The intriguing low-accretion Be/BH binary MWC 656

AGILE workshop, 8 and counting

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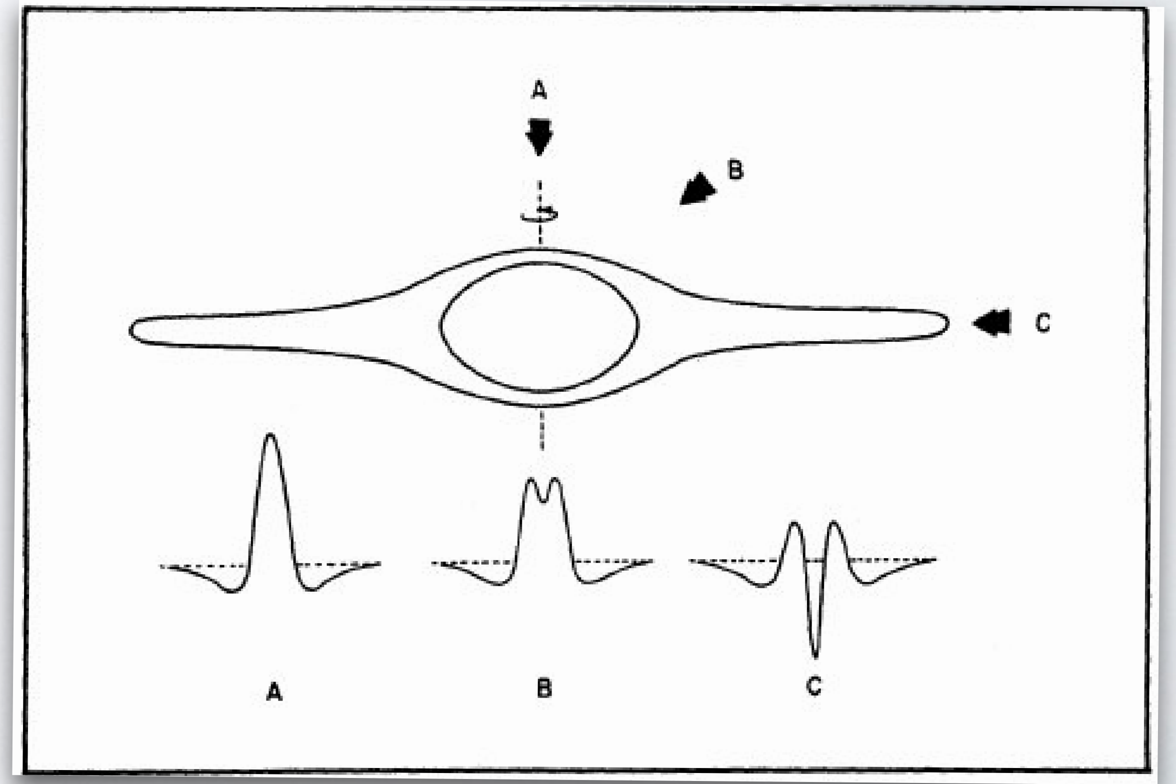
OUTLINE

- Introduction
- MWC 656
- AGILE flares
- X-ray observations
- The missing Be/BH systems
- Work in progress
- Conclusions

INTRODUCTION

Be stars

- Be stars are B stars with spectral emission lines of hydrogen (Hα, Hβ, etc.) and a high projected rotational velocity (close to critical when de-projected).
- It well established that Be stars have a circumstellar envelope in the form of a quasi-Keplerian deccretion disk surrounding the star

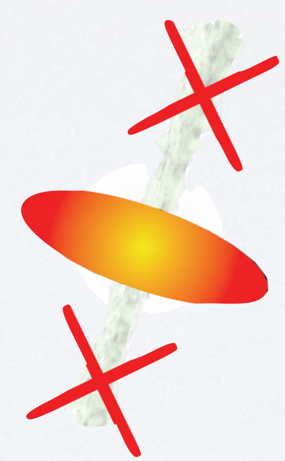


INTRODUCTION

ACCRETION-EJECTION COUPLING IN XRBS

- 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.



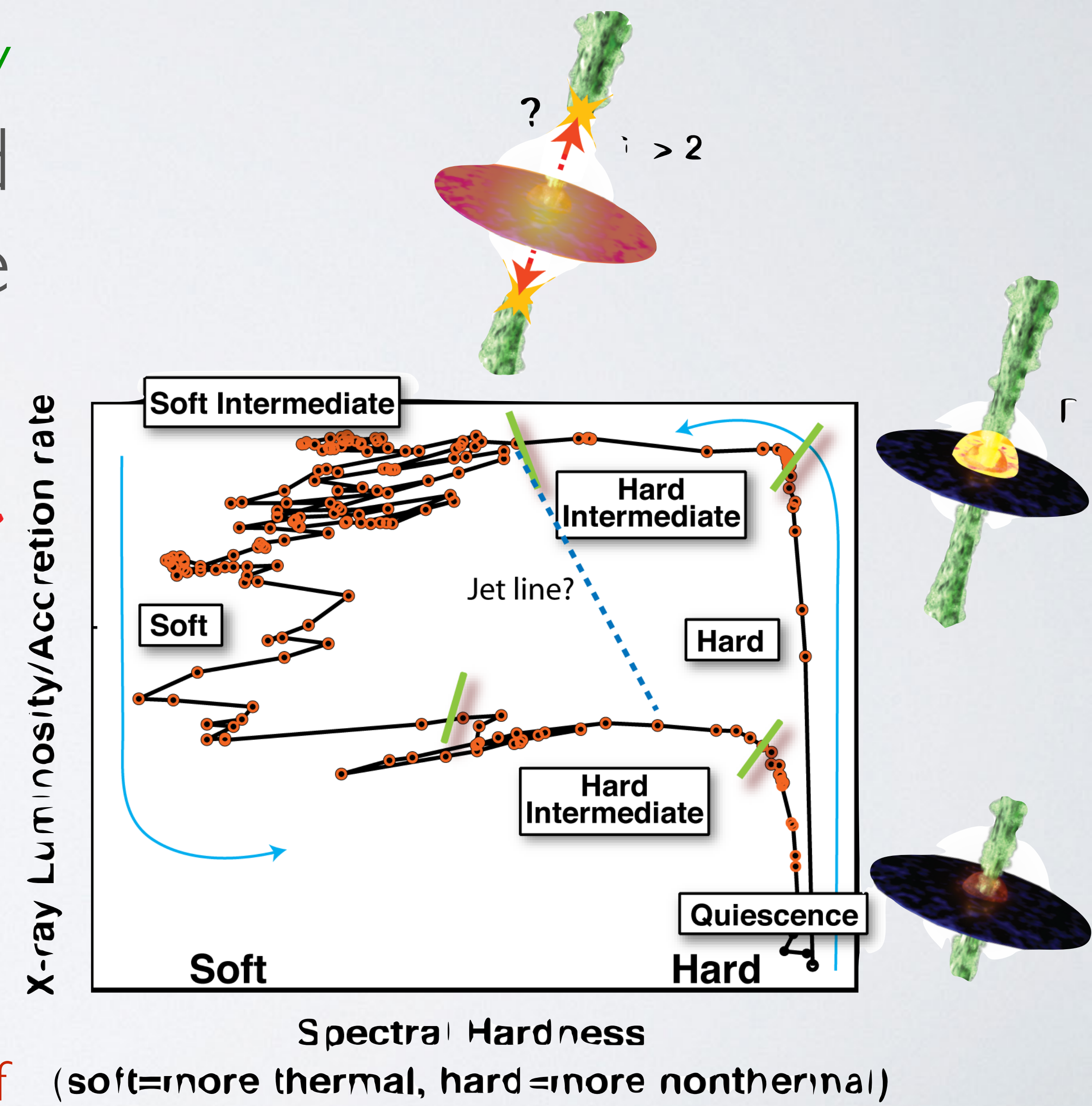


Image credit: Sera Markoff

THE MISSING Be/BH SYSTEMS

- Binary population synthesis models predict a high number of Be/NS systems and a low number of Be/BH systems. 10 to 50 Be/NS for each Be/BH (Belczynski & Ziolkowski 2009)
- Fate of MWC 656-like systems: they are potential progenitors of BH-NS binaries (77% probability)
- Need of more Be/BH systems to map the distribution of orbital periods and improve our understanding of BH natal kicks and inner workings of CE
- Currently: 184 Be/compact object binary system (119 NS, 1 BH)
- Latest work on binary synthesis and evolution (Gudzinska et al. 2015, code with several assumptions) conclude that:
  - Be/BH progenitors experience common envelope (CE) phase
  - 90% of the cases the companion star is an evolved star, increasing probabilities to eject the CE and survival of the binary
  - 10 to 100 Be/BH binaries in the Galaxy at given time, but only ~1% of MWC 656-like systems present

MWC 656

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

Table 1 | Orbital elements for MWC 656

Parameter	Value
P_{orb} (days)	60.37 (fixed)
T_0 (HJD – 2,450,000)	3,243.70 ± 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)

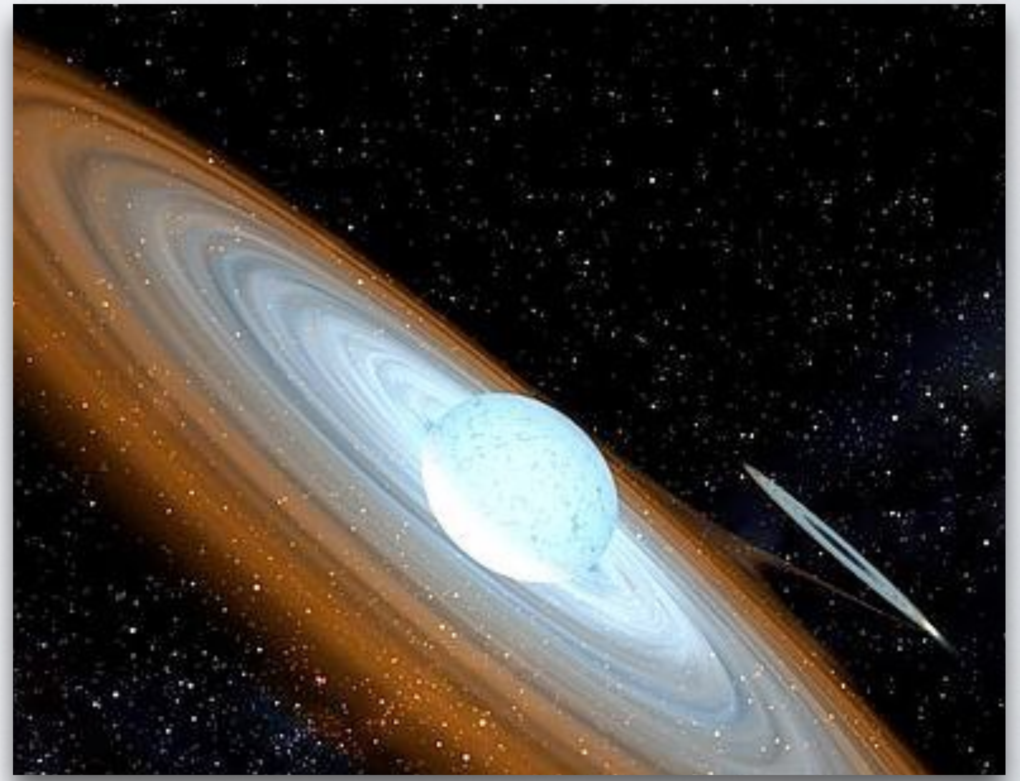


Image credit: Gabriel Pérez - SMM (IAC)

AGILE FLARES

- 10 flaring events registered by *AGILE* between 2007 and 2014
- follow up of the source

Position (l,b)	Start	Stop	Gal	Iso	$\sqrt{TS}$	Flux (photon $cm^{-2} s^{-1}$)
(100.28,-13.22)	2007-11-23 00:02:10	2007-11-24 12:02:10	0.5	8.3	4.53	$(145 \pm 48) \times 10^{-8}$
(100,22,-12,61)	2008-06-28 12:03:15	2008-06-30 06:03:15	0.5	8.3	3.23	$(64 \pm 27) \times 10^{-8}$
(101,74,-11,25)	2009-01-04 12:02:12	2009-01-07 00:02:12	0.5	8.3	3.11	$(52 \pm 22) \times 10^{-8}$
(100.94,-12.65)	2010-06-13 12:01:06	2010-06-14 18:01:06	0.42	9.56	3.2	$(142 \pm 115) \times 10^{-8}$
(99.273,-11.50)	2010-06-30 00:01:06	2010-07-02 00:01:06	0.42	9.56	3.1	$(131 \pm 61) \times 10^{-8}$
(99.96,-12.24)	2010-07-25 00:02:12	2010-07-27 00:02:12	0.42	9.56	3.8	$(141 \pm 59) \times 10^{-8}$
(99.94,-12.76)	2011-10-08 00:02:12	2011-10-10 00:02:12	0.42	9.56	3.41	$(255 \pm 115) \times 10^{-8}$
(101.7,-12.51)	2011-04-09 00:02:12	2011-04-11 00:02:12	0.42	9.56	3.13	$(216 \pm 106) \times 10^{-8}$
(100.38,-12.70)	2013-07-10 00:00:00	2013-07-12 00:00:00	0.42	9.56	3.46	$(320 \pm 158) \times 10^{-8}$
(100.34,-11.81)	2013-03-07 00:00:00	2013-03-08 09:00:00	0.42	9.56	3.11	$(260 \pm 137) \times 10^{-8}$

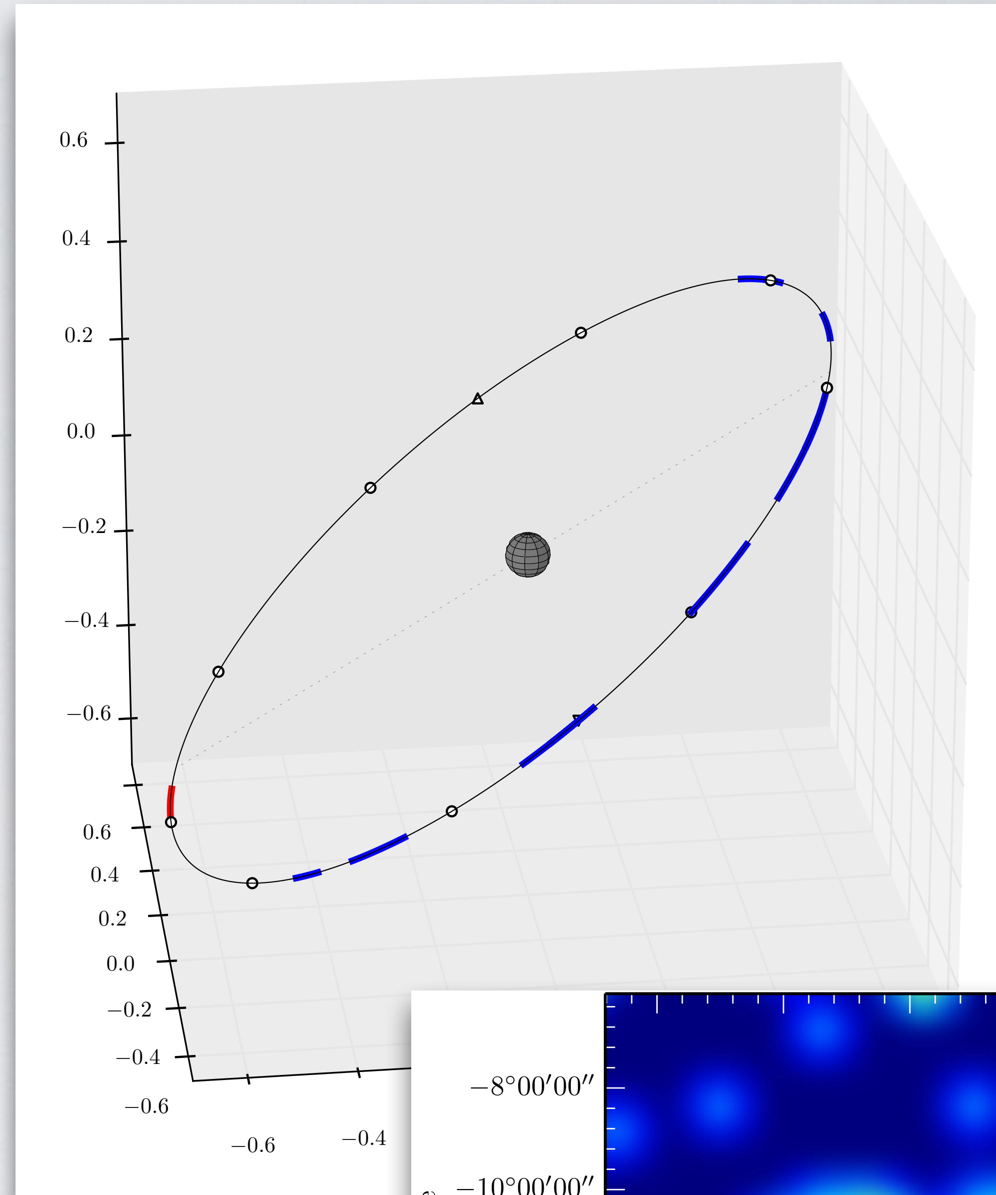
from Le Hoang master thesis (2014)

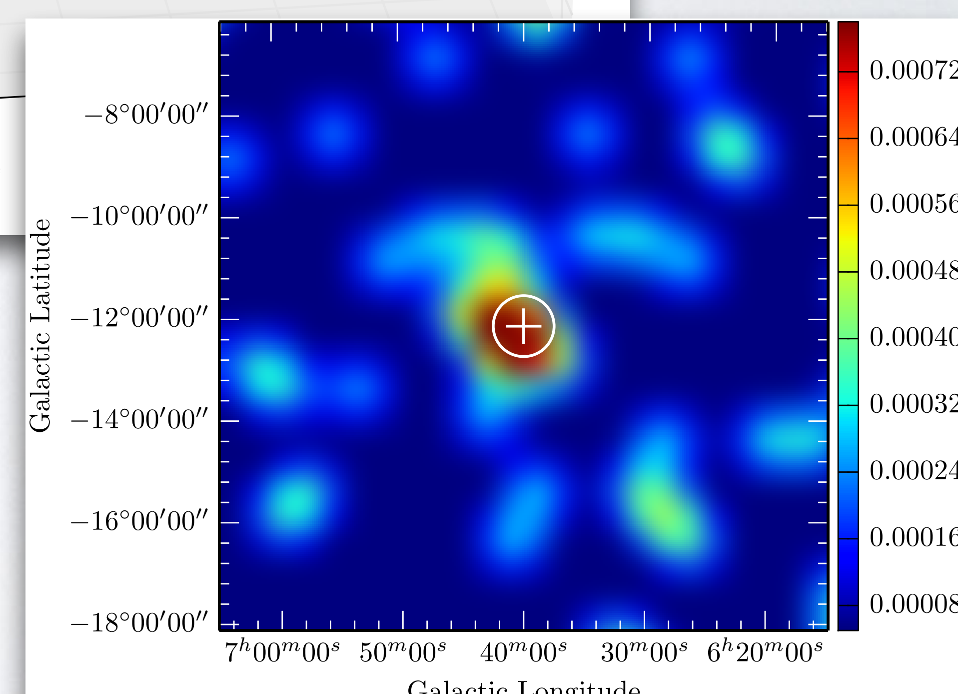
AGILE FLARES

- Approximate observer's view of the binary orbit, according to Casares et al. (2014) results

- Flares seem to be concentrated on half of the orbit

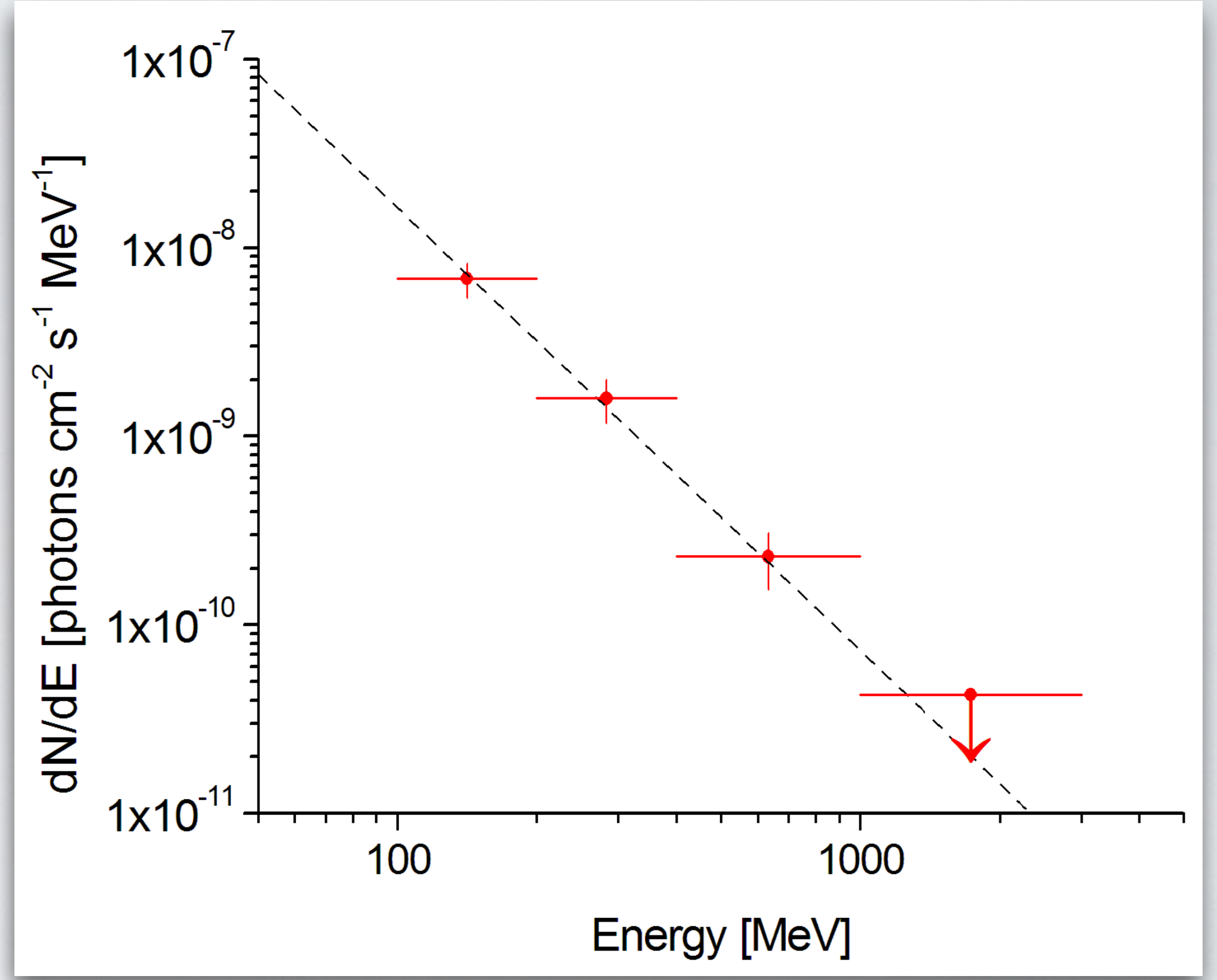
- We do not know the extension of the Be disk





AGILE FLARES

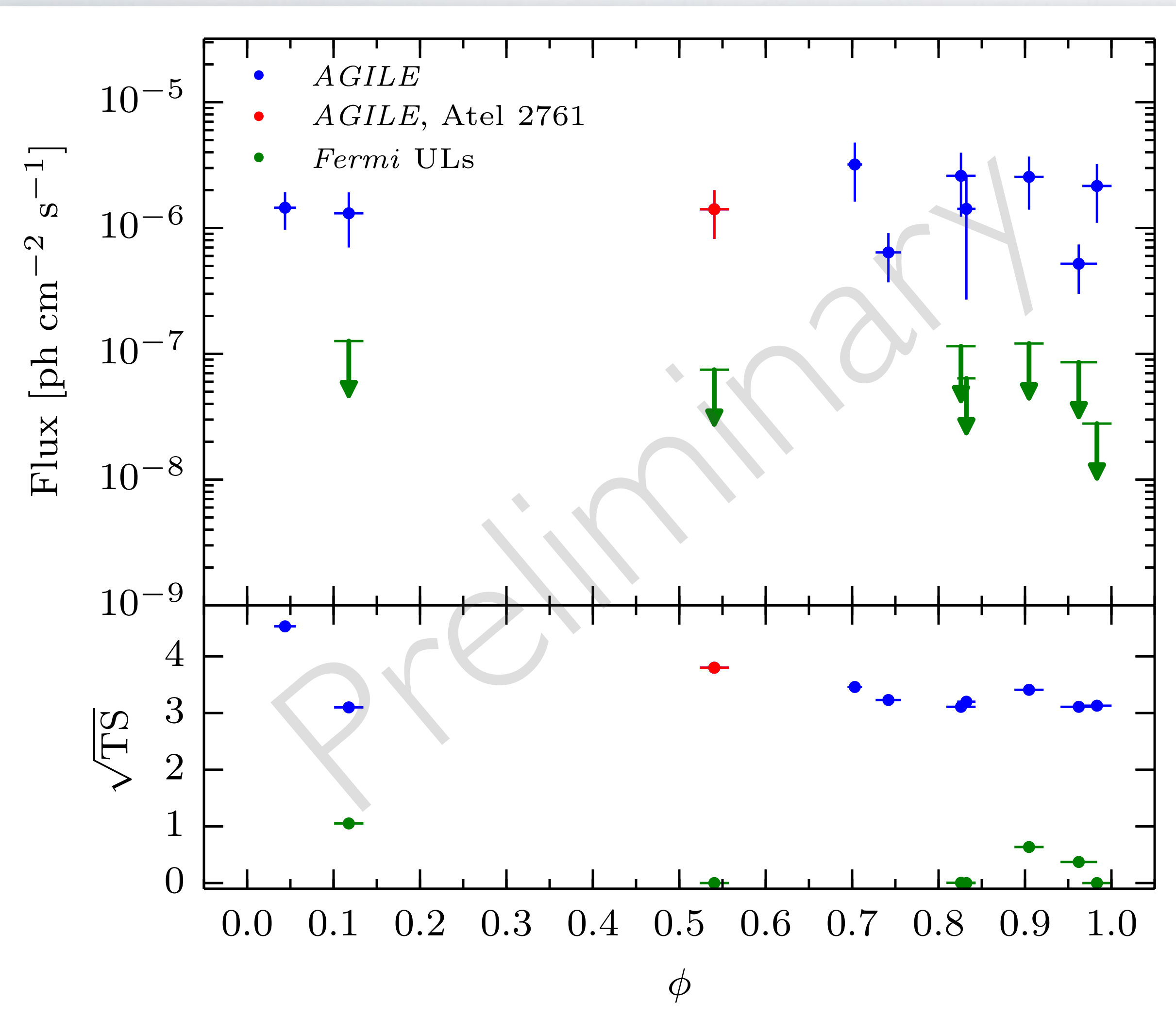
- *AGILE* spectrum between 100 MeV and 3 GeV
- Integrating over all detected gamma-ray flares
- Spectral fit with photon index $\Gamma = 2.35 \pm 0.16$



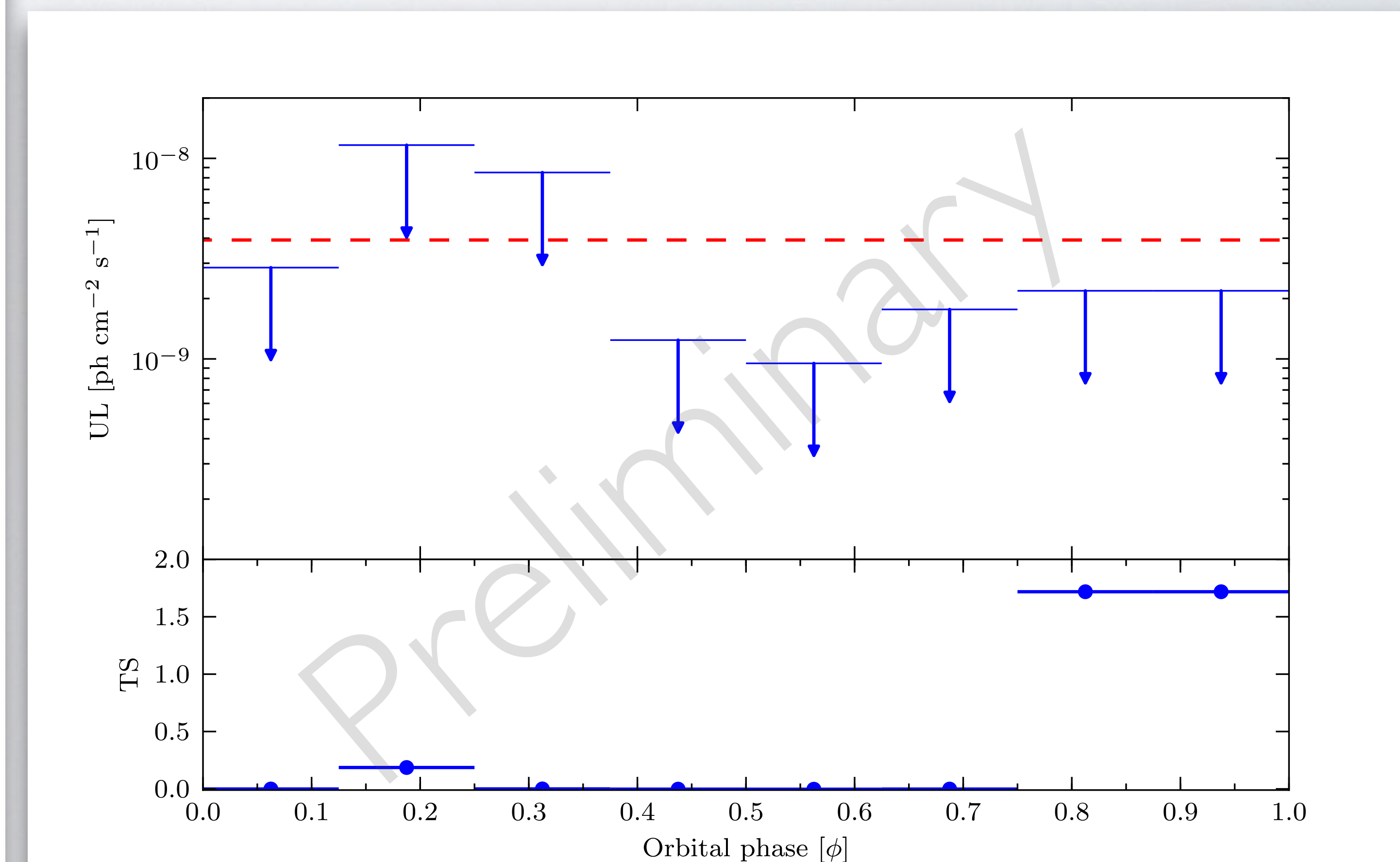
from Le Hoang master thesis (2014)

AGILE FLARES

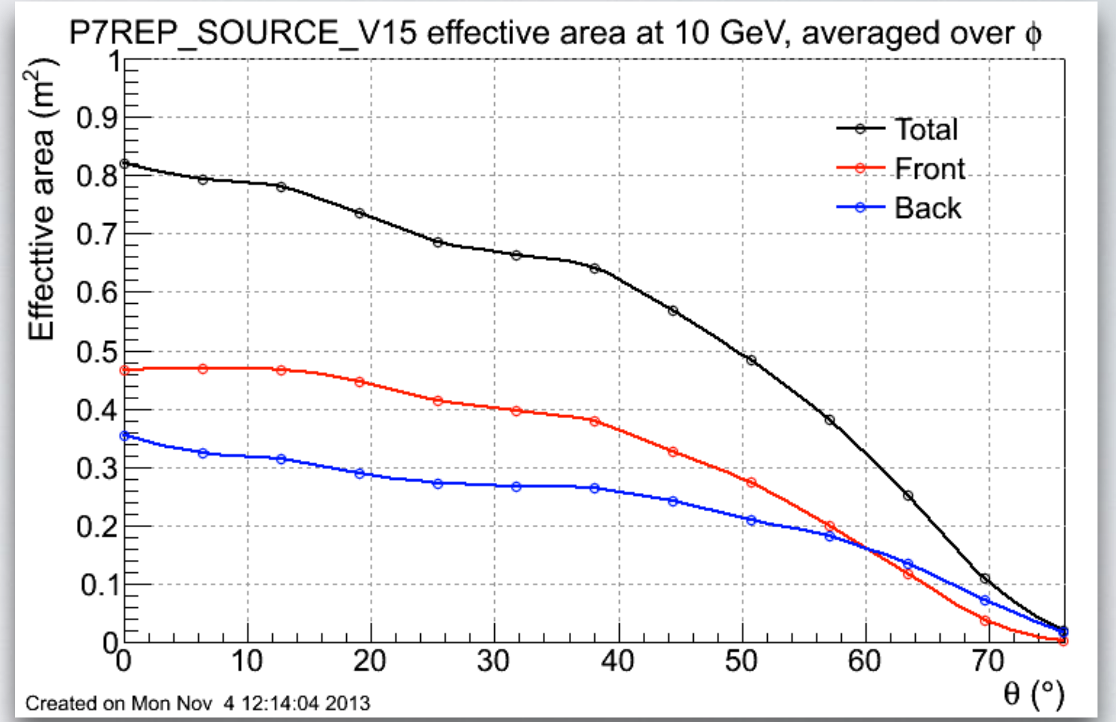
- *Fermi* likelihood analysis of each flaring event:



- *Fermi* likelihood phase folded analysis:

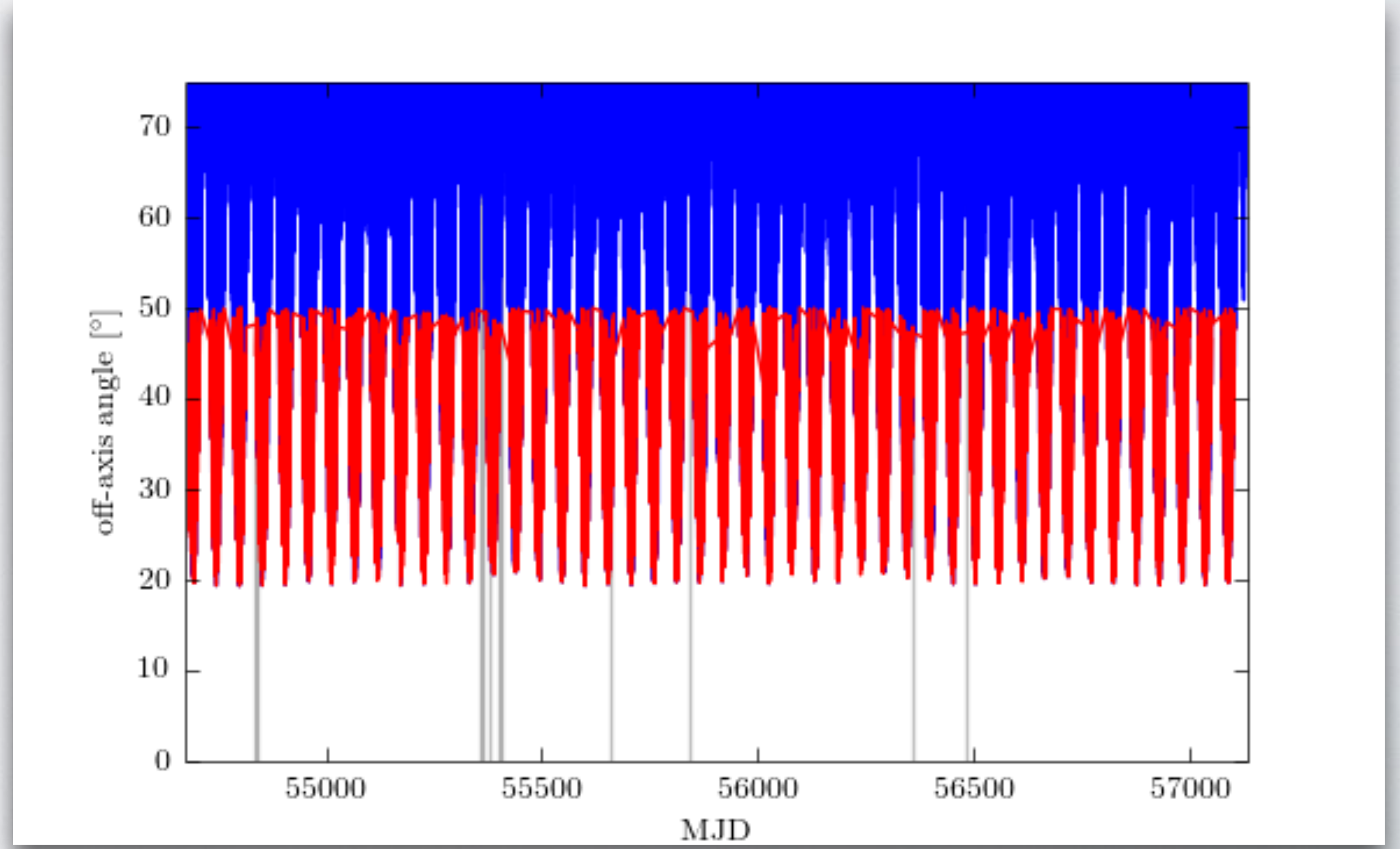


WHY *FERMI* DID NOT SEE THE FLARES?



- *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°

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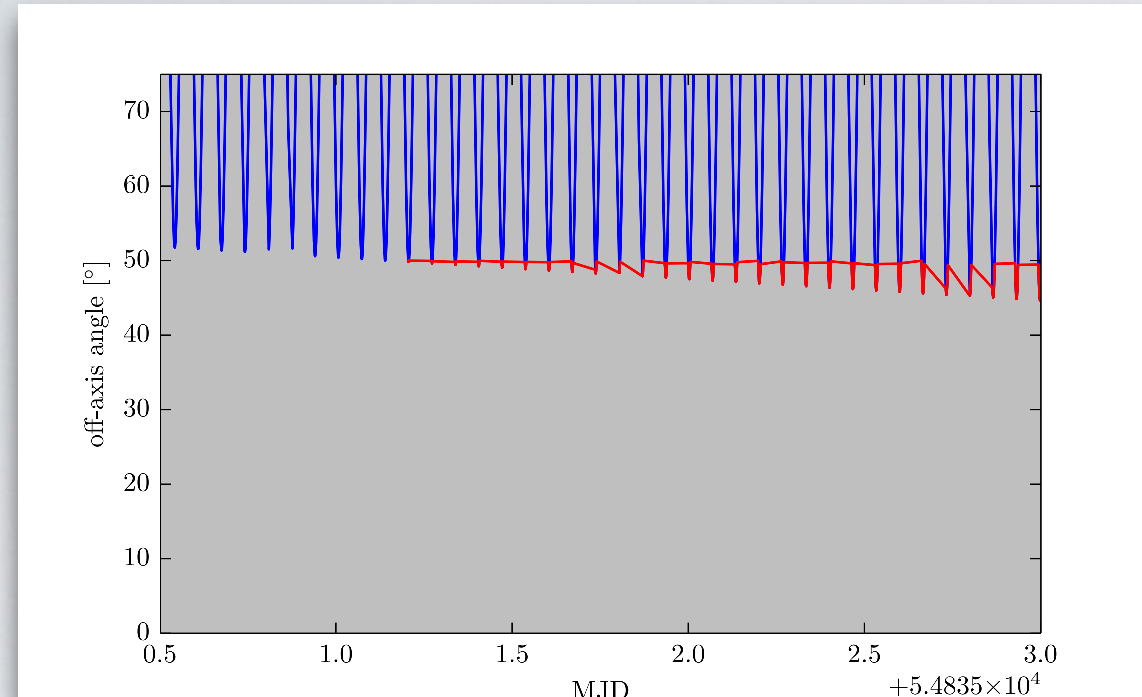

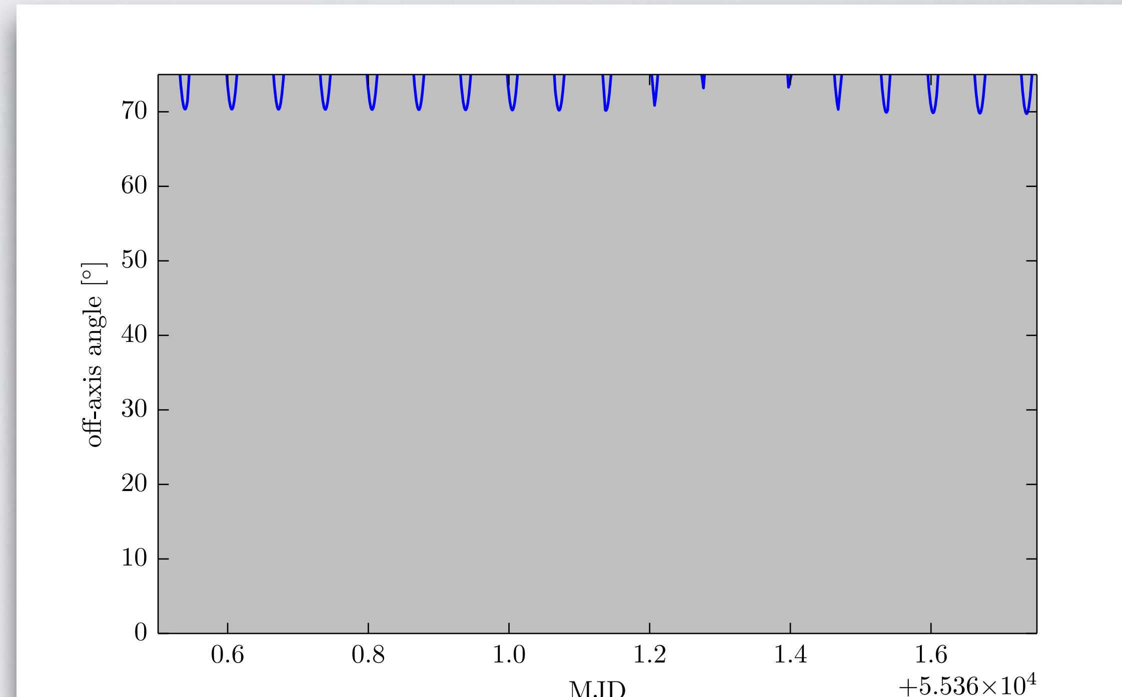

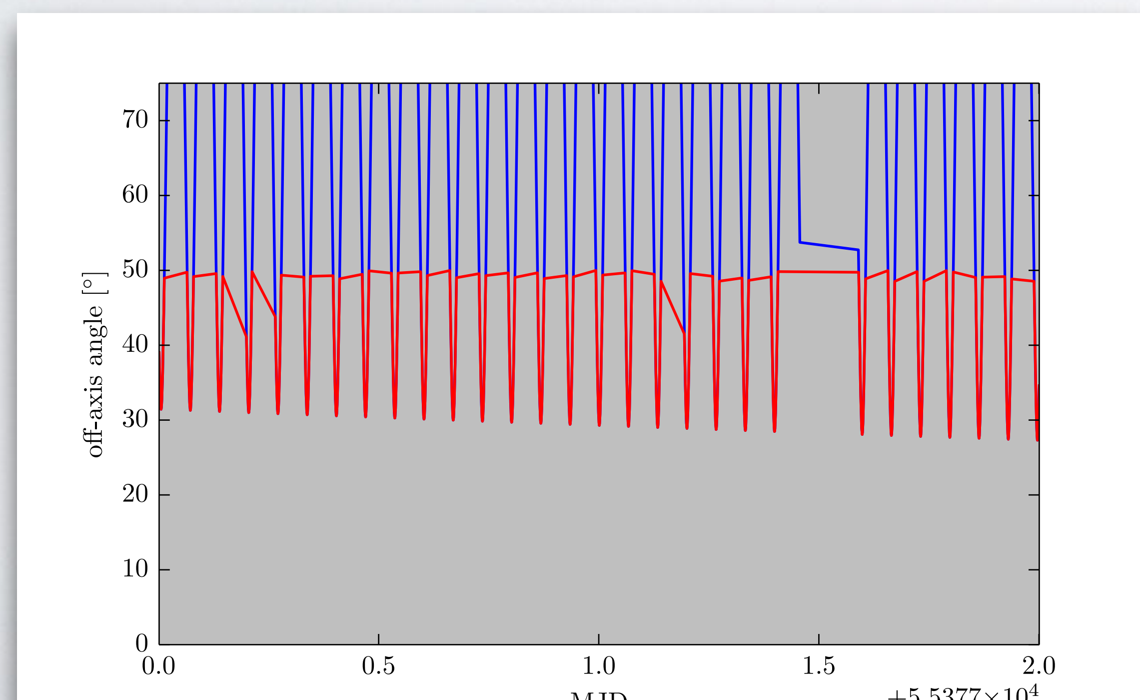

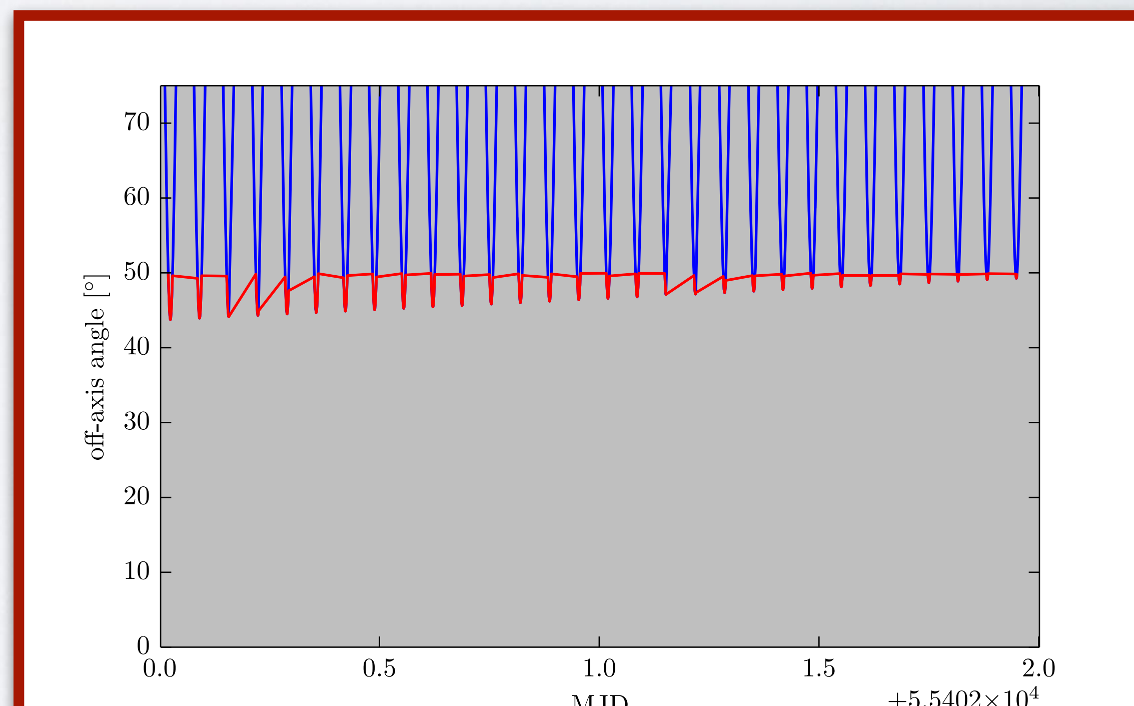

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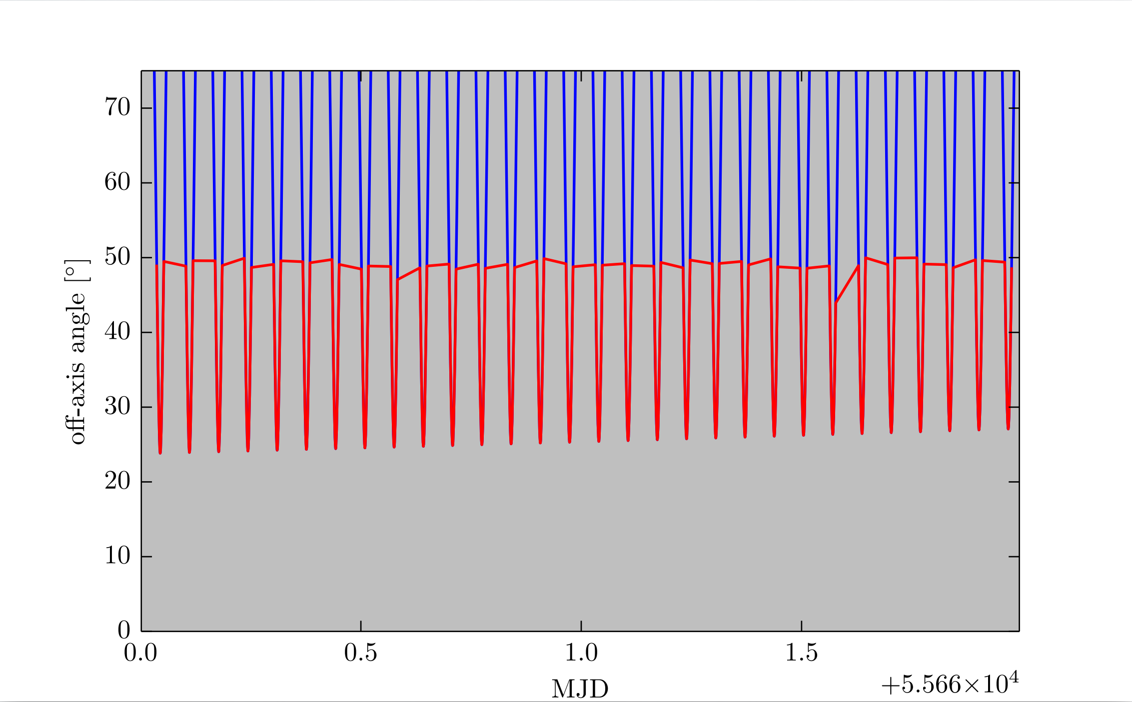
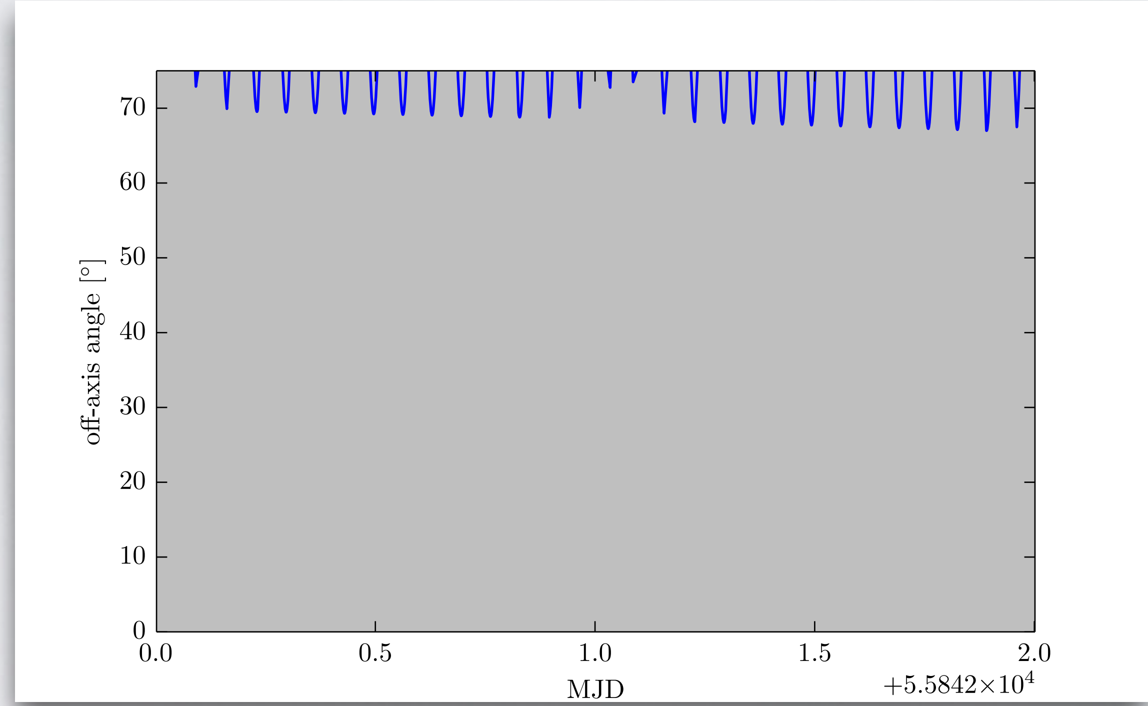
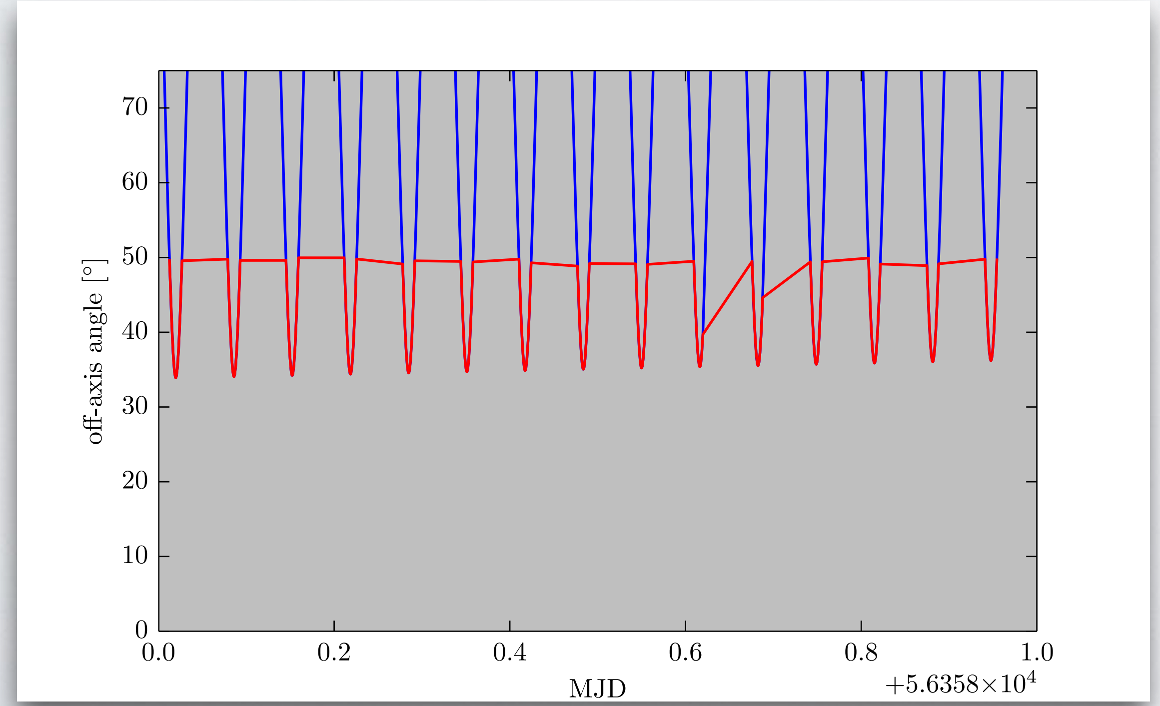
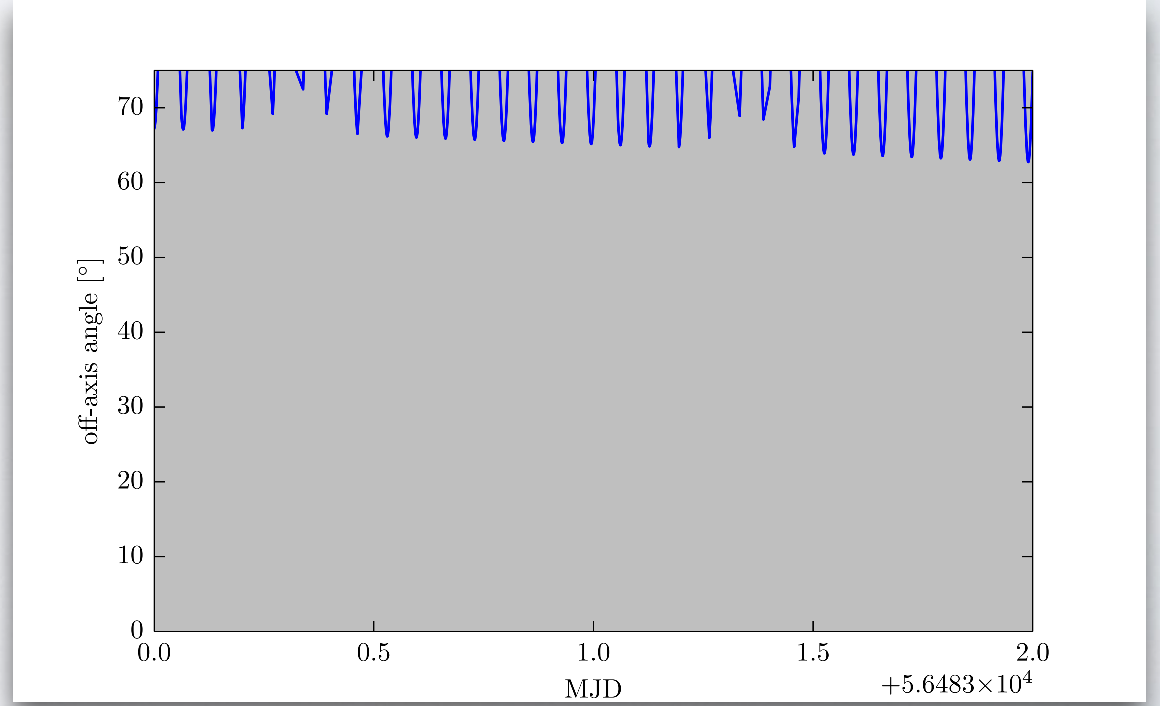


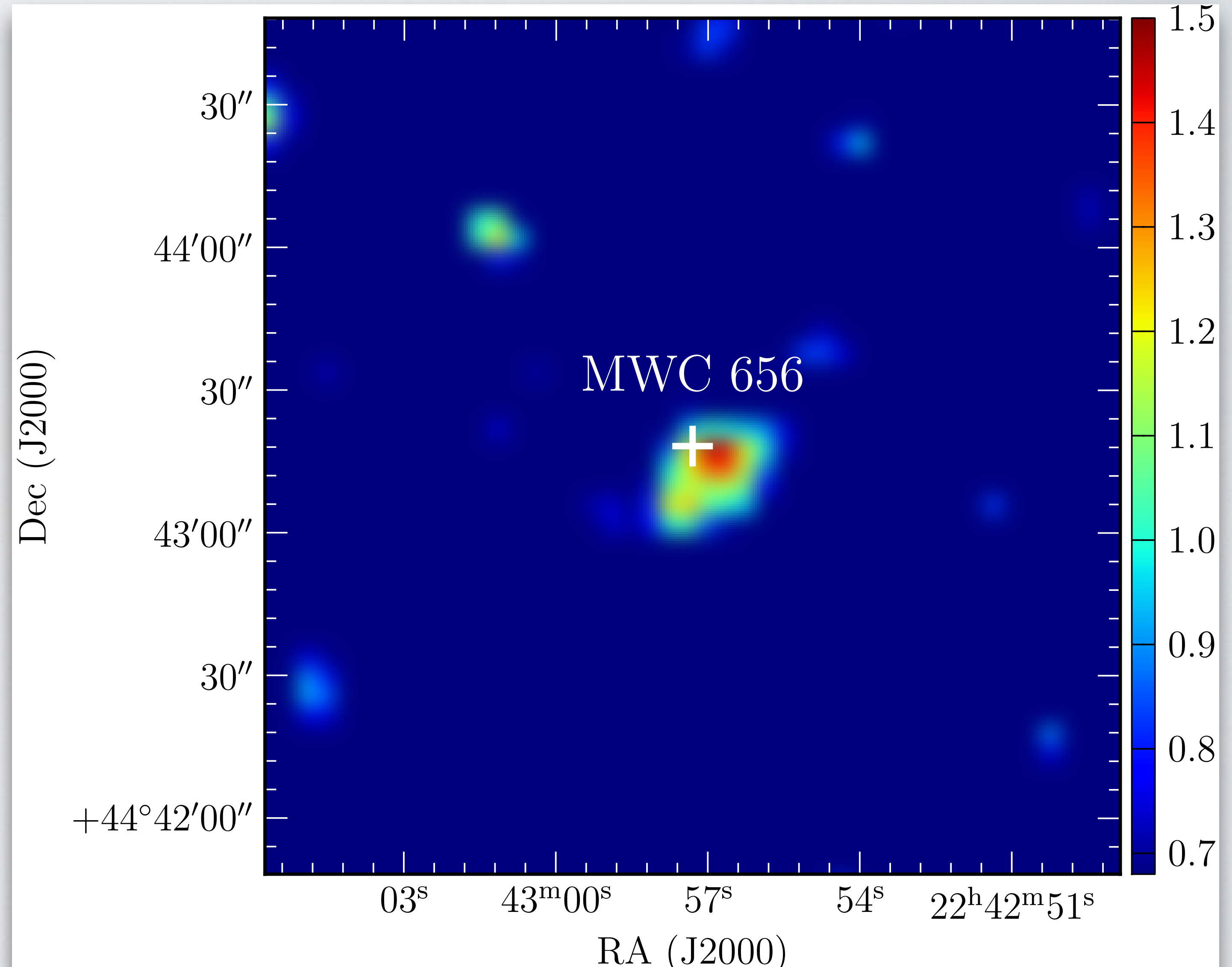






X-RAY DATA

- Observed once by *XMM-Newton* (15 ks)
- Standard analysis chain using SAS v12.0.1
- We detect a faint source at 4σ c.l. coincident with the position of MWC 656
- Detected only with the EPIC-pn detector in the 0.3-5.5 keV range
- X-ray source position compatible with the *Hipparcos* position of MWC 656 at 2.4σ
- Spectrum with low number of counts (0.3-5.5 keV energy range)



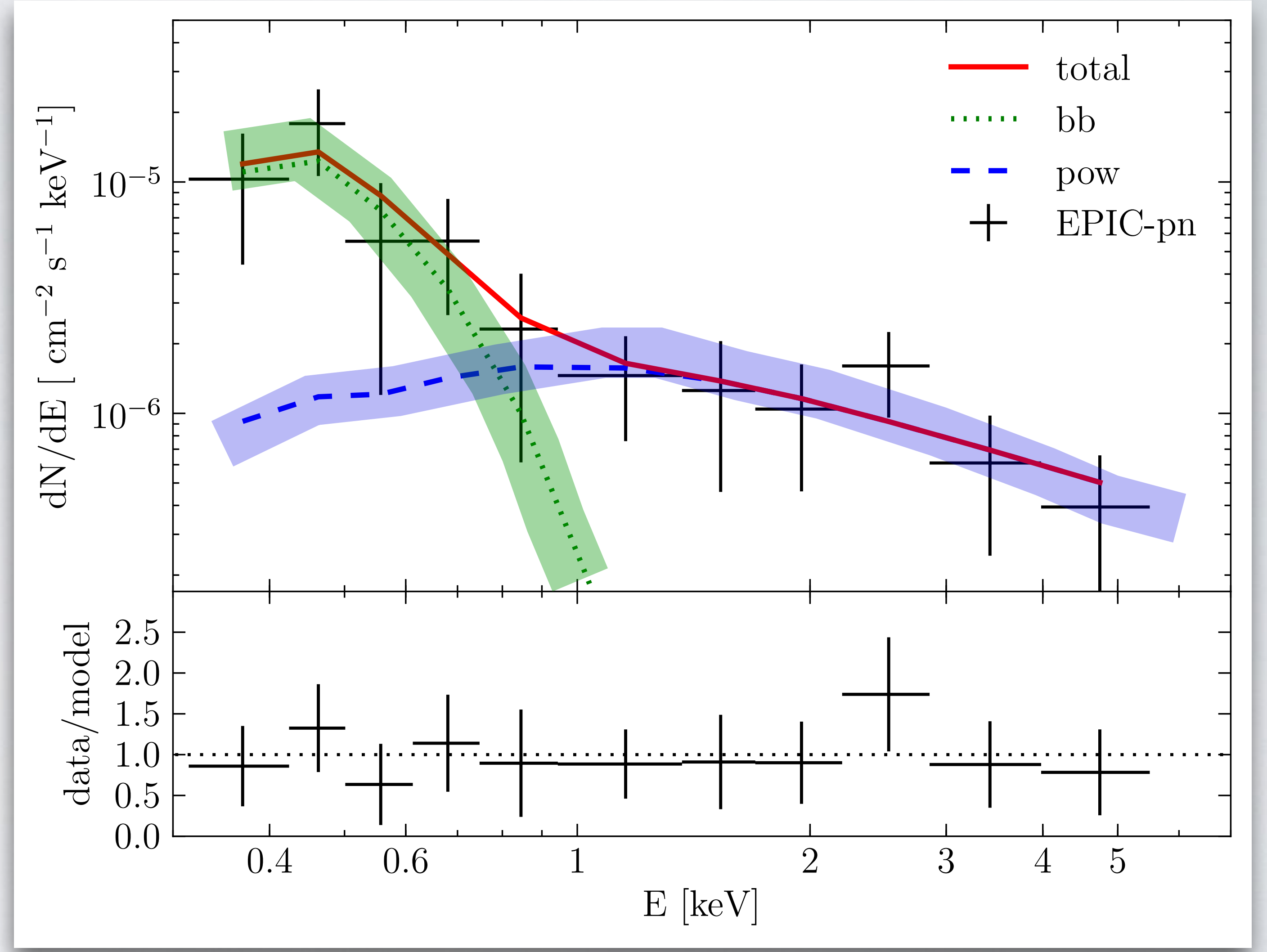
Munar-Adrover et al. (2014)

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 $L_X/L_{Bol} \sim 3\times10^{-7}$



- Non thermal component

  -Photon index $\Gamma = 1.0\pm0.8$ roughly compatible with the average photon index for XRBs in quiescence from Plotkin et al. (2013)

  -Possible origin in the vicinity of the black hole

X-RAY DATA ANALYSIS

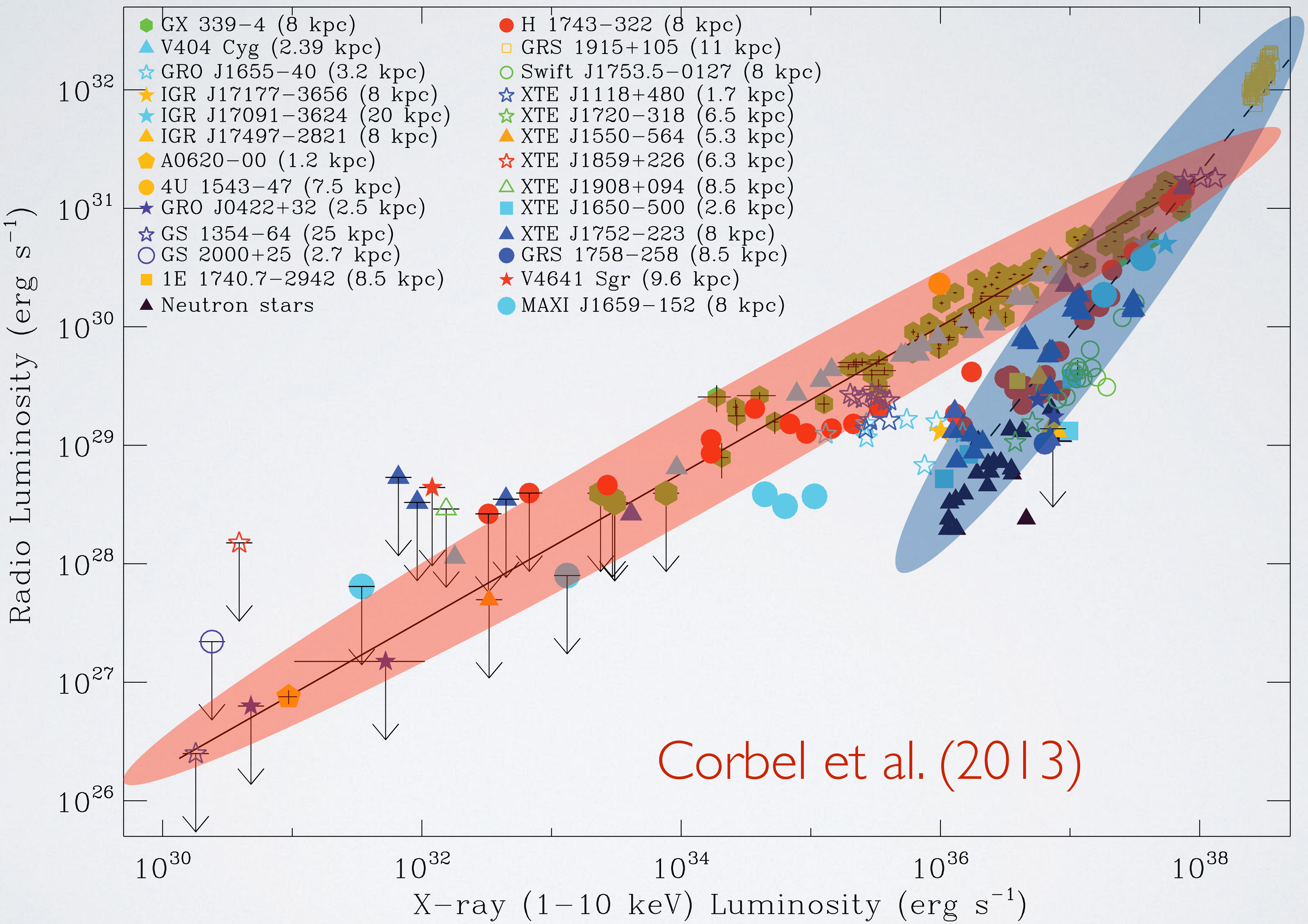
- The non thermal luminosity in the 0.3-5.5 keV range is $L_X=(1.6^{+1.0}_{-0.9})\times10^{31}$ erg s^{-1} ≡ $(3.1\pm2.3)\times10^{-8}\ L_{Edd}$

- 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 LUMINOSITY vs RADIO LUMINOSITY CORRELATION



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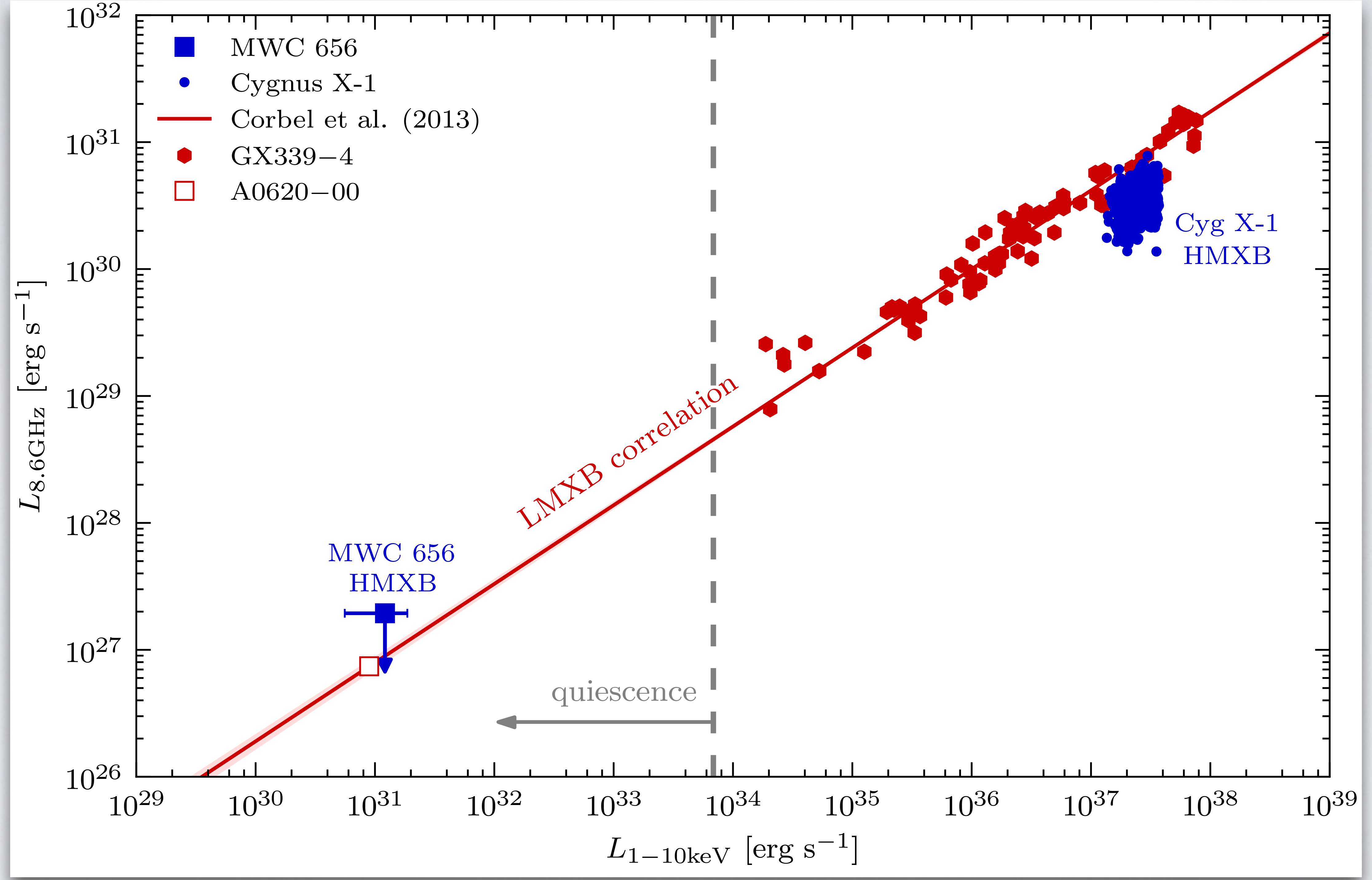
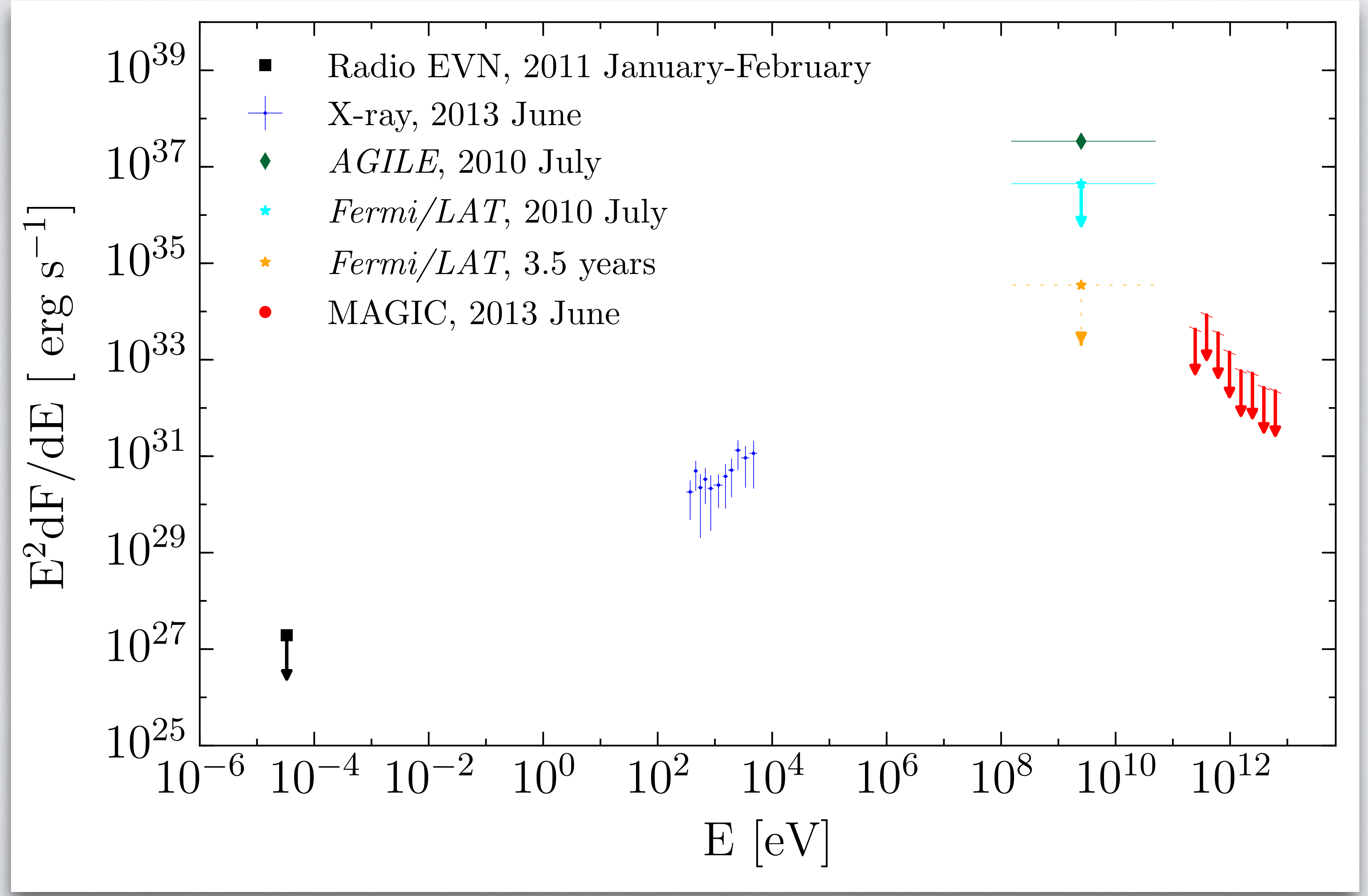


Munar-Adrover et al. (2014)

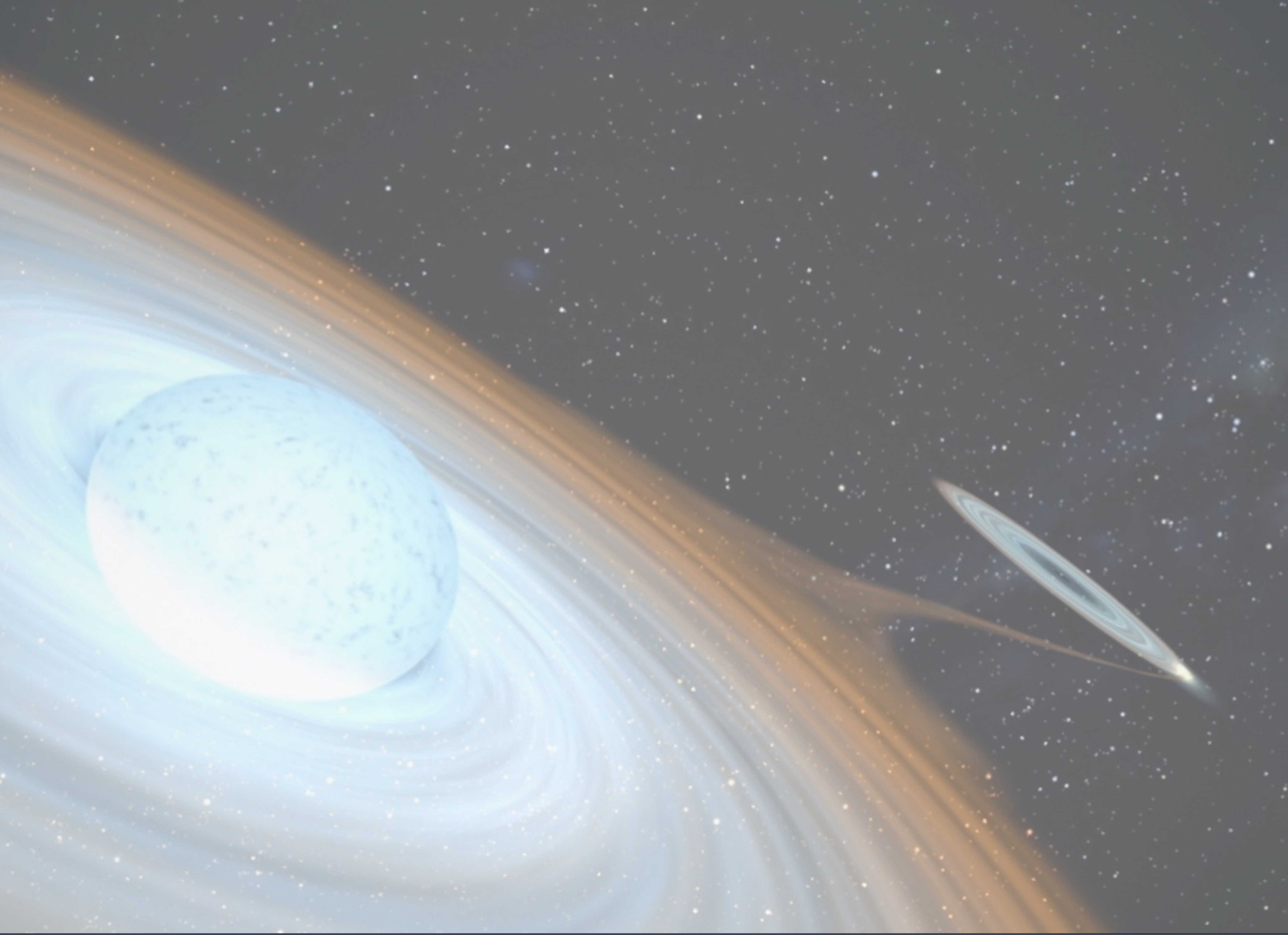
AT TeV ENERGIES

- Observations with the MAGIC Telescopes contemporaneous to the *XMM-Newton* observation did not provide a detection at TeV energies (Aleksic et al. 2015)



CONCLUSIONS

- The first Be/BH system was discovered thanks to the *AGILE* detection of a transient gamma-ray flare (Lucarelli et al. 2010). Nine more flares detected
- *Fermi* analysis of the system does not provide evidence of gamma-ray activity, neither during the detected flares by *AGILE* nor phase folding *Fermi* data
- Munar-Adrover et al. (2014) discovered the X-ray counterpart of MWC 656 confirming it to be a high-mass X-ray binary. Two spectral components: thermal and non thermal. The system is at the quiescent state during the X-ray observation with a low luminosity
- MWC 656 compatible with the radio/X-ray correlation found by Corbel et al. (2013) and Gallo et al. (2012), allowing for the study of accretion/ejection processes in HMXBs at very low luminosities
- Evolutionary models predict low number of MWC 656-like systems. They might be progenitors of BH-NS systems
- 2015 joint *Chandra*/VLA observation might help us to better understand this system



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