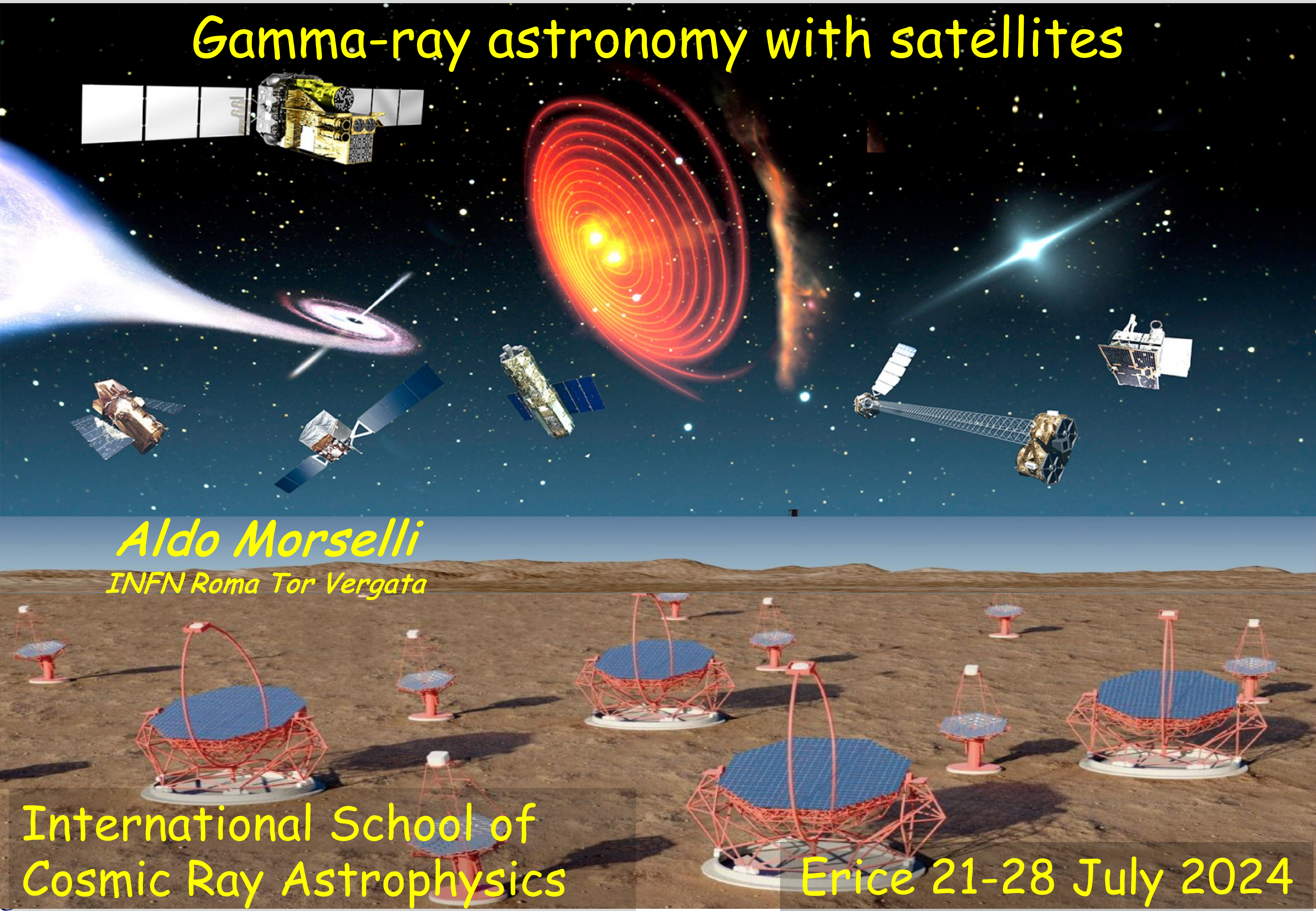
Gamma-ray astronomy with satellites



Aldo Morselli
INFN Roma Tor Vergata

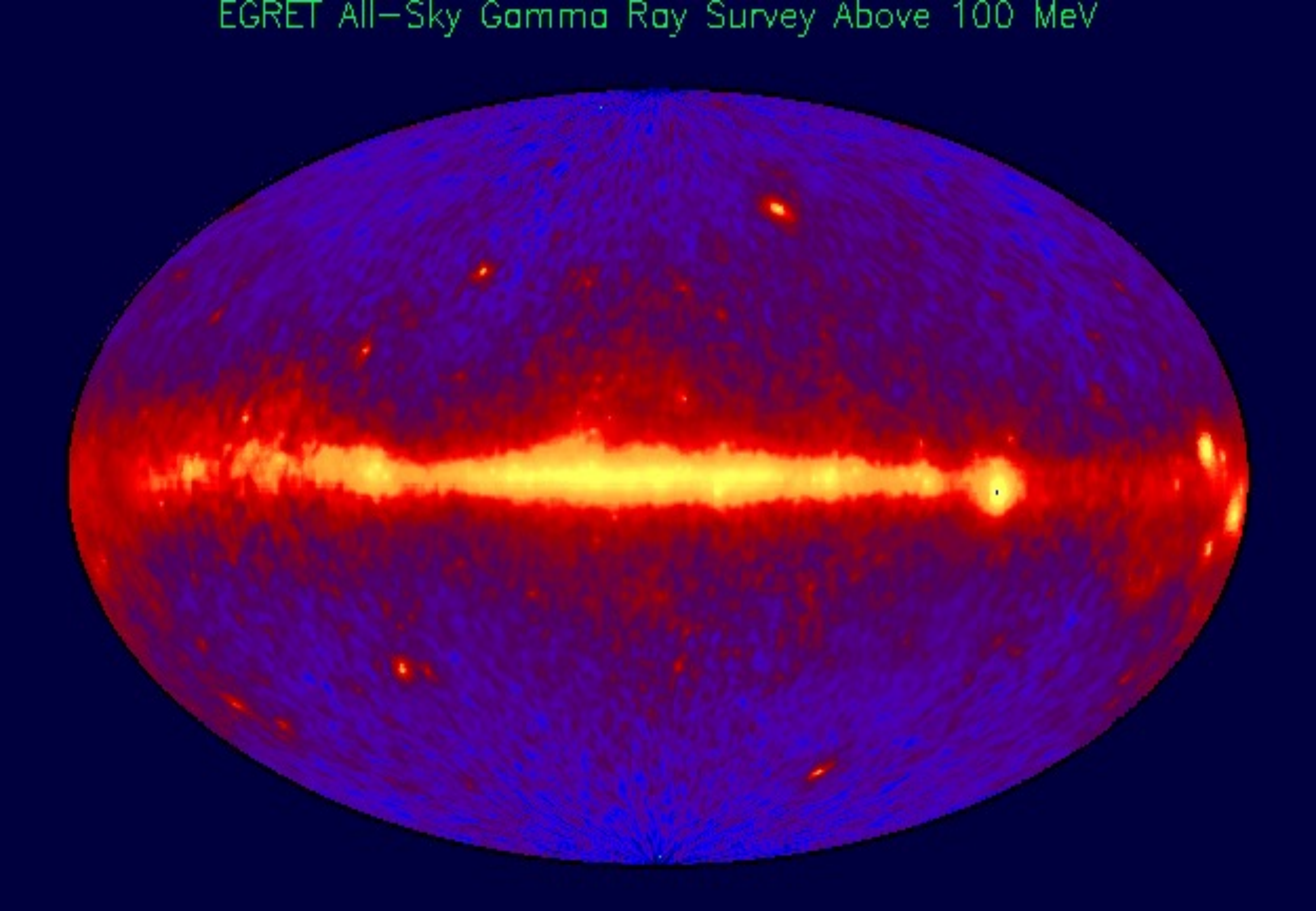
International School of Cosmic Ray Astrophysics

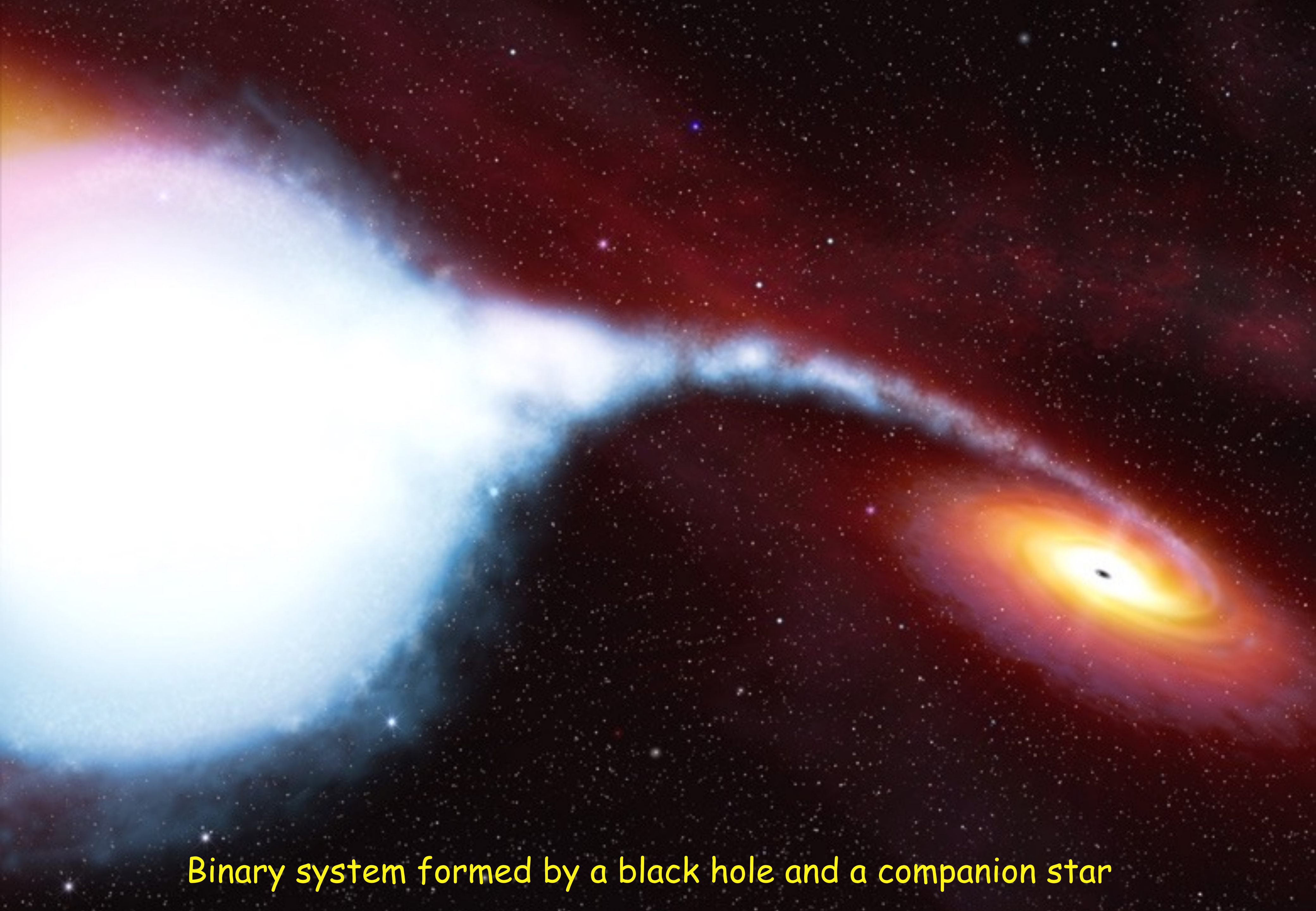
Erice 21-28 July 2024

Why to study gamma rays?

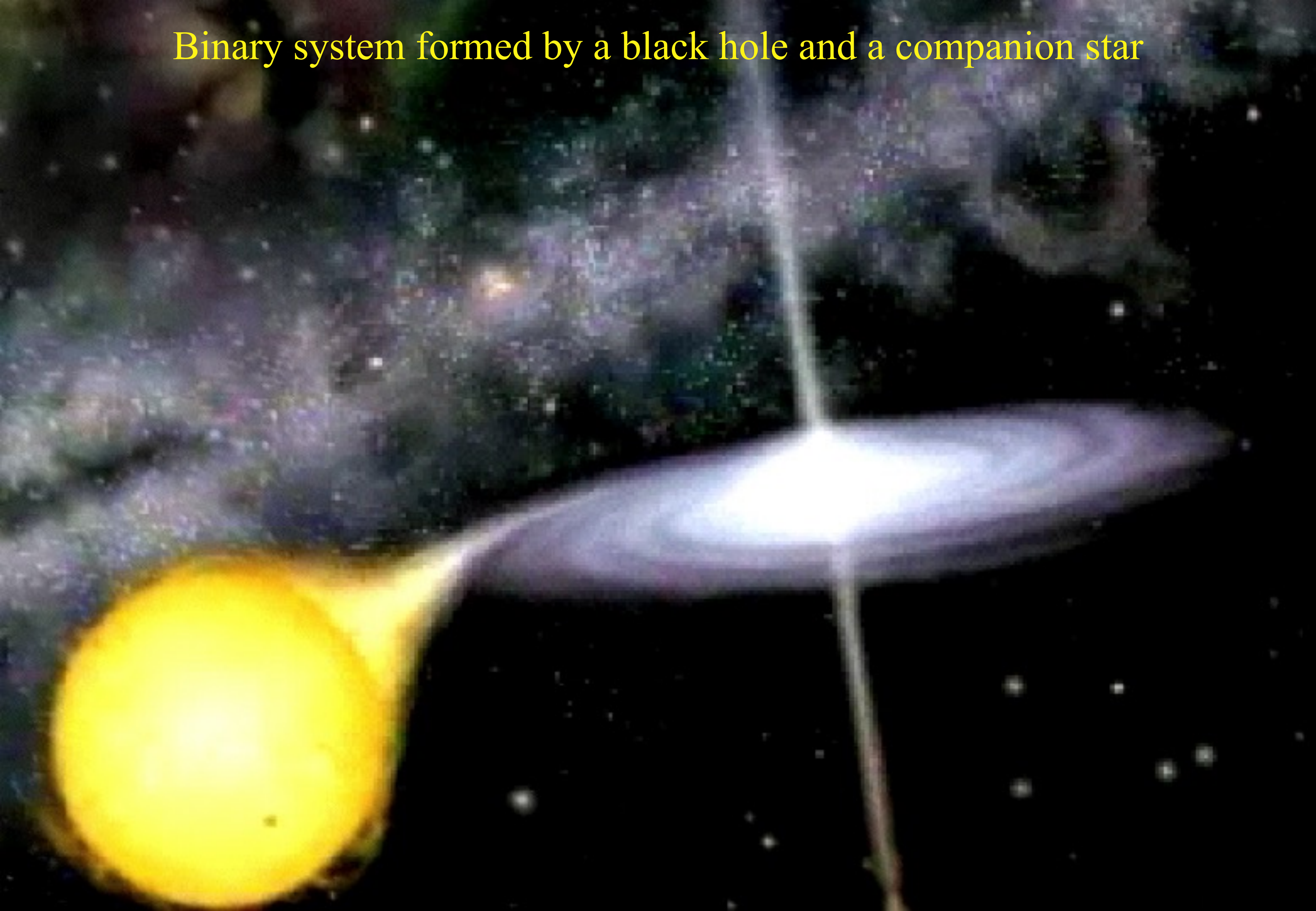
- γ rays offer a direct view into Nature's largest accelerators.
- the Universe is mainly transparent to γ rays with < 20 GeV that can probe cosmological volumes. Any opacity is energy-dependent for higher energy.
- particle relics of the early universe produce γ rays when they annihilate or decay.

The Deep Sky


EGRET All-Sky Gamma Ray Survey Above 100 MeV

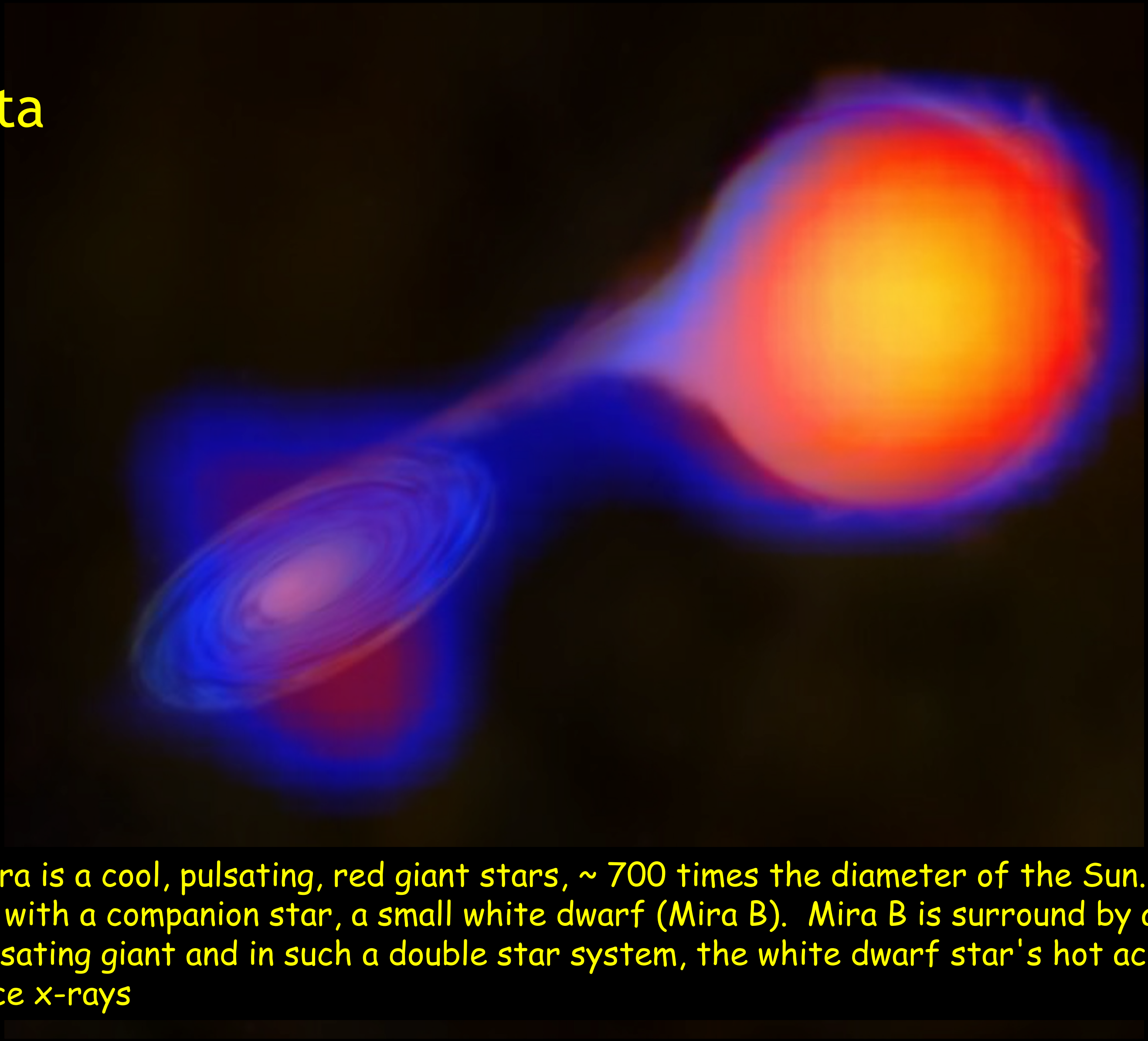


Binary system formed by a black hole and a companion star

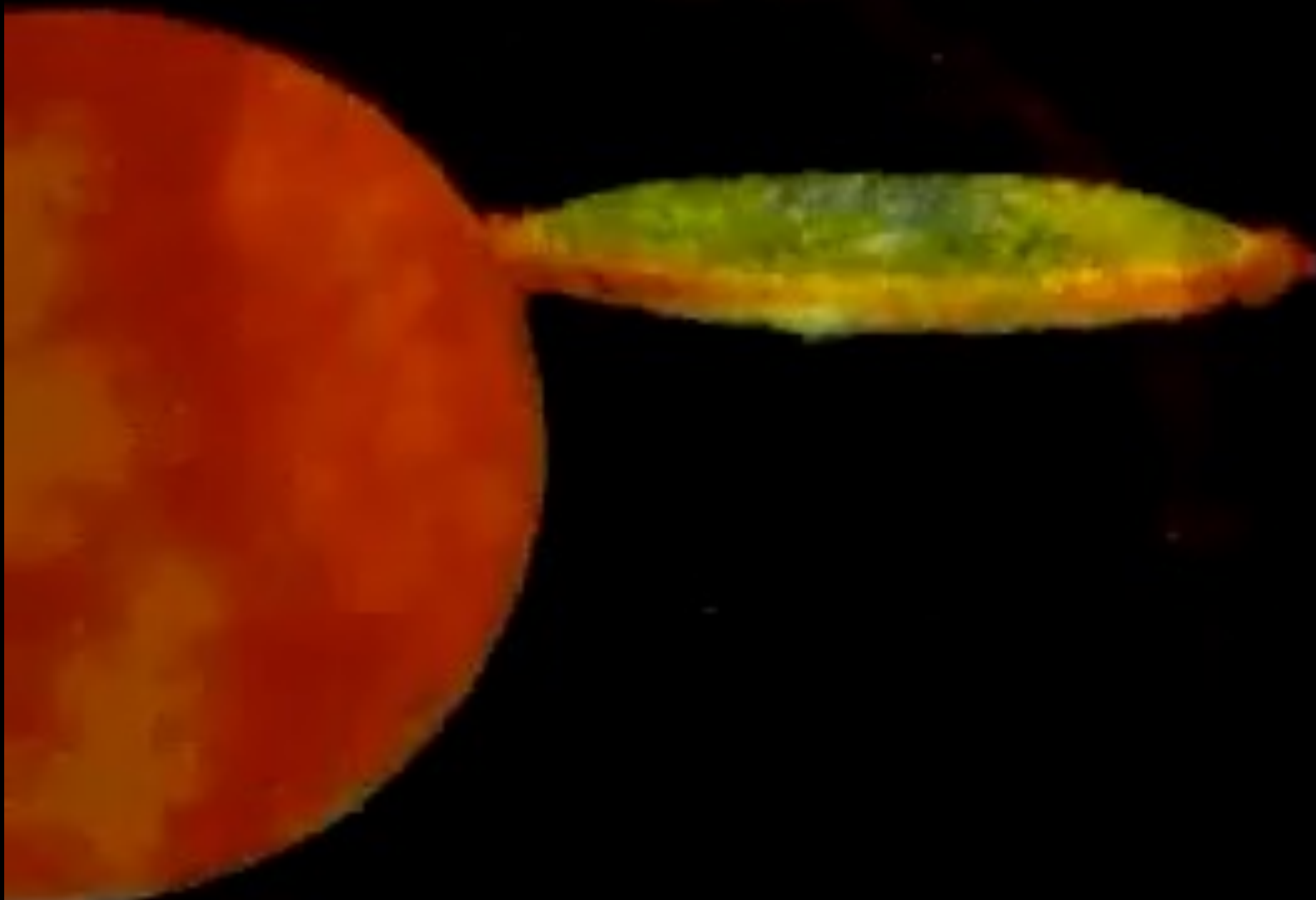

Binary system formed by a black hole and a companion star

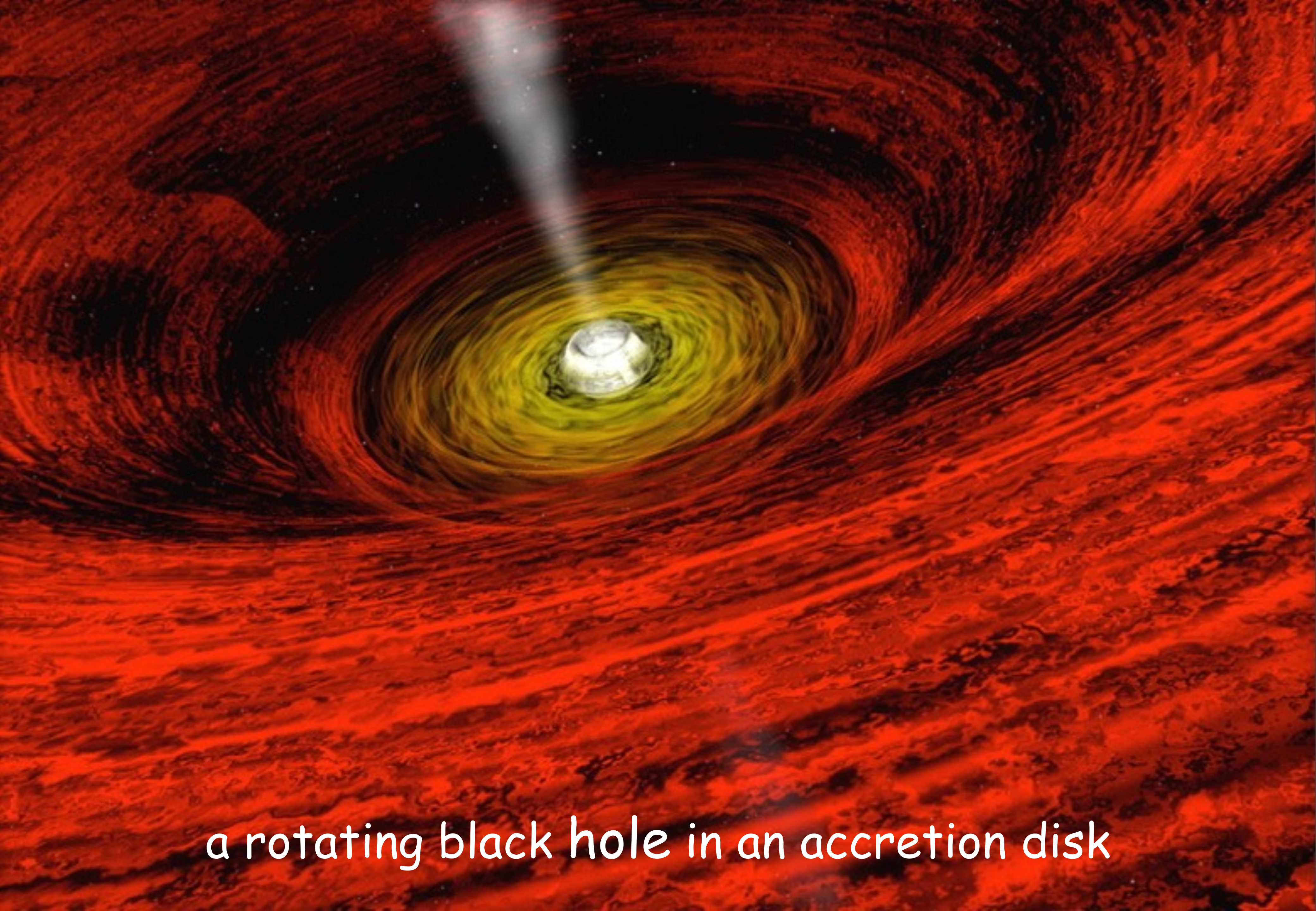
Binary system formed by a black hole and a companion star

Chandra data



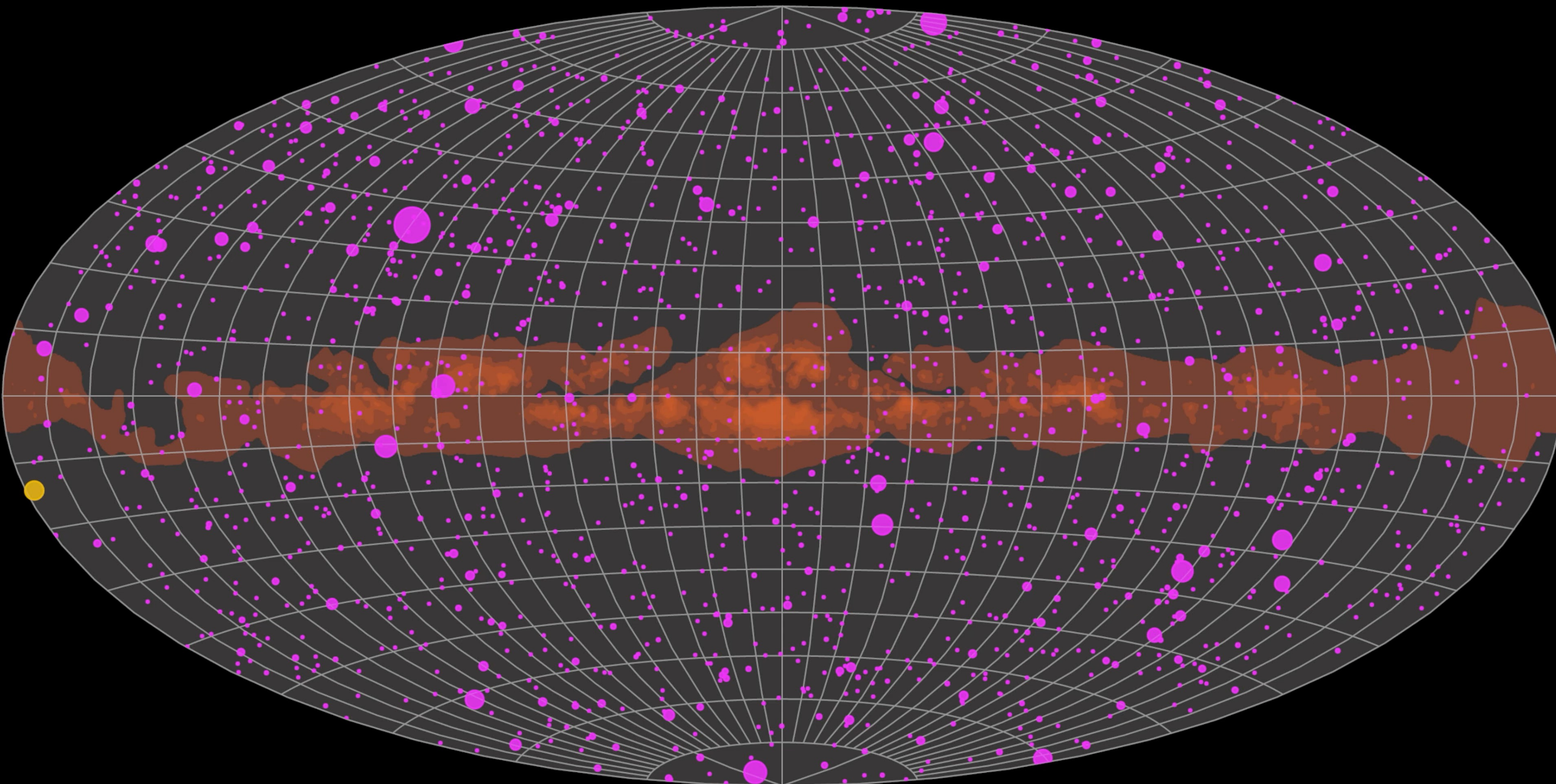
Omicron Ceti or Mira is a cool, pulsating, red giant stars, ~ 700 times the diameter of the Sun. Only 420 light-years away and co-orbits with a companion star, a small white dwarf (Mira B). Mira B is surround by a disk of material drawn from the pulsating giant and in such a double star system, the white dwarf star's hot accretion disk is expected to produce x-rays



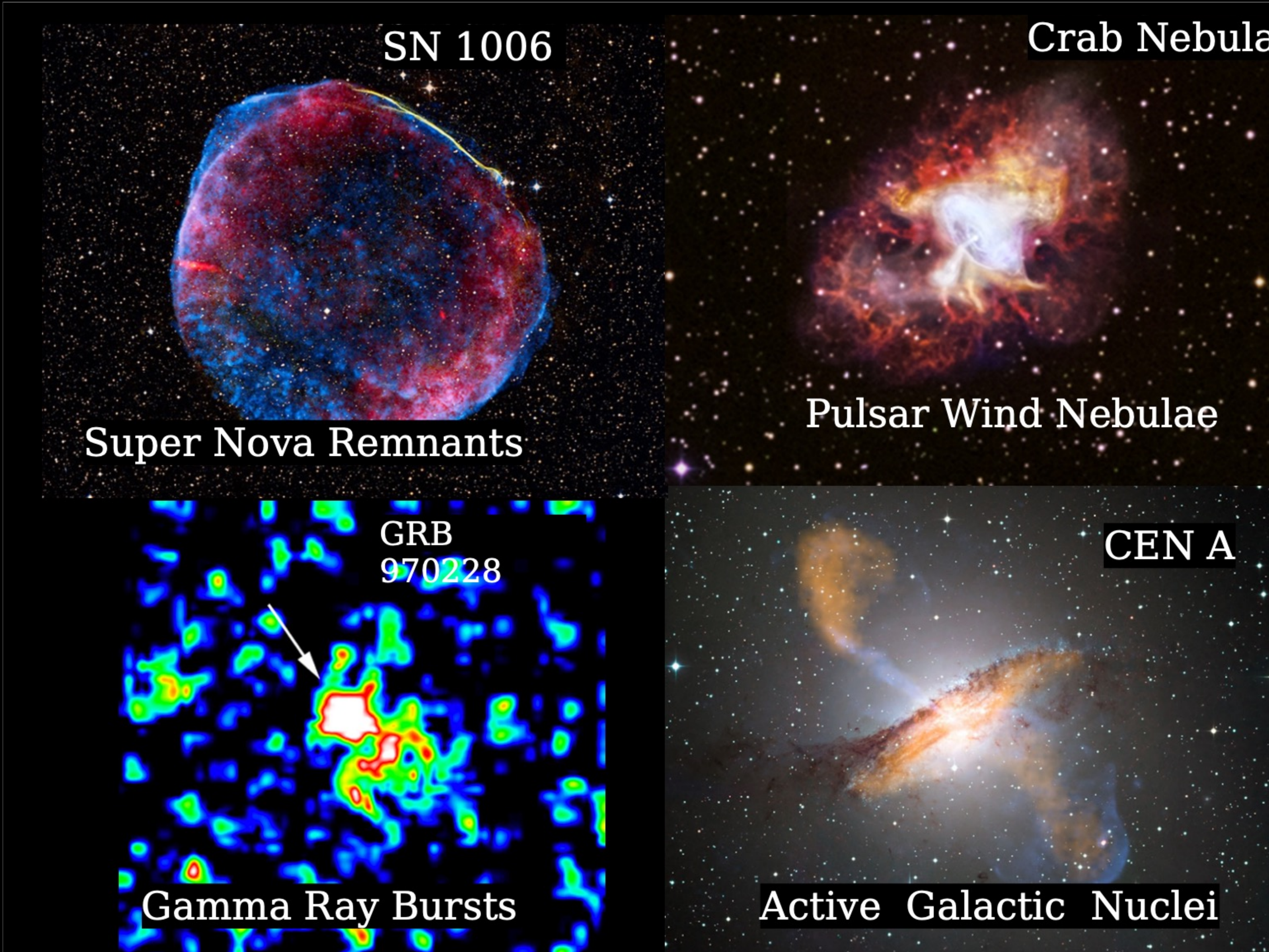


a rotating black hole in an accretion disk

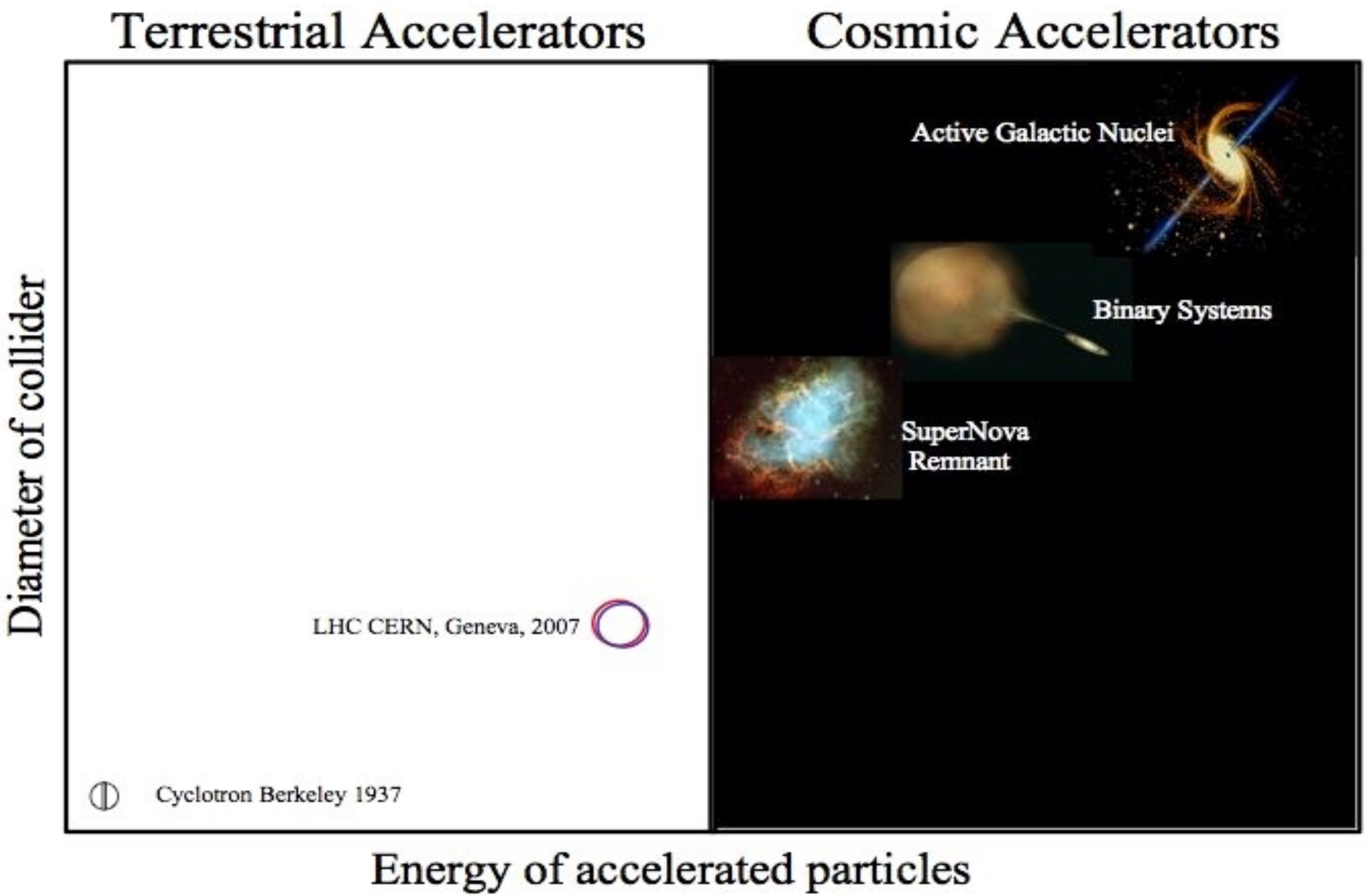
Fermi Dynamic Gamma-ray Sky



Feb 22- Feb 23

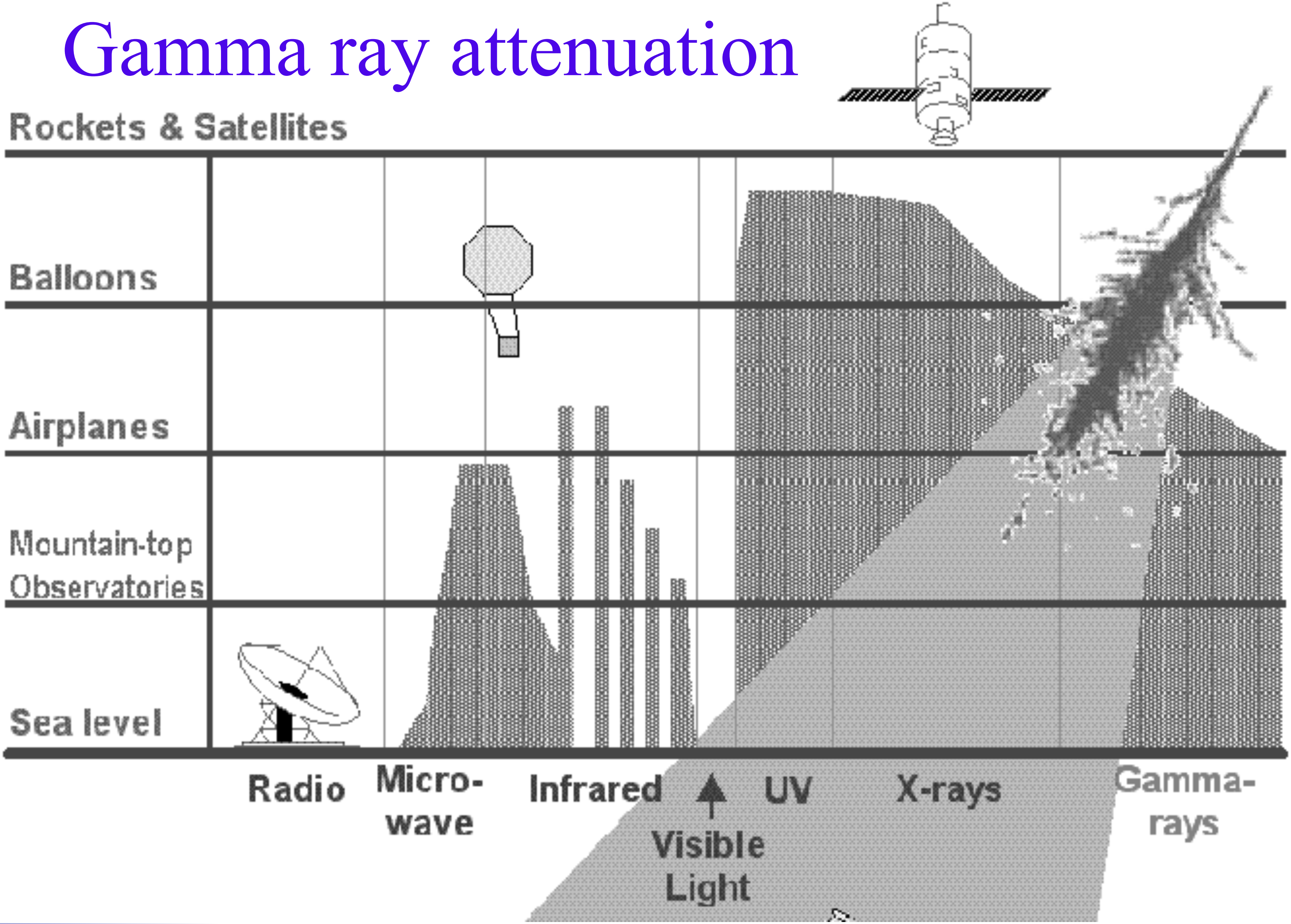

SN 1006
Super Nova Remnants
Crab Nebula
Pulsar Wind Nebulae
GRB 970228
Gamma Ray Bursts
CEN A
Active Galactic Nuclei

Particle Physics => Particle Astrophysics

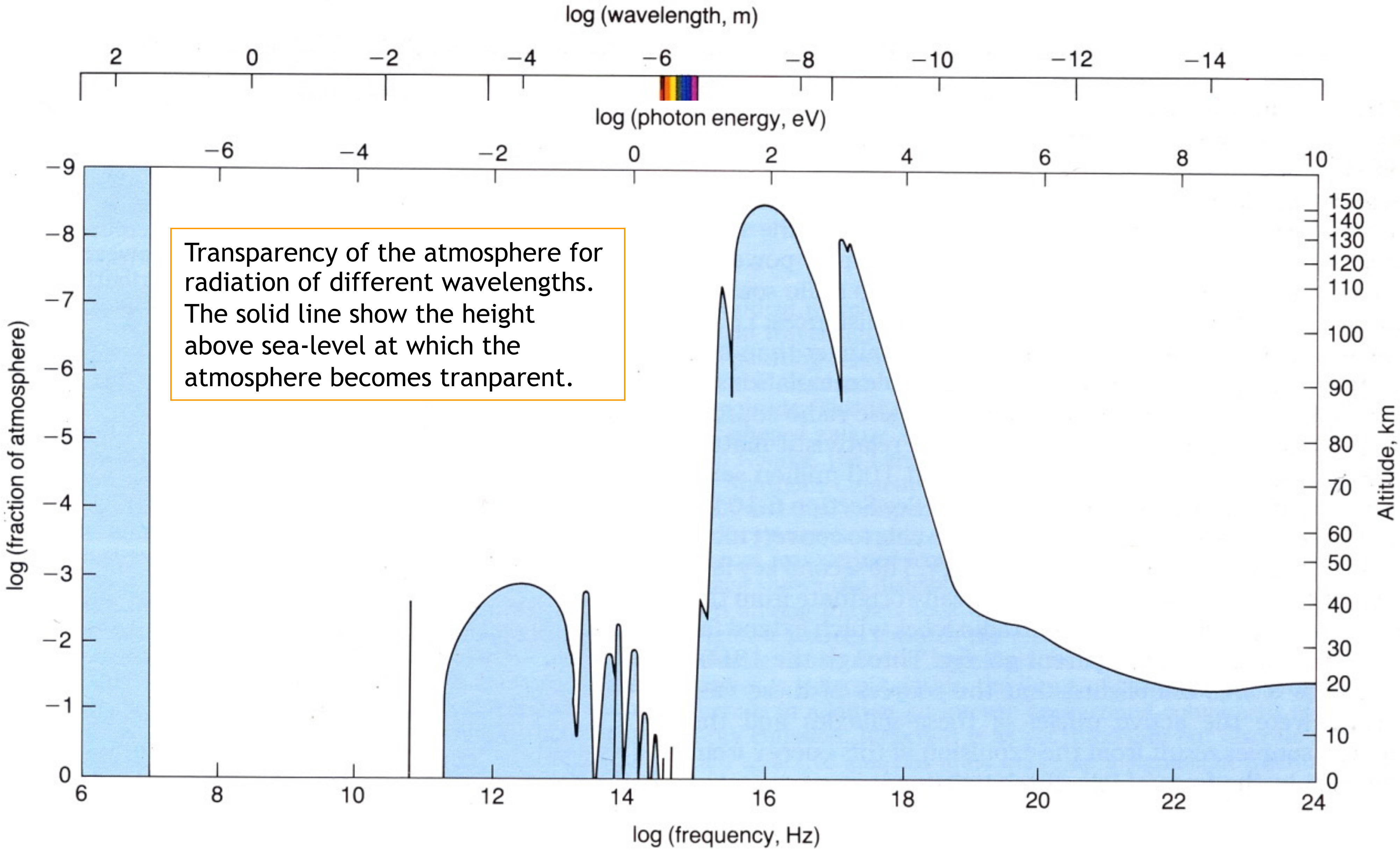


Extraordinary beasts in the sky

Gamma ray attenuation



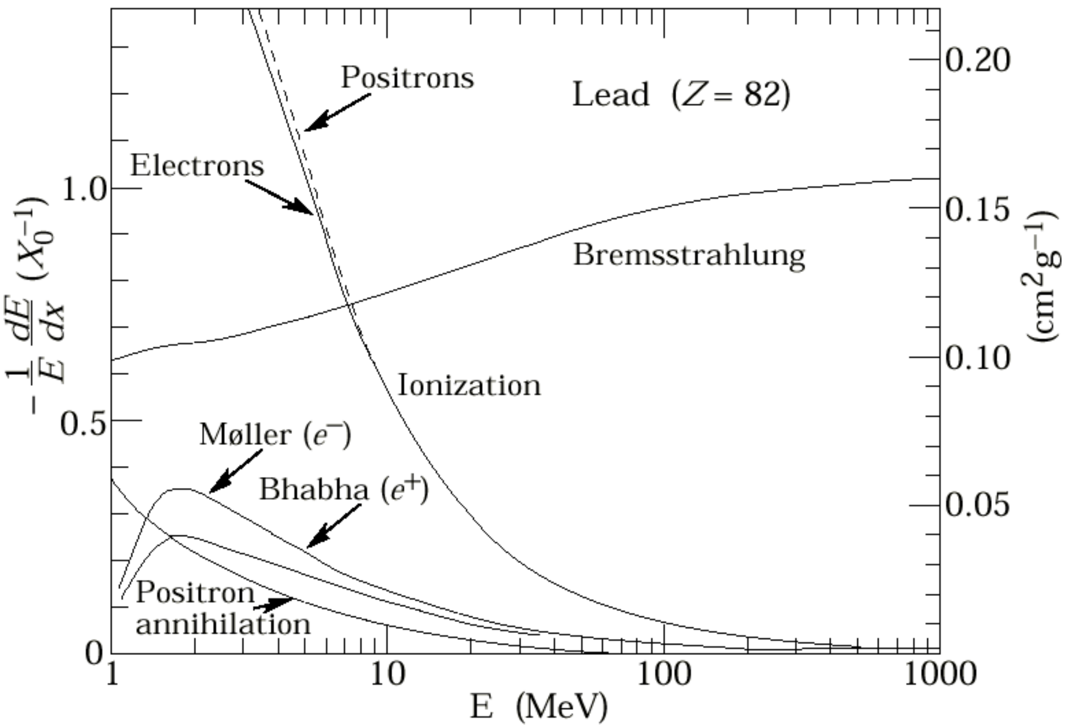
Gamma ray attenuation (2)



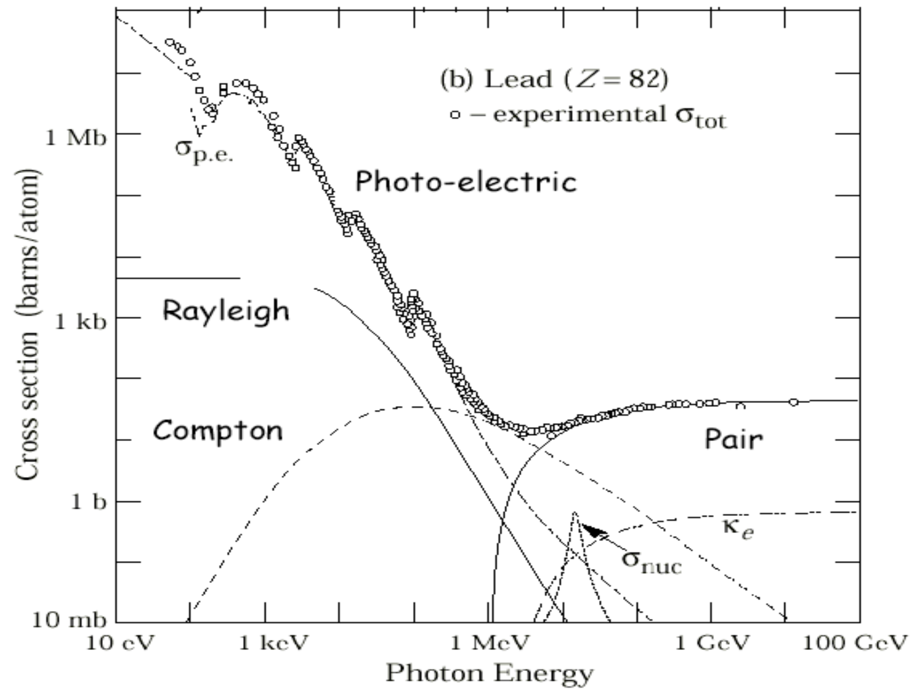
Transparency of the atmosphere for radiation of different wavelengths. The solid line show the height above sea-level at which the atmosphere becomes tranparent.

Interaction of photons with matter

Fractional energy loss for e⁺ and e⁻ in lead



Photon total cross sections



$$\frac{dE}{dx}_{Brems} = -\frac{E}{X_0} \Rightarrow E(x) = e^{-\frac{x}{X_0}}$$

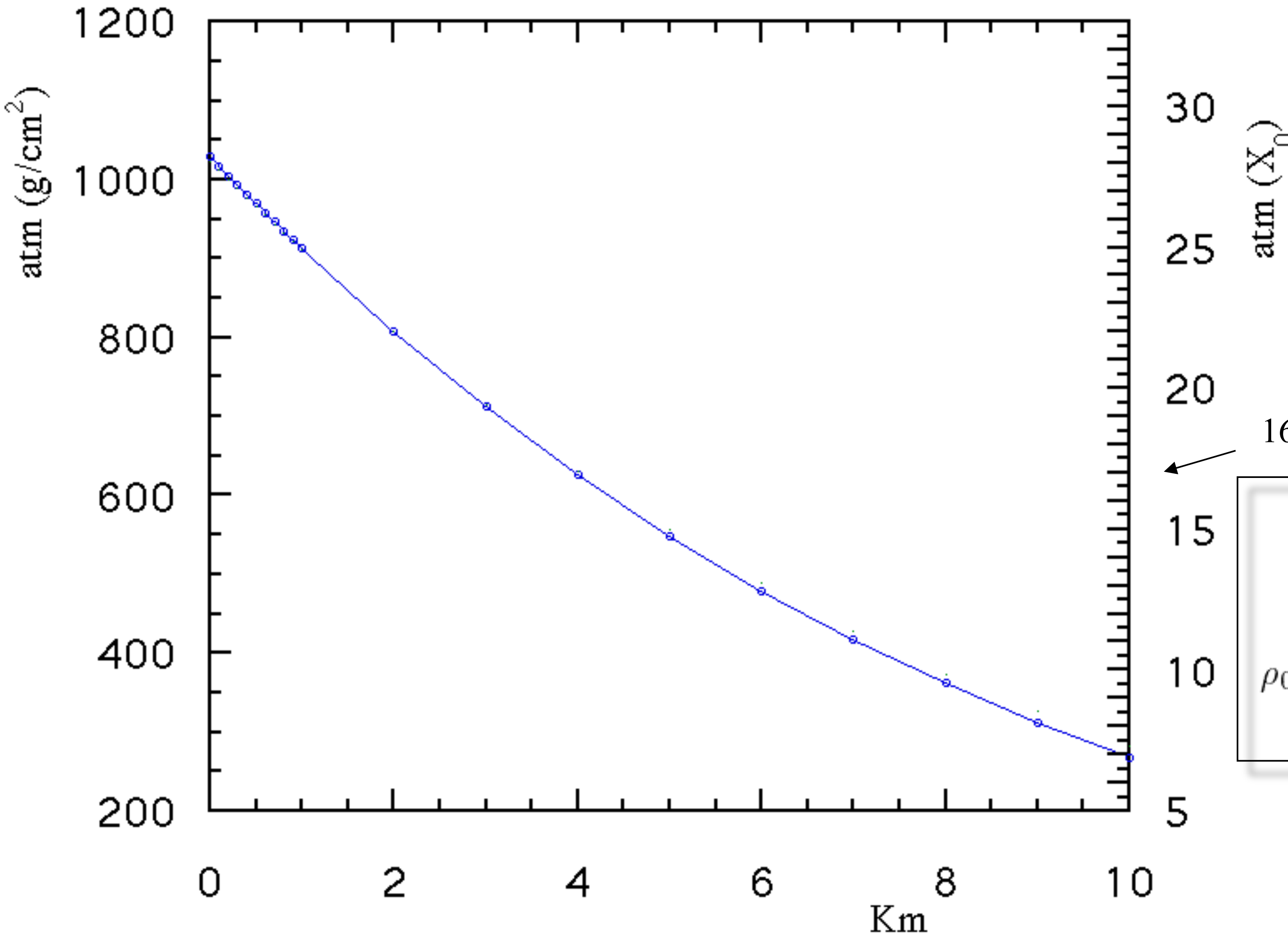
with X_0 = radiation length

$$X_0 = 716.4\ \mathrm{g\,cm^{-2}} \frac{A}{Z(Z+1)\ln\frac{287}{\sqrt{Z}}}$$

$$\text{Prob. of Int.} = 1 - \exp^{-\frac{7}{9}\frac{x}{X_0}}$$

x/X_0	Prob Int.
0.5	0.40
1	0.54
2	0.79
7	0.995

Relation between altitude, number of Radiation Length and g/cm² traversed



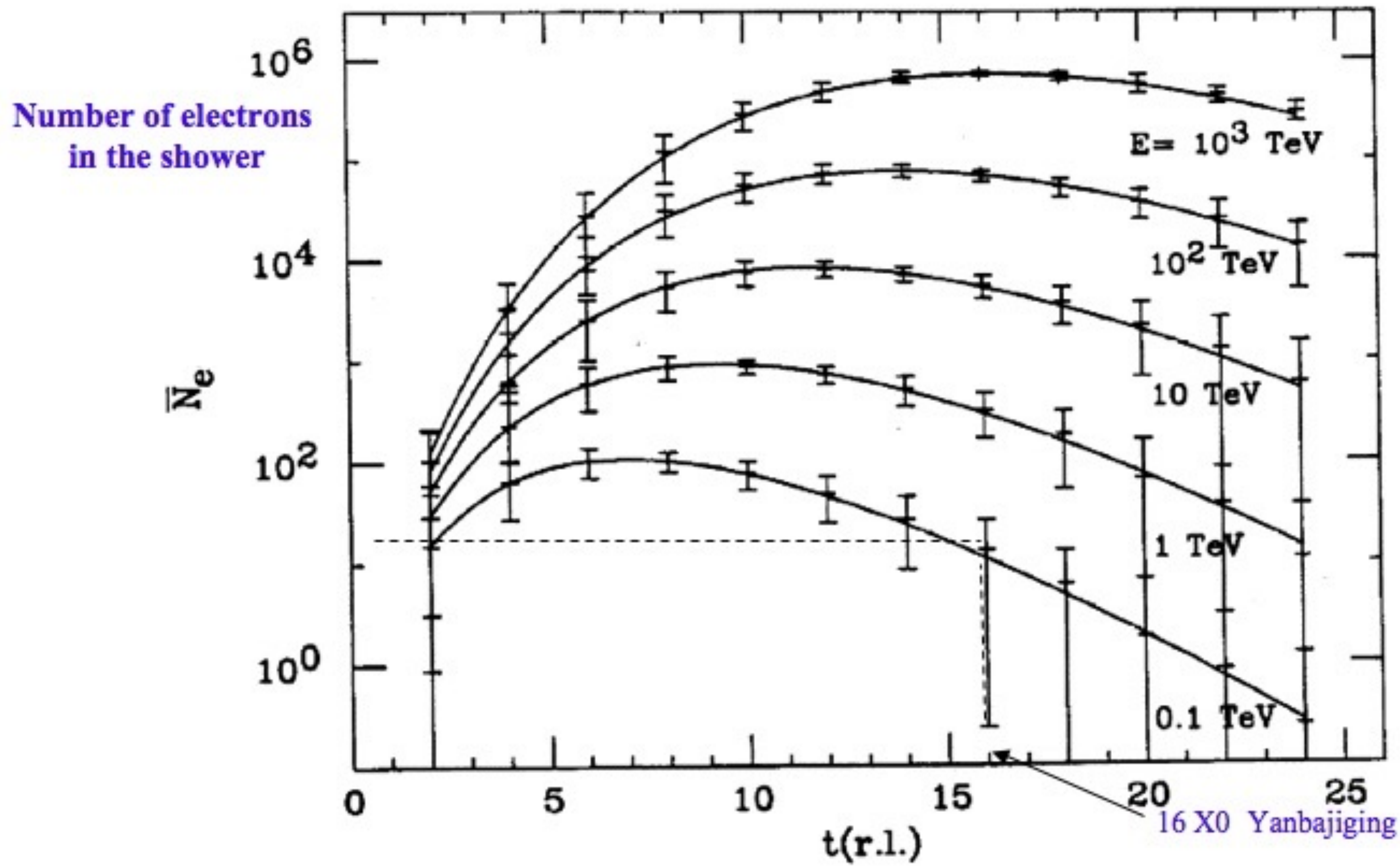
$$\rho = \rho_0 \; h_0 \; e^{-h/h_0}$$

$$h_0 \sim 6.4 \; Km$$

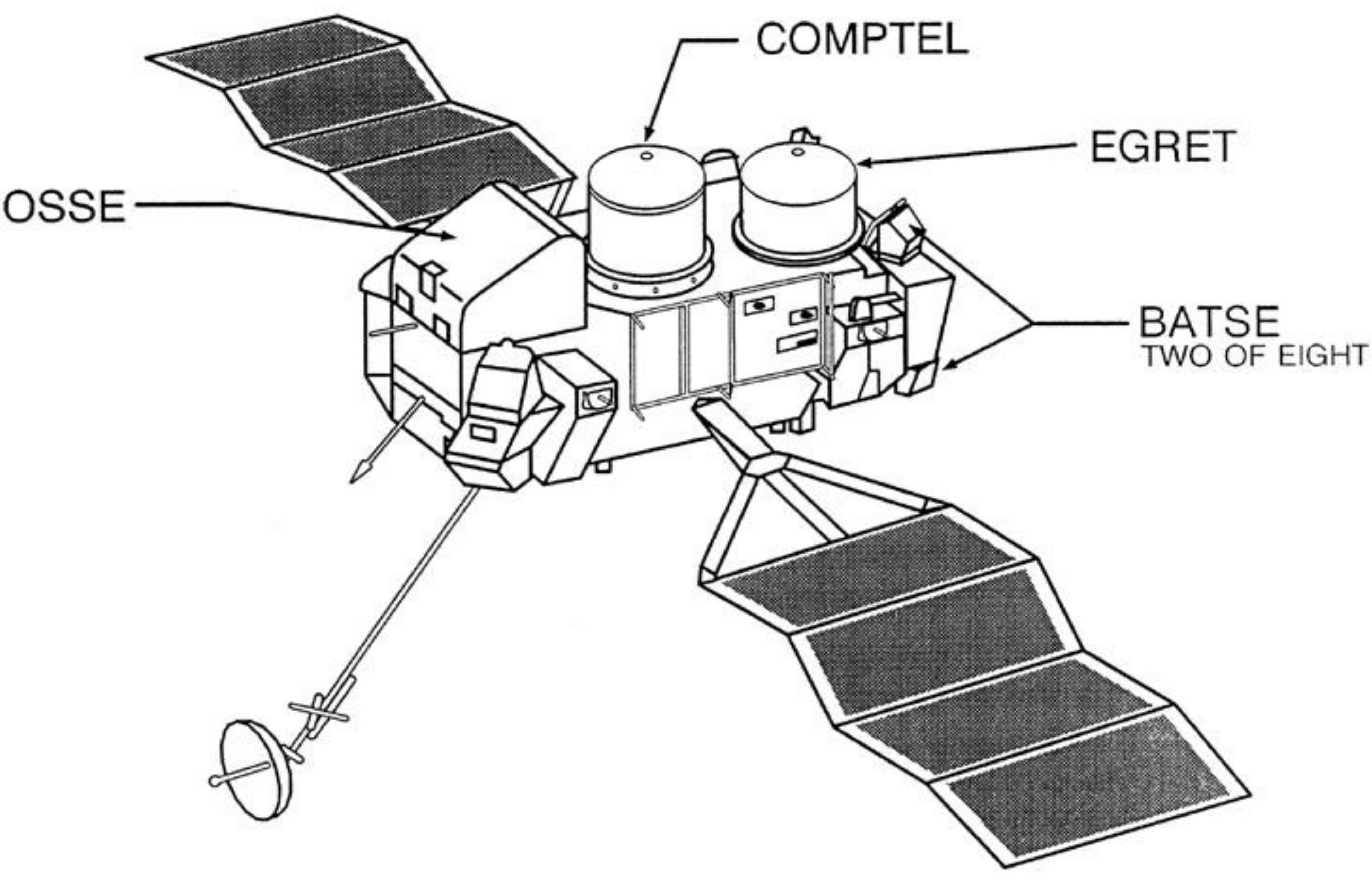
$$\rho_0 \sim 161 \; g/(cm^2 Km)$$

Longitudinal development of the electron component of photon initiated shower

(with electron threshold energy of 5 MeV and fluctuations superimposed)



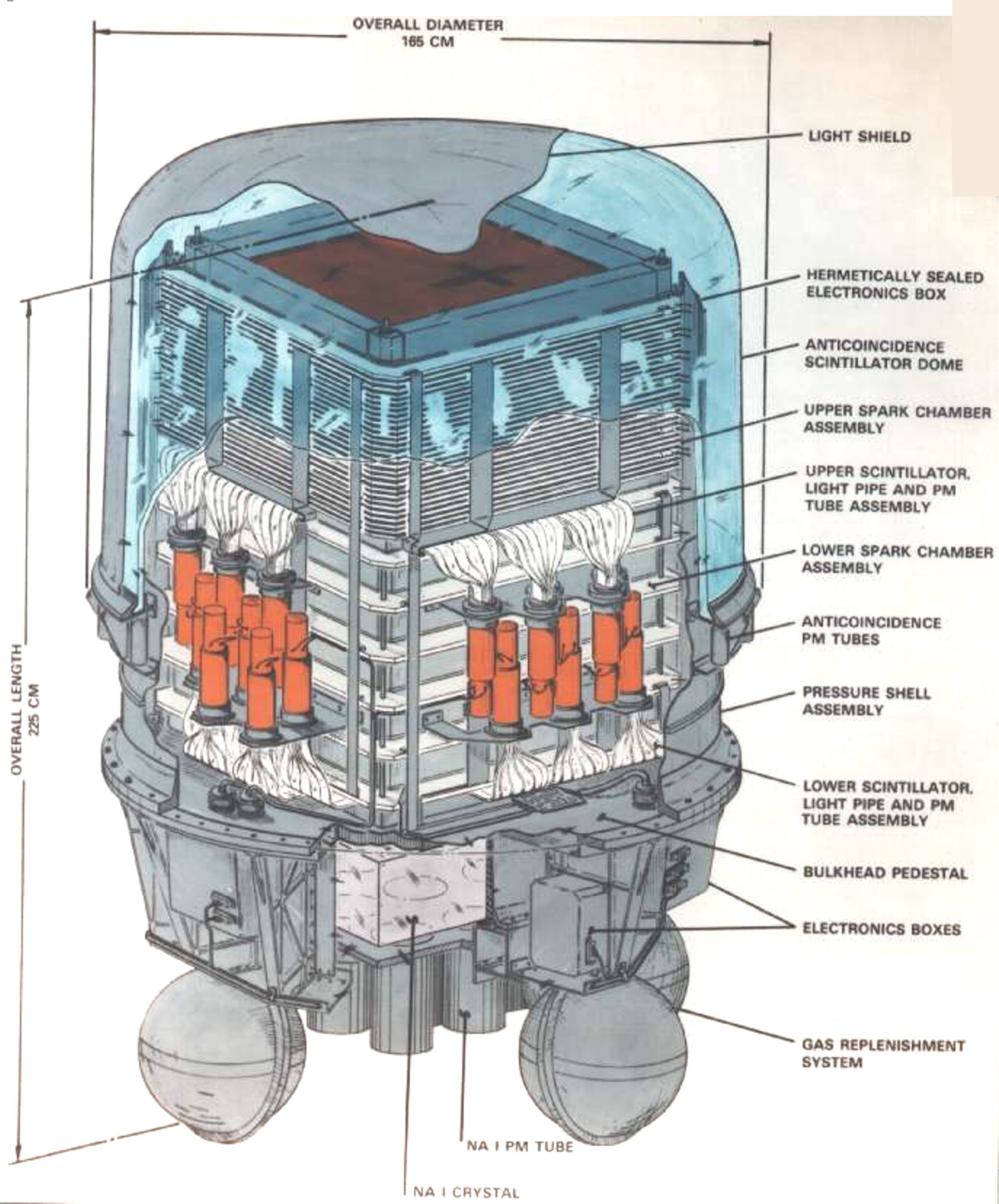
COMPTON OBSERVATORY INSTRUMENTS

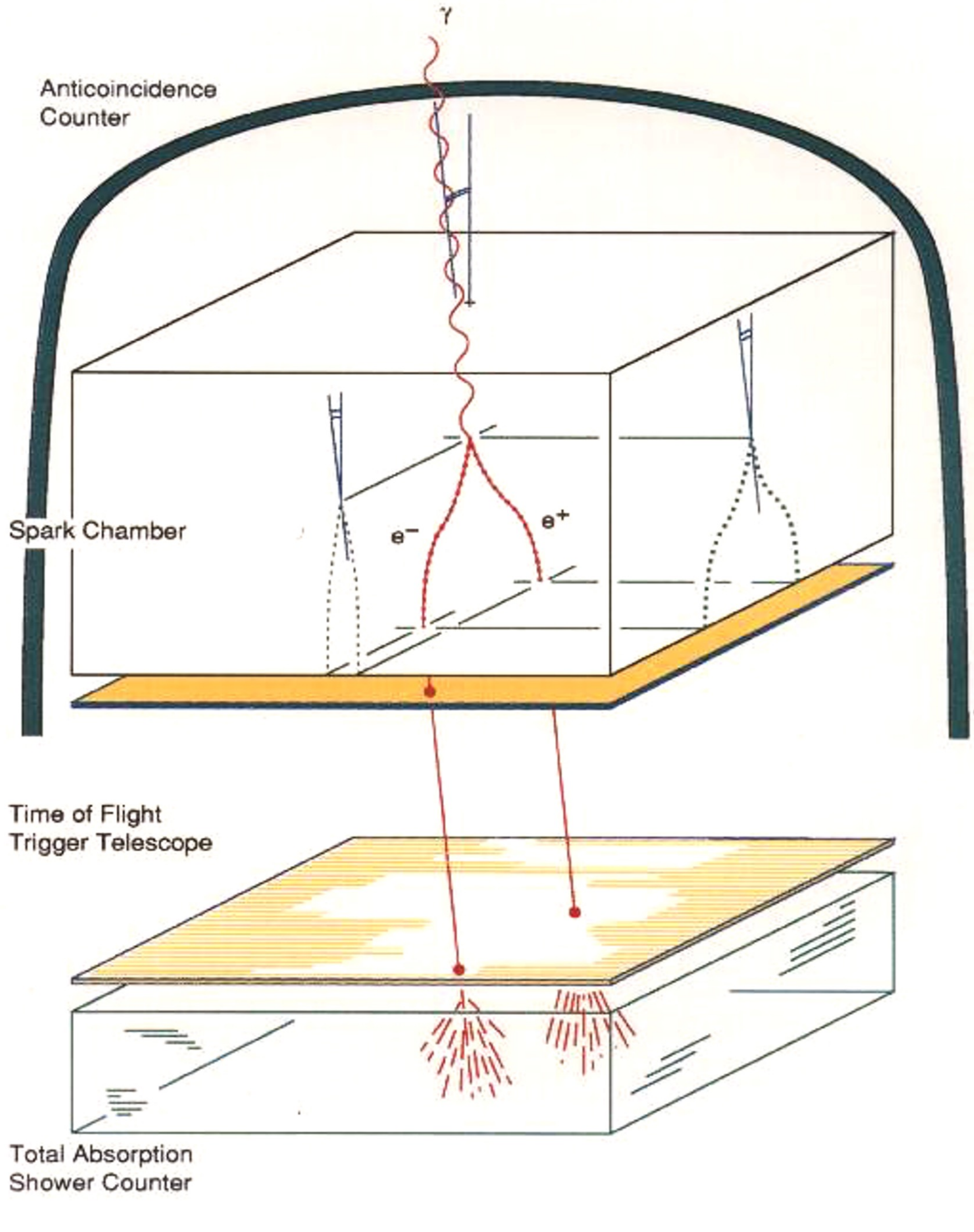


EGRET:the detector

Energy range: 20 MeV - 30 GeV
Weight: 1820 Kg
Power: 160 W
Field of view: 0. 5 sr
Dead Time: 100 ms
Effective Area (@1GeV) 1200 cm^2
Angular resolution (@100MeV) 5.8

Sensitivity for point sources (ph cm-2 s-1)*	0.1 GeV	5x10^{-8}
	1 GeV	1x10^{-8}
	10 GeV	2x10^{-8}





EGRET: Principle of Detection of High Energy Gamma Rays

EGRET – Principle of gamma ray detection

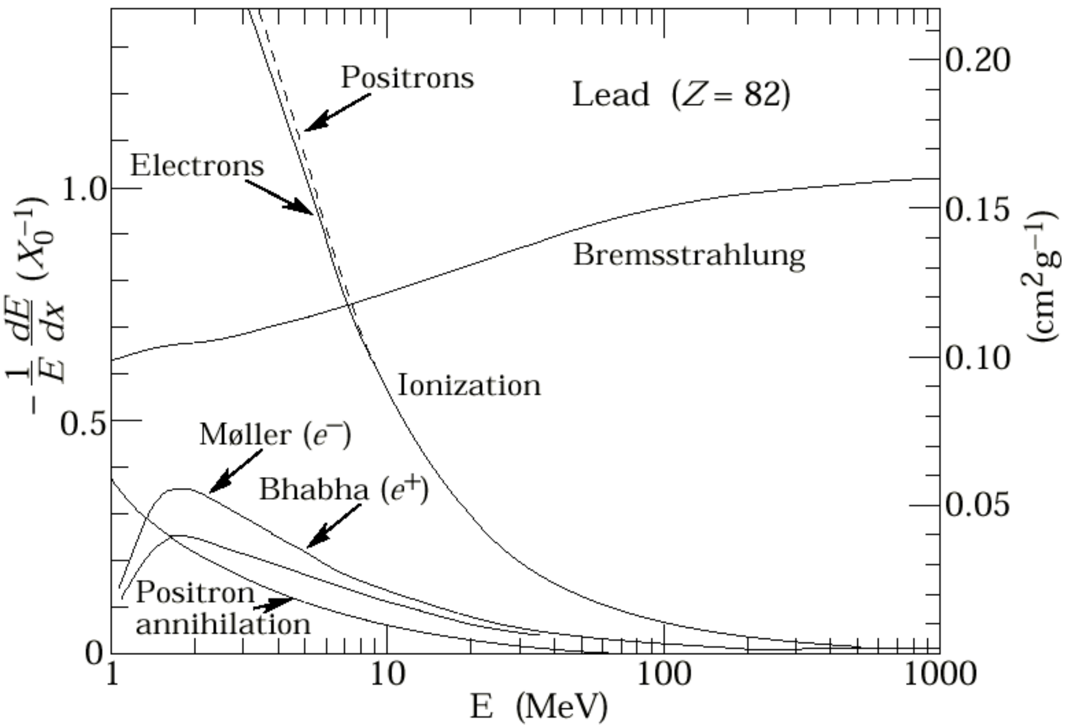
A γray which enters the top of the EGRET instrument will pass undetected through the large anticoincidence scintillator surrounding the spark chamber and has a probability 33% of converting into an electronpositron pair in one of the thin tantalum (Ta) sheets interleaved between the 28 closely spaced spark chambers in the upper portion of the instrument.

Below the conversion stack are two 4 x 4 arrays of plastic scintillation detector tiles spaced 60 cm apart which register the passage of charged particles. If the timeofflight delay indicates a downward moving particle which passed through a valid combination of upper and lower scintillator tiles, and the anticoincidence system has not been triggered by a charged particle, the track information is recorded digitally. In this manner, a three dimensional picture of the path of the electronpositron pair is measured.

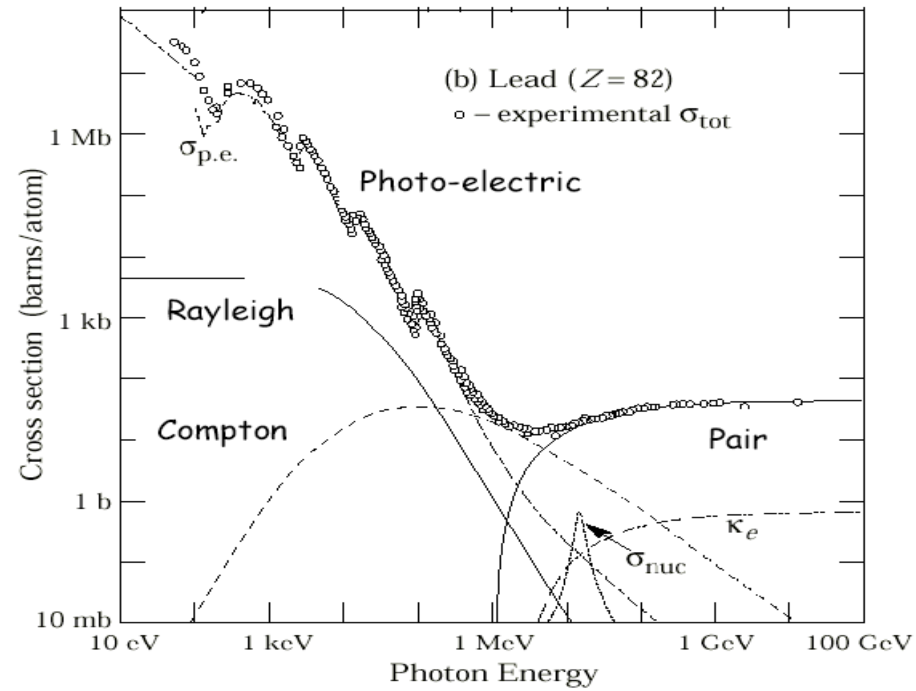
The energy deposition in the NaI(Tl) Total absorption Shower Counter (TASC) located directly below the lower array of plastic scintillators is used to estimate the photon energy.

Interaction of photons with matter

Fractional energy loss for e⁺ and e⁻ in lead



Photon total cross sections



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with X_0 = radiation length

$$X_0 = 716.4\ \mathrm{g\,cm^{-2}} \frac{A}{Z(Z+1)\ln\frac{287}{\sqrt{Z}}}$$

$$\text{Prob. of Int.} = 1 - \exp^{-\frac{7}{9}\frac{x}{X_0}}$$

x/X_0	Prob Int.
0.5	0.40
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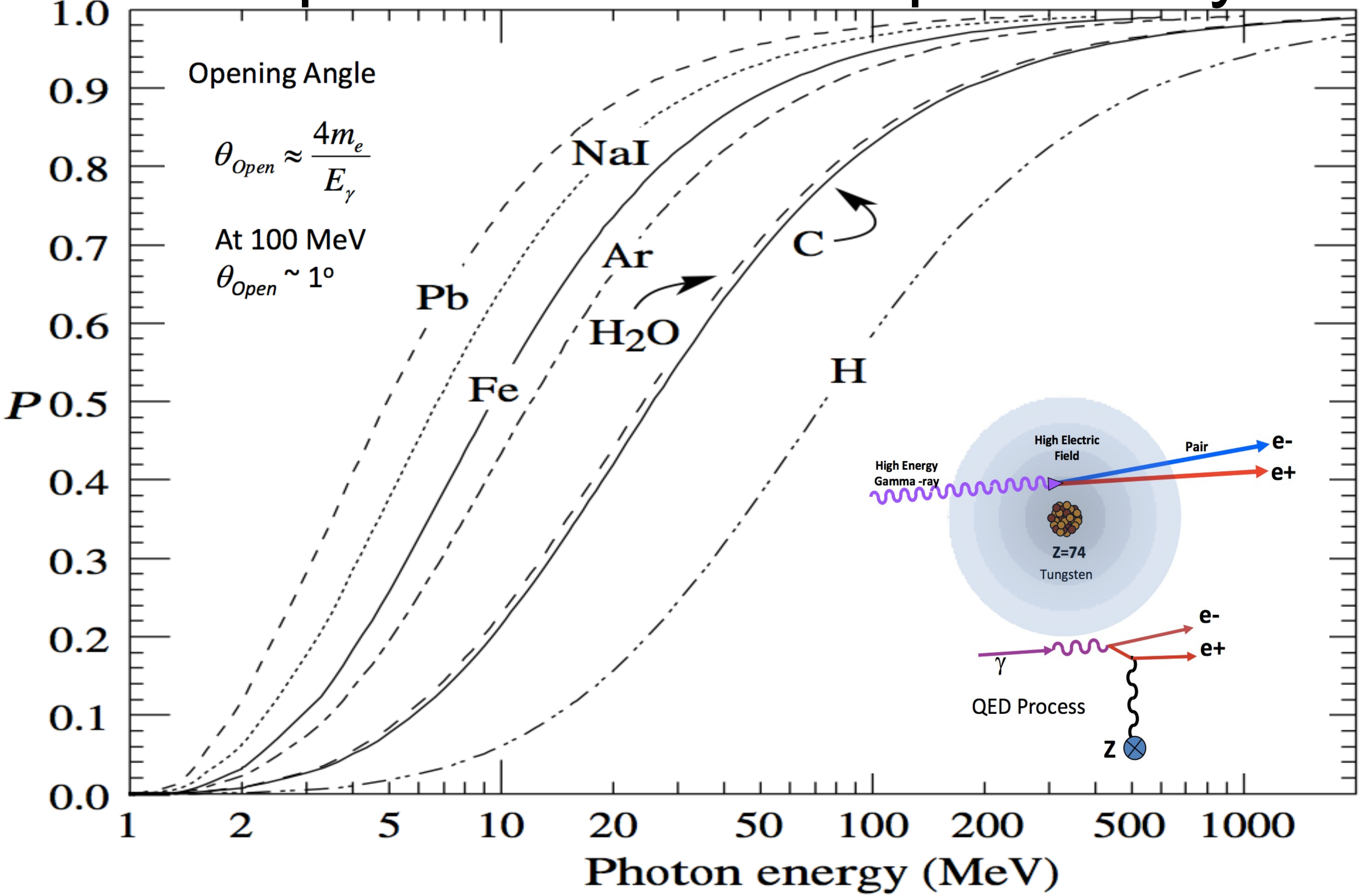
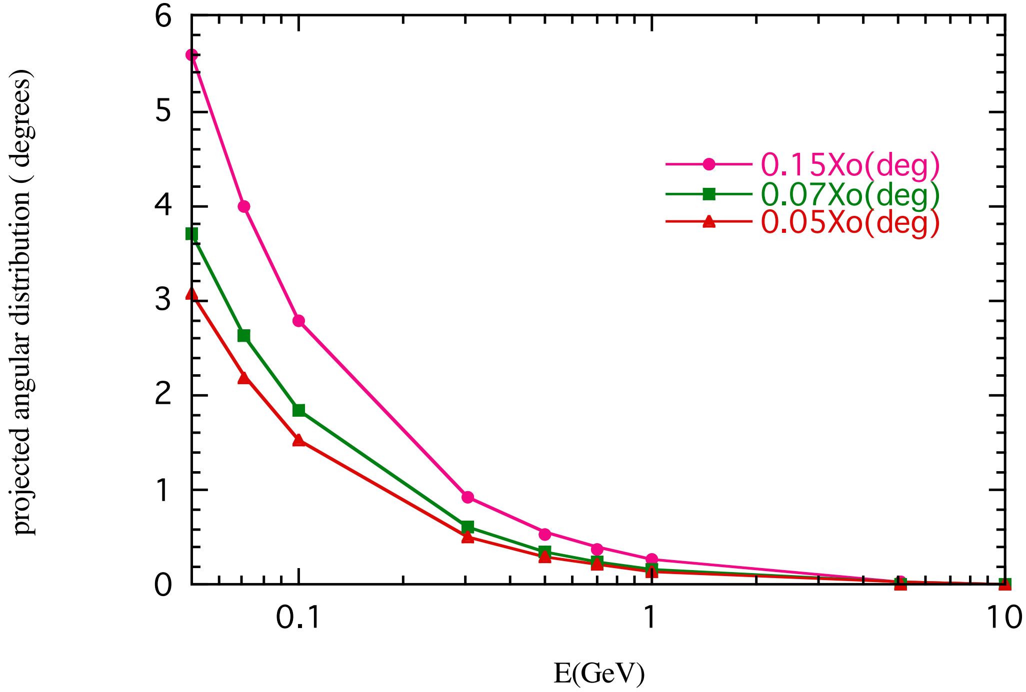
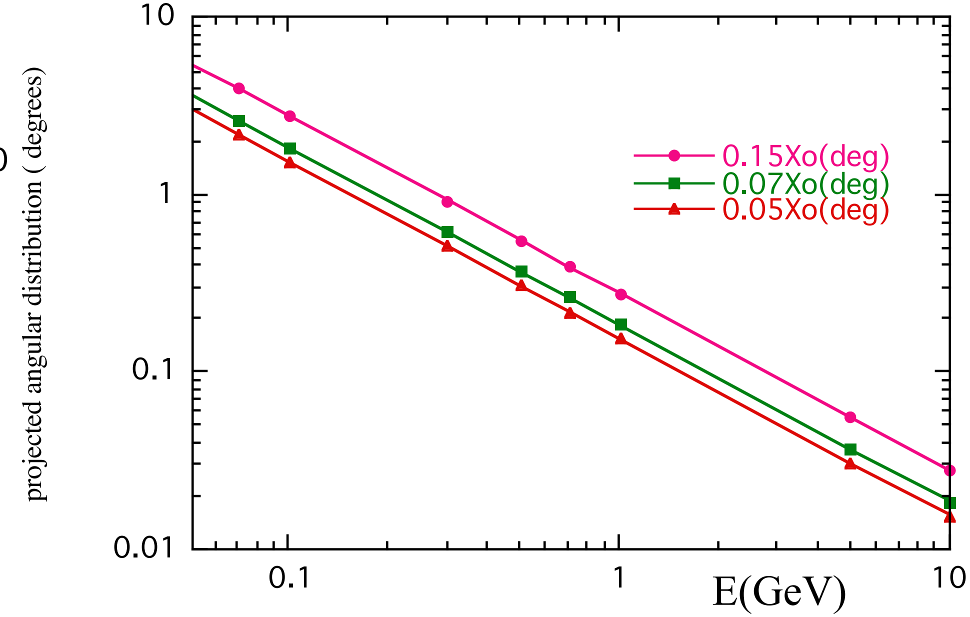
Pair photon interaction probability



Multiple Scattering

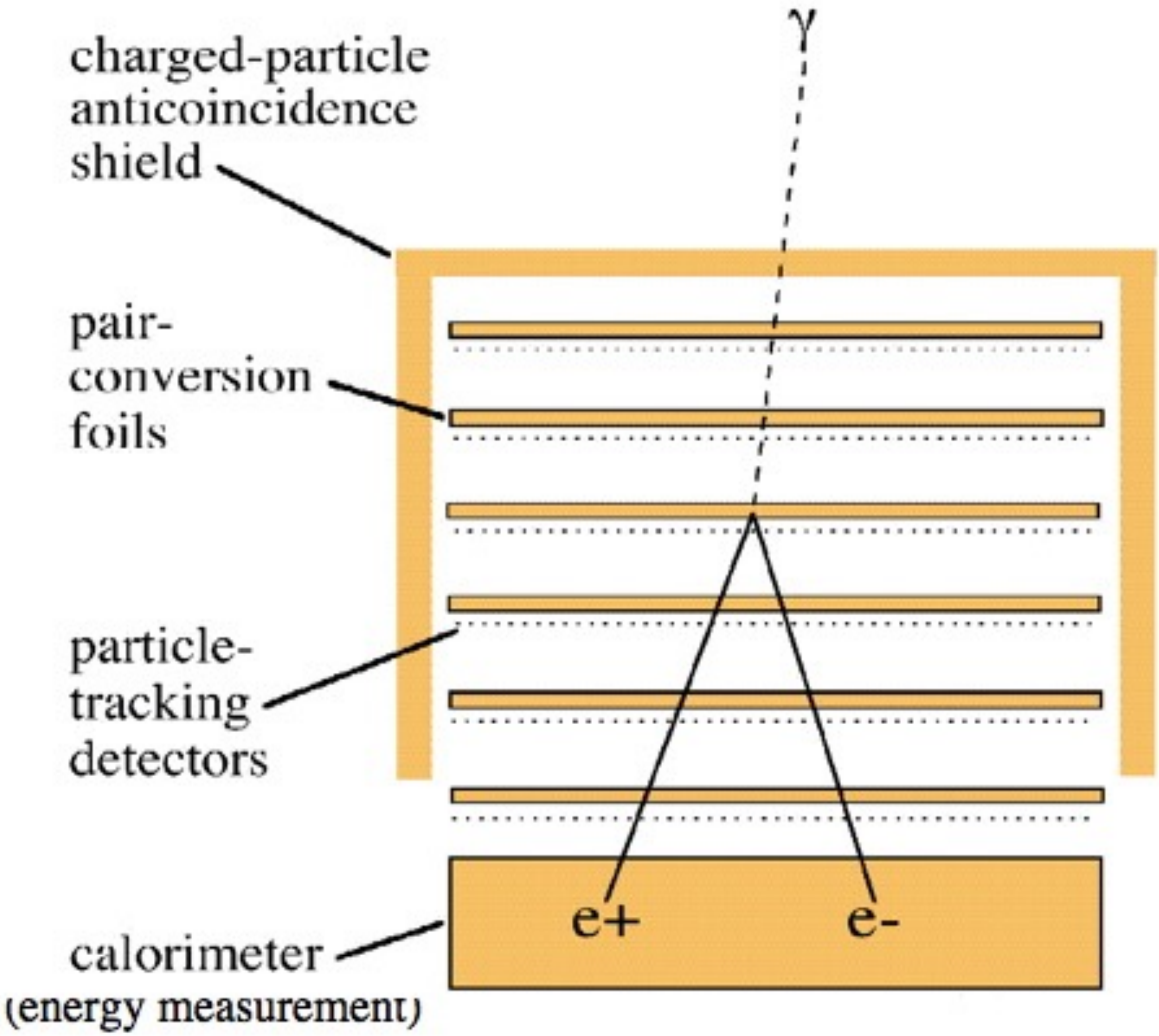




$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\,[1 + 0.038\ln(x/X_0)]$$

Elements of a pair-conversion telescope



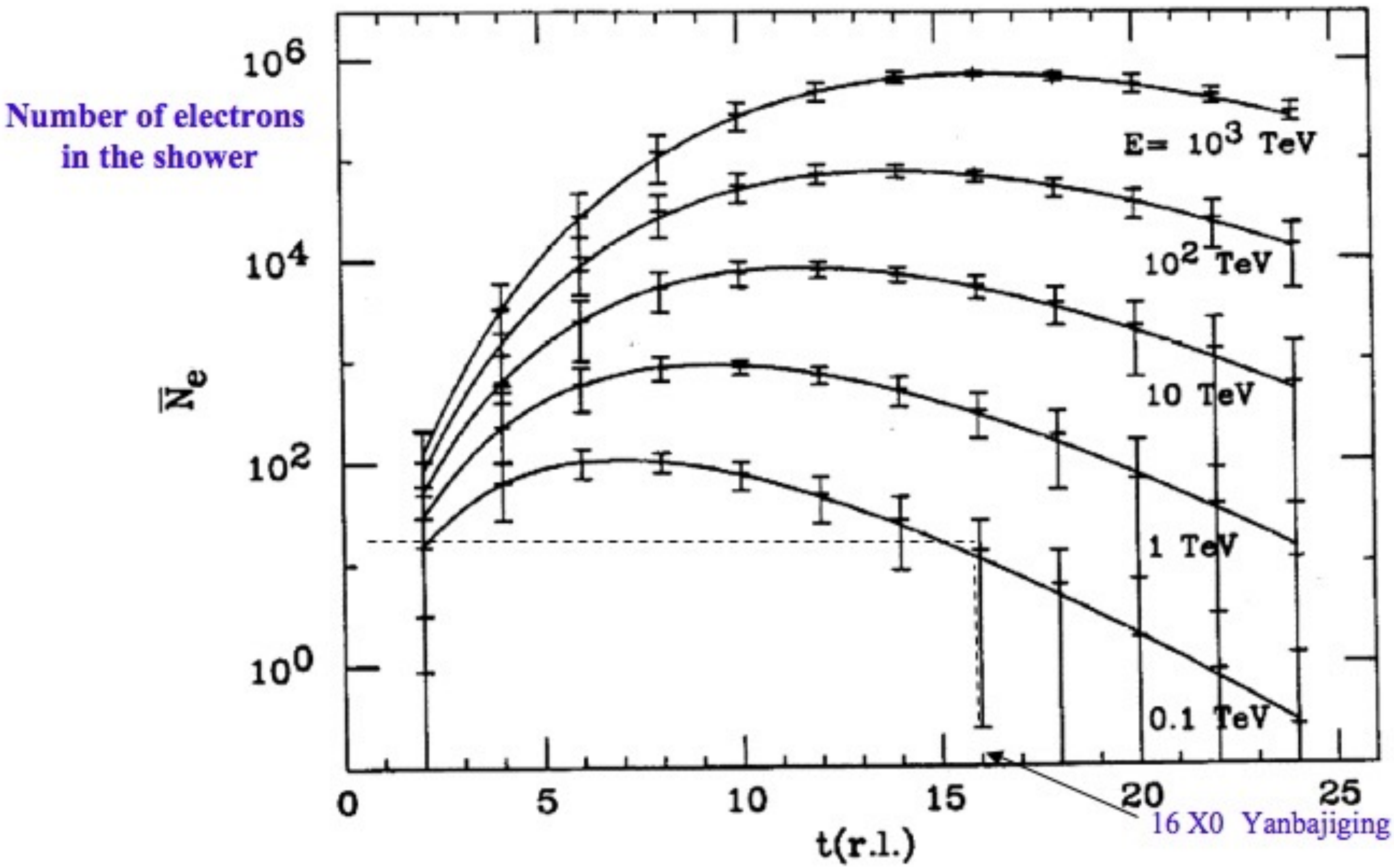
- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e+}c^2 + m_{e-}c^2$

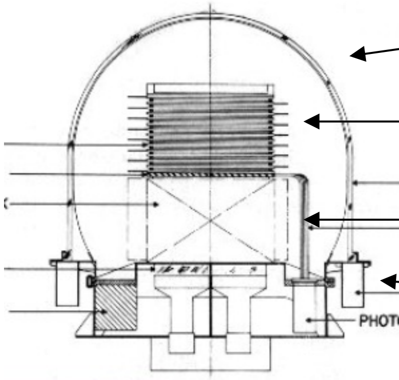
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Longitudinal development of the electron component of photon initiated shower

(with electron threshold energy of 5 MeV and fluctuations superimposed)



The gamma-ray missions



SAS-2 11/1972-7/1973

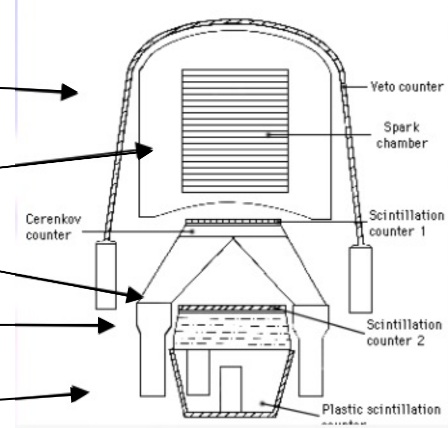
Anti-Coincidence Dome

Spark Chamber

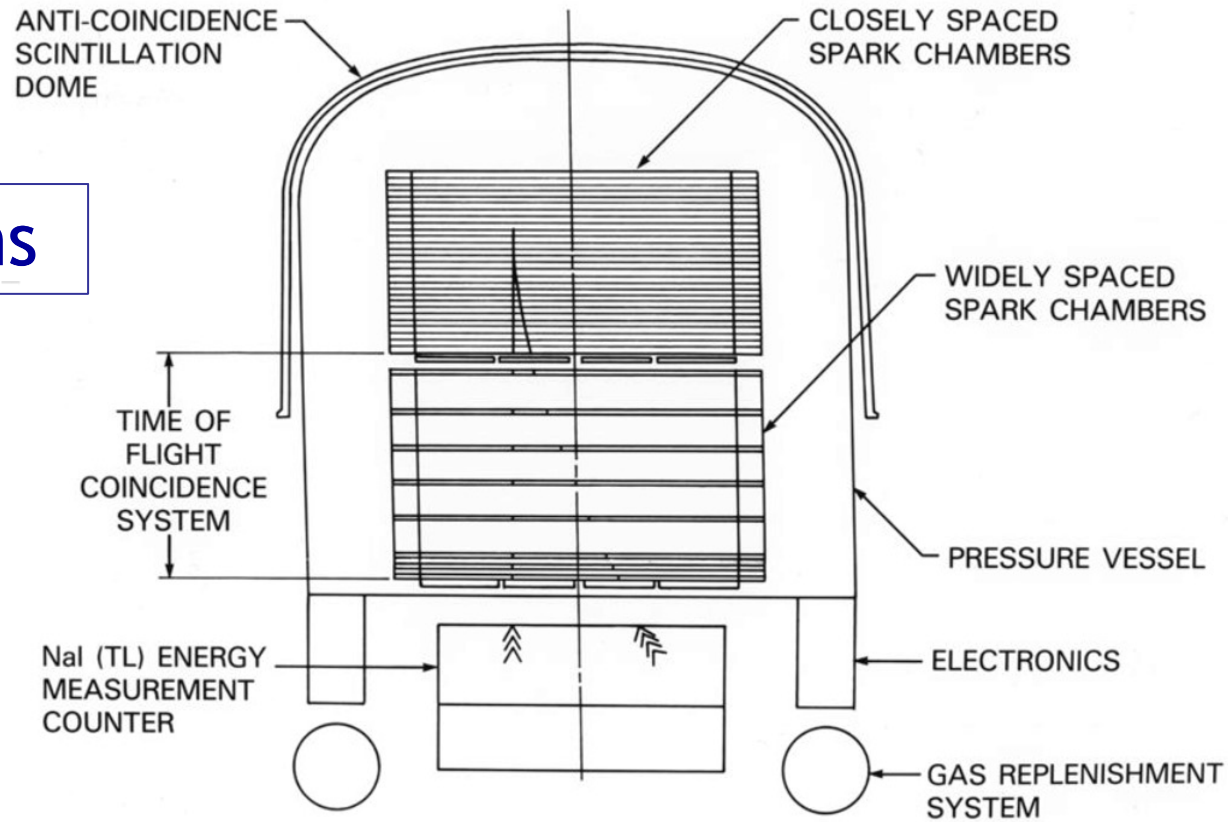
Trigger Telescope

Cerenkov Counter

Energy Calorimeter

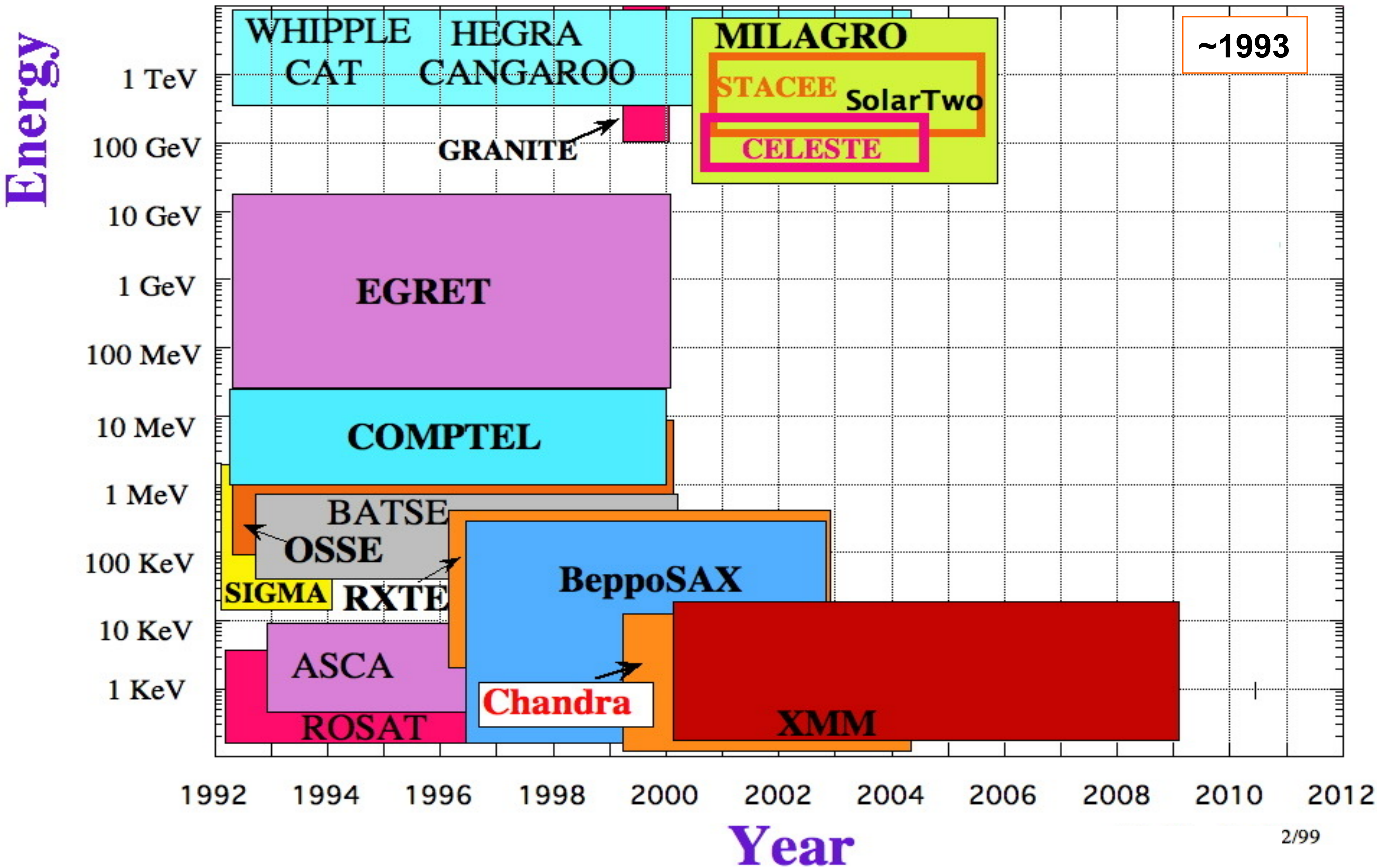


Cos-B 8/1975-4/1982



EGRET 4/1991-1999

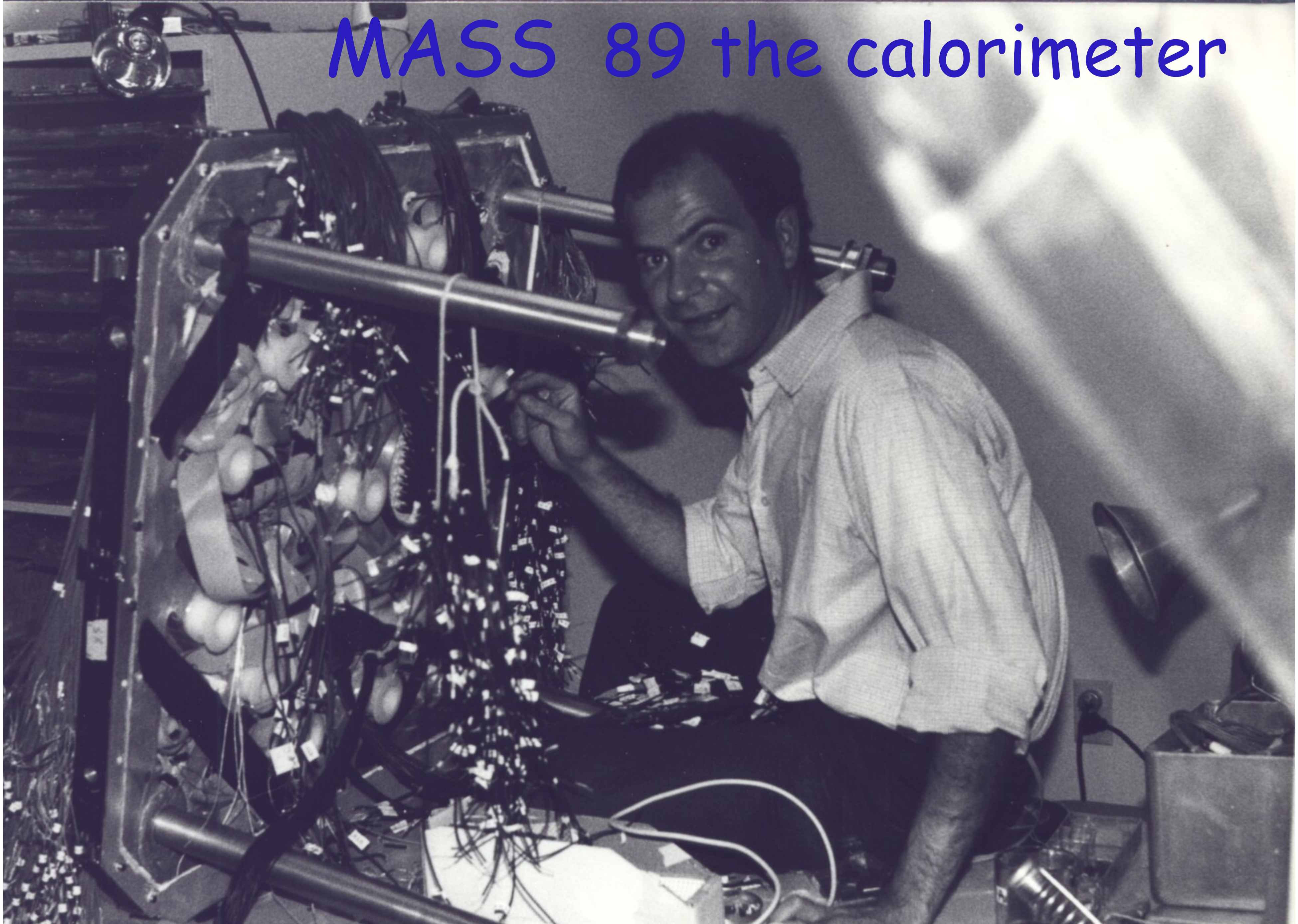
High Energy Gamma Experiments Experiments




The CAPRICE 94
flight


HOLD

MASS 89 the calorimeter

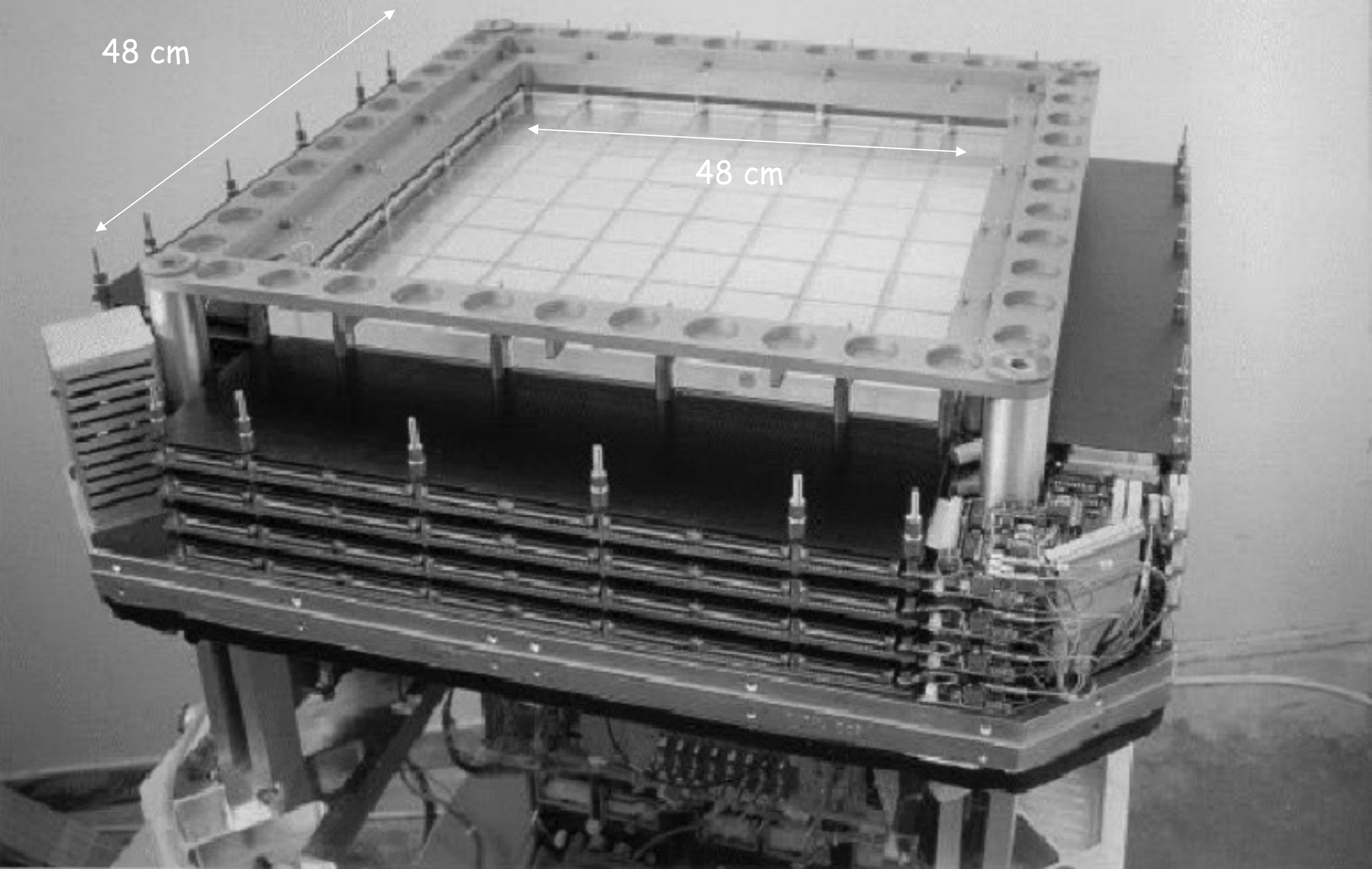



MASS 89 flight


MASS 89 flight


MASS 89

The TS93 and CAPRICE silicon-tungsten imaging calorimeter.



N·H
ELSEVIER

Nuclear Instruments and Methods in Physics Research A 354 (1995) 547–552

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

The GILDA mission: a new technique for a gamma-ray telescope in the energy range 20 MeV–100 GeV

G. Barbiellini [a], M. Boezio [a], M. Casolino [b], M. Candusso [b], M.P. De Pascale [b], A. Morselli [b,*], P. Picozza [b], M. Ricci [d], R. Sparvoli [b], P. Spillantini [c], A. Vacchi [a]

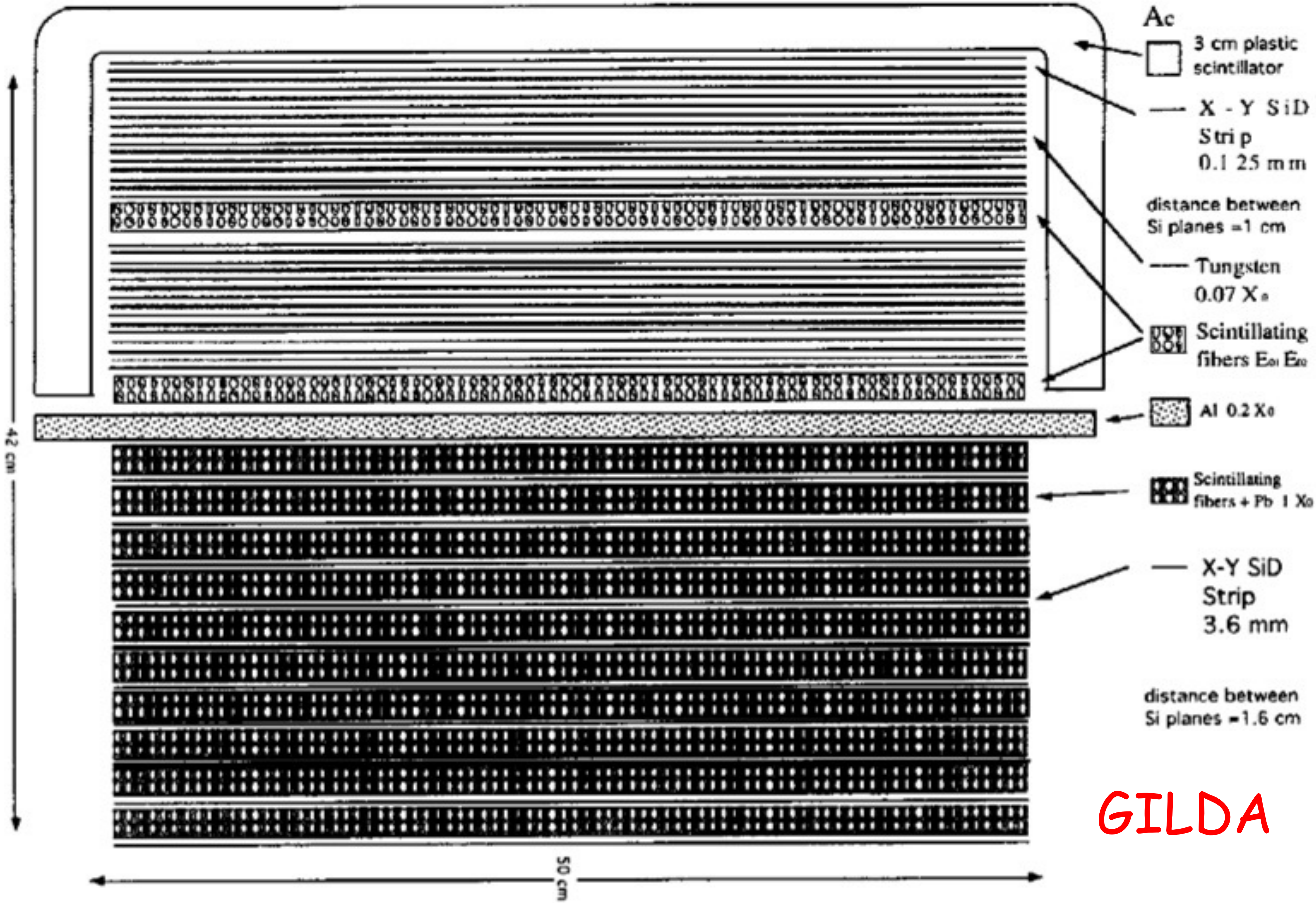
[a] *Dept. of Physics, Univ. of Trieste and INFN, Italy*
[b] *Dept. of Physics, II Univ. of Rome "Tor Vergata" and INFN, Italy*
[c] *Dept. of Physics, Univ. of Firenze and INFN, Italy*
[d] *INFN Laboratori Nazionali di Frascati, Italy*

Received 5 August 1994

Abstract

In this article a new technique for the realization of a high energy gamma-ray telescope is presented, based on the adoption of silicon strip detectors and lead scintillating fibers. The simulated performances of such an instrument (GILDA) are significatively better than those of EGRET, the last successful experiment of a high energy gamma-ray telescope, launched on the CGRO satellite, though having less volume and weight.

* Corresponding author.


Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
distance between Si planes =1 cm
Tungsten 0.07 X0
Scintillating fibers
Al 0.2 X0
Scintillating fibers + Pb 1 X0
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm
GILDA

Quindi eravamo pronti per rispondere alla Call for Ideas ASI per Piccole Missioni (Scienze dell'Universo) 26 giugno 1997
e rispondemmo con due proposte:

- GILDA 40

e

- AGILE

Proposta per la *Call for Ideas* ASI per Piccole Missioni (Scienze dell'Universo)
26 giugno 1997

GILDA40: rivelatore di raggi gamma al Silicio

A. Morselli[1], G. Barbiellini[2], M. Boezio[2], P. Caraveo[3], M. Casolino[1], M. P. De Pascale[1], S. Mereghetti[3], A.Perrino[2], P. Picozza[1], P. Schiavon[2], R. Sparvoli[1], M. Tavani[3,4], A. Vacchi[2]

1. Dipartimento di Fisica, Universitá "Tor Vergata" e INFN.
2. Dipartimento di Fisica, Universitá di Trieste e INFN.
3. Istituto di Fisica Cosmica e Tecnologie Relative, CNR, Milano.
4. Columbia Astrophysics Laboratory, Columbia University, New York, USA.

Introduzione

La proposta del telescopio gamma GILDA40 nasce dall'attivita' consolidata della collaborazione internazionale denominata WiZard che prevede le missioni *Nina* (prevista volare per l'autunno 1997) e *Pamela* (programmata per la seconda meta' del 2000). Cio' significa che esiste un contesto scientifico in cui GILDA40 si inserisce naturalmente. Costi e tempi di sviluppo possono essere realisticamente e sensibilmente bassi visto che e' possibile attingere a tutto il lavoro di progettazione, realizzazione e test gia' esistente (vedi descrizione tecnica). Il telescopio GILDA40 fa infatti uso di rivelatori al silicio ad alta risoluzione spaziale. Questi offrono grandi vantaggi per la rivelazione astrofisica di radiazione gamma: non presentano problemi di rifornimento di gas, non necessitano di alti valori di tensione nè di fotomoltiplicatori per l'analisi del segnale, presentano un tempo morto breve ($1\mu s$) e un trigger dato esclusivamente dai piani di silicio. Lo strumento consiste in un tracciatore al silicio e di un calorimetro di dimensioni e peso opportunamente configurati in base all'orbita scelta. GILDA40 puo' volare sia su un satellite a puntamento con orbita equatoriale, che in *scanning mode* su un satellite elio-sincrono. GILDA40 puo' essere realizzata interamente in Italia entro tre anni con un costo dello strumento inferiore ai 10 miliardi di lire.

Proposta per la *Call for Ideas* ASI per Piccole Missioni (Scienze dell'Universo)
26 giugno 1997

AGILE: Rivelatore a immagini gamma leggero

M. Tavani[1,2], G. Barbiellini[3], M. Boezio[3], P. Caraveo[1], M. Casolino[4], M. P. De Pascale[4], S. Mereghetti[1], A. Morselli[4], A.Perrino[4], P. Picozza[4], P. Schiavon[3], R. Sparvoli[4], A. Vacchi[3]

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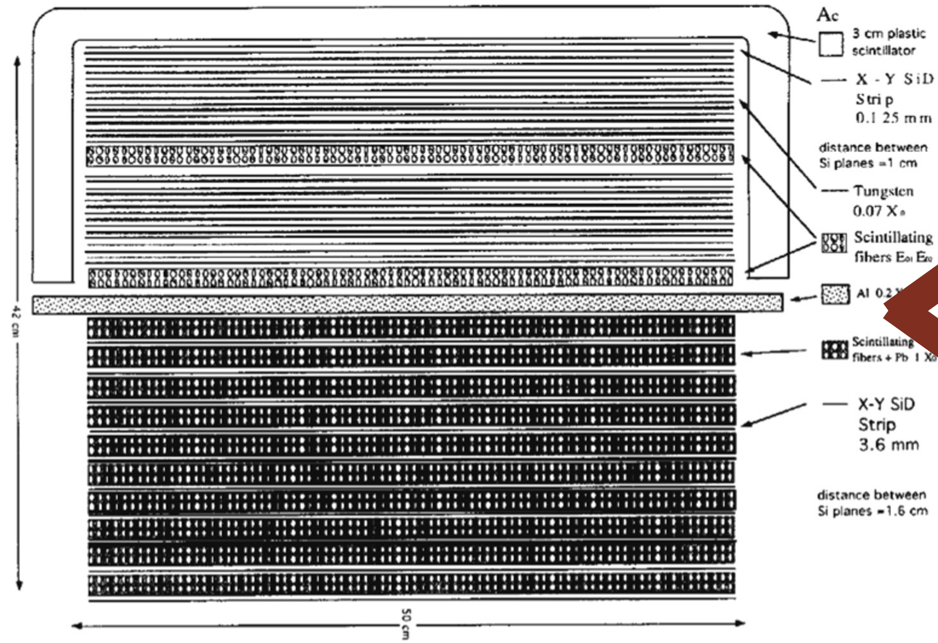
3. Dipartimento di Fisica, Universitá di Trieste e INFN
4. Dipartimento di Fisica, Universitá di Roma II, "Tor Vergata" e INFN

Introduzione

L'astrofisica gamma delle alte energie nella banda 30 MeV–10 GeV beneficierebbe enormemente durante i primi anni del 2000 dall'esistenza di un rivelatore al silicio a largo campo e con sensibilita' e accuratezza confrontabili o migliore di EGRET. Presentiamo qui il concetto di tale missione leggera, AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) dalle dimensioni e peso (inferiore ai 50 kg) ridotte ma dall'elevata e unica capacita' di rivelare sorgenti gamma galattiche e extragalattiche. La tecnologia al silicio permette di rivelare radiazione gamma con enormi vantaggi rispetto a EGRET. AGILE non presenterá problemi di rifornimento di gas, non necessita di alti valori di tensione, e' caratterizzata da un tempo morto breve ($1\mu s$) e da un trigger fornito esclusivamente dai piani di silicio. L'assenza di un calorimetro non consente di avere informazione spettrale dettagliata. Tuttavia, l'enorme vantaggio di realizzare uno strumento molto leggero e dalle elevate prestazioni di rivelazione (sia di risoluzione angolare che di flusso) rende AGILE altamente competitivo rispetto a future missioni astrofisiche di alta energia. AGILE sfrutta l'esperienza del gruppo proponente nella realizzazione di satelliti astrofisici con tecnologia al silicio. L'intero rivelatore e' da realizzarsi in Italia con un costo dello strumento inferiore ai 10 miliardi e costo complessivo della missione inferiore ai 25 miliardi di lire.

GILDA



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Tungsten 0.07 X_0
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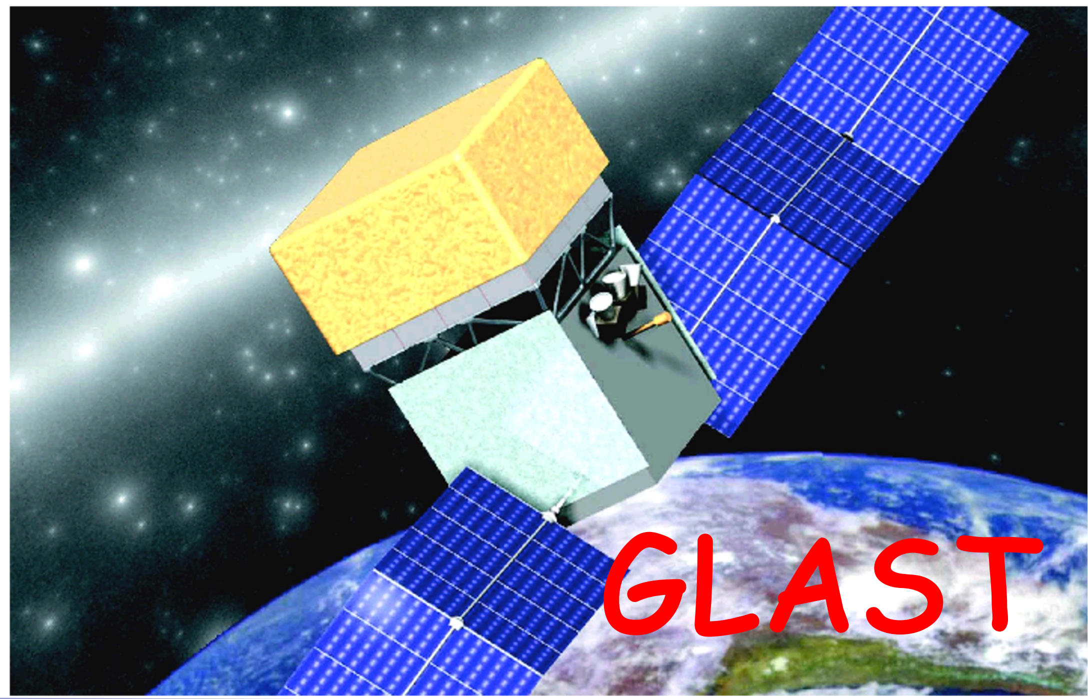
Scintillating fibers + Pb 1 X_0
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm

agile
Astro-rivelatore Gamma
a Immagini Leggero
INAF
INFN
Alenia
telespazio



GLAST


agile
Astro-rivelatore Gamma
a Immagini Leggero
agenzia spaziale italiana
INAF
INFN
Alenia
telespazio

THE AGILE MISSION

agenzia spaziale italiana

INAF

INFN

CARLO GAVAZZI
Carlo Gavazzi Space SpA

ALCATEL ALENIA SPACE
An Alcatel/Finmeccanica company

OERLIKON CONTRAVES

telespazio
A Finmeccanica/Alcatel company

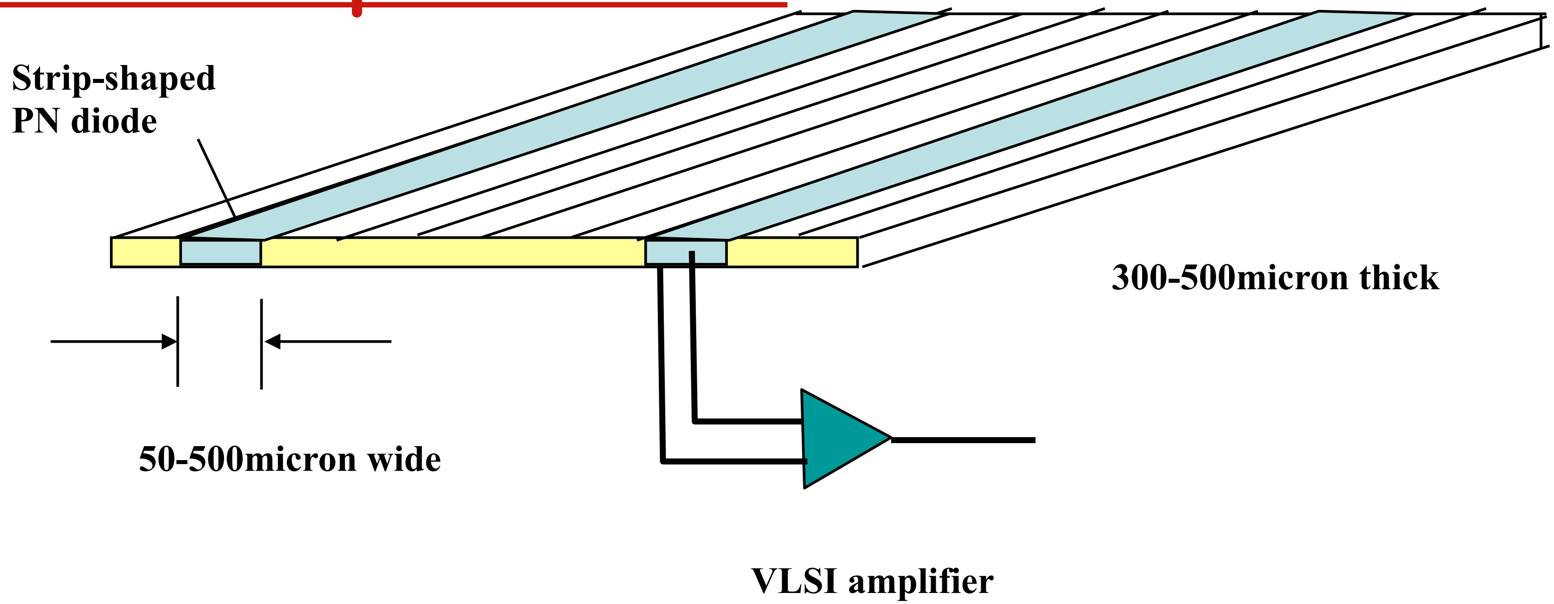
Galileo Avionica

MIPOT

ENEA

New Detector Technology

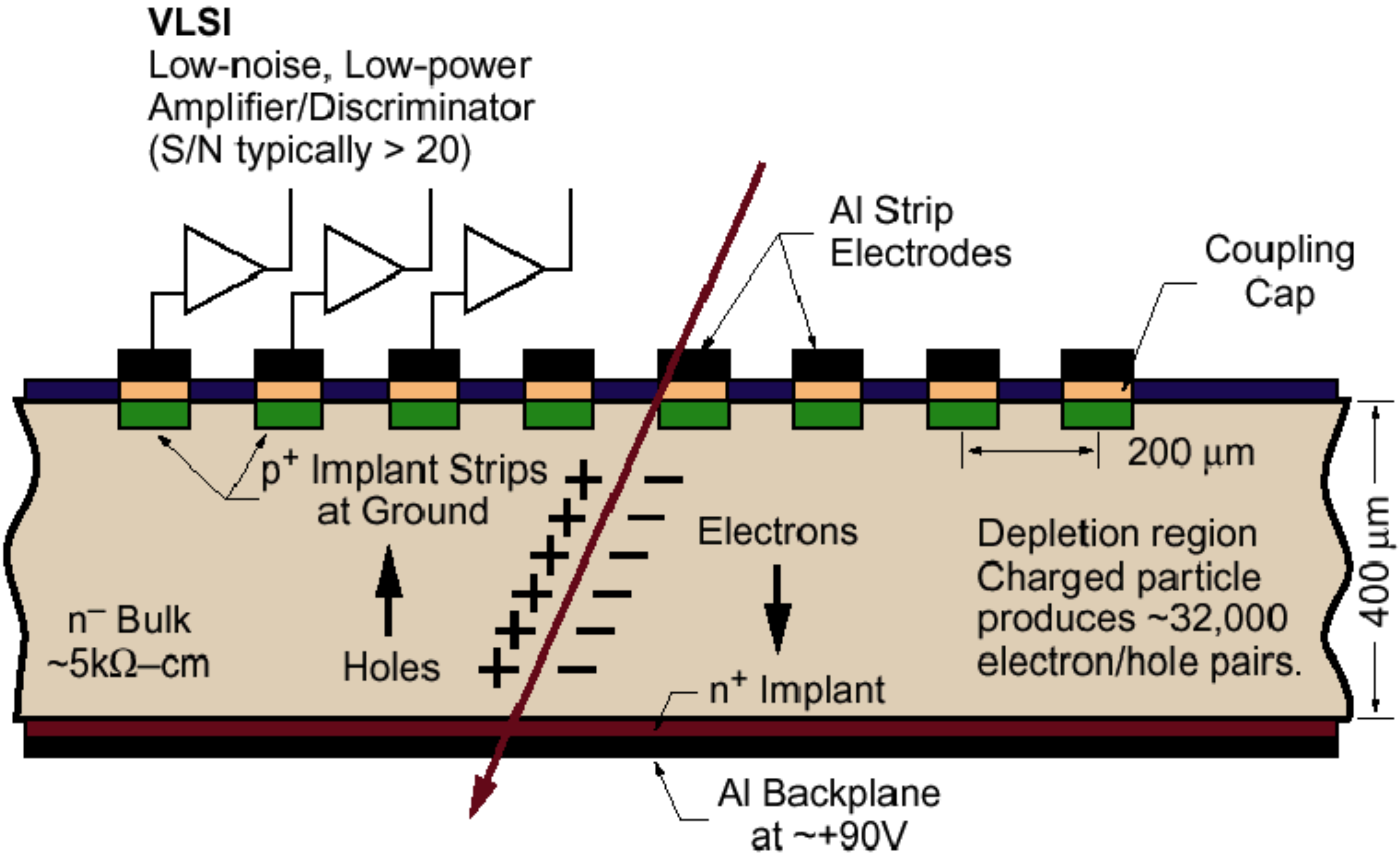
- Silicon strip detector



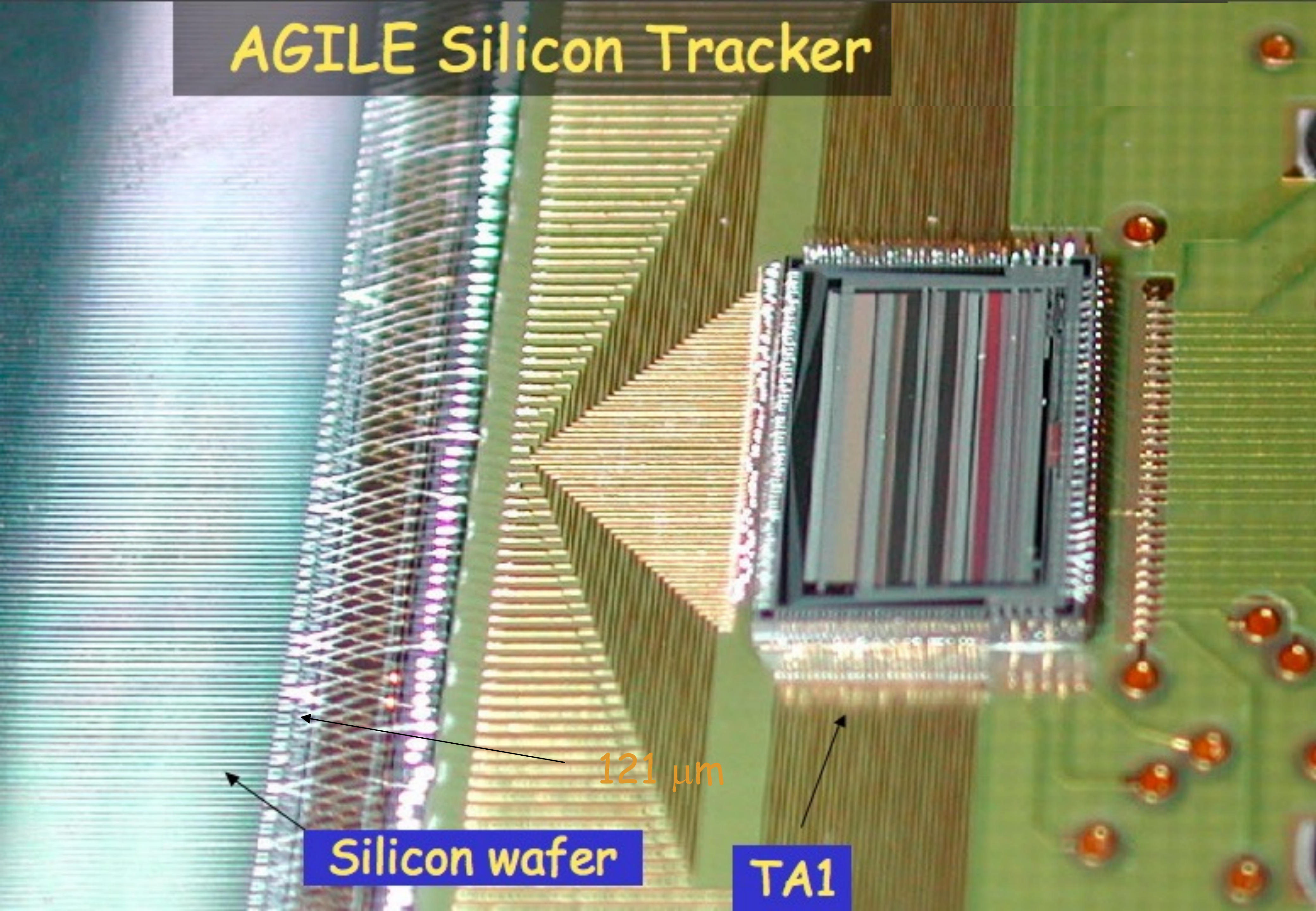
Stable particle tracker that allows micron-level tracking of gamma-rays

Well known technology in Particle Physics experiments.
Used by our collaboration in balloon experiments (MASS, TS93, CAPRICE), on MIR Space Station (SilEye) and on satellite (NINA)

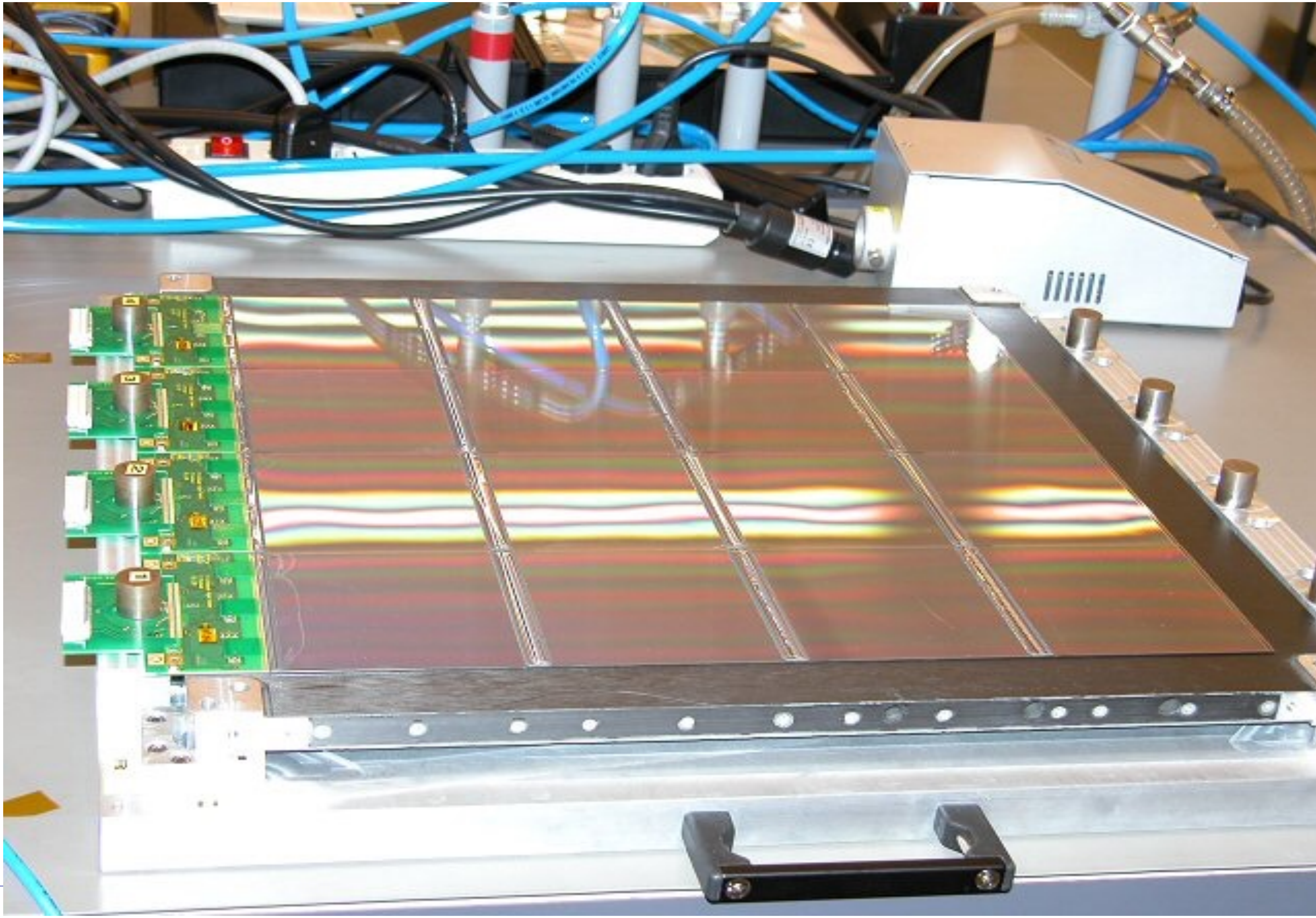
Silicon Strip Detector Principle



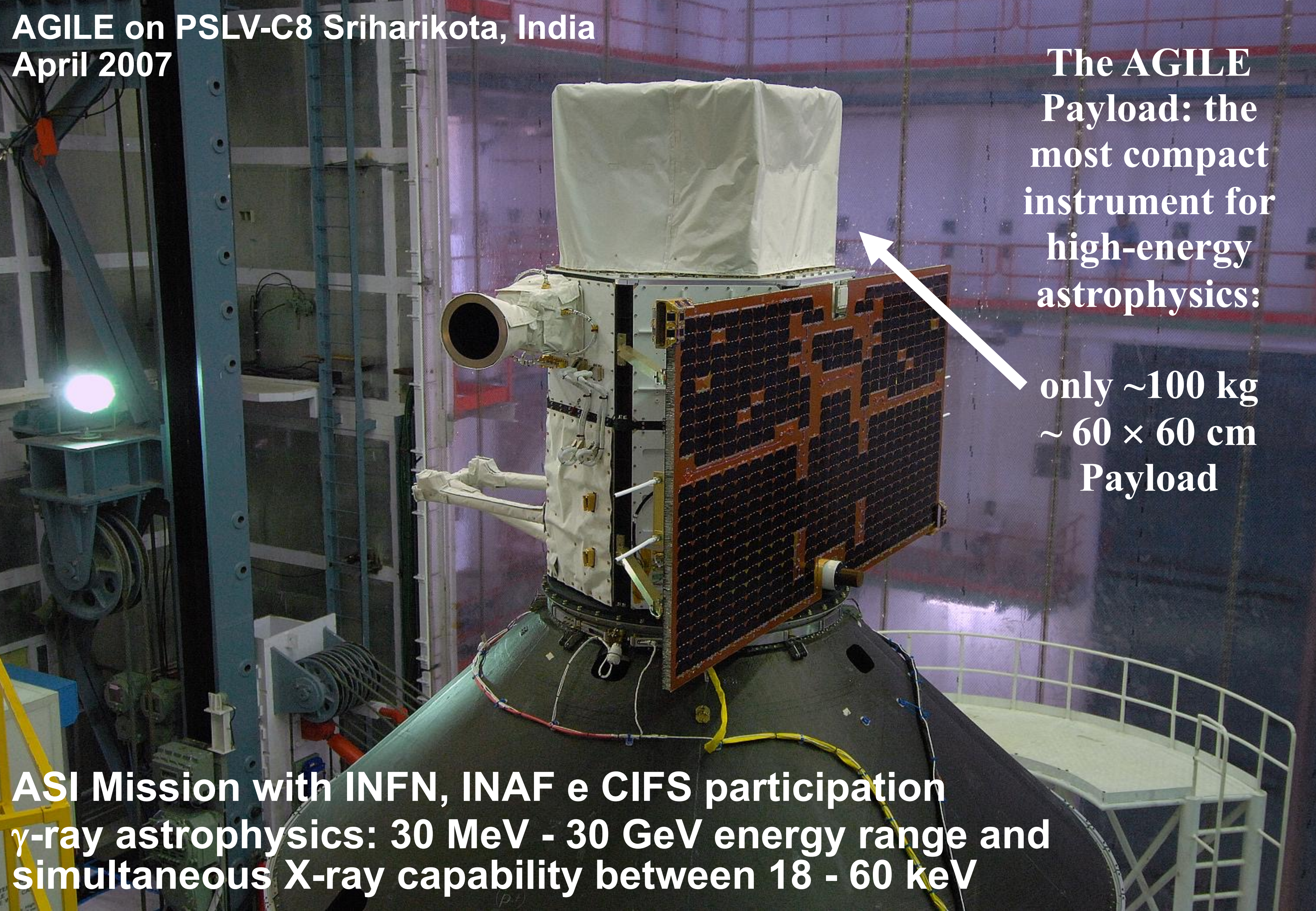
AGILE Silicon Tracker



The Silicon Tracker



The Silicon Tracker


AGILE on PSLV-C8 Sriharikota, India
April 2007
The AGILE Payload: the most compact instrument for high-energy astrophysics:
only ~100 kg
~ 60 × 60 cm
Payload
ASI Mission with INFN, INAF e CIFS participation
γ-ray astrophysics: 30 MeV - 30 GeV energy range and simultaneous X-ray capability between 18 - 60 keV

April 23, 2007: Launch!

SHAR base (Chennai), India

Equatorial orbit: 550 Km, < 3° inclination angle

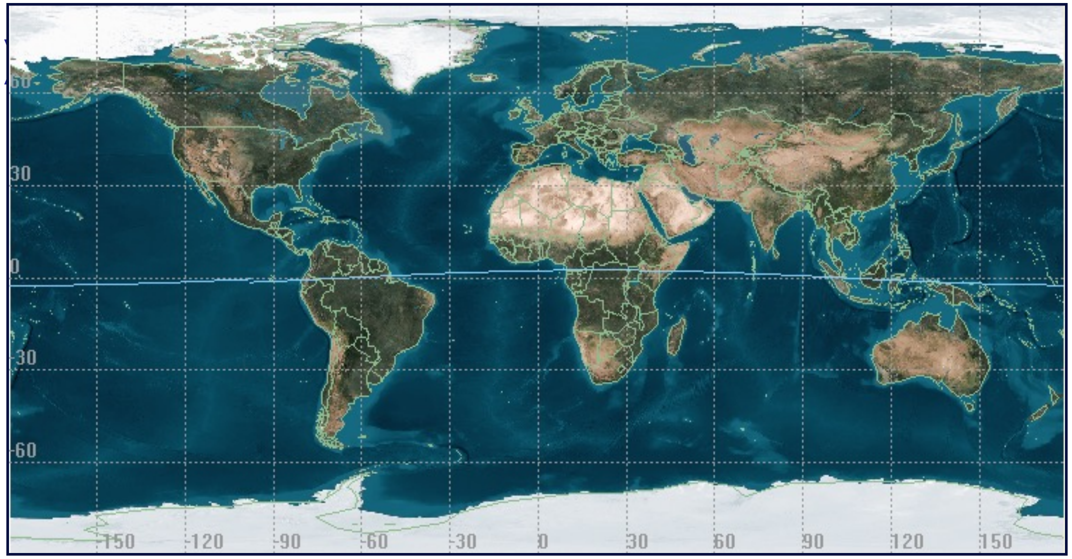
AGILE orbital parameters

Baseline equatorial orbit: 550 Km, 3° inclination

Semi-major axis: 6922.5 km (± 0.1 km)
Requirement: 6928.0 ± 10 km

Inclination angle: 2.48° (±0.04°)
Requirement: < 3°

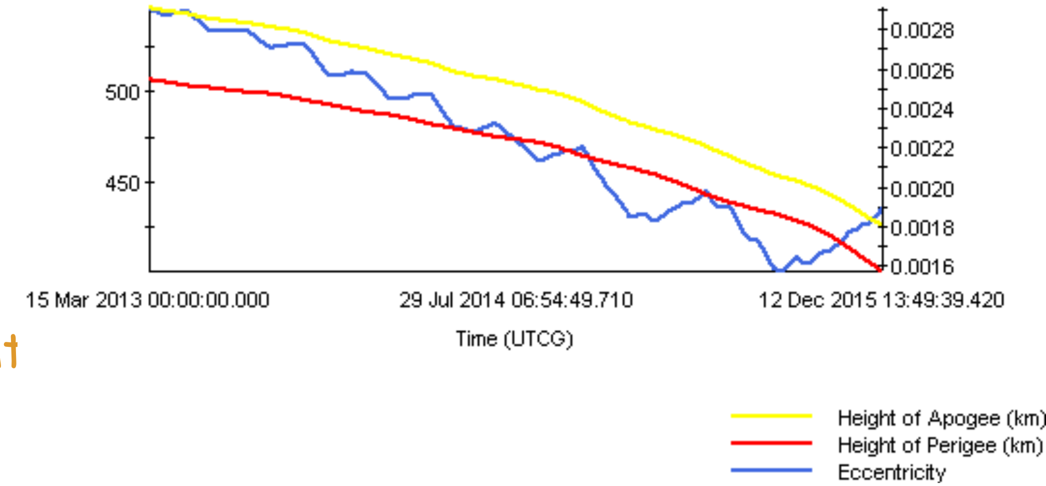
Eccentricity: 0.002 (±0.0015)
Requirement: < 0.1°



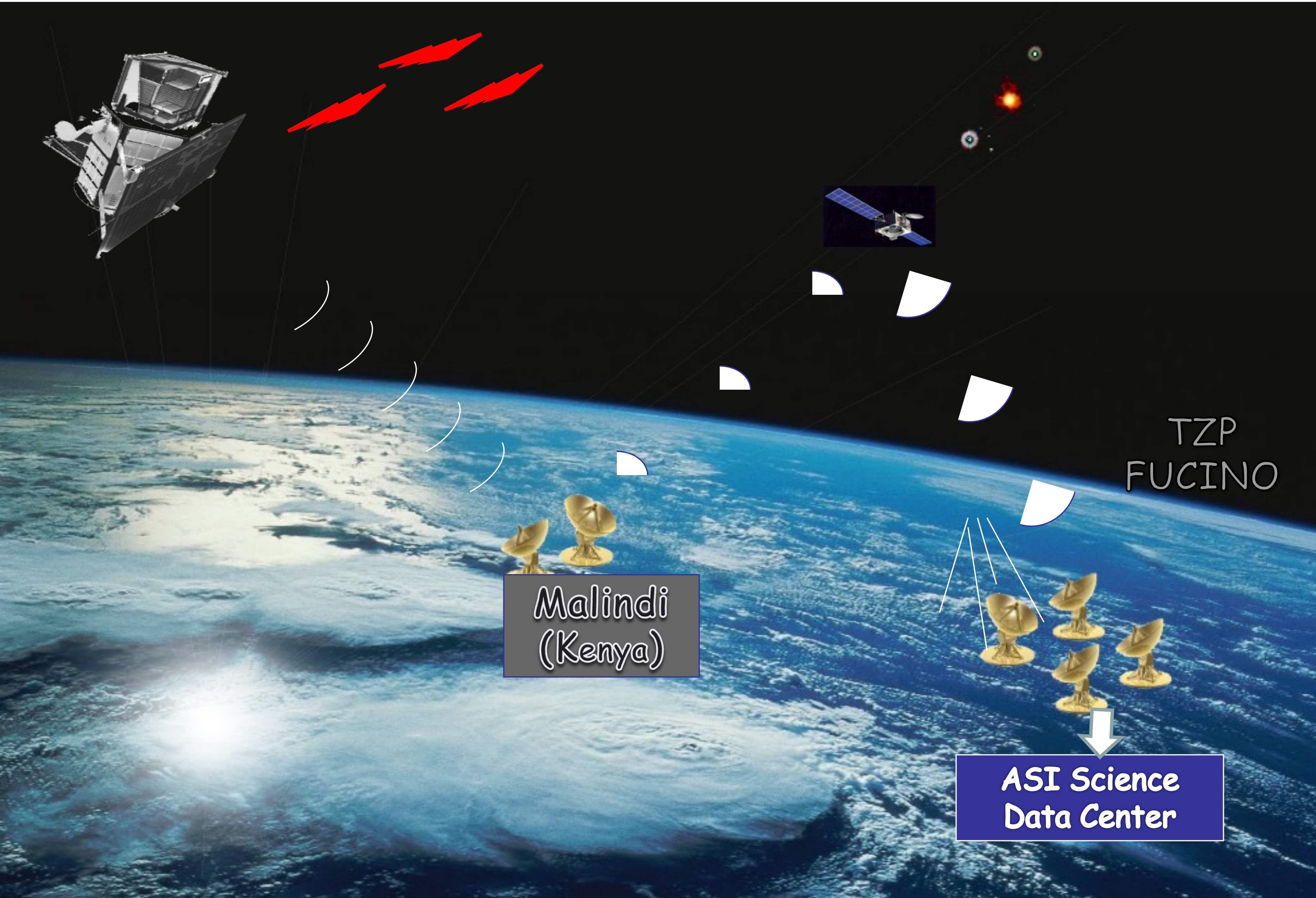
Satellite-AGILE - 28 Mar 2013 10:08:13

TPZ orbital decay estimate:
Height < 400Km on **20/04/2017**
(A/M=0.009 sqm/Kg)
Worst case (A/M=0.012 sqm/Kg):
02/11/2015
Best case (A/M=0.006 sqm/Kg):
29/04/2023

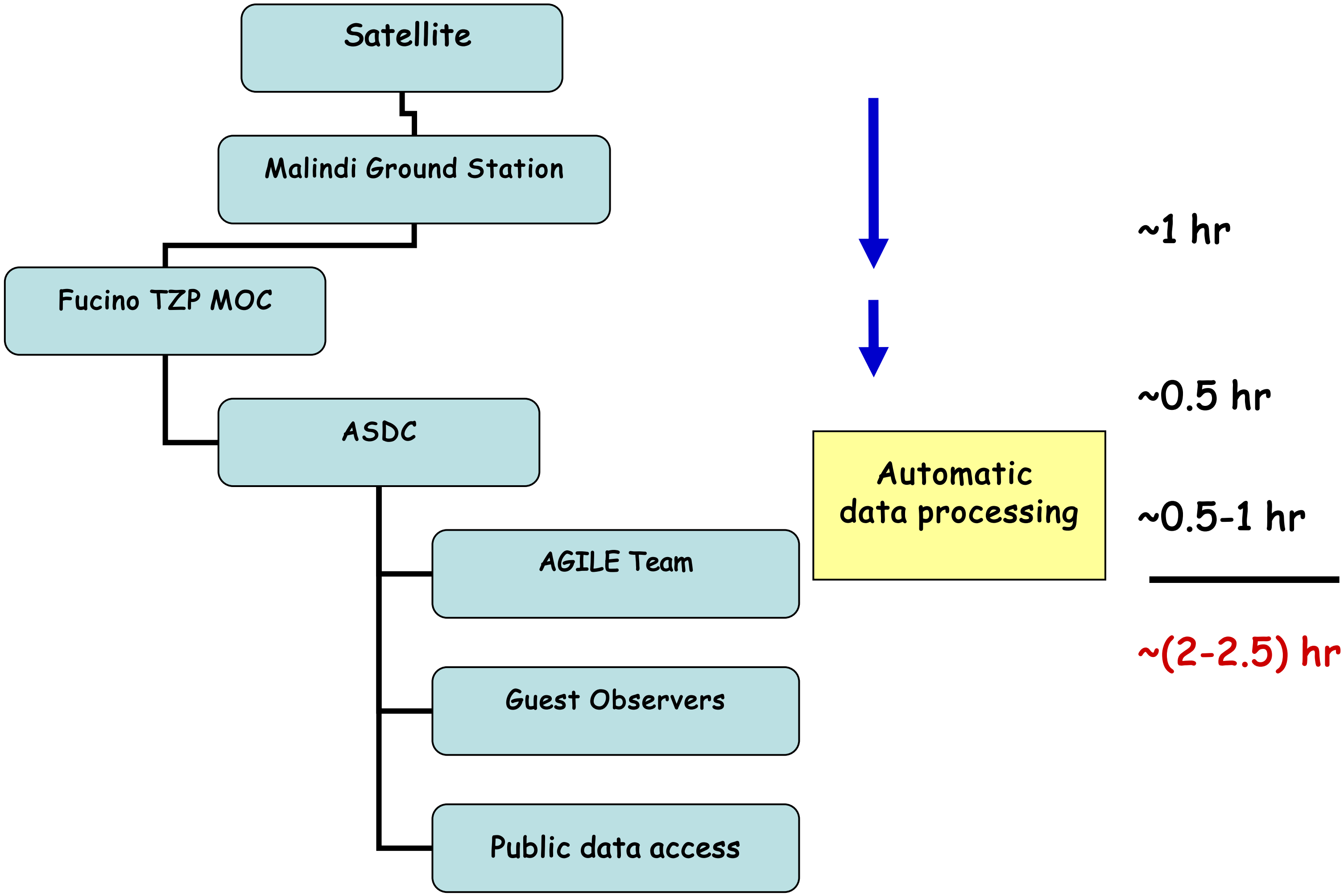
(March 2013 updated estimate, using recent solar flux "Schatten" forecasts + 2σ) →



You can follow AGILE with AGILE Science App. (when it was in operation)

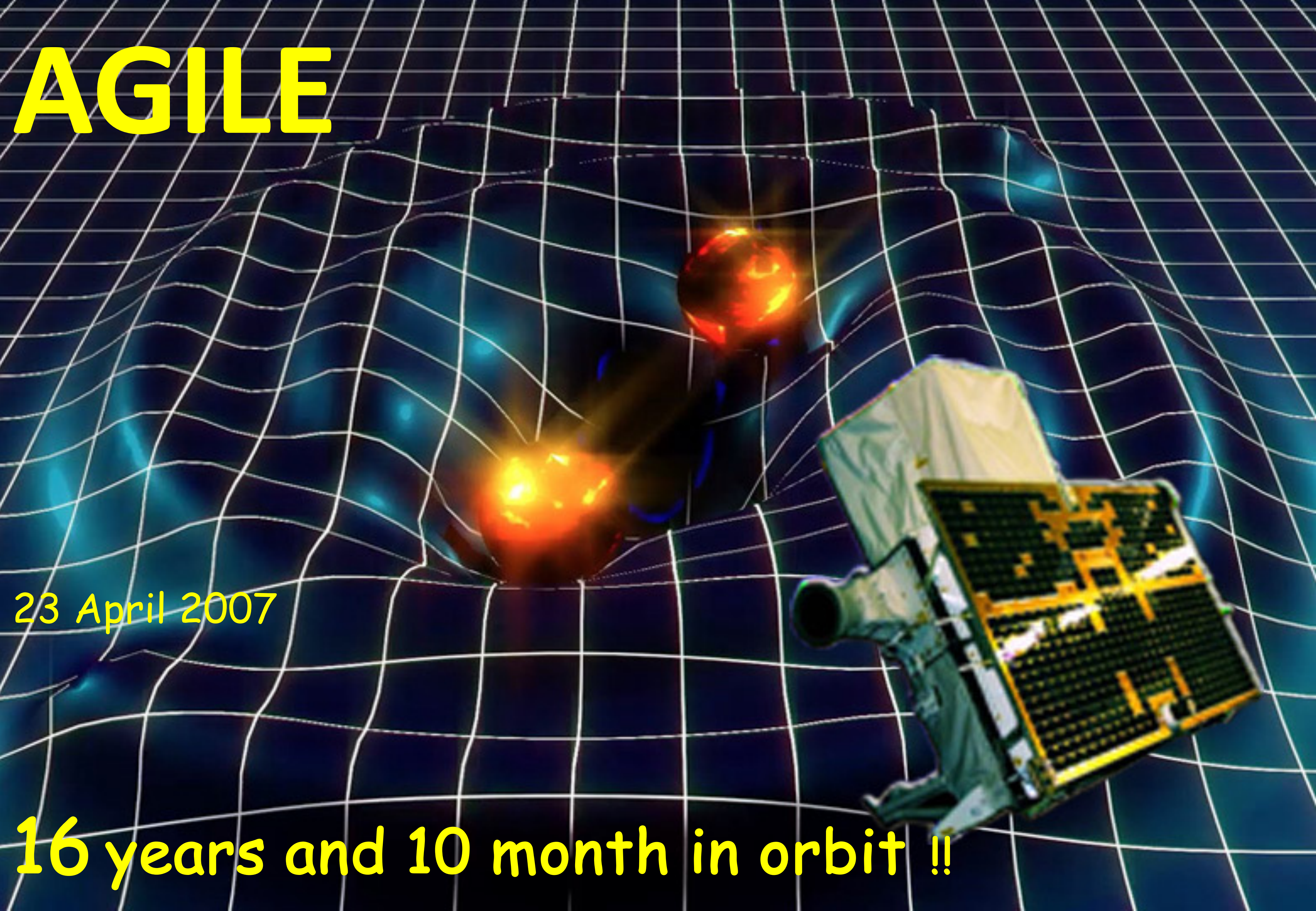

TZP
FUCINO
Malindi
(Kenya)
ASI Science
Data Center

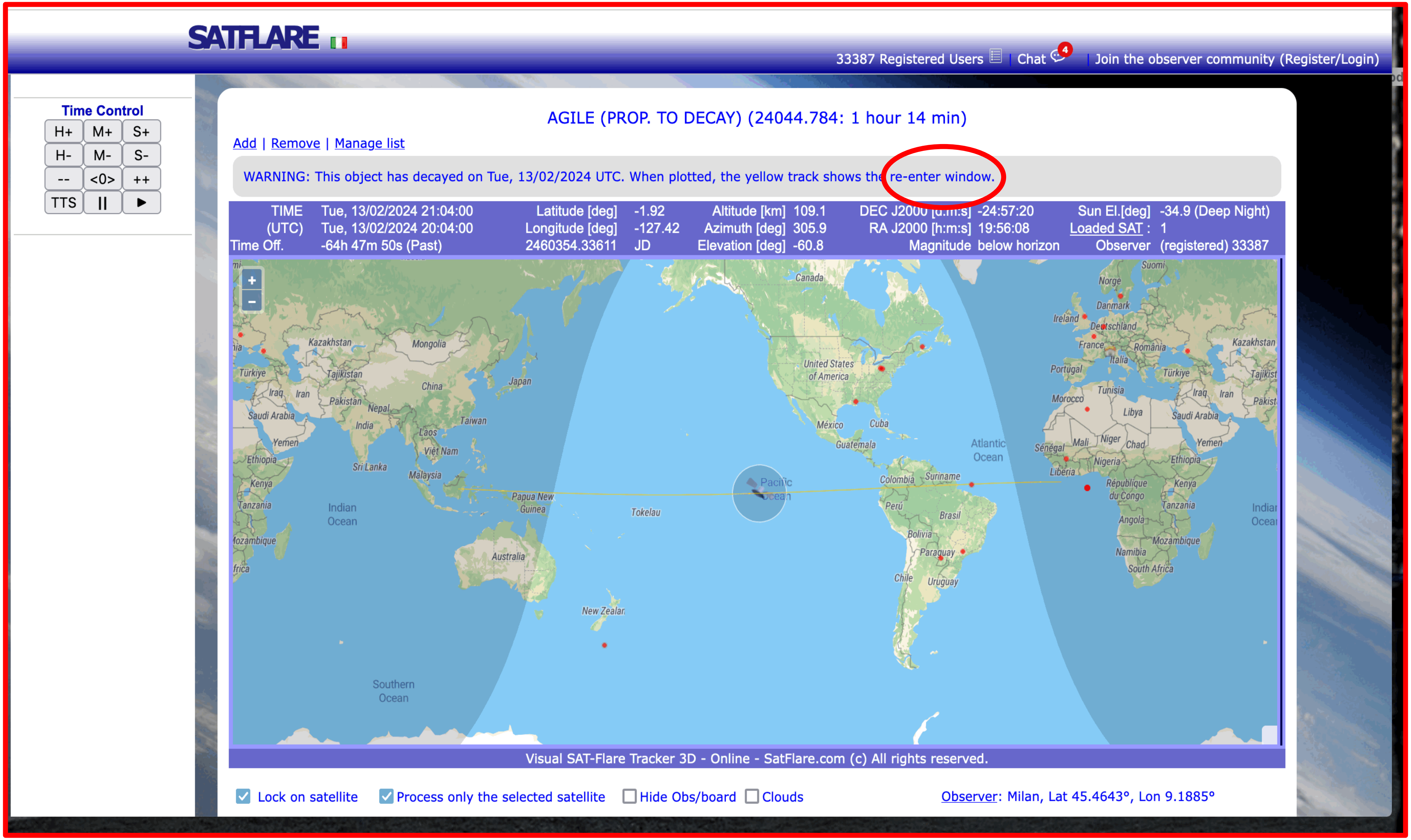
AGILE: "very fast" Ground Segment (with contained costs)



Record for a gamma-ray mission!


AGILE
23 April 2007- 23 April 2022
Happy 15th Birthday Agile !!
ASI
Agenzia Spaziale Italiana


AGILE
23 April 2007
16 years and 10 month in orbit !!


SATFLARE
33387 Registered Users | Chat | Join the observer community (Register/Login)
Time Control
H+ M+ S+
H- M- S-
-- <0> ++
TTS || ▶
AGILE (PROP. TO DECAY) (24044.784: 1 hour 14 min)
Add | Remove | Manage list
WARNING: This object has decayed on Tue, 13/02/2024 UTC. When plotted, the yellow track shows the re-enter window.
TIME Tue, 13/02/2024 21:04:00
(UTC) Tue, 13/02/2024 20:04:00
Time Off. -64h 47m 50s (Past)
Latitude [deg] -1.92
Longitude [deg] -127.42
2460354.33611 JD
Altitude [km] 109.1
Azimuth [deg] 305.9
Elevation [deg] -60.8
RA J2000 [h:m:s] 19:56:08
Magnitude below horizon
Sun El.[deg] -34.9 (Deep Night)
Loaded SAT : 1
Observer (registered) 33387
Visual SAT-Flare Tracker 3D - Online - SatFlare.com (c) All rights reserved.
Lock on satellite
Process only the selected satellite
Hide Obs/board
Clouds
Observer: Milan, Lat 45.4643°, Lon 9.1885°

Summary of AGILE results in >16 years of operations

- **Publications:** the scientific production of the AGILE Team consists of **> 800 bibliographic references in ADS, of which> 160 refereed articles.**
- The monitoring of the sky with a rapid and efficient alert system led to the publication of **>240 ATels** and **>300 GCNs**. From May 2019, **101 MCAL GCN automatic notices** have been published.

- The Quick Look system developed by INAF-OAS, distributed between the data center at SSDC and INAF-OAS in Bologna, produced **scientific results within ~ 25 min** from the data downlink to the ASI Malindi ground station: an absolute record for gamma astrophysics. The Team has also developed **AGILEScience - App on Google Play and App Store** to monitor and follow the observations of the AGILE satellite on mobile devices.

- **AGILE and the search for GW counterparts:** participation of Team members with shifts 24/7 during LIGO-VIRGO observational runs. AGILE follow-up of all **pre-O4 GW events**, with **96 GW-AGILE type GCNs published during O3** and collected in a dedicated web page in SSDC**:** *https://agile.ssdc.asi.it/news_gw.html* AGILE completed the follow-up of all GW events **up to the end of LVK O4a (first part) on Jan 16, 2024**.

- AGILE contribution to **Fast Radio Bursts** science: **very important discovery** on April 28, 2020 published in **Nature, Tavani et al. 2021** (2021NatAs...5..401T)

Three of the most important AGILE discoveries:

- **Discovery of a new acceleration mechanism inducing intense and rapid flux variations in the Crab Nebula in the energy band above 100 millions of elettronvolt!**

- **First direct evidence of cosmic ray acceleration in Supernovae remnants with the AGILE observations of the SNR W44**

- **Direct evidence that extreme particle acceleration and non-thermalized emission above 100 MeV can occur in microquasars (Cyg X-3 and Cyg X-1) with a repetitive pattern.**

THE AGILE LEGACY

AGILE archives and catalogs are available to the community through the ASI SSDC.

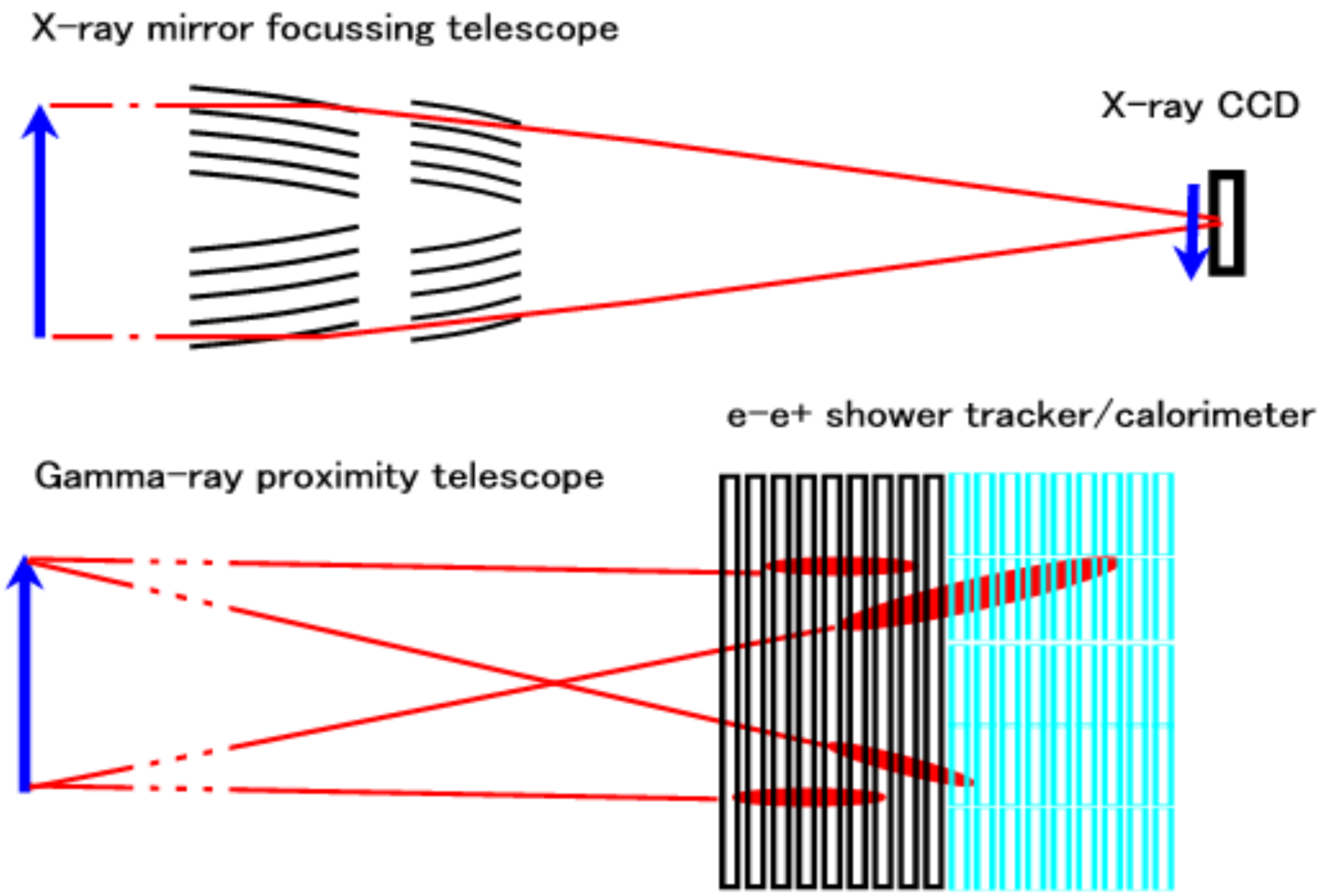
Science activities continue. We have just published on Feb. 29, 2024 all AGILE-GRID data **up to January 15, 2024. A data reprocessing is in progress.**

Open-source Python software package **Agilepy** (INAF-OAS) and/or **SSDC AGILE-LV3 online data analysis tool.**

With AGILE's re-entry, the in-orbit operational phase ended, but a new phase of scientific work on the satellite legacy data archive opens.

Work in progress on new catalogs with and without **Machine Learning** techniques. **Stay tuned for further results**.

Detector Technology: X-ray vs. Gamma-ray



X-ray (0.5 - 10keV)
Focusing possible

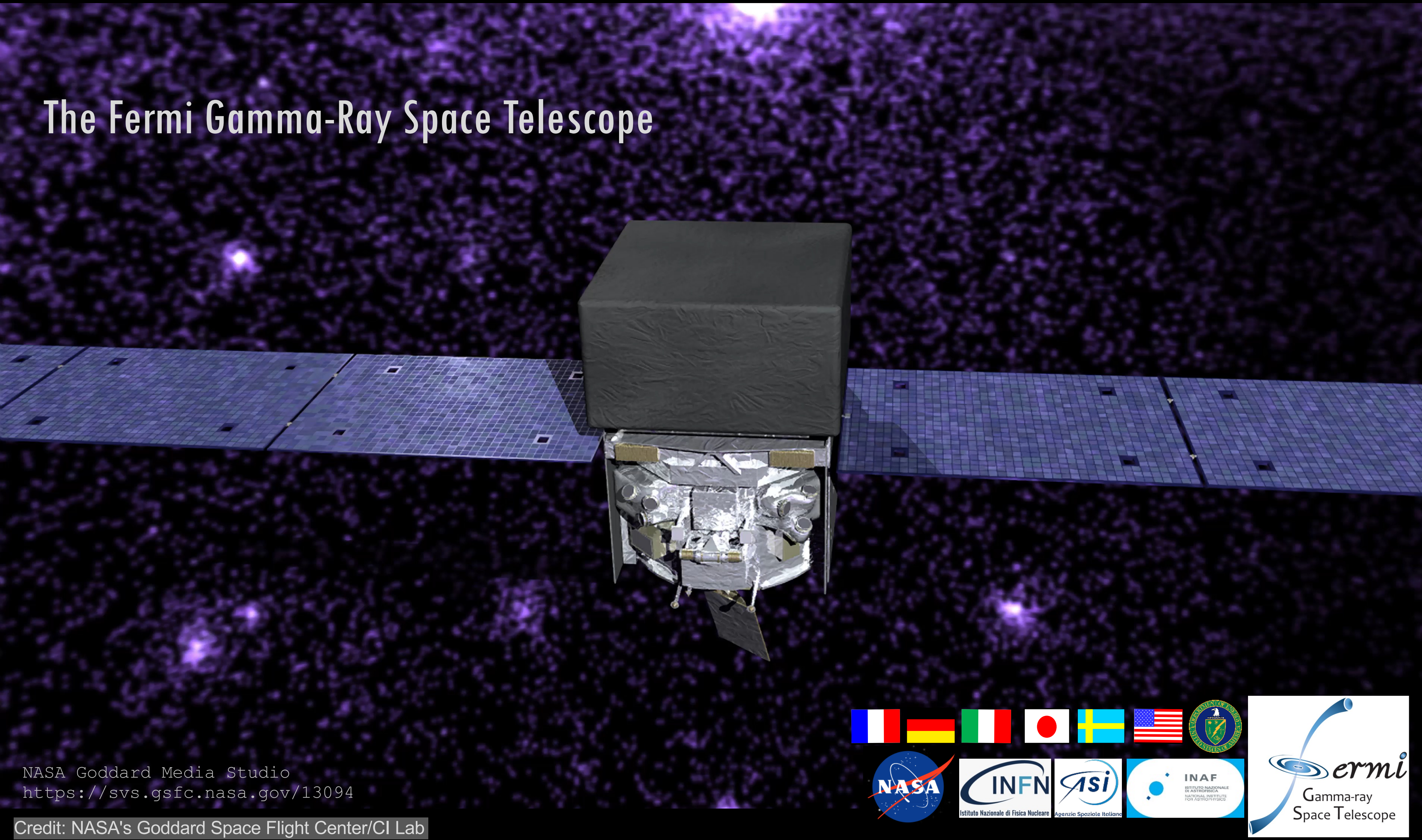
↓

Large effective area
Excellent energy resolution
Very low background
Narrow view

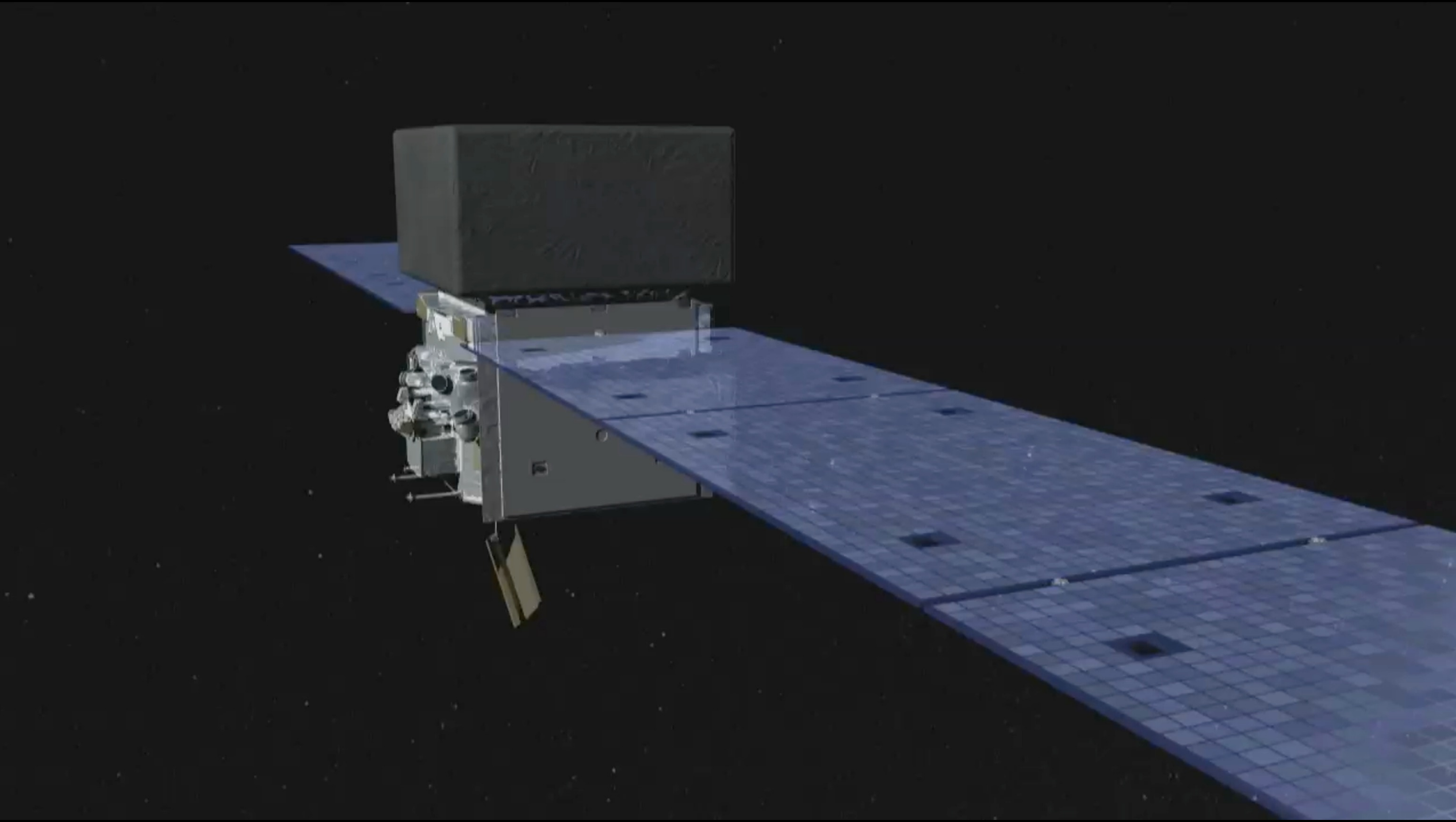
Gamma-ray(0.1-500GeV)
No focusing possible

↓

Wide field of view
Limited effective area
Moderate energy resolution
High background



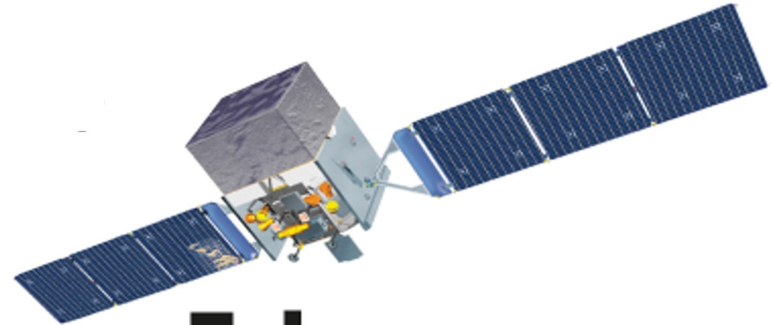
Credit: NASA's Goddard Space Flight Center/CI Lab

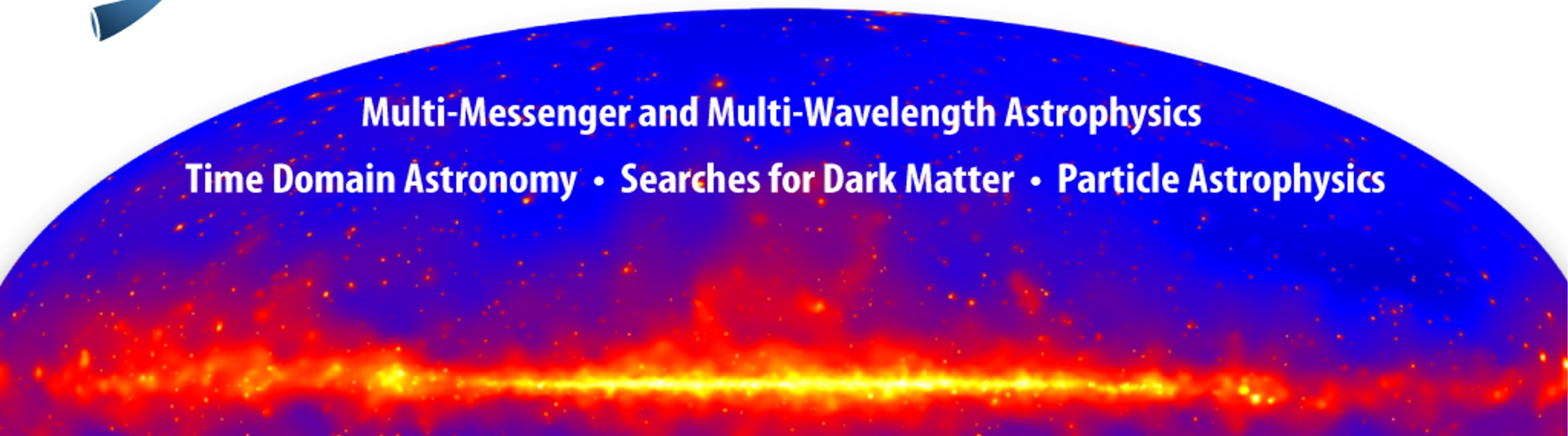


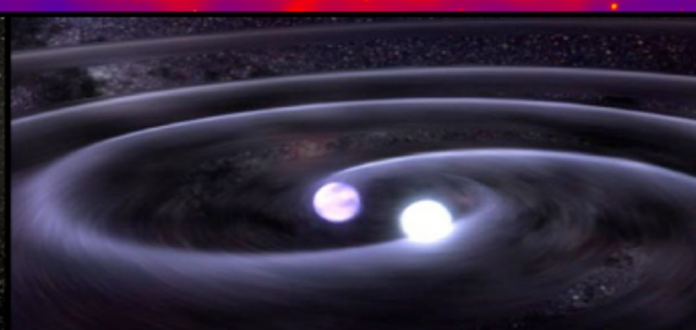
FERMI

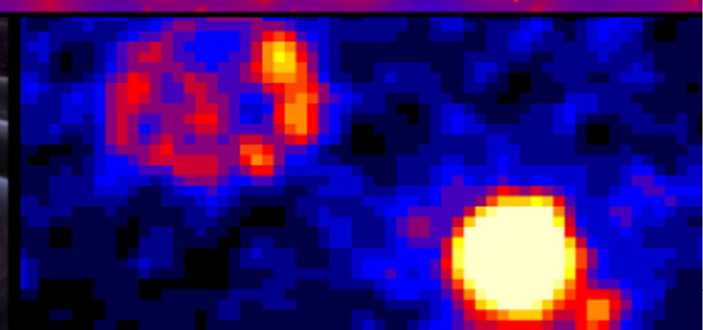
Large Area Telescope

Fermi Gamma-Ray Space Telescope



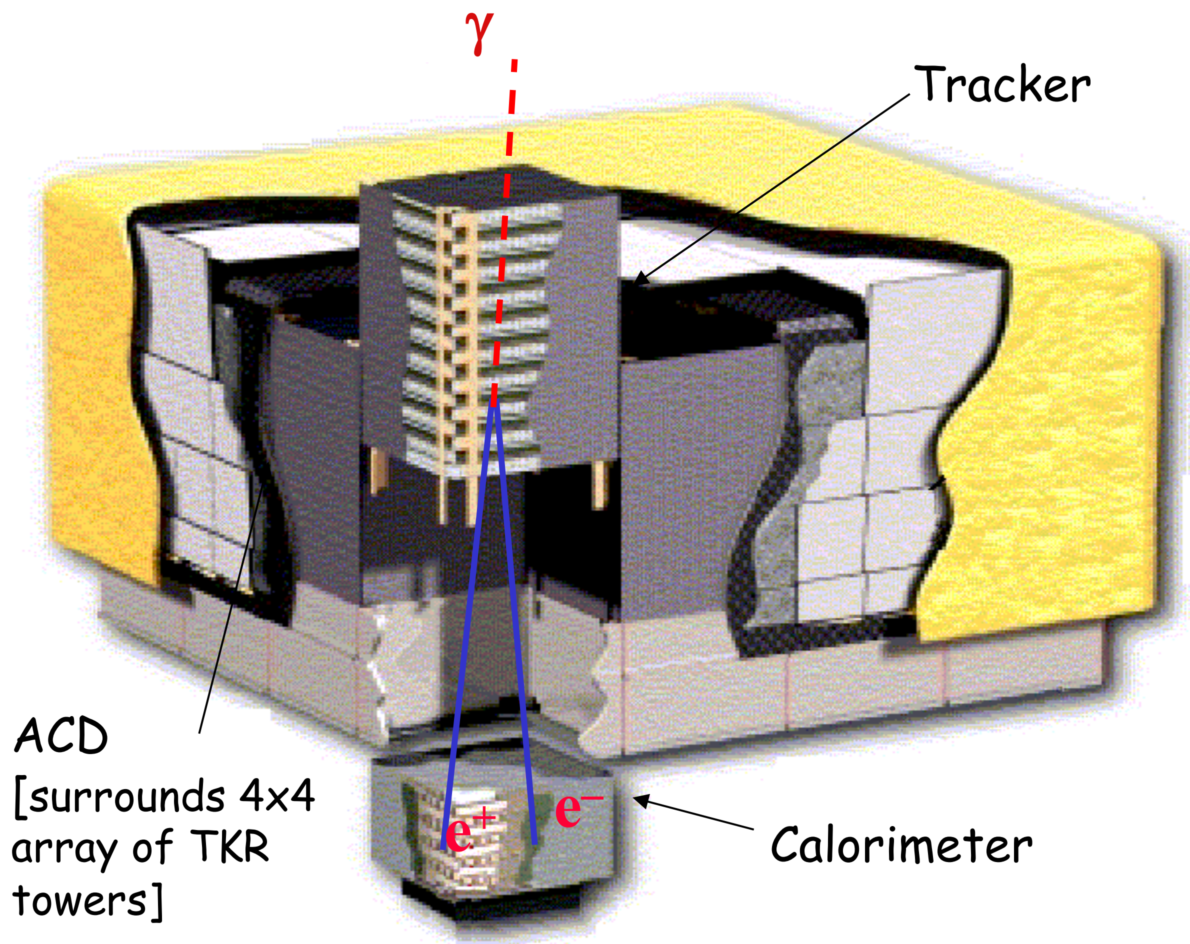




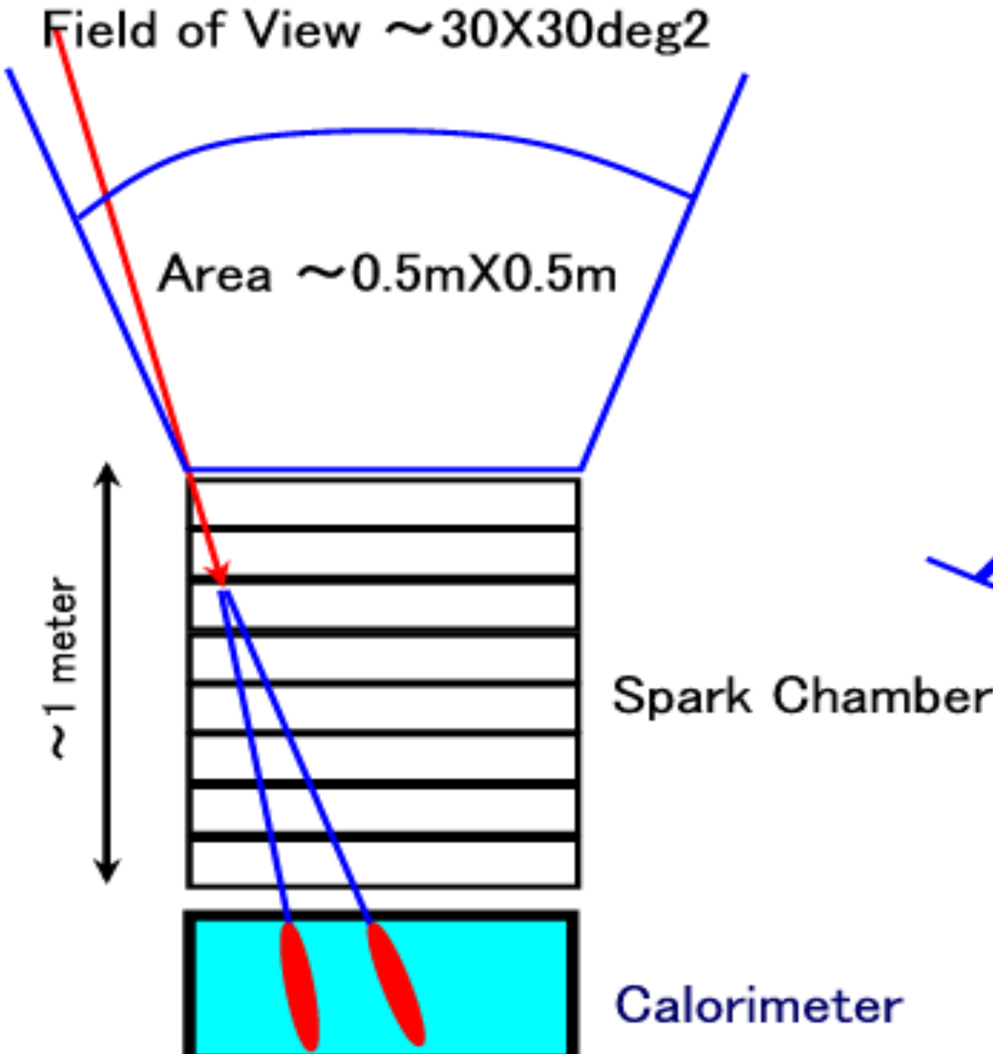


Fermi LAT: A Telescope Without Lenses

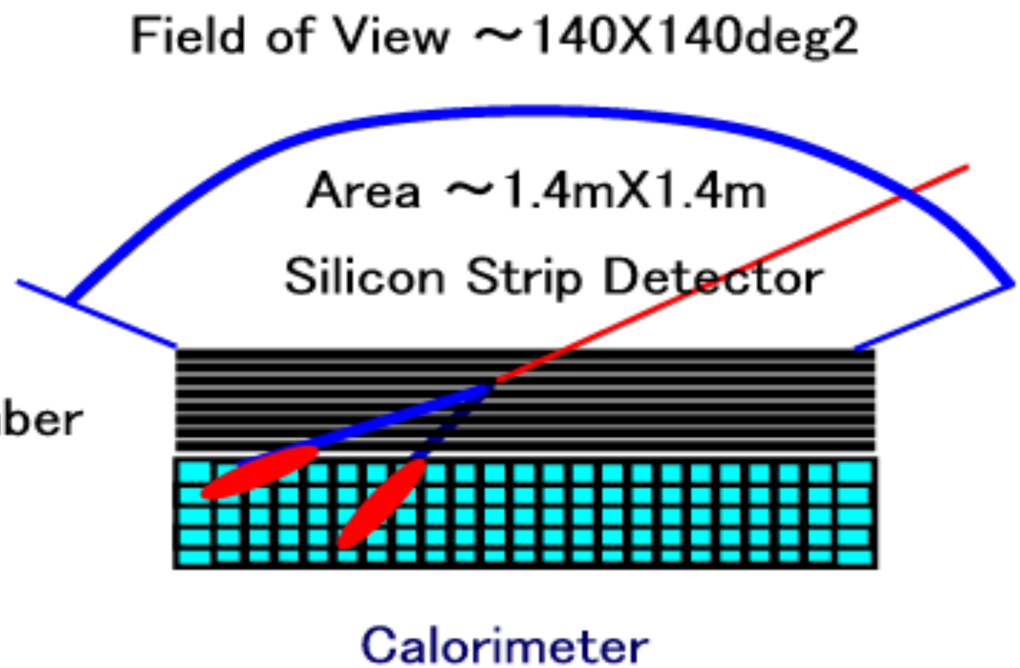
- Precision Si-strip Tracker (TKR) 70 m^2 of silicon detectors arranged in 36 planes. 880,000 channels.
- Hodoscopic CsI Calorimeter(CAL) 1536 CsI(Tl) crystals in 8 layers, total mass 1.5 tons.
- Segmented Anticoincidence Detector (ACD) 89 plastic scintillator tiles.
- Electronics System Includes flexible hardware trigger and onboard computing.



EGRET(Spark Chamber) VS. Fermi LAT (Silicon Strip Detector)

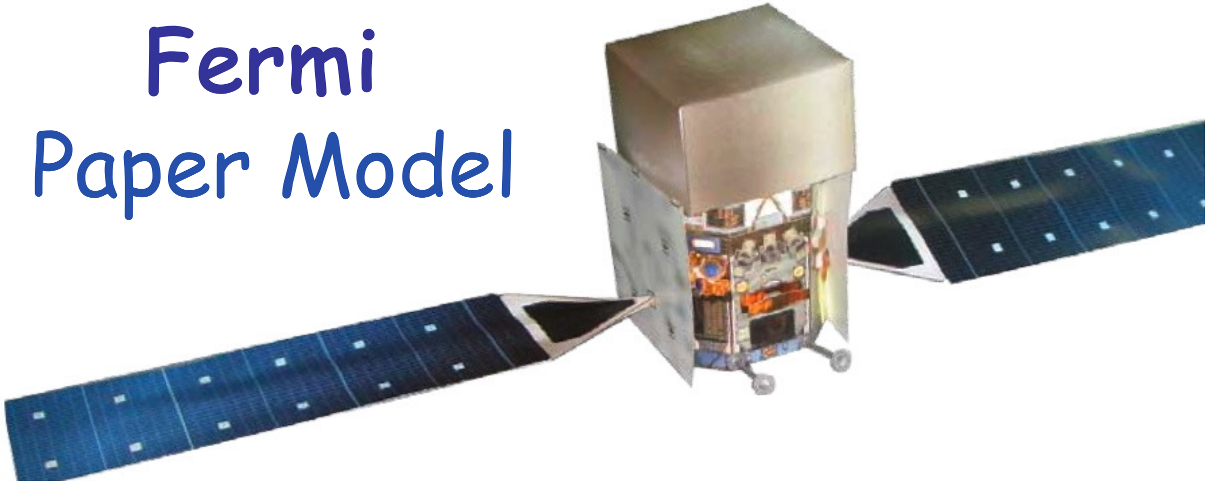


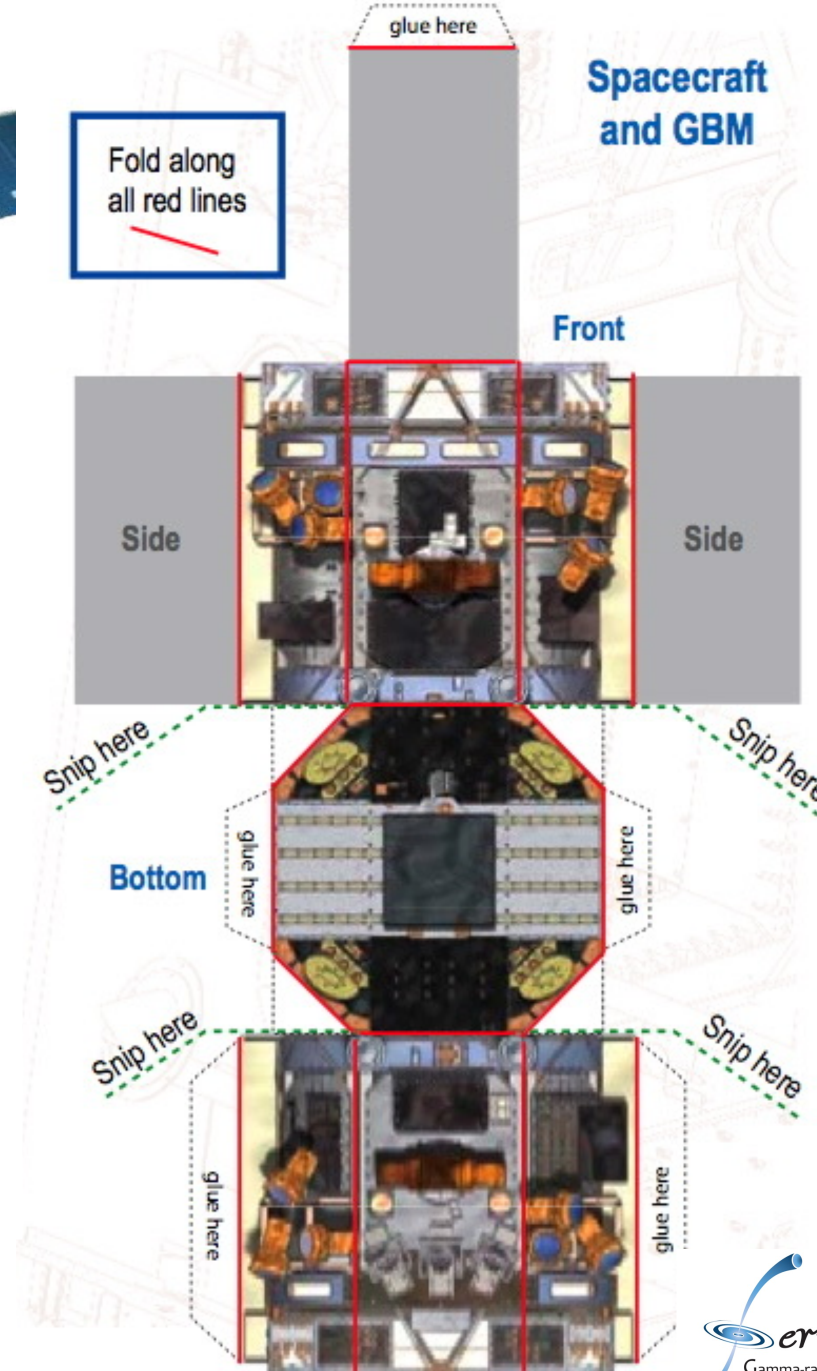
EGRET on Compton GRO
(1991-2000)



Fermi Large Area Telescope
(2008-2018)

Fermi Paper Model





- https://owncloud.roma2.infn.it/index.php/s/yvpYj8NMDV2Bip7

Fermi Gamma-ray Space Telescope

The Fermi LAT Participating Institutions

American Institutions

SU-HEPL Stanford University, Hanson Experimental Physics Laboratory , ,
SU-SLAC Stanford Linear Accelerator Center, Particle Astrophysics group
GSFC-NASA-LHEA Goddard Space Flight Center, Laboratory for High Energy Astrophysics
NRL - U. S. Naval Research Laboratory, E. O. Hulburt Center for Space Research, X-ray and gamma-ray branches UCSC- SCIPP University of California at Santa Cruz, Santa Cruz Institute of Particle Physics
SSU- California State University at Sonoma, Department of Physics & Astronomy , WUStL-Washington University, St. Louis
UW- University of Washington , TAMUK- Texas A&M University-Kingsville, Ohio State University

Italian Institutions

INFN - Istituto Nazionale di Fisica Nucleare and Univ. of Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine ASI - Italian Space Agency
IASF- Milano, Roma

Japanese Institutions

University of Tokyo
ICRR - Institute for Cosmic-Ray Research
ISAS- Institute for Space and Astronautical Science Hiroshima University

French Institutions

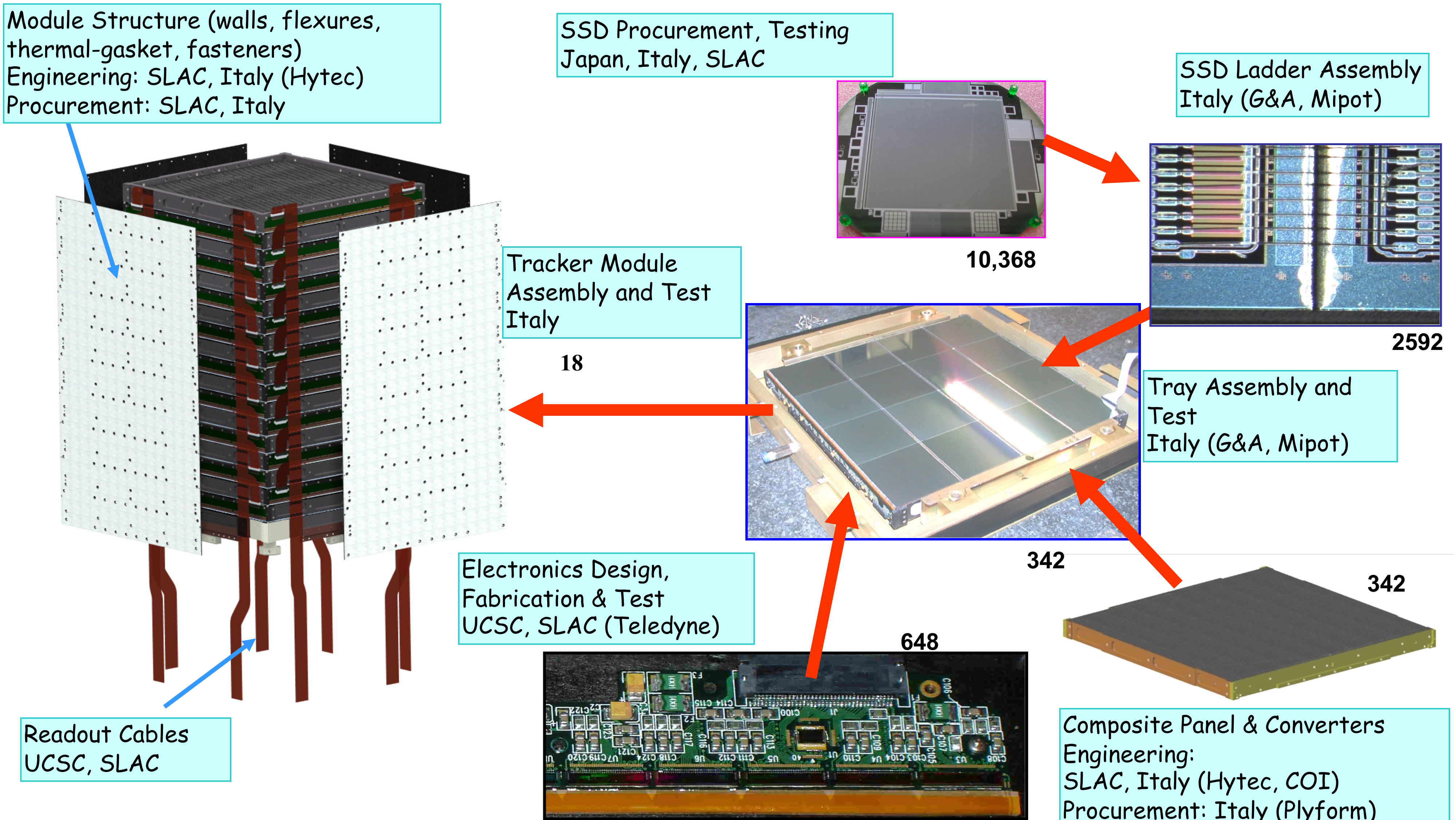
CEA/DAPNIA Commissariat à l'Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nucliaire et de l'Instrumentation Associée, CEA, Saclay
IN2P3 Institut National de Physique Nucléaire et de Physique des Particules, IN2P3 IN2P3/LPNHE-X Laboratoire de Physique Nucléaire des Hautes Energies de l'École Polytechnique IN2P3/PCC Laboratoire de Physique Corpusculaire et Cosmologie, Collège de France IN2P3/CENBG Centre d'études nucléaires de Bordeaux Gradignan
IN2P3/LPTA Laboratoire de Physique Theorique et Astroparticules, Montpellier

Swedish Institutions

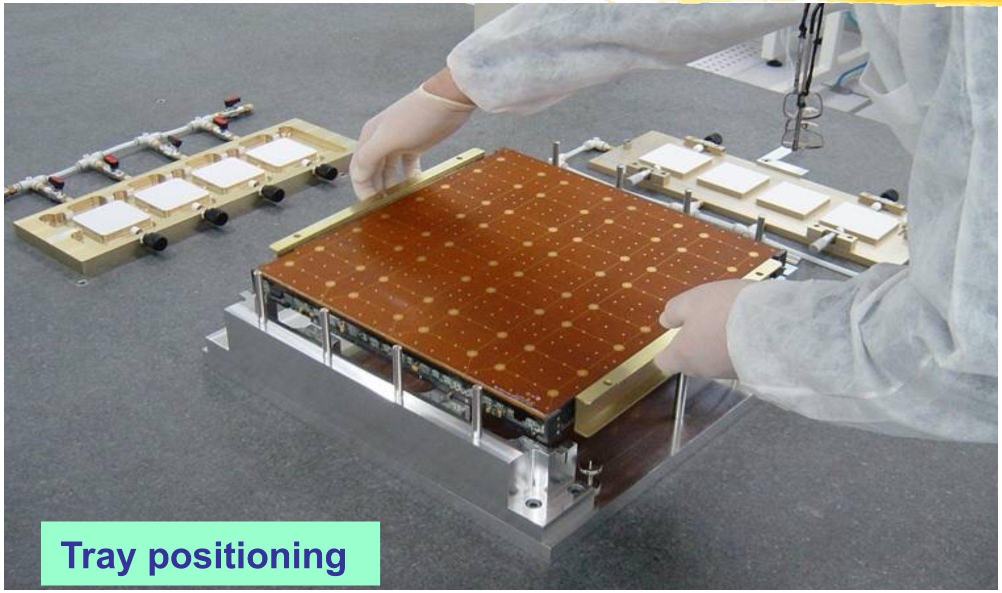
KTHRoyal Institute of Technology
Stockholms Universitet

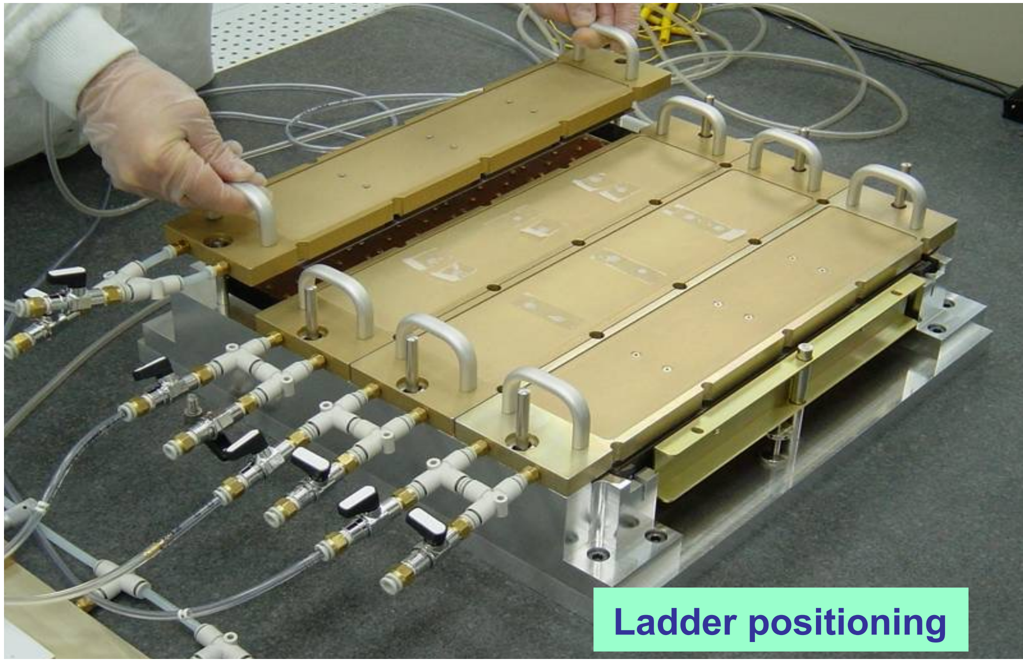
Collaboration members: ~270
Members: 95
Affiliated Scientists ~90
Postdocs: 37
Graduate Students 48

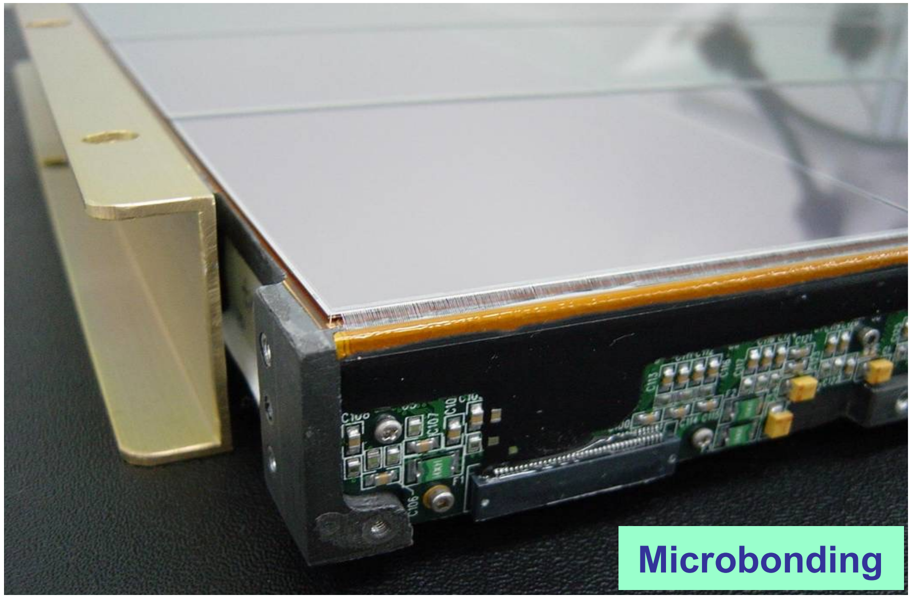
Tracker Production Overview



Tray assembly in G&A

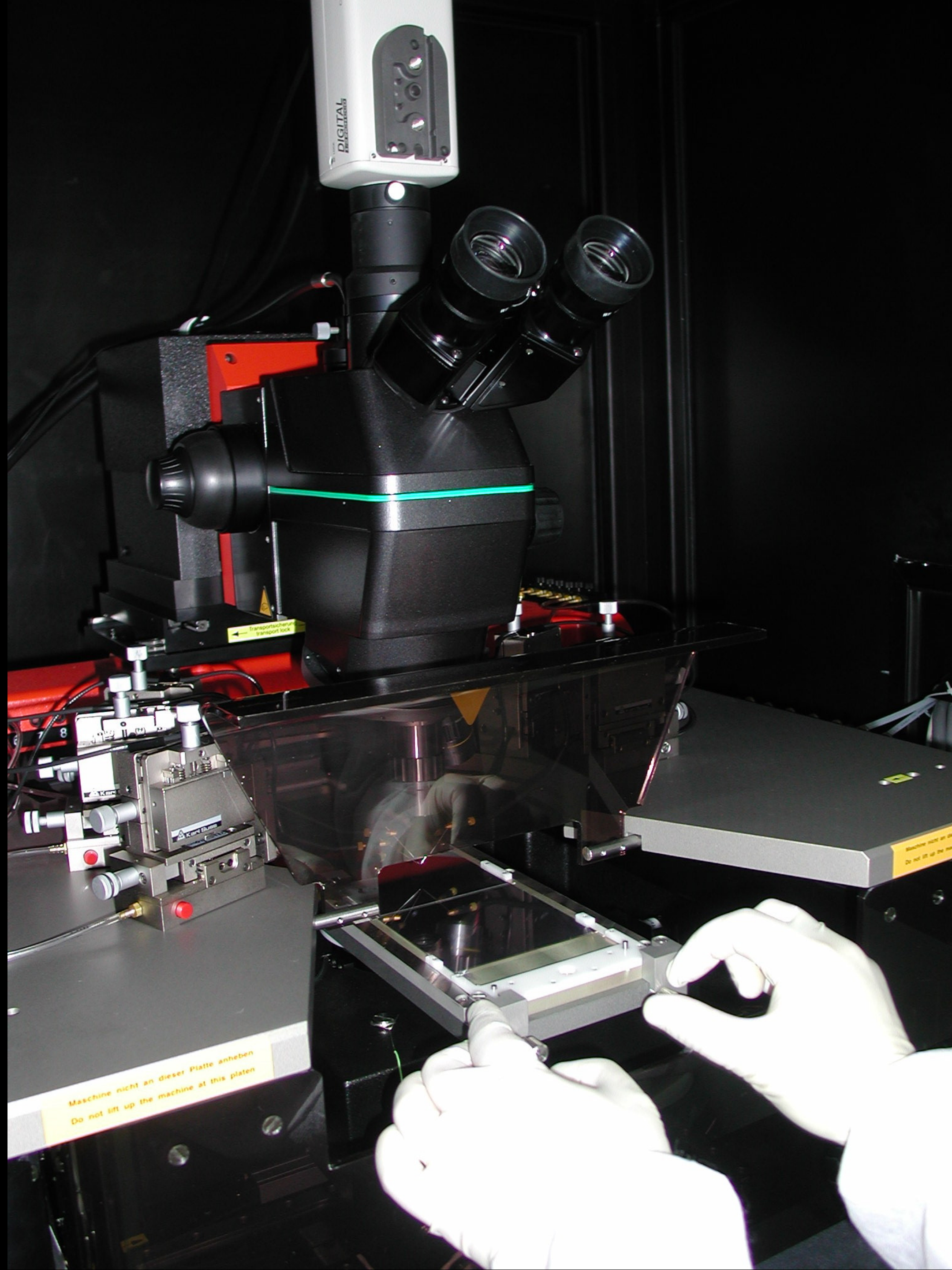


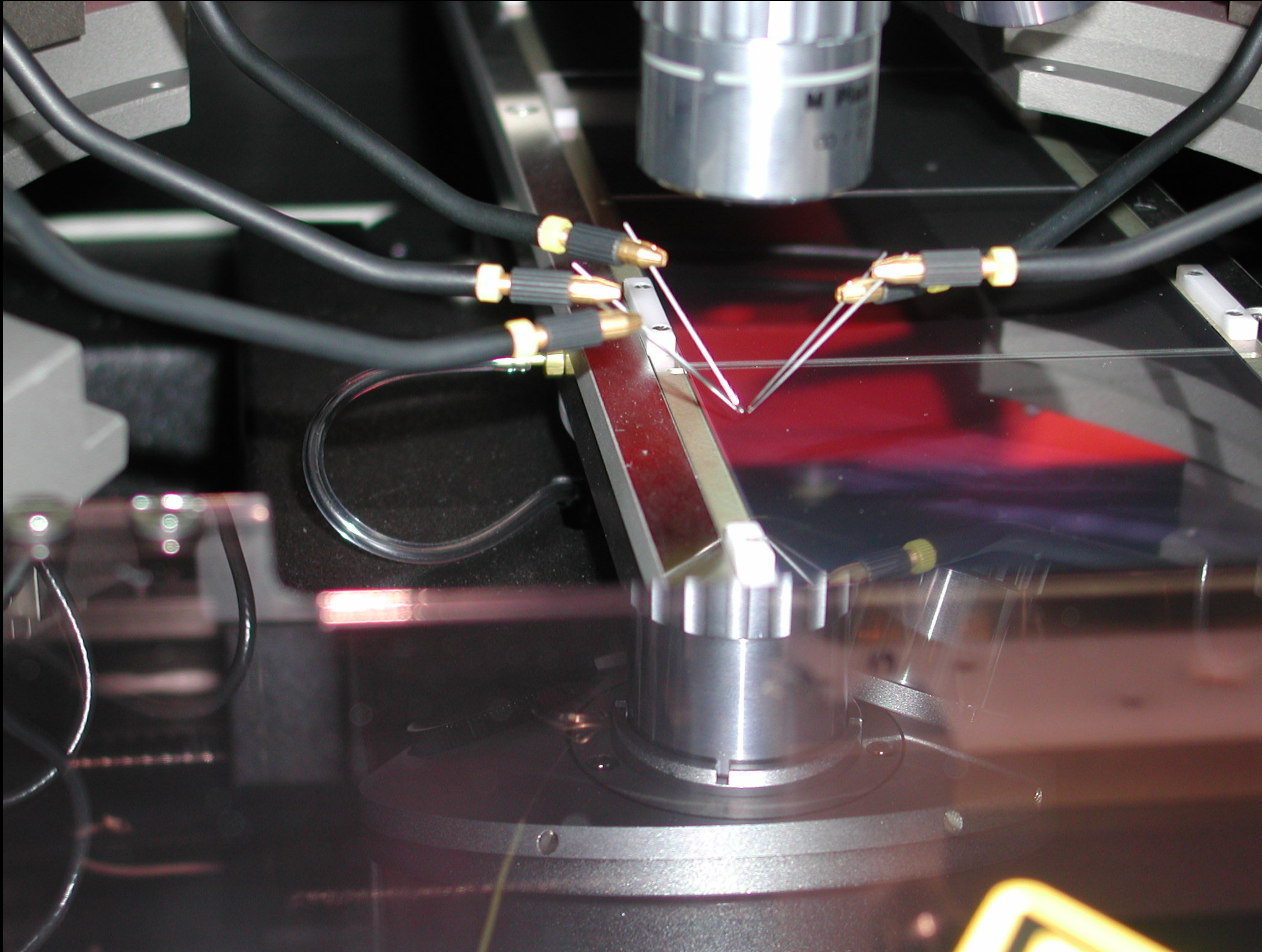


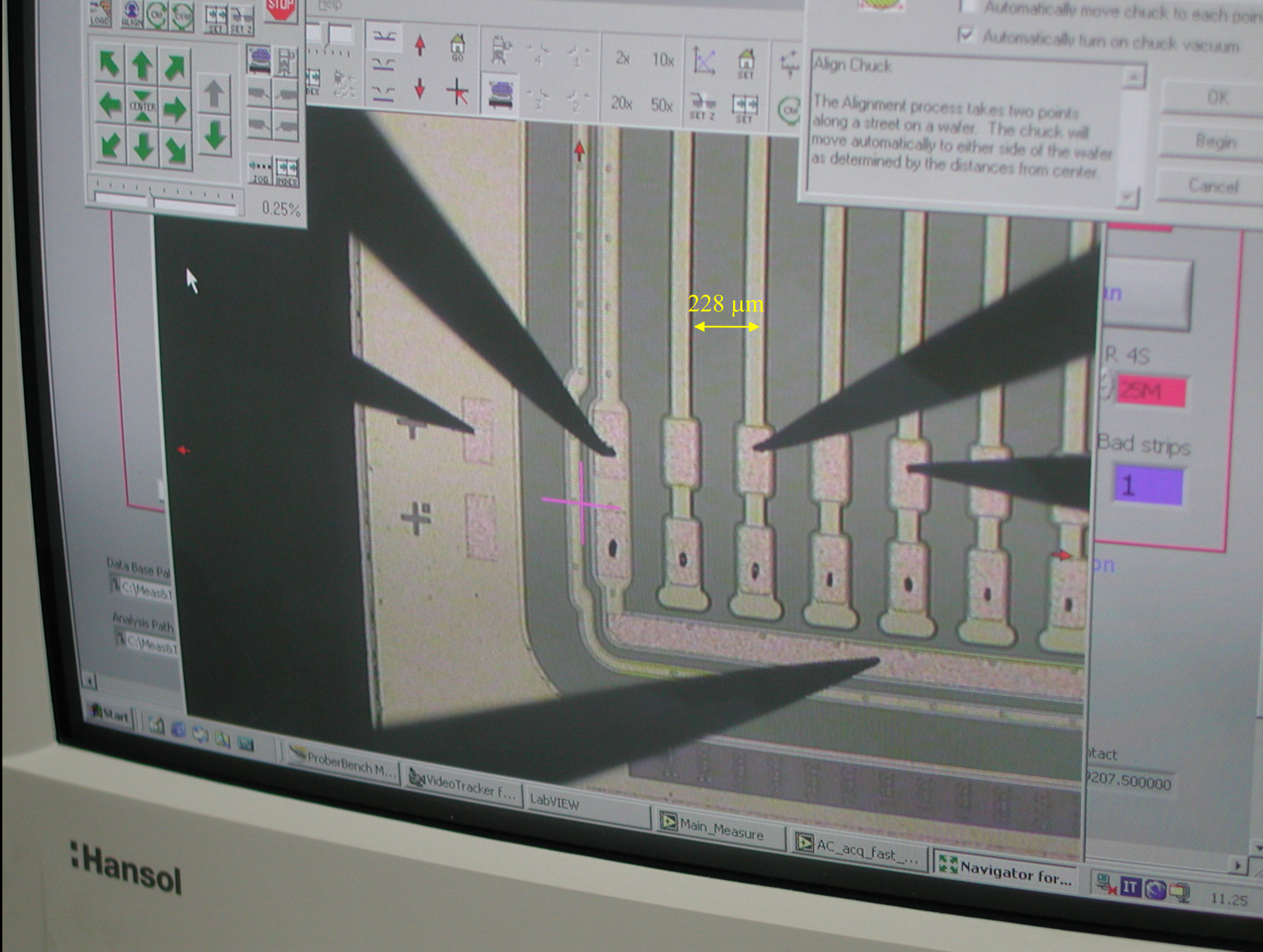


- **160 bare panels produced**
- **100 tested and qualified for integration with ladders**
- **completed trays for 3.3 towers**
- **6 assembly chain ready**
- **Max assembly rate : 3 trays/day/shift**


EMERGENCY STOP


DIGITAL
Maschine nicht an dieser Platte anheben
Do not lift up the machine at this platen




228 μm
Automatically move chuck to each point
Automatically turn on chuck vacuum
Align Chuck
The Alignment process takes two points along a street on a wafer. The chuck will move automatically to either side of the wafer as determined by the distances from center.
OK
Begin
Cancel
2x
10x
20x
50x
0.25%
STOP
CENTER
Bad strips
1
Data Base Pa
Analysis Path
Start
ProberBench M...
VideoTracker f...
LabVIEW
Main_Measure
AC_acq_fast_...
Navigator for...
11.25
Hansol

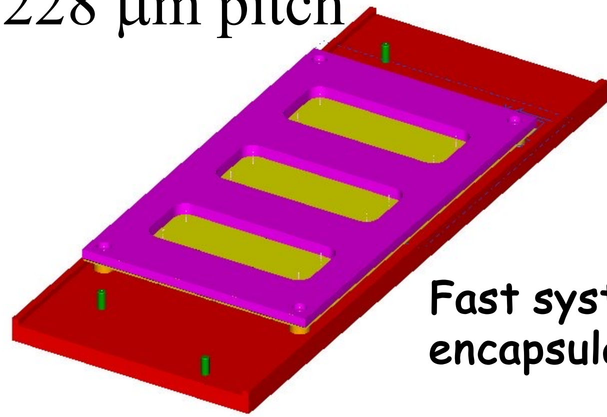
Encapsulation

Dam & Fill encapsulation

Dam Nusil 1142
Fill Nusil 15-2500

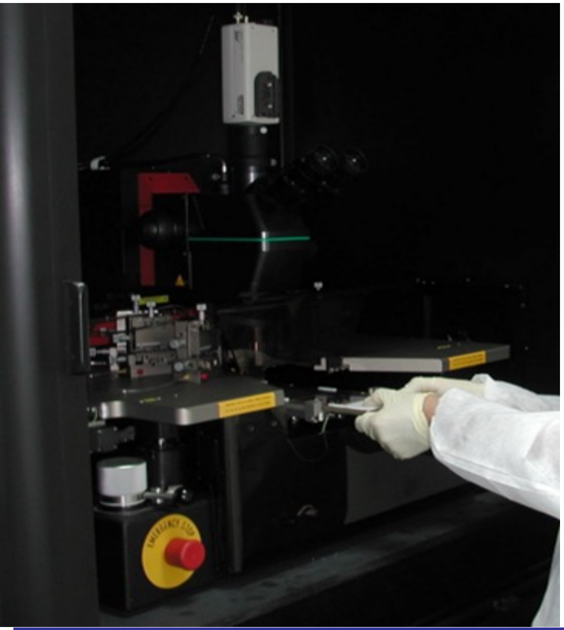
Requirements:
1. **Height <0.5mm**
2. **Lateral overflow <0.05mm**
3. **Coverage of all the bondings and pads**

228 μm pitch

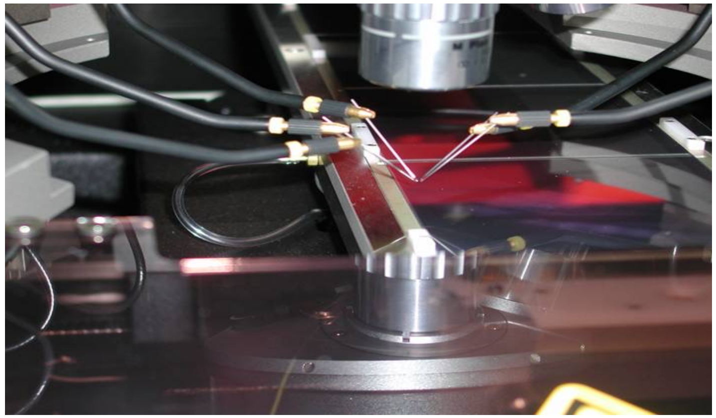


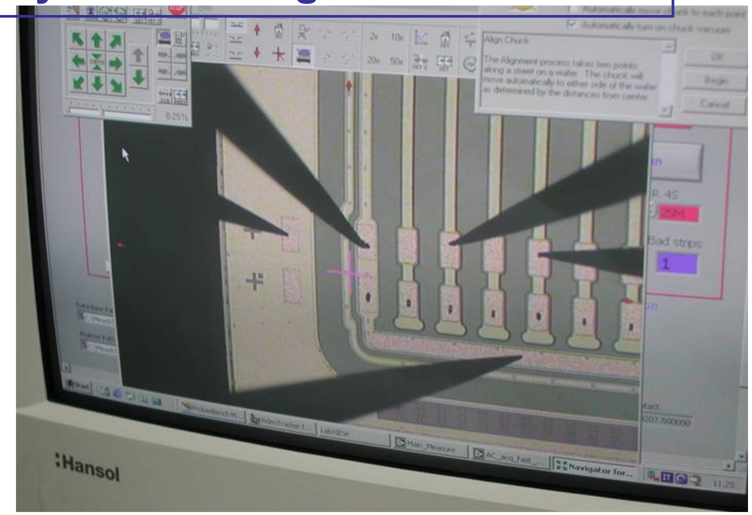
Fast system to check encapsulation height

Ladders testing



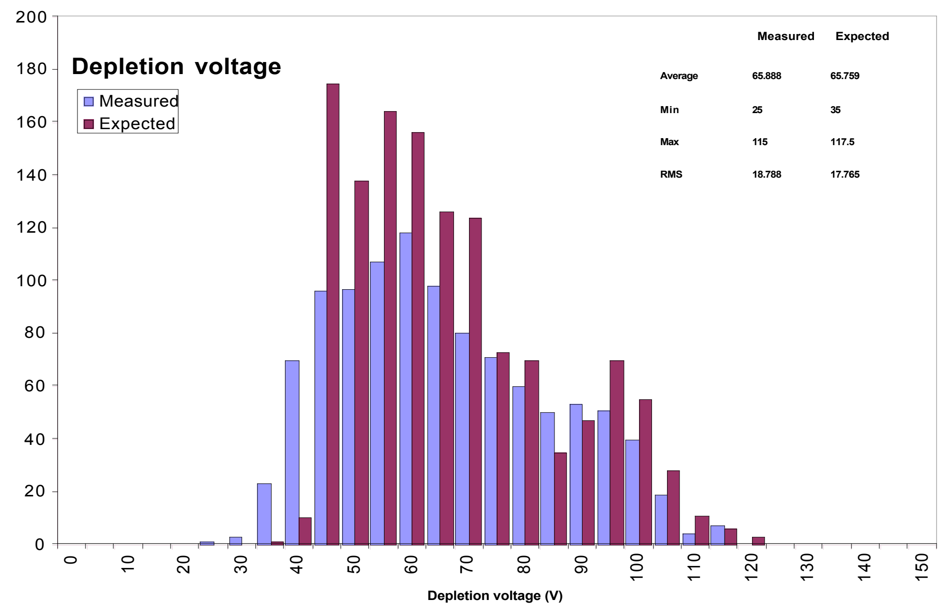
Ladders probe station: 5 probes are used to measure body and single strip I, C to check sanity of each single channel



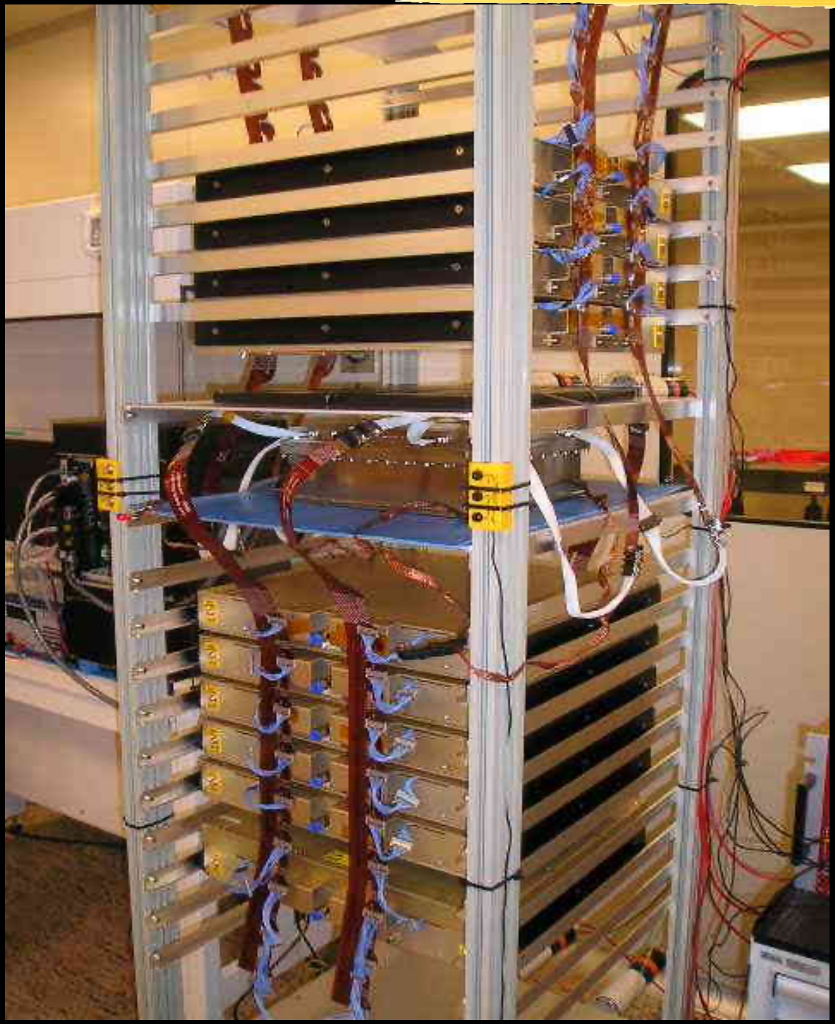


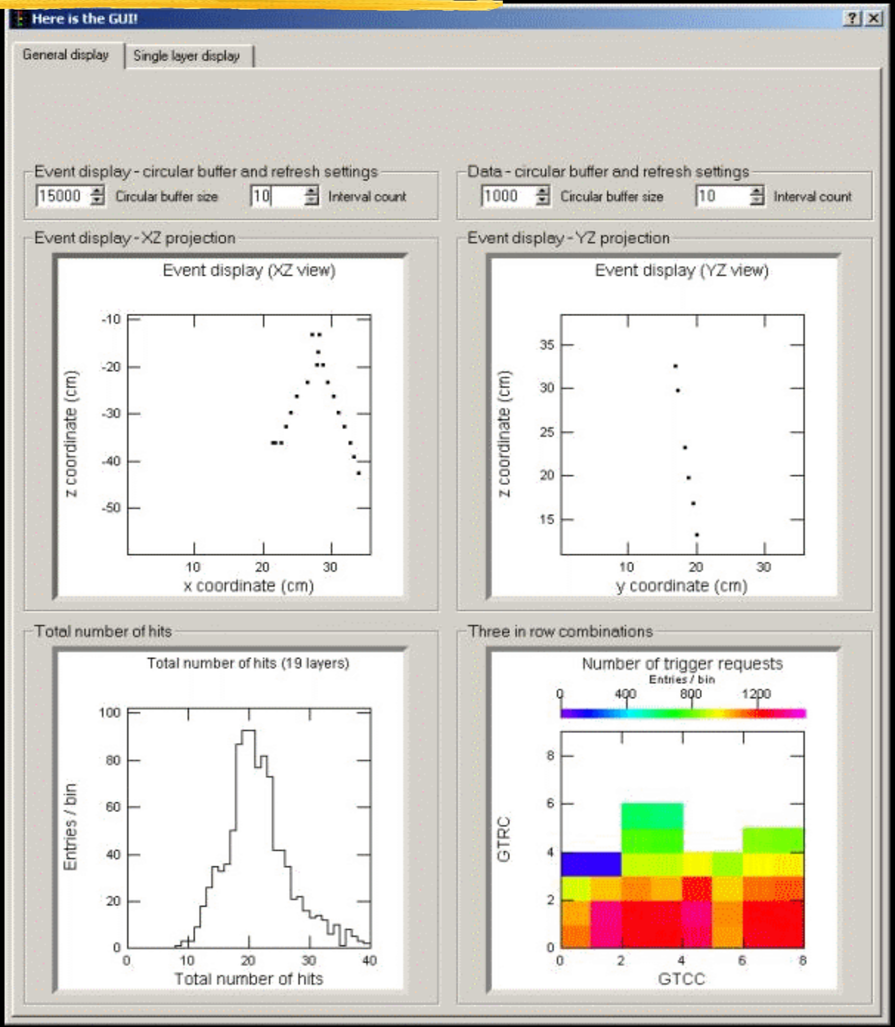
Flight ladders production status:

- Completed and tested (INFN BA/RM2/PG) 1900
- Under construction 800
- rejected ~ 1%
- 0.016% bad chans caused by bonding or probing
- 2μm RMS alignment spread
- All results in good agreement with what expected from SSDs



Tray test at INFN



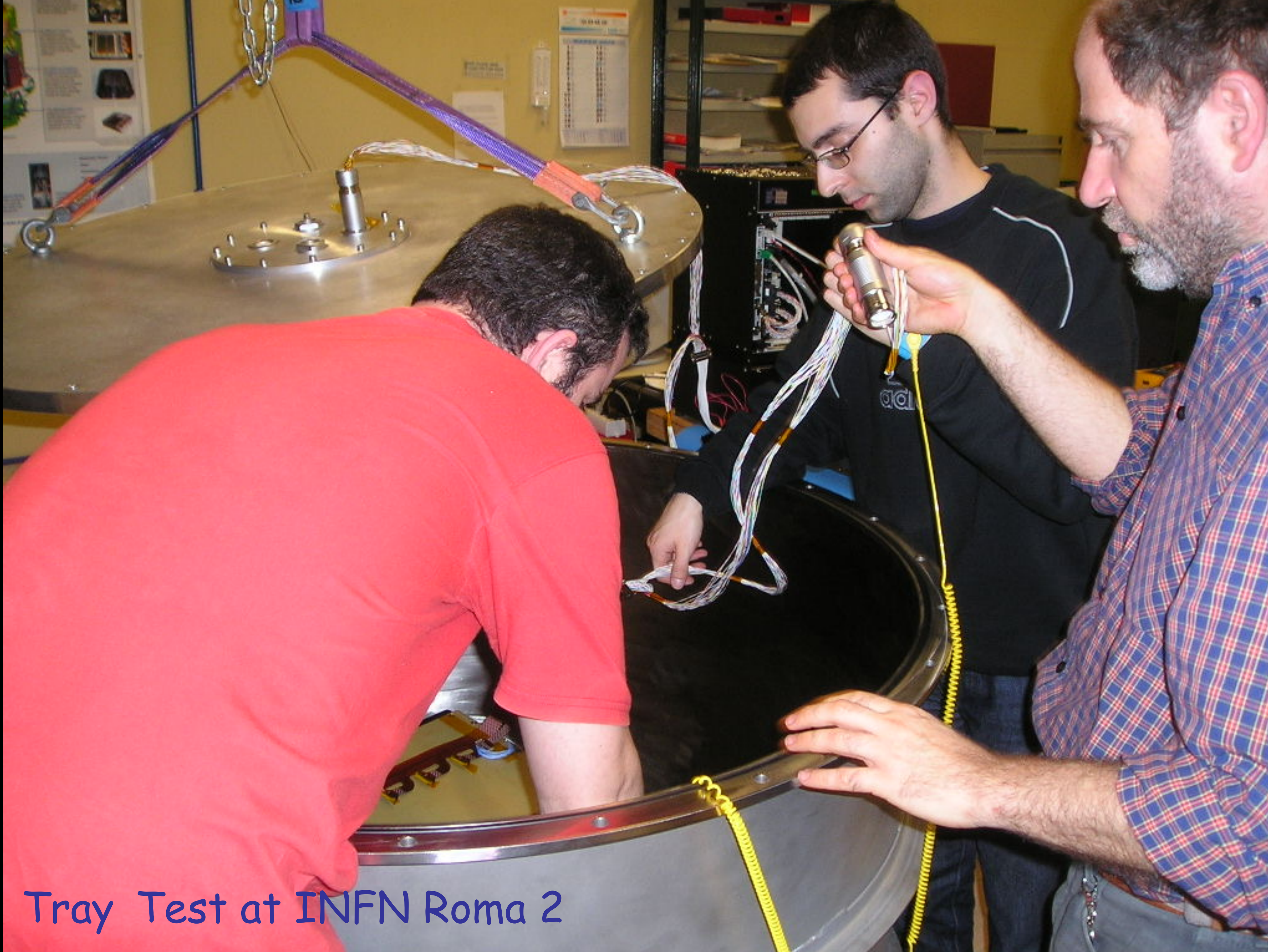


Stack of trays:

- functional tests/CR burn-in for a whole tower in parallel
- external trigger capability
- 4 stacks operating in parallel at INFN (Pi/Pg/Rm2/Ba)

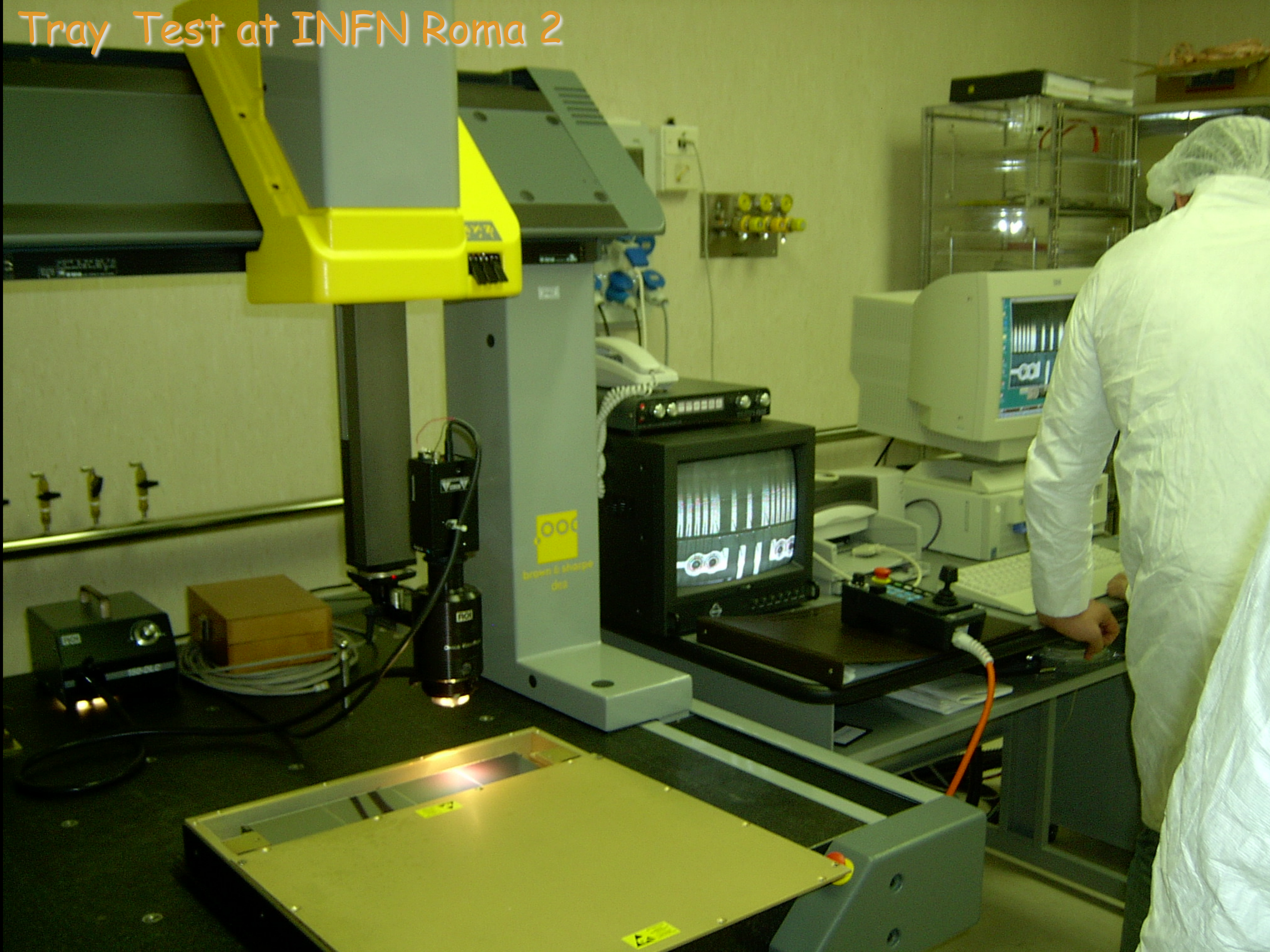

PaMeLa
Tray Test at INFN Roma 2

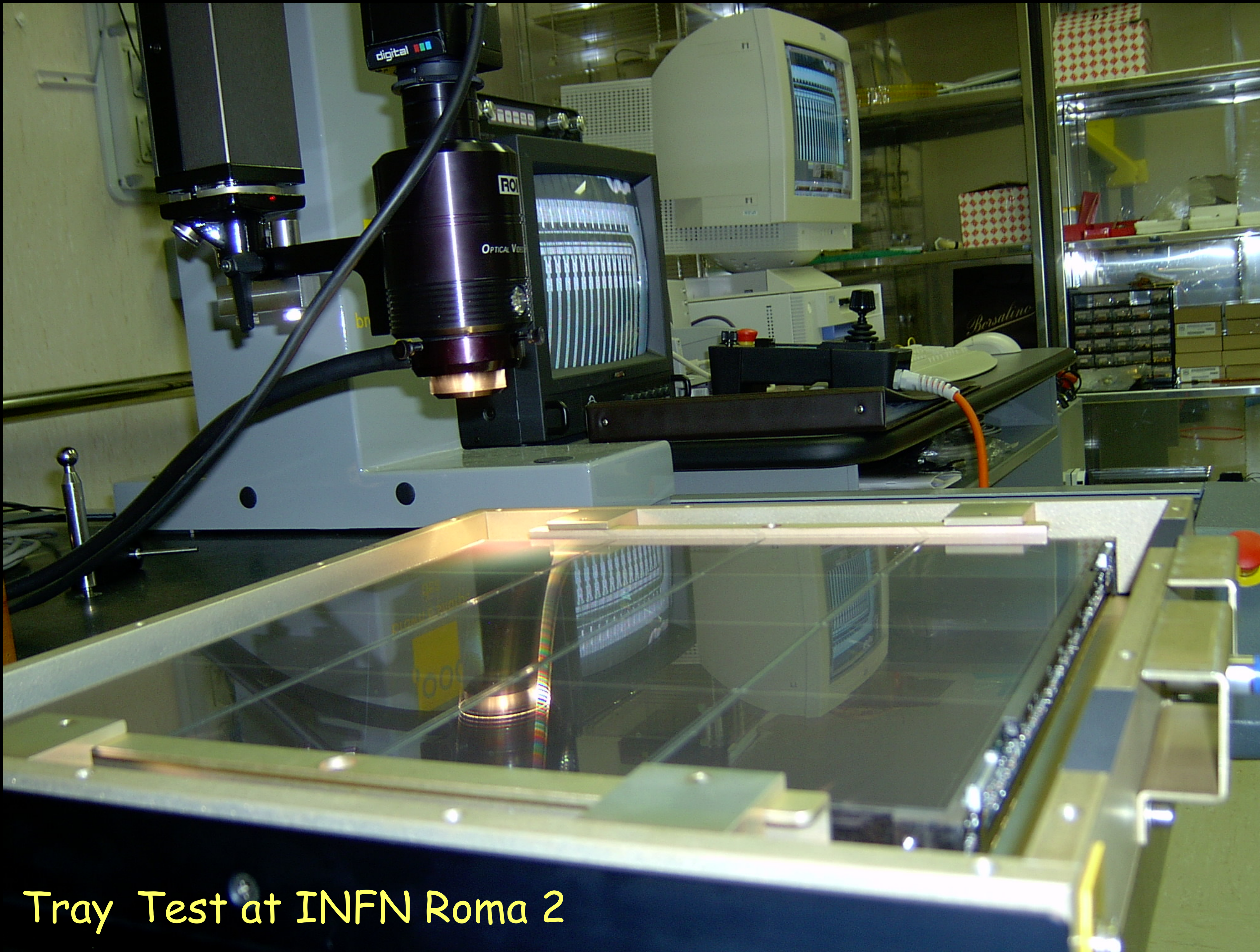

LAMINAR FLOW
ASALAIR 1200
LAMINAR FLOW
1200FLV
PROIBITO
FUMARE
VIETATO
L'ACCESSO
a chi non è
autorizzato


Tray Test at INFN Roma 2

Tray Test at
INFN Roma 2

Tray Test at INFN Roma 2



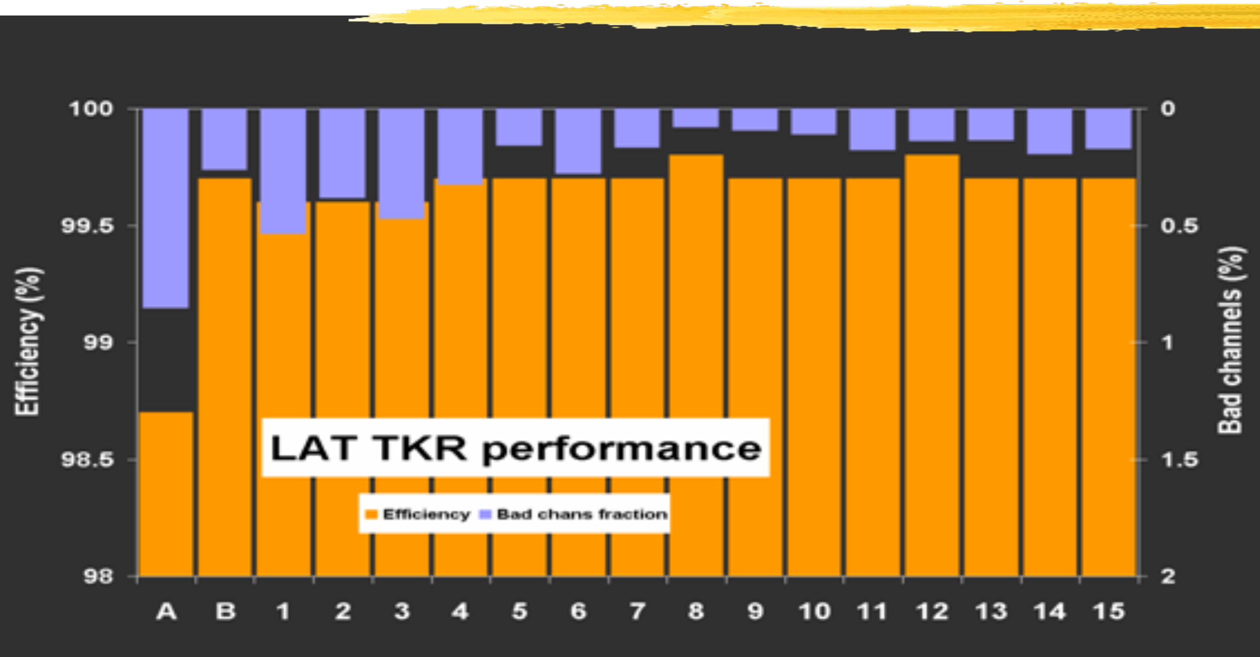


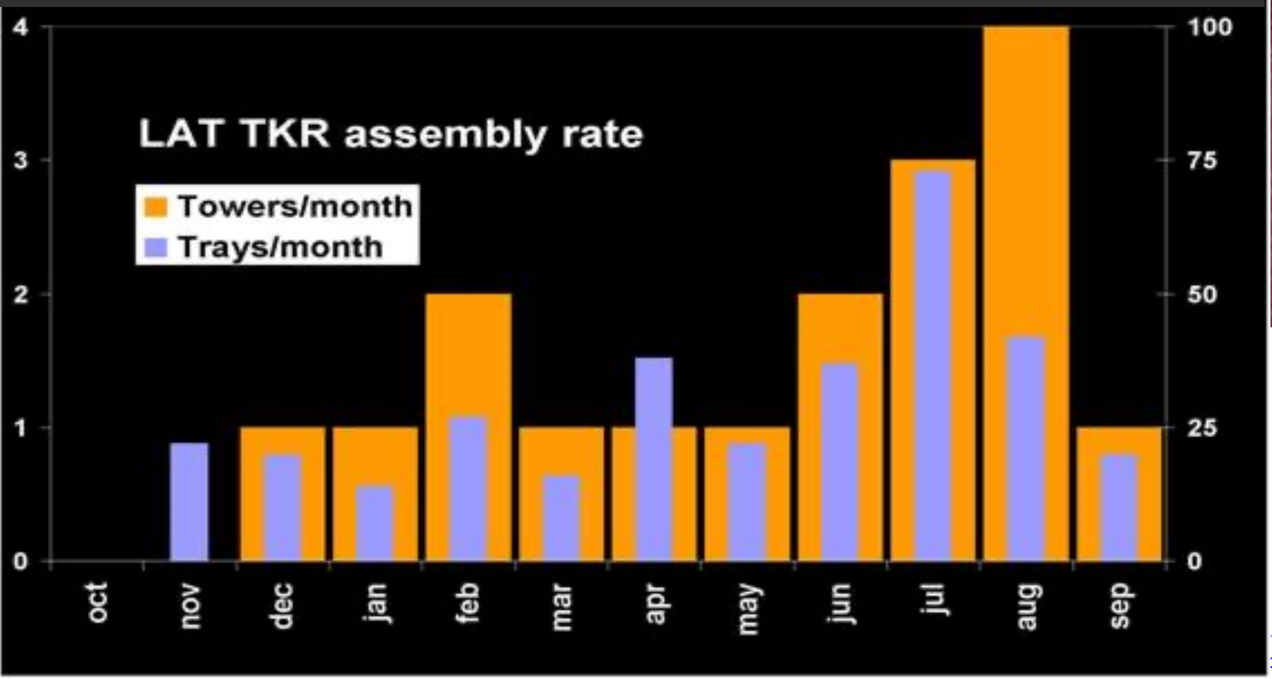
Tray Test at INFN Roma 2

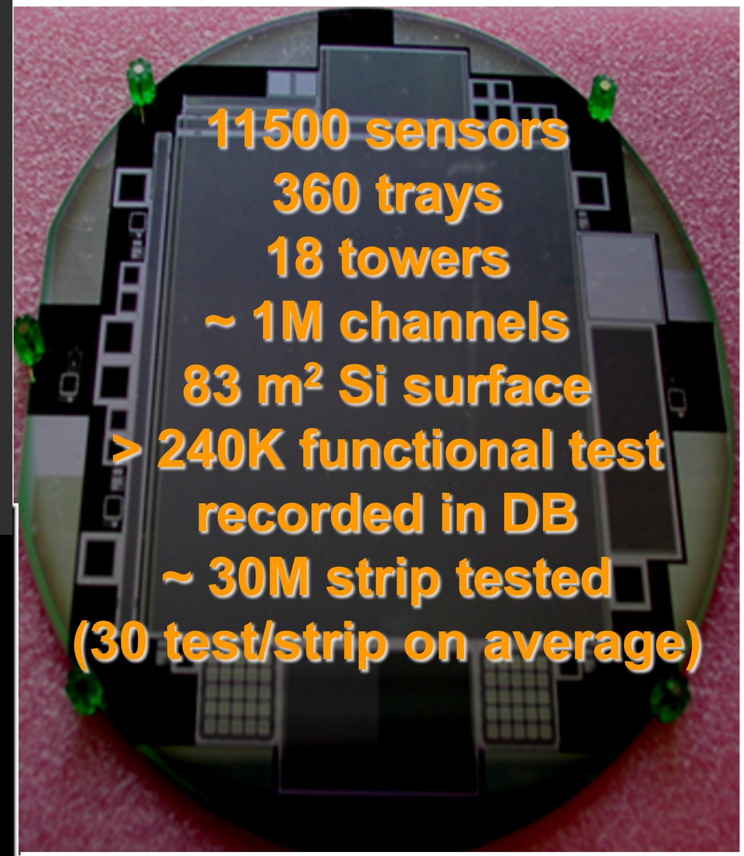
40 CHANNEL
VOLTAGE SYSTEM
Mod. SY 127


INFN

The LAT Tracker numbers



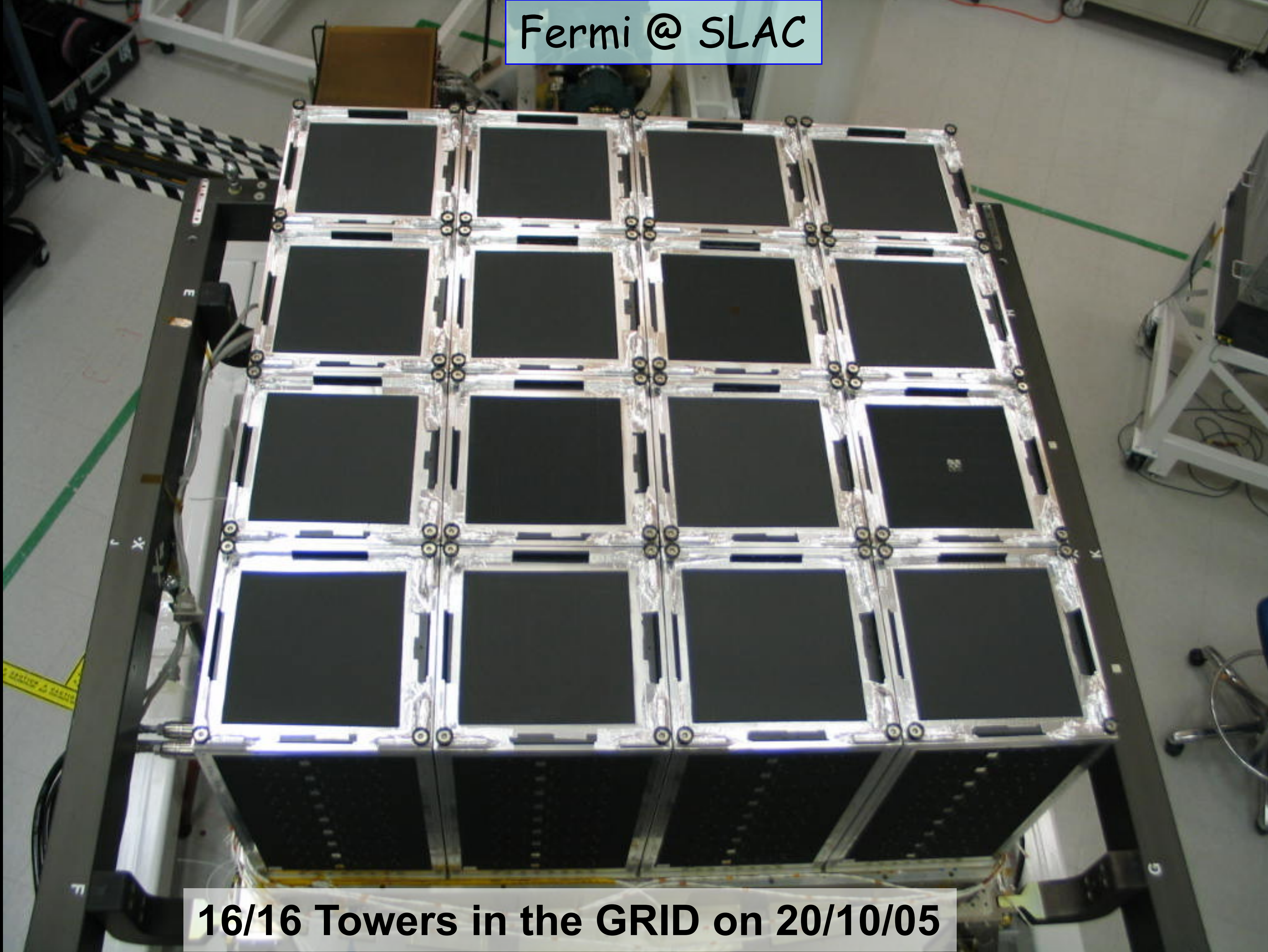




GLAST @ SLAC

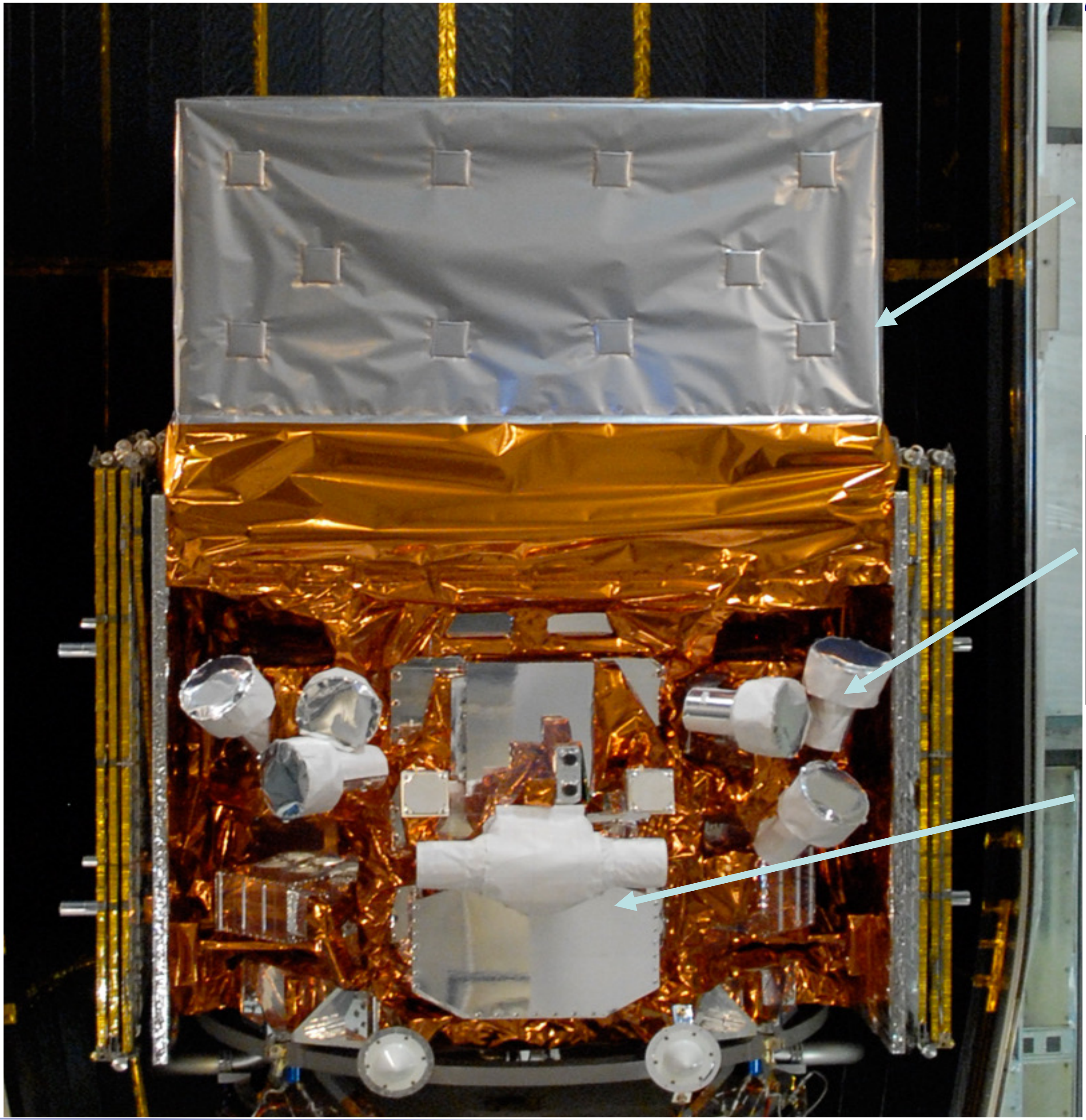
12/16 Towers in the GRID on 7/10/05

Fermi @ SLAC



16/16 Towers in the GRID on 20/10/05

The Fermi Observatory



LAT
Large
Area
Telescope
20 MeV-300 GeV

GBM
Sodium Iodide
Detector
8 KeV- 1 MeV
> 8 sr

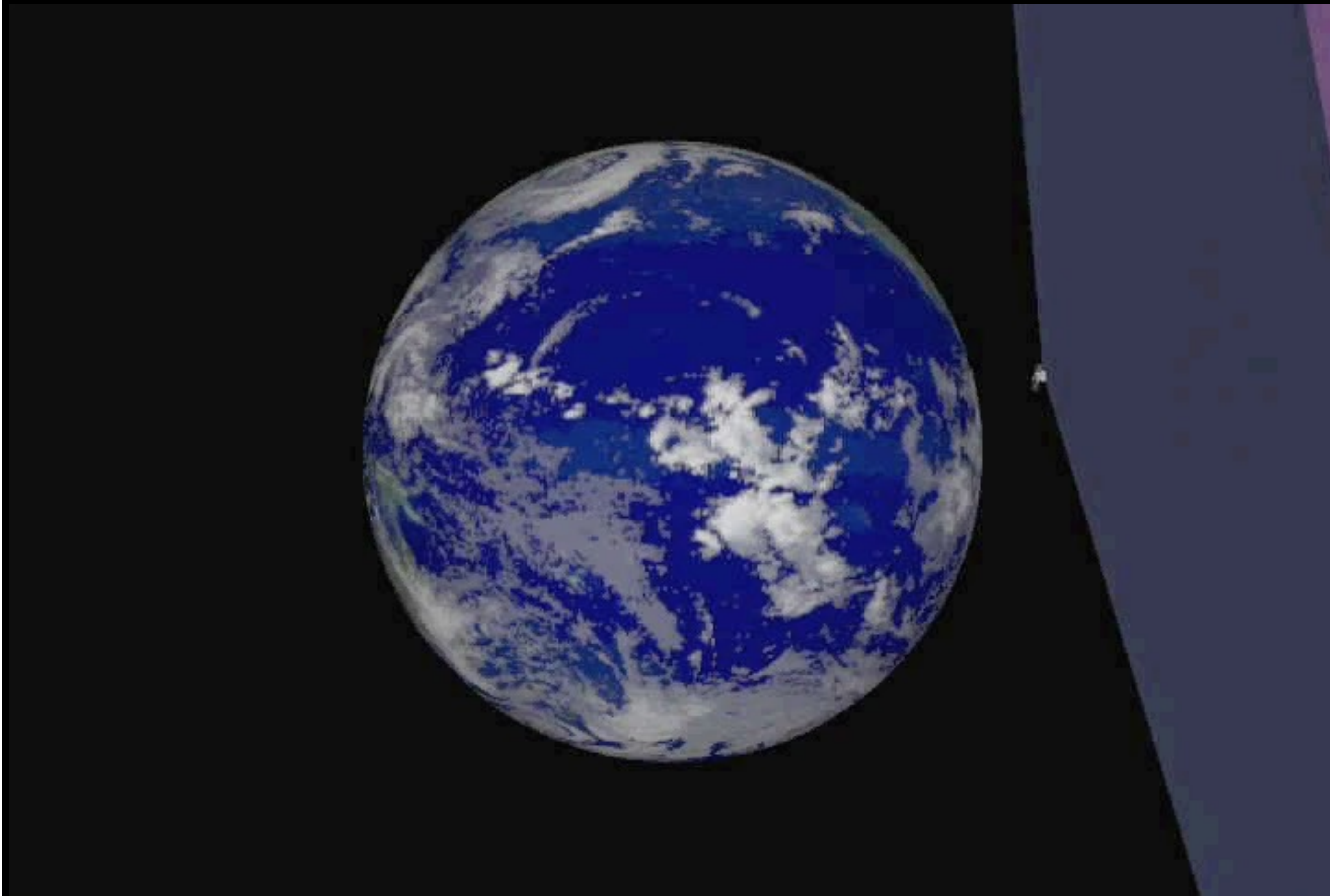
GBM
Bismuth
Germanate
Detector
200 KeV- 40 MeV

Fermi Prior to Fairing Installation

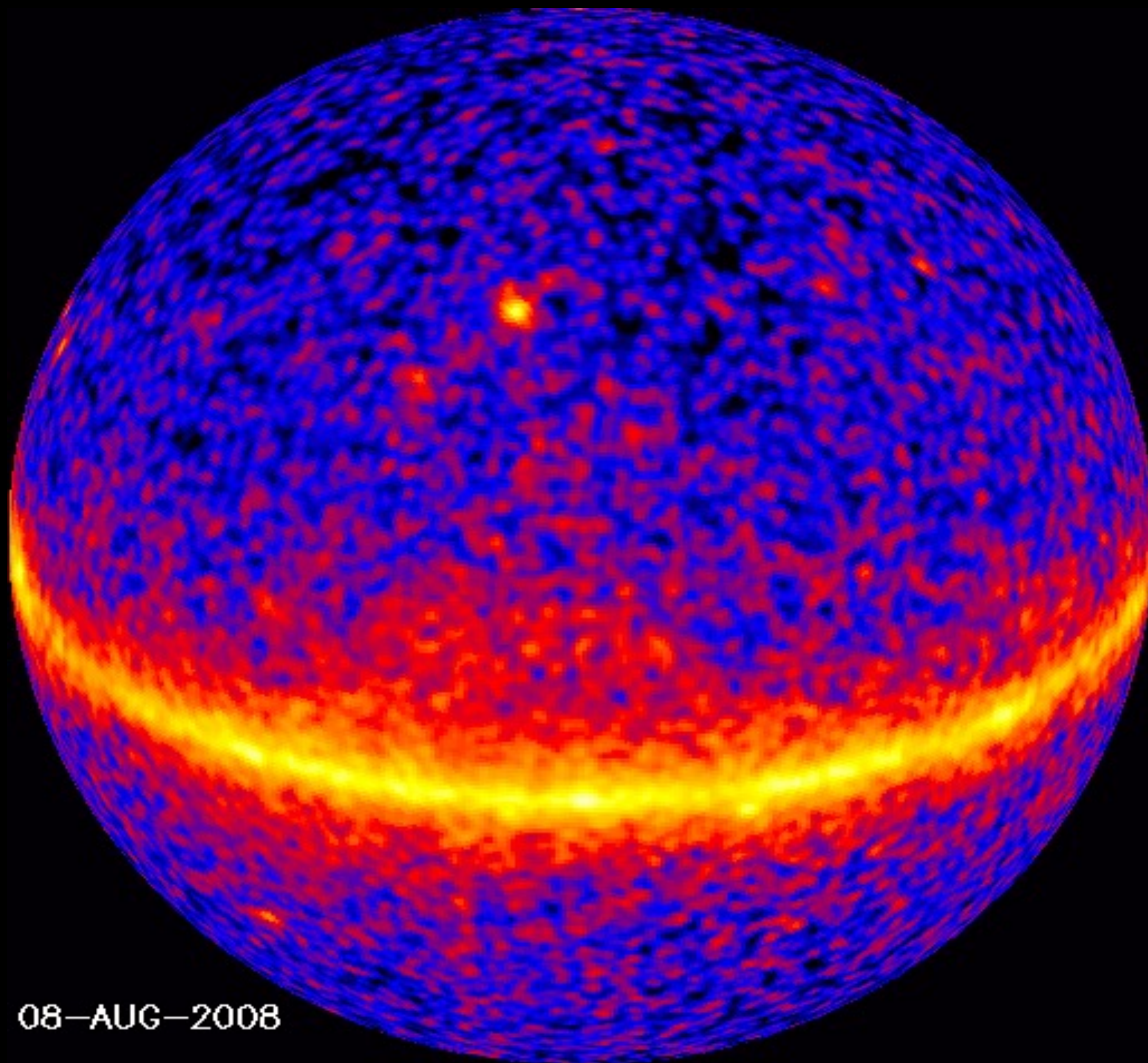

11 June 2008

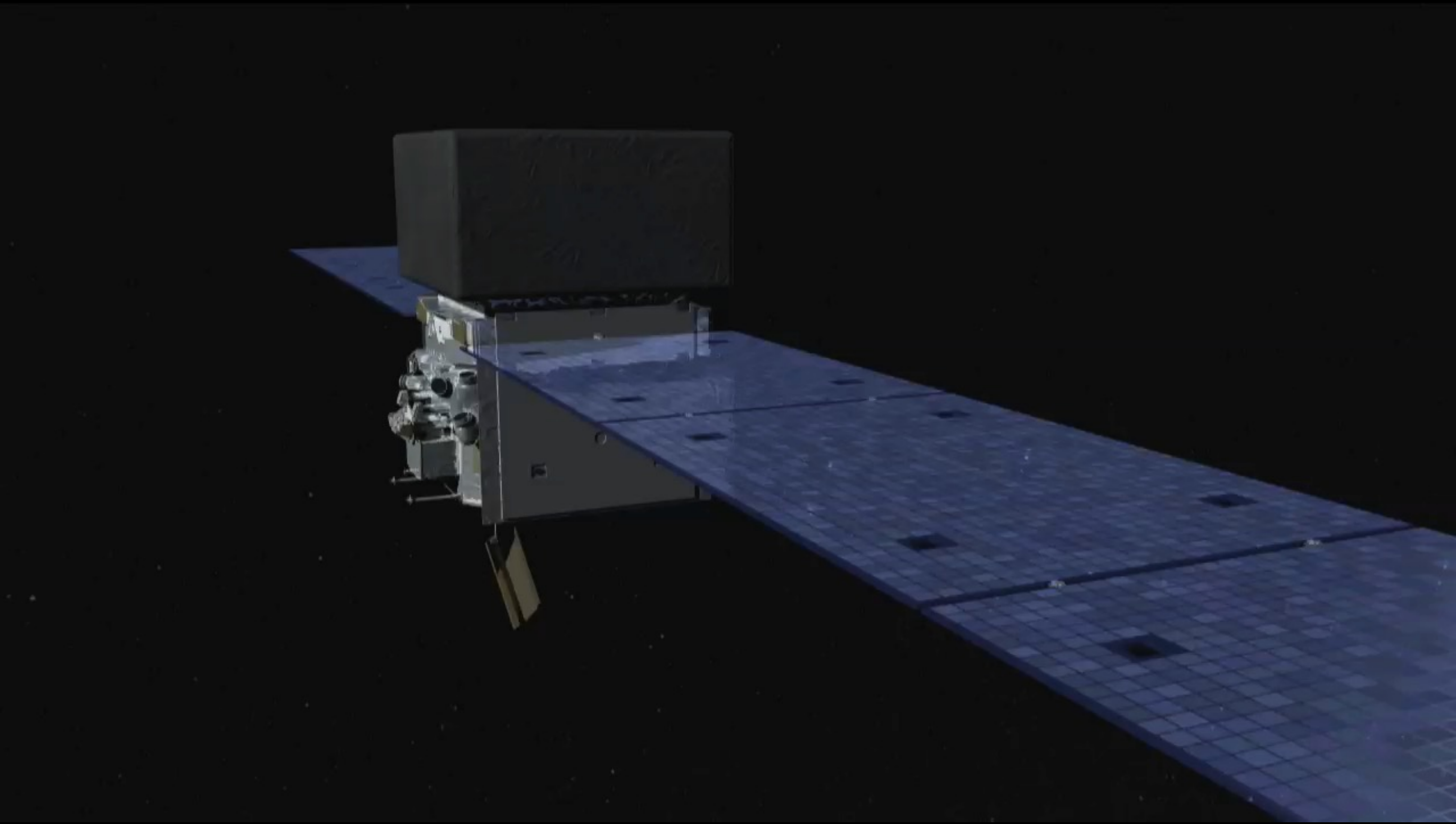

Fermi
Gamma-ray Space Telescope
Happy 16th Birthday Fermi !!
11 June 2008

Pisa 15 March 2018

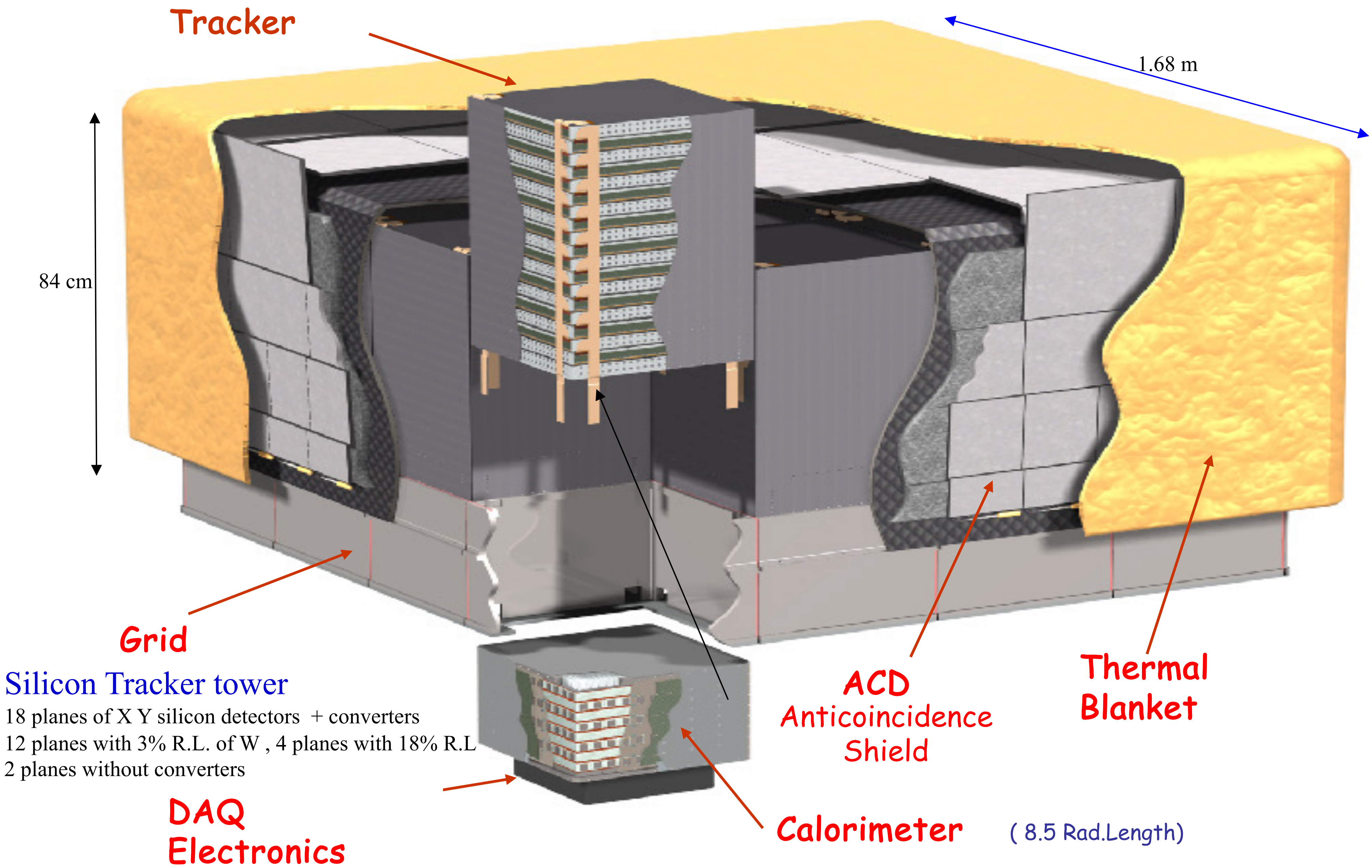


Daily Gamma-ray Sky

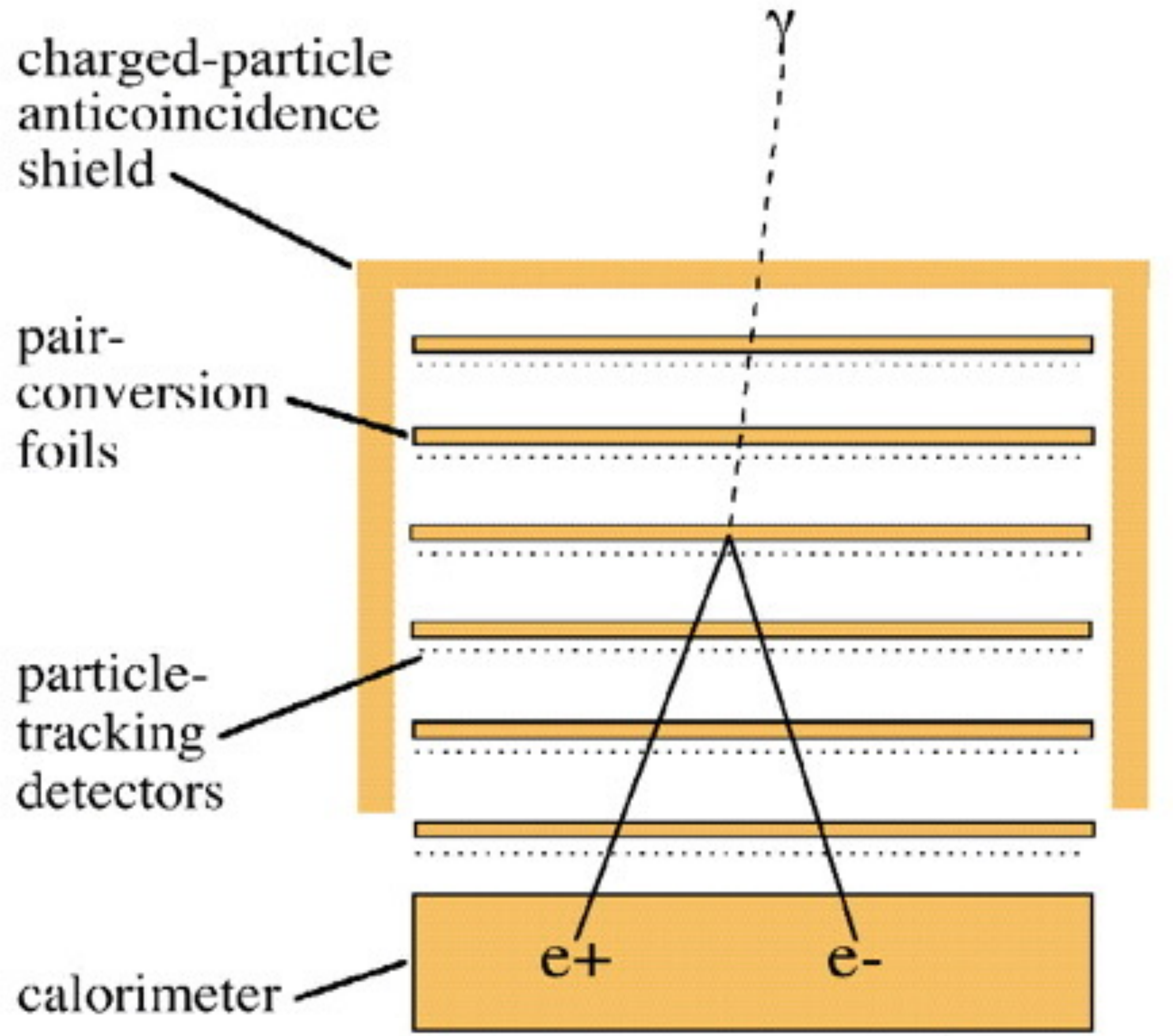




Fermi Gamma-Ray Large Area Space Telescope



Elements of a pair-conversion telescope



(energy measurement)

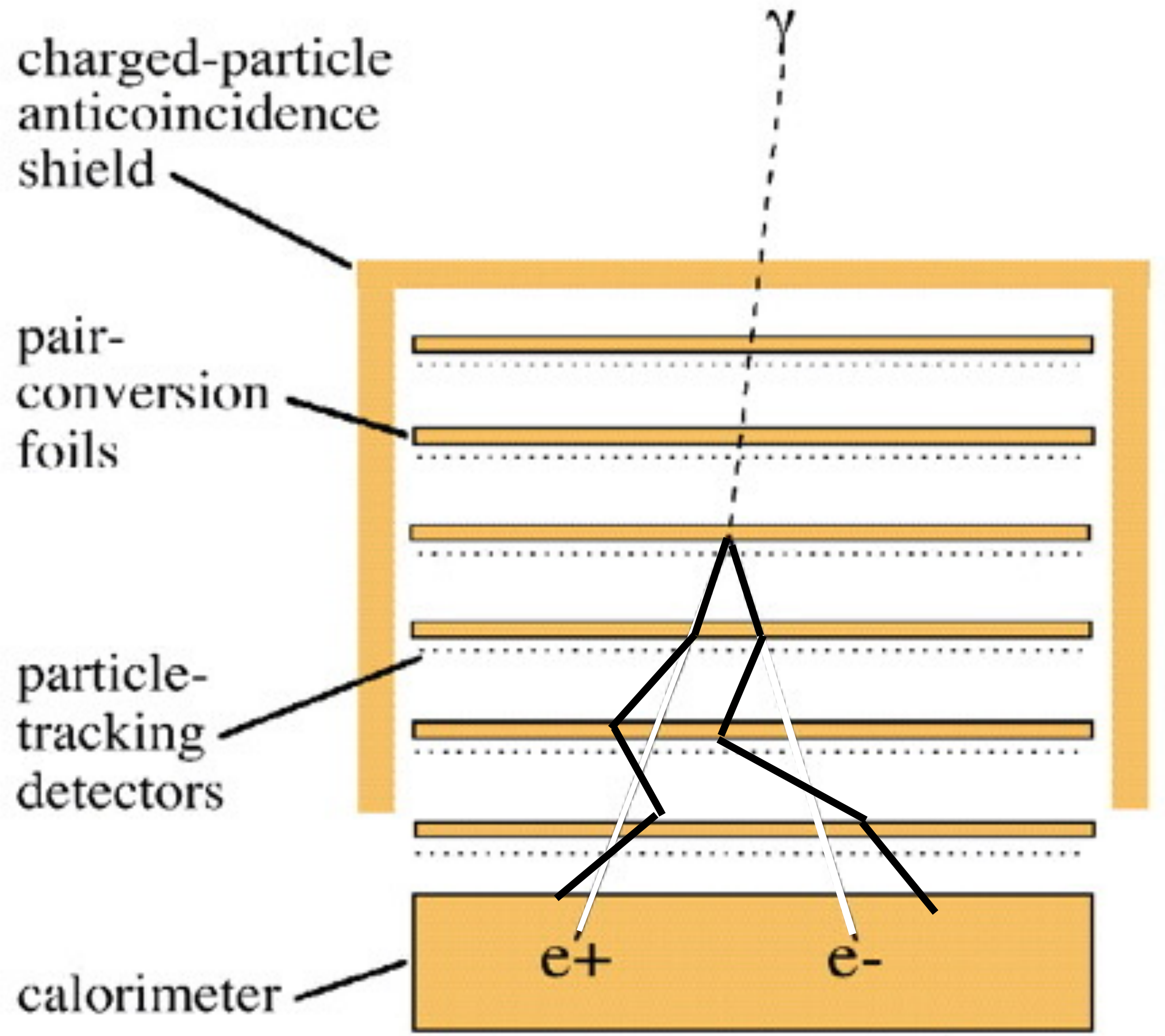
- photons materialize into matter-antimatter pairs:

  $E_\gamma \;\text{-->}\; m_{e^+}c^2 + m_{e^-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

Elements of a pair-conversion telescope

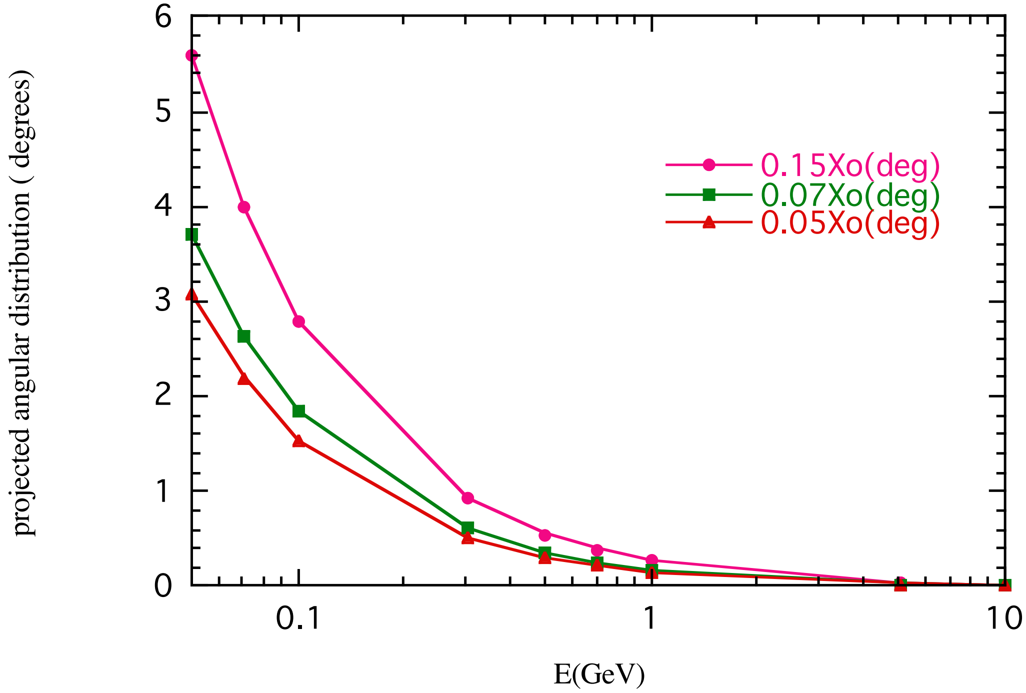
(more realistic scheme)

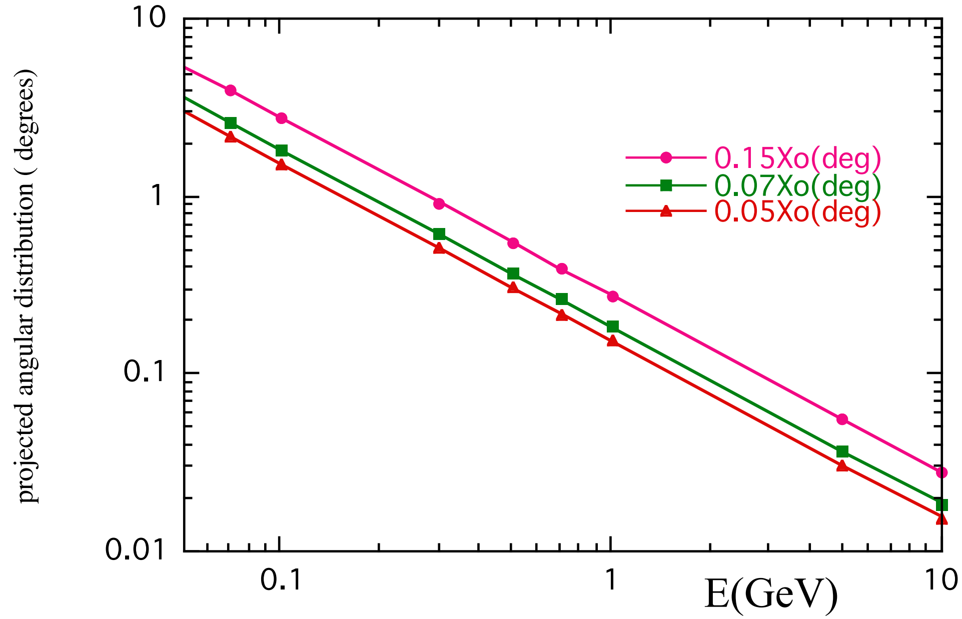


(energy measurement)

- photons materialize into matter-antimatter pairs:
  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering

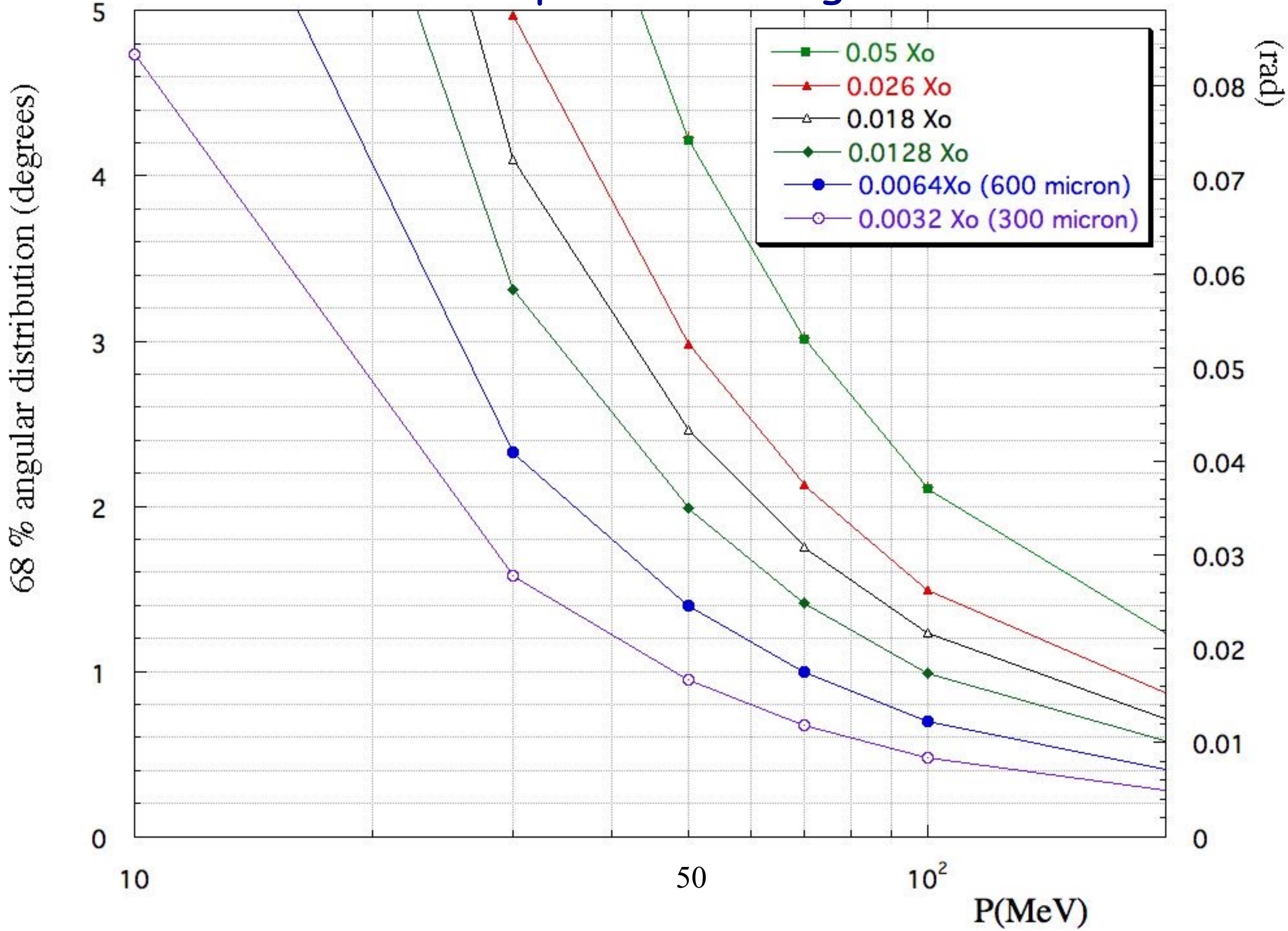




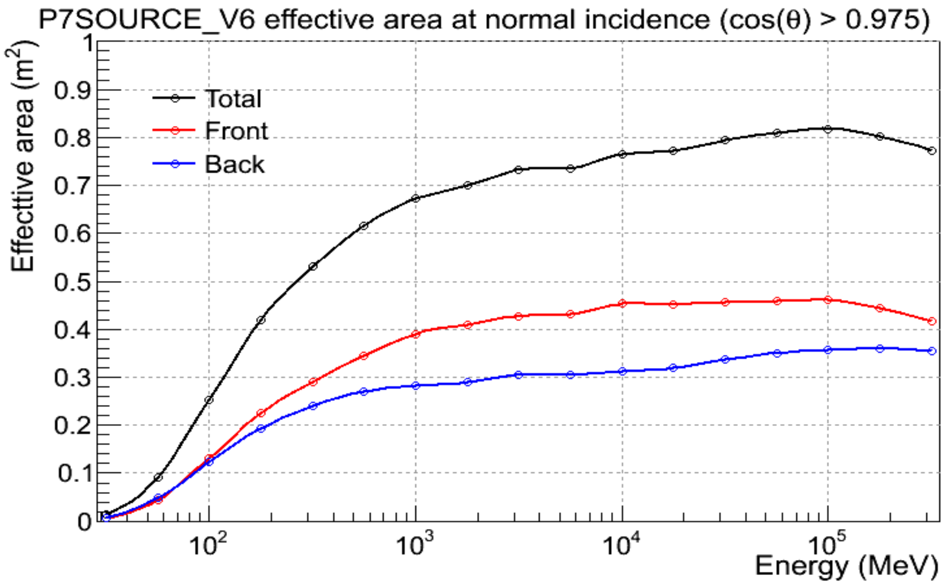
$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

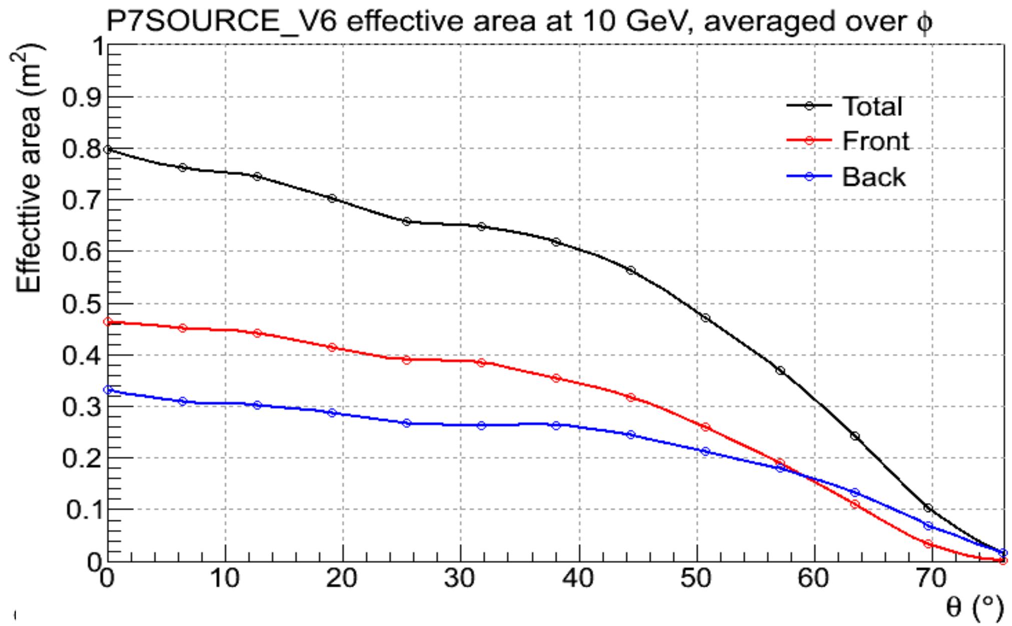
$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\,[1 + 0.038\ln(x/X_0)]$$

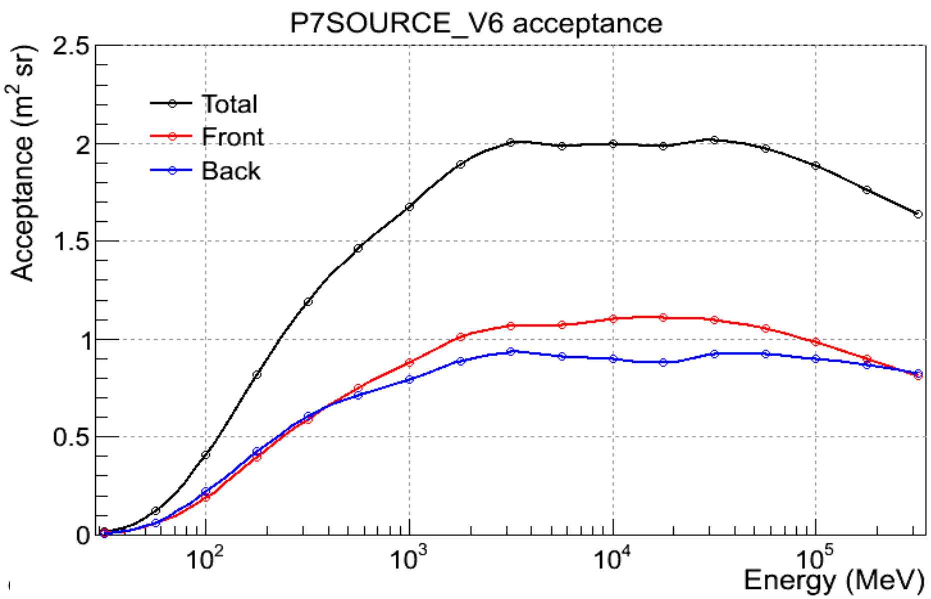
Multiple Scattering

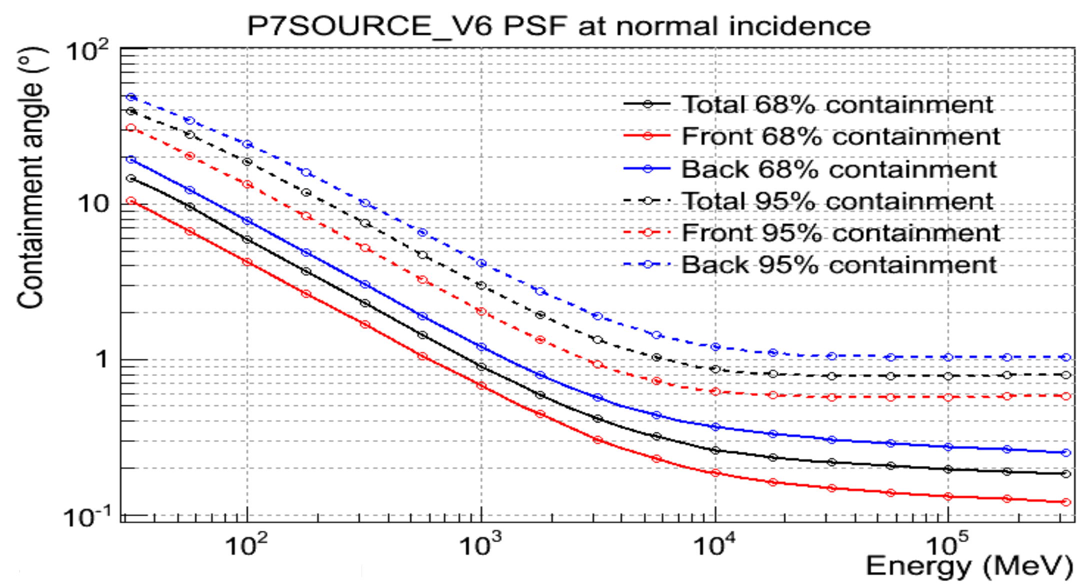


Fermi Instrument Response Function





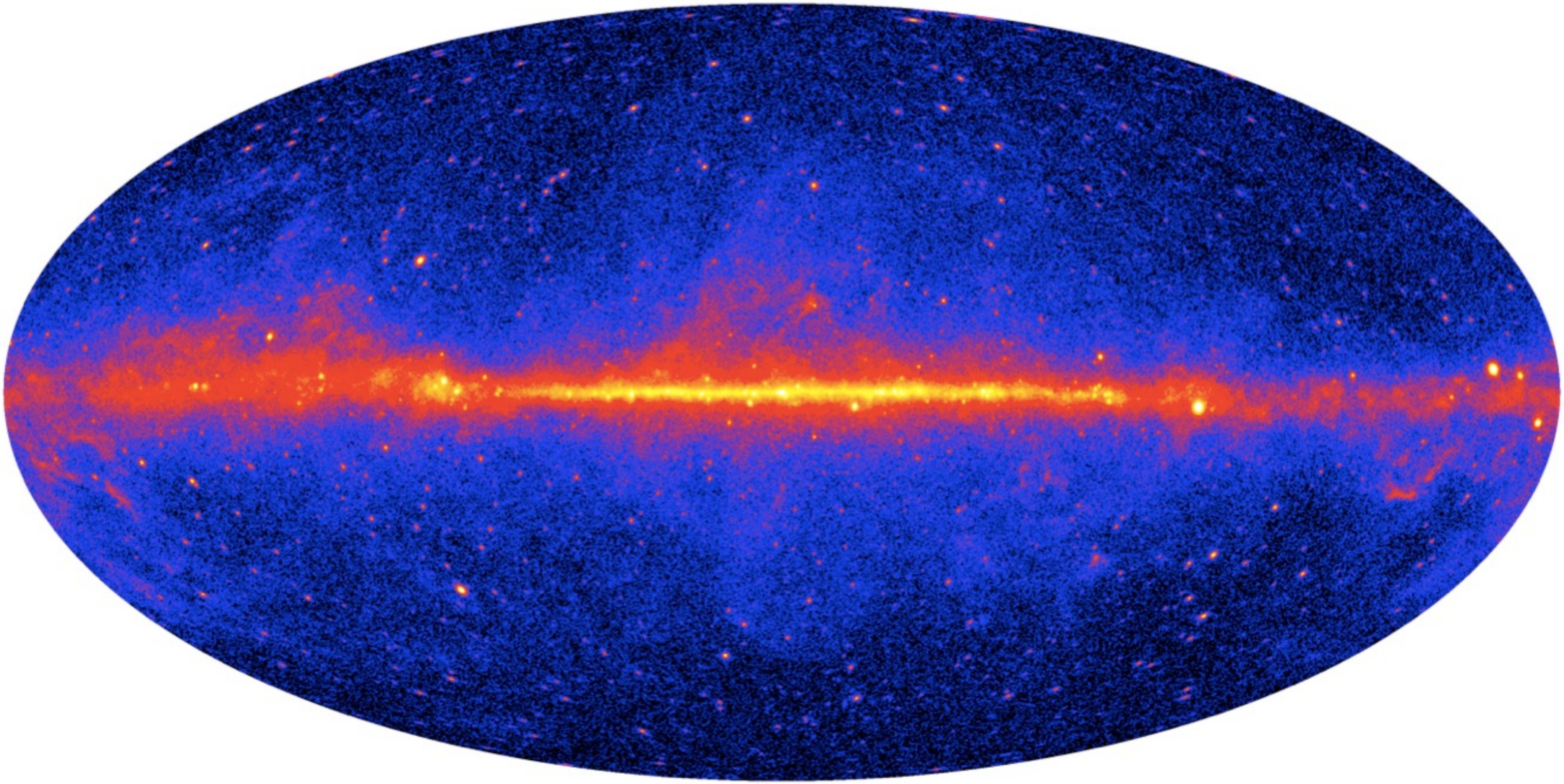




http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

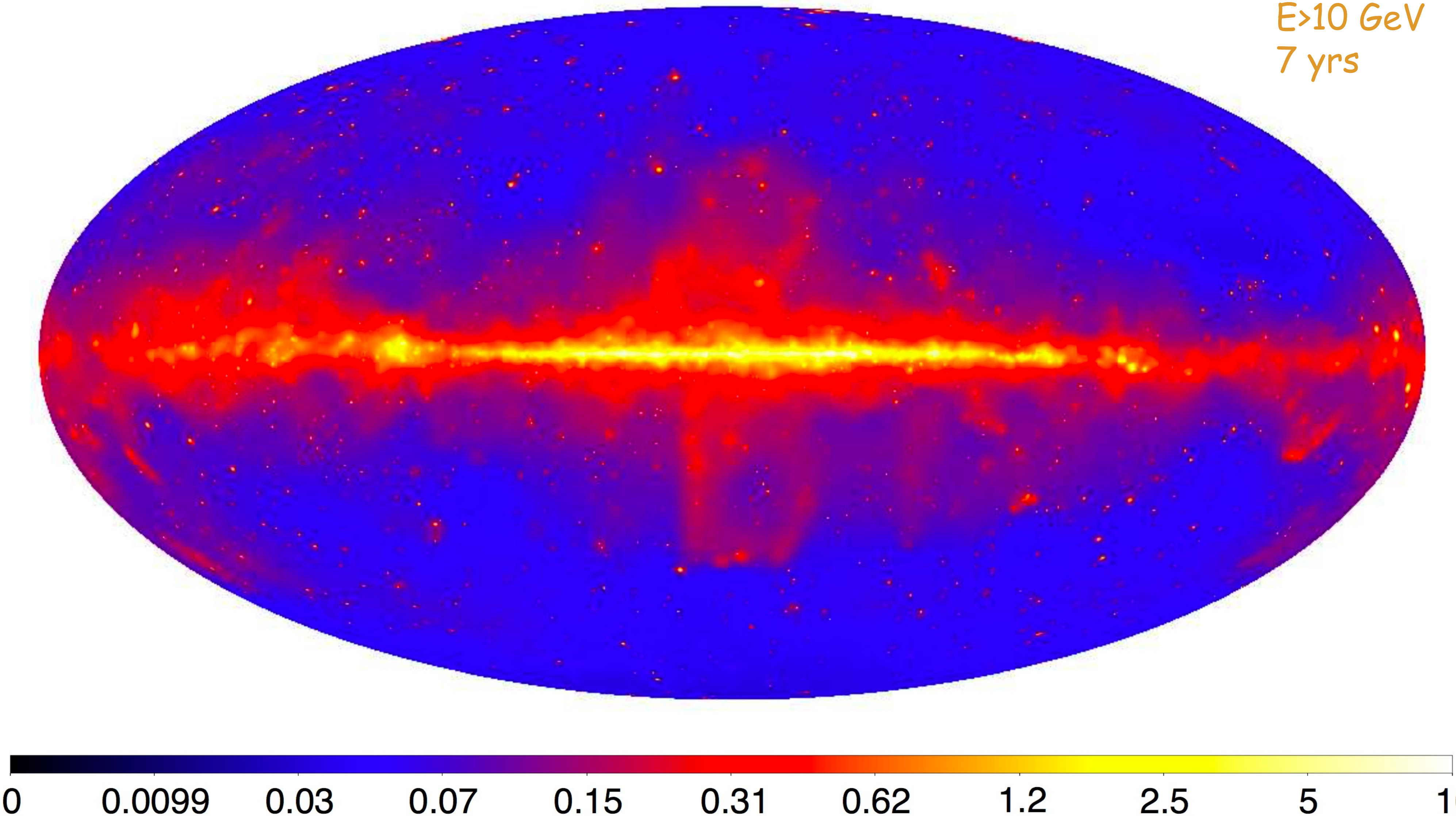
The Fermi LAT gamma-ray sky

3-year all-sky map, E > 1 GeV



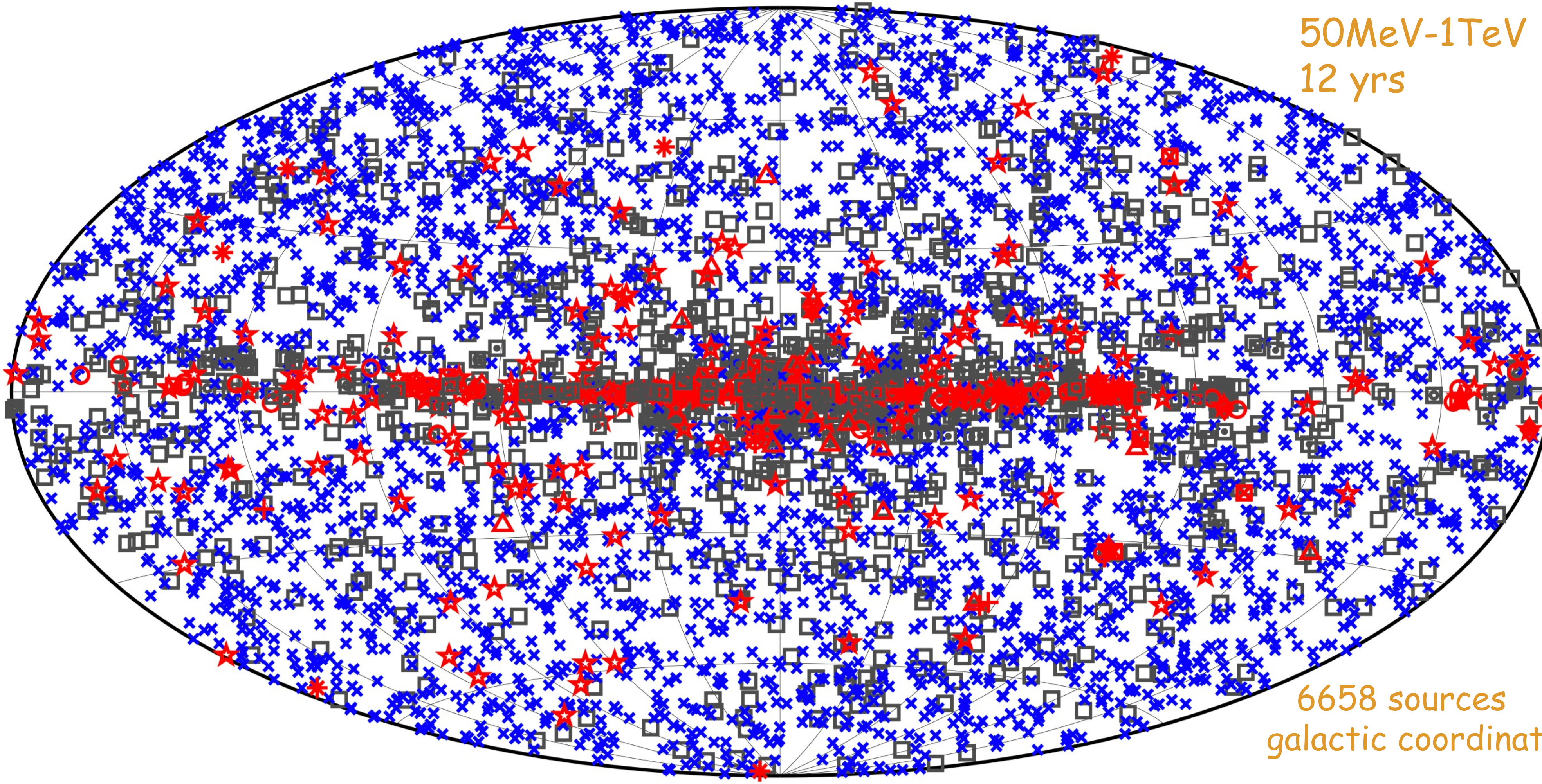
The sky in gamma-rays

E>10 GeV
7 yrs



M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources arXiv:1702.00664

The sky in gamma-rays 4th source catalog

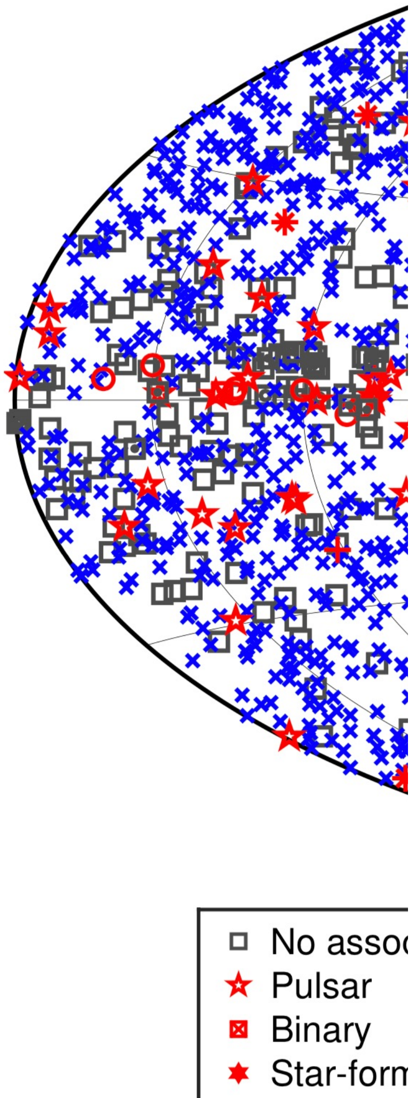


No association	Possible association with SNR or PWN		AGN
Pulsar	Globular cluster	Starburst Galaxy	PWN
Binary	Galaxy	SNR	Nova
Star-forming region	Unclassified source		

Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

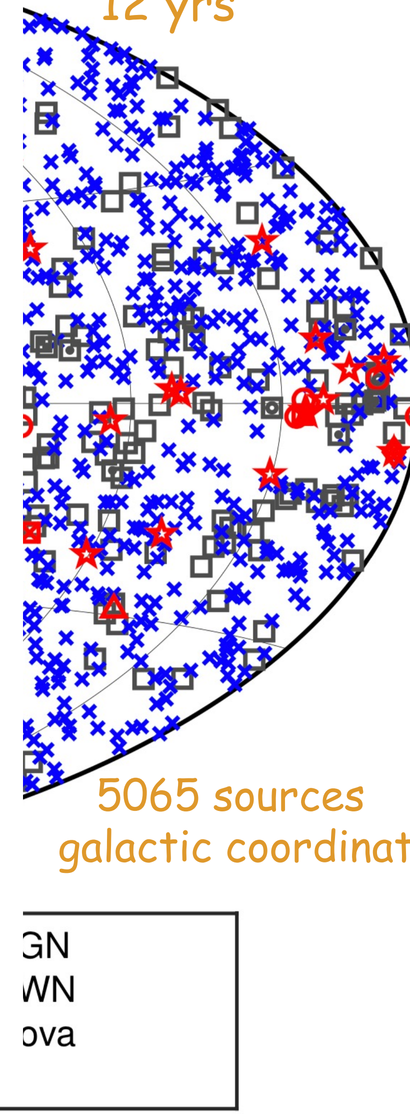
The sky in gamma-rays 4th source catalog

50MeV-1TeV
12 yrs



Description	Identified		Associated	
	Designator	Number	Designator	Number
Galactic center	GC	1	...	...
Young pulsars, identified by pulsations	PSR	135	...	...
Young pulsars, no pulsations seen in LAT yet	...	...	psr	2
Millisecond pulsars, identified by pulsations	MSP	120	...	...
Millisecond pulsars, no pulsations seen in LAT yet	...	...	msp	35
Pulsar wind nebula	PWN	11	pwn	8
Supernova remnant	SNR	24	snr	19
Supernova remnant / Pulsar wind nebula	SPP	0	spp	114
Globular cluster	GLC	0	glc	35
Star-forming region	SFR	3	sfr	2
High-mass binary	HMB	8	hmb	3
Low-mass binary	LMB	2	lmb	6
Binary	BIN	1	bin	6
Nova	NOV	4	nov	0
BL Lac type of blazar	BLL	22	bll	1435
FSRQ type of blazar	FSRQ	44	fsrq	750
Radio galaxy	RDG	6	rdg	39
Nonblazar active galaxy	AGN	1	agn	8
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact steep spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	1	bcu	1491
Narrow-line Seyfert 1	NLSY1	4	nlsy1	4
Seyfert galaxy	SEY	0	sey	2
Starburst galaxy	SBG	0	sbg	8
Normal galaxy (or part)	GAL	2	gal	4
Unknown	UNK	0	unk	134
Total	...	389	...	4112
Unassociated	...	...	...	2157

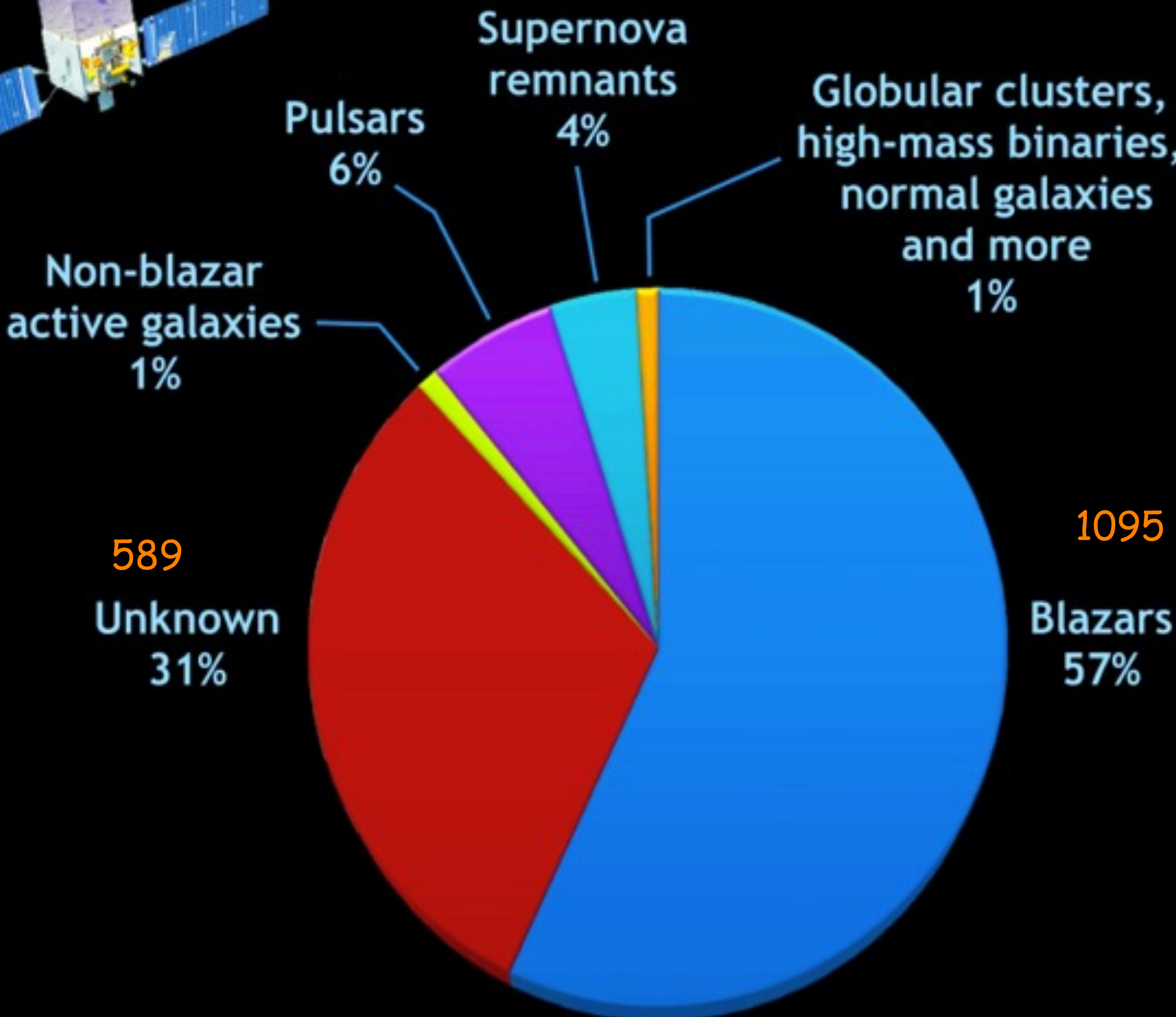
NOTE—The designation 'spp' indicates potential association with SNR or PWN. 'Unknown' are $|b| < 10^\circ$ sources solely associated with the likelihood-ratio method from large radio and X-ray surveys. Designations shown in capital letters are firm identifications; lower-case letters indicate associations.



5065 sources
galactic coordinates

Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

What has Fermi found: The LAT two-year catalog



Gamma Astronomy has revealed a a *very rich, fascinating landscape*

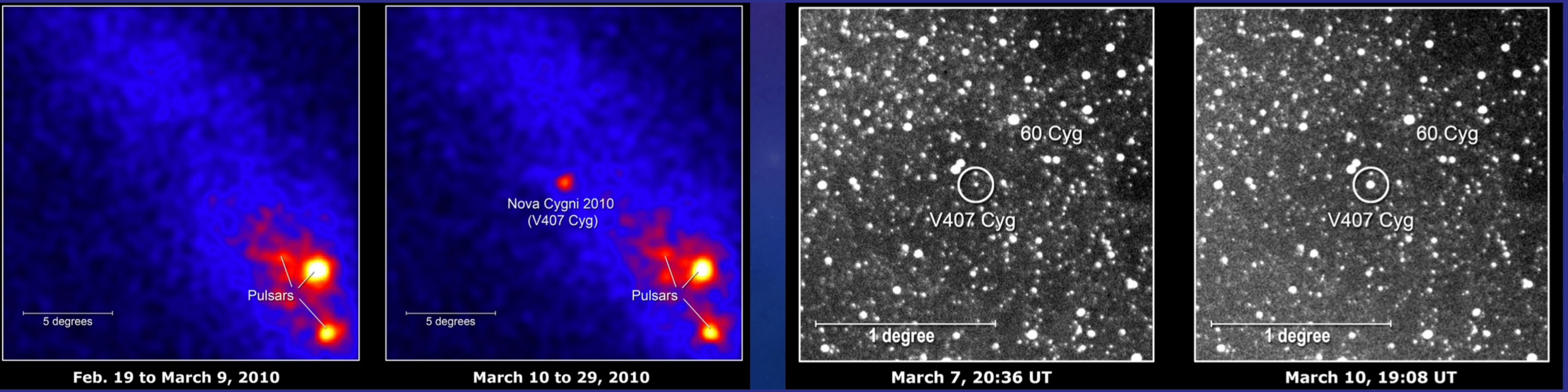
- Many sources have been identified [GeV , TeV ranges]

- Several classes of objects
[SNR, Pulsars, PWN, AGN, GRB, ...]

- Probably different acceleration mechanisms.

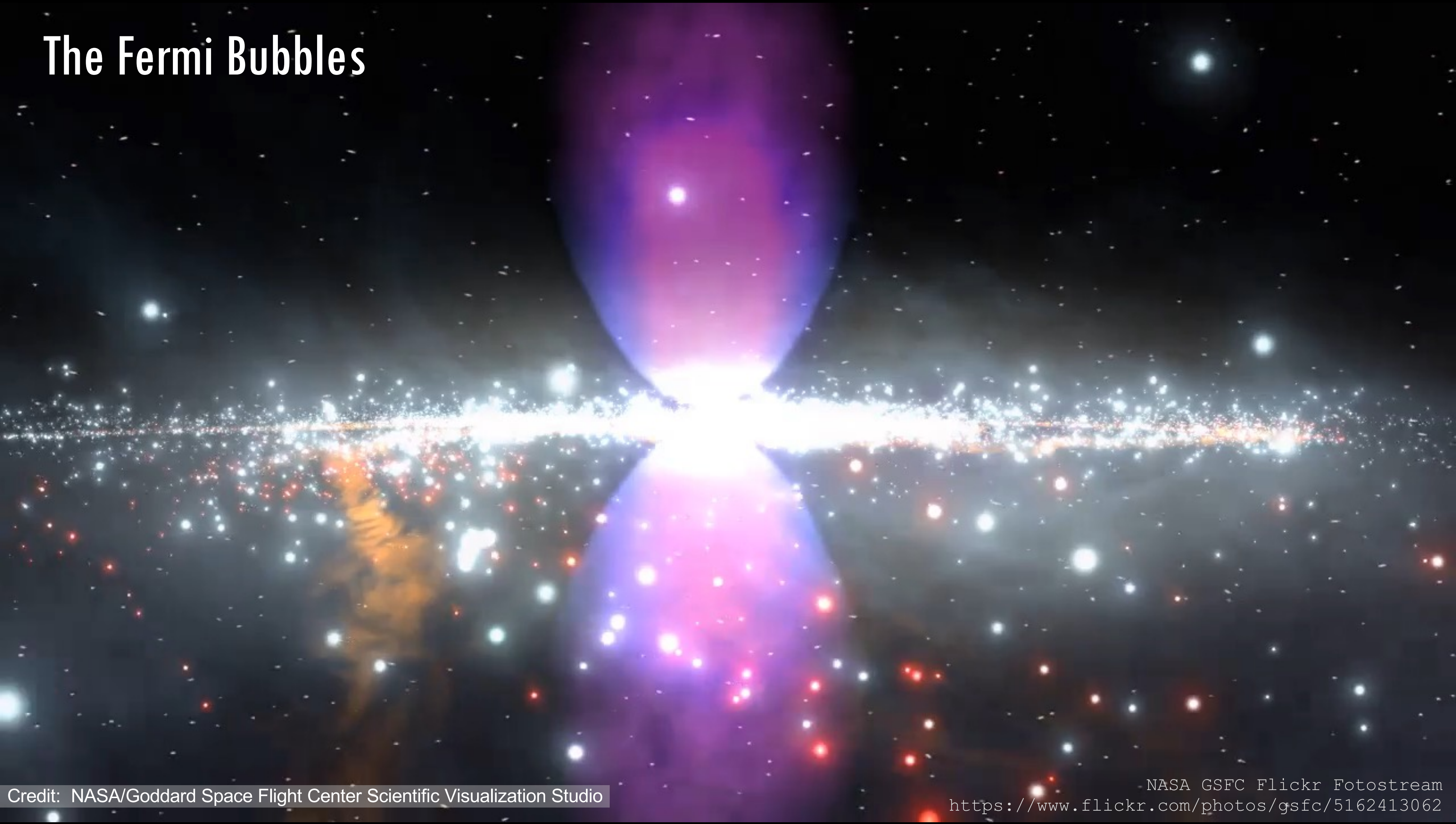
Still developing an understanding many questions remain open

ASSOCIATION: SNR, PWN, BINARY AND NOVAE

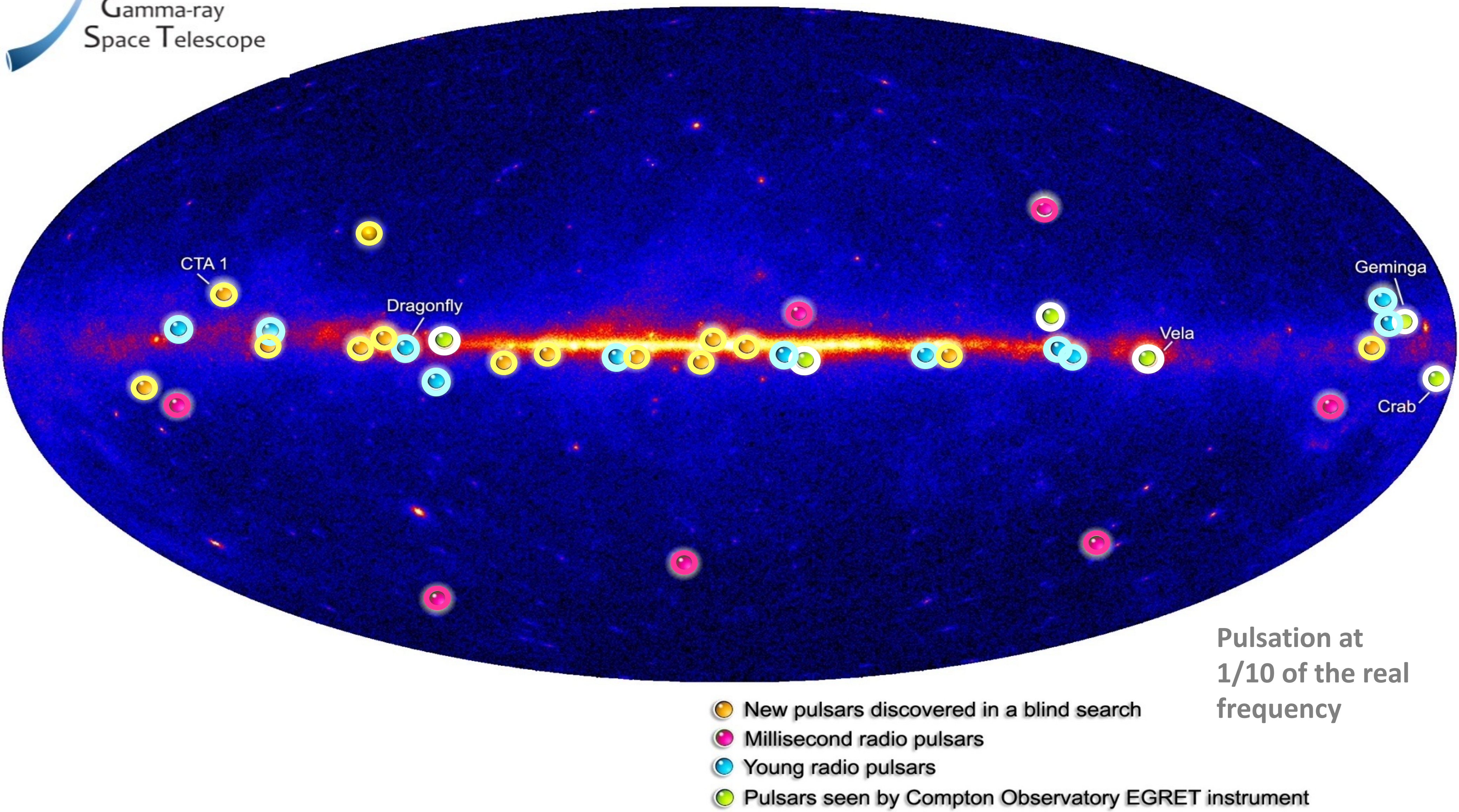


- for these classes of sources we rely on the images on optical and spatial coincidence

The Fermi Bubbles



The pulsating gamma rays sky

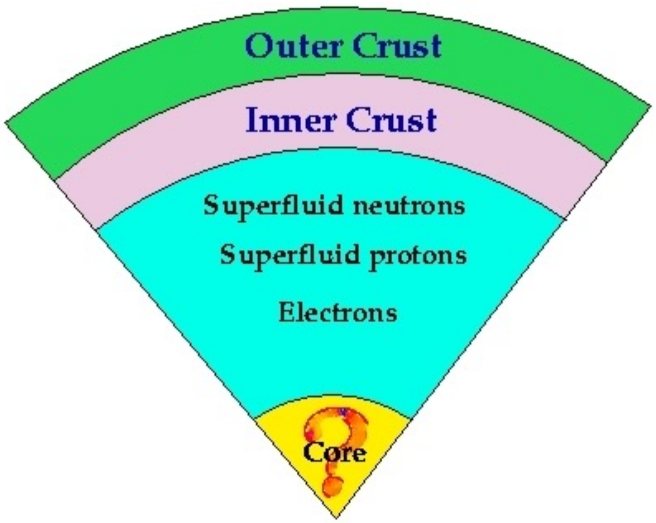


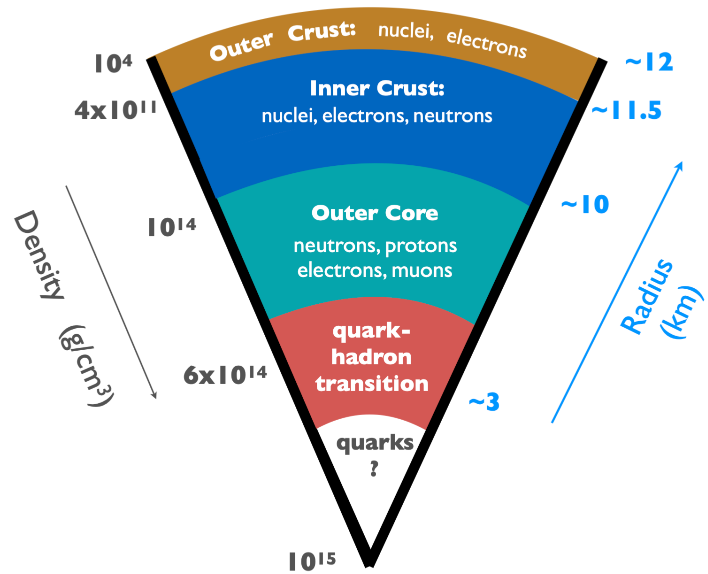
Pulsation at 1/10 of the real frequency

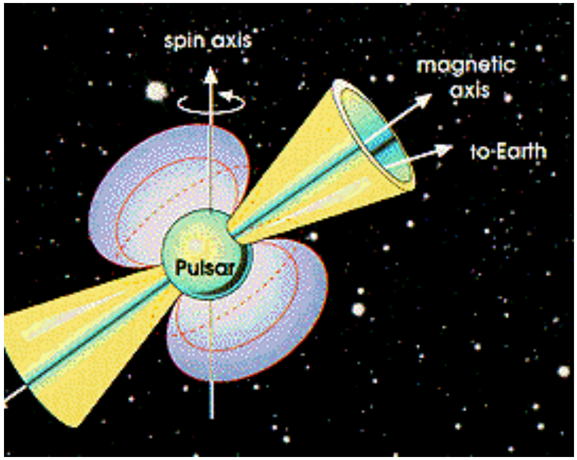
Neutron Star and Pulsars

In 1934 Walter Baade and Fritz Zwicky predicted the existence of neutron stars: stars which have collapsed under their own gravity during a supernova explosion. Stars like our Sun will not form neutron stars. After exhausting all their fuel, such small stars become white dwarfs. Only very massive stars (at least a few times more massive than our Sun) will undergo a supernova explosion and become neutron stars. Even more massive stars will collapse to form black holes.

The interior structure of a neutron star consists of iron, neutron rich nuclei and electrons in the outer crust. The inner crust contains neutron rich nuclei, free superfluid neutrons and electrons and the interior, superfluid neutrons, superfluid protons and electrons. The makeup of the core is unknown.

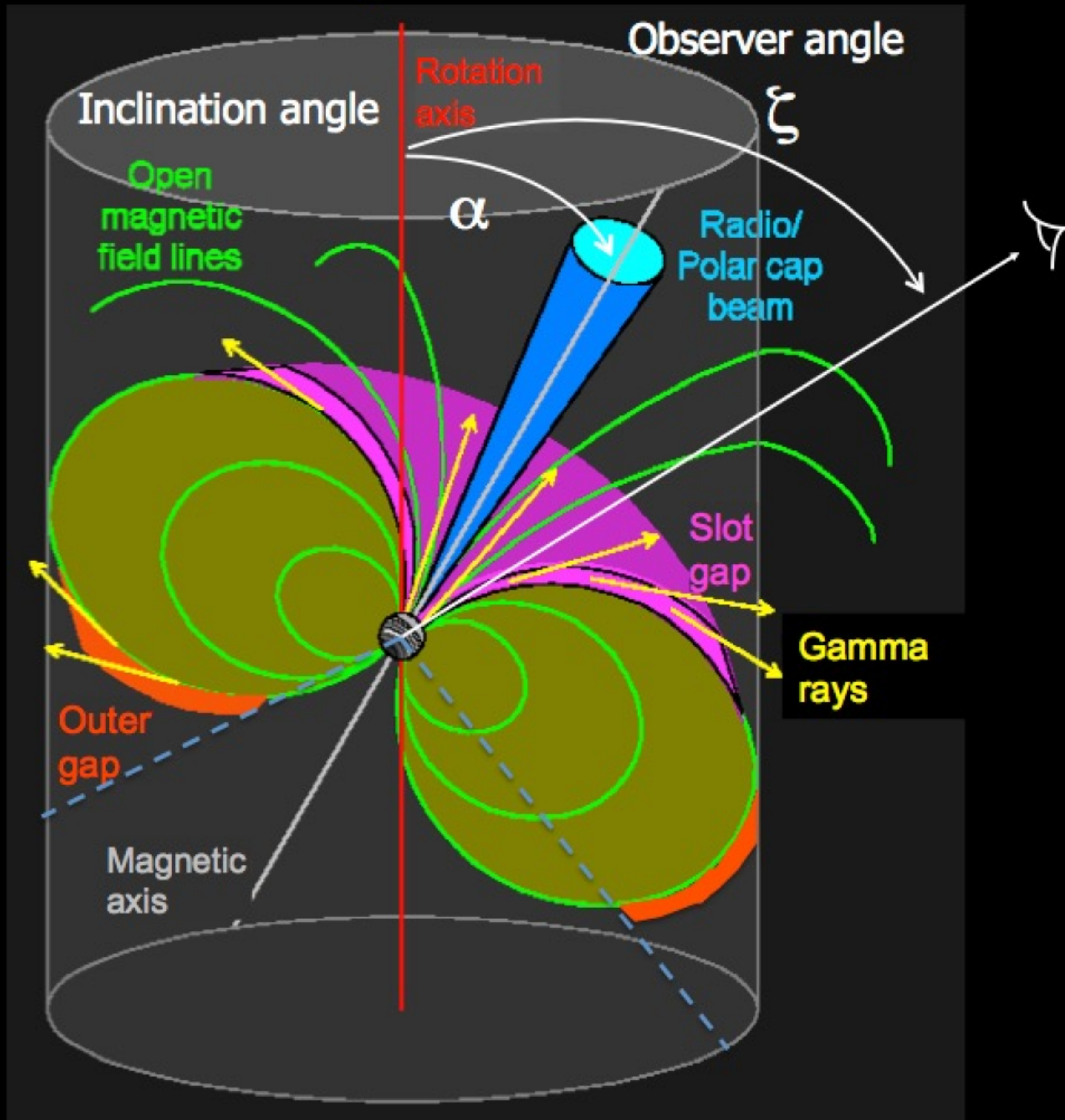




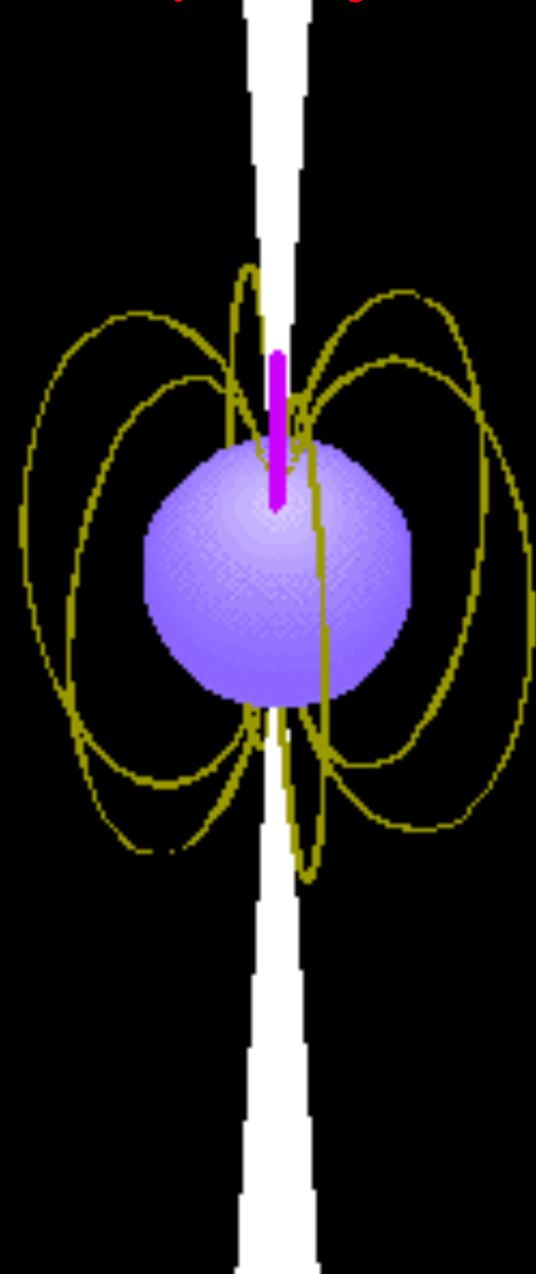


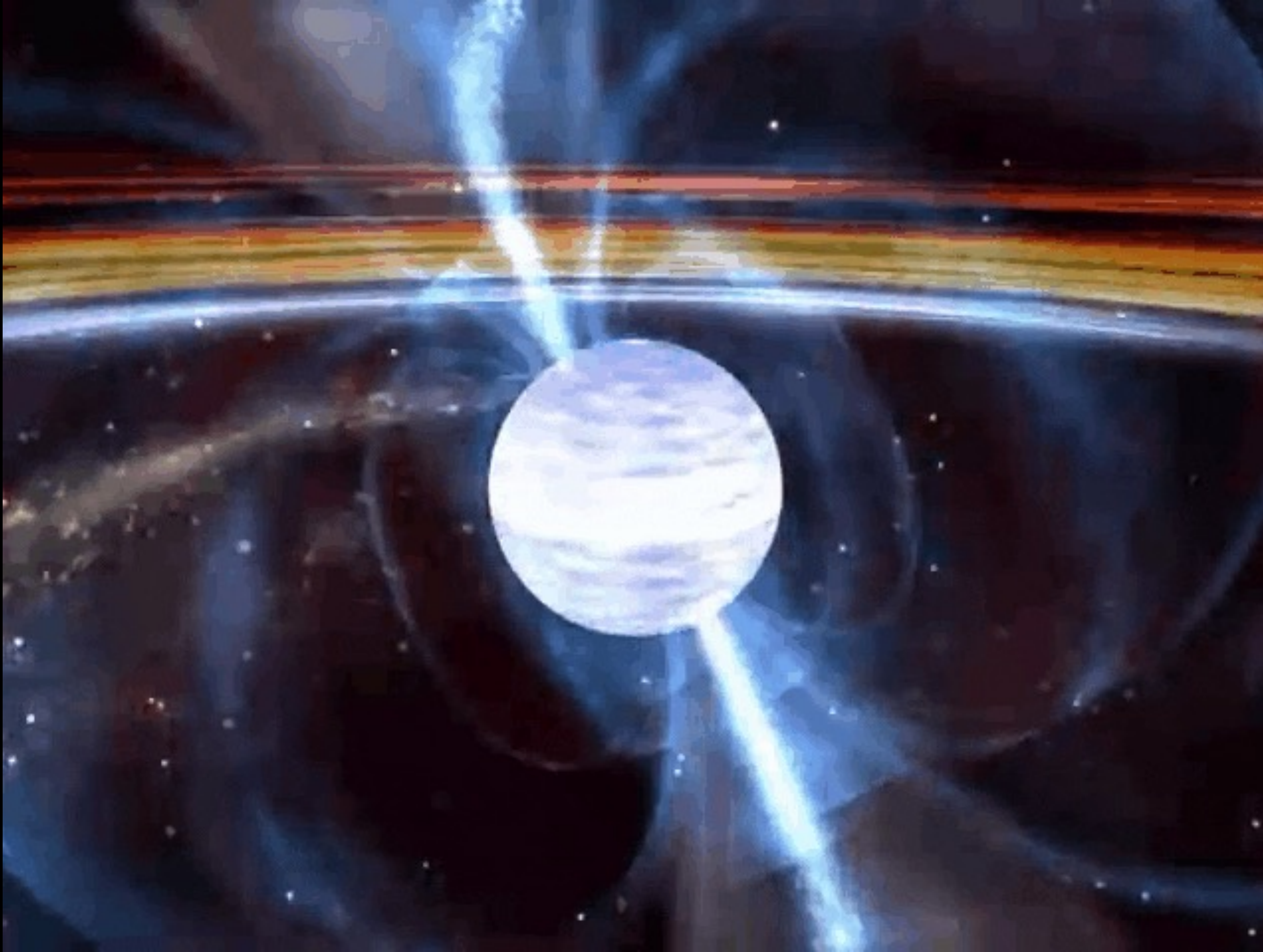
Neutron stars were predicted to be very dense, to spin very fast, have a tiny radius of only about 10km and to possess large magnetic fields. However, we now know that charged particles moving along the magnetic field could cause beams of radiation to be emitted from the magnetic poles. Then, as the neutron star rotates, the beam would sweep across space. When this beam is in the direction of the Earth, a pulse may be detectable

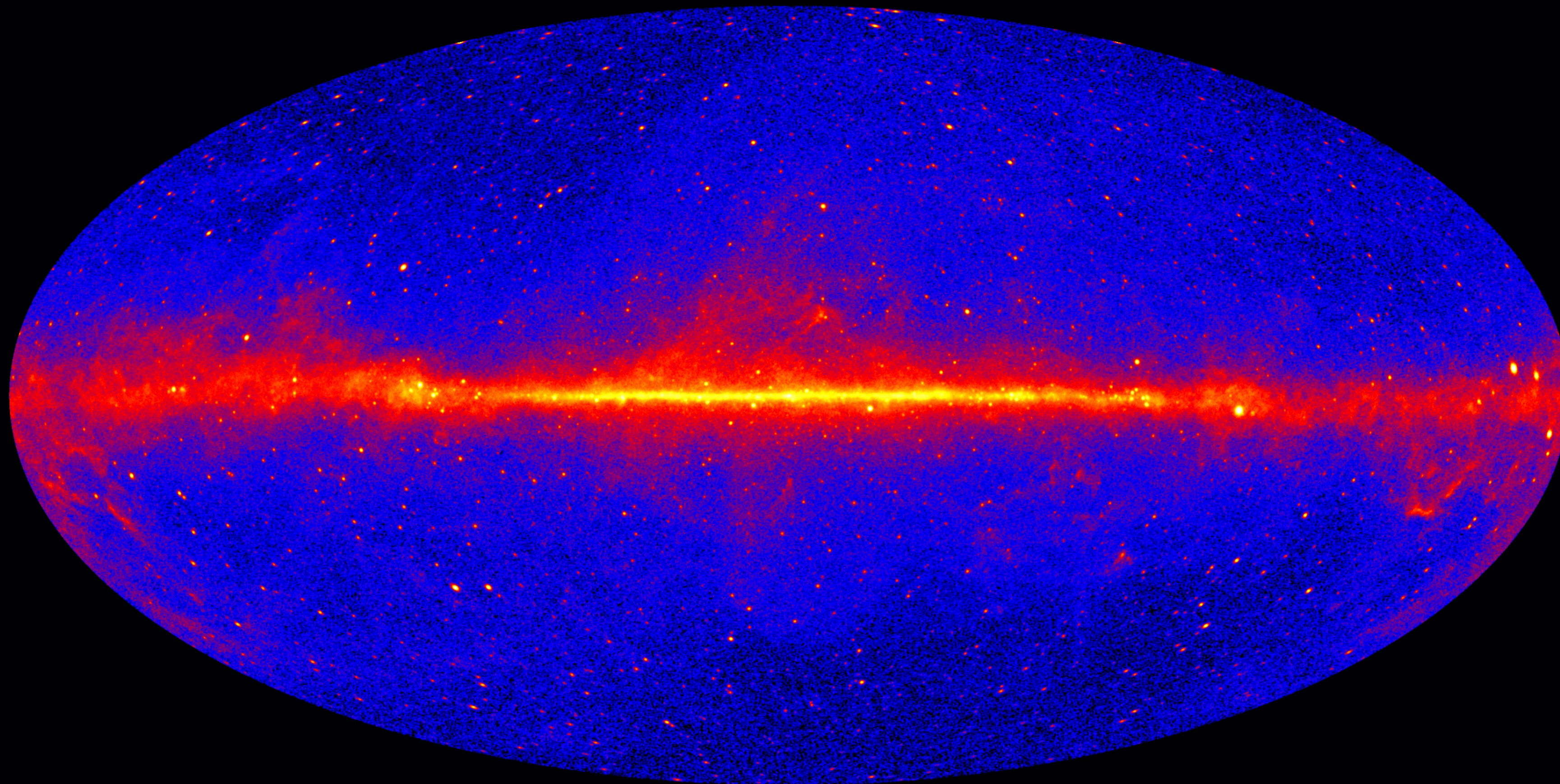
Gamma-ray emission sites



Pulsar astronomy in γ-rays



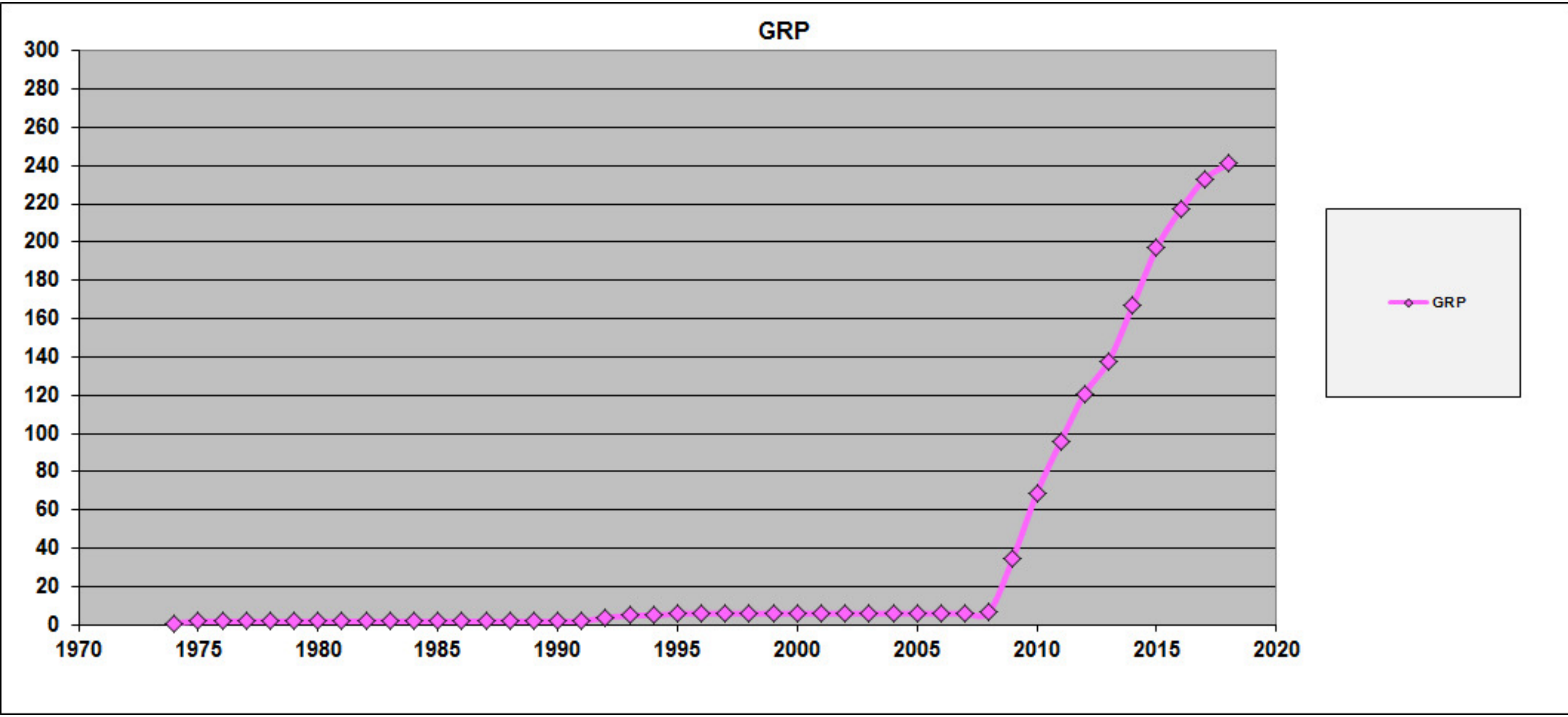




Milky Way in gammas: cosmic ray protons → gas & dust → pions,
then $\pi^\circ \rightarrow \gamma\gamma$ and $\pi^\pm \rightarrow \mu^\pm\nu \rightarrow e^\pm\nu\nu$, $e^\pm \rightarrow \gamma$'s.

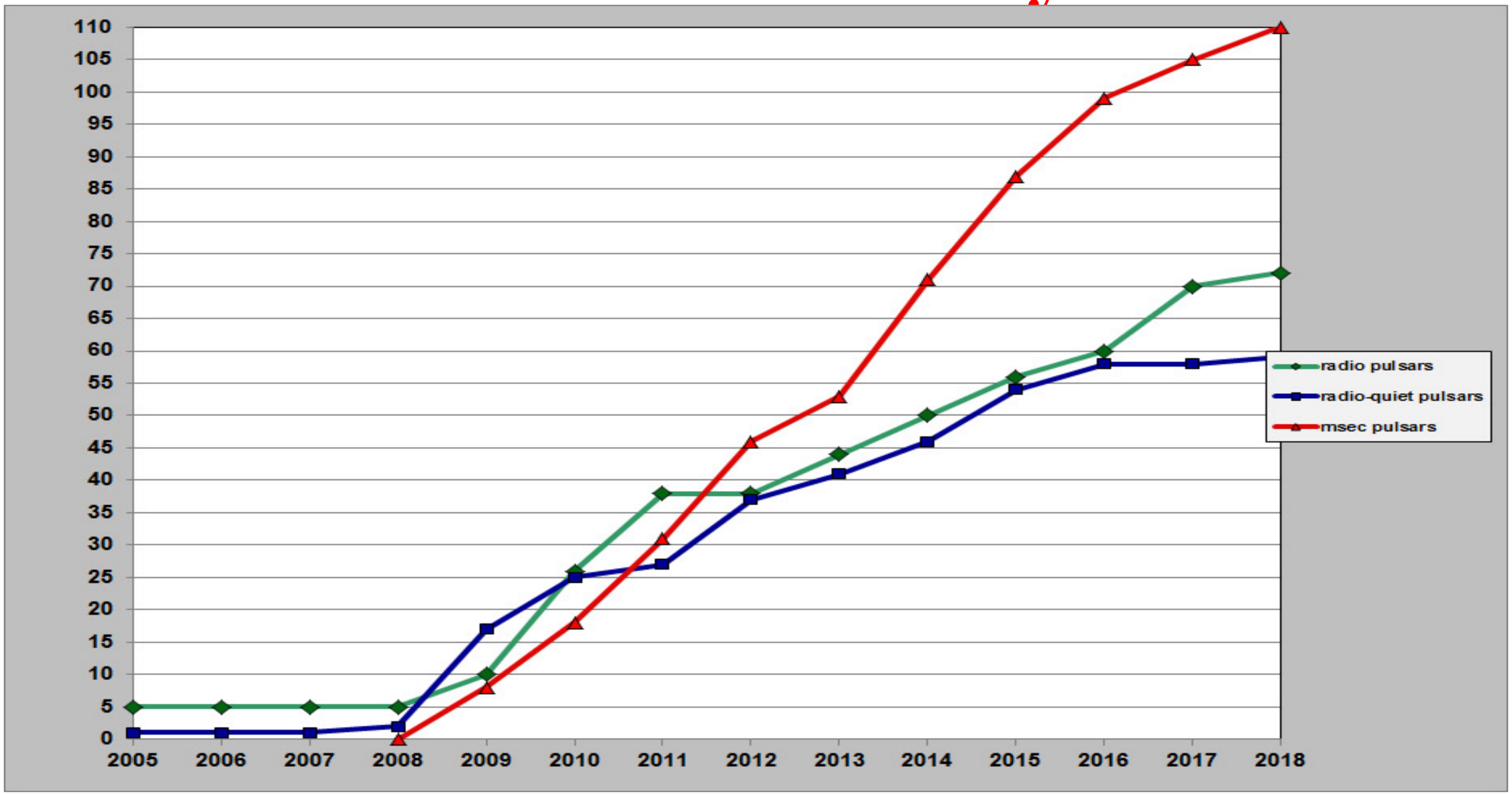
Point sources in the plane are mostly pulsars.
Off the plane, mostly blazars (and some MSP)

γ-ray PULSAR CENSUS



Not just an increase in number

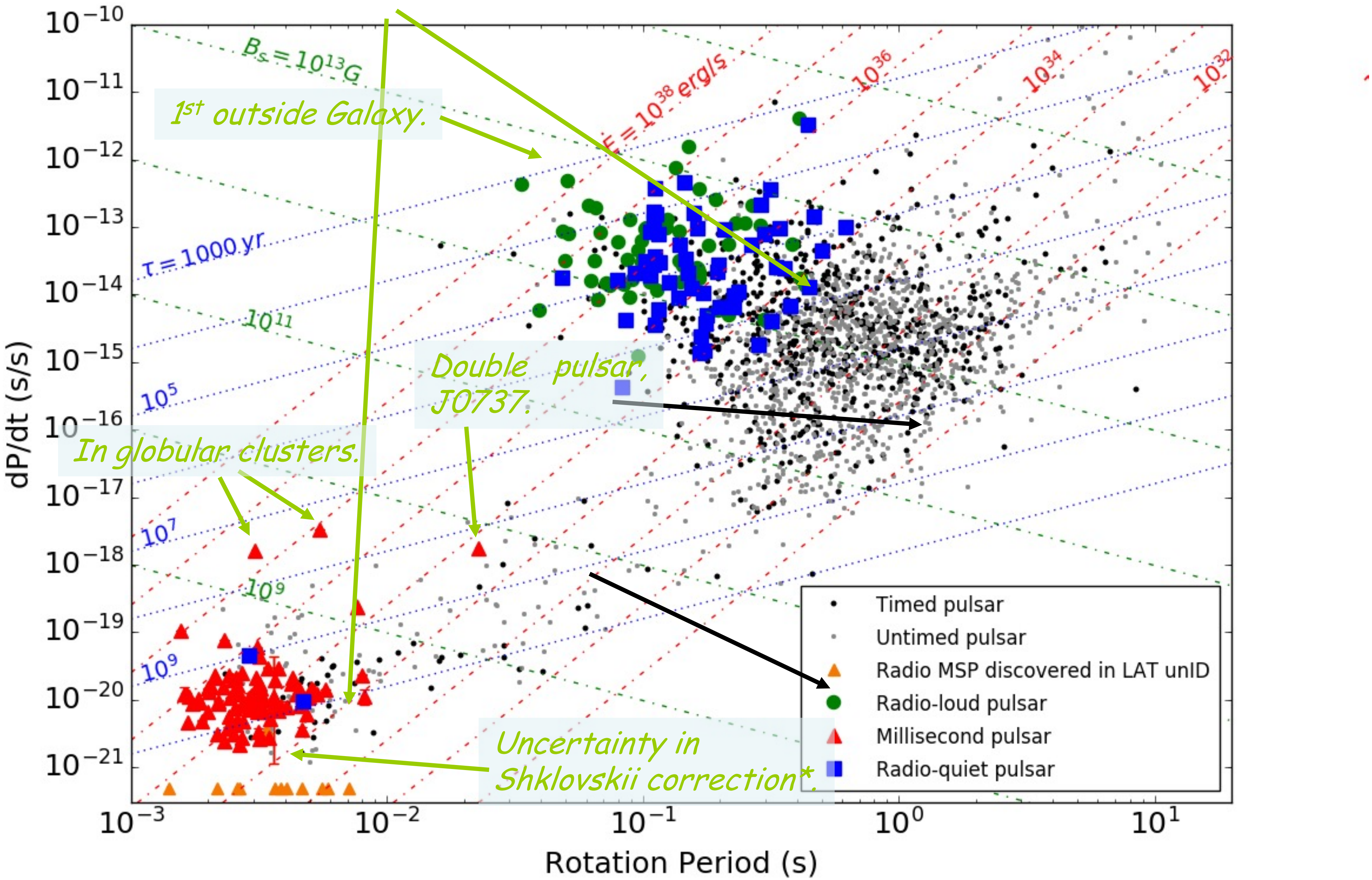
Diverse Family



millisecond pulsars - can be explained by assuming that all of the millisecond pulsars were originally in orbit with another star. After the pulsar formed, matter was pulled from the companion star on to the pulsar. During this process the pulsar rotated faster and faster until it became one of the millisecond pulsars. Later, the companion star died and became either a white dwarf, neutron star or black hole depending on its original size. If the companion star remained in orbit with the pulsar, a binary millisecond pulsar system would be formed.

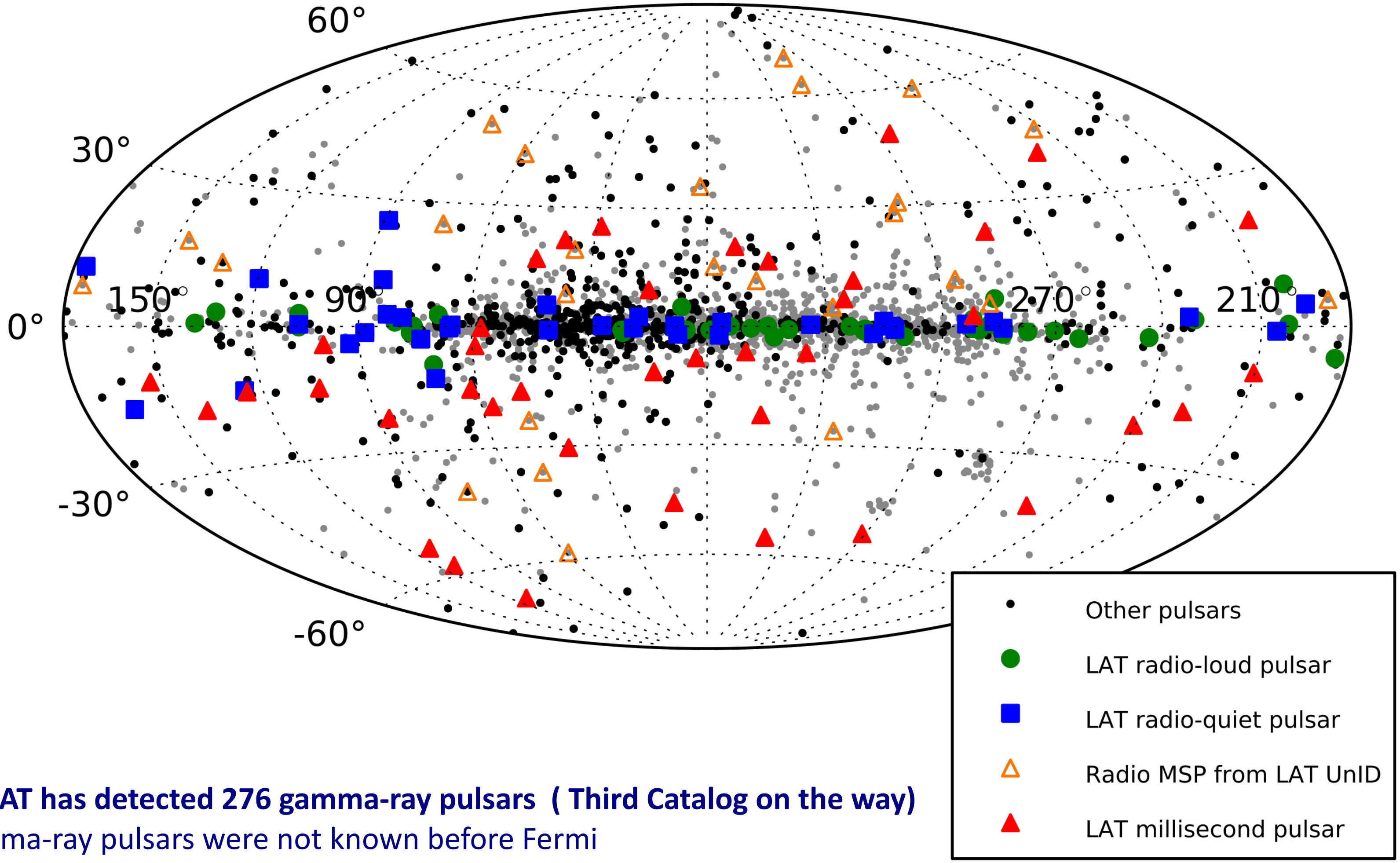
Gamma-ray deathline near spin-down power
$\dot{E} = 4I\pi^2 \dot{P} / P^3$ of ~3E33 erg/s

The Second Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
The Astrophysical Journal Supp 208 (2013) 17 [arXiv:1305.4385]



Fermi LAT pulsars

The Second Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
The Astrophysical Journal Supp 208 (2013) 17 [arXiv:1305.4385]



At present the LAT has detected 276 gamma-ray pulsars (Third Catalog on the way)

- Half of the gamma-ray pulsars were not known before Fermi
- Pulsar science represents an example of successful cooperation between radio, X-ray and gamma-ray astronomers.
- A Pulsar Search Consortium (PSC) undertook searches at radio and X-ray wavelengths at the positions of unidentified LAT gamma-ray sources.

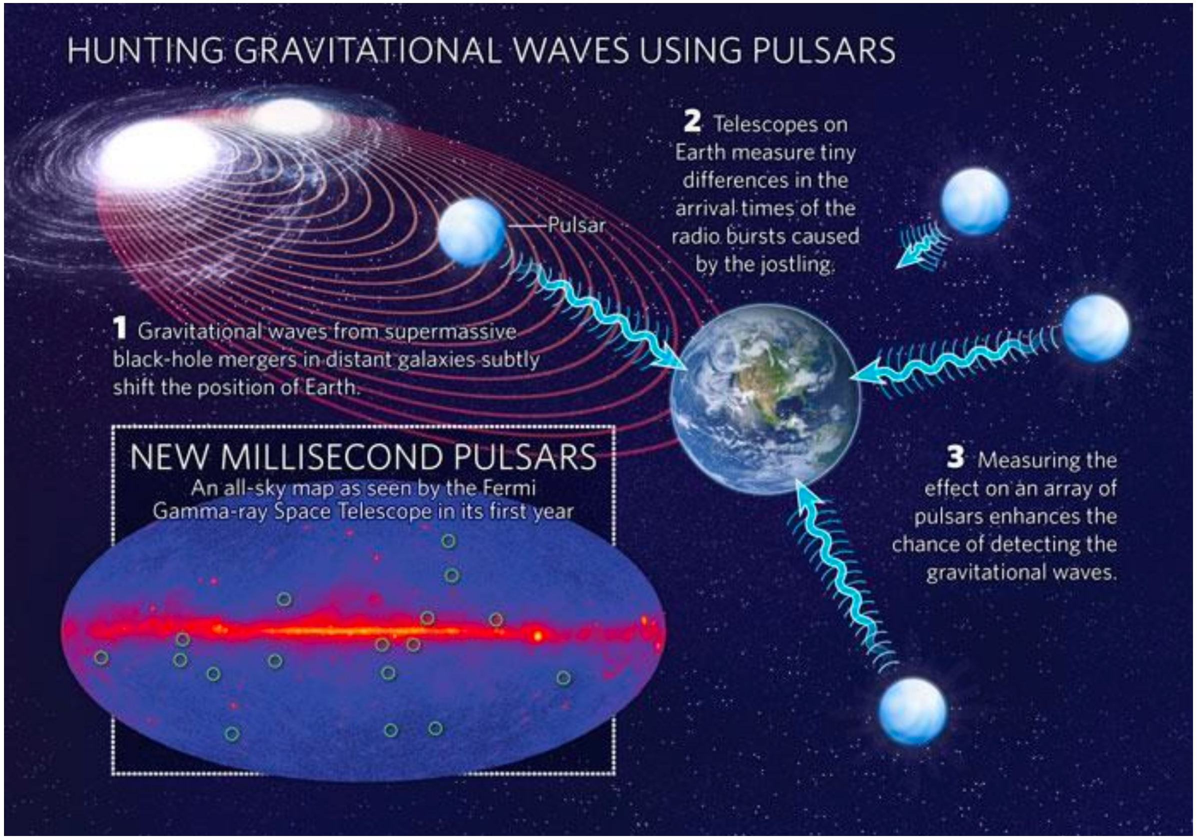
- For a complete list of the Fermi LAT pulsars see:

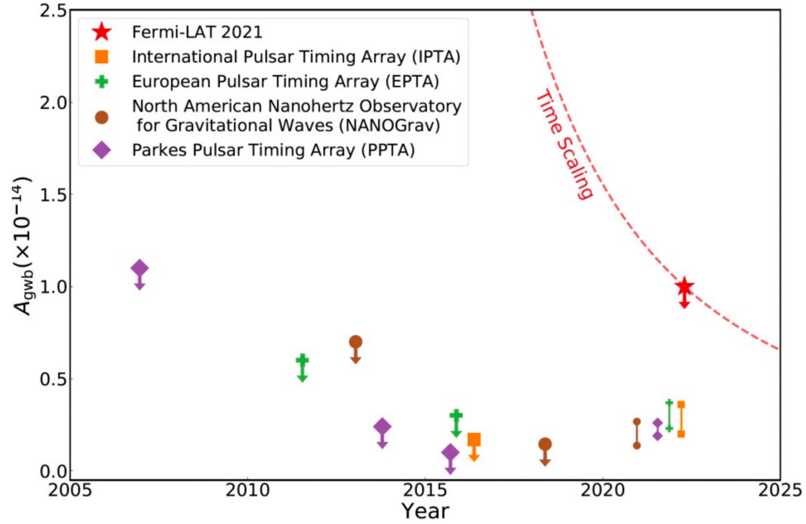
https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

Fermi LAT pulsars

Gravitational waves can be detected by monitoring the times of arrival of the steady pulses from each pulsar, which arrive earlier or later than expected due to the spacetime perturbations.

- After large galaxies merge, their central supermassive black holes (SMBH) are expected to form binary systems whose orbital motion generates a *gravitational wave background* (GWB) at nHz frequencies.
- Using 12.5 years of LAT data to form a gamma-ray pulsar timing array (PTA) formed by 35 bright gamma-ray pulsars, it was possible to constrain the emission from the gravitational wave background (GWB).

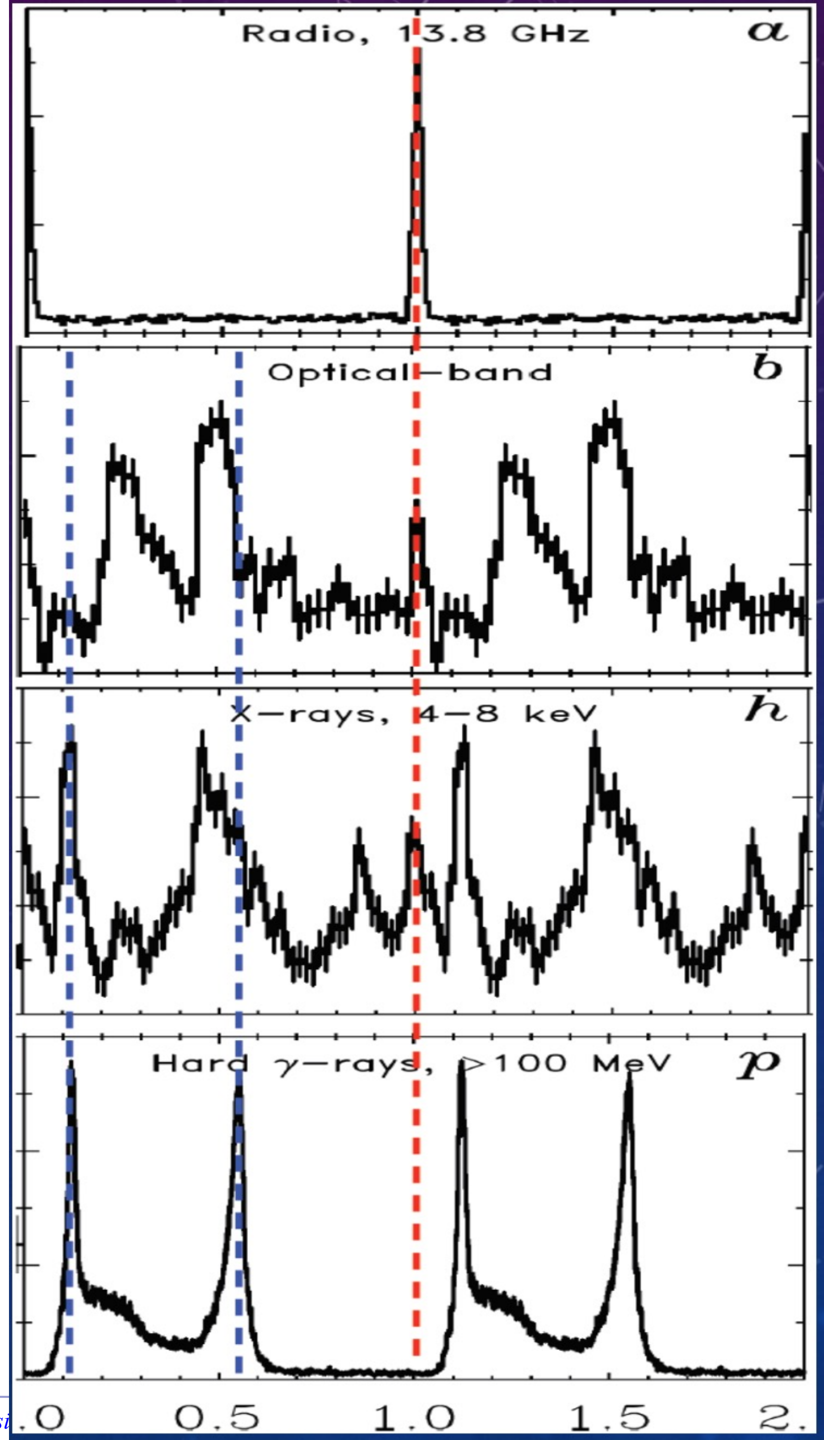




A gamma-ray pulsar timing array constrains the nanohertz gravitational wave background Science 376 (6592) April 2022 [arxiv:2204.05226]

ASSOCIATION: PULSARS

•Most of the pulsars are well known in radio and X
• Ephemerides (timing parameters) are available for a large number of pulsars
Gamma-ray data can be folded according to ephemerides in other bands to show the pulsation.
Some pulsars are visible only in gamma and no ephemerides are there to help:
• Need a search in all the possible periods to search for a significative pulse
• Time and CPU consuming



Why is important to find more pulsars?

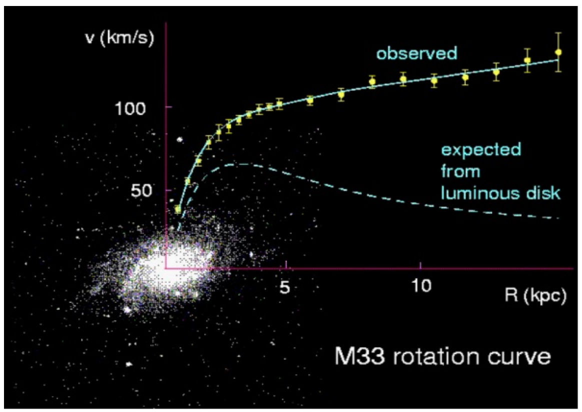
A physics case: The Galactic Center

Dark Matter EVIDENCE

In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies.

Since then, even more evidence:

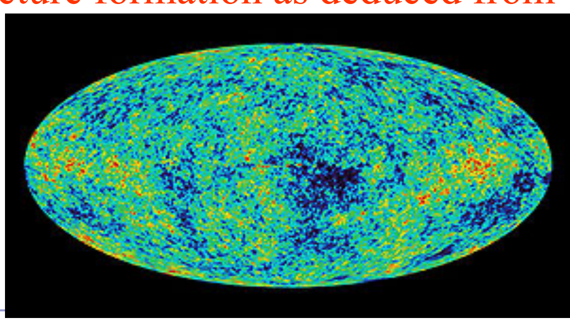
Rotation curves of galaxies



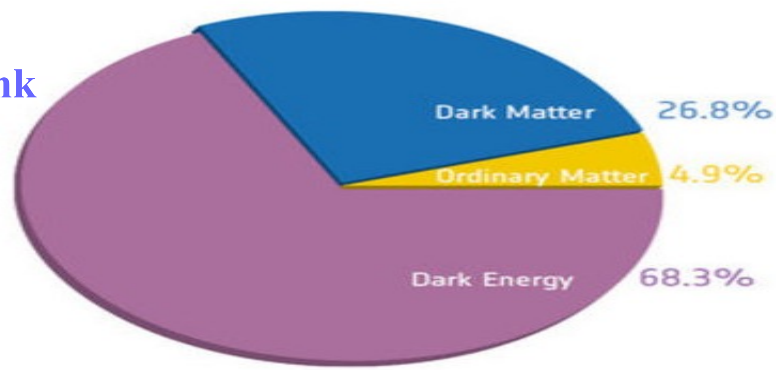
Gravitational lensing

Bullet cluster

Structure formation as deduced from CMB



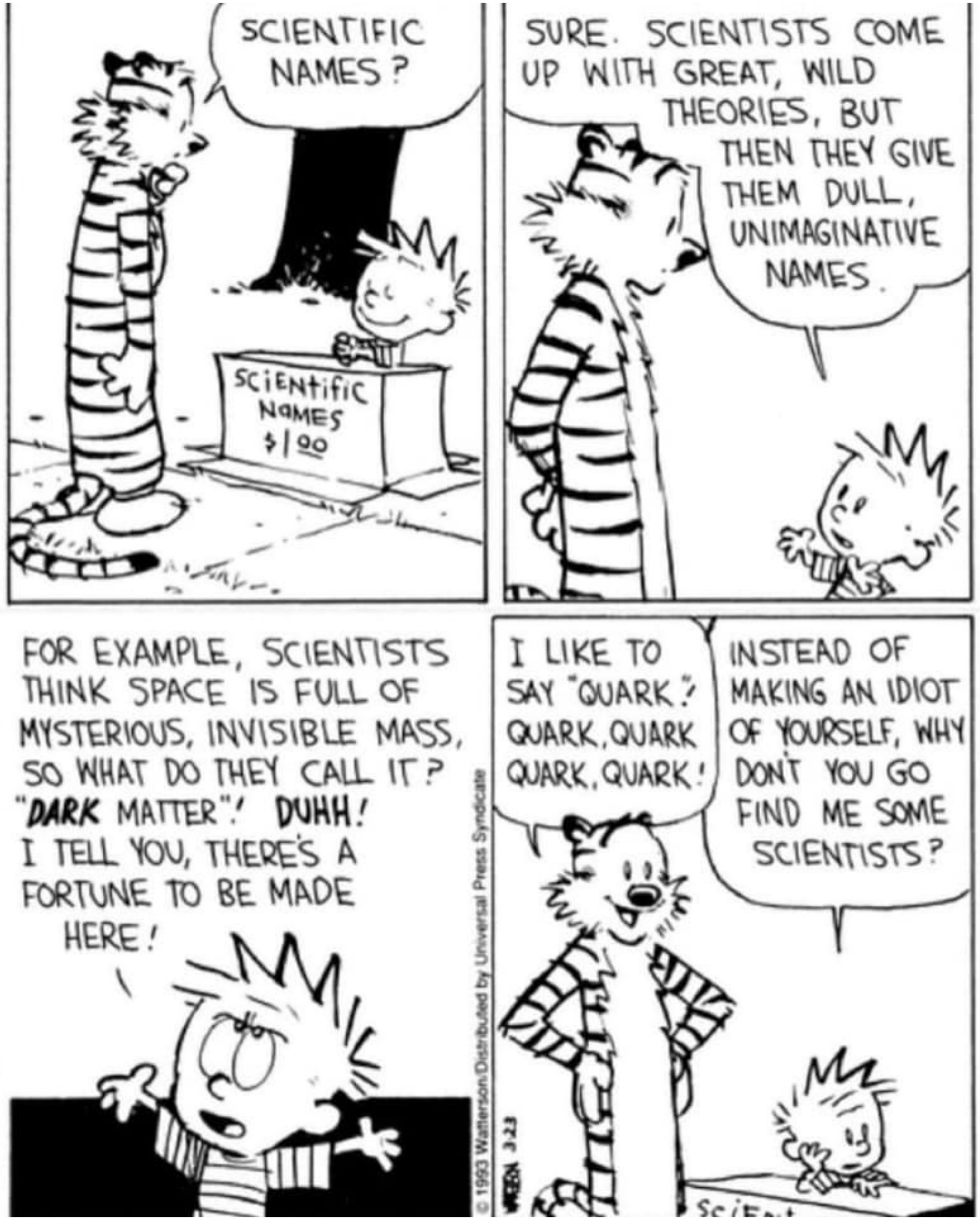
Data by Plank imply:



$\Omega_{Dm} \approx 26.8\%$

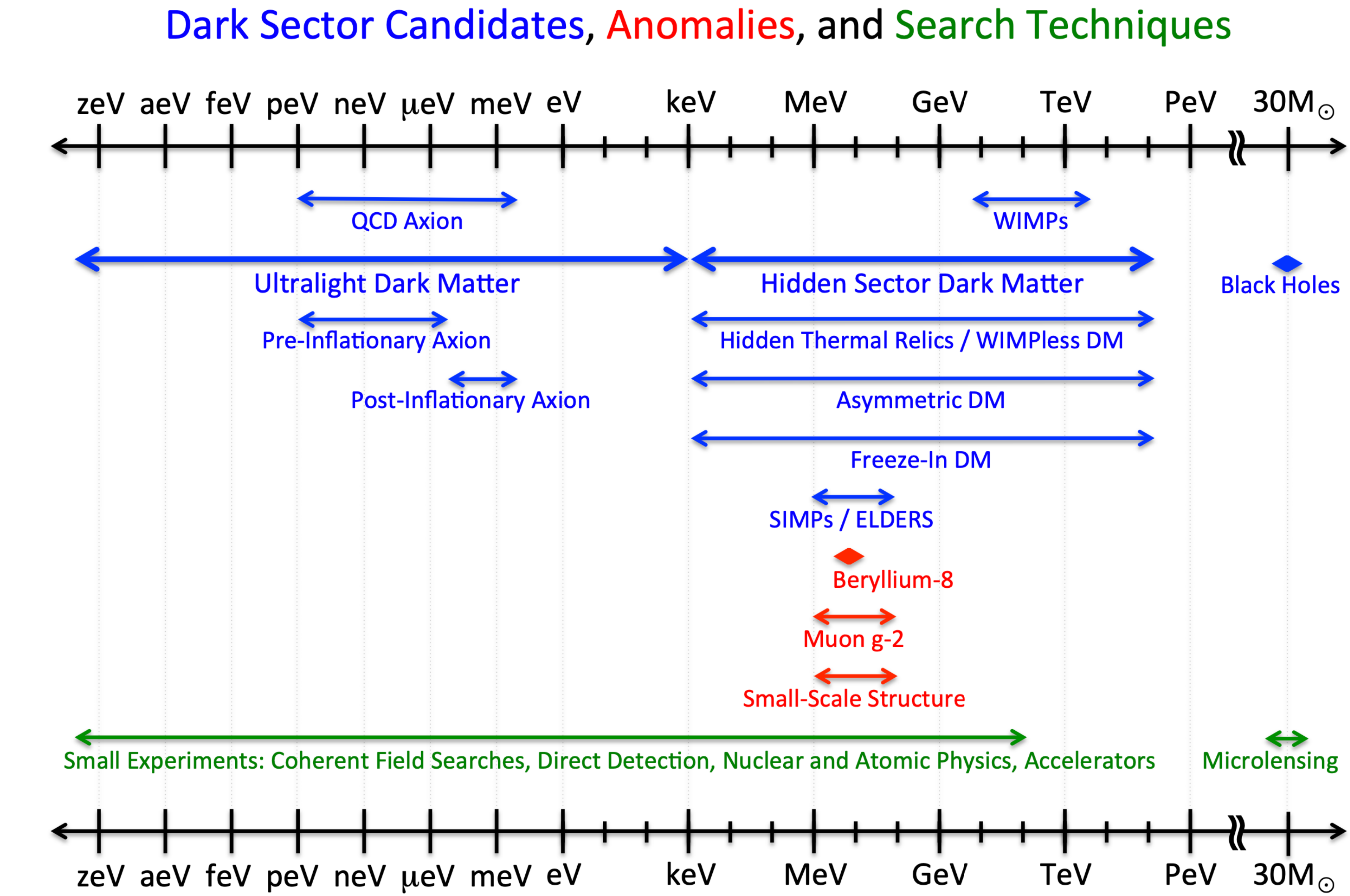
$\Omega_M \approx 4.9\%$

Dark Matter


SCIENTIFIC NAMES?
SCIENTIFIC NAMES $1.00
SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.
FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS, SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!
I LIKE TO SAY "QUARK." QUARK, QUARK QUARK, QUARK!
INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?
© 1993 Watterson/Distributed by Universal Press Syndicate

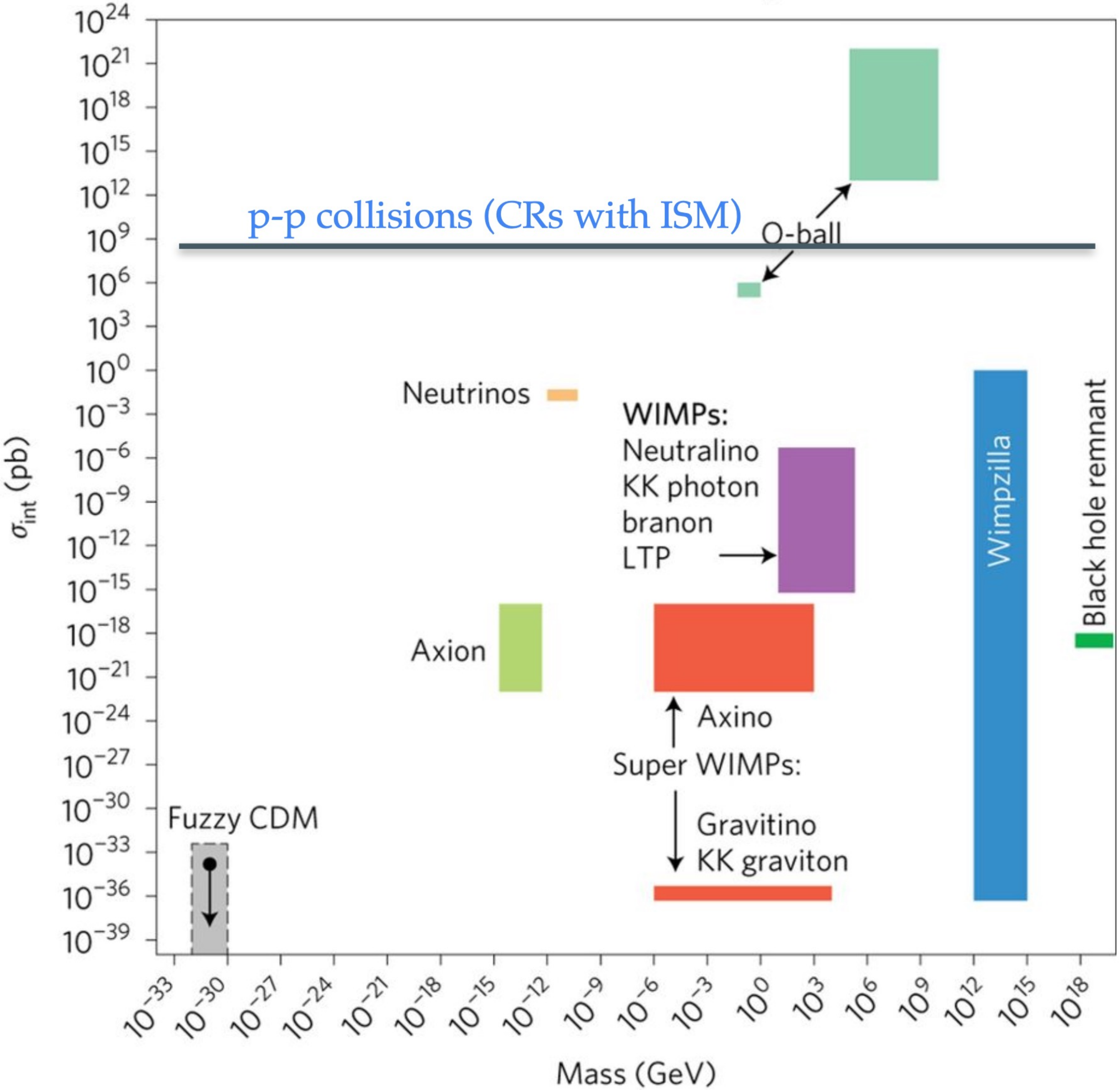
What is dark matter made of ?

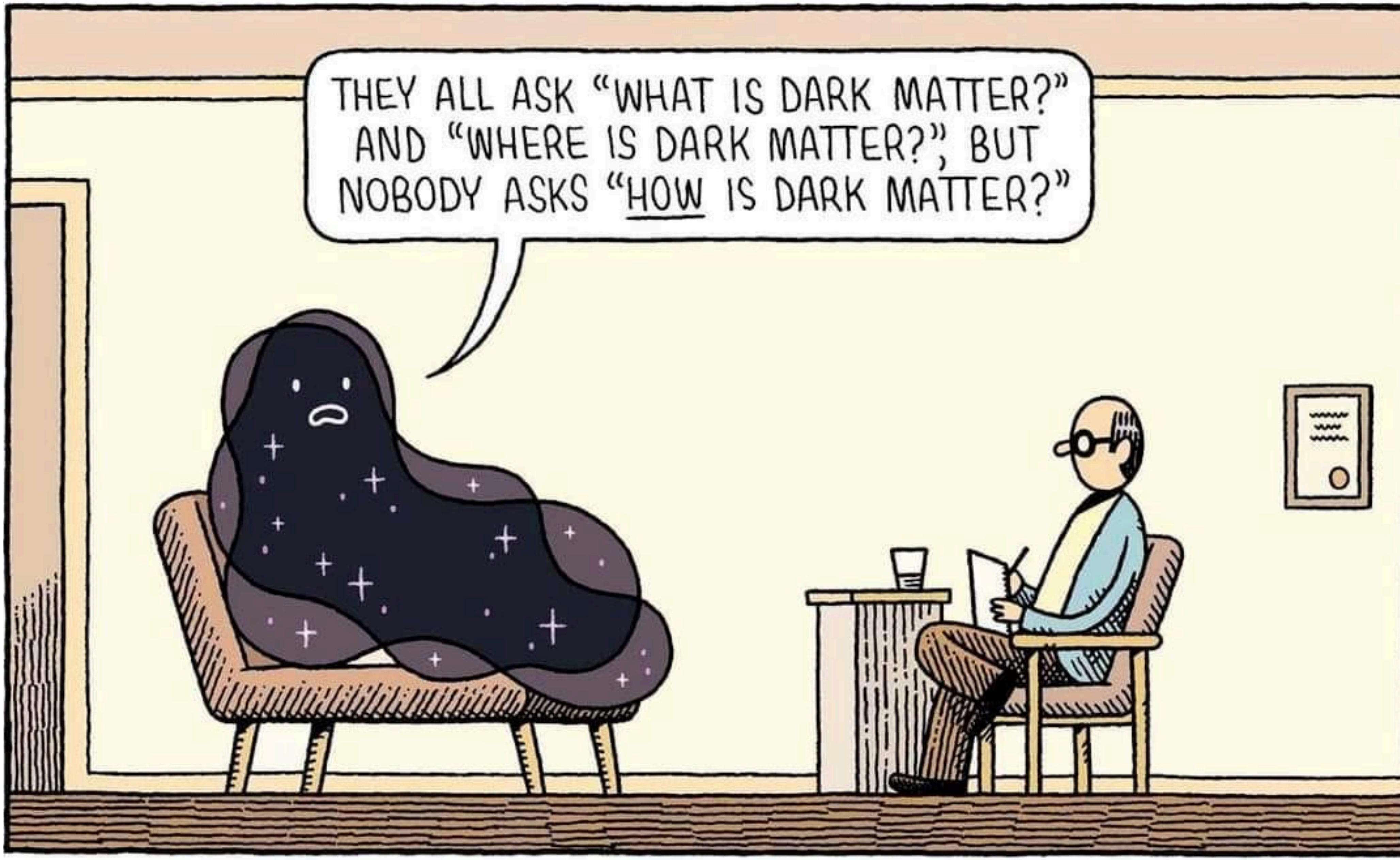
Dark Sector Candidates, Anomalies, and Search Techniques



New Ideas in Dark Matter 2017 : Community Report arXiv:1707.04591

Some particle dark matter candidates

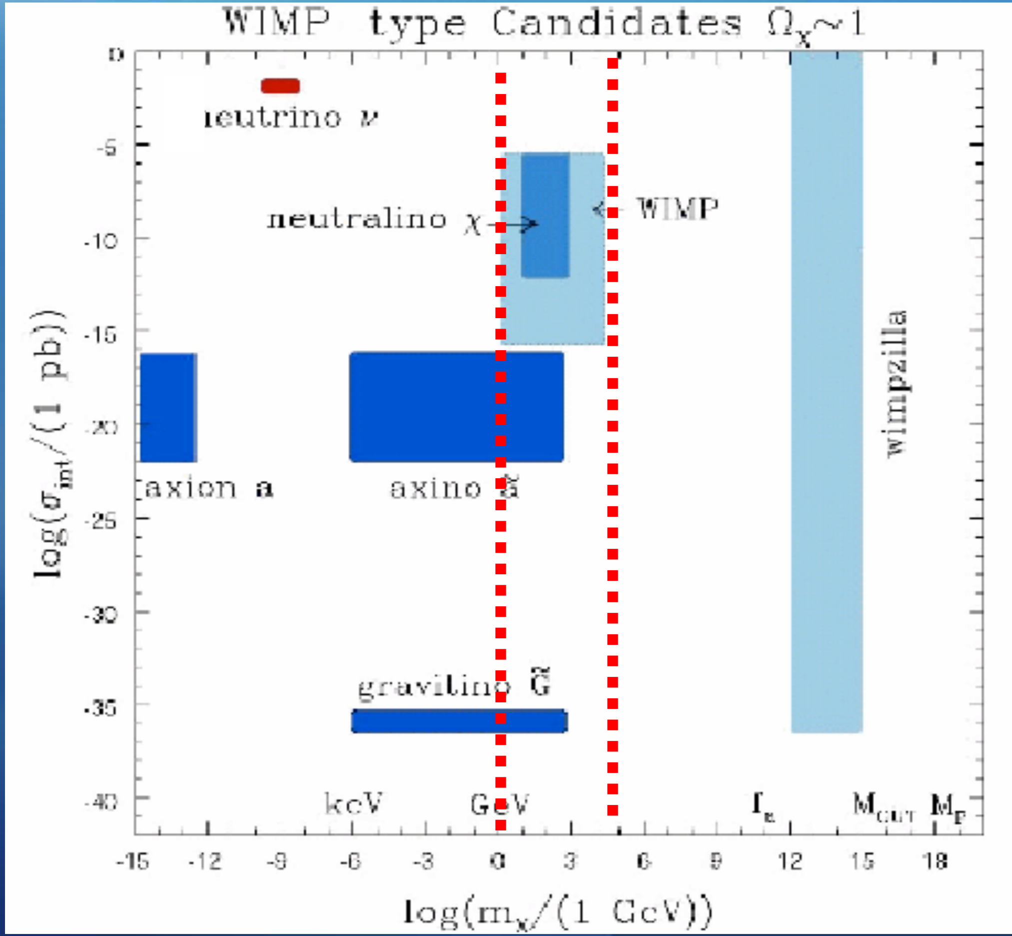




TOM GAULD for NEW SCIENTIST

Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



Dark Matter Candidates

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- **NEUTRALINO**
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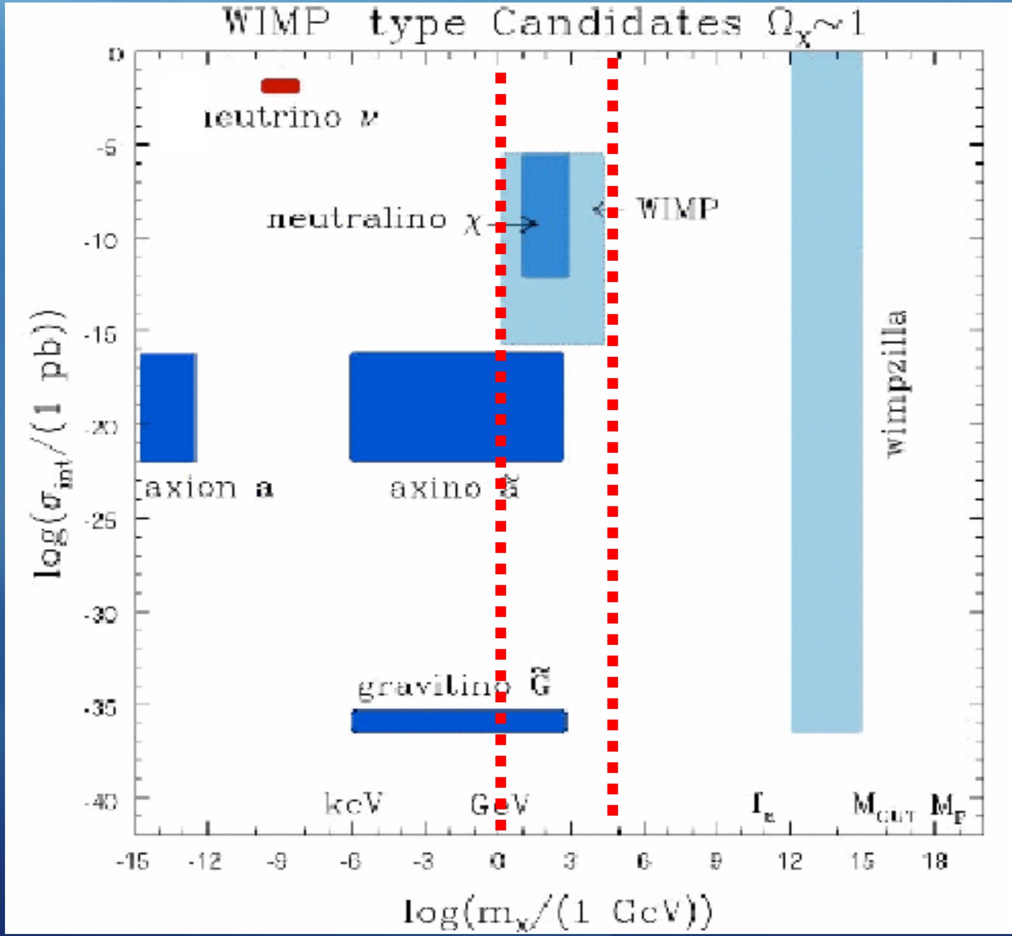
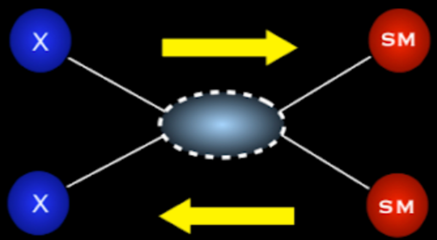


WIMPs

By far the most studied class of dark matter candidates.

The WIMP paradigm is based on a simple yet powerful idea:

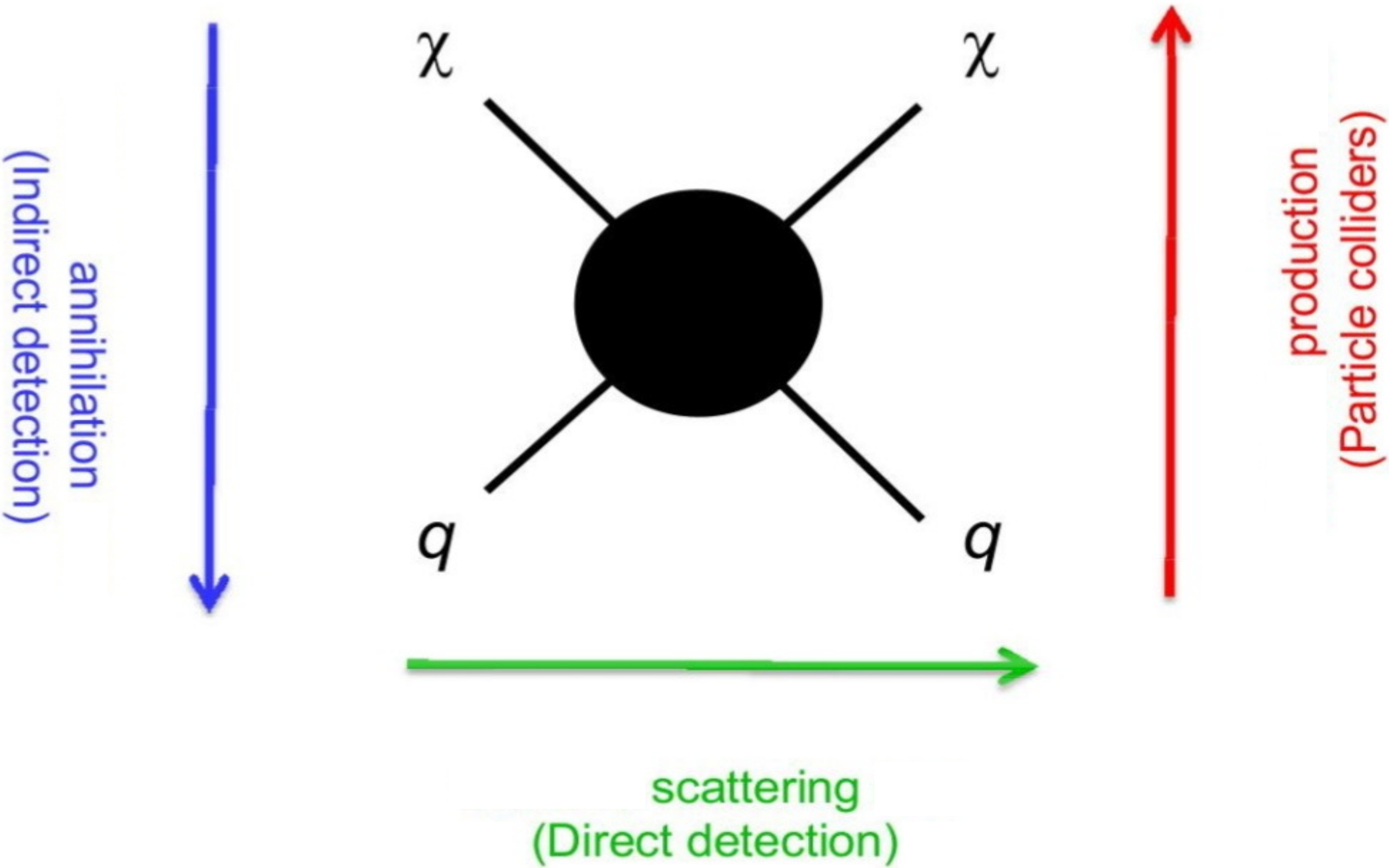


$$\frac{dn_\chi}{dt} - 3Hn_\chi = -\langle \sigma v \rangle \left[n_\chi^2 - (n_\chi^{eq})^2 \right]$$

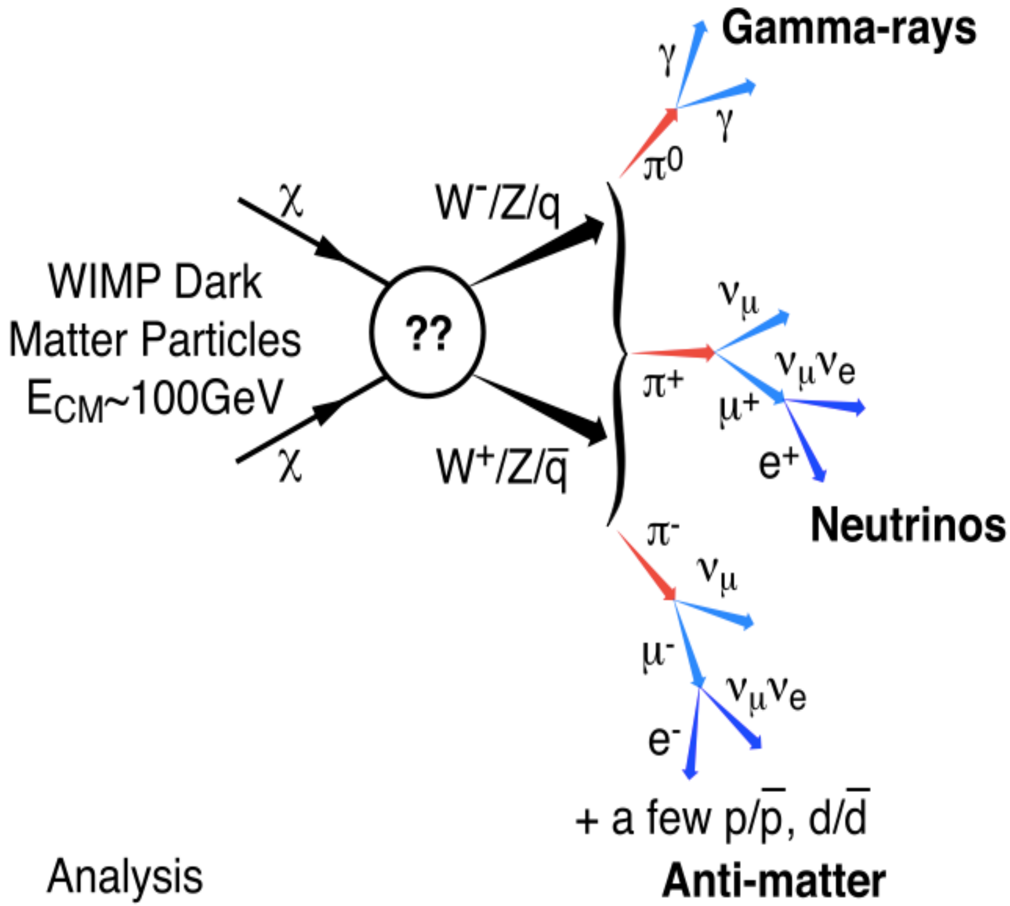
Weak-scale cross sections can reproduce observed relic density

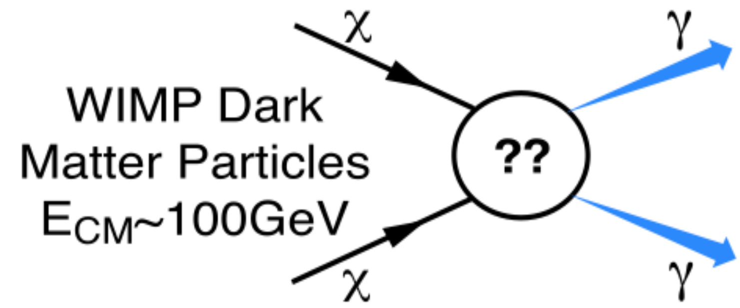
$$\Omega h^2 \approx \frac{3 \times 10^{-27} cm^3 s^{-1}}{< \sigma v >}$$

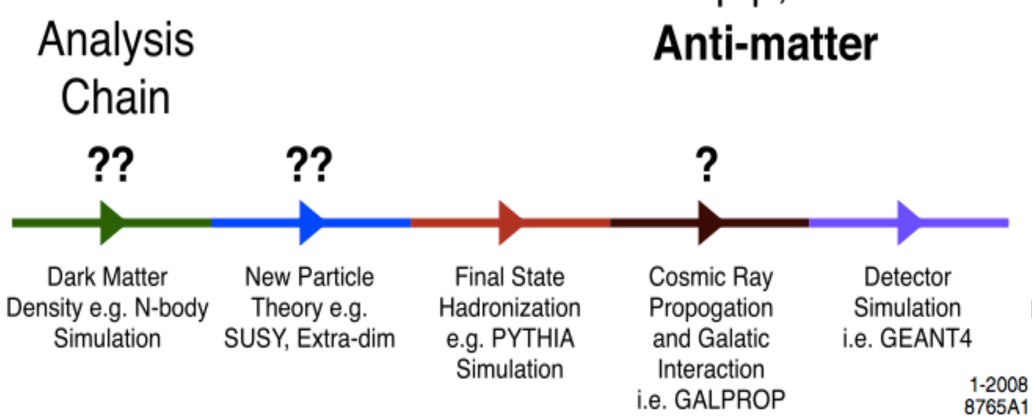
'WIMP miracle': new physics at ~1TeV solves at same time fundamental problems of particle physics (*hierarchy problem*) AND DM

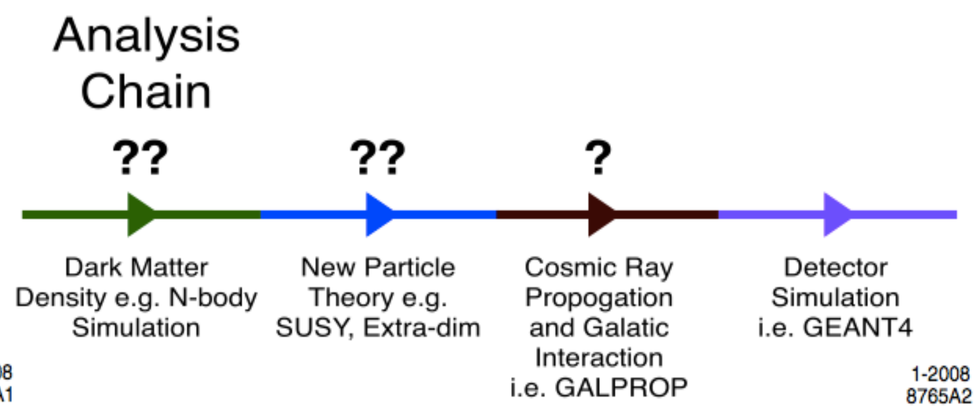

χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)

Annihilation channels

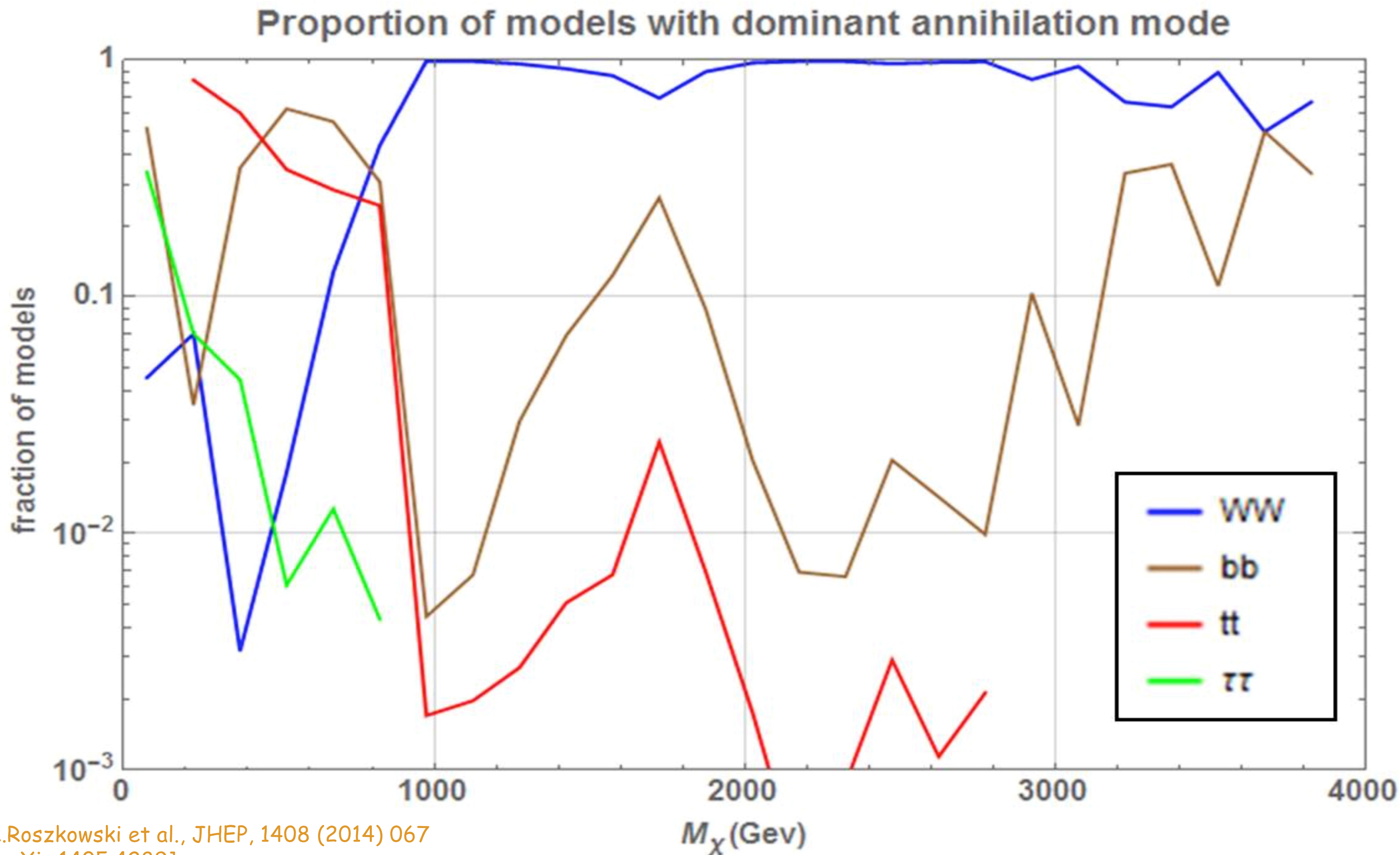








Which channel to choose?
Example: The dominant annihilation modes in the pMSSM scan



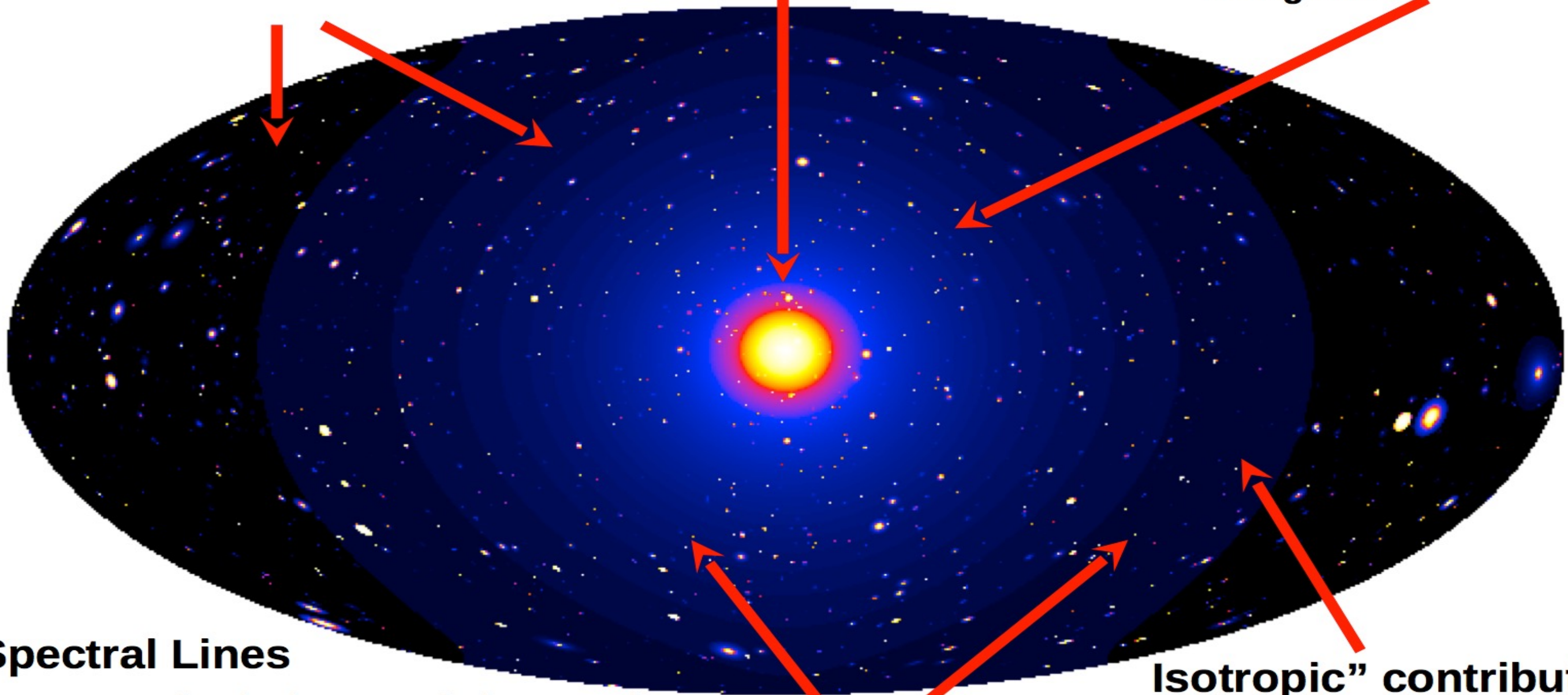
L.Roszkowski et al., JHEP, 1408 (2014) 067
[arXiv:1405.4289]

Dark Matter Search: Targets and Strategies

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

Galaxy Clusters
Low background, but low statistics

Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195