Technology Roadmap - PhysPAG Technology SAG - 10/15/11 *

Decadal Survey 2010 (New Worlds New Horizons)

	WFIRST	LISA	IXO-like	Inflation Probe	Fundamental Physics
		Table 1	**Table 2**	**Table 3**	**Tables 4a, 4b**
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.	Study the Inflationary Epoch of the Universe by observing the CMB B-mode polarization signal.	Precision measurements of space-time istoropy and gravitational effects.
Architecture	Single 1.5 m diaiameter 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.	High-throughput cooled mm-wave meter-class telescope with large-format polarization-sensitive detector arrays.	Individual spacecraft for space-time measurement and gravitational effects. Multiple spacecraft for precision timing of interferometric measurements.
Wavelength	0.6 to 2.0 μm	Interferometer λ= 1.064 μm - gravity wave period 10-10,000 sec.	0.3 to 40 keV	1 - 10 mm	
Telescopes and Optical Elements	Wide FOV, ~1.5 m diameter mirror.	Classical optical design; Surface roughness < 1 λ/30, backscatter/ stray light.	lightweight, replicated X-ray optics.	High-throughput, light, low-cost, cold mm-wave telescope operating at low backgrounds; Anti-reflection coatings; Polarization modulating optical elements.	
		Alignment sensing, Optical truss interferometer, Refocus mechanism.			Coupling of ultra-stable lasers with high-finesse optical cavities for increased stability.
	Classic telescope structure - HST heritage	Athermal design with a Temp gradient Dimensional stability: pm/sqrt(Hz) and um lifetime, angular stability < 8 nrad.	lightweight precision structure		

Detectors & Electronics	HgCdTe CMOS (H4RG?)	Laser: 10 yr life, 2W, low noise, fast frequency and power actuators; Quadrant detector, low noise, 10 yr 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 10^{-15} precision over orbital period; 10^{-17} precission over 1-2 year experiment. Cooled atomic clocks with 10^{-18} to 10^{-19} precision over 1-2 year experiment.
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 10^{-8} K variation.
Distributed Space Craft		Spacecraft in separate Keplerian orbits. No formation flying or station-keeping. Low contamination μ-Newton thrusters with low thrust noise.			Applicable as precision timing standard in distributed constellations.

* Derived and updated from 2005 Strategic Roadmap-8 and Universe Roadmap

TRL7-9	TRL 4-6	TRL 1-3

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Near Term Push Technologies **

	Advanced mm-wave/far-IR Arrays	Next Generation Hard X-ray Observatory	Next Generation EUV/Soft X-ray Observatory	Next Generation X-ray timing	Next Generation Medium-energy γ–ray Observatory	21cm Cosmology Array
	Table 3	**Tables 5a, 5b**	**Table 6**	**Table 7**	**Table 8**	**Table 9**
Science Summary	Enhanced sensitivity or reduced resources for the Inflation Probe; far-infrared astrophysics.	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.	Track evolution of Universe from the Dark Ages (before the first stars), through Cosmic Dawn, and into the Epoch of Reionization using the highly-redshifted 21 cm hyperfine transition of neutral hydrogen.
Architecture	High-sensitivity, large-format, multi-color focal planes for mm-wave to far-infrared imaging, polarimetry & spectroscopy.	Two wide-field (~130 x ~65 deg) coded mask telescopes. Full sky each ~95 min (5a); Alternatively a Nu-STAR architecture (5b).	Focusing optics with high resolution spectrometers based on advanced gratings.	large (>3 m^2) pointed arrays of solid state devices, with collimation to isolate sources or with arrays of concentrators.	Single platform designs to measure γ-ray lines.	Synthesis array of long-wavelength receptors distributed over a notional area of 10 km operating in an environment with extremely low levels of radio frequency interference.
Wavelength	30 μm - 10 mm	Two architecture concepts within 5-600 keV range	5-500 Angstroms	2-80 keV	100 keV - 30 MeV	5–30 m
Telescopes and Optical Elements	Large throughput, cooled mm-wave to far-infrared telescope operating at background limit.	Coded aperture imaging: ~5 mm thick W and ~2.5 mm holes; ~0.5 mm W and ~0.2 mm holes.	Gratings, single and multilayer coatings, nano-laminate optics.	Either X-ray concentrators or collimators.	Compton telescope on single platform.	Polyimide film-based dipole antennas.
		Hard X-ray grazing incidence telescope with multilayer coatings.	Actuators			Self-deploying magnetic helices
		(5a) 5 arcmin aspect requirement; (5b) 5 arcsec aspect requirement.	Arcsecond attitude control to maintain resolution.	Moderate accuracy pointing of very large planar array.		

Detectors & Electronics	Very large format (> 10^5 pixels) focal plane arrays with background-limited performance and multi-color capability.	CZT detectors matched to system requirements.	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.	Low-power radio frequency (RF) components, capable of operation and survival under large temperature variations.
Coolers & Thermal Control	Cooling to 50 - 300 mK	LHP to radiators for -~30 deg (Si) and ~-5 deg (CZT) over large areas (5a).		Passive cooling of pixel arrays.	Active cooling of germanium detectors.	Science antennas not thermally controlled, electronics controlled only to the minimal level necessary, most likely at high temperature extremes.
Distributed Space Craft			Use low-cost launch vehicles for single payloads with few month mission duration.			Science antennas must be distributed, likely location is lunar far side.

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** Emerging technologies needed for applications in next decade (near-term push) and beyond (long-term push)

TRL7-9 | TRL 4-6 | TRL 1-3

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Long Term Push Technologies **

	Beyond LISA (Big Bang Observer)		Beyond IXO (Gen-X)	Next Generation γ–ray Focusing
	Table 10		Table 11	Table 12
Science Summary	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.
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	0.1-10 keV	100 keV-3 Mev
Telescopes and Optical Elements	~3 m 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.
	LISA Heritage	Wavefront sensing with cold atoms; large area atom optics	0.1 arcsec adjustable optic	
	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, ~1 kWatt 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 <100 mK 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.

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** Emerging technologies needed for applications in next decade (near-term push) and beyond (long-term push)

TRL7-9	TRL 4-6	TRL 1-3