Envisioning the Future of Gamma-Ray Astronomy in Space

*An Overview of NASA's **FIG-SAG** Effort*

Milena Crnogorčević
on behalf of the FIG-SAG Leadership*

ICRC, Geneva
July 17, 2025

ICRC 2025
The Astroparticle Physics Conference
Geneva July 15-24, 2025

*Michelle Hui, Chris Fryer, Paolo Coppi, MC, Tiffany Lewis, Marcos Santander, Zorawar Wadiasingh

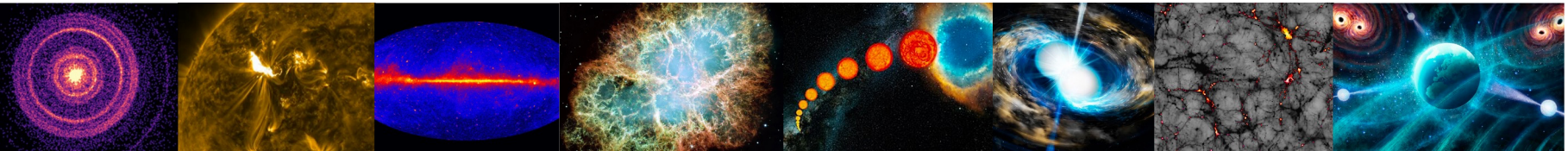
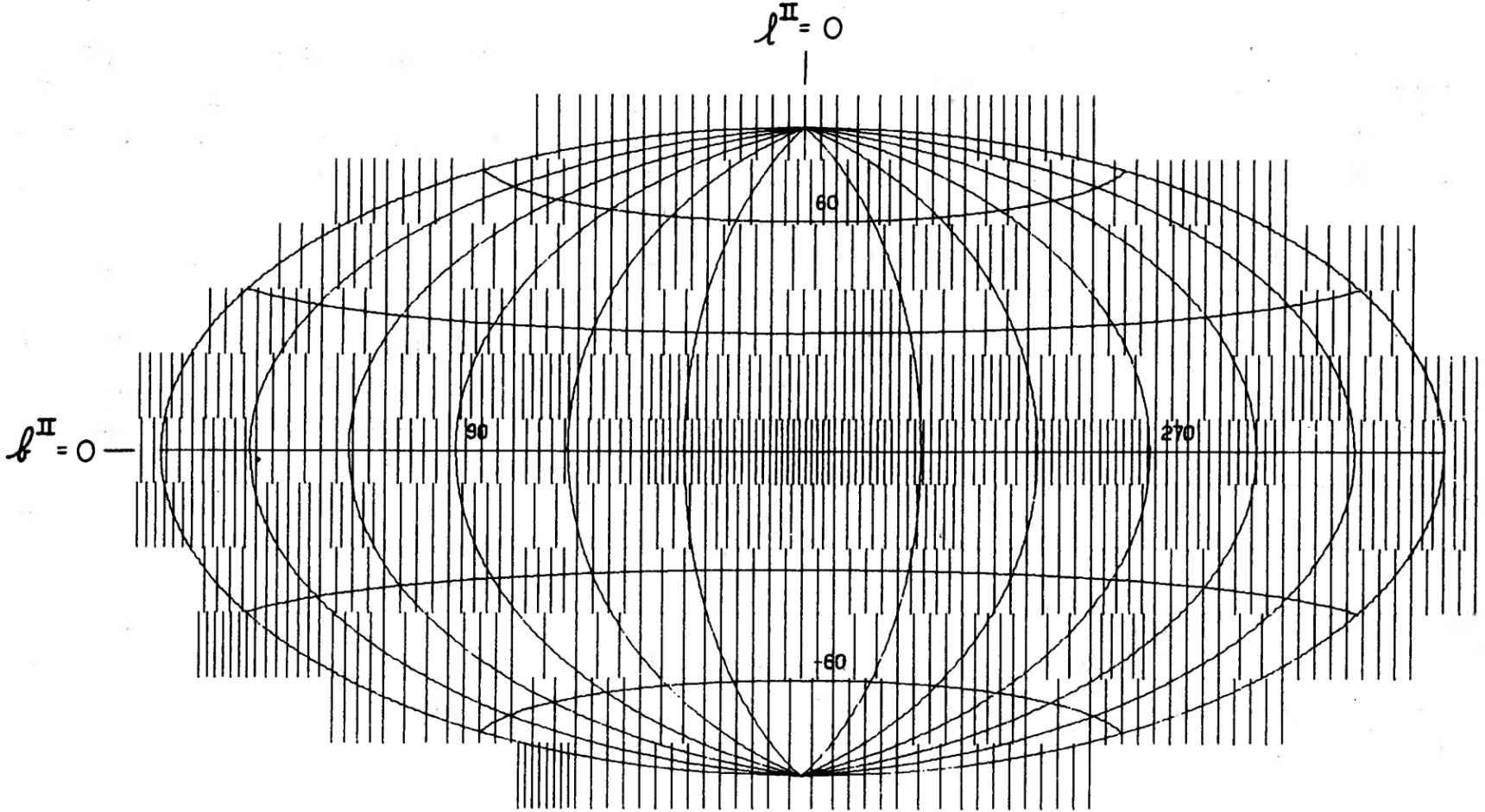
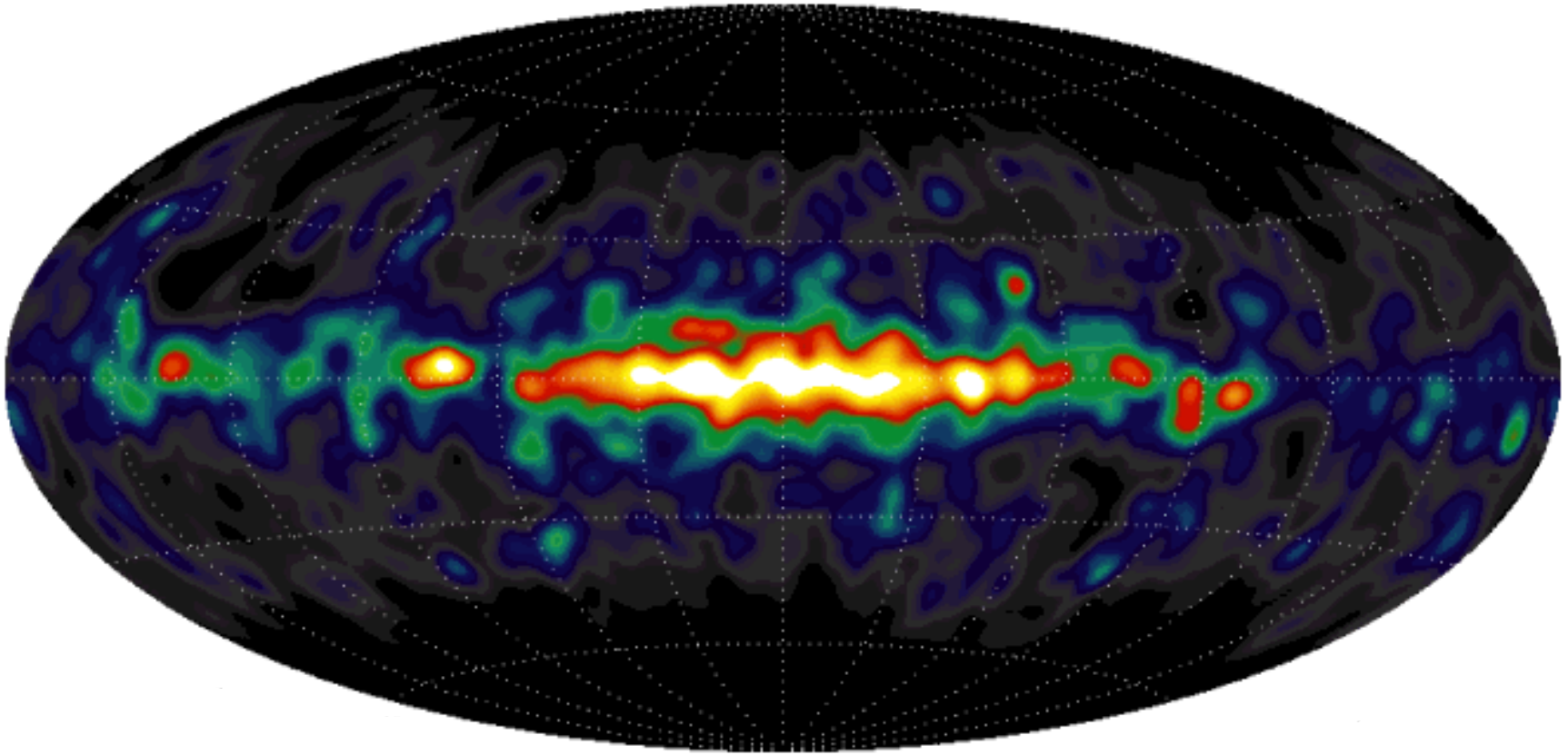


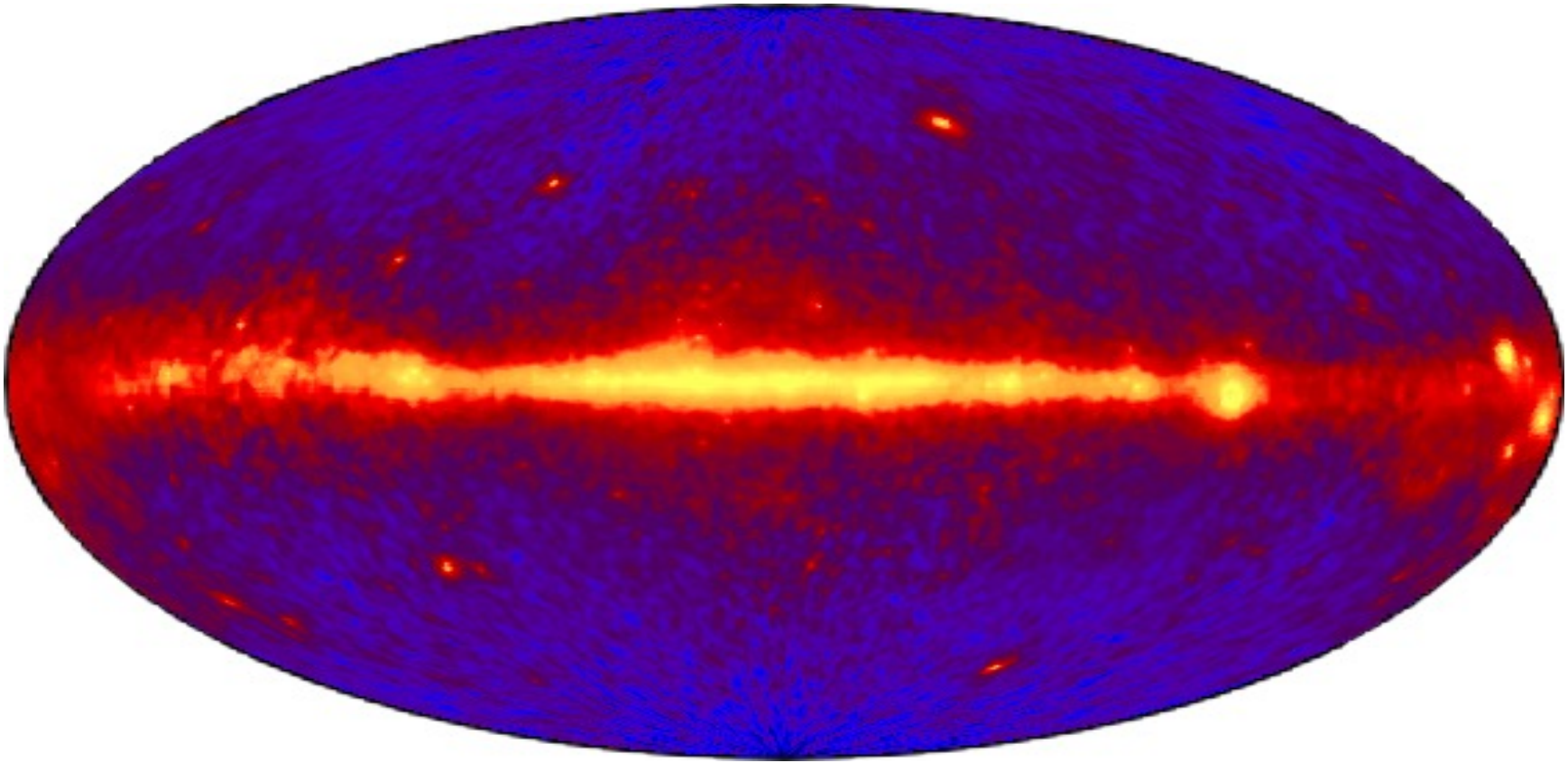
FIG-SAG



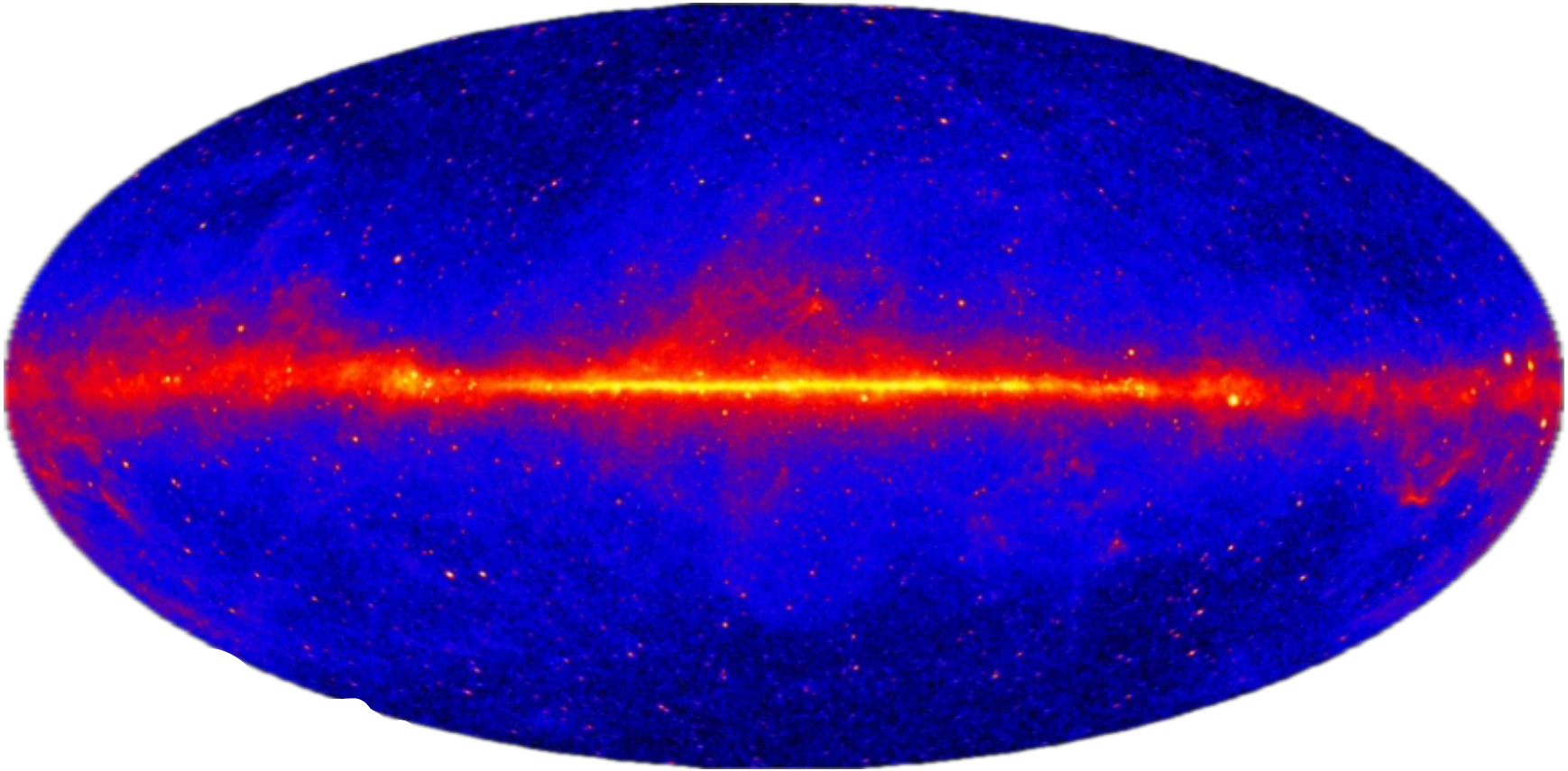
1968, Orbiting Solar Observatory, OSO-3 (~50 MeV)



2000, COMPTEL (onboard CGRO), 1–30 MeV



2000, EGRET (onboard CGRO), above 100 MeV



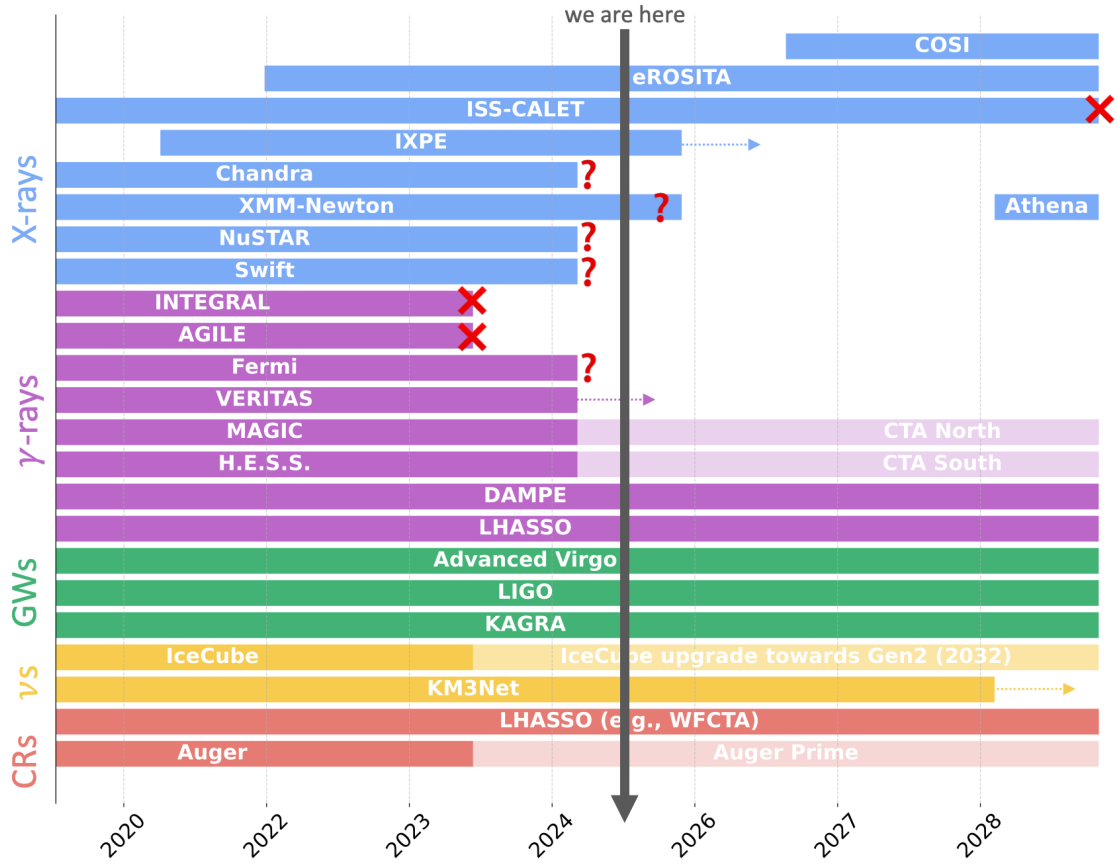
2020, LAT (onboard *Fermi*), above 500 MeV

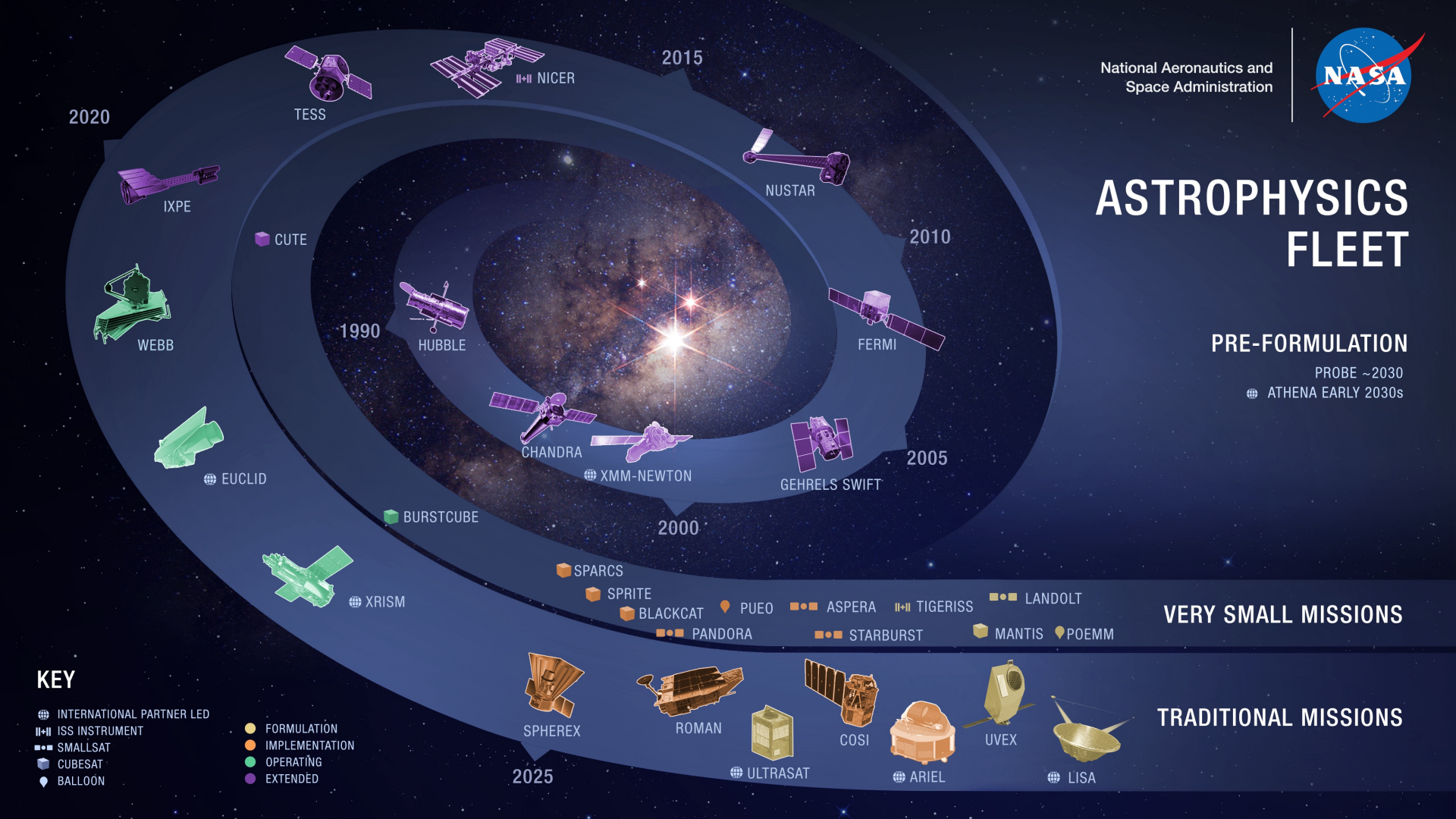
Gamma-ray astronomy: the importance of continuous observations

Discoveries:
new classes of transients and flares (GRBs, magnetars, novae, AGNs), large-scale/extended structures (Fermi bubbles), CR acceleration sites (SNR), particle interactions and accelerations (pulsars, jets etc.), constraints on DM.

Issue:
current major missions are all in their decade+ extended operation. Only smaller-scale missions have been funded.

Action:
Reassess current and future priorities for a gamma-ray vision towards 2040.




National Aeronautics and Space Administration
NASA
ASTROPHYSICS FLEET
PRE-FORMULATION
PROBE ~2030
ATHENA EARLY 2030s
2015
2020
2010
1990
2005
2000
2025
TESS
NICER
IXPE
NUSTAR
CUTE
WEBB
HUBBLE
FERMI
CHANDRA
XMM-NEWTON
GEHRELS SWIFT
EUCLID
BURSTCUBE
XRISM
SPARCS
SPRITE
BLACKCAT
PUEO
ASPERA
TIGERISS
LANDOLT
PANDORA
STARBURST
MANTIS
POEMM
VERY SMALL MISSIONS
SPHEREX
ROMAN
COSI
UVEX
ULTRASAT
ARIEL
LISA
TRADITIONAL MISSIONS
KEY
INTERNATIONAL PARTNER LED
ISS INSTRUMENT
SMALLSAT
CUBESAT
BALLOON
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

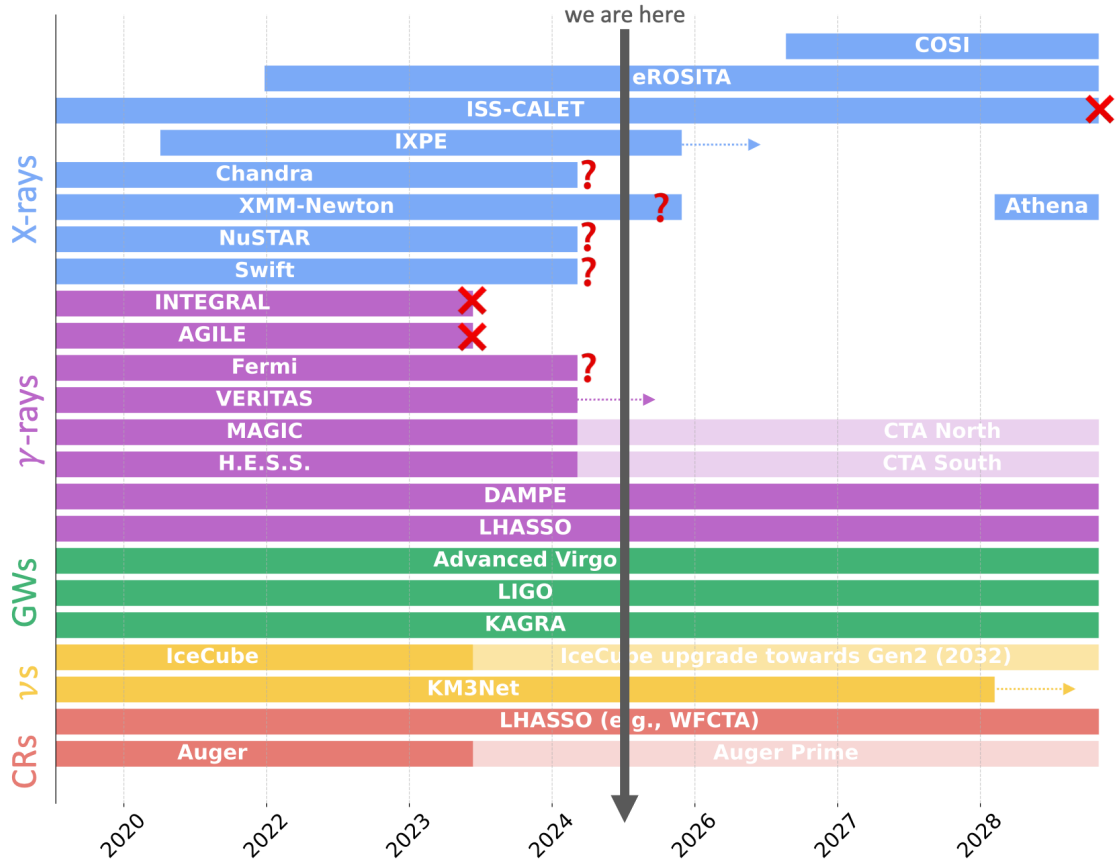

National Aeronautics and Space Administration
NASA
ASTROPHYSICS FLEET
PRE-FORMULATION
PROBE ~2030
ATHENA EARLY 2030s
2020
2015
2010
2005
2000
1990
2025
TESS
NICER
IXPE
NUSTAR
CUTE
WEBB
HUBBLE
FERMI
CHANDRA
XMM-NEWTON
GEHRELS SWIFT
EUCLID
BURSTCUBE
XRISM
SPARCS
SPRITE
BLACKCAT
PUEO
PANDORA
STARBURST
LANDOLT
MANTIS
POEMM
VERY SMALL MISSIONS
SPHEREX
ROMAN
COSI
UVEX
ULTRASAT
ARIEL
LISA
TRADITIONAL MISSIONS
KEY
INTERNATIONAL PARTNER LED
ISS INSTRUMENT
SMALLSAT
CUBESAT
BALLOON
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

Gamma-ray astronomy: the importance of continuous observations

Discoveries:
new classes of transients and flares (GRBs, magnetars, novae, AGNs), large-scale/extended structures (Fermi bubbles), CR acceleration sites (SNR), particle interactions and accelerations (pulsars, jets etc.), constraints on DM.

Issue:
current major missions are all in their decade+ extended operation. Only smaller-scale missions have been funded.

Action:
Reassess current and future priorities for a gamma-ray vision towards 2040.



Gamma-ray astronomy: the importance of continuous observations

Discoveries:
new classes of transients and flares (GRBs, magnetars, novae, AGNs), large-scale/extended structures (Fermi bubbles), CR acceleration sites (SNR), particle interactions and accelerations (pulsars, jets etc.), constraints on DM.

Issue:
current major missions are all in their decade+ extended operation. Only smaller-scale missions have been funded.

Action:
Reassess current and future priorities for a gamma-ray vision towards 2040.

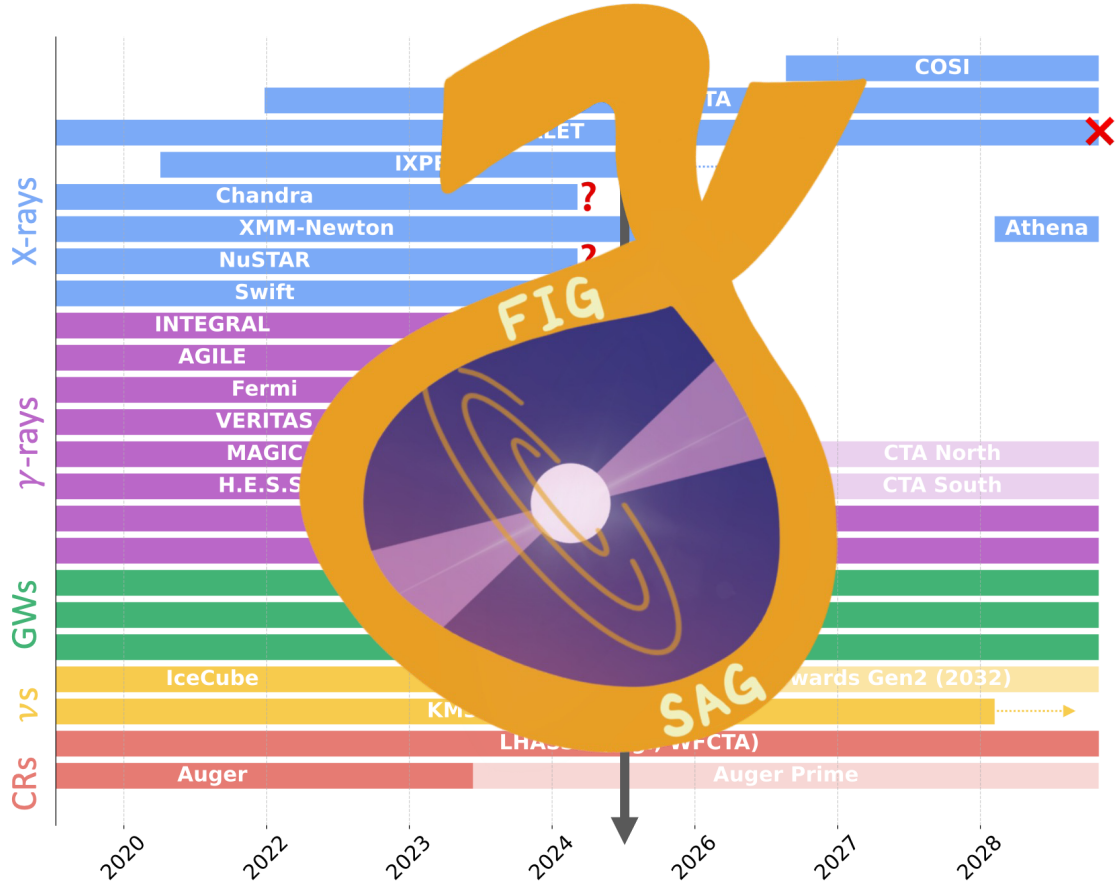
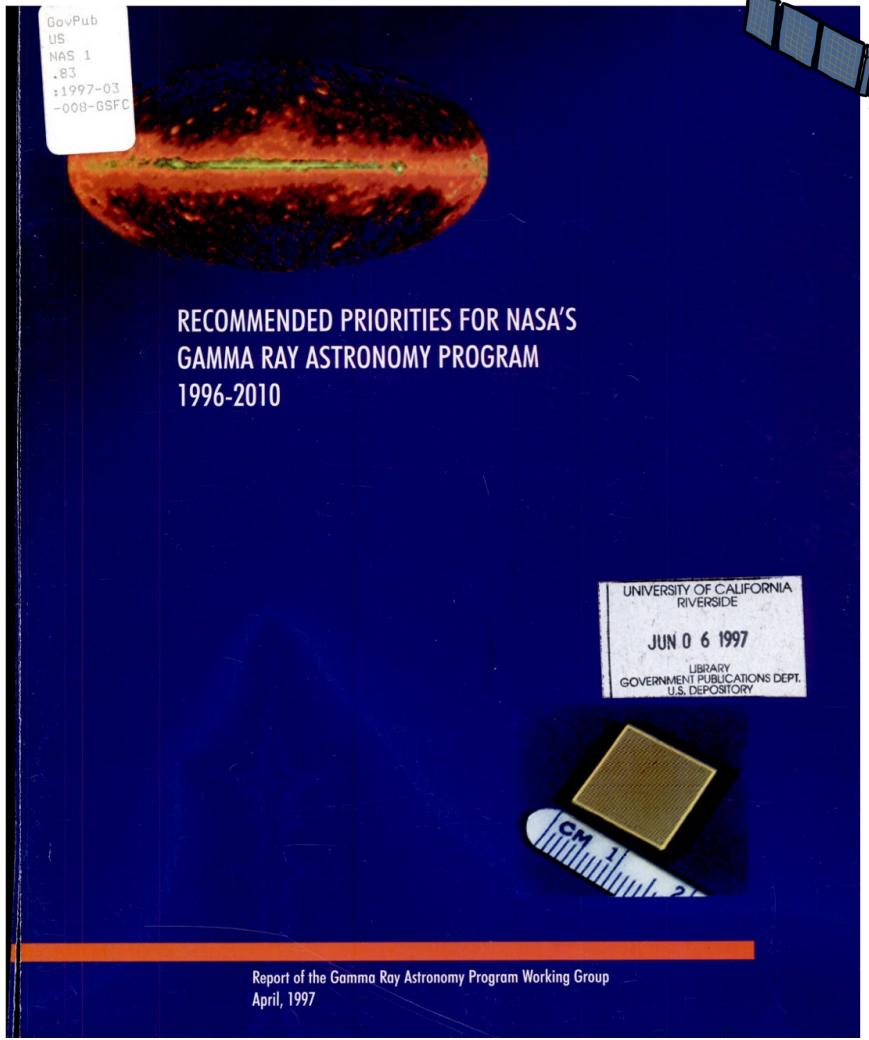


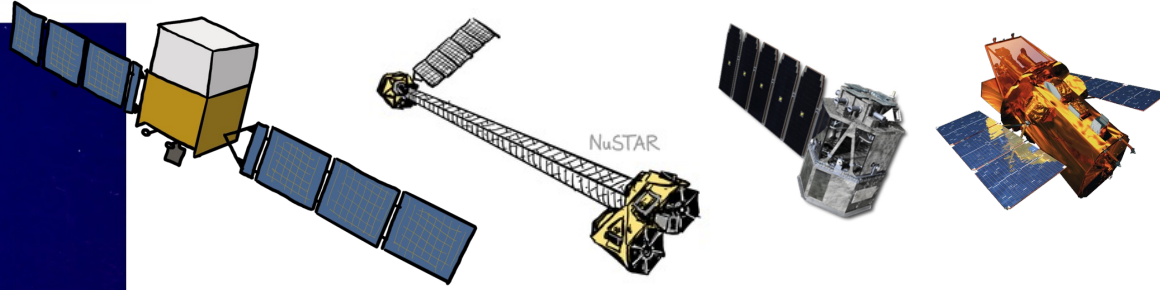
FIG SAG Motivation & Goals

…to explore gamma-ray science priorities, necessary capabilities, new technologies, and theory/modeling needs drawing on the 2020 Decadal **to inspire work toward 2040.**

FIG SAG Motivation & Goals

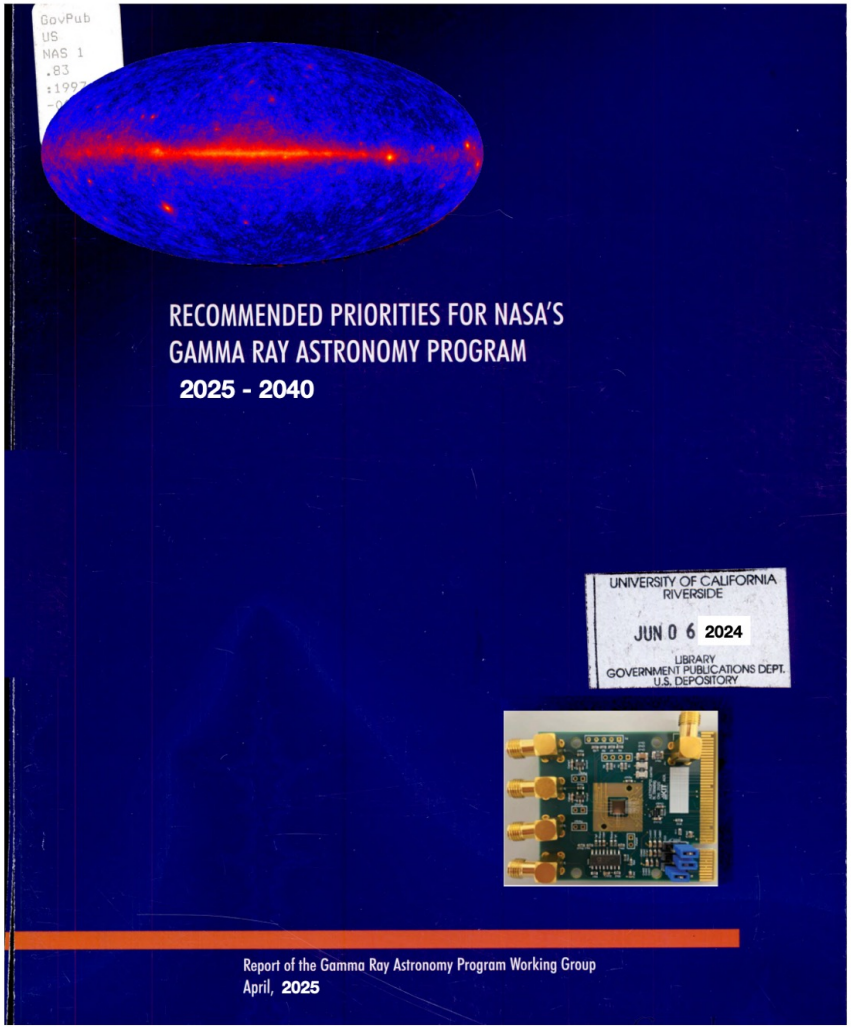
…**produce a report** to help and inform NASA about topics and the community's priorities leading into Decadal Reports focusing on science drivers, necessary capabilities, and prioritizing the future of space-based gamma-ray astronomy.





- Intermediate Missions: Fermi, NuSTAR and now COSI
- MIDEX and SMEX: Swift and NICER
- Technology: a robust technology development program (SiPMs, new scintillators, upgraded silicon detectors, etc)
- Balloons (+ CubeSats!): long duration balloons enabled COSI, LEAP, etc.
- Data Analysis & Theory: mainly supported through "Guest-Investigator" programs
- TeV Astronomy: VERITAS, HESS, HAWC, MAGIC, LHASSO, CTA.

Adapted from Regina Caputo's slides, TeVPA 2024

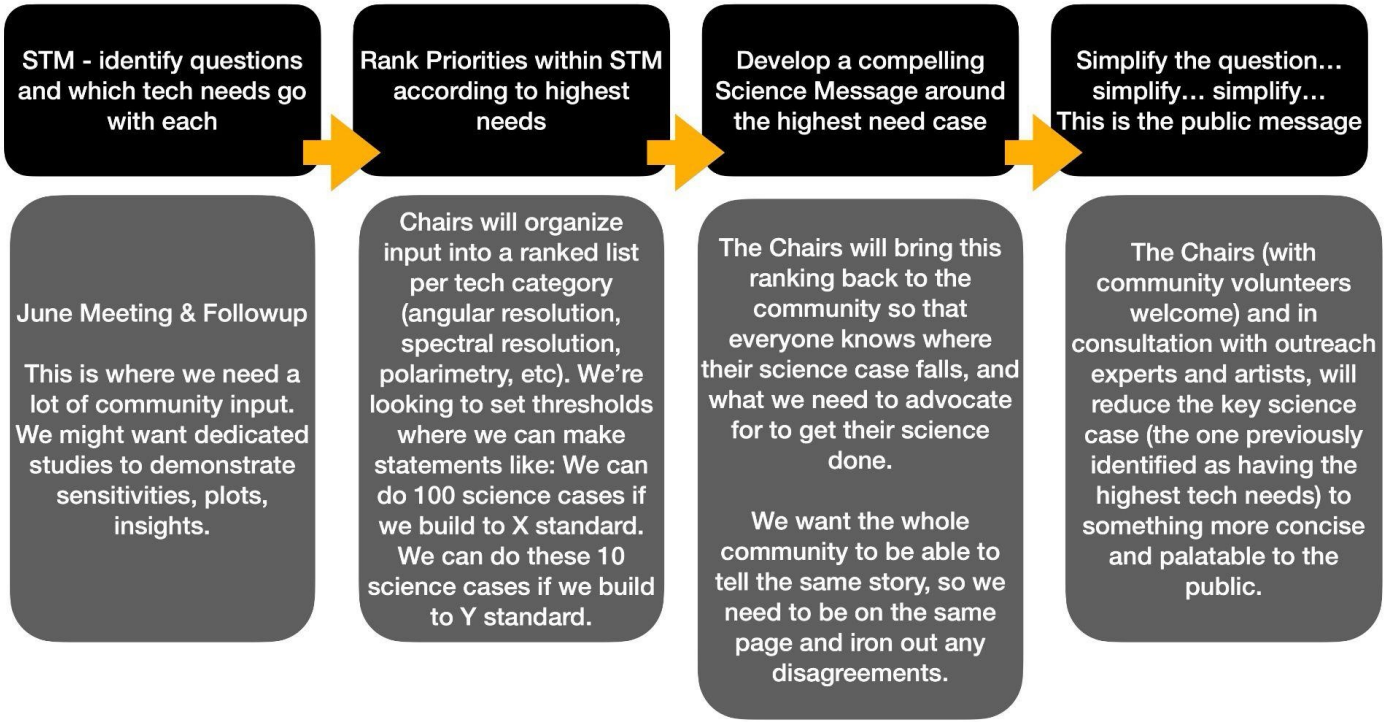


[insert your space-based gamma-ray wish list]

FIG SAG Themes

1. **Gamma-ray Science Priorities:** Identify opportunities uniquely afforded by gamma-ray observations.
2. **Gamma-ray Mission Capabilities:** Which science objectives are only done or best done by space-based gamma-ray missions, considering the current missions in extended operation and funded missions in development.
3. **Technology Investment:** What new technologies/methodologies exist and what is needed to achieve the science priorities.
4. **Theory and Analysis Needs:** What advances do we need to make in theory and analysis to achieve the science priorities.
5. **Synergies with Other Programs:** How do these goals tie to the broader astrophysics and physics community. What are the timelines to align with current priorities in multi-messenger astronomy. Coordinate with international gamma-ray efforts (e.g., THESEUS, e-ASTROGAM). Incorporate science drivers and timeline to inform complementary FIG-SAG priorities.

What does this mean, practically?



Jan 9, 2024		Kick-off at AAS meeting (in person)
February 29	zoom	Gamma-ray Science Priorities
March 21	zoom	Theory/Modeling/Analysis/Fundamental Physics Needs
April 10		Special Session at the HEAD Meeting (in person)
May 23	zoom	Technology Investment
June 24 – 28		FIG SAG Workshop at Michigan Tech (in person)
August 1		Workshop Summary and Report
August 22	zoom	Technology Missions and Capabilities
Sep 13		FIG-SAG @ Fermi Symposium
Jan 15, 2025		FIG-SAG @ AAS meeting
Feb-Apr 2025	zoom	Theory Telecons
May-June 2025		Polishing up the requirements
July 2025		ICRC 2025

It is strategically important to define *gamma-ray science* in terms of *gamma-ray science*

Science Traceability Matrix: example

Observable	Sensitivity Requirement	Key Achievable Science
Polarization	1% MDP in 1 day	Definitive blazar jet composition and particle acceleration
	10% MDP in 1 week	?
Angular Resolution	0.05 deg	Resolving galactic center
	0.05 deg	DM in the Galactic Center
Energy Resolution	1%	Doppler shift velocities for SNe
	3%	Nuclear lines in our galaxy
Effective Area	> 30x LAT at 0.1–1GeV	PTA
	> 10x COSI	Galactic line science

See more: https://smd-cms.nasa.gov/wp-content/uploads/2023/04/Launchpad_Session3_STM_18Nov2019_smf_final.pdf

Final product: Report

1. Overview:
    a. Status Quo, context of current gamma-ray missions & facilities
2. Primary Baseline Science Cases:
    a. Details about the science and required sensitivity, etc
3. Secondary and tertiary Baseline Science Cases
    a. Details about science cases that require slightly less sensitivity, etc
    b. What science cases can be accomplished per observable requirement?
4. Complementarity
    a. Gamma rays first messaging, but also broader context of multiwavelength and mutlimessenger

Synergies as Secondary

- 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
- Are there key facilities that set necessary timelines for future gamma-ray missions?
- What synergies exist with other agencies?
  - Efforts in detector technology, electronics research and development, data analysis techniques, laboratory astrophysics, modeling methods, software, data archiving?
- International landscape: timelines for gamma-ray and MeV missions like THESEUS, e-ASTROGAM, VLAST, HERD, etc. Identify opportunities for joint missions or data interoperability.

Driving Science Cases

- **Nuclear Lines** - requires high angular resolution and high spectral resolution together
- **GRBs** - requires high sky-coverage, precision timing, fast alerts, (spectropolarimetry would also be useful)
- **Blazars** - requires high effective area for short timescale spectropolarimetry
- **PTAs** - requires consistent monitoring over long timescales; fundamentally multimessenger; far more scalable than radio PTAs
- **Dark Matter** - long timescale problem that unites elements of a lot of other objects under one purpose.

Future Innovations in Gamma Rays Science Analysis Group: A Report on Science Needs Beyond 2025

Chris Fryer[1], C. Michelle Hui[2], Paolo Coppi[3], Milena Crnogorcevic[4], Tiffany R. Lewis[5], Marcos Santander[6], and Zorawar Wadiasingh[7]

[1]Los Alamos National Laboratory
[2]NASA Marshall Space Flight Center
[3]Yale University
[4]Stockholm University
[5]Michigan Technological University
[6]University of Alabama, Huntsville
[7]University of Maryland, College Park

Future Innovations in Gamma Rays Science Analysis Group:
A Report on Science Needs Beyond 2025

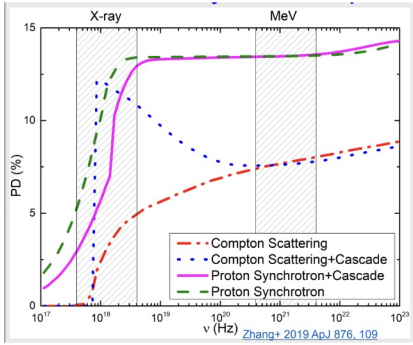
C[illegible]er[1], [illegible]Hu[illegible]on[illegible]ppi[3], Mi[illegible]C[illegible]go[illegible][4], [illegible]my[illegible]ew[illegible]Ma[illegible]
S[illegible]nc[illegible]and Zora[illegible]dias[illegible][7]

[1][illegible]amos Nationa[illegible]atory
[2]N[illegible]arshall Space[illegible]Center
[3]Yale Univer[illegible]
[illegible]tockholm Uni[illegible]
[illegible]gan Technologi[illegible]versity
[6]University of Alabama, Huntsville
[7]University of Maryland, College Park

AND YOU!

What's Next?

GOAL	REQUEST	TIMELINE
Define the ***science drivers*** for the **next several decades** of gamma-ray astrophysics, connecting to ***sensitivity thresholds***, ***technology requirements***, and ***infrastructure needs*.**	**Quantify sensitivity and performance needs**. Plots of angular resolution, sky coverage, and effective area requirements for the driving science cases. **What are we missing?**	Draft report for community feedback by **Fall 2025**. Target submission to the ***NASA Astrophysics Advisory Committee*** by **year-end 2025**. Publish in a special edition in the ***Journal of High Energy Astrophysics– open for contributions!***



or link: https://www.overleaf.com/read/xfpkphvsncsx#c78748

General Info

Website	https://pcos.gsfc.nasa.gov/sags/figsag.php
Slack Workspace	https://docs.google.com/forms/d/e/1FAIpQLSfsgnb1OUQ3jISGiIM_3abQsKoHvzlgWBZP3meMXJxUwRHI5w/viewform
All-group listserv	fig-sag@lists.nasa.gov
Chairs e-mail addresses	Michelle Hui (c.m.hui@nasa.gov) Chris Fryer (fryer@lanl.gov)
Co-chairs e-mail addresses	Paolo Coppi (paolo.coppi@yale.edu) Milena Crnogorčević (milena.crnogorcevic@fysik.su.se) Tiffany Lewis (tiffanylewisphd@gmail.com) Marcos Santander (jmsantander@ua.edu) Zorawar Wadiasingh (zorawar.wadiasingh@nasa.gov)
Google Drive	https://drive.google.com/drive/folders/1ucUW9TTghyb7P_u2_QY-aqkwB3Nf41TV?usp=sharing

Website:

Full link: https://pcos.gsfc.nasa.gov/sags/figsag.php

Join Slack here:

Full link: https://docs.google.com/forms/d/e/1FAIpQLSfsgnb1OUQ3jISGiIM_3abQsKoHvzlgWBZP3meMXJxUwRHI5w/viewform

THIS SESSION

10 min	The Physics of the Cosmos Program	Francesca Civano (NASA)
15 min	The Cosmic Ray and Neutrino Science Interest Group	Tsuguo Aramaki (Northeastern)
15 min	Gamma-Ray Science Priorities in Coming Decades	Milena Crnogorcevic (Stockholm Univ)
30 min	Panel Discussion	

Keith McBride (Univ. of Chicago)

Johannes Eser (Columbia Univ.)

Eun-Suk Seo (UMD)

Jamie Holder (Univ. of Delaware)

Alexander Moiseev (NASA GSFC)

Valerie Connaughton

Thomas Hams (NASA HQ)

Questions

1. How do neutrino, cosmic ray, and gamma-ray space-based observatories contribute to NASA's goals of understanding the origin and evolution of galaxies, stars, and black holes?

2. What are the leading opportunities in cosmic ray, neutrino, and gamma ray astroparticle physics that NASA is uniquely suited to address? What unique astrophysical questions can only be answered with neutrinos, cosmic rays, or gamma rays from space that cannot be addressed with ground-based observatories?

3. What role do you see cosmic rays / neutrinos / gamma rays missions in time-domain and multi-messenger astrophysics (TDAMM)? How can space-based projects work in tandem with ground-based experiments to enhance the science output of both projects? What should NASA and the CRNSIG / GRSIG / TDAMM community be doing to ensure coordination?

4. What role do you see for different space-based platforms (balloons, satellites, cubesats, rockets, lunar) for cosmic ray, neutrino, and gamma ray science?

5. What technology gaps do you see related to your science topic and how could NASA invest in future missions?