Brainstorming Session #1

Science & Missions

Cosmic Structure, X-rays, Gamma Rays,
Gravitational Waves,
Cosmic Microwave Background

Group Moderators

- Group #1 Cosmic Structure: Johannes Lange, Rebekah Hounsell, Tim Eifler
- Group #2 X-Ray: Rob Petre, Renee Ludlam
- Group #3 Gamma Ray: Liz Hays, Chris Karwin
- Group #4 GW: Ann Hornschemeier
- Group #5 CMB: Tom Essinger-Hileman, Brendan Crill

Group 1: Cosmic Structure

- What is the best mix of explorers / probes / flagships for PhysCOS science?
  - Idea: All sky spectroscopic survey (we will have imaging over the full sky by 2035)
    - Very deep and high resolution
    - Blue grism (less than 1 micron) and wide field of view (0.5 sqr deg), high resolution (R2000-3000), large mirror 6+ m (starship-ish if non-foldable)
  - Because of the numerous cosmological probes you really need a flagship which focuses on spectroscopy to capture all necessary information
  - Fundamental physics questions: cosmic acceleration, modified gravity, neutrino physics, and primordial Non-Gaussianity - better understanding of growth-geometry tests
  - Multi-probe cosmology+NG statistics (Higher-order statistics, field-level inference, kinematic lensing) without being systematics limited
  - Synergies with CMB (CMB secondaries, CMB Lensing)
  - Strong lensing time delays and substructure DM probe
  - Local group cosmology with stellar streams
  - All sky spectroscopic surveys also enables stellar physics studies , mapping spatial structure of IGM, etc
  - Could use explorers or probes for targeted studies i.e., strong lensing, SNe
- Which outstanding questions can be addressed with explorers? What requires a probe? What requires a flagship?
  - Rapid response missions to get SN light curves and spectra
  - Lots of ideas to measure the Hubble constant: eg. using solar-scale level interferometry: https://arxiv.org/pdf/2210.07159

Group 1: Cosmic Structure

- What can we do now to close science gaps for future missions?
  - Develop better understanding of systematics entering analysis - e.g. Weak Lensing is systematics limited
  - Develop infrastructure for new analysis methods that can best exploit future data - higher order statistics, field-level inference etc.
  - Develop frameworks for utilizing joint-survey data (Roman/Rubin) to address systematics (such as blending) for downstream cosmological tasks like weak lensing
  - Better simulations (DM only+hydro, including survey specific systematics and features) inference techniques
- Are there science gaps for a future flagship that require an explorer / MOO / balloon flight to address?
  - Calibration or systematic studies ?
  - SuperBIT like ideas (Superpressure Balloon above 99% of the atmosphere for space like imaging, especially in the blue 280-350nm)

Group 2: X-rays

- What is the best mix of explorers / probes / flagships for PhysCOS science?
  - There is a need for more frequent calls for probes
  - The Mid-Ex/SMEX mix is good
  - Need to reassess cost for making a probe (constrained fiscal environment)
    - Cost caps need to be reassessed for each mission class
    - Probes are 1B which is cost of old flagship
    - Can do a lot more science with less money these days
  - Flagships seem to be the only class with enough money for tech development
    - Biggest science breakthroughs come from flagships
  - Probes do compelling science and can be used develop technology needed for flagships
  - More international collaboration
    - Explorers are limited to ⅓ total cost
    - Paths to tech development with international partners
  - MOOs are missing
    - Bring back!

Group 2: X-rays

- What are the set of science questions we would like to address?
    - COSMIC ECOSYSTEMS!!!
        - Galaxy formation
        - Population: high sensitivity and high angular resolution
        - feedback/growth
        - Environment
        - Imaging the Cosmic web - needs a flagship!!! (a lot of area)
    - populations/surveys: high sensitivity and high angular resolution
    - Large scale structures/galaxy evolution: low surface brightness, high resolution, high field of view, imaging
    - Transient phenomena: Rapid response
    - Direct detection of BH seeds: angular resolution and high sensitivity

Group 2: X-rays

- Which outstanding questions can be addressed with explorers? What requires a probe? What requires a flagship?
  - This really depends on the depth needed to address the science questions
  - Imaging the Cosmic web - needs a flagship!!! (a lot of area, low surface brightness, micro-cal)
    - Direct comparison to simulations

Group 2: X-rays

- What can we do now to close science gaps for future missions?
  - Support for Laboratory astrophysics! (e.g., atomic databases, transition lines)
  - Need tech demonstrations!
- Are there science gaps for a future flagship that require an explorer / MOO / balloon flight to address?
  - Probing the corona in Galactic XRBs
    - MOO: staring at a single source during an entire outburst, High timing resolution, long term data

Group 3: Gamma Rays

- What is the best mix of explorers / probes / flagships for PhysCOS science?
  - One Probe/small flagship to meet effective area needs, and many explorers and smaller missions.
  - Smaller missions can help to better identify and define sciences cases that motivate the bigger missions.
  - Explorers can be more easily motivated
  - We would benefit from smaller missions having a higher risk tolerance – faster time to science, but NASA would need to be onboard with this.
- Which outstanding questions can be addressed with explorers? What requires a probe? What requires a flagship?
  - Explorers:
    - Nucleosynthesis, e.g. Ni56 – energy and position resolution, higher angular resolution studies
    - Polarization measurements: e.g. blazars – are jets leptonic or hadronic. Polarization signal from GRBs. Needs large FoV and good polarization sensitivity, i.e. large and segmented
    - Pulsar timing array: Study BH mergers.
  - Probe/small flagship: generally will meet effective area needs
  - Galactic science example: GC excess and positron puzzle (requires good angular resolutions and flux sensitivity): Explorer (and smaller missions) leading to probe/small flagship?

Group 3: Gamma Rays

- What can we do now to close science gaps for future missions?
  - Explorers and smaller missions can help to better identify and define science cases to motivate future probes/flagships.
- Are there science gaps for a future flagship that require an explorer / MOO / balloon flight to address?
  - This ties into previous questions. For example, with a Pioneers we can begin to identify gamma-ray point sources in the Galactic center, but ultimately will require a larger mission (probe, flagship)
  - Balloon flights are critical to gamma-ray instrument development
  - Ultra-long duration balloon flights at high altitudes can be scientifically interesting.
- We need a SAG for gamma-ray probe/flagship

Group 4: Gravitational Waves

- **What is the best mix of explorers / probes / flagships for PhysCOS science?**
  - NB: We assume that the ESA-NASA flagship LISA launches in 2035, as planned
  - Next generation GW facilities would be Probe and/or Flagship-level investments (community groups such as a SAGs, should explore further):
    - Outside LISA band: noting a community group/SAG should develop further:
      - Higher frequency (deciHz), gives early warning for LIGO-like detectors, Probe and/or Flagship concepts (Note also: CLPS/Artemis and/or Seismometers for Moon) - focus on interferometry
      - Lower frequency (Micro-Hz) - higher mass BH mergers - 1AU scale, focus on gravitational reference system
    - MilliHz (LISA) follow-on: might not involve much tech development! Fly 2 LISAs?
  - For explorers, multi-messenger complimentarity to GW is very important, with lots of community support for TDAMM and Gamma ray capabilities. TDAMM and GammaSIG folks are doing this work.
- **Which outstanding questions can be addressed with explorers? What requires a probe? What requires a flagship?**
  - For space-based GW measurements, there is not as much that can be directly accomplished with Explorers, however for EM follow-up/complimentarity to GW, there are Explorer concepts.
  - Next-generation GW capabilities likely requires a Probe, and possibly a Flagship-level investment

Group 4: Gravitational Waves

- **What can we do now to close science gaps for future missions?**
  - There is already a LISA science gap list being maintained, just started in 2024

NASA LISA science gaps exist

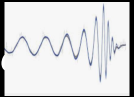
(Nov 2024, informing LISA Preparatory Science call)

Galactic Binary Gaps &
Massive Black Hole Binary Gaps

- *GB1: Modeling of LISA Galactic Binary Sources and Populations*
- *GB2: Modeling Additional Effects in Galactic Com Binary Systems*
- *MBHB1: Observational Constraints on Black Hole Seeding and Early Growth*
- *MBHB2: Connections Between Massive Black Hole Binary Mergers and Dual AGN*
- *MBHB3: Improved Methodology for Characterizing th Variability Signatures of MBHBs*
- *MBHB4: Realistic Predictions of Electromagnetic Counterparts to Extragalactic LISA Sources*
- *MBHB5: Multimessenger Interdisciplinary Investigations for Gas-driven Gravitational Wave Sources*

Extreme Mass Ratio Inspiral Gaps

- *EMRI1: Rapid Waveform Models for EMRI systems*
- *EMRI2: Detection Algorithms and Parameter Estimation for EMRI Systems*



Data Analysis and Waveform Gaps

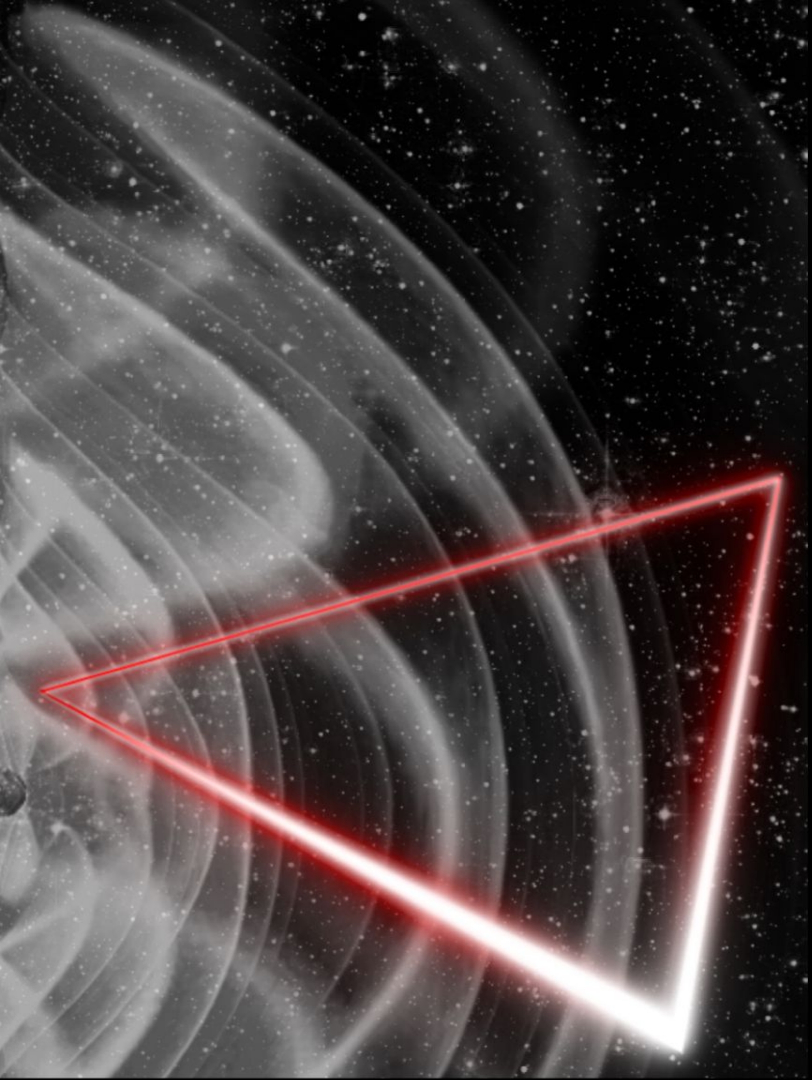
- *DA1: Tests of Strong Gravity, Numerical Relativity and Waveform Modeling*
- *DA2: Interpreting and Utilizing Global Fit Outputs*
- *DA3: Mitigating Data Gaps and Disturbances*

Group 4: Gravitational Waves

- **What can we do now to close science gaps for future missions?**
  - There is already a LISA science gap list being maintained, just started in 2024
  - **Continue funding and INCREASE funding for LISA Preparatory Science:**
    - Additional science gaps mentioned include :
      - characterizing the “error volume” of LISA (misleading impostor counterparts), developing schemes for making predictions and determine how to communicate the information quickly to observers
      - developing joint GW–γ-ray forward models that connect GW-inferred geometry to expected polarization signatures in compact objects
      - Modeling/studying number and nature of compact object binaries in the galaxy, particularly with pulsars, and how many can be jointly detected in gamma-rays.
  - **Allocate time with Roman to characterize both LISA sources and the LISA error volume.**
    - Roman is the best current planned capability with its wide field of view, excellent sensitivity and angular resolution. Suggest mission-level agreements (start now!) that would allow the use of some Roman time for characterizing LISA sources. (Roman-LISA SAG?)

Group 4: Gravitational Waves

- **Are there science gaps for a future flagship that require an explorer / MOO / balloon flight to address?**
  - Wrt Explorers, see responses to other questions on multi-messenger complimentarity
  - Next generation GW may also take advantage of other parts of the NASA program: CLPS and Artemis, for example, for Moon-based projects



WANT TO KNOW MORE?

ATTEND THE LISA SYMPOSIUM: JUNE 21–26, 2026 COLLEGE PARK, MD

Group 5: Cosmic Microwave Background

- What is the best mix of explorers / probes / flagships for PhysCOS science?
- Which outstanding questions can be addressed with explorers? What requires a probe? What requires a flagship?
    - Probes are probably right-sized to accomplish inflationary science and spectral distortion science (separately). A small flagship could accommodate both.
    - LiteBird (JAXA mission) is larger than a midex - sigma r is ~1e-3 (tau to cosmic variance). Provides a possible opportunity for NASA involvement in precursor to Probe.
    - PICO study showed a probe-class can get to r ~1e-4 along with much more science with larger aperture.
    - Spectral distortions (y and mu) can be best done from space. Mu distortion hard with Explorer (e.g., PIXIE). ESA Voyage 2050 prioritized spectral distortions. US community has consistently prioritized imager (e.g., PICO) first.
    - Complementarity between ground, balloon, and space missions. CMB-S4 was cancelled, but SO/SPO making progress from the ground (frequencies below 300 GHz). Taurus (balloon) and CLASS (ground) working toward large-scale E-modes for optical depth (tau), but true CV only from space.
    - Space gives full-sky coverage, full frequency coverage, greater sensitivity per detector, stability. COBE, WMAP, Planck show legacy value of full-sky maps.

Group 5: Cosmic Microwave Background

- What can we do now to close science gaps for future missions?
  - Better simulations of foreground removal and delensing, which set fundamental limits on r recovery. How complex are the Galactic foregrounds.
  - Revisit mission architecture choices in light of technology developments (cryo, detector), launch vehicles.
  - Delensing - what aperture do you need to do this to get r=1e-4?
  - Time-domain science is an emerging area that needs further study.
  - Forecasting of space versus ground across full range of CMB science: lensing, kSZ, clusters
  - Cosmology theory continues to evolve and needs support: inflation, reionization, galaxy evolution.
- Are there science gaps for a future flagship that require an explorer / MOO / balloon flight to address?
  - Participation in LiteBIRD could provide better knowledge of foregrounds and performance of bolometer arrays in space.
  - Balloons and ground continue to provide important precursor science.
    - And continue to develop a thriving community of scientists and technologists