NASA Astrophysics Precursor Science Workshop Summary Report

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Abstract

NASA Astrophysics sponsored a workshop on 20-22 April 2022 ("Precursors to Pathways: Science Enabling NASA Astrophysics Future Great Observatories") to initiate community-wide discussion about precursor science for the Future Great Observatories (FGOs) recommended by the Astro 2020 Decadal Survey. The goals of this workshop were to help NASA Astrophysics set the scope for the upcoming ROSES[1] proposal call (D.16 Astrophysics Decadal Survey Precursor Science), and to enable the community to start to understand precursor science and be able to write effective proposals in response to this forthcoming solicitation. This short report summarizes the first Precursor Science workshop in order to motivate the community to refine input on precursor science for the FGOs for the 2nd Precursor Science workshop to be held virtually on August 2-4, 2022.

1. Introduction

NASA Astrophysics sponsored a virtual workshop, Precursors to Pathways: Science Enabling NASA Astrophysics Future Great Observatories on 20-22 April 2022 as the first of two planned workshops for the astrophysics community. The workshop consisted of plenary presentations, group discussion, and breakout discussions. About 200 people attended the first day of the workshop; ~70-100 people attended the other days.

The goals of this workshop were as follows:

1. Help NASA Astrophysics start to scope the upcoming Precursor Science ROSES call for proposals
2. Help the community start to understand and be able to write proposals for the upcoming Precursor Science ROSES call (ROSES element D.16 Astrophysics Decadal Survey Precursor Science)
3. Do so inclusively and continue learning how to act more inclusively

This report provides a brief summary and highlights of the workshop. **Section 2** provides highlights and features from the plenary sessions. **Section 3** provides an overview of the breakout sessions. **Section 4** provides a summary of science gap ideas; it references a companion spreadsheet document. Note that most of the presentations referenced here are linked through the Workshop Agenda website[2].

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[1] ROSES: Research Opportunities in Space and Earth Sciences https://science.nasa.gov/researchers/sara/grant-solicitations . See e.g., ROSES-2022 call.

[2] https://exoplanets.nasa.gov/exep/astro2020-precursor-sciws1-agenda/

2. Plenary Sessions

The first plenary session defined ***precursor science*** as *science investigations that inform future mission architecture, and that may reduce design and/or development risk* (see **Box 1).** Precursor science was distinguished from ***preparatory science***, which refers to science that may inform the use of a new observatory (but which is not needed to affect the mission architecture). In planning for the Future Great Observatories that were recommended by the Astro2020/Pathways Decadal Survey, precursor science is more urgent to accomplish than preparatory science.

Precursor Science: Science investigations that inform future mission architecture, ideally by reducing design and/or development risk.

Box 1. Definition of precursor science used in this workshop

Subsequent presentations and discussions introduced the conceptual process of framing a new mission concept. Presentations were given as part of a panel discussion by the representatives of four main Science and Technology Definition Teams (STDTs; Lynx, LUVOIR, HabEx and Origins). Presentations highlighted the importance of starting with science; however, the maturation process inevitably involves back and forth between science needs and engineering issues and capabilities.

Aki Roberge (from LUVOIR study) pointed out that the flagships have multiple interconnected science cases (e.g., LUVOIR had 12). We want to know the sensitivity of science return to various hardware parameters (which may flow back & forth during early trades; see for example Stark et al. 2015[3]) and understand the correlations and derivatives for early architecture trades. Bertrand Mennesson (from HabEx study) noted to start with the science and define criteria for trades *before* one starts to look at options and make decisions. Define the figures of merit first, then compare architectures. Science modeling tools are needed, as this is an iterative process where parameters need to be tuned and many cases explorers. A Science Traceability Matrix (STM) is essential as it helps to document important aspects of the mission. Lesson: *Start the STM as soon as possible*. Margaret Meixner (from Origins study) solicited community input and created science working groups. Community was asked: *What science do you want? What measurements do you want to make*? The proposals were received; a TAC process selected proposals; and the science themes were down-selected. The highest priority science led to the mission design. Need to think that flagship is really an intergenerational mission and need whole demographics of diversity. She emphasized the importance of keeping the community engaged

[3] https://ui.adsabs.harvard.edu/abs/2015ApJ...808..149S/abstract

throughout the process. Jessica Gaskin (from Lynx study) note that "*while science is the primary driver, the science objectives must be developed in parallel with engineering and other elements*." She noted that science gaps were selected and very high-level performance criteria were identified which contributed constraints to the architecture and payload.

John Zeimer gave a widely-discussed presentation introducing ***Concept Maturity Levels (CMLs)***, which are a way of articulating the maturation process of conceptual ideas. CML 1 is a cocktail napkin idea. CML 4 is a mission point design. Maturation is an iterative process to advance the science mission concept along six axes in parallel: Science, Engineering, Cost/Schedule, Implementation, Strategy and Story.

A panel discussion focused on diversity and inclusion in planning of future missions. Inclusion plans are being evaluated and there will be toolkits so people know what to include (Dara Norman). Individuals need to take personal responsibility for inclusion, in order to avoid history repeating itself. Some comments from workshop participants mentioned that PIs' inclusion plans rarely tackle the most difficult issues surrounding the themes of diversity equity and inclusion, such as evaluating the inclusivity of the environment. Further participant comments focused on how pipeline problems lead to explaining limited representation as a deficit of skill rather than a problem of exclusionary principles. This couples with individual biases such as the presumption of incompetence. There was concern expressed about "how little has changed" over the years. See further highlights in the Section 3 part on "Diversity, Equity, Inclusion and Accessibility."

Karl Stapelfeldt presented on ***science gaps***, as relevant to the NASA Exoplanet Exploration Program (ExEP). That Program maintains and updates a list of science gaps to organize and guide its research community. A needed goal for the astrophysics community is to develop similar science gaps relevant to Cosmic Origins (COR) and Physics of the Cosmos (PCOS) in the coming years, or at least the gaps that bear on the future great observatories.

Science gap is a research area where additional work:

- Enhances the science return of a *mission already flying* – usually through *follow-up science*
- Enhances the science return & helps plan operations for an *upcoming mission* that is already designed – usually as *preparatory science*
- Provides information needed to quantify a *future mission*'s ability to meet its science goals, and to assess mission design options – this is *precursor science*

Box 2. Definition of science gap used in this workshop

The importance of simulations was underscored through presentations and comments and discussion by individuals throughout the workshop. End-to-end simulations used in X-ray astronomy encompass the full detection chain: everything from the astrophysical source through instrument/optics detection process to the final data product. Several participants highlighted the importance of developing simulation tools to inform the architecture of future missions. Such tools require science knowledge of the astrophysical sources of interest, as well as details of how signals are gathered and ultimately detected by the observatory and its instruments. Thinking about the requirements for simulation tools may be useful to identify new precursor science needs.

3. Breakout Sessions

Breakout discussions were organized by both mission concept and science topics, and discussions were scheduled to enable cross fertilization of ideas between them. Brief highlights are listed below by topic and session moderator.

IROUV Exoplanets (Karl Stapelfeldt)

There was discussion of multiple systems: how does planet frequency get affected by stellar multiplicity? What about the hot dust that has been detected could affect coronagraph performance? (some claimed excesses ~1%, could be important? Or avoid those stars?). Other discussion topics included stellar activity, properties of other (big) planets - surveys of the full exoplanetary system to understand context for the temperate rocky planets, architectures, requirements for detecting liquid water oceans, and the nature of sub-Neptune planets.

IROUV Other Astrophysics (Peter Kurczynski)

This discussion talked a lot about the importance of simulations to inform architecture trades. Science topics included multi-messenger transient astrophysics, stellar populations, distance indicators for nearby galaxies, some discussion of planet demographics, luminosity functions for e.g. “green pea” galaxies - all of these will require simulations. IROUV flagship design (and to some degree X-ray flagship) design will also be informed by the need to observe the circum-galactic medium of galaxies. Topics that involve stellar populations often impact field of view requirements; however, field of view is not very critical for exoplanet science goals. So there is a synergy between exoplanet and general astrophysics needs here.

X-ray (Eric Tollestrup and Brian Williams)

This discussion included a general need for laboratory astrophysics, as well as the need for end-to-end simulations in order to be able to have the tools to inform trade studies. Discussion about supernova remnants (SNRs), how the inhomogeneities on small scales require high spatial resolution observatories. There was substantial discussion about the advances in theory and modeling necessary to understand the origins of supermassive black holes in the early universe.

Far-IR (Dominic Benford & Barb Grofic)

There is lots of discovery space in the far-IR, and the ability to predict how well we will do in answering science questions is limited by the fact that there is so much unexplored science territory. Risk for future missions: we haven't explored that parameter space very thoroughly; it's always going to be quite the extrapolation. What is the technology that enables this new parameter space? A larger telescope: capable of getting more photons, importantly cryogenic, lots of pixels in large format arrays: hundred kilopixel arrays. We don't have a large range of spectroscopic data for extragalactic objects in the wavelength range covered by the Origins concept study to inform. Extrapolations to higher redshift, and extrapolations to smaller fainter objects, are difficult.

Electromagnetic counterparts (John Zeimer)

One important consideration for the FGOs would be in how they are operated to allow quick scheduling of observations, slewing / pointing, field of view, etc., but also to allow for deep observations and longer-term follow-up, of these events. The group also talked about how ground based data systems might need to be designed to organize the event information and follow-on data from various observations / observatories. Thinking ahead (now) on how to integrate time-domain and multi-messenger astronomy (TDA/MMA) into the FGOs should be a good topic for discussion and focus area for formulation and precursor science.

Main ideas for precursor science:

- Follow-up on new gravitational wave (GW) detections, analyze data from follow-up observations
- Utilize existing observatories and develop ground systems for planning, data, analysis
- Develop methods and models for GW analysis
- Analyze and model neutrino behavior along with expected observables
- Develop sensitivity requirements for FGO instruments, across all bands; start with existing measurements (including expected JWST observations) and build predictive models, both for expected observables, but also in the time domain (before, during, after, and longer term follow-up).
- TDA/MMA science should influence all FGOs; NASA should work with GW and other teams to understand requirements and impacts (i.e. observatory lifetime)
- Study if a wide-field instrument and/or on-board autonomy on FGOs would be useful to help locate and detect new events and sources vs. using or developing smaller missions for this purpose
- Look at science of obscured transient populations to inform value of special accommodations from X-ray, infrared, and far-IR missions

Census of dusty quasars (Marie Wingyee Lau)

The group discussion considered intrinsically faint active galactic nuclei (AGN), not just those that are faint due to dust obscuration. For instance, low luminosity galaxies can host AGN too.

Support analysis of archival data with e.g. Keck. What about Near Earth Surveyor (planetary) mission - archival data? What about AGN behavior over the range of galaxy masses? Possible precursor science topics: better characterize nearby AGN to improve extrapolation to higher z? Descoping of Decadal recommended far-IR mission: does it need to be scoped up again? What was the loss of science by descoping of Origins?

Laboratory Astrophysics (Grant Tremblay)

The X-ray community has gotten integral field units (IFUs) for free with energy and time, and has been building photon-starved observatories for decades. Big X-ray mapping would map the largest structures in universe. However, architecture trades in X-rays are more of spaghetti-ball. For SNR Cas A, below 2” scale – the source looks homogeneous, running into a wall of limited spectral resolution. OK, if we increase resolution, then one may be photon-starved, but may need more area to populate those spectral/energy bins. Be maximally aggressive in size and point spread function (PSF). Sub-1” resolution is needed to cover cosmic ecosystem cases, confusion limit, and deep sight lines through galaxies.

Lab Astrophysics is a pillar that supports the whole field (agnostic to wavelength). Going to higher resolutions, we are running into a wall where existing opacity tables, line lists, etc. are insufficient. For some parameters, we now need to extrapolate to physical parameter regimes not yet covered. Lab astrophysics work is needed to support all three FGOs.

Eta-Earth for single and multiple stars (Eric Mamajek)

Eta-Earth (or analogous factor gamma-Earth) is the frequency of exoplanets with parameters (range of sizes, orbital periods, or instellations) similar to that of Earth. Its value has been based mostly on the Kepler survey and has considerable uncertainty. There is risk to the IR/O/UV flagship that the real eta-Earth that is significantly lower than that assumed in the Decadal’s deliberations and recommendations, and could put the Decadal goal of delivering ~25 spectra of potentially habitable worlds at risk given future choices of aperture and architecture. Surveys for nearby habitable exoplanets are limited by the samples of known stars of sufficient proximity and brightness (mostly naked eye stars). The group mentioned the importance not only of eta-Earth for single stars but binaries/multiples – given their commonality, and as high-contrast imaging of nearby binaries to reach exo-Earths may yet be technically achievable. Conditional probabilities of exoplanet frequency may also be desirable - if a star has an exo-Neptune detected, what is the probability of it having an exo-Earth? The degree to which radial velocity observations with the current generation of precision radial velocity (PRV) spectrographs can help with bounding eta-Earth - through improving knowledge of the exoplanet frequency distribution near the eta-Earth parameter space (perhaps mainly for super-Earths or closer-in planets) - was discussed, and further community analysis is needed. The topic overlaps with the advancement of extreme precision radial velocity (EPRV) and sub-microarcsecond level astrometry - the main techniques anticipated for detecting and measuring masses for non-transiting Earth-sized planets around nearby stars that may be IR/O/UV targets. Earth twin planets orbiting typical IROUV targets (V ~ 5mag, d ~ 10pc) will have radial velocity amplitudes of ~9 cm/s and astrometric amplitudes of ~0.3 microarcseconds – beyond current capabilities.

EPRV Capability to detect Earth Analogues (Karl Stapelfeldt)

We need to determine whether Extreme Precision Radial Velocity (EPRV) can be advanced to the level needed for exo-Earth detection – which is the key question for precursor science here. The IR/O/UV mission itself may not be able to measure sub-microarcsec astrometry required to detect and measure masses for the imaged small rocky planets around nearby stars (but further exploration is warranted). Yet masses are needed to interpret exoplanet spectra. Will EPRV or astrometry or a mix of these methods deliver masses of the imaged habitable zone rocky planets? For EPRV, we already know there are target stars too hot/fast rotating/active that EPRV probably won't be able to work (likely tens of percent, per the EPRV Working Group report).

Initial to final mass functions for stars (Peter Kurczynski)

Stars are fundamental for a wide range of topics e.g., distance scale, exoplanet hosts. Initial vs. final mass functions in different contexts are important to compare, e.g. clusters, galaxies, different chemical environments, metallicity, binarity. Stellar variability on long timescales for stars other than the Sun needs to be explored. Accurate measurements of very bright stars are actually hard to do: photometry of bright stars may be a fruitful area to investigate for precursor science topics.

Diversity, Equity, Inclusion and Accessibility (Keivan Stassun)

Dr Dara Norman noted "*PIs[' inclusion plans] rarely tackle the most difficult issues surrounding the themes we covered, such as evaluating the inclusivity of the environment*." There is an upcoming toolkit of inclusive collaborative practice.

Dr Keivan Stassun noted the upcoming National Academies' report on increasing competed space missions' diversity of leadership[4]. Given the discussion of science 'gaps,' what are the DEI gaps? What would be on that list, and how would that help what investigators build into present science projects? Precursor science teams may be the seeds for future efforts with the future great observatories, so we need to ask "*how are teams forming?*" and make sure there is some effort for all teams to engage a diverse pool of people.

Dr Marcel Agüeros: noted how little has changed since 1974 (see Jenkins oral history[5])

[4] https://www.nationalacademies.org/our-work/increasing-diversity-in-the-leadership-of-competed-space-missions

[5] https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/NASA_HQ/Administrators/JenkinsHG/JenkinsHG_8-5-11.pdf

Dr Christa Porter: noted the importance of data disaggregation, hidden labor, the lack of substantive institutional support, and *how important it is to enact not just espouse* the changes needed.

Dr Sharla Alegria noted that the focus on pipeline problems leads to explaining limited representation as a deficit of skill rather than a problem of exclusionary principles. This couples with individual biases such as the presumption of incompetence. *Address the pipeline problems.*

Dr. Rachael Beaton mentioned the Sloan (SDSS) DEI program where Faculty and Student Teams pair faculty members with minority serving institutions with a technology knowledge mentor buddy. They put together a project, faculty members mentor the students at their institution, and the students are funded (this is important).

Dr. Ryan Hickox noted that the discussion featured two related topics: (1) What kind of PI/institution can get funding? (2) How do funded PIs focus on inclusion? Progress is being made on (2) at NASA. There is a recently announced NASA study will investigate barriers to funding.

Dr. Steve Ertel noted that a proposing PI may not know much about DEI issues but wants an advisory source. For programs to be stable, they need to be look beyond the 1-3 yr horizon of a funded award. Dr. Shawn Domagal-Goldman wanted to see the plan forward beyond the level of single ROSES investigations, and how connections are maintained on projects beyond the 1-off proposals. Dr. Jonathan Crass asked *how do you retain and support people, and especially minorities, for longer-term activities*? Looking at funding for positions may be the best away. NSF has broader impacts but NASA does not have a comparable criterion for review.

The #DEI Slack channel was very active and contained further comments and responses: https://nasaprecursor-opk3135.slack.com/archives/C03C8PB89NJ

4. Summary of science gap ideas

Outputs from the first workshop's four mission science gap breakout sessions, and the eight topical precursor science brainstorming sessions, have been collated and condensed into a summary spreadsheet document[6]. This sheet has four tabs, one for each FGO science area (IROUV Exoplanets, IROUV Astrophysics, Far-IR, and X-ray). Each row captures the community inputs received on potential science gaps or potentially relevant near-term science activities. For the most part these rows are incomplete and need further work to become a well-defined precursor science gap to address through ROSES proposal funding. For the

[6] https://docs.google.com/spreadsheets/d/1QfIAudqh-_LMH3CyqIE95gJzysnaDAmKLlcGzbbF8Qo/edit#gid=1059299038

suggested gaps, further work on the language would be helpful; for the suggested activities, language needs to be developed for the science gap each activity would address. The green highlighted columns are the most important to complete, as they define what the science gap is and its importance to the mission architecture. Working through the PAGs (ExoPAG, COPAG, PhysPAG) now, and at the second workshop, we ask the community to make progress in fully populating each row, so that the definition of each suggested science gap could be mature enough to merit funding in response to a ROSES precursor science solicitation. It is hoped that talking through the ideas and understanding their level of importance and urgency to developing the FGOs will not only help inform the precursor science ROSES call, but will lead to people developing new proposal ideas, writing better proposals, and finding new collaborators. Our immediate goal is to complete the process of collecting and filling out science gaps suggested by the community, and identify those that are most important for affecting FGO mission architecture.

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Appendix

Source material for this summary report can be found as follows:

Outputs from the first workshop's four mission science gap breakout sessions, and the eight topical precursor science brainstorming sessions, have been collated and condensed into a summary spreadsheet document[7]

An integrated spreadsheet document containing the raw breakout session outputs, lightly edited for content, can be found here[8]

[7] https://docs.google.com/spreadsheets/d/1QfIAudqh-_LMH3CyqIE95gJzysnaDAmKLlcGzbbF8Qo/edit#gid=1059299038

[8] https://docs.google.com/spreadsheets/d/1G1_uAIMQ497WtyaTCFxNdrKRUdmOKpGllnUeCOxjnuw/edit?usp=sharing

An online Google Drive folder with general information from the workshop can be found here[9] This folder contains notes and presentations.

The Slack channel for the 1st Precursor Science Workshop is at nasaprecursor-opk3135.slack.com.

To sign up for additional notices about the Precursor Science workshops, including attending the second virtual Precursor Science workshop August 2-4, 2022, register at this website.

The website for the 2nd workshop will launch in early July 2022.

[9] https://drive.google.com/drive/u/1/folders/1DkieQDoi504LmGUsDinhhFJxsK5bmM_Q