High Energy Gamma Ray Astrophysics From Space – Experimental Techniques

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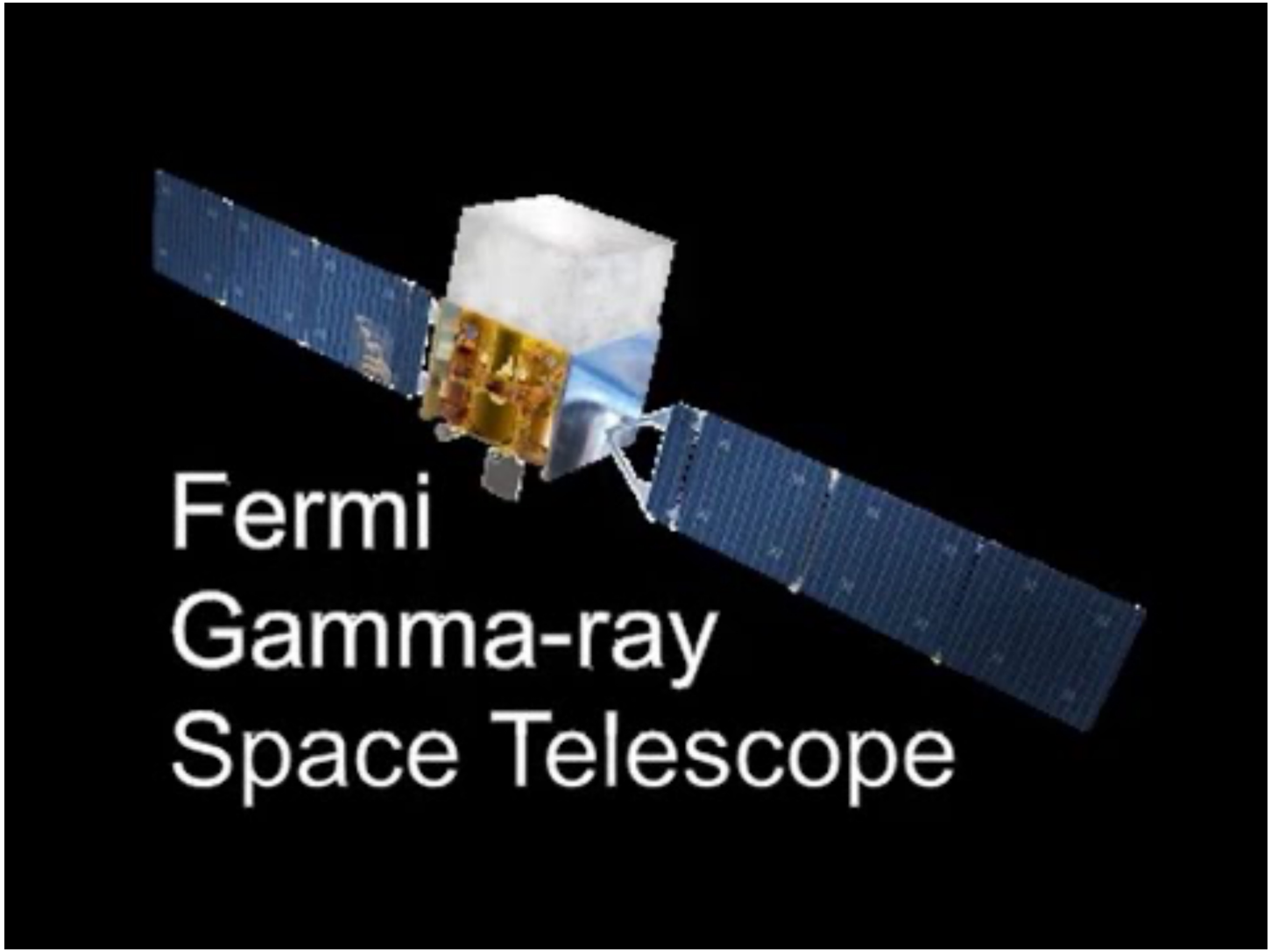
Lecce, June 11, 2025

INFN TRIESTE
Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

UNIVERSITÀ DEGLI STUDI DI TRIESTE

Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

June 11, 2008

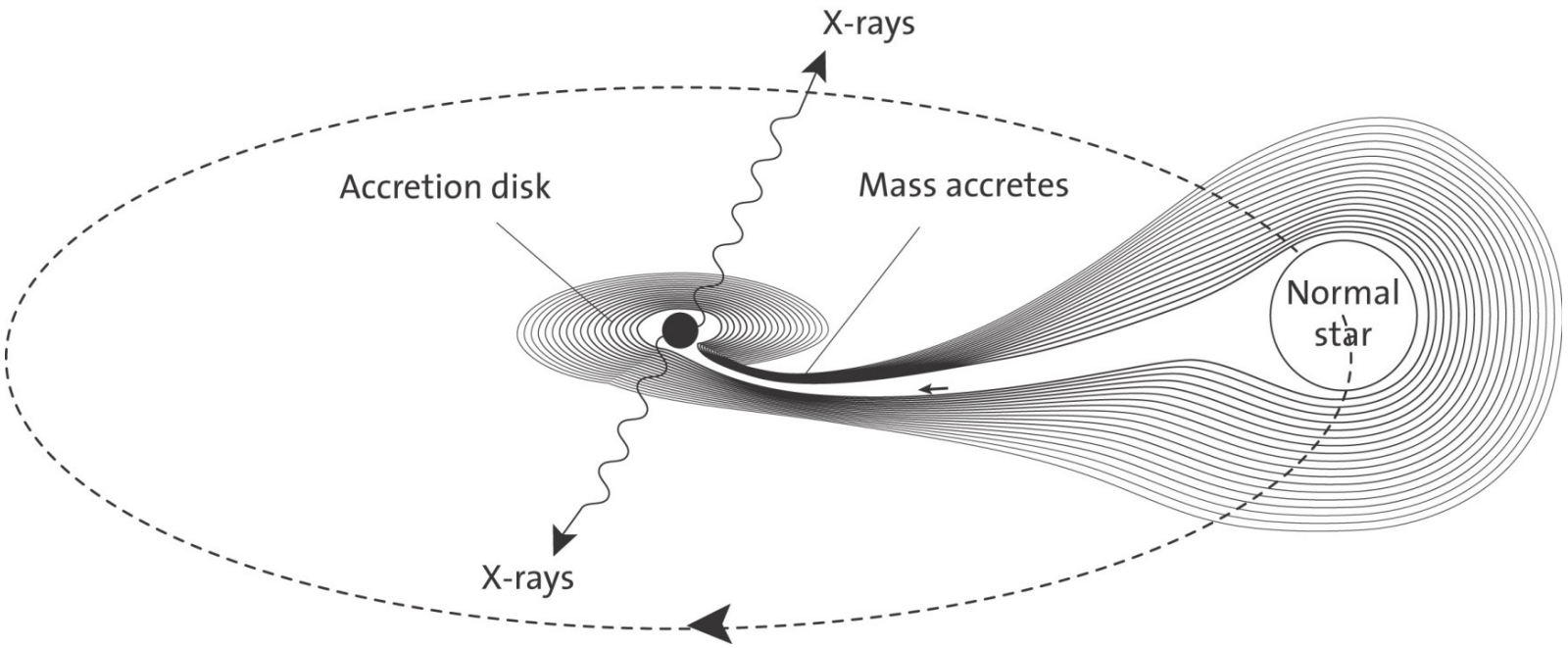


https://www.youtube.com/watch?v=pbrnMtMq9Tc

In memory …

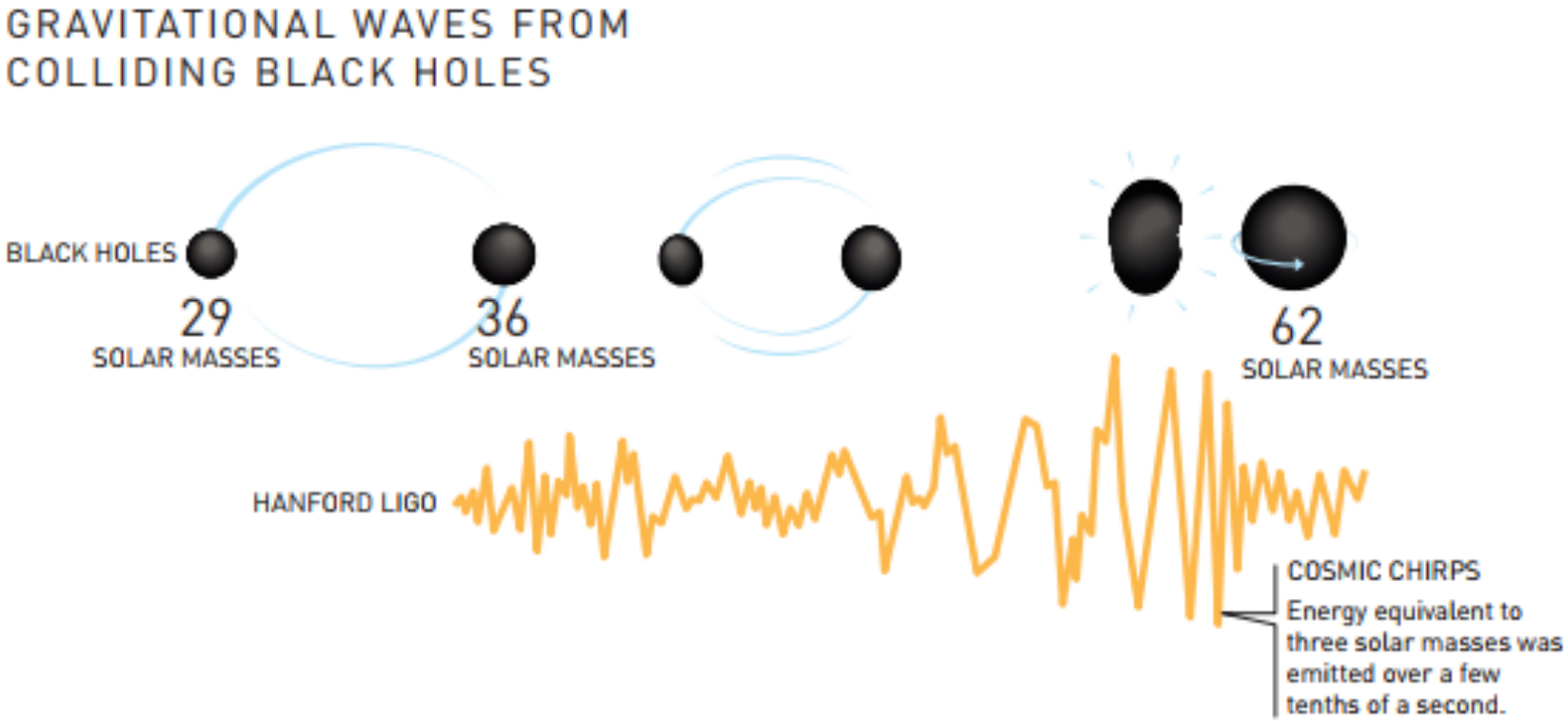
High Energy Astrophysics

- **Nobel Prize 2002:**
  - **Riccardo Giacconi "for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"**



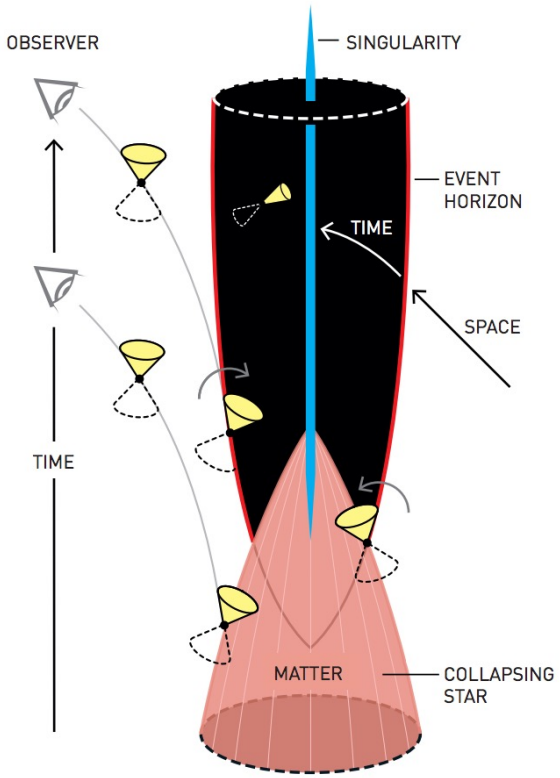
High Energy Astrophysics

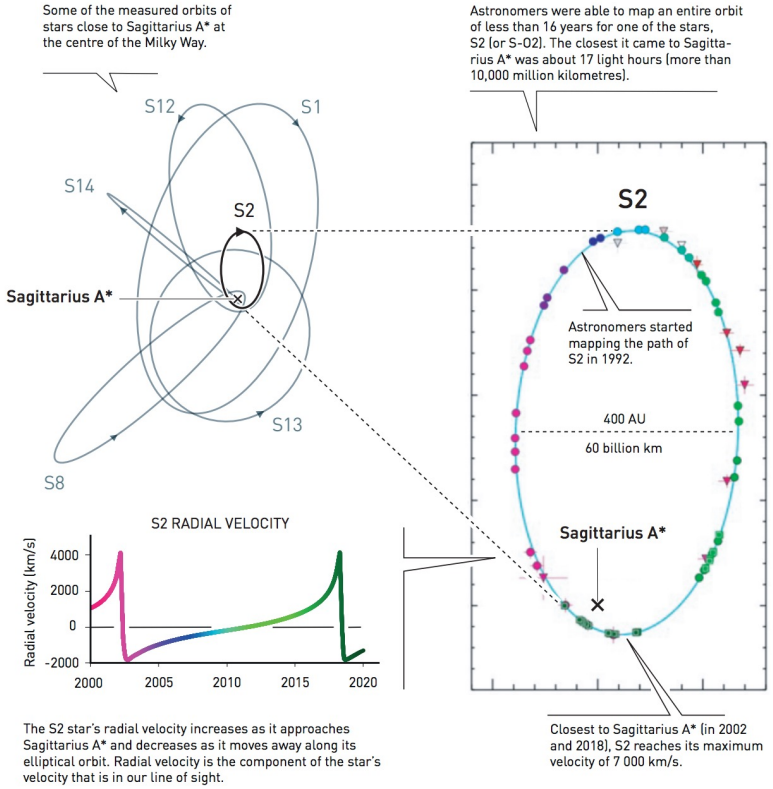
- **Nobel Prize 2017:**
  - **Rainer Weiss, Barry C. Barish and Kip S. Thorne "for decisive contributions to the LIGO detector and the observation of gravitational waves"**



High Energy Astrophysics

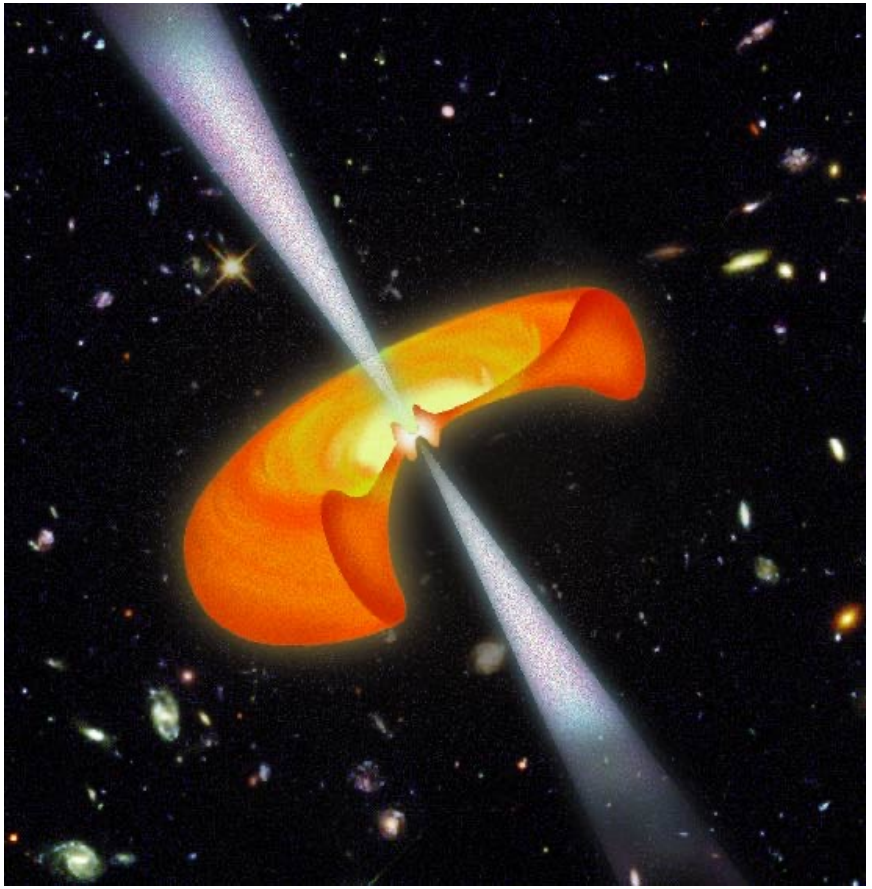
- **Nobel Prize 2020:**
  - **Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity", to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive compact object at the centre of our galaxy."**





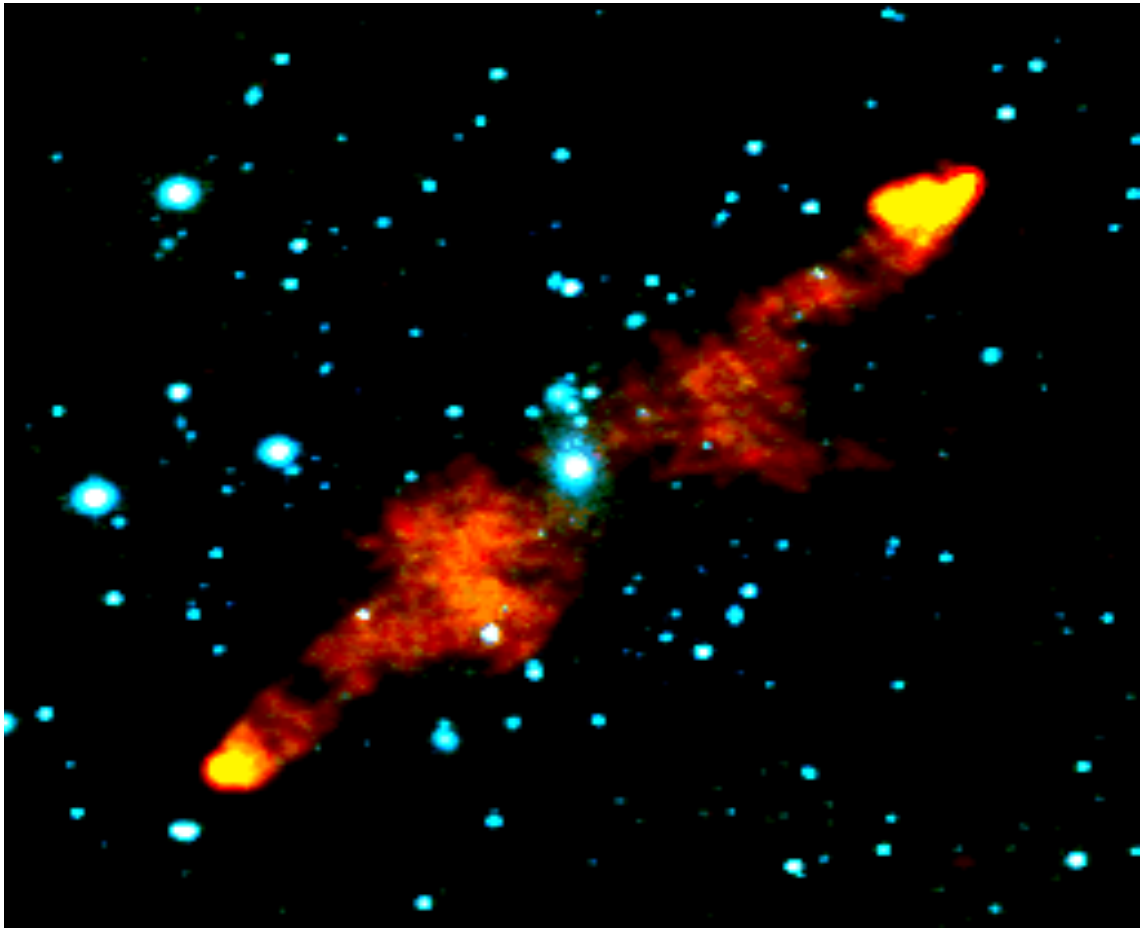
Outline

- HE gamma astrophysics
  - General Introduction
    - "The concepts"
  - Multi-wavelength astrophysics
  - Multi-messenger astrophysics
- MeV Astrophysics
  - Detector techniques
  - Fermi/GBM, COSI …
- GeV Astrophysics
  - Detector techniques
  - AGILE , Fermi/LAT
- The "near" future
  - GammaAstrophysics in the MWL and MM context …
  - Where to … ?

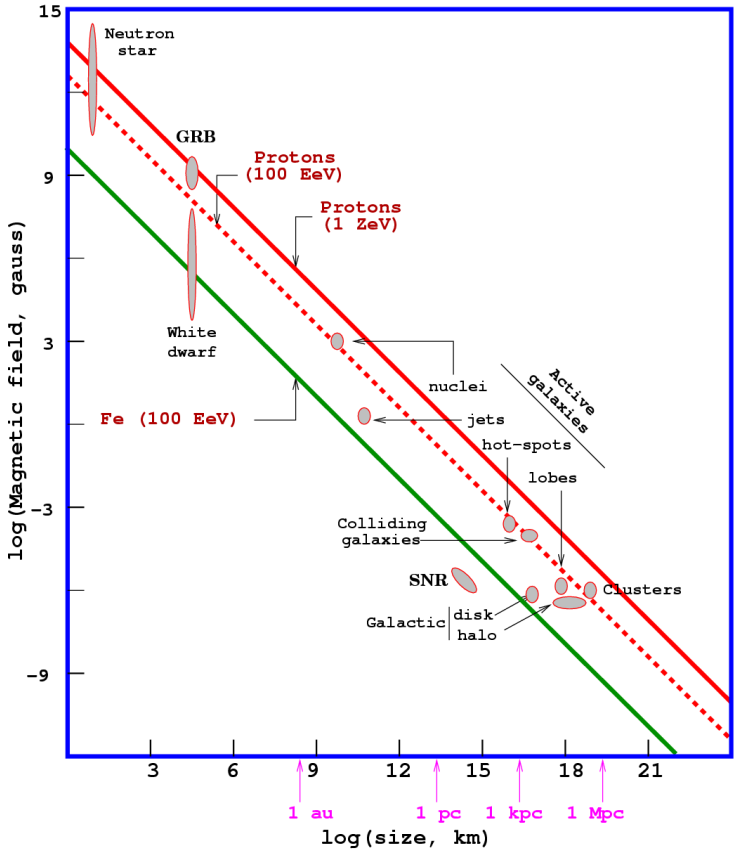


“Historical” Introduction

High Energy astrophysical sources



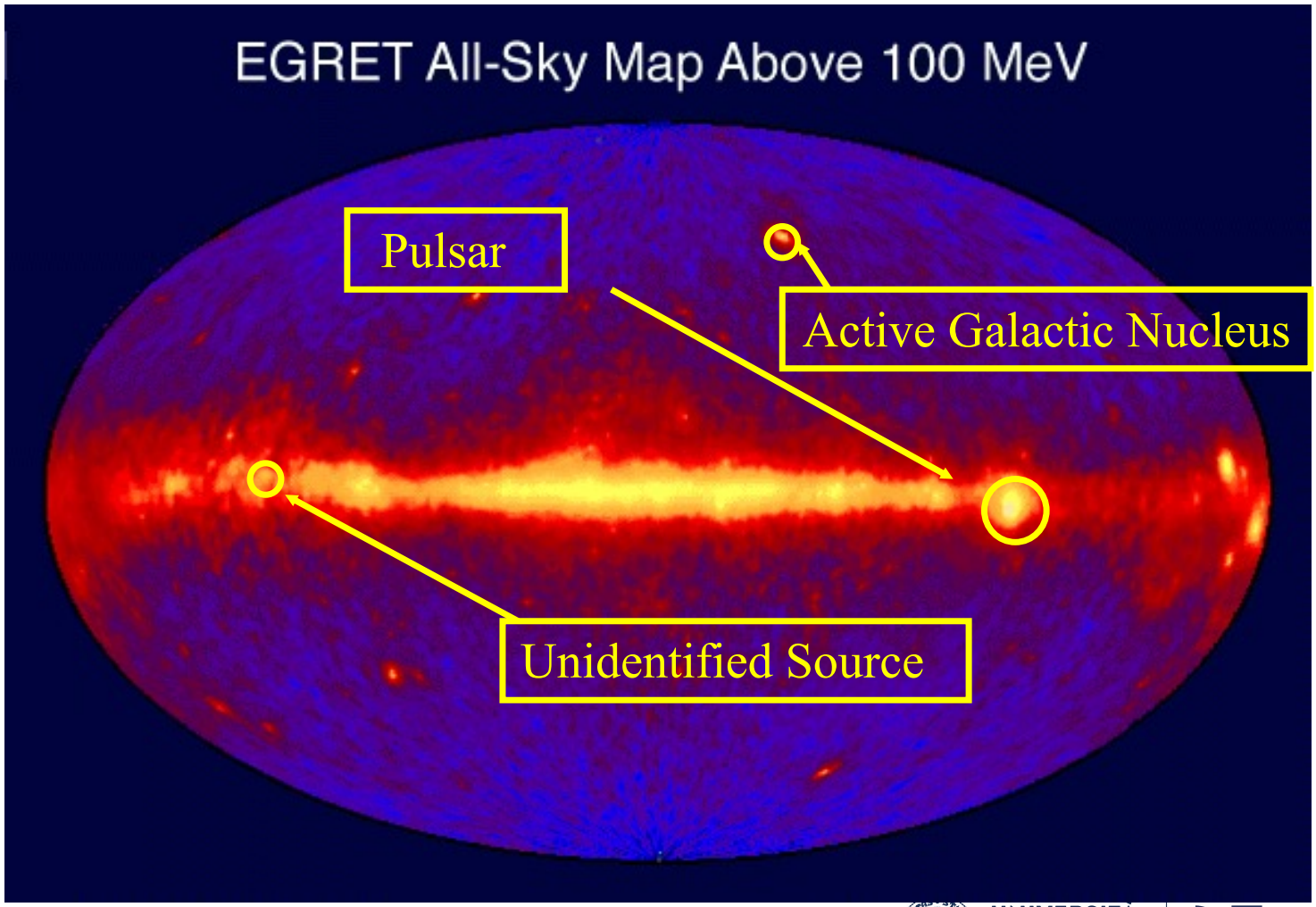
Hillas-plot
(candidate sites for E=100 EeV and E=1 ZeV)



$E_{max} \sim ZBL$ (Fermi)

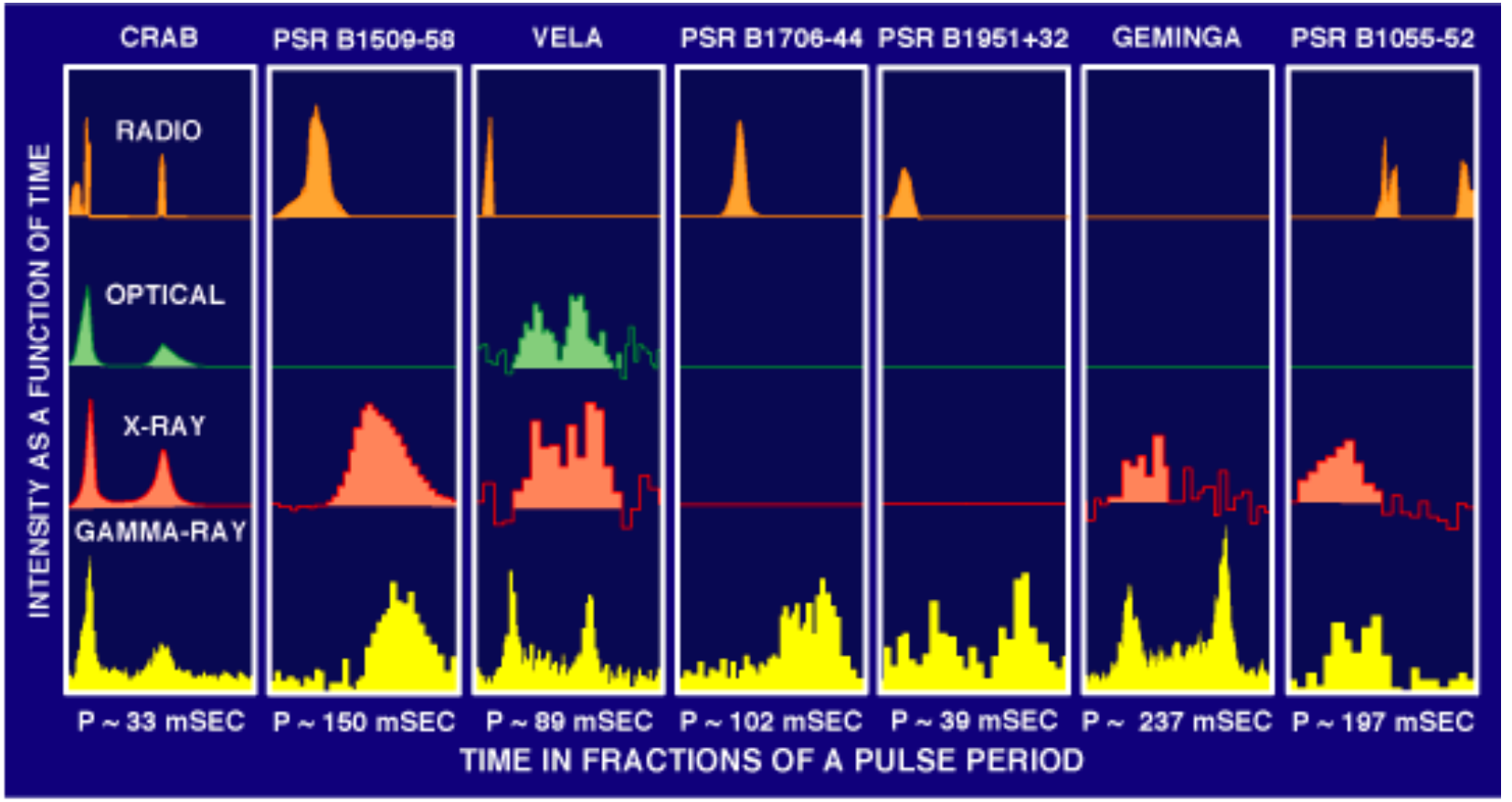
$E_{max} \sim ZBL\,\Gamma$ (Ultra-relativistic shocks-GRB)

Introduction



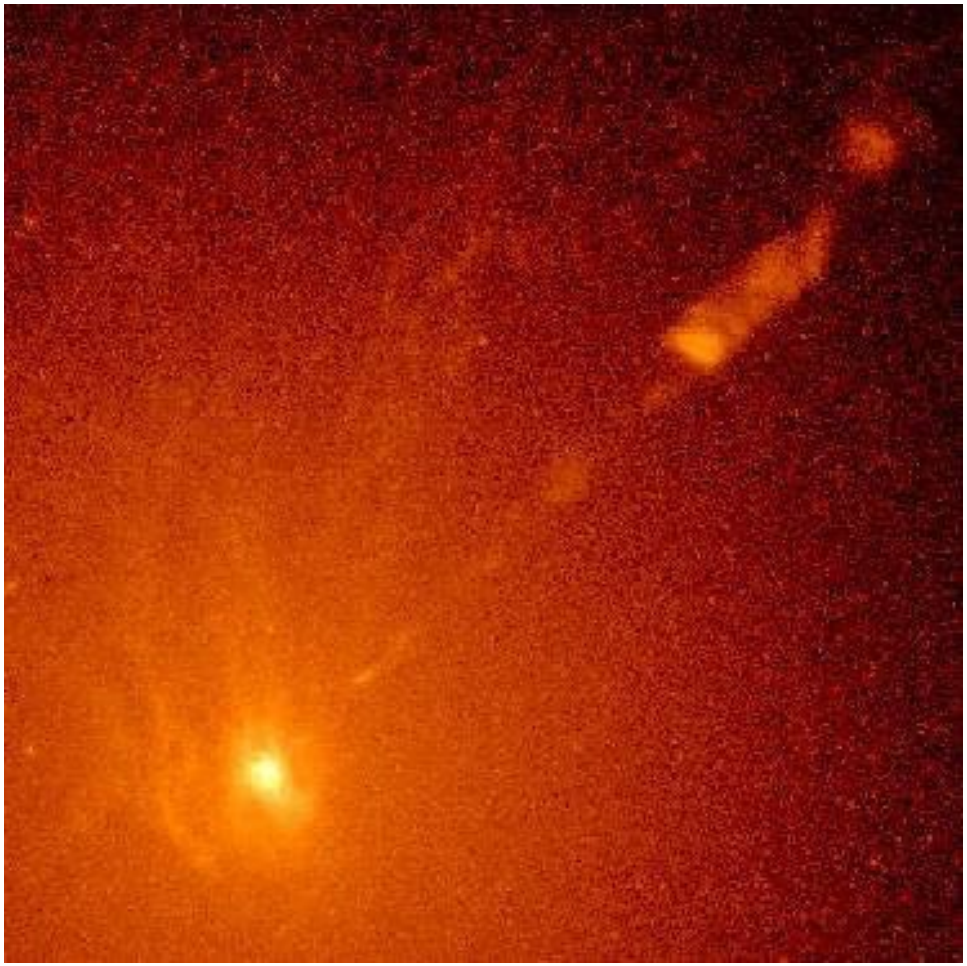
Introduction

Gamma Ray Pulsars



Introduction

Active Galactic Nuclei



Introduction

Unidentified Sources

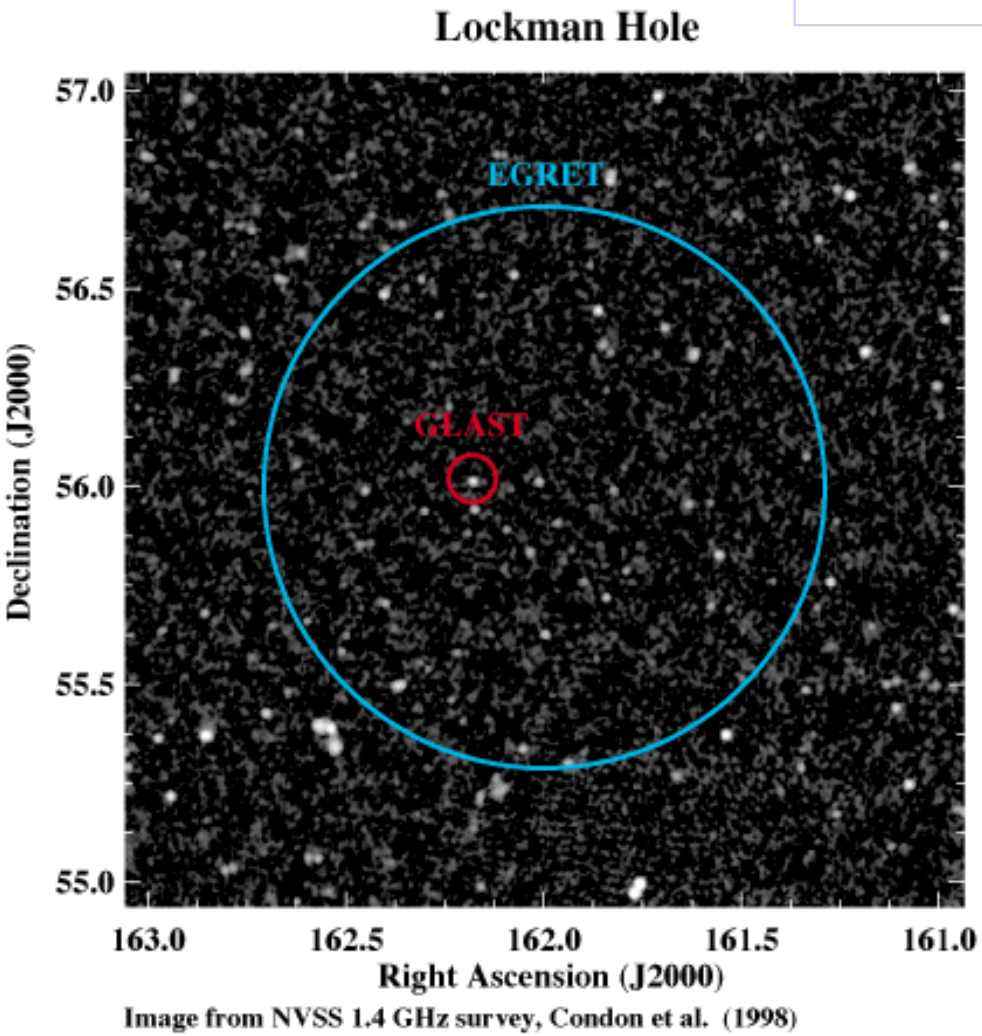
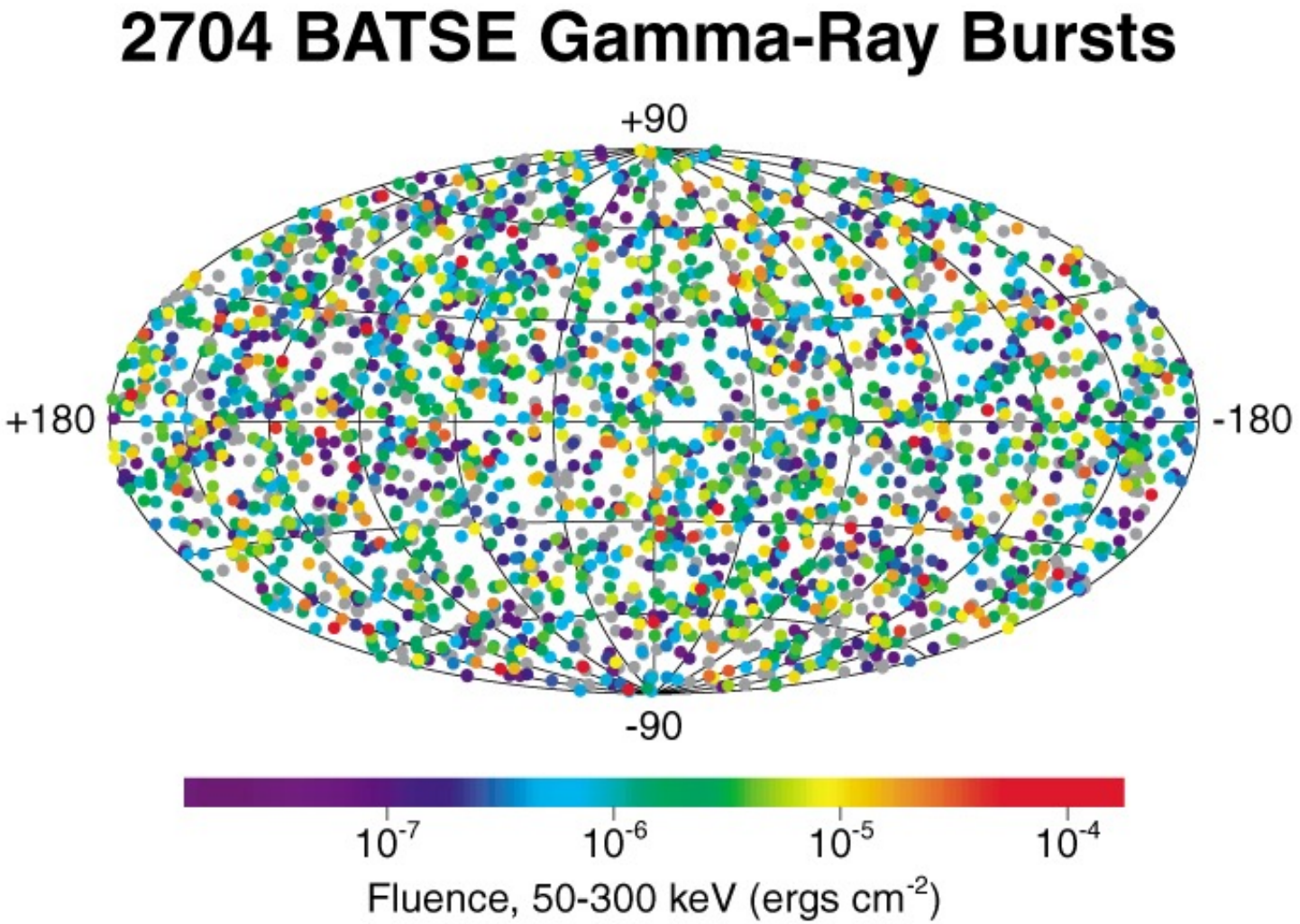


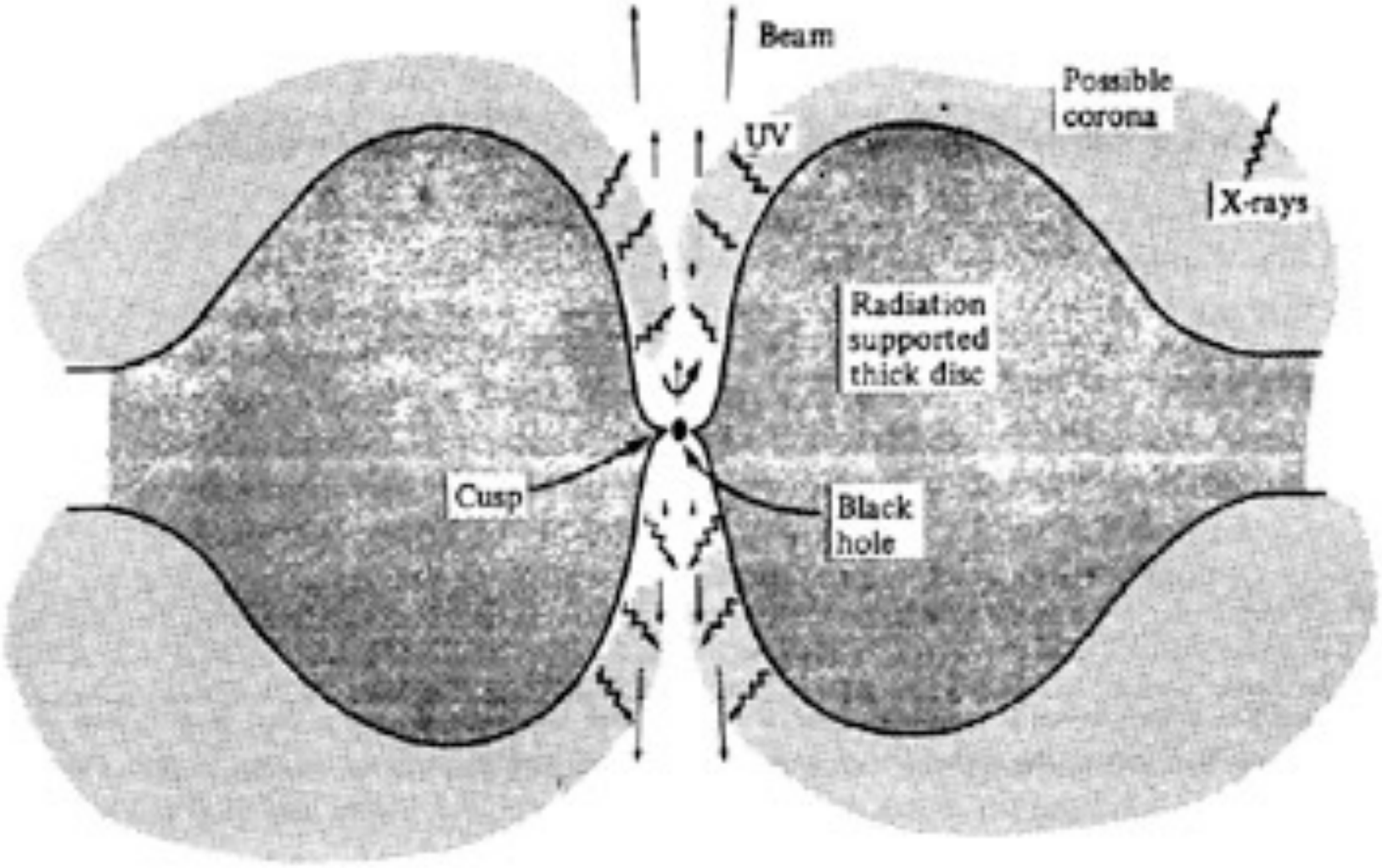
Image from NVSS 1.4 GHz survey, Condon et al. (1998)

Introduction

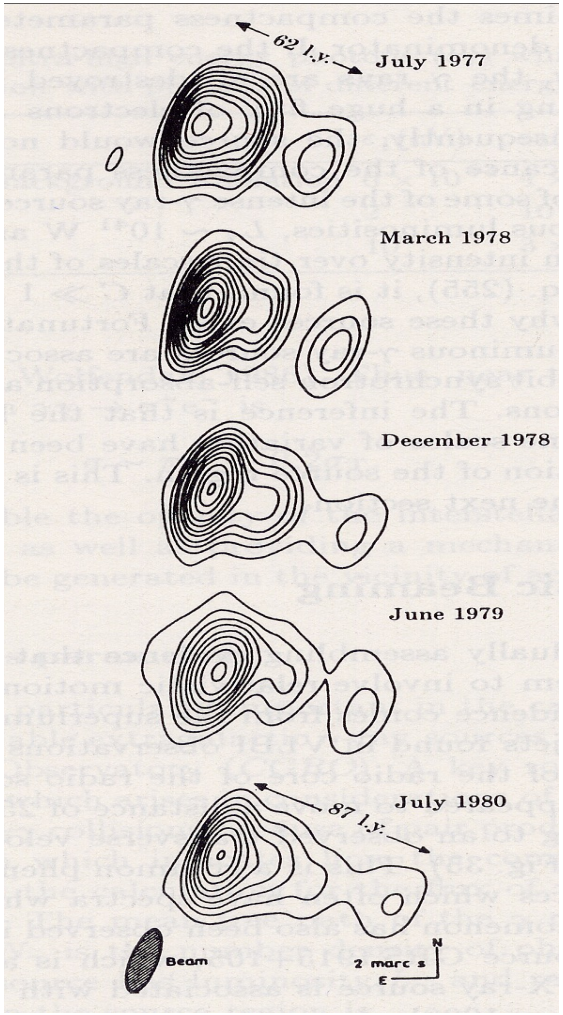


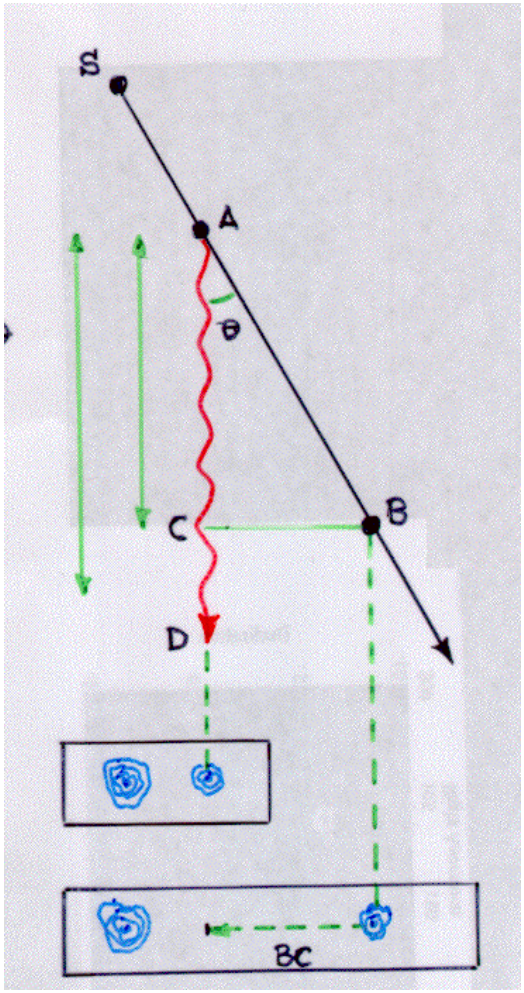
The framework

Accretion and Jets



Superluminal motion



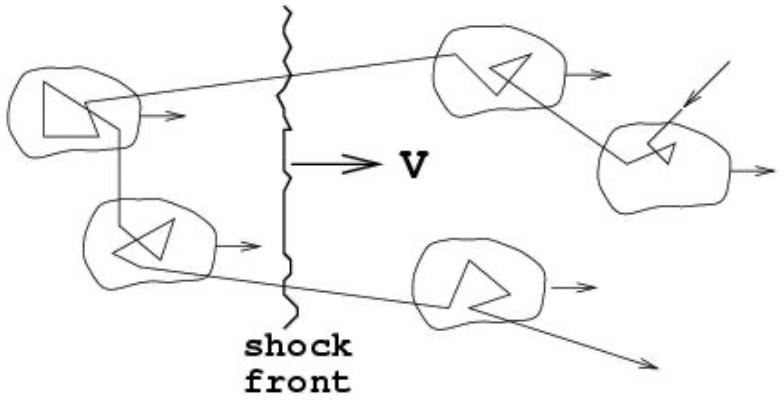


see e.g. Ghisellini astro-ph/9905181

1st order Fermi mechanism

- **Basic principles:**
  - **Strong shock**
  - **Scattering by irregularities**
  - **Isotropic with respect to the shock frame**
  - **Relativistic transformations**

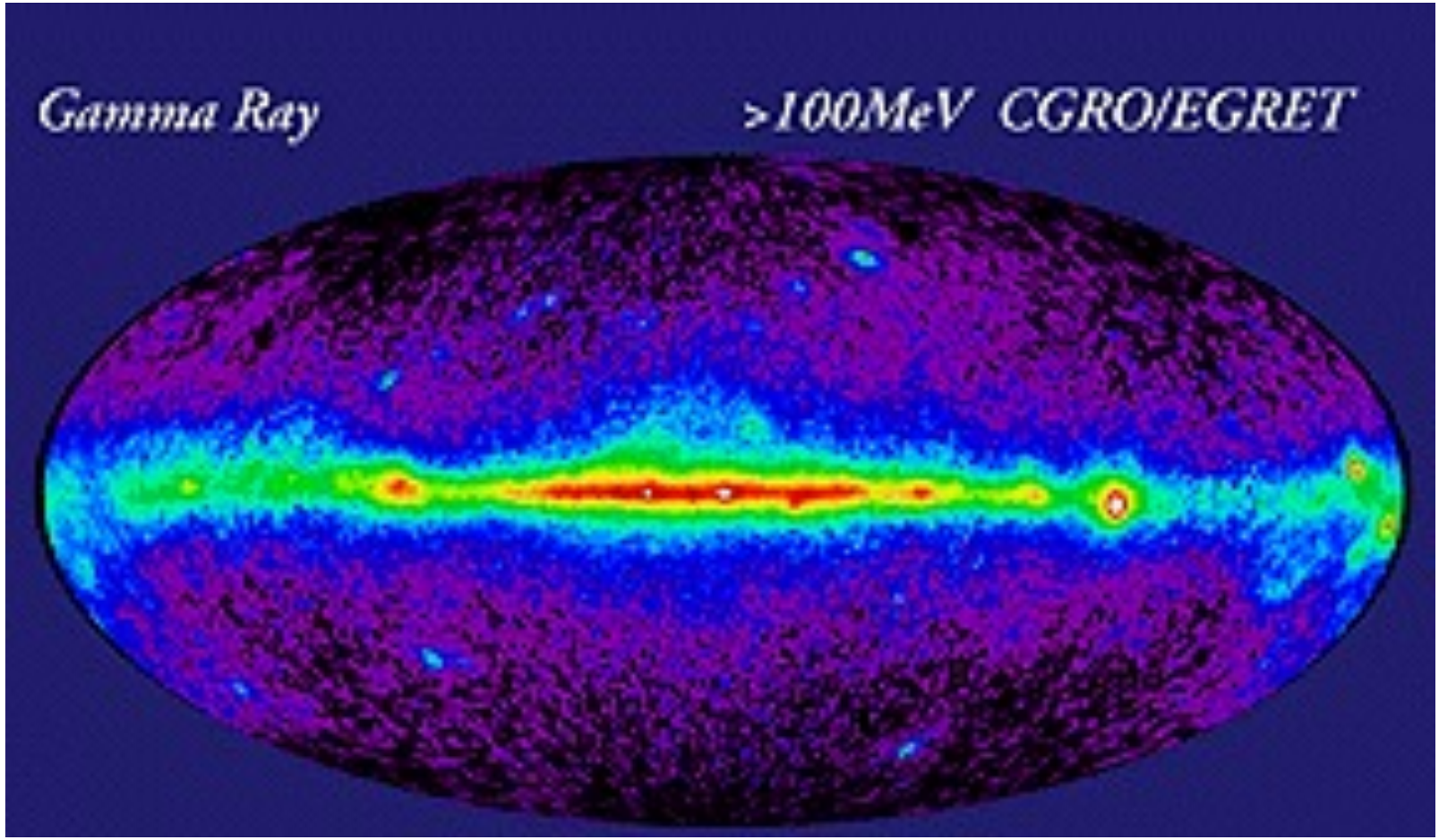
1st order :
acceleration in strong shock waves
(supernova ejecta, RG hot spots...)



$$\left\langle \frac{\Delta E}{E} \right\rangle = \frac{4}{3}\left(\frac{v}{c}\right)$$

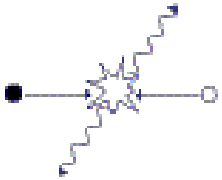
$$\frac{\Delta E}{E} \sim \beta \qquad \beta = \frac{V}{c} \lesssim 10^{-1}$$

Gamma-Ray sky

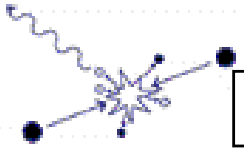


Emission Processes

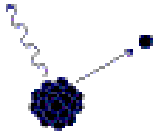
Synchrotron radiation



Matter Antimatter Annihilation

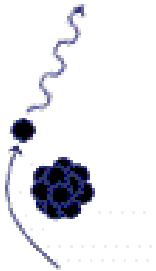


High Energy Collisions



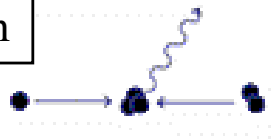
Nuclear decay

Bremssthralung

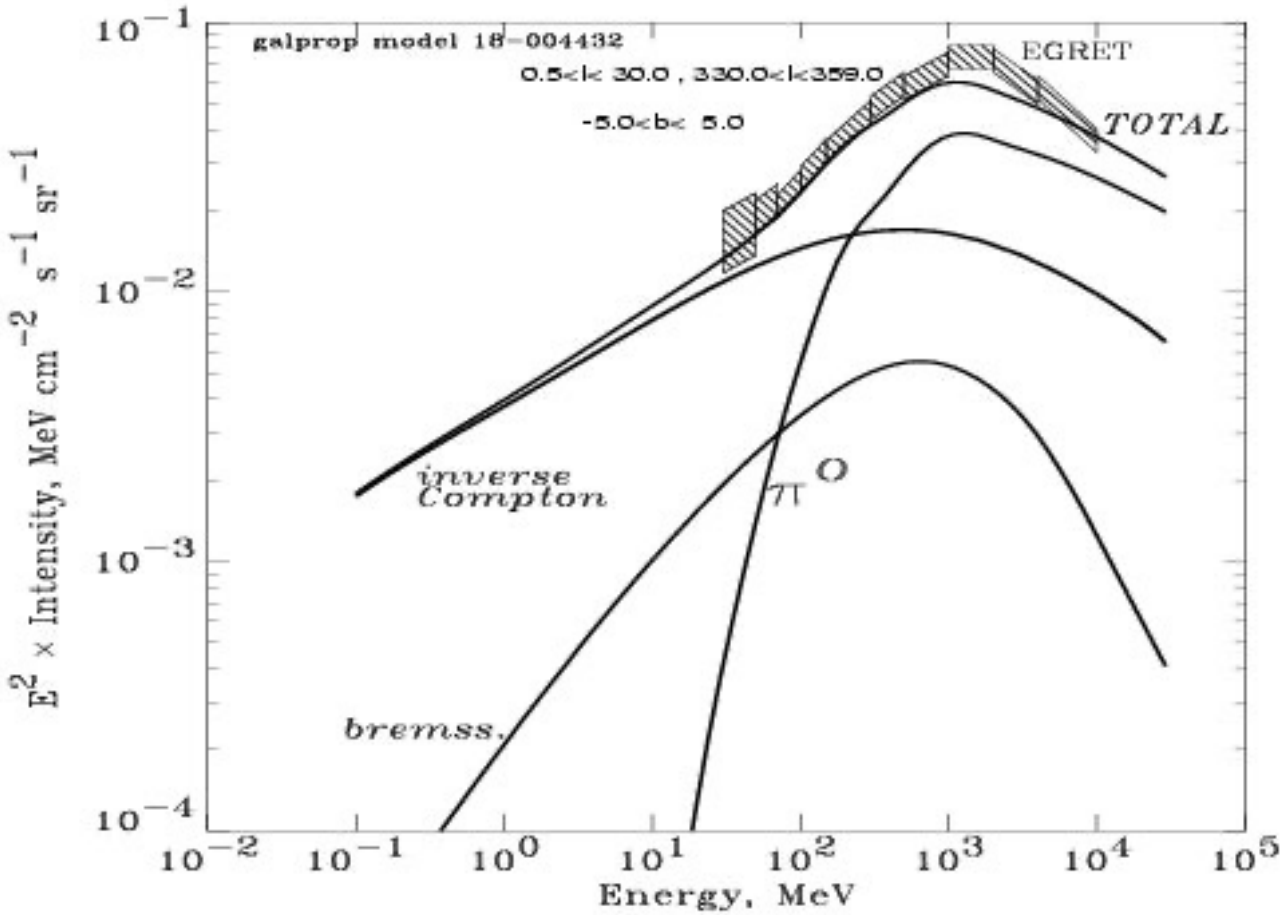


Inverse Compton Scattering

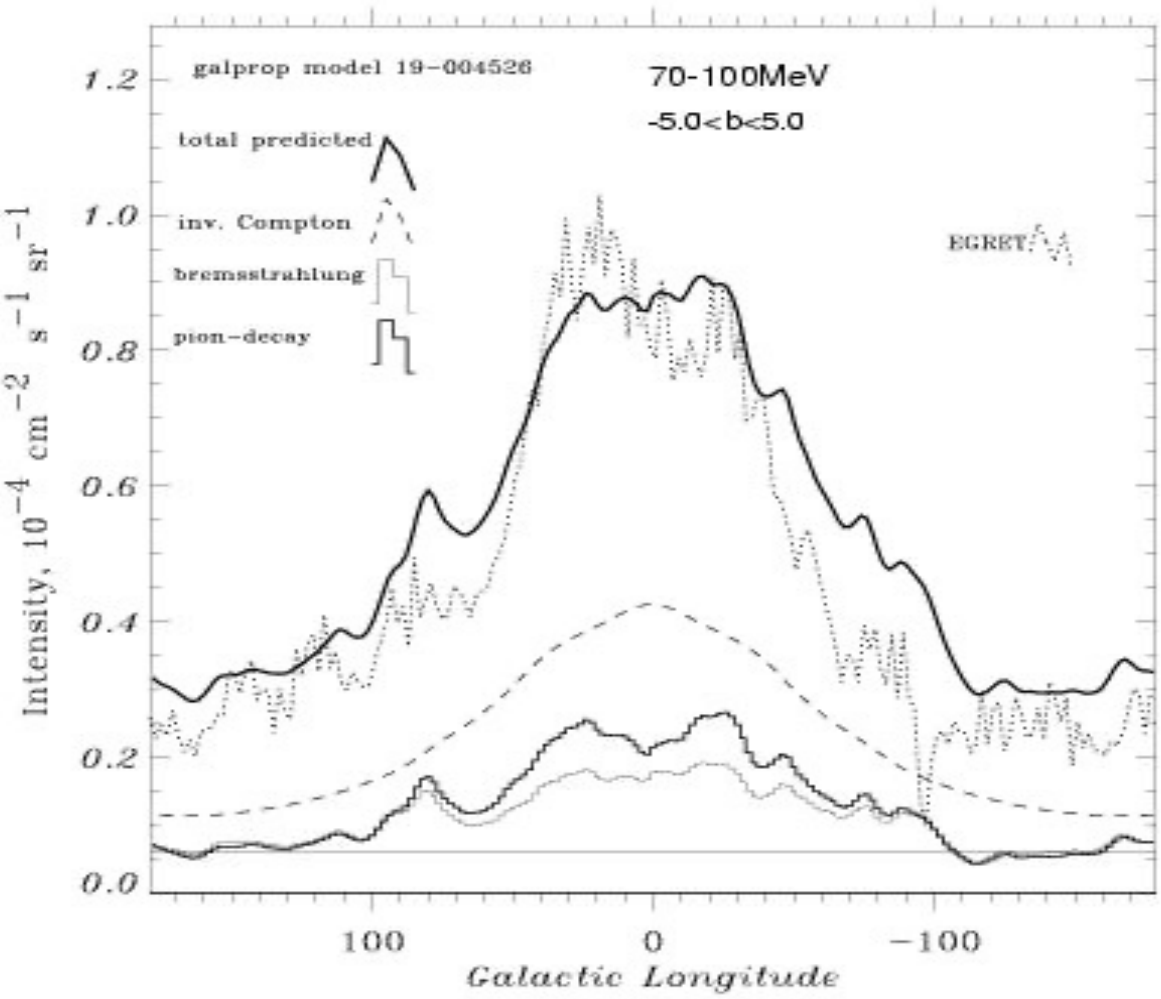
Nuclear Fusion



GalProp: results

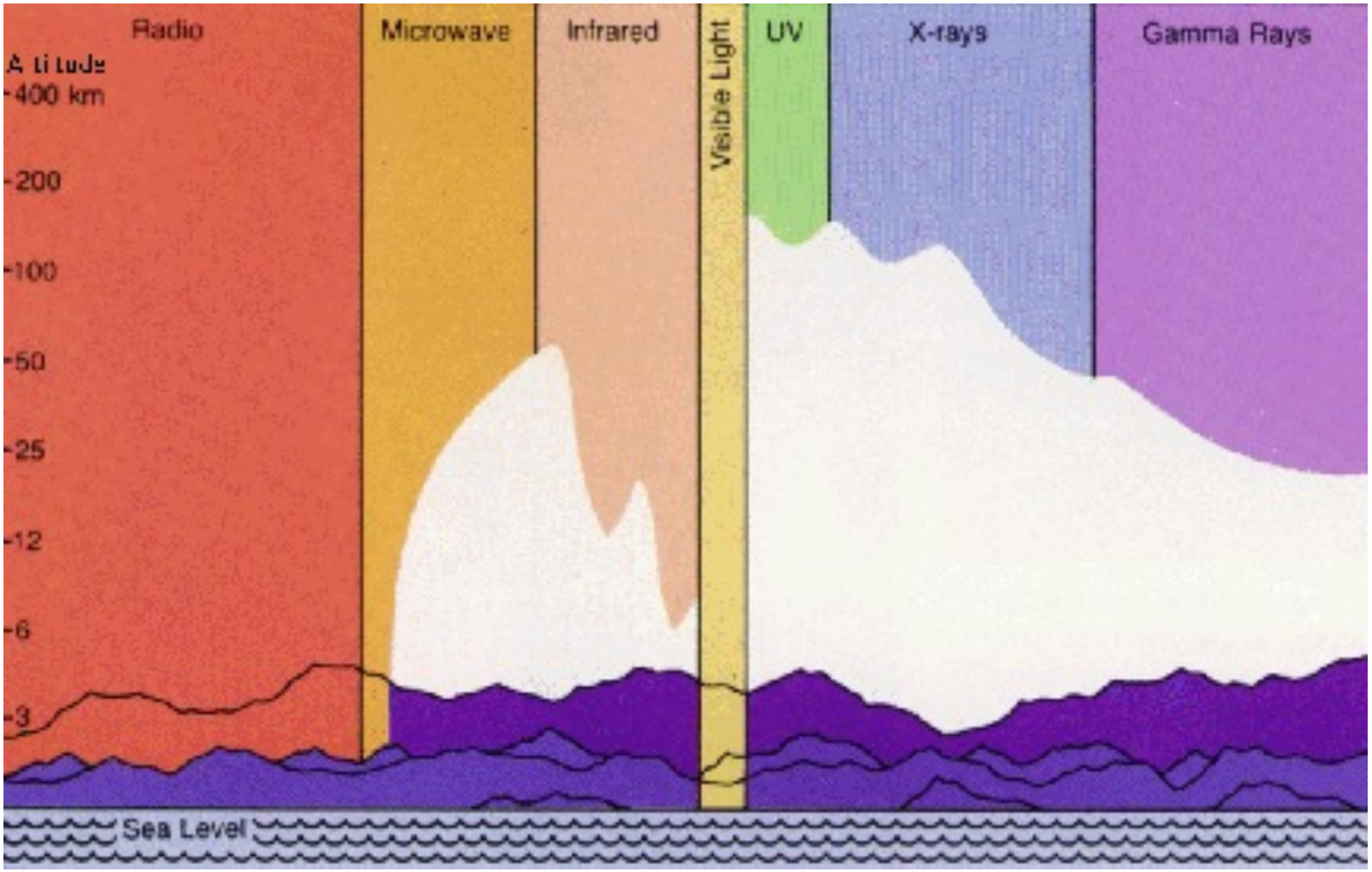


GalProp: results



Multifrequency Astronomy

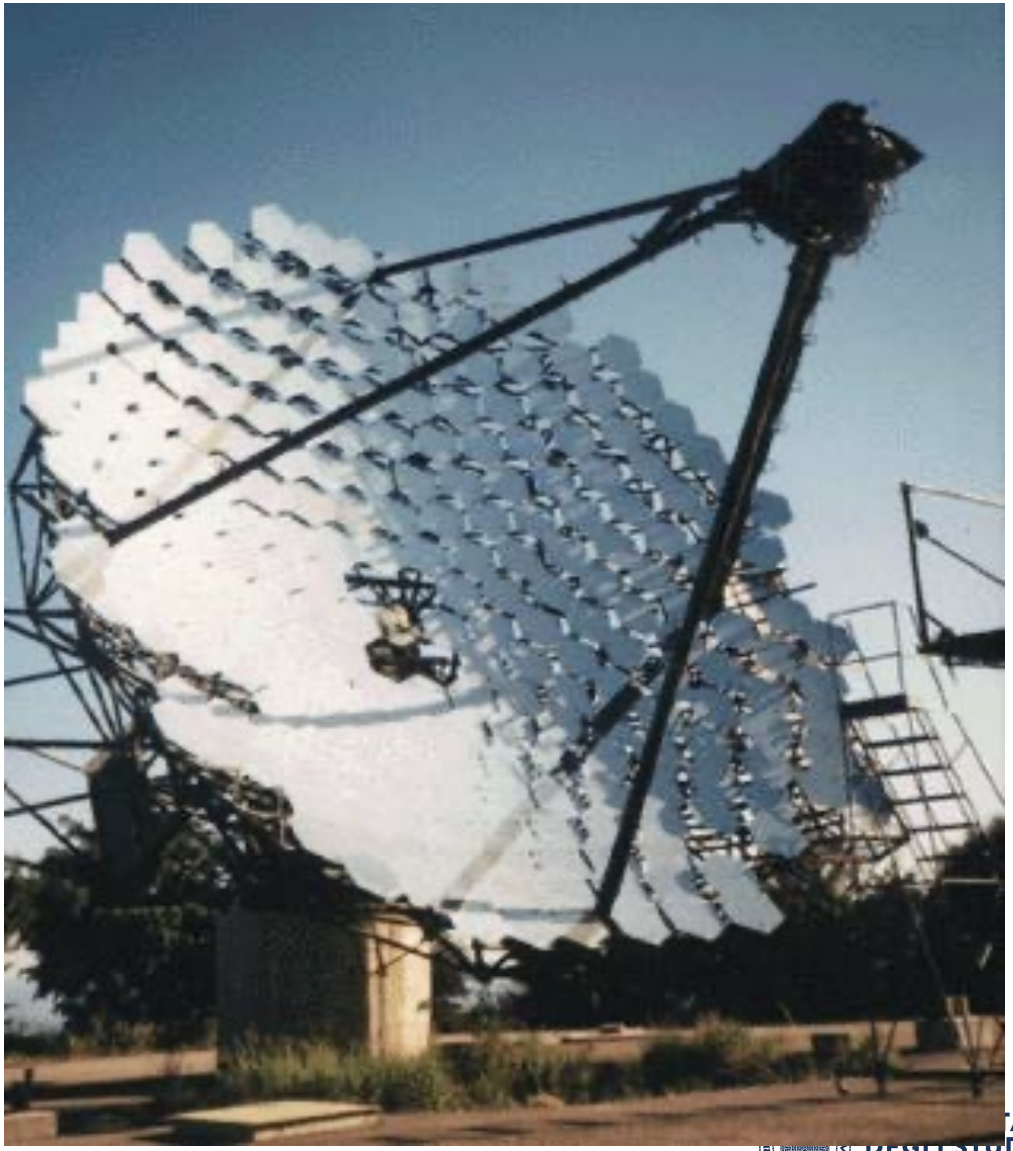
Introduction



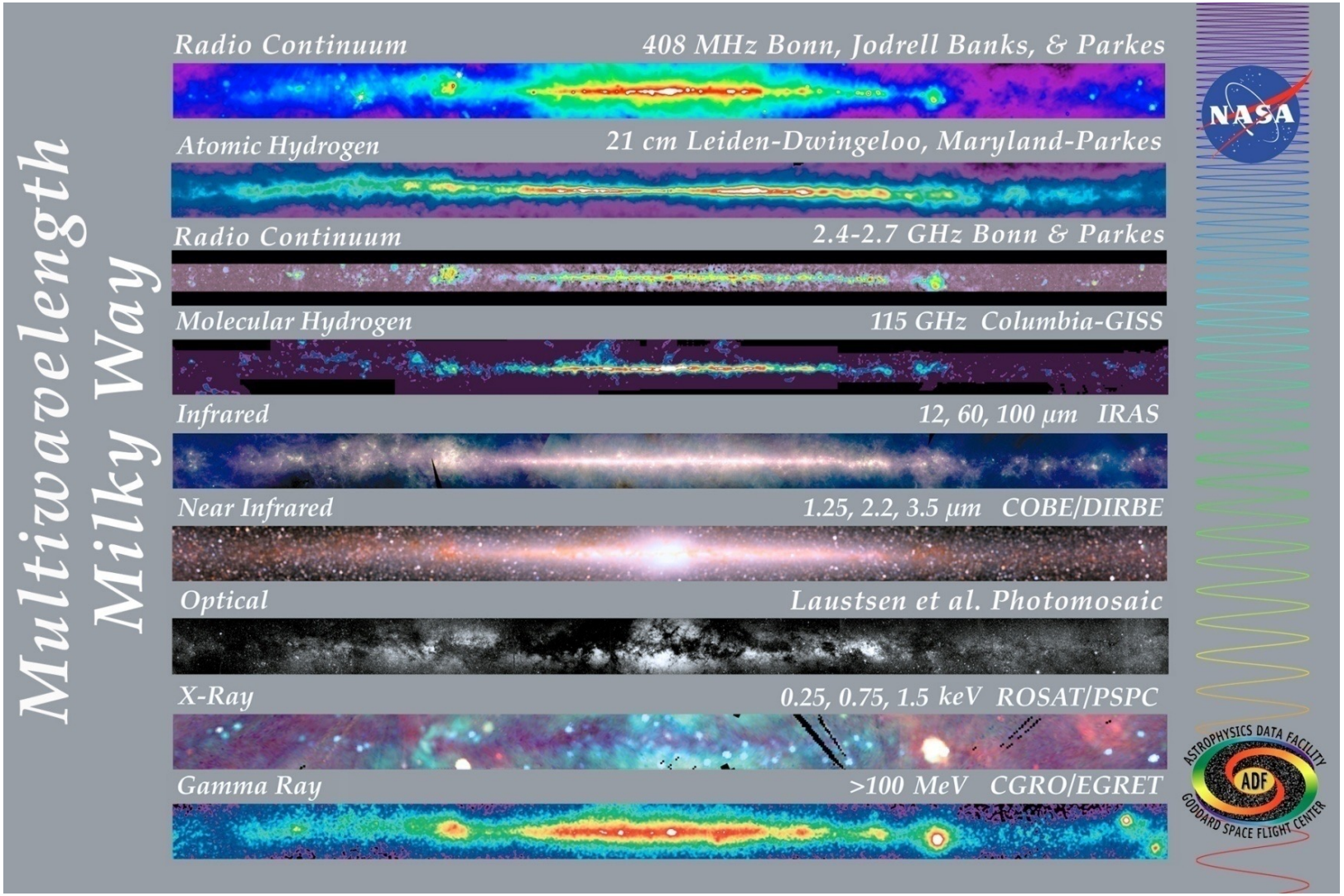
X-ray telescopes

Gamma-ray Telescopes

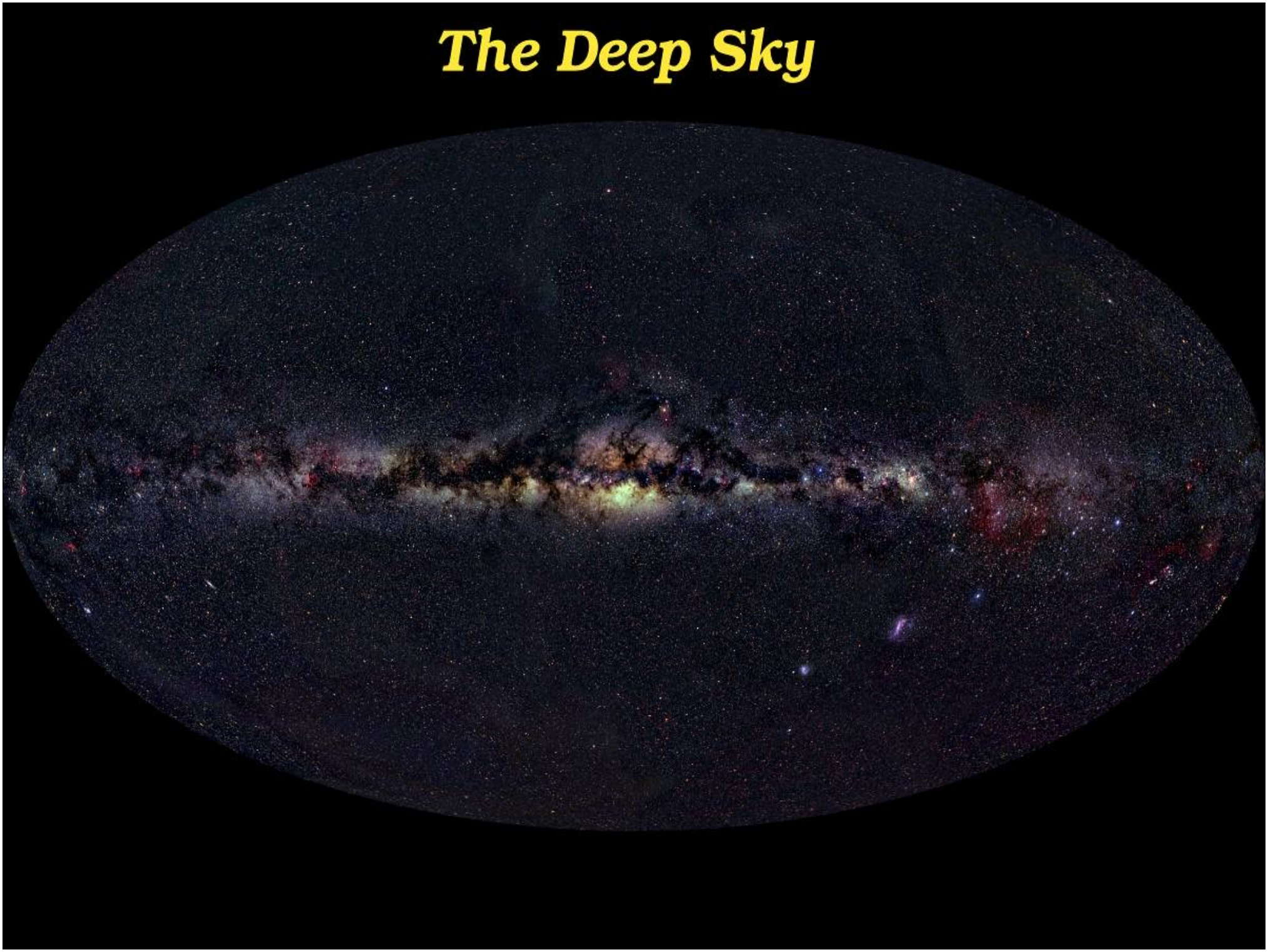
VHE Gamma-ray telescopes

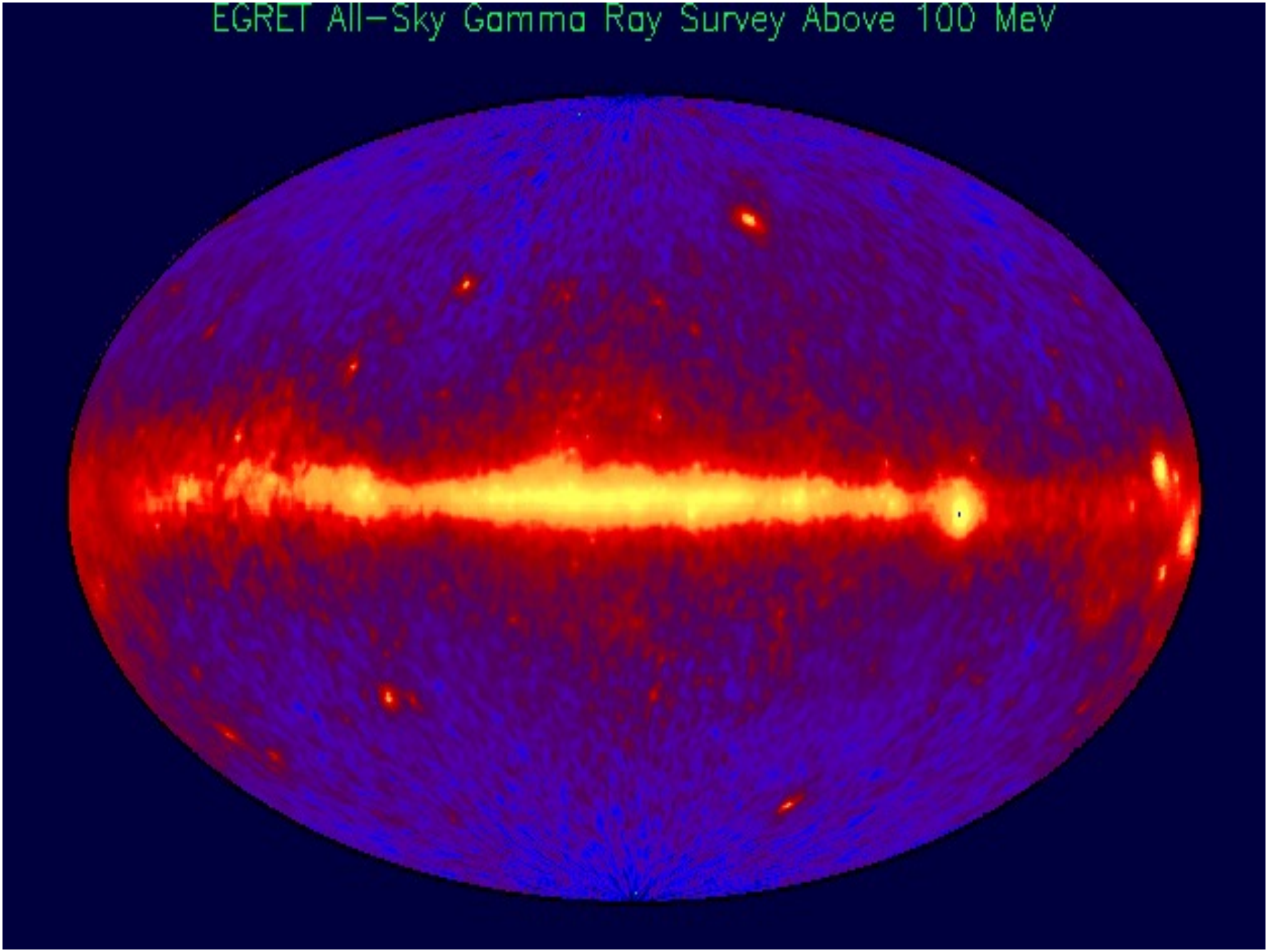


The Galaxy


Multiwavelength Milky Way
Radio Continuum
408 MHz Bonn, Jodrell Banks, & Parkes
Atomic Hydrogen
21 cm Leiden-Dwingeloo, Maryland-Parkes
Radio Continuum
2.4-2.7 GHz Bonn & Parkes
Molecular Hydrogen
115 GHz Columbia-GISS
Infrared
12, 60, 100 μm IRAS
Near Infrared
1.25, 2.2, 3.5 μm COBE/DIRBE
Optical
Laustsen et al. Photomosaic
X-Ray
0.25, 0.75, 1.5 keV ROSAT/PSPC
Gamma Ray
>100 MeV CGRO/EGRET
NASA
ASTROPHYSICS DATA FACILITY
ADF
GODDARD SPACE FLIGHT CENTER

The Deep Sky

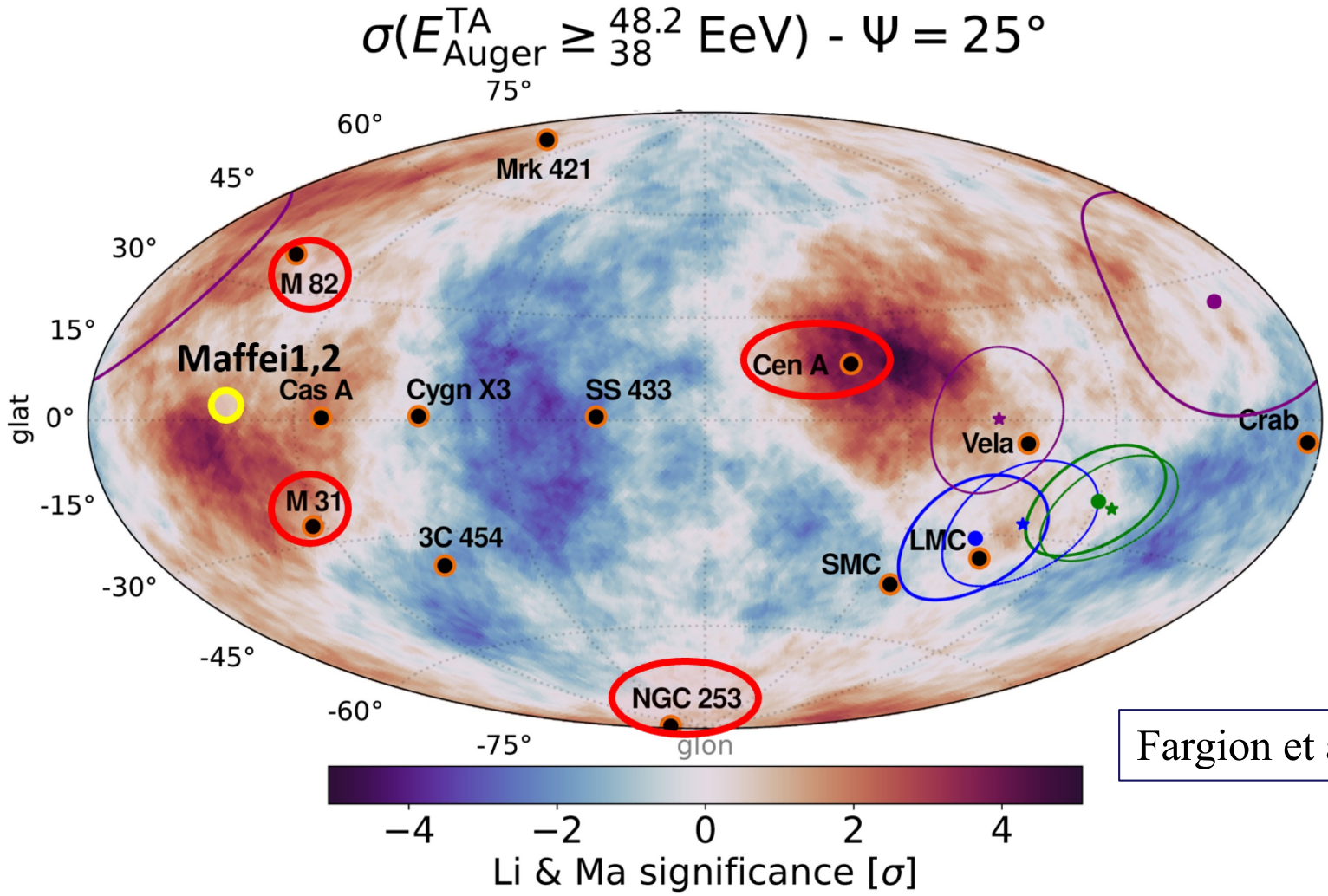



EGRET All-Sky Gamma Ray Survey Above 100 MeV

Multimessenger Astrophysics

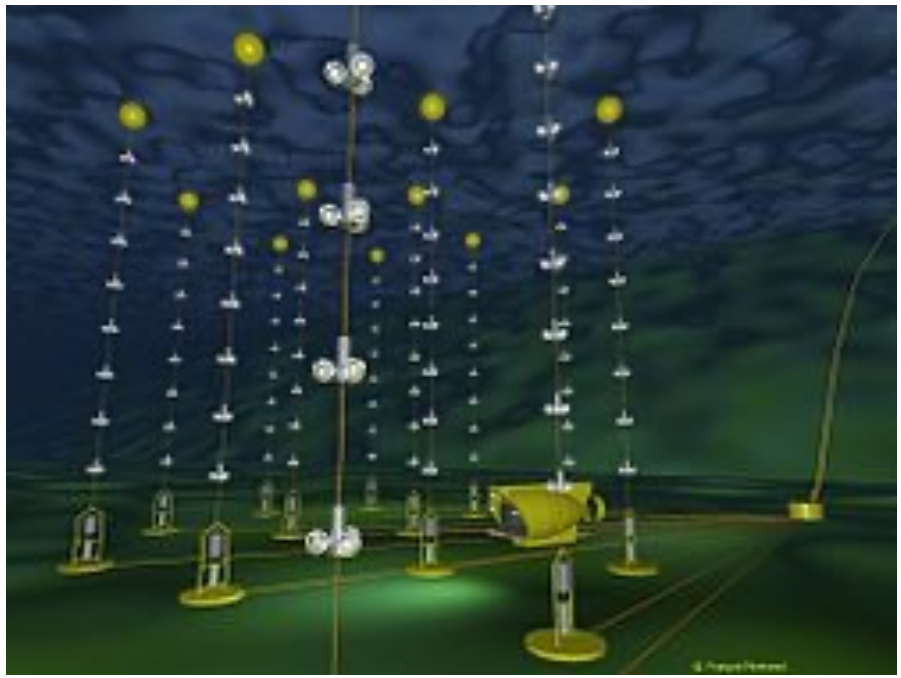
UHECR detectors

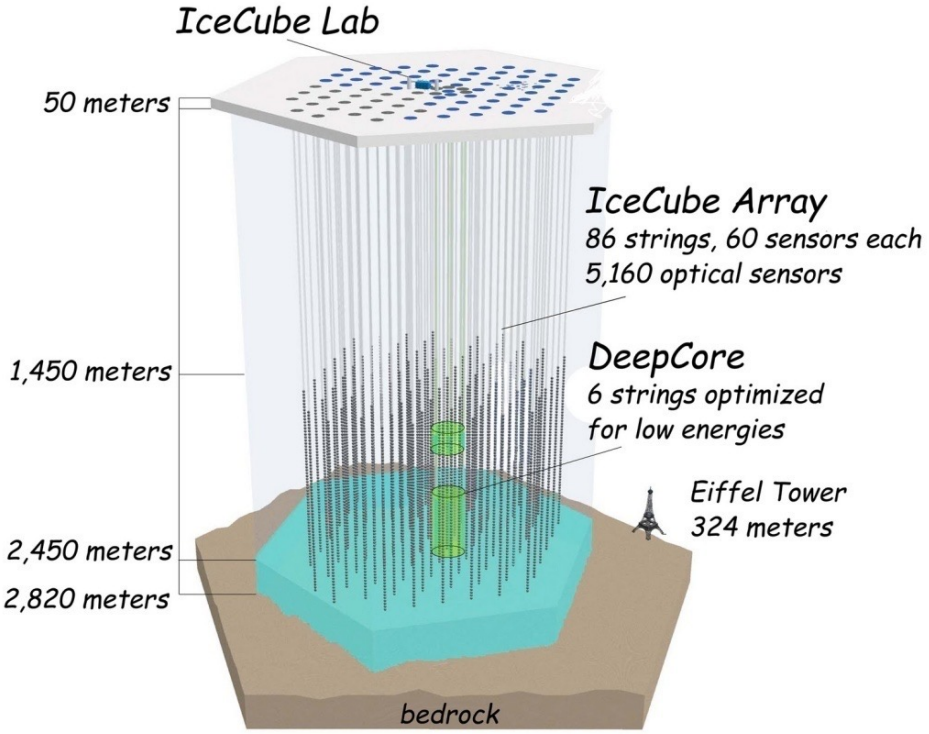
UHECR



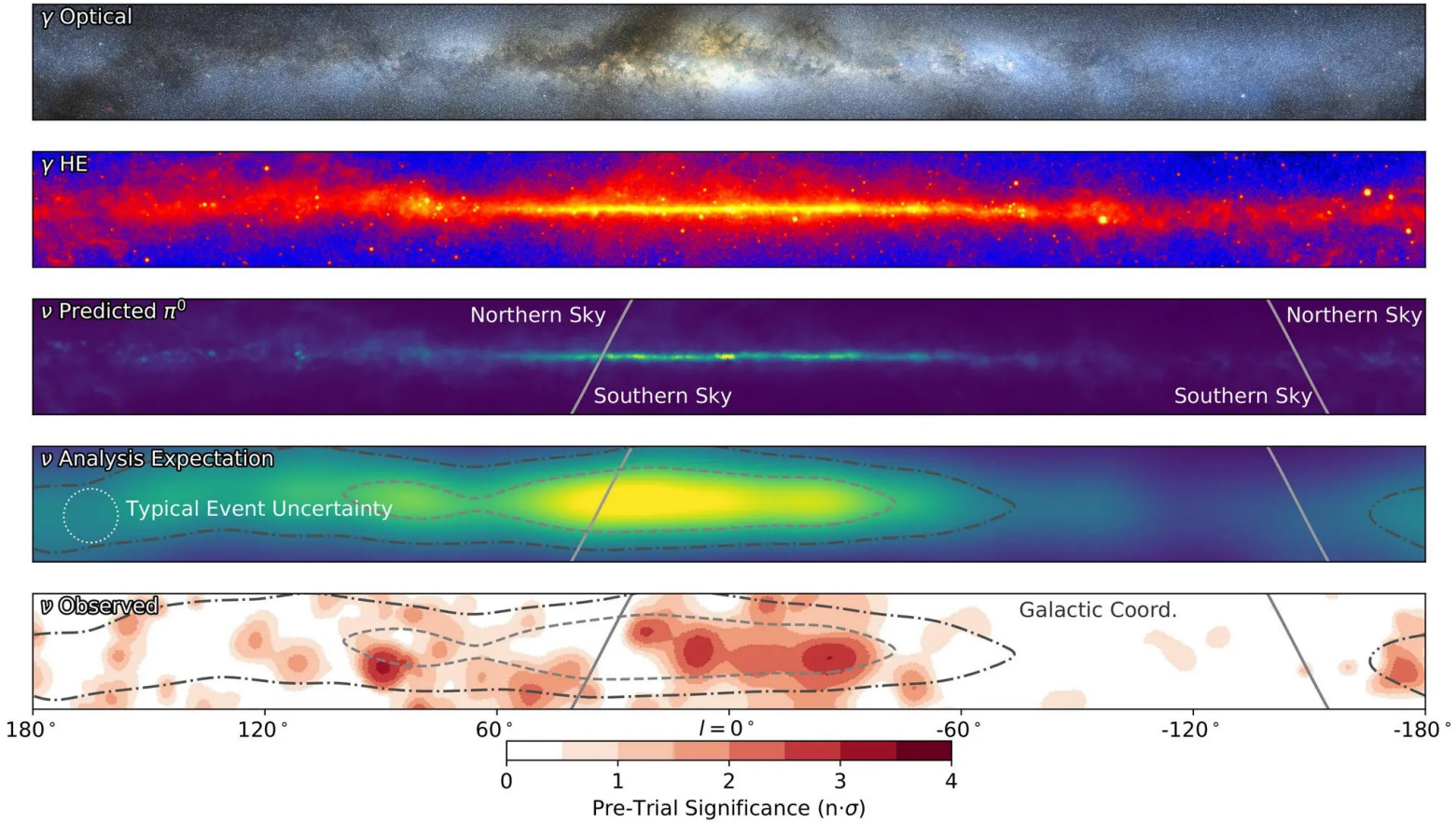
Fargion et al 2024

Neutrino detectors



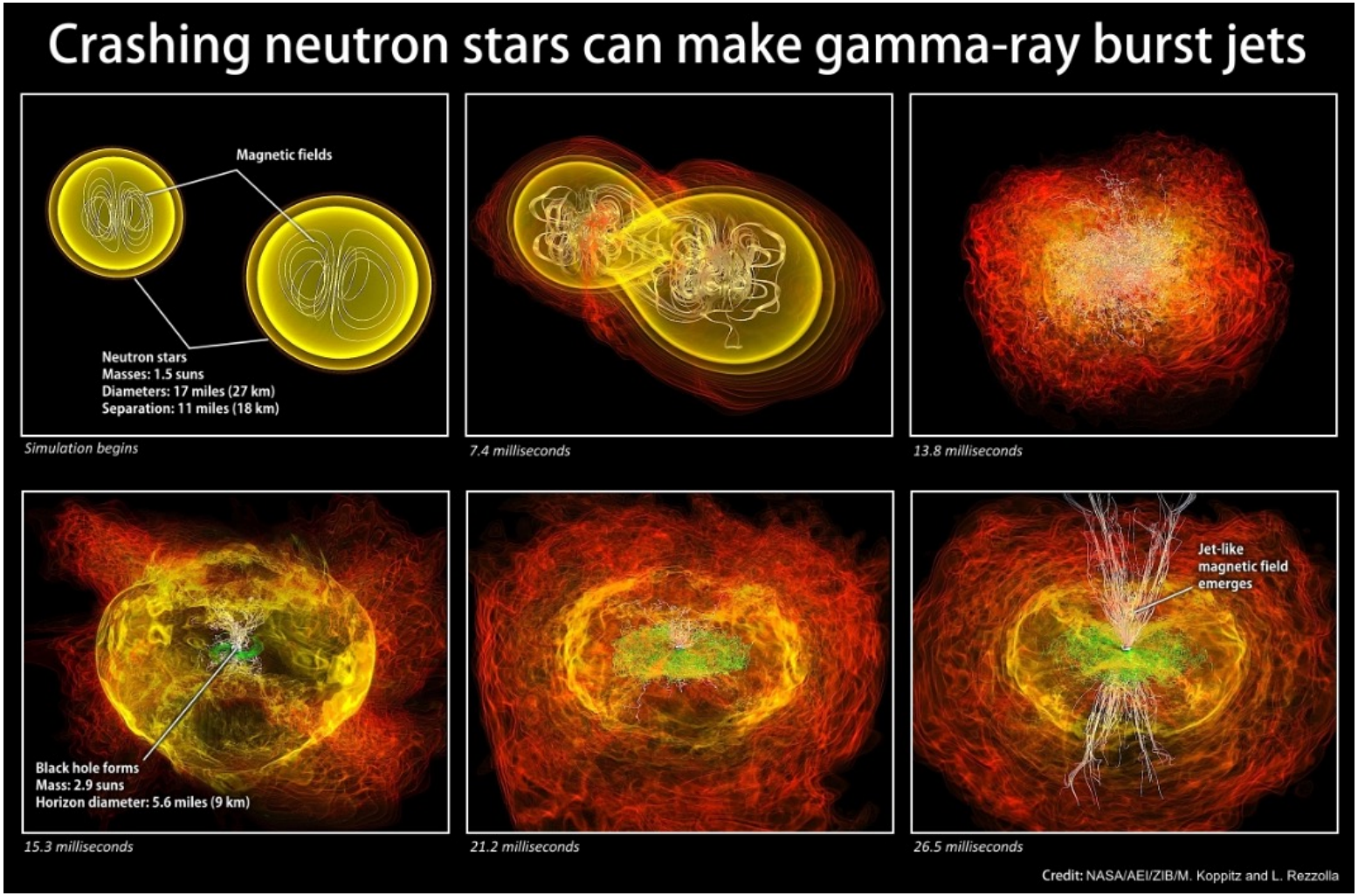


Neutrino searches



GW detectors

Short GRB


Crashing neutron stars can make gamma-ray burst jets
Magnetic fields
Neutron stars
Masses: 1.5 suns
Diameters: 17 miles (27 km)
Separation: 11 miles (18 km)
Simulation begins
7.4 milliseconds
13.8 milliseconds
Black hole forms
Mass: 2.9 suns
Horizon diameter: 5.6 miles (9 km)
15.3 milliseconds
21.2 milliseconds
Jet-like magnetic field emerges
26.5 milliseconds
Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

Outline

- HE gamma astrophysics
  - General Introduction
    - "The concepts"
  - Multi-wavelength astrophysics
  - Multi-messenger astrophysics
- MeV Astrophysics
  - Detector techniques
  - `Fermi/GBM, COSI …
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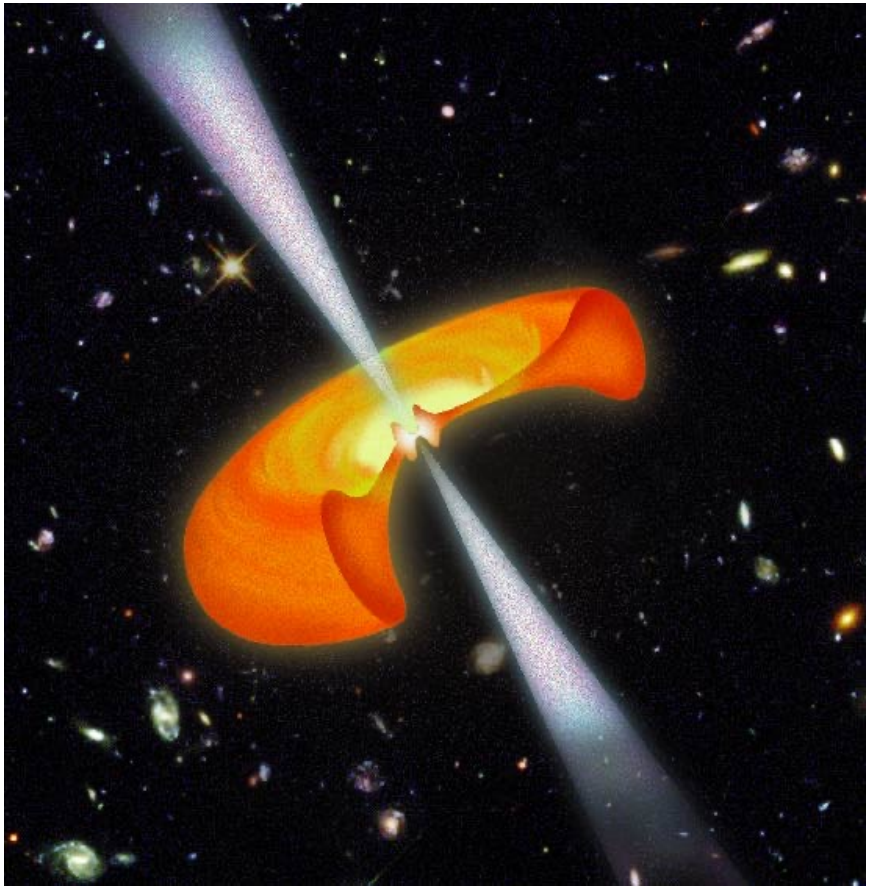
- The "near" future
  - GammaAstrophysics in the MWL and MM context …
  - Where to …?



MeV Gamma Ray Astrophysics

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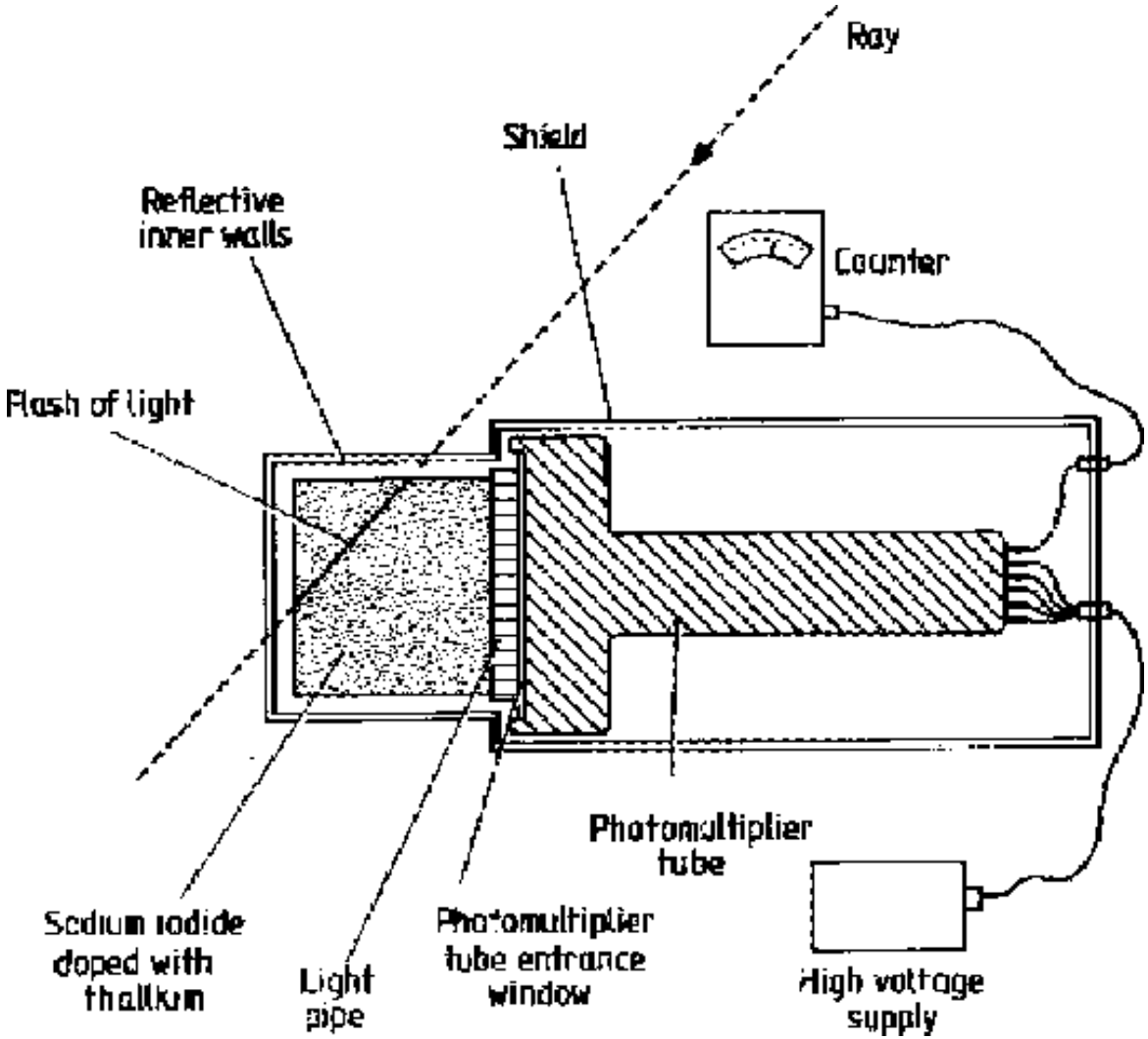
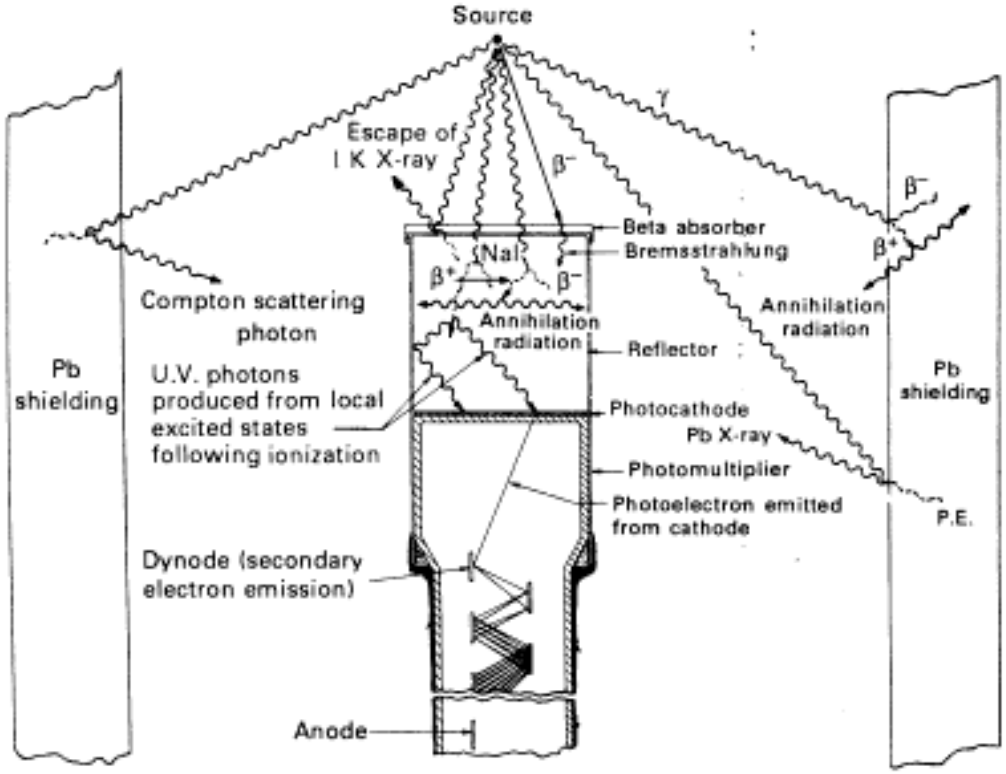
UNIVERSITÀ DEGLI STUDI DI TRIESTE

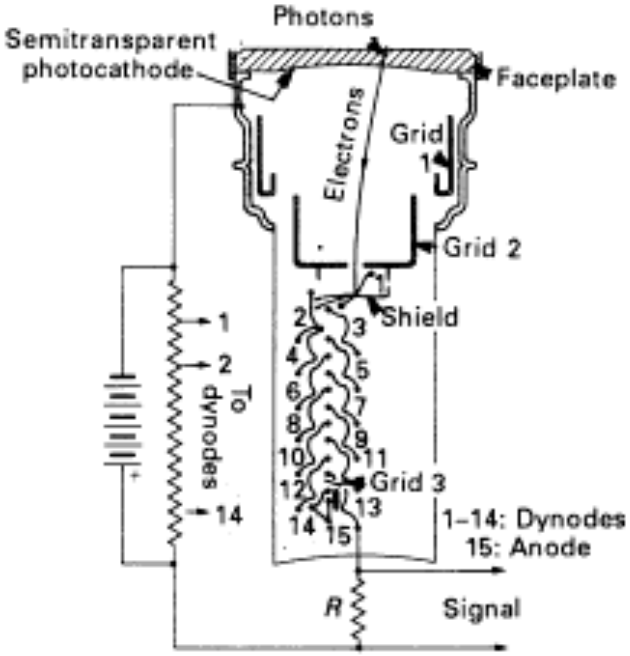
Dipartimento di
Fisica
Dipartimento d'Eccellenza 2023-2027

Scintillator Detectors

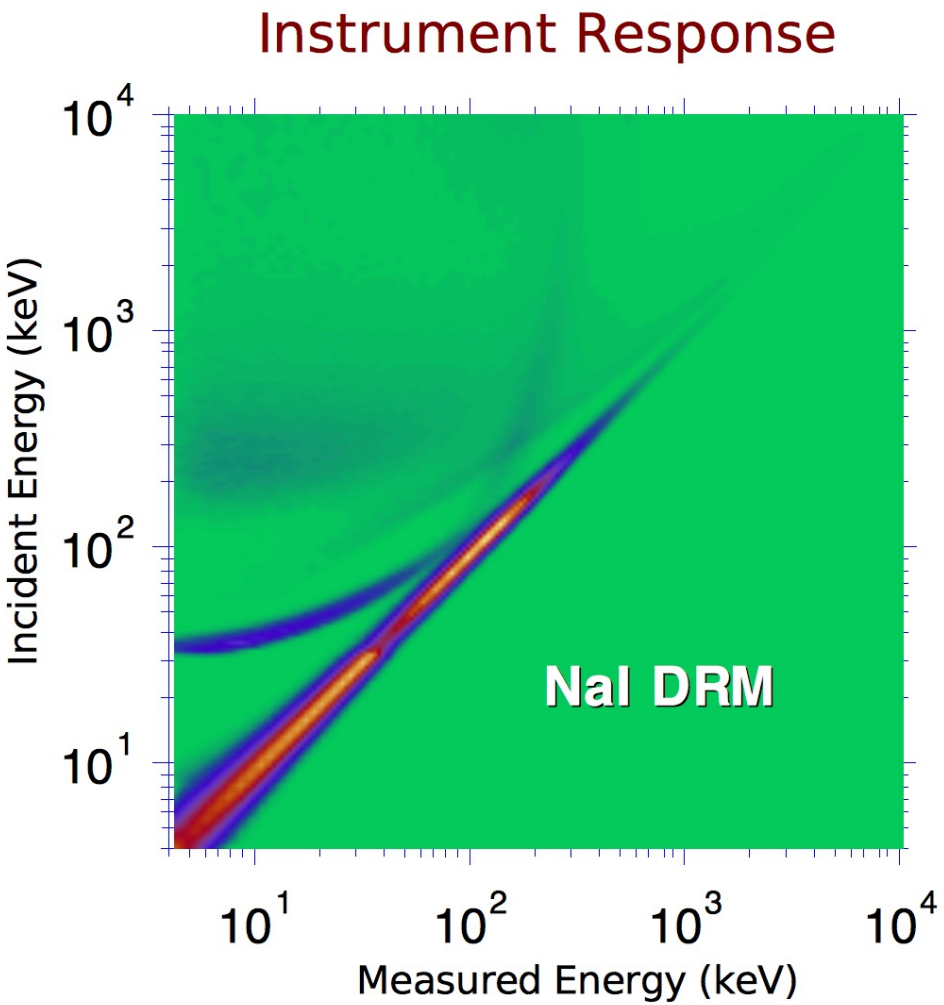


Scintillation Detectors

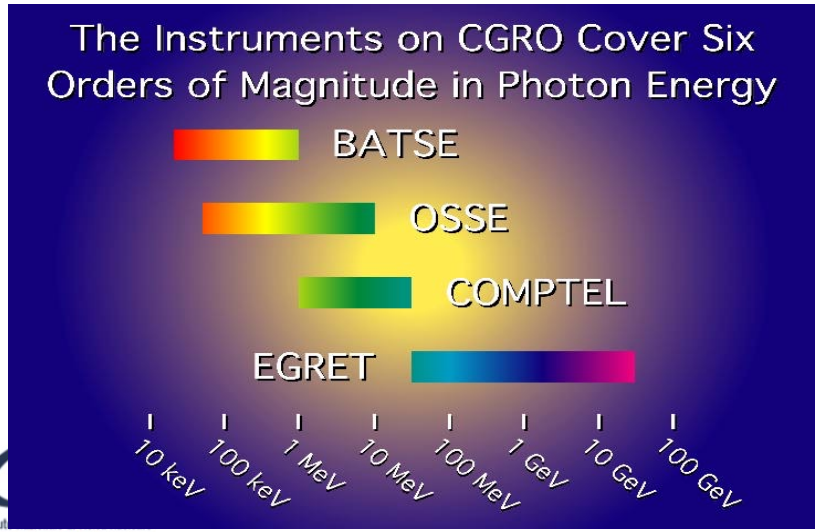


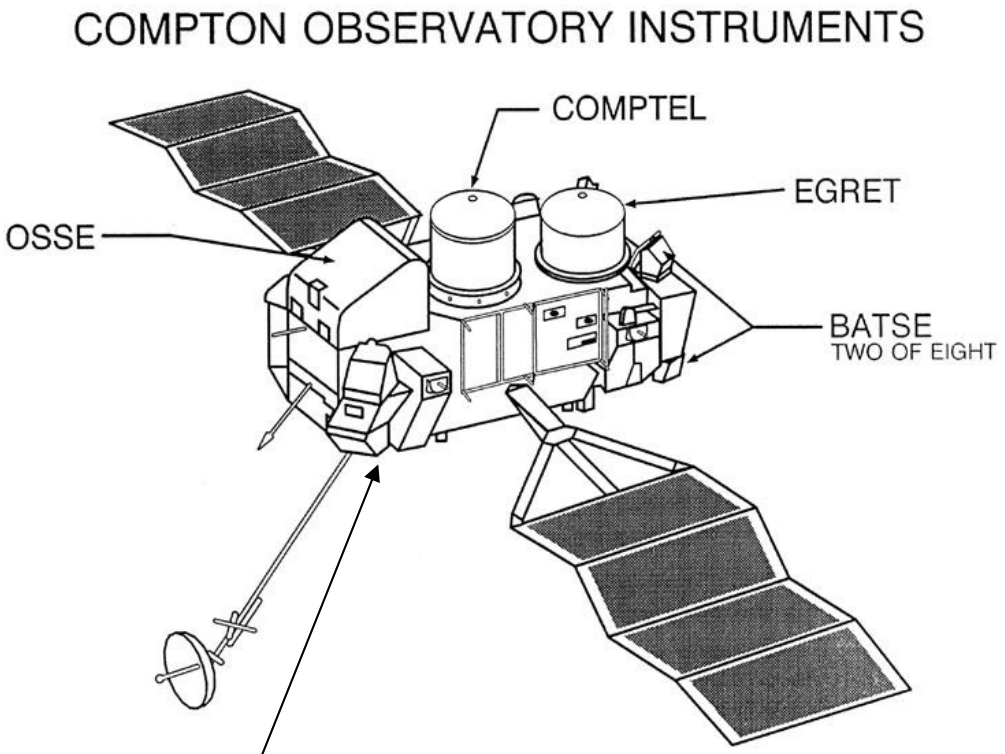


Detector Response Matrix



CGRO

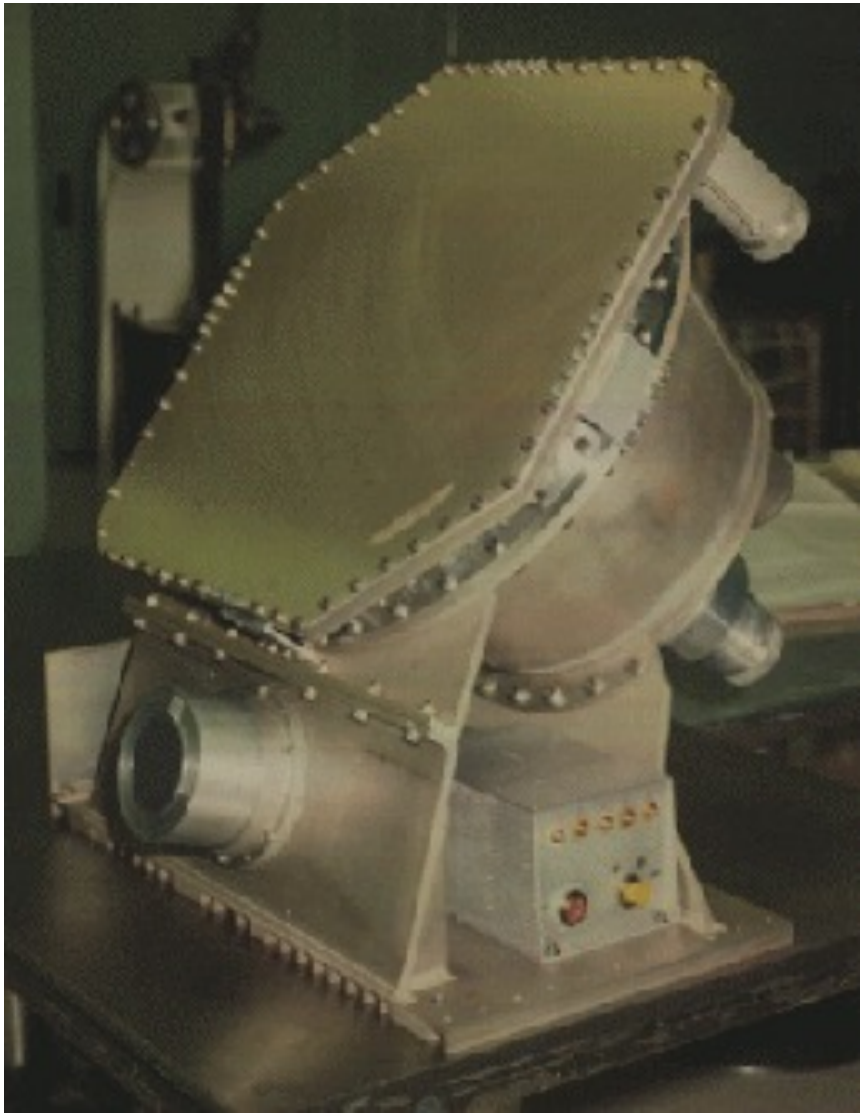




CGRO/BATSE (20 keV÷10 MeV)

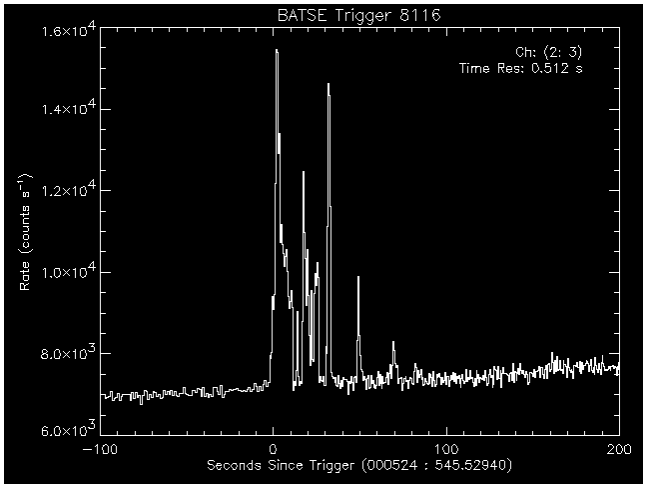
The BATSE instrument

- NaI scintillators
- 20 keV – 10 MeV
- FoV 4π (LAD) – 2 MeV
- SD spectroscopy – 10 MeV

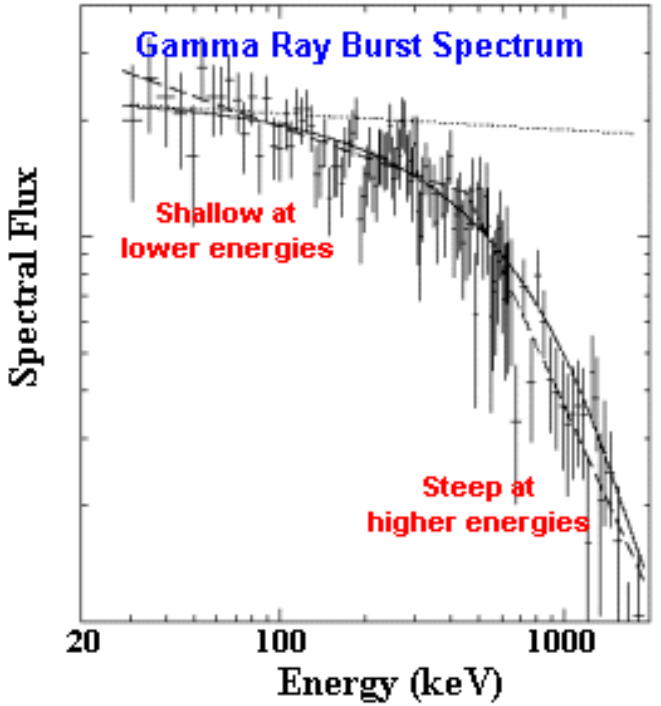


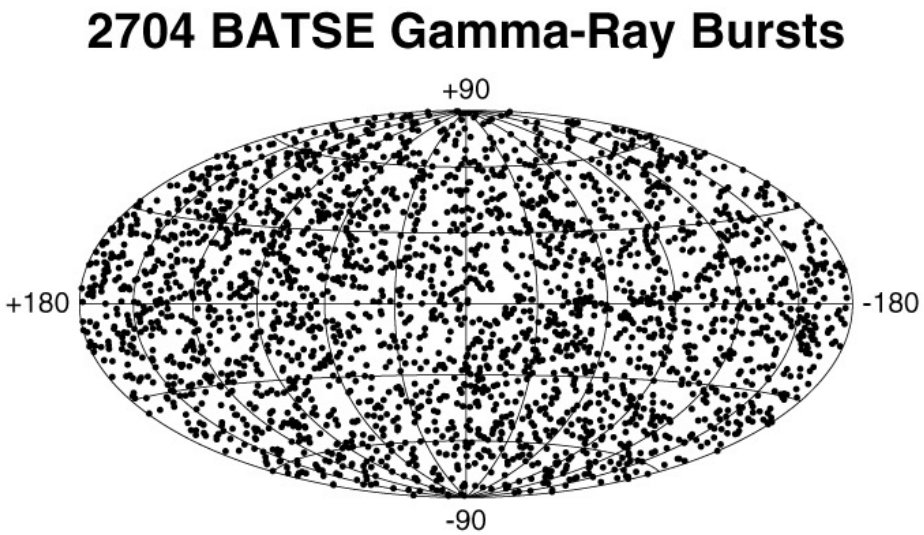
Gamma-Ray Bursts

Temporal behaviour



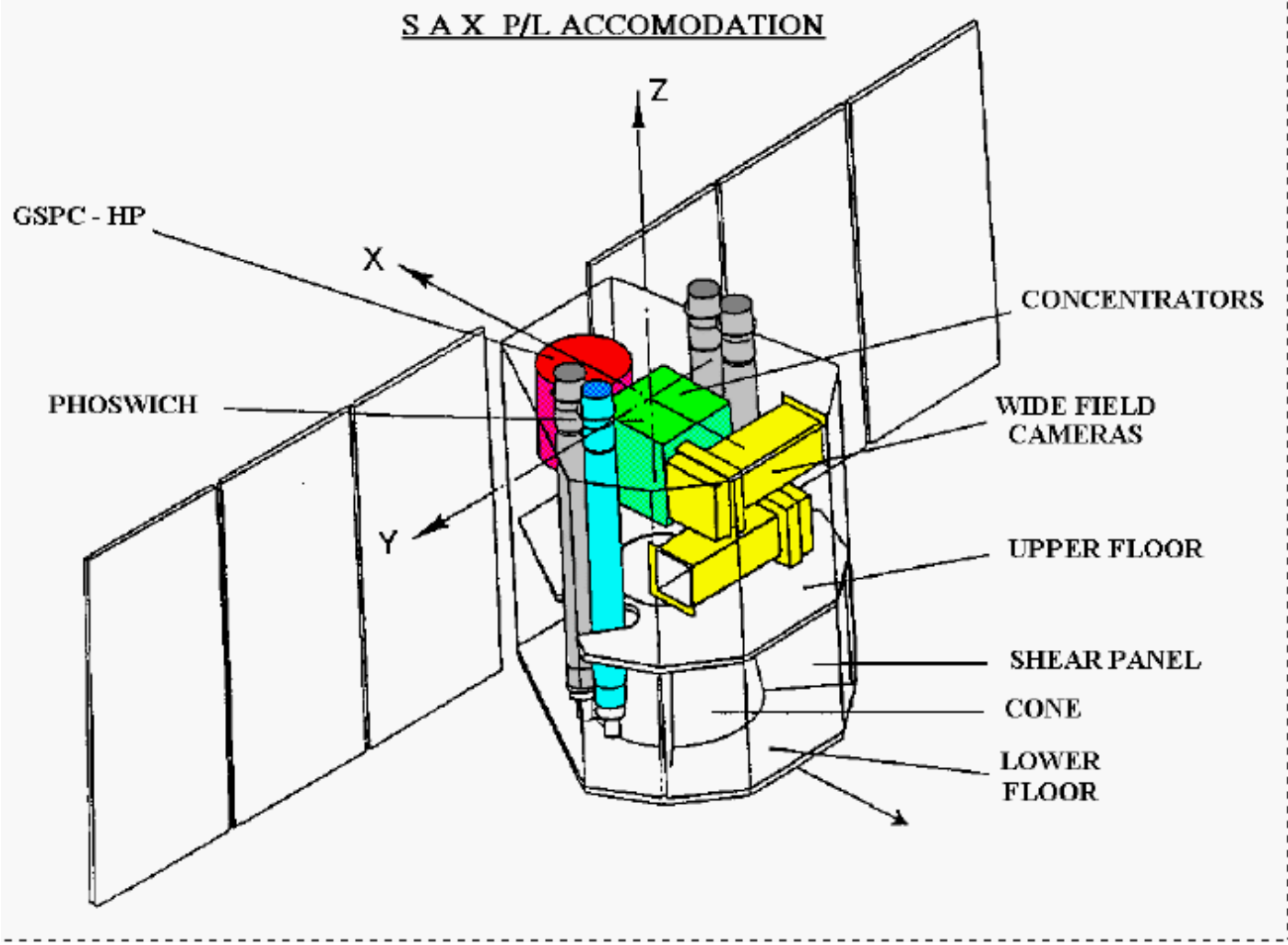
Spectral shape



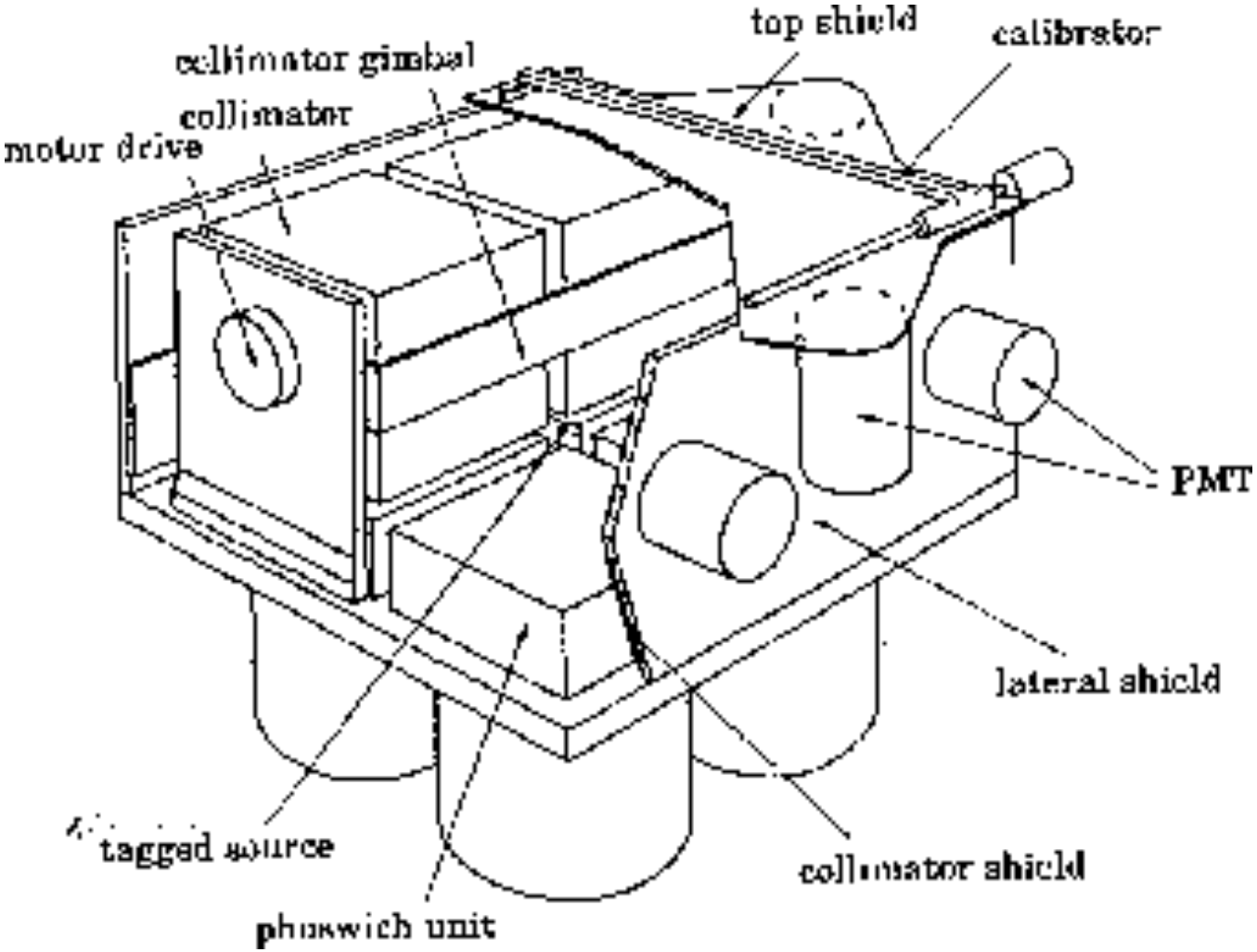


Spatial distribution

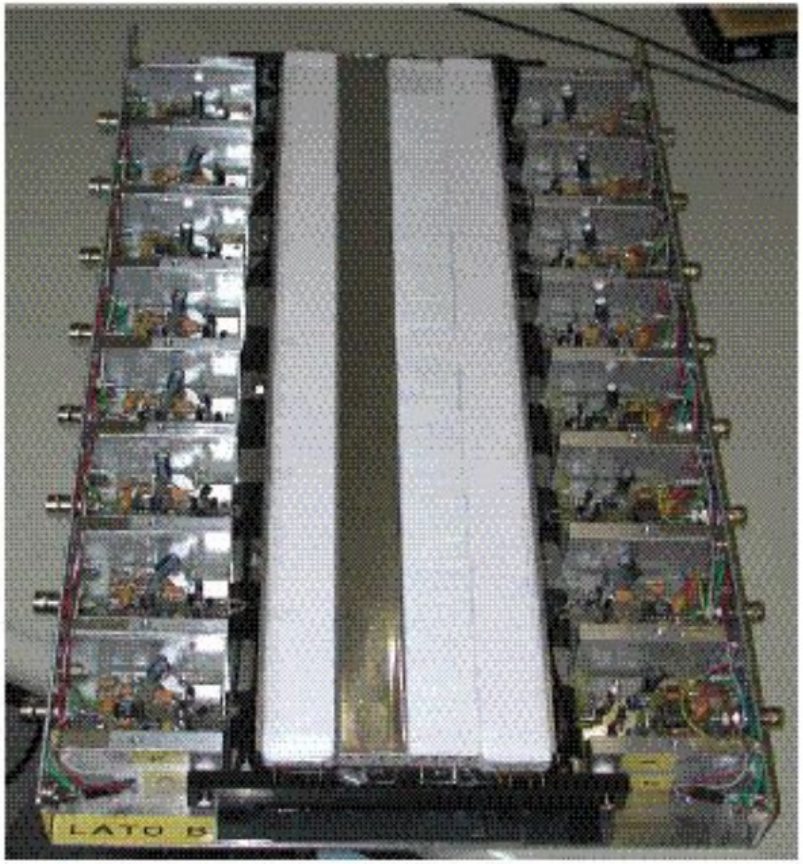
BeppoSAX (1995 - 2002)



BeppoSAX (1995 - 2002)



AGILE MCAL (2007-2024)



MINI-CALORIMETER

DETECTOR

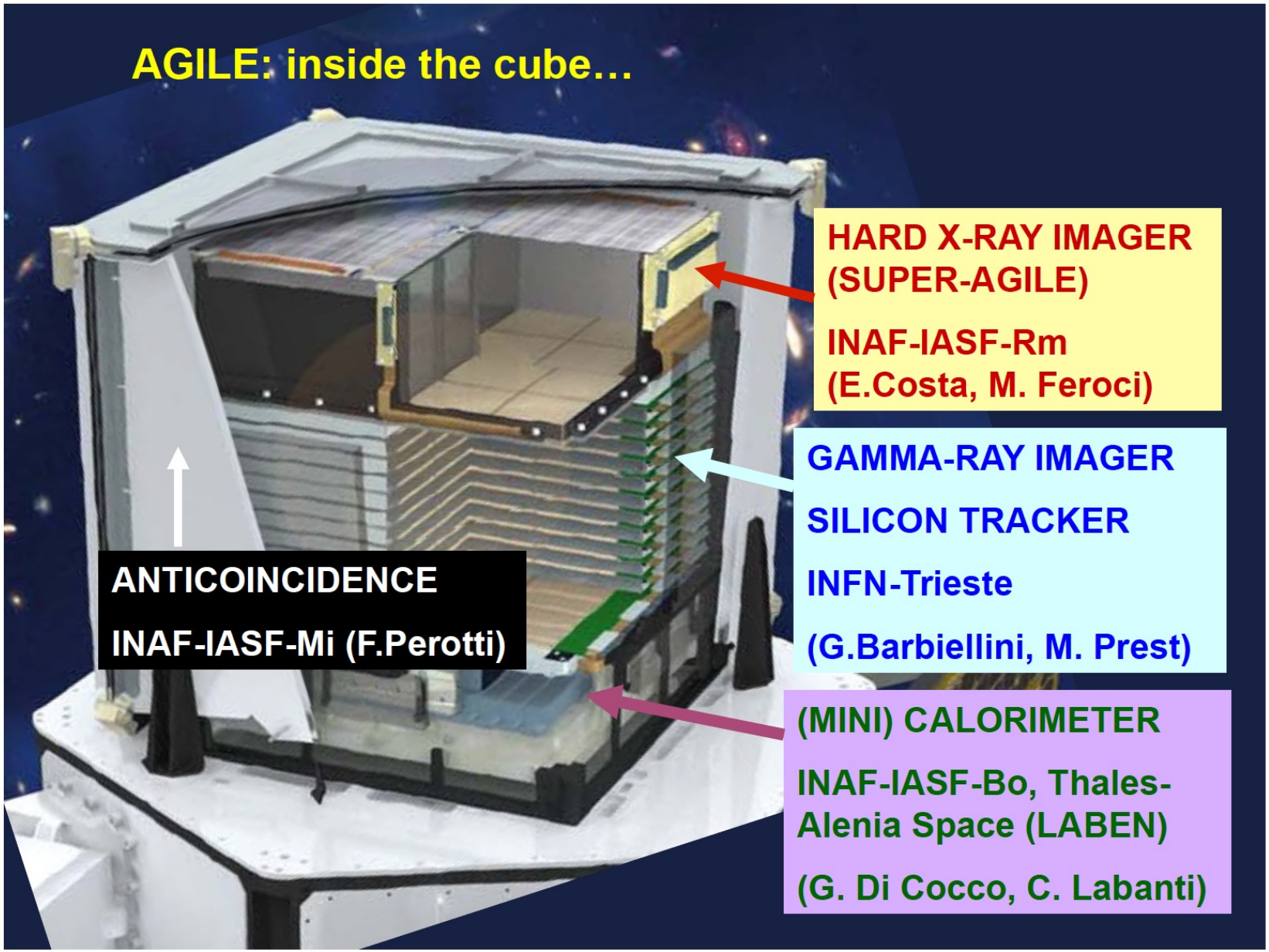
30 CsI bars wrapped with tight diffusion material organized in 2 orthogonal trays
- bar dimension: 40x2.3x1.5 cm^3
- total radiation length: $1.5X_0$ (in axis)

FRONTEND ELECTRONICS
- 1 photodiode on each side of the bar
- optically coupled

GOAL
- measure energy deposit of the photon conversion pair (GRID mode)
- detect GRBs and transients in the range 0.25-250MeV (BURST mode)

SCIENTIFIC FEATURES
- energy resolution: 22-24%(FWHM) @ 1MeV
  0.7% @ 100MeV
- spatial resolution: 15mm @ 1MeV
  2mm @ 100MeV
- timing resolution: 2μs (BURST mode)

AGILE MCAL (2007-2024)



MCAL GRB Catalog

The Second AGILE-MCAL GRB Catalog

AGILE GRBs observed from November 2007 to November 2020

Help

Show/hide columns

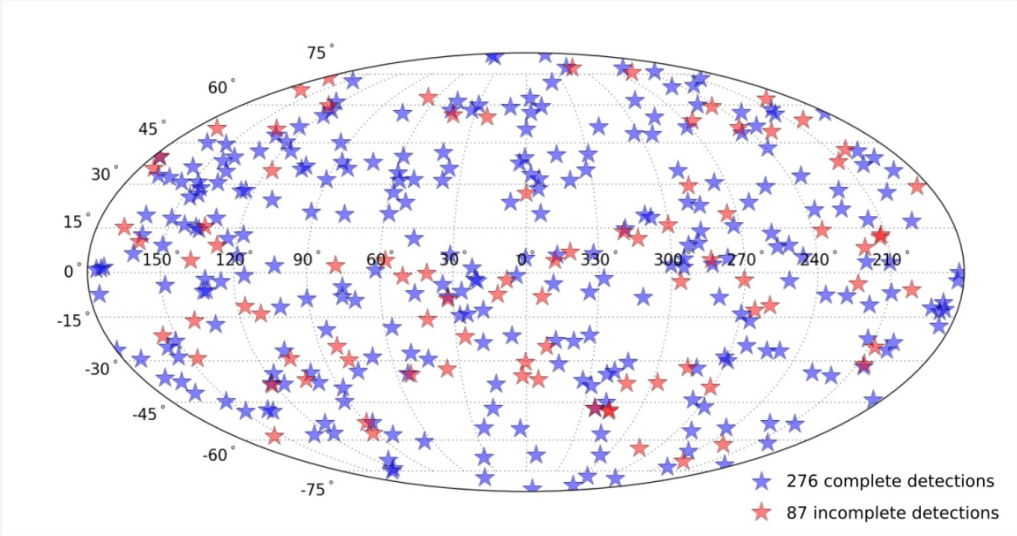
Advanced filtering

Print current view of table

Print complete table

Reset all filters

Catalog Description



Work in Progress SSDC VO Tools

Search table columns

Search

Cone Search

Source Name

Resolve name and search

R.A., Dec. I, b Clean

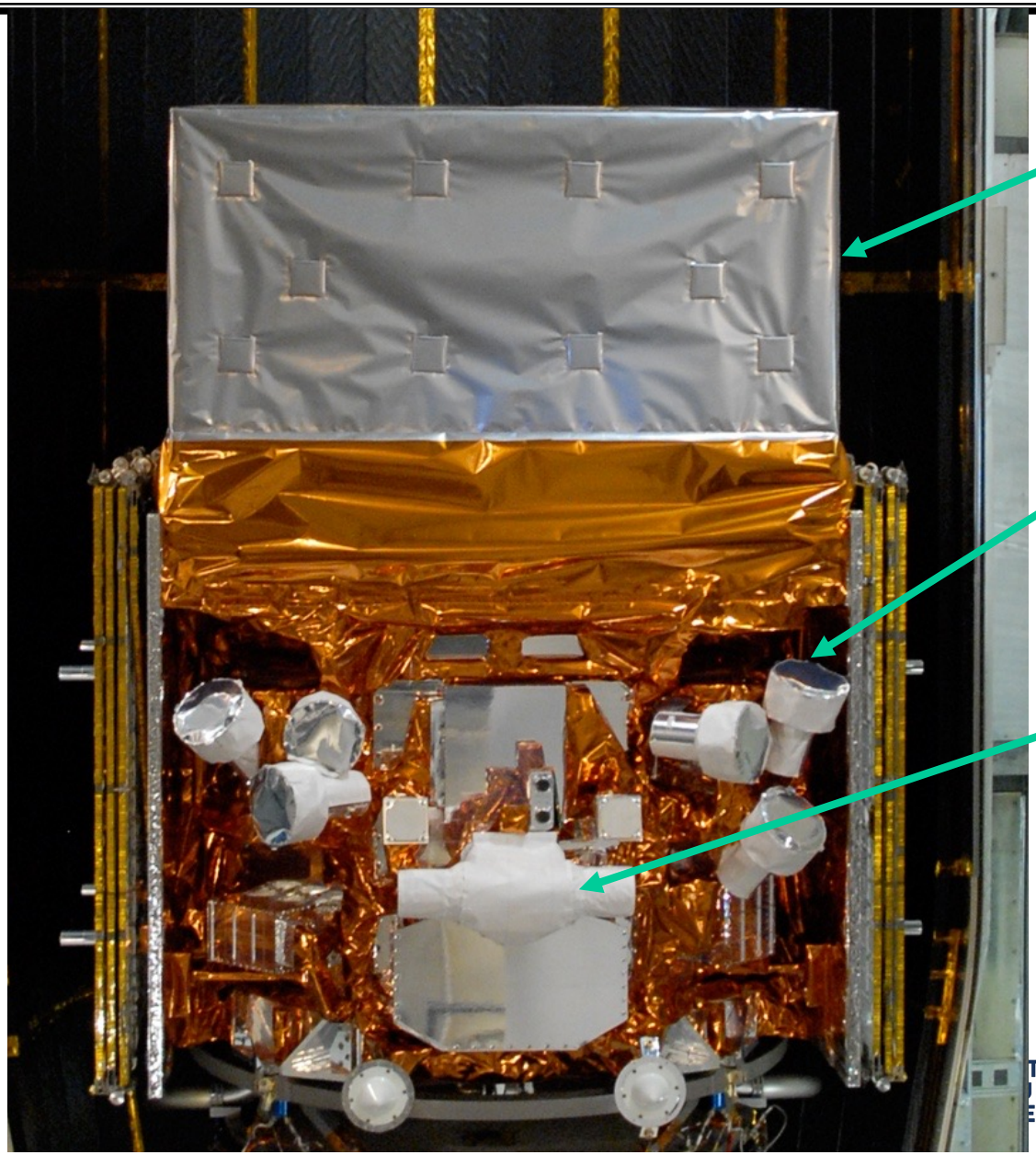
(e.g. 00 02 34.6,-53 01 10.2 or 0.64417,-53.0195)

radius 60 arcmin Search

Reset filter

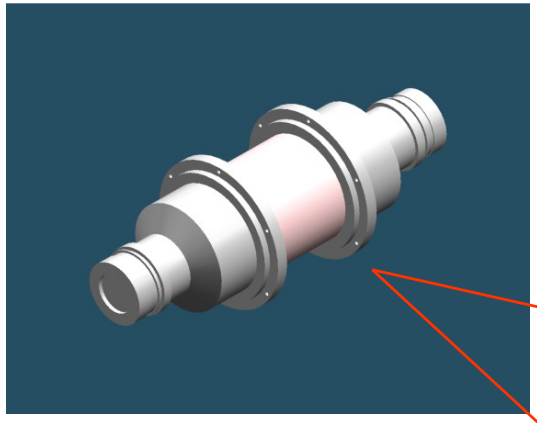
https://www.ssdc.asi.it/mcal2grbcat/

Fermi/GBM detector (2008 -- ..)



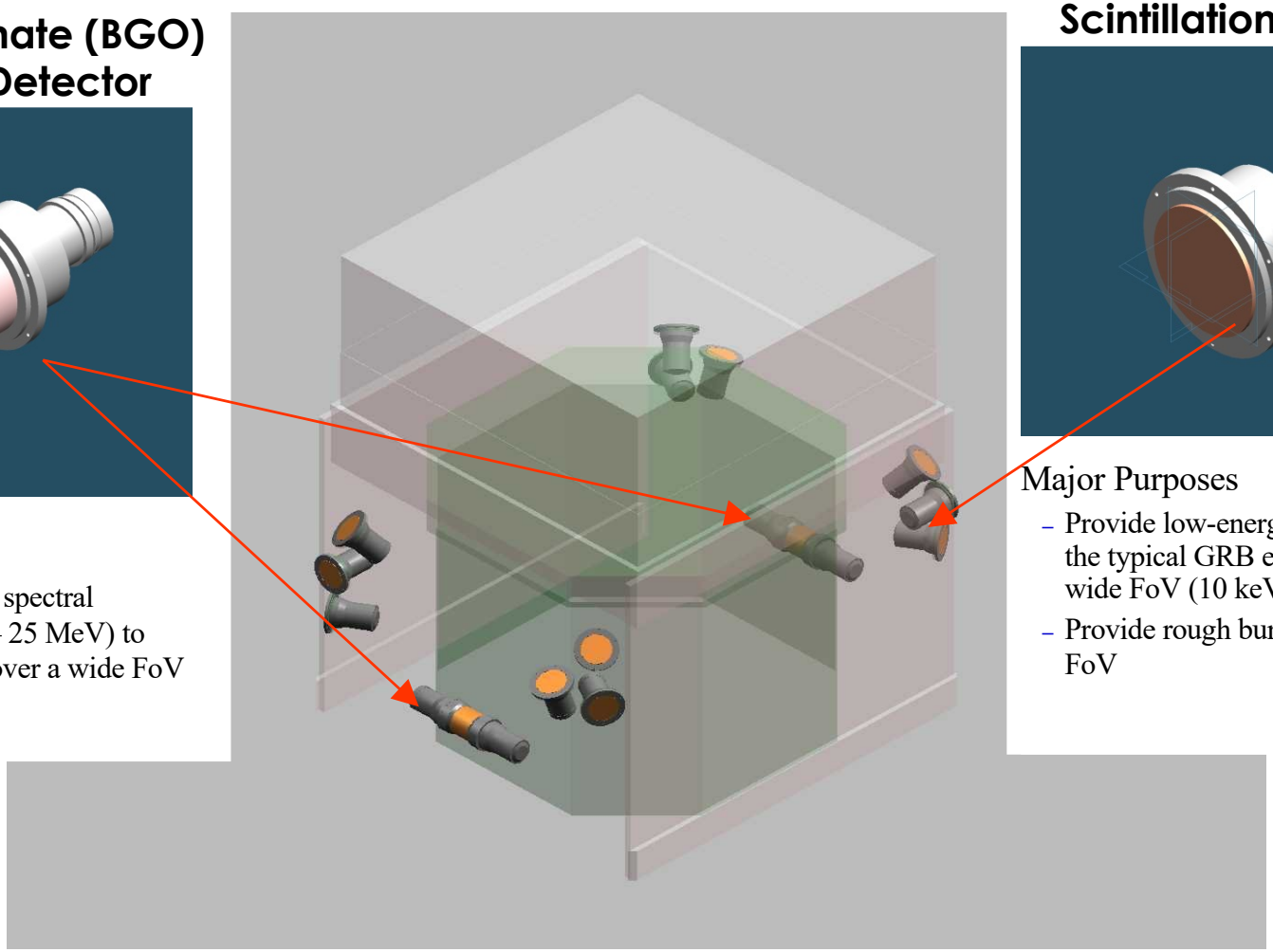
Fermi/GBM Detectors

Bismuth Germanate (BGO) Scintillation Detector



Major Purpose

- Provide high-energy spectral coverage (150 keV – 25 MeV) to overlap LAT range over a wide FoV



(12) Sodium Iodide (NaI) Scintillation Detectors

Major Purposes

- Provide low-energy spectral coverage in the typical GRB energy regime over a wide FoV (10 keV – 1 MeV)
- Provide rough burst locations over a wide FoV

Provides spectra for GRB from 10 keV to 30 MeV.

Provides wide sky coverage (8 sr)

GBM GRB Catalog

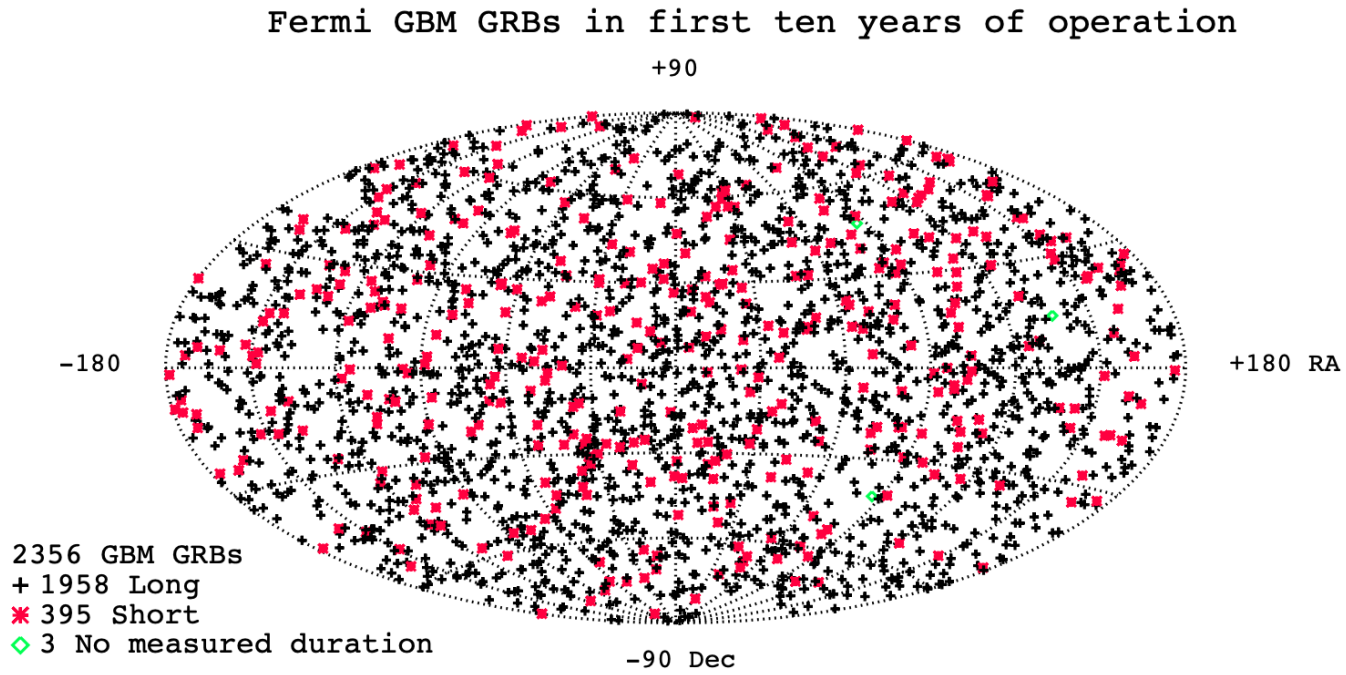
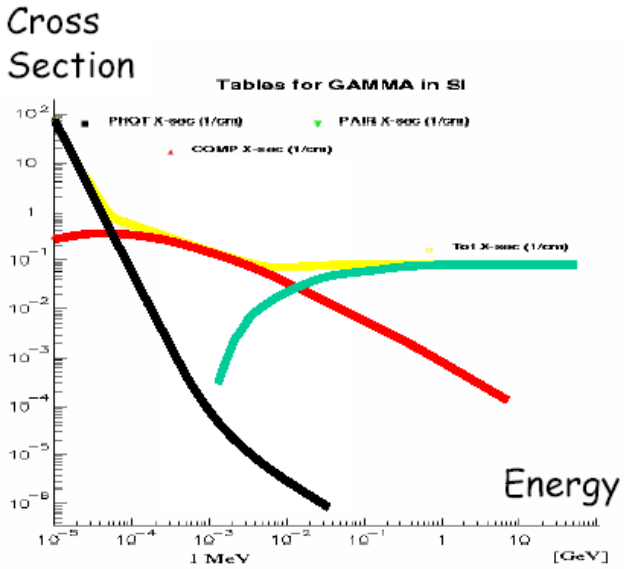


Figure 3. Sky distribution of GBM-triggered GRBs in celestial coordinates. Crosses indicate long GRBs ($T_{90} > 2$ s); asterisks indicate short GRBs.

Von Kienlin et al (2020)

Compton Imaging

Detection of Gamma Radiation



Photoeffect(< 100 keV)

Photons effectively blocked and stopped

Telescopes:

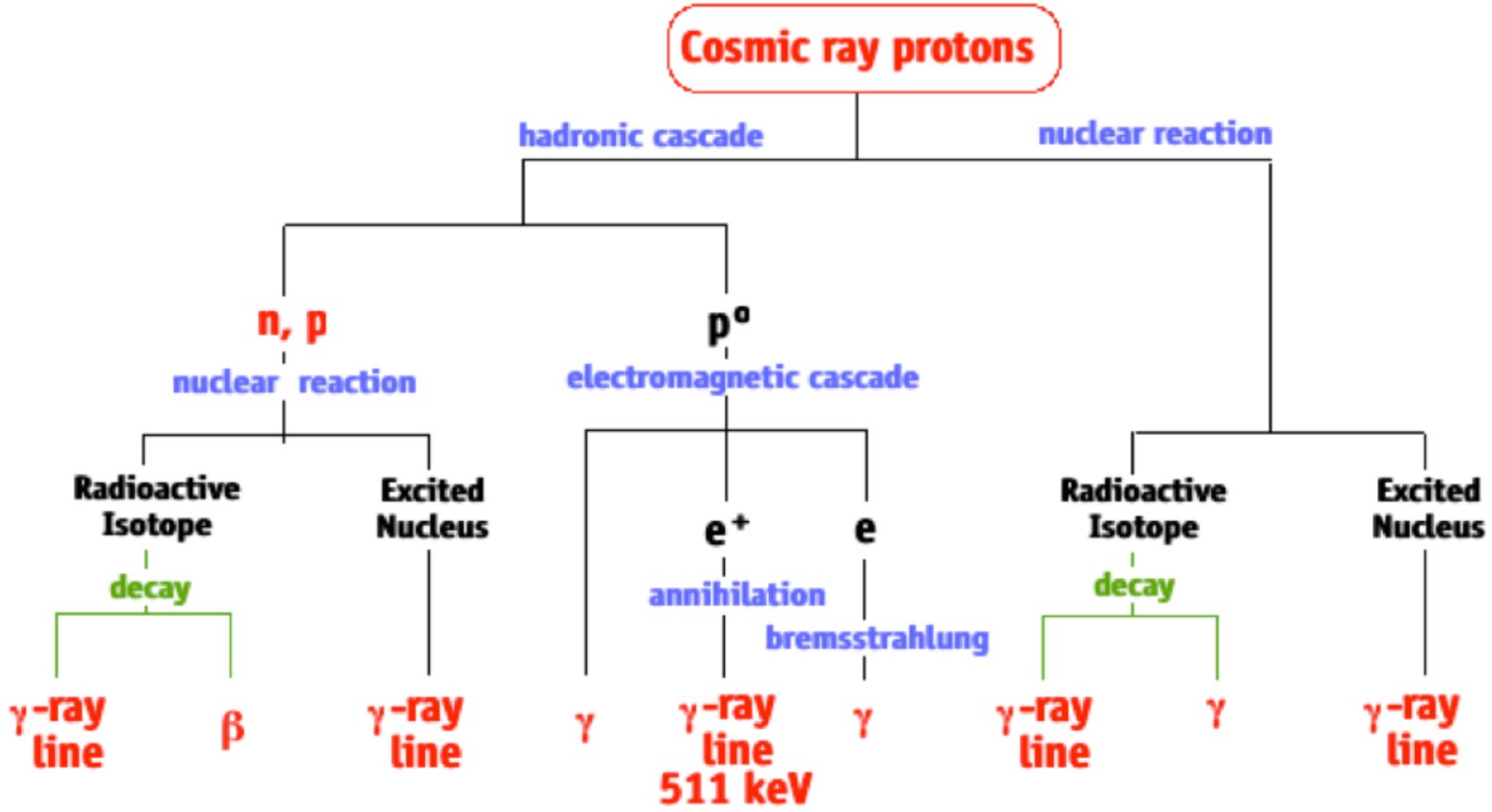
Collimators
Coded Mask Systems

Compton Scattering (0.2-10 MeV)
Photon Crossection Minimum
Scattered photons with long range
Telescope:
Compton Camera Coincidence System

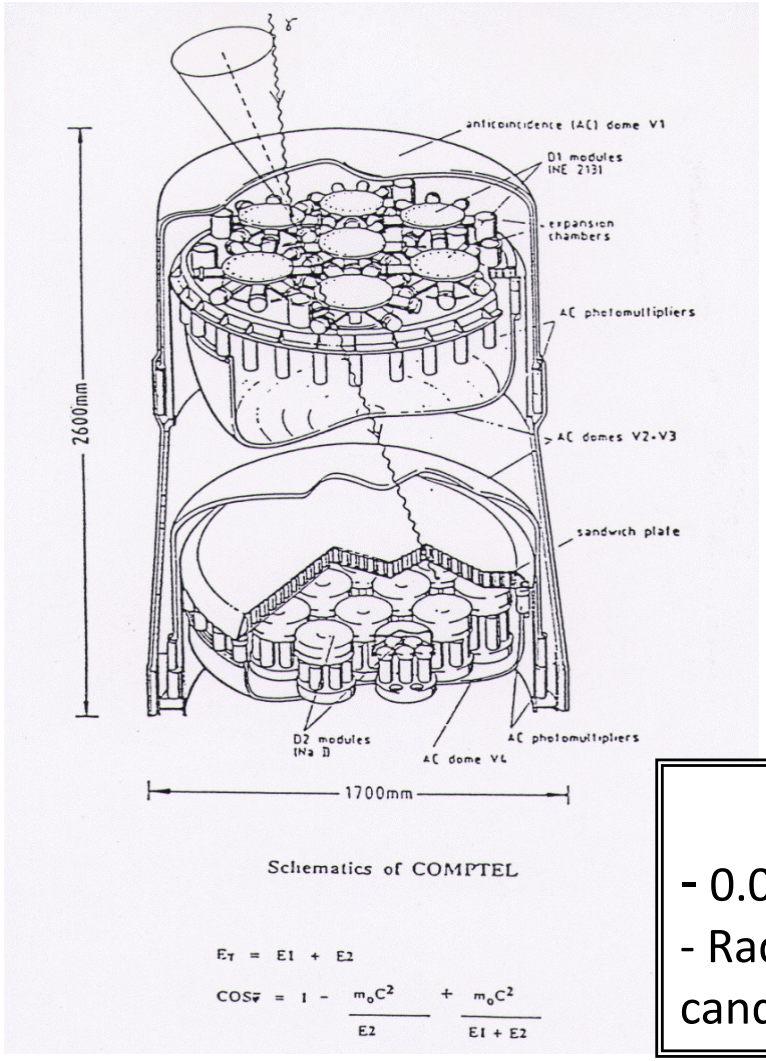
Pair Creation (> 10 MeV)
Photons completely converted to e^+e^-

Telescope:
Tracking chambers to visualize the pairs

Cosmic Ray interactions and γ-ray background



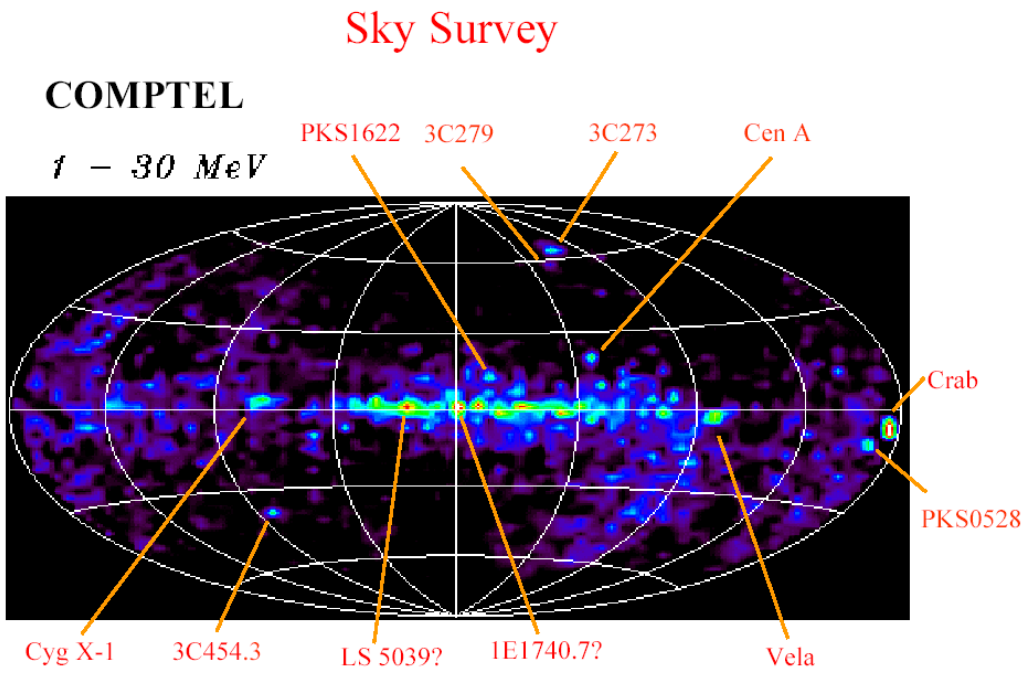
CGRO



Schematics of COMPTEL

$$E_T = E1 + E2$$

$$\cos\bar{\varphi} = 1 - \frac{m_0c^2}{E2} + \frac{m_0c^2}{E1 + E2}$$

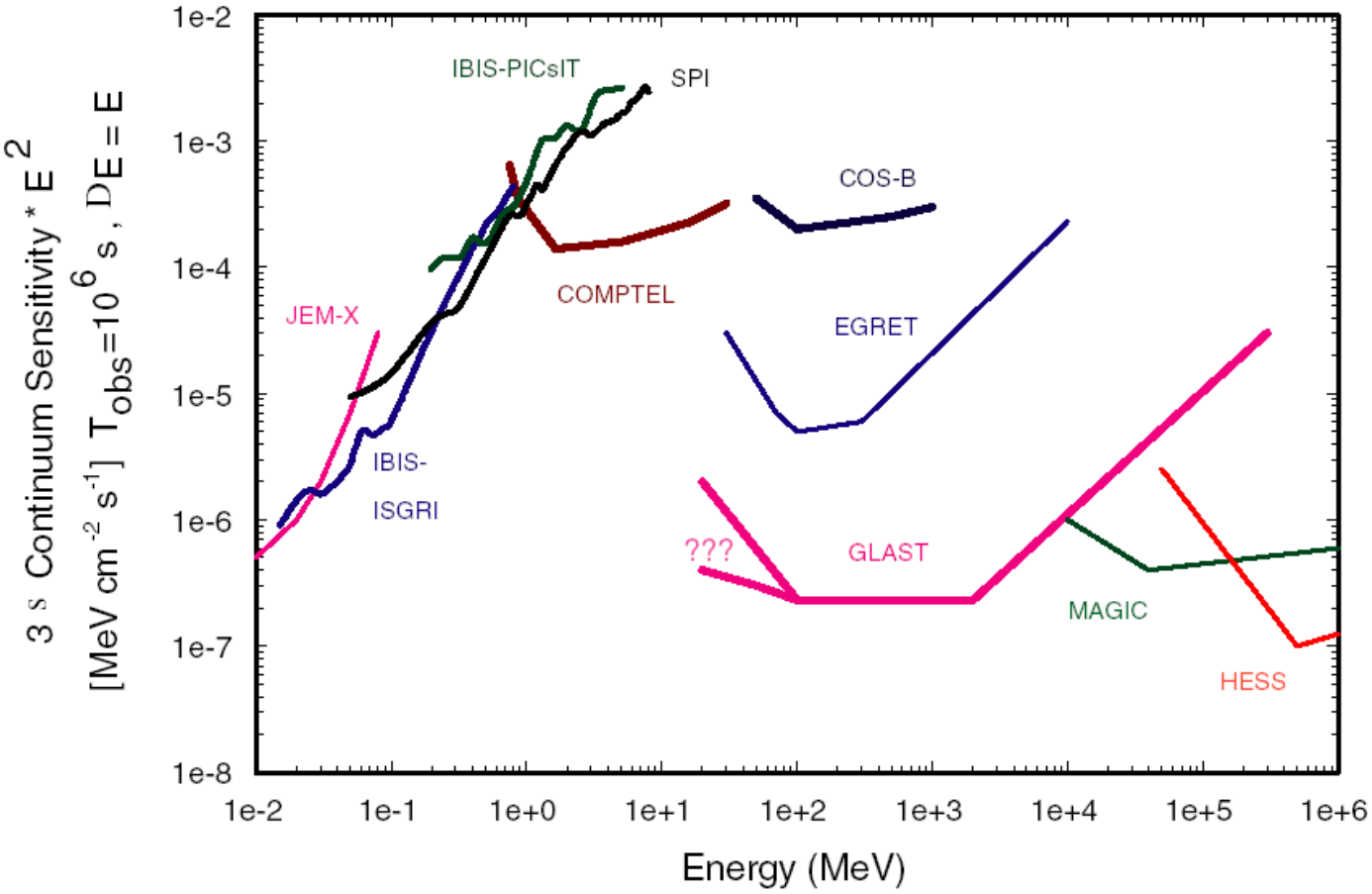


COMPTEL

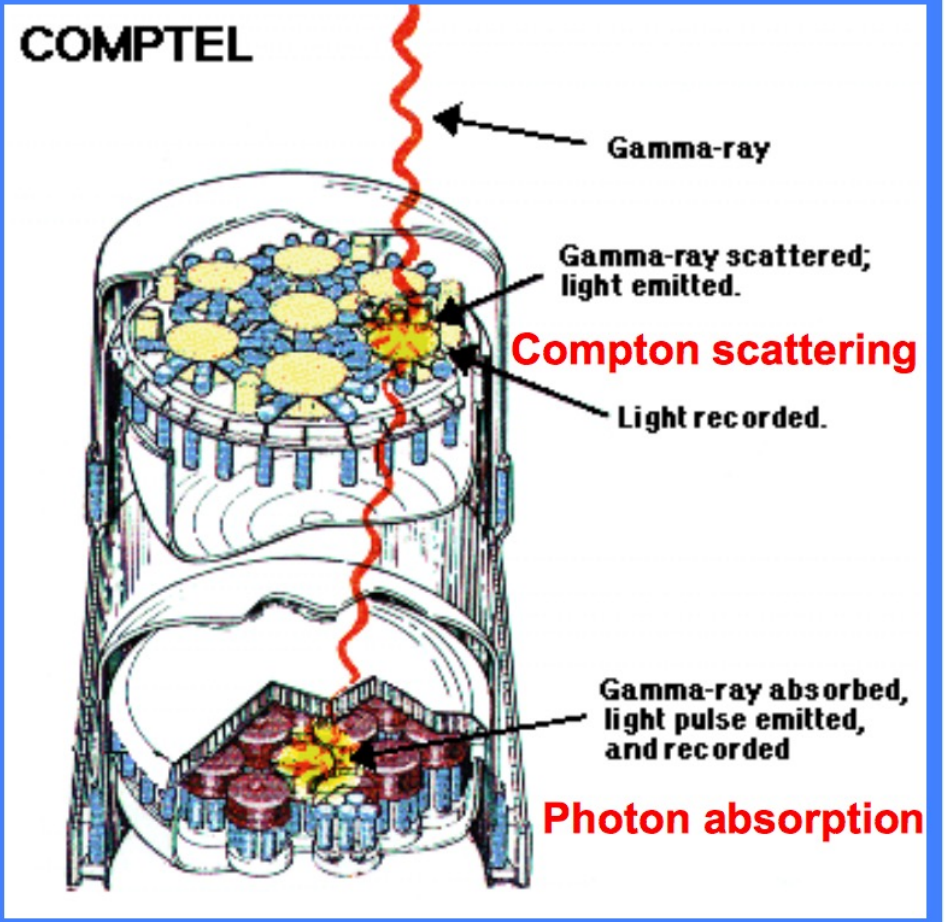
- 0.05-30 MeV
- Radioactive elements map, pulsars, a flaring black hole candidate, blazars, solar flares

Sensitivity

G. Kanbach et al. / New Astronomy Reviews 48 (2004) 275–280



Compton Telescopes



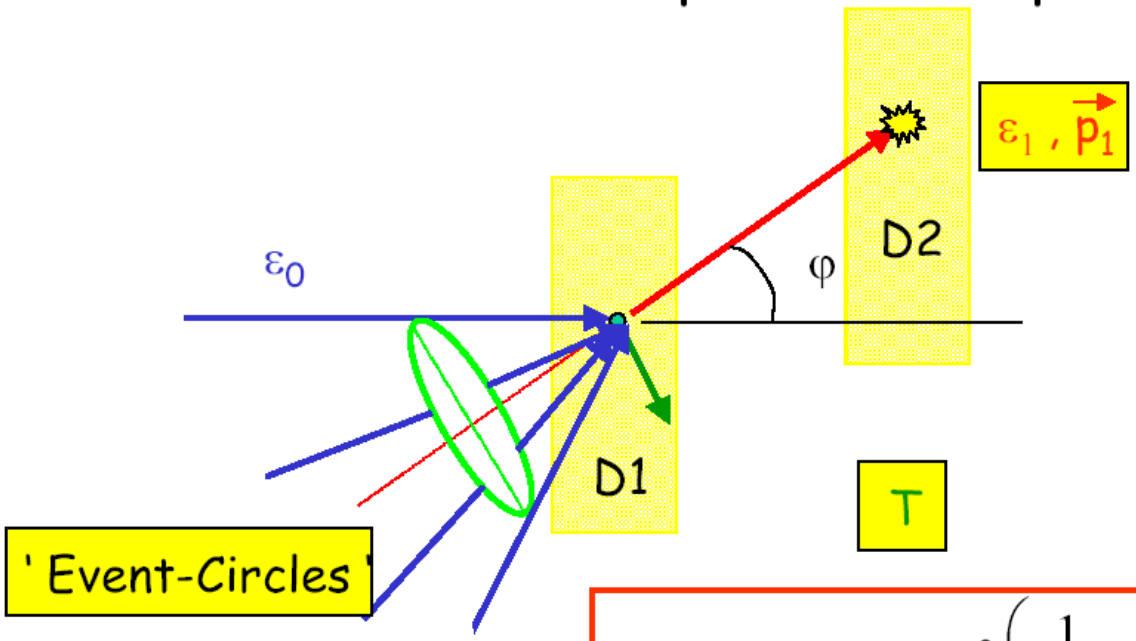
Two-level instruments:
1st level: the γ-ray Compton scatters off an electron in a **liquid scintillator**. The scattered photon enters into a **2nd level scintillator** (NaI) and is absorbed. Phototubes can determine the interaction points at the two layers and record the amount of energy deposited in each layer.

It is possible to reconstruct the angle of incidence the photon made wrt the original direction using the Compton scattering law, linking this angle and the energy of the scattered photon
(2nd level) and the scattering electron (1st level).

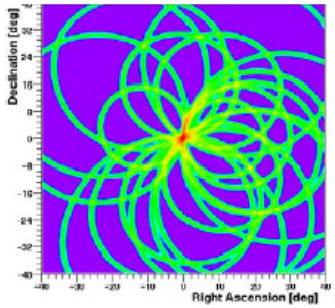
"Event circle" (ring on the sky), poor angular resolution (but multiple photons can help to reconstruct the position)

Compton Imaging

The ‚classical' Compton telescope



$$\cos\varphi = 1 - m_0 c^2 \left(\frac{1}{\varepsilon_1} - \frac{1}{\varepsilon_0} \right)$$



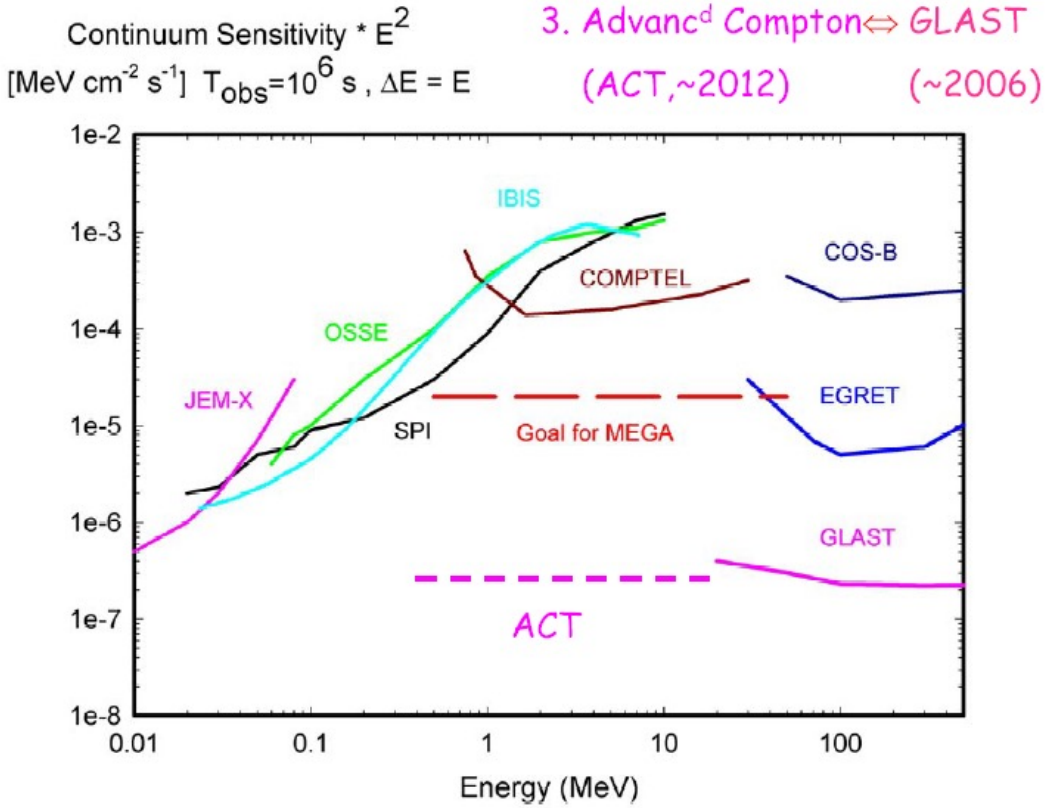
July 2002

Compton Imaging

Sensitivities

Generations of γ-ray Missions:

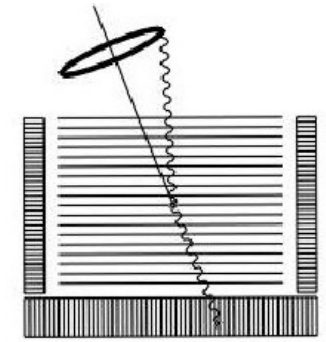
1. COMPTEL ⇔ COS-B
2. MEGA (~2006) ⇔ EGRET
3. Advanc^{d} Compton ⇔ GLAST
   (ACT, ~2012) (~2006)

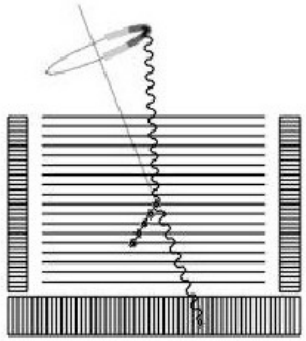


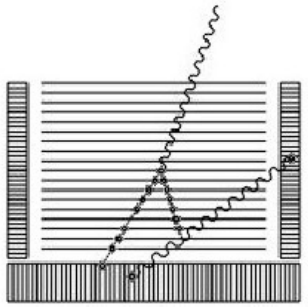
Compton Imaging

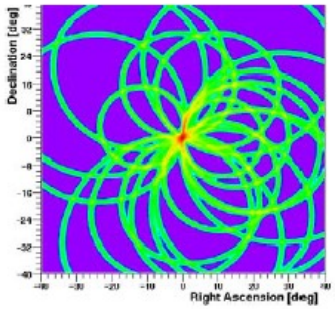
Coincidence Detector Schematics

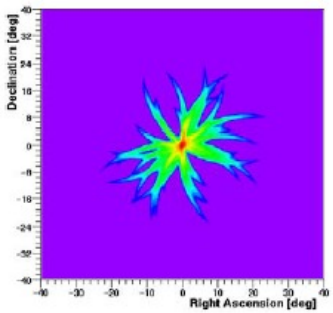
Classical Compton Event Circles (no electron tracking)	Reduced Compton circles of events with electron track	Direct imaging of pair-creation events

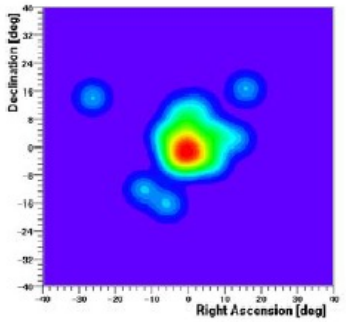






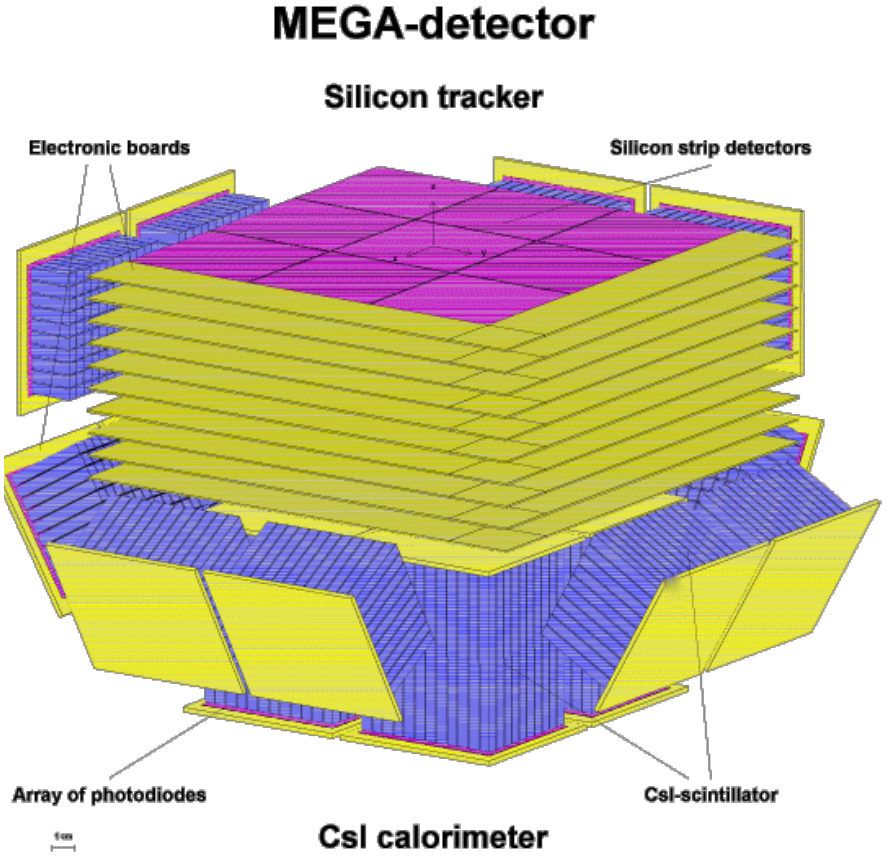






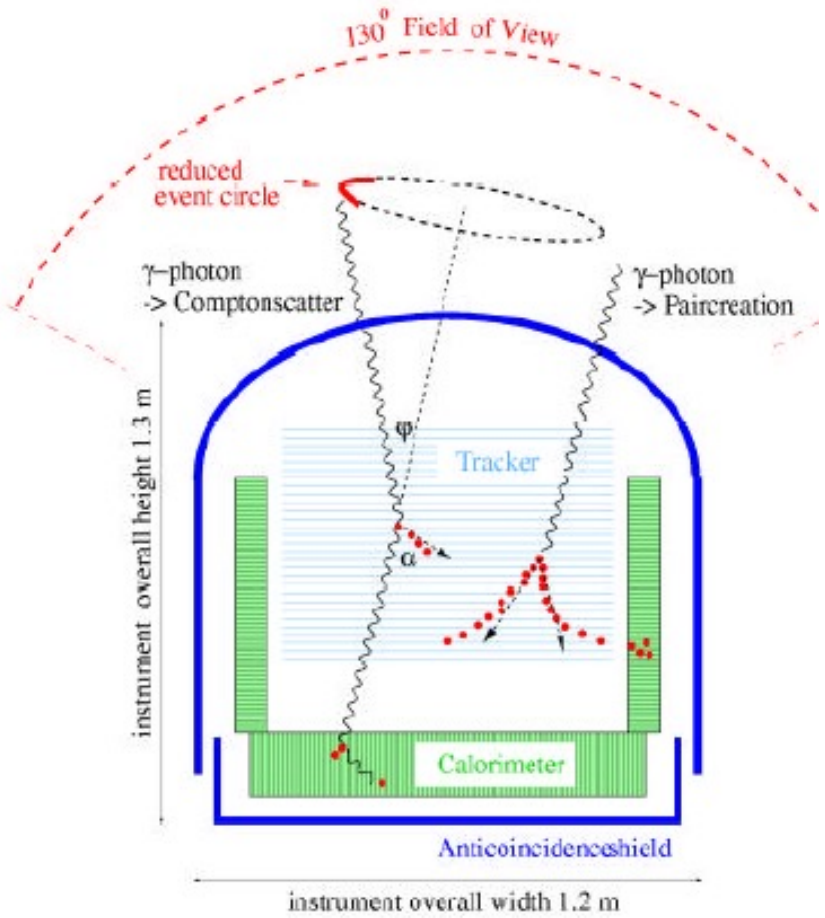
MEGA

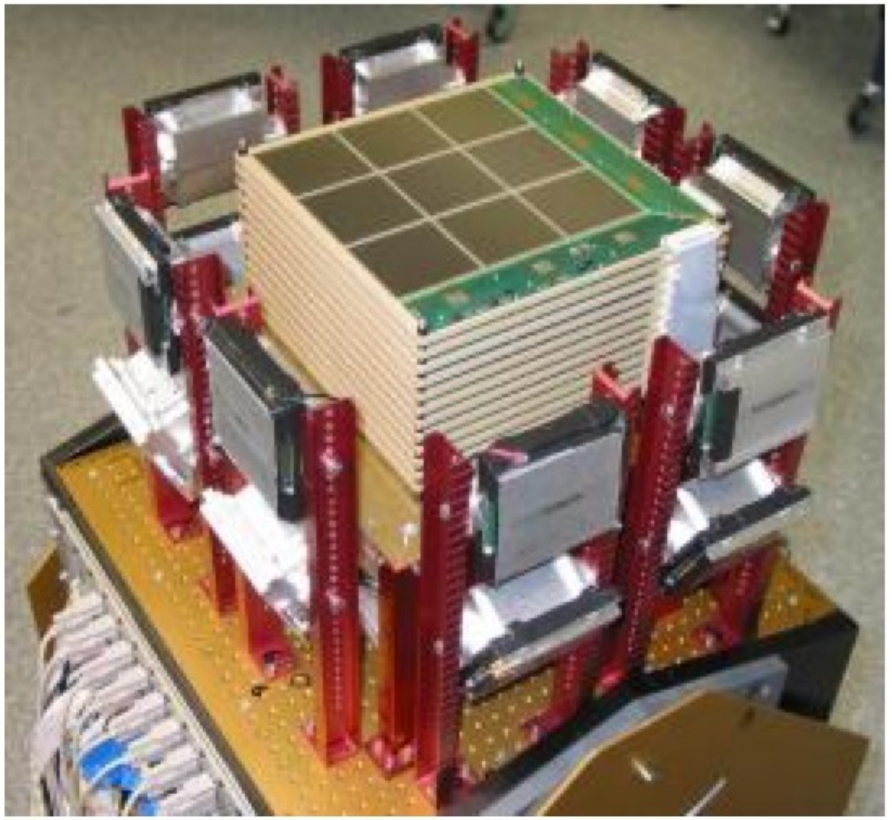
MEGA was planned as a telescope for
Medium **E**nergy **G**amma-Ray **A**stronomy
in the energy range between 400 keV and 50 MeV.
In this energy range MEGA exploited the two dominating interaction mechanisms for gamma rays:
Compton scattering and Pair creation.
MEGA had two detectors: A tracker, consisting of double-sided silicon strip detectors,
and a calorimeter, consisting of highly segmented CsI(Tl) bars. In the tracker the Compton and Pair interactions take place and the direction and energy of the participating electrons and positrons is measured.
In the calorimeters the Compton scattered gamma rays are stopped and thus their energy and direction is determined.



https://www.mpe.mpg.de/35072/MEGA

MEGA


130° Field of View
reduced event circle
γ-photon -> Comptonscatter
γ-photon -> Paircreation
Tracker
Calorimeter
Anticoincidenceshield
instrument overall height 1.3 m
instrument overall width 1.2 m



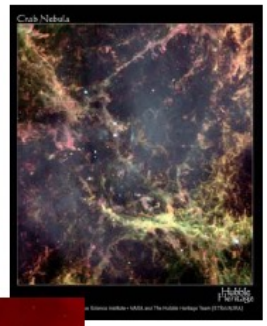
Compton Astrophysics

Cosmic Accelerators:

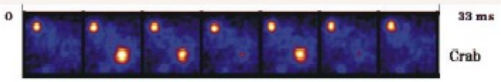
- Accretion on compact objects (relativistic jets):

  AGN, μBlazars, Binaries

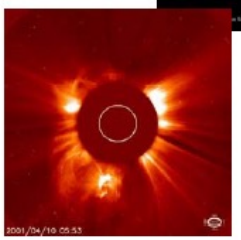
- Explosions and Shocks: GRBs, SNRs, mass. stellar winds, ISM
  Novae, Supernovae



- Rotation of NS: pulsars



- electro-magnetic dissipation: solar flares



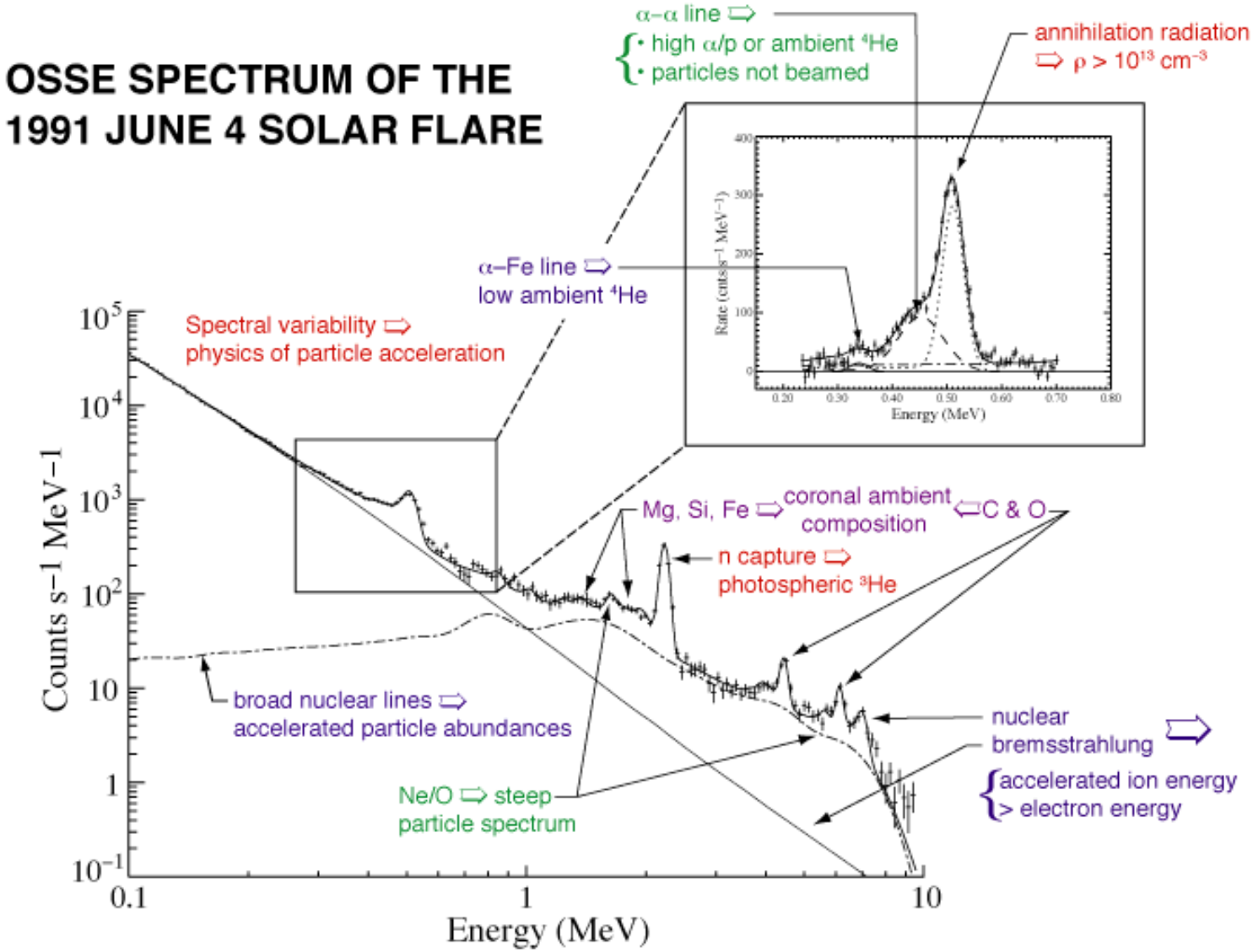
July 2002

Compton Astrophysics

Origin and characteristics of astrophysically important γ-ray lines

Isotope	Energy	$t_{1/2}$	origin
^{57}Ni	1378 keV	2.14 d	SN
^{56}Ni	812 keV	8.5 d	SN
^{56}Co	847 keV 1238 keV	111.5d	SN
^{22}Na	1275 keV	3.8 yr	Novae
^{44}Ti	1157 keV	79 yr	SNR
^{26}Al	1809 keV	1Myr	AGB and massive stars (O & WR), Novae, core-collapse SNe
$^{12}C^*$ $^{16}O^*$	4.4 MeV 6.1 MeV	prompt	cosmic ray induced ISM lines, flares
e^+, e^-	511 keV		β^+ activity, jet sources, PSR, Novae, flares etc.
$n+p \rightarrow d$	2.21 MeV		flares, flare stars?

Solar Flares lines



COSI

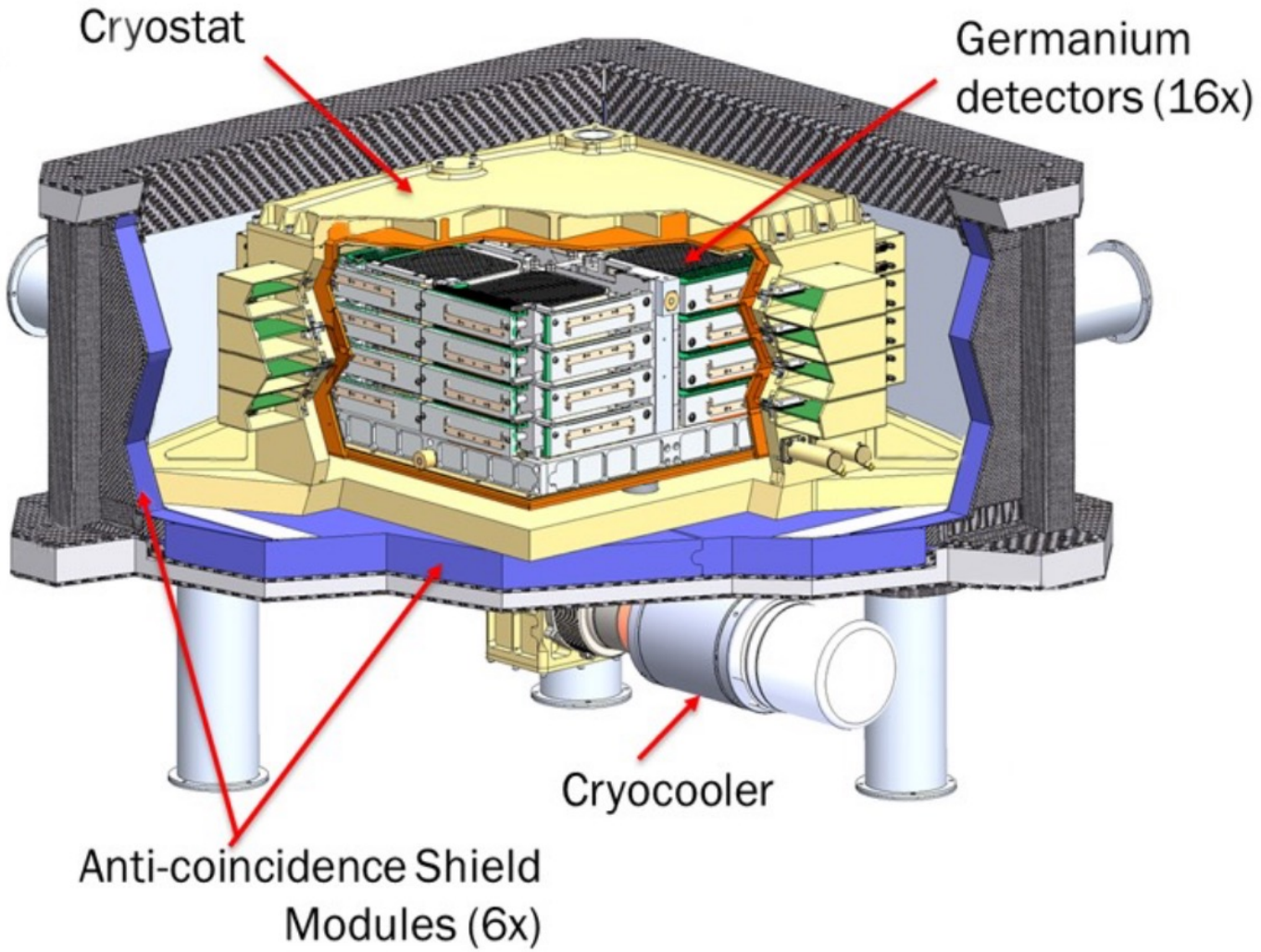
COSI

THE COMPTON SPECTROMETER AND IMAGER

HOME SCIENCE INSTRUMENT BALLOON MORE

https://cosi.ssl.berkeley.edu/

COSI



https://cosi.ssl.berkeley.edu/

COSI

COSI Science Goals

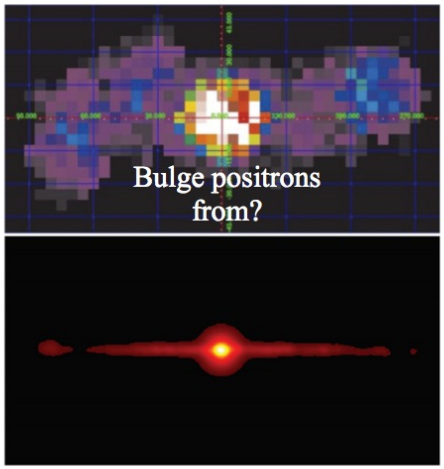
Revolutionizing our understanding of creation and destruction of matter in our Galaxy and beyond

Energy range: 0.2-5 MeV γ-rays

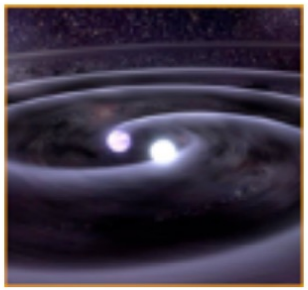
1. Uncover the origin of Galactic positrons
2. Reveal Galactic element formation
3. Gain insight into extreme environments with polarization
4. Probe the physics of multi-messenger events

511 keV with INTEGRAL (Bouchet+10)

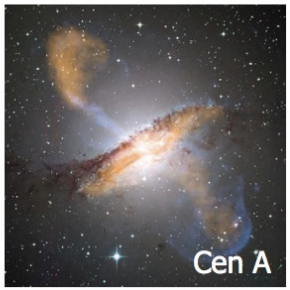
Goal 1: Positrons



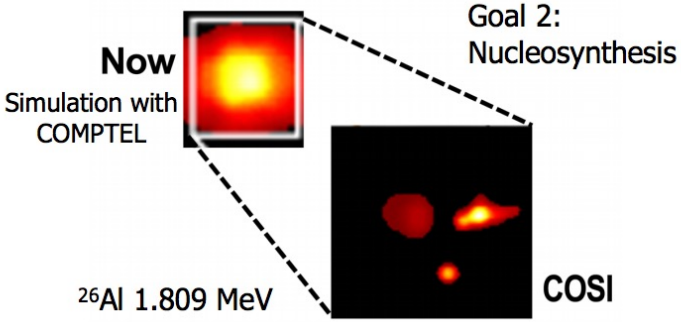
Goal 4: MMA



Goal 3: Polarization



Cygnus region



COSI

COSI: A Gamma-ray Space Explorer

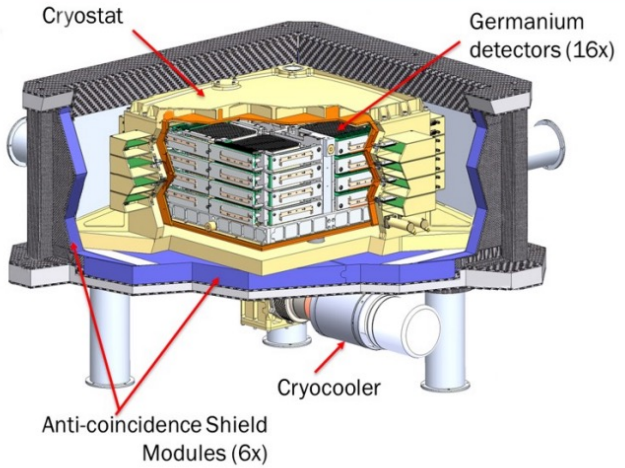
Tomsick (2021) ICRC 2021 proceedings: https://arxiv.org/abs/2109.10403
Astro2020 APC White Paper: https://arxiv.org/pdf/1908.04334.pdf

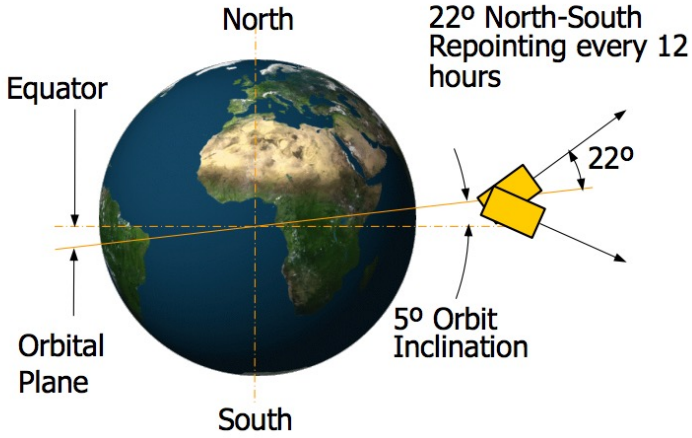
Oct 18, 2021
RELEASE 21-134

NASA Selects Gamma-ray Telescope to Chart Milky Way Evolution

https://www.nasa.gov/press-release/nasa-selects-gamma-ray-telescope-to-chart-milky-way-evolution

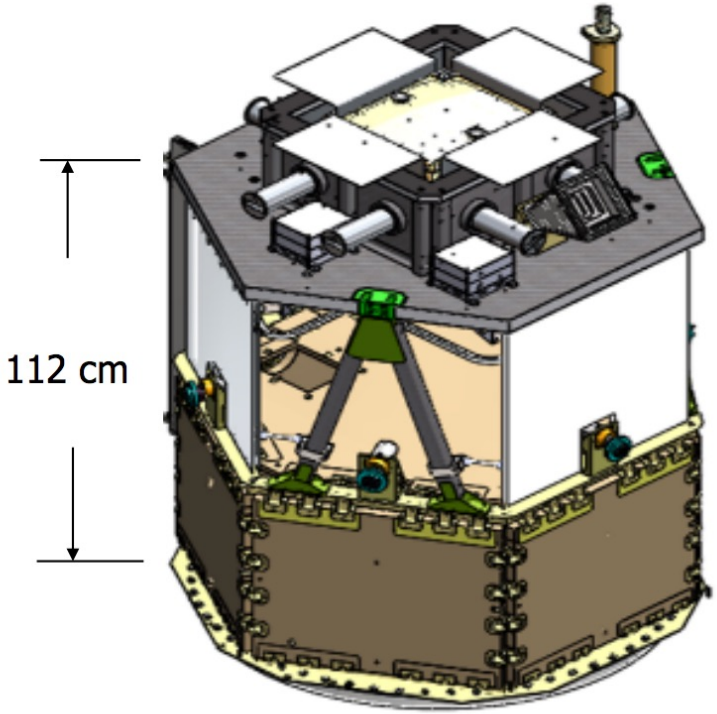
- Low-Earth orbit
- 4 more germanium detectors than COSI-APRA
- COSI constantly points away from Earth and alternates between North and South to cover the whole sky in 24 hours
  - Instantaneous FOV >4x larger than COMPTEL and >12x larger than INTEGRAL/SPI





COSI

Overview of Instrument and Requirements

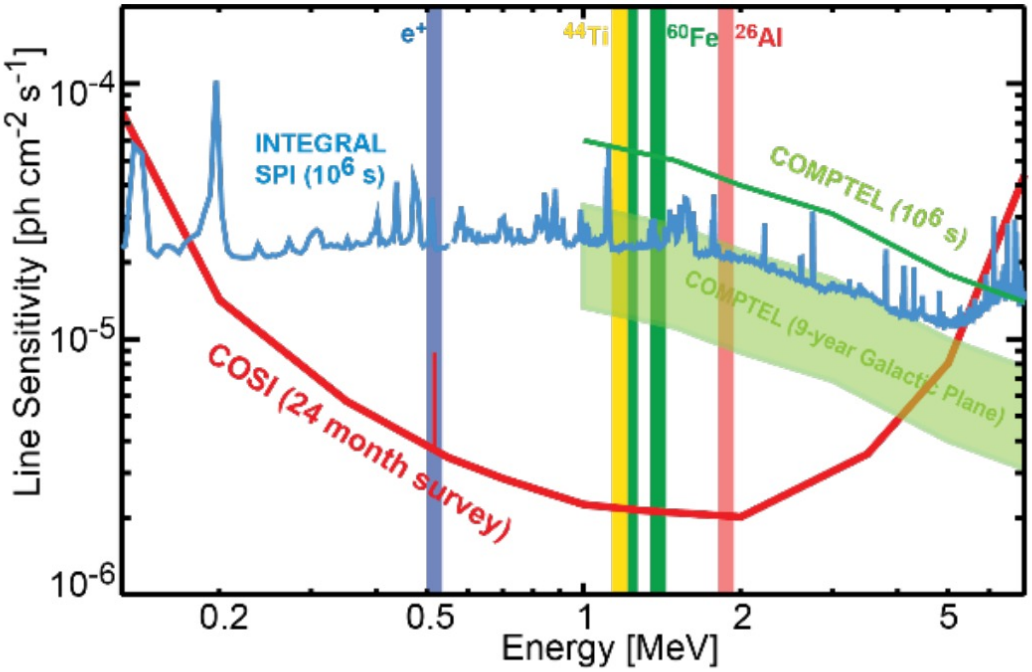


COSI instrument/payload and spacecraft

Parameter	Requirements
Energy range	0.2-5 MeV
Sky coverage	100% per day
Energy resolution	0.4% FWHM @ 1.8 MeV
Angular resolution	2.0º FWHM @ 1.8 MeV
Localizations	<1.0º for GRBs

COSI

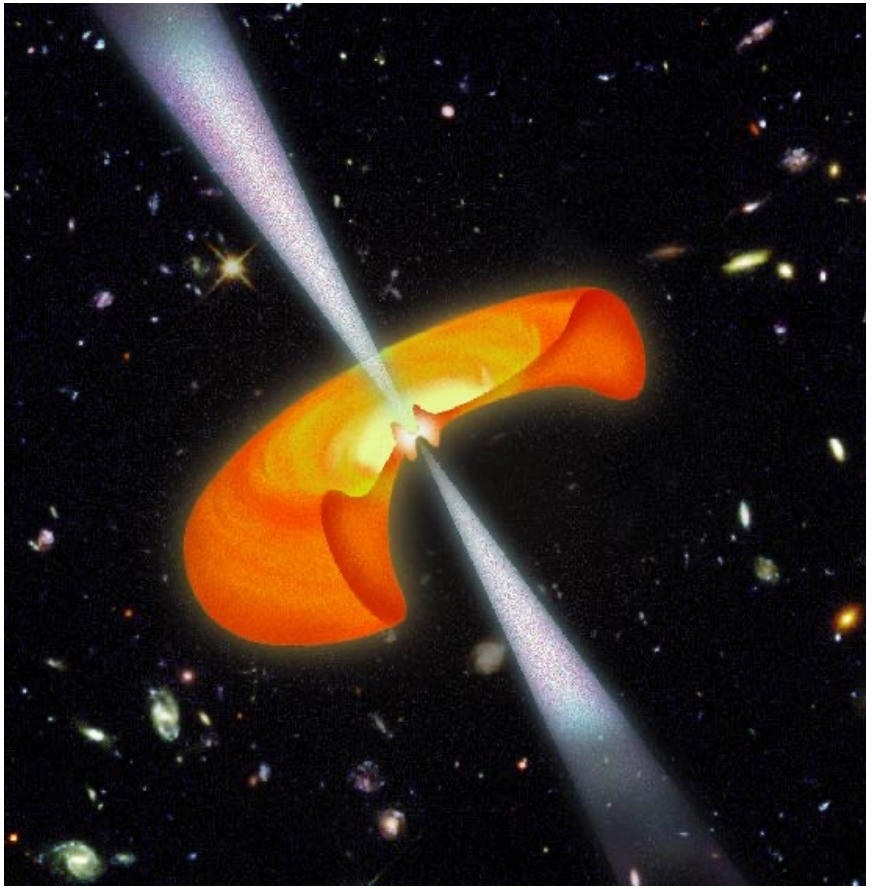
Improvement over previous and current missions



3σ line sensitivities for the 2-year COSI prime mission compared to INTEGRAL/SPI and COMPTEL

Outline

- HE gamma astrophysics
  - General Introduction
    - "The concepts"
  - Multi-wavelength astrophysics
  - Multi-messenger astrophysics
- MeV Astrophysics
  - Detector techniques
  - Fermi/GBM, COSI …
- GeV Astrophysics
  - Detector techniques
  - AGILE , Fermi/LAT
- The "near" future
  - GammaAstrophysics in the MWL and MM context …
  - Where to … ?

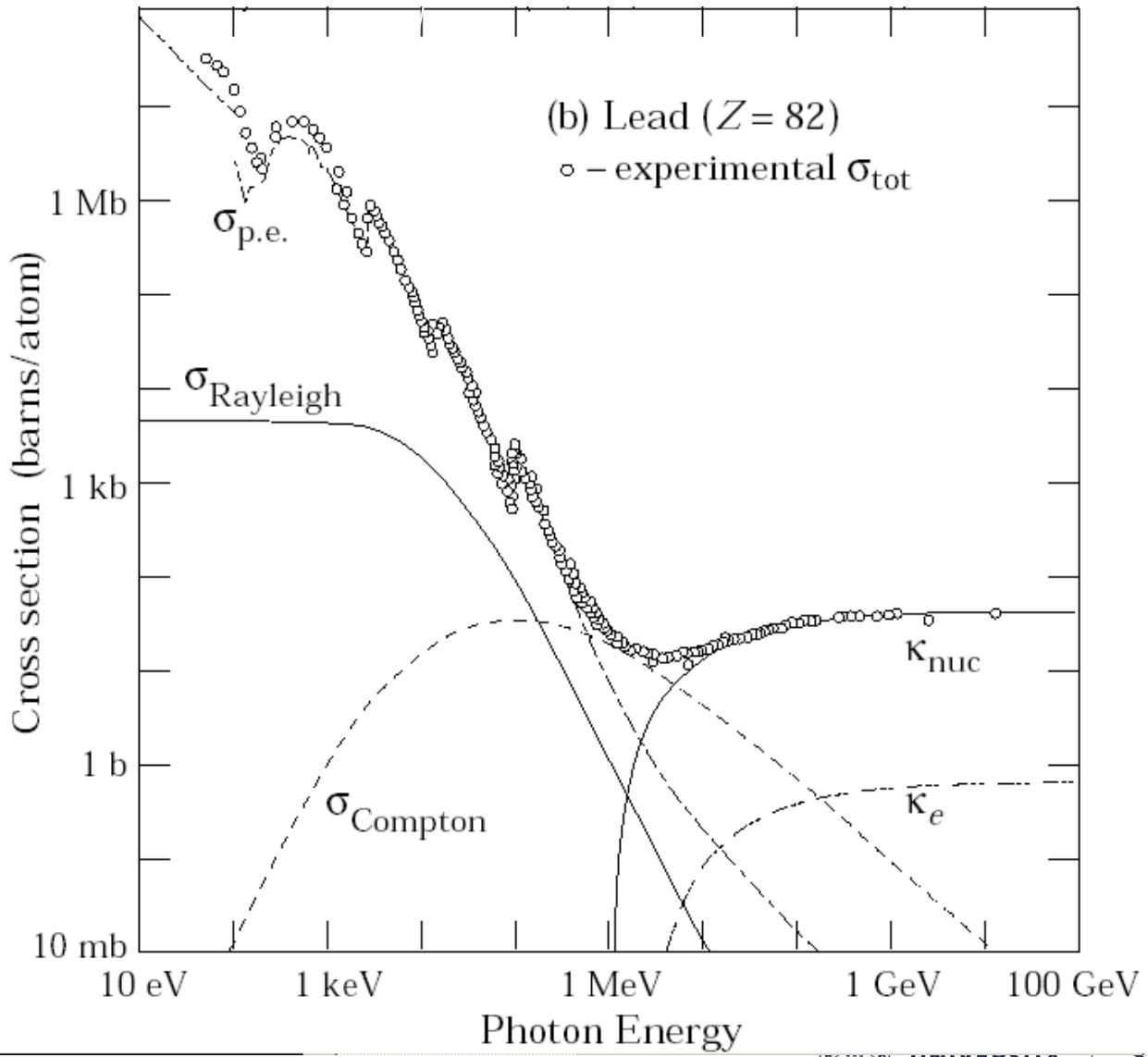


GeV Gamma-ray Astrophysics

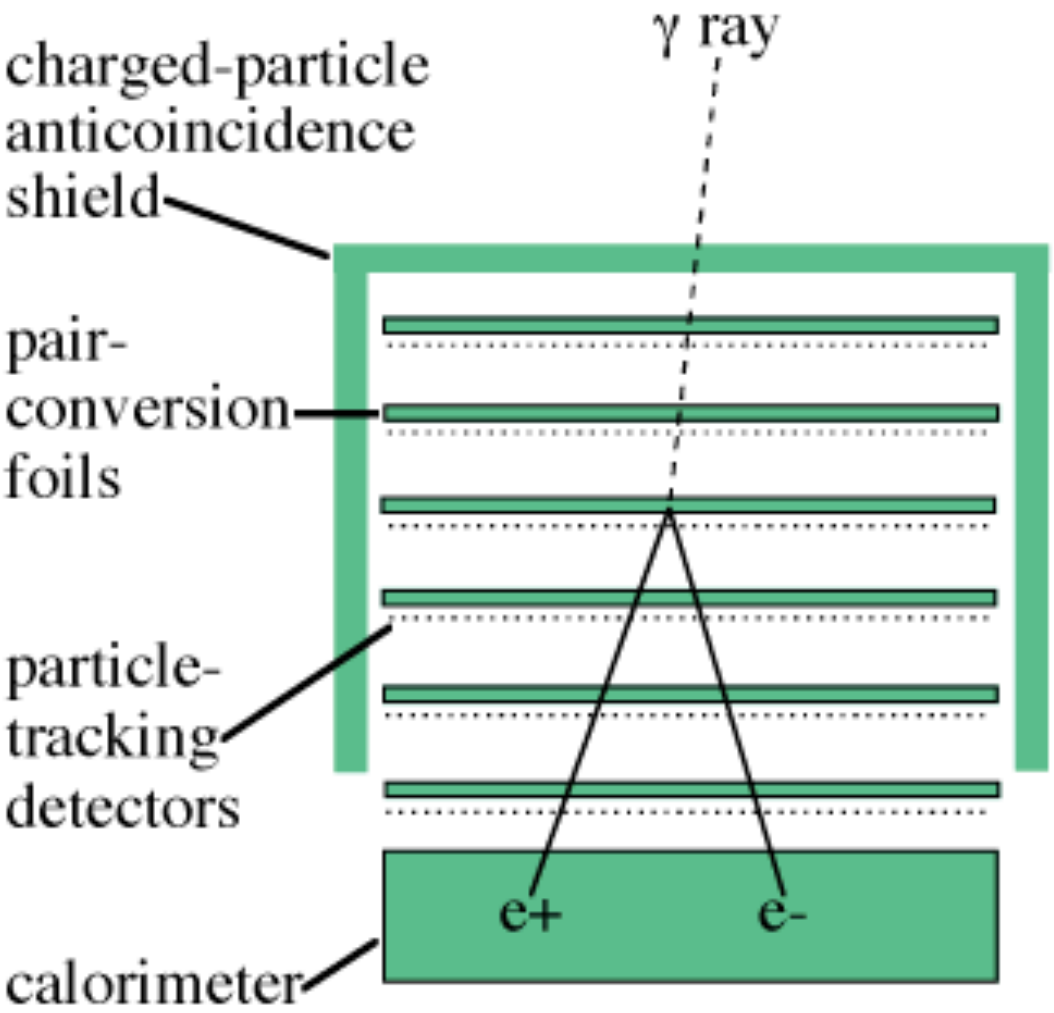
INFN TRIESTE
Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

UNIVERSITÀ DEGLI STUDI DI TRIESTE
Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

Photon Interactions



Detector Project

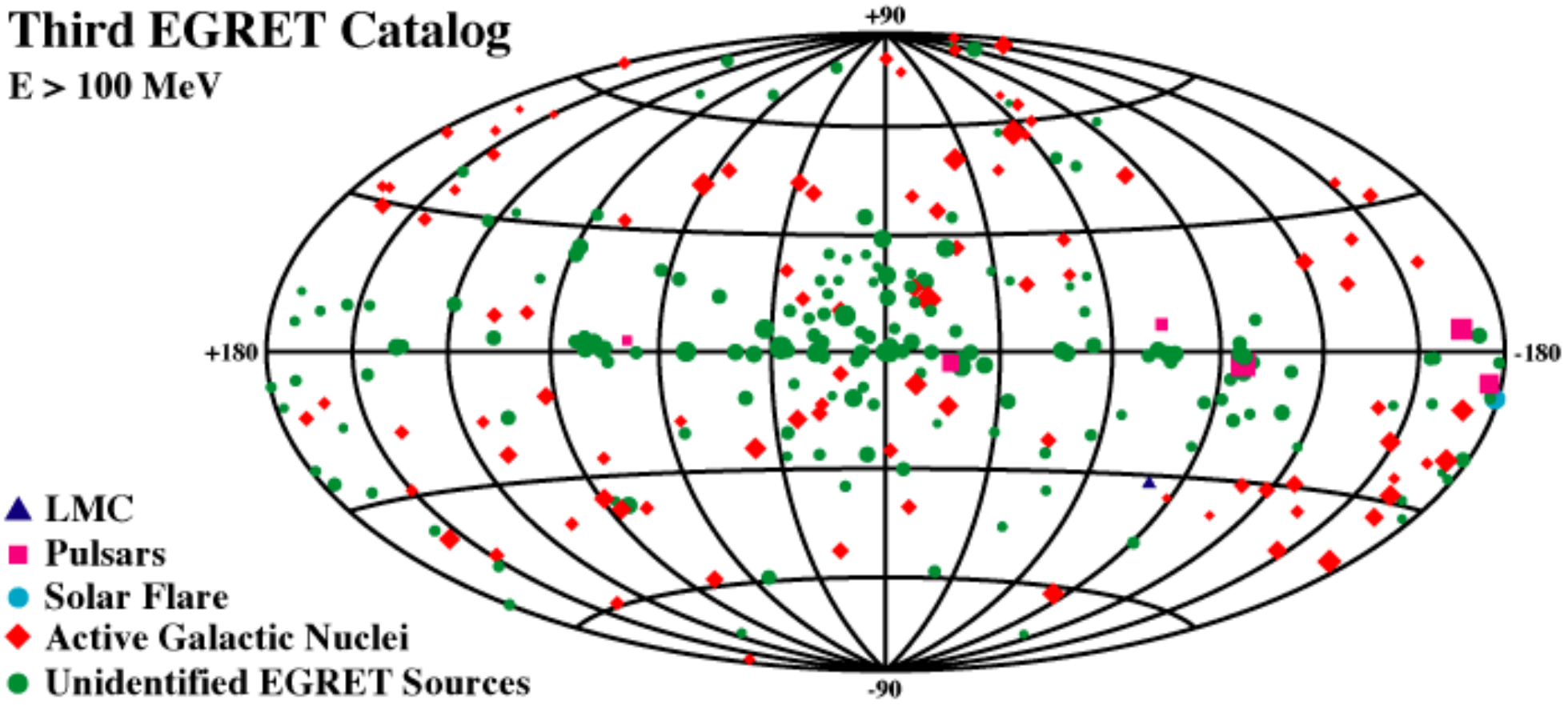


HE Gamma-ray Astrophysics
The EGRET legacy

INFN TRIESTE
Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

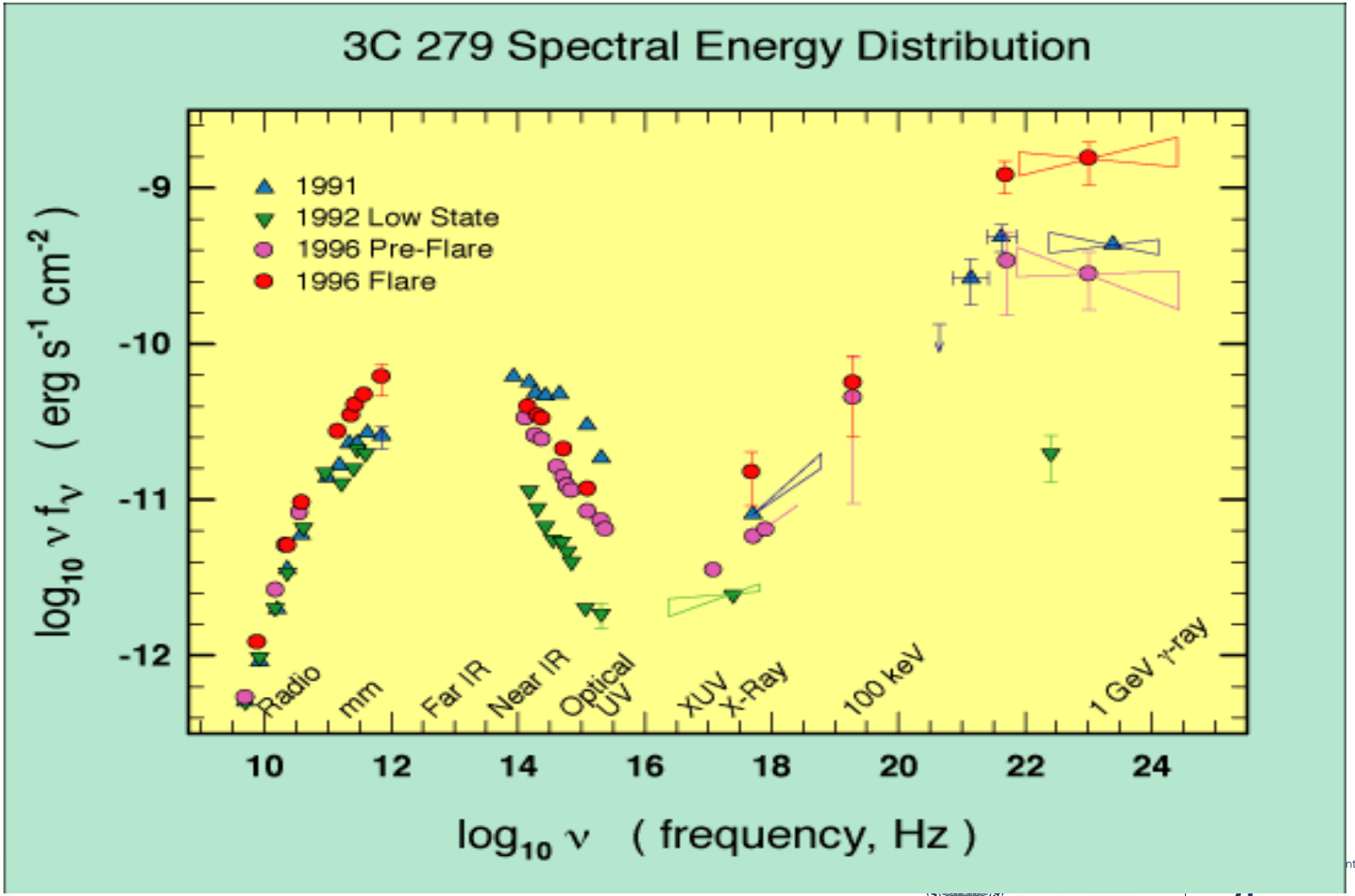
UNIVERSITÀ DEGLI STUDI DI TRIESTE
Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

EGRET Gamma-ray Sources

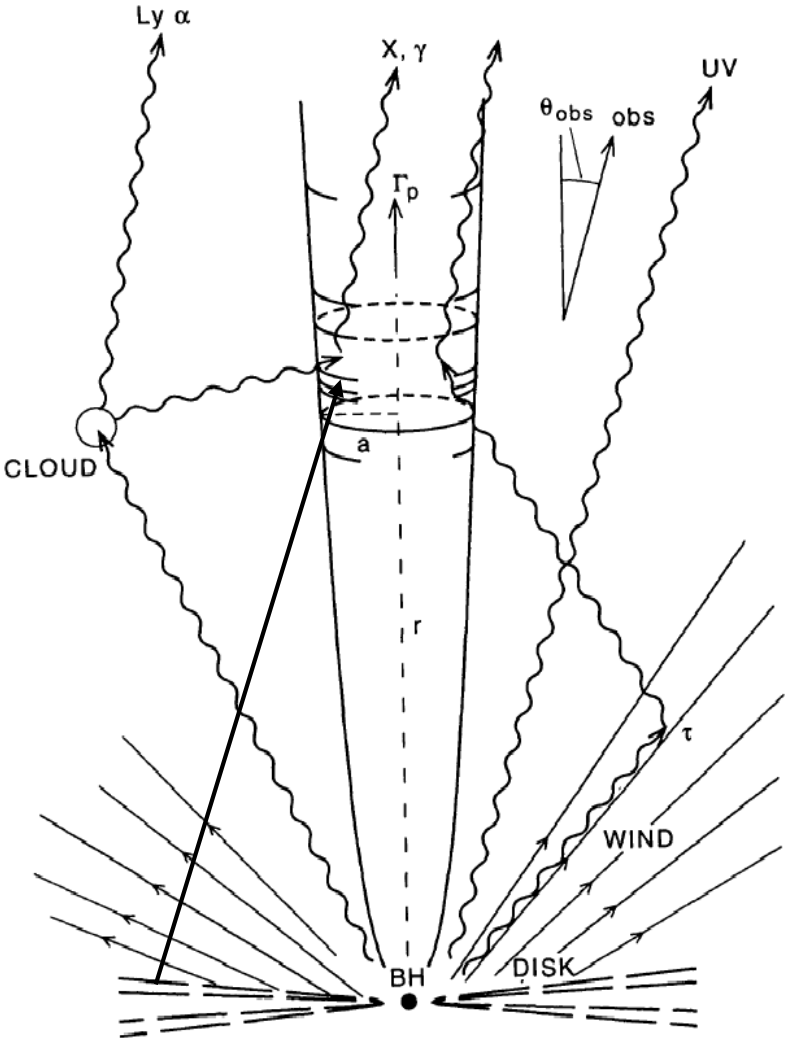


Challenge # 1

- **Need simultaneous multiwavelength data to study variability and emission processes**

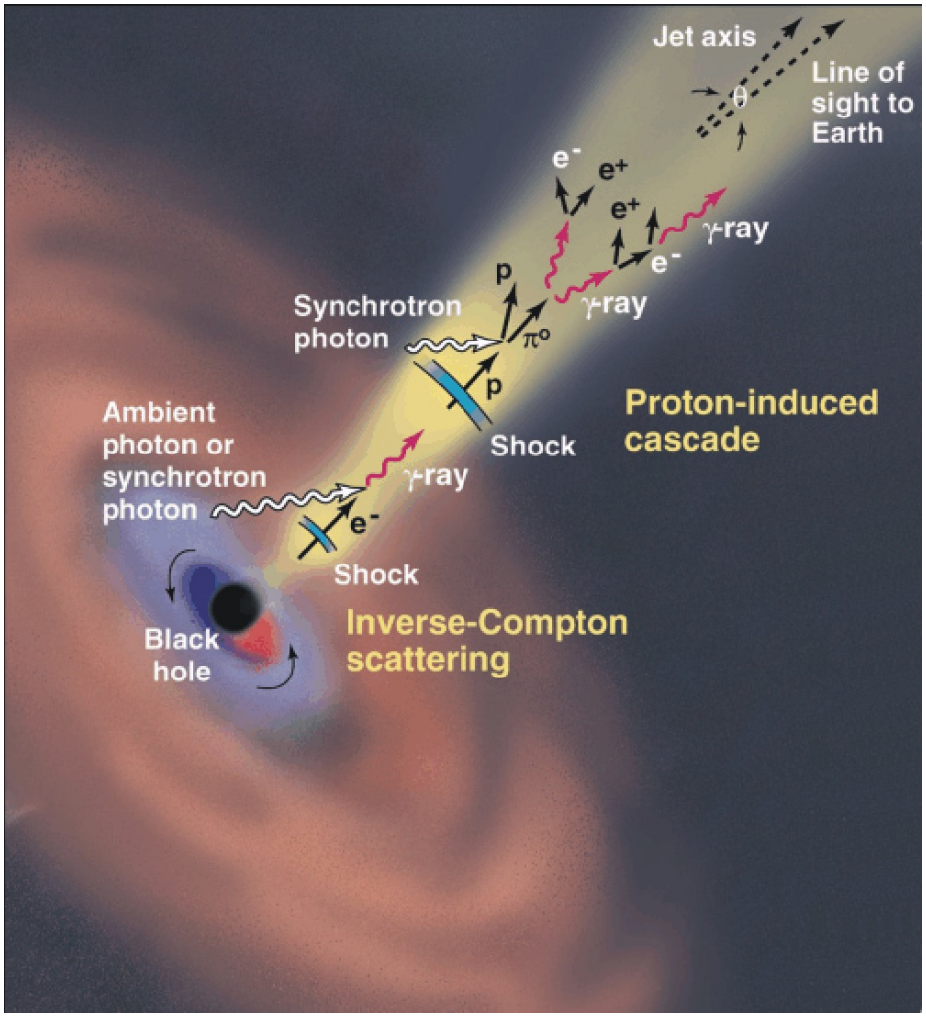


Models of AGN Gamma-ray Production



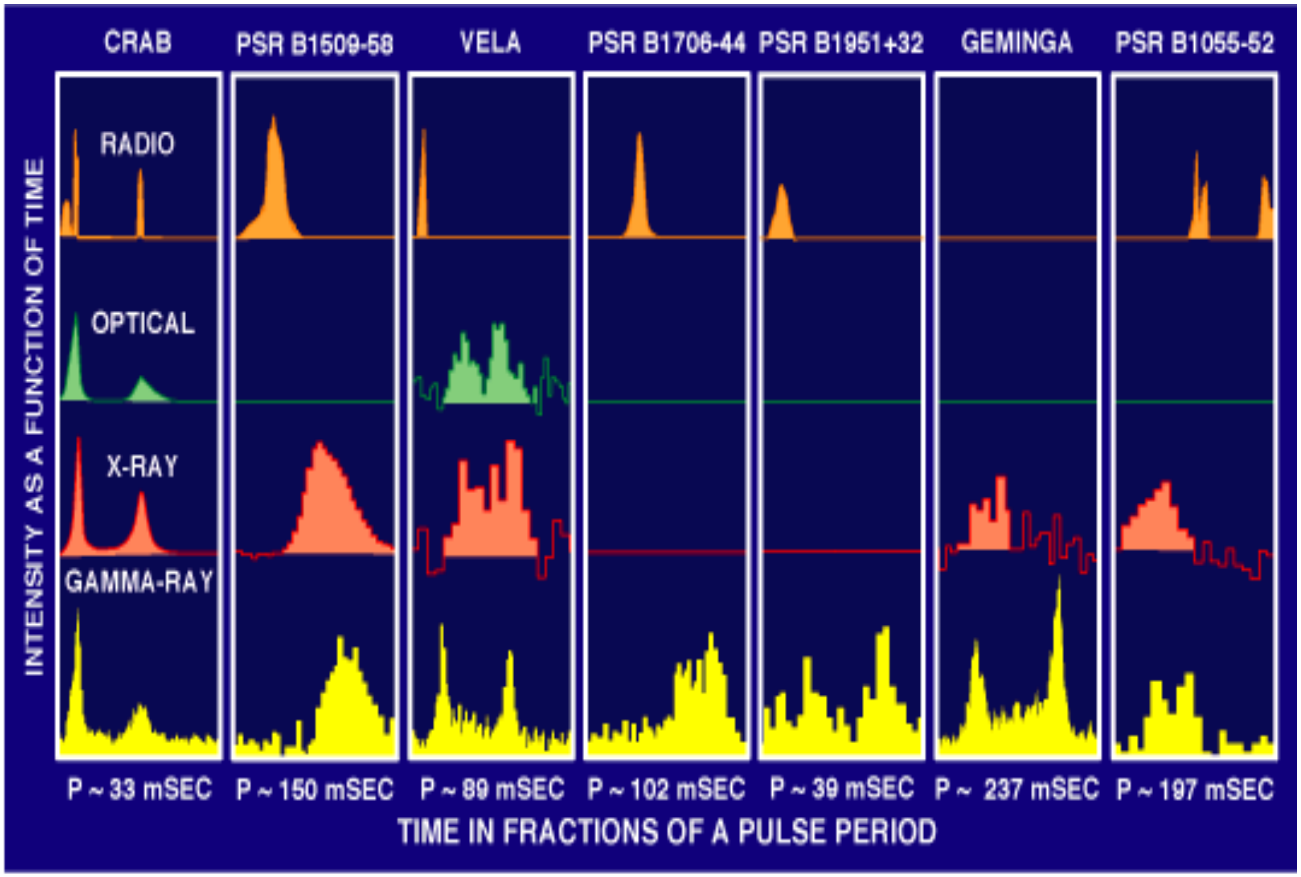
(from Sikora, Begelman, and Rees (1994))

(credit:J. Buckley)

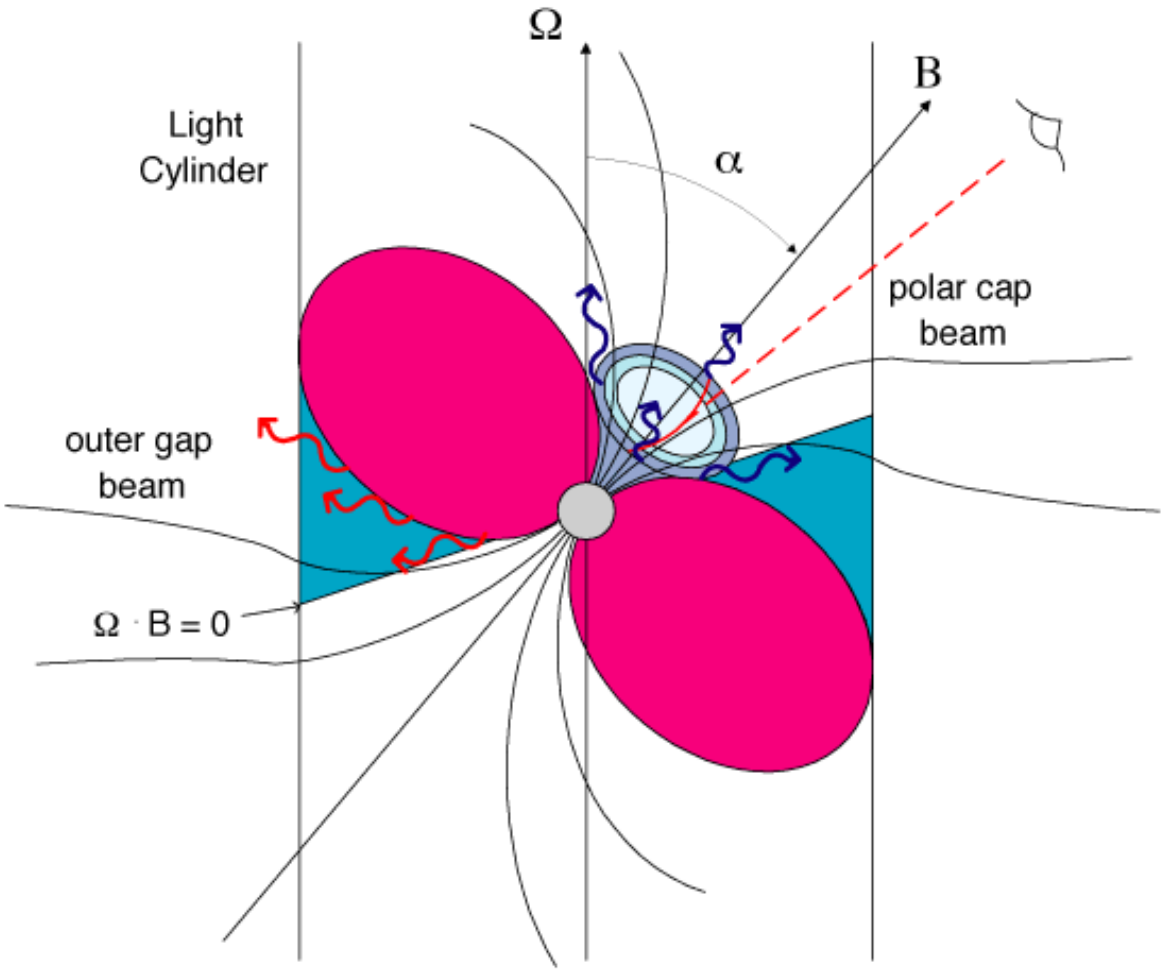


Challenge # 2

- **Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.**



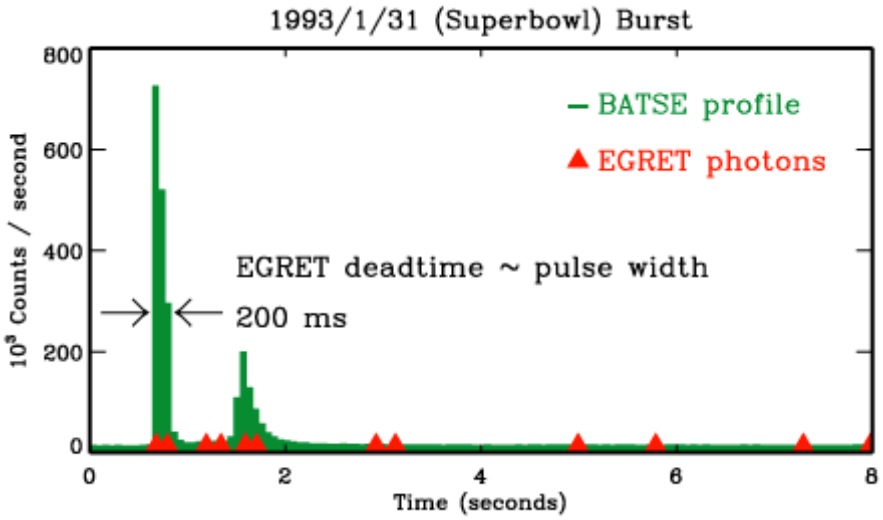
Pulsars



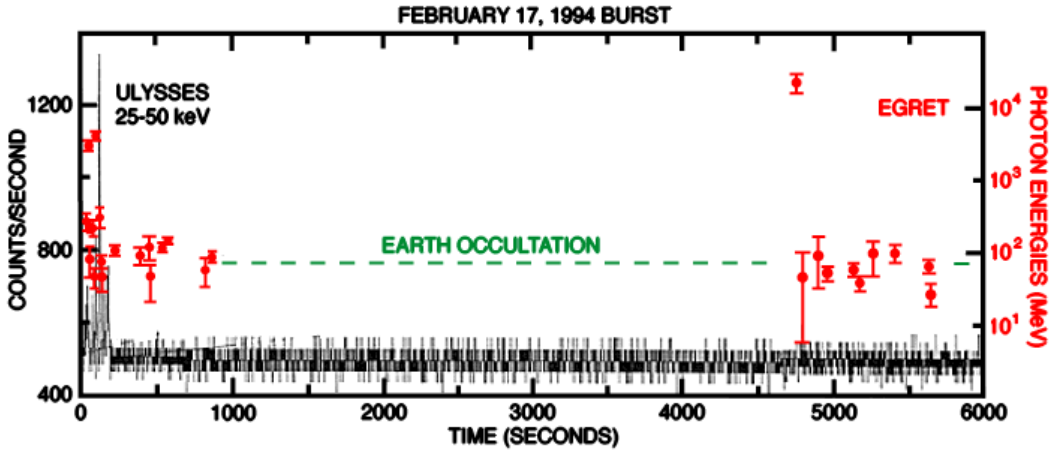
Challenge # 3

- **Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).**

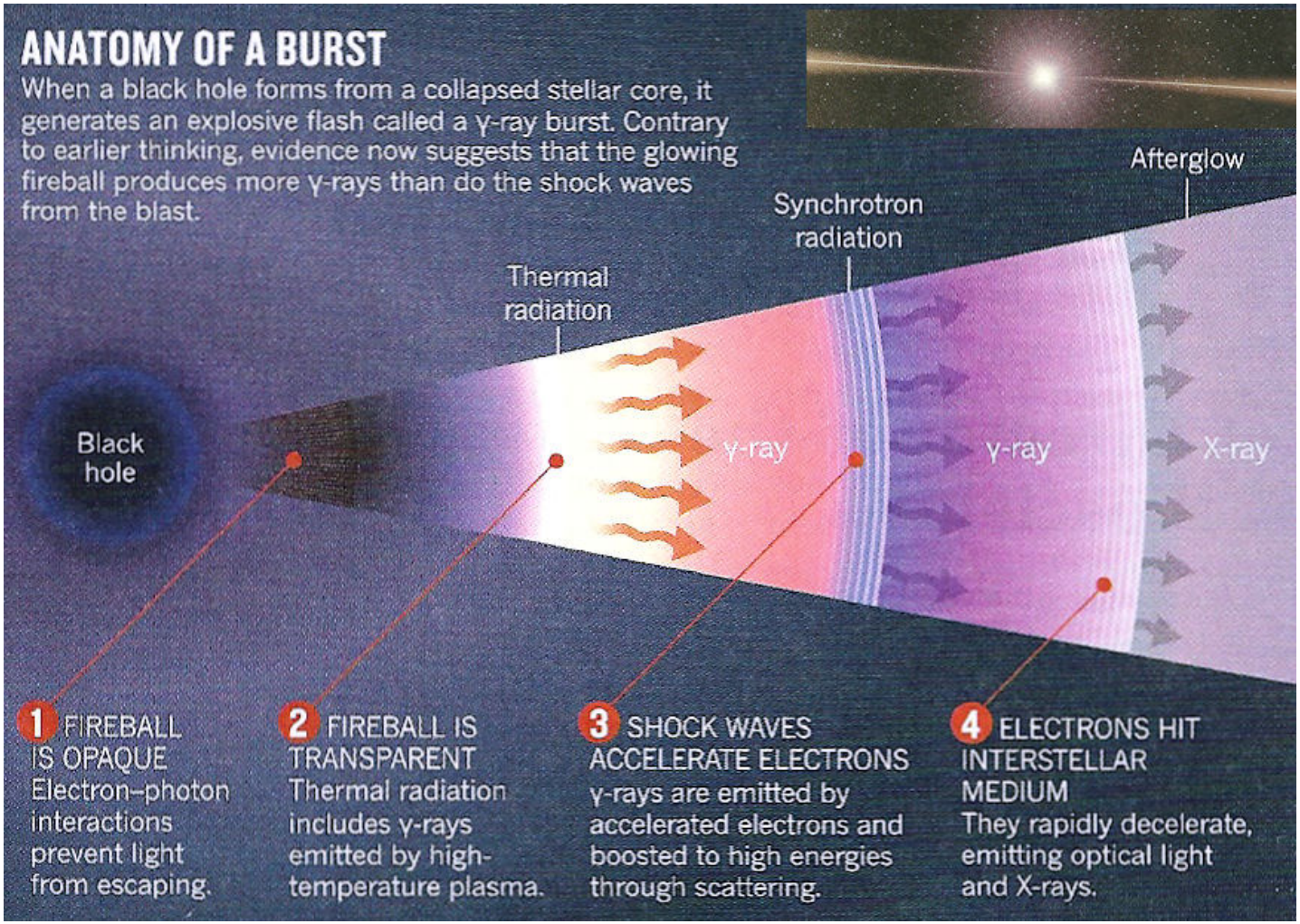
Prompt Emission (GRB 930131)



Delayed Emission (GRB 940217)

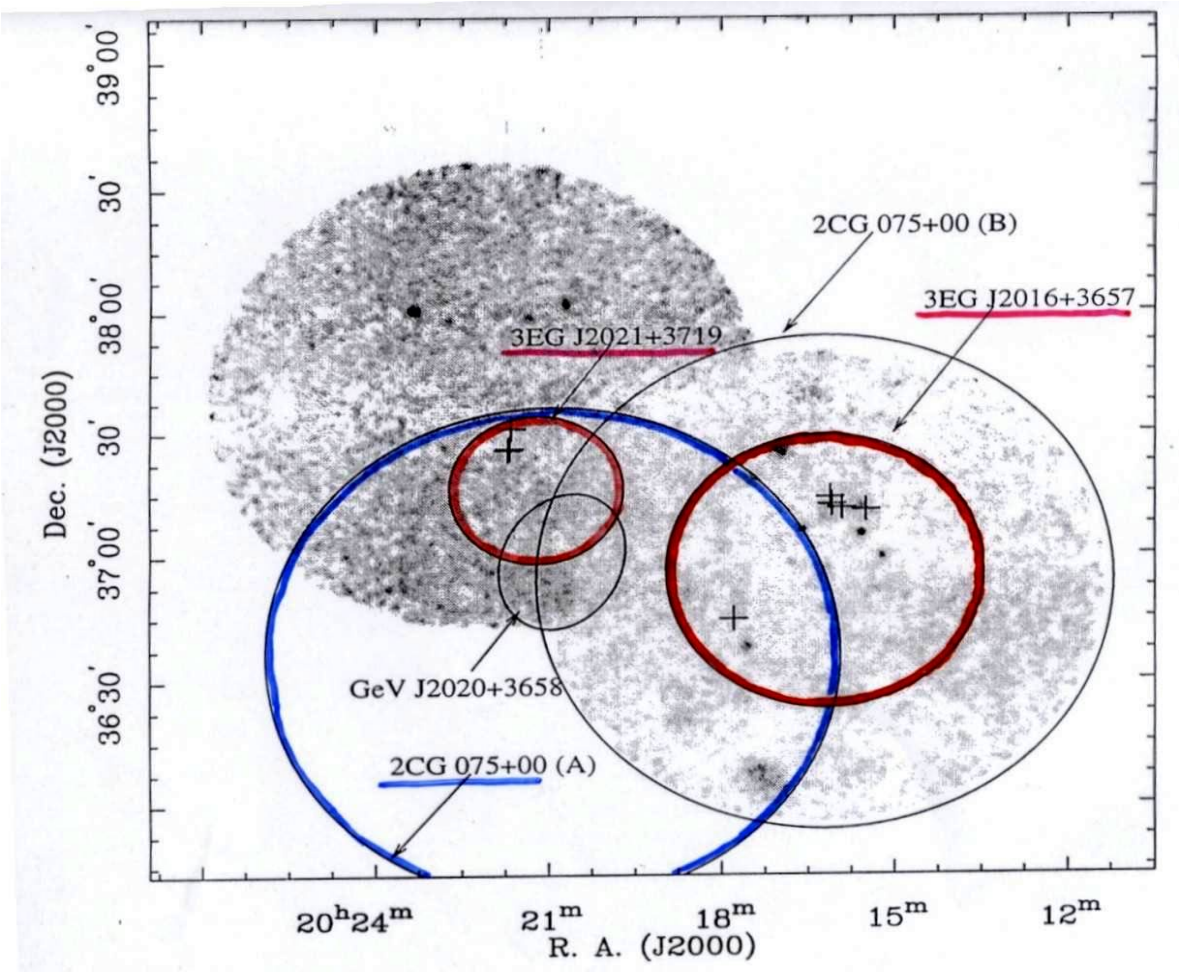


The GRB fireball model

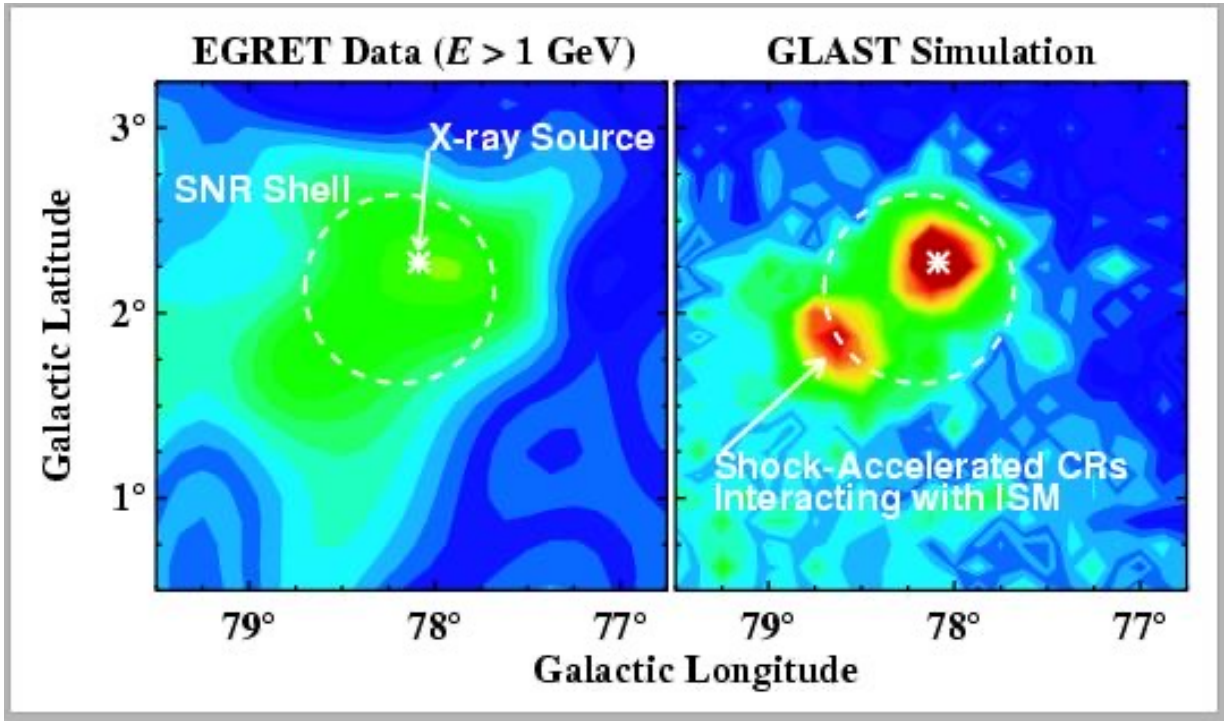


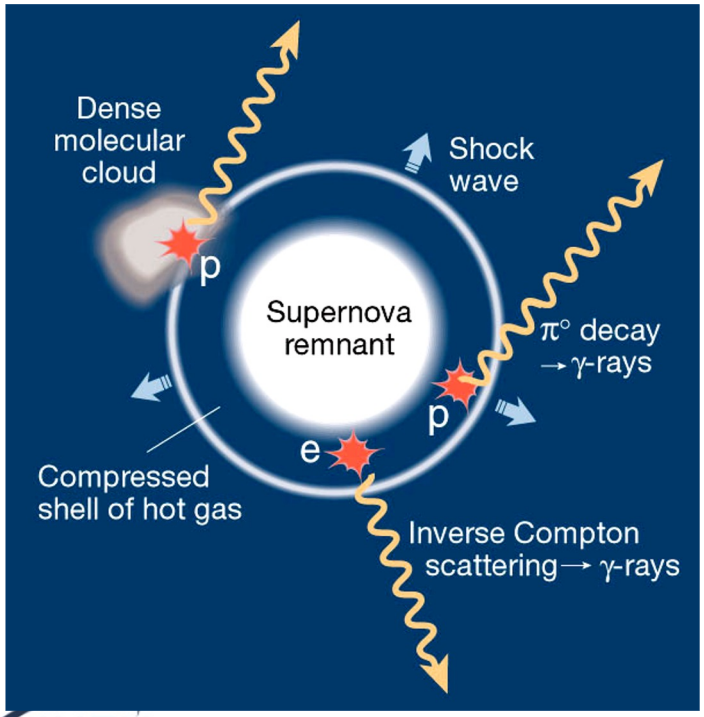
Challenge # 4

- **Need arcminute positioning of gamma-ray sources (improving EGRET error box radii by a factor of 2-10).**



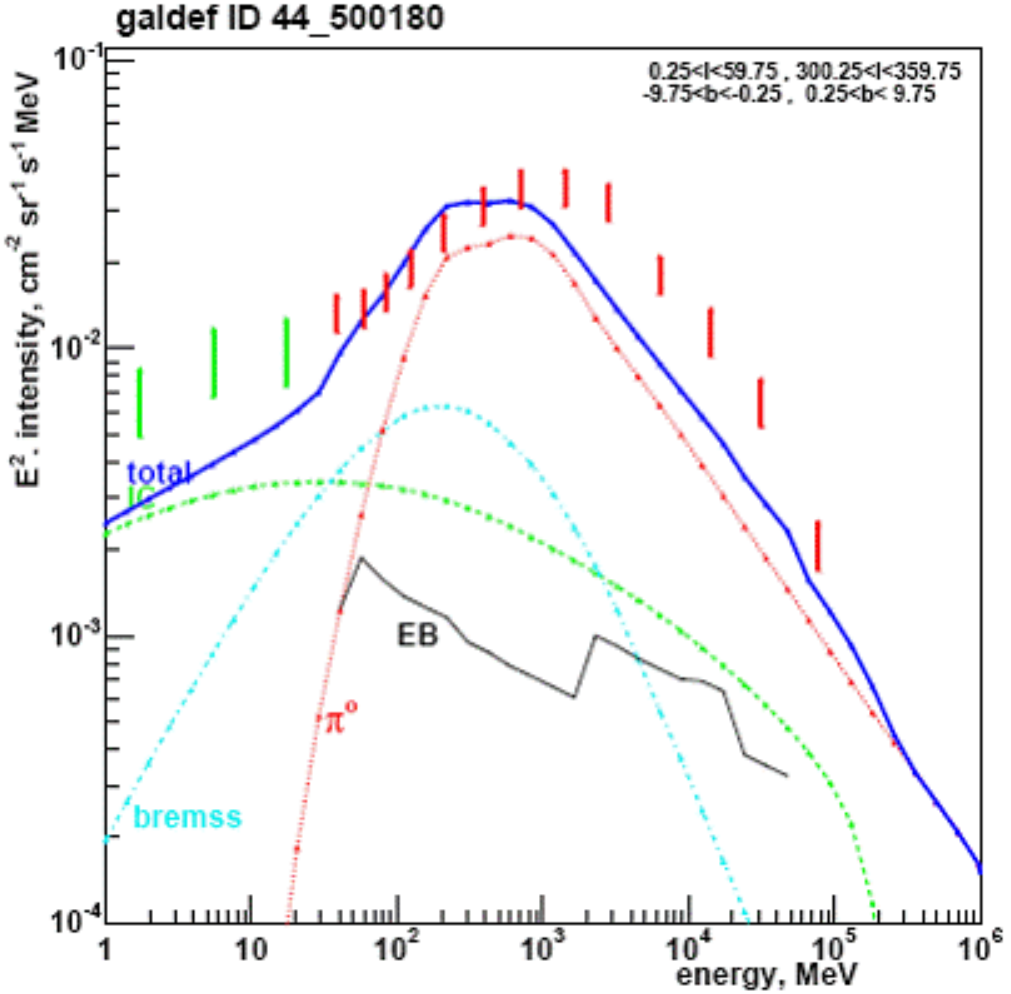
SNR


EGRET Data ($E > 1$ GeV)
GLAST Simulation
X-ray Source
SNR Shell
Shock-Accelerated CRs
Interacting with ISM
Galactic Latitude
3°
2°
1°
79°
78°
77°
79°
78°
77°
Galactic Longitude

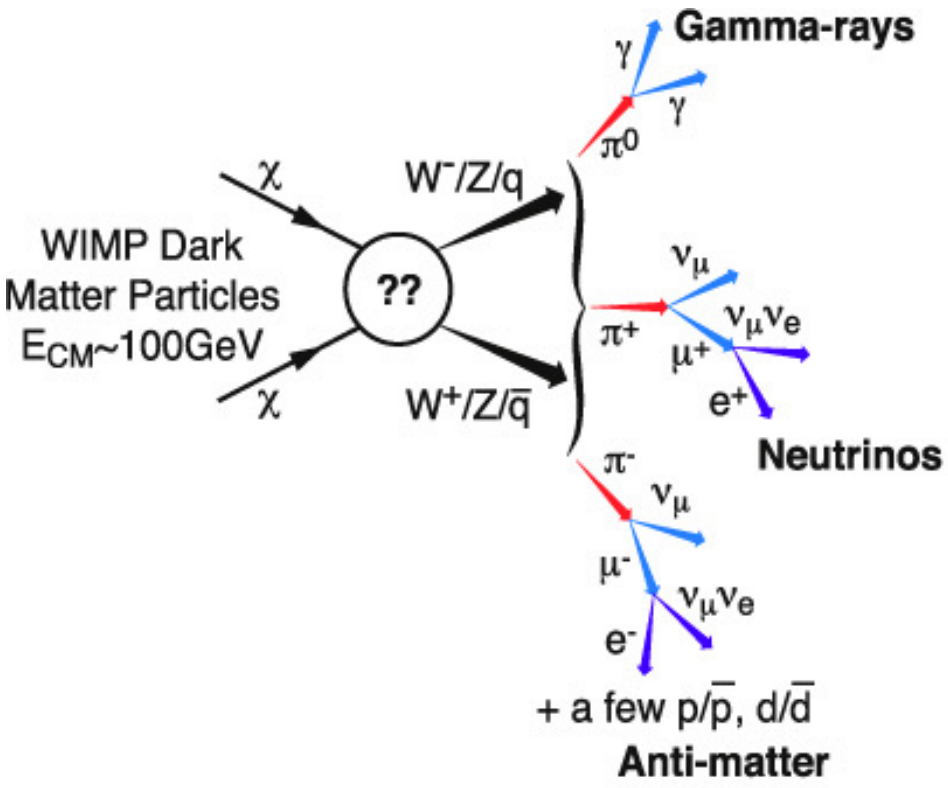

Dense
molecular
cloud
Shock
wave
p
Supernova
remnant
π° decay
→ γ-rays
p
e
Compressed
shell of hot gas
Inverse Compton
scattering → γ-rays

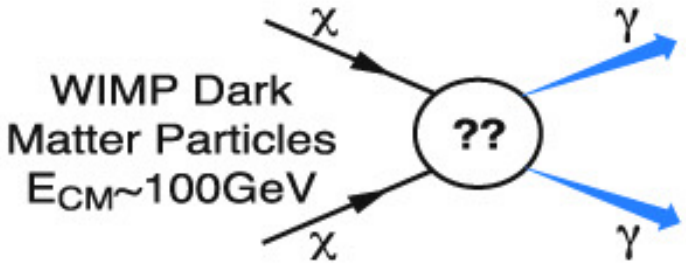
Challenge # 5

- **Need improvements in Spectral Resolution fo check for DM signals**

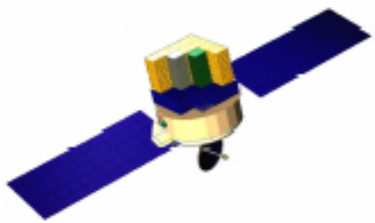


Dark Matter


Gamma-rays
γ
γ
π0
χ
W-/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q
νμ
π+
νμνe
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter


χ
γ
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
γ

Detector Project



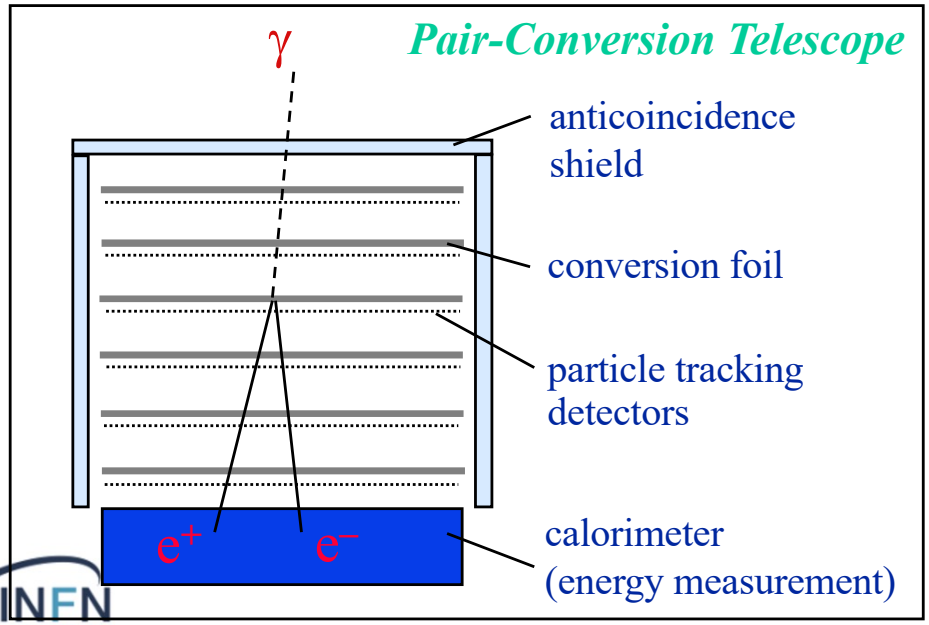
Sources Classes Predicted for GLAST

Source Class	Basis for Prediction
Active Galactic Nuclei (AGN)	EGRET quasars
Diffuse Cosmic Background	EGRET, Theory
Gamma Ray Bursts (GRBs)	EGRET, BATSE, Milagrito
Molecular Clouds, Supernova Remnants Normal Galaxies	COS-B, EGRET, Theory
Galactic Neutrons Stars (NS) & Black Holes (BHs)	COS-B, EGRET
Unidentified Gamma-ray Sources	COS-B, EGRET
Dark Matter	Theory

Detector Project

- Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):

  - photon interactions with matter in GLAST energy range dominated by pair conversion:
    - ➡ determine photon direction
    - ➡ clear signature for background rejection
  - limitations on angular resolution (PSF)
    - **low E: multiple scattering => many thin layers**
    - **high E: hit precision & lever arm**



Energy loss mechanisms:

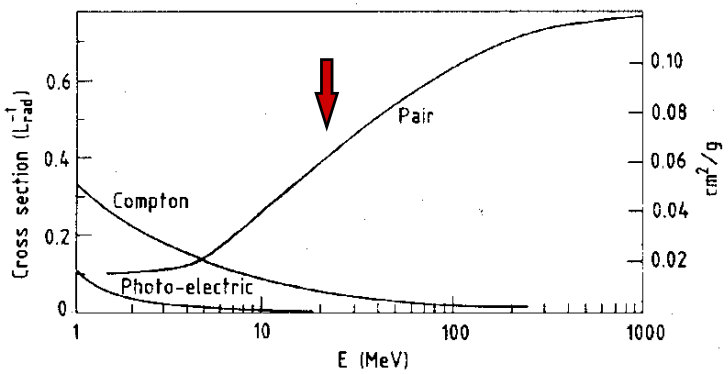


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- must detect γ-rays with high efficiency and reject the much larger (~10^4:1) flux of background cosmic-rays, etc.;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.

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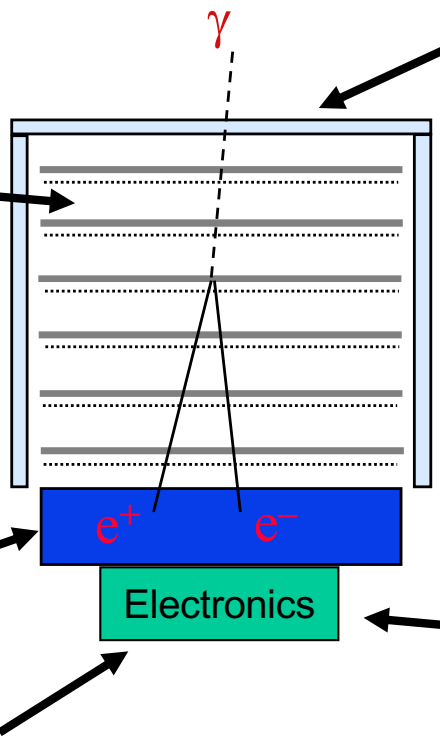
Detector Project

Effective area and PSF requirements drive the converter thicknesses and layout. PSF requirements also drive the sensor performance, layer spacings, and drive the design of the mechanical supports.

Energy range and energy resolution requirements bound the thickness of calorimeter

On-board transient detection requirements, and on-board background rejection to meet telemetry requirements, are relevant to the electronics, processing, flight software, and trigger design.



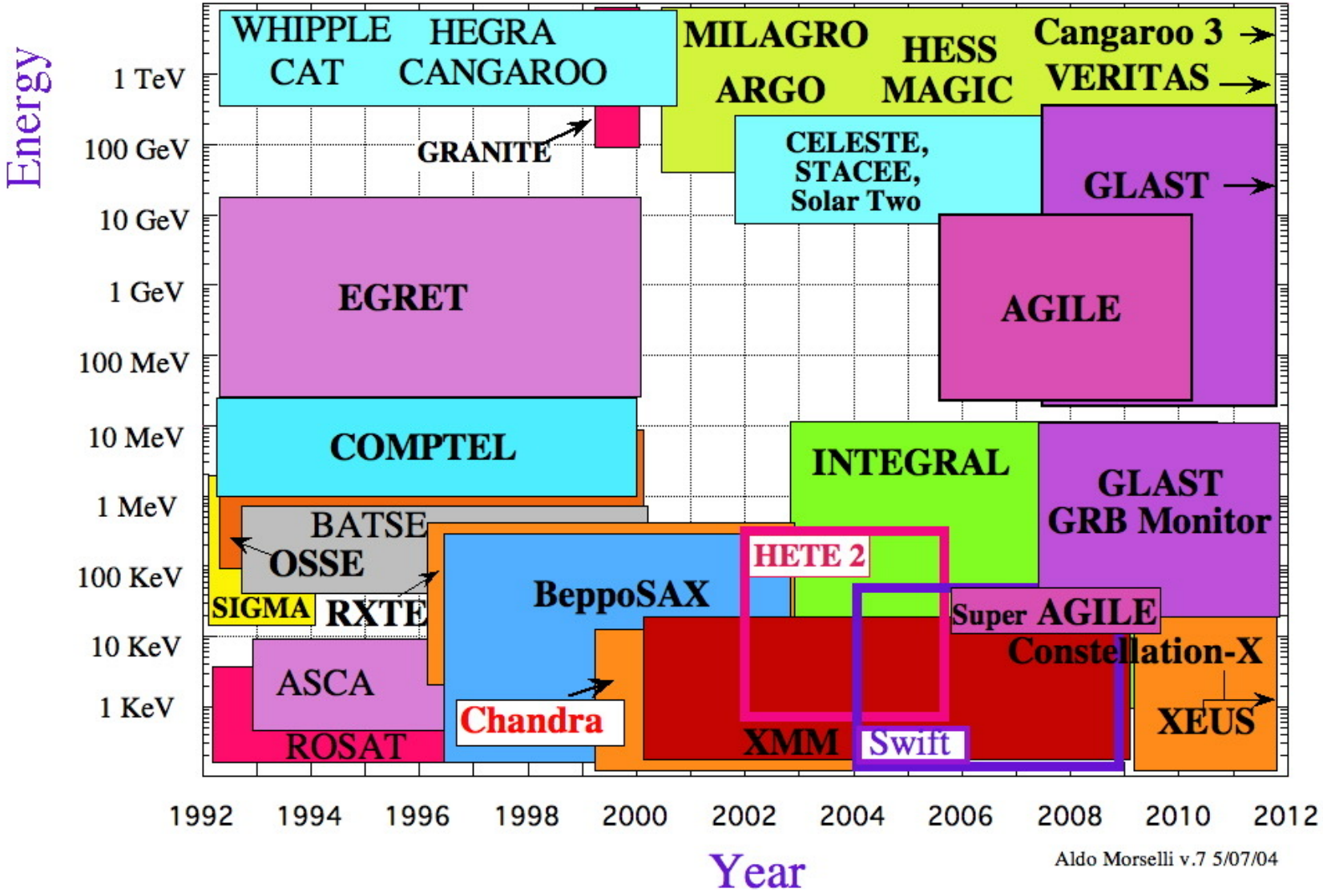
Background rejection requirements drive the ACD design (and influence the calorimeter and tracker layouts).

Field of view sets the aspect ratio (height/width)

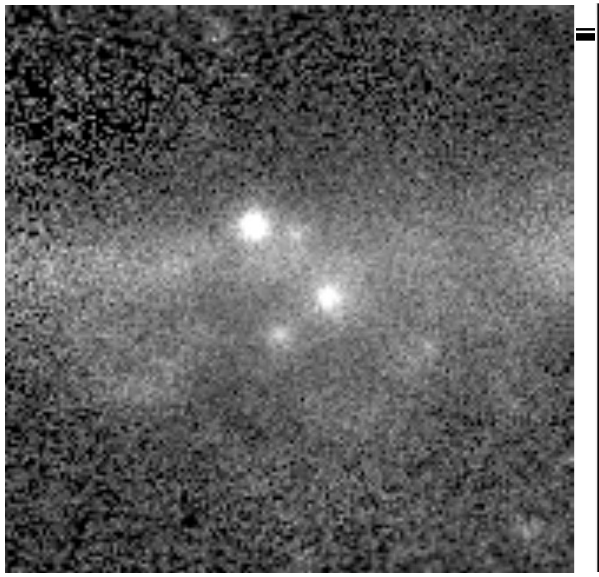
Time accuracy provided by electronics and intrinsic resolution of the sensors.

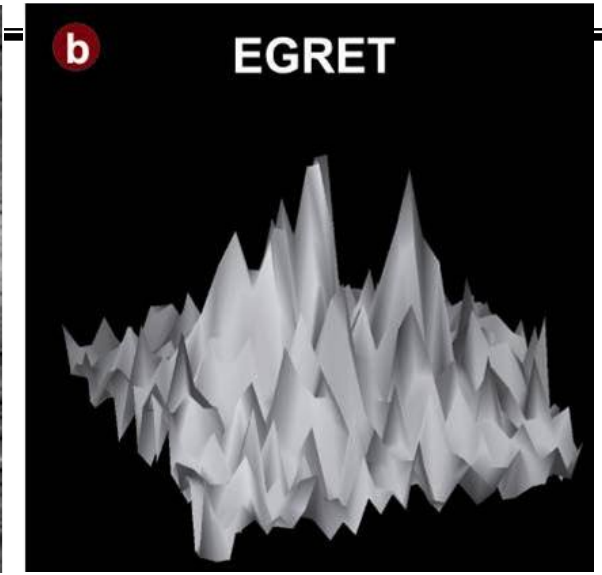
Instrument life has an impact on detector technology choices.
Derived requirements (source location determination and point source sensitivity) are a result of the overall system performance.

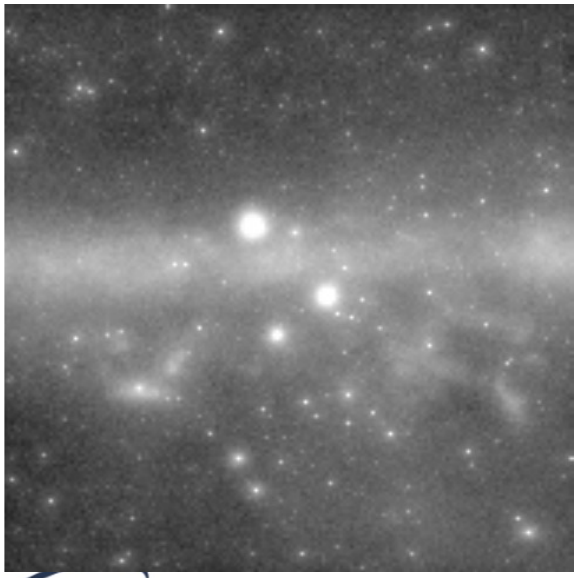
After a long story ...

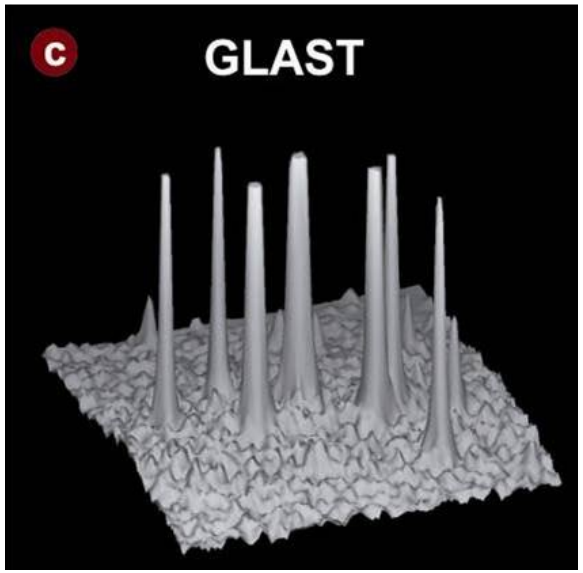


Technology impact -- PSF









EGRET
(1991-2000)
Phases 1-5

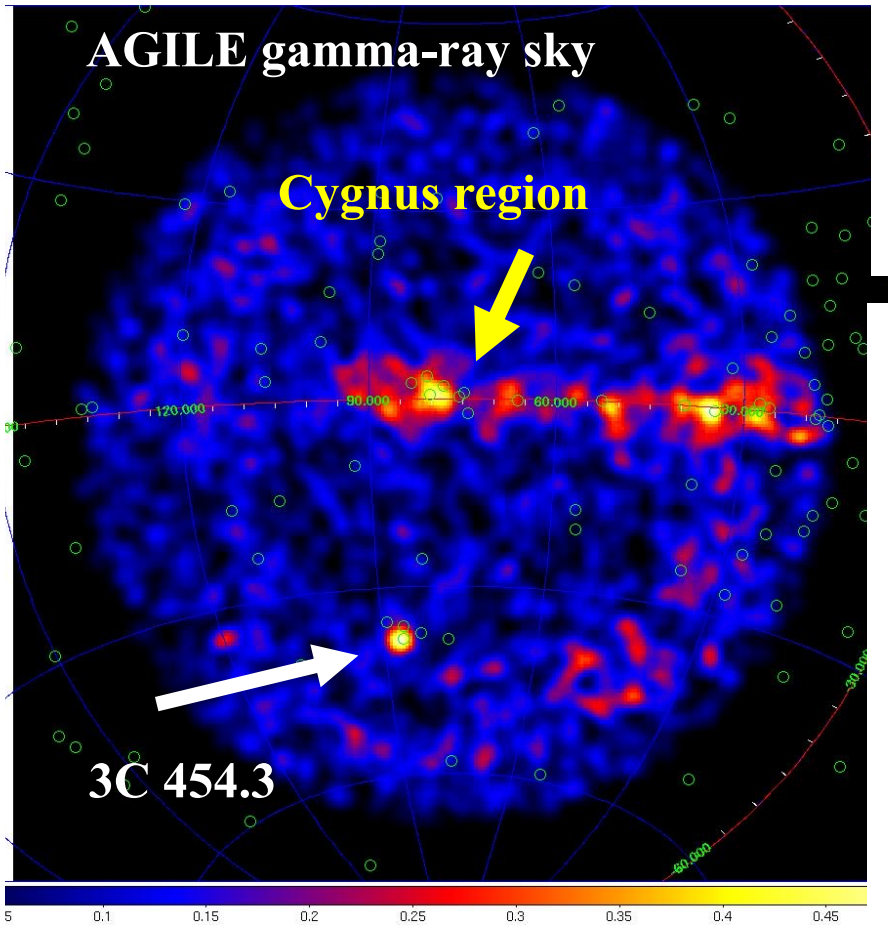
Spark chamber
- **sense electrode spacing ~mm**
- **sensitive layer depth ~cm**
  - ***up to 28 hit over >1m***

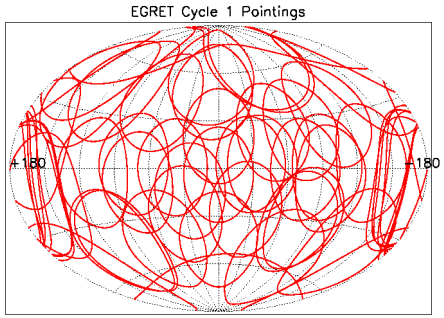
LAT
(2008- >2013)

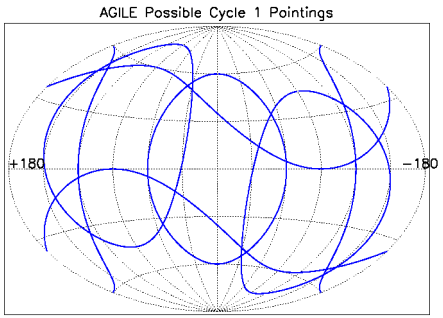
Si-strip detectors
- **sense electrode spacing ~0.2mm**
  - ***better single hit resolution***
- **sensitive layer depth ~0.4mm**
  - ***up to 36 hit over 0.8m***
  - ***converter proximity to minimize MCS***

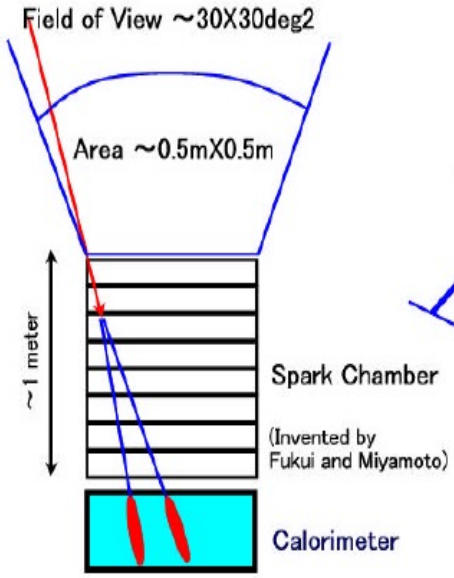
Cygnus region (15^0 x 15^0), $E\gamma > 1$ GeV

Technology impact - FoV

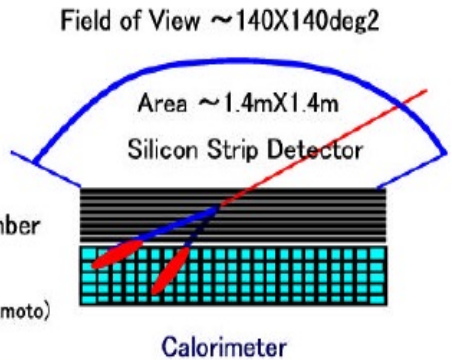








EGRET on Compton GRO



GLAST Large Area Telescope

Fermi
Gamma-ray
Space Telescope

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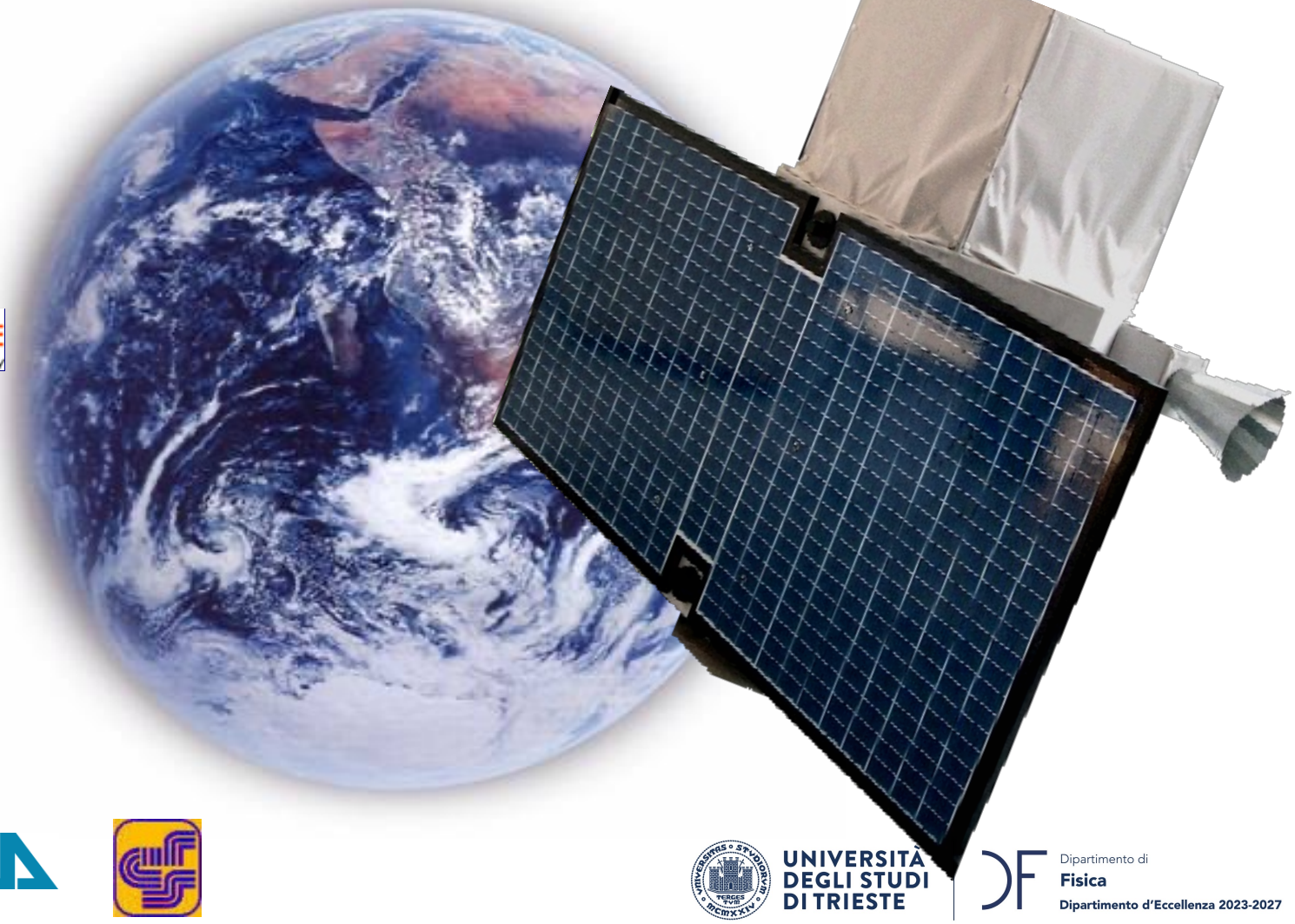
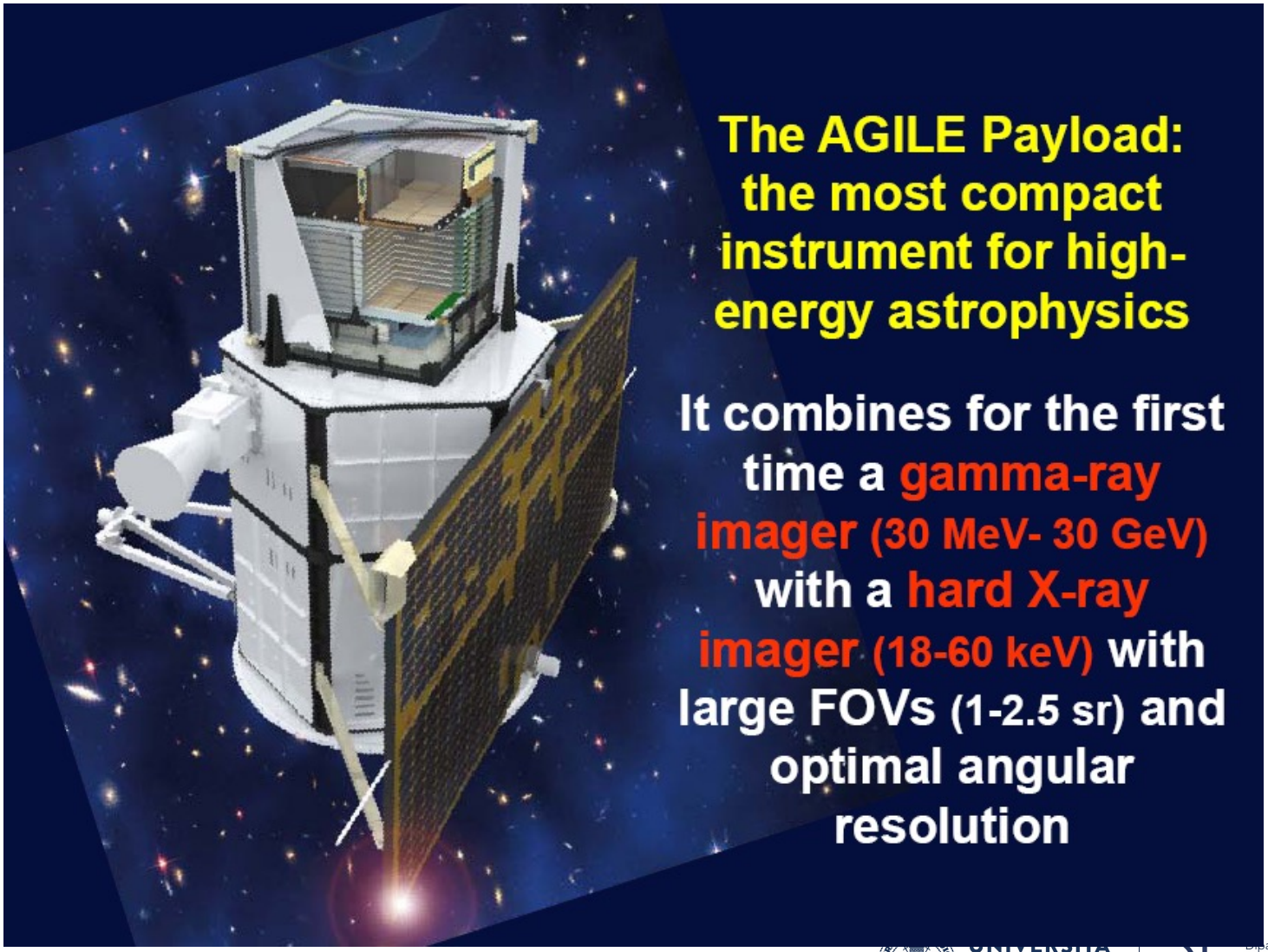
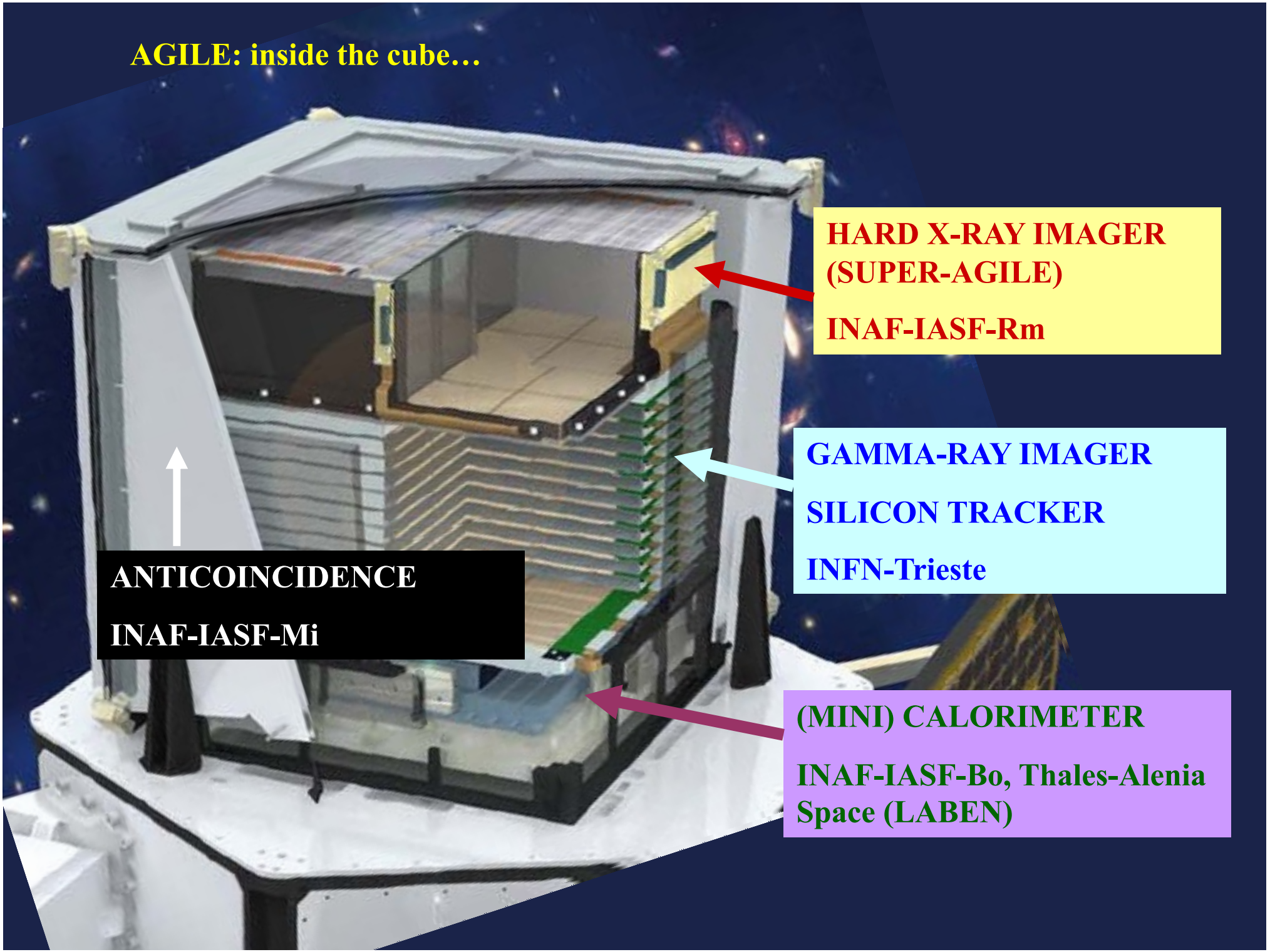
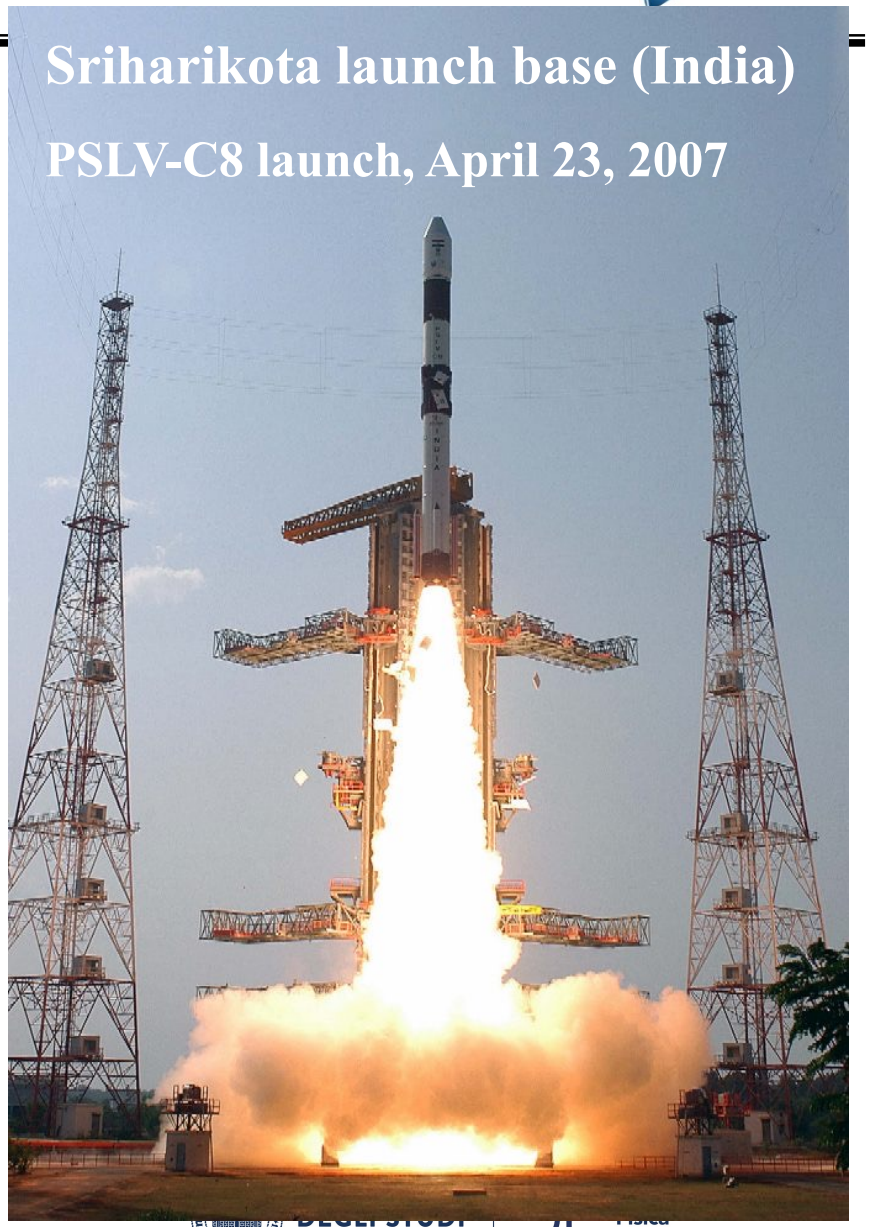


AGILE instrument




AGILE: inside the cube…
HARD X-RAY IMAGER
(SUPER-AGILE)
INAF-IASF-Rm
GAMMA-RAY IMAGER
SILICON TRACKER
INFN-Trieste
ANTICOINCIDENCE
INAF-IASF-Mi
(MINI) CALORIMETER
INAF-IASF-Bo, Thales-Alenia Space (LABEN)

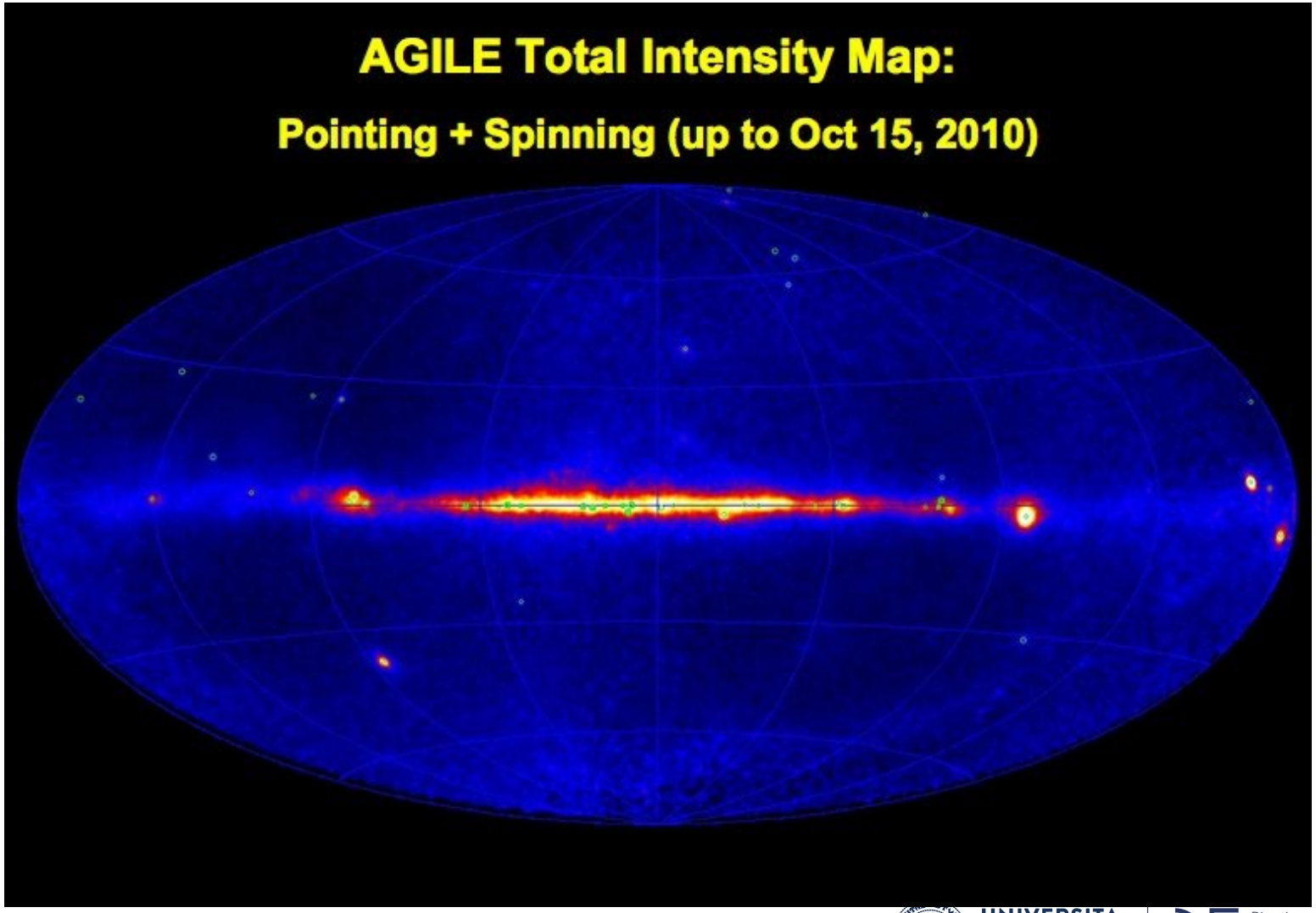
The AGILE launch



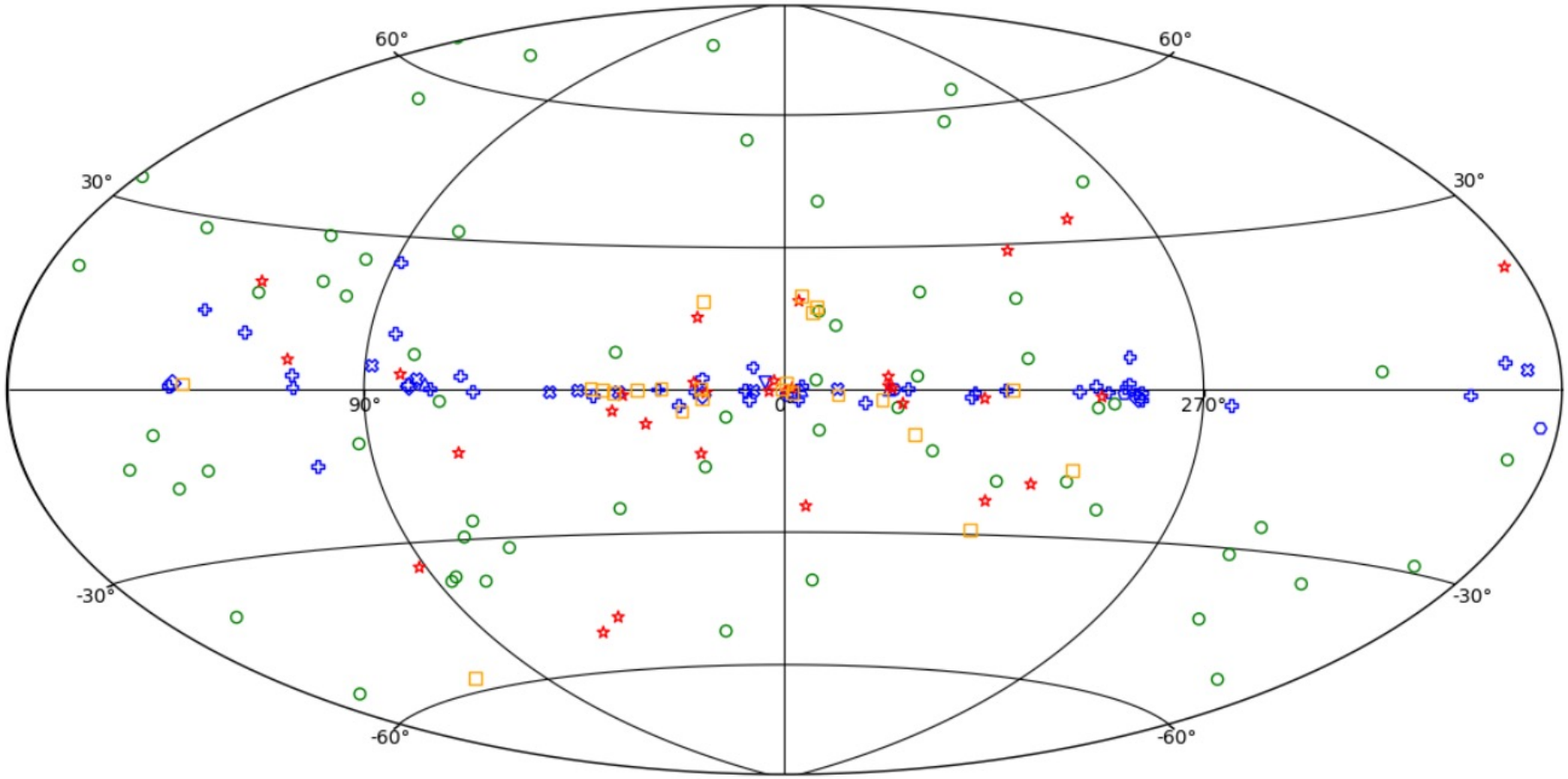
Sriharikota launch base (India)

PSLV-C8 launch, April 23, 2007

The AGILE sky

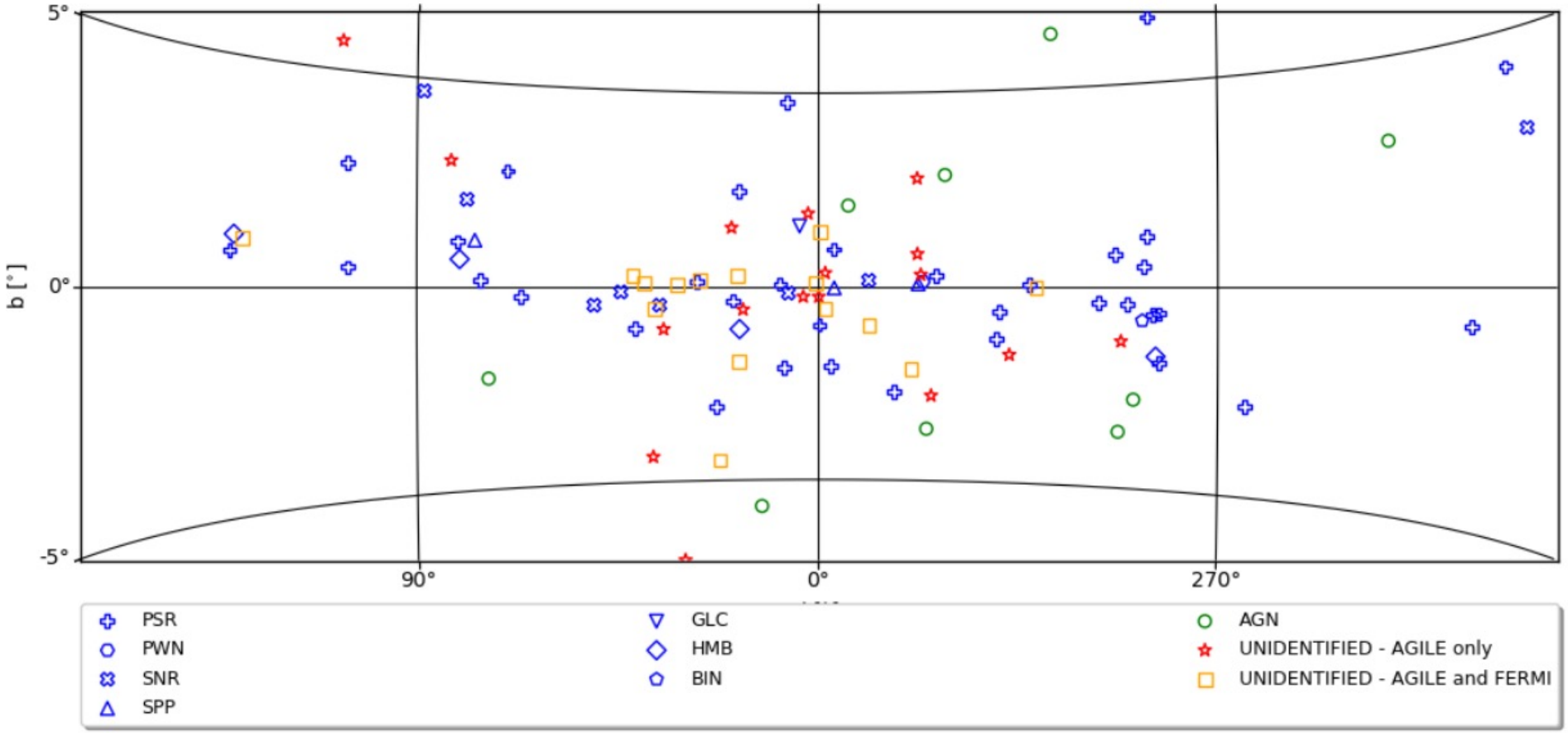


AGILE sources



Bulgarelli et al. 2019

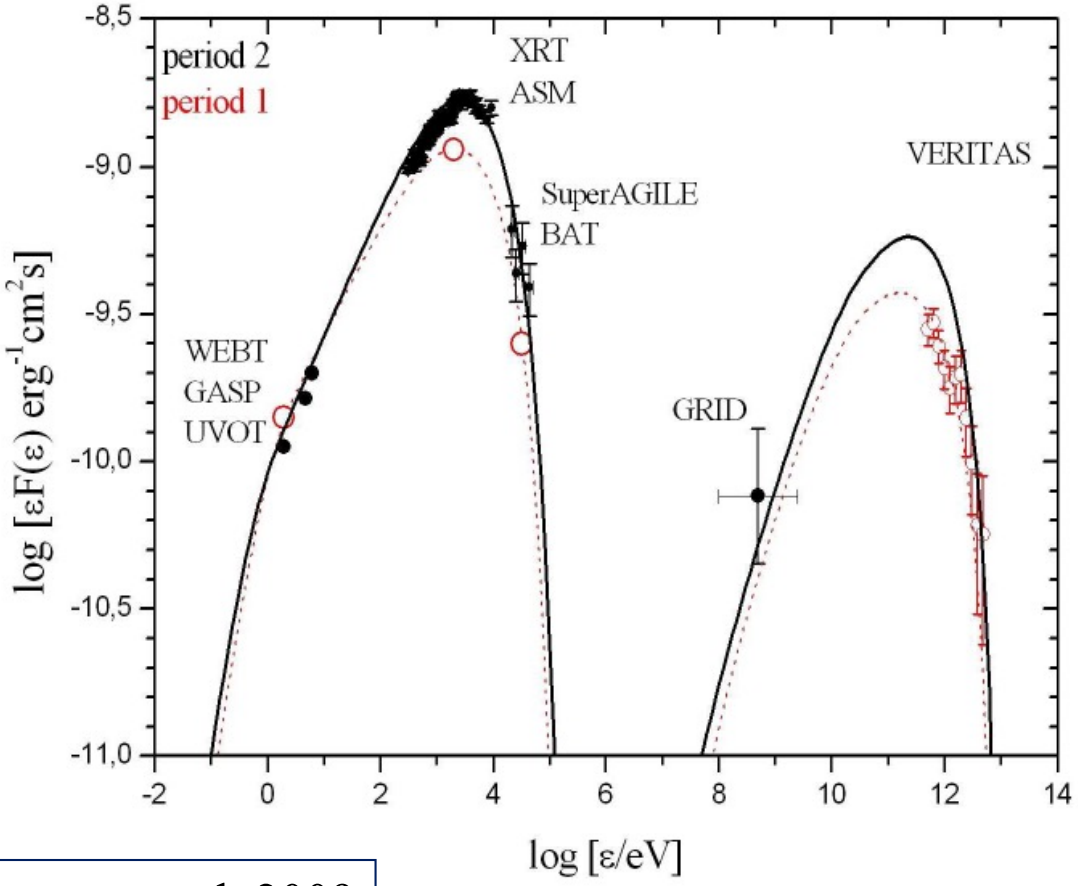
AGILE sources



Bulgarelli et al. 2019

Challenge # 1 – AGN

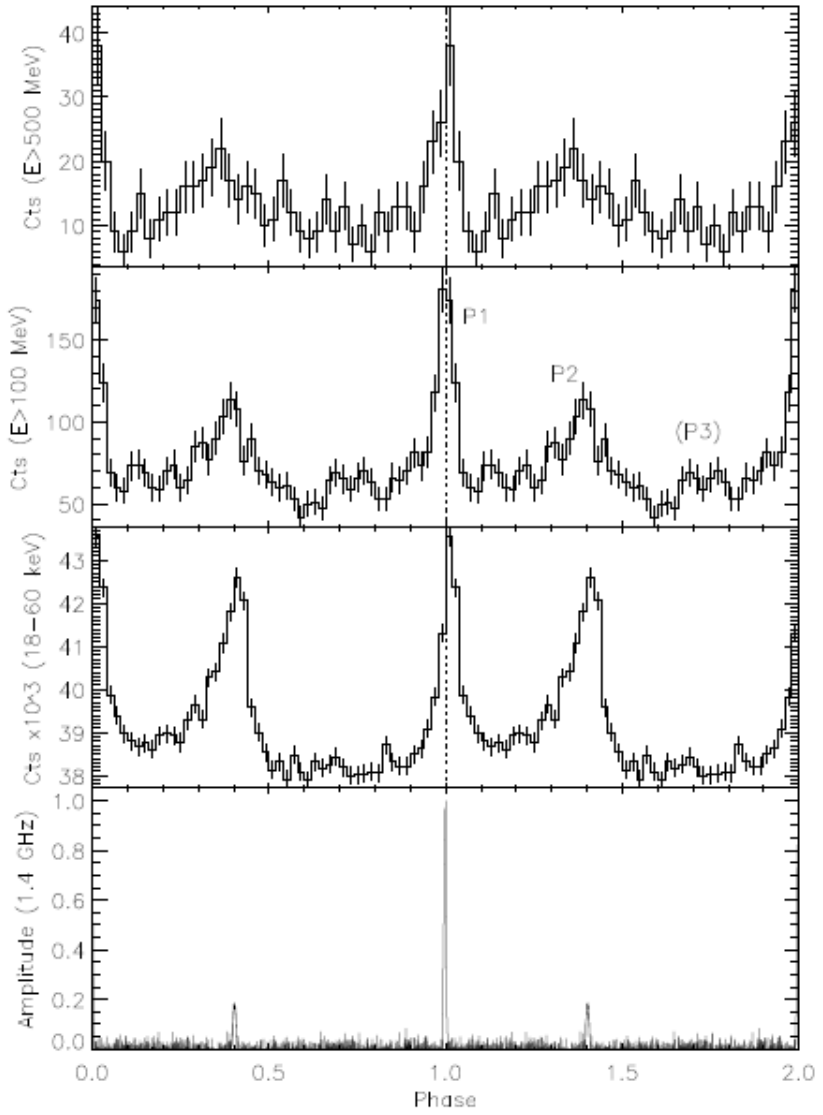
Joint campaign with MAGIC and VERITAS on Mkn 421



Donnarumma et al. 2009

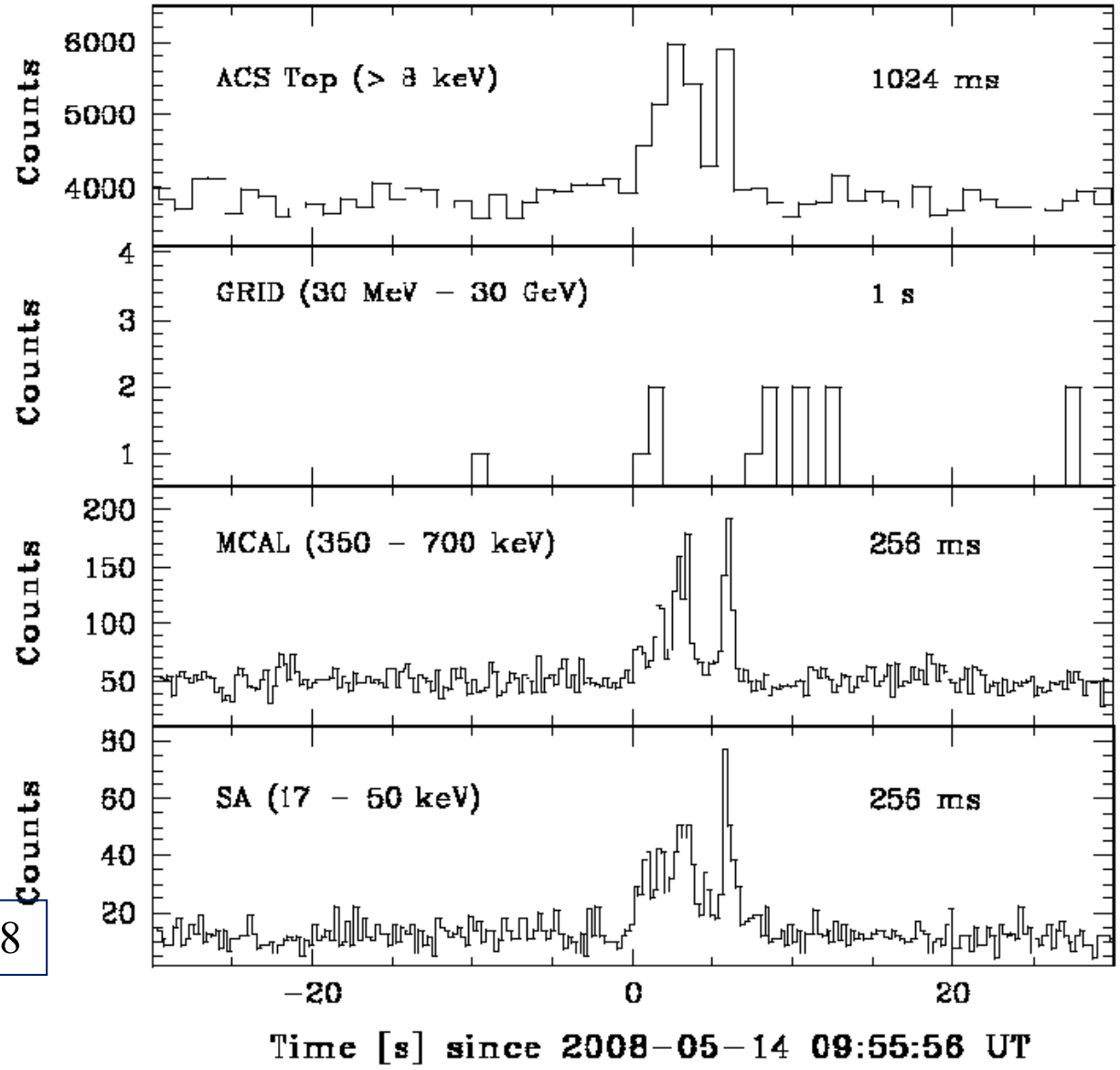
Challenge # 2 – Pulsar

High Precision Timing (eg. Crab PSR)



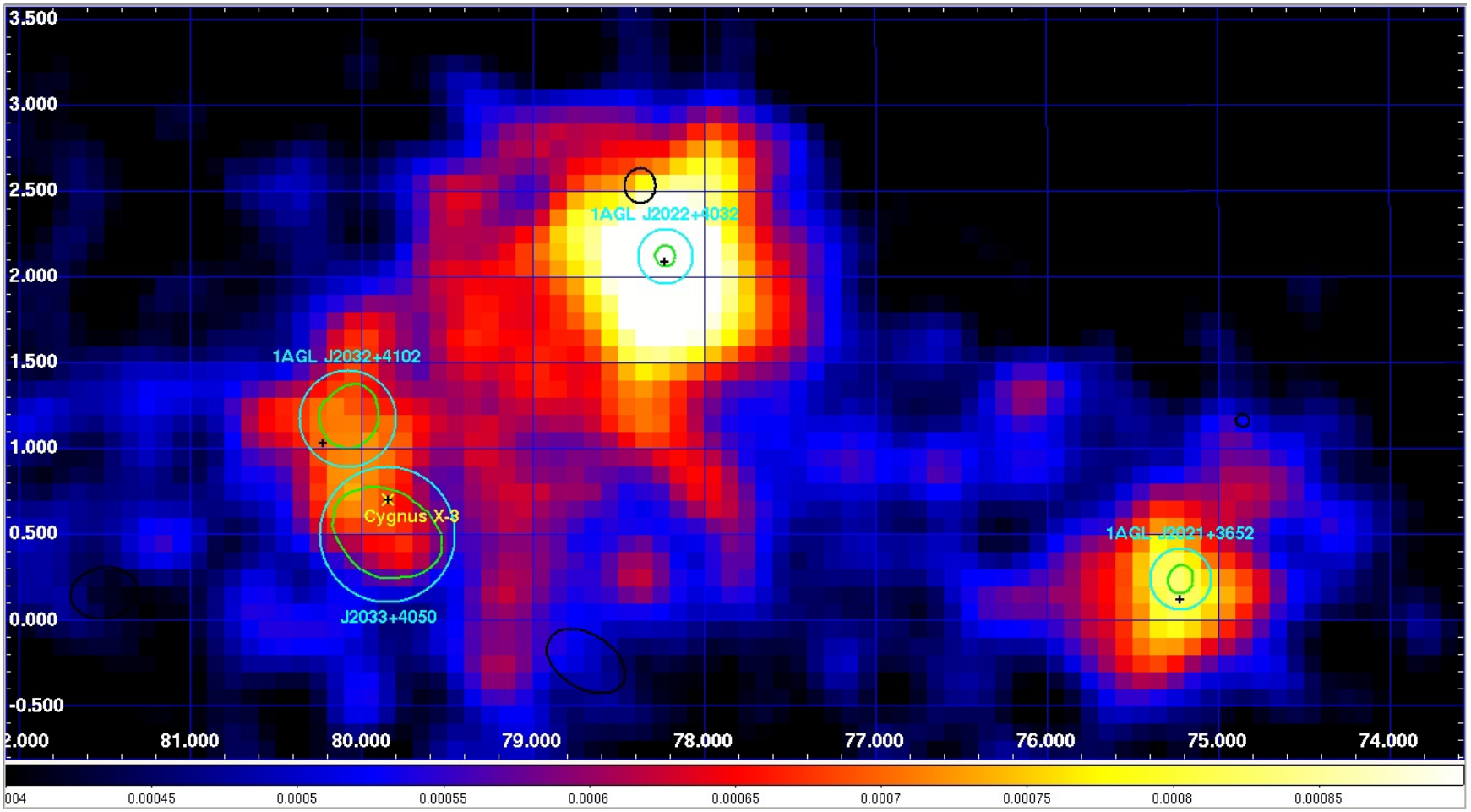
Pellizzoni et al. 2009

Challenge # 3 – GRB



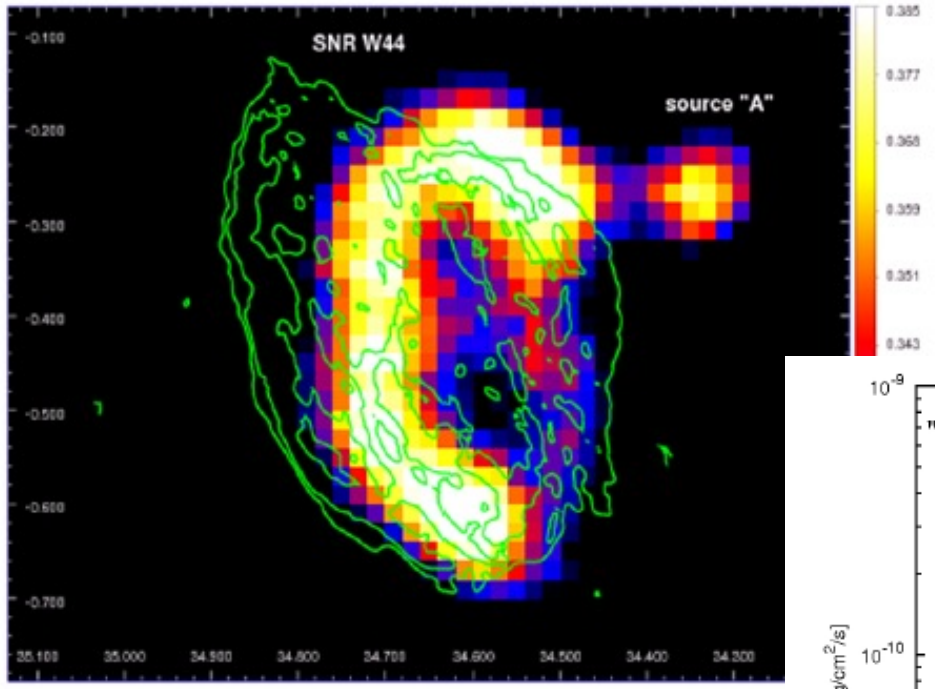
Giuliani et al. 2008

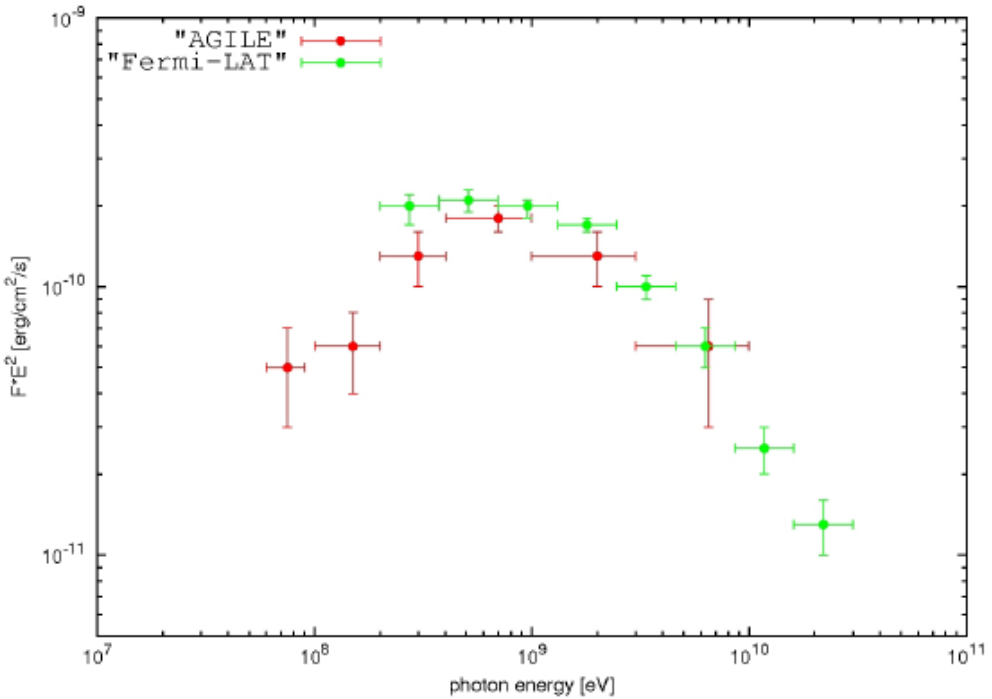
Challenge # 4 – Unidentified



Chen et al. 2011

Challenge # 5 – Spectral resolution

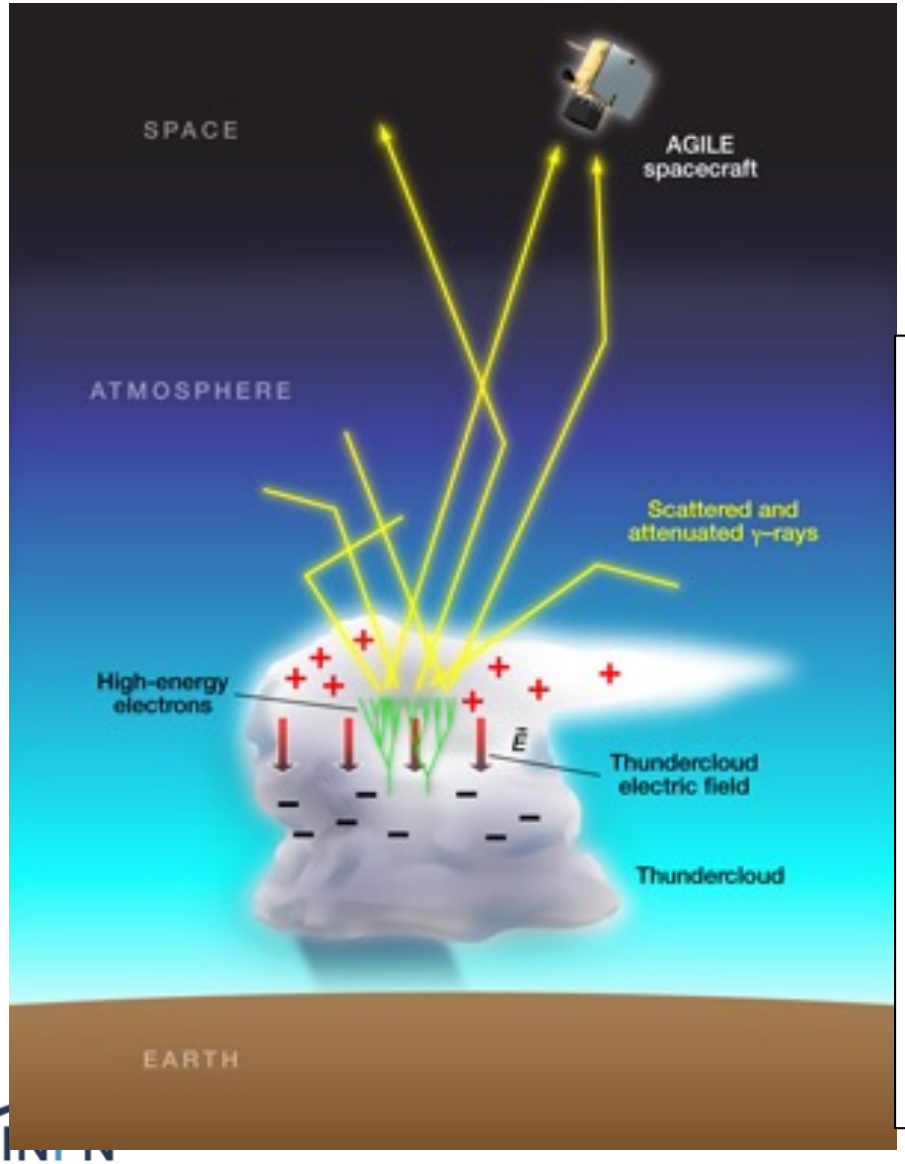


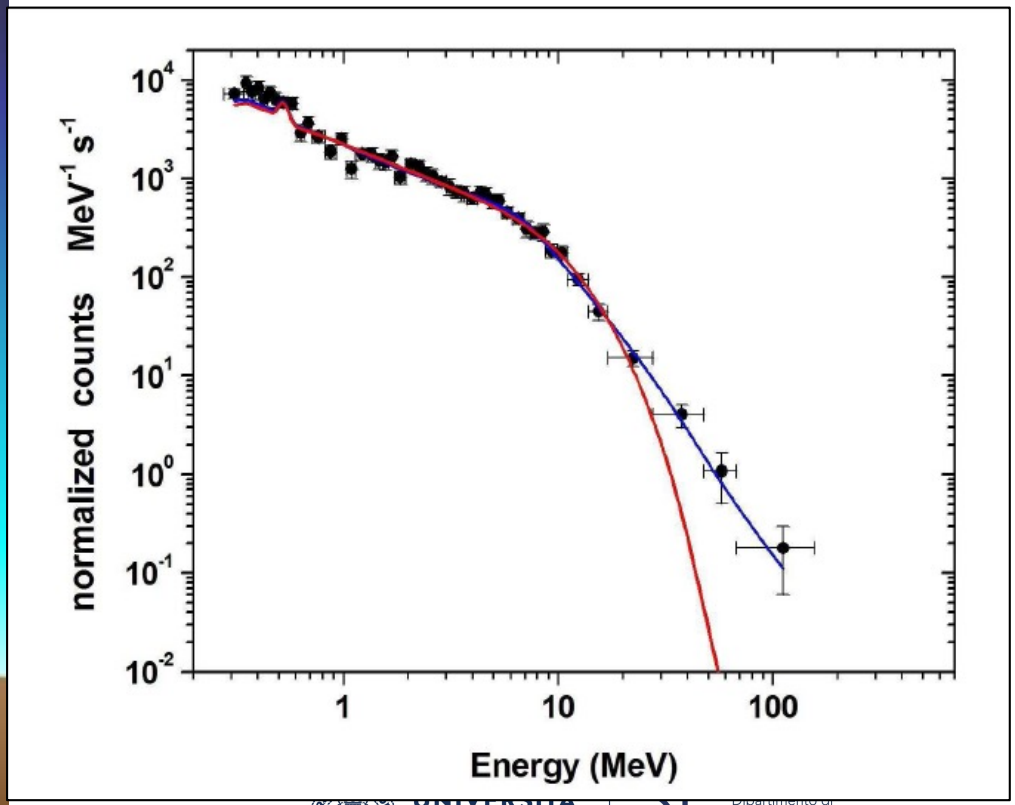


Giuliani et al. 2011

Surprises! TGF !

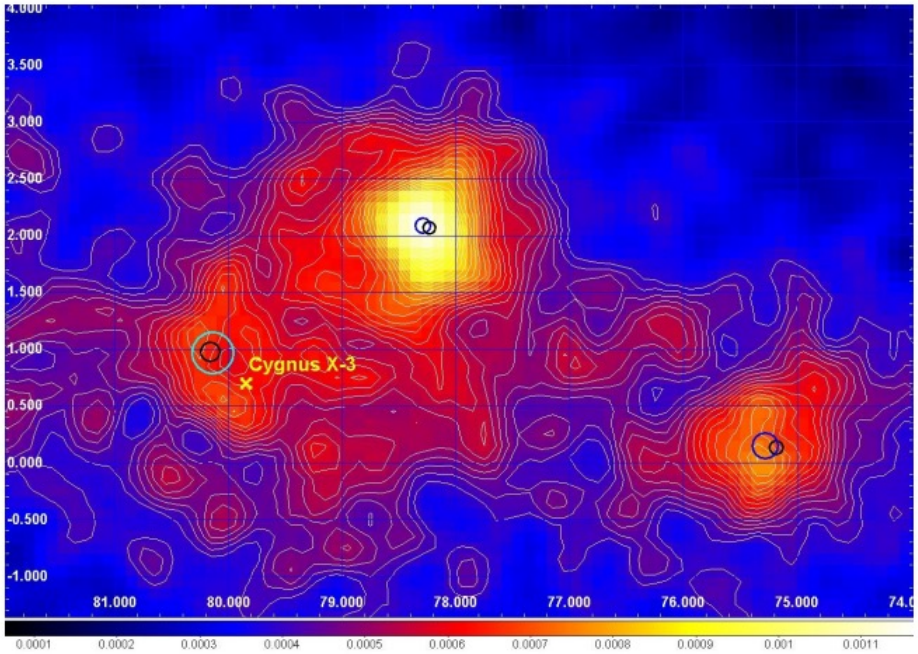
Marisaldi et al. 2010

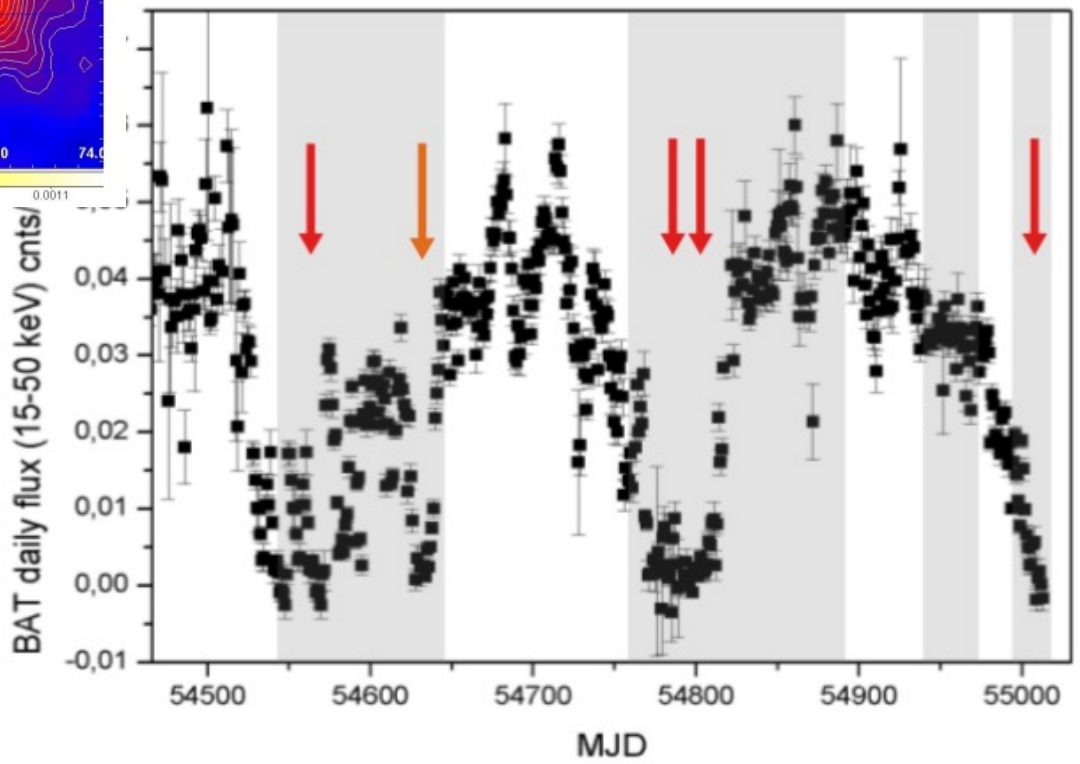




Surprises! Cygnus X3 !

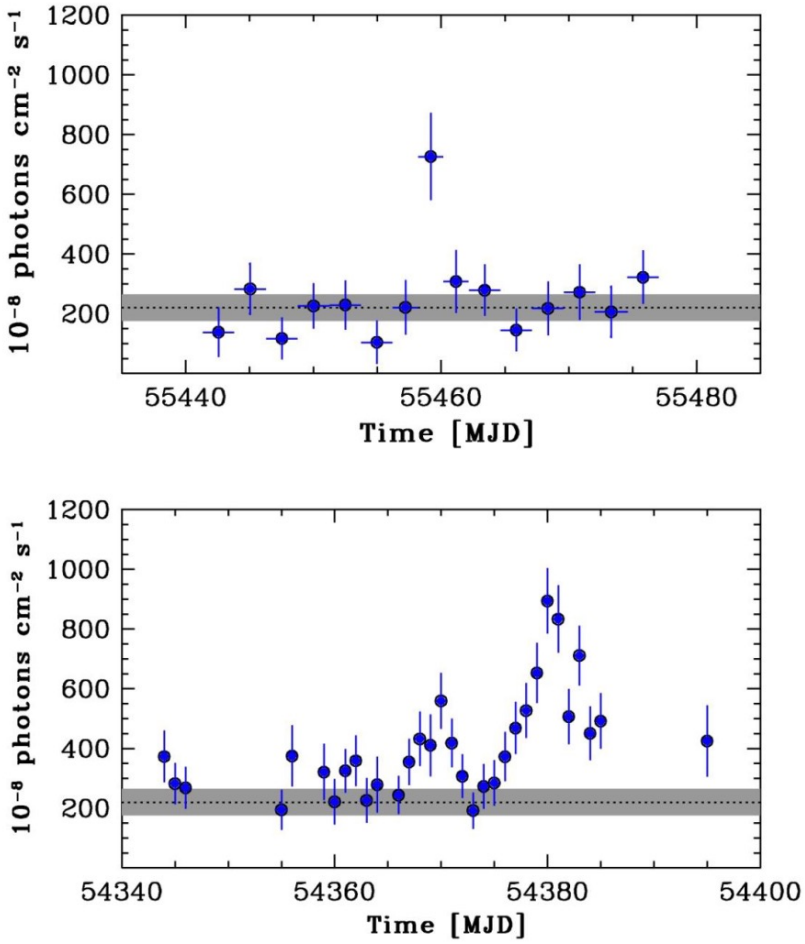
Tavani et al. 2009

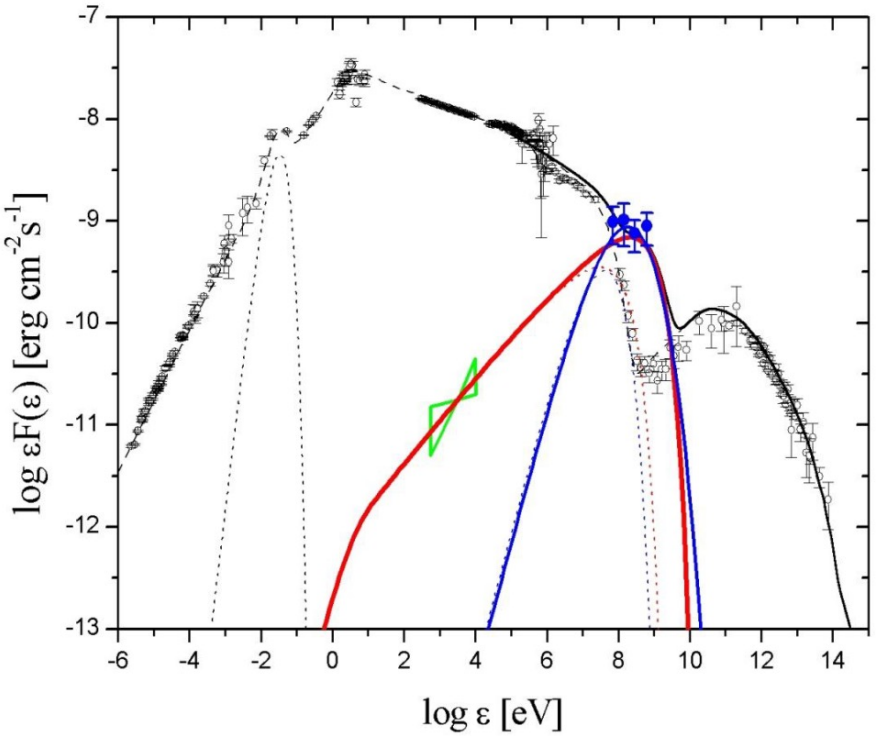




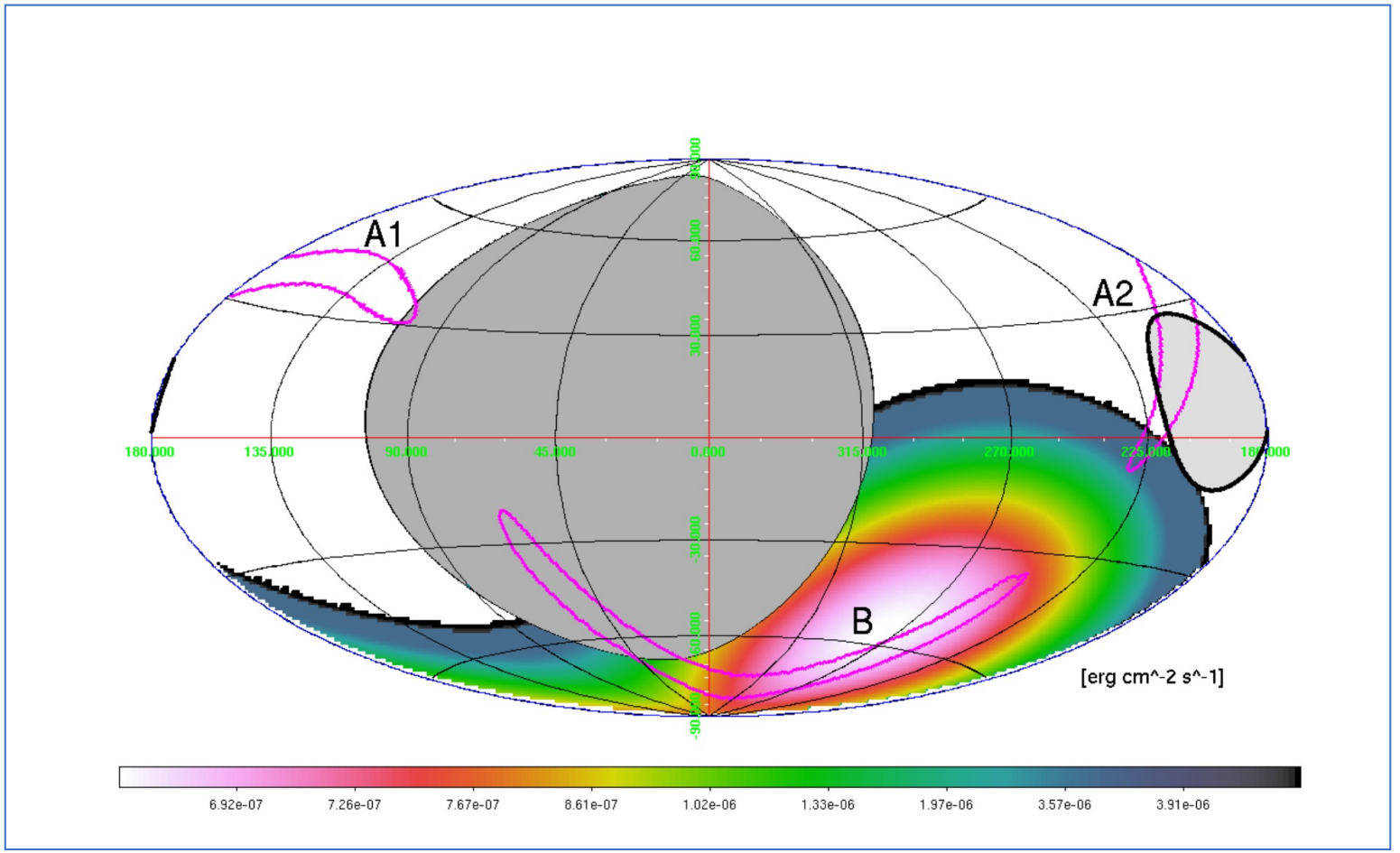
Surprises! The Flaring Crab !

Tavani et al. 2011



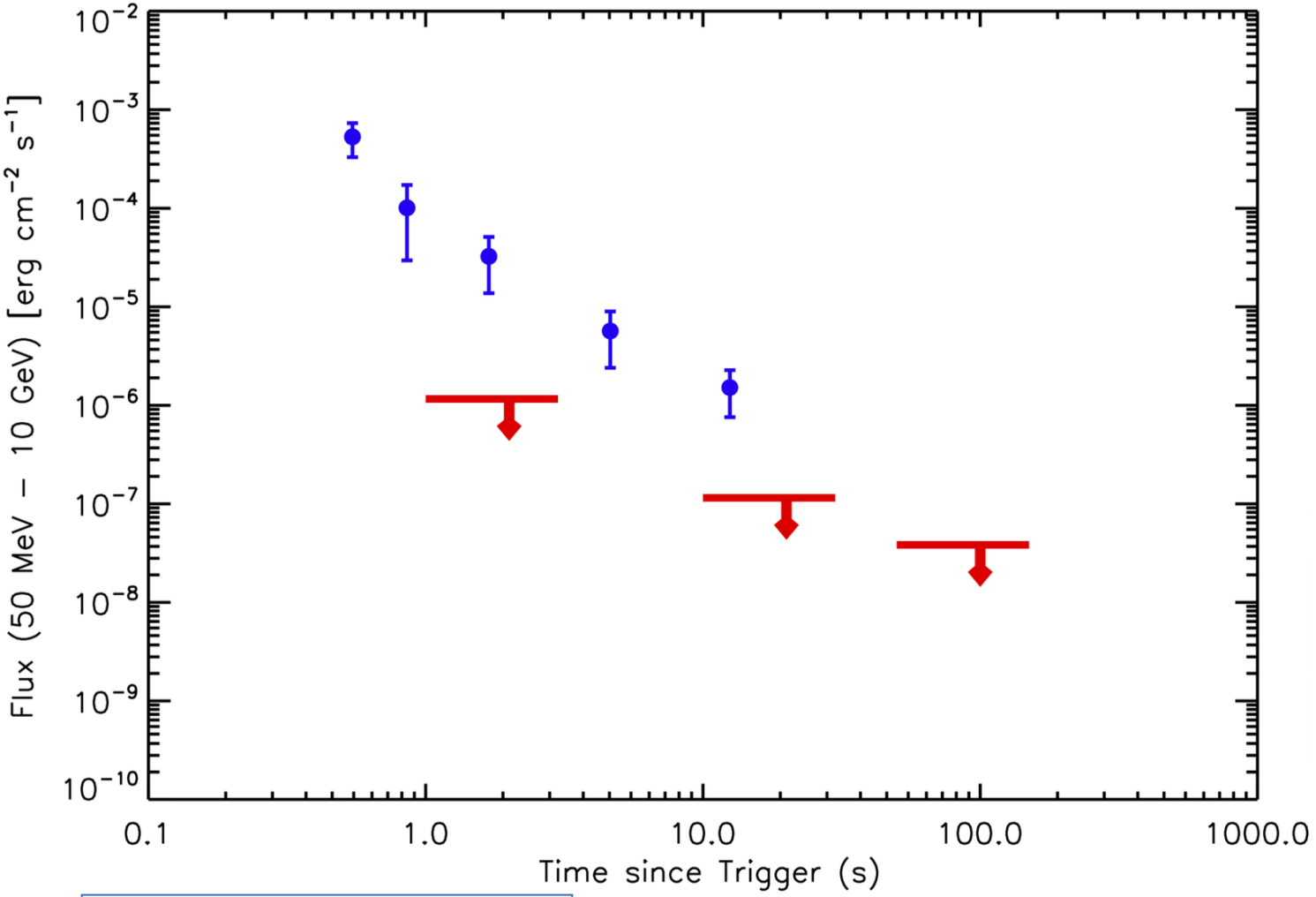


Follow up of GW events



Verrecchia et al 2017

Follow up of GW events



Verrecchia et al 2017

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Welcome to the AGILE Data Center Home Page at SSDC

These pages provide updated information and services in support to the general scientific community for the mission AGILE, which is a small Scientific Mission of the Italian Space Agency (ASI) with participation of INFN, IASF/INAF and CIFS .

AGILE is devoted to gamma-ray astrophysics and it is a first and unique combination of a gamma-ray (AGILE-GRID) and a hard X-ray (SuperAGILE) instrument, for the simultaneous detection and imaging of photons in the 30 MeV - 50 GeV and in the 18 - 60 keV energy ranges. After more than 13 years of operations, AGILE is working nominally, providing valuable data and important scientific results.

AGILE operations:
Launch date 23 April, 2007
Planned Nominal Phase: 2 + 2 extended years
Elapsed: 13 years in orbit completed on 23 April, 2020
Current Extended Phase: ASI extended AGILE operations up to 31 May, 2022

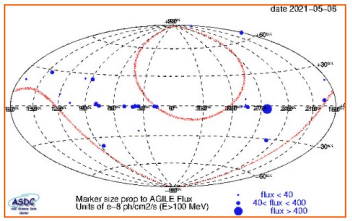
The AGILE Mission Board (AMB) has executive power overseeing all the scientific matters of the AGILE Mission and is composed of:

- AGILE Principal Investigator: Marco Tavani, INAF Rome (Chair)
- ASI Project Scientist: Paolo Giommi, ASI
- ASI Mission Director: Fabio D'Amico, ASI
  (Former ASI Mission Directors: Luca Salotti, up to September 20, 2010 and Giovanni Valentini up to January 22, 2015)
- AGILE Co-Principal Investigator: Guido Barbiellini, INFN Trieste
- 1 ASI representative: Elisabetta Tommasi di Vignano
  (Former ASI representative: Sergio Colafrancesco up to June, 2010)

- INAF Project Scientist: Carlotta Pittori (from November 10, 2020)

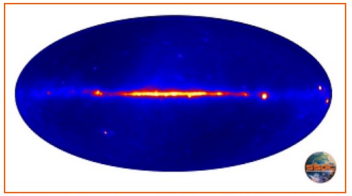
AGILE current spinning sky view

(Click here for previous pointing details)



Click here to access the AGILE Spinning FOV plotter

Click here to access the AGILE Real Data FOV Plotter



AGILE total intensity map up to Sep. 30, 2017.

https://agile.ssdc.asi.it/

Fermi
Gamma-ray
Space Telescope

Fermi LAT

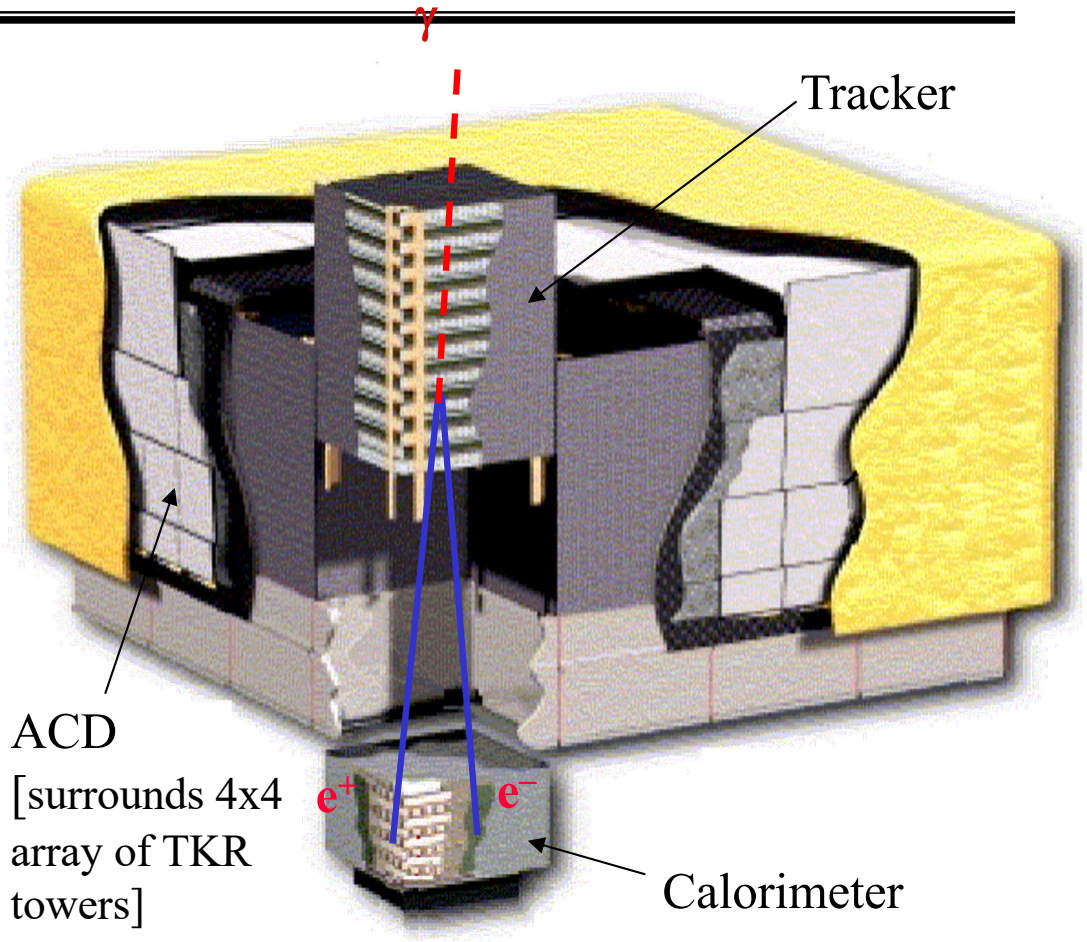
INFN
TRIESTE
Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

Dipartimento di
Fisica
Dipartimento d'Eccellenza 2023-2027

Overview of LAT

- **Precision Si-strip Tracker (TKR)** 18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter(CAL)** Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- **Segmented Anticoincidence Detector (ACD)** 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- **Electronics System** Includes flexible, robust hardware trigger and software filters.



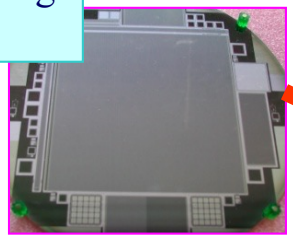
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV

Tower Structure

18

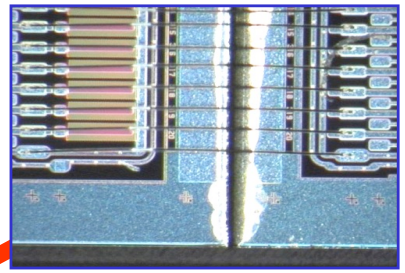
Cable Plant
UCSC

SSD Procurement, Testing
Japan, Italy, SLAC



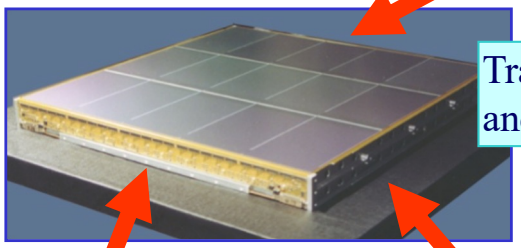
10,368

SSD Ladder
Assembly



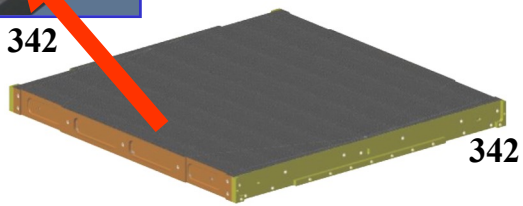
2592

Tower Assembly and Test



Tray Assembly
and Test

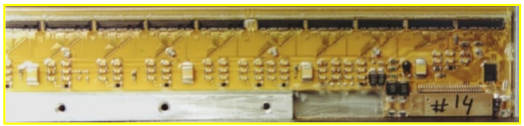
342



342

Composite Panel & Converters

Electronics



648

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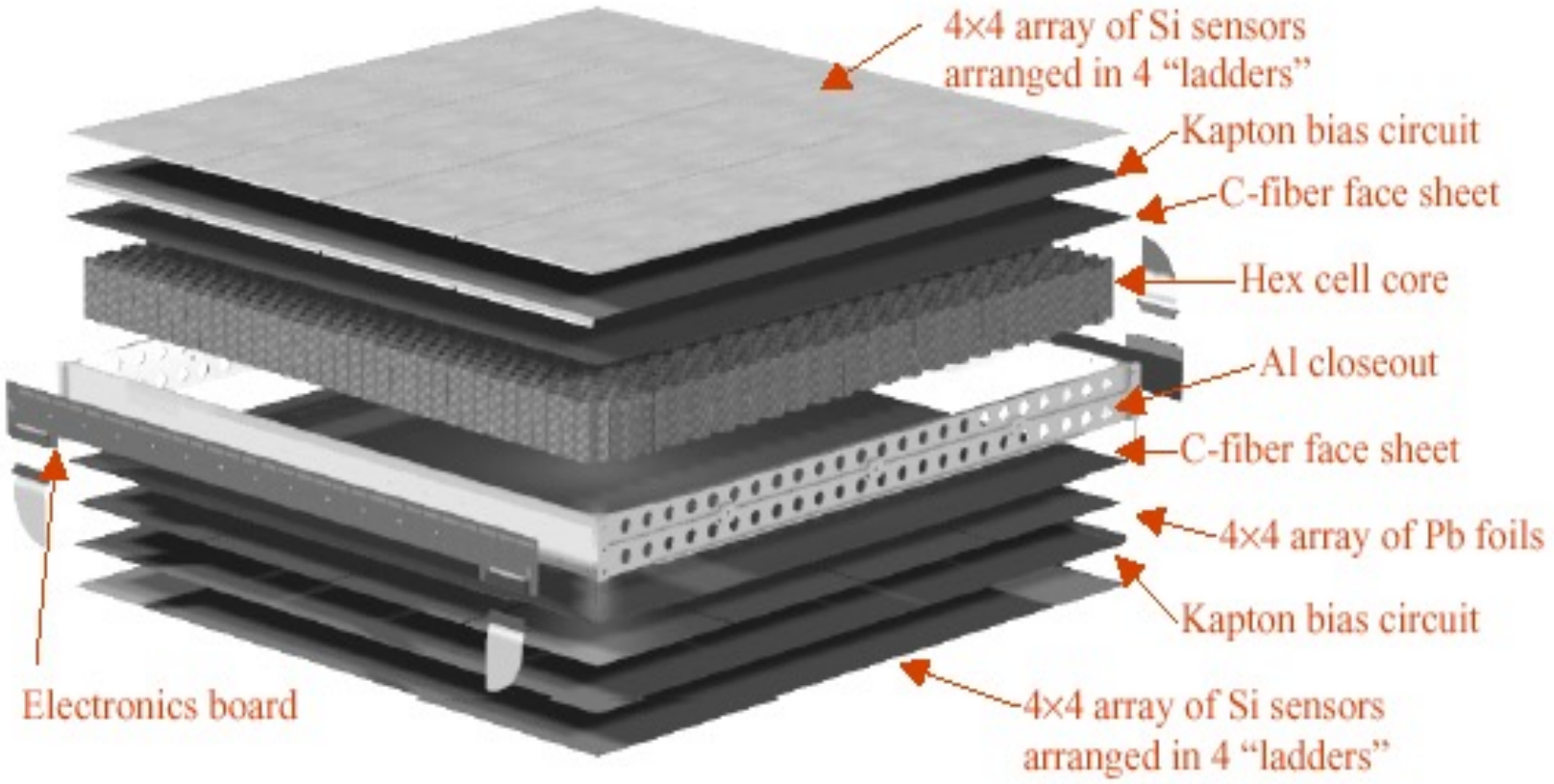
Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

Silicon Detectors



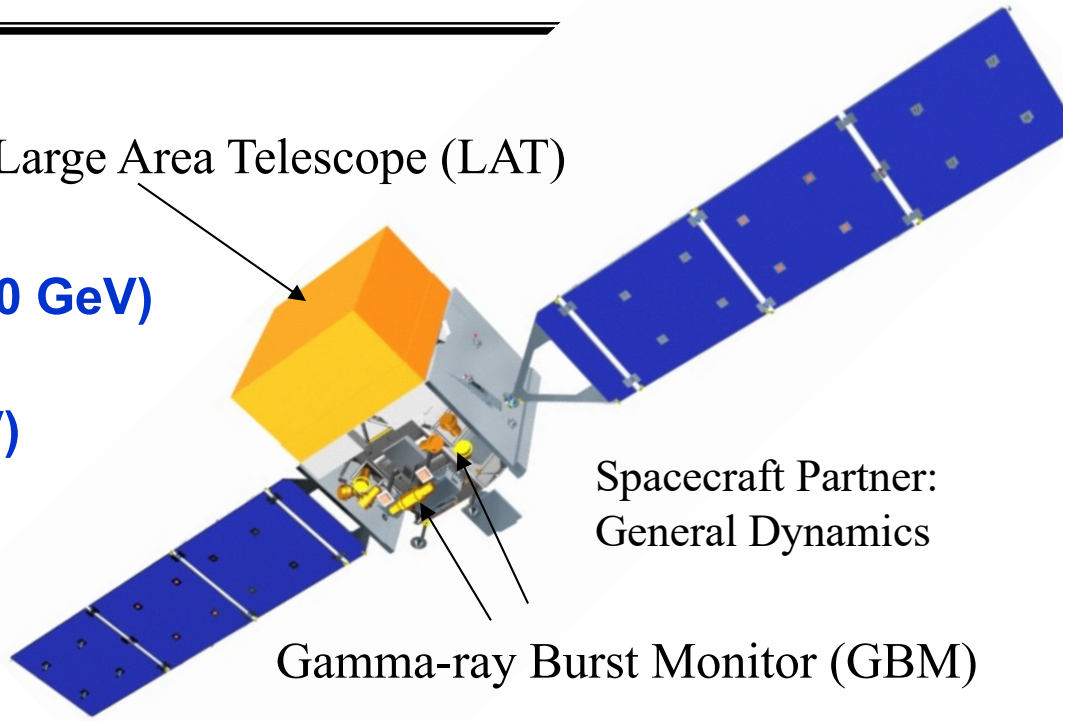
GLAST silicon tracker tray

Launch!

- **Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT**
- **Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.**

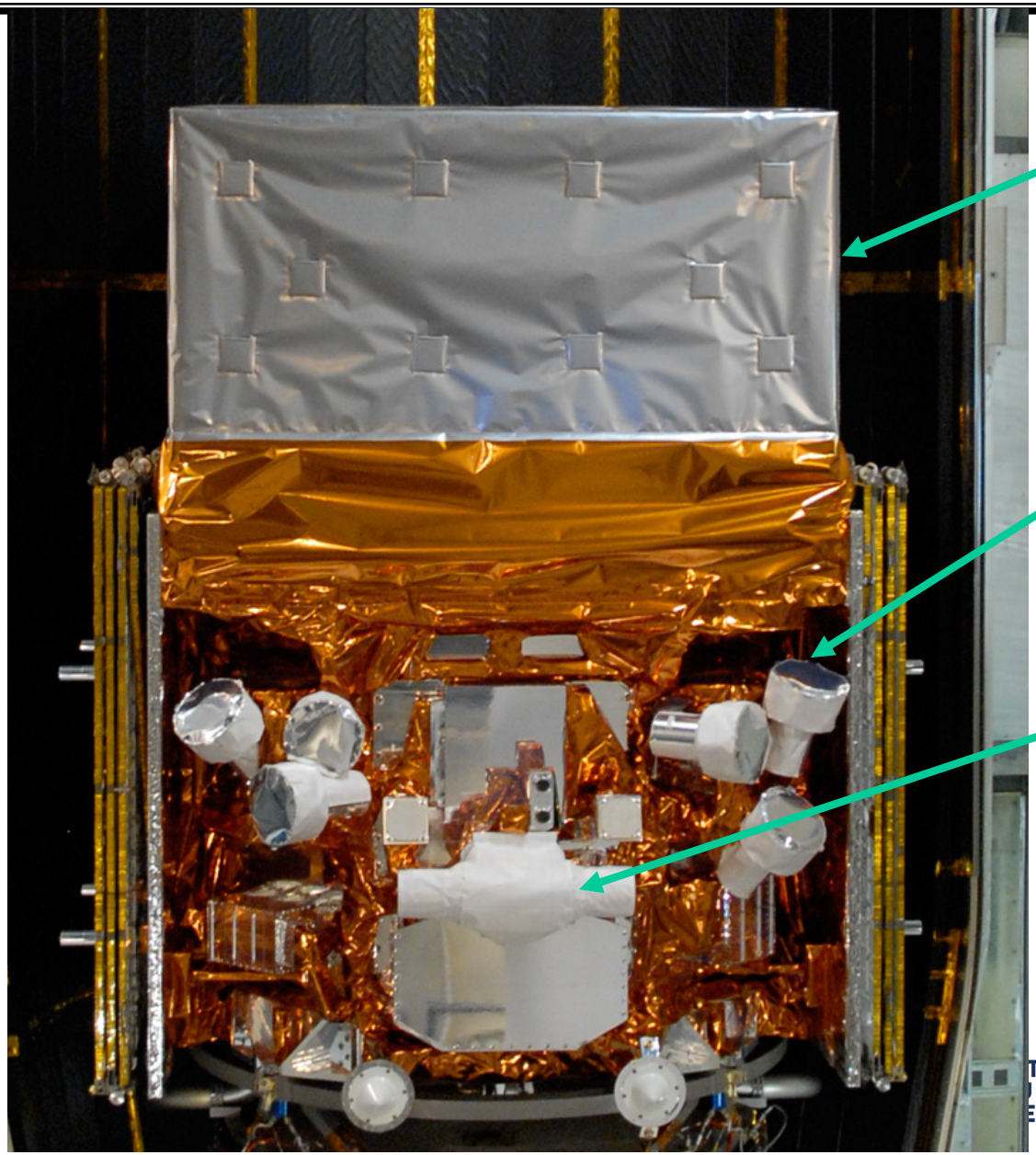
Key Features

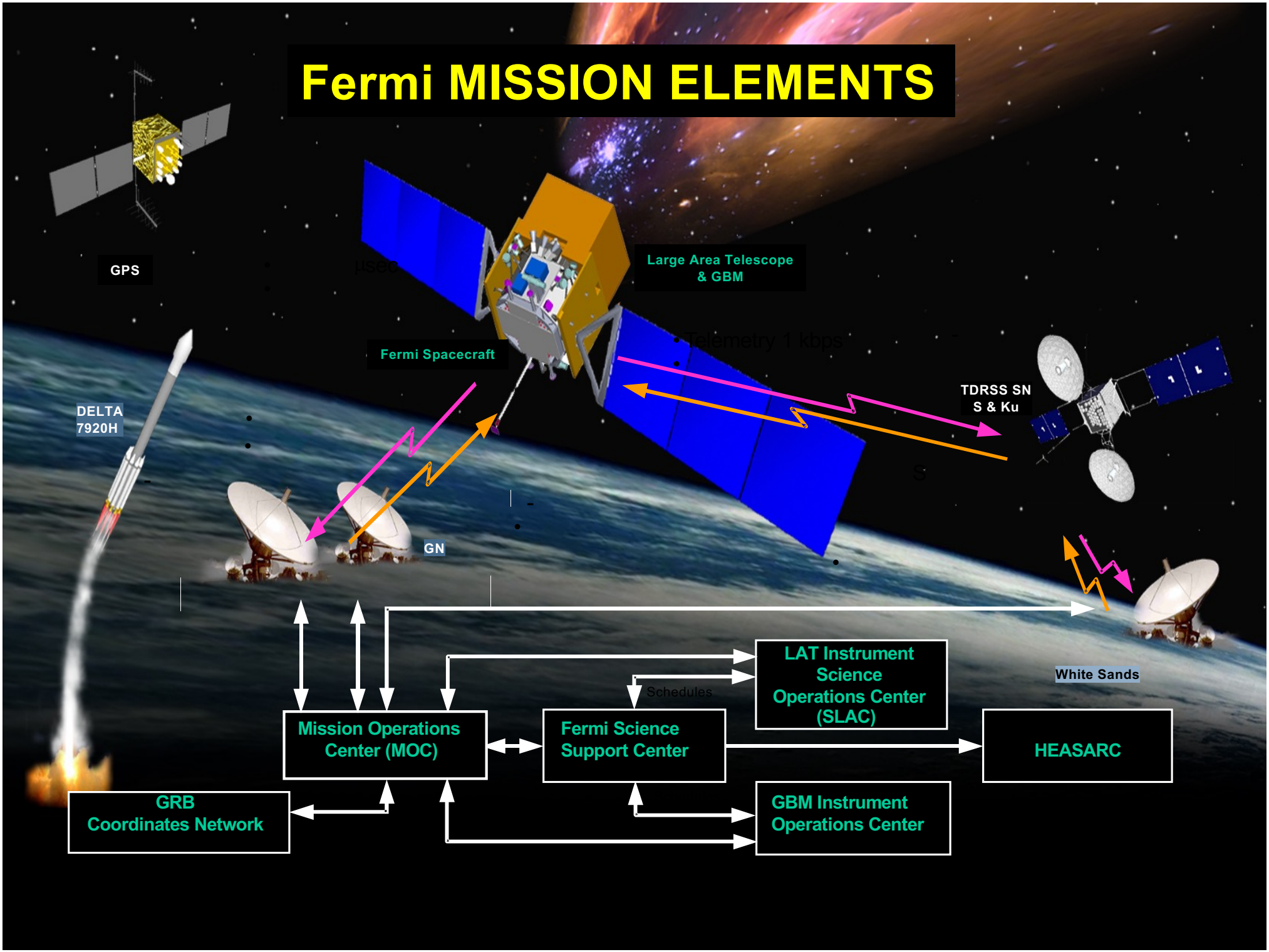
- **Two instruments:**
  - **LAT:**
    - **high energy (20 MeV – >300 GeV)**
  - **GBM:**
    - **low energy (8 keV – 40 MeV)**



- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV**
- **Large leap in all key capabilities. Great discovery potential.**

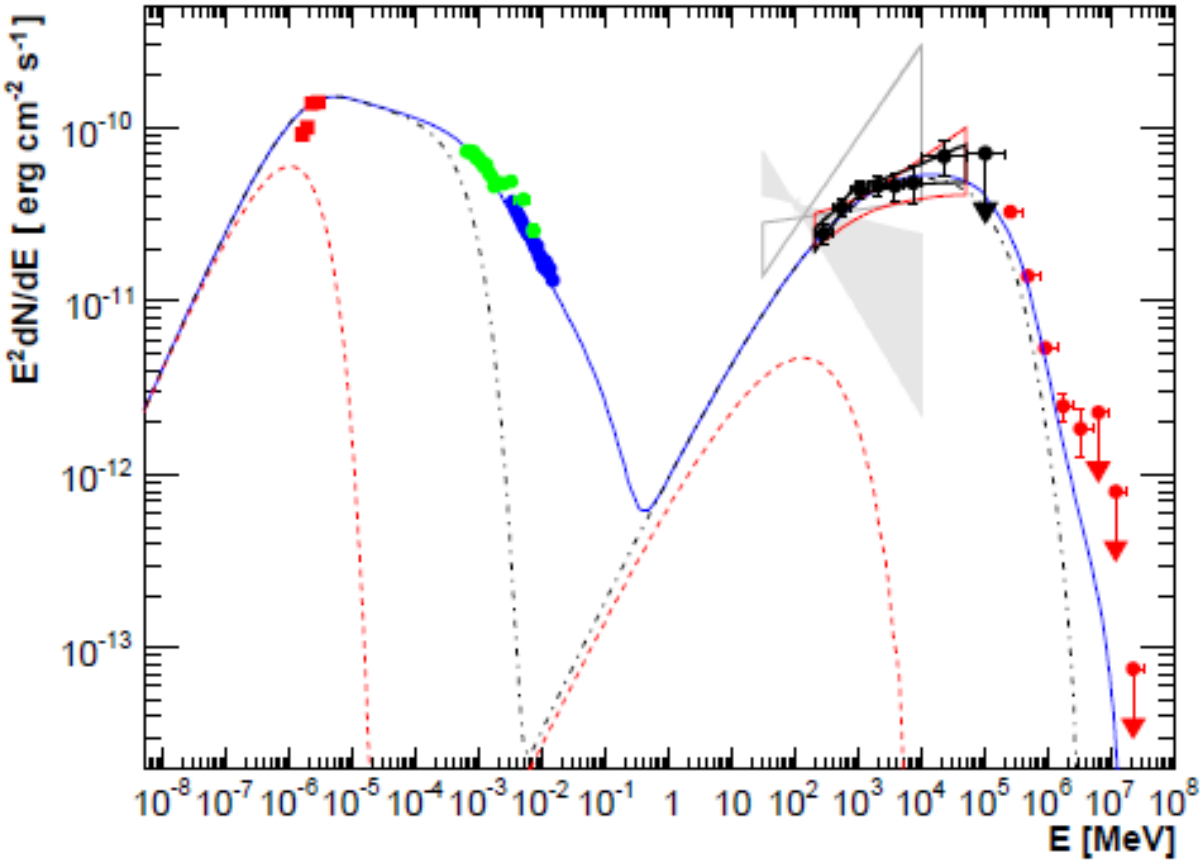
The Observatory




Fermi MISSION ELEMENTS
GPS
Large Area Telescope
& GBM
Fermi Spacecraft
DELTA
7920H
TDRSS SN
S & Ku
GN
White Sands
LAT Instrument
Science
Operations Center
(SLAC)
Schedules
Mission Operations
Center (MOC)
Fermi Science
Support Center
HEASARC
GRB
Coordinates Network
GBM Instrument
Operations Center

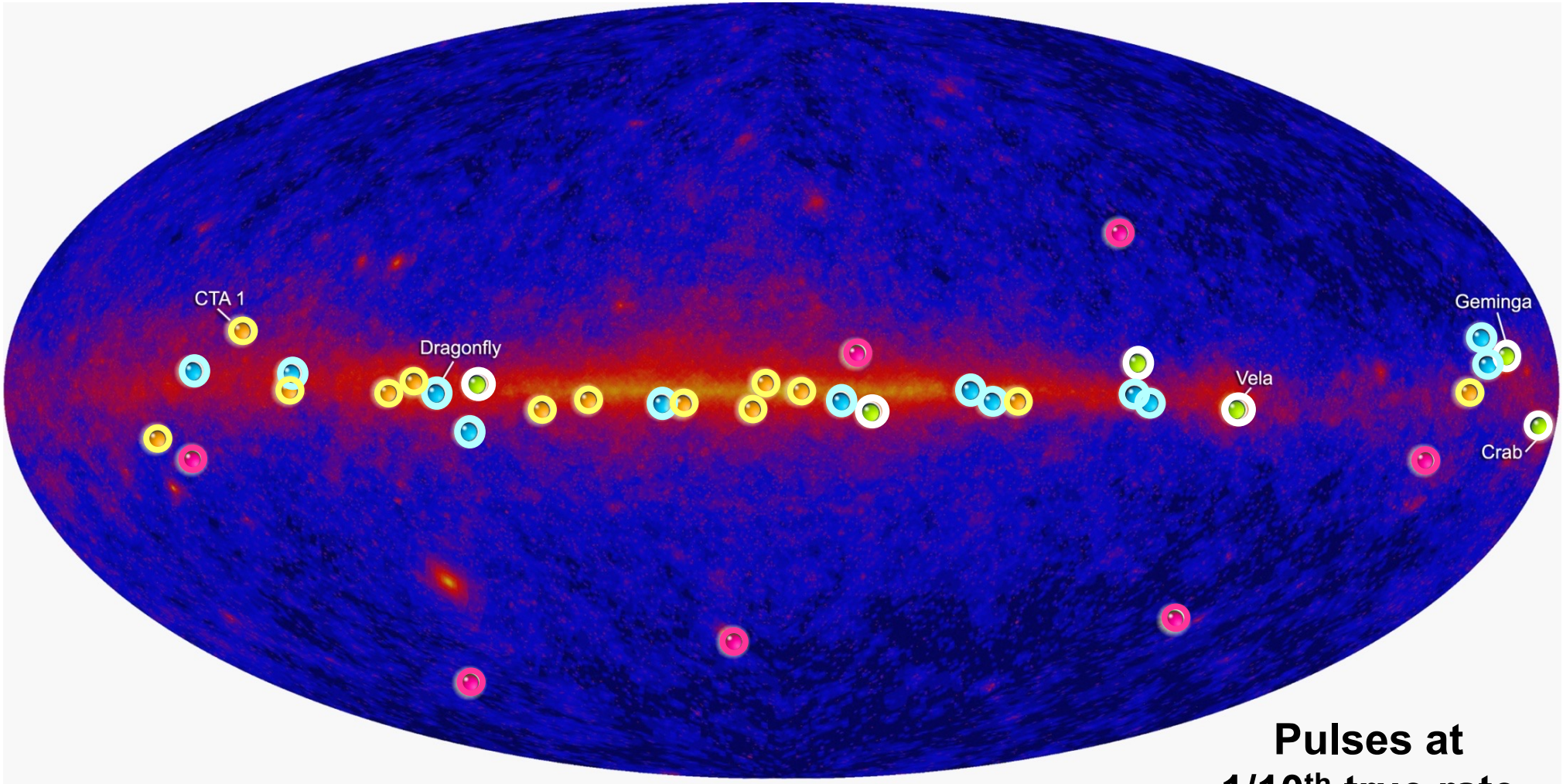
Challenge # 1 – AGN

Joint campaign on PKS 2155 with HESS



Aharonian et al. 2009

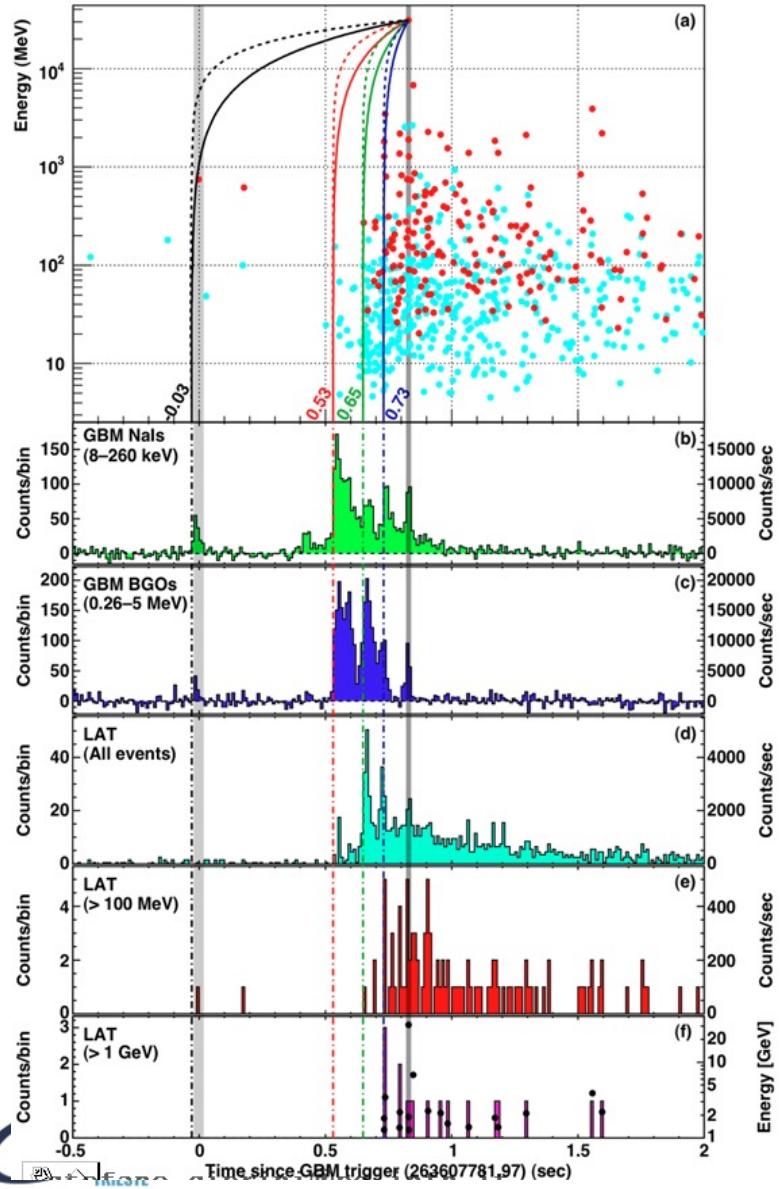
Challenge # 2 – Pulsars Blind Search



Fermi Pulsar Detections

Abdo et al..2010

Challenge # 3 – GRB



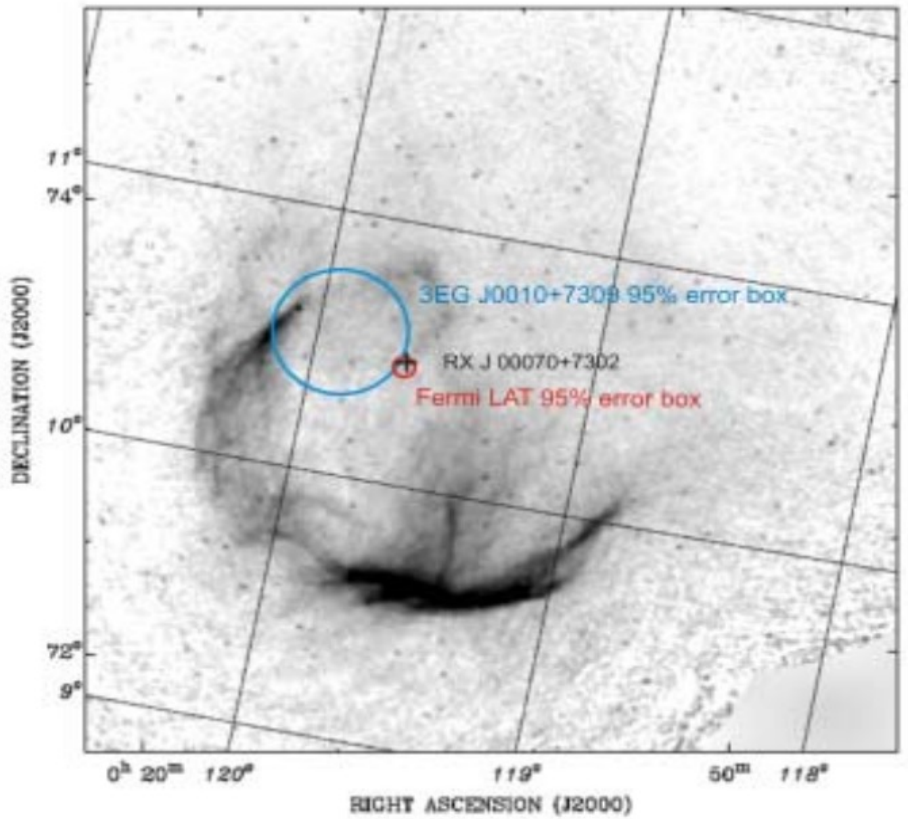
- This GRB is a perfect case for studying Lorentz Invariance Violation
  - z = 0.9 (5.381 Gyr)
  - Emission of 31 GeV photon after 859 ms since the trigger
- Only conservative assumption!
  - the HE photon is not emitted *before* the LE photons, at different events.

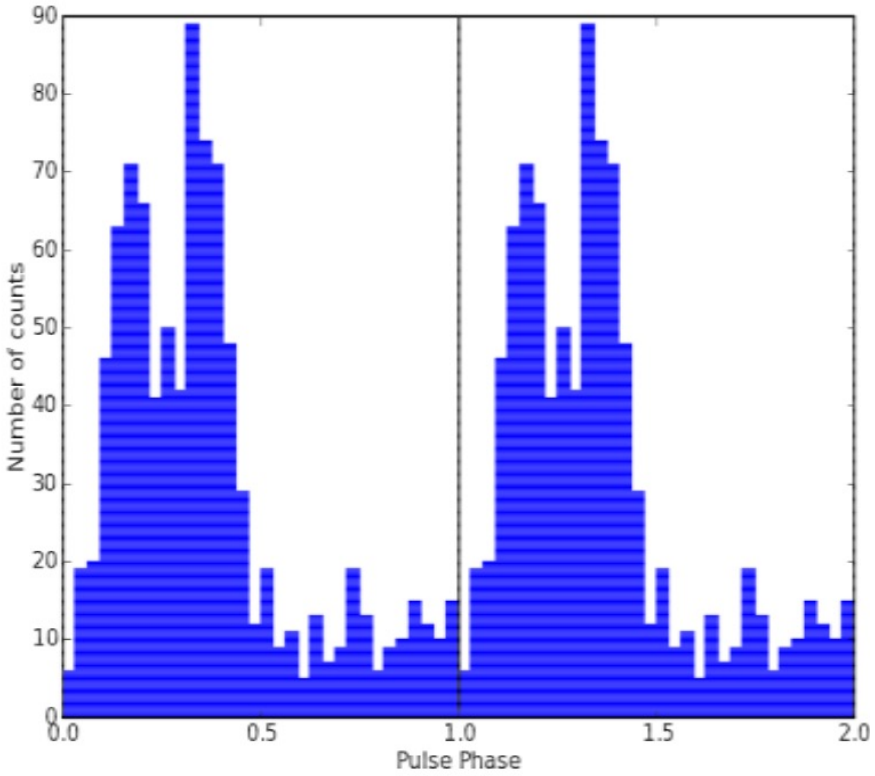
Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\|\Delta t\|$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\|\Delta t/\Delta E\|$	E_l † (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)❖	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)❖	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)❖	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)❖	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	±1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	−1	> 1.33
(g)♠	$\|\Delta t/\Delta E\|$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	±1	> 1.22

Challenge # 4 – Unidentified

CTA 1 Discovery

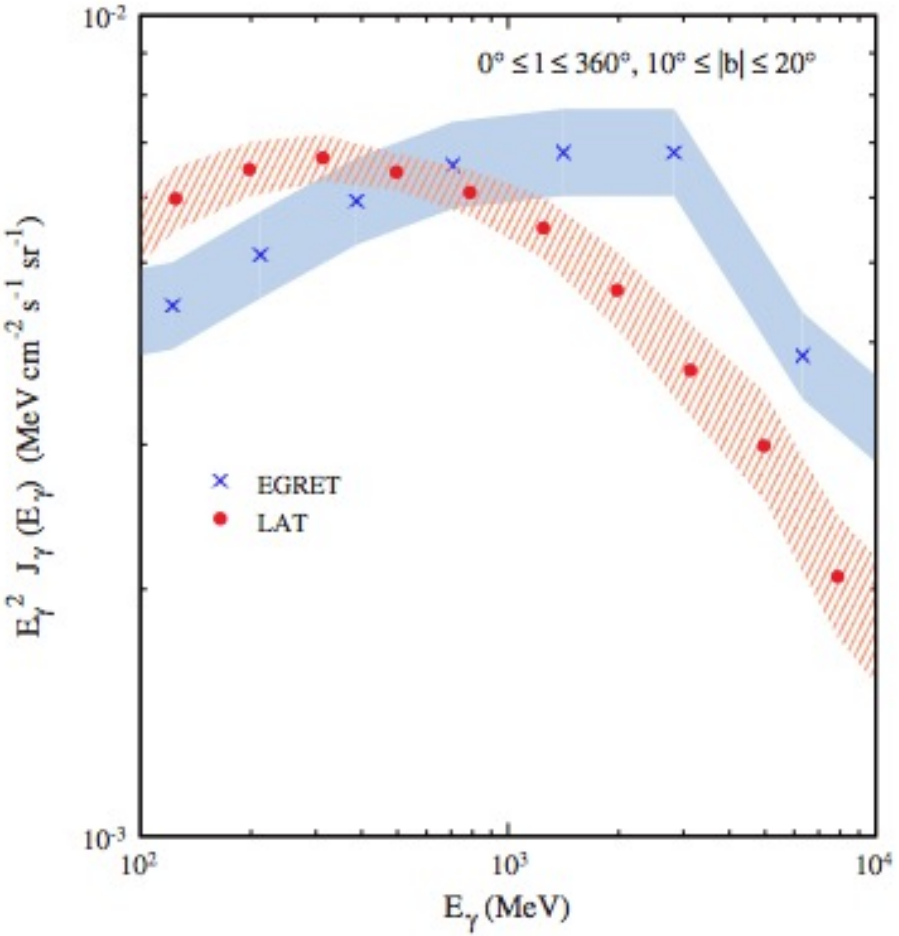


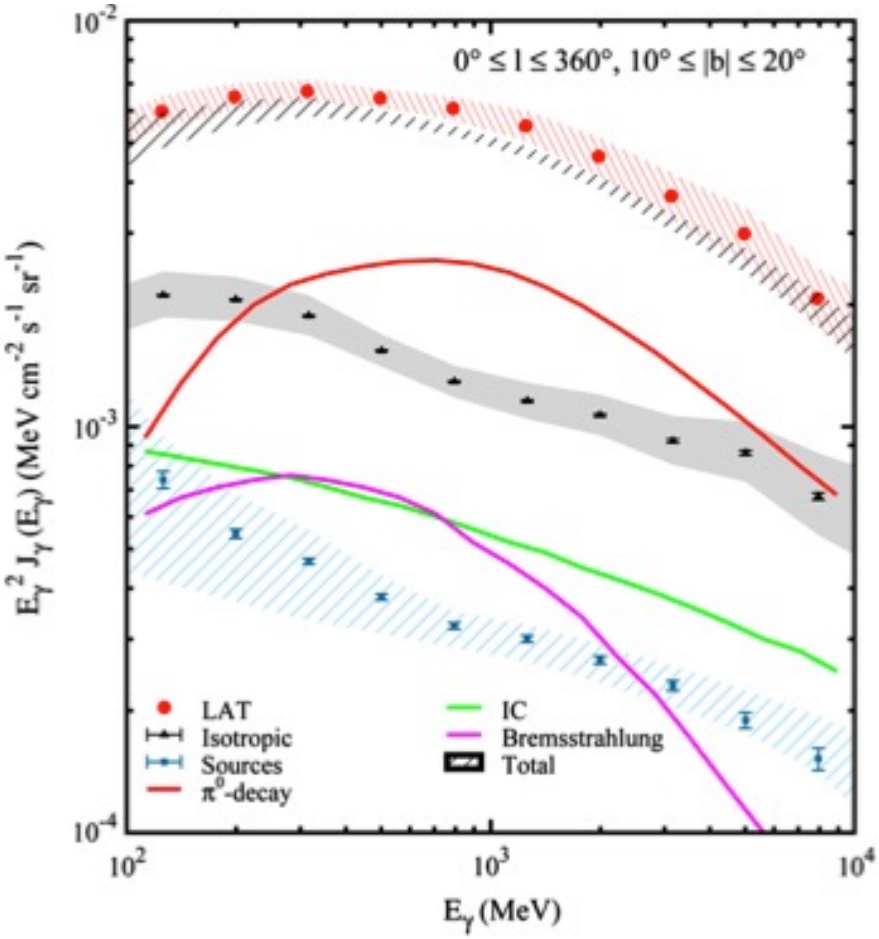


Abdo et al. 2008

Challenge # 5 – Spectral Resolution

Fermi Large Area Telescope Measurements of the Diffuse Gamma-Ray Emission at Intermediate Galactic Latitudes



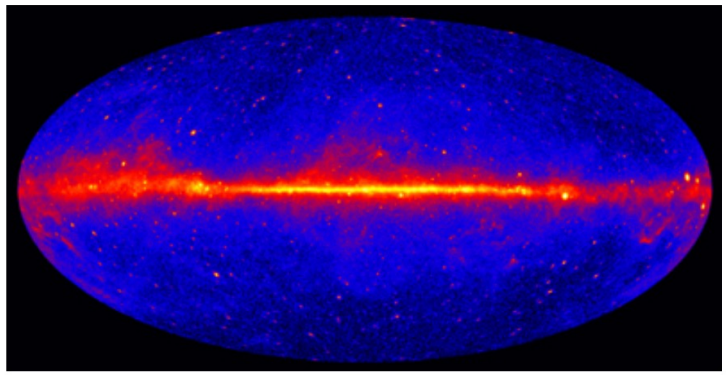


Fermi/LAT

Fermi
Gamma-ray Space Telescope

Home | Support Center | Observations | Data | Proposals | Library | HEASARC | Help

The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This view shows the entire sky at energies greater than 1 GeV based on five years of data from the LAT instrument on NASA's Fermi Gamma-ray Space Telescope. Brighter colors indicate brighter gamma-ray sources.
Image Credit: NASA/DOE/Fermi LAT Collaboration

Look into the "Resources" section for finding schedules, publications, useful links etc. The "Proposals" section is where you will be able to find the relevant information and tools to prepare and submit proposals for guest investigator projects. At "Data" you will be able to access the Fermi databases and find the software to analyse them. Address all questions and requests to the helpdesk in "Help".

Fermi Observations for MW 675

Mission week 675 starts with a continuation of the asymmetric rocking +50/-60 profile from the previous week. On day of year 126 (2021-05-06) at 01:59 there is a 10 minute freeze observation during which an updated asymmetric profile is loaded. This profile continues until DOY 129 (2021-05-09) at 03:01 when there is a 10 minute freeze observation during which a symmetric +/-50 deg. profile is loaded. This profile continues until the end of the week. Note that positive rock angles are south, and negative angles are north.

» More Timeline Info

Latest News

» Fermi Sky Blog
» Fermi Blog

Apr 20, 2021

Updated Spacecraft Position and History Files Available

The updated files include the addition of the SC_VELOCITY column. This column contains a vector with the spacecraft velocity in meters per

https://fermi.gsfc.nasa.gov/ssc/

Fermi/LAT

Stanford | The Fermi Large Area Telescope

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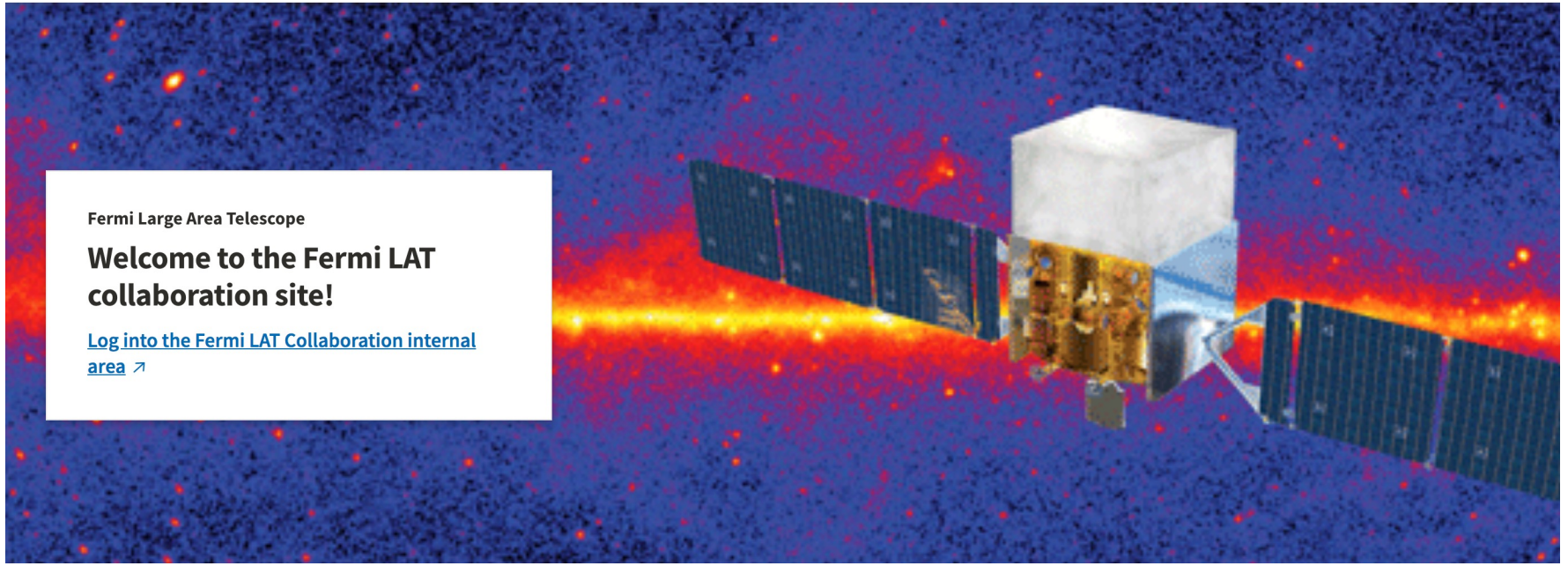
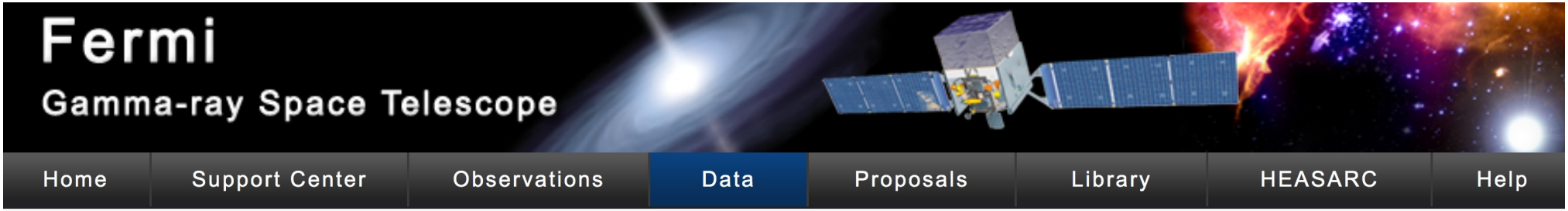
Past Events LAT Pictures LAT documents LAT Rapid Publications LAT Publications Fermi Overview Presentation

Resources Latest Results



https://glast.sites.stanford.edu/

Data Dissemination



Data

- Data Policy
- **Data Access**
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

Currently Available Data Products

The Fermi data released to the scientific community is governed by the data policy. The released instrument data for the GBM, along with LAT source lists, can be accessed through the Browse interface specific to Fermi. LAT photon data can be accessed through the LAT data server.

The FITS files can also be downloaded from the Fermi FTP site. The file version number is the 'xx' in the characters before the extension in each filename; you should keep track of the version numbers of files you analyze since the instrument teams may update them.

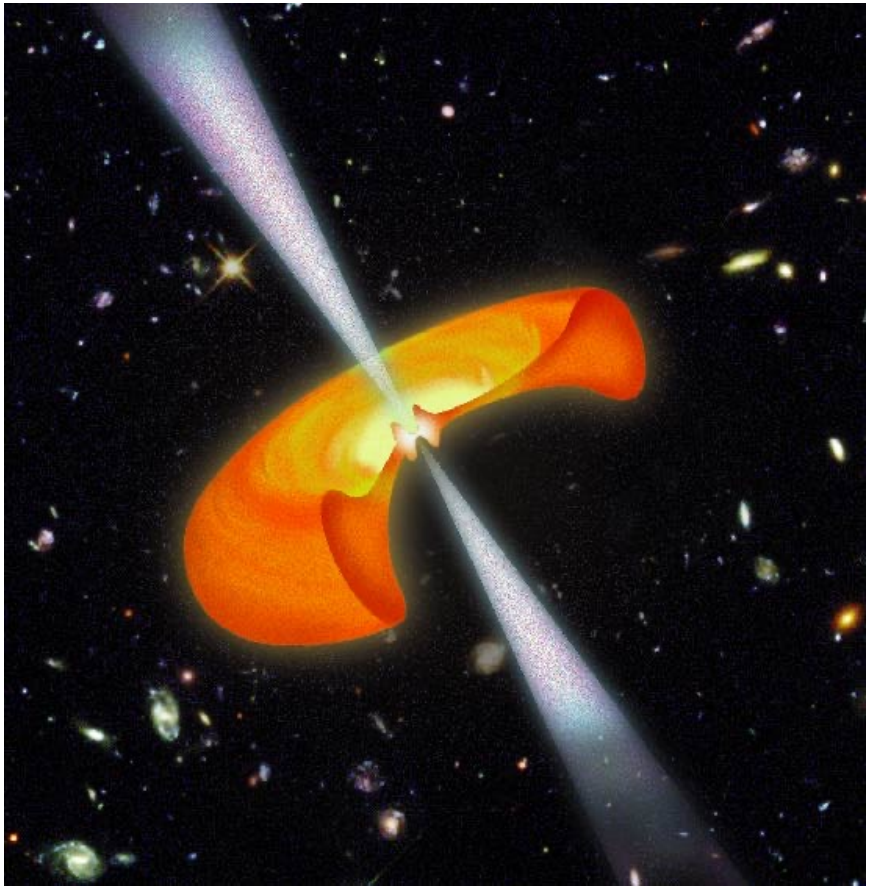
Note that the LAT and GBM data are accompanied by caveats about their use.

- LAT Photon and Extended Data
  - LAT Data Server (updated with P8R3 data 26-Nov-2018)
  - LAT Low-Energy (LLE) Data (Browse table)
  - Products available on the FTP Site (current processing version of the data).
    - Weekly Photon Files
    - Weekly Spacecraft Files

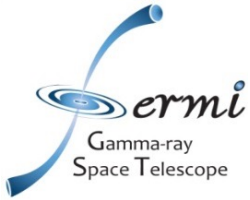
https://fermi.gsfc.nasa.gov/ssc/data/access/

Outline

- HE gamma astrophysics
  - General Introduction
    - "The concepts"
  - Multi-wavelength astrophysics
  - Multi-messenger astrophysics
- MeV Astrophysics
  - Detector techniques
  - Fermi/GBM, COSI …
- GeV Astrophysics
  - Detector techniques
  - AGILE , Fermi/LAT
- The "near" future
  - GammaAstrophysics in the MWL and MM context …
  - Where to … ?

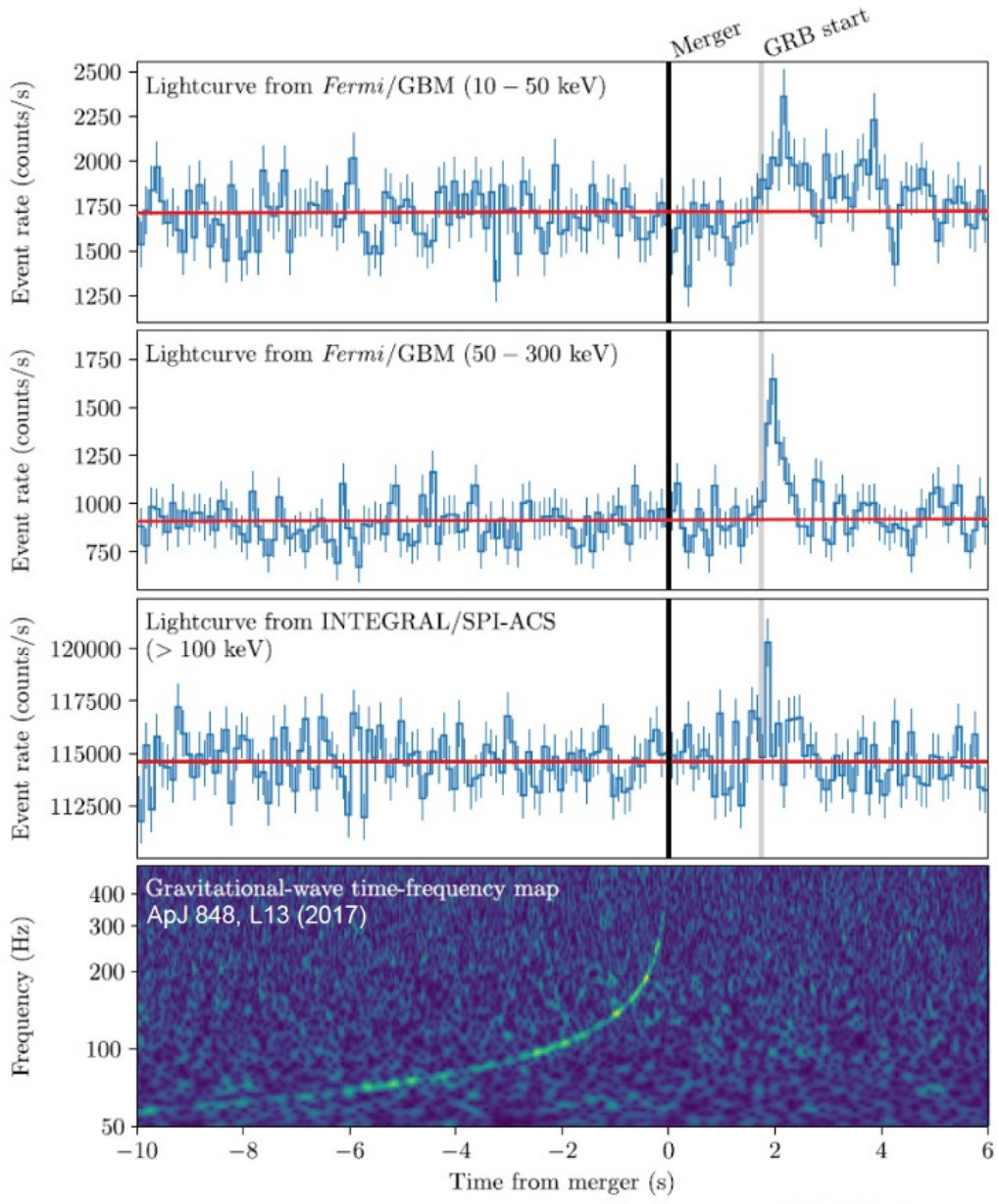



agile
Astro-rivelatore Gamma a Immagini LEggero

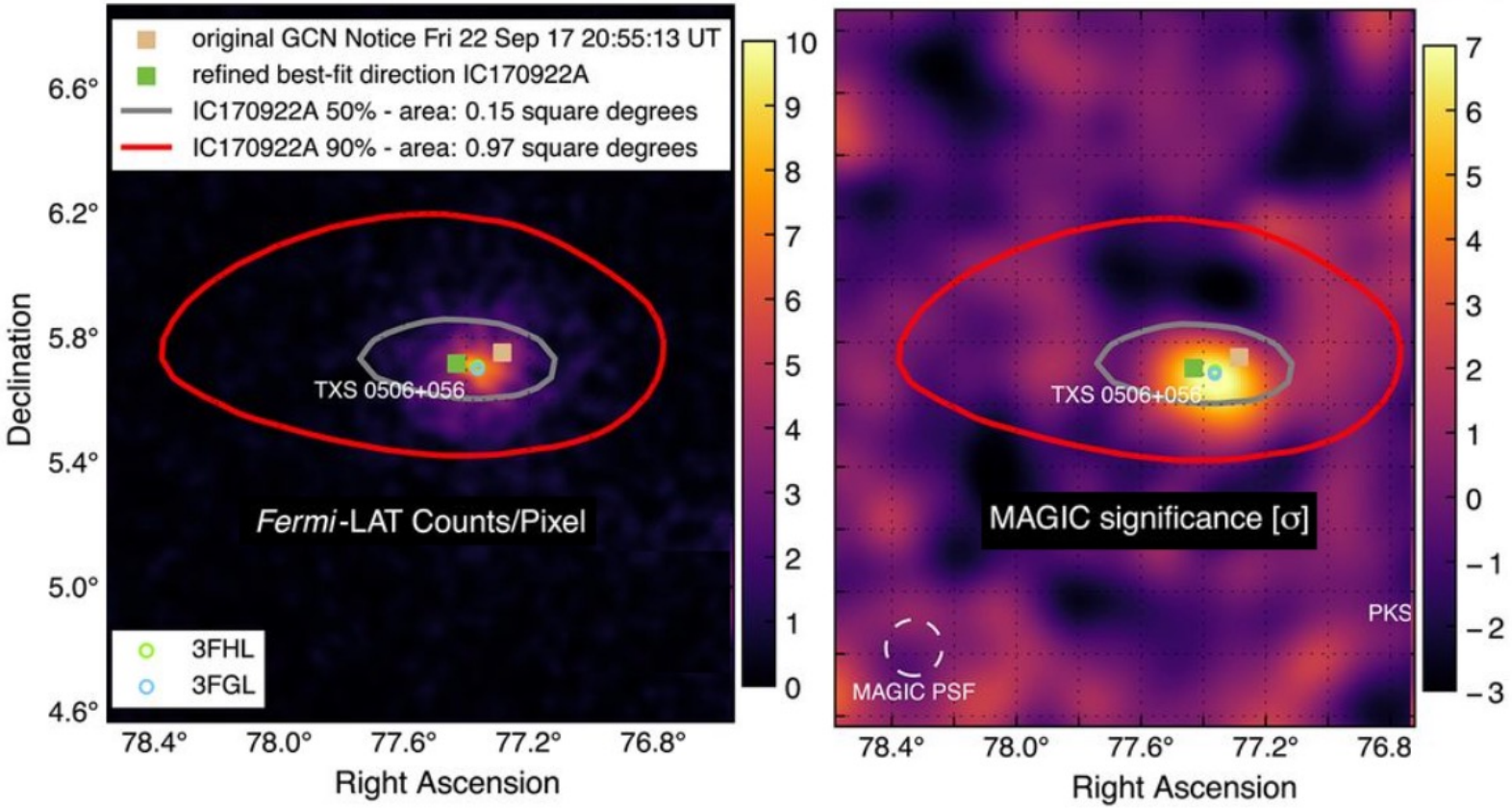

ermi
Gamma-ray
Space Telescope

The future

GW 170817A

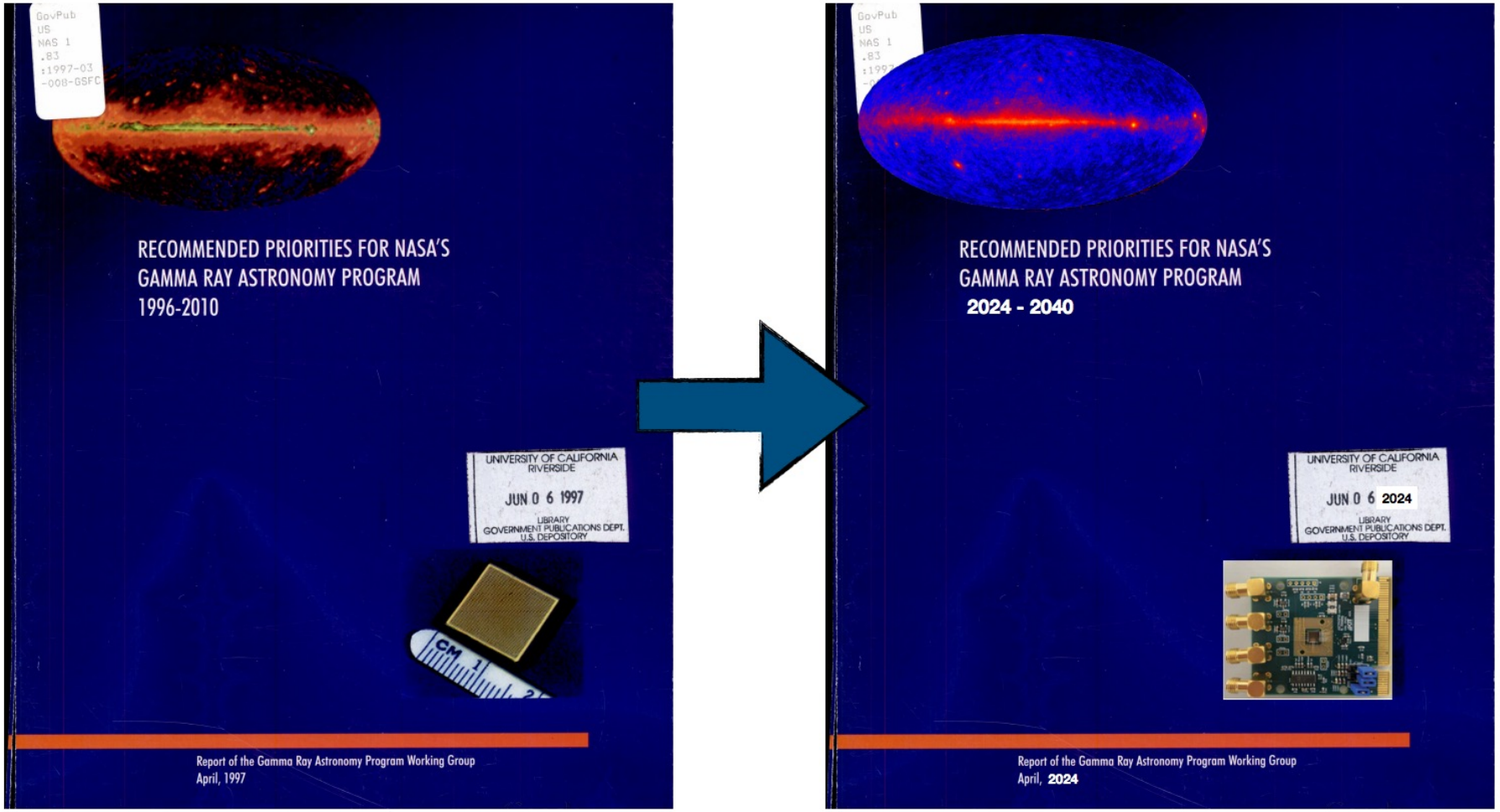

Merger
GRB start
Lightcurve from *Fermi*/GBM (10 – 50 keV)
Event rate (counts/s)
2500
2250
2000
1750
1500
1250
Lightcurve from *Fermi*/GBM (50 – 300 keV)
Event rate (counts/s)
1750
1500
1250
1000
750
Lightcurve from INTEGRAL/SPI-ACS
(> 100 keV)
Event rate (counts/s)
120000
117500
115000
112500
Gravitational-wave time-frequency map
ApJ 848, L13 (2017)
Frequency (Hz)
400
300
200
100
50
−10
−8
−6
−4
−2
0
2
4
6
Time from merger (s)

TXS 0506+056


original GCN Notice Fri 22 Sep 17 20:55:13 UT
refined best-fit direction IC170922A
IC170922A 50% - area: 0.15 square degrees
IC170922A 90% - area: 0.97 square degrees
TXS 0506+056
Fermi-LAT Counts/Pixel
3FHL
3FGL
Declination
6.6°
6.2°
5.8°
5.4°
5.0°
4.6°
78.4°
78.0°
77.6°
77.2°
76.8°
Right Ascension
10
9
8
7
6
5
4
3
2
1
0
TXS 0506+056
MAGIC significance [σ]
PKS
MAGIC PSF
78.4°
78.0°
77.6°
77.2°
76.8
Right Ascension
7
6
5
4
3
2
1
0
−1
−2
−3

Where to ..?

R.Caputo @ 2nd CTAO symposium



Where to …?

R.Caputo @ 2nd CTAO symposium

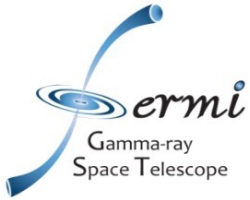
KEY QUESTIONS IN GAMMA-RAY ASTRONOMY FROM 1997

- **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.

Where to …?



Scientific Motivations and Technical Design Considerations for Future High-Energy γ-ray Telescopes in Light of Lessons Learned from the Fermi Large Area Telescope.

Eric Charles[a]
on behalf of the *Fermi* Large Area Telescope Collaboration

[a]Kavli Institute for Particle Astrophysics and Cosmology, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, M/S 29 Menlo Park, CA 94025, USA;

ABSTRACT

Five years into the *Fermi Gamma-ray Space Telescope* (*Fermi*) mission we have learned a great deal about the γ-ray sky, yet many open questions remain, and many new puzzles have arisen. In this contribution we will consider the science drivers for a variety of topics in high-energy gamma-ray astronomy, and how these drivers map into design considerations for future gamma-ray instruments in the energy range above 5 MeV. Specifically, we take the performance parameters and data set of the Large Area Telescope on the *Fermi* observatory (*Fermi*-LAT) as a baseline, and consider the scientific questions that could be probed by improving those parameters. We will also discuss the current state of detector technologies used in space-based γ-ray telescopes and discuss the magnitude of advances that would be required to make a future *Fermi*-like mission transformational enough to warrant the cost and effort. These summaries are intended to be useful for selecting technologies and making basic design decisions for future γ-ray telescopes.

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Dipartimento di Fisica
Dipartimento d'Eccellenza 2023-2027

Where to …?

Table 1. Summary of the importance of instrument performance parameters for science topics in high-energy γ-ray astronomy. Key performance parameter are marked as "1", other important parameters as "2", marginally relevant parameters as "3" and irrelevant parameters are unmarked. The performance parameters are background rejection ("Bkg"), point-source sensitivity ("Source"), on-axis $A_{\rm eff}$ ("$A_{\rm eff}$"), field-of-view (FOV), point-source localization ("PSF Loc."), extension detection/ associating a given γ ray with a particular source ("PSF Ext."), energy bandpass ("Band"), energy resolution ("Energy Res."), spectral resolution ("Energy spec."), relative timing and deadtime between readouts ("Timing Rel.") and absolute timing ("Timing Abs.").

			Acceptance		PSF		Energy			Timing	
Topic	Bkg.	Source	$A_{\rm eff}$	FOV	Loc.	Ext.	Band	Res.	Spec.	Rel.	Abs.
GRB Detection	2	1	1	1	3	-	2	-	-	-	-
GRB Localization	2	2	2	2	1	-	-	-	-	-	-
GRB Modeling	2	2	1	1	-	2	1	2	1	2	3
GRB EBL Studies	2	3	1	1	-	2	2	2	-	-	3
GRB LIV Studies	3	-	1	1	-	2	2	2	-	1	2
AGN Pop. Studies	3	1	1	2	1	-	1	3	2	-	-
AGN Variability	3	1	1	1	-	-	2	3	2	-	-
AGN EBL Studies	3	1	1	2	-	1	2	3	3	-	-
Nearby Galaxies	3	1	1	2	3	1	1	3	2	-	-
Galactic Diffuse	1	2	2	2	-	1	3	3	2	-	-
Extra-Galactic Diffuse	1	2	2	2	-	2	1	3	2	-	-
Radio Timed Pulsars	3	1	1	1	-	2	2	3	2	3	1
Blind Search Pulsars	2	2	1	1	1	2	2	3	2	3	1
Pulsar Radio Targets	3	1	1	2	1	-	3	3	3	-	-
Pulsar Modeling	3	2	1	2	-	2	2	2	1	3	1
SNR / PWN	2	2	1	2	3	1	1	2	1	-	-
X-ray Binaries	2	1	1	2	2	3	1	3	2	-	-
Galactic Novae	2	1	1	2	1	3	1	3	2	-	-
Earth	-	-	3	2	-	3	1	3	1	-	-
Sun / Moon	2	1	1	2	3	1	1	3	2	-	-
Solar Flares	2	1	1	1	1	3	1	3	2	2	-
TGFs	-	-	2	2	-	-	3	-	-	1	2
DM dSph	2	1	1	2	-	2	2	3	2	-	-
DM Galaxy Clusters	2	1	1	2	-	1	2	3	2	-	-
DM Inner Galaxy	3	2	2	2	1	1	1	3	1	-	-
DM Lines	1	-	2	2	-	3	1	1	1	-	-

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- MeV Astrophysics
  - Detector techniques
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  - AGILE , Fermi/LAT
- The "near" future
  - GammaAstrophysics in the MWL and MM context …
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