Physics of the Cosmos

Future Innovations in Gamma Rays Science Analysis Group

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Our Charge & Scope of Work

- Gamma-Ray Science Priorities
  - How can future gamma-ray observations advance our current understanding?
  - What are the observational capabilities and requirements for these future studies?
- Theory / Modeling / Analysis / Fundamental Physics Needs
- Technology Investment
- Gamma-Ray Mission Capabilities
- Synergies with Other Programs

Goals & Strategies

- We want to describe the science justification and technical needs of future gamma-ray missions in a way that will be readily understood by administrators with no specific background in the subfield.
- Gamma rays span ten decades in energy, and the sources and phenomena are as multifarious as one would expect for such a range. However, it is not reasonable to expect that any reader from outside the field would be able to absorb and appreciate that much information
- Thus our goal is to streamline the science cases to just those that are most vital to justifying the build requirements needed in order to accomplish all the science, including phenomena that we do not describe.

Synergies as Secondary

- Part of the aim of this report is to define a gamma-ray identity.
  - We support other wavelengths and messengers really well, but gamma-rays are intrinsically important to a number of science cases, and we need to be able to communicate both our intrinsic value and our collaborative value to other subfields.
- While synergies are secondary in terms of messaging, they are a full section of the report on their own. How can future gamma-ray missions
  - complement the fleet of NASA missions
  - multi-messenger astronomy
  - ground-based facilities

Messaging

- Developing cohesive messaging around gamma-ray science
  - We want members of the gamma-ray community to be able to articulate a similar message about what we want as a field
  - So, we then have to identify what that message could be - to funding agencies, to the public, to Congress, to other subfields
- Developing Materials around messaging
  - Working with the artists who made the exoplanet vacation poster series
  - Struggling with the message behind the medium
  - Maybe baseline science cases (as vacation destinations?)

A Preliminary Strategic Framework

- Atomic / Nuclear / particle physics decay
  - Counterpart to nonthermal particle acceleration, decay; Bottlenecks of not quite knowing which process causes observed emission
- Spectral resolution
  - gamma ray lines; DM / ALPs, CR, LIV; lensing of GRBs against compact objects; Need to develop threshold cases; Doppler shifts of lines can break degeneracies in distances in other galaxies
- Timing & effective area
  - GRBs ~100ms; Magnetars / Pulsars, time a millisecond pulsar ~ms; flux, photon arrival time; localization
- Polarization
  - MDP per flux, energy range; AGN, Magnetars / Pulsars, GRBs; Sensitivity to get better time resolution on polarization measurements for variable sources

Organization of the Science Chapter

- Nuclear Decay, especially Ni-56 in Supernovae
  - In the next 50 years, gamma-rays from the decay of radioactive isotopes provide the only nearly-direct probe at sufficiently high distances to build the samples of events to study these engines.
  - Require high spectral resolution, probably pointing
- Gamma-ray Bursts
  - Important to localizing the GRBs for MM & MWL, probe the structure and particle acceleration within the jet.
  - Require wide-FOV, excellent timing resolution and low latency, and benefits from spectropolarimetry
- Blazars
  - Jet composition has implications for jet launching mechanism, particle acceleration, etc
  - Require spectropolarimetry, which will need a large effective area, and wide-FOV helps with monitoring long term and unpredictable behavior.
- Pulsars for Timing Arrays & SMBH Mergers
  - Naive extrapolation of Fermi-LAT's LogN-LogS implies a gamma-ray PTA being complementary and perhaps surpassing the capability of radio PTAs of the 2030s due to its scalability.
  - Requires very high timing resolution & precision

Meetings & Remaing Work for the Science Chapter

- For about 6 months, we held structured virtual meetings about monthly
  - Broad input from the community, cast a wide net for potential topics, areas that are making good progress or are challenging with current facilities
  - About 90 min, including a plenary, breakout rooms, open discussions
- In-Person Meeting at Michigan Tech in June 2024
  - Mix of plenary talks and parallel discussions.
  - Developed arguments to link science cases with intrument requirements and theoretical and analysis development needs
- Report Organization & Science Chapter Writing managed by the Chairs
- Still need figures for most of the sections

Organization of the Theory Chapter

- By Source type?
  - This has the benefit of mirroring the Science chapter, and helping to draw clear lines of reasoning between all of the chapters
  - Some of the areas of theory that need the most development might help our highlighted science cases, but would be more naturally developed for others.
- By Method?
  - Nucleosynthesis simulations rely on MHD codes
  - MHD also informs our understanding of flows and acceleration in jets
  - PIC tells us more about the mirophysical interactions
  - Transport is needed to compare with data due to the scaling problem
  - Hybrid methods have received a lot of attention recently, but massively multiphysics implementations are not universally popular

Meetings & Remaing Work for the Theory Chapter

- Nuclear Decay
  - Discussed CCSNe and MGFs; need for additional measurements; need to identify stable isotopes
- Particle-in-Cell
  - Concerns about future computing hardware, some problems don’t require many skin depths but others require a hybrid approach, Radiation problem
- Magnetohydrodynamics & Transport
  - Upcoming
- Chairs will discuss how to proceed with chapter structure to bring out the necessary points and tie into other chapters.

The Instrumentation & Infrastructure Chapters

- Imaging Techniques, Detector Technologies, & Analysis
  - Discussion of recent and anticipated advancements relevant to gamma-ray missions
- Capabilities & Needs
  - Ties into the driving science cases to point to thresholds of polarization degree, timing, effective area, and spectral resolution that enable and advance the key science areas
- Communications Infrastructure
  - Enable fast followup
- Support for Analysis Infrastructure
  - On-board processing

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Future Innovations in Gamma Rays

We will explore gamma-ray science priorities, necessary capabilities, new technologies, and theory needs to inspire work toward 2040.

Get involved and stay informed:
https://forms.gle/VBijBgapMRwJm9dU6

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Questions?