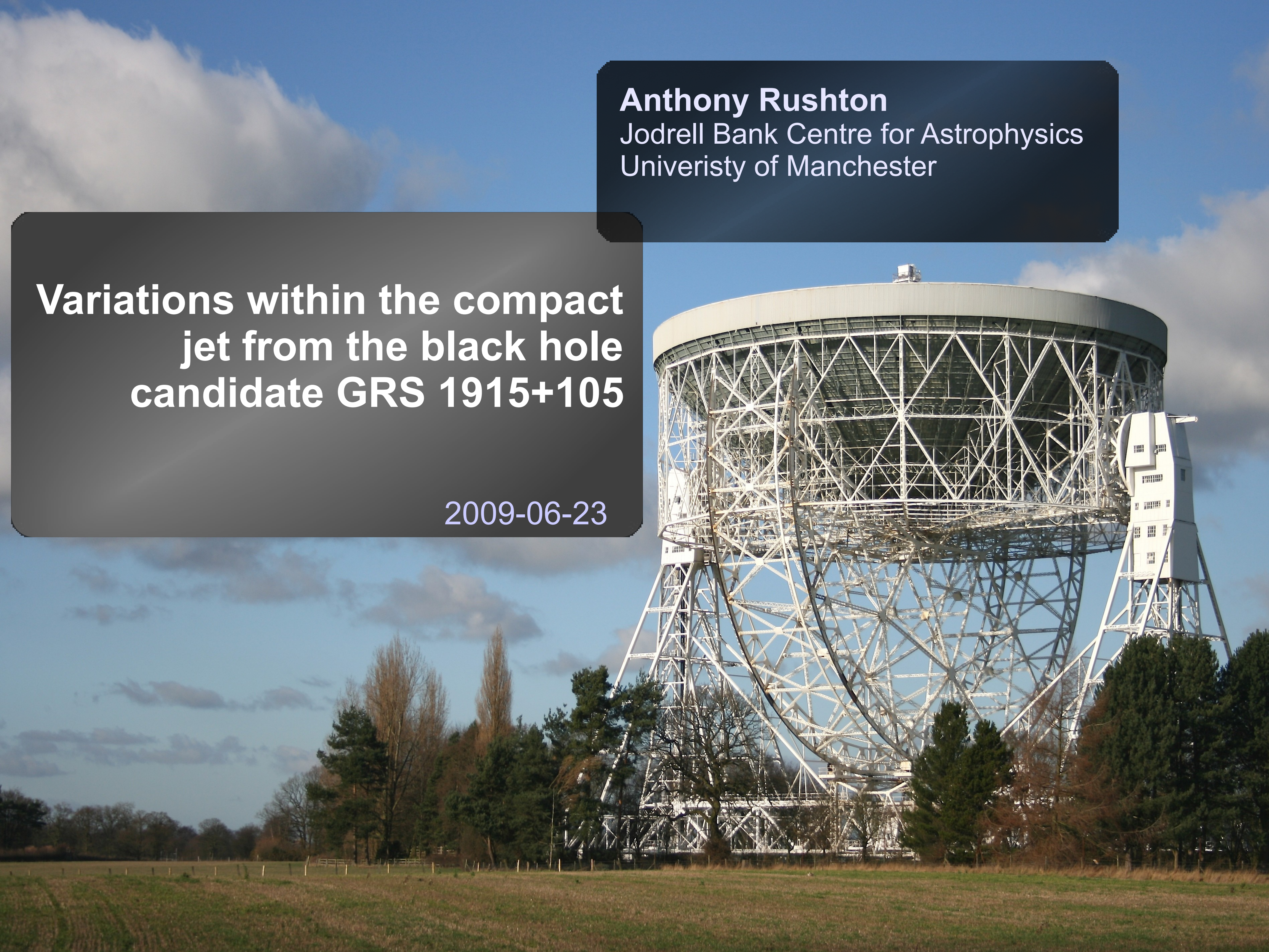

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Variations within the compact jet from the black hole candidate GRS 1915+105

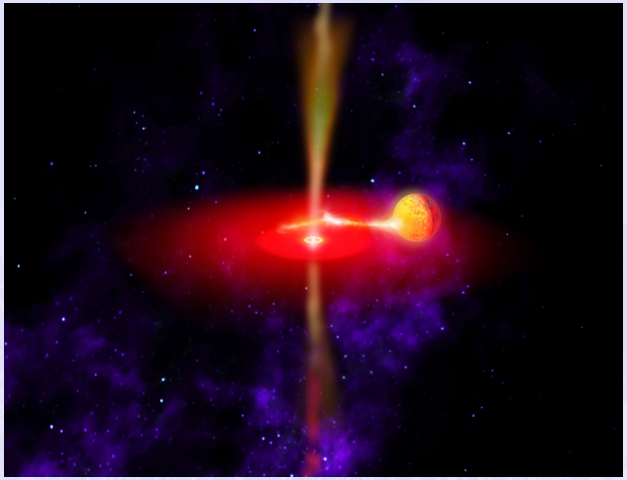
2009-06-23

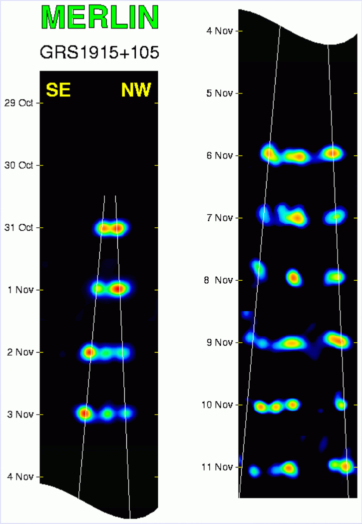
Aim

- Study the long term X-ray/radio relationship in GRS 1915+105
- Used high-resolution observations to selected monitoring data
- Model fit (e.g. the fundamental plane)

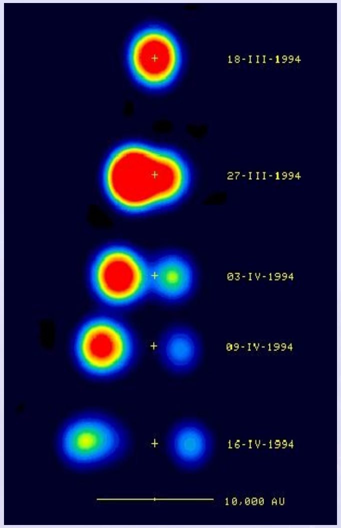
Introduction – GRS 1915+105

- GRS 1915+105:
  - X-ray binary
  - Distance ~ 11 kpc
  - Black hole candidate ~ 14 $M_{\odot}$
  - Low-mass companion





Fender et al. (1999) MERLIN

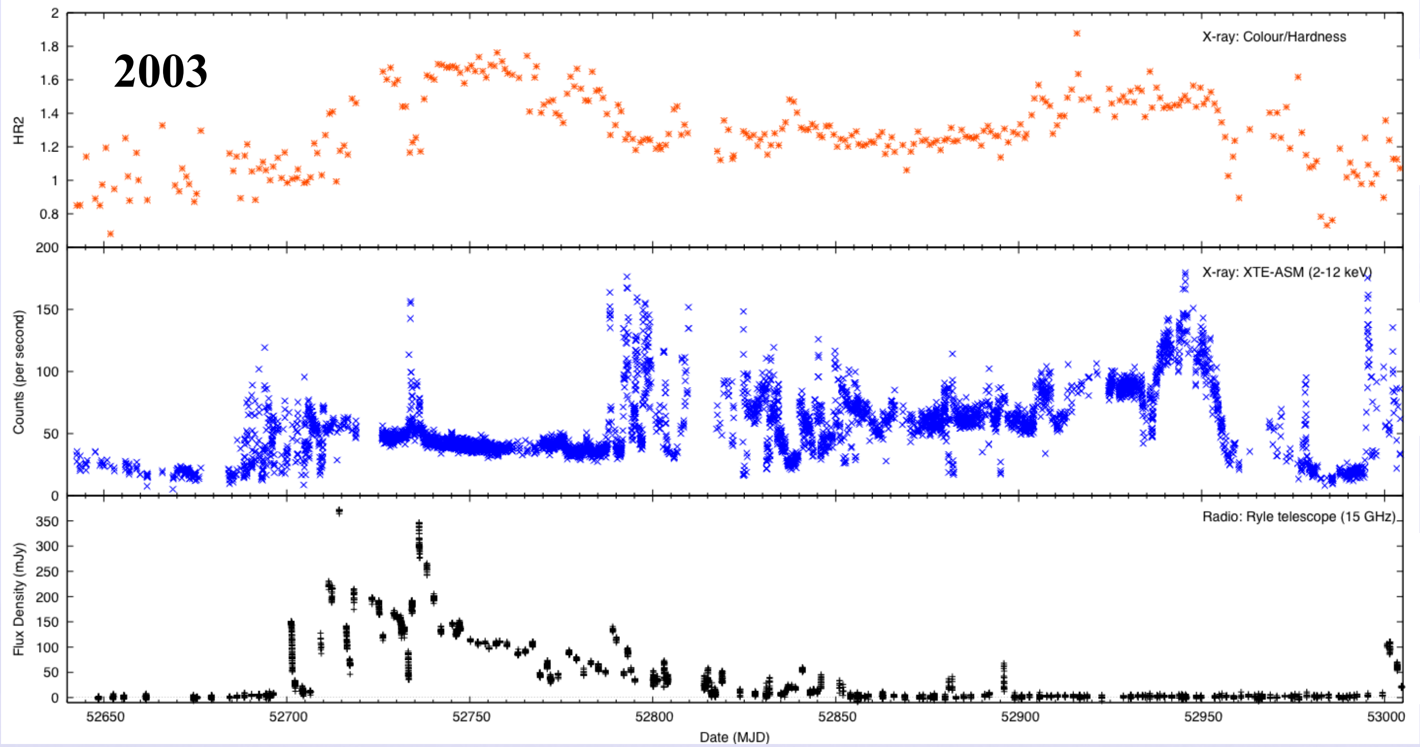


Mirabel & Rodríguez (1994) VLA

- Superluminal motion
  - Ejected knots ~ 0.9c
  - Occurs after a state change low/hard → high/soft

Radio and X-ray monitoring

Results provided by:
Guy Pooley (radio) &
the ASM/RXTE teams at MIT and at the RXTE SOF and GOF at NASA's GSFC (X-ray)

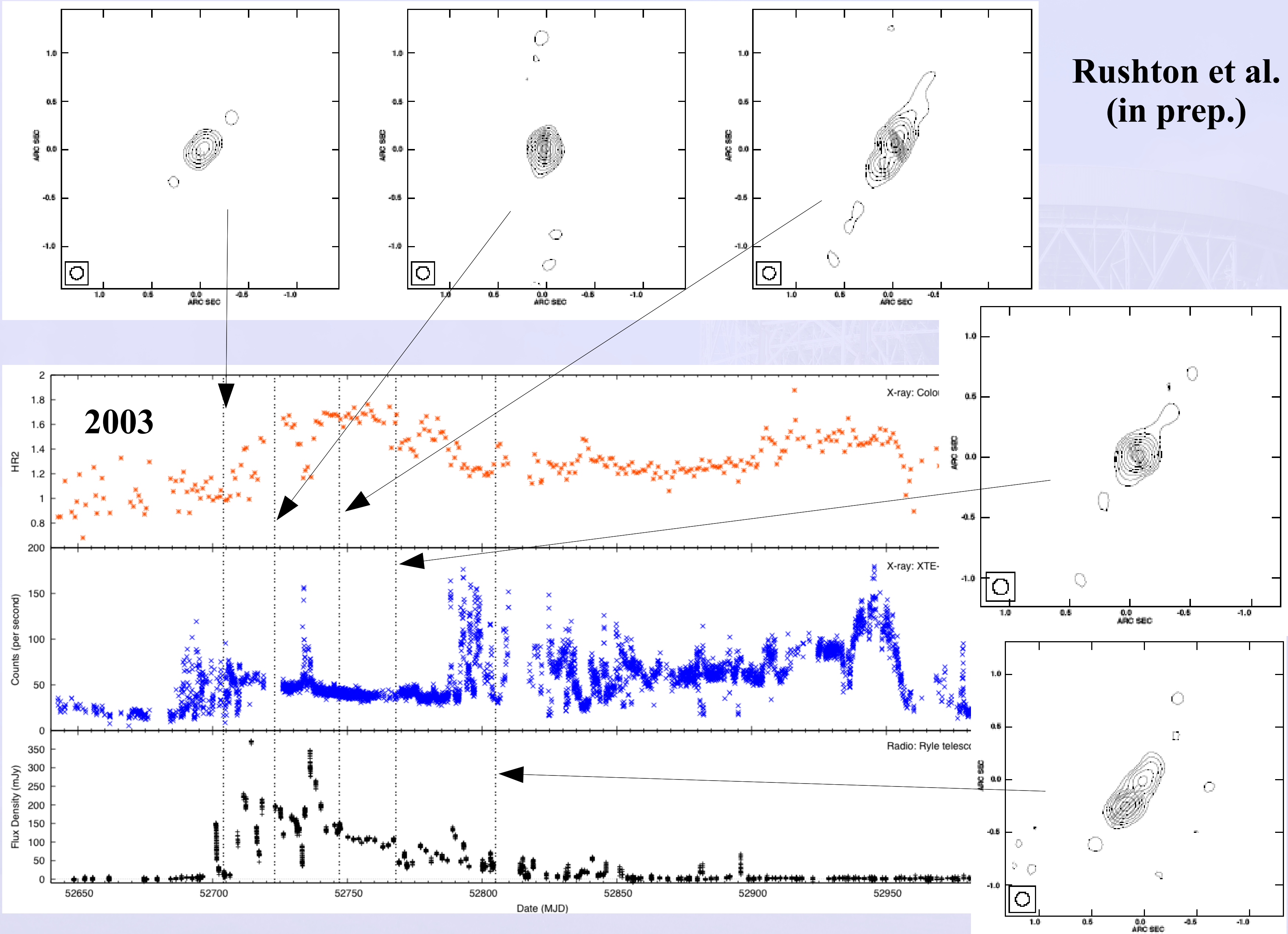


RXTE-ASM (Hardness ratio)

RXTE-ASM (2-12 keV)

Ryle Telescope (15 GHz)

1.6 GHz MERLIN observations

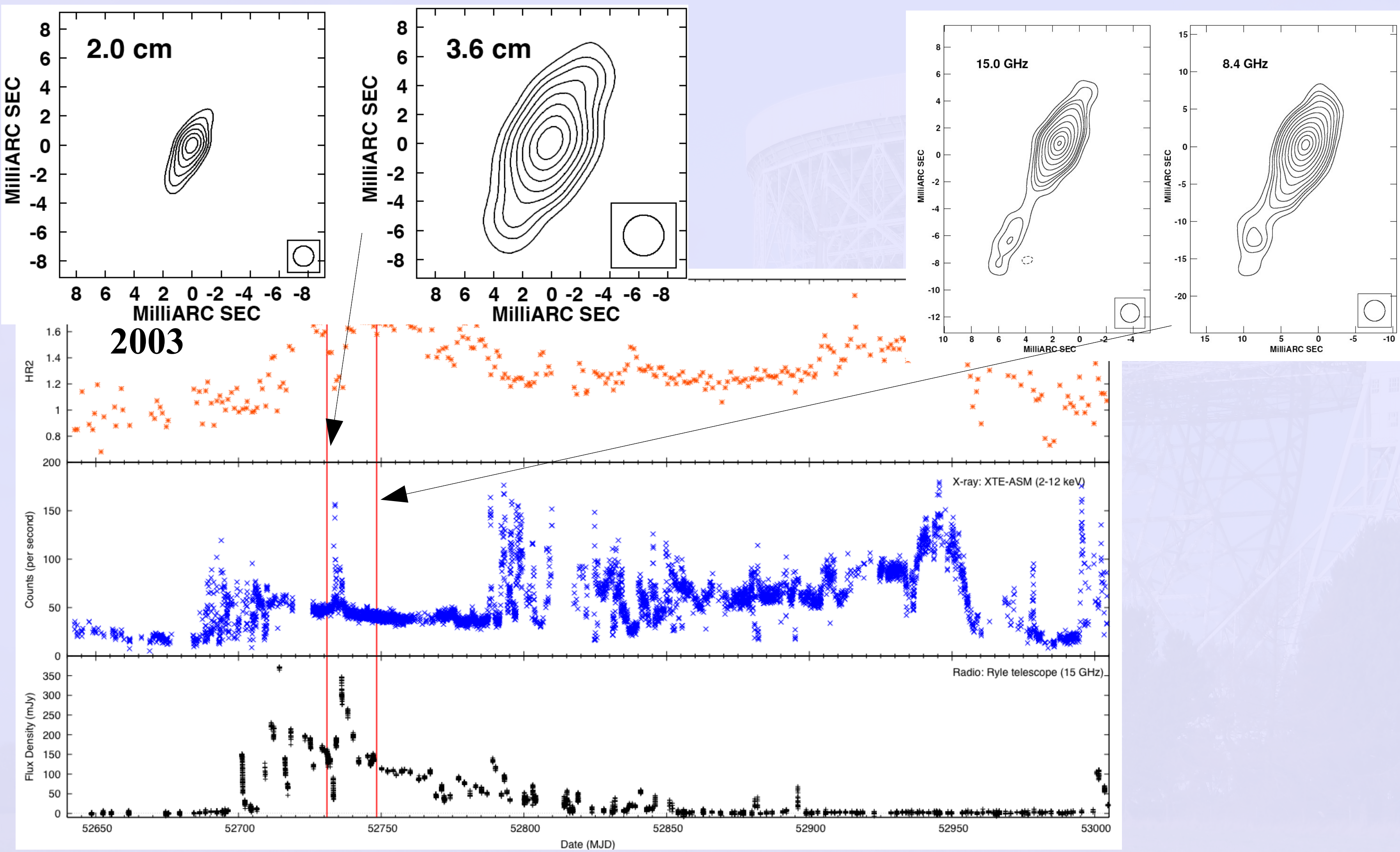


Rushton et al. (in prep.)

8.4 & 15 GHz VLBA observations

Fuchs et al. (2003)

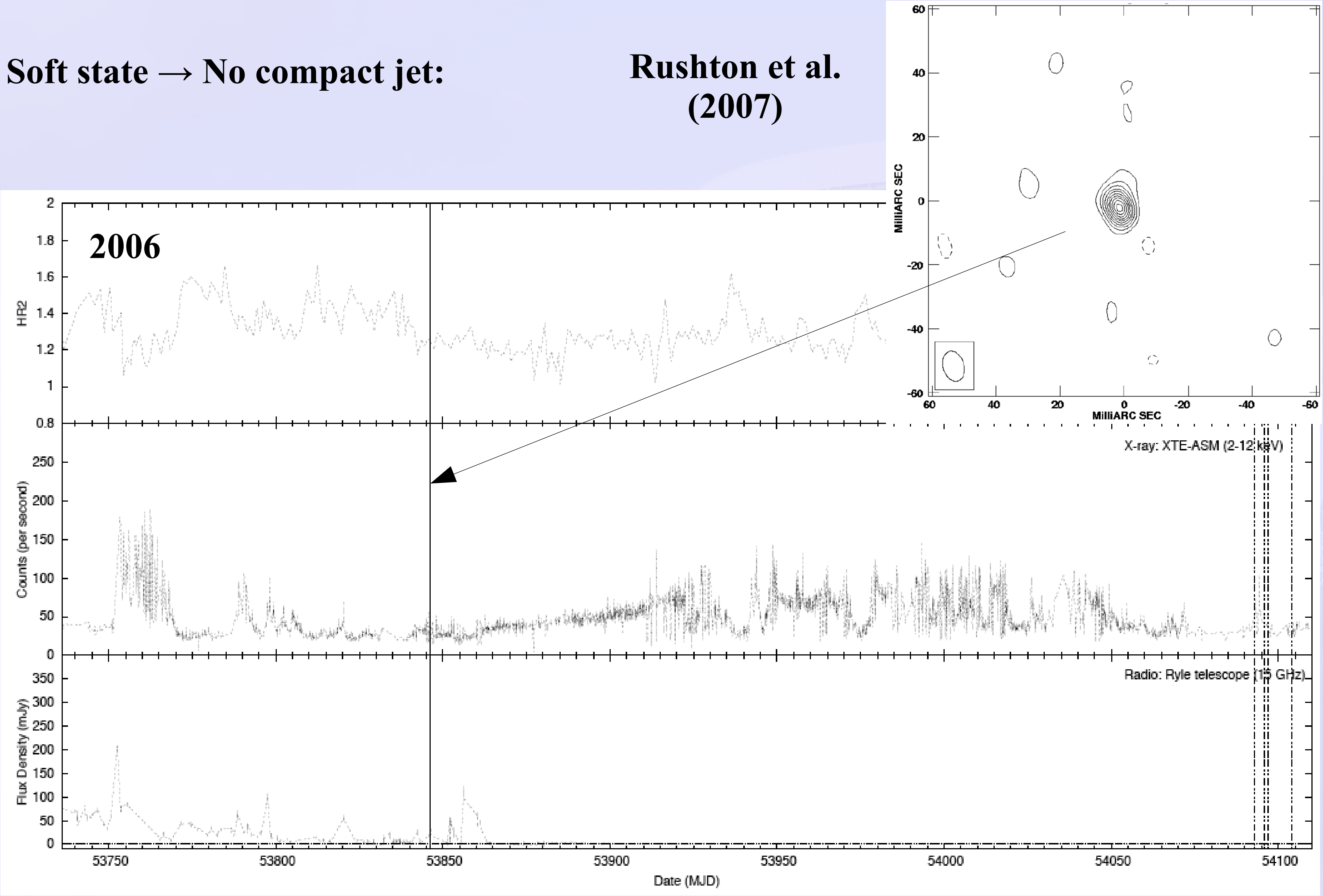
Ribó, Dhawan & Mirabel (2004)



5 GHz e-EVN observation

Soft state → No compact jet:

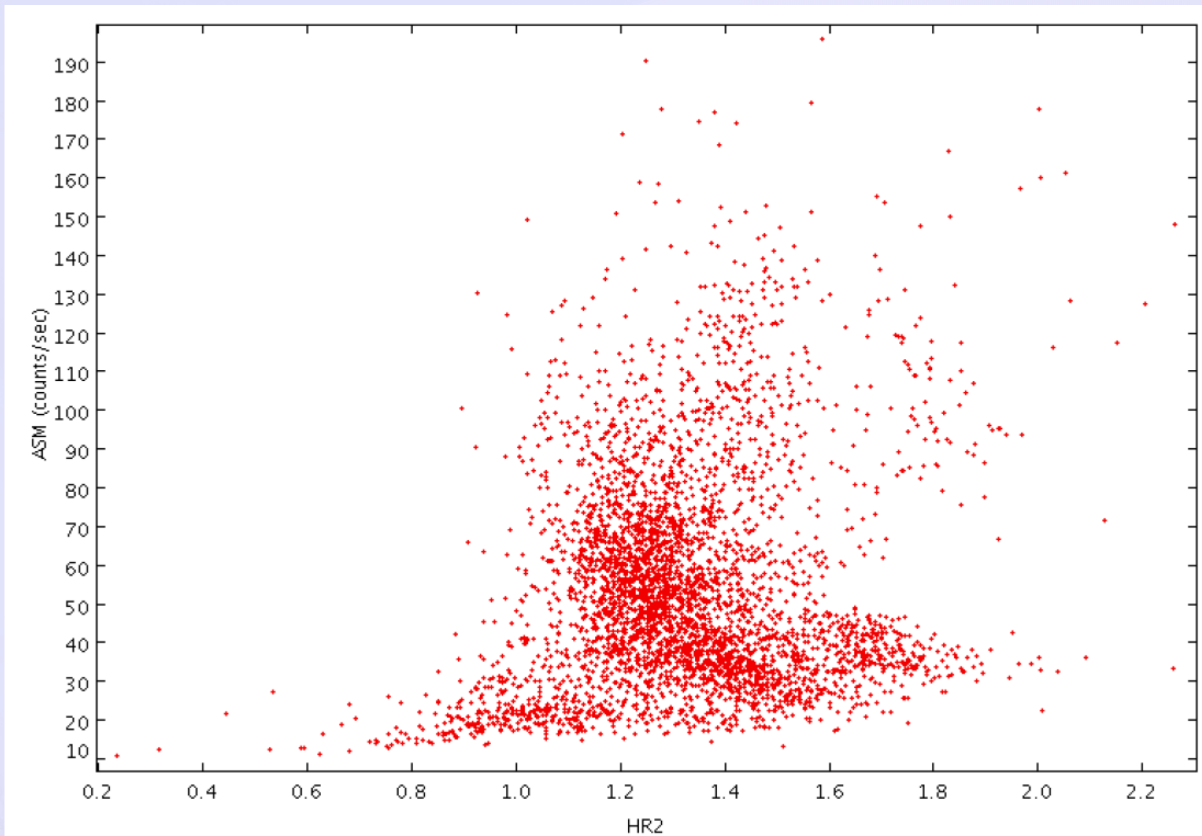
Rushton et al. (2007)



Selecting data in the “plateau” or low/hard state

- Hardness Intensity Diagram (HID)

X-ray intensity (1.5-12 keV)

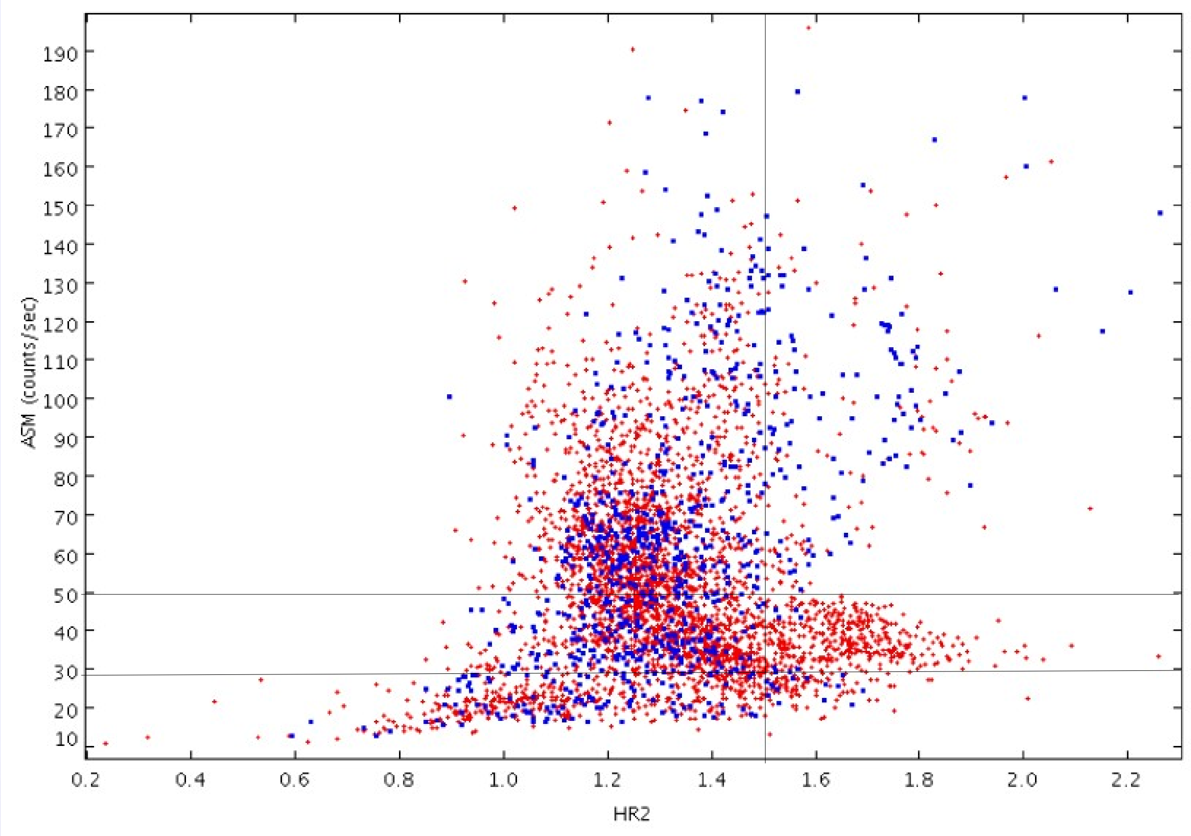


Hardness ratio (5-12 keV/1.5-2 keV)

Selecting data in the "plateau" or low/hard state

- Persistent radio emission
- ASM rates of 30-50 c/s
- HR2 of greater than >1.5

X-ray intensity (1.5-12 keV)

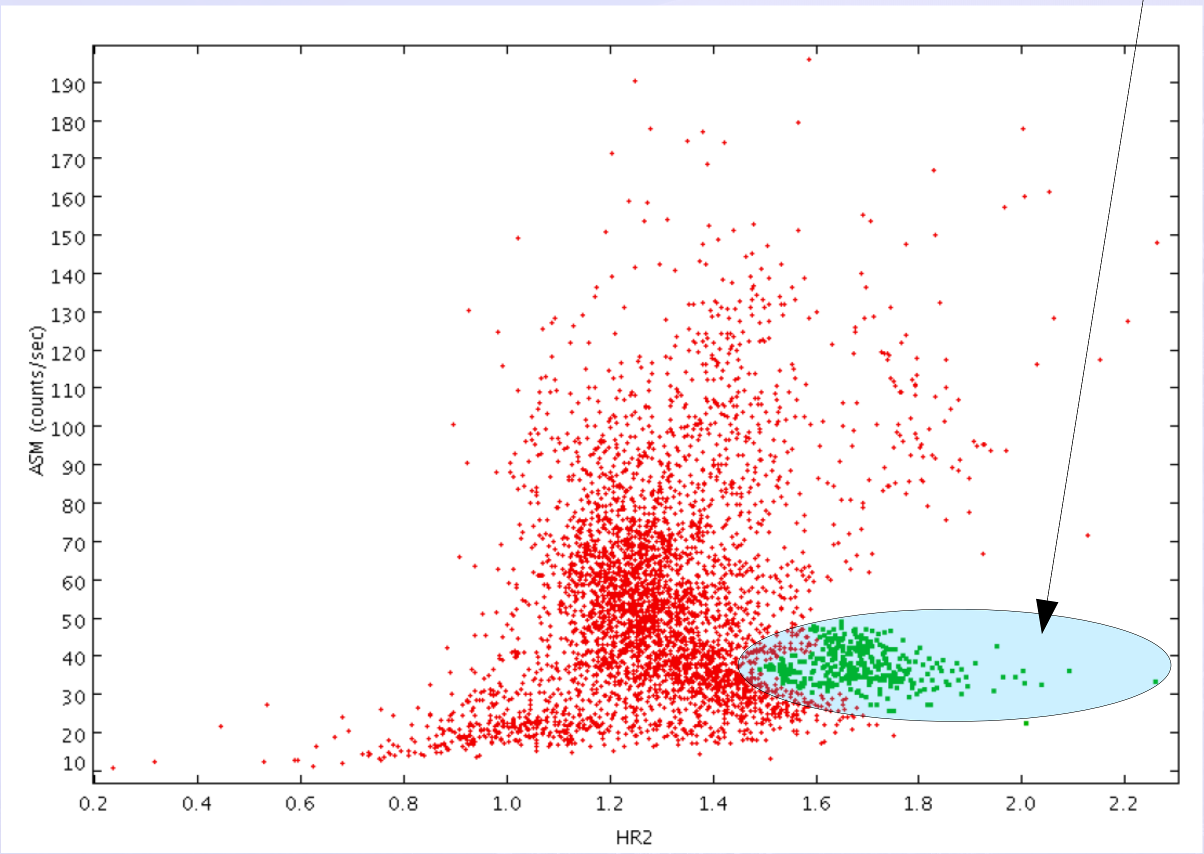


Hardness ratio (5-12 keV/1.5-2 keV)

Selecting data in the "plateau" or low/hard state

Data from the compact jet

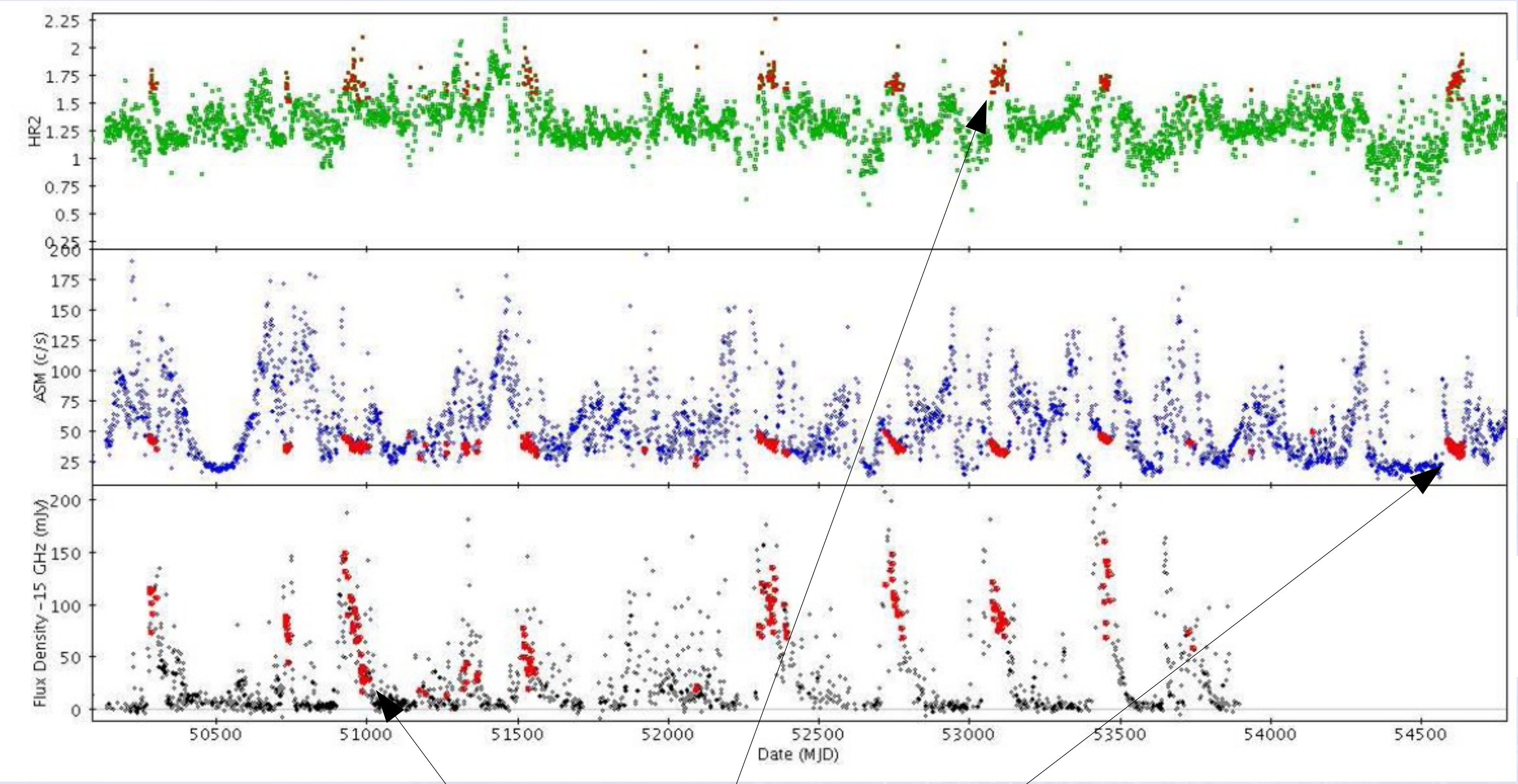
X-ray intensity (1.5-12 keV)



Hardness ratio (5-12 keV/1.5-2 keV)

Selecting data in the "plateau" or low/hard state

Between Jan 1996 and May 2006



RXTE-ASM (Hardness ratio)

RXTE-ASM (2-12 keV)

Ryle Telescope (15 GHz)

Selected *red* points are dominated by the "compact jet"

Mean event rate of the "plateau" or low/hard state

Between Jan 1996 and May 2006

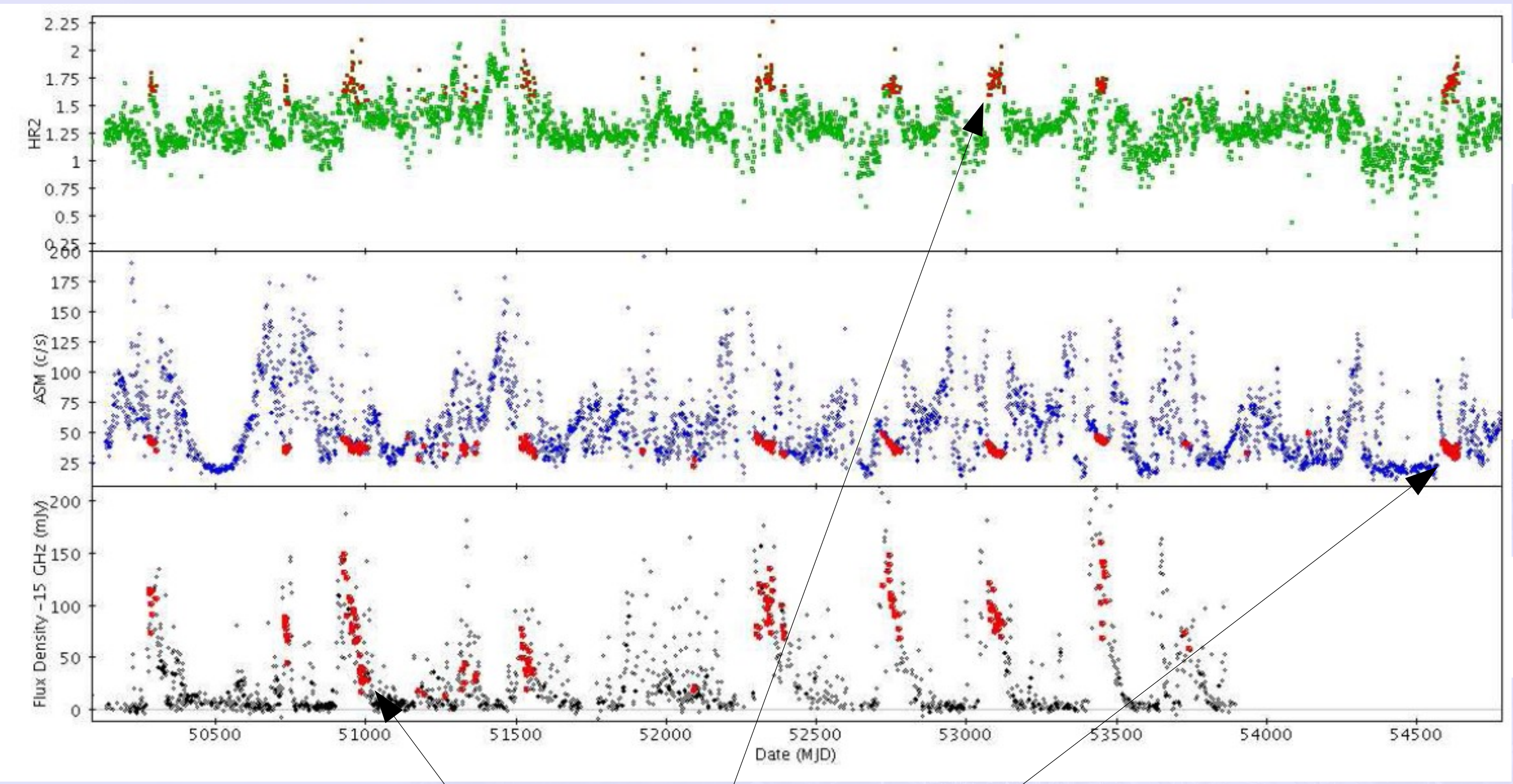
Start date (MJD)	End date (MJD)	Change in X-rays[†] (counts/second)	Change in radio[‡] (mJy)	Duration (Days)
50286	50297	$42 \rightarrow 40$	$110 \rightarrow 100$	11
50732	50736	$36 \rightarrow 33$	$94 \rightarrow 87$	4
50926	50989	$45 \rightarrow 34$	$154 \rightarrow 31$	63
51522	51546	$39 \rightarrow 33$	$78 \rightarrow 50$	24
52315	52354	$43 \rightarrow 36$	$122 \rightarrow 73$	41
52729	52783	$46 \rightarrow 33$	$163 \rightarrow 68$	54
53077	53116	$39 \rightarrow 31$	$122 \rightarrow 70$	39
53416	53466	$52 \rightarrow 42$	$197 \rightarrow 112$	50

- Typical duration: few to ~ 60 days

- Mean event rate 0.8 yr^{-1}

Selecting data in the “plateau” or low/hard state

Between Jan 1996 and May 2006



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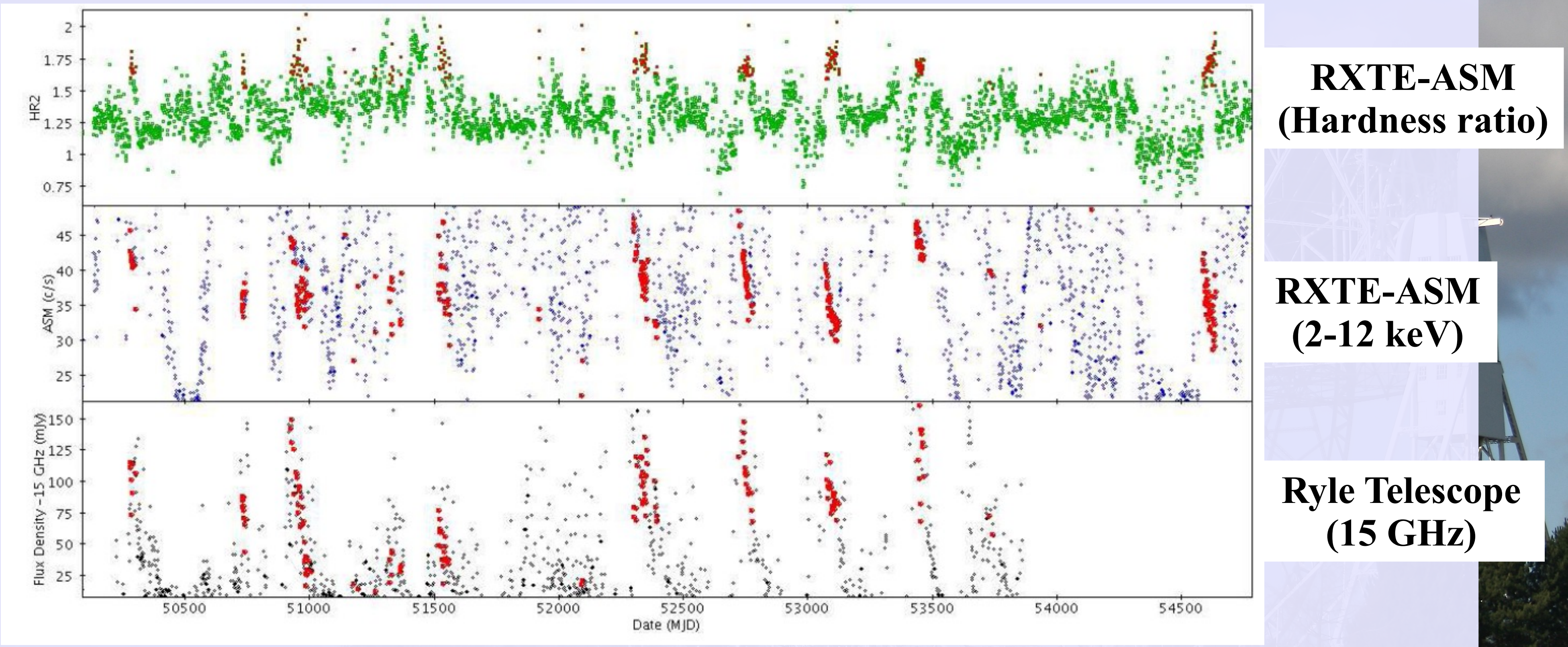
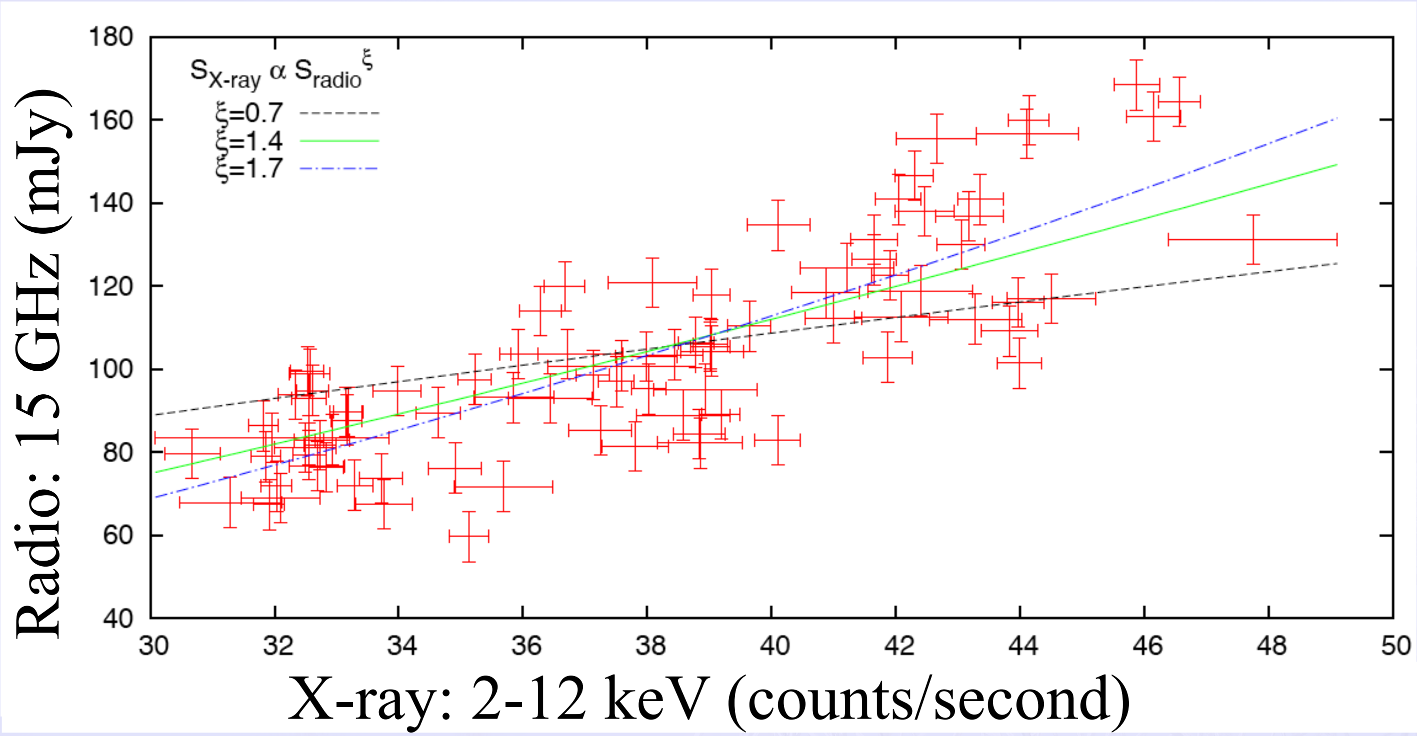


- Y-axis re-scaled
- A close relationship between radio and X-ray emission *in this state*

Radio/X-ray correlation



Power law relationship: $S_{\mathrm{X-ray}} \propto S_{\mathrm{radio}}^{\xi}$

Best fit = $\xi \sim 1.7$

The inflow/outflow relationship

- The X-ray and radio emission is related to the inflow-outflow mechanism
- The radio emission comes from the compact jet
- The bolometric (X-ray) luminosity might be related to the accretion disk

Outflow from the compact jet

- The radio luminosity is related to the power of the jet $L_{\rm Radio} \propto Q_{\rm jet}^{17/12}$ Blandford & Konigl (1979)

- *Assume* the jet forms a linear inter-dependency with the mass accretion rate $Q_{\rm jet} = q\dot{m}c^2$ Falcke & Biermann (1995)

- We therefore can use the compact jet to scale the **mass accretion rate**

$$\dot{m} = \dot{m}_0 \left(\frac{L_{\rm Radio}}{L_{\rm Radio,0}} \right)^{12/17} \quad (1)$$

Radiative efficiency of the inflow

- A geometrically thin disk can efficiently radiate heat
  - This has successfully described thermal emission
  - Bolometric luminosity is linearly proportional to mass accretion rate

$$L_X \propto \dot{m}_{\rm in} \quad (2)$$

Shakura & Sunyaev (1973)

- Alternative accretion models have been used to describe low/hard state in XRBs
  - Geometrically thick disks
  - Heat energy is lost through *advection dominated flows*
  - Mechanism is radiatively inefficient

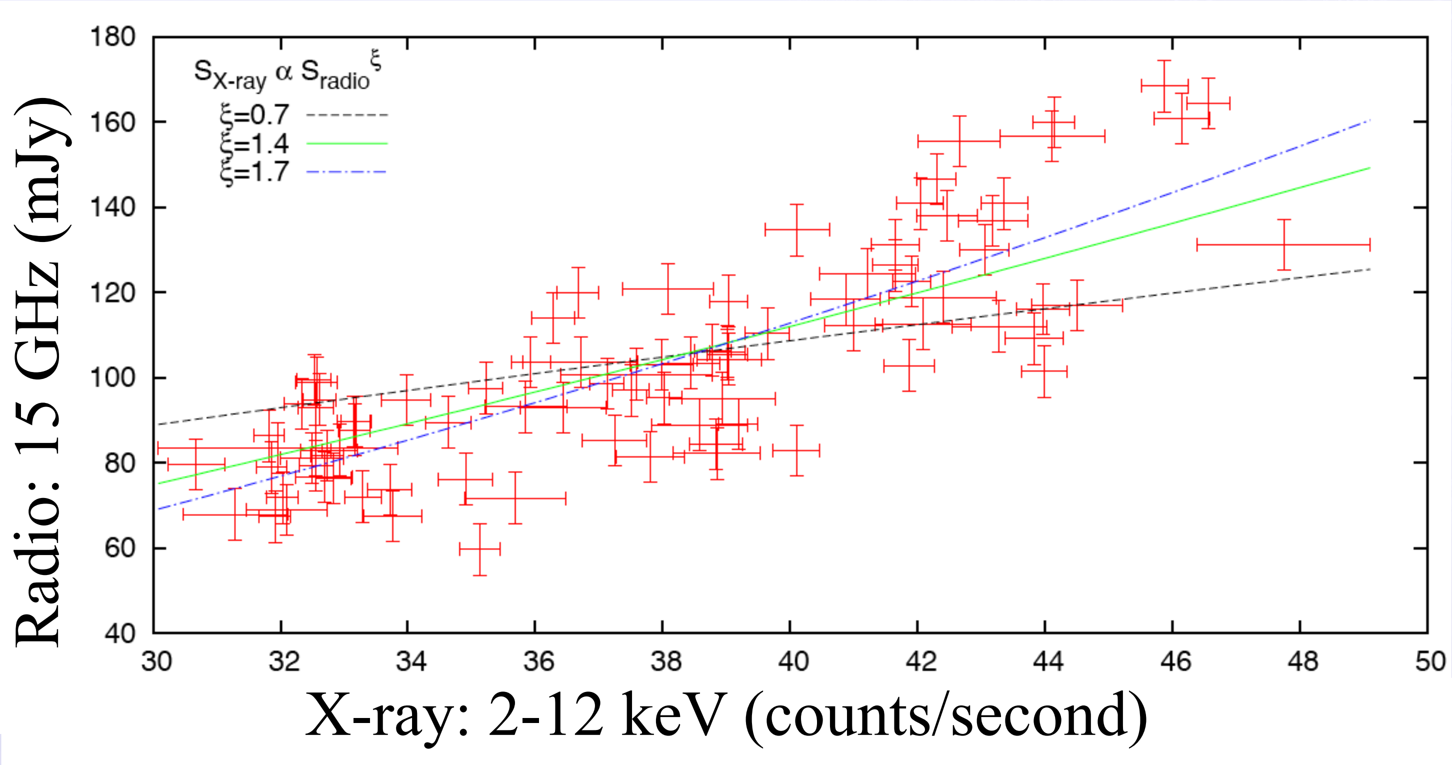
$$L_{\rm X-ray} \propto \dot{m}_{\rm in}^2 \quad (3)$$

Rees et al. (1982); Abramowicz et al. (1995)

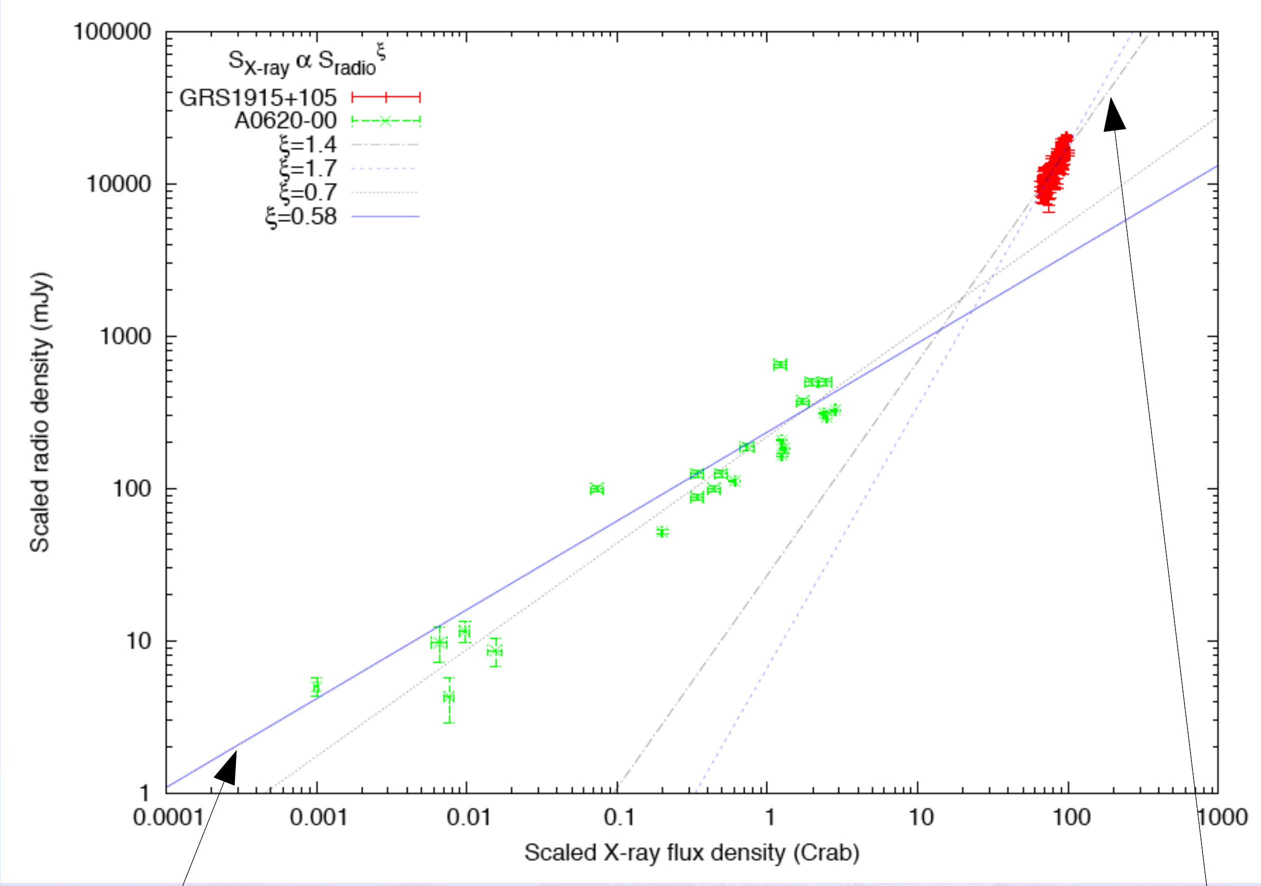
Radiative efficiency of the inflow

(1) + (2) ▶ Radiatively efficient $L_{\rm rad} \propto L_{\rm X}^{1.4}$

(1) + (3) ▶ Radiatively in-efficient $L_{\rm rad} \propto L_{\rm X}^{0.7}$



Scale and compared to other XRBs



Green: A0620-00 radiatively inefficient? (Gallo et al. 2006)

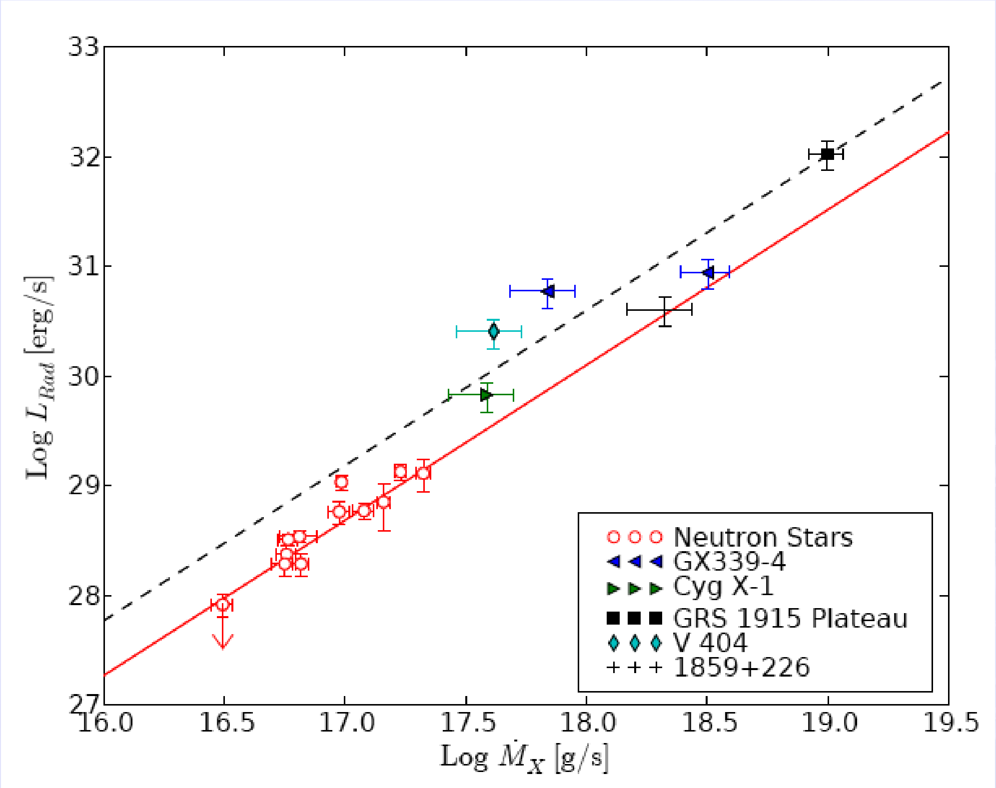
$\xi \sim 0.7$

Red: GRS 1915+105 radiatively efficient?

$\xi \sim 1.4$

Estimating the mass accretion rate

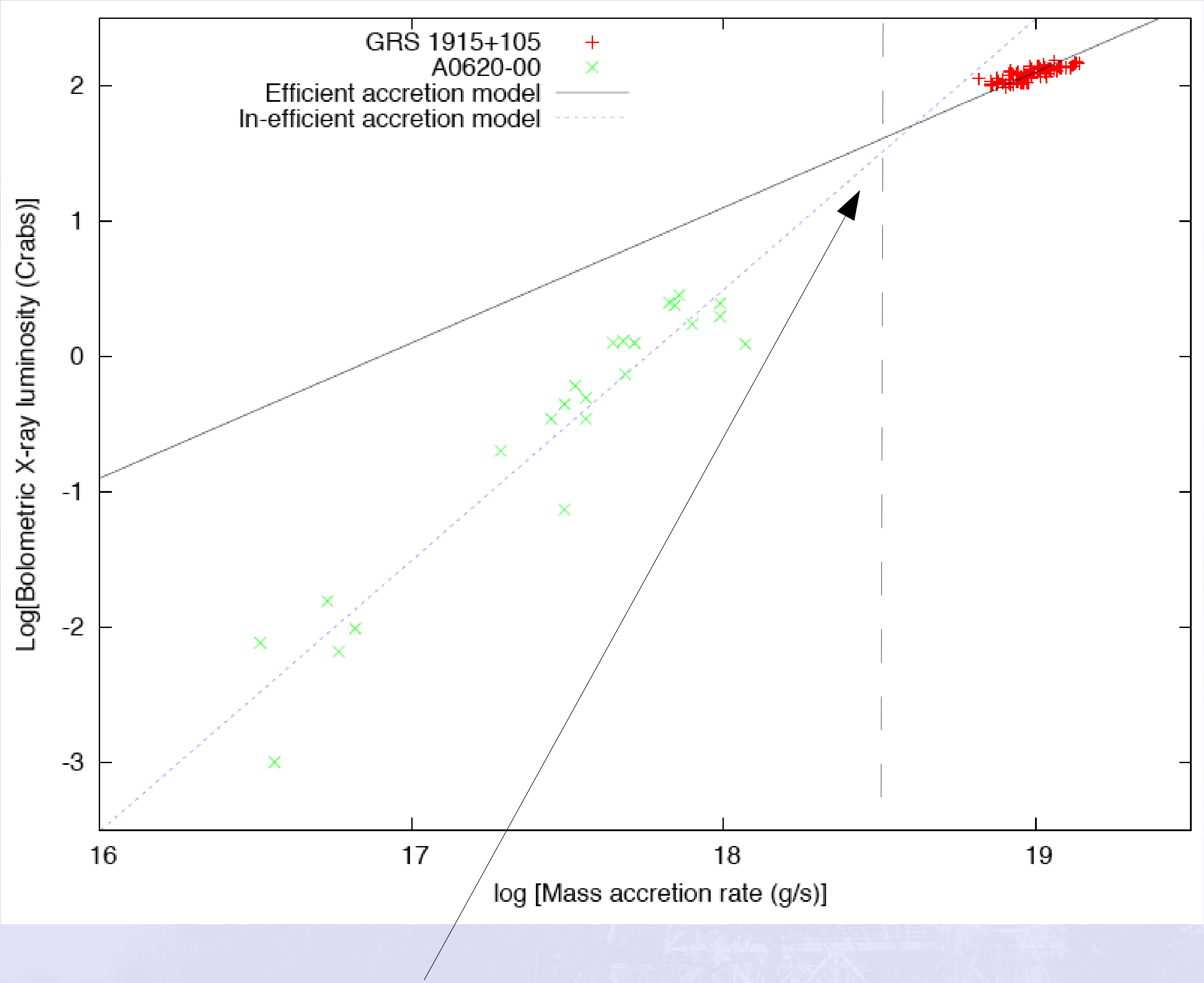
- Measure the accretion before a transition to the low/hard state
- This estimates the mass accretion rate for a given radio luminosity
- The variations in the compact jet can then be used as a tracer for the accretion rate



Körding et al. (2006)

$$\dot{m}_0^{\mathrm{NS}} = 7.7 \times 10^{17}\ \mathrm{g/s}, \qquad \dot{m}_0^{\mathrm{BH}} = 4.0 \times 10^{17}\ \mathrm{g/s}$$

Estimating the mass accretion rate



Turnover ~ $10^{18.5}$ g/s ~ 0.1 – 1% L_{edd}

Advection Dominated Inflow-Outflow Solution (ADIOS)

During the low/hard state:

- *Assume* the overall accretion rate does not change significantly during outburst
- The observed mass accretion rate varies with the size the advection zone
- Thus the X-ray luminosity is proportion to the thick disk and the outflow rate

$$\dot{m} \propto r^p,$$

where $0 \leq p \leq 1$:

p=0 ADAF solution (i.e. No wind/jet dependence on r)

p=1 Full ADIOS solution.

Blandford & Begelman (1999, 2004)

Conclusions for GRS 1915

- We find a direct relationship between the X-rays and radio in the compact jet state (i.e. plateau state)
- The relationship scales with a power law fit of $\xi \sim 1.7$
  - much higher than an inefficient flow ($\xi \sim 0.7$)
- A turnover in the radiative efficiency might be observed
- We need more high-resolution observation
  - separate emission from superluminal knots and compact jets

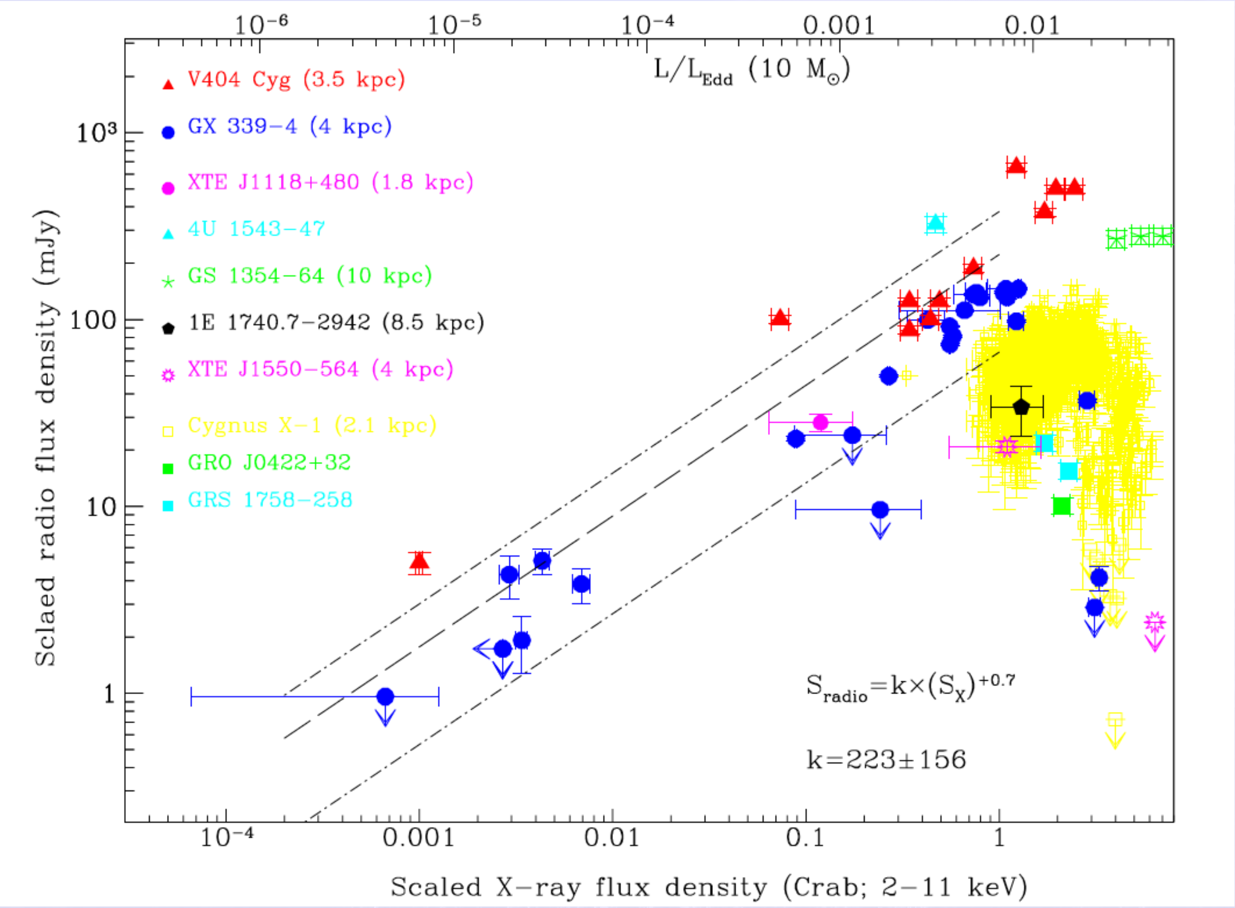
Outline

- Background to GRS 1915+105
- High-resolution and monitoring results
- Radio/X-ray correlations in the low/hard or "plateau" state
- Models of the inflow/outflow relationship

Summary

- Radio interferometry calibration and data reduction:
  - MERLIN
  - VLBA
  - EVN
- Software development for calibration and modeling of radio astronomy:
  - Python scripting of MERLIN calibration.
  - Lightcurve extraction.
  - Polarimetry calibration.
- The application of e-Science:
  - Commissioning of the e-EVN.
  - Network testing for radio astronomy.
  - Investigation into internet protocols.
- Experienced in:
  - C/C++
  - Python

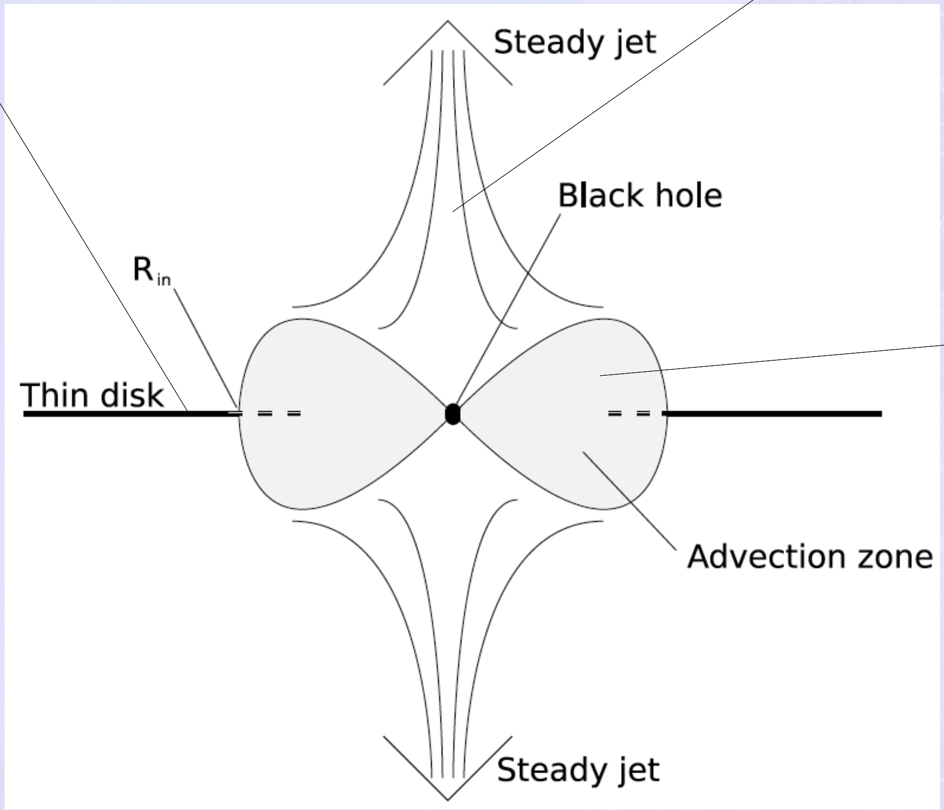
Universal XRB relationship



The X-ray binary emission models

Thermal emission (soft X-rays)

Synchrotron emission (radio)



Non-thermal emission (hard X-rays)