics multiples get a 150 evolution is all control with a multiples get and hadden into the relation control to gate and testing of the addent control to explore an addent control to explore and the addent control to explore and the addent control to explore a denomics and the addent control to explore addent control to</li></ol>	TES sensor are used by a wide marge of astrophysics and high-energy physics operiments induding CMS, X-ray, far- finered astrophysics, dark matter searches, and neutrinoless double beta deay. Every separater with beneff from madout technology that displates small amounts of heat, requires less electrical power, and is light weight, reliable and robust against EMs and coarter org.	CMB Probe, FarlR Probe or Flagship.         A CMB space mission akin to PEO (https://anix.org/abd/1902.10541) or similar. Could also be relevant to farl R missions (probe or flagship).         HWO: other future standards missions         HWO: other future standards missions         HWO: other future standards missions         HWO         HWO <td< td=""><td>Level of complexity (single tech, system of tech, or system of tech system): system of techs. Level of officially (straightforward, stretch, or major stretch): stretch. Years to estimated baunch or other schedule driver: 10. Level of officially, straightforward, because we already have a strategy on how to move forward that has been success for . Level of difficulty, straightforward because we already have a strategy on how to move forward that has been success for . However, mestments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated baunch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer h 2030s. Level of complexity (single tech, system of techs, or system of tech systems); system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch); straightforward. TRL 6 needed by mission PDR. TRL 6 needed by mission PDR. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for space-based RV is identified, then need TRL 6 in the like 2020s. If ground-based supporting role is dentified, then capability is needed well ahead of bunch in early 2030s. Need to demonstrate TRL 6 by mission PDR. Level of complexity (single tech. system of techs, or system of tech system;); combination of 3 technologies that have already been developed and tested in neivenit environments. Level of difficulty (straightforward, stretch, or major stretch); Straightforward. Years to estimated bunch or other schedule driver: 10 Level of omplexity (single tech. system of techs, or system of tech system;); singl</td></td<>	Level of complexity (single tech, system of tech, or system of tech system): system of techs. Level of officially (straightforward, stretch, or major stretch): stretch. Years to estimated baunch or other schedule driver: 10. Level of officially, straightforward, because we already have a strategy on how to move forward that has been success for . Level of difficulty, straightforward because we already have a strategy on how to move forward that has been success for . However, mestments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated baunch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer h 2030s. Level of complexity (single tech, system of techs, or system of tech systems); system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch); straightforward. TRL 6 needed by mission PDR. TRL 6 needed by mission PDR. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for space-based RV is identified, then need TRL 6 in the like 2020s. If ground-based supporting role is dentified, then capability is needed well ahead of bunch in early 2030s. Need to demonstrate TRL 6 by mission PDR. Level of complexity (single tech. system of techs, or system of tech system;); combination of 3 technologies that have already been developed and tested in neivenit environments. Level of difficulty (straightforward, stretch, or major stretch); Straightforward. Years to estimated bunch or other schedule driver: 10 Level of omplexity (single tech. system of techs, or system of tech system;); singl
P   P   Optical Elements for a CMB Space Missi   P   P   P   E   Starshade Deployment and Shape Stab   E   Starshade Starlight Suppression and M   Validation   E   Stellar Reflex Motion Sensitivity:   Astrometry   E   Stellar Reflex Motion Sensitivity: Extrem   Precision Radial Velocity   E   C   Broadband X-ray Polarimeter   P   Charged-Particle-Discriminating X-	assembly, in the necessary to induption to record. The redoct system in targets benchow as how-loss and regions motopools inspace to respective system in the operating of the target instruments. The regions must be recurs approximate in the instrument instruments in the process and rights the reduction as the recurs approximate in the instrument instruments. The regions must be subset with reduction instruments in the result against (2 to relation an encomponent instruments). The regions must be subset with reduction in the result against (2 to relation and reduction instruments in the result against (2 to relation and reduction instruments). The regions are not an efficient instrument instrument instrument instruments in the result in the result in reduction in the result is a bandward with the relation instruments in the regions in the result in reduction in the result in reduction in the result is a bandward with the relation of reduction in the result is a result in the result instrument in reduction in the result is a result in the result in reduction in the result is a result in the result in reduction in the result is a result in reduction in the result is a result in reduction in the result is a result in reduction in the result is result in result in reduction in the result is result in result in reduction in the result is result in result in result in reduction in the result is result in re	Integrand (data) multiplication (Toppers) datasets): Top of a local data (frame which must be leaved of the Control of the multiplication) of Toppers) datasets (toppers) datasets (toppers) datasets): Top of a local data (frame which are determined at a multiplication) of the multiplication of toppers) datasets (toppers) datasets (toppers) datasets): Toppers): TopPers are determined at a multiplication of toppers) datasets (toppers) datasets): Toppers): TopPers are determined at a multiplication of toppers): TopPers are determined at toppers): TopPers are determined at toppers are determined at toppers): TopPers are determined at the determined at toppers are determined at the determined at toppers are determined at to	Constraints in Response 1 to the state of intermediates     Constraints in Response 1 to the state of intermediates and the give that where the state in Response 1 to the state of intermediates and the give that the state intermediates and the state of intermediates and t	TES sensors are used by a wide mage of astrophysics and high-energy physics experiments including CMB. X-rey, far- findred astrophysics, dark matter searches, and neutrinoless double beta decay. Every experiment with benefit from readout technology that degrades are amounts of heat, requires is as electrical power, and is light weight, reliable and obust against EMB and coartic rays.	OVB Probe, FariR Probe or Pagetip.  A CMB space mission akin to PICO (https://anit.org/abs/1902.10541) or sinter. Could also be relevant to fariR missions (probe or flogshp).  HWO: other future standarde missions  HWO: other future standarde missions  HWO Coller future standarde missions  HWO HWO  HWO  HWO  HWO  HWO  HWO  HWO	Level of complexity (single tech, system of tech, or system of tech system): system of techs. Level of officially (straightforward, stretch, or major stretch): stretch. Years to estimated baunch or other schedule driver: 10. Level of officially, straightforward, because we already have a strategy on how to move forward that has been success for . Level of difficulty, straightforward because we already have a strategy on how to move forward that has been success for . However, mestments in the short term are critical and if deferred further, could convert this to a stretch. Years to estimated baunch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer h 2030s. Level of complexity (single tech, system of techs, or system of tech systems); system of techs: telescope + optical components. Level of difficulty (straightforward, stretch, or major stretch); straightforward. TRL 6 needed by mission PDR. TRL 6 needed by mission PDR. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for a precision astrometry mode in the IR/DUUV Great Observatory is identified, then demonstration of feed and as much risk reduction as possible prior to mission formulation. TRL 6 in the kite 2020s. If a need for space-based RV is identified, then need TRL 6 in the like 2020s. If ground-based supporting role is dentified, then capability is needed well ahead of bunch in early 2030s. Need to demonstrate TRL 6 by mission PDR. Level of complexity (single tech. system of techs, or system of tech system;); combination of 3 technologies that have already been developed and tested in neivenit environments. Level of difficulty (straightforward, stretch, or major stretch); Straightforward. Years to estimated bunch or other schedule driver: 10 Level of omplexity (single tech. system of techs, or system of tech system;); singl
P       CMB Polarimetry         P       Optical Elements for a CMB Space Mission         P       Starshade Deployment and Shape Stab         E       Starshade Starlight Suppression and Mission         E       Starshade Starlight Suppression and Mission         E       Starshade Starlight Suppression and Mission         P       Starshade Starlight Suppression and Mission         E       Stellar Reflex Motion Sensitivity: Extrements         Precision Radial Velocity       Precision Radial Velocity         E       Warm Readout Electronics for Large-Format Far-IR Detectors         C       Broadband X-ray Polarimeter         P       Charged-Particle-Discriminating X-ray/Gamma-ray Detectors         P       Dynamic Switching for Ultra-Low-Powe	methy, 1 bit messions to attribute the methy and the process of the pack in the device and table in the order of process of the proce	Hand the induced matching (2017) are called a logic baddy applied on matching the matching of an analysis of the matching of	<ul> <li>Understanding Registering of NUMERADES is below to the Second Proceeding Second Process Proces Process Process Process Proce</li></ul>	The sentence are used by a web range of astrophysics and high-energy physics experiments including CABL X-ray, fair finance distributions, dust makes exactles, and neutrinoles clubble cleary. Every reperment with benefit from madeut inducting but dispetitions and another of heat, neutrinoles clubble deary. Every reperment with benefit from madeut dishordby that dispetitions of the set, neutrinoles is as elected power, and is right weight, relative and movies of the set. The set of the set o	CMB Probe, FarlR Probe or Flegatip.           ACMB reace means ake to PROD (https://reax.org/ab//1902/10541) or enter. Could also be relevant to farlR mealows (probe or flegatip).           NVO, other future standards mealons           NVO, other future standards mealons           NVO, other future standards mealons           NVO           NVO </td <td>Level of diffully (single toch, system of techs, or system of tech systems): system of techs. Level of diffully (single toch, system of techs, in major stretch): stretch. Years to estimate bunch or other schedule driver: 10. Level of diffully, single toch, system of techs. Level of diffully straightforward, stretch, or major stretch): stretch Years to estimate bunch or other schedule driver: 10 years to CMB probe, or for a farit probe that might defer to 2020a. Level of omplexity (single toch, system of techs, or system of techs, systems): system of techs: telescope - optical components. Level of diffully (single toch, system of techs, or system of techs, steraightforward. TRL 6 needed by masion PDR. TRL 6 in the tele 2020s. If a need for a precision as possible proto mission formulation. TRL 6 in the tele 2020s. If a need of or approximate as possible proto mission formulation. TRL 6 in the tele 2020s. If a need of or approximate the schedule driver. 5-10 years. Level of diffully (single toch, system of techs, or system of tech systems): combination of 3 technologies that have anady been developed and telefel in mission PDR. Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech. Level of diffully (singl</td>	Level of diffully (single toch, system of techs, or system of tech systems): system of techs. Level of diffully (single toch, system of techs, in major stretch): stretch. Years to estimate bunch or other schedule driver: 10. Level of diffully, single toch, system of techs. Level of diffully straightforward, stretch, or major stretch): stretch Years to estimate bunch or other schedule driver: 10 years to CMB probe, or for a farit probe that might defer to 2020a. Level of omplexity (single toch, system of techs, or system of techs, systems): system of techs: telescope - optical components. Level of diffully (single toch, system of techs, or system of techs, steraightforward. TRL 6 needed by masion PDR. TRL 6 in the tele 2020s. If a need for a precision as possible proto mission formulation. TRL 6 in the tele 2020s. If a need of or approximate as possible proto mission formulation. TRL 6 in the tele 2020s. If a need of or approximate the schedule driver. 5-10 years. Level of diffully (single toch, system of techs, or system of tech systems): combination of 3 technologies that have anady been developed and telefel in mission PDR. Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech Level of diffully (single toch, system of techs, or system of tech systems): single tech. Level of diffully (singl
P       CMB Polarimetry         P       Optical Elements for a CMB Space Mission         P       Starshade Deployment and Shape State         P       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and M Validation         E       Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity         E       Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity         E       Broadband X-ray Polarimeter         P       Broadband X-ray Polarimeter         P       Charged-Particle-Discriminating X-ray/Gamma-ray Detectors         P       Dynamic Switching for Ultra-Low-Power High-Resolution Charge Readout         P       High-Energy-Resolution Gamma-ray Detectors         P       High-Energy-Resolution Gamma-ray Detectors	<ul> <li>amento, is all or receives to indicate the endoce regions and gives in the case backed and an in-role metabolish at cognits the endoced in the indicate the endoced in the indicate the endoced in the indicate the endoced in the endoced intervent indicates intervent indicate</li></ul>	Reparation in the control of products. The Disk end of the control for an information to the control the contro	<ul> <li>International according to the second second</li></ul>	The sentence are used by a web range of astrophysics and high-energy physics experiments including CABL X-ray, fair finance distributions, dust makes exactles, and neutrinoles clubble cleary. Every reperment with benefit from madeut inducting but dispetitions and another of heat, neutrinoles clubble deary. Every reperment with benefit from madeut dishordby that dispetitions of the set, neutrinoles is as elected power, and is right weight, relative and movies of the set. The set of the set o	CME Prote, FaniR Probe or Flagelip.            ACME space meteor alon to PICO (https://www.org/aba/1902.10541) or sinter. Gould also be relevant to faniR missions (probe or flagent).           ARMO, other future standards masons           HNO, other future standards masons           HNO, other future standards masons           HNO	Level of diffully (single tech, system of tech, or system of tech system): system of techs. Level of diffully (single tech, system of techs, or major stretch): stretch. Years to estimated bunch or other schedule driver: 10. Level of diffully straightforward, stretch, or major stretch): stretch Years to estimated bunch or other schedule driver: 10 years to CMB probe, or for a far-IR probe that might defer to 2010. Level of diffully straightforward, stretch, or major stretch): straightforward. Level of diffully (single tech, system of techs, or system of techs. Letescope + optical components. Level of diffully (single tech, system of techs, or system of techs. Letescope + optical components. Level of diffully (single tech, system of techs, or system of techs. Letescope + optical components. Level of diffully (single tech, system of techs, or system of techs. Letescope + optical components. Level of diffully (single tech, system of techs, or system of techs. Letescope + optical components. Level of diffully (single tech, system of techs, or major stretch): straightforward. TRL 6 meeded by mesion PDR. TRL 6 meeded by mesion PDR. TRL 6 meeded by mesion PDR. If a need for a precision as possible portor insiston formulation. TRL 6 in the size 2020s. If a need of or approximation as possible portor insiston formulation. TRL 6 in the size 2020s. If a need for demonstrate TRL 6 by mesion PDR. Level of diffully (single tech, system of techs, or system of tech systems): combination of 3 technologies that have aready been deveload and teaded in neisent andomenits. Level of diffully (single tech, system of techs, or system of tech systems): single tech Level of diffully (single tech, system of techs, or system of tech systems): single tech Level of diffully (single tech, system of techs, or system of tech systems): single tech Level of diffully (single tech, system of techs, or system of tech systems): single tech Level of diffully (single tech, system of techs, or system): single tech Level of
P       CMB Polarimetry         P       Optical Elements for a CMB Space Mission         P       Starshade Deployment and Shape State         P       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and M Validation         E       Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity         E       Stellar Reflex Motion Sensitivity: Extreme Precision Radial Velocity         E       Broadband X-ray Polarimeter         P       Broadband X-ray Polarimeter         P       Charged-Particle-Discriminating X-ray/Gamma-ray Detectors         P       Dynamic Switching for Ultra-Low-Power High-Resolution Charge Readout         P       High-Energy-Resolution Gamma-ray Detectors         P       High-Energy-Resolution Gamma-ray Detectors	escretly, 14 the mostly is integrate the rescuent. The model appears to receive function the appears approach appears to be appeared to the appears appears appears to be appeared to the appears appears appears appears to be appeared to the appears	Experience in the function in tables of the service of the barry barry and and any service as the service as th	<ul> <li>Internationary begins of a 10 million back back out is in tables of back back back back back back back back</li></ul>	Consistence water by a wite angle of starbyholds and high energy thytics waterment is fouring (166, Kon, fair- ringed antiphysics, dots mater subtracts and traditions for bits but device. Since supervised is the since it is a starbyholds and high energy to the since it is a starbyhold with a starbyhold in the since it is a starbyhold with a starbyhold in the since it is a starbyhold with a starbyhold in the since it is a starbyhold with a starbyhold wit	CMB Probe, FairiR Pobe or Pagerip.  ACIAR space means also to PCO https://anxio.org/sbi/1902.10541) or airlist. Could also be relevant to fairiR meaners (probe or fagerip).  HVO, other fabue atomised meaners  HVO  AVO  HVO  HVO  HVO  HVO  HVO  HVO	Level of comparisity (argin tech, system of facts, or region of facts system): <b>system of bobs</b> . Level of diffusity (argin tech, or major stratisty): <b>strate</b> th. Yean to estimated auroch or other schedule direct: 10. Level of diffusity vertices of techs: we wanted y have a strategy on how to move forward that has been success to far. However, investments in the short term are article and <i>f</i> defended further, outil convect this to a detech. Yean to estimated auroch or other schedule direct: 10 years to CAB probe, or for a far-R probe that might defer to 2015s. Level of afficusty (drag bloch, system of techs, or system of tech system); <b>system of techs</b> : telescope = optical components. Level of afficusty (drag bloch, system of techs, or system of tech system); <b>system of techs</b> : telescope = optical components. Level of an precision autometry mode in the IR/OUV Geal Observatory is identified, then demonstration of fixed at a nucl may are based RV is identified, then need TRL 6 in the bite 2020s. If a need for space based RV is identified, then need TRL 6 in the bite 2020s. If a need for space based RV is identified, then need TRL 6 in the bite 2020s. If a need for space based RV is identified, then need TRL 6 in the bite 2020s. If a need for space based RV is identified, then need TRL 6 in the bite 2020s. If a need of approach system of techs, or system of tech system), continuation of 3 technologues that have abendy been developed and state in miserant environments. Level of demonstrate TRL 6 by massen PDR. Years to estimated auroch or other schedule direct: 5-10 years. Level of directly (single tech, system of techs, or system of tech system), single tech Level of directly (single tech, system of techs, or system of tech system), single tech Level of directly (single tech, system of techs, or system of tech system), single tech Level of directly (single tech, system of techs, or system of tech system), single tech Level of directly (single tech, system of techs, or system of tech system
P       CMB Polarimetry         P       Optical Elements for a CMB Space Miss         P       Starshade Deployment and Shape State         E       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and M Validation         B       Starshade Starlight Suppression and M Validation         E       Starshade Starlight Suppression and M Validation         B       Starshade Starlight Suppression and M Validation         D       Broadband X-ray Polarimeter         P       Dynamic Switching for Ultra-Low-Powe High-Resolution Charge Readout         P       High-Energy-Resolution Gamma-ray Detectors         P       High-Energy-Resolution Gamma-ray Detectors         <	storp:         A constrainty in table to extract it the match gaters in the storp in the sended to any spectrometer in the storp	<pre>https://www.inter.com/com/com/com/com/com/com/com/com/com/</pre>	Constructions before of the Standard method was defined as the file of the standard of th	Sonapproximate and the web may of decoplants and high energy chains another the individe (DR). Key fully a sonapproximate data and another data built data and the sonapproximate data and the data	CHB Prote, Fai-R Pebe or Plagate.  A CHB space makes aim to PICO (https://anx.org/abs/1602.10541) or anter. Could also be relevant to farR makers (prote or figure).  HVD, other future dambate makers  HVD, other future dambaters  HVD, other fut	Level of complexity (single tach, system of tach, or region of tach system); system of techs. Level of difficulty (single tach, system of techs, or region of tach system); Varies to estimated bunch or other schedule their: 10. Level of difficulty (single tach, system of techs, or region of tach system); system of techs, the standard or other schedule their region in our to rever forward that has been succe as the 10 exercise, investments in the short term are obtained differend buffer, could convert this to a started). Varies to estimated bunch or other schedule their: <b>19 years</b> to CME probe, or for a fair IR probe that regin idents 2009. Level of complexity (single tach, system of techs, or region of tach system); system of techs: telescope - optical components. Level of difficulty (single) filoward, started, or region strateging therward. TRL 6 heredge by reason PDR. TRL 6 heredge by reason PDR. True to estimated bunch or other schedule their: 5-10 years. Level of difficulty (single) filoward, when all the true of the schedule supporting robe is deriffied, then apporting is needed well these for years and the system; complexition of 3 technologies that have also a strateging (region tack), spean of facts, years and the system; complexition of 3 technologies that have also a difficulty (single) filoward, when of facts, years and the system; complexition of 3 technologies that have also a difficulty (single) filoward, strated, there: 5-10 years. Level of difficulty (single) filoward, strated, or region of facts system; single tech. Level of difficulty (single) filoward, strated, or region of facts system; single tech. Level of difficulty (single) filoward, strated, or region distory, strateging tack), system of facts, system;
P       CMB Polarimetry         P       Optical Elements for a CMB Space Miss         P       Starshade Deployment and Shape State         E       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and M Validation         B       Starshade Starlight Suppression and M Validation         E       Starshade Starlight Suppression and M Validation         B       Starshade Starlight Suppression and M Validation         D       Broadband X-ray Polarimeter         P       Dynamic Switching for Ultra-Low-Powe High-Resolution Charge Readout         P       High-Energy-Resolution Gamma-ray Detectors         P       High-Energy-Resolution Gamma-ray Detectors         <	exemple 1 where exemples to table the second prevent of the second prevent of the second section is some specific bin in the second prevent of the second section is a second second second section is a second section is a second section is	Imputed by California and Califor	Contract managements (15) Standards in care ower, the last is the last is the last of the device boost is not a last of the last of t	Sonapproximate and the web may of decoplants and high energy chains another the individe (DR). Key fully a sonapproximate data and another data built data and the sonapproximate data and the data	CHB Prote, Fai-R Pebe or Plagate.  A CHB space makes aim to PICO (https://anx.org/abs/1602.10541) or anter. Could also be relevant to farR makers (prote or figure).  HVD, other future dambate makers  HVD, other future dambaters  HVD, other fut	Level of omposity length level, system of tachs, or region of tach system(): system of techs. Level of afficulty (singliftlowed, direction direct 10. Level of afficulty given of feds. Level of afficulty (singliftlowed, because we already of takes a battery on how to move fromest that as decide. Name to administ a worker wheelue direct 10 years to CNE probe, or for a fair-R probe that regist direct afficience. Prestments in the short terms as abrained 12 defense function, and amount that a decide. Name to administ a worker wheelue of techs, or years to CNE probe, or for a fair-R probe that regist direct and as much its coher wheelue in the HROUV Great Observatory is deminist. These demonstrations of fed and as much its registration (FRR. 11 a needed by mascion FRR. 12 a needed by mascion FRR. 13 a need for a proceed advormation (FRR. 14 a needed by mascion FRR. 15 a needed by mascion FRR. 15 a needed by mascion FRR. 16 a needed by mascion FRR. 17 a need for space based for latential of solution of inter interval (Deservatory is definited. 19 a need for space based for latential of solution in early 2005e. 11 a need for space based for latential of solution in early 2005e. 11 a need for space based for latential of solution in early 2005e. 11 a need for space based for latential of solution in early 2005e. 12 a need for space based for latential of solution in early 2005e. 13 a need for space based for latential of solution is early as a solution of 3 bedratogiptic based. 14 a need for space based for latential of solution is early as a solution of 3 bedratogiptic based. 15 a solution of the coherer wheeluk direct 10 15 and of demonstration TRL E by meson FDRR. 15 a solution of a solution of solution of solution of tech spacemal; single tech. 15 and of demonstration or other solut
CMB Polarimetry P CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry Comparison of the second	exact ( Add to include to include the sound) in the status genes A maximum balance in the sound experiment on the sound experiment of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part of the sound exact ( Add to include a part	<ul> <li>Bernson Alleker, TMA Leise waker vaker of all and alle strate and the information of the section of the section. The section protection of the section of the</li></ul>		Contract and a vision maps of a strange place and high-exercing. Carry presents of Control Contro	CKS https://facility.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/secondary.com/seco	Level of comparing large both, spetered factor or registered factor granted: Level of officially (stepphones), sheath, or mays results; strateh. Were to estimated launch or other schedule office; 10. Level of ontpacky spetere of levels. Level of ontpacky spetere of levels. The officially (statightforward, decide, or major and had spectral: spetere of levels: taxacops - optical components). The officially (statightforward, decide, or major and had spectral: spetere of levels: taxacops - optical components). The official by response PDR. The official by response PDR. Level Official by response PDR. The official by response
P       CMB Polarimetry         P       Optical Elements for a CMB Space Mission         P       Distribution         P       Starshade Deployment and Shape State         E       Starshade Deployment and Shape State         E       Starshade Starlight Suppression and Mission         E       Starshade Starlight Suppression and Mission         E       Starshade Starlight Suppression and Mission         E       Starshade Motion Sensitivity: Extreme         P       Precision Radial Velocity         E       Warm Readout Electronics for Large-         Format Far-IR Detectors       Format Far-IR Detectors         P       Disordband X-ray Polarimeter         P       Disordband X-ray Detectors         P       Large Cryogenic Optics for the Mid IR        Far IR       C	<ul> <li>method is offer consisting of the product of the prod</li></ul>	beyond with a start with a s	1              Provide and provide a final state of a state and a state an	Constraints of a variable sign of a single single sign of a single sign of a single si	CRE Robe, Park Proce or Region Addition of the PCD Physicilian organization (CLE 1041) is similar. Guid at bits referent to the PL measure addition of taglet).  FND other More starting entering of the PCD Physicilian organization (CLE 1041) is similar. Guid at bits referent to the PL measure PCD other More starting entering of the PCD Physicilian organization (CLE 1041) is similar. Guid at bits referent to the PL measure PCD other More starting entering of the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilian organization (CLE 1041) is similar to the PCD Physicilia	Level of comparing large both, spetered factor or registered factor granted: Level of officially (stepphones), sheath, or mays results; strateh. Were to estimated launch or other schedule office; 10. Level of ontpacky spetere of levels. Level of ontpacky spetere of levels. The officially (statightforward, decide, or major and had spectral: spetere of levels: taxacops - optical components). The officially (statightforward, decide, or major and had spectral: spetere of levels: taxacops - optical components). The official by response PDR. The official by response PDR. Level Official by response PDR. The official by response
P       CMB Polarimery         P       Optical Elements for a CMB Space Max         P       Starshade Deployment and Shape Stats         P       Starshade Deployment and Shape Stats         P       Validation         E       Starshade Starlight Suppression and M         Q       Starshade Starlight Suppression and M         P       Validation         E       Starshade Starlight Suppression and M         P       Precision Radial Velocity         E       Precision Radial Velocity         F       Precision Radial Velocity         F       Precision Radial Velocity         F       Precision Radial Velocity         P       C         O       Dynamic Switching for Ultra-Low-Power         P       High-Energy-Resolution Gamma-ray         P       Detectors         P       High-Energy-Resolution Gamma-ray         P       Large Cryogenic Optics for the Mid IR         F       F         C       C         P       Large Field-of-Mew and Effective Area         P       Large Field-of-Wew and Effective Area         P       Large Aperture Deployable Antennas for Field and Field Precision Tor Silicon         P       Large Aperture Deplo	<ul> <li>Bernigh L &amp; Lossenberg L Starter Starter</li></ul>	<pre>bit control the control t</pre>	Important Section 2.	<ul> <li>The process are and by a who mage of patiently and high who you have a parameter had ing CMA. Some you find an exploration of the patient of the state o</li></ul>	CEB Paces, Farik Peter or Fagdes.  CEB Paces, Farik Peter or Fagdes.  A DB agost mission with a DEC (Right Hockogenet 192,1951) or white. Cost are be retrained to the Right endower makes a management of the Right endower	sourd composing length state, speakers of states, an agent of team speakers in year and teams in a speaker in teams
CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Control Co	Image: Image: And the sector is the set of	<ul> <li>And Andree Marken (1990) And an extent of a barren by the property in a set of a barren by the property in a barren by the proper</li></ul>	<ul> <li>Constanting of Constanting of Constanting and Constanting of Constanting Cons</li></ul>	Constraints and the set of any product in the terms of the set of the se	CSD Press, for R Free or Taples,         A 100 excess minimum for L-INCO 2012/101/101/2012/10011102/00011102/00011102/000110011	Load of data, joing tout, upper of both, or option of both spatianty system of boths. Load of data, yringsphoreaus, stoch, or maps stochy, serves. Name to carbonic system of both. Load of data, yringsphoreaus, stoch, or maps stochy are a stategy on here is more forcer if an in the server. In the in-excess, inclusions in the social issue of the state of Advance Subsec, or for a first Results built in a state. In the in-excess, inclusions in the social issue of the state of Advance Subsec, or for a first Results built in a state. In the in-excess, inclusions in the social issue of the state of Advance Subsec, or for a first Results built indicated issue of data. In the in-excess inclusions in the social issue of the state of Advance Subsec, or for a first Results built indicated issue of data. In the in-excess inclusions in the social issue of the state of
CMB Polarimetry         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p         p	Image: Image: And the sector is the set of		Image: Section of the sectio	Constant we well a well merel at any space of by personnel in data (2011, 2011, 2011), the space of the	Coll Proce. For 41 fields of Progen.     Coll Proce. The field of Progenet.     Coll Proce. The field of Proce (https://www.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.internet.	and dromphalp jongh lock, speen of hole on spore of and speen groups of sets. Let of diffusly targetificated data, a major data thates is have a scheme burd or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be extended burds or other schedule datas is 1 have be determined by its burds. FOR. The for exceed by indian (FOR. The for exceed barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control, new exceeder barred on other schedule datas is 6 control of major datas is control schedule datas is 6 control of major datas is control schedule datas is 6 control of major datas is control schedule datas is 6 control of major datas is control schedule datas is 7 control of major datas is control schedule datas is 7 control of major datas is control schedule
CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Control Co	metric information in water sectors in water sectors in water in the owner and the information is a sector in the owner is		Image: Description of the second se	The question and if you have build a set oppose of it you and you have build and you have build and you have build a grant of how and you have	Coll Note: Note the Coll Coll Physics Construction (Coll Physics Coll	une of contrade lange and under some setter ( per some some some some some some some some
CMB Polarimety CMB CMB Comparison of M CMB Comparison of	Interference         Interference           Interference         Interference         Interference           Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference           Interference         Interference         Interference         Interference         I		Image:	Landstein er gelt is akte met insteringen en terken proves gemente kong officiales in met insteringen en terken en terken en terken en terken en terken proves gemente kong officiales in en terken en terken en terken en	EVER THE CONTRACT OF THE CONTRACT OF THE CONTRACT OF THE THE CONTRACT OF THE THE CONTRACT OF THE THE CONTRACT OF THE CONTRACT OF THE CONTRACT OF THE CONTRACT OF THE THE CONTRACT OF THE	<ul> <li>and damping legislawing space during a space during space dur</li></ul>
CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Polarimetry CMB Carling Contents for a CMB Space Main CMB Contents CMB Contents CMB Carling Contents CMB Carling Contents CMB Con	Image: Section of the sectio		International and information and an according to the second	Lance to evaluate a strategy of all and space of programs of the strategy of all and space of the strategy of	Children fan de Terrere Reger	<ul> <li>and damping jugs have, so in the second of second grants.</li> <li>And damping jugs have, so in the second of second se</li></ul>