The energy distribution of electrons in radio jets

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(with Alexandros Tsouros)

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GX 339-4
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
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 \(\alpha\) flips 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 $\Gamma$ – 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- Had you discovered an important correlation in your Thesis, would you leave it unpublished?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 $\Gamma$ 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)
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. $\Gamma$ (all data)
Timelag vs. $\Gamma$ (rise only)
Timelag vs. $\Gamma$ (decay only)
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 $\Gamma$) 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

[Graphs showing a comparison between model predictions and data.]

Legend:
- Red diamonds: Monte Carlo $\gamma=2.24$
- Black circles: Data
- Red line: Best-fit ($\gamma=2.24$)
The two parameters are correlated
Detailed modeling of GX 339-4

- To put our model on a more stringent test, we have fitted the $\Gamma$ – 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 $\Gamma$ – timelag correlation

GX 339-4
The values of the two model parameters ($\tau$, $R_0$) are correlated.
Prediction

Break frequency in radio spectrum vs. $\Gamma$

GX 339-4
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