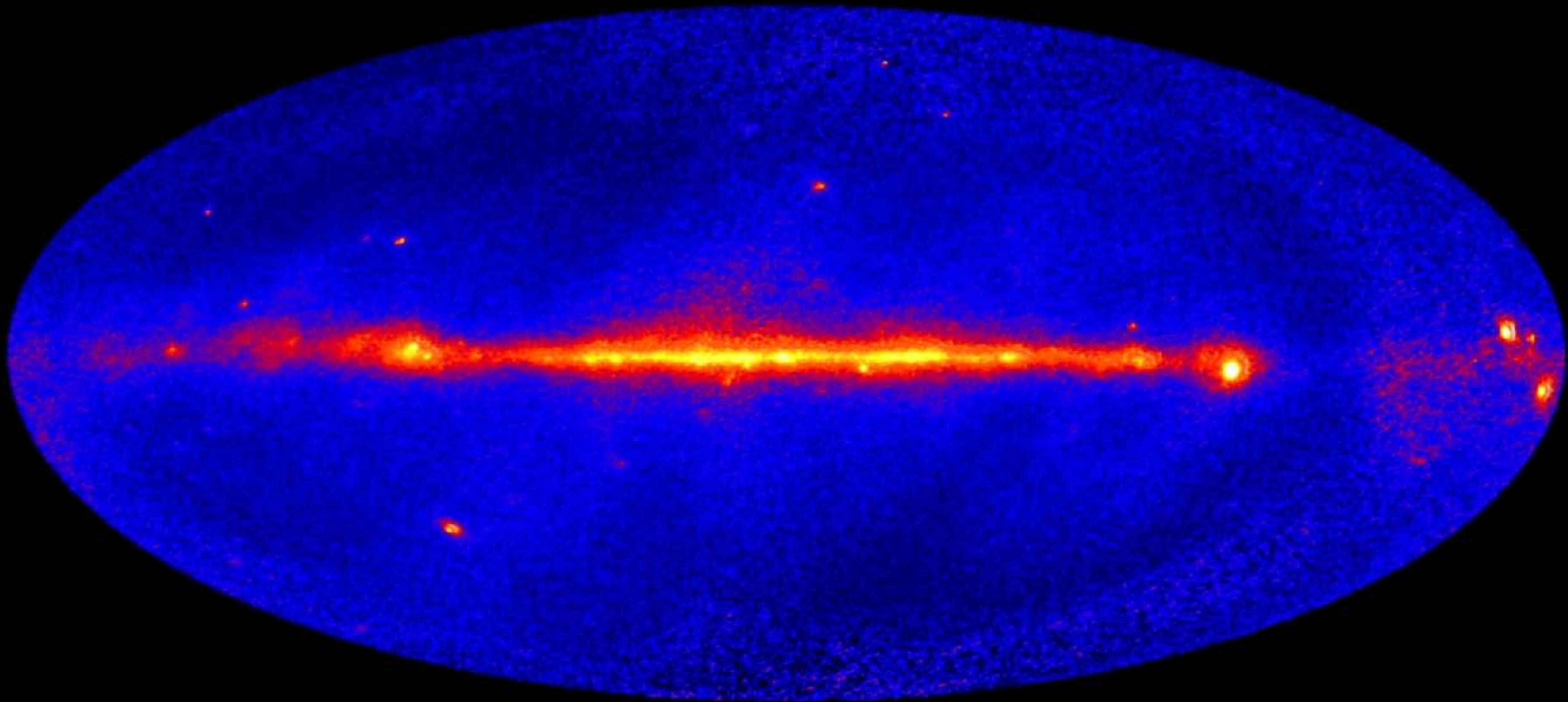
AGILE and Fermi satellites: recent highlights in γ-ray astrophysics



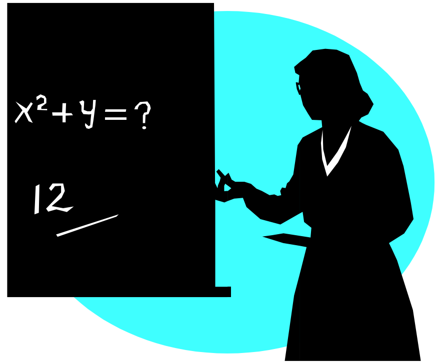
Carlotta Pittori

AGILE ***Collaboration, ASI Science Data Center***

LPT Orsay, March 10, 2011

Carlotta Pittori: a brief presentation

An outsider ?

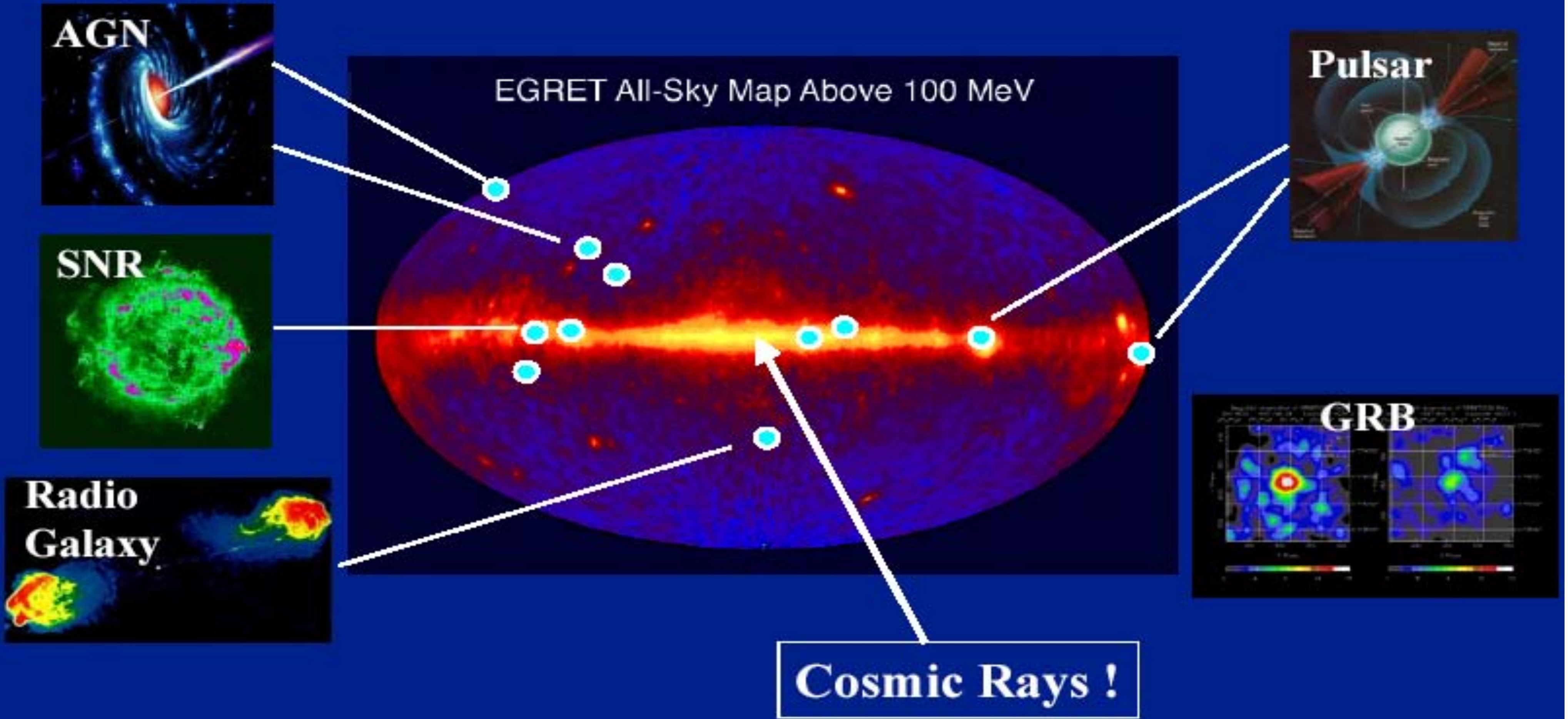


• Background: PhD in Theoretical Physics. **1993-1997:** CE fellow researcher **at "LPTHE" Orsay**. Elementary particle physics, Standard Model, Renormalisation and Lattice QDC.

• 1999-Present: 11-year experience in **gamma-ray astrophysics** and astroparticle physics as a team member of the Italian Space Agency **AGILE Mission.** Affiliated Scientist of the NASA **Fermi**/GLAST collaboration.

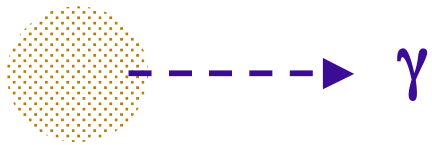
• Since 2003: **Coordinator of the AGILE Data Center** c/o the ASI Science Data Center (ASDC)

Study of γ-ray cosmic accelerators

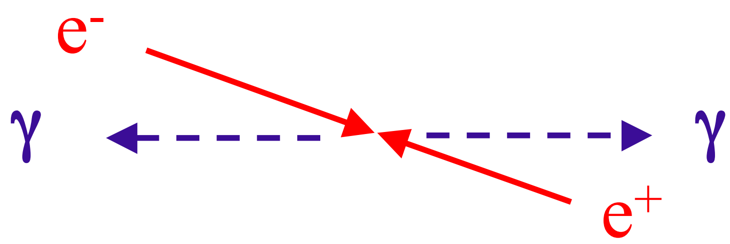


Production Mechanisms of Photons

Hot plasma (surface of stars)

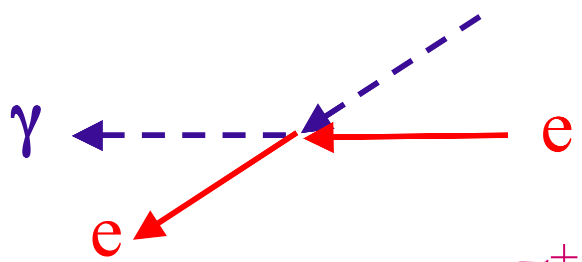


Annihilation of matter/antimatter

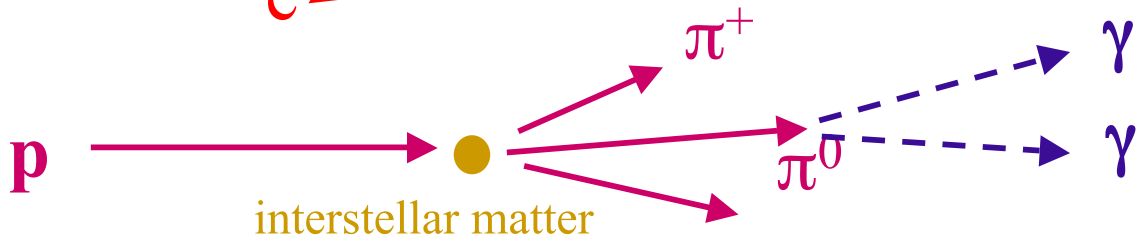


Bremsstrahlung /
Synchrotron Radiation

Inverse Compton Scattering



High energy showers



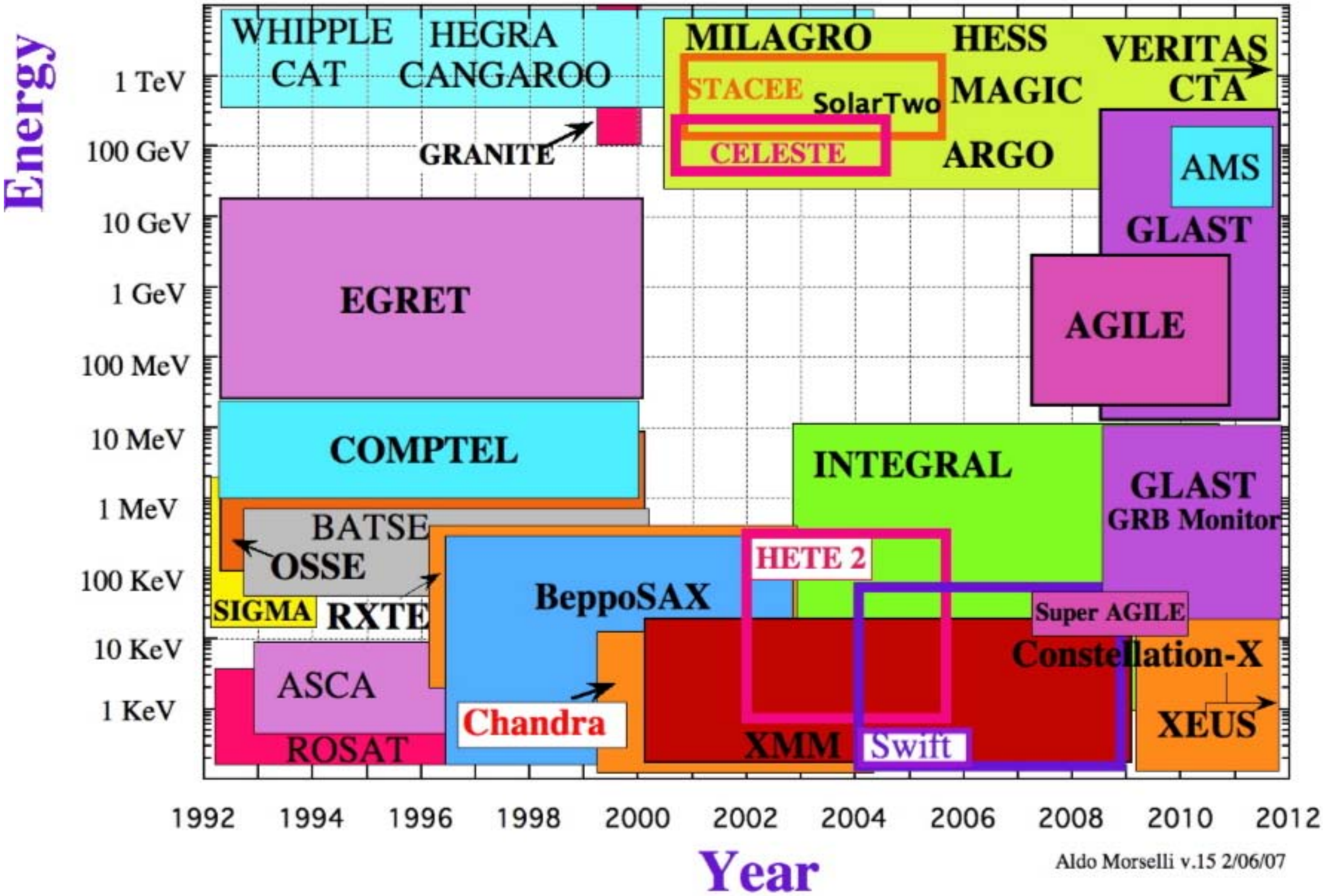
GeV Gamma Rays

High-energy gamma rays are primarily produced by interactions of energetic particles:

- **typical processes are inelastic nuclear collisions (pion production), inverse Compton scattering, curvature and synchrotron radiation.**

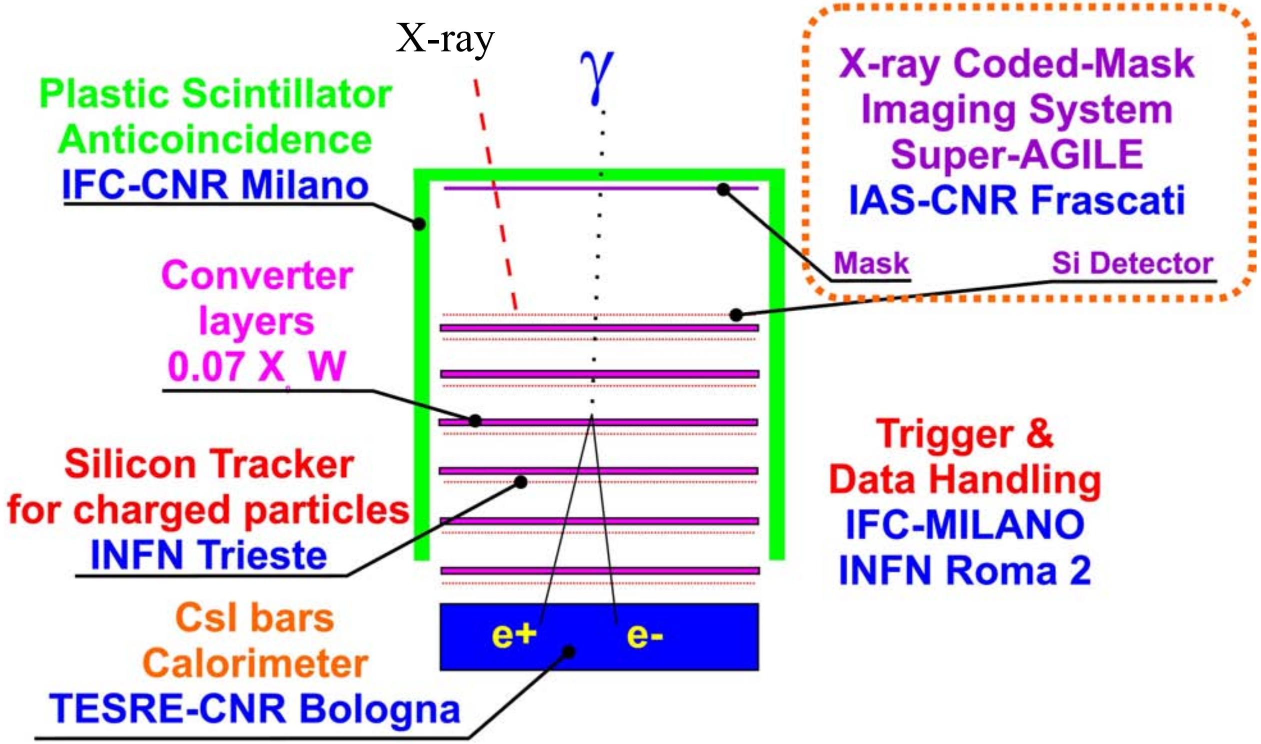
The Universe is mainly transparent to gamma rays with energies less than 20 GeV, so they can probe distant or obscured regions:

- **potential to image regions of cosmic ray acceleration and interaction.**

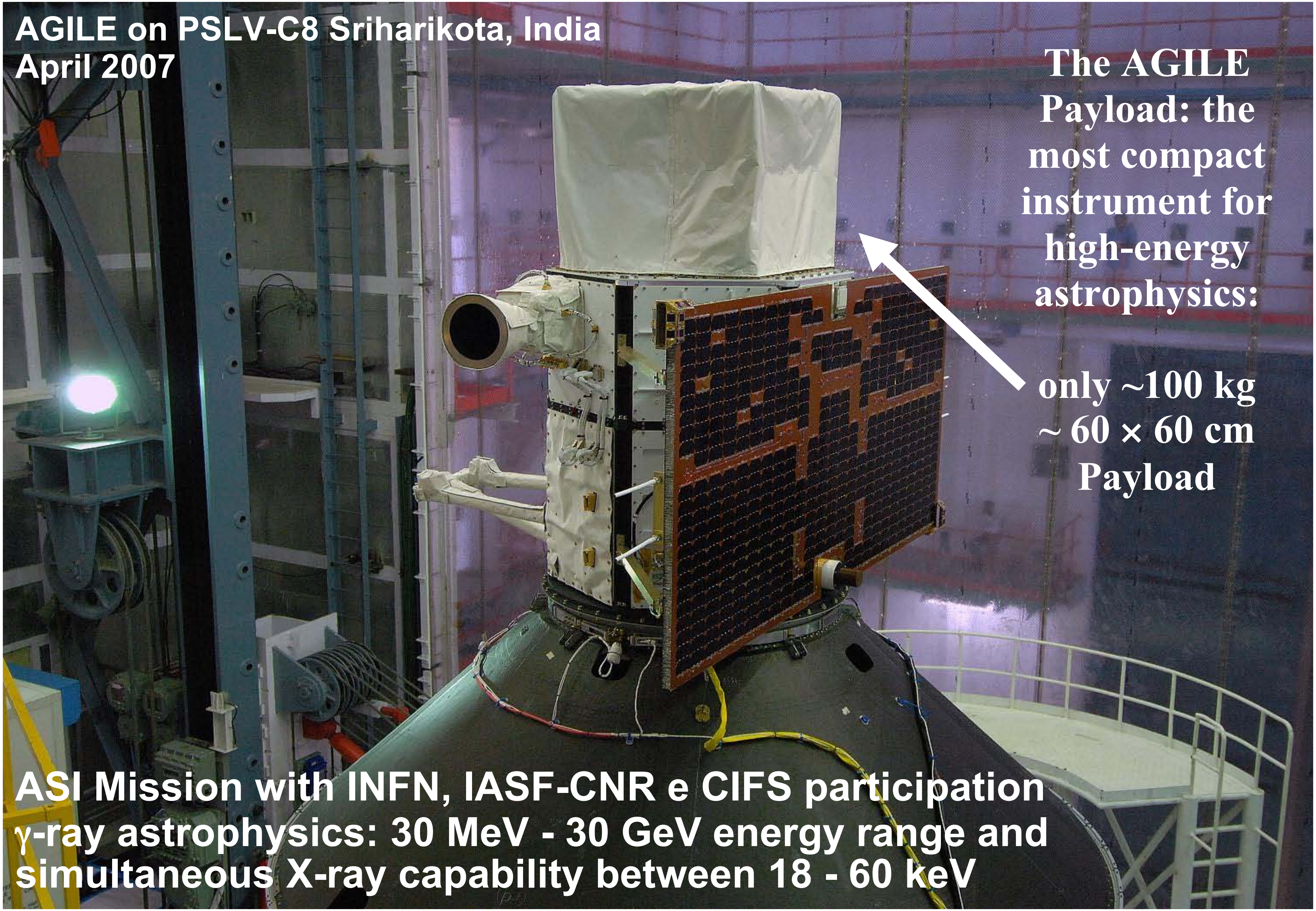

Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
CAT
HEGRA
CANGAROO
GRANITE
MILAGRO
STACEE
SolarTwo
CELESTE
HESS
MAGIC
ARGO
VERITAS
CTA
AMS
GLAST
EGRET
AGILE
COMPTEL
INTEGRAL
GLAST
GRB Monitor
BATSE
OSSE
SIGMA
RXTE
BeppoSAX
HETE 2
Super AGILE
Constellation-X
ASCA
ROSAT
Chandra
XMM
Swift
XEUS
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Year
Aldo Morselli v.15 2/06/07

Working principle of AGILE and Fermi/GLAST:
PAIR PRODUCTION $\gamma \Rightarrow e^+ + e^-$

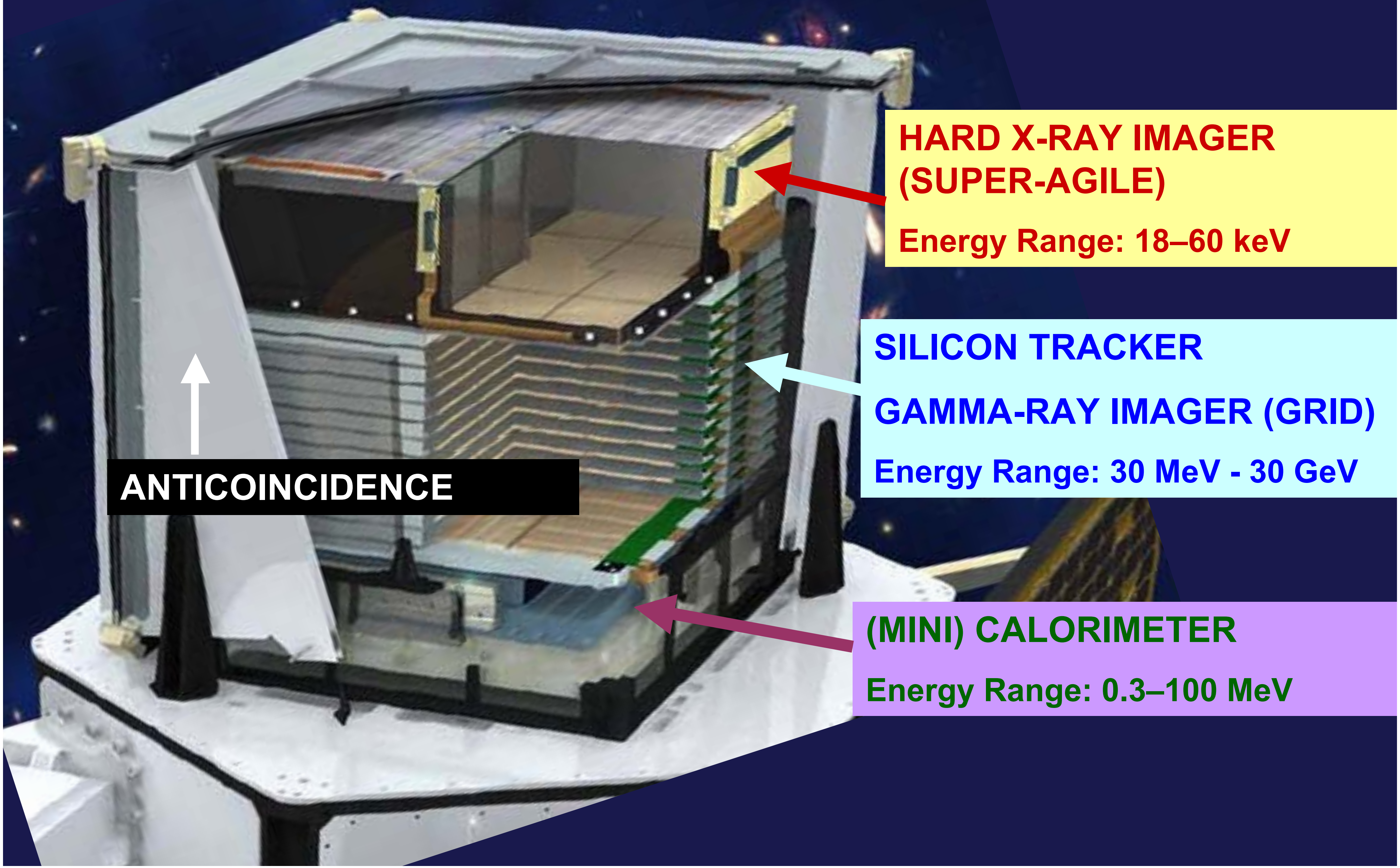
- **Pair production Si-Tracker telescopes** with a calorimeter to measure energy and a scintillator system to veto charged particles background
- **Charged particle background: 10^4-10^5 times larger than the γ signal**
- Trigger based on the silicon planes
- Low power electronics



AGILE P/L components


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, IASF-CNR e CIFS participation
γ-ray astrophysics: 30 MeV - 30 GeV energy range and simultaneous X-ray capability between 18 - 60 keV

AGILE: inside the cube…

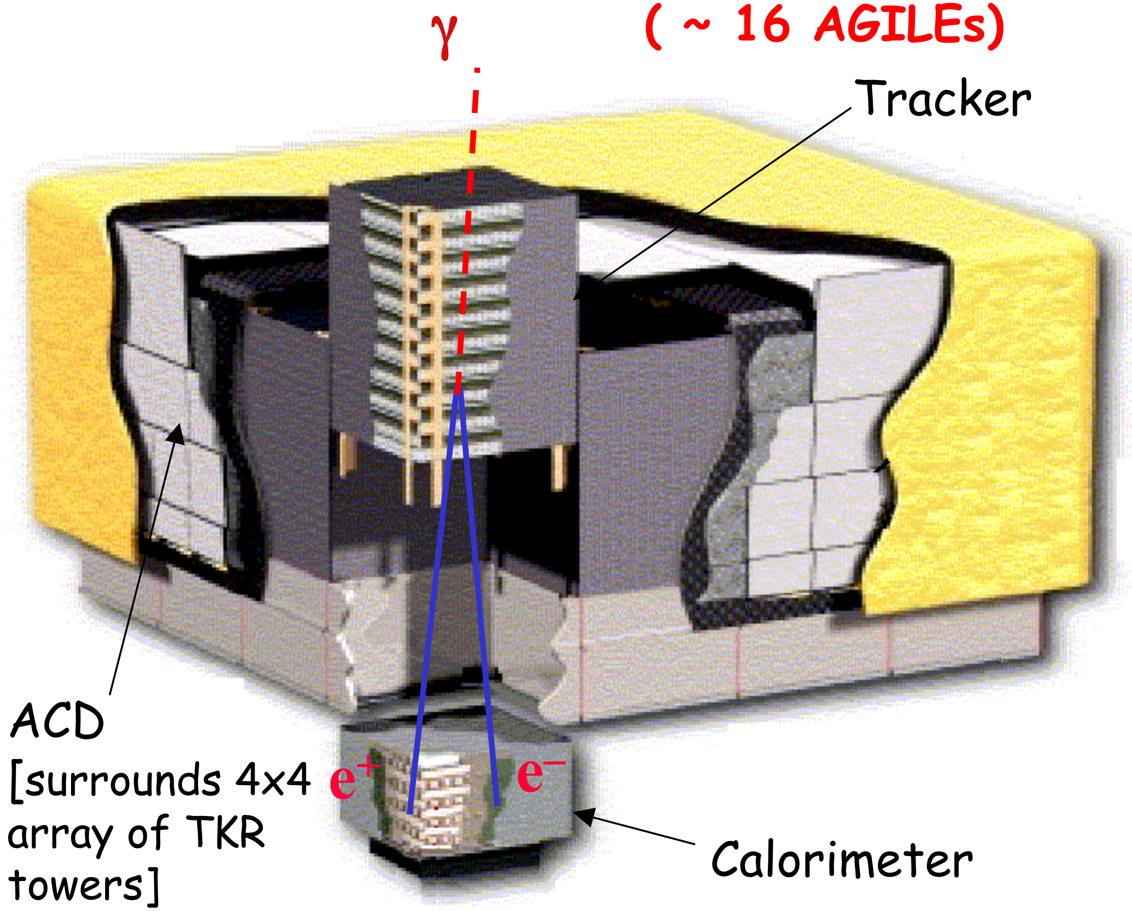


Fermi (formerly GLAST): launched June 11, 2008

(~ 16 AGILEs)

KEY FEATURES

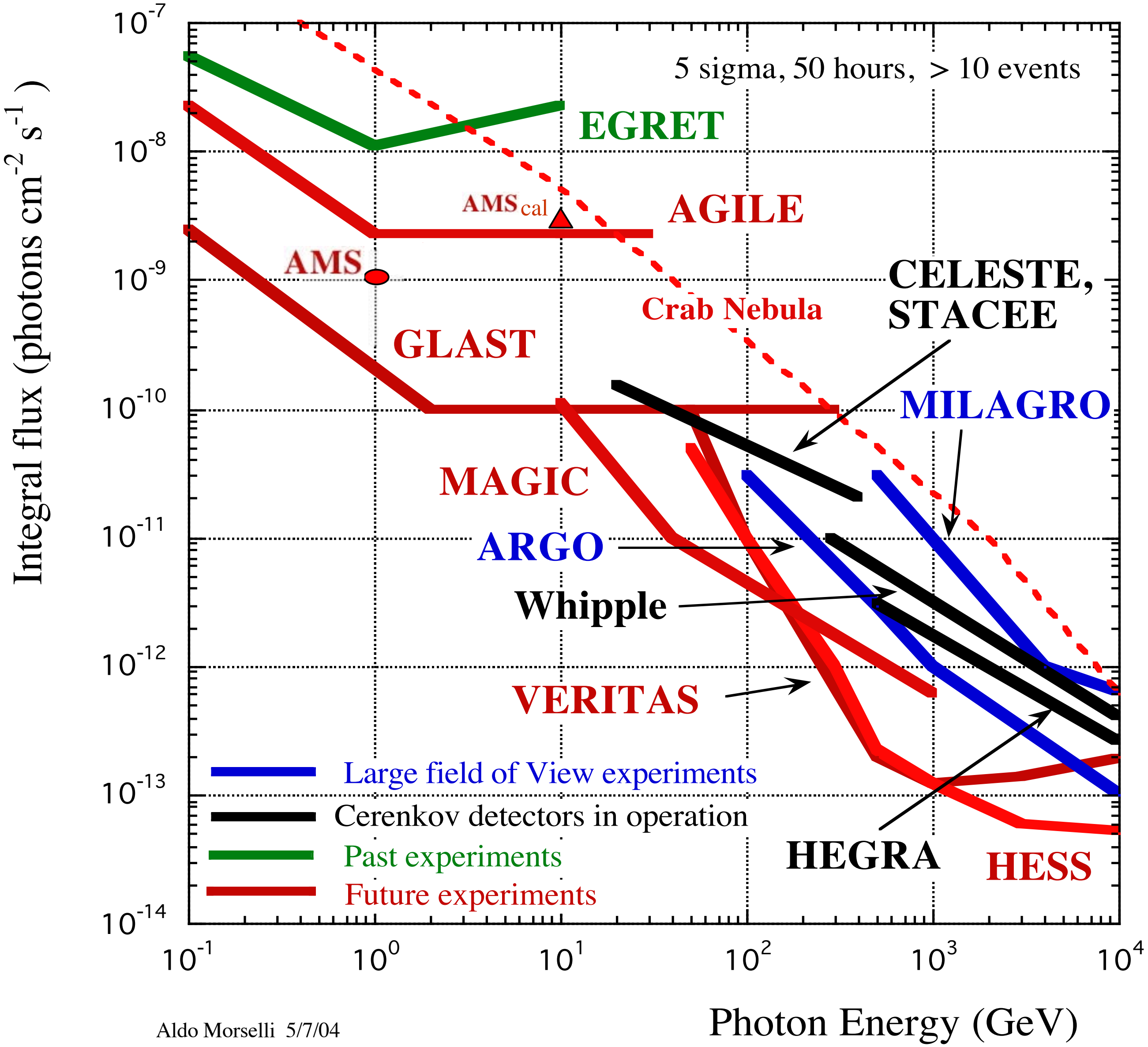
- 20 MeV -> >300 GeV
- 2.4 Steradian field of view
- Operated in scanning mode, so views the entire sky every 3 hours.
- Peak effective area ~8000 cm^2 (> 1GeV)
- Single photon angular resolution 0.8^o at 1 GeV, better at higher energies.
- Source location capability 1-10 arcmin.
- Energy resolution 10-20%



Total power 650 W
Total mass 2,789 kg

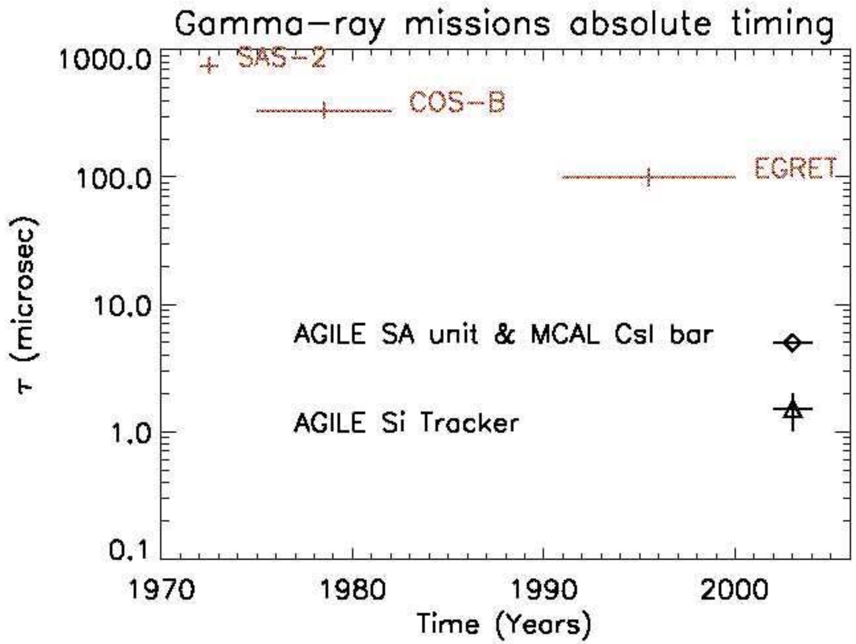
Fermi Gamma-ray Space Telescope

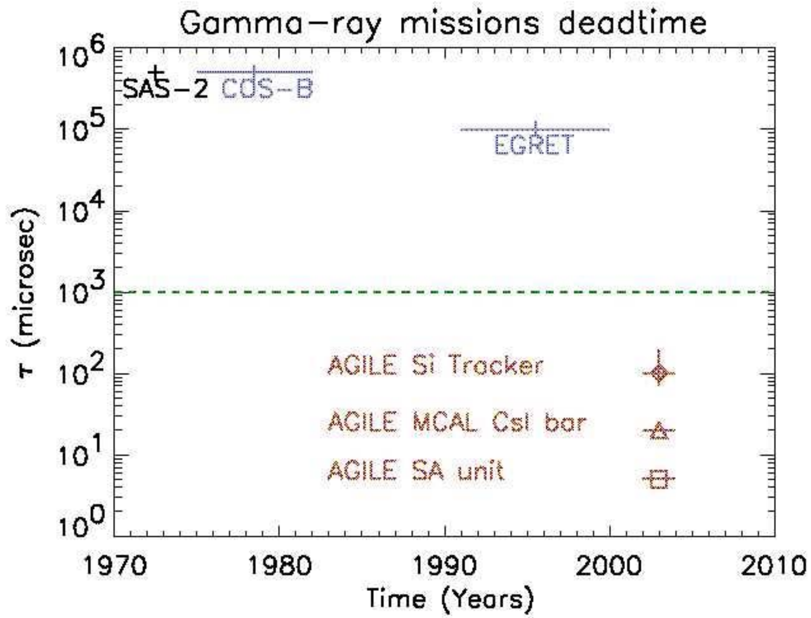
Integral sensitivity of γ-ray detectors



All sensitivities are at 5σ. Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations. Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO, AMS) are for 1 years of observation.

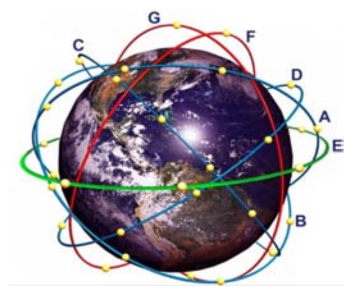
AGILE Temporal Resolution





AGILE fast timing allows, for the first time, a search for sub-millisecond transients in the γ-ray energy range.

ORBCOMM ***AGILE*** **Fast Link**

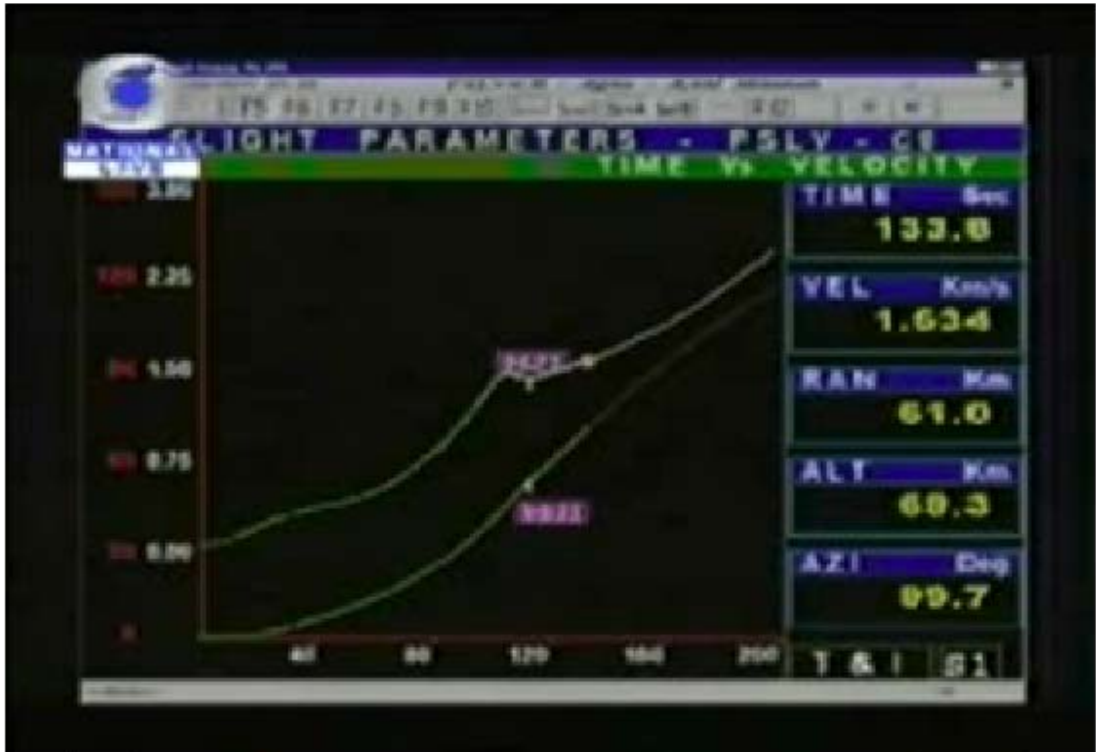


April 2007

Shriharikota, India :
closing the AGILE Payload…

April 23, 2007: Launch!

Equatorial orbit: 550 Km, < 3º inclination angle



AGILE launch event as seen **live** in Telespazio Control Center in Fucino ....

Personal though:

1999-2007: more than 8 years of work hanged on a two-hour show…

"La sofisticata macchina è partita alle 12 (ora italiana) dalla base di Shriharikota in India, ventitre minuti dopo è entrata in orbita a circa 550 Km di altezza sull'Equatore e **alle 13,30 ha mandato a Terra i primi impulsi!"**

E' fatta!

From Italian press release:

"Il satellite AGILE ora sta girando attorno all'equatore terrestre e passa sopra la stazione di terra ASI a Malindi circa **ogni ora e mezza**. Fin dal primo "contatto" invia i suoi dati ogni ora e mezza al Fucino e da li **all'ASI Science Data Center (ASDC)**"

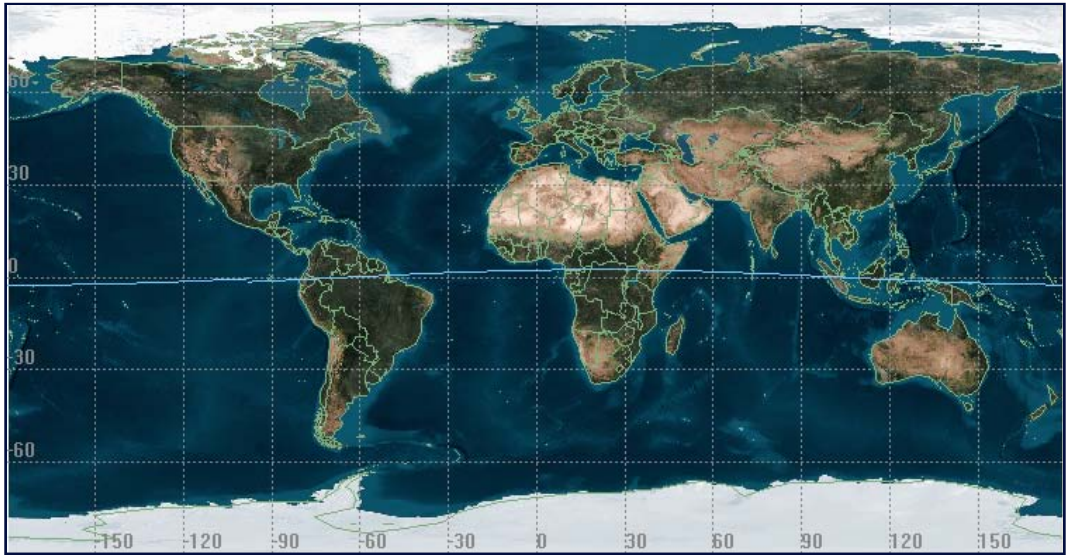
AGILE orbital parameters

Baseline equatorial orbit: 550 Km, 3º inclination

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

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

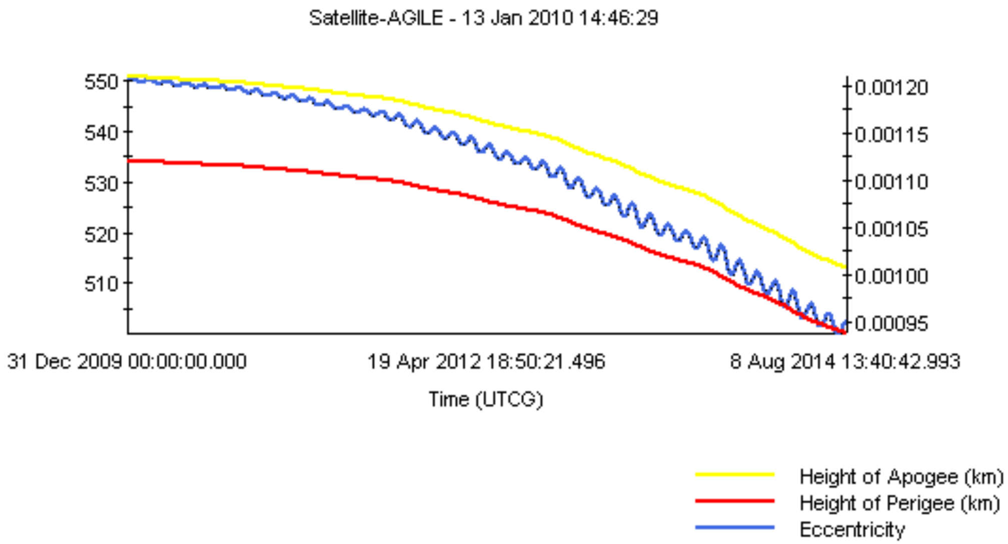
Eccentricity: 0.002 (±0.0015)
Requirement: < 0.1°

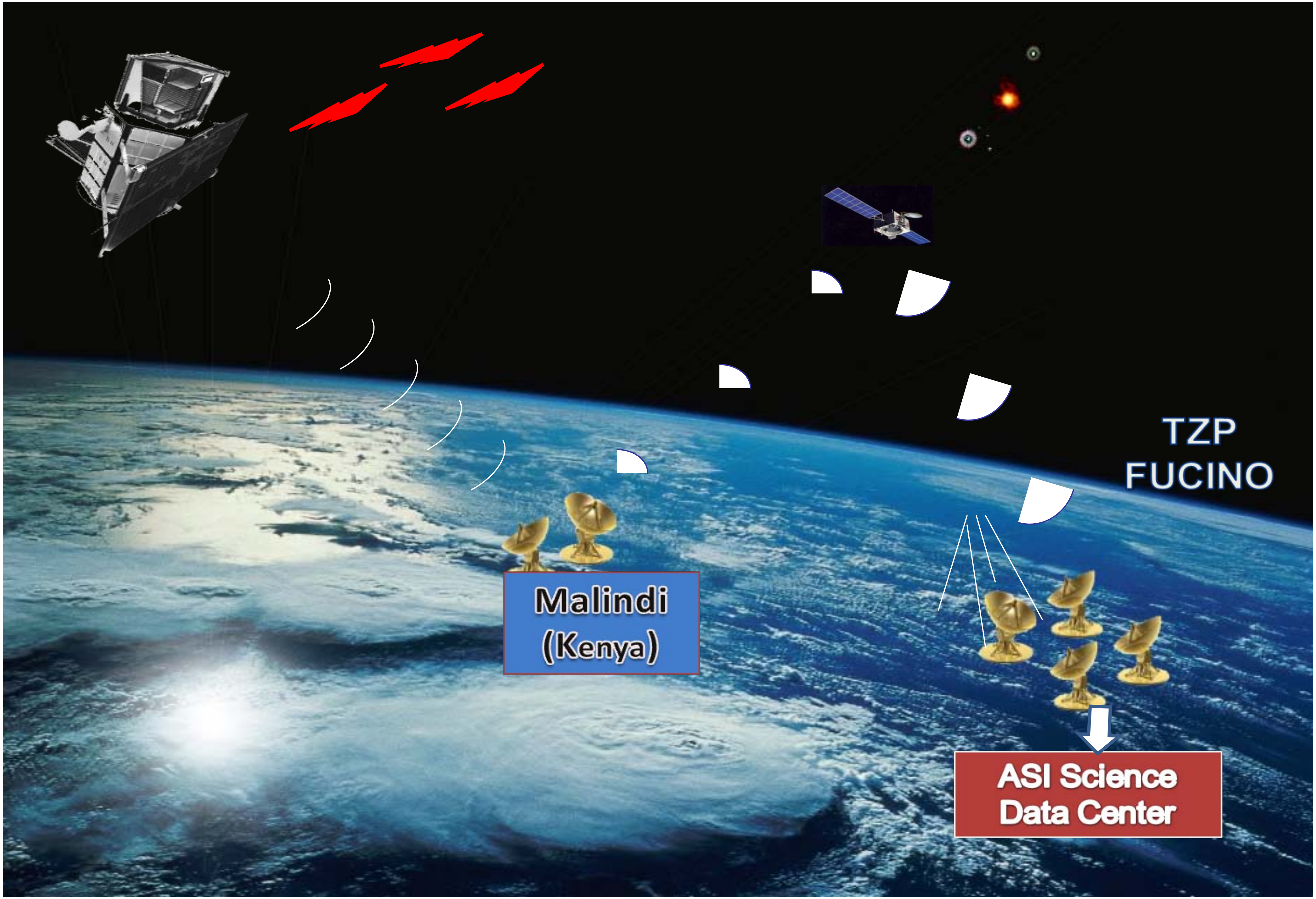


TPZ orbital decay estimate:

Height < 500Km **08 Agosto 2014**

(Jan 13, 2010 **updated estimate**, using recent solar flux "Schatten" forecasts + 2σ)



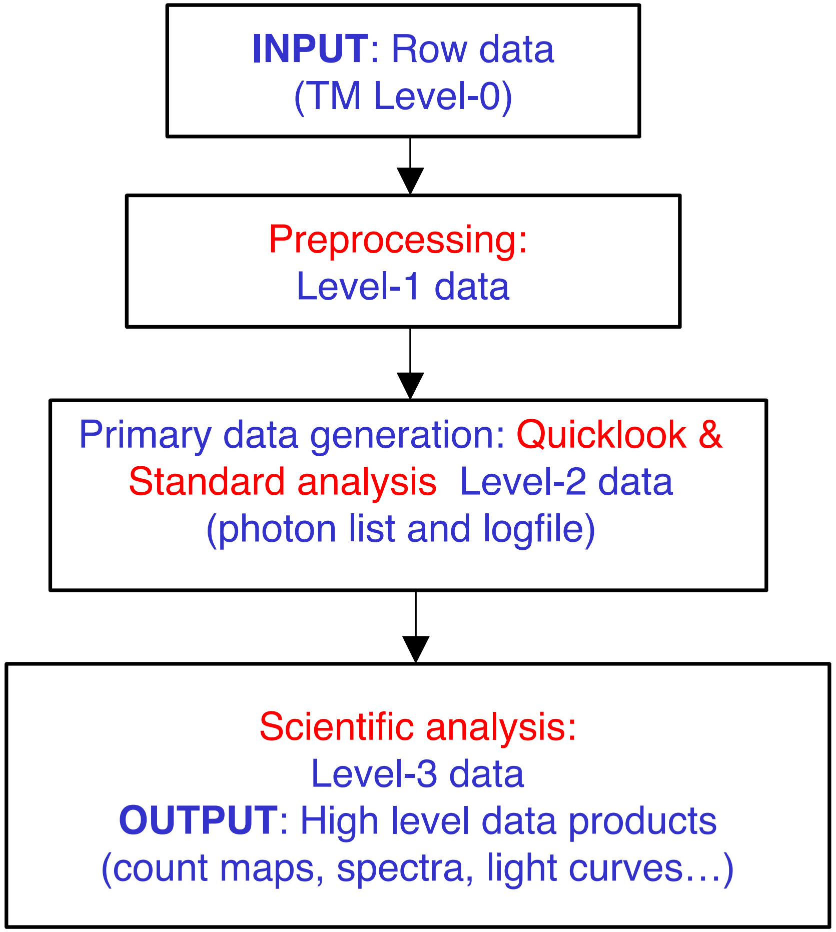

TZP
FUCINO
Malindi
(Kenya)
ASI Science
Data Center

The AGILE Data Center at ASDC – ESRIN

- The ADC, based at ASDC-ESRIN, is in charge of all the scientific oriented activities related to the analysis and archiving of AGILE data:

From scientific telemetry (TM) Level–0:

- ✓ Preprocessing → Level-1 data
- ✓ Quick-Look Analysis (transient detection)
- ✓ Standard analysis → Level-2 data (photon list)
- ✓ Scientific analysis (source detection, diffuse gamma-ray background)
- ✓ Archiving and distributing all scientific AGILE data

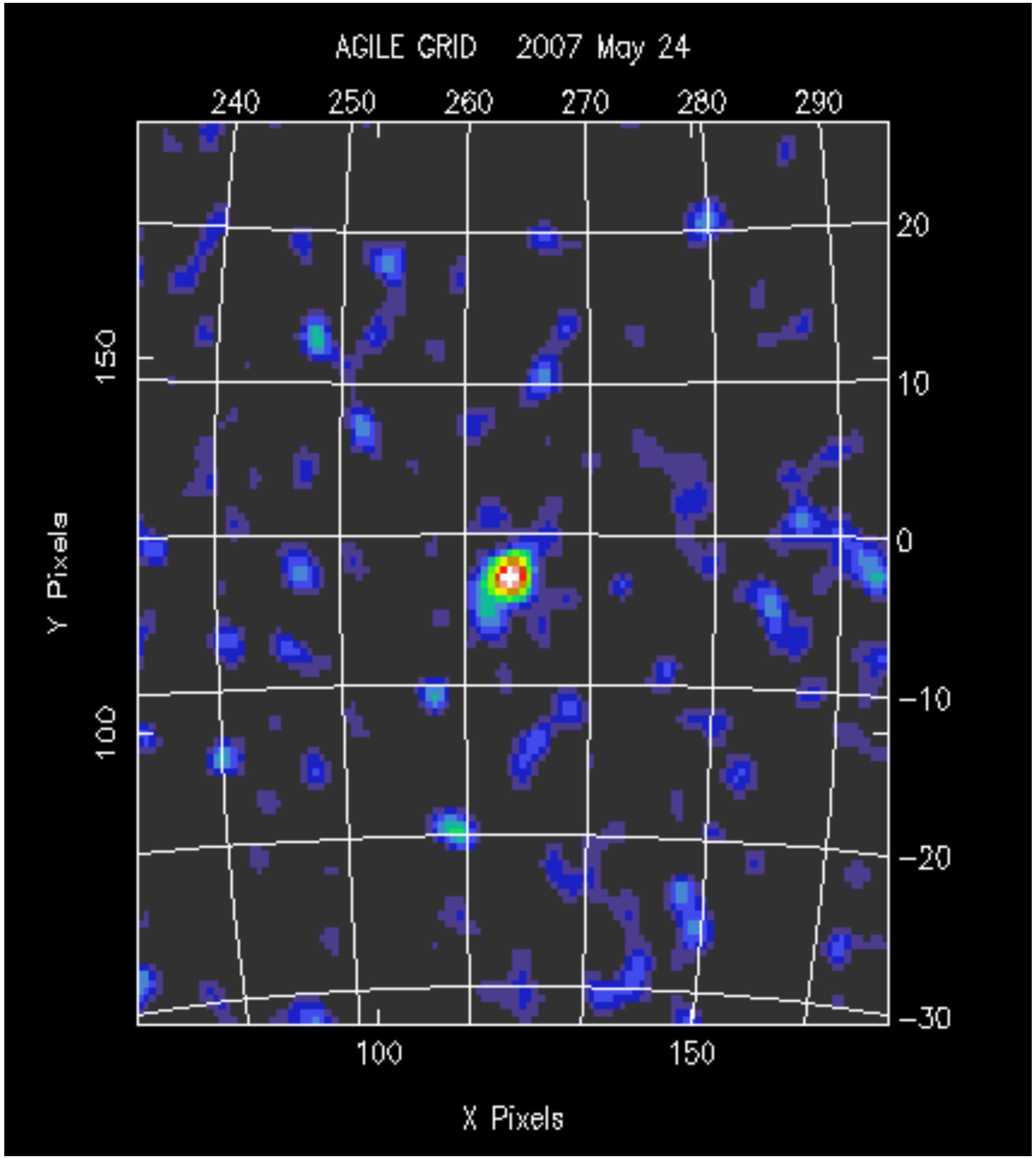


Commissioning Phase:

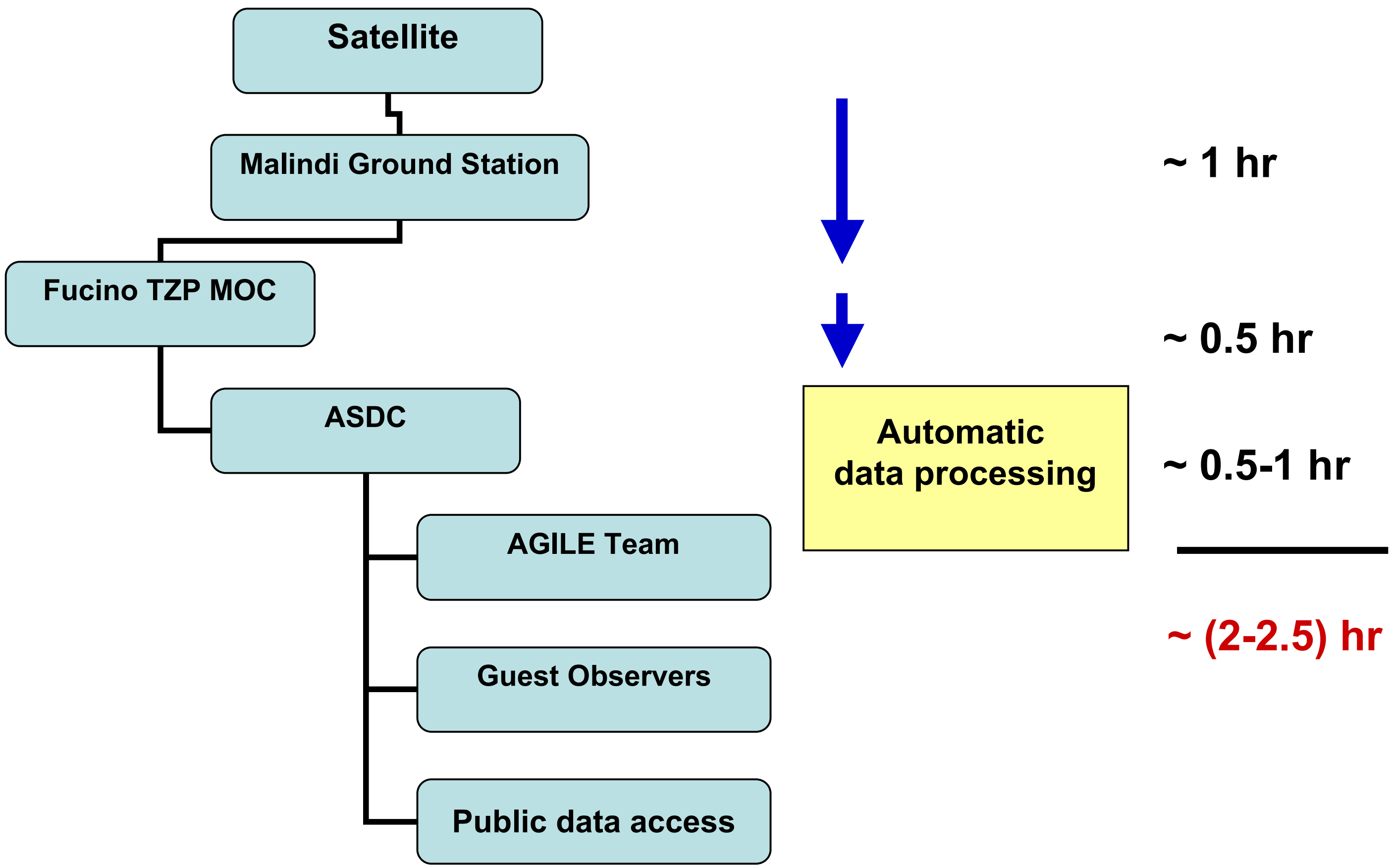
First GRID light

AGILE **Vela PSR** Count Map **by ADC, 24/5/2007**

(~ 20000 s)



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



Record for a gamma-ray mission!

AGILE Science Alert System

- The system is distributed among the ADC @ ASDC and the AGILE Team Institutes

- Automatic Alerts to the AGILE Team are generated within **T_0 + 45 min (SA) and T_0 + 100 min (GRID)**

- GRID Alerts are sent via email (and sms) both on a contact-by-contact basis and on a daily timescale

- Refined manual analysis on most interesting alerts performed every day (daily monitoring)

AGILE: 4th years in orbit

• AGILE demonstrates for the first time the covering of ~ 1/5 of the entire gamma-ray sky (FoV ~ 2.5 sr) with excellent angular resolution and competitive sensitivity.

• AGILE shows for the first time an optimal performance of its gamma-ray and hard X-ray imagers.

• **> 20000 orbits TODAY!!, March 10, 2011 ,01:33 UT**

• **Pointing observation** mode up to October 18, 2009 and **spinning observation mode** since October 2009.

• **Very good scientific performance, especially at ~ 100 MeV**

• **Guest Observer Program open to the scientific community:**

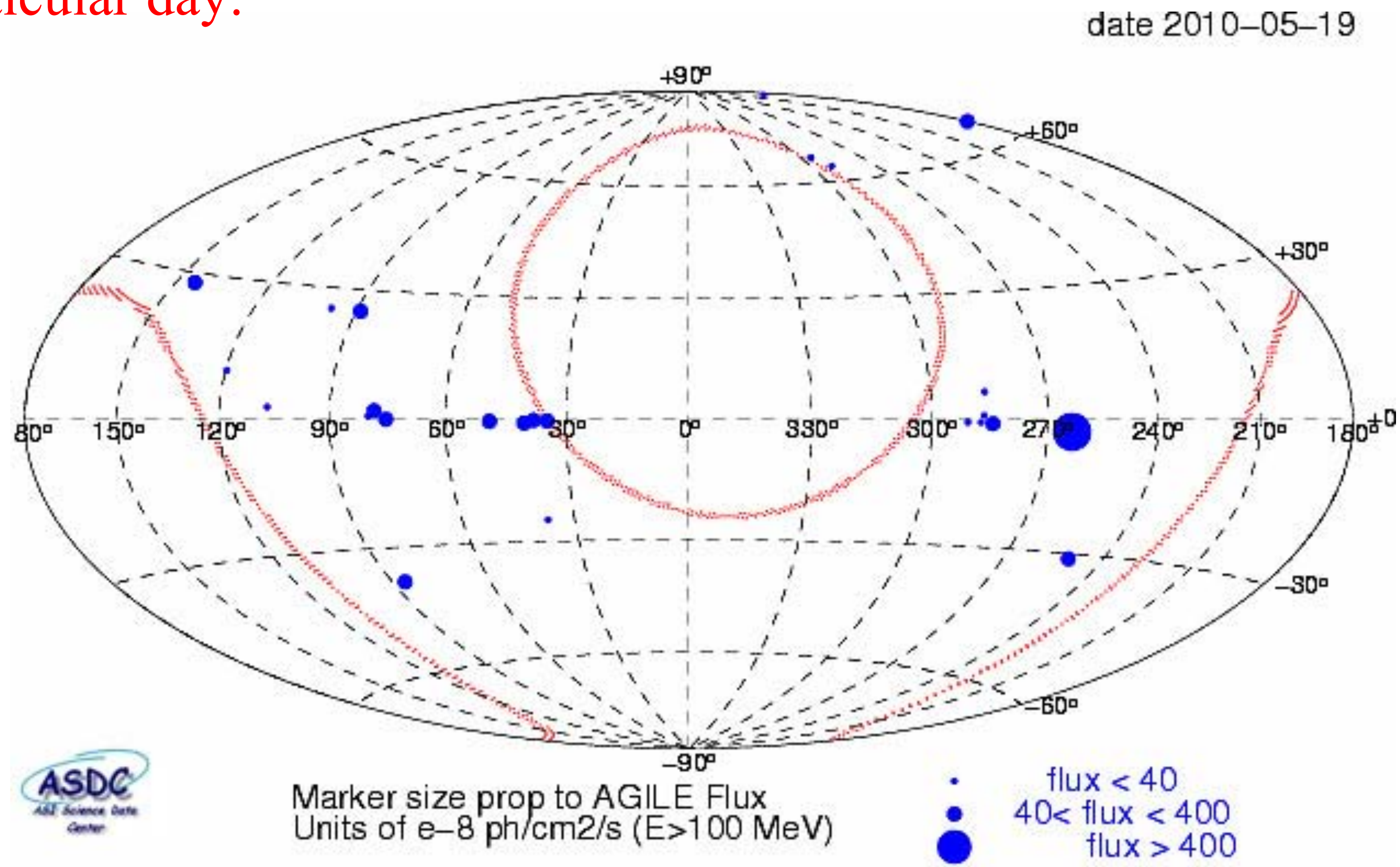
Cycle-1 completed, Dec. 1, 2007 – Nov. 30, 2008

Cycle-2: completed, Dec. 1, 2008 – Nov 30, 2009

Cycle-3: completed, Dec. 1, 2009 – Nov 30, 2010

Cycle-4: on-going, Dec. 1, 2000 – Nov 30, 2011

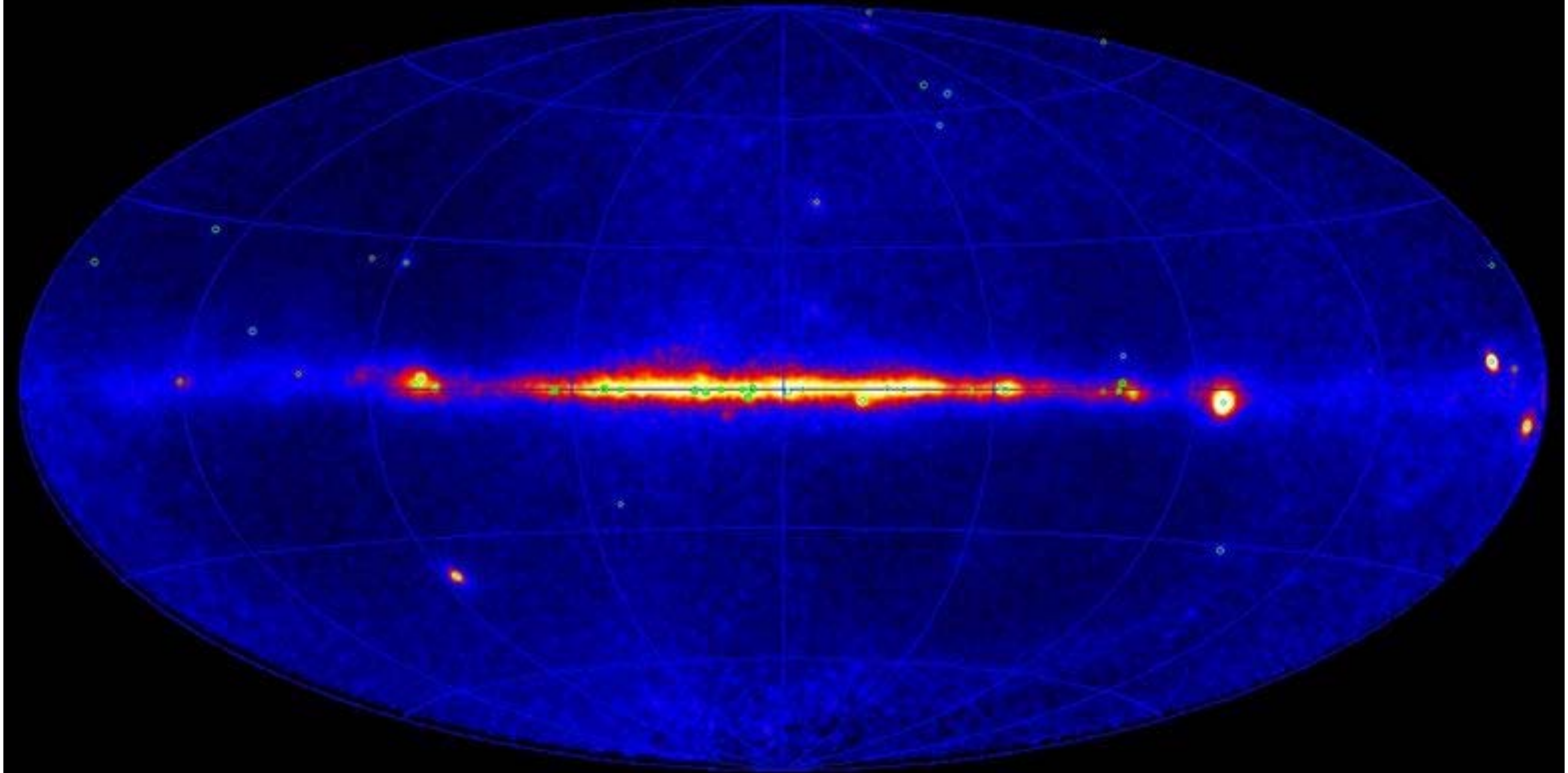
On November 4, 2009, toward the end of Cycle-2, AGILE scientific operations were reconfigured following a malfunction of the reaction wheel. The satellite is currently operating in a **spinning observing mode** and it is now surveying a large fraction of the sky every day. Example of the AGILE spinning sky-view on a particular day:

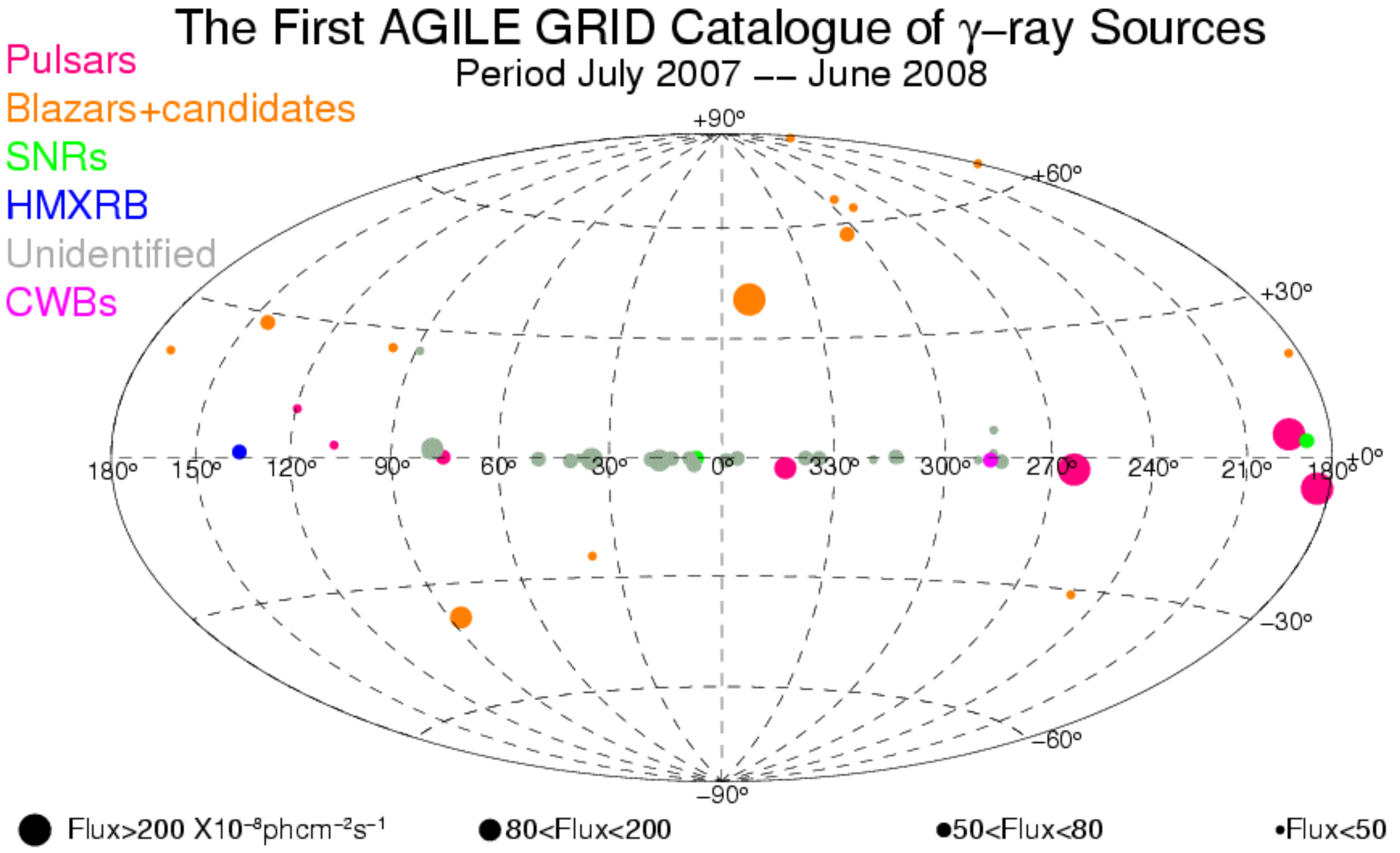


On December 3-4, 2009 the AGILE satellite detected the strongest γ-ray flare ever observed (E > 100 MeV). The flaring γ-ray source is in the active galaxy 3C454.3 (z=0.859, $F_\gamma > 2 \times 10^{-5}$ ph cm^{-2} s^{-1}, $L_{iso} = 6 \times 10^{49}$ erg s^{-1})

AGILE Total Intensity Map:

Pointing + Spinning (up to Oct 15, 2010)





- **C. Pittori et al., A&A 506, 2009 - arXiv:0902.2959**

First AGILE Catalog of High Confidence Gamma-Ray Sources

• **First year of scientific operations:** observations from July 9, 2007 to June 30, 2008. **Conservative analysis,** with a high-quality gamma event filter.

47 high confidence sources E> 100 MeV:

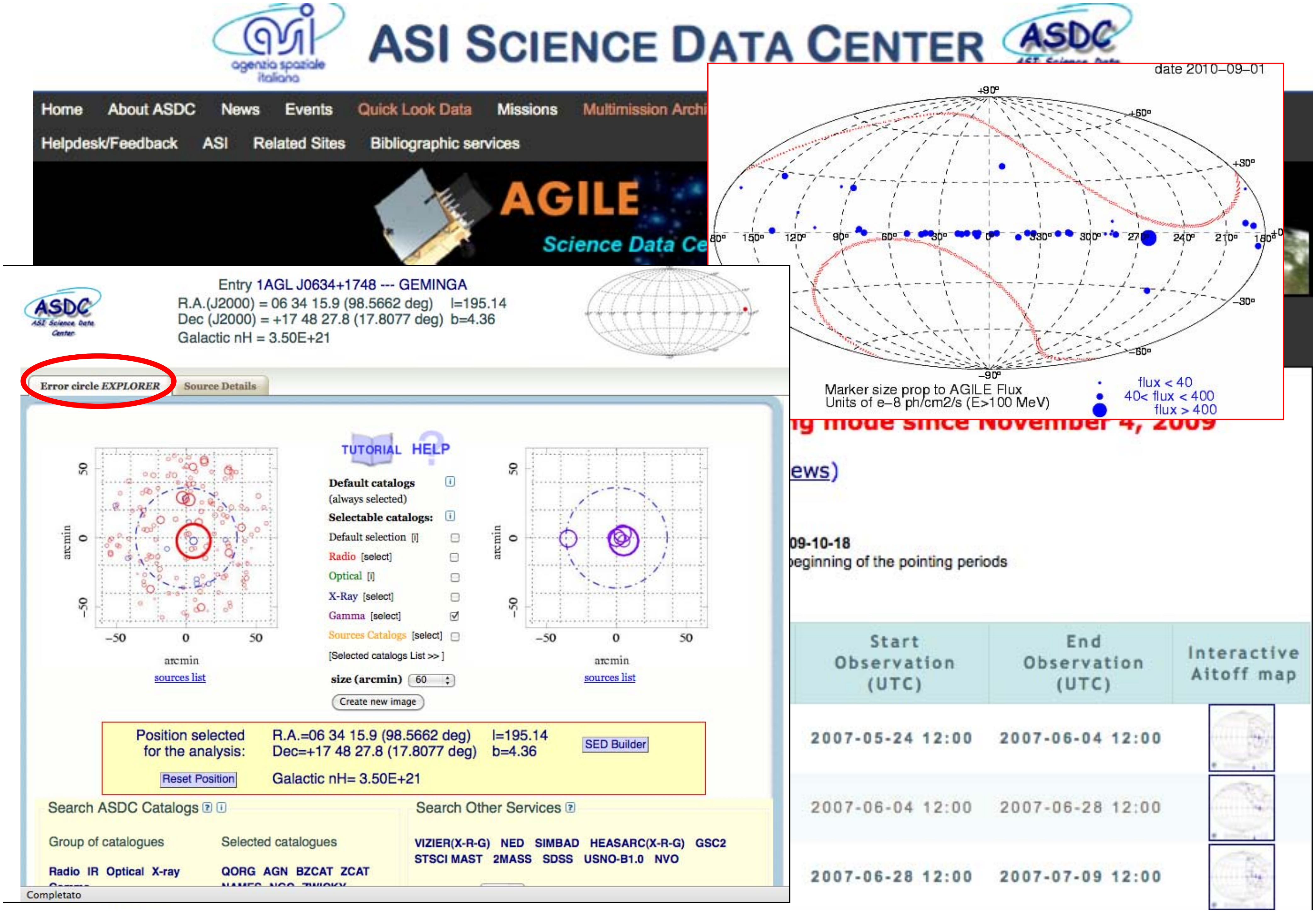
• 21 confirmed and candidate **Pulsars**,
• 13 **Blazars** (7FSRQ, 4BL Lacs, 2 unknown type),
• 2 possible **HMXRB**s,
• 2 possible **SNR**s,
• 1 **Colliding-wind Binary System** (Eta-Car)
• 8 **Unidentified** sources.

Interactive on-line version of the the First AGILE-GRID Catalog from ADC web page http://agile.asdc.asi.it/

The First AGILE-GRID Source catalog at ASDC – Netscape

http://www.asdc.asi.it/agilebrightcat/

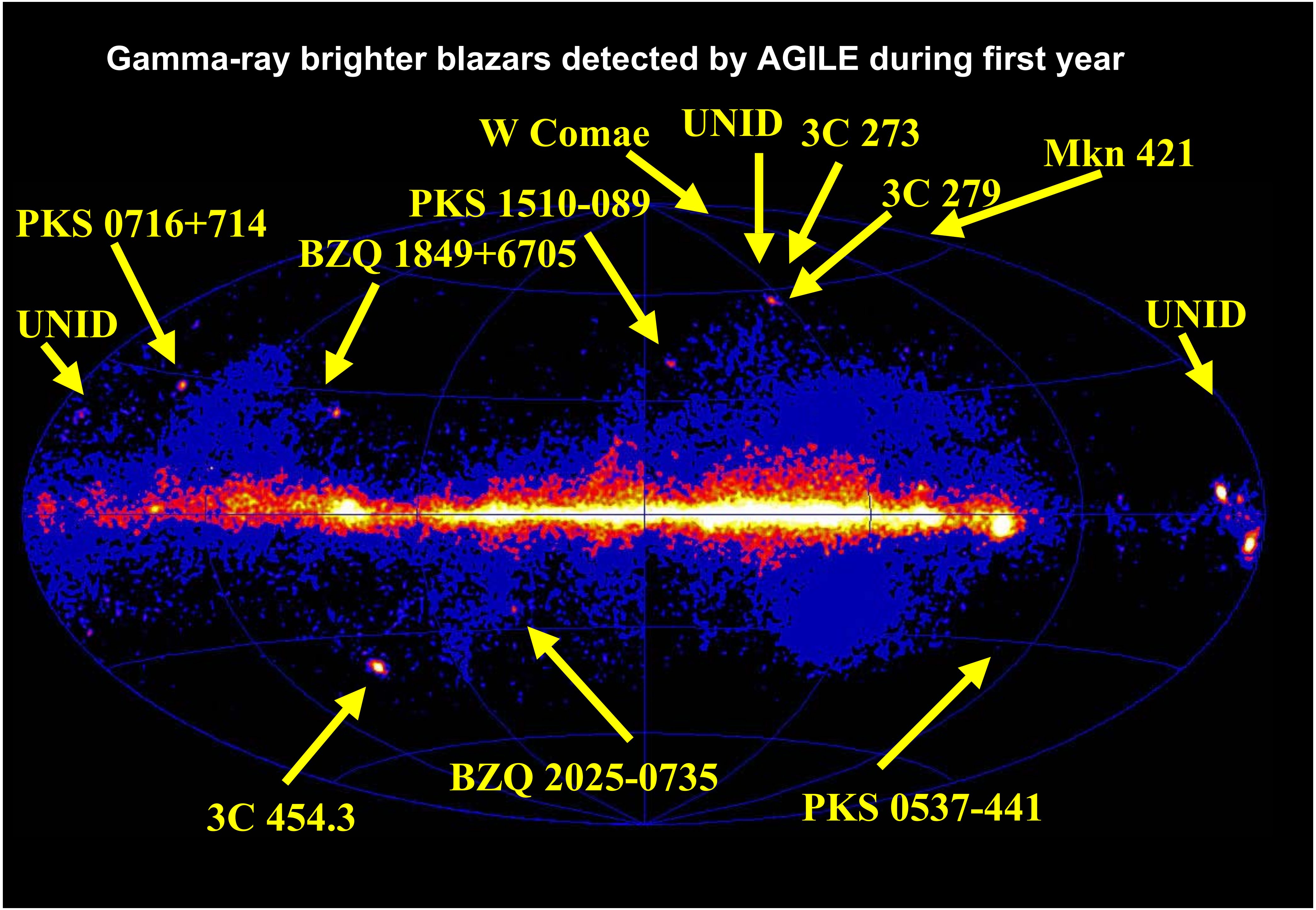
Entry number		AGILE Name	RA (J2000) hh mm ss.d	Dec (J2000) dd mm ss.d	Position Error 95% (deg)	sqrt(TS)	Mean Flux E>100MeV (10^-8 ph/cm2/s)	Mean Ring Exposure (cm2 day)	Classification	Confirmed Counterpar
Subset selection mode: inclusive					Stat	Stat		Stat		
1 Select	ASDC Data Explorer	1AGL J0006+7311	00 06 34.2	+73 11 06.6	0.63	5.1	23 +/- 5	3486	GammaPulsar*	CTA1
2 Select	ASDC Data Explorer	1AGL J0242+6111	02 42 13.6	+61 11 06.7	0.64	5.3	54 +/- 12	1356	HMXRB	LSI+61303
3 Select	ASDC Data Explorer	1AGL J0535+2205	05 35 05.9	+22 05 41.7	0.09	47.2	220 +/- 15	3229	Pulsar	Crab
4 Select	ASDC Data Explorer	1AGL J0538-4424	05 38 29.6	-44 24 17.8	0.5	5.9	43 +/- 10	934	Blazar-BLLac	PKS0537-4
5 Select	ASDC Data Explorer	1AGL J0617+2236	06 17 21.7	+22 36 14.2	0.27	9.9	69 +/- 9	3229	Unclassified	---
6 Select	ASDC Data Explorer	1AGL J0634+1748	06 34 15.8	+17 48 27.7	0.05	63	320 +/- 10	3229	Pulsar	GEMINGA
7 Select	ASDC Data Explorer	1AGL J0657+4554	06 57 29.2	+45 54 14.5	0.55	5.8	31 +/- 6	2288	Blazar*	---
8 Select	ASDC Data Explorer	1AGL J0714+3340	07 14 29.4	+33 40 37.3	0.85	4.2	18 +/- 5	2978	Blazar*	---
9 Select	ASDC Data Explorer	1AGL J0722+7125	07 22 22.9	+71 25 31.1	0.37	10.9	68 +/- 9	1614	Blazar-BLLac	S50716+71
10 Select	ASDC Data Explorer	1AGL J0835-4509	08 35 13.3	-45 09 09.0	0.09	41.7	780 +/- 32	933	Pulsar	VelaPSR
11 Select	ASDC Data Explorer	1AGL J1022-5822	10 22 08.8	-58 22 17.0	0.36	10.1	59 +/- 7	5616	Unclassified	---


agenzia spaziale italiana
ASI SCIENCE DATA CENTER
ASDC
Home About ASDC News Events Quick Look Data Missions Multimission Archi
Helpdesk/Feedback ASI Related Sites Bibliographic services
AGILE
Science Data Ce
date 2010–09–01
Marker size prop to AGILE Flux
Units of e–8 ph/cm2/s (E>100 MeV)
flux < 40
40< flux < 400
flux > 400
Entry 1AGL J0634+1748 --- GEMINGA
R.A.(J2000) = 06 34 15.9 (98.5662 deg) l=195.14
Dec (J2000) = +17 48 27.8 (17.8077 deg) b=4.36
Galactic nH = 3.50E+21
Error circle EXPLORER
Source Details
TUTORIAL HELP
Default catalogs
(always selected)
Selectable catalogs:
Default selection [i]
Radio [select]
Optical [i]
X-Ray [select]
Gamma [select]
Sources Catalogs [select]
[Selected catalogs List >>]
size (arcmin) 60
Create new image
arcmin
sources list
Position selected for the analysis:
R.A.=06 34 15.9 (98.5662 deg) l=195.14
Dec=+17 48 27.8 (17.8077 deg) b=4.36
Galactic nH= 3.50E+21
SED Builder
Reset Position
Search ASDC Catalogs
Group of catalogues
Selected catalogues
Radio IR Optical X-ray
QORG AGN BZCAT ZCAT
Search Other Services
VIZIER(X-R-G) NED SIMBAD HEASARC(X-R-G) GSC2
STSCI MAST 2MASS SDSS USNO-B1.0 NVO
Completato
ng mode since November 4, 2009
ews)
09-10-18
beginning of the pointing periods
Start Observation (UTC)
End Observation (UTC)
Interactive Aitoff map
2007-05-24 12:00 2007-06-04 12:00
2007-06-04 12:00 2007-06-28 12:00
2007-06-28 12:00 2007-07-09 12:00

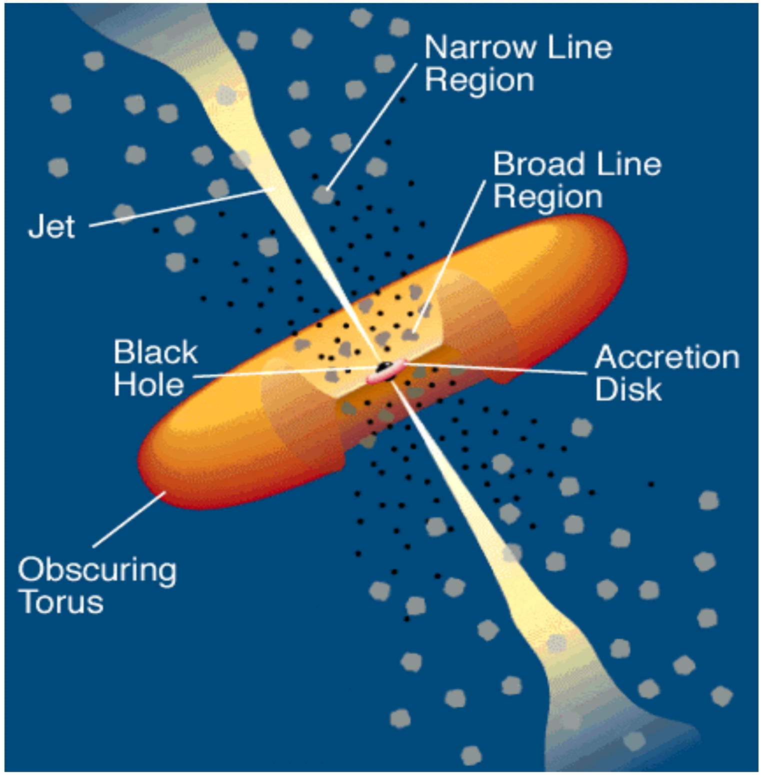
AGILE HIGHLIGHTS

Main topics and AGILE discoveries

- **Bright gamma-ray blazars**
(3C 454.3, PKS 1510-089, TX 0716+714, Mrk 421,…)
- **Several new pulsars (one millisecond pulsar in the globular cluster M28)**
- **Discovery of E > 100 MeV emission in PWNs (Vela X)**
(A. Pellizzoni et al., Science, 2010)
- **Discovery of γ-ray transients in the Galaxy**
- **Colliding Wind Binary gamma-ray emission (η-Car), Microquasar studies (Cygnus X-1 and Cygnus X-3)**
- **SNRs and origin of cosmic rays (W28) (A. Giuliani et al. A&A 2010)**
- **GRBs, millisecond triggers, Terrestrial γ-ray Flashes**


Gamma-ray brighter blazars detected by AGILE during first year
W Comae
UNID
3C 273
Mkn 421
PKS 1510-089
3C 279
PKS 0716+714
BZQ 1849+6705
UNID
UNID
3C 454.3
BZQ 2025-0735
PKS 0537-441

Blazars



Almost all galaxies contain a massive black hole
- 99% of them are (almost) silent (e.g. our Galaxy)

- 1% per cent is active (mostly radio-quiet AGNs): BH+disk: most of the emission in the UV-X-ray band

- 0.1% is radio loud: jets mostly visible in the radio

Blazar characteristics:

- Compact radio core, flat or inverted spectrum
- Extreme variability (amplitude and t) at all frequencies
- High optical and radio polarization

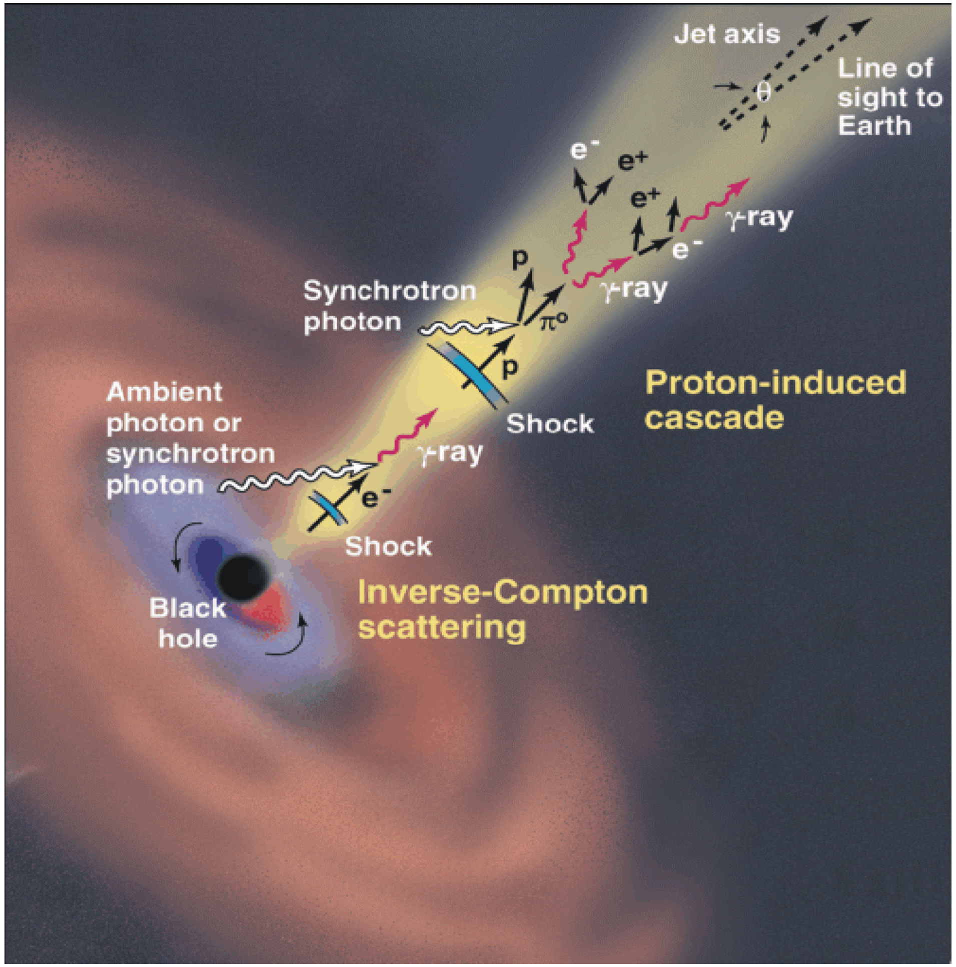
FSRQs: bright broad (1000-10000 km/s) emission lines often evidences for the "blue bump" (acc. disc)

BL Lac: weak (EW<5 Å) emission lines no signatures of accretion

Open questions about Blazar Physics

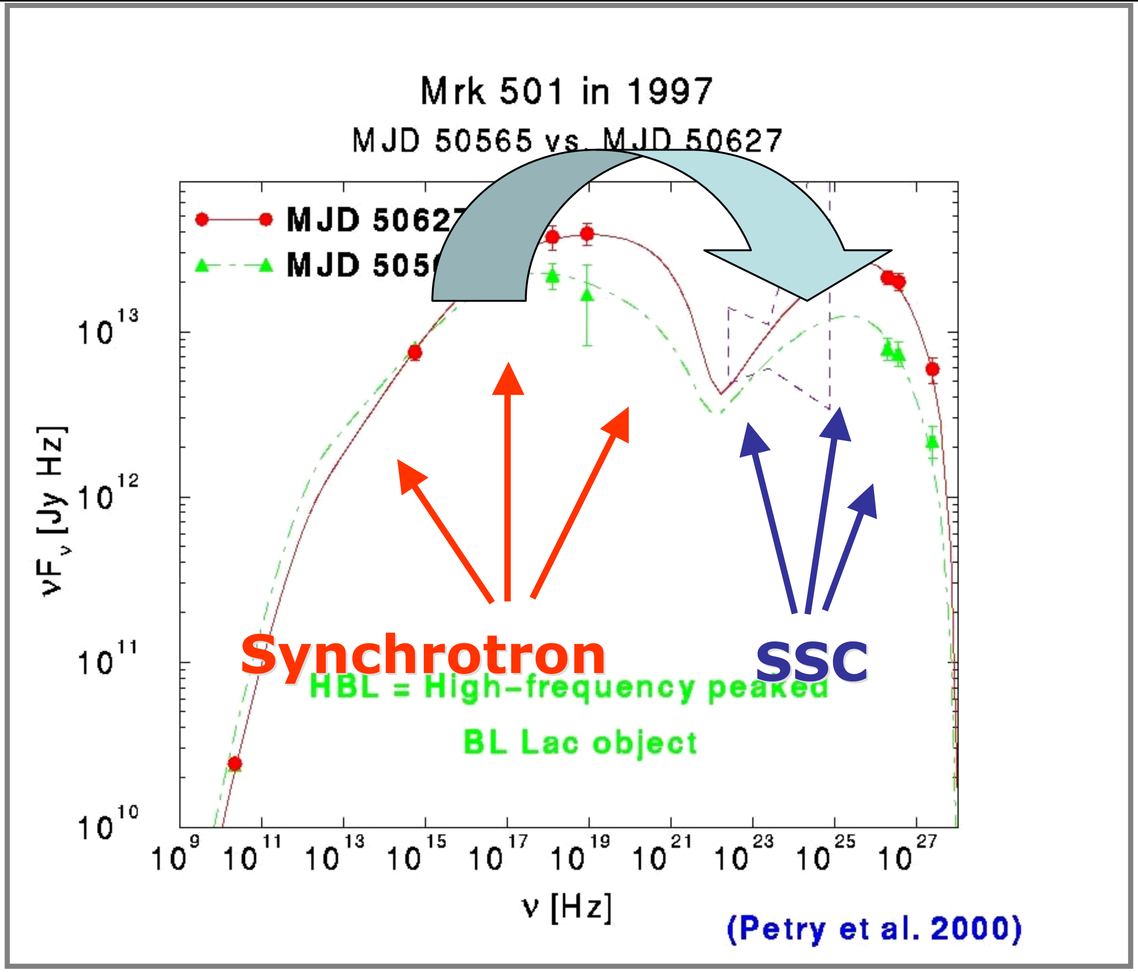
Although blazars comprise only a few per cent of the overall AGN population, they dominate the extragalactic high-energy sky

- How are jets made by accreting black holes?
- How and where are jets accelerated (why they have high Lorentz factors)?
- How are jets focused to opening angles less than a few degrees?
- How do shocks, turbulence, instabilities, jet bending and precession arise?
- What is the jet matter content (electron-proton vs. pair plasmas)?
- How are the relativistic electrons accelerated?
- Which is the jet emission mechanism ?
- How and where jets emit gamma-ray ?
- What are the mechanisms producing blazar variability?
- Which is the blazar duty-cycle?



Synchrotron Self-Compton (SSC)

Electrons in a magnetic field can work twice: first producing Synchrotron radiation, and then Comptonizing it



In External Compton model the seed photons come from outside to the jet

AGILE first-year blazar studies summary:

• AGILE (as EGRET and now Fermi) detected only few objects with flux greater than 100 x 10^{-8} ph cm^{-2} s^{-1}. Selection effects or there is a subclass of blazar with peculiar characteristics?

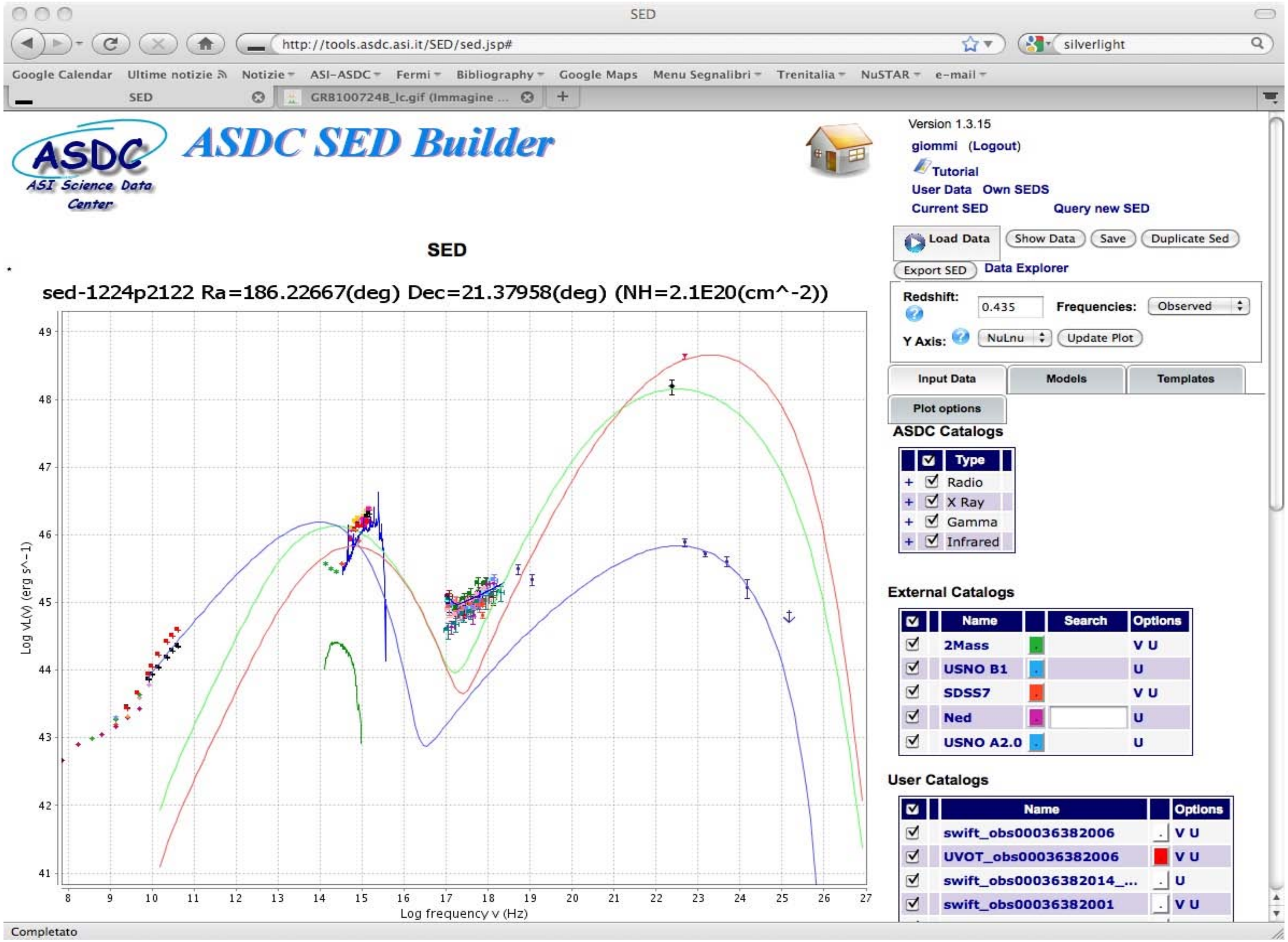
• AGILE observations has brought to light a **more complex behaviour of blazars with respect to the standard SSC models**:

- the presence of two emission components in any BL Lacs

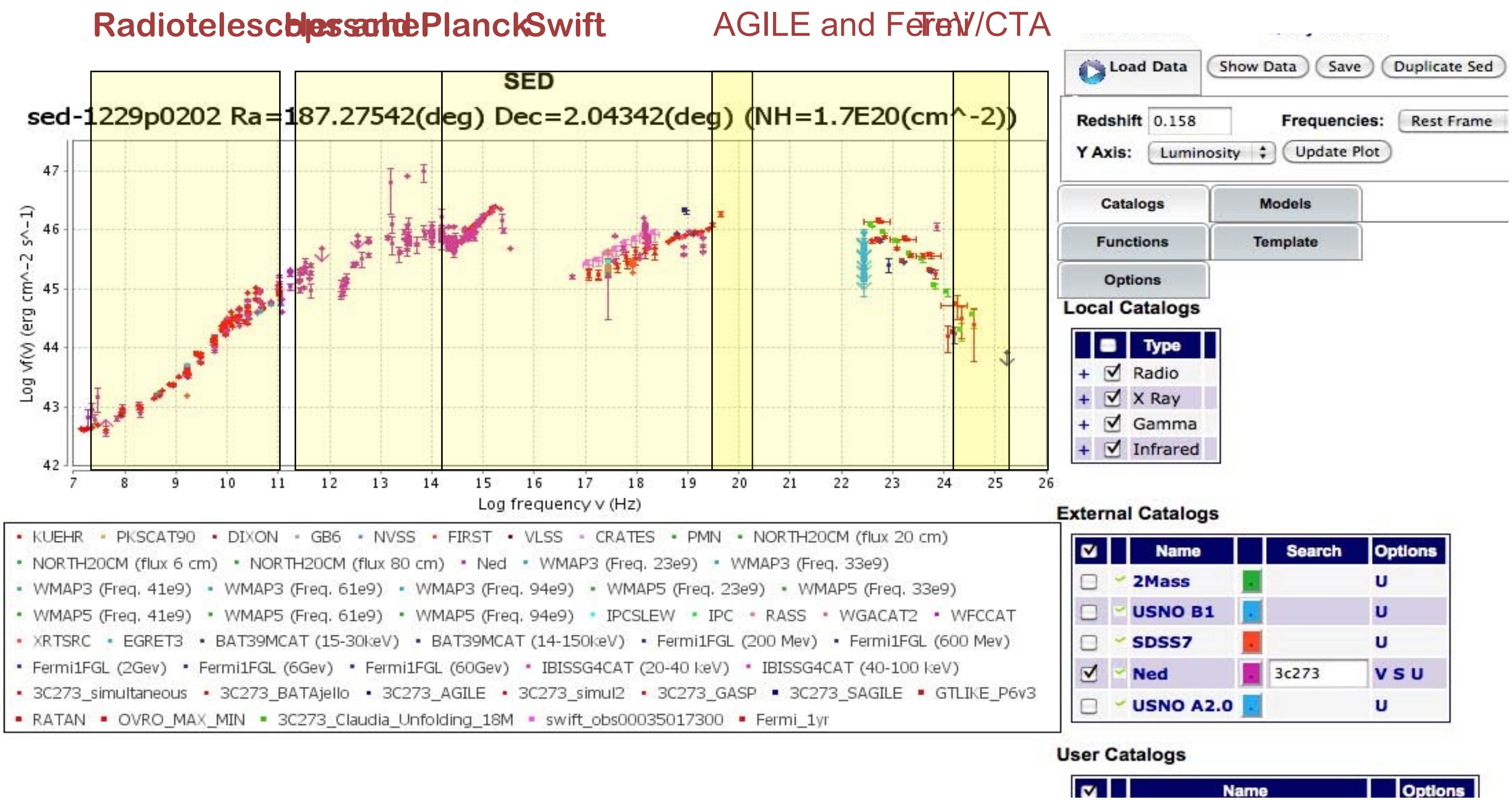
- the possible contributions of an hot corona as source of seed photons for the EC in FSRQs

• The study of multi-wavelength correlations is the key to understanding the structure of the inner jet and the origin of the seed photons for the IC process. (Mrk 421 from optical toTeV, Donnarumma et al., 2009, ApJ 691, 4C 21.35 (PKS 1222+21) flare, Atel #2686..)

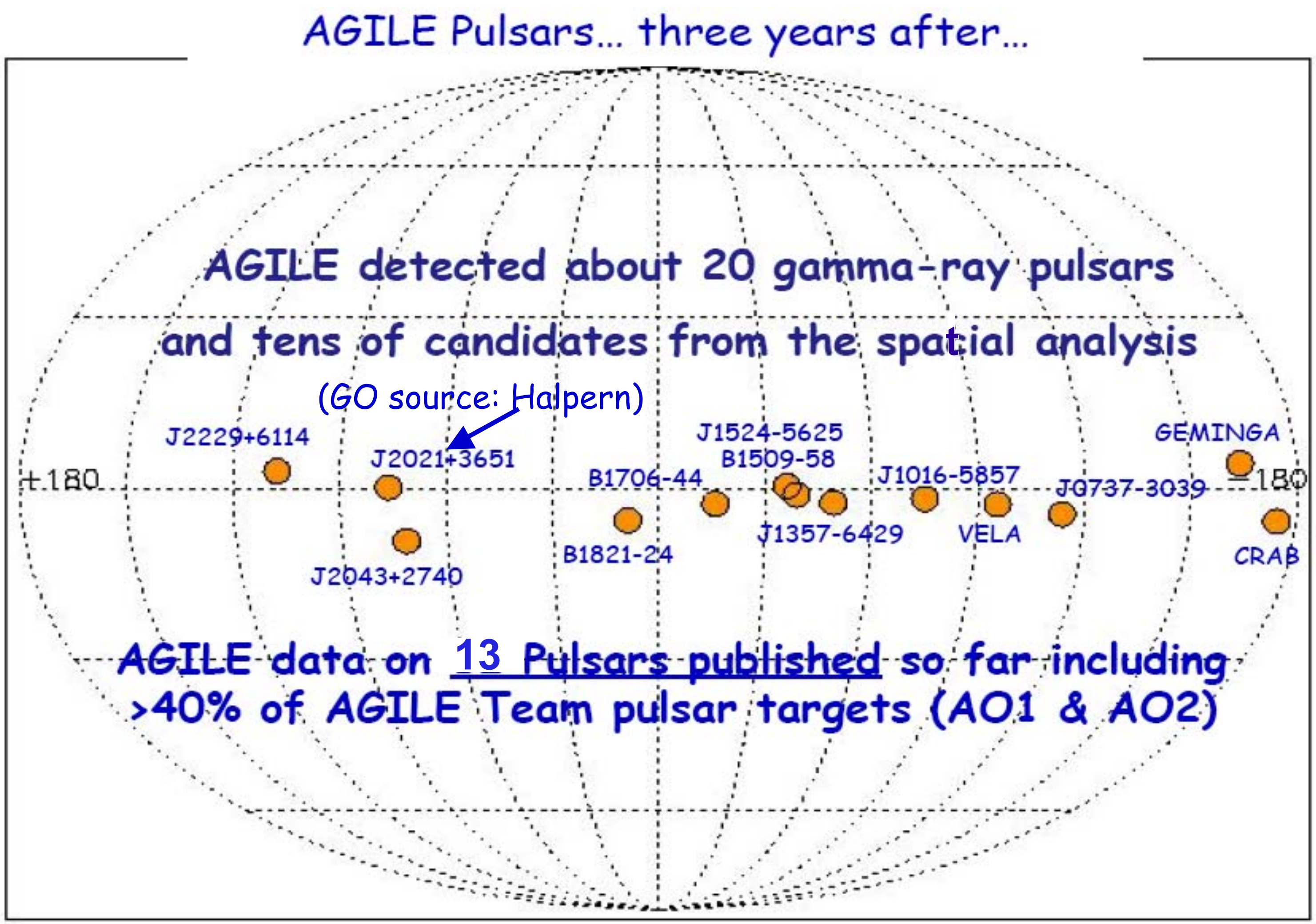
The γ-ray flare of PKS 1222+21



The ASDC SED Builder



Gamma-ray Pulsars by AGILE



Slide adapted from: Alberto Pellizzoni - The Bright Gamma Ray Sky, ASI-ESRIN '09

Pulsar emission

In the simplest model, the emission should depend on 4 parameters: spin period, magnetic field, magnetic dipole inclination, and viewing angle

- luminosity derived from rotational energy

  $E_{rot} = ½ \, I \, \Omega^2$

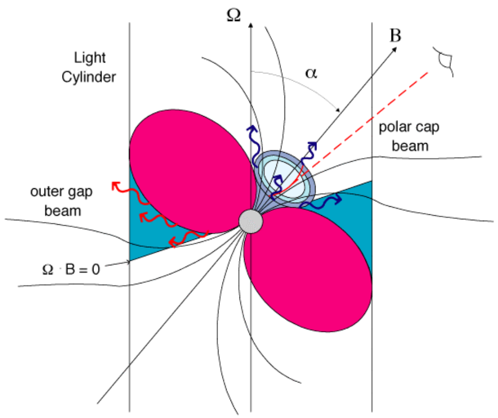
  $\dot{E} = - B^2 R^6 \Omega^4 / c^3$

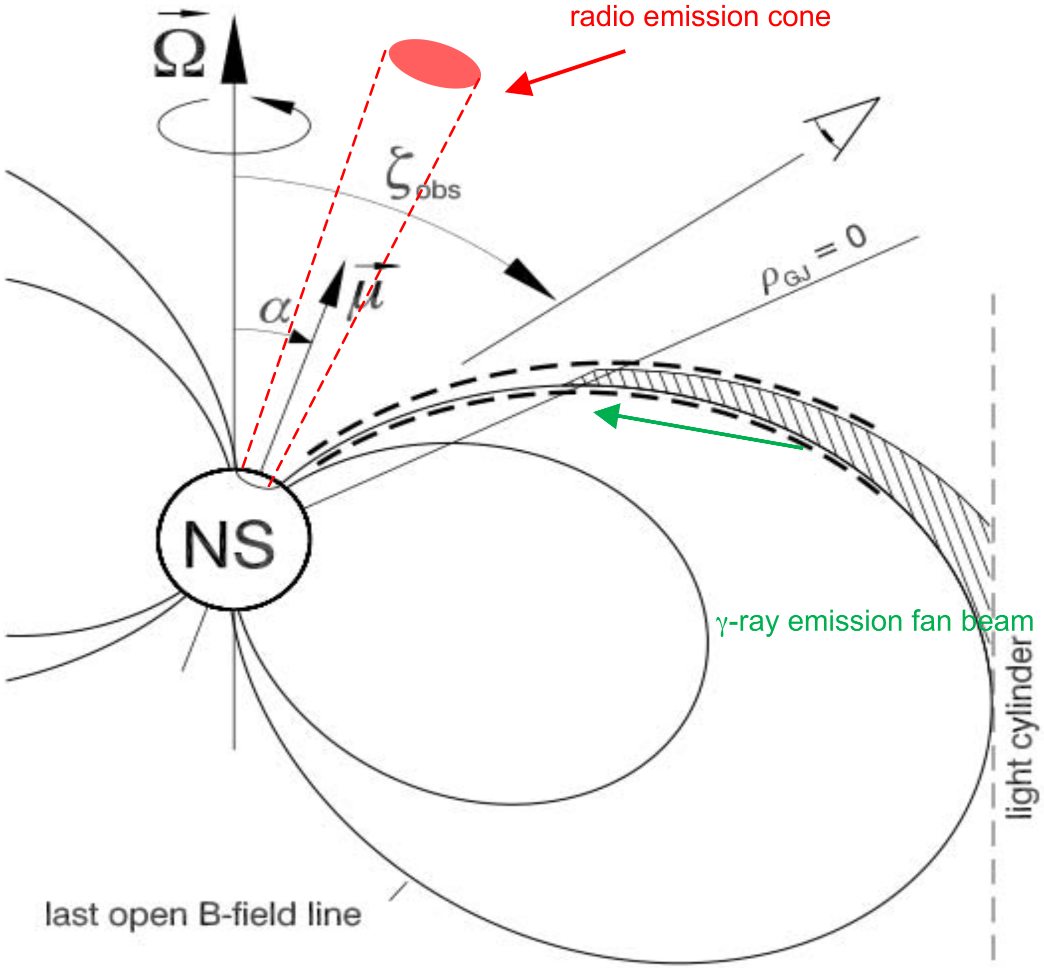
- derived parameters:

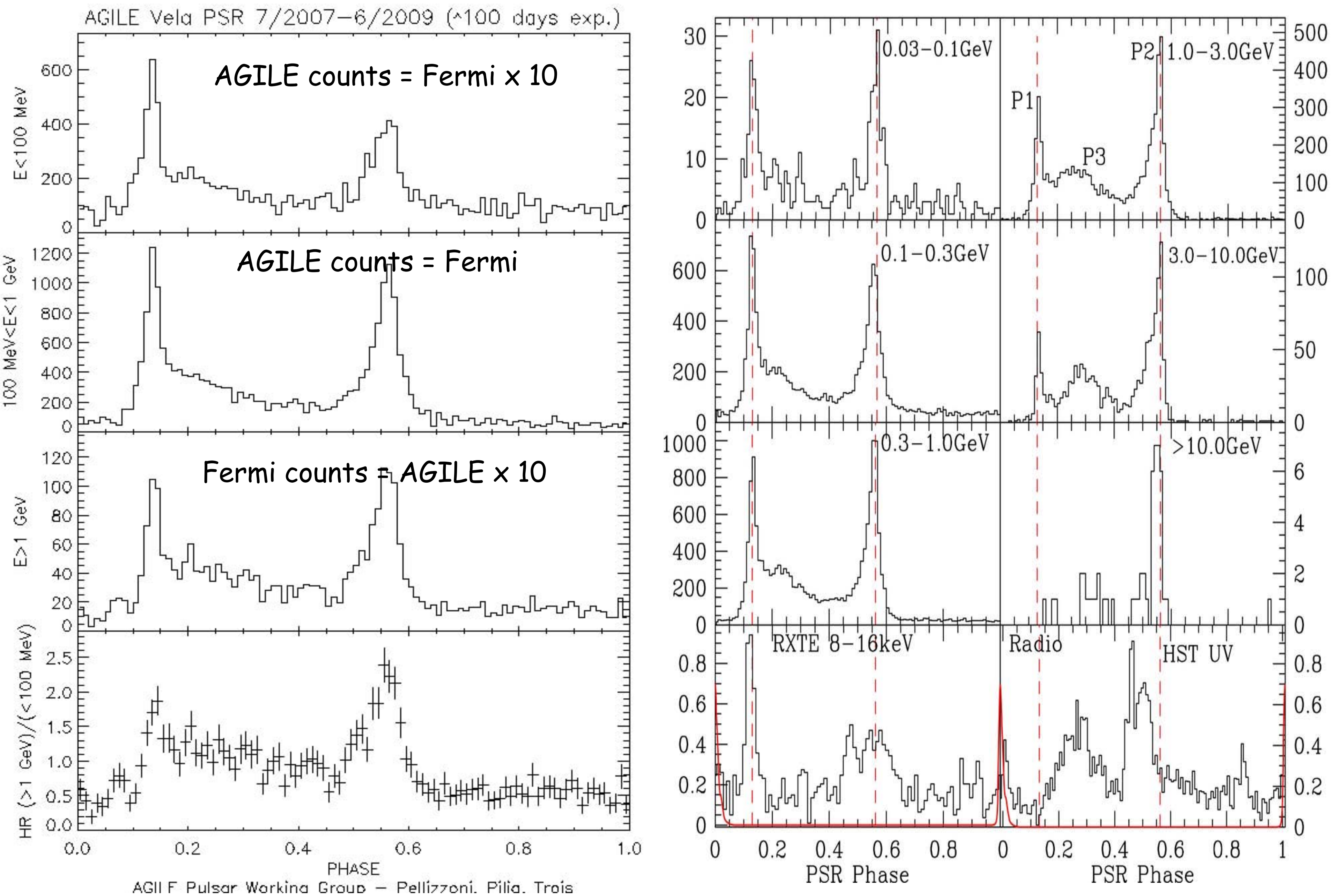
  rotational age: $\tau = \Omega / 2\dot{\Omega}$

  B field: $B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G

  spin-down power: $L = I\Omega\dot{\Omega}$







AGILE Vela PSR 7/2007−6/2009 (^100 days exp.)
AGILE counts = Fermi x 10
AGILE counts = Fermi
Fermi counts = AGILE x 10
E<100 MeV
100 MeV<E<1 GeV
E>1 GeV
HR (>1 GeV)/(<100 MeV)
PHASE
AGILE Pulsar Working Group − Pellizzoni, Pilia, Trois
0.03−0.1GeV
0.1−0.3GeV
0.3−1.0GeV
RXTE 8−16keV
P1
P2
P3
1.0−3.0GeV
3.0−10.0GeV
>10.0GeV
Radio
HST UV
PSR Phase
PSR Phase

AGILE Pulsar main results:

(from AGILE Pulsar working group)

Among the newcomers from timing analysis:

• the remarkable PSR B1509-58 with very high rotational energy losses, with a magnetic field in excess of 10^{13} Gauss

• PSR J2229+6114 providing a reliable identification for the previously unidentified EGRET source 3EG 2227+6122.

• Moreover, the powerful **millisecond** pulsar B1821-24, in the globular cluster M28, is detected

• Structured **energy-dependent peaks** (more than two) are evident in pulsar light curves.

• **Full exploitation of <100 MeV band in progress (exposure competitive with Fermi)**

AGILE Galactic gamma-ray discoveries

- **Carina region: γ-ray detection of the colliding wind massive binary system η-Car with AGILE**

Tavani et al., ApJ, 698, L142, 2009 (arXiv:0904.2736)

- **Cygnus region microquasars:**
  - **AGILE observations of Cygnus X-1 gamma-ray flares**

Sabatini et al., ApJ 2010, Del Monte et al., A&A 2010

  - **AGILE detects several gamma-ray flares from Cygnus X-3, and also weak persistent emission above 100 MeV**

Tavani et al., Nature 462, 620, 2009 (arXiv:0910.5344)

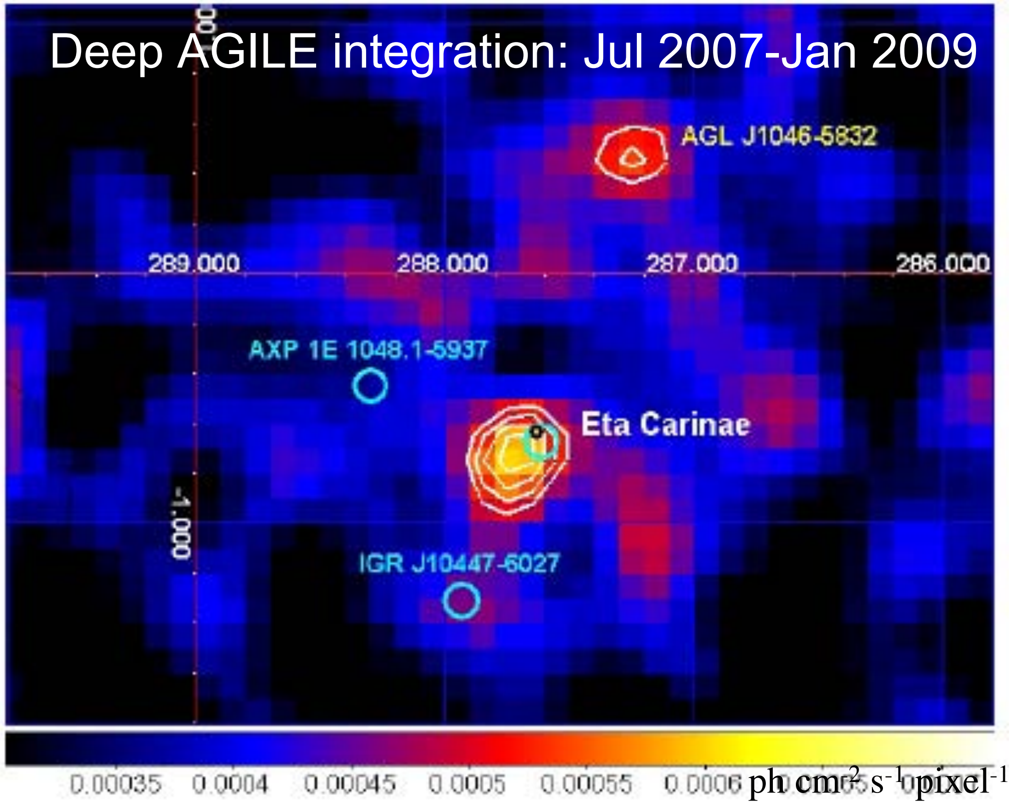
- **Detection of Gamma-Ray Emission from the Vela Pulsar Wind Nebula with AGILE**

Pellizzoni et al., Science 327, 2010

The Eta Carinae region

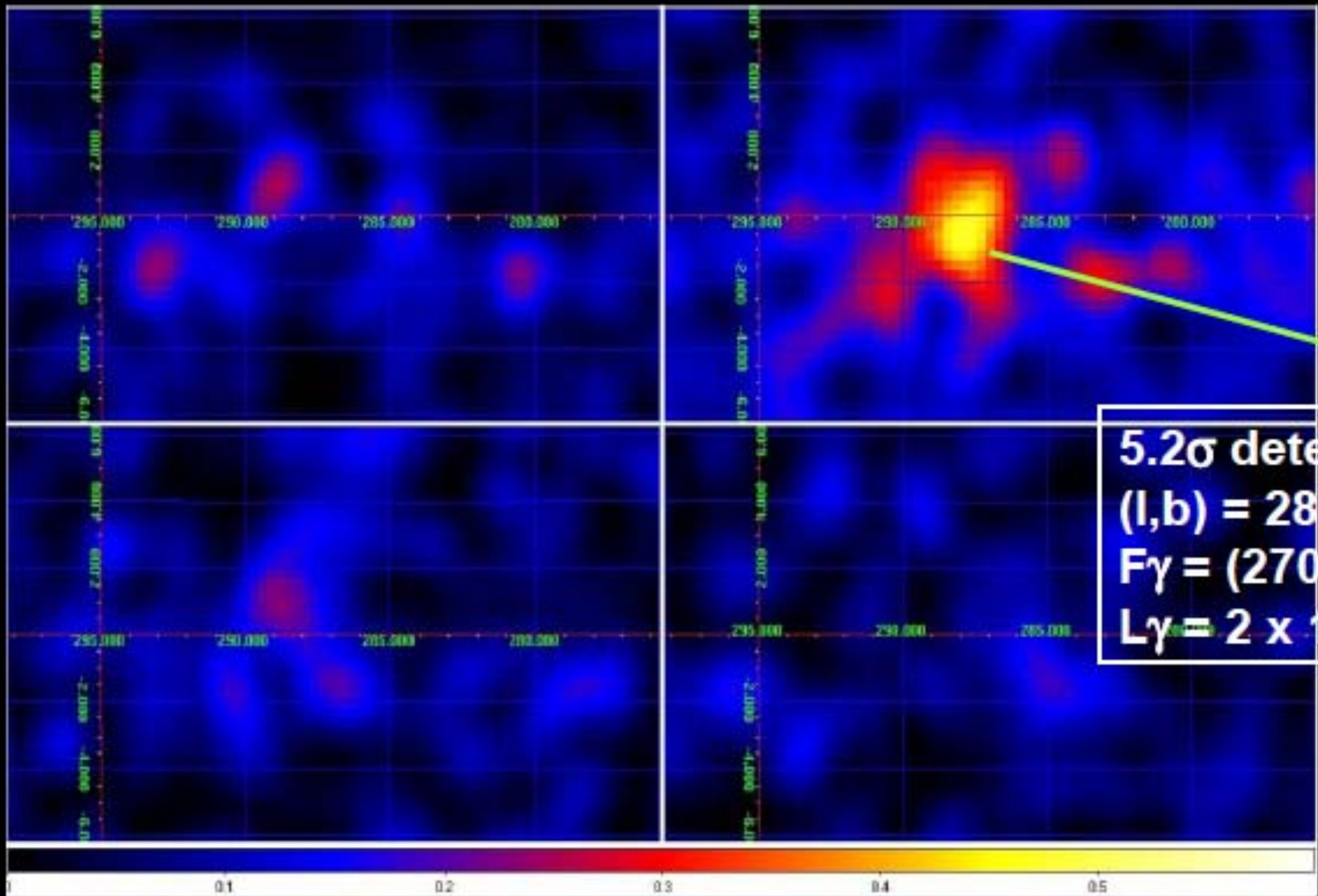
Extensive AGILE observations of the Galactic region hosting the Carina nebula and the colliding wind binary Eta Carinae (η-Car). One flaring episode in Oct 2008.

AGILE remarkable result: first detection above 100 MeV of a colliding wind binary system, confirming the efficiency of particle acceleration and the highly non-thermal nature of the strong shock in a CWB.



Tavani et al., ApJ 698, 2009

The 11-13th Oct 2008 Eta Car Flare



Pre-periastron flare

Period:5.54 years

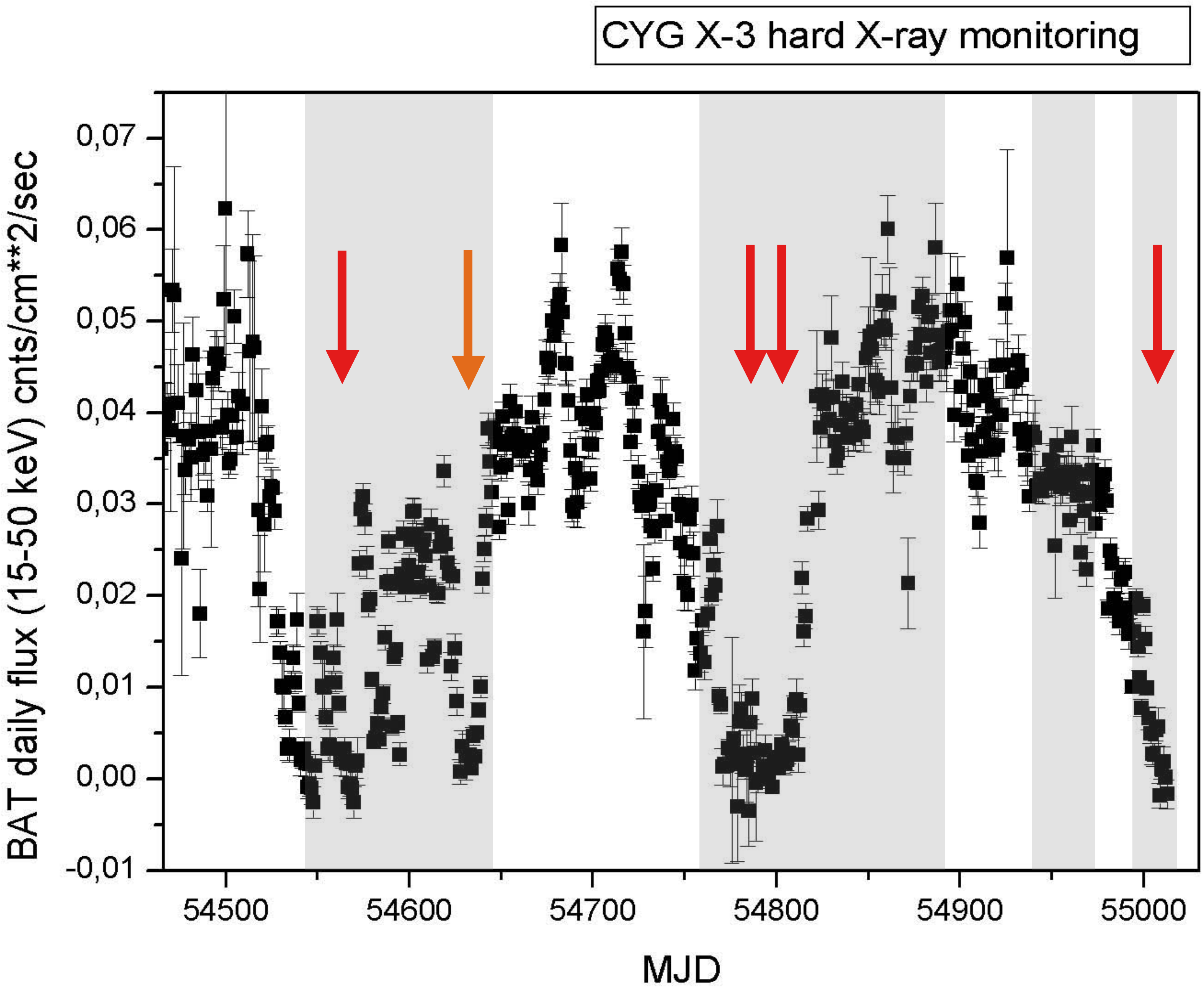
Last periastron:
11 January 2009

5.2σ detection
(l,b) = 288.0, -0.4 ± 0.6
$F\gamma$ = (270 ± 65) x 10^{-8} ph/cm^2/s
$L\gamma$ = 2 x 10^{35} erg/s

Binary systems containing such a massive star (~100 M_{sun}) and a compact object have strong colliding winds causing strong shocks where both e- and p may be efficiently accelerated

AGILE and Cygnus X-3

- **AGILE detects weak persistent emission above 100 MeV and several gamma-ray flares from Cygnus X-3 microquasar**
  - **16-17 Apr 2008 (First E> 100 MeV gamma-ray detection !!)**
  - **2-3 Nov 2008**
  - **11-12 Dec 2008**
  - **20-21 Jun 2009**
- **Pattern in the gamma-ray emission: flares are all associated with special CygX-3 radio and X-ray/hard X-ray states**
- **Gamma-ray flares usually *before* major radio flares !!**


CYG X-3 hard X-ray monitoring
BAT daily flux (15-50 keV) cnts/cm**2/sec
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0,00
-0,01
54500
54600
54700
54800
54900
55000
MJD

Major gamma-ray flares in special transitional states in preparation of radio flares!

- Gamma-ray flares tend to occur in the **rare** low-flux/pre-flare radio states.

- For all gamma-ray flaring episodes, the radio and hard-X-ray fluxes are low or very low, while the soft X-ray flux is large

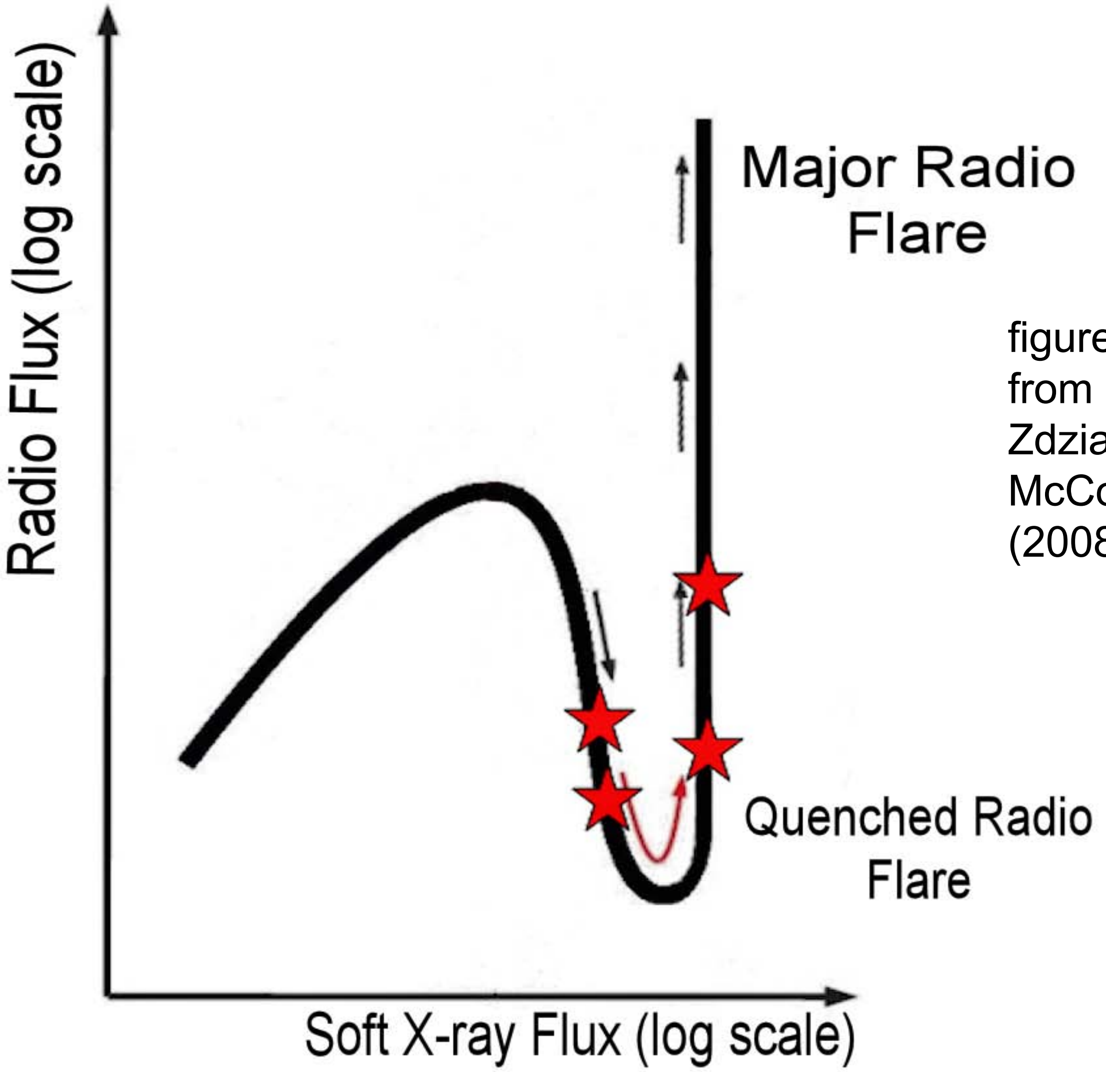
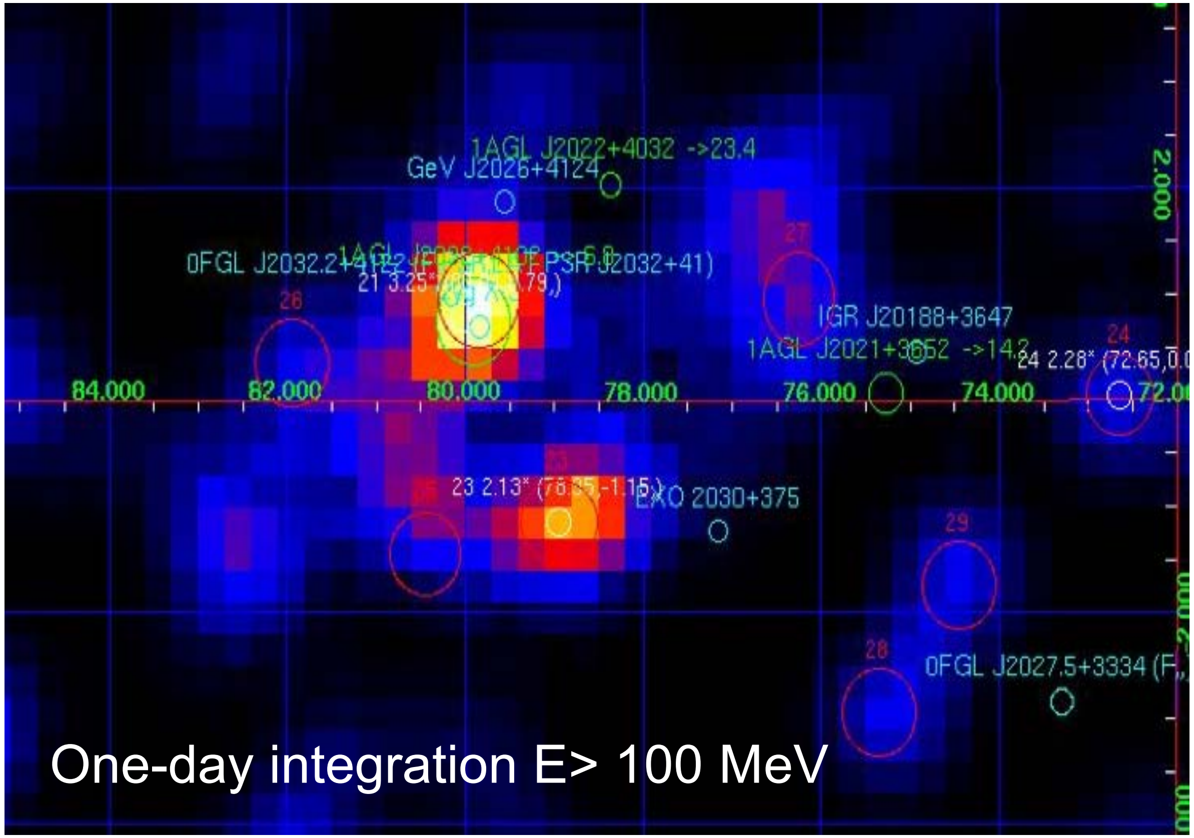


figure adapted from Szostek Zdziarski & McCollough (2008)

Cygnus X-3 lessons:

- Direct evidence that extreme particle acceleration (above 100 MeV) and non-thermalized emission can occur in microquasars with a repetitive pattern
- Emission must be produced not to far away from the central object (4,8 hours orbital modulation recently revealed by Fermi!)
- Cyg X-3 is capable of accelerating particles by a very efficient mechanism leading to photon emission at energies thousands of times larger than the maximum energy previously detected (E ~ 300 keV)
- Comptonization models (thermal and non-thermal) that reproduce the spectral states up to 300 keV must take into account the new data above 100 MeV

On May 27, 2010: new (expected) Cyg X-3 flare!!!



3 ATels:

2646 RFO: Fermi LAT detection of increasing gamma-ray activity from the microquasar Cygnus X-3

2645 AGILE detection of gamma-ray emission from Cygnus X-3

2644 INTEGRAL observations of Cygnus X-3

INTEGRAL confirms evidence that Cygnus X-3 has been transitioning to its soft state. Gamma-ray flare (E> 100 MeV) expected: **AGILE and Fermi detection of the expected flare!**

Impulsive events: GRBs and TGFs

- SuperAGILE has detected several GRBs in its energy band (18-60 keV) at a rate of about **1 per month** while the AGILE **Minicalorimeter** (MCAL) observes about **1 GRB per week** in the energy range 0.7-1.4 MeV on several time scales (Marisaldi et al.). **GRID energies: only three confirmed GRBs up to now with HE component E > 50 MeV. Delayed HE emission.**

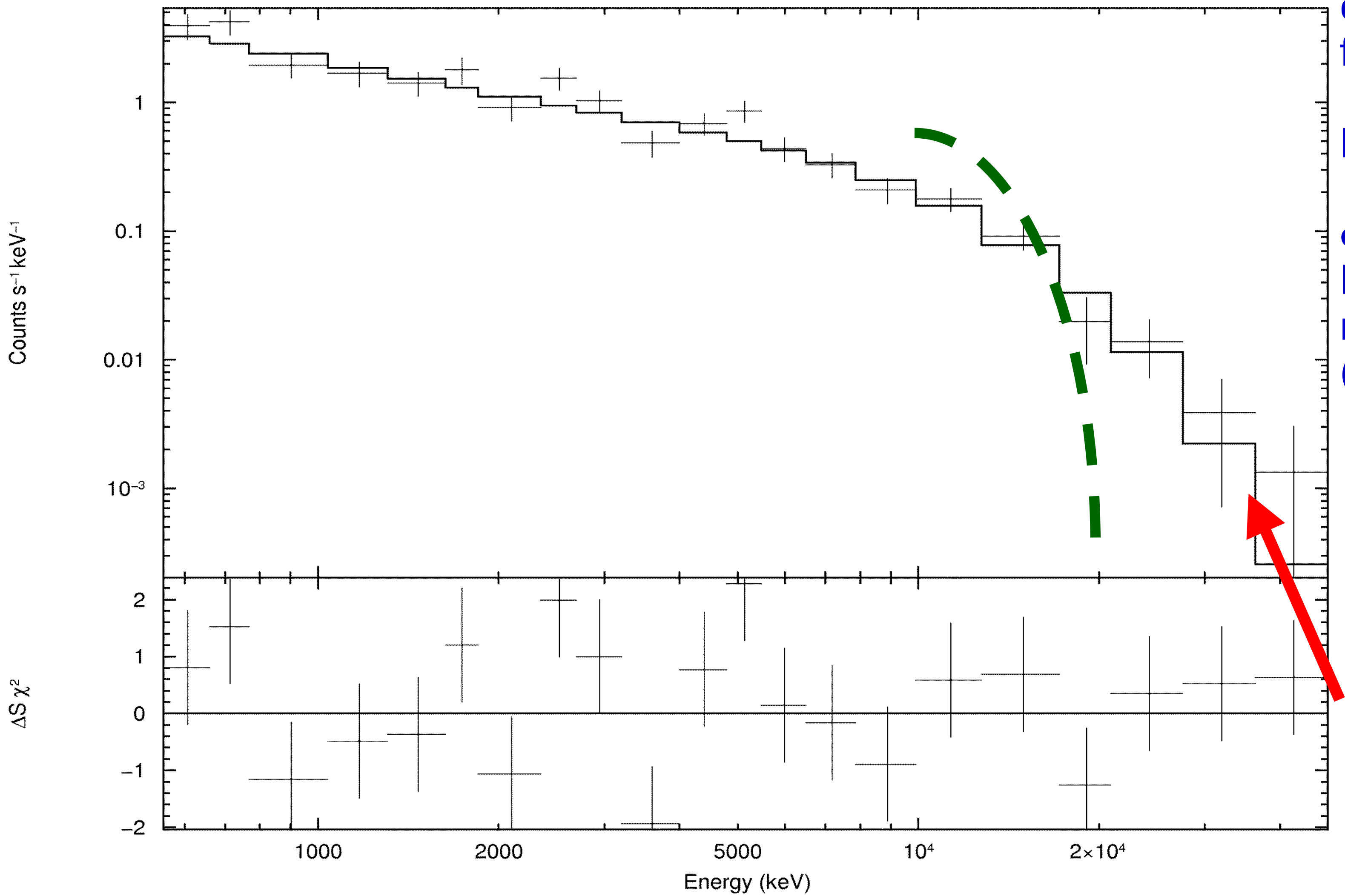
- The AGILE Minicalorimeter also detects **Terrestrial gamma-ray flashes, very interesting events up to 40 MeV on timescales < 5 ms** (Marisaldi et al., JGR 115, A00E13, 2010, available online from ADC webpage)

- Normal lightnings involve a potential difference ~ 500 kVolts
- **Terrestrial Gamma-Ray Flashes (TGF) involve DV > 100 MVolts !**
- Models: **Relativistic Runaway Electron Avalanche** (RREA) with relativistic feedback (Dwyer 2008). Bremsstrahlung + Compton scattering
- RHESSI cumulative spectrum compatible with a production altitude of 15-21 km (just above tropical thunderstorms)

AGILE MCAL: an optimal detector for TGF

- MCAL energy range is extended **up to 100 MeV**
- Efficient trigger at **ms and sub-ms time scale** (the TGF time scale)
- AGILE **equatorial orbit** at 2.5° inclination is optimal for mapping the equatorial region, where most of the events take place
- A real-time monitoring and alert system can be implemented for correlation with other meteo resources (work in progress)

MCAL TGF cumulative spectrum
(Marisaldi et al., 2009)

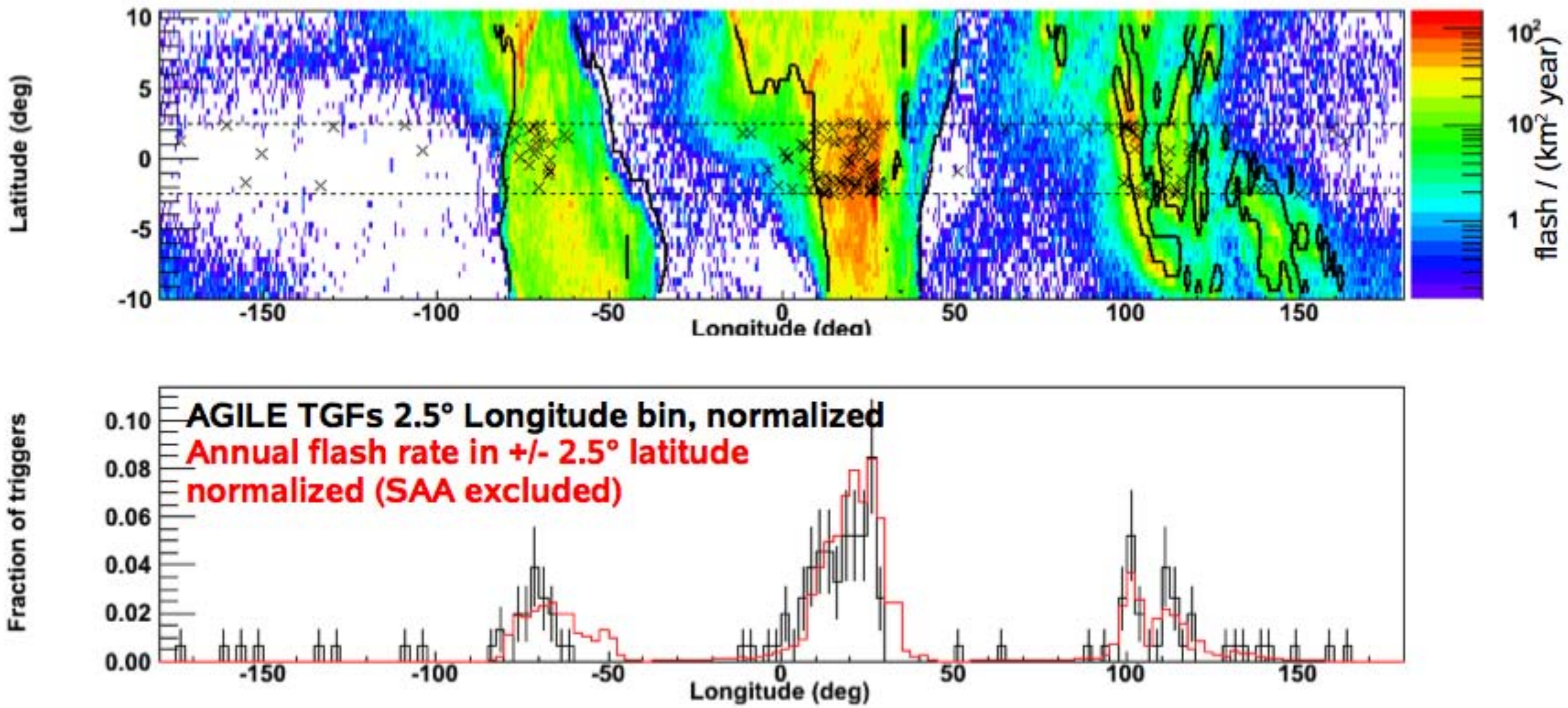


cutoff PL model
fitting with XSPEC

$F(E) \sim E^{-\alpha}\, e^{-E/E0}$

α = 0.4 +/- 0.3
E_0 = 8.5 +/- 1.6 MeV
red. chi^2 = 1.4
(18 d.o.f.)

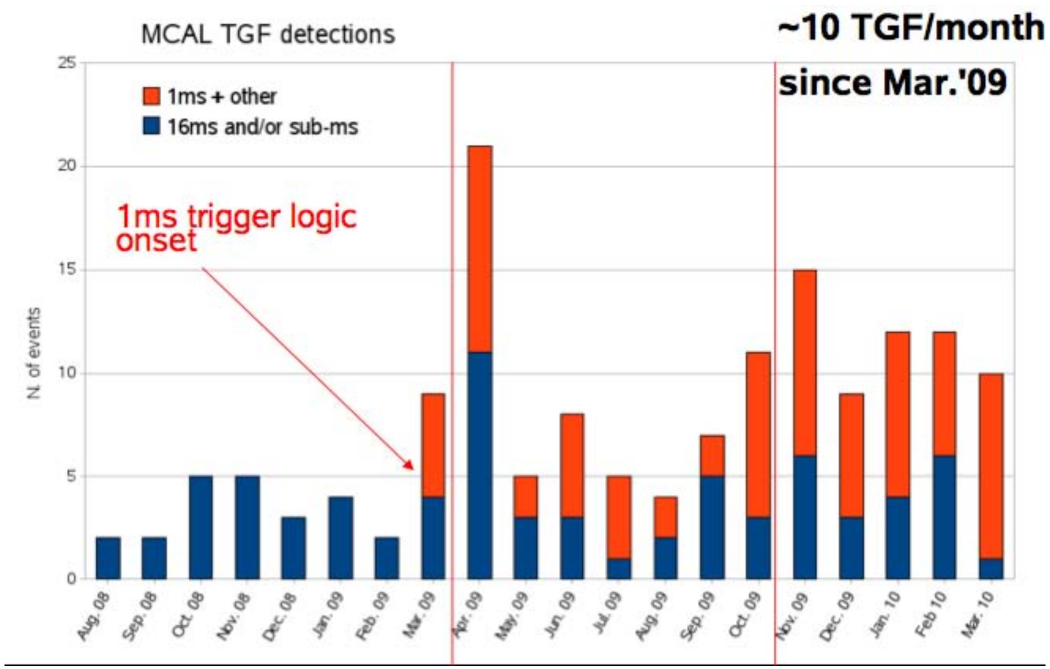
AGILE-MCAL crucial spectral contribution



Good match between AGILE TGF pattern and lightning map

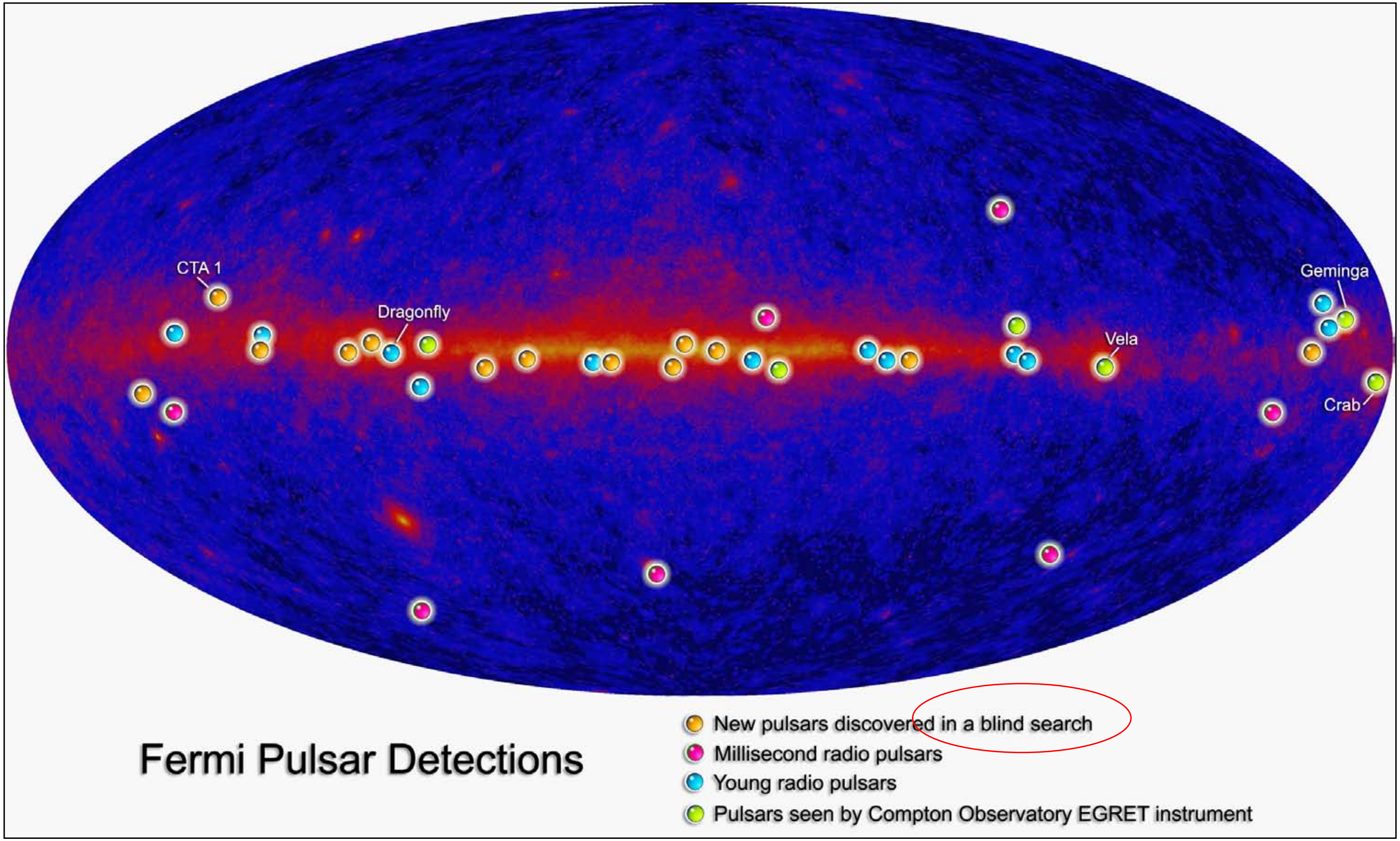
34 TGFs Published in **M. Marisaldi et al., J. Geoph. Res., 115, A00E13, 2010**

153 good candidates between June '08 and Mar. '10

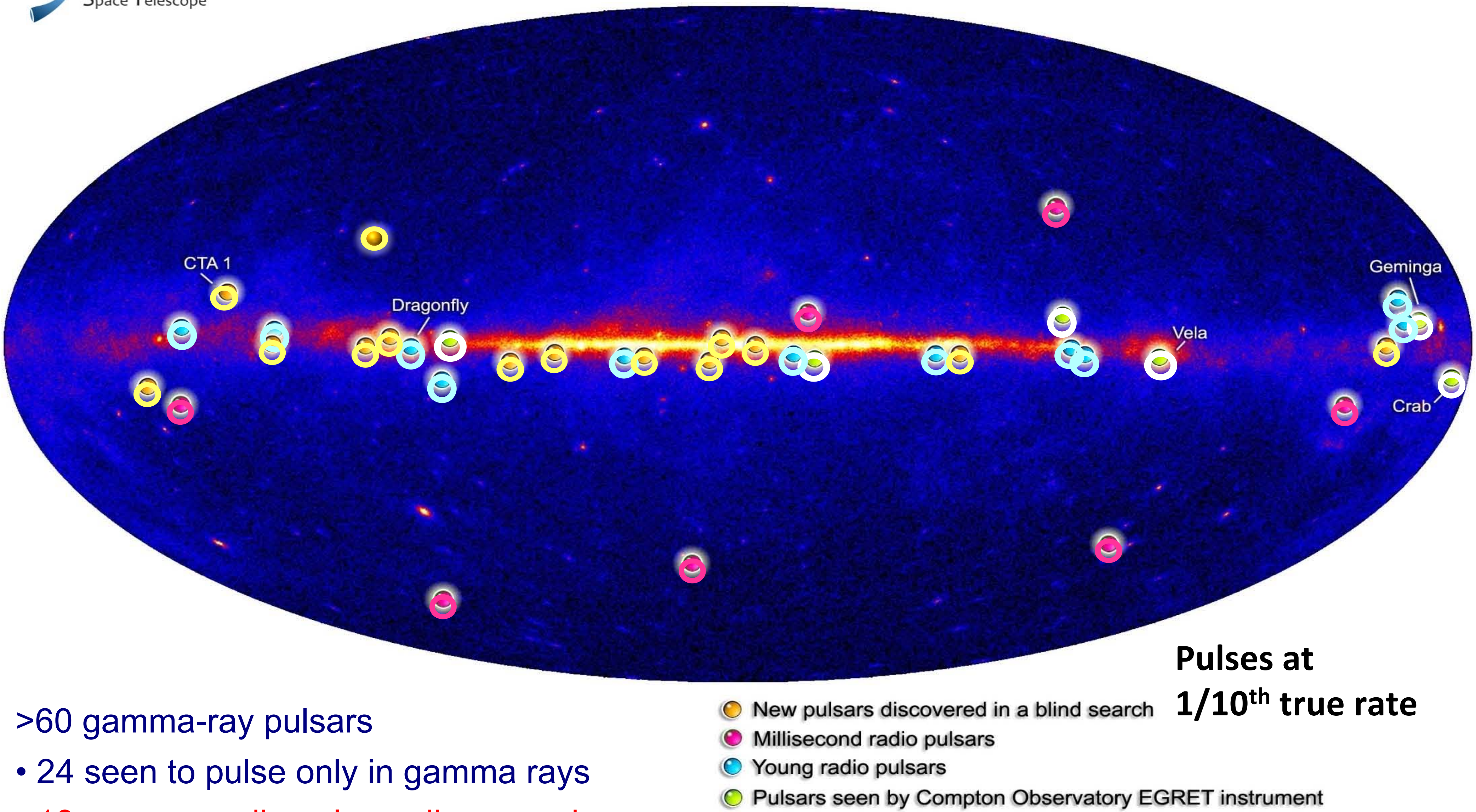


Fermi HIGHLIGHTS

Fermi discovery of a new class of gamma-ray pulsars in blind search



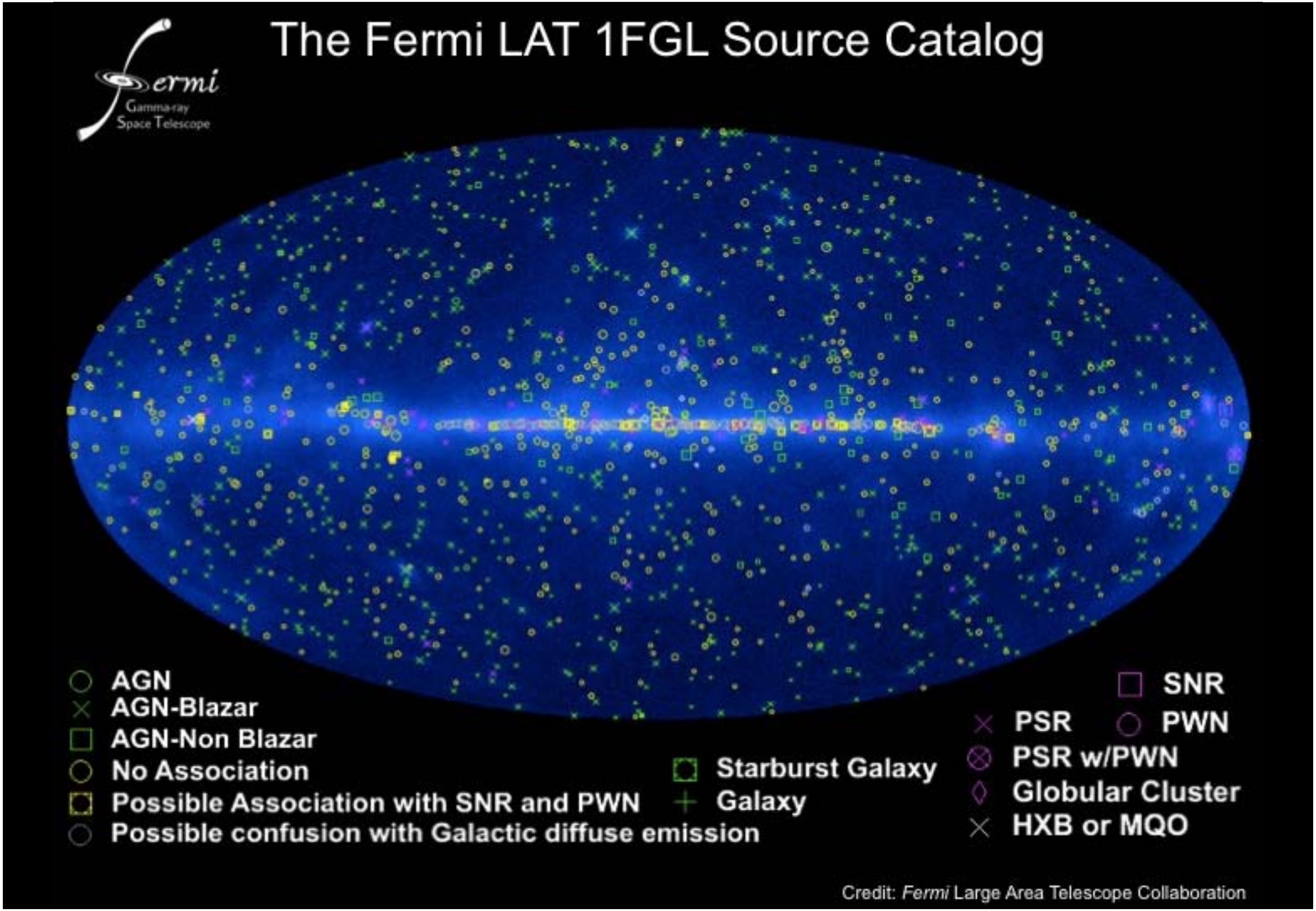
The Pulsating γ-ray Sky



Pulses at $1/10^{th}$ true rate

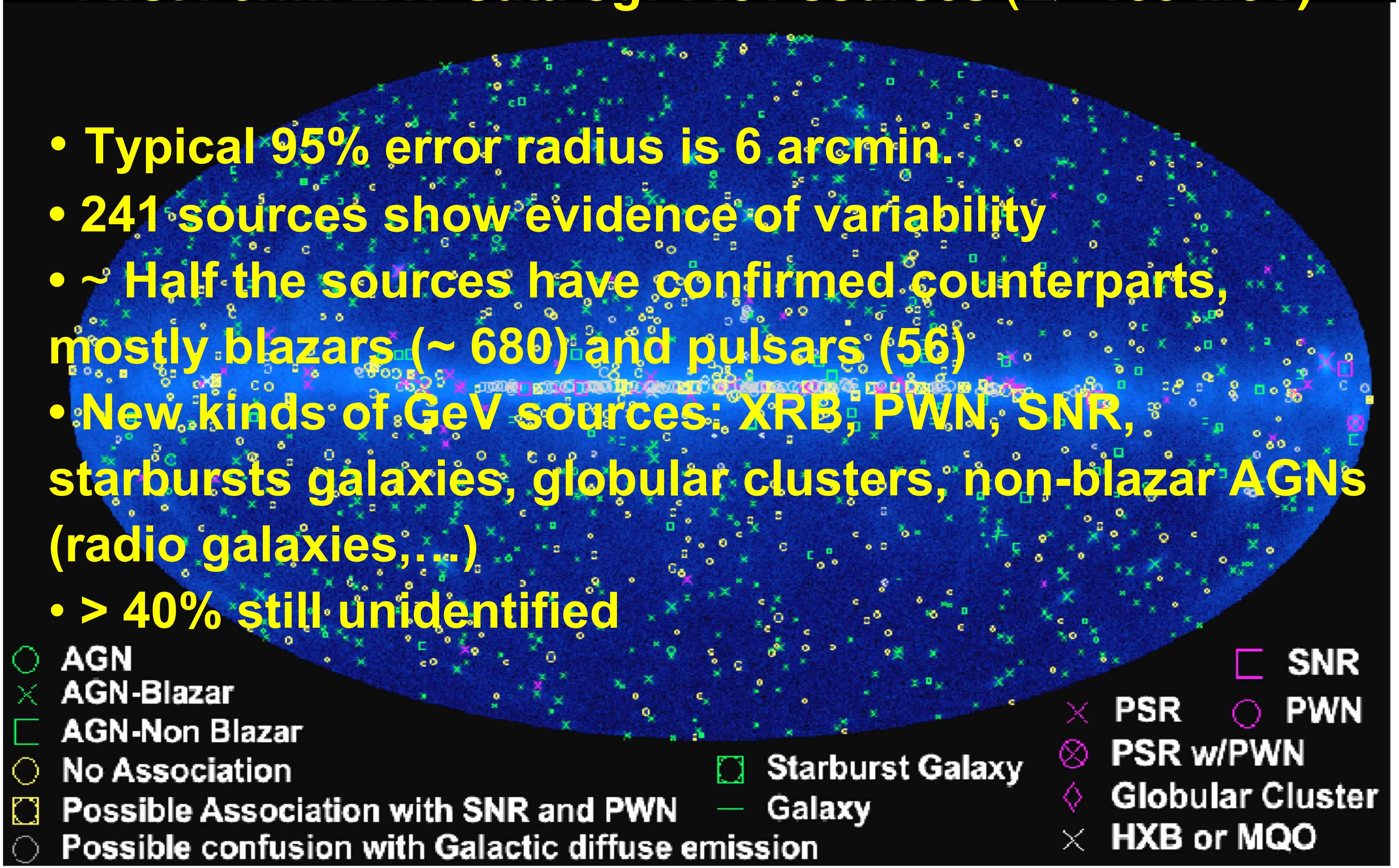
>60 gamma-ray pulsars

- 24 seen to pulse only in gamma rays
- 19 new ms radio pulsars discovered


The Fermi LAT 1FGL Source Catalog
Fermi
Gamma-ray
Space Telescope
AGN
AGN-Blazar
AGN-Non Blazar
No Association
Possible Association with SNR and PWN
Possible confusion with Galactic diffuse emission
Starburst Galaxy
Galaxy
SNR
PSR
PWN
PSR w/PWN
Globular Cluster
HXB or MQO
Credit: Fermi Large Area Telescope Collaboration

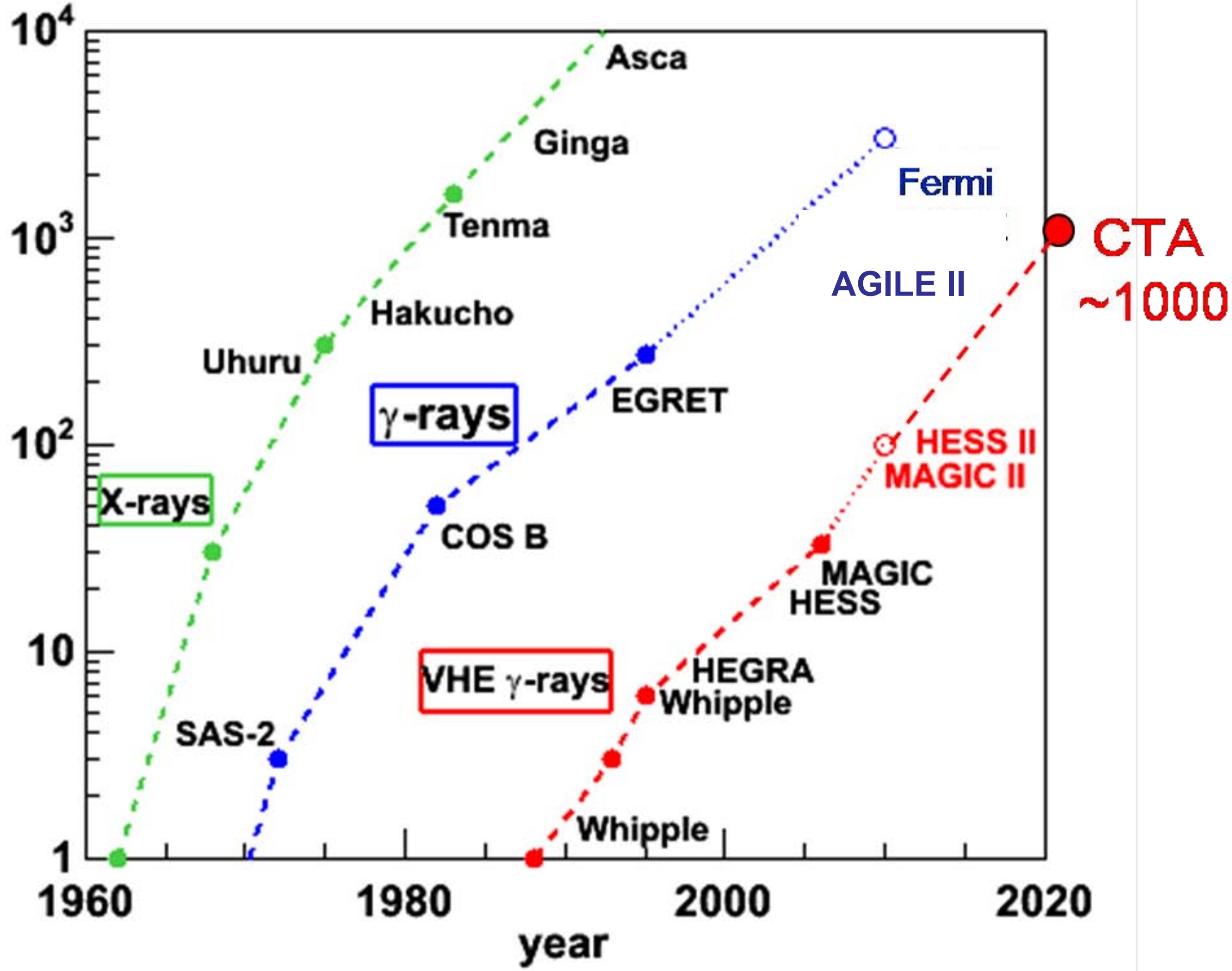
First Fermi LAT Catalog: 1451 sources (E> 100 MeV)

- Typical 95% error radius is 6 arcmin.
- 241 sources show evidence of variability
- ~ Half the sources have confirmed counterparts, mostly blazars (~ 680) and pulsars (56)
- New kinds of GeV sources: XRB, PWN, SNR, starbursts galaxies, globular clusters, non-blazar AGNs (radio galaxies,…)
- > 40% still unidentified



Kifune plot (updated)

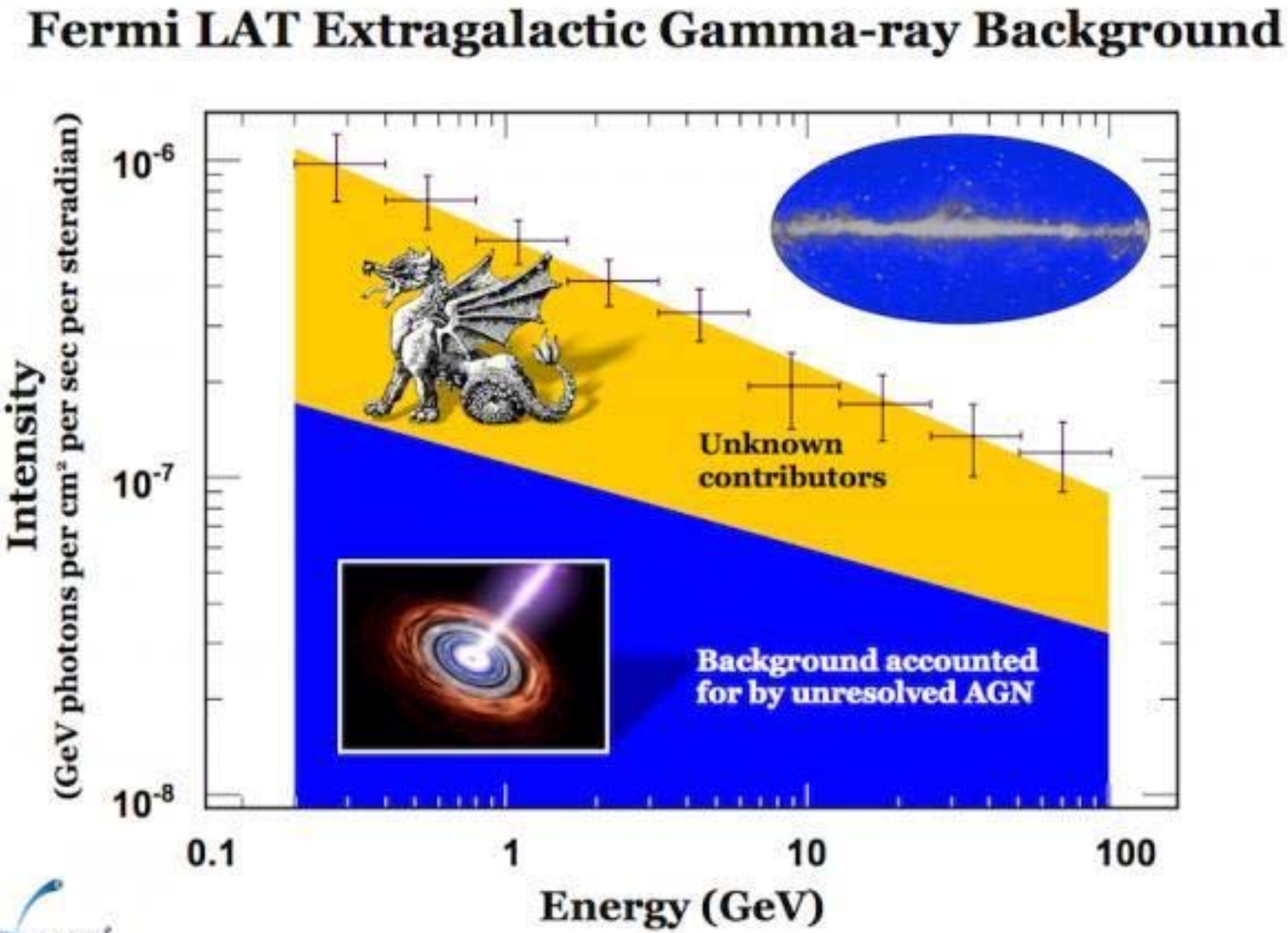
Number of sources (logarithmic scale!) vs year



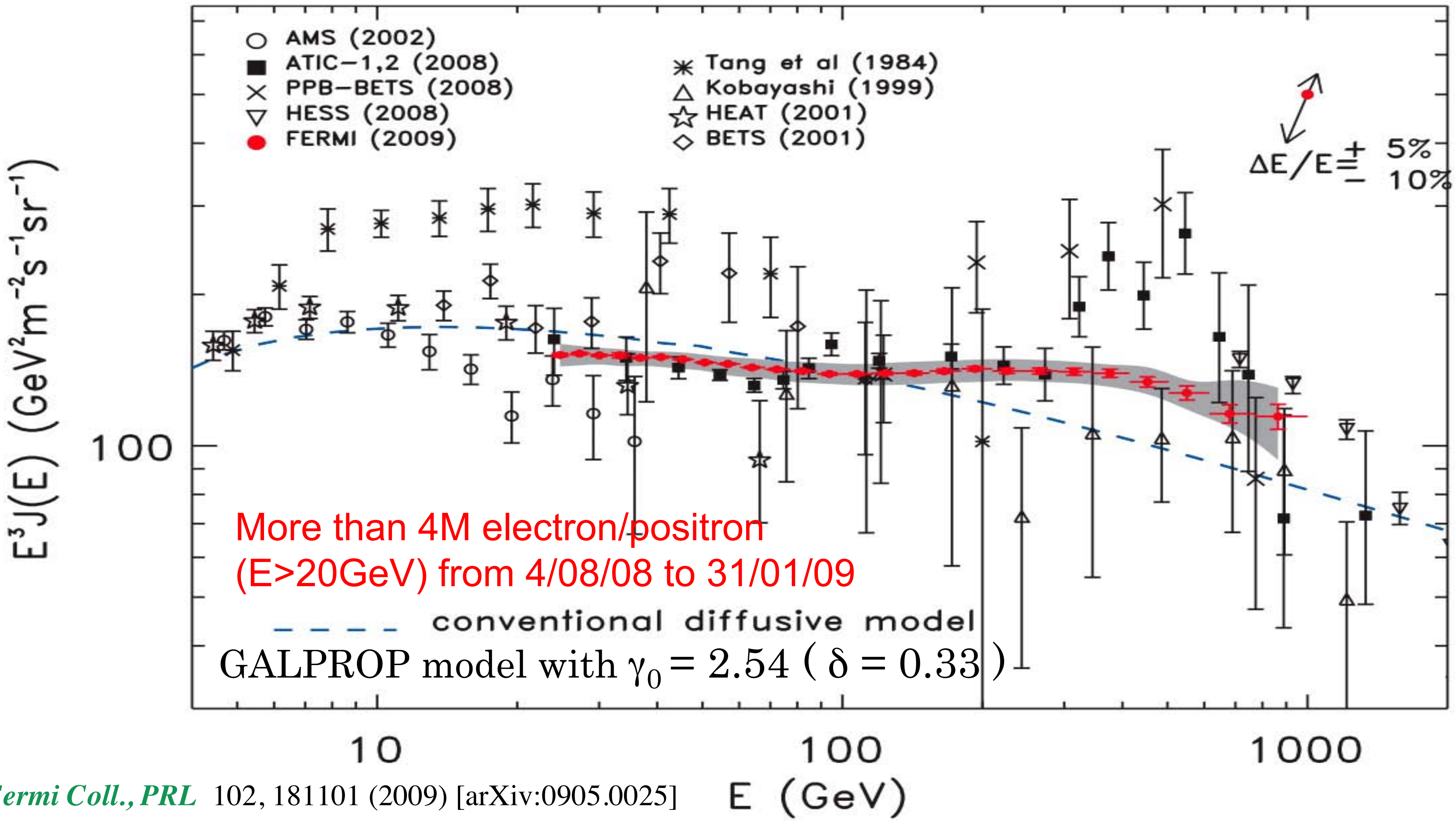
Fermi Dragons?

Contribution of point-sources to the **diffuse GeV EG-background** obtained by extrapolating and integrating the log N–log S to zero flux.

It seems that less than a third of the observed extragalactic γ-ray emission arises from faint and distant unresolved blazars.



Fermi electron + positron spectrum

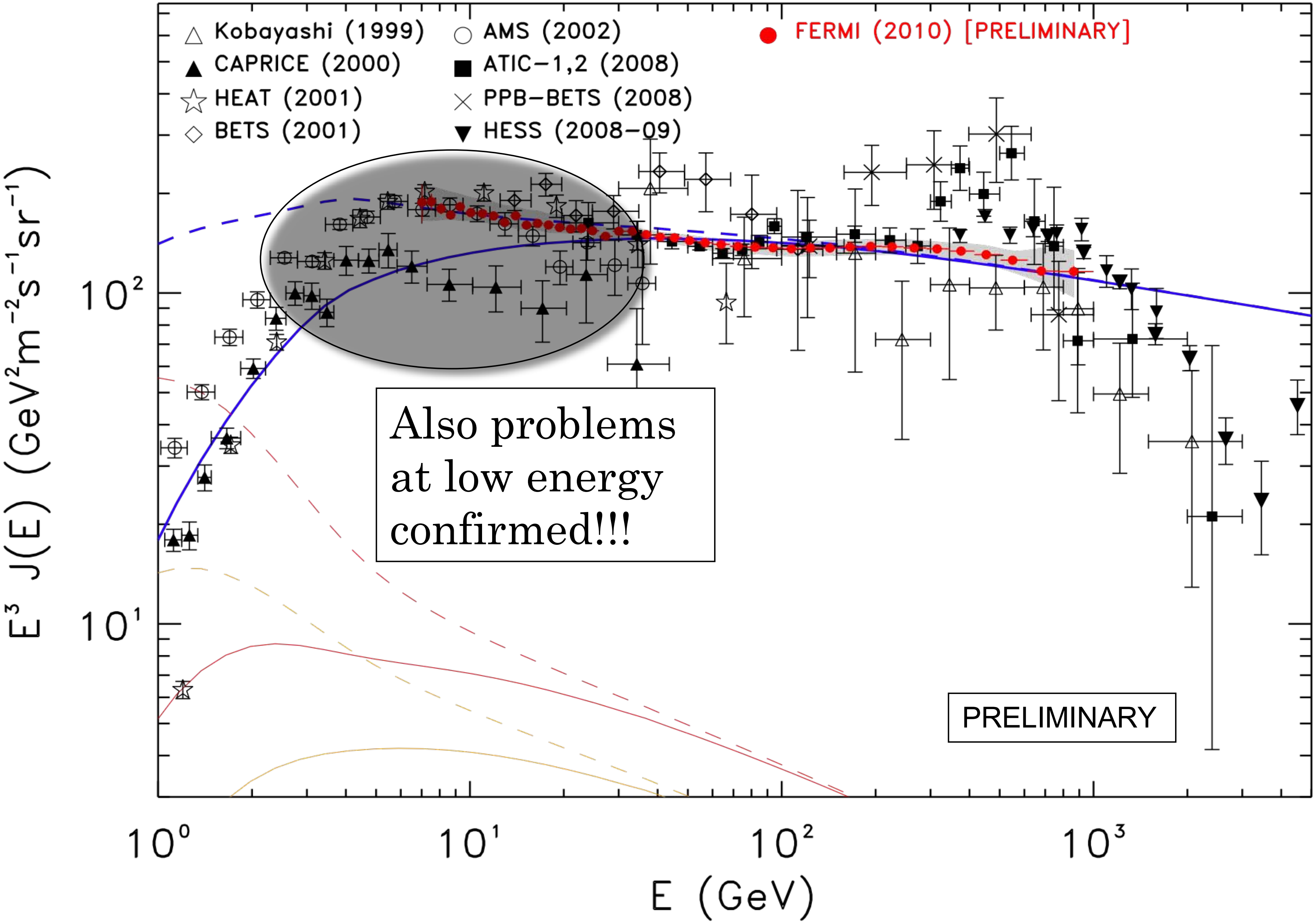


Fermi Coll., PRL 102, 181101 (2009) [arXiv:0905.0025]

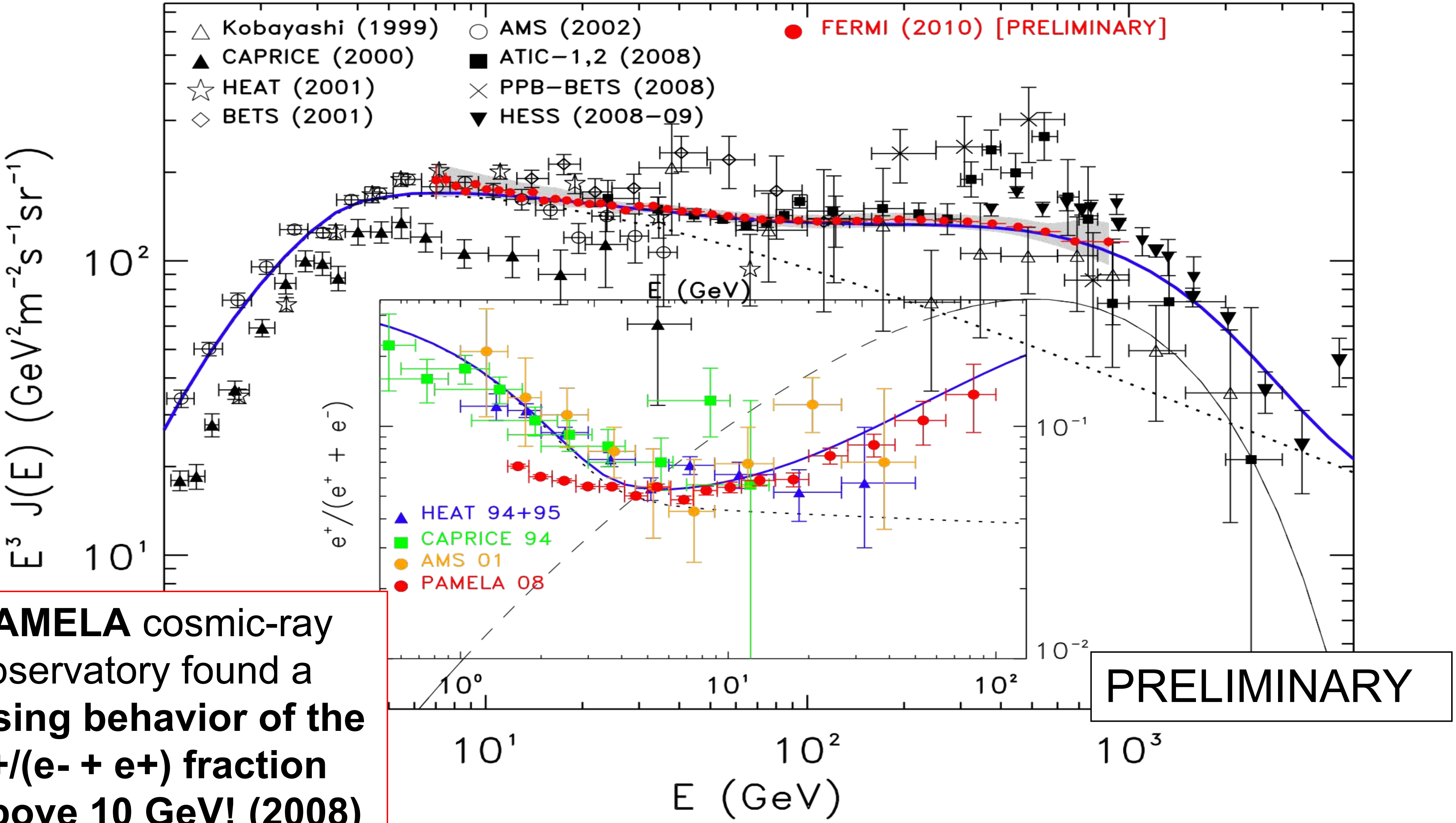
Although the feature @~600 GeV measured by ATIC is not confirmed
Some changes are still needed respect to the *pre-Fermi conventional model*

Fermi Gamma-ray Space Telescope

New Fermi-LAT data at low energy

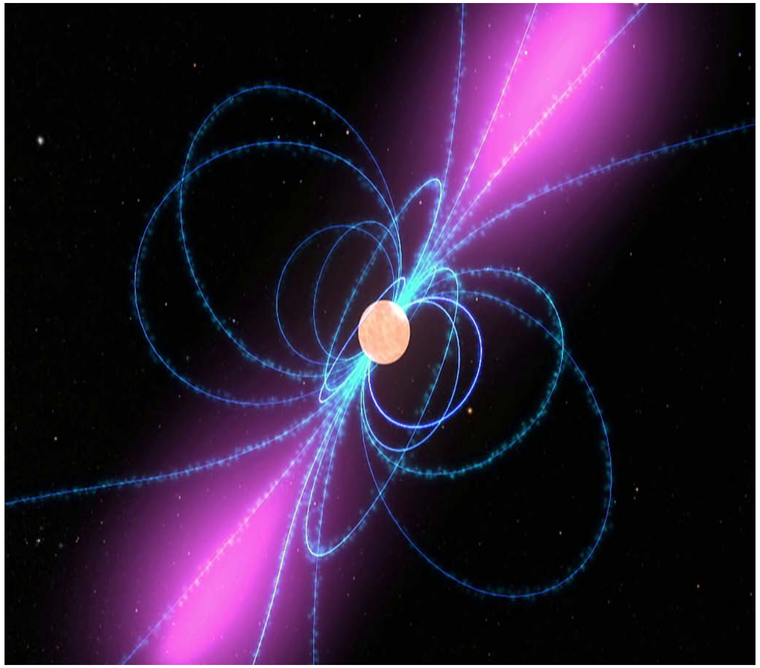


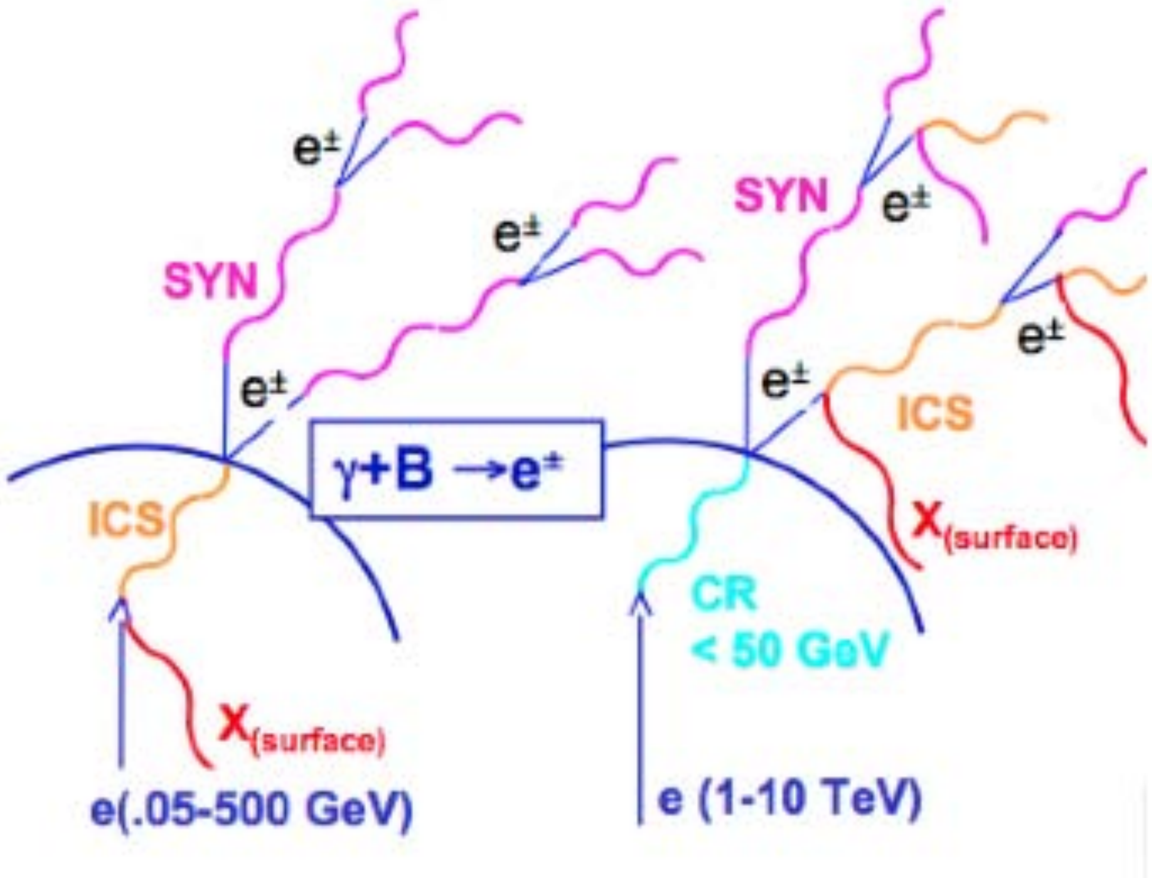
An **extra-component** with injection index = 1.5 and an exponential cutoff at 1 TeV gives a good fit of all datasets!



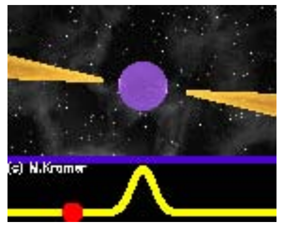
PAMELA cosmic-ray observatory found a **rising behavior of the e+/(e- + e+) fraction above 10 GeV! (2008)**

Pulsars as sources of $e^{-/+}$ pairs?



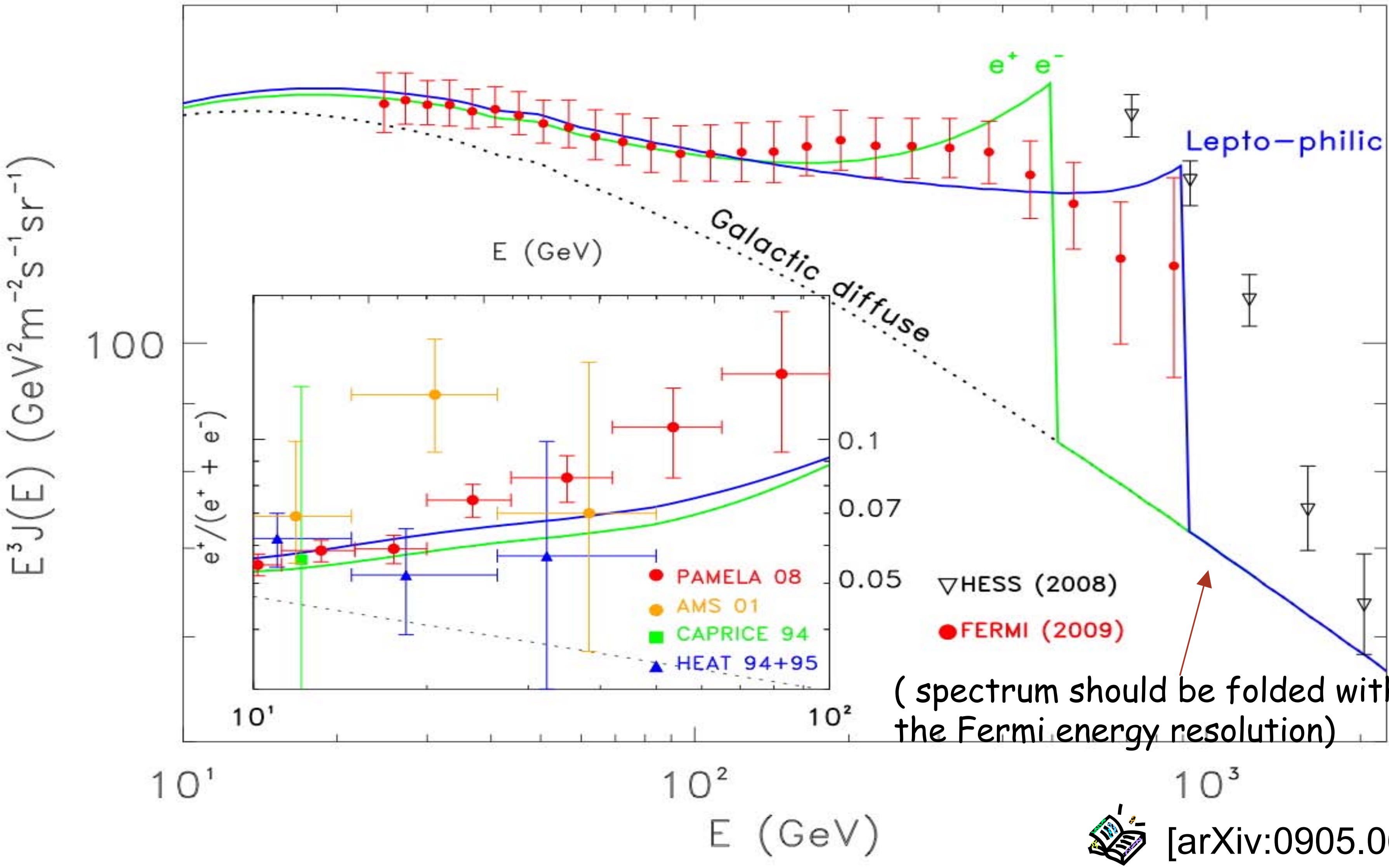


e± pairs are produced in the magnetosphere and accelerated by the electric fields and/or the pulsar wind.



A Dark Matter contribution on the observed CRE spectrum?

Predictions from two specific dark matter models:

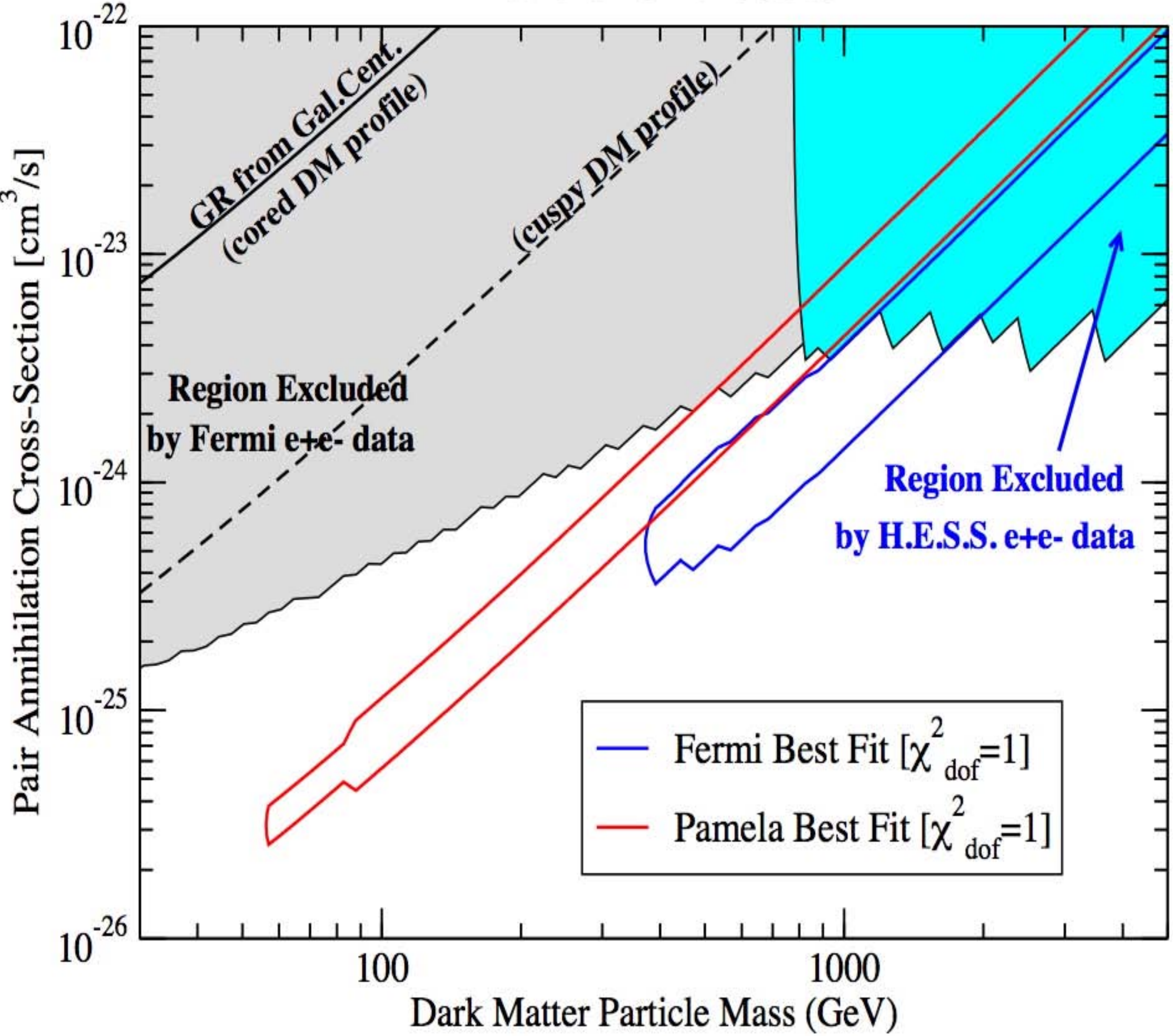


(spectrum should be folded with the Fermi energy resolution)

[arXiv:0905.0636]

Pure e+e- Models

the dark matter pair annihilation always yields a pair of monochromatic e+e-, with injection energies equal to the mass of the annihilating dark matter particle



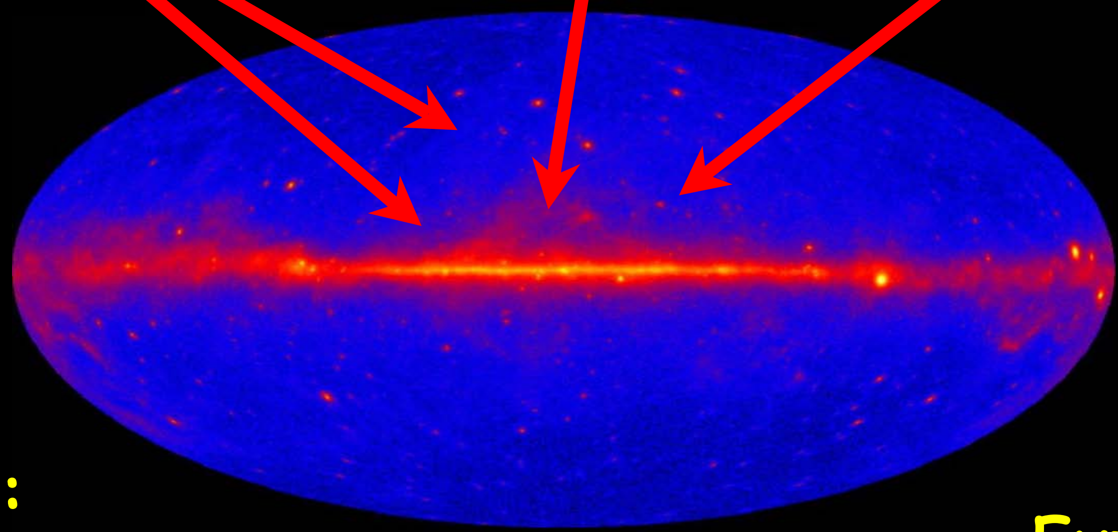
[arXiv:0905.0636]

DM Search Strategies

Satellites dwarf gal:
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



And electrons!

and

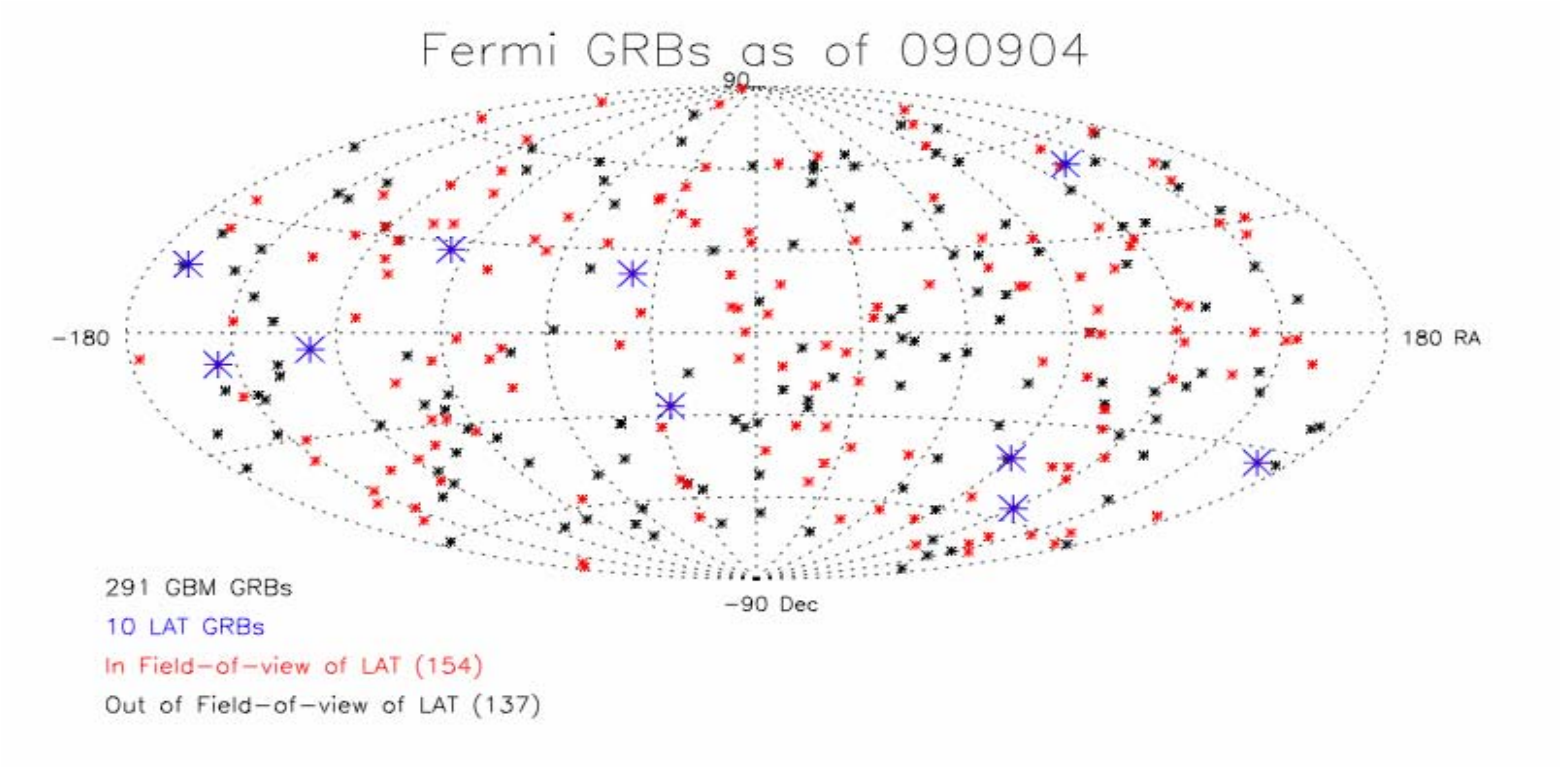
Anisotropies

Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:
Low background but low statistics

Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

Fermi GRB detections



- ✓ **1 year GBM observations: 252 GRBs, 138 in the LAT FoV**
- ✓**11 GRB detection at high energy (update 2010: 20), 9 in the first year**

9 long bursts (080825C, 080916C, 081215a, 090323, 090328, 090626, 090902b & 090926) &

2 short bursts (081024b & 090510)

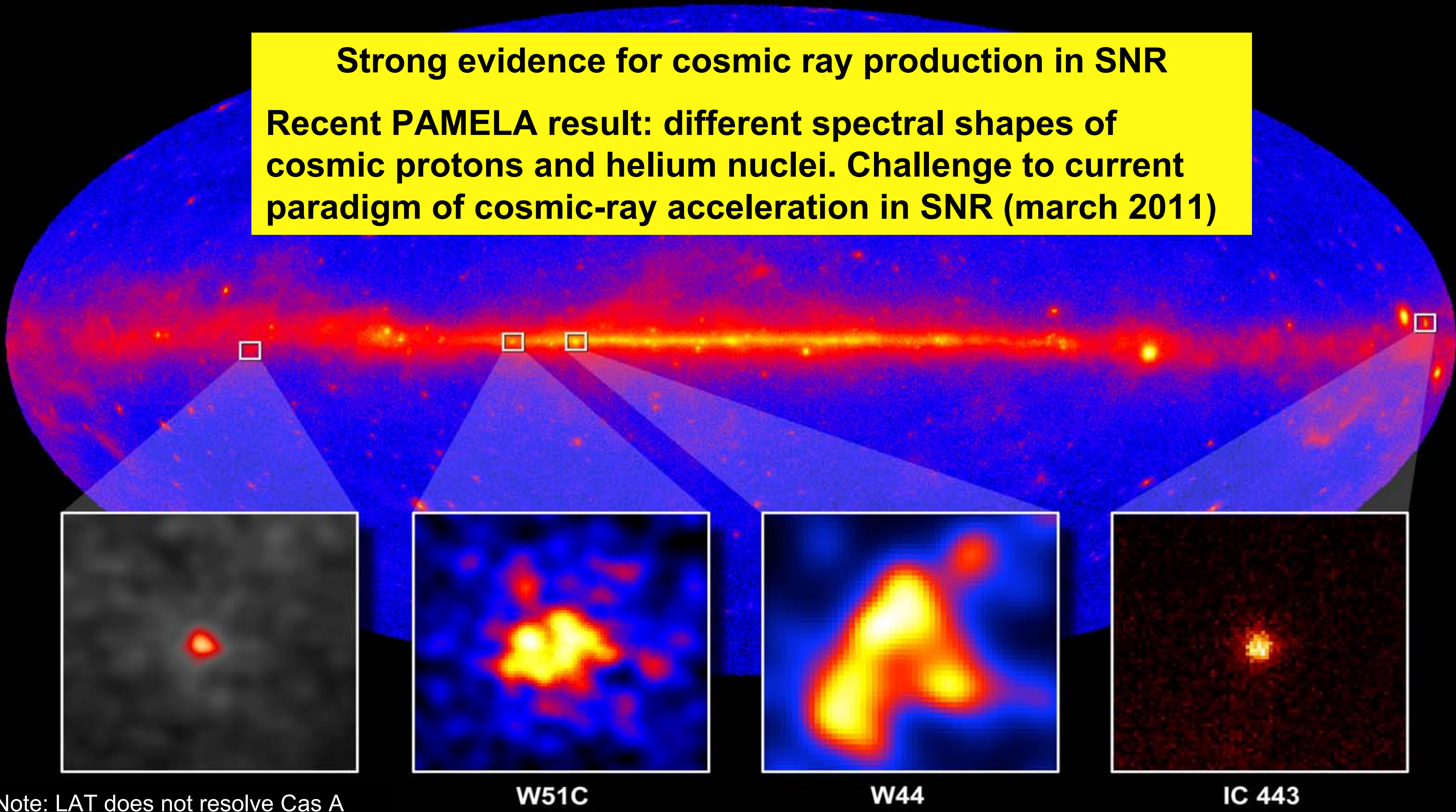
Fermi GRB summary

- ~ 9 LAT GRBs/yr suggest that most GRBs do not strongly deviate from a Band spectrum in LAT range
- Spectra: most LAT GRBs are consistent with a single dominant component; 090510 has a distinct HE spectral component (temporally correlated with low energy comp.)
- Many LAT GRBs show **later onset & longer duration** of the high-energy emission, relative to low energies
- short & long GRBs seem to have similar HE properties: HE delayed onset & longer duration, high Γ_{min}
- GRB080916C: $\Gamma \gtrsim 900$, $M_{QG,1}/M_{Planck} > 0.1$

Supernova Remnants - Spatially Resolved

Strong evidence for cosmic ray production in SNR

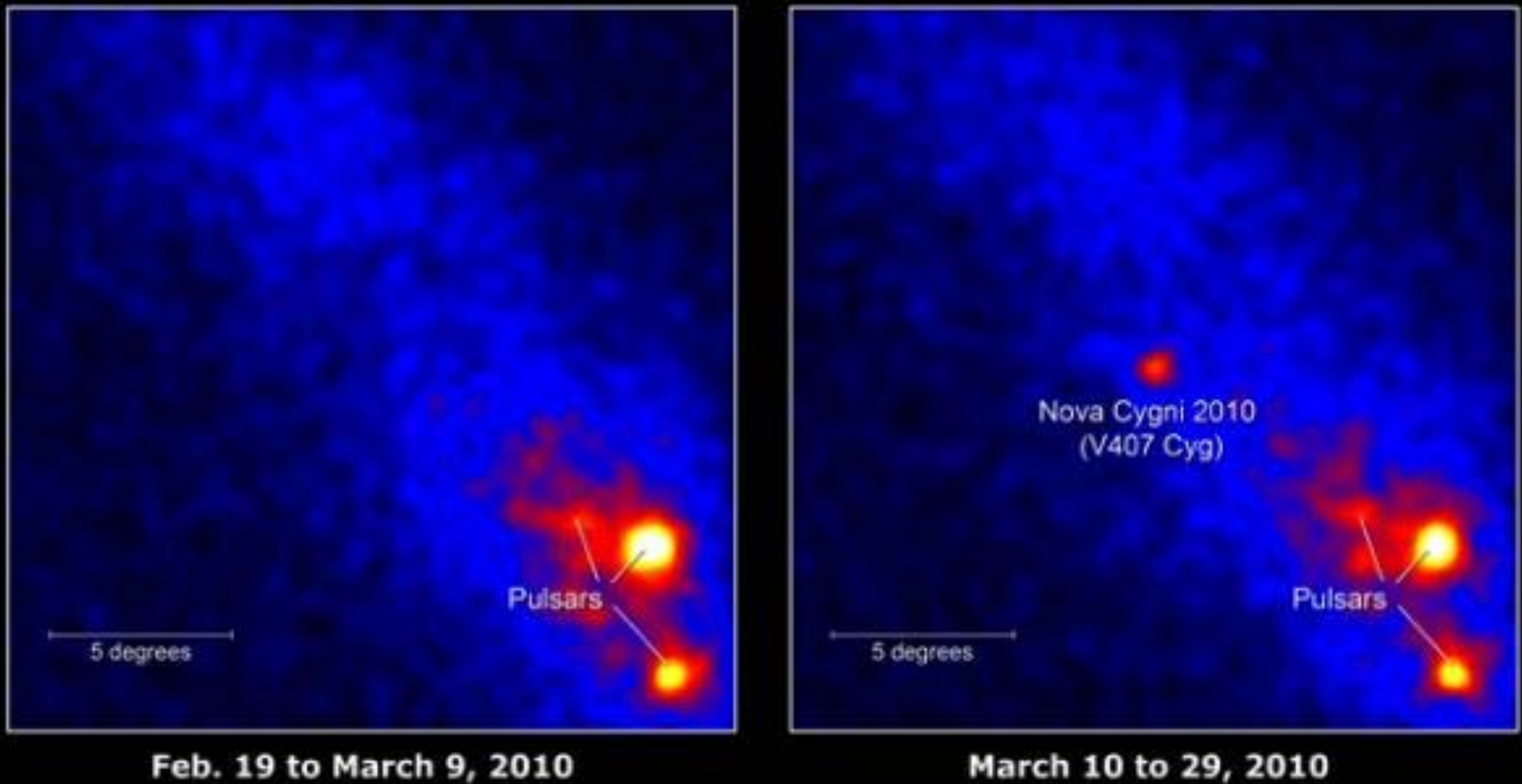
Recent PAMELA result: different spectral shapes of cosmic protons and helium nuclei. Challenge to current paradigm of cosmic-ray acceleration in SNR (march 2011)



Note: LAT does not resolve Cas A

Surprise: Fermi detects gamma rays from exploding Nova for the first time!

Science, 13 August 2010, Vol. 329. no. 5993, pp. 817 - 821



LATEST UNEXPECTED NEWS FROM THE γ-RAY SKY:

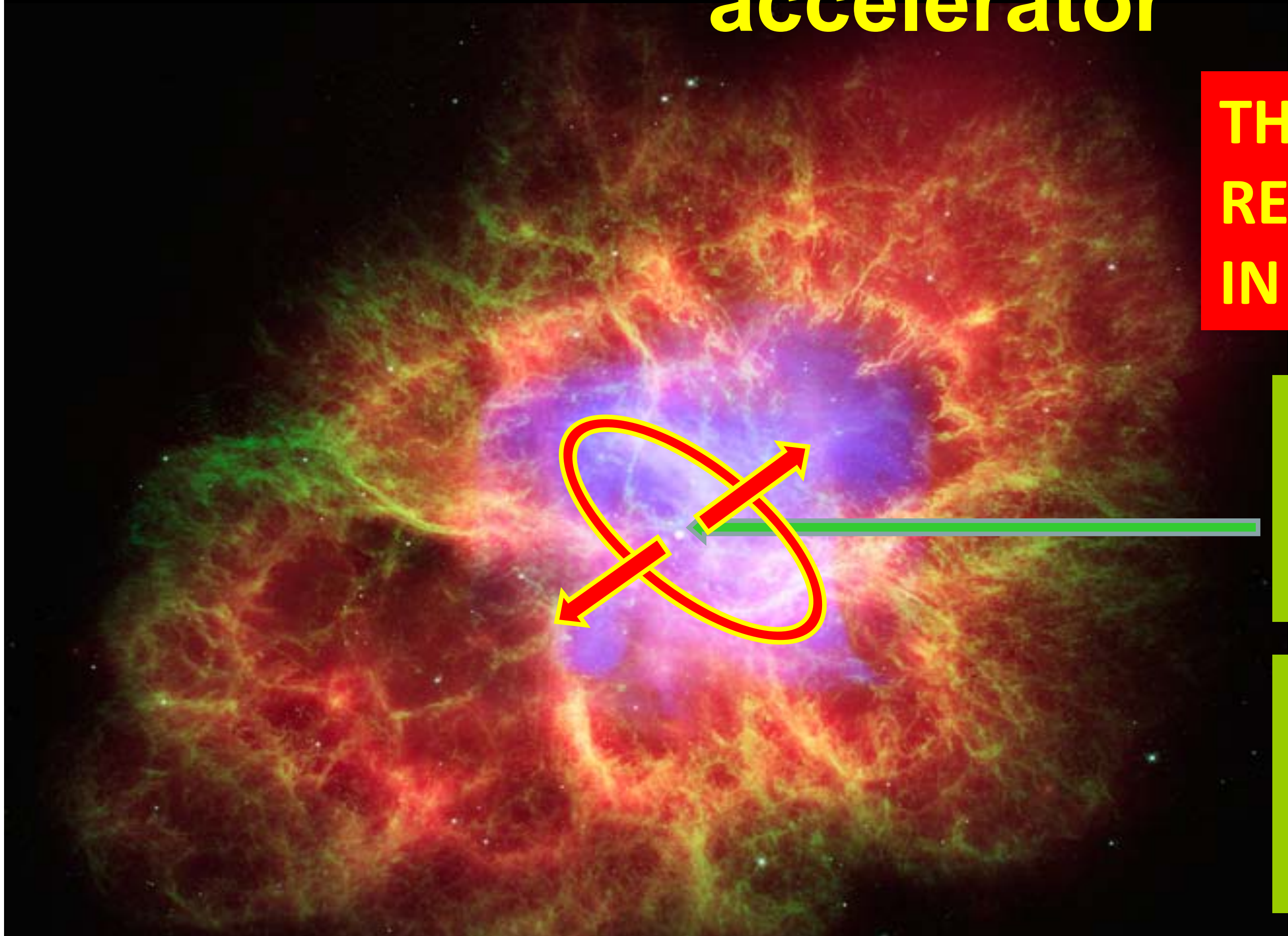
AGILE DISCOVERY OF THE CRAB NEBULA VARIABILITY IN γ-RAYS

Tavani et al., Science, 331, 736 (2011)

Fermi confirmation:

Abdo et al., Science, 331, 739 (2011)

The Crab Nebula: a spectacular cosmic accelerator



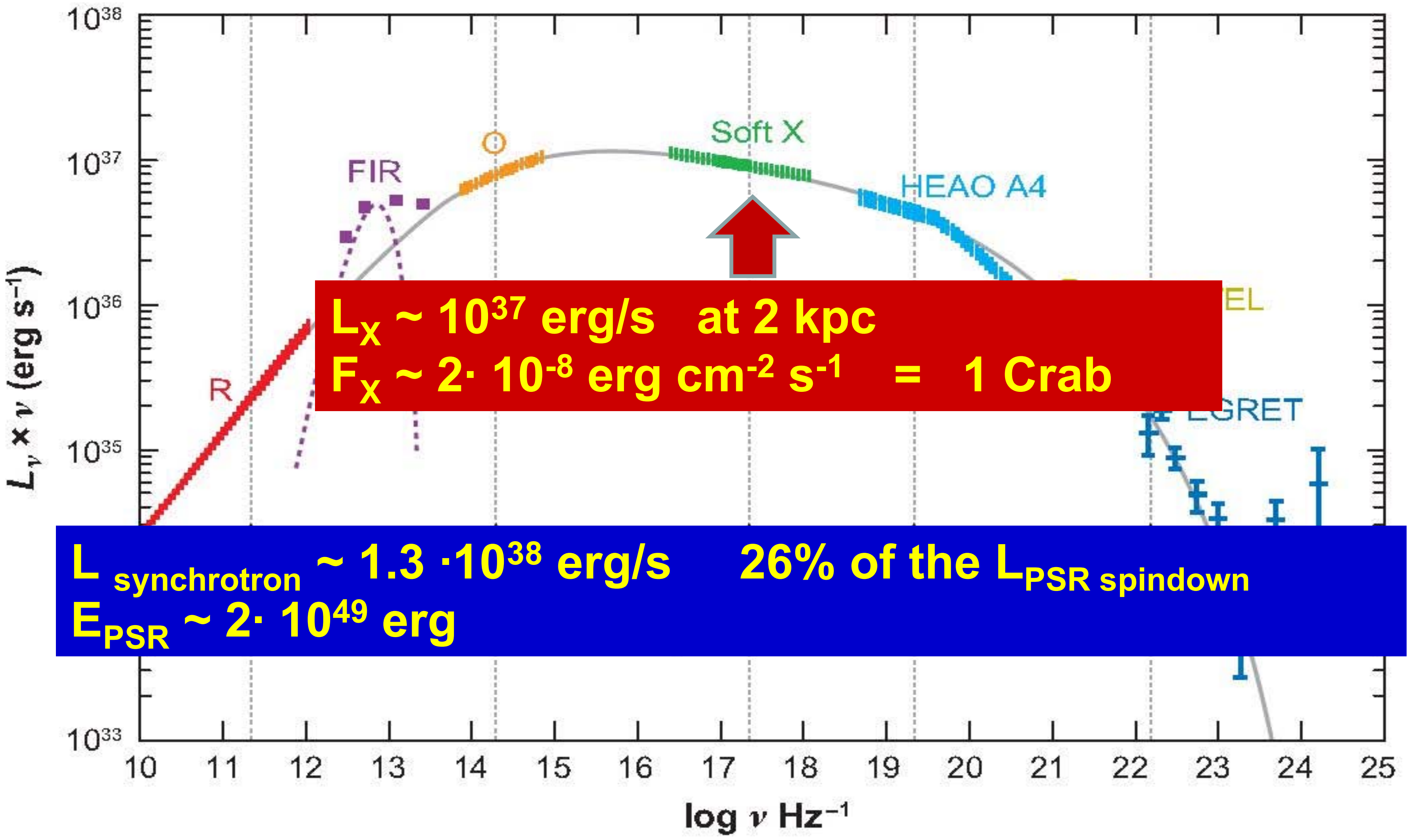
THE STANDARD REFERENCE SOURCE IN ASTROPHYSICS

POWERFUL PULSAR (Neutron Star rotating 30 times a sec)

NEBULA SHOCKED BY THE PULSAR WIND

Crab Nebula: a remnant of a supernova that exploded in AD 1054 (Chinese astronomers). X-ray data from Chandra (light blue), visible light data from Hubble (dark blue and green) and infrared data from Spitzer (red), 31/1/2001

Crab Nebula spectrum (Hester 2008)

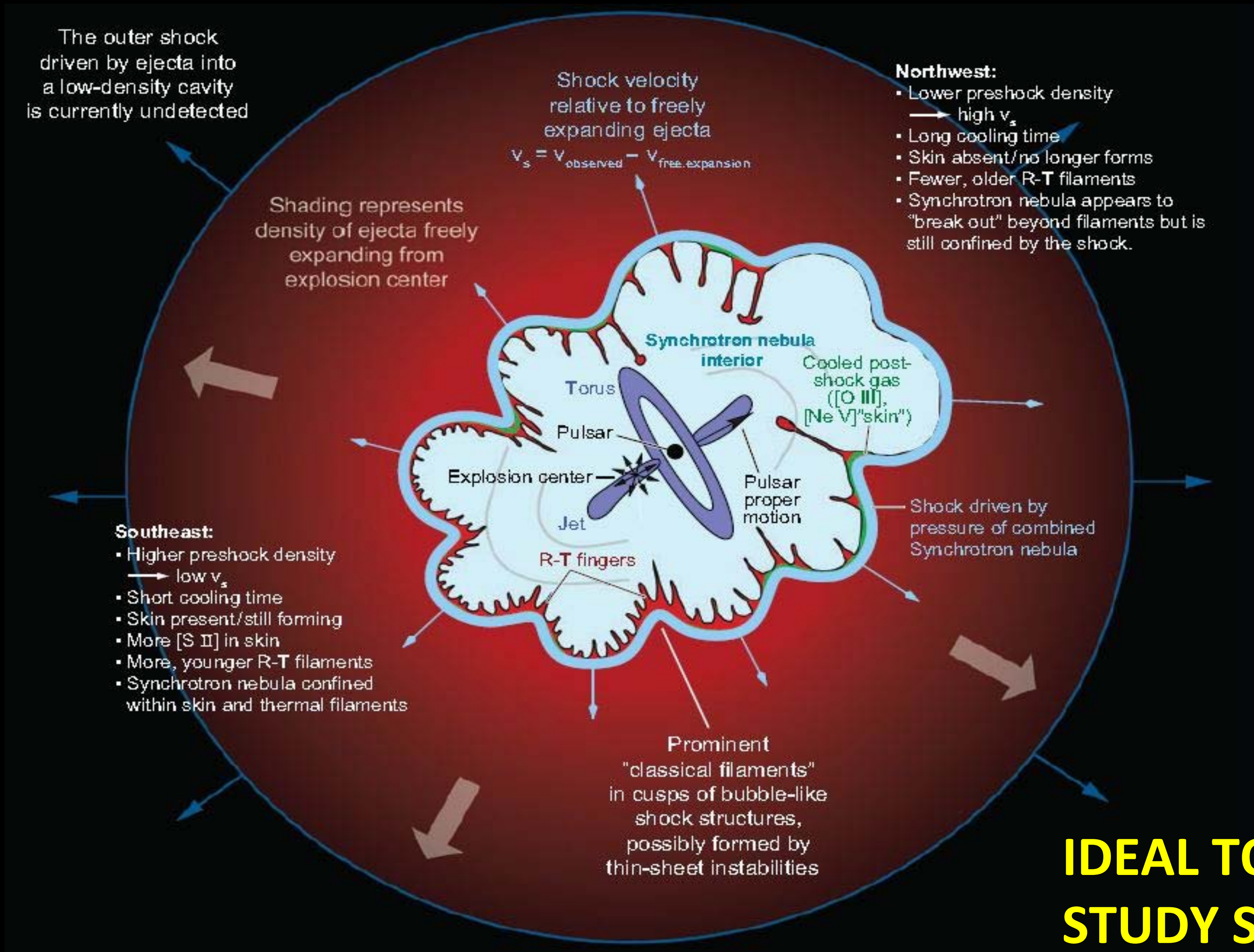


$L_X \sim 10^{37}$ erg/s at 2 kpc

$F_X \sim 2 \cdot 10^{-8}$ erg cm^{-2} s^{-1} = 1 Crab

$L_{\text{synchrotron}} \sim 1.3 \cdot 10^{38}$ erg/s 26% of the $L_{\text{PSR spindown}}$

$E_{PSR} \sim 2 \cdot 10^{49}$ erg

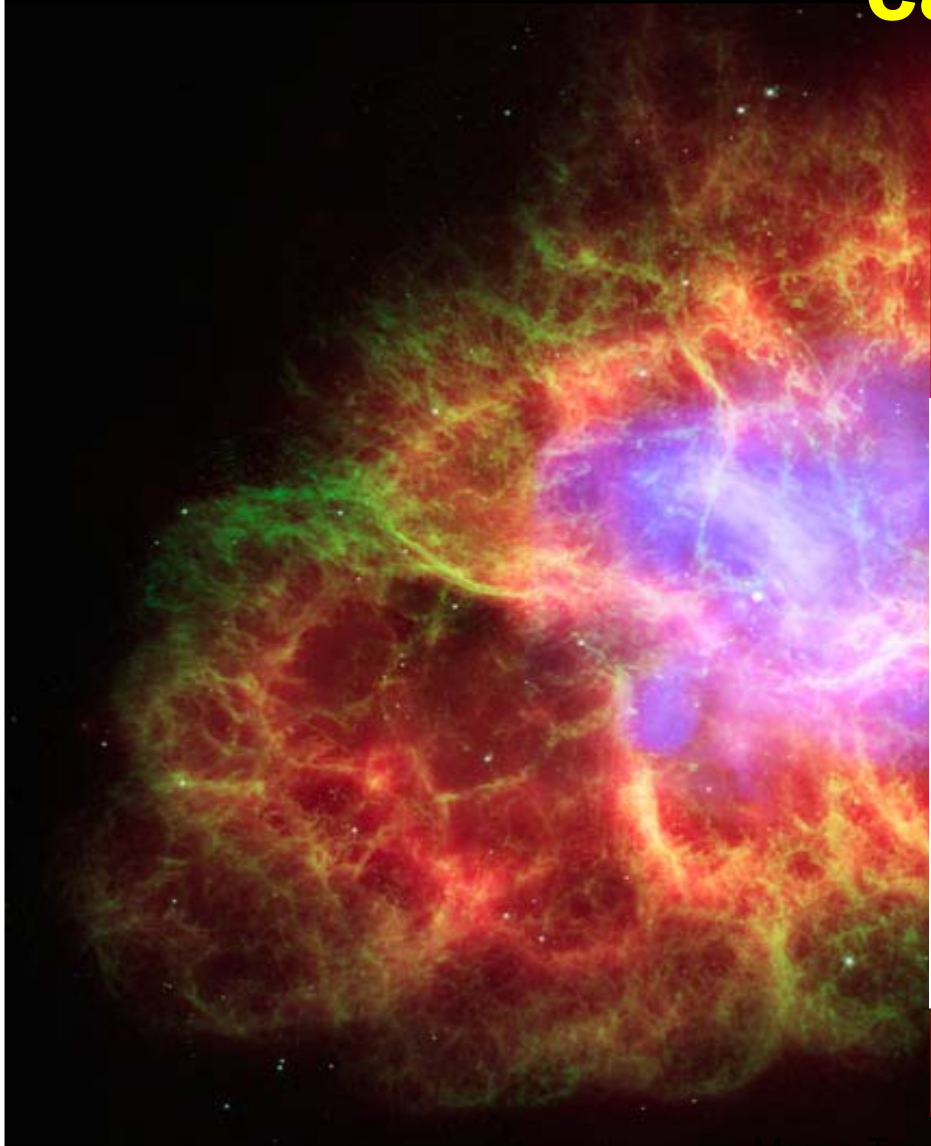


IDEAL TO STUDY SHOCK ACCELERATION

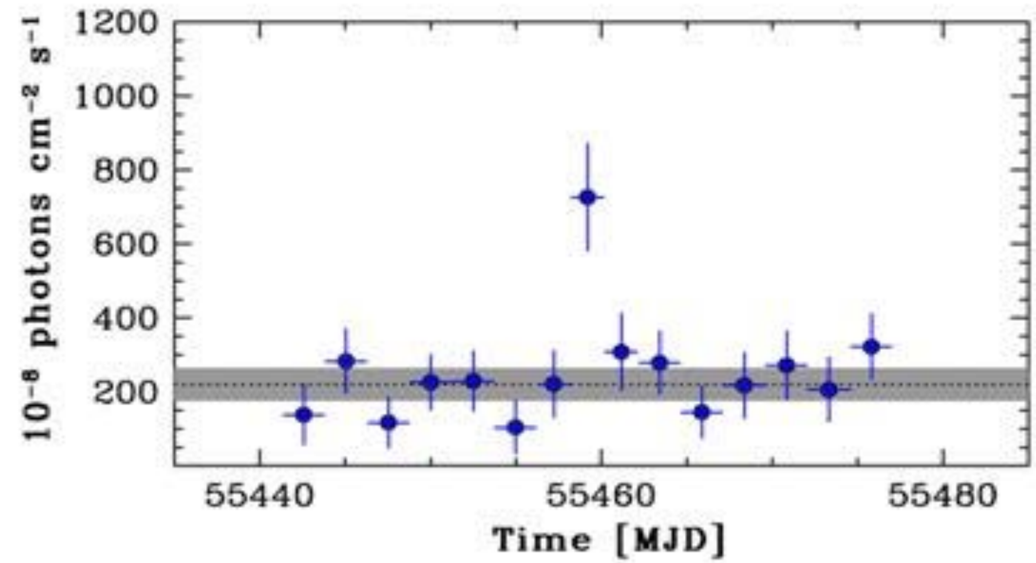
Crab Nebula "standard" modelling

- Average nebular magnetic field B = 200 μ G
- PSR-injected particles dN/dt ~ $10^{40.5}$ s^{-1}
- Total emitting particles, N ~ 2 $\cdot 10^{51}$
- Many shock accelerating sites in the Nebula
- Inner Nebula variability (weeks-months)
  - **Toroidal structures (wisps)**
  - **Jet-like structures (knots)**

The Crab Nebula: a standard candle…?

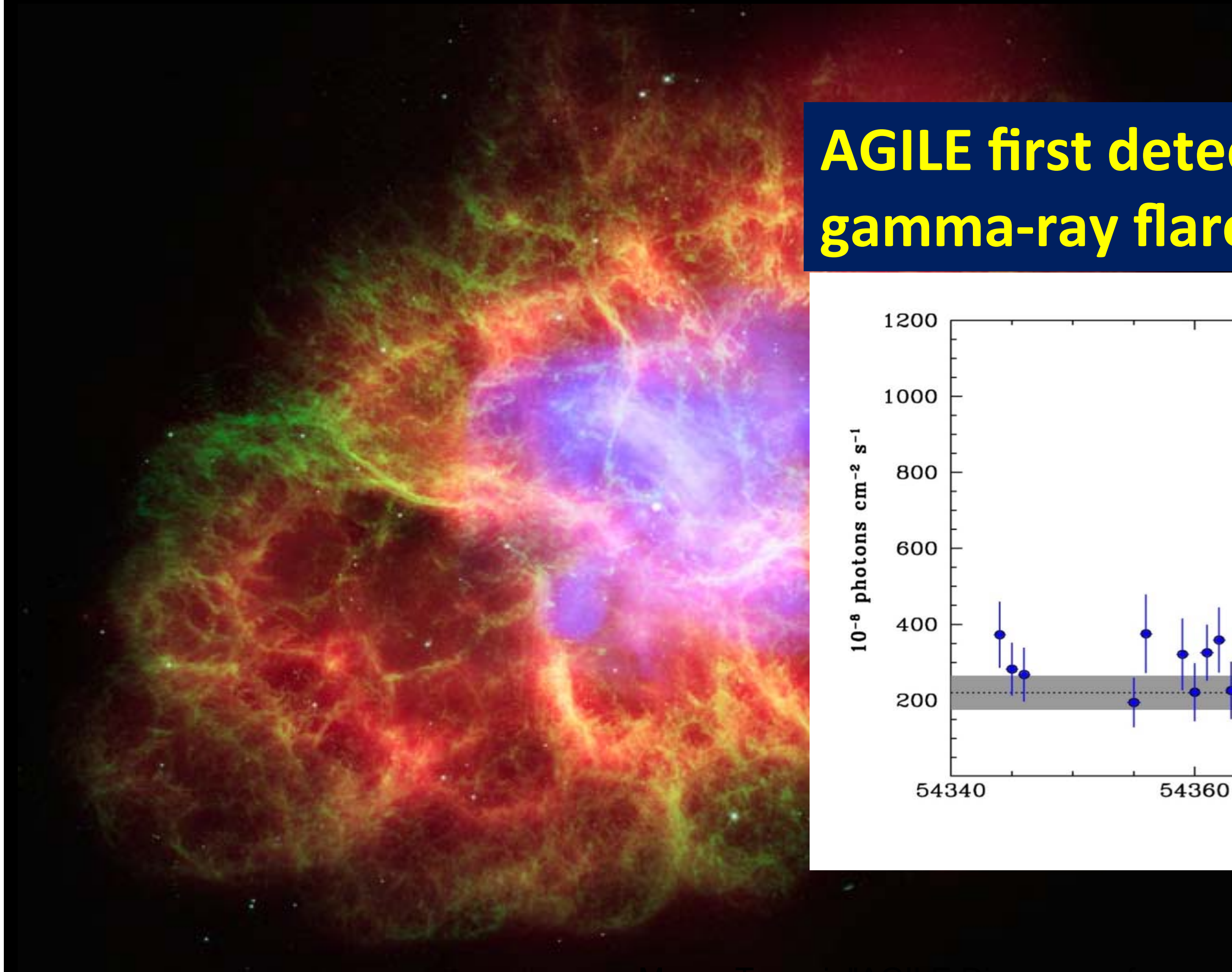


FIRST PUBLIC ANNOUNCEMENT
Sept. 22, 2010: AGILE issues the Astronomer's Telegram n. 2855

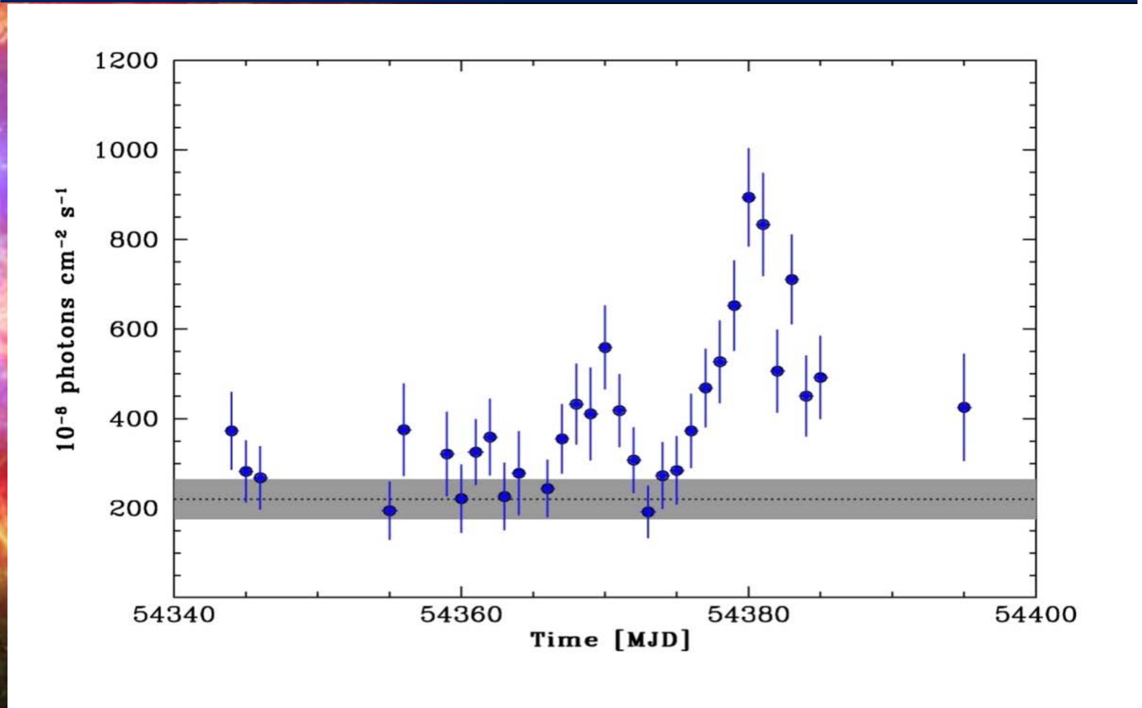


Science Express **(6 January 2011)**

The variable Crab Nebula !



AGILE first detection of a strong gamma-ray flare in Oct. 2007



A&A 506, 1563–1574 (2009)
DOI: 10.1051/0004-6361/200911783

Astronomy & Astrophysics

First AGILE catalog of high-confidence gamma-ray sources

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1AGL J0535+2205 and 1AGL J0634+1748 (Crab and Geminga). These two well known strong γ-ray pulsars, together with the Vela pulsar, were used for in-flight AGILE calibrations. We report the flux values obtained during calibration subperiods. These values agree with pulsed flux values reported in (Pellizzoni et al. 2009). We note, however, that we observed higher flux values, over 1σ from the reported mean flux, for both sources when merging all the data, including shorter (1 day) integration periods during 2007. This point is under investigation.

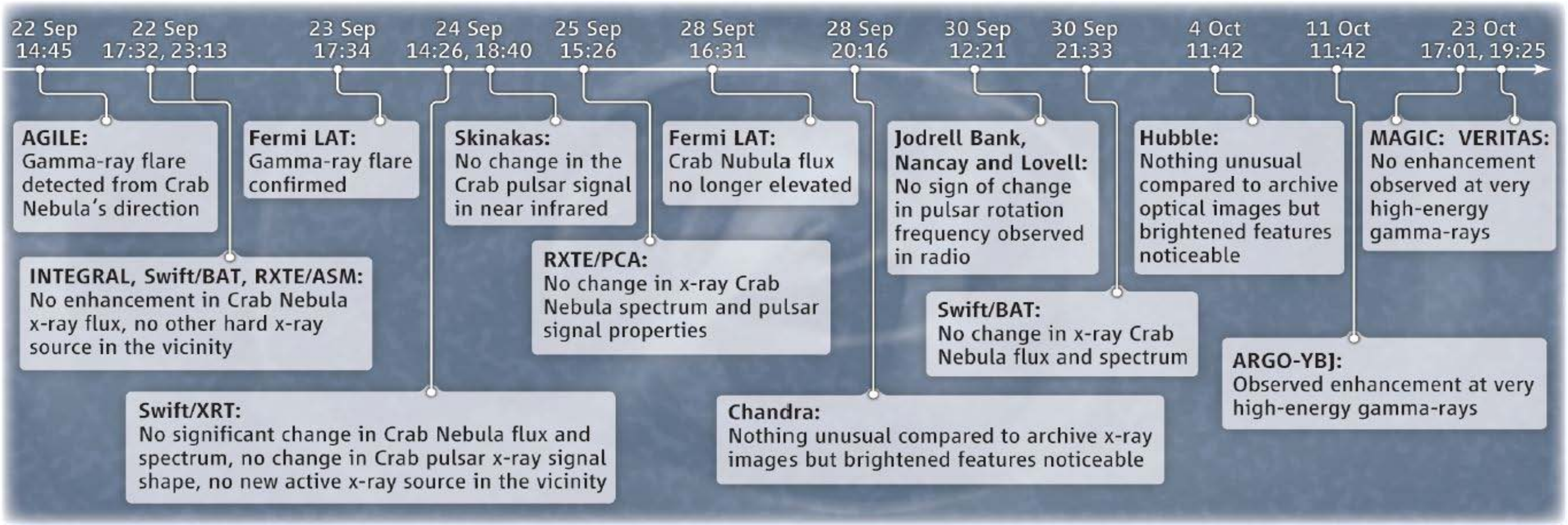
1AGL J0617+2236. This AGILE detection provides an improved positioning compared to the 3EG J0617+2238 error box. This source is positionally coincident with the SNR IC443 (Tavani et al. 2009c). The AGILE error box also contains the PSR J0614+2229.

1AGL J0657+4554 and 1AGL J0714+3340. These two high-latitude ($|b| > 10$ deg) AGILE sources, associated with blazars

AGILE Discovery of Crab Nebula Variability: a Chronology

- April 2007: AGILE launch.
- October 2007: AGILE detects the first "anomalous" gamma-ray flare from the Crab.
- Oct. 23, 2007: AGILE team meeting and first discussion of the Crab event (STAG n. 39 Minutes of Meeting).
- **Sept. 2009: Pittori et al. *Astron. & Astrophys*., 509, 1563, 2009**:"the anomalous flux from the Crab in Oct. 2007 is under investigation."
- Sept. 19-21, 2010: detection of the second Crab γ-ray flare by the AGILE Alert System: **evidence for a repetitive phenomenon**.
- **Sept. 22, 2010: AGILE issues Astronomer's Telegram 2855 announcing the discovery of a γ-ray flare from the Crab.**
- **Sept. 23, 2010: *Fermi* issues ATel 2861 confirming the flare.**
- Sept. 28, 2010: first post-flare ***Chandra*** pointing.
- Oct. 2, 2010: ***Hubble*** points at the Crab; several **Swift** pointings

post-flare excitement



Bernardini E., 2011

Crab Sept. 2010 flare

- gamma-ray flare peak luminosity

$$L \approx 5 \cdot 10^{35} \text{ erg cm}^{-2} \text{ s}^{-1}$$

- kin. power fraction of PSR spindown L_{sd},

$$\varepsilon \approx 0.001\ (\eta_{-1}/0.1) \approx 0.01$$

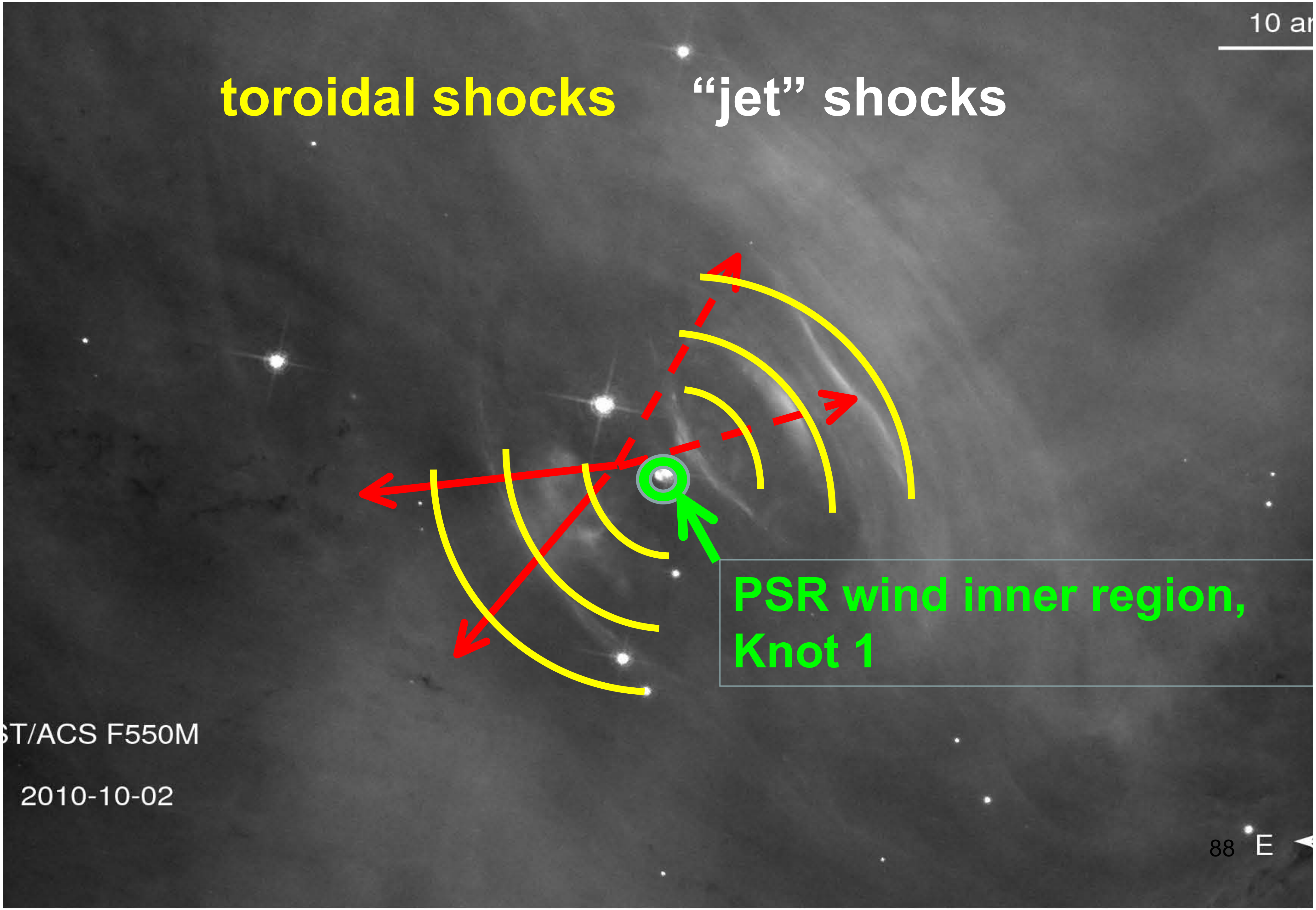
- timescales:
  - risetime: ≤ 1 day
  - decay: $\sim$ 2-3 days

very efficient acceleration !

fast cooling, B, Lorentz γ

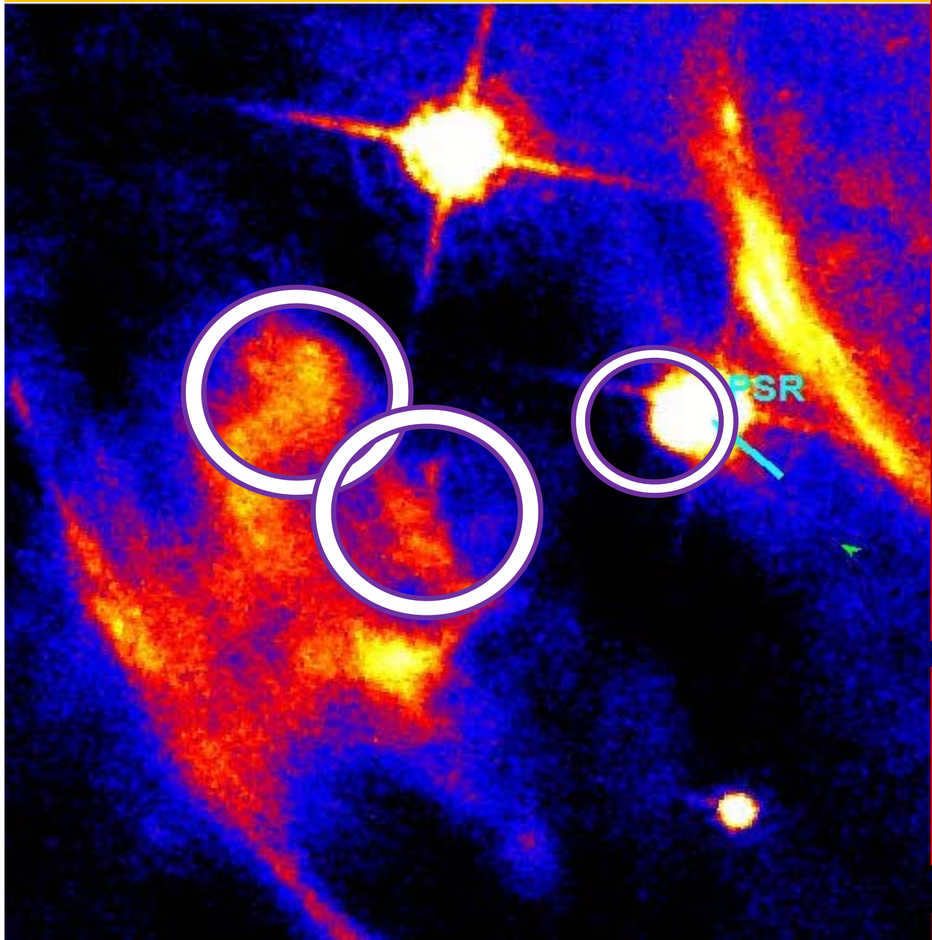
- Crucial constraints on shock particle acceleration theory !
  - e-/e+ shock acceleration by magnetic turbulence (diffusive vs. non-diffusive)
  - ion cyclotron absorption (e.g., J.Arons et al.)

- Crab Nebula shocks able to accelerate electrons/positrons at $\gamma \sim 10^9$ (PeV) !
  - already inferred from “static” Nebula models (e.g., deJager & Harding, Atoyan & Aharonian)
  - never observed within a 1 day timescale !



10 ar
toroidal shocks
"jet" shocks
PSR wind inner region,
Knot 1
ST/ACS F550M
2010-10-02
E

Hubble (optical) Oct. 2, 2010



PUZZLING ACCELERATION:

• fast flares imply VERY EFFICIENT particle acceleration at shocks, and "small" emission sites

• ***FAST ACCELERATION inconsistent with "slow" diffusion processes, a challenge to shock acceleration theory !***

• acceleration up to 10^{15} eV, 1000 times larger than Tevatron or LHC

• shock structures might be the sites of transient gamma-rays, HST and Chandra candidates

Summing up

- very exciting: the Crab Nebula is not a standard candle in gamma-rays

Flare date	Duration	Peak γ-ray flux	Instruments
October 2007	~ 15 days	~ $6 \cdot 10^{-6}$ ph cm^{-2} s^{-1}	AGILE
February 2009	~ 15 days	~ $4 \cdot 10^{-6}$ ph cm^{-2} s^{-1}	*Fermi*
September 2010	~ 4 days	~ $5 \cdot 10^{-6}$ ph cm^{-2} s^{-1}	AGILE, *Fermi*

- we "lost" the stability of an ideal reference source, but gained tremendous information about the fundamental process of particle acceleration
- a big theoretical challenge
- (study of vacuum energy in extreme gravity conditions?)
- the ultimate source of particle enhancements in the pulsar wind needs to be established: future surprises

Conclusions

- **AGILE and Fermi** in orbit: exciting time for gamma-ray astrophysics, many interesting results and unique scientific contributions
- **Pulsars and PWN, blazars, X-ray binaries, SNR, CWB, starburst galaxies and gamma-ray burst: highly populated and variable gamma-ray sky**
- **Multiwavelength/multimessenger studies are critical for learning the nature of unidentified sources and test theoretical models**
- **Look at Multimission ASDC Archive, try ASDC MW tools and give us your feedback**