The gamma-ray monitoring of newly discovered Be/BH binary system MWC 656

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OUTLINE

- The *AGILE* satellite
- The *Fermi* satellite
- Motivation
- Counterparts
  - MWC 656
  - RX J2243.1+4441
- Follow-up
  - *AGILE* data analysis
  - *Fermi* data analysis
  - Comparison *AGILE* vs *Fermi*
- Conclusions

THE *AGILE* SATELLITE

- AGILE (Astrorivelatore Gamma a Immagini LEggero)
- Two main instruments:
  - Super Agile: hard X-ray detector
  - GRID: gamma-ray camera
    - Energy range: 50 MeV - 50 GeV
    - PSF: 4°@100MeV - 0.°8@ 1GeV
- Operation modes:
  - Pointing, from launch until october 2009
  - Spinning, from october 2009 on

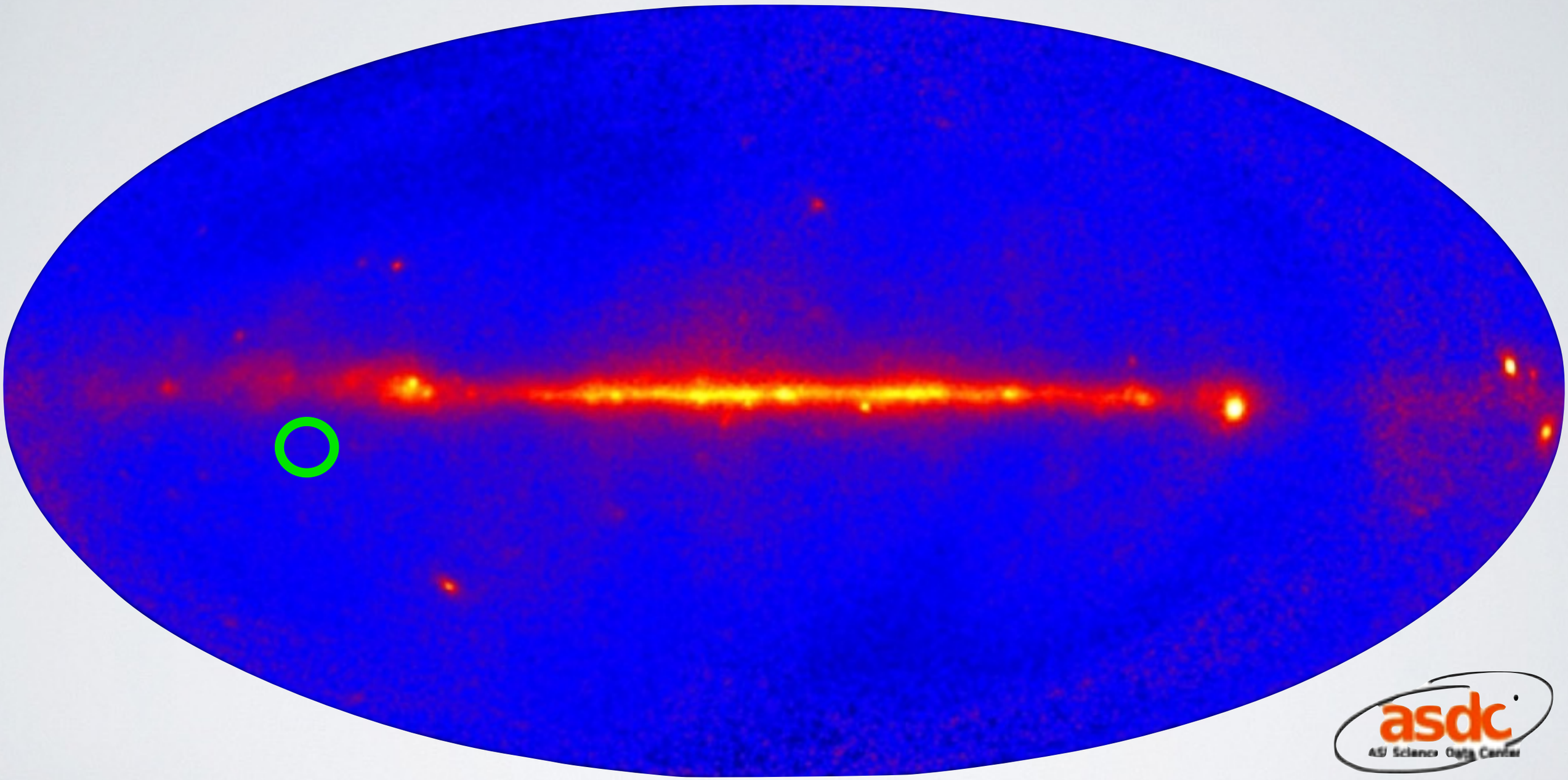
THE *FERMI* SATELLITE

- *T*wo instruments
  - GBM
  - The LAT (Large Area Telescope)
    - Energy range: 30 MeV - 300 GeV
    - PSF: 2°@300MeV - 0.°8@ 1GeV

- Operation mode:
  - Scanning: covering most of the sky every few hours

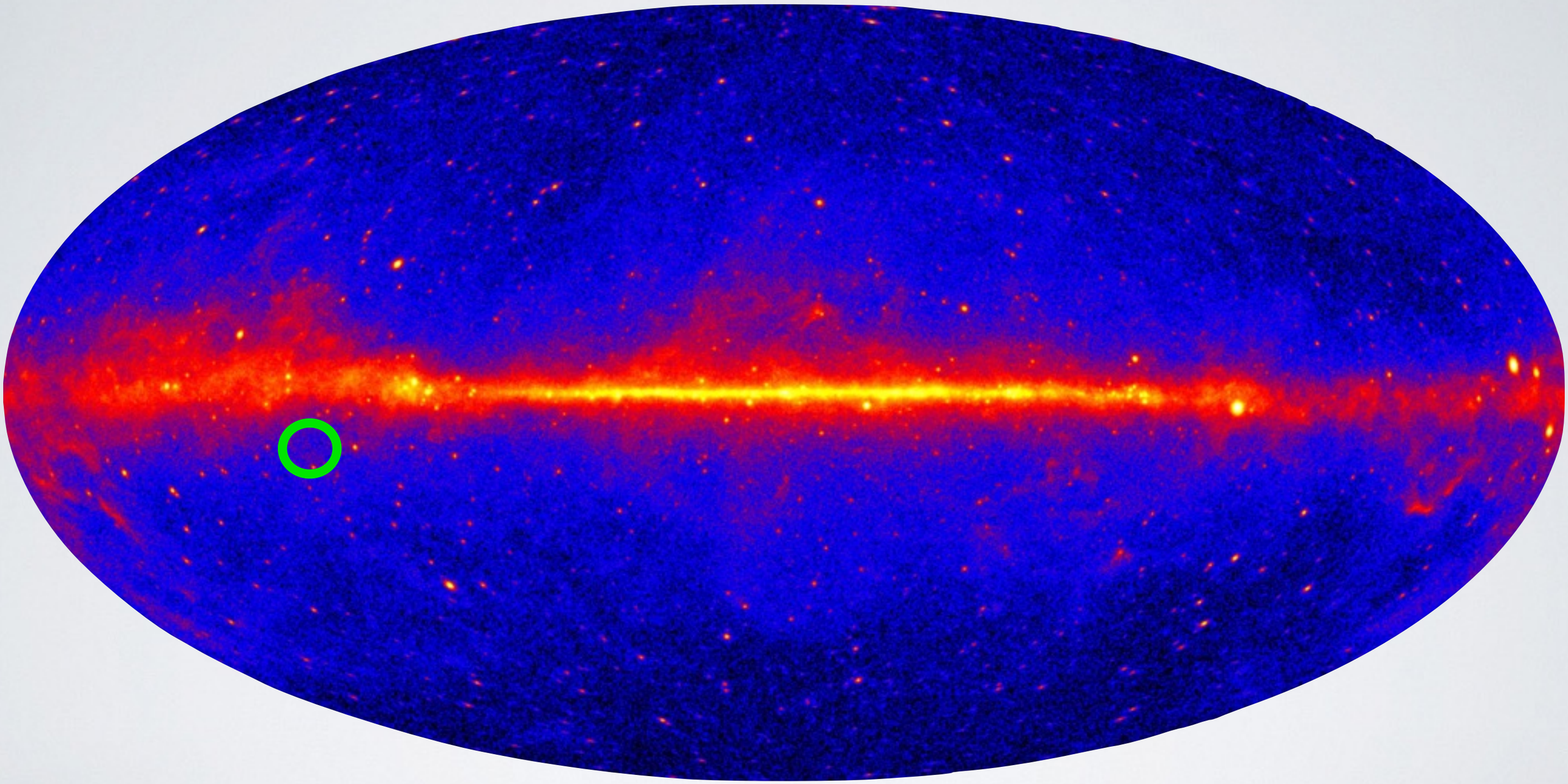
THE *AGILE* SATELLITE

Full band (E>100 MeV) *AGILE* all-sky map (pointing + spinning up to 2012)



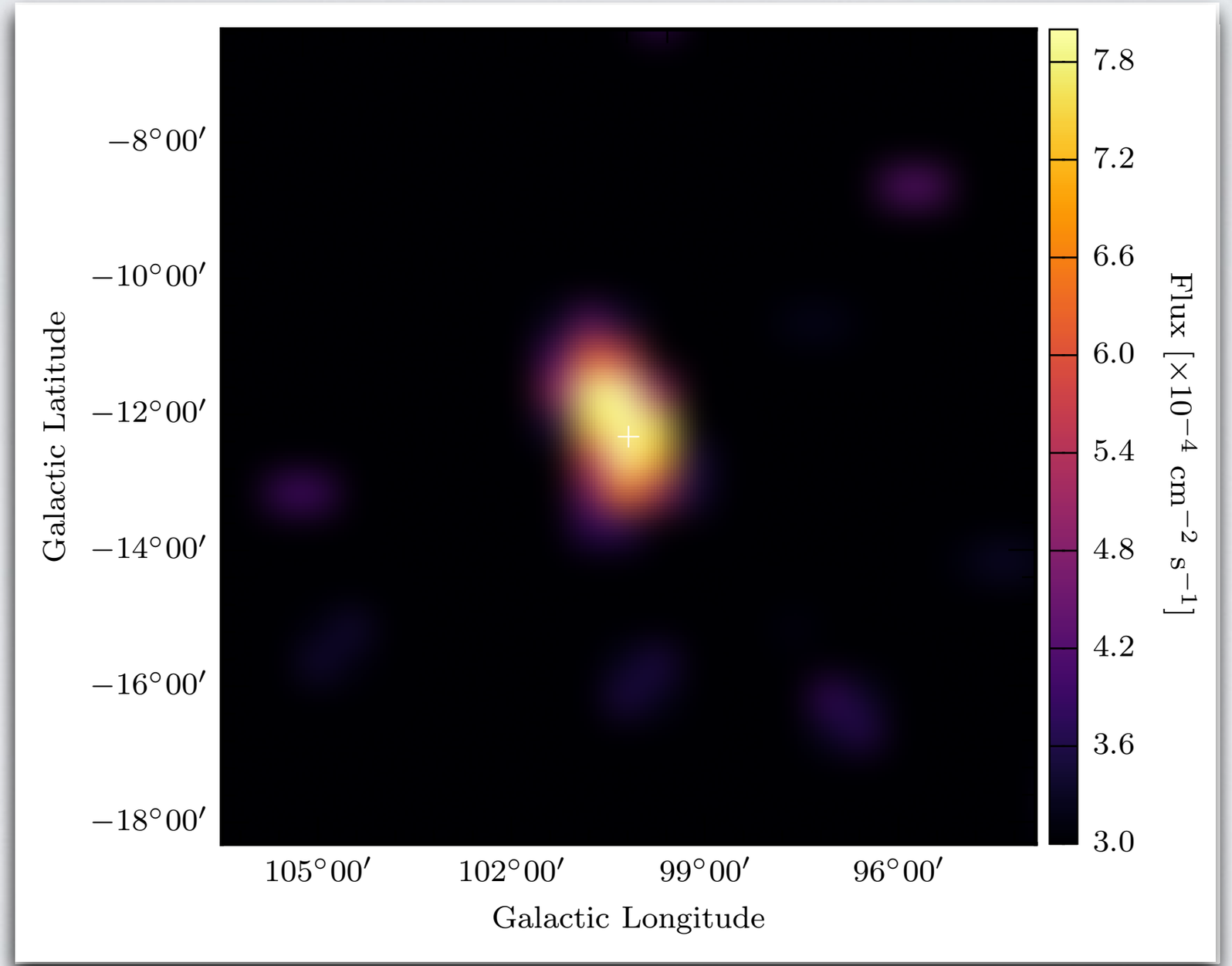
THE *FERMI* SATELLITE

Fermi/LAT (E>1GeV) all-sky map after 5 years of observation

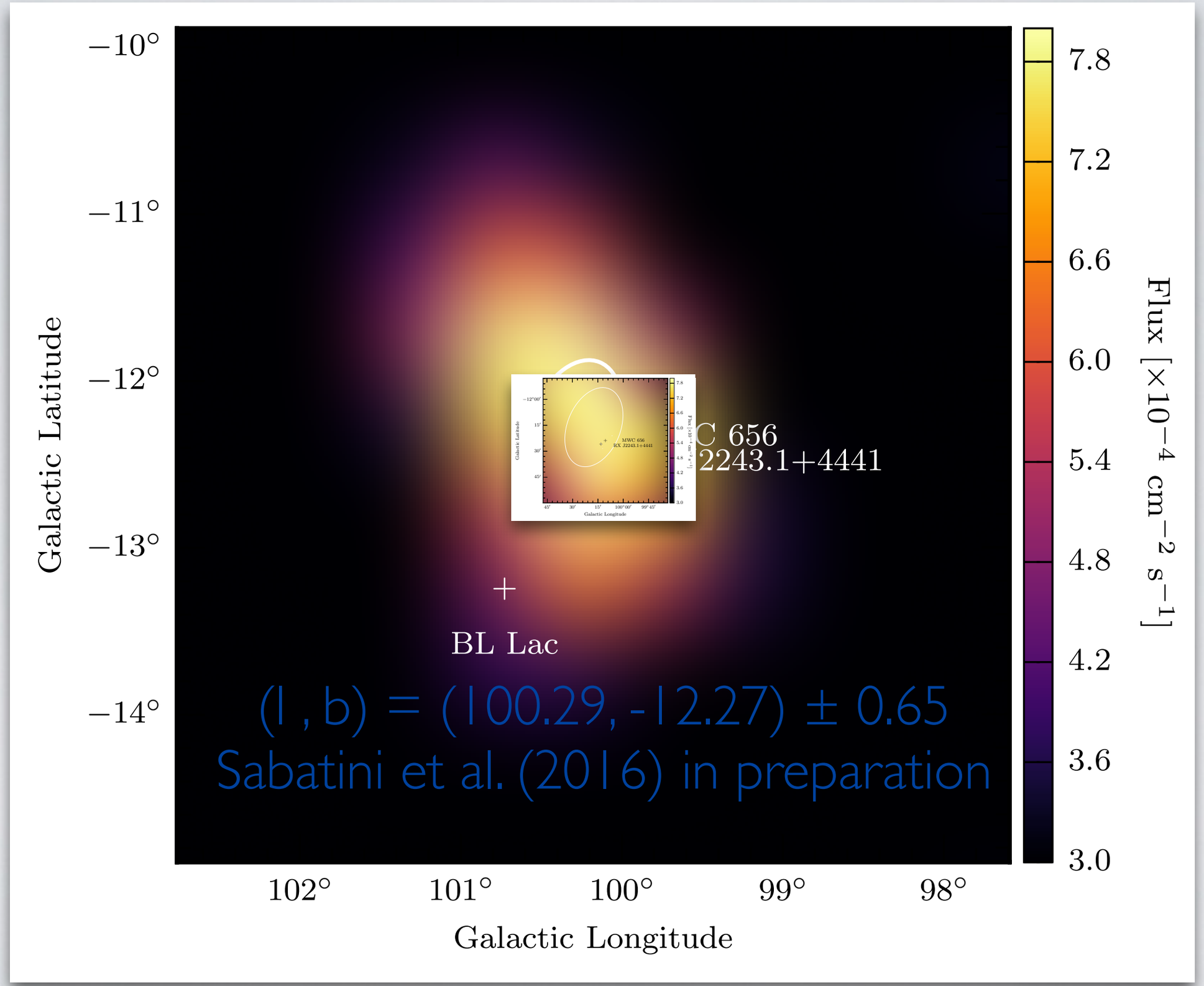


MOTIVATION

- In July 2010 *AGILE* detected transient gamma-ray source AGL J2241+4454 (Lucarelli et al. 2010) at galactic coordinates (l , b) = (100.°0, -12.°0) ± 0.°6
- Significance > 5σ , Flux(E>100MeV)=1.5x10^{-6} ph cm^{-2} s^{-1}



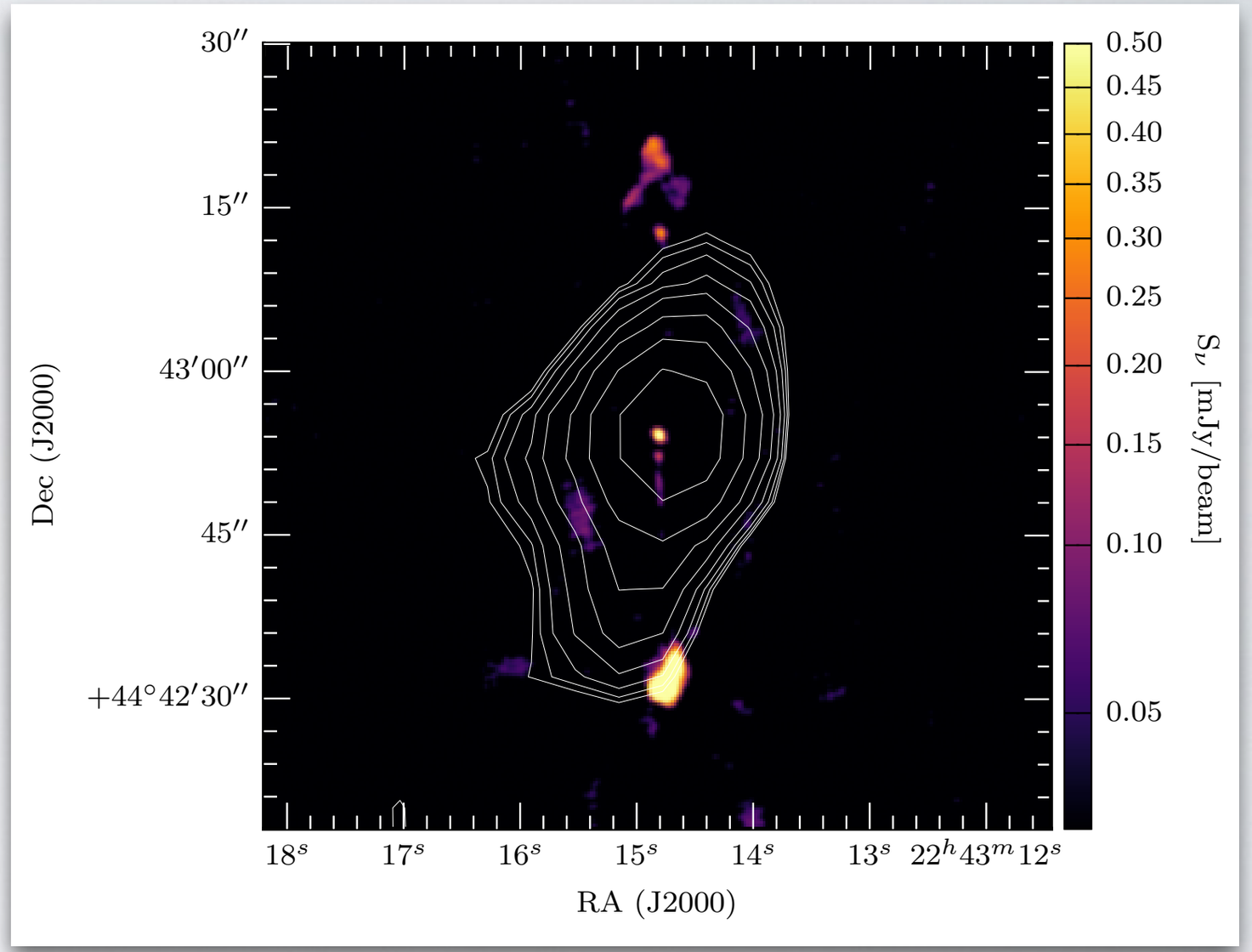
MOTIVATION


−10°
−11°
−12°
−13°
−14°
Galactic Latitude
102°
101°
100°
99°
98°
Galactic Longitude
7.8
7.2
6.6
6.0
5.4
4.8
4.2
3.6
3.0
Flux [×10−4 cm−2 s−1]
C 656
2243.1+4441
+
BL Lac
(l , b) = (100.29, -12.27) ± 0.65
Sabatini et al. (2016) in preparation

POSSIBLE COUNTERPARTS: RX J2243.1+4441

- Observed with *XMM-Newton* (15 ks) and VLA
- Detected at more than 5σ in both
- Difficult to obtain X-ray spectrum because it is at the border of the ccd
- Radio core flux 2.2mJy/beam
  - South lobe seems variable (galactic source overlaped?)
- Morphology similar to FR-II
  - less probability of gamma-ray emission?

VLA 3GHz + *XMM* 0.2-10 keV contours



Adapted from Marcote 2015, PhD Thesis

POSSIBLE COUNTERPARTS: MWC 656

- Discovered thanks to the *AGILE* detection of a gamma-ray flare (Lucarelli et al. 2010)
- Williams et al. (2010) found photometric eriodicity. Binary system?
- Confirmed as a binary system by Casares et al. (2012)
- Be star orbited by a BH (Casares et al. 2014) with a mass between 3.8 and 6.9 $M_\odot$
- MWC 656 is the **first known binary system of this class**
- Confirmed as a HMXB by Munar-Adrover et al. (2014)

Table 1 | Orbital elements for MWC 656

Parameter	Value
P_{orb} (days)	60.37 (fixed)
T_0 (HJD − 2,450,000)	$3{,}243.70 \pm 4.30$
e	0.10 ± 0.04
ω (degrees)	163.0 ± 25.6
γ (km s^{-1})	-14.1 ± 2.1
K_1 (km s^{-1})	32.0 ± 5.3
K_2 (km s^{-1})	78.1 ± 3.2
$a_1 \sin i$ ($R_\odot$)	38.0 ± 6.3
$a_2 \sin i$ ($R_\odot$)	92.8 ± 3.8
$M_1 \sin^3 i$ ($M_\odot$)	5.83 ± 0.70
$M_2 \sin^3 i$ ($M_\odot$)	2.39 ± 0.48
M_2/M_1	0.41 ± 0.07
σ_f (km s^{-1})	16.7

Casares et al. (2014)

Image credit: Gabriel Pérez - SMM (IAC)

POSSIBLE COUNTERPARTS: MWC 656

Be star

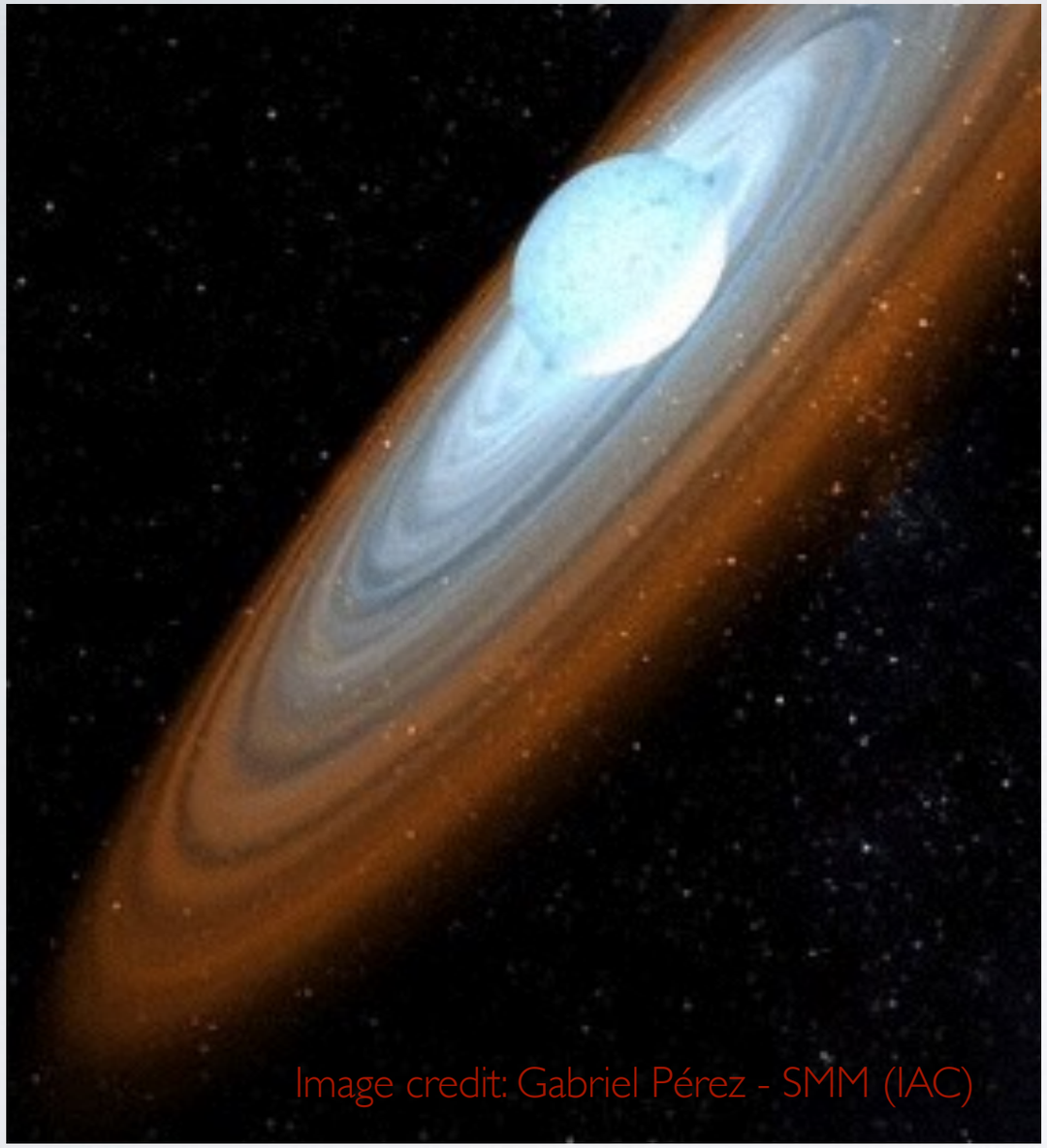


Image credit: Gabriel Pérez - SMM (IAC)

Accretion-ejection coupling in XRBs

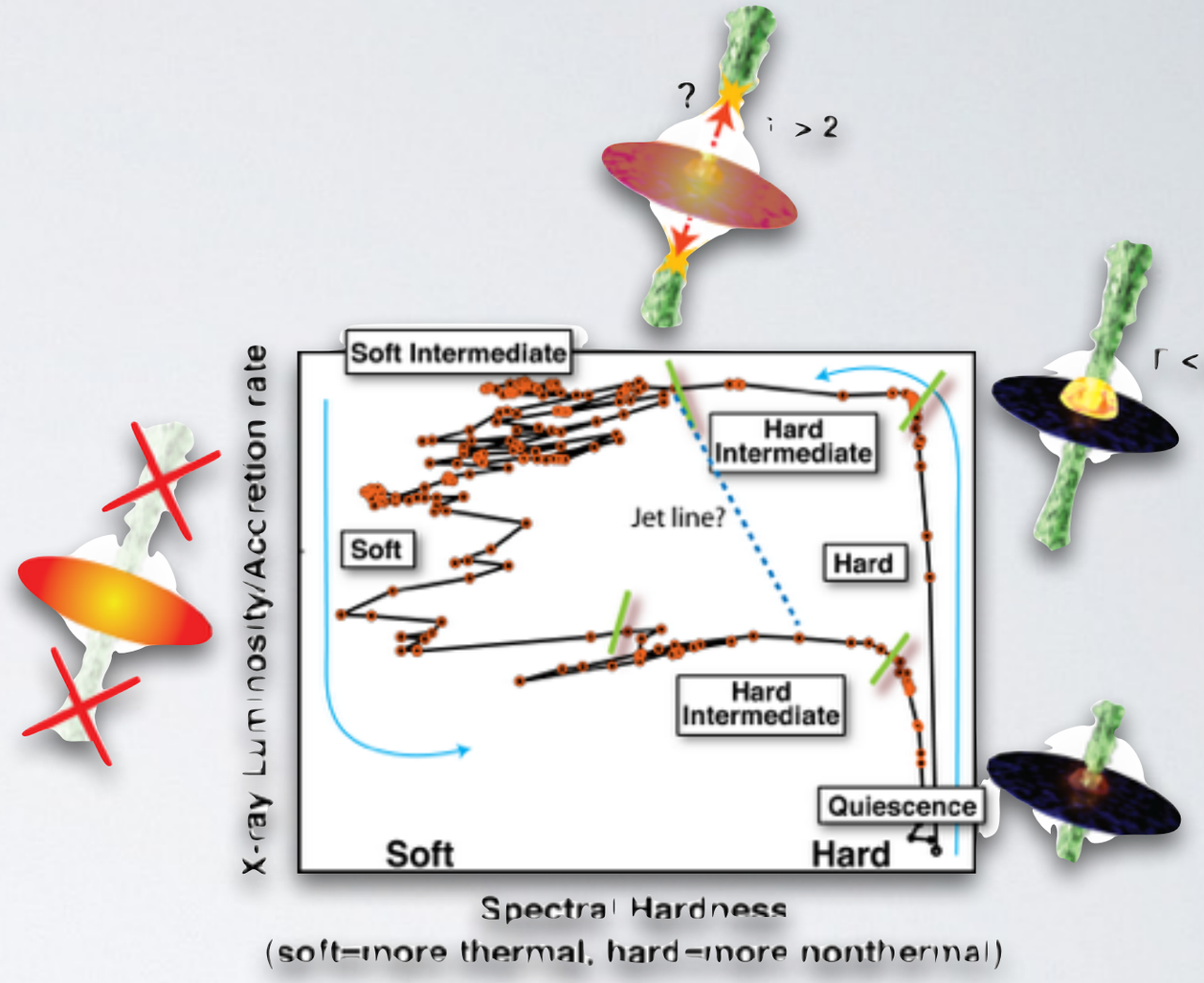
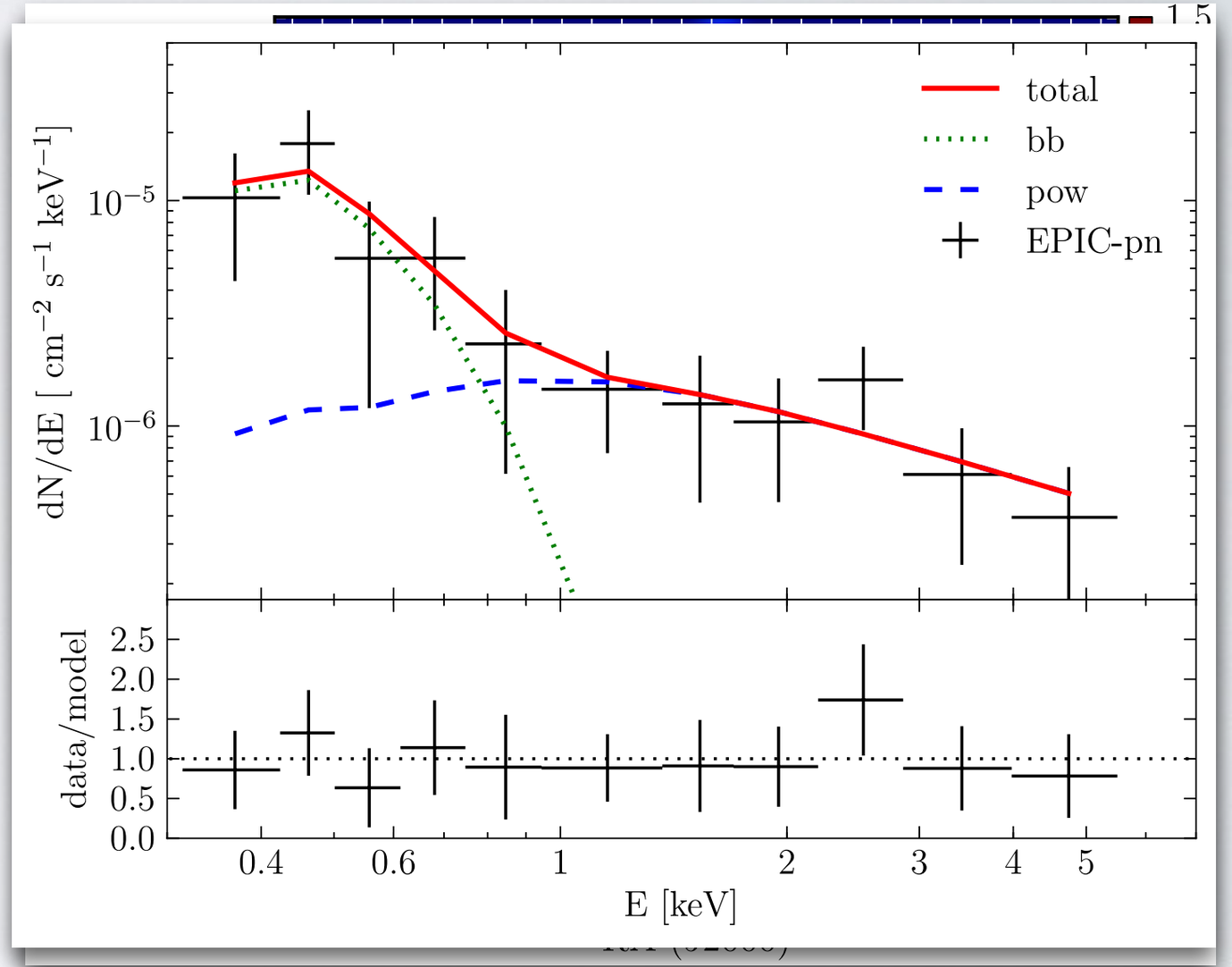


Image credit: Sera Markoff

Interesting because it is the first known case of a binary system containing a Be star and a BH

POSSIBLE COUNTERPARTS: MWC 656

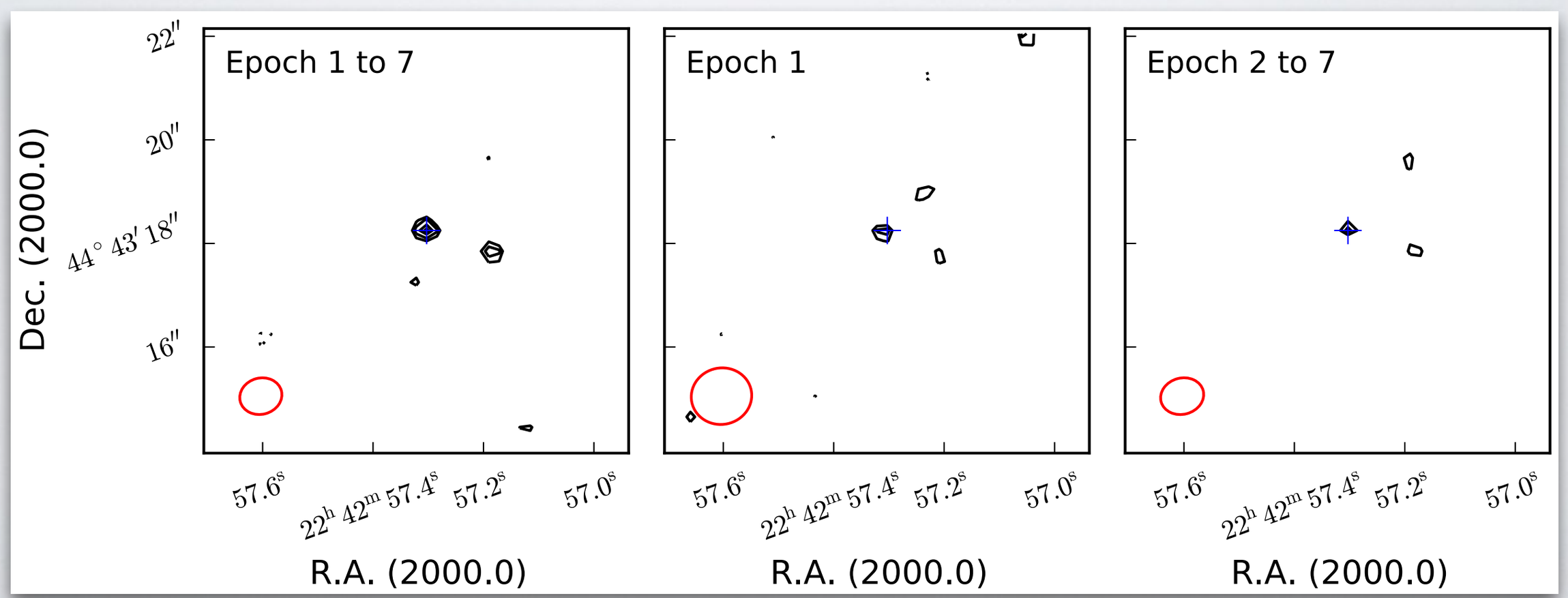
- Observed with *XMM-Newton* (15 ks)
- We detect a faint source at 4σ c.l. coincident with the position of MWC 656
- X-ray source position compatible with the *Hipparcos* position of MWC 656 at 2.4σ
- Detected only in the 0.3-5.5 keV range
- Spectrum with low number of counts (0.3-5.5 keV energy range)



Munar-Adrover et al. (2014)

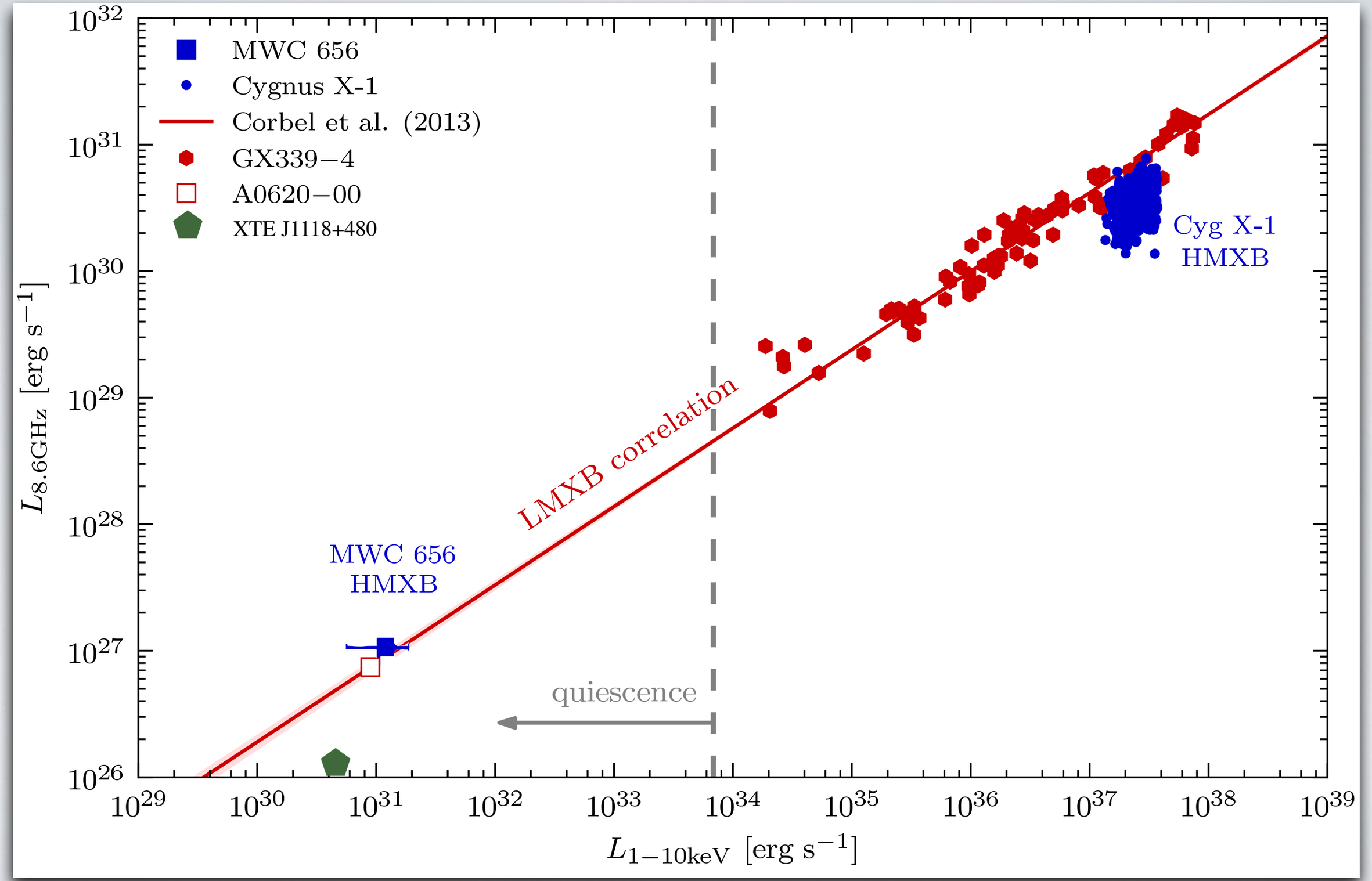
POSSIBLE COUNTERPARTS: MWC 656

- Radio observations with VLA (Dzib et al. 2015): 7 dedicated obs. in 2015
- Detection of a source compatible with the position of MWC 656
- Variable radio flux in week scales
  - 2h obs @ 8-12 GHz: 14.2 ± 2.9 μJy (epoch 1, orbital phase 0.49)
  - integration of 6 obs @ 8-12 GHz: 3.7 ± 1.4 μJy (epoch 2-7)



Dzib et al. (2015)

POSSIBLE COUNTERPARTS: MWC 656



Munar-Adrover et al. (2014)

- Analysis strategy (*AGILE* and *Fermi*/LAT):
  - Blind search in 2-days bins
  - Search for periodicity
  - Search for steady emission
  - Stack detected events to get a spectrum

AGILE DATA ANALYSIS

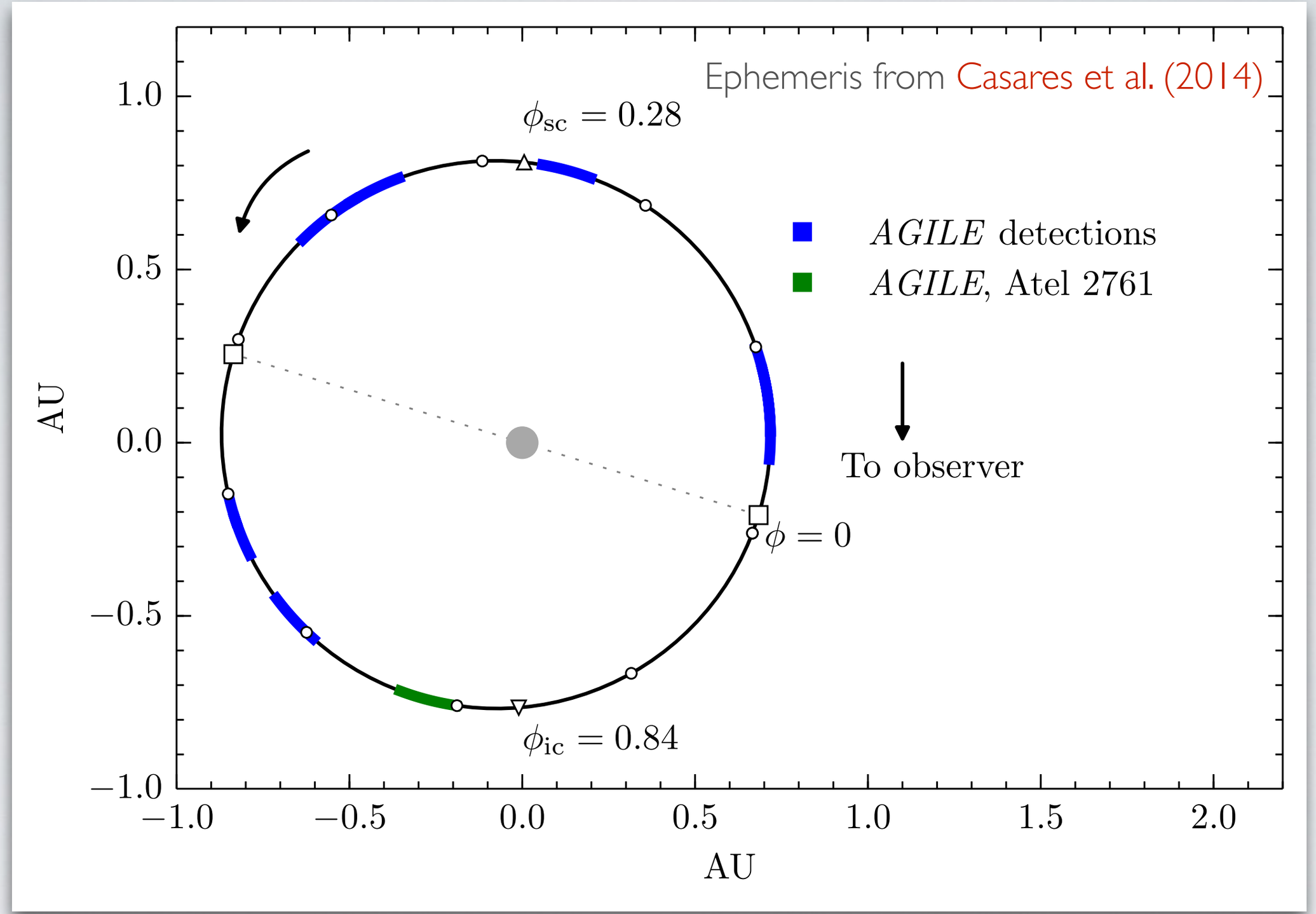
- Blind search: 10 flaring events registered by *AGILE* between 2007 and 2013

AGILE GAMMA-RAY TRANSIENT DETECTIONS AROUND THE POSITION OF MWC 656.

l [°]	b [°]	t_{start} [UT]	t_{end} [UT]	Flux [$\times 10^{-6}$ cm^{-2} s^{-1}]	$\sqrt{TS}$
100.28	-13.22	2007-11-23 UT00:02:10	2007-11-24 UT12:02:12	1.5 ± 0.5	4.5
100.22	-12.61	2008-06-28 UT12:03:15	2008-06-30 UT06:03:15	0.6 ± 0.3	3.2
101.74	-11.25	2009-01-04 UT12:02:12	2009-01-07 UT00:02:12	0.5 ± 0.2	3.1
100.94	-12.65	2010-06-13 UT12:01:06	2010-06-14 UT18:01:06	1.4 ± 1.1	3.2
99.27	-11.50	2010-06-30 UT00:01:06	2010-07-02 UT00:01:06	1.3 ± 0.6	3.1
99.96	-12.24	2010-07-25 UT00:02:12	2010-07-27 UT00:02:12	1.4 ± 0.6	3.8
99.94	-12.76	2011-10-08 UT00:02:12	2011-10-10 UT00:02:12	2.5 ± 1.1	3.4
101.70	-12.51	2011-04-09 UT00:02:12	2011-04-11 UT00:02:12	2.2 ± 1.1	3.1
100.38	-12.70	2013-07-10 UT00:00:00	2013-07-12 UT00:00:00	3.2 ± 1.6	3.5
100.34	-11.81	2013-03-07 UT00:00:00	2013-03-08 UT09:00:00	2.6 ± 1.4	3.1

from Le Hoang master thesis (2014)

AGILE DATA ANALYSIS



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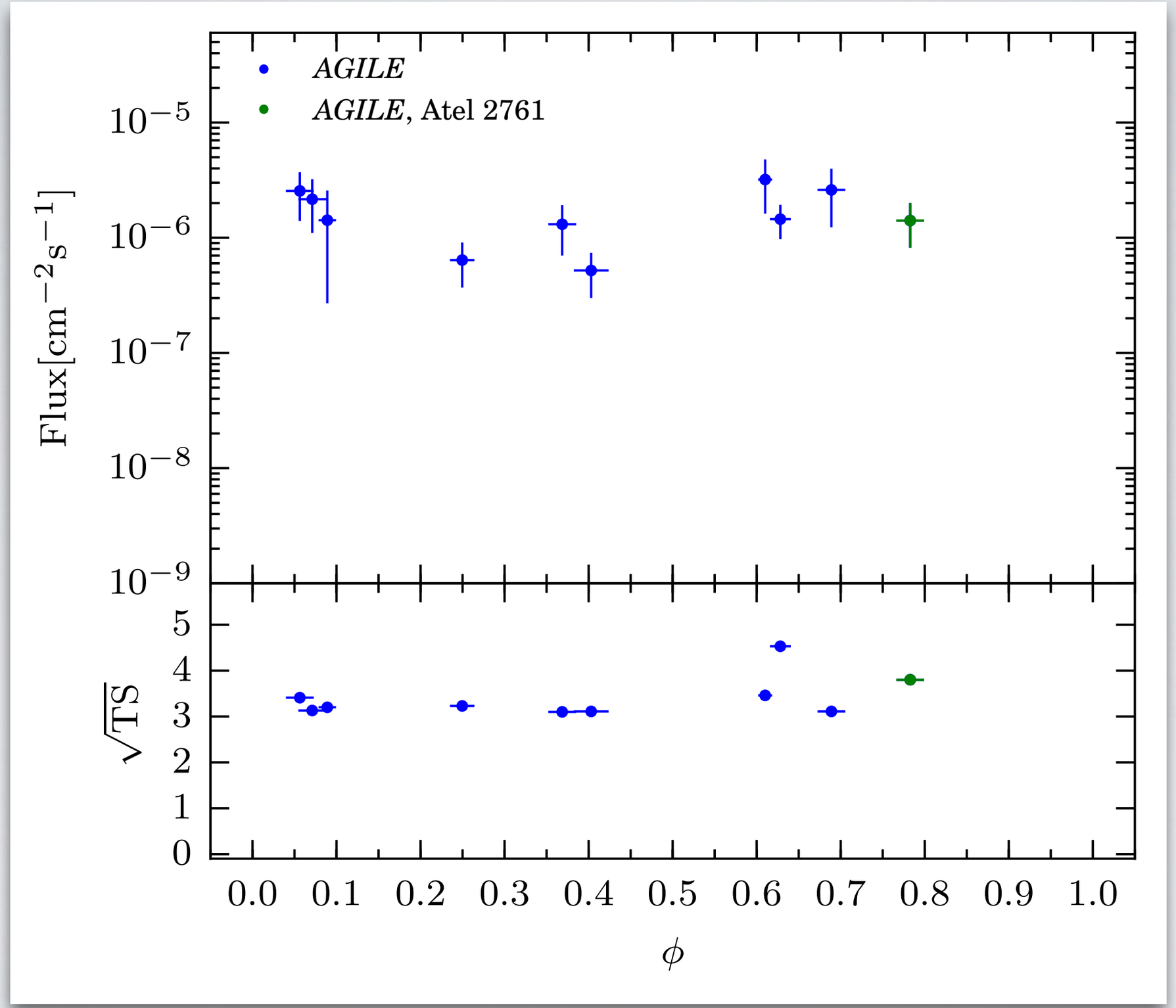
AGILE DATA ANALYSIS



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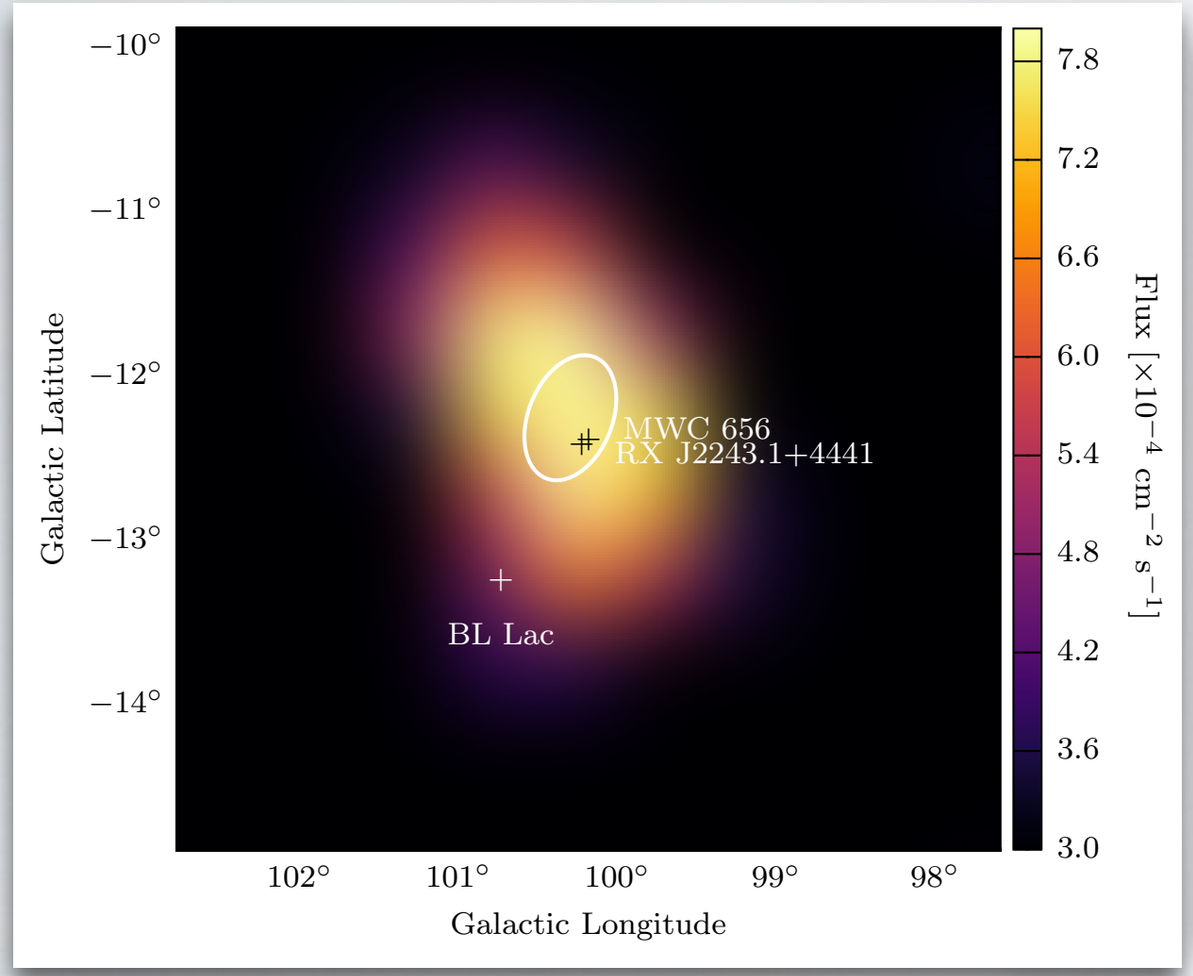
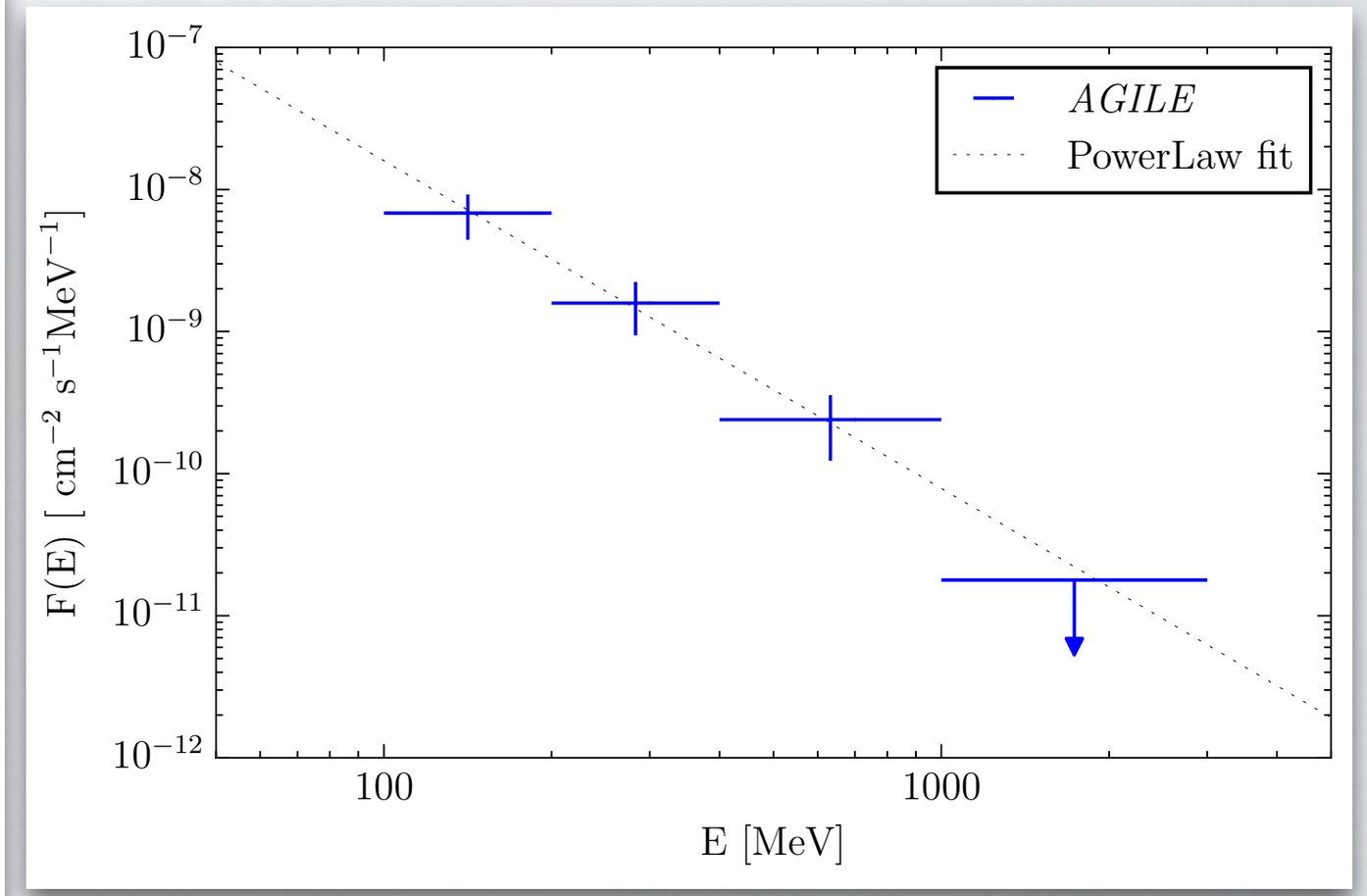
AGILE DATA ANALYSIS

- *AGILE* spectrum between 100 MeV and 3 GeV
- Integrating over all detected gamma-ray flares
- Spectral fit with photon index $\Gamma = 2.3 \pm 0.2$





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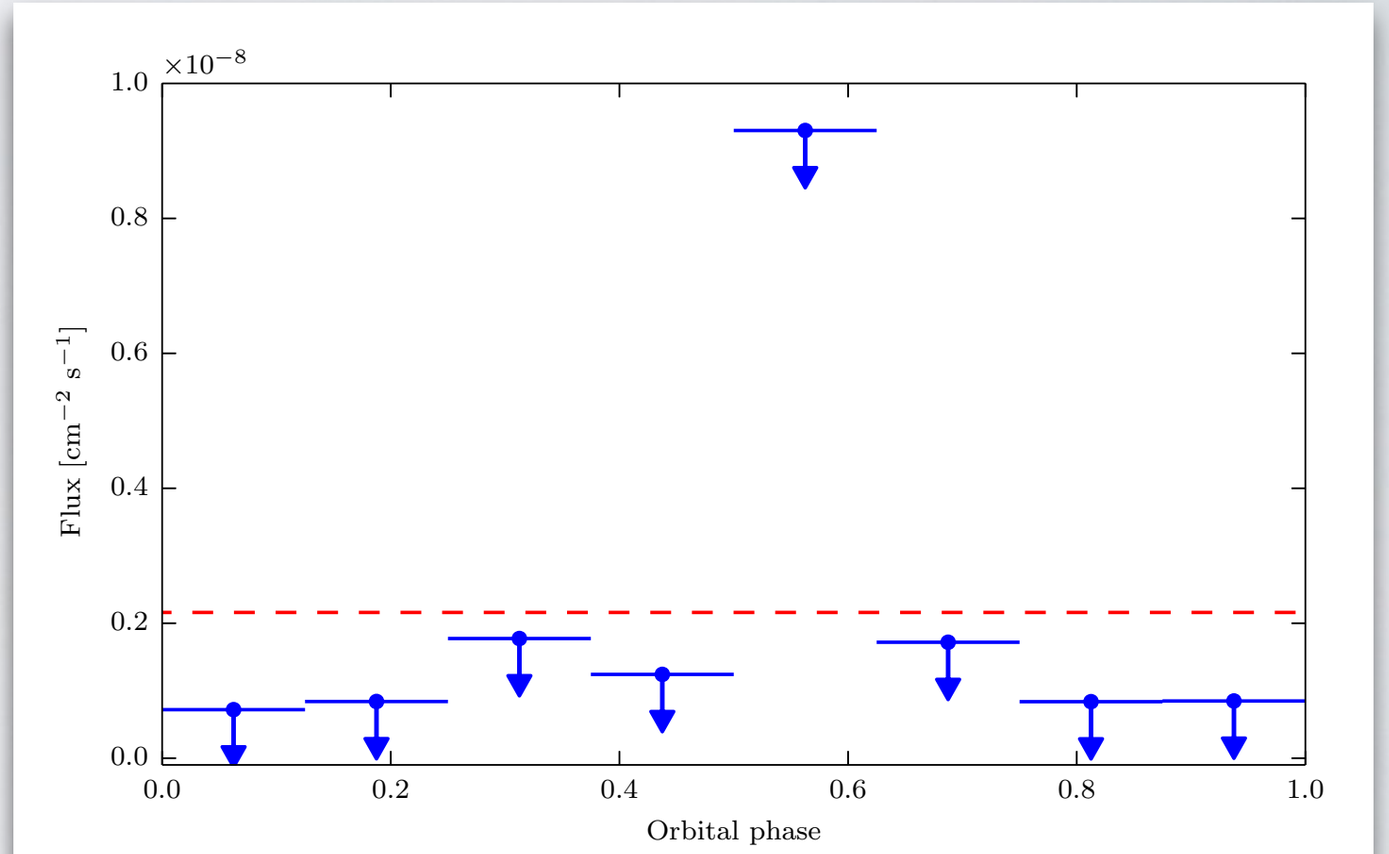
FERMI/LAT DATA ANALYSIS

- Pass 8 data
- Blind search in 2-day bins: no significant events
- Steady emission: UL for 6 years integration: 2.2×10^{-10} cm^{-2} s^{-1}
- Stacking of *AGILE* detected flares: UL integrating all flares: 3.0×10^{-8} cm^{-2} s^{-1}
- Search for periodic emission



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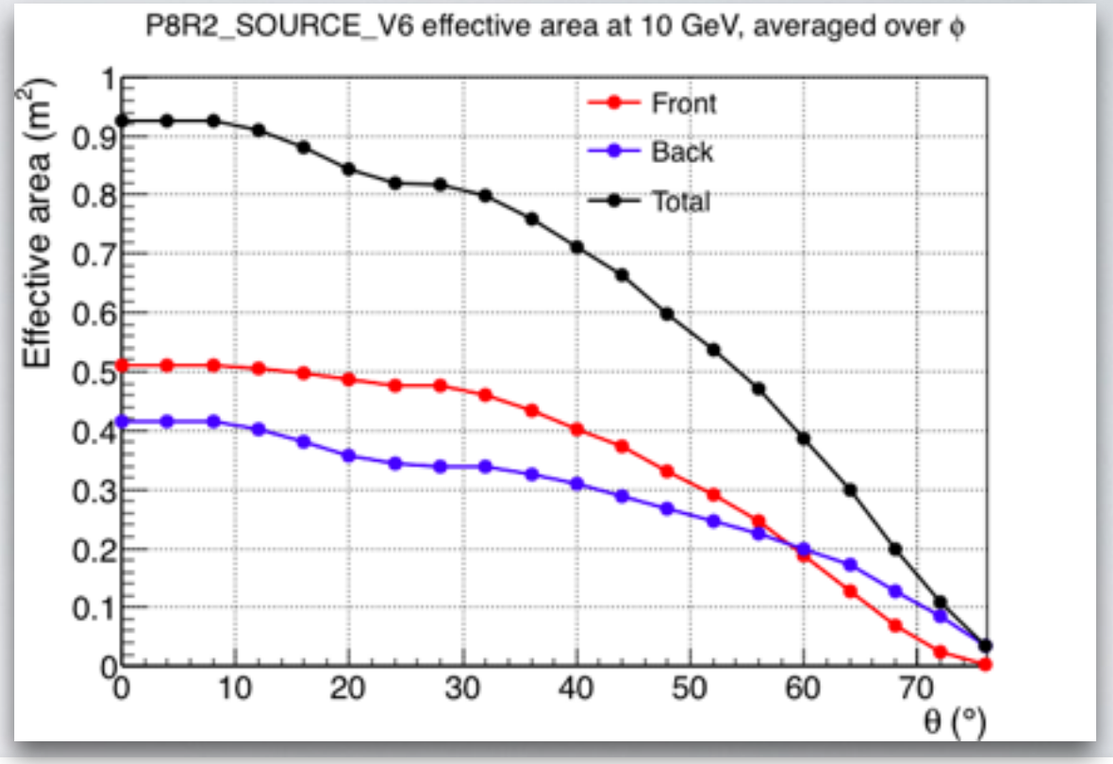
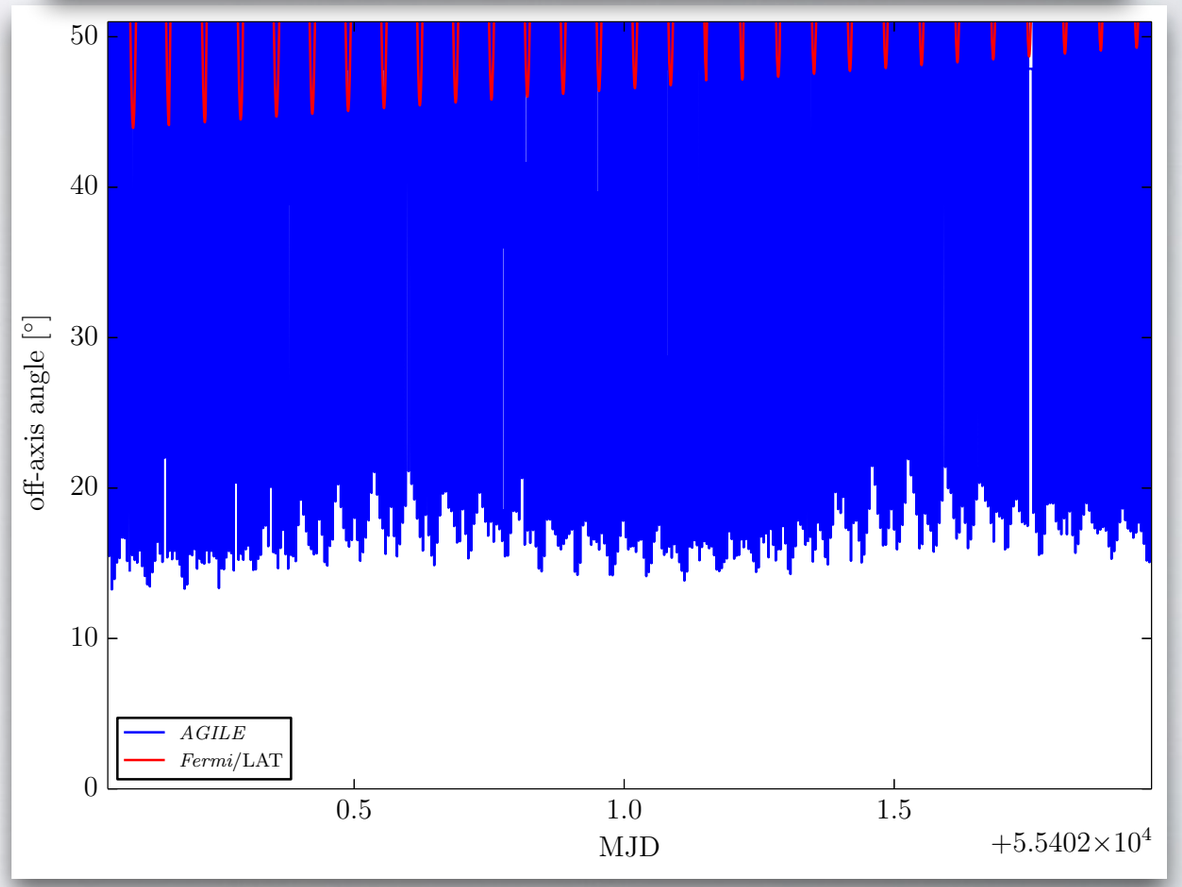
COMPARISON: *AGILE* vs *FERMI*

- *Fermi* and *AGILE* effective area decrease with zenith distance (ZD), specially above 50°

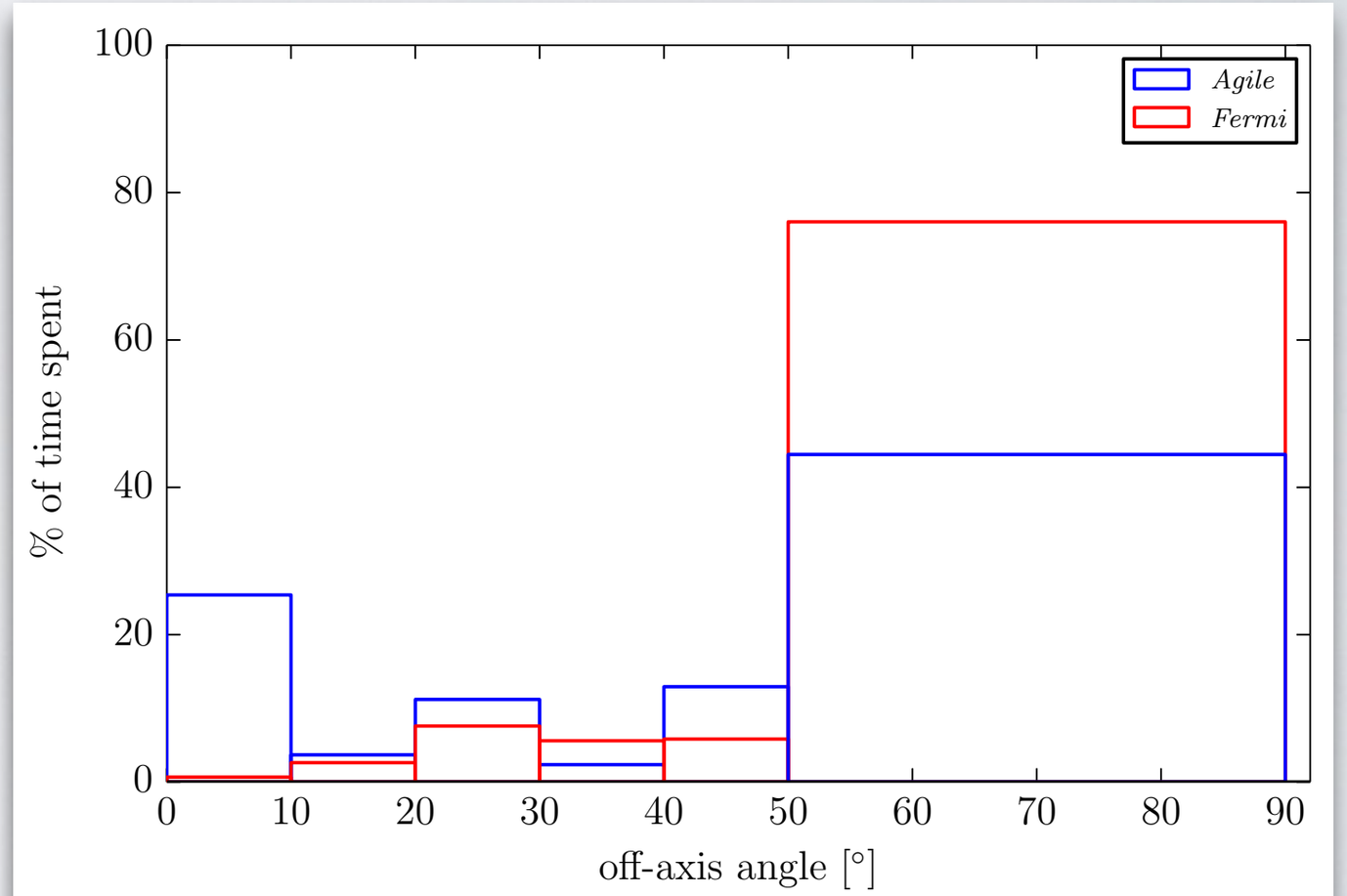


- We checked the source ZD at any given moment for the entire *Fermi* and *AGILE* missions
- During *AGILE* 2010 flare, MWC 656 is almost always at ZD > 50° for *Fermi*



COMPARISON: *AGILE* vs *FERMI*

- Time spent by *AGILE* and *Fermi*/LAT observing MWC 656 at diferent ZD
- Flares:
  - *AGILE*: more than 50% of time at ZD < 50°
  - *Fermi*/LAT: only 20% of time at ZD < 50°
- Rest of time:
  - *AGILE*: on average 30% of time spent at ZD < 50°
  - *Fermi*/LAT: on average 12% of time spent at ZD < 50°



Sabatini et al. (2016) in preparation

CONCLUSIONS

- AGILE detection by Lucarelli et al. (2010) of AGL J2241+4454 triggered the study of this region of the sky
- The first Be/BH system was discovered
- Munar-Adrover et al. (2014) discovered the X-ray counterpart of MWC 656. It is a high-mass X-ray binary. Two spectral components: thermal and non thermal. System at the quiescent state with very low luminosity
- *AGILE* follow-up revealeded 10 flares. Spectrum derived by stacking them. No sign of periodicity or recurrence
- *Fermi*/LAT does not detect the flares or any other episode of activity from MWC 656 field
- Reason of discrepancy might be diferences in off-axis position of MWC 656 between *AGILE* and *Fermi*/LAT during the occurence of the flares
- *Future work:* theoretical modelling (ADAF, etc.)

Thank you

- AGILE detection by Lucarelli et al. (2010) of AGL J2241+4454 triggered the study of this region of the sky
- The first Be/BH system was discovered
- Munar-Adrover et al. (2014) discovered the X-ray counterpart of MWC 656. It is a high-mass X-ray binary. Two spectral components: thermal and non thermal. System at the quiescent state with very low luminosity
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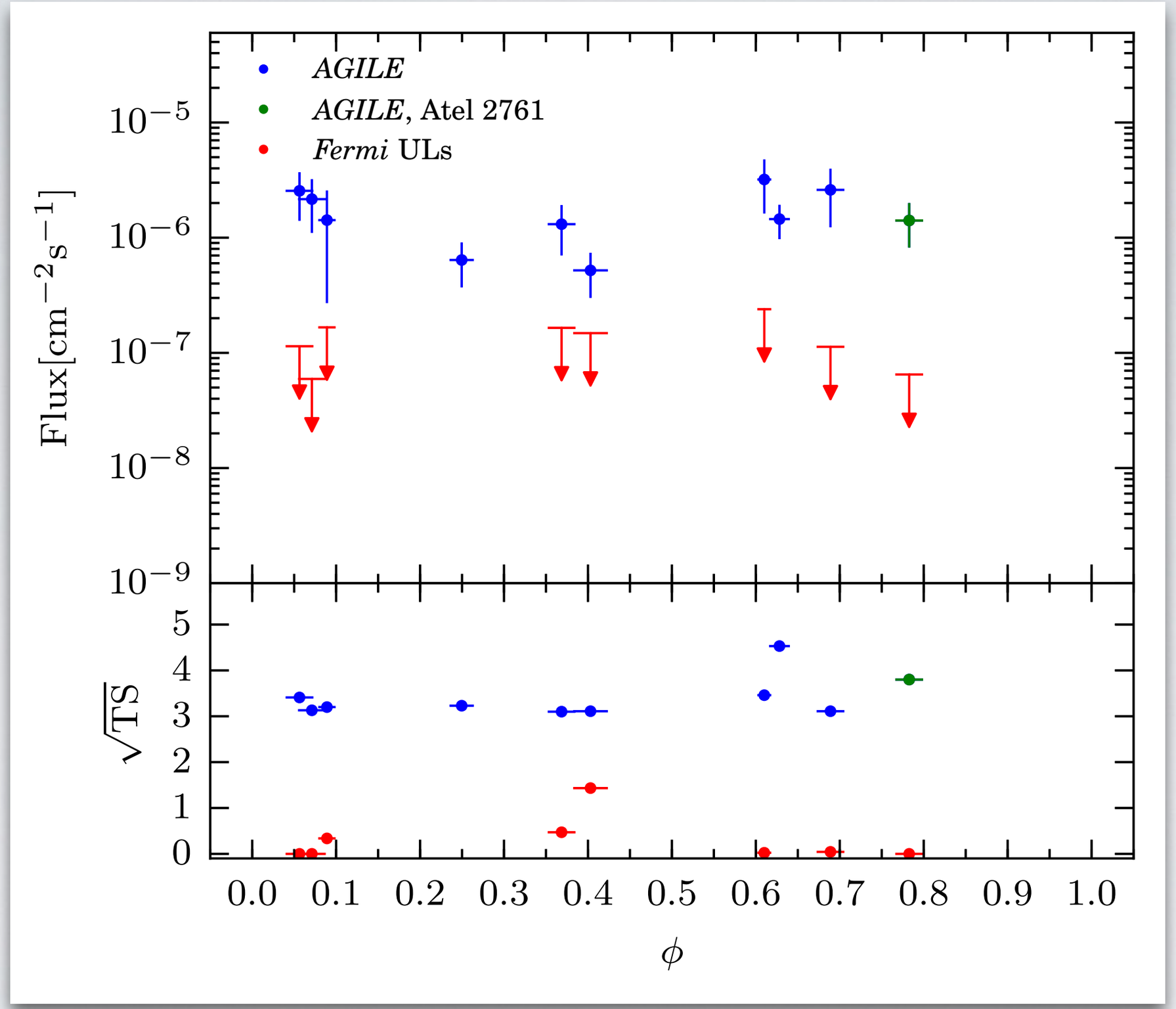
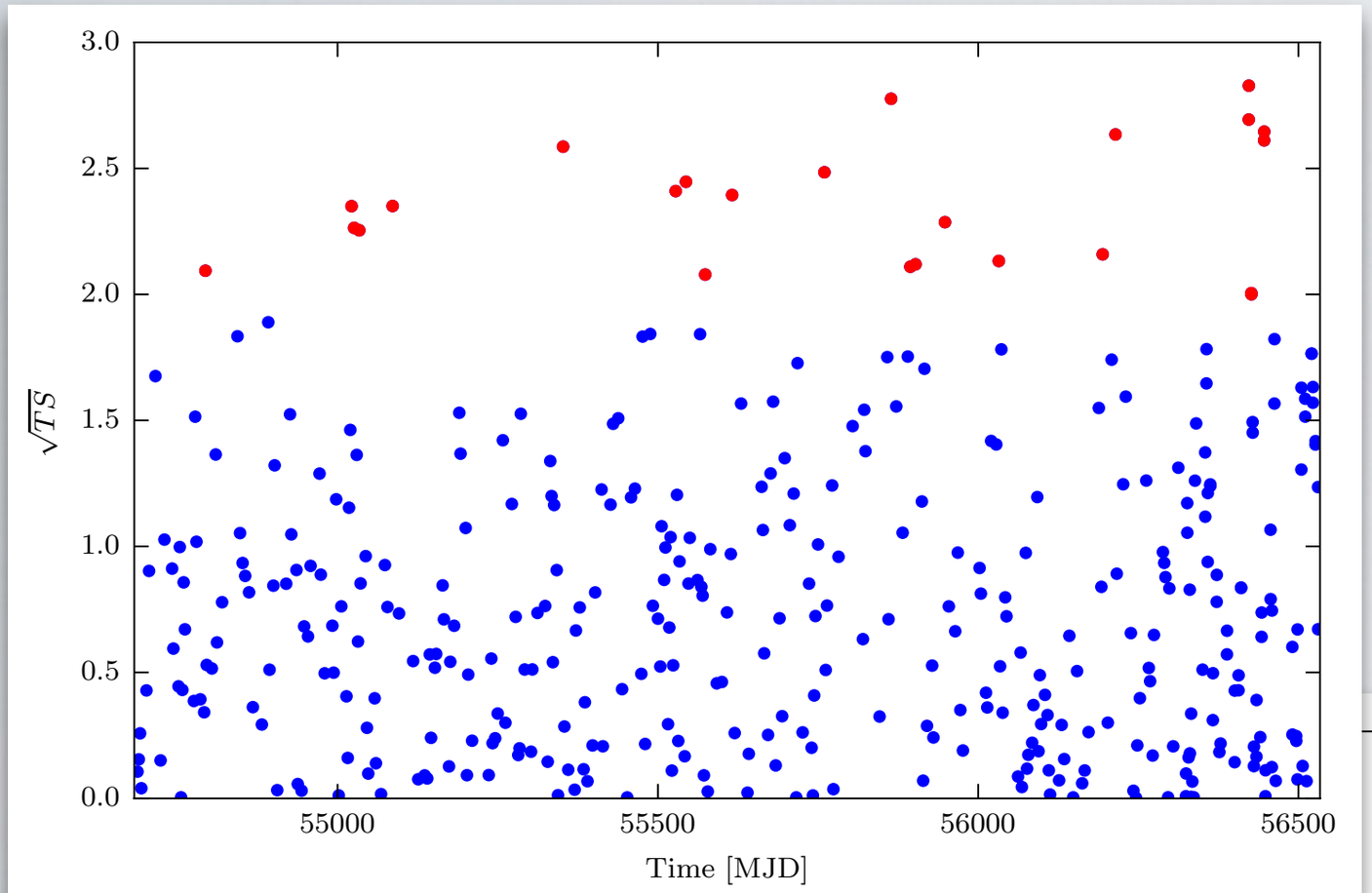
Back up

COMPARISON: *AGILE* vs *FERMI*

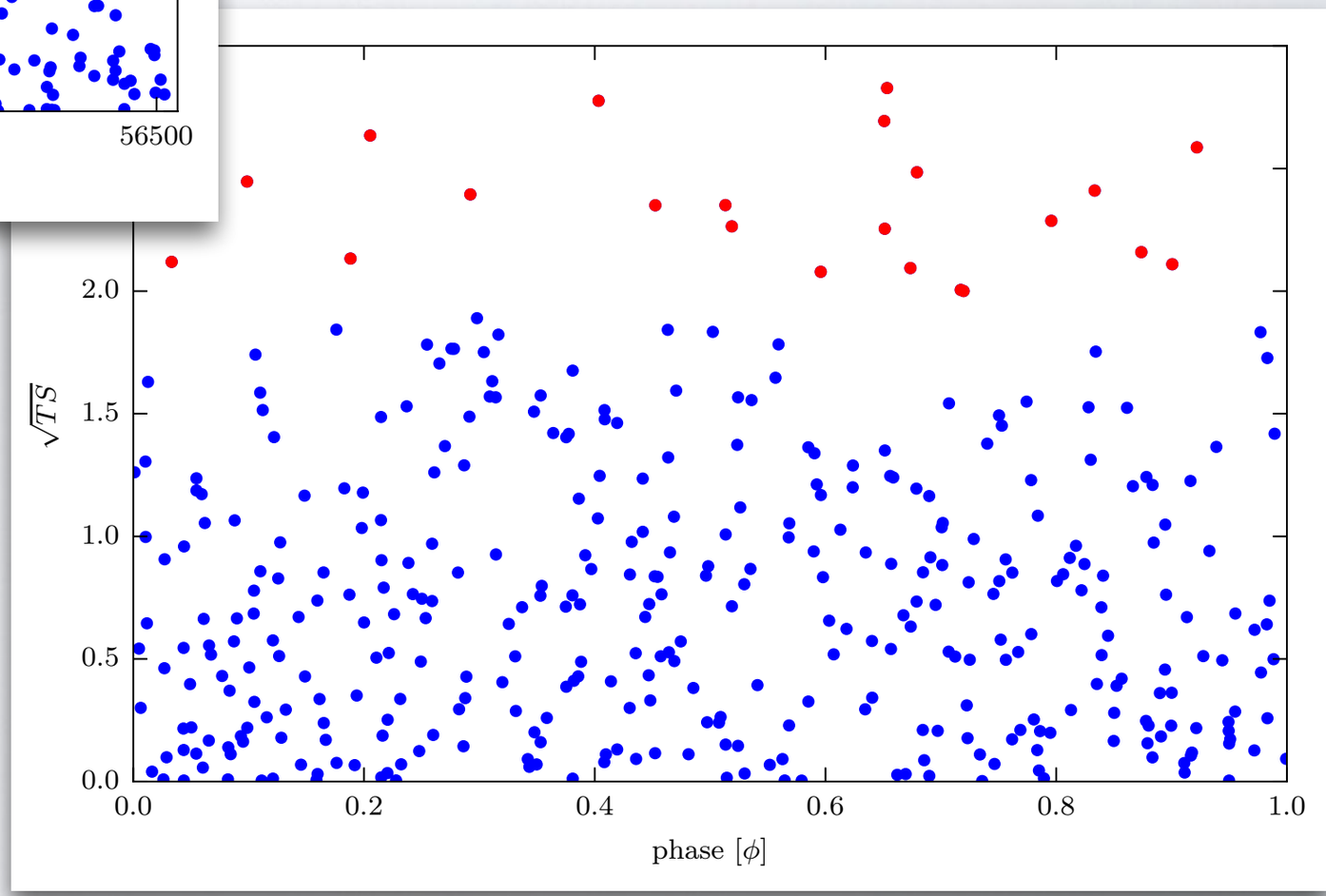


Sabatini et al. (2016) in preparation

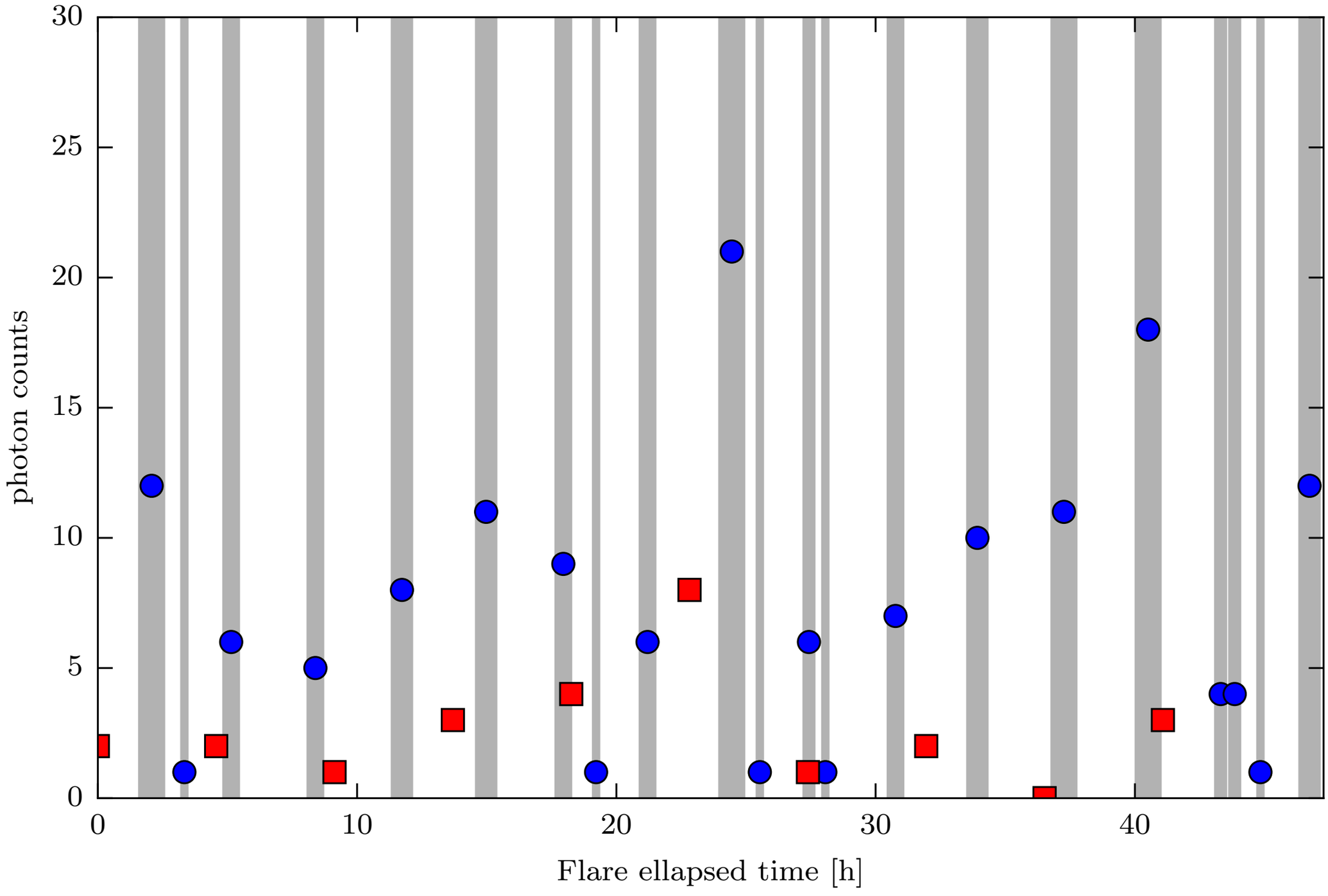
FERMI BLIND SEARCH



2-day bins

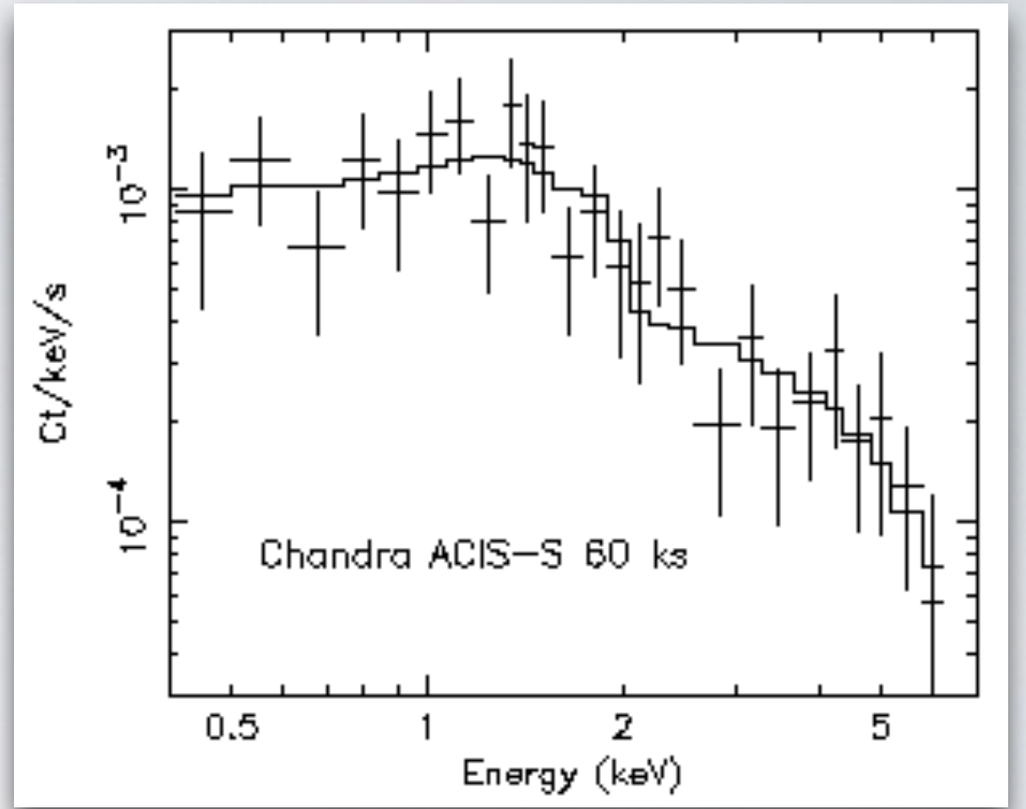


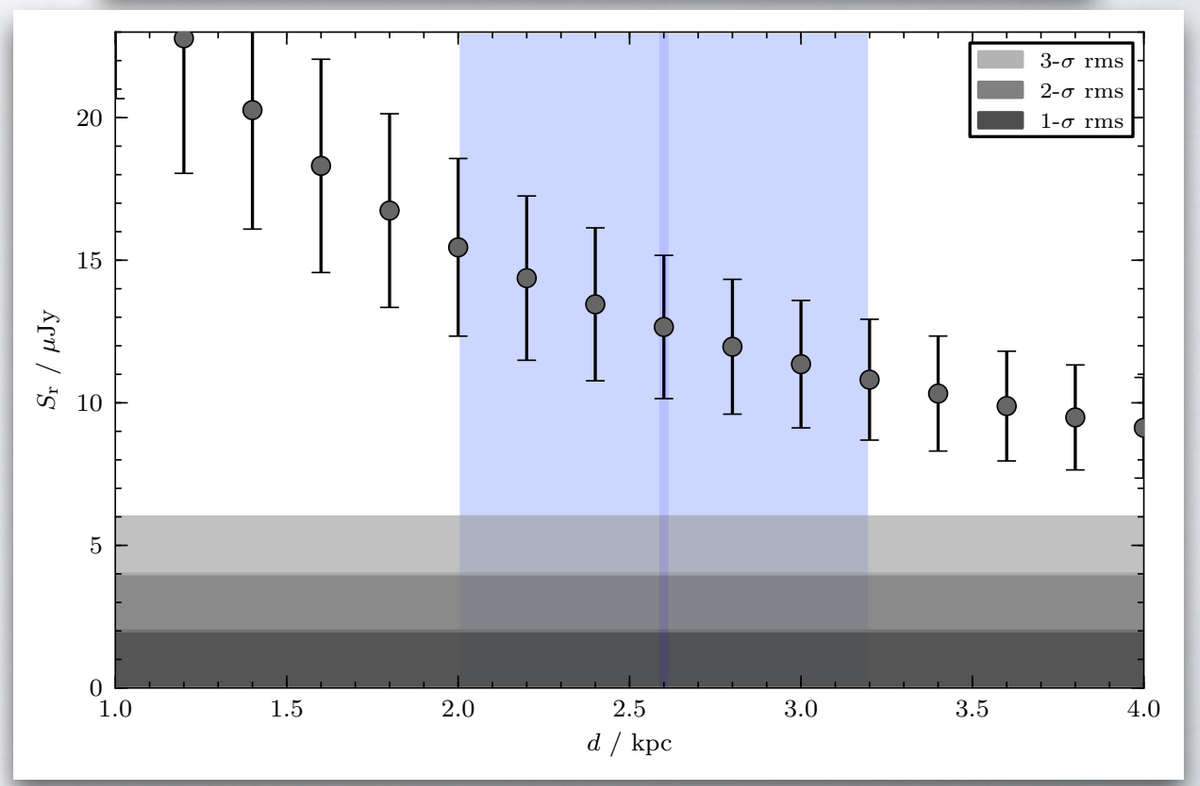
FERMI FLARE PHOTON ARRIVAL TIME



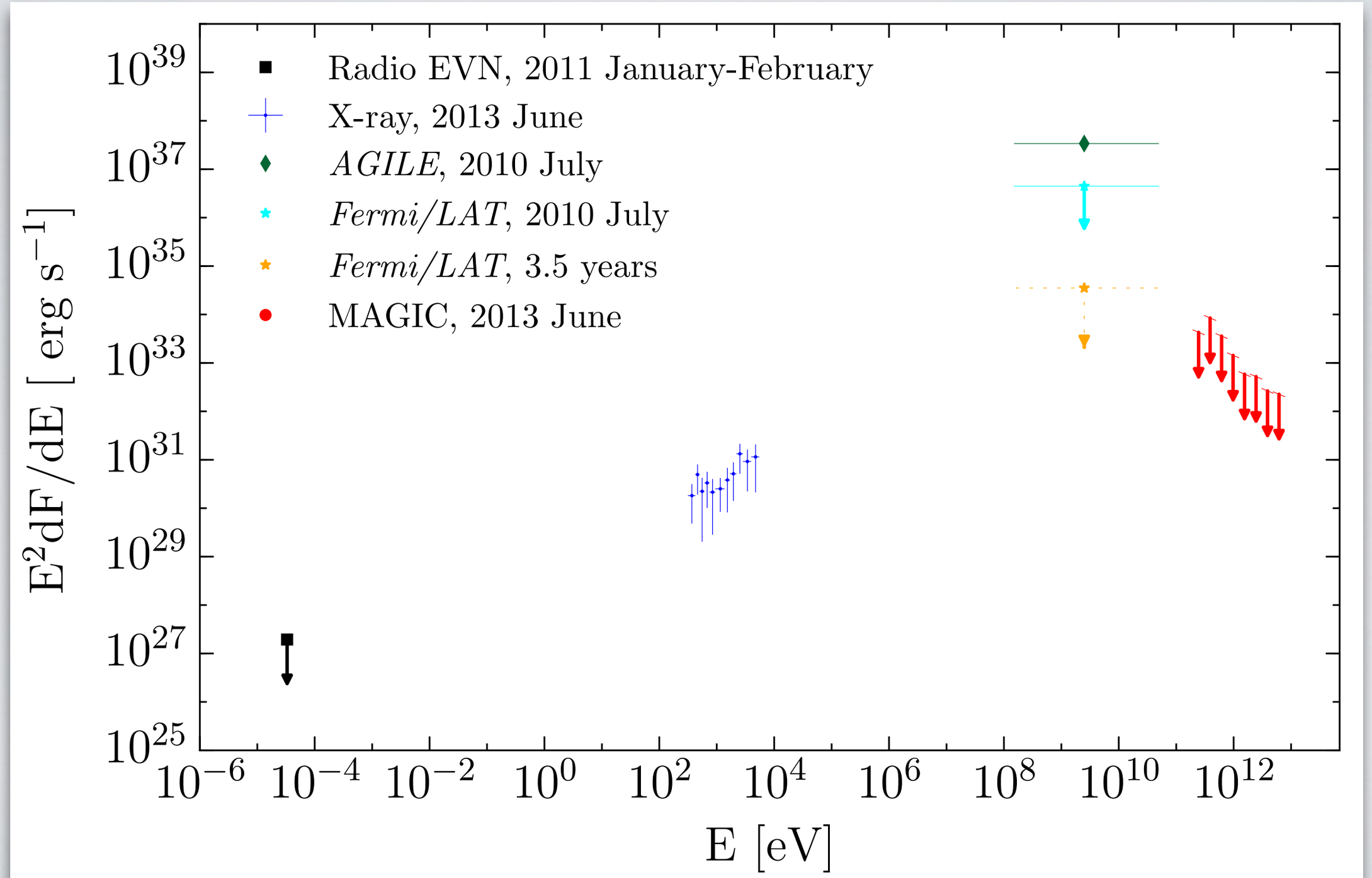
WORK IN PROGRESS: JOINT *CHANDRA*-VLA OBSERVATION

- Joint *Chandra*/VLA observations to:
  - Obtain good X-ray position and spectrum
  - Detect the source in radio
  - Check accretion/ejection coupling in the first quiescent HMXB
- 60 ks obs with *Chandra* + 6 h obs with VLA (8 -12 GHz)
- Expected radio flux density between 9 and 18 μJy





AT TeV ENERGIES



X-RAY DATA ANALYSIS

- The non thermal luminosity in the 0.3-5.5 keV range is $L_X=(1.6^{+1.0}_{-0.9})\times10^{31}$ erg $s^{-1} \equiv (3.1\pm2.3)\times10^{-8}\, L_{Edd}$

- The value of non thermal luminosity is well below the threshold of $10^{-5}\, L_{Edd}$ set by Plotkin et al. (2013) to indicate the quiescent state of XRBs, making our results compatible with MWC 656 being in quiescence

- This is the first case of a detection of a HMXB with a BH in quiescence

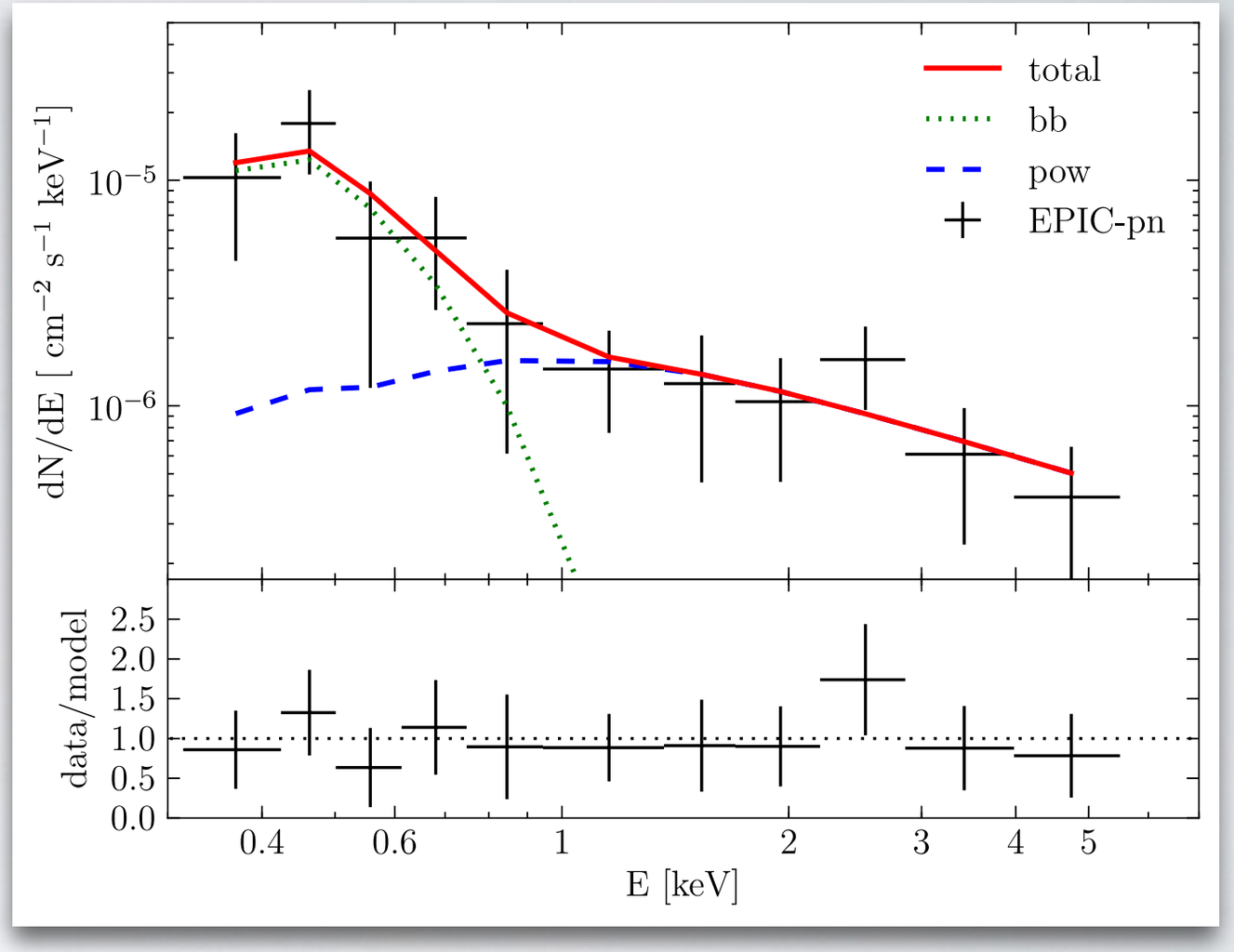
- Might be interpreted as an ADAF which leads to the low X-ray luminosity

X-RAY DATA ANALYSIS

- Thermal component

  -Might be arising from the hot wind of the Be star

  -The luminosity of this component is compatible with the $L_X/L_{Bol} \sim 10^{-7}$ relation from Cohen et al. (1997). Our results are $L_X/L_{Bol} \sim 3 \times 10^{-7}$



- Non thermal component

  -Photon index $\Gamma = 1.0 \pm 0.8$ compatible with Plotkin et al. (2013)

  -Possible origin in the vicinity of the black hole

  -The non thermal luminosity in the 0.3-5.5 keV range is $L_X = (1.6^{+1.0}) \times 10^{31}$ erg s^{-1} $\equiv (3.1 \pm 2.3) \times 10^{-8}\, L_{Edd}$