Superorbital variability of LSI +61° 303 at different wave bands

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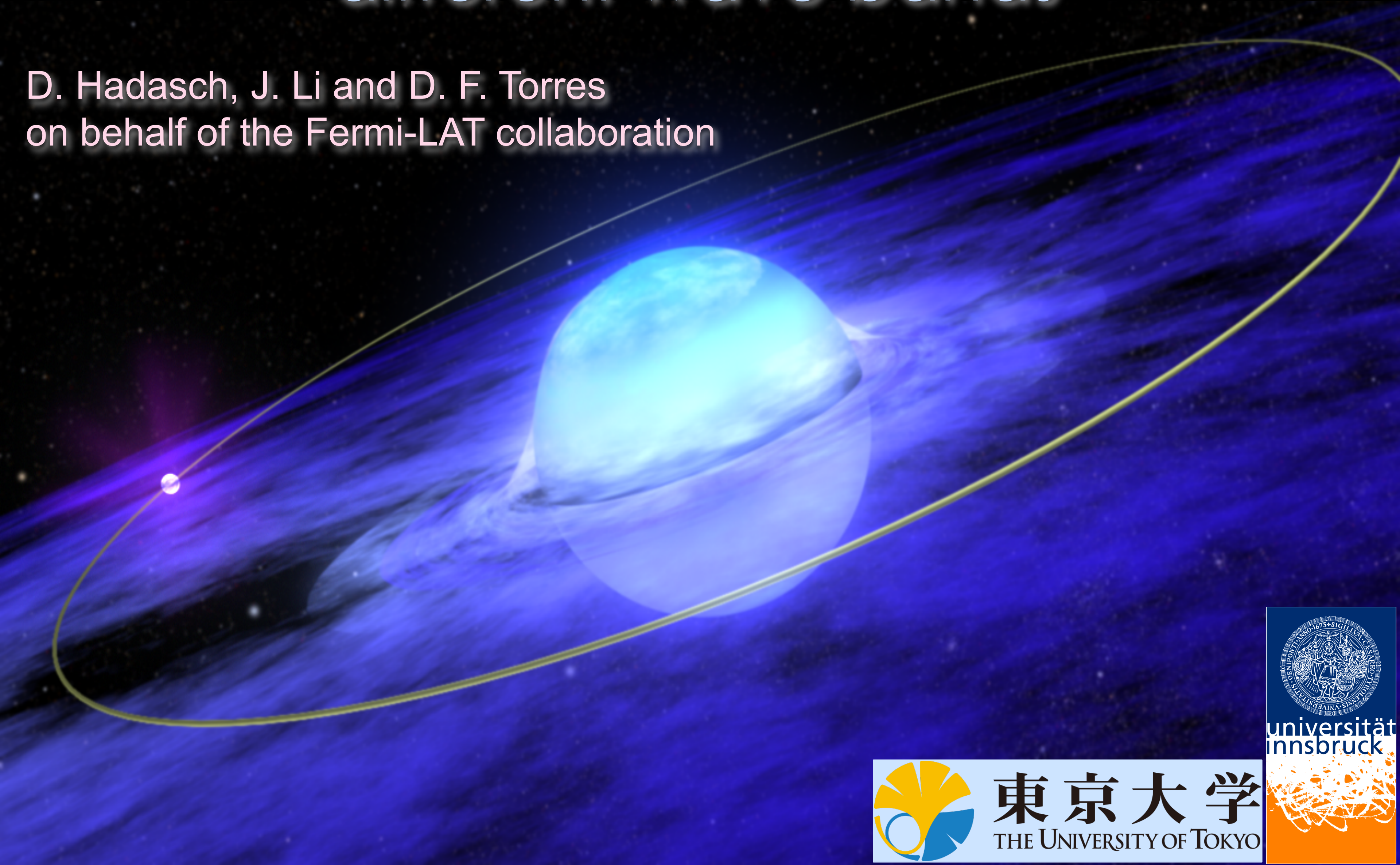
on behalf of the Fermi-LAT collaboration



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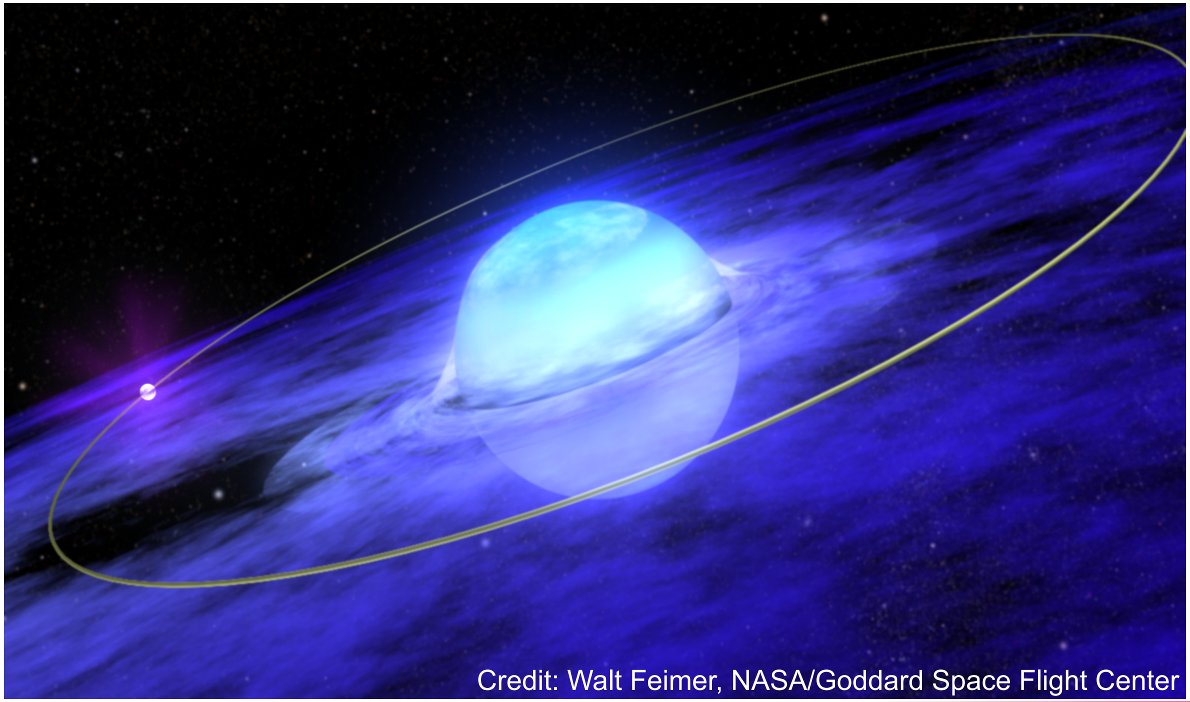
Overview

- Short introduction of LS I +61° 303
- Instruments
- Present findings in the GeV energy regime
  - Using Fermi/LAT data
- Putting results into multi wavelength context
  - Comparing GeV data with radio, X-ray and optical data
- Summary



Introduction LS I +61° 303

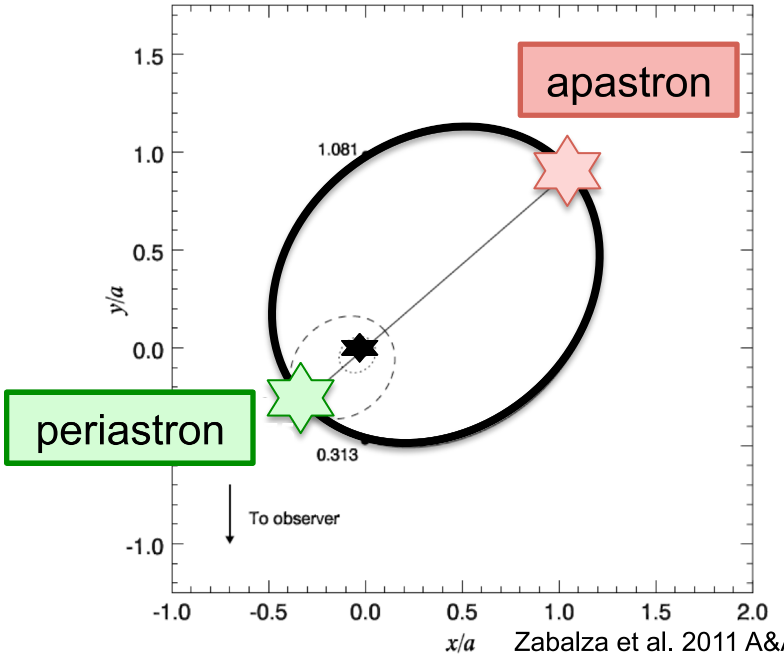
- GeV source discovered in 1977 by Cos B
  - at **TeV** energies by MAGIC (2006); follow-ups by MAGIC and VERITAS
  - at **GeV** energies by Fermi (2009)
  - **Periodicity** found in TeV (MAGIC) and GeV (Fermi/LAT)

- Compact object + Be star
  - **Be star**: ~10-12 M_{sun}
  - B-type stars lose mass in equatorial, **circumstellar disk**
  - Compact object: 1.4M_{sun} (**neutron star**) to 4 M_{sun} (**black hole**)

- **Orbital** period
  - (**26.496** +/- 0.0028) days (Gregory et al. 2002)

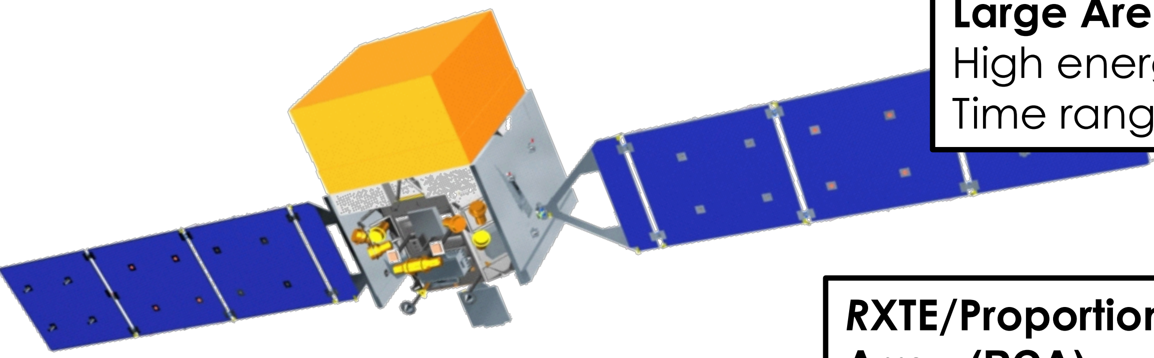
- Periodic radio outbursts (Gregory et al. 2002)
  - **Superorbital** period: (**1667** +/- 8) days

- What is happening at GeV energies?
  - Relation to other wavelengths?



Zabalza et al. 2011 A&A

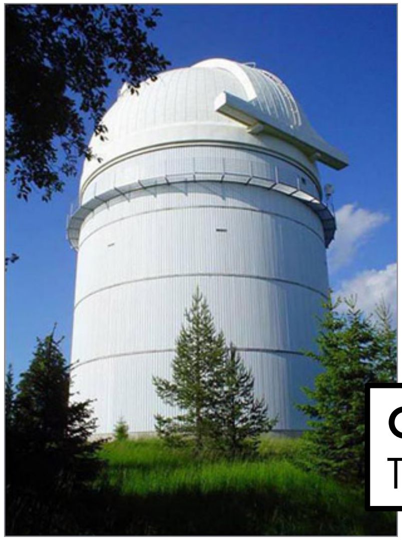
Instruments



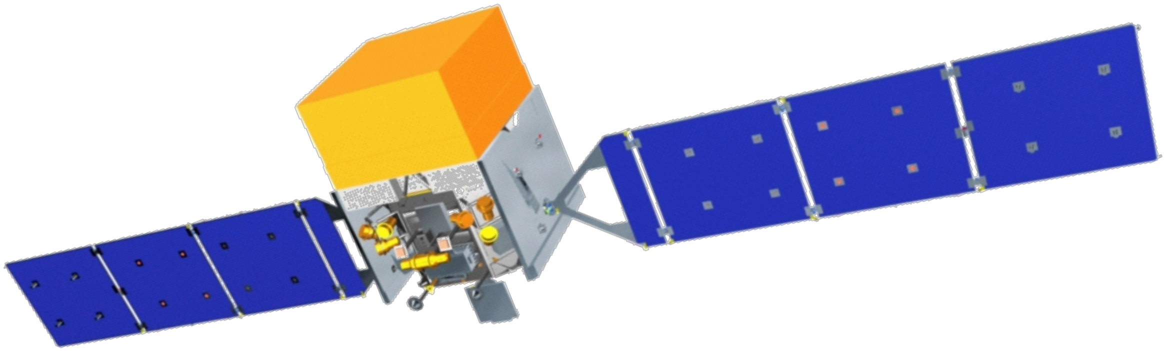
Large Area Telescope (LAT)
High energy: 100 MeV – 300 GeV
Time range: August 2008 – March 2013 (2014)

***RXTE*/Proportional Counter Array (PCA)**
Energy range: 3 – 30 keV
Time range: 2007 - 2011

Green Bank Interferometer (GBI)
Two Frequencies: 2.25 GHz & 8.3 GHz
Time range: 1994 - 2000



Optical data: EW(Hα)
Time range: 1989 - 2015



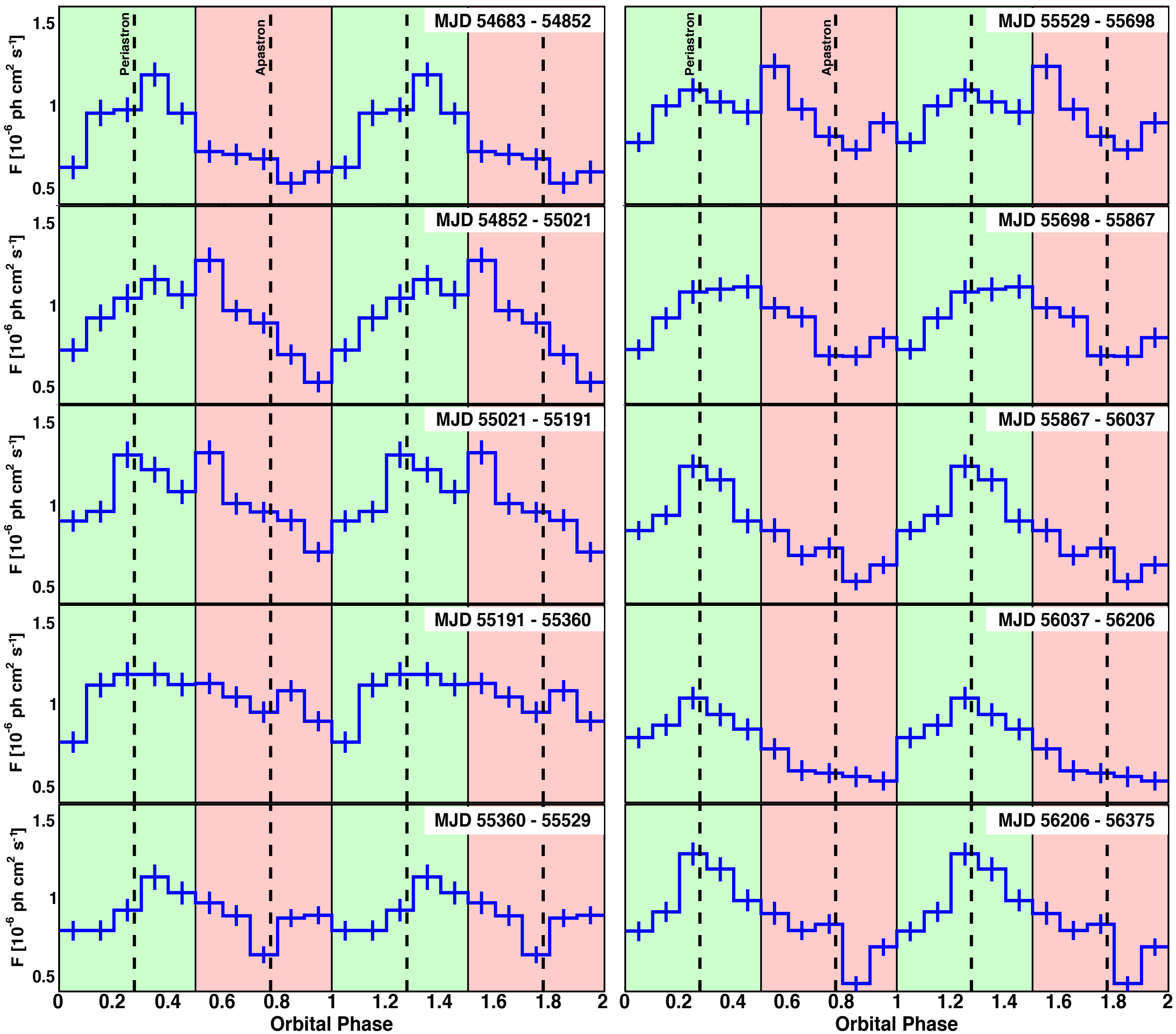
GEV DATA

Fermi/LAT data

100 MeV – 300 GeV

2008 – 2013/14

Lightcurve folded in superorbital phase



Each panel is ~6 months integration of Fermi data.

Green and red background represents regions of **periastron** and **apastron**, respectively

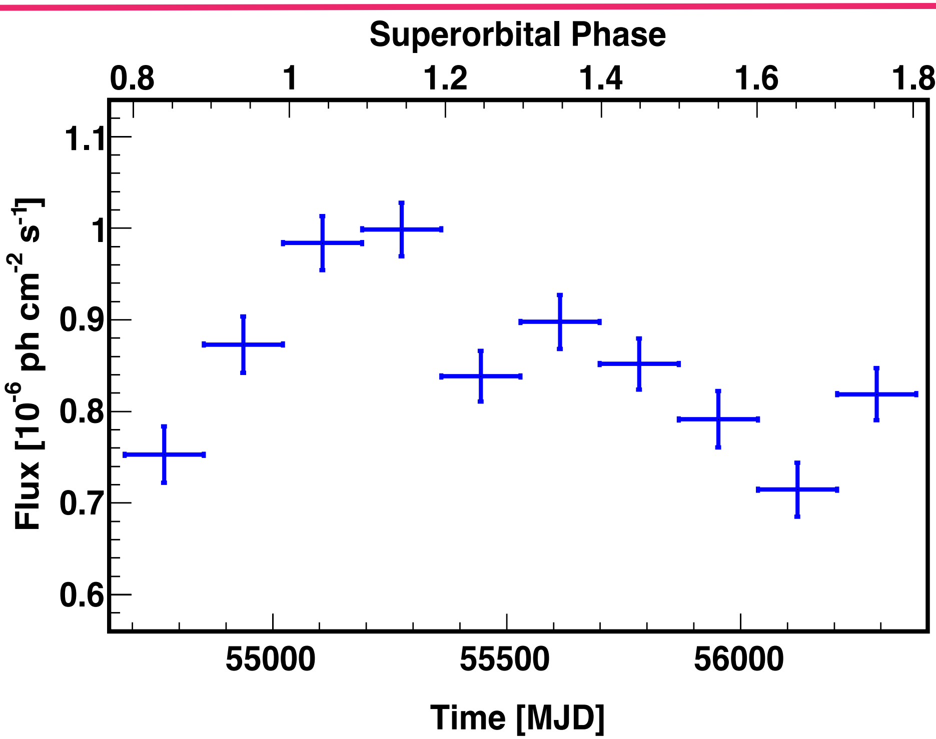
Trends for location of max and min

Maximum near periastron, but with significant variability

Ackermann et al. 2013

Is there variability in the superorbit?

YES

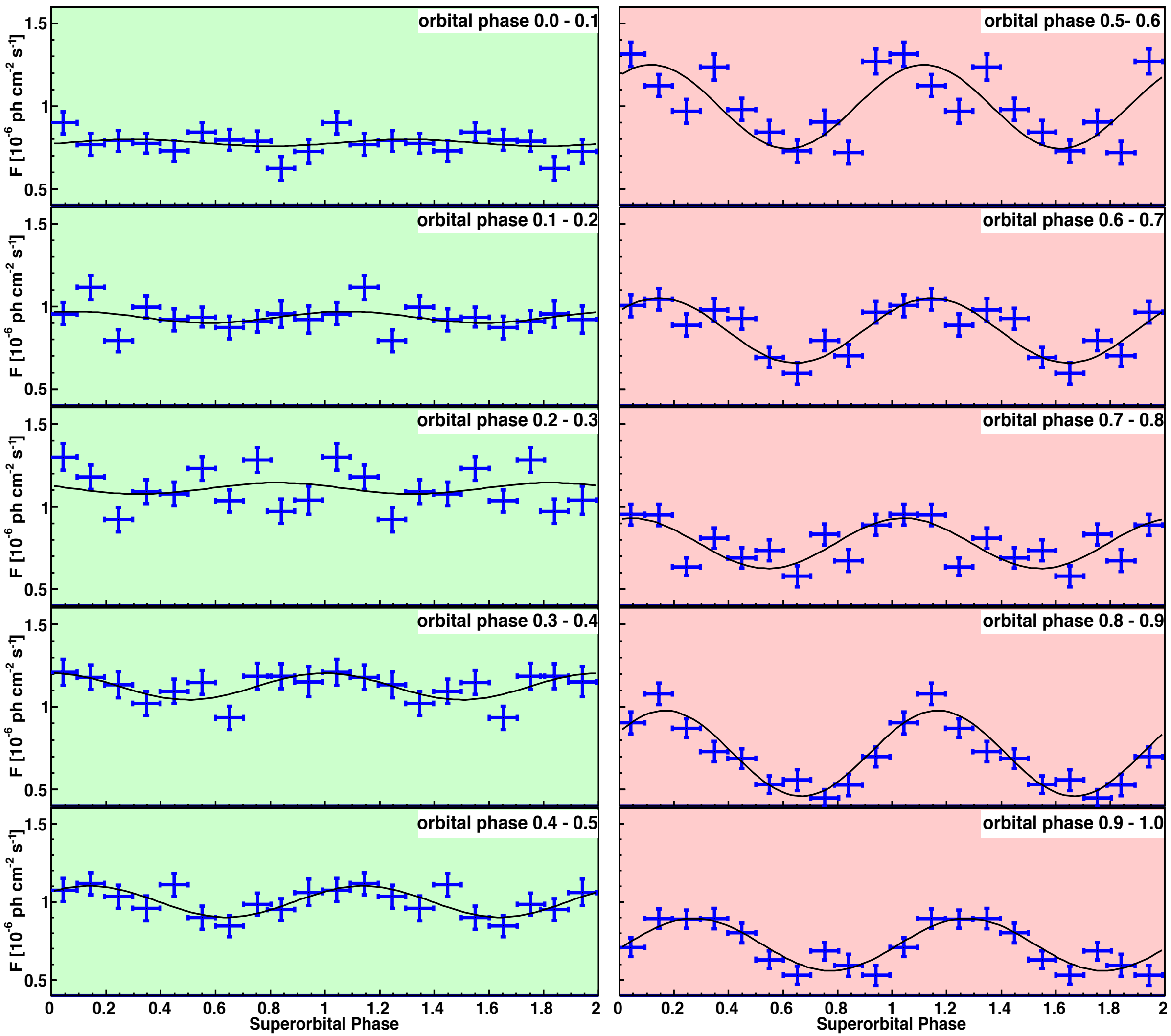


Ackermann et al. 2013

• Best determined superorbital period from radio campaign: (lasting 23 years): 1667±8 days
→Probability that γ-ray flux evolution is a random result: $< 1.1 \times 10^{-12}$

→ Source is variable along the superorbit in the GeV regime

Orbital phase bins in superorbit



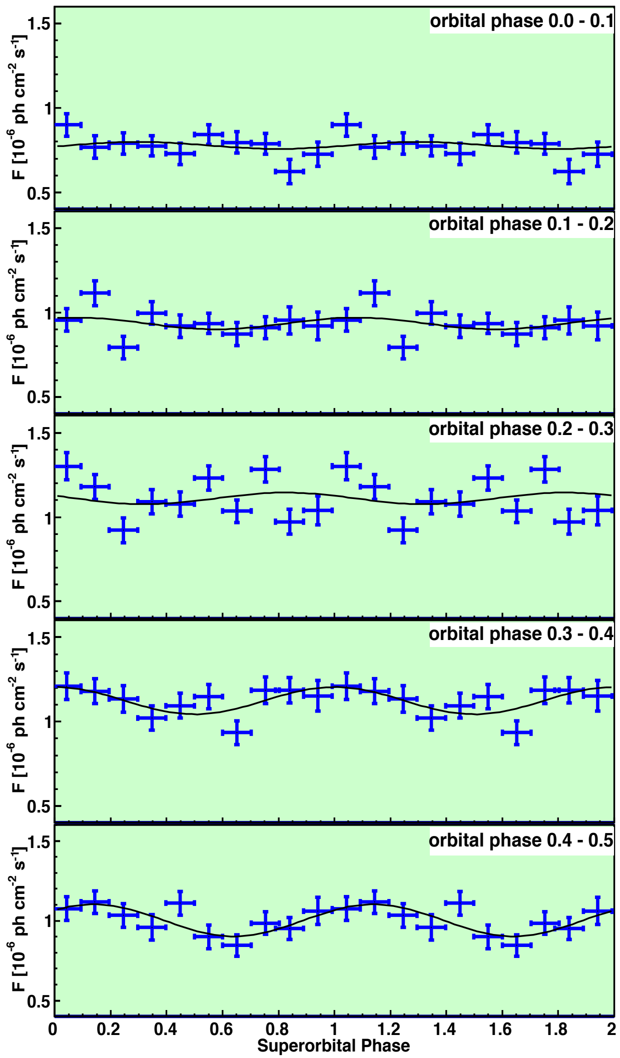
Each panel shows the GeV flux at a fixed orbital position, along a period of 4.5 years

Green and red background represent the region of **periastron** and **apastron**, respectively

Black line: Fit sinusoidal with fixed superorbital period

Ackermann et al. 2013

Orbital phase bins in superorbit

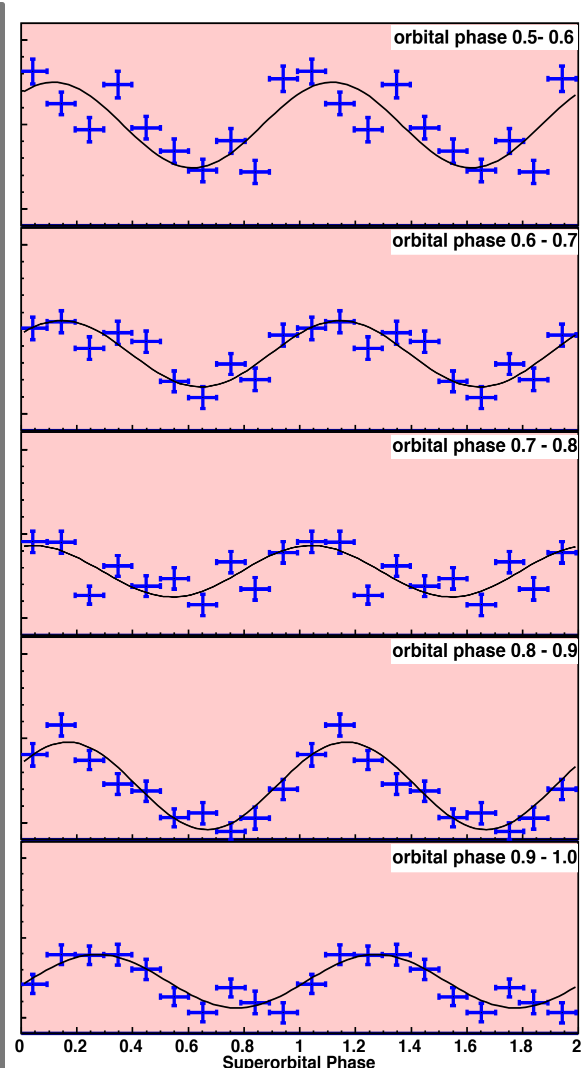


- From orbital phase 0.1 to 0.5, including the periastron region, there is no significant flux variation along the superorbit.
- As soon as we depart from periastron we start to see superorbital variability (see phase 0.5)
- Conditions for GeV generation must not significantly change

Ackermann et al. 2013

Orbital phase bins in superorbit

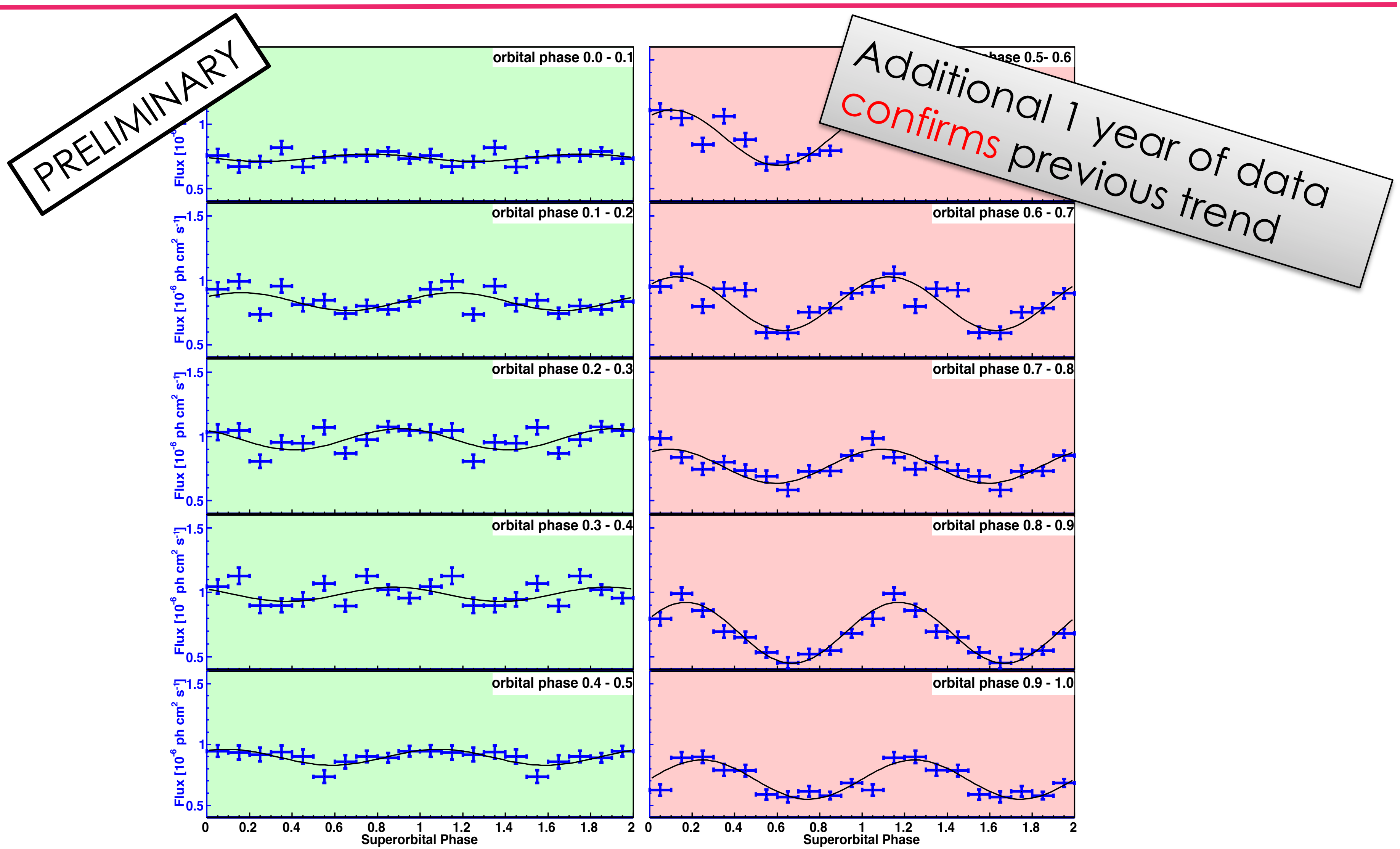
- From orbital phase 0.6 to 1.0, including the apastron region, there is significant flux variation in the superorbit.
- The variation is maximal before and after apastron
- Concurrently, a sine with a **fixed period** of 1667 days is at all orbital bins a better fit to the data than a constant
- Close to apastron, the superorbit induces clear variations. GeV emission conditions change.



Ackermann et al. 2013

Orbital phase bins in superorbit

NEW



X-RAY DATA

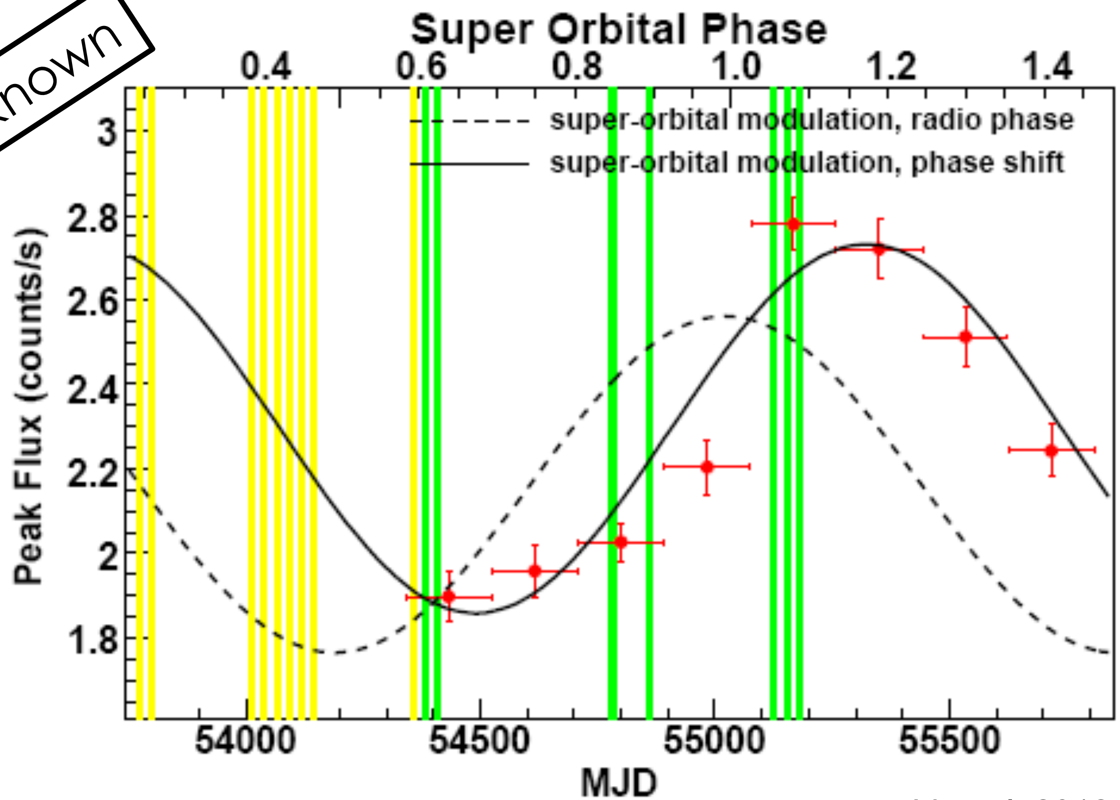
*R*XTE data

3-30 keV

2007 - 2011

Superorbital behavior in X-rays

Known

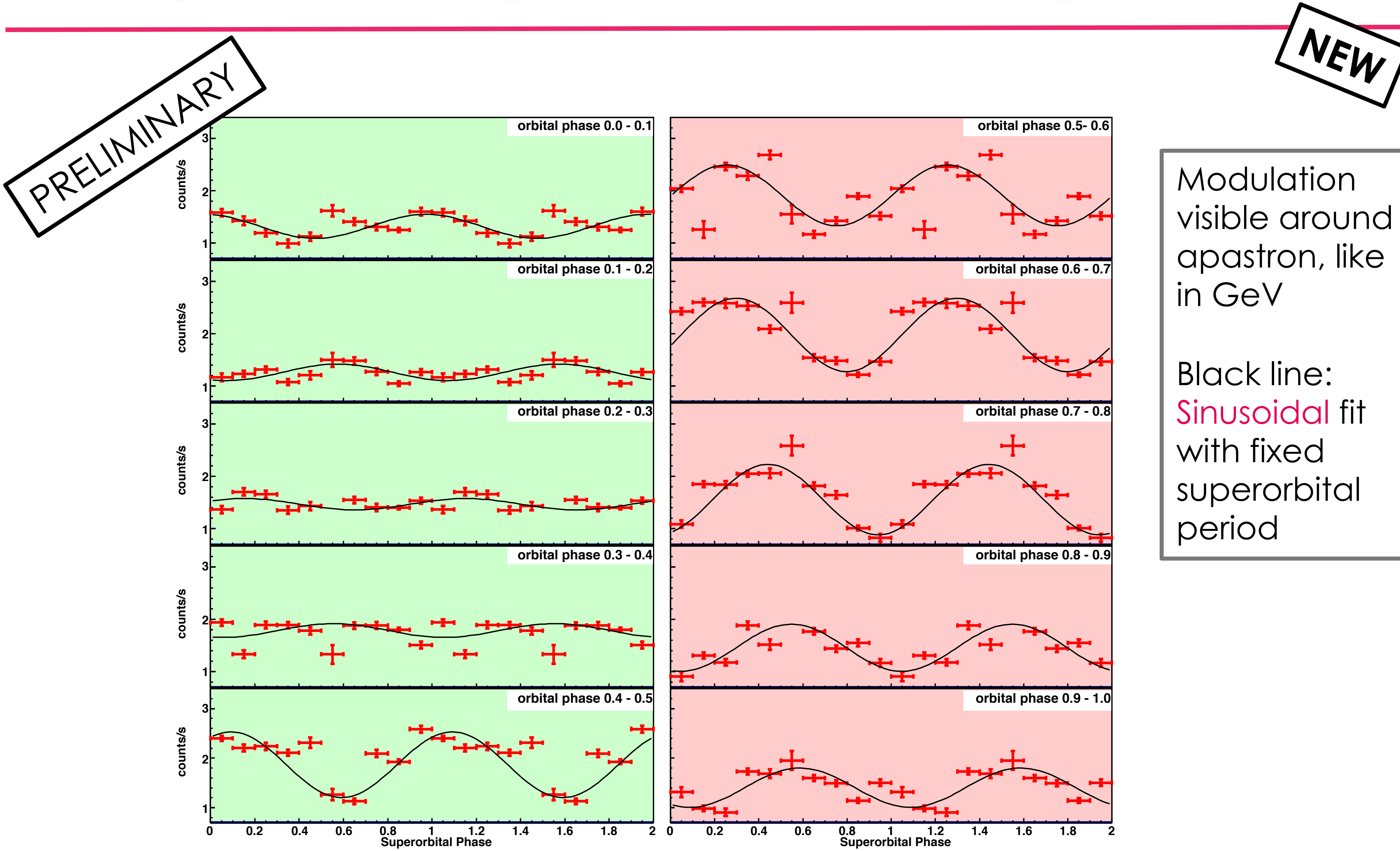


Li et al. 2012

Dotted line: behavior in radio
Solid curve: sinusoidal fit to X-ray data (red) obtained by fixing the period to 1667 days
Green boxes: TeV emission in low state
Yellow boxes: TeV emission in high state

Hinting super-orbital modulation in X-rays

X-ray: Orbital phase bins in superorbit



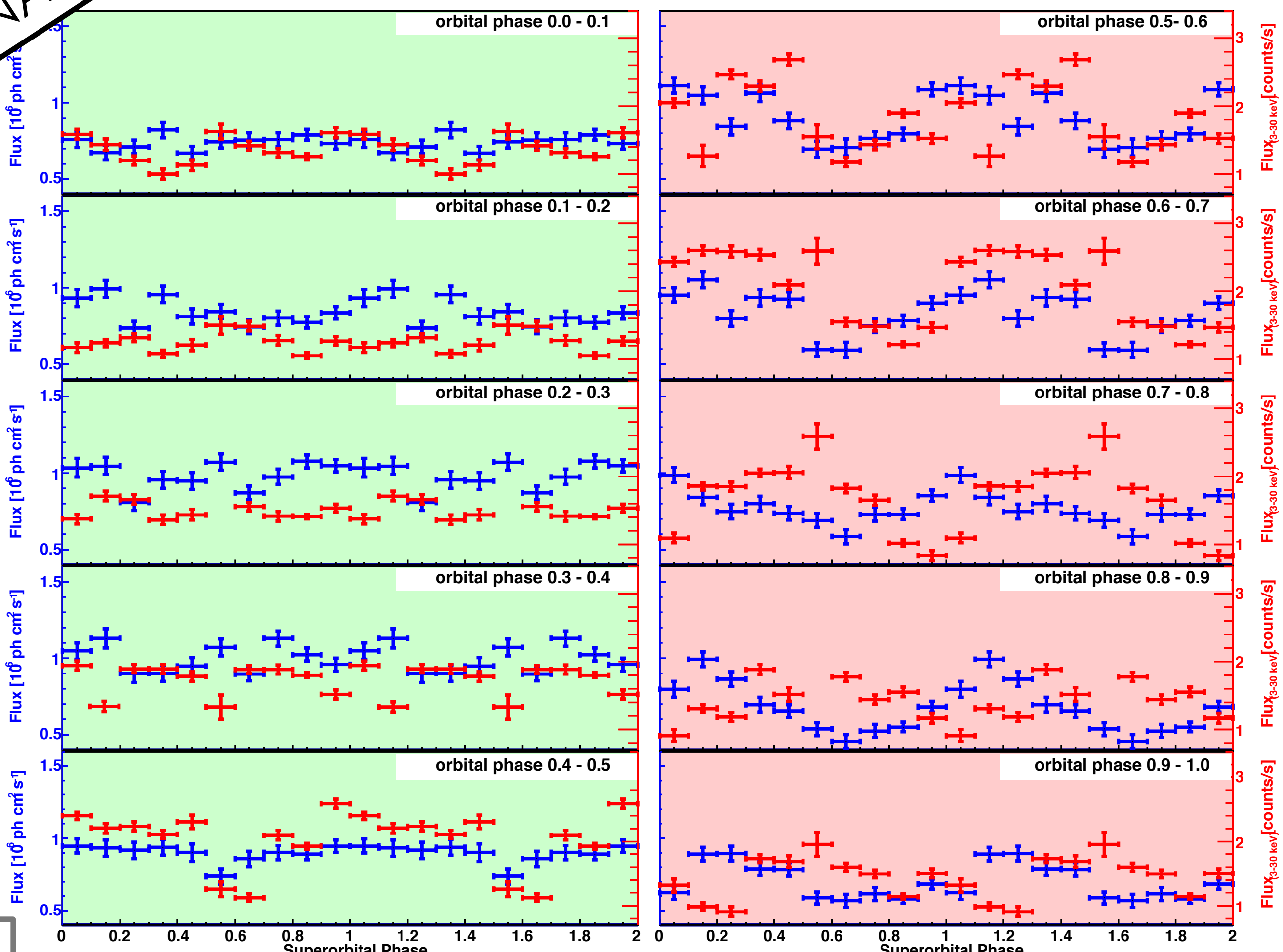
Modulation visible around apastron, like in GeV

Black line: Sinusoidal fit with fixed superorbital period

X-ray & GeV

NEW

PRELIMINARY



Pearson Corr. Coefficient: **No significant correlation** nor anticorrelation visible

X-ray emission shifted wrt GeV?

Blue: GeV
Red: X-ray

RADIO DATA

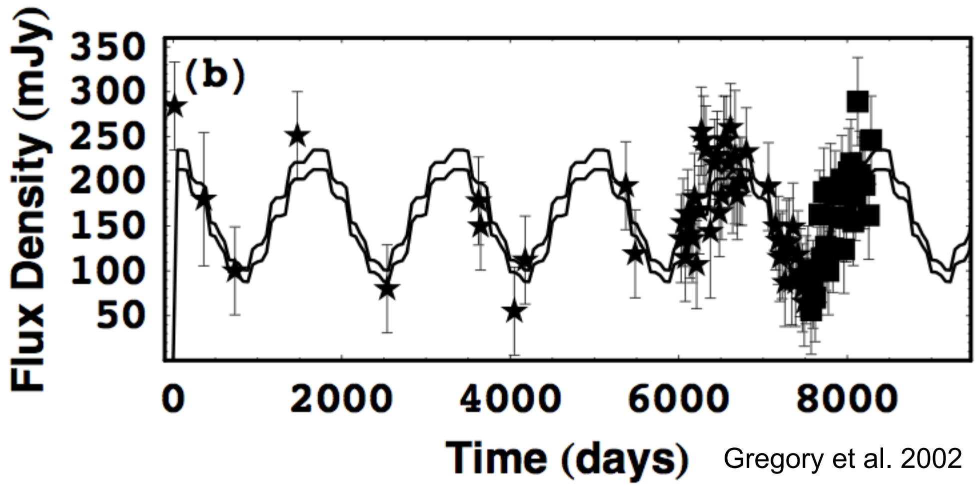
GBI data

2.25 GHz & 8.3 GHz

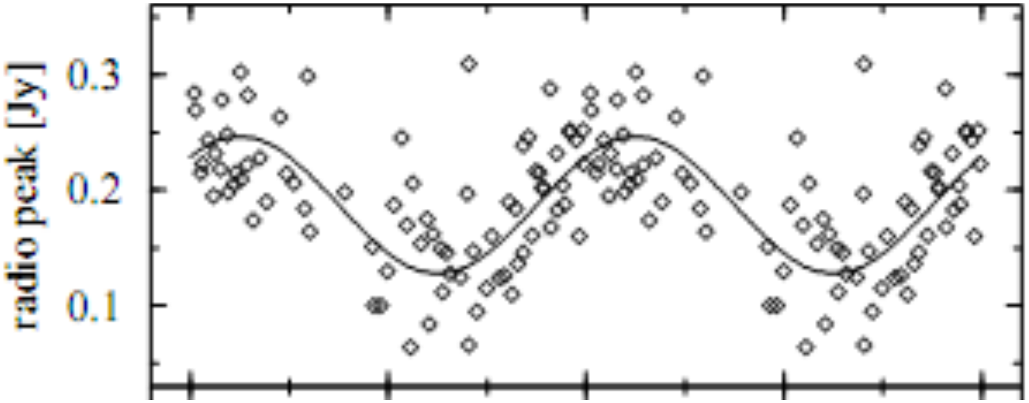
1994 - 2000

Superorbital behavior in radio

Known



Gregory et al. 2002

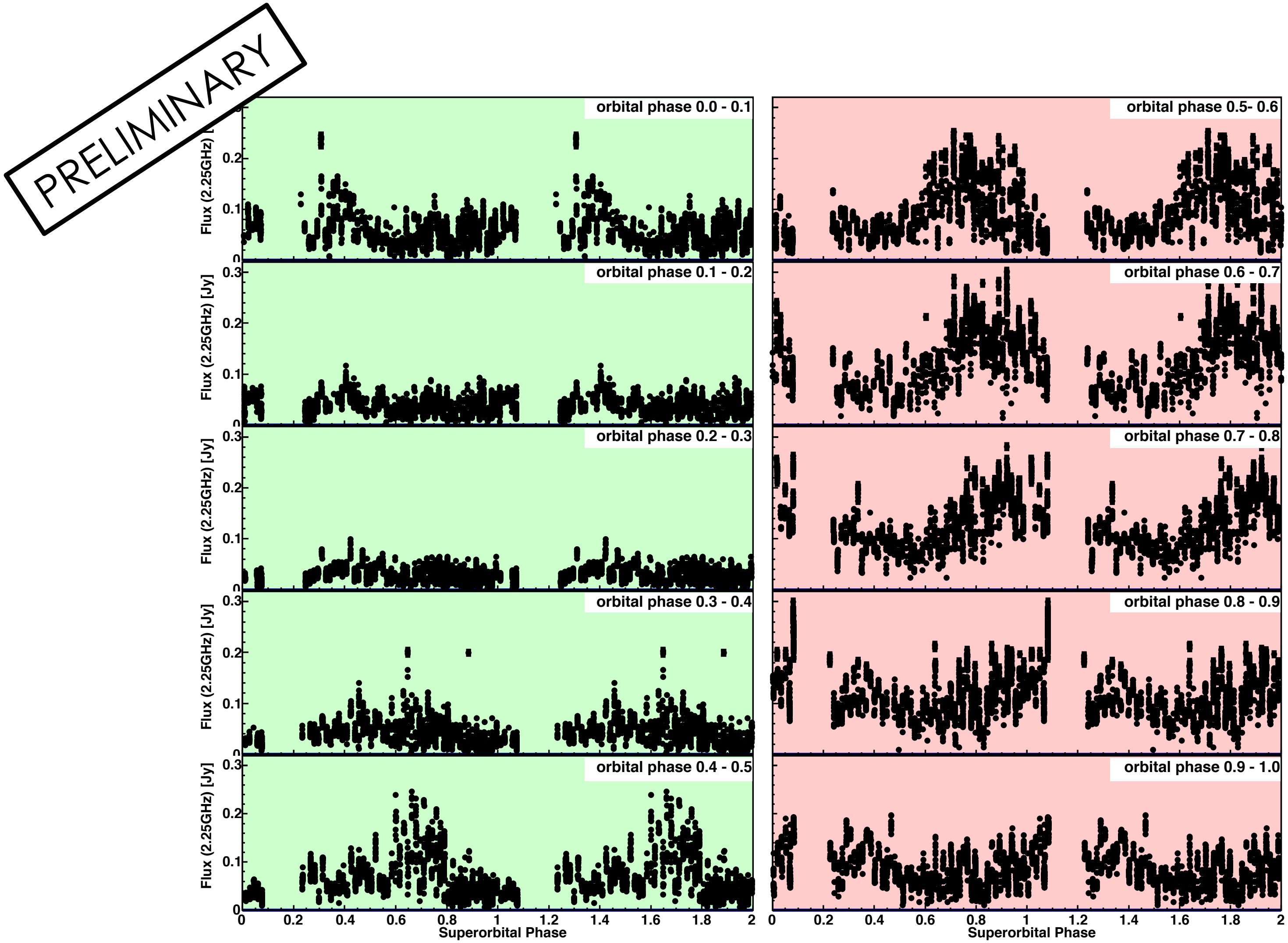


Zamanov et al. 2000

- > 20years of radio observations
- Superorbital period found: 1667 +/- 8 days

2.25 GHz

NEW



Same folding like in GeV

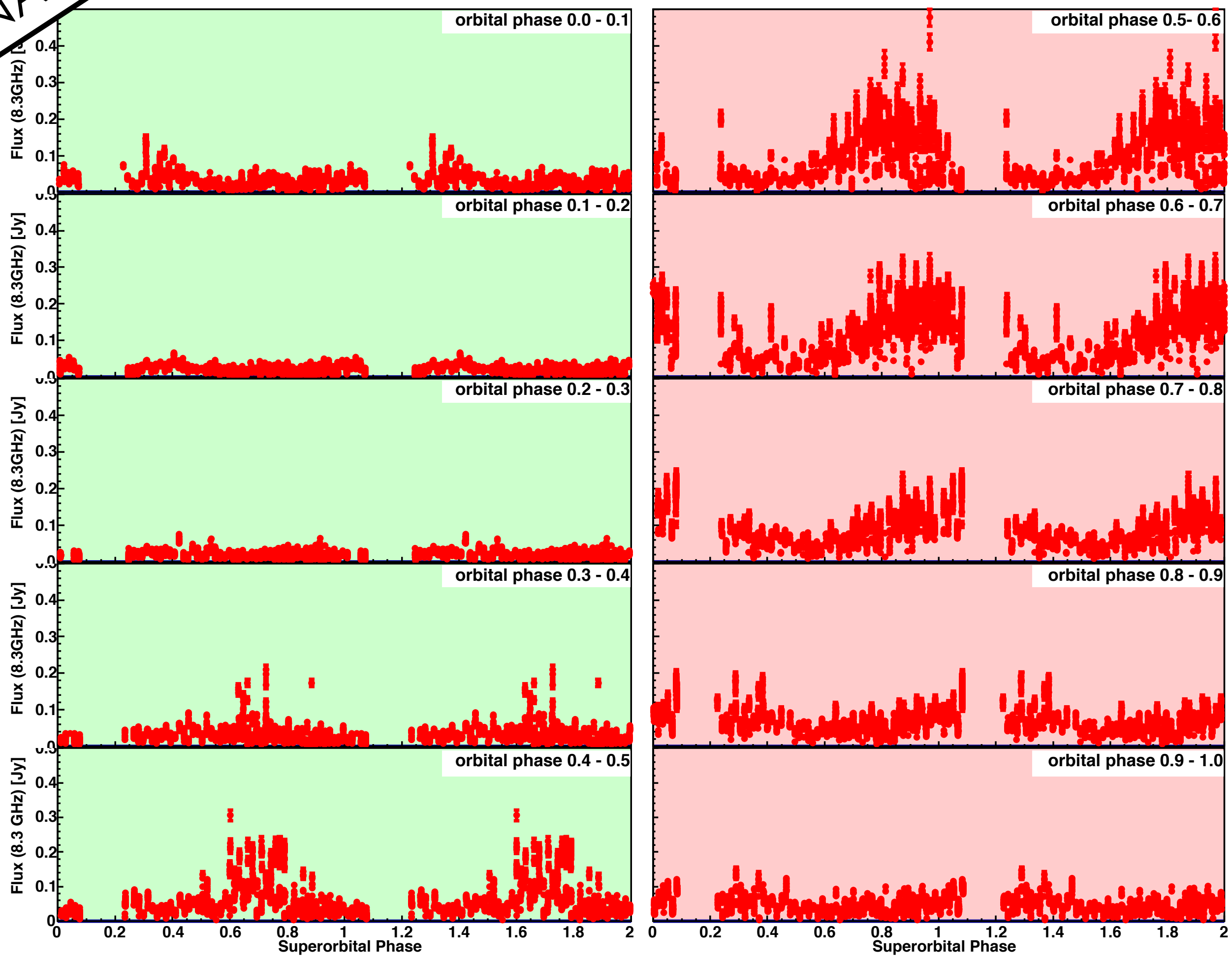
→Modulation visible around apastron

→Modulation starting earlier in orbital phase than in GeV?

8.3 GHz

NEW

PRELIMINARY



Same folding like in GeV

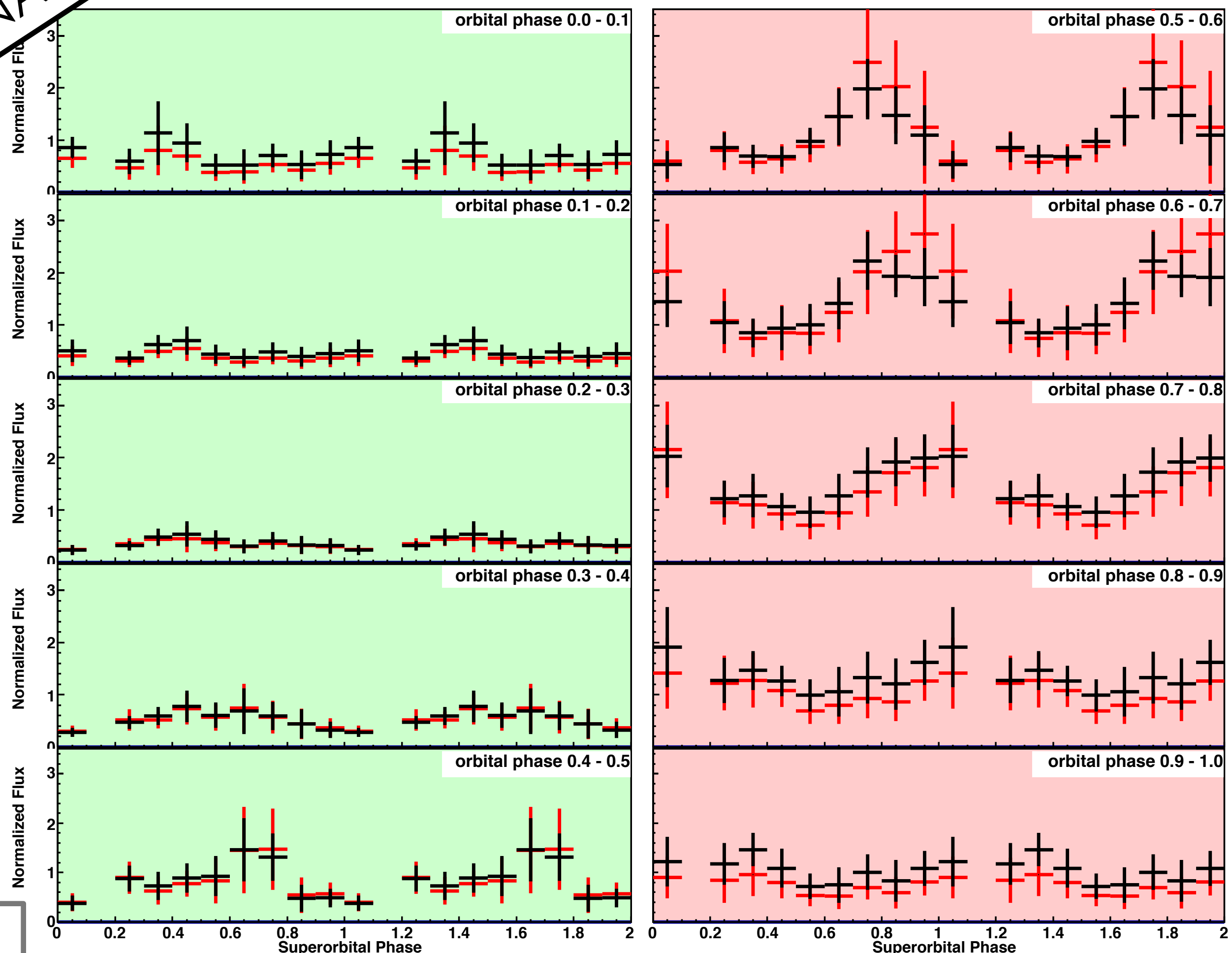
→Modulation visible around apastron

→Modulation starting earlier in orbital phase than in GeV?

2.25 GHz & 8.3 GHz

NEW

PRELIMINARY



Average radio data in superorbital bins of 0.1

Error = RMS

Both frequencies show almost same behavior

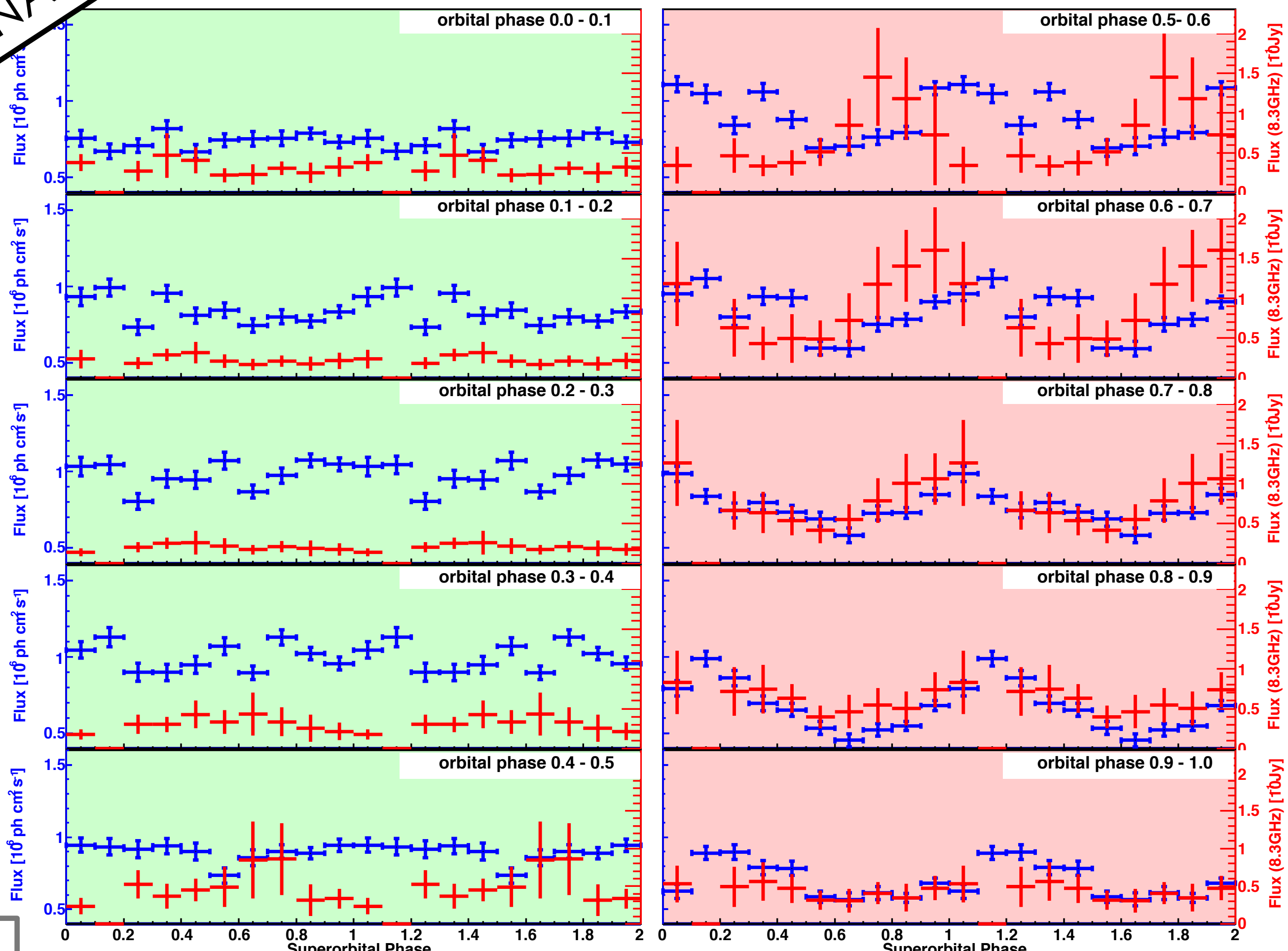
Modulation visible around apastron, like in GeV

Black: 2.25 GHz
Red: 8.3 GHz

GeV & 8.3 GHz

NEW

PRELIMINARY



Pearson Corr. Coefficient:

Correlation GeV – Radio on 3σ level around apastron

Blue: GeV
Red: Radio

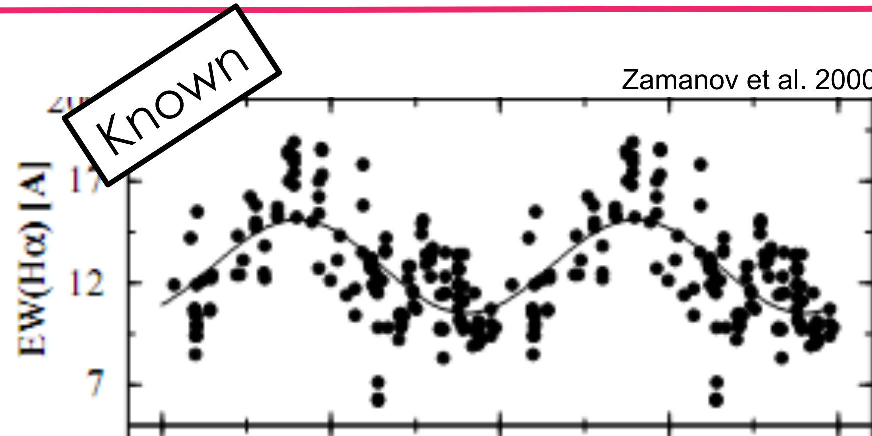
OPTICAL DATA

Data from several instruments

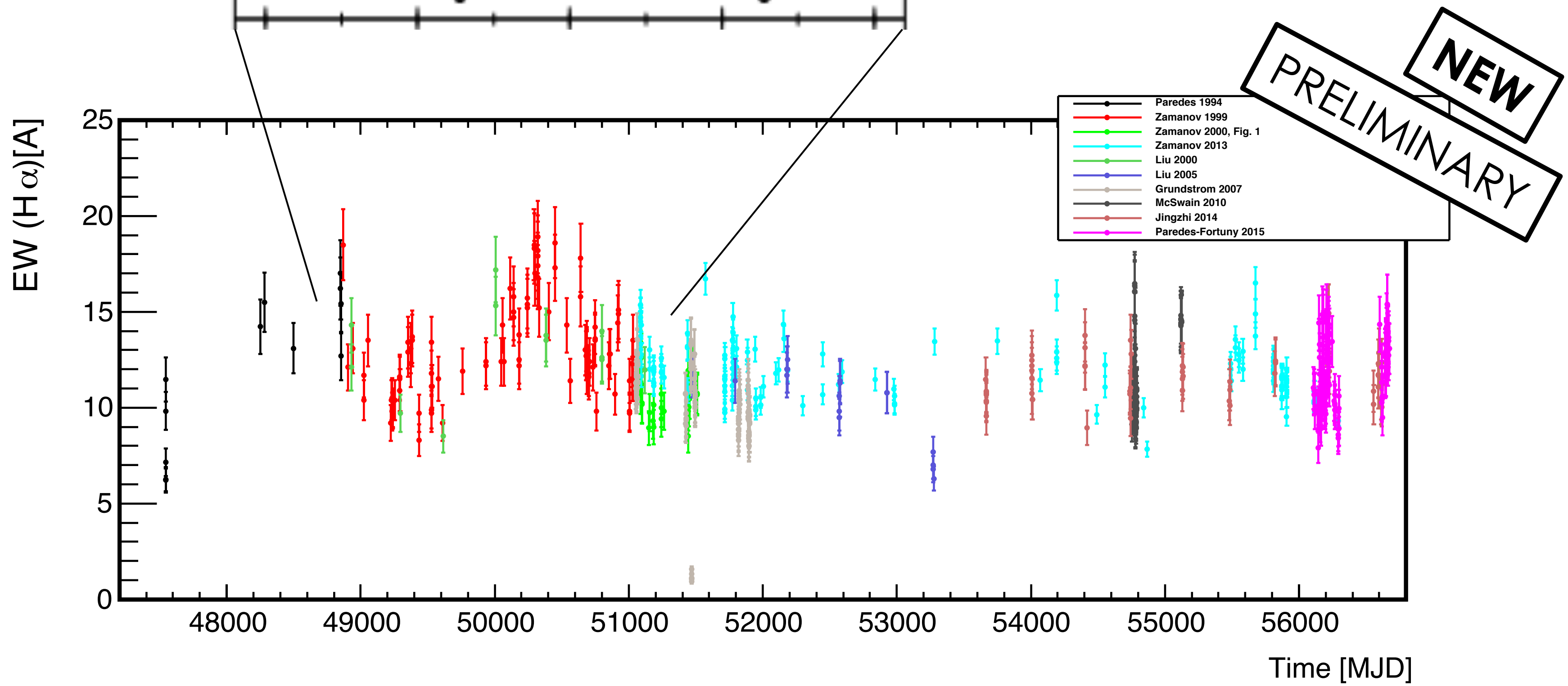
EW(Hα)

1989 - 2015

Hα data over several years

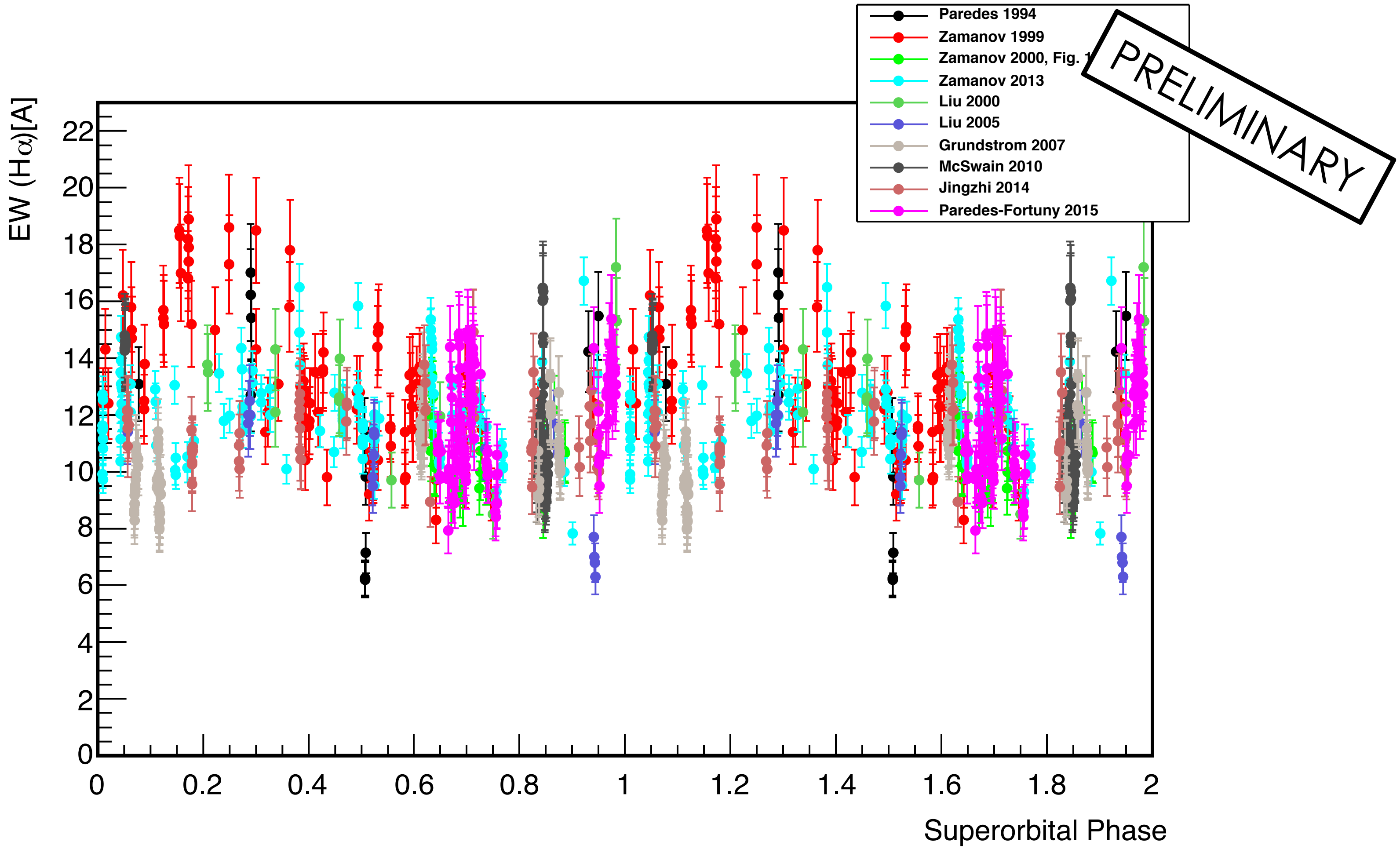


- **Equivalent width of Hα emission line showed superorbital variability after one superorbit**
- **Strong intra night variability**



Hα in superorbit

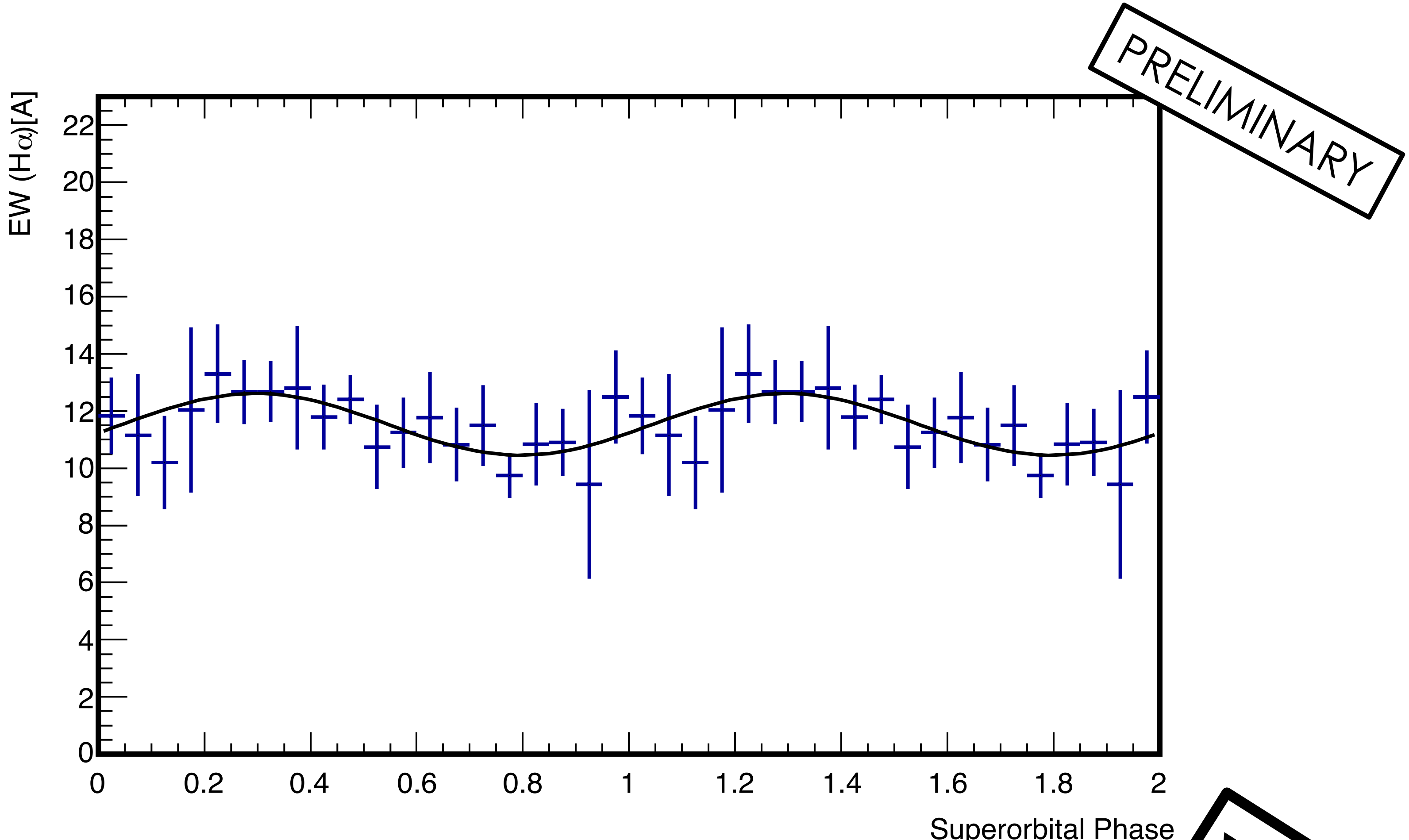
NEW



- **Large spread of data**
- **Superorbital modulation visible?**

Hα binned in superorbit

NEW



- Data binned into 0.05 of superorbit (error = RMS)

→Probability that EW (Hα) evolution is a random result: 0.02

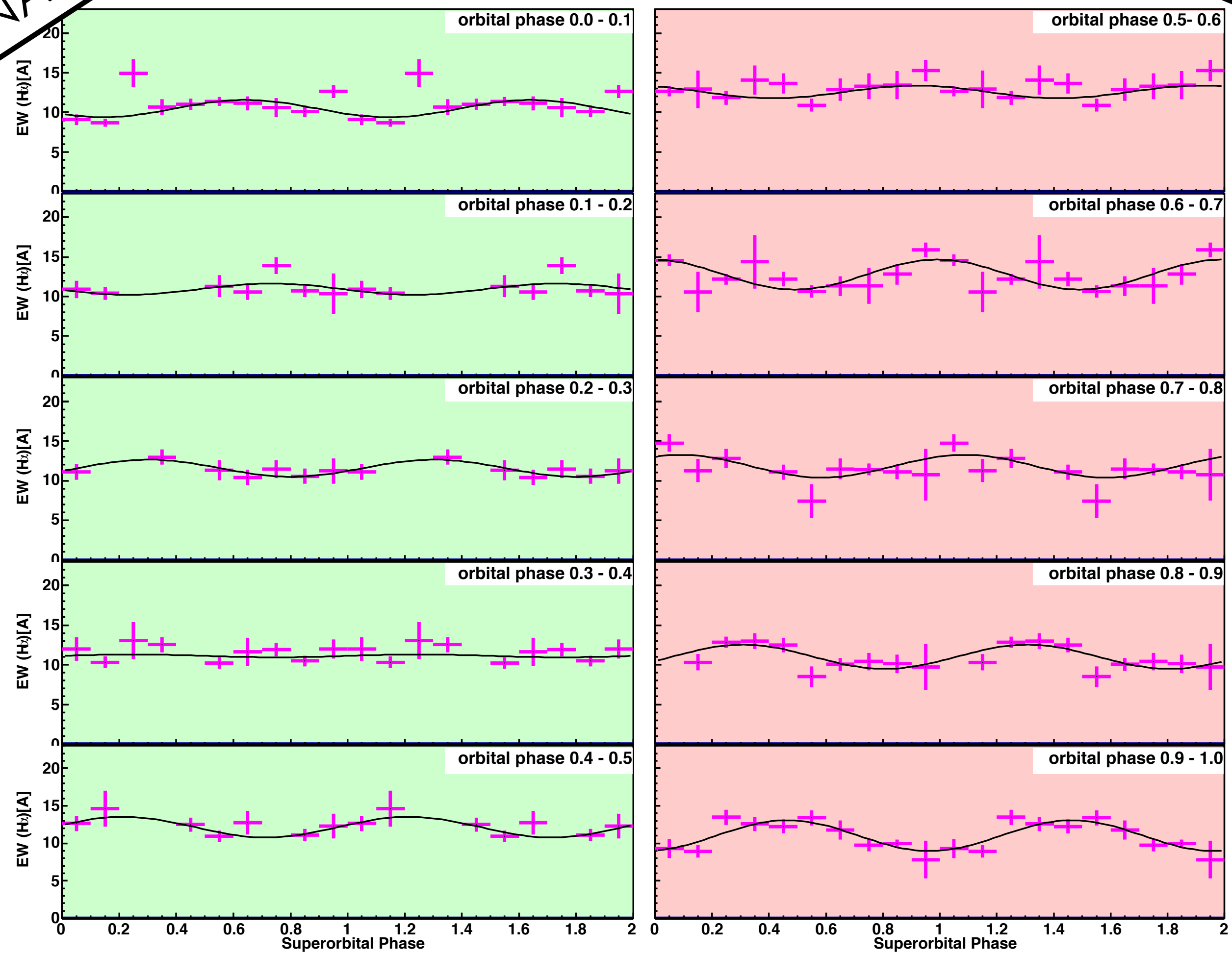
→ **EW (Hα) is variable along the superorbit**

YES

EW(Hα): Orbital phase bins in superorbit

PRELIMINARY

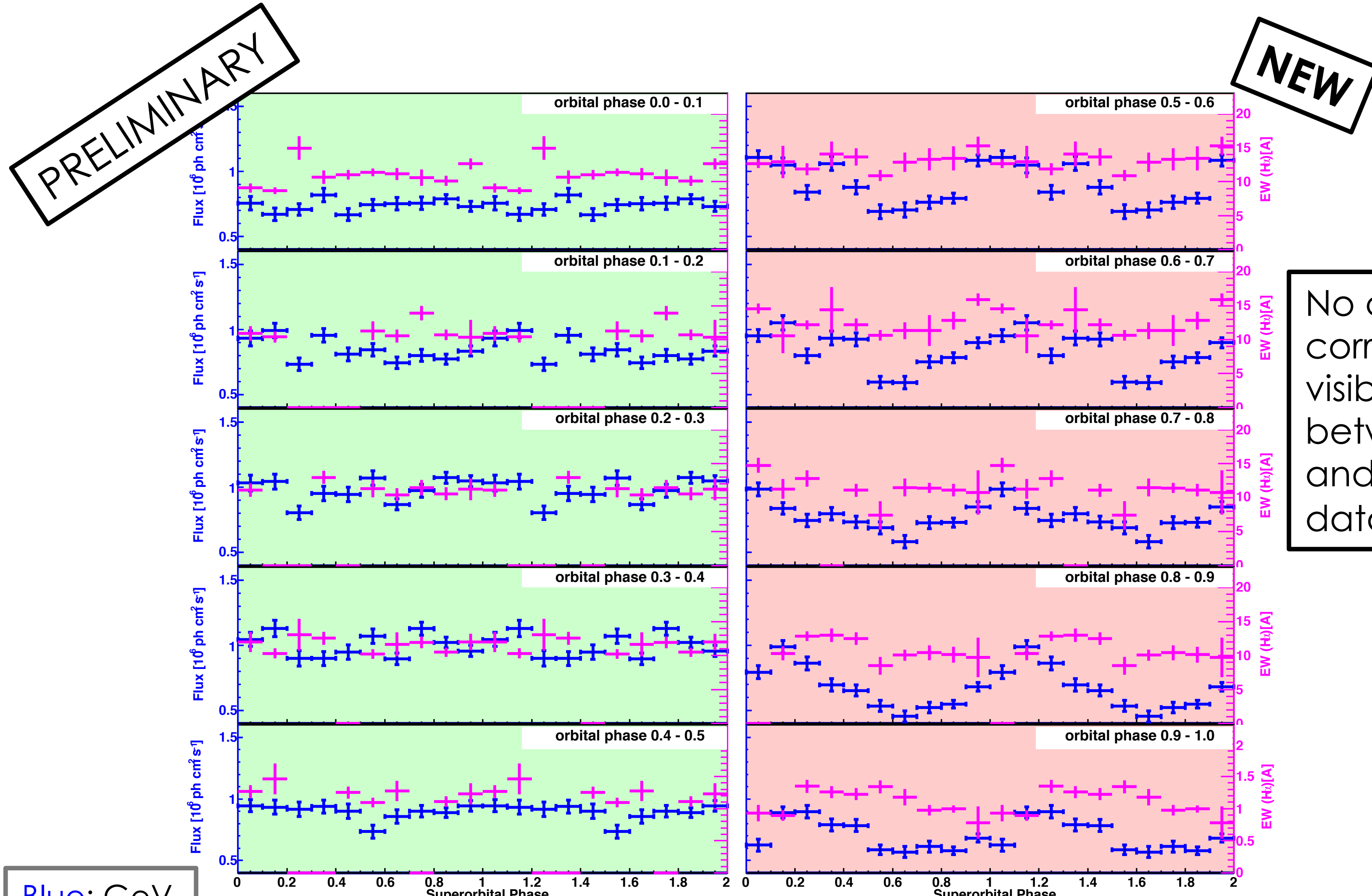
NEW



Same folding like in GeV

→Modulation also here visible around apastron

EW(Hα) & GeV



No clear correlation visible between Hα and GeV data

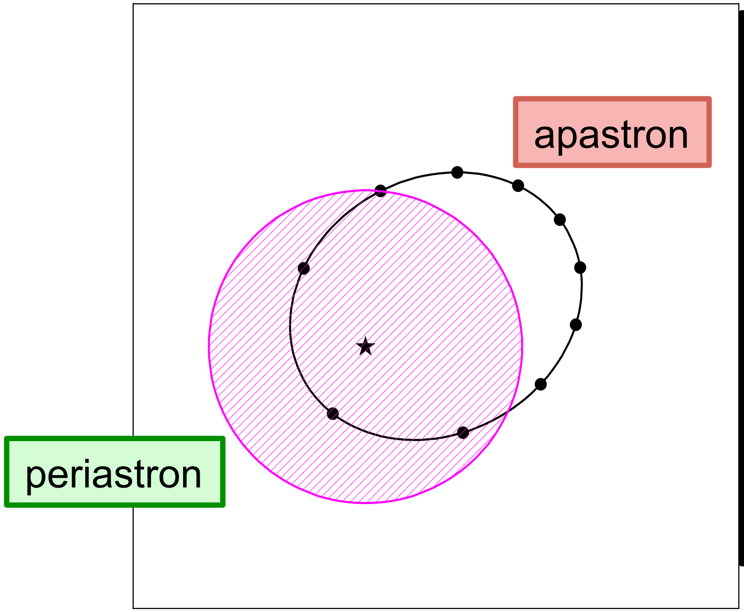
Blue: GeV
Pink: Hα

A possible interpretation for modulation

The superorbital variability in Be binary could be understood as a quasi-cyclical increase of the circumstellar disc size or mass decretion rate

The influence of the matter stripped off from the disk by the compact object's passage can be larger and located farther out in periods of higher mass loss

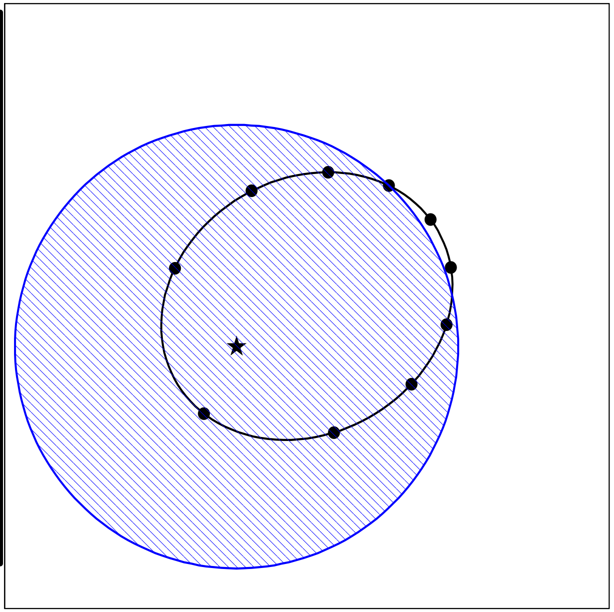
Periods of a relatively smaller disc



In periastron the influence of the cyclical increase of the disc is minor or nil, since the compact object is always affected by it.

In apastron the influence of the cyclical increase of the disc is larger, but likely not maximal since the disc may not reach to overtake it.

Periods of a relatively larger disc



Summary

- Superorbital modulation detected in all wavelengths studied here
- All wavelengths show superorbital modulation distinguishing apastron from periastron regions
  - **GeV energies:** Behavior stays the same with additional one year of data
  - **Radio:** GeV → Correlation at level of 3 sigma (Pearson corr. Coeff.)
  - **X-rays:** no clear (anti)correlation with GeV visible. Emission shifted wrt GeV?
  - **EW(Hα):** Shown for the first time the superorbital modulation around apastron
- Possible connection to cyclic mass-loss phenomena in Be stars

- Future plan:
  - Complete multi wavelength picture with TeV data

THANK YOU