AGILE highlights in gamma-ray astrophysics

#### Giovanni Piano

(INAF-IAPS Roma) on behalf of the AGILE Team

#### "RICAP-14"

September 30<sup>th</sup> – October 3<sup>rd</sup> 2014 Noto (SR)

Giovanni Piano

# The AGILE Satellite

- Italian Space Agency (ASI: *Agenzia Spaziale Italiana*)
- Launch: April 23, 2007. PSLV-C8 rocket. Sriharikota, India.
- Low Earth Orbit (altitude ~ 550 km, inclination =  $2.5^{\circ}$ )
- more than ~38000 orbits around the Earth
  - > Until October 2009 → "Pointing mode" data-taking
  - > From November 2009  $\rightarrow$  "Spinning mode" data-taking (full scanning)

# The AGILE Payload

#### Anticoincidence Shield (AC) Plastic scintillator + photomultipliers

#### SuperAGILE (SA)

Silicon strips detector + coded-mask Energy range: 18 – 60 keV



Silicon Tracker (ST) → (AGILE-GRID) 12 trays of tungsten / silicon strips Energy range: 30 MeV – 30 GeV

MiniCALorimeter (MCAL) CsI(TI) bars with photodiodes Energy range: 0.3 – 100 MeV

Volume : ~ 0.25 m<sup>3</sup> Power Consumption : ~ 60 W Mass : ~ 100 Kg

The most compact instrument for high-energy astrophysics

### AGILE-GRID: Excellent performance @ 100 MeV



Pass 7

Front LAT evt class = 4(ultraclean)

### AGILE-GRID: Excellent performance @ 100 MeV



5

#### 1-day AGILE Pointing map



**Fig. 25.** The AGILE-GRID 1-day gamma-ray counts map for photons above 100 MeV obtained on 2007 September 28. The unprecedently large FOV includes for the first time in a single map all three of the most important gamma-ray pulsars: Vela, Crab, and Geminga.

180,000

# Pointing mode (2007-2009 Oct)

#### 2-day AGILE Spinning map



Spinning mode (2009 Nov → now)



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



Record for a gamma-ray mission!

# OUTLINE → AGILE Highlights

#### **Galactic sources**

- Variability of the Crab nebula
- SNRs  $\rightarrow$  W44: direct evidence of CR acceleration
- γ-ray emitting microquasars in the Cygnus region
- Galactic  $\gamma$ -ray transients possibly associated with HMXBs

#### **Extragalactic sources**

• Most luminous  $\gamma$ -ray Blazar  $\rightarrow$  3C 454.3

## AGILE

#### (Astrorivelatore Gamma a Immagini LEggero)



### HST optical image of our galaxy

### AGILE

#### (Astrorivelatore Gamma a Immagini LEggero)



### AGILE $\gamma$ -ray image of our galaxy (E > 100 MeV)

Pointing mode: July 2007 – July 2009

# AGILE and the Crab Nebula



# AGILE and the Crab Nebula



# AGILE and the Crab Nebula

Science Express (6 January 2011)

#### FIRST PUBLIC ANNOUNCEMENT Sept. 22, 2010: AGILE issues the Astronomer's Telegram #2855 announcing a gamma-ray flare from the Crab Nebula





Bruno Rossi Prize from HEAD-AAS in 2012



(Tavani et al., 2011) (Striani et al., 2011) (Striani et al., 2013)





Flare date	Duration	Peak γ-ray flux	Instruments
October 2007	~ 15 days	~ 9 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	AGILE
February 2009	~ 15 days	~ 4 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	<i>Fermi</i> -LAT
September 2010	~ 4 days	~ 7 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	AGILE, <i>Fermi</i> -LAT
April 2011	~ 10 days	~ 22 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	AGILE, <i>Fermi</i> -LAT
March 2013	~ 20 days	~ 11 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	AGILE, <i>Fermi</i> -LAT
October 2013	~ 7 days	~ 12 ·10 <sup>-6</sup> ph cm <sup>-2</sup> s <sup>-1</sup>	<i>Fermi</i> -LAT
16  14	March 2013		er 2013
	06 Mar		+ 17 Oct

(Tavani et al., 2011) (Striani et al., 2011) (Striani et al., 2013) 10<sup>-6</sup> photons cm<sup>-2</sup>s<sup>-1</sup>

10 8 6

4

2

Fermi-LAT



16

### AGILE and the Crab Nebula γ-ray monitoring: April 2011



### AGILE and the Crab Nebula The Crab Nebula steady spectrum



Linear accelerator in ideal MHD framework

 $t_{acc} = rac{\gamma}{\omega_B} rac{B}{E}$   $t_{synch} = rac{3m^3c^5}{2e^4B^2\gamma}$  $E_{\gamma,\max} = rac{9}{4} rac{\mathrm{mc}^2}{lpha} \cdot \mathrm{E/B} \simeq 150 \ \mathrm{MeV} \cdot \mathrm{E/B}$  Nebula → B = 200  $\mu$ G E/B ≤ 1 (ideal MHD)

### AGILE and the Crab Nebula The Crab Nebula γ-ray flaring spectrum



## AGILE and the Crab Nebula The Crab Nebula γ-ray flaring spectrum



[eV]

Strong and impulsive particle acceleration ( $\gamma_{peak}$ mc<sup>2</sup> ~ 10<sup>15</sup> eV)

Magnetic reconnection? But where?

# SNRs in gamma-rays



# SNRs in gamma-rays







- Strong evidence supporting the hadronic scenario (neutral pion decay)
- No data below 200 MeV ( $\rightarrow \pi^0$  "signature": fast steepening spectrum)







- A dominant leptonic contribution is excluded for W44
- Direct proof of  $\pi^0$  "bump"  $\rightarrow$  accelerated hadrons
- "Smoking gun" of CR acceleration process in a Galactic source

# **AGILE and Galactic microquasars**

AGILE-*GRID* <u>INTENSITY MAP</u> (100 MeV-10 GeV) November 2007 – July 2009, ~275 days, ~11 Ms net exposure time





Comptonization models: spectral ULs from long-term integration in the  $\gamma$ -ray energy band both for hard and soft states



### $\gamma$ -ray activity discovered in late 2009

AGILE  $\rightarrow$  (Tavani et al, *Nature*, 2009); *Fermi*-LAT  $\rightarrow$  (Abdo et al., Science, 2009)

#### 7 $\gamma$ -ray flares have been detected between November 2007 and July 2009:

- significance  $\geq 3\sigma$
- $\gamma$ -ray fluxes more than 10 times the steady flux [F<sub>steady</sub> = (14 ± 3) x 10<sup>-8</sup> ph cm<sup>-2</sup> s<sup>-1</sup>]



Multi-wavelength light curve (December 2007  $\rightarrow$  September 2009)



#### Repetitive multi-frequency emission pattern:

- STRONG ANTICORRELATION between hard X-ray and  $\gamma$ -ray emission:  $\gamma$ -ray activity associated with sharp/local minima in the hard X-ray light curve (*Swift*/BAT count rate  $\leq 0.02$  counts cm<sup>-2</sup> s<sup>-1</sup>)
- >  $\gamma$ -ray flares coincident with soft spectral states (*RXTE*/ASM count rate  $\geq$  3 counts s<sup>-1</sup>)
- >  $\gamma$ -ray flares around hard-to-soft or soft-to-hard spectral transitions
- >  $\gamma$ -ray flares a few days before major radio flares



Multi-wavelength light curve (December 2007  $\rightarrow$  September 2009)



#### Repetitive multi-frequency emission pattern:

- STRONG ANTICORRELATION between hard X-ray and  $\gamma$ -ray emission:  $\gamma$ -ray activity associated with sharp/local minima in the hard X-ray light curve (*Swift*/BAT count rate  $\leq 0.02$  counts cm<sup>-2</sup> s<sup>-1</sup>)
- >  $\gamma$ -ray flares coincident with soft spectral states (*RXTE*/ASM count rate  $\geq$  3 counts s<sup>-1</sup>)
- >  $\gamma$ -ray flares around hard-to-soft or soft-to-hard spectral transitions
- >  $\gamma$ -ray flares a few days before major radio flares



# Both leptonic and hadronic emission models can account for the $\gamma$ -ray flaring spectrum detected by AGILE



# AGILE and Galactic γ-ray transients possibly associated with binary systems

AGILE source	binary system	binary type	orbital period
AGL J1734-3310	IGR J17354-3255	SFXT (HMXB)	8.45 days (Sguera et al., 2011)
AGL J2022+3622	IGR J20188+3647	SFXT (HMXB) ?	? (ATel #1313: Sguera et al., 2006)
AGL J1037-5708	4U 1036-56	Be-NS (HMXB)	61.0 days (Cusumano et al., 2013)
AGL J2241+4454	MWC 656	Be-BH (HMXB)	60.37 days (Casares et al., 2014)



### AGILE and Galactic $\gamma$ -ray transients: AGL J1037-5708

- Transient  $\gamma$ -ray activity detected in November 2010 (ATel #3059).
- Possibly associated with a Be/NS HMXB 4U 1036-56 (Li et al., 2012)
- Ongoing analysis:
  - > several  $\gamma$ -ray events found, positionally consistent with 4U 1036-56
  - > search for periodicity of the  $\gamma$ -ray activity consistent with the orbital period (~61.0 days) detected in the X-ray band



### AGILE and Galactic $\gamma$ -ray transients: AGL J1037-5708



#### $\sqrt{TS} = 9.76$ flux = (146 ± 20) 10<sup>-8</sup> photons cm<sup>-2</sup> s<sup>-1</sup> (l, b) = (285.50, 1.30) ± 0.24° (stat) ± 0.10° (syst)

#### AGILE and Galactic $\gamma$ -ray transients: AGL J2241+4454

- Transient  $\gamma$ -ray activity detected in July 2010 (ATel #2761).
- AGILE detection → discovery of the first Be-HMXB hosting a Black Hole: MWC 656 (Casares et al., 2014 → optical data)









### AGILE and Galactic $\gamma$ -ray transients: AGL J2241+4454

#### • Ongoing analysis:

- > several  $\gamma$ -ray events found, positionally consistent with MWC 656
- > search for periodicity of the  $\gamma$ -ray activity consistent with the orbital period (60.37 days) inferred from optical data



### AGILE and Galactic $\gamma$ -ray transients: AGL J2241+4454



 $\sqrt{TS} = 8.78$ flux = (97 ± 15) 10<sup>-8</sup> photons cm<sup>-2</sup> s<sup>-1</sup> (l, b) = (100.31, -12.47) ± 0.34° (stat) ± 0.10° (syst)

### AGILE and extragalactic sources: Blazars

Name	Туре	$\begin{array}{c} \textbf{redshift} \\ (H_0=70.5; \\ \Omega_{matter}=0.27; \\ \Omega_{vacuum}=0.73) \end{array}$	main characteristics (AGILE papers)
GB6 J1239+0443	FSRQ	z = 1.759	flat $\gamma$ -ray spectrum up to ~15 GeV: no absorption from BLR (Pacciani et al., 2012)
MRK 421	BL Lac (HBL)	z = 0.030	highly variable in optical, X-ray, HE and VHE $\gamma\text{-rays}$ (Donnarumma et al., 2009)
PKS 0537-441	BL Lac (LBL)	z = 0.894	two SSC components to account for both NIR/OPT and X-ray/ $\gamma$ -ray data (Pucella et al., 2010)
PKS 1510-089	FSRQ	z = 0.360	little and big blue bumps in the SED during the $\gamma$ -ray activity (D'ammando et al., 2009, 2011)
PKS 1830-211	FSRQ	z = 2.507	gravitational lensed blazar (Donnarumma et al., 2011)
S5 0716+714	BL Lac (IBL)	z = 0.300	during the $\gamma$ -ray flare, approaching the maximum power extractable from a rotating BH of $10^9~M_\odot$ (Vittorini et al., 2009)
W Comae	BL Lac (IBL)	z = 0.102	VERITAS trigger $\rightarrow$ strong variability in X-rays, HE and VHE $\gamma$ -rays on hours/day timescale (Acciari et al., 2009)
3C 273	FSRQ	z = 0.158	anti-correlated variability between X-rays and $\gamma$ -rays $\rightarrow$ fast acceleration of emitting electrons (Pacciani et al., 2009)
3C 279	FSRQ	z = 0.536	$\gamma$ -ray flare detected two months later an optical minimum $\rightarrow$ low accretion state before the jet outburst (Giuliani et al., 2009)
3C 454.3	FSRQ	z = 0.859	the brightest γ-ray flaring blazar in the sky (Vercellone et al., 2008, 2009, 2010, 2011) (Striani et al., 2010)
4C +21.35	FSRQ	z = 0.432	(ATel #2348, #2641, #2686)
4C +38.41	FSRQ	z = 1.813	(ATel #5234)

#### AGILE and extragalactic sources: 3C 454.3

#### November 2010

- November 17, 2010:
  fast rising (12h) in the γ-ray lightcurve
- November 20, 2010 (MJD: 55520): giant  $\gamma$ -ray flare  $F_{\gamma} \sim 7000 \ 10^{-8}$  photons cm<sup>-2</sup> s<sup>-1</sup>,  $L_{iso} = 2 \ 10^{50}$  erg s<sup>-1</sup> (the most luminous source in the  $\gamma$ -ray sky,
- ~ 8 times the Vela PSR)







#### AGILE and extragalactic sources: 3C 454.3

May – June 2014

• Recent strong  $\gamma$ -ray activity: three AGILE ATels (#6182, #6217, #6234)



agile.asdc.asi.it

The public AGILE archive now contains all data from Dec 2007 up to Nov 2012 (from Cycle 1 to Cycle 5)



Giovanni Piano