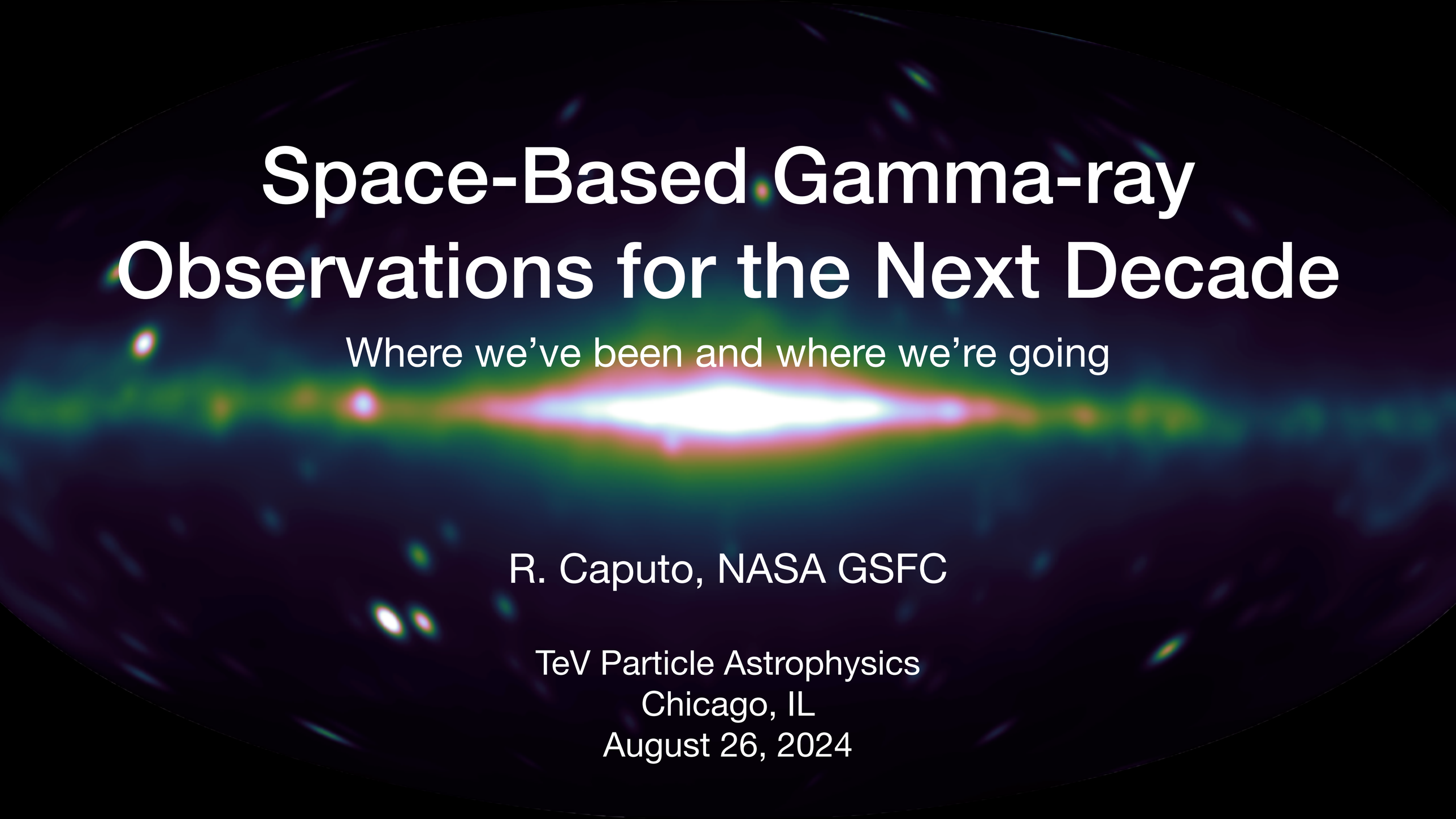


Space-Based Gamma-ray Observations for the Next Decade

Where we've been and where we're going

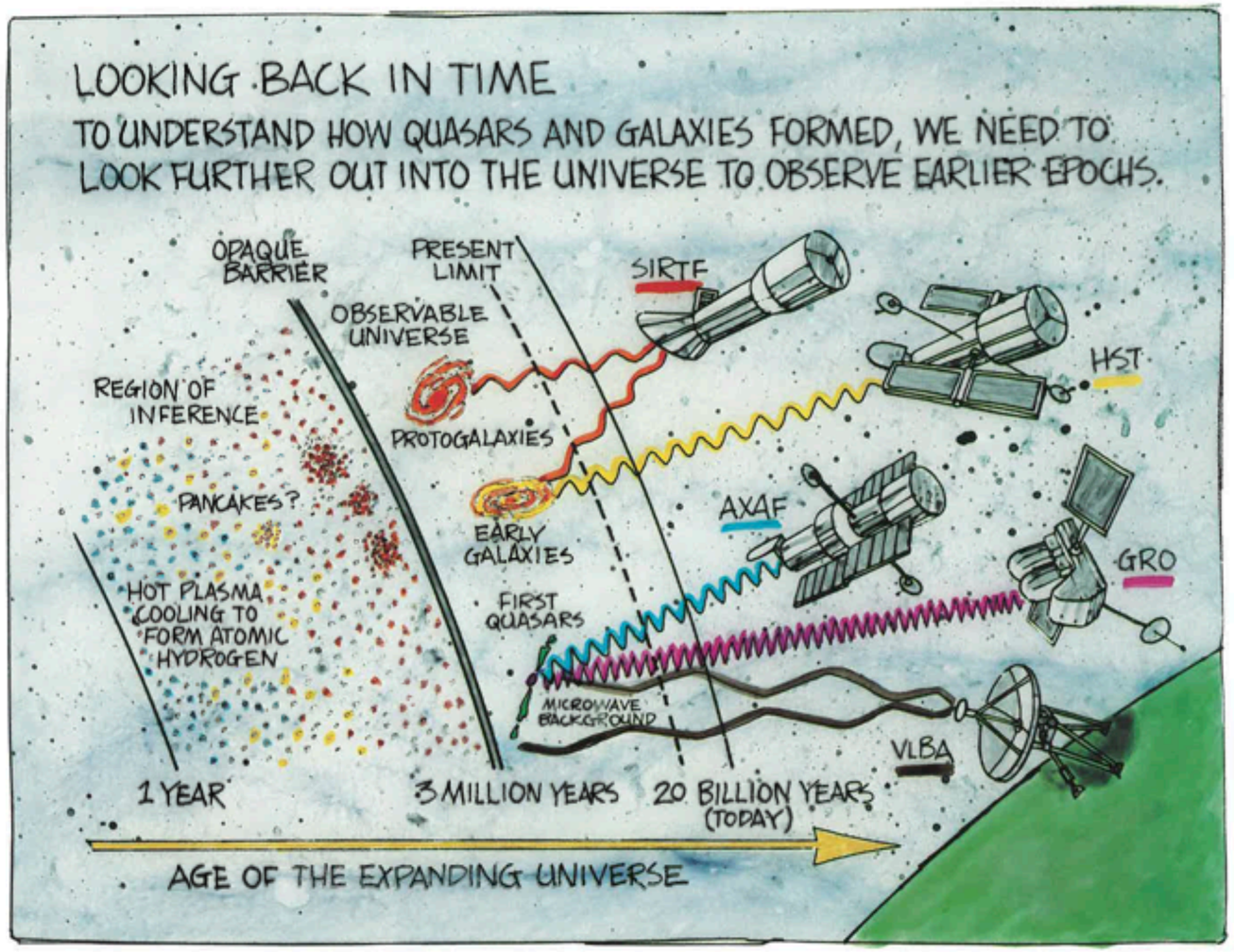
R. Caputo, NASA GSFC

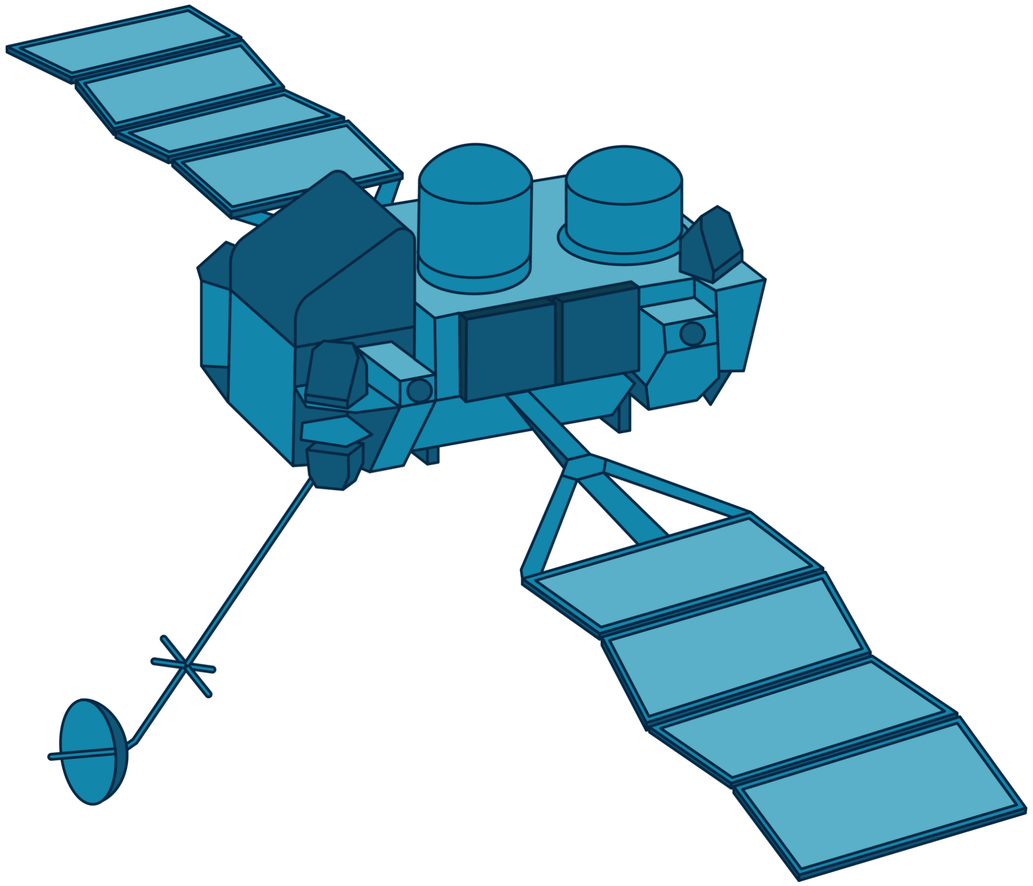
TeV Particle Astrophysics
Chicago, IL
August 26, 2024

Where have we been?*

***Note: this is a NASA Centered perspective ie: US**

Great Observatories Program





Launching from 1990 to 2003

Compton Gamma-ray Observatory

- One of the original **Four Great Observatories.** Launched 1991 and de-orbited in 2000

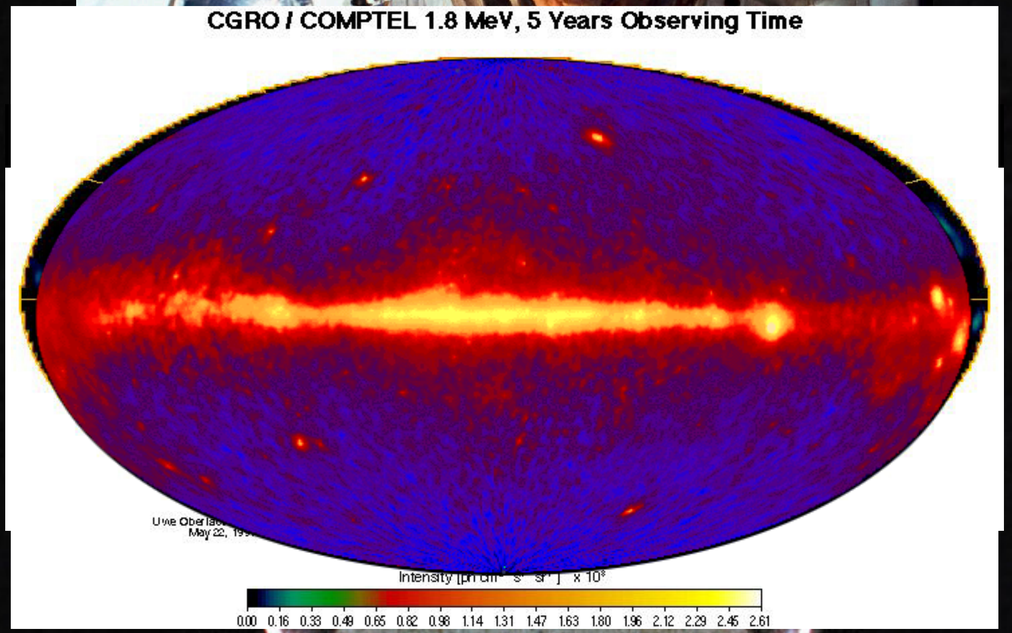
- Four Instruments:

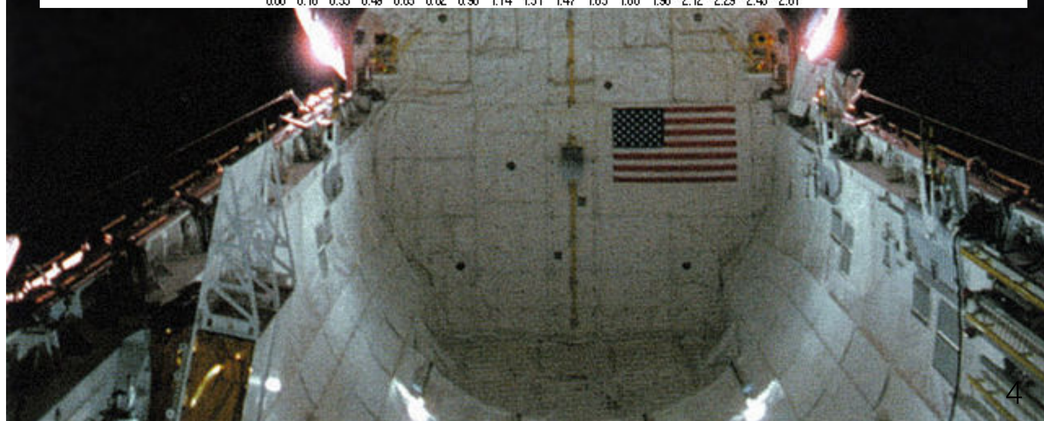
  - The Burst Alert and Transient Source Experiment (BATSE) an all sky monitor 20 keV to 1 MeV

  - The Oriented Scintillation Spectrometer Experiment (OSSE) for the 0.05 to 10 MeV range

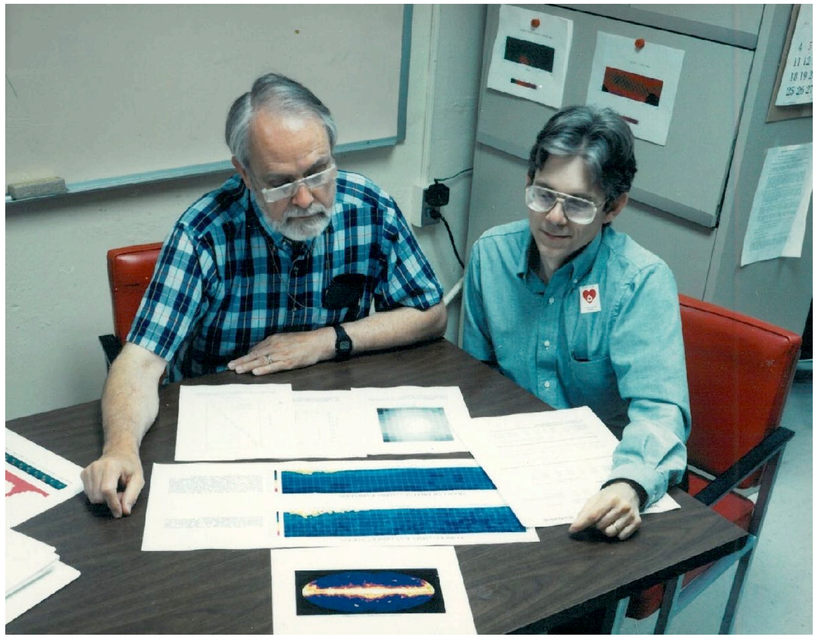
  - The Compton Telescope (CompTel) in the 0.8 to 30 MeV range capable of imaging 1 steradian.

  - The Energetic Gamma-Ray Experiment Telescope (EGRET) in the 30 MeV to 10 GeV range.



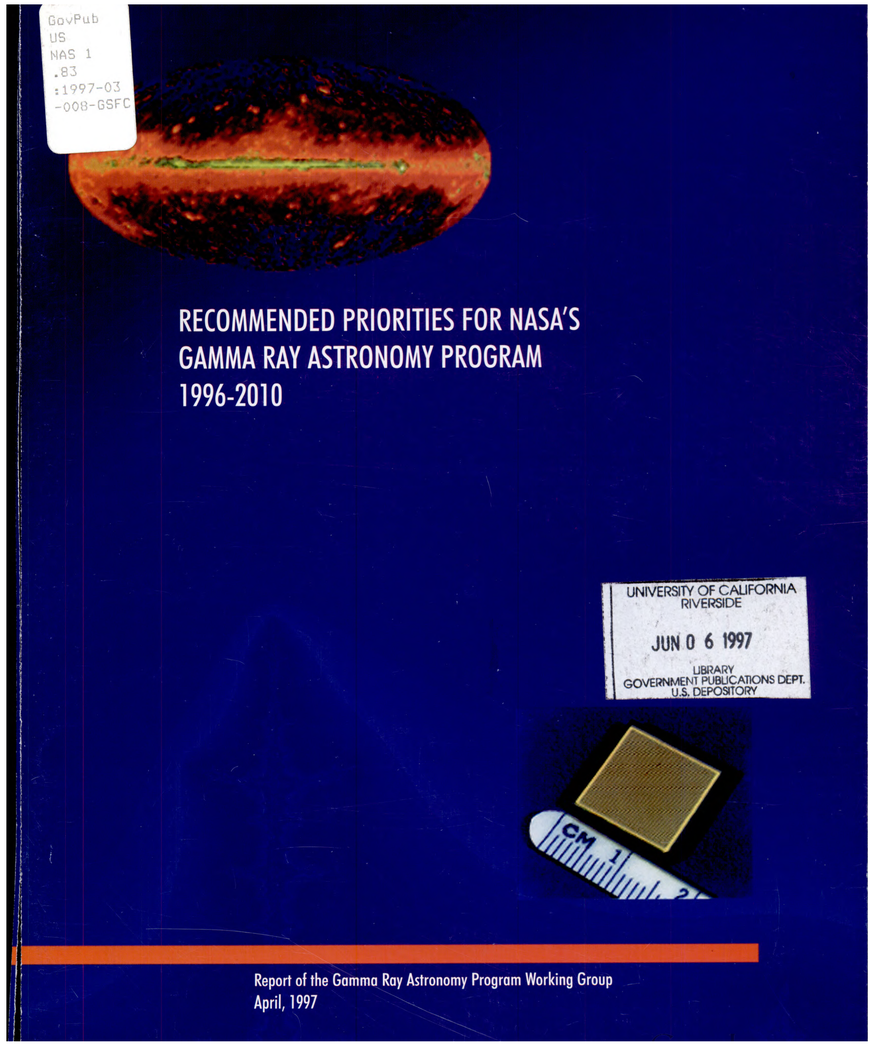


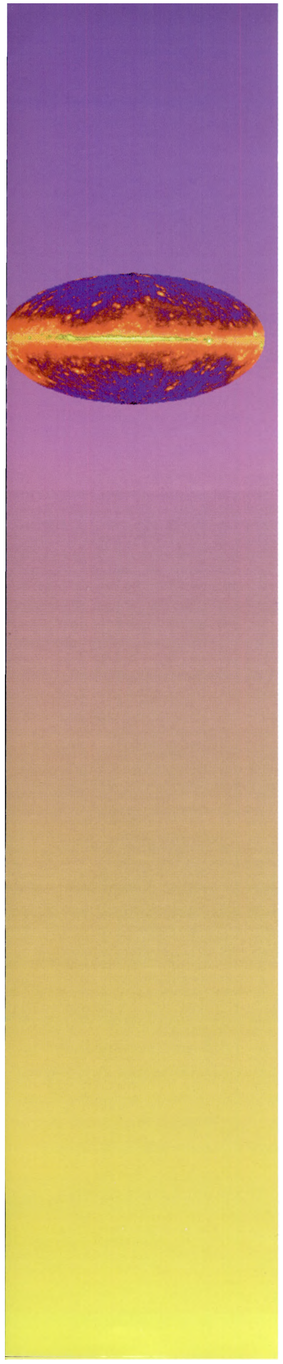
Inspired by the success of CGRO:



Bob Hartman and Dave Thompson working on EGRET in 1993

"The mandate of the working group is to recommend a road map to the future for use as an input to the next NASA strategic plan…"





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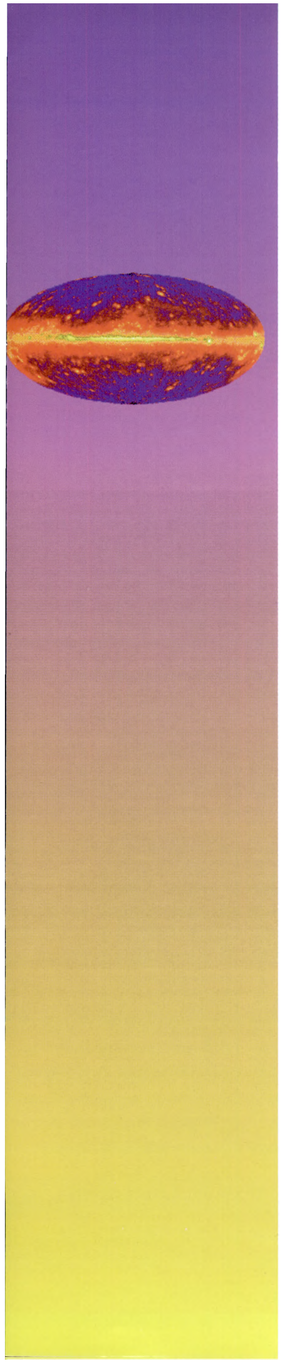

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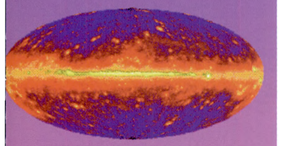

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GAMMA-RAY ASTRONOMY PROGRAM WORKING GROUP MEMBERS:

Elena Aprile (Columbia)
Alan Bunner (NASA) [Ex-Officio (NASA Headquarters)]
Neil Gehrels (GSFC) [Co-Chair]
Jonathan Grindlay (Harvard)
Gerald Fishman (MSFC)
W. Neil Johnson (NRL)
Kevin Hurley (UCB/SSL)
Steve Kahn (Columbia)
Richard Lingenfelter (UCSD)
Peter Michelson (Stanford)
Thomas Prince (Caltech) [Co-Chair]
Roger Romani (Stanford)
James Ryan (UNH)
Bonnard Teegarden (GSFC)
David Thompson (GSFC)
Trevor Weekes (Harvard/Smithsonian)
Stanford Woosley (UCSC)

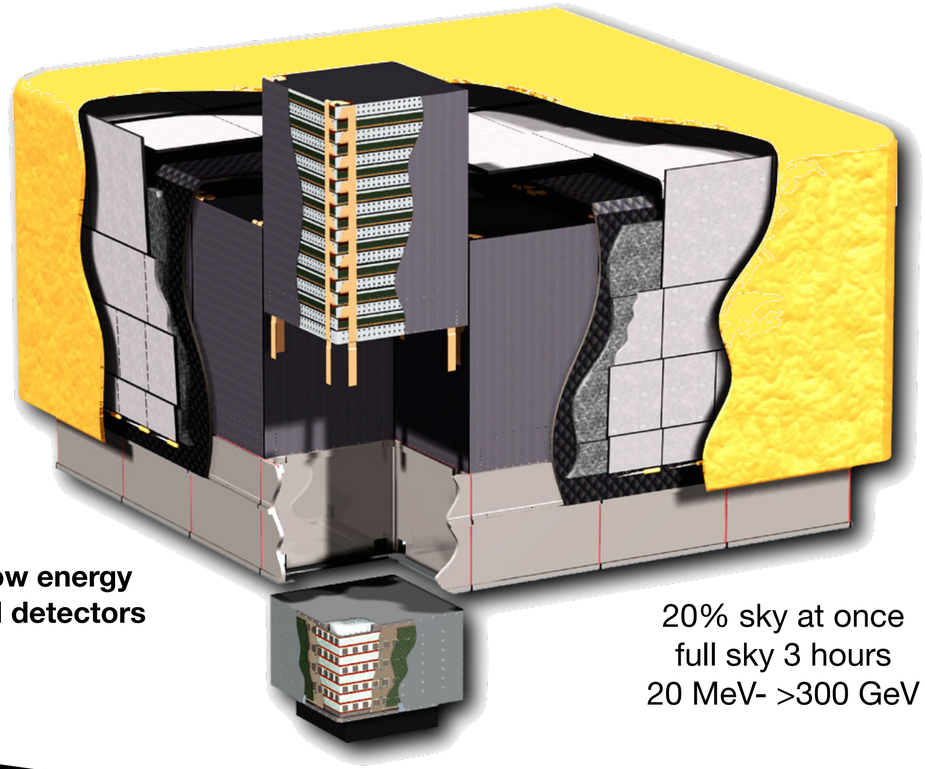
Intermediate Missions

The HIGHEST PRIORITY recommendation is:

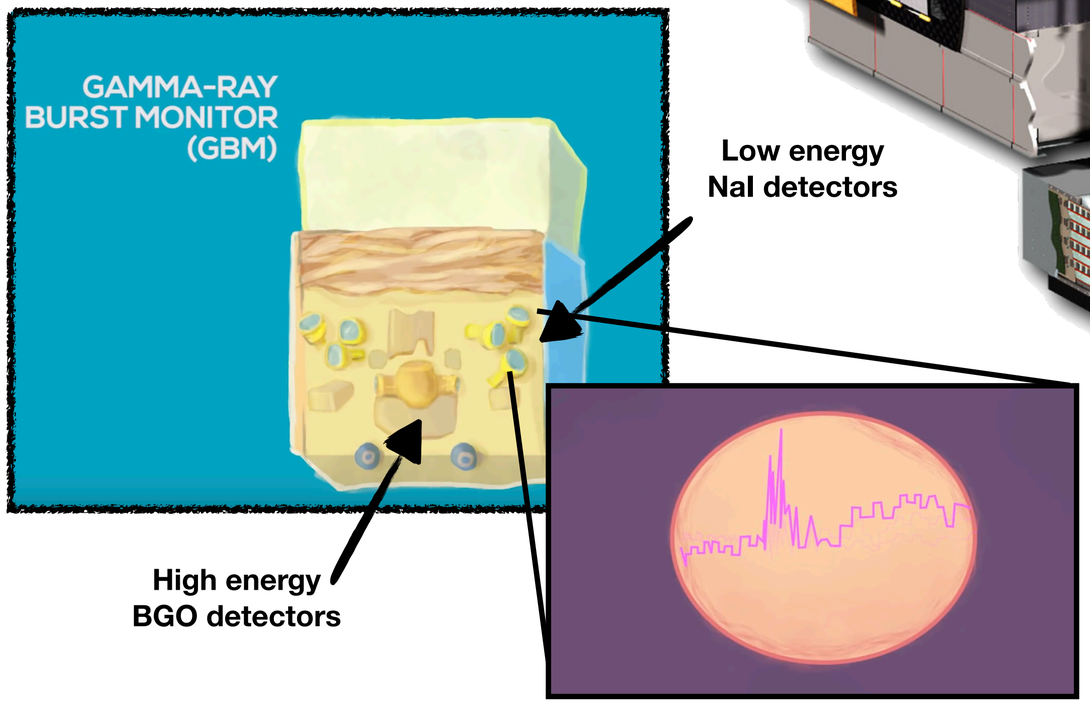
A next generation 10 MeV to 100 GeV gamma-ray mission such as GLAST.
1 to 2 orders of mag improvement in sensitivity compared to EGRET.

Fermi Gamma-ray Space Telescope

Large Area Telescope

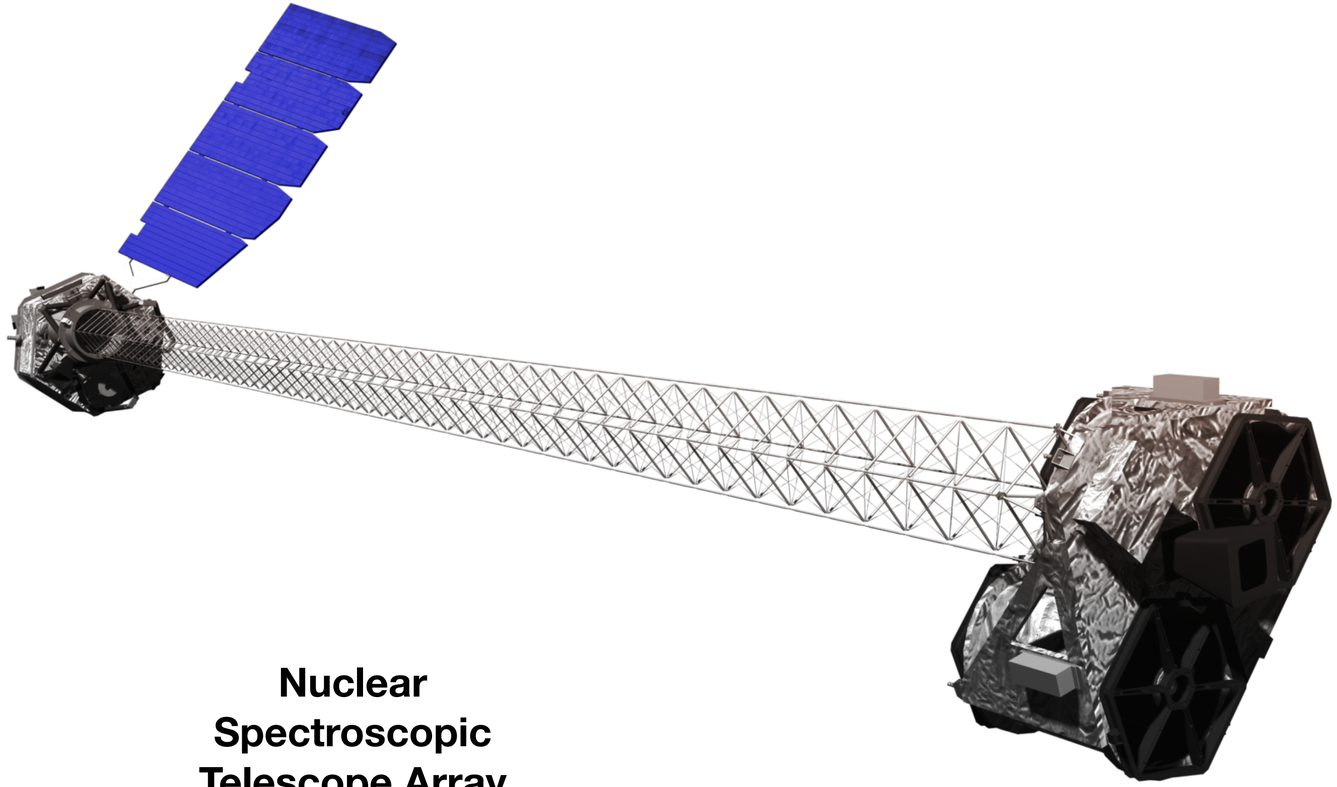


20% sky at once
full sky 3 hours
20 MeV- >300 GeV



full unocculted sky continuous
8 keV - 40 MeV

Intermediate Missions

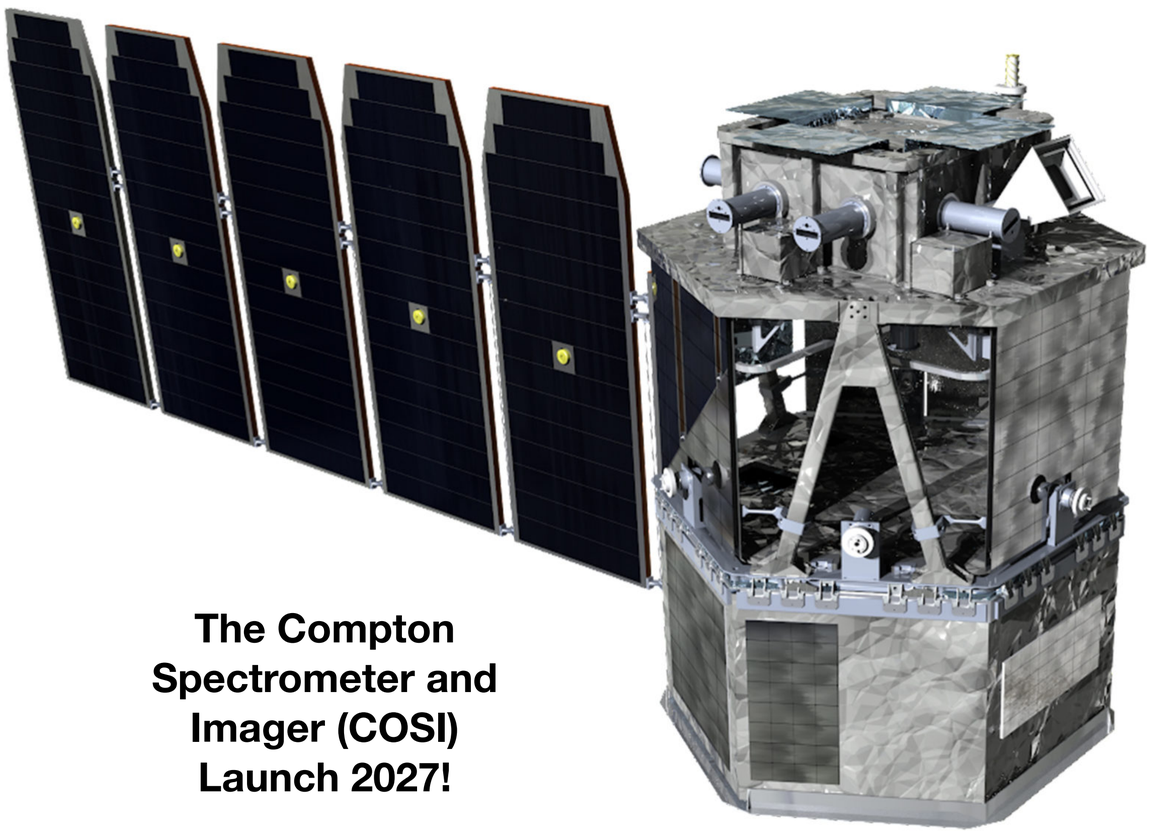


Nuclear Spectroscopic Telescope Array (NuSTAR) launched 2012

Another very-high priority:

A Focusing Hard X-ray Telescope.

Intermediate Missions



The Compton Spectrometer and Imager (COSI) Launch 2027!

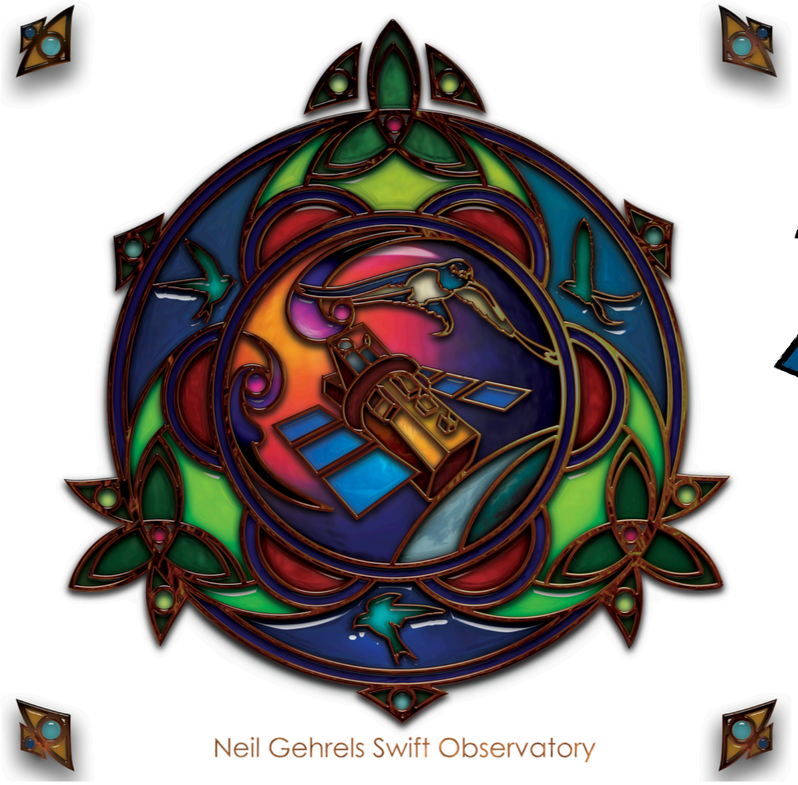
The second very-high priority:

A next-generation nuclear line and MeV continuum mission. A major step forward compared to INTEGRAL in both sensitivity and energy range.

More info: https://science.nasa.gov/mission/cosi/

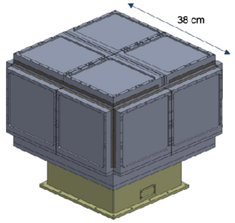
Participate in the COSI 2nd data challenge: https://github.com/cositools/cosi-data-challenge-2

MIDEX and SMEX Missions



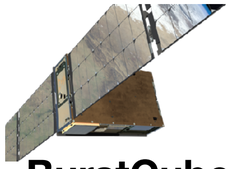
A gamma-ray burst localization mission. Such a mission would address the origin of gamma-ray bursts. Missions with coding apertures or an array of small telescopes would fill this need.

Coming Soon!



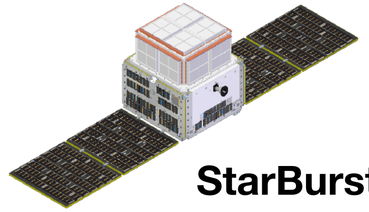
Glowbug

On the ISS



BurstCube

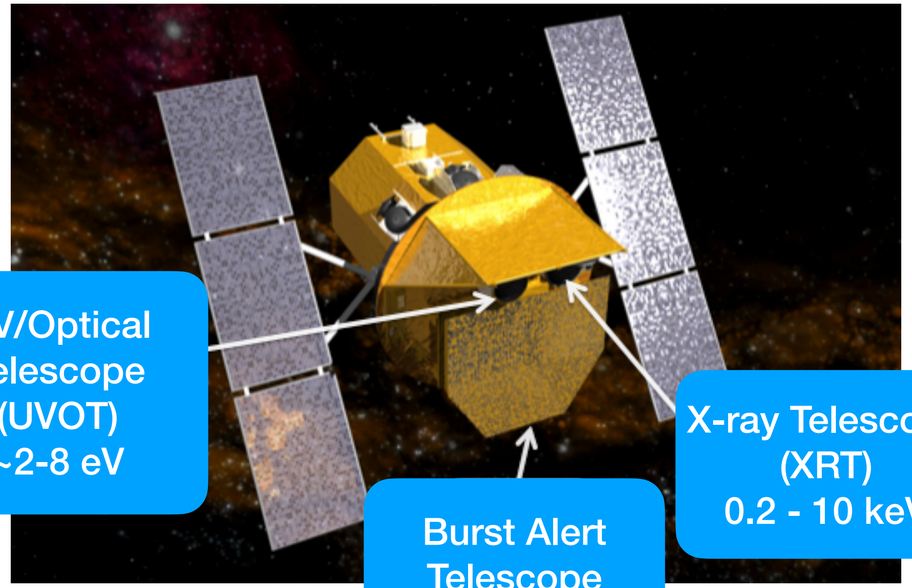
Currently on Orbit

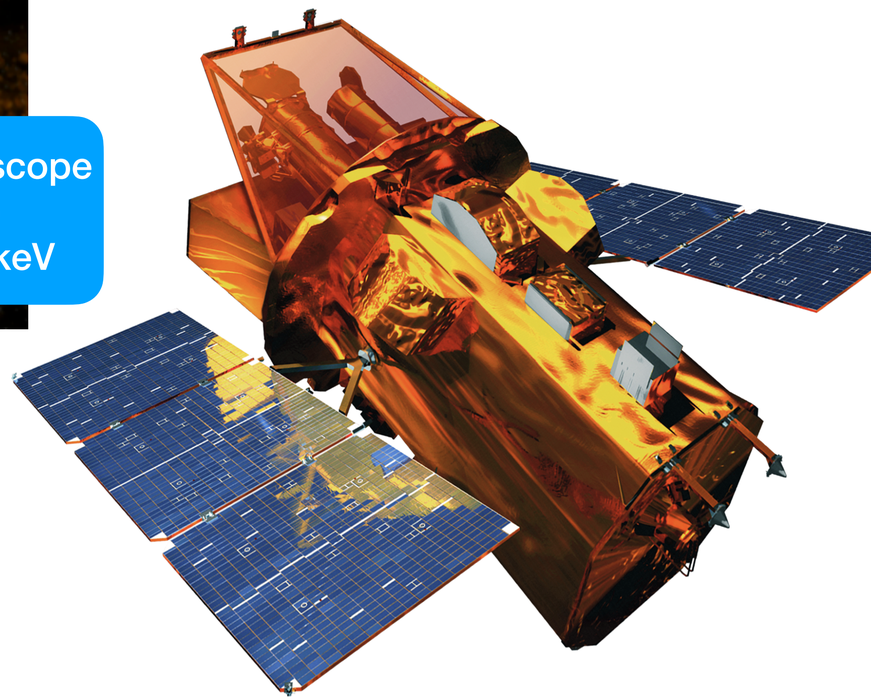


StarBurst

Launch 2025 (?)

Neil Gehrels Swift Observatory





KEY QUESTIONS IN GAMMA-RAY ASTRONOMY FROM 1997

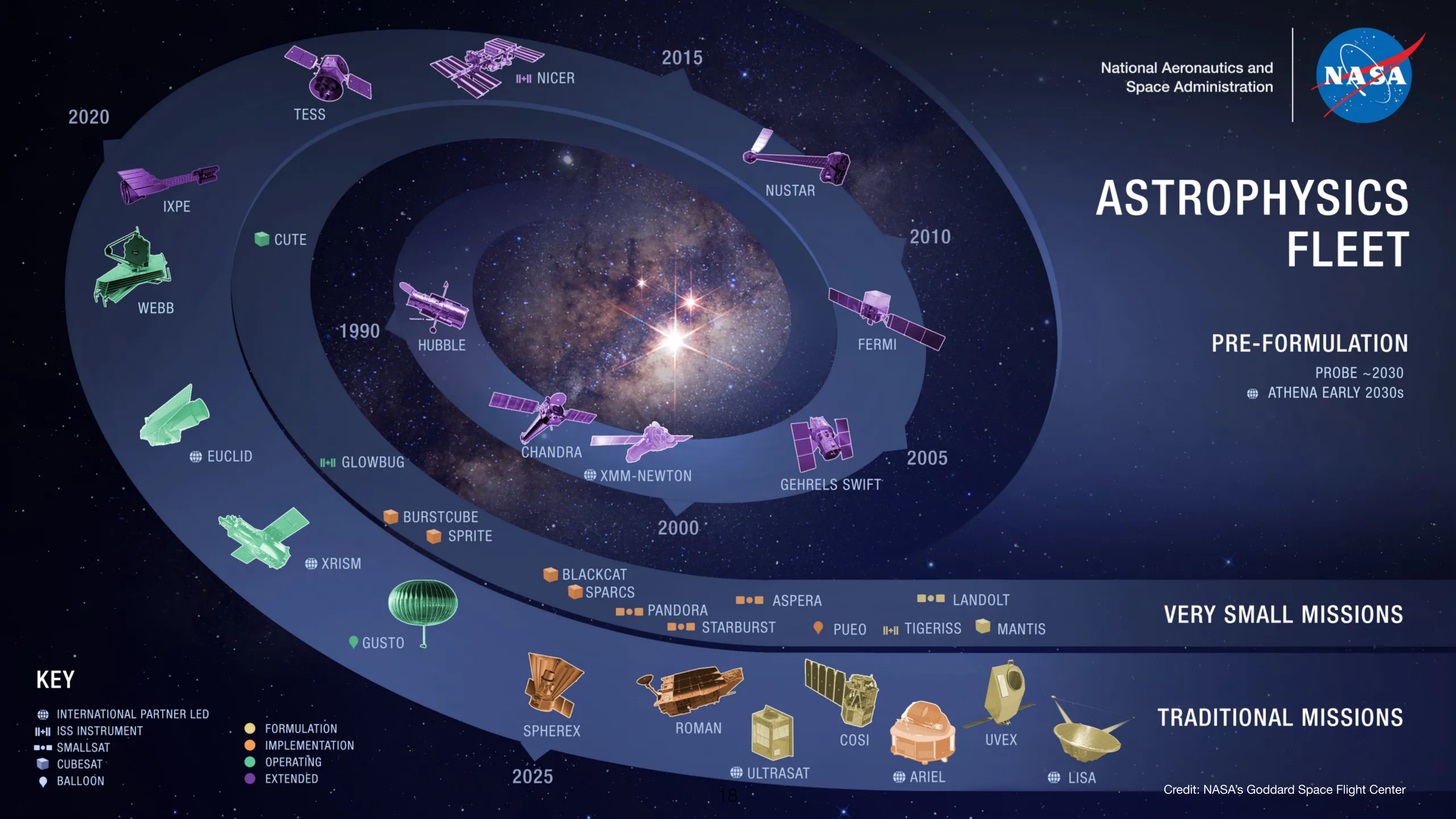
- **What is the origin and nature of gamma-ray bursts?**
- **What are the physical conditions and processes near accreting black holes and neutron stars?**
- **How does matter behave in extreme conditions like those in neutron stars, supernova expulsions and active galactic nuclei?**
- **How do astrophysical accretion processes work and what are their instabilities, periodicities and modes?**
- **What is the nature of the jets emanating from galactic black holes and AGN and how are the particles accelerated?**
- **What is the origin of the diffuse gamma-ray background?**
- **What is the nature of the unidentified high energy gamma-ray sources?**
- **What are the sites of nucleosynthesis?**
- **How do supernovae work? What are the progenitors and explosion mechanisms? What has bene the rate in the last several hundred years?**
- **What and where are the sites of cosmic ray acceleration?**

Why did they recommend these missions?

- They developed a series of **Key Science Questions** that pointed to the need for this diverse set of missions.
  - Lesson: Lead with the Science
  - Lesson: Don’t shy away from the big problems
  - Lesson: Make strong/bold recommendations
- Many of these questions are still open but we have made significant progress.

’97 Report Checklist

- ✓ Intermediate Missions: Fermi, NuSTAR and now COSI
- ✓ MIDEX and SMEX: Swift and NICER (EXIST in the report)
- ✓ 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.



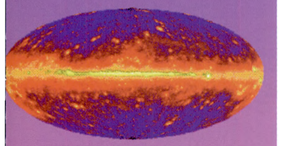
Credit: NASA's Goddard Space Flight Center

Takeaways

- The Gamma-ray sky has been observed by large observatories since 1991 via CGRO and then followed with INTEGRAL, Swift, Fermi, and AGILE
- Gamma-ray observations have enabled huge discoveries over the past ~2 decades and most recently as we have entered the era of multi messenger astrophysics
  - Progress on all fronts of the checklist!
- The next generation of discoveries in astrophysics need all-sky gamma-ray observatories complement CTA, and GW and neutrino observatories

Where are we going?

“The test of a first-rate intelligence is the ability to hold two opposed ideas in mind at the same time and still retain the ability to function.” - F. Scott Fitzgerald



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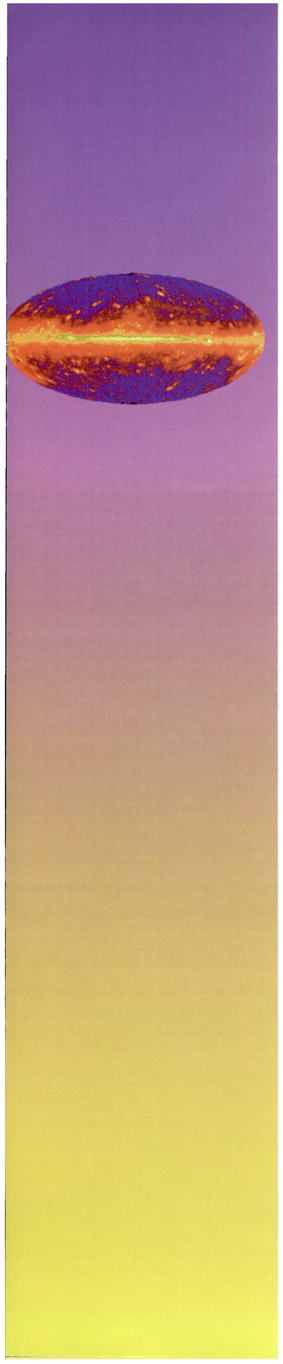

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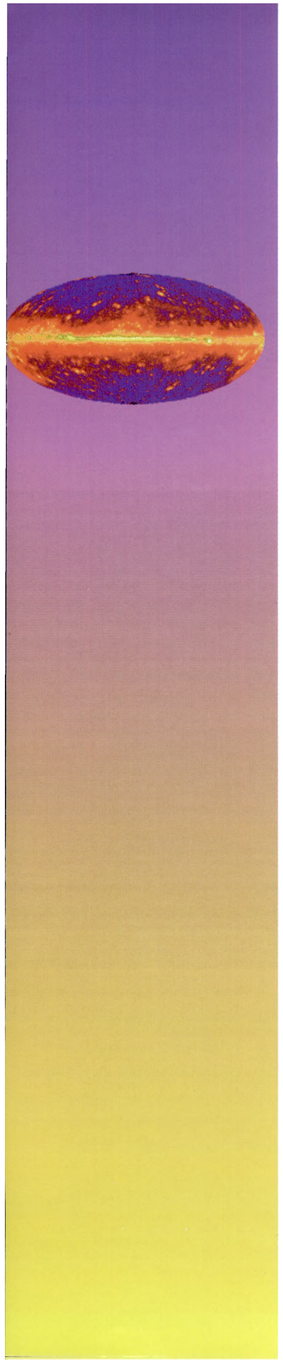


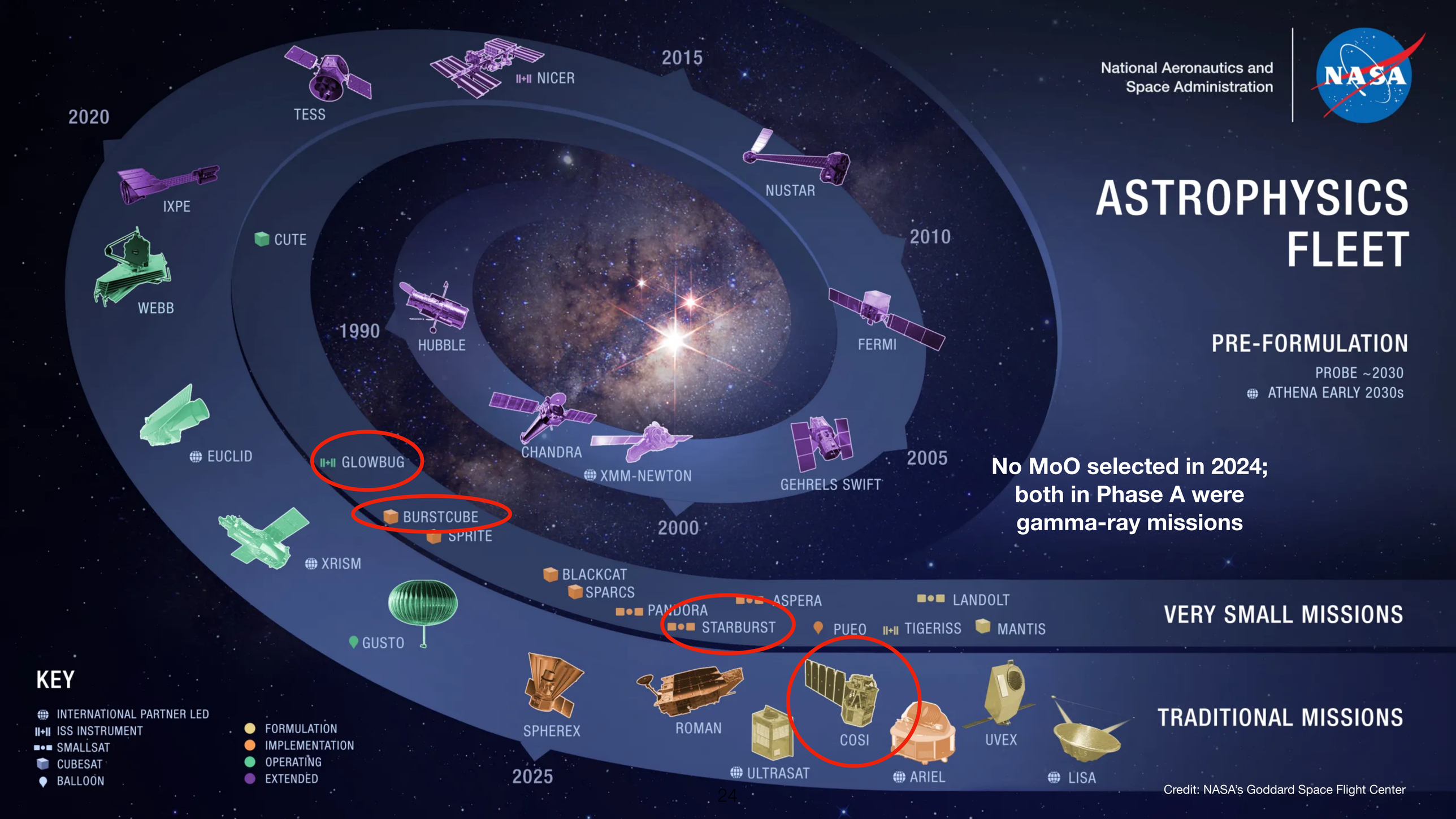
EXECUTIVE SUMMARY

With new results from the Compton Gamma Ray Observatory (CGRO), the Rossi X-ray Timing Explorer (RXTE), and GRANAT, hard X-ray and gamma-ray astronomy are in a period of discovery and vigor unparalleled in their history. The CGRO mission in particular has made fundamental contributions to understanding many classes of galactic and extragalactic objects. The CGRO discoveries of gamma-ray blazars, an isotropic distribution of gamma-ray bursts, bright black hole and neutron star transients, sites of galactic nucleosynthesis, and a large class of unidentified high energy sources have intrigued astronomers and the public alike. These discoveries have prompted a wide range of correlated observations by X-ray satellites and ground-based radio, IR, and optical observatories, adding to our rapidly expanding knowledge of the nature of high-energy emission. We now have the beginnings of a better understanding of the astrophysics of gamma-ray sources, and this in turn has raised fundamental new questions about the origin and evolution of high-energy objects and about the nonthermal astrophysical processes that occur in them.

Looking ahead to the next decade, further discoveries in hard X-ray and gamma-ray astronomy are anticipated with further CGRO and RXTE observations and with the ESA INTEGRAL mission (launch ~2001). However, there are currently no major missions being planned beyond INTEGRAL and none being planned at all by NASA. Of particular concern is the high-energy regime (100 MeV - 100 GeV), where observations will soon come to a virtual halt in the next 2 years as the EGRET instrument on CGRO runs out of spark-chamber gas. Also of concern is the present lack of plans for missions that would 1) significantly improve on the BATSE capabilities to study gamma-ray bursts as well as conduct a full-sky survey and monitor transient source 2) follow-on the first exploration of the MeV band by COMPTEL with much better sensitivity, and 3) continue the important studies of nucleosynthesis begun by balloon instruments OSSE and COMPTEL. From a scientific standpoint, there is an urgent need for new observational missions. From a technical standpoint, the timing is excellent since powerful new detector and imaging technologies are in hand that promise major steps in observational capabilities.

With this in mind, the GRAPWG recommends the following program in hard X-ray and gamma-ray astronomy.

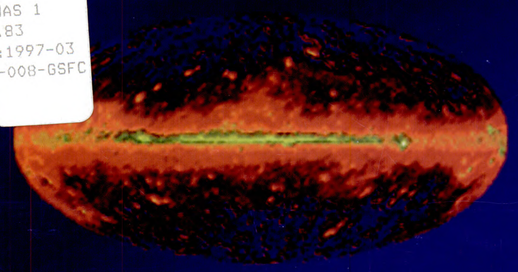
COMPTEL. From a scientific standpoint, there is an urgent need for new observational missions. From a technical standpoint, the timing is excellent since powerful new detector and imaging technologies are in hand that promise major steps in observational capabilities.



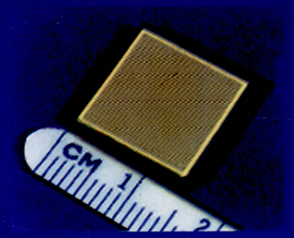
No MoO selected in 2024; both in Phase A were gamma-ray missions

Credit: NASA's Goddard Space Flight Center

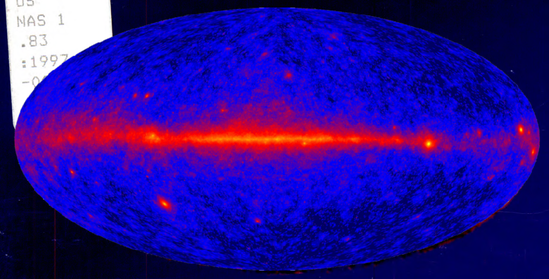
How can we replicate this success?



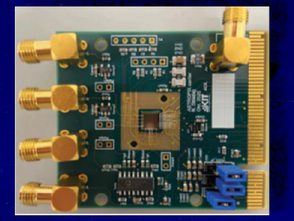
RECOMMENDED PRIORITIES FOR NASA'S GAMMA RAY ASTRONOMY PROGRAM 1996-2010



Report of the Gamma Ray Astronomy Program Working Group
April, 1997



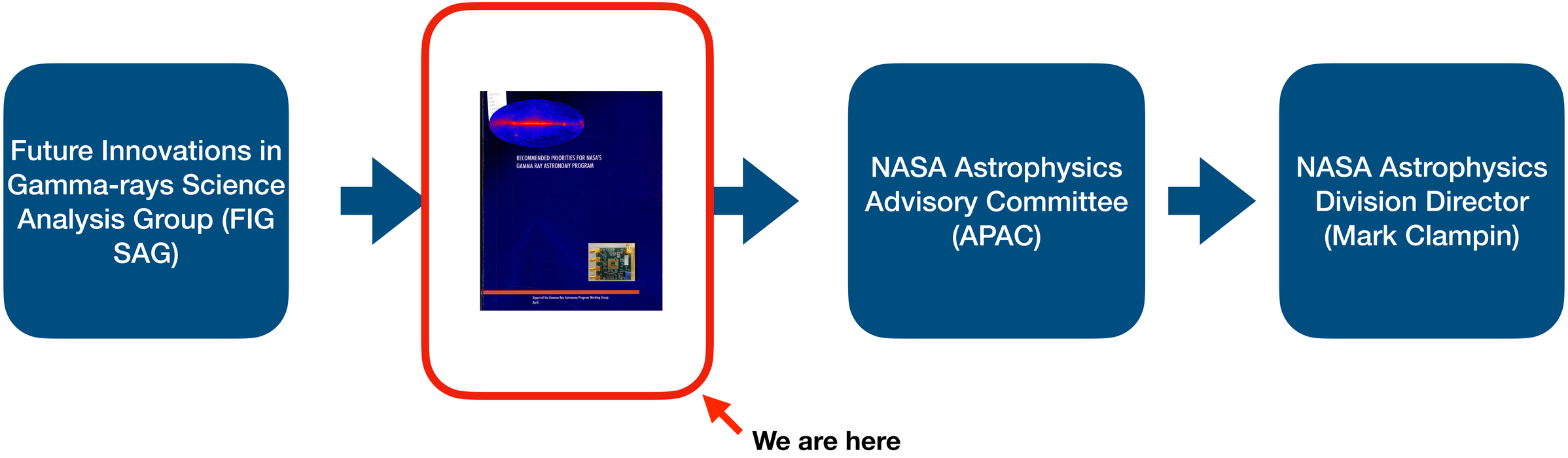
RECOMMENDED PRIORITIES FOR NASA'S GAMMA RAY ASTRONOMY PROGRAM
2025 - 2040



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

Help develop the Roadmap

- Need the world wide gamma-ray, high-energy and multimessenger communities to contribute/provide input



Future Innovations in Gamma-ray Science Analysis Group (FIG SAG)

Astrophysical gamma rays span ten orders of magnitude in energy and capture key physics from a broad range of astrophysical phenomena. This SAG will explore gamma-ray science priorities, necessary capabilities, new technologies, and theory/modeling needs drawing on the 2020 Decadal to inspire work toward 2040.

To get involved and stay informed, please enter your contact information here: https://forms.gle/VBijBgapMRwJm9dU6

Lead Chairs:
Chris Fryer & Michelle Hui

Co-chairs: Paolo Coppi, Milena Crnogorčević, Tiffany Lewis, Marcos Santander, and Zorawar Wadiasingh

Gamma-SIG: https://pcos.gsfc.nasa.gov/sigs/grsig.php
FIG SAG: https://pcos.gsfc.nasa.gov/sags/figsag.php

The FIG SAG report for 2025

- Of course, the ’97 roadmap led to new questions as well. Three key ones that should be included:
  - The report recommended an MeV all-sky mission but that did not materialize <— **we can emphasize that this is still missing from the portfolio**
  - Multimessenger Astronomy is (of course) not mentioned.
    - This report directly led to the advent of MMA (Fermi and Swift)
  - Inclusion, Diversity, and Equity are not mentioned.

Fermi/Swift capabilities are an Astro2020 Decadal priority

Sustaining Programs (Space)

Time-Domain Program (highest priority)

- A program of competed missions and
of opportunity to realize
of capabili
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Probe Li

- Comp
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capabilities– this decade Far-IR and an X-ray complement to Athena
- $1.5 billion/mission, cadence of approx. one/decade

broader set of
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senger program of
robe missions to be
goals. For the
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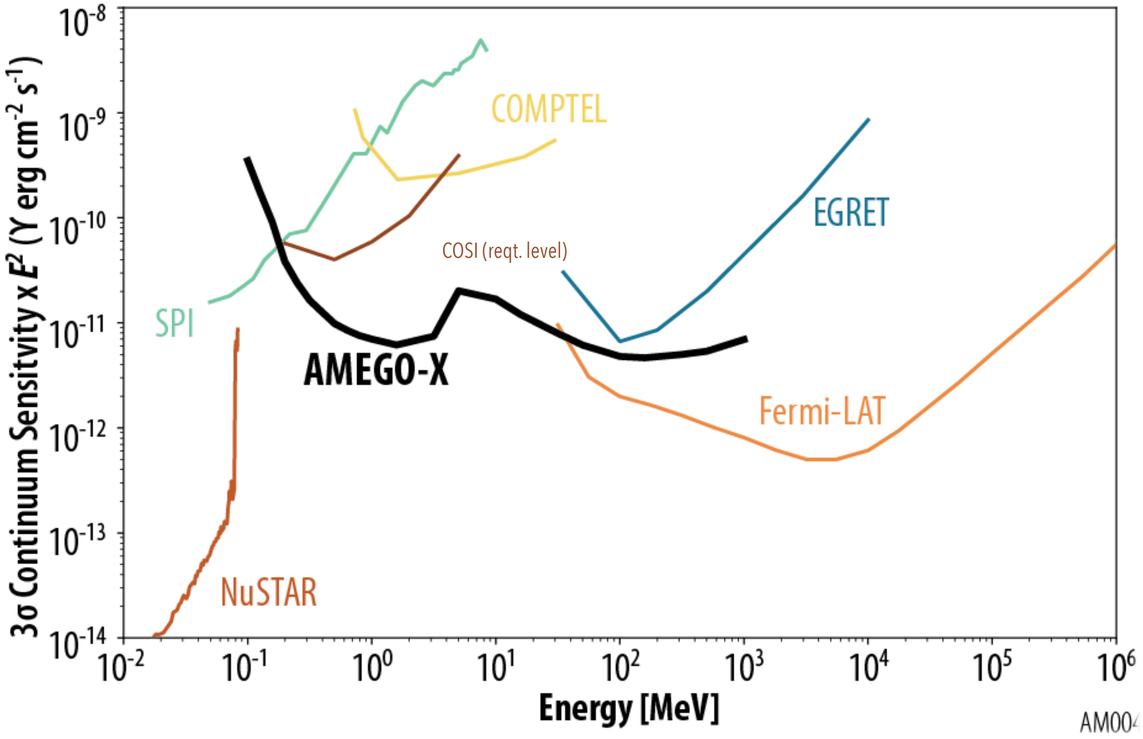
apabilities not possible at the Explorer scale.
compared to a large strategic mission, and a cost cap of
mission per decade is realistic. The selection of a probe mission in
replace the need for a future large, strategic mission. For ground-based projects, the
priority sustaining activity is **a significant augmentation and expansion of mid-scale programs**, including the addition of strategic calls to support key survey priorities. The survey also strongly endorses investments in **technology development for advanced gravitational wave interferometers**, both to upgrade NSF's Laser Interferometer Gravitational-Wave Observatory (LIGO), and to prepare for the next large facility.[5]

Astro2020: New Messengers, New Physics Decadal Priority!

A Telescope for the MeV Gamma-ray Regime

All-sky Medium Energy Gamma-ray Observatory eXplorer: AMEGO-X



AMEGO-X: arXiv:2208.04990
AstroPix: 2302.00101

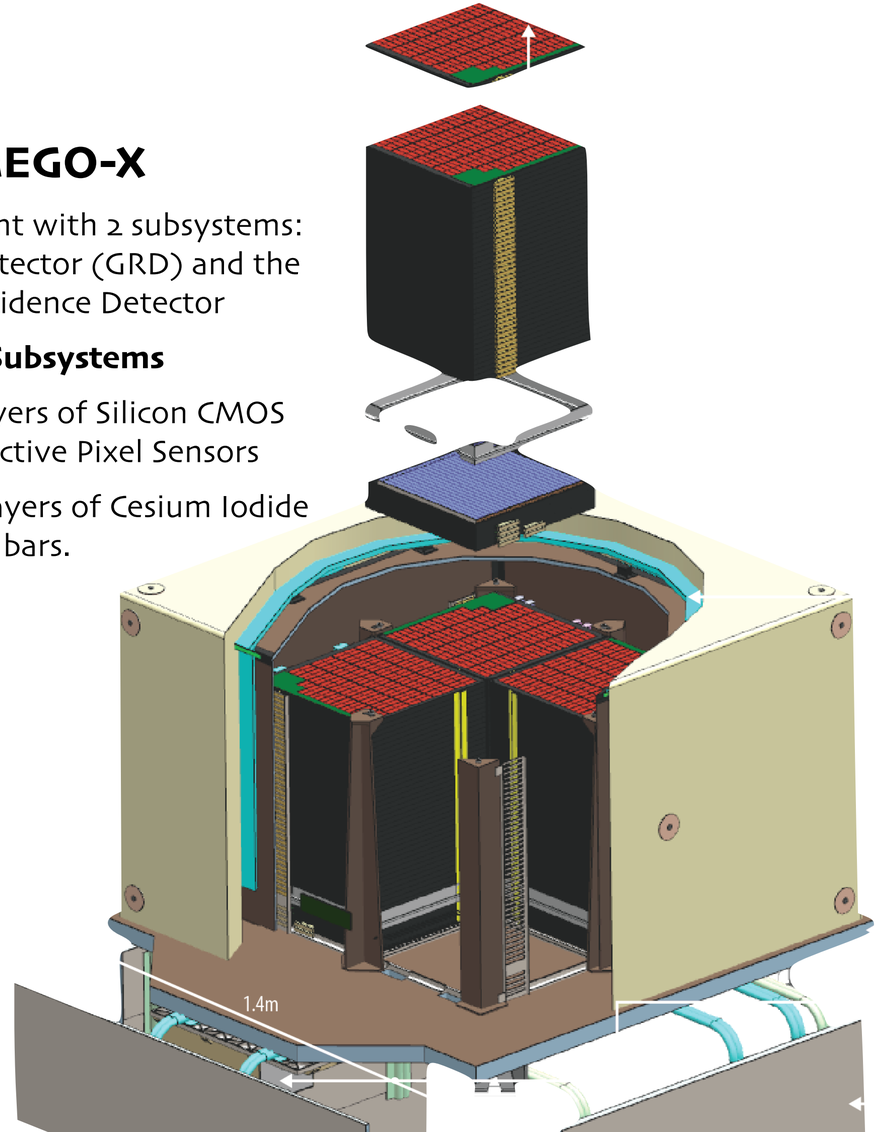
AMEGO-X

Single instrument with 2 subsystems: Gamma-Ray Detector (GRD) and the Anti-Coincidence Detector

GRD Subsystems

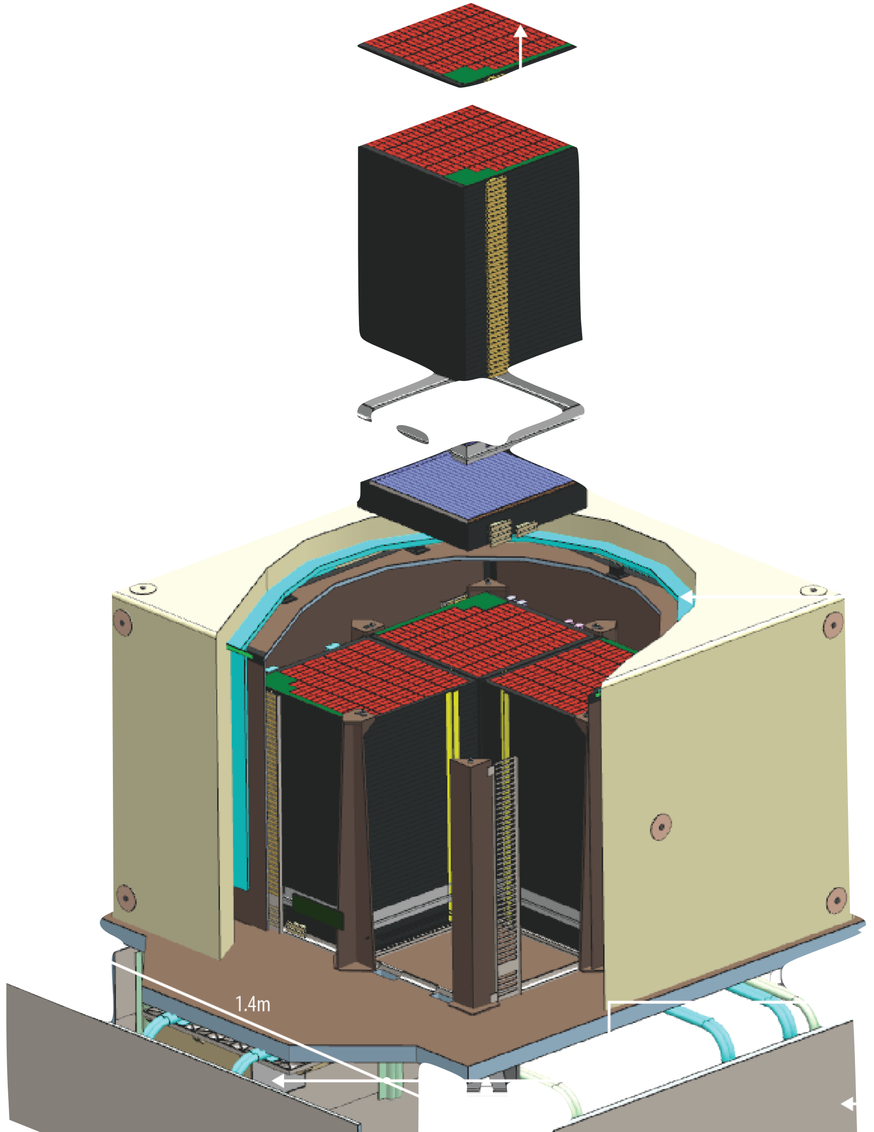
Tracker: 40 layers of Silicon CMOS monolithic Active Pixel Sensors

Calorimeter: 4 layers of Cesium Iodide bars.



AMEGO-X: Status and Plans

- Resubmit in the next MIDEX round (~2027)
  - New folks welcome! (Email me)
  - Important for the science team to keep publishing on the need for MeV instrumentation (we're happy to share sensitivity, effective area, energy/angular resolution etc…)
- Participate in gamma-ray roadmap activities



Friends observing space

- Support Fermi/Swift! Senior review preparation NOW
  - Fermi Symposium in DC area (September 9-13)
  - FIGSAG meeting on Sept 13 (afternoon)
  - Swift@20 in Rome Spring 2025
- Join the Gamma-ray Science Interest Group (GammaSIG)
  - https://pcos.gsfc.nasa.gov/sigs/grsig.php
- Advocate with your own funding agency to support FIG SAG (Gamma-ray Roadmap) and a new Gamma-ray Observatory(s).
- Thanks to the TeVPA organizers!