MULTI-WAVELENGHTS STUDIES OF

# ACCRETION AND FEEDBACK IN X-RAY BINARIES

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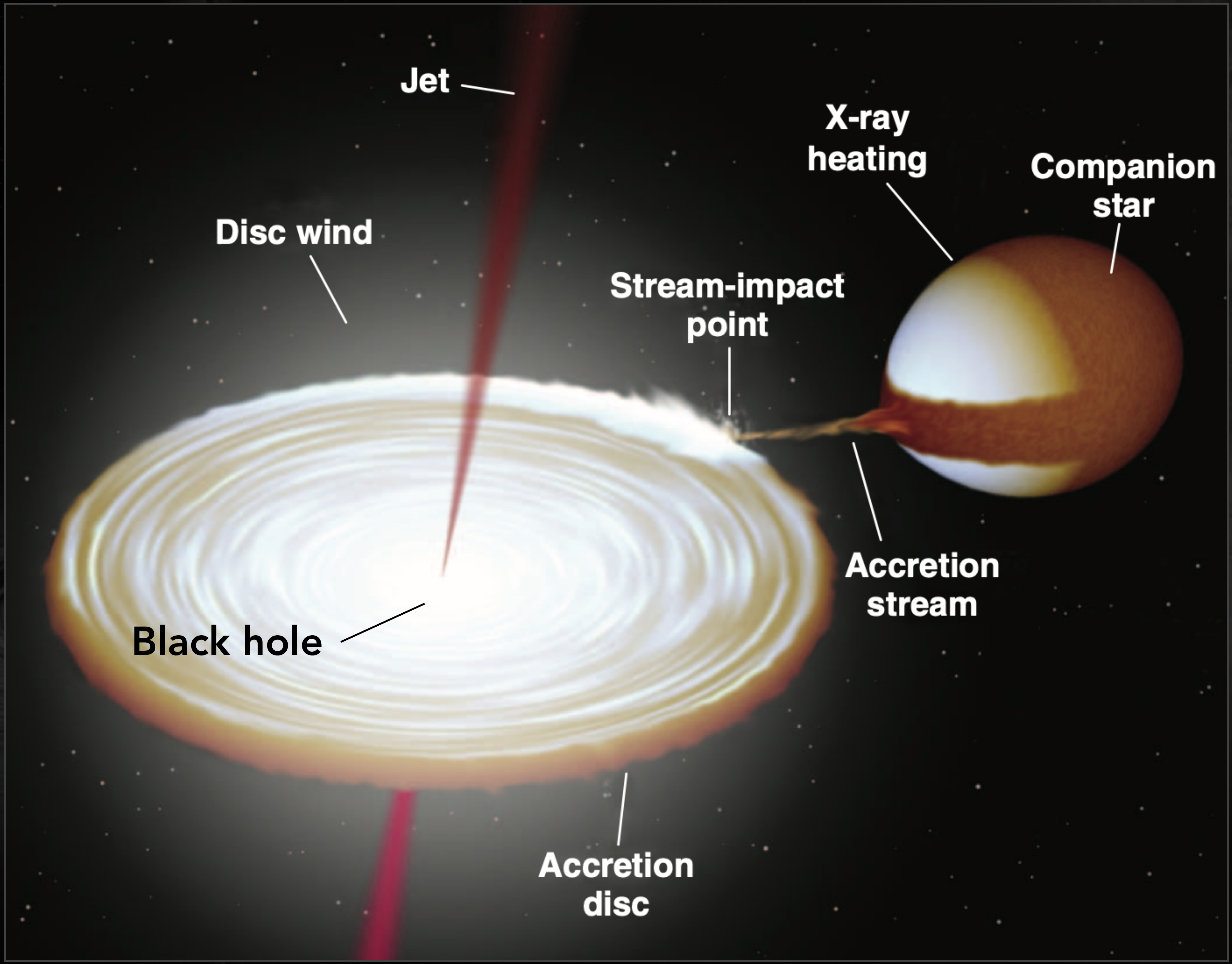
EVN SYMPOSIUM, JULY 2022, CORK

# (LOW MASS) X-RAY BINARIES

## ACCRETION AND FEEDBACK

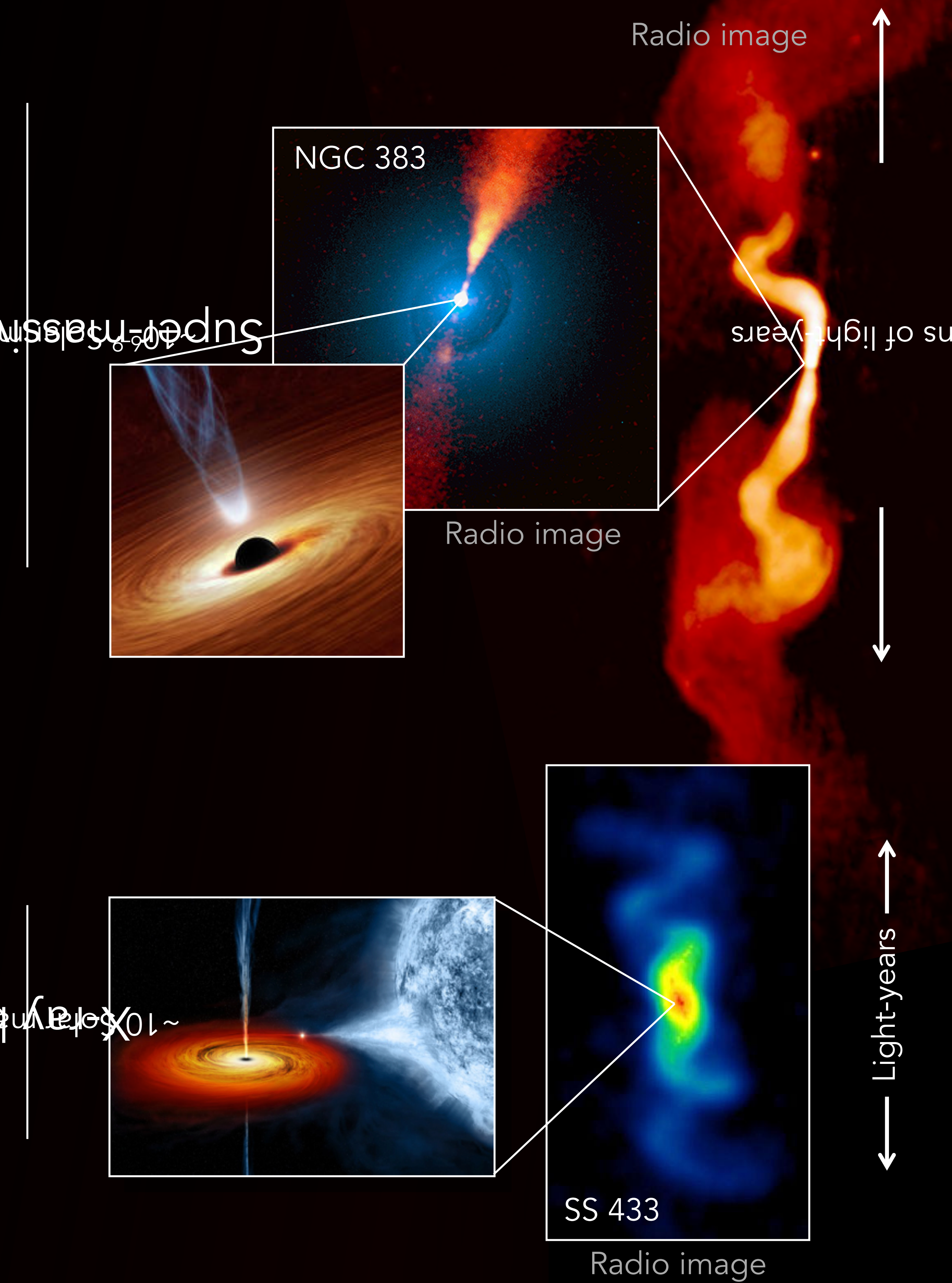



Fender & Belloni 2012

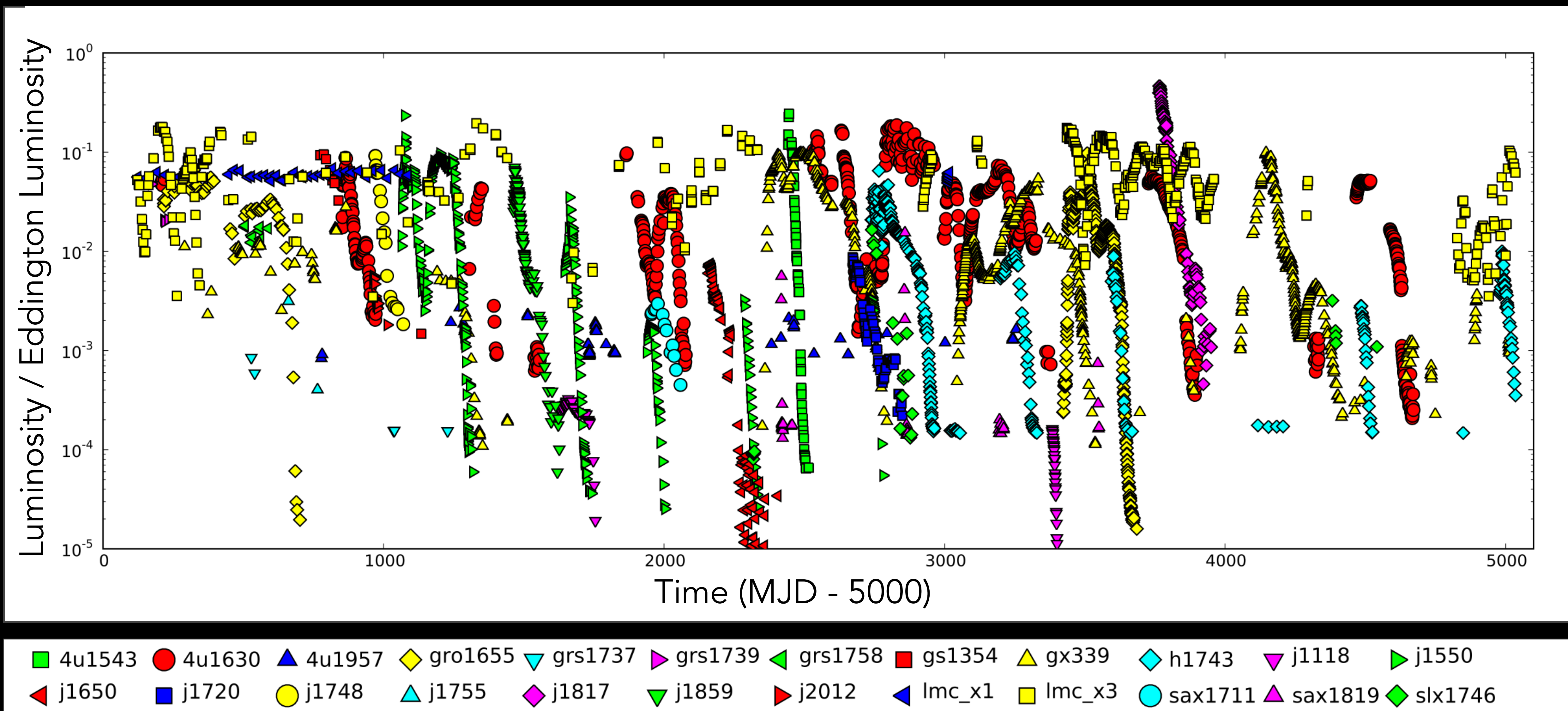
# WHY DO WE STUDY BINARIES

- Nearby **laboratories of extreme physics** - ultra-dense matter, strong gravity, super-energetic particle acceleration

- Accretion and ejection follow the **same principles at all masses. Real time** accretion and feedback in binaries!



# LOW-MASS X-RAY BINARIES: TRANSIENT AND VARIABLE



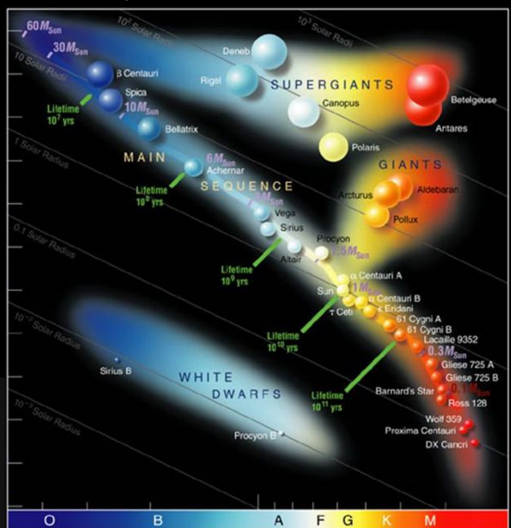

14 years

X-ray light curves from black hole transients

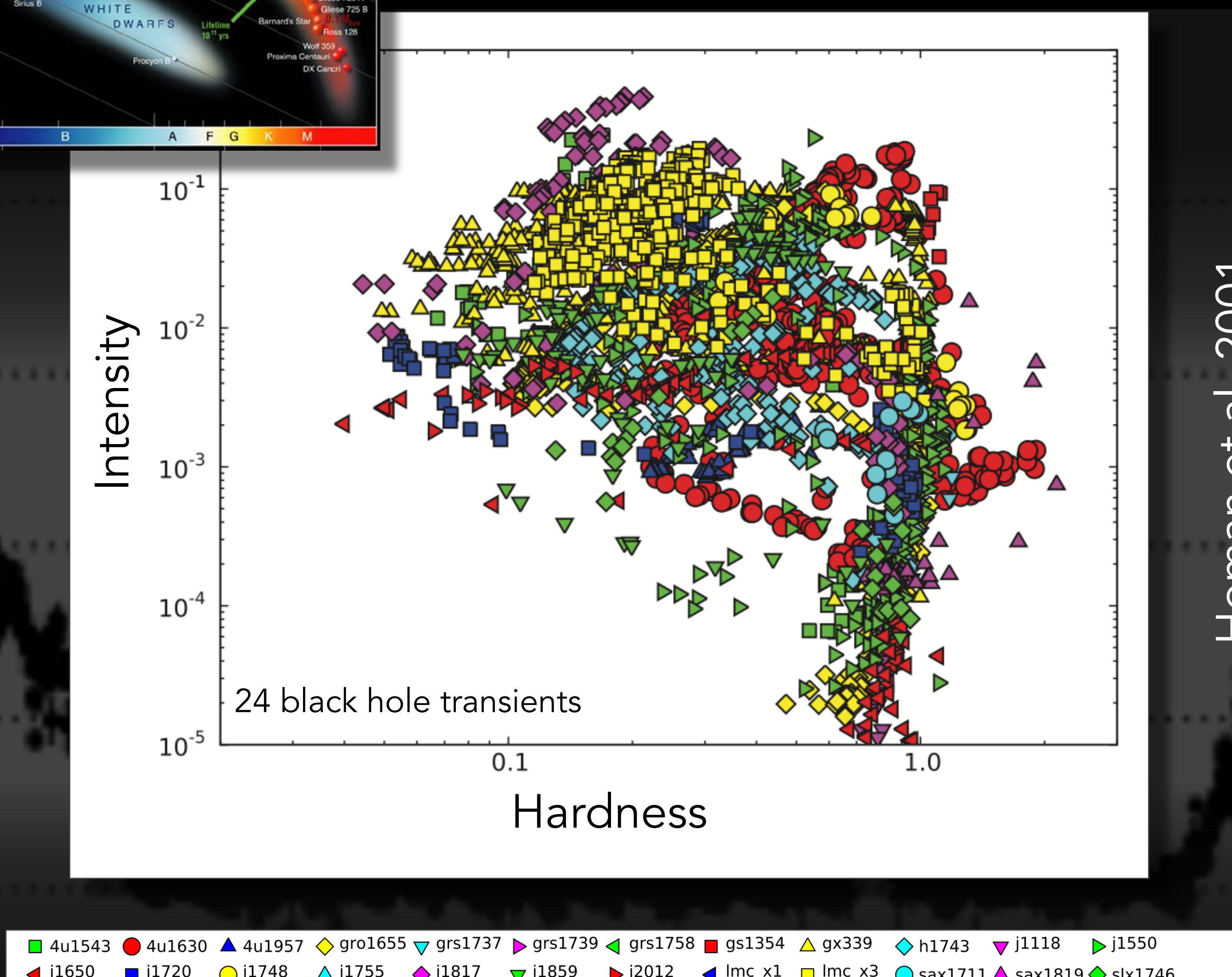
Dunn et al. 2010

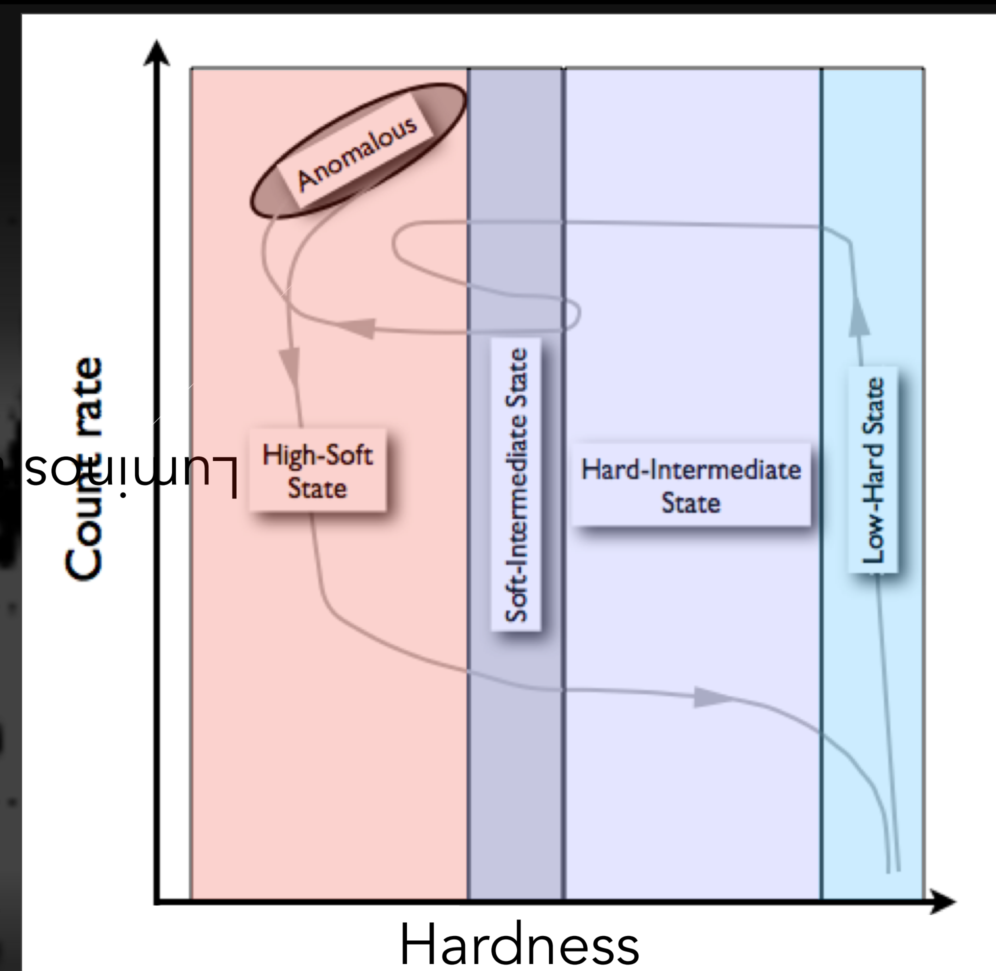
# LOW-MASS X-RAY BINARIES: TRANSIENT AND VARIABLE

Hertzsprung–Russell diagram



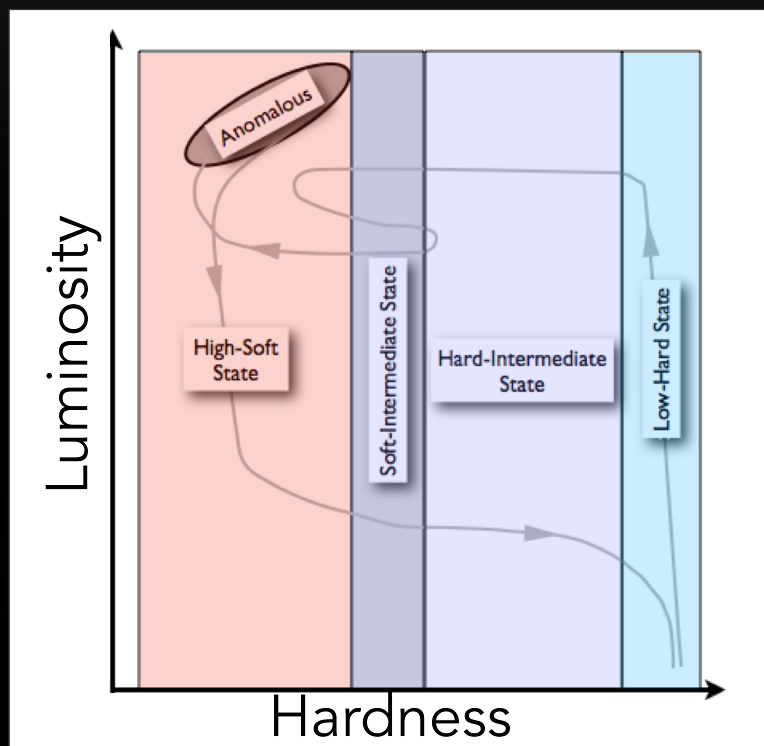

Hardness Intensity diagram



# A TRUNCATED (THIN) DISC

Truncation radius
becomes smaller

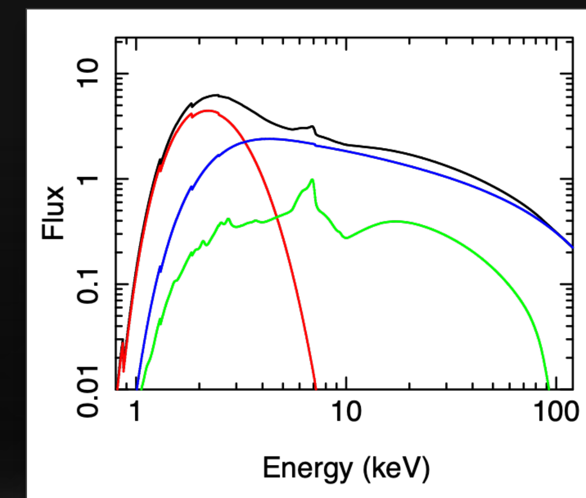


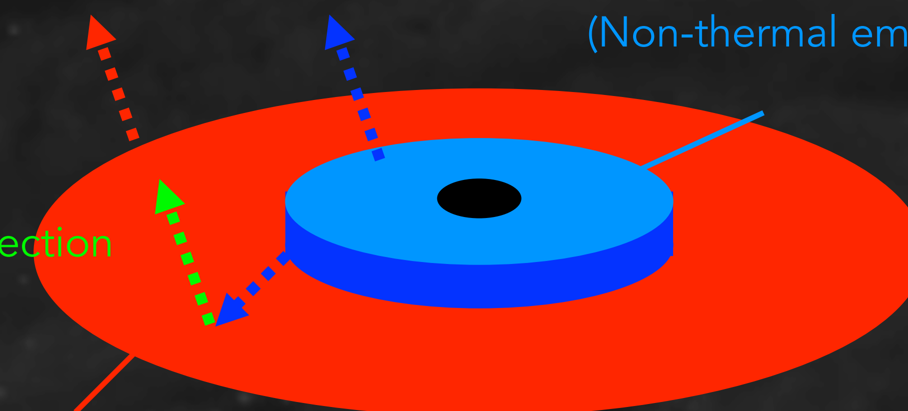

Truncation radius
becomes larger

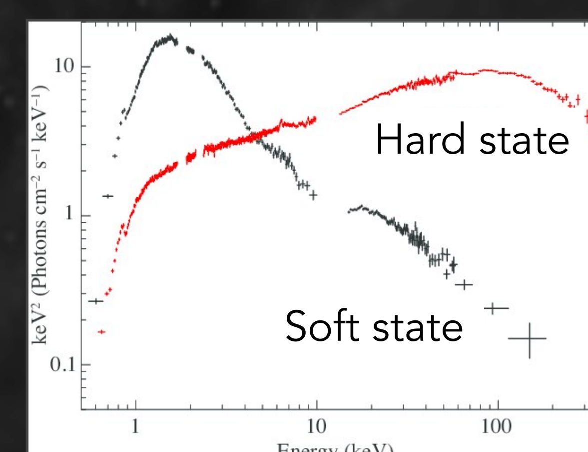
Small
truncation radius
Low variability
No Jet

Large
truncation radius
High variability
Steady radio jet

Esin et al. 1997; Poutanen et al.1997



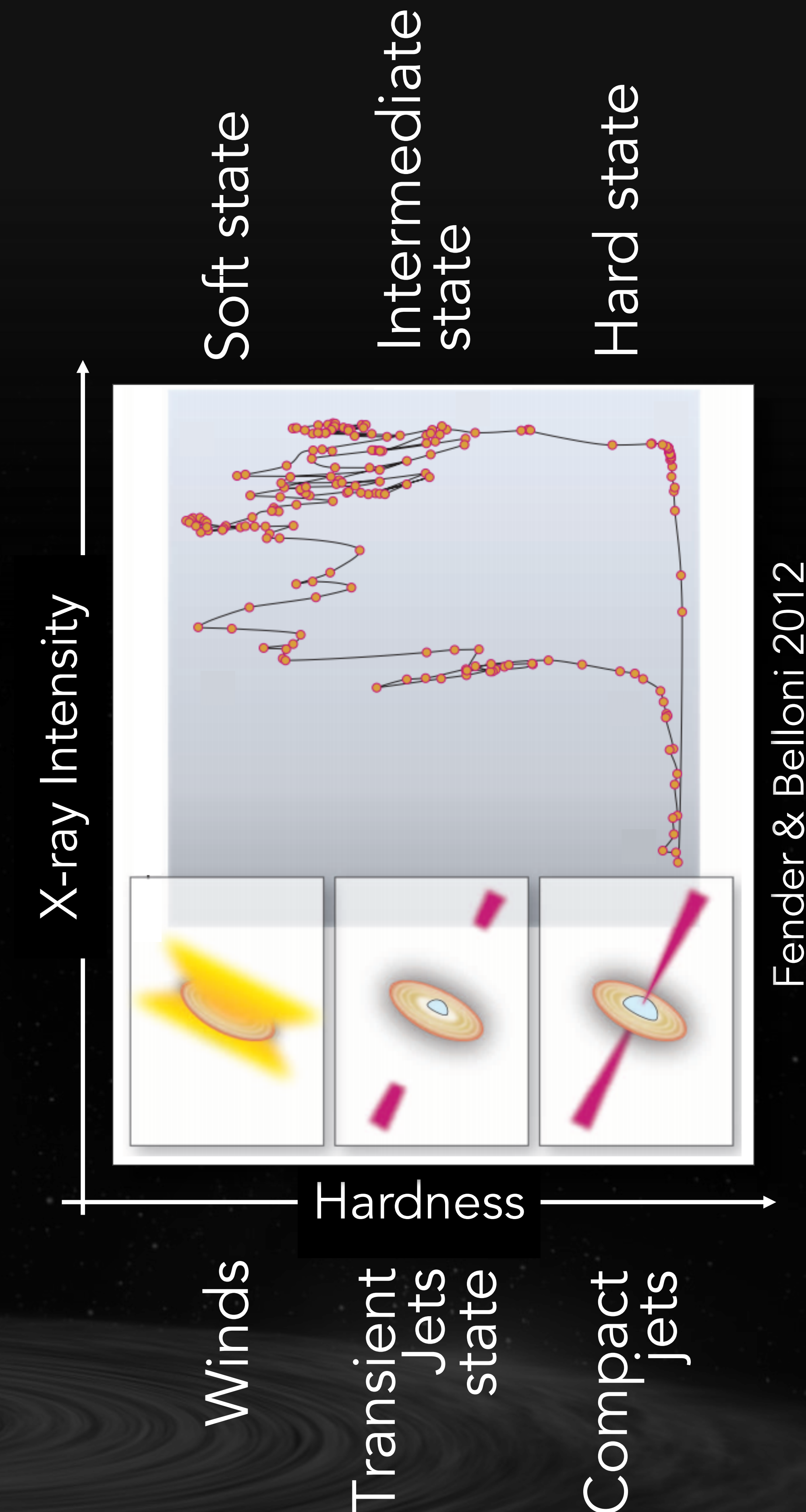




Yamada et al. 2012

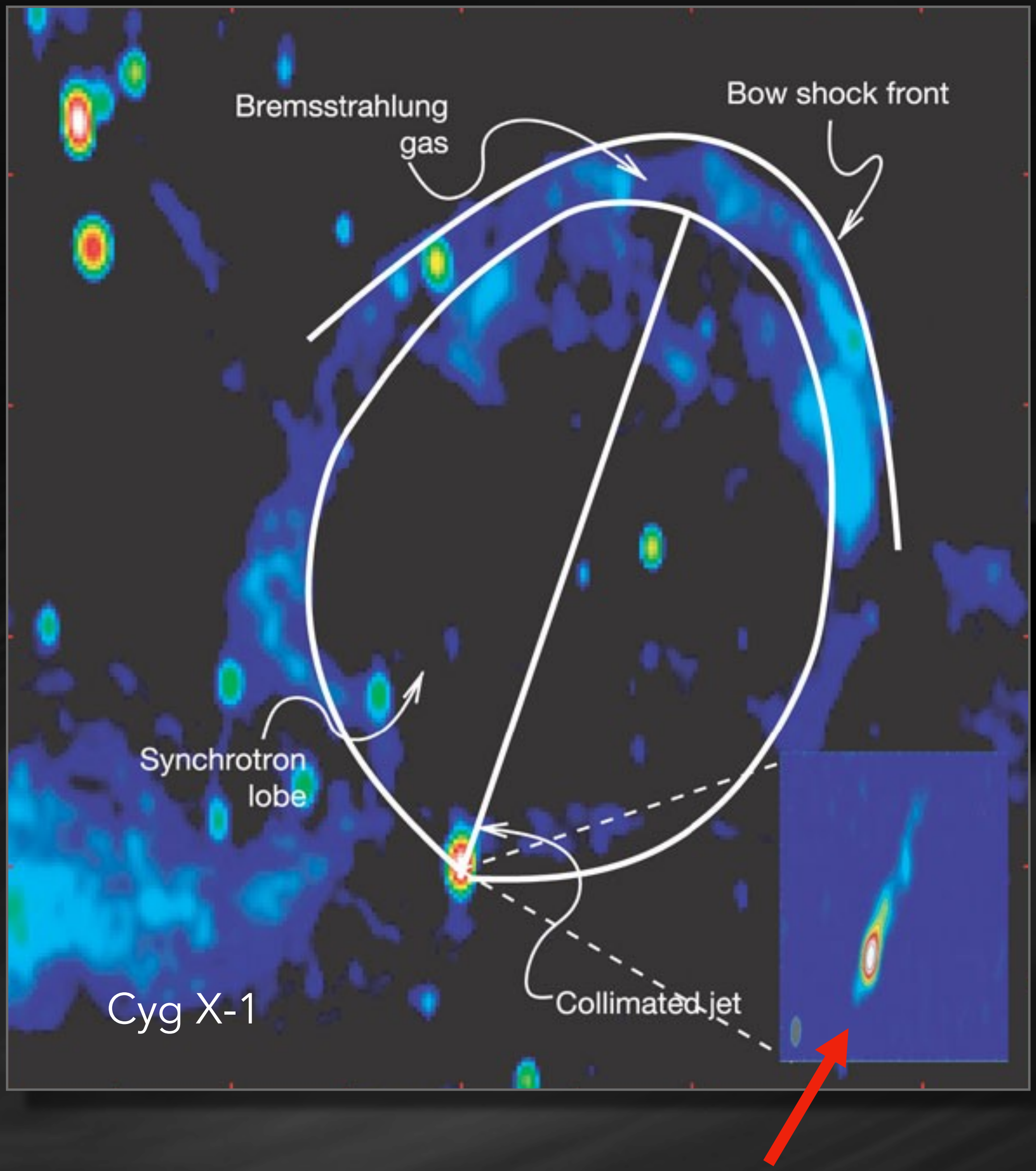
# STATES, TRANSITIONS AND OUTFLOWS

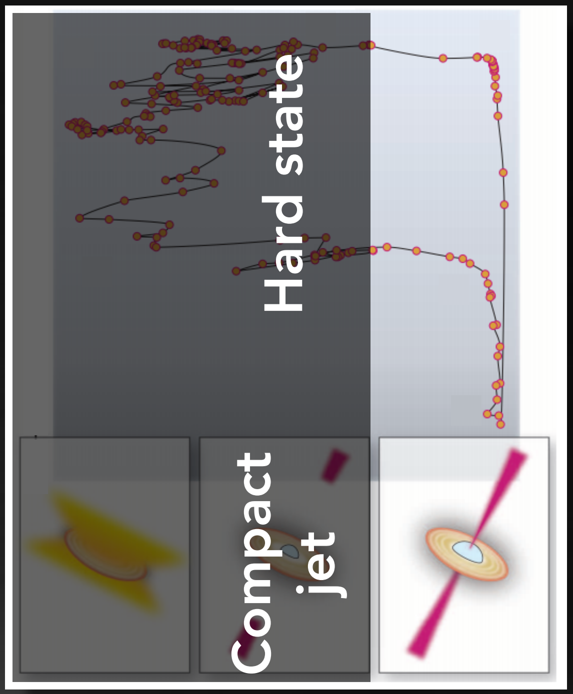
- **States** are largely defined based on **X-ray spectral and fast-time variability properties**
- States and transitions are connected to different **modes of outflows** (Fender et al. 2004, 2009, …)



# COMPACT JETS IN THE HARD STATES
## DARK JETS BLOWING BUBBLES

Gallo et al. 2005

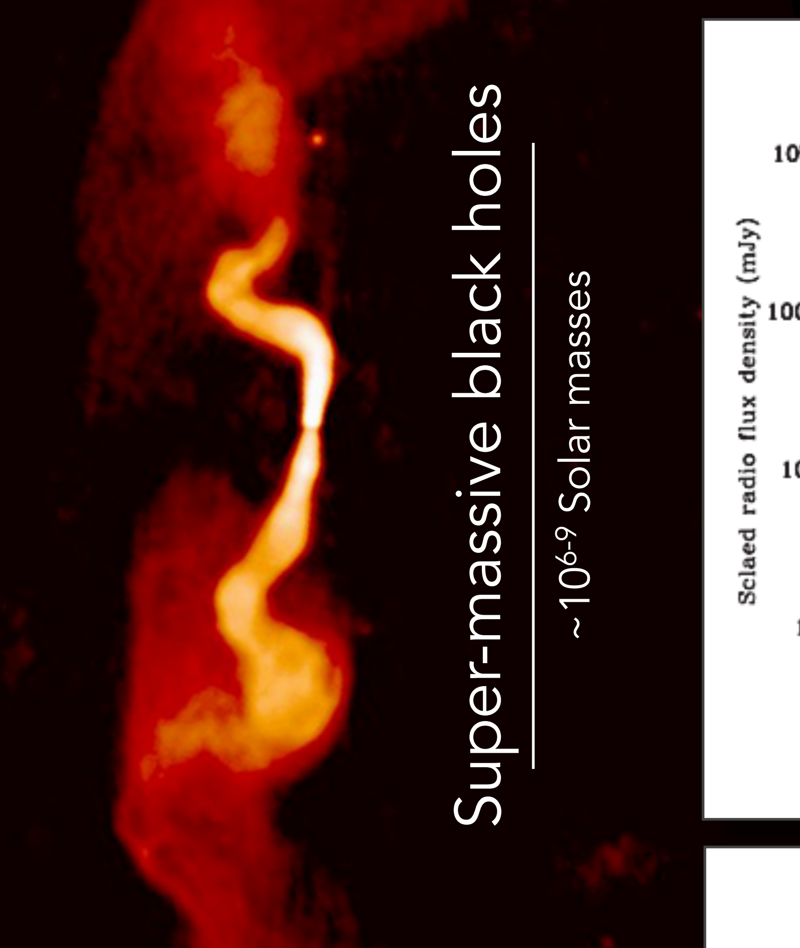



- Long-lived, mildly relativistic
- Typically not resolved
- Transport a large amount of kinetic energy

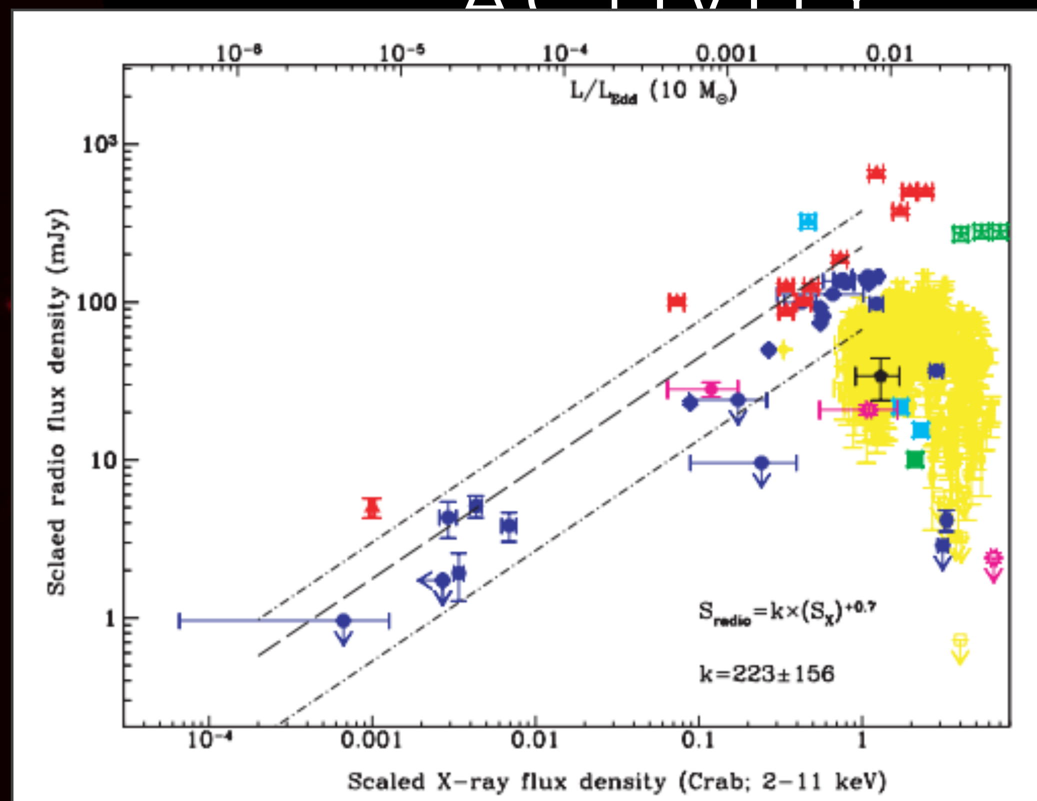
# THE RADIO:X-RAY CORRELATION

## A FUNDAMENTAL PLANE OF BLACK HOLE ACTIVITY

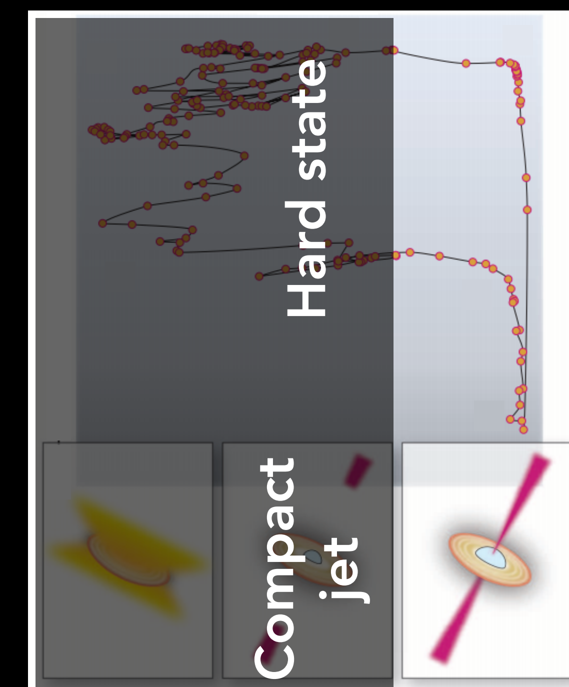


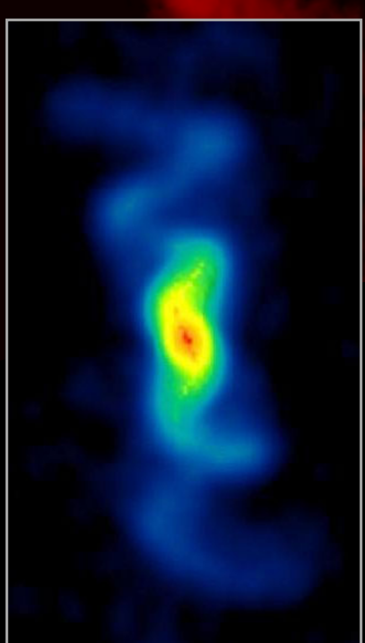
Super-massive black holes

~$10^{6-9}$ Solar masses



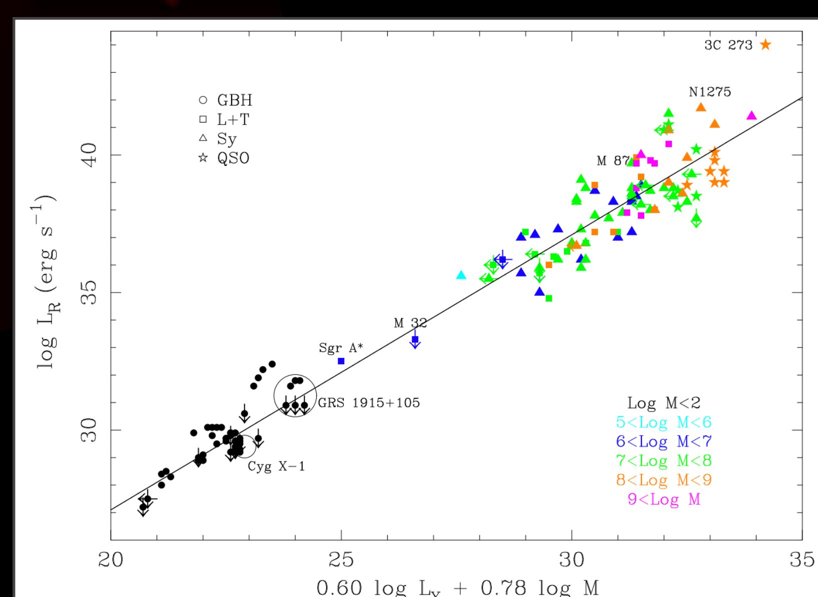

Gallo et al. 2003



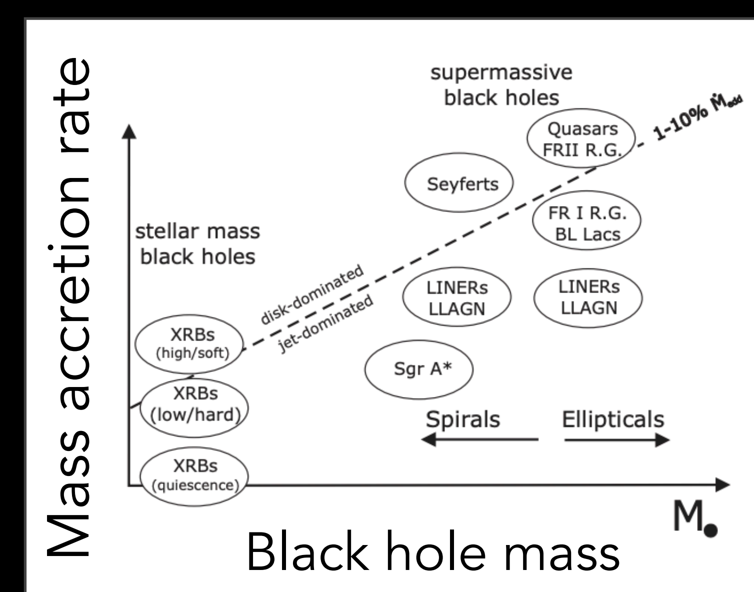



X-ray binaries

~10 Solar masses




Merloni et al. 2003

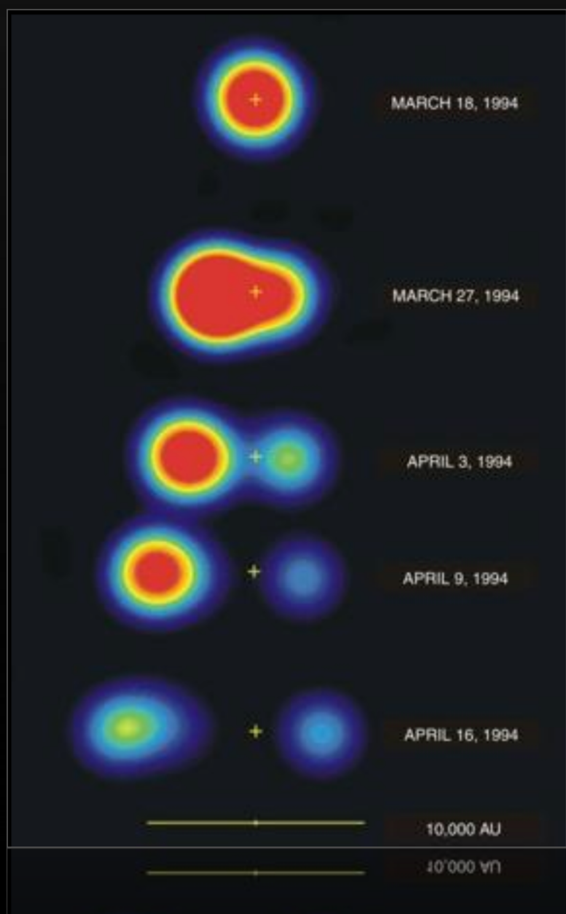



Falcke et al. 2004

See also Corbel et al. 2013, Gallo et al. 2014, Gallo et al. 2018, Motta et al. 2018, Gültekin et al. 2019, Plotkin et al. 2021, Carotenuto et al. 2021, Bariuan et al. 2022, and many others…

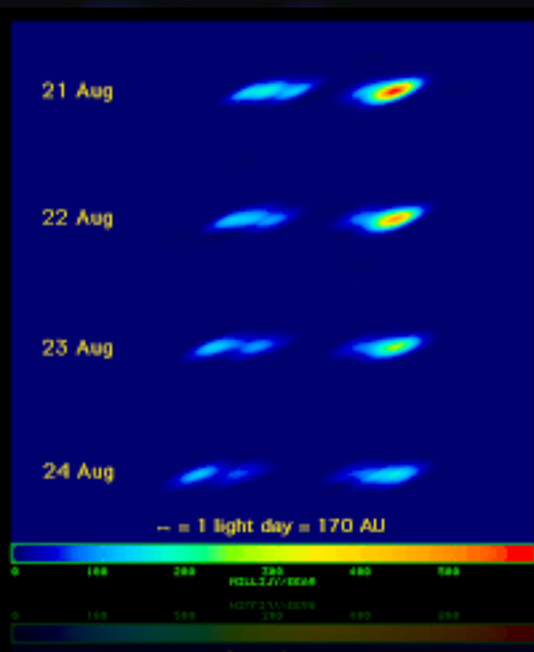
# JETS IN THE INTERMEDIATE STATES

## TRANSIENT RELATIVISTIC EVENTS




Mirabel & Rodríguez 1994

GRS 1915+105

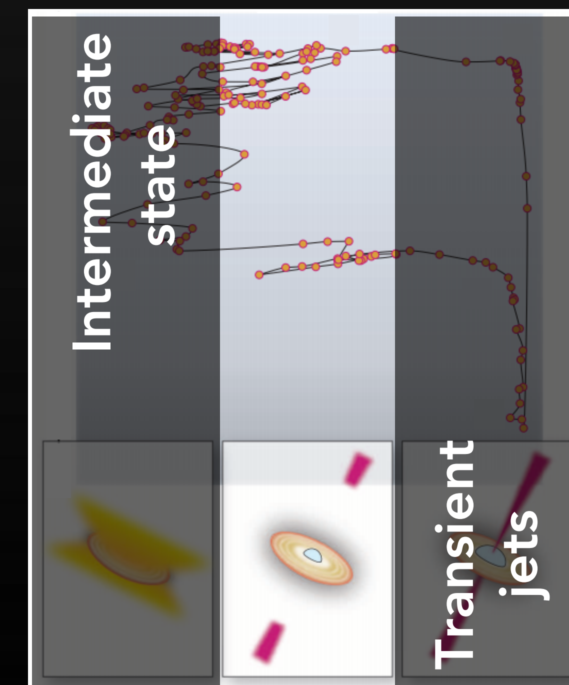


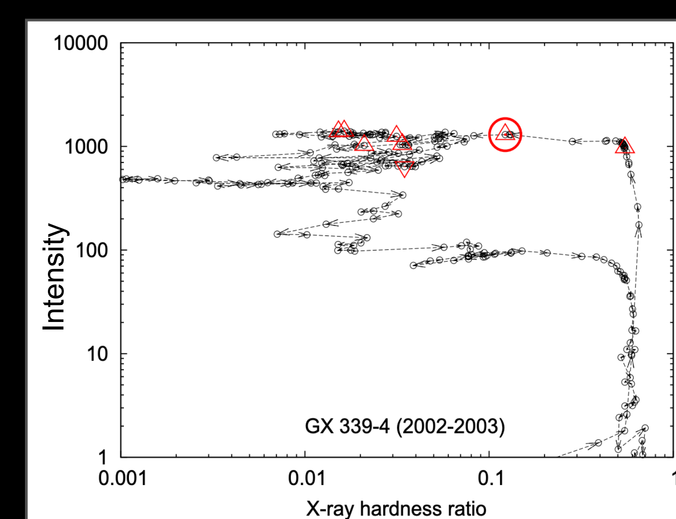

Hjellming & Rupen 1995

GRO J1655-40

- Transient, relativistic ejections
- Proper motion sometimes observed
- Not easy to catch

~10-100 mas



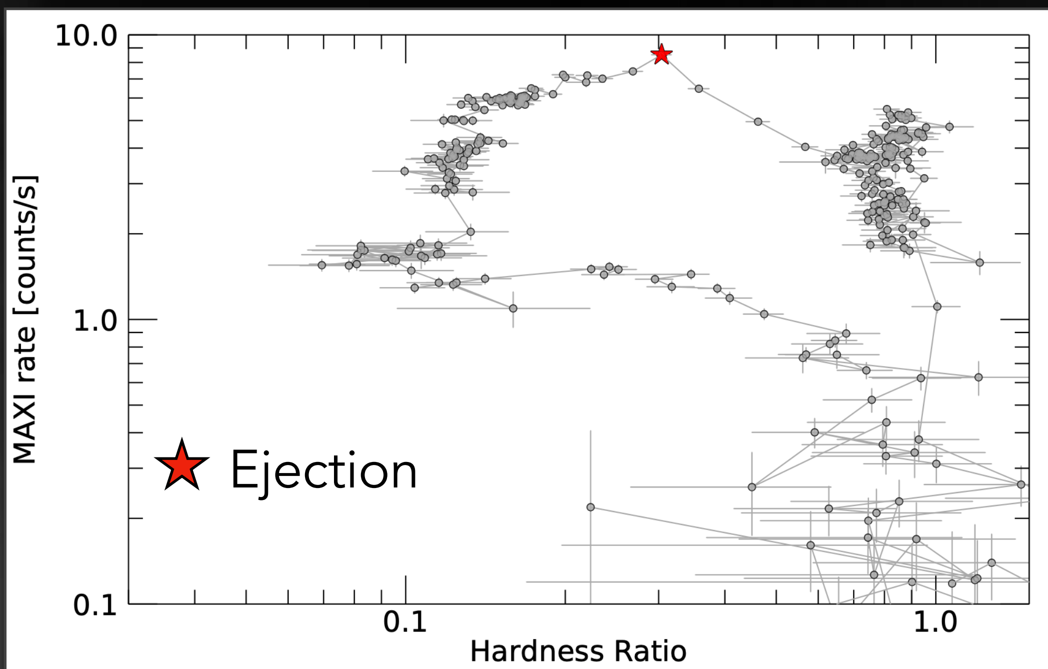




Fender et al. 2009

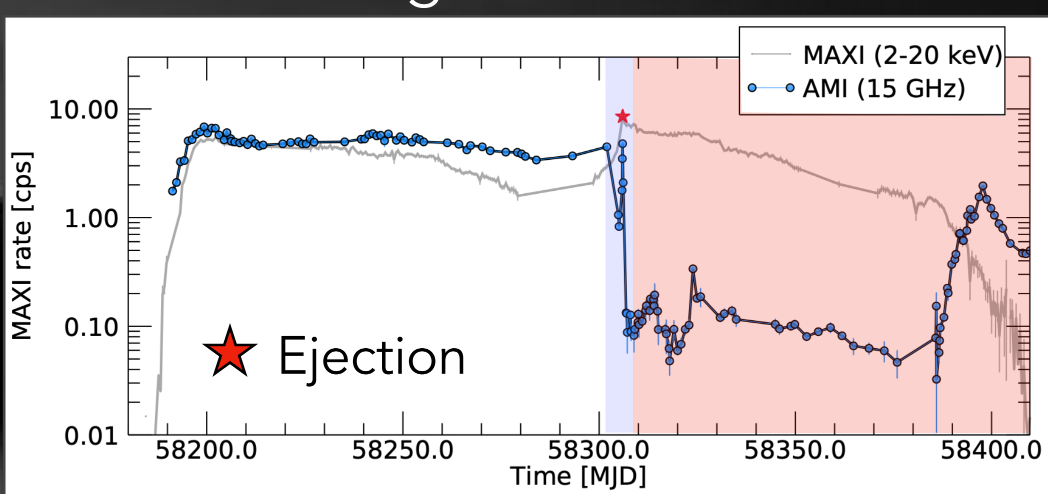
# ARCSEC JETS FROM MAXI J1820+070

Bright, Fender, Motta et al. 2020, Nature Astronomy

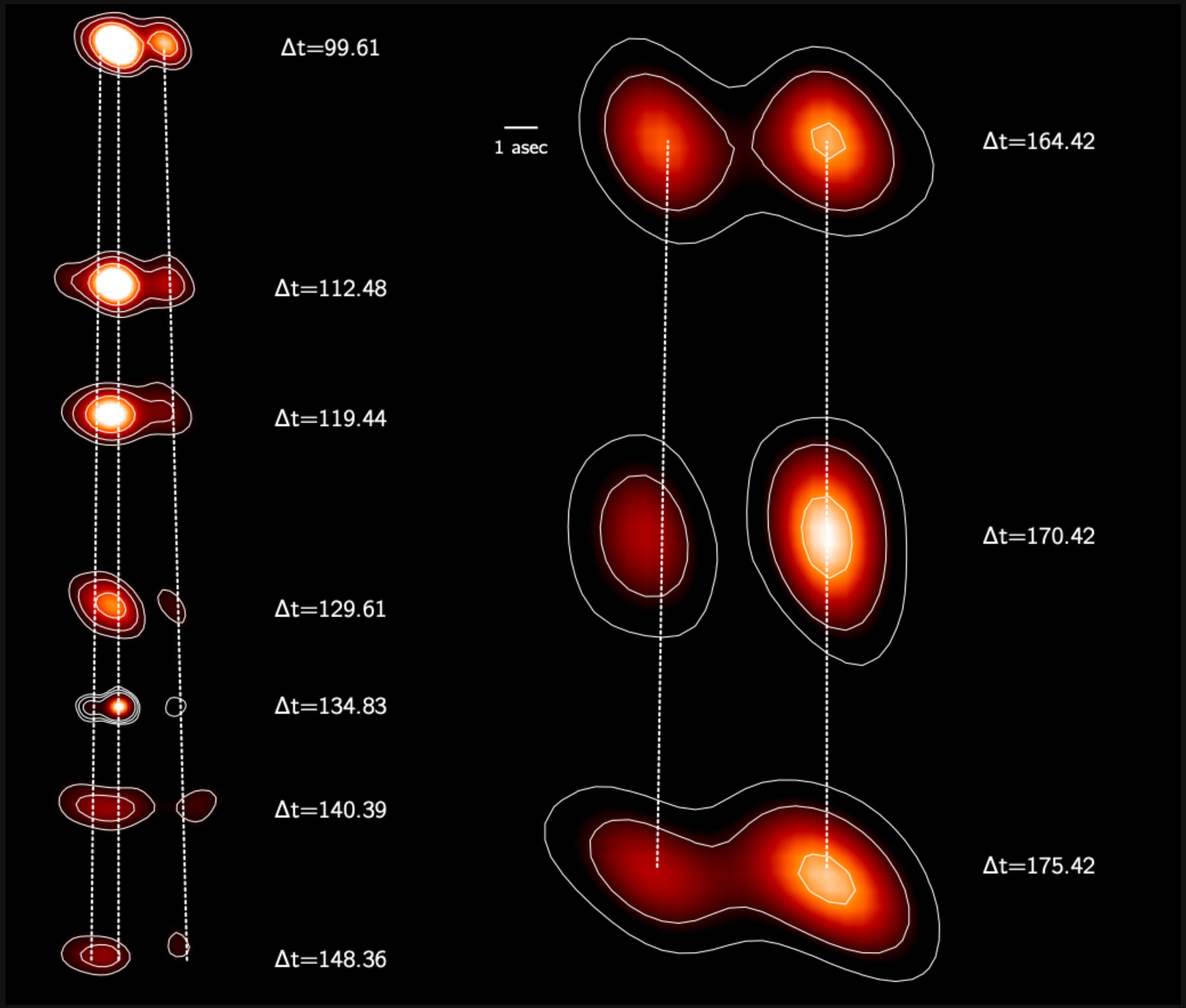
## Hardness-Intensity diagram




## Light curves




Hard state Intermediate State Soft state

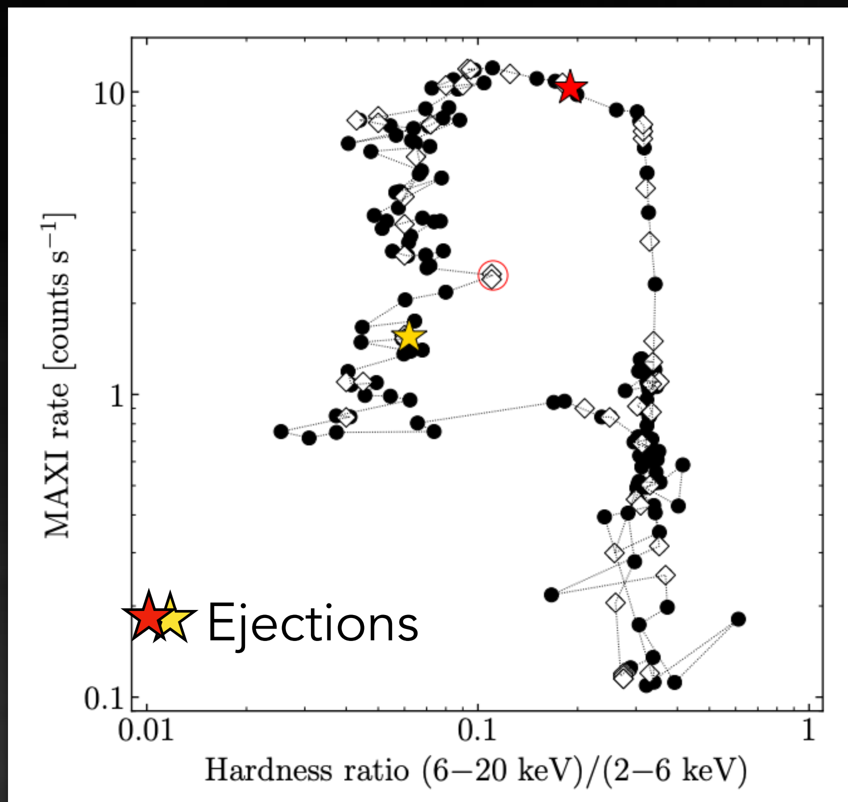



MeerKAT data

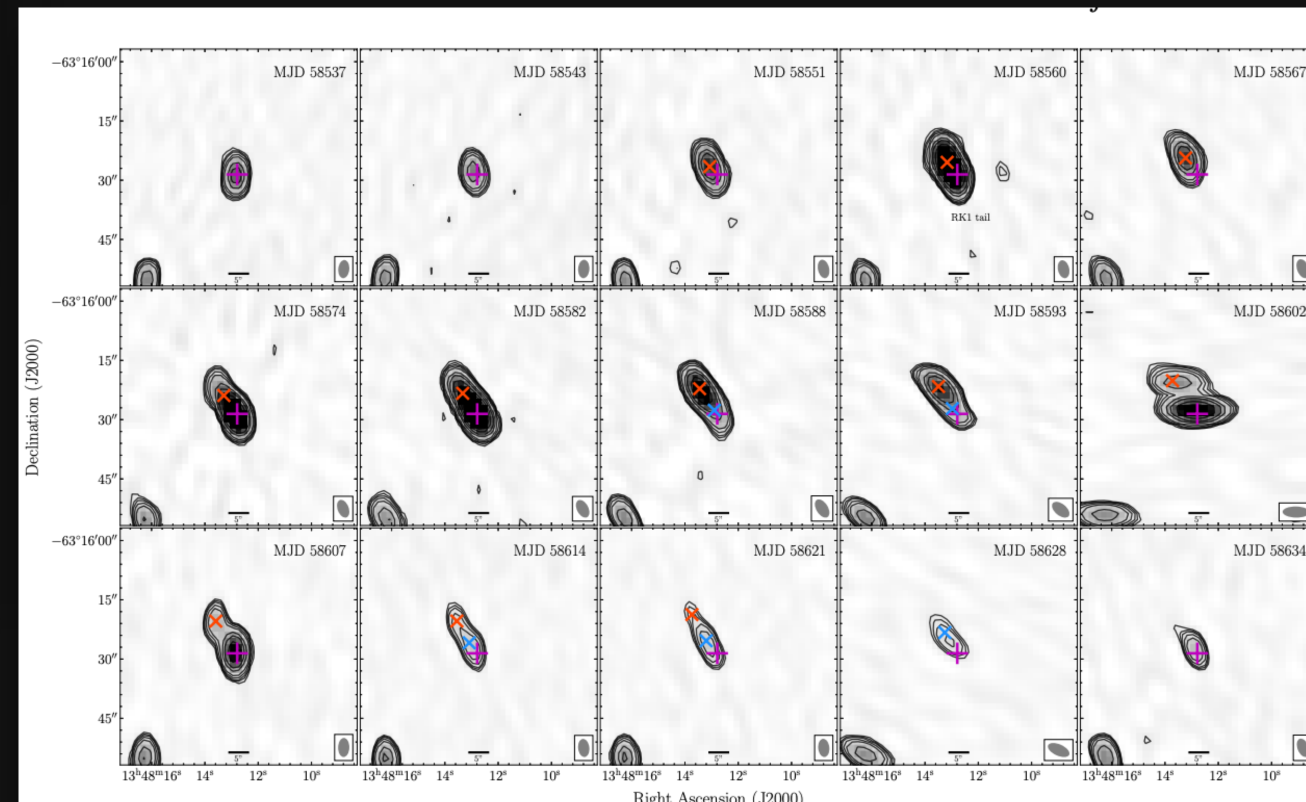
- Jets moving **~80 mas/day**
- Extended up to **0.005 pc from the core**

# MORE JETS FROM MAXI J1348–630

Hardness-Intensity diagram

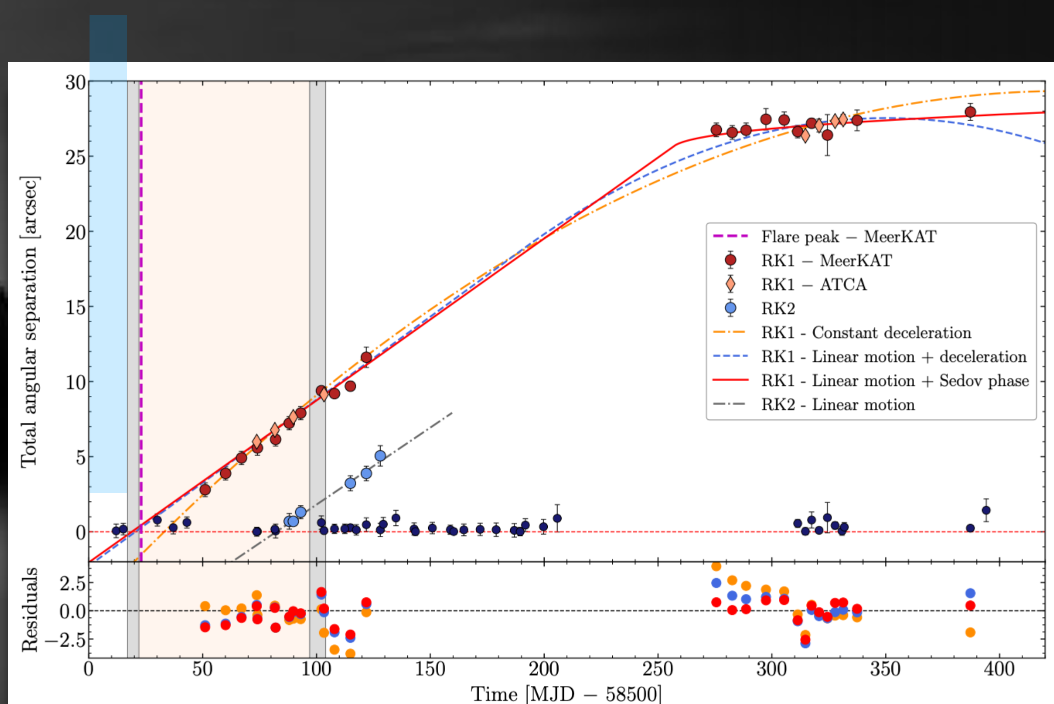



MeerKAT data




Carotenuto et al. 2021a,b

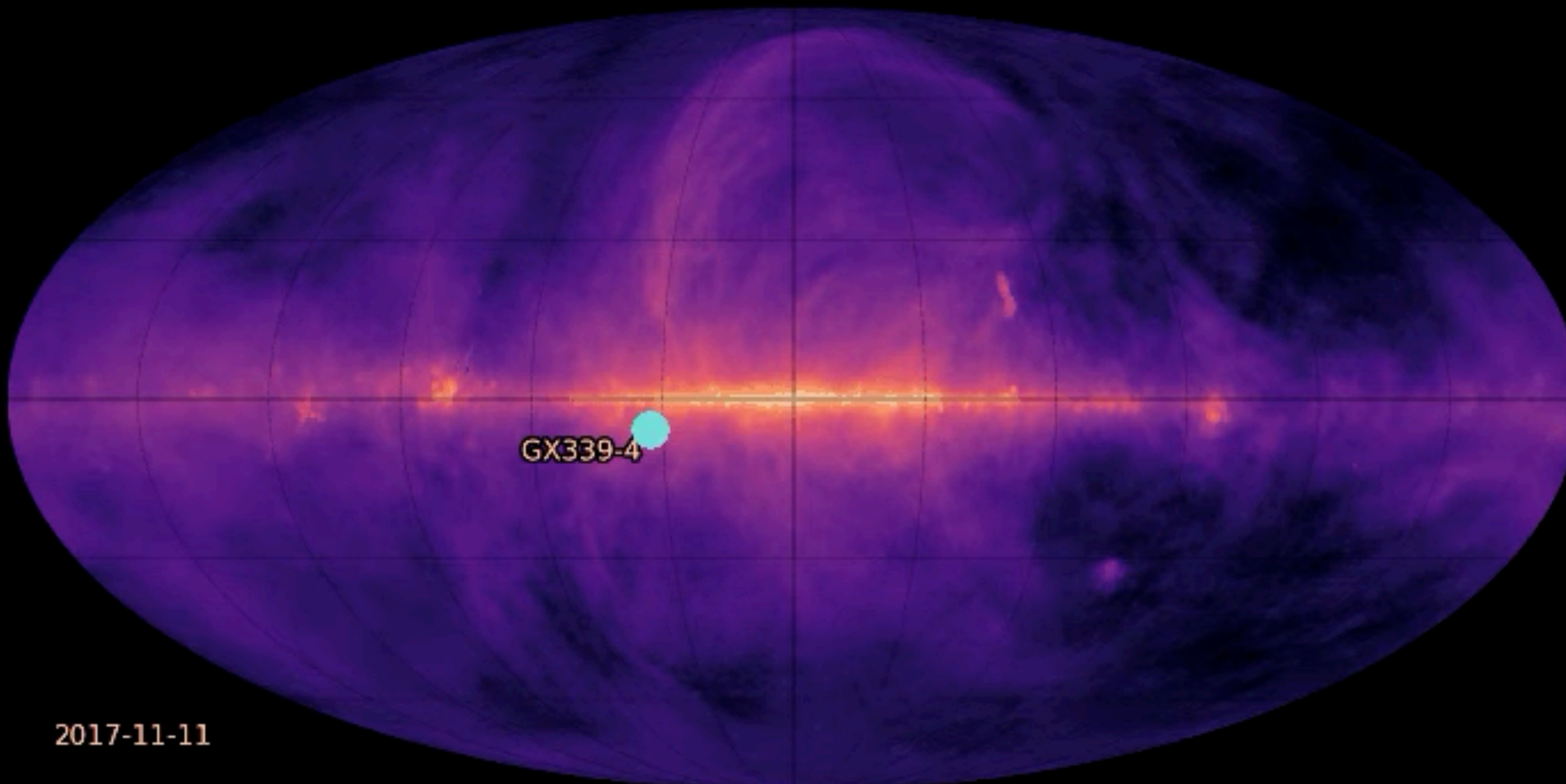
Core-jet separation




- Jets moving **~110 mas/day**
- Extended up to **0.6 pc from the core**
- Observations complementing VLBI

# THE **MEERKAT** VIEW OF TRANSIENTS GALACTIC XRBs

Results from the ThunderKAT collaboration




Follow us on Twitter!

@ThunderKAT_MLSP

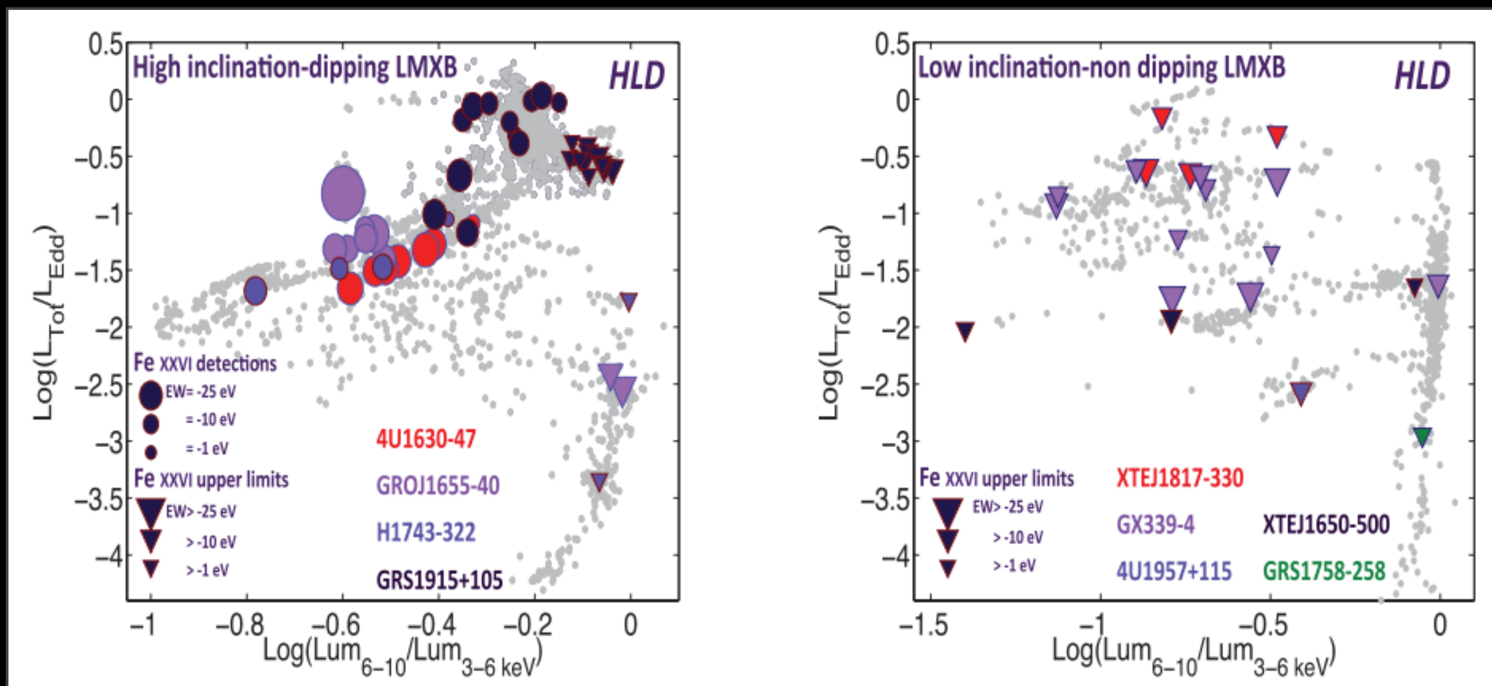
Curtesy of Alex Andersson
(ThunderKAT collaboration)

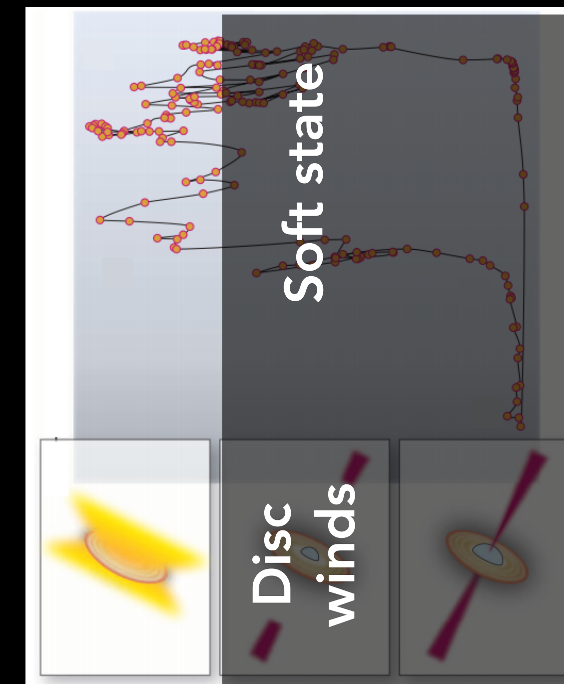
# X-RAY WINDS IN THE SOFT STATE

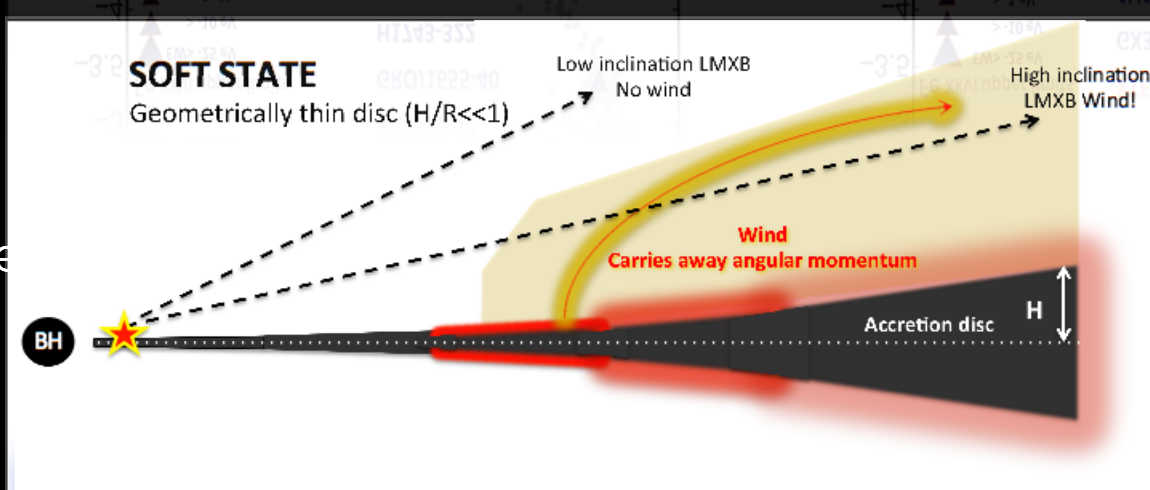
## INCLINATION MATTERS

High inclination Low inclination

Ponti et al. 2012



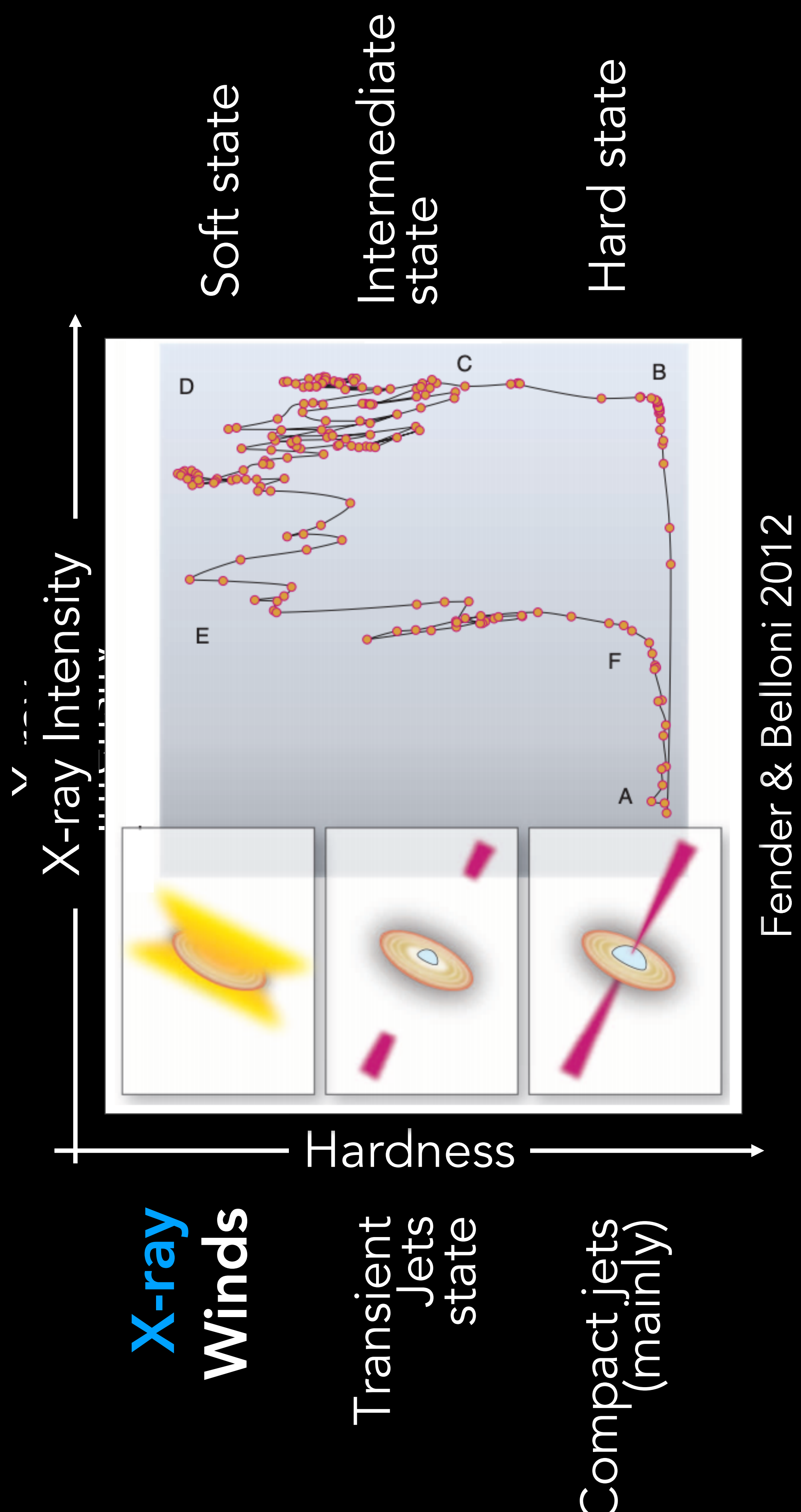



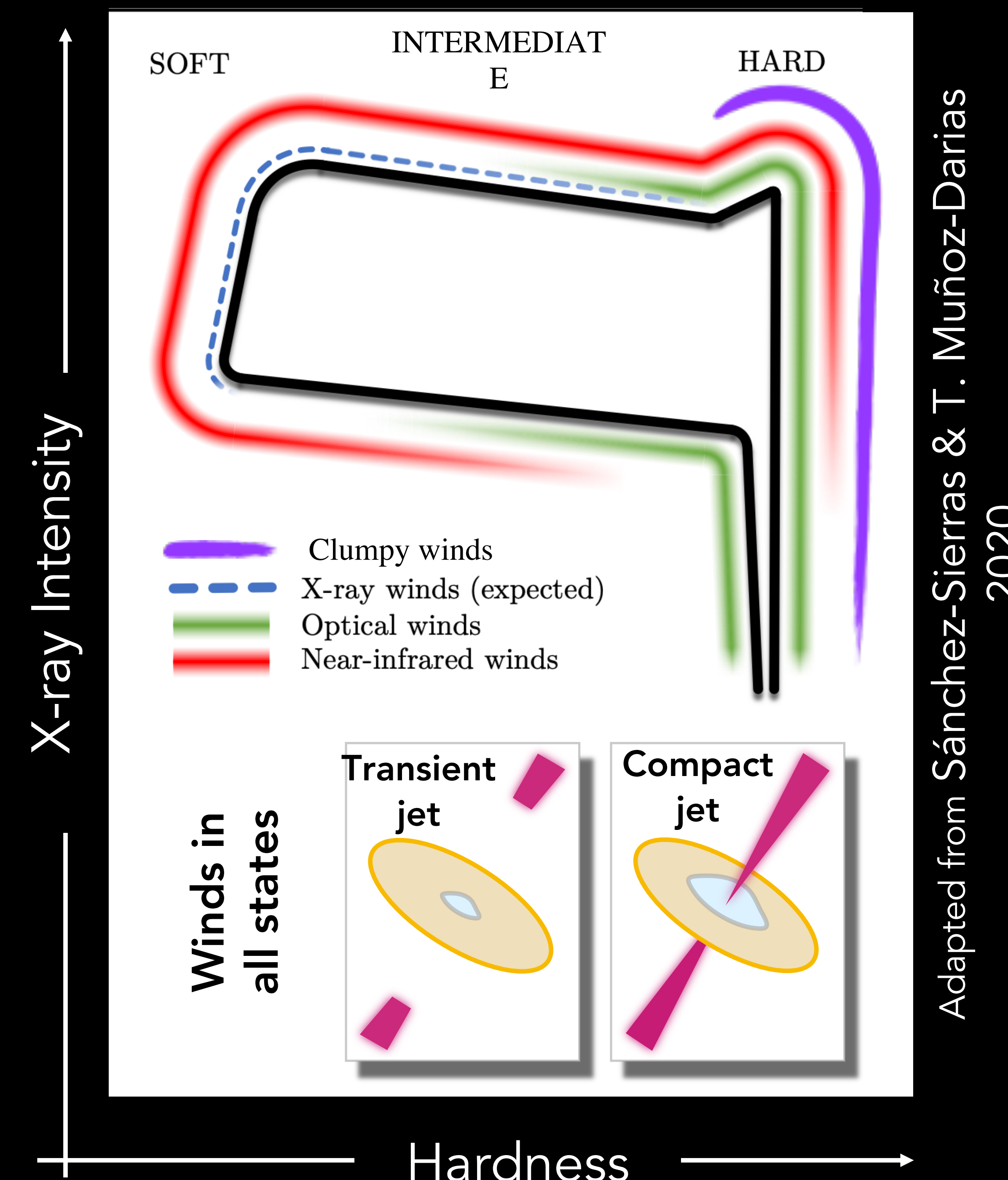




- Winds launched equatorially
- matter and angular momentum removed from the disc

See also Lee et al. 2002, Neilsen & Lee 2009, Dìaz Trigo et al. 2006

# THE ACTUAL WIND PICTURE



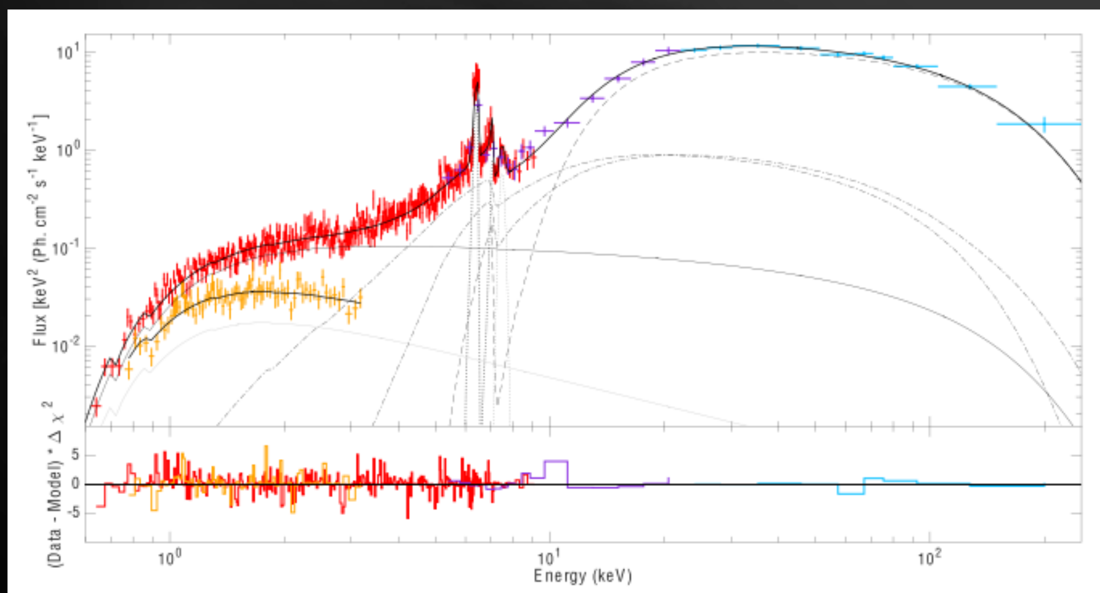




See also Munoz-Darias et al. 2016, Homan et al. 2016, Dubus et al. 2019, Motta et al. 2017, Casares et al. 2019, Miller et al. 2020, and many others

# AGN WINDS IN X-RAY BINARIES

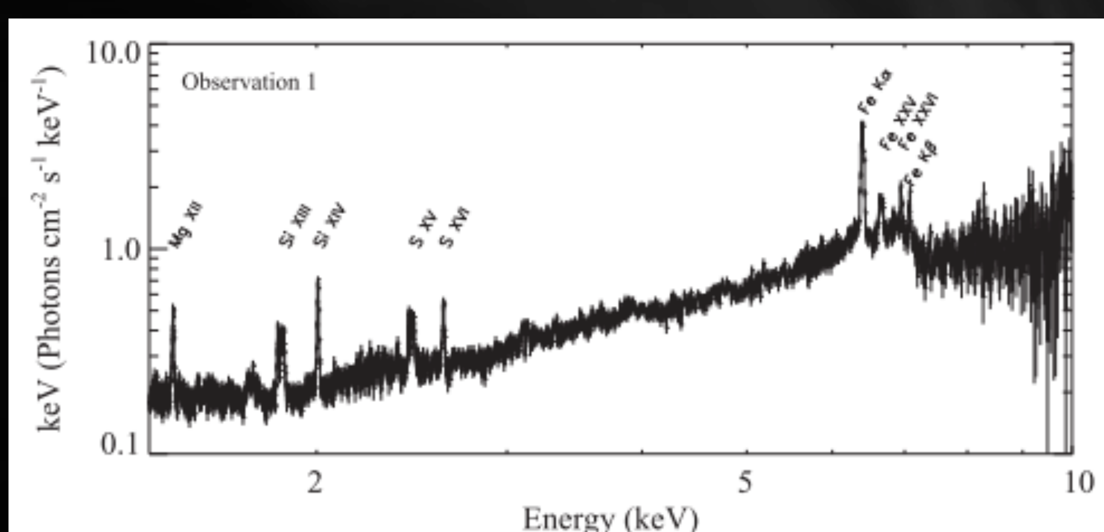
V404 Cyg

Clumpy winds in a obscured state




Motta et al. 2017a

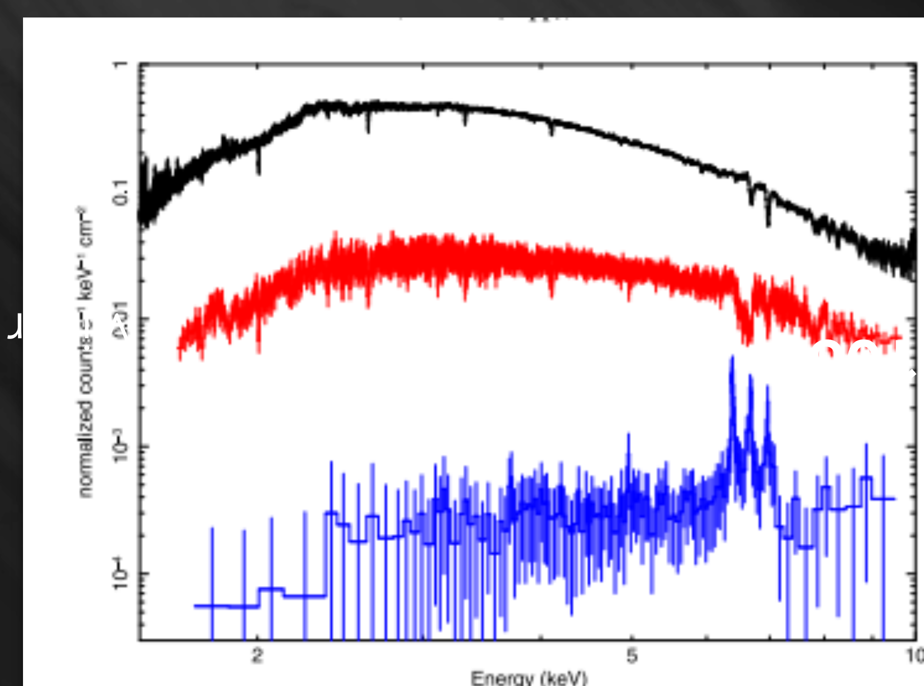
Highly ionised X-ray winds




King et al. 2015

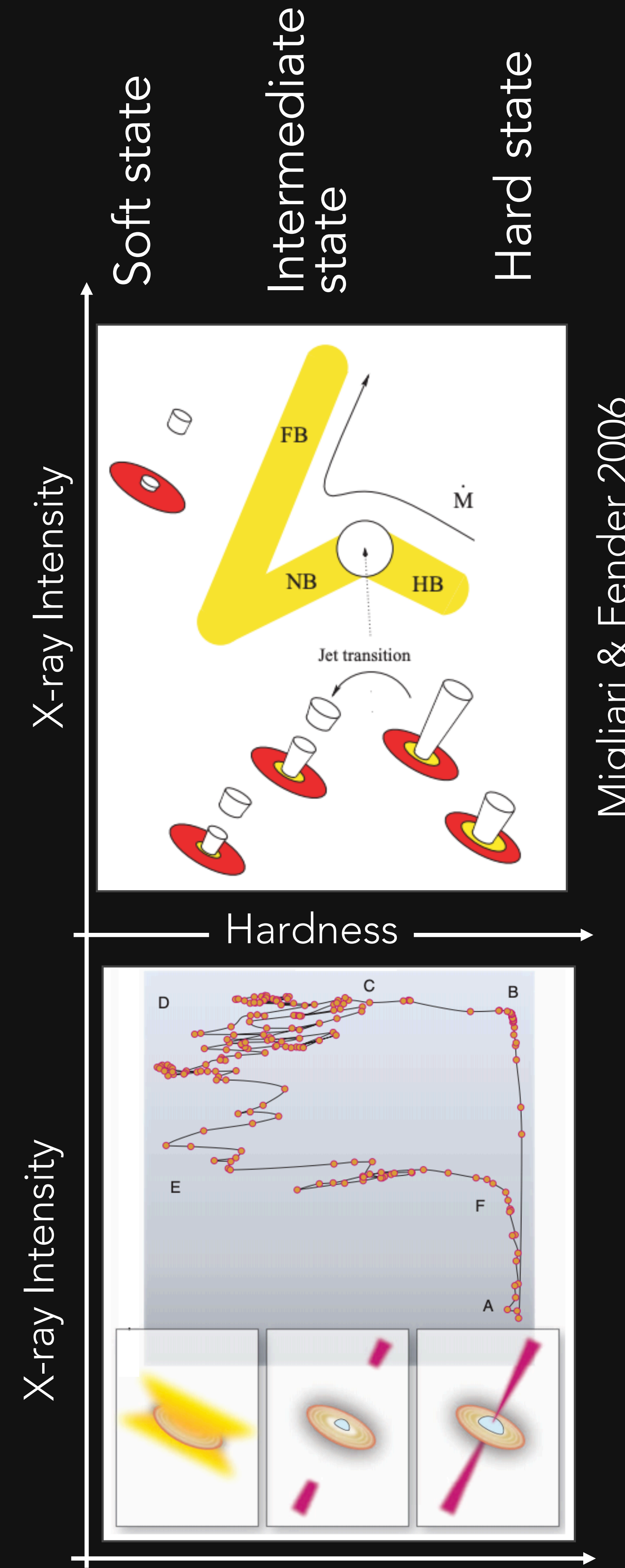
- The **accretion-feedback coupling** holds for winds as well
- …and it works the same as in AGN

Failed winds in a Seyfert 2 state



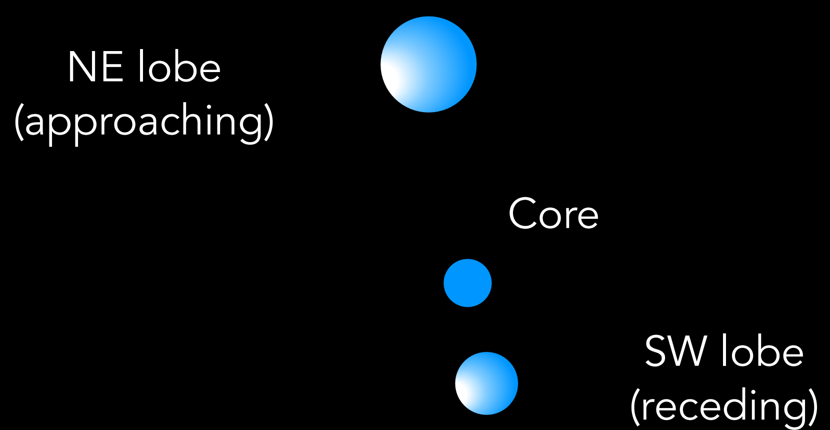
# DISK JET COUPLING IN NEUTRON STAR X-RAY BINARIES

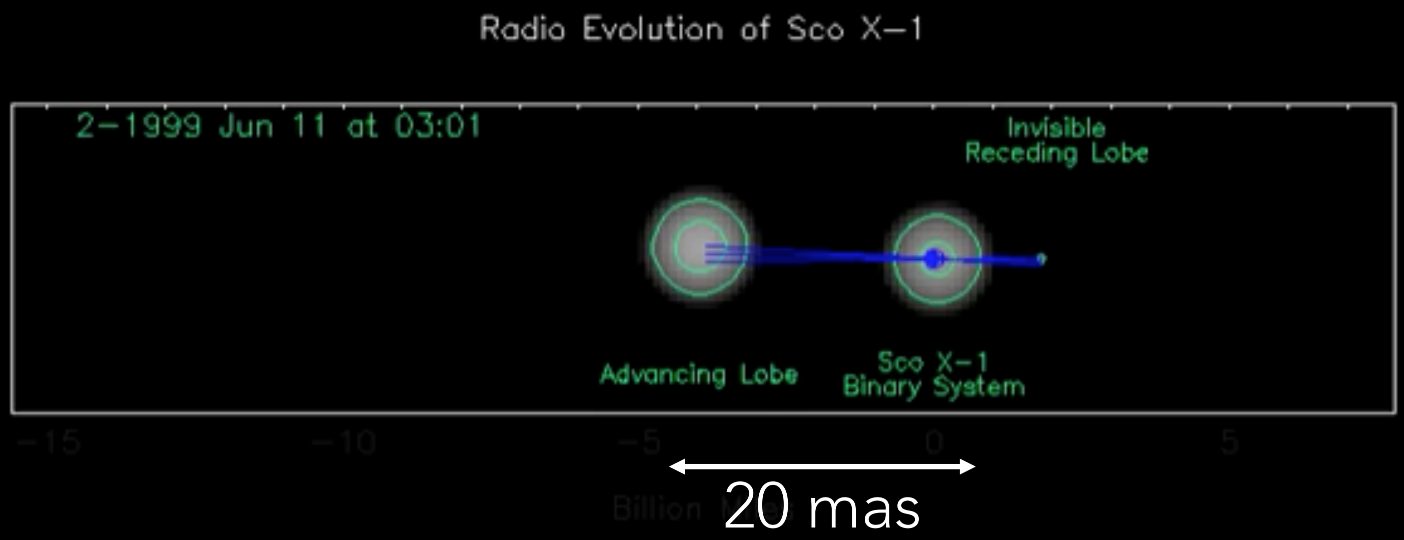
- Neutron stars and black hole X-ray binaries show **same accretion-outflow coupling**
- Similar state/transition patterns, but **faster in neutron stars t**han in black holes
- **Neutron stars** shows **U**ltra **R**elativistic out**F**lows



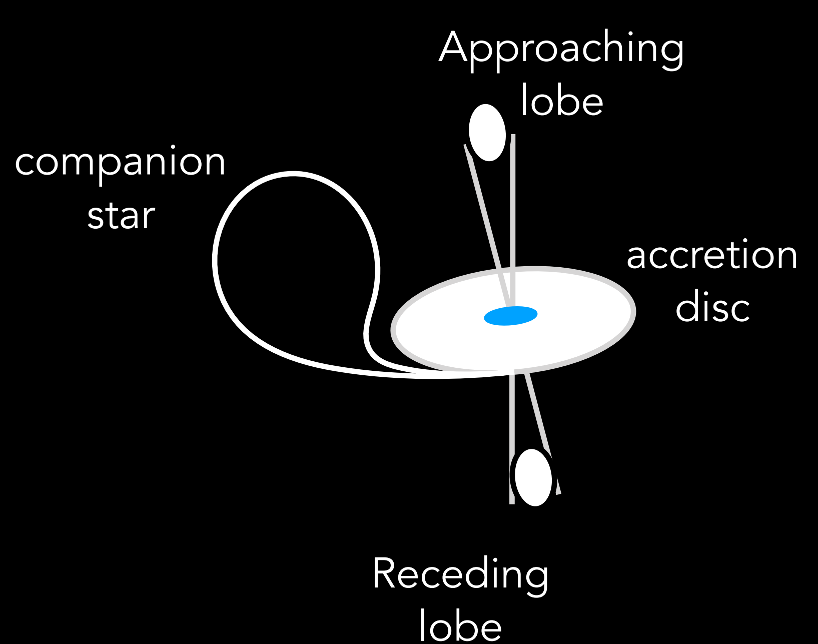
# JETS IN SCO X-1

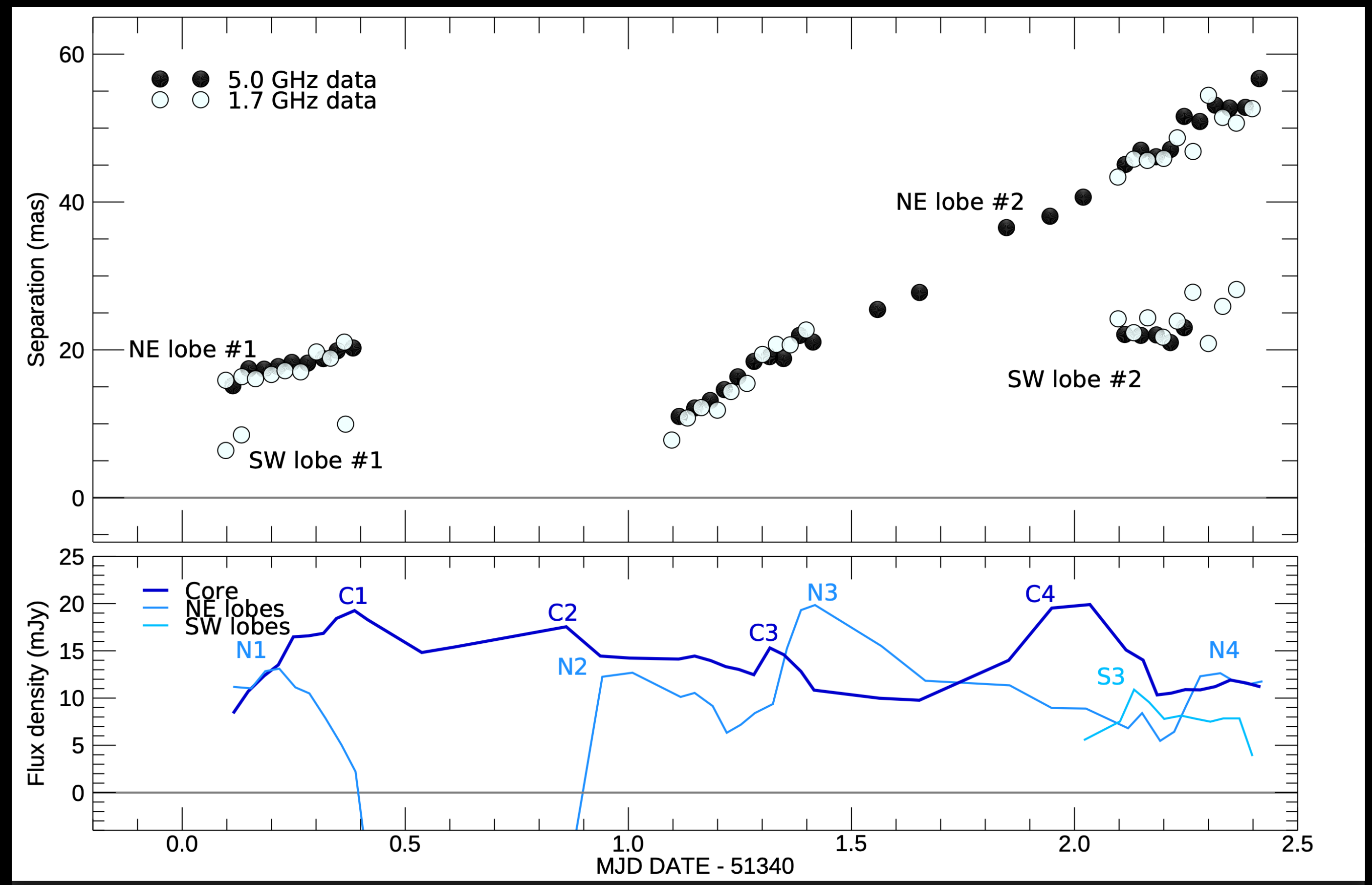
## VLBI OBSERVATIONS OF A FAMOUS NEUTRON STAR




Credit: NRAO

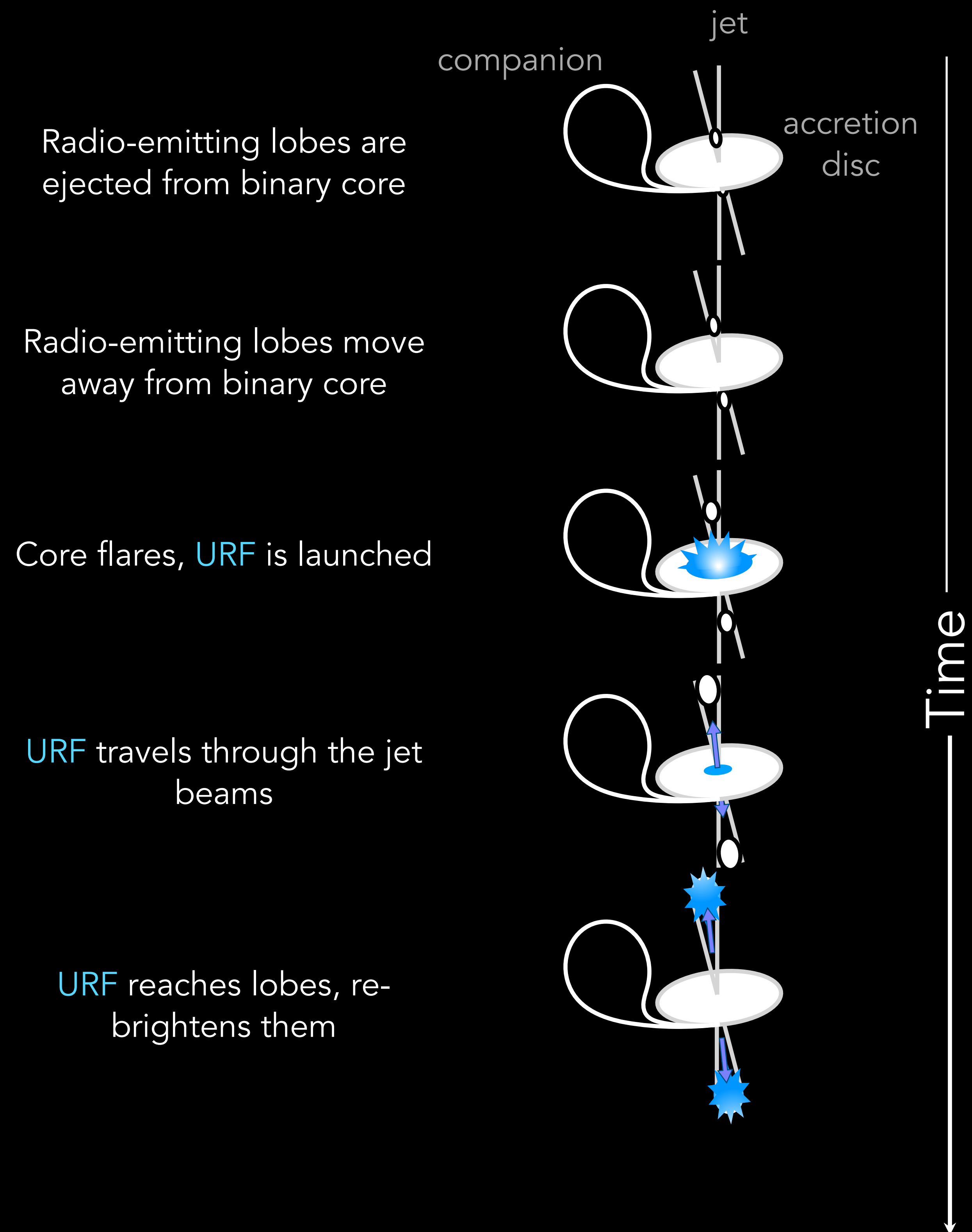



Fomalont et al. 2001a,b; Motta & Fender 2019

*Same as in black hole X-ray binaries*

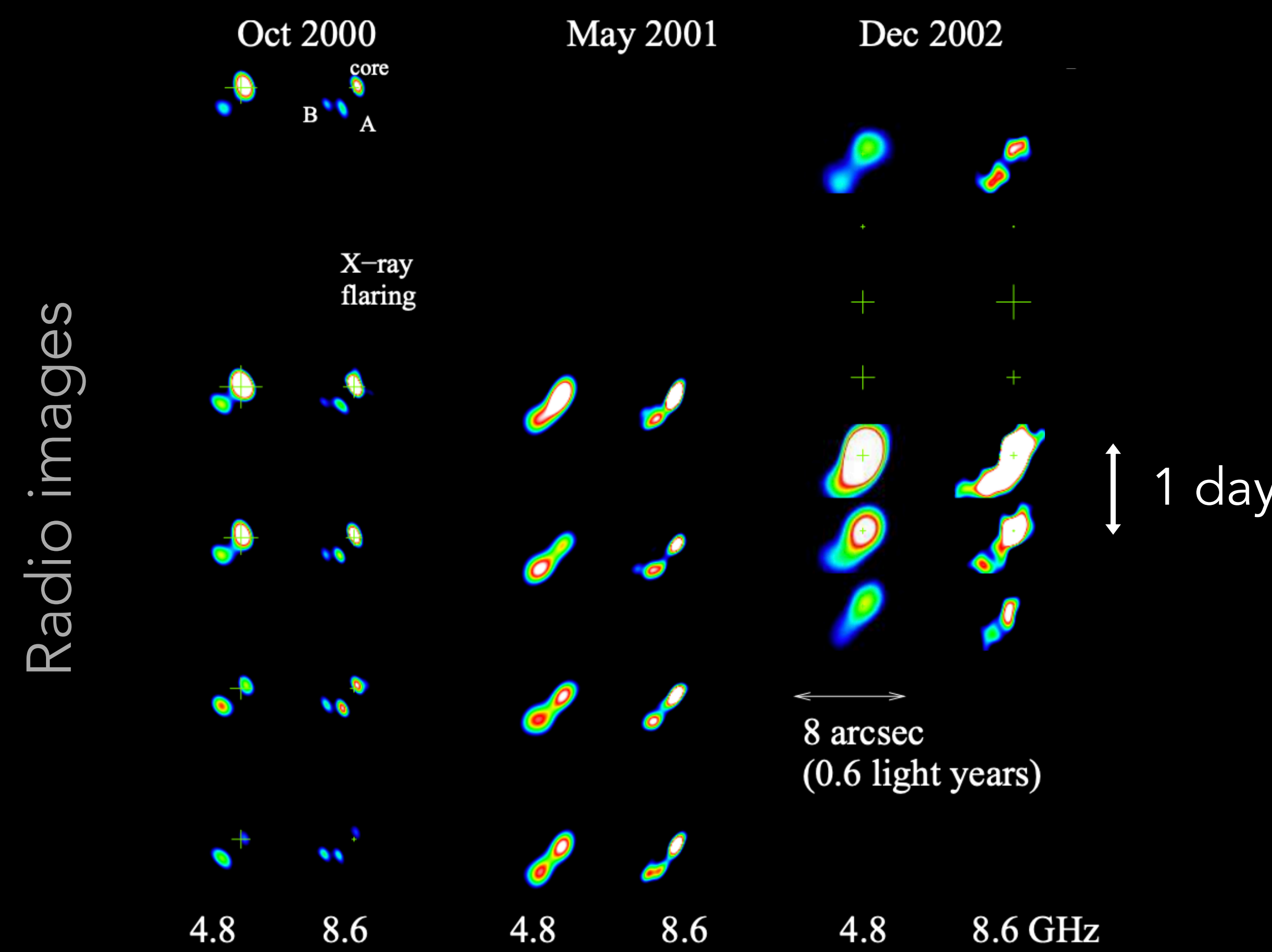
# ULTRA RELATIVISTIC OUTFLOWS

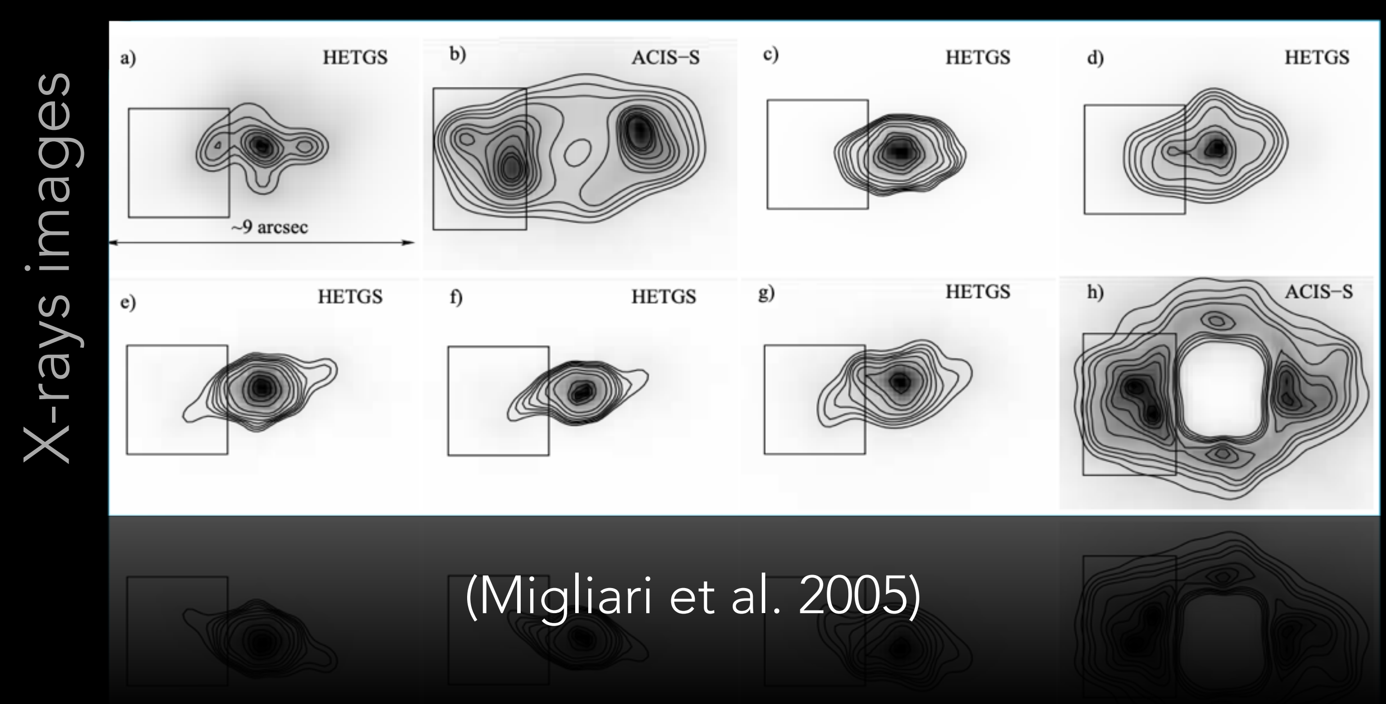



- **URFs are invisible**, can be observed only indirectly
- URFs travel along jet beams at ~the **speed of light**
- URFs energise radio jets making them re-brighten

# URFS IN OTHER SYSTEMS

Fender et al. 2004



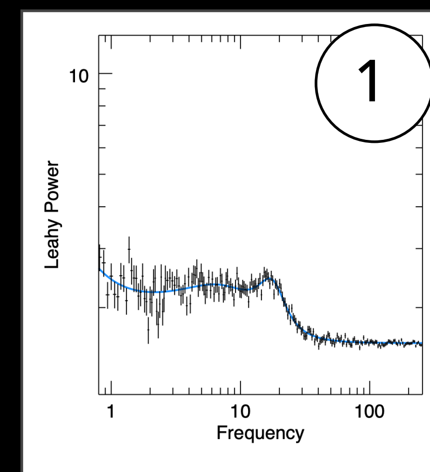



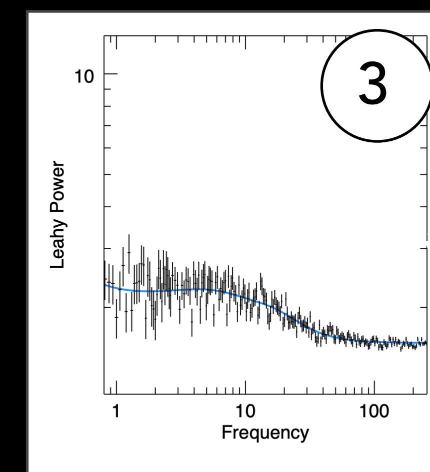

(Migliari et al. 2005)

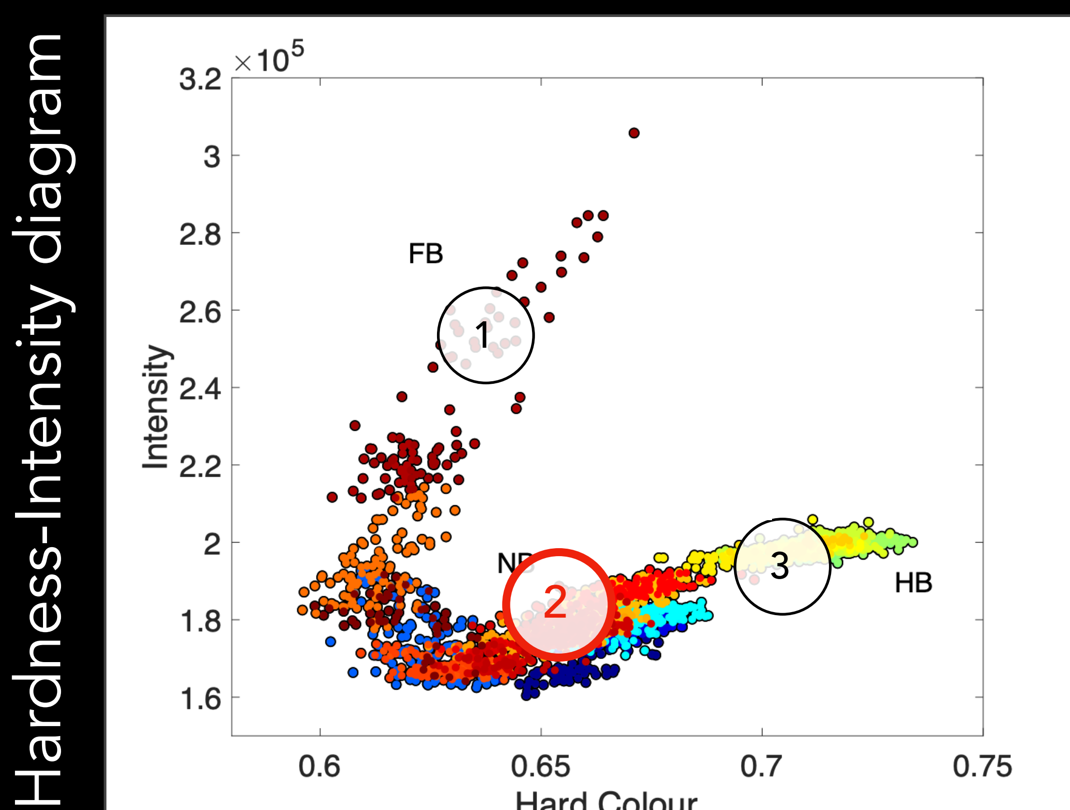
- URFs discovered in Cir X-1 on larger scales (arcsec)
- URFs found in SS 433 in the X-rays
- No URF in a confirmed black hole system

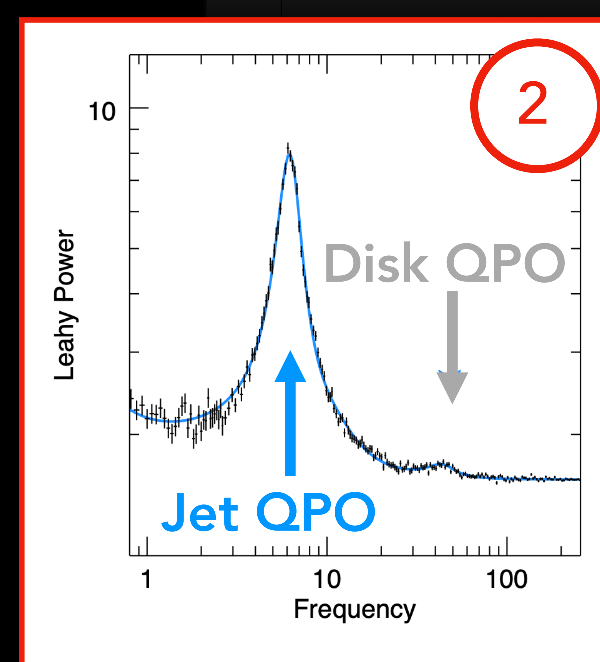
# DISK-JET CONNECTION VIA FAST TIME VARIABILITY

- Quasi-periodic oscillations (**QPOs**): features in power density spectra from X-ray light curves
- Different QPOs in different states



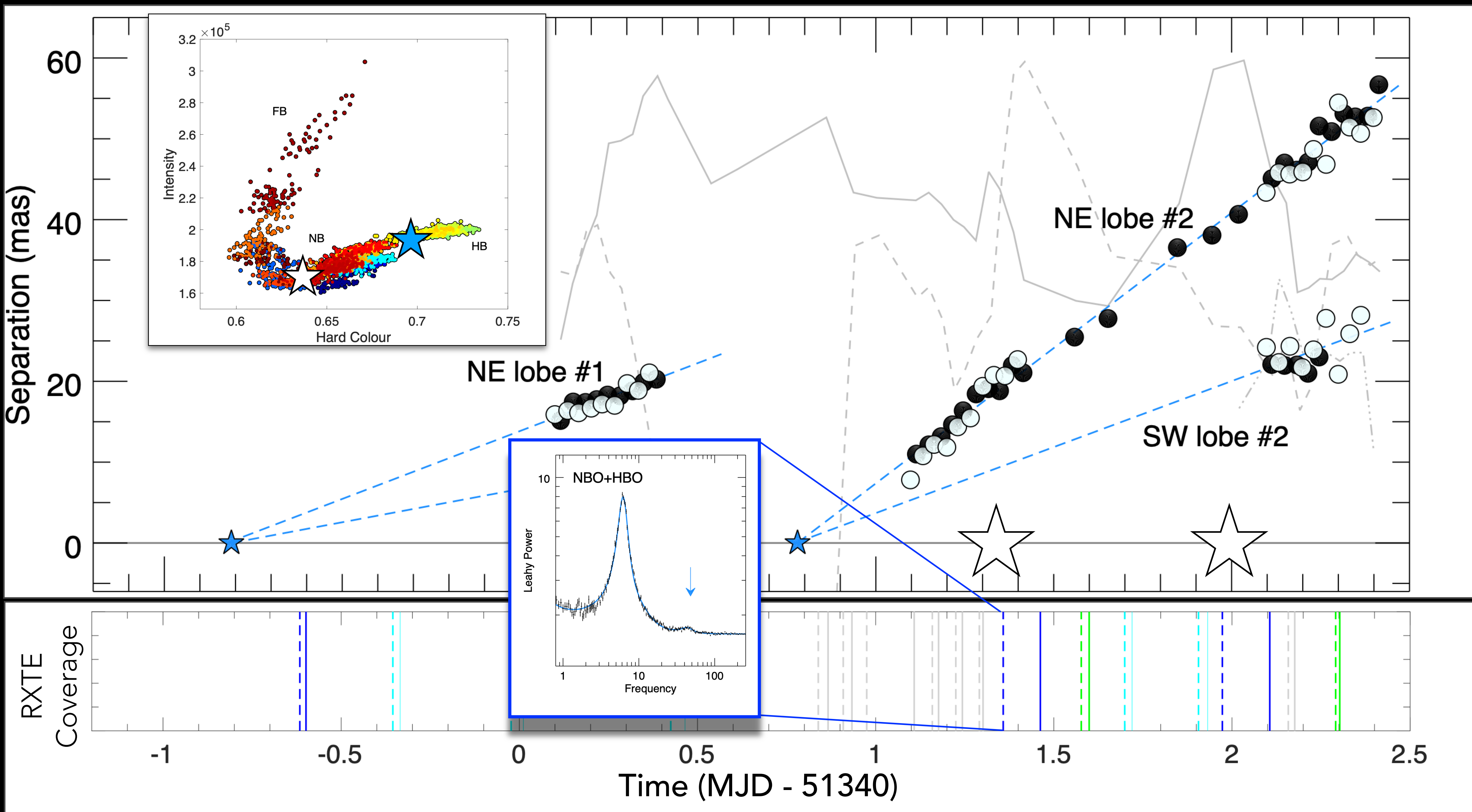




A very special (and rare) power density spectrum yielding **crucial info on the accretion disc**

# URFs ARE LINKED WITH A CLEAR ACCRETION FEATURE




Motta & Fender 2019

Lobes ejection

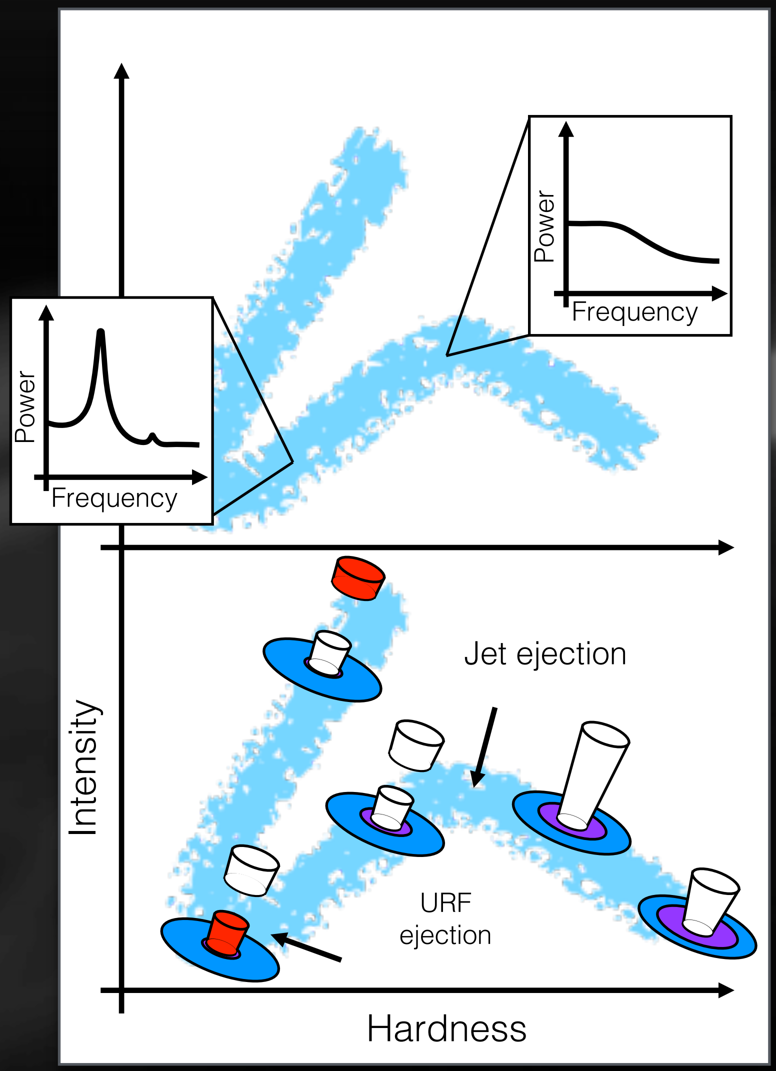
URF ejections

# ON THE DISC-JET COUPLING IN NEUTRON STARS

Neutron stars and black hole X-ray binaries show **same disc-jet coupling**

**BUT**

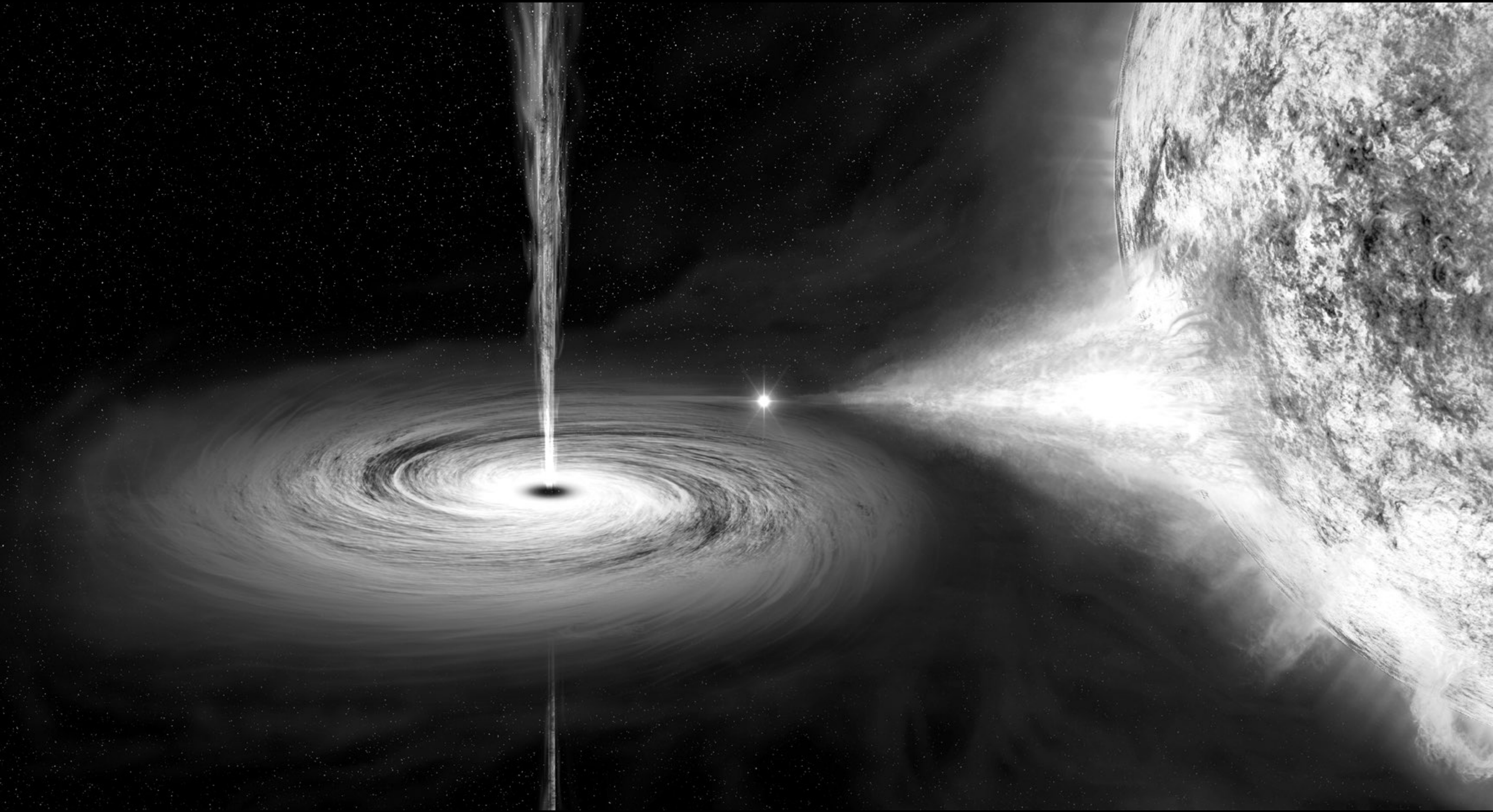
- **URFs have never been seen in black holes systems**
- URFs have a specific **disc-related X-ray signature**
- Relativistic jets have no special X-ray signature. Different from black hole binaries (maybe?)
- Small but very relevant differences between black hole and neutron stars binaries




Migliari & Fender 2006; Motta & Fender 2019

# SOME (UNSURPRISING) CONCLUSIONS


- X-ray binaries are excellent probes of **accretion and feedback in real time**
- Accretion and feedback follow the **same principles at all mass scales**: stellar mass BHs, NSs and SMBHs all follow the same rules
- Differences are in the **details!** NSs are the best control sample of BHs



Thanks!