Do jets vibrate???

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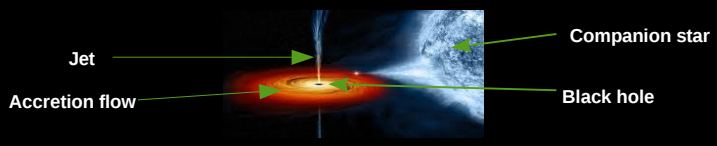
Introduction

Black hole X-ray binaries are systems in which a black hole accretes matter from a companion star. This leads to the formation of an accretion flow - an accretion disc and a inner hot flow/corona, and, outflows - collimated jets (and weak disc winds).



***Motivation*: Fast multi-wavelength variability is observed in black hole X-ray binaries. Where does emission in each energy band originate and what drives its variability?**

Emission from various components:

1. Jet – Synchrotron emission extending from radio through optical/infra-red (OIR) and possibly in X-rays

2. Hot flow/corona – Comptonized emission in the hard X-rays (above 2 keV); also suggested to emit in OIR

3. Accretion disc – Thermal emission from inner disc close to the black hole contribute to soft X-rays (below keV), outer disc to OIR and ultraviolet.

Data Analysis

Source: GX 339-4
Date: March 28, 2010
Hard state observation (radiatively inefficient)

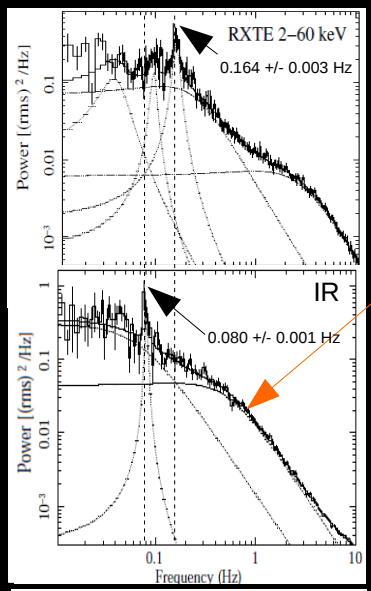
Simultaneous observations in
1. Infra-red with ESO-ISAAC
2. Optical with *XMM-Newton*-OM
3. X-rays with *RXTE*

Spectral results reported synchrotron emission from jet from radio to OIR, Comptonization in hard X-rays, weak disc in soft X-rays, an additional excess in OIR (after accounting for reprocessing)

Light curves obtained to calculate power spectra and cross correlation function

Power density spectra

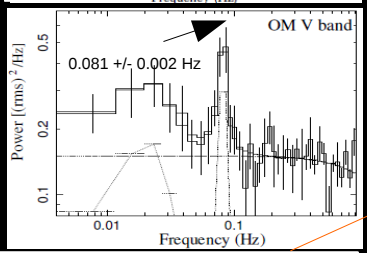
Typical X-ray power spectrum with a Quasi Periodic Oscillation (QPO) accompanied by broad band noise



First report of a QPO in the IR band

IR QPO frequency at half the strongest X-ray QPO frequency

Typical broad band noise, reported before with strong indications of origin in the jet



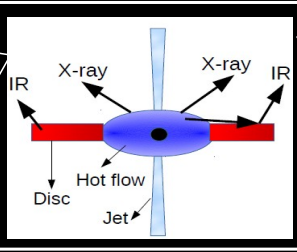
Optical QPO at the IR QPO frequency, accompanied by very weak broad band noise

Origin of variable IR emission?

Scenario: X-ray emission from the hot flow
Broad band variability generated by propagating mass accretion rate fluctuations in the hot flow

Is IR the thermal emission from outer disc? NO!

Intrinsic outer disc emission: observed IR variability time scales too fast

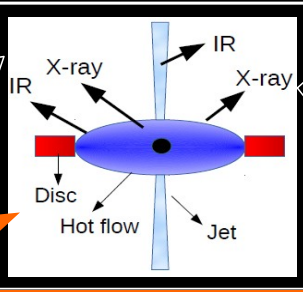


Reprocessing of variable X-ray emission incident on outer disc: too short IR time delay

Is IR the synchrotron emission from outer hot flow? NO!

Is IR the synchrotron emission from the jet? YES!!!

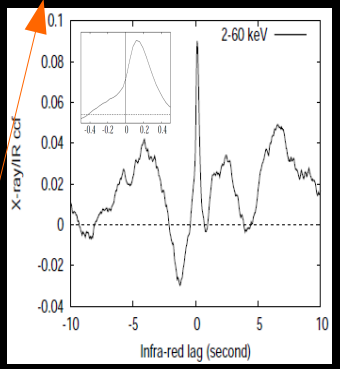
Synchrotron emission from outer hot flow: the IR variability should lead the X-rays and not lag



Malzac et al. 2014 Model: Internal shocks driven by rapid fluctuations in the jet velocity
These fluctuations follow the mass accretion rate fluctuations in accretion flow (which drive the X-ray variability)
Simulations -> the jet synchrotron emission in IR is variable on time scales similar to what we see here
CCF narrow peak shown here can be reproduced by this model
The variable IR is jet synchrotron emission!

Cross correlation function

X-ray leads IR by 111ms



Origin of the QPO?

X-ray QPO -> Lense-Thirring precession of hot flow
Veledina et al. 2013 model proposes that:
1. Outer hot flow emits in OIR
2. OIR QPO fundamental stronger than X-ray fundamental
3. X-ray harmonic is stronger than its fundamental

This matches our observations!

Conclusions

1. ***A Quasi Periodic Oscillation is detected for the first time in infra-red band in a black hole X-ray binary (GX 339-4)***
2. ***The IR QPO and the optical QPO are at half the frequency of the X-ray QPO***
3. ***The variable IR emission is jet synchrotron emission***
4. ***The IR emission variable on the QPO time scale could be from Lense-Thirring precession of the hot flow (but difficult to reconcile with the broad band variability)***

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References

Casella et al., 2010, MNRAS, 404, L2
Ingram et al., 2011, MNRAS, 415,2323
Veledina et al., 2013, ApJ, 778,165
Malzac 2014, MNRAS, 443, 299

The full analysis based on which these conclusions are drawn will be soon published (Kalamkar et al. in prep). Only a part of the results are presented here.