Summary of Existing Science Gap inputs from the Community

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APD Program Chief Scientists

Peter Kurczynski (COR)
Karl Stapelfeldt (ExEP)
Brian Williams (PCOS*)

Elements of a Science Gap

(essential elements in boldface)

- **Title of Proposed Science Gap**
- **Summary of Proposed Science Gap**
- **Capability Needed (to inform architecture trade)**
- Capability Today
- Mitigations in Progress
- **Effect on Mission Architecture, Cost, and Risk**
- Idea for Proposed Science Activity
- Category: Lab Astro, Theory, Observations, Analysis
- Class: **Precursor**, Preparatory, Follow-up

Workshop #1 April 20-22 2022

- In two breakout sessions, crowdsource editing of two spreadsheets recorded numerous suggested science gaps
- Many participants had trouble distinguishing between the science the mission was supposed to do, and the precursor science needed to inform the mission design & architecture trades (the science gaps the ROSES funding is intended to support). The former was decided by the Decadal, while the latter needs our attention here.
- The most important attribute of a precursor science gap - a description of the suggested gap's effect on mission architecture, cost, and risk - was not provided for about half of the inputs. We will not be able to move forward with these gap ideas unless this key information gets added. A job for today's breakouts !

Workshop #1 Key products

- Kurczynski et al. provided a 10-page descriptive summary of the meeting. It included:
- Numerous links to supporting documents
- Definitions of precursor science and science gaps
- A record of breakout session highlights
- Highlight comments from the participants
- The need for better DEI practices in these multi-generational missions was much-discussed
- The importance of simulating FGO performance dictates that software tool development for this purpose is a valid precursor science activity
- Science gap ideas were merged with precursor science investigation ideas into a single spreadsheet listing 35 separate suggestions. But in terms of the 4 key attributes needed to define a science gap, most of the suggestions were incomplete and still need work !

Adding Google Sheets input, Sept 2022

- In late August, the community was invited to submit additional science gap ideas via Google Forms.
- Experience from WS#1 allowed the survey questions to be better-posed vs. the April inputs. 30 responses were received, many of which overlapped with the previous ones but in general were better defined than before
- The combined total of science gap ideas in hand at the start of today is 65, with some overlap. The breakdown is as follows:
  - 12 for far-IR
  - 13 for X-ray
  - 10 for IROUV-Astro
  - 30 for IROUV-Exo (18+4 unique)
- The gap ideas are evenly distributed across theory, observations, and analysis. But Lab Astro is very under-represented, with only a few.

Far-IR suggested gaps

1. Extragalactic source confusion in the far-infrared
2. Climate Studies of Rocky Venus and Earth Analogs around Nearby Cool Stars
3. M-dwarf Opportunity: The upcoming bonanza of non-transiting M-dwarf HZ planets.
4. Characterizing far-IR line luminosity functions at z~1-3
5. No Constraints on the Galactic Polarized Dust Emission at Its Peak Wavelengths
6. Planetary Infrared Excess
7. Lack of reliable diagnostics of magnetic field strength in star forming clouds.
8. Lack of high angular-resolution dust polarization maps of the diffuse ISM
9. Understanding the emergence of first life in the universe
10. ISM conditions of dusty galaxies at z~0-7
11. The science loss from dropping the mid-IR capability of the far-IR mission
12. Extragalactic magnetism using infrared polarimetric observations

X-ray suggested gaps

1. How to translate detections into knowledge of galaxy formation processes?
2. How to constrain galaxy formation & feedback near peak of cosmic star formation (z=~2)?
3. Expectations for the early SMBH populations
4. EM emissions from early SMBH
5. How to translate detections of high-z SMBH to constraints on the seed models?
6. Feasibility of SMBH spin and mass measurements out to high redshifts, including in gravitationally lensed quasars
7. Improve understanding of relationship between XRB statistics & stellar evolution tracks
8. Relationship between SNR structure (3D distribution of elements & velocity field) and explosion physics
9. How to extrapolate knowledge of XRB populations at z=0-6 to z=10-20?
10. Relationship between X-ray obscuration of quasars and small and large scale environment
11. Follow-up on GW detections in a timely way - we need to reduce the size of the search elipse
12. Science of obscured transient populations to inform value of special accommodations from X, IR, FIR missions
13. Analysis to disambiguate dark matter annihilation products in the x-ray from baryonic sources of x-rays in x-ray binaries; map x-ray source to an OIR source; could benefit with a study of binaries in nearby systems to constrain orbital architectures in different environments (stellar density, metallicity, age); distribution of orbital separations and mass loss estimates in order to estimate X-ray luminosity (again placing priors on source matching in a star field); understand the variation of the X-ray binary population with stellar population properties (stellar density, metallicity, age); why does the LMC have a large population and other dwarfs of similar mass have fewer?

IROUV-Astro suggested gaps

1. **Knowledge of Lyman continuum emitter areal density luminosity function**
2. **MMA Roadmap**
3. **Update foundational broad-band photometry on bright nearby stars**
4. **Integrate massive spectral surveys with broad band photometry to revise bolometric corrections used in stellar models (that are used for everything)**
5. **What do massive black hole binaries, and massive black hole binary mergers, look like with EM/particle messengers?**
6. **What are the most metal poor stars that produce dust?**
7. Translation of decadal science goals to architecture properties
8. Mapping Galaxy-Scale Accretion Flows
9. Near-UV spectroscopy
10. Emission Mapping of the CGM and IGM in the FUV and EUV

IROUV-Exo suggested gaps

1. **EPRV [Survey]: Radial Velocity survey of likely target stars of IROUV direct imaging missions to probe system architectures**
2. **Exo demographics: Exoplanet demographics and eta-Earth among binary stars**
3. **Exo demographics: exoplanet demographics and eta-Earth for single stars**
4. **EPRV [Capability]: Extreme Precision Radial Velocity capability to detect Earth analogs and precisely measure their masses**
5. **EPRV [Capability]: Develop and validate the capability to measure precise and accurate EPRVs for likely UVOIR FGO targets in the presense of stellar variability.**
6. **Atmospheres: Key signatures of exoplanet atmosphere diversity**
7. **Precursor Surveys: Exoplanets Orbiting IROUV Targets**
8. **Precursor Surveys: Exoplanets Orbiting Binary IROUV Targets**
9. **Exo Demographics: Understand connection between small temperate planets and outer gas giants.**
10. **Exozodi: Exozodi dust brightness for IROUV target stars**
11. **Stellar High Energy Emissions: [high energy stellar emission + atmosphere evolution?]**
12. **Exozodi: Better understand hot exozodiacal dust**
13. **Signal Extraction: Separate planet light from exozodi light falling in the same spatial resolution element.**
14. **Habitability [SubNeptunes]: Are some sub-Nepunes water worlds?**
15. **Exoplanet radii uncertainty**
16. **Architectures: Presence, architecture and dynamics of minor bodies in HZs, and influence on planet habitability**
17. Signal Extraction: Exo-Earth Photobombers: Time and wavelength varying blends of additional planets/moons in the same spatial resolution element as a potential Exo-Earth
18. High Energy Emission: Host star spectral grid: high-energy emission for prediction of key spectral signatures
19. Theoretical and computational trade studies in key mission parameters and exoplanet yield impact
20. Exoplanet Demographics
21. Precursor RVs of Direct Imaging IROUV Targets - pre-mission target identification and characterization
22. The minimum requirements to characterizing an Earth analog with TTV.
23. Occurrence rates of earth-like planets around sunlike stars
24. Exozodi: Exozodi dust brightness for IROUV target stars
25. Exozodi: Better understand the impact of hot exozodiacal dust on exo-Earth imaging performance
26. Architectures: Presence, distribution, and dynamics of minor bodies in HZs, implications for planets and planet habitability
27. Separate planet light from exozodi light falling in the same spatial resolution element.
28. Surveys: Direct imaging search for rocky, HZ planets around the nearest, suitable stars in the mid-infrared
29. Stellar Abundances: Understanding the chemical connection between stars and their planet (interiors)
30. Observing Earth as an Exoplanet

IROUV-Exo suggested gaps (re-sorted, combined)

- **EAr-1: Architectures: Presence, distribution, and dynamics of minor bodies in HZs, implications for planets and planet habitability (prev. #16, #26)**
- **EAt-1: Atmospheres: Key signatures of exoplanet atmosphere diversity (prev. #6)**
- **EC-1: Stellar Abundances: Understanding chemical connection between stars and their planet (interiors) (prev. #29)**
- **ED-1: Demographics of Exoplanets (prev. #20)**
  - **ED-1e: Demographics: Occurrence rates of earth-like planets around sunlike stars ("eta-Earth") (prev. #23)**
  - **ED-1b: Demographics: Exoplanet demographics and eta-Earth among *binary* stars (prev. #2)**
  - **ED-1s: Demographics: exoplanet demographics and eta-Earth for *single* stars (prev. #3)**
- **ED-2: Demographics: Understand connection between small temperate planets and outer gas giants. (prev. #9)**
- **EE-1: Earth: Observing Earth as an Exoplanet (prev. #30)**
- **EH-1: High Energy Emission: Host star spectral grid: high-E emis for prediction of key spectral signatures (#18)**
- **EH-2: Stellar High Energy Emissions: [high energy stellar emission + atmosphere evolution?] (prev. #11)**
- **ER-1: Exoplanet radii uncertainty (prev. #15)**
- **ERV-1: EPRV [Capability]: Develop and validate the capability to measure precise and accurate EPRVs for likely IROUV targets in the presence of stellar variability. (prev. #4, #5)**
- **ES-1: Signal Extraction: Exo-Earth Photobombers: Time and wavelength varying blends of additional planets/moons in the same spatial resolution element as a potential Exo-Earth (prev. #17)**
- **ES-2: Signal Extraction: Separate planet light from exozodi light falling in same spatial resolution element. (#13,#27)**
- **EU-1: Surveys: Exoplanets Orbiting IROUV Targets, Pre-Mission Target Selection, Architectures (e.g. EPRV, astrometry) (prev. #1,#7,#21)**
  - **EU-1b: Surveys: Surveys for Exoplanets Orbiting Binary IROUV Targets (prev. #8)**
- **EU-2: Surveys: Direct imaging search for rocky, HZ planets around the nearest, suitable stars in the mid-IR (#28)**
- **ET-1: TTVs for Transiting ExoEarths: Minimum requirements to characterizing an Earth analog with TTV (#22)**
- **EW-1: Habitability [SubNeptunes]: Are some sub-Neptunes water worlds? (prev. #14)**
- **EZ-1: Exozodi: Exozodi dust brightness for IROUV target stars (prev. #10, #24)**
- **EZ-2: Exozodi: Better understand the impact of hot exozodiacal dust on exo-Earth imaging performance (#12,#25)**

30 submitted gaps => combined into ~18 gaps and ~4 subgaps (for now!)

Suggestions for the breakout sessions

- Review the spreadsheet of science gap ideas for your group's mission science area
- The green column headers show the most essential attributes that need to be defined for each suggested gap. Via crowdsource editing, fill in the missing information where possible
- Merge redundant or closely related gaps (there has been a preliminary sorting and grouping of related/IROUV-exo gaps that were submitted)
- Cross out vague gap ideas, i.e. the ones with no explained relevance to mission architecture, cost, and risk
- Add new gap ideas if you have time, again via crowdsource editing
- Expect that the most important gaps will be called out in the ROSES solicitation, and (after PAG review) become the starter science gap lists for the Physics of the Cosmos and Cosmic Origins Programs - and merged into the existing Exoplanet Exoploration Program science gap list

QUESTIONS ?