Radio and high energy characteristics of the gamma-ray binary LSI +61°303

L. Zimmermann M.Sc.

Max Planck Institute for Radio Astronomy, Germany, Bonn

Outline

1. LS I +61 303
    1.1 Periodicities in LS I +61303
    1.2 Radio and X-ray states in LS I +61303

2. High energy observations and the radio spectral index

3. High energy observations of LS I +61303 and Θ

4. Summary

1. LSI +61 °303

1.1 Periodicities in LS I+61303

High mass X-ray binary system

Compact object: 2-3.5 M☼

Companion: Be star (5-15 M☼)

Orbital period: 26.5 d (phase Φ)

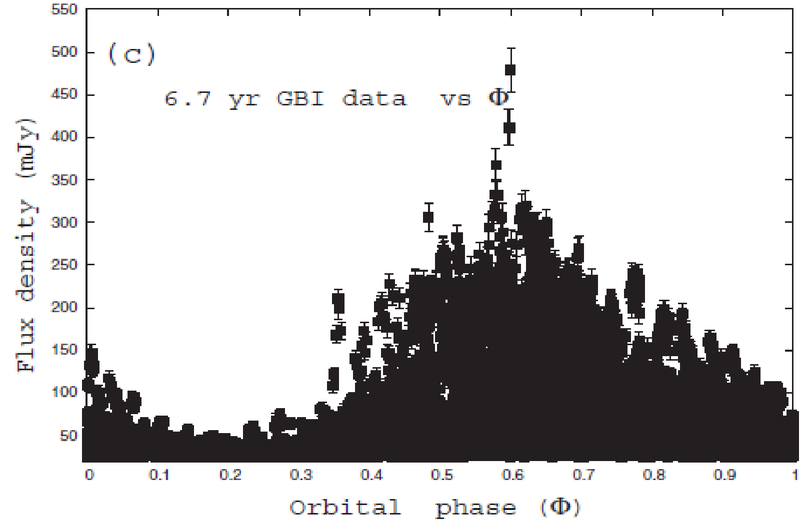
Periastron passage ~0.25

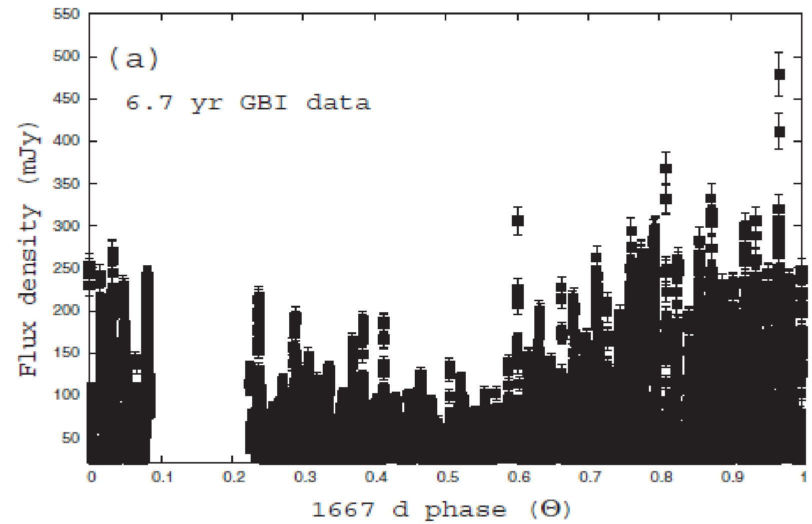
Highly eccentric orbit

Detected at high and very high energies

Two radio periodicities:

1. 26.5 days
   - ➔ corresponds to orbital period
   - ➔ large outburst around apoastron
2. ~ 4.6 yr (phase Θ)
   - ➔ modulates amplitude and orbital occurrence of large outburst



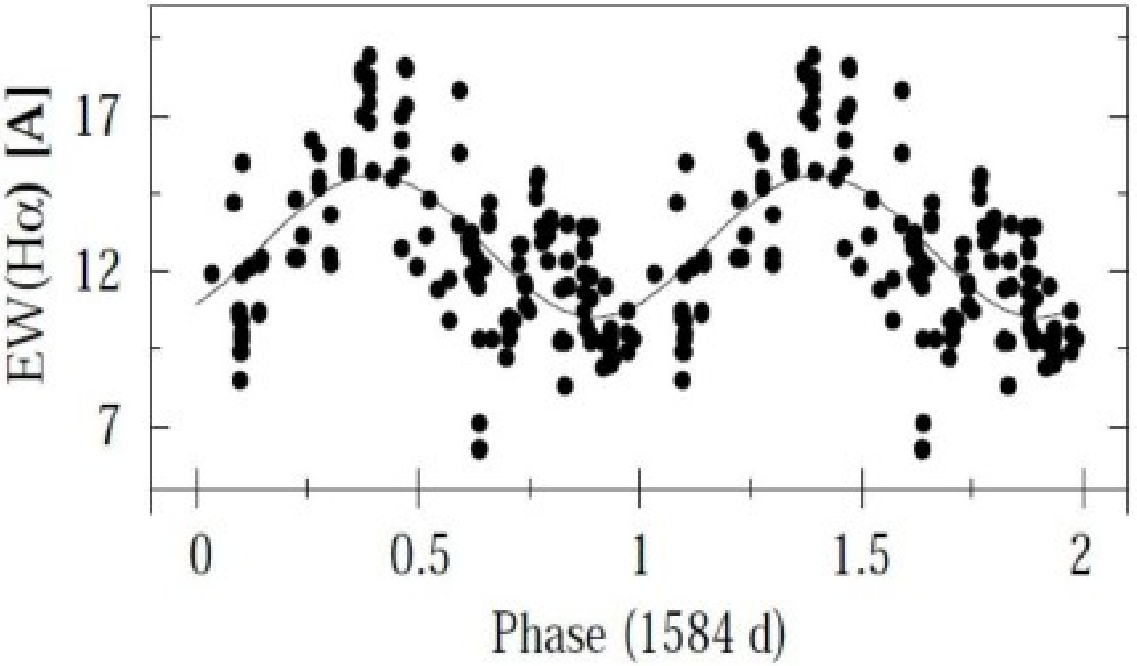


(a): Radio light curve (8.3 GHz) vs. Θ, where Θ is related to (t−t0) P2 with t0 = JD2443366.775 and period P2 = 1667 d (Gregory 2002). The maximum of the cycle is at Θ □ 0.97.
(c): Radio light curve vs. Φ, the orbital phase, with Φ related to (t−t0) P1, with P1 = 26.496 d (Gregory 2002). Massi & Kaufman Bernadó 2009

1.1 Periodicities in LS I+61303

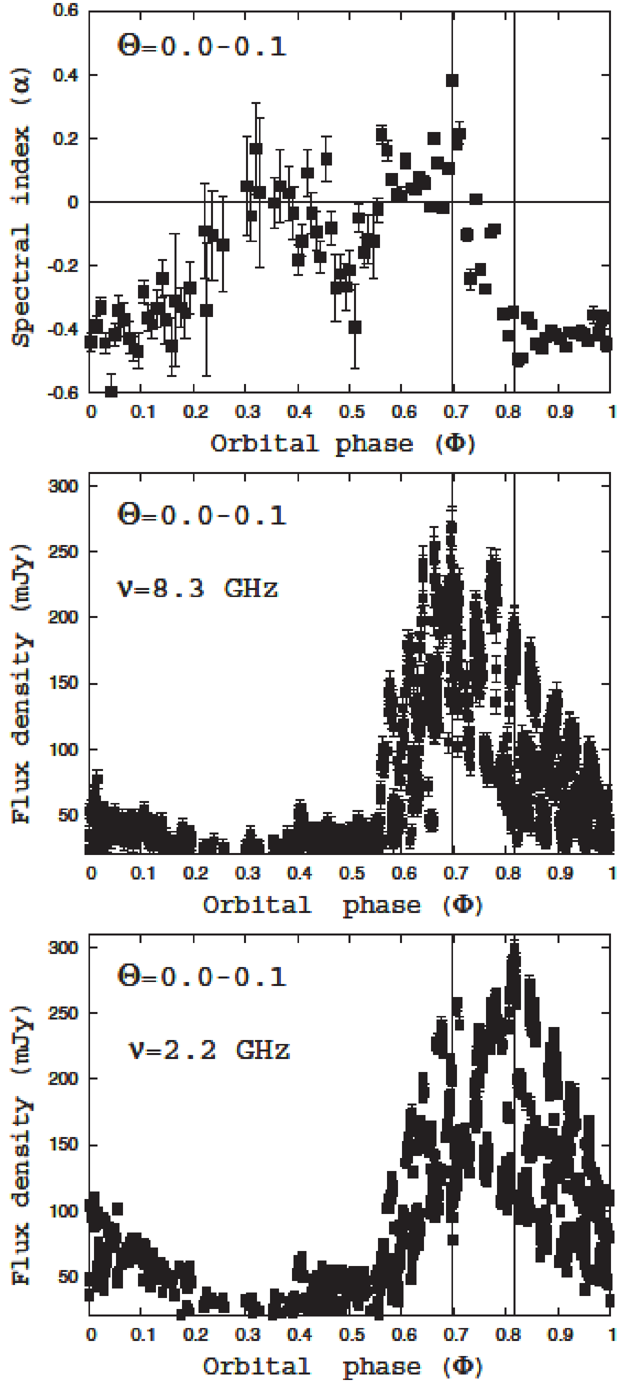
- Φ modulates flux in radio, infrared, H-alpha, X-rays, high energy, very high energy
- Θ has been observed in H-alpha aswell

→ Possibly due to perioidic shell ejections from the companion star



H-alpha lightcurve from LS I +61303 showing the long period Θ (Zamanov & Marti 2000).

1.1 Periodicities in LS I+61303



Radio spectral index along the orbital phase ($S \propto \nu^{\alpha}$):

Switch from α>0 to α<0 around apoastron

Two different radio outbursts:

→ 1. **optically thick** then 2. **optically thin**

For microquasars:
Evolution from optically thick (steady jet) to optically thin (transient jet) is expected

In LS I +61303: Evolution detected **twice** along the orbit

Left: Spectral index and flux density, at 8.3 GHz and 2.2 GHz vs. orbital phase, □, for the GBI data in the interval T=0.0-0.1. The spectral index, a, is averaged over Δ□=0.009 (6hr). It changes from positive to negative during the small and the large radio outburst. Note that the evolution from an optically thick to an optically thin specrum occurs twice, the second change lying close to apoastron (Massi & Kaufman Bernadó 2009).

1.1 Periodicities in LS I+61303

<u>The two peak accretion/ejection model for LS I+61 303:</u>

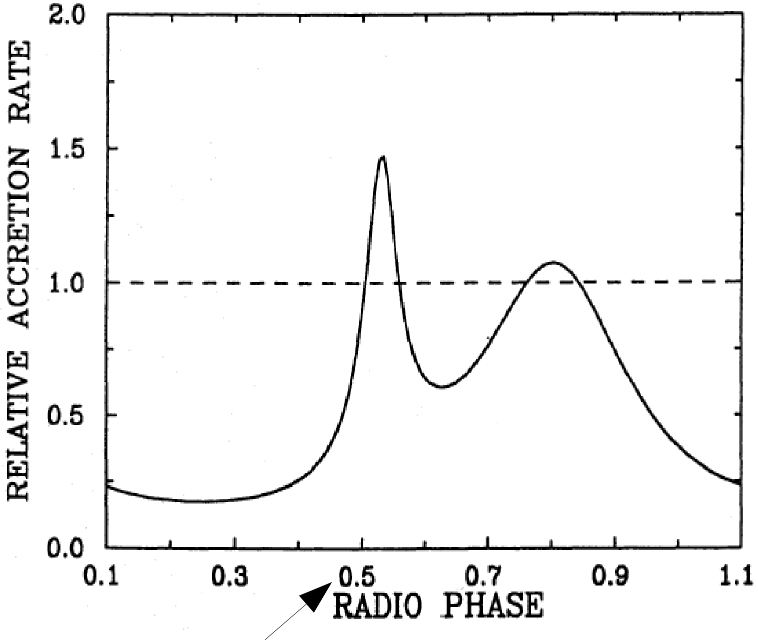
Accretion rate: $$\dot{M} \propto \frac{\rho_{wind}}{v_{rel}^3}$$

Proportional to density of the stellar wind and drops with decreasing velocity of the compact object

Along an eccentric orbit it develops two peaks:

1. around periastron, where the density of the stellar wind is highest

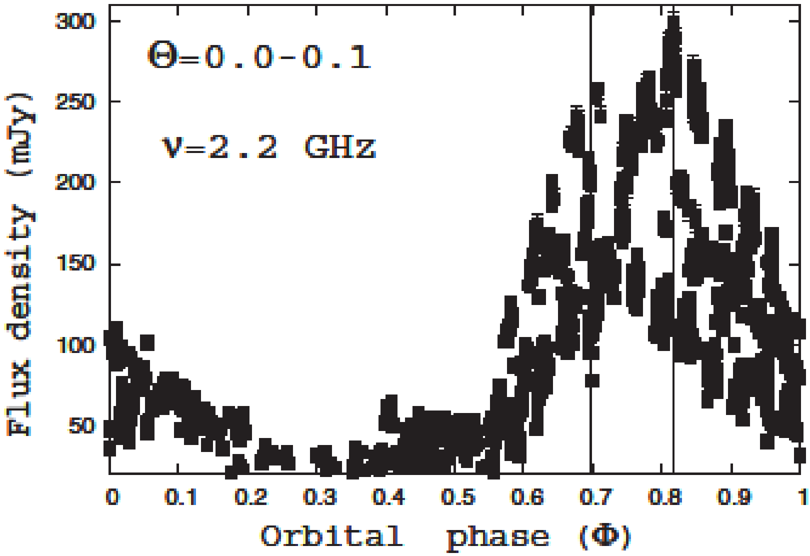
2. where the drop in density is compensated by the decreasing velocity

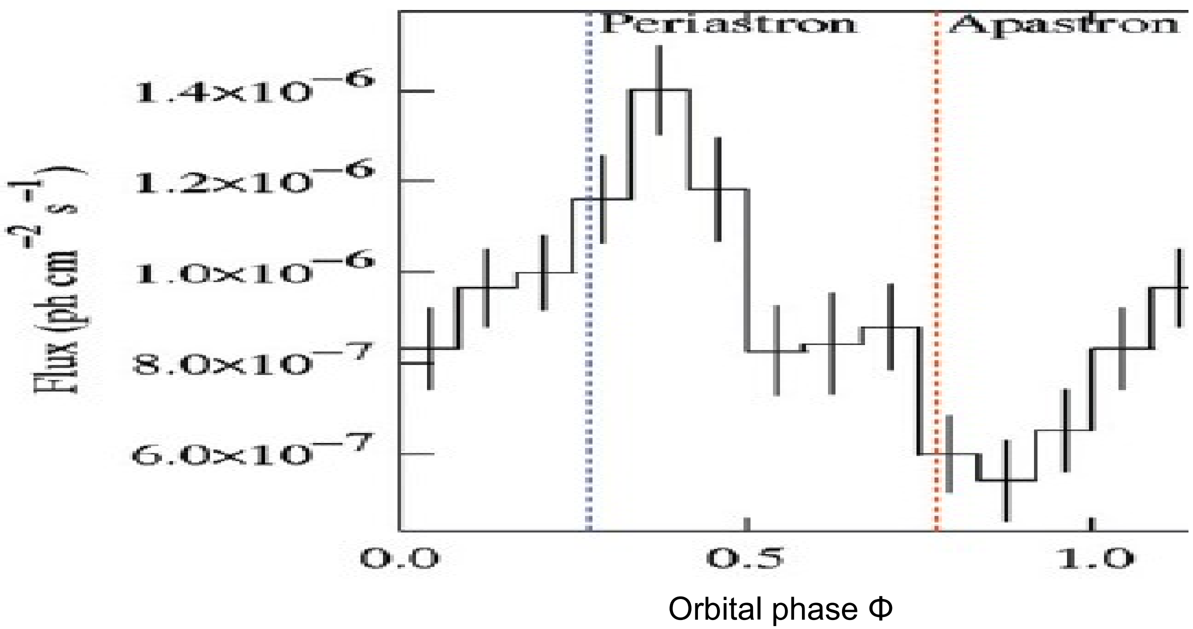


New value: 0.2

Accretion rate plotted against radio phase. The dashed line marks the Eddington limit (Martí & Paredes 1995)

1.1 Periodicities in LS I+61303





Top: Radio lightcurve from GBI of LS I at 2.2 Ghz for Θ=0.0-0.1(Massi & Kaufman Bernado 2009). *Bottom*: Fermi-LAT observations (20 MeV-100 GeV). Folded light curve of LS I +61◦303 binned in orbital phase (Abdo et al 2009)

Two peaks in high energy expected

- Accretion rate peak is associated with an ejection
- Radio peak at periastron is attenuated
- External inverse Compton losses of the electrons in the dense stellar UV field

→ HE emission

High energy observations show two peaks along the orbit:

- VERITAS (Ong 2010): peak around apoastron and peak at periastron
- FERMI-LAT (Abdo & al. 2009): peak around periastron and peak around apoastron
- EGRET (Tavani & al. 1998): peak around periastron and towards apoastron

1.1 Periodicities in LS I+61303

Two peak accretion/ejection model for LS I +61303

Radio:

- Large outburst around apoastron
- Peak around periastron attenuated by inverse Compton losses
- From spectral index: outburst consists of two outbursts

→ optically thick then optically thin

High energy:

- Expect large peak around periastron from inverse Compton losses
- e.g. FERMI-LAT: peak around periastron and peak around apoastron

Now: Connection between radio and X-ray/high energy states in LS I +61303

X-ray states model:

Distinguishing feature: Energy spectra

Four accretion states:

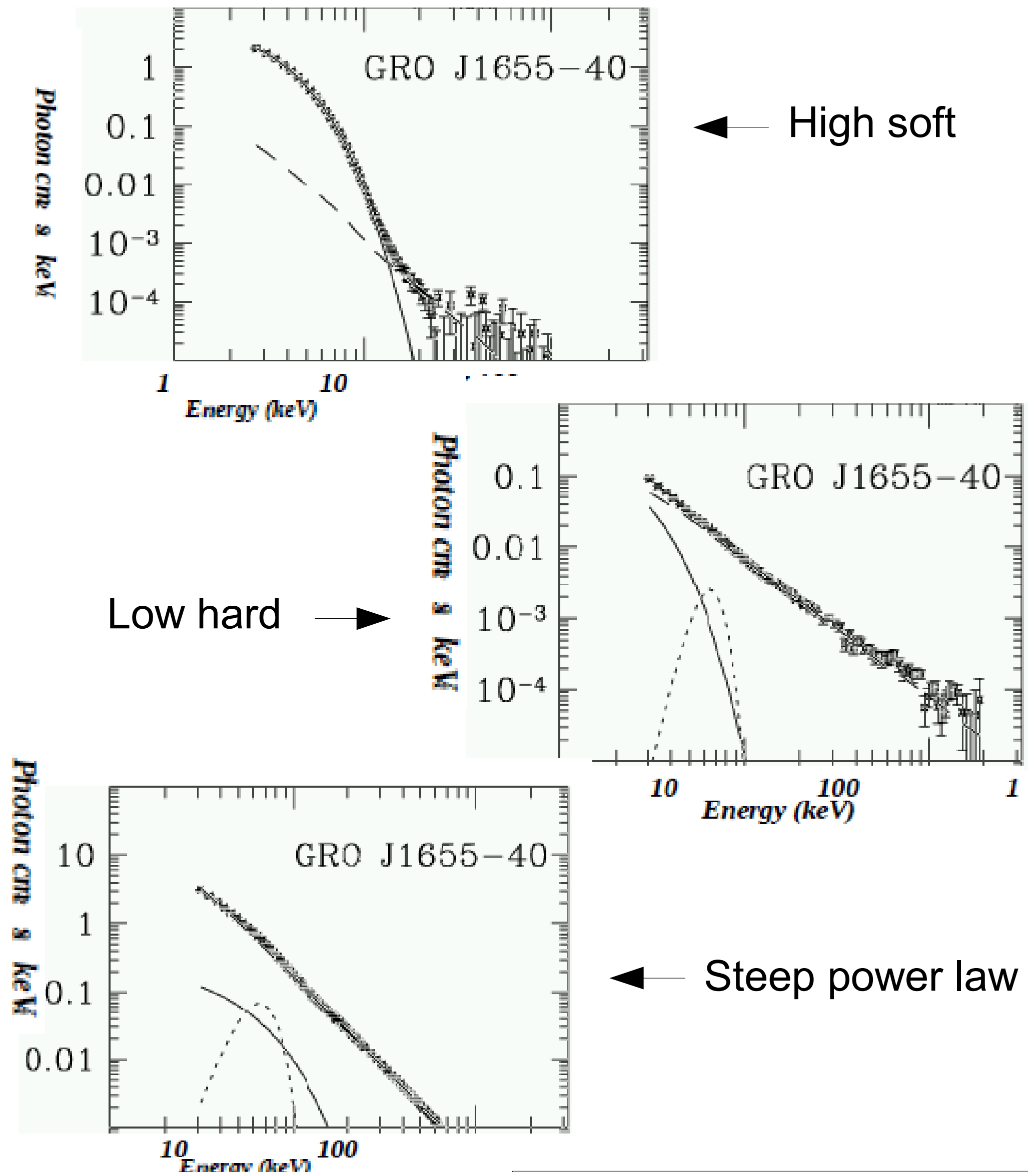
High soft: Dominated by blackbody component (thermal X-rays) from disk + small power law component (hard X-rays) from IC

Low hard: Power law with Γ~1.7 + high energy cut-off + small thermal disk component

Quiescent: Like low-hard but much less luminous

Steep power law: Power law with Γ>2.5 + no cut-off + small thermal component

→ gamma-rays possible



Energy spectra for GRO J1655-40. (McClintock & Remillard 2006)

Radio states:

Observationally two states are distinguishable which emit in radio:

→ Low-hard state
→ Steep power law state

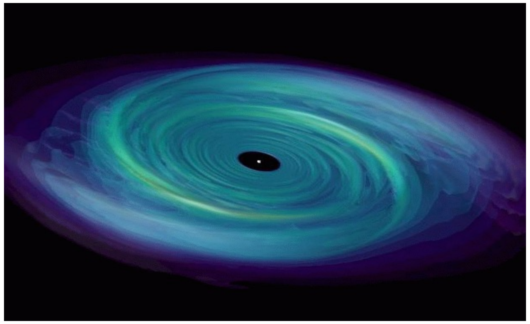
No radio emission in the high-soft state

Radio from jets: energetic electrons gyrating around a magnetic field

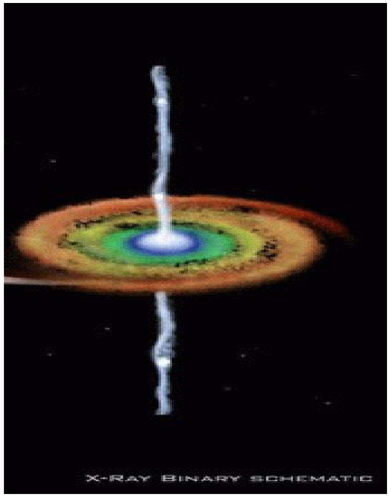
Radio jets have different synchrotron spectra in the two states

Low-hard:
flat / inverted spectrum (α>0)
→ conical jet centered on the compact object

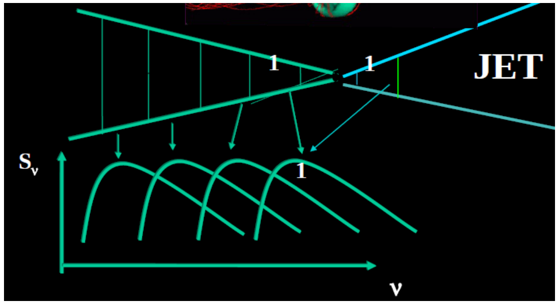
Steep power law:
steep synchrotron spectrum (α<0)
→ shock front detached from the center



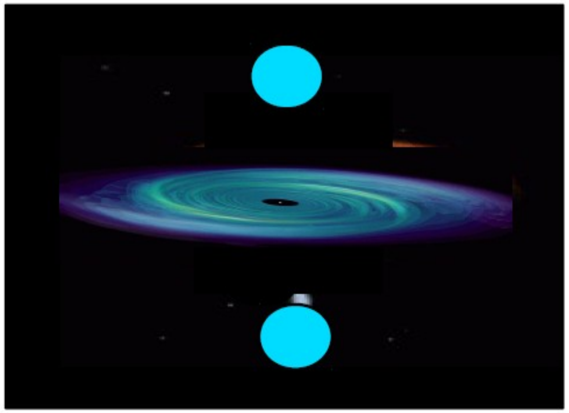
High-soft state

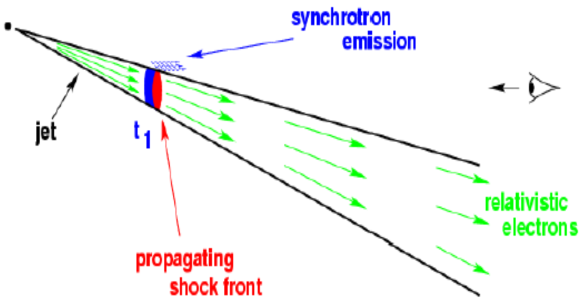


Low-hard state



Steep power law

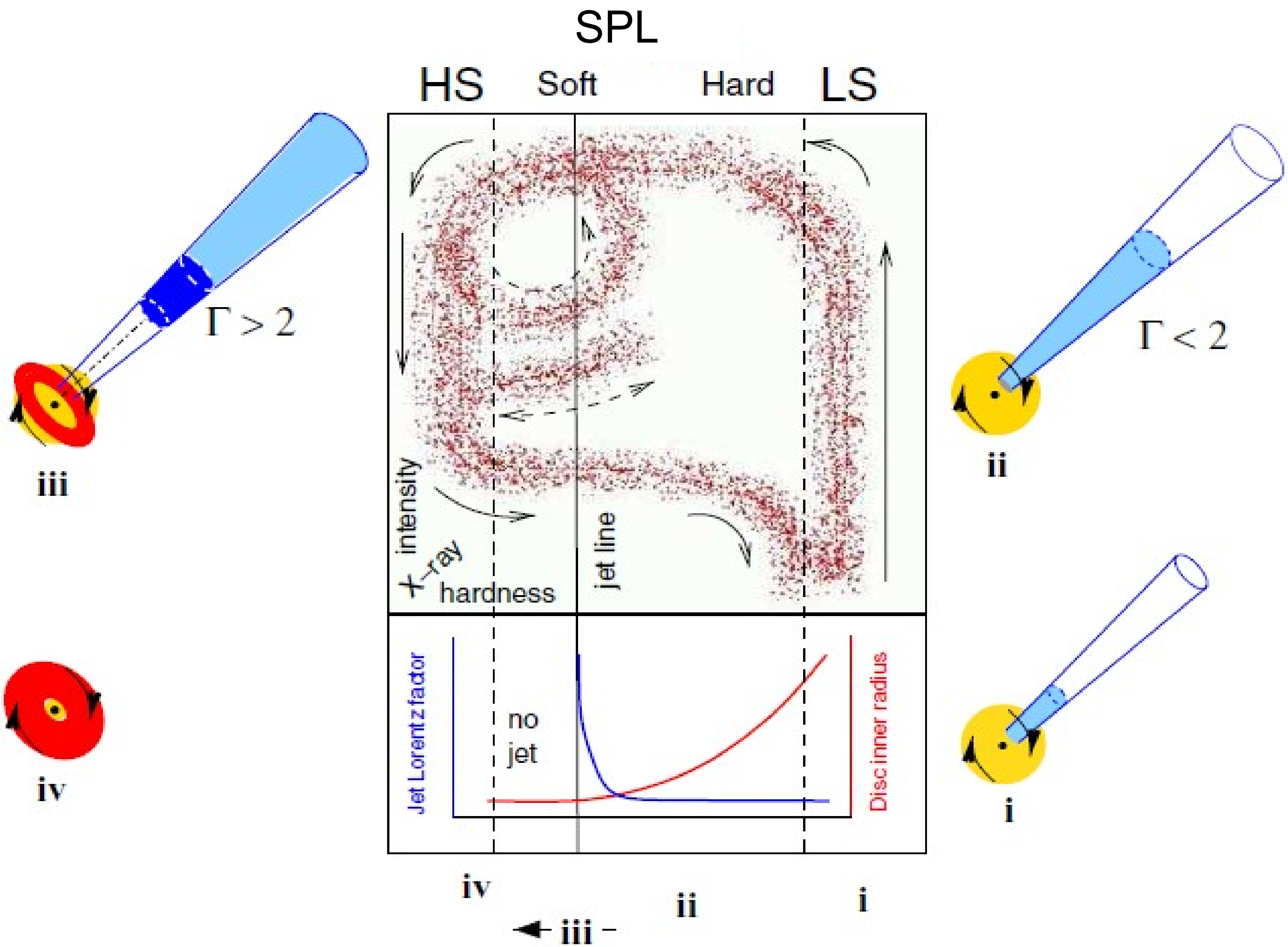




1.2 Radio and X-ray states in LS I +61303

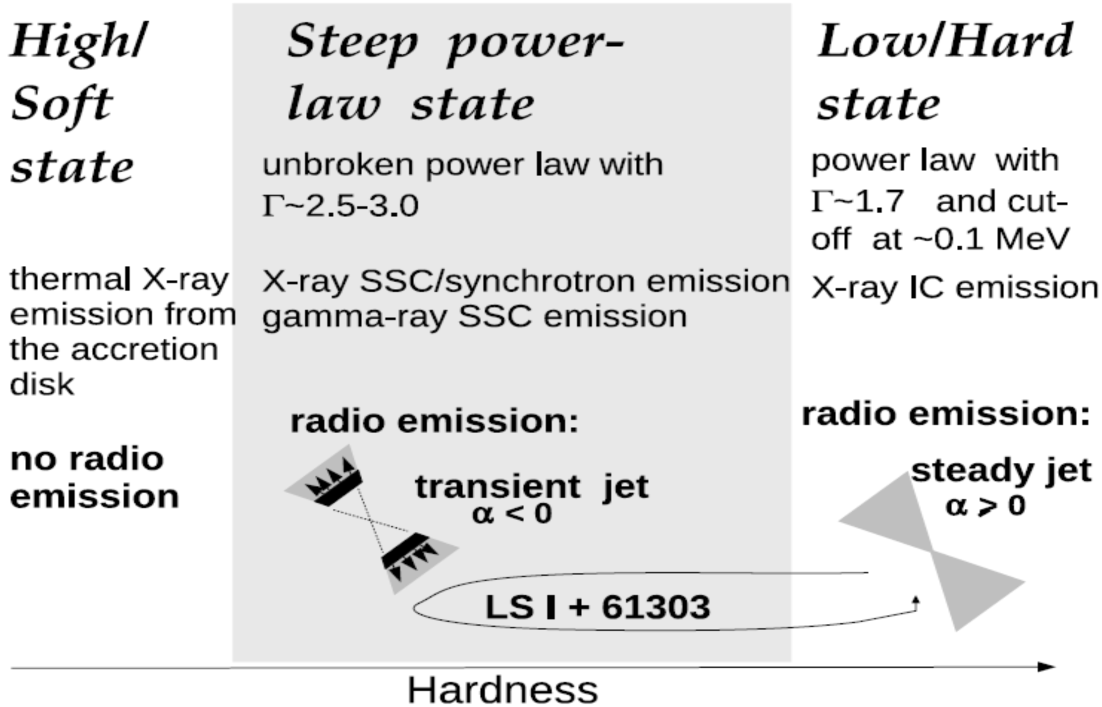
Disk-Jet coupling

- Low-hard state:
  - steady jet
  - hard X-rays
  - increasing intensity,
  - truncated disk + coronal flow
- Steep power law state:
  - internal shock disrupts jet and decouples it
  - jet production ceases
  - X-rays become softer
  - disk can reach last stable orbit
- High soft state:
  - no jet
  - soft X-rays
  - intensity decreases
  - disk reaches last stable orbit



Schematic for jet-disk coupling (Fender et al. 2004)

1.2 Radio and X-ray states in LS I +61303



Massi & Zimmermann 2010, A&A, 515, A82

- LS I +61◦303 evolves from a very low/hard state to a steep power law state
- Then it develops again a steady jet centered on the system (i.e. low/hard state) and never reaches the thermal high/soft state.

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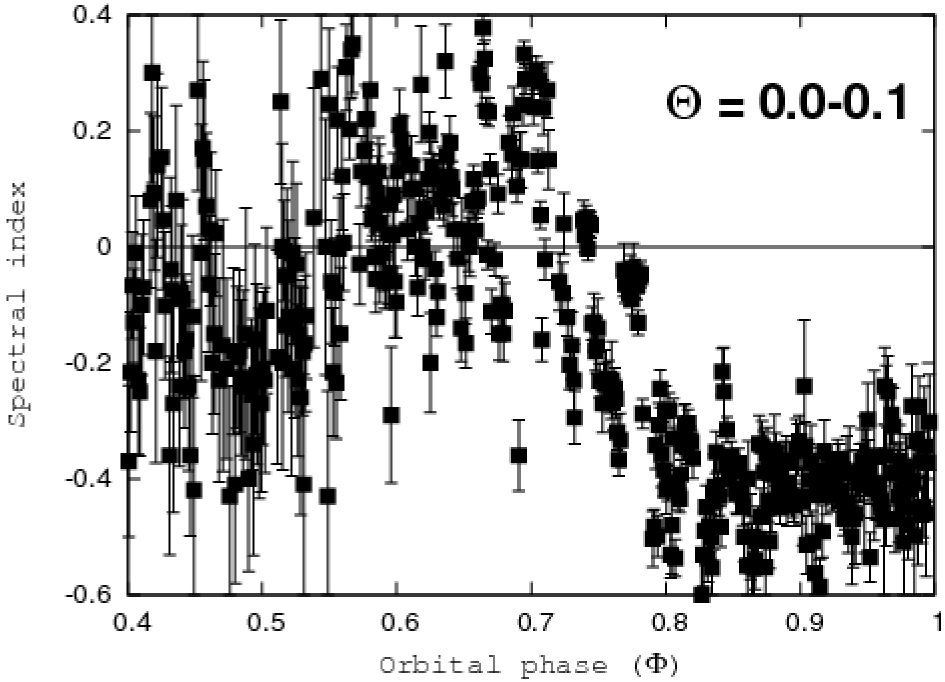

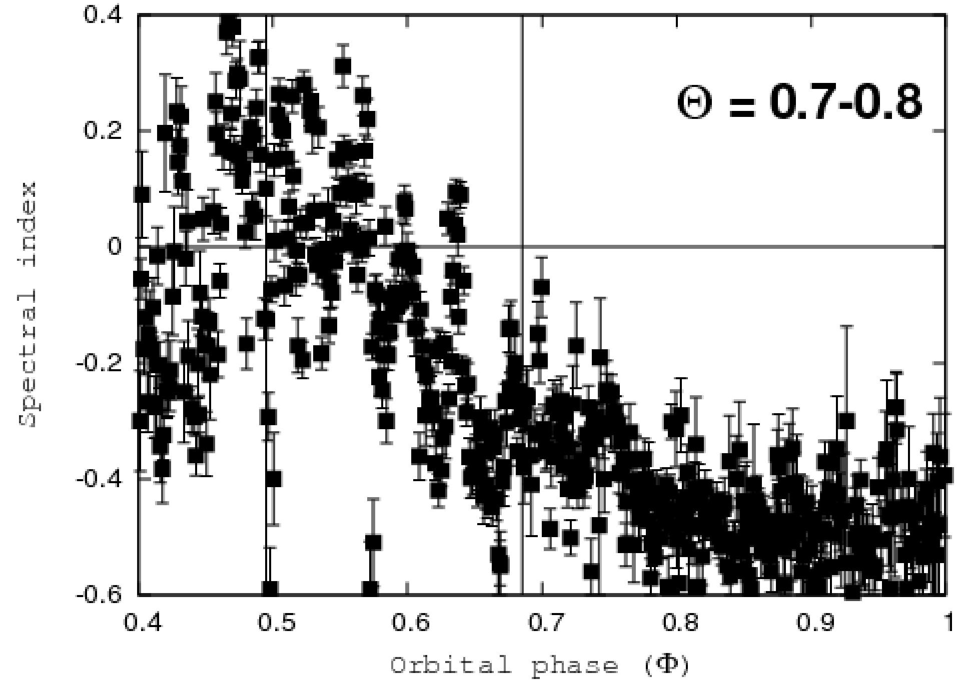

Radio spectral index against Φ for two different Θ intervals (0.0-0.1 and 0.7 to 0.8). The orbital occurrence of the switch, Φ_{crit}, changes from around 0.6 to around 0.75 for the two Θ intervals (Zimmermann, Massi, 2010, in preparation).

From radio spectral index analysis:

Θ modulates - the amplitude of the large radio outburst around apoastron

- the orbital occurrence of the large radio outburst

- **the orbital occurrence of the switch, Φ_{crit}, from $\alpha > 0$ to $\alpha < 0$**

3. High energy observations and the radio spectral index

Direct connection from the radio to the X-ray states:

→ Modulation by Θ also crucial for analysis of X-ray/high energy data:

- <u>Switch between radio states:</u>
  Change in radio spectral index **α**
- <u>Switch between X-ray states:</u>
  Change in photon index **Γ**

Spectral analysis of hard X-ray/high energy data of LS I +61303 should give heed to Θ

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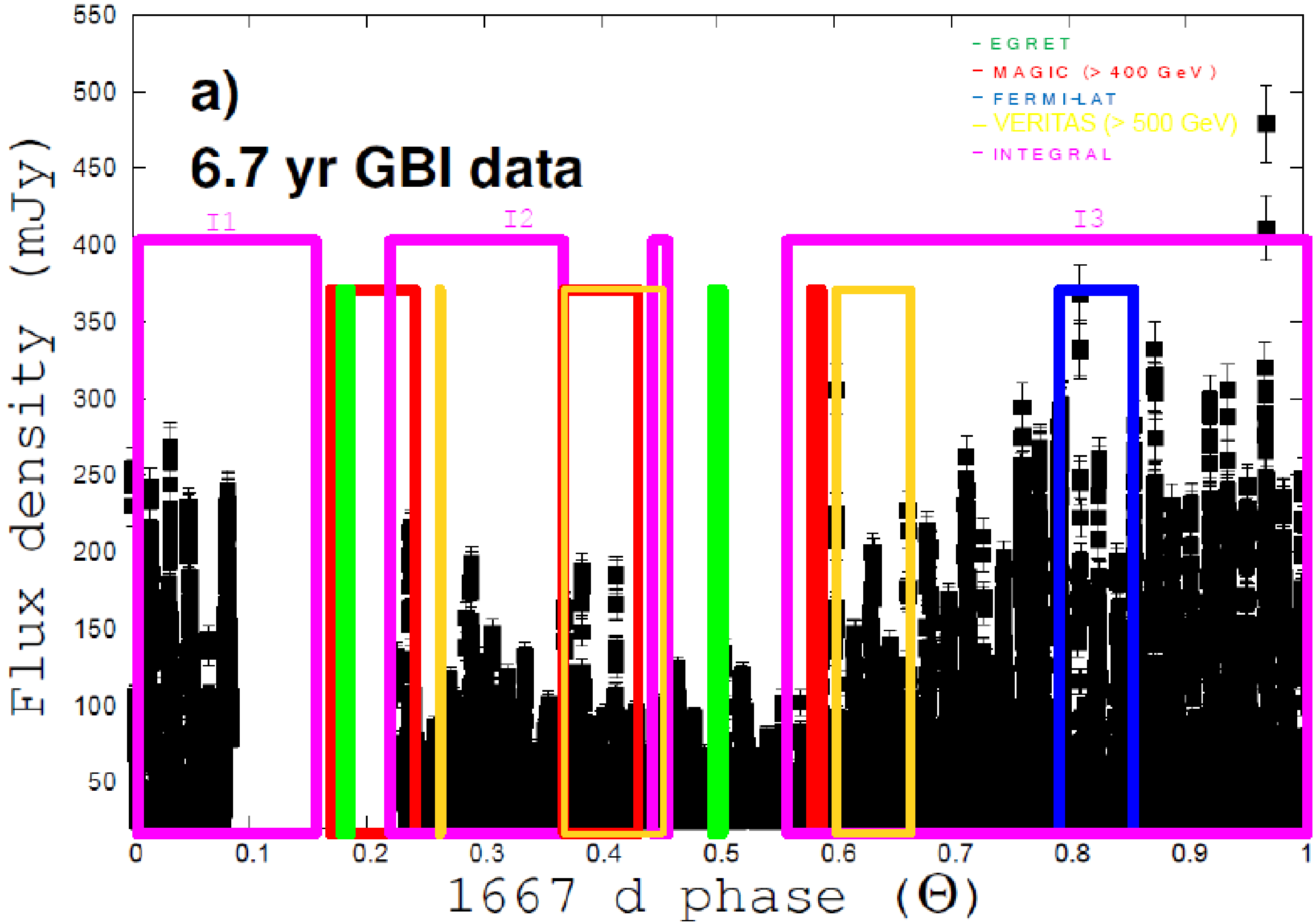


High and very high energy data from LS I +61303 in terms of Θ (Zimmermann, Massi, 2010, in preparation)

- MAGIC, VERITAS, EGRET observed only sparcely sampled intervals of Θ
- Largest intervals observed by INTEGRAL: I1, I2, I3

3. High energy observations and the radio spectral index

When comparing high energy data with radio data: take Θ into account

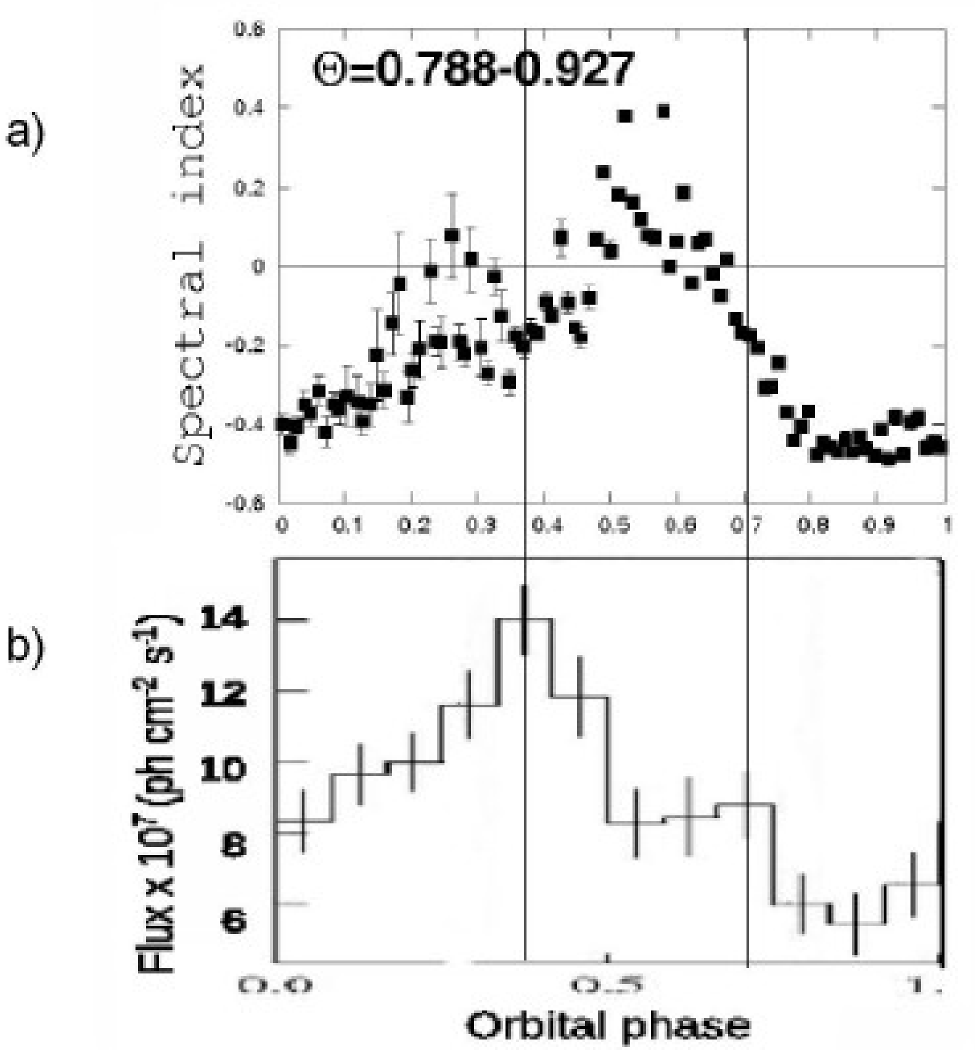
→ otherwise no clear association with the ejections

TeV observations:

- Θ around 0.4:
  - MAGIC and VERITAS detection: Φ=0.5-0.9
- Θ=0.6-0.67 and Θ=0.26-0.27:
  - VERITAS detection: Φ=0.15-0.3

GeV observations

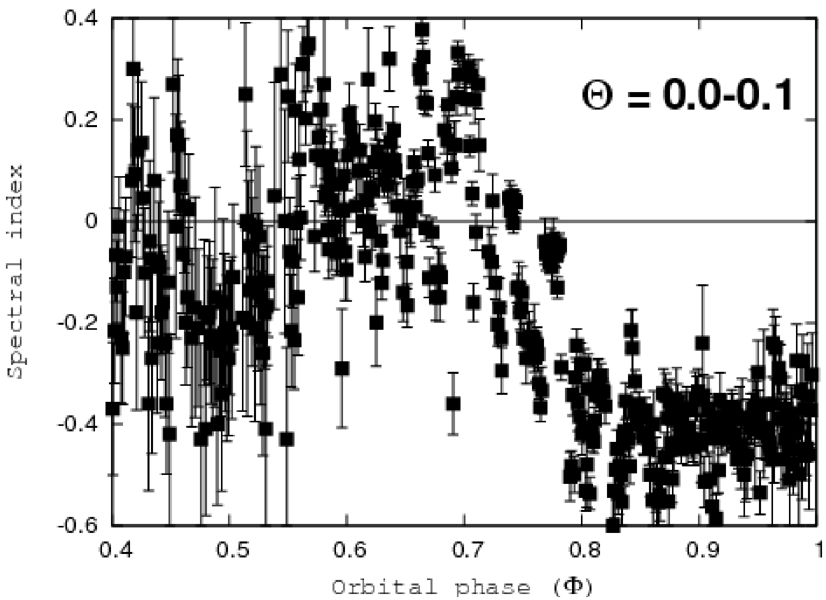
- FERMI-LAT data vs. α on the same Θ interval:
  - both peaks are associated to optically thin emission → transient jet
  - population of ultra-relativistic particles

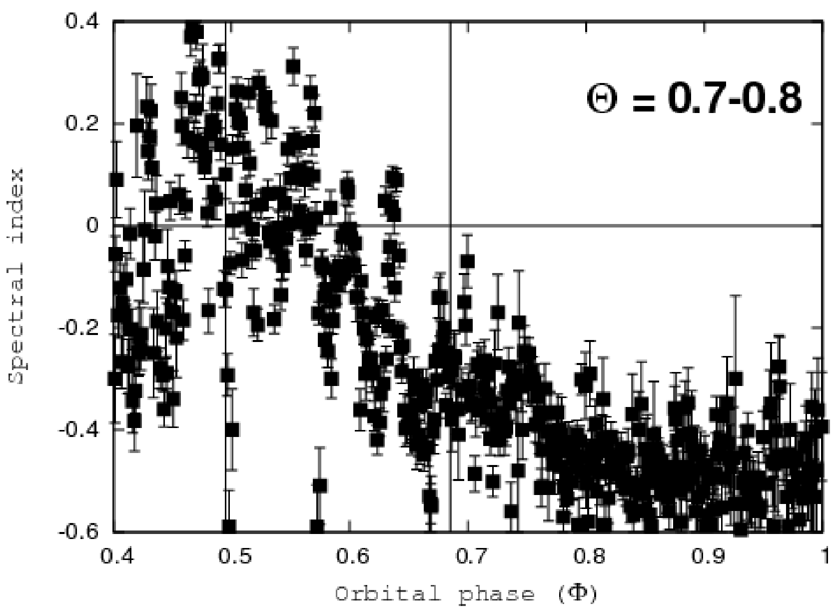


Top: Radio spectral index data for Θ=0.788-0.927 from GBI (Massi 2010). Bottom: FERMI lightcurve obtained by Abdo et al. 2009. The two vertical lines indicate the peaks around periastron and around apoastron. They both correspond to a negative spectral index in the radio data, which corresponds to optically thin emission in both cases.

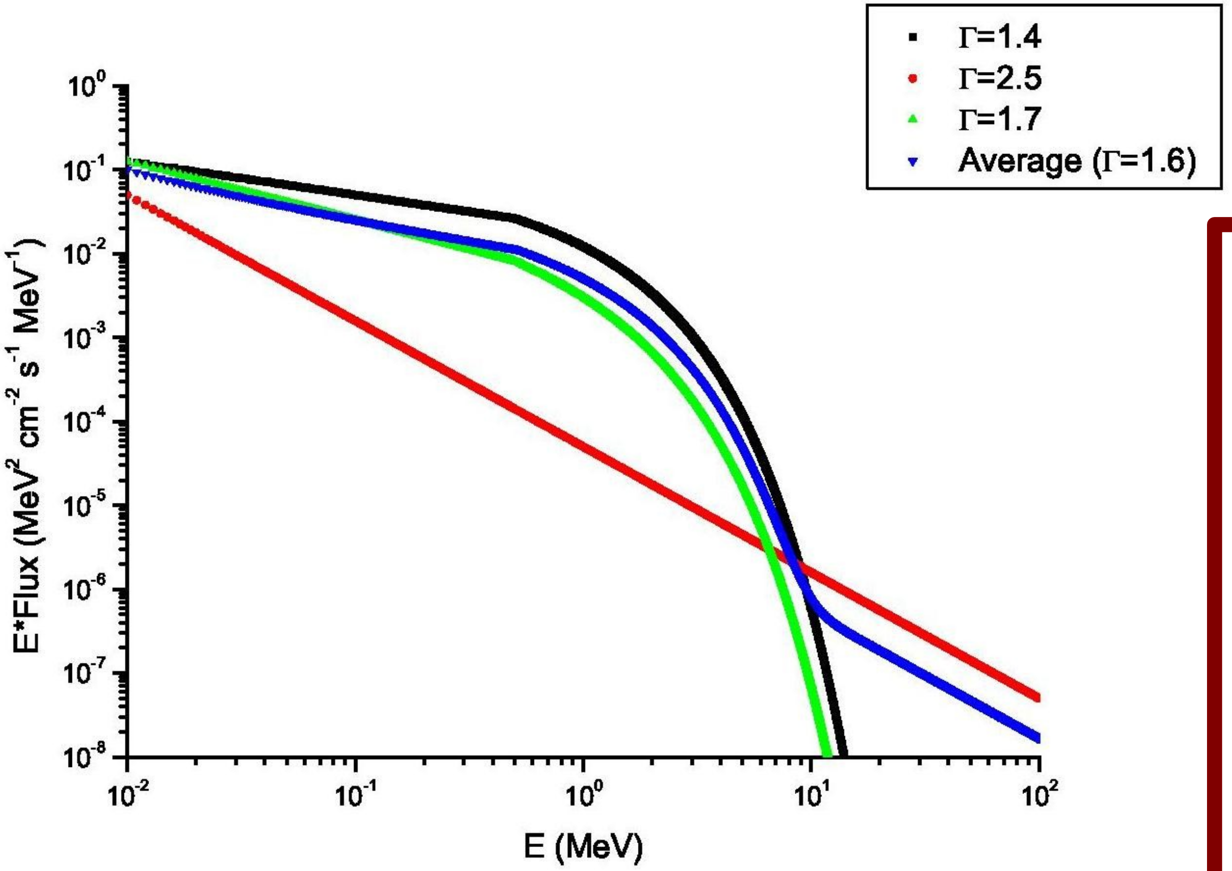
4. High energy observations of LSI +61 °303 and Θ

- Chernyakova et al. 2006 use parts of I3 and I1
  - Spectral analysis along the orbit find Γ=
    1.4 (Φ=0.4-0.6)
    1.7 (Φ=0.8-1.4)
    3.6 (Φ=0.6-0.8)
  - Averaging over the orbit gives Γ=1.6 without a cut-off
- Zhang et al. 2010 use I1, I2 and I3:
  - find Γ between 1.4 and 1.9 along the orbit
  - Averaging over the orbit gives 1.7 without a cut-off





3. High energy observations and the radio spectral index



Model spectra for the low hard (Γ=1.4 and 1.7), the steep power law state (Γ=2.5) and a weighted average of the three spectra which yields Γ=1.6 above the cut-off energy of 100 keV (Zimmermann, Massi, 2010, in prep).

- Typical model spectra:

  power law with/without cut-off

- Mixing or averaging over different spectra can yield:
  - Misleading photon index below the cut-off energy
  - Disguise the cut-off, because an extended powerlaw tail is part of the data

4. Summary

- **Two important periodicities:** Φ modulates the flux (radio, Halpha, X-rays, HE, VHE) along the orbit
  Θ modulates the amplitude and **orbital occurrence** of the large radio (and Halpha) outburst around apoastron

- Large outburst consists of two outbursts:
  - **optically thick then optically thin**
  - in microquasars: steady jet then transient jet

→ **Θ modulates the orbital occurrence of the switch from optically thick to thin emission**

- Unified model of X-ray states with radio jets:
  direct connection between radio and X-ray states:
  low hard (Γ ~ 1.5) ↔ steady jet
  steep power law (Γ > 2.5) ↔ transient jet

- Relevance of Θ for the analysis of hard X-ray/high energy data of LS I +61303:
  - **Folding over Θ** can lead to **mixing of ejection processes** and corrupt the spectral index analysis
  - **Comparison of high energy data with the radio spectral index** should be done on the **same Θ interval**

Thank you for your attention!