

Attachment 1.

Technology Roadmap April 2011 PhysPAG Technology SAG \*\*

Decadal Survey 2010 (New Worlds New Horizons)

Near Term Push Technologies

Long Term Push Technologies

	WFIRST	LISA	IXO	Inflation Probe	Fundamental Physics	Next Generation Hard X-ray Obs.	Soft X-ray and EUV	Next generation X-ray timing	Next generation Medium-energy $\gamma$ -ray Observatory	Beyond LISA (Big Bang Observer)		Beyond IXO (Gen-X)	Next generation $\gamma$ -ray Focusing
<b>Science Summary</b>	Study the nature of dark energy via BAO, weak lensing and SNIa, IR survey, census of exoplanets via microlensing	Probe black hole astrophysics & gravity signatures from compact stars, binaries, and supermassive black holes	Conditions of matter accreting onto black holes, extreme physics of neutron stars, chemical enrichment of the Universe	Observe the polarization signature of inflation in the very early Universe	Precision measurements of space-time isotropy and gravitational effects	Hard X-ray (5-600 keV) imaging all sky survey for BHs	Spectroscopy of million degree plasmas in sources and ISM to study composition	EOS of neutron stars, black hole oscillations, and other physics in extreme environments	Signatures of nucleosynthesis in SNR, transients, and other sources; AGN and black hole spectra	To directly observe gravitational waves resulting from quantum fluctuations during the inflation of the universe		Observe the first SMBH, study growth and evolution of SMBHs, study matter at extreme conditions	Signatures of nucleosynthesis in SNR, transients, and other sources
<b>Architecture</b>	Single 1.5 M dia. Telescope, with focal plane tiled with HgCdTe (TBD).	Three space craft constellation, each in Keplerian orbit. Sub nm displacement measured by lasers (Michelson interferometer).	Single 2.5 - 3 M grazing incidence 20 M focal length X-ray telescope	Wide-field of view cooled submm 2-M class telescope with large arrays of CMB polarimeters.	Individual spacecraft for space-time measurement and gravitational effects. Multiple spacecraft for precision timing of interferometric measurements.	Two wide-field (~130 x ~65deg) coded mask telescopes. Full sky ea. ~ 95min	Focusing optics with high resolution spectrometers based on advanced gratings	large(>3m <sup>2</sup> ) pointed arrays of solid state devices, with collimation to isolate sources	Single platform designs to measure $\gamma$ -ray lines	Four Michelson interferometers each of three s/c (~12 s/c total), ~50,000 km separation, LISA like	Constellation of at least 2 cold atom differential accelerometers, 10,000 km measurement baseline	16 M (50 M <sup>2</sup> *2 grazing incidence telescope with 60 M focal length	2-platform designs to measure $\gamma$ -ray lines
<b>Wavelength</b>	0.4 to 1.7 $\mu$ m (TBD)	Interferometer $\lambda$ =1.064 $\mu$ m - gravity wave period 10-10,000 sec.	0.3 to 40 keV	50 - 500 GHz		5-30 and 10-600keV	5-500 Angstroms	2-80 keV	100 keV - 30 MeV	visible & near IR: gravity waves periods of ~1-10 sec	gravity wave periods 0.01 - 10 Hz	1-10 keV	100 keV-3 MeV
<b>Telescopes: Optics</b>	Wide FOV, ~1.5-M diameter mirror	Classical optical design Surface roughness < $\lambda/30$ , backscatter/ stray light	lightweight, replicated x-ray optics.	Wide field of view, cryogenic telescope		Coded aperture imaging: ~ 5mm thk W & ~ 2.5mm holes; ~0.5mm W & ~0.2mm holes	Gratings, single and multilayer coatings, nano-laminate optics	No optics; source isolation by collimator	Compton telescope on single platform	~ three meter precision optics	~ one meter precision optics (l/1000)	Lightweight adjustable optics to achieve 0.1 arcsec. High resolution grating spectrometer	Focusing elements (e.g., Laue lens) on long boom or separate platform
<b>Telescopes: Wavefront Sensing &amp; Control and Interferometry</b>		Alignment sensing, Optical truss interferometer, Refocus mechanism			Coupling of ultra-stable lasers with high-finesse optical cavities for increased stability		Actuators			LISA Heritage	wavefront sensing with cold atoms; large area atom optics	0.1 arcsec adjustable optic	
<b>Telescopes: Metrology &amp; Structures &amp; Lasers</b>	Classic telescope structure - HST heritage	Athermal design with a Temp gradient Dimensional stability: pm/sqrt(Hz) and $\mu$ m lifetime, angular stability < 8mrad	lightweight precision structure	Spitzer Heritage		~ 5" aspect req. over ~6x~3x~1.5m tel. structures	Arcsecond attitude control to maintain resolution	Moderate accuracy pointing of very large planar array		LISA Heritage	10 W near IR, narrow line	Extendable optical bench to achieve 60 M focal length	Long booms or formation flying
<b>Detectors &amp; Electronics</b>	HgCdTe CMOS (H4RG?)	Laser: 10yr life, 2W, low noise, fast frequency and power actuators Quadrant detector, low noise, 10yr life, low noise (amplitude and timing) ADC's	X-ray calorimeter central array (~1,000 pixels); 2.5 eV FWHM @ 6 keV; extended array; 10 eV FWHM @ 6 keV. High rate Si detector (APS). High resolution gratings (transmission or reflection)	Large format (1,000 - 10,000 pixels) arrays of CMB polarimeters with noise below the CMB photon noise and excellent control of systematics	Molecular clocks/cavities with 10E-15 precision over orbital period; 10E-17 precision over 1-2 year experiment. Cooled atomic clocks with 10E-18 to 10E-19 precision over 1-2 year experiment.	1m <sup>2</sup> Si (~0.2mm strips)+~ 6m <sup>2</sup> CZT (~1.2mm pixels); ASIC on ea. ~20x20mm crystal. photon-counting over cont. scan	Photocathodes, micro-channel plates, crossed-grid anodes	>3 m <sup>2</sup> Si (or CZT or CdTe) pixel arrays or hybrid pixels, with low-power ASIC readouts, possibly deployable	Cooled Ge; arrays of Si, CZT or CdTe pixels and ASIC readouts	Laser interferometer, ~1kWatt laser, gravity reference unit (GRU) with ~100x lower noise	Megapixel ccd camera	Gigapixel X-ray active pixel sensors, magapixel microcalorimeter array	Scintillators, cooled Ge
<b>Coolers &amp; Thermal Control</b>	Passively cooled telescope, actively cooled focalplane?	Low CTE materials, passive thermal shielding, power management for avionics thermal stability	Cryocooler needed to cool detectors and other parts of instruments	Passive Spitzer design plus cooling to 100 mK	Thermal stability/control, less than 10E-8 K variation.	LHP to radiators for ~-30deg (Si) and ~-5deg (CZT) over large areas		Passive cooling of pixel arrays	Active cooling of germanium detectors	LISA Heritage	Sun-shield for atom cloud	Cryocooler <100mK with 1 mK stability (IXO Heritage)	Active cooling of germanium detectors
<b>Distributed Space Craft</b>		Spacecraft in separate Keplerian orbits. No formation flying or station-keeping. Low contamination $\mu$ -Newton thrusters with low thrust noise			Applicable as precision timing standard in distributed constellations.		Use low-cost launch vehicles for single payloads with few month mission duration			~12 s/c total ~50,000 km separation, sub-micron position control.	Multi-platform s/c system to support above architecture		2-platform formation flying is one approach

\*\* Derived and updated from 2005 SRM8 and Universe RM

TRL7-9

TRL 4-6

TRL 1-3

# Attachment 2: LISA

Name of Technology (256 char) Brief description of the technology (1024)	Laser Subsystem (or Master Oscillator)	Phasemeter system	Alignment Sensing	Telescope	Gravitational Reference Sensor	Thrusters
	LISA laser requires power of P=2W in a linear polarized, single frequency, single spatial mode. It requires built-in fast actuators (BW > 10kHz) for intensity and frequency stabilization to enable laser phase locking and relative intensity noise of <math>10^{-9}</math>/rtHz. Lifetime > 10yrs. Shotnoise limited at 1mW laser power above 2MHz. Potential laser types: Diode pumped solid state lasers Diode pumped fiber lasers Extended Cavity diode lasers Potentially followed by power amplifier: Optical power amplifier can be core-pumped (<math><1.5</math> W) or cladding pumped (>1.5 W). May be able to eliminate if power requirement can be reduced to ~ 1 W.	The phasemeter measures the phase of laser beat signals with ucycl/rtHz sensitivity. It is the main interferometry signal for LISA. The phasemeter consists of a fast photo receiver which detects the beat signal, an ADC which digitizes the laser beat signal, and a digital signal processing board which processes the digitized signals.	Alignment sensing in interferometric space missions like LISA or formation flying missions is required maintain the alignment between the individual spacecraft. This is done with differential wavefront sensing between a local and the received laser beam. The missing key element is a four element fast, non-dispersive photo detector. Such a detector has been developed in collaboration with industry through the SBIR program, but is at a low TRL level. Space qualification is needed.	Free falling constellations like LISA and also formation flying missions require telescopes to exchange laser fields for position and alignment sensing. The requirements for these telescopes include either unusual length and alignment stability requirements at the pm and nrad level or the capability to monitor and potentially even actively control the length and alignment. Scattered light from within the telescope could affect the interferometric measurements.	Gravitational Wave detectors (LISA and LISA follow-on missions) as well as other fundamental physics missions require gravitational reference sensors. For LISA, the residual acceleration of the GRS has to be in the sub-fg/rtHz range. ESA has developed a gravitational reference sensor for the LISA pathfinder and will test it in flight in the upcoming years. This reference sensor consists of a proof mass in an electro-static housing. Key technologies include magnetic cleanliness, charge mitigation, gas damping, thermal noise, and actuator noise. <b>Gravitational reference sensors are completely missing in the TABS with the exception of the atomic interferometer.</b>	Thrusters for in-space operation with very low noise, tunable thrust, long lifetime (> 5 years) are required for LISA, LISA follow-on missions, and for formation flying missions. LISA needs low noise with less thrust (uN/rtHz and 100uN thrust). The requirements for formation flying missions are mission specific, require usually more thrust but can also tolerate more noise compared to LISA. Note that LISA does not do formation flying.
<b>TABS category</b>	8.1.5	8.1.2	8.1.2	8.1.3	8.2.4 (?) need new number	2.2.1
<b>Goals and Objectives (1024)</b>	The goal is to reach TRL 6 in 2015 with a laser system that meets LISA requirements. Frequency Comb has nothing to do with the LISA laser. Low noise or Ultra-low noise is not necessary because of active stabilization. The laser is at the beginning of the optical train and the required modulators, fibers, optical components, etc depend on the laser type. A change to a different laser system later could require a complete redesign of large portions of the optical system.	The goal is to reach TRL 6 by 2015 with the phasemeter system that meets LISA requirements. This system is essential to support tests of other subsystems at the ucycl/rtHz level and should be developed as soon as possible. Should be developed with Alignment sensing photodetector.	The goal is to reach TRL 6 by 2016 with the alignment sensing system. It should be developed together with the phasemeter system. Understanding the capabilities and the sensitivity of the alignment sensing system enables more targeted technology developments for LISA and allows to develop realistic designs for formation flying mission.	Athermal telescope designs have to be developed to meet the length and alignment requirements. Materials have to be tested for creep at the pm/nrad level. Geometries have to be tested which include an optical truss interferometer to monitor and maybe also control length and alignment of the telescope structure.	The initial goal has to be the support of the LISA pathfinder and technology import to learn as much as possible from the pathfinder. This could raise the TRL above 6 immediately. Future R&D in this direction has to depend on the outcome of the pathfinder mission. The lessons learned should help to evaluate how far this technology can be pushed or if radically new ideas should be investigated.	TRL 6 for colloid thrusters meeting the LISA requirements. Scalability of these and other thrusters to meet formation flying requirements needs to be investigated.
<b>TRL</b>	4 TRL is between 4 and 5. Requires now efforts towards space qualification and testing in relevant environment. Demonstration of "as packaged" lifetime required.	5 The phasemeter has been demonstrated but only with single element photodetectors and most of the components are not space qualified.	4. This might just be testing commercially available quadrant detectors and identifying one that meets the requirements.	4 for length and alignment stability 2 for backscatter.	Pathfinder GRS: TRL > 6 Atomic interferometry TRL 1	Colloids: TRL 6
<b>Tiping Point (100 words or less)</b>	Laser meeting these requirements exist already. Several designs have reached TRL 4. A focused effort could increase this to TRL 6 or at least identify most issues in a fairly short time. This would then enable lifetime tests which are obviously time consuming.	The main missing elements are the quadrant photodetector and ADC's with low enough timing jitter. A focused effort could solve this problem in a fairly short time. A quadrant photodetector has been developed that meets most if not all of the technical specs and is currently in a Phase II SBIR. Flight qualification still required.	A survey of the available quadrant detectors and simple tests of the most promising ones might be sufficient to get this to TRL 6.	Length and alignment stability: This requires to build a real LISA telescope and test it. Note that a 40cm telescope is not a gigantic investment but developing the measurement capabilities requires some funding. The integration of an optical truss telescope is also fairly straight forward The coherent backscatter has never been seriously analyzed and an initial	Yes, if NASA can take advantage of the LISA pathfinder. No for atomic interferometry	This should be an ongoing effort
<b>NASA capabilities (100 words)</b>	NASA's capabilities in this area appear to be restricted to testing and space qualification. Commercial laser companies or specialized groups in academia have the expertise and capabilities to collaborate with NASA on this effort.	NASA's does not have the capabilities to develop the individual components alone but could collaborate with industry to design and test them. NASA and some groups in academia have the expertise to test these components and later the entire system.	NASA and several university groups have the capability to test these components. If the currently available components don't meet the requirements, NASA needs to work with industry to improve them. NSF-funded LIGO research could benefit from progress in this area.	NASA has the capability to build a 40cm LISA telescope but the capabilities to measure the length and alignment variation need to be developed. NASA (and many others) could analyze and test the back scatter.	ESA is building it and collaborates with NASA on the pathfinder. Atomic interferometry: NASA has no capabilities in this area.	Well within NASA capabilities
<b>Benefit/Ranking</b>	It would allow to define the interfaces between the laser and all other subsystems in LISA. This simplifies and in some cases enables R&D on other important components. The laser system itself would also be useful for other laser interferometric missions such as formation flyers, multiple aperture missions, or Grace-follow on missions. Ranking: iv	The capability to measure noise at the ucycl/rtHz level is essential for the R&D on many other components. Having well tested phasemeter system would enable this work and accelerate the R&D in general. Ranking: iv	Maintaining the relative alignment between multiple components on one spacecraft and between separated spacecraft is essential for LISA and for formation flying missions. Having a sensing system early allows tests of newly developed subsystems and integration tests early on. Ranking: vi	Develop passive on-axis telescopes for less demanding and actively controlled telescopes for more demanding applications is an enabling technology for free falling constellations like LISA and also for formation flying missions. Ranking: ii	Yes. A gravitational reference sensor with sub fg/rtHz residual acceleration is critical for gravitational wave missions. Making sure that NASA has access to this technology should be one of the top priorities.	Formation flying would be a game changer. Thrusters are only a part of this. On going effort.
<b>NASA needs/Ranking</b>	LISA and other laser interferometric missions such as formation flying missions, Grace follow-on Ranking: iv	LISA is the main customer but other interferometric space missions are planning to use similar phasemeter. Having a completely characterized system with ucycl/rtHz sensitivity would meet many NASA needs. Ranking: iv	Required for LISA and formation flying missions. Having a completely characterized system with ucycl/rtHz sensitivity would meet many NASA needs. Ranking: iv	Would significantly simplify LISA and formation flying missions. Ranking: iv	LISA and LISA-follow on missions depend on it. Ranking: iii	Formation flyer depend on it. Need for LISA solved with pathfinder demonstration except for lifetime. Ranking: iv
<b>Non-NASA but aerospace needs</b>	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Several other applications are possible for the quadrant detectors, including an equivalence principle test and some commercial applications. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	No non-NASA needs as far as I know Ranking: i	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii
<b>Non aerospace needs</b>	Non. Non space-qualified lasers which meet the requirements are commercially available. Ranking i	Science and Engineering applications. Ranking: iii	Science and Engineering applications. Ranking: iii	Ranking: i	No non-NASA needs as far as I know Ranking: i	Ranking: i

## Attachment 2: LISA

<b>Technical Risk</b>	The technical risk is low. Several commercial systems exist that meet the requirements except space qualification. No commercial company will space qualify a LISA laser to commercialize it. Ranking ii.	Technical risk is low. The main challenge is to get the temperature dependent dispersion under control. Ranking ii	Technical risk is low. The main challenge is to get the temperature dependent dispersion under control without reducing bandwidth and area to much. Ranking ii	Technical risk for the longitudinal and alignment stability is low. Materials have been tested at the sub-pm level. The integration of a suitable optical truss interferometer is also low risk. Backscatter: No risk. This is an assessment if on-axis telescopes will meet the requirements or if substantial R&D is required to develop an off-axis telescope.	Pathfinder GRS: ESA is taking most of the financial risk right now. If the pathfinder reaches the performance, technical risks for NASA are minimal. No ranking possible. Atomic interferometry: It is completely unrealistic that this technology can reach TRL 6 within the next 20 years. Ranking: v	Continuous development. Technical risk low
<b>Sequencing/Timing</b>	Should come as early as possible. The development of many other components depends on the specific laser system. Ranking iv	Should come as early as possible. The development of many other components depends on the availability of a phasemeter with $\mu\text{cycl/rHz}$ sensitivity. Ranking iv	Requires phasemeter. Should start before phasemeter development is finished and should be finished 1-2 years after phasemeter is at TRL 6. Ranking: iv	Length and alignment: The current status is sufficient for planning purposes. Tests on real models should start 2017. Backscatter: Start immediately as small effort. Ranking: iv	Pathfinder GRS: The timing is set by ESA. No ranking possible. Atomic interferometry: No, the timing is not appropriate. Given the latest news about LISA, this technology is not needed. Ranking: i	Continuous development.
<b>Time and Effort to achieve goal</b>	3 year collaboration between industry and NASA. Ranking: iii (Except for lifetesting.)	3 year collaboration between industry, academia, and NASA. Ranking iv	2 year collaboration between academia and NASA, Ranking iv	3 year academia project. Ranking: iv	Pathfinder GRS: Effort and time depends on form of collaboration with ESA. Atomic interferometry requires many technologies which have barely been demonstrated on the ground. Ranking: ii	Continuous development.

# Attachment 3: Inflation Probe

Name of Technology (256 char) Brief description of the technology (1024)	Detectors	Electronics and multiplexers	Optical coupling elements	Optical system	Cryogenic system
<b>TABS category</b> <b>Goals and Objectives (1024)</b>	8.1.1 The goal is to demonstrate arrays of sensors in multiple sub-orbital instruments, and to demonstrate the sensitivity appropriate for a satellite-based instrument in the laboratory.	8.1.2 The goal is to demonstrate multiplexed arrays of thousands of pixels in both ground- and balloon-based missions.	8.1.3 The goal is to demonstrate arrays polarization sensitive receivers to demonstrate optical coupling with sufficient control of polarization systematics in multiple sub-orbital and ground-based instruments.	8.1.3 The goal is to demonstrate all elements of an appropriate optics chain in multiple sub-orbital and ground-based instruments.	8.1.6 Develop and mature appropriate sub-Kelvin coolers for the Inflation Probe
<b>TRL</b>	TES: TRL is between 4 and 5. Noise equivalent power (NEP) appropriate for a satellite has been demonstrated in the laboratory, and TES instruments have been deployed and used for scientific measurements in both ground-based and balloon-borne missions. However, not all required wavelengths have been demonstrated. MKID: TRL 3. Appropriate sensitivity needs to be demonstrated, small ground-based instruments are in development.	TDM: TRL 4-5. Ground based arrays of up to 10,000 multiplexed pixels are working on ground-based telescopes. Kilopixel arrays will shortly fly in balloons. FDM: TRL 4-5. Ground based arrays of up to 1,000 multiplexed pixels are working on ground-based telescopes, and initial balloon flights has occurred. Superconducting microresonators: TRL 3-4; 2,000-channel ground-based MKID instruments are in preparation. Laboratory systems have been developed for small TES arrays (microwave SQUIDs in superconducting microresonators).	No technology has been developed at all wavelengths of interest for the Inflation Probe. Corrugated platelet feedhorn polarimeter arrays: TRL 4. Corrugated feeds have extensive flight heritage, but coupling kilopixel arrays of silicon platelet feeds to bolometers requires maturation. Ground-based array in this configuration are soon to be deployed. Planar antenna polarimeter arrays: TRL 4-5. Ground based arrays deployed and producing science, balloon-borne arrays will soon be deployed. Lens-coupled antenna polarimeter arrays: TRL 4. Ground based arrays soon to be deployed.	Corrugated feeds with dual offset reflector systems and modeling codes: TRL 7. Corrugated feeds with refractive optics: TRL 4-5. In use on the ground in multiple instruments. Planar antennas or lens-coupled antennas with reflective or refractive optics: TRL 4. Now in use in ground based systems; tools to simulate still in development. Millimeter AR coatings: TRL 2-5 (multi-layer to single-layer coatings). Polarization modulators: either half-wave plate modulators, variable polarization modulators, or on-chip solid-state modulators	TRL for all options varies considerably from TRL 3 to TRL 9.
<b>Tippling Point (100 words or less)</b>	For the TES, investment is required to demonstrate appropriate sensitivity at all relevant wavelengths, and ground-based measurements experiments must be conducted, but TRL 5 could be achieved in the next few years. MKID instruments require a larger effort: they need to demonstrate that they can reach appropriate sensitivity, and they need to be operated in full ground-based and suborbital instruments.	For TDM, the full scale required for the Inflation Probe has been demonstrated on the ground- balloon-borne measurements are required. For FDM, larger scale demonstrations are required. For superconducting microresonators, a breakthrough is required on the room-temperature readout electronics.	The technology is working well in all three technology options; extensive analysis of data from ground-based and balloon experiments is required to demonstrate control of systematics. Demonstrations required at all wavelengths of interest.	Many suborbital and ground-based experiments are testing relevant optical system designs, including reflective and refractive optics, millimeter AR coatings, and half-wave plate polarization modulators. Experimental results will guide future development.	
<b>NASA capabilities (100 words)</b>	NASA has extensive experience in fabricating both TES and MKID instruments in partnership with university groups and other government laboratories (principally NIST).	NASA has extensive experience in fabricating multiplexed arrays in partnership with university groups and federal labs (NIST).	NASA has extensive experience in fabricating planar antenna arrays and feedhorn-coupled arrays in partnership with university groups and federal labs (NIST). Lens-coupled arrays are best developed in specialized university groups.	NASA has extensive experience in fabricating optical systems in collaboration with specialized university groups.	NASA has extensive heritage appropriate to the task, and some elements are commercially available.
<b>Benefit/Ranking</b>	The development of large sensitive arrays is a major breakthrough that enables precision cosmology. Ranking: iv.	The capability to read out 1,000-10,000 pixels arrays is a major breakthrough that enables precision cosmology. Ranking: iv.	The control of systematics required for a measurement of primordial B modes is a major breakthrough that enables precision cosmology. Ranking: iv.	Optical system developments will continue to improve the capability of missions requiring strong control of systematic error. Ranking: ii.	Cryogenic system developments will continue to improve the capability of any missions requiring sub-Kelvin cooling. Ranking: ii.
<b>NASA needs/Ranking</b>	Sensitive detector arrays are a must for the Inflation Probe to be a success. The TFCR endorsed direct detectors as the primary way to achieve this goal. In addition to the Inflation Probe, the technology developed would leverage many other missions requiring low-temperature superconducting detectors, including IXO, Generation-X, and future submm missions such as SPIRIT or SPECS. Ranking: iv	The capability to read out 1,000-10,000 pixels are a must for the Inflation Probe mission to be a success. The TFCR recognized the need to develop multiplexed electronics for this goal. In addition to the Inflation Probe, the technology developed would leverage many other missions requiring low-temperature superconducting detectors, including IXO, Generation-X, and future submm missions such as SPIRIT or SPECS. Ranking: iv.	Polarization-sensitive optical coupling elements with exquisite control of systematics are a must for the Inflation Probe to be a success. Ranking: ii	Improvements in optical systems will benefit not only the Inflation Probe, but any other future satellite mission in the millimeter or the submillimeter. Ranking: iii. Ranking: iv	Improvements in optical systems will benefit not only the Inflation Probe, but any other future satellite mission requiring sub-Kelvin cooling, including IXO, SPICA, SAFIR, etc. Ranking: iii. Ranking: iv
<b>Non-NASA but aerospace needs</b>	Arrays of sensitive bolometers may have national security applications either in thermal imaging of the earth, or in gamma spectroscopy of nuclear events. Ranking ii.	Large, multiplexed arrays of sensitive bolometers may have national security applications either in thermal imaging of the earth, or in gamma spectroscopy of nuclear events. Ranking ii.	Unknown. Ranking: i	Unknown: Ranking: I	Unknown: Ranking: I
<b>Non aerospace needs</b>	Sensitive mm-wave bolometer arrays have applications in remote sensing, including concealed weapons detection, suicide bomber detection, and sensing through fog. Ranking iii.	Science and Engineering applications. Ranking: iii	Unknown. Ranking: i	Unknown: Ranking: i	Unknown: Ranking: i
<b>Technical Risk</b>	The technical risk is medium. Commercial solutions do not exist, but multiple university groups, NASA centers (JPL and GSFC), and federal laboratories (NIST) have extensive capabilities. TRL 5 is within reach, and multiple ground- and balloon-borne instruments will be tested in the next few years. Ranking iv.	The technical risk is medium. Commercial solutions do not exist, but multiple university groups, NASA centers (JPL and GSFC), and federal laboratories (NIST) have extensive capabilities. TRL 5 is within reach, and multiple ground- and balloon-borne instruments will be tested in the next few years. Ranking iv.	The technical risk is medium. Commercial solutions do not exist, but multiple university groups, NASA centers (JPL and GSFC), and federal laboratories (NIST) have extensive capabilities. TRL 5 is within reach, and multiple ground- and balloon-borne instruments will be tested in the next few years. Ranking iv.	While individual elements have technical risk until proven (including notably the millimeter AR coatings and polarization modulators), the simpler optical system designs have relatively low risk. Ranking: ii	The risk varies considerably between different options, but some options have flight heritage. Ranking: ii
<b>Sequencing/Timing</b>	Should come as early as possible. The entire Inflation Probe system is dependent on the capabilities of the sensors. Ranking iv	Should come as early as possible. The entire Inflation Probe system is dependent on the capabilities of the sensors. Ranking iv	Should come as early as possible. The entire Inflation Probe system is dependent on the choice of optical coupling elements. Ranking iv	Most aspects of the optical system design are being verified in ground-based and suborbital missions.	The development will leverage many missions, but details of the cryogenic system are not as time critical as other system elements.
<b>Time and Effort to achieve goal</b>	5 year collaboration between NASA, NIST, and university groups. Ranking: iii	5 year collaboration between NASA, NIST, and university groups. Ranking: iii	5 year collaboration between NASA, NIST, and university groups. Ranking: iii	5 year collaboration between NASA and university groups.	Continued NASA development

## Attachment 4: Fundamental Physics

# Attachment 5: Next Generation Hard X-ray Observatory

Name of Technology (256 char)	Large-Area, finely pixelated,thick CZT Detectors	Low-Noise, Low-power ASICs for Solid State Detectors	Active shield using avalanche photodiode
<b>Brief description of the technology (1024)</b>	A large array (4.5 m <sup>2</sup> ) of imaging (0.6 mm pixel) CZT detectors are needed to perform the first hard X-ray survey (5-600 keV) with well-localized (<20" at 5-sigma threshold) sources down to 0.06 mcrab (5-150 keV). Thick CZT detectors (0.5 cm) allow broad-band energy coverage for GRBs.	Low power ASICs (<20 microW/pixel) are needed to provide accurate time of arrival and energy for each photon but with low aggregate power per square meter.	BGO scintillators read out by two light guides on opposite edges, each coupled to two Avalanche Photo Diodes used as active shields to reduce in flight atmospheric albedo and cosmic-ray induced backgrounds.
<b>TABS category</b>	8.1.1	8.1.2	8.1.1
<b>Goals and Objectives (1024)</b>	The goal is to achieve CZT detectors with 0.6mm pixels, 2.4' angular resolution.	A reduction of power consumption by a factor of ~4 compared to current designs (e.g. NuSTAR) is needed to implement the large detector array with typical solar panels and batteries. A low energy threshold of ~5 keV is needed.	The goal is to minimize cosmic ray induced internal background and to reduce the physical size of the active shielding system.
<b>TRL</b>	TRL is 6. Prototype detectors have flown on ProtoEXIST in 2009. Detectors with improved pixel size scheduled for flight.	TRL is 6. Portions of the functionality have been demonstrated but a full prototype that meets both the noise and power requirements has not yet been produced.	TRL is 4-5. Prototype designs are planned for flight.
<b>Tippling Point (100 words or less)</b>	Designs have reached TRL 6. Successful flights with 0.6mm pixel detectors will increase the TRL to 7-8.	The ASIC is the key ingredient in achieving a system that meets the performance requirements. One successful design and fabrication will allow systems to be tested in relevant environments.	Prototypes to be flown.
<b>NASA capabilities (100 words)</b>	NASA's capabilities support test but pixel arrays are custom procurements from commercial sources.	NASA has an engineering group that can produce ASICs of this kind but suitable groups also exist in DoE or at commercial sources.	NASA has experience with scintillators and test capabilities. Scintillators and avalanche photodiodes can be procured from commercial sources.
<b>Benefit/Ranking</b>	Ranking: iii. Thick pixelated CZT detectors will provide good position and energy resolution for an unprecedentedly broad energy range.	Ranking: iii. The ASIC is the principal limiting factor for the power budget, energy resolution, time resolution. ASIC performance directly translates into mission performance improvements.	Ranking: ii. Compact active shielding is important for NASA astrophysics missions and can produce reductions in mass and volume.
<b>NASA needs/Ranking</b>	Ranking: iii. Pixelated CZT detectors of this type can be applied to various missions that need large area wide-field imaging and spectroscopy with broad energy coverage.	Ranking: iii. Low power, low-noise ASICs coupled with pixelated CZT detectors of this type can be applied to various missions that need large area wide-field imaging, and spectroscopy.	Ranking: ii. Compact active shielding is important for NASA astrophysics missions and can produce reductions in mass and volume
<b>Non-NASA but aerospace needs</b>	Ranking: ii. Space-based monitoring programs in other agencies	Ranking: ii. Space-based monitoring programs in other agencies	
<b>Non aerospace needs</b>	Ranking: i. Nuclear medicine and ground-based nuclear materials detection applications	Ranking: i. Nuclear medicine and ground-based nuclear materials detection applications	
<b>Technical Risk</b>	Ranking: ii. Technical risk is low. The design principles are generally understood but progress comes through design iterations to refine performance based on completed units.	Ranking: iii. Technical risk is moderate given access to (rare) analog ASIC design expertise. The history of analogous flight projects shows this task must not be underestimated. The main challenge is to get low power with low noise.	Ranking: iii. Technical risk is low.
<b>Sequencing/Timing</b>	Ranking: iv. CZT detectors with the required pixel size are currently being adapted from those flown on ProtoEXIST1.	Ranking: iv. ASICs based upon the NuStar ASIC are currently being adapted.	Ranking: iv. This concept will be tested in ProtoEXIST 2-3 and compared with existing active shielding concepts.
<b>Time and Effort to achieve goal</b>	Ranking: iv. 3 year collaboration between industry and NASA	Ranking: iv. 3 year collaboration between industry and NASA	Ranking: iv. 3 year collaboration between industry and NASA

## Attachment 6: Next Generation EUV/Soft X-ray

Name of Technology (256 char)	extended duration rockets	EUV or Soft X-ray detector systems	Gratings
<b>Brief description of the technology (1024)</b>	Modest launch vehicles capable of putting a few hundred kg in orbit for a few weeks, but also supportive of the objective of converting existing sounding rocket payloads into short-life satellites.	Existing EUV detectors suffer from low quantum efficiency which must be compensated by long observing time. Improved photocathodes and electronics improvements can be multipliers for system performance numbers	High-resolution blazed gratings for high power, replicated by emerging nanolayer technologies. This capability delivers high spectral resolution to analyze source spectral lines and separate them from spectral features of the interstellar medium.
<b>TABS category</b>	TA 1.1 - 1.2	TA8.1.1	TA8.1.3
<b>Goals and Objectives (1024)</b>	The goal is to reach flight readiness around 2015	The goal is to reach TRL 6 by 2015	The goal is to reach TRL 6 by 2015
<b>TRL</b>	Suitable vehicles have been tested a few times, hence have TRL 9. Satellite systems to match have not been developed	4 TRL is between 4 and 5. Requires efforts towards space qualification and testing in relevant environment.	TRL is 2 for new designs. Prototyping for new concepts has only begun
<b>Tippling Point (100 words or less)</b>	A single demonstration flight, such as was done for the SPARTAN concept in the 1980s would bring the concept to maturity	Pixel designs require custom ASIC development to meet targets for power combined with noise level.	Prototypes exist involving nano-fabrication using high-Z materials to deliver performance at higher energies.
<b>NASA capabilities (100 words)</b>	NASA's capabilities at WFF are central to this concept. There is no realistic alternative but DoD may be able to contribute constructively.	NASA's does not have an engineering group producing detectors of this kind but suitable commercial sources exist	NASA has no appropriate facilities but they also exist in other government departments and in industry.
<b>Benefit/Ranking</b>	Ranking iv. The benefit of a short orbital mission over a sounding rocket flight is roughly the ratio of the durations, i.e., $10^{6.5} \text{ s} / 10^{2.5} \text{ s}$ , or $10^4$ .	The detector unit is crucial for envisioned next-generation systems. Ranking iv.	Gratings and multilayer coatings are essential for normal incidence spectrometers. Fabrication technologies for both are applicable at X-ray and UV wavelengths. Ranking iv.
<b>NASA needs/Ranking</b>	Ranking iv. Mission capability intermediate between sounding rockets and explorers enables a strategy for maintaining the astrophysics community and training students in a time of lean budgets	The detectors that support EUV can with modifications be used on optical/NUV missions planned for later years. Ranking: iv	Gratings remain the preferred way to reach high spectral resolution at these energies ranking iv.
<b>Non-NASA but aerospace needs</b>	There is synergy with DoD use of similar LV and satellite systems, creating potential for partnerships	potential remote sensing applications	potential remote sensing applications
<b>Non aerospace needs</b>	Not applicable, by definition	Can be used in synchrotron and laser plasma research	Can be used in synchrotron and laser plasma research

## Attachment 6: next Generation EUV/Soft X-ray

<b>Technical Risk</b>	Technical risk is low; development paths are straightforward	Technical risk is low but there is some risk of backsliding in the industrial capabilities. Ranking ii	Technical risk is moderate for completely new approach.
<b>Sequencing/Timing</b>	Needed immediately to establish programmatic viability	Should come as early as possible. Development of other system components depends on it. Ranking iv	Essential to development of explorer class mission
<b>Time and Effort to achieve goal</b>	Ranking iii. Moderate effort. 3 year collaboration between industry and NASA	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA



## Attachment 7: Next Generation X-ray Timing

Name of Technology (256 char)	Pixelated Large-Area Solid State X-ray Detectors	Low-Noise, Low-power ASICs for Solid State Detectors	Thin, Lightweight X-ray Collimators
<b>Brief description of the technology (1024)</b>	X-ray timing science objectives call for achieving several square meters of X-ray sensitive collection, over range 2-30 keV, obtaining time of arrival and energy for each photon. Silicon pixel arrays, silicon drift detectors, pixel arrays of high-Z materials, or hybrids are possible choices but all need development.	Low power ASICs are needed to provide accurate time of arrival and energy for each photon but with low aggregate power per square meter.	Requirements of new X-ray timing instruments built around solid state elements require re-thinking design of the collimator unit that provides source isolation. In order to not dominate the mission mass and volume budgets, the collimator must be much thinner and lighter than previous honeycomb collimator designs.
<b>TABS category</b>	8.1.1	8.1.2	10.1.1
<b>Goals and Objectives (1024)</b>	The goal is to achieve large area detectors that are thick enough to have significant stopping power above 30 keV. The technology should reach TRL 6 in by 2014, to meet opportunities for near-term explorers.	The ASIC must achieve noise performance good enough to allow a low energy threshold of $\leq 2$ keV and an energy resolution $\leq 600$ eV with a total power budget less than $100 \text{ W/m}^2$ . The ASIC must reach TRL 6 by 2014 to meet opportunities for near-term Explorers.	The goal is to produce collimators with FWHM $\leq 1$ deg that are $<1$ cm thick, and have stopping power sufficient to effectively collimate X-rays at 50 keV.
<b>TRL</b>	TRL is between 4 and 5. Requires efforts towards space qualification and testing in relevant environment.	TRL is 3. Portions of the functionality have been demonstrated but a full prototype that meets both the noise and power requirements has not yet been produced.	TRL is 3 for new designs. Prototyping for new concepts has only begun
<b>Tippling Point (100 words or less)</b>	Designs have reached TRL 4. A focused effort could increase this to TRL 6. A few cycles of fabrication and test are realistically necessary, but must be coordinated with ASIC development.	The ASIC is the key ingredient in achieving a system that meets the performance requirements. One successful design and fabrication will allow systems to be tested in relevant environments.	Prototypes exist involving nano-fabrication using high-Z materials to deliver performance at higher energies.
<b>NASA capabilities (100 words)</b>	NASA's capabilities support test but pixel arrays are custom procurements from commercial sources.	NASA's does not have an engineering group producing custom ASICs of this kind but suitable groups exist in DoE or at commercial sources.	NASA has nano-fabrication facilities but they also exist in other government departments and in industry.
<b>Benefit/Ranking</b>	Ranking: iii. The transition of X-ray missions from gas proportional counters to solid state designs will allow a 5-10x increase in effective area and a quantum leap in detector reliability.	Ranking: iii. The ASIC is the principal limiting factor for the power budget, energy resolution, time resolution. ASIC performance directly translates into mission performance improvements.	Ranking: iii. Older collimator designs are needlessly high in areal density ( $\text{gm/cm}^2$ ) and have vertical thickness that is disadvantageous if detector units are stacked for launch and then deployed. Older collimator designs can needlessly dominate the mass budget for explorer-class missions.
<b>NASA needs/Ranking</b>	Ranking: iii. Pixelated silicon detectors of this type can be applied to various missions that need large area X-ray timing, wide-field imaging, and spectroscopy.	Ranking: iii. Low power, low-noise ASICs coupled with pixelated silicon detectors of this type can be applied to various missions that need large area X-ray timing, wide-field imaging, and spectroscopy.	Ranking: iii. Thin, light collimators with good stopping power can be used in a variety of NASA and laboratory settings.
<b>Non-NASA but aerospace needs</b>	Ranking: ii. Such devices might be used in certain envisioned applications such as X-ray navigation of satellites.	Ranking: ii. Such devices might be used in certain envisioned applications such as X-ray navigation of satellites.	Ranking: ii. Collimators might function in flight X-ray systems for applied uses.
<b>Non aerospace needs</b>	Ranking: i. Non space-qualified systems exist to meet non-space needs such as inspections.	Ranking: i. Similar ASICs have commercial applications, but any connection is really via maintaining development teams that can support space and non-space needs.	Ranking: ii. Such collimators could be used for X-ray detector systems on the ground where collimation was a requirement
<b>Technical Risk</b>	Ranking: ii. Technical risk is low. The design principles are generally understood but progress comes through design iterations to refine performance based on completed units.	Ranking: iii. Technical risk is moderate given access to (rare) analog ASIC design expertise. The history of analogous flight projects shows this task must not be underestimated. The main challenge is to get low power with low noise.	Ranking: iii. Technical risk is moderate for completely new approaches. Lacking such investment there would be fallback to older designs mis-matched to requirements, resulting in sub-optimized mission performance.
<b>Sequencing/Timing</b>	Ranking: iv. Should come as early as possible. Development of other system components depends on detector unit parameters.	Ranking: iv. Should come as early as possible. Development of other system components depends on ASIC power performance.	Ranking: iv. Should come fairly early in mission development because it drives overall system characteristics.
<b>Time and Effort to achieve goal</b>	Ranking: iv. 3 year collaboration between industry and NASA	Ranking: iv. 3 year collaboration between industry and NASA	Ranking: iv. 3 year collaboration between industry and NASA

## Attachment 8: Next Generation Gamma-Ray - Compton

Name of Technology (256 char)	Si, Ge, CZT or CdTe strip detectors	ASICS	Active Cooling
<b>Brief description of the technology (1024)</b>	High spectral resolution is needed to obtain nucleosynthesis signatures and spatial resolution is needed to isolate sources and maximize signal to noise. This leads to Compton telescope designs with solid state detector arrays. Si, CZT and CdTe do not need cooling. Ge delivers better resolution.	Low power ASICs are needed to provide accurate energy for each photon but with low aggregate power per square meter.	Germanium arrays need active cooling below 100K, but on the scale needed for a Compton telescope this is a challenge.
<b>TABS category</b>	TA8.1.6	TA8.1.2.	TA8.1.3
<b>Goals and Objectives (1024)</b>	The goal is to reach TRL 6 in 2015, to meet opportunities for near-term explorers	The goal is to reach TRL 6 by 2015	The goal is to reach TRL 6 by 2015
<b>TRL</b>	TRL is between 4 and 5 depending on whether it is Si, CZT, CdTe or Ge. Requires efforts towards space qualification and testing in relevant environment.	TRL is essentially undefined until the detector is specified. The ASIC is specific to the detector and developed in co-evolution with it.	TRL is between 4 and 5. Primary effort is achieving large scale in heat removal per unit time, followed by space qualification and testing in relevant environment.
<b>Tipping Point (100 words or less)</b>	Designs have reached TRL 4. A focused effort could increase this to TRL 6. A few cycles of fabrication and test are realistically necessary, but must be coordinated with ASIC development.	Pixel designs require custom ASIC development to meet targets for power combined with noise level.	If a breakthrough in refrigeration is not achieved, Ge will tend to be eliminated in favor of the room temperature semiconductor options
<b>NASA capabilities (100 words)</b>	NASA's capabilities support test but strip arrays are custom procurements from commercial sources.	NASA has engineering groups producing custom ASICs at GSFC but suitable groups also exist in DoE or at commercial sources.	Refrigeration development capabilities exist in NASA but also in industry.
<b>Benefit/Ranking</b>	Ranking iv. The detector array is the primary factor determining system performance, setting the size scale, sensitivity and other factors, enabling the entire mission concept, hence the science.	Ranking ii. Detector capability alone without an ASIC suitably matched to it could lead to prohibitive system power and make the concept unworkable. Multiple turns of development are likely needed. Ranking: TBD	Ranking iii. Solving refrigeration for this application would conceivably be enabling for other missions
<b>NASA needs/Ranking</b>	NASA needs a next generation medium-energy gamma-ray mission to advance understanding of nuclear astrophysics and black hole sources.	The detector alone is not sufficient and requires the ASIC. If the material is Ge, the ASIC is probably external to the refrigeration, but still needs to be low power.	Refrigeration is a general need for germanium detectors in space use
<b>Non-NASA but aerospace needs</b>	Such devices might have applied uses, including charged particle and other environmental monitoring done from space platforms	ASICs are an integral part of the system hence contribute similarly to detectors	
<b>Non aerospace needs</b>	Detector systems might have use in sea-level environmental monitoring e.g., for nuclear materials as well as nuclear medicine, etc. Ranking iv	ASICs are an integral part of the system hence contribute similarly to detectors; Ranking iv	

## Attachment 8: Next Generation Gamma-Ray - Compton

<b>Technical Risk</b>	Technical risk is low. The design principles are generally understood but progress comes through design iterations to refine performance based on completed units. Cost risk may drive material preferences. Ranking ii	Technical risk is low to moderate given access to (rare) analog ASIC design expertise. The history of analogous flight projects shows this task must not be underestimated. The main challenge is to get low power with low noise. Ranking ii	
<b>Sequencing/Timing</b>	Should come as early as possible. Development of other system components depends on detector unit parameters. Ranking iv	ASIC design must be matched to design of the detector element and cannot precede it, but should be roughly simultaneous.	Refrigeration system needs to be designed as part of mission system engineering
<b>Time and Effort to achieve goal</b>	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA	Ranking iii. Moderate effort, 3 year collaboration between industry and NASA

1. Can you list/describe emerging technologies that have the potential for radical improvement in a measurement capability over the next 30 years?

**A) High stability optical platforms:**

Includes optical benches, telescopes, etc, requiring passive thermal isolation for temperature stability. Hydroxide or silicate bonding for precision alignment capability and dimensional stability. Precision materials such as Silicon Carbide and single crystal silicon.

**B) Precision interferometry:**

Requires CW single-frequency and frequency-stabilized lasers for space (GSFC applications so far are pulsed). Digital techniques including coded modulation for time-of-flight resolvable interference, and flexible in-flight changes. Time-Domain Interferometry (LISA's equal-path-length synthesis techniques).

**C) Frequency combs:**

Could be used for LIDAR/remote sensing applications to distinguish types of vegetation and resolve shrubs vs. trees on a slope. Requires frequency stabilization, pulsed lasers, and good detectors.

**D) single-mode fiber optic technology for space (now using multimode, mostly):**

Now developed for wavelengths not usually used in space: 1550 nm

Fiber Bragg Gratings for frequency stability, references, and filters.

Modulators, isolators, and circulators. No alignment required and lightweight.

Changing traditional wavelengths to take advantage of telecom technology where possible

**E) Scattered light suppression:**

Includes masks and apodization, black coatings, and cleaning/particulate/contamination techniques.

**F) Optical communications:**

Phase-array capabilities would obsolete DSN or single-pointing-capable telescopes.

Orbiting TDRS-style relay network could obsolete DSN, form basis of a high reliability space-borne NETWORK for long-duration space flights/bases but also comm-constrained missions such as to the outer planets.

2. Of those technologies listed in question 1, can you identify those that cut across many different potential applications?

High Stability and/or fiber optics: atom interferometry, LISA, Grace, Exoplanets

Frequency combs: LIDAR/Remote sensing, atom interferometry

Scattered light suppression: atom interferometry, LISA, Grace, Exoplanets

Precision interferometry: optical communications, LISA, Grace

3. Can you list/describe measurement techniques that could enable new NASA missions not currently thought about in our agency strategic planning?

Precision interferometry and phase-sensitive optical detection (good for optical comm)

Frequency combs (sort of part of precision interferometry)

Time-Domain Interferometry

## Attachment 10: Next Generation Gamma-Ray - Laue

Name of Technology (256 char)	pixelated Ge or CZT detectors	ASICS	focusing optics
<b>Brief description of the technology (1024)</b>	High spectral resolution is needed to obtain nucleosynthesis signatures and spatial resolution is needed to isolate sources and maximize signal to noise. In this approach signal to noise is optimized using a focusing optical element in front of the detector array, thereby reducing the total number of detectors but requiring operation at higher count rates. Germanium and CZT have been considered as materials.	Low power ASICs are needed to provide accurate time of arrival and energy for each photon but with ability to handle higher counting rates produced by focusing	Science objective is achieved in a set of narrow energy bands but with high signal to noise in those bands achieved using focusing optics
<b>TABS category</b>	TA8.1.1.	TA8.1.2.	TA8.1.3
<b>Goals and Objectives (1024)</b>	The goal is to reach TRL 6 in 2015, to meet opportunities for near-term explorers	The goal is to reach TRL 6 by 2015	The goal is to reach TRL 6 by 2015
<b>TRL</b>	TRL is 4 for CZT or Ge. Requires efforts towards space qualification and testing in relevant environment.	TRL is essentially undefined until the detector is specified. The ASIC is specific to the detector and developed in co-evolution with it.	TRL is 4.
<b>Tippling Point (100 words or less)</b>	Designs have reached TRL 4. A focused effort could increase this to TRL 6. A few cycles of fabrication and test are realistically necessary, but must be coordinated with ASIC development.	Pixel designs require custom ASIC development to meet targets for power combined with noise level.	If a breakthrough in optics is not achieved, the preferred option will be Compton telescopes meaning larger array dimensions but without optics
<b>NASA capabilities (100 words)</b>	NASA's capabilities support test but strip arrays are custom procurements from commercial sources.	NASA has engineering groups producing custom ASICs at GSFC but suitable groups also exist in DoE or at commercial sources.	NASA has no special facilities but they exist in other government departments, industry, and elsewhere, with choice of source depending on requirements and approach
<b>Benefit/Ranking</b>	Ranking ii. The detector array is the primary factor determining system performance, setting the size scale, sensitivity and other factors, enabling the entire mission concept, hence the science.	Ranking ii. Detector capability alone without an ASIC suitably matched to it could lead to prohibitive system power and make the concept unworkable. Multiple turns of development are likely needed. Ranking: TBD	Ranking iii. Producing optics for this application would be largely mission specific and not transferable to other uses, but the optical solution is enabling for this approach to a medium gamma-ray mission.
<b>NASA needs/Ranking</b>	NASA needs a next generation medium-energy gamma-ray mission to advance understanding of nuclear astrophysics and black hole sources.	The detector alone is not sufficient and requires the ASIC. If the material is Ge, the ASIC is probably external to the refrigeration, but still needs to be low power.	Without optical system the NASA needs for a medium-energy gamma-ray mission are most likely to be achieved using Compton telescope designs.
<b>Non-NASA but aerospace needs</b>	none	none	none

## Attachment 10: Next Generation Gamma-Ray - Laue

<b>Non aerospace needs</b>	Detector systems might conceivably find use in sea-level environmental monitoring but would face competition from other approaches. Ranking ii	ASICs are an integral part of the system hence contribute similarly to detectors; Ranking iv	
<b>Technical Risk</b>	Technical risk is low. The design principles are generally understood but progress comes through design iterations to refine performance based on completed units. Ranking ii	Technical risk is low to moderate given access to (rare) analog ASIC design expertise. The history of analogous flight projects shows this task must not be underestimated. The main challenge is to get low power with low noise. Ranking ii	Technical risk is moderate for completely new approaches. Lacking such investment there would be fallback to older designs mismatched to requirements, resulting in sub-optimized mission performance.
<b>Sequencing/Timing</b>	Should come as early as possible. Development of other system components depends on detector unit parameters. Ranking iv	Should come as early as possible. Development of other system components depends on ASIC power performance. Ranking iv	Should come first in mission development because it is a prerequisite
<b>Time and Effort to achieve goal</b>	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA	Ranking iv. Minimal effort. 3 year collaboration between industry and NASA	Ranking iii. Moderate effort, 3 year collaboration between industry and NASA