Predicting Jets in Cygnus X-2

Monika Balucinska-Church

X-ray Binaries Group,
School of Physics and Astronomy, University of Birmingham, U.K.

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Cygnus X-2

- **Luminous neutron star LMXB:**
  L > 10^{38} erg s^{-1} (> L_{Edd})

- **Z-track source :**
  Cyg X-2, GX 5-1, GX 340+0,
  Sco X-1, GX 349+2, GX 17+2 and LMC X-2
  Transient XTE J1701-462

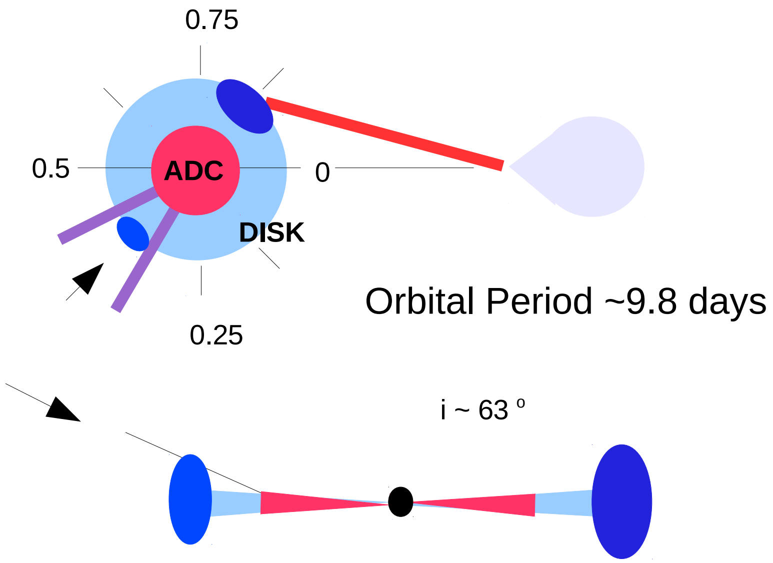
- **Long-term variability:** non-periodic: 50 – 90 days

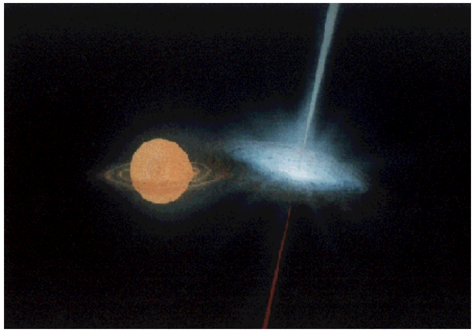
- **Radio emission shows relativistic jets:**
  observed only in certain states of the source

- Need observations of > 2 days: X-ray + radio –
  For movement between states – jets may not be seen

- Can we find a trigger that jet launch imminent

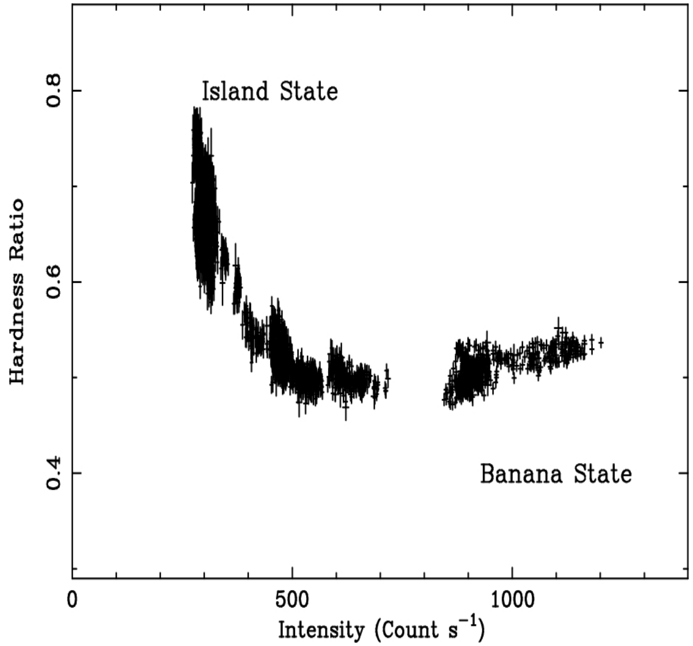
- Monitor instruments (RXTE ASM, MAXI) can provide this



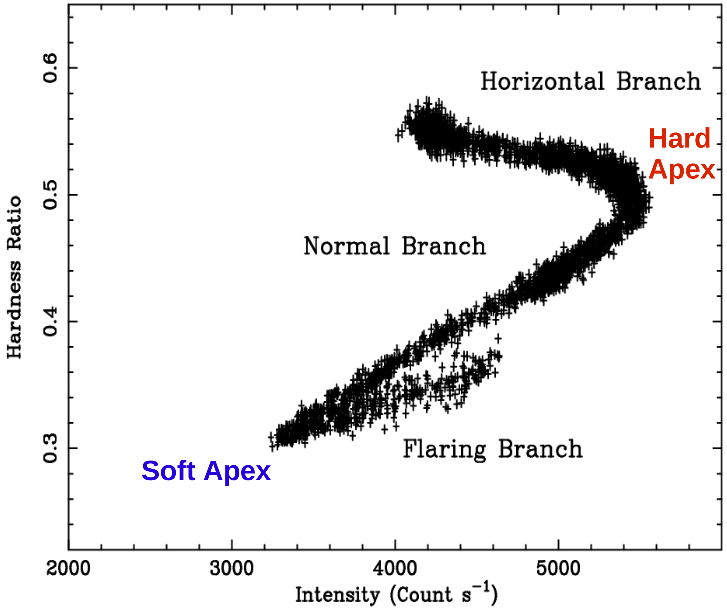


Low Mass X-ray Binaries

Atoll L < 10^{38} erg s^{-1}



Z-track L > 10^{38} erg s^{-1}



Nature of Island/ Banana states have not been understood

Nature of HB, NB and FB have not been understood

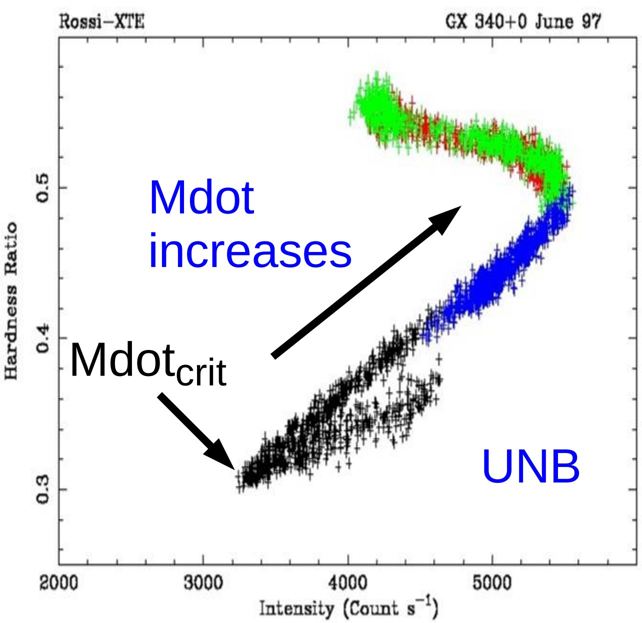
Extended ADC model for Z-sources (*)

- Based on realization that **accretion disk corona is *extended* in LMXB**
  (dipping studies and work of Schulz on line emission of the ADC)

- Investigations of the Z-sources: Cyg X-2, GX 340+0, GX 5-1
  Sco X-1, GX 17+2 GX 349+2
  based on the extended ADC
  provide a convincing physical explanation

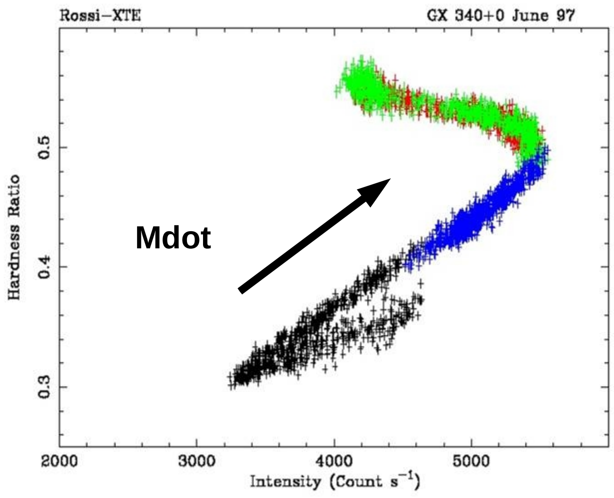
- Mdot increases on NB (decreases on HB)
  Radiation pressure launches jet

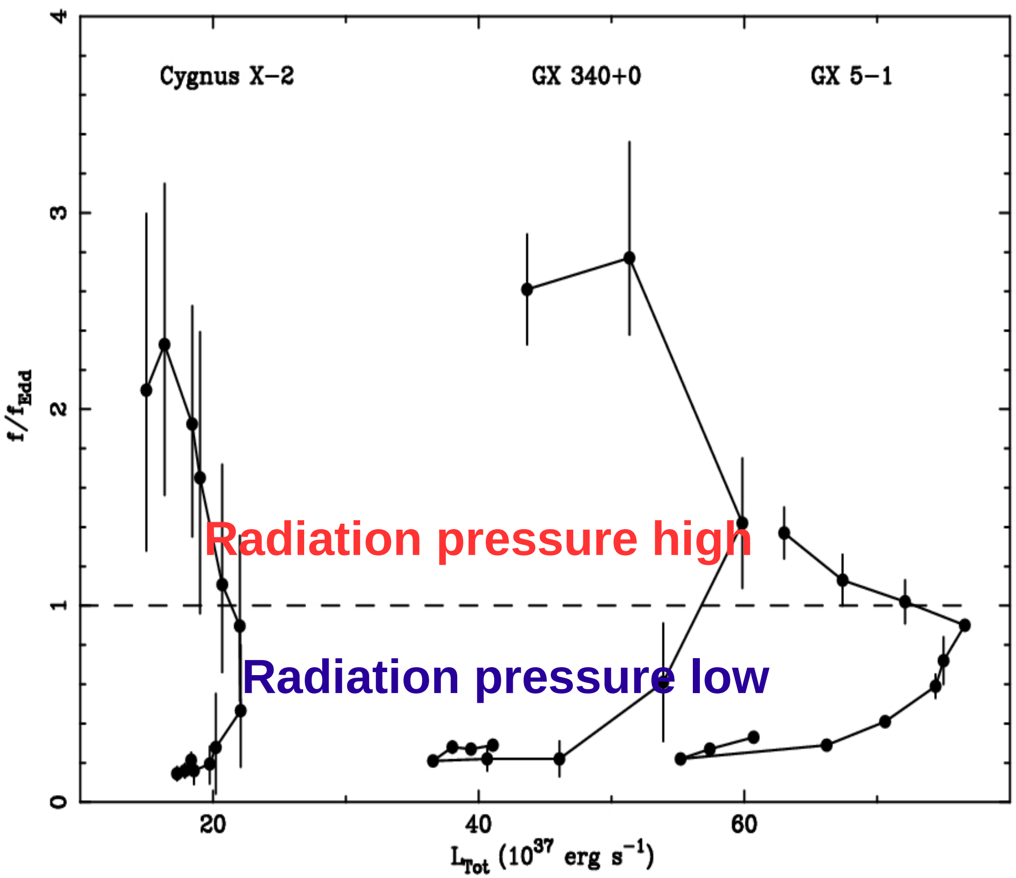
- Flaring Branch = **Unstable Nuclear Burning**
  Mdot > $\mathrm{Mdot_{crit}}$ --- Stable burning
  Mdot < $\mathrm{Mdot_{crit}}$ --- Unstable burning



(*) Church et al. (2006); Balucinska-Church et al. (2010)

High radiation pressure launches jet



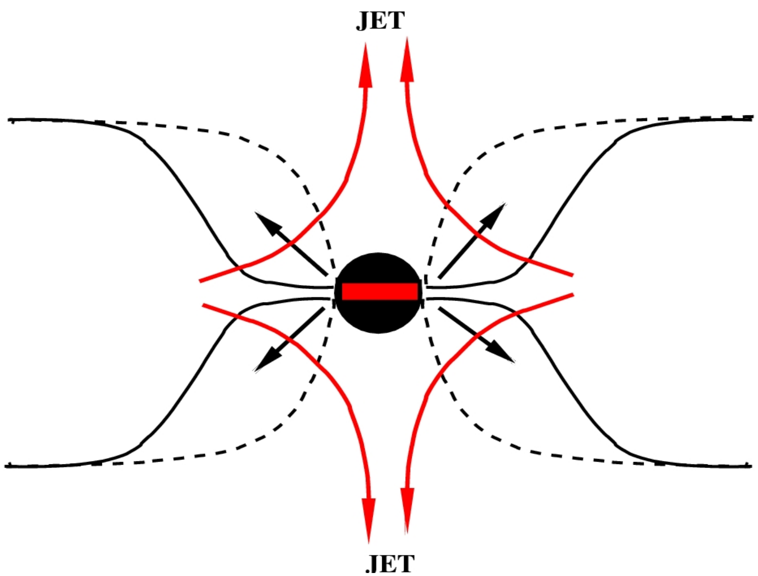


- **Normal Branch**:
  kT_{BB} increases
  as Mdot increases

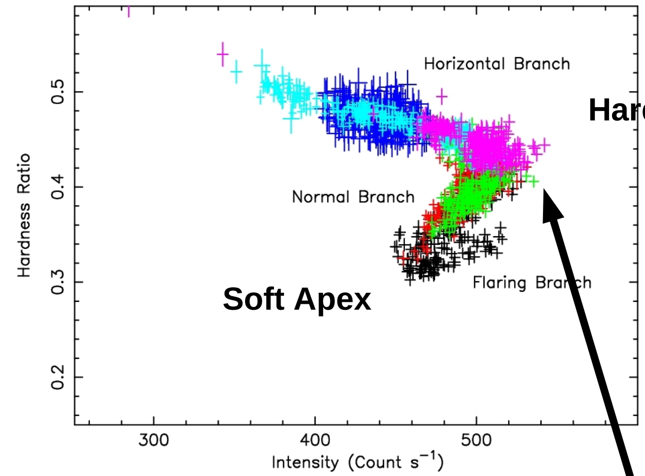
- **Jets:**
  large increase in T^4 =>
  high radiation pressure →
  disk disruption → jet

Jet formation

Hardness -v- intensity



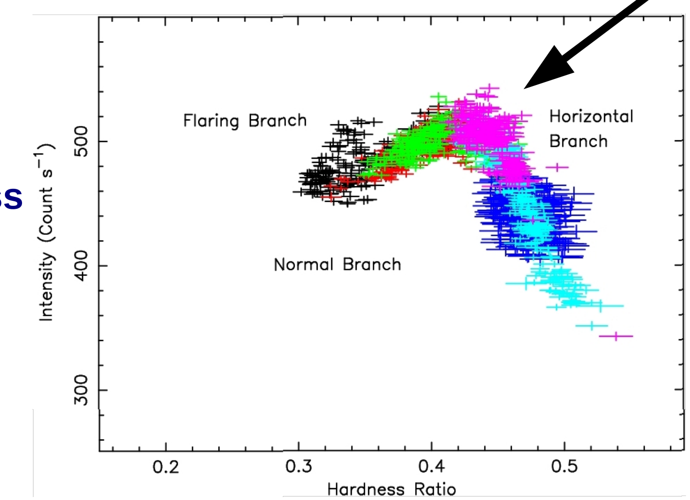
Accretion flow



Hard Apex

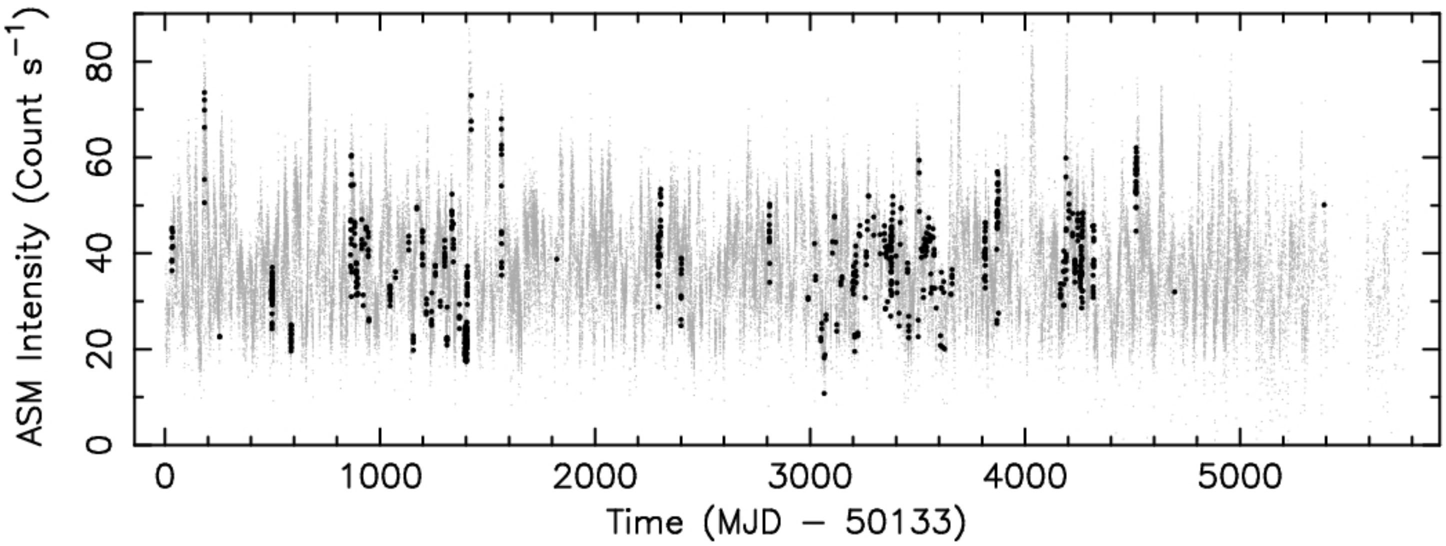
Jet launched

BH version: intensity -v- hardness



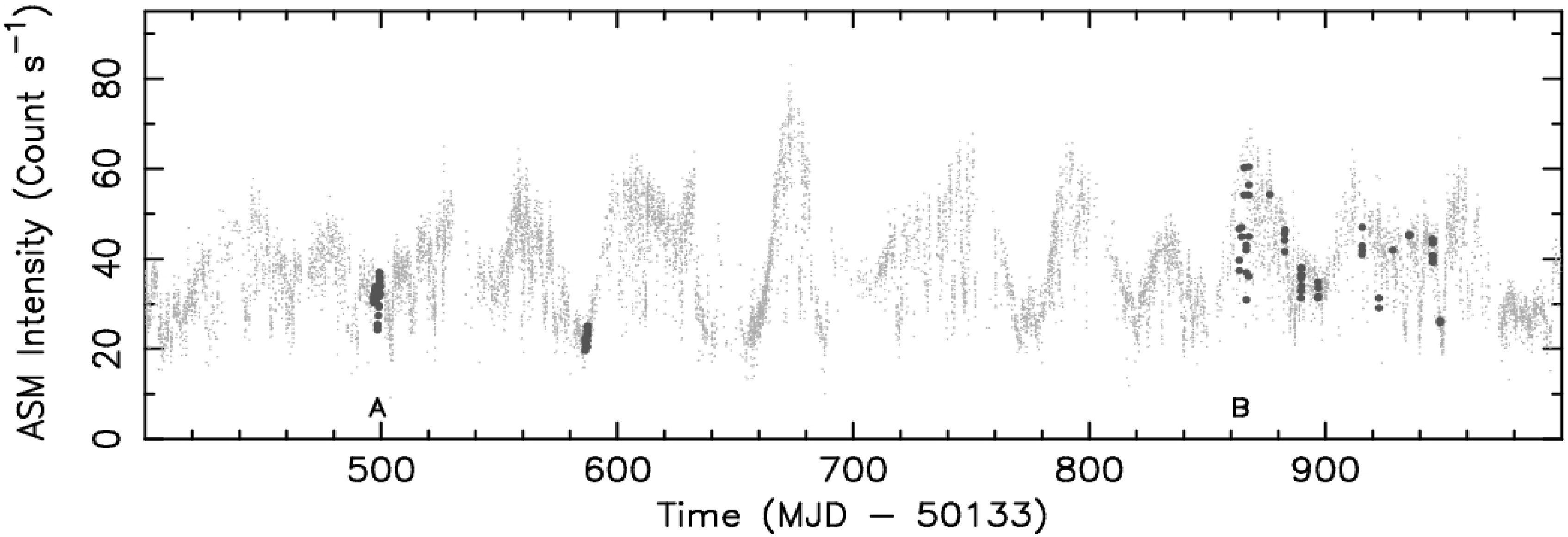
Cygnus X-2 in the *RXTE* ASM

- 16 years of data (February 1996 – December 2011)
- We have superimposed all pointed data on the ASM data
- Aim is to recognize the 3 states of the Z-track
- In particular, the state that produces radio jets



- 8% of ASM data simultaneous with RXTE/PCA pointed observations
- Duration of the XTE pointed observations: 50 days

Cygnus X-2: Longterm variability



Not obviously periodic: 40 – 90 days

warped/precessing disk   ----   (Clarkson, Charles, Coe & Laycock 2003a,b)
(Charles et al. 2008; Kotze & Charles 2012)

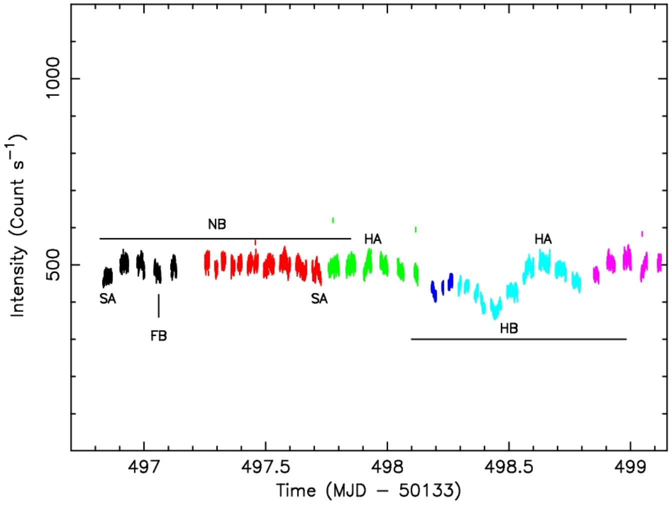
may cause variation in emitting area
may modify disk temperature, viscosity changing Mdot through disk

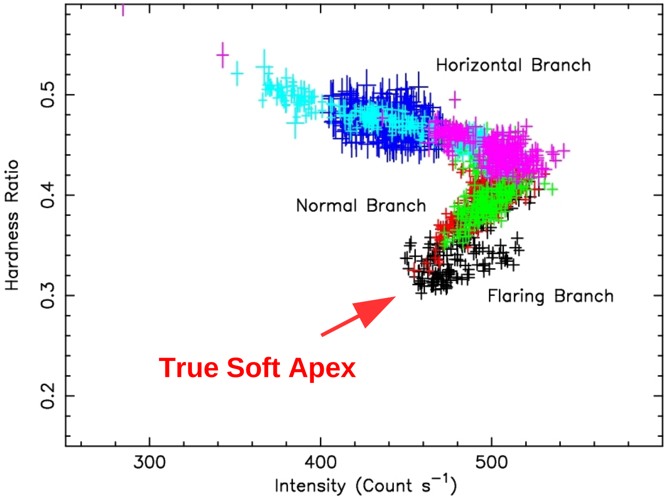
Power spectrum = Porb + harmonics   (Boyd & Smale 2004)

Dark points: ASM data simultaneous with the pointed observations

Cygnus X-2: RXTE/PCA Pointed Data

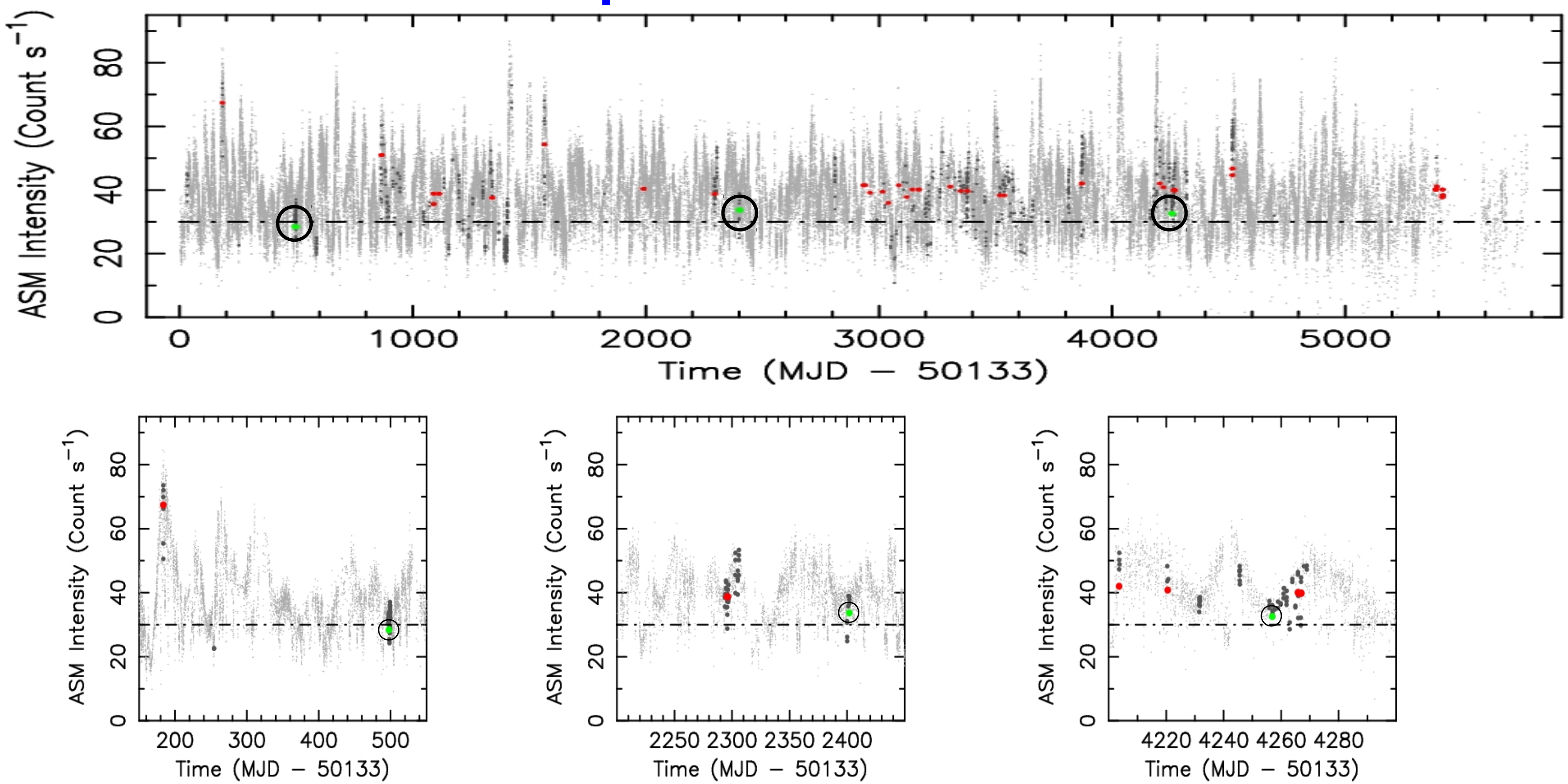
A





Case A: Complete Z-track

The Soft Apex in the RXTE/ASM



Only 3 points **(green)** at real Soft Apex (I ~30 count s^{-1})

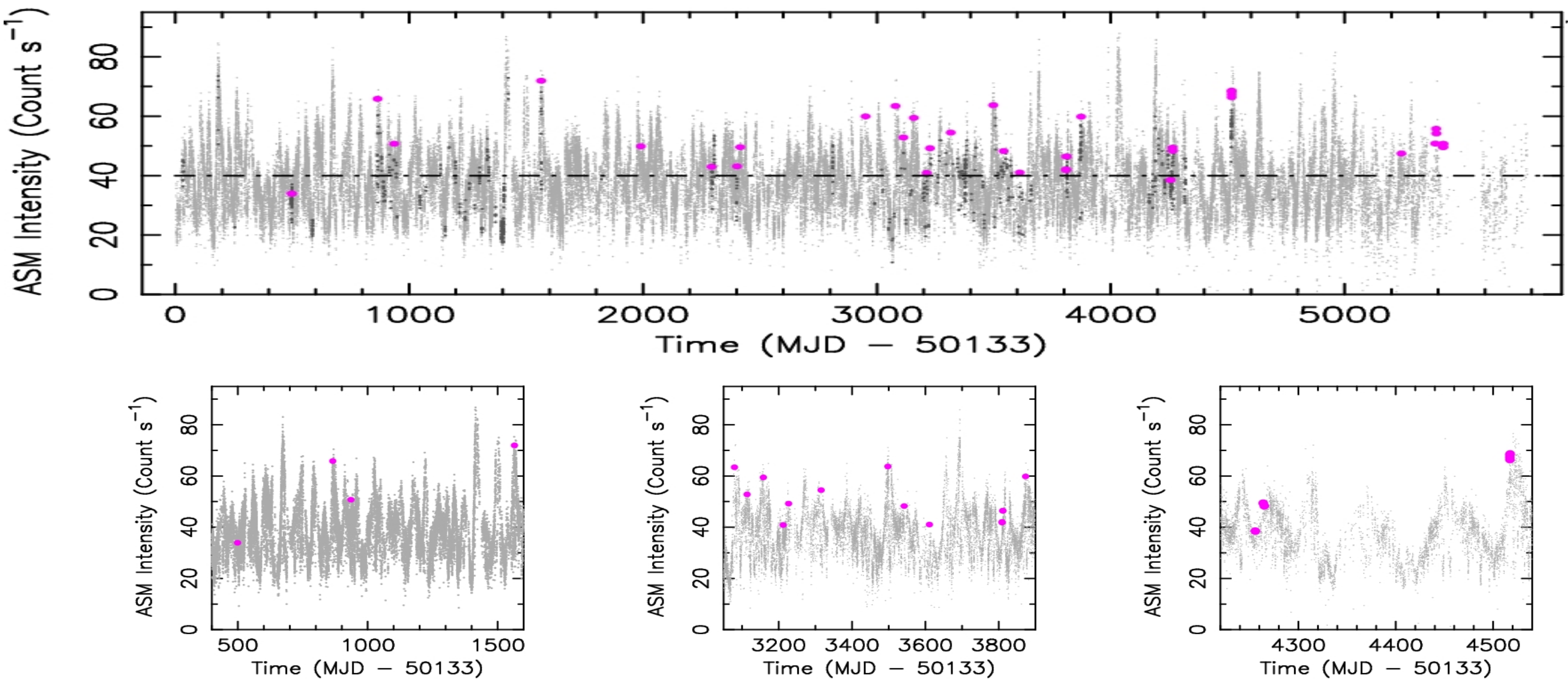
Other points **(red)** - in many obs. the Soft Apex never reached (I > 35 count s^{-1})

Reason: **Mdot rarely falls to Mdot$_{crit}$**

Only at minima of long-term variability

This clearly suggests that long-term variability is due to change of Mdot

The Hard Apex in the RXTE/ASM



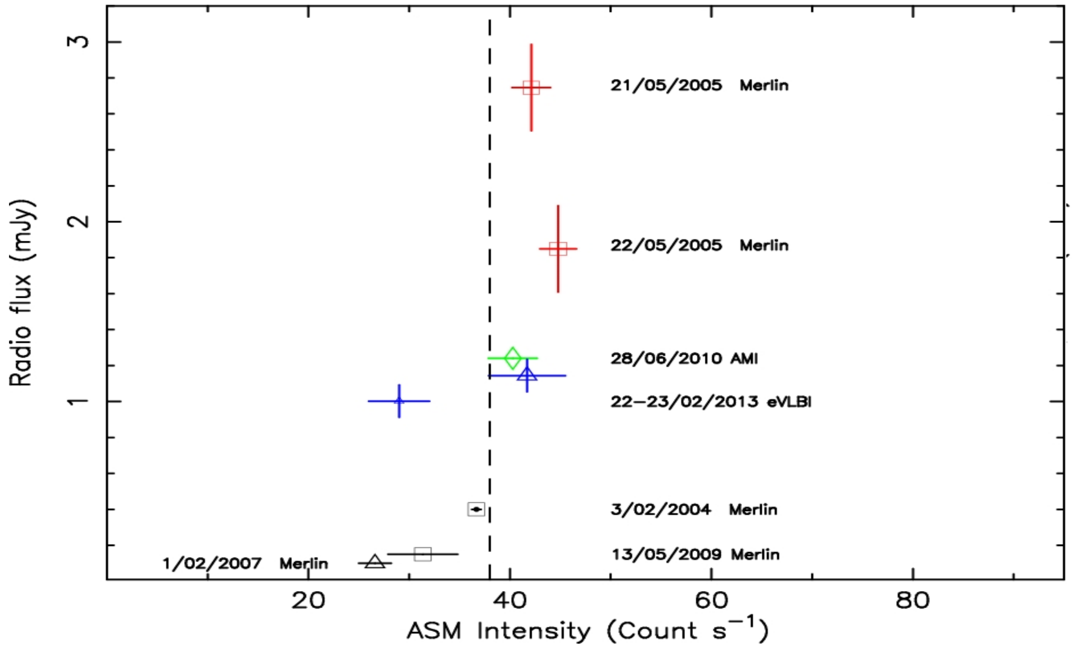
Majority of Hard Apex points: **ASM intensity > 40 count s^{-1}**

Width of ASM track = Z-track motion on NB: 20 – 45% in intensity

Superimposed on long-term variations

The Hard Apex can be at various count rates depending on the level of the long-term variability

Cygnus -2: Radio detections in the RXTE era



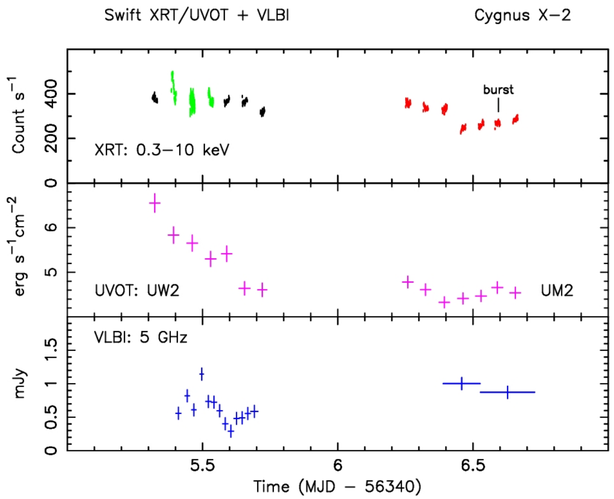
2013 – Only observation to catch switch-on of jets:
simultaneous X-ray (Swift) and eVLBI
Spencer, Rushton, Balucinska-Church, Paragi, Schulz, Wilms, Pooley, Church; MNRAS (2013)

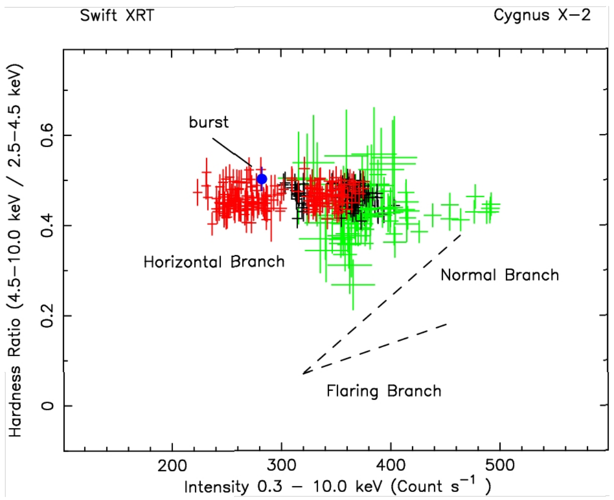
2009 – simultaneous X-ray (XMM) and eVLBI; only radio flux upper limit
Balucinska-Church, Schulz, Wilms, Gibiec, Hanke, Spencer, Rushton, Church; A&A (2011)

2005 – simultaneous X-ray (RXTE) and Merlin observations (Rushton PhD)

Simultanous X-ray/radio observations of Cygnus X-2: *Swift* and *European VLBI* network

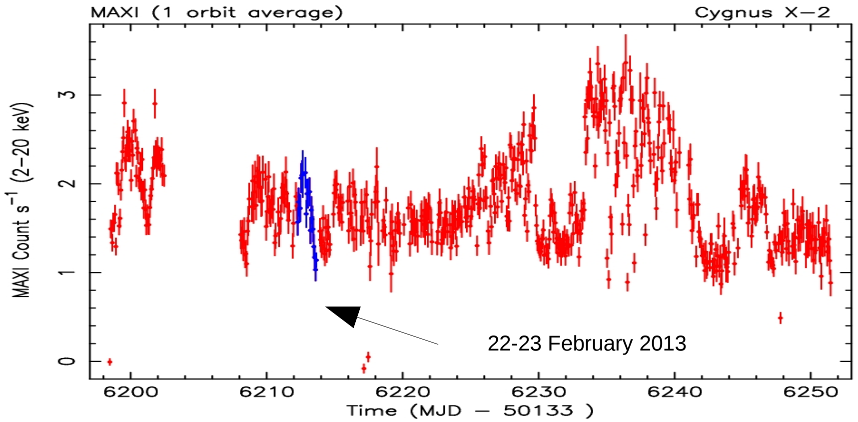
(Spencer, Rushton, Balucinska-Church, Paragi, Schulz, Wilms, Pooley, Church; MNRAS (2013)





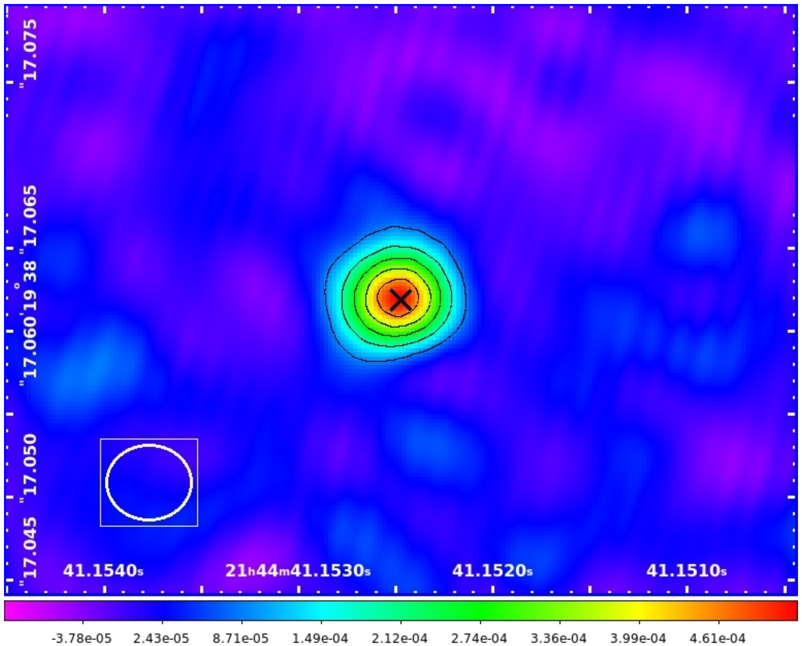
Observations: 22 - 23 February 2013 (Hard Apex / Horizontal Branch)

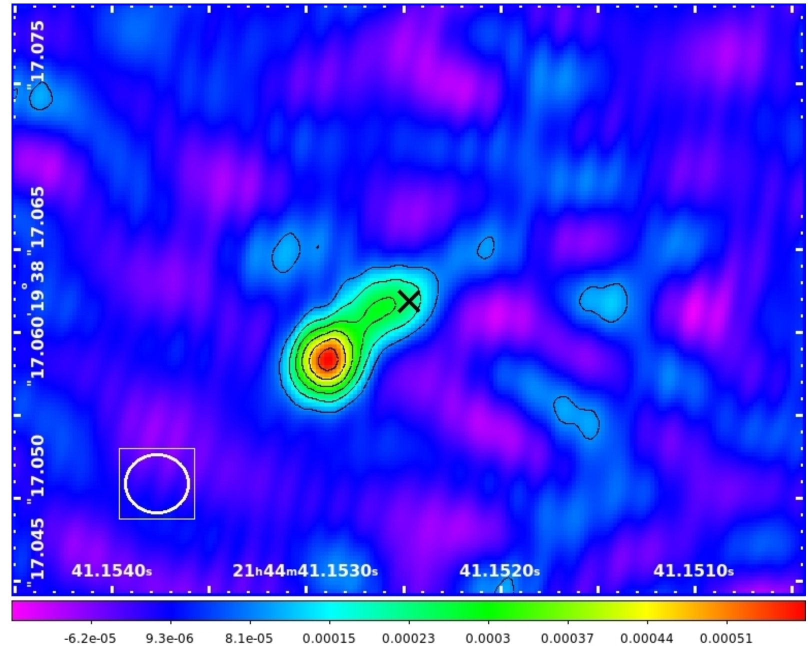
X-ray luminosity (1 - 30 keV): 1.3 – 1.7 · 10^{38} erg/s (9 kpc)

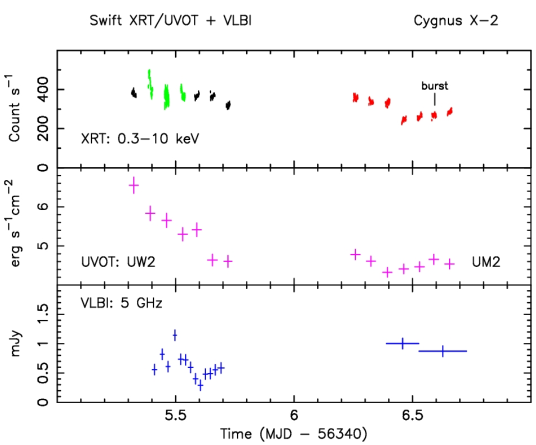


Simultanous X-ray/radio observations of Cygnus X-2: Swift and European VLBI network

Spencer, Rushton, Balucinska-Church, Paragi, Schulz, Wilms, Pooley, Church; MNRAS (2013)





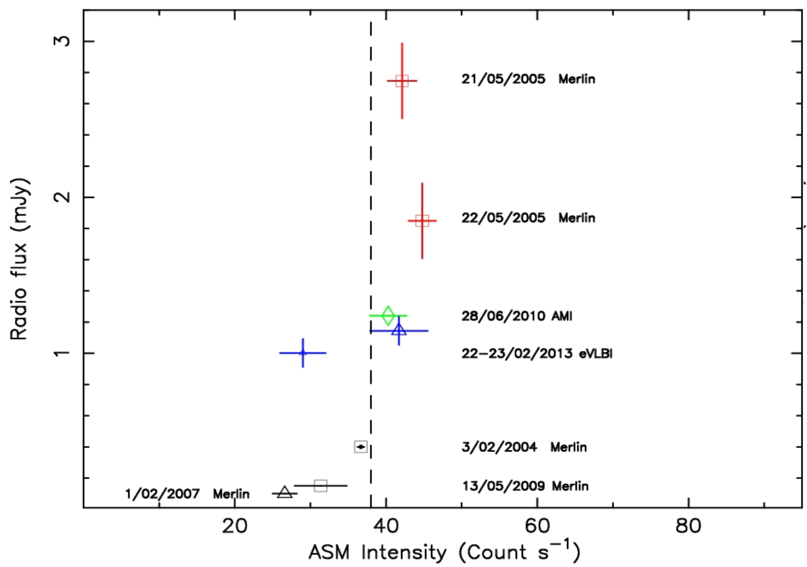


Peak flux density/rms:
22 Feb 2013: 523/20 microJy beam^{-1}
23 Feb 2013: 583/30 microJy beam^{-1}

23 Feb, 2013: Core – SE : ~ 5 mas

jet velocity v/c = 0.33 +/- 0.12
weak detection of a counter jet

Jet launching criterion

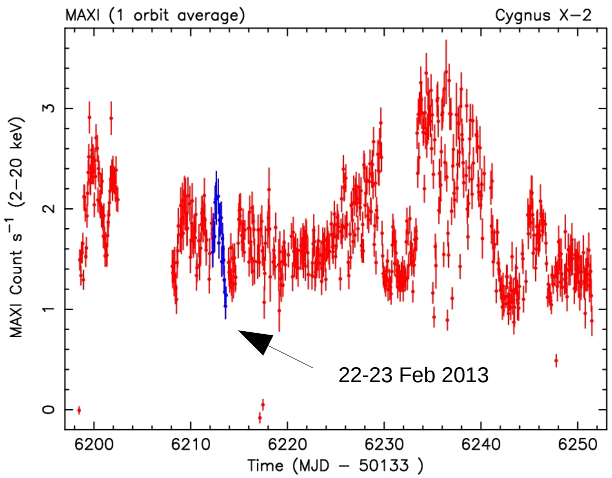


Jets are seen at > 40 count s^{-1} in the ASM

i.e. when Cygnus X-2 gets to the Hard Apex

by ascending the NB of the Z-track

MAXI for jet launching ?



40 count s^{-1} in the RXTE ASM is equivalent to 1.8 count s^{-1} in MAXI

Thus low count statistics make jet prediction more difficult

However, the longterm variability can still be monitored to detect the periods of high luminosity

A Unified Model of LMXB

- We want to predict jets for ***more certain triggering*** of observations

- More important - ***to understand the physics of jet formation***

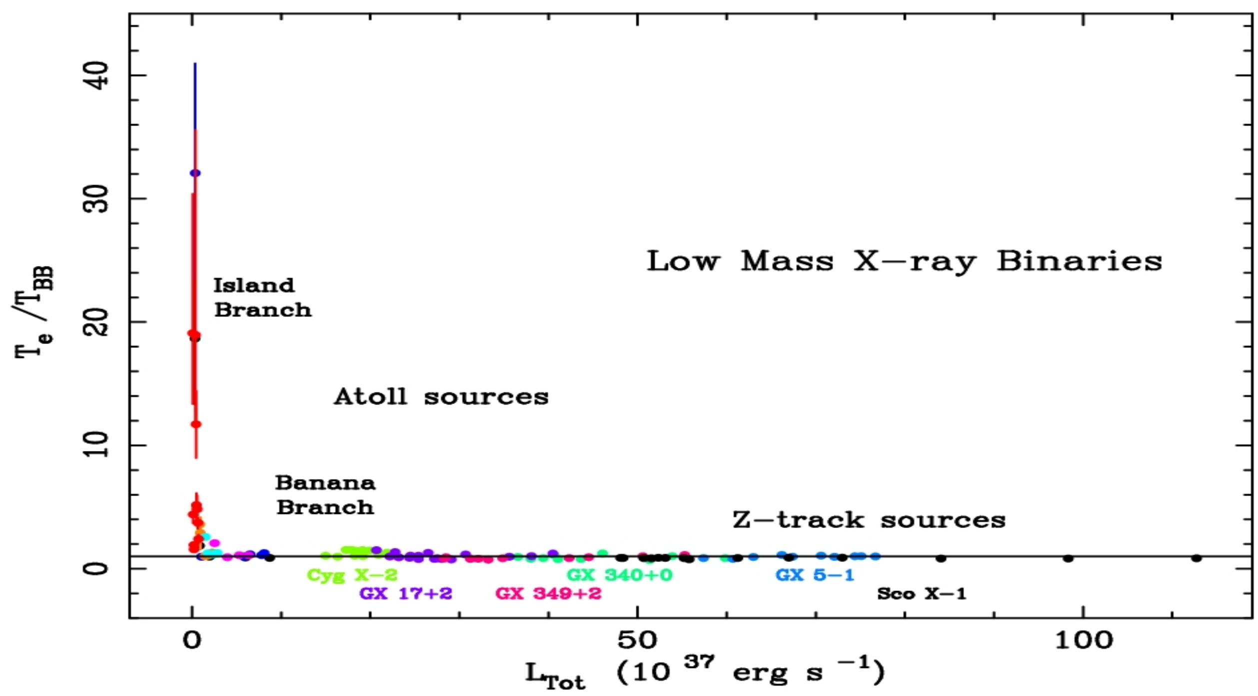
- We have a ***model of the Z-track sources predicting jet formation***

- We now have ***model of Island and Banana states in Atolls***
  predicting that jets may be seen in Atolls

- Combining these gives a ***Unified Model*** of LMXB (Church et al. 2014)

Unified Model of LMXB*

MNRAS **438**, 2784-2797 (2014)

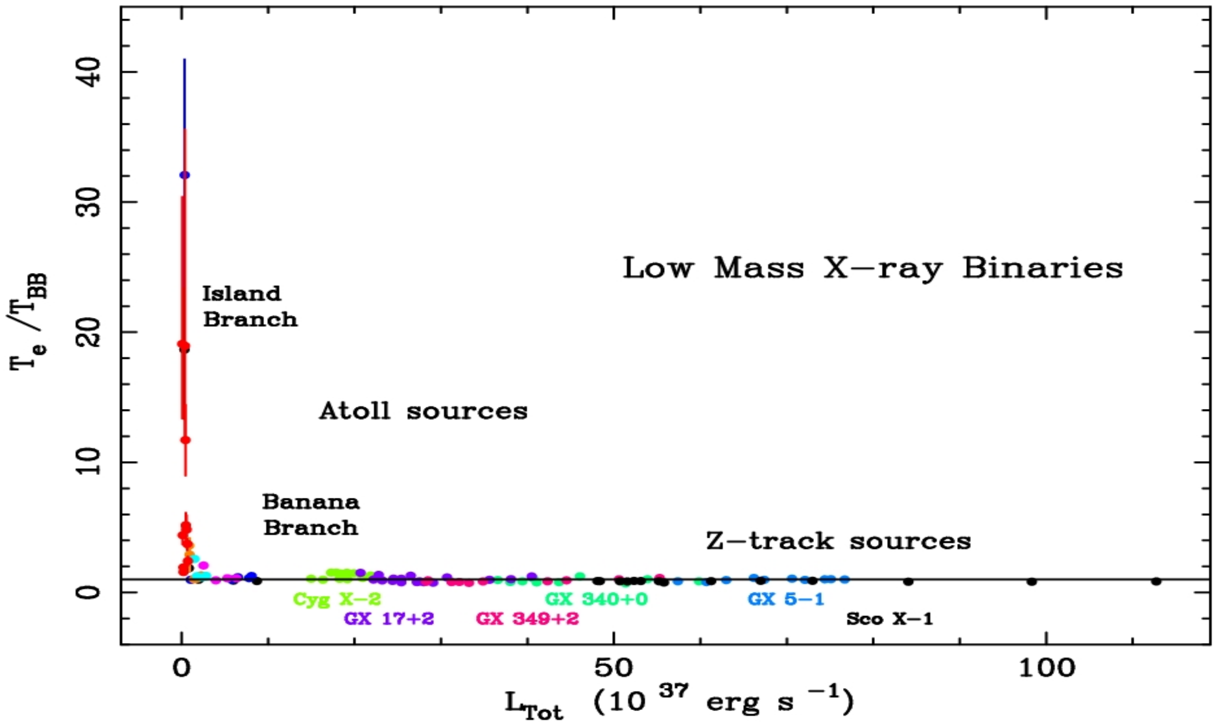


Thermal equilibrium:

electron temperature of Comptonizing region equals NS temperature for *all LMXB* with $L > 1 \cdot 10^{37}$ erg s^{-1}

* ***See Poster B01***

The Unified Model: Atoll sources



Banana State: the basic state of Atolls: L > 1 · 10 ^{37} erg s^{-1}
thermal equilibrium $kT_{NS} = kT_{ADC}$
motion on banana due to Mdot variations (like NB of Z-sources)

Island state: L < 1 · 10^{37} erg s^{-1}
thermal equlb lost: $kT_{ADC} >> kT_{NS}$
heating of ADC by unknown mechanism

Radiation pressure
measured values can be high
suggesting jet formation

The Unified Model

Atoll sources:

Banana State: basic state Mdot varies

Island State: ADC heated producing hard spectrum

Jets may also be formed by high radiation pressure

Z-track sources:

Normal Branch: Mdot increases as in Banana state

Flaring Branch: Unstable nuclear burning when

Mdot falls below critical value for Unstable Nuclear Burning on NS (as in Bildsten theory 1998)

Horizontal Branch: recovery after jet launch

Flaring Branch: not possible in Atolls – far from critical value

Island Branch: not possible in Z-sources as $kT_{ADC} = kT_{NS}$ always

CONCLUSIONS

- **ASM data or similar can be used to predict jet launching**
- **Jets are formed at the Hard Apex of the Z-track strongly suggesting that the high, measured radiation pressure launches the jets**
- **High radiation pressure under certain conditions in Atolls => jets**