Mid-infrared studies of X-ray binaries: a new window on jets

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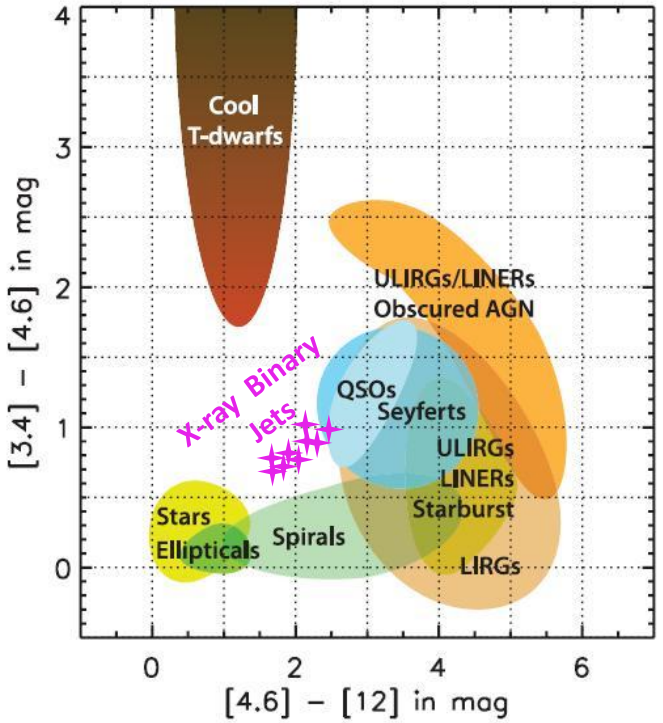
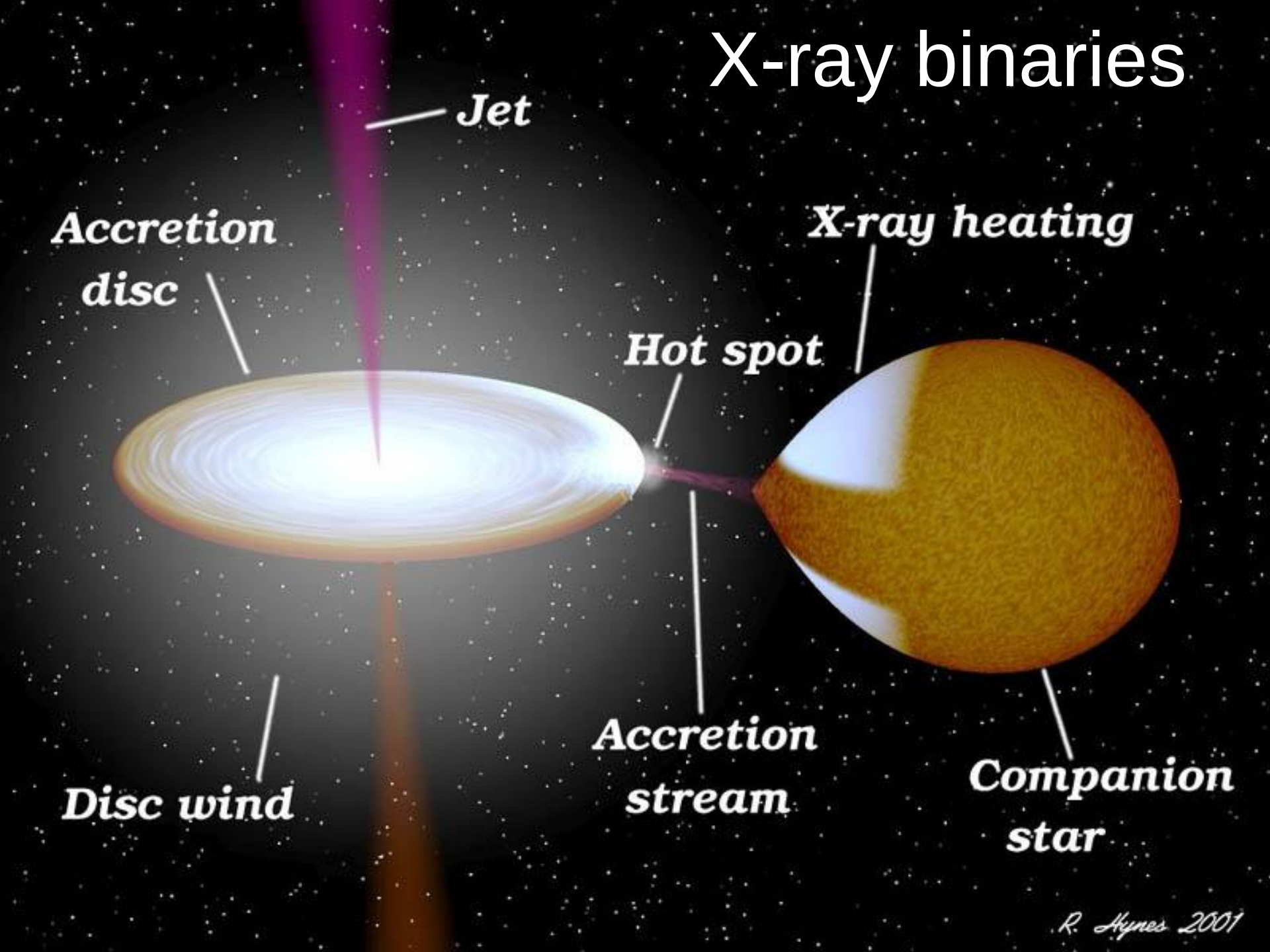
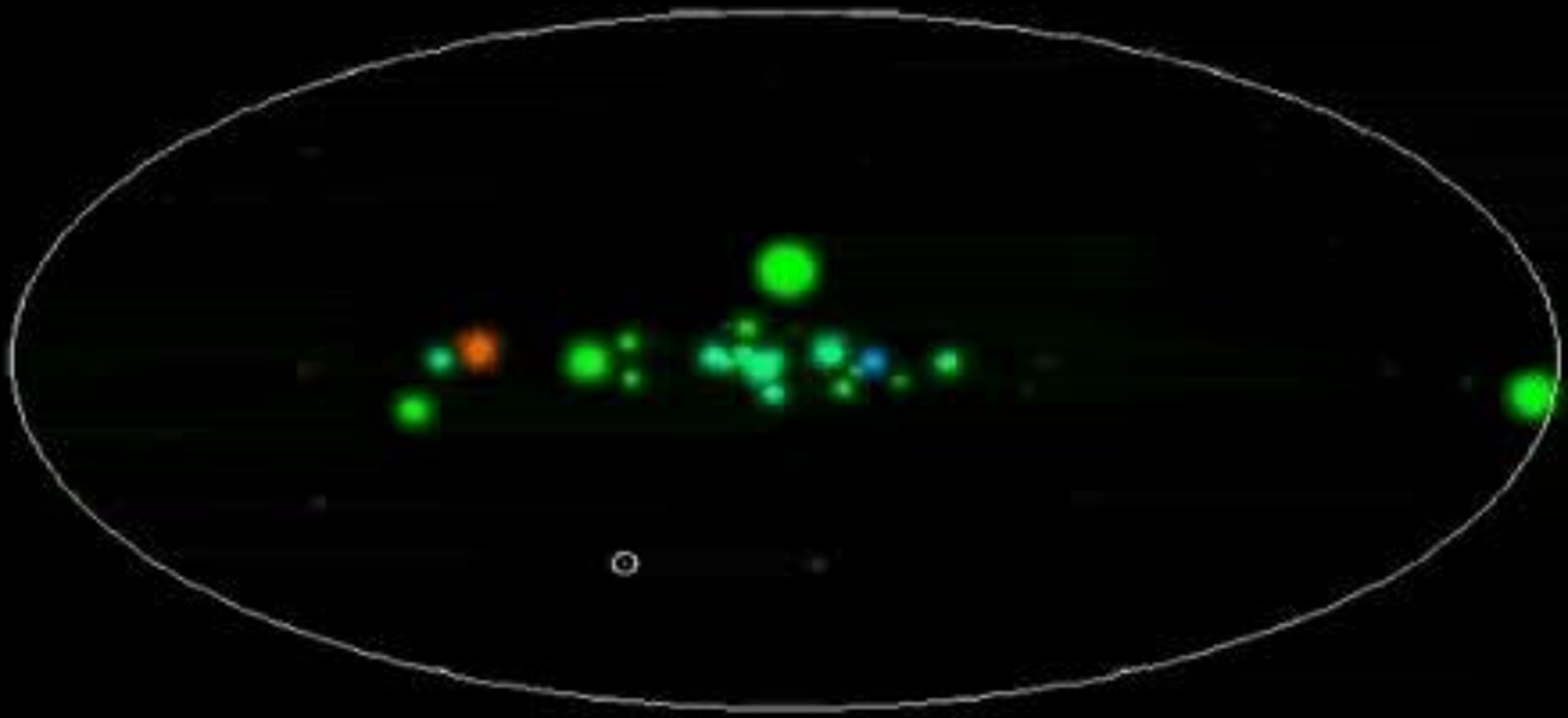


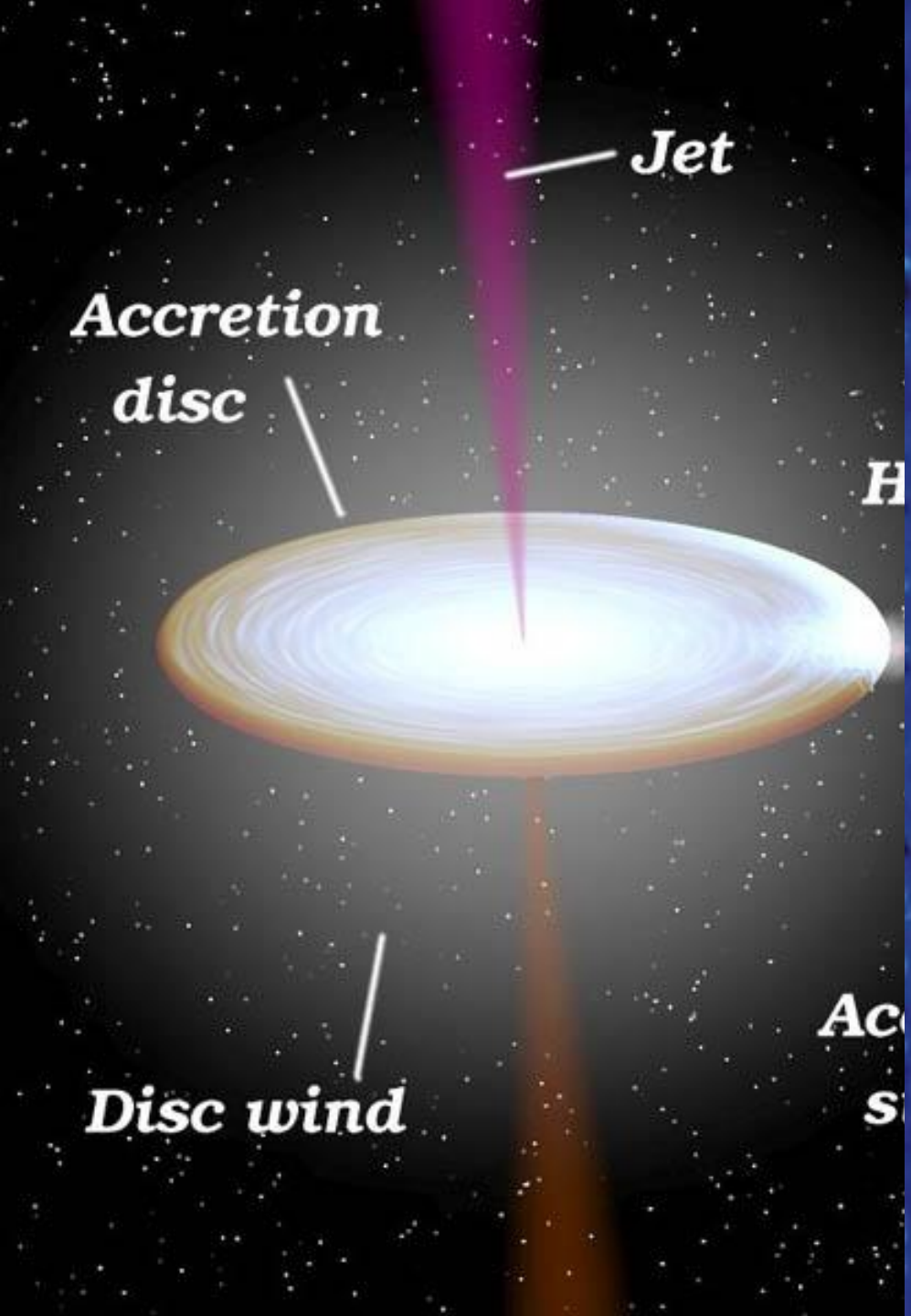
X-ray binaries

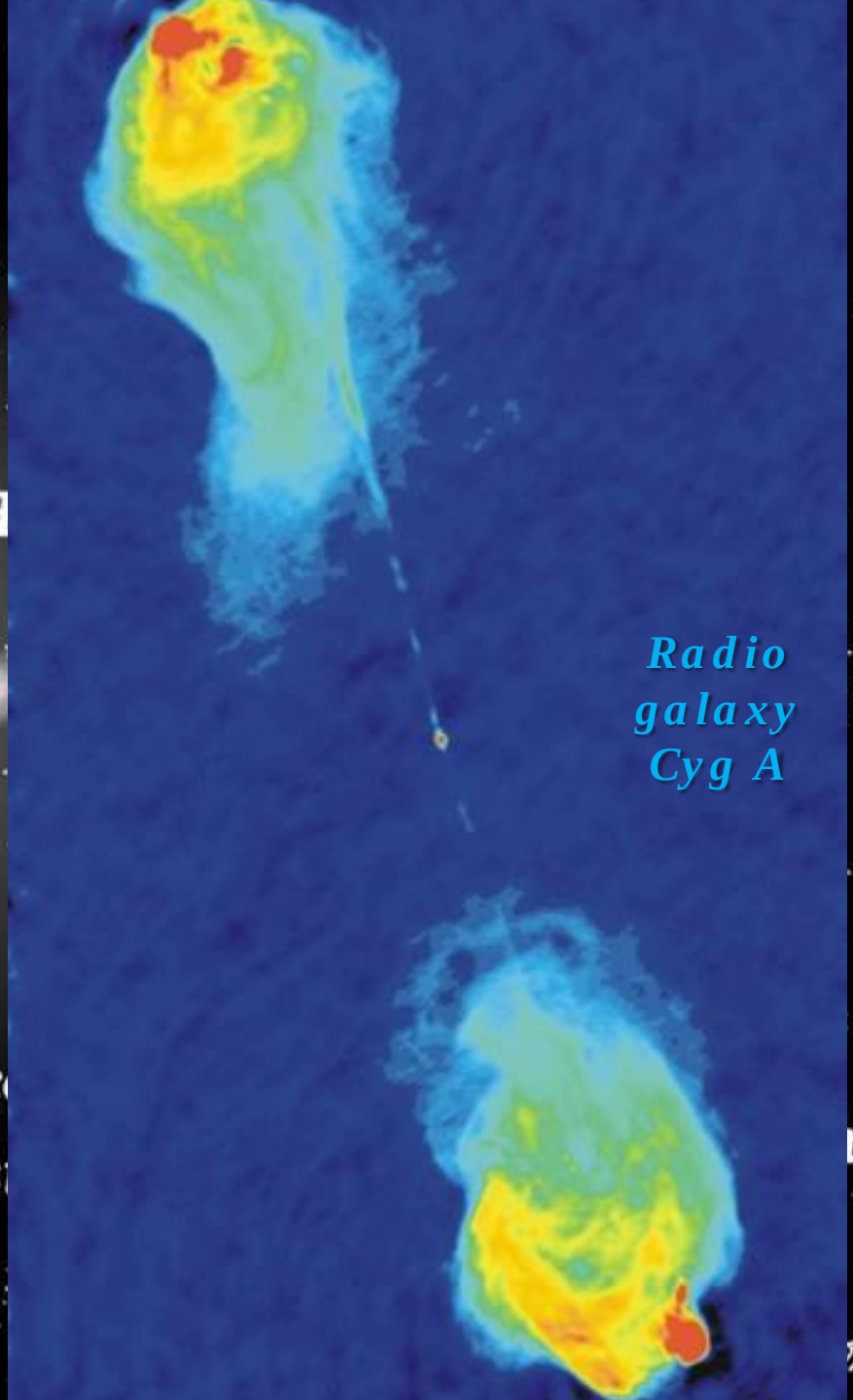


The RXTE All-Sky Monitor Movie

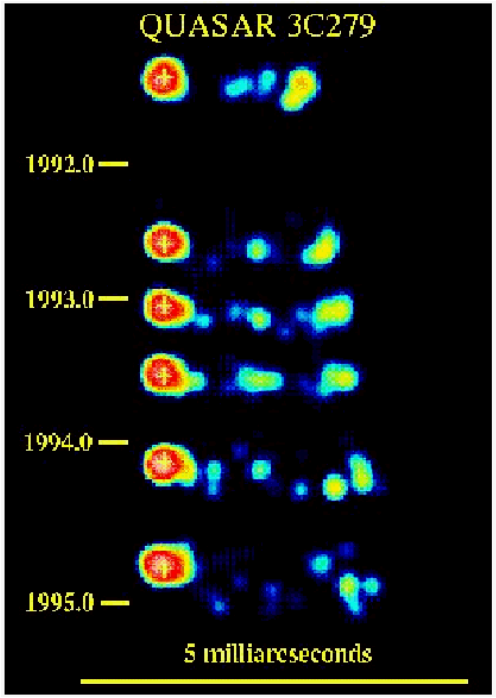


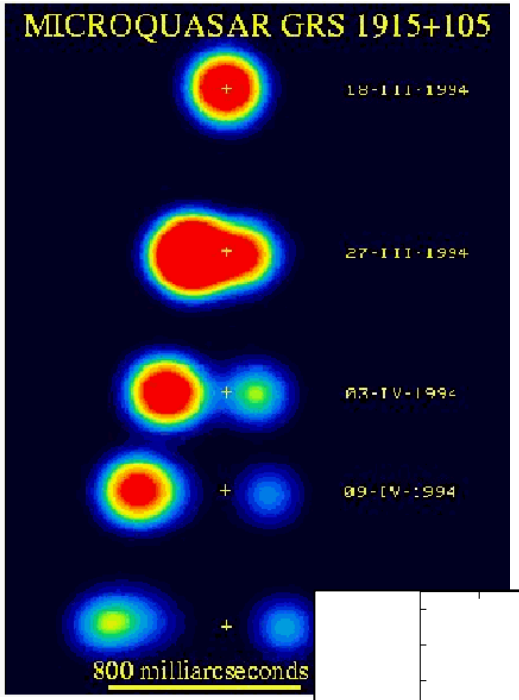
02 / 23 / 2002


Jet
Accretion disc
Disc wind


Radio galaxy Cyg A

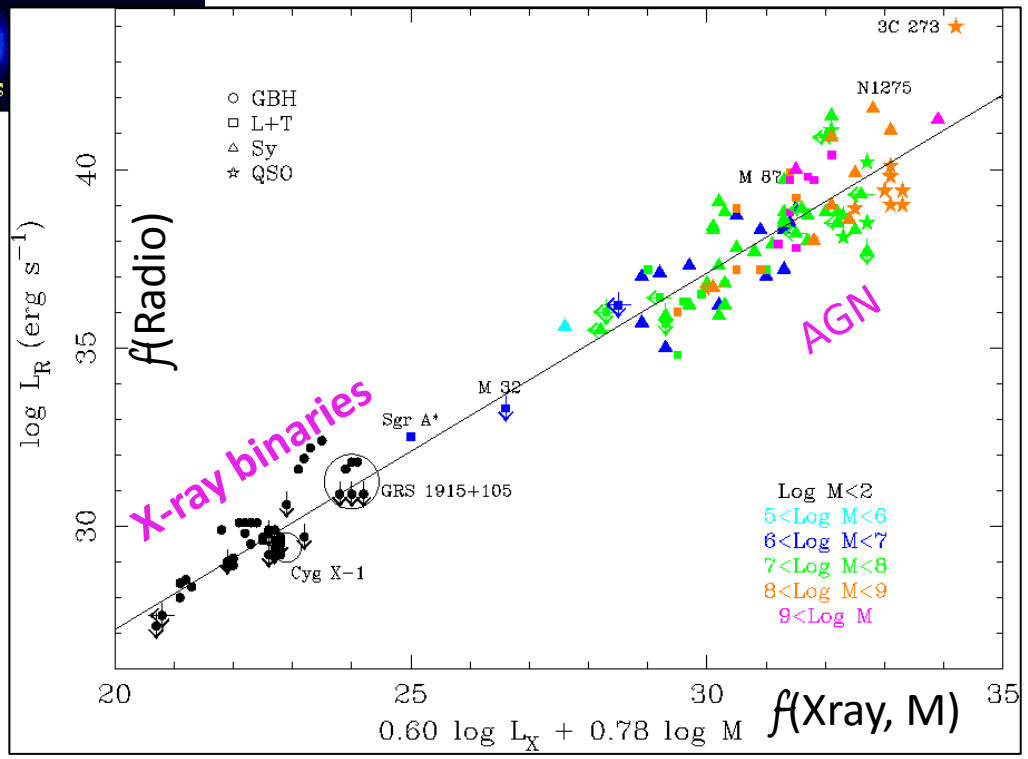
Scale invariant jet/accretion physics





Superluminal motion
(e.g. Mirabel et al.)

Black hole fundamental plane
(e.g. Merloni+03)



Key problems of astrophysical jets

- What is the process of collimation and plasma/particle **acceleration**?
- What is the jet **composition**?
- How does jet **feedback** impact on the ISM/IGM?

Key problems of astrophysical jets

- What is the process of collimation and plasma/particle **acceleration**?

Need to first measure **physical conditions** at the base of the jet near acceleration zone

- Magnetic field strength (*B*)
- Size (*R*) of acceleration zone
- and many more…

Synchrotron emission

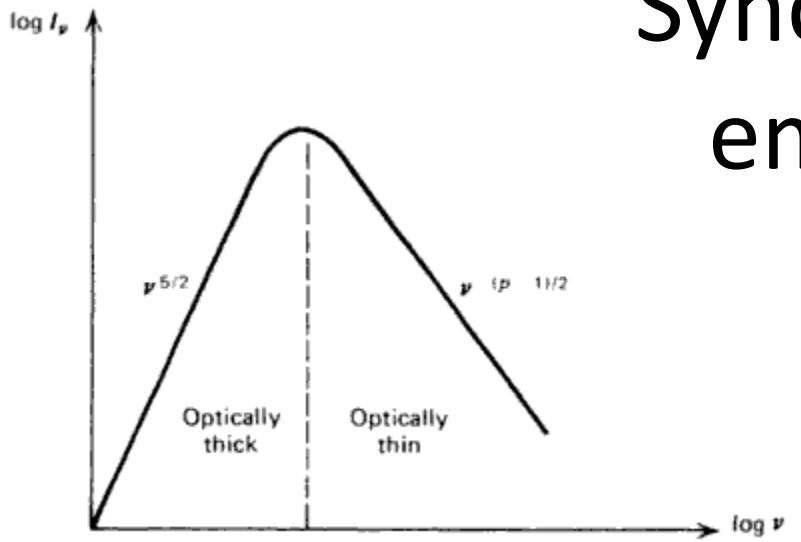


Figure 6.12 Synchrotron spectrum from a power-law distribution of electrons.

For a *power-law distribution of electrons*, Eq. (6.20b), it can be shown from Eqs. (6.33) and (6.35a) that the total power per unit volume per unit frequency, $P_{\text{tot}}(\omega)$, is

Power:

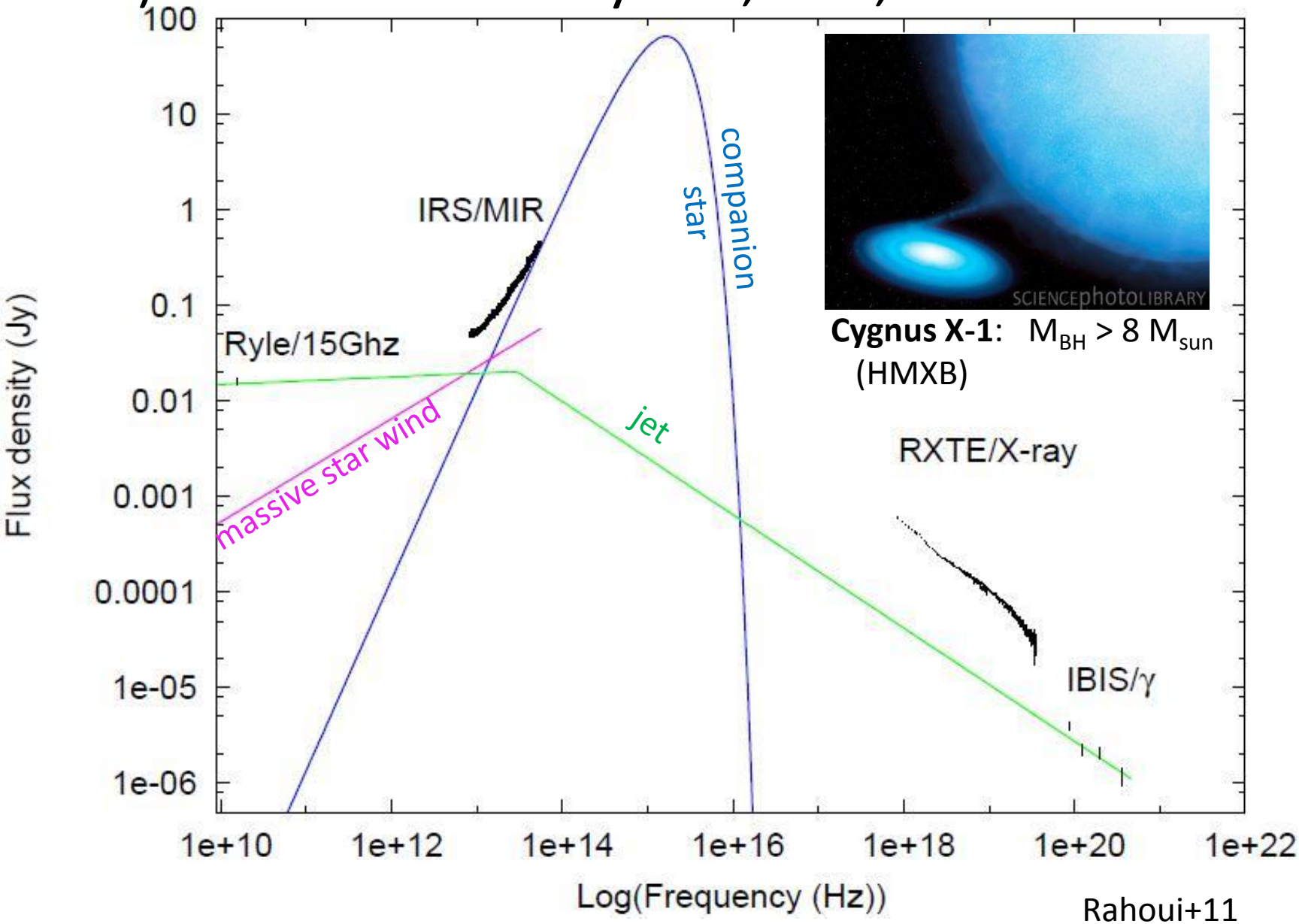
$$P_{\text{tot}}(\omega) = \frac{\sqrt{3}\, q^3 C B \sin\alpha}{2\pi m c^2 (p+1)} \Gamma\left(\frac{p}{4} + \frac{19}{12}\right) \Gamma\left(\frac{p}{4} - \frac{1}{12}\right) \left(\frac{mc\omega}{3qB\sin\alpha}\right)^{-(p-1)/2} \tag{6.36}$$

Absorption coefficient:

$$\alpha_\nu = \frac{\sqrt{3}\, q^3}{8\pi m} \left(\frac{3q}{2\pi m^3 c^5}\right)^{p/2} C (B\sin\alpha)^{(p+2)/2} \Gamma\left(\frac{3p+2}{12}\right) \Gamma\left(\frac{3p+22}{12}\right) \nu^{-(p+4)/2}. \tag{6.53}$$

(Radiative processes in astrophysics: Rybicki & Lightman)

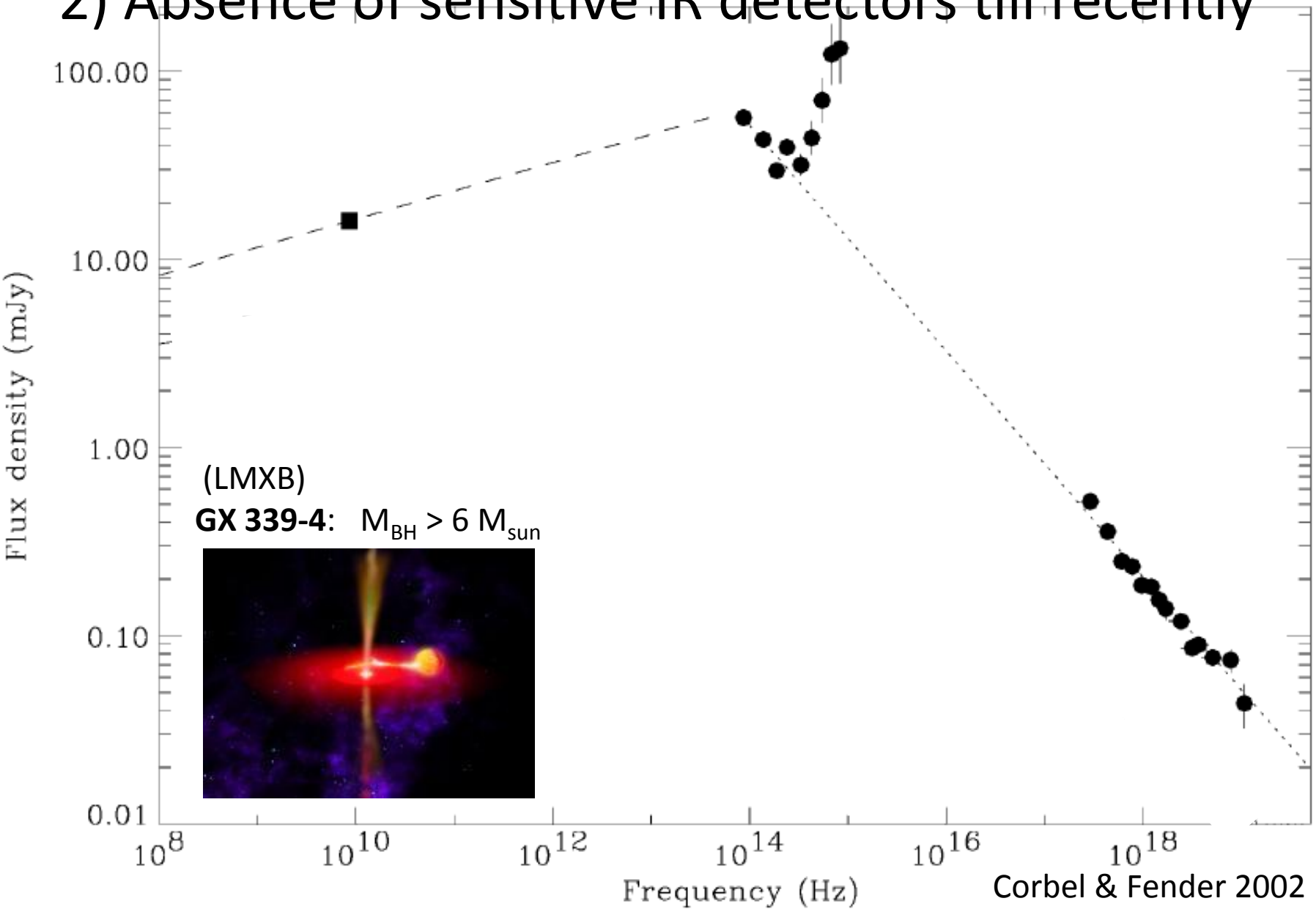
Jet infrared observations: problems
1) Contamination by star, disk, dust clouds



Cygnus X-1: $M_{BH} > 8\ M_{sun}$ (HMXB)

Rahoui+11

Jet infrared observations: problems
2) Absence of sensitive IR detectors till recently



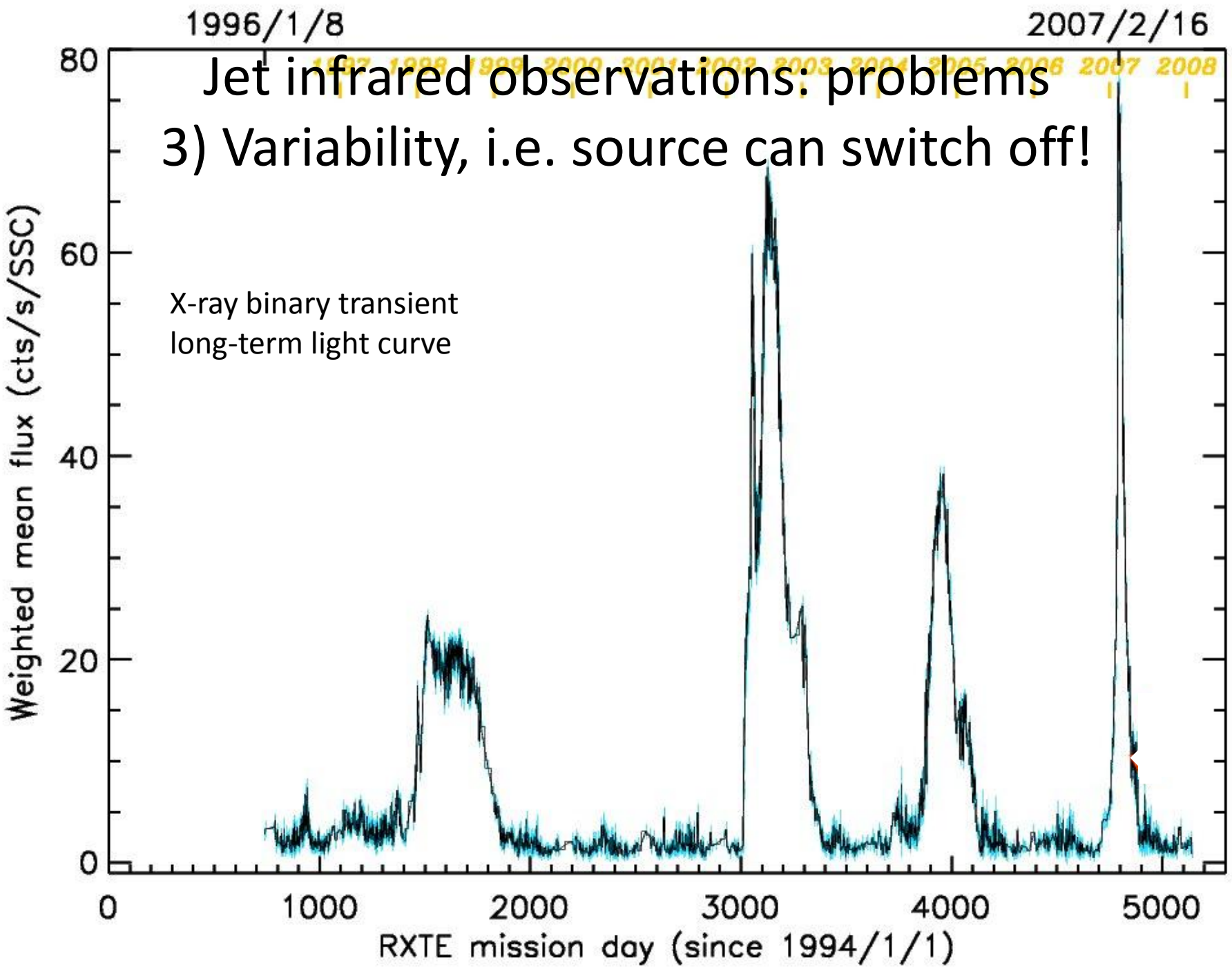
(LMXB)

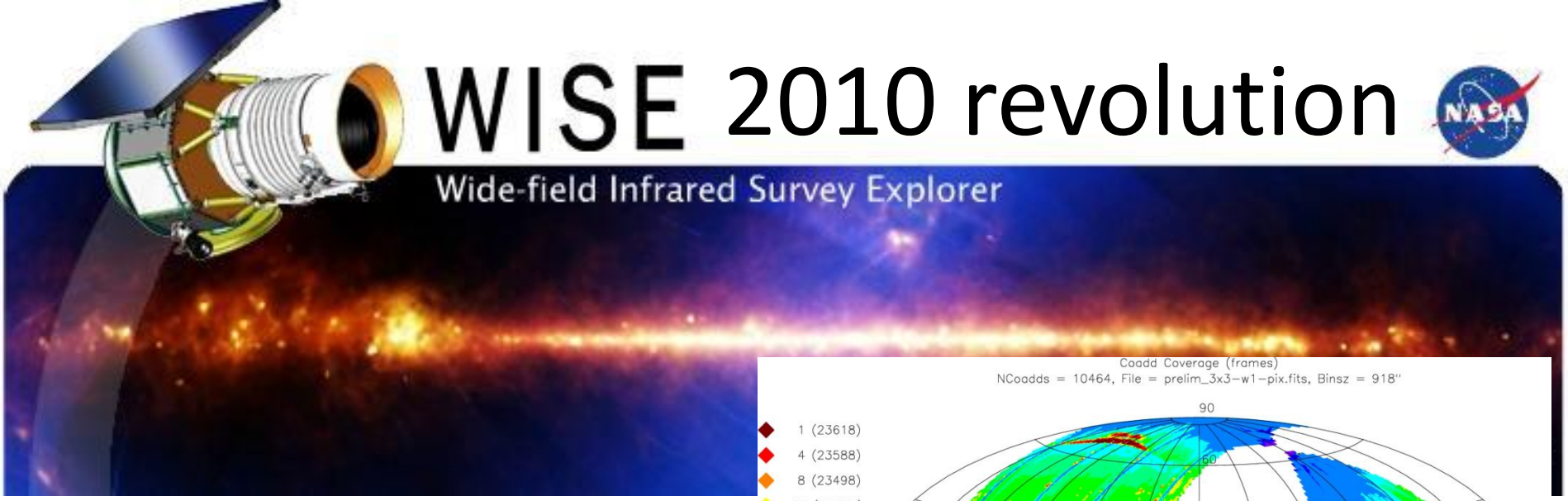
GX 339-4: $M_{BH} > 6\ M_{sun}$

Corbel & Fender 2002

Jet infrared observations: problems

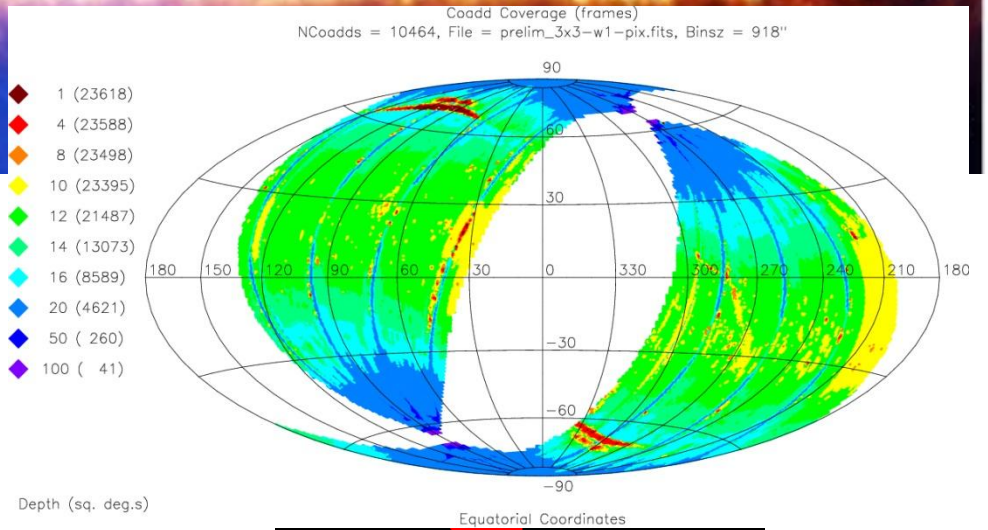
3) Variability, i.e. source can switch off!



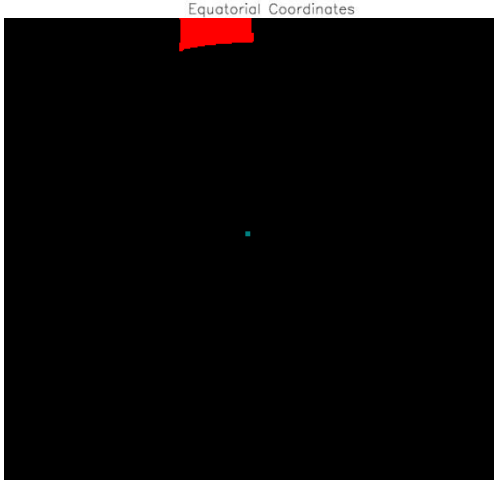


2010 revolution

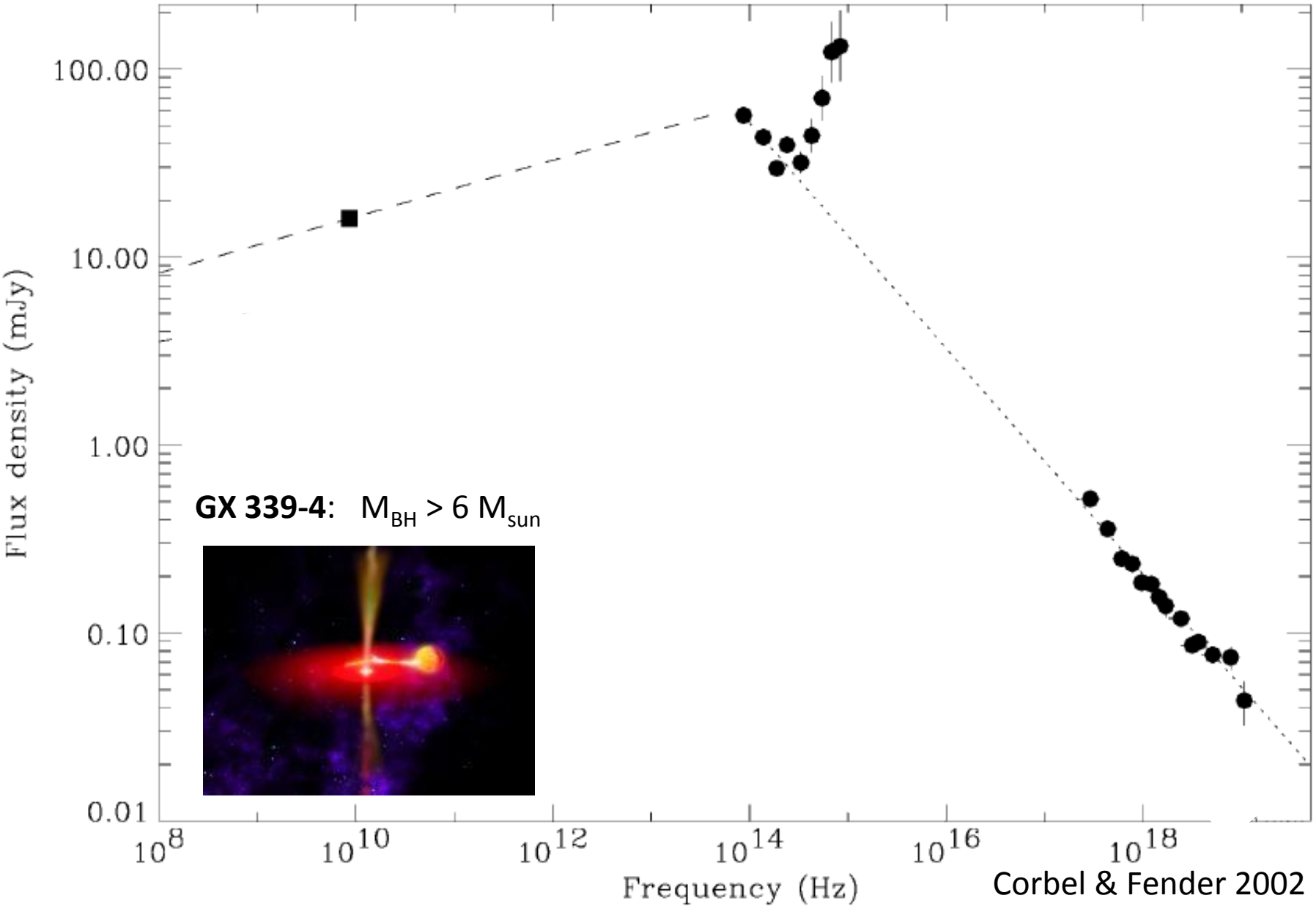
- Sensitive
- All sky



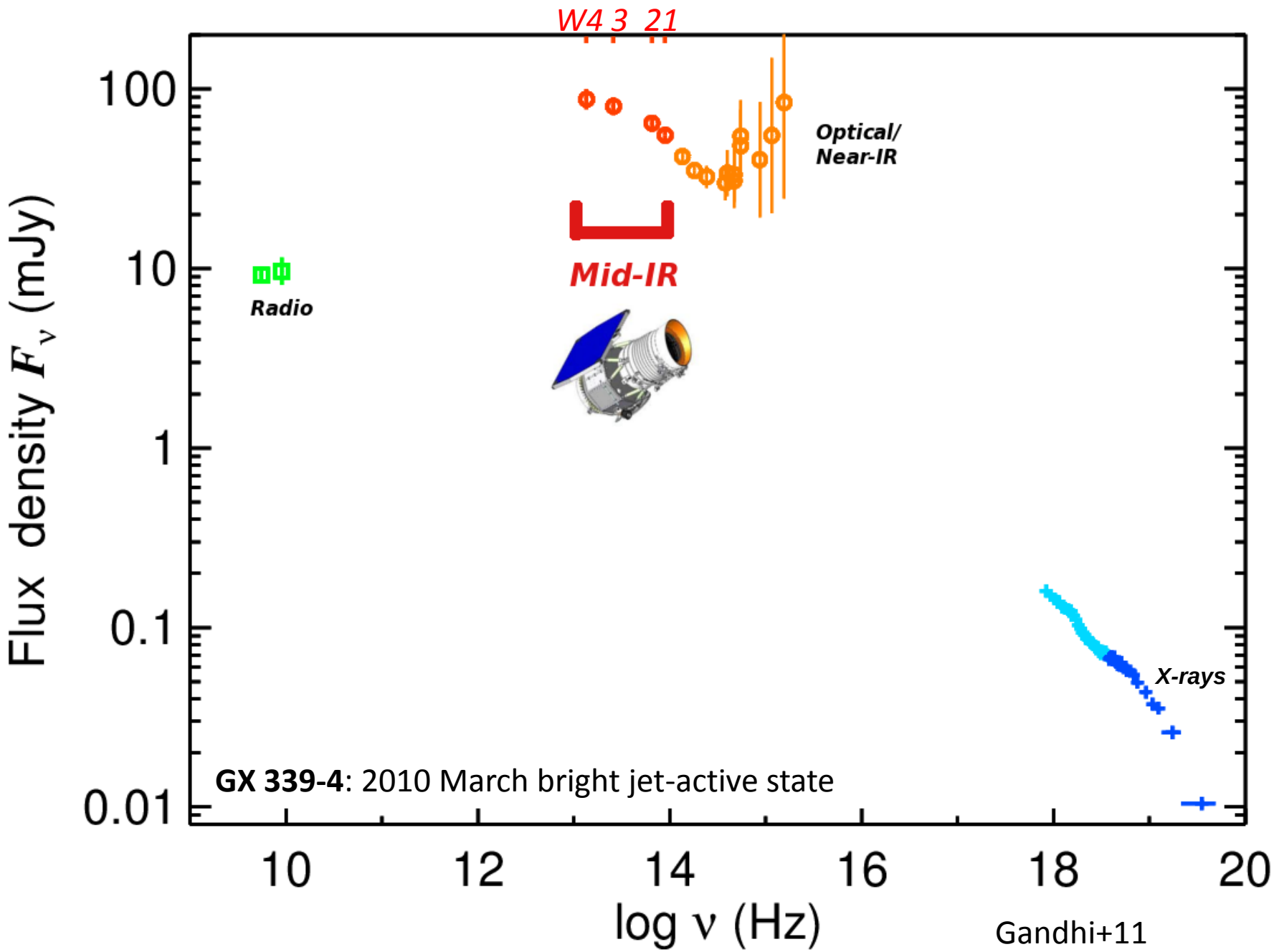
- Variability
- Simultaneous bands



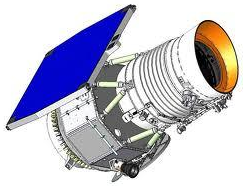
Broad-band jet observations: constraints so far

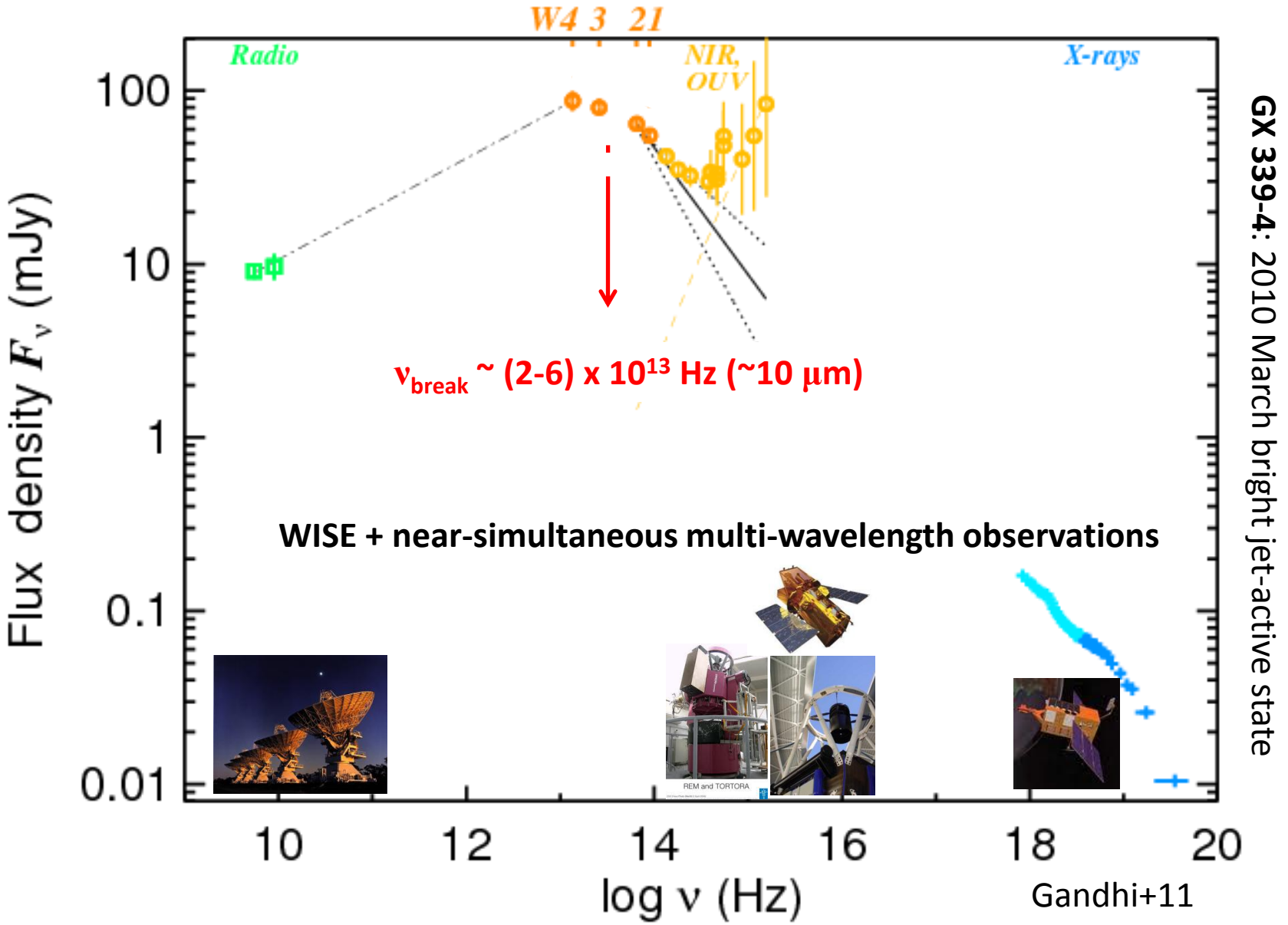


Corbel & Fender 2002

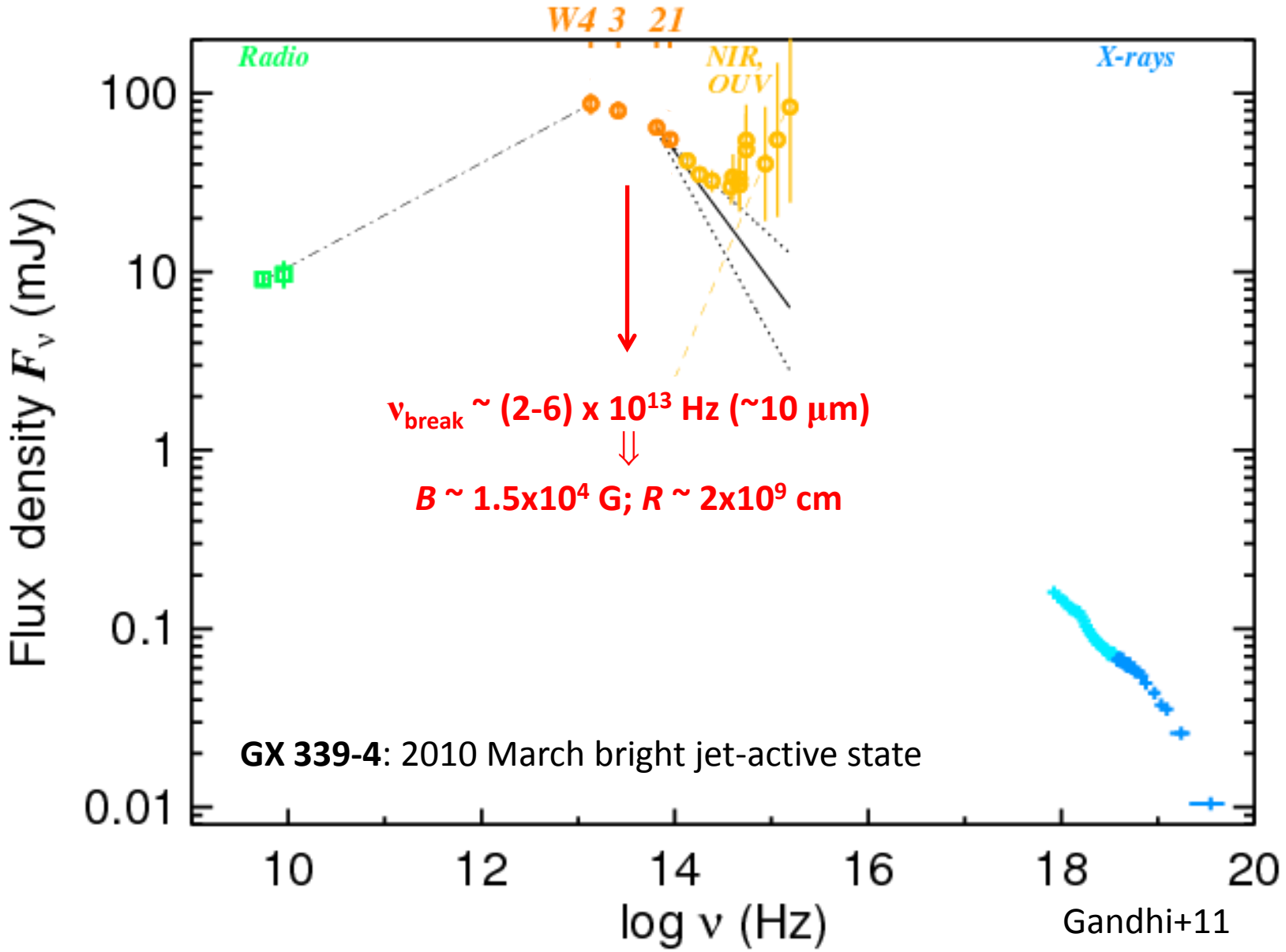

W4 3 21
Optical/
Near-IR
Mid-IR
Radio
X-rays
GX 339-4: 2010 March bright jet-active state
Flux density F_ν (mJy)
100
10
1
0.1
0.01
10
12
14
16
18
20
log ν (Hz)
Gandhi+11

Mid-infrared synchrotron break





Best constraints on inner jet of X-ray binary



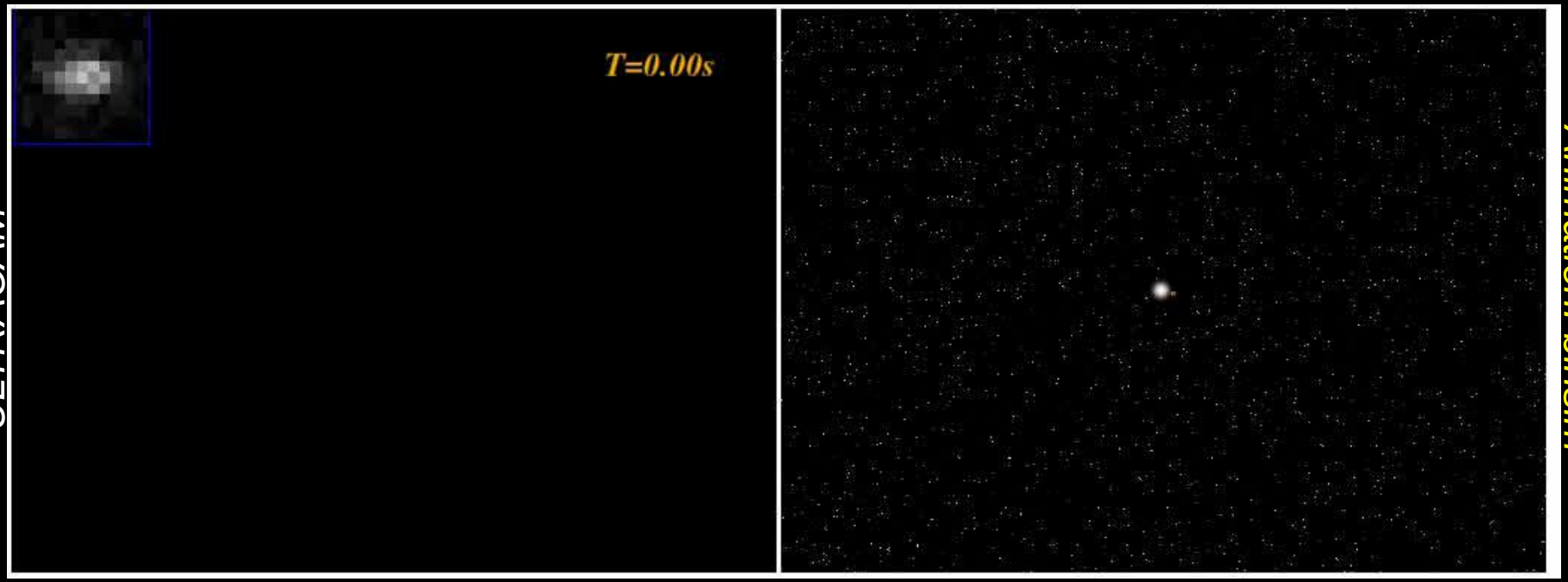
Gandhi+11

Jet variability

ULTRACAM @ VLT

Rapid *optical* flickering

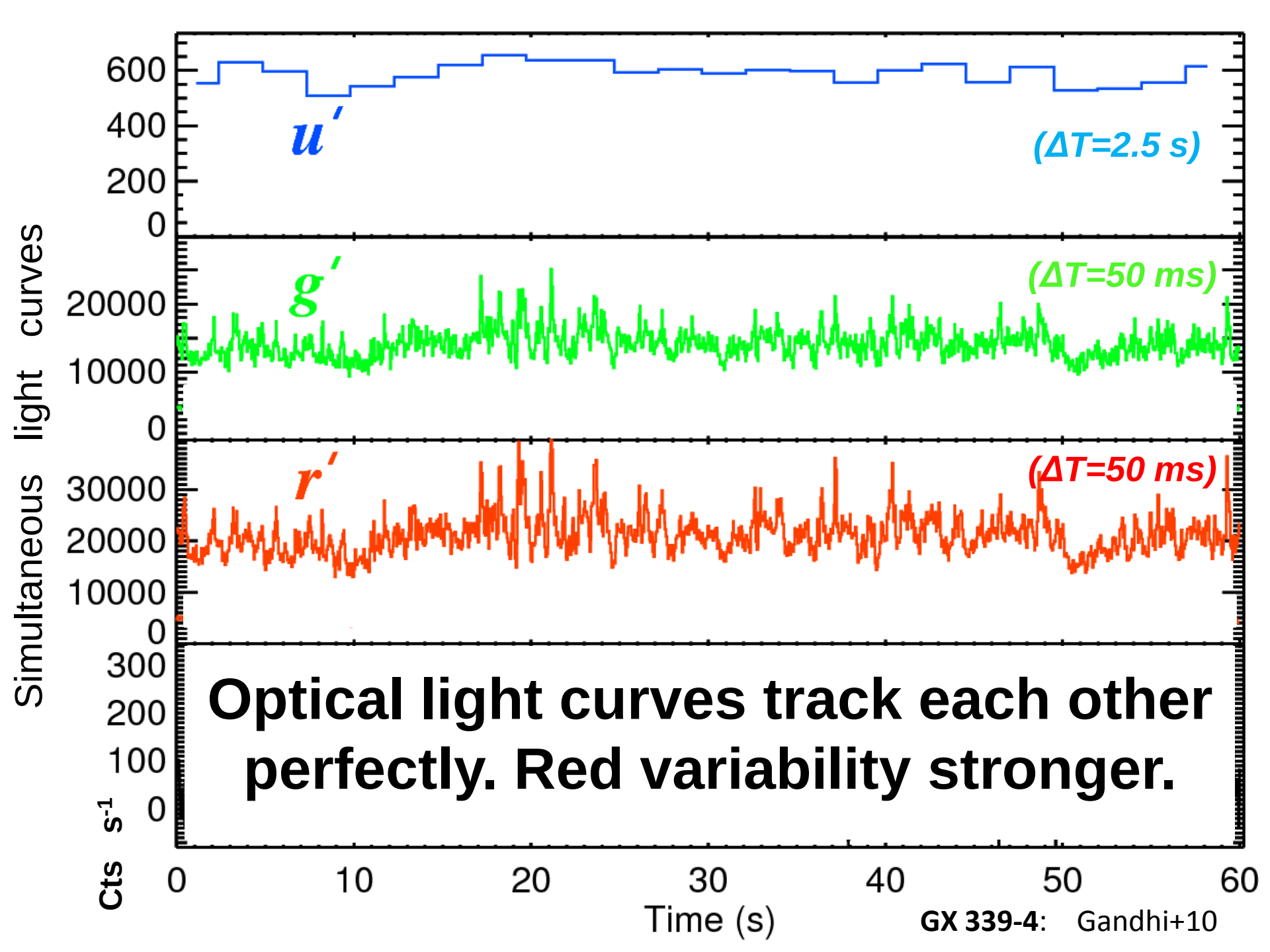
ΔT=50 ms



ULTRACAM

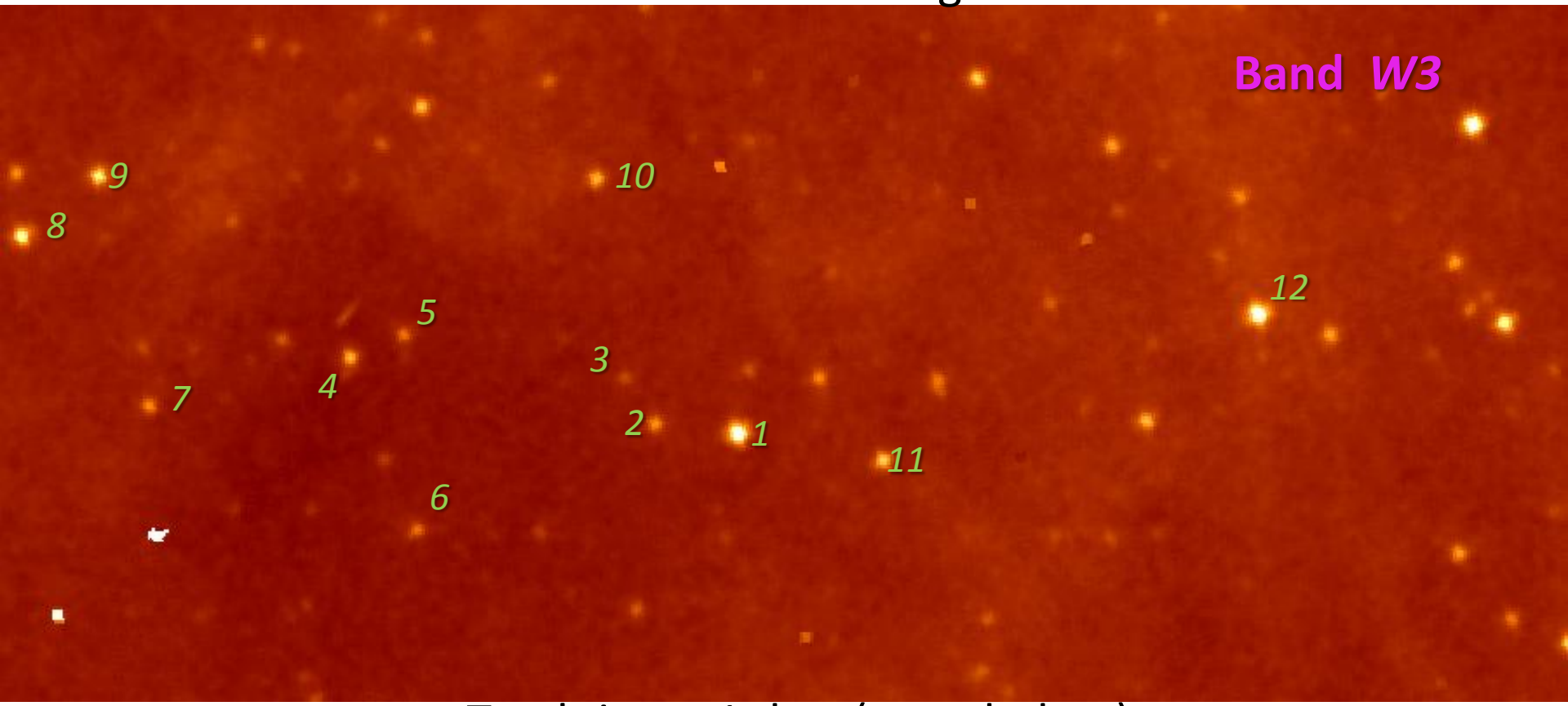
Animation: binsin

GX 339-4: Gandhi+08, 09, 10


Simultaneous light curves
u′
(ΔT=2.5 s)
g′
(ΔT=50 ms)
r′
(ΔT=50 ms)
600
400
200
0
20000
10000
0
30000
20000
10000
0
300
200
100
0
Cts s-1
0
10
20
30
40
50
60
Time (s)
Optical light curves track each other perfectly. Red variability stronger.
GX 339-4: Gandhi+10

Spot the black hole!

13 Level 1b images

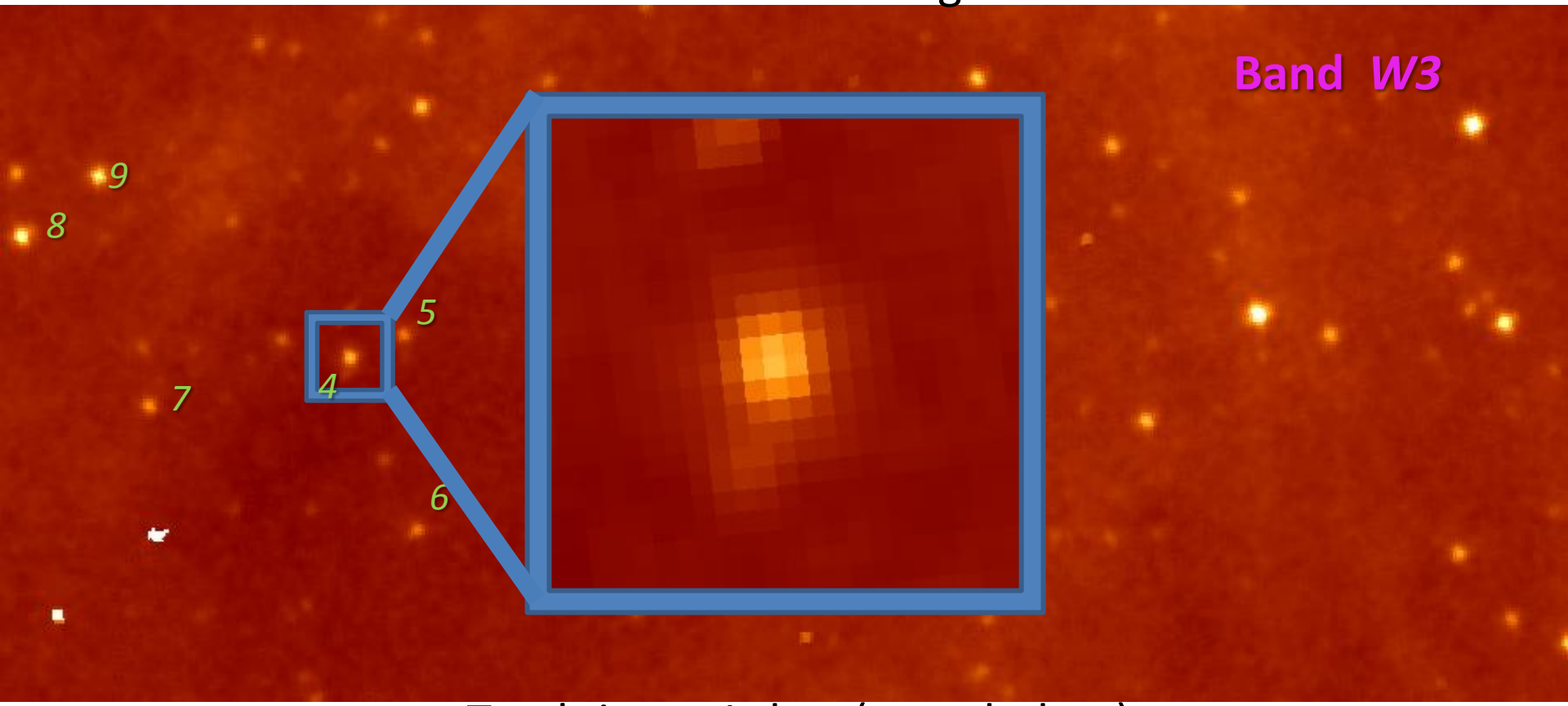


Total time ~1 day (speeded up)

GX 339-4: Gandhi+11

Spot the black hole!

13 Level 1b images



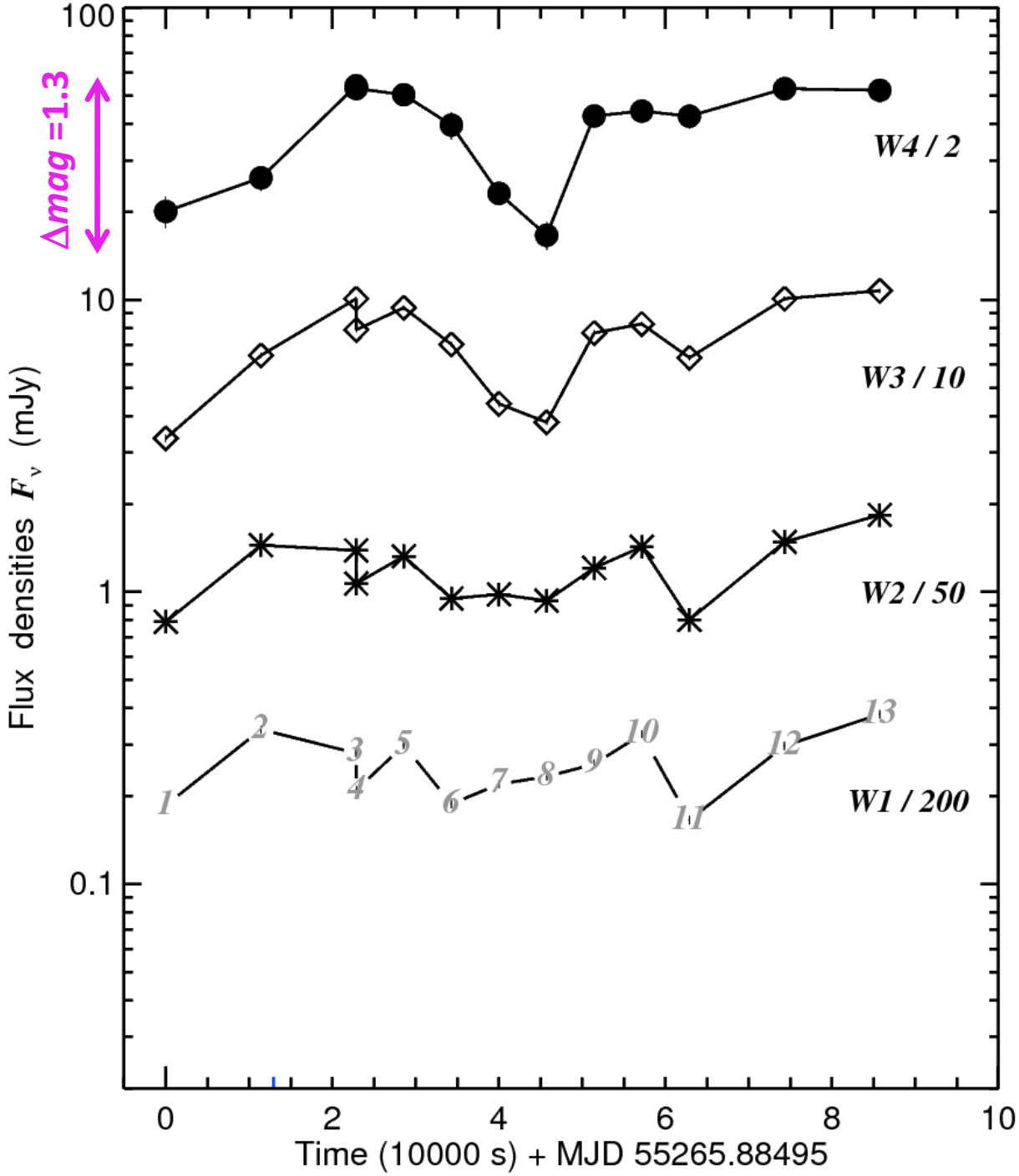
Total time ~1 day (speeded up)

GX 339-4: Gandhi+11

GX 339-4 WISE variability

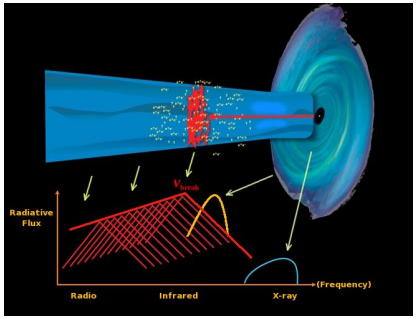
1. Very strong WISE variability (> 3 x)
2. Longer bands more variable
3. Bands not in-step

Gandhi+11

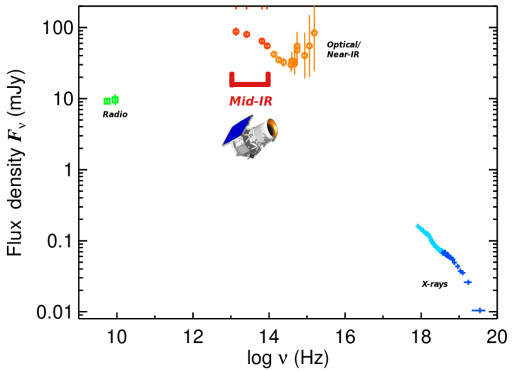


Summary

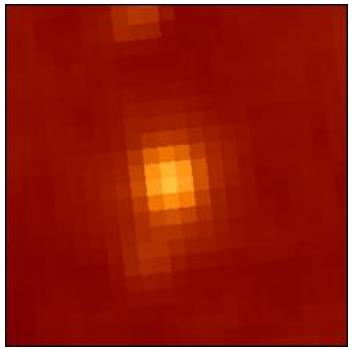
- Mid-IR allows us to probe inner jet of X-ray binaries



- For GX 339-4, we measure ν_{break}, $B \sim 1.5 \times 10^4$ G and $R \sim 2 \times 10^9$ cm



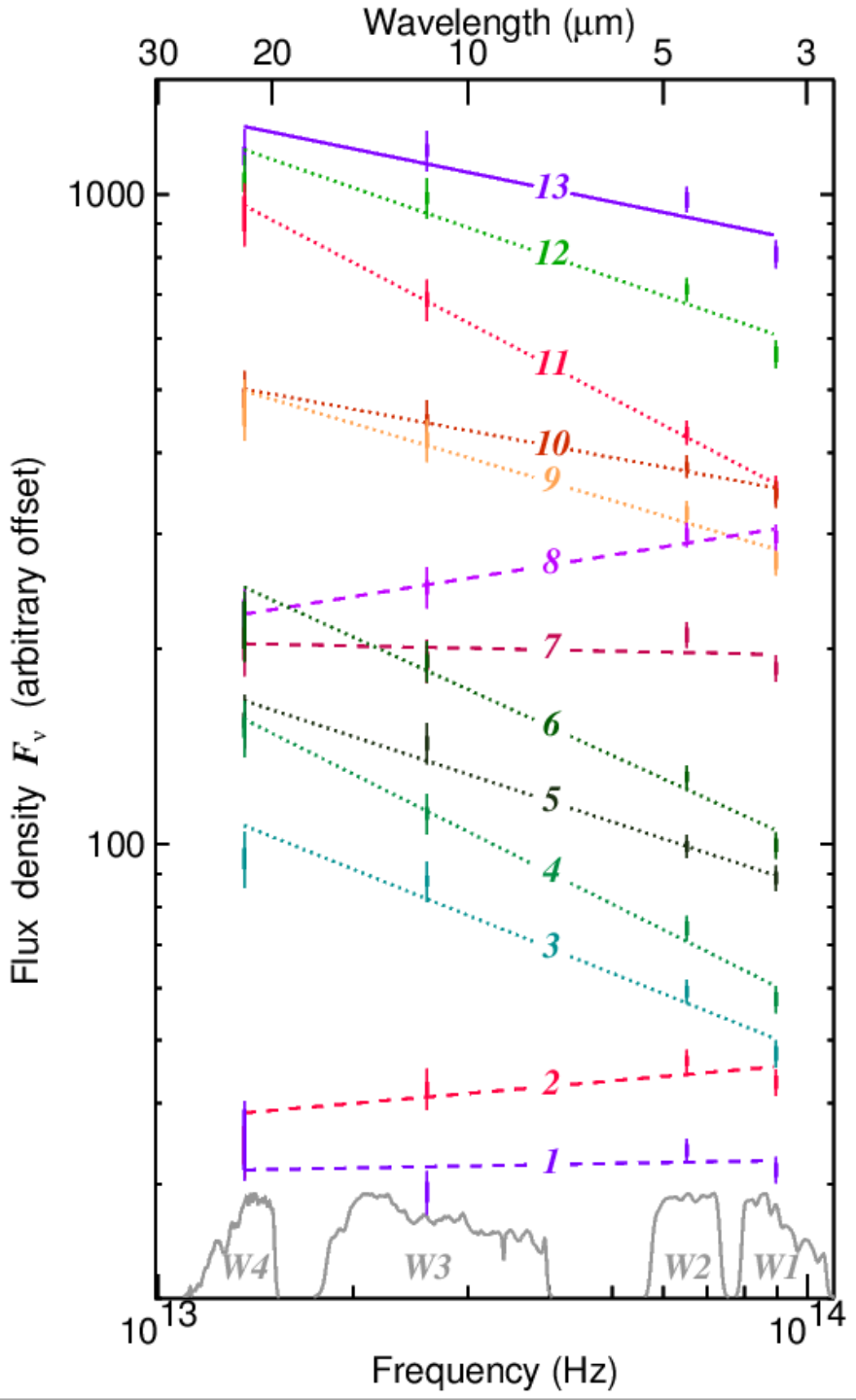
- *Simultaneous band* variability
  $\Rightarrow$ *B, R* change by >10x on relatively short times.



Next step : What we need

- Accurate color corrections and lowering systematic errors

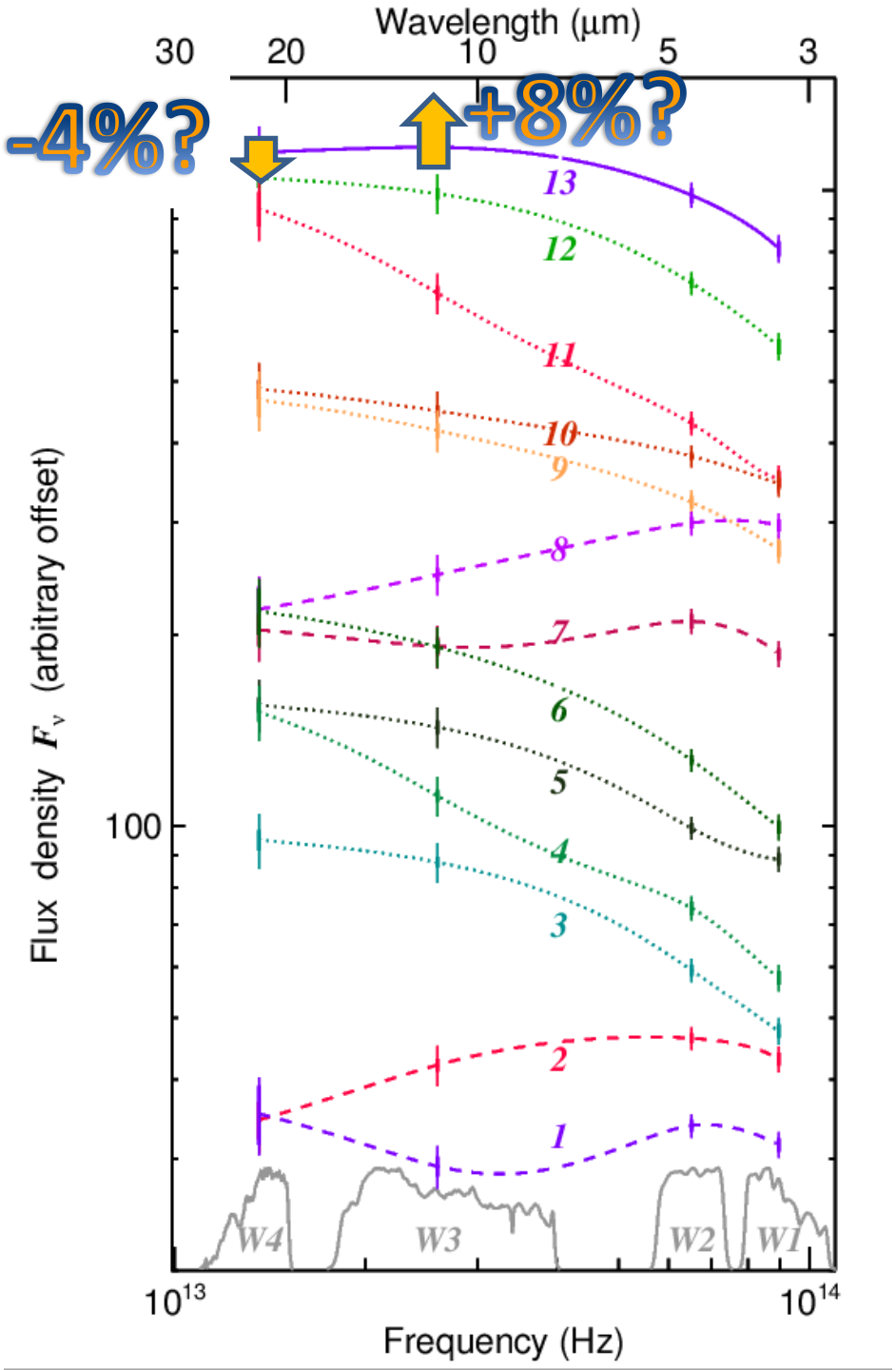
Systematics limit ν_{break} measurement



GX 339-4: Gandhi+11

Red vs. blue discrepancy can change zeropoints.

How much for flat spectrum ($F_\nu \propto \nu^0$) sources?



GX 339-4

Next step : What we need

- Accurate color corrections and lowering systematic errors

- Thank you for building WISE!
  Anyone for WISE II ?!

Summary

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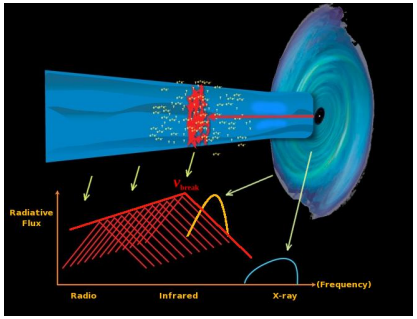

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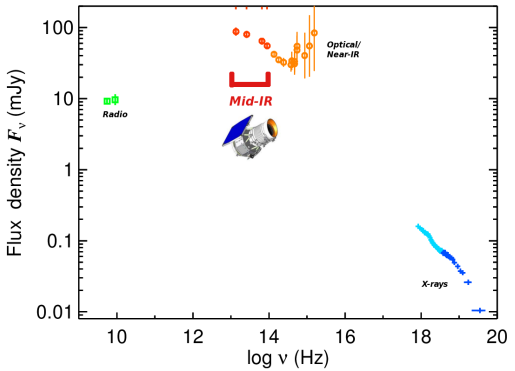

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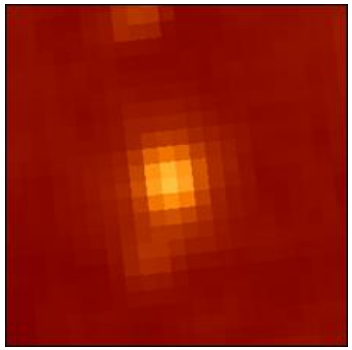

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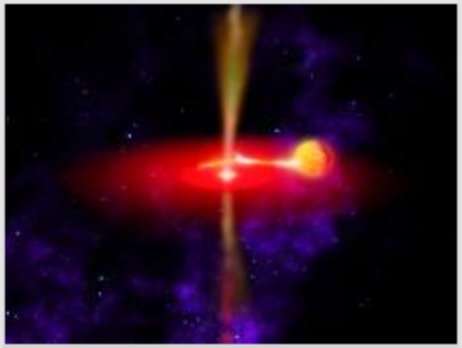
NASA's WISE Mission Captures Black Hole's Wildly Flaring Jet

09.20.11

PASADENA, Calif. -- Astronomers using NASA's Wide-field Infrared Survey Explorer (WISE) have captured rare data of a flaring black hole, revealing new details about these powerful objects and their blazing jets.

Scientists study jets to learn more about the extreme environments around black holes. Much has been learned about the material feeding black holes, called accretion disks, and the jets themselves, through studies using X-rays, gamma rays and radio waves. But key measurements of the brightest part of the jets, located at their bases, have been difficult despite decades of work. WISE is offering a new window into this missing link through its infrared observations.

"Imagine what it would be like if our sun were to undergo sudden, random bursts, becoming three times brighter in a matter of hours and then fading back again. That's the kind of fury we observed in this jet," said Poshak Gandhi, a scientist with the Japan Aerospace Exploration Agency (JAXA). He is the lead author of a new study on the results appearing in the Astrophysical Journal Letters. "With WISE's infrared vision, we were able to zoom in on the inner regions near the base of the stellar-mass black hole's jet for the first time and observe the physics of jets in action."



This artist's concept illustrates what the flaring black hole called GX 339-4 might look like. Image credit: NASA

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The black hole, called GX 339-4, had been observed previously. It lies more than 20,000 light-years away from Earth near the center of our galaxy. It has a mass at least six times greater than the sun.