The energy distribution of electrons in radio jets

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(with Alexandros Tsouros)

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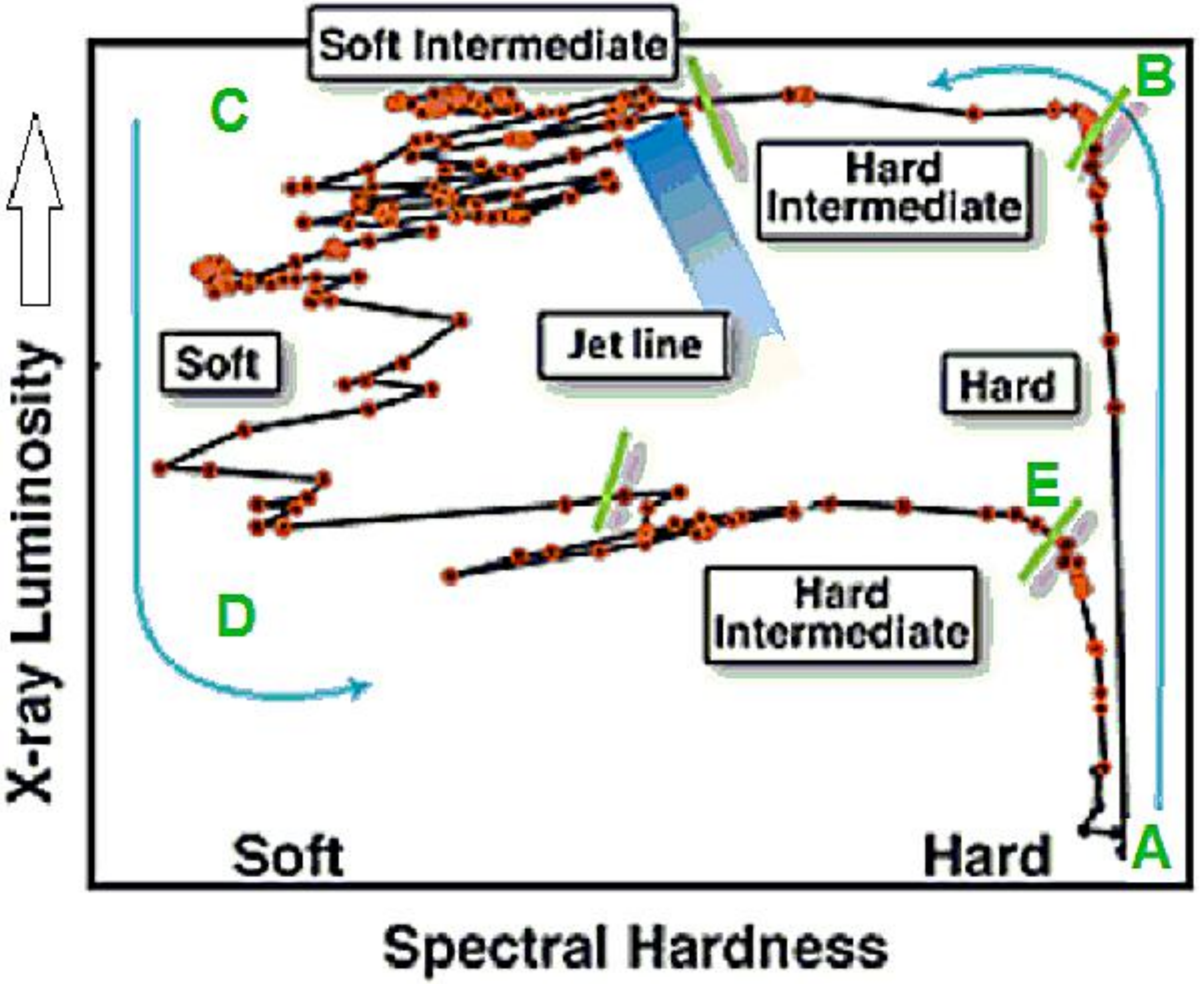
GX 339-4

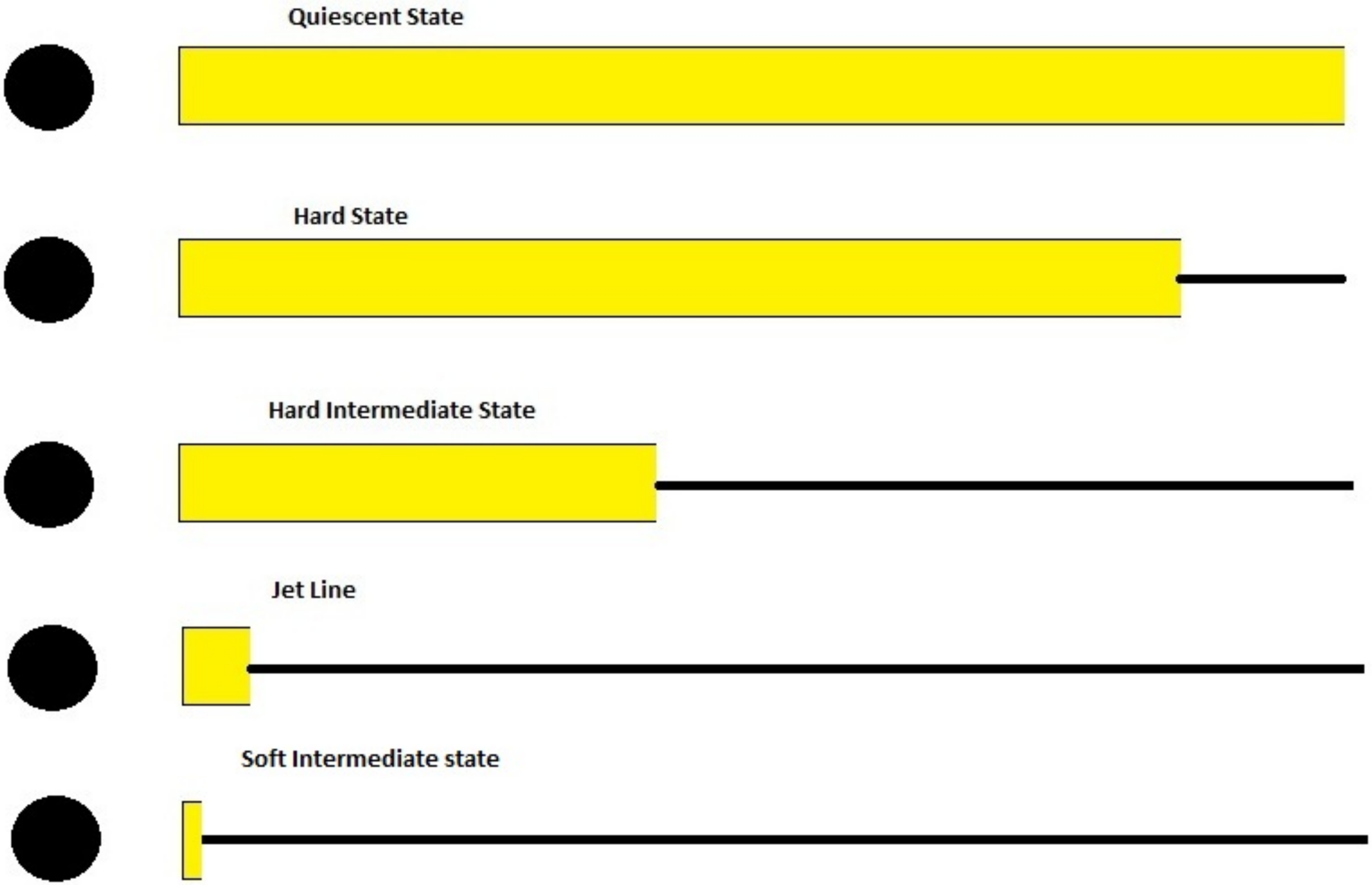

Soft Intermediate
B
C
Hard Intermediate
Jet line
Soft
Hard
E
D
Hard Intermediate
X-ray Luminosity
Soft
Hard
A
Spectral Hardness

Introduction

- Extending the work of Esin et al. (1997), and in order to explain the observed phenomenology,Tomaso Belloni and I (2015) considered the following picture regarding the accretion flow in BHXRTs.

- The transition radius moves **inwards** in the **upper** branch of the q-curve and **outwards** in the **lower** branch.

- Schematically then we have



Quiescent State

Hard State

Hard Intermediate State

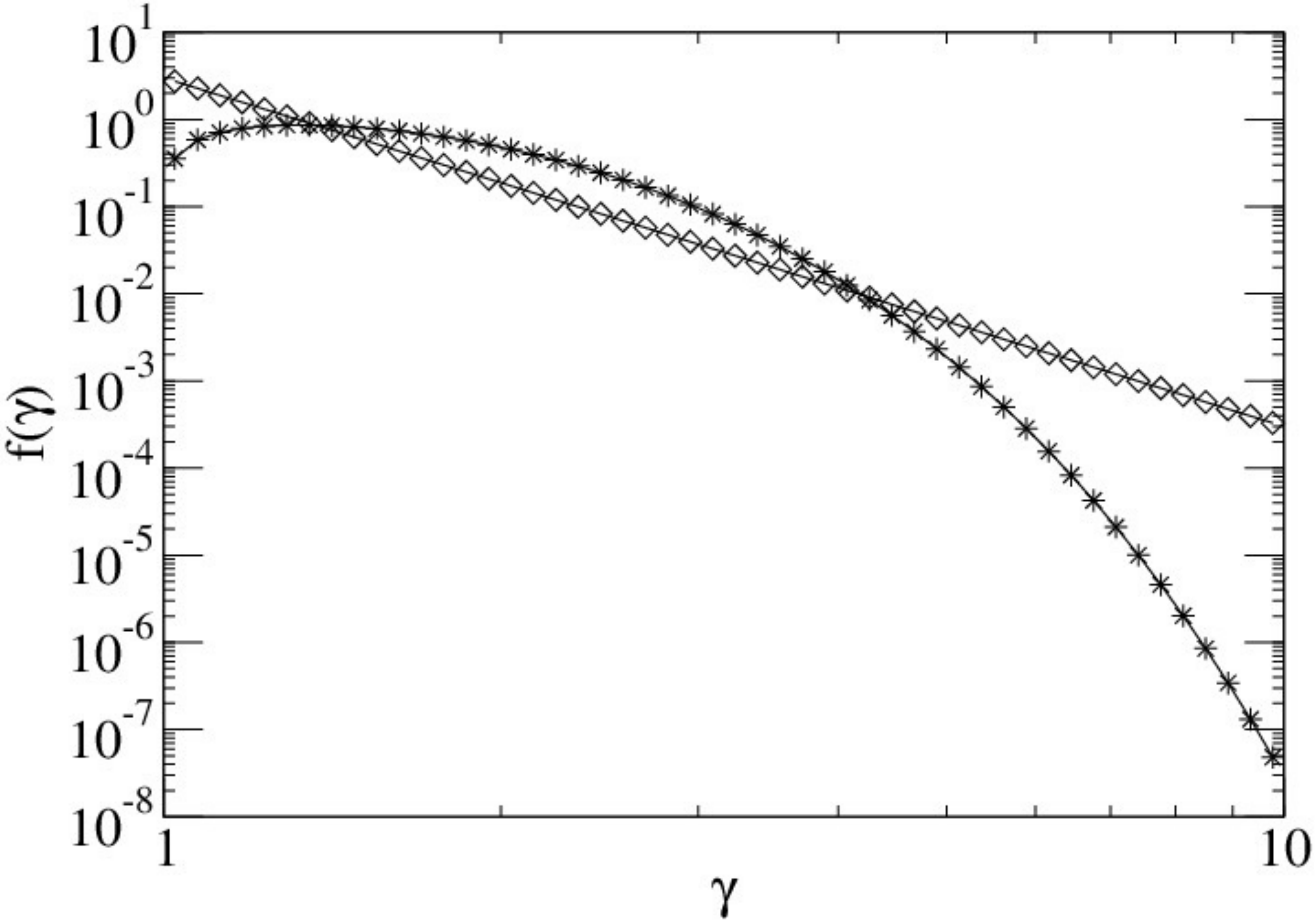
Jet Line

Soft Intermediate state

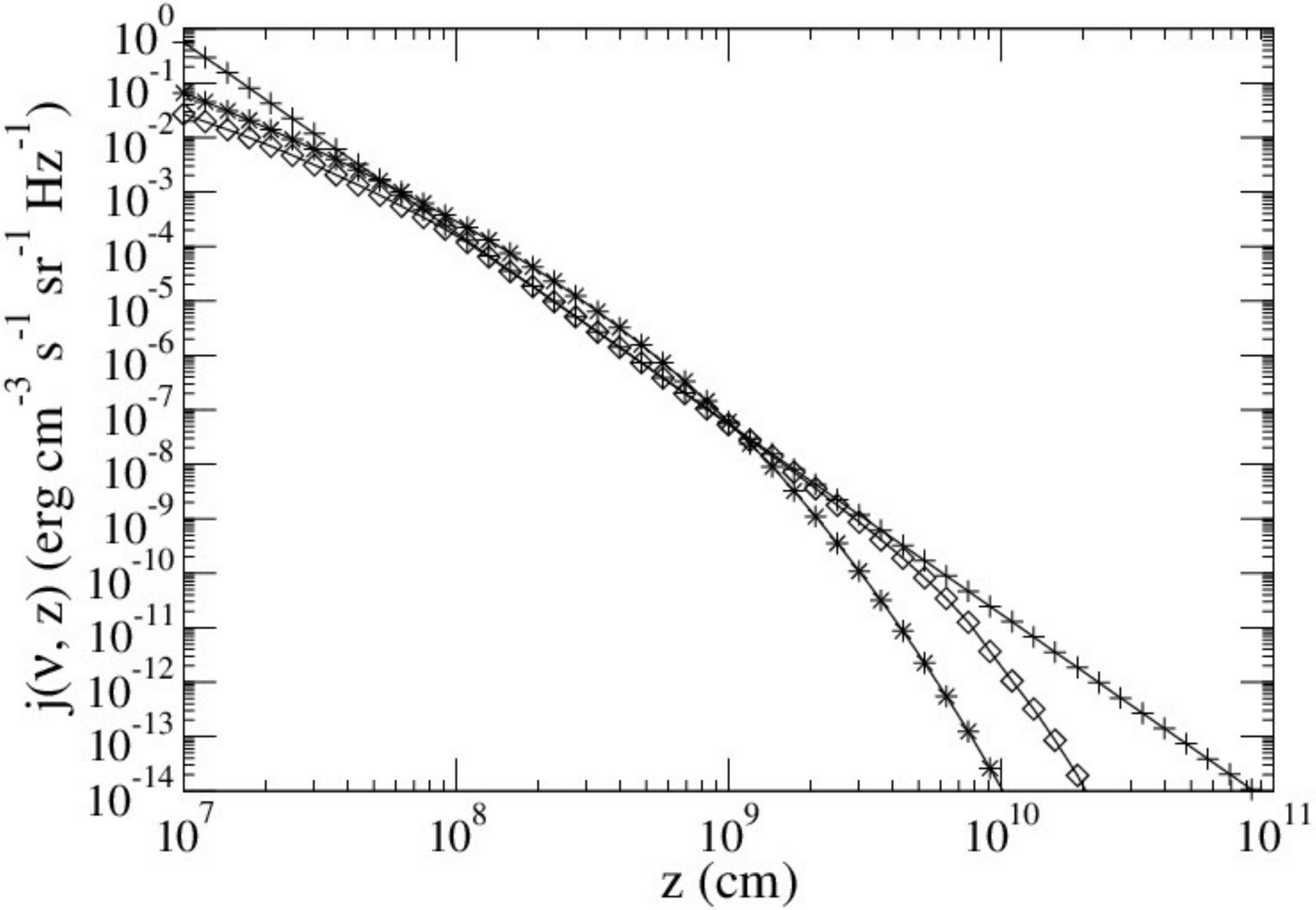
An unexpected result: Tsouros & Kylafis (2017)

- Let me ask a rhetoric question: **what is the energy distribution of the electrons in the jet?**
- Answer: **power law**, of course! We know this since 1979 (Blandford & Koenigl 1979; but see also Jones & Hardee 1979).
- However, now we know that the jet originates in the **hot inner flow** (ADAF-like).
- Thus, at least at the bottom of the jet, and possibly higher up, the electrons obey a **thermal distribution.**
- Question: what radio spectrum does a thermal jet produce?
- Answer: the same as a power-law distribution of electrons!!!

Thermal and power-law distributions



Emissivity of the various distributions at frequency 10^11 Hz



We have found that:

- Both distributions give **flat to slightly inverted radio spectra.**
- For a power-law distribution, 0 < alpha < **0.2**.
- For a thermal distribution, 0 < alpha < **0.5**.
- As the source MAXI J1836-194 (Russell T.D. et al. 2014) traverses its q-shaped curve, the radio spectral index alpha flip-flops between **0.2** and **0.5**.
- It is too early to draw any definite conclusion for the energy distribution of the electrons, but it is intriguing.
- Shocks may come and go in the jet (talks of Mathias Peault and Julien Malzac).

Summary & conclusions

- Work on jets with a thermal distribution of electrons (Falcke & Markoff 2000, for Sgr A*; Pe’er & Casella 2009).
- Largely, however, our community has ignored the possibility of a thermal distribution of electrons in jets.
- This must change! Now we know more than in 1979!!!

The Γ – timelag correlation in BHXRTs

(with P. Reig, I. Papadakis, & M. Costado)

A rhetoric question

- Had you discovered an important correlation in your Thesis, would you leave it unpublished?
- The answer is generally NO, but for our friend Emrah the answer is YES.
- In his PhD Thesis (Kalemci 2002), he found a nice correlation between Γ and timelag.
- I encouraged him to publish it, but he is too busy.
- This led Pablo Reig to start the data analysis from scratch.

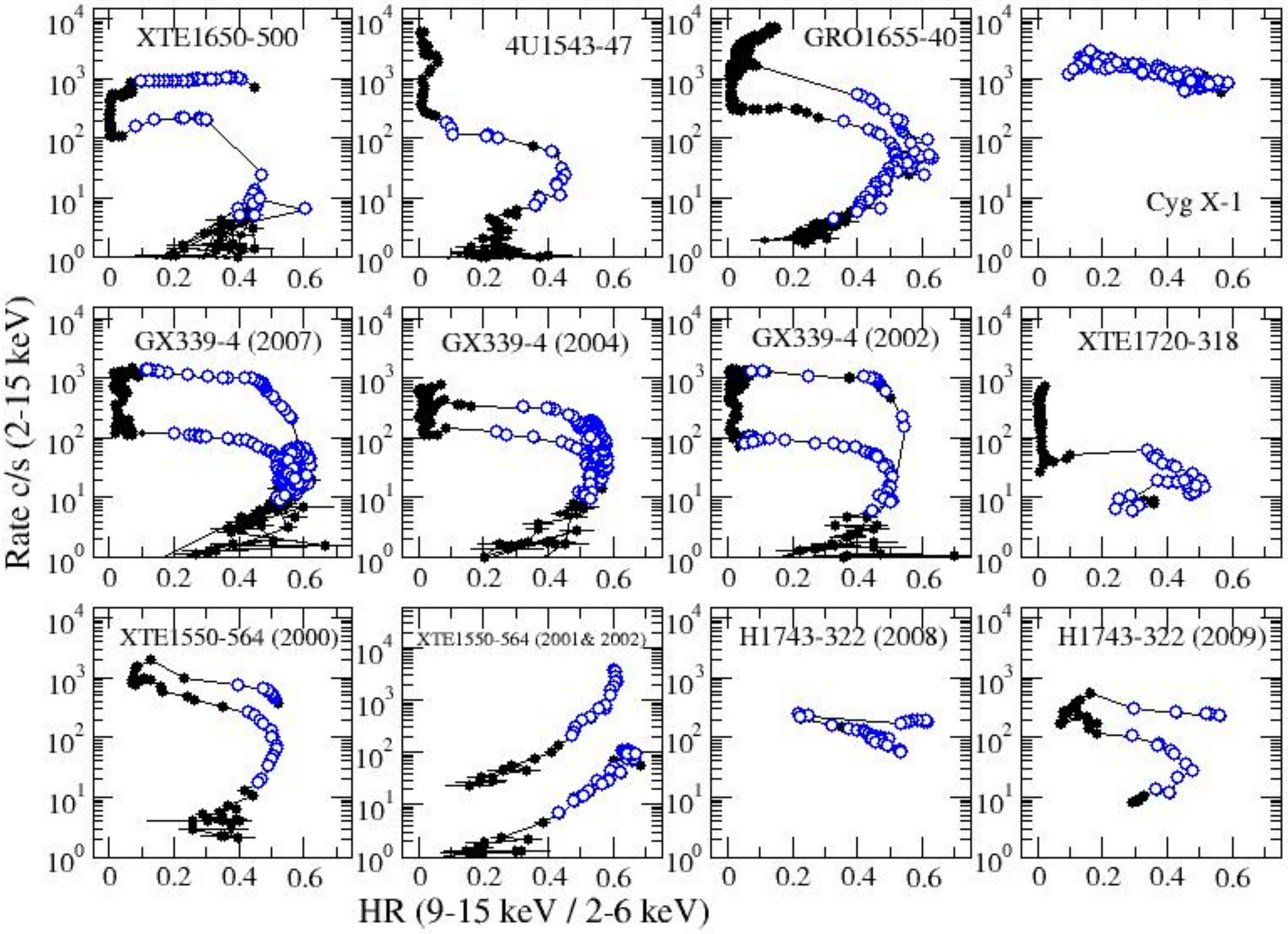
Observations

- Pablo analyzed RXTE data for 8 sources (12 outbursts), including Cyg X-1.

- He decided to select hard-state and intermediate-state data using the **rms variability only**.

- The results are shown as empty blue circles in the next viewgraph.

Hardness – Intensity plots for 8 sources (12 outbursts)



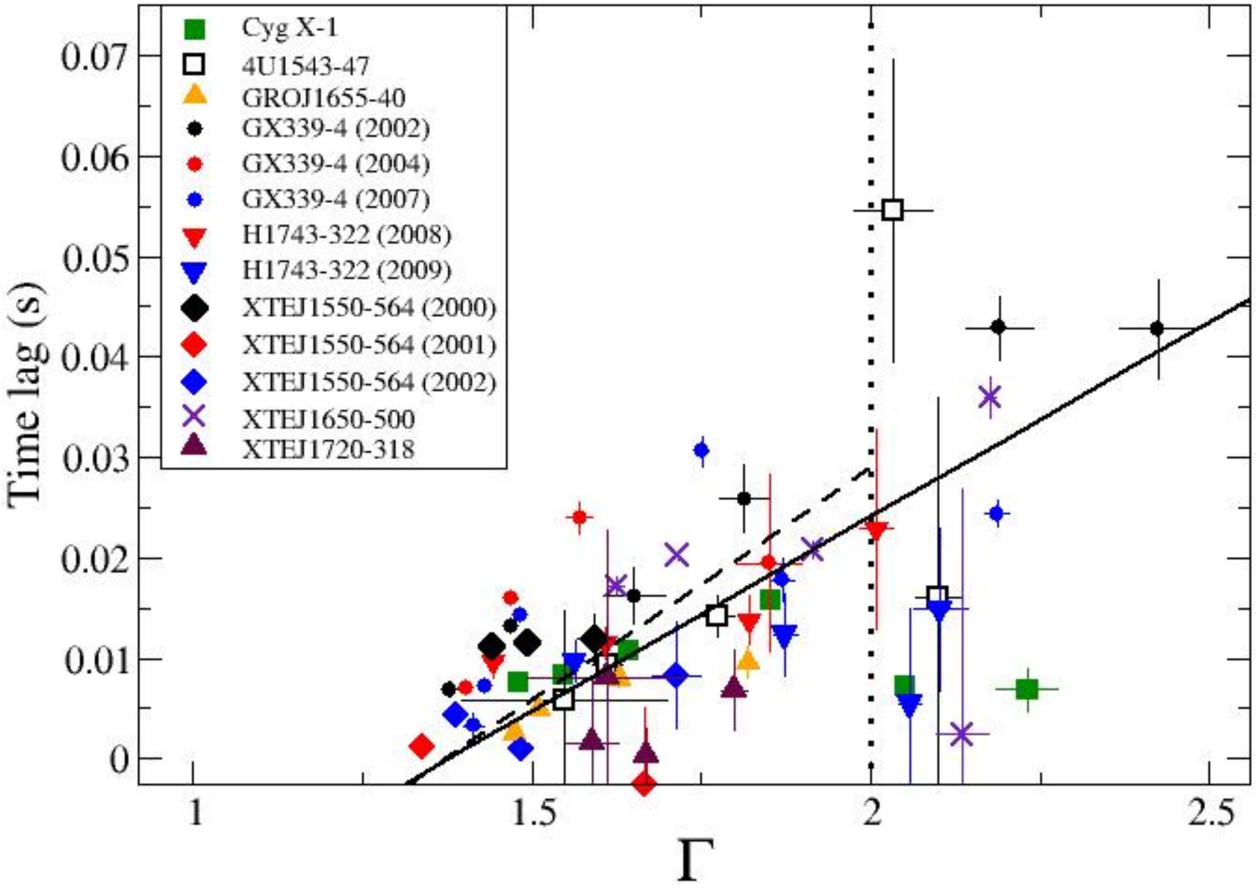
Spectral index Γ and timelag.

- For the spectral analysis we used the 3 – 150 keV spectra.

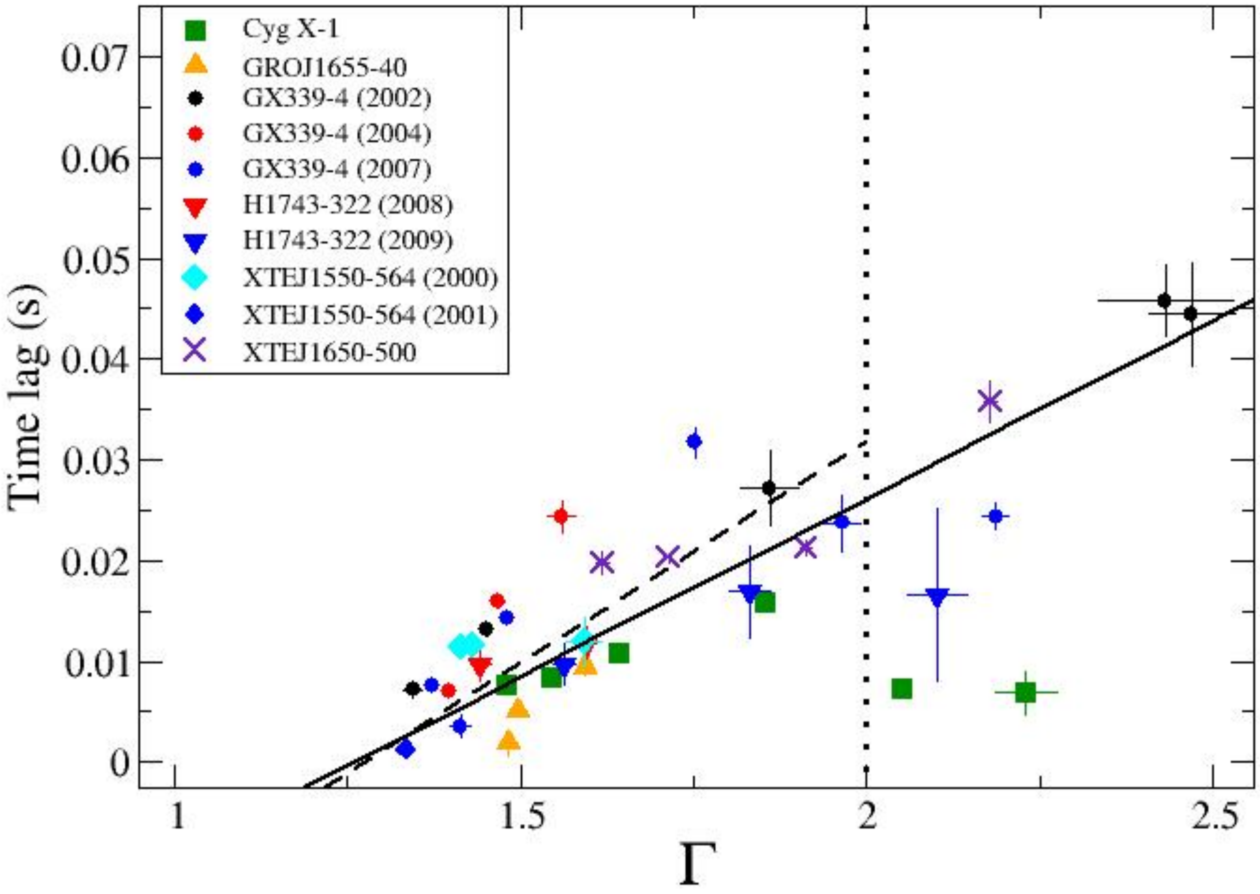
- We computed the timelag of the 9 – 15 keV photons w.r.t. the 2 – 6 keV ones. We averaged over the frequency range 0.05 – 5 Hz.

- I will show you first all the data and then separately the **rise** and the **decay** of the outbursts.

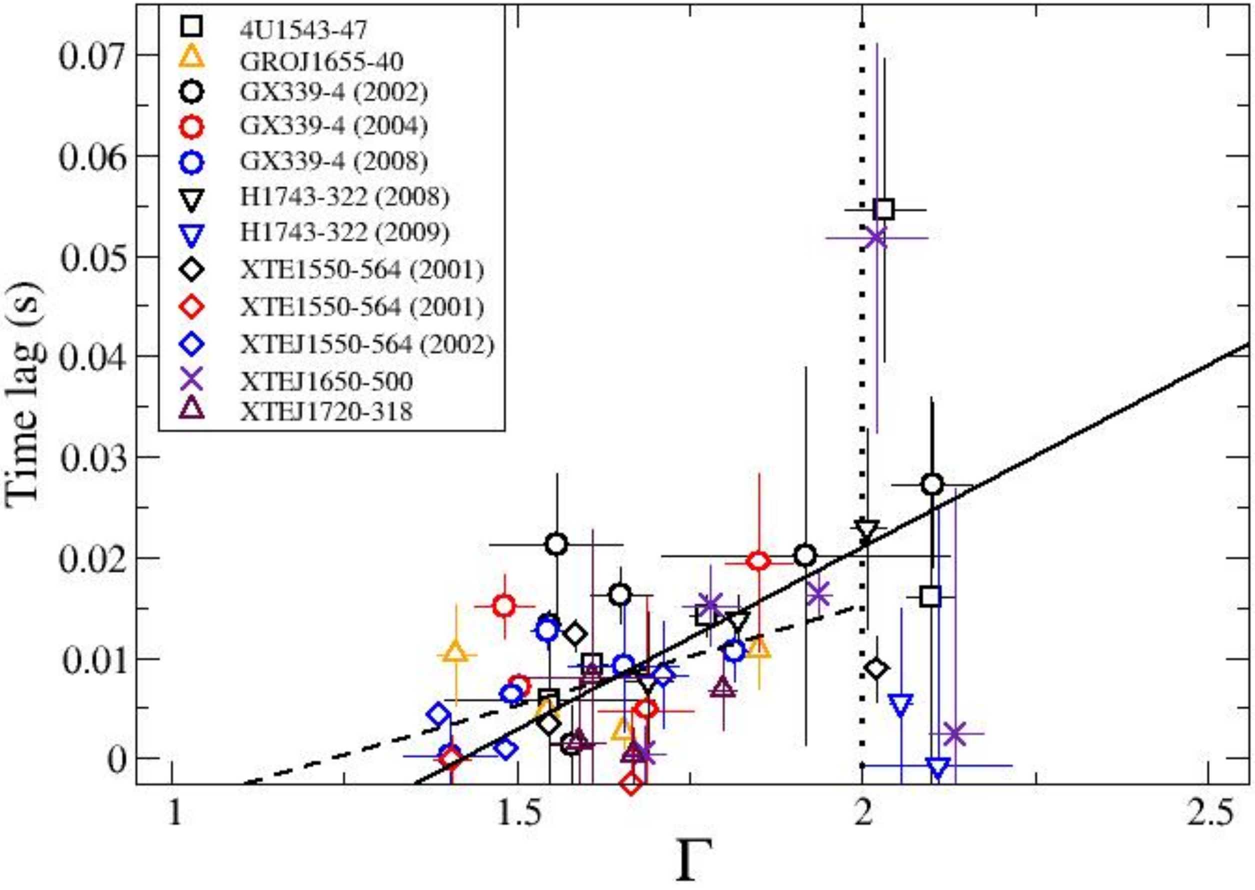
Timelag vs. Γ (all data)



Timelag vs. Γ (rise only)



Timelag vs. Γ (decay only)



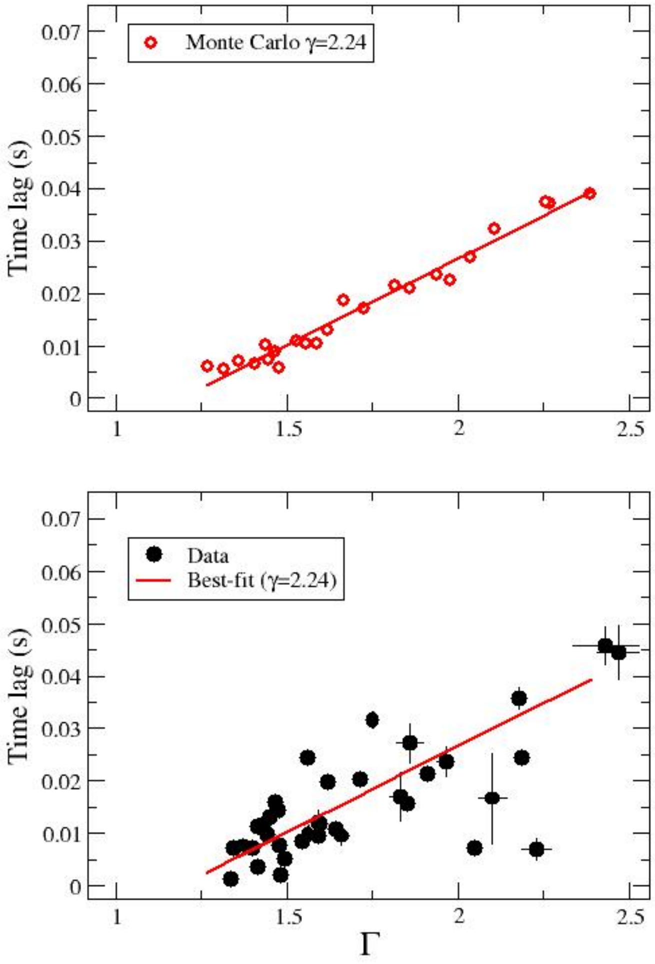
Jet model

- We have used our published jet model, i.e., Comptonization in the jet.

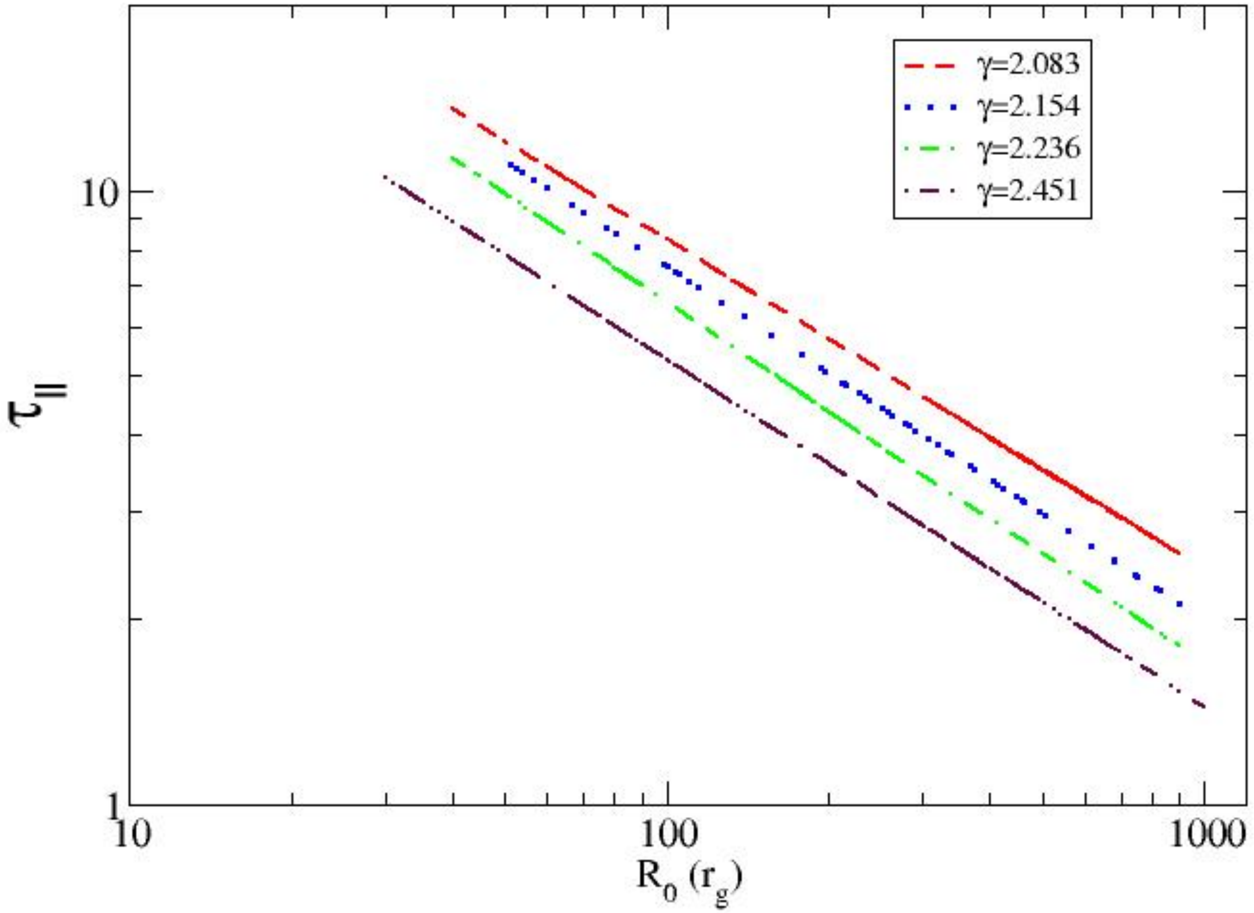
- We have varied two parameters: the optical depth along the jet (which mainly affects Γ) and the size of the jet (which mainly affects the timelag).

- As I will show you, the two parameters are correlated and not free.

Comparison of the model with the data



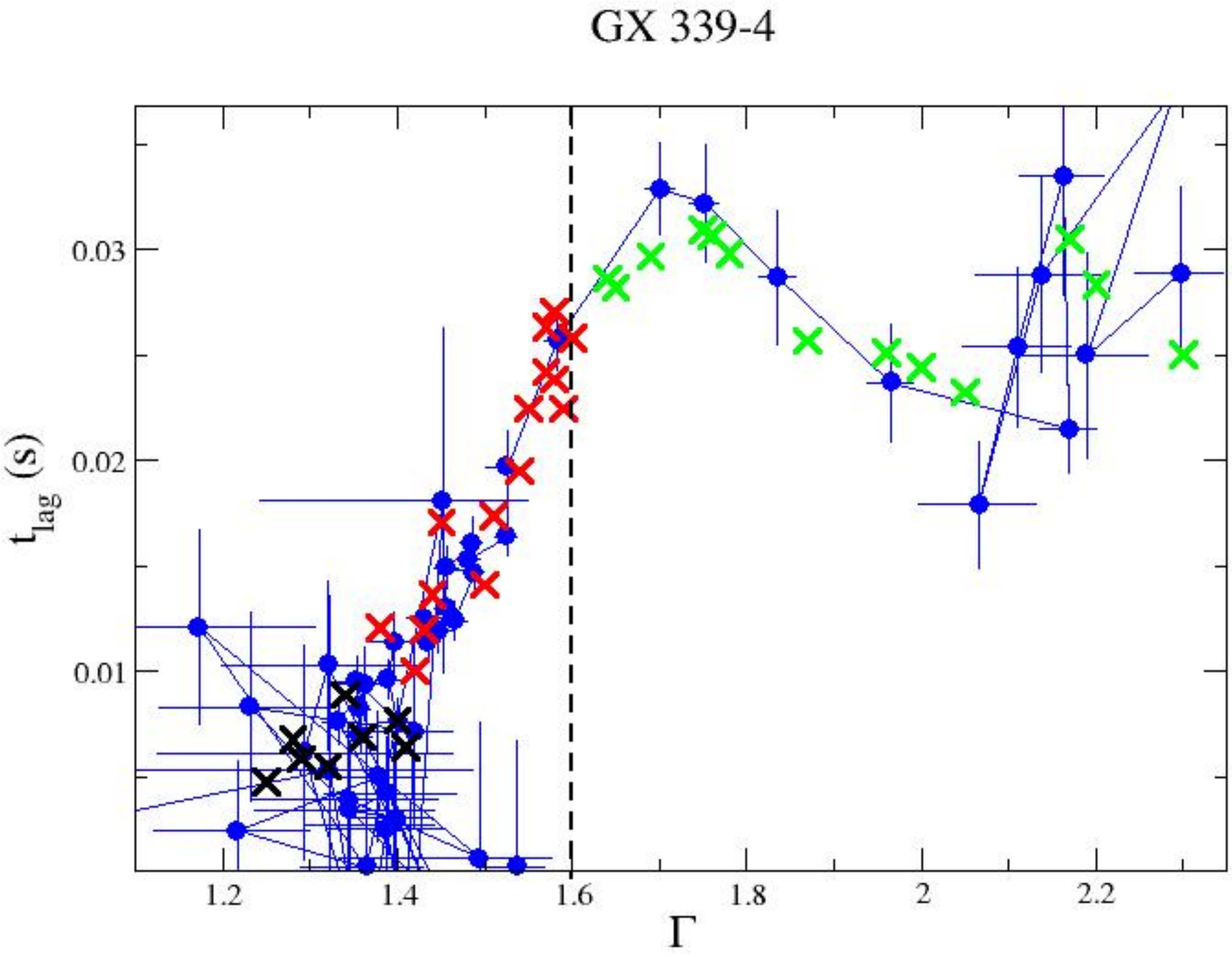
The two parameters are correlated



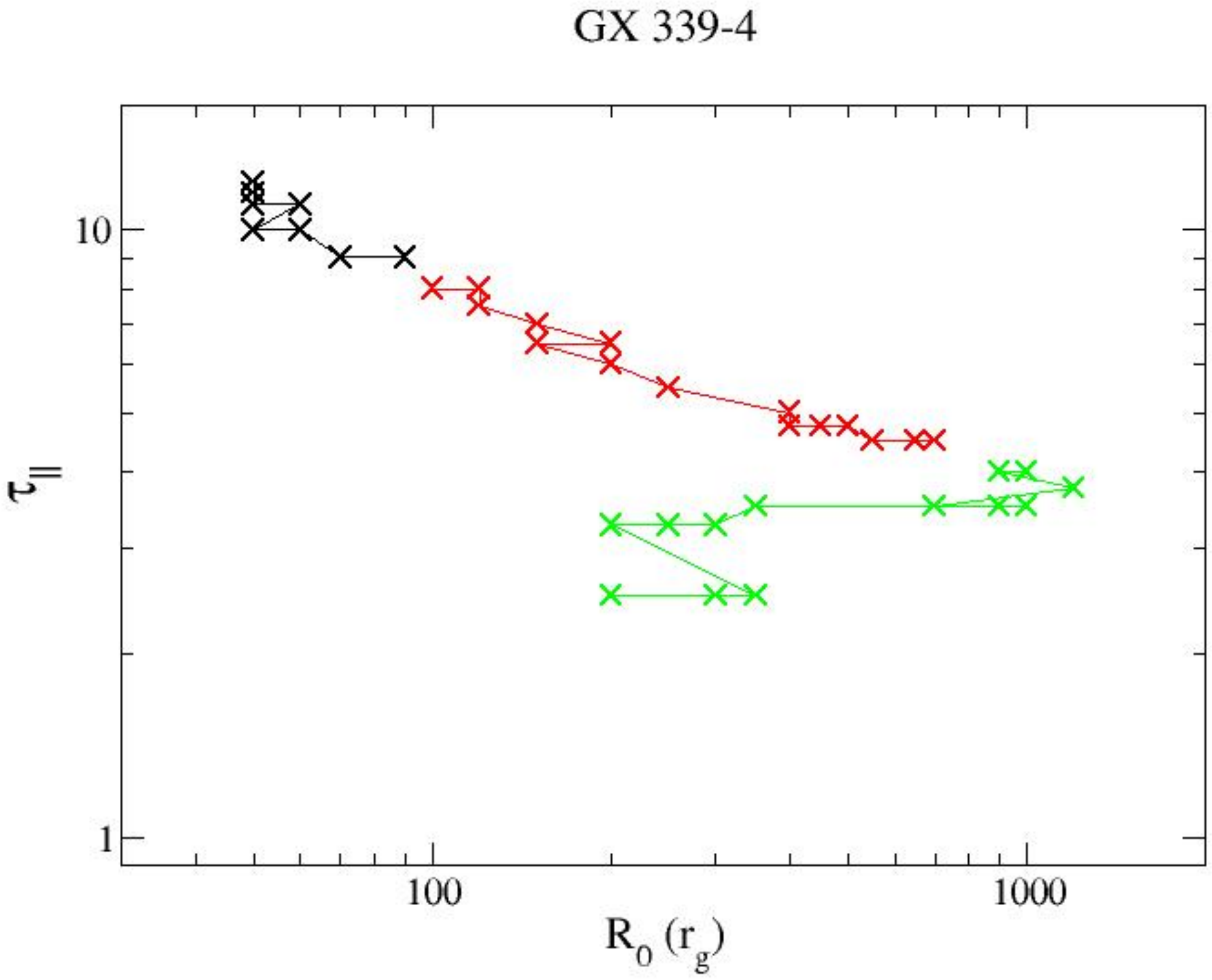
Detailed modeling of GX 339-4

- To put our model on a more stringent test, we have fitted the Γ – timelag correlation of GX 339-4 **from quiescence to the hard intermediate state**.
- We varied again, the optical depth and the size of the jet.

Detailed fit of the Γ – timelag correlation

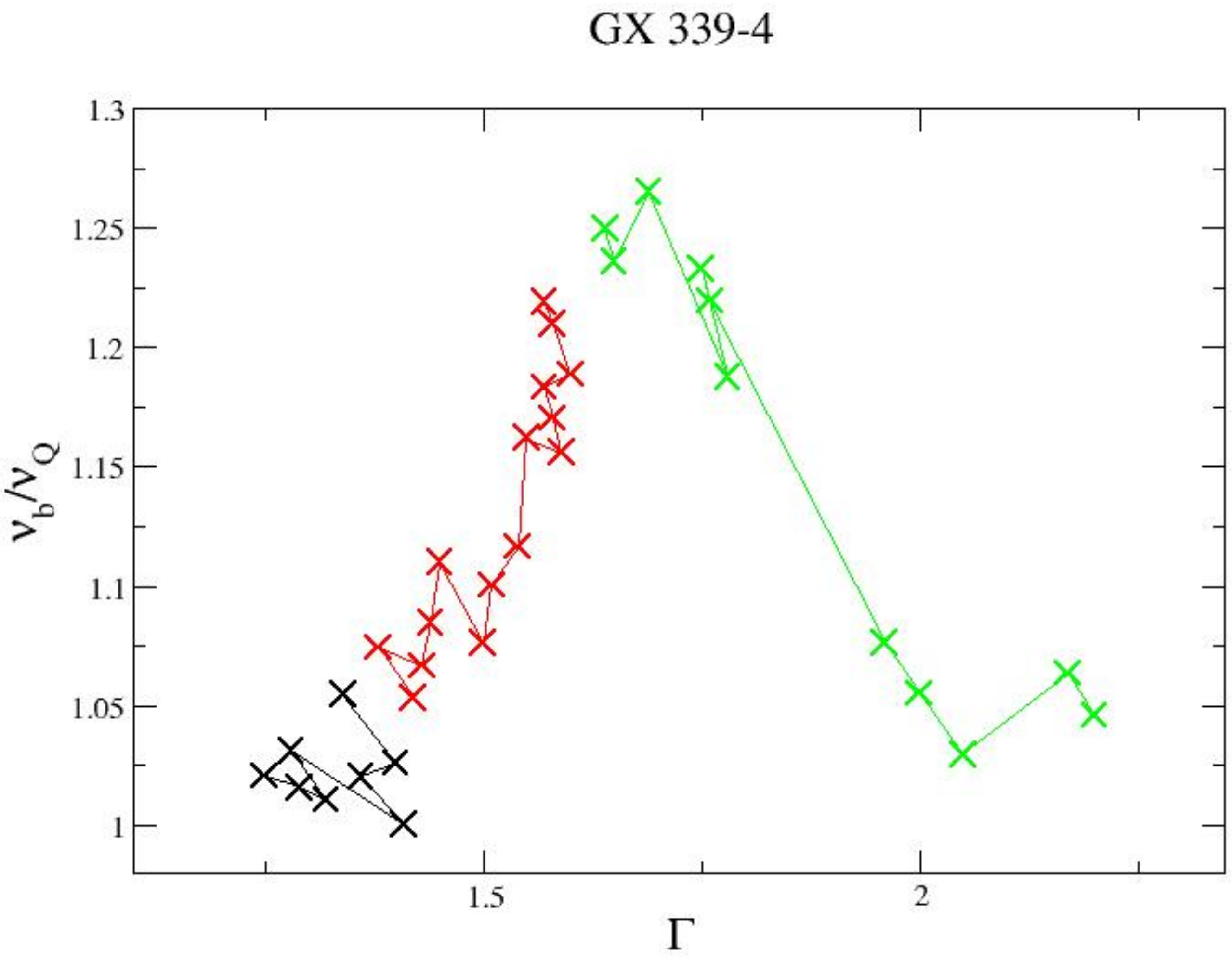


The values of the two model parameters (τ , R0) are correlated



Prediction

Break frequency in radio spectrum vs. Γ



Comments

- It is unavoidable that **propagating fluctuations** play a role in time lags.

- In my opinion, equally unavoidable is that a fraction of the seed photons will be **scattered in the jet**. This is because

- the jet lies **just above** the Comptonizing region, which is optically thin! **There is nothing that will prevent the photons from entering the jet**.

- Can we tell if one of the two dominates?

Another prediction

- Use the timelag of the optical or the infrared w.r.t. the X-rays.
- Compute this timelag **not for the whole X-ray band**, but for different bands, e.g. 3 – 10, 10 – 30, 30 – 100 keV.
- If the Comptonization takes place in a **small region**, then the timelag will be the same for all bands.
- If the Comptonization takes place in the **jet**, there will be different timelags.

THANKS