X-ray Precursor Science Gaps

X-ray Science Interest Group (XR SIG) Co-Chairs

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Landscape of Gaps

Science Gaps can be divided into several categories:

- Follow-up science: Enhances the science return of a mission already flying.
- Preparatory science: Enhances the science return & helps plan operations for an upcoming mission that is already designed.
- Precursor science: Provides information needed to quantify a future mission's ability to meet its science goals and to assess mission design options.
- Non-strategic: Open science questions not connected to a currently planned/future mission.

from https://pcos.gsfc.nasa.gov/physpag/science-gaps/science-gaps.php

PhysCOS Activity

- PhysCOS Chief Scientists (Francesca Civano and Brian Humensky) have solicited gaps of all flavors via email blasts and presentations
- Co-chairs of all SIGS (CR, CoS, GR, GW, IP, TDAMM, XR) have solicited gaps of all flavors within their groups.
- Francesca and Brian compile suggestions and maintain up-to-date lists of gaps of all flavors.
- Recent focus on Precursor Gaps for X-ray future great observatory (FGO)

XR SIG Activity in Context

- Identifying Science Gaps has become a common activity across all Astrophysics Division programs, but the concept is relativity new for the X-ray community. There has been a learning curve.
- From the community workshops in April, 2022, and October 2022, only three gaps were identified for an X-ray Future Great Observatory (FGO) for the ROSES-2022 Precursor Science proposal call.
- Community outreach was needed.
    - Francesca and Brian gave talks at GSFC
    - Additional email solicitations were sent out
    - Community XR SIG zoom on Dec. 7, 2023

Many good suggestions!

- 35 gaps submitted between June—December, 2023
- 13 gaps self-identified as Precursor Science for X-ray FGO
- PhysCOS Chief Scientists and XR SIG Co-chairs went through new and old science gaps to consolidate / merge
- PhysCOS Chief Scientists will submit ~9 X-ray Precursor Science gaps to HQ by Jan. 15, 2024, as topics for ROSES-2023 precursor science proposals
- Proposals due on Apr. 26, 2024
- Mandatory NOI due Mar. 29, 2024.
- ***Many thanks to community members submitting gaps: Xiurui Zhao, Tyler Parsotan, Haocheng Zhang, Erin Kara, Javier Garcia, Kim Weaver***

X-ray Precursor Science Gaps

- Probe the X-ray emitter of AGN with broadband hard X-ray telescope
- High Redshift Gamma-ray Bursts
- Blazars across the cosmic time: evolution of jetted AGN
- Modeling the blazar particle acceleration and multi-wavelength variability
- Multi-messenger observations of supermassive black holes
- Understanding SMBH growth across cosmic time
- Improving the Understanding of Jet Launching Regions
- Atomic Data Needs for High-Resolution X-ray Spectroscopy
- Modeling Feedback in Galaxy Evolution to better understand impact of magnetic fields and outflows *(existing gap)*

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Probe the X-ray emitter of AGN with broadband hard X-ray telescope	The extragalactic Cosmic X-ray Background (CXB) is predominantly attributed to AGN. The X-ray emissions are thought to be produced by the hot electron nearby the central supermassive black hole (SMBH) in AGN, namely the corona. So far, hundreds of thousands of AGN have been detected in X-ray. Yet, the properties of the X-ray emitter, i.e., the corona, is still unclear. This is mainly constrained by the band coverage of the current X-ray telescope in the hard X-ray. The most prominent feature of the corona in X-ray is the so-called high-energy cutoff (typically at a 50-500 keV depending on their luminosity). Current hard X-ray telescope, NuSTAR, although has detected the the cutoff energy of a few sources, covers only up to 80 keV (with high background at 24-80 keV, so pretty low signal-to-noise ratio at >24 keV). A systematical study of the AGN corona needs a broadband hard X-ray telescope with large effective area, low background at >50 keV. With such a telescope, we are able to provide a comprehensive insight into the AGN X-ray emitter, the corona, by creating an extensive sample of AGN with well-characterized coronal properties.	An extensive sample of AGN with well-characterized coronal properties is needed.	Aperture, energy range (maybe can extend to 20 keV which could measure a z=5 cutoff at 120 keV)

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
High Redshift Gamma-ray Bursts	High redshift gamma-ray bursts are a relatively unknown class of object. These cataclysmic events have the potential to shed light on the early universe up to redshifts of ~9, which is the current highest redshift GRB ever observed. An X-ray future great observatory can shed light on these objects if it is able to detect them and make spectroscopic measurements, allowing for greater understanding of these events and their relation to other GRBs in the nearby universe and understanding their potential use as probes of the high redshift universe. The major gap is a lack of theoretical modeling of high redshift GRBs, to predict their timescales, energetics, and spectral energy distributions. These all play a role into the energy range and sensitivity needed for an X-ray future great observatory to detect these events.	Increased modeling	Wavelength range, Spectral resolution, Instantaneous field of regard (response time), Polarization

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Blazars across the cosmic time: evolution of jetted AGN and theoretical interpretation	The number density and luminosity distribution of blazars across different redshifts are not understood. At low redshifts, observations can identify blazars with low and high luminosity as well as misaligned jetted AGNs (i.e., radio galaxies). But at high redshifts, current X-ray telescopes can only detect the brightest blazars.This results in significant biases about the blazar number density and luminosity at high redshifts, thus whether and how jetted AGNs evolve in cosmic time cannot be constrained. Theoretical interpretations of the number density and luminosity of jetted AGNs are left behind, merely empirical relations by fitting the observed (and probably biased) distributions are available. Preliminary studies of magnetohydrodynamic and particle transport simulations can provide solid physical basis for particle acceleration in jets. Radiation transfer simulations can help to constrain the multi-wavelength emission.	Detailed numerical simulations that can calibrate the blazar power and multi-wavelength luminosity. Such global numerical simulations need significant theoretical efforts and computational resources.	sensitivity and angular resolution

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Modeling the blazar particle acceleration and multi-wavelength variability	Blazars are variable on both short and long time scales in all wavelengths, which reflect the jet fluid dynamics (such as changes in magnetic fields) and particle acceleration (shock, magnetic reconnection, turbulence, etc.). While the synchrotron variability in the low-energy spectral component is better studied, the X-ray to gamma-ray variability lacks physically solid modeling. A major issue lies in that there is no fully 3D ray-tracing code for Compton scattering that can account for inhomogeneous and variable synchrotron seed photon field. Additionally, while particle acceleration has been well studied with kinetic simulations, no large-scale particle transport simulations are available. This results in that the fluid dynamics (such as magnetohydrodynamic simulations), particle acceleration and transport, and radiation transfer cannot be self-consistently connected. Thus multi-wavelength variability patterns in X-rays and gamma-rays cannot confirm or rule out any particle acceleration mechanisms.	Full 3D ray-tracing code for Compton scattering and/or hadronic processes that can consider the inhomogeneous and variable seed photon field. Self-consistent combination of magnetohydrodynamics, particle-in-cell, particle transport, and radiation transfer. Parameter surveys with the combined simulation toolset for typical blazar parameter ranges.	sensitivity, energy range, spatial resolution

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Multi-messenger observations of supermassive black holes	Theoretical modeling and Observational discovery of extreme black holes (Tidal Disruption Events, Supermassive black hole binaries, Stellar mass black holes in AGN disks, Changing Look AGN)	Simulations including radiation, to predict light curves corresponding to extreme SMBH events.	Wavelength range, Pointing agility, Pointing stability, Spectral resolution, Instantaneous field of regard, Field of view, Operations concepts

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Understanding SMBH growth across cosmic time	Probing cosmic growth of supermassive black holes using measurements of black hole angular momenta derived from X-ray reflection spectroscopy, and compared against expectations from hydrodynamical cosmological simulations	Consistent spin parameter evolution post-processing for major cosmological simulation suites. Reducing model systematics, breaking parameter degeneracies, further exploration of parameter space, enhanced treatment of physics / geometries / realistic accretion flows. Improve the microphysics of gas (atomic parameters, high-density plasma effects, etc.)	Aperture, Wavelength range, Spectral resolution, Spectroscopic modes/ methods, Field of view

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Improving the Understanding of Jet Launching Regions in Astrophysical Sources	There is not a one-to-one connection between observations and theory regarding jets in general and specifically jet-launching regions. This is a time-intensive computational problem.	intensive 3-D computational modeling and simulations, with relativistic effects included. The models need to be self-consistent, including magnetic field effects and other relevant physics.	Wavelength range, Spectroscopic modes/ methods, Polarization, Imaging capability

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Atomic Data Needs for High-Resolution X-ray Spectroscopy	X-ray spectroscopy is a powerful tool for studying extreme environments in astrophysical sources. The X-ray band simultaneously covers the emission and absorption of almost all astrophysically relevant elements, but its diagnostic potential relies strongly on the accuracy of the atomic data needed to produce reliable spectral models. The XRISM team has identified a long list of atomic data needs for the upcoming high spectral resolution observations. These needs will be exacerbated in the next decades when even larger missions fly micro-calorimeter detectors. This is a wide science gap that requires large and coordinated efforts on the experimental and computational sides of Laboratory X-ray Astrophysics.	Calculations of large sets of inner-shell transitions for all astrophysically relevant ions (carbon through nickel) with accuracies of future micro-calorimeters. Experimental measurements of similar atomic quantities to serve as a benchmark for calibrating both the atomic databases and the spectral models to be produced.	Aperture, Wavelength range, Spectral resolution, Spectroscopic modes/ methods

X-ray Precursor Science Gaps

Title	Description	Capability Needed	Mission Params
Modeling Feedback in Galaxy Evolution to better understand impact of magnetic fields and outflows *(existing gap)*	Revise to Include X-rays in this: " In particular, outflows are multi-phase, with a large number of potential critical probes in the far-IR and X-ray, …"	Revise to include X-rays: "...and coupling of these models to JWST and ALMA and/ or existing X-ray observatory observations…"	Wavelength range, Pointing stability, Spectral resolution, Spectroscopic modes/ methods, Field of view, Operations concepts