Science Gaps

Gamma Ray Science Interest Group (GRSIG)

Science Gaps

- 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.

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

Precursor Science Gaps

- New ROSES program element ASTROPHYSICS DECADAL SURVEY PRECURSOR SCIENCE.
- Support science investigations that will reduce future Great Observatory mission risk and inform mission designs and trades when those activities begin.
  - a large Infrared/Optical/Ultraviolet space mission to search for biosignatures from nearby exoplanets and to perform transformative astrophysics investigations
  - a large Far Infrared mission
  - a large X-ray mission.

Precursor Science Gaps

- #21 Black holes at the cosmic dawn: expectations for the early SMBH populations
- #22 Improved understanding of the relation between X-ray Binary emission, galaxy properties and theoretical predictions
- #23 Probe the corona emission in Active Galactic Nuclei at hard X-ray energies
- #24 Theoretical modeling of High Redshift Gamma-ray Bursts
- #25 Blazars across cosmic time: evolution of jetted AGN and theoretical interpretation
- #26 Multi-messenger observations of extreme supermassive black holes
- #27 Understanding SMBH growth across cosmic time using black hole spin
- #28 Improving the Understanding of Jet Launching Regions in Astrophysical Sources

Out now! Due April 26

https://nspires.nasaprs.com/external/solicitations/summary.do?solId=%7bA621FB7D-1D57-40F9-FE89-70107E303940%7d&path=&method=init

GRSIG Science Gaps

- 17 gaps related to GRSIG have already been submitted.
- Thanks to Henric Krawczynski, Michela Negro, Zorawar Wadiasingh, Haocheng Zhang, Naoko Kurahashi, Marcos Santander, Bindu Rani for submitting gaps on behalf of the gamma-ray community.
- Plan for this meeting:
  - Briefly discuss submitted gaps.
  - Identify areas that are not already covered by current gaps and encourage the community to submit more gaps.

Title	Description	Capability Needed	Mission parameters
Study of QED effects through X-ray and gamma-ray polarization	X-ray and gamma-ray observations of sources with strong magnetic fields make it possible to study Quantum Electrodynamics in the strong field regime, that cannot be accessed in terrestrial laboratories.	(i) Theory: Support for theoretical studies of polarized radiation transport; (ii) missions with broadband polarimetric capabilities at energies bracketing the IXPE energy range, i.e. 0.1-2 keV and 8 keV to 100 GeV.	Polarization

Title	Description	Capability Needed	Mission parameters
gamma-ray polarization	sensitive imaging+polarimetry monitor in the sub-GeV band (pair-production regime below 100 MeV) for polarization study of steady sources and bright transients.	very fine spatial resolution to separate e+ e- pairs	Polarization
MeV polarization of blazars	MeV polarization of blazars is not known, but it is crucial to understand potential hadronic processes, neutrinos, and acceleration of cosmic rays in jets.	Good polarization sensitivity with spectral and temporal resolution is needed. Also, since blazars are variable, continuous monitoring is important, which requires all-sky capability.	Wavelength range, Polarization

Technology gap?

Could be a Science gap if predictions for polarization in hadronic processes need more work to allow mission definition?

Mission capability need?

Title	Description	Capability Needed	Mission parameters
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. All above need significant supports for theoretical efforts.	

Title	Description	Capability Needed	Mission parameters
Establishing the connection between gamma-ray and neutrino emission	Recent results from the IceCube neutrino telescope point to neutrino emission from AGN, and the first evidence for neutrino emission from the Milky Way. Both signals have deep connections with gamma-ray observations. Establishing the link between both observational channels is critical to determine the capabilities required in the gamma-ray band to identify hadronic signatures, and to derive mission specifications.	Modeling of hadronic gamma-ray emission in AGN and the Milky Way in a multimessenger framework. Determination of requirements for future missions based on the resulting emission models.	Wavelength range, Modeling efforts

Title	Description	Capability Needed	Mission parameters
Improved Understanding of GRB Polarization	As polarization measurements of the prompt GRB emission continue to improve, it will become increasingly important to better understand how the observed polarization measurements depend on a number of GRB parameters. More detailed modeling, coupled with improved polarization studies, will lead to a refined understanding of GRB physics. Modeling may also guide the use of context measurements (e.g., optical observations) in the interpretation of the polarization data.	GRB polarization measurements are widely considered to be of value in better understanding the underlying physics of the GRBs. High-fidelity models and simulations are needed to predict polarization measurements over a broad range of possible parameter space. The parameters of interest include(but may not be limited to) the jet Lorentz factor, the jet opening angle, the jet viewing angle, the magnetic field configuration, and the underlying particle spectra. A comprehensive understanding of how all of these parameters relate to polarization will be needed to maximize the science return from the polarization data and help to guide follow-on mission requirements.	Polarization

Title	Description	Capability Needed	Mission parameters
Sources and propagation of positrons	We know that the strong 511 keV emission from the galactic center region is emitted by positrons annihilating with electrons. However, the sources of the positrons are not well studied, nor how fast the positrons diffuse through the Milky Way. 511-keV astronomy presents new ways of studying the sources of positrons, the propagation of positrons, and to have a new probe of the Interstellar Medium in the Milky Way Galaxy.	Study positron production in different source classes; make detailed models of positron diffusion.	Aperture, Spectral resolution, Spectroscopic modes/ methods, Field of view

Title	Description	Capability Needed	Mission parameters
Polarization of the X-ray and gamma-ray emission of different sources	The modeling of the polarization of the X-ray emission and gamma-ray emission of different source classes, including stellar mass black holes, supermassive black holes, magnetars, and pulsars is still rudimentary, hampering the interpretation of the data from the IXPE mission. New missions planned (i.e. COSI) and in preparation (i.e. IXPE follow up experiments with a broader energy range) will need better models to harvest the potential of these upcoming and new missions.	Modeling of compact sources to predict the polarization of the emitted X-rays and gamma-rays.	Aperture, Wavelength range, Spectral resolution, Spectroscopic modes/ methods, Polarization

Title	Description	Capability Needed	Mission parameters
Gamma-ray pulsar timing array	What are the technologies necessary to realize a highly capable gamma-ray pulsar timing array for detecting gravitational waves, possibly strategic	Effective area and field of view requirements for a gamma-ray timing mission which results in number of millisecond pulsar that greatly supersedes ground-based radio efforts in precision and systematics. Assessments of systematics.	Aperture, Wavelength range, Field of view, Polarization

Technology gap?

Title	Description	Capability Needed	Mission parameters
MeV monitoring of blazar variability	MeV band is crucial to blazar physics and TDAMM in general, as they are known to provide important constraints on hadronic processes, particle acceleration. This band can be the transition from the synchrotron self Compton to external Compton in some leptonic blazar models or the transition from hadronic cascading to leptonic or proton synchrotron emission if the blazar high-energy emission has a hadronic component. The above requires long-term, no-gap, simultaneous monitoring of blazars in MeV. The monitoring program needs to be able to reveal fast variability, which is typical for leptonic processes, and good sensitivity on the spectral shape to examine the transition from the synchrotron self Compton to external Compton or from hadronic cascading to leptonic processes or proton synchrotron.	Long-term, no-gap, simultaneous blazar monitoring in MeV bands needs all-sky coverage and adequate sensitivity. Identifying fast MeV variability needs good time resolution, and determining the spectral shape needs good spectral resolution.	Wavelength range

Mission capability need?

Title	Description	Capability Needed	Mission parameters
GeV blazar variability and polarization	GeV band is crucial to blazar physics and TDAMM in general, as they are known to provide important constraints on hadronic processes and particle acceleration. Fermi has observed minute-scale variability in this band, but fast variability in more blazars is not known. The above requires continuous monitoring of blazars in GeV. The monitoring program needs to be able to reveal fast variability, which can be signatures of magnetic reconnection. Additionally, the polarization in this band is not known, which can reveal proton synchrotron emission as predicted by theories.	Continuous blazar monitoring in GeV bands needs all-sky coverage and adequate sensitivity. Identifying fast GeV variability needs good time resolution. Polarization sensitivity is important for examining proton synchrotron	Polarization

Mission capability need?

Title	Description	Capability Needed	Mission parameters
Identify supermassive black hole binary with multi-wavelength blazar monitoring	If blazar jets are powered by supermassive black hole binaries, quasi-periodic oscillations (QPOs) are expected in X-ray and gamma-ray bands. However, in situ physical processes, such as kink instabilities, can also lead to QPOs. Long term, no gap, simultaneous X-ray to gamma-ray monitoring of blazars can distinguish the two types of QPOs and help to identify supermassive black hole binaries, crucial to TDAMM sciences.	Long term, no gap, simultaneous X-ray to gamma-ray blazar monitoring is necessary.	

Mission capability need?

Title	Description	Capability Needed	Mission parameters
Gamma-ray mission to support next generation ground-based gravitational-wave observatories	We want to be able to detect (and ideally localize to arcmin level) short GRBs up to z~1-2 to complement ground-based GW observatories being envisioned for the 2035+ era. This would enable to map progenitors (via GWs; masses and mass ratios) to jets (short GRBs) up to close to the star formation peak. Something inaccessible today which is critical to shed light on the physics of jet formation.	Detection and localization	Wavelength range, Pointing agility, Field of view, Operations concepts

Mission capability need?

Title	Description	Capability Needed	Mission parameters
Future joint neutrino-gamma observations	With Fermi entering its 16th year in space, a future MeV-GeV mission will be needed to perform correlated neutrino-gamma studies in the next decade. At the moment, multiple new neutrino observatories (or extensions of existing ones) are planned but wide-field, survey capabilities in the GeV band depend exclusively on the continued operation of Fermi, and are non-existent in the MeV band (a range deemed critical to identify EM hadronic signatures). The neutrino-gamma connection is still an unsolved puzzled, but new mission will be needed to answer this question.	Sensitivity in the MeV band. Broadband, wide-field, sensitive monitoring of the gamma-ray sky to search for correlated neutrino-gamma emission.	Aperture, Wavelength range, Instantaneous field of regard, Field of view, Operations concepts, Operations concepts refer to the longevity of Fermi.

Mission capability need?

Title	Description	Capability Needed	Mission parameters
Unveiling the Universe: High-Energy Polarimetry Holds the Key	Active galactic nuclei (AGN), powered by accretion onto supermassive black holes, stand out as the most luminous and enduring entities in the Universe. They offer unique laboratories for investigating the physics of matter and elementary particles under extreme conditions—such as strong gravity, magnetic fields, low matter density, and high-energy density plasmas moving at relativistic speeds—that remain unattainable on Earth. Pivotal to deciphering these astrophysical processes are multi-wavelength and multi-messenger observations. However, a notable challenge in high-energy astronomy persists: the measurement of polarization. While the capability to measure polarization is currently emerging at X-ray energies (e.g., with IXPE), there is still a lack of sensitive gamma-ray telescopes for this purpose. In tandem with multi-wavelength and multi-messenger observations, gamma-ray polarimetry is poised to play a crucial role in exploring the extreme physics of high-energy radiation, neutrino production, and cosmic ray acceleration in AGN jets. Specifically, high-energy polarimetry offers exclusive insights into the acceleration mechanism and physical conditions by revealing the magnetic field structure and its temporal evolution.		Polarization

Technology gap?

Mission capability need?

Title	Description	Capability Needed	Mission parameters
Magnetars and Fast Radio Bursts	Magnetars are the only place in the universe we have access to strong-field QED. There are several important questions related to the physics of magnetars, and their connection to fast radio bursts that can only be answered with soft gamma-ray polarization capability and sensitivity in the MeV. Among them are what and where QED processes are operating in magnetars (e.g. photon splitting, which >50 keV polarization can reveal), what causes magnetars to undergo episodic bursting activity, how many magnetars are there in the local universe, and how and why fast radio bursts are produced in only a small fraction of magnetar bursts. There are also an emerging class of potentially very old magnetars that have emerged with new radio surveys (e.g. Hurley-Walker et al. 2022, 2023). These as yet do not have a multiwavelength counterpart, but are possibly dim IR/opt/UV sources. A Roman galactic plane survey should find some, but would be useful for Roman data to have sufficiently high time resolution (~100 seconds) available.	A new gamma-ray emission with continuum sensitivity in the MeV surpassing COSI, comparable to GammaTPC or AMEGO. Transient sensitivity should be high enough to detect extragalactic magnetar giant flares well beyond the local universe, up to 100 Mpc. This requires studies what MeV concepts are cost effective and tenable, and support for technology development. Some investment in COSI for galactic transients and GRBs should also be supported.	Wavelength range, Instantaneous field of regard, Field of view, Polarization, Time resolution

Mission capability need?

Title	Description / Capability Needed	Mission parameters
Unlocking the MeV Frontier: Bridging the Observational Gap in Gamma-Ray Pulsar Studies	Fermi-LAT has revolutionized the study of gamma-ray pulsars by detecting more than 300 young and millisecond pulsars. Fermi-LAT observations immediately indicated that the gamma-ray pulsar emission is emitted in the outer magnetosphere. The significant number of detected gamma-ray pulsars led to the discovery of several trends and correlations. The patterns of LAT gamma-ray light curves and the reported correlation between the radio-lag (delta), i.e., the phase lag between the radio peak and the first gamma-ray peak, and the peak separation (Delta), i.e., the phase difference between the two gamma-ray peaks seems to be consistent with a gamma-ray emission the is produced near the equatorial current sheet outside the light cylinder. Moreover, carefully considering the LAT spectra and assuming that these are produced near the equatorial current sheet and that the spectral cutoff energy is determined by curvature radiation in the radiation reaction limited regime determines the corresponding accelerating electric field components and their dependence on the spin-down power. The implied relation for both young and millisecond pulsars reveals the operational regime of pulsars, which are closer to the force-free conditions, i.e., more ideal, towards high spin-down powers. A comprehensive analysis that combines Fermi pulsar observations, state-of-the-art global kinetic particle-in-cell (PIC) simulations, and theoretical insights demonstrated that four observables, i.e., the surface magnetic field, B, the spin-down power Edot, the total gamma-ray luminosity Lg, and the spectral cutoff energy, ecut, are not independent but are related by a relation the describes a 3D plane, i.e., the fundamental plane (FP) of gamma-ray pulsars, embedded in a 4D space. This observed fundamental plane (FP) is remarkably close to the theoretical relation, Lg \propto ecut^(4/3)*B^(1/6)*Edot^(5/12), that is obtained, assuming that the pulsar gamma-ray emission is due to curvature radiation. Advanced kinetic particle-in-cell (PIC) models reproduce both the shape patterns of the gamma-ray light curves and the FP. At the same time, they challenge the conventional estimations of total gamma-ray luminosities in Fermi catalogs. Fermi pulsars occupy specific regions within the fundamental plane, which reveals that the gamma-ray emission is regulated by the pair production efficiency in the separatrix zone that separates the open and closed field lines. Moreover, these results illuminate the role of the radiation reaction limit, delineating the 'death lines' and 'death valleys' for young and millisecond gamma-ray pulsars. More specifically, the highest ecut values corresponding to the radiation reaction limited regime scale as Edot^(7/16)*B^(-1/8). However, below an Edot value (~10^31 erg/s), the particles cannot reach the energies corresponding to the radiation reaction limited values because the available potential drop becomes smaller. At this regime, the highest ecut values scale as Edot^(7/4)*B^(-1/2). So, below an Edot value, the spectral ecut decreases considerably faster, which is mainly the reason why we do not observe gamma-ray pulsars below some Edot. On the one hand, the Lg values decrease, which requires higher sensitivities, but on the other hand, the ecut values also drop fast below the LAT range. This exploration suggests the existence of an as-yet-undetected population of MeV pulsars, underscoring the potential of upcoming MeV space telescope missions, e.g., AMEGO-X. Finally, these results and considerations align with recent breakthroughs, such as the detection of very-high-energy (up to 20 TeV) emission from the Vela pulsar. The integration of observations with PIC simulations and fundamental theoretical analysis provides a comprehensive description of gamma-ray pulsars. The necessity of an MeV space telescope emerges from the limitations of current gamma-ray observations. While Fermi-LAT has been instrumental in expanding our understanding of gamma-ray pulsars, it primarily focuses on higher energy bands. An MeV telescope would fill a crucial observational gap, enabling the study of gamma-ray emissions in the medium energy range. This range is vital for a more subtle understanding of pulsar dynamics. The detection and analysis of a currently undiscovered MeV pulsar population will offer a more complete picture of pulsar characteristics and behaviors. This is increasingly important in light of recent discoveries, such as high-energy emissions from pulsars, which challenge existing models and hint at complex processes occurring at energy levels that current telescopes may not adequately capture.	Wavelength range, Spectral resolution, Spectroscopic modes/ methods, Field of view, Polarization, Operations concepts

There must exist an undetected population of MeV pulsars.

Mission capability need?

What areas are not covered?

Title	Description	Capability Needed	Mission parameters