Draft Terms of Reference: Future Innovations in Gamma rays Science Analysis Group

Astrophysical gamma rays span from ~100 keV (10^5 eV) to several PeV (10^{15} eV), a range encompassing ten orders of magnitude in energy. Their detection enables the study of a similarly broad range of astrophysical phenomena and markers of fundamental physics. This energy range is as wide as the rest of the astronomically relevant electromagnetic spectrum, from radio to X-rays, thus relying on several different detector technologies. Within a single gamma-ray observation of a high-energy event, we may be witnessing numerous processes, including synchrotron radiation from highly accelerated charged particles and the emission from the decay of radioactive isotopes or subatomic particles, as well as potential signatures of new physics. Disentangling the contributions of different physical processes at play, and their connection to other multi-wavelength or multi-messenger observations, is exciting—but challenging—and it requires abundant and recurrent broadband gamma-ray observations.

Gamma rays are produced by the most extreme objects and events in the Universe. They are closely linked to sources of gravitational waves, neutrinos, and cosmic rays. In turn, gamma-ray observations play a pivotal role in constructing a comprehensive multi-messenger picture of both transient and steady high-energy emission in the Universe. In addition to providing critical insights into the nature of these energetic phenomena, gamma-ray astronomy provides a direct window to probe the nature of new physics that is otherwise inaccessible through and complementary to laboratory experiments on Earth. For example, gamma rays probe many particle acceleration phenomena relevant to cosmic-ray sources and the underlying plasma physics of their origin. Similarly, gamma-ray spectral lines produced in radioactive isotope decays are one of the most direct probes into the explosion mechanisms responsible for their production and the fundamental nuclear physics at play. Finally, gamma-ray observations also provide some of the most stringent constraints of the properties of dark matter candidates.

Since the launch of the Vela satellites in the 1960s, gamma-ray astronomy has benefitted from a continuous set of missions capable of studying a broad range of astrophysical objects including persistent and transient phenomena. These missions have made a number of remarkable discoveries that have revolutionized astrophysics. However, many of the current major missions are reaching the end of their extended operational phases and, at this time, only few comparable future missions have found support. The combined wealth of recent discoveries and the need to identify next-generation missions places the gamma-ray astronomy community in an ideal position to reassess its future priorities.

To that end, this group's activity will focus on identifying future science drivers, necessary capabilities, and priorities for the future of gamma-ray astronomy. Questions to be evaluated include:

1) Gamma-ray Science Priorities: What are the opportunities to probe astrophysical phenomena, fundamental physics, and cosmology that are uniquely afforded by gamma rays? How do these opportunities connect to the priorities of the wider astrophysics community? For each of these phenomena, how can future gamma-ray observations

advance our current understanding and what is lost by not including gamma-ray constraints? What are the observational capabilities and requirements for these future studies?

2) Theory/Modeling/Analysis/Fundamental Physics Needs: What theoretical or analysis (e.g. Machine Learning) advances are needed to maximize the impact of these observations and low-level data products? What connections to physics disciplines should be developed to maximize science impact. Which observations require higher fidelity analysis or modeling methods and implementations?
3) Technology Investment: What are new technologies/methodologies available since the launch of Swift and Fermi? How do these map to the science priorities outlined above, and what areas need further development and investment in order to enable that science?
4) Gamma-ray Mission Capabilities: What science can only be done or is best done by future space-based gamma-ray missions? What science will be done by currently funded missions in development, such as COSI? What gamma-ray science can be accomplished by small-, medium-, and large-scale missions?
5) Synergies with Other Programs: How can future gamma-ray missions complement the fleet of NASA missions and current thrusts like multi-messenger astronomy and its ties to ground-based missions? Are there key facilities that set necessary timelines for future gamma-ray missions? What synergies exist with other agencies with efforts in detector technology, physics, and analysis research (e.g., detector or associated electronics research and development, data analysis techniques, laboratory astrophysics, modeling methods, software, data archiving)?

To address these questions in a timely manner in order to provide input to NASA to meet the needs of future gamma-ray missions, we propose to create a Future Innovations in Gamma rays Science Analysis Group (FIG SAG). This SAG would have open membership, including volunteers from PhysPAG and the broader astrophysical community. It will be chaired by Chris Fryer (co-lead), Michelle Hui (co-lead), Paolo Coppi, Milena Crnogorčević, Tiffany Lewis, Marcos Santander, and Zorawar Wadiasingh with the goal of analyzing the above questions and gathering community inputs starting at the 243rd AAS meeting and the 21st HEAD meeting through special sessions. The group plans to hold monthly meetings and a dedicated workshop in 2024, with the goal of delivering a report with the above findings edited by the co-chairs and community members of the SAG to NASA HQ in 2025.