Beyond X-ray timing

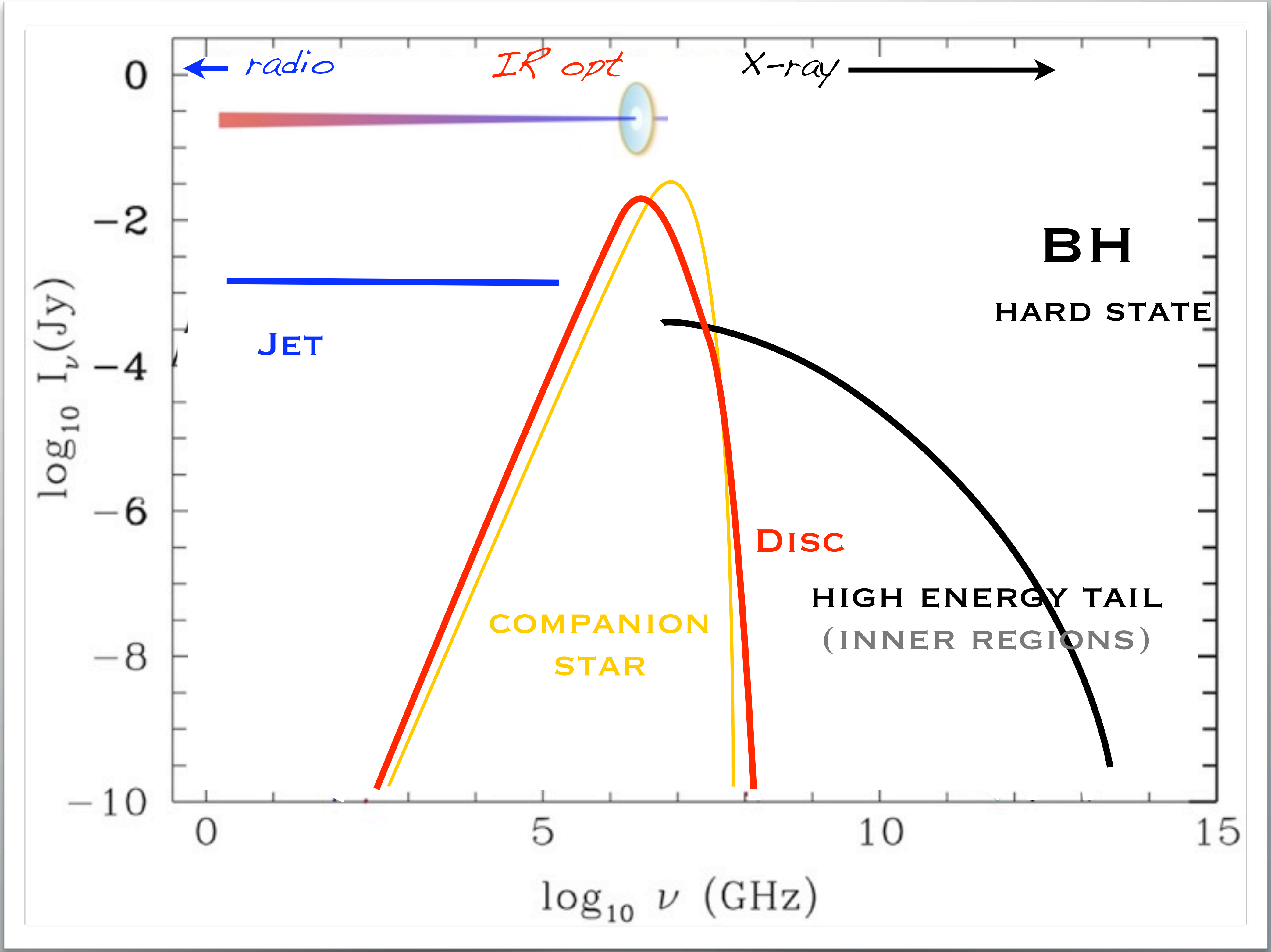
Fast multi-λ variability (from jets) in XBs

Piergiorgio Casella (Southampton)

with: T. Maccarone (Southampton), K. O'Brien (USCB)

and: R. Fender (Southampton), D. Russell (Amsterdam), A. Pe'er (STScI/CfA), M. van der Klis (Amsterdam), T. Belloni (INAF-OAB), J. Malzac (Toulouse), ...and others...

BH X-ray binaries



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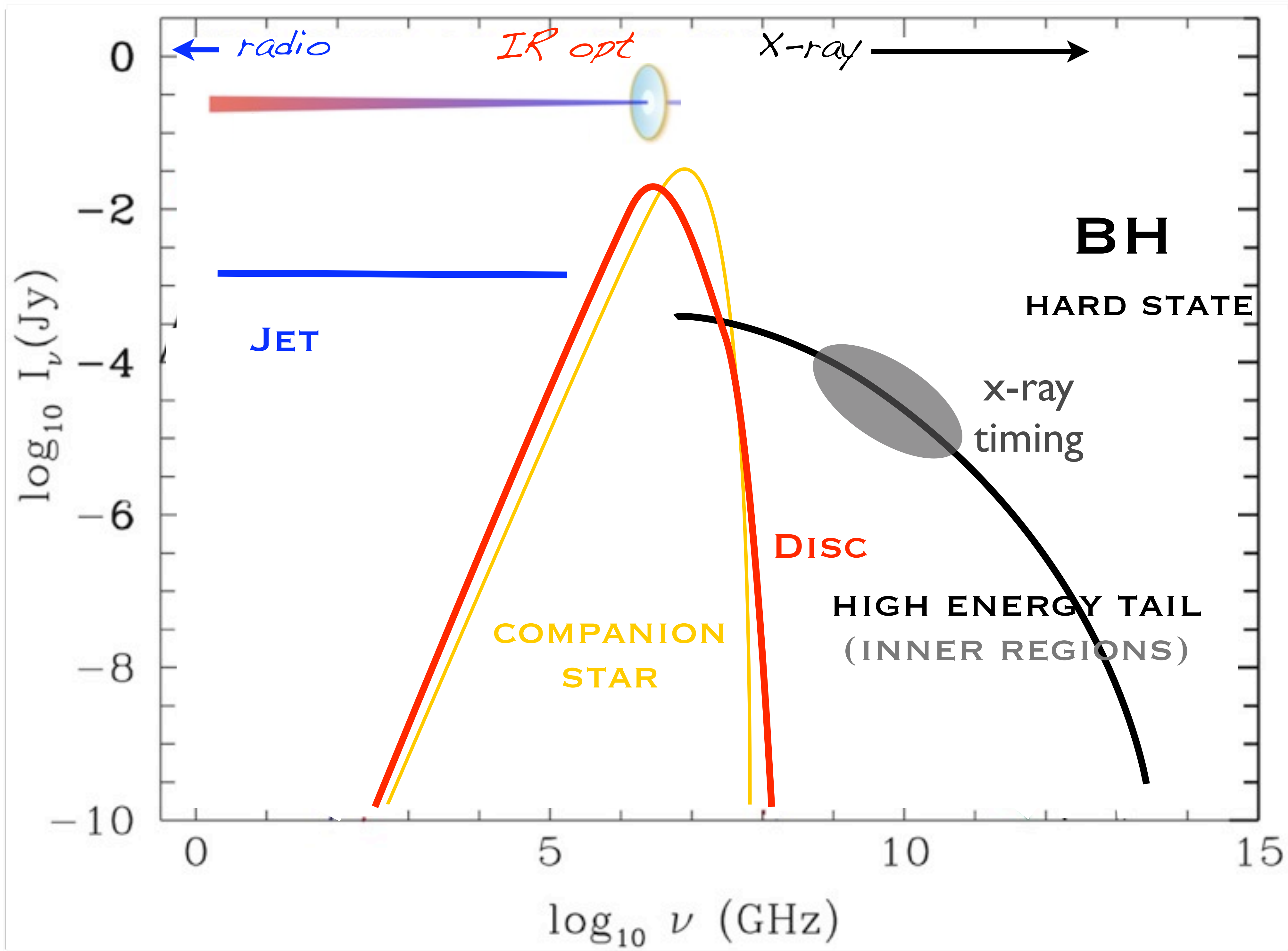

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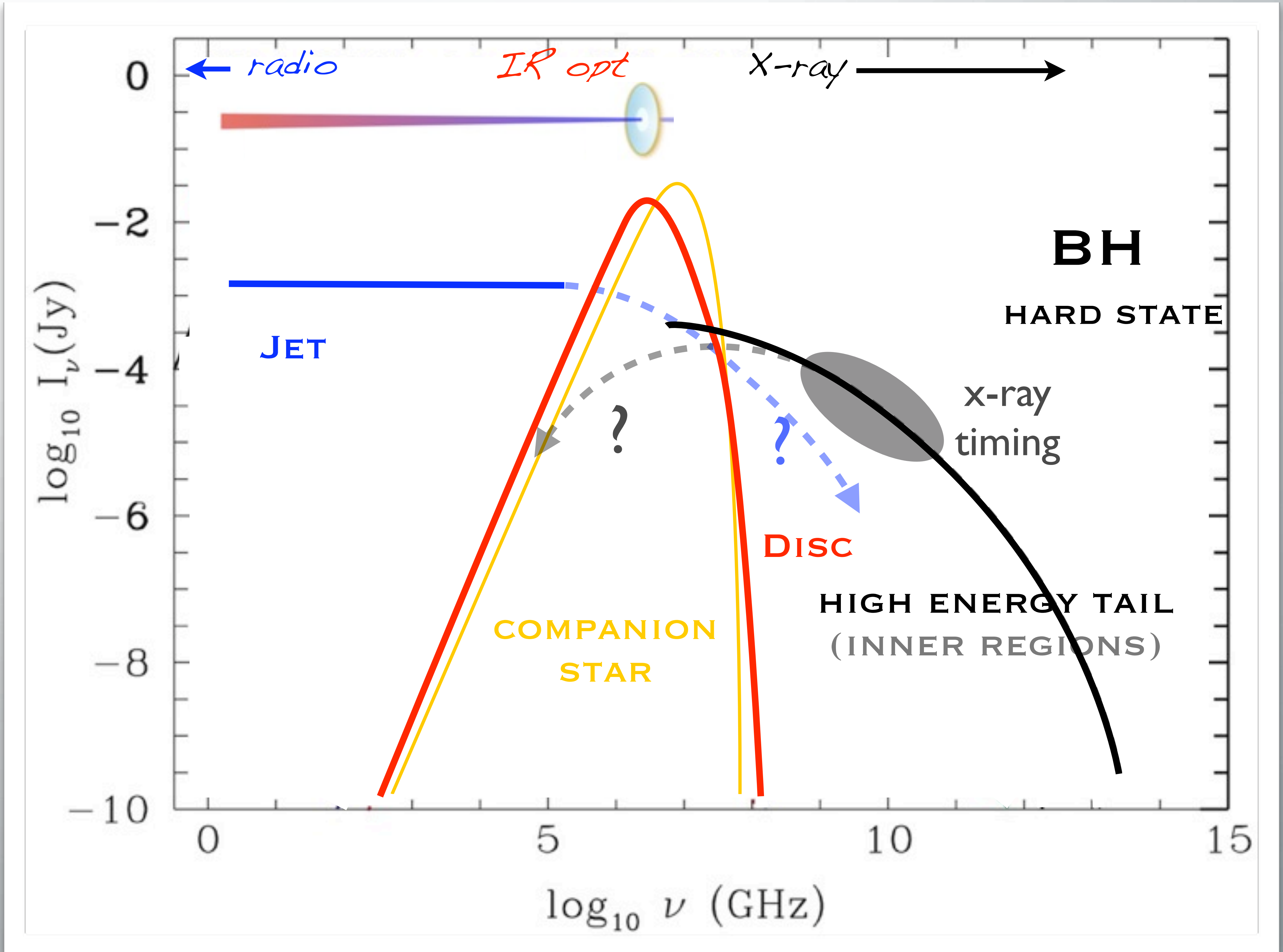

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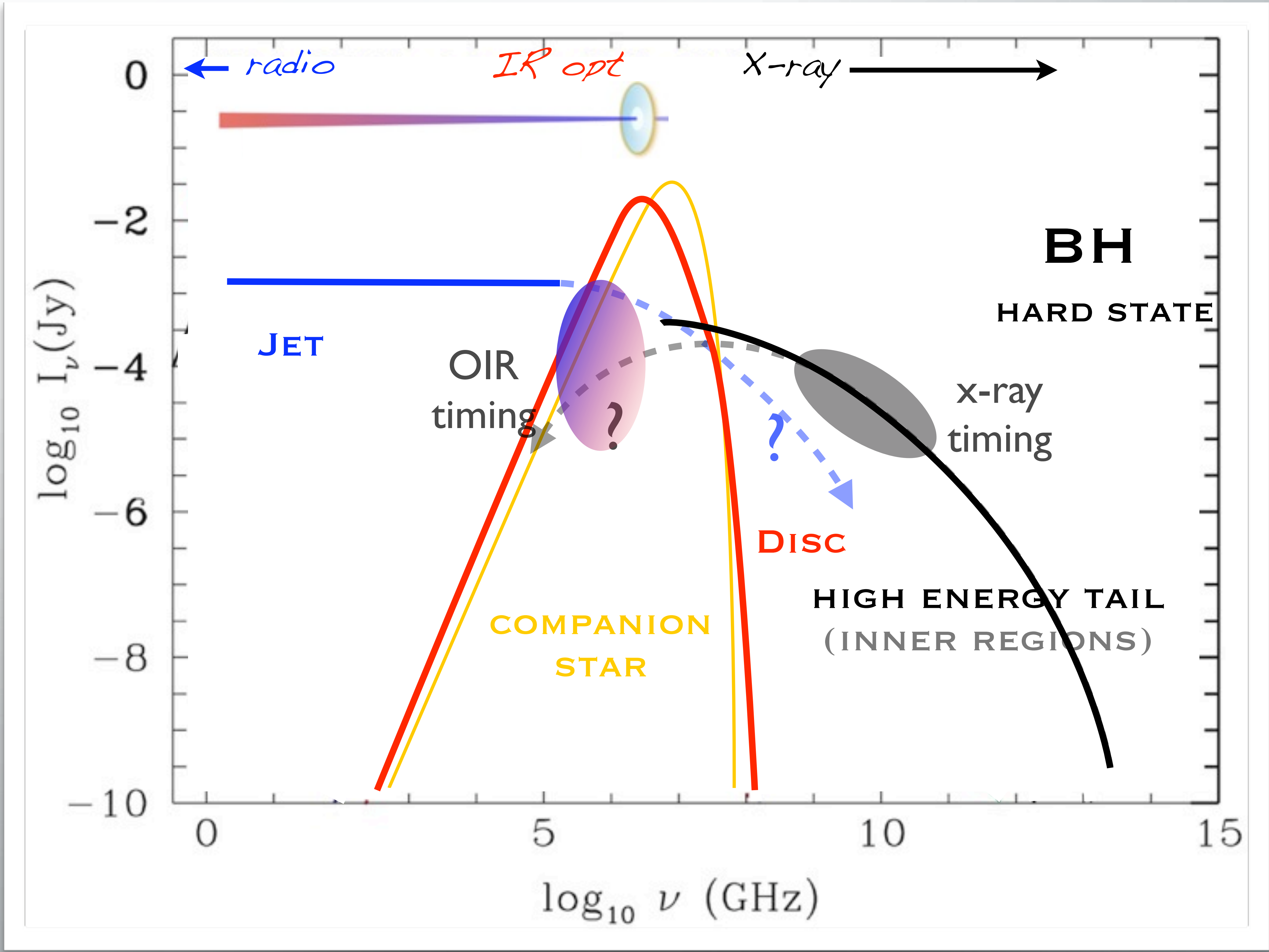
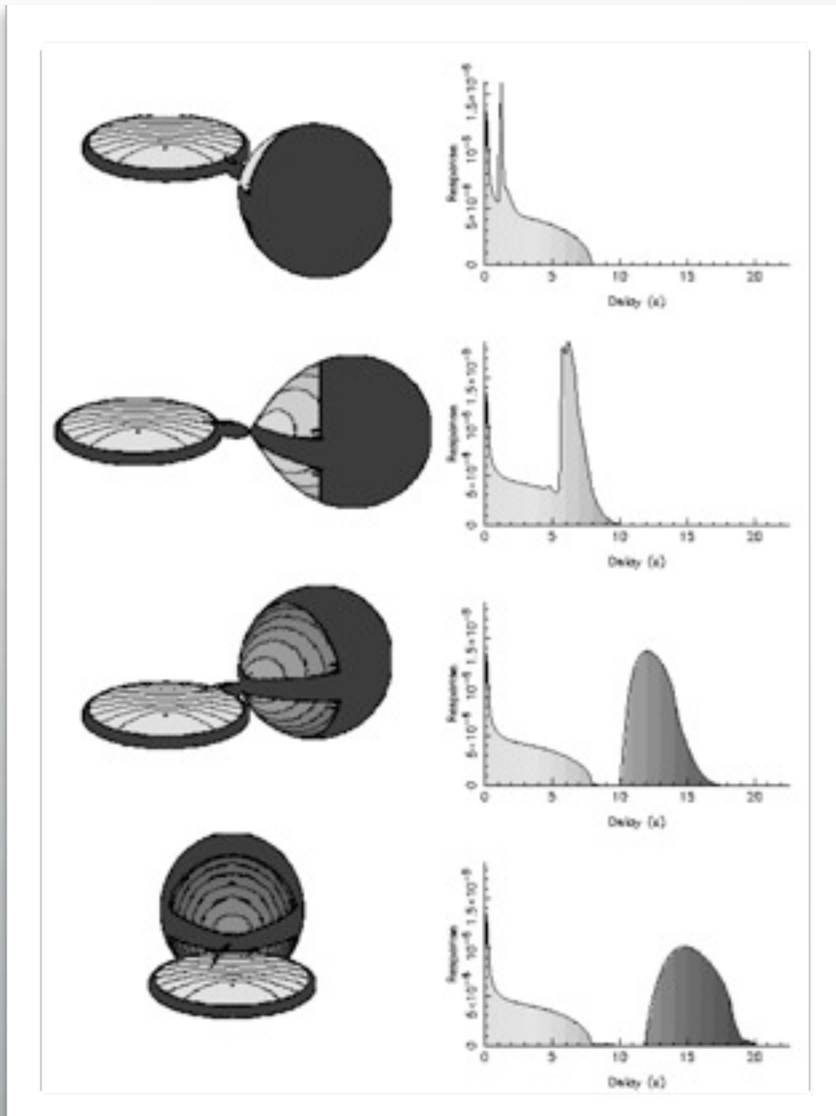


First hints for jet variability: X-ray/optical CCFs

HARD state

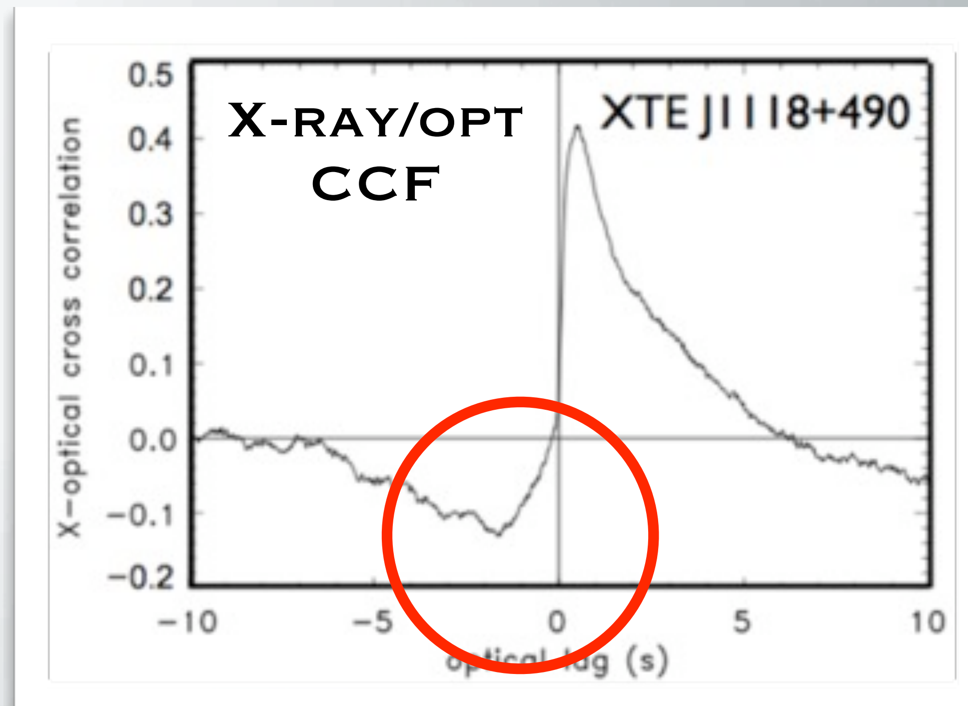
(Motch et al. 1982)
Kanbach et al. 2001

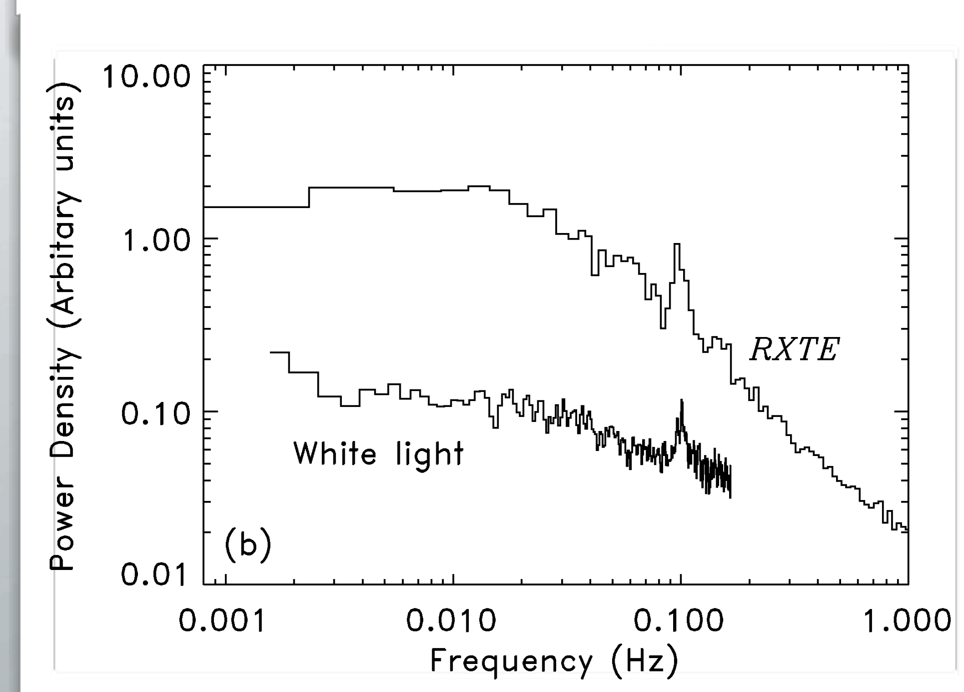
Reprocessed variability:



O'Brien et al. 2002

≠

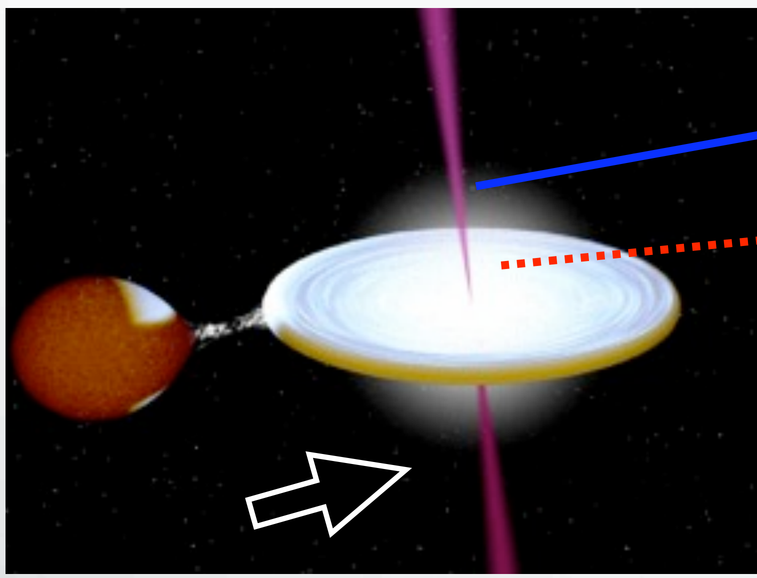




(Hynes et al. 2003, 2006)

First hints for jet variability: X-ray/optical CCFs

The "common reservoir model" (Malzac, Merloni & Fabian 2004)



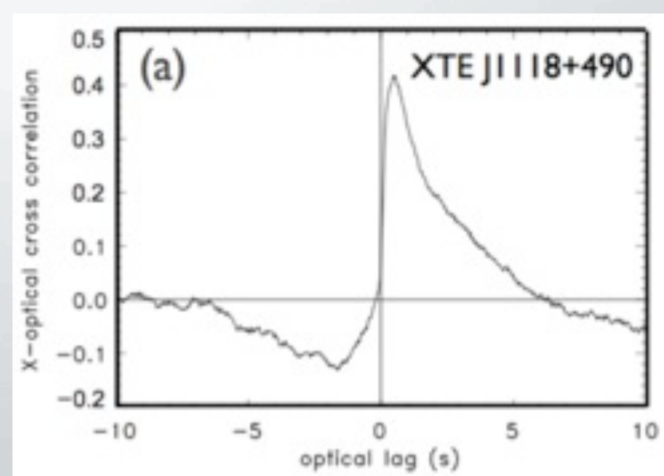
OPTICAL FROM THE JET

X-RAYS FROM THE CORONA

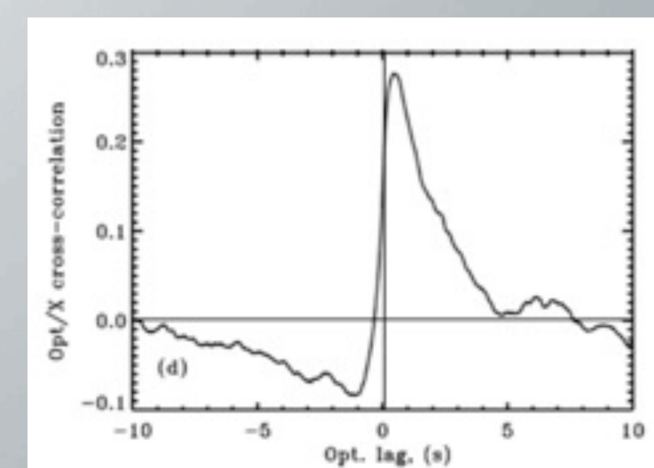
SAME ENERGY RESERVOIR

FOR A JET-DOMINATED SYSTEM:

Data



Model



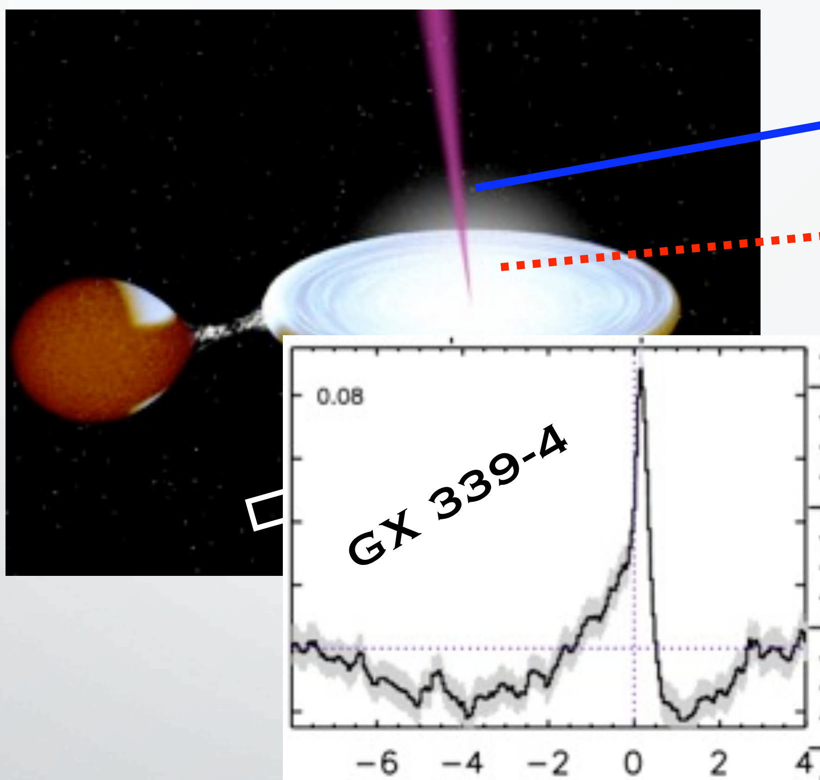
First hints for jet variability: X-ray/optical CCFs

The "common reservoir model" (Malzac, Merloni & Fabian 2004)

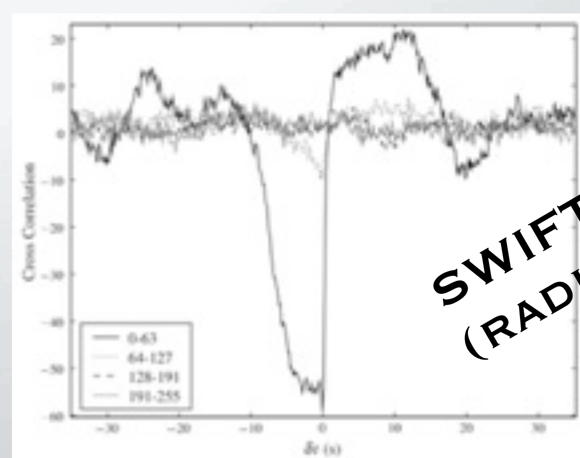
Optical from the jet

X-rays from the corona

Same energy reservoir



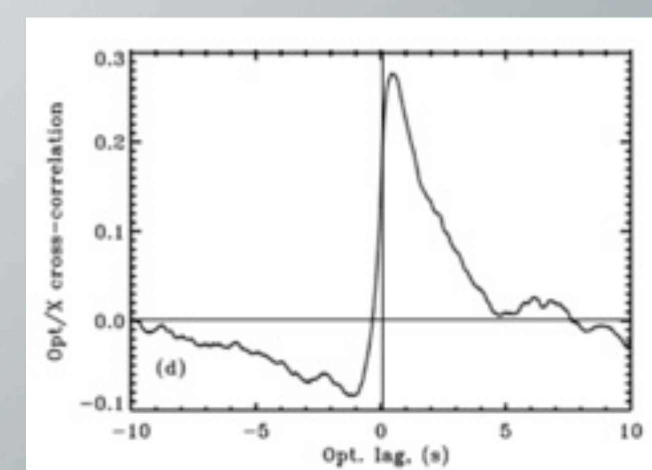
Gandhi et al. 2008



Durant et al. 2008

Swift J1753 (radio quiet)

Model



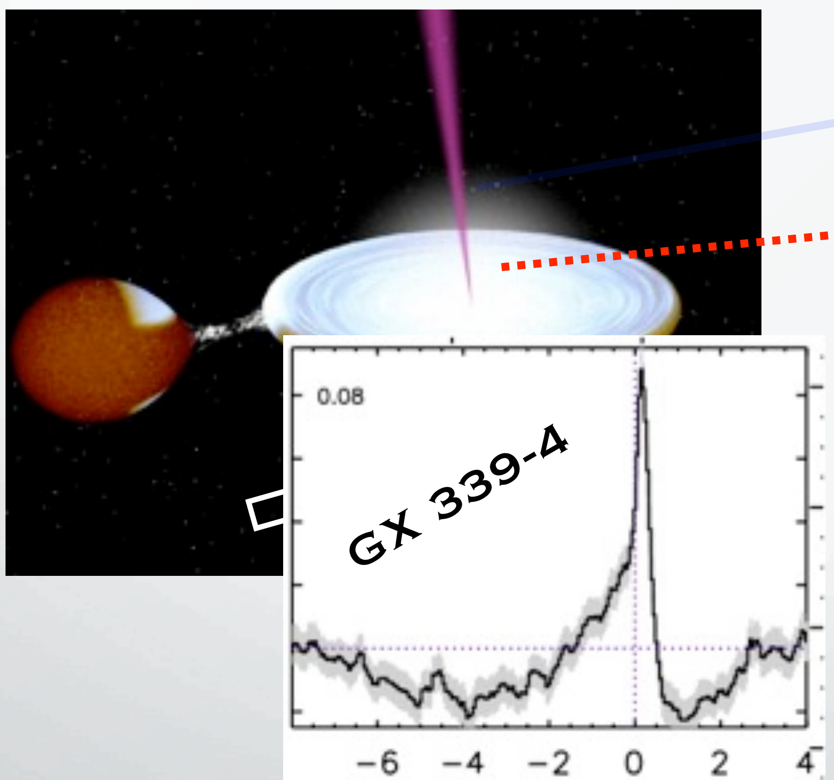
Jet hypothesis tottering *(but see Casella & Pe'er 2010)*

Probable need for other components

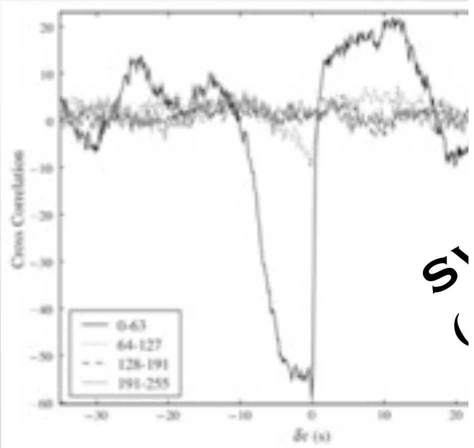
e.g. a magnetic corona? *(Merloni et al. 2000; Veledina et al. 2011)*

First hints for jet variability: X-ray/optical CCFs

The "common reservoir model" (



Gandhi et al. 2008



Durant et al. 2008

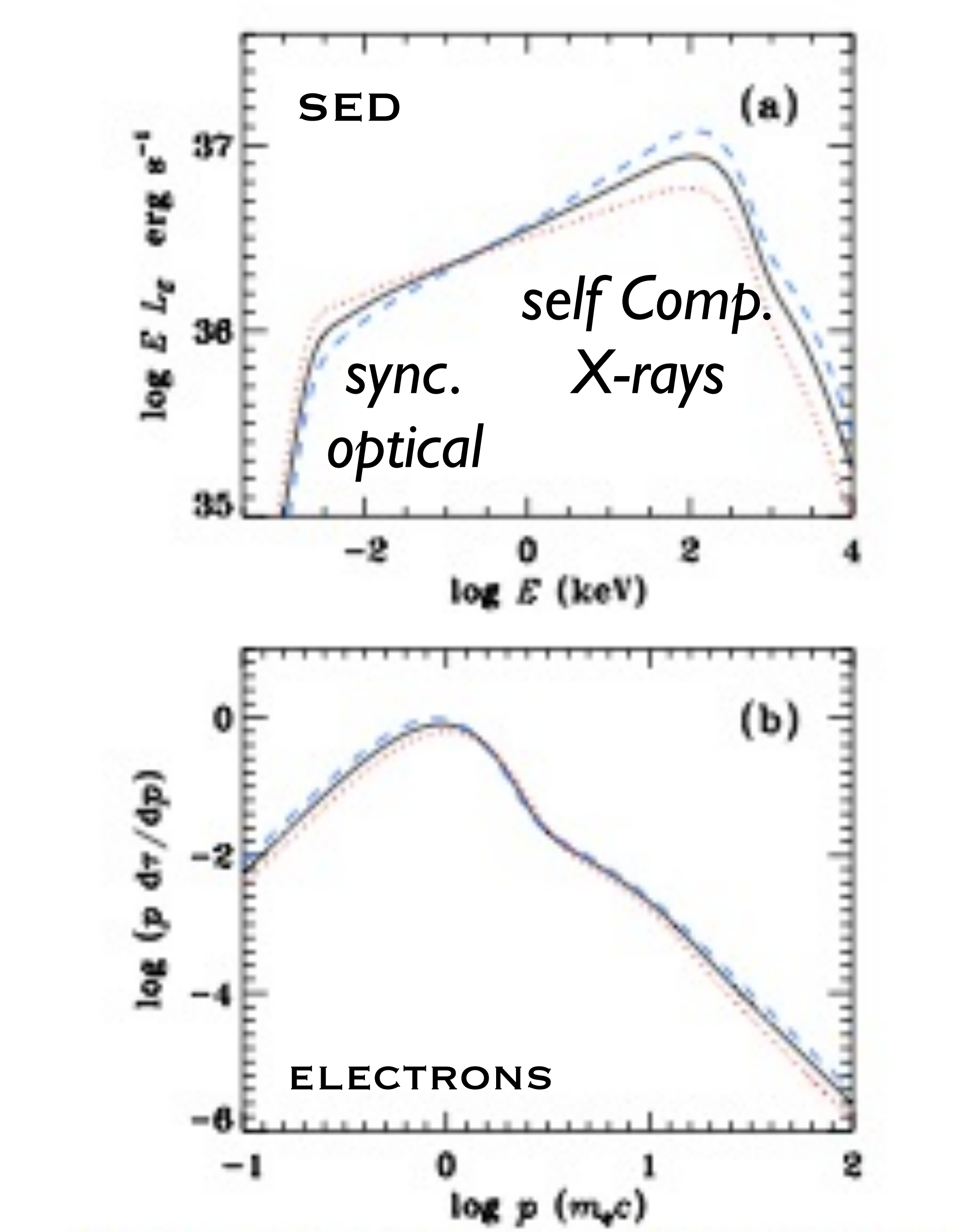


Figure 1. Simulated spectra (a) and electron distributions (b) for fiducial parameters (solid line), for increased by 20% mass accretion rate (blue dashed line) and for decreased by 20% accretion rate (red dotted line).

HARD states

Jet hypothesis in do

Probable need for o

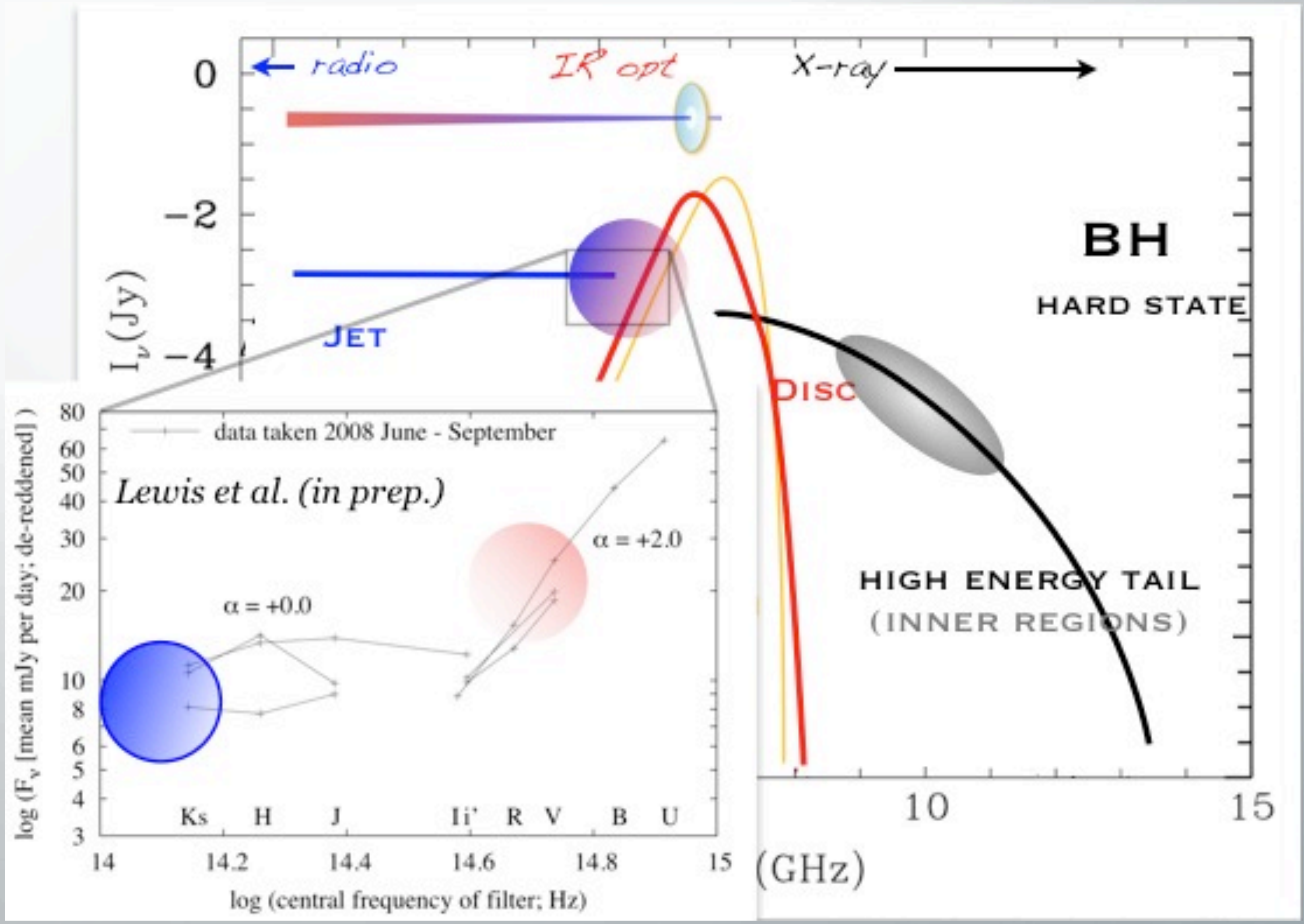
e.g. <u>a magnetic corona?</u> (*Merloni et al. 2000; Veledina et al. 2011*)

First evidence for fast jet variability: in infrared

Casella et al. 2010

HARD state

GX 339-4 - ISAAC@VLT - 62.5ms - K=12.5



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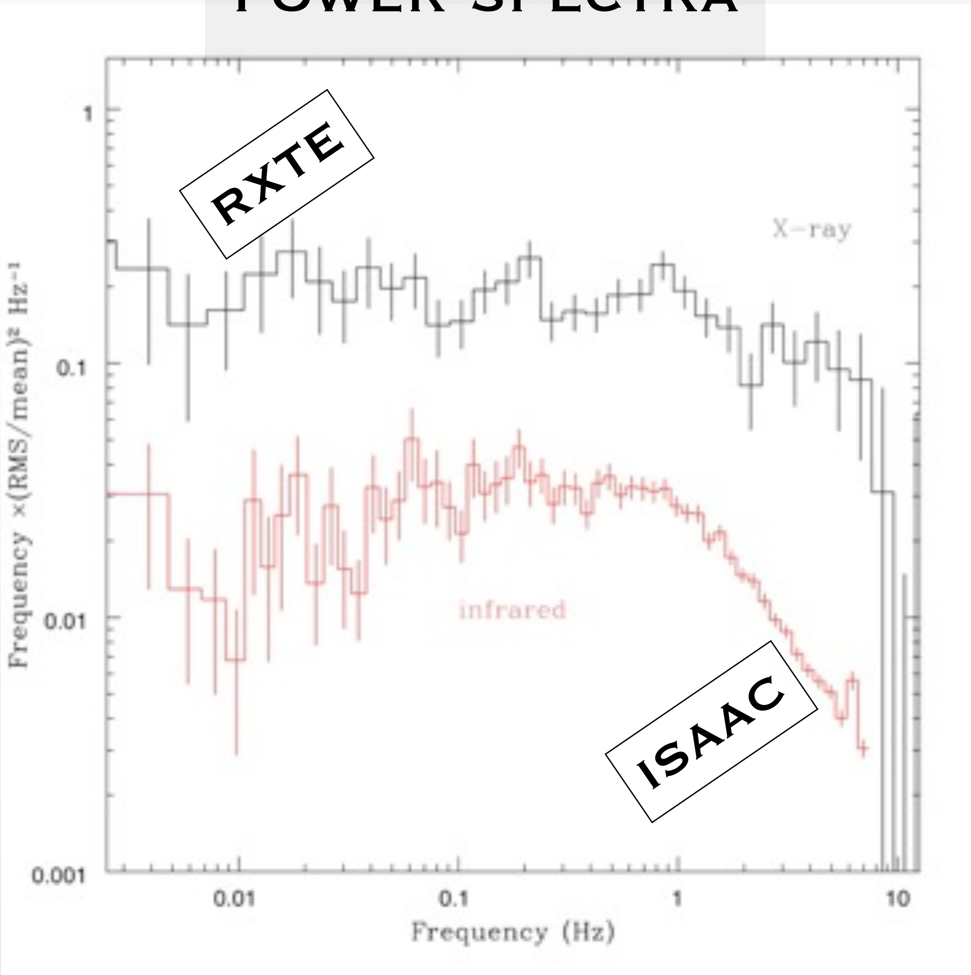
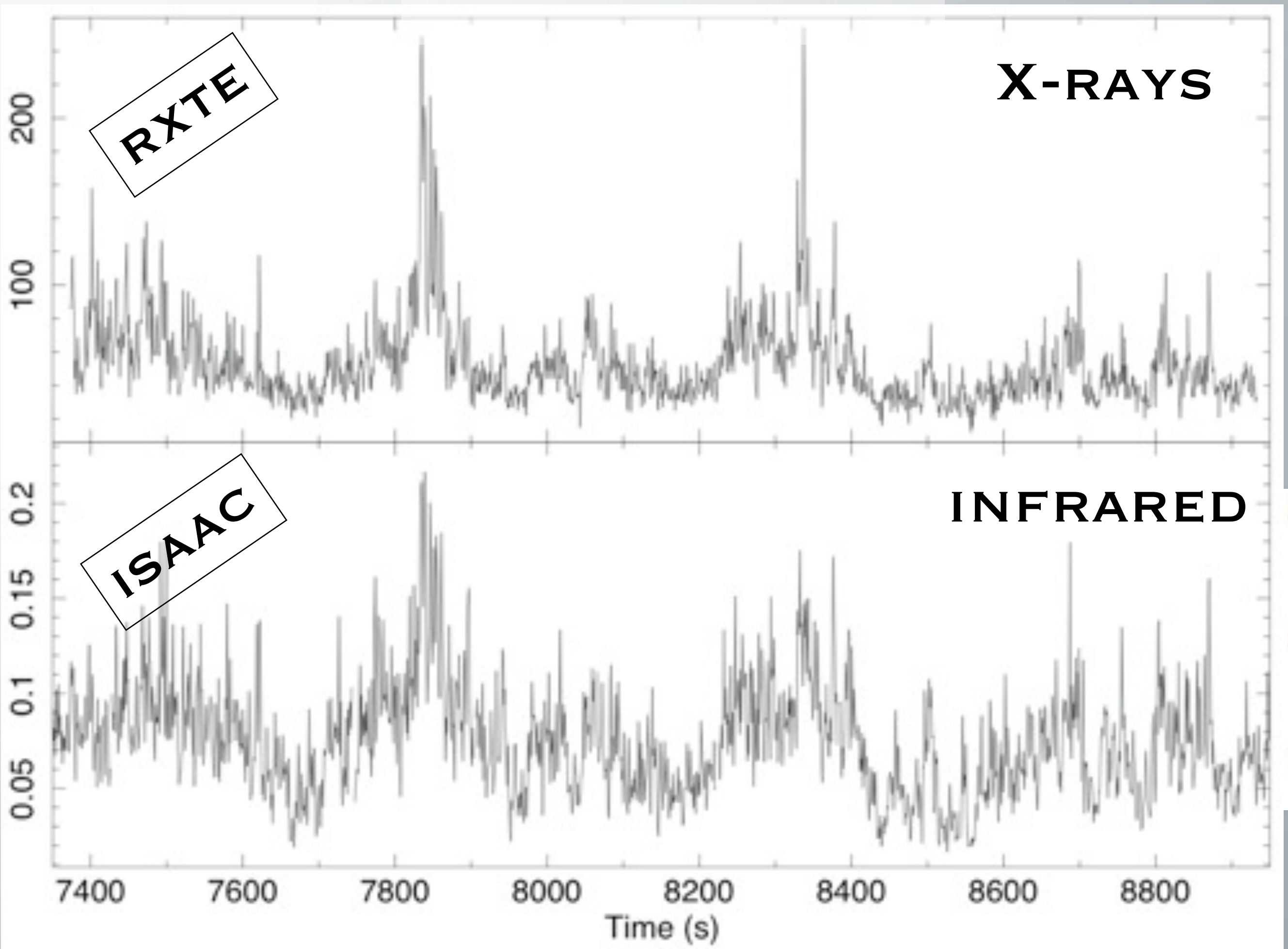
Power spectra



Light Curves



Infrared (jet) lags X-rays by 0.1 seconds

Variability can be used to track the matter

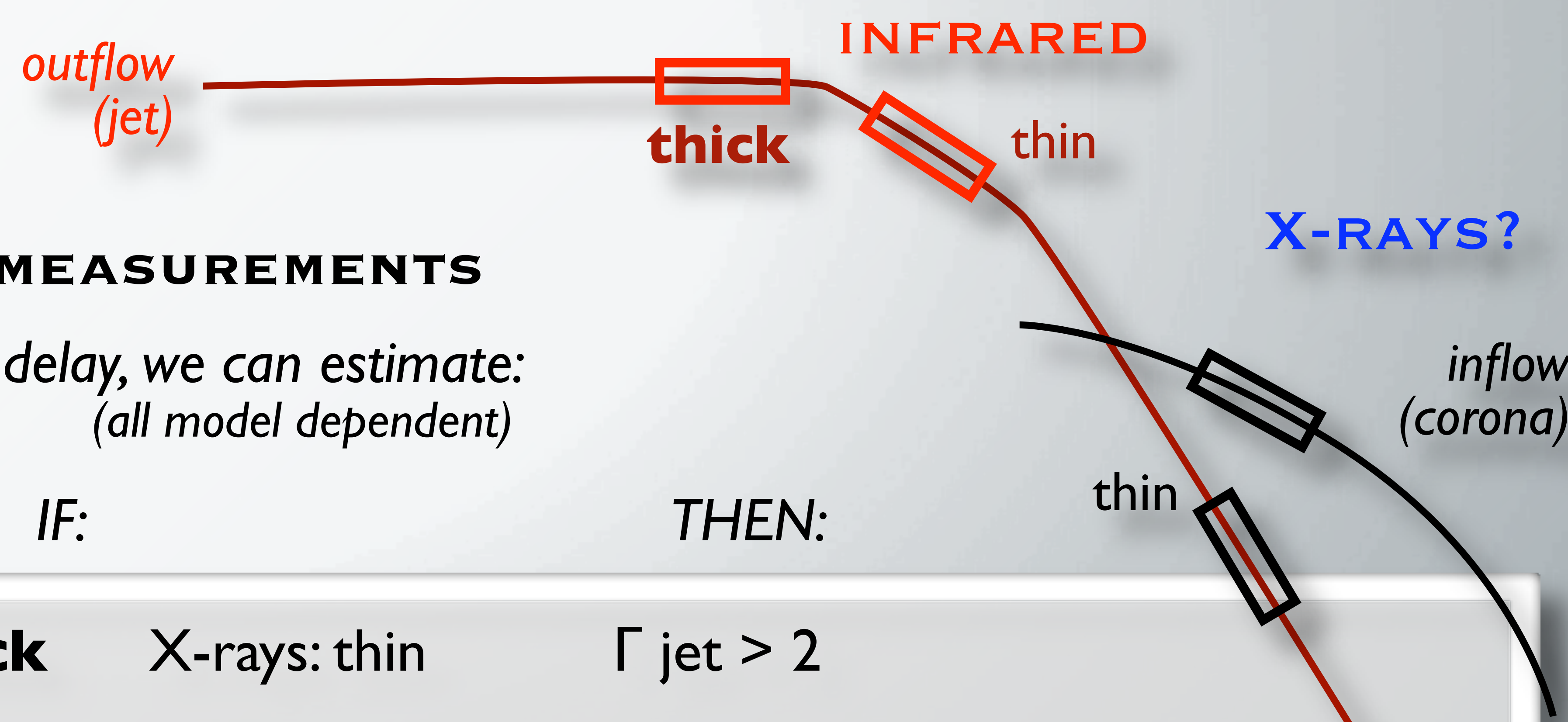
and make **physical measurements**

First evidence for fast jet variability: in infrared

Casella et al. 2010

HARD state

GX 339-4 - ISAAC@VLT - 62.5ms - K=12.5



Physical measurements

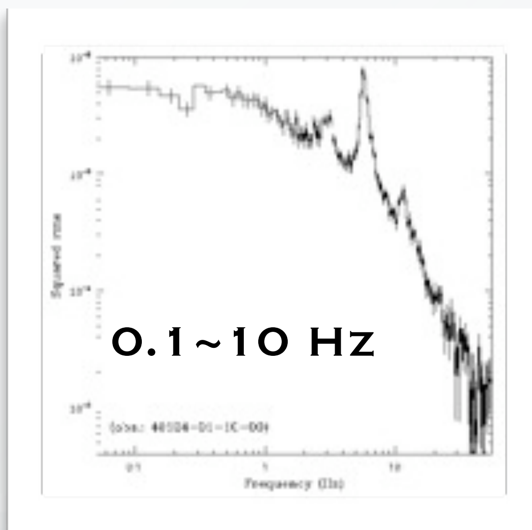
From the 0.1s delay, we can estimate:
(all model dependent)

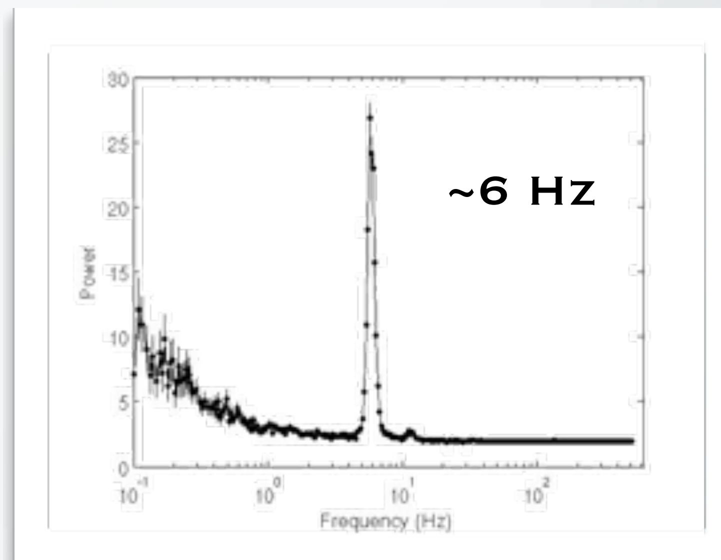
	IF:		*THEN:*
(1)	IR: **thick**	X-rays: thin	Γ jet > 2
(2)	IR: thin	X-rays: thin	B~10^4G *and* Γelec. ~10^4 → 50
(3)	IR: thin	X-rays: *inflow*	ejection timescale < 0.1 s
(4)	IR: **thick**	X-rays: *inflow*	Γ jet >> 2 *and* ejec. timesc. << 0.1s

X-RAY VARIABILITY
AND BROAD-BAND SED COMPONENTS

HARD states | transition | SOFT state

BHs:





LITTLE X-RAY VARIABILITY

HARD states	transition	SOFT state
"STEADY" JET	SINGLE EJECTIONS	NO JET
THERMAL COMPT.	NON-THERMAL COMPT.	LITTLE COMPT.

EITHER A JET OR A CORONA

PROPERTIES SHOULD CHANGE ACROSS TRANSITION

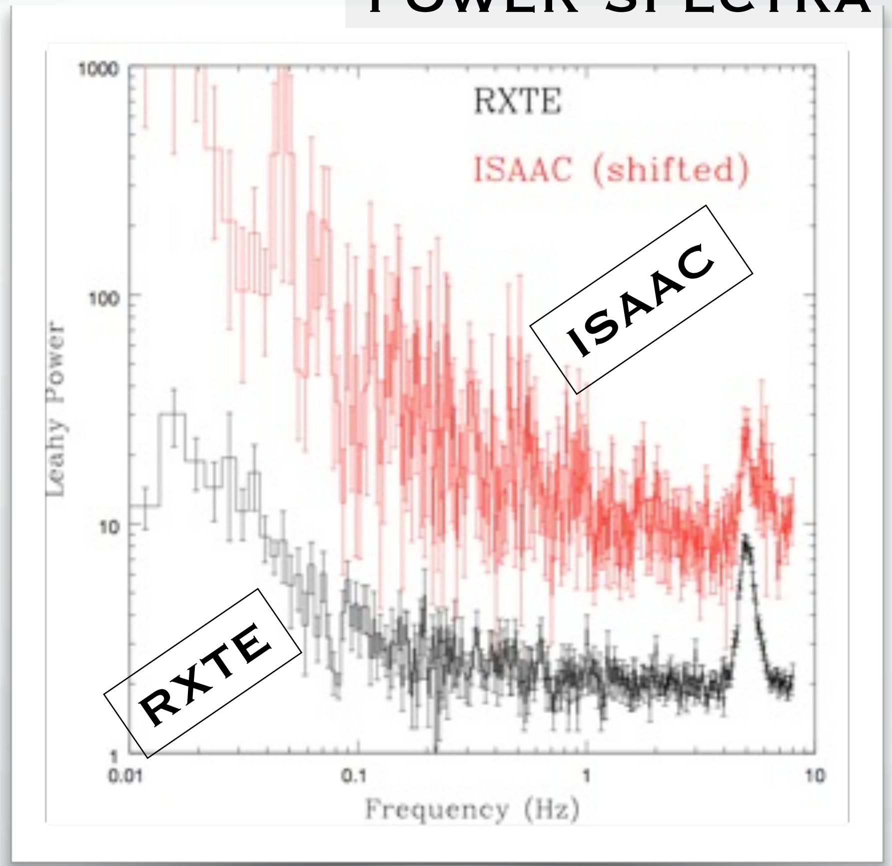
transition

Discovery of a 5 Hz IR QPO

GX 339-4 - ISAAC + ULTRACAM - 62.5ms

Casella et al. (in prep.)

POWER SPECTRA



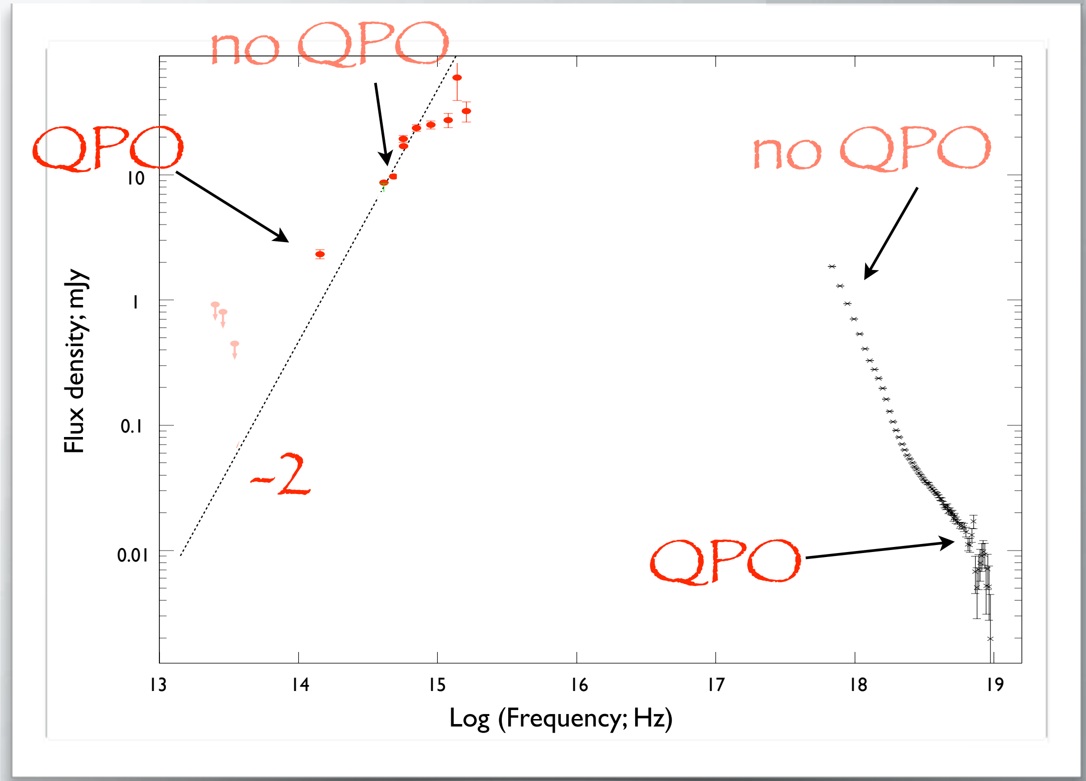
QPO RMS

X-rays ~ 6%

IR ~ 3%

opt < 0.8%

SED



TYPE-B QPO SIMULTANEOUS IN X-RAYS AND IR

NO QPO IN OPTICAL → THE IR QPO IS NON THERMAL

IF ONE-ZONE MODEL (MAGNETIC CORONA):

ν_{break} ~ 1.4×10^{14} Hz → B ~ 10^4 G R ~ 6×10^7 $h^{-0.5}$ cm

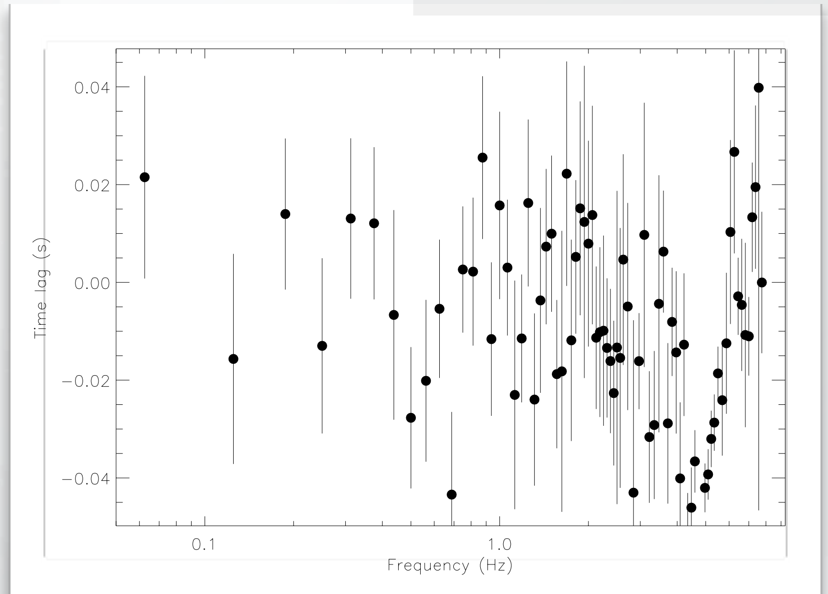
transition

Discovery of a 5 Hz IR QPO

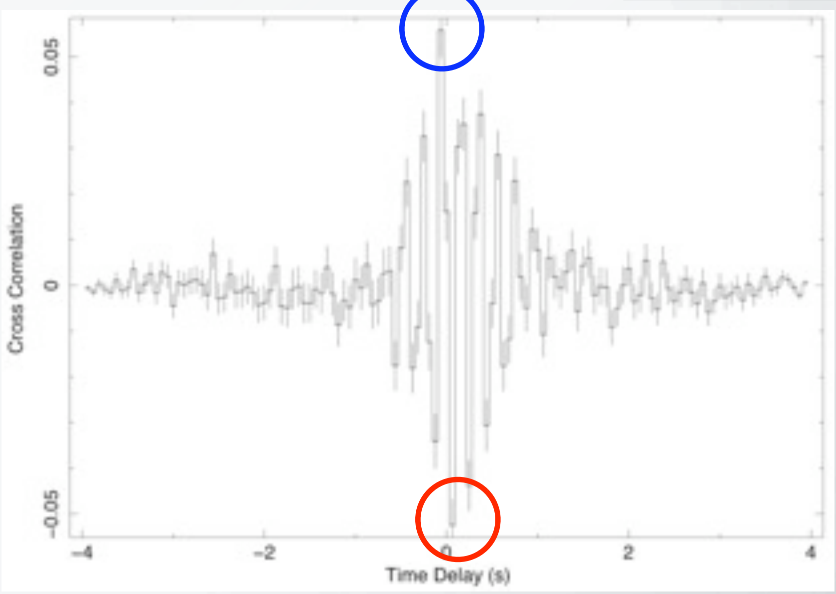
GX 339-4 - ISAAC@VLT - 62.5ms

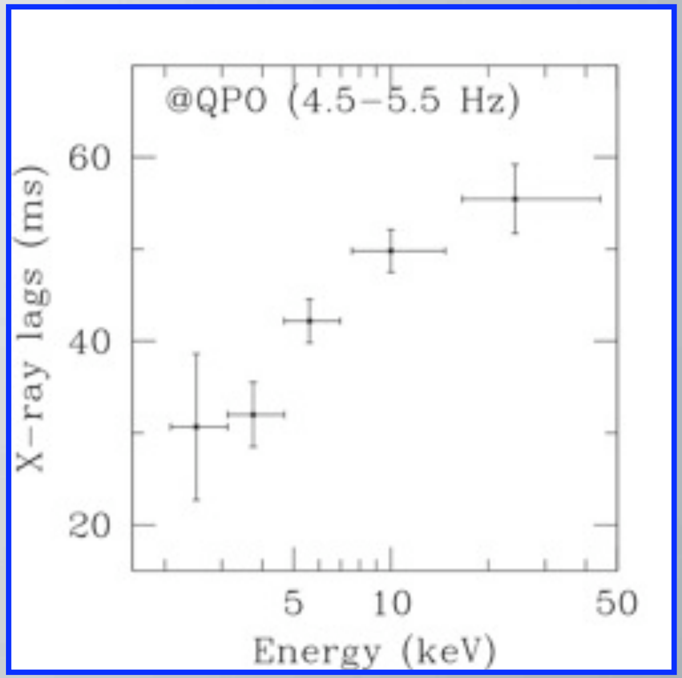
Casella et al. (in prep.)

TIME LAGS



CCF



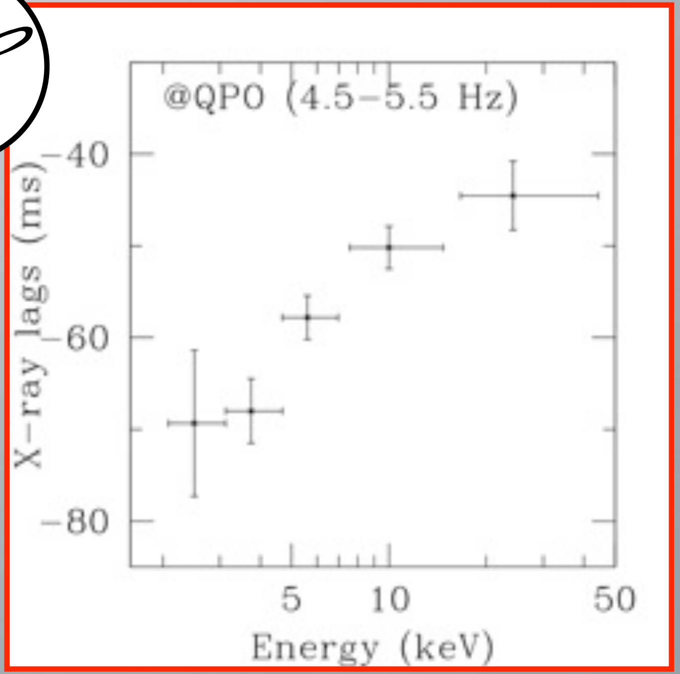


THE X-RAYS LAG ~30-60 ms BEHIND THE IR

OR

THE IR IS ANTI-CORRELATED

AND LAGS ~40-70 ms BEHIND THE X-RAYS



TIME LAGS VS. ENERGY

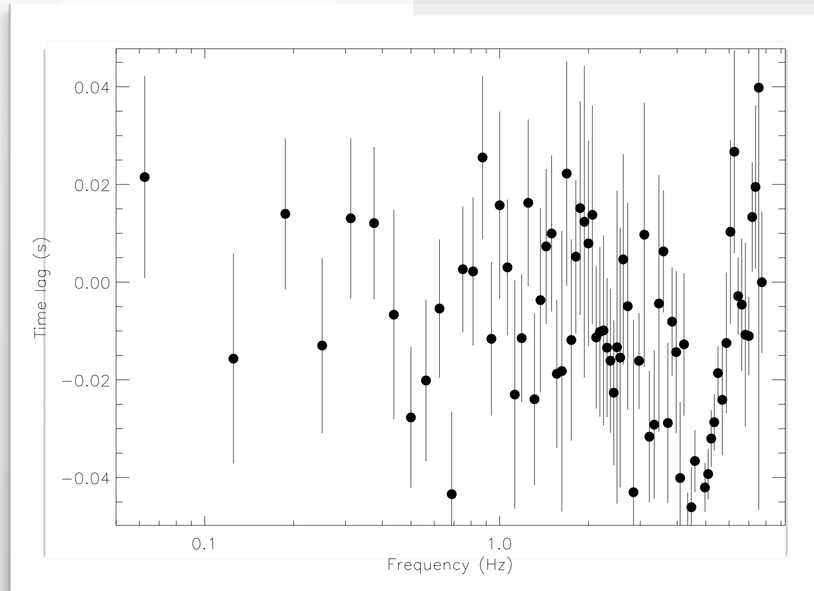
transition

Discovery of a 5 Hz IR QPO

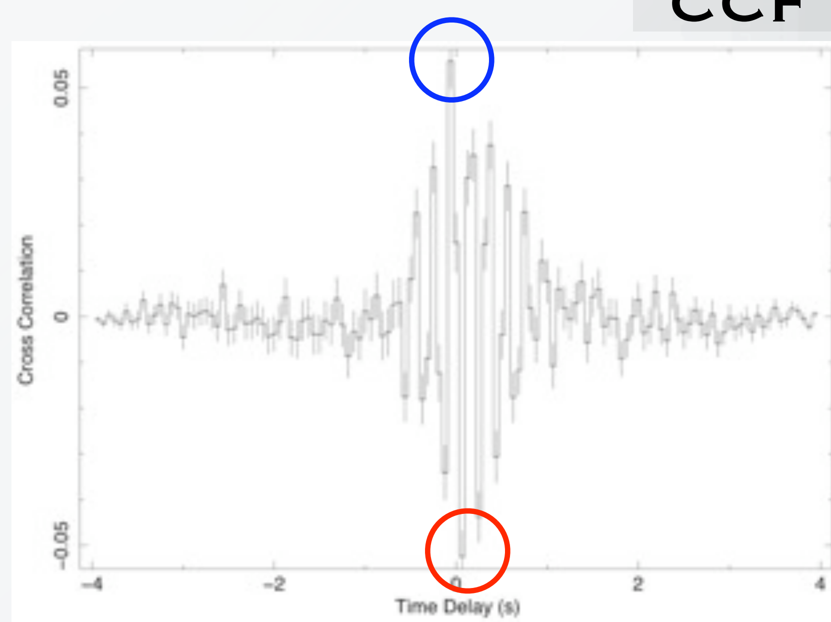
GX 339-4 - ISAAC@VLT - 62.5ms

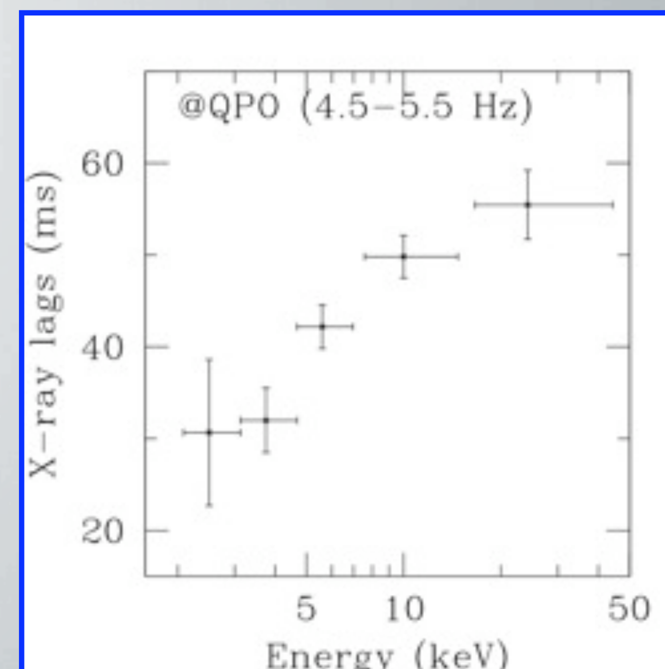
Casella et al. (in prep.)

TIME LAGS



CCF





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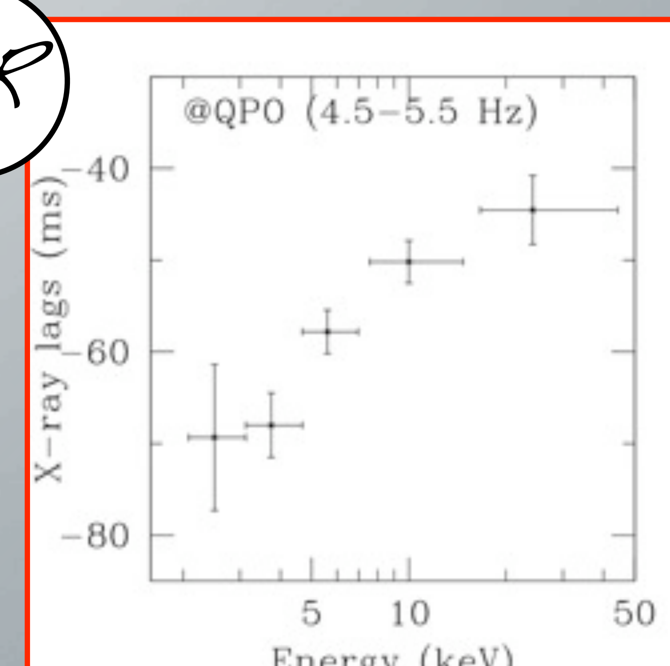

TIME LAGS VS. ENERGY

Once again, timing leaves us with a mix of knowledge and confusion...?

CONCLUSIONS - FUTURE

- Fast variability from the inner regions can be studied at other wavelengths than X-rays
- New field. Enormous potential
  - ★ We **observe** matter along the jet. Measure **physical quantities**
  - ★ We probably observe matter in the corona. Ditto
- monitor, monitor, monitor! evolution is fundamental
- **Need new instrumentation**

  - **faster OIR detectors**
    - simultaneous optical-infrared fast timing (now difficult)
    - fast-photometers permanently mounted, for ToO & monitoring
  - **larger X-ray detectors** (but we can live with XMM / ASTROSAT)
- The future: **LOFT** (and/or **E-ELT**):

  - RXTE -> LOFT would give access to many sources, and states

    ⇘ POPULATION STATISTICS!

What & How

ULTRACAM at ING and ESO -- Optical

High temporal resolution (~500 Hz)

Triple beam CCD (3x1024x1024)

Covers 3 different bands simultaneously

Several filters available, including narrow

Pipeline: data on real time!

- Visitor instrument -

ISAAC at ESO -- Near Infrared

"Burst" and "FastJitter" modes available since 2007

High temporal resolution (~300 Hz)

H, J, K available

Pipeline: conversion to ULTRACAM

What & How

- OPTIMA (on small telescopes, but important results)
- fast modes available for instruments at VLT, KECK, ...
- ...and more... (IquEye, GASP, SALTICAM, etc...)

Optical

- New technologies
  - EMCCDs -- getting rid of that readout noise
    - "expanded" normal optical CCD
  - wider energy range
    - HgCdTe e-APD (mercury-cadmium-telluride Avalanche Photodiode Detectors)
    - MKID (microwave kinetic induction devices)
    - STJ (superconducting tunnel junctions)

Growing field