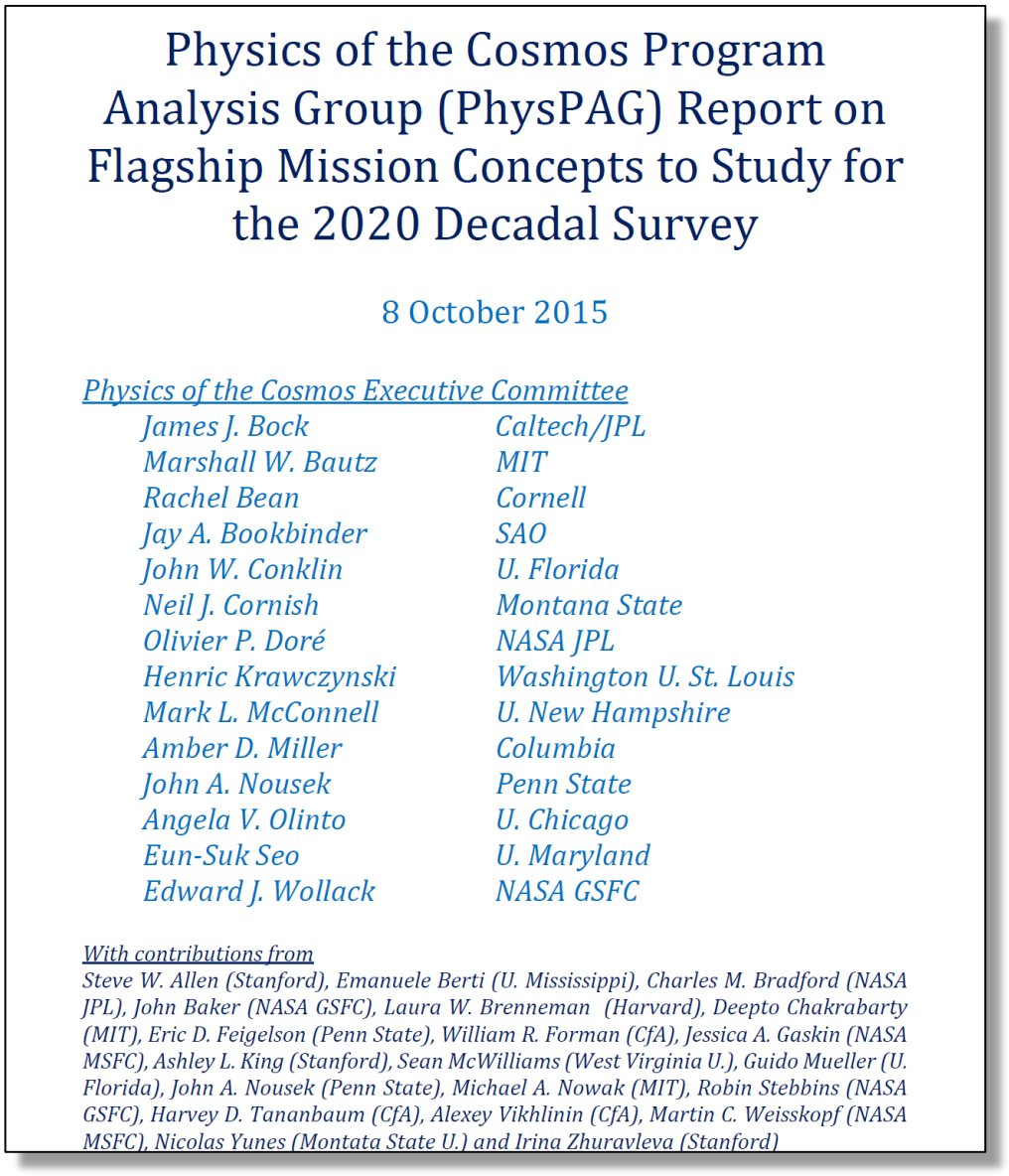

Physics of the Cosmos Program Analysis Group (PhysPAG) Report on Flagship Mission Concepts to Study for the 2020 Decadal Survey

8 October 2015

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PhysPAG Report on Flagship Mission Studies

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Gathering Community Input and PAG Coordination

Date (2015)	Location	Meeting
4 January	Seattle, WA	PhysPAG and Joint PAG meetings at the **American Astronomical Society** conference
		Gamma-ray and X-ray SIG splinters at the AAS
		GW special session The Centennial of General Relativity at AAS
14-17 January	Minneapolis, MN	Inflation Probe SIG meeting at Physics of the **CMB and Its Polarization Conference**
5-6 February	Greenbelt, MD	Gamma-ray SIG meeting at **Future of Space-Based Gamma-ray Observatories Workshop**
19 March	Baltimore, MD	Joint PAG Executive Committee meeting
11-14 April	Baltimore, MD	PhysPAG session at **American Physical Society** conference
		Meetings of the Gravitational-wave, Cosmic-ray and Gamma-ray SIGs at APS
29 April	Telecon	PhysPAG EC meeting
22 May	Telecon	PhysPAG EC meeting
8 June	Telecon	PhysPAG EC meeting
26 June	Telecon	PhysPAG EC meeting
1 July	Chicago, IL	Panel discussion at **AAS High Energy Astrophysics Division** meeting
		X-ray and Gamma-ray SIG meetings at HEAD
3 July	Telecon	Joint PAG chair planning meeting
20 July	Telecon	PhysPAG EC meeting
7 August	Honolulu, HI	Joint PAG session at **International Astronomical Union** conference
28 August	Telecon	PhysPAG EC meeting
31 August	Pasadena, CA	Joint PAG presentation at special session of the **American Institute of Aeronautics and Astronautics**

Joint PAG Findings

1) All 4 large mission concepts should be studied in detail: Far-IR Surveyor, HABEX, UV/Optical/IR Surveyor, X-Ray Surveyor

2) This finding is predicated on the stated assumptions in the charge.
   - Development would not start until after the implementation phases of JWST and WFIRST
   - NASA will partner with ESA on L3 Gravitational Wave Surveyor, conducting the necessary preparations for the 2020 Decadal Review
   - The Inflation Probe is a probe-class mission and will be developed according to the technology and mission planning recommendations in the 2010 Decadal report.

   If these assumptions changed, our findings would need to be reevaluated

3) The STDT should contain broad and interdisciplinary representation of the science community. Cross STDT cooperation is important, especially for the UV/Optical/IR Surveyor and HABEX

4) Strong community support for studying probe missions

Summary of PhysPAG Findings (#1)

The ESA L3 gravitational wave mission is compelling and we look forward to seeing this mission being fully prepared for the US 2020 Decadal review.

Summary of PhysPAG Findings (#1)

Immediate work is needed to determine the US role in the L3 Gravitational Wave Surveyor mission in order to prepare it for the 2020 Decadal Review. These activities are consistent with the 2010 Decadal Review recommendations.

1. Evaluate all technologies needed to realize the gravitational wave mission architecture guided by ESA's and NASA's latest studies and define the combinations of technologies that are compatible with the needs and capabilities of the space agencies involved.

2. Define a range of options for various potential NASA contributions to the L3 mission. The study should evaluate a set of perhaps three or four options which span a large range of potential NASA contributions to evaluate their science return, cost and risk.

3. Assess the science cases for U.S. participation options, and update the science case based on knowledge gained since the preparation for the 2010 Decadal Survey.

4. Assess the size and scope of the U.S. LISA Science Team and needs for a U.S. Data Center to support the L3 collaboration in science, technology, and data analysis.

Summary of PhysPAG Findings (#2)

We agree with the assumption given in the charge that the Inflation Probe mission should be planned as probe-class… however a more definitive statement about the cost of a NASA mission requires a dedicated study, which will be necessary for the 2020 Decadal Review, and which may help better define the parameters of a probe mission category or categories.

Summary of PhysPAG Findings (#2)

The cost and scope of the Inflation Probe analogs CORE+ (ESA; 2015), LITEBIRD (JAXA; 2015) and EPIC-IM (NASA; 2009) are approximately probe class. Therefore the Inflation Probe can be developed as a probe-class mission following the 2010 Decadal Review recommendations

1. The technology program recommended by the 2010 Decadal Review is needed to prepare detection, optics, and cooling technologies that will be needed for the 2020 Decadal Review.

2. Science and technology are best advanced by balloon-borne and ground-based experiment platforms.

3. NASA planning should be coordinated with the recent DOE CMB-S4 ground-based program to maximize the natural synergies between ground-based and space-based observations. This is a natural opportunity to enhance science return and maximize technical synergies.

4. The Inflation Probe mission concept will need to be advanced for the 2020 Decadal Review. It is the natural candidate for advancing and defining the probe mission category (or categories).

Summary of PhysPAG Findings (#3)

We assume that the ESA L2 ATHENA mission will progress with NASA participation to a stage of development such that it will not be reviewed by the 2020 Decadal Review. If this is not the case, then we urge NASA, in coordination with ESA, to make appropriate preparations for presenting ATHENA to the 2020 Decadal Review.

Summary of PhysPAG Findings (#4)

The flagship mission studies should fulfill scientific objectives broadly, to the extent possible. We encourage the STDTs to build upon these PCOS themes in planning the scientific capabilities when developing the flagship missions.

Summary of PhysPAG Findings (#4)

We find exciting PCOS science in each of the four flagship-class missions. Very briefly (report has full details):

X-Ray Surveyor

- Origin of supermassive black holes – detects 10^4 $M_\odot$ SMBHs at z = 10
- Feedback and accretion of hot coronal gas in galaxy formation to z ~ 1
- Large-scale structure of galaxies – role of AGN, the hot IGM, cosmic web
- Point source flux detection limit is 100x fainter than ATHENA

Far-Infrared Surveyor

- Cosmic history of embedded star formation and black hole accretion
- Cosmology via measurements of far-infrared large-scale structure at z = 2-3
- Role of molecular hydrogen cooling in high-z galaxy formation
- 3D spectral mapping out to the epoch of reionization

LUVOIR

- Mapping out dark matter in our Galaxy and in dwarfs using precision dynamics
- Dynamical measurements of large-scale dark matter distribution at z =1-3
- UV/Optical/IR measurements of EM counterparts to gravitational-wave emitters

HABEX

- Gravitational dynamics and stability of young planetary systems
- Role of gravitational stability and phase transitions in protoplanetary disks, e.g. getting water to rocky planets forming inside the snow line

Summary of PhysPAG Findings (#5)

For possible future development of probe missions, we note the historical success of the NASA Explorer mission line of competed missions, and its strong support in the scientific community. We anticipate that the scientific community will benefit from NASA guidance in defining the probe-class mission category or categories as part of the process of developing probe missions for the 2020 Decadal Review.

Summary of PhysPAG Findings (#5)

We received quite a lot of unsolicited PhysPAG community interest in probe missions. Because we were not charged with a specific determination, we noted the opinions we heard from the community but without synthesis.

- Enthusiasm for developing probe missions as a vital component for planning the next decade was widespread and strongly expressed. The community finds both the cost and schedule of probe missions attractive. Compared to the price and development time for a flagship, several probe missions could be flown in a decade, leading to rapid science return across a broad scientific spectrum. This higher rate of missions may offer scientific synergies, such as multi-wavelength observational capability.

- Many in the community are interested in developing specific probe missions, and a number of new probe-class concepts were brought before the PhysPAG. These generally cover new scientific territory outside of the reach of foreseeable flagship missions.

- Many in the community stressed the importance of the cost and schedule discipline of the NASA Explorer program, which has returned excellent science while carefully managing costs. These proponents reason that Explorer missions are less susceptible to the large and unfortunate cost, scope and schedule growth encountered in recent flagship missions. This group advocates for an expansion of the Explorer program to larger mission categories, and that developing the parameters of a category (or categories) of larger competed Explorers is as important as defining particular scientific concepts.

- Some pointed out that Explorer missions are not currently integrated into the strategic scientific planning process, in that they follow an open proposal process outside of the scientific investigations directed by the Decadal Review. Others noted that the planetary community has incorporated a degree of strategic planning for their larger competed Discovery and New Frontiers missions in their most recent decadal review.

Summary of PhysPAG Findings (#5)

We received a number of unsolicited new PhysPAG probe mission concepts addressing important Physics of the Cosmos science questions:

- **X-ray Grating Spectrometer Probe Mission** to study WHIM, outflows from SMBHs, bursting neutron stars

- **Large X-ray Timing Observatory Probe Mission** to measure neutron star matter, structure of black hole and neutron star accretion flows.

- **Transient X-ray Astrophysics Probe Mission** wide FOV X-ray and near infrared telescopes: gamma-ray bursts, tidal disruption events, supernova shock breakouts, counterparts of gravitational wave detections.

- **High Energy X-ray Probe Mission** spins of stellar and supermassive black holes, SMBH survey, Type Ia supernovae.

- **Soft X-ray Wide-Field Survey Telescope Probe Mission** evolution of SMBHs, clusters, and groups of galaxies over cosmic time.

- **Advanced Gamma-ray Telescope Probe Mission** keV to MeV energy range to study o511 keV emission from the galactic center, a supernova census, and polarimetric studies of the jets

- **Advanced Cosmic Ray Probe Mission** for ultrahigh energy cosmic rays by observing air showers from space, increasing number of events at the highest energies