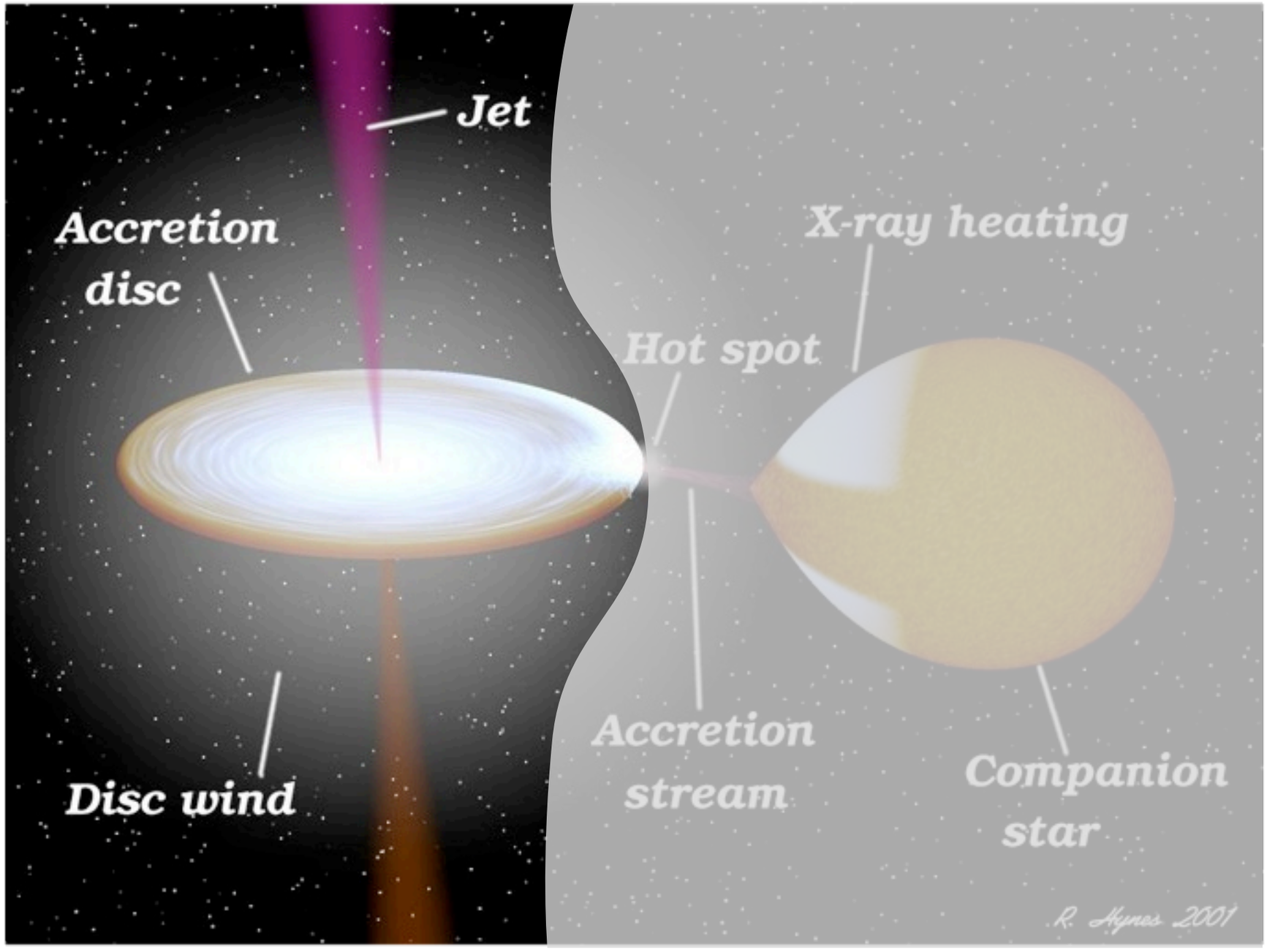
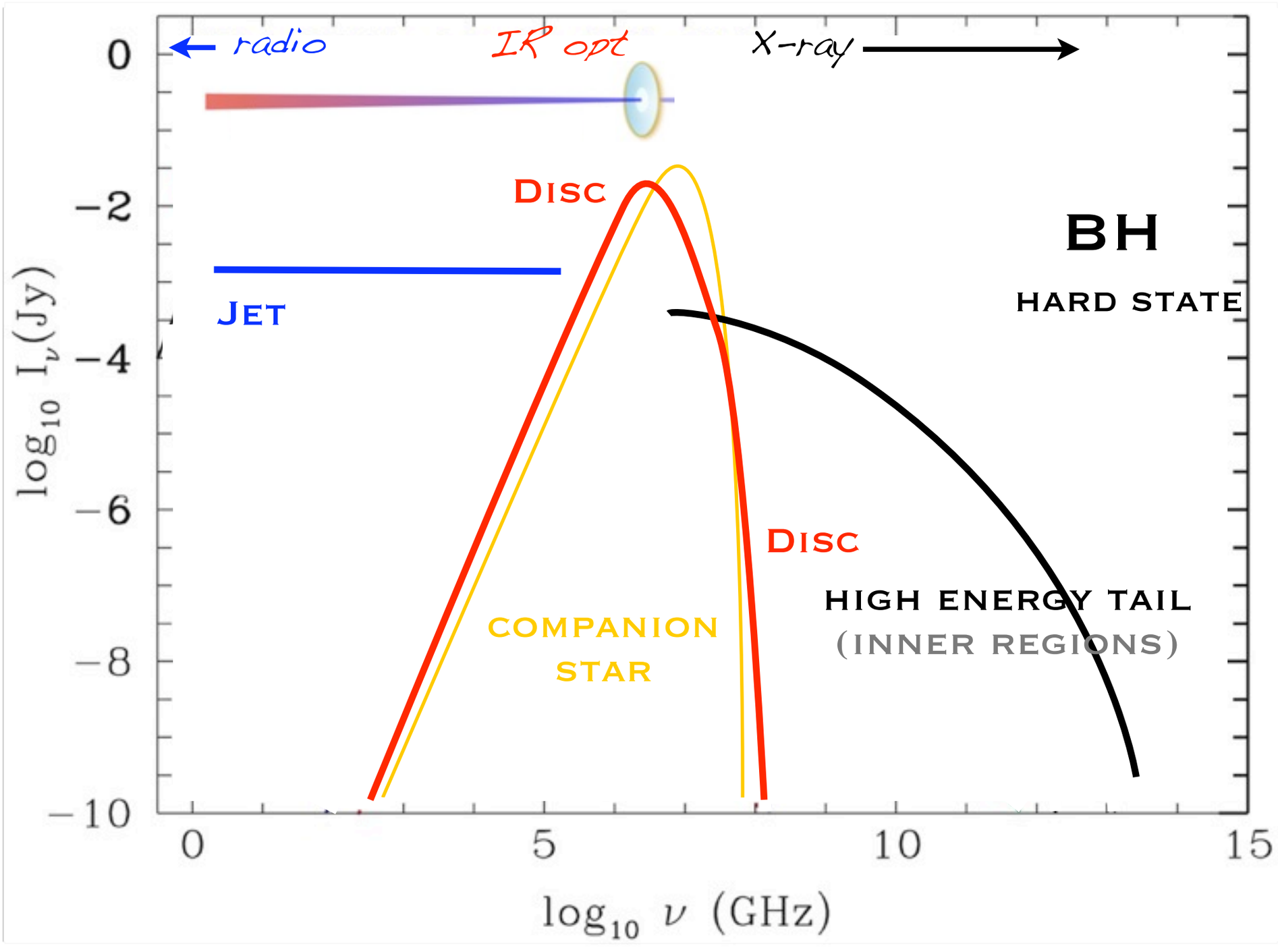
Multi-wavelength variability: Accretion and Ejection onto BHs at the fastest timescales

Piergiorgio Casella (INAF - OA Roma)

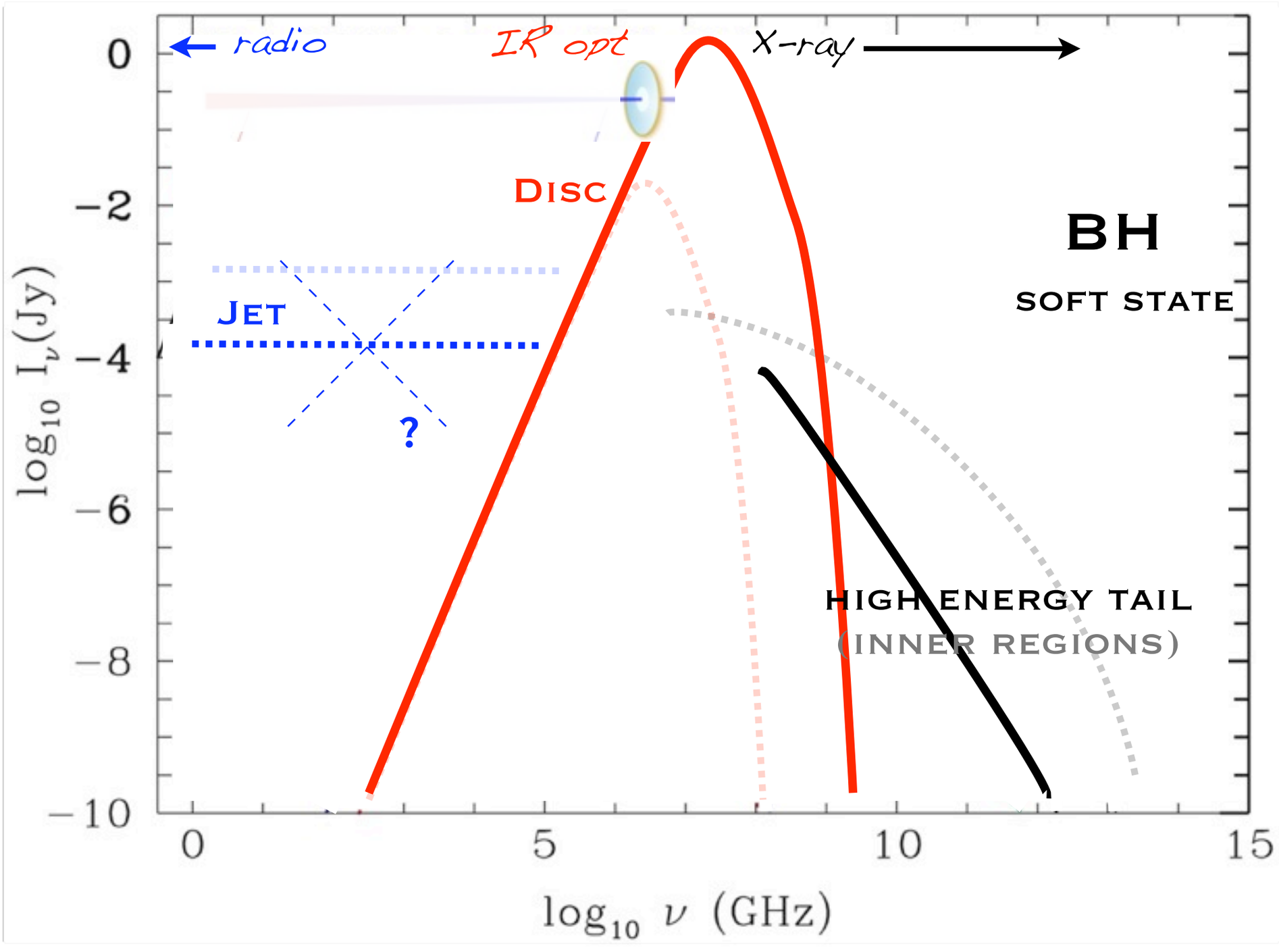
ACCRETING BHs (X-RAY BINARIES)



BH X-RAY BINARIES

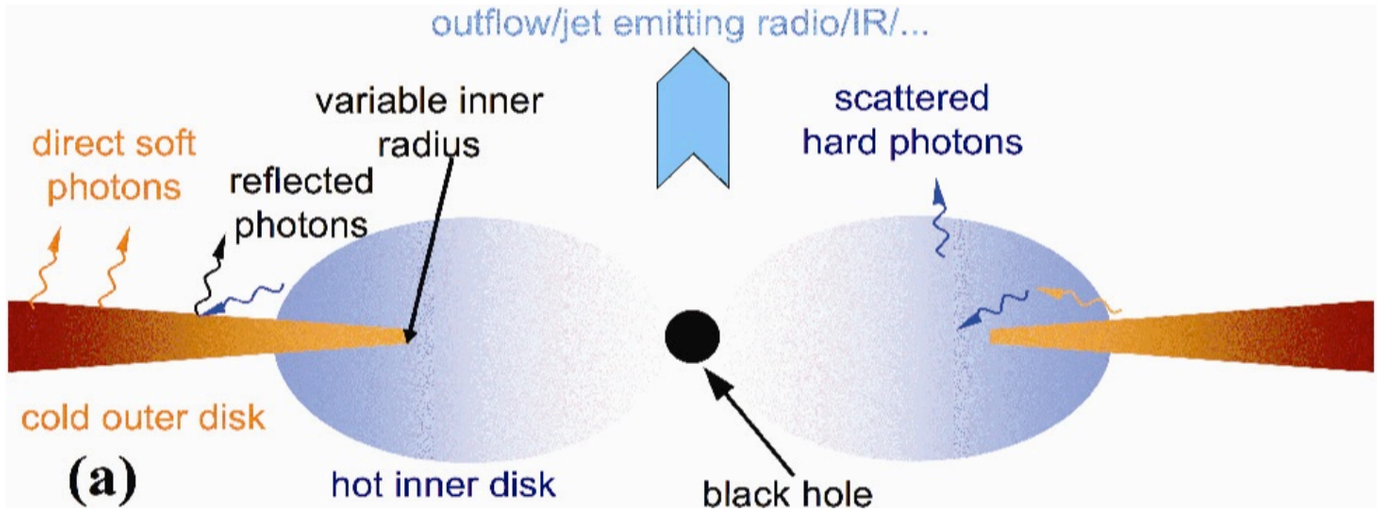


BH X-RAY BINARIES

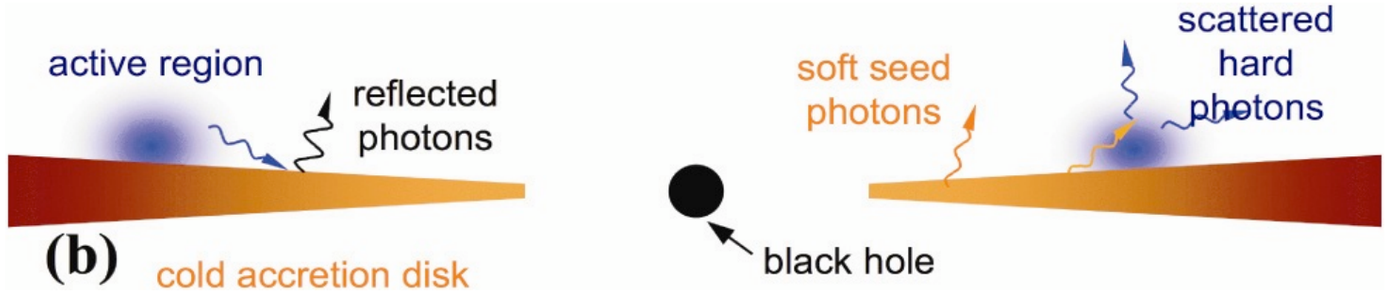


BH X-RAY BINARIES

hard state



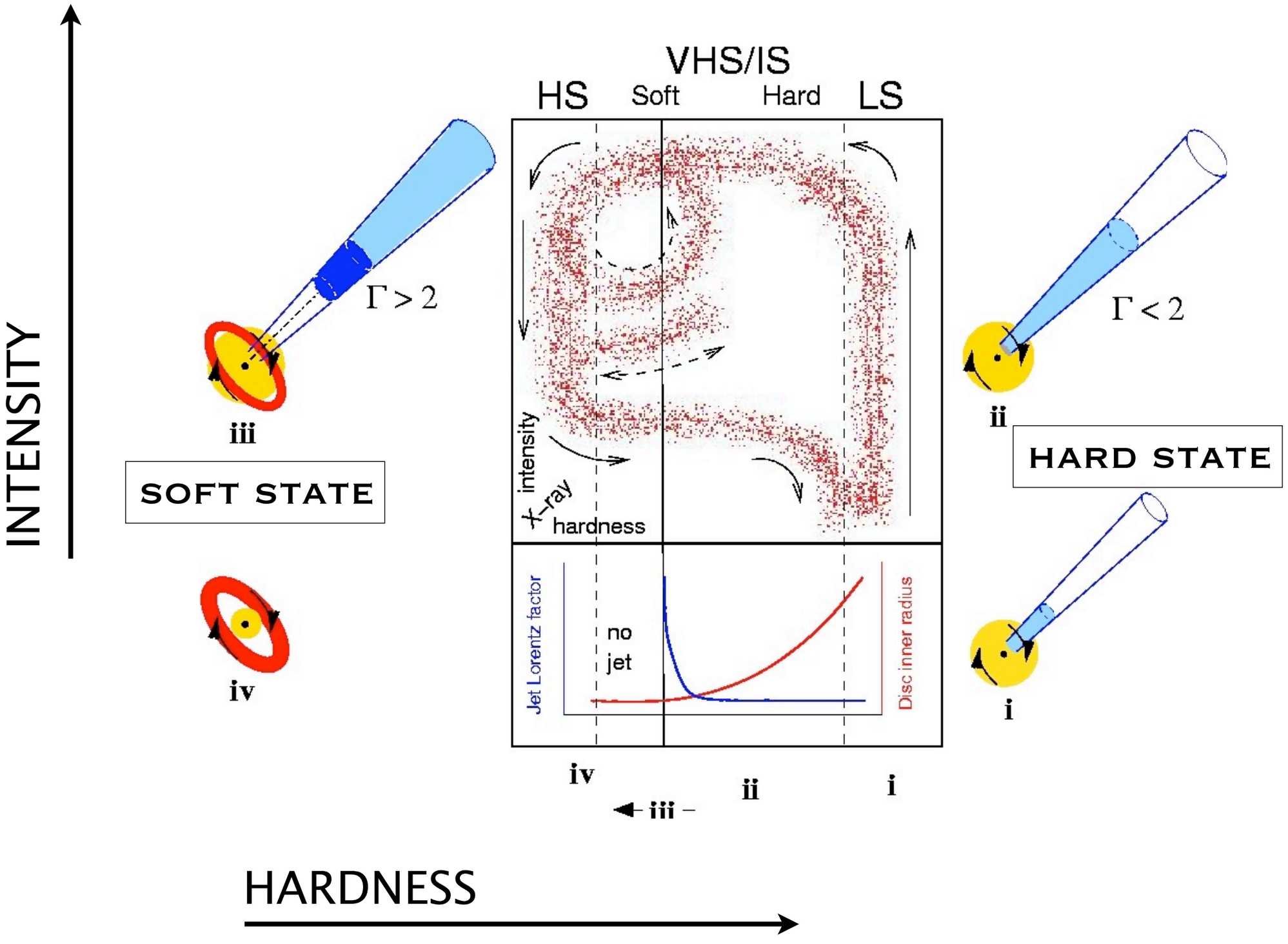
soft state



Zdziarski & Gierlinski (2004)

BH X-RAY BINARIES

WEEKS/MONTHS EVOLUTION

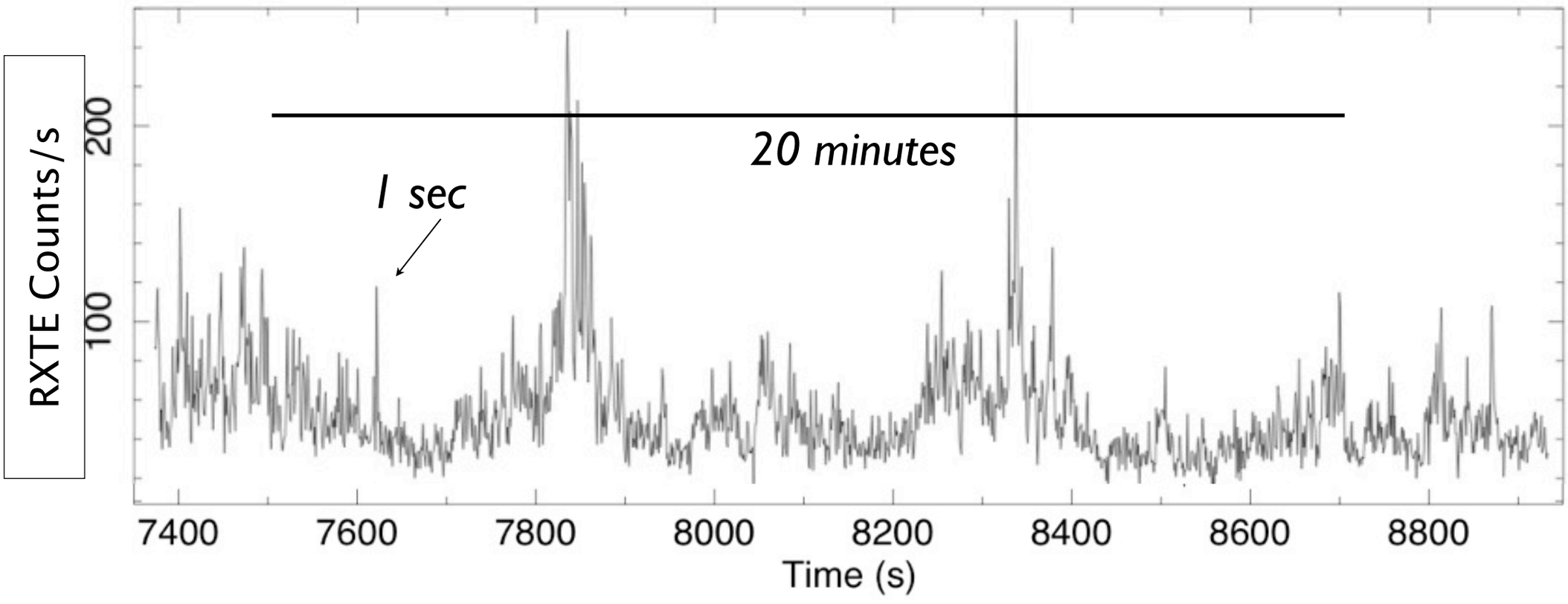


Fender, Belloni & Gallo (2004)

BH X-RAY BINARIES

EXPECTED AND OBSERVED FAST VARIABILITY

GX 339-4 low-luminosity Hard State



BH X-RAY BINARIES

EXPECTED AND OBSERVED FAST VARIABILITY

FIGURE OF MERIT: CHARACTERISTIC TIMESCALES

Light crossing	0.3 ms
Dynamical	1 ms
Thermal	0.1 ms
Viscous	1 s

Assuming $M \sim 10 M_{sun}$, $\alpha \sim 0.1$, $\frac{h}{r} \sim 0.1$, $r \sim 6 r_g$

AGN vs. BHXBs

Characteristic Timescales

Timescale	e.g. *GX 339-4* 10 M_{sun}	e.g. *NGC 7213* 10^8 M_{sun}
Light crossing	0.3 ms	3000 s
Dynamical	1 ms	10 ks
Thermal	0.1 ms	1000 s
Viscous	1 s	~100 day

Assuming $\alpha \sim 0.1$, $\frac{h}{r} \sim 0.1$, $r \sim 6r_g$

AGN vs. BHXBs

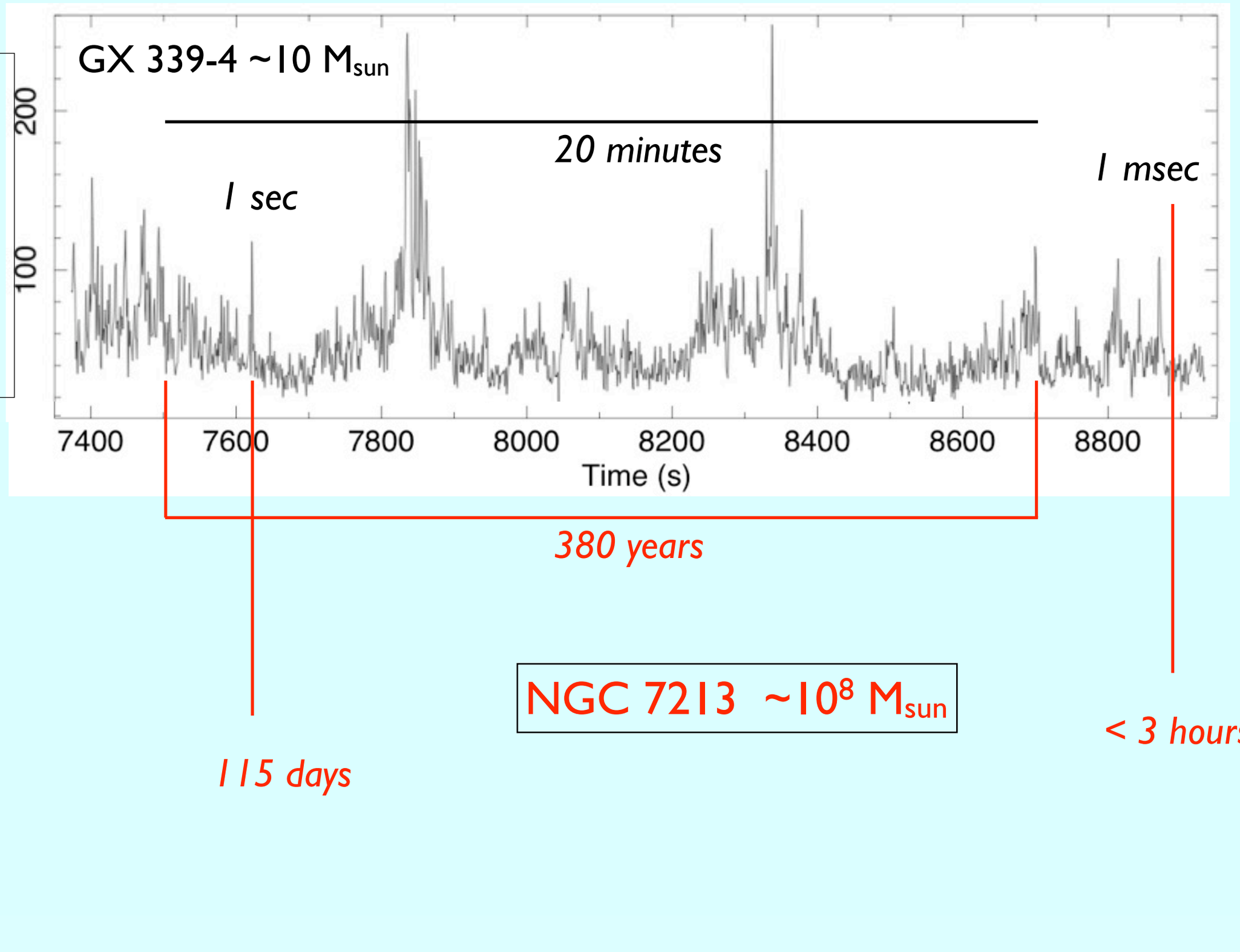
Figure of Merit

available Information

e.g. XMM	10 M_{sun}	10^7 M_{sun}
cts/s	100	1
cts/dynamical	0.1	100
typical observ.	10 ks	100 ks
viscous/observ.	10^4	~0.1

for a given L/L_{Edd}

AGN vs. BHXBs


GX 339-4 ~10 M_{sun}
RXTE Counts/s
200
100
20 minutes
1 sec
1 msec
7400
7600
7800
8000
8200
8400
8600
8800
Time (s)
380 years
NGC 7213 ~10^8 M_{sun}
115 days
< 3 hours

AGN vs. BHXBs

Figure of Merit

available Information

e.g. XMM	10 M_{sun}	10^7 M_{sun}
cts/s	100	1
cts/dynamical	0.1	100
typical observ.	10 ks	100 ks
viscous/observ.	10^4	~0.1

more cycles *more counts/cycle*

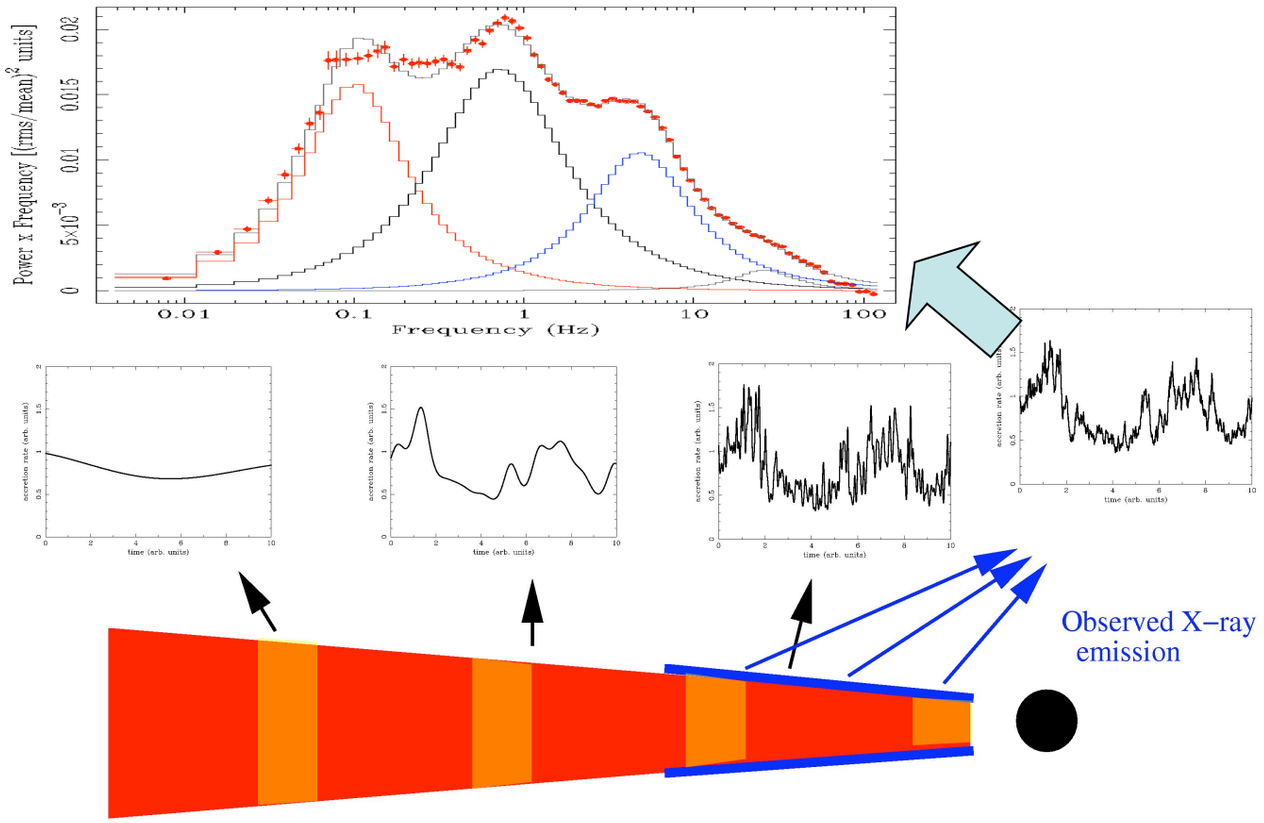
BHXBs
average processes
(stochastic)

AGN
details of individual events
(micro-Physics)

population
statistics

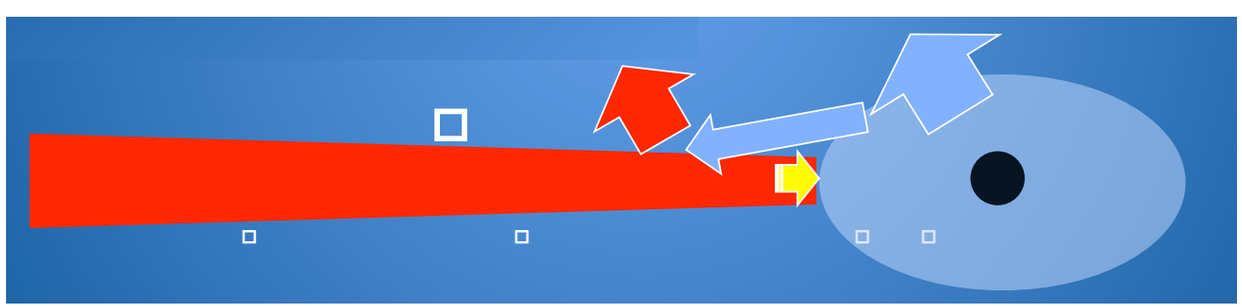
BH X-RAY BINARIES

FLUCTUATIONS PROPAGATE THROUGH THE INFLOW...



Lyubarskii (1997); Kotov et al. (2001); Arevalo & Uttley (2006); ...

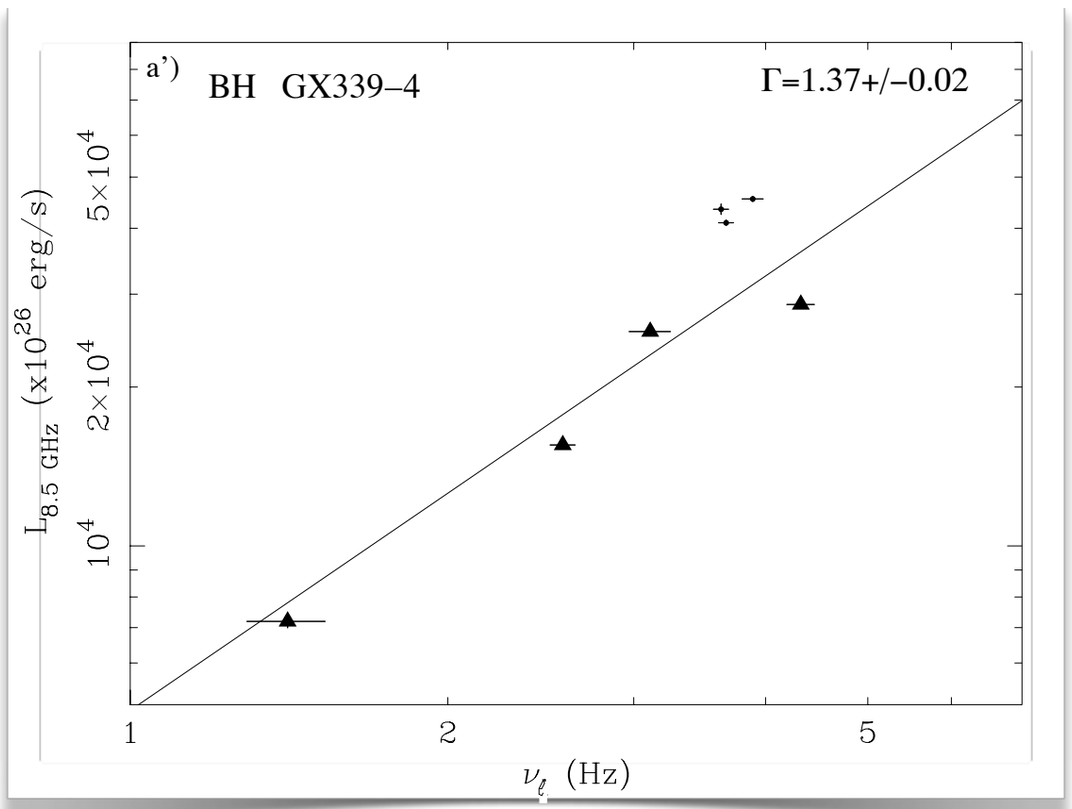
...THEN REFLECTED FROM CORONA TO DISK.



Wilkinson & Uttley et al. (2009)
Uttley et al. (2011)
Cassatella et al. (2012 a,b)

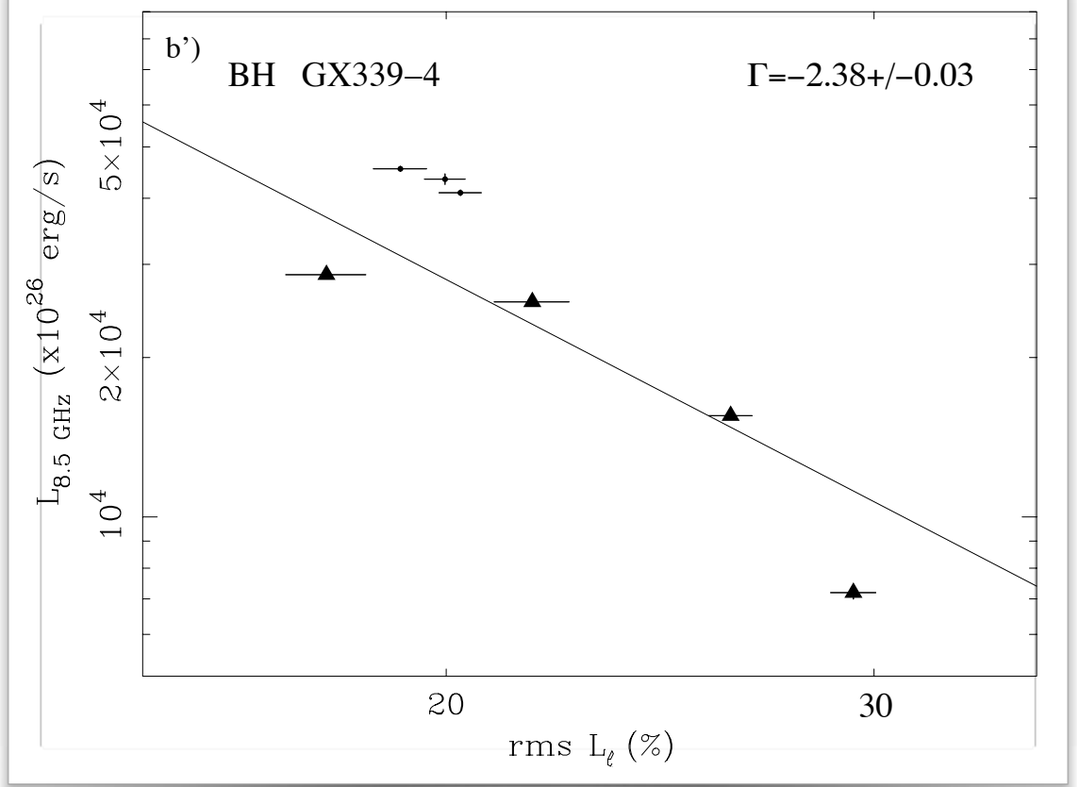
AND THE JET ?

IT CORRELATES WITH X-RAY VARIABILITY



RADIO LUMINOSITY

FREQUENCY



RMS

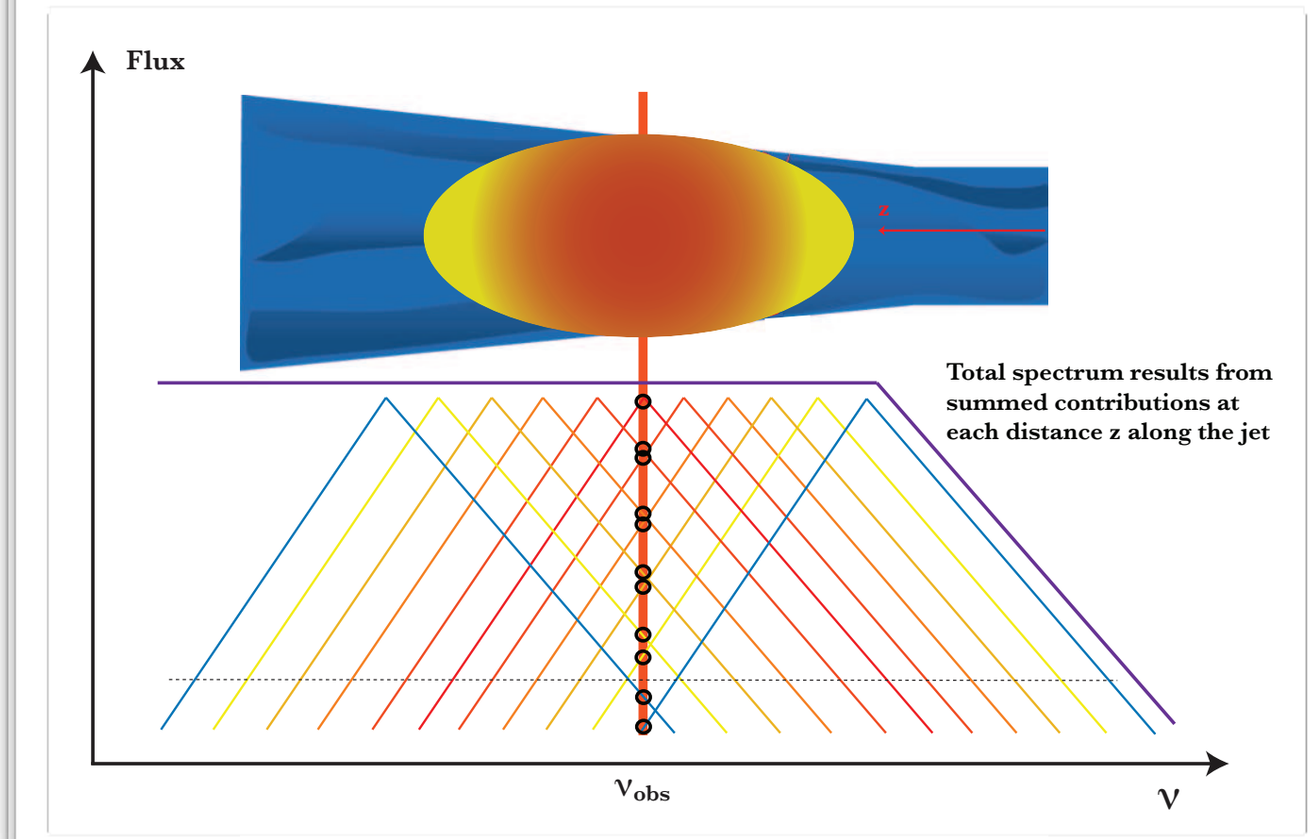
Migliari, Fender & van der Klis (2005)

Jet fast variability?

but see:

Pe'er & Casella (2009)

Zdziarski et al. (2012)



Blandford & Konigl (1979)

picture from Markoff (2010)

Basic assumptions

$n=c\Upsilon^{-p}\sim r^{-2}$

$B(r) \sim r^{-1}$

+

Basic synchrotron theory

$\nu_{break}=\nu|_{\tau_\nu=1} \sim r^{-1}$

=> Flat radio spectrum

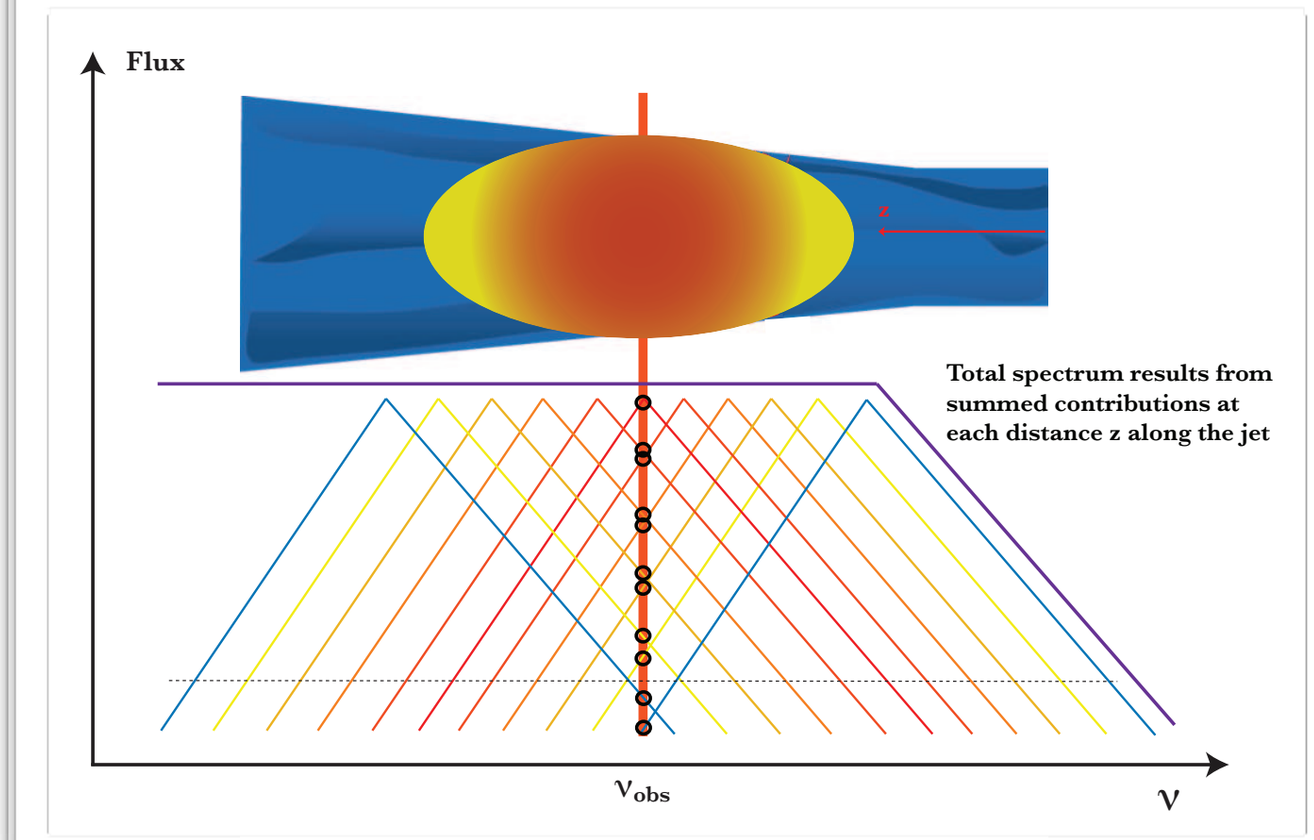
Jet fast variability?

the well known missing-energy problem

but see:

Pe'er & Casella (2009)

Zdziarski et al. (2012)



Blandford & Konigl (1979)

picture from Markoff (2010)

1979

(measured in the frame of the fluid) which will vary as r^{-}, where r is the distance from the apex (cf. the model of NGC 6251 in Readhead, Cohen, and Blandford 1978). We assume that relativistic electrons can be accelerated continuously within the jet, and that their distribution function is $N(\gamma_e) = K\gamma_e^{-2}$, with $\gamma_{e\,\min} < \gamma_e < \gamma_{e\,\max}$ and $\gamma_{e\,\max} \gg \gamma_{e\,\min}$. These electrons will radiate synchrotron radiation with a spectral index $\alpha = \frac{1}{2}$. The electron energy

energy losses act very fast:

we should not see the radio jet

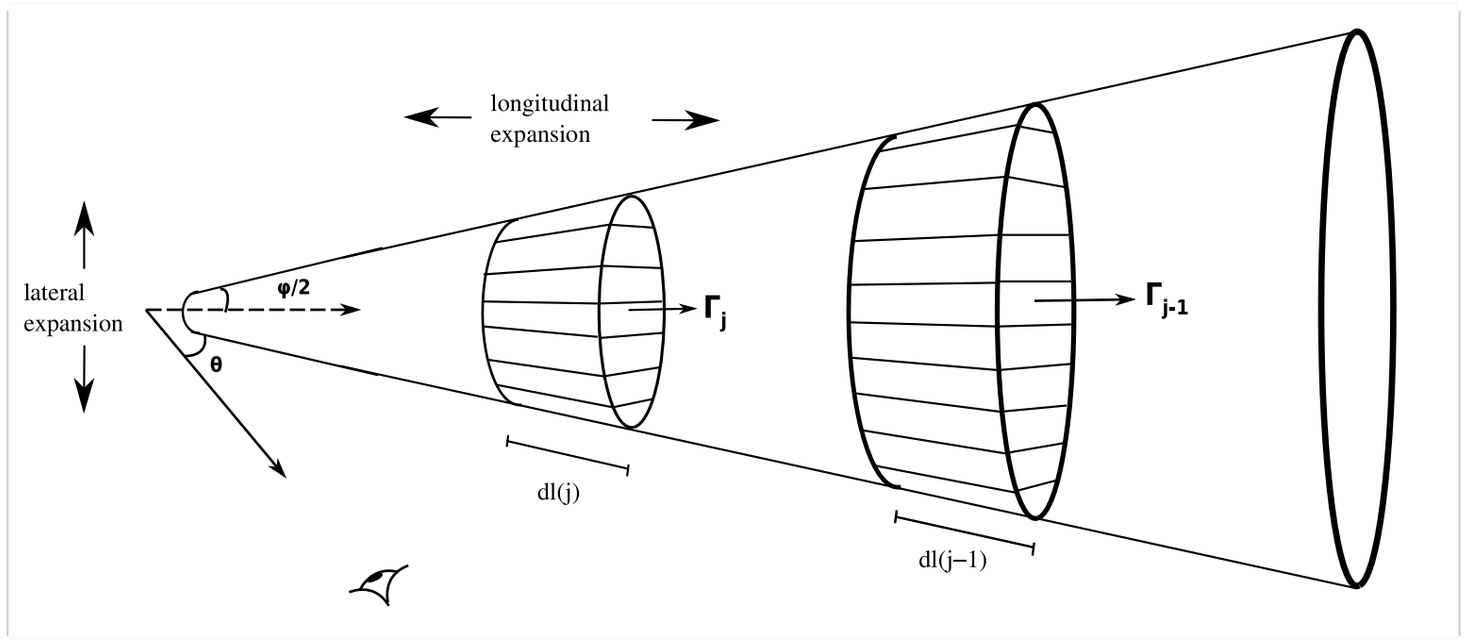
Jet fast variability?

the well known missing-energy problem

re-heating from internal shocks
shells with different velocity

GRB jet emission theory ⟶ *blazars (Spada et al. 2001)*

recent works on XBs: Jamil, Fender & Kaiser 2010; Malzac 2013



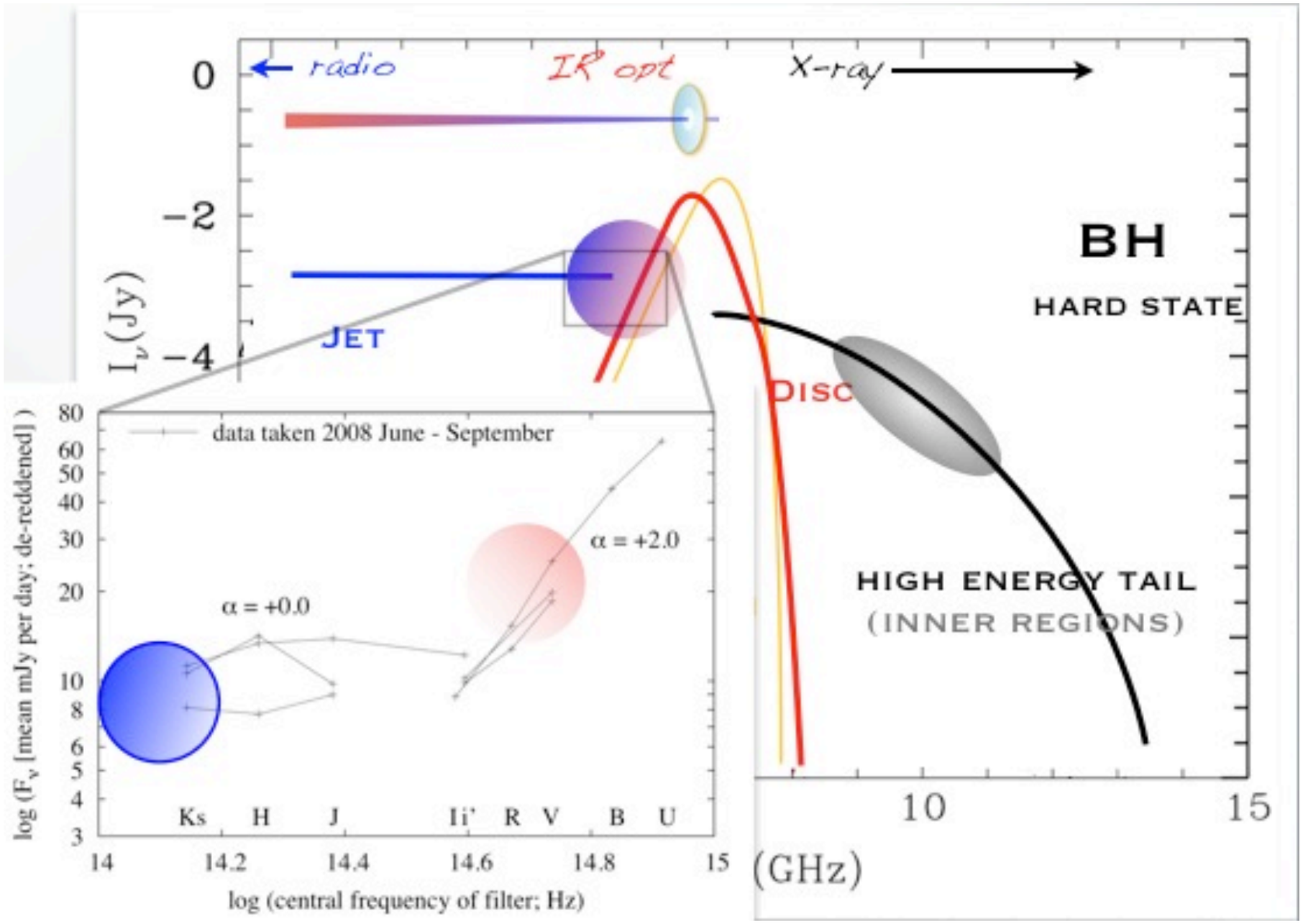
re-heating linked to inflow variability?

best to study variability: X-ray Binaries

Jet fast variability

(Casella et al. 2010)

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

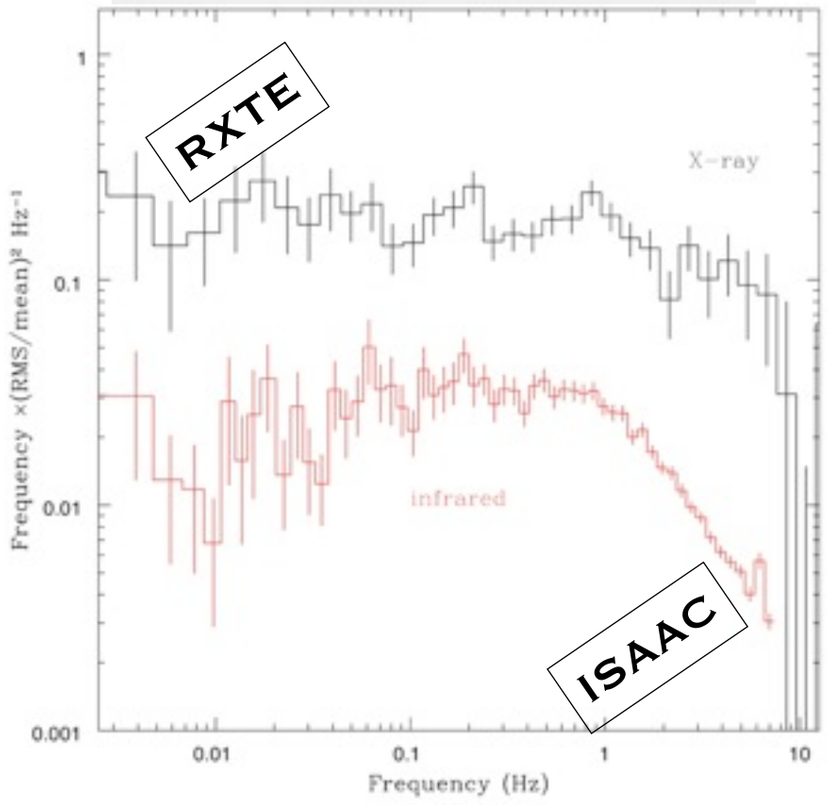


Jet fast variability

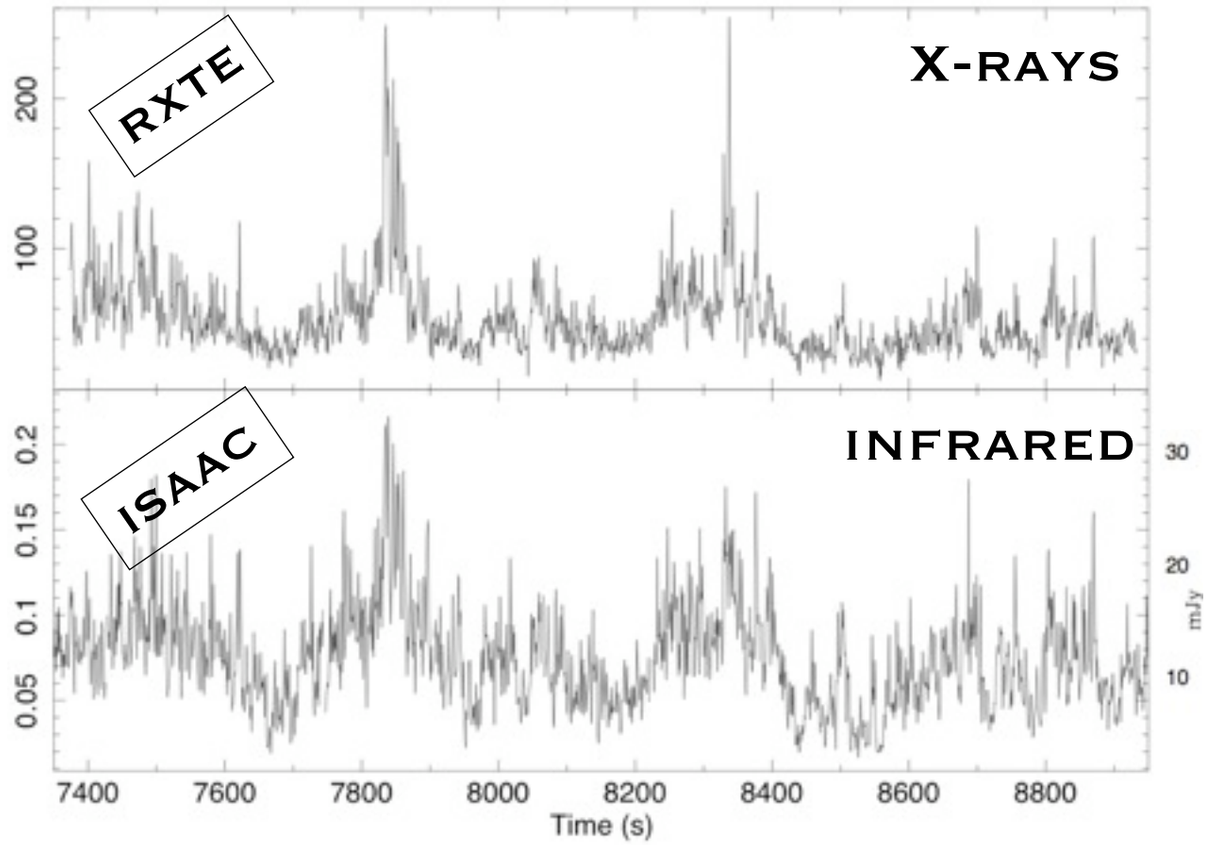
(Casella et al. 2010)

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

Fourier spectra



Light Curves



VARIABILITY AT > 5 Hz : EMITTING REGION < 6 10^9 CM

IF THERMAL EMISSION, UNIQUE SOLUTION (BLACK BODY)

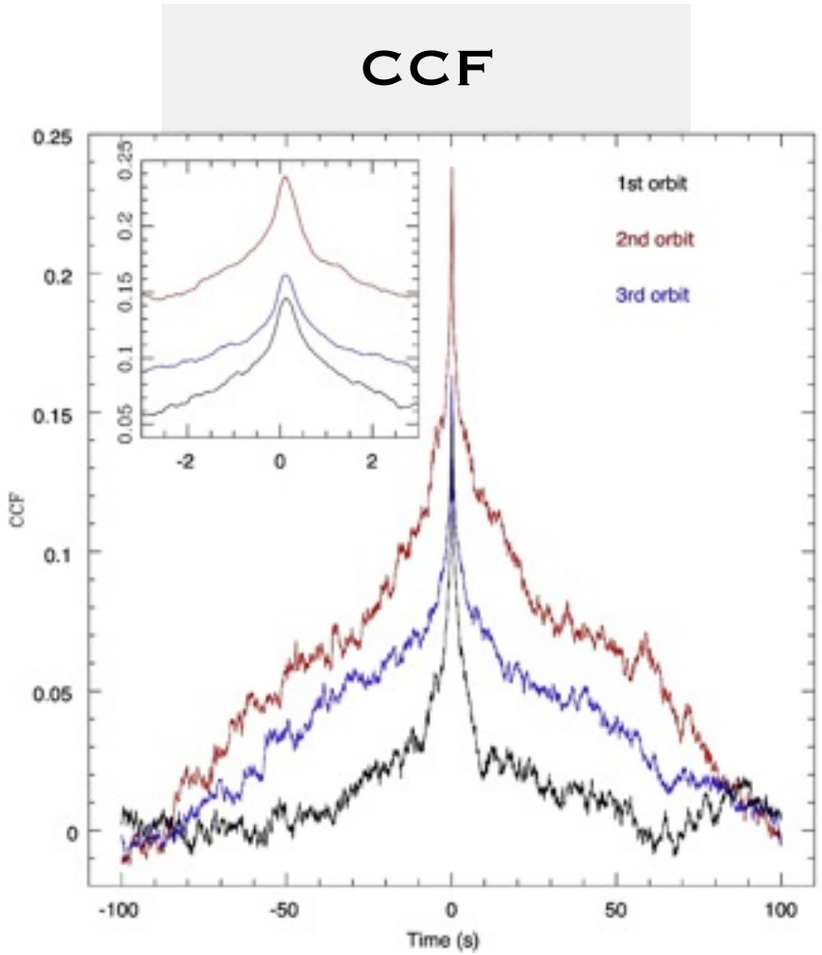
-> IT WOULD EMIT MUCH MORE IN X-RAYS

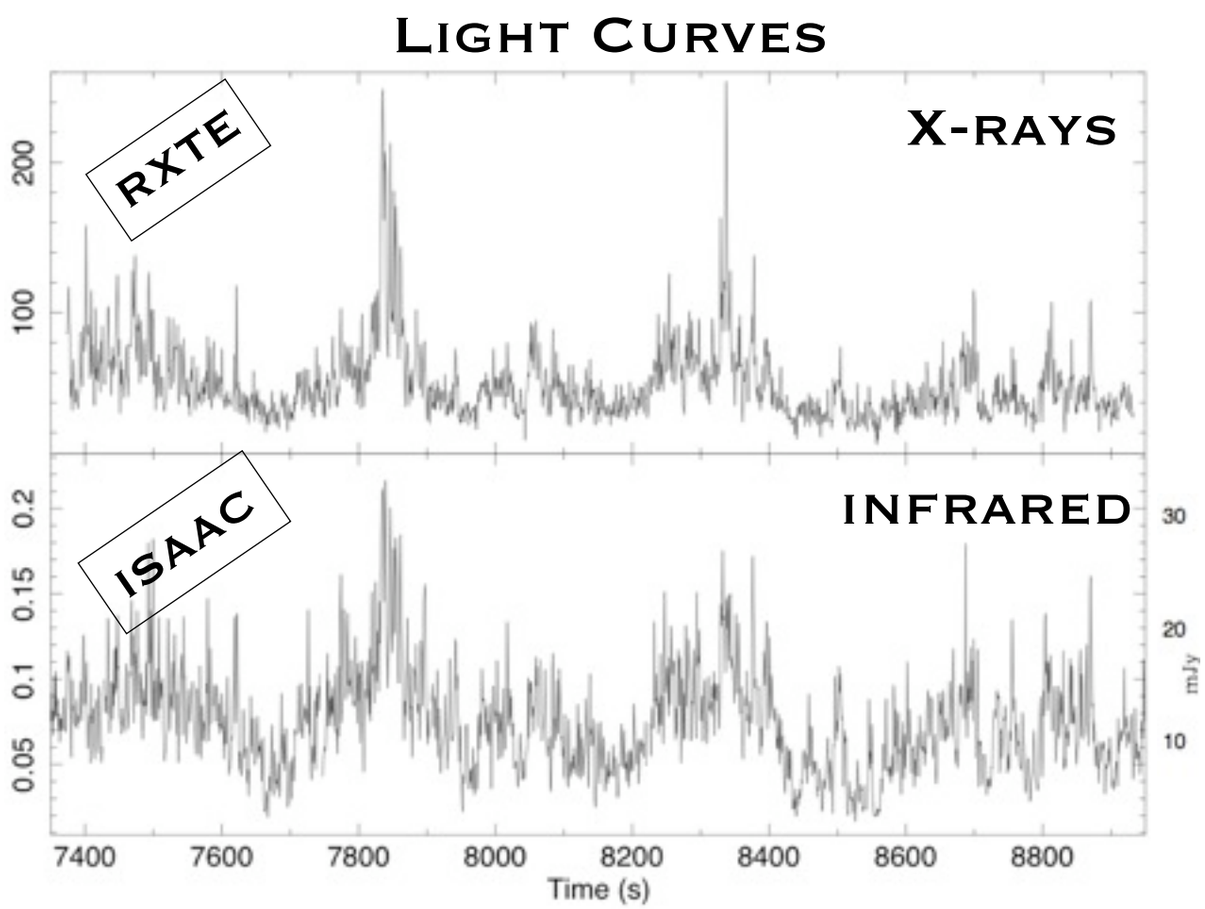
DEFINITELY NOT THERMAL

Jet fast variability

(Casella et al. 2010)

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



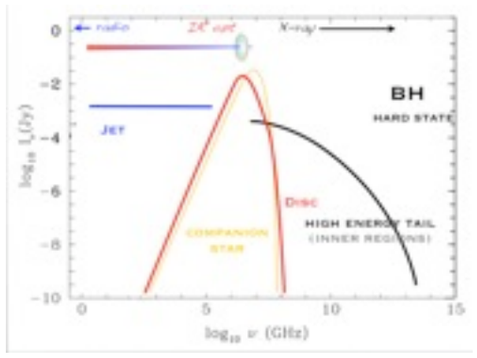


they CORRELATE: it's a JET

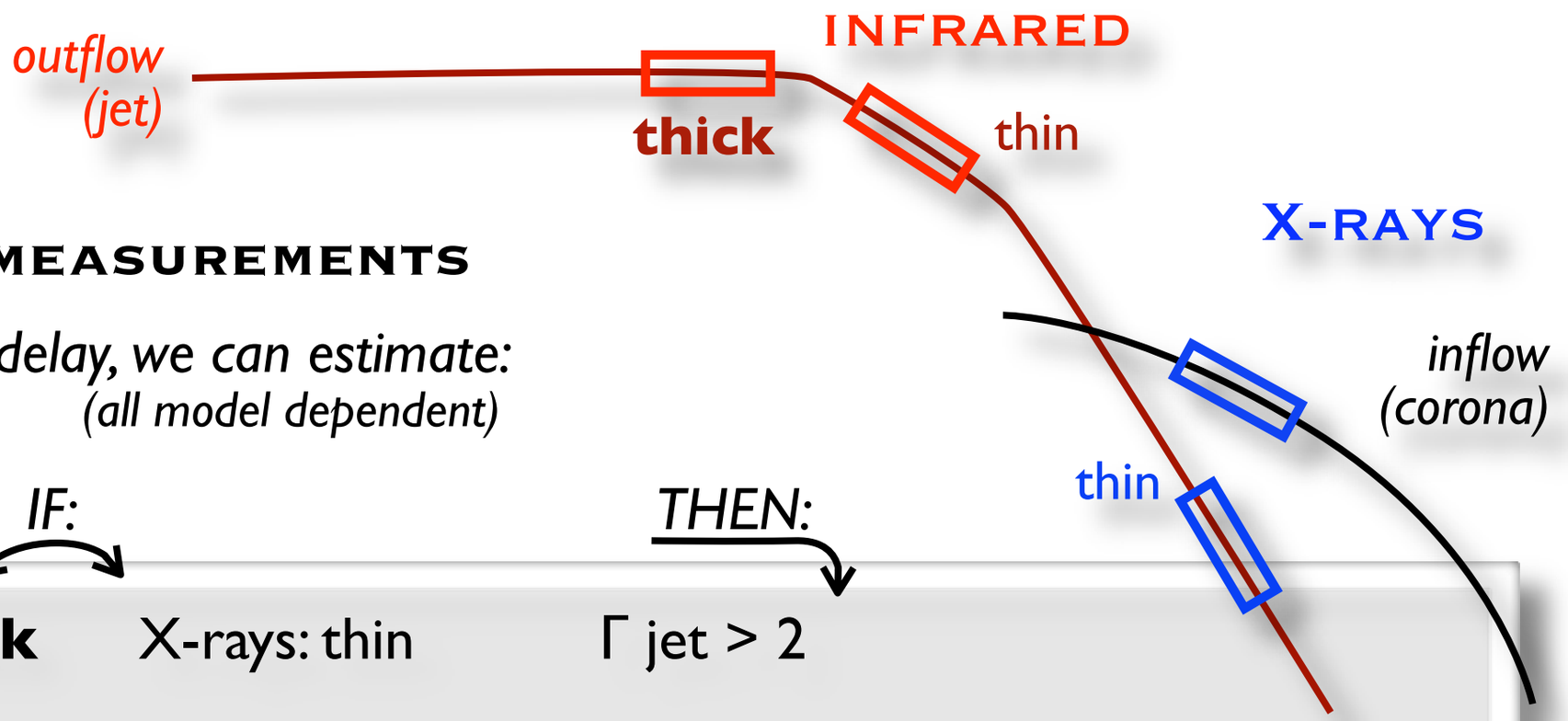
infrared lags X-rays by 0.1 seconds

-> PHYSICAL MEASUREMENTS

JET FAST VARIABILITY



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



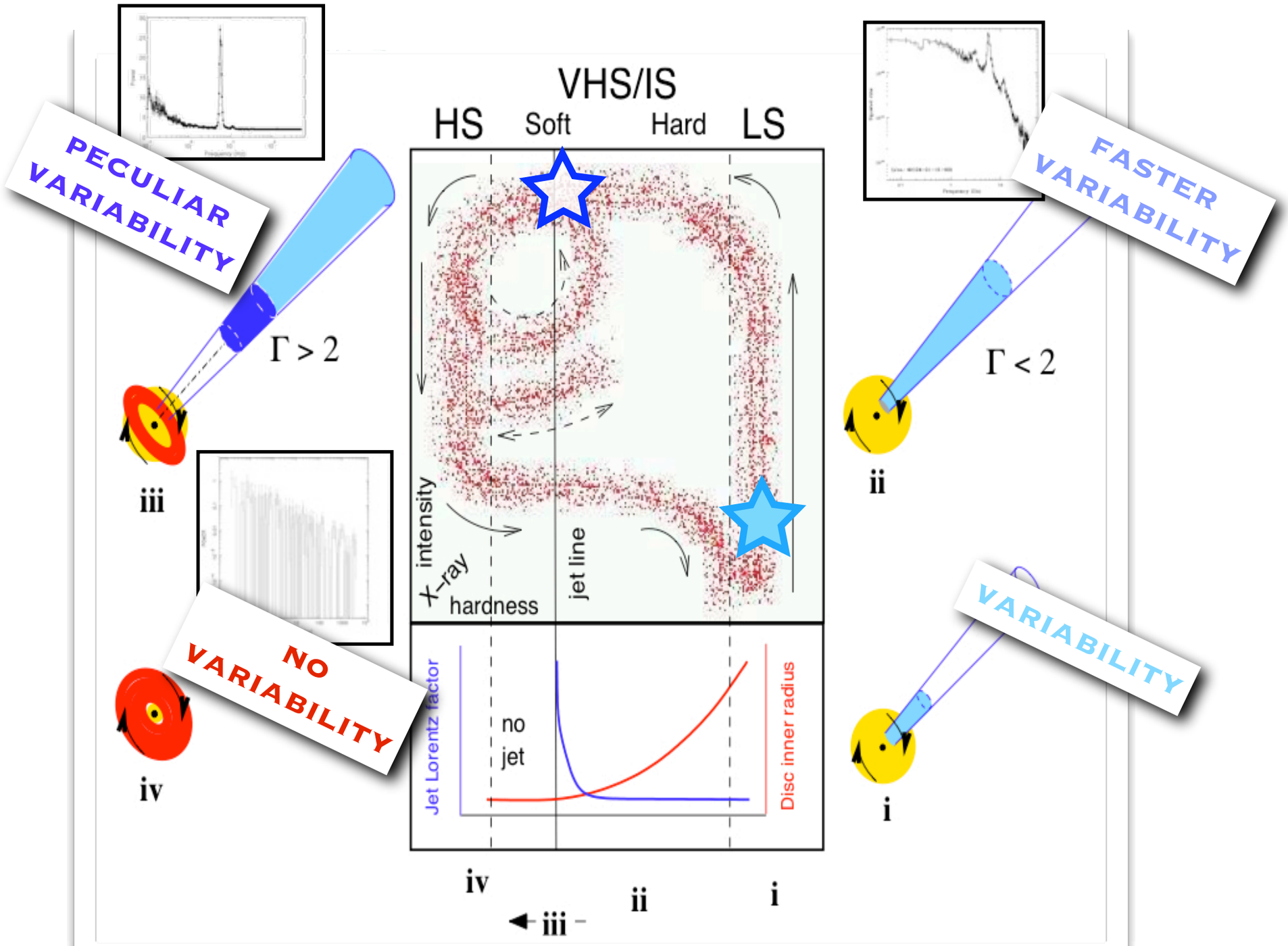
PHYSICAL MEASUREMENTS

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

(Casella et al. 2010)

DIFFERENT ACCRETION REGIMES

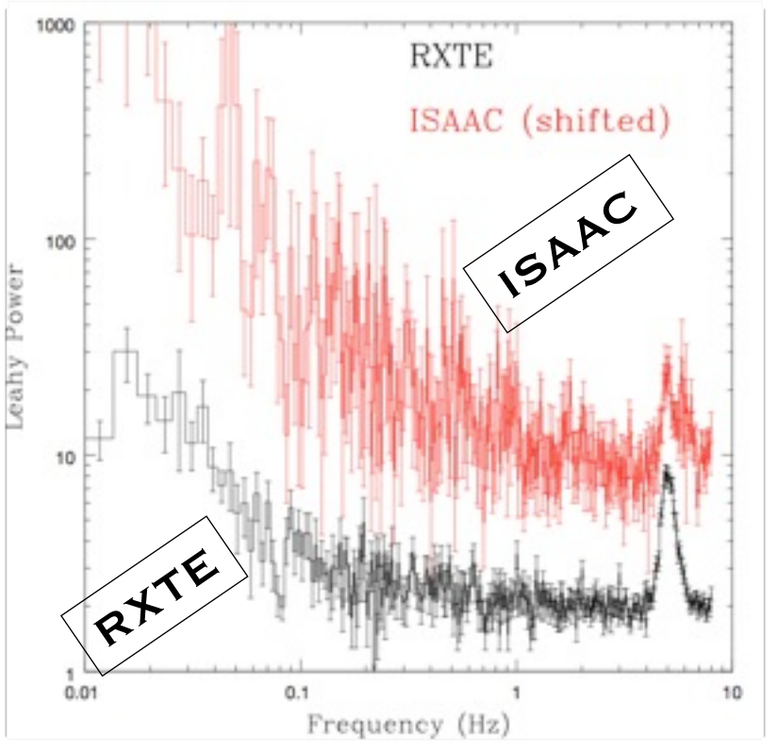


DIFFERENT ACCRETION REGIMES

GX 339-4

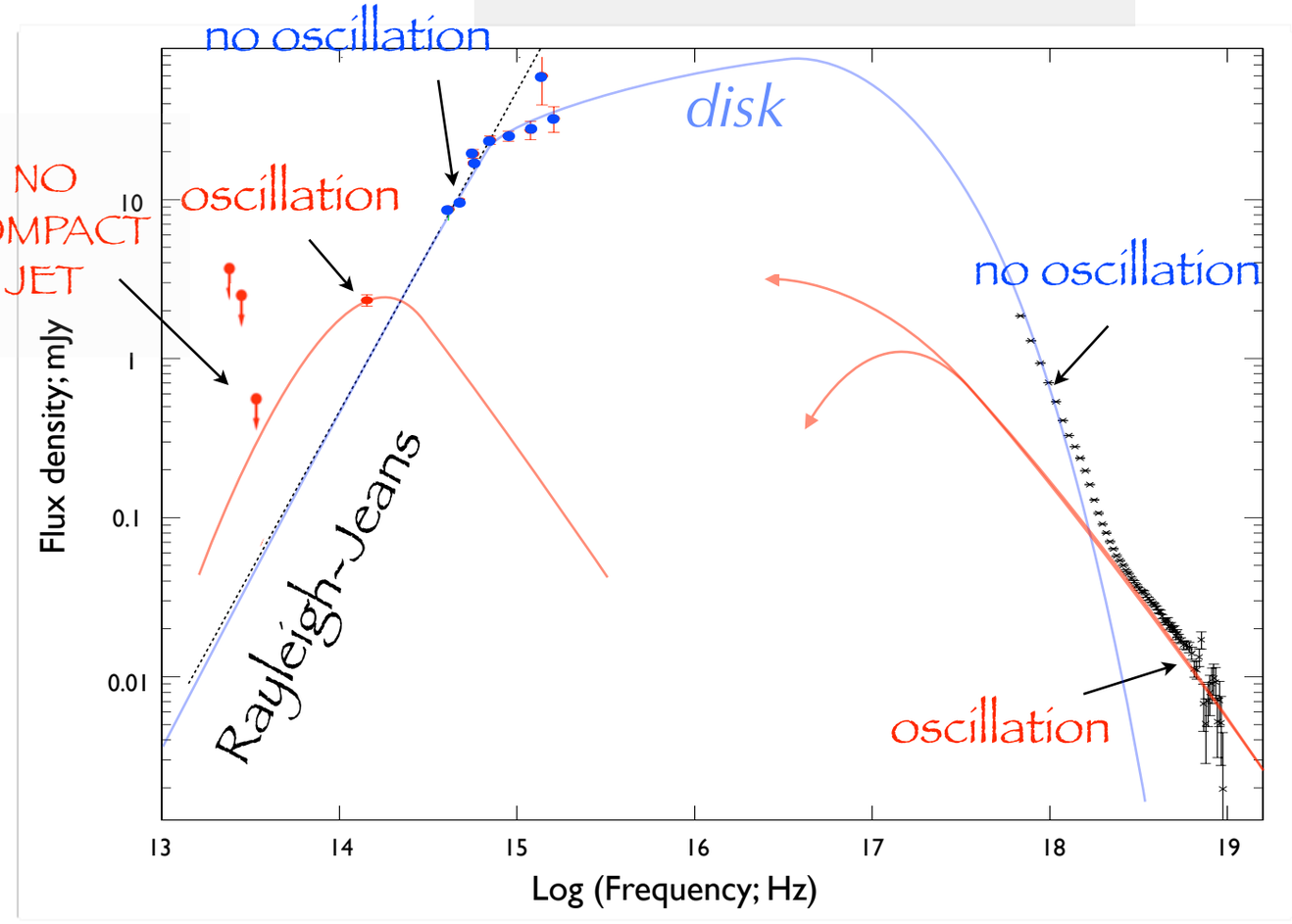
Casella et al. (in prep.)

POWER SPECTRA



X-RAYS + OPTICAL + IR

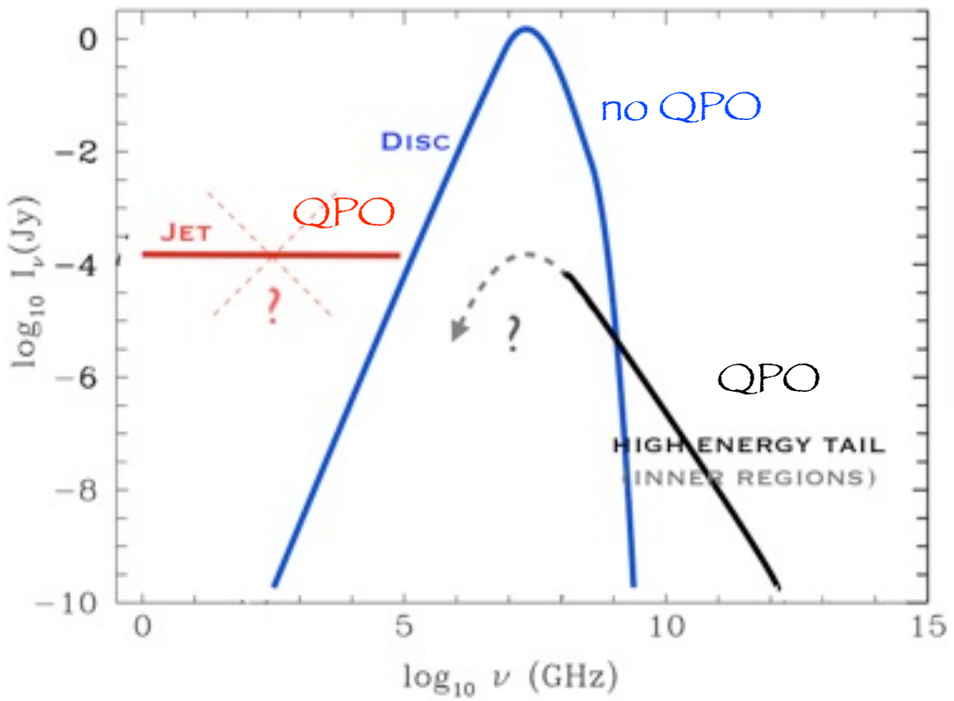
ENERGY SPECTRUM



DIFFERENT ACCRETION REGIMES

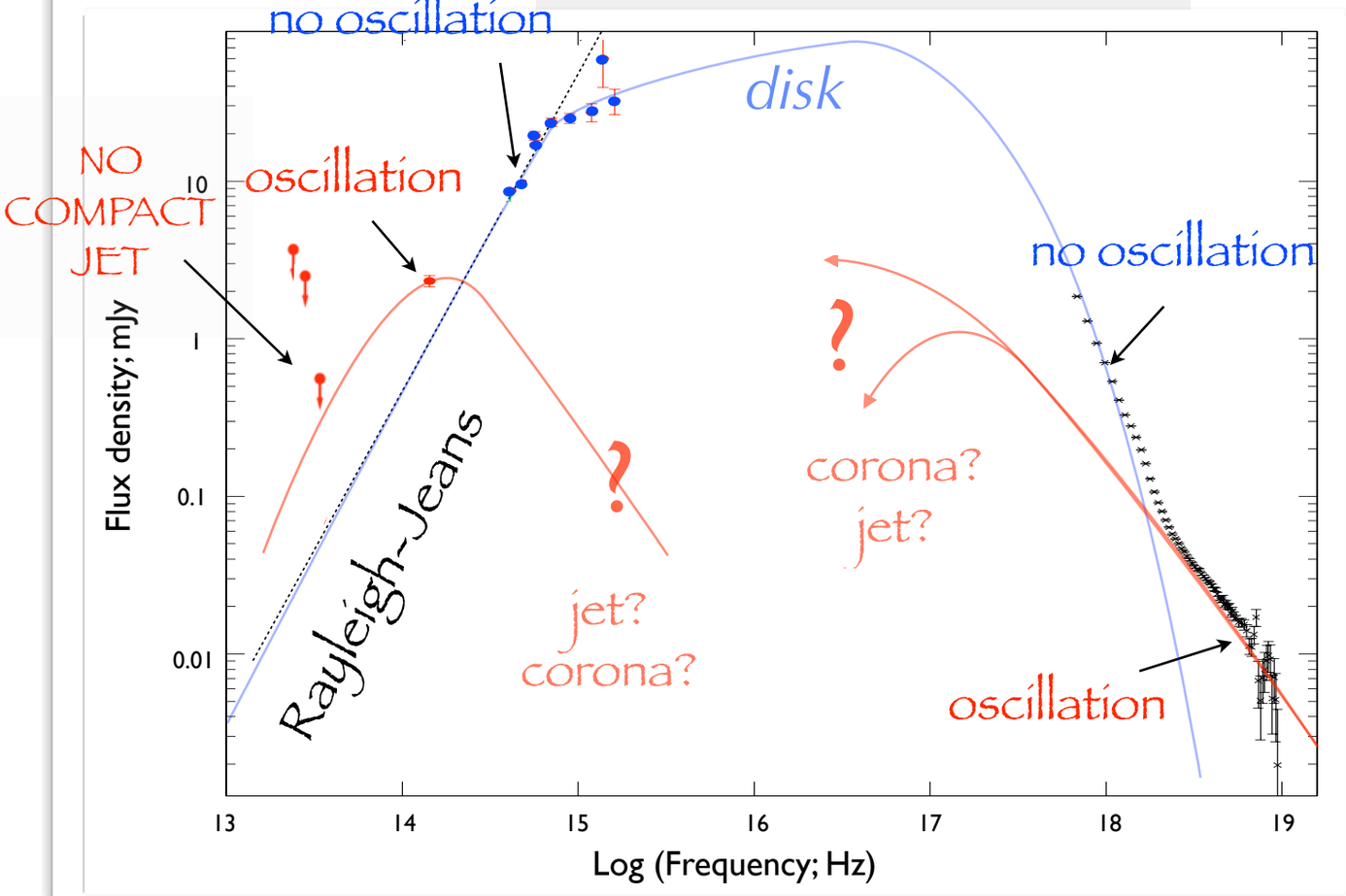
GX 339-4

Casella et al. (in prep.)



NON THERMAL

ENERGY SPECTRUM

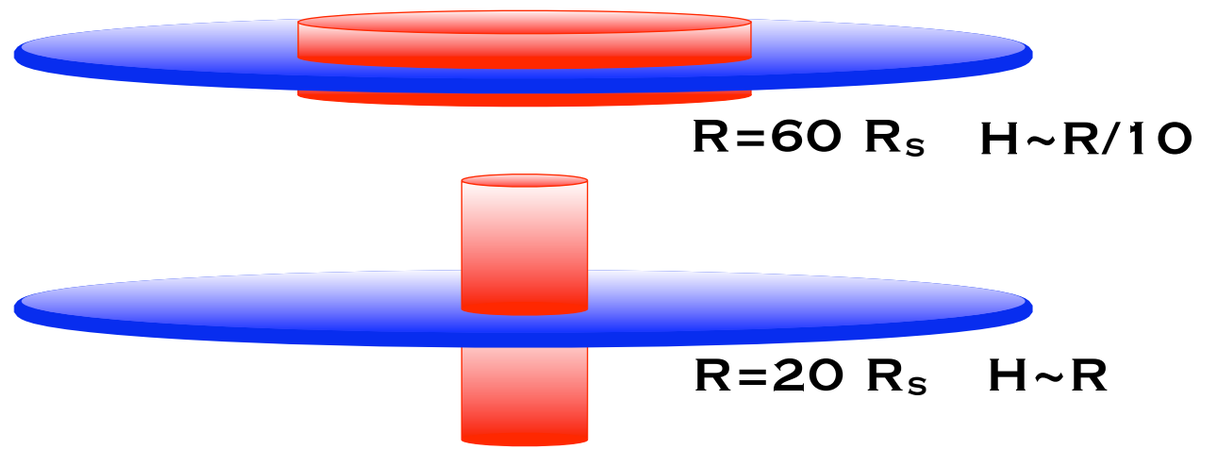


ONE-ZONE MODEL

$\nu_{break} \sim 1.4 \times 10^{14}$ Hz

$B \sim 10^4$ G

$R \sim 6 \times 10^7$ $h^{-0.5}$ cm

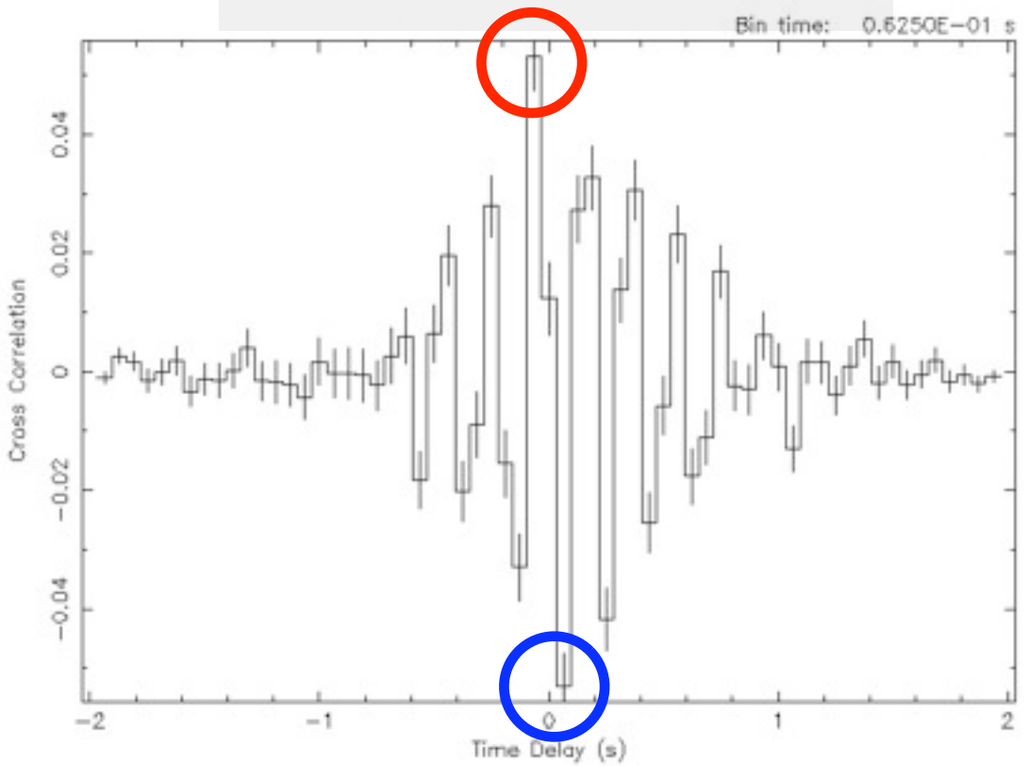


DIFFERENT ACCRETION REGIMES

GX 339-4

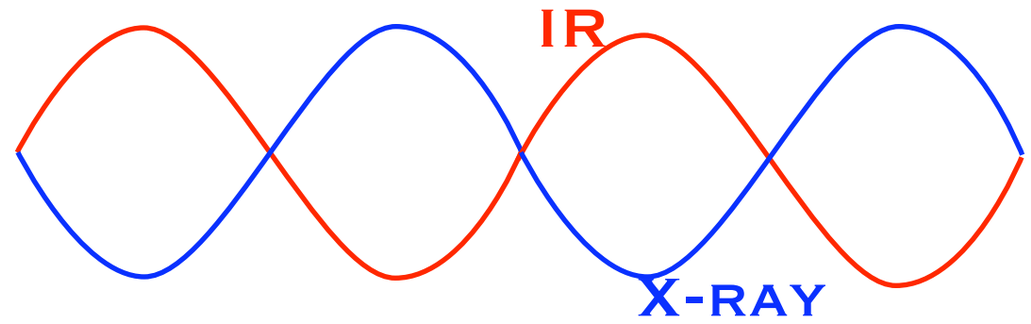
Casella et al. (in prep.)

CCF IR/X-RAYS



IR AND X SHIFTED BY ~π

precession?



CORRELATION ⟵ IR LEAD

?

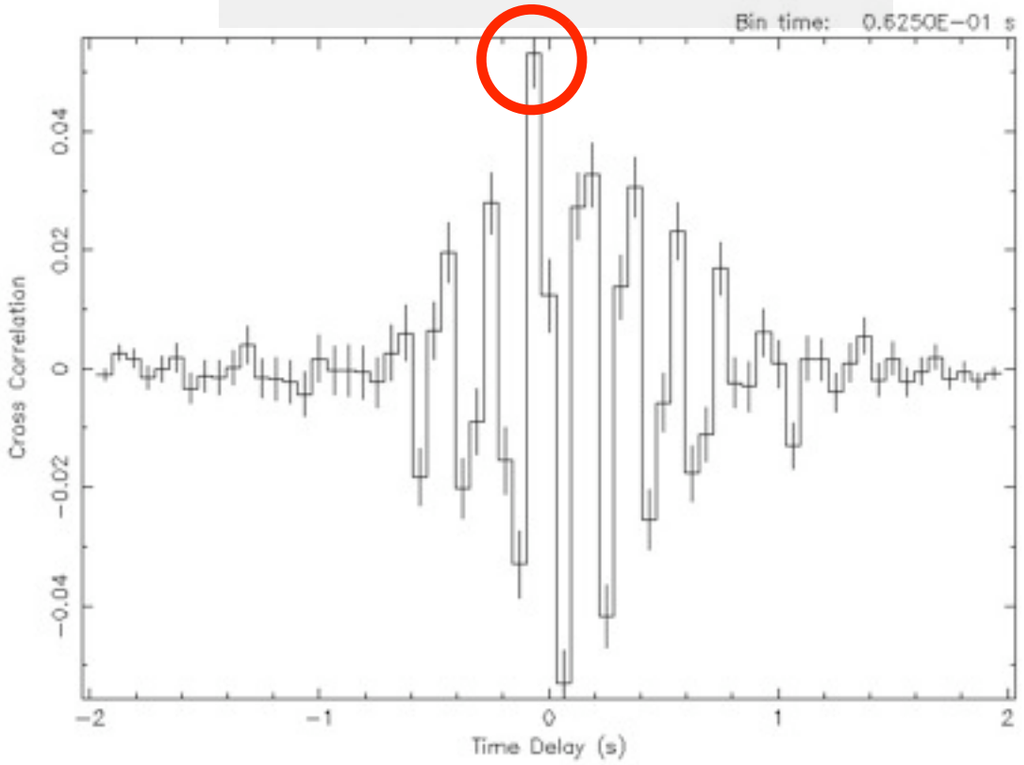
ANTICORRELATION ⟵ X-RAY LEAD

DIFFERENT ACCRETION REGIMES

GX 339-4

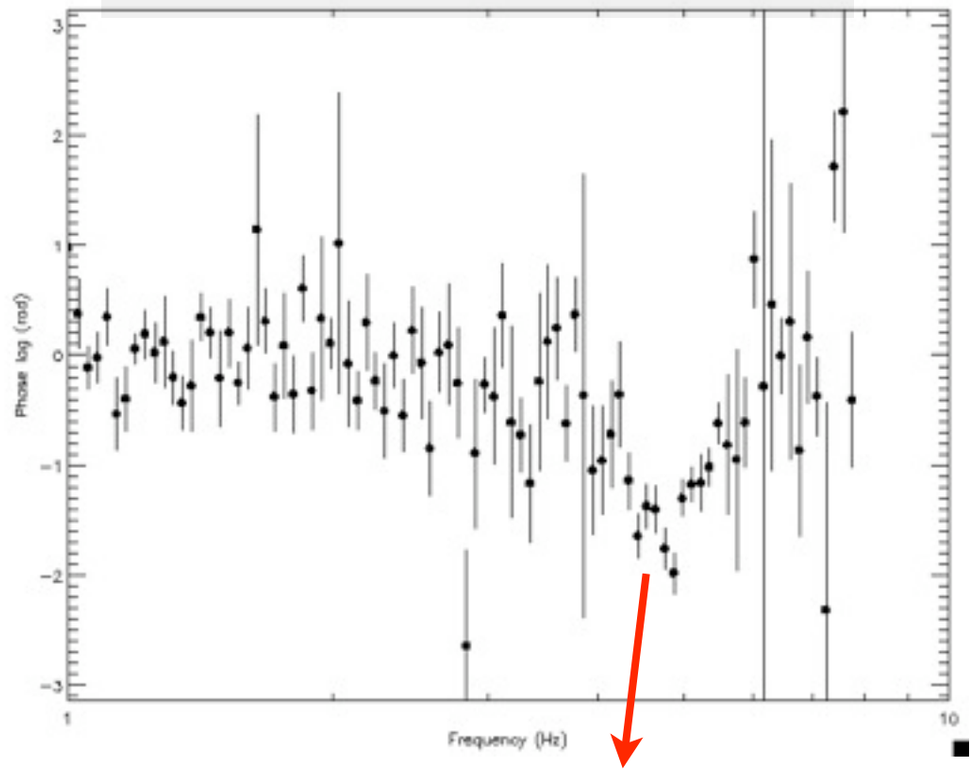
Casella et al. (in prep.)

CCF IR/X-RAYS



CORRELATION

PHASE LAGS IR/X-RAYS



IR LEAD X-RAYS

2 HYPOTHESIS

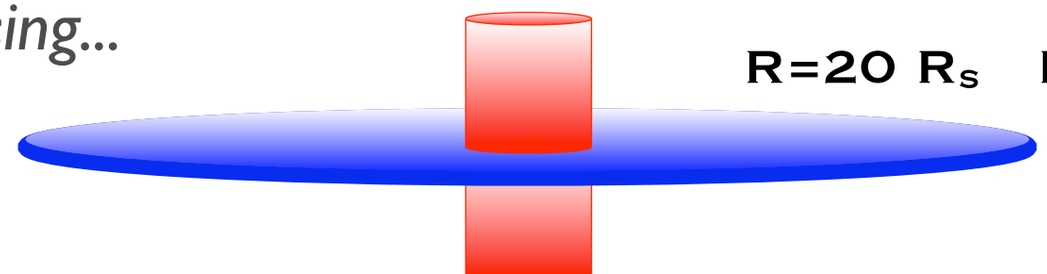
INFLOW (ON TOP OF DISC)

R=60 R_S H=R/10

...precessing...

JET BASE (TRANSIENT ONE)

R=20 R_S H~R



Which instruments?

- ☐ (20% of) RXTE: ~50 cts/s — statistics limited
- ☑ ISAAC @ VLT: ~50.000 cts/s (HAWK-I) — technology limited

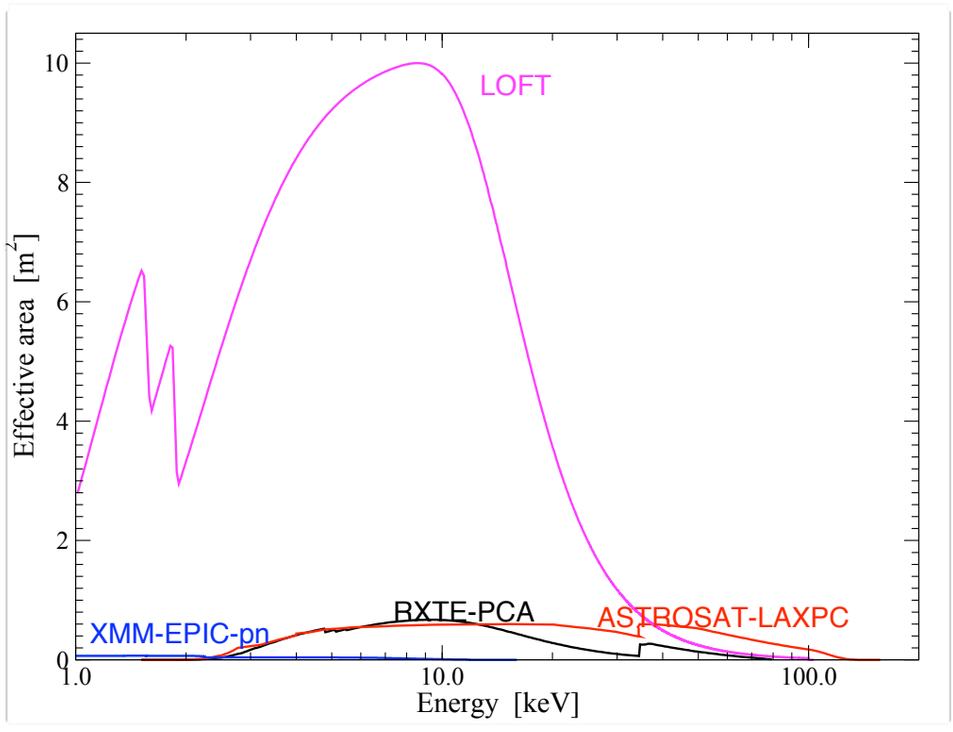
- New technologies — **Growing field**
  - getting rid of that readout noise... — available now
    - EMCCDs ("expanded" normal optical CCD)
  - ...and widening the energy range — near future
    - HgCdTe e-APD (mercury-cadmium-telluride Avalanche Photodiode Detectors)
    - MKID (microwave kinetic induction devices)
    - STJ (superconducting tunnel junctions)

- ASTROSAT: X-rays (+ UV) (2014)
- LOFT: population statistics + full outburst coverage + much broader energy range

Which instruments?

☑ (5x)20x RXTE: ~5.000 cts/s statistics! **LOFT**

☑ Upcoming technology @4 or 8 meters



A mission proposal selected by ESA as a candidate CV M3 mission

Devoted to X-ray timing and designed to investigate
the space-time around collapsed objects

CONCLUSIONS - FUTURE

- FAST VARIABILITY FROM THE INNER REGIONS
  AT OTHER WAVELENGTHS THAN X-RAYS

  - WE **OBSERVE** MATTER ALONG THE JET.
    TRACKING THE VARIABILITY >> **GEOMETRY CONSTRAINTS**
    PHYSICAL QUANTITIES

- THEORETICAL EFFORTS

  - VARIABLE JET EMISSION - INTERNAL SHOCKS IMPLEMENTED:

    SELF-CONSISTENT CODE, SPECTRAL EVOLUTION OF EACH INTERNAL SHOCK
    JOINED APPROACHES: *Pe'er & Casella (2009)* + *Jamil et al. (2010)*

- NEW TECHNOLOGIES/INSTRUMENTS AT ALL WAVELENGTHS