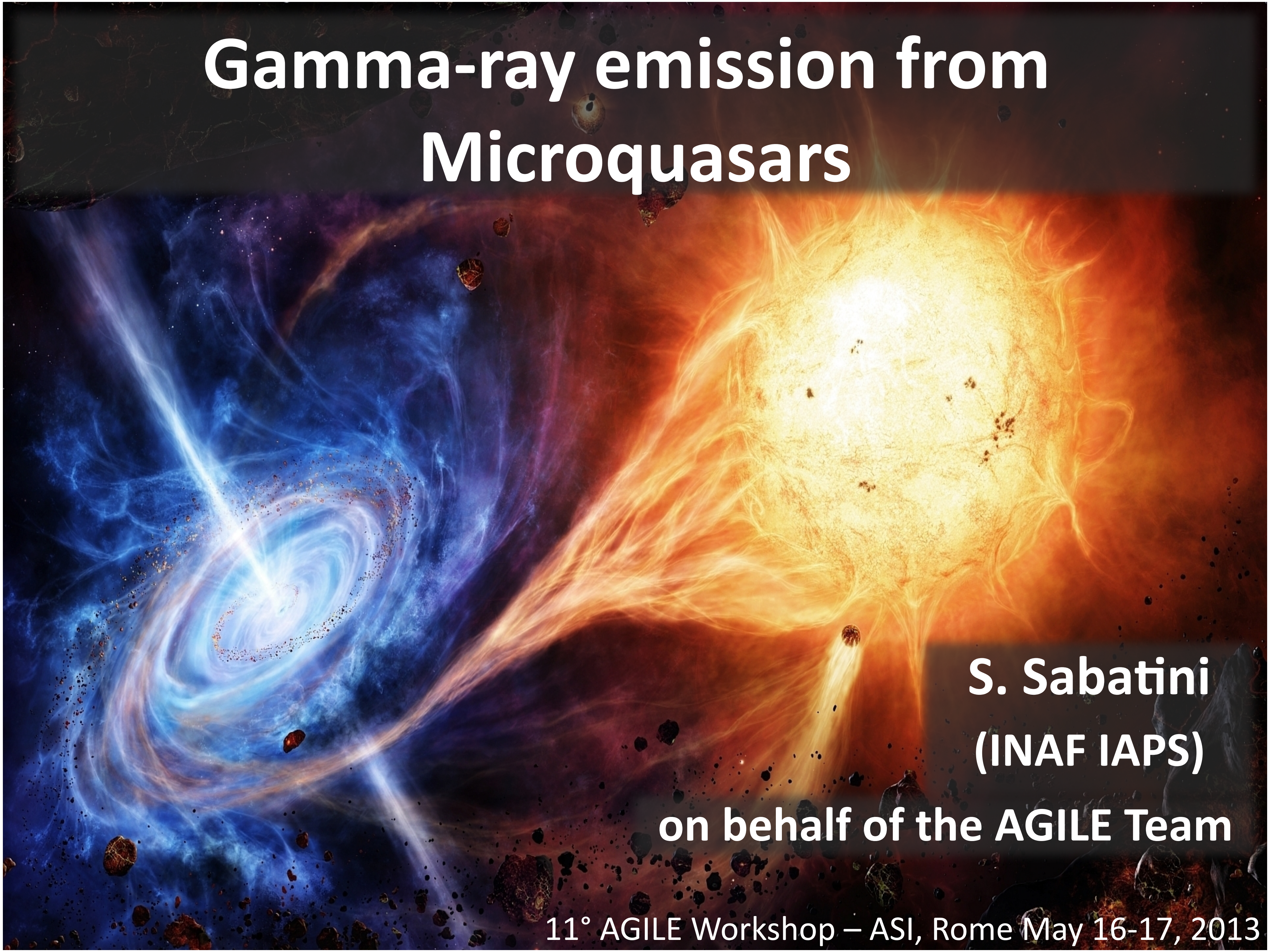
Gamma-ray emission from Microquasars



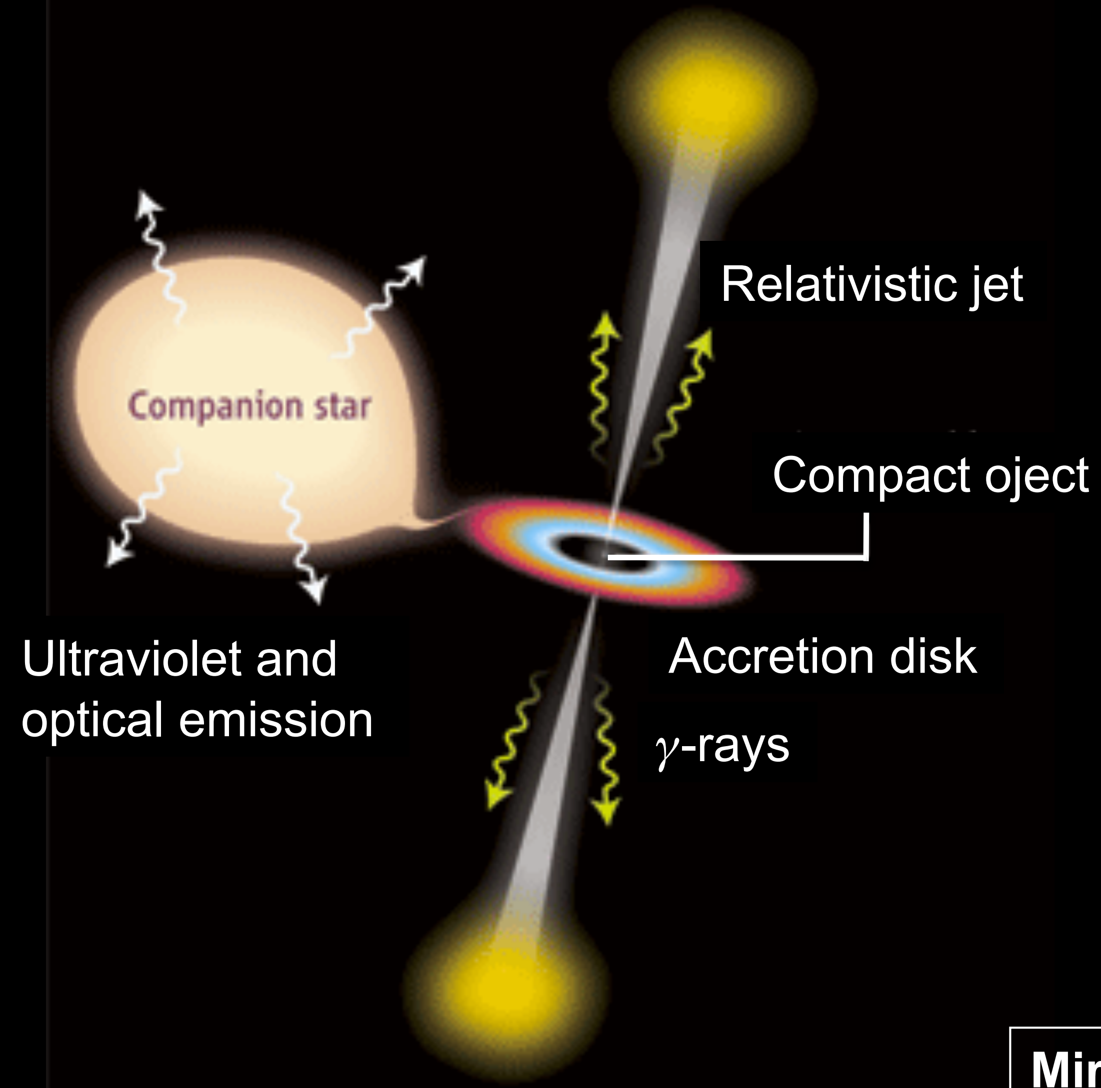
S. Sabatini

(INAF IAPS)

on behalf of the AGILE Team

11° AGILE Workshop – ASI, Rome May 16-17, 2013

MICRO-QUASAR

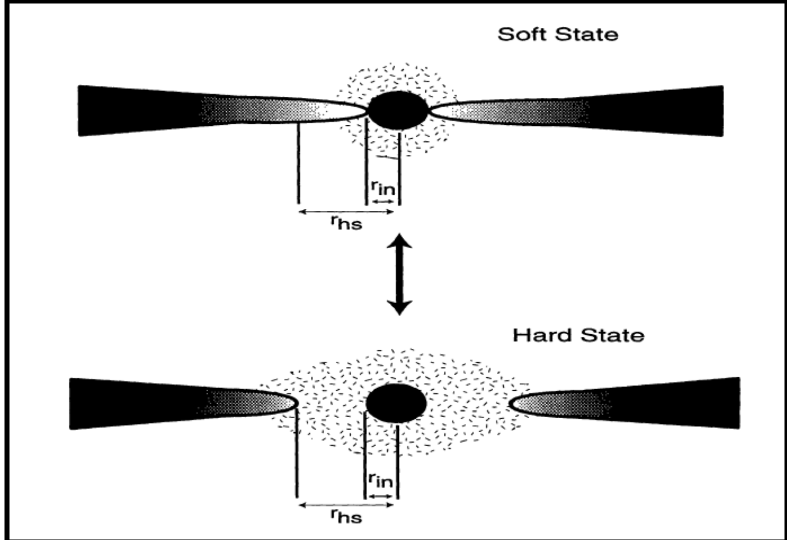


Mirabel, 2006; 2012

Microblazars

Micro-quasars before the AGILE/Fermi era: The X-ray picture

Comptonization of soft thermal photons from disk by a hybrid population of electrons (thermal + non-thermal) in the corona.



2 main X-ray spectral states:

Soft → thermal emission (BB) from disk
+ Comptonization by cold thermal electrons (Soft Excess)
+ Comptonization by non-thermal high-energy electrons (power-law tail)

Hard→ Comptonized emission by hot quasi-thermal population of electrons

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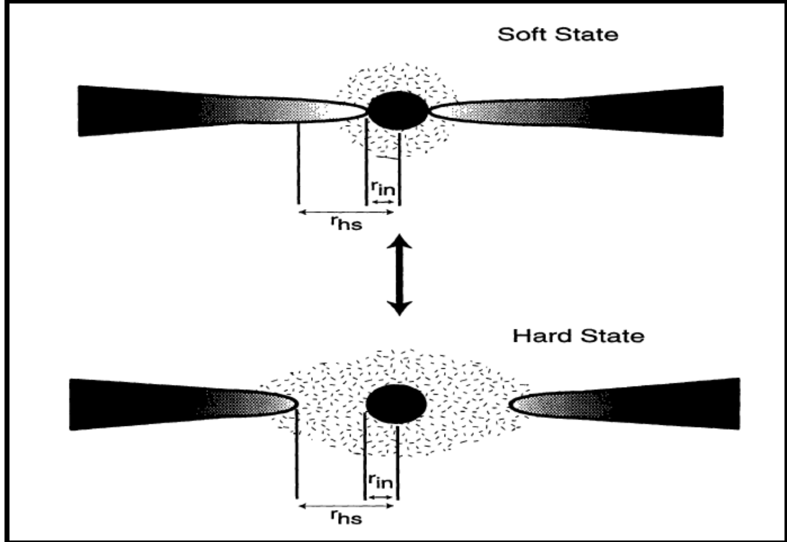

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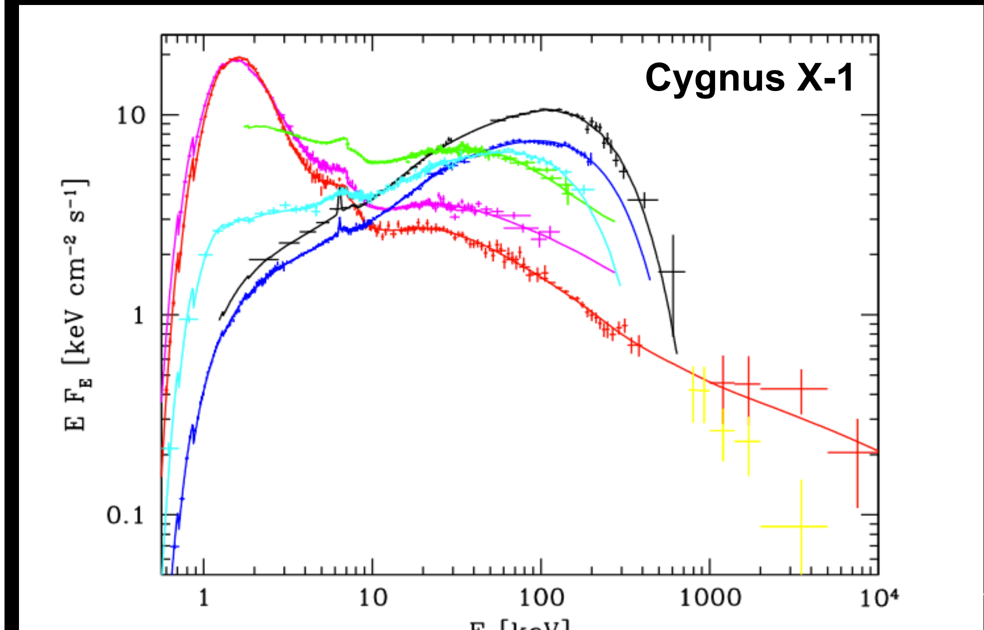
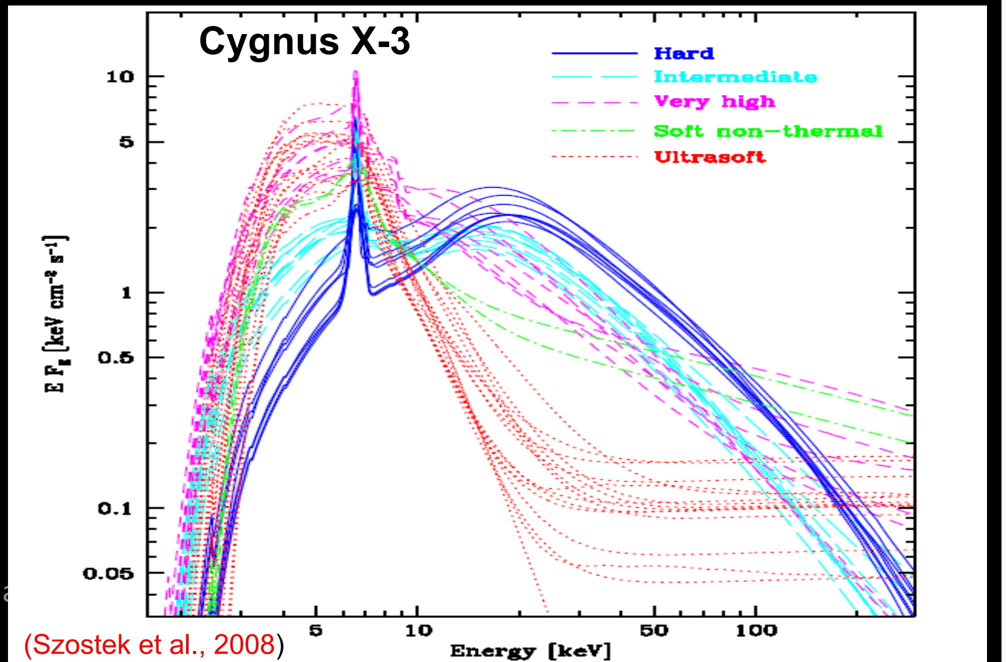


(Zdziarski et al. 2002)



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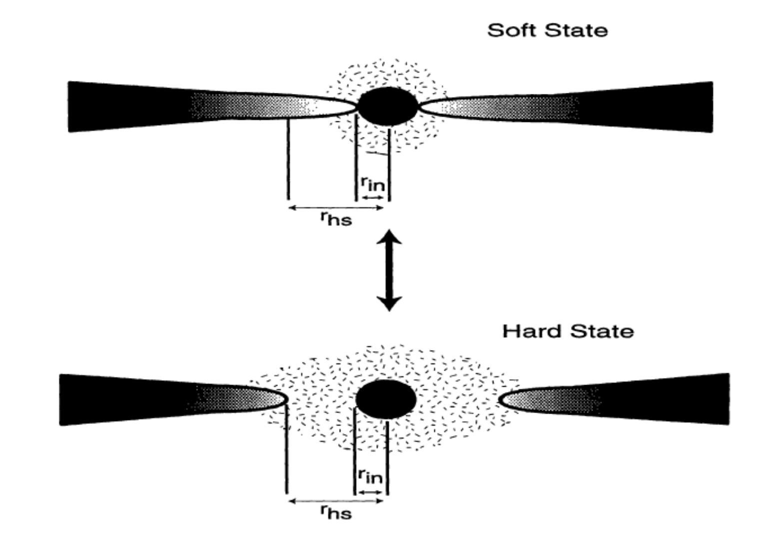

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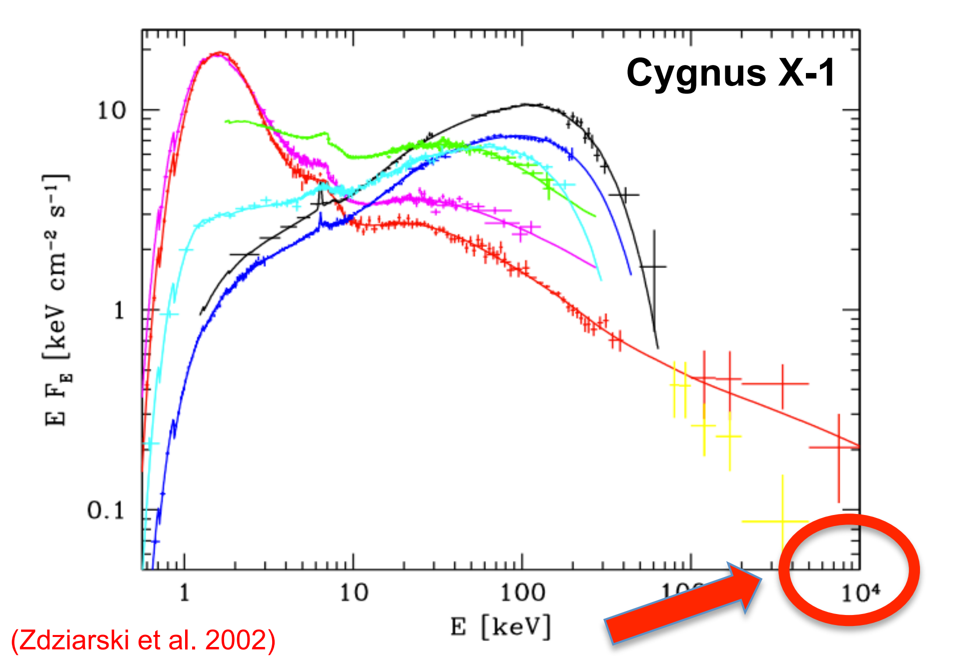

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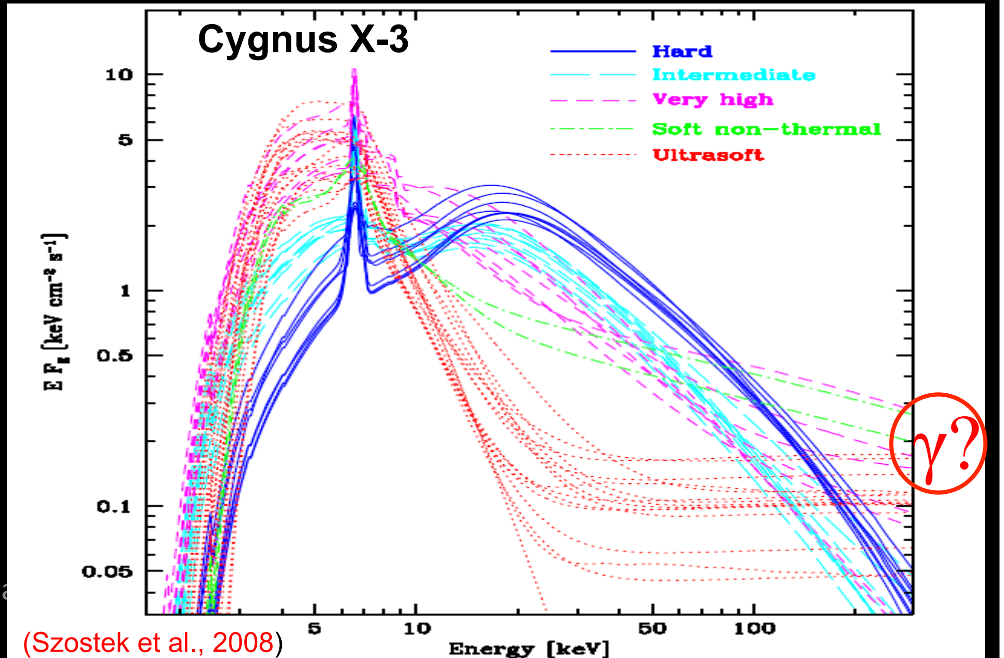
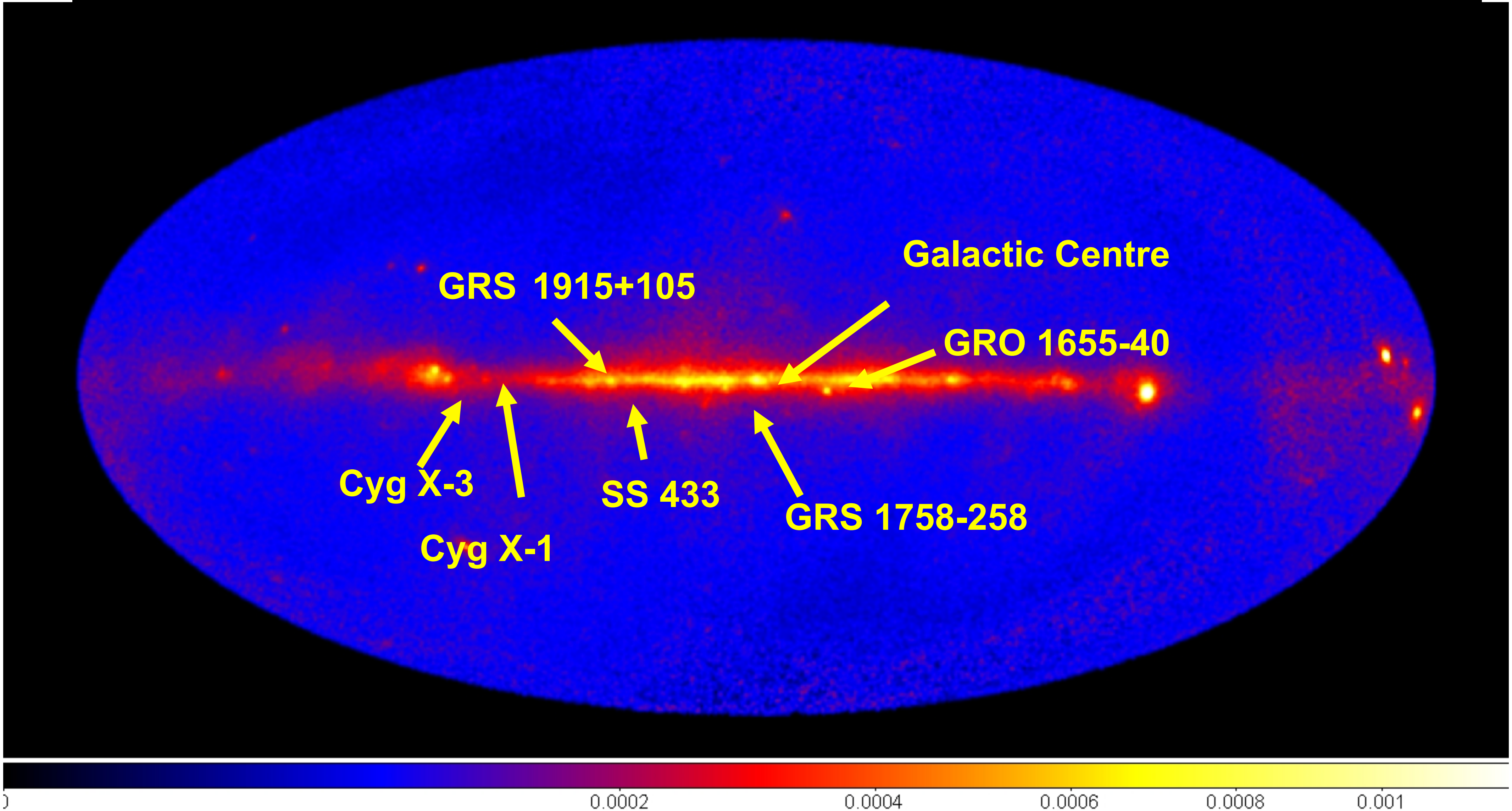


(Szostek et al., 2008)

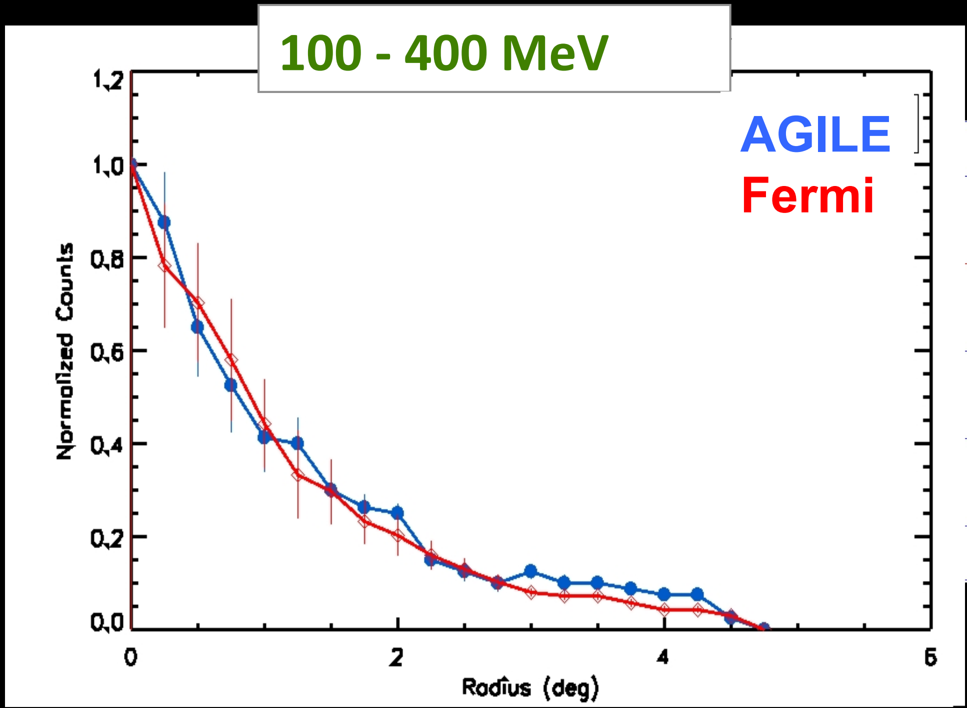
AGILE all sky map (E > 100 MeV)

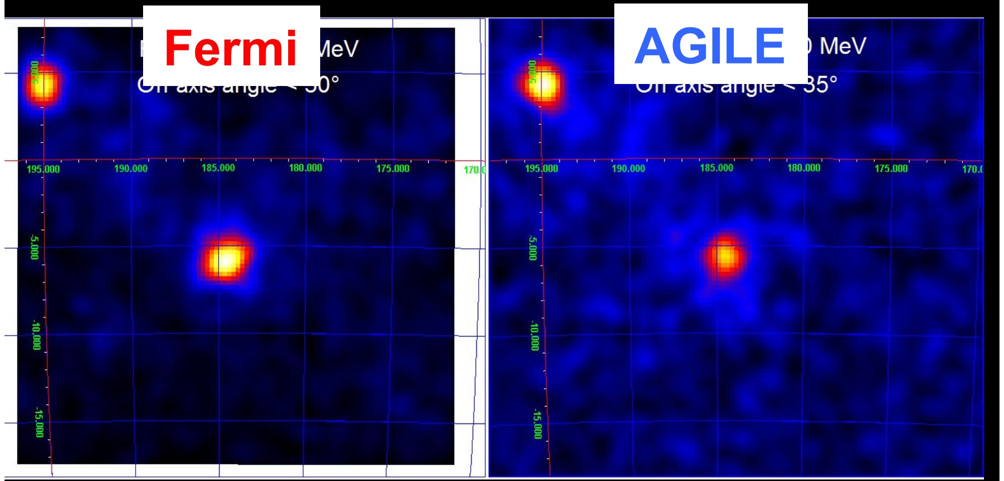


Agile monitoring of the galactic sources and micro-quasars is **on-going**

optimal PSF

Gamma-Ray PSF: AGILE vs. Fermi (front-LAT) - Crab





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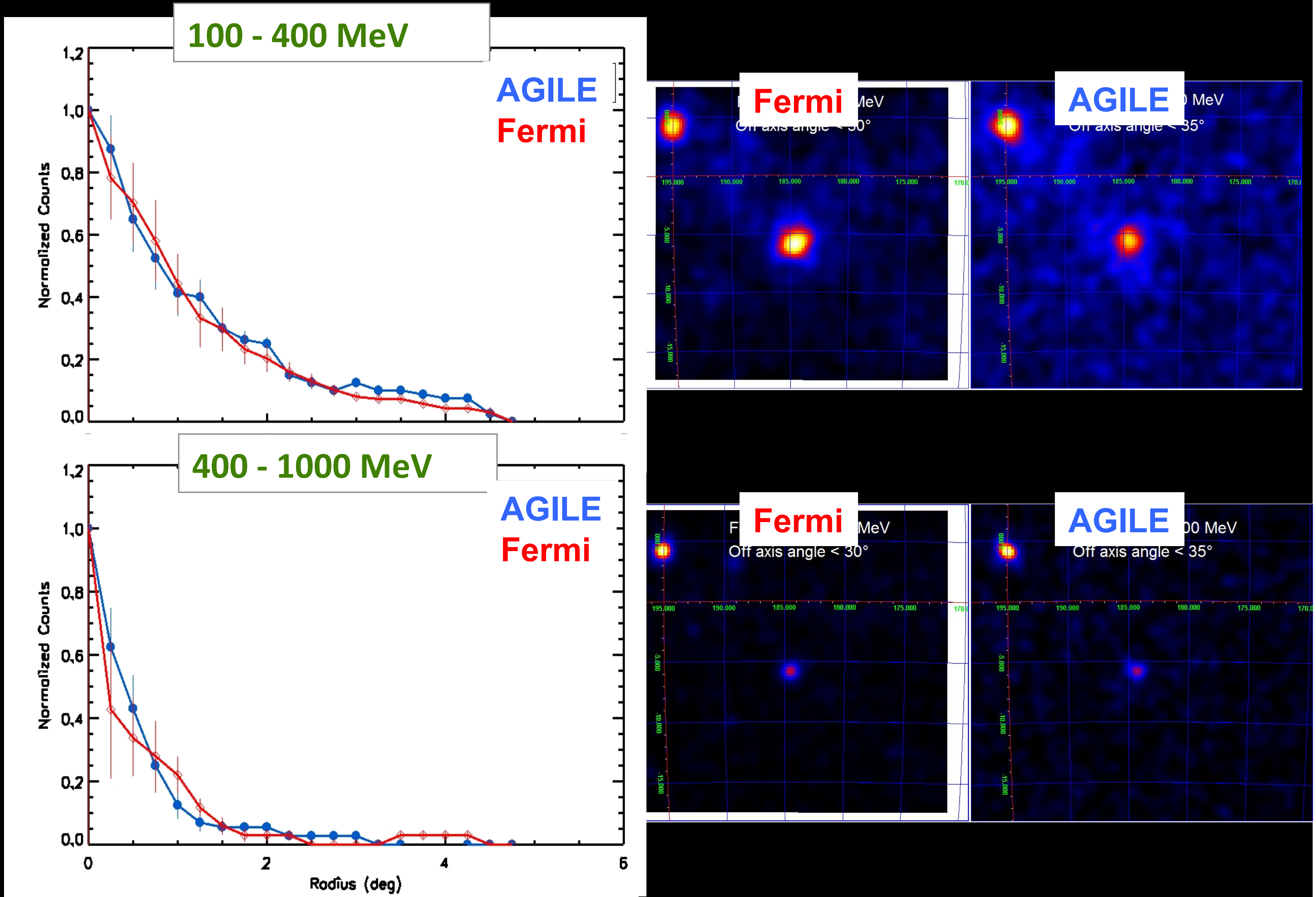

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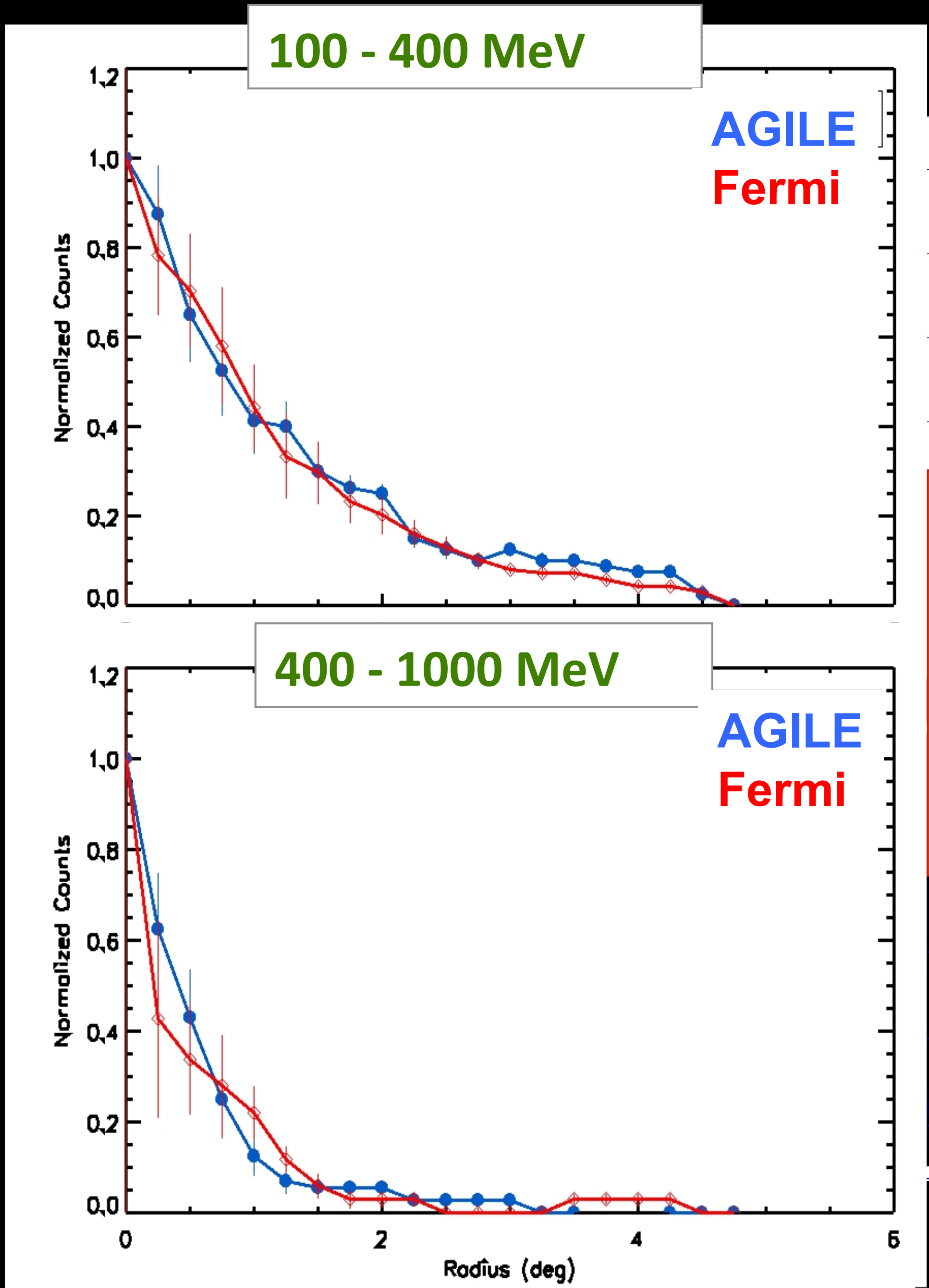
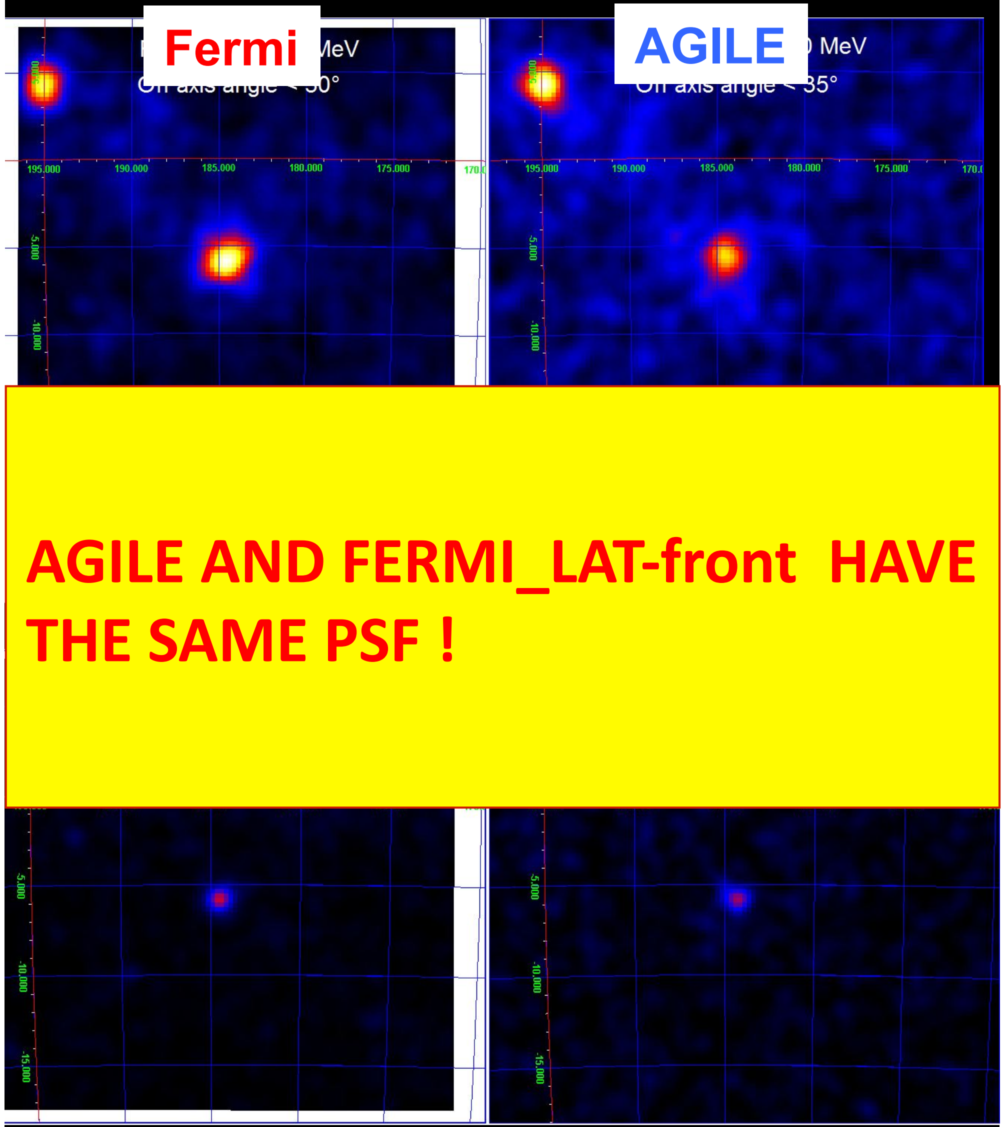




AGILE AND FERMI_LAT-front HAVE THE SAME PSF !

Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF

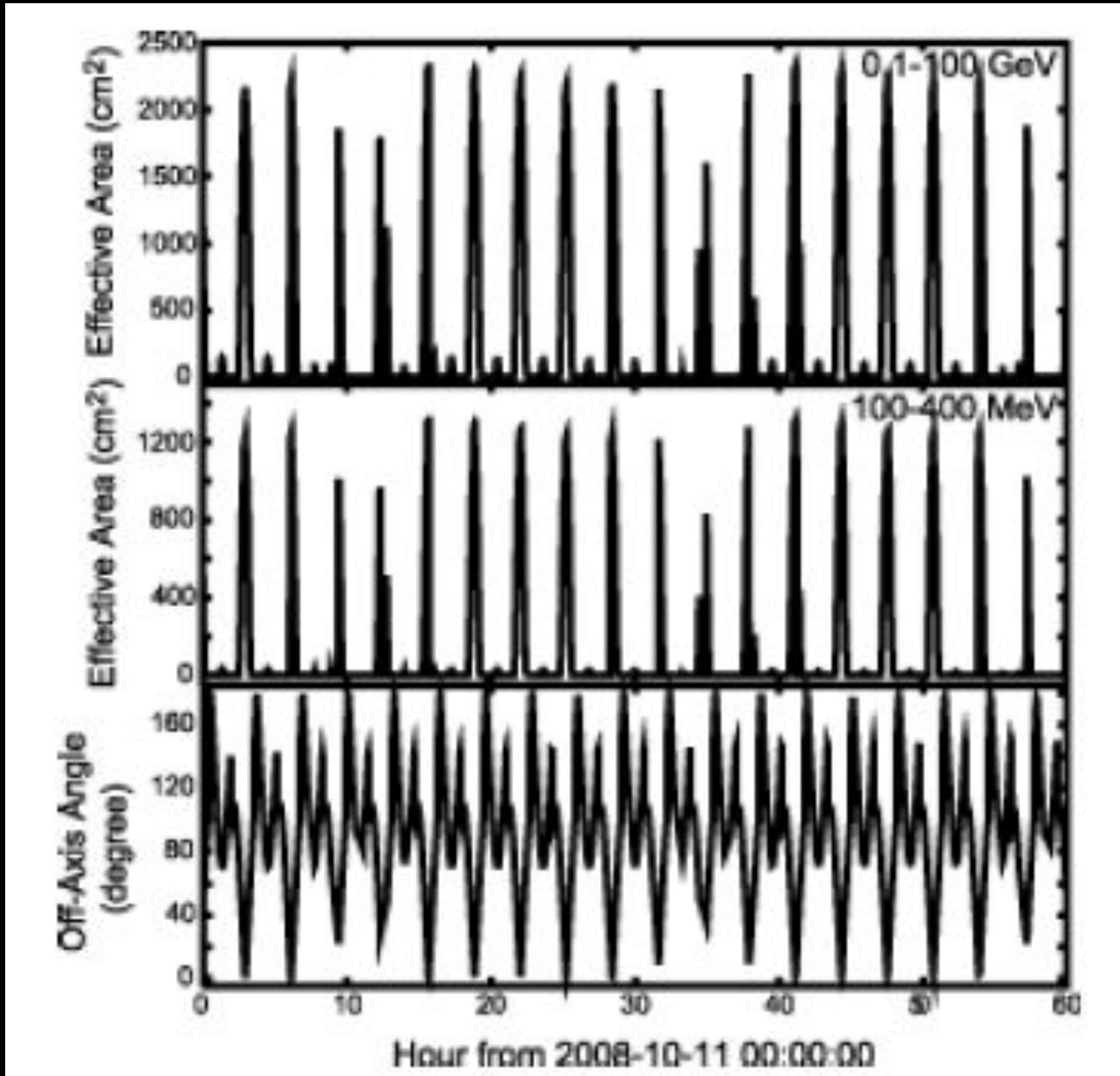
+

source exposure

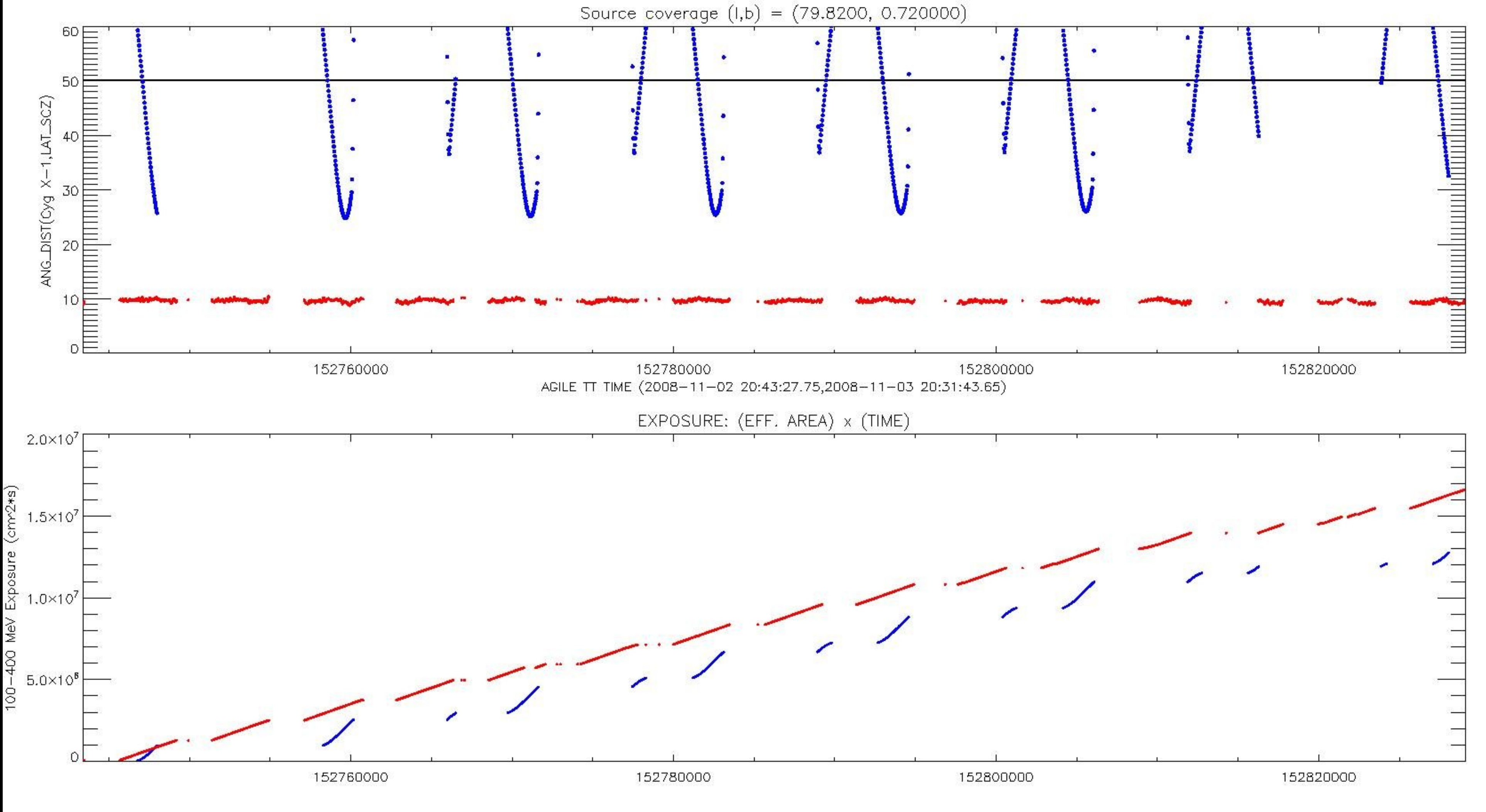
Fermi exposure vs. time

(arXiv:1008.3235)

20 min every 3 hours



Daily source visibility of AGILE (pointing mode) vs. Fermi : Cyg X-3 flare (3 Nov 2008)



Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF

+

source exposure

=

daily monitoring of sources

Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF

+

source exposure

=

daily monitoring of sources

↓

First detection at gamma-rays for micro-quasars

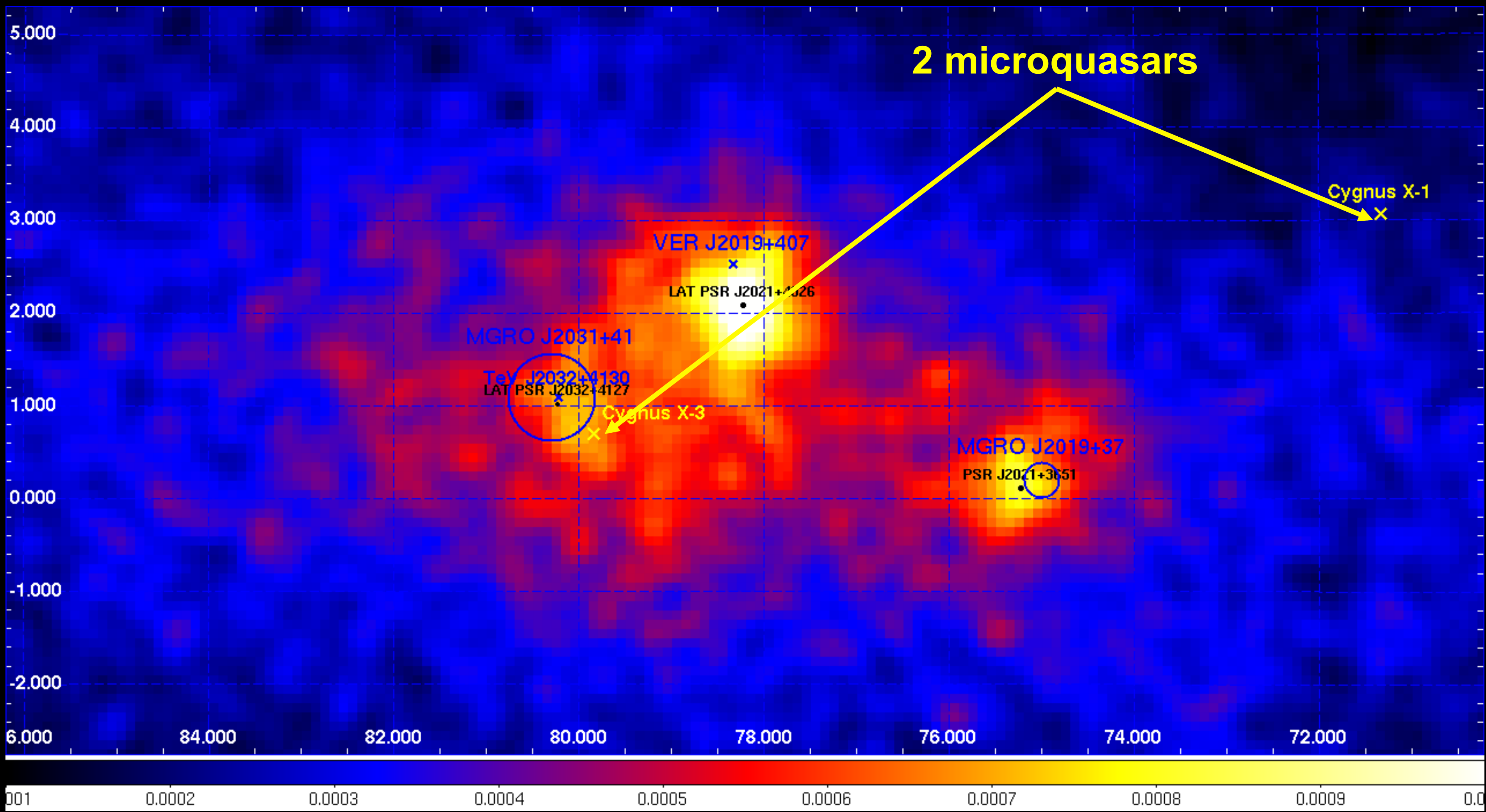
Intense gamma-ray emission is rare

	Θ (degrees)	β	Γ	L_X/L_E	γ/TeV
Cyg X-1	30?	?	?	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+105	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

Microquasars in the Cygnus region:

AGILE-*GRID* INTENSITY MAP (100 MeV-10 GeV)

November 2007 – July 2009,



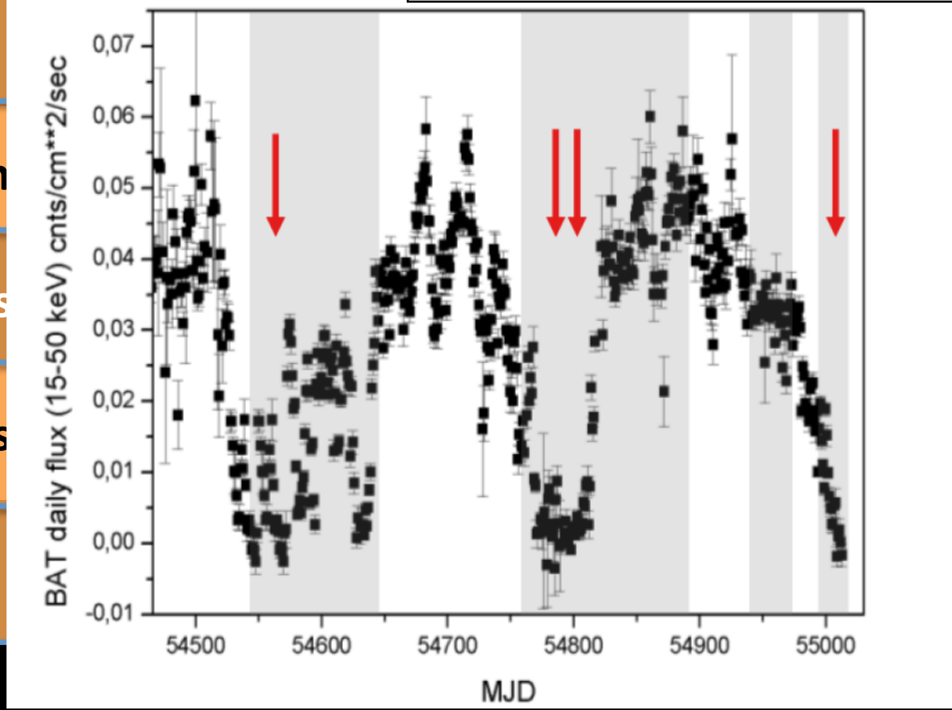
	Cygnus X-1	Cygnus X-3
Compact Object	4-15 $M_\odot$ BH	1.4 $M_\odot$ NS or 10 $M_\odot$ BH
Period	5.6 days, orb. r. ~ 3.4×10^{12} cm	4.8 h, orb. r. ~ 3×10^{11} cm
Companion	O9.7 Supergiant, L ~ 10^{39} erg/s	Wolf Rayet, L ~ 10^{39} erg/s
Companion wind	~ 10^{-6} $M_\odot$/yr, v ~ 2000 km/s	~ 10^{-5} $M_\odot$/yr, v ~ 1000 km/s
Inclination Angle	30?	< 14

Cygnus X-3 is unique in orbital separation, luminosity of the companion star and inclination -> different processes are expected to dominate in the two systems

Cygnus X-1   Cygnus X-3

	Cygnus X-1	Cygnus X-3
Compact Object	4-15 $M_{\odot}$ BH	
Period	5.6 days, orb. r. ~ 3.4 x 10^{12} cn	
Companion	O9.7 Supergiant, L ~ 10^{39} erg/s	
Companion wind	~ 10^{-6} $M_{\odot}$/yr, v ~ 2000 km/s	
Inclination Angle	30?	

Tavani et al. Nature 2009



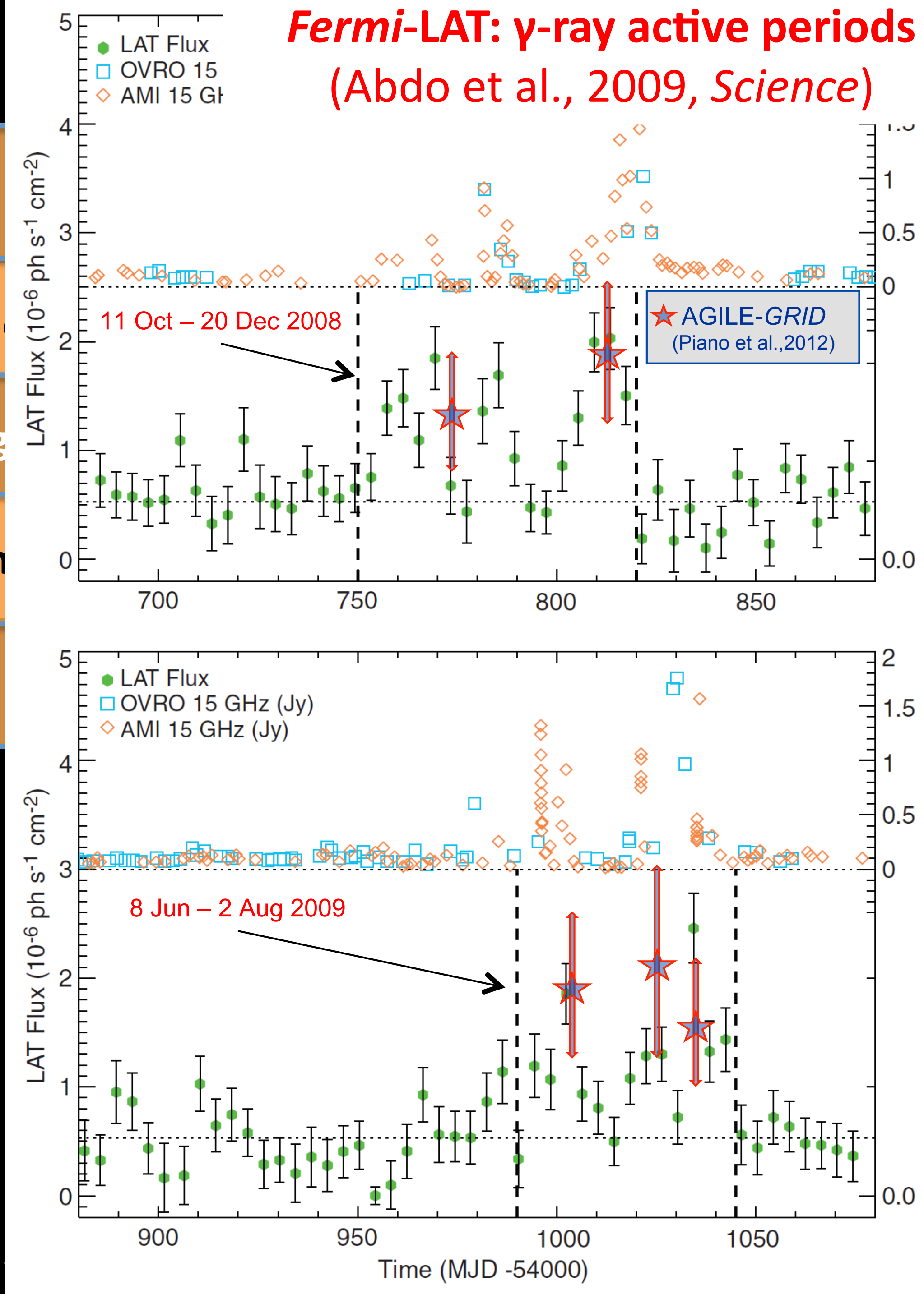
REPETITIVE PATTERN !!

- bright soft X-ray states (soft-to-hard state transitions)
- state preceeding strong radio flares.

Cygnus X-1

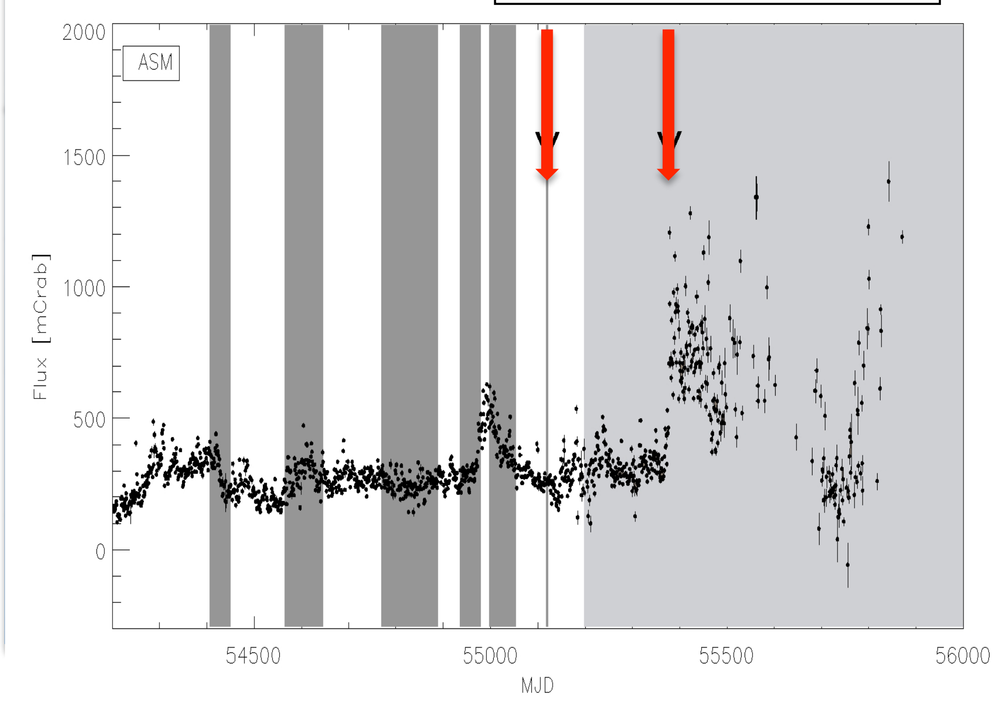
Compact Object	4-15 $M_{\odot}$ BH
Period	5.6 days, orb. r. ~ 3.4 x 10^{12}
Companion	O9.7 Supergiant, L ~ 10^{39} erg
Companion wind	~ 10^{-6} $M_{\odot}$/yr, v ~ 2000 km
Inclination Angle	30?

***Fermi*-LAT: γ-ray active periods**
(Abdo et al., 2009, *Science*)



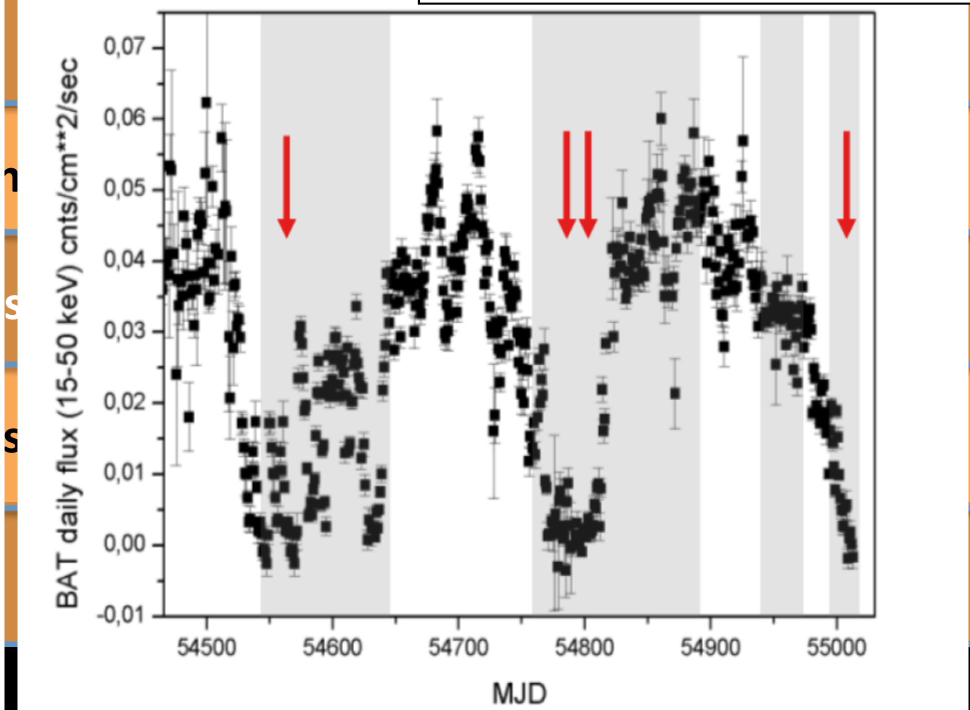
Cygnus X-1

Sabatini et al. 2012



Cygnus X-3

Tavani et al. Nature 2009



SPORADIC

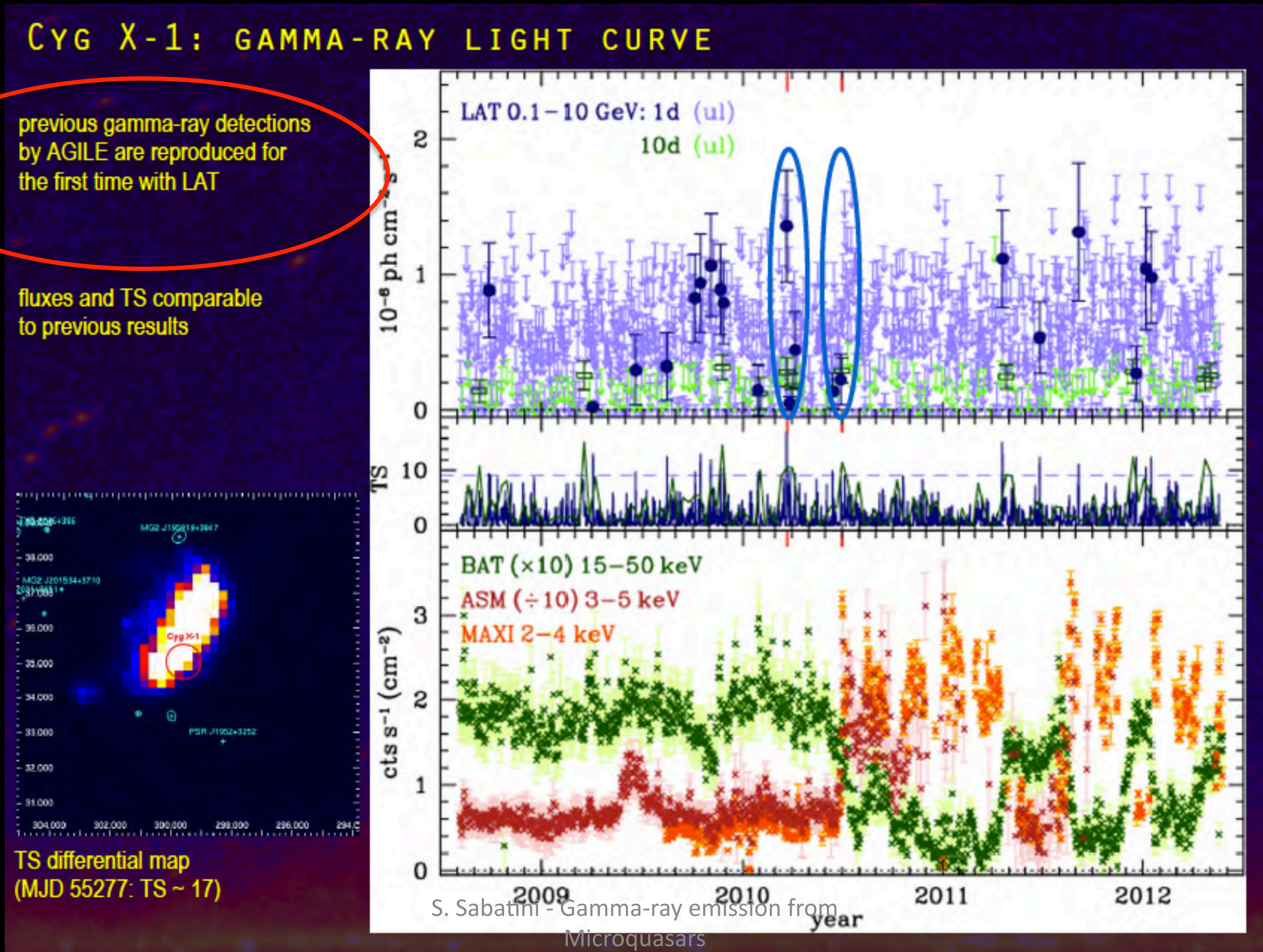
2 episodes:

- **Hard state**
- **Hard-to-soft transition**

REPETITIVE PATTERN !!

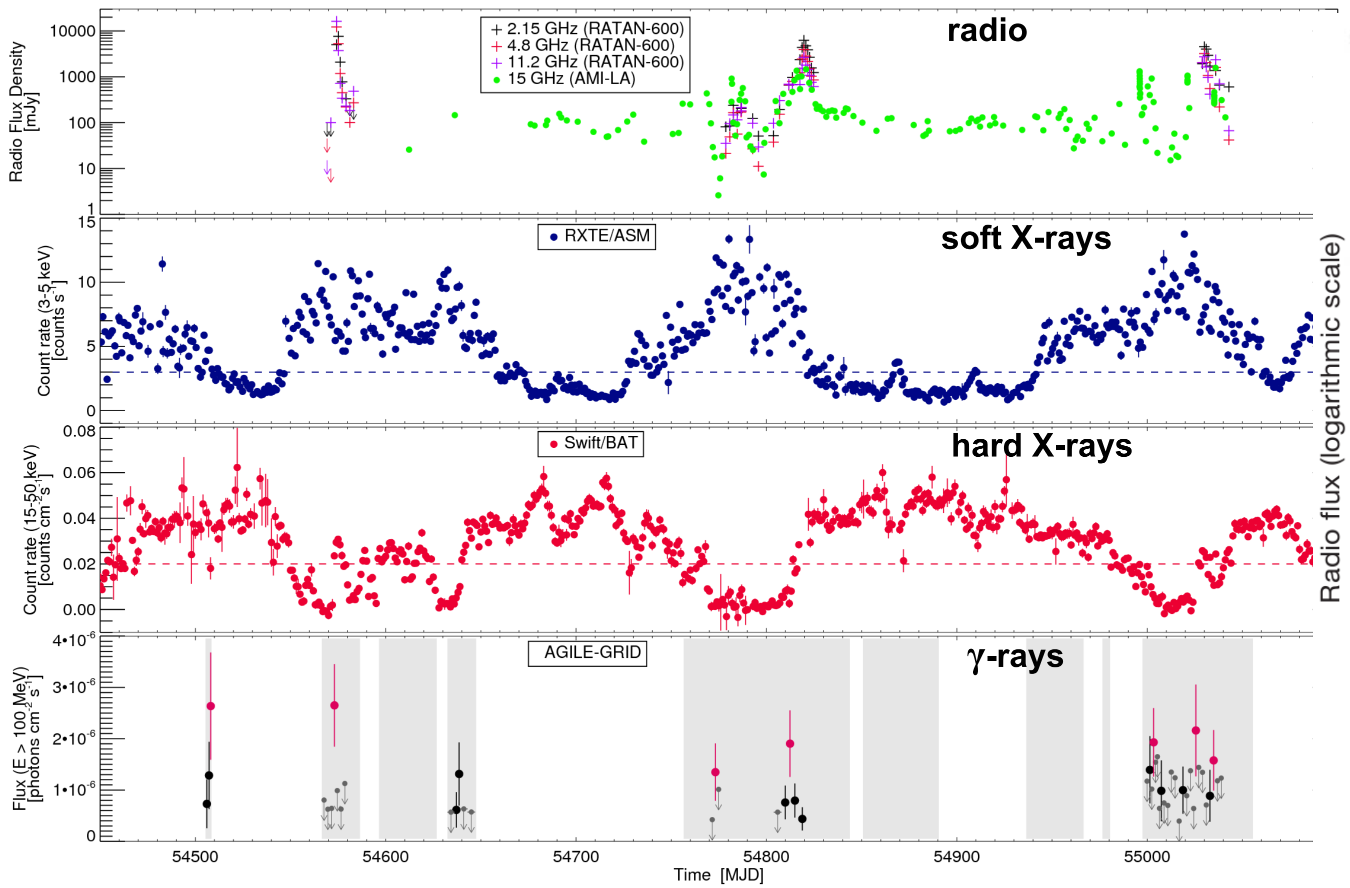
- **bright soft X-ray states (soft-to-hard state transitions)**
- **state preceeding strong radio flares.**

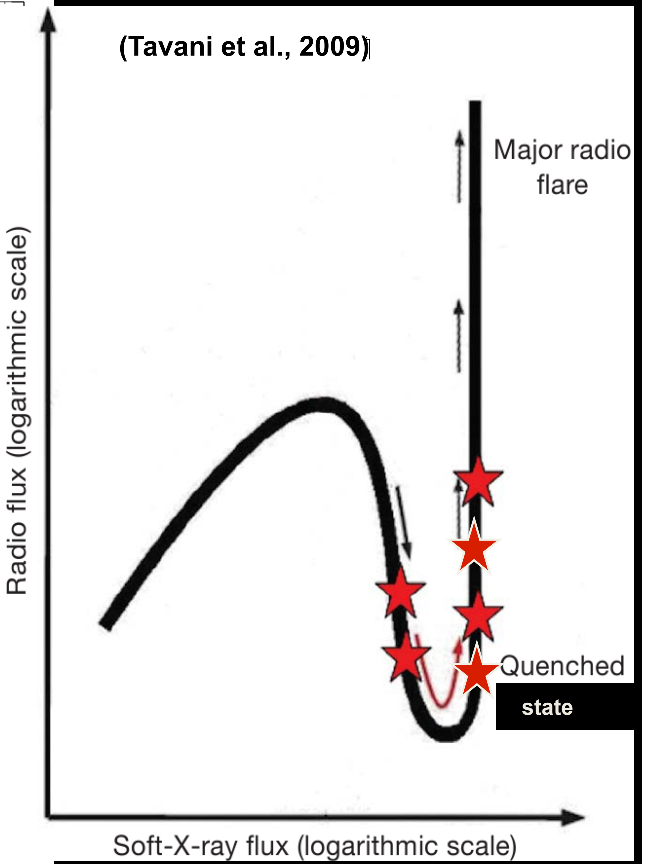
A. BODAGHEE – Fermi Symp 2012



CYGNUS X-3

γ-ray activity detected by AGILE (November 2007 → July 2009) in the context of the multiwavelength emission





All the flaring episodes are associated with:

- **bright soft X-ray states (soft-to-hard state transitions)**
- **very low hard X-ray emission**
- **state preceeding strong radio flares.**

Cygnus X-3 γ-ray spectrum

By integrating the 7 γ-ray flares:

(E ≥ 100 MeV)

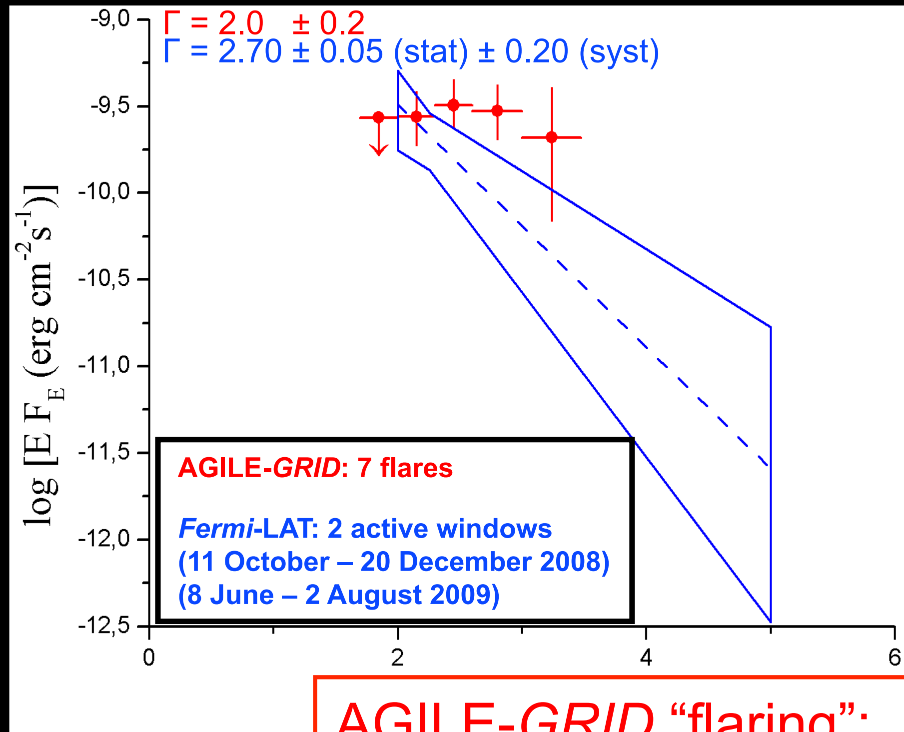
6.7σ pre-trial

5.5σ post-trial

(l,b) = (79.7, 0.9) ± 0.4° (stat.) ± 0.1° (syst.),

F = (158 ± 29) x 10^{-8} ph cm^{-2} s^{-1}

[F_{steady} = (14 ± 3) x 10^{-8} ph cm^{-2} s^{-1}]



AGILE-*GRID* "flaring":
[158 ± 29] ·10^{-8} ph cm^{-2} s^{-1}

Fermi-LAT "active":
[119 ± 6 (stat) ± 37 (syst)] ·10^{-8} ph cm^{-2} s^{-1}

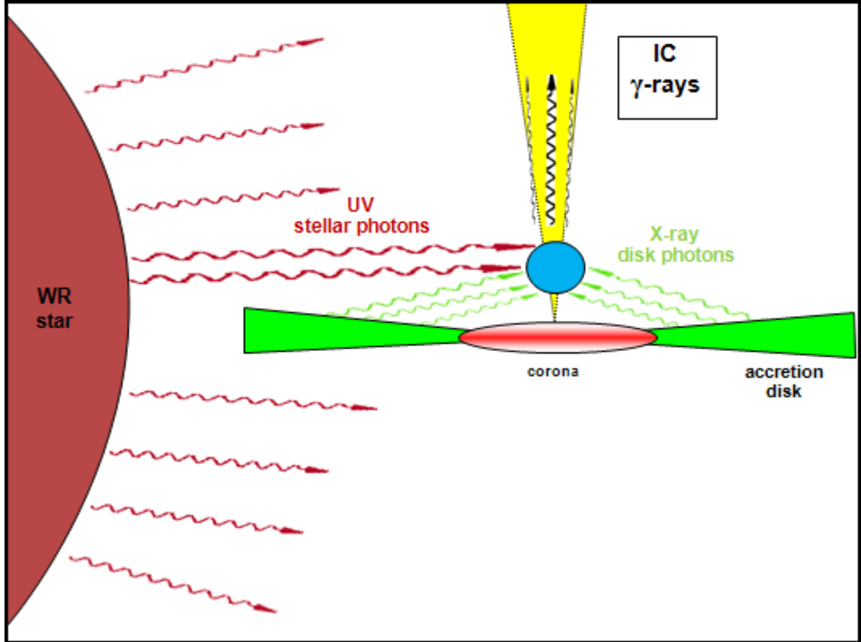
(Piano et al., 2012)

LEPTONIC model:

- corona “evacuation” (→ Hypersoft State)
- relativistic electrons/positrons scattering

off soft photons (disk + WR star)

- > gamma-rays from IC processes in the jet



Star: L ~ 10^{39} erg/s

Disk: T_{bb} ~ 1.3 keV

plasmoid: r ~ $3 \cdot 10^{10}$ cm

Inclination: $i = 14°$

(Piano et al., 2012)

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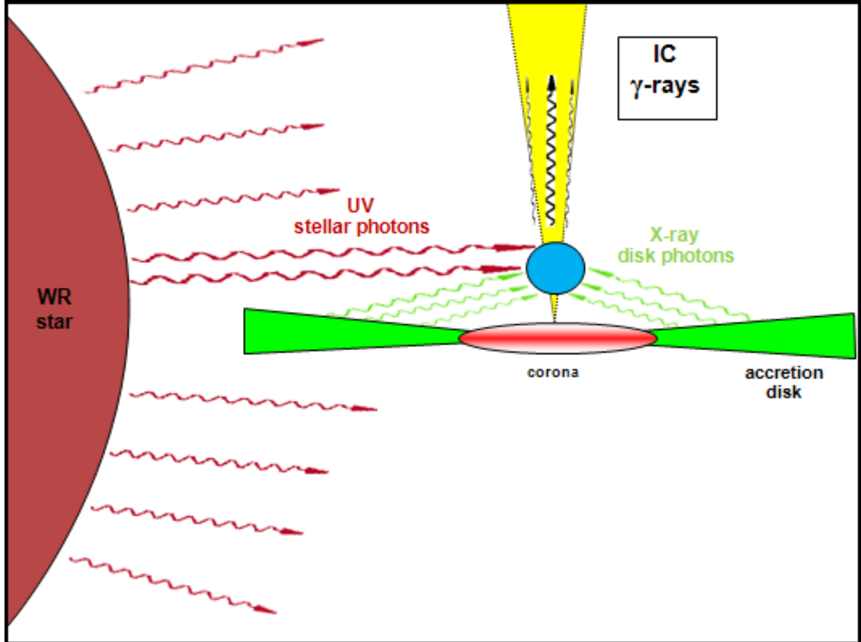


Star: L ~ 10^{39} erg/s

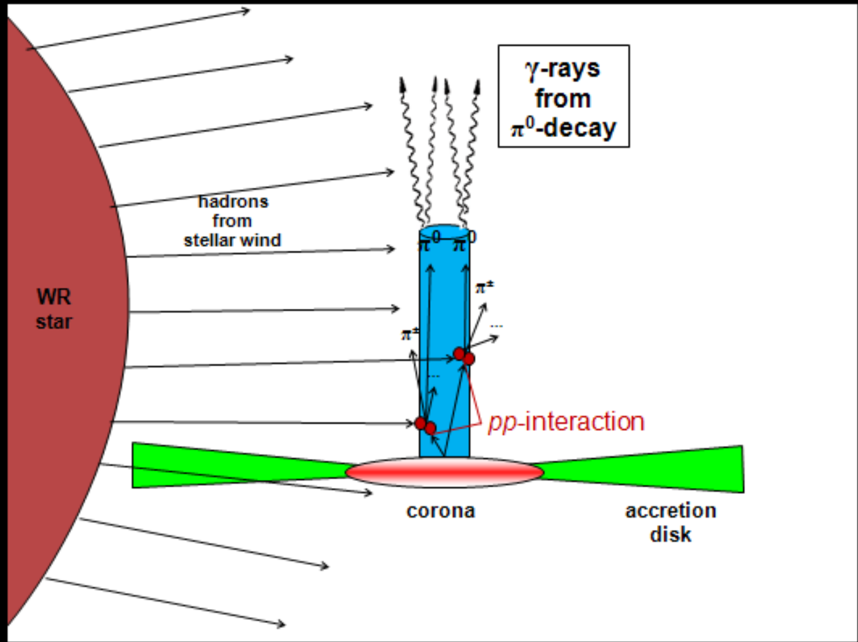
Disk: T_{bb} ~ 1.3 keV

plasmoid: r ~ $3 \cdot 10^{10}$ cm

Inclination: i = 14°

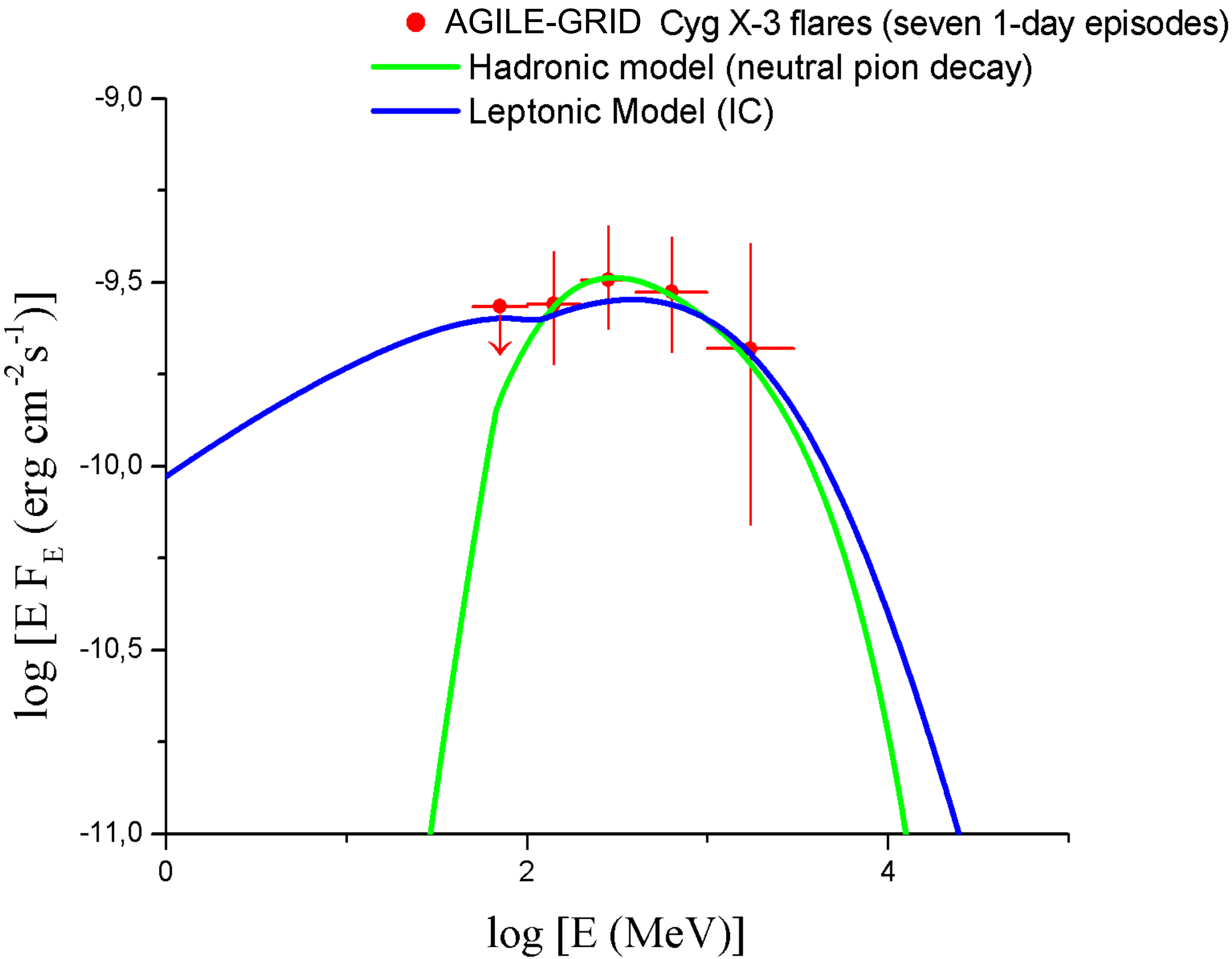
HADRONIC model:

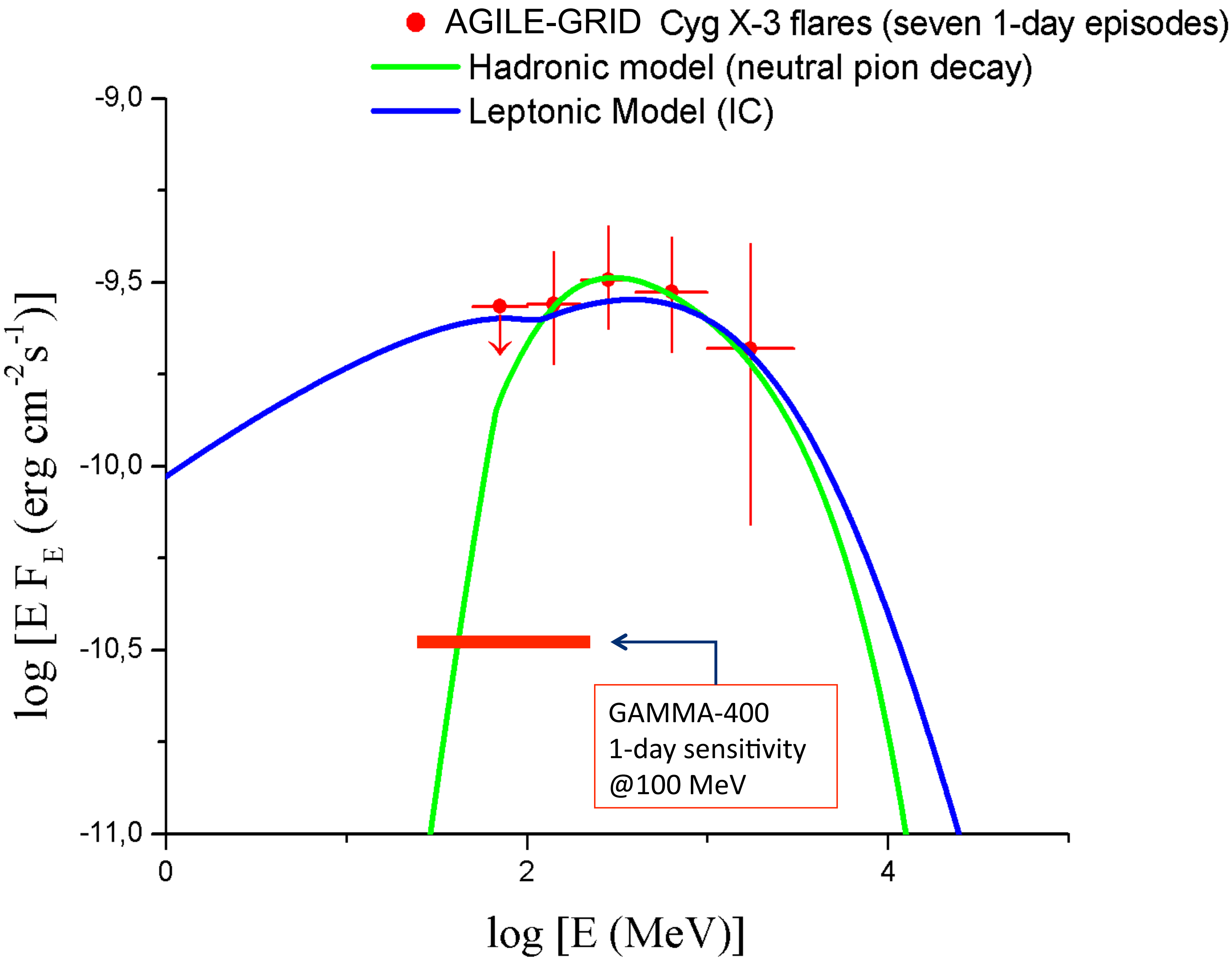
- **injection of mildly relativistic protons**
- **inelastic scattering of hadronic gas of the WR strong wind with hadrons in the jet :** $p + p \rightarrow \pi^0 + \ldots$; $\pi^0 \rightarrow \gamma + \gamma$



radius R~ $3 \cdot 10^{10}$ cm

height H ~ $3 \cdot 10^{12}$ cm


AGILE-GRID Cyg X-3 flares (seven 1-day episodes)
Hadronic model (neutral pion decay)
Leptonic Model (IC)
-9,0
-9,5
-10,0
-10,5
-11,0
0
2
4
log [E F_E (erg cm^-2 s^-1)]
log [E (MeV)]



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-9,0
-9,5
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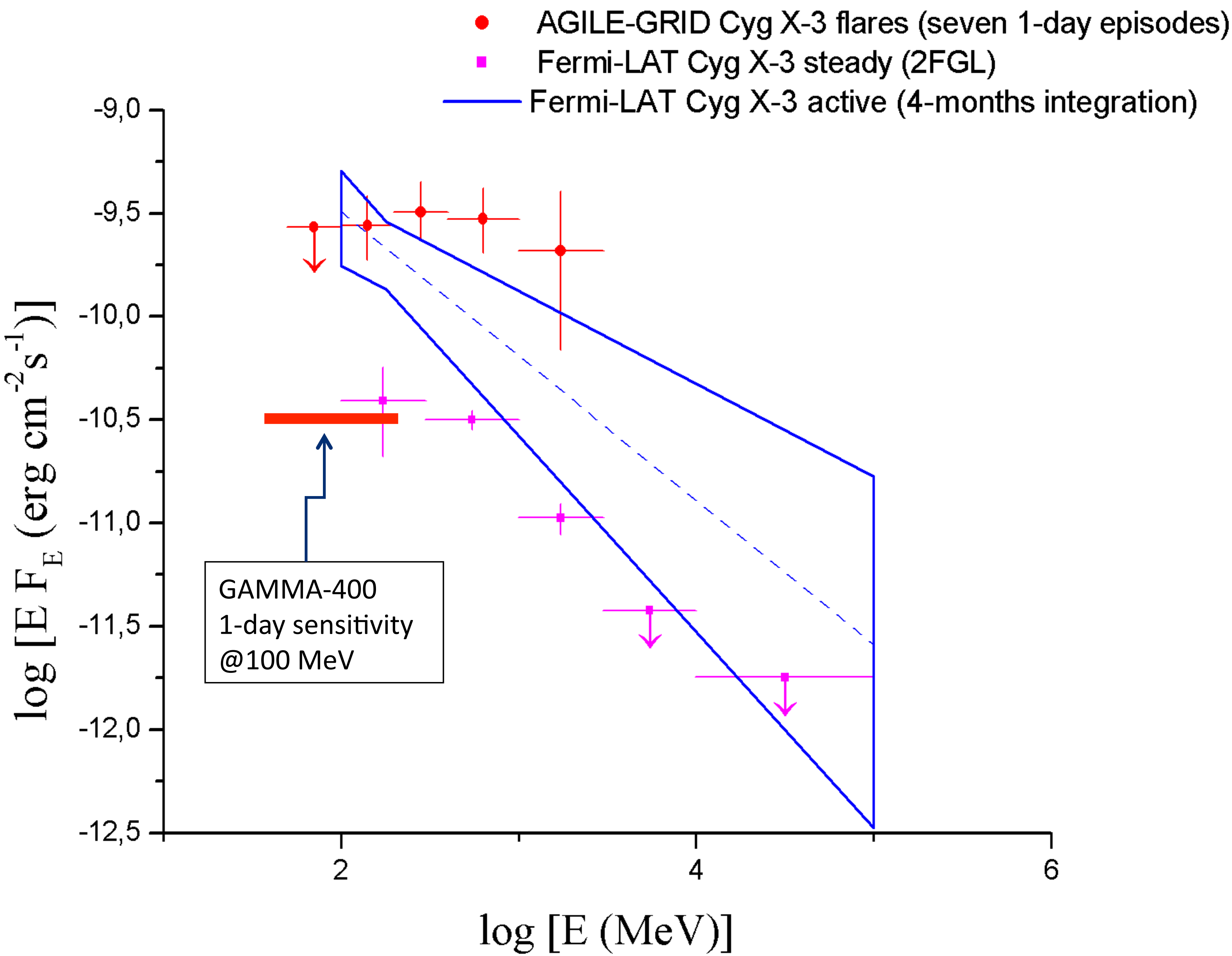
-10,5
-11,0
0
2
4
log [E F$_E$ (erg cm^{-2}s^{-1})]
log [E (MeV)]
GAMMA-400
1-day sensitivity
@100 MeV

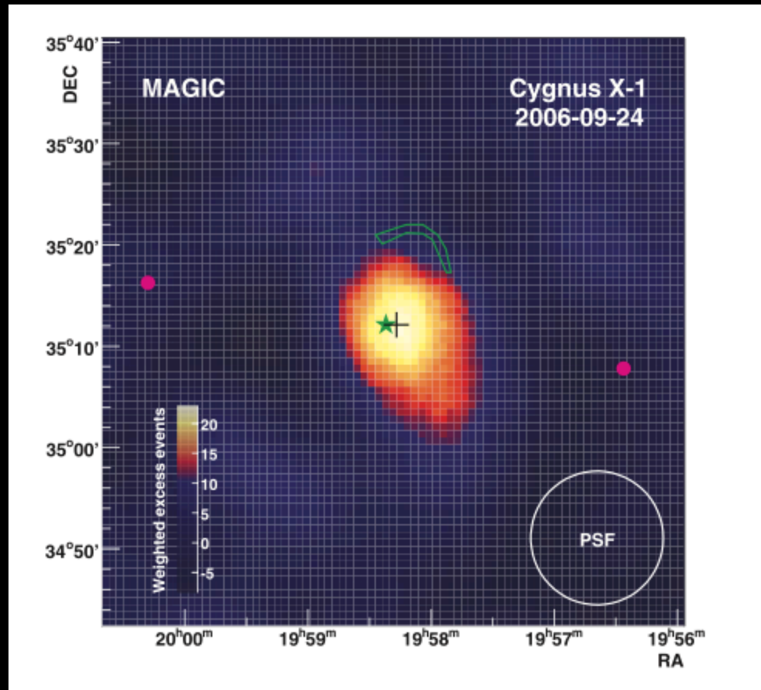


AGILE-GRID Cyg X-3 flares (seven 1-day episodes)
Fermi-LAT Cyg X-3 steady (2FGL)
Fermi-LAT Cyg X-3 active (4-months integration)
GAMMA-400
1-day sensitivity
@100 MeV
log [E F_E (erg cm^-2 s^-1)]
log [E (MeV)]
-9,0
-9,5
-10,0
-10,5
-11,0
-11,5
-12,0
-12,5
2
4
6

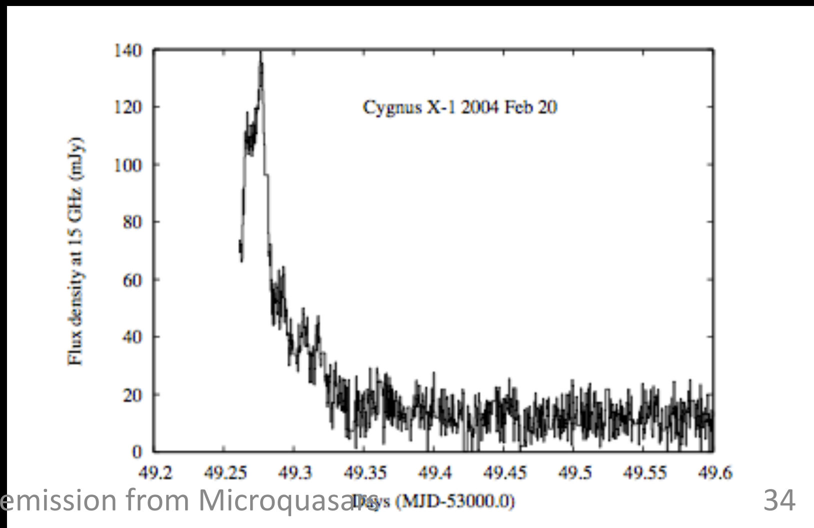
Cyg X-1 TRANSIENT ACTIVITY in GAMMA-RAYS

FAST FLARING ACTIVITY

- VHE (>100GeV) flare lasting ~1hr (MAGIC; Albert 2007)
  - An intense peak in hard X-rays followed it (INTEGRAL; Malzac 2008)



- Transient relativistic RADIO jet ~20min (MERLIN; Fender 2006)

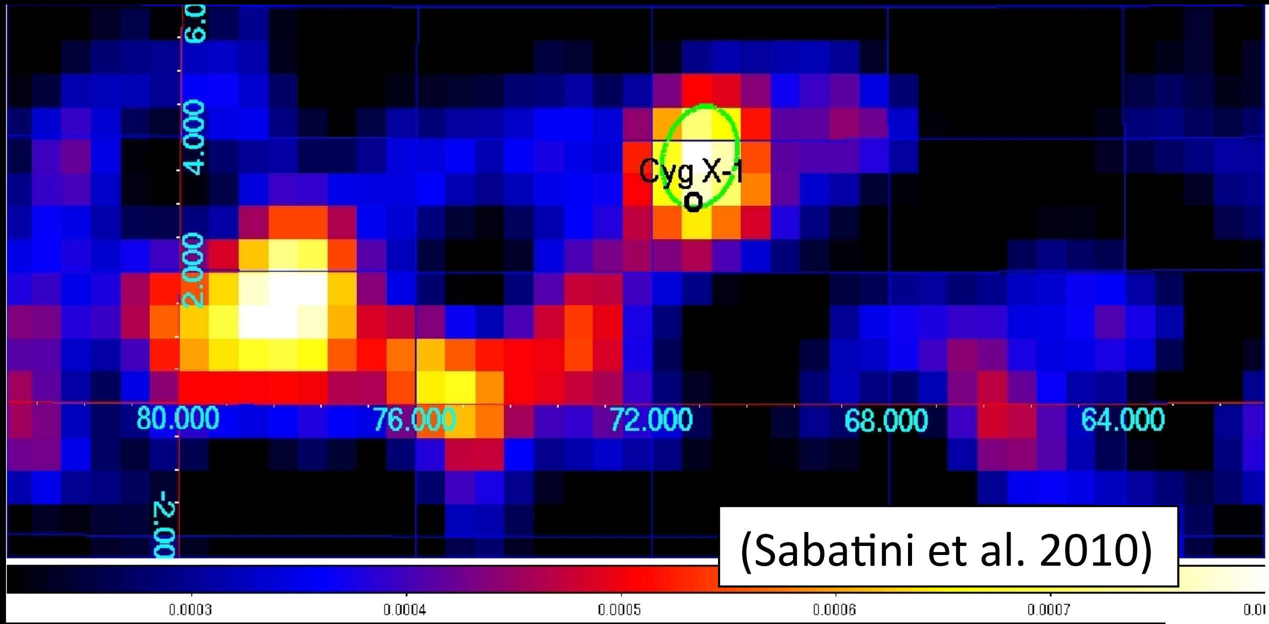


GAMMA-RAY FLARING EPISODES

HARD STATE

1-day duration (or less)

SIGNIFICANCE: 5.3σ
F_{γ} = 232±66 x 10^{-8} ph/cm^2/s



(Sabatini et al. 2010)

GAMMA-RAY FLARING EPISODES

HARD STATE

1-day duration (or less)

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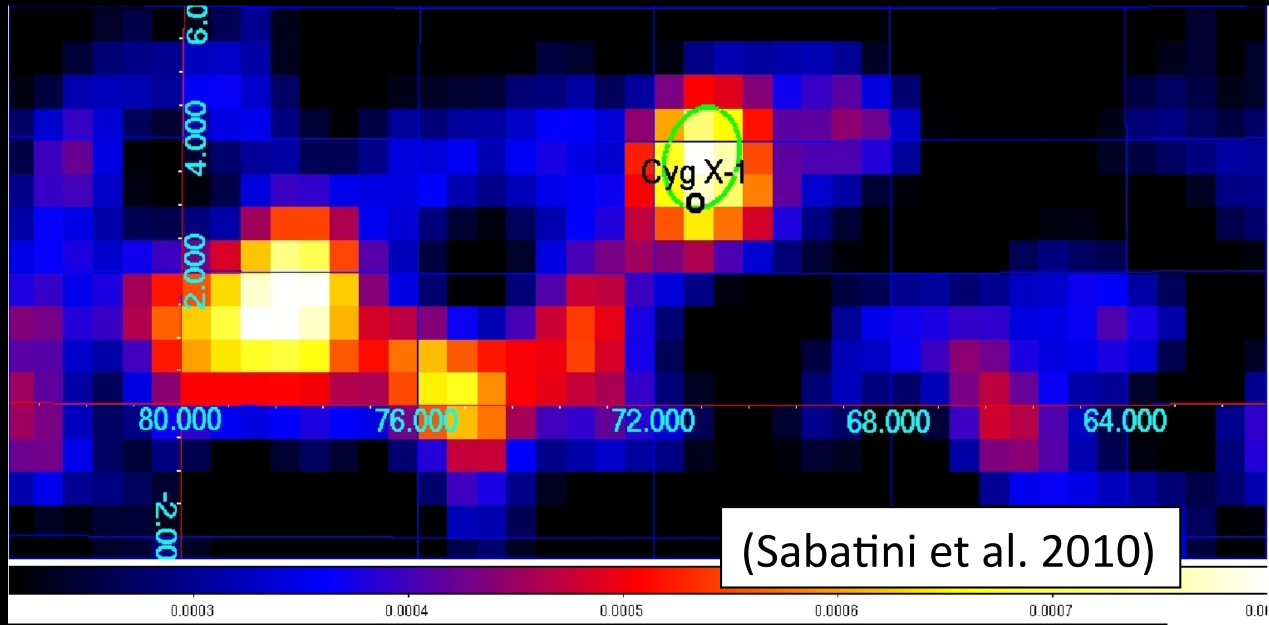
$F_{\gamma} = 232 \pm 66 \times 10^{-8}$ ph/cm²/s

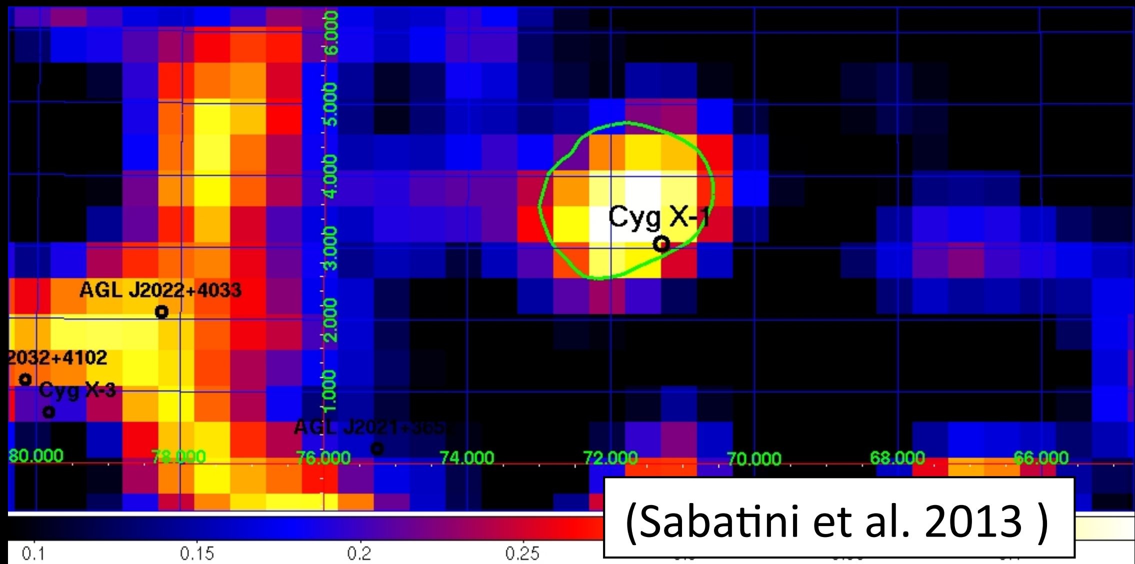


(Sabatini et al. 2010)

SOFT STATE

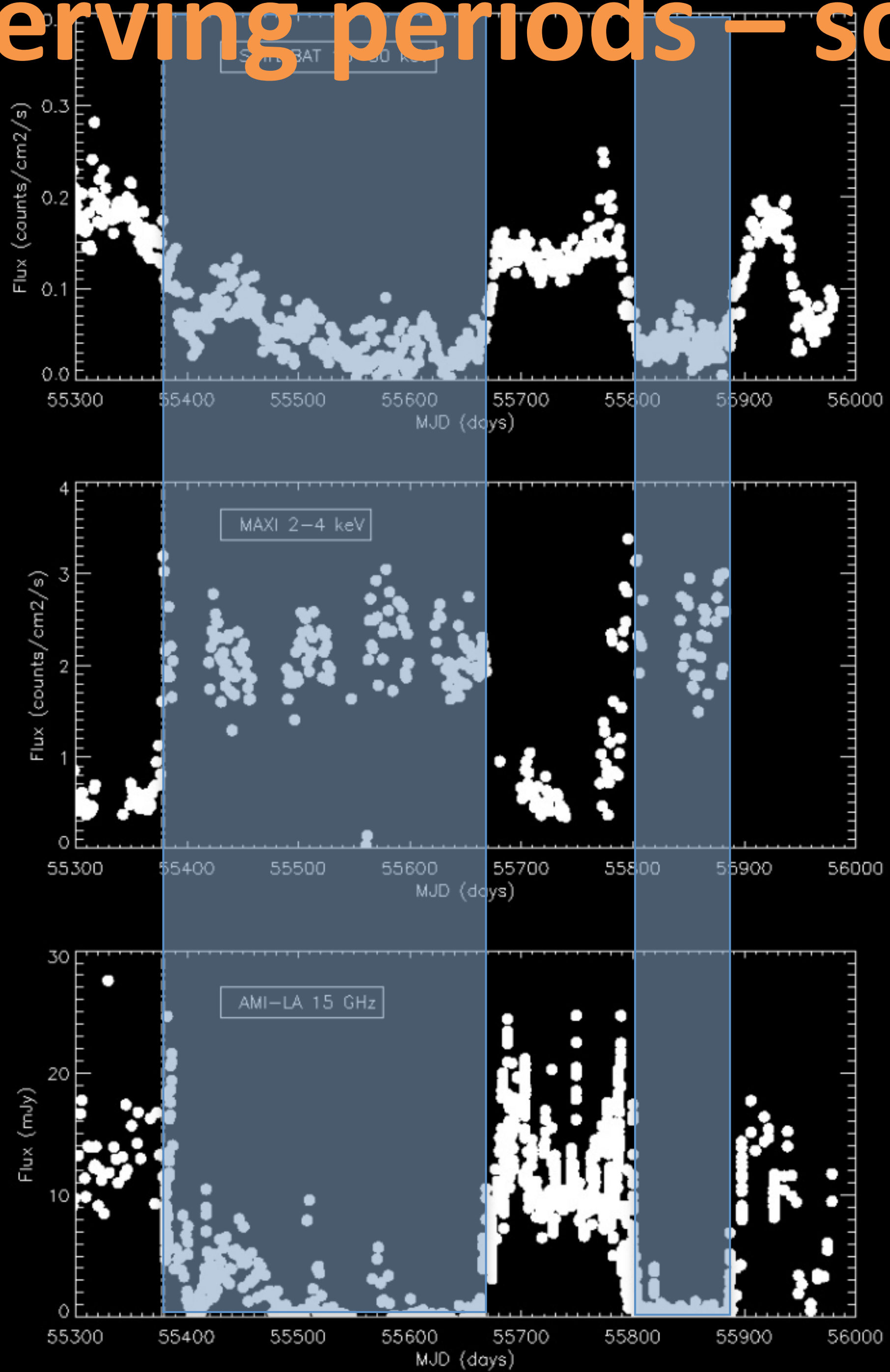
2-days duration (or less)

SIGNIFICANCE: 3σ
$F_{\gamma} = 145 \pm 78 \times 10^{-8}$ ph/cm²/s



(Sabatini et al. 2013)

AGILE observing periods – soft state

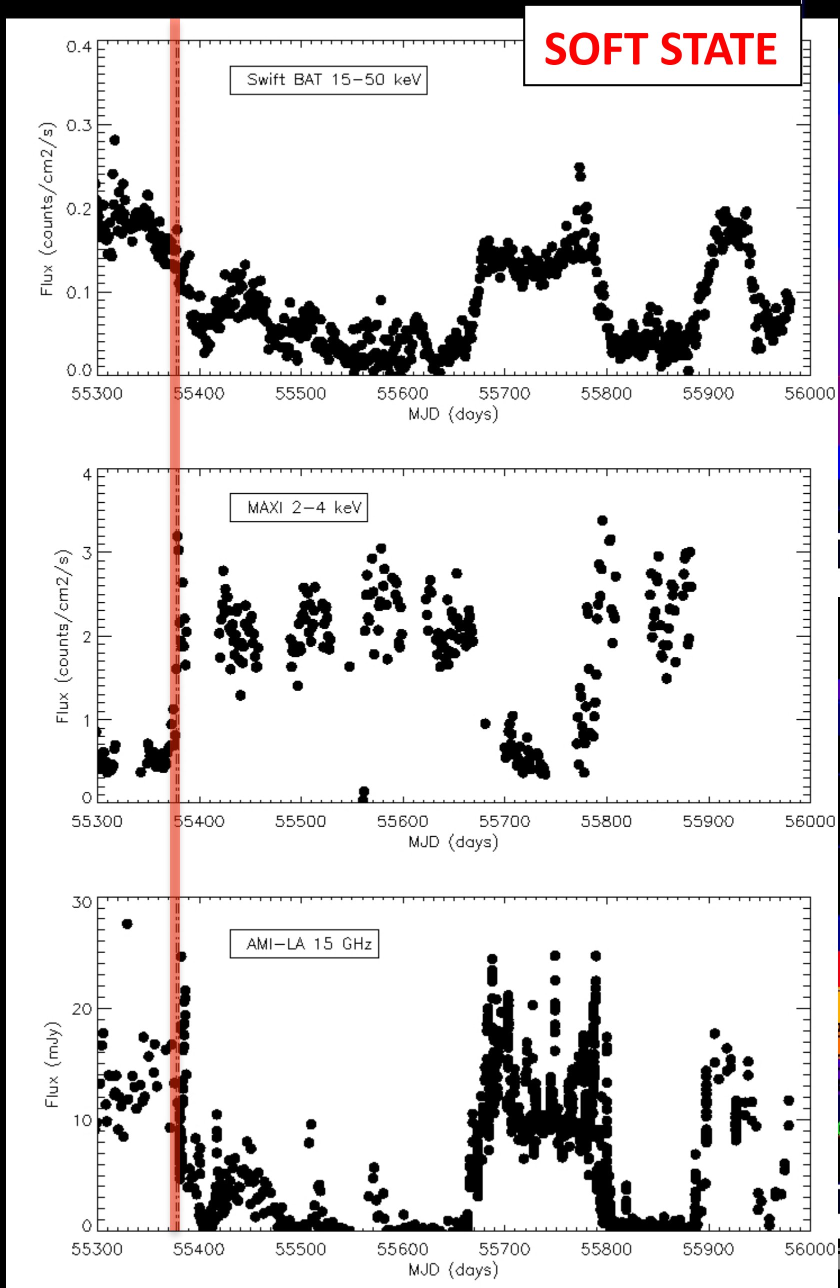


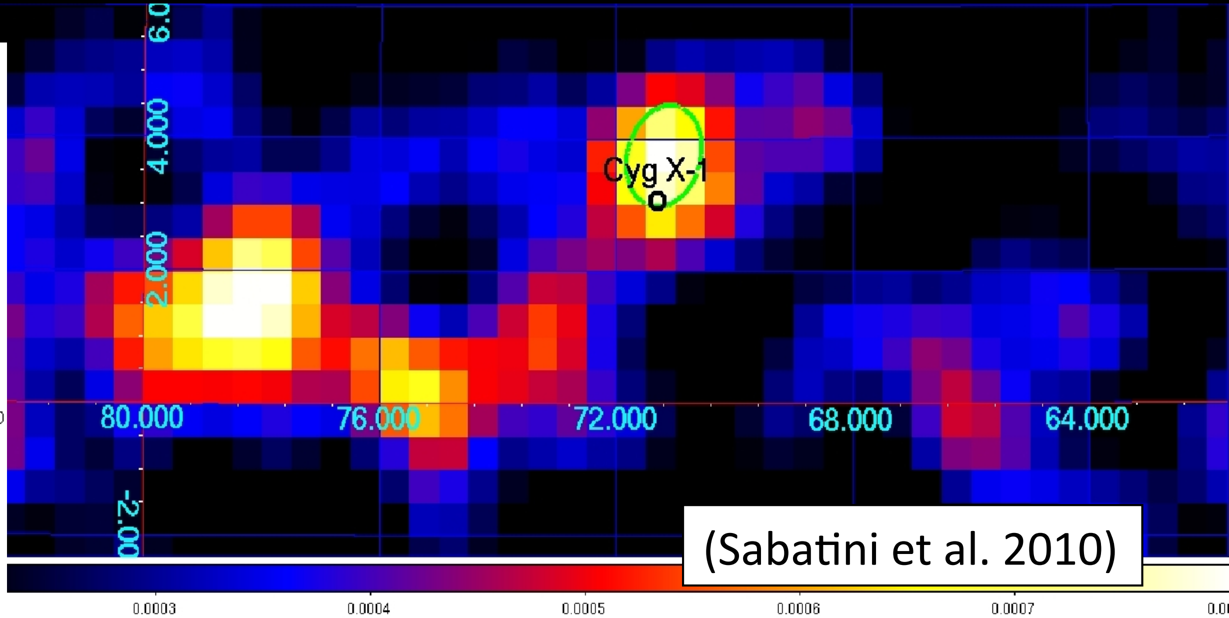
BAT/Swift
hard X-rays

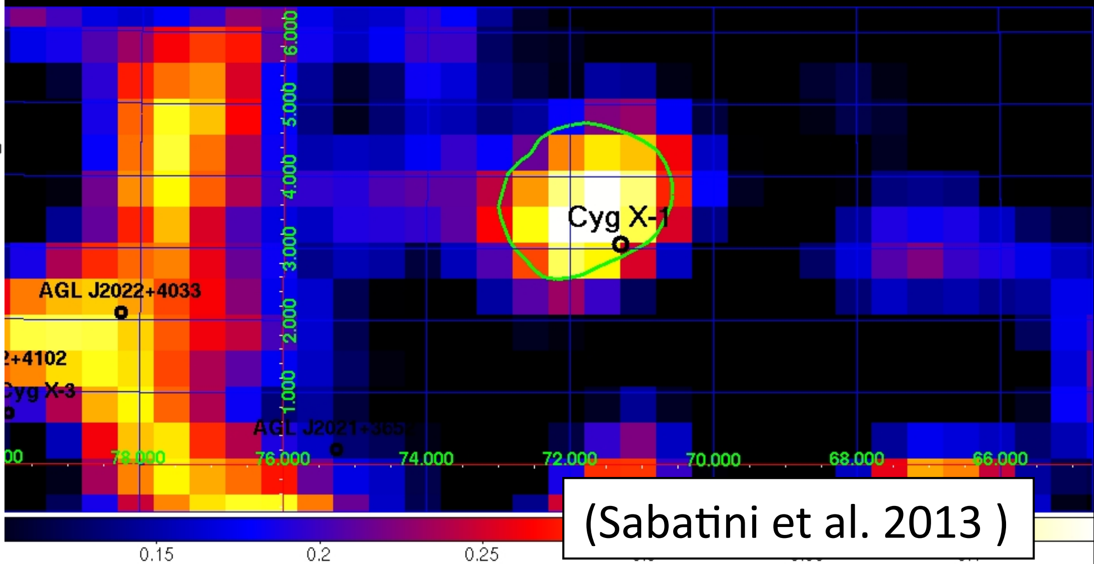
MAXI
X-rays

AMI-LA
radio, 10 GHz

GAMMA-RAY FLARING EPISODES



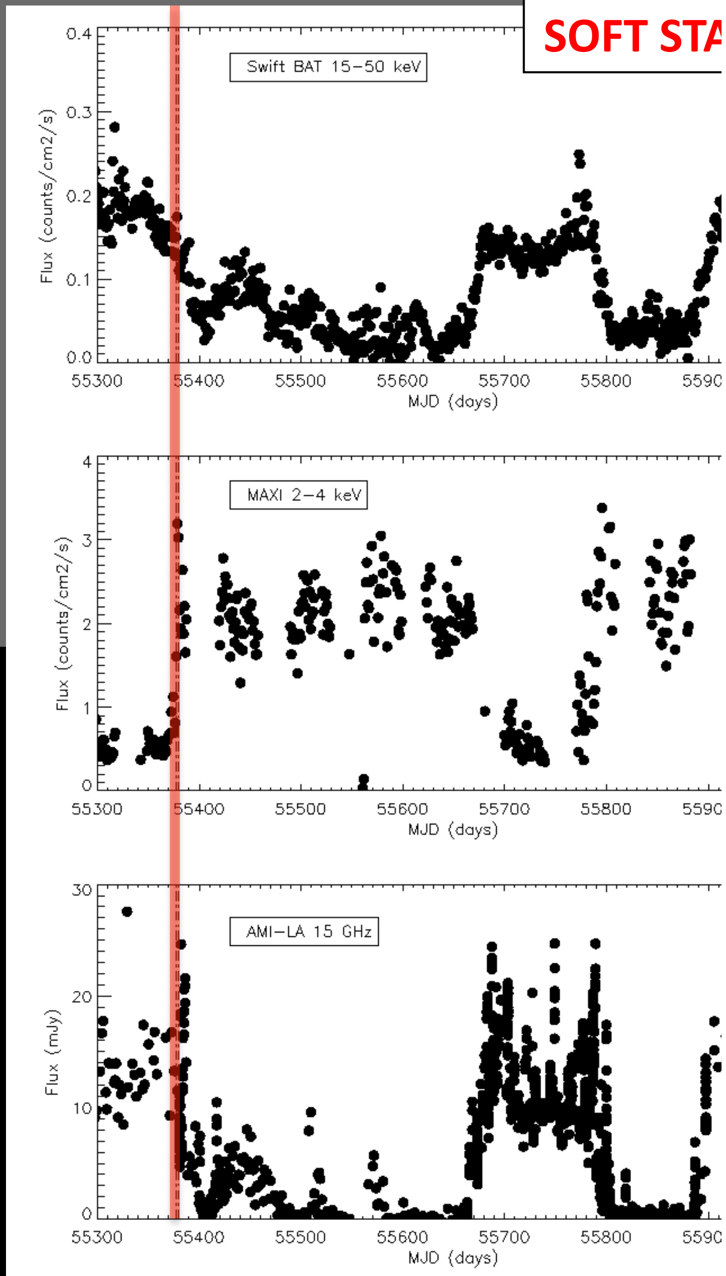


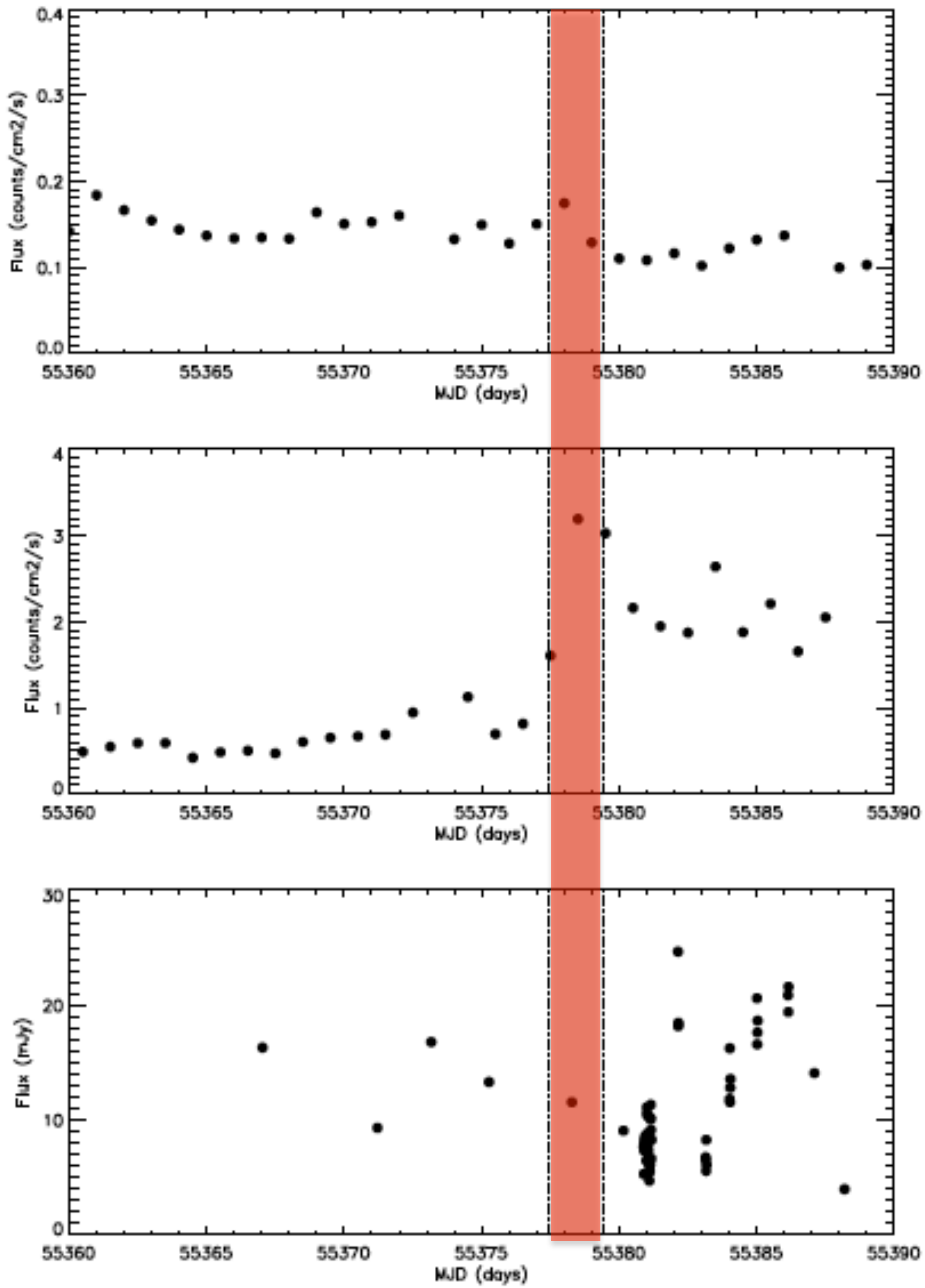


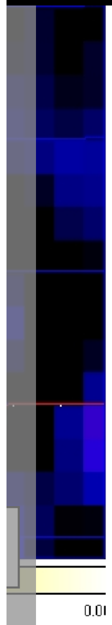
38

GAMMA-

SOFT STA

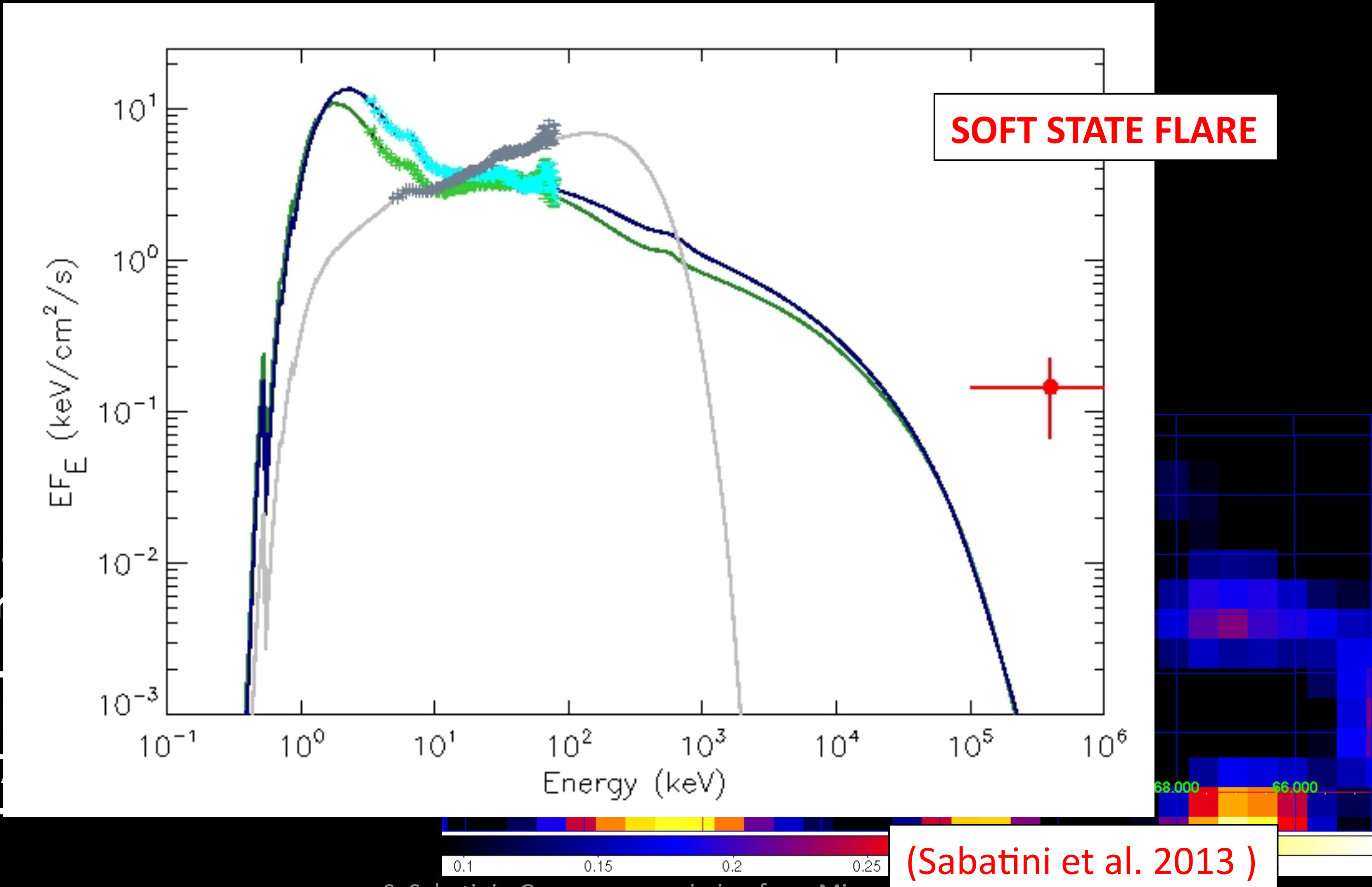






AGILE candidate flare: 30 June – 2 July 2010

Possible violations of comptonization model during gamma-ray flares



2-days dur

SIGNIFICA

F_{γ} = 145±

Modelling the jet component

672 *A. A. Zdziarski, P. Lubiński and M. Sikora*

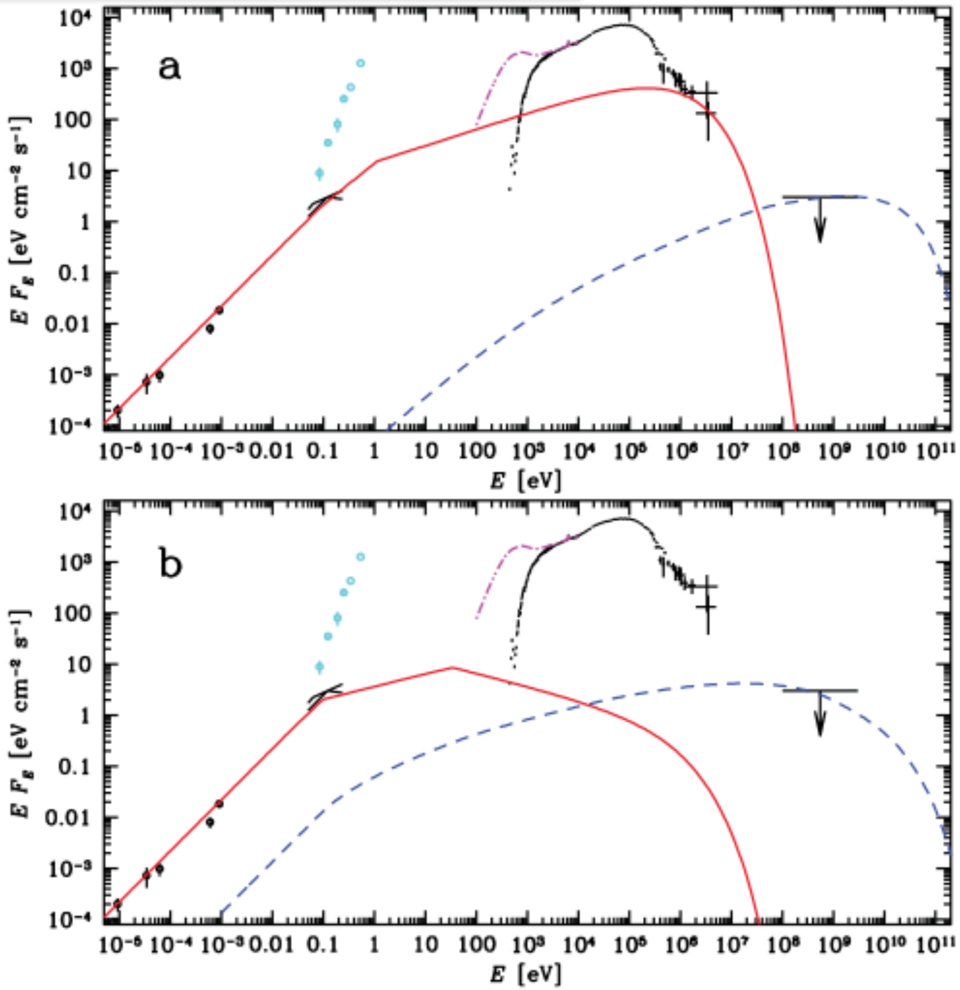
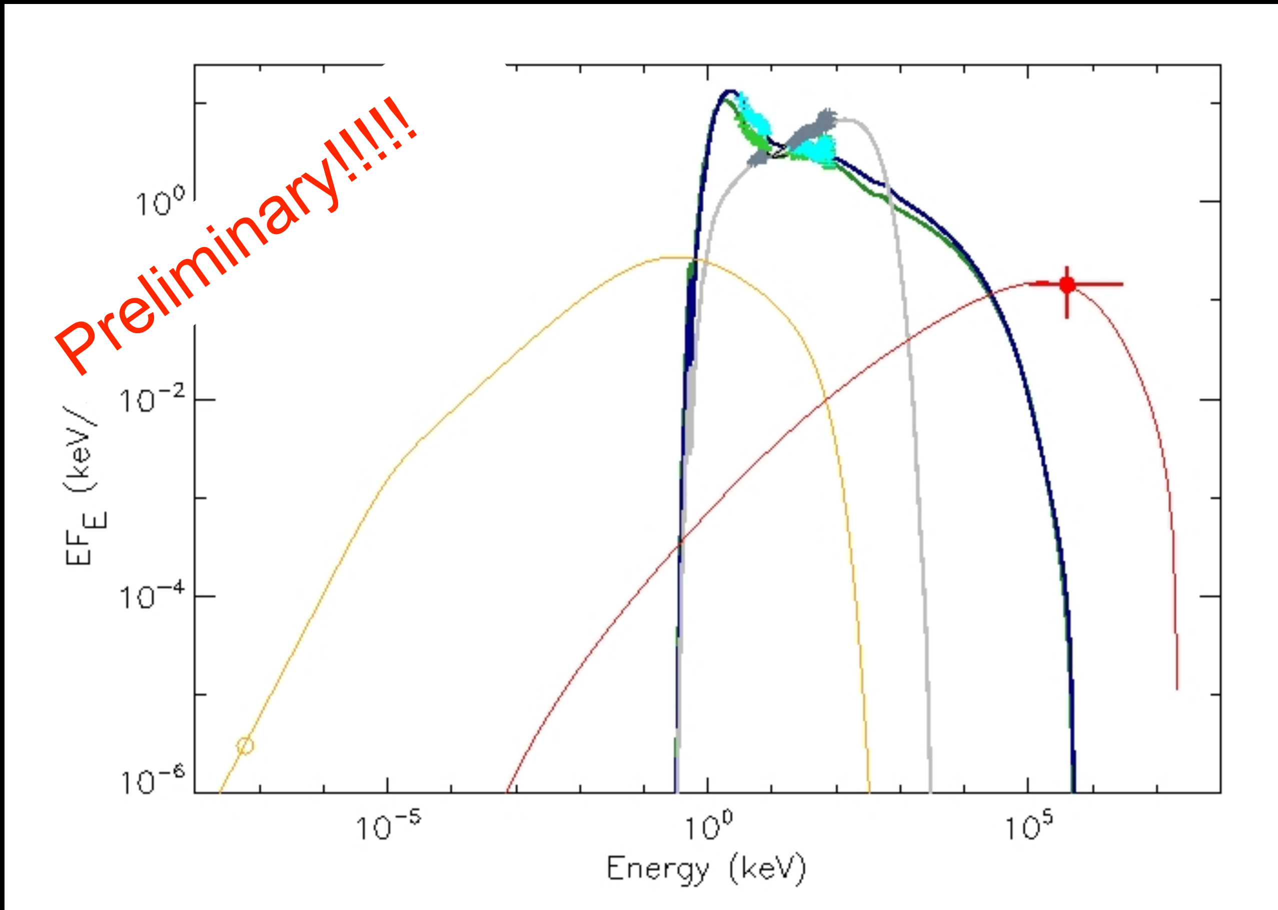


Figure 5. The data are the same as in Fig. 1. The red solid and blue dashed curves show the model synchrotron and Compton components, respectively. (a) Model 1 for $p = 1.35$, accounting for the observed MeV tail, which corresponds to the approximately maximum jet emission allowed by the data. (b) Model 2 for $p = 2.5$, in which case the jet emission is well below the MeV tail, which tail is then most likely emitted by hybrid plasma in the accretion flow. See

ONE ZONE MODEL

SSC only

Possible modelling of the jet component



broken power-law (gamma_b=1800, gamm_max=gamma_b)

δ~ 2

K=10^9cm^-3

B=2e3 Gauss

r=10^9cm.

Not univocally determined (other parameters are allowed, eg δ =1.5 and r=5x10^9 with a smaller K…)

CONCLUSIONS

- Intense gamma-ray emission is **rare** in microquasars

	Θ (degrees)	β	Γ	L_X/L_E	γ/TeV
Cyg X-1	30?	?	?	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+105	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

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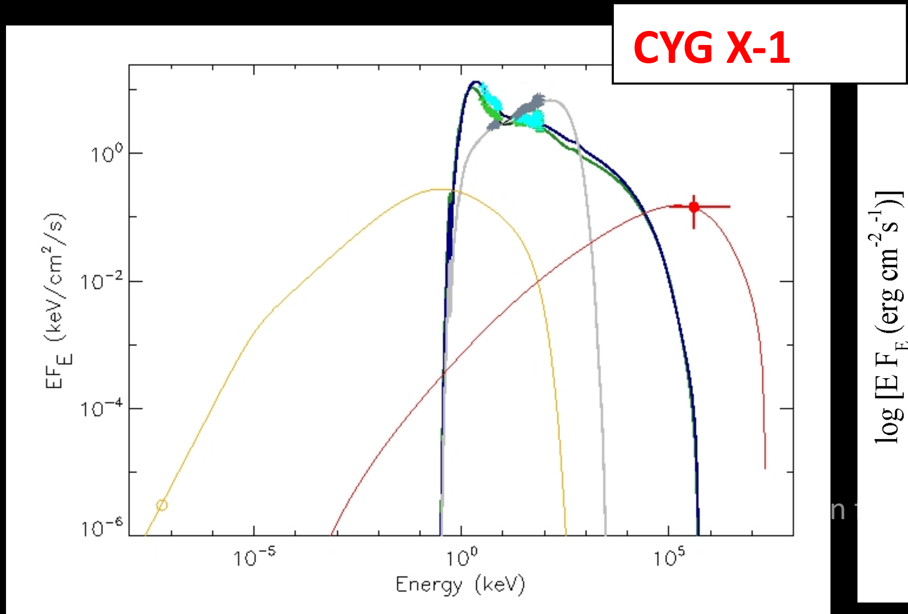
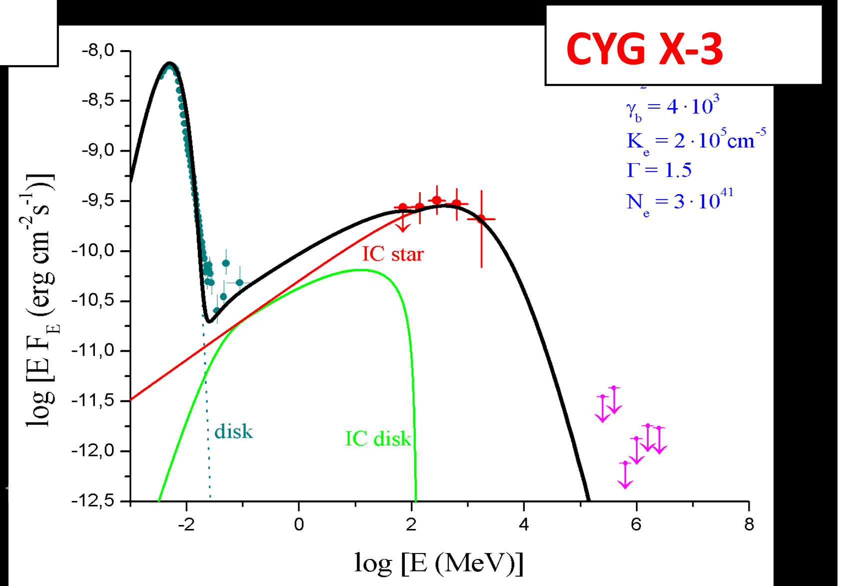
- **Contribution of the jet** observed for the first time at **gamma-rays** -> during transitions (Cyg X-3 and possibly Cyg X-1)



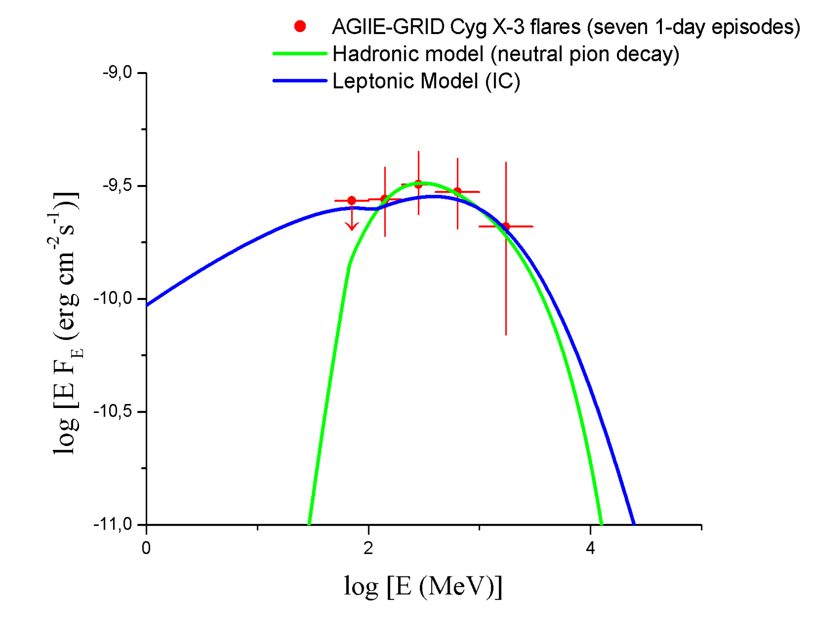


CONCLUSIONS

- Intense gamma-ray emission is **rare** in microquasars
- **Contribution of the jet** observed for the first time at **gamma-rays** -> during transitions (Cyg X-3 and possibly Cyg X-1)
- Cyg X-3 repetitive pattern is deterministic. Leptonic or hadronic scenario still

allowed ⟶

improved sensitivity is needed!



Next generation of gamma-ray instruments (GAMMA-400?):

- give **strong constraints to the SED** of the γ-ray flares
- give strong constraints to the **duration** of the γ-ray flares (do they really last 1-2 days, or less?)
- discriminate **leptonic/hadronic** scenarios

- detect the **steady emission in 1 day** @100 MeV (?)
- analyze the **spectral evolution** during the γ-ray flares

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THANKS FOR YOUR ATTENTION

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