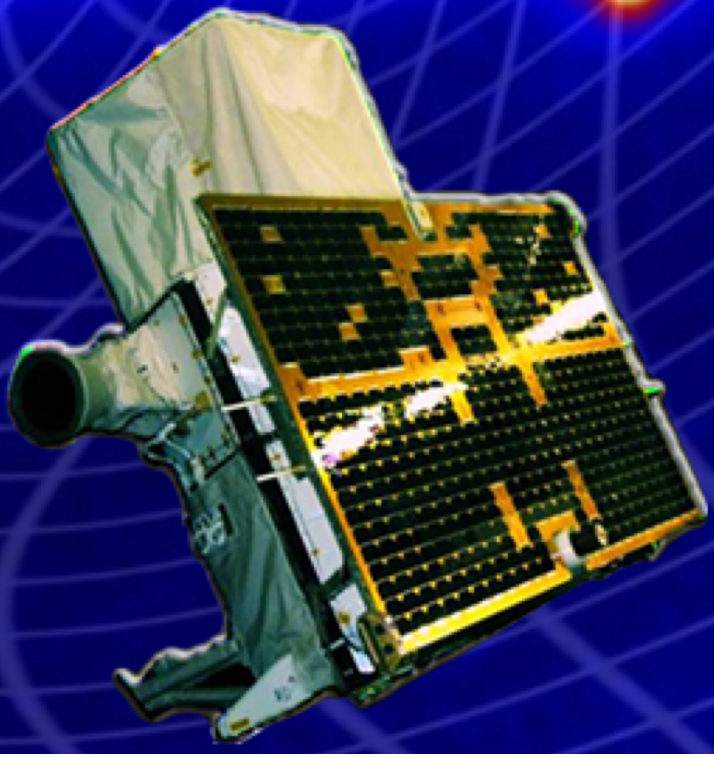
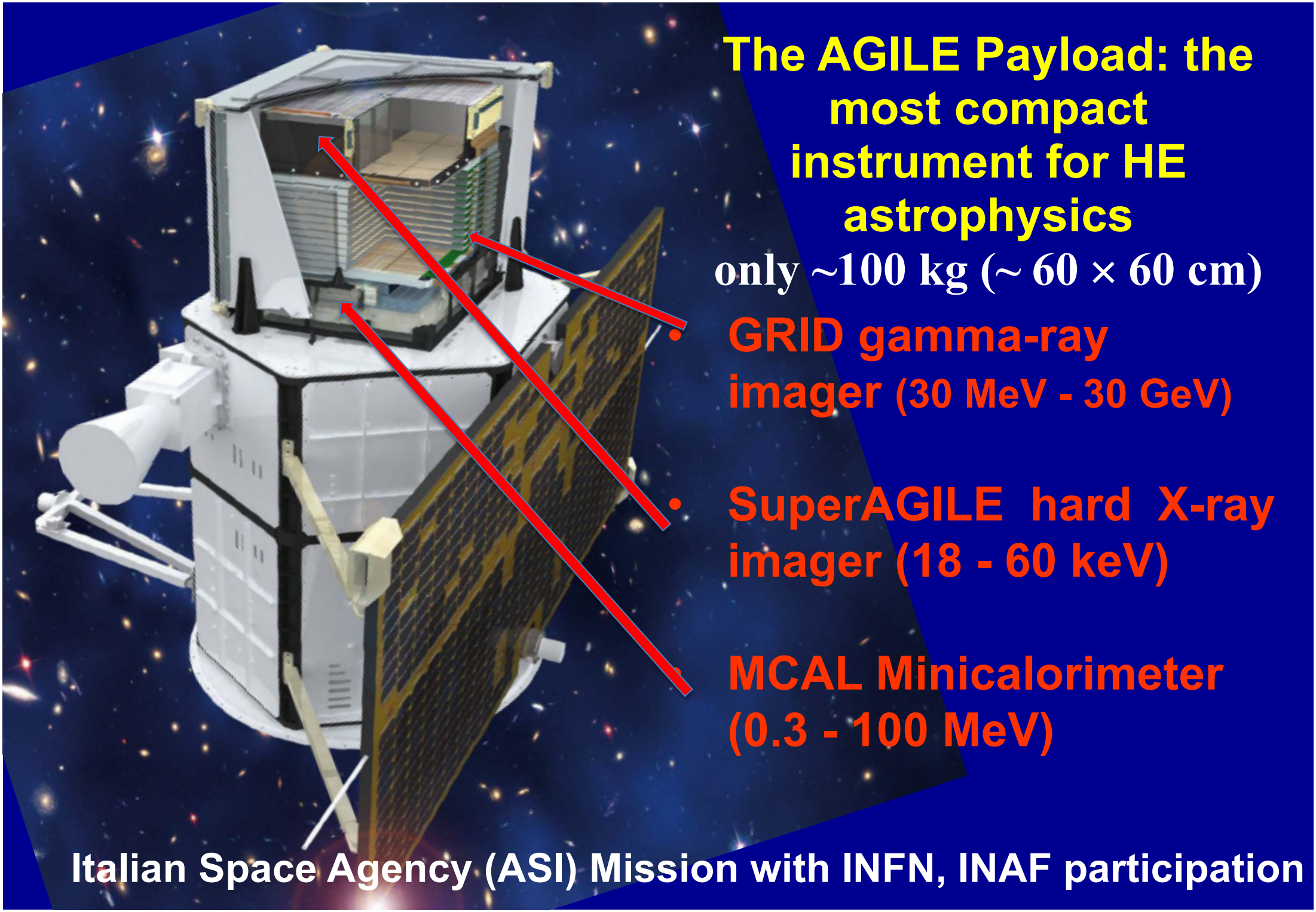
Space Science Data Center

AGILE HIGHLIGHTS

Carlotta Pittori, on behalf of the AGILE Collaboration

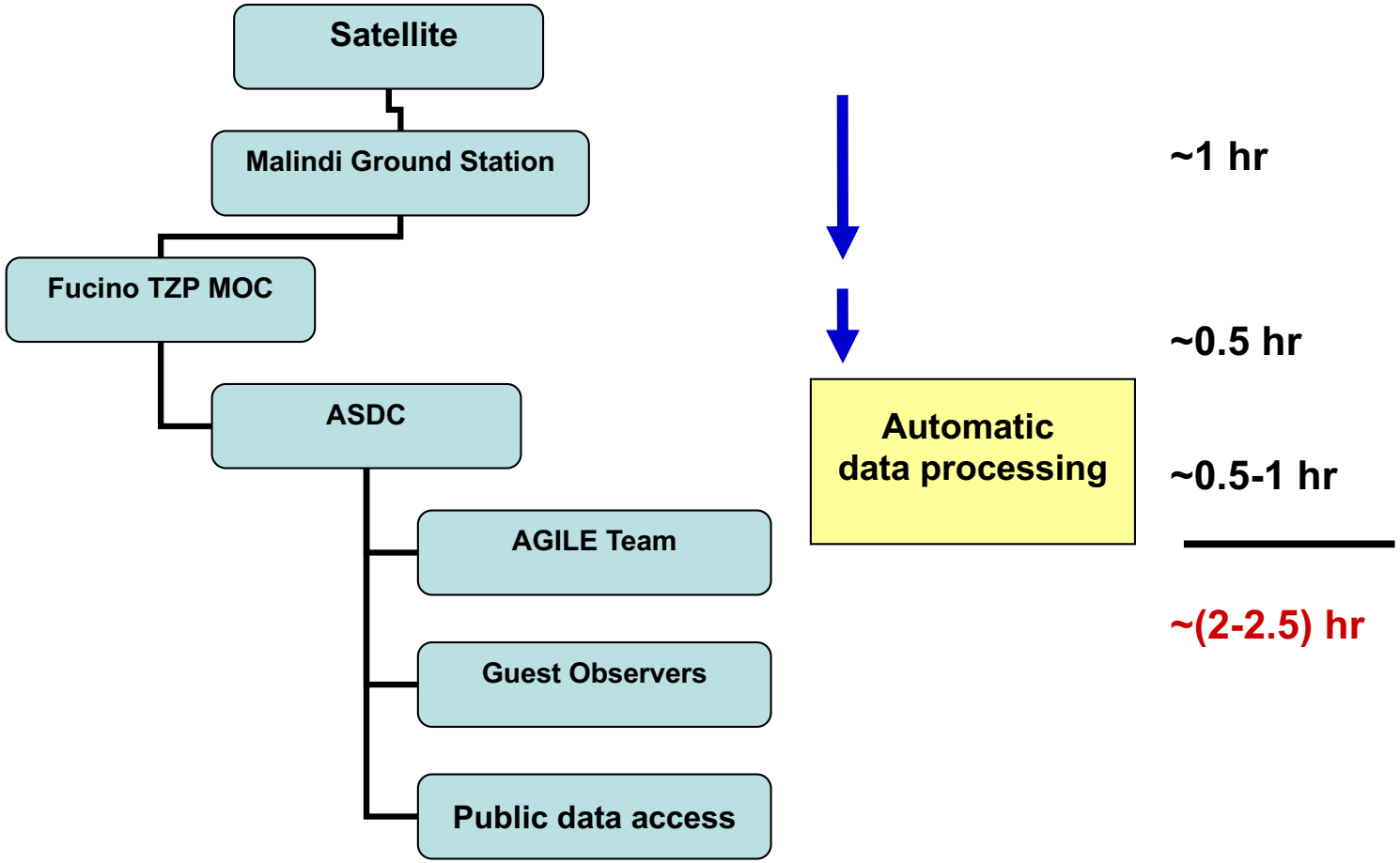


C. Pittori, INAF-OAR and SSDC
Vulcano Workshop, May 22, 2018


The AGILE Payload: the most compact instrument for HE astrophysics
only ~100 kg (~ 60 × 60 cm)
GRID gamma-ray imager (30 MeV - 30 GeV)
SuperAGILE hard X-ray imager (18 - 60 keV)
MCAL Minicalorimeter (0.3 - 100 MeV)
Italian Space Agency (ASI) Mission with INFN, INAF participation

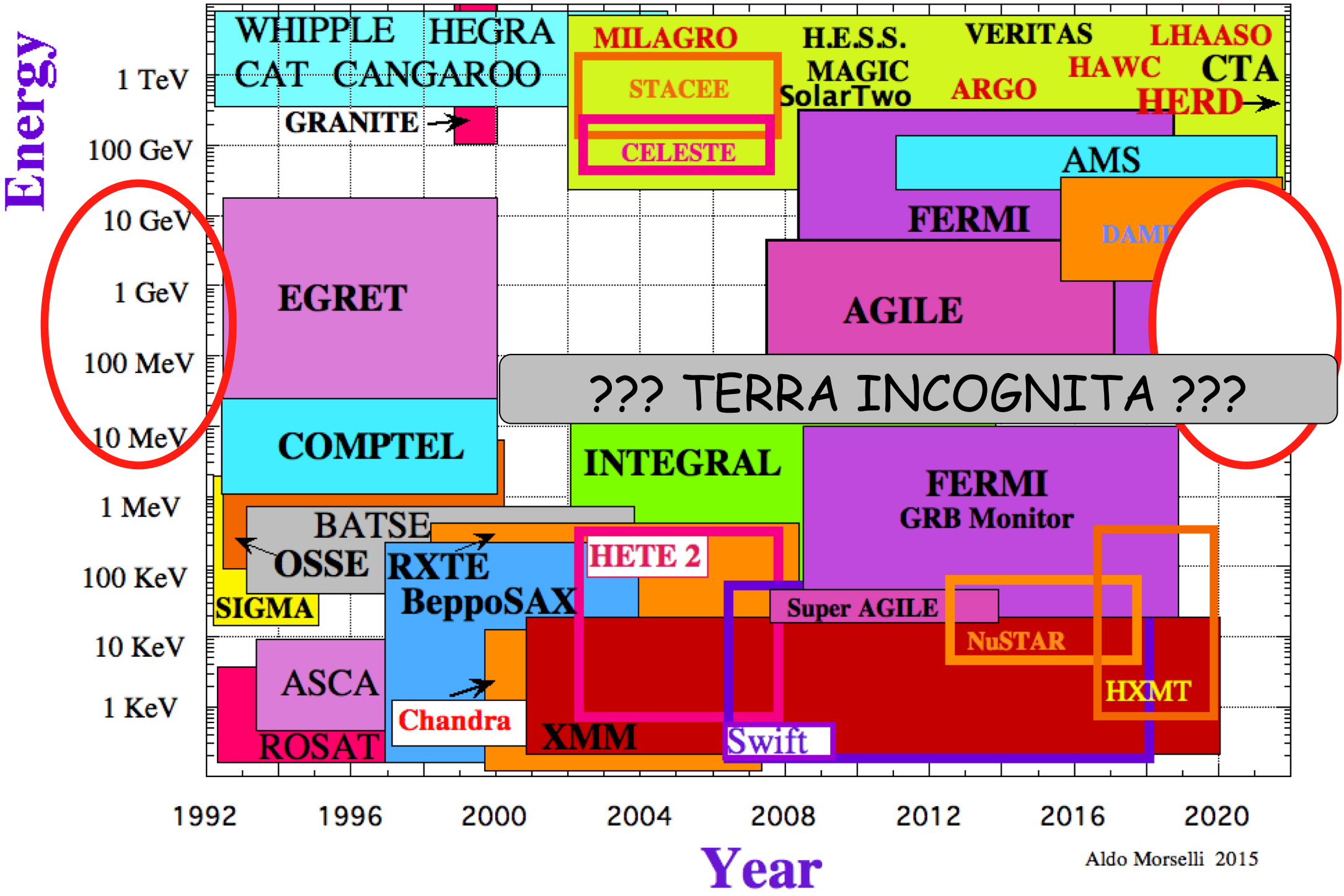

Fast and AGILE: 11 years in orbit
India April 23, 2007: Launch
Low Earth equatorial orbit: 550 Km and < 3º inclination angle

AGILE: "very fast" Ground Segment



Record for a gamma-ray mission! App AGILEScience for mobile dev

Now even faster: ~ 25 min latency. Optimized for GW counterpart hunt!


Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
HEGRA
CAT
CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
LHAASO
CTA
HERD
AMS
FERMI
DAMI
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
NuSTAR
HXMT
ASCA
Chandra
XMM
Swift
ROSAT
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli 2015

Recent discovery from HE astrophysics above 100 MeV

Gamma-ray intense transients on short timescales (< minutes, days) in different astrophysical systems:

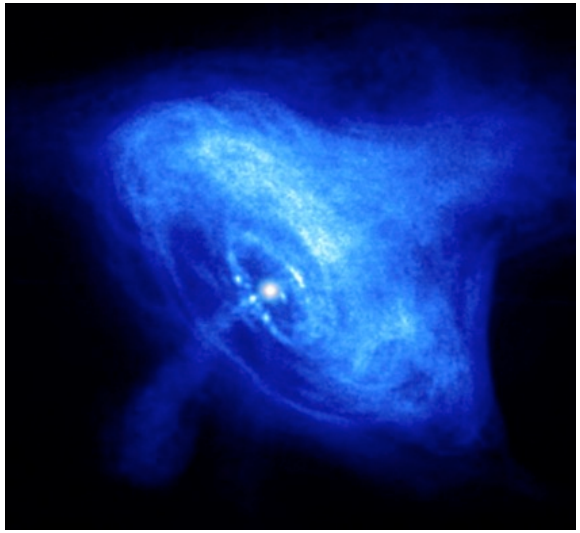
1. Gamma-ray flares E>100 MeV in Microquasars (binary systems as Cyg X-3 and Cyg X-1)

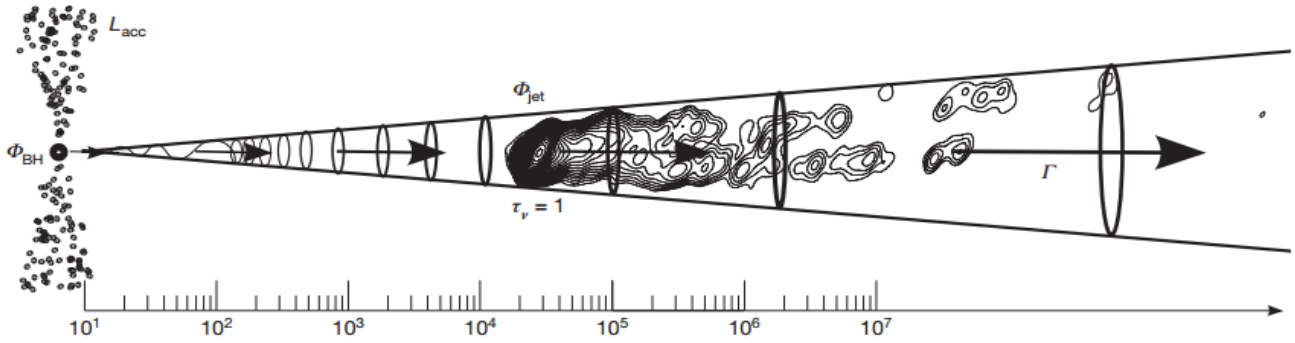
2. Almost monochromatic gamma-ray flares from Crab Pulsar Wind Nebula

3. Gamma-ray flares up to TeV from FSRQ, with fast observed timescale variability of the order of minutes

High Energy Astrophysics: new lessons

- Role of the magnetic field
- New acceleration mechanism (e.g. Crab flares)
- Plasma instabilities
  - Galactic compact objects (e. g. Cygnus X-3)
  - Blazars and relativistic jets, GRBs



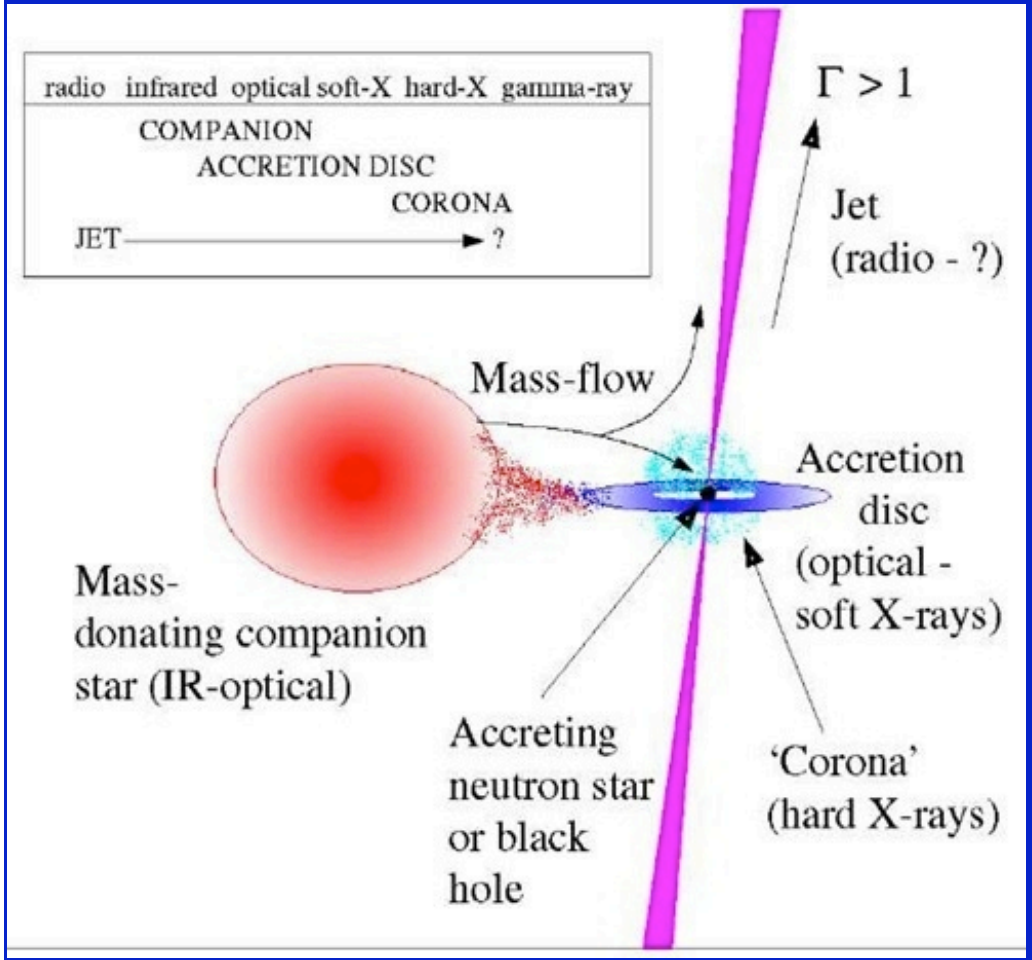


Other results for which AGILE *should* be remembered:

- First direct evidence of cosmic ray acceleration in Supernova Remnants with the AGILE observations of the SNR W44 (2017 Matteucci Medal of the National Academy of Sciences to M. Tavani)
- Transient and subsequent discovery of the "hidden black hole" MCW 656 in a Be star binary
- Surprises also from the Earth atmosphere: detection of Terrestrial Gamma-Ray Flashes (TGF) up to 100 MeV!!

Microquasars:

Galactic X-ray binary sources with radio emitting rel. jets



Open questions pre-AGILE and Fermi:

- **Can jet formation accelerate relativistic particles?**
- **Can the jet emit γ-rays above 100 MeV?**

The discovery of the γ-ray activity from Cygnus X-3 is the proof of extreme particle acceleration in microquasars!

The γ-ray detection of Cygnus X-3: brief story of a discovery

- December 2, 2009:

  The AGILE-*GRID* detects 4 γ-ray flares from C

  ("*Extreme particle acceleration in the microquasar Cygnus X-3*", Tava

  - γ-ray flaring-fluxes greater than 1 order of magnitude with
  - coincident with **prominent minima** of the hard X-ray flux
  - a few days before major radio flares

- December 11, 2009:

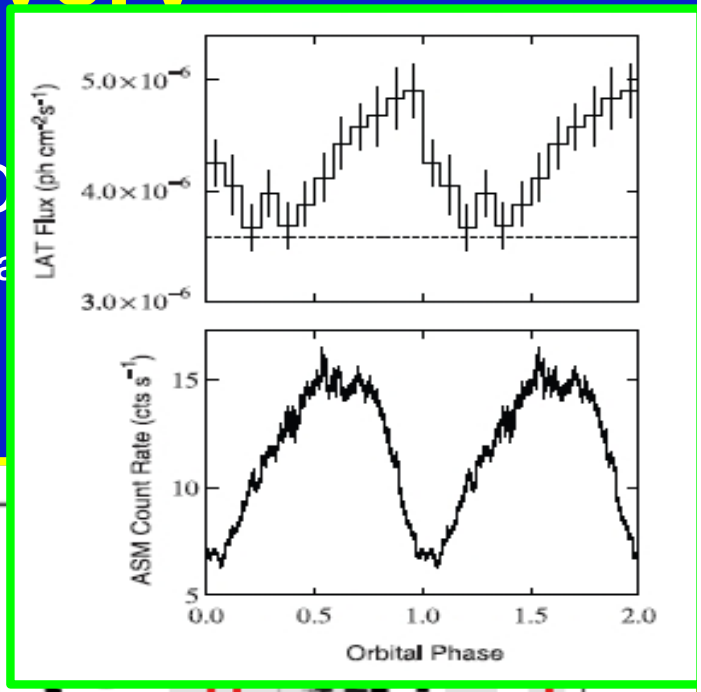
  Fermi-LAT confirms AGILE det

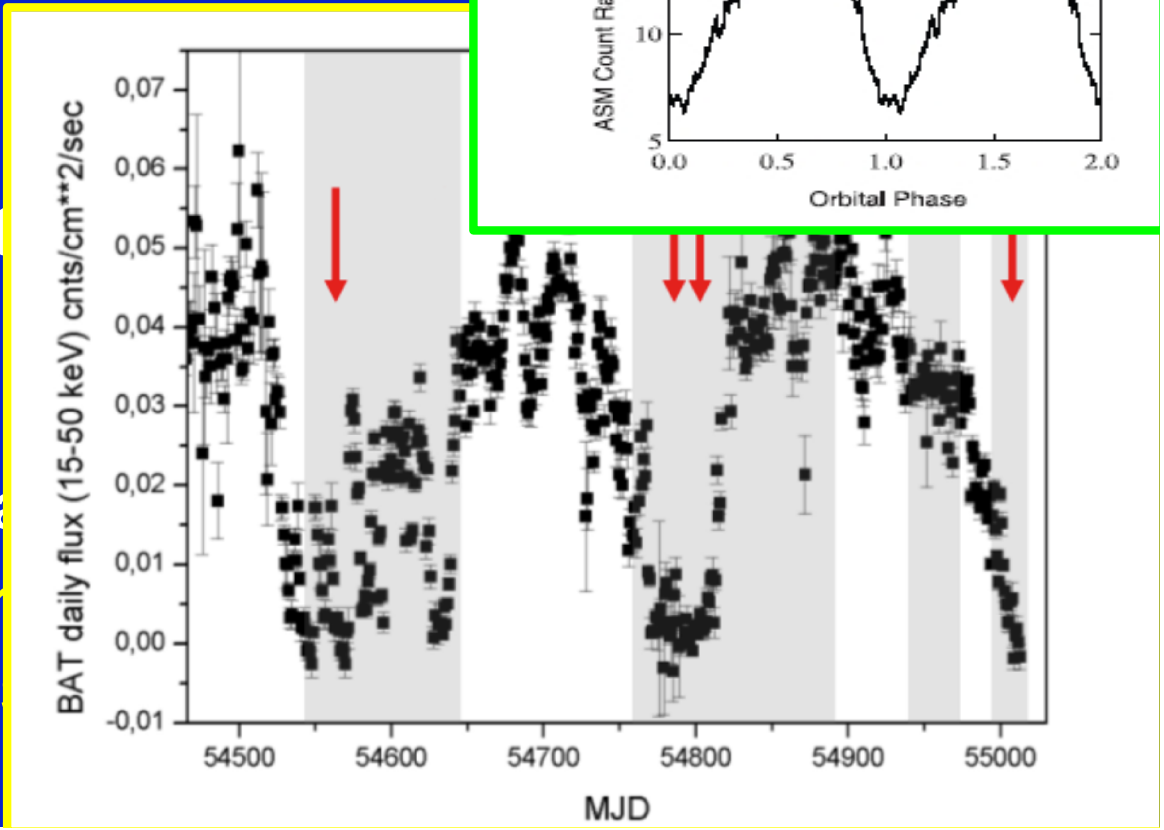
  ("*Modulated High-Energy Gamma-Ray Emission*

  - γ-ray detection of the **orbital period** microquasar

In 9 days a long-lasting mystery ha

Cygnus X-3 is able to accele energies and to emit γ-ray





Major gamma-ray flares in special transitional states in preparation of radio flares! (Tavani et al, Nature 2009)

- **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**

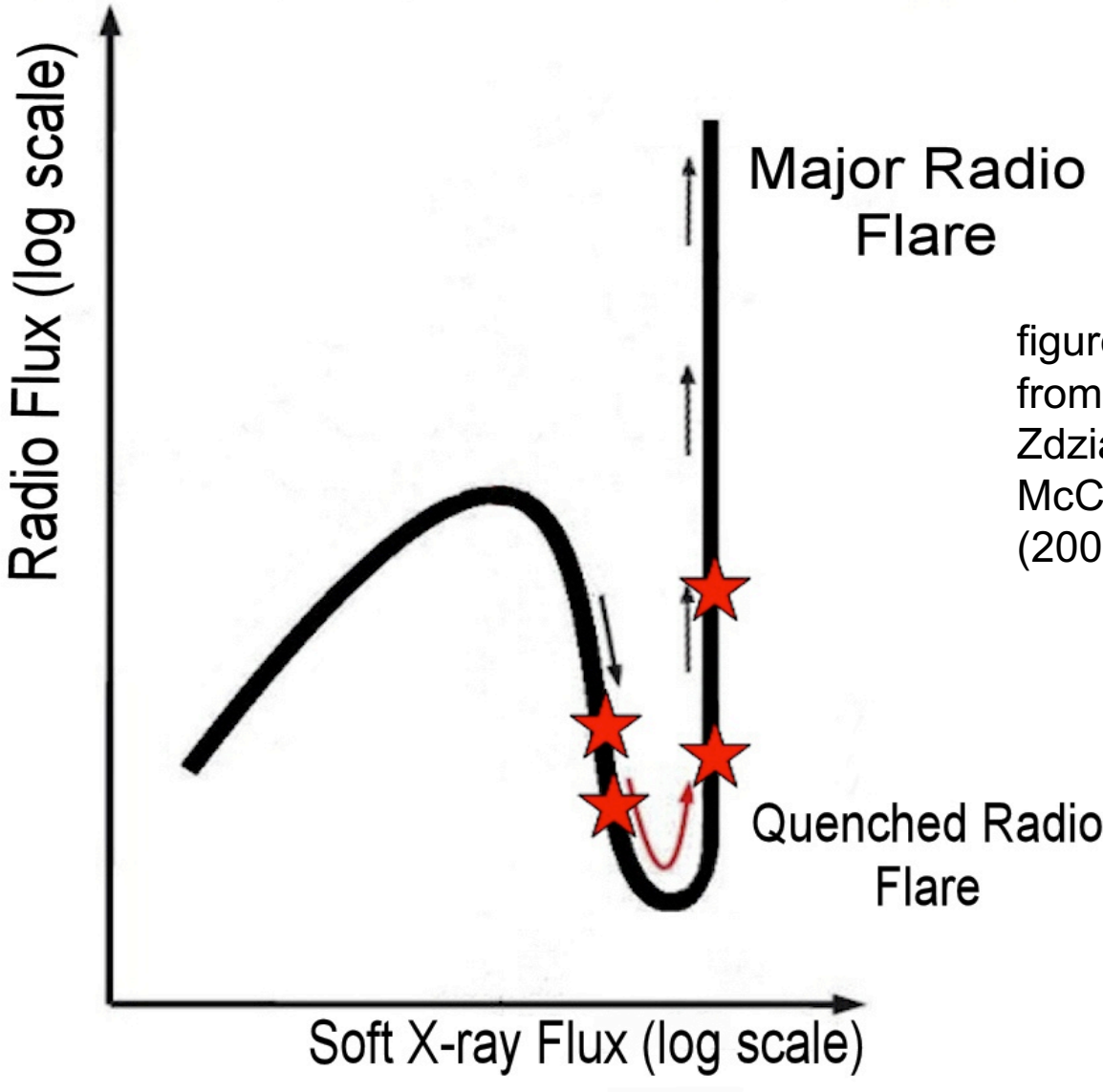


figure adapted from Szostek Zdziarski & McCollough (2008)

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 (latest gamma-ray flares in March - April 2017)

- Emission must be produced not to far away from the central object (4,8 hours orbital modulation revealed by Fermi!)

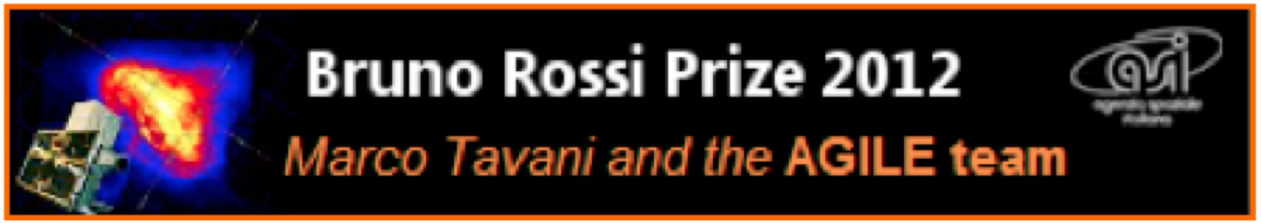
- Cyg X-3 is capable of accelerating particles by a very efficient mechanism leading to photon emission at energies thousands of times larger than the max energy previously detected (E ~ 300 keV)

- Comptonization models (thermal and non-thermal) that reproduce the spectral states up to 300 keV must take into account the recent data above 100 MeV

MOST UNEXPECTED DISCOVERY FROM THE γ-RAY SKY:

AGILE DISCOVERY OF THE CRAB NEBULA VARIABILITY IN γ-RAYS

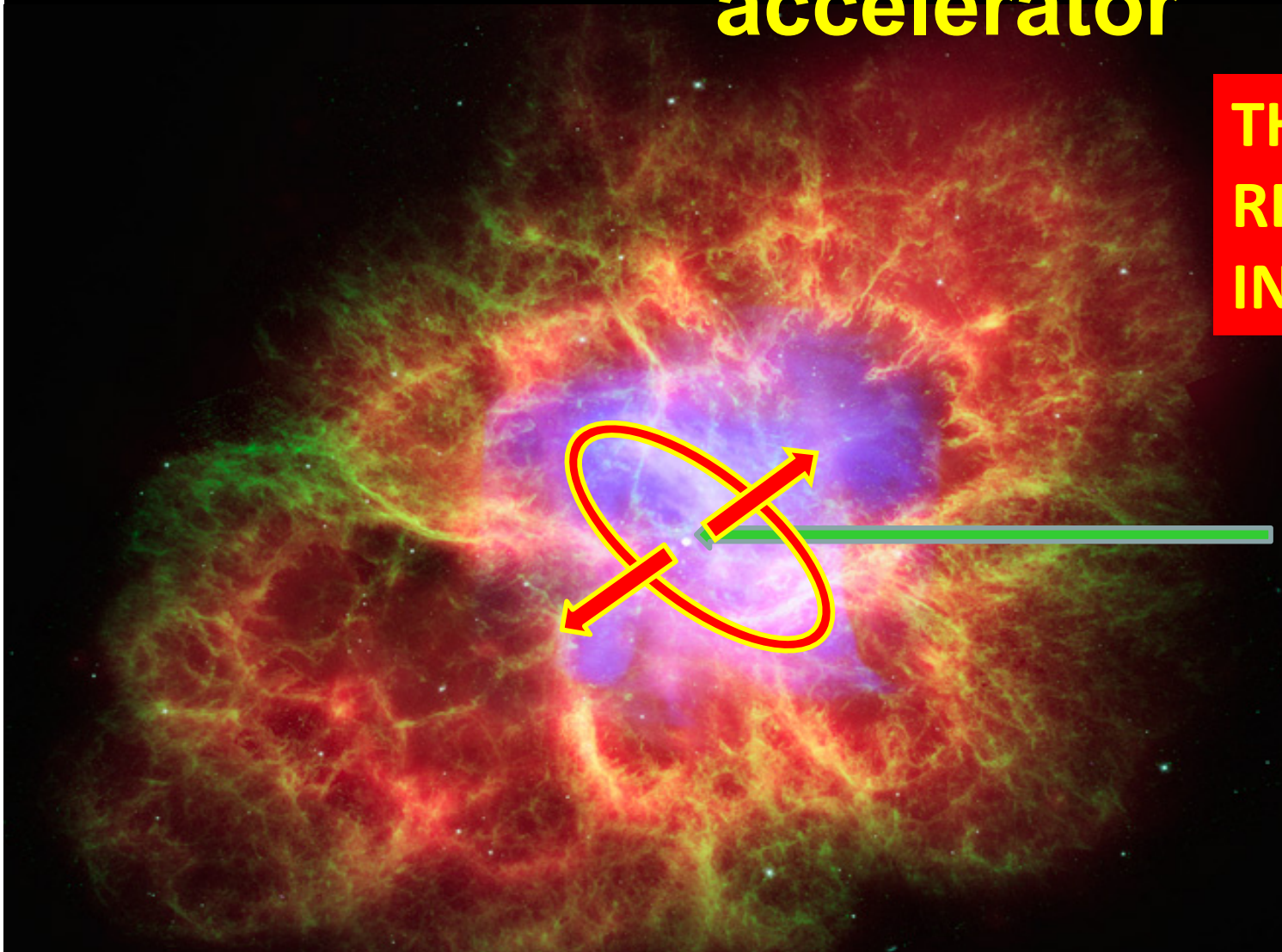
Tavan



Fermi confirmation:

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

The Crab Nebula: a spectacular cosmic accelerator



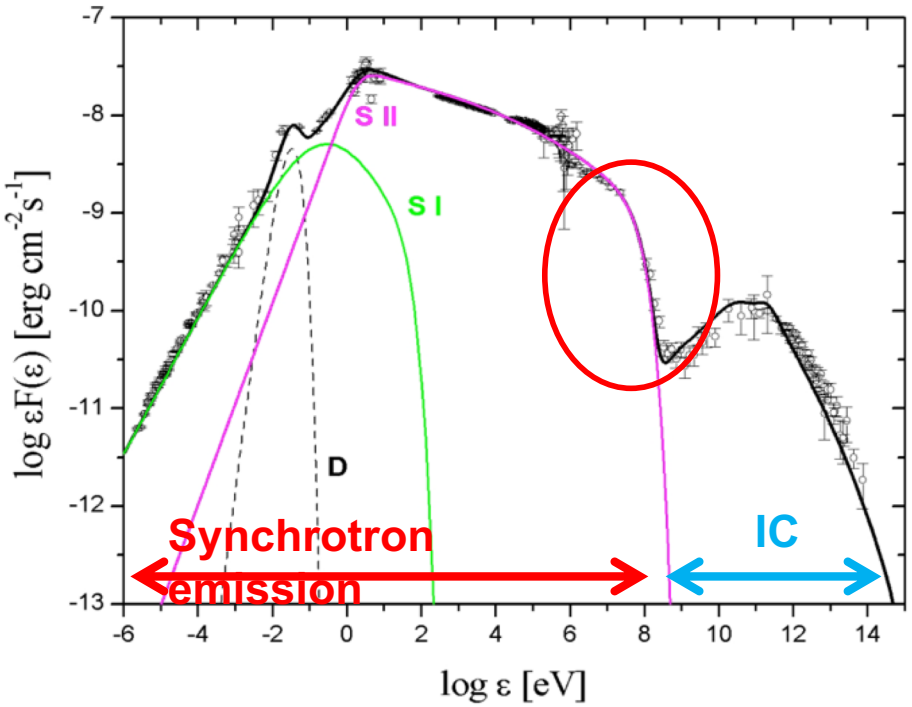
THE STANDARD REFERENCE SOURCE IN ASTROPHYSICS

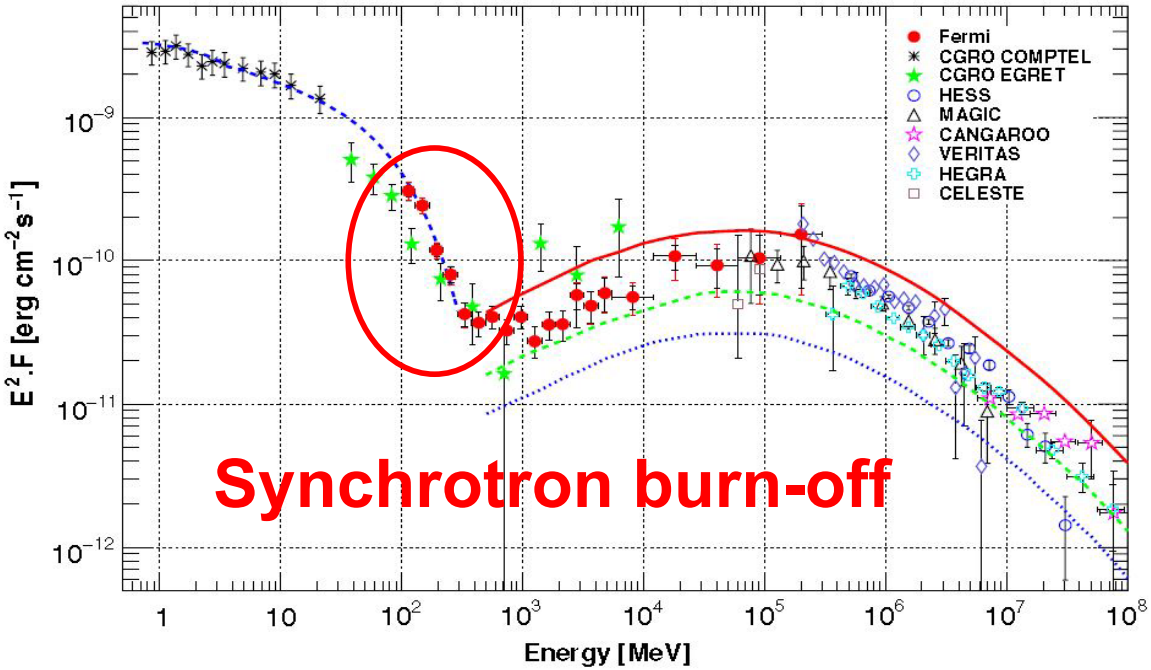
POWERFUL PULSAR (Neutron Star rotating 30 times a sec)

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 from radio to TeV





Diffusive acceleration

$E_{\gamma,max} \approx 25$ MeV

Linear accelerator in ideal MHD framework

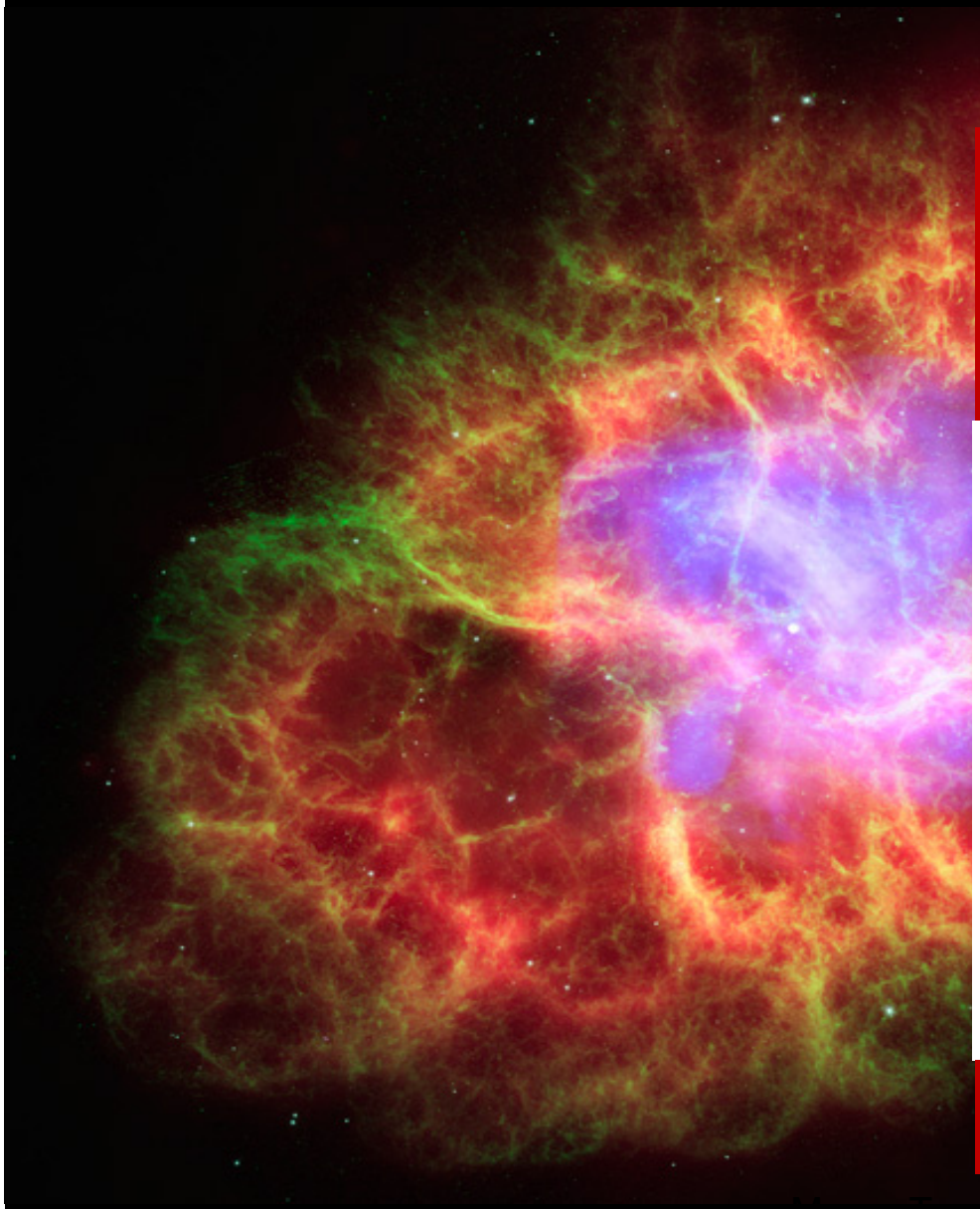
$E_{\gamma,max} = 9/4\ mc^2/\alpha$ **E/B** ≈ 150 MeV **E/B**

Synchrotron burn-off (E/B<1)

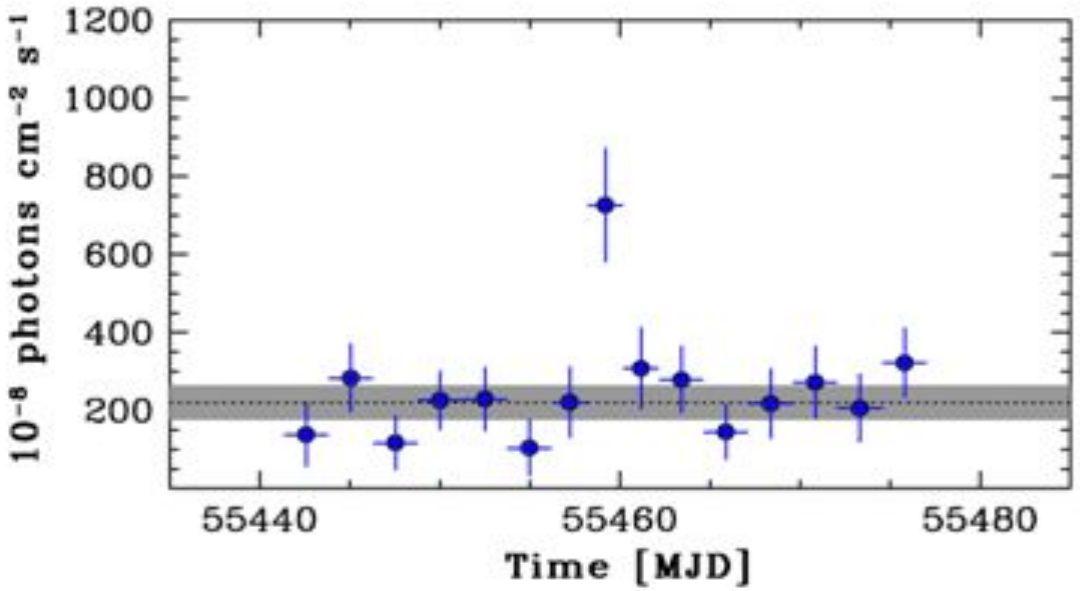
(De Jager et al. 92, Arons 2012)

(Slide adapted from E. Striani, PhD Thesis)

The variable Crab Nebula!



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



Science Express **(6 January 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 ← 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)**

- **Crab Nebula *shocks* able to accelerate electrons/positrons at $\gamma \sim 10^9$ (PeV) !?**

- **Variability never observed before within a 1-day timescale**

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*
April 2011	~ 2 days	~ $30 \cdot 10^{-6}$ ph cm^{-2} s^{-1}	*Fermi*, AGILE

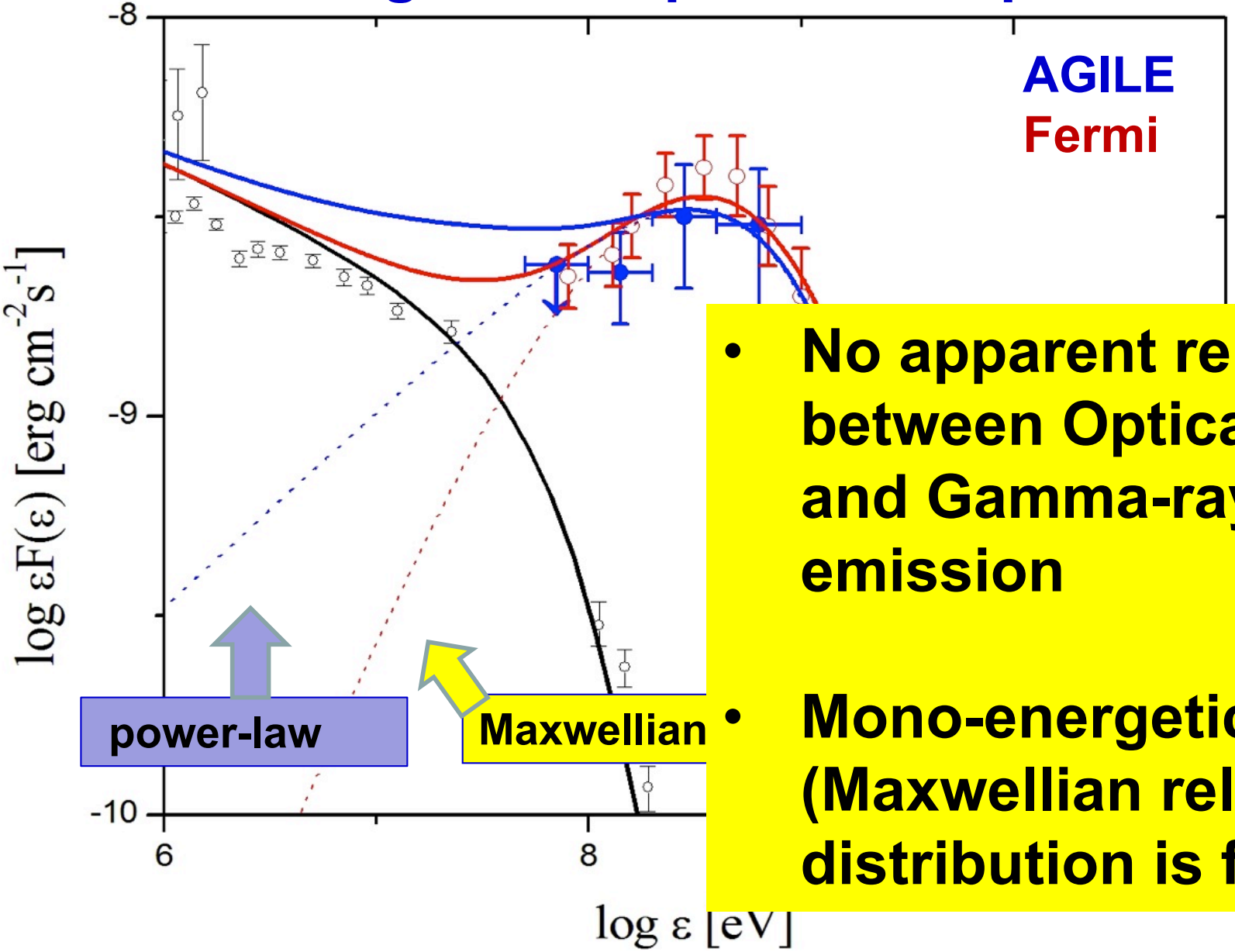
Other γ-ray flaring states seen by Fermi and AGILE:

Mar and Oct 2013, Aug 2014, Oct 2016... **Rate: ≈1/year**

Big theoretical challenge:

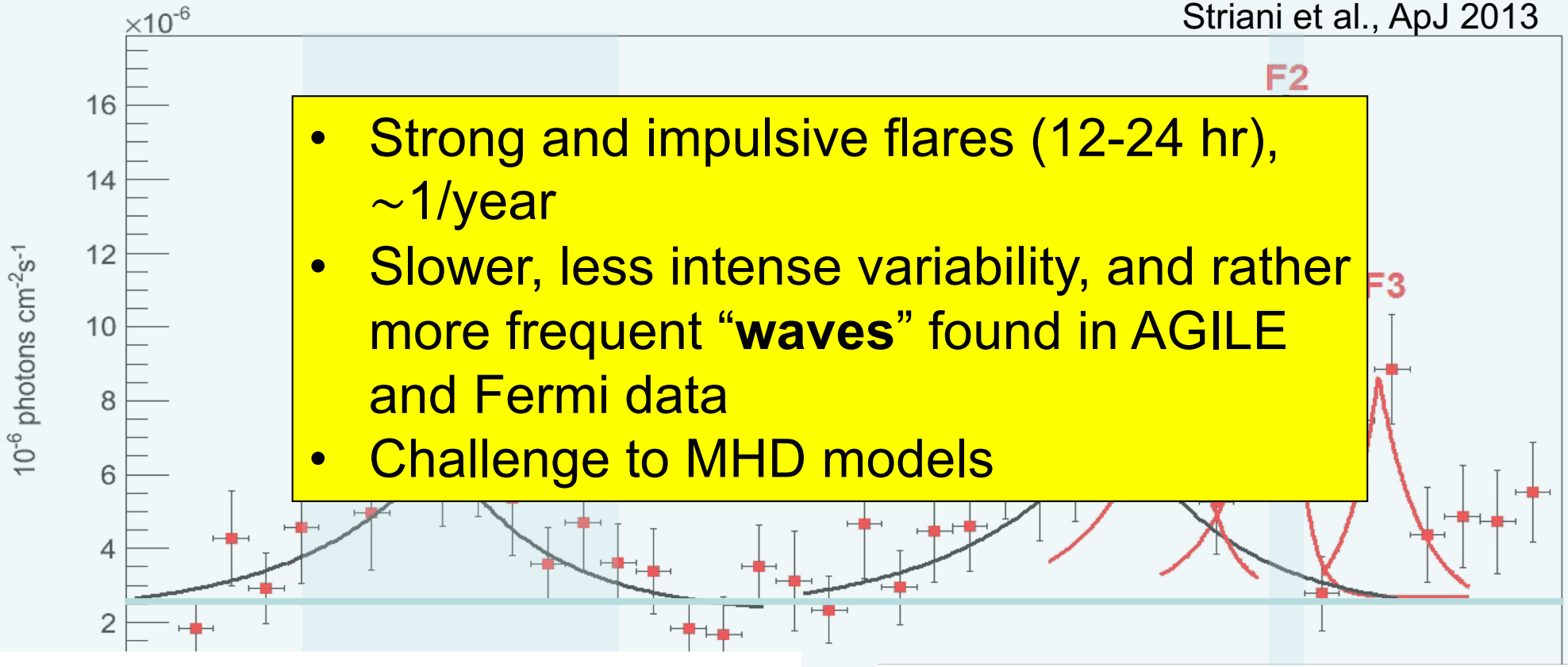
the Crab Nebula is not a standard candle in gamma-rays!

Modelling of the April 2011 super-flare

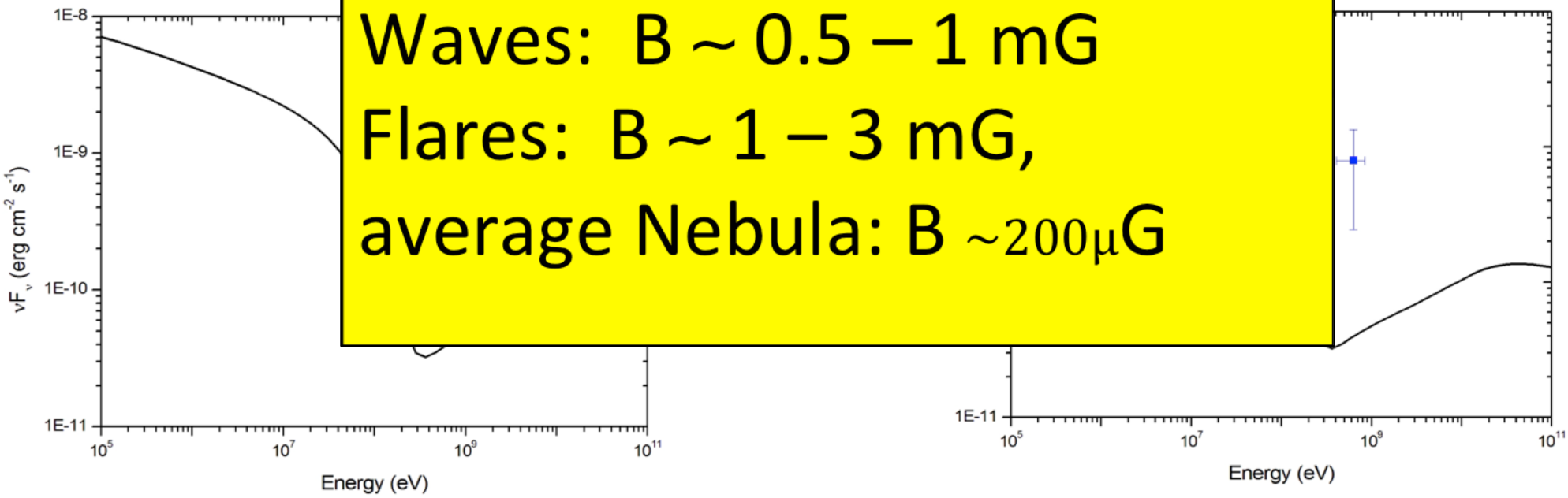


- **No apparent relation between Optical, X-ray and Gamma-ray flaring emission**
- **Mono-energetic (Maxwellian relativistic) distribution is favored**

Striani et al., ApJ 2013



- Strong and impulsive flares (12-24 hr), ~1/year
- Slower, less intense variability, and rather more frequent "**waves**" found in AGILE and Fermi data
- Challenge to MHD models



Waves: B ~ 0.5 – 1 mG

Flares: B ~ 1 – 3 mG,

average Nebula: B ~200μG

Crab lessons:

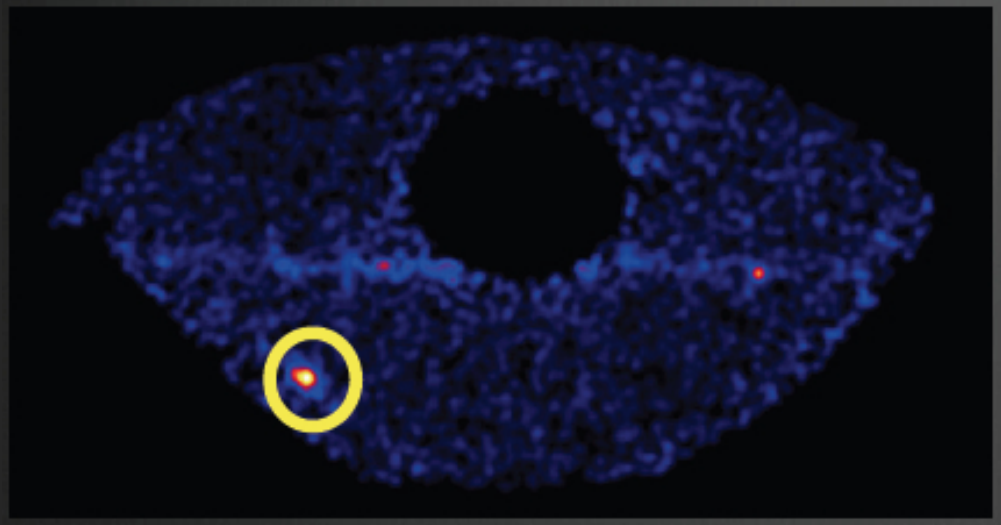
- very exciting: the Crab Nebula is not a standard candle in gamma-rays
- we “lost” the stability of an ideal reference source, but gained tremendous information about the fundamental process of particle acceleration
- a big theoretical challenge, crucial feedback with laboratory plasma physics
- the ultimate source of particle enhancements in the pulsar wind needs to be established: future surprises

Gamma-ray flaring blazars: 3C 454.3, 3C 279

- Ratios between optical and γ-rays variation factors may be > 2 or more. Compton dominance varies
- Gamma-ray only "orphan" flares. The Compton dominance attains values of 100 or more.
- Very fast variability: γ-flux shows doubling times of few minutes
- High energy spectrum can be unusually hard

3C 454.3
The monster flare in 2010

16-19 Nov 2010→ 10σ in 5,8 days



Most intense gamma-ray source ever detected: 3C 454.3

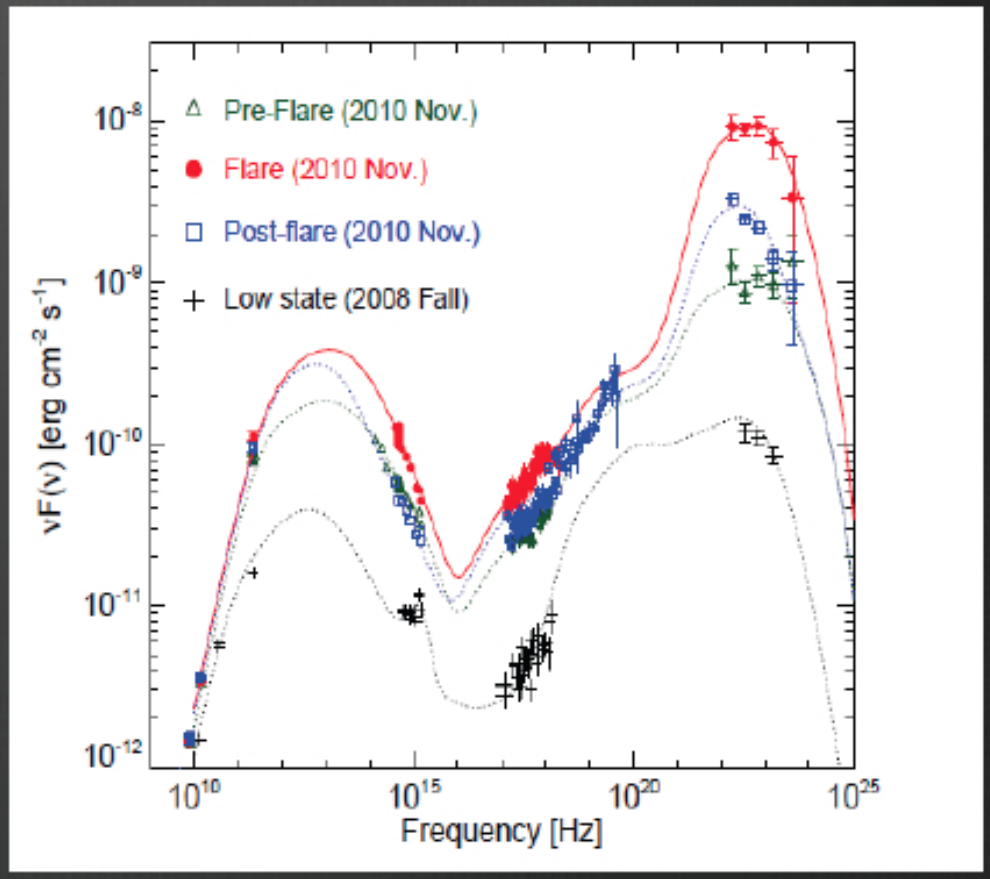
z=0.859,

$F_\gamma > 8000\ 10^{-8}$ ph. cm^{-2} s^{-1},

$L_{iso} = 2 \times 10^{50}$ erg s^{-1},

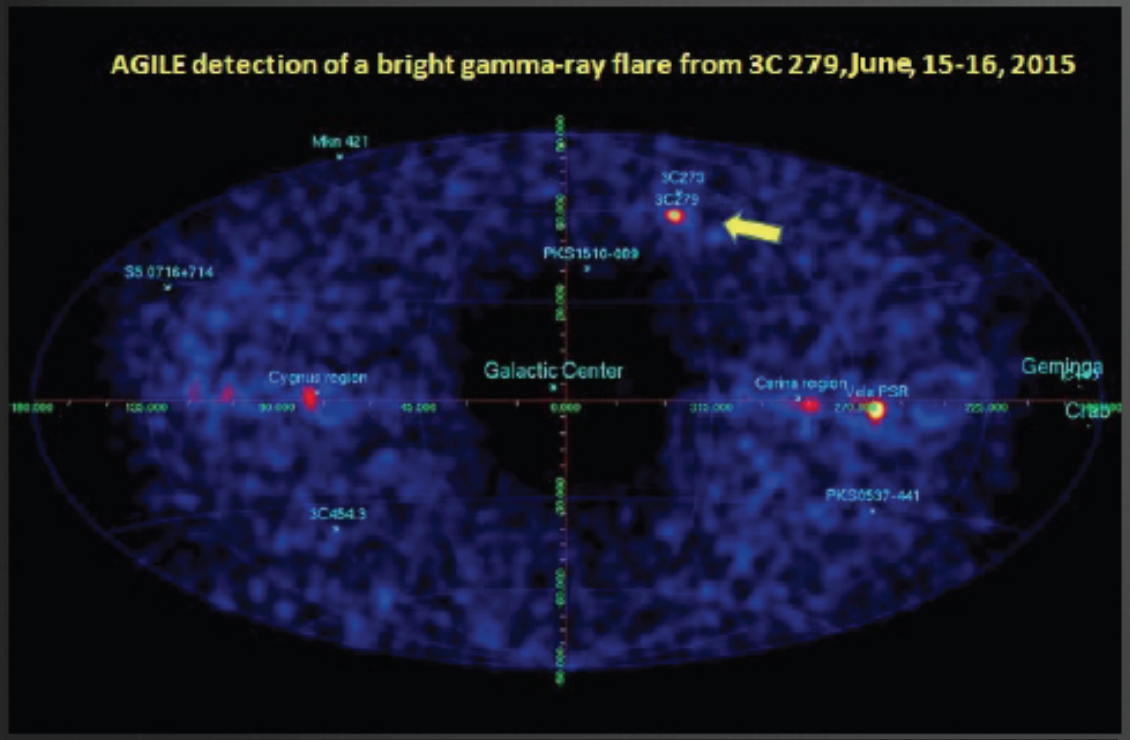
for $\delta = 10$, $L_{jet} \approx 1$ Earth/sec)

Superflare may require two electron populations (see Pacciani et al., 2010)

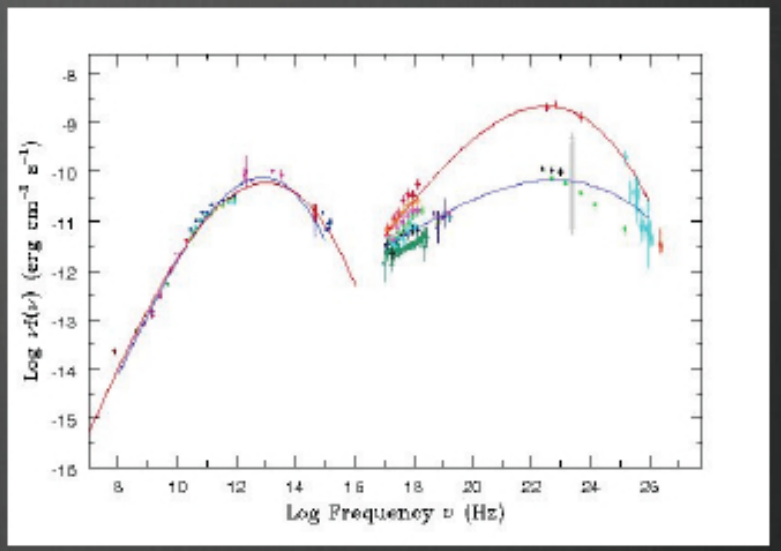


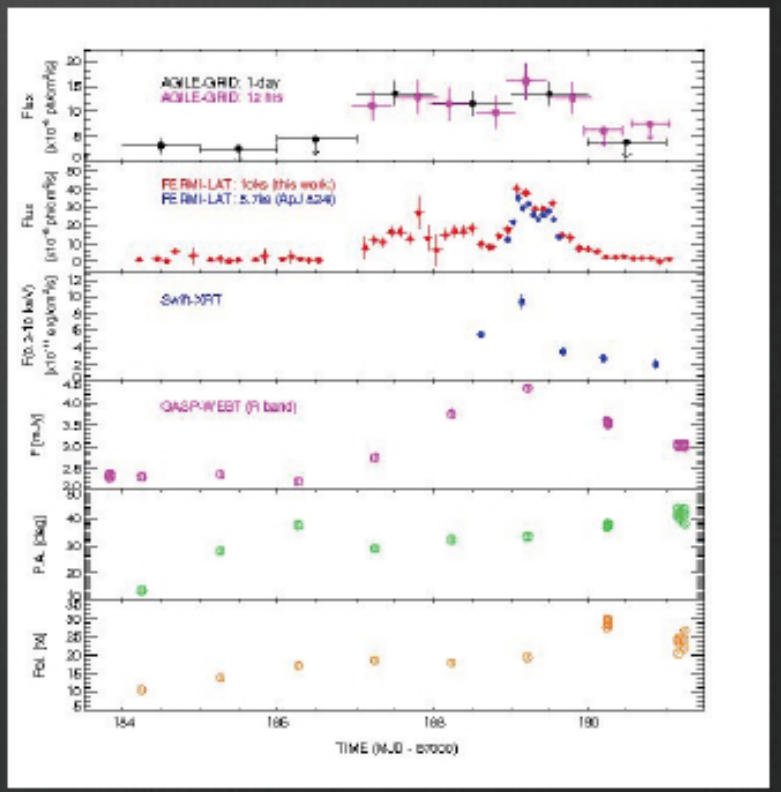
Vercellone et al., 2010, 2011

3C 279
The monster flare in June 2015



Pittori et al., ApJ 856 (2018)





z=0.536,

$F_\gamma > 3000\ 10^{-8}$ ph. cm^{-2} s^{-1},

γ-ray emitting region at the outer edge of the broad line region or farther out from it

Minute timescale observed by Fermi

Many challenges for theory

All the phenomenology challenges the standard models

- Where … e nature of seed …
- How … Sync emissi…
- What is the dominant particle acceleration mechanisms to simultaneously account for far emitting regions and rapid variability (even minute timescale)?

Variations required in the external photon field seen by the moving blobs:
mirrowing effect between plasmoids?
(See Vittorini et al., ApJL 2017)

Lessons learned from the CRAB flare discovery

Adapted from Donnarumma

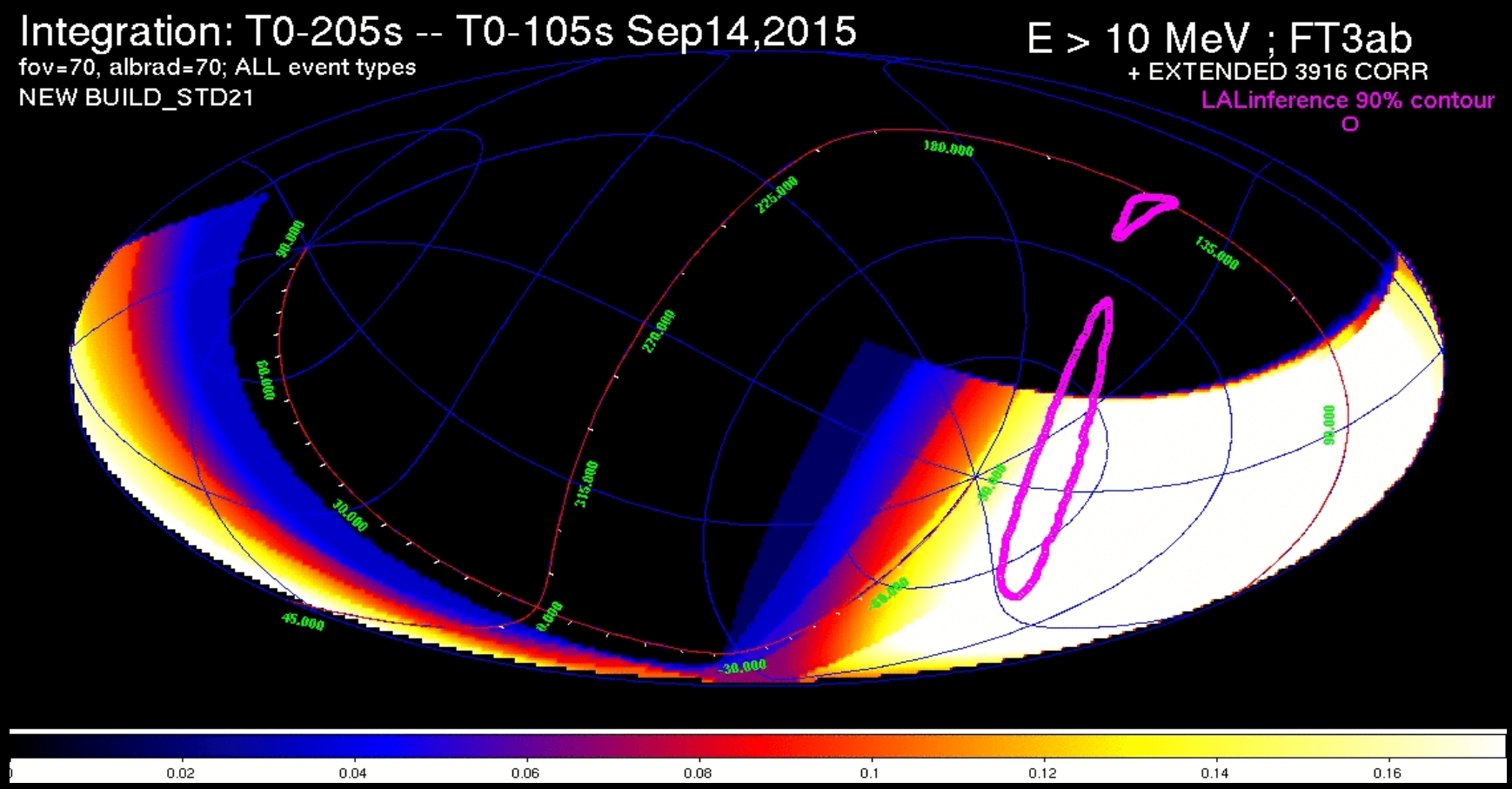
AGILE and GW astrophysics

- very fast reaction to external GW trigger
- new processing pipelines
- great potential for fast discovery of gamma-ray transients associated with NS-NS, NS-BH and BH-BH (if any) coalescences
- AGILE GW-Team monitoring shifts (24/7) during the O2 GW LIGO-Virgo observing run.

First gravitational wave event: GW150914

- T_0 = 9:50:45 UT, 14 September, 2015
- Announced by LIGO/Virgo on Feb. 11, 2016
- We learned about the event on Feb. 11, 2016 (no MoU active yet): archival search
- AGILE publication on the first GW event: Tavani et al., ApJ. 825, L4 (2016)

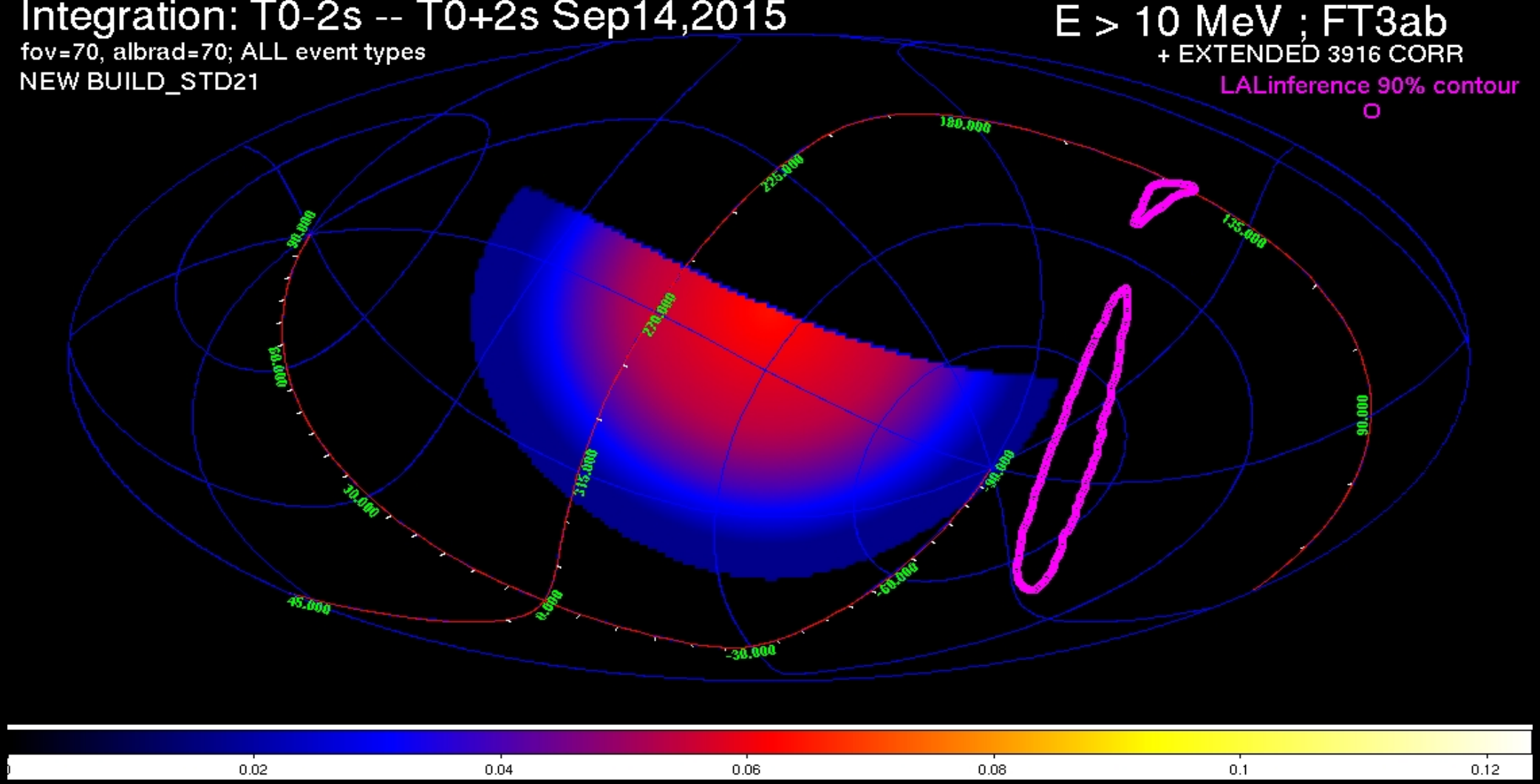
AGILE-GRID in spinning: revolution including T_0 of GW150914



Adapted from F. Verrecchia

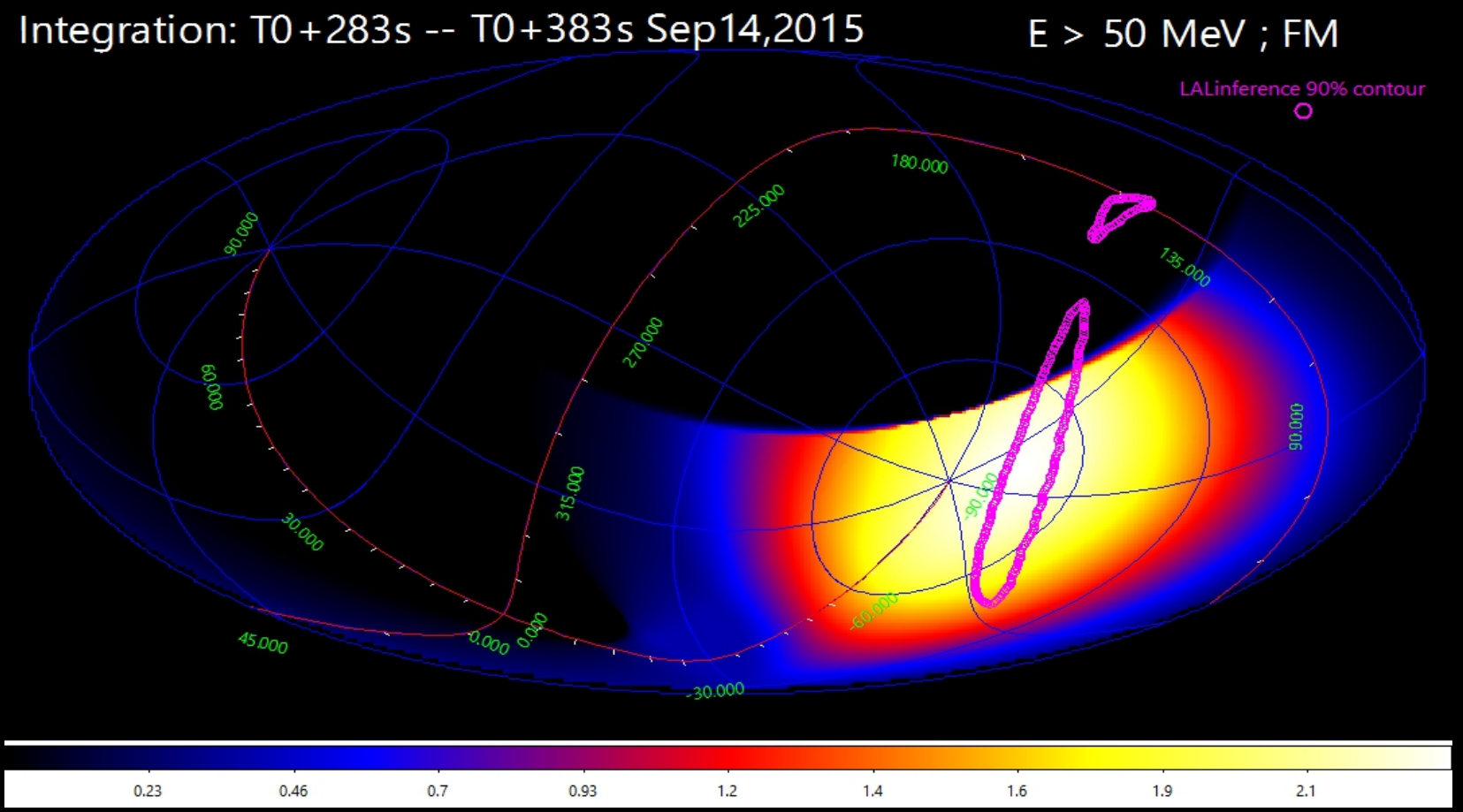
AGILE field at T_0 = 09:50:45 UT

AGILE just missed the T0 !



but only ~300 sec later…

AGILE exposure 330 sec (+/- 50 sec)



The “short” GRB 090510 lightcurve used as a possible HE template counterpart of the GW event

AGILE and the “short” GRB 090510

”AGILE DETECTION OF DELAYED GAMMA-RAY EMISSION FROM THE SHORT GAMMA-RAY BURST GRB 090510”

A. Giuliani et al., ApJL 708, 2010

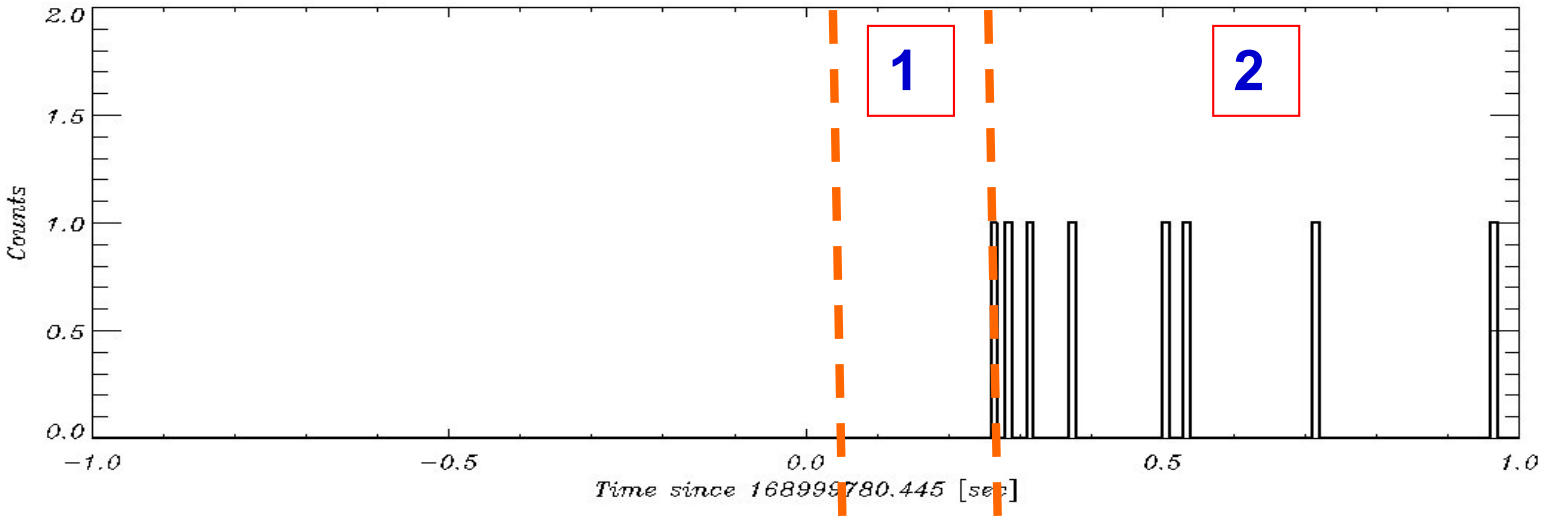
z = 0.9

AGILE and the short GRB 090510

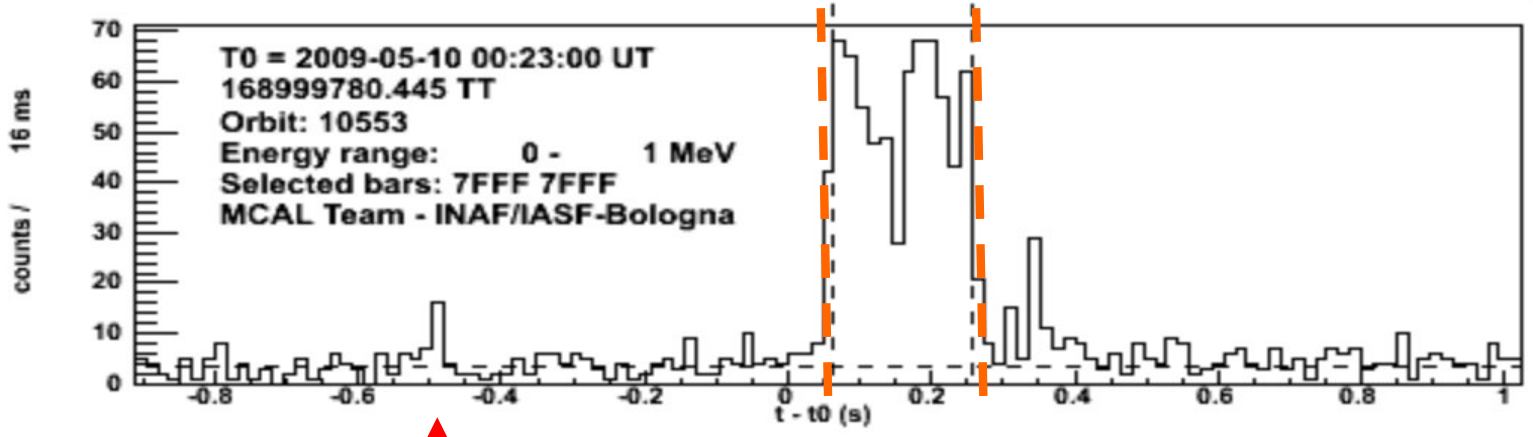
(61 degrees off-axis)

Delayed HE emission

GRID counts



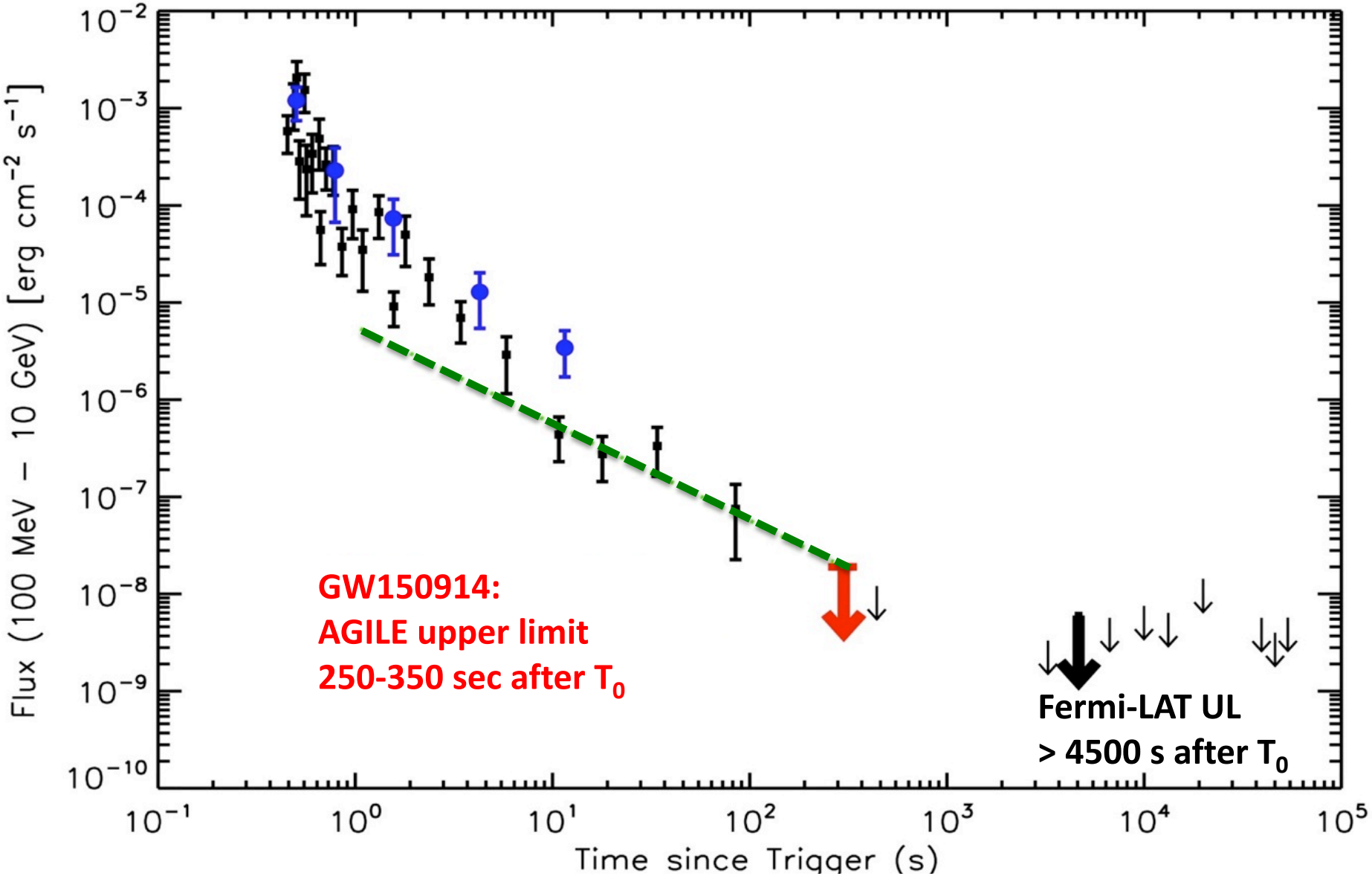
MCAL counts



MCAL precursor < 1 MeV

AGILE and Fermi-LAT upper limits in the GRB 090510 light curve as a template for GW events scaled at z = 0.1 (adapted from Fermi-LAT Collab., 2016)

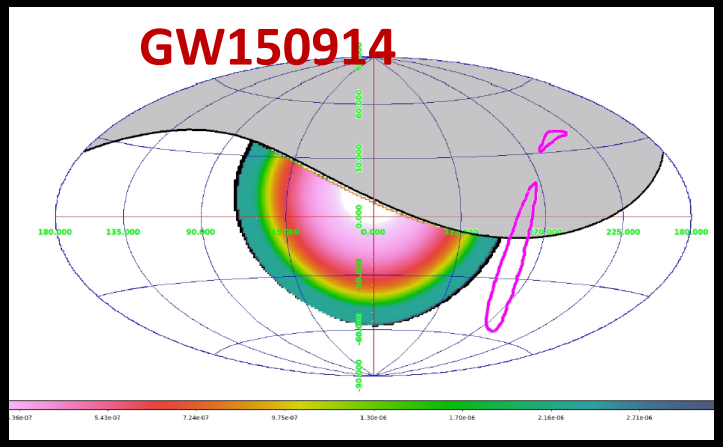
AGILE-GRID: blu, Fermi/LAT: black, **AGILE-GRID UL: red** , AGILE UL extrapolation back to 1 s: green

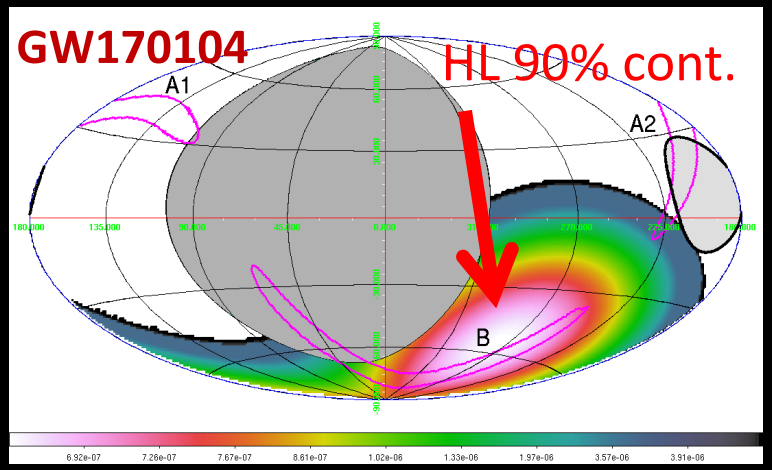


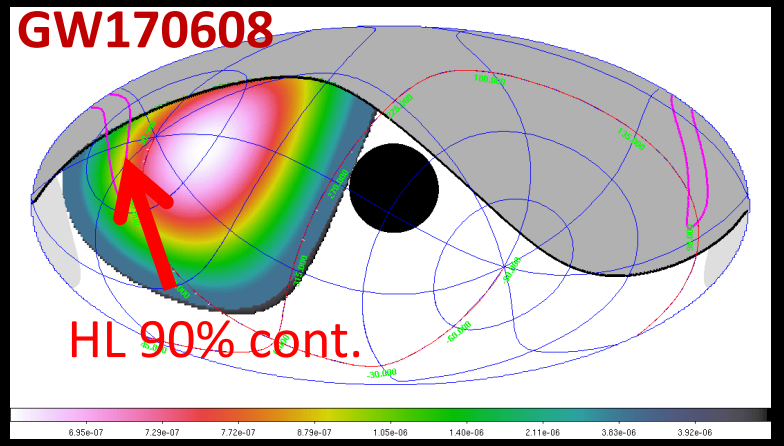
2016-2017:

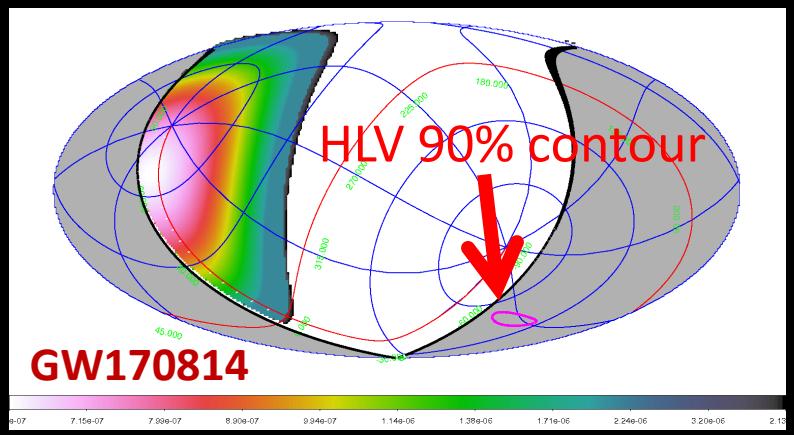
- AGILE in the MoU since Nov 2016 promptly reacted to GW candidate events communicated by LIGO-Virgo
- Several AGILE internal LVC-GCN Circulars were issued with reaction time of 2-3 hrs (including manual refined validation)
- 1 possible AGILE-MCAL gamma-ray transient candidate found as counterpart of GW170104 (Verrecchia et al., ApJL 847, 2017)
- AGILE and GW170817: first γ-ray instrument with exposure on the localization region starting at ~ T_0 + 930s (Verrecchia et al., ApJL 850,2017)
- AGILE observations provided the fastest response and the most significant upper limits above 100 MeV to all GW events detected up to now!!

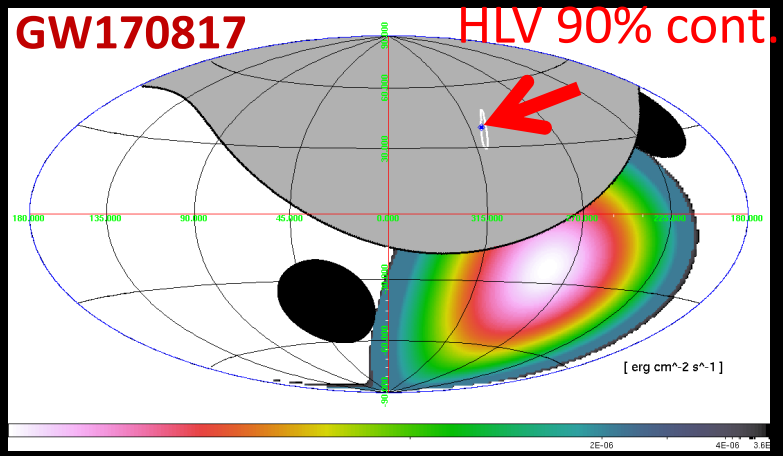
AGILE prompt maps of main GW events (at T0):





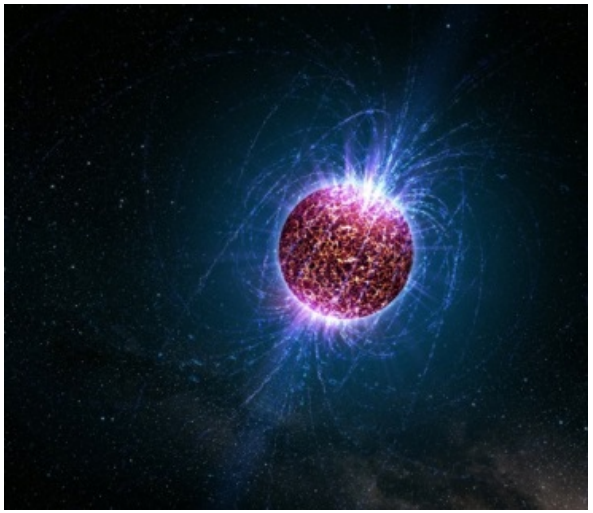






AGILE limits on magnetar emission:

AGILE set important constraints in the early phases to exclude a highly magnetized magnetar for the remnant of GW170817- GRB170817A



Future GW hunt:

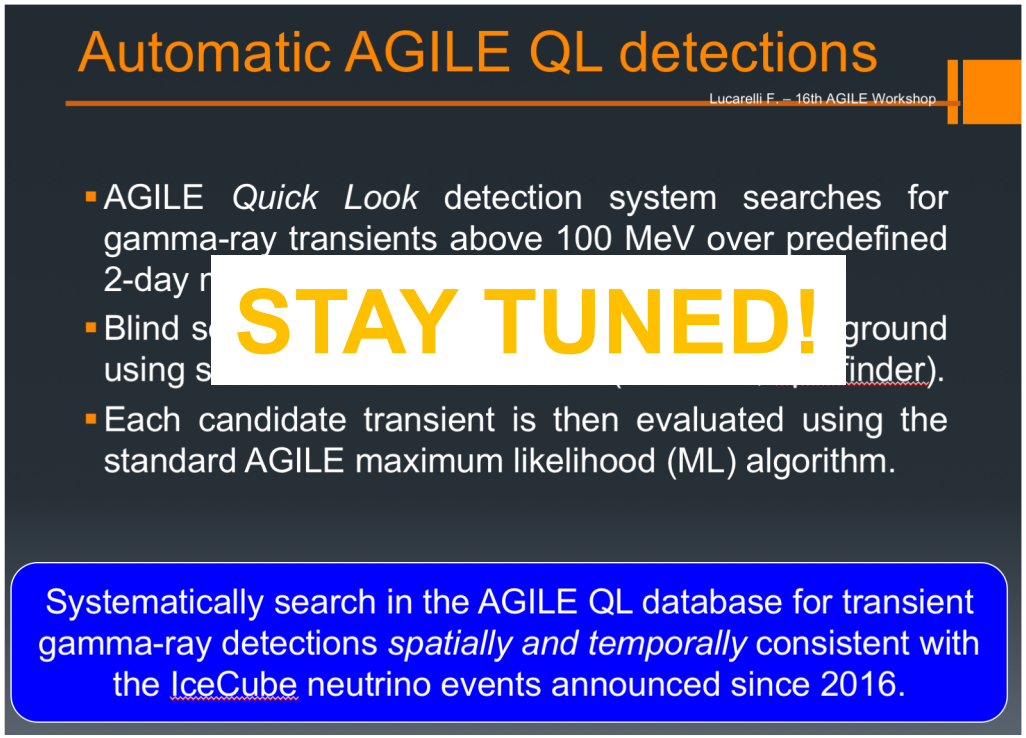
- **AGILE fast and unique hard X/γ-ray coverage**
- **Improved performance with NEW MCAL pipeline developed for "sub-threshold events" btw 4 ÷ 5 sigma pre-trial significance**
- **Alerts will be issued to LVC for AGILE-detected events (new channel)**
- **Can play an important role in the new Astronomy of gravitational waves. Waiting for Ligo-Virgo O3 run!**

Last (but not least): AGILE and neutrinos

- **AGILE and IC-160731**: Gamma-ray emission announced by AGILE in ATel. #9265 and further investigated in **ApJ 846 (Lucarelli et al. 2017)**.

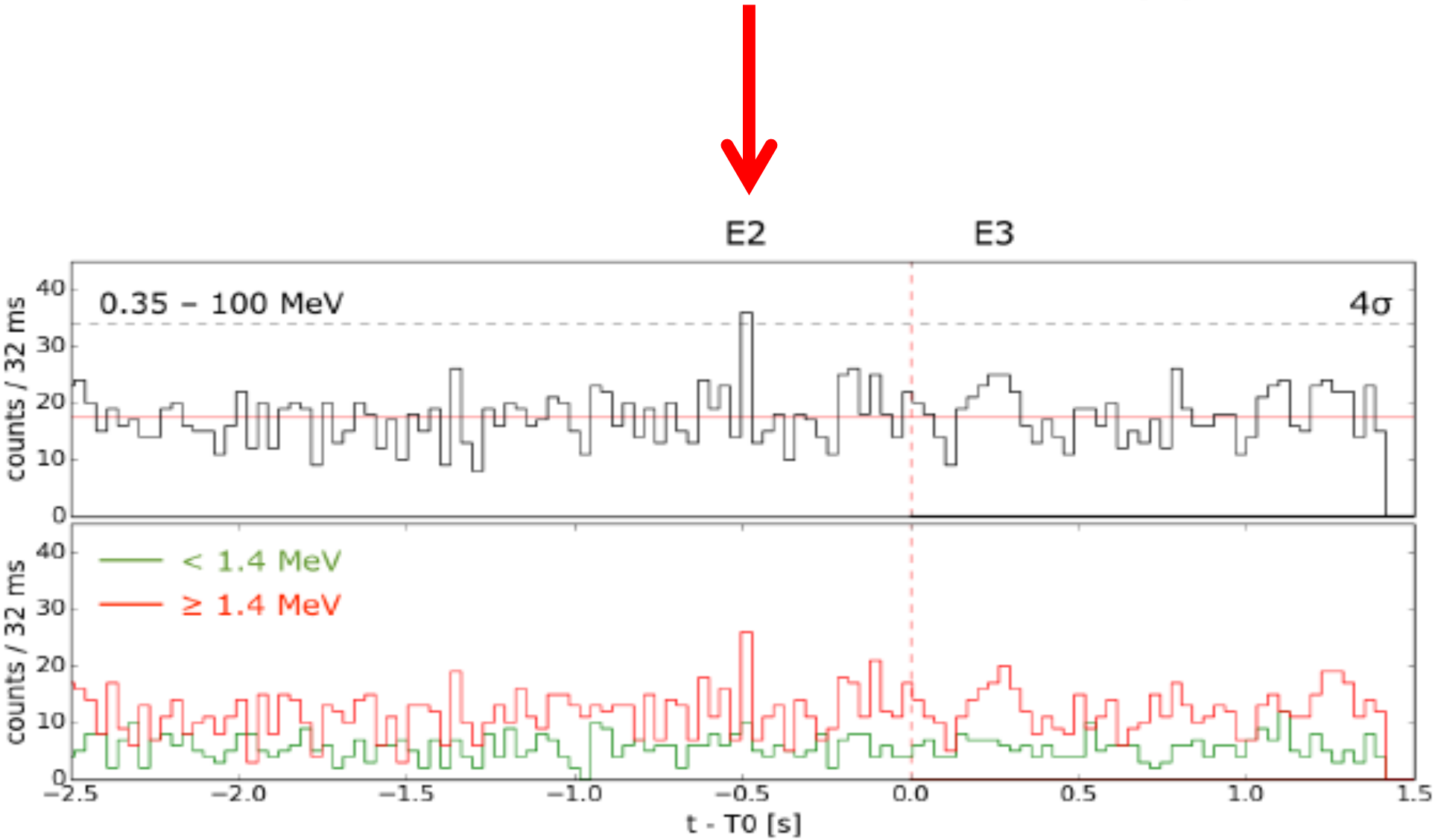
- **AGILE and IC-170922**: Gamma-ray emission observed by Fermi-LAT (ATel. #10791) from the direction of the BL Lac blazar TXS 0506+056. Confirmed by AGILE in ATel. #10801 (to be published).

- In progress:



THANK YOU!

an MCAL candidate event (!)



- MCAL candidate event E2 occurring 0.46 sec before the final BH-BH coalescence time.
- E2 very similar in timing and intensity to the 2009 precursor of GRB 090510
- E2 post-trial probability between 2.5 and 3 sigma (low signif., but similar to other claims)
- NEW MCAL pipeline developed for “sub-threshold events” (STE) btw 4 ÷ 5 sigma pre-trial
- Waiting for Ligo-Virgo O3 run!

The 3 results for which AGILE will be remembered:

- **Discovery of transient gamma-ray emission above 100 MeV from Cygnus X-3 microquasar in correlation with a repetitive pattern of multiwavelength (radio and X-ray) emission**

- **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 Supernova Remnants with the AGILE observations of the SNR W44**
  (2017 Matteucci Medal of the National Academy of Sciences to M. Tavani)