American Physical Society
Anaheim, CA

PhysPAG Technology Study Analysis Group (SAG)

Roger Brissenden
for the TechSAG team

1 May 2011

Technology SAG

- TechSAG formed to provide quantitative analysis and assessment to NASA via the Astrophysics Subcommittee (APS) in regard to PCOS technology needs
- SAG formed and two tasks defined at the Seattle AAS
- Tasks approved by the APS at February meeting:
  - Conduct a review of NASA technology roadmaps from PCOS perspective and provide input to the present NRC review (complete)
  - Technology development planning for Explorer science and beyond (next)

Technology SAG Membership

- Present Technology SAG membership:
  - Jay Bookbinder (CfA)
  - Roger Brissenden (chair; CfA)
  - Randall Correll (Ball)
  - Kathy Flanagan (STScI)
  - Liz Hays (GSFC)
  - Shaul Hanany (UMN)
  - Kent Irwin (NIST)
  - Guido Mueller (U. Florida)
  - Steve Murray (JHU)
  - Jason Rhodes (JPL)
  - Dan Schwartz (CfA)
  - Colleen Wilson-Hodge (MSFC)
  - Kent Wood (NRL)
  - PCOS Program Office (GSFC): Jean Cottam, Carl Stahl, Jackie Townsend
  - NASA HQ Observers: Jaya Bajpayee, Mike Moore, Rita Sambruna
- Membership open to the community. Email *rjb@cfa.harvard.edu* and watch the PhysPAG website: *http://pcos.gsfc.nasa.gov/physpag.php*

Technology Roadmap Task

- NRC reviewing NASA Office of the Chief Technologist (OCT) technology road maps
  - Workshops held to solicit community input
  - Deadline for input via web forms, 4/15/11

- PhysPAG Technology SAG task to review roadmaps for gaps against PCOS needs and provide NRC input

NRC Input

- NRC requested input via workshops and web form:
  - Name, goal, TRL, tipping point, NASA capabilities, benefit, alignment with NASA and non-NASA needs, risk, timing, required effort
  - See *http://www8.nationalacademies.org/asebsurvey/tabs/*

- TechSAG benefitted from interactions with two NRC Workshop (Irvine; 3/29/11) presenters who are also TechSAG members:
  - X-ray Photon Detectors (Steve Murray)
  - Development of microcalorimeters for both sub-mm and X-ray applications (Kent Irwin)

PhysPAG Technology SAG Process

- SAG Telecons held 2/25, 3/10, 3/30
- Updated 2005 Technology Roadmap to provide framework
- Assessed PCOS technology areas against Draft Science Instruments, Observatories, and Sensor Systems Roadmap (TA08) for gaps and required updates
- Presented roadmap and inputs to the Astrophysics Subcommittee on 4/7: approved
- Submitted inputs by 4/15 to NRC study website
- A community input gathering activity, not a critical assessment.

PCOS Technology Checklist

	Mission Technology	TechSAG relative to TA08
2010 Decadal	WFIRST	ok
	LISA	input to NRC
	IXO	ok
	Inflation Probe	input to NRC
	Fundamental Physics	input to NRC
Near-term push	Next Generation Hard X-ray	input to NRC
	Soft X-ray and EUV	input to NRC
	Next Generation X-ray Timing	input to NRC
	Next Generation Medium-Energy Gamma-Ray: Compton	input to NRC
Long-term push	Next Generation Medium-Energy Gamma-Ray: Laure	input to NRC
	Beyond LISA	input to NRC
	Beyond IXO	ok

- Gathered technology needs *vs*. near- and long-term PCOS needs
- Input to NRC for gaps/updates identified for 9 of 12 mission areas

PhysPAG Technology Roadmap

	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 γ-ray Observatory**	**Beyond LISA (Big Bang Observer)**		**Beyond IXO (Gen-X)**	**Next generation γ-ray Focusing**
Science Summary	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 istoropy 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 evolutionof SMBHs, study matter at extreme conditions	Signatures of nucleosynthesis in SNR, transients, and other sources
Architecture	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 withj 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^2) pointed arrays of solid state devices, with collimation to isolate sources	Single platform designs to measure γ-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**2 grazing incidence telescope with 60 M focal length	2-platform designs to measure γ-ray lines
Wavelength	0.4 to 1.7 um (TBD)	Interferometer λ= 1.064 um - 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
Telescopes: Optics	🟩 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 opitcs to achieve 0.1 arcsec. High resolution grating spactrometer	🟪 Focusing elements (e.g., Laue lens) on long boom or separage platform
Telescopes: Wavefront Sensing & Control and Interferometry		🟨 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	
Telescopes: Metrology & Structures & Lasers	🟩 Classic telescope structure - HST heritage	🟨 Athermal design with a Temp gradient Dimensional stability: pm/sqrt(Hz) and um lifetime, angular stability < 8nrad	🟨 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	🟨 Extendale optical bench to achieve 60 M focal length	🟨 Long booms or formation flying
Detectors & Electronics	🟨 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 precission over 1-2 year experiment. Cooled atomic clocks with 10E-18 to 10E-19 precision over 1-2 year experiment.	🟩 1m^2 Si (~0.2mm strips)+~ 6m^2 CZT (~1.2mm pixels); ASIC on ea. ~20x20mm crystal. photon-counting over cont. scan	🟨 Photocathodes, micro-channel plates, crossed-grid anodes	🟪 >3 m^2 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
Coolers & Thermal Control	🟨 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
Distributed Space Craft		🟩 Spacecraft in separate Keplerian orbits. No formation flying or station-keeping. Low contamination μ-Newton thrusterswith 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

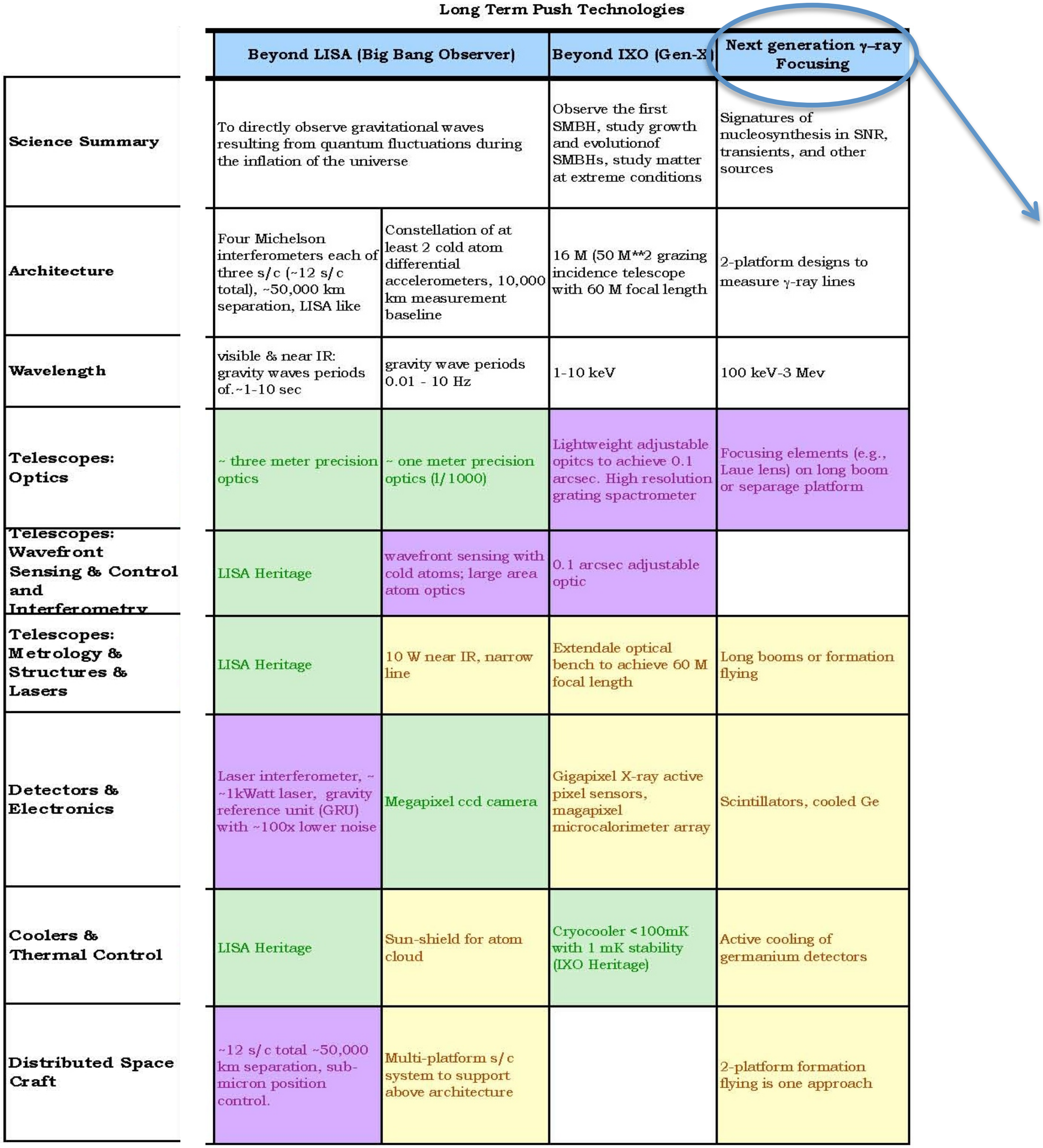
Near Term Push Technologies

	Next Generation Hard X-ray Obs.	Soft X-ray and EUV	Next generation X-ray timing	Next generation Medium-energy γ–ray Observatory
Science Summary	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
Architecture	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^2) pointed arrays of solid state devices, with collimation to isolate sources	Single platform designs to measure γ-ray lines
Wavelength	5-30 and 10-600keV	5-500 Angstroms	2-80 keV	100 keV - 30 MeV
Telescopes: Optics	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
Telescopes: Wavefront Sensing & Control and Interferometry		Actuators		
Telescopes: Metrology & Structures & Lasers	~ 5" aspect req. over ~6x~3x~1.5m tel. structures	Arcsecond attitude control to maintain resolution	Moderate accuracy pointing of very large planar array	
Detectors & Electronics	1m^2 Si (~0.2mm strips)+~ 6m^2 CZT (~1.2mm pixels); ASIC on ea. ~20x20mm crystal. photon-counting over cont. scan	Photocathodes, micro-channel plates, crossed-grid anodes	>3 m^2 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
Coolers & Thermal Control	LHP to radiators for -~30deg (Si) and ~-5deg (CZT) over large areas		Passive cooling of pixel arrays	Active cooling of germanium detectors
Distributed Space Craft		Use low-cost launch vehicles for single payloads with few month mission duration		

NRC Input
on next page

Name of Technology (256 char)	**Next Generation X-ray Timing (1 of 3): Pixelated Large-Area Solid State X-ray Detectors**	**Next Generation X-ray Timing (2 of 3): Low-Noise, Low-power ASICs for Solid State Detectors**	**Next Generation X-ray Timing (3 of 3): Thin, Lighweight X-ray Collimators**
Brief description of the technology (1024)	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 colllimator designs.
TABS category	8.1.1	8.1.2	10.1.1
Goals and Objectives (1024)	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 <= 2 keV and and energy resolution <= 600 eV with a total power budget less than 100 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 <= 1 deg that are <1 cm thick, and have stopping power sufficient to effectively collimate X-rays at 50 keV.
TRL	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
Tipping Point (100 words or less)	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.
NASA capabilities (100 words)	NASA's capabilities support test but pixel arrays are custom procurements from commercial sources.	If NASA' does not have an engineering group producing custom ASICs of this kind, 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.
Benefit/Ranking	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 (gm/cm2) 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.
NASA needs/Ranking	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.
Non-NASA but aerospace needs	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.
Non aerospace needs	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
Technical Risk	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.
Sequencing/Timing	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.
Time and Effort to achieve goal	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

Long Term Push Technologies



	Beyond LISA (Big Bang Observer)		Beyond IXO (Gen-X)	Next generation γ–ray Focusing
Science Summary	To directly observe gravitational waves resulting from quantum fluctuations during the inflation of the universe		Observe the first SMBH, study growth and evolutionof SMBHs, study matter at extreme conditions	Signatures of nucleosynthesis in SNR, transients, and other sources
Architecture	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**2 grazing incidence telescope with 60 M focal length	2-platform designs to measure γ-ray lines
Wavelength	visible & near IR: gravity waves periods of.~1-10 sec	gravity wave periods 0.01 - 10 Hz	1-10 keV	100 keV-3 Mev
Telescopes: Optics	~ three meter precision optics	~ one meter precision optics (l/1000)	Lightweight adjustable opitcs to achieve 0.1 arcsec. High resolution grating spactrometer	Focusing elements (e.g., Laue lens) on long boom or separage platform
Telescopes: Wavefront Sensing & Control and Interferometry	LISA Heritage	wavefront sensing with cold atoms; large area atom optics	0.1 arcsec adjustable optic	
Telescopes: Metrology & Structures & Lasers	LISA Heritage	10 W near IR, narrow line	Extendale optical bench to achieve 60 M focal length	Long booms or formation flying
Detectors & Electronics	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
Coolers & Thermal Control	LISA Heritage	Sun-shield for atom cloud	Cryocooler <100mK with 1 mK stability (IXO Heritage)	Active cooling of germanium detectors
Distributed Space Craft	~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

NRC Input
on next page

Name of Technology (256 char)	**pixelated Ge or CZT detectors**	**ASICS**	**focusing optics**
Brief description of the technology (1024)	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 withability 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. A separation of several tens of meters between optics and detectors is realized with a deployable boom.
TABS category	TA8.1.1.	TA8.1.2.	TA8.1.3
Goals and Objectives (1024)	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
TRL	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.
Tipping Point (100 words or less)	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
NASA capabilities (100 words)	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.	N ASA has no special facilities but they exist in other government departments, industry, and elsewhere, with choice of source depending on requirements and approach
Benefit/Ranking	Ranking iii.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 iii. 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.
NASA needs/Ranking	NASA needs a next generation medium-energy gamma-ray mission to advance understanding of nuclear astrophysics and black hole sources.Ranking iii	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. Ranking iii	Without optical system the NASA needs for a medium-energy gamma-ray mission are most likely to be achieved using Compton telescope designs. Ranking iii
Non-NASA but aerospace needs	none. Ranking i.	none. Ranking i.	none. Ranking i.
Non aerospace needs	Detector systems mightconceivably 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 ii	none. Ranking i.
Technical Risk	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 mis-matched to requirements, resulting in sub-optimized mission performance.
Sequencing/Timing	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. Ranking iv.
Time and Effort to achieve goal	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

2. Explorer Technology Task

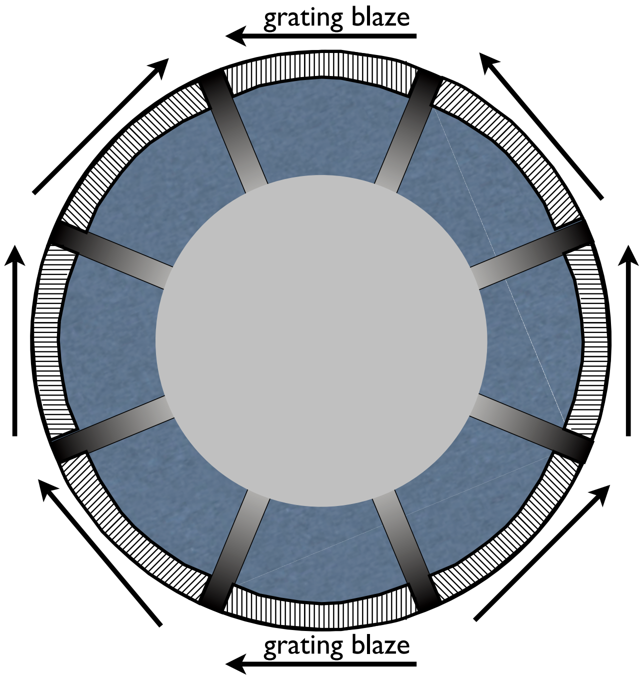
- Interest expressed at Seattle AAS PhysPAG meeting in assessing technology development needs for PCOS Explorer class missions
- Possible Approach:
  - Build on roadmap review task to identify subset of PCOS science objectives applicable to Explorers
  - Assess technology needs
  - Provide input to APS
- Current Explorer class missions: Suzaku, Swift, RXTE, NuSTAR, Astro-H and GEMS

Example: Soft X-ray Spectropolarimeter mission*

- Science
  - Pulsar B-field modeling
  - QED effects in strong magnetic fields
  - Tests of GR near Galactic black hole binaries
  - Modeling structure in quasar and BL Lac jets
  - Modeling atmospheres of AGN accretion disks
- Architecture concept
  - Polarimeter that uses blazed transmission gratings to disperse X-rays to multilayer coated flat mirrors
  - Explorer with EA~25 cm^2 (0.4 KeV) could measure ~15% polarization of a BL Lac or a pulsar in several bands in 1-2 days

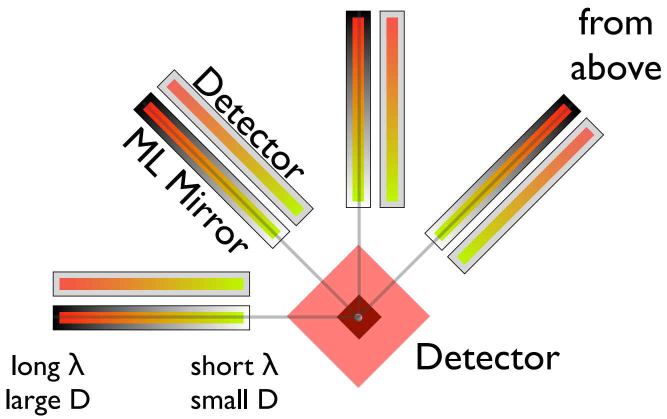
* Example provided by Herman Marshall (MIT)

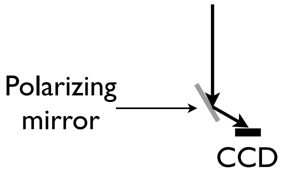
A Soft X-ray Spectropolarimeter

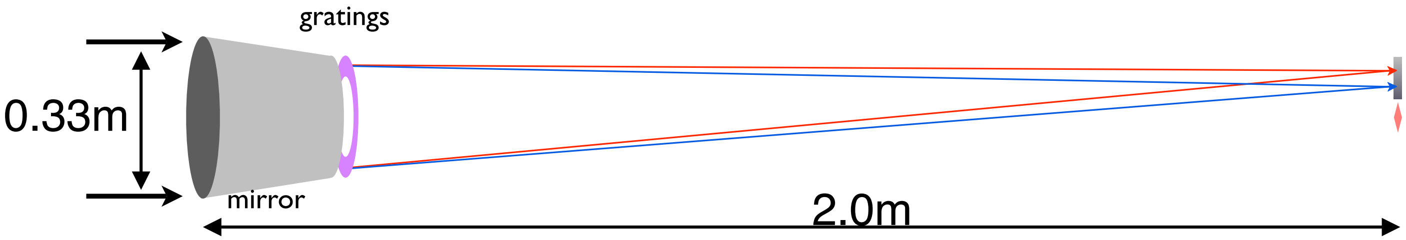


View of front aperture

View of focal plane







Technology Assessment

Technology	Heritage	TRL
Mirrors	Suzaku, Astro-D	9
Gratings*	HETG/LETG; but Critical Angle Transmission (CAT) grating design gives higher efficiency	3-4
Multilayer Coating*	Solar missions; but laterally graded gives higher efficiency	4
Detectors	Any CCD type	9

*Gratings and ML coatings would require ~2-3 years of development to be ready for a sounding rocket opportunity to raise the TRL readiness for Explorer

Areas for Discussion

– Detailed task definition and approach
– How to obtain community input
– Explorers used as pathfinders?
– Form of input to Astrophysics Subcommittee?

Discussion today and through future TechSAG telecons and meetings