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*

TeVPA, Chicago 2024
August 29, 2024

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

FIG-SAG

FIG-SAG *(proper noun)*:

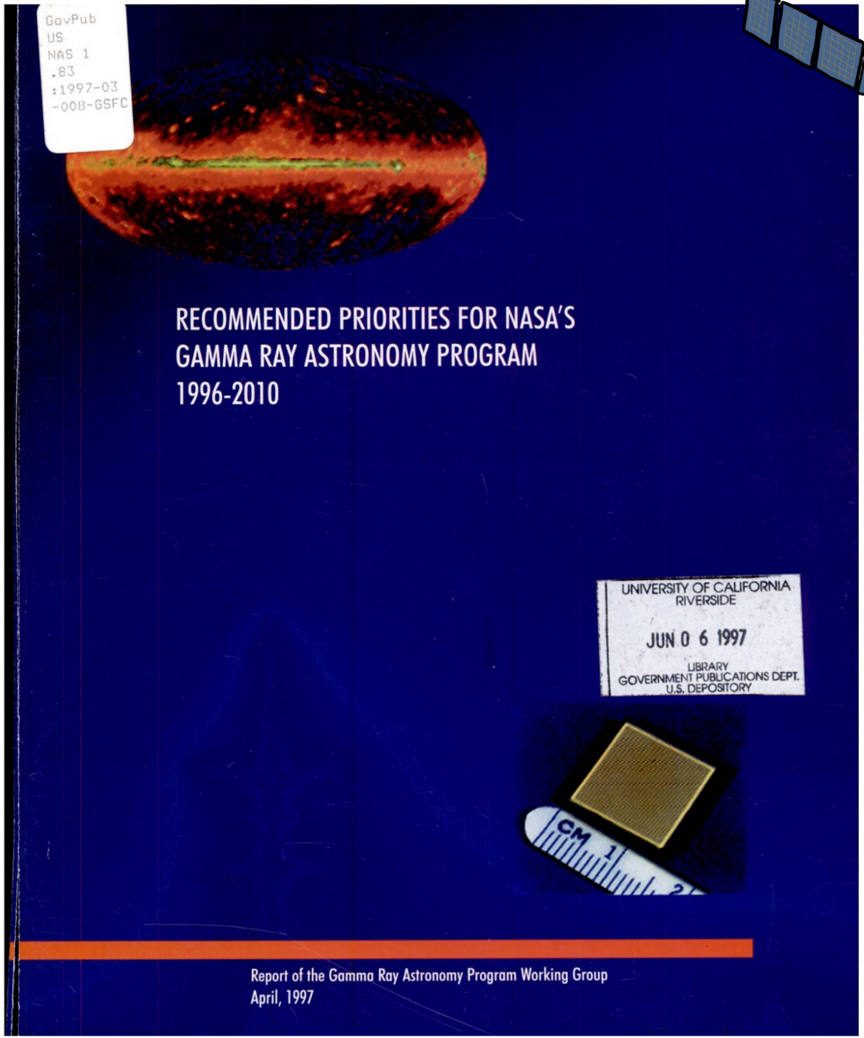
Future Innovations in Gamma Rays Science Analysis Group

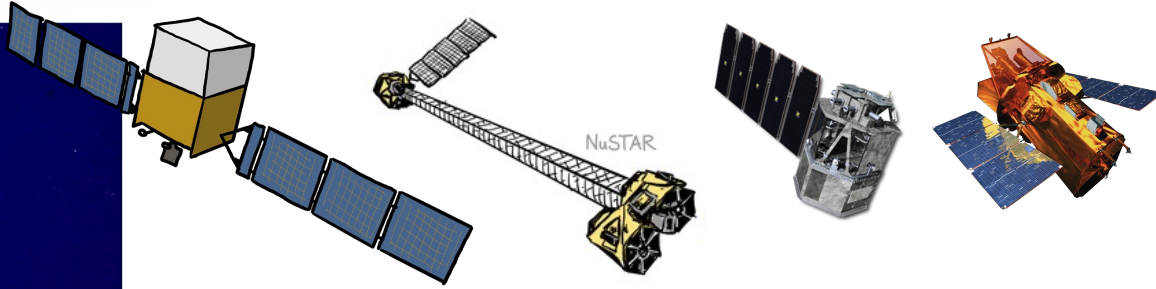
FIG SAG Motivation & Goals

…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

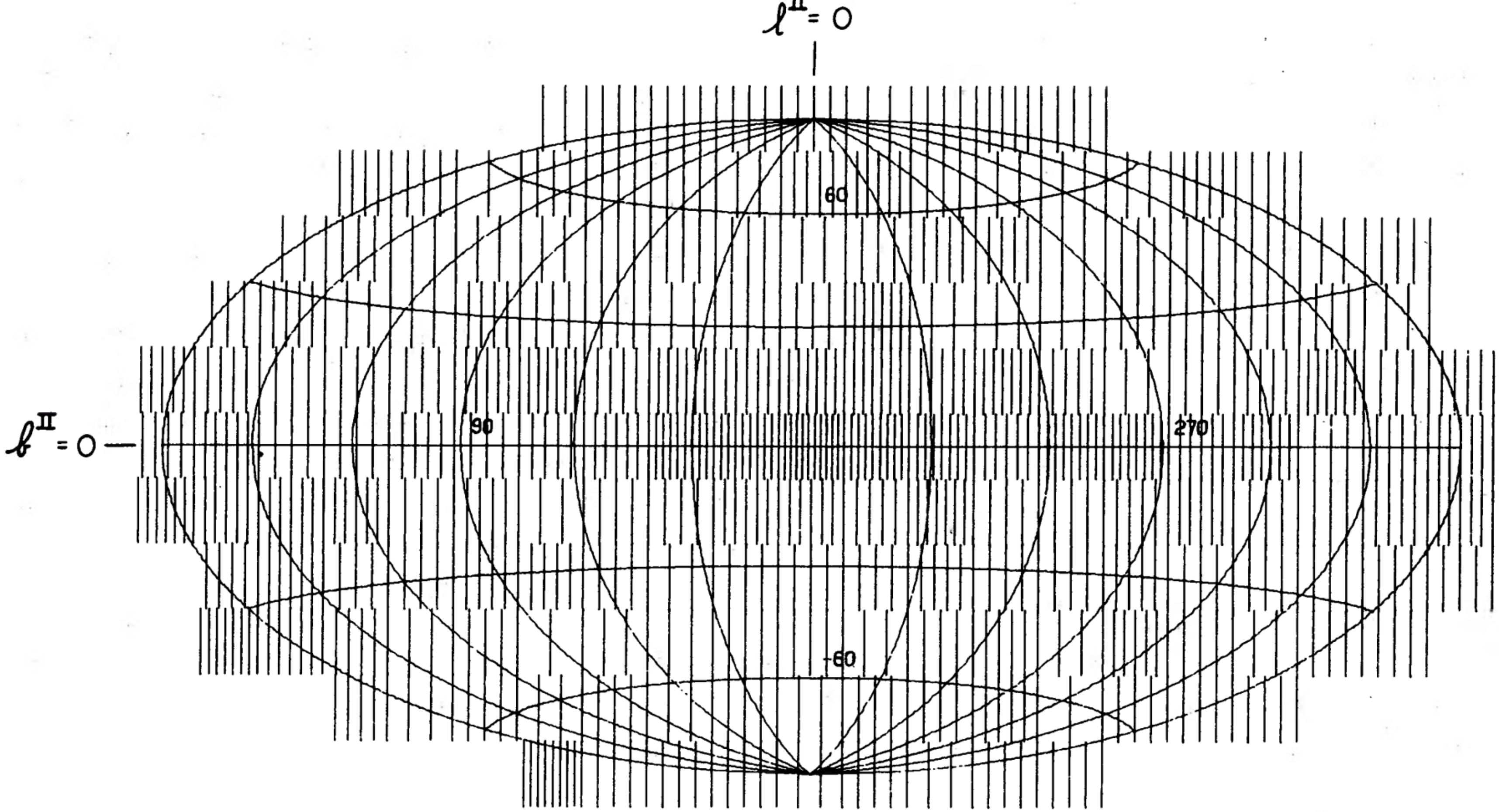
…<u>produce a report</u> to help and inform NASA about topics and the community's priorities leading into Decadal Reports focusing on science drivers, necessary capabilities, and prioritizing the future of gamma-ray astronomy.



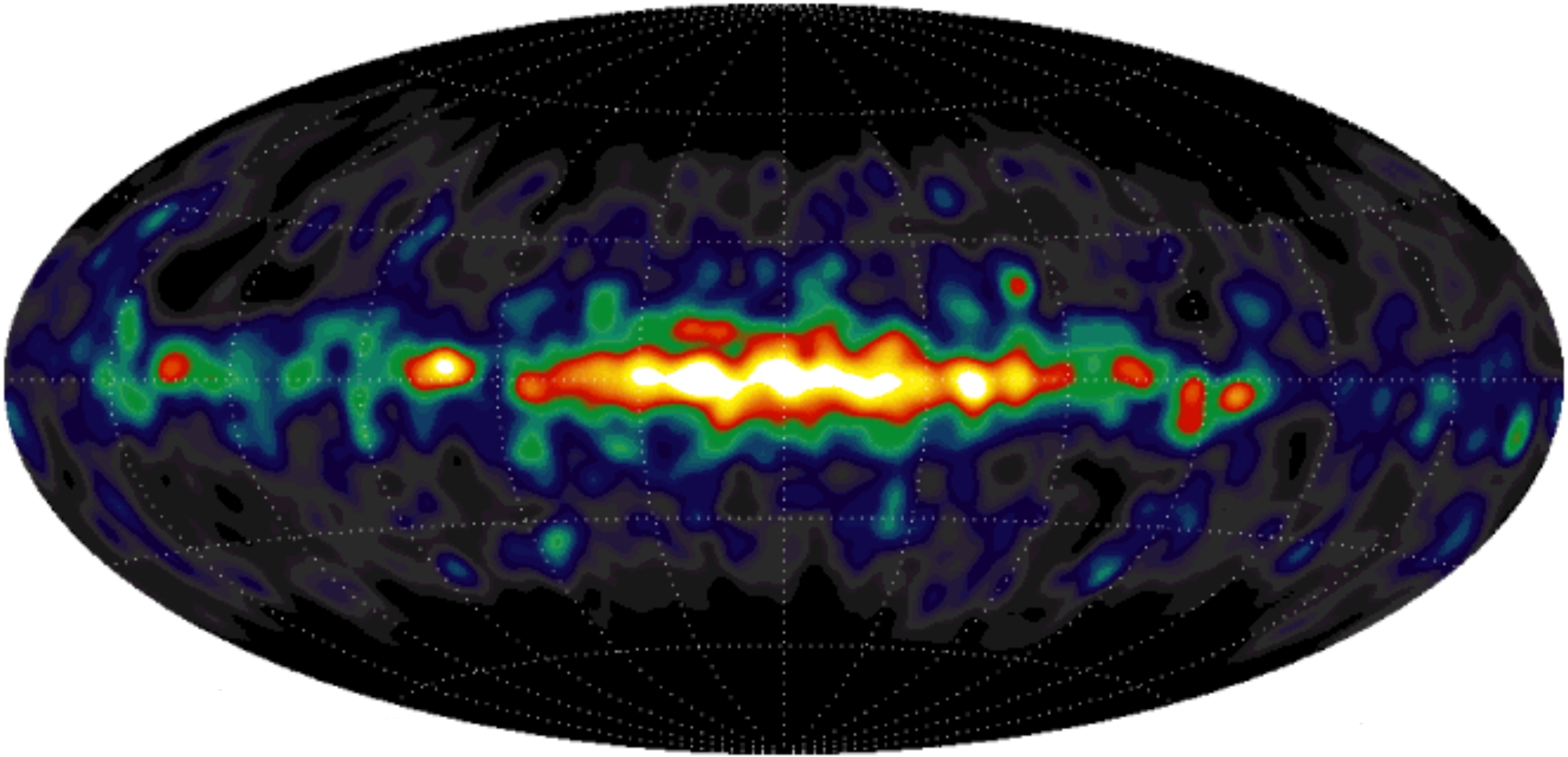


- Intermediate Missions: Fermi, NuSTAR and now COSI
- MIDEX and SMEX: Swift and NICER
- Technology: a robust technology development program (SiPMs, new scintillators, upgraded silicon detectors, etc)
- Balloons (+ CubeSats!): long duration balloons enabled COSI, LEAP, etc.
- Data Analysis & Theory: mainly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

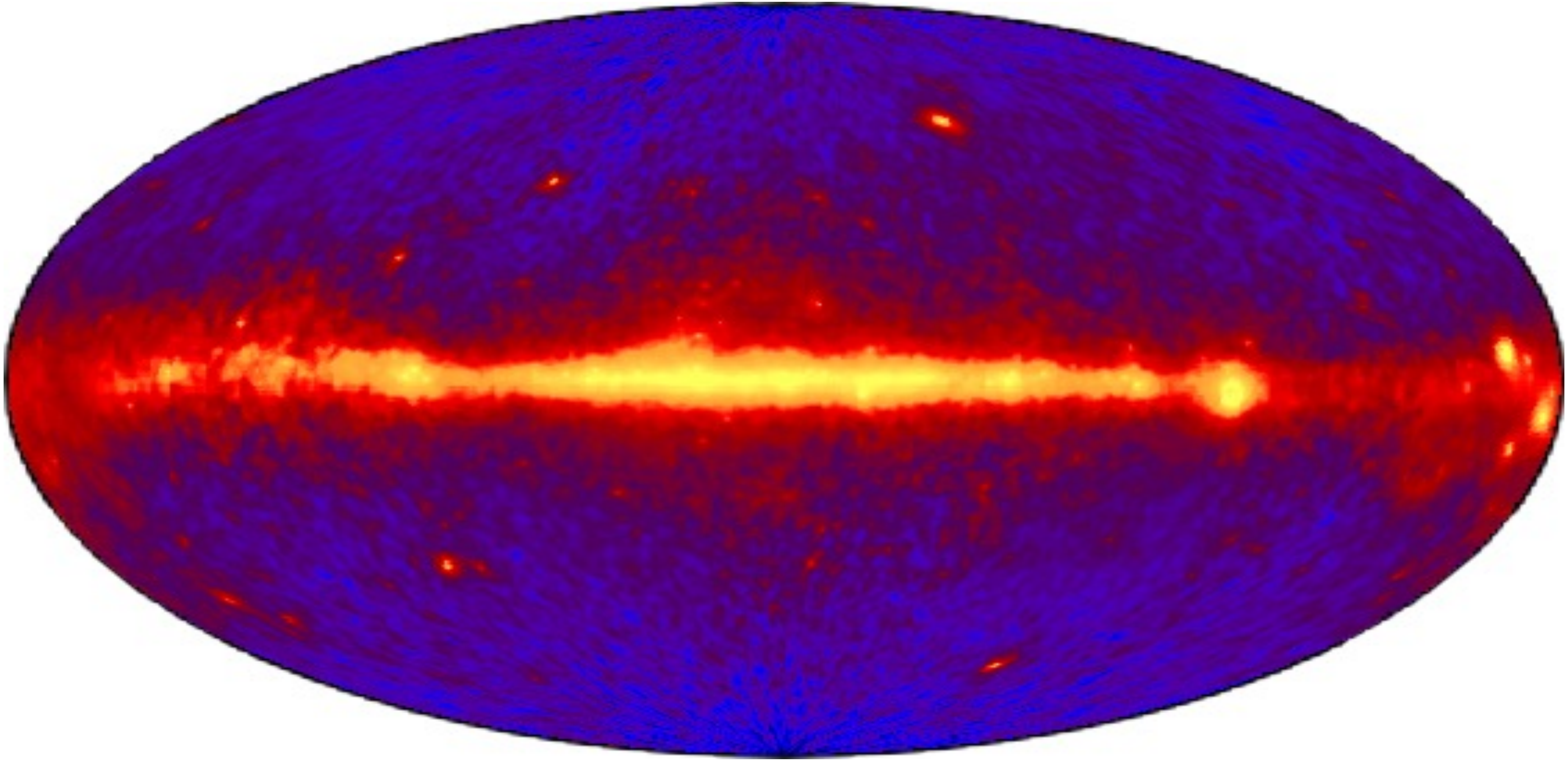
Adapted from Regina Caputo's slides, TeVPA 2024



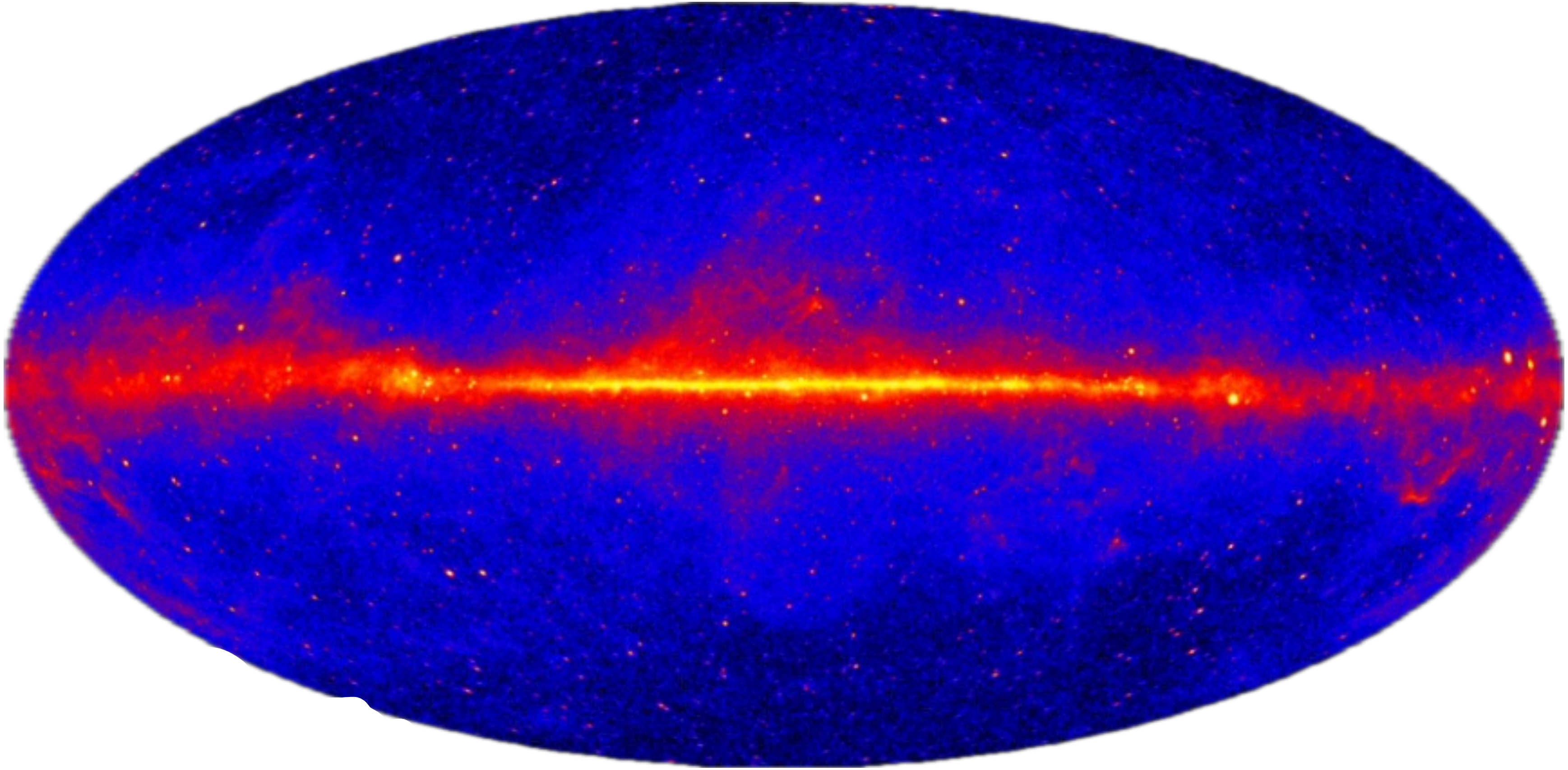
1968, Orbiting Solar Observatory, OSO-3



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

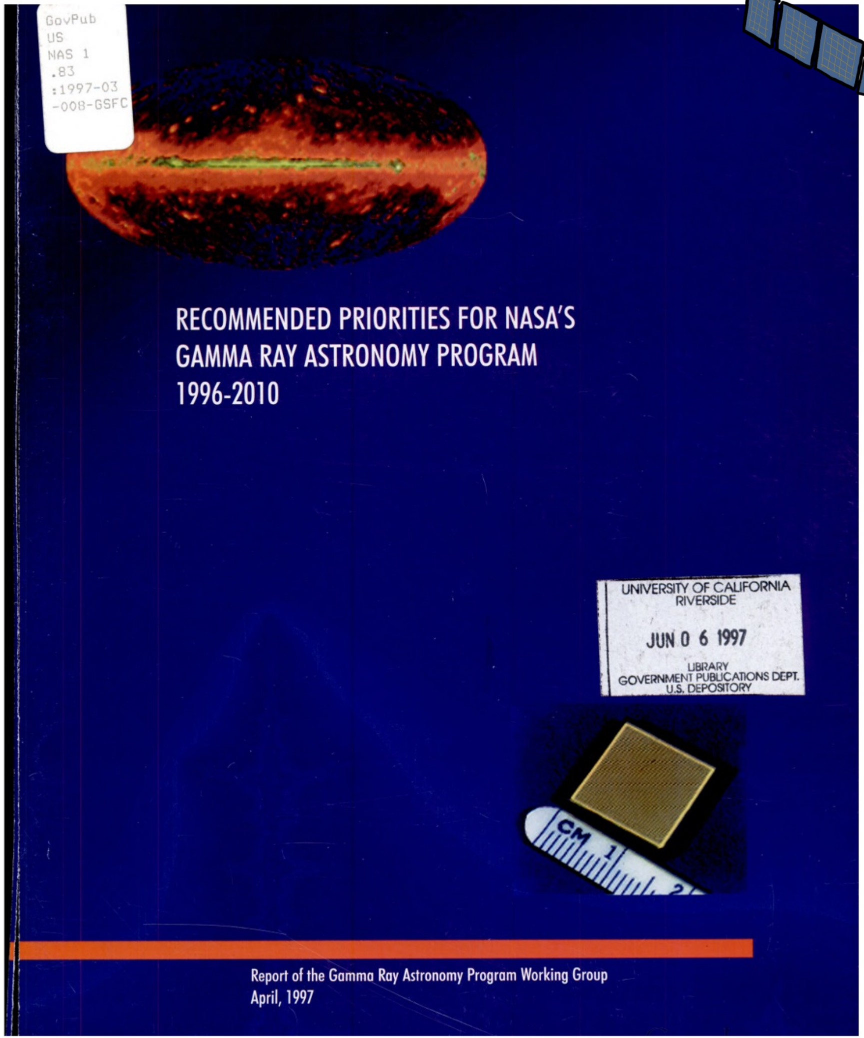


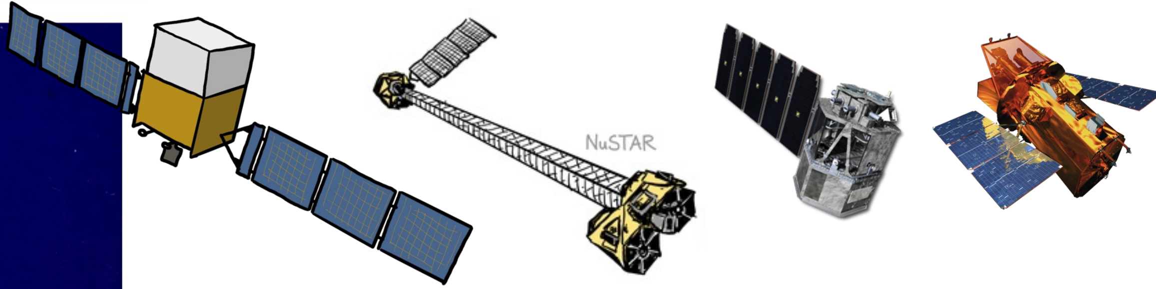
2000, EGRET (onboard CGRO), above 100 MeV



2000, LAT (onboard *Fermi*), above 500 MeV

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





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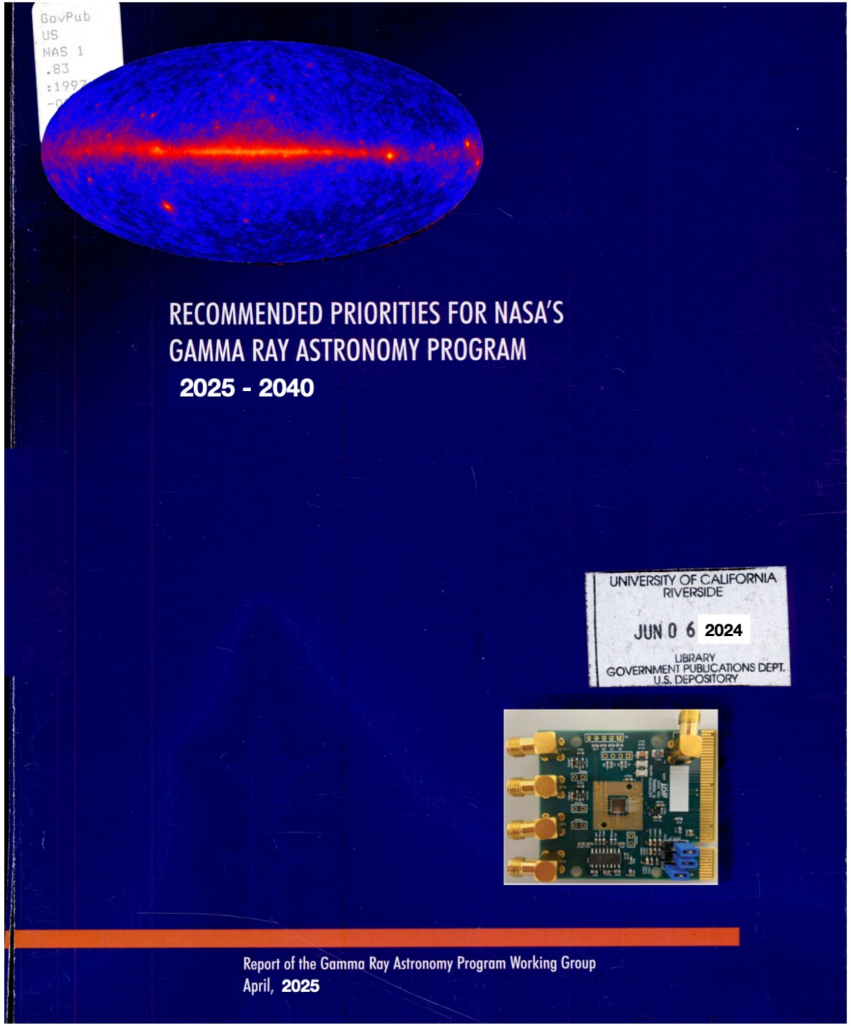

RECOMMENDED PRIORITIES FOR NASA'S
GAMMA RAY ASTRONOMY PROGRAM
2025 - 2040

Report of the Gamma Ray Astronomy Program Working Group
April, 2025

[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.

How to convey the importance of gamma-ray astronomy?

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multimessenger
astronomy

How to convey the importance of gamma-ray astronomy?

multimessenger astronomy

multiwavelength astronomy

How to convey the importance of gamma-ray astronomy?

We risk our message to be:
‘our only importance is in how well we support other subfields’

How to convey the importance of gamma-ray astronomy?

We risk our message to be:
'our only importance is in how
well we support other subfields'

We should not expect
that any mission will be
funded *primarily* due to
its ability to support
other facilities.

It is strategically important to define

gamma-ray science

in terms of

gamma-ray science

Monthly Virtual Meetings

February 29	Gamma-ray Science Priorities zoom
March 21	Theory/Modeling/Analysis/Fundamental Physics Needs zoom
April 25	Technology Investment zoom
May 30	Gamma-ray Mission Capabilities zoom
June 24 – 28	FIG SAG Workshop at Michigan Tech *(in-person)*
August 1	Workshop Summary and Report zoom
August 22	Technology Missions and Capabilities zoom

Meeting structure

- 90 min total on Zoom
- All-group discussions (recorded) combined with breakout sessions (not recorded) for more in-depth discussions – or presentation by experts in the field
- Notes and Summaries available after the meeting

Meeting 1: Gamma-ray Science Priorities

Document Structure:

- General Information & Resources
- Science Topics Summaries:
    - Nature of Dark Matter/Dark Energy
    - Formation and Merging of Supermassive Black Holes
    - Origins of Heavy Elements in our Galaxy
    - Sources of Cosmic Ray Accelerations
    - Existence of Life in Our Galaxy
    - Questions not Included Above

General Information & Resources

Date & Time: February 29, 2026, 1 PM GMT-5, Zoom.
Presentation Slides: Gamma-ray Science Priorities
Video recording: Meeting1_Zoom_recording.mp4
Timeline of the Video recording:
4:30 – 11:50: Welcome & Introduction to FIG SAG
11:50 – 32:00: General Group Discussion
32:00 – 53:40: Breakout session 1 (Only DM & Dark Energy Breakout Room recorded)
53:40 – 1:20:00: General Group Discussion
1:20:00 – 1:44:00: Breakout session 2 (Only DM & Dark Energy Breakout Room recorded)
1:44:00 – end: Concluding remarks

Science Topics Summaries

Nature of Dark Matter/Dark Energy

Link to the notes: Nature of Dark Matter/Dark Energy

Summary: We discuss the future of Dark Matter and Dark Energy searches, focusing on the potential contributions of gamma-ray observations and the synergies between various types of astronomical objects. We discuss the construction of telescopes with better spectral resolutions, such as ~50 eV, that would be able to pin down the 511 eV line and search the substructure of emission lines to identify DM candidates. We also discuss the importance of building a compelling case for gamma-ray research in identifying DM candidates, referencing Fermi's role, and the potential for future observatories about reaching the thermal relic line. We also highlight the importance of integrating the gamma-ray searches within the already-existing and future optical and radio observatories infrastructure to gain a better understanding of DM. We discuss

Overview of Science Priorities Discussion

Nature of Dark Matter/Dark Energy	511 keV emission, thermal relic (or else?), Galactic Center Excess, PSF improvements, GeV polarization to help identification of ALPs
Formation and Merging of Supermassive Black Holes	
Origins of Heavy Elements in our Galaxy	nuclear line datasets; angular resolution
Sources of Cosmic-ray Accelerators	MeV gap, proton transport, energy and imaging resolution, polarization, high-precision timing
Existence of Life in Our Galaxy	techno signatures, biological signatures, host star activity & effects on the habitable zone

Overview of Theory & Simulations Discussion

Plasma Physics Theory & Modeling (Standard Model Physics)	PIC codes, MHD codes, hybrid models. Current models insufficient to explain time-dependent data. Insufficient timing data on AGN/magnetars
Nuclear Modeling & Simulations (Cross sections & Lines)	Combined atomic and nuclear model; gaps in nuclear physics; 511 annihilation line; different nuclear networks get different yields; map from HPC to a phenomenological model; AI for gamma-spectra
Data Analysis & Simulation Methods	Challenges in multimission analysis; GRBs - connecting observational signatures with physical models.
Particle Physics Modeling & Simulations (Beyond Standard Model)	GC excess is tested against rudimentary models of DM; better astrophysical understanding; background worries

… and more …

Science Traceability Matrix

1	2	3	4
		Scientific Measurement Requirements	
Science Goals	Science Objectives	Observables	Physical Parameters

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?

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

AND YOU!

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S… n… and Zora… dias [7]

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

The status of the Draft

Gap between supernova and kilonova Unique proge
neutron star-black hole. New accretion physics. Need binary
Jetted TDEs add to the black hole mass ladder on how
works. Three of have been detected by Swift and these ar
references and more experts to chime in.

1.1.4 Energy resolution

- $< 1\%$ for doppler shifts of nuclear lines - measures velocity (more strict for novae than supernovae)gives the composition of r-process in our galaxy (also needs >10x COSI line sensitivity); structure in diffuse emission - galactic magnetic fields
- $\sim$ 0.01 (Mx < 400 GeV) - DM interaction with SM (be more specific)
- $< 3\%$ for 511 keV & nuclear lines in our galaxy; pion bumps; These could help with understanding the origin of the Fermi Bubbles

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activity and starburst activity

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The following **theoretical needs** were identified:

- Advancement in cosmic-ray (CR) transport codes
- Advancement in 3D modelling of the Galaxy
- Advancement in DM interaction modelling (e.g., self-interactions, interactions with the Standard Model particles, etc.

• surveys - PBHs, A

its profile cuspiness. The following **instrumentation needs** were identified:

- High angular resolution is paramount, with target resolution of approximately arcminutes (Hooper et al. work approximates this roughly, but additional calculations needed.

a 10%

ut 90%

vs 100%?

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

Friday, September 13, 2 pm – 5 pm

Location: Physical Sciences Complex Room 3150
University of Maryland, College Park

General Info

Website	https://pcos.gsfc.nasa.gov/sags/figsag.php
Slack Workspace	https://docs.google.com/forms/d/e/1FAIpQLSfsgnb1OUQ3jISGiIM_3abQsKoHvzlgWBZP3meMXJxUwRHI5w/viewform
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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