THE MICROQUASARS OF THE CYGNUS REGION: GAMMA-RAY EMISSION AND PERSPECTIVES WITH CTA

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THIS WORK WAS CONDUCTED IN THE CONTEXT OF THE CTA CONSORTIUM

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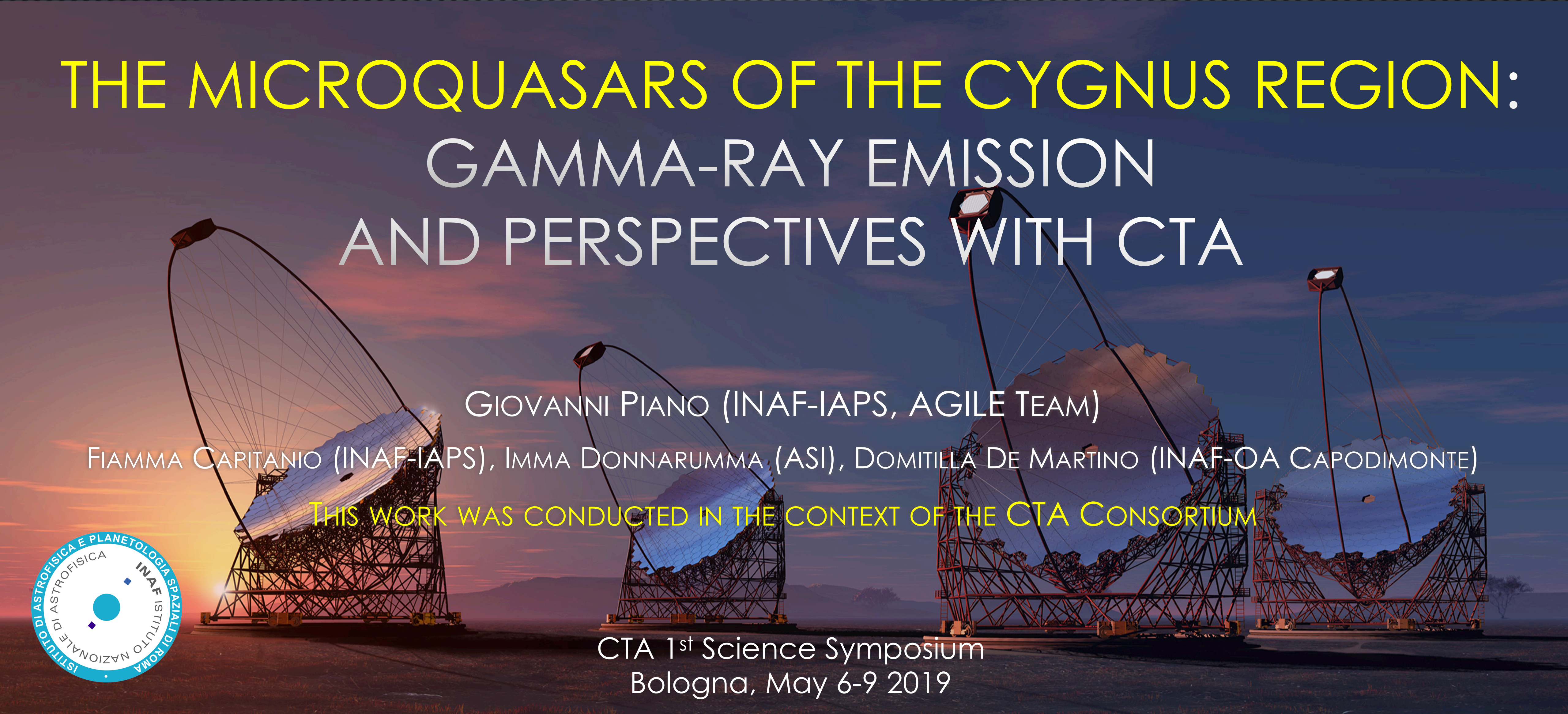
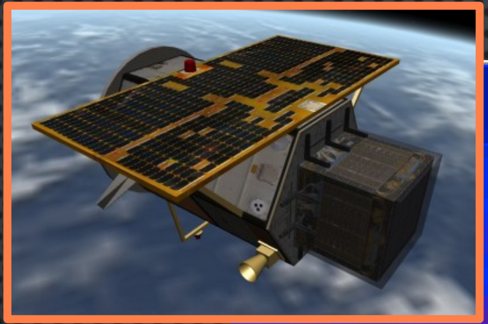
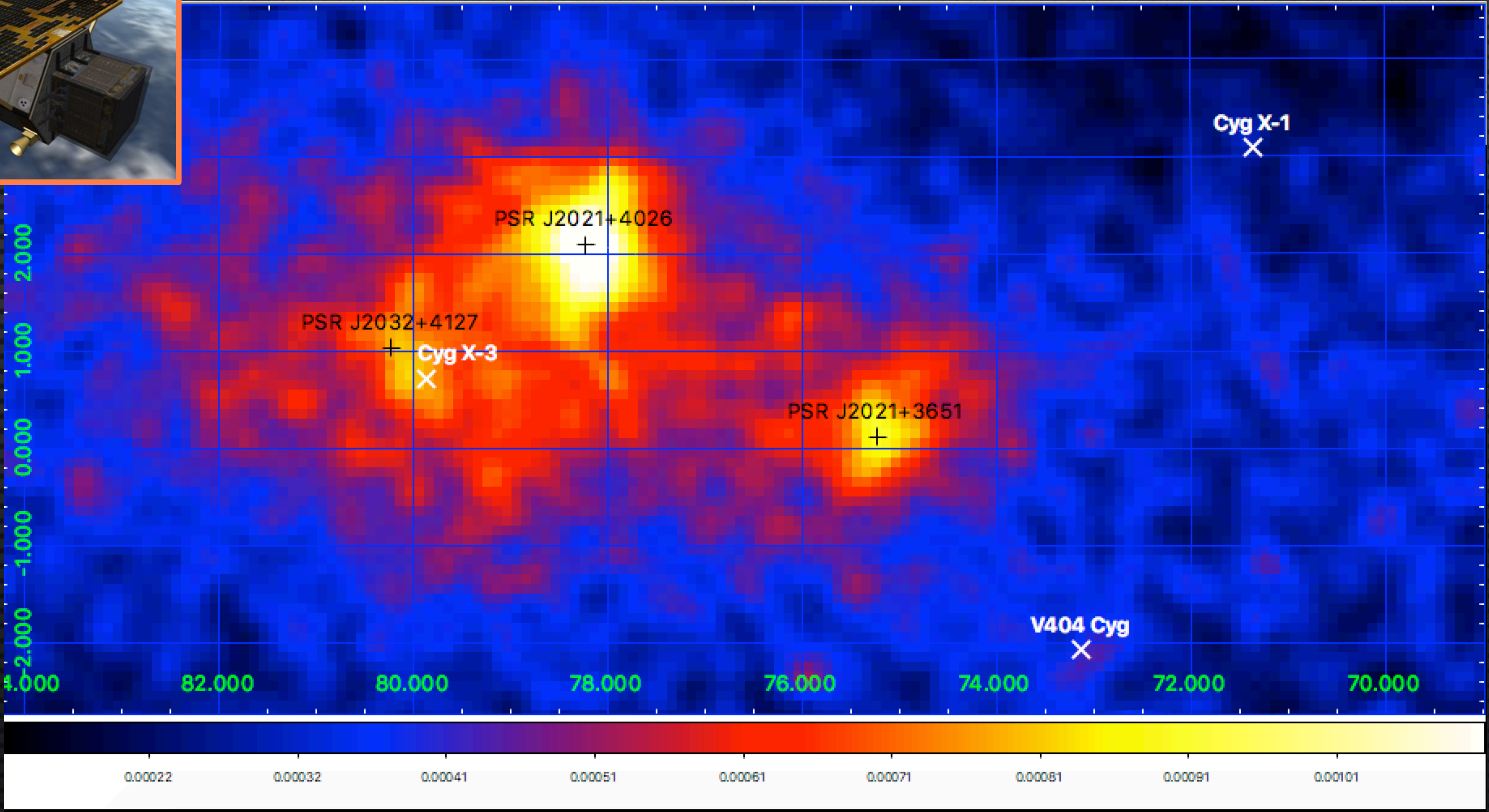


THE CYGNUS REGION AS DETECTED BY AGILE (E > 100 MeV)

IN GALACTIC COORDINATES





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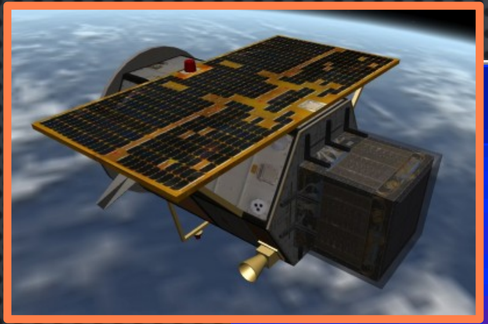
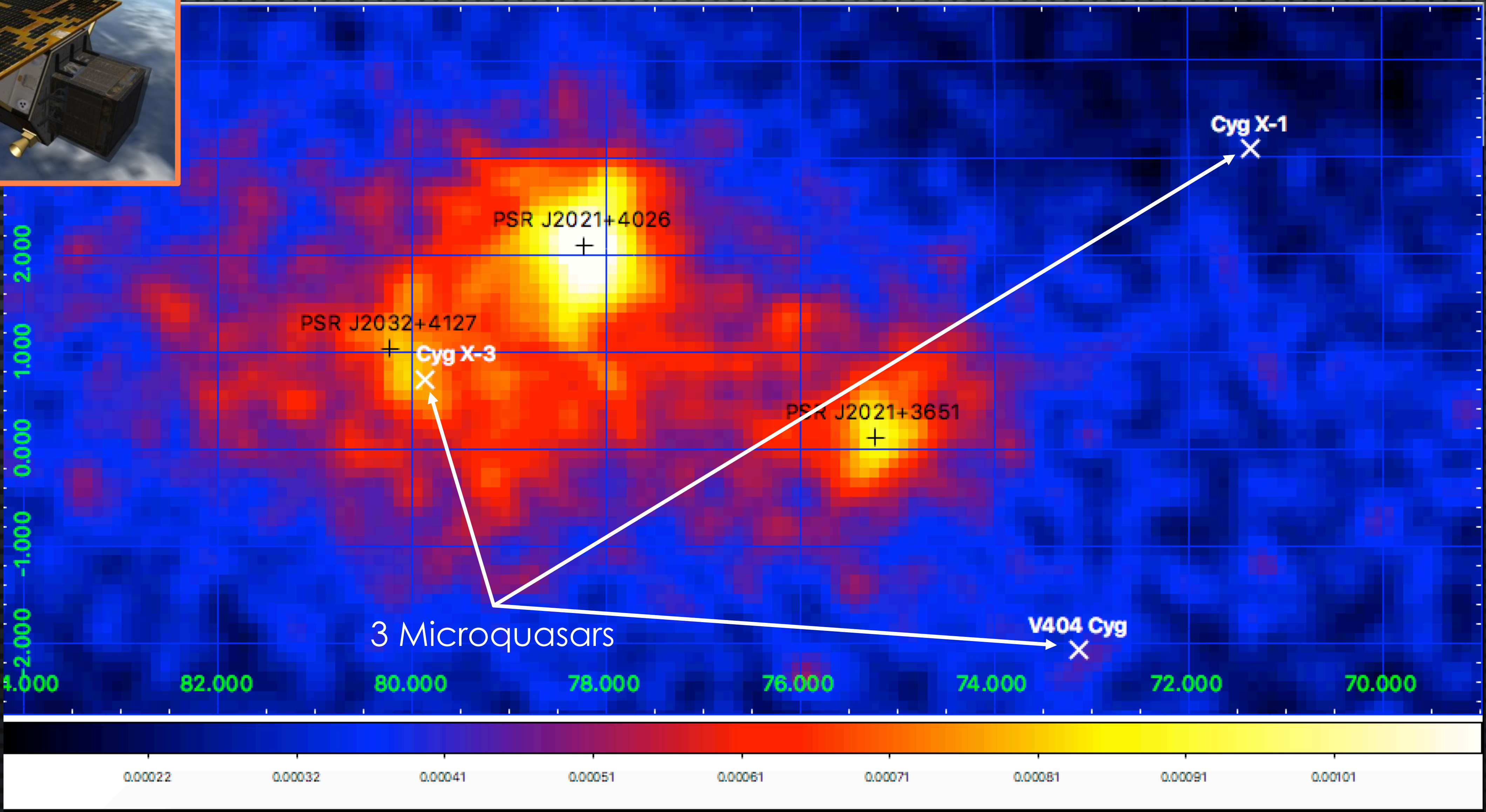
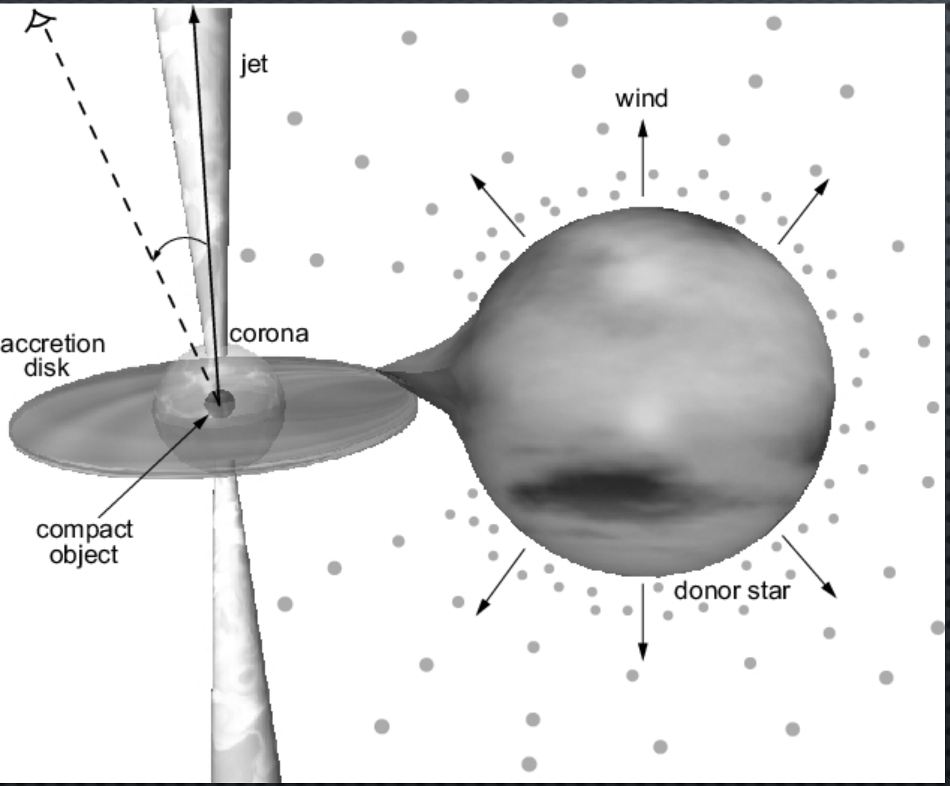




Microquasar



- X-ray binary systems: accreting NS or BH + jets
- Variable X-ray emission
- Radio emission: variable low-level flux + giant flares (Cyg X-3)
- Typically, correlated radio/soft X-ray/hard X-ray emission
- Transient γ-ray activity above 50 MeV

Microquasars in the Cygnus region

	V404 Cygni	Cygnus X-3	Cygnus X-1
type	LMXB	HMXB	HMXB
compact object	BH (9 $M_\odot$)	BH or NS (?)	BH (4.8-14.8 $M_\odot$)
companion star	K3 III (0.7 $M_\odot$)	WR (> 7 $M_\odot$)	09.7 Iab (17-31 $M_\odot$)
distance	2.39 kpc	7.4 kpc	1.9 kpc
orbital period	6.47 days	4.8 hours	5.6 days

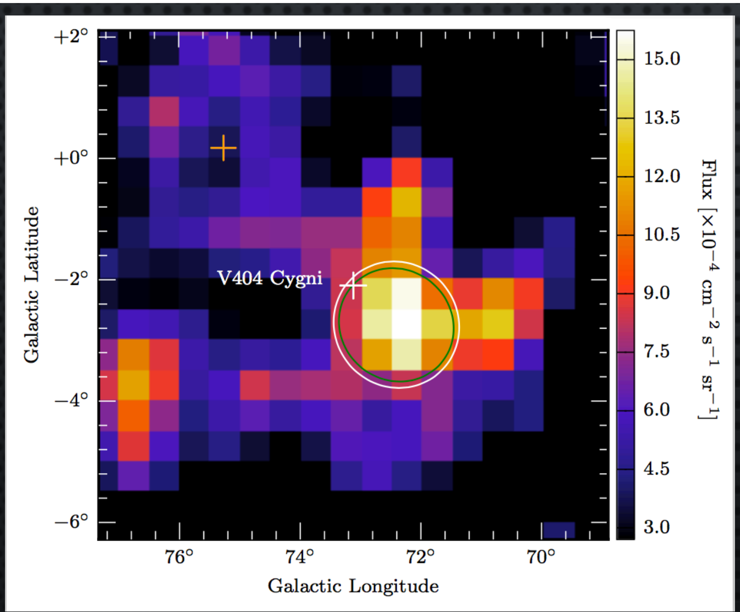
V404 Cygni

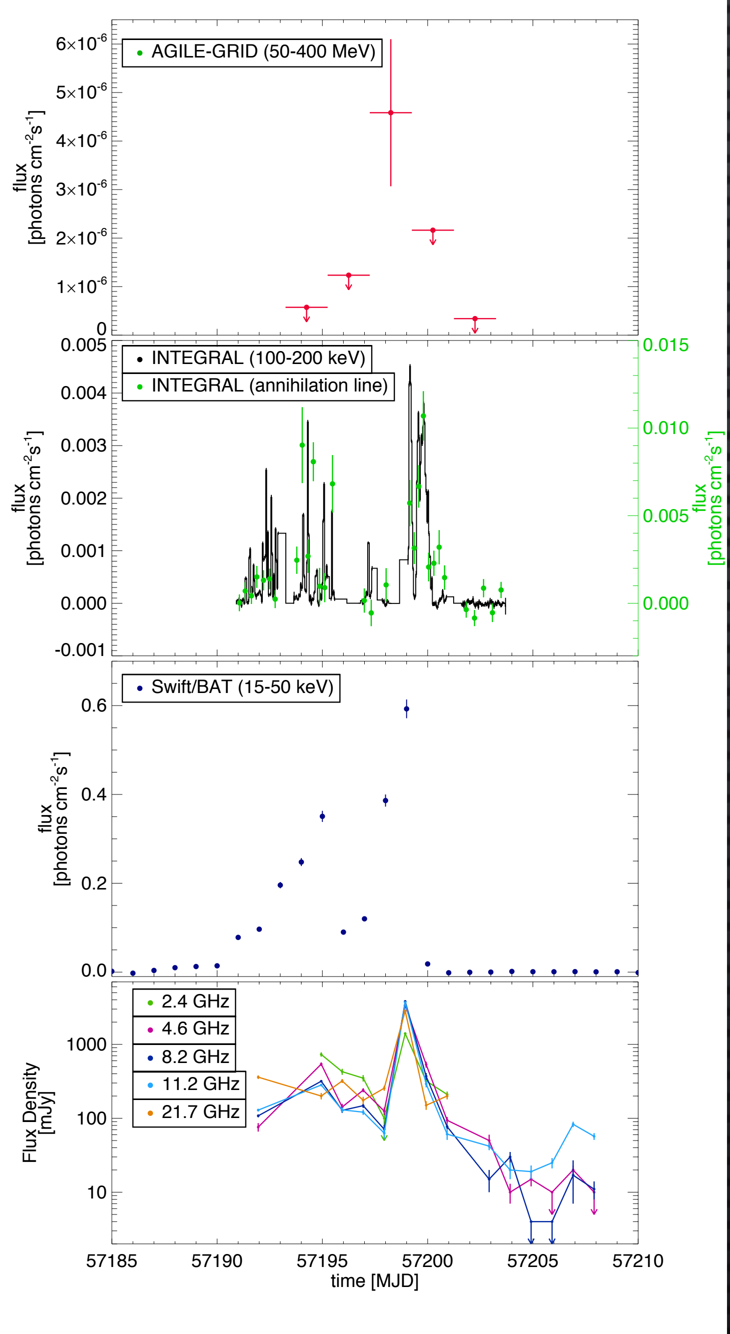
After ~26 years of quiescence → active phase in June 2015

High Energy γ-ray flare (50-400 MeV) coincident with outbursts in:

- radio
- X-ray
- soft γ-rays (continuum & 511 keV annihilation line)

AGILE 2-day intensity map (50-400 MeV)

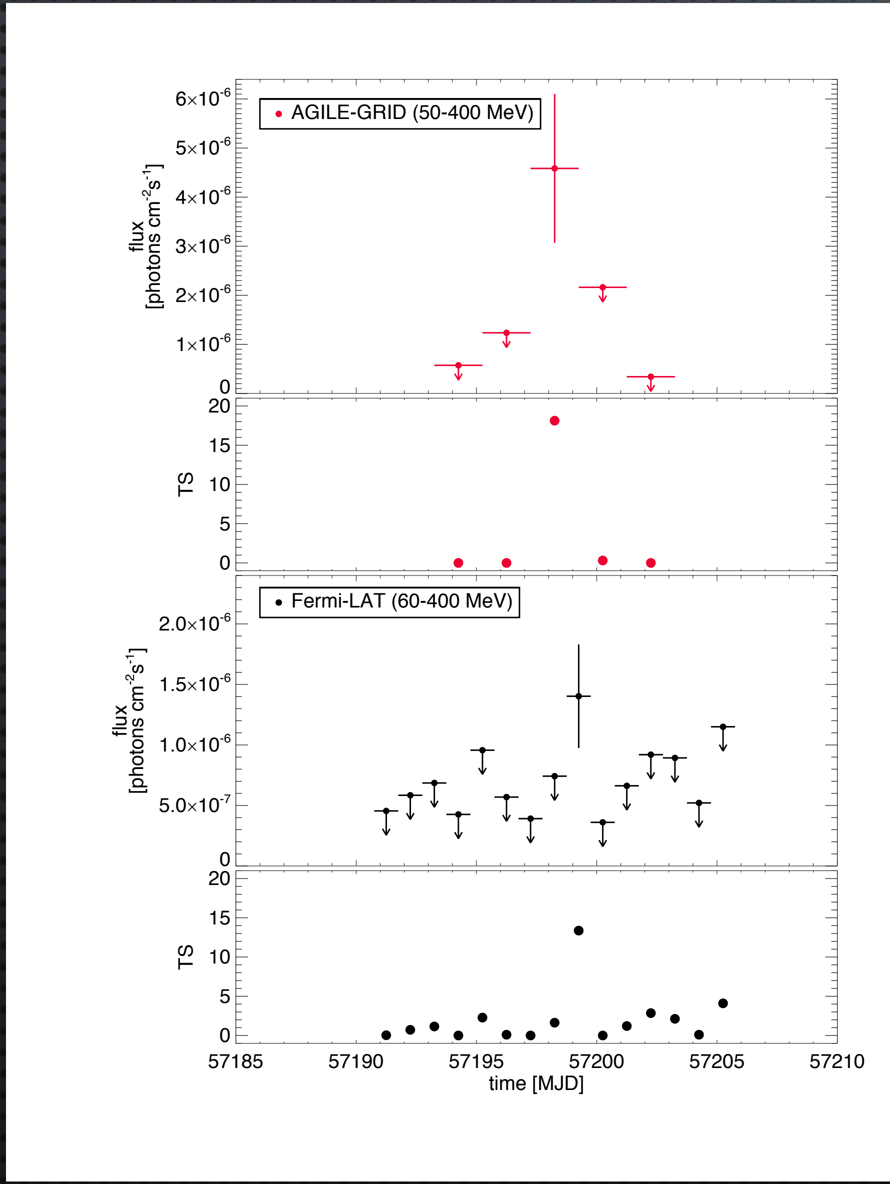




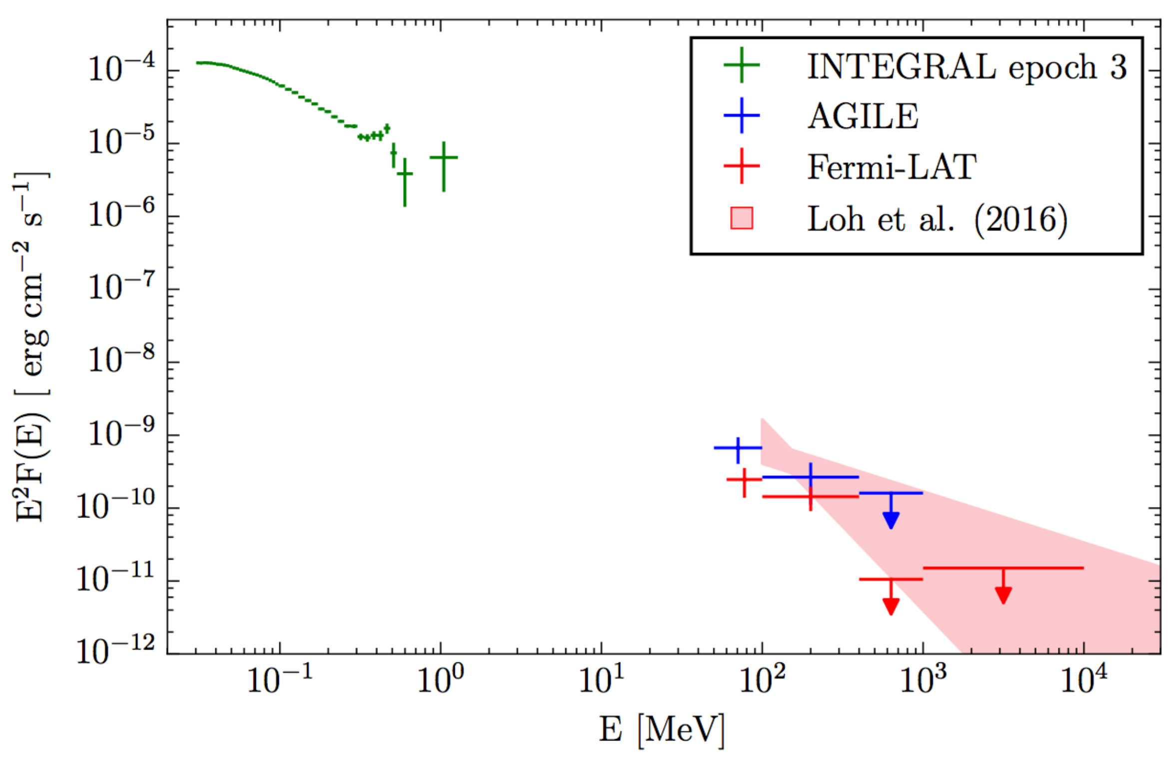
Piano et al., ApJ, 839, 84 (2017)

V404 Cygni: AGILE and Fermi-LAT observations

AGILE (50-400 MeV) simultaneous
with Fermi-LAT (60-400 MeV)



Simultaneous flaring SED



Piano et al., ApJ, 839, 84 (2017)

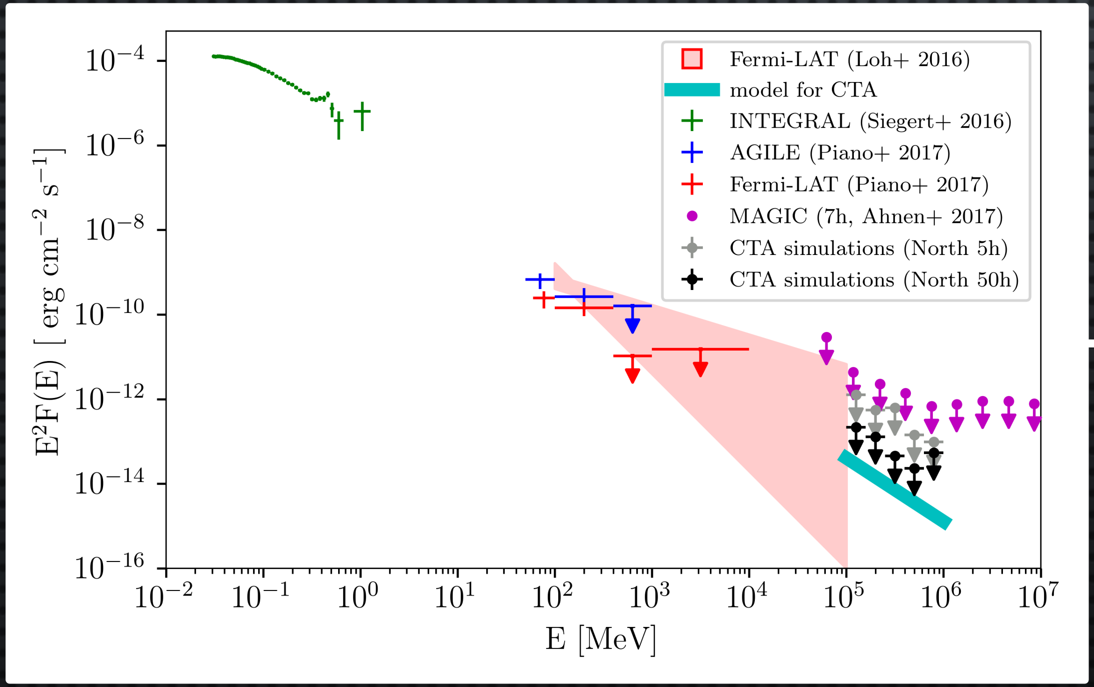
V404 Cygni: CTA simulations

- Input spectral model → extension of the Fermi-LAT flaring spectrum

  Power Law: Prefactor = 8.0 x 10^{-22} MeV^{-1} cm^{-2} s^{-1}
  Index = 3.5
  PivotEnergy = 1 TeV

- 5h/50h observations with CTA North [ctools]

  CTA IRF → North_z20_average(_5h, _50h)
  prod3b-v1 calibration database
  binned analysis (10 bins): 100 GeV – 1 TeV



Results:
NO DETECTION!

CTA observations → constraints to the emission

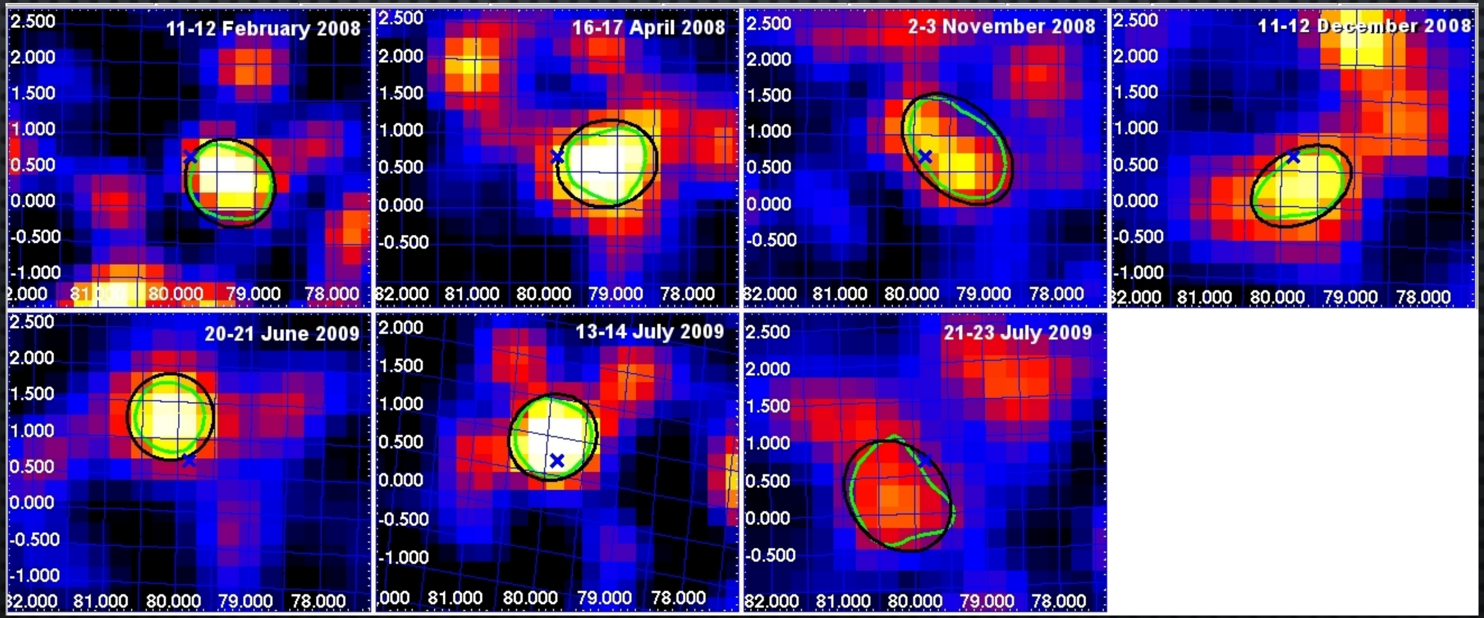
Cygnus X-3: AGILE observations

γ-ray activity discovered in late 2009

AGILE → (Tavani et al, *Nature*, 2009); *Fermi*-LAT → (*Fermi*-LAT Collaboration et al., Science, 2009)

7 γ-ray flares have been detected between November 2007 and July 2009:

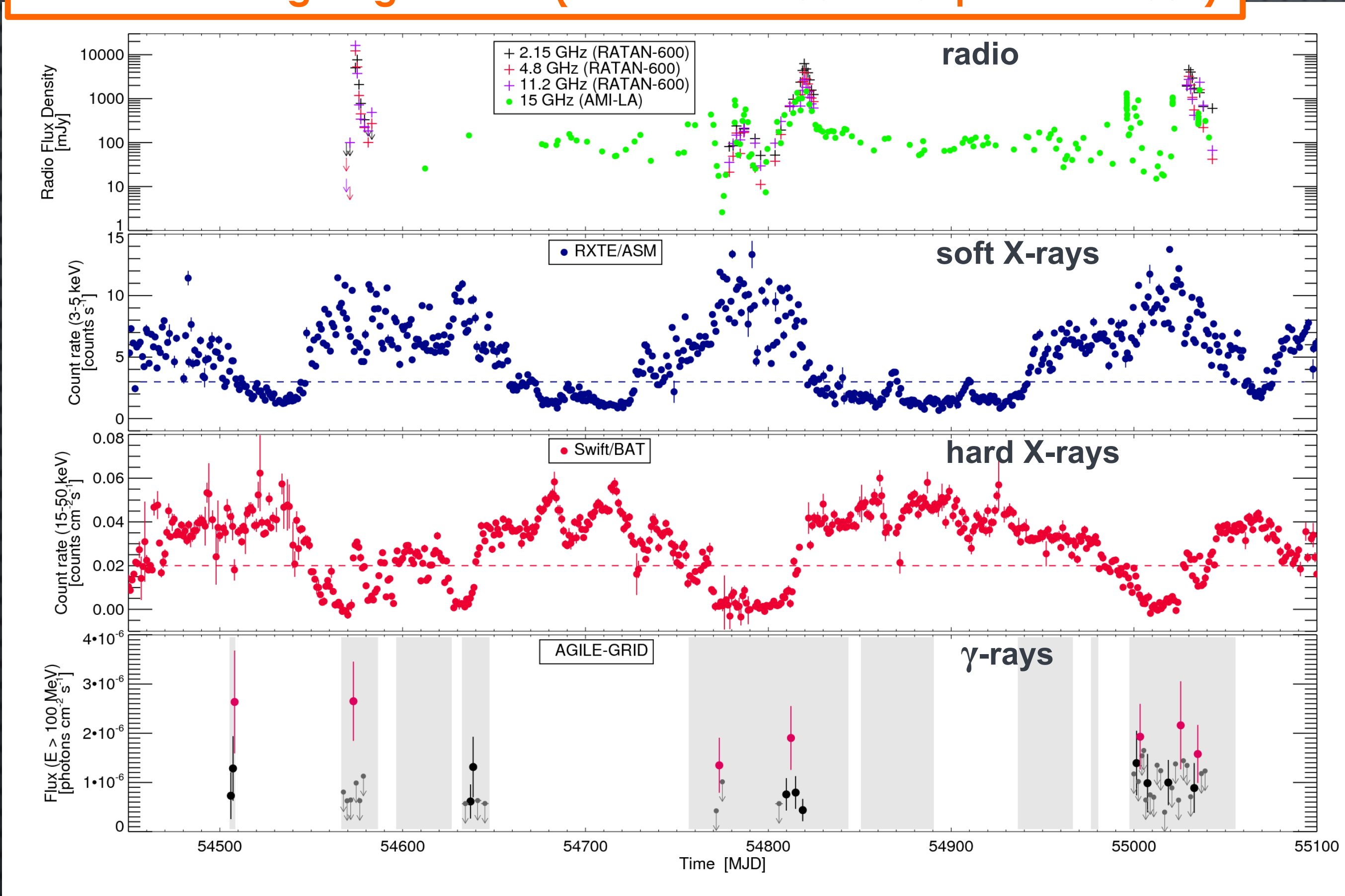
- significance $\geq 3\sigma$
- γ-ray fluxes more than 10 times the steady flux [$F_{steady} = (14 \pm 3) \times 10^{-8}$ ph cm^{-2} s^{-1}]



Piano et al., A&A, 545, A110 (2012)

Cygnus X-3: AGILE observations

Multi-wavelength light curve (December 2007 → September 2009)



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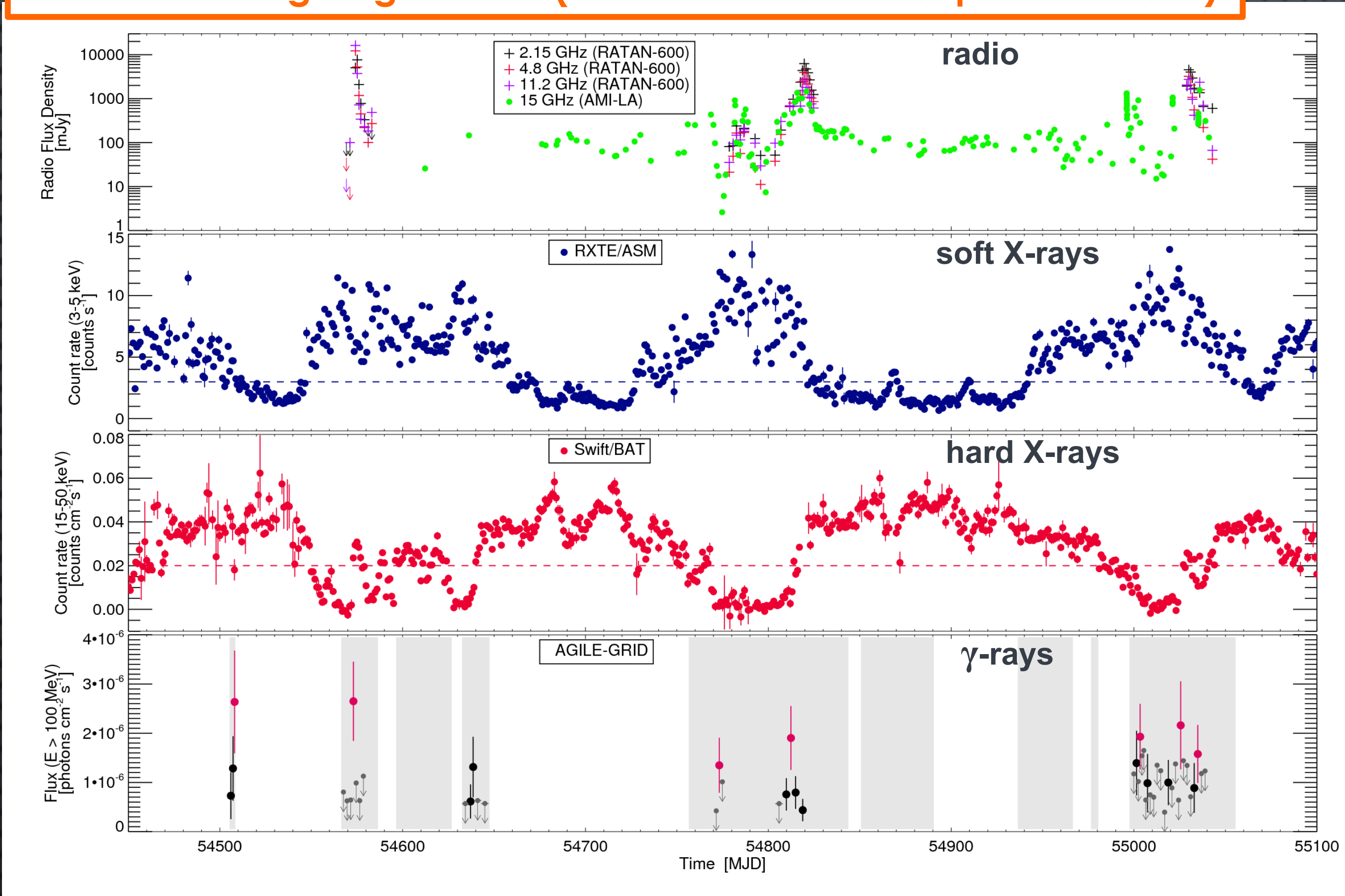

Repetitive multi-frequency emission pattern:

- γ-ray activity associated with sharp/local minima in the hard X-ray light curve (*Swift*/BAT count rate ≤ 0.02 counts cm^{-2} s^{-1})
- γ-ray flares coincident with soft spectral states (*RXTE*/ASM count rate ≥ 3 counts s^{-1})
- γ-ray flares around hard-to-soft or soft-to-hard spectral transitions (when it is moving into or out of the quenched state)
- γ-ray flares a few days before major radio flares

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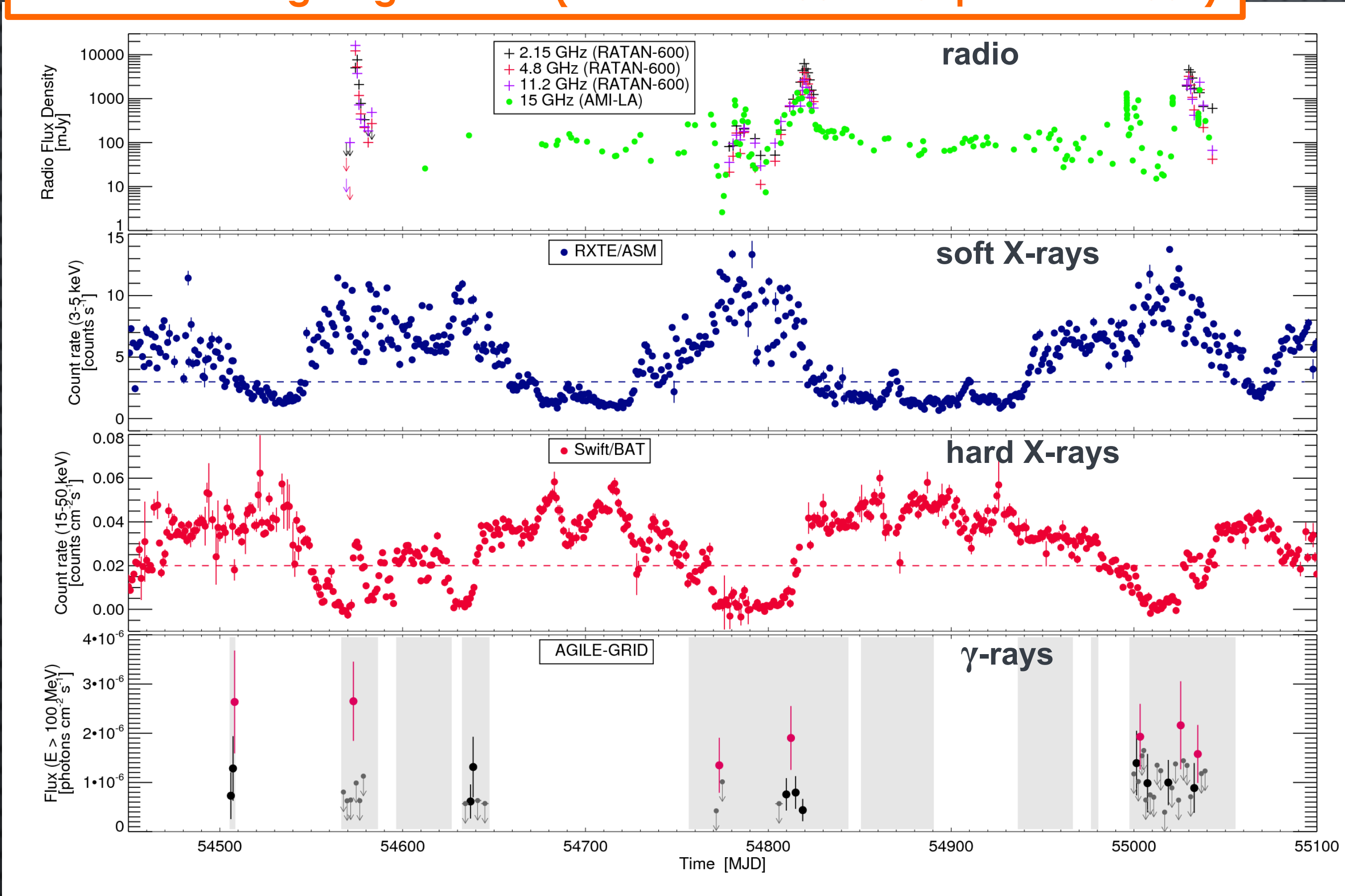

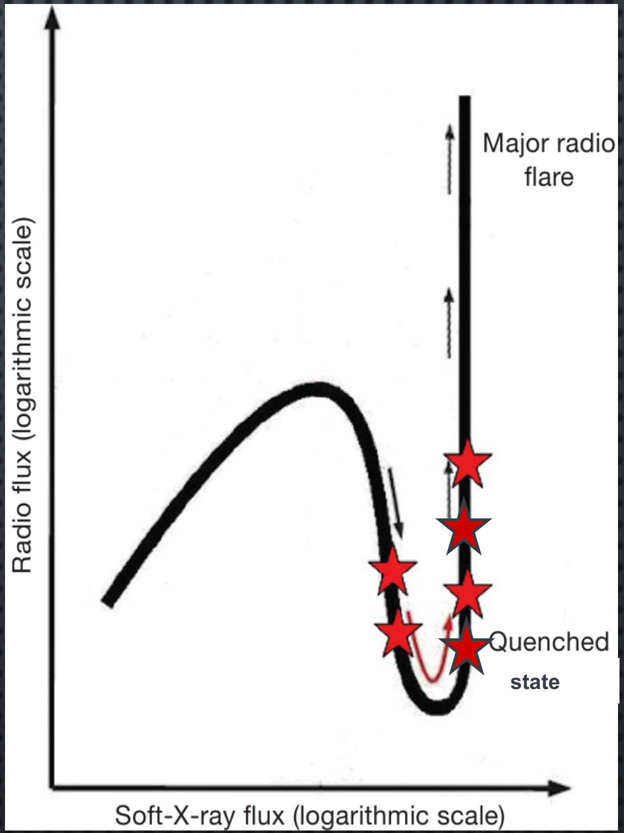

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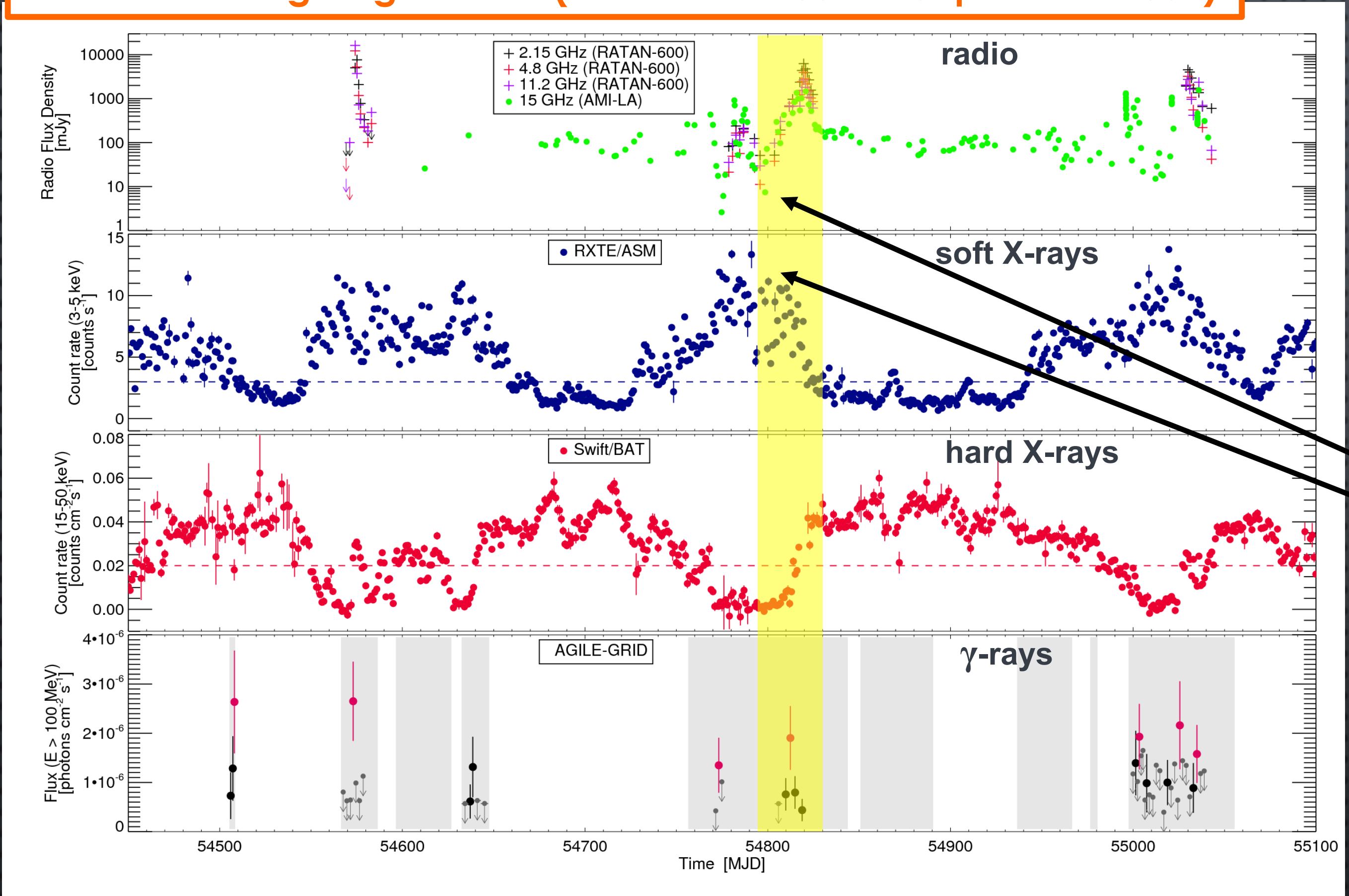
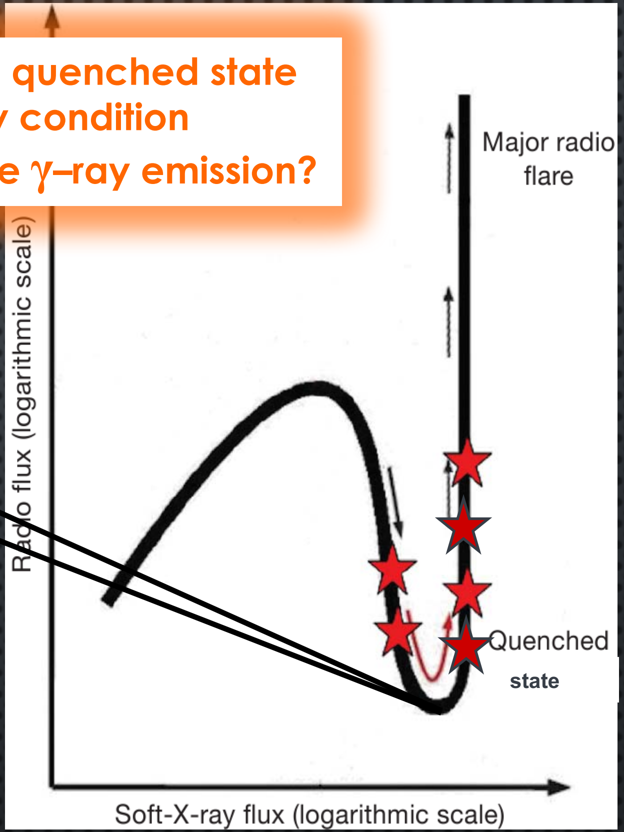


Is the quenched state a key condition for the γ–ray emission?



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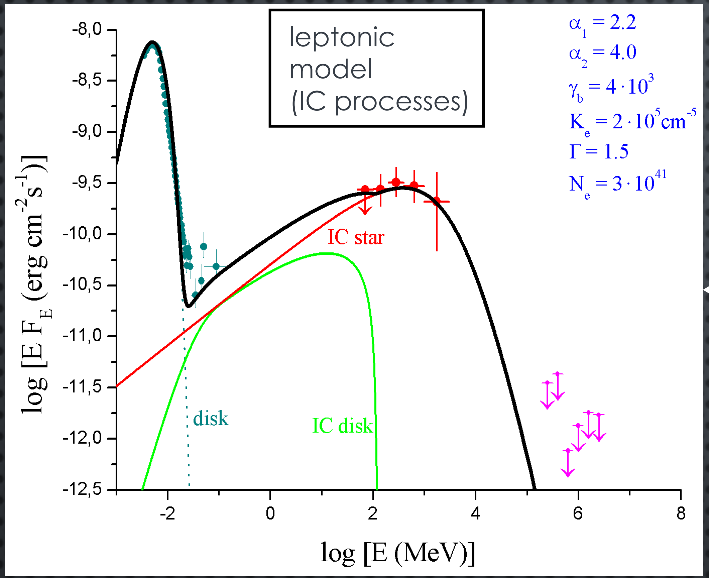
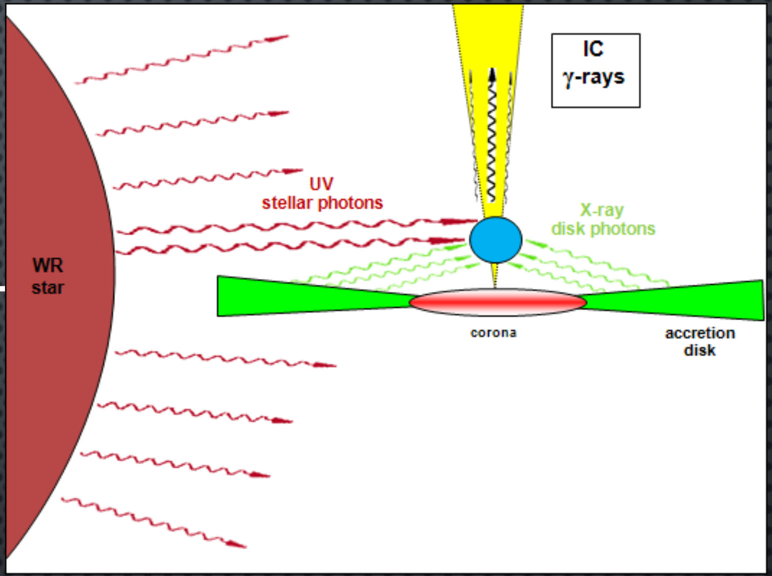
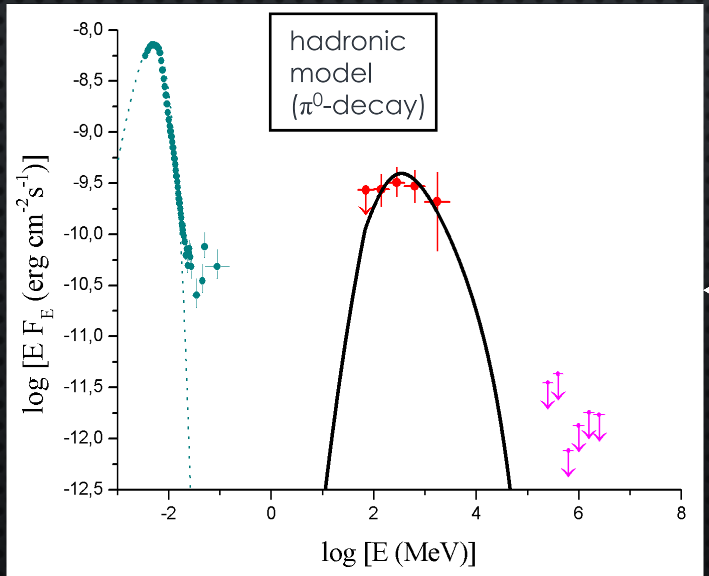
Cygnus X-3: AGILE observations

Both leptonic and hadronic emission models
can account for the γ-ray flaring spectrum detected by AGILE







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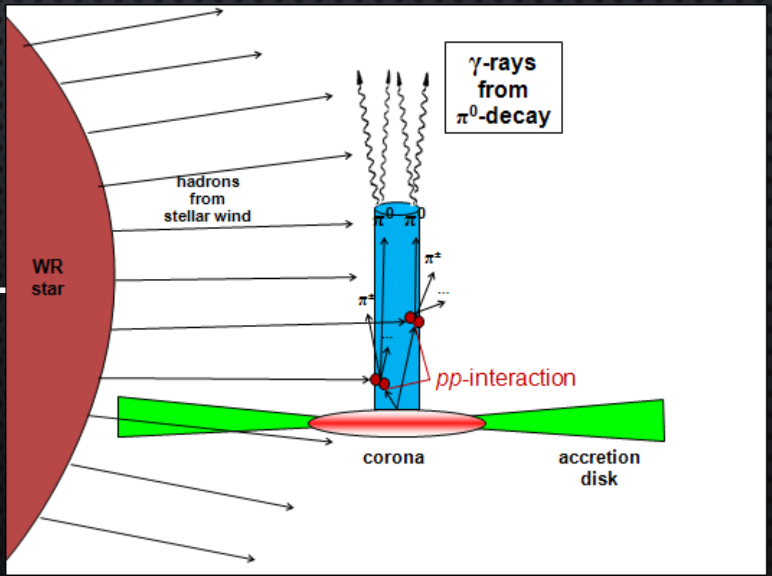

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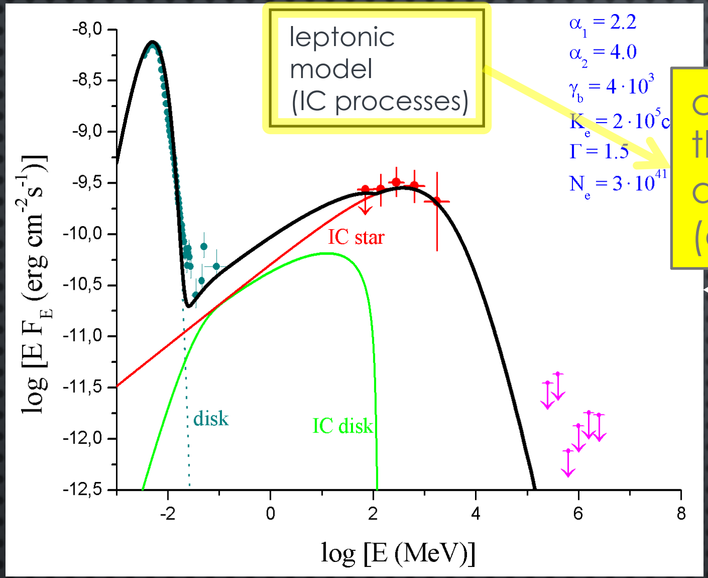
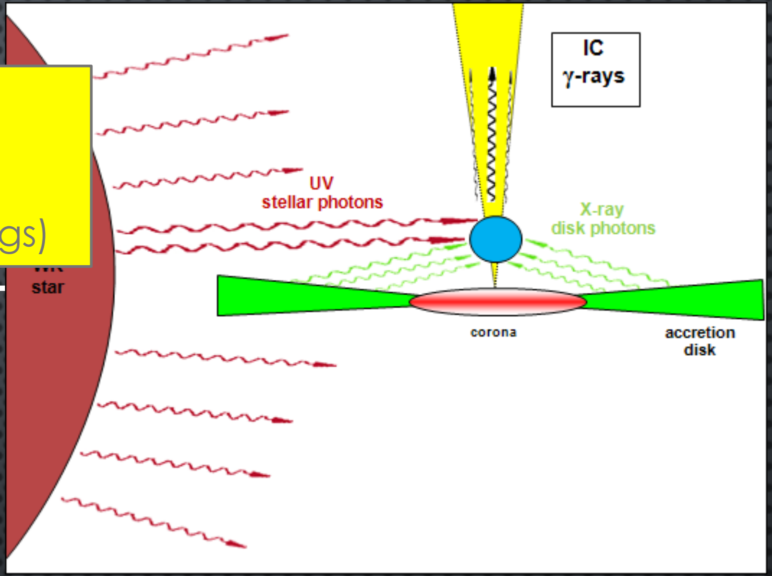
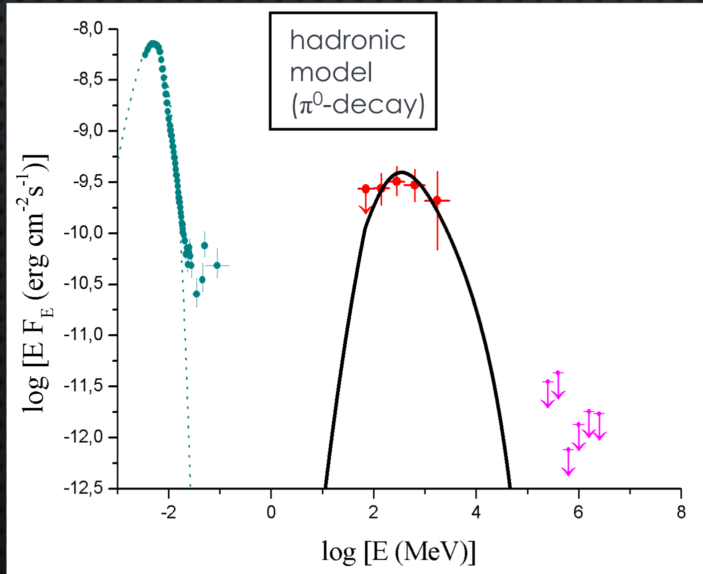
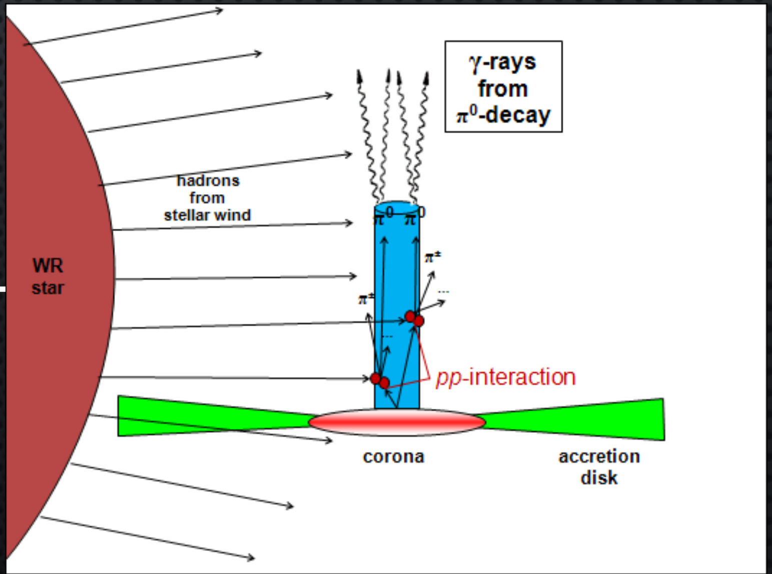


can easily account for the γ-ray modulation detected by *Fermi*-LAT (anisotropic IC scatterings)



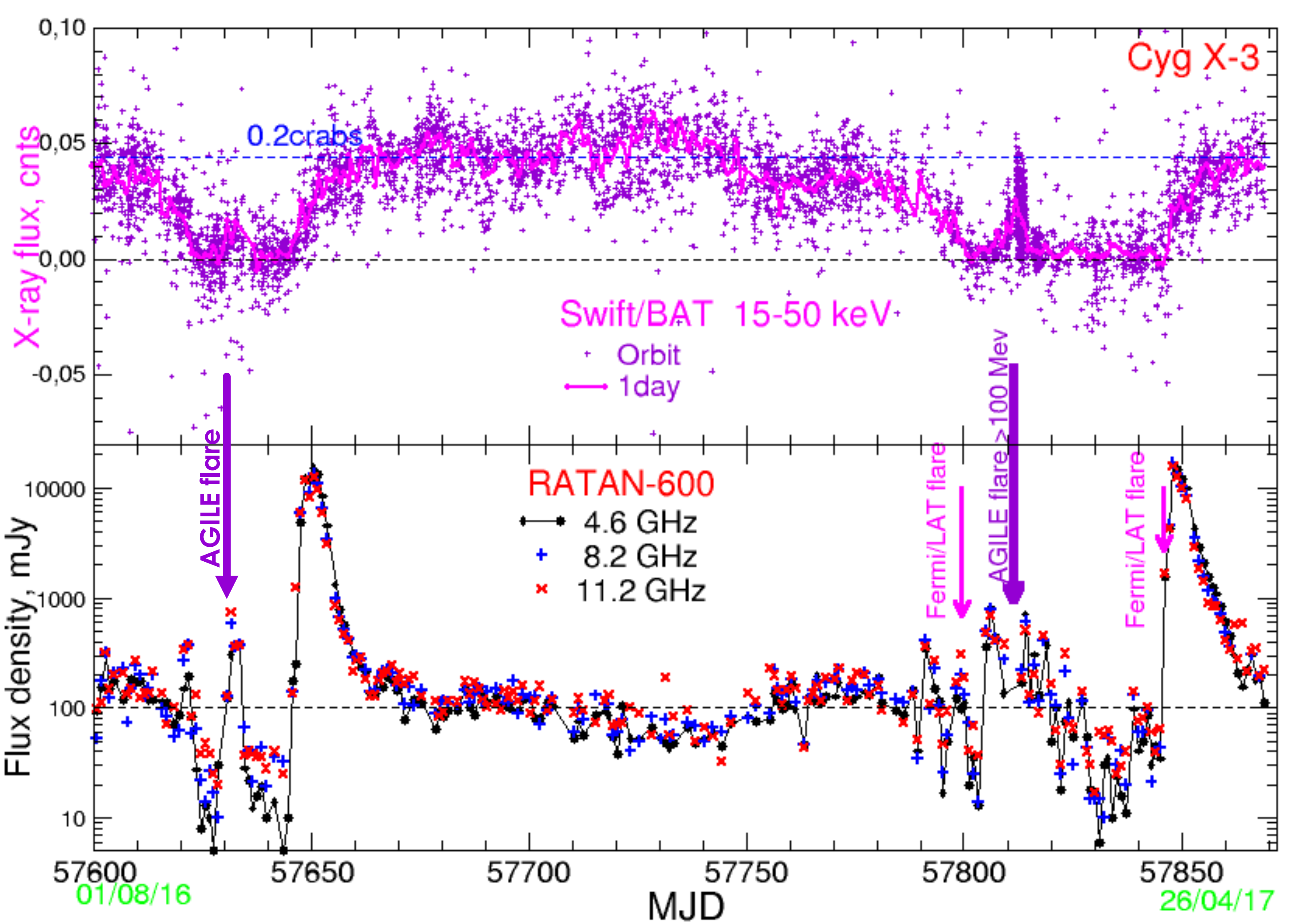




Piano et al.,
A&A, 545, A110 (2012)

Cygnus X-3: AGILE and Fermi-LAT observations

Recent γ-ray activity → 2016 – 2017 (Koljonen et al., A&A, 612, A27, 2018)



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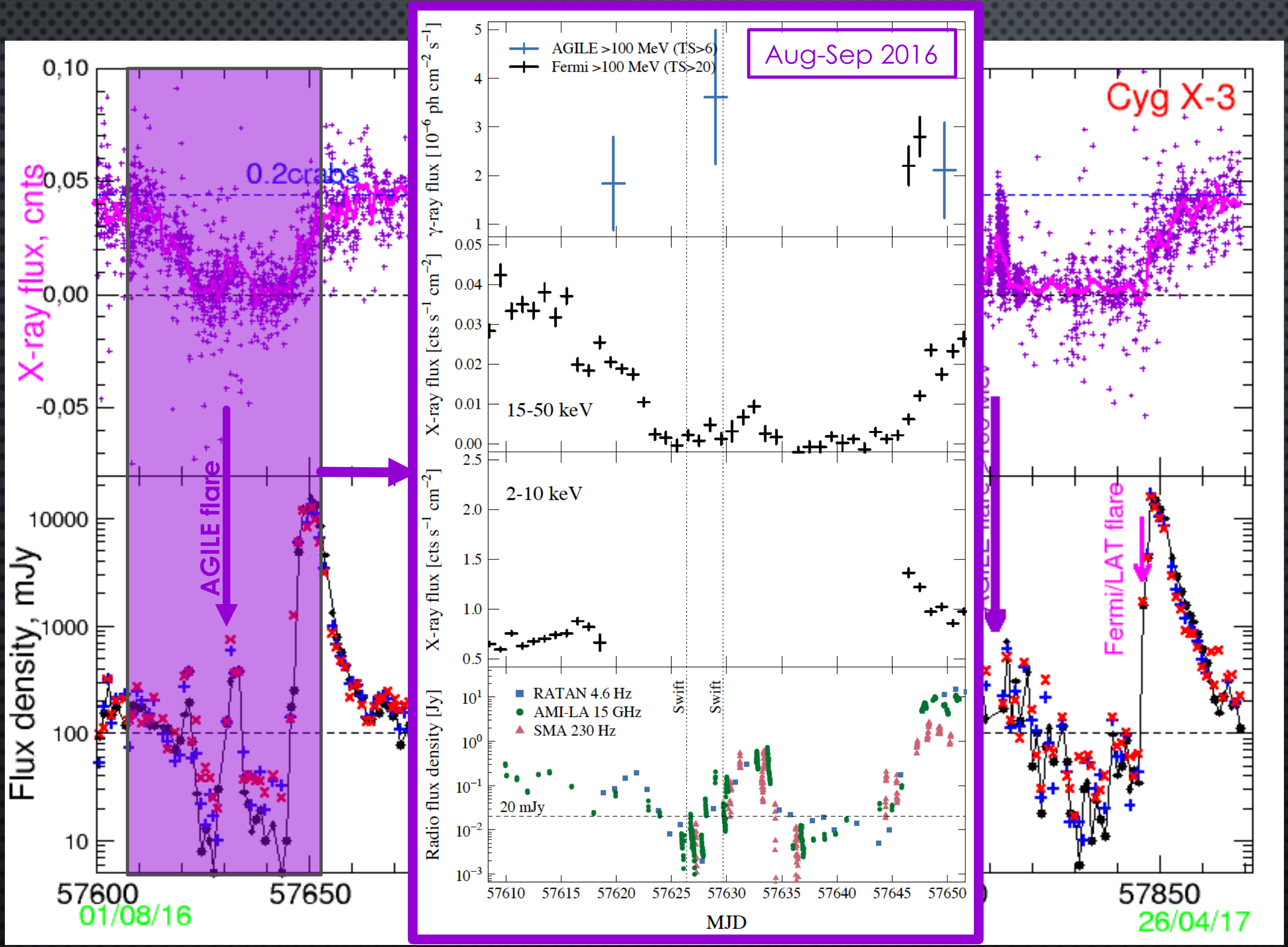

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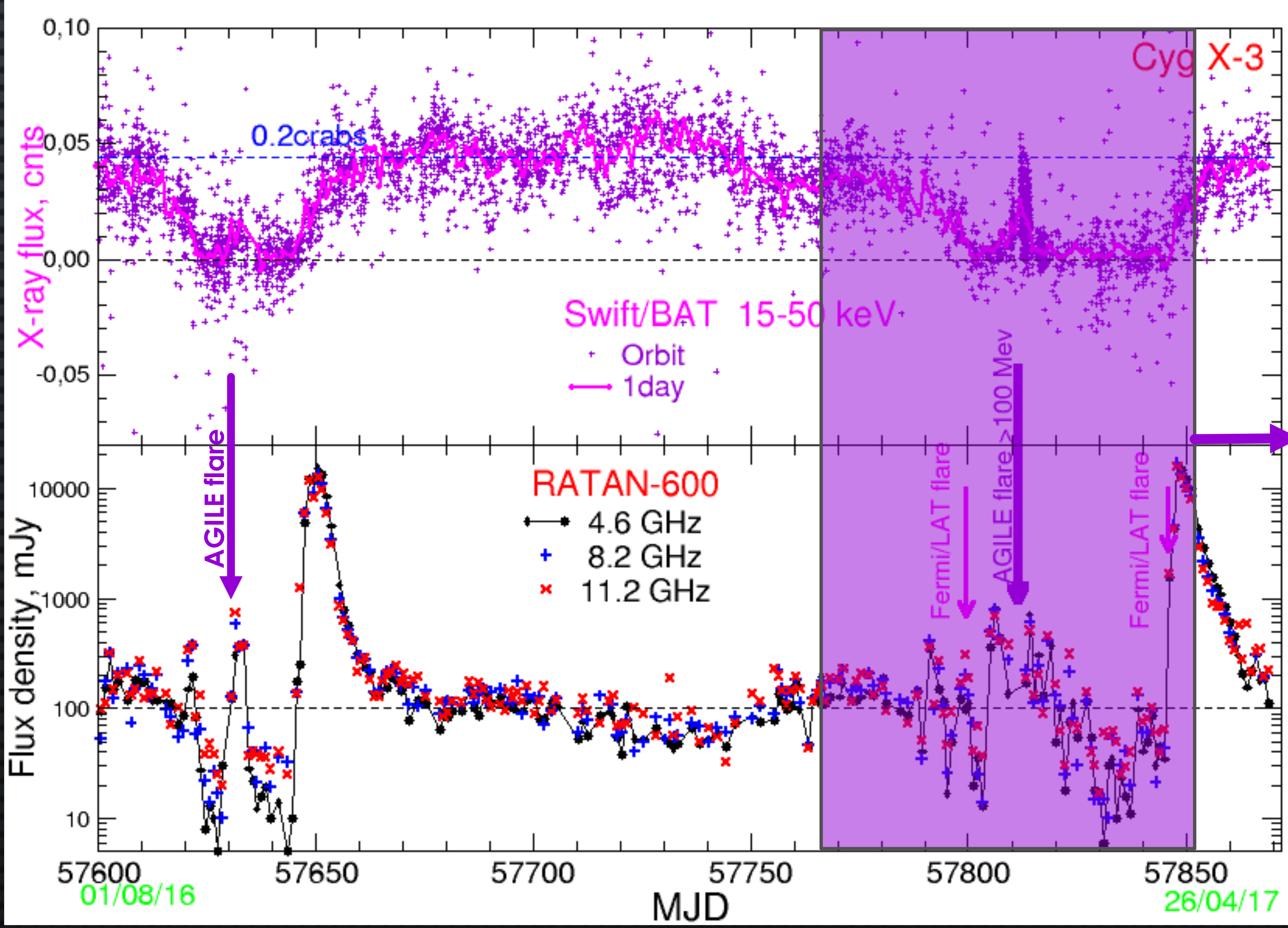
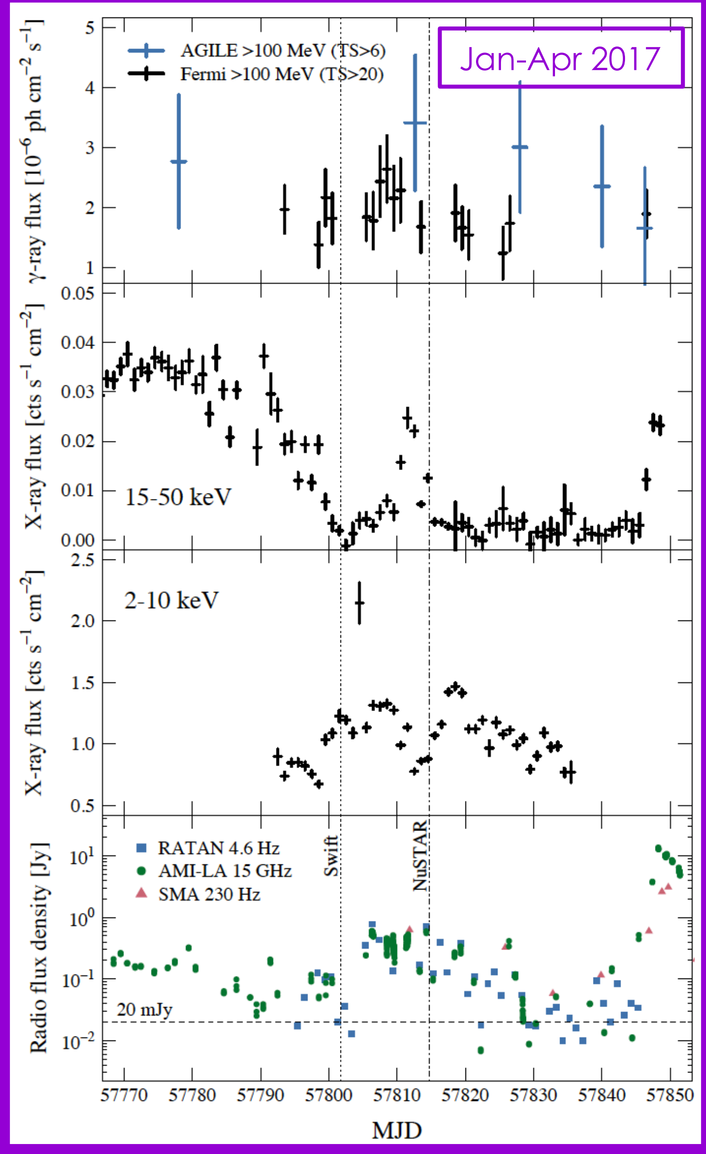
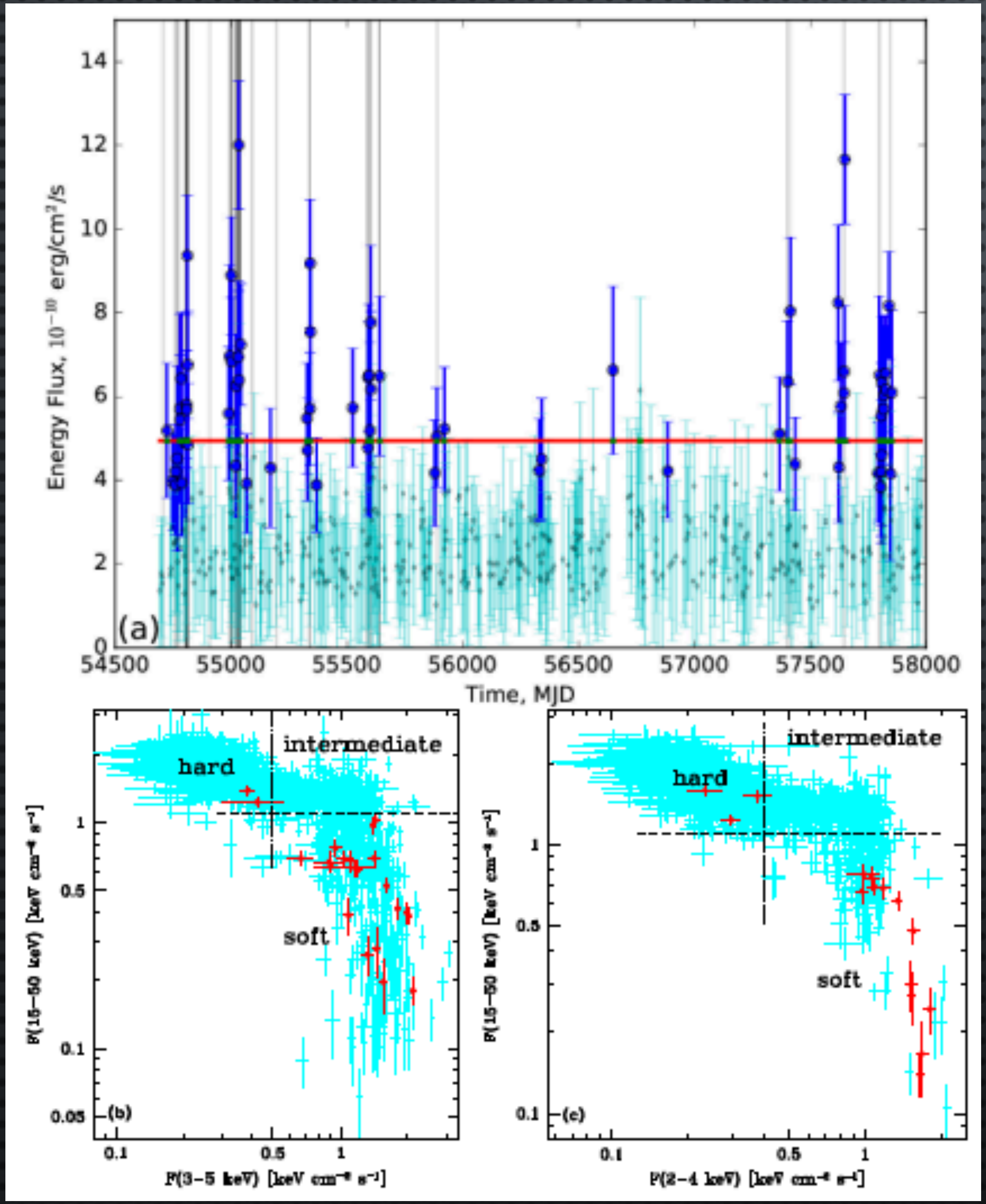


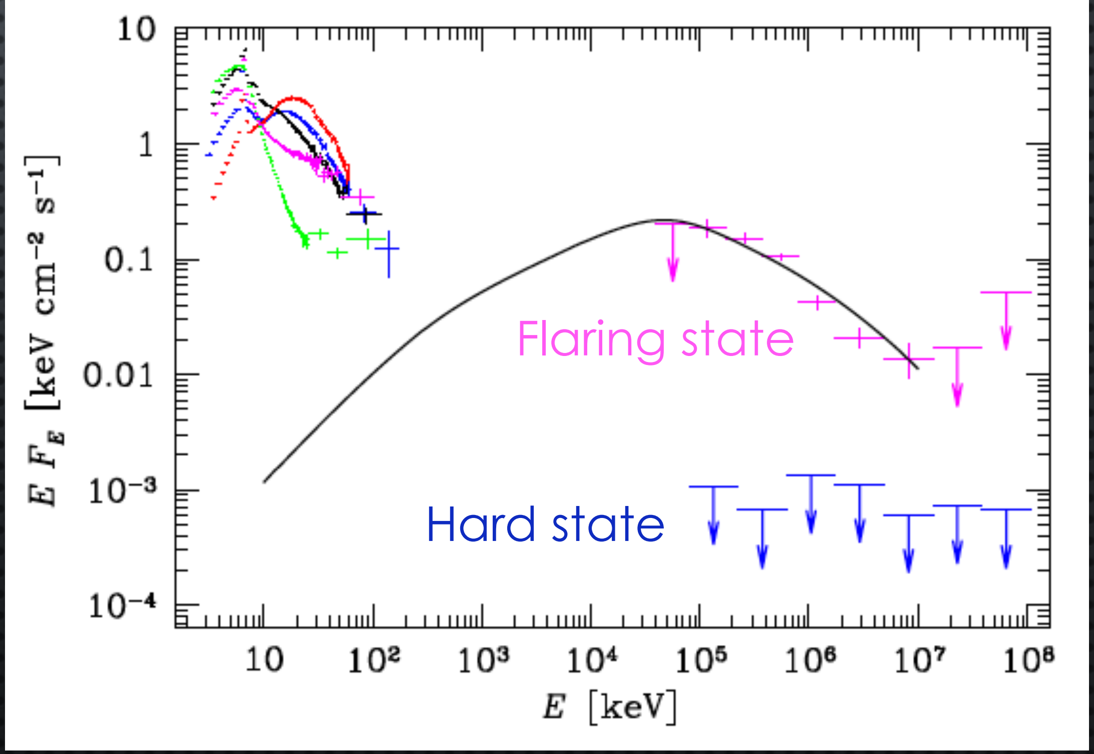


Cygnus X-3: Fermi-LAT observations



(Zdziarski et al., MNRAS, 479, 4399, 2018)

Zdziarski+ 2018 found 49 1d γ-ray flares by analyzing the Fermi-LAT data between August 2008 and August 2017. 43 of them are in soft spectral states.



Cygnus X-3: CTA simulations

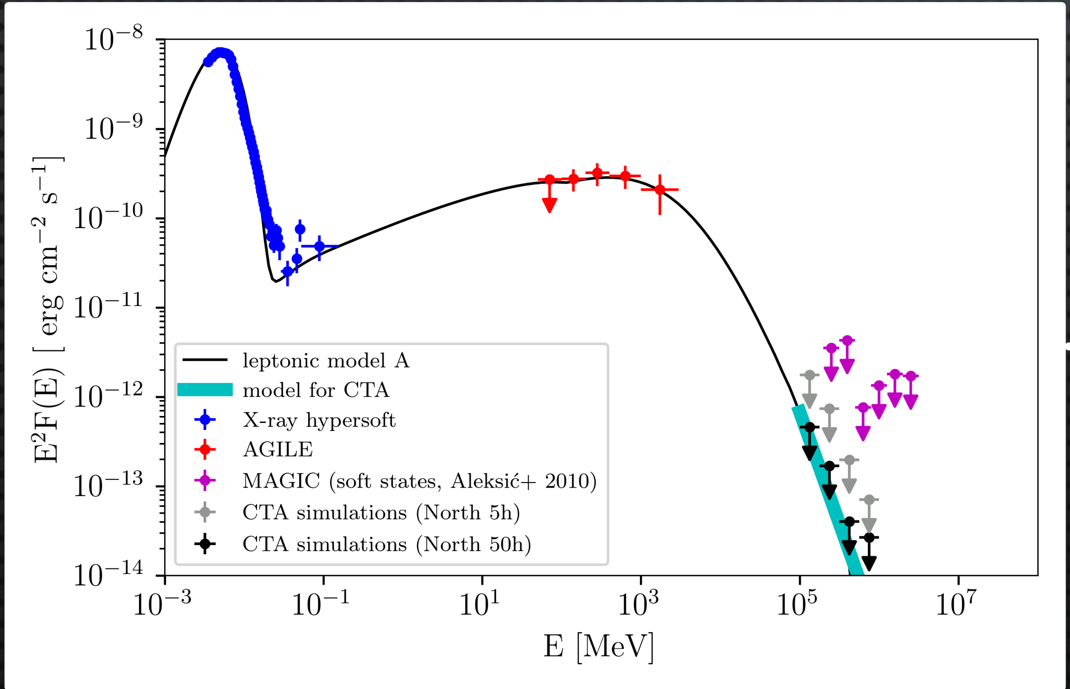
- Input spectral model → inferred spectrum from a leptonic model

  Power Law: Prefactor = 1.34 x 10^{-21} MeV^{-1} cm^{-2} s^{-1}
  Index = 4.5
  PivotEnergy = 1 TeV

- 5h/50h observations with CTA North [ctools]
  CTA IRF → North_z20_average(_5h, _50h)
  prod3b-v1 calibration database
  binned analysis (12 bins): 100 GeV – 1 TeV

Similar investigations published in:

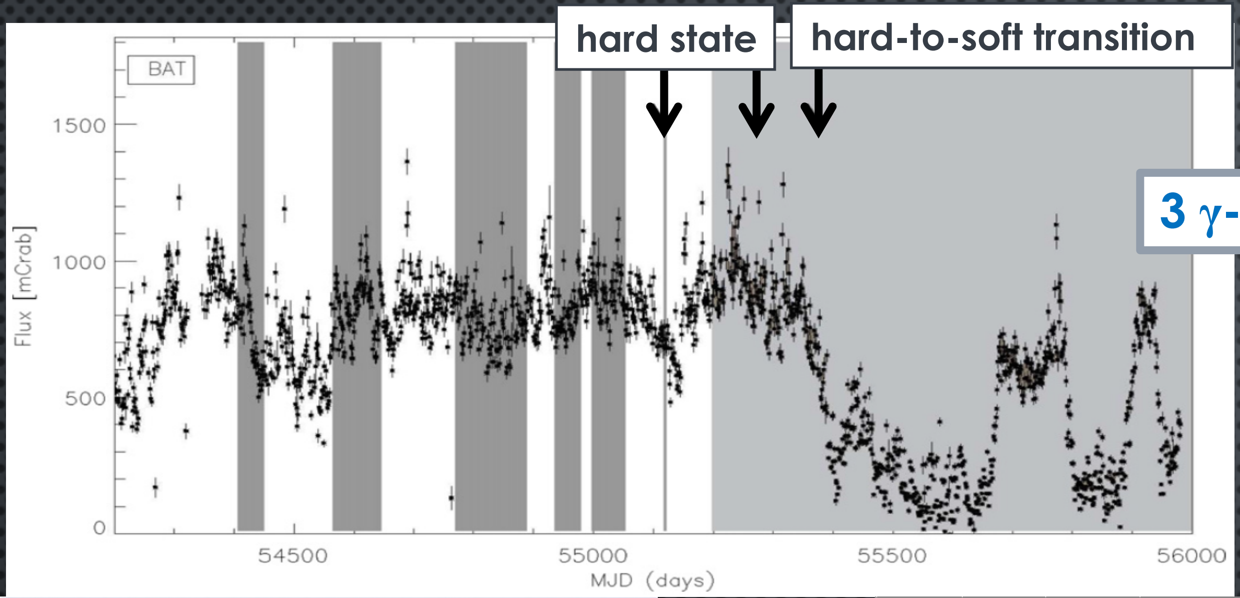
- Paredes et al., Aph, 43, 301 (2013)
- "Science with the Cherenkov Telescope Array" CTA Consortium (2019)



Results:
NO DETECTION!

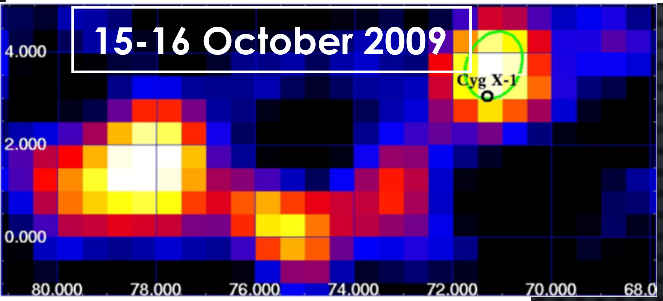
a CTA detection would represent a challenge for the current emission models

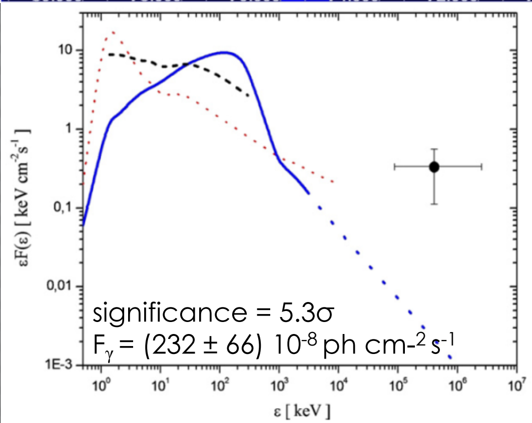
Cygnus X-1: flaring activity - AGILE observations

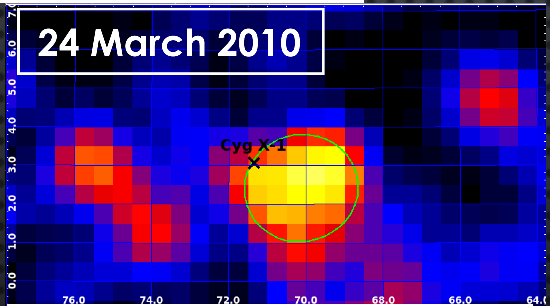


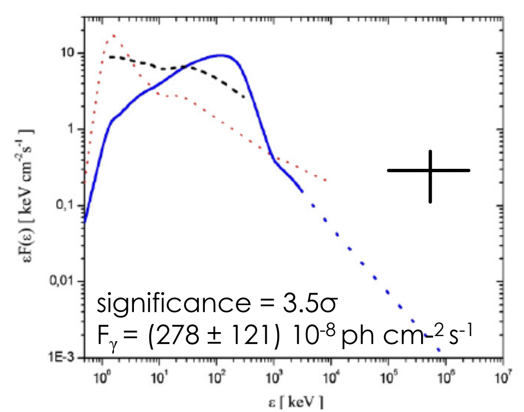
3 γ-ray flares detected by AGILE

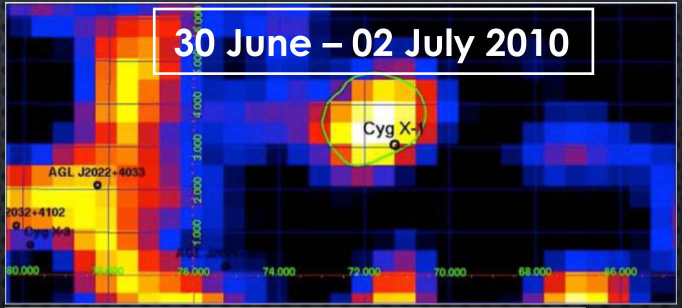
Sabatini et al., ApJL, 712, L10 (2010)
Bulgarelli et al., ATel #2512 (2010)
Sabatini et al., ApJ, 766, 83 (2013)

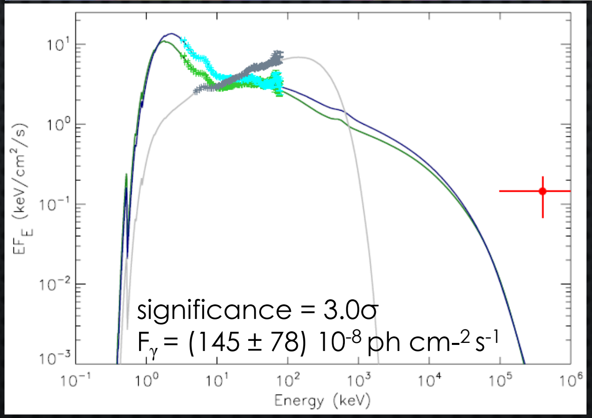






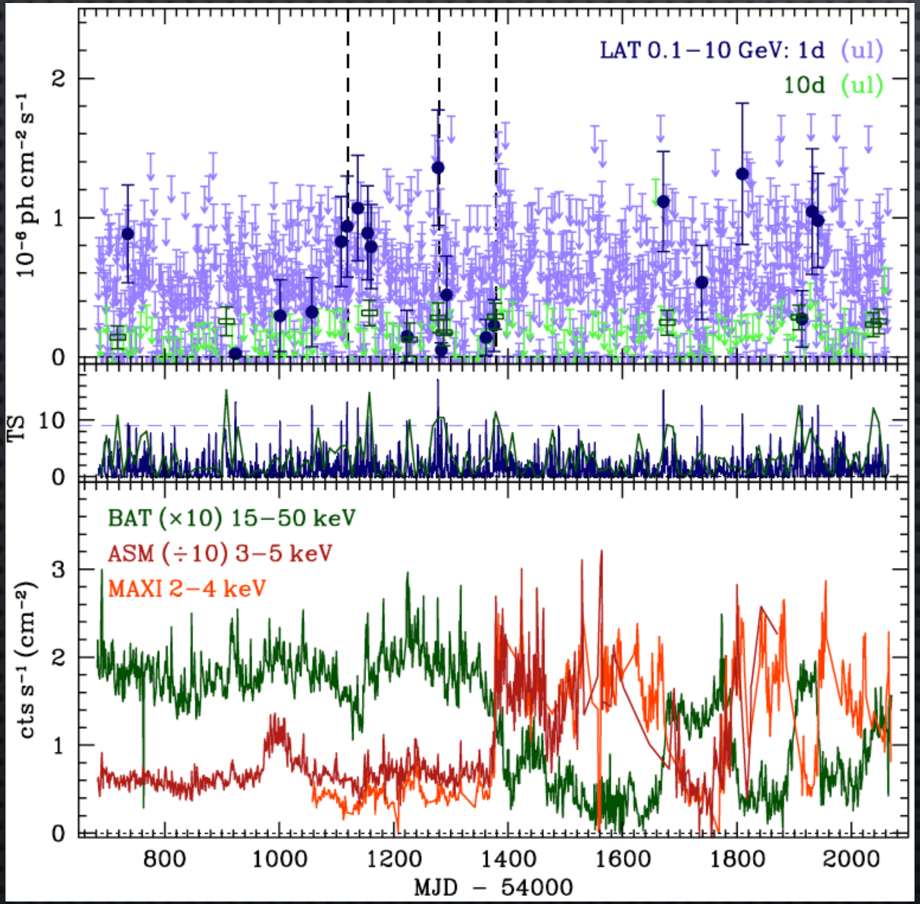




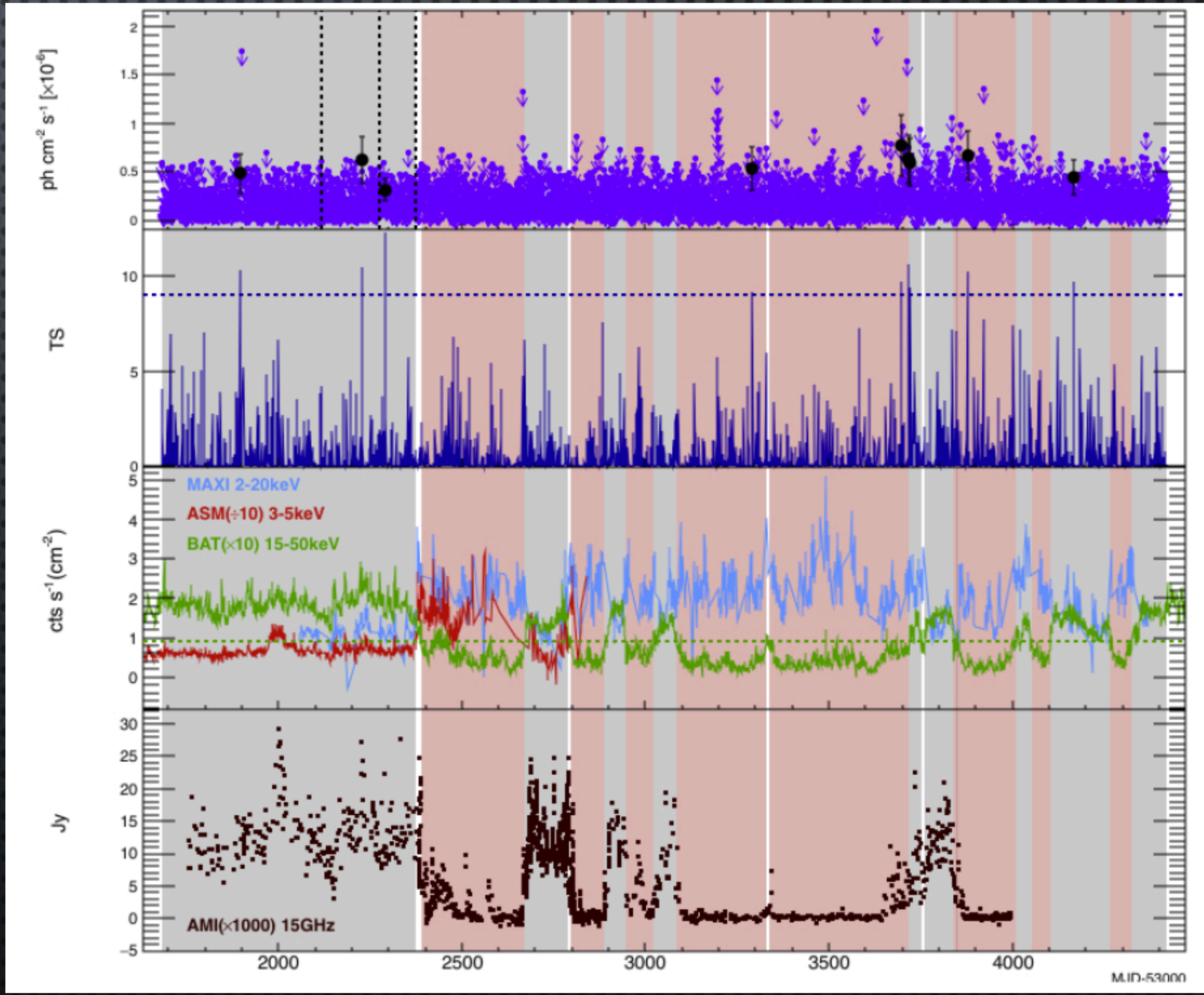


Cygnus X-1: flaring activity – Fermi-LAT observations

Several short (1-2d) γ-ray flaring episodes detected both during hard and soft spectral states
(Bodaghee+ 2013, Zanin+ 2016)

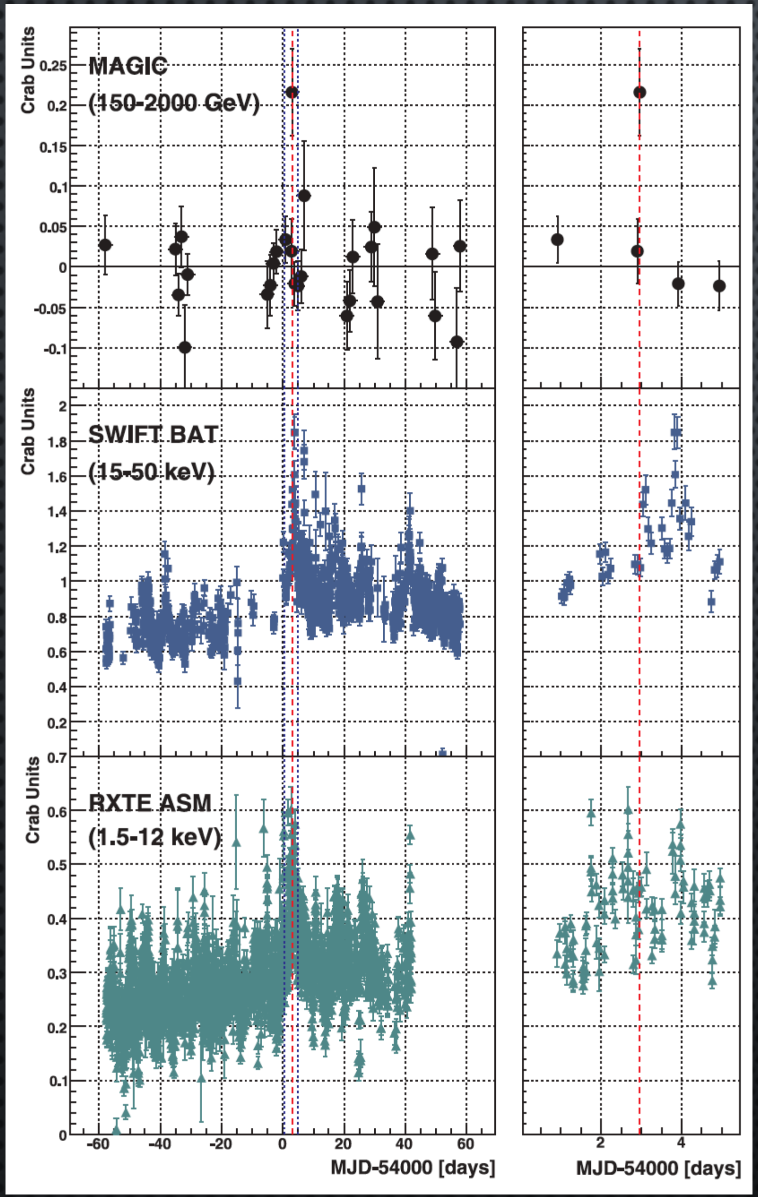


Bodaghee et al., ApJ, 775, 98 (2013)



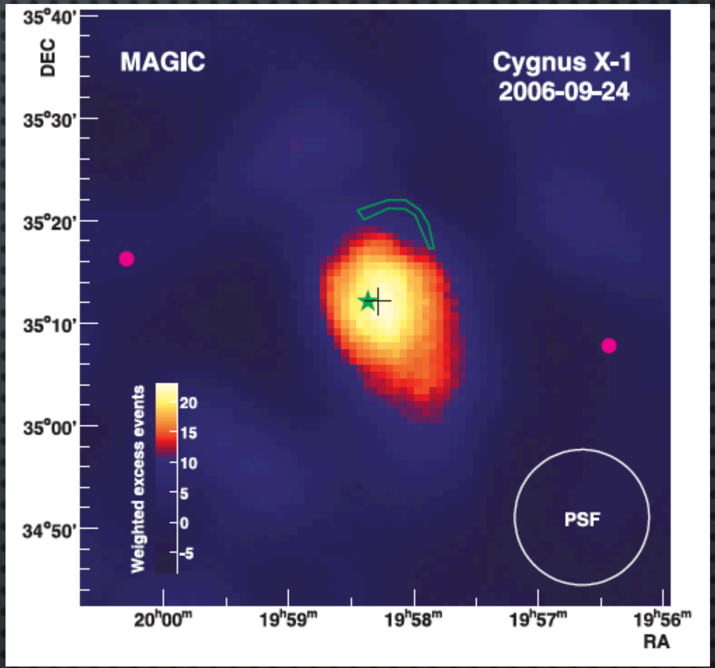
Zanin et al., A&A, 596, A55 (2016)

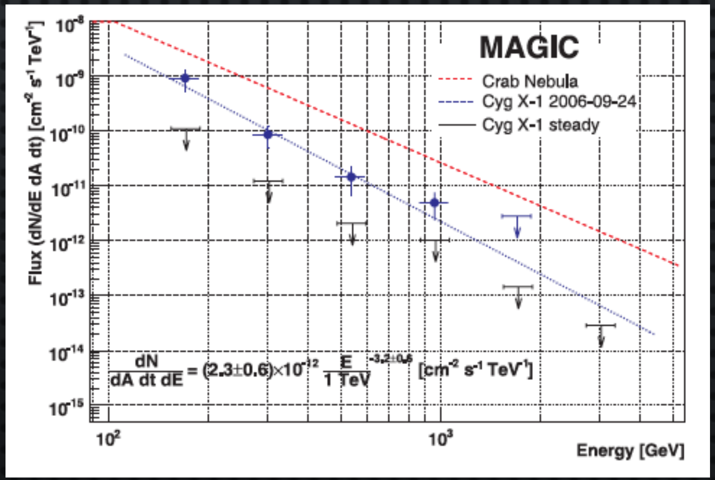
Cygnus X-1: flaring activity - MAGIC observations



- ~4σ hint of detection:
  2006-09-24 20:58-23:41
- During a hard X-ray flare
  INTEGRAL, *Swift*/BAT, *RXTE*/ASM

(Albert et al., ApJ, 665, L51, 2007)





Cygnus X-1: flaring activity - CTA simulations

- Input spectral model → MAGIC flaring spectrum
  Power Law: Prefactor = 2.3 x 10^{-18} MeV^{-1} cm^{-2} s^{-1}
  Index = 3.2
  PivotEnergy = 1 TeV

- 30m observations with CTA North [ctools]
  CTA IRF → North_z20_average_30m
  prod3b-v1 calibration database
  binned analysis (20 bins): 100 GeV – 1 TeV

Similar investigations published in:
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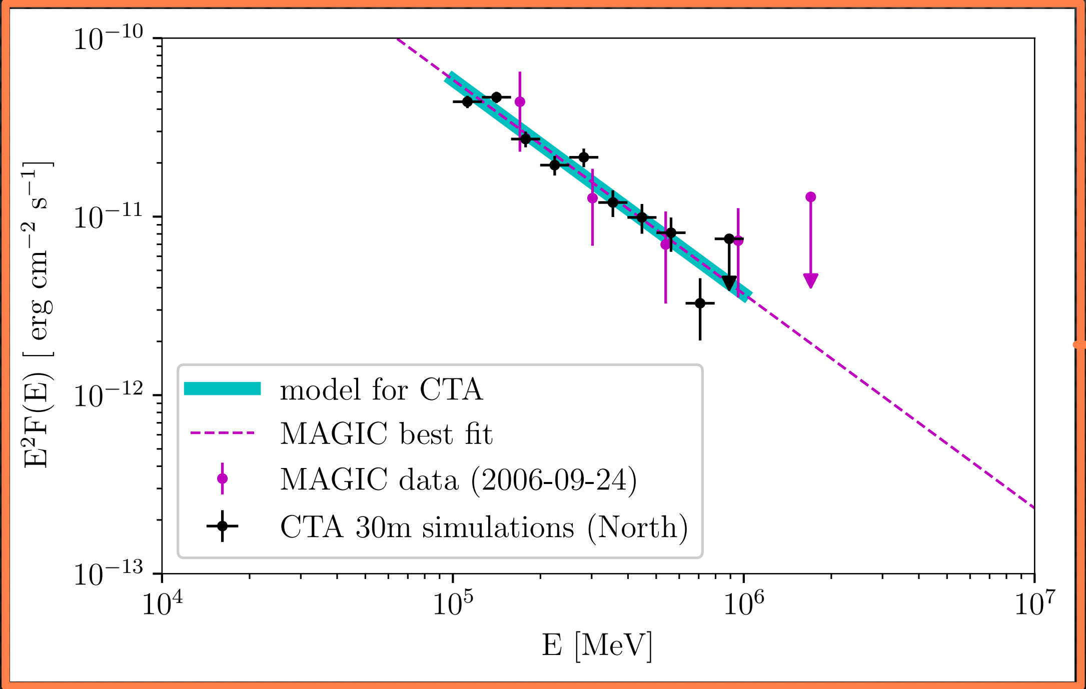
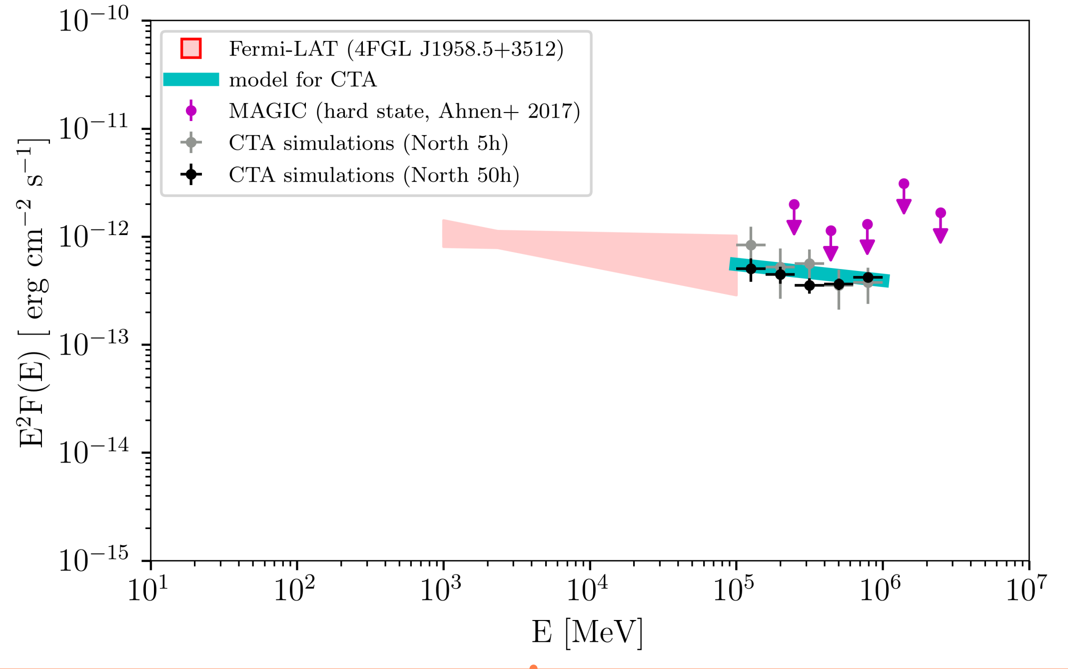
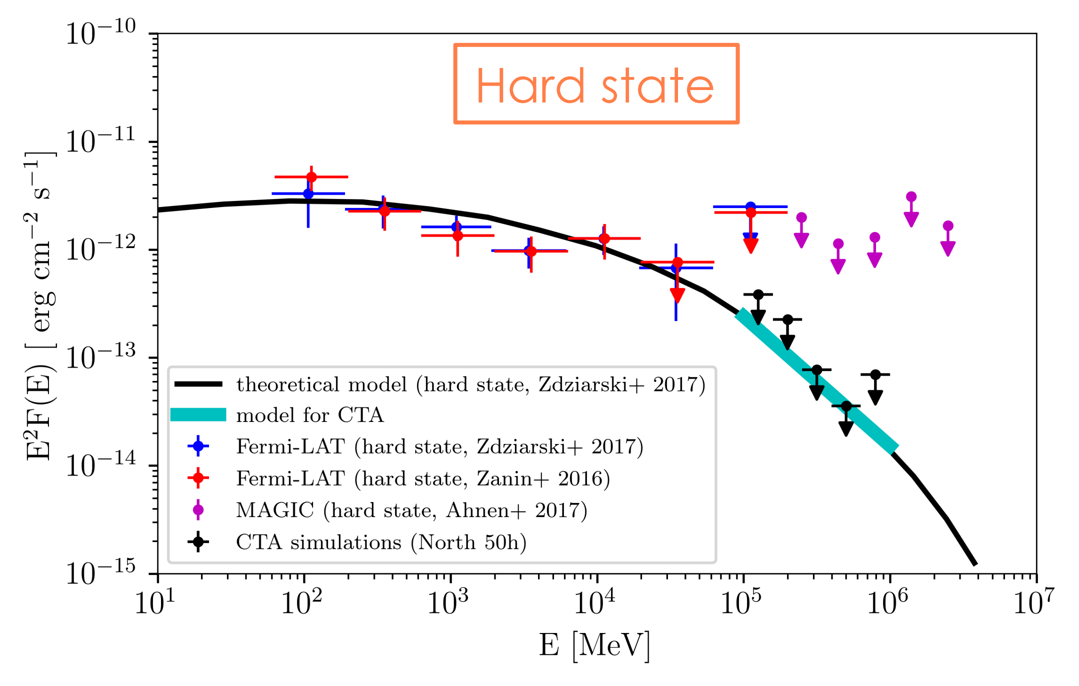


Results:
a MAGIC-like sub-TeV flare would be easily detected by CTA North (significance ~40σ) in a 30m observation

Cygnus X-1: steady emission

- Detected as steady source by Fermi-LAT (8y data) → 4FGL J1958.5+3512
- Persistent γ-ray emission associated with hard spectral state (Zdziarski+ 2014, 2017; Zanin+ 2016;…)





Results:
if no cut-off around 100 GeV → detection!
(5h → ~6.5σ, 50h → ~ 19.3σ)

Results:
Theoretical model (IC) for hard state → cut-off
(KN regime, $\gamma\gamma$ absorption) → no detection

Microquasars in the Cygnus region

CTA simulations

- V404 Cygni → flare: according to a GeV-fit spectrum → no detection at TeV (50h obs.)
- Cygnus X-3 → flare: according to a GeV-optimized emission model → no detection at TeV (50h obs.)
- Cygnus X-1 → flare: CTA North would detect a MAGIC-like flare in a 30m observation
  → steady: CTA North would detect persistent emission if no sharp cut-off at ~100 GeV

CTA observations → crucial, even if no detection → physical constraints to:

- timing of possible TeV transient emission (simultaneous to GeV flare?)
- (spectral cut-off): extreme limit of particle acceleration in the jet
  TeV opacity for e^+e^- pair production

Search for persistent and transient γ-ray emission at TeV energies:

- ➢ Steady: Galactic Plane Survey (GPS) + Star-Forming Systems KSP for the Cygnus region
- ➢ Transient: prompt reaction to multi-wavelength triggers

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Thanks for your attention