Multi-wavelength variability from BHs tracking the matter along the jet

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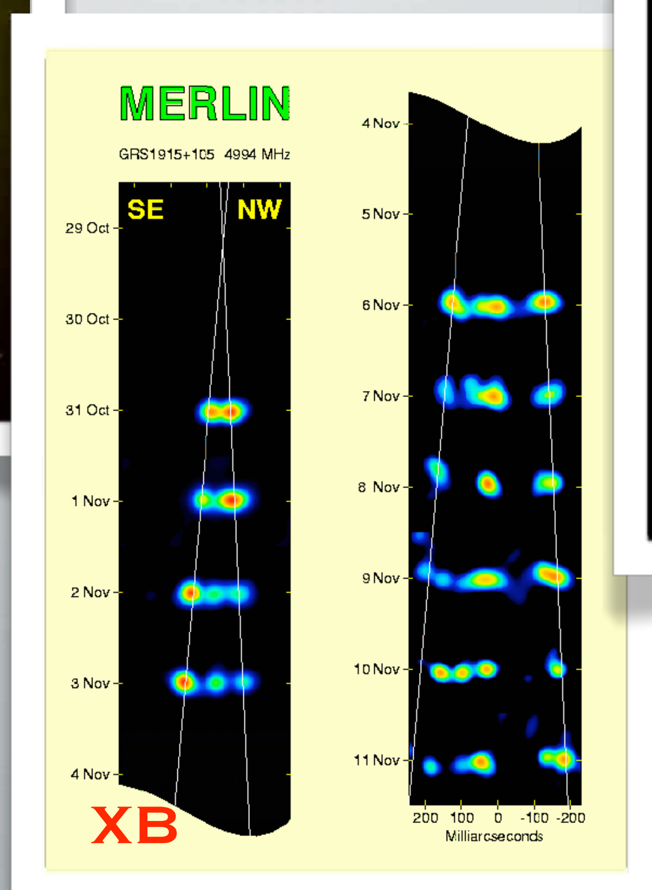
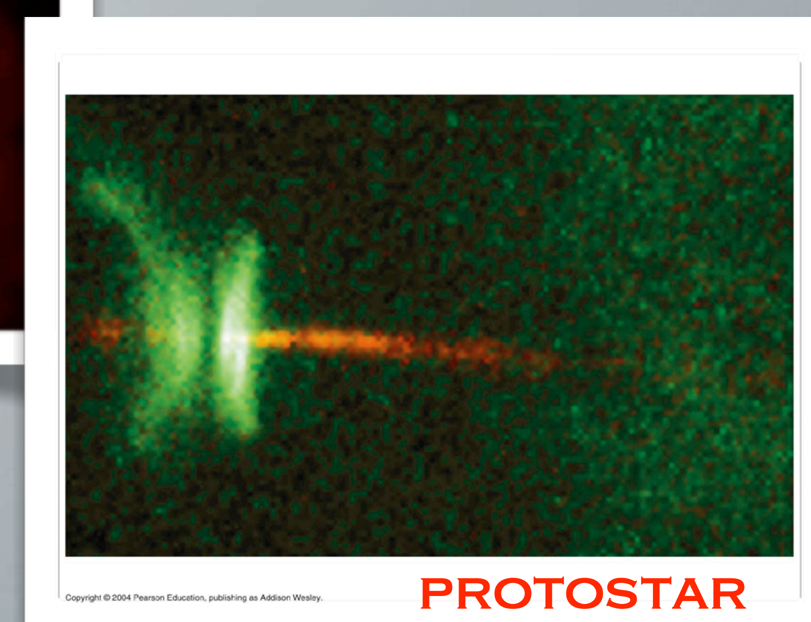
with: T. Maccarone (Southampton), K. O'Brien (USCB), D. Russell (Amsterdam), A. Pe'er (STScI/CfA), R. Fender (Southampton), T. Belloni (Milan), M. van der Klis (Amsterdam) ...and others...

WHY ARE JETS IMPORTANT?

- AGN - X-ray Binaries - GRBs - WDs - SNe - Protostars - (ULX?)
- General phenomenon >>> General knowledge



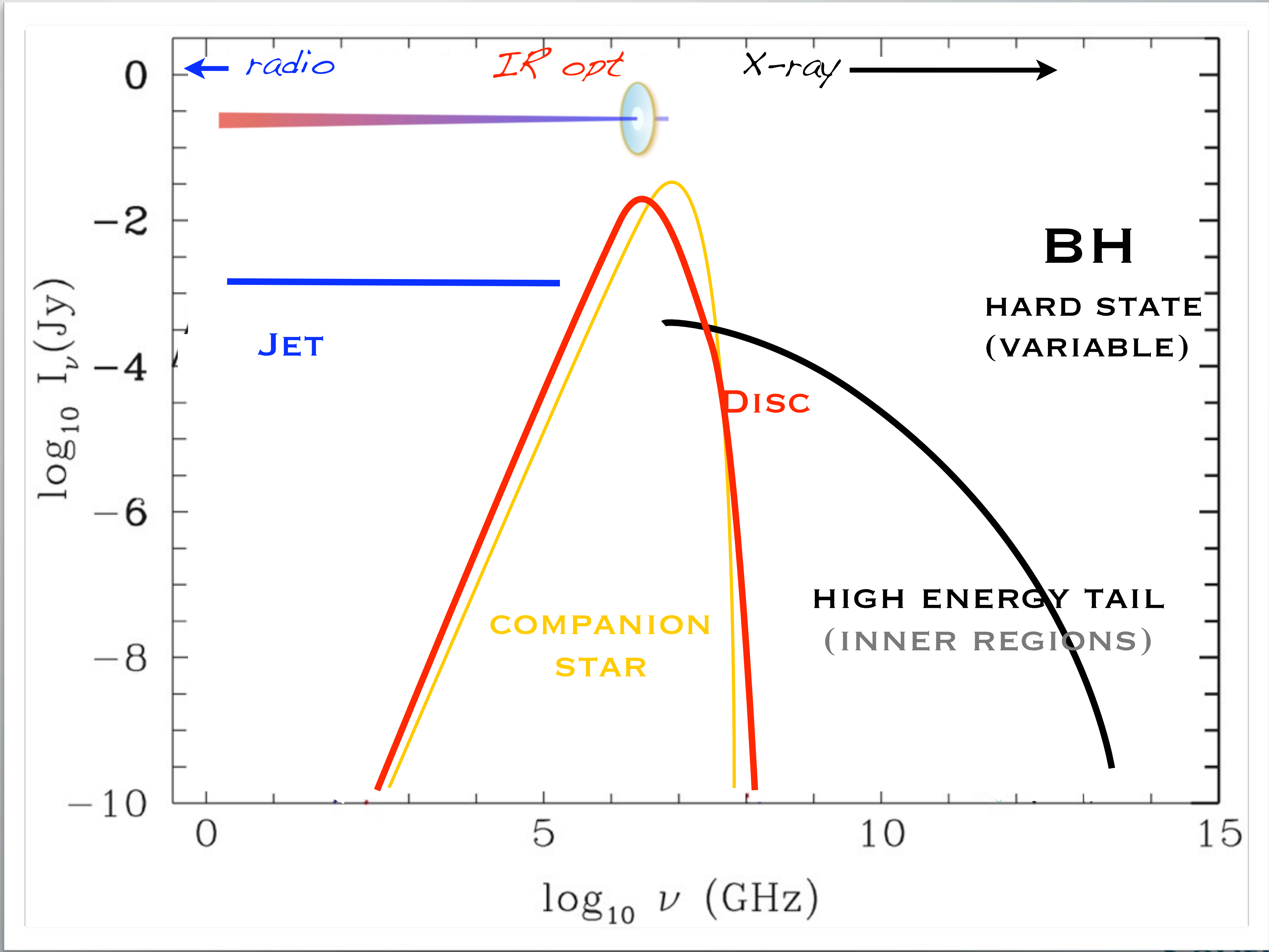


WHY ARE JETS IMPORTANT?

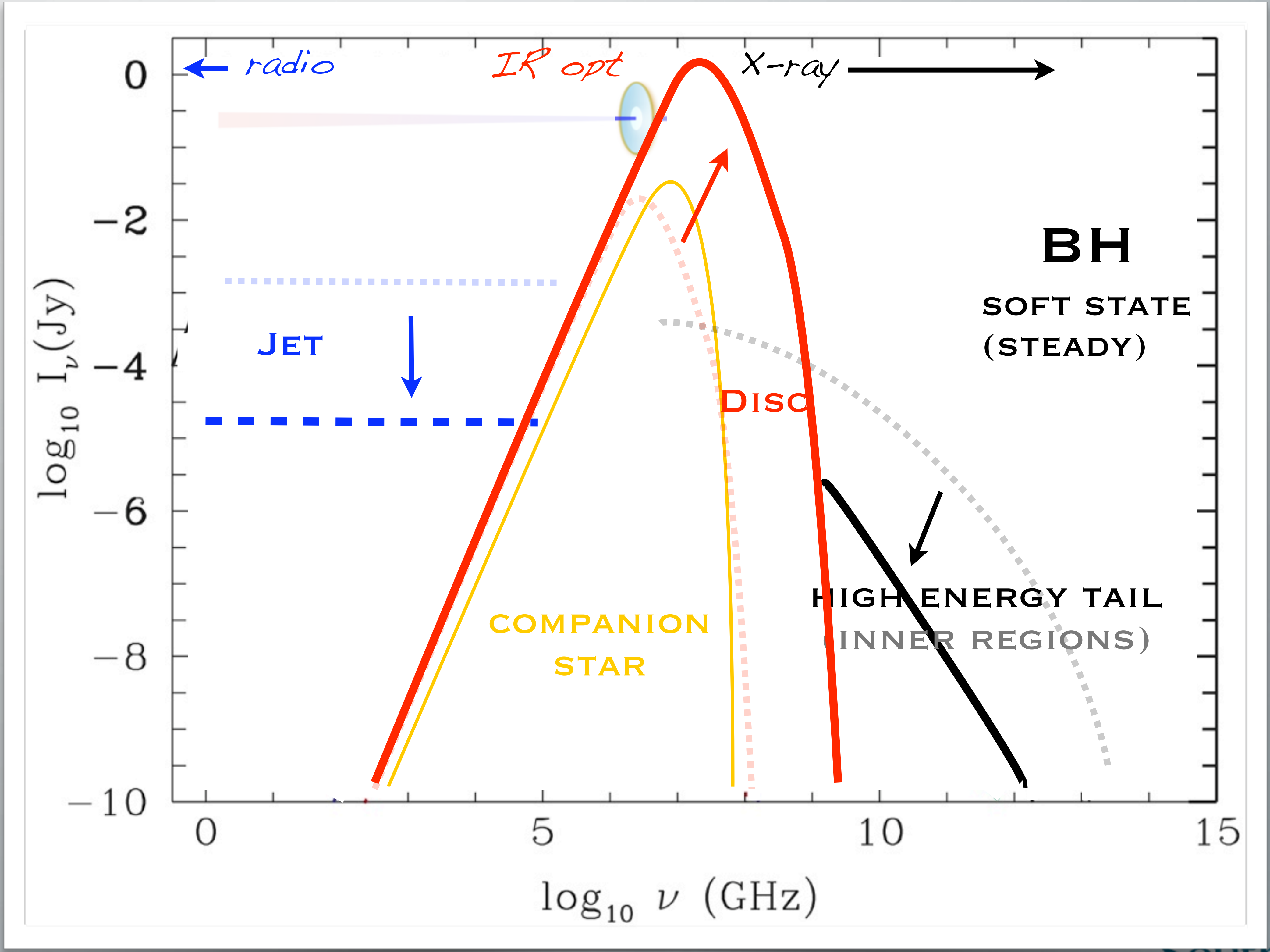
- AGN - X-ray Binaries - GRBs - WDs - SNe - Protostars - (ULX?)
- General phenomenon >>> General knowledge

- Physics of jets (launch, structure, composition)
- They influence the evolution of the launching system
- They influence their surroundings (ISM, IGM)

Black Hole Transients

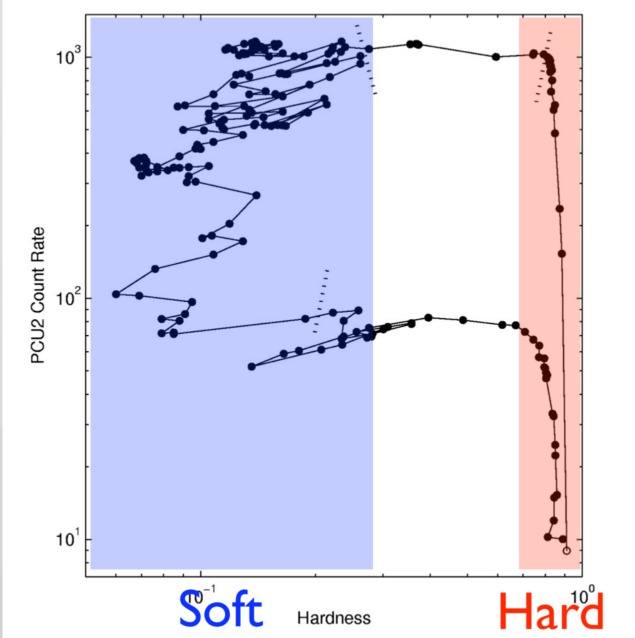


Black Hole Transients



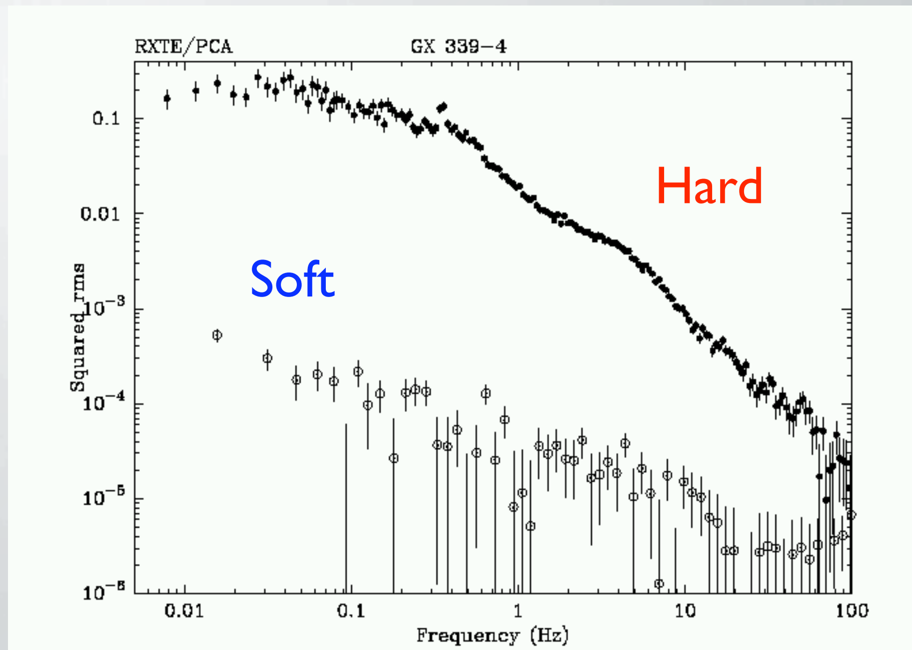
Black Hole Transients

Hardness-Intensity Diagram



(radio quiet) (radio loud)

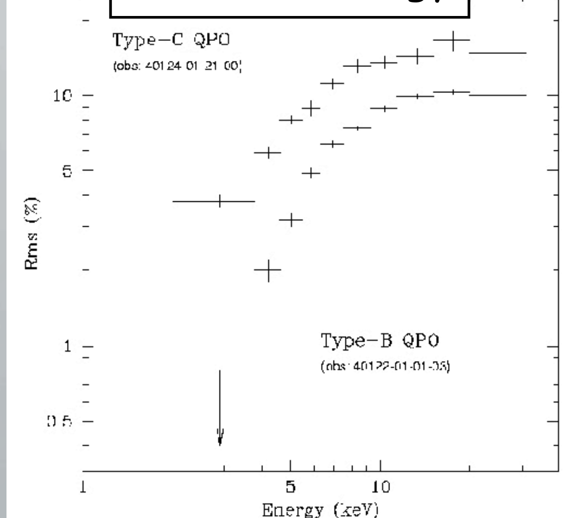
Power Spectra

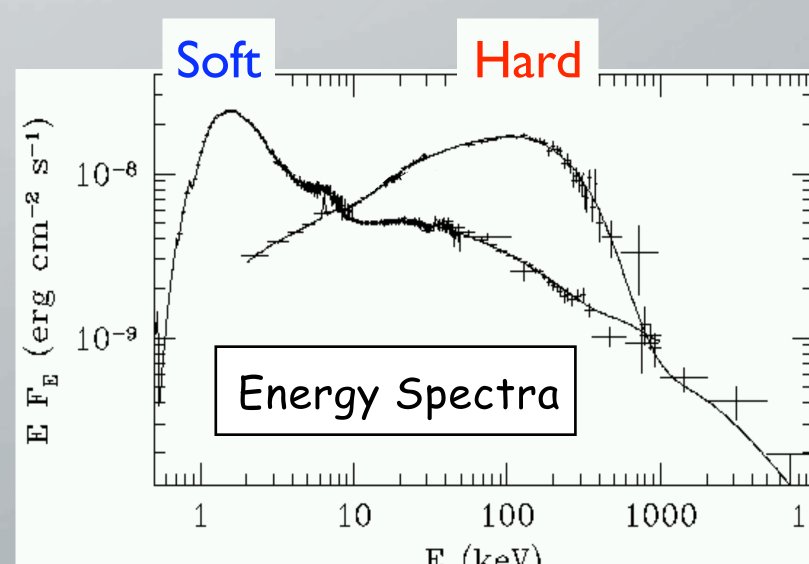


- Hard State
- Strong X-rays variability
- Jet

- Soft State
- no X-rays variability
- No Jet

RMS vs. Energy





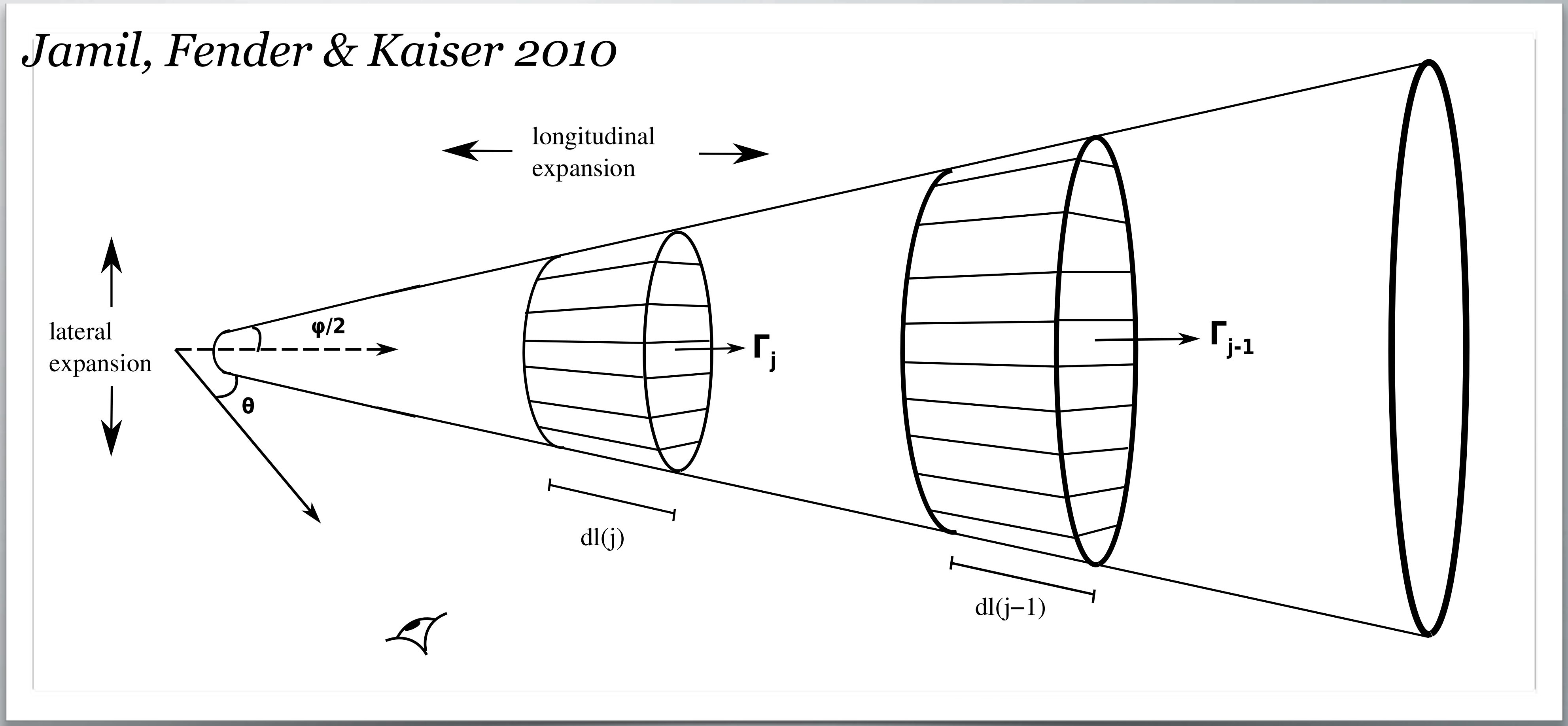
The high-energy component seems to be turbulent

The disc seems to be quiet

WHY JET VARIABILITY?

A PROBLEM: THE MISSING RE-HEATING

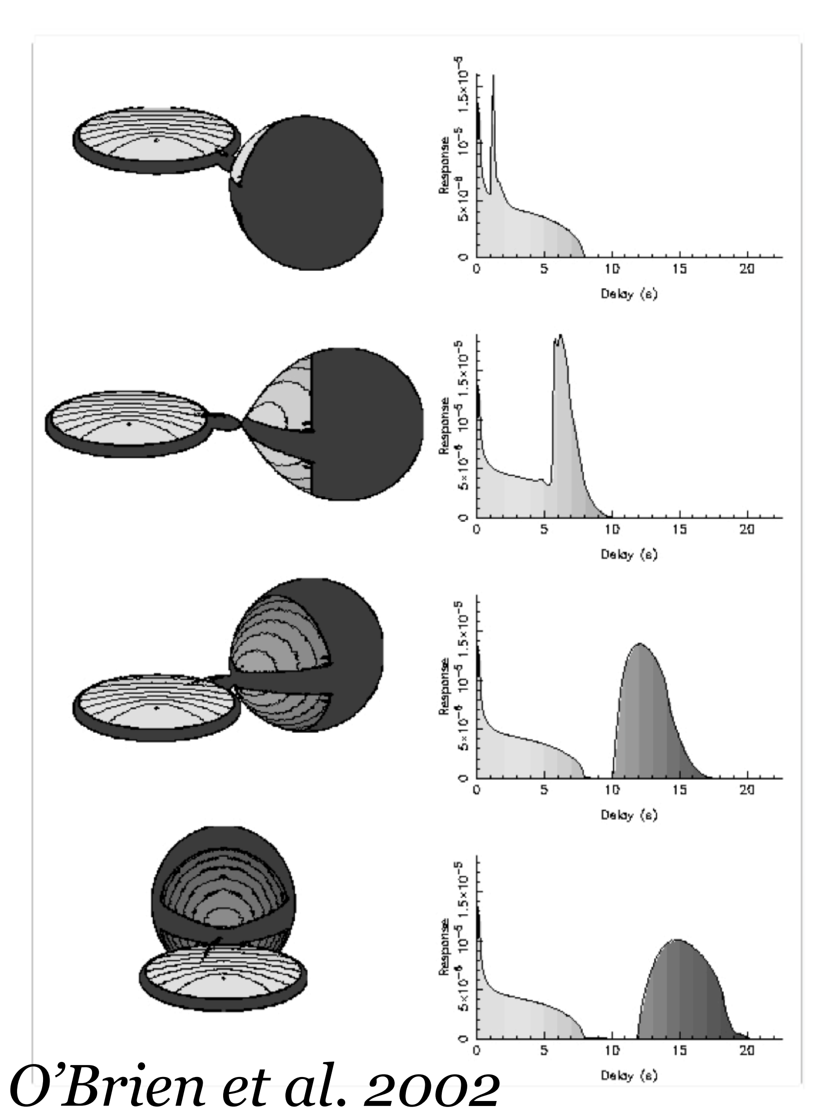
A POSSIBILITY: INTERNAL SHOCKS BETWEEN DISCRETE SHELLS WITH DIFFERENT VELOCITY.



IS THE JET POWERED BY VARIABILITY FROM THE ACCRETION FLOW?

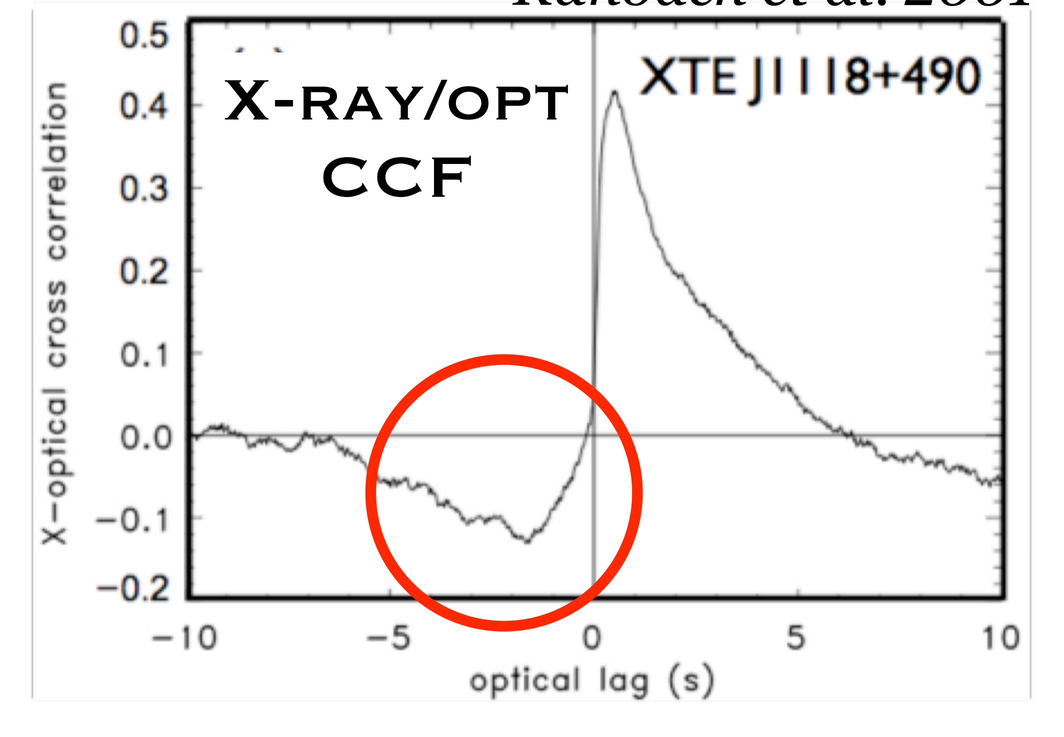
First hints for jet variability: X-ray/optical CCFs

Reprocessed variability:



O'Brien et al. 2002

≠



Kanbach et al. 2001

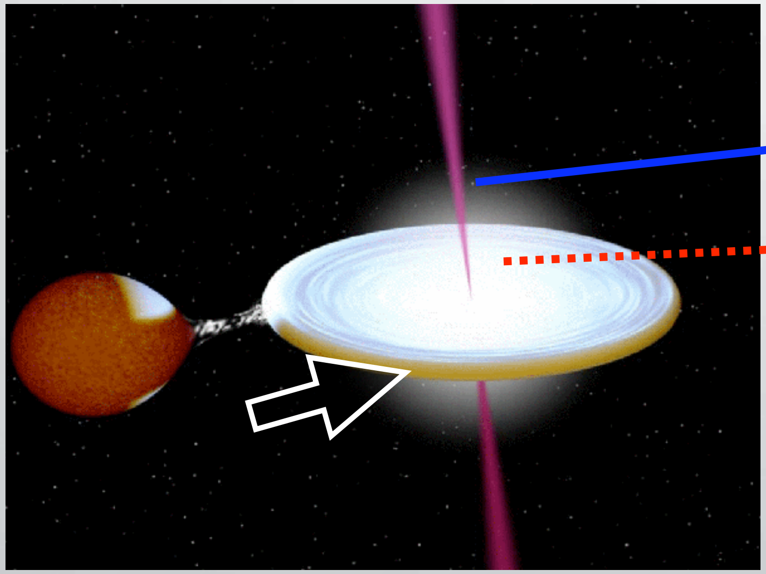
The optical variability is anti-correlated, and precedes the X-rays! Not reprocessing...what?

(e.g. Hynes et al. 2003)

AN EXPLANATION: A POWERFUL JET

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

JET-CORONA coupling through common energy reservoir

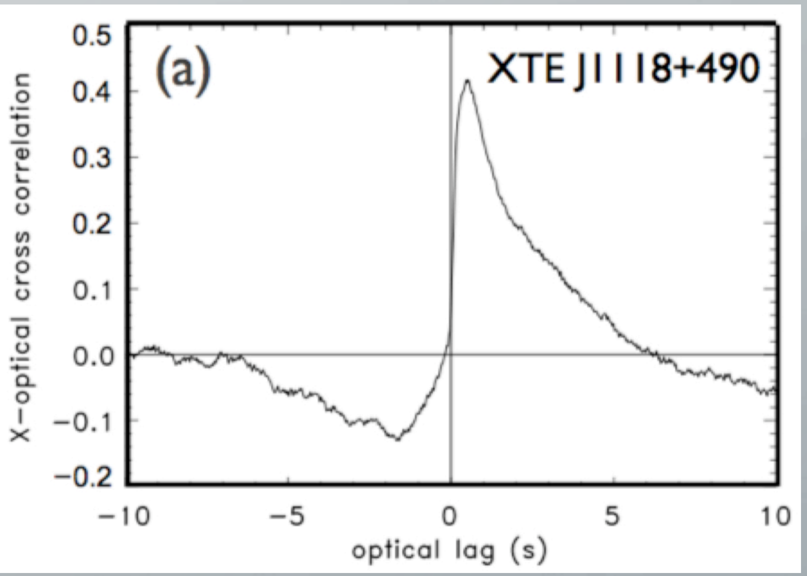


OPTICAL FROM THE JET

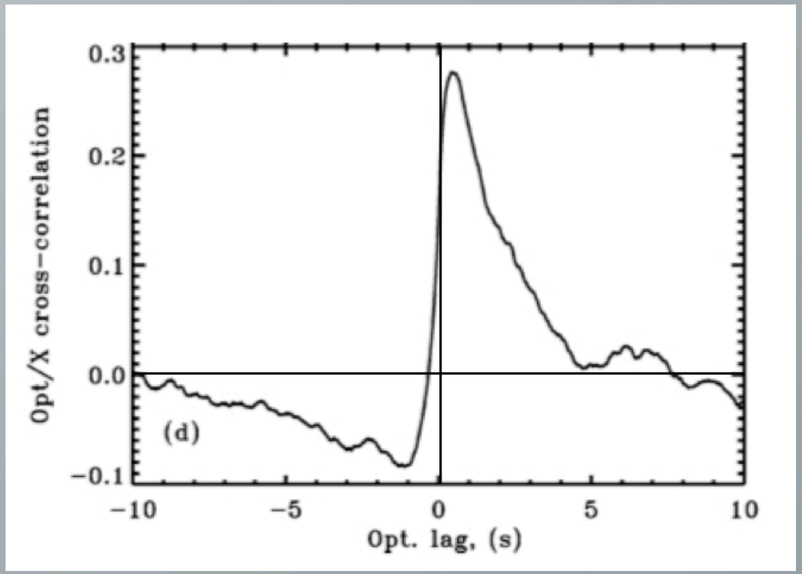
X-RAYS FROM THE CORONA

IF THE SYSTEM IS "JET DOMINATED", IT WORKS:

Data



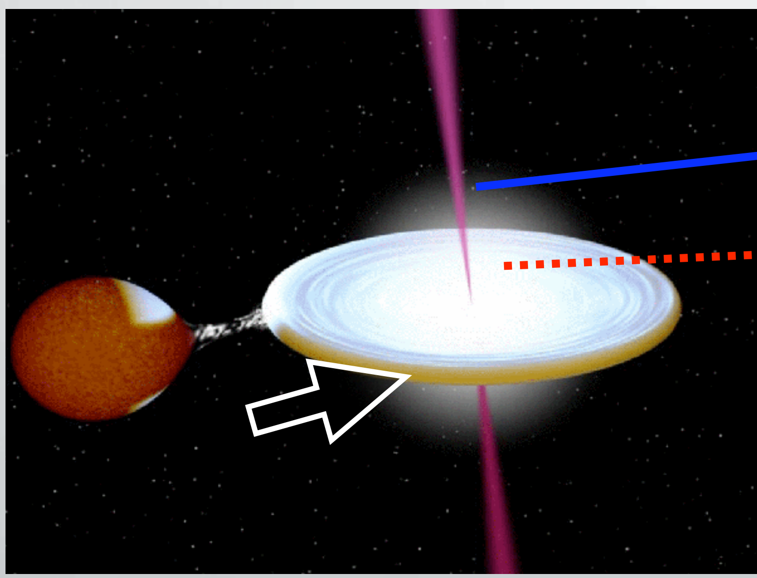
Model



AN EXPLANATION: A POWERFUL JET

THE "COMMON RESERVOIR MODEL" (MALZAC, MERLONI & FABIAN 2004)

JET-CORONA COUPLING THROUGH COMMON ENERGY RESERVOIR



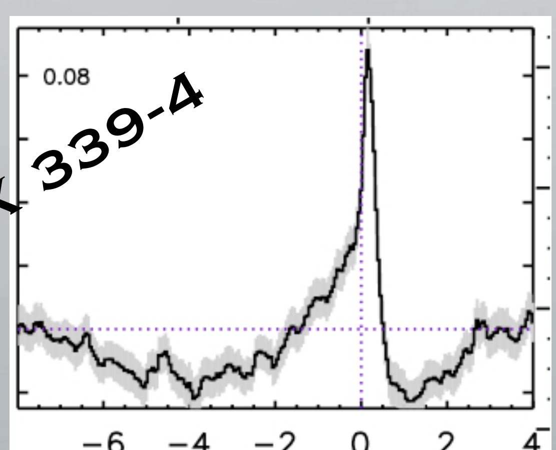
OPTICAL FROM THE JET

X-RAYS FROM THE CORONA

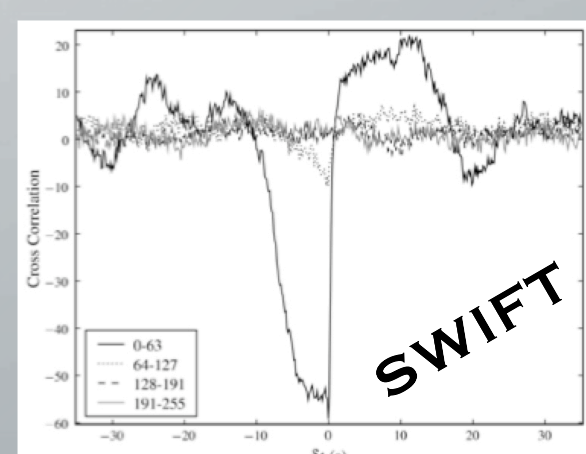
REALITY SEEMS MORE COMPLEX:

NEW DATA:

GX 339-4



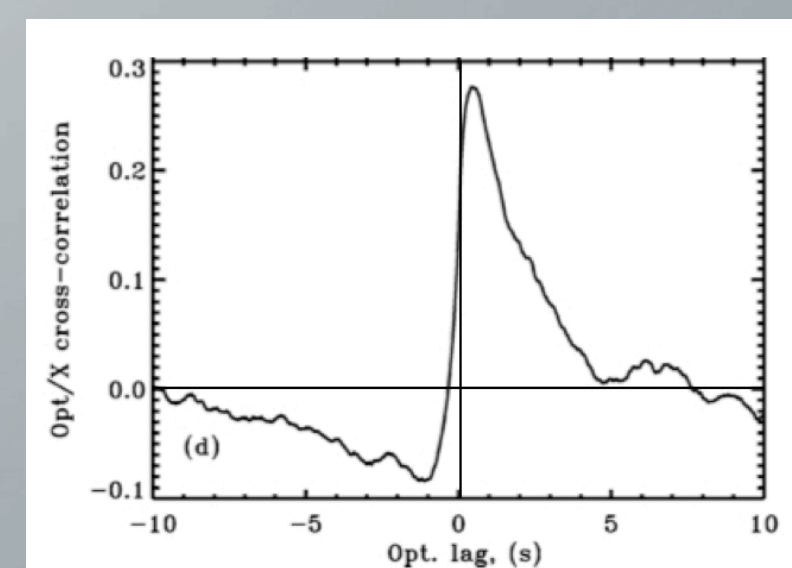
Gandhi et al. 2008



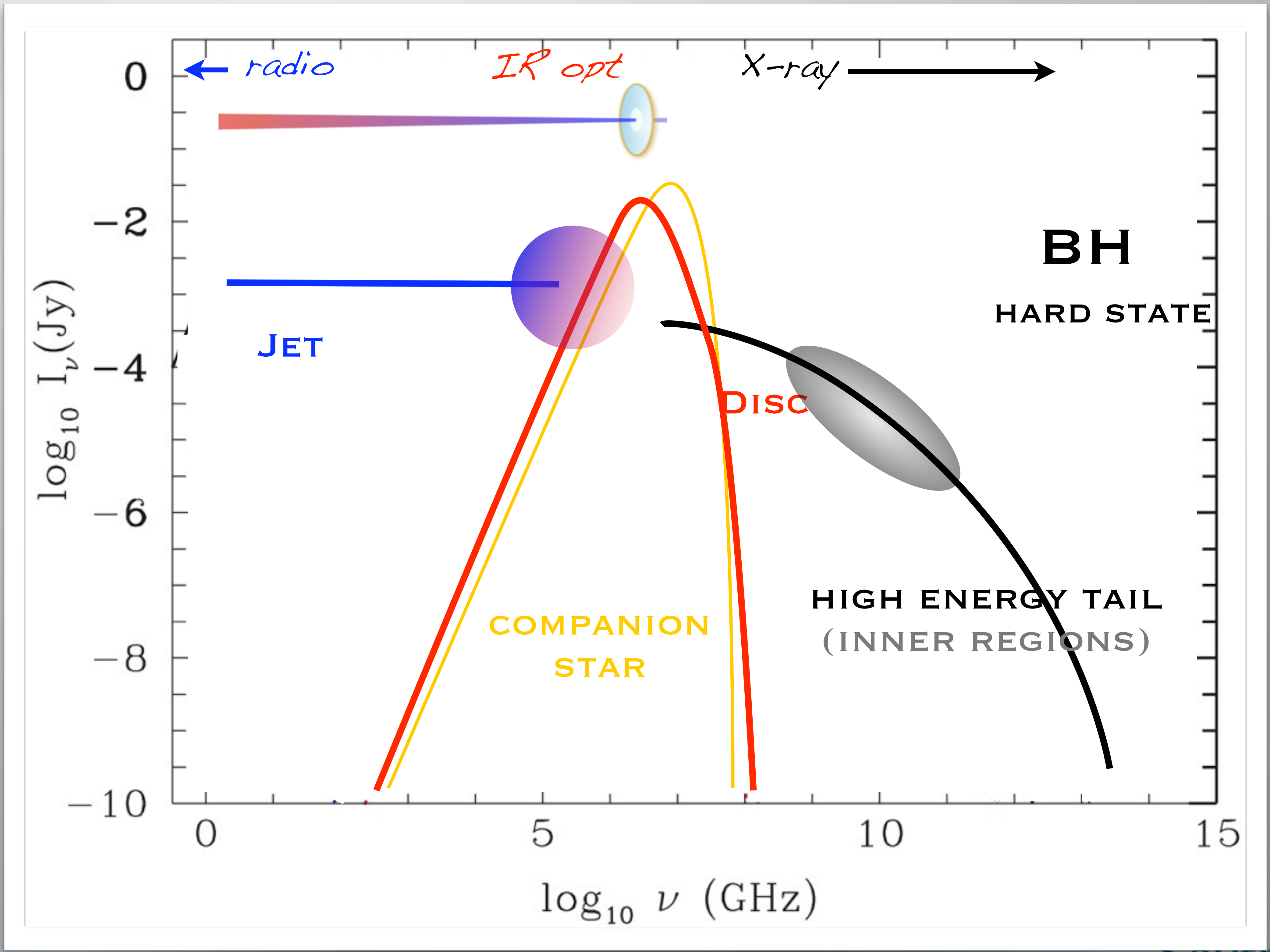
SWIFT J1753

Durant et al. 2008

MODEL



IF YOU WANT THE JET..GO WHERE THE JET IS



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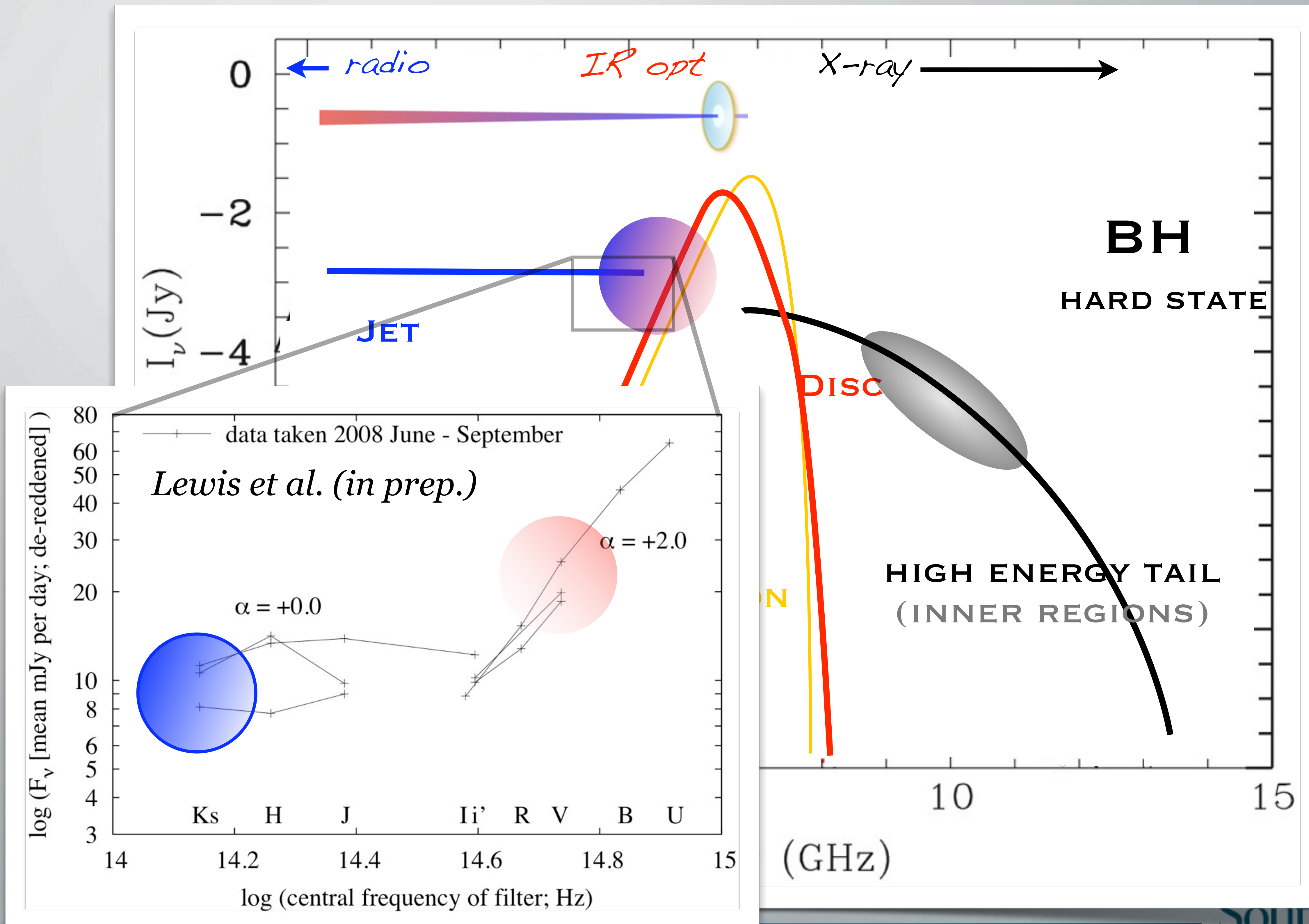
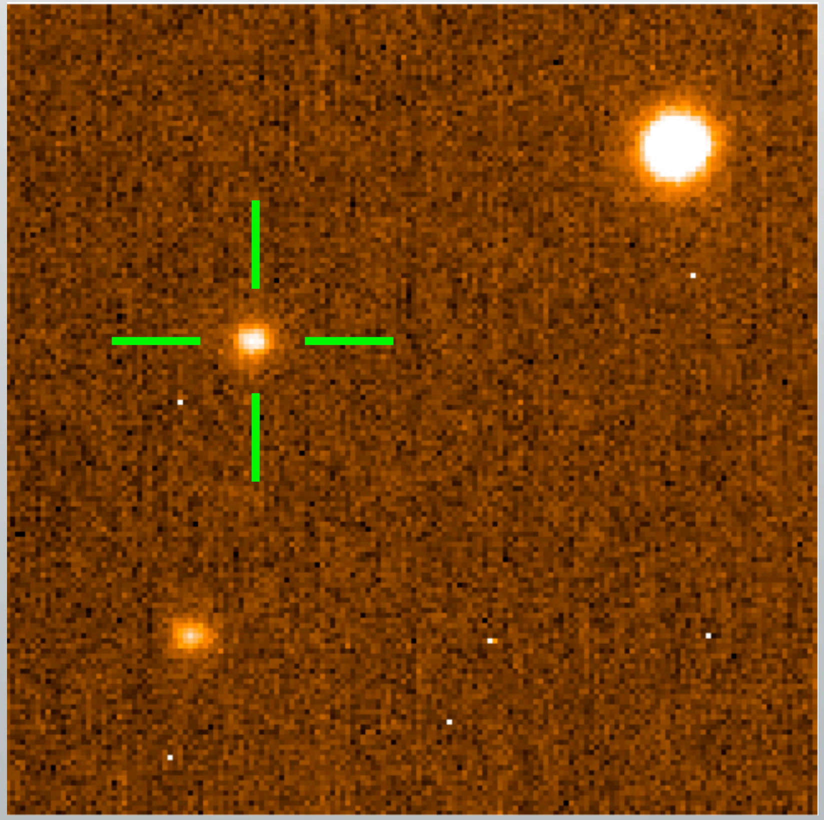


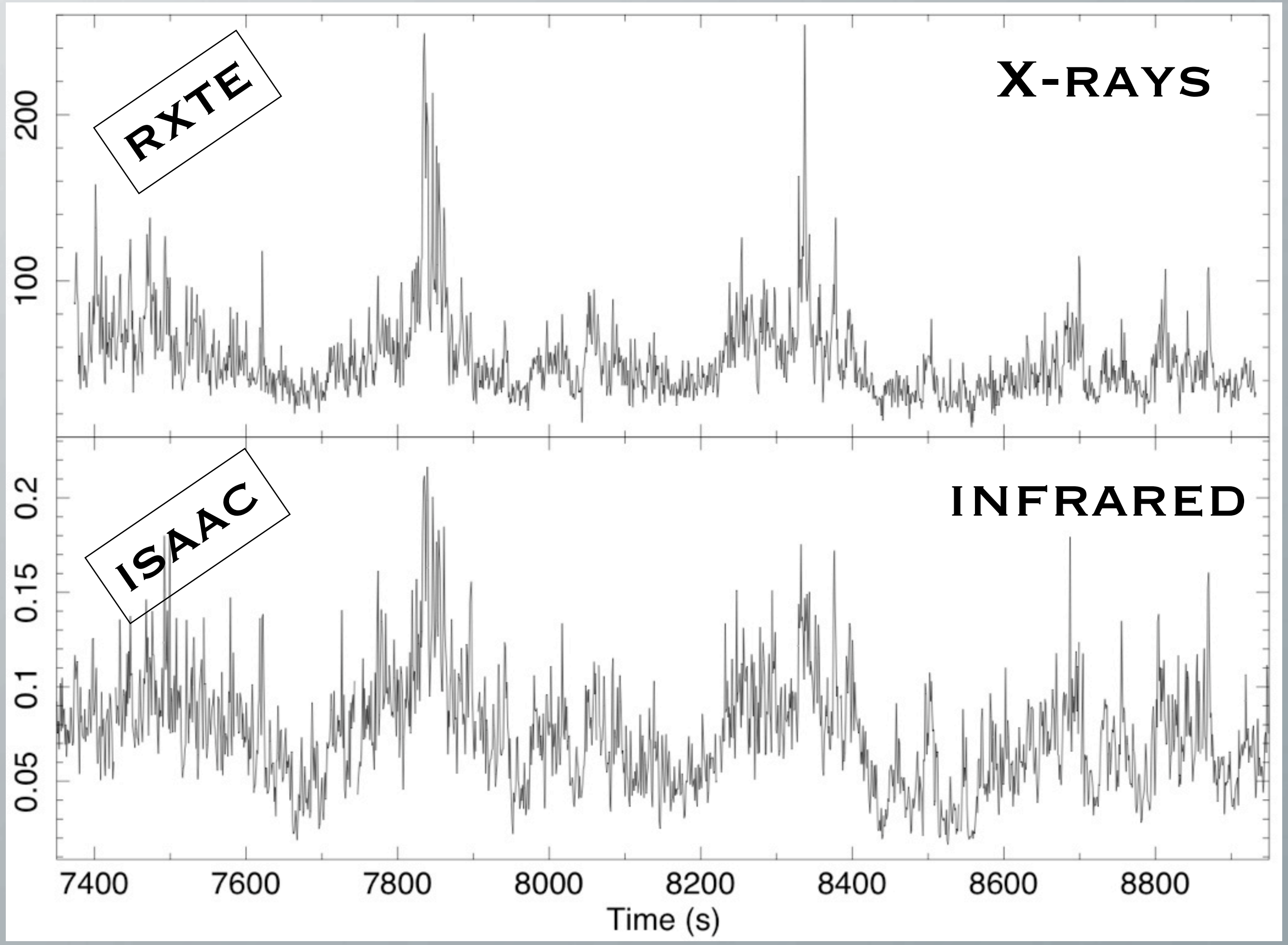
LET'S GO REDDER: INFRARED FAST PHOTOMETRY

So far, in optical.
The jet/disk ratio is (much) higher in <u>infrared</u>

GX 339-4 - ISAAC@VLT - 62.5ms - K=12.5
Casella, Maccarone et al. 2010



23" x 23"



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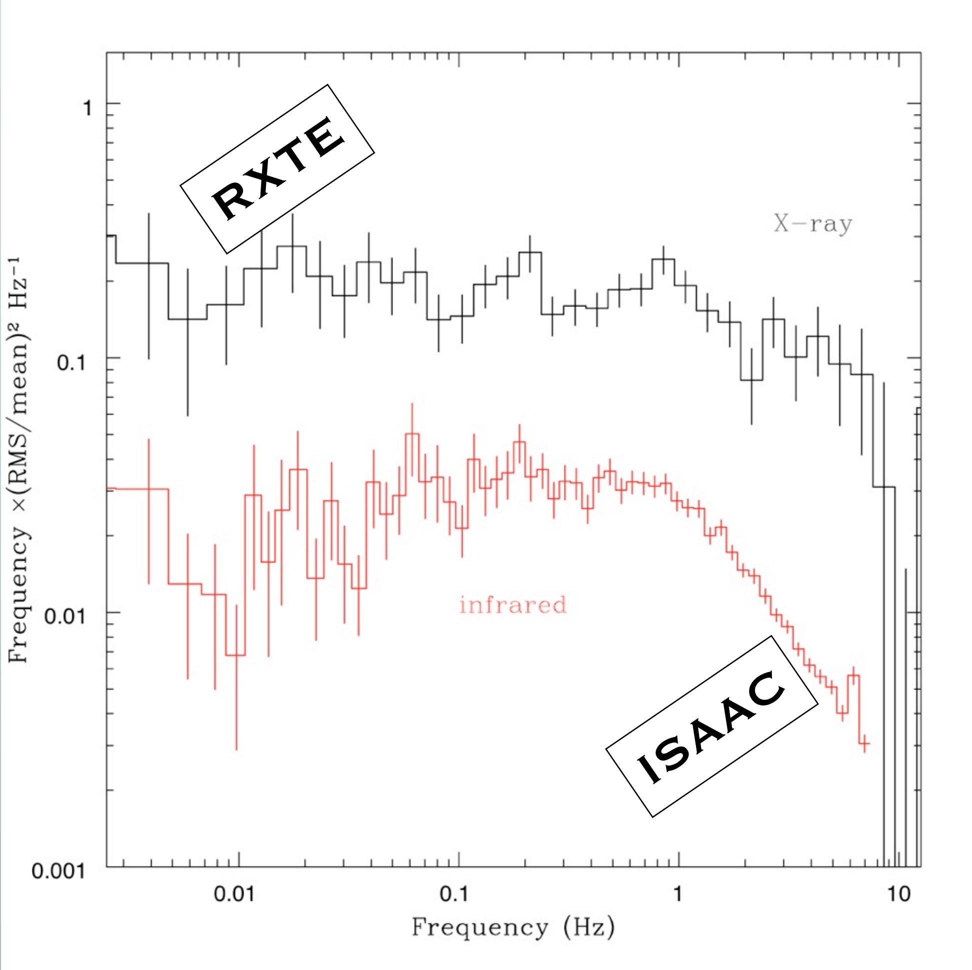

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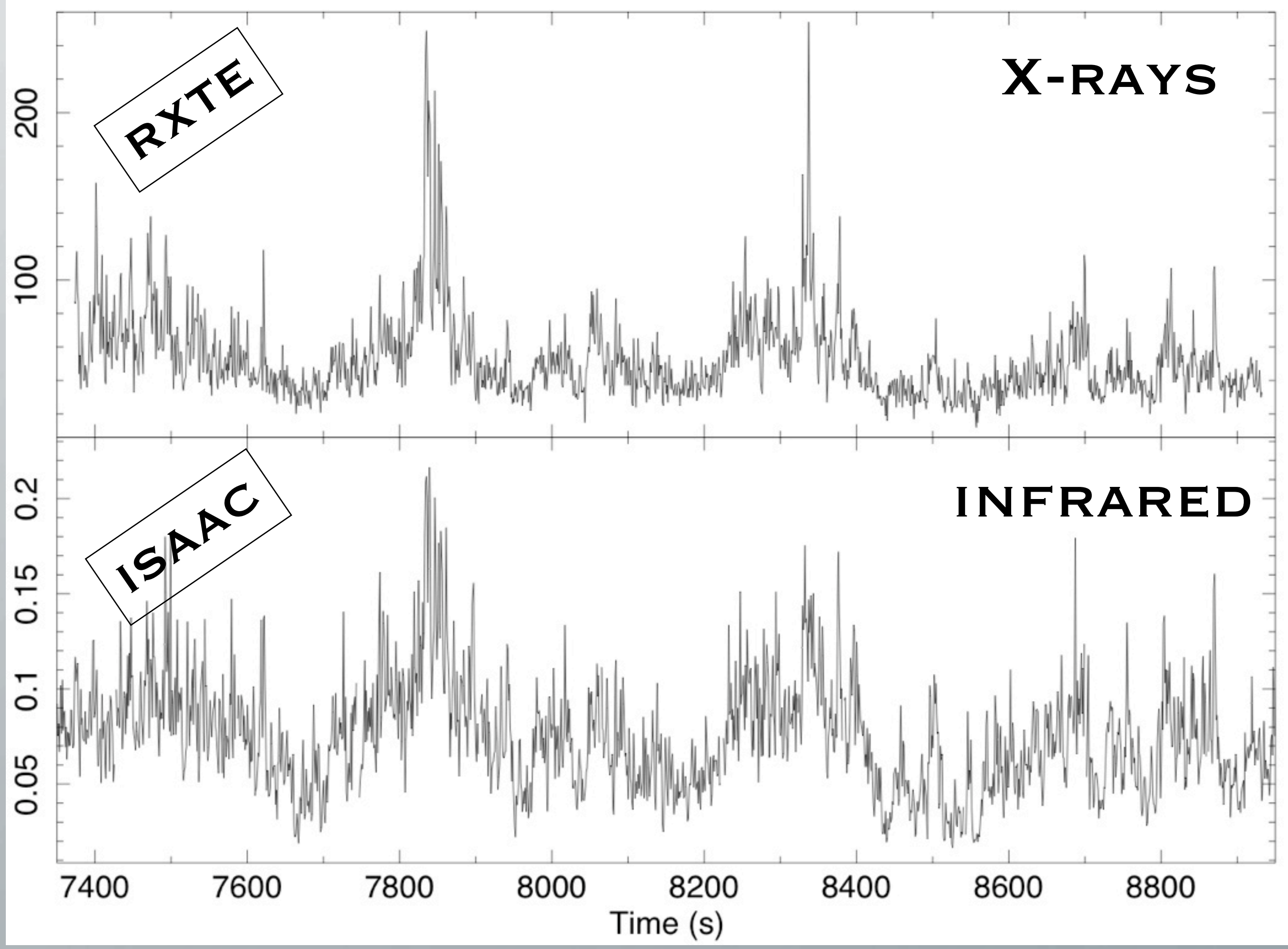

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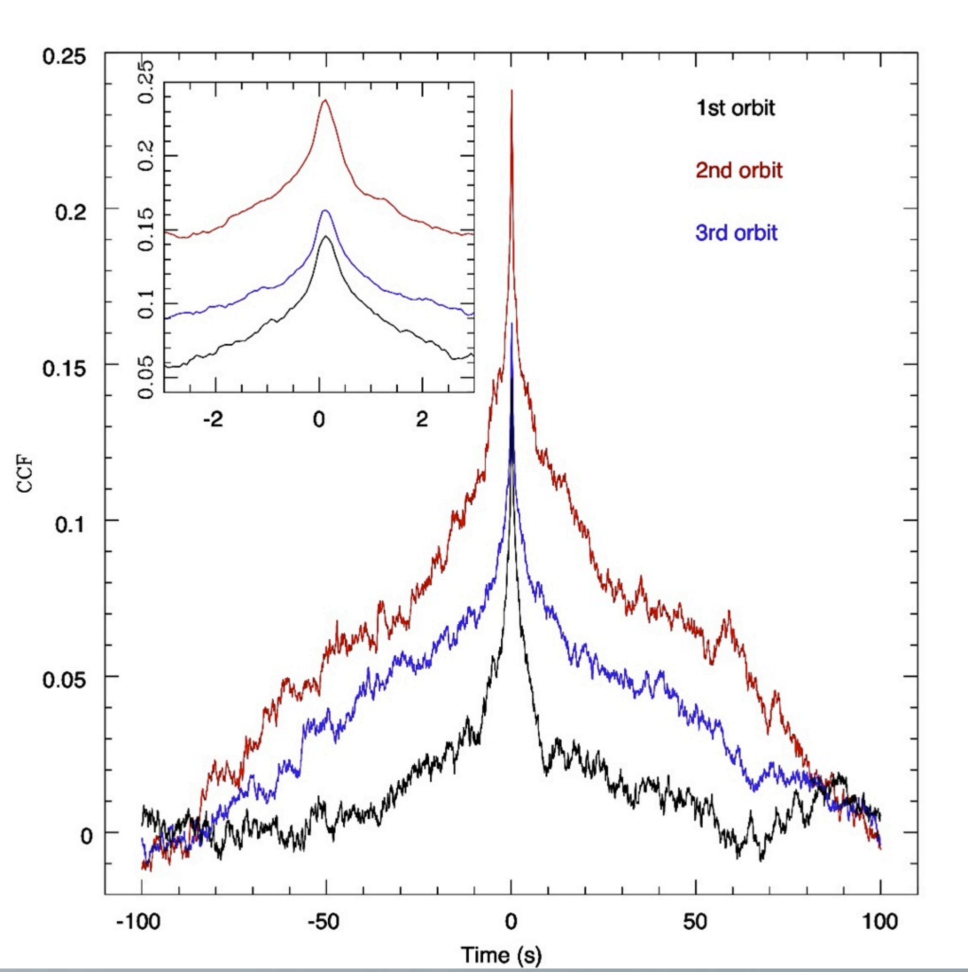
Casella, Maccarone et al. 2010

- Infrared and X-rays are correlated
- **Infrared lag X-rays by 100 milliseconds**
- Very high brightness temperature (>10^6K)
- Flat spectral slope
- **We are observing the JET varying on timescales as short as 67 millisec.**



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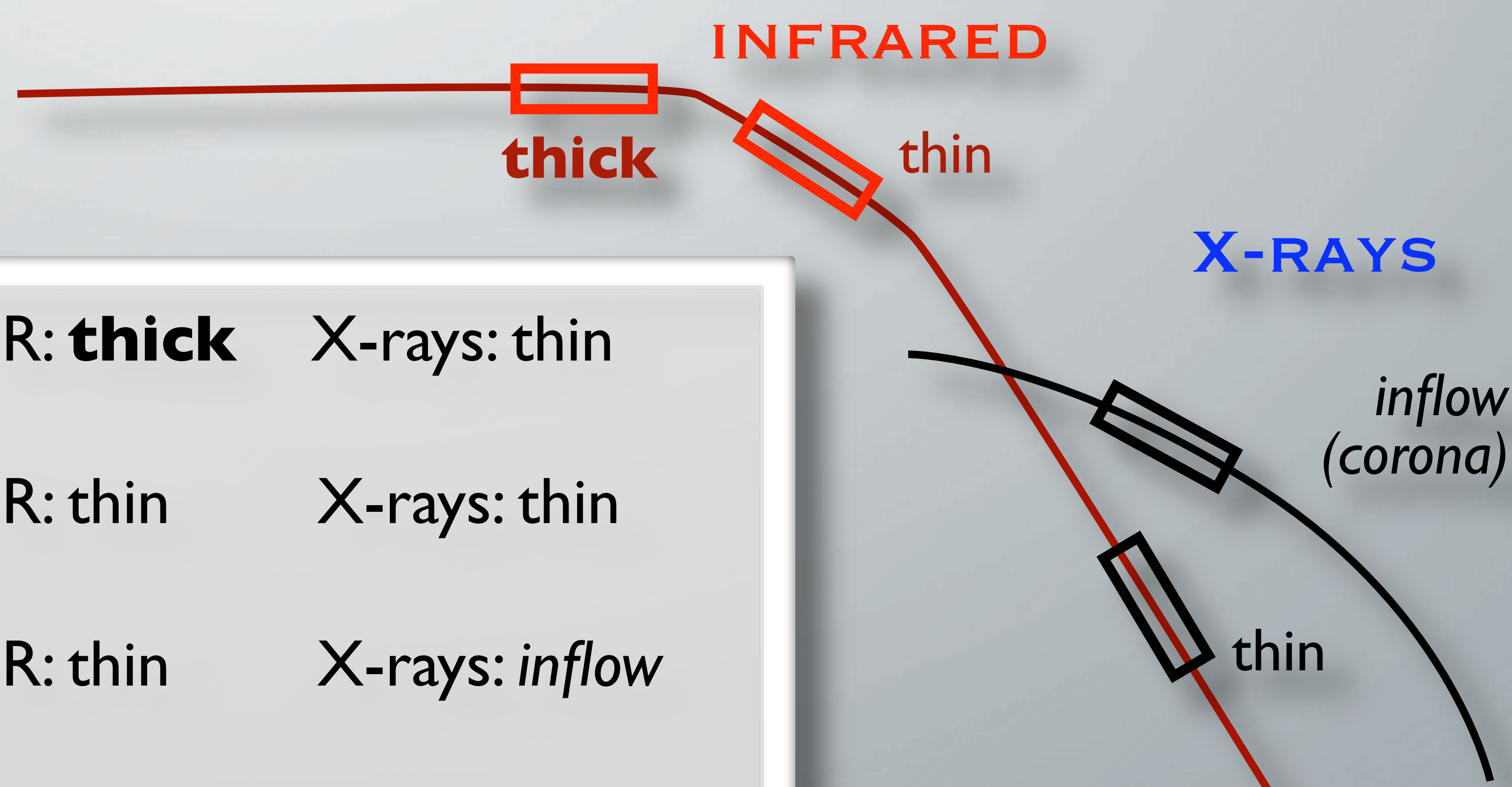

(1)	IR: **thick**	X-rays: thin
(2)	IR: thin	X-rays: thin
(3)	IR: thin	X-rays: *inflow*
(4)	IR: **thick**	X-rays: *inflow*

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

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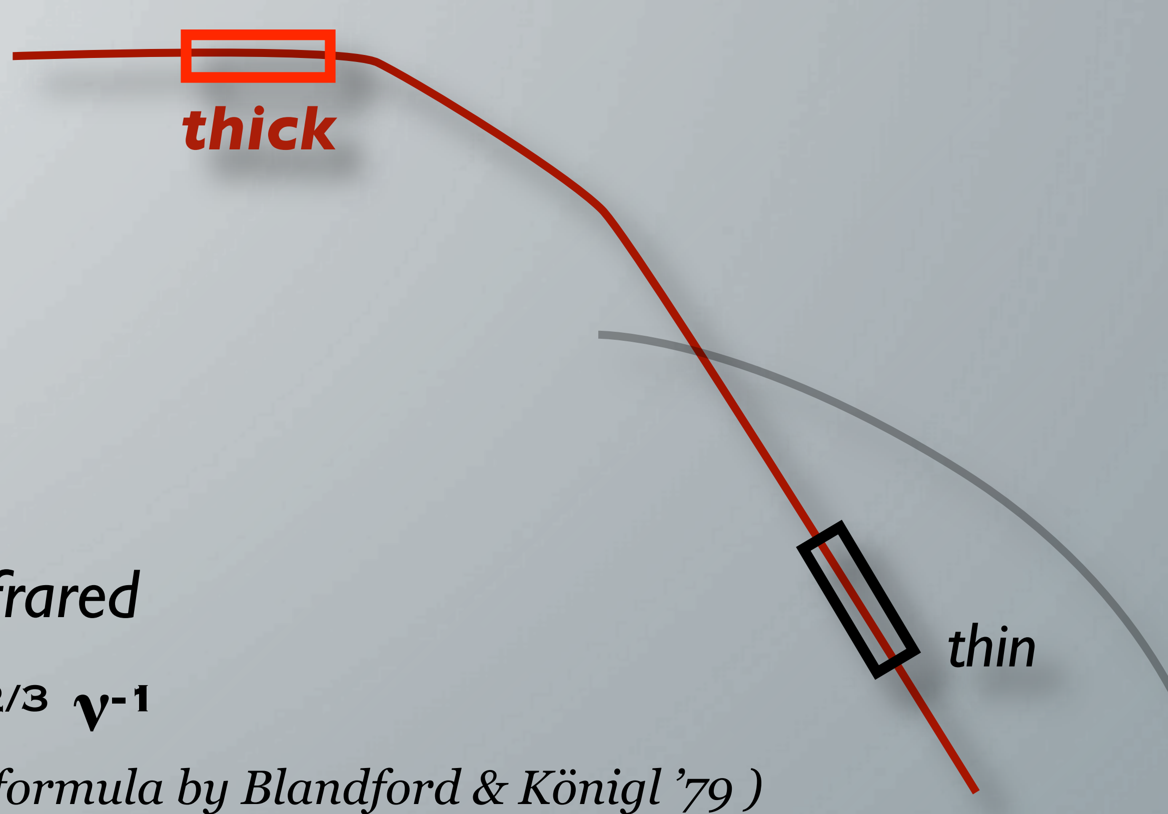

- *It takes 0.1s for the matter to get there*
- *we assume all jets in X-ray binaries are similar*
- *we scale from Cyg X-1 in radio to GX 339-4 in infrared*

$$R_{MAX} \sim \gamma^{-4/3}\, \beta^{-2/3}\, D^{2/3}\, \sin\theta^{-1/3}\, \Phi^{-1}\, L^{2/3}\, \nu^{-1}$$

("standard" formula by Blandford & Königl '79)

- *we measure the speed for many sets of parameters*

$\Gamma > 2$ **A MEASURE OF THE JET SPEED**

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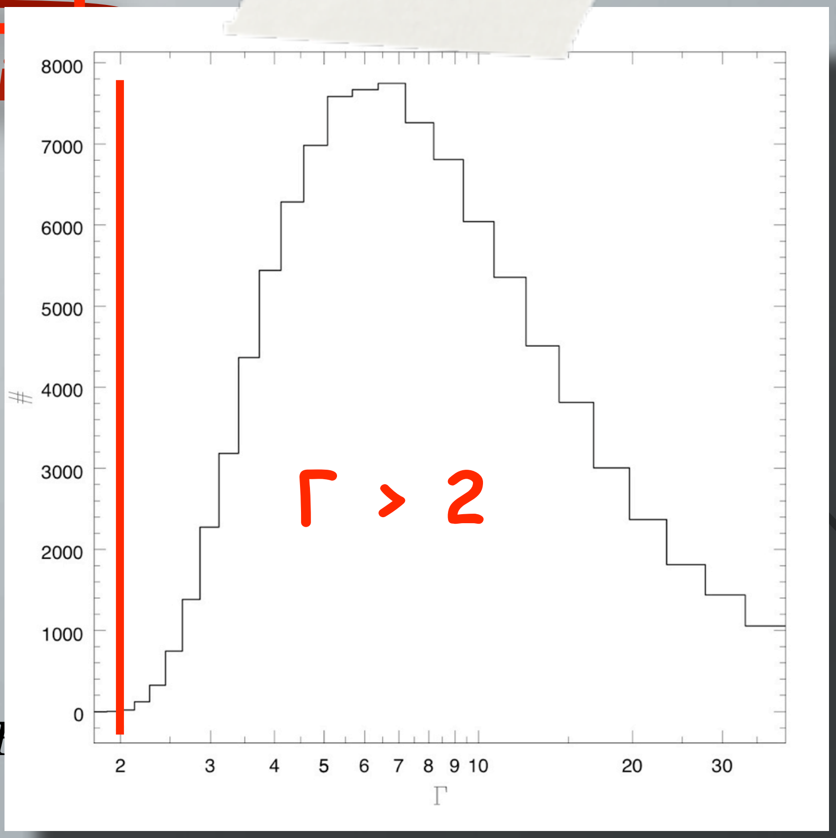

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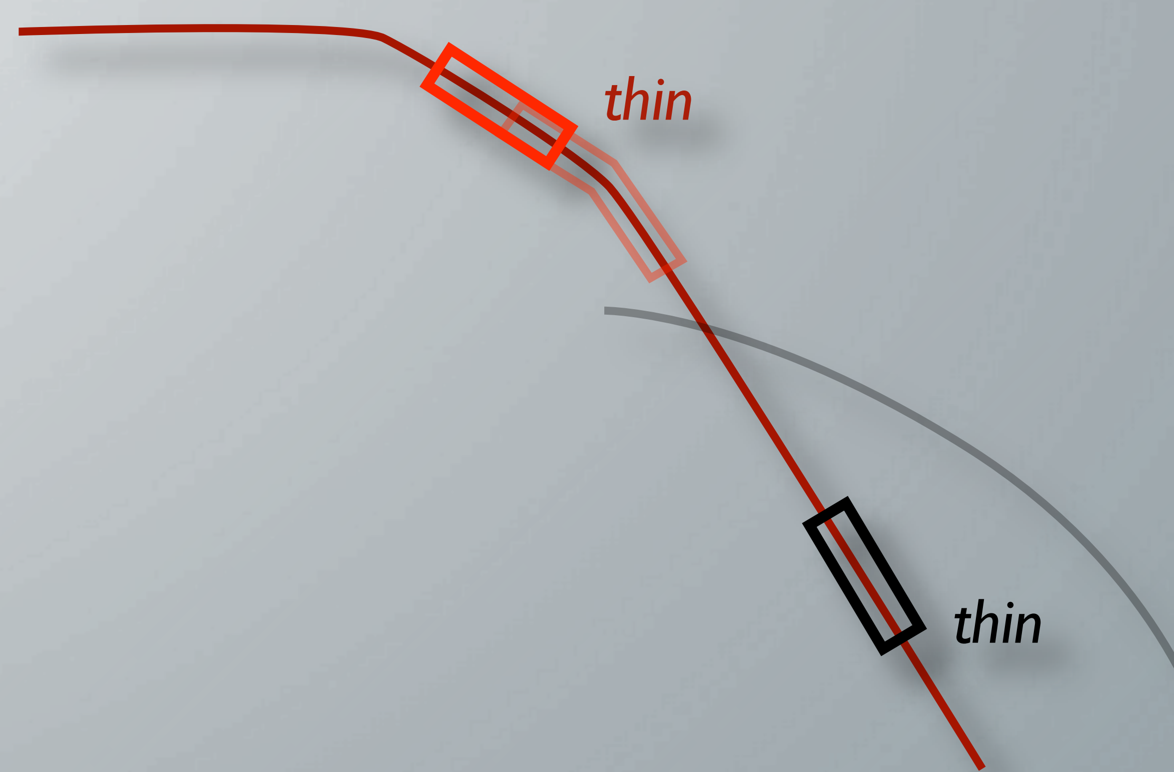
Casella, Maccarone et al. 2010
GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(2) IR: thin X-rays: thin



- *we observe a time delay: IR must come after cooling*
- ***$T_{cooling}$ = 100 ms***
- *we assume E_0 ~ X-rays and E_1 ~ IR*
- *we find a unique solution:* $\gamma_0 \sim 10^4$ $\gamma_1 \sim 50$ $B \sim 10^4$ G

A GLIMPSE OF JET PHYSICS

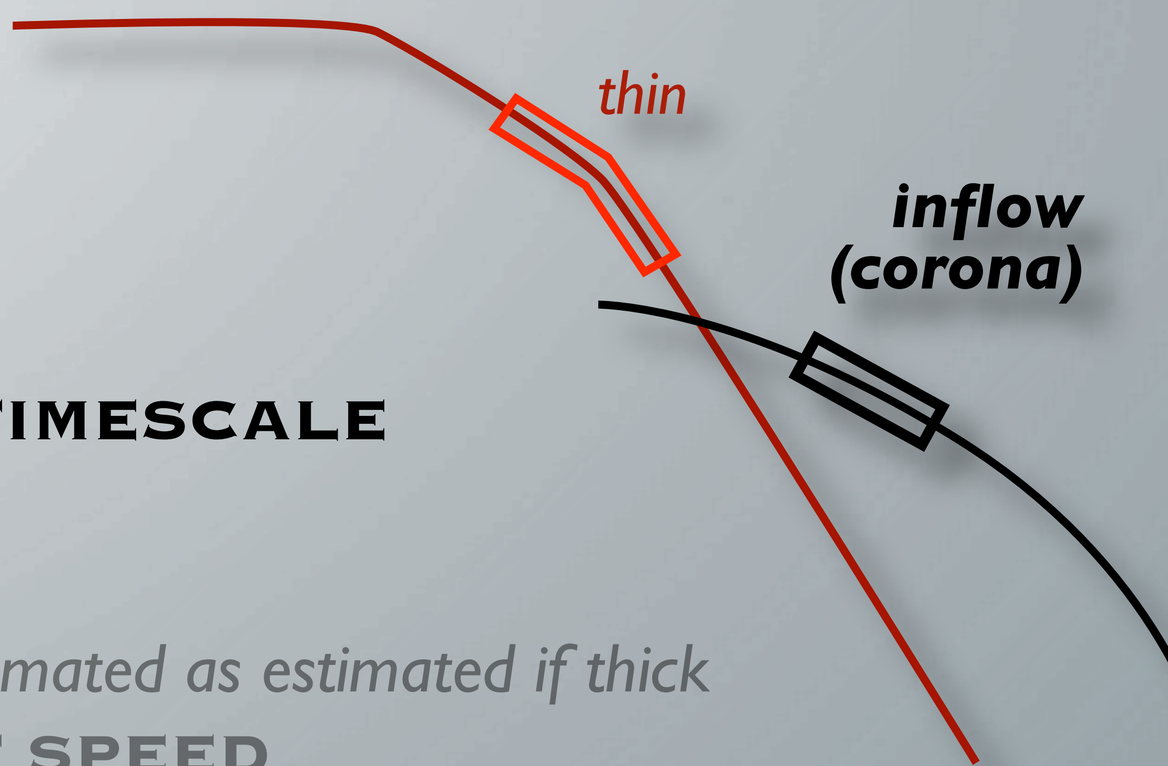
the way forward: optical + infrared + ...

LET'S GO REDDER: INFRARED FAST PHOTOMETRY

SO FAR, IN OPTICAL.
THE JET/DISK RATIO IS (MUCH) HIGHER IN <u>INFRARED</u>

Casella, Maccarone et al. 2010
GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(3) IR: thin X-rays: *inflow*



a) *before cooling:* ***T_{eject} < 0.1 s***

A MEASURE OF THE EJECTION TIMESCALE

b) *after cooling:*

- *can't be too far off the break... can be approximated as estimated if thick*

$\Gamma > 2$ A MEASURE OF THE JET SPEED

- *can't be too far from the base either... looser upper limit:*

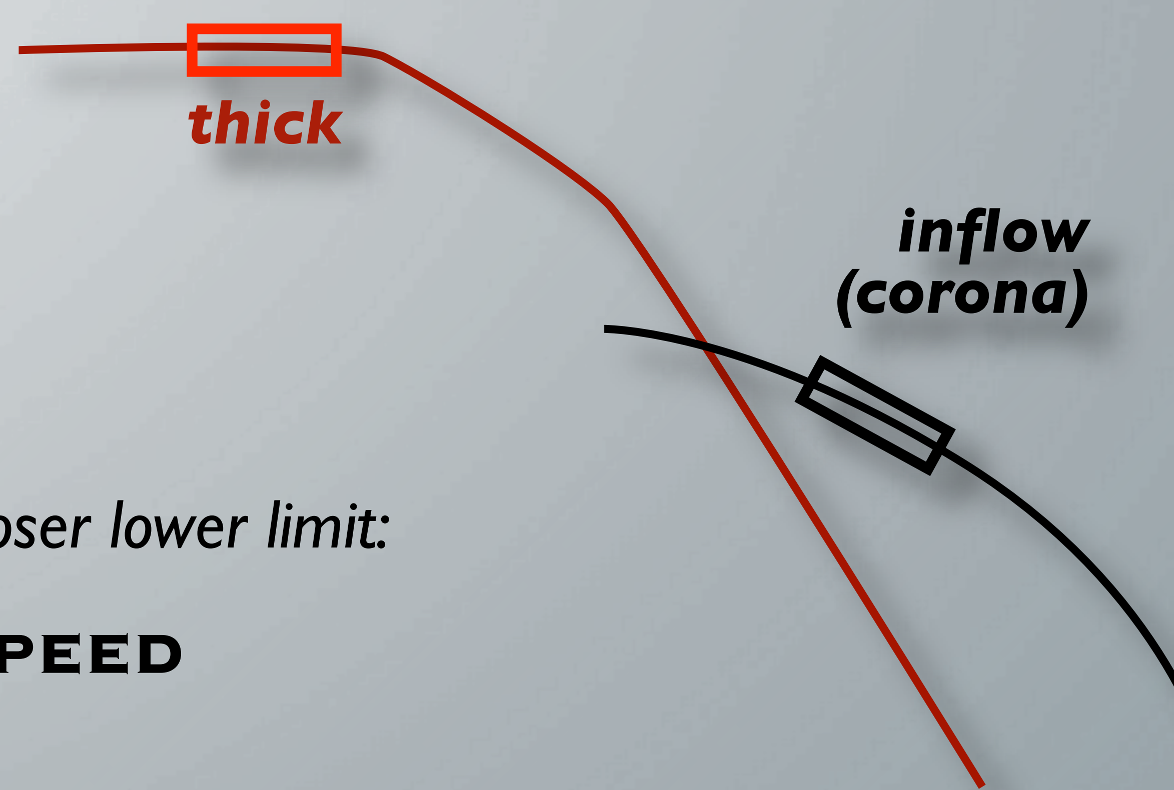
T_{eject} < 0.1 s A MEASURE OF THE EJECTION TIMESCALE

LET'S GO REDDER: INFRARED FAST PHOTOMETRY

SO FAR, IN OPTICAL.
THE JET/DISK RATIO IS (MUCH) HIGHER IN <u>INFRARED</u>

Casella, Maccarone et al. 2010
GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(4) IR: **thick** X-rays: *inflow*



- *The reasoning on the jet speed still holds, but with looser lower limit:*

$\Gamma >> 2$ **A MEASURE OF THE JET SPEED**

- *Similarly, looser upper limit on the ejection timescale:*

$T_{EJECT} << 0.1$ s **A MEASURE OF THE EJECTION TIMESCALE**

Conclusions - Future

1) We are tracking matter along the jet!

2) More data. Monitoring of one outburst needed. Spectral transitions

3) The same for NS. Less powerful jets? Difficult statistics.

4) Longer wavelengths: further away along the jet
   Radio. (WSRT - ATCA) Mid-IR. (SPITZER)

5) Doing things properly:
   ESO proposal approved } / Infrared + Optical + X-ray
   some performed -- BH & NS
   more submitted \ monitoring!

6) Need for better models... VARIABLE models!

7) Need for new instrumentation: Opt + IR ; E-ELT!
   Dedicated space mission?