TeV & X-ray emission from the binary HESSJ 0632+057

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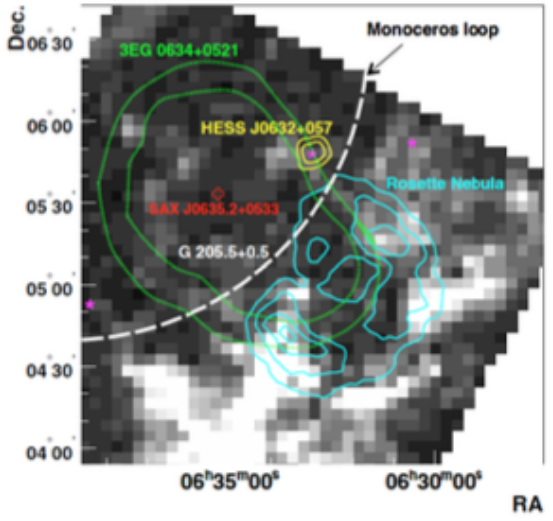
for the H.E.S.S., MAGIC, and VERITAS Collaborations, Y. Moritani

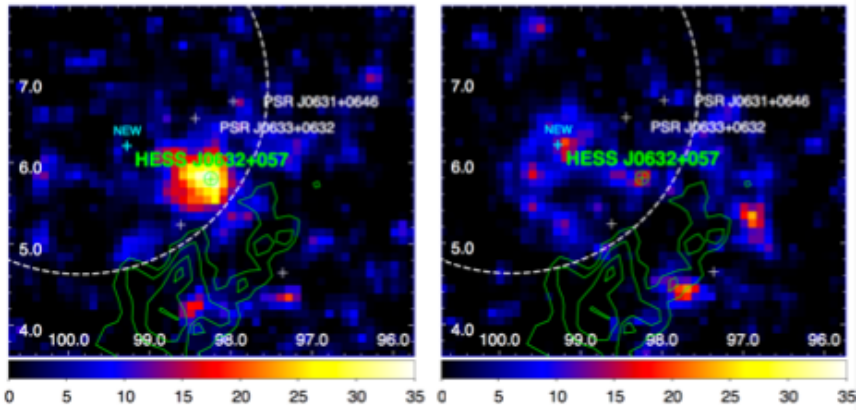
Overview

- Introduction of HESSJ0632+057
- Observations in **TeV**
- Updated **orbital solutions** from **optical** observations
- **Period search** in **TeV & X-rays**
- **Spectral behavior** along the orbit
- Correlation studies **TeV, X-rays & optical**
- Summary

Introduction

- Compact object + MWC 148: B0pe star
  - M=13.2-19$M_\odot$,R=6.0-9.6$R_\odot$,T=(2.8-3.0)x10^4 K, Distance: 1.1-1.7 kpc (Aragona et al. 2010)
- Nature of compact object in binary system unknown
  - Despite deep observation campaigns: no pulsation found neither in radio nor in X-rays
- **Discovered** as point-like VHE γ-ray source (H.E.S.S.) in 2004 (Aharonian et al. 2007)
- Discovery of **orbital period** of 320 days through Swift XRT data in 2011 (Bongiorno et al. 2011)
- **Detections** by H.E.S.S., MAGIC and VERITAS after X-ray outburst (Aleksic et al. 2012; Aliu et at. 2014; this work: Adams et al 2021)
- Detection in **GeV** after 9 years of Fermi data (Li et al. 2017)



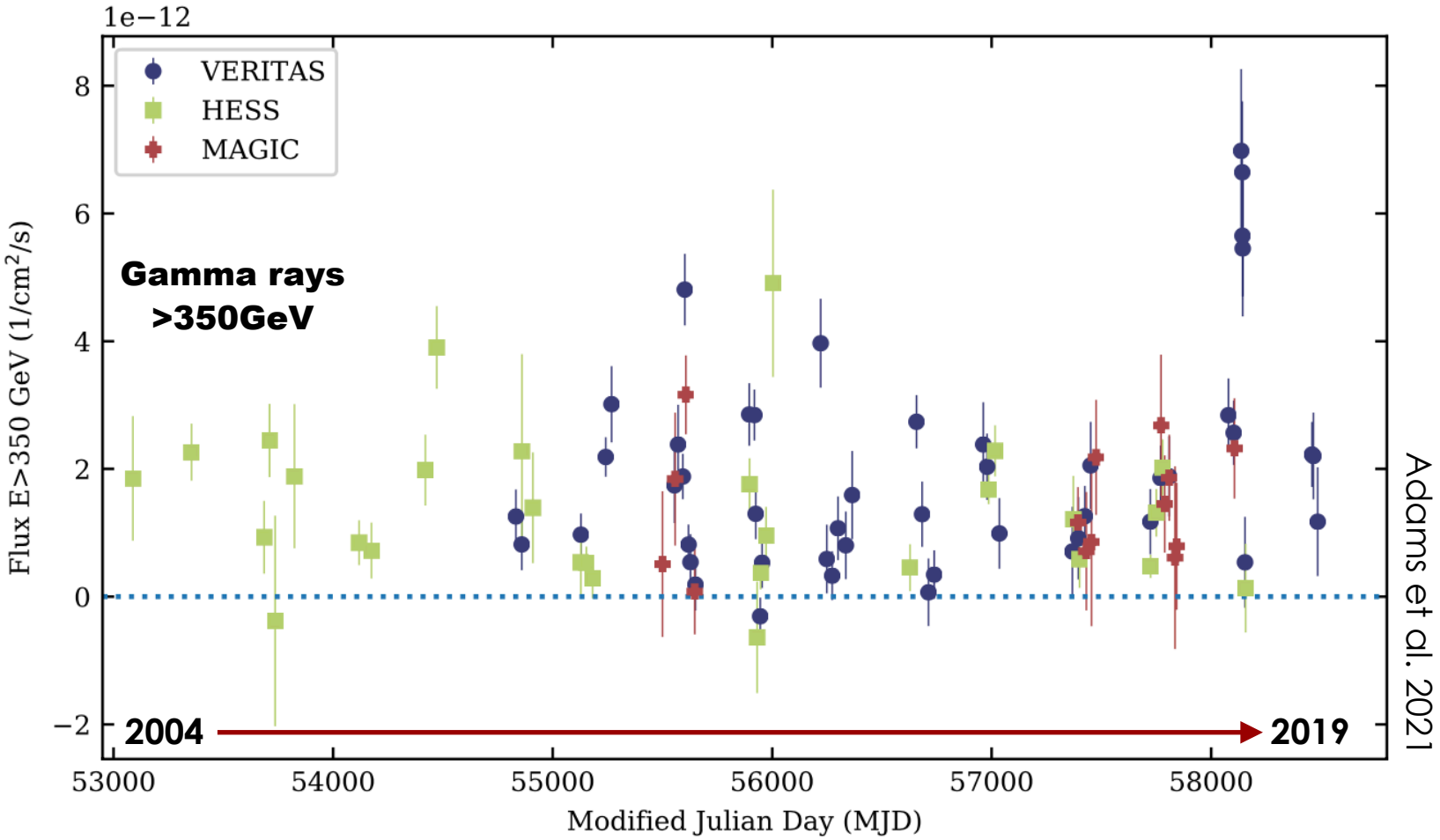


Li et al. 2017

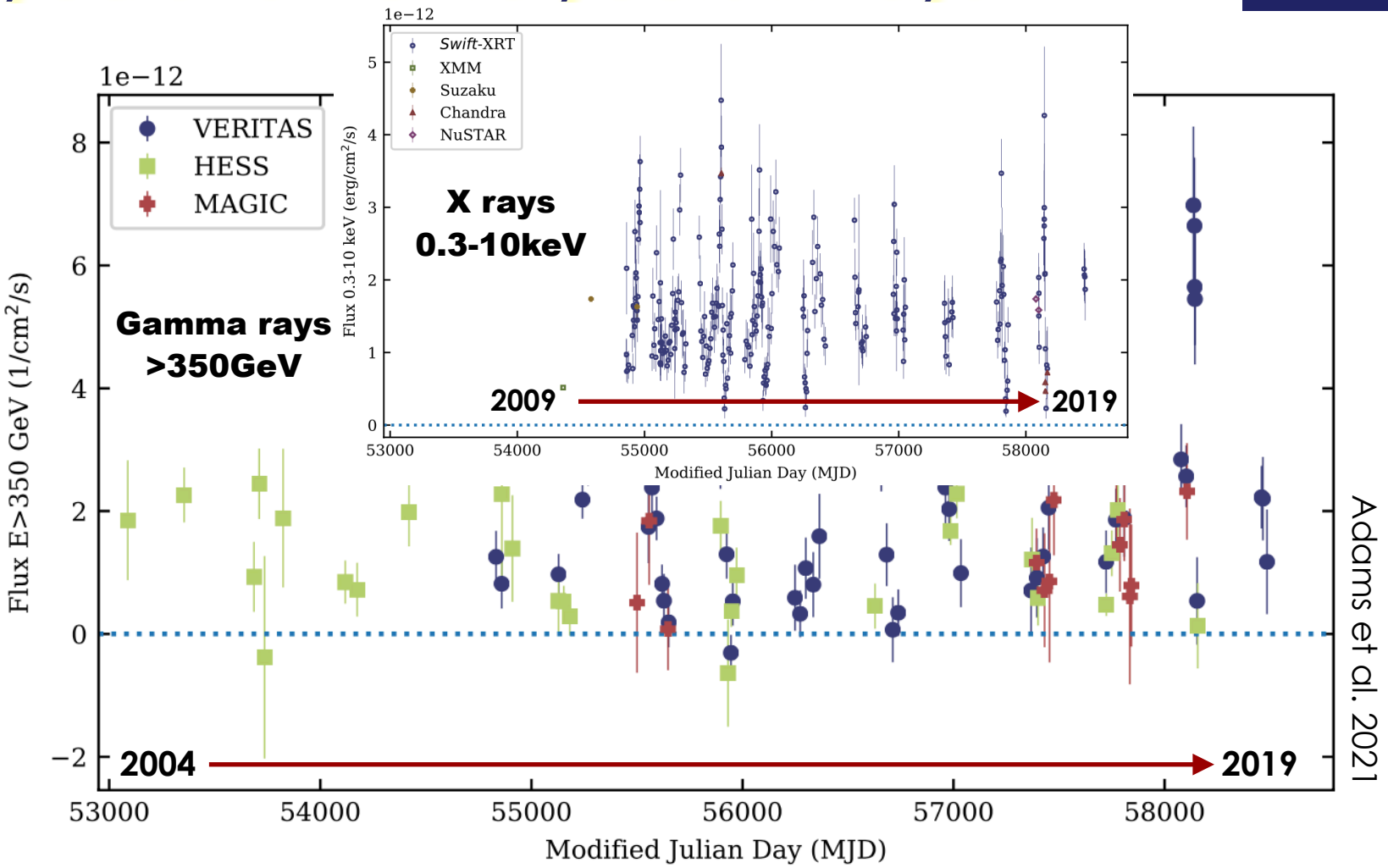
Observations@ Very High Energies

- Large data set of 450 h obtained from 2004-2019
- H.E.S.S.
  - CT1-4: 99 h
  - CT1-5: 15 h
  - CT5: 18 h
- MAGIC
  - 68 h
- VERITAS
  - pre-T1 move: 20 h
  - post-T1 move: 117 h
  - post-camera upgrade: 112 h
  - bright moon (red. HV): 11 h

Long-term light curve over 15 years TeV

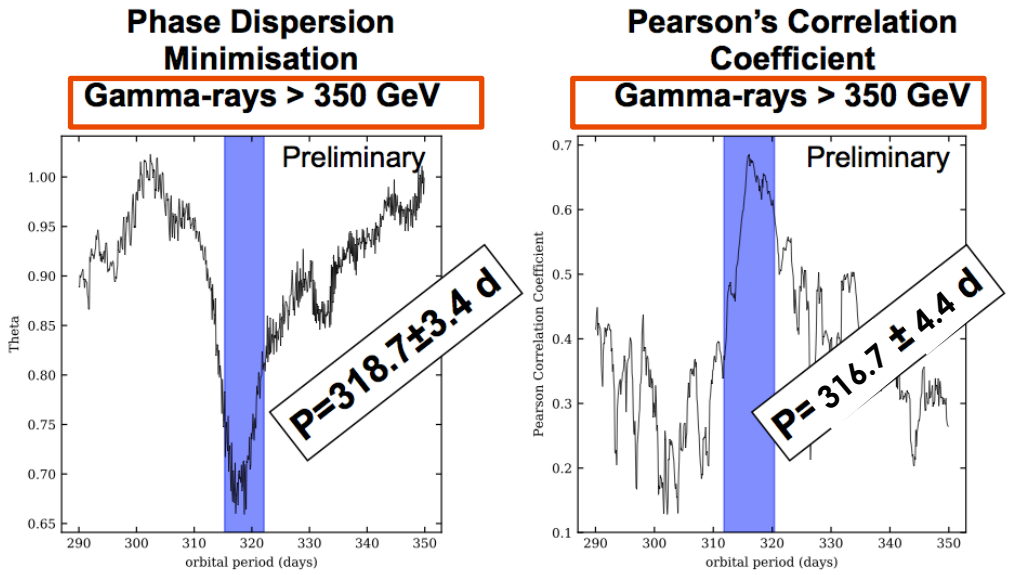


Long-term light curve over 15 years TeV & 10 years X-rays



Orbital period search with gamma-rays

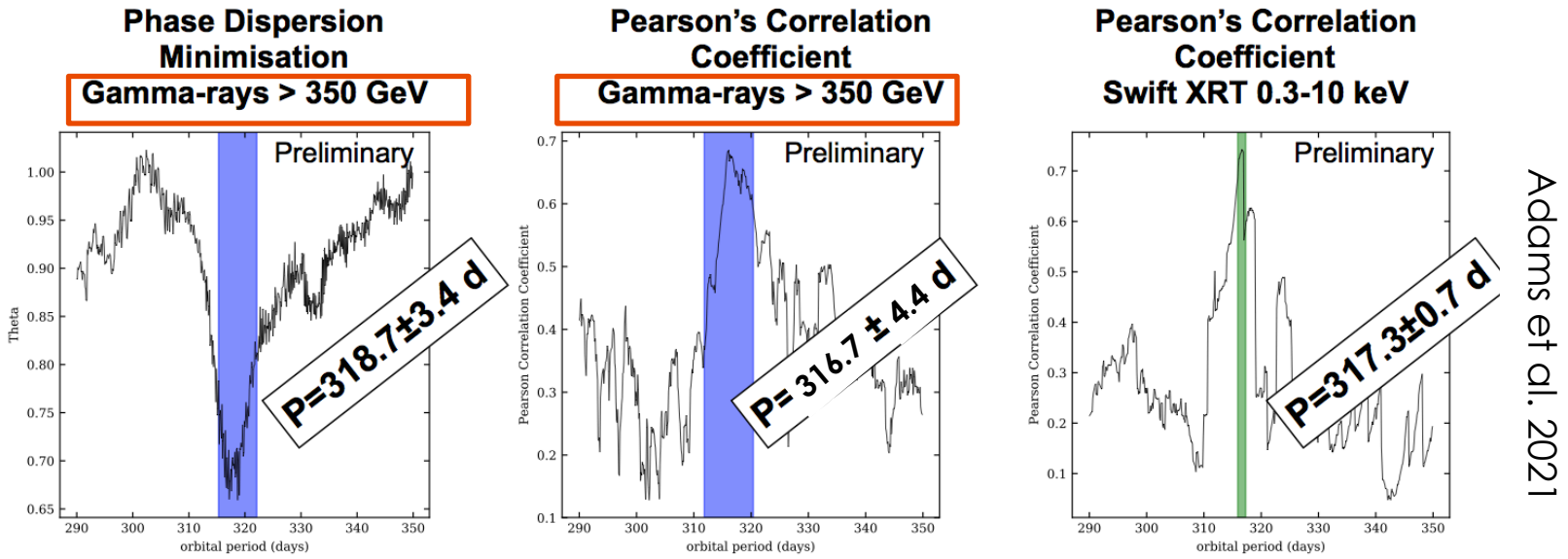
- Orbital period determined for the first time from gamma-ray data
  - Methods applied using Monte Carlo-generated light curve



Adams et al. 2021

Orbital period search with gamma-rays

- Orbital period determined for the first time from gamma-ray data
  - Methods applied using Monte Carlo-generated light curve
- Updated X-ray analysis using all available XRT data
  - (MJD 54857–58168)



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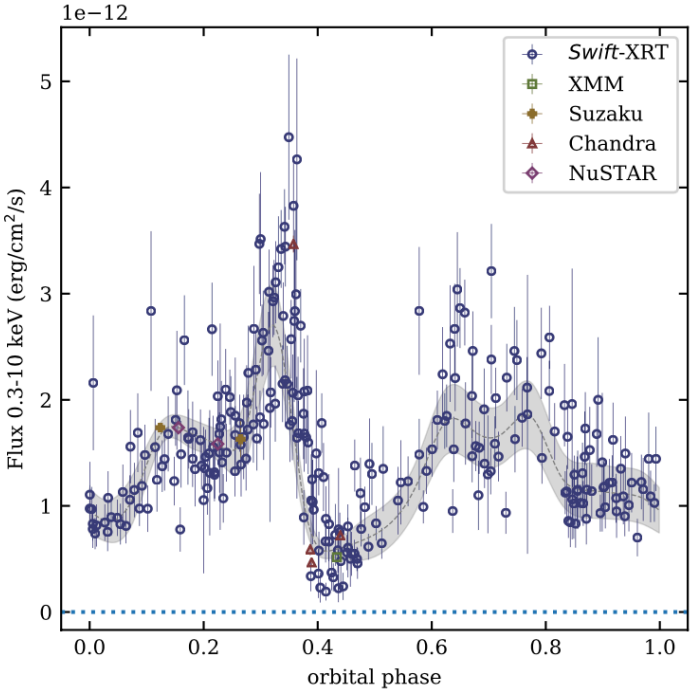
Folded light curves



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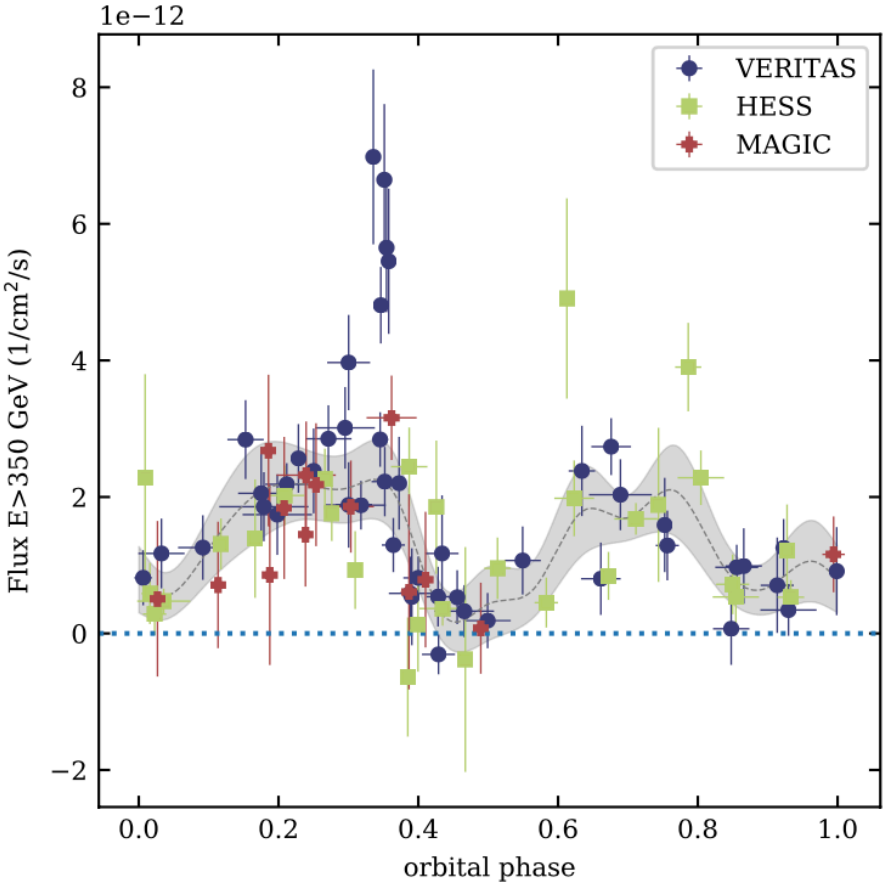
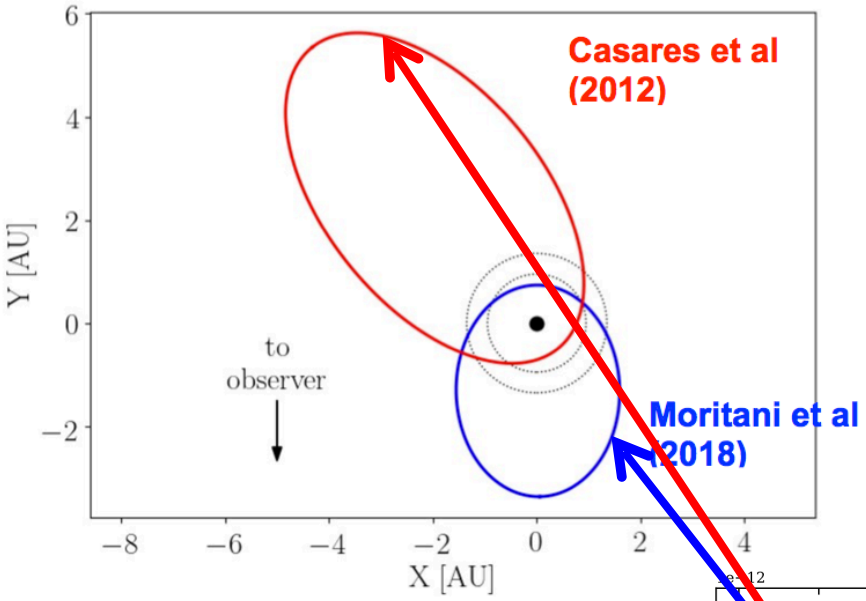
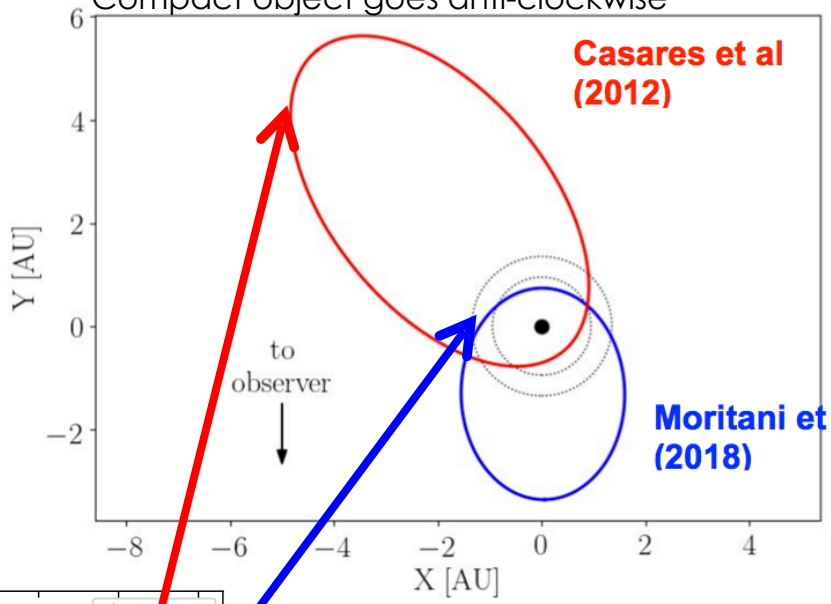


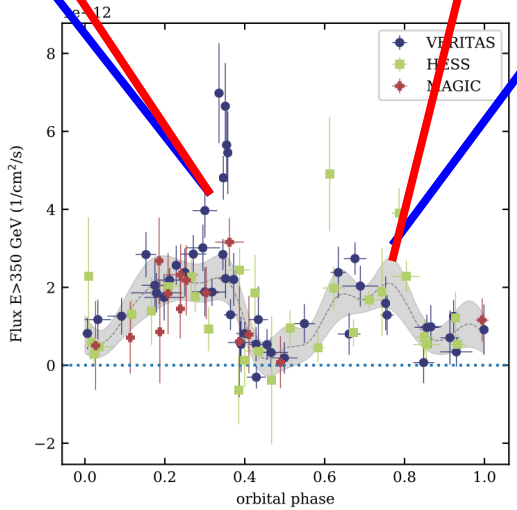
Orbital solutions



Compact object goes anti-clockwise



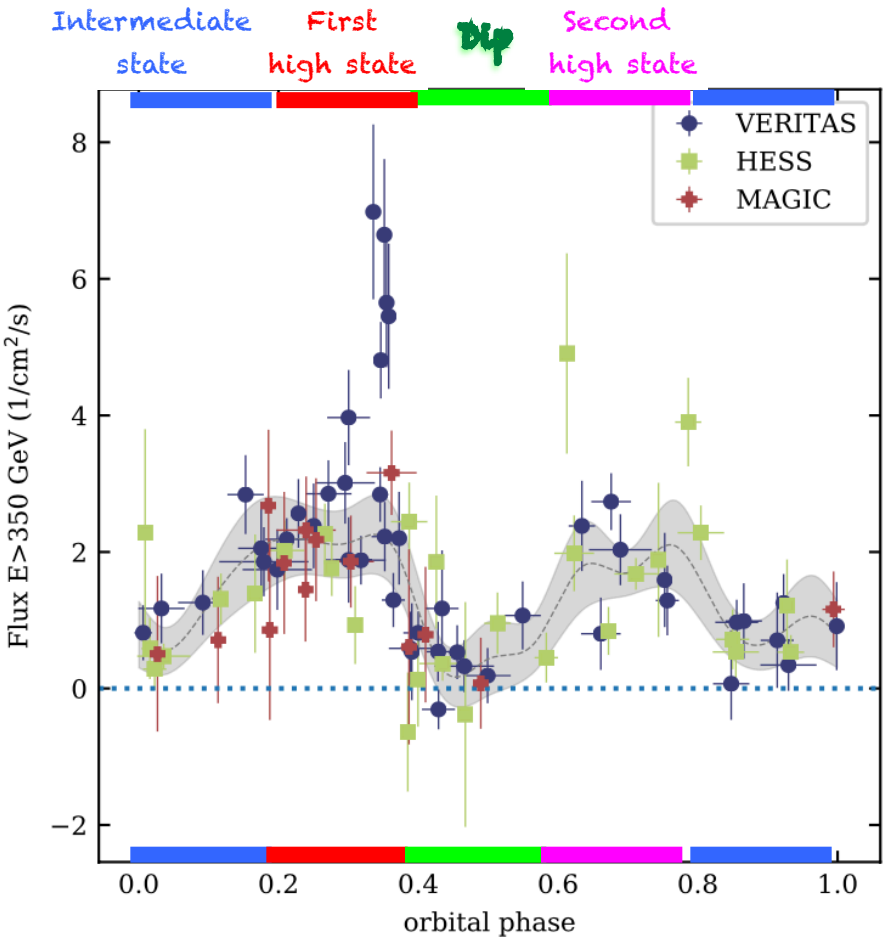
G. Maier, ICRC 2019

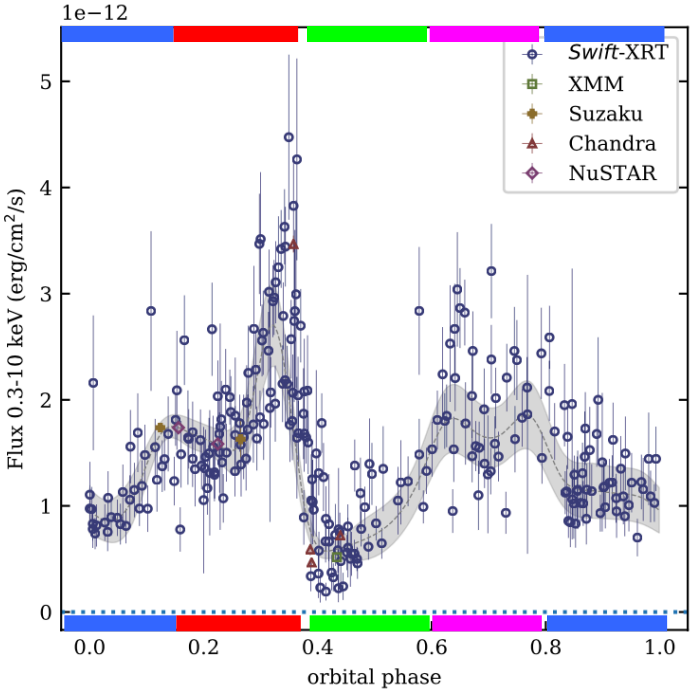


Casares: Maxima before & after apastron —> environment around compact object least disturbed by winds of massive star

Moritani: Maxima after apastron & shortly after periastron —> two other long-period systems show VHE emission around periastron

Folded light curves





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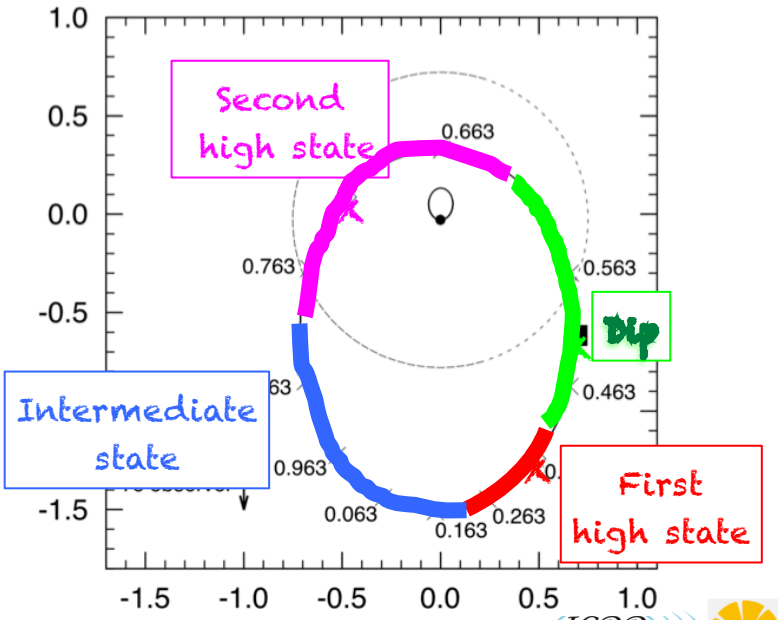
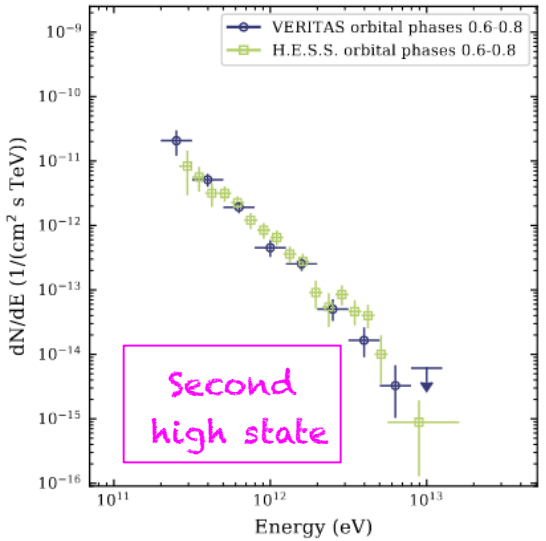
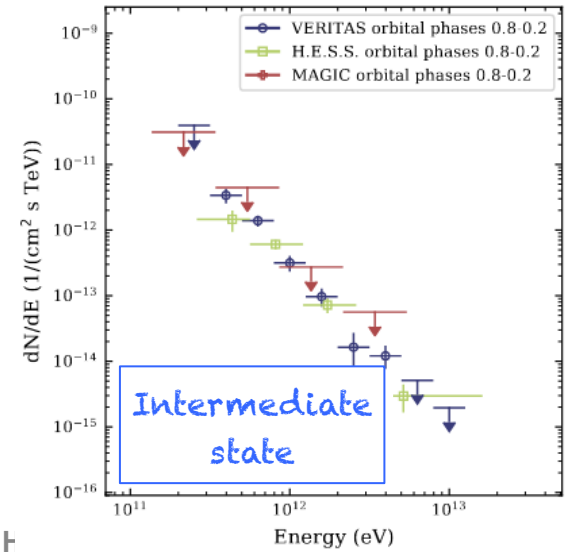
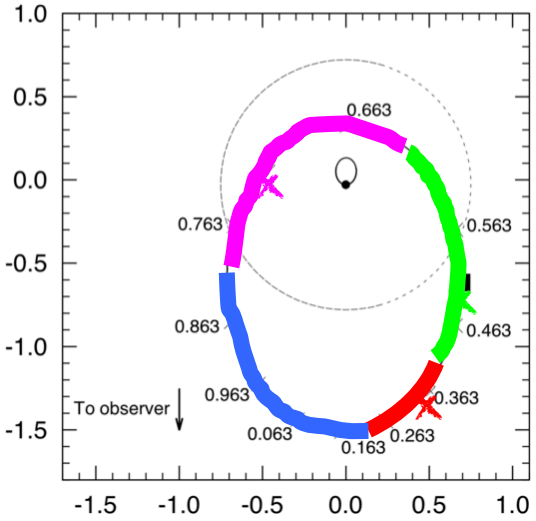


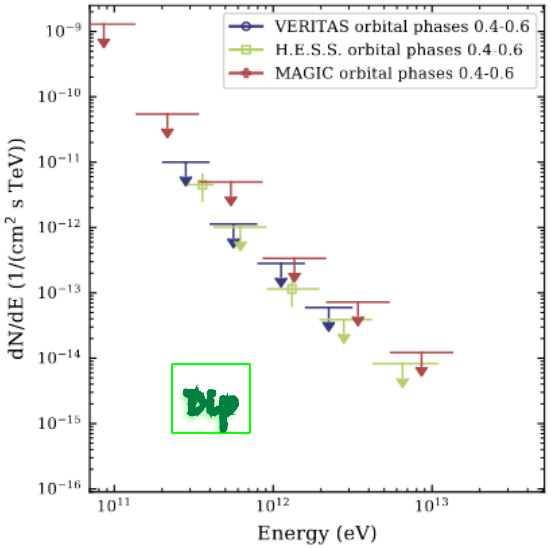
Spectra during different orbital phases

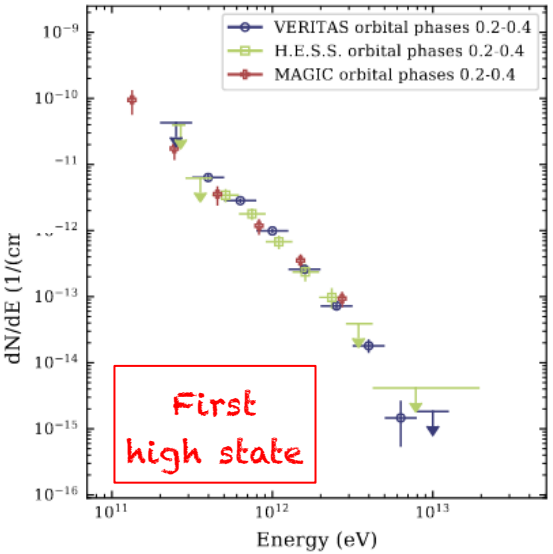
- Simple power law
- No variation of index
- Measurements between experiments compatible
- Exception: 0.2-0.4
—> cutoff at 1.75 TeV











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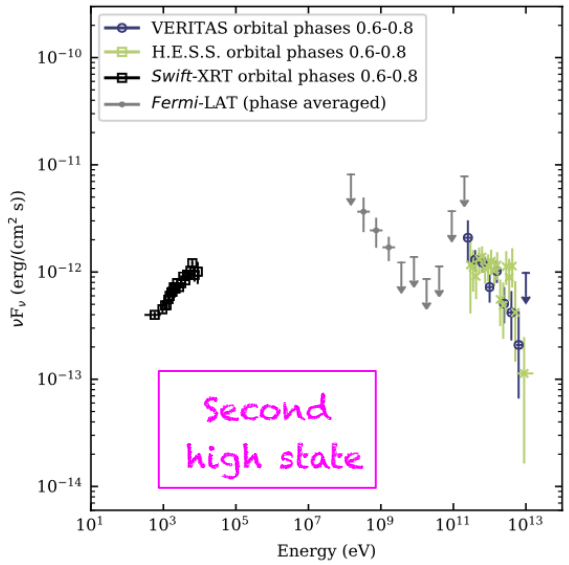
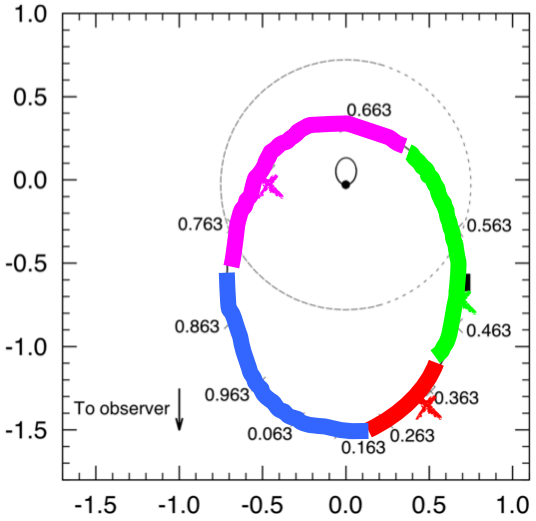
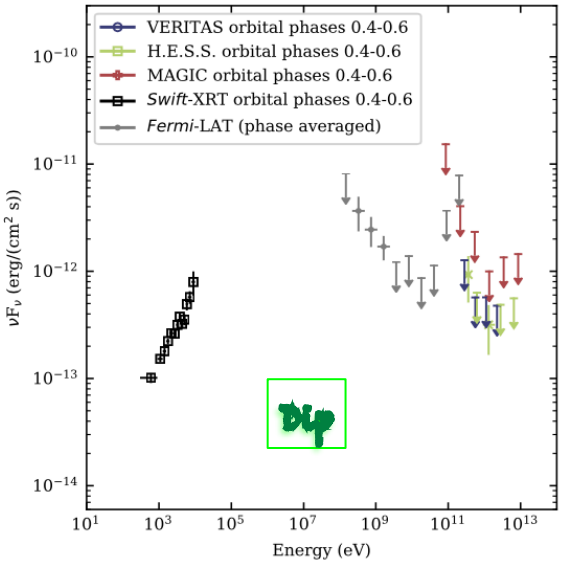
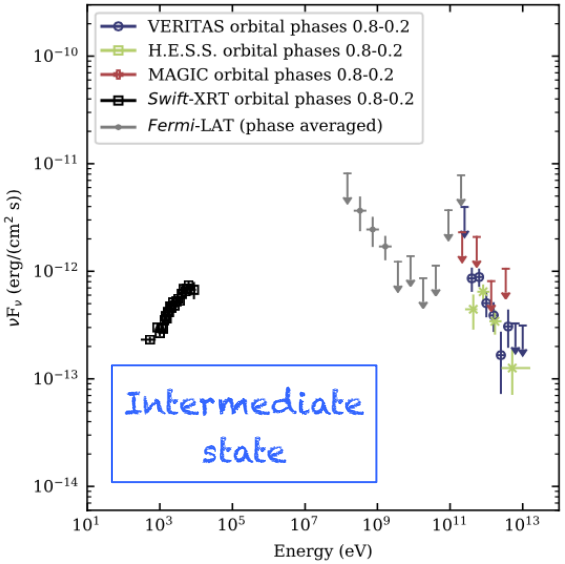
Spectra during different orbital phases

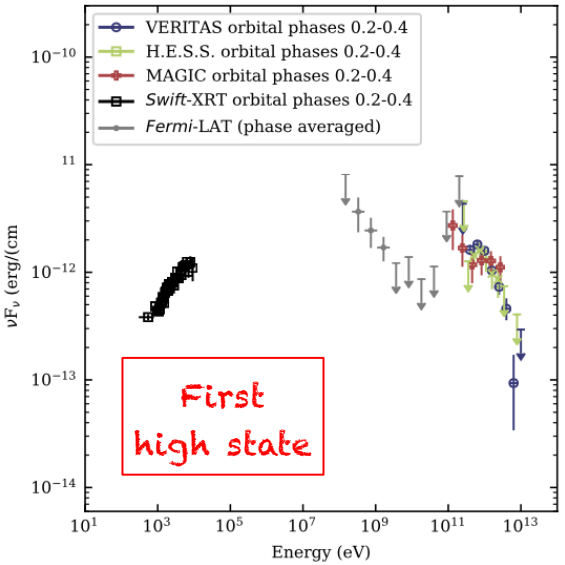
- Weakly detected with Fermi —> phase averaged spectrum











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Correlation analysis: gamma - X-rays

- Both X-rays and gamma-ray **variable on timescales as short as hours** and **X-ray exposure typically small fraction of gamma-ray exposure**
  - —> Might contribute to some scattering between fluxes
- Correlation coefficient is **0.82 for time lag = 0.**
  - Close- to-linear correlation
- **Ratio gamma-ray to X-ray flux ~2.9 +/- 0.3** —> equality or even dominance of gamma-ray energy range for the emission with respect to X-ray regime
- Non-zero X-ray flux for vanishing gamma-ray component —> **X-rays maybe partially not related to the gamma-ray emission**
-

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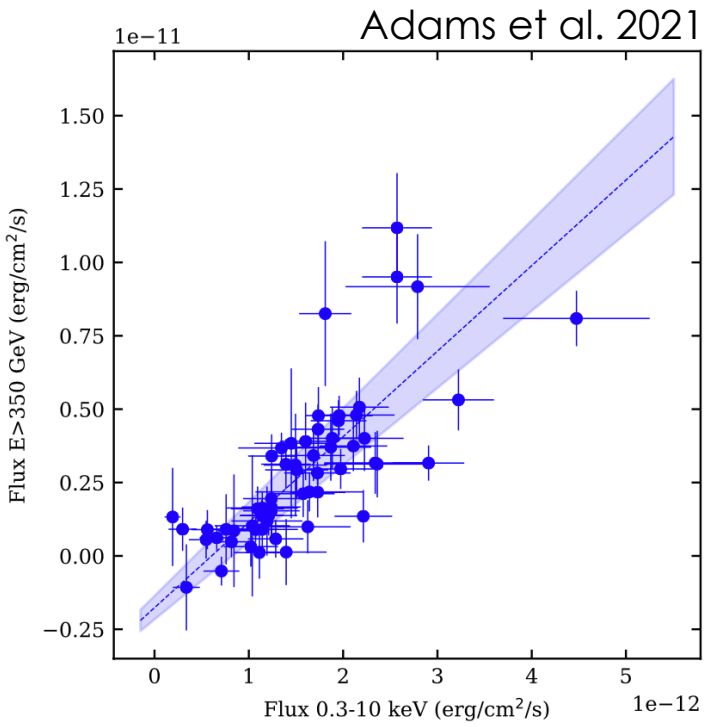

Correlation analysis: gamma/ X-ray - Halpha

- Relaxed definition for contemporaneous data is used to get reasonable number of data point pairs —> might obscure variability on shorter timescales
- Imperfect coverage of orbital phases
- **No correlation found**

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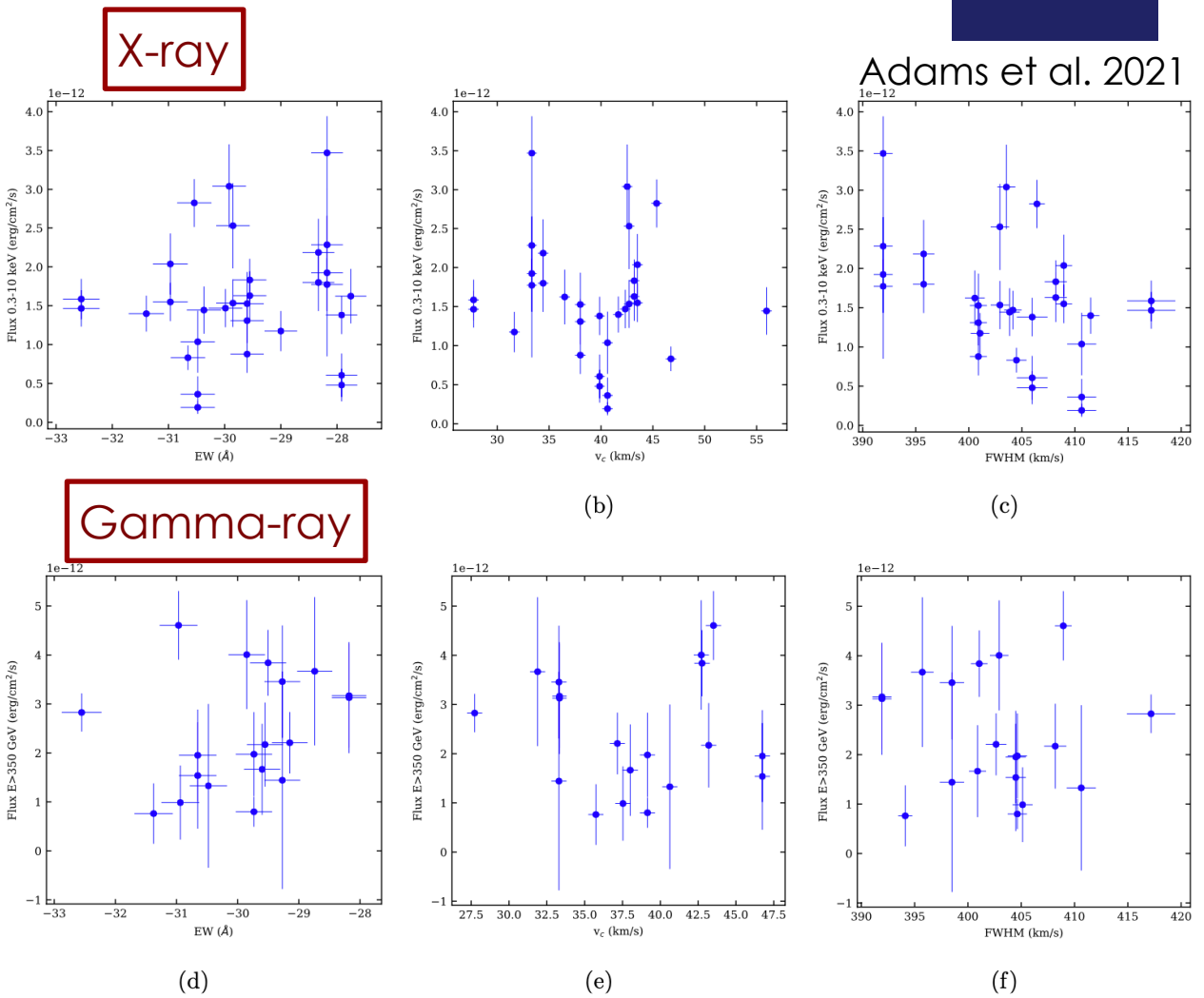
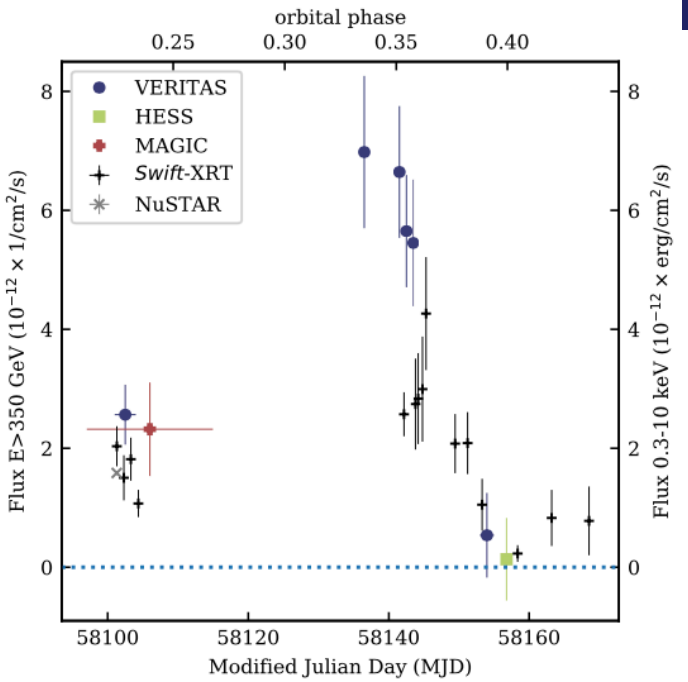


Figure 6. Hα-measurements of MWC 148 vs X-ray and gamma-ray measurements. In total 31 (18) measurements were selected with a maximal difference of observation dates of 5 days for the X-ray/Hα (gamma-ray/Hα) correlation analysis.

Detailed light curves

- Orbit17: **bright state**
- Determination of **variability time scales** limited by cadence of observations
- Orbit 17: flux changes from highest state on MJD 58136 to a flux below the detection limit on MJD 58153 —> **flux decay time faster than 17 days**
- Similar time scale of roughly 20 days or less, again limited by the cadence and detection statistics of the observations is observed for orbit 9.



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Orbit 17:
H-alpha emission increased → structural changes in outer parts of the **circumstellar disc**, where the H-alpha emission is formed
(Zamanov+, ATel#11233)

Summary

- First time detection of **orbital period at TeV energies**: **316.7 ± 4.4 days**.
- We have characterized the light curve and spectral energy distribution along the orbit.
- VHE SEDs for all of these phases (except the dip phase) **characterized as power-laws**, showing **no variability**. Only during **phases 0.2–0.4 a power-law with exponential cutoff at 1.75 TeV is favored.**
- Strong correlation between X-rays and gamma rays —> **common origin of the radiation, indicating the existence of a unique population of particles**. However, we also find indications for an X-ray source partially not related to the gamma-ray emission.
- The **lack of correlation between Hα and X-ray or gamma-rays** may be simply an effect of fast variability of Hα versus the sparse overlap of the datasets at different energies.
- Flux decay of roughly 20 days or less was detected for two orbits. **Contemporaneous Hα data** indicate that the size of the **circumstellar disk had increased during those days, suggesting that the decretion disk was larger and its structure had changed.**

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THANK YOU

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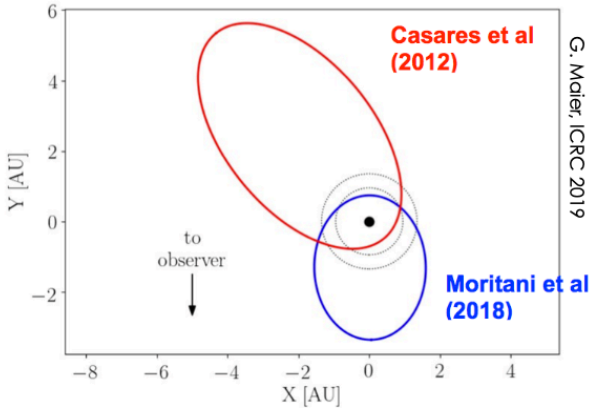
BACKUP

Orbital solution

- New orbital solution through Hα measurements (Moritani et al 2018)
  - Measured radial velocity of the Hα emission line



	Parameter	Casares et al. (2012)	Hα	X-ray	
Period	$P_{\rm orb}$ [d]	321†	308‡	313§	→ **consistent**
	$T_{\rm peri}$ [d]	2455167.907	2455076 ± 10	2455065 ± 11	
Periastron	$\phi_{\rm peri}$*	0.967	0.709	0.663	→ **different**
Eccentricity	e	0.83 ± 0.08	0.62 ± 0.16	0.64 ± 0.29	→ **smaller**
	ω [°]	129 ± 17	249 ± 26	271 ± 29	
	K_1 [km s^{-1}]	22.0 ± 5.7	6 ± 1	5 ± 2	
	γ [km s^{-1}]	48.3 ± 8.9	36.9 ± 0.8	36.7 ± 0.9	
	$a_1 \sin i$ [au]	0.362 ± 0.261	0.136 ± 0.029	0.120 ± 0.029	
Mass function	$f\,[M_\odot]$	$0.06^{+0.15}_{-0.05}$	0.0035 ± 0.0022	0.0024 ± 0.0017	→ **smaller**

(Moritani et al 2018)

Detailed light curves

- 4 orbits show **good coverage in X-ray and gamma-ray** —> first maximum and flux decay
- Shape of light curves differ notably —> **orbit-to-orbit variability**
- Orbits 9+17: **bright state**
- Orbits 10+16: X-ray flux factor ~1.5 lower
- Determination of **variability time scales** limited by cadence of observations
- Orbit 17: flux changes from highest state on MJD 58136 to a flux below the detection limit on MJD 58153 —> **flux decay time faster than 17 days**
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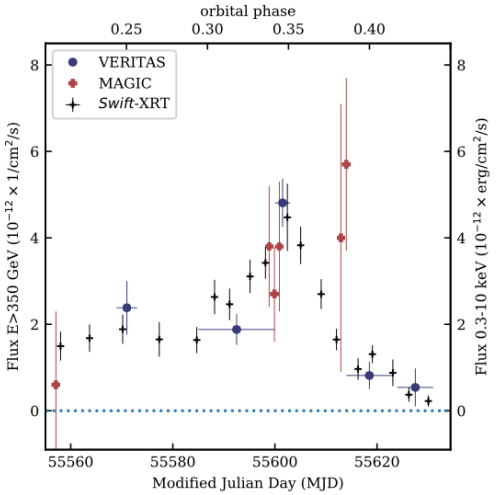
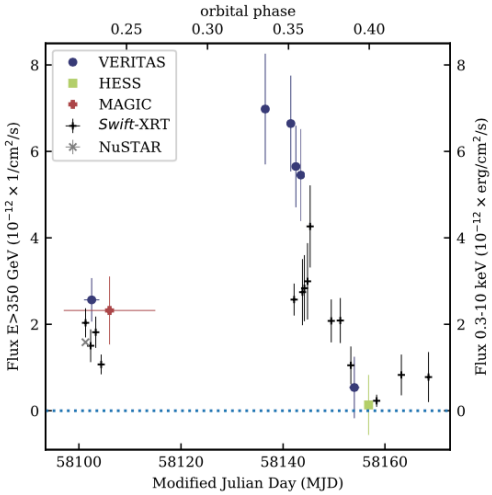
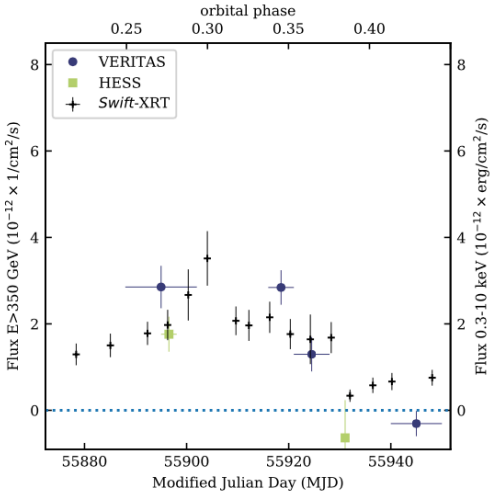


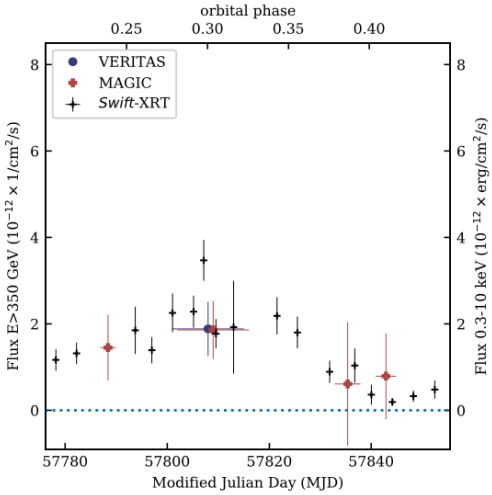
Orbit 9



Orbit 17



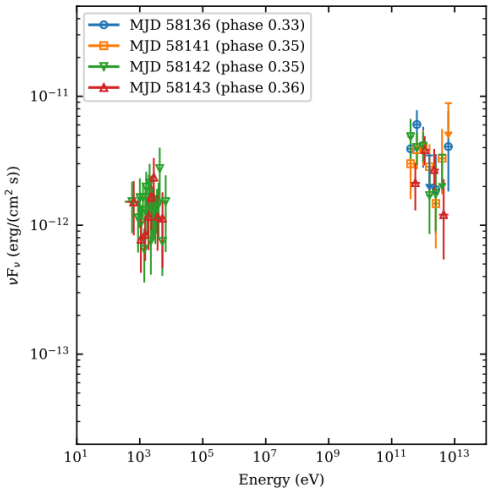
Orbit 10



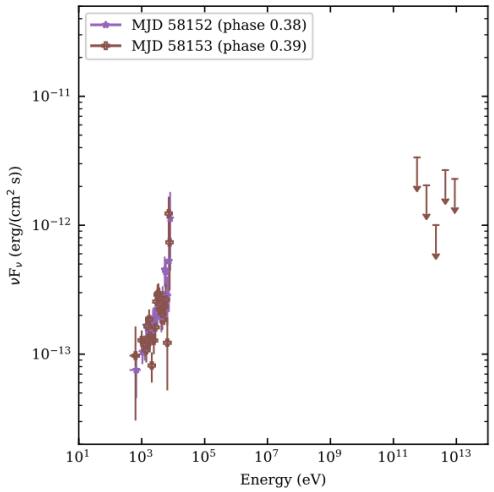
Orbit 16

SEDs with deep coverage during high state

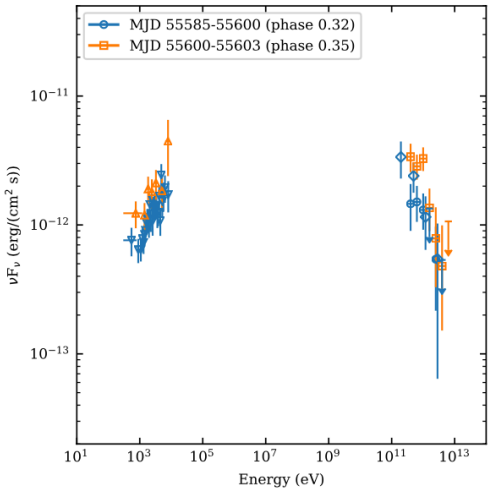
- Despite dramatic changes of the overall flux levels, **no evidence for variability of the spectral index**, within statistical errors.



Orbit 17 (higher flux states)



Orbit 17 (lower flux states)



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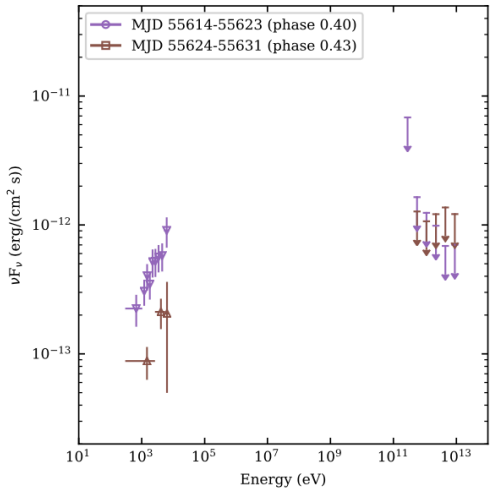
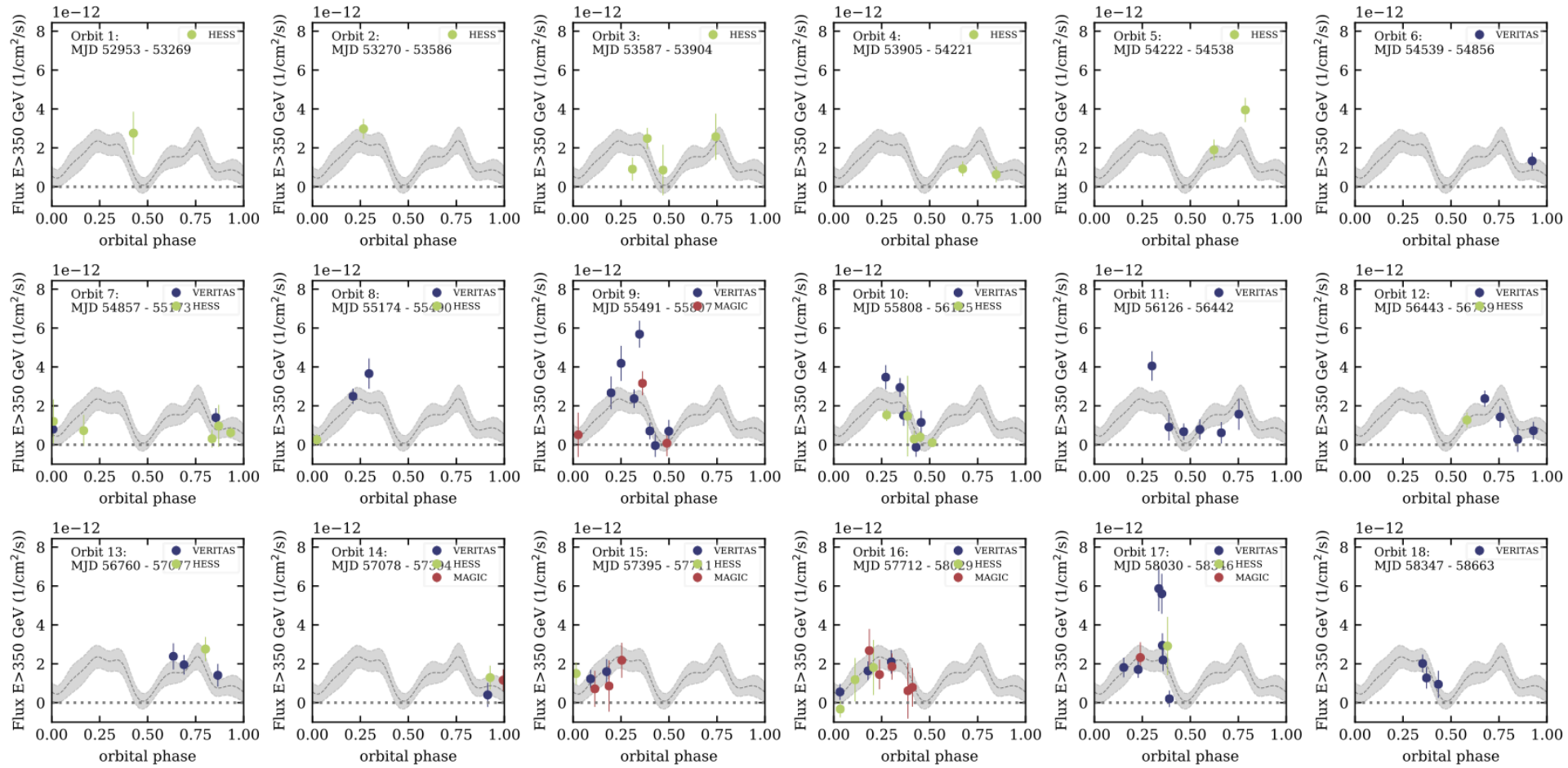


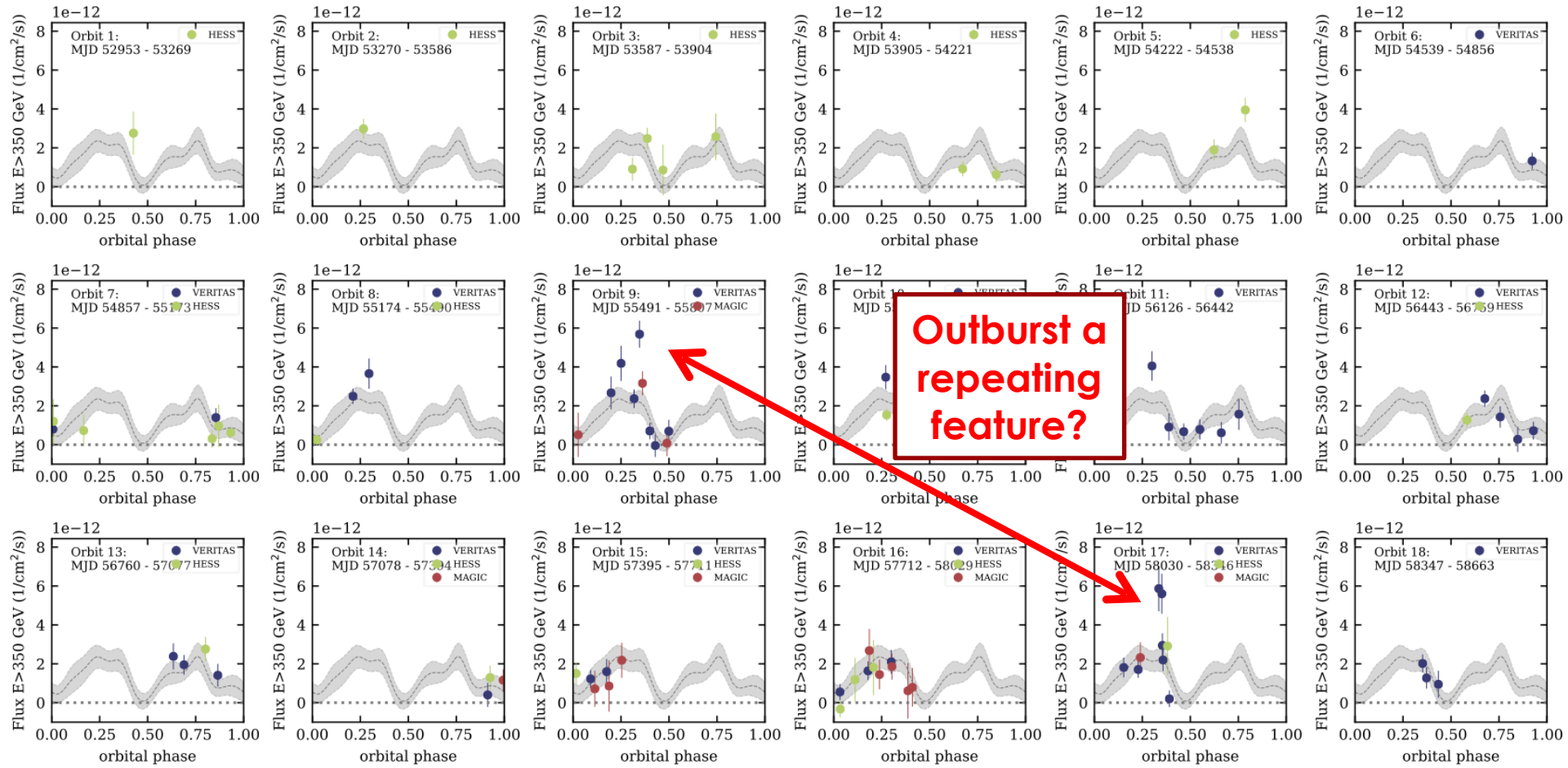
Orbit 9 (lower flux states)

TeV coverage per orbit – 18 orbits



Assuming an orbital period of 317.3 days
Grey band: average Gamma-ray light curve (68% uncertainty band)

TeV coverage per orbit – 18 orbits



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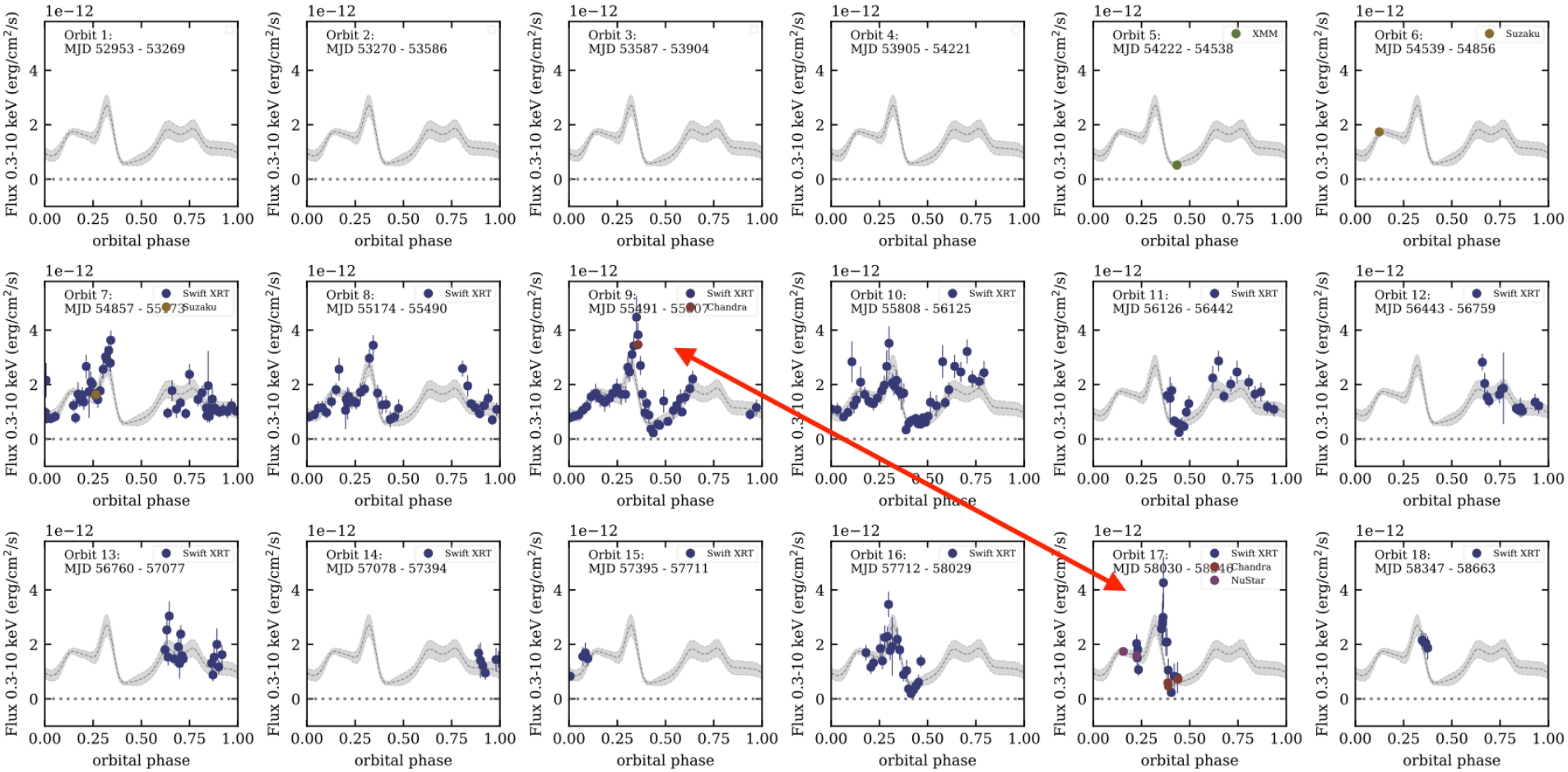
X-ray coverage per orbit



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