Long-term campaign on Cygnus X-3 with the MAGIC telescopes

E. Molina*, L. Barrios-Jiménez, M. Carretero-Castrillo, J. Becerra González, M. Ribó and J.M. Paredes, for the MAGIC Collaboration

*Instituto de Astrofísica de Canarias (IAC)

Microquasar Workshop XI
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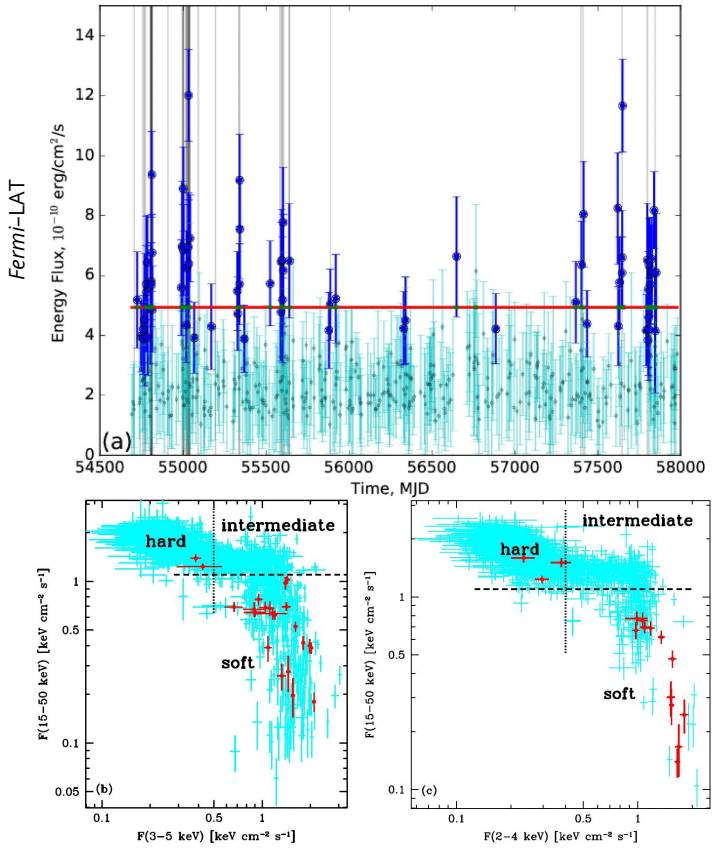
Introduction: Cygnus X-3

- Cyg X-3 is a **high-mass microquasar** with an unknown compact object and a Wolf-Rayet star.
  - Distance: 9.7 ± 0.5 kpc Reid+23
  - Orbital period: 4.792354 ± 0.00001 h Parsignault+76
- **High-energy** (HE; > 100 MeV) flares are periodically observed in the **soft X-ray state**.
  - Orbitally modulated and correlated with **radio**.
  - Likely explained by **inverse Compton** and **synchrotron** emission from jet electrons.
- High expected **absorption at very high energies** (VHE; > 100 GeV).
- **No confirmed detection above ~20 GeV**.



Zdziarski+18

Introduction: The MAGIC telescopes

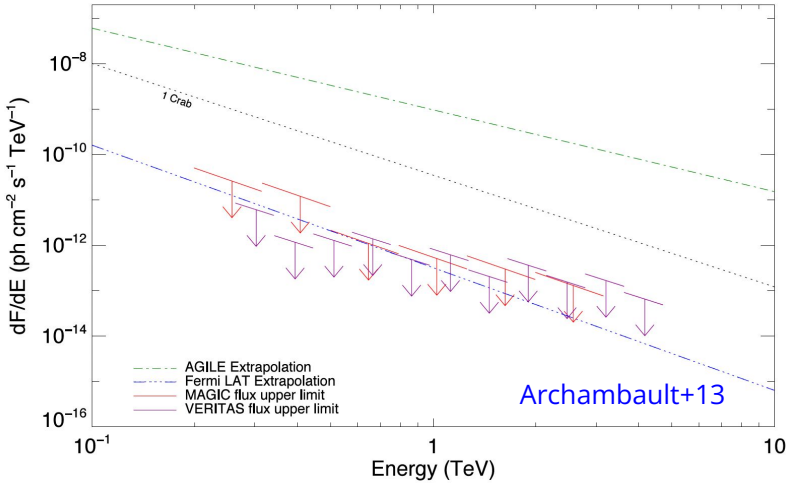
- Two 17-m Cherenkov telescopes located in the Canary island of La Palma, Spain.
- Photomultiplier cameras with a **~3.5º FoV**.
- Energy range: **~50 GeV – 100 TeV**
- Differential sensitivity at hundreds of GeV **below 2% of the Crab Nebula flux in 50h**.
- Energy resolution: **15 – 23%**
- Angular resolution: **~0.09º at 100 GeV**

Aleksić+16

https://magic.mpp.mpg.de/

Previous VHE observations

- MAGIC and VERITAS have been observing Cyg X-3 for several years. Publications:
  - MAGIC: **57h** after cuts, between 2006 and 2009 (**mono** data). Aleksic+10
  - VERITAS: **44h** after cuts, between 2007 and 2011. Archambault+13
- **No detection** or significant hints obtained.



New(er) VHE observations

- Further Cyg X-3 observations were performed with MAGIC between 2010 and 2024, for a total of 190h.
- After quality selection cuts, **132.2h** of data remain, spanning 12 years of data (2013 – 2024).
- Around half of the observations were done **during flaring states at HE**.
- Complex region with a **bright diffuse background**.

Year	Month	Obs. time (h)	Zenith angles (°)
2013	Nov	1.3	31 – 49
2014	May	6.6	15 – 40
	Jun	1.0	14 – 31
	Oct	4.8	11 – 58
2015	Jul	0.8	12 – 39
	Nov	1.3	33 – 47
2016	May	1.0	19 – 31
	Aug	9.6	12 – 45
	Sep	42.8	11 – 52
2018	Jul	2.1	12 – 37
	Aug	6.2	11 – 22
2019	Apr	1.0	38 – 50
	Jun	11.3	11 – 51
2020	Jun	4.4	12 – 25
	Jul	5.0	12 – 23
	Aug	3.2	12 – 30
	Sep	8.0	12 – 20
	Oct	1.9	22 – 44
2021	Apr	1.2	29 – 46
	Jun	1.9	27 – 50
2024	Apr	0.7	53 – 58
	Jun	2.0	23 – 49
	Jul	14.1	12 – 47
Total		132.2	11 – 58

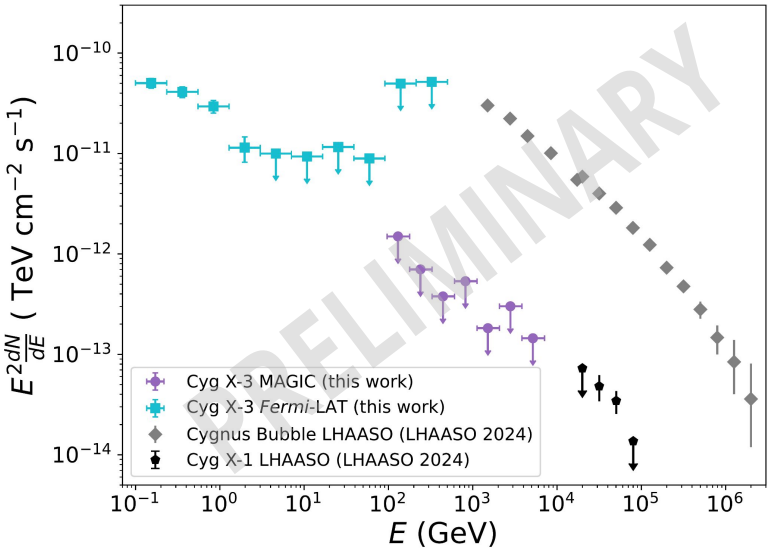
MAGIC analysis by:

Luis Barrios-Jiménez

Mar Carretero-Castrillo

Results: SED

- Still, **no detection at VHE**.
- Most constraining upper limits (ULs) up to date.
- **MAGIC ULs** are consistent with an extrapolation of the ***Fermi*–LAT** spectrum.
- No significant dependency of the VHE signal with orbital phase or HE flaring state is found.
- Below 10 TeV, the contribution of Cyg X-3 to the **Cygnus Bubble** flux **has to be less than ~1%**.



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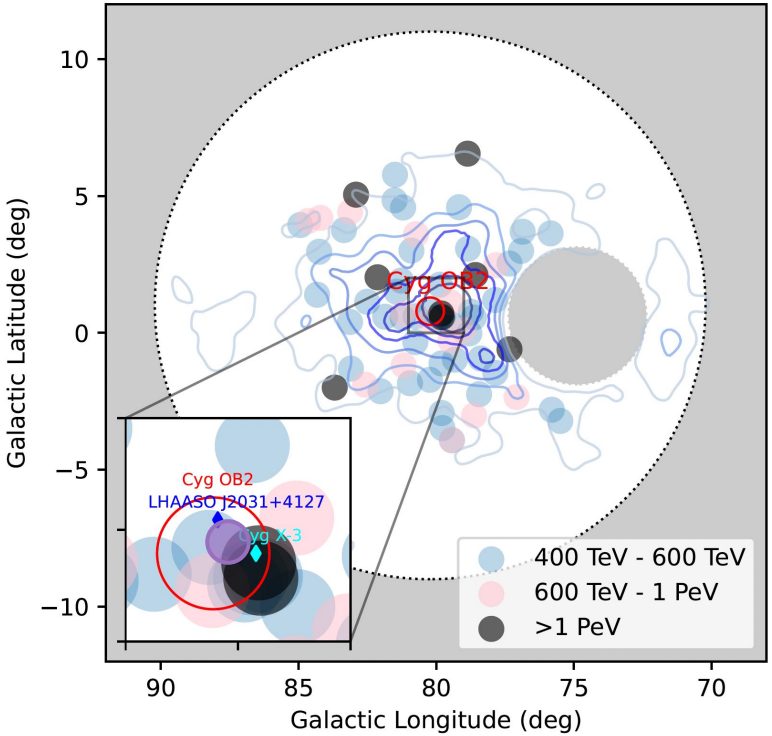
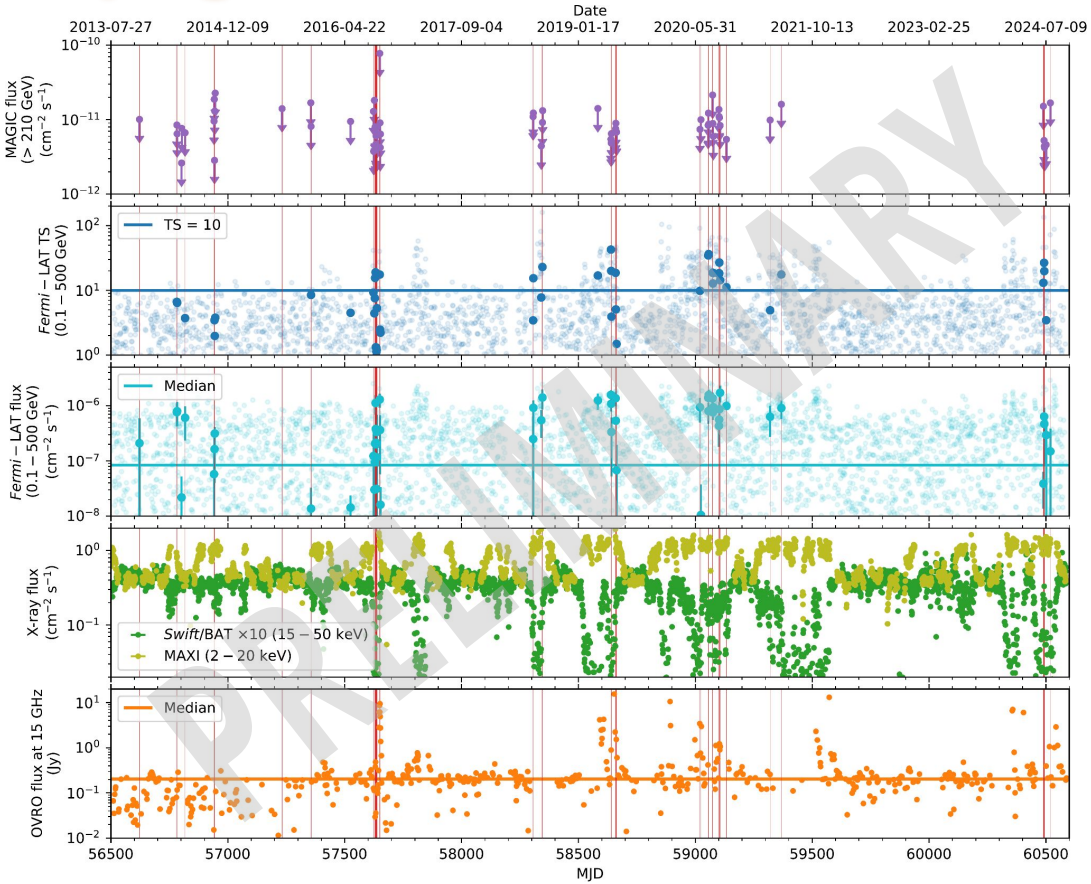


LHAASO+24

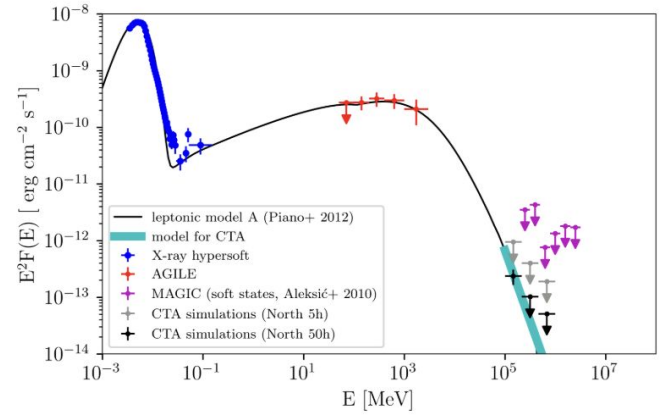
Results: Daily light curve

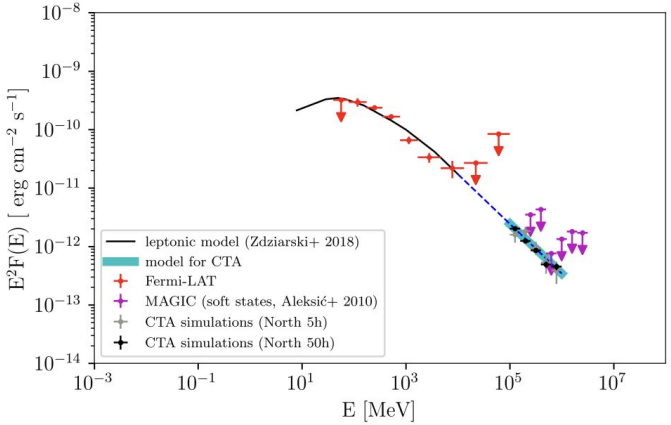
MAGIC observations |



Future prospects

- Based on the HE data, a detection of Cyg X-3 in flare with CTAO may be possible **in a few (tens of) hours**.
- Highly dependent on the assumed model, and in particular on the extrapolation of the HE flux to VHE.
- Alternatively, one may focus on the higher energies to bridge the gap with LHAASO.
  - High zenith angle observations.
  - ASTRI observations at tens of TeV.





Abe+24

Summary

- Cyg X-3 is not detected after analyzing more than 130h of MAGIC observations.
- The non-detection might be explained by a high background “veiling” the emission of the source.
- Most constraining VHE ULs up to date.
- No changes in the VHE signal with orbital phase or HE flaring state.
- MAGIC ULs are compatible with the *Fermi*-LAT spectrum, and limit to < 1% the contribution of Cyg X-3 to the LHAASO Bubble flux below 10 TeV.
- Forthcoming paper with interpretation and more details.

THANK YOU FOR YOUR ATTENTION

Edgar Molina
(emolina@iac.es)

in collaboration with:
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AGENCIA ESTATAL DE INVESTIGACIÓN

Backup

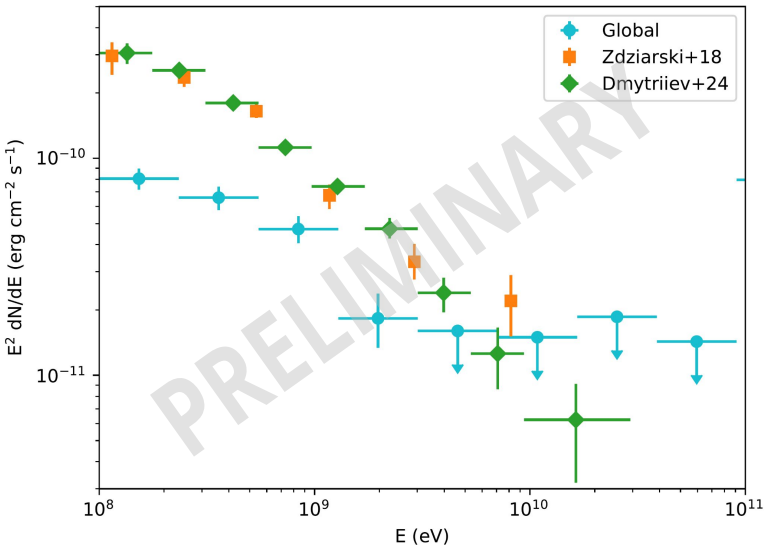
Introduction: Microquasars in gamma rays above 100 MeV

Source	HE (0.1 - 100 GeV)	VHE (0.1 - 100 TeV)	UHE (> 100 TeV)	Comments
Cygnus X-1	Yes	4.1σ excess	No	VHE excess in a single observation night. 4.0σ hint above 25 TeV with LHAASO.
Cygnus X-3	Yes	No	No?	UHE emission from a region compatible with the source position.
GRS 1915+105	Yes	No	Yes	Different emitting regions for each energy range.
MAXI J1820+070	No	No	Yes	
SS 433	Yes	Yes	Yes	Different emitting regions for each energy range. Emission far from the binary, except for UHE.
V404 Cygni	4.5σ excess?	No	No	Updated *Fermi*–LAT analysis shows no excess.
V4641 Sgr	No	Yes	Yes	Emission far from the binary.

Acero+09, Aleksić+10, Archambault+13, Loh+16, Ahnen+17, Piano+17, Abeysekara+18, Fang+20, Abe+22, Harvey+22, LHAASO+23, H.E.S.S.+24, Dmytriiev+24, LHAASO+24, Martí-Devesa+24

Results: SED – HE

- *Fermi*–LAT data **coincident with the MAGIC observations** were also analysed.
  - To have enough statistics, **daily time bins** centered at midnight UTC are used, for a total of 67 days of LAT data.
- Complex region that needs some care with the analysis.
- Our fluxes are a factor ~2 below those in the literature, which **only use flaring states**.
  - Discrepancies likely explained by **different datasets** and choice of analysis parameters.



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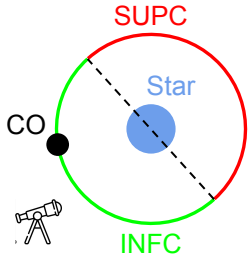
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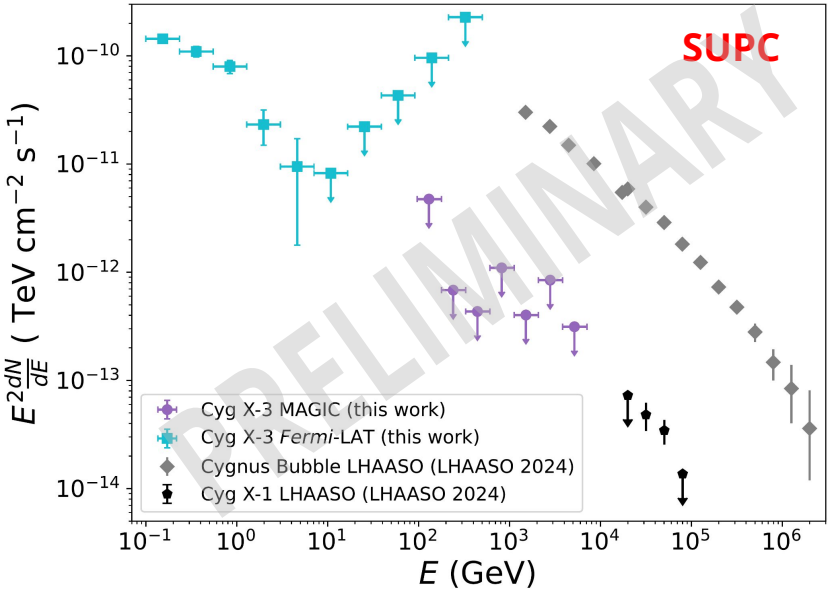
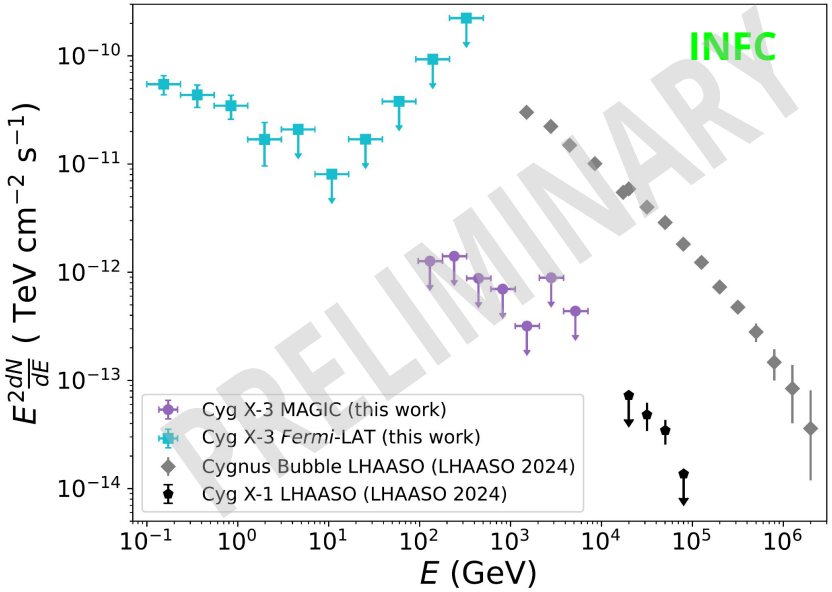

SUPC
PRELIMINARY
Cyg X-3 MAGIC (this work)
Cyg X-3 Fermi-LAT (this work)
Cygnus Bubble LHAASO (LHAASO 2024)
Cyg X-1 LHAASO (LHAASO 2024)
$E^2\frac{dN}{dE}$ (TeV cm^{-2} s^{-1})
E (GeV)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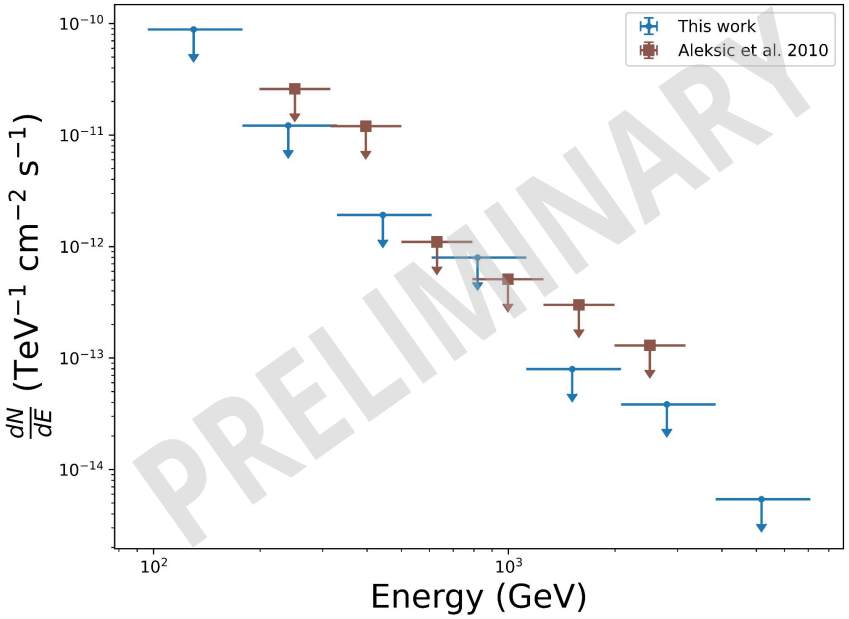
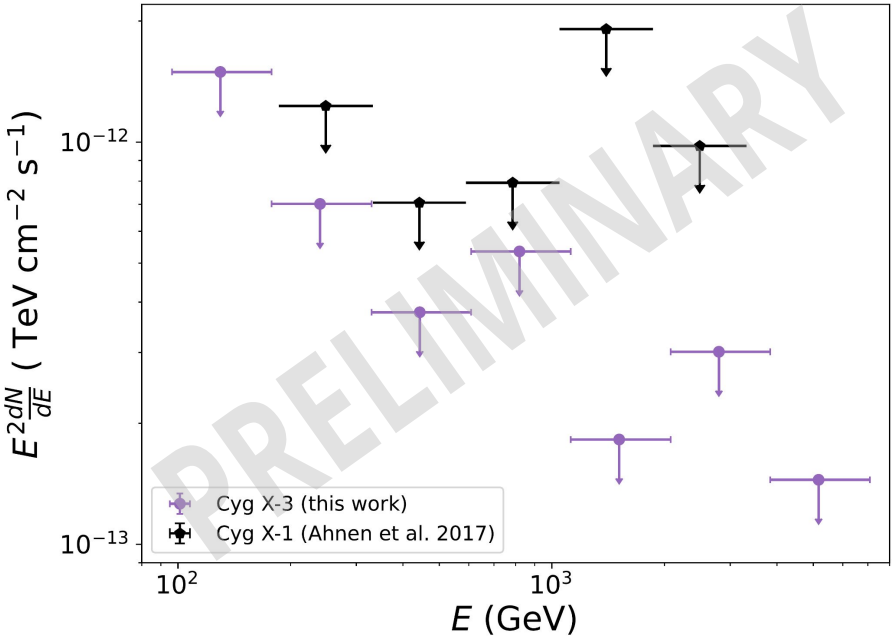
Results: SED – VHE comparisons





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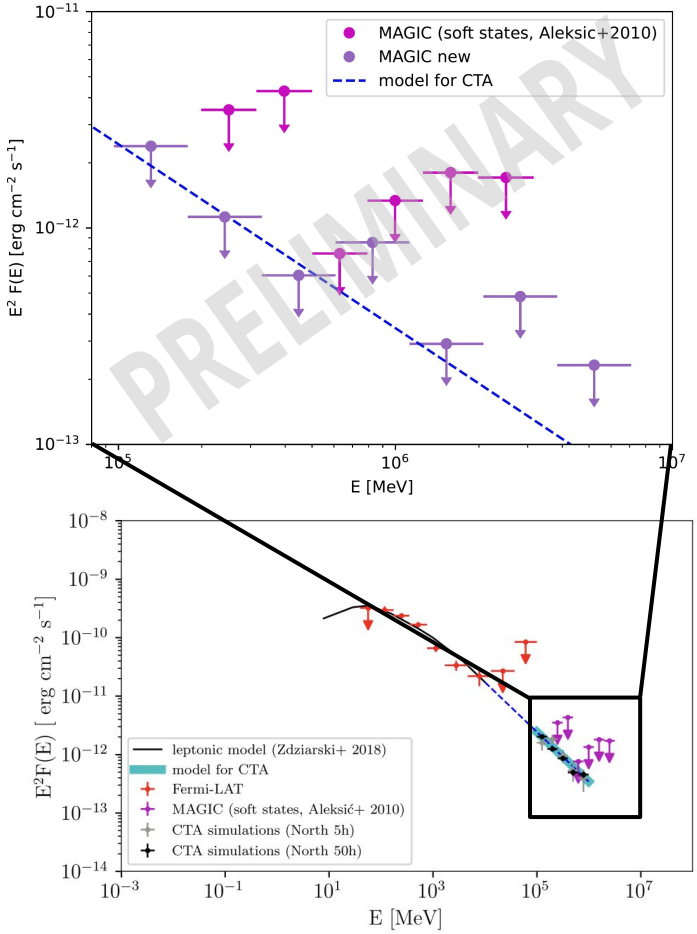

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