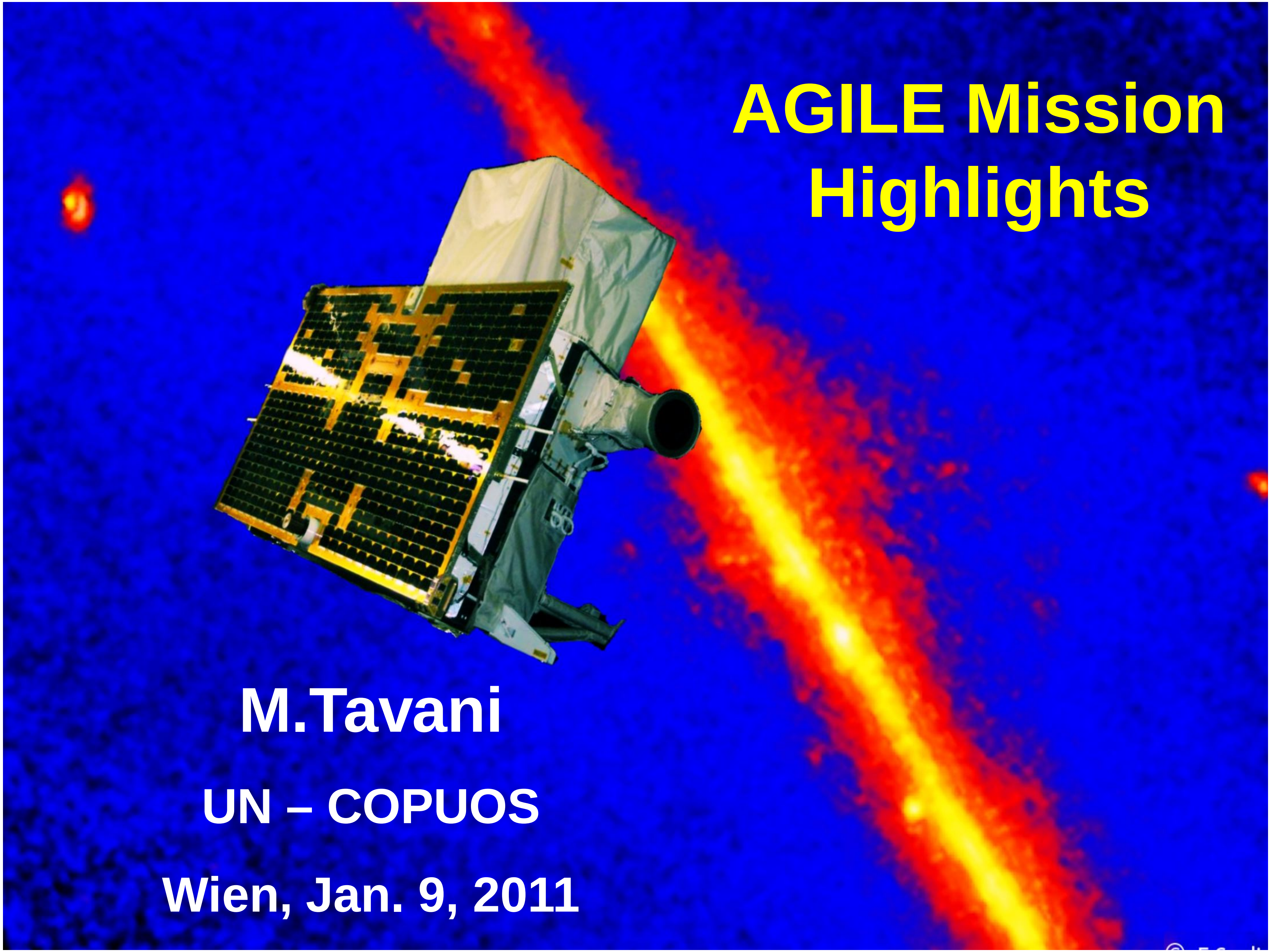
AGILE Mission Highlights



M.Tavani

UN – COPUOS

Wien, Jan. 9, 2011

AGILE: an Italian Mission

asi agenzia spaziale italiana

INAF

INFN

CARLO GAVAZZI
Carlo Gavazzi Space SpA

OERLIKON CONTRAVES

ALCATEL ALENIA SPACE
An Alcatel/Finmeccanica company

telespazio
A Finmeccanica/Alcatel company

Galileo Avionica

MIPOT

ENEA

AGILE: 4th year in orbit…

- ~ 19.800 orbits, Feb. 9, 2011.

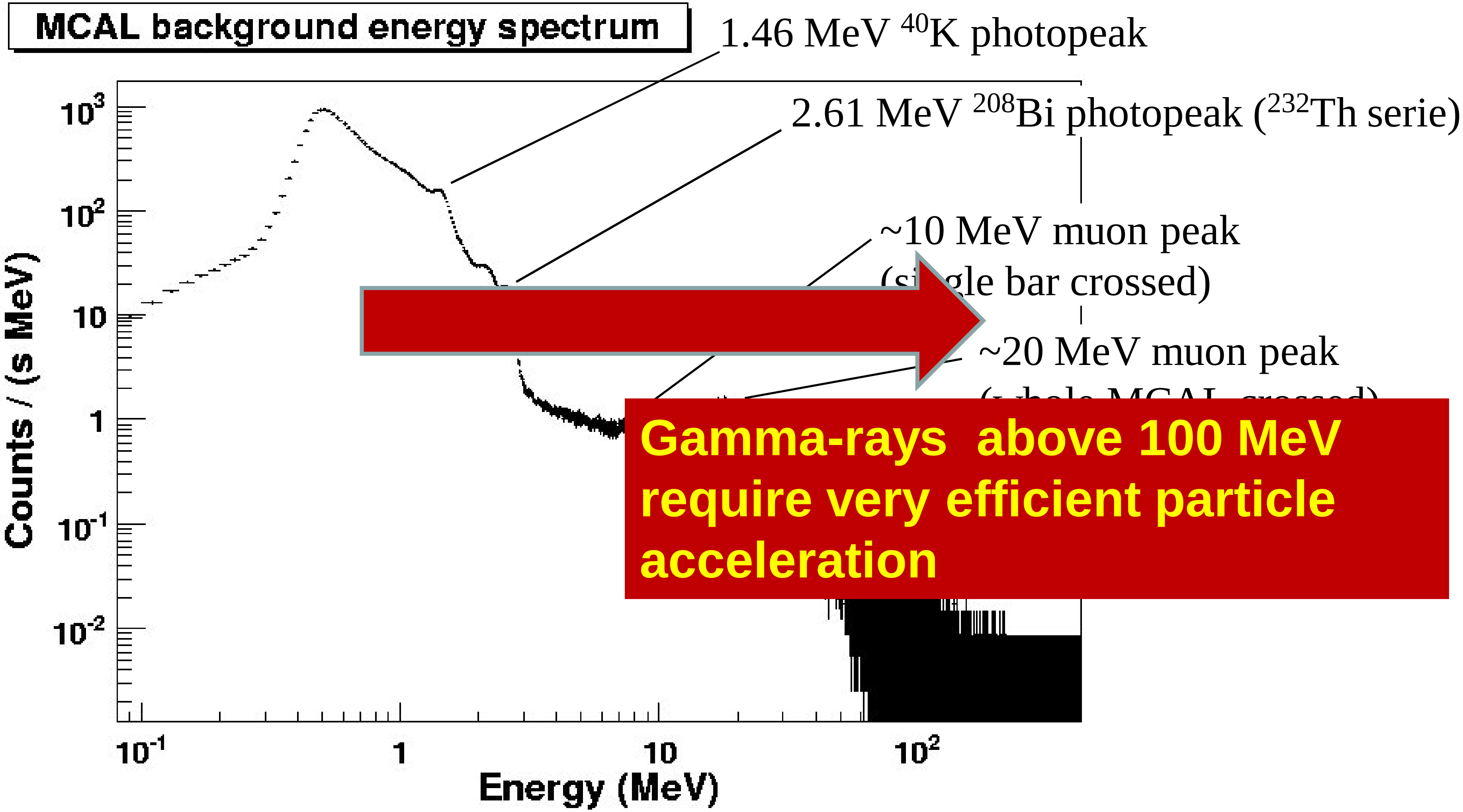
- very good scientific performance

- Scientific program open to the international community
- Cycle-1: Dec. 2007- Nov. 2008
- Cycle-2: Dec. 2008- Nov. 2009
- Cycle-3: Dec. 2009- Nov. 2010
- Cycle-4: Dec. 2010- Nov. 2011

- **Introduction to High-Energy Astrophysics**

- **Focus on gamma-rays, Very High Energy gamma-rays**
  - **30 MeV – 30 GeV (HE γ – rays)**
  - **30 GeV – 100 TeV (VHE γ – rays)**

EXAMPLE: Room Radioactivity (measured in the lab)



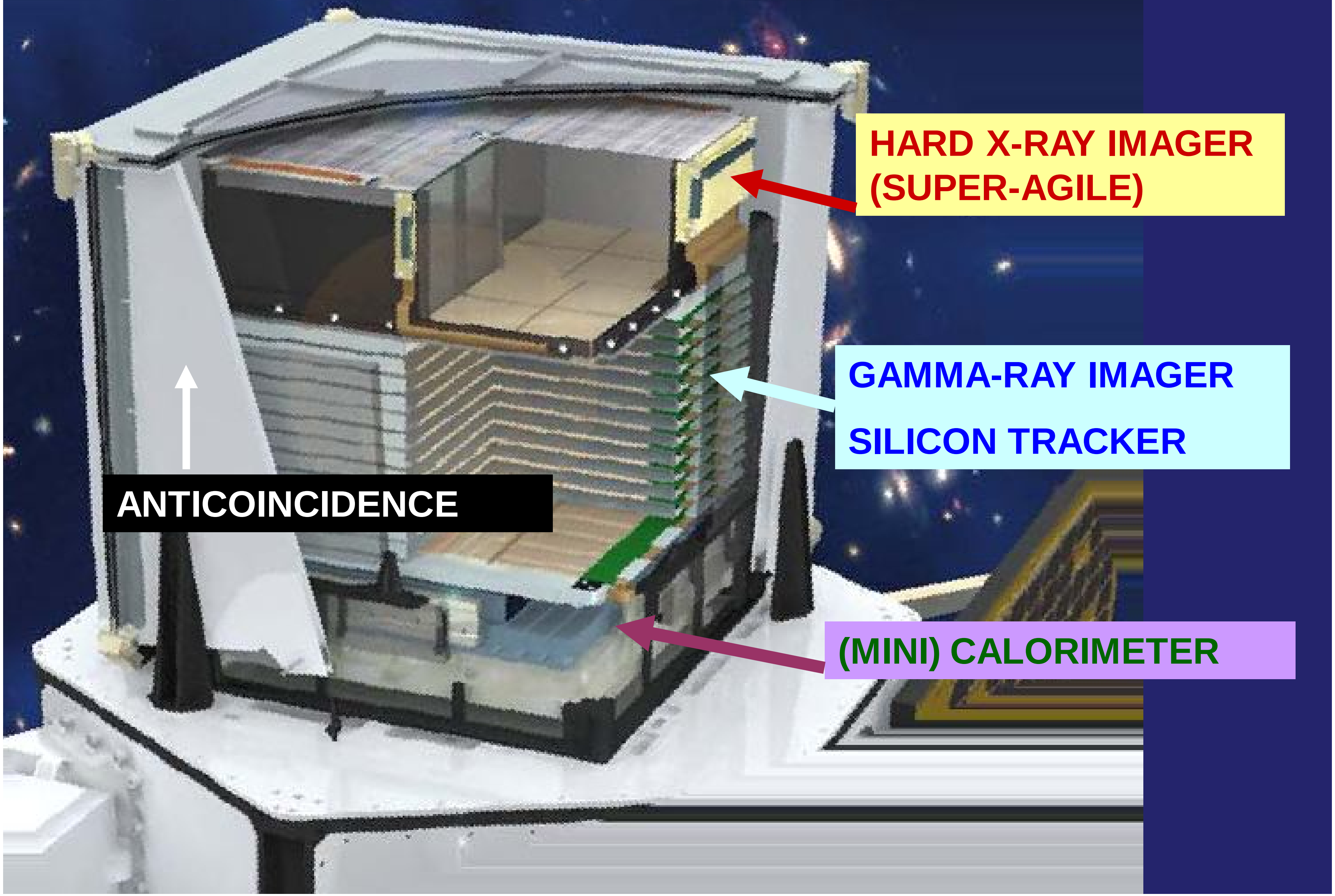
Gamma-rays above 100 MeV require very efficient particle acceleration

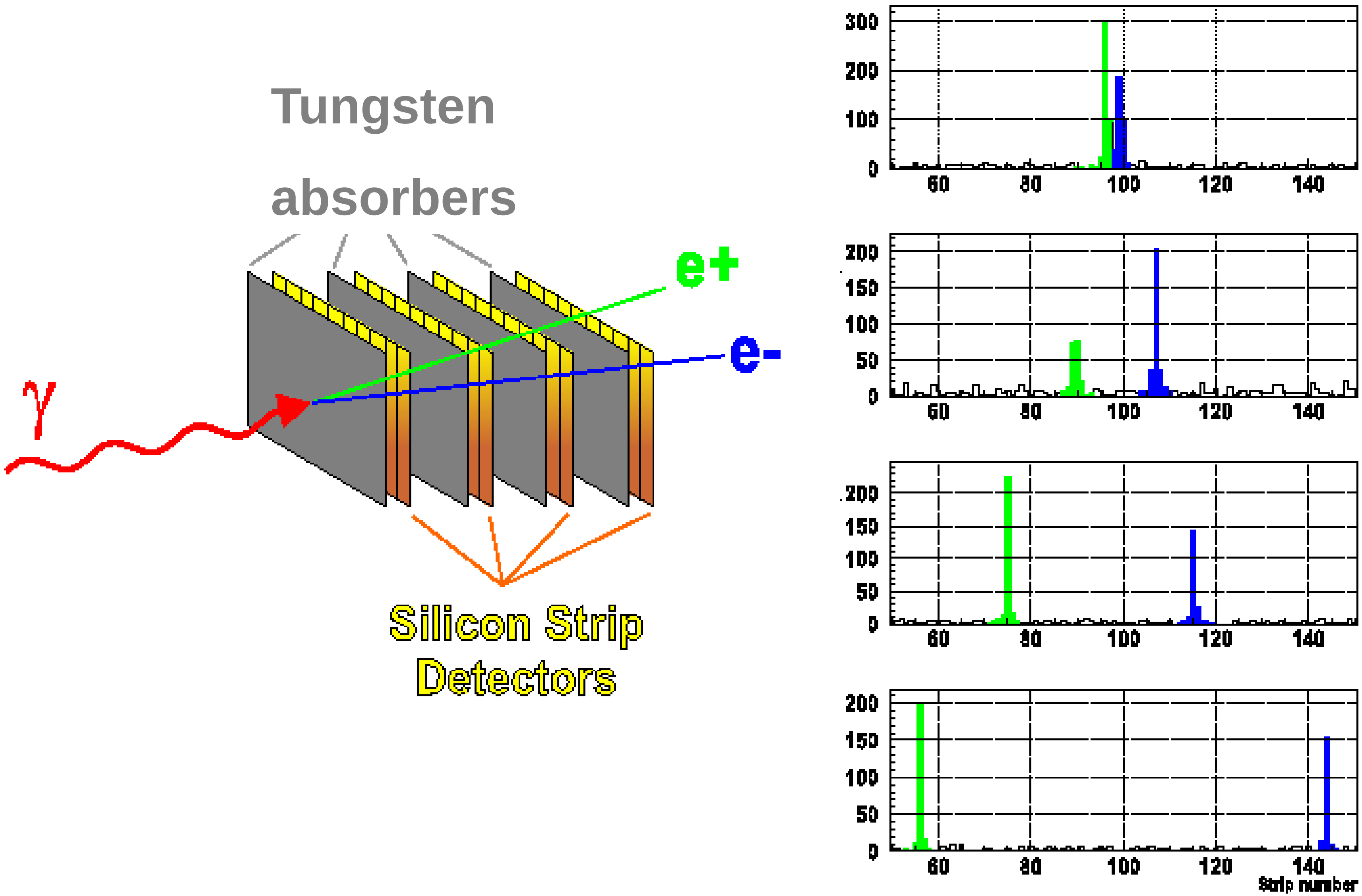
Broad band background energy spectrum measured by a CsI detector (MCAL of AGILE) sensitive in the 400 keV – 100 MeV energy range.Several features due to radioisotopes in the environment and atmospheric muons can be identified.

The AGILE Payload: the most compact instrument for high-energy astrophysics

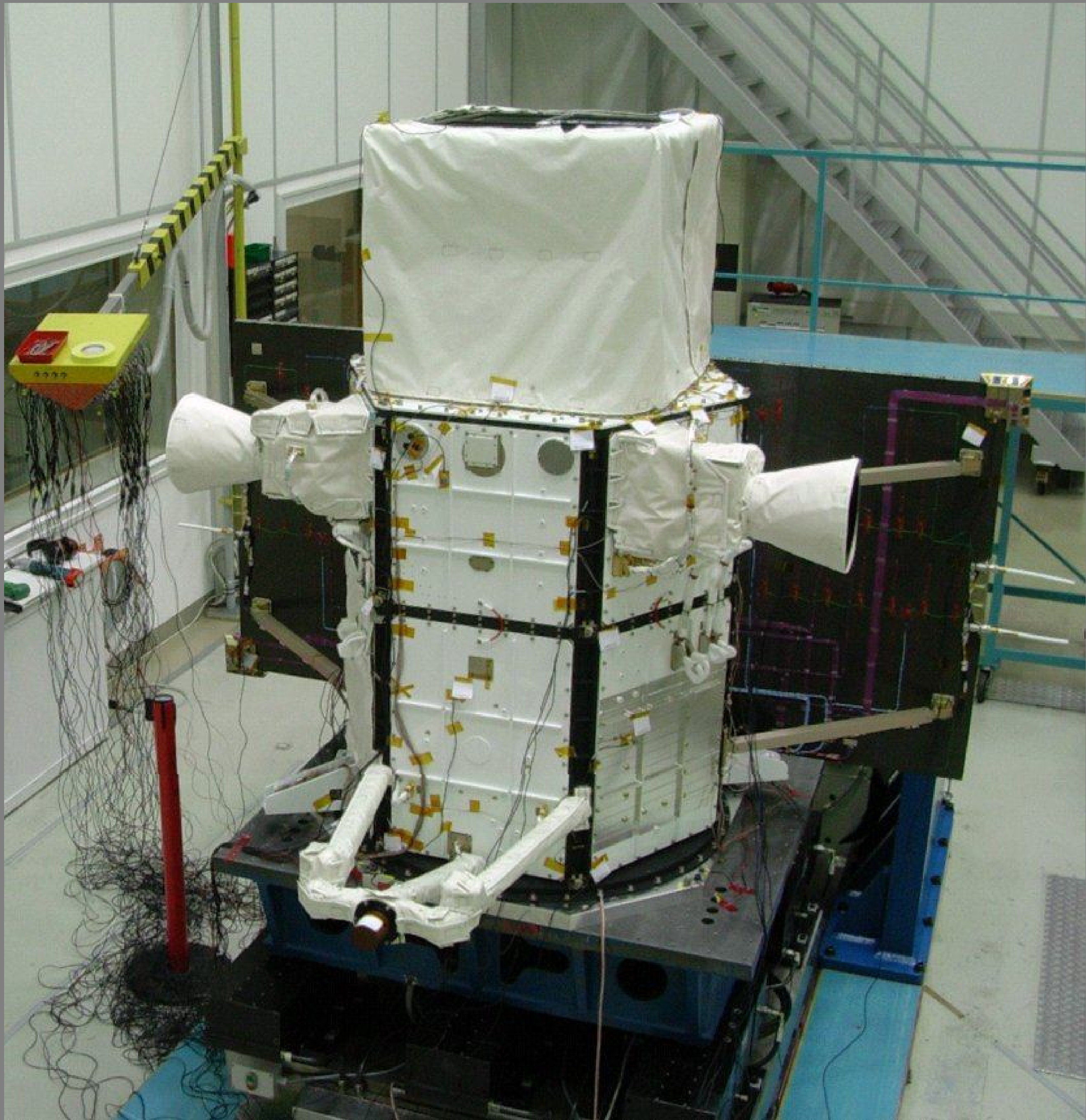
It combines for the first time a gamma-ray imager (30 MeV- 30 GeV) with a hard X-ray imager (18-60 keV) with large FOVs (1-2.5 sr) and optimal angular resolution

AGILE: inside the cube…





PHOTAG TESTBEAM - INFN TS/IFC MI



AGILE Satellite (IABG, Munich 16 June, 2006)

350 kg satellite


AGILE
CARLO GAVAZZI
INAF
agenzia spaziale italiana
CARLO GAVAZZI
INFN
AGILE
OERLIKON CONTRAVES
ALCATEL ALENIA SPACE
TELESPAZIO
GALILEO AVIONICA

Om agnim ile purohitan
yajnasya devam rtvijam
hotaram ratnadhatamam
Rig Veda, I, 1

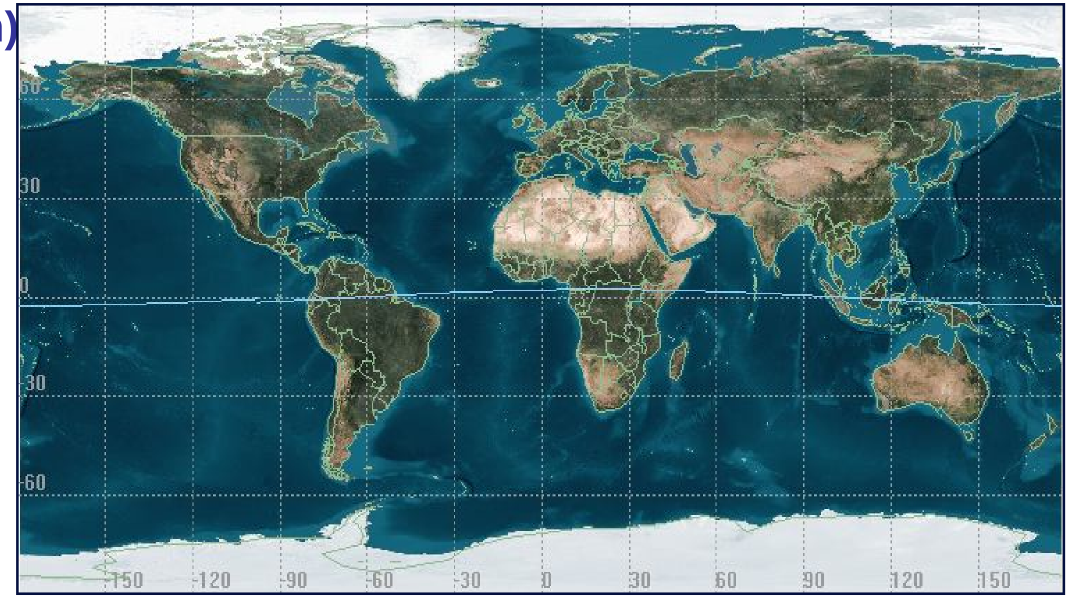
Launch !
(23 April 2007)

AGILE orbital parameters

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°



Gamma-ray astrophysics missions (above 30 MeV)

SAS-2	NASA	Nov. 1972 – July 1973
COS–B	ESA	Aug. 1975 – Apr. 1982
CGRO	NASA	Apr. 1991 – Jun. 2000
AGILE	ASI	April 23, 2007
Fermi	NASA	June 11, 2008

AGILE's scientific strengths

- **combination of co-aligned gamma-ray (50 MeV – 5 GeV) and hard X-ray (20-60 keV) imagers**

- **optimal sensitivity near 100 MeV**

- **millisecond data acquisition**

- **Cosmic and Terrestrial phenomena studied by the same Mission**

- **Efficient particle acceleration**

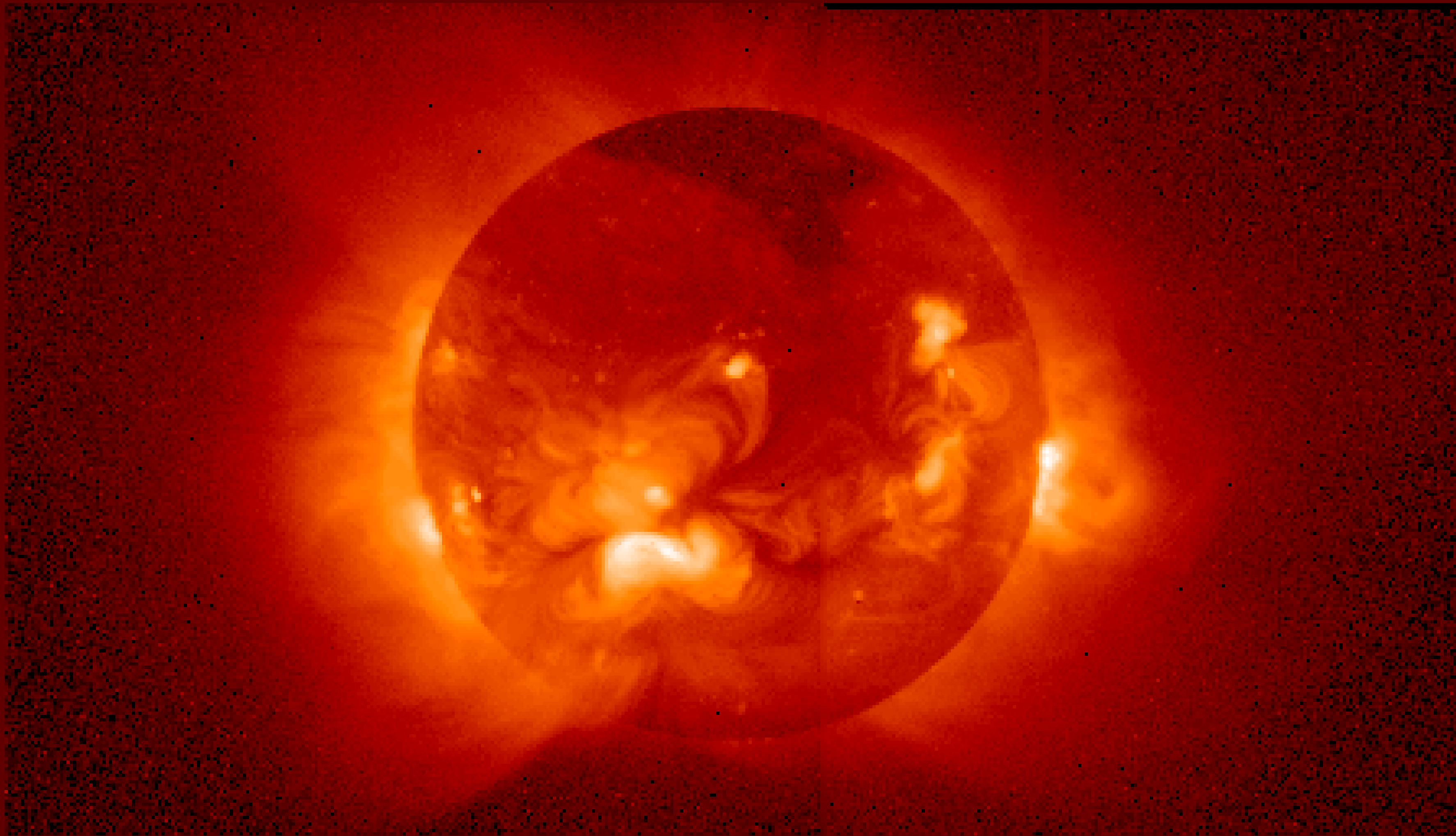
- **Radiation processes**

- **Ultimate origin: matter in extreme conditions under the influence of strong gravity+electromagnetic+nuclear+weak interactions**

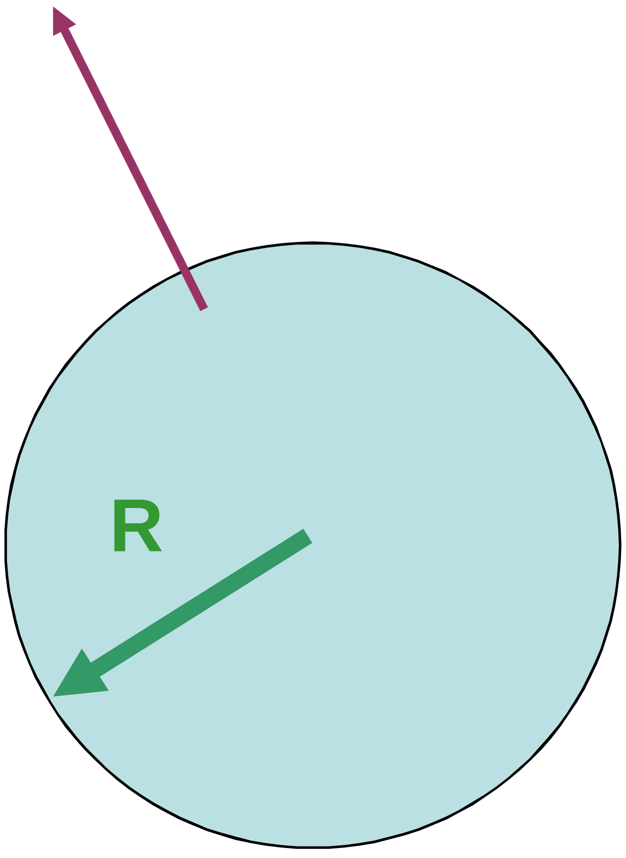
A short summary

- Physics of Black holes
- Surprising results for particle acceleration theory (Crab Nebula)
- Gamma-rays from the planet Earth: a special kind of lightning

Our Sun…



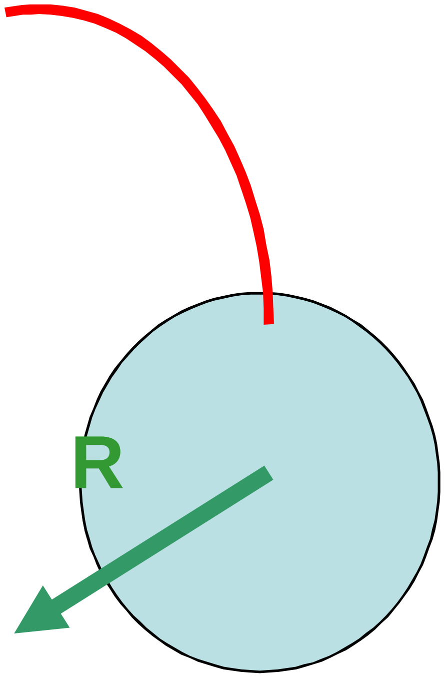
M = mass within radius R



$$F_g = \frac{G\,M}{R}$$

"weak" gravity case

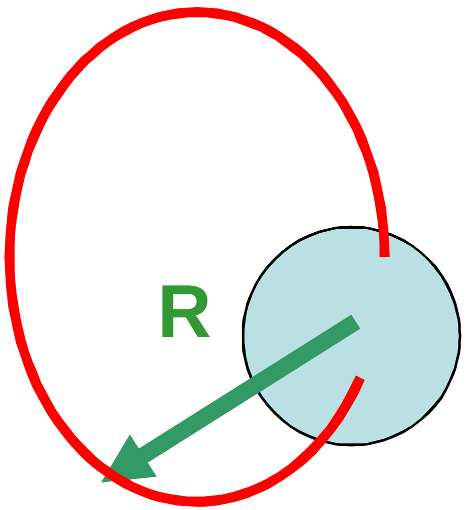
M = mass within radius R



$$F_g = \frac{G\,M}{R}$$

"intermediate strength" gravity case

M = mass within radius R

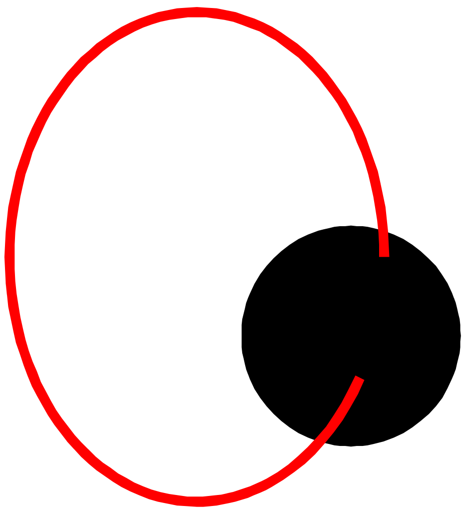


$$F_g = \frac{G M}{R}$$

“maximal” gravity case

BLACK HOLE =

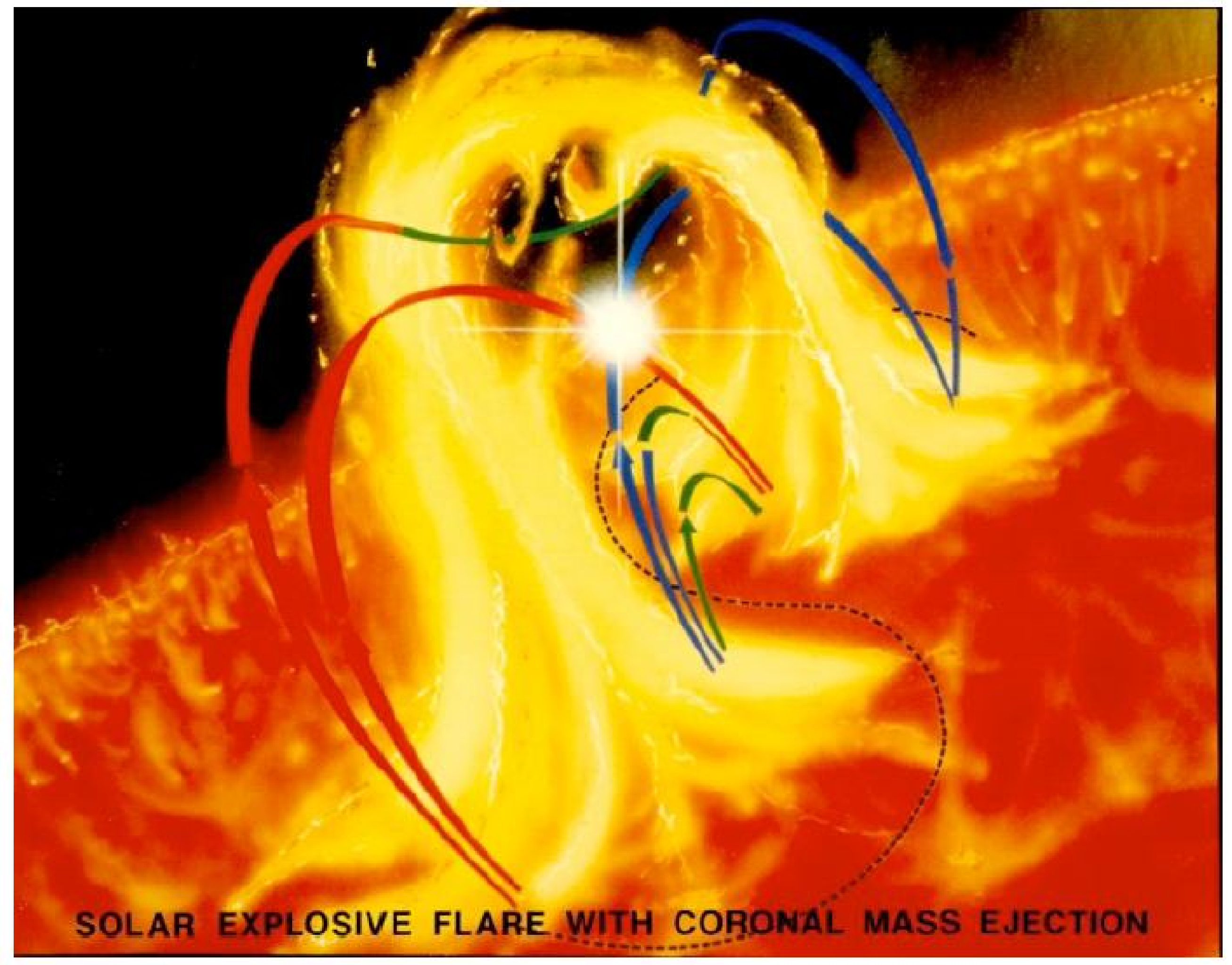
SPACE-TIME SINGULARITY



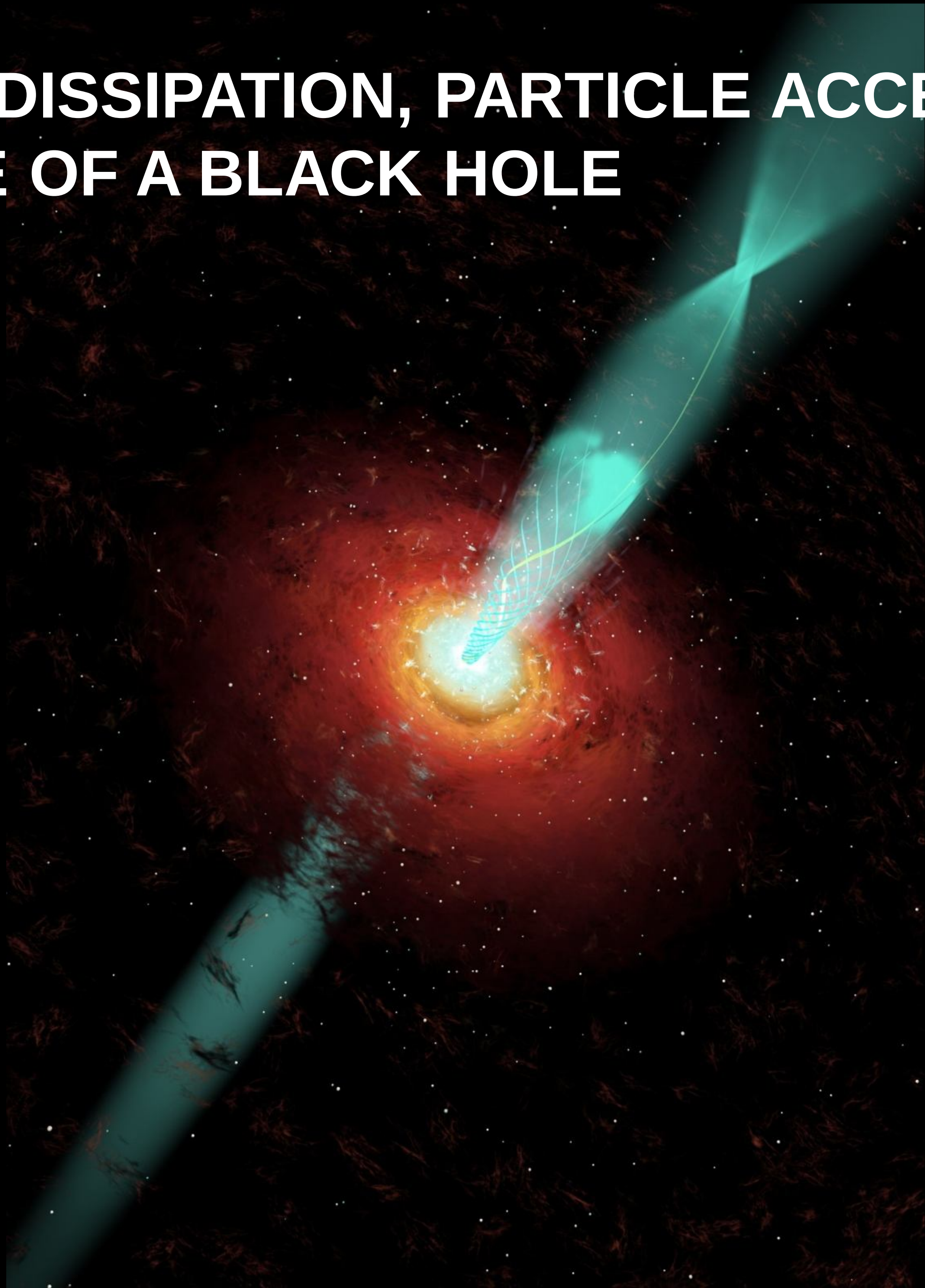
$$F_g = \frac{G\,M}{R}$$

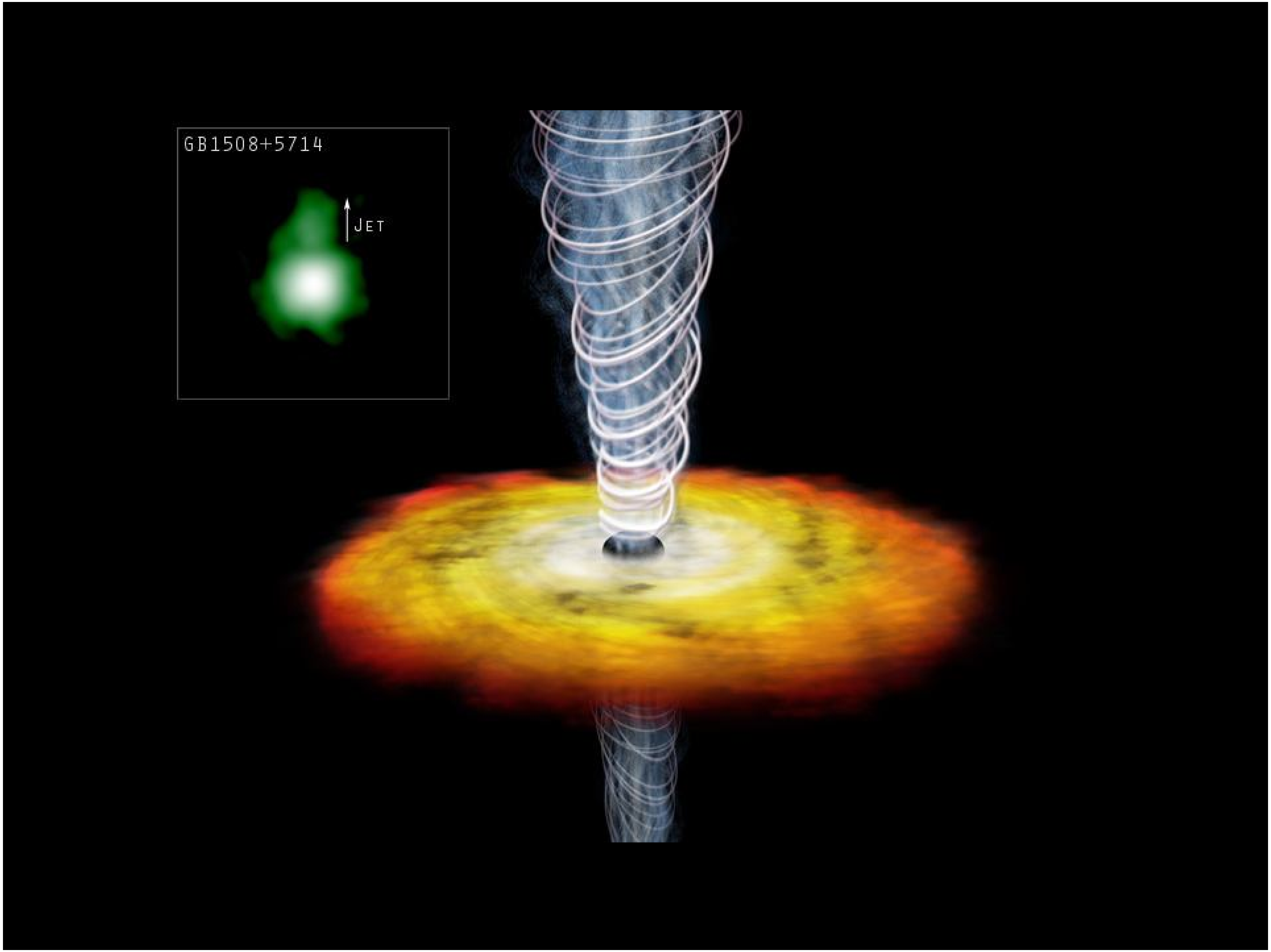
$$F_g \sim c^2$$

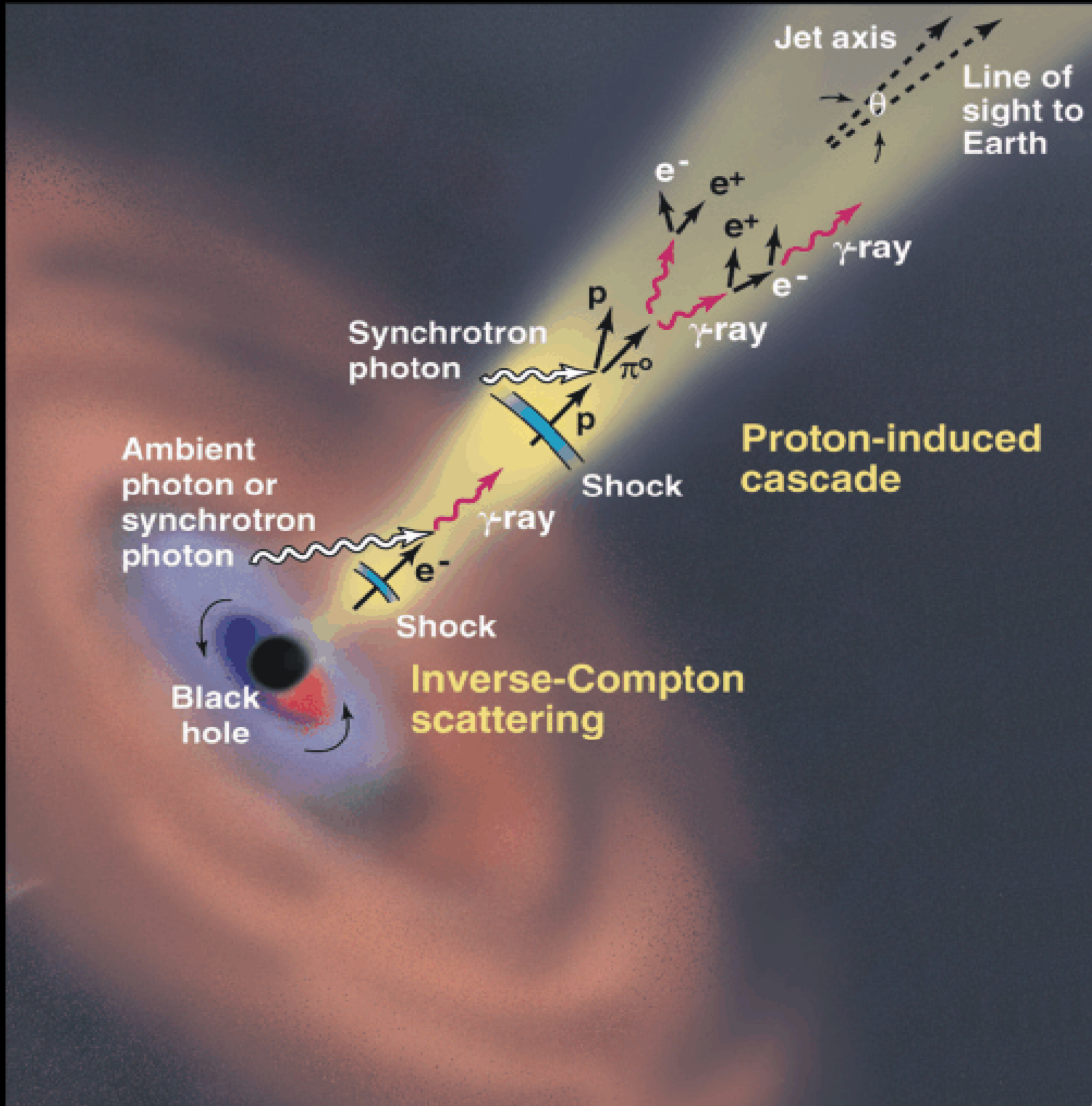
ENERGY DISSIPATION, PARTICLE ACCELERATION: THE CASE OF THE SUN



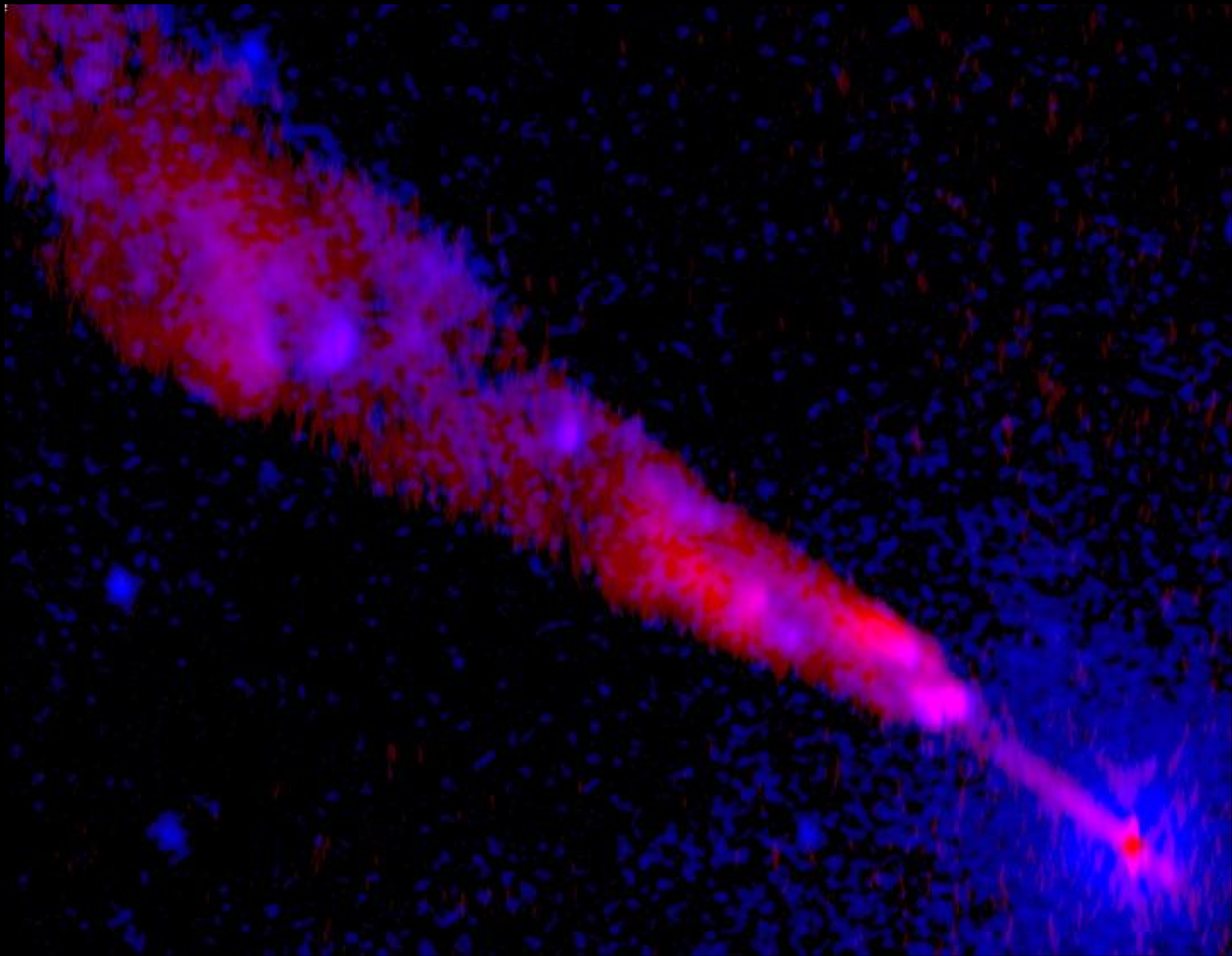
ENERGY DISSIPATION, PARTICLE ACCELERATION: THE CASE OF A BLACK HOLE

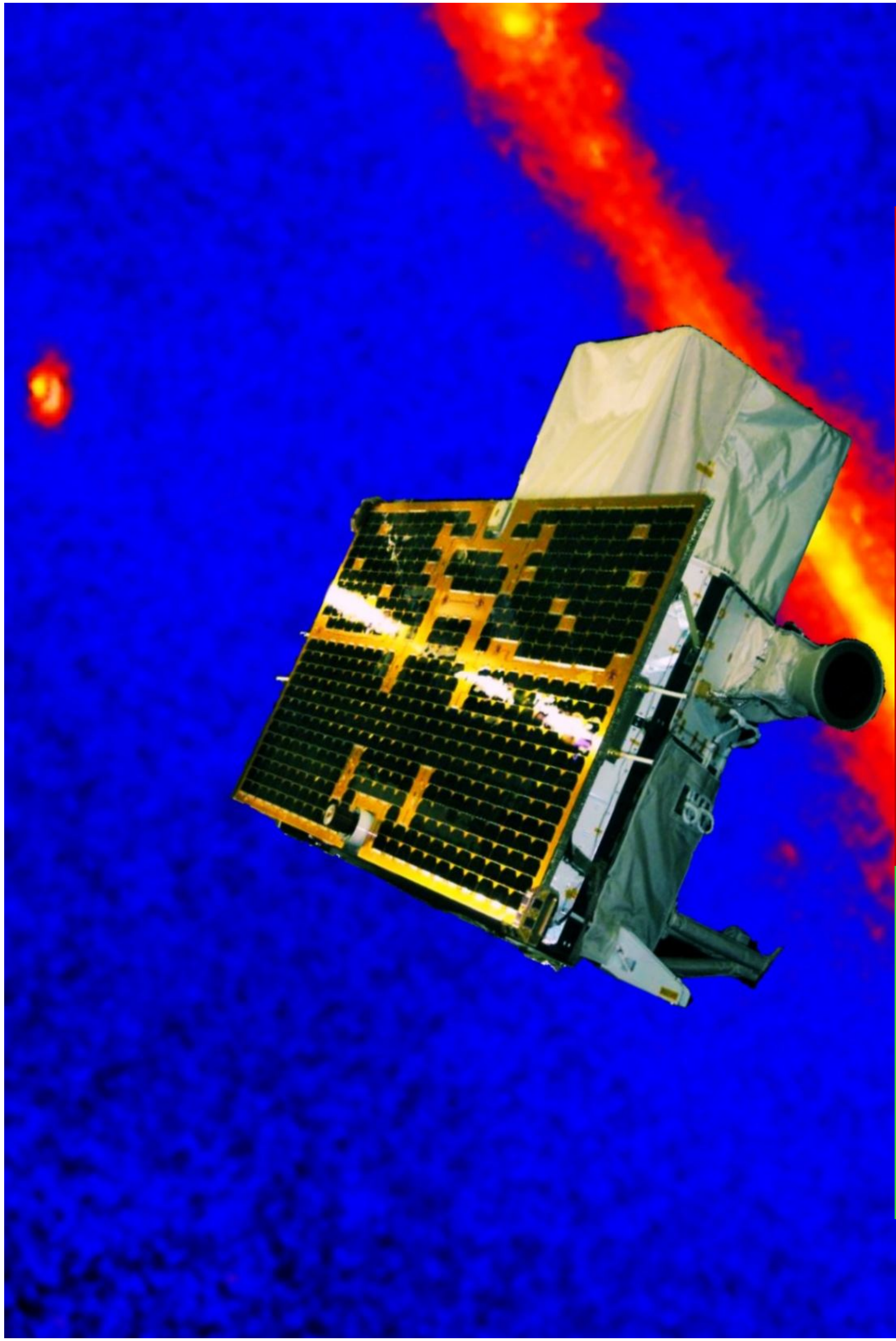



GB1508+5714
JET


Jet axis
Line of sight to Earth
θ
e⁻
e⁺
e⁺
γ-ray
e⁻
p
Synchrotron photon
π°
γ-ray
p
Proton-induced cascade
Shock
Ambient photon or synchrotron photon
γ-ray
e⁻
Shock
Inverse-Compton scattering
Black hole

Centaurus A





The AGILE Mission

• **Gamma-rays from microquasars (Cygnus X-3, Cygnus X-1)**

• ***Bright blazar states***

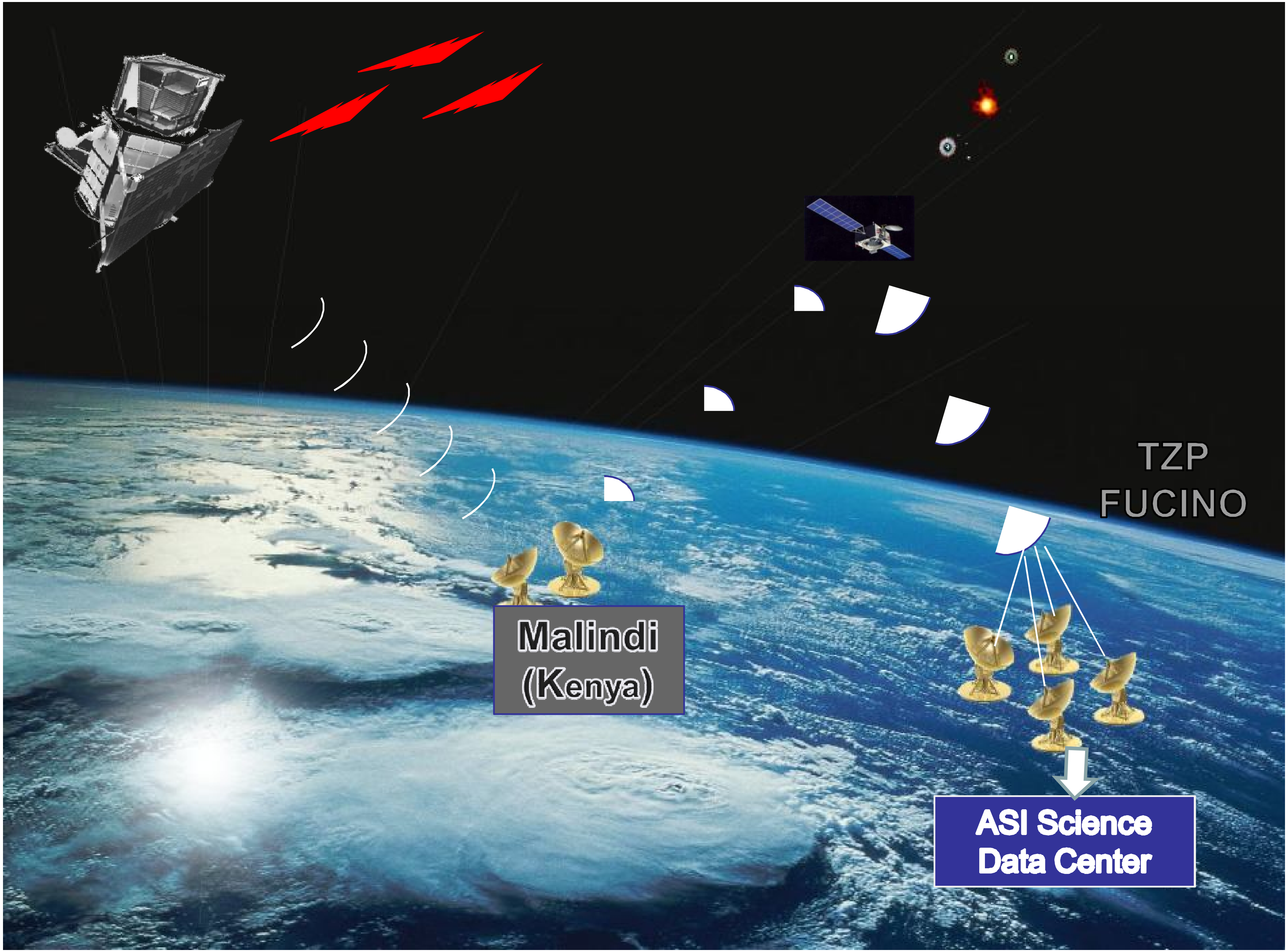
• **SNRs and cosmic-ray acceleration**

• ***Terrestrial Gamma-Ray Flashes up to 100 MeV***

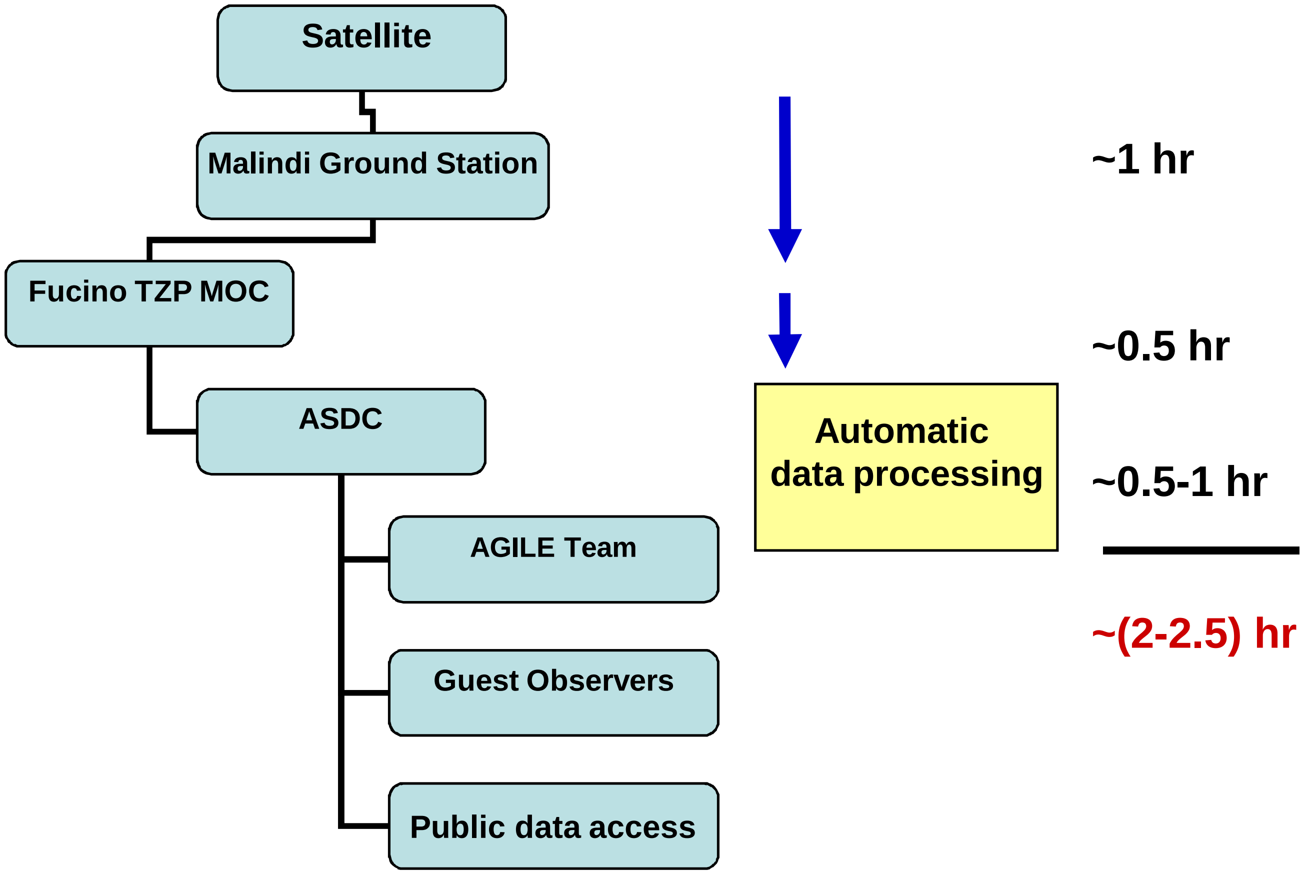
• **the Crab Nebula is variable !!!**

• **optimal sensitivity at “low” energies (E < 200 MeV)**

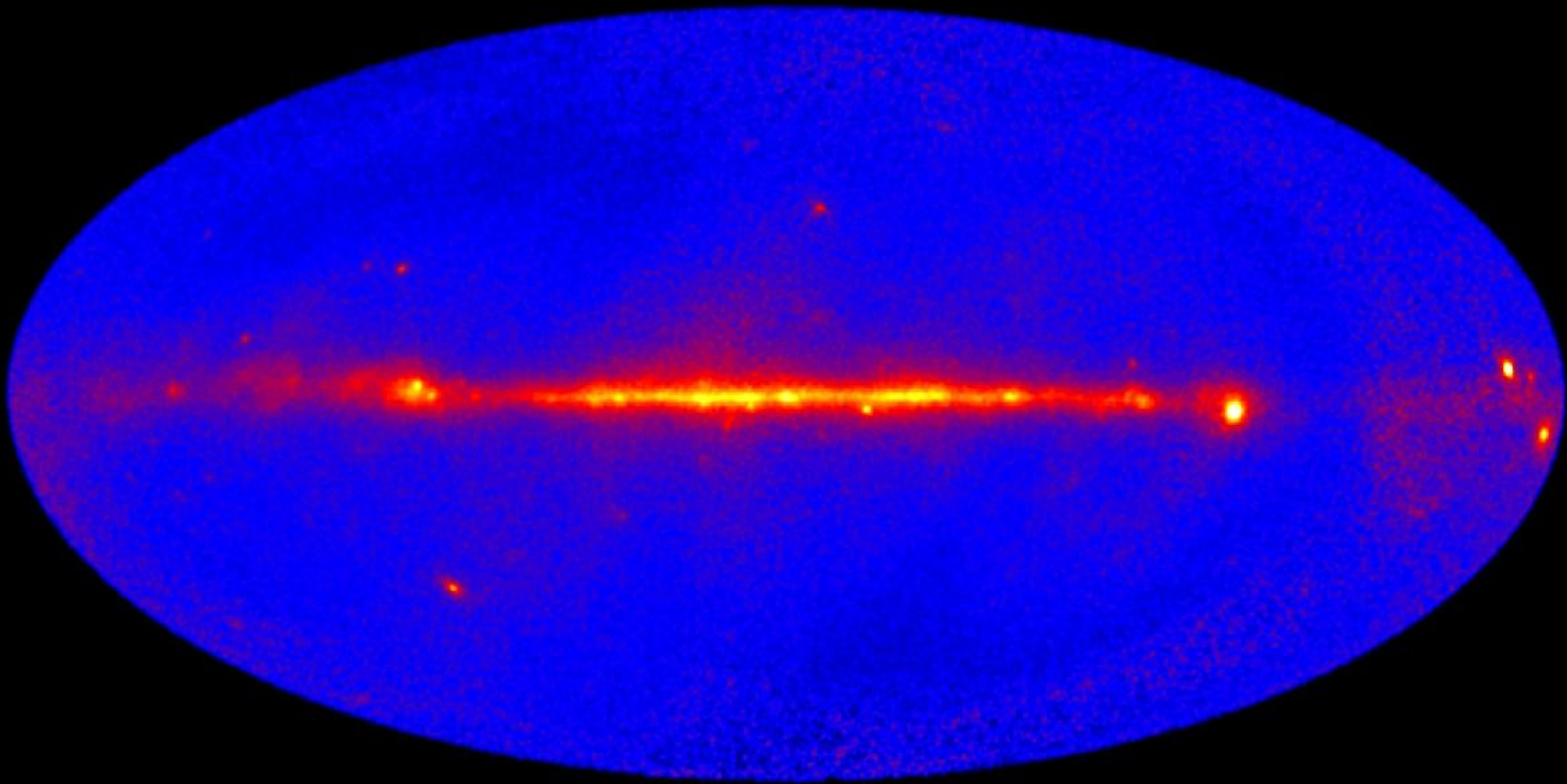
• **VERY EFFICIENT ALERT SYSTEM FOR TRANSIENTS**


TZP
FUCINO
Malindi
(Kenya)
ASI Science
Data Center

AGILE: the "fastest" Ground Segment

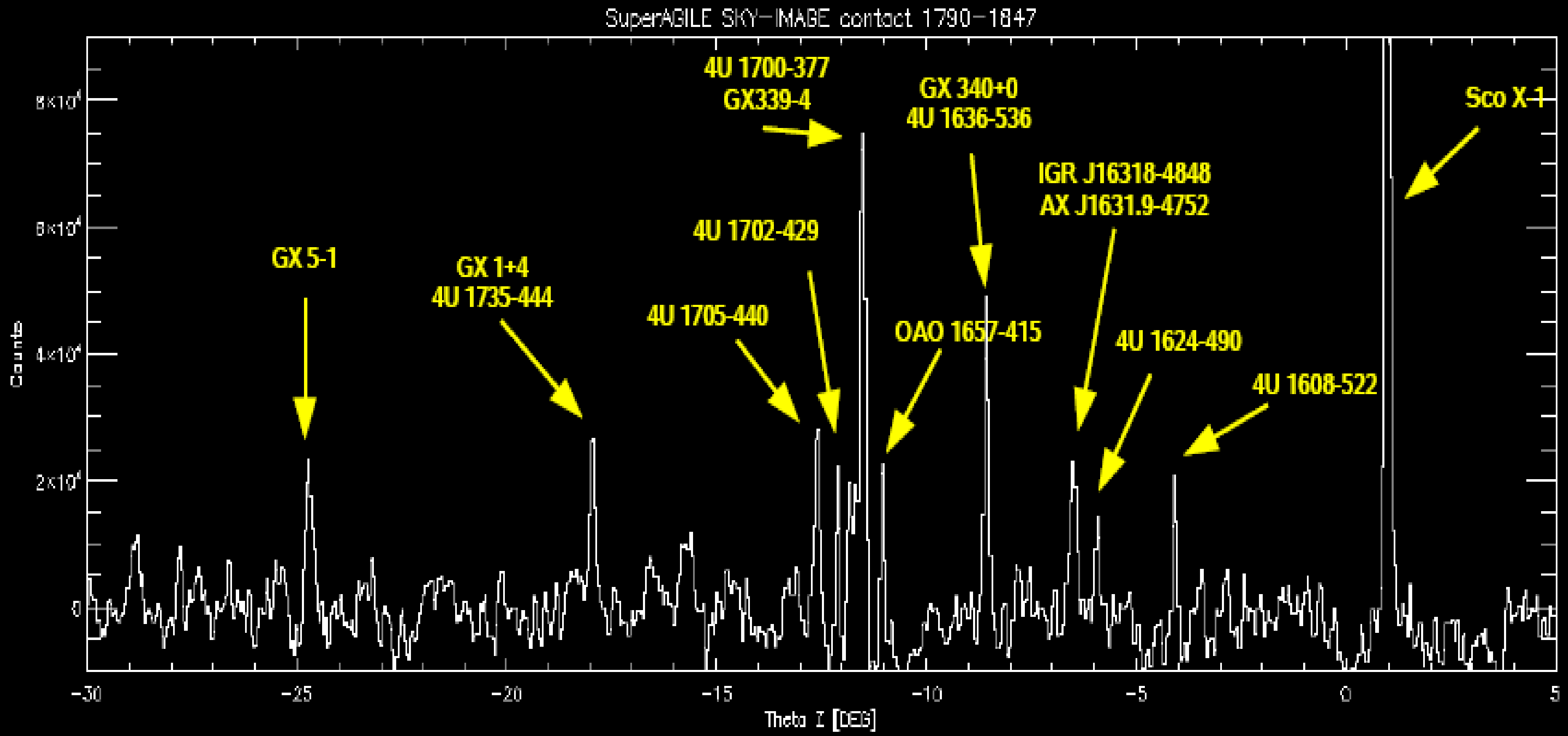


The AGILE gamma-ray sky (E > 100 MeV)
2 year exposure: July 2007 – June 2009

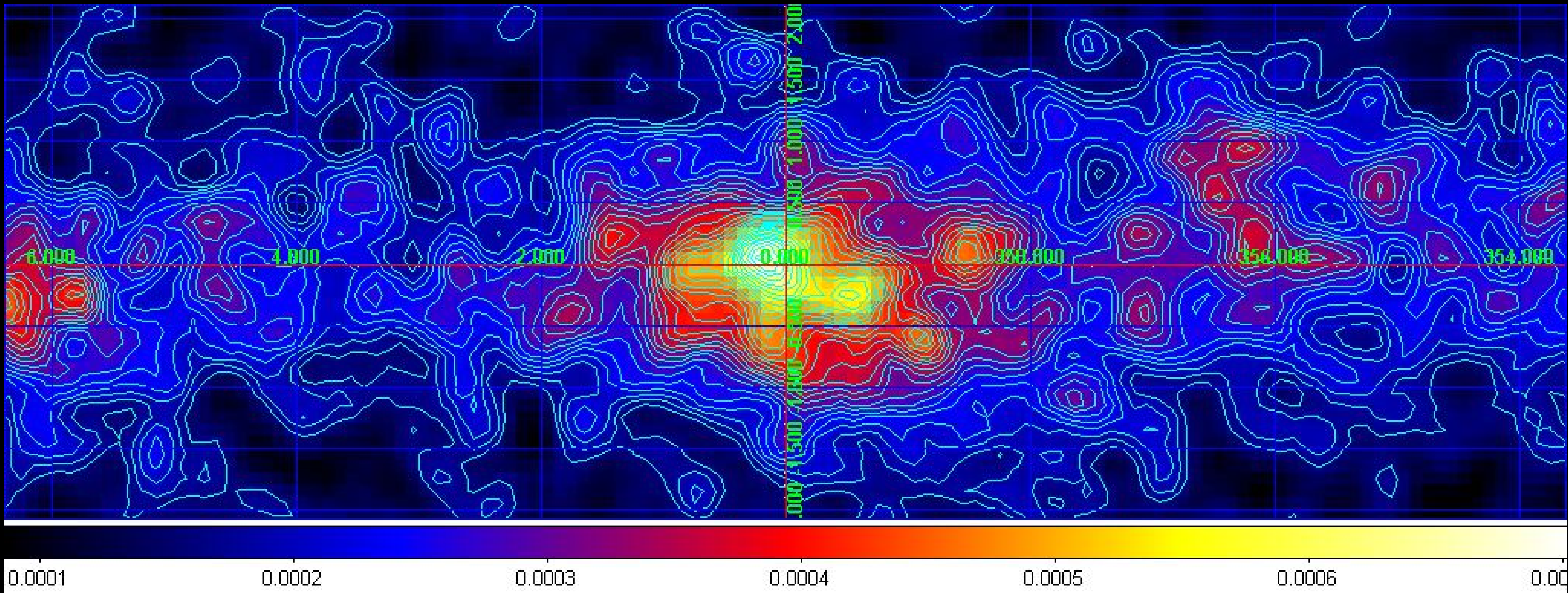


The Galactic Center

Example of the Super-AGILE View of the Galactic Plane (3.6 days, l=337, b=8)

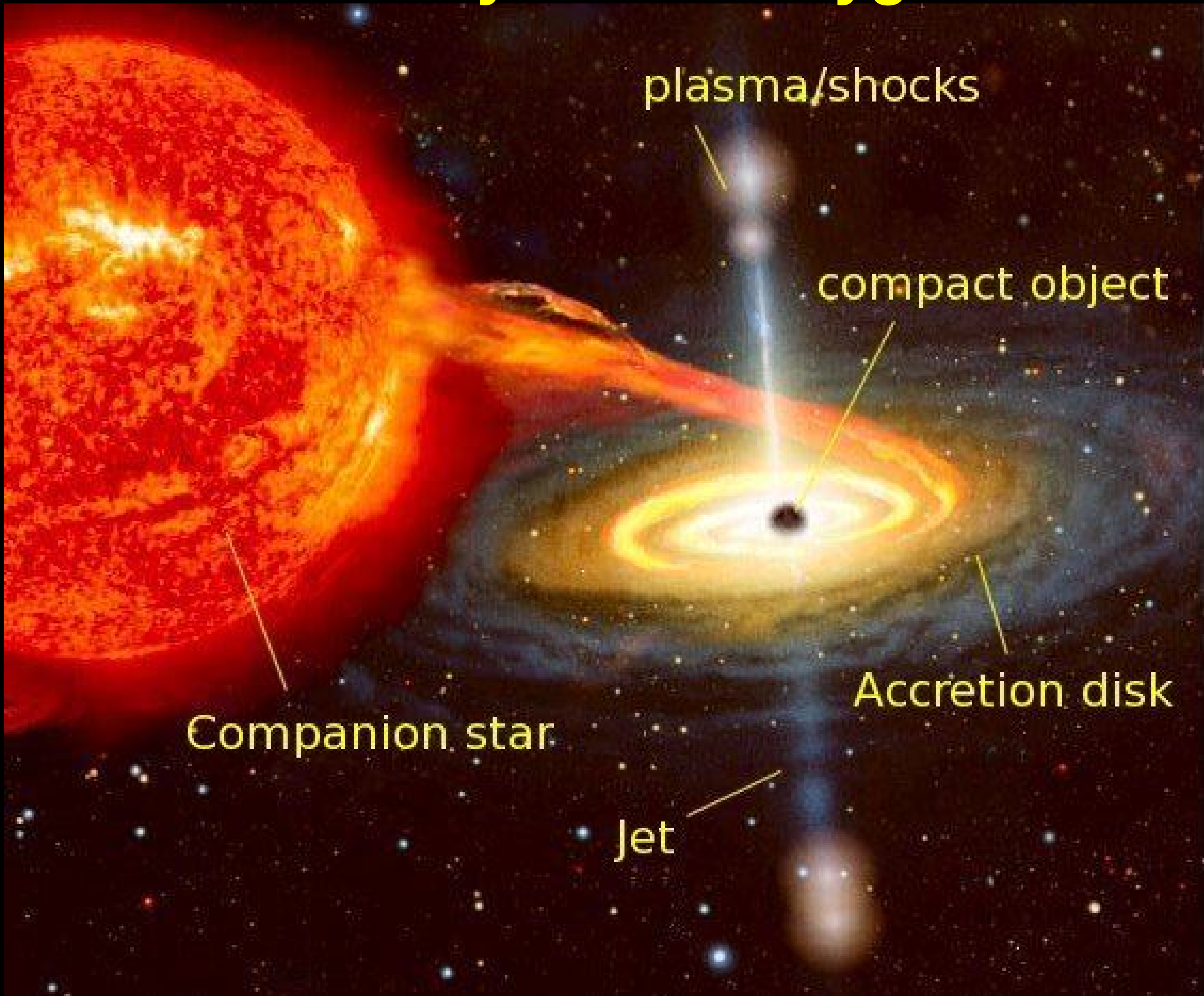


GC region, AGILE B19b,FM (E > 400 MeV)



Accreting Compact Objects

The mysterious Cygnus X-3

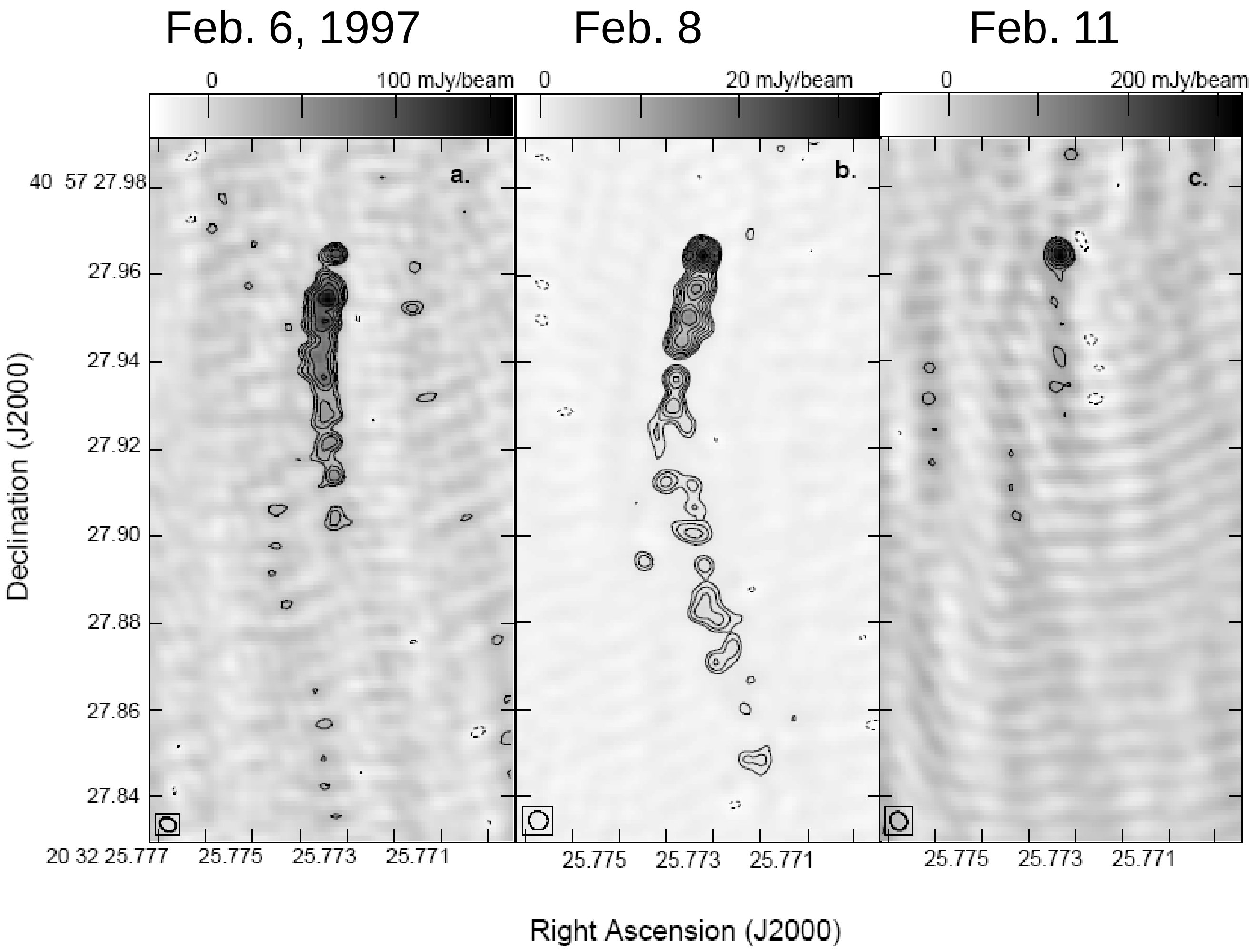


Cygnus X-3 is “special”

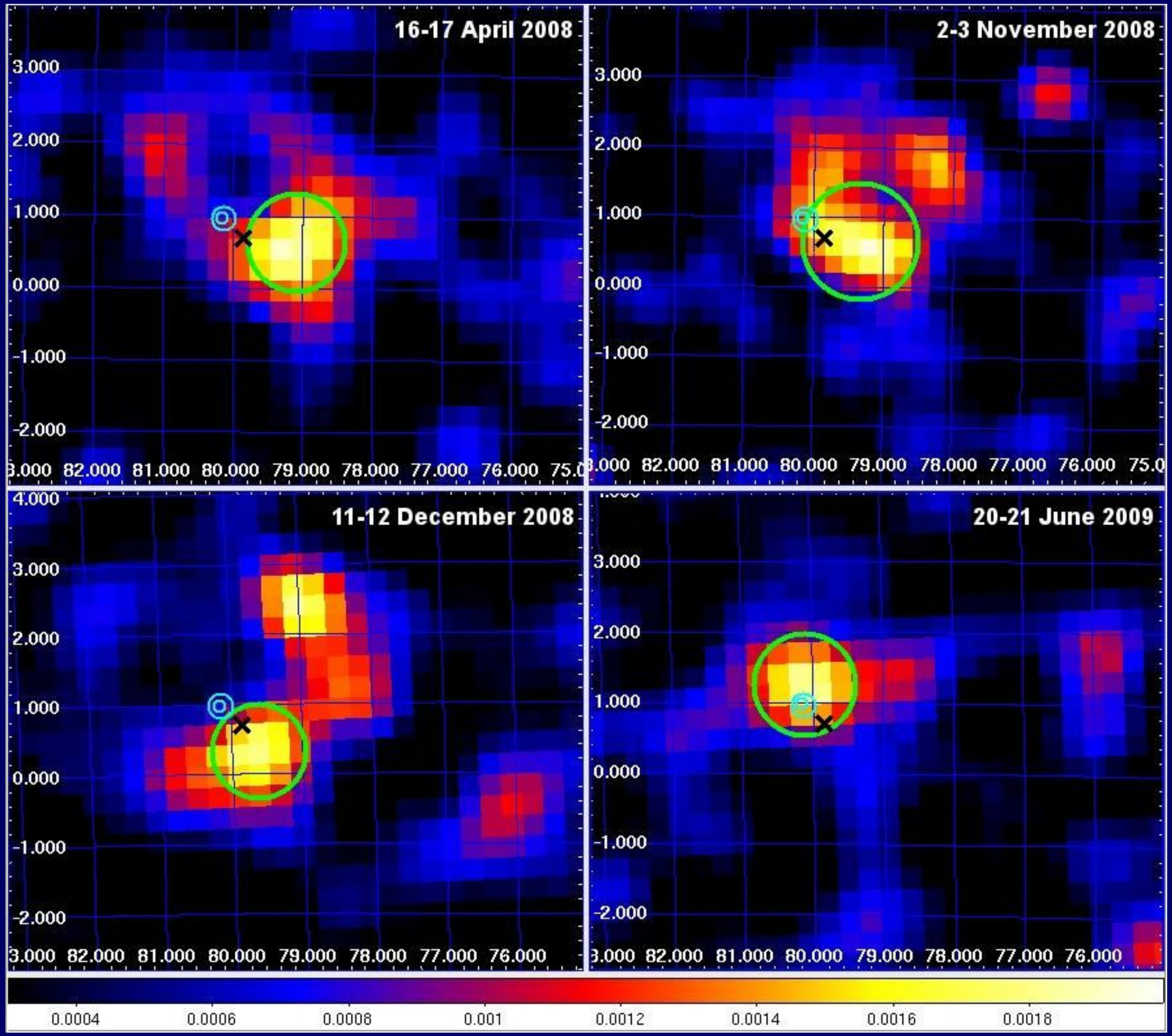
- A very variable microquasar (black hole)
- Very strong (up to 10-20 Jy) radio flares
- **Jets pointing towards the Earth**
- Correlated radio/soft X-ray/hard X-ray states

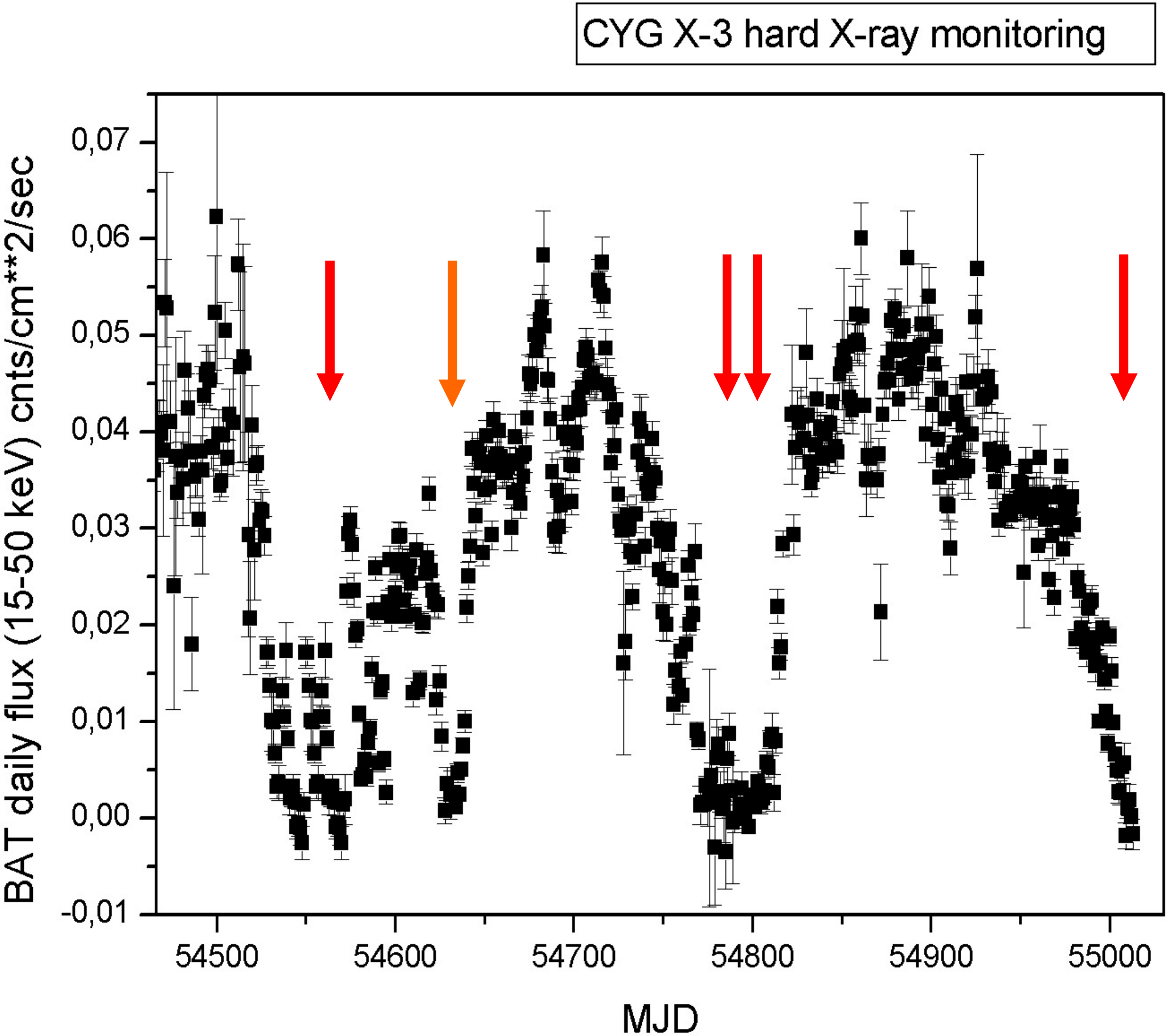
Cyg X-3 radio jets

(Mioduszewski, Rupen, Hjellming, Pooley, Waltman, 2001)



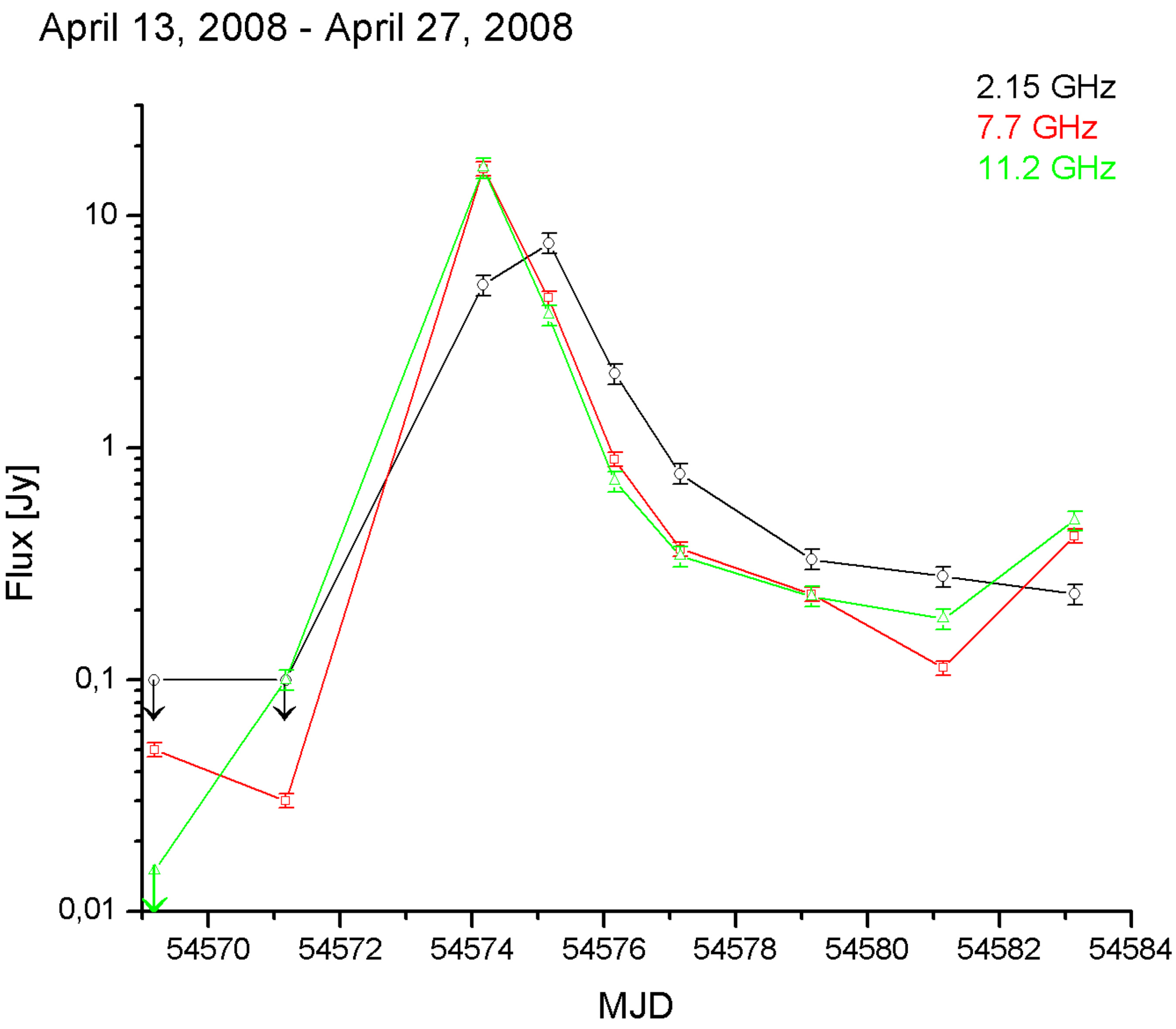
AGILE discovery of gamma-ray emission from Cygnus X-3





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

RATAN Obs. (S. Truskhin et al.) Apr. 13 – Apr. 27, 2008

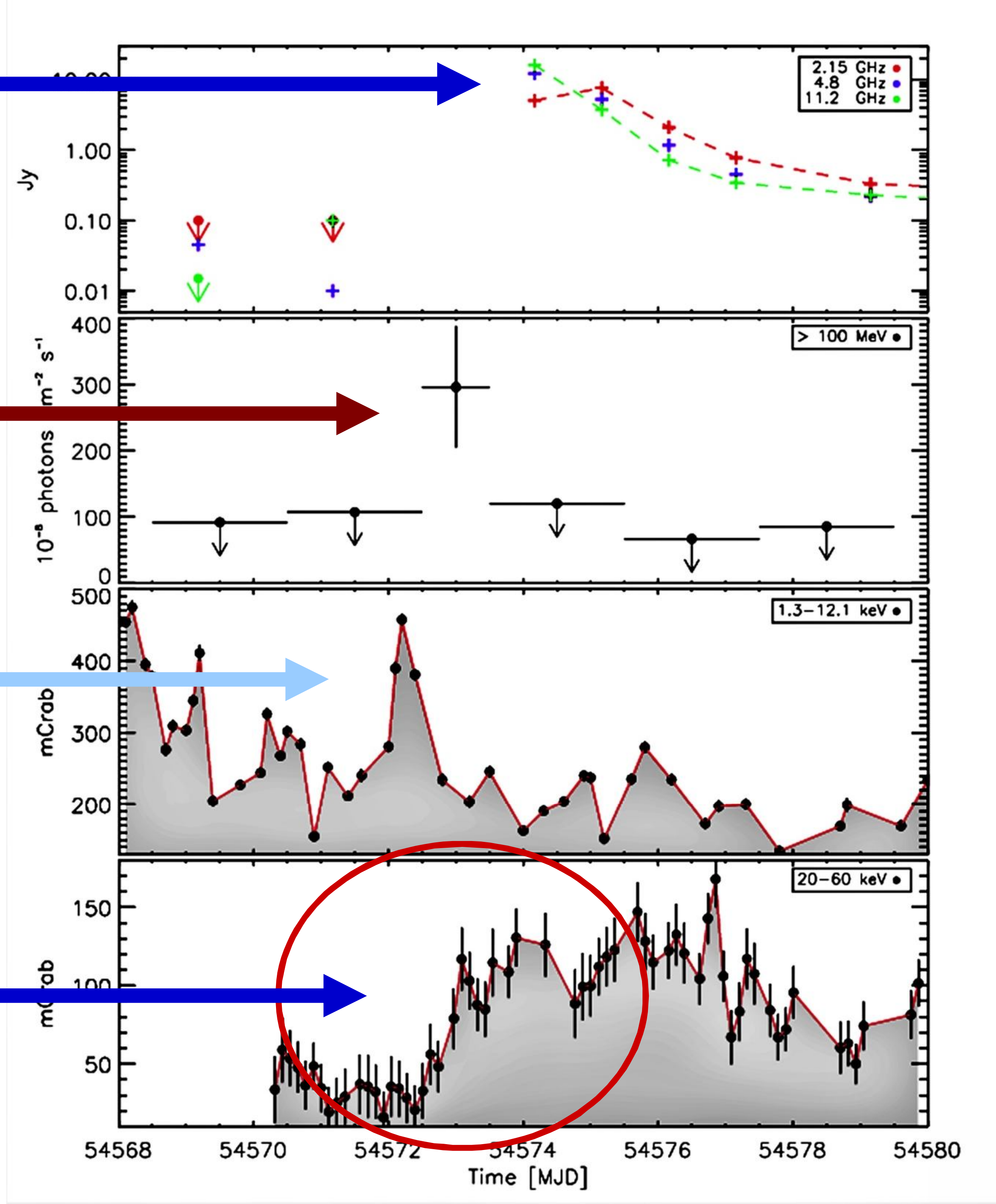


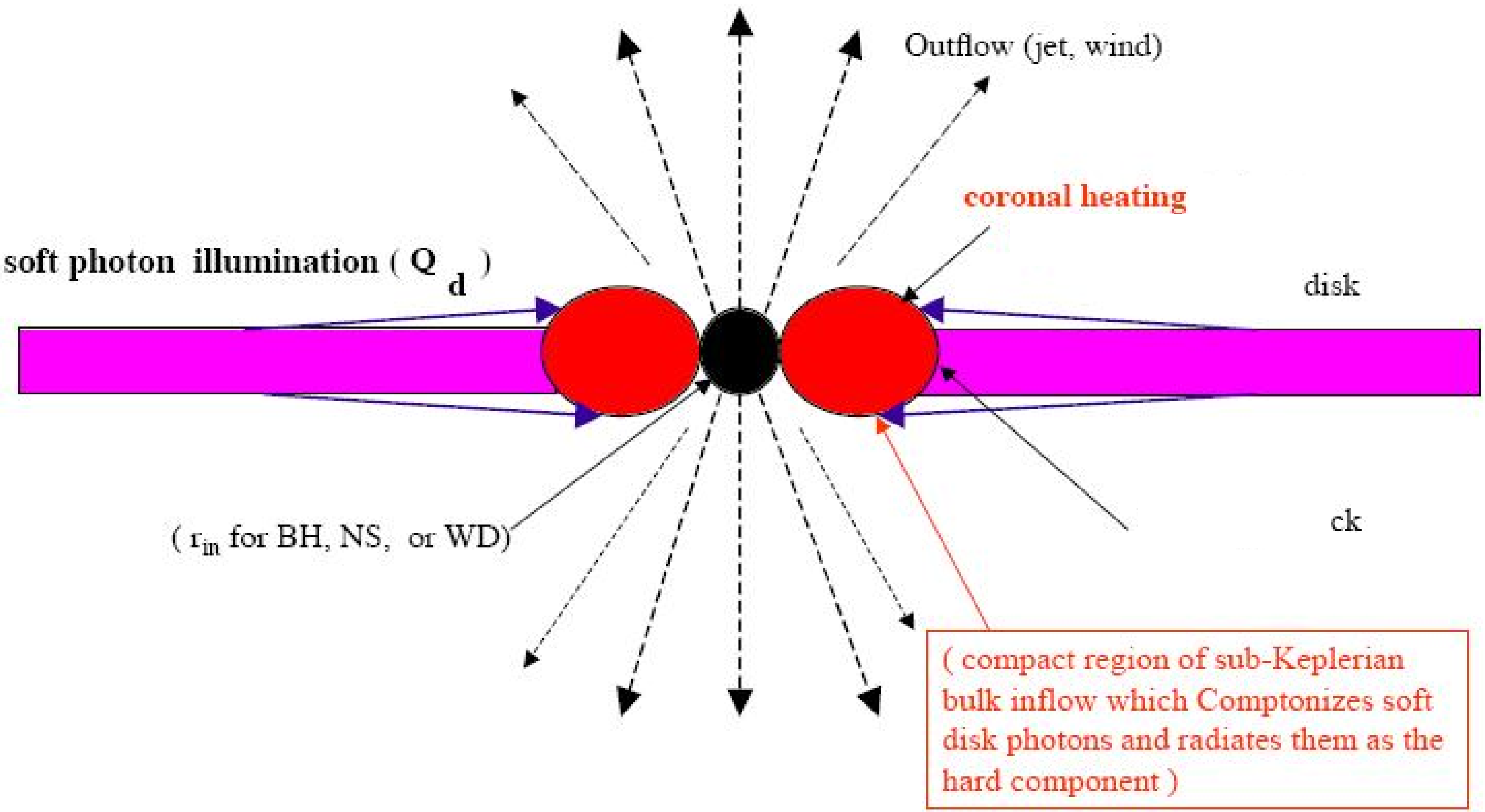
very strong radio flare, presumably with jet ejection

AGILE strong gamma-ray flare

X-ray (1-10 keV) flare

Hard X-ray flux state change (Super-A monitoring)

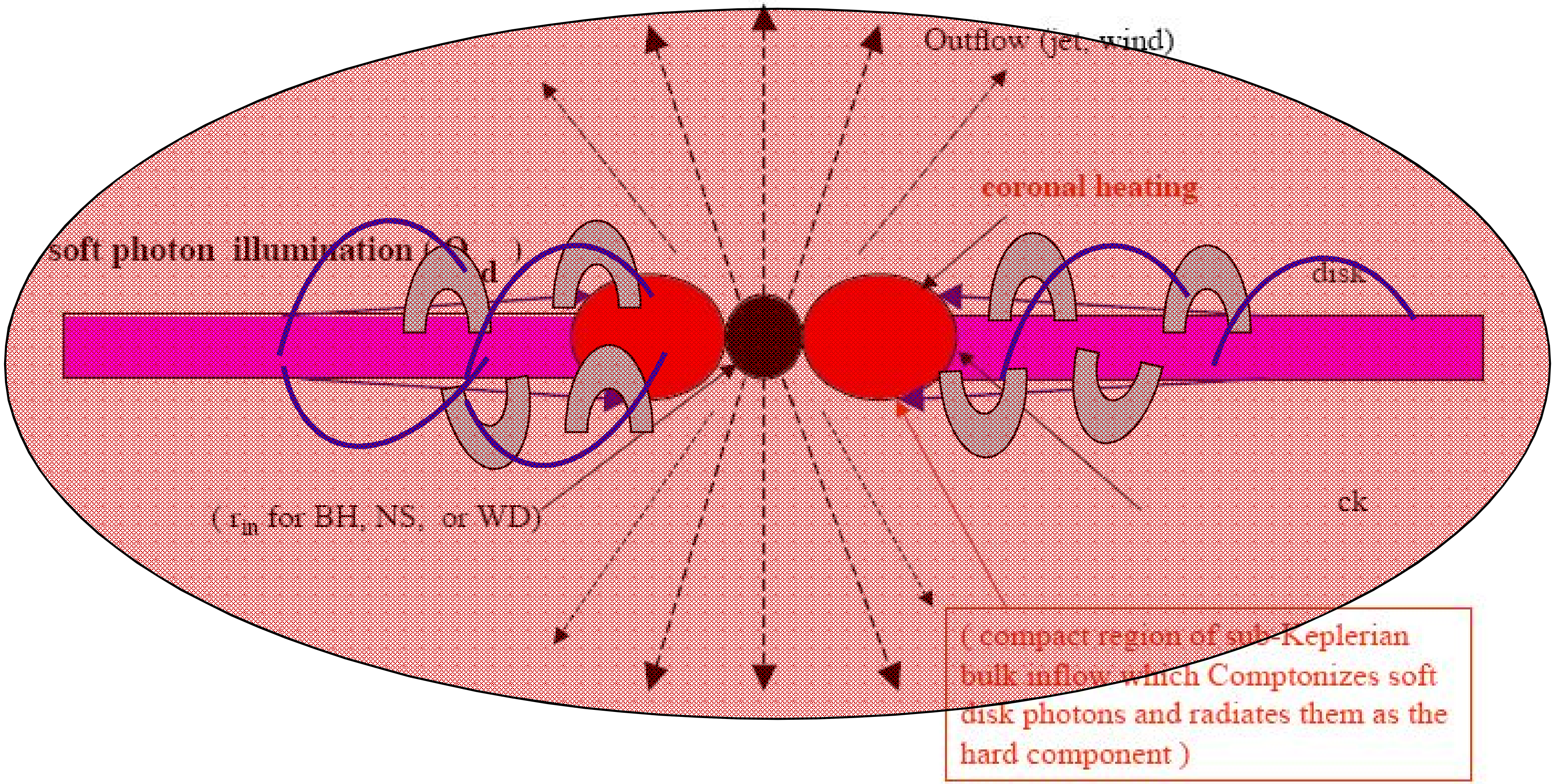




Outflow (jet, wind)
coronal heating
soft photon illumination (Q d)
disk
(r_{in} for BH, NS, or WD)
ck
(compact region of sub-Keplerian bulk inflow which Comptonizes soft disk photons and radiates them as the hard component)

Comptonizing cloud

Compton-thick, t = s_T n R ~ 1-10   **n ~ (10^{16} cm^{-3}) R^{-1}_8**



Major gamma-ray flares in special transitional states in preparation of radio flares ! (Tavani etal. Nature 2009)

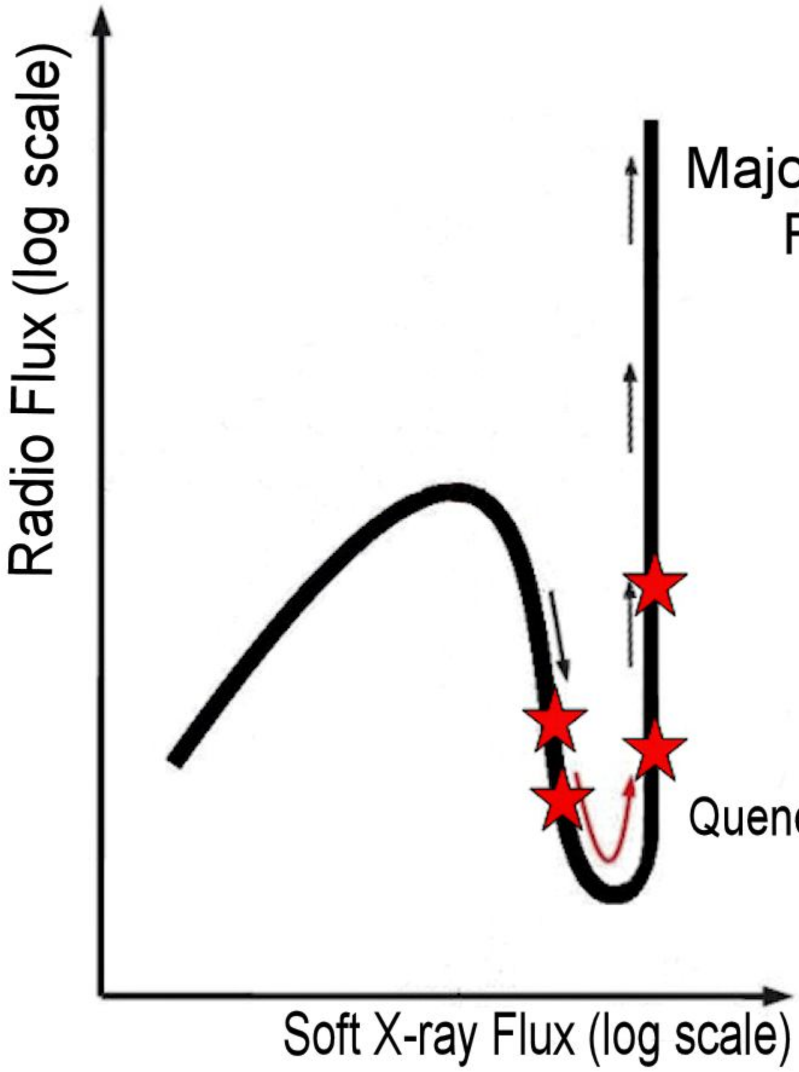
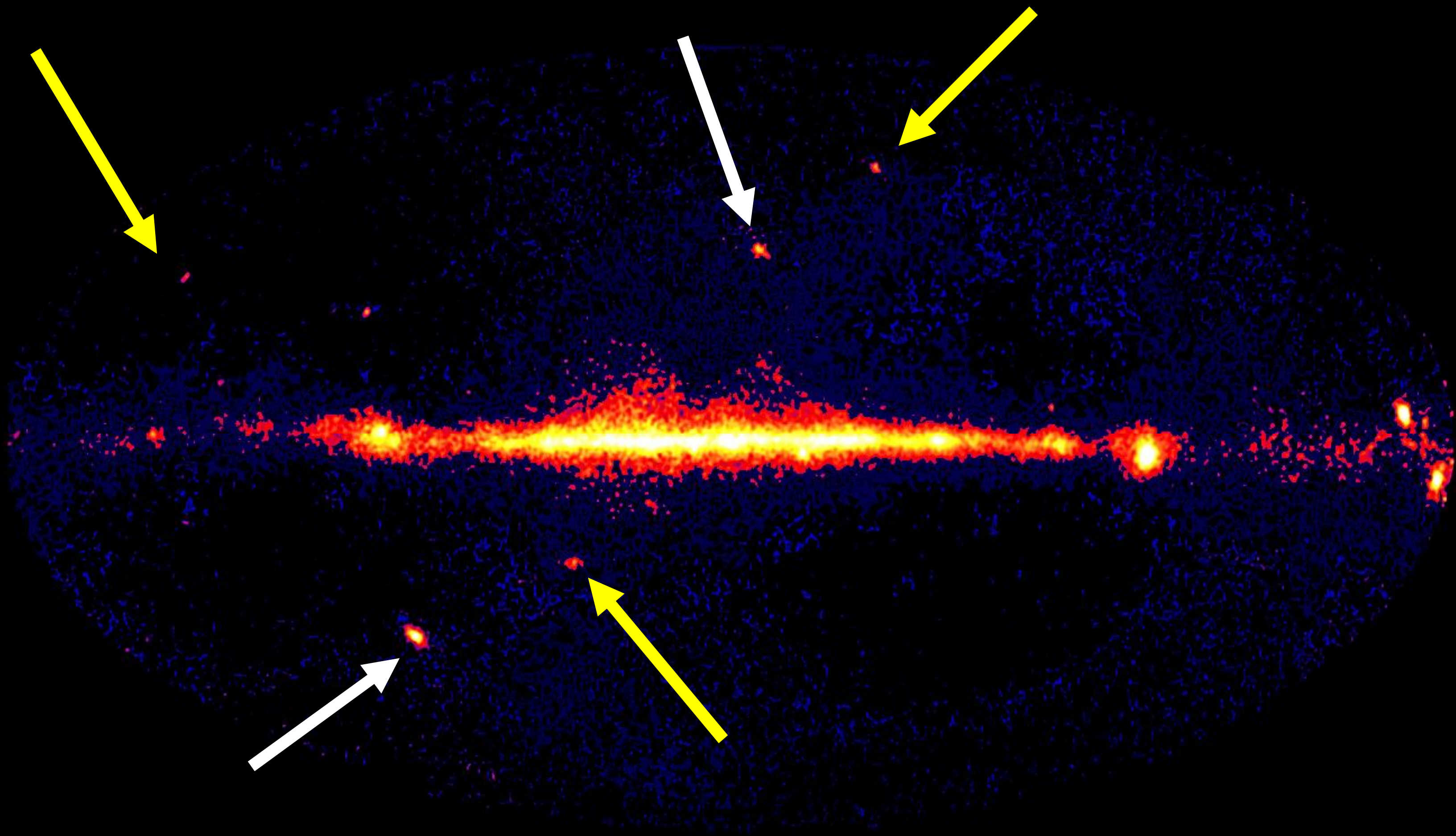


figure adapted from Szostek Zdziarski & McCollough (2008)

Galactic “Micro-QSOs” (radio “jet” sources)

	Θ (degrees)	*β*	*Γ*	*L_X/L_E*	*γ/TeV*
Cyg X-1	?	?	?	0.1-1	YES
Cyg X-3	< 14	> 0.8	> 1.6	0.1-1	YES
SS 433	80	0.26	1.03	0.01	no
GRS 1915+104	70	0.92	2.5	0.1-1	no
GRO J1655-40	> 70	0.9	2.5	1	no
GRS 1758-258	?			0.1-1	no
XTE J1550-564	60-70	> 0.8	1.5	0.1-1	no
Sco X-1	> 70	> 0.8	> 1.6	0.1-1	no
LS I 61 303	?	?	?	10^{-4}	yes
LS 5039	< 80	> 0.2	?	10^{-4}	yes

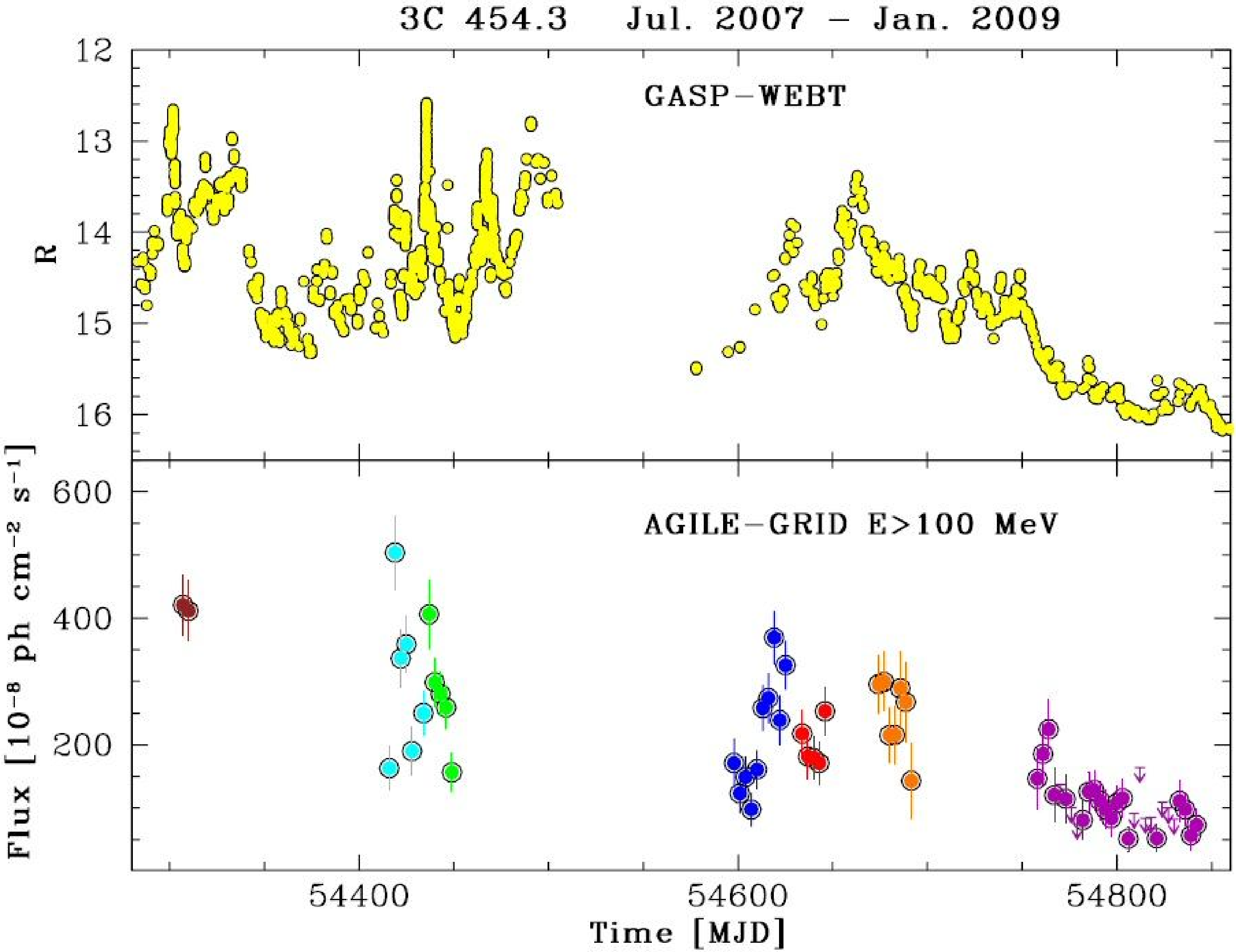
The brightest Galaxies detected by AGILE



3C 454.3
the Crazy Diamond

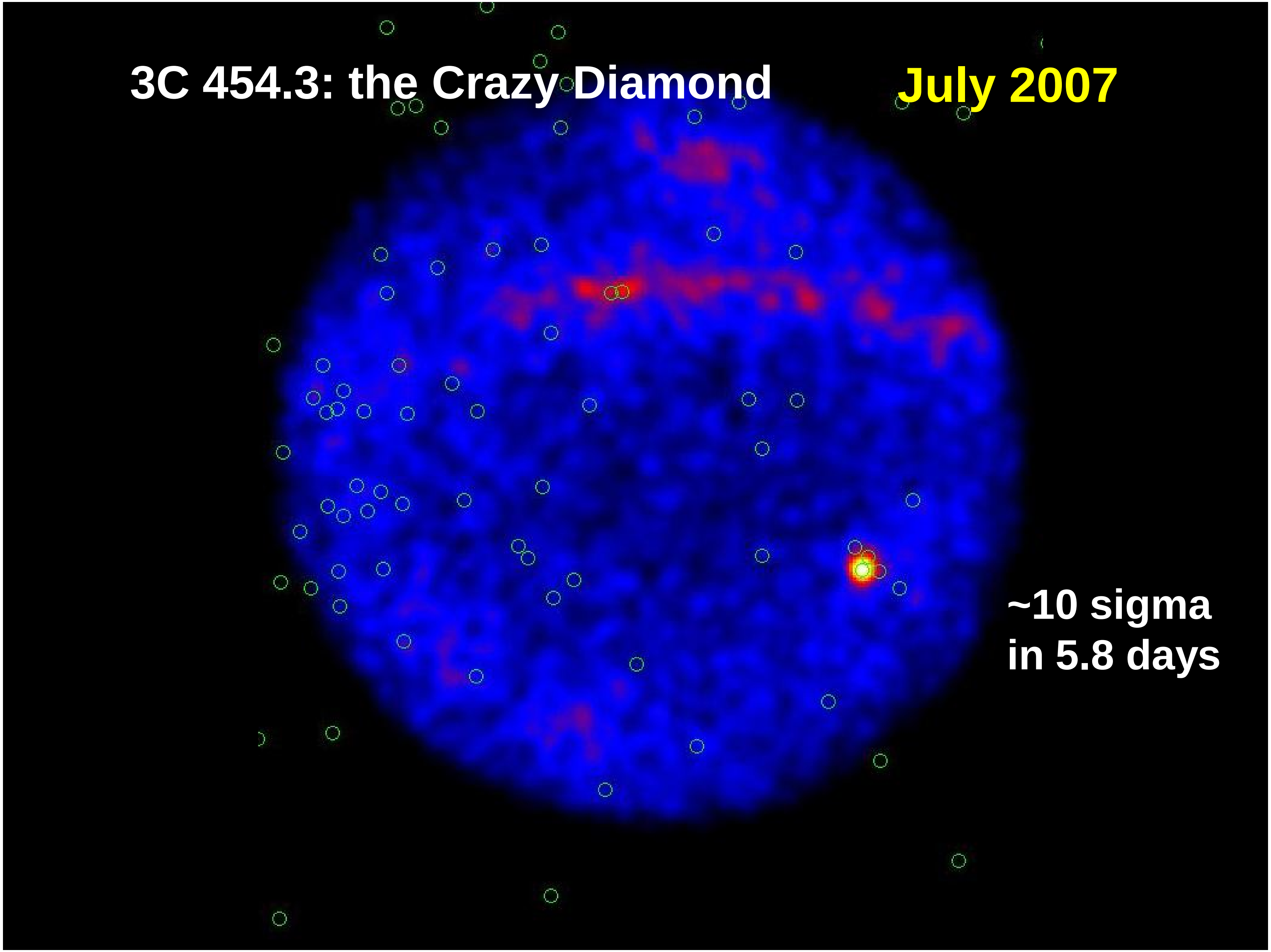
3C 454.3: the Crazy Diamond of 2007-2008

(Vercellone et al. 2007-2008-2009, Donnarumma et al. 2009)

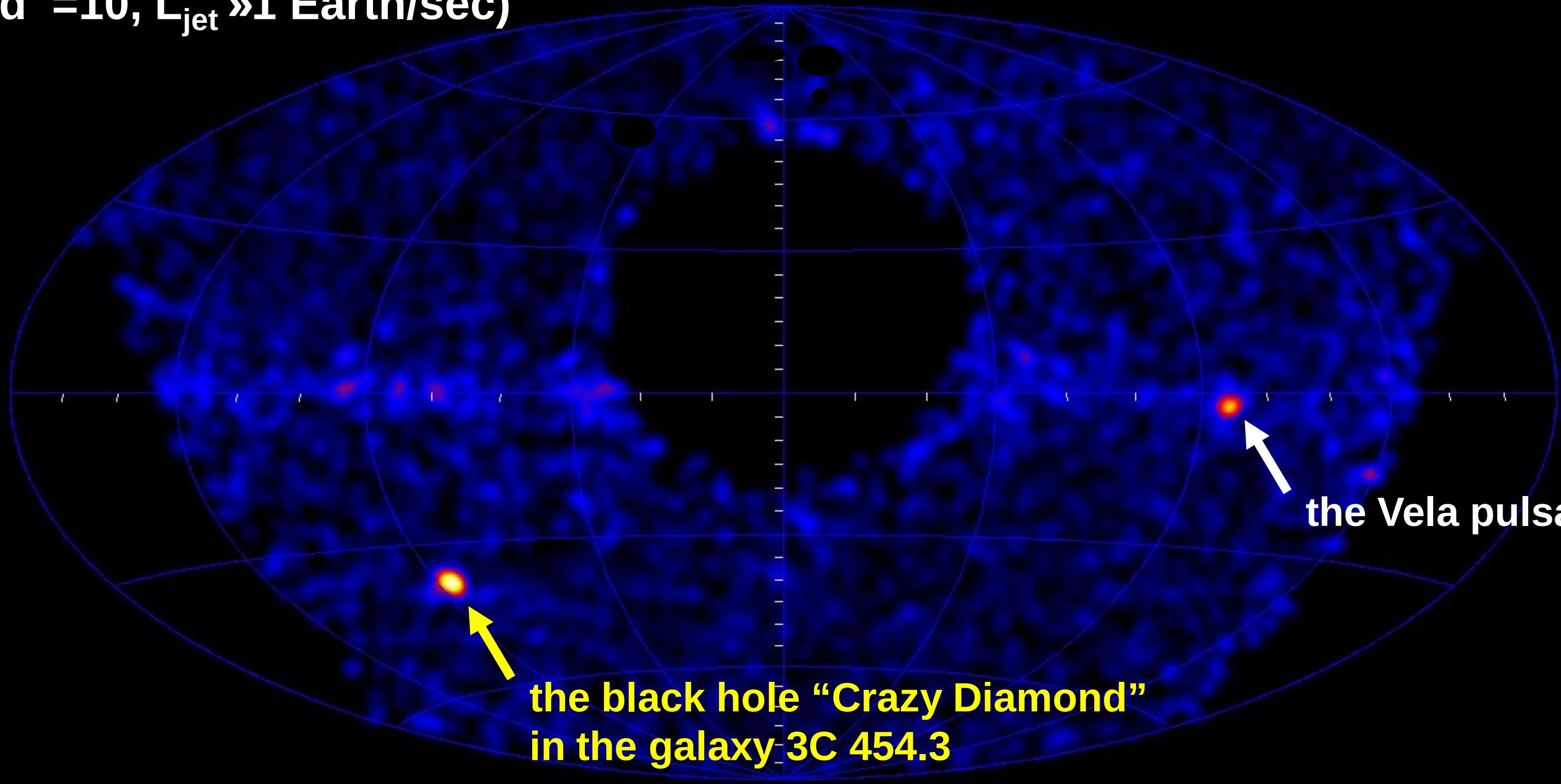


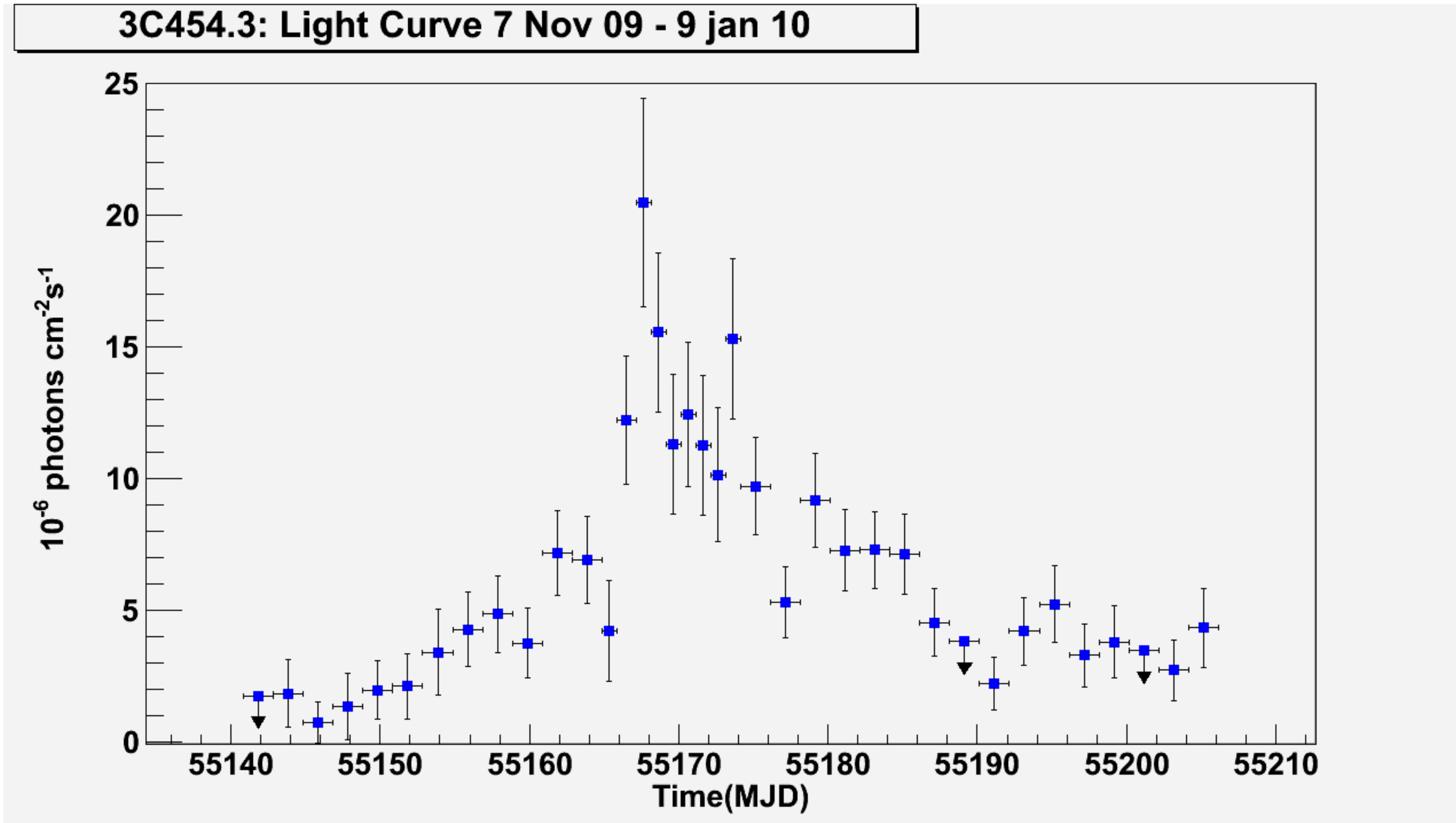
optical

gamma


3C 454.3: the Crazy Diamond
July 2007
~10 sigma
in 5.8 days

The AGILE gamma-ray sky, 3-4 December, 2009. Detection of the strongest gamma-ray flaring source ever observed: the black hole ("Crazy Diamond") in the active galaxy 3C 454.3 (z=0.859, F_g > 2000 10^{-8} ph. cm^{-2} s^{-1},L_{iso}= $6x10^{49}$ erg s^{-1}, for d =10, L_{jet} »1 Earth/sec)



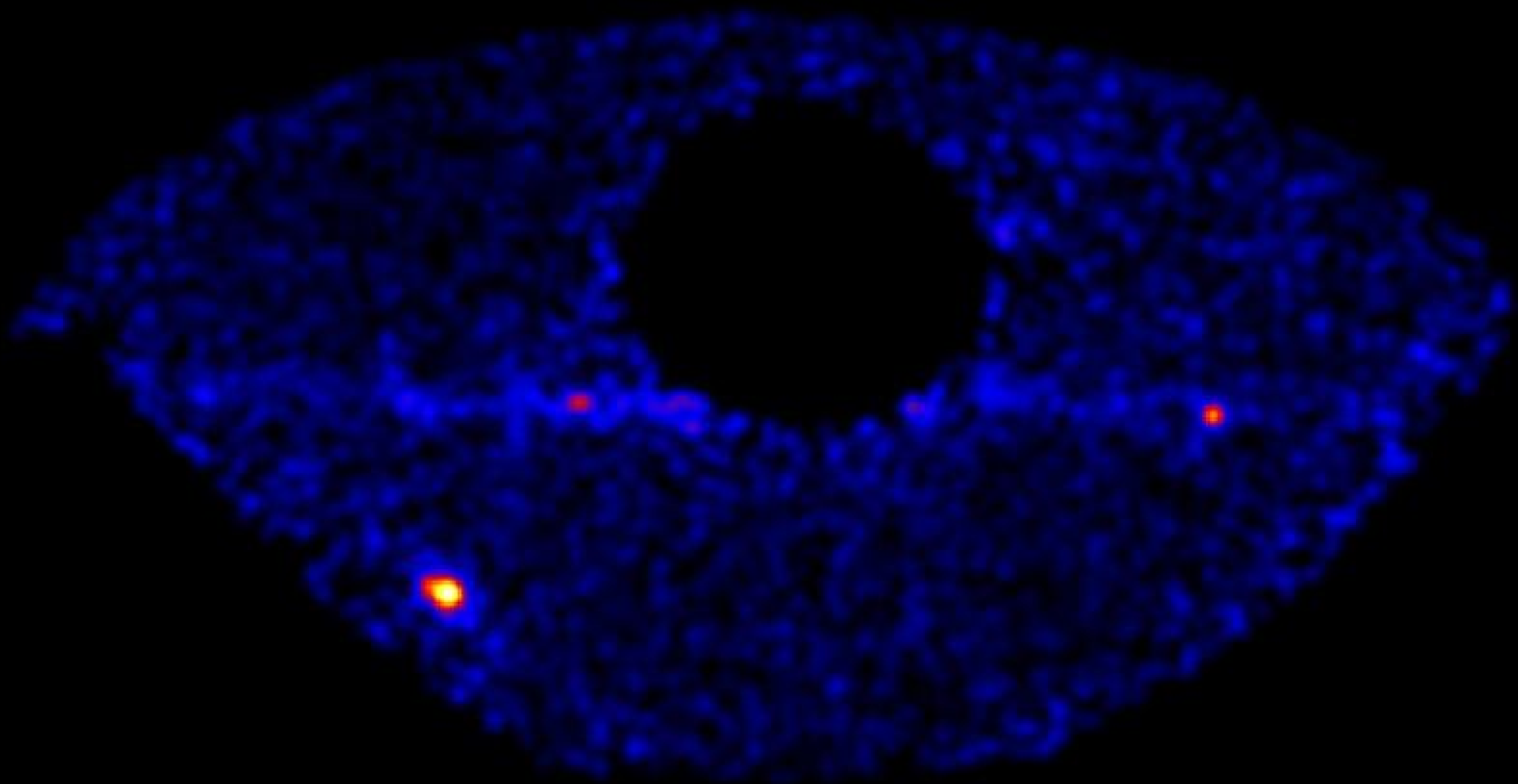

3C454.3: Light Curve 7 Nov 09 - 9 jan 10
25
20
15
10
5
0
10-6 photons cm-2s-1
55140
55150
55160
55170
55180
55190
55200
55210
Time(MJD)

3C 454 Dec. 2009 flare

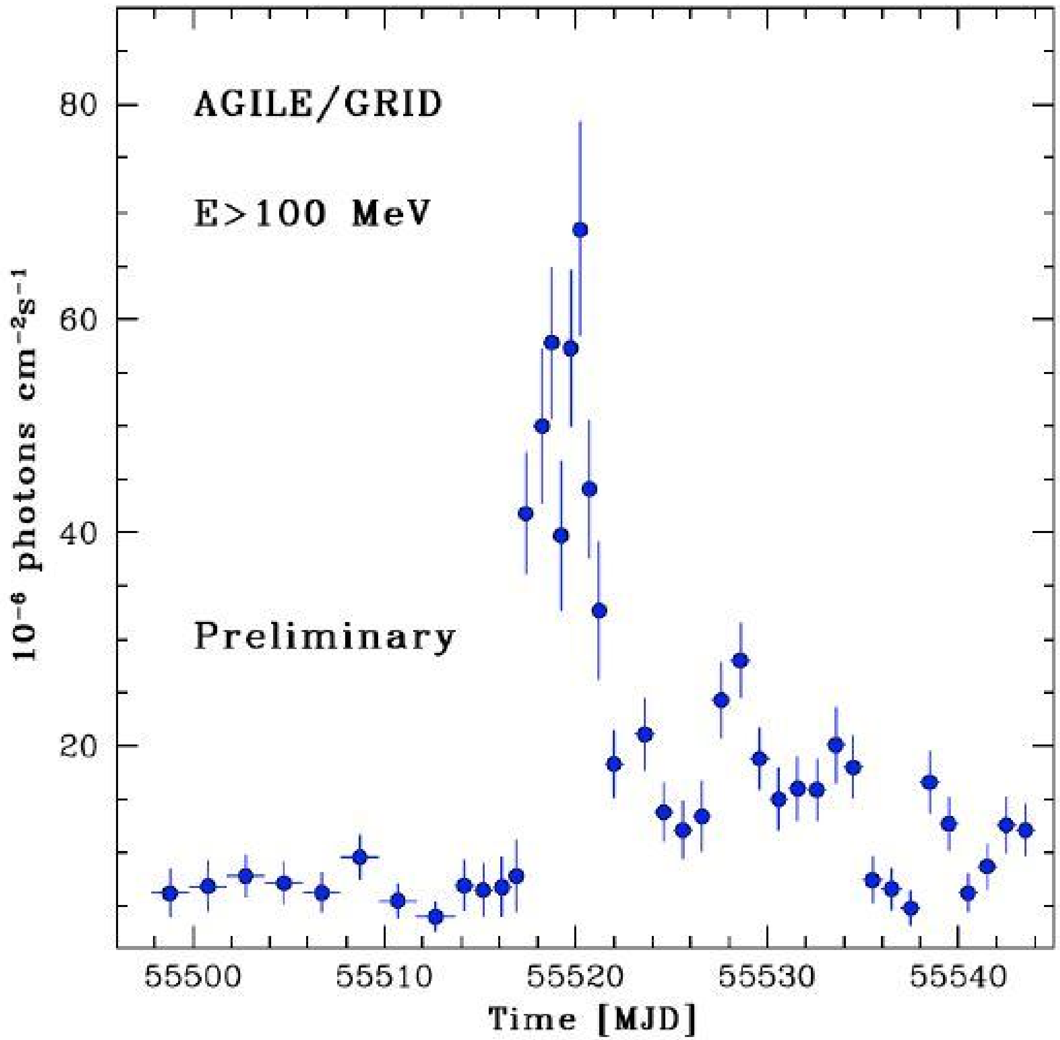
- **Energetics**
  - **dE/dt (kinetic jet power) = M_{Earth} / 10 sec**
  - **L (gamma-ray) = L (iso) / G^2 = 4×10^{46} erg/s**

- **Spectral components (sync, SSC, EC)**
  - **C-1 (PL, p_1 = 2.3, g_b = 500)**
  - **C-2 (Maxwellian, g_b = 150)**

3C 454.3 superflare (16-19 Nov. 2010)



3C 454.3 super-flare in Nov.-Dec. 2010



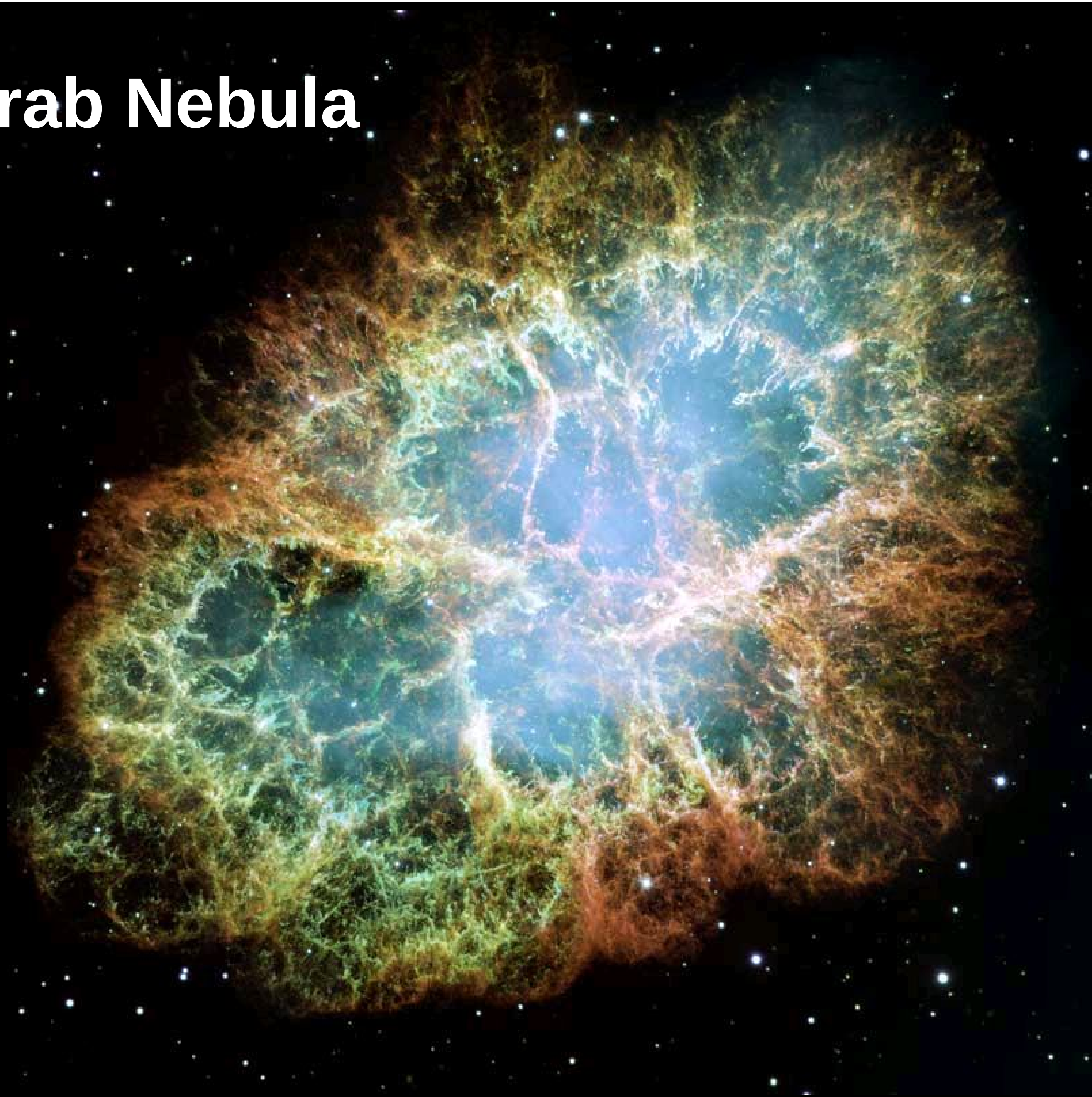
GRID light curve

AGILE DISCOVERY OF THE CRAB NEBULA VARIABILITY IN GAMMA-RAYS

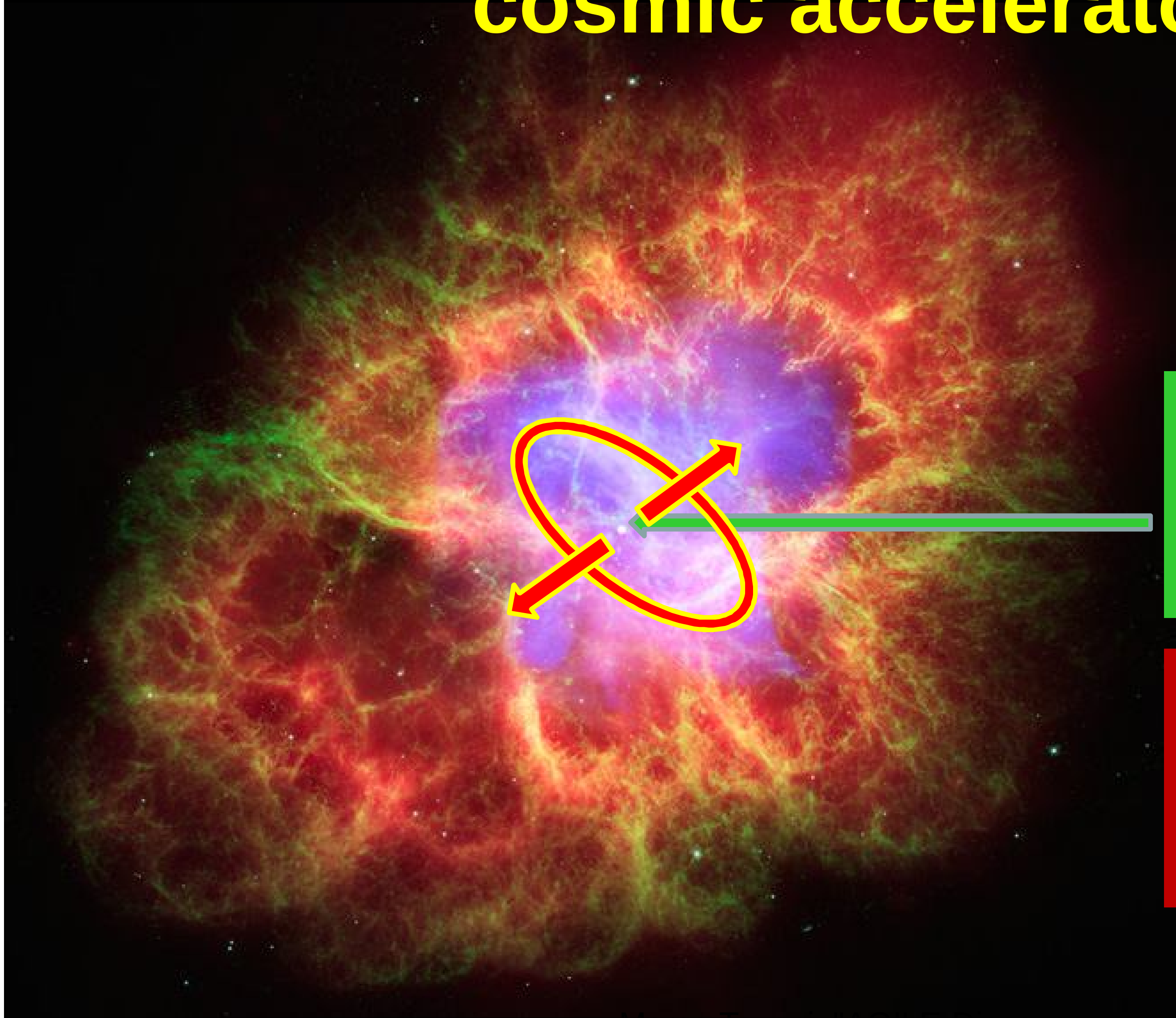
Tavani et al. Science Express, Jan. 6, 2011

Abdo et al., Science Express, Jan. 6, 2011

Crab Nebula

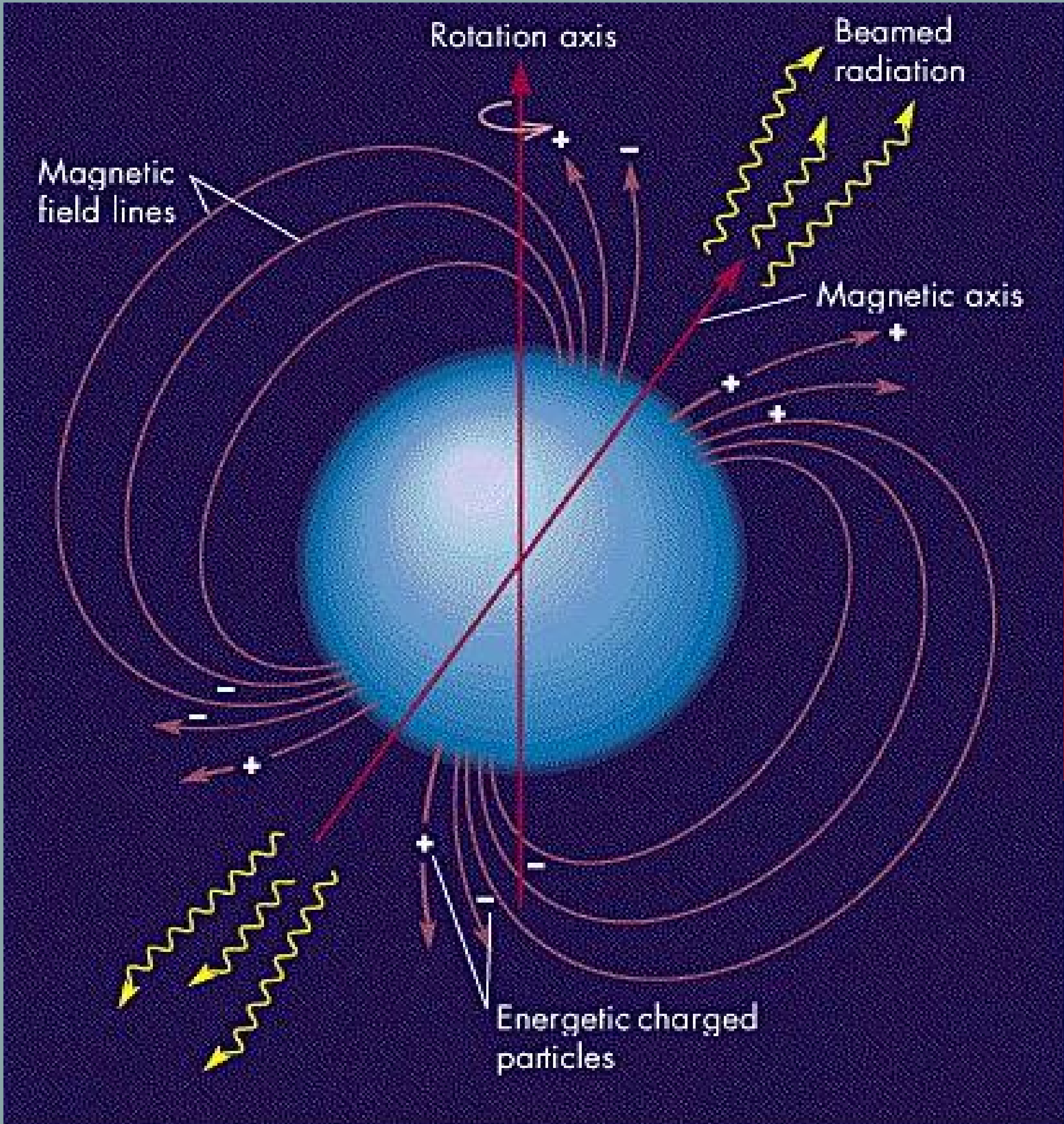


The Crab Nebula: a spectacular cosmic accelerator



POWERFUL PULSAR (rotating 30 times a second)

NEBULA SHOCKED BY THE PULSAR WIND



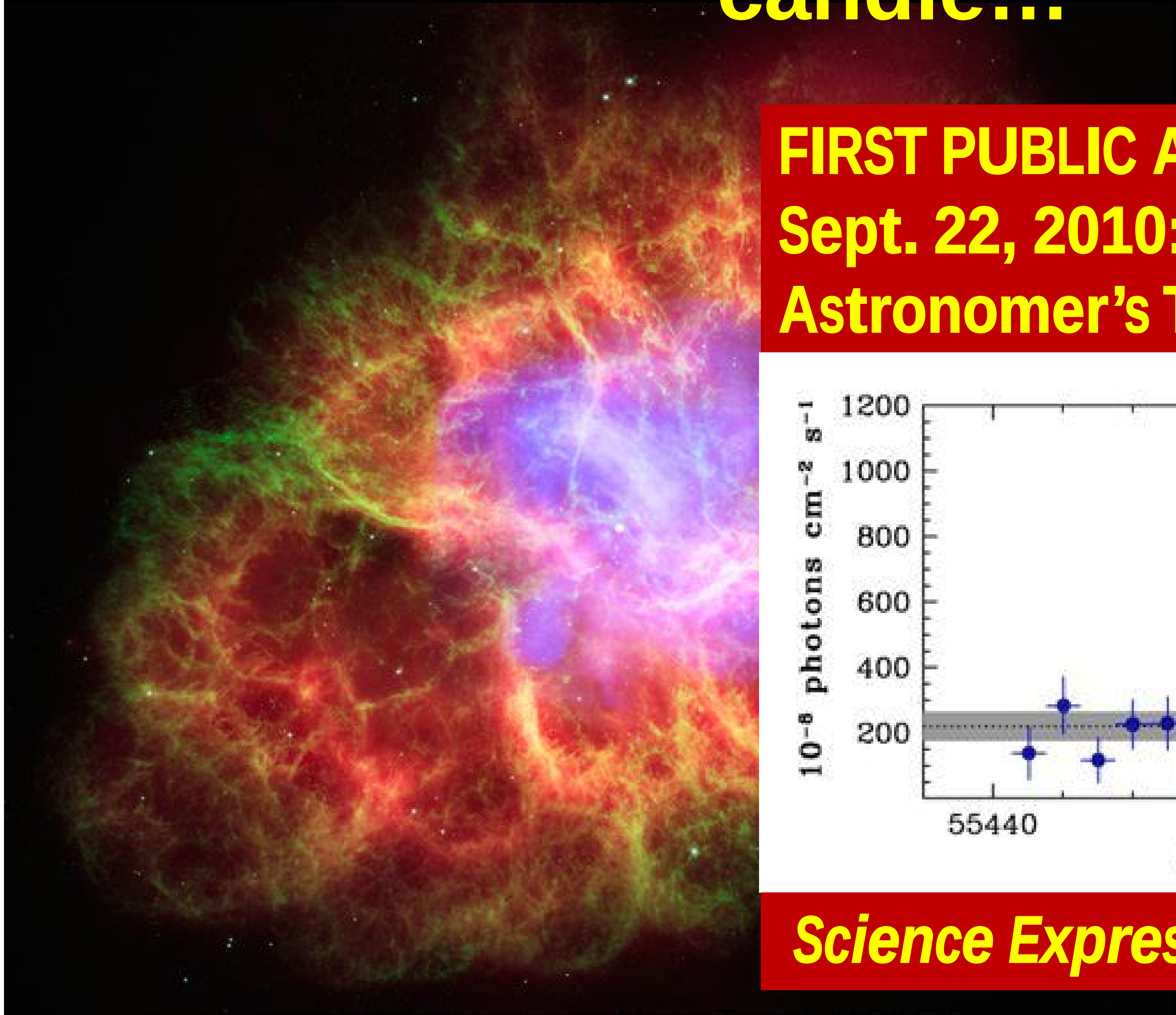
A NEUTRON STAR WITH A STRONG MAGNETIC FIELD, FAST ROTATING: A PULSAR !

The Crab Nebula: a spectacular cosmic accelerator

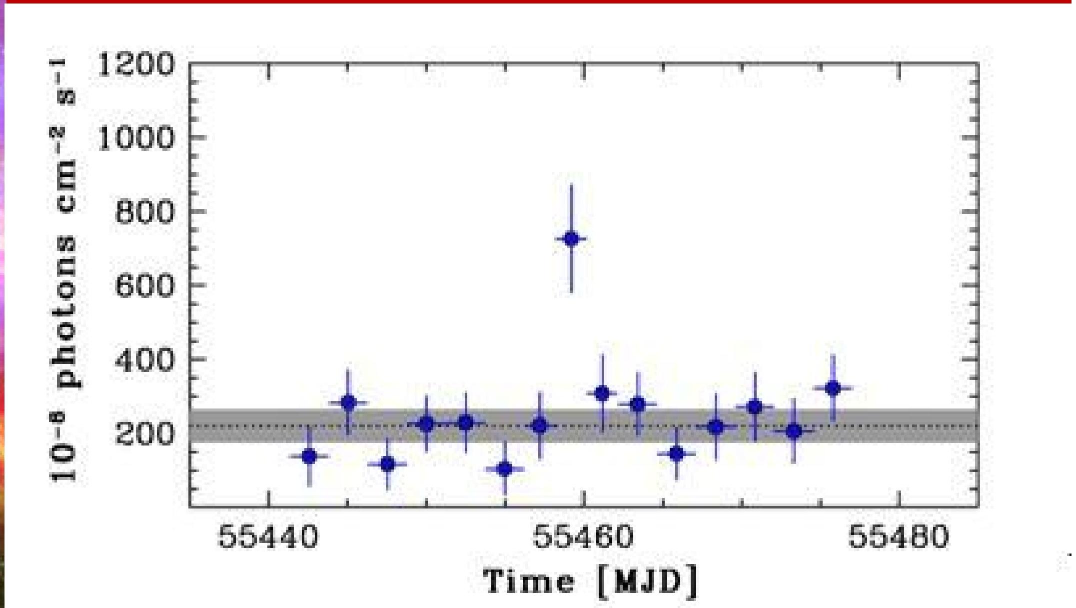
THE STANDARD REFERENCE SOURCE IN ASTROPHYSICS

IDEAL TO STUDY SHOCK ACCELERATION

The Crab Nebula: a standard candle…

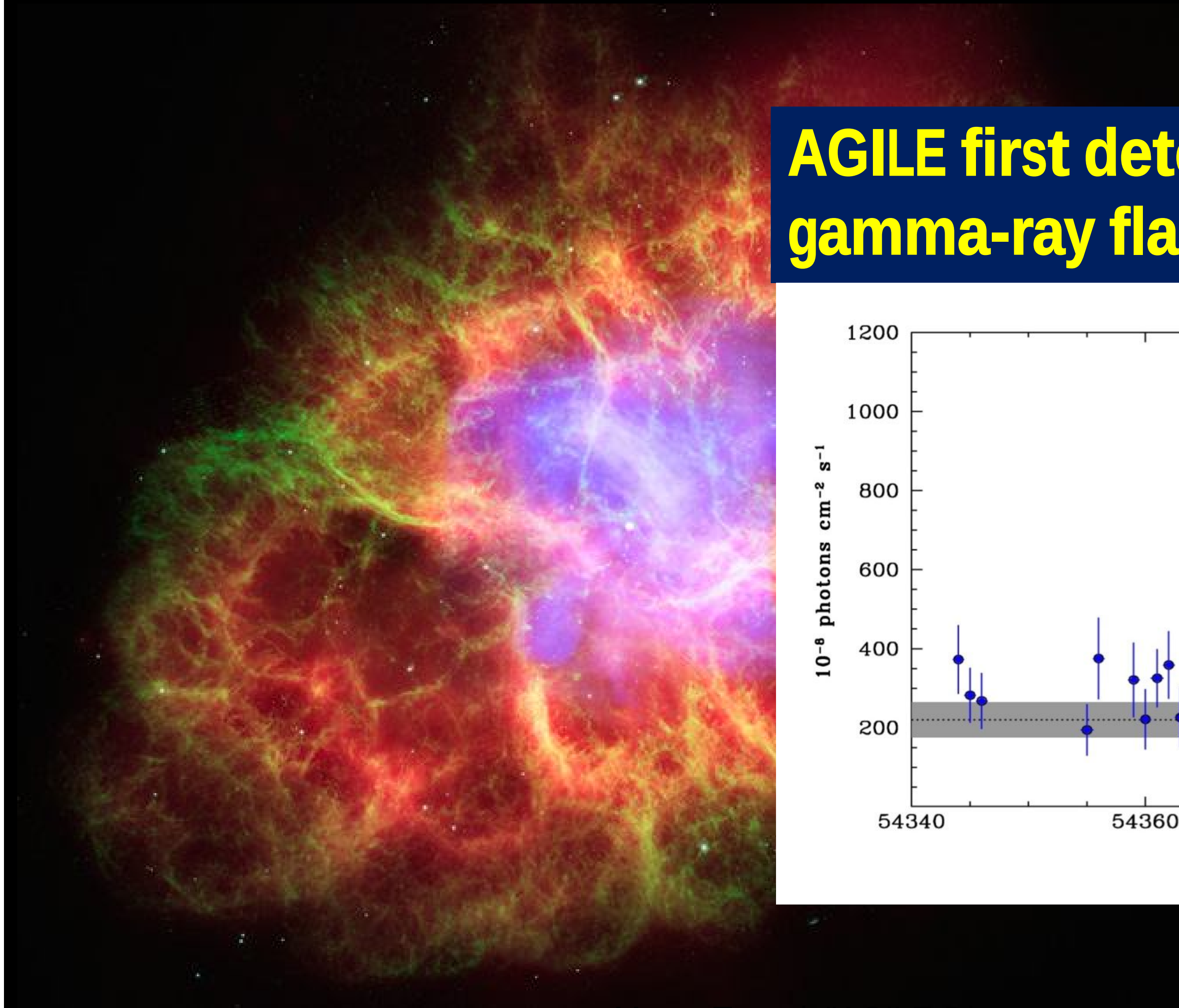


FIRST PUBLIC ANNOUNCEMENT
Sept. 22, 2010: AGILE issues the Astronomer's Telegram n. 2855

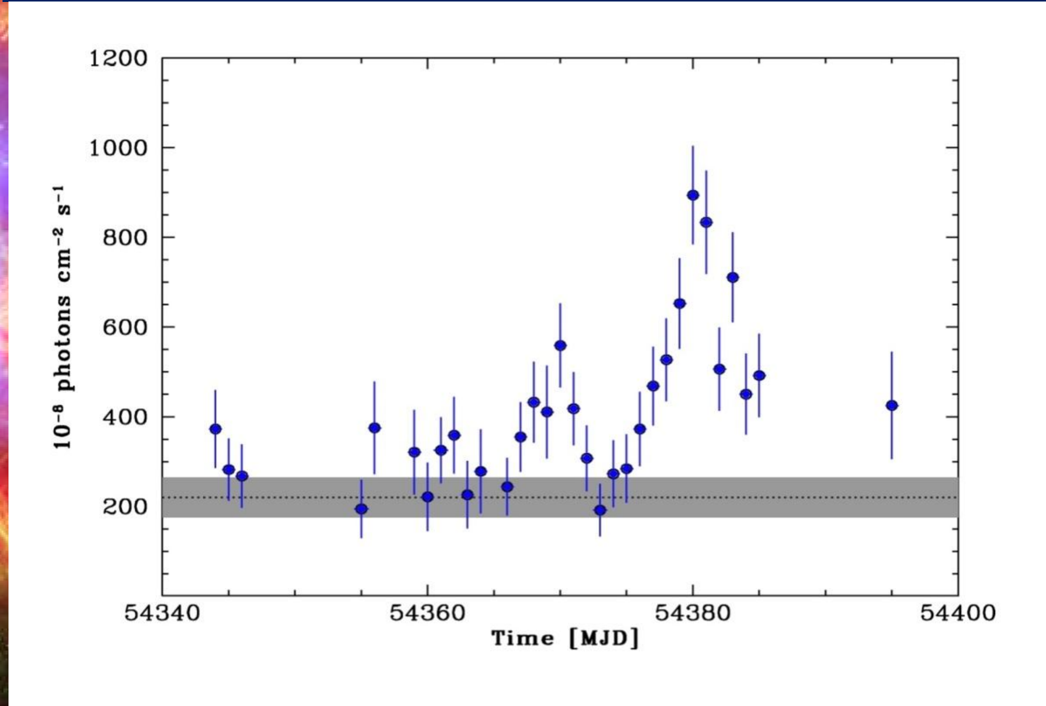


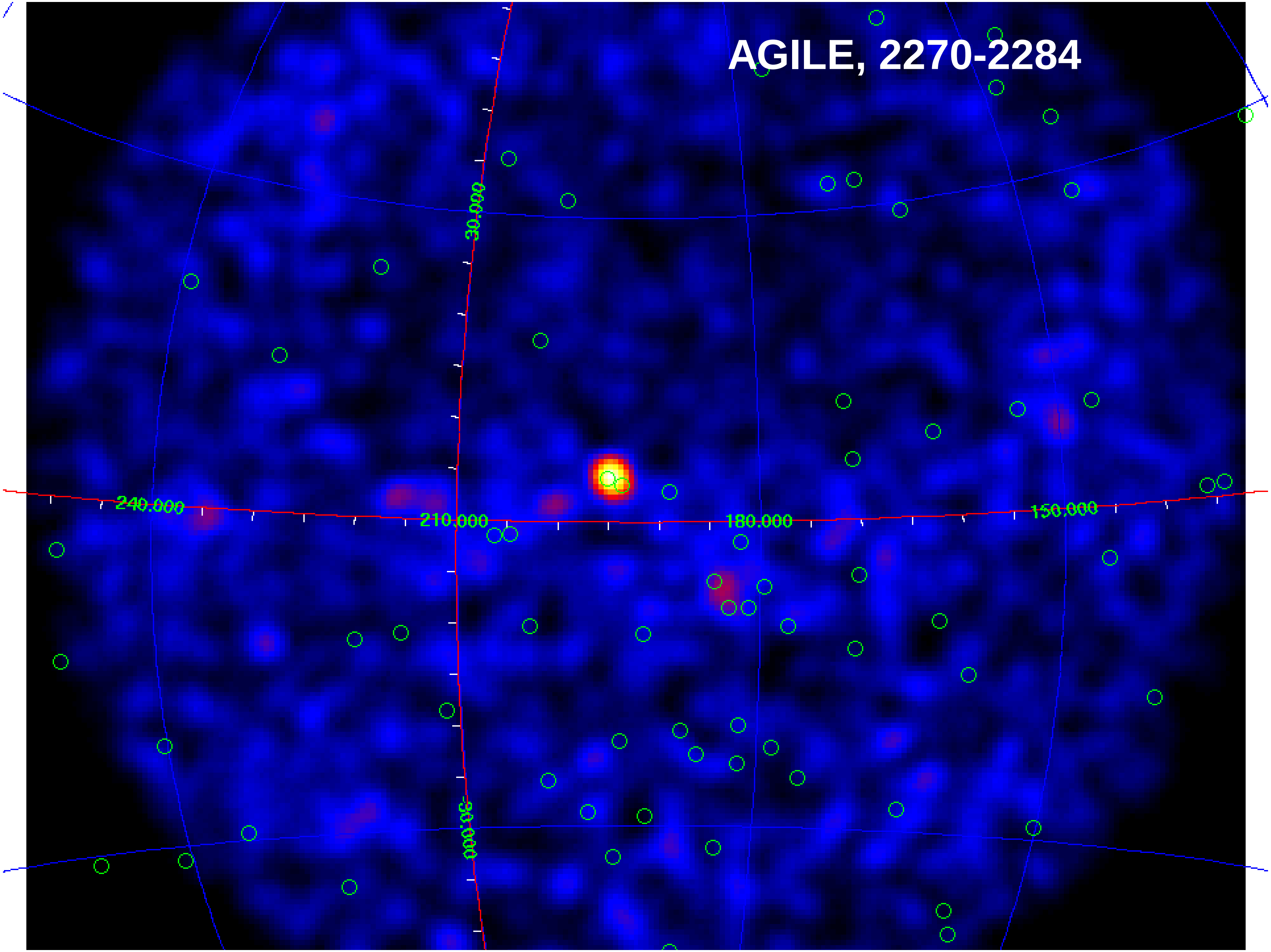
***Science Express* (6 January 2011)**

The variable Crab Nebula !

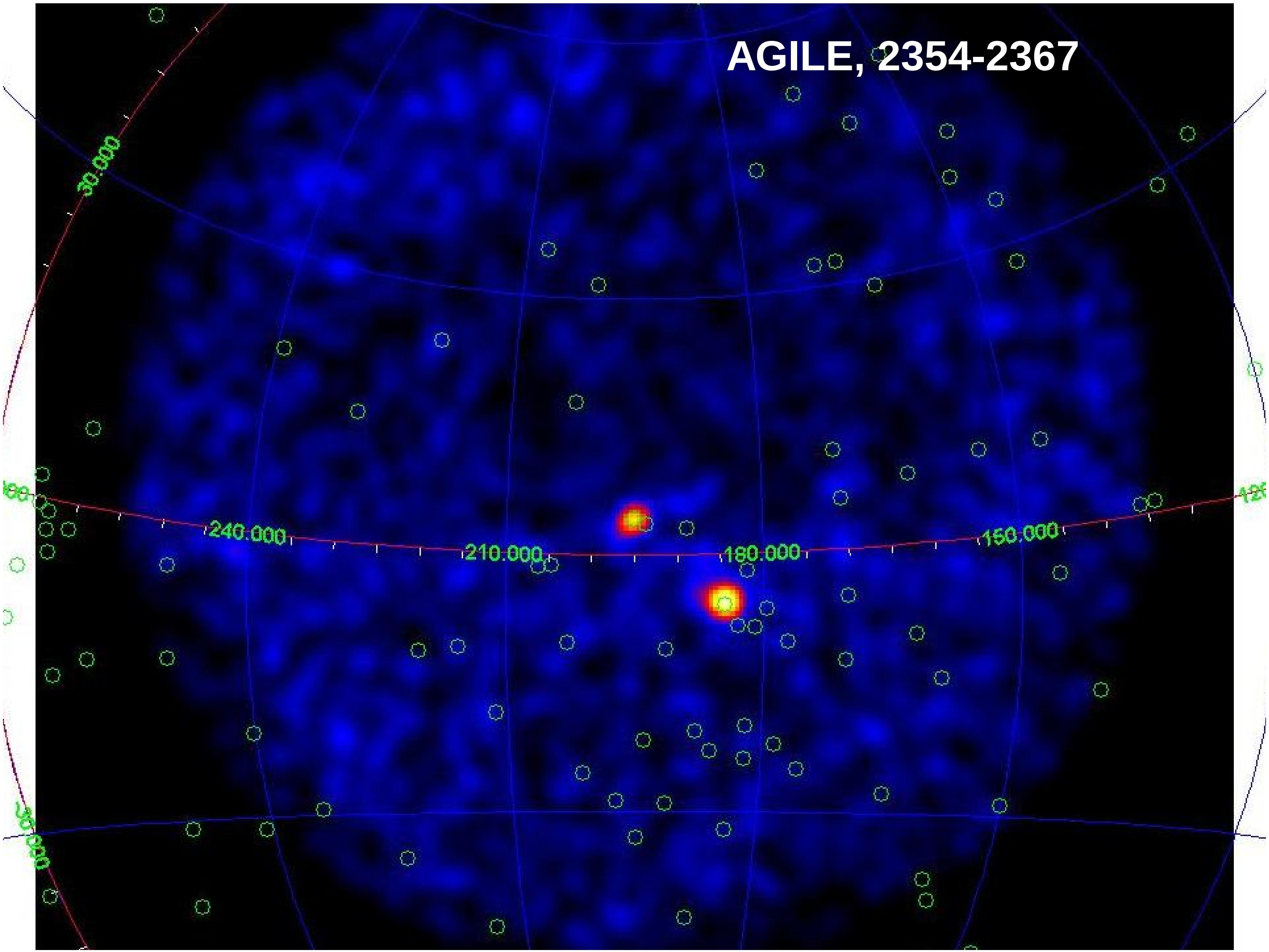


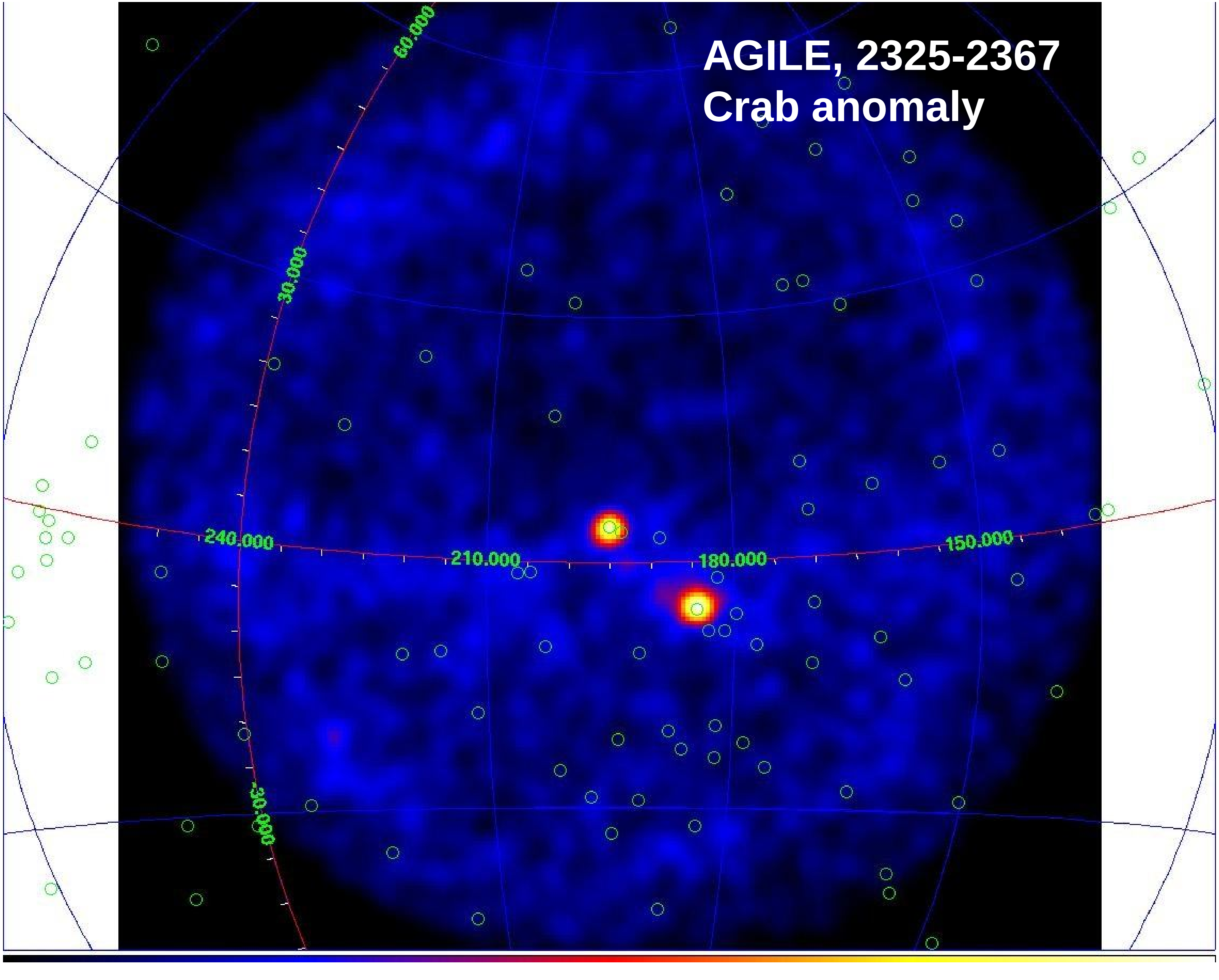
AGILE first detection of a strong gamma-ray flare in Oct. 2007





AGILE, 2270-2284
30.000
240.000
210.000
180.000
150.000
-30.000

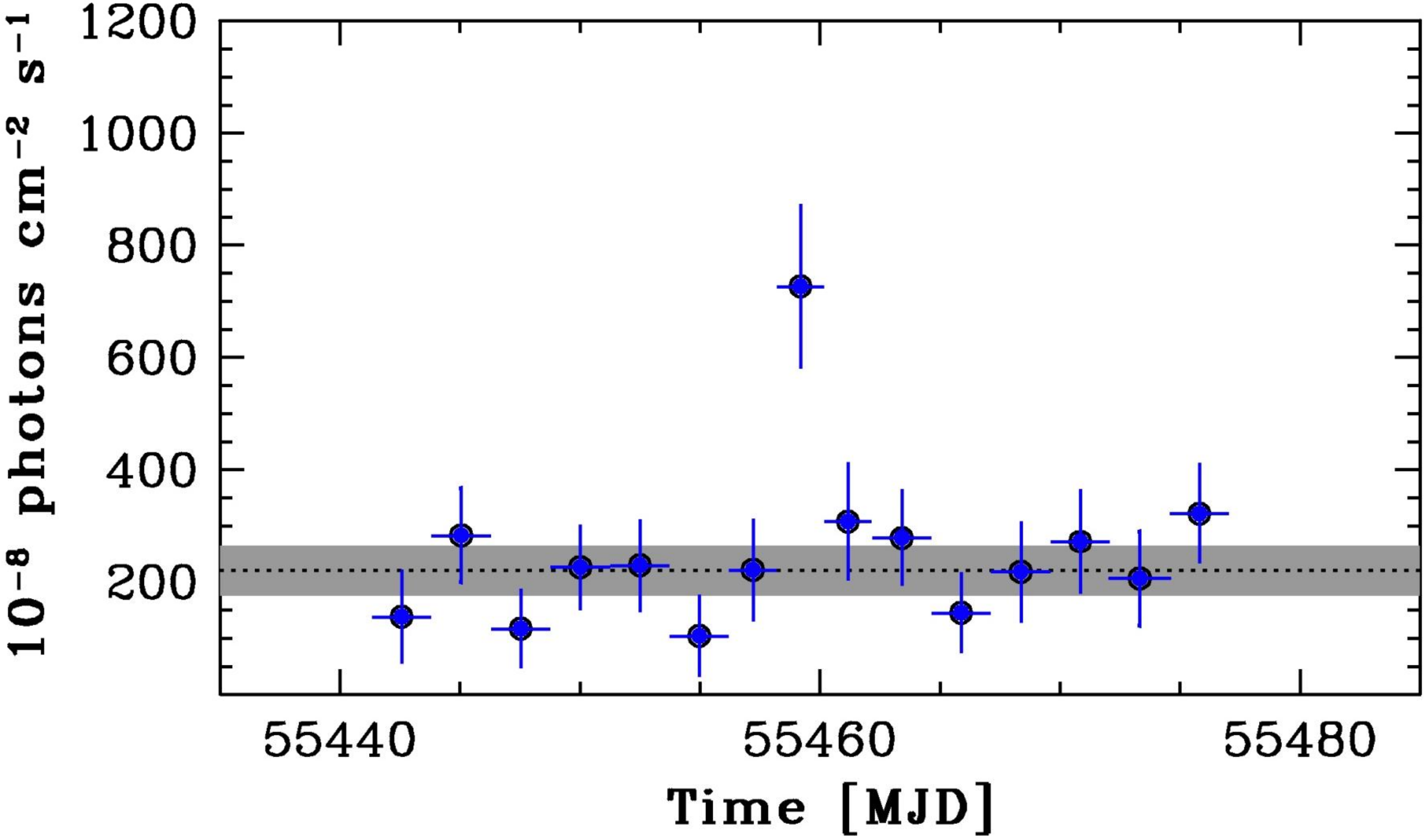

AGILE, 2354-2367
30.000
240.000
210.000
180.000
150.000
-30.000



AGILE, 2325-2367
Crab anomaly
60.000
30.000
-30.000
240.000
210.000
180.000
150.000

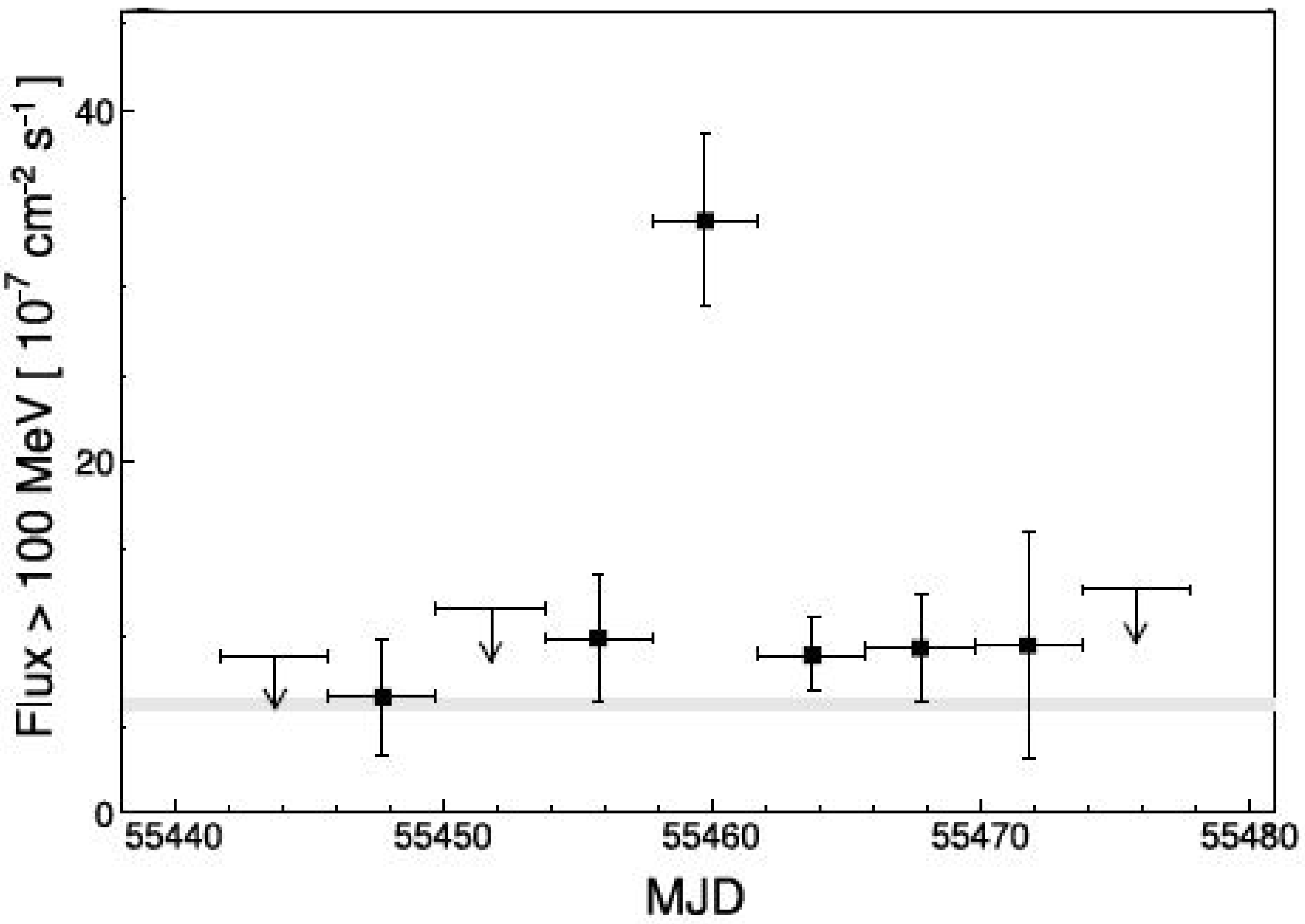
AGILE lightcurve (2-day binning)

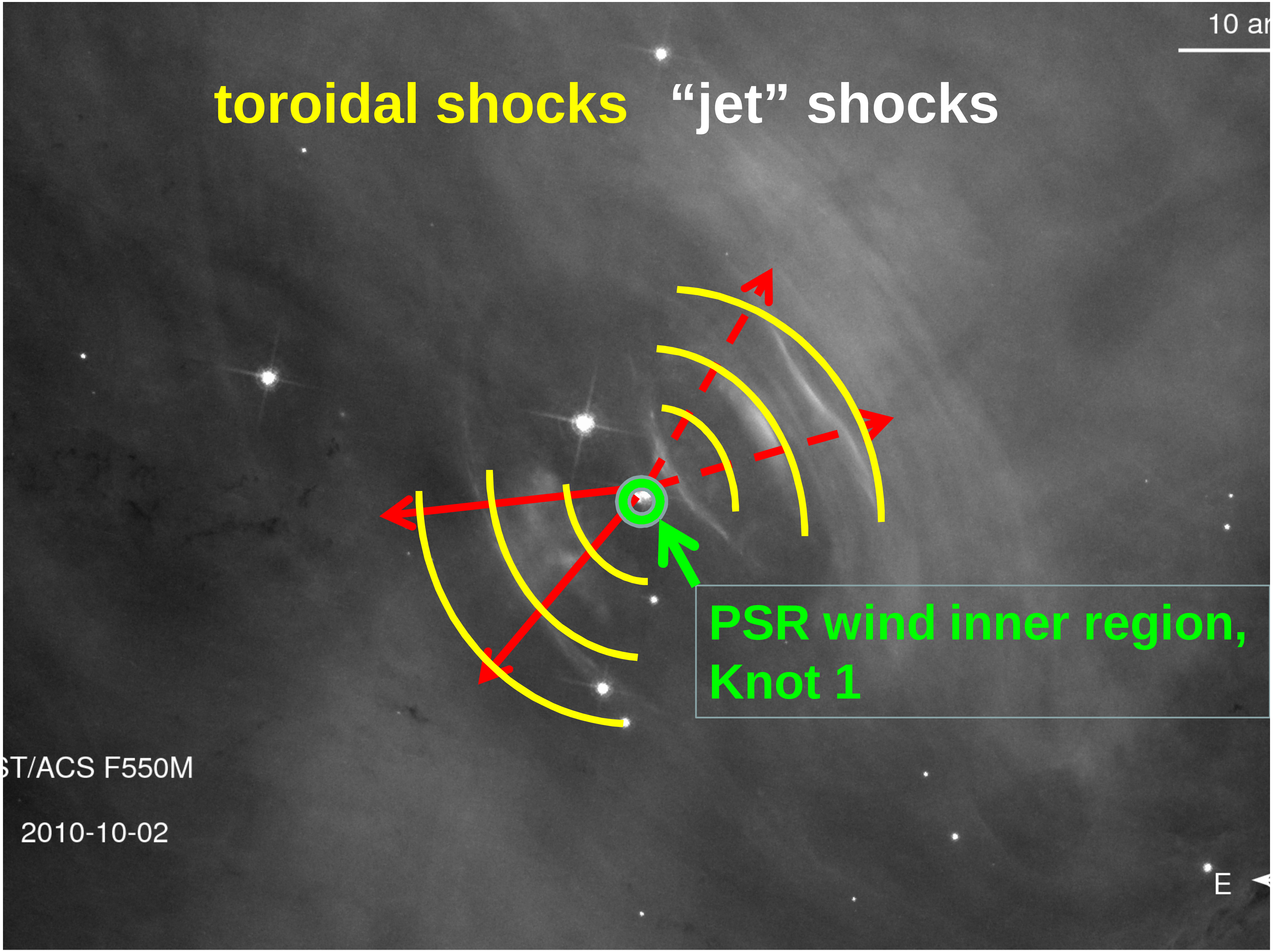
(PSR + Nebula)



Fermi-LAT lightcurve (4-day binning)

(Nebula only)





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

Crab Sept. 2010 flare

- **gamma-ray flare peak luminosity**

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

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

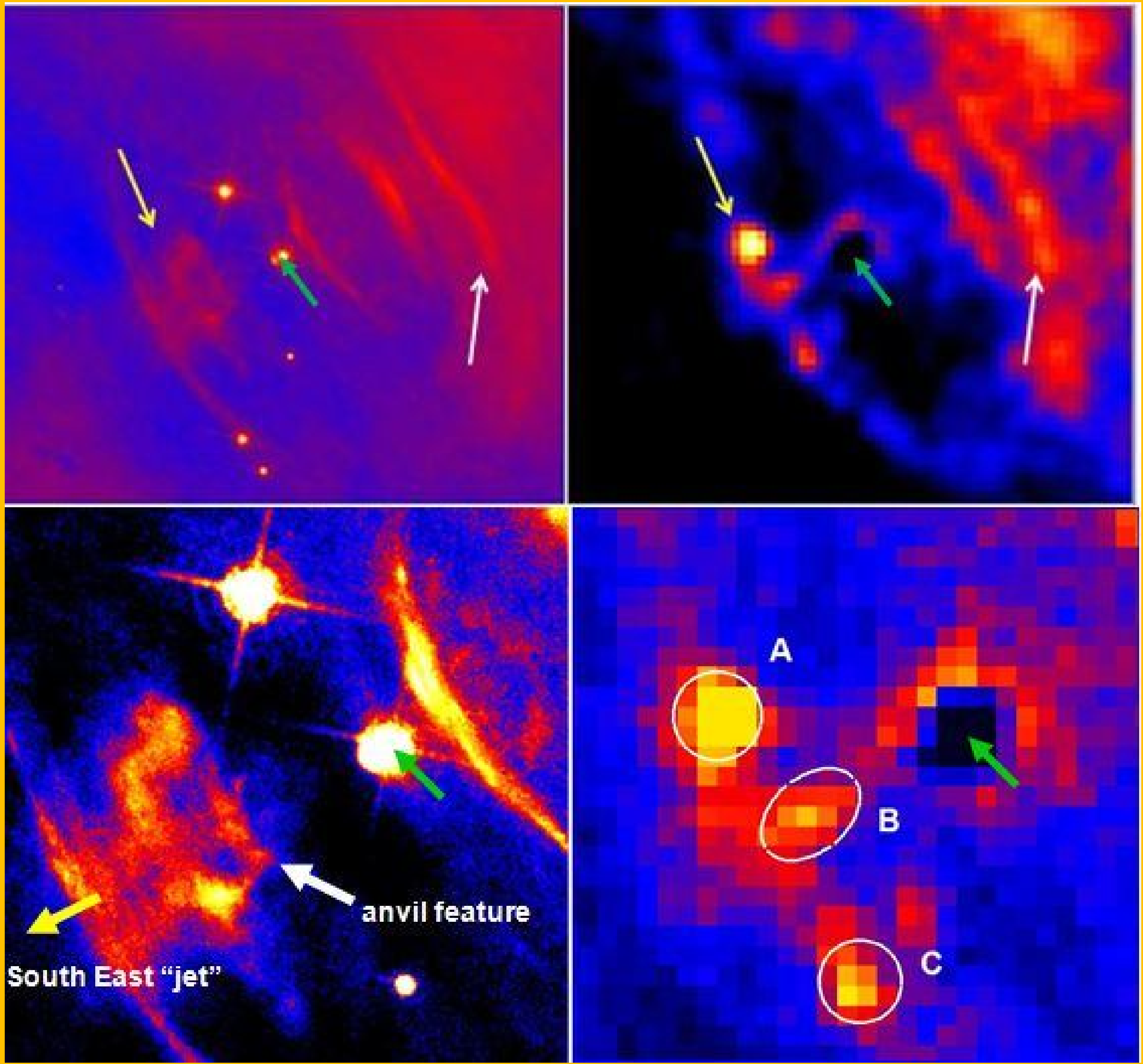
  $$\varepsilon \approx 0.001\ (\eta_{-1}/0.1) \approx 0.01$$

- **timescales:**
  - **risetime:** ≤ 1 day ← very efficient acceleration !
  - **decay:** ~ 2-3 days ← fast cooling, B, Lorentz γ

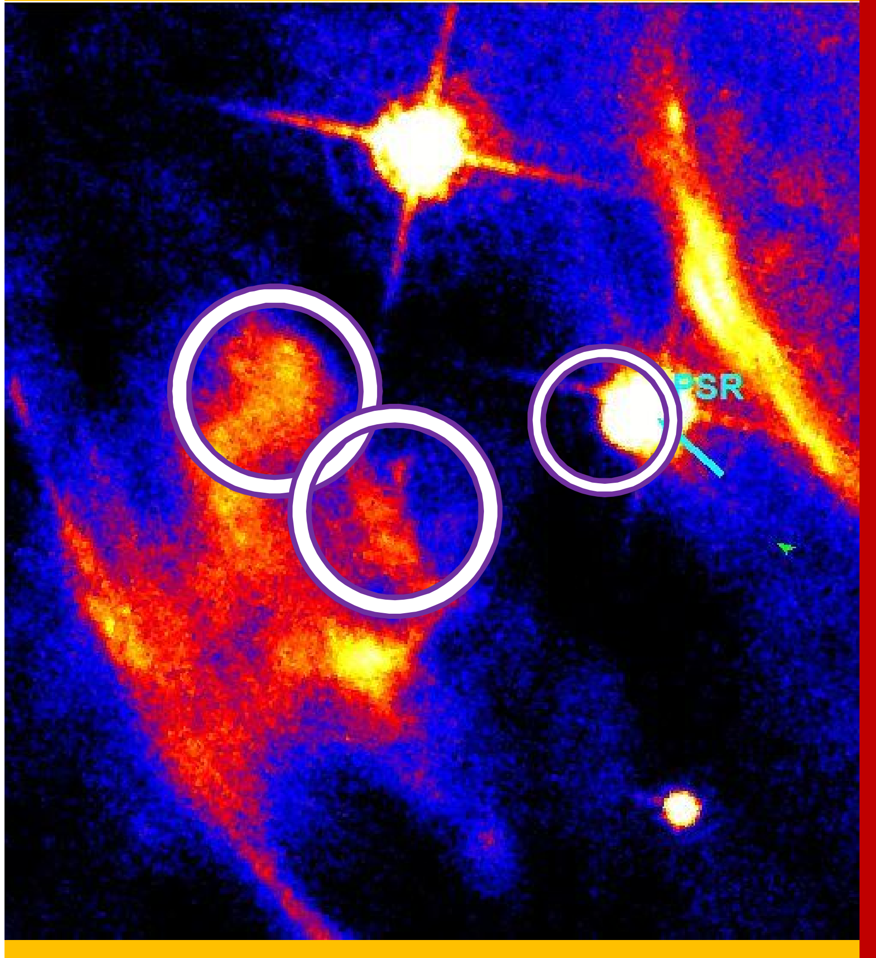
- crucial constraints on shock particle acceleration theory !
  - e-/e+ shock acceleration by magnetic turbulence (diffusive vs. non-diffusive)
  - ion cyclotron absorption (e.g., J.Arons et al.)

- 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 !

Hubble **(optical) Oct. 2, 2010** ***Chandra*** **(X-rays) Sept. 28, 2010**



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

- **short timescale Crab variability:**
  what is causing it?

  - **PSR wind enhancement (density, local B, change of sigma)**
  - **Plasma physics, shock changes, sudden change of B-configuration, reconnection (?)**
  - **near PSR effects (?)**
  - **Knot-1 (?)**
  - **"Anvil" region (?)**

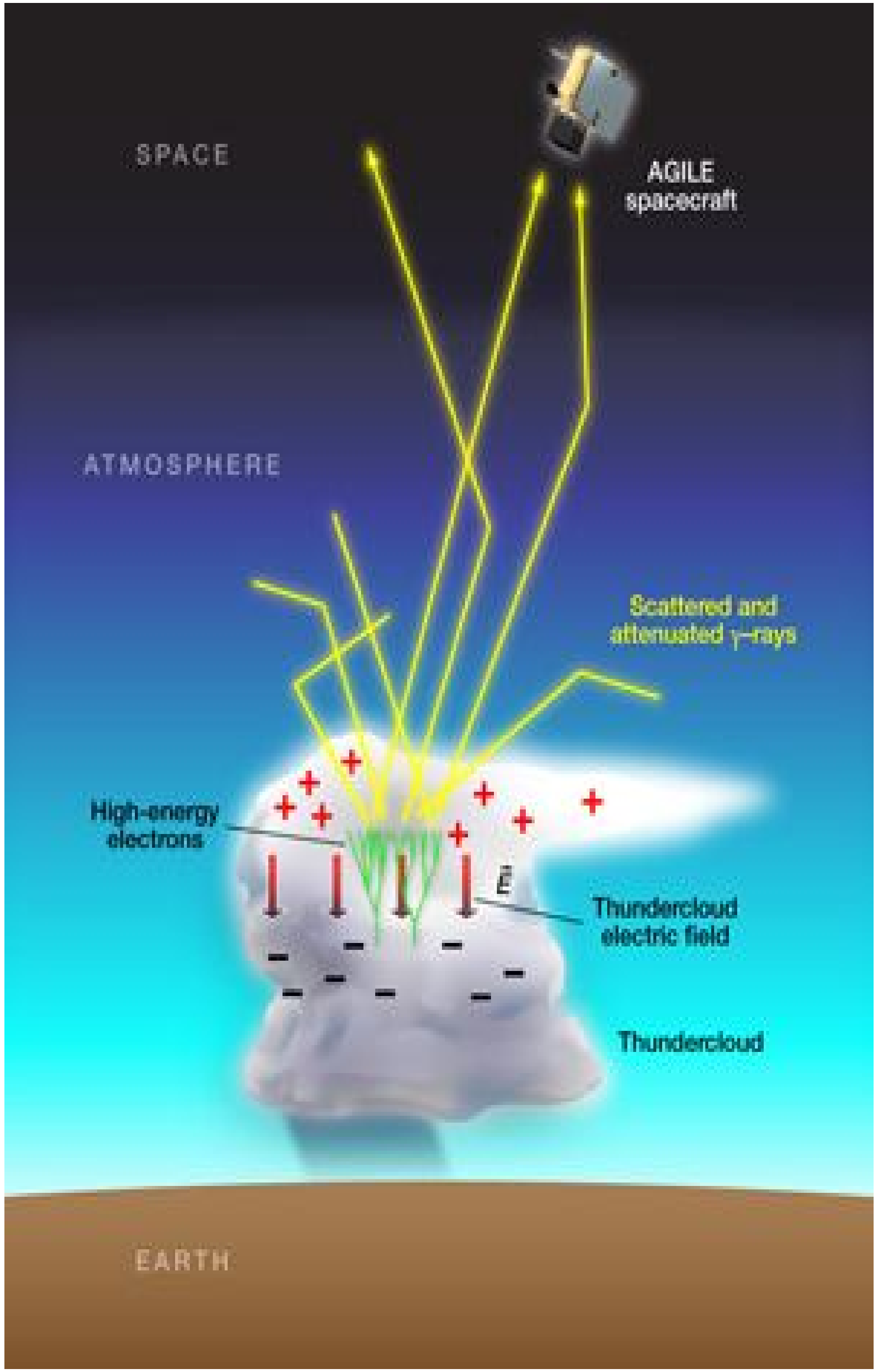
- very exciting: the Crab Nebula is not a standard candle in gamma-rays

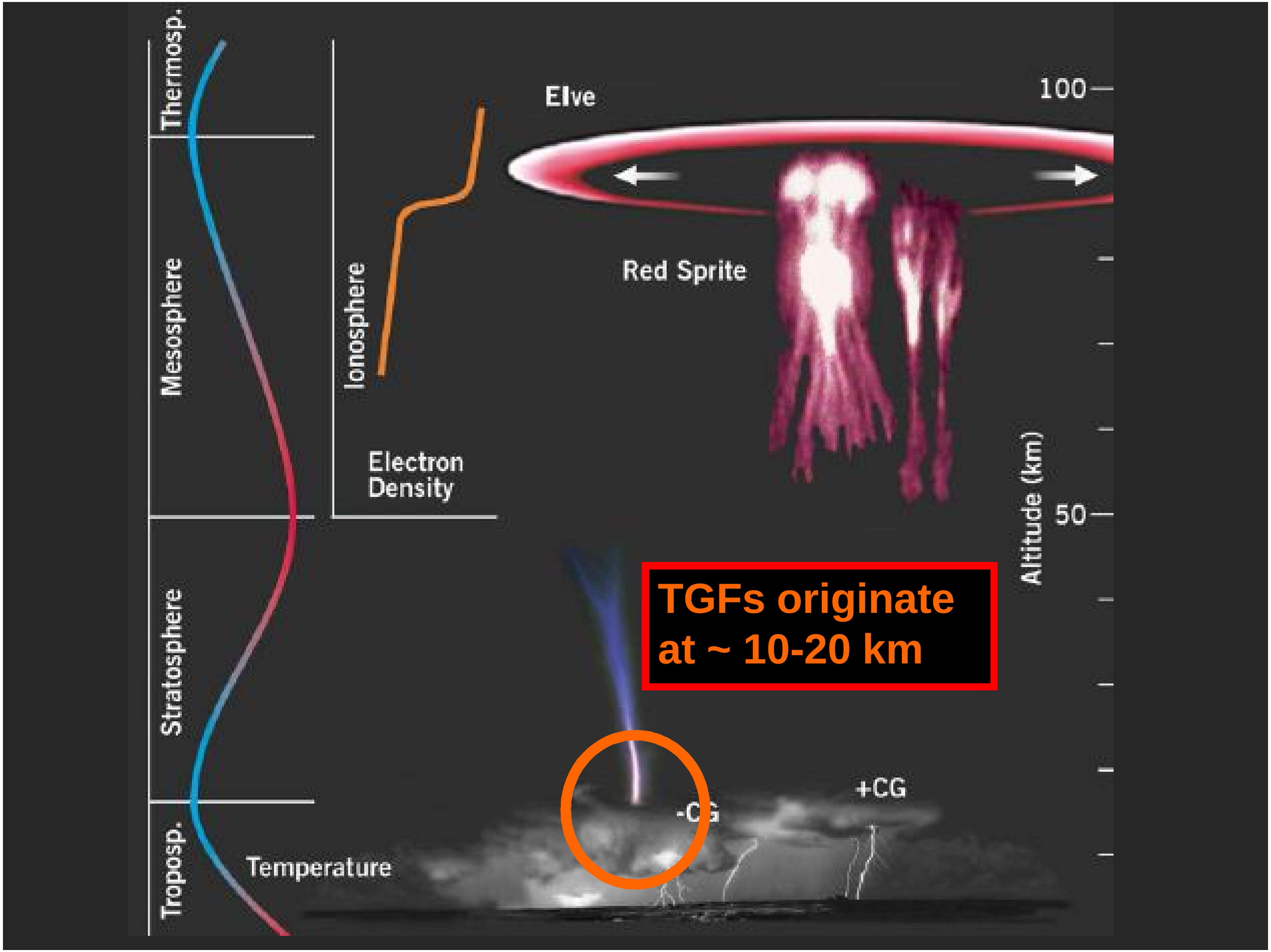
Flare date	Duration	Peak γ-ray flux	Instruments
October 2007	~ 15 days	~ $6{\cdot}10^{-6}$ ph cm^{-2} s^{-1}	AGILE
February 2009	~ 15 days	~ $4{\cdot}10^{-6}$ ph cm^{-2} s^{-1}	*Fermi*
September 2010	~ 4 days	~ $5{\cdot}10^{-6}$ ph cm^{-2} s^{-1}	AGILE, *Fermi*

- we “lost” the stability of an ideal reference source, but gained tremendous information about the fundamental process of particle acceleration
- a big theoretical challenge
- the ultimate source of particle enhancements in the pulsar wind needs to be established: future surprises

AGILE observations of the Earth: from astrophysics to a study of lighting (particle acceleration in the atmosphere)

- **Normal lightnings involve a particle accelerating potential DV ~ a few MegaVolts**
- **Terrestrial Gamma-Ray Flashes (TGF) involve DV > 100 MegaVolts**

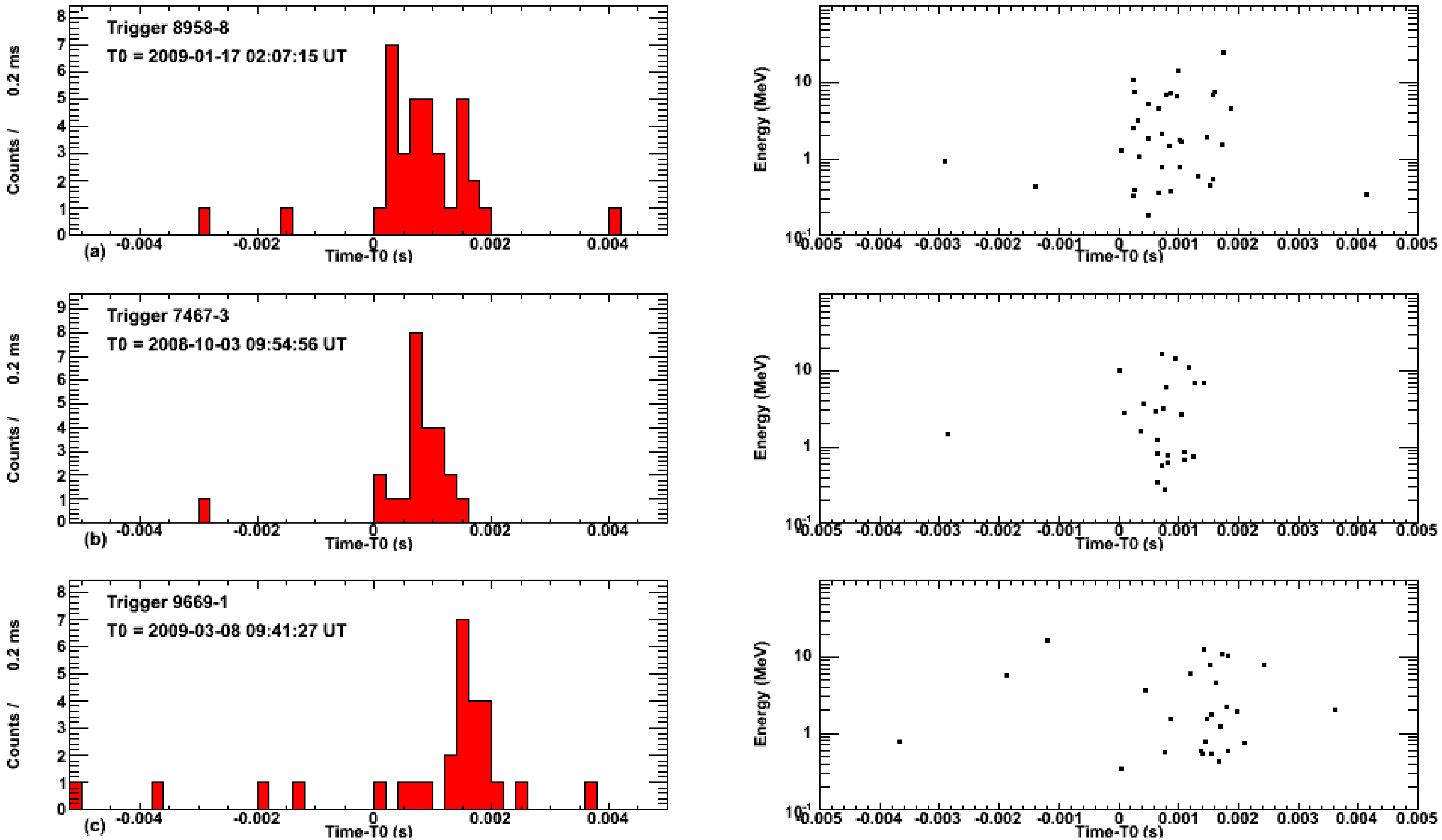

SPACE
AGILE spacecraft
ATMOSPHERE
Scattered and attenuated γ–rays
High-energy electrons
$\vec{E}$
Thundercloud electric field
Thundercloud
EARTH



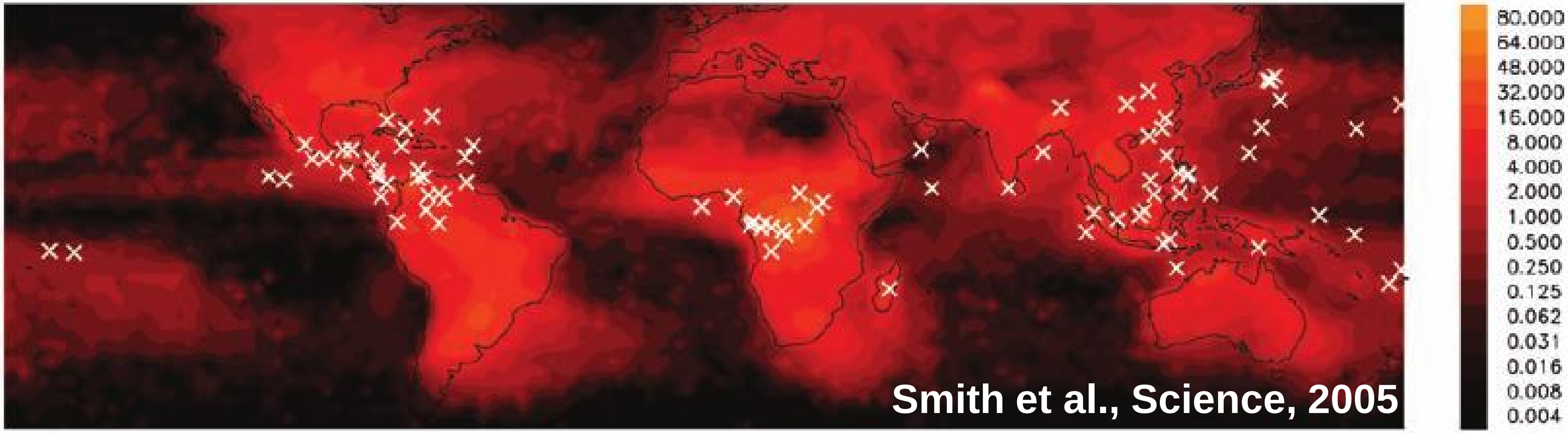
Thermosp.
Mesosphere
Stratosphere
Troposp.
Temperature
Ionosphere
Electron Density
Elve
Red Sprite
100
50
Altitude (km)
TGFs originate at ~ 10-20 km
-CG
+CG

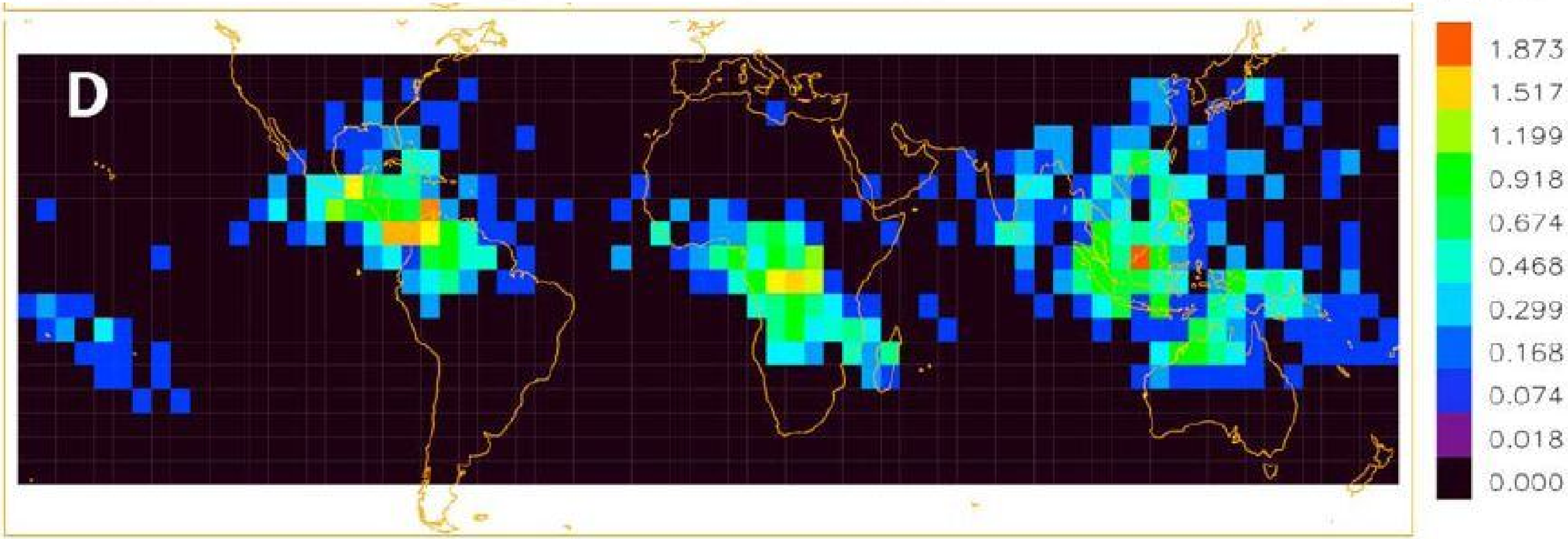
AGILE Terrestrial Flashes lightcurves

The bright events



Terrestrial Gamma-Ray Flashes (RHESSI map up to 20 MeV)





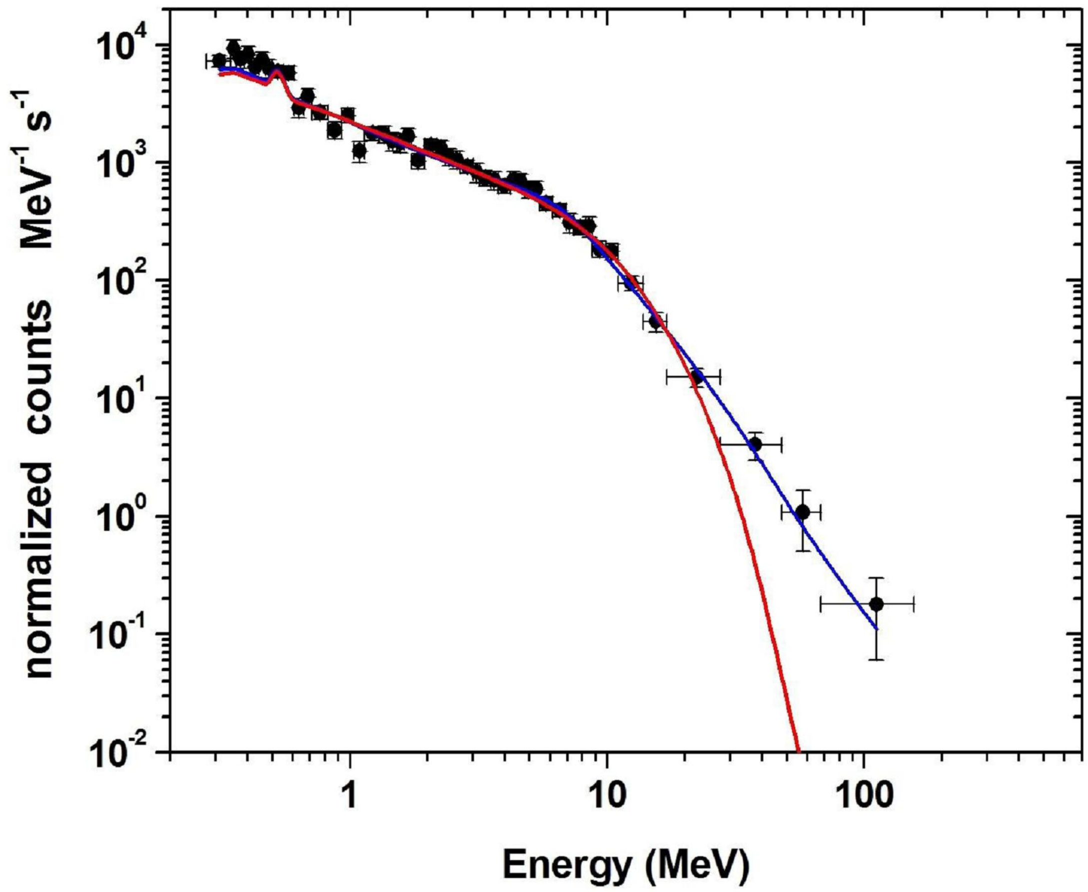
AGILE: what makes MCAL unique for TGFs:

- Only instrument in equatorial orbit
  - TGF on the equator
  - low-background
- Only instrument with sub-msec trigger capability
- Instrument with the best capability at E > 30-40 MeV

AGILE contribution to Earth studies

- **breakthrough AGILE discovery of gamma-ray emission up to 100 MeV !**

Tavani et al., Phys. Rev. Letters (Jan. 3, 2011)



The study of Terrestrial Flashes need more data

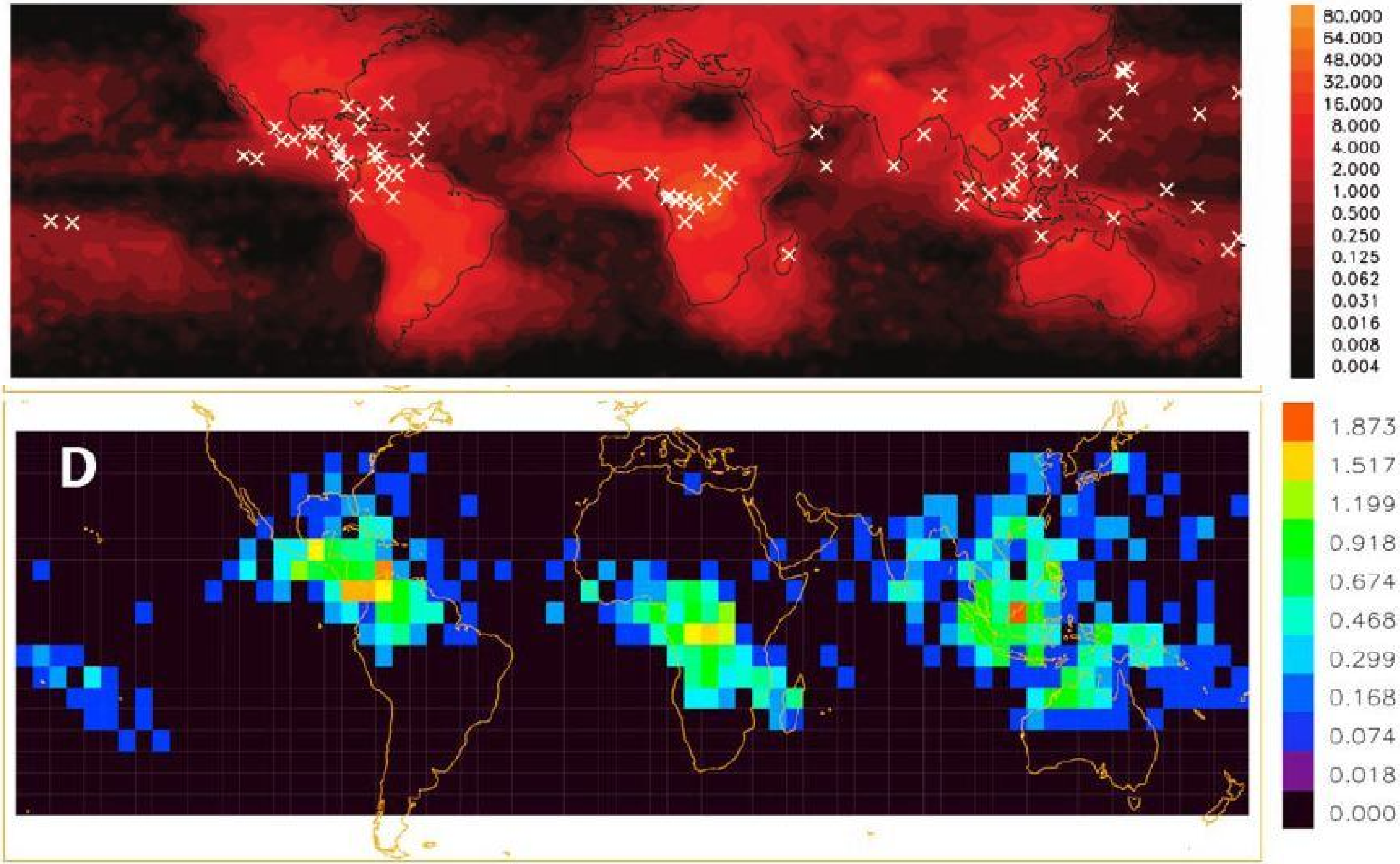
- **Study the acceleration process (what is the maximum energy ?)**

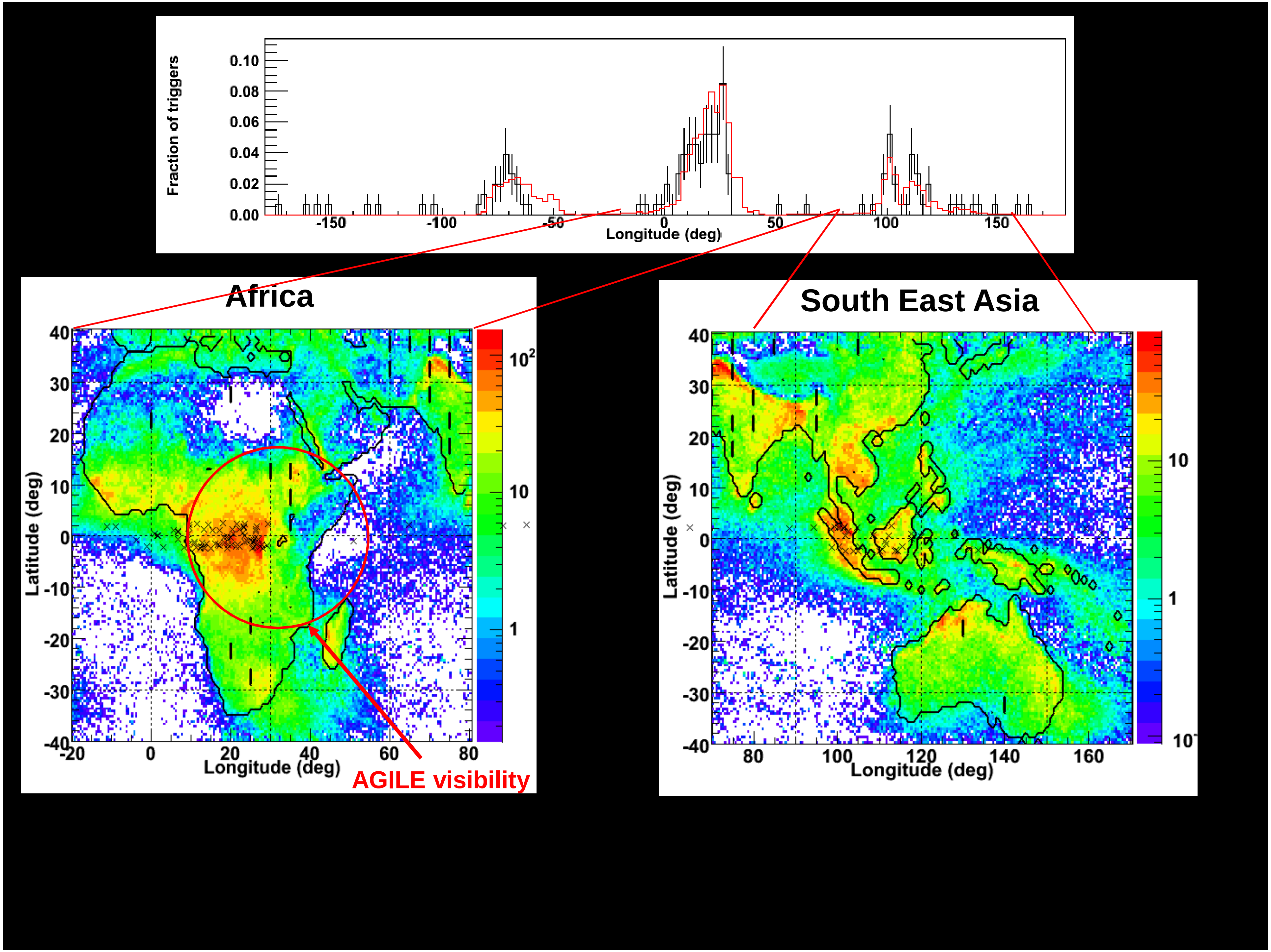
- **Geographical distribution (what is the real one ?)**

- **Impact on climate, chemistry**

- **ALERT system**

Terrestrial Gamma-Ray Flashes (RHESSI map up to 20 MeV)




Fraction of triggers
Longitude (deg)
Africa
South East Asia
Latitude (deg)
Longitude (deg)
AGILE visibility

Conclusions

- Black hole physics
  - Patterns of emission
  - massive black hole jet ejections, particle acceleration

- Variable Crab Nebula: too fast acceleration !

- Terrestrial Gamma-Ray Flashes: astrophysics and Earth observations