Supergiant Fast X-ray transients as best candidate counterparts of unidentified transient γ-ray sources

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In collaboration with:

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Bulgarelli A. and the AGILE team

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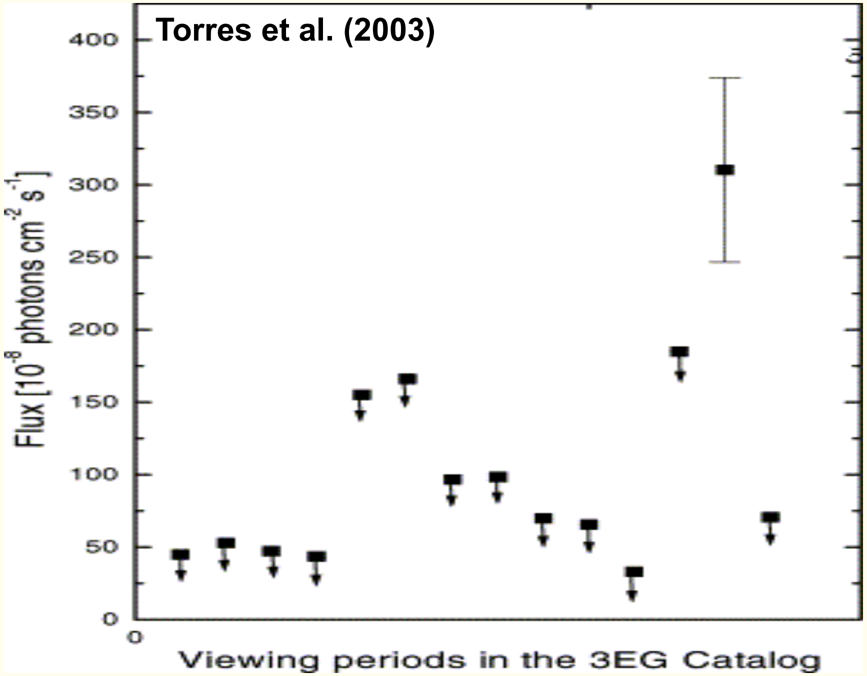
3EG J1837-0423: the EGRET legacy on galactic transients



Tavani et al. 1997

- **detected only once (~6σ) and never again, bright γ-ray flare (4×10^{-6} ph cm^{-2} s^{-1}) lasting only ~ 3.5 days**
- **no blazar-like counterpart** inside the 99% error circle

3EG J1837-0423 as best prototype for a new class of galactic fast gamma-ray transients

very unique case → not a big surprise because the EGRET pointing strategy was not particularly suited to detect short events on the plane

3EG J1837-0423 is not alone anymore

emerging new population of galactic fast γ-ray transients

(Hays et al 2009, Pittori et al. 2008, Bulgarelli et al 2009,2010,2011, Chen et al. 2007, Longo et . 2008, ecc. ecc.)

1FGL J0910-5041 **1FGL J1057-6027** **AGL J1410-6143** **AGL J1734-3310**

1FGL J0902-4624 **AGL J2241+4454** **AGL J2103+5630** **AGL J2022+3622**

1FGL J1746-2858 **AGL J1037-5708** **AGL J1958+3401**

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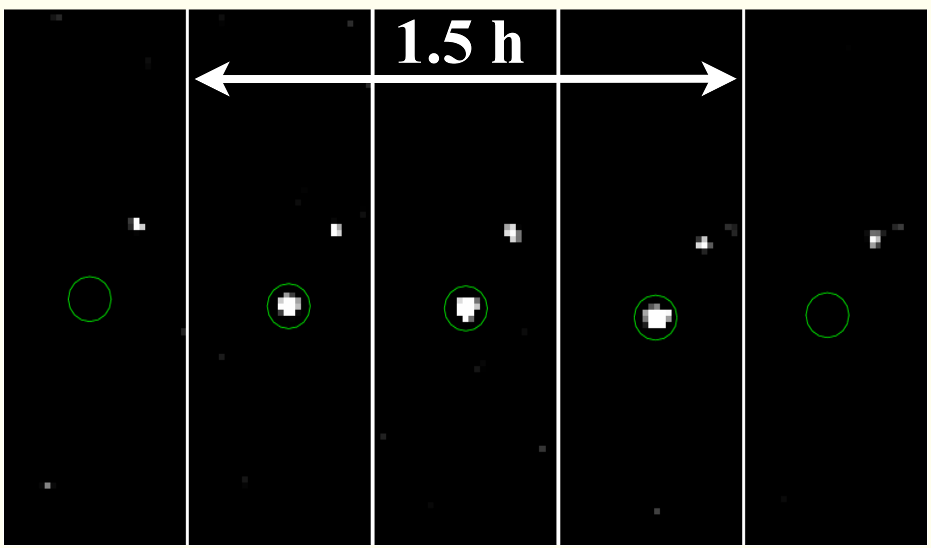
the identification of their counterparts at lower energies is a very challenging task ➞ large error boxes, fast transient nature

INTEGRAL observations (20-100 keV) are particularly suited to search for reliable best candidate counterparts because of:

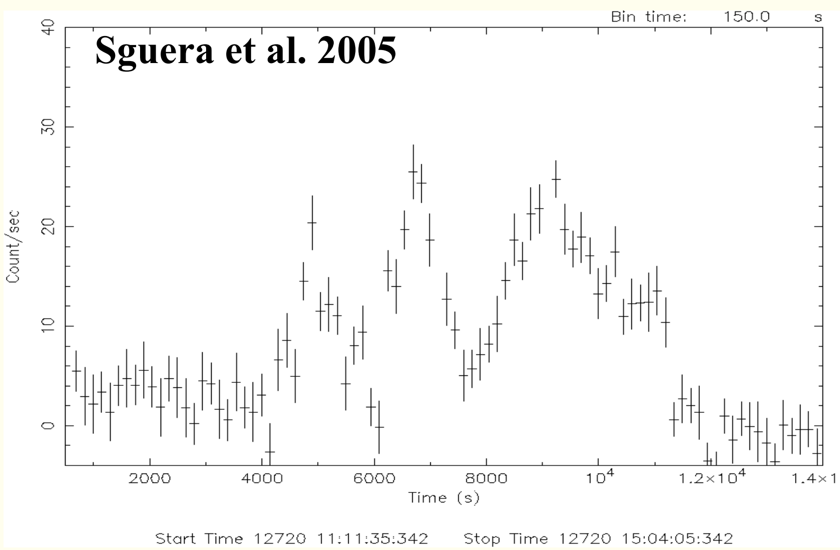
- large field of view (30x30 degrees)
- good sensitivity (< 0.5 mCrab level for deep exposures)

Supergiant Fast X-ray Transients (SFXTs)

- recently newly discovered class of **transient HMXBs** (Sguera et al. 2005, 2006), **massive blu supergiant (OB) + compact object (mainly NS)**



Sequence of 20-60 KeV IBIS significances images



20-60 KeV IBIS light curve, bin time 150 s

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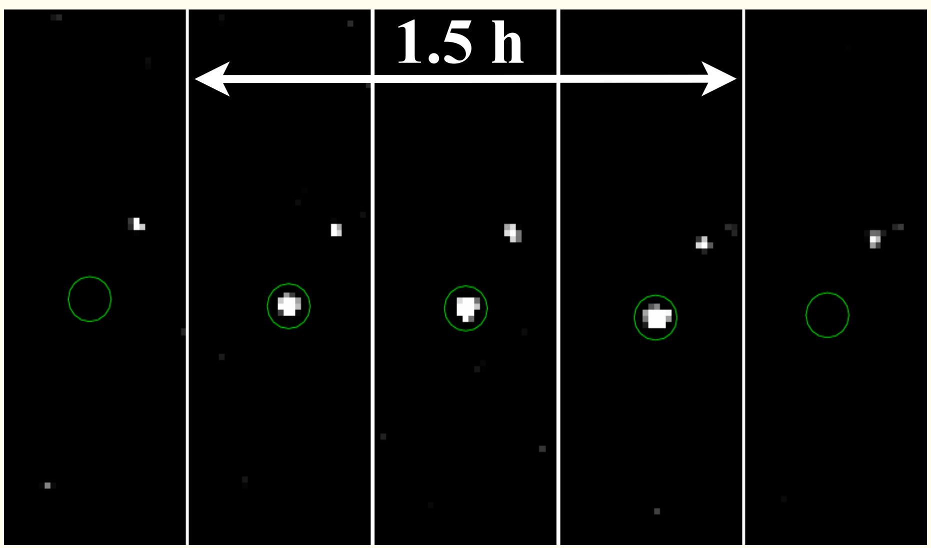

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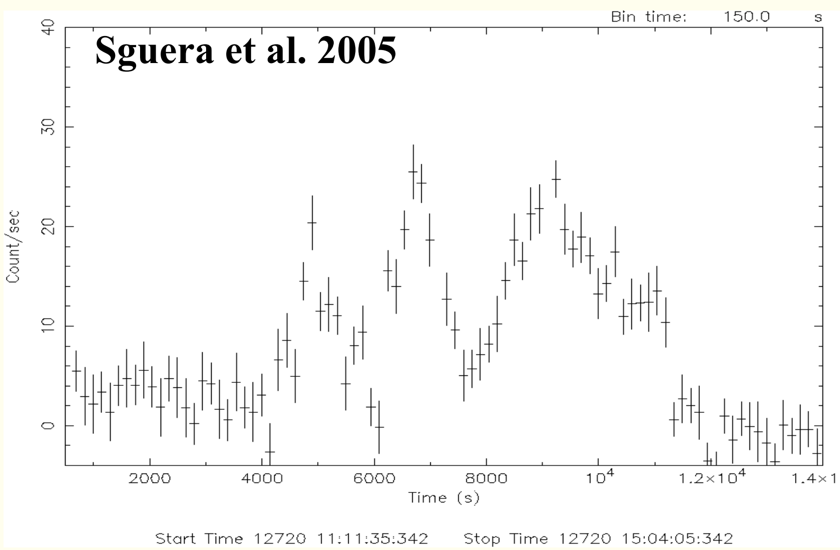

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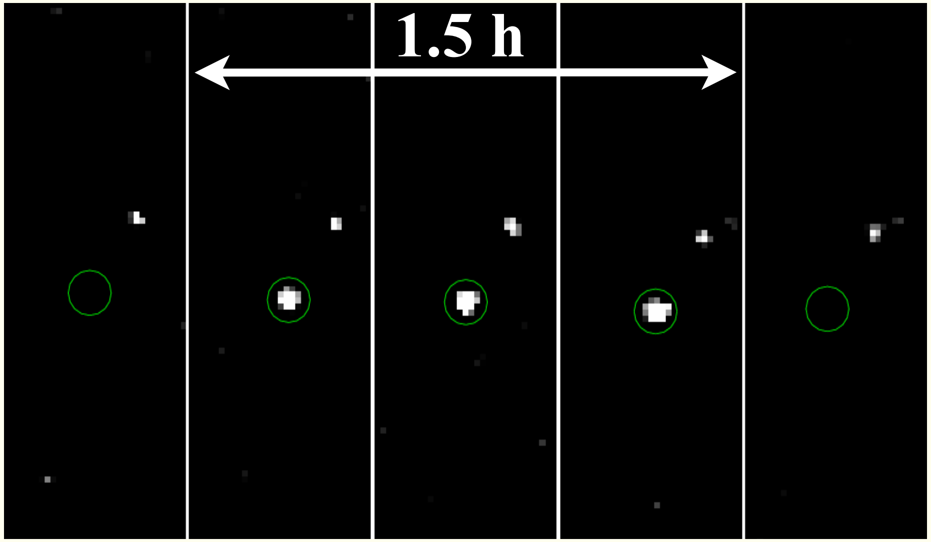

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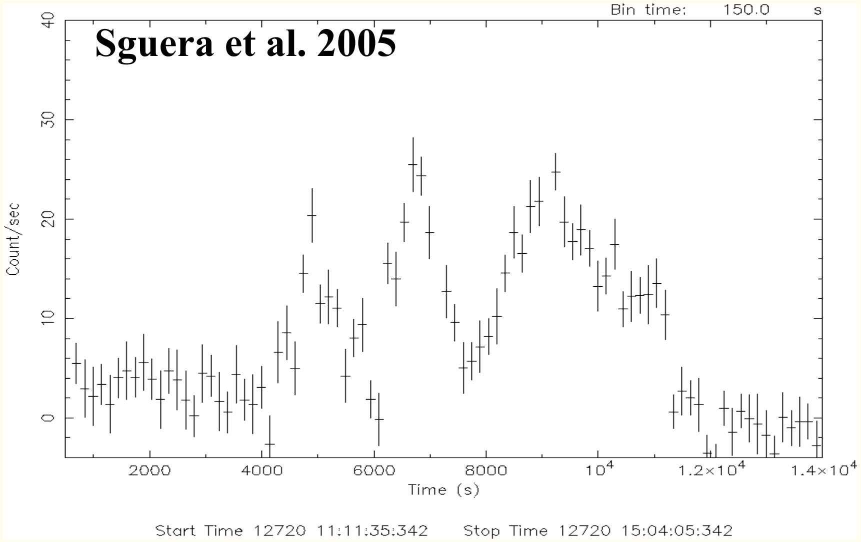

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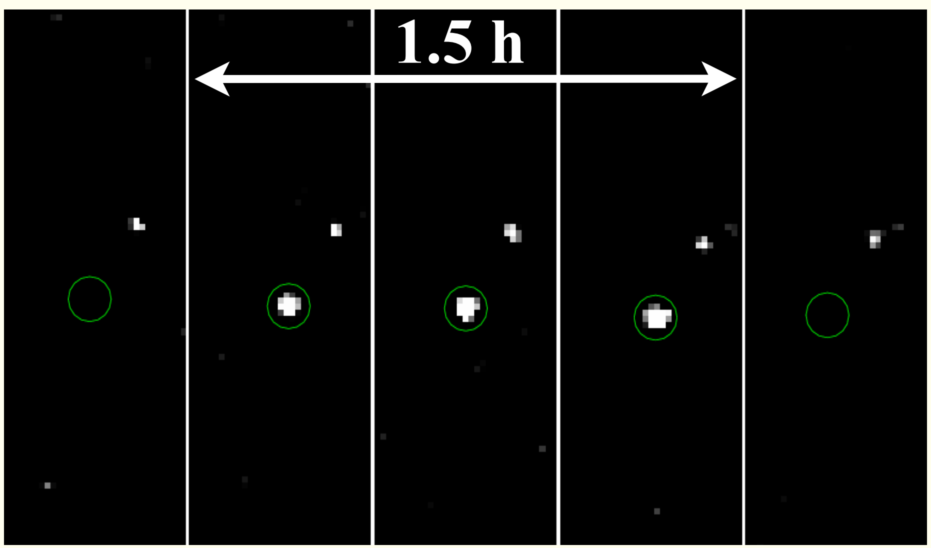

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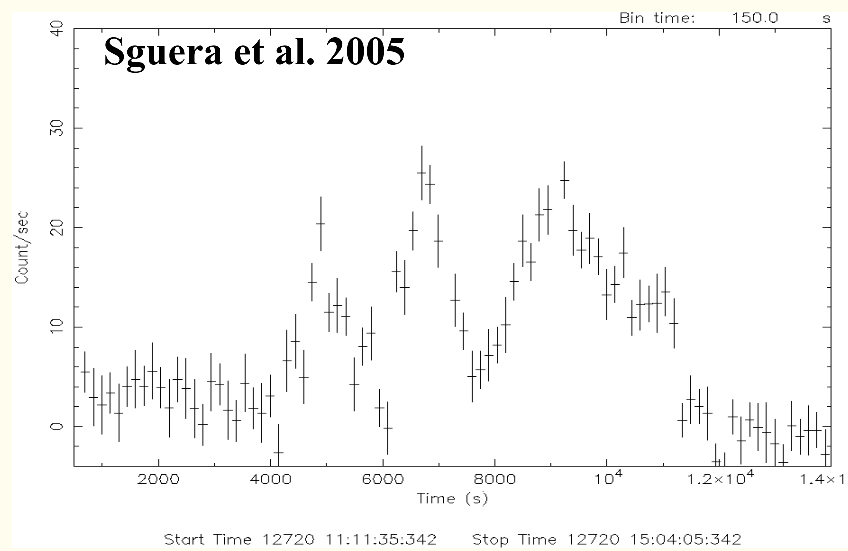

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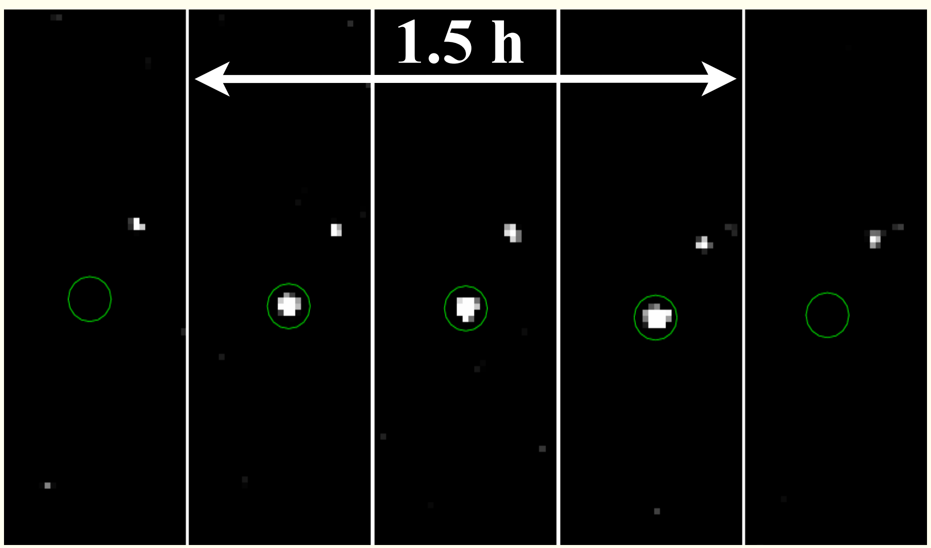
- **clumpy wind scenario? centrigual/magnetic barrier?**
- to date **10** firm SFXTs plus about **10** candidate SFXTs



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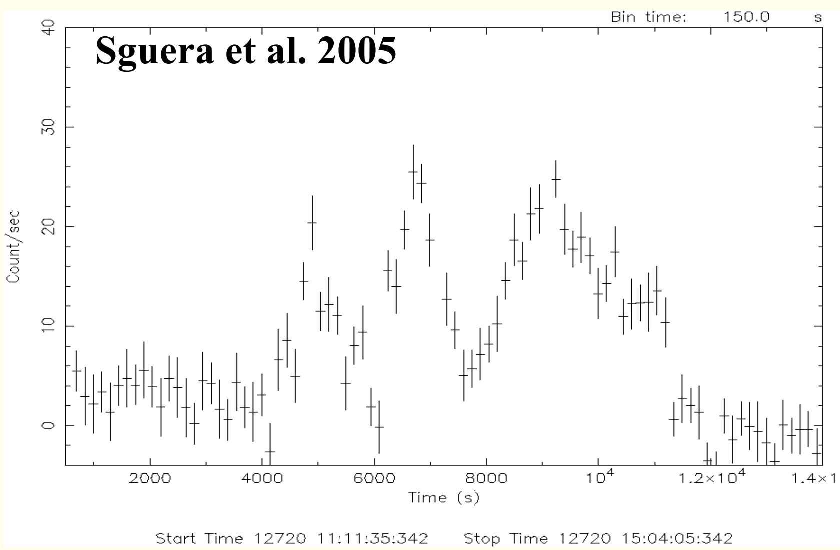

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SFXTs as γ-ray emitters: a timely idea

exciting time to explore this possibility!

- **HMXBs firmly detected as persistent (and variable) MeV to TeV emitters**

  LS 5039, LS I +61 303, PSR B1259-63, HESS J0632+057, 1FGL J1018.6-5856; Abdo et al. 2010, Paredes 2008, Corbet et al. 2011, Hinton et al. 2008

- **microquasars HMXBs detected as fast γ-ray emitters on few days timescale**

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Plenty of models to explain high energy emission from HMXBs

* **Microquasar accretion/jet framework,** both leptonic and hadronic scenarios (Bosch-Ramon et al. 2006, Paredes et al. 2006, Dermer & Boettcher 2006, Romero et al. 2003, 2009)
* **Interaction between the relativistic wind of a young NS and the wind of the massive stellar companion** (Maraschi & Treves 1981, Tavani & Arons 1997, Dubus 2006)
* **Cheng-Ruderman mechanism** in the magnetosphere of accreting NS (Orellana et al. 2007)

In principle, SFXTs have all the "ingredients" to possibly be MeV to TeV emitters:

☑ **accreting compact object** (neutron star or black hole)

☑ **bright and massive supergiant OB star** which could be the source of seed photons (for the inverse Compton emission) and target nuclei (for hadronic interactions)

Drawback

flaring γ-ray emission should be very difficult to detect because of:

- very short duration **(from hours to few days)**
- very short duty cycles **(0.05% - 3 %)**

Associations between unidentified transient γ-ray sources and SFXTs or candidates:

- ✓ **IGR J11215-5952 / EGR J1122-5946** **(Sguera et al. 2009)**
- ✓ **IGR J20188+3657 / AGL J2022+3622** **(Sguera et al. 2009)**
- ✓ **AX J1841.0-0536 / 3EG J1837-0423** **(Sguera et al. 2010)**
- ✓ **MAXI J1409-619 / AGL J1734-3310** **(Sguera et al. 2010)**
- ✓ **IGRJ 17354-3255 /AGL J1735-3258** **(Sguera et al. 2011)**

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✱ **good test cases** in order to get **quantitative proofs for a real physical association**

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AGL J1734-3310

- unidentified fast γ-ray transient **discovered by AGILE on April 2009** (Bulgarelli et al. 2009)
- **fast flare lasting only ~ 1 day, ~5σ detection**
- **flux (3.5±1)x10^{-6} photons cm^{-2} s^{-1}** (E>100 MeV)
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systematic search for additional transient γ-ray emission

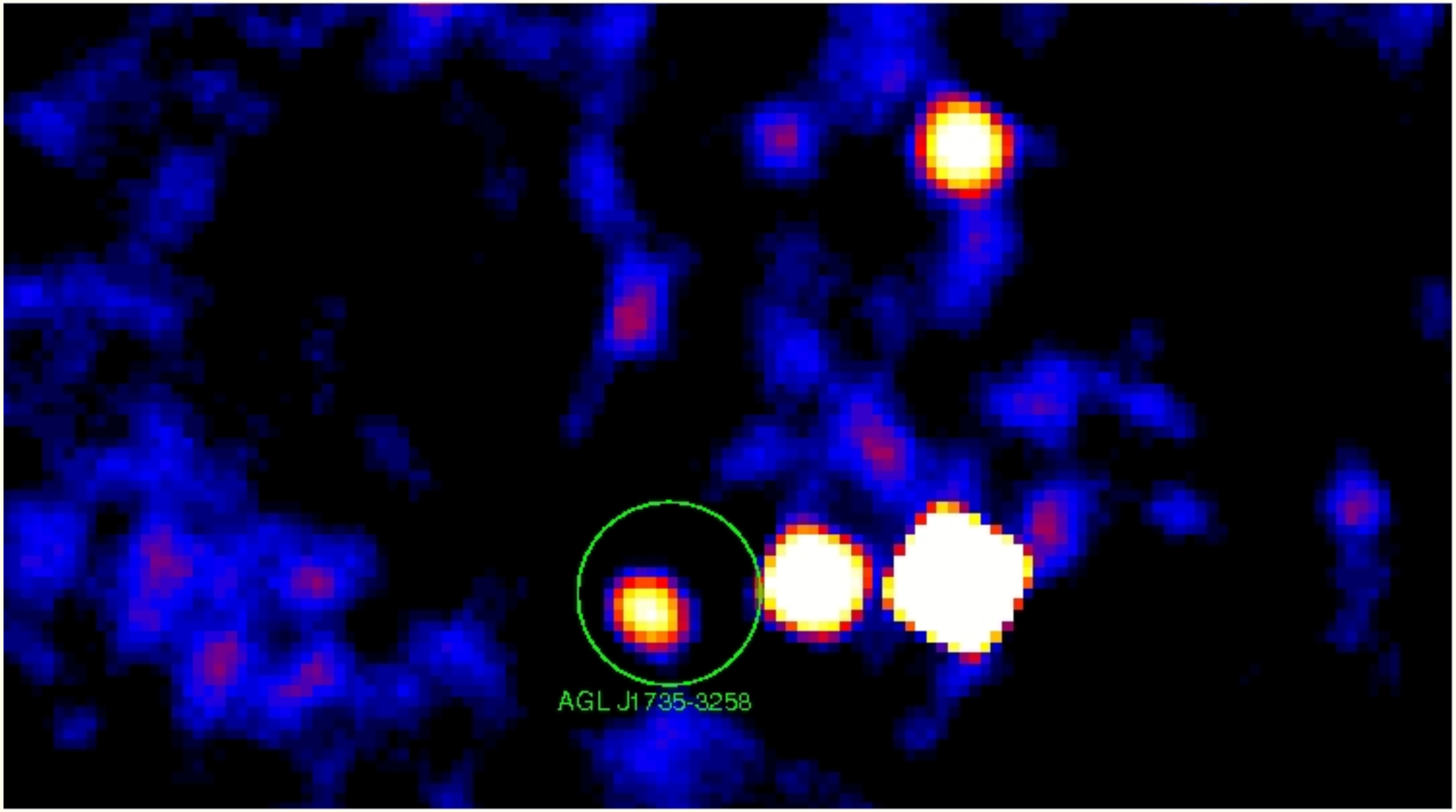
- 100 MeV - 50 GeV
- **1-day level**
- **$(TS)^{1/2}$ ≥ 3 sigma**
- dataset (July 2007- October 2009), **174 days in pointing mode**

Bulgarelli et al. in preparation

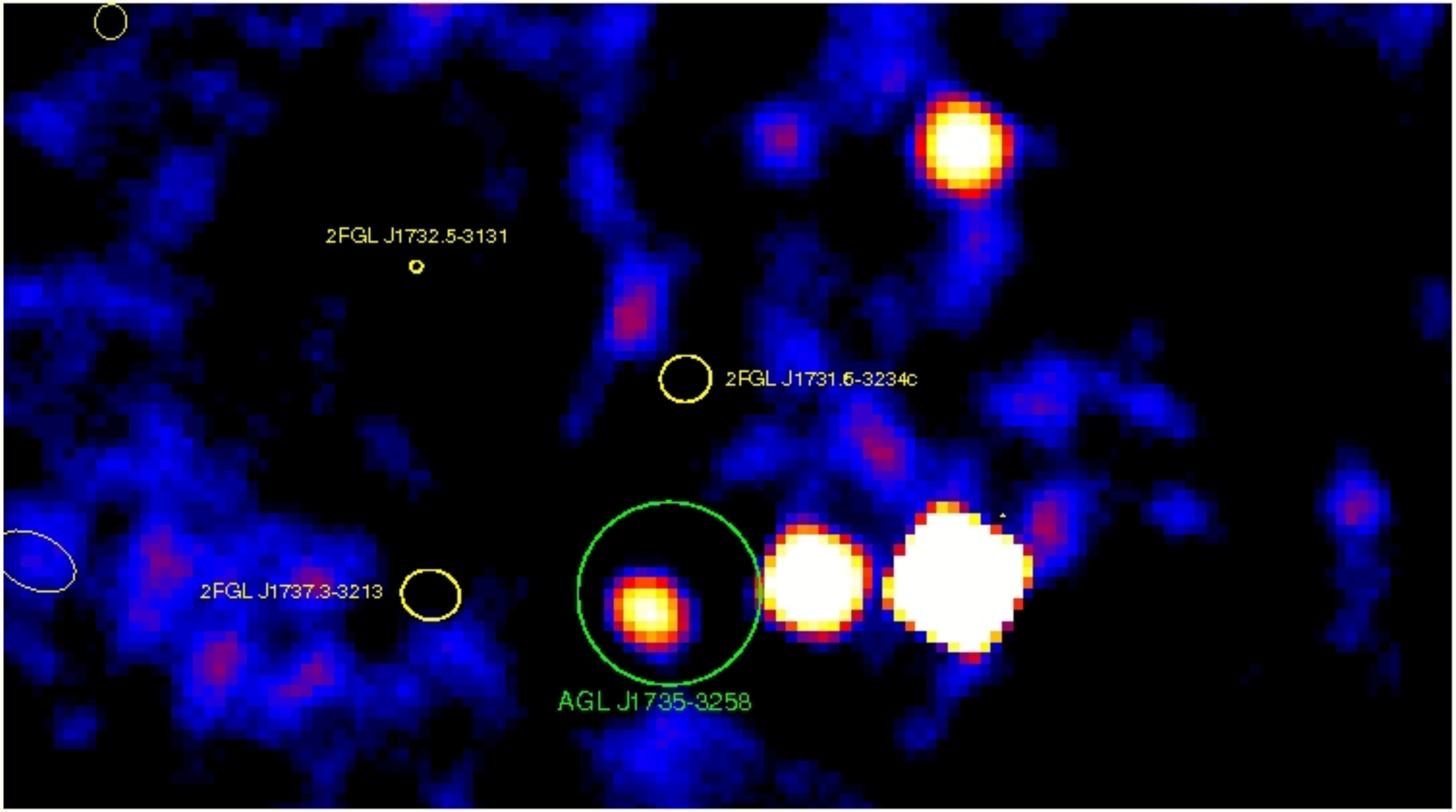
- **14** fast γ-ray flares
- typical duration **1 day at most** (in some cases even less)
- **significance detection** in the range **3σ - 5σ**
  as comparison, 11 fast γ-ray flares (1-2 days) detected from Cyg X-3
  have significance in the range 3.3σ - 4.2σ (Bulgarelli et al. 2012)
- **(1.7 - 3.5) x10^{-6}** photons cm^{-2} s^{-1} (100 MeV - 50 GeV)

summing up all the flares detected by AGILE

- **8.5σ detection**
- error circle radius of **0.34 degrees (statistical + systematic)**
  centered at l = 355.36 and b = -0.2



INTEGRAL/IBIS deep mosaic significance image **(~ 10 Ms, 18-60 keV)**



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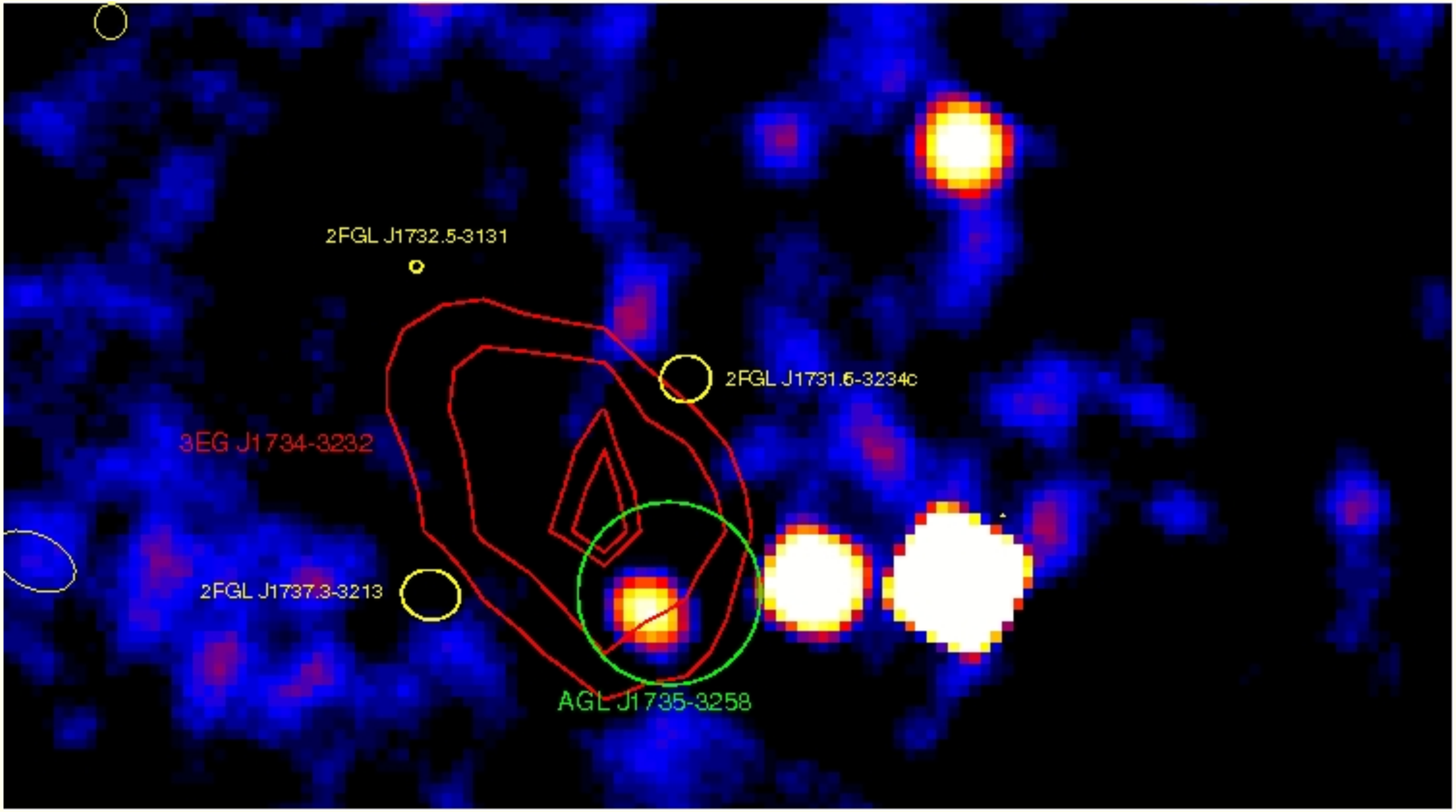
- **2FGL J1732.5-3131 γ-ray pulsar**, **2FGL J1731.6-3234c** probably **fake source**, **2FGL J1737.3-3213 likely SNR or PWN, persistent and non variable**



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- **3EG J1734-3232**: **unidentified and persistent** with average flux $(40.3 \pm 6.7)10^{-8}$ ph cm^{-2} s^{-1} It is **likely the blend** of 2FGL J1732.5-3131 (20×10^{-8} ph cm^{-2} s^{-1}) and AGL J1735-3258 $(18 \pm 5) \times 10^{-8}$ ph cm^{-2} s^{-1} . **Hint of variability in the EGRET data**

IGR J17354-3255 (Sguera et al. 2011)

INTEGRAL/IBIS dataset: from **February 2003** to **October 2008** for a total on source time of ~ **10 Ms, (18-60 keV)**

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- It spends the **majority of the time during out-of-outburst X-ray state**, i.e. low X-ray flux level of **1.4×10^{-11} erg cm^{-2} s^{-1}** (18-60 keV) with **no sign of flaring activity**

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- Occasionally **fast X-ray flares** (16 in total)

* **duration:** typically **0.5 - 10 hours**, occasionally a **few days**

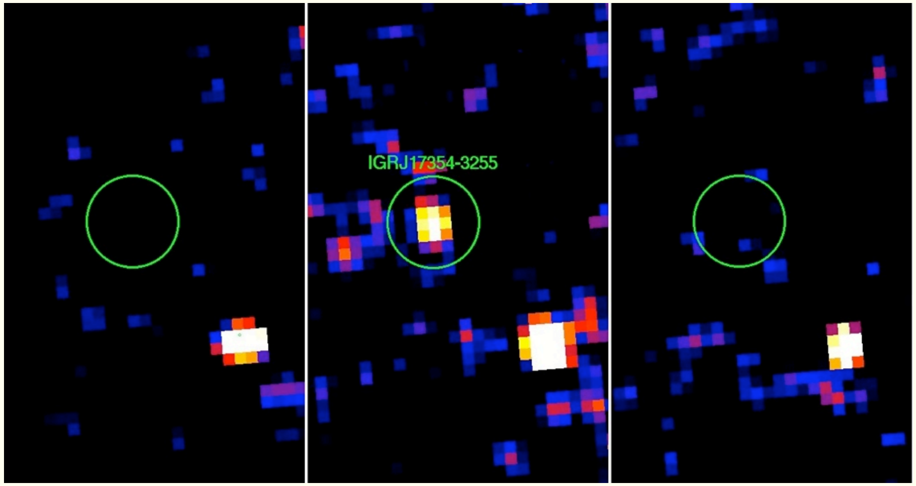
* **duty cycle ~ 0.1%**

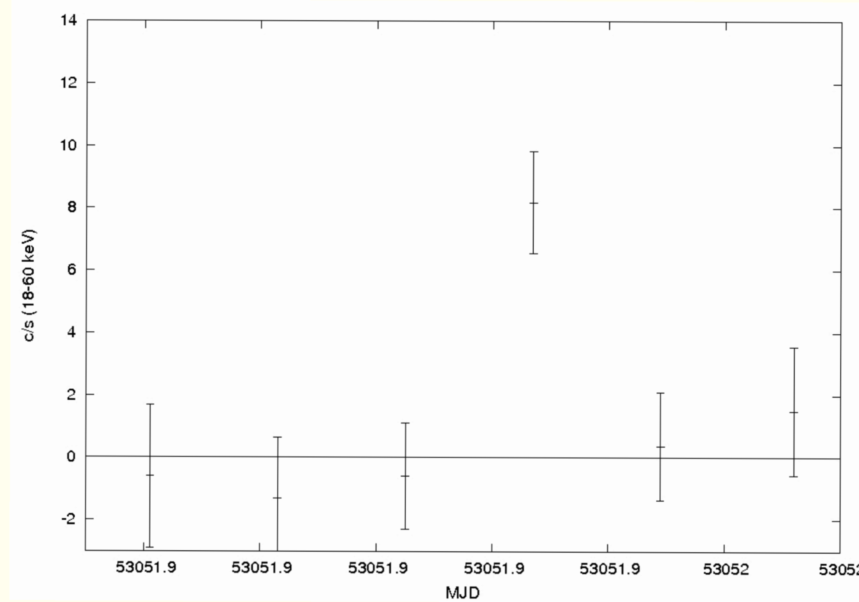
* **X-ray flux**: as high as **10^{-9} erg cm^{-2} s^{-1}** (18-60 keV)

* **dynamic range** as high as **200**

* **detection significance:** in the range **5σ - 10σ**

flare lasting 0.5 hour, 5.5σ detection, 1.4×10^{-9} erg cm^{-2} s^{-1} (18-60 keV)





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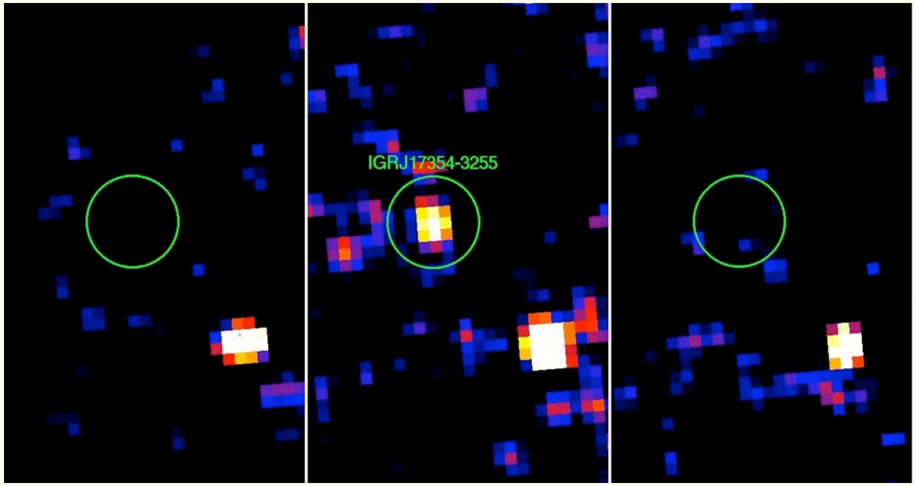
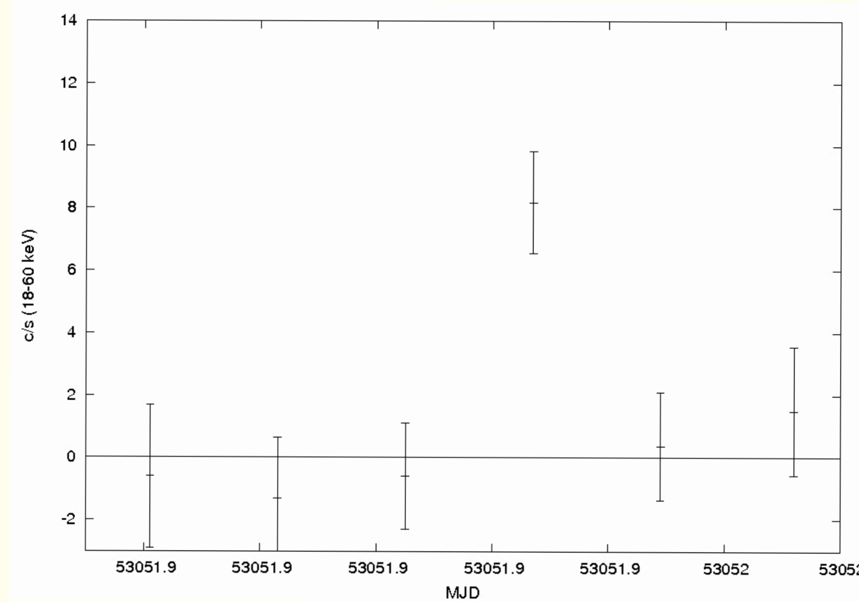
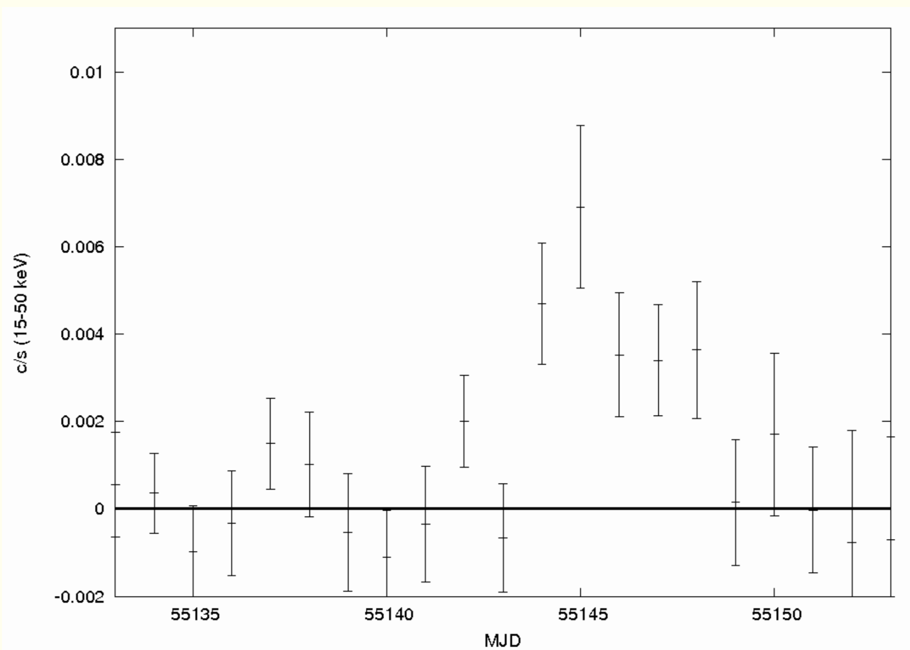




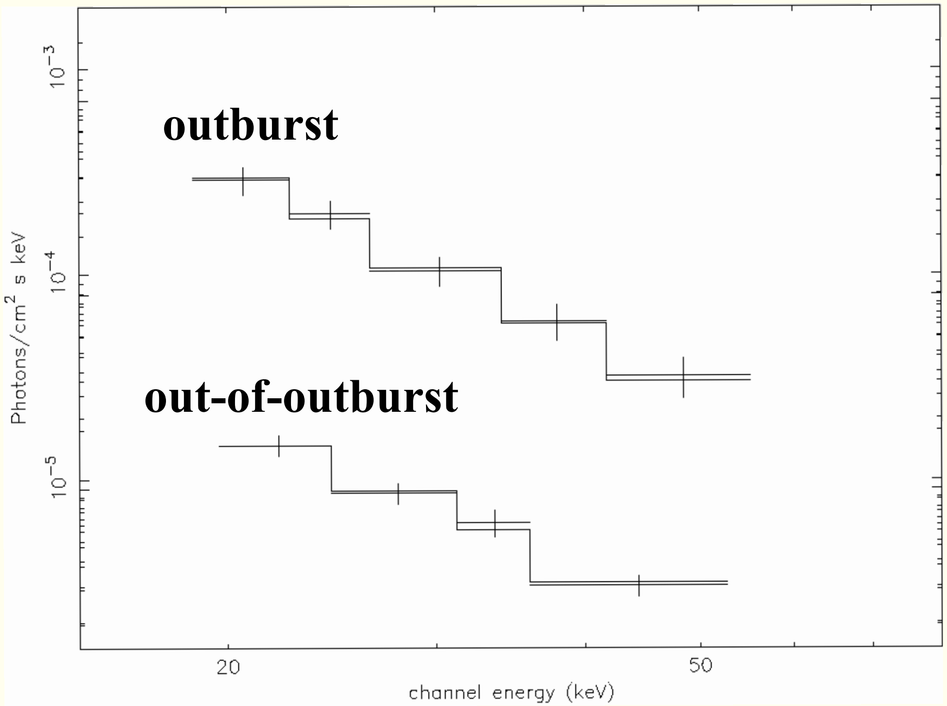


flare lasting **~5 days**

6.5σ detection

3×10^{-9} erg cm^{-2} s^{-1} (18-60 keV)

spectral shape (18-60 keV)



Γ =2.4±0.4 **(out-of-outburst)**

Γ =2.4±0.4 **(flares)**

accretion at work in both states although at different rates

clumpy wind scenario

- **fast X-ray flares** likely due to the accretion of dense **clumps**
- **out-of-outburst X-ray state** likely due to accretion from the less dense **background wind**

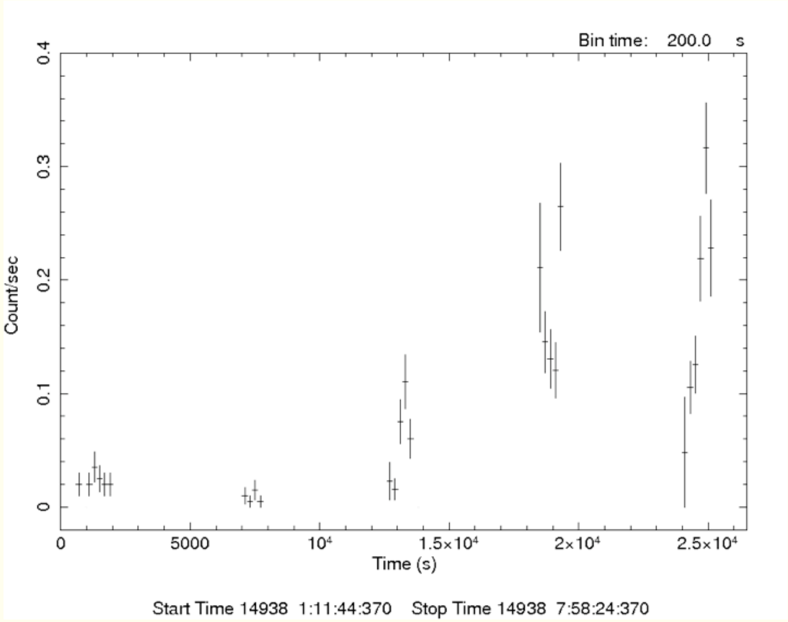
High dynamic range also in the softer X-ray band 0.2-10 keV: >311

* **Swift/XRT** obs on 11 March 2008 (4.4 ks)

no detection, **3σ upper limit < 2.8×10^{-13} erg cm^{-2} s^{-1}** (0.2-10 keV)

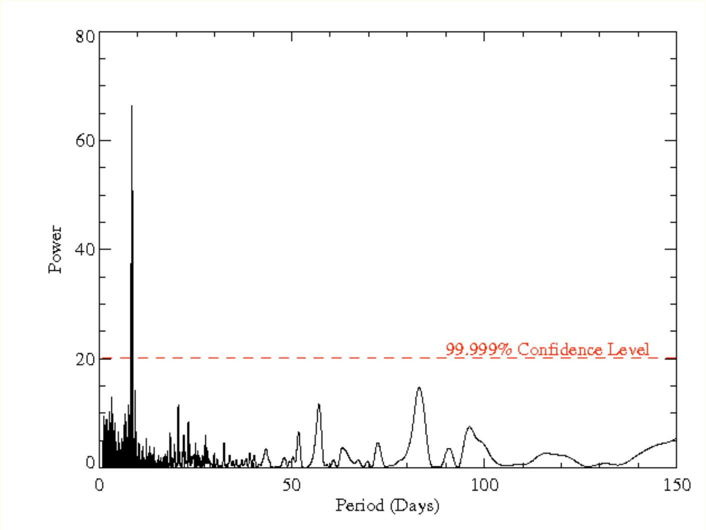
* **Swift/XRT** obs on 17 April 2009 (5.3 ks)

detection, **8.7×10^{-11} erg cm^{-2} s^{-1}** (0.2-10 keV)

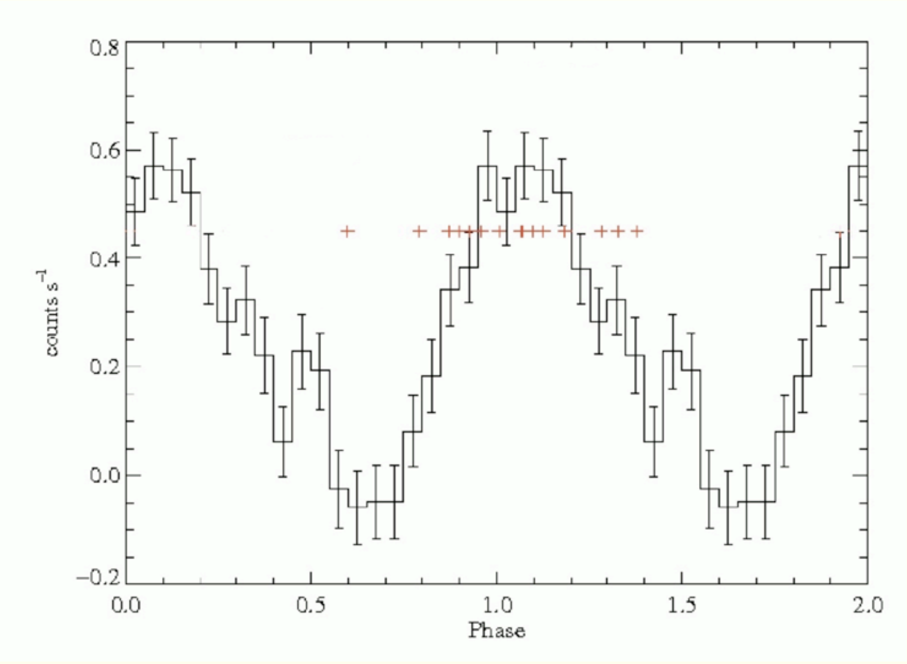


strongly variable by a factor of ~ **50** on **few tens min** timescale

INTEGRAL periodicity analysis



periodicity = 8.4474 ± 0.0017 days
very likely the **orbital period** of a binary system



X-ray flux **peaks** at **periastron** and is consistent with **zero** at **apastron**

X-ray flares are clustered around **periastron**, they occur during **26%** of periastron passages

shape rather **smooth**, **dominated by lower level X-ray emission** rather than outbursts

All the reported findings strongly suggest that IGR J17354-3255 is a candidate SFXT

A **Chandra** observation (Tomsick et al. 2009) allowed to pinpoint a **single 2MASS infrared** counterpart but **no optical** counterpart

NIR spectroscopy is strongly needed to:

- fully confirm the SFXT nature
- estimate the distance

IGR J17354-3255 as best candidate counterpart of the fast γ-ray transient AGL J1734-3310

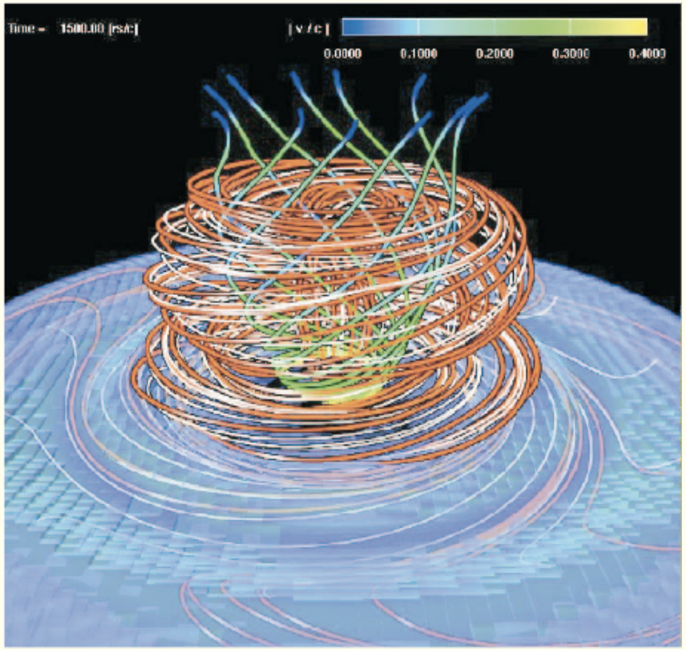
based on intriguing hints such as:

i) spatial correlation

ii) similar transient behaviour on short timescale
(although not simultaneous yet)

Is there a physical mechanism to support such proposed association?

formation of a **transient magnetic-tower jet** during the accretion of a clump



Kato et al. 2004,2006,2007

Jets driven by magnetic pressure could be formed along the rotation axis of the disk.

Creation of a **magnetic tower** inside which the accelerated material is collimated as bipolar jets (0.1-0.2 c). Plasmoids, injected at the base of the tower, can collide giving rise to shocks. Diffusive acceleration at these **shocks can accelerate proton and electrons up to relativistic energies**

- **electrons** cool mainly by synchrotron radiation in the magnetic field producing **X-ray**
- **protons** interact with synchrotron photon field to produce **γ-rays, mesons, secondary pairs, neutrinos** and **neutrons** according to the following reactions

(see Romero & Vila 2008 for details)

$$p + \gamma \rightarrow p + a\pi^0 + b\left(\pi^+ + \pi^-\right)$$

$$p + \gamma \rightarrow n + \pi^+ + a\pi^0 + b\left(\pi^+ + \pi^-\right)$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu, \quad \mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

$$\pi^0 \rightarrow 2\gamma$$

$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu, \quad \mu^- \rightarrow e^- + \overline{\nu}_e + \nu_\mu$$

✱ proposed association between IGR J17354-3255 and AGL J1734-3310 merely based on **intriguing hints**

✱ **Next step** is to get **quantitative proofs** of a real physical association:

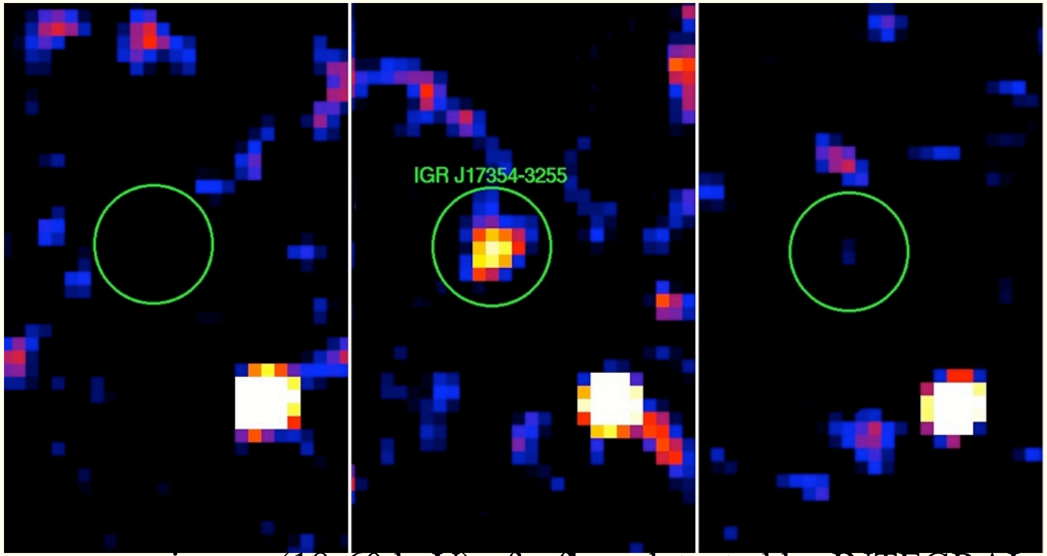
1) **flare simultaneously detected** in hard X and γ-rays

2) 8.4 days **periodicity** detected in γ-rays

We are on the right path to get quantitative proofs

• simultaneous flares

two flares quasi-simultaneously detected by INTEGRAL and AGILE



sequence image (18-60 keV) of a flare detected by INTEGRAL

INTEGRAL flare

~2.5 days, **7σ** (18-60 keV), $\mathbf{4.3\times10^{-11}}$ erg cm^{-2} s^{-1}, $\Gamma=3.2\pm1$

AGILE flare

~1 day, **3.5σ** (E>100 MeV), $\mathbf{(2.2\pm0.8)\times10^{-6}}$ ph cm^{-2} s^{-1}

Conclusions

* Fermi and AGILE observations are revealing a likely **population of galactic fast γ-rays transients**

* **INTEGRAL observations suggest that SFXTs could be reliable best candidate counterparts**, we are on the right path to hopefully get some quantitative proofs....

* **The firm detection** of high energy emission from SFXTs will have **important consequences** in:

1) opening the study to an unexplored energy window

2) allowing a deep inspection of the extreme physical mechanisms able to accelerate particles up to MeV - TeV