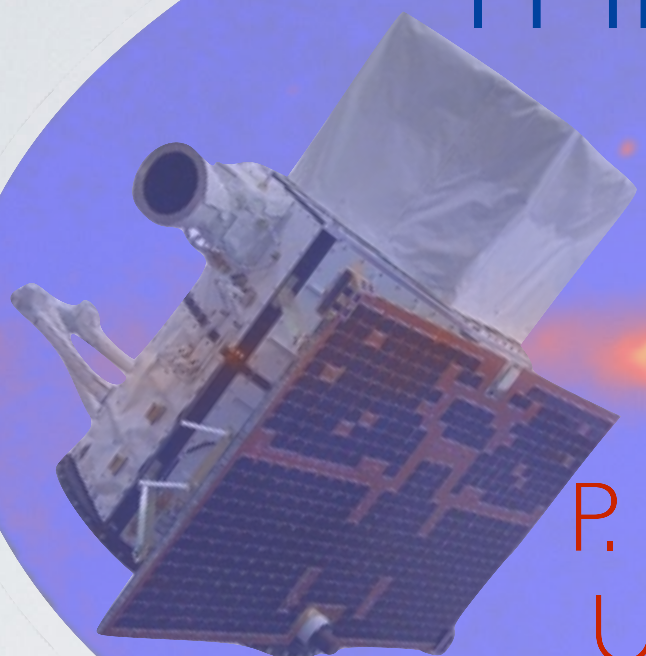
THE BLACK HOLE BINARY MWC 656



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OUTLINE

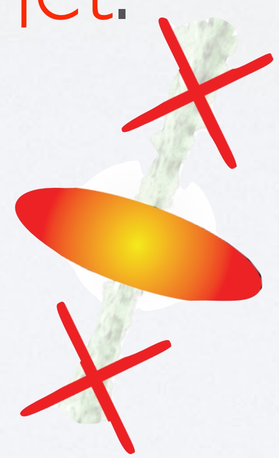
- X-ray binaries
- Introduction to MWC 656
- AGILE observations: AGL J2241+4454
- Chandra - VLA observations
- Conclussions

X-RAY BINARIES

- Binary systems with the peak of emission at X-rays

- Low-mass X-ray binaries undergo a series of changes in their X-ray spectrum and luminosity associated to the accretion process and to the presence/absence of a radio jet.

- This is known as the accretion/ejection coupling.



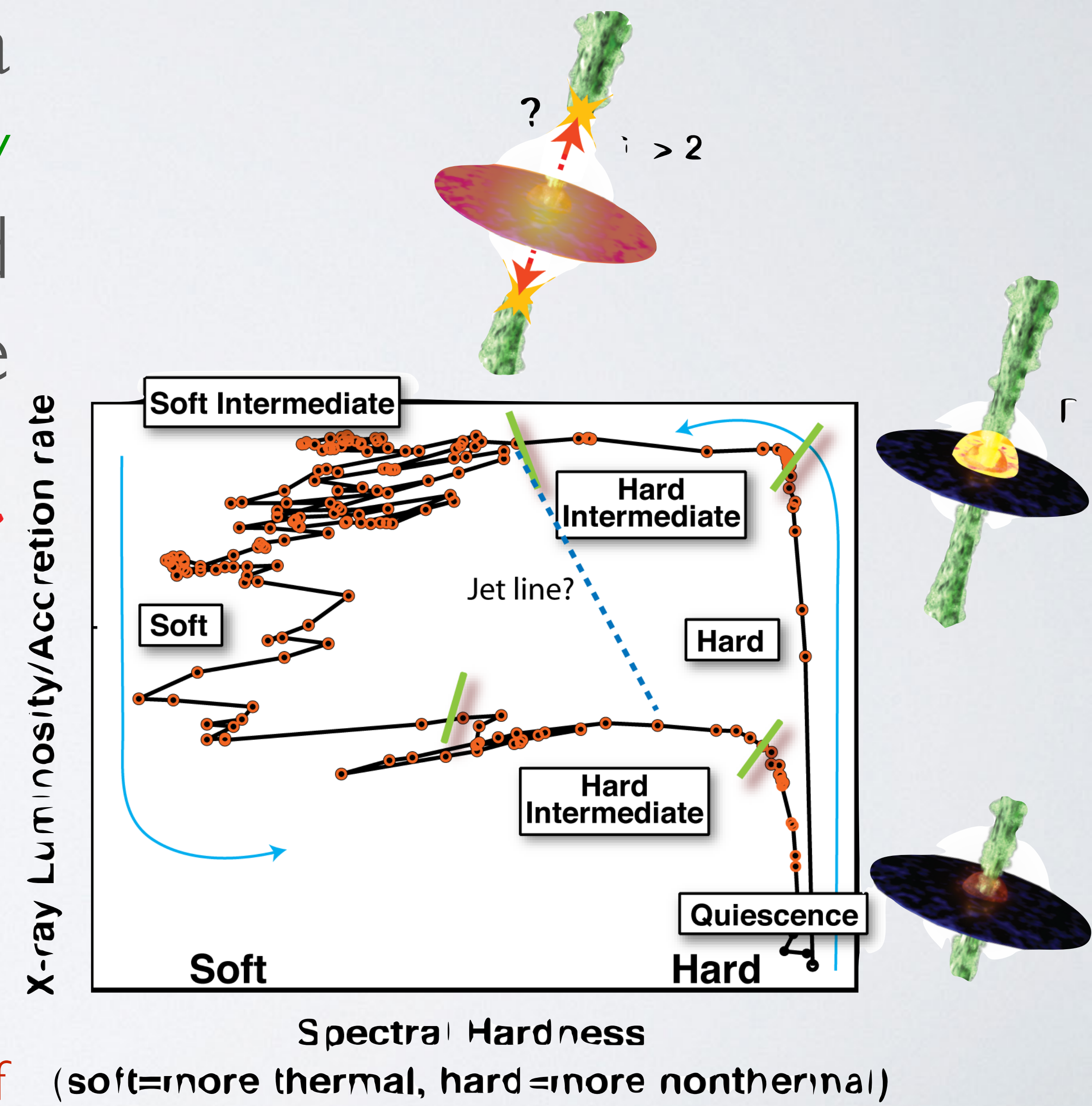
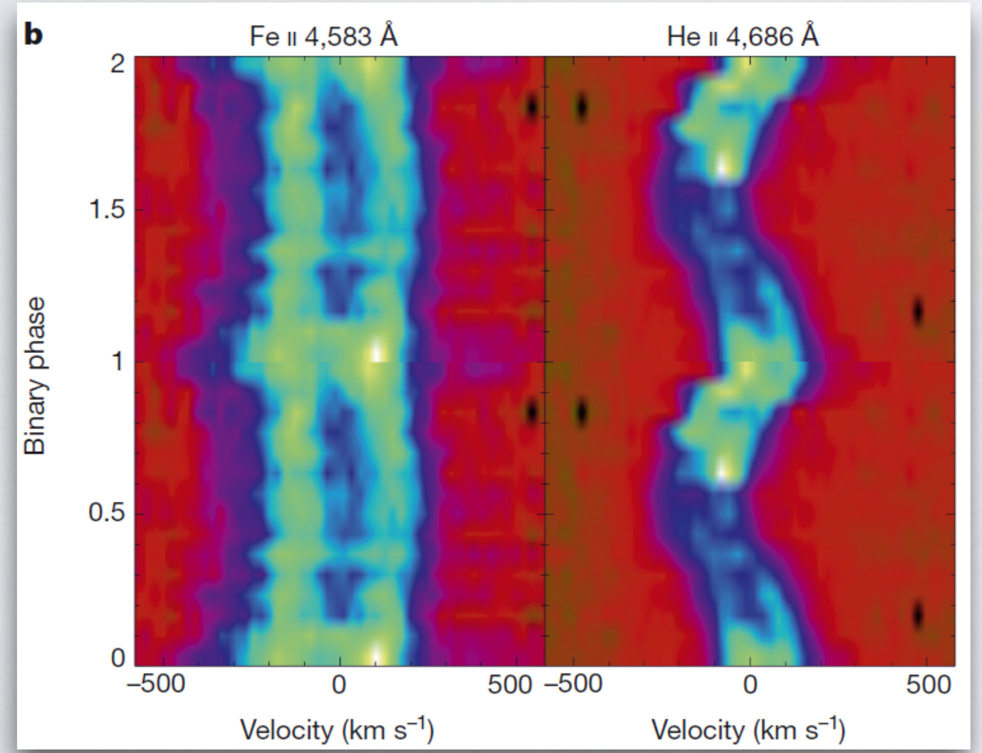


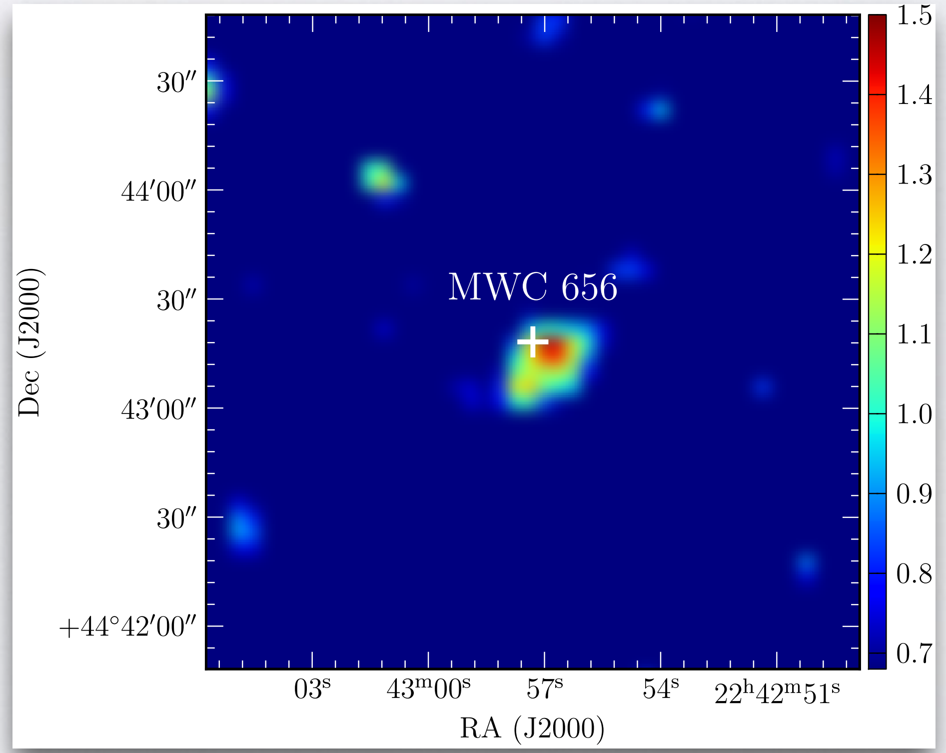
Image credit: Sera Markoff

INTRODUCTION TO MWC 656

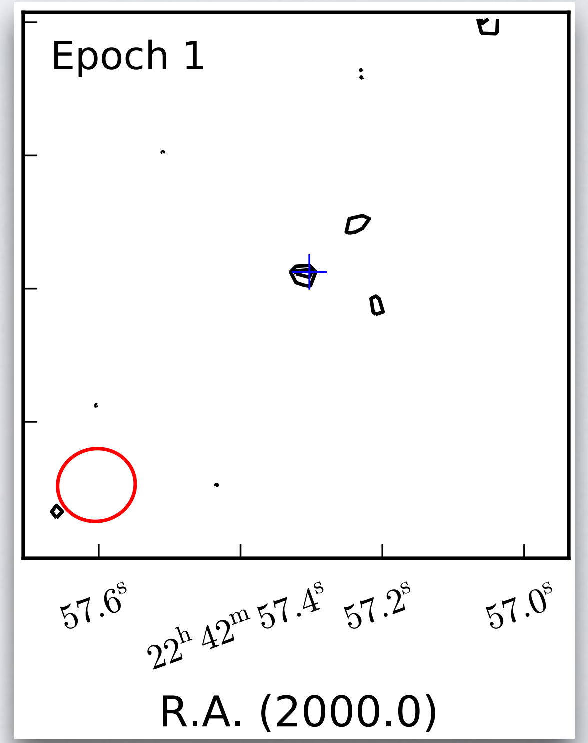
- Confirmed as a binary system by Casares et al. (2012), might be associated to AGL J2241+4454 (Lucarelli et al. 2010)
- MWC 656: Be star orbited by a BH (Casares et al. 2014) with a mass between 3.8 and 6.9 $M_\odot$. The **first known binary system of this class.** Confirmed as a high-mass X-ray binary (Munar-Adrover et al. 2014)
- Radio detection at GHz (Dzib et al. 2015). Proof of variable nature and emission of high-energy particles



Casares et al. (2014)



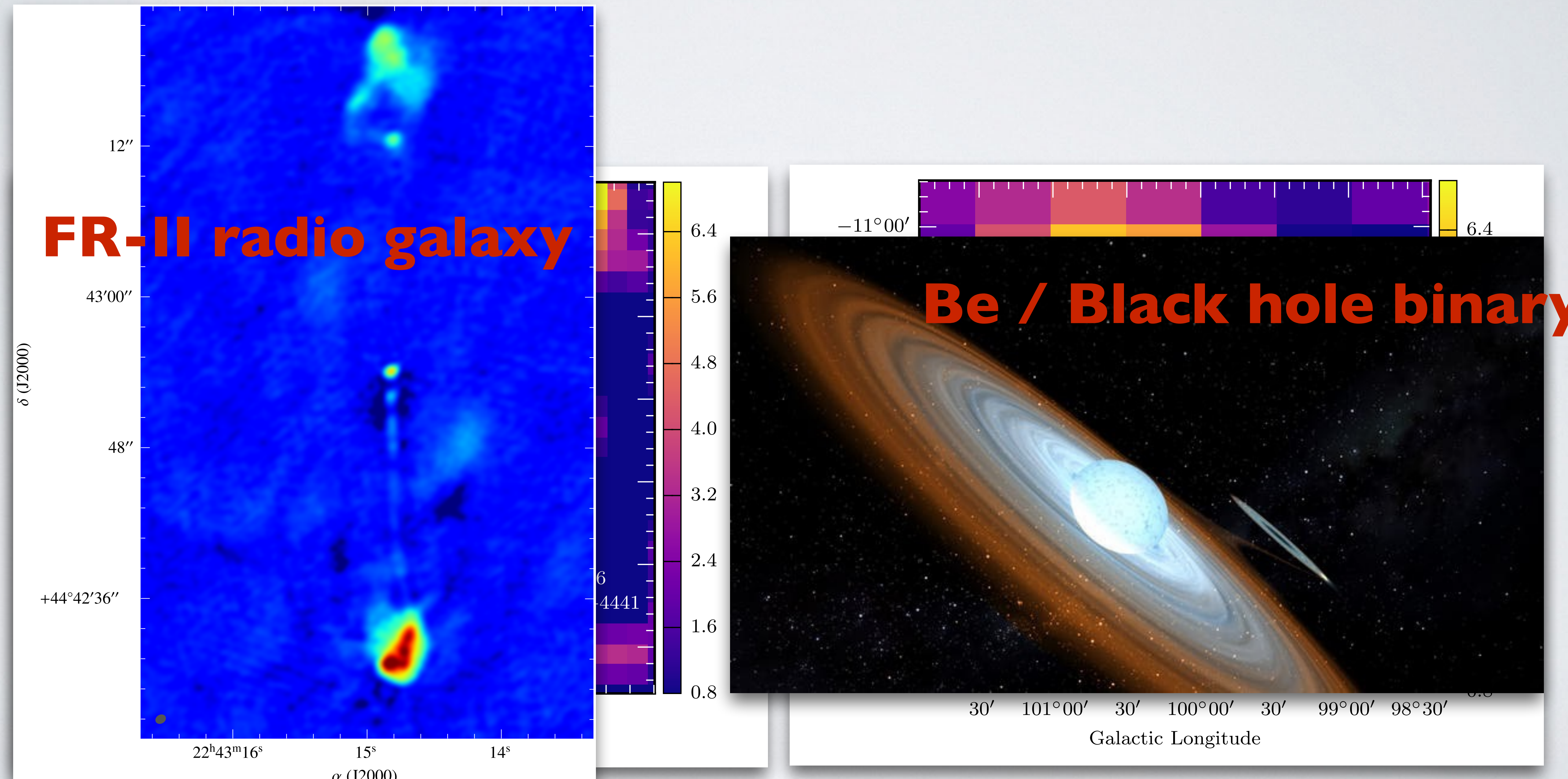
Munar-Adrover et al. (2014)



Adapted from Dzib et al. (2014)

AGILE OBS. AGL J2241+4454

- *AGILE* detection of a gamma-ray flare (Lucarelli et al. 2010)
- *Fermi* did not confirm the detection (UL of 10^{-7} ph cm^{-2} s^{-1} at 95% c.l.)



Munar-Adrover et al. (2016)

AGILE OBS. AGL J2241+4454

- Searching for transient gamma-ray emission
- Blind search in 2-day bins (spinning and pointing)
- **10 flaring events registered by AGILE between 2007 and 2013**
- follow up of the source

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

t_{start} [UT]	t_{end} [UT]	Flux [$\times 10^{-6}$ cm^{-2} s^{-1}]	$\sqrt{TS}$
2007-11-23 UT00:00:00	2007-11-24 UT00:00:00	1.5 ± 0.5	4.5
2008-06-28 UT00:00:00	2008-06-30 UT00:00:00	0.6 ± 0.3	3.2
2009-01-04 UT00:00:00	2009-01-07 UT00:00:00	0.5 ± 0.2	3.1
2010-06-13 UT00:00:00	2010-06-14 UT00:00:00	1.4 ± 1.1	3.2
2010-06-30 UT00:00:00	2010-07-02 UT00:00:00	1.3 ± 0.6	3.1
2010-07-25 UT00:00:00	2010-07-27 UT00:00:00	1.4 ± 0.6	5.3
2011-04-09 UT00:00:00	2011-04-11 UT00:00:00	2.2 ± 1.1	3.1
2011-10-08 UT00:00:00	2011-10-10 UT00:00:00	2.5 ± 1.1	3.4
2013-03-07 UT00:00:00	2013-03-08 UT09:00:00	2.6 ± 1.4	3.1
2013-07-10 UT00:00:00	2013-07-12 UT00:00:00	3.2 ± 1.6	3.5

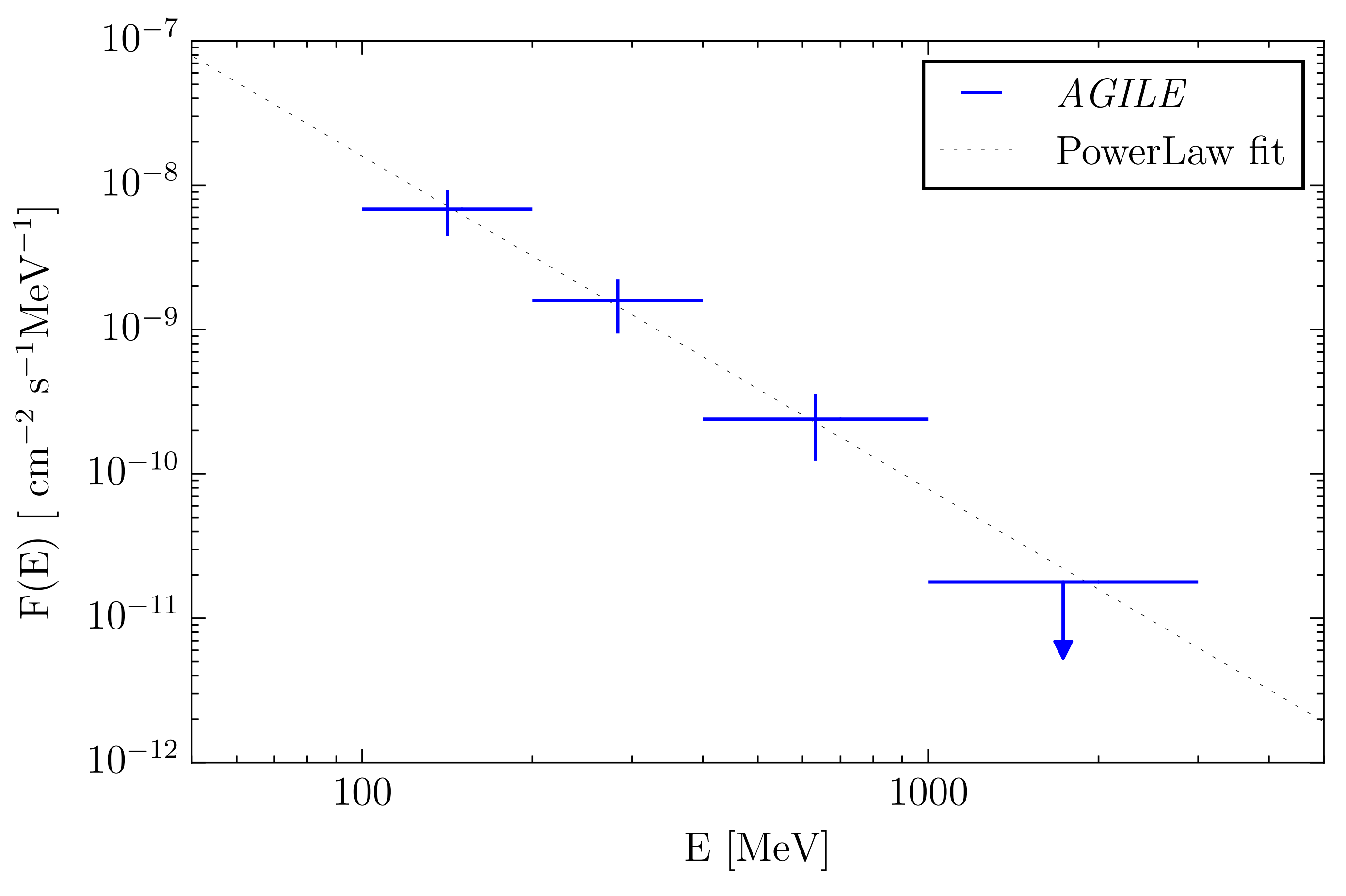
Munar-Adrover et al. (2016)

AGILE OBS. AGL J2241+4454

- Spectral analysis stacking all the events:
  - *AGILE* spectrum between 100 MeV and 3 GeV
  - Integrating over all detected gamma-ray flares
  - Spectral fit with photon index $\Gamma = 2.35 \pm 0.16$
  - Best fit position:

    (l, b) = (100°.37, -12°.39) ± 0°.35
  - Post trial analysis:
    - 909 2-day bins, min TS = 9
    - $$P(N,k) = 1 - \sum_{j=0}^{k-1} \binom{N}{j} p^j (1-p)^{N-j}$$

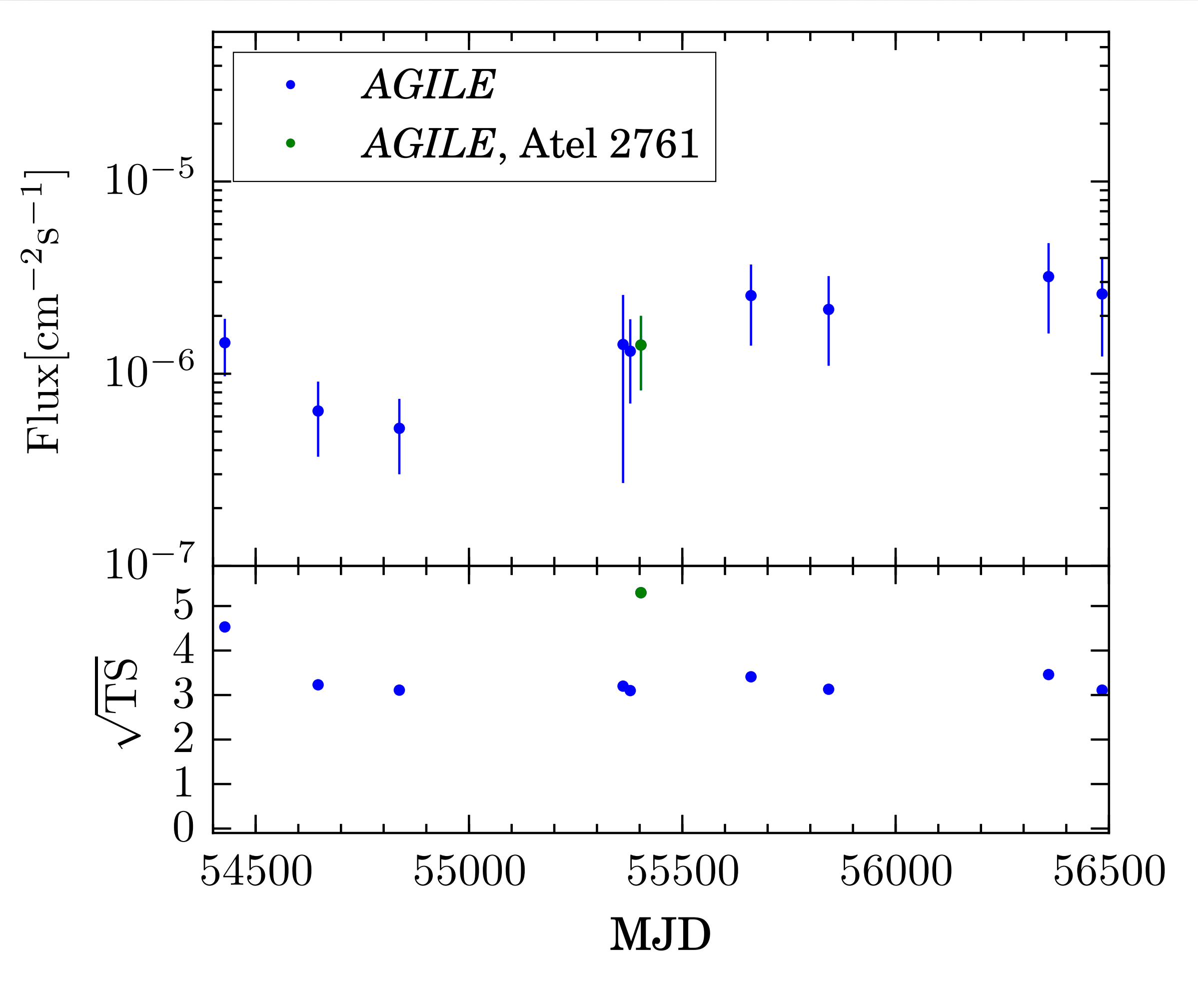
      from Bulgarelli et al. (2012)
    - $P = 6.8 \times 10^{-7}$

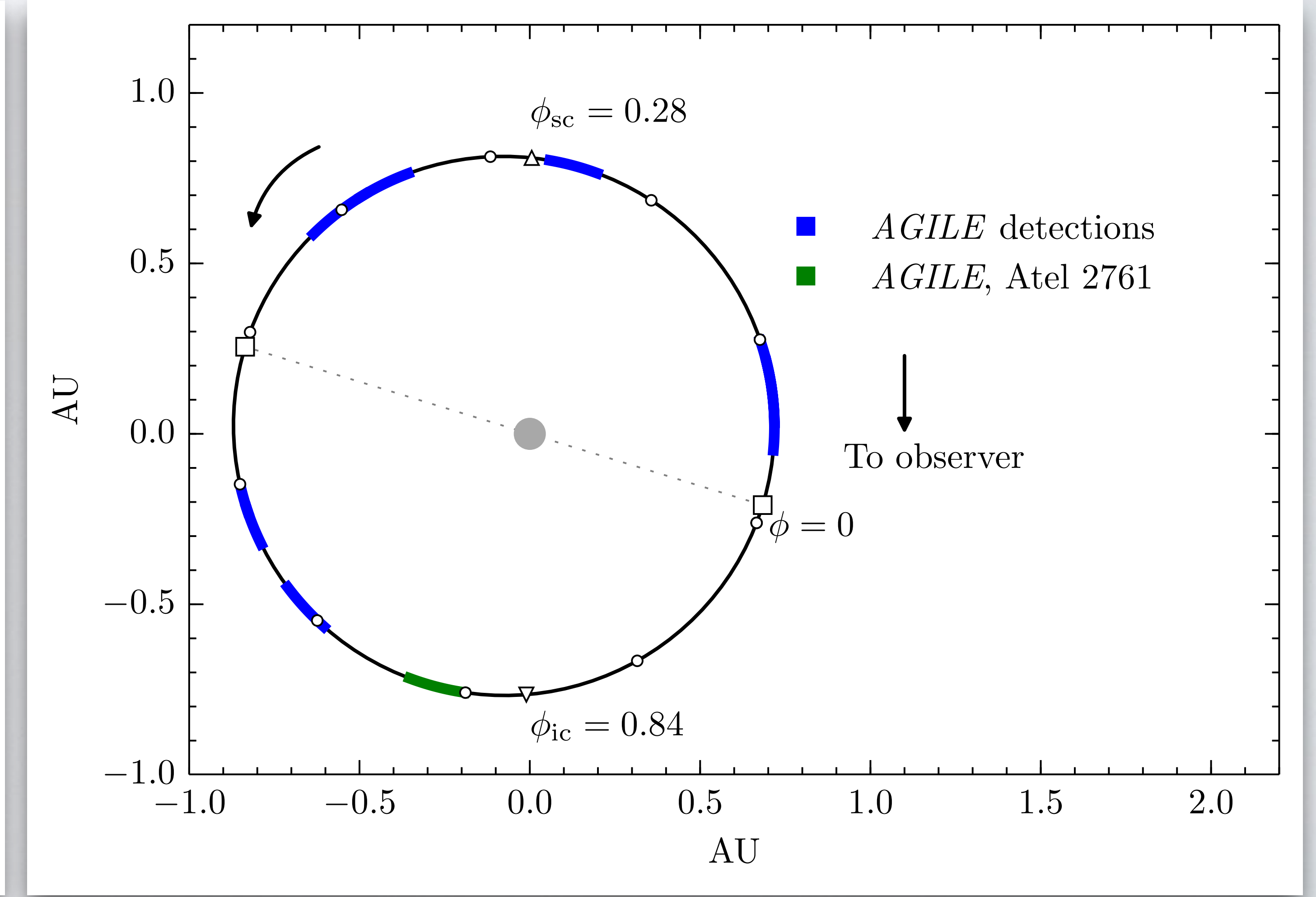


Munar-Adrover et al. (2016)

AGILE OBS. AGL J2241+4454

- Searching for periodic gamma-ray emission
  - Folding data with the 60.37 d period

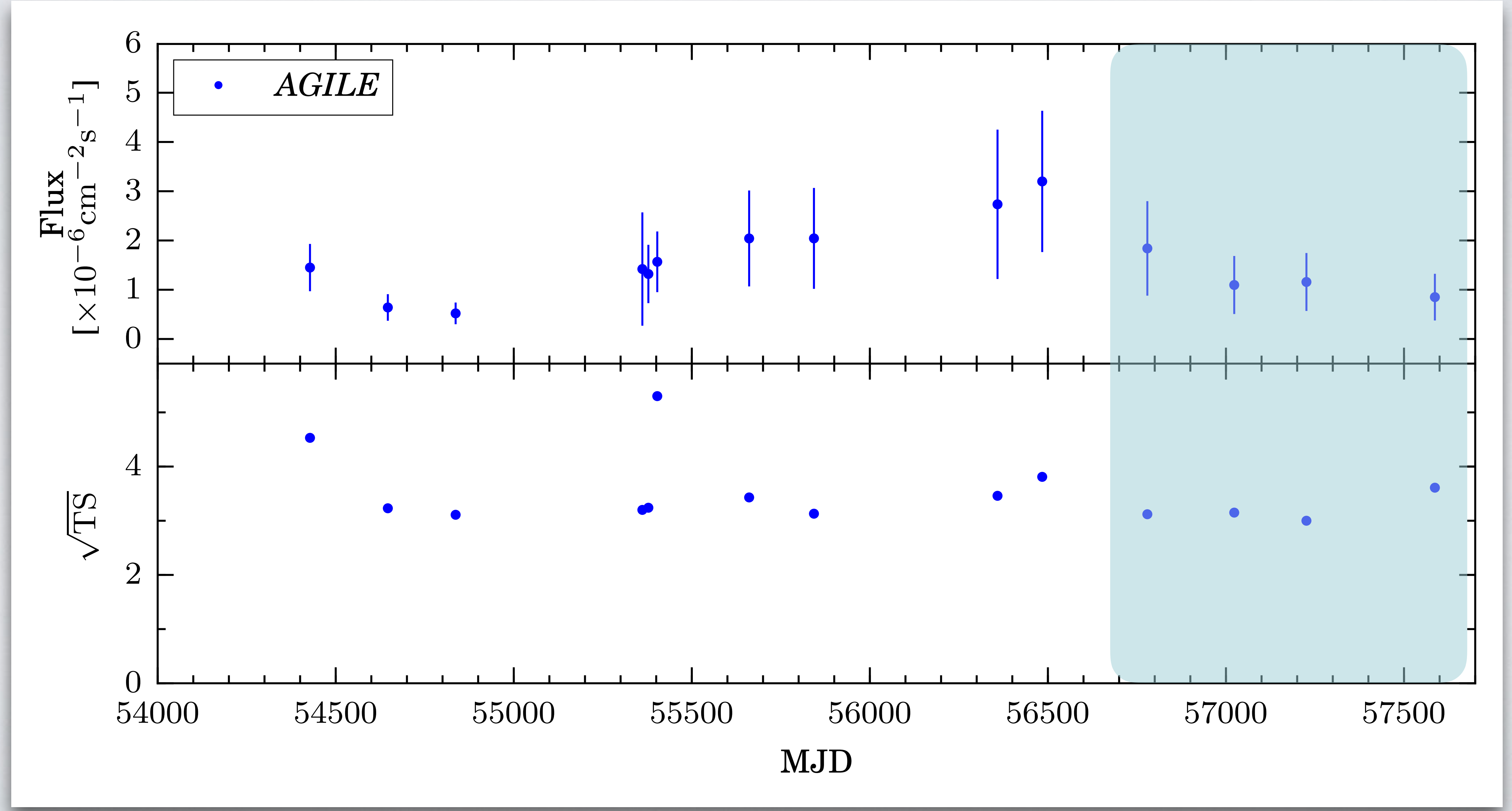




Munar-Adrover et al. (2016)

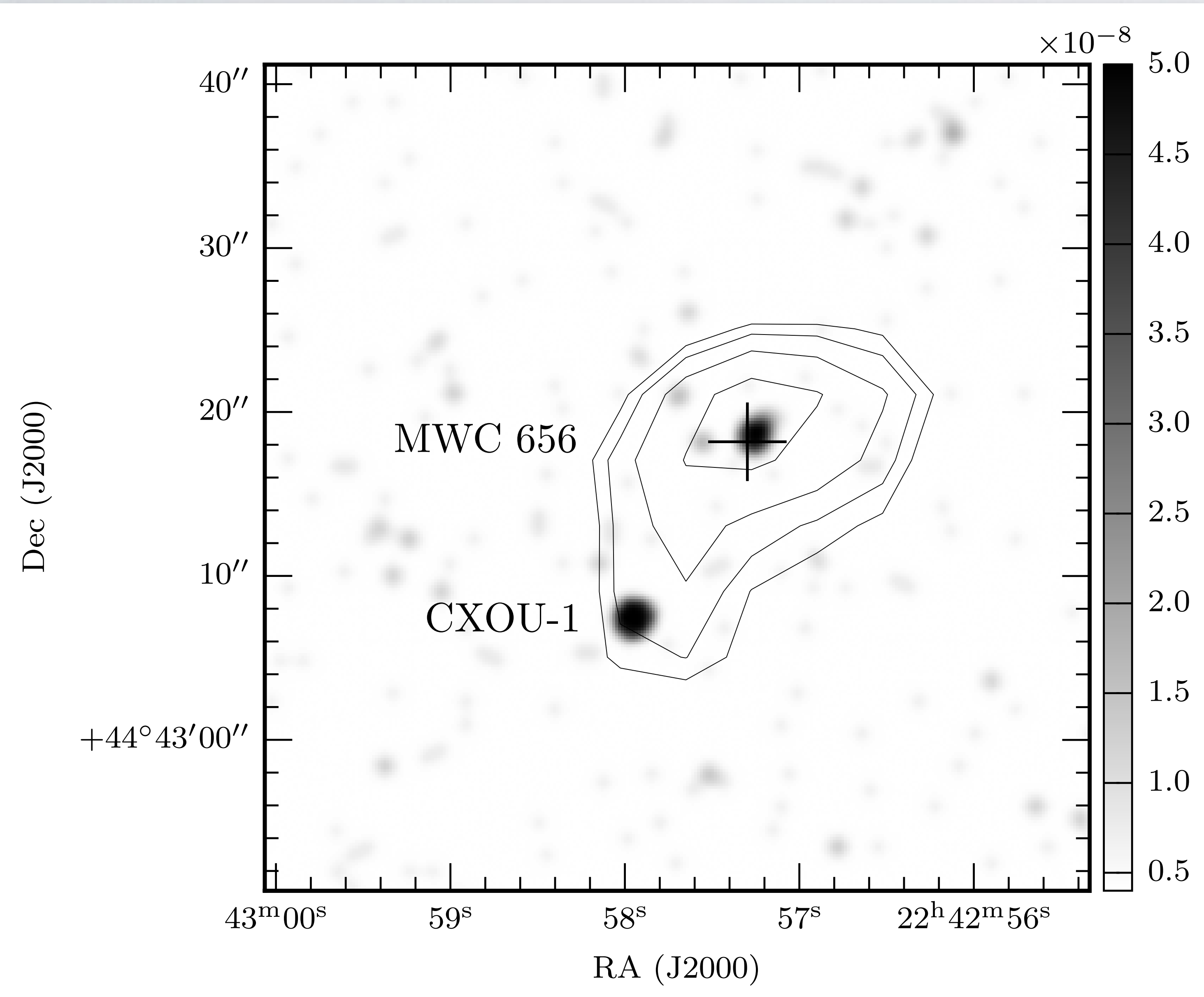
AGL J2241+4454 LONG-TERM LIGHT-CURVE

- AGILE gamma-ray LC over 9 years
  - 14 detections (4 new detections from 2014 to 2017!!!)

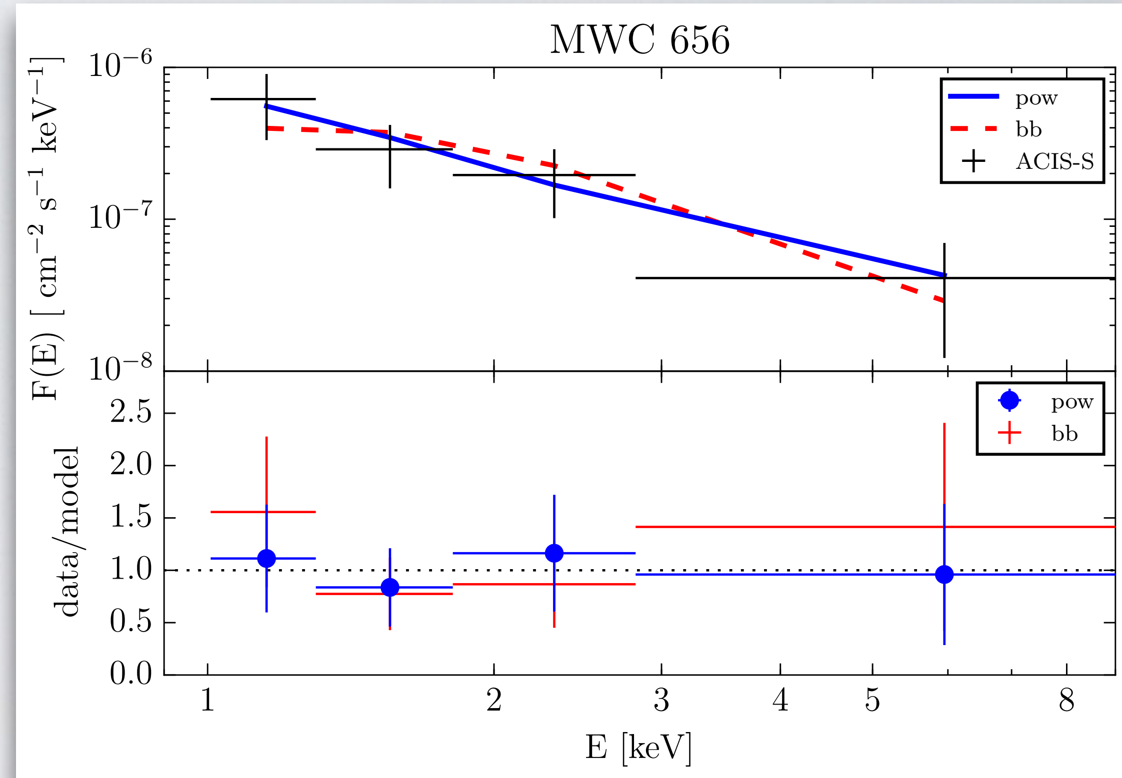


X-RAY OBS. MWC 656

NEW RESULTS: Chandra reveals two X-ray sources



Ribó et al. (2017)



Flux (0.5-8 keV) = $(4.1\pm1.9)\times10^{-15}$ erg cm^{-2} s^{-1} (Quiescence)

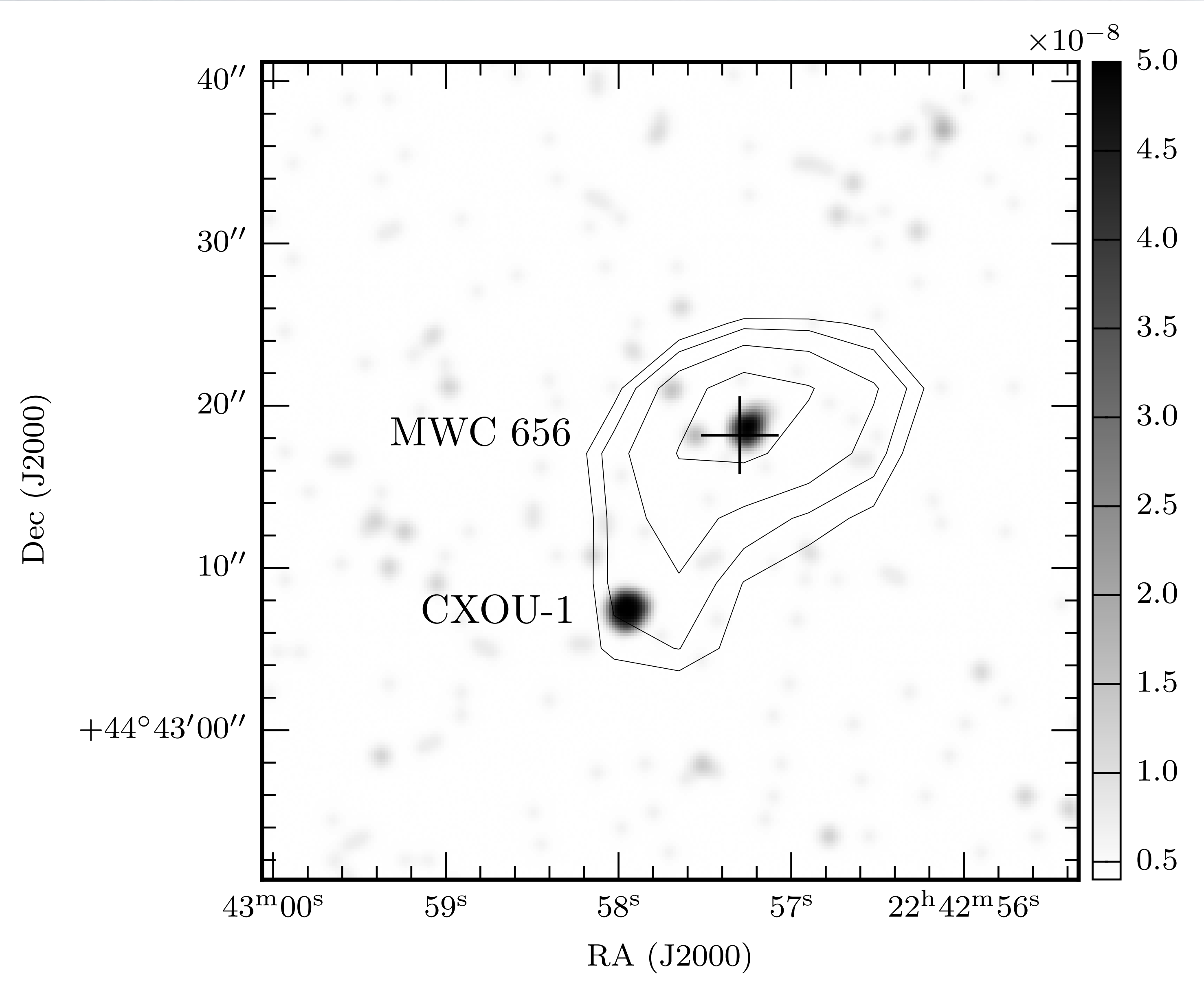
No difference between powerlaw and black body spectral fit, although C-stat favors pow

Comparison with *XMM-Newton* extrapolated flux in the 0.5-8 keV energy range:

Flux(XMM) = 2.7×10^{-14} erg cm^{-2} s^{-1}

X-RAY OBS. MWC 656

NEW RESULTS: Chandra reveals two X-ray sources

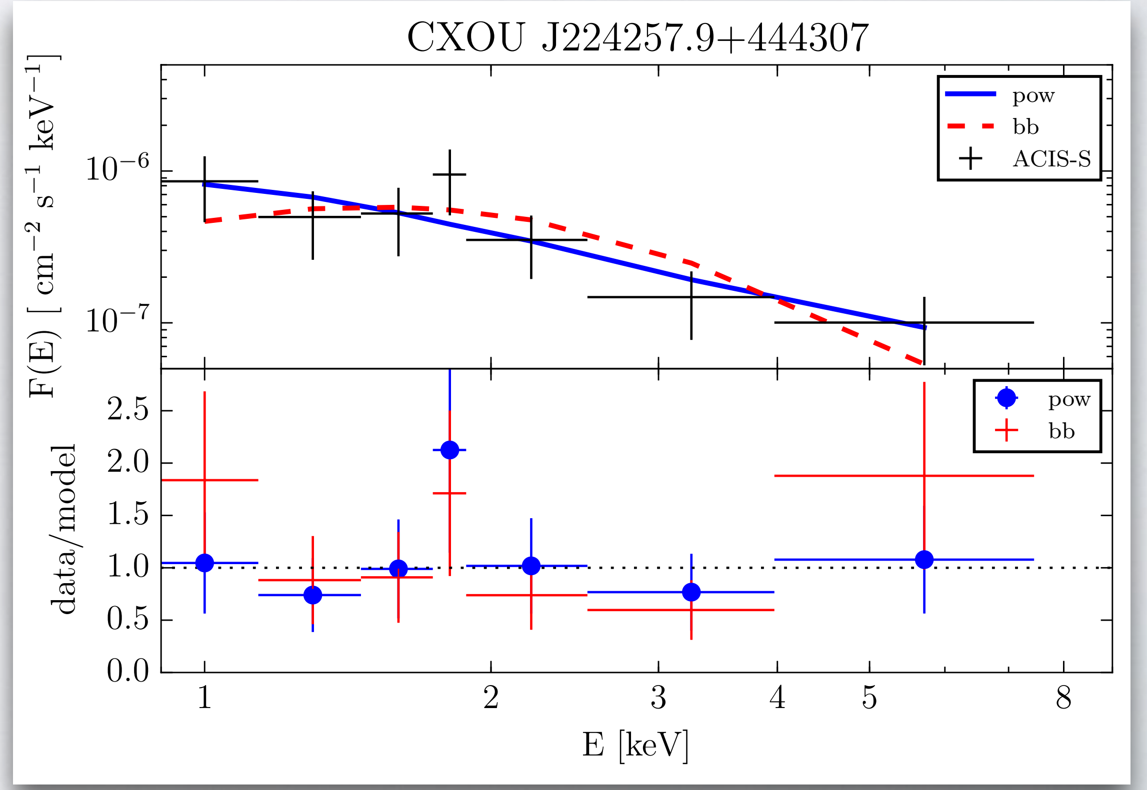


Ribó et al. (2017)

Flux (0.5-8 keV) = $(8.0 \pm 2.4) \times 10^{-15}$ erg cm^{-2} s^{-1}

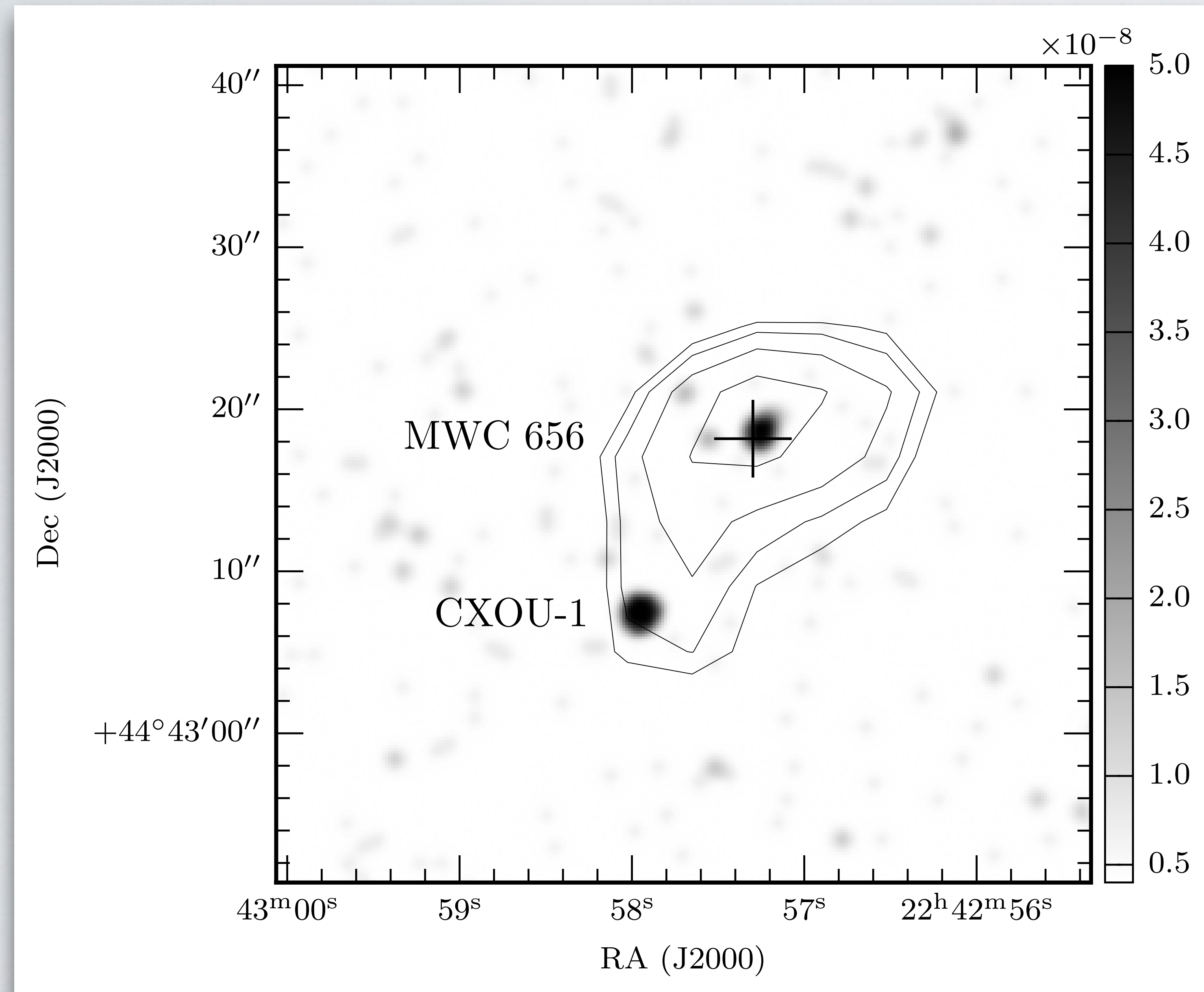
No difference between powerlaw and black body spectral fit, although C-stat favors pow

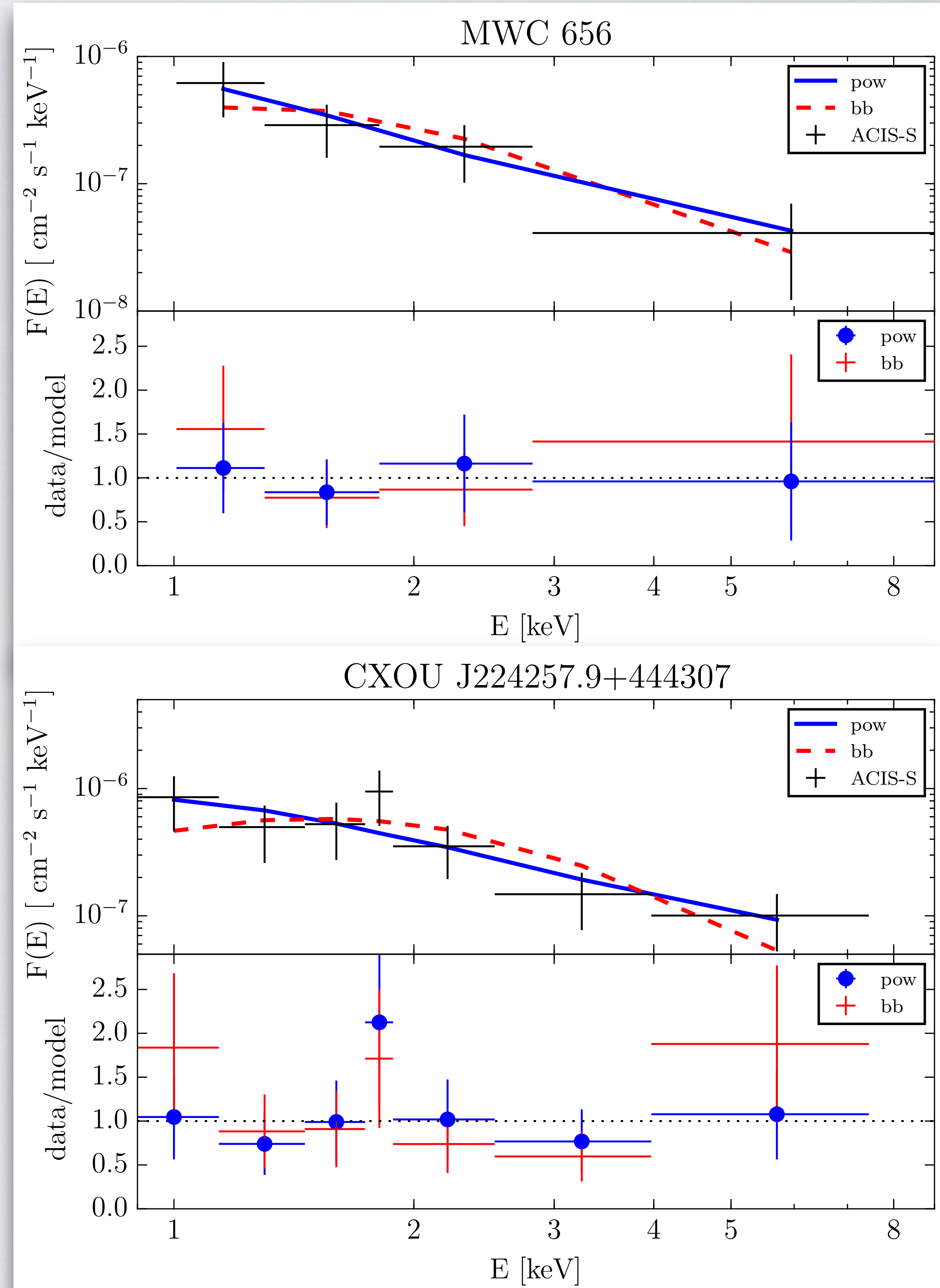
Assuming that in the XMM-Newton obs. The flux was the same



X-RAY OBS. MWC 656

NEW RESULTS: Chandra reveals two X-ray sources

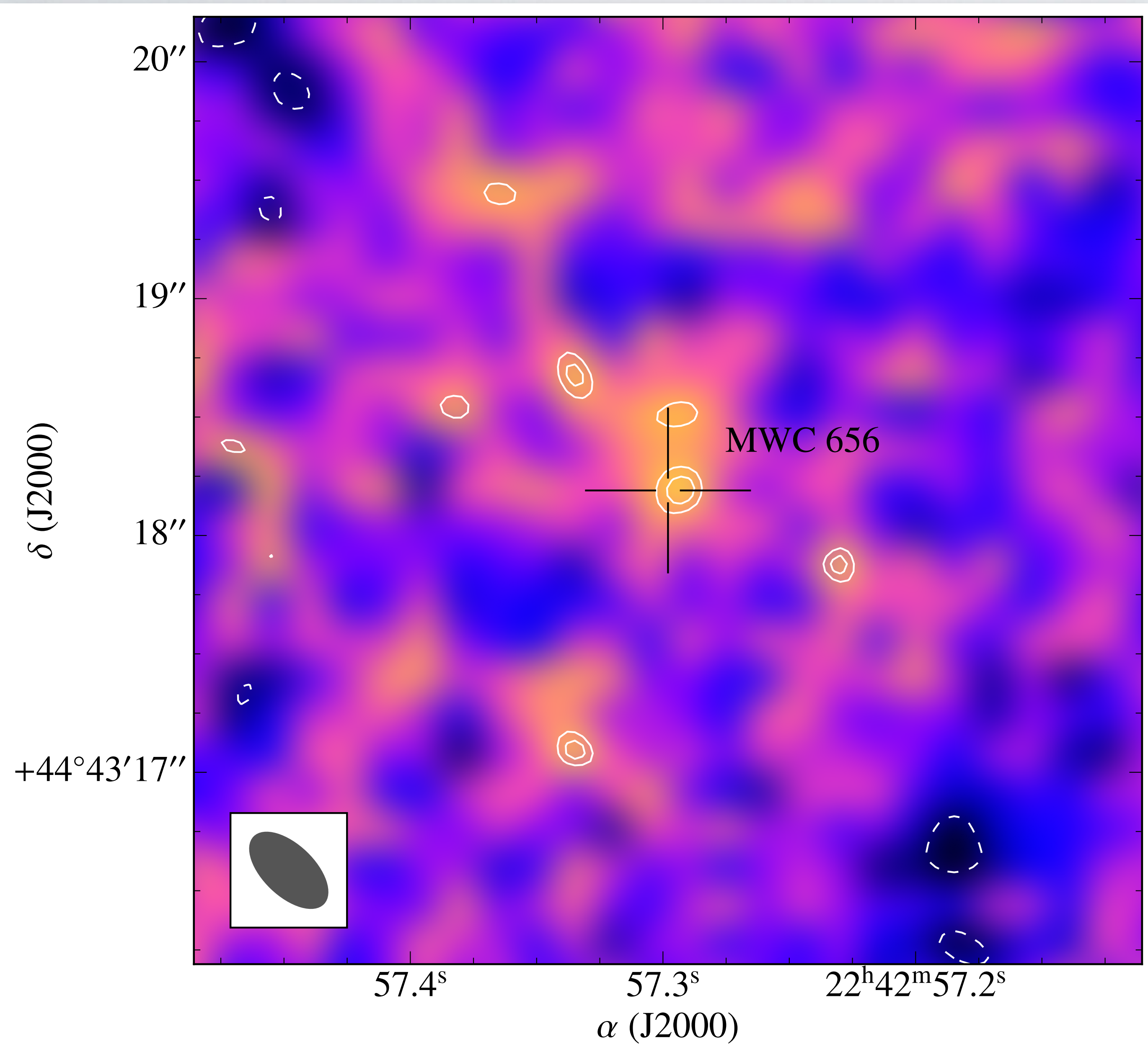




Ribó et al. (2017)

RADIO OBS. MWC 656

Radio counterpart (variability)



VLA simultaneous observation (6h, A config)

Flux density (10 GHz) = 3.5±1.1 μJy (marginal 3σ detection)

Compatible with the Chandra position

Compatible with the optical Gaia position

No detection of CXOU-1, flux density UL of 3.2 μJy at 3σ c.l.

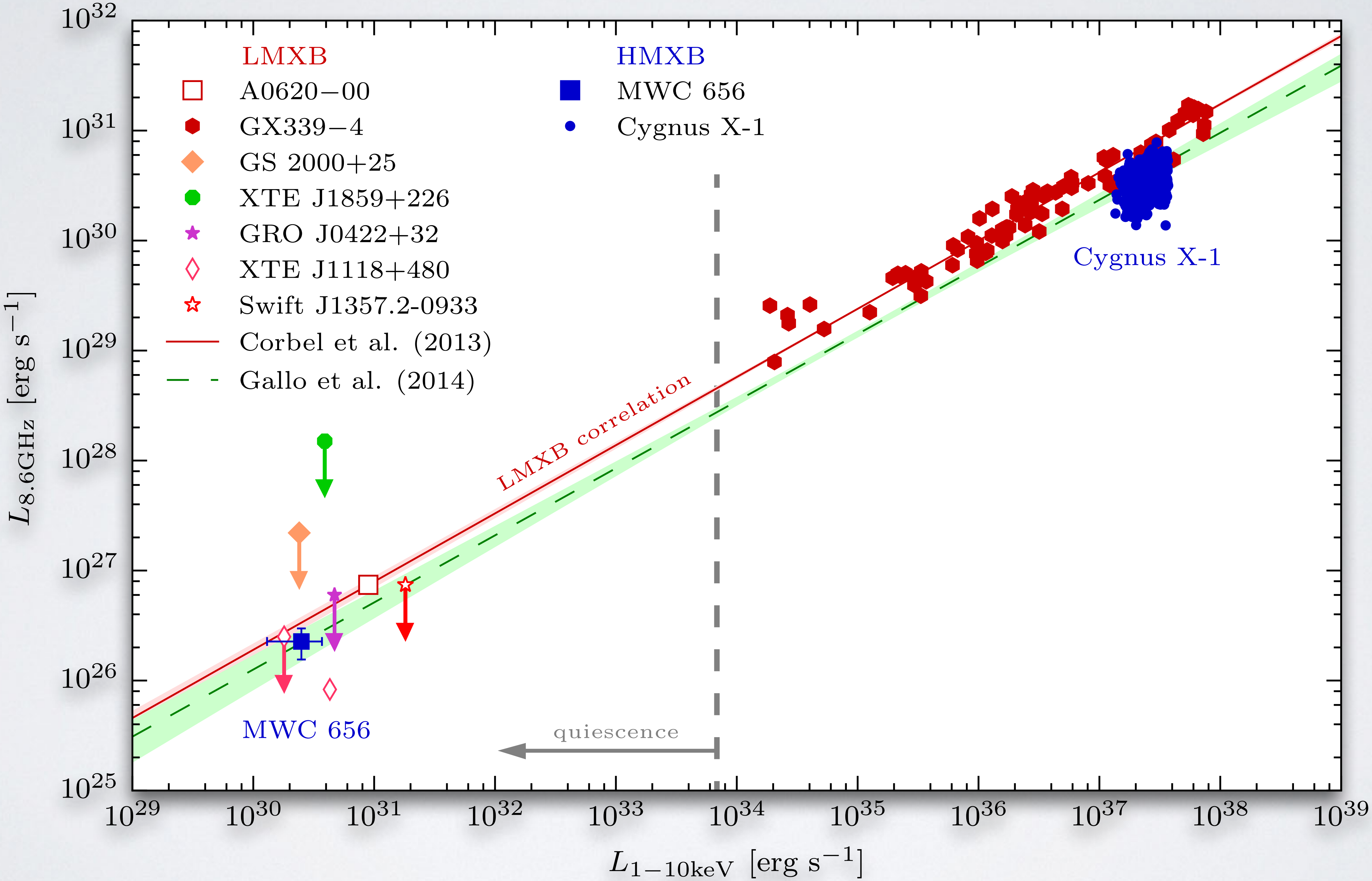
Gyro-synchrotron emission produced by magnetic field in the Be star is discarded (too high magnetic field requested)

Origin: Synchrotron emission in a jet.

Ribó et al. (2017)

RADIO/X-RAY OBS. MWC 656

Comparing to the radio/X-ray correlation



Ribó et al. (2017)

CONCLUSSIONS

- AGL J2241+4454 might be associated to the Be/BH binary system MWC 656. *AGILE* reveals 14 flares that allow for a spectral characterization of the gamma-ray source.
- No periodic or persistent emission is observed
- *Chandra* revealed a possible decrease in the soft X-ray flux of almost one order of magnitude w.r.t 2013
- VLA simultaneous observation revealed a faint radio source compatible with MWC 656
- For the first time we can study the source in the radio vs X-ray correlation with simultaneous data, and extend the correlation to HMXBs at very low luminosities. Correlation is independent of the nature of the donor star
- Discovery of a nearby X-ray source. Other possible counterpart of AGL J2241+4454?

BACK UP

AGILE FLARES

- *Fermi* likelihood analysis of each flaring event:

Start	Stop	TS	UL $[cm^{-2}s^{-1}]$
2009-01-04 12:02:12	2009-01-07 00:02:12	0.4	8.6×10^{-8}
2010-06-13 12:01:06	2010-06-14 18:01:06	-2.5×10^{-5}	6.4×10^{-8}
2010-06-30 00:01:06	2010-07-02 00:01:06	1.05	1.3×10^{-7}
2010-07-25 00:02:12	2010-07-27 00:02:12	-2.6×10^{-6}	7.5×10^{-8}
2011-04-09 00:02:12	2011-04-11 00:02:12	-6.4×10^{-5}	2.8×10^{-8}
2011-10-08 00:02:12	2011-10-10 00:02:12	0.6	1.2×10^{-7}
2013-03-07 00:00:00	2013-03-08 09:00:00	0.005	1.1×10^{-7}
2013-07-10 00:00:00	2013-07-12 00:00:00	–	–

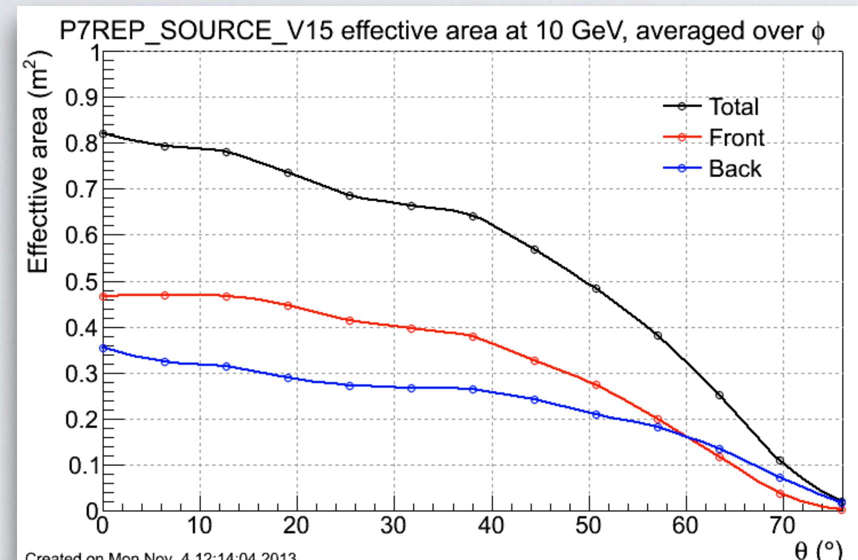
- *Fermi* likelihood phase folded analysis:

ϕ	UL $[ph\ cm^{-2}\ s^{-1}]$	TS
0.063	2.85×10^{-9}	-0.0008
0.188	1.16×10^{-8}	0.19
0.313	8.50×10^{-9}	-9.9×10^{-5}
0.438	1.24×10^{-9}	-0.0019
0.563	9.50×10^{-0}	-0.003
0.688	1.77×10^{-9}	-0.0014
0.813	2.19×10^{-9}	1.72
0.938	2.19×10^{-9}	1.72

- *Fermi* likelihood analysis of stacking of the events: UL = 3×10^{-7} cm^{-2} s^{-1}

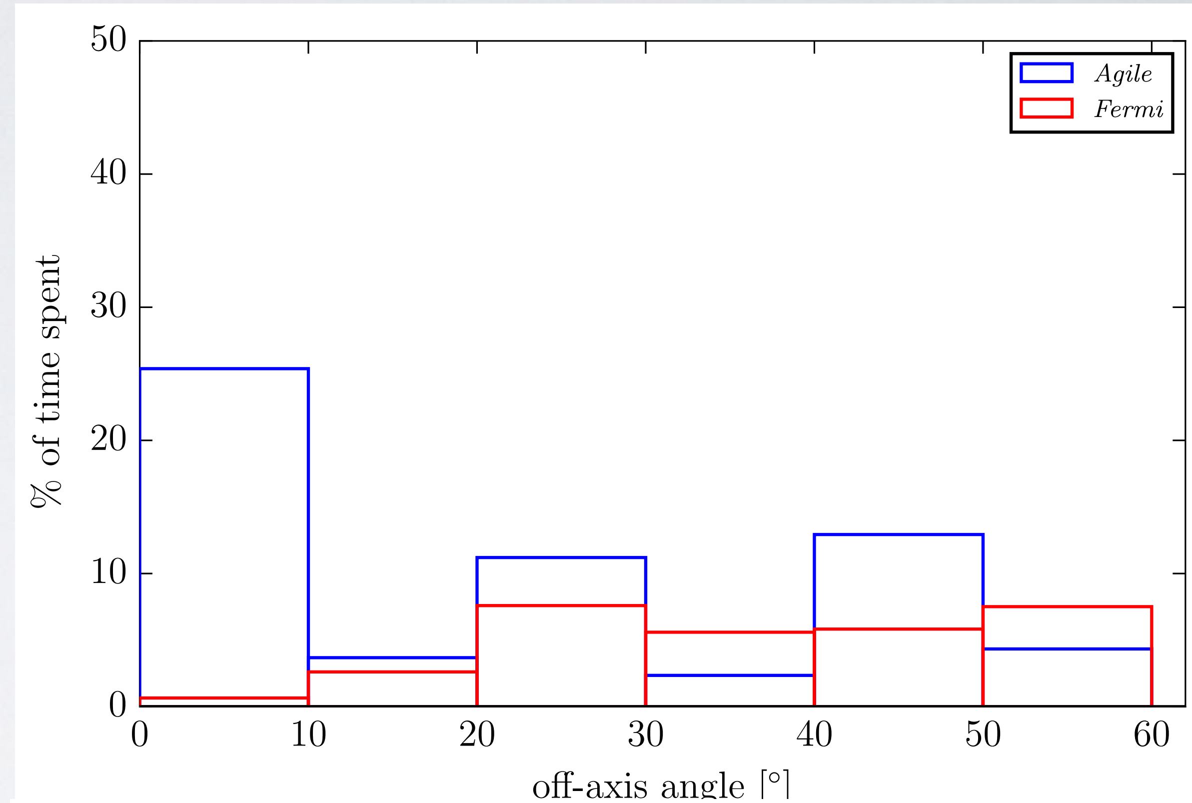
WHY *FERMI* DID NOT SEE THE FLARES?

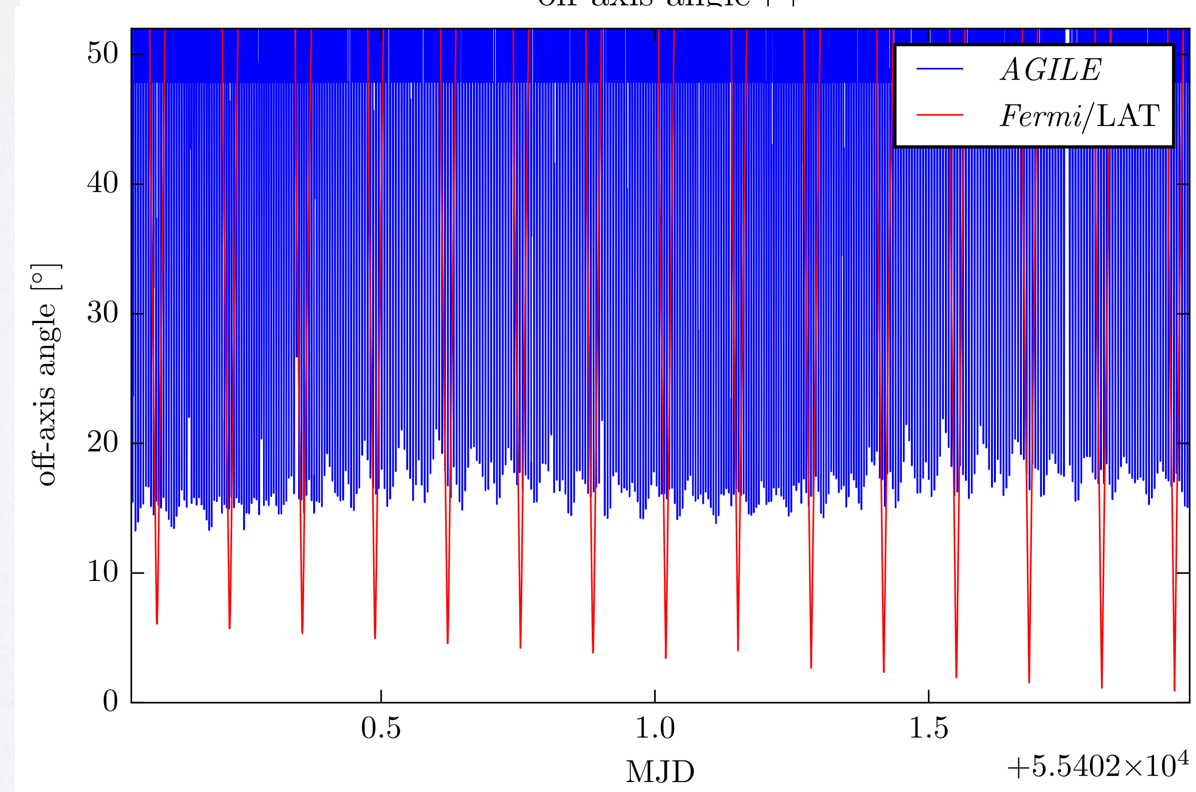
- *Fermi's* effective area decreases fast for zenith distance (ZD) > 50°



http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

- We checked the source ZD at any given moment for the whole *Fermi* mission
- During *AGILE* flares, MWC 656 is almost always at ZD > 50°





PHASE FOLDED LC