# The Role of Jets in Black-hole X-ray Binaries

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Agios Nikolaos, 5 May 2010

# Introduction

- In my opinion, the jets from compact X-ray sources have not been given proper attention.
- Most people treat jets simply as “fireworks”, which do nothing else than emit radio waves.

# I hope to convince you that

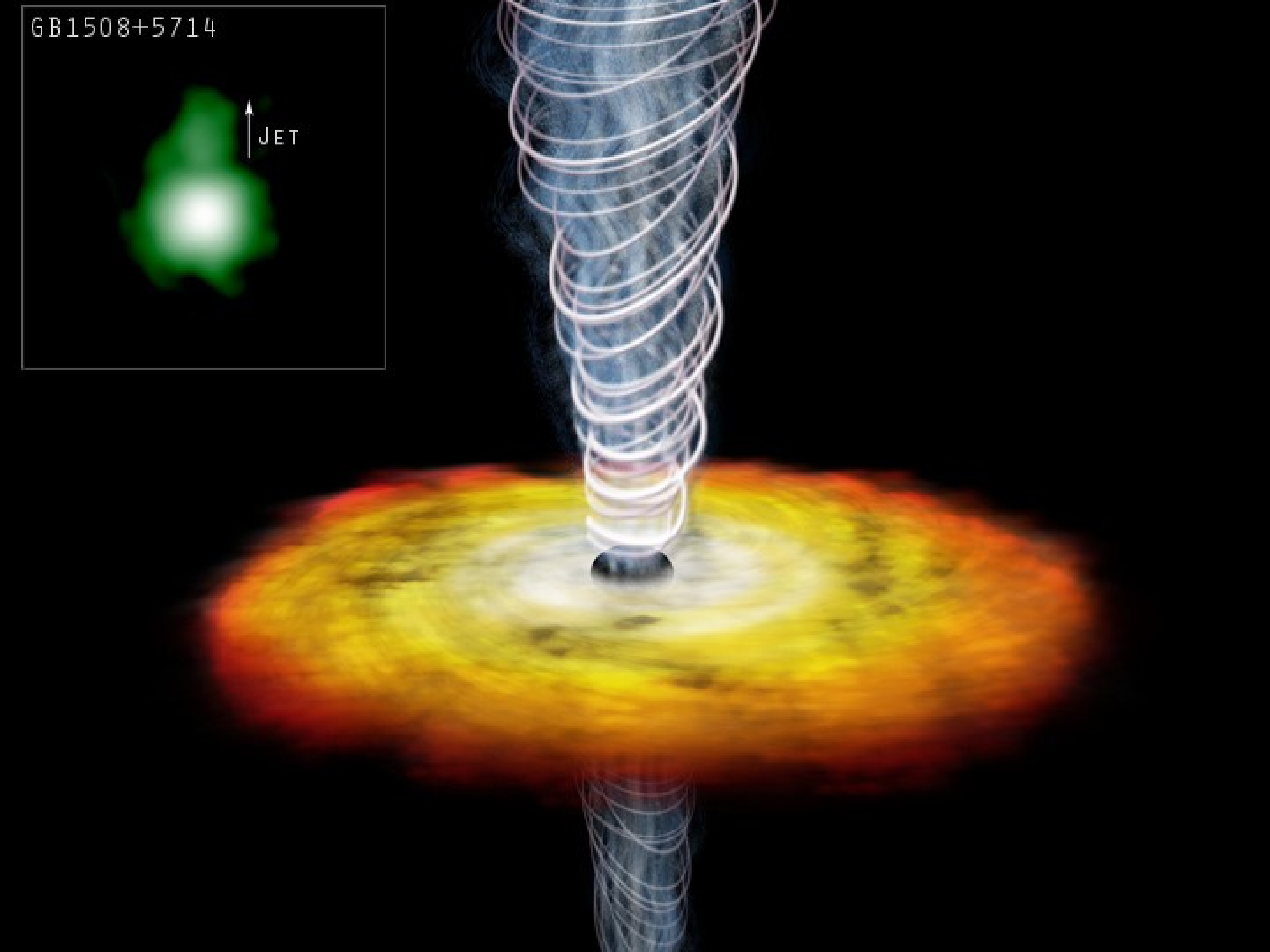
- The jet is a central player in the observed phenomena and not simply an embellishment.

# The jet model

- In a series of four papers

  Reig, Kylafis, Giannios 2003, A&A
  Giannios, Kylafis, Psaltis 2004, A&A
  Giannios 2005, A&A
  Kylafis, Papadakis, Reig, Giannios, Pooley, 2008

  we proposed a jet model that explains a number of observational facts, when the black-hole X-ray sources are in the hard state.


GB1508+5714
JET

# Ingredients of the model

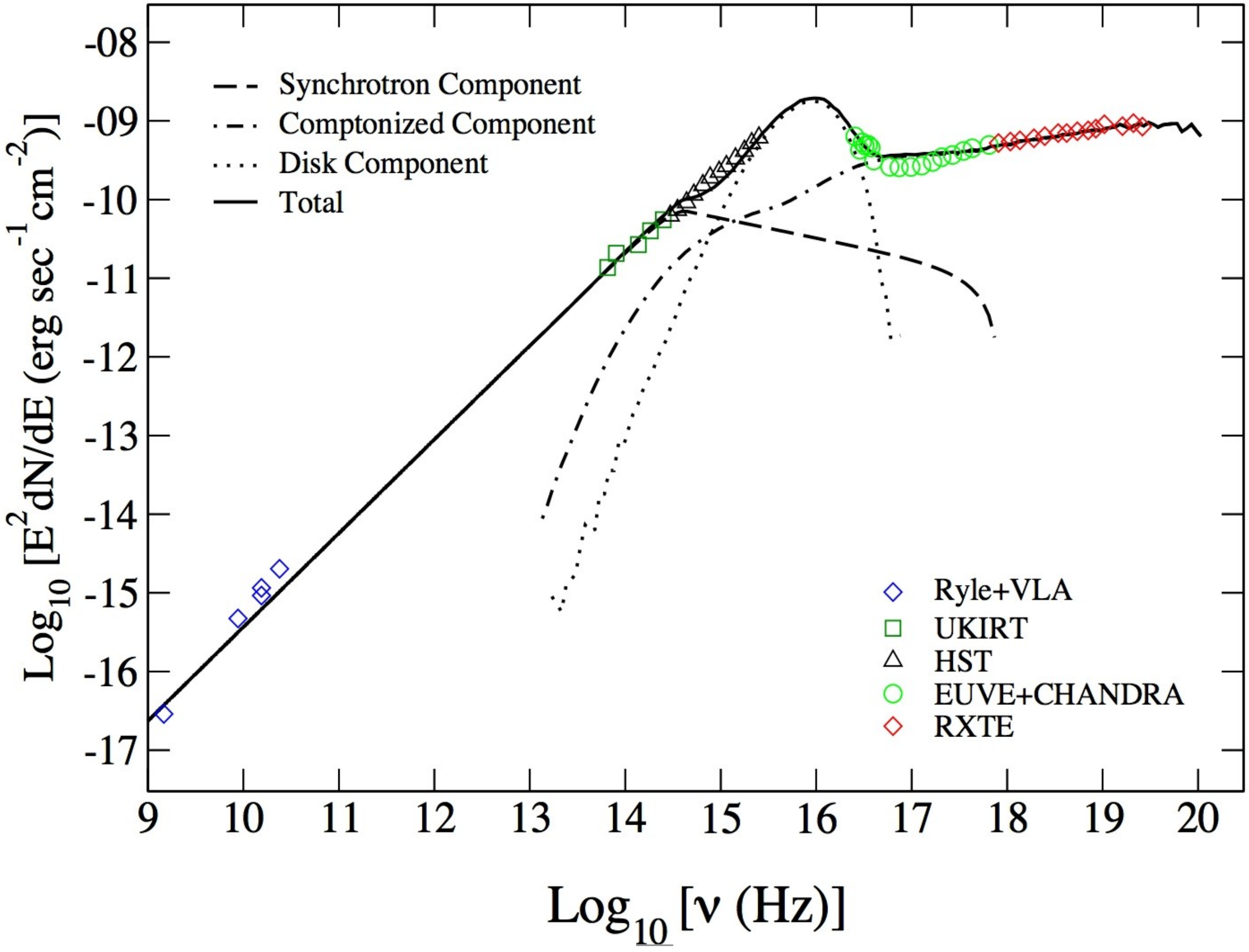
- The jet is semi-relativistic (v ~ 0.8 c).
- The density in the jet falls off inversely proportional to distance from the black hole.  Such flows are allowed theoretically (Vlahakis & Koenigl).
- In the rest frame of the flow, there is a power-law distribution of electron γ's (standard assumption for radio jets).
- Soft photons from the accretion disk get up-scattered in the jet and a power-law spectrum is produced in hard X-rays (photon number index Γ).

# Observational facts

- ENERGY SPECTRUM

- Up to now, only for one source (XTE J 1118+480) we have simultaneous observations from radio to hard X-rays.

# Giannios 2005, A&A



- Model and observations for XTE J 1118+480

# Life is not so easy however ☹

- Impressive as the model fit may be, it DOES NOT constrain the model!

- Equally good fits to the data are produced by other models:

  Markoff, Falcke, Fender 2001, A&A
  Vadawale, Rao, Chakrabarti 2001, A&A
  Corbel & Fender 2002, ApJ
  Markoff et al. 2003, A&A

Let’s see why.

# Comptonization

- One can get a power-law X-ray spectrum with either thermal or non-thermal electrons.
- Also, the shape of the Comptonizing region can be spherical, cylindrical, planar, whatever!
- Thus, the energy spectrum alone CANNOT constrain the model.

# Time lag between hard and soft X-rays

- It has been observed (Nowak et al. 1999; Ford et al. 1999) that the hard X-rays (say 8 -14 keV) lag the soft X-rays (say 2 - 4 keV).

- This is expected for Comptonization models.

- However, the time-lag is a function of Fourier frequency!!!

- This is contrary to intuition for simple Comptonization models.

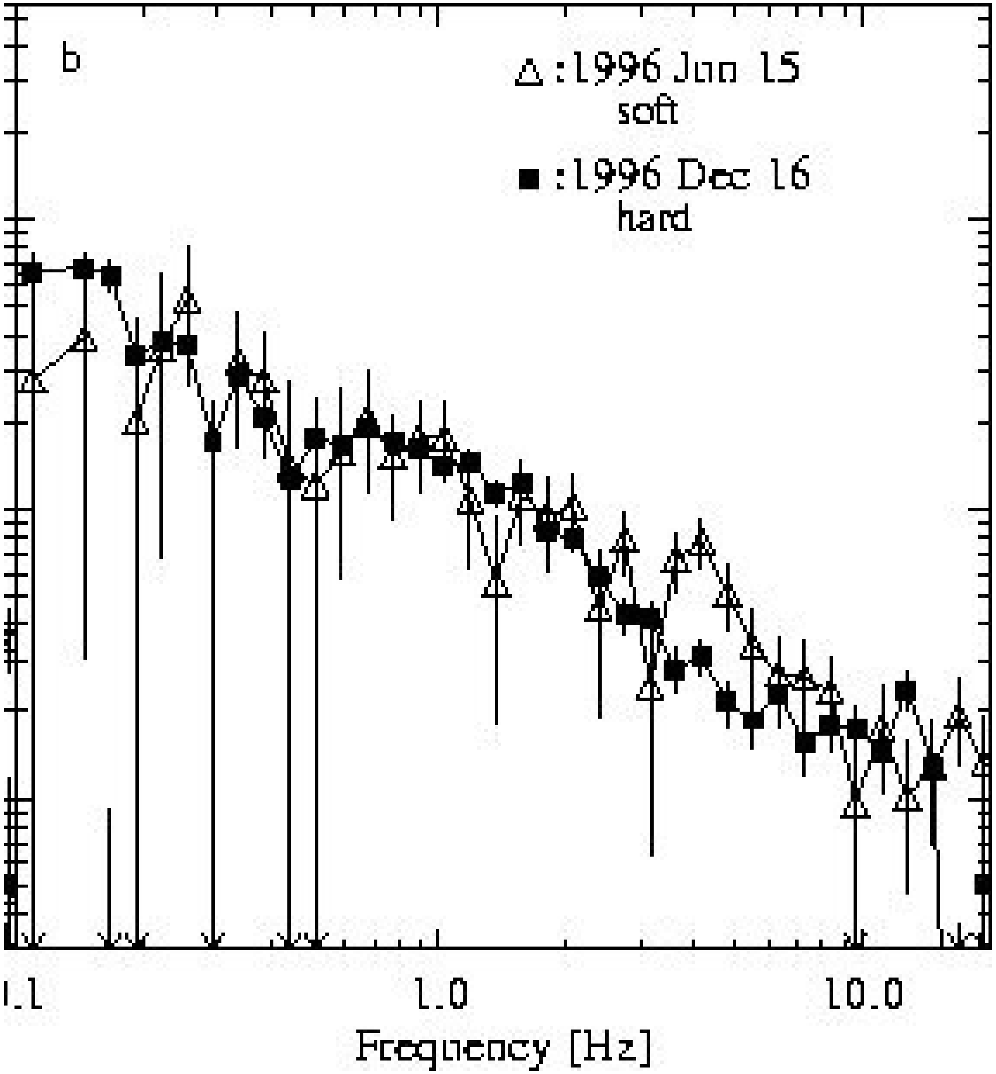
# Time lag between hard and soft X-rays

- For Cyg X-1,

$$t_{lag} \propto \nu^{-\beta}, \beta \approx 0.7$$

# Time lag vs Fourier frequency

Time lag



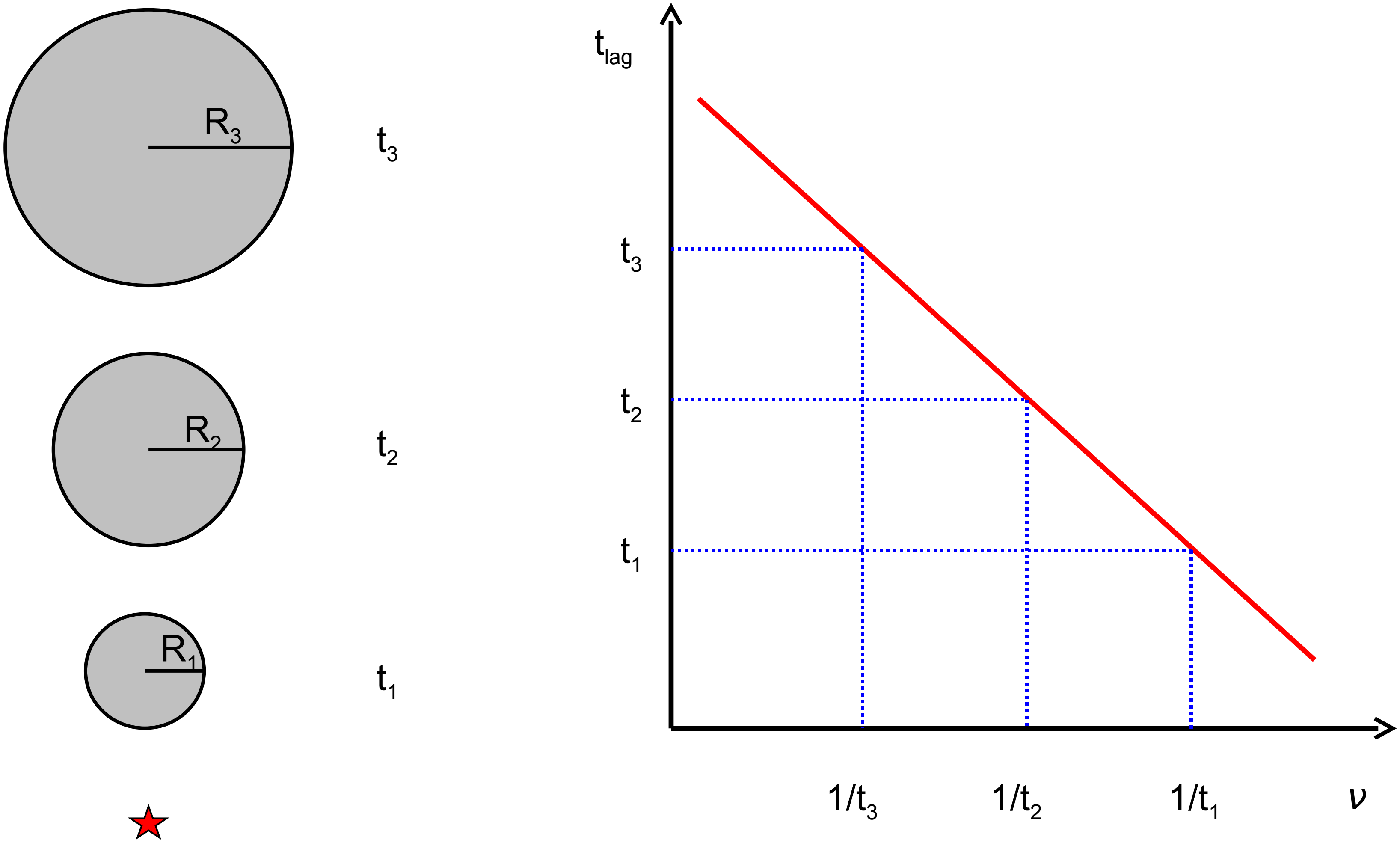
# Compton scattering acts like a filter

- It cuts off the high frequencies.

- If (period of variability) < (time lag), the variability is washed out.

- Therefore, frequencies > 1/(time lag) are not observed.

# Schematic picture of our jet



# Other models

- Constraining as it is, the time lag vs Fourier frequency relation has been explained by other models also:

Poutanen & Fabian 1999, MNRAS
Kotov, Churazov, Gilfanov 2001, MNRAS
Koerding & Falcke 2004, A&A

Therefore, even more constraints are needed.

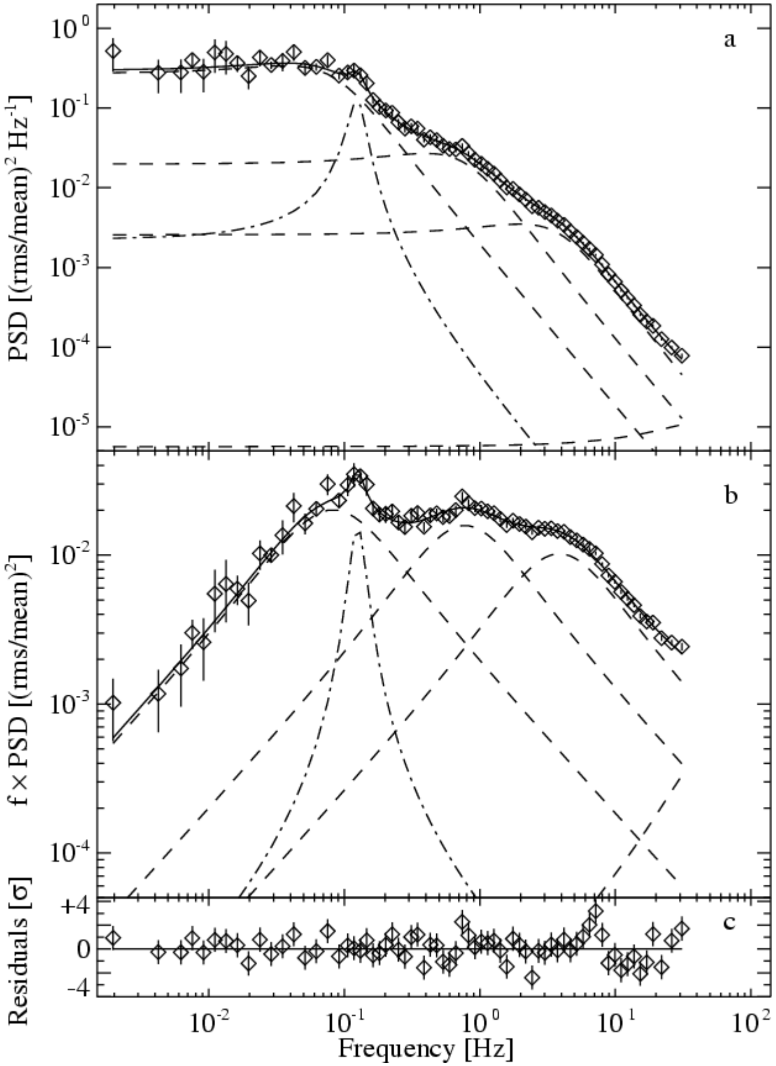
# More observational constraints

- The long-term variability of Cyg X-1 has been studied by Pottschmidt et al. (2003), A&A (see also Shaposhnikov & Titarchuk 2006; 2007).
- When the source was in the hard state, the study revealed a number of very stringent constraints.
- These are:

# Pottschmidt et al. (2003), A&A

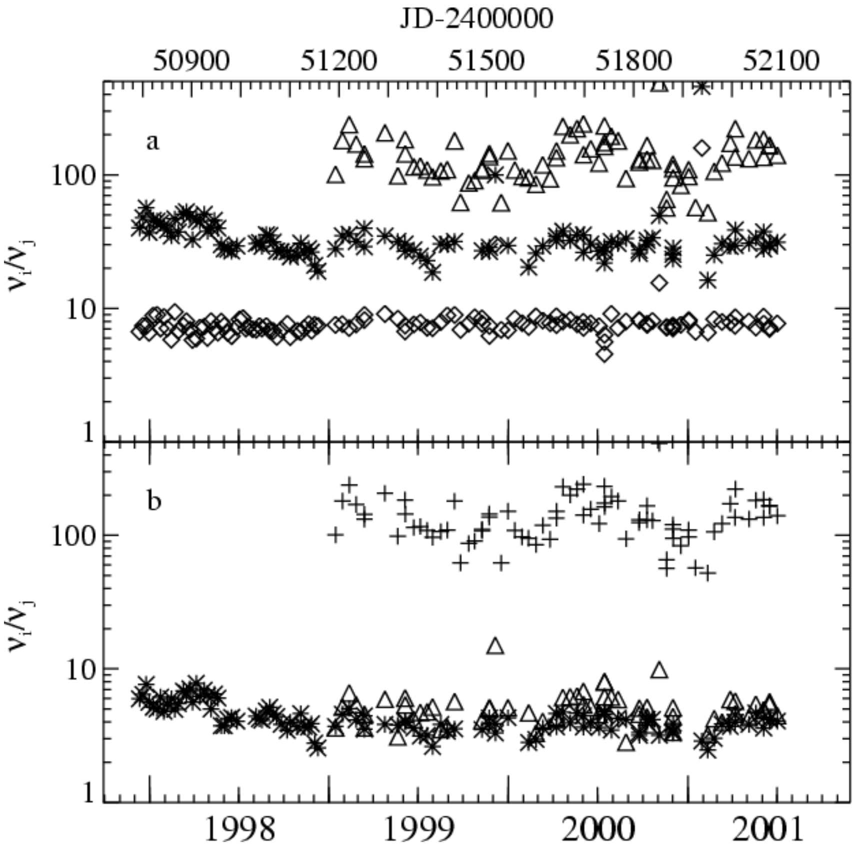
- The power spectrum of Cyg X-1 was fitted with four broad Lorentzian profiles that have peak frequencies

$$\nu_1, \nu_2, \nu_3, \nu_4$$



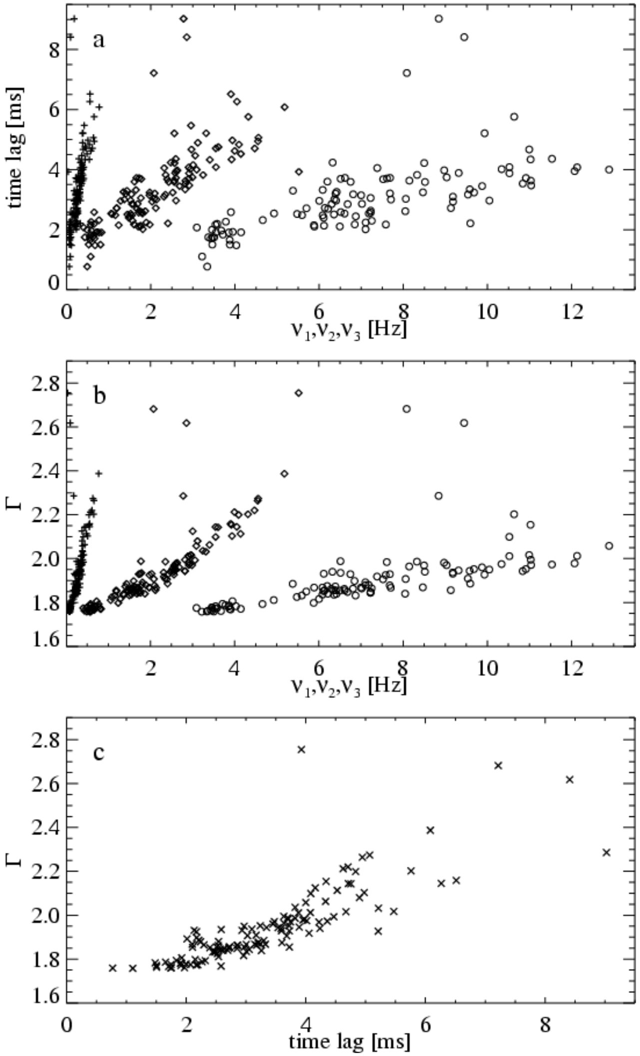
# Pottschmidt et al. (2003), A&A

- The ratios of the peak frequencies are CONSTANT!!!



# Pottschmidt et al. (2003), A&A

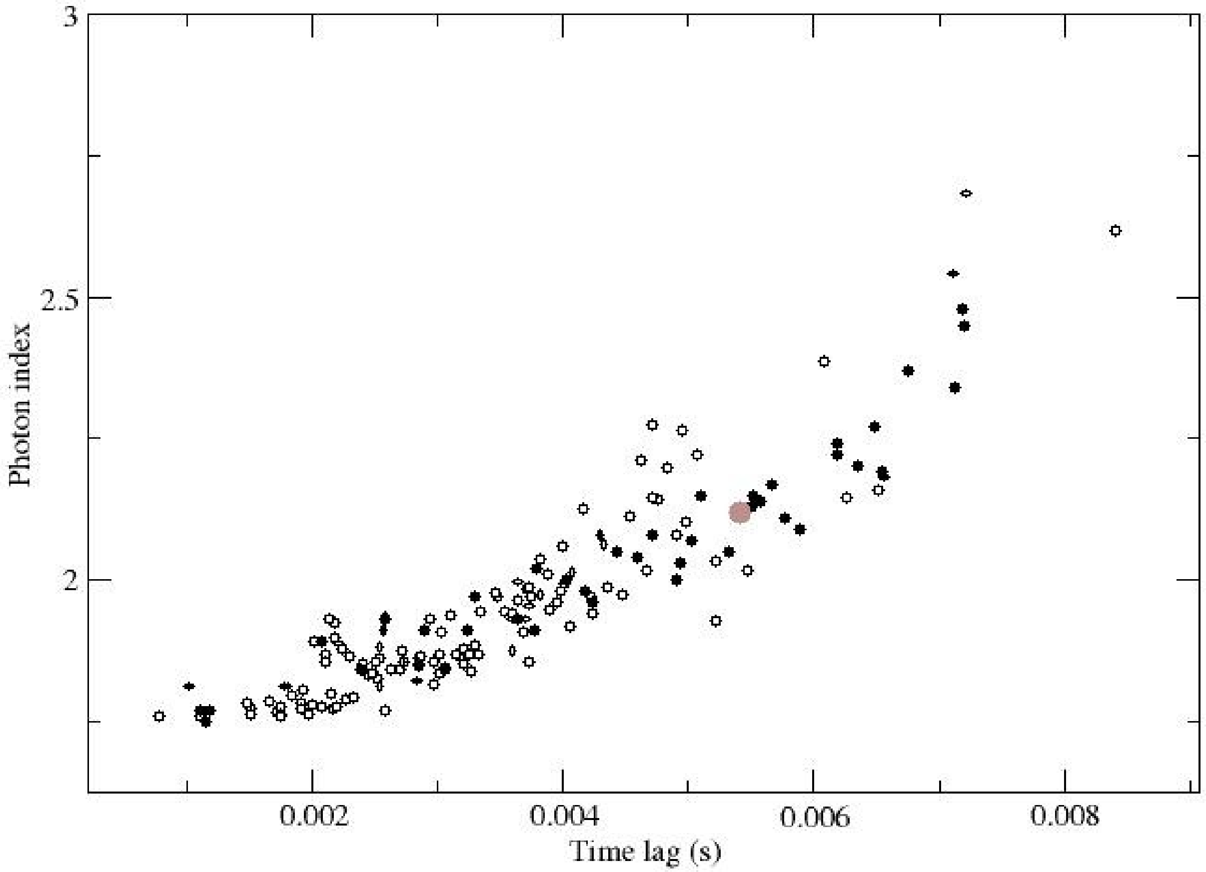
- Very stringent correlations:



# Our jet model

- Question: Can we explain these correlations by simply varying the parameters of our model around their typical values?
- The answer is YES! (else I would not pose the question).
- We varied only two parameters: The density (or equivalently the optical depth) and the radius of the base of the jet.
- We were thus able to reproduce the $\Gamma$ - <timelag> correlation.

# Gamma vs. <timelag>



# Identification of the Lorentzian peak frequencies.

- Using just the density and the radius at the base of the jet, can we think of a combination that has the dimensions of frequency (inverse timescale)?

# Identification of the Lorentzian peak frequencies.

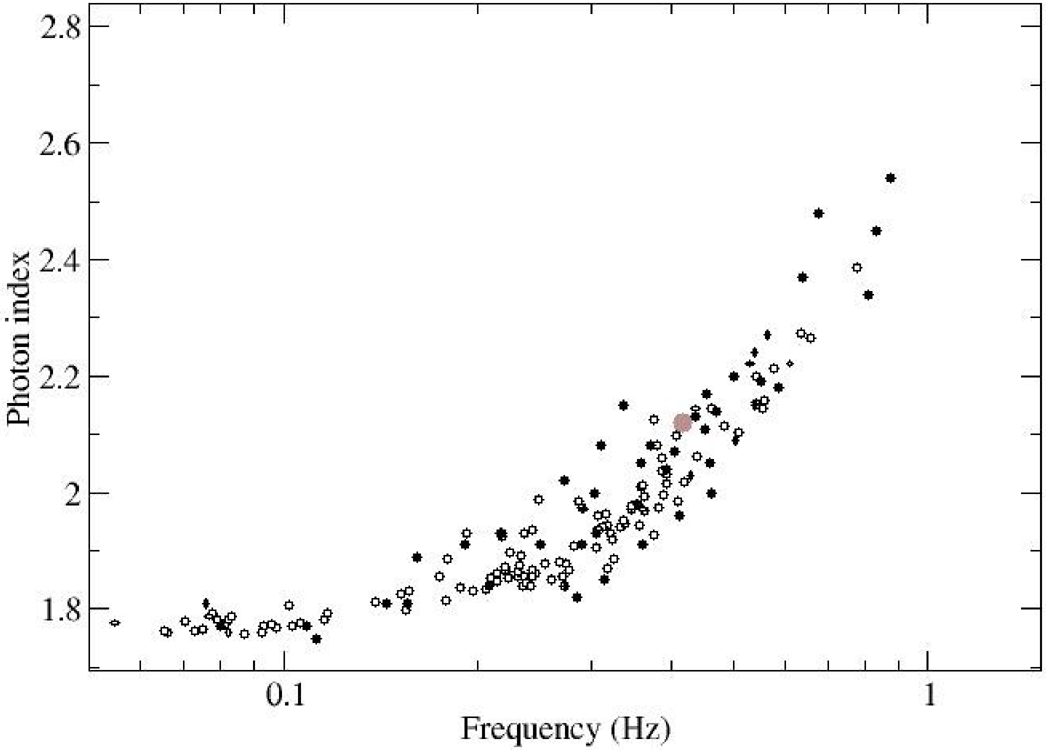
- The only inverse timescale, that we can think of, is

$$\frac{\dot{M}_{outflow}}{M_{available\ for\ outflow}}$$

# Identification of the Lorentzian peak frequencies

$$\frac{\dot{M}_o}{M_o} = \frac{\pi R_0^2 n_0 u_{flow}}{M_o} = C R_0^2 n_0 \propto \nu_1$$

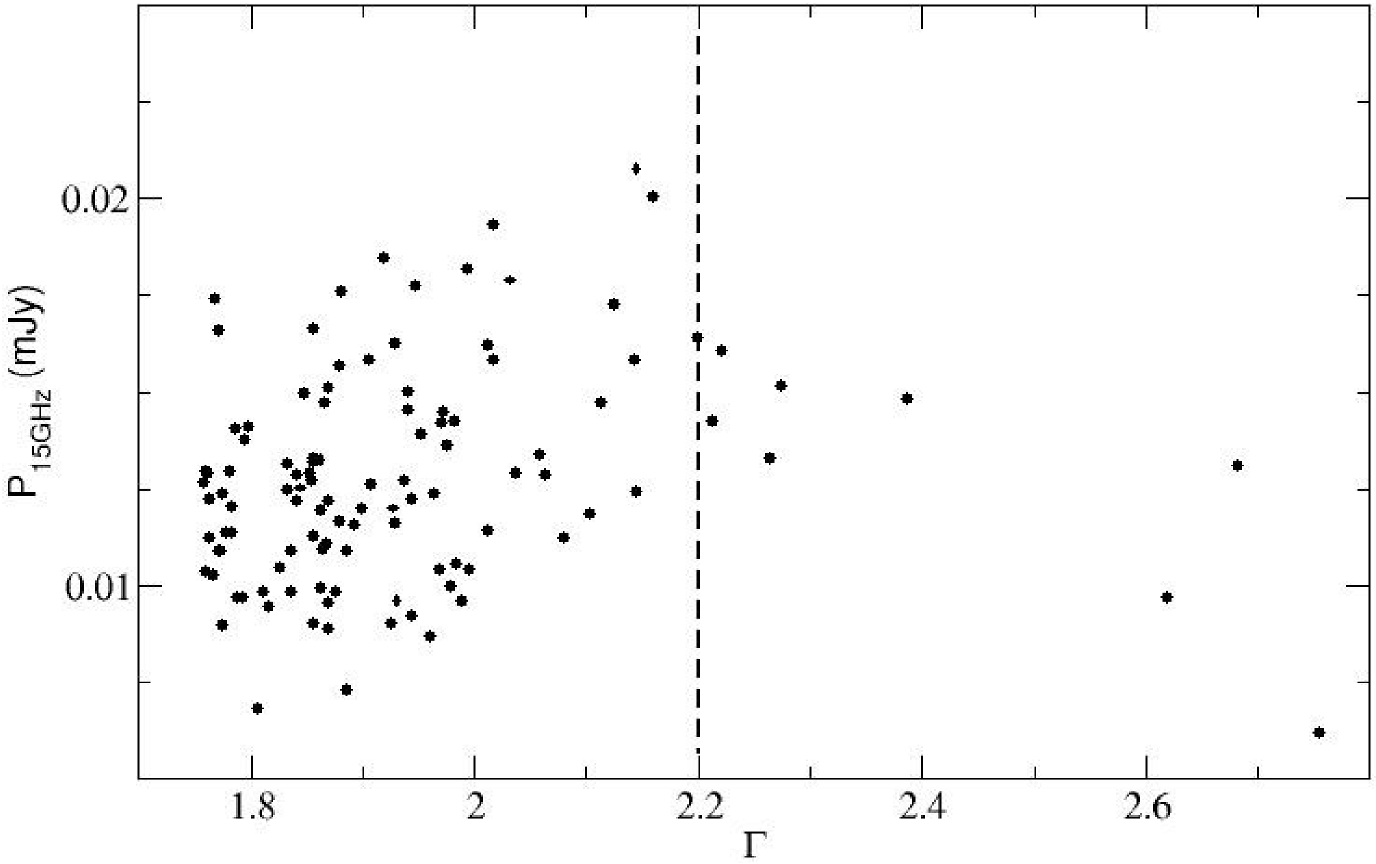
# Gamma vs. peak frequency 1



# Additional constraint

- Our jet model predicts a positive correlation between radio flux and Γ.
- Such a correlation has not been seen or proposed before.
- In Cyg X-1 we have found this correlation. It is not very tight, but it is certain (Kendall’s tau=0.21, i.e., probability < 0.2% that there is no correlation).

# Radio flux vs Gamma



# Additional constraints

- Our jet model **must** predict/confirm the reflection component and its correlations with other observables.
- It must also explain the 0.1 s lag of the IR with respect to X-rays in GX 339-4 (Casella et al. 2010).
- Our simplifying, but unphysical assumption, that the jet velocity is constant throughout the jet must be modified. The acceleration of the jet must be taken into account.

# Additional constraints

- Simple estimates suggest that we can explain both the time lag and the reflection component.
- We must make sure though that the introduction of an acceleration region at the base of the jet does not affect all our previous results.
- We are currently working on it.
- Thanks