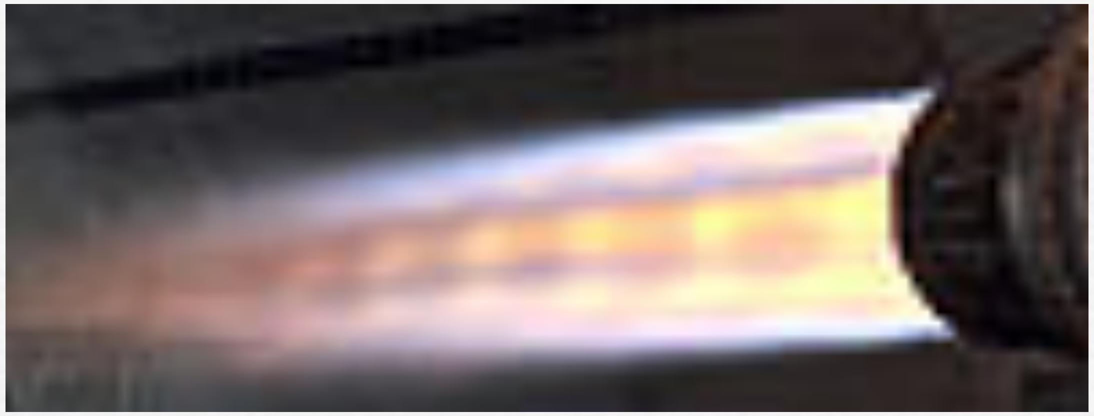


and jet engines!

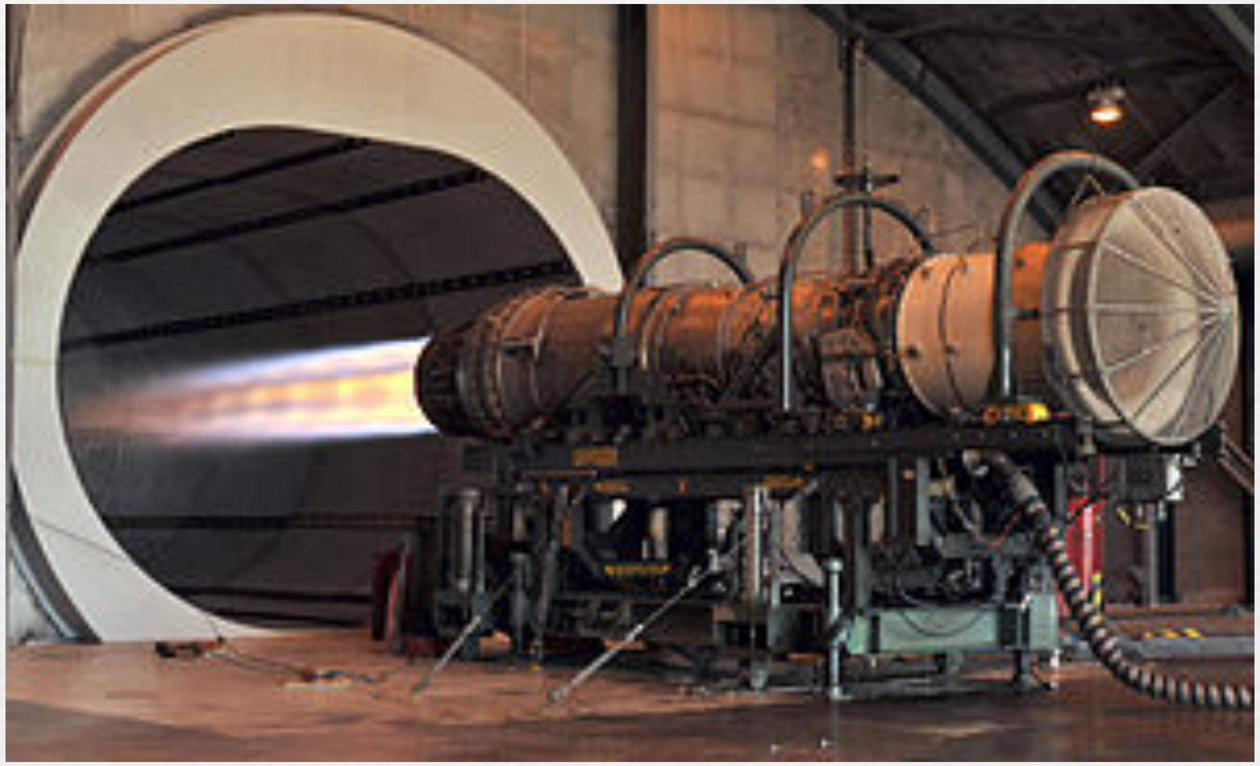
# Unification CV-BH-NS-ULX-AGN: Observation

Elmar Körding

Radboud University Nijmegen

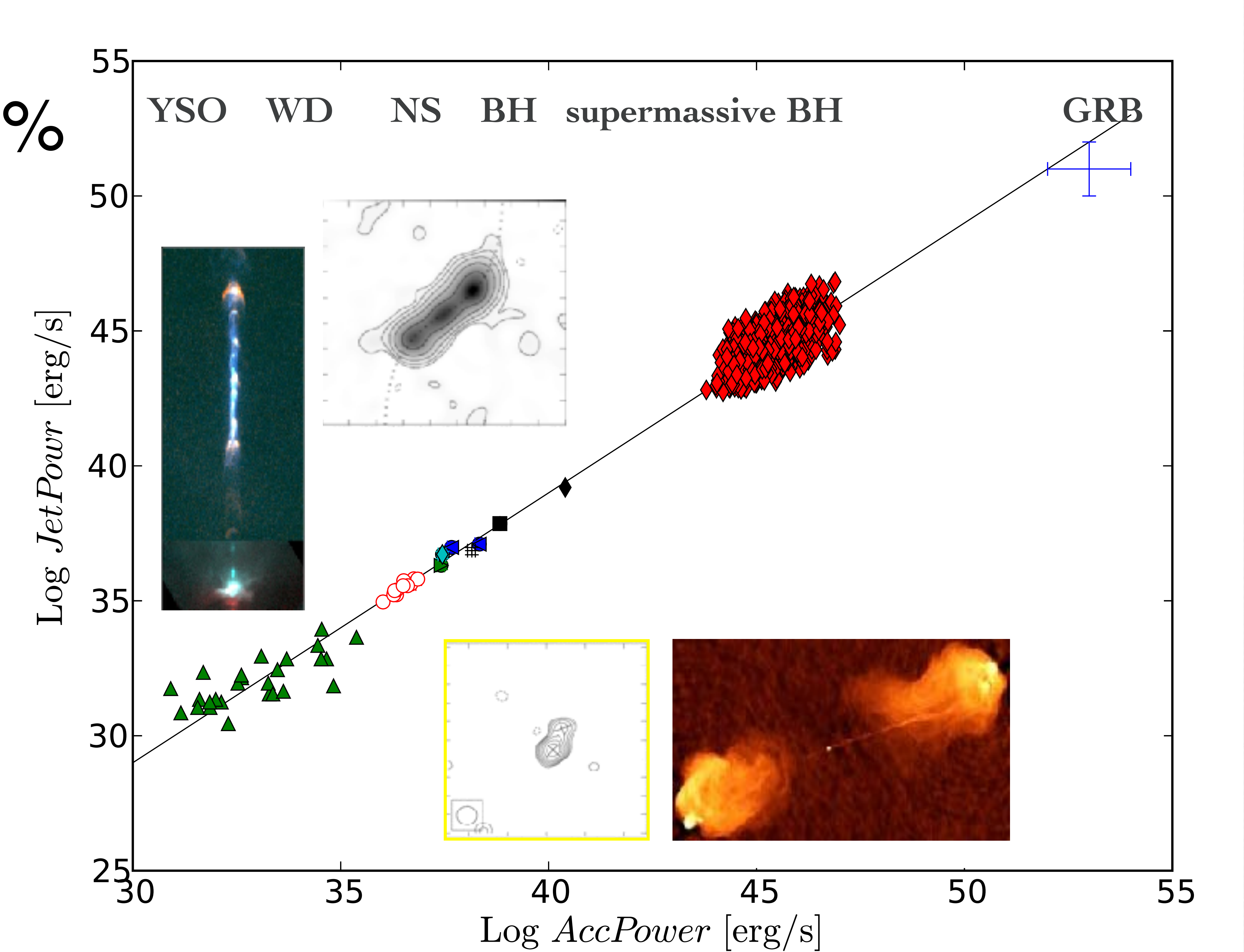
# Pratt F100

- Jet engine, clear signature of a jet coupled to a fuel line
- can observe sheath/spline structure
- Fuel Power 3e15 erg/s
- Jet power: 1.5e14 erg/s



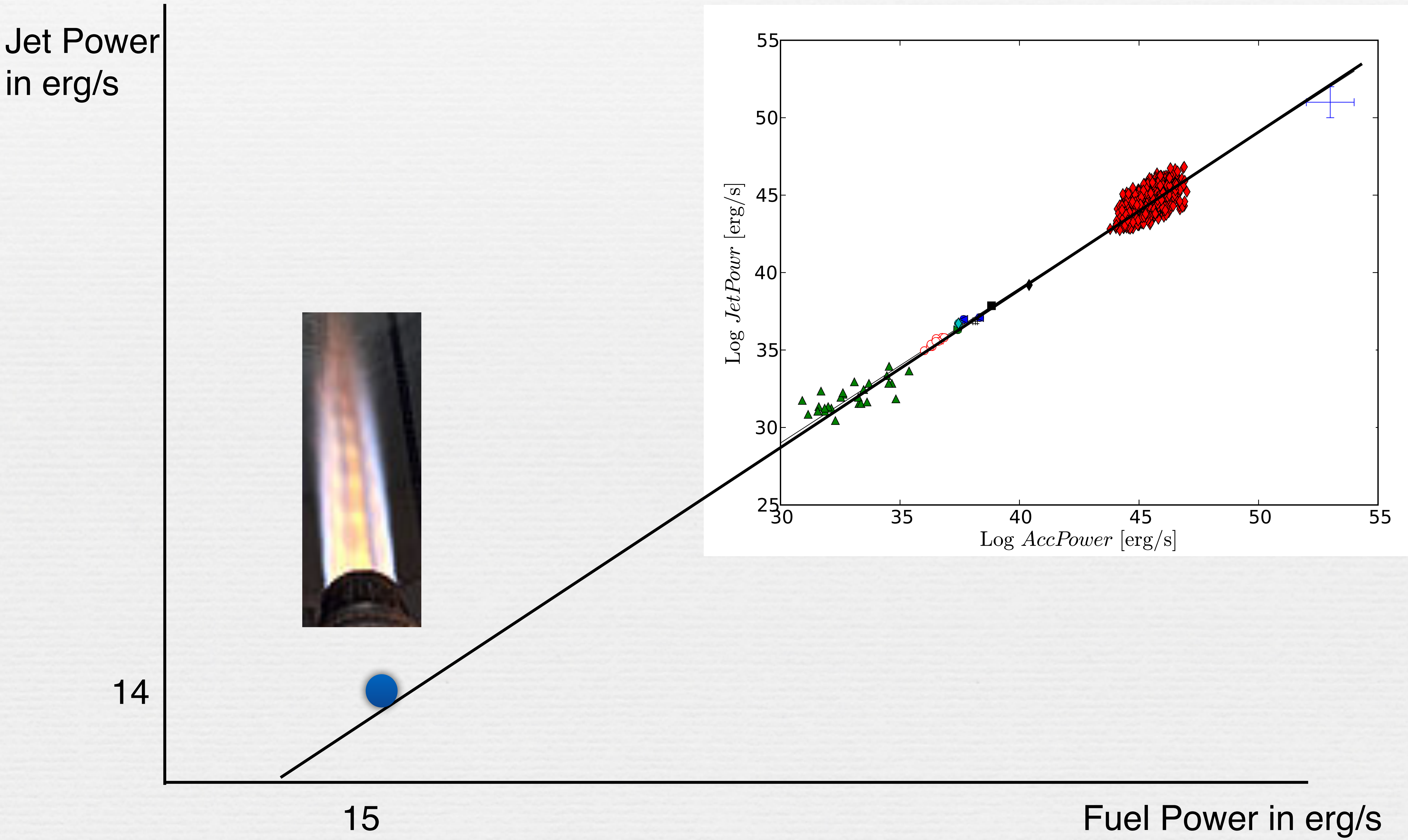
# Jets vs Accretion

10 %

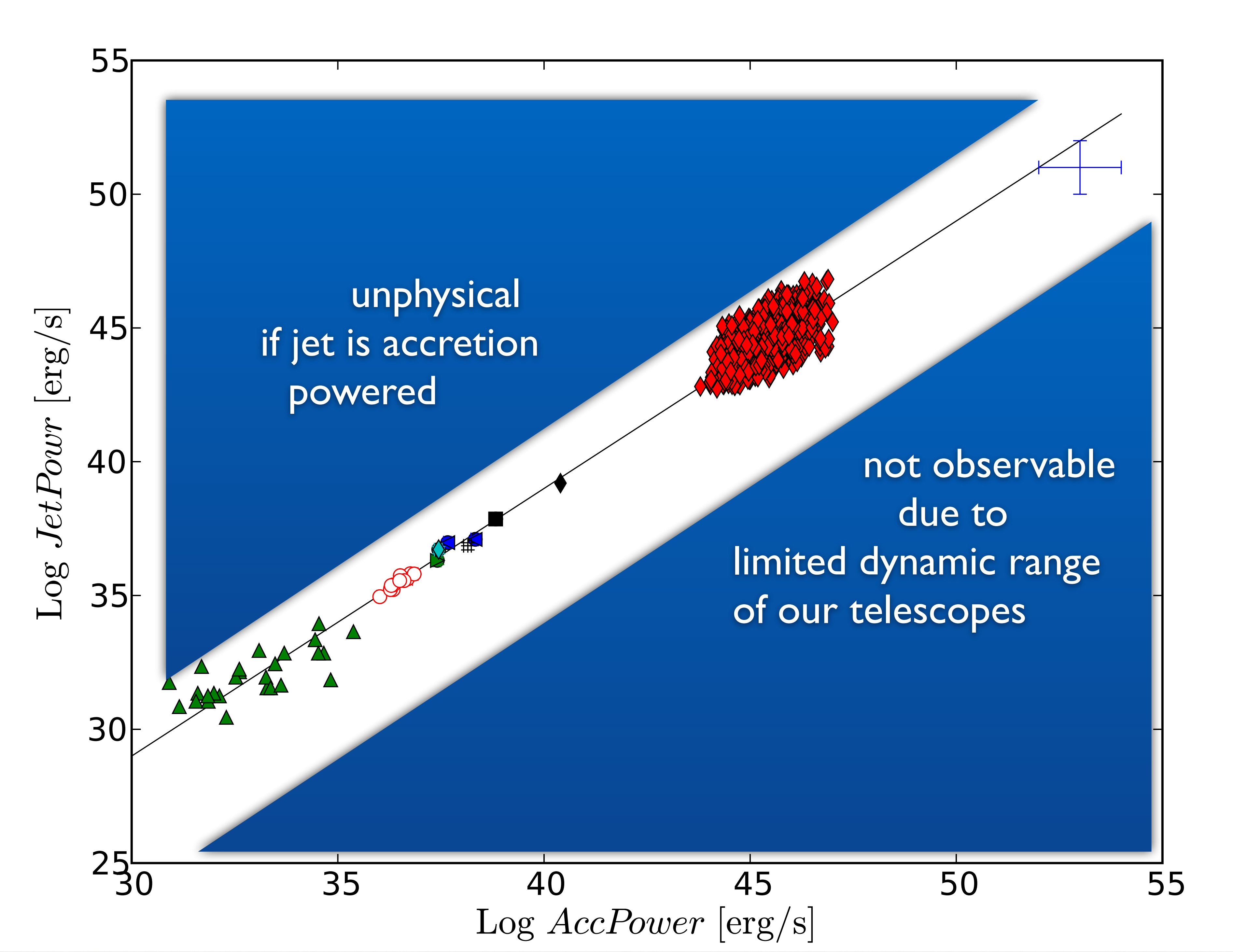



Tudose et al. 2008, Sterling et al. 2001, Crocker et al. 2007

# Jet engine vs Accretion



# Jets vs Accretion



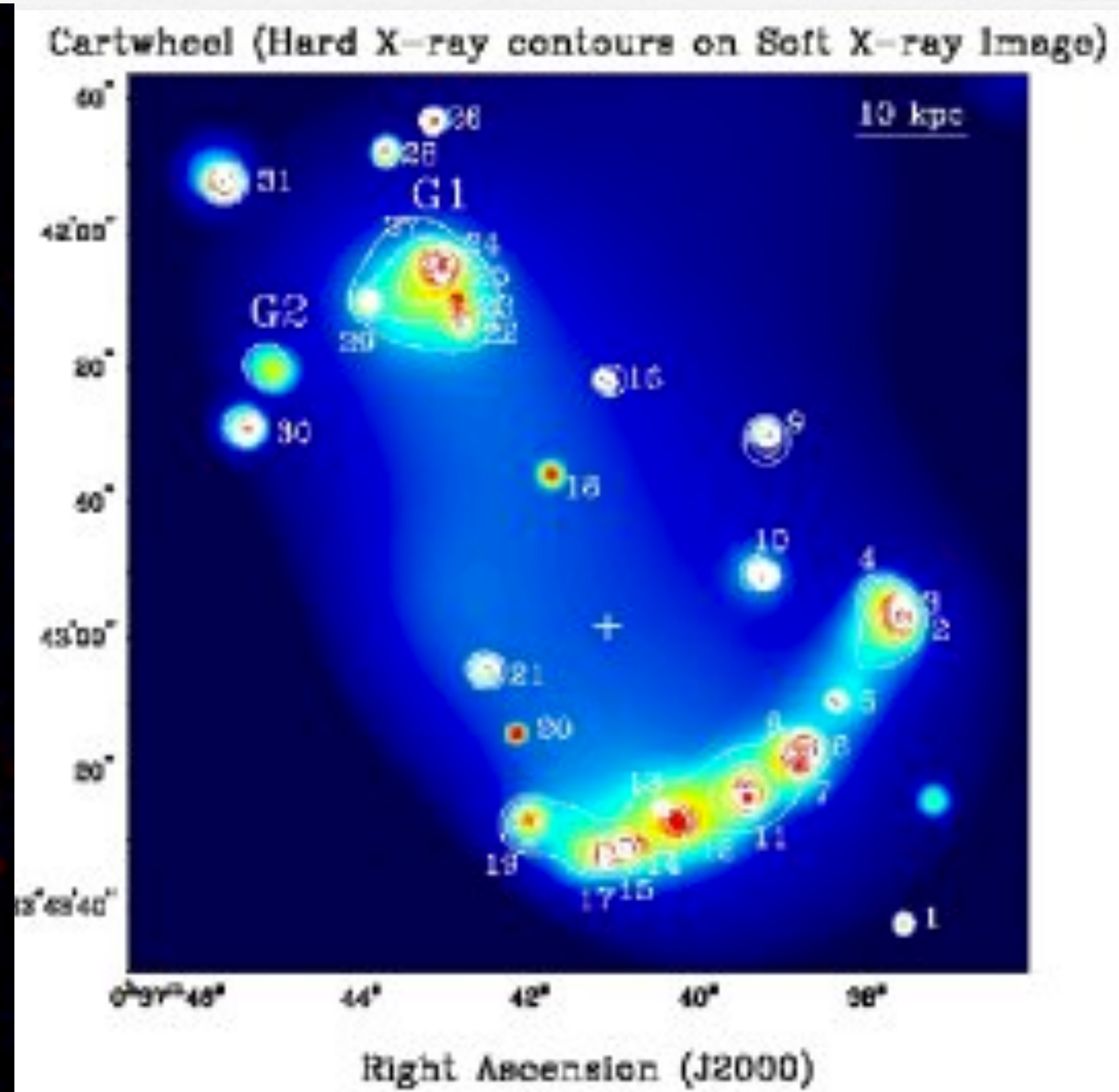

Simple mathematical check like partial correlation analysis or Monte Carlo simulations can check if any effect is an artefact

# Unification CV-BH-NS-**ULX**-AGN: Observation

Elmar Körding

Radboud University Nijmegen

# Ultra-luminous X-ray sources

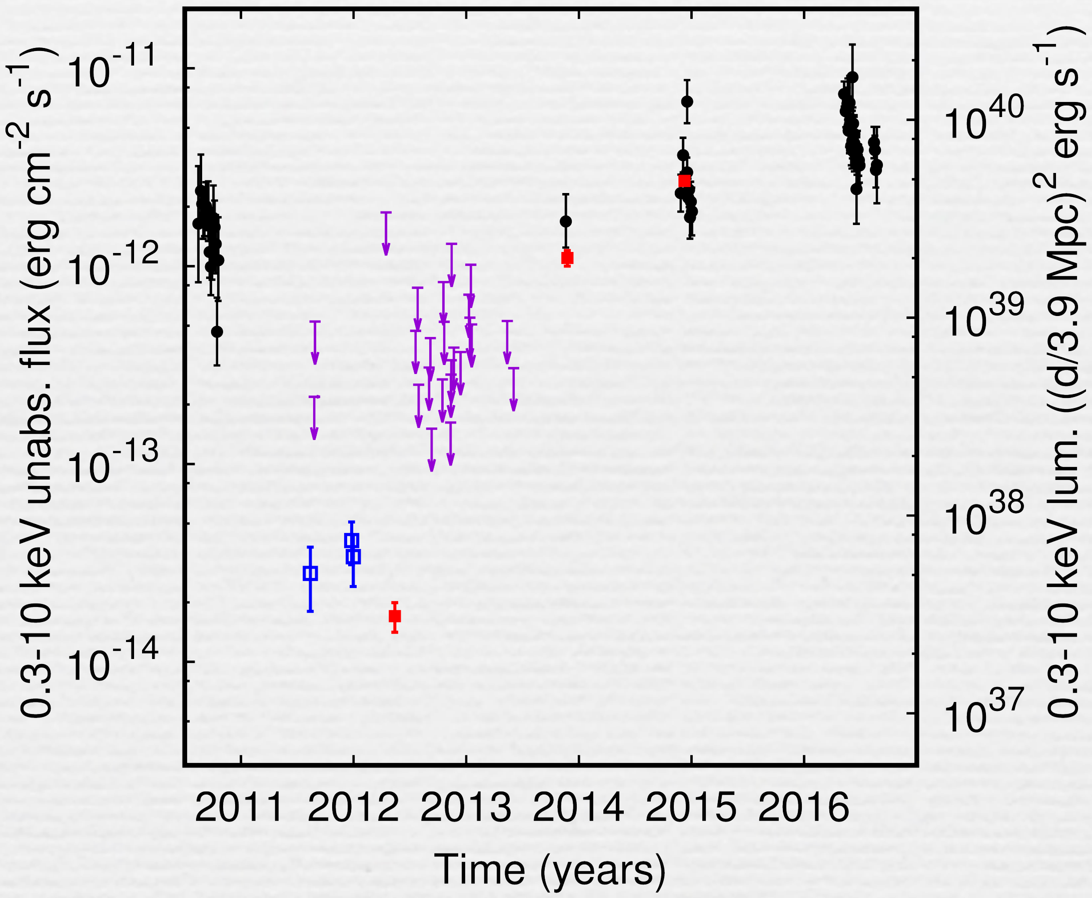



Off nuclear X-ray point sources with luminosities brighter than $\sim 10^{39}$ erg/s

Image credit: NASA/GALEX/Chandra/Hubble

# ULXs

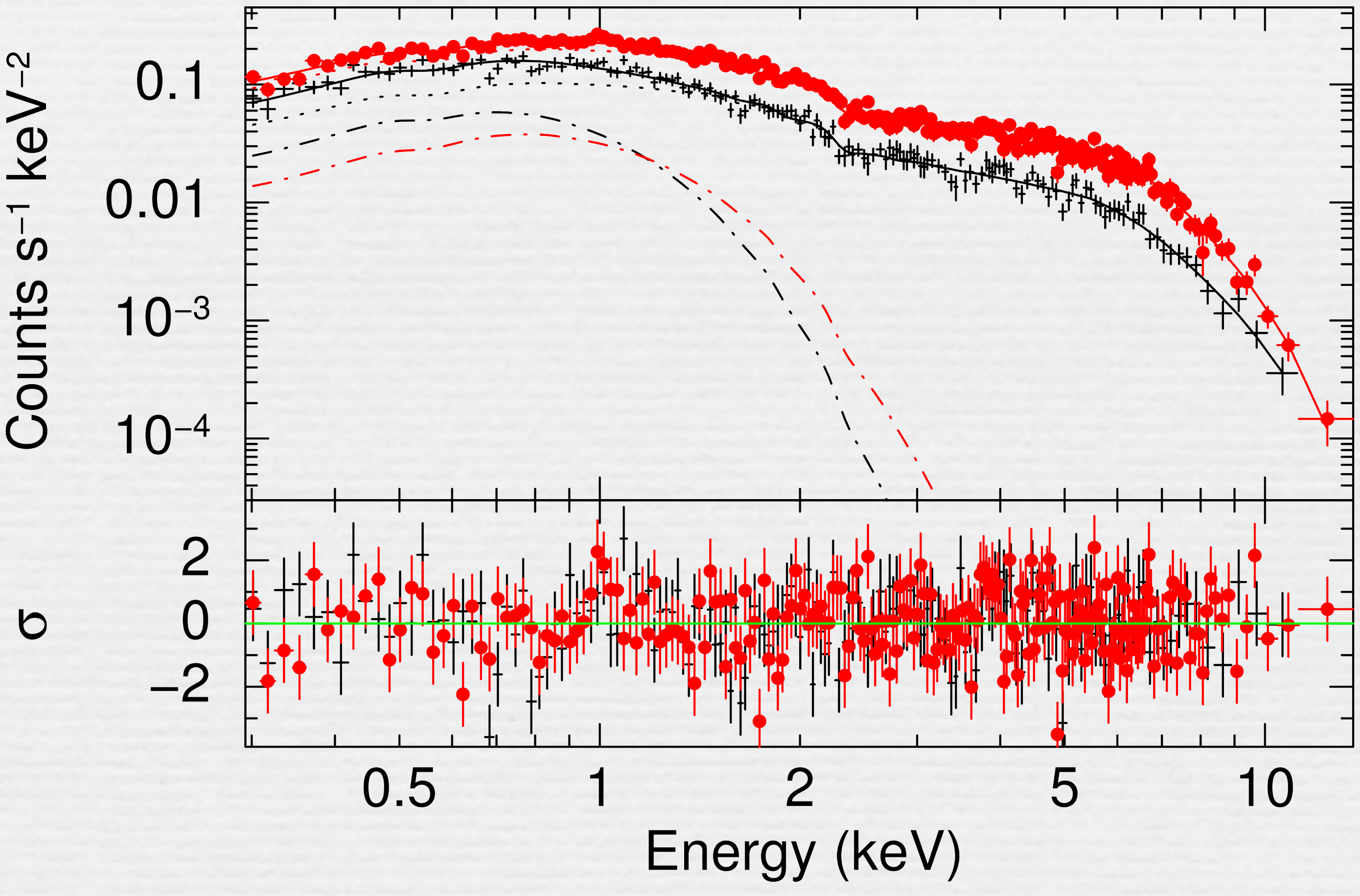
- Highly variable light-curves in the X-rays reaching up to $10^{42}$ erg/s
- high luminosities and low disc BB temperatures: ULXs might harbour IMBHs




NGC 7793 P13; Israel et al. 2017

# ULX spectra

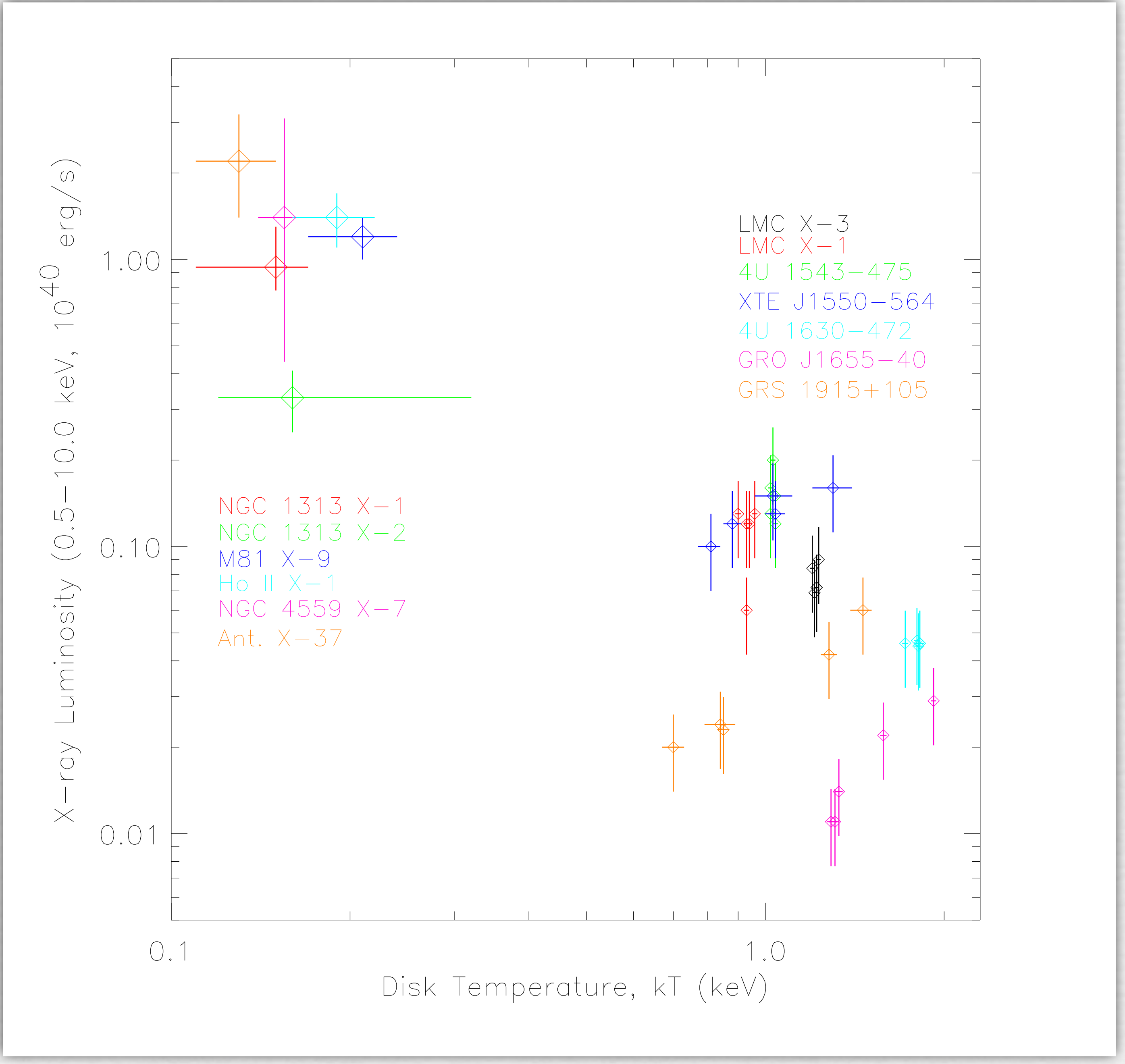
- Fit with absorbed power law + black body+high energy cut-off
- Low BB temperatures around 0.2 keV




NGC 7793 P13; Israel et al. 2017

# Low BB temperatures common

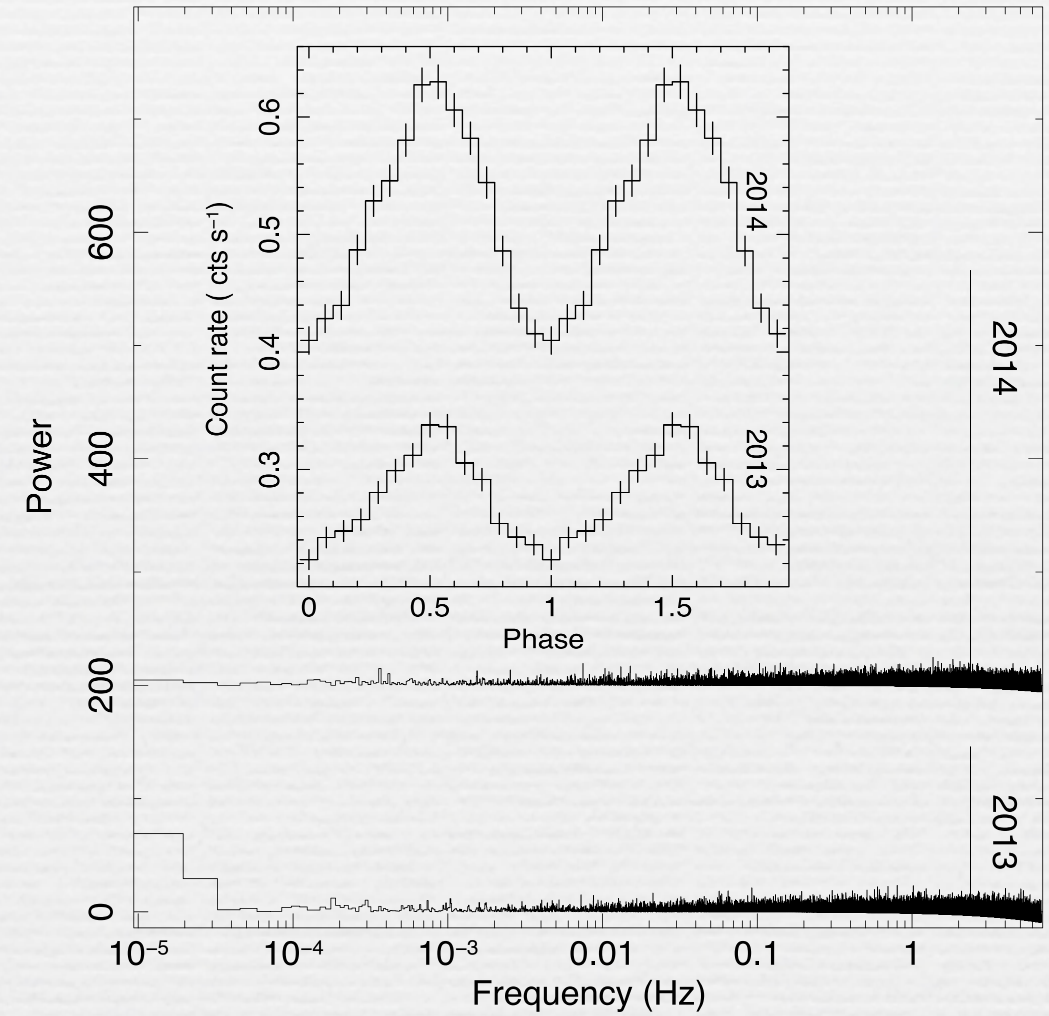
- ULXs show low temperature BBs in their spectra
- BUT at least in some cases the source could not be an IMBH:
  - e.g., Motch et al. 2014 found a 64 day orbit in NGC 7793 P13; constrain mass to be below 14 Msol




Miller et al. 2004

# ULXs can be neutron stars

- Bachetti et al. 2014 find pulsations with NUSTAR in one ULXs (M82-X2)
- subsequently found in at least 3 ULXs
- brightest NGC 5907 ULX-1 with $10^{41}$ erg/s or ~ 500 * Eddington
- All pulsars spinning up rapidly

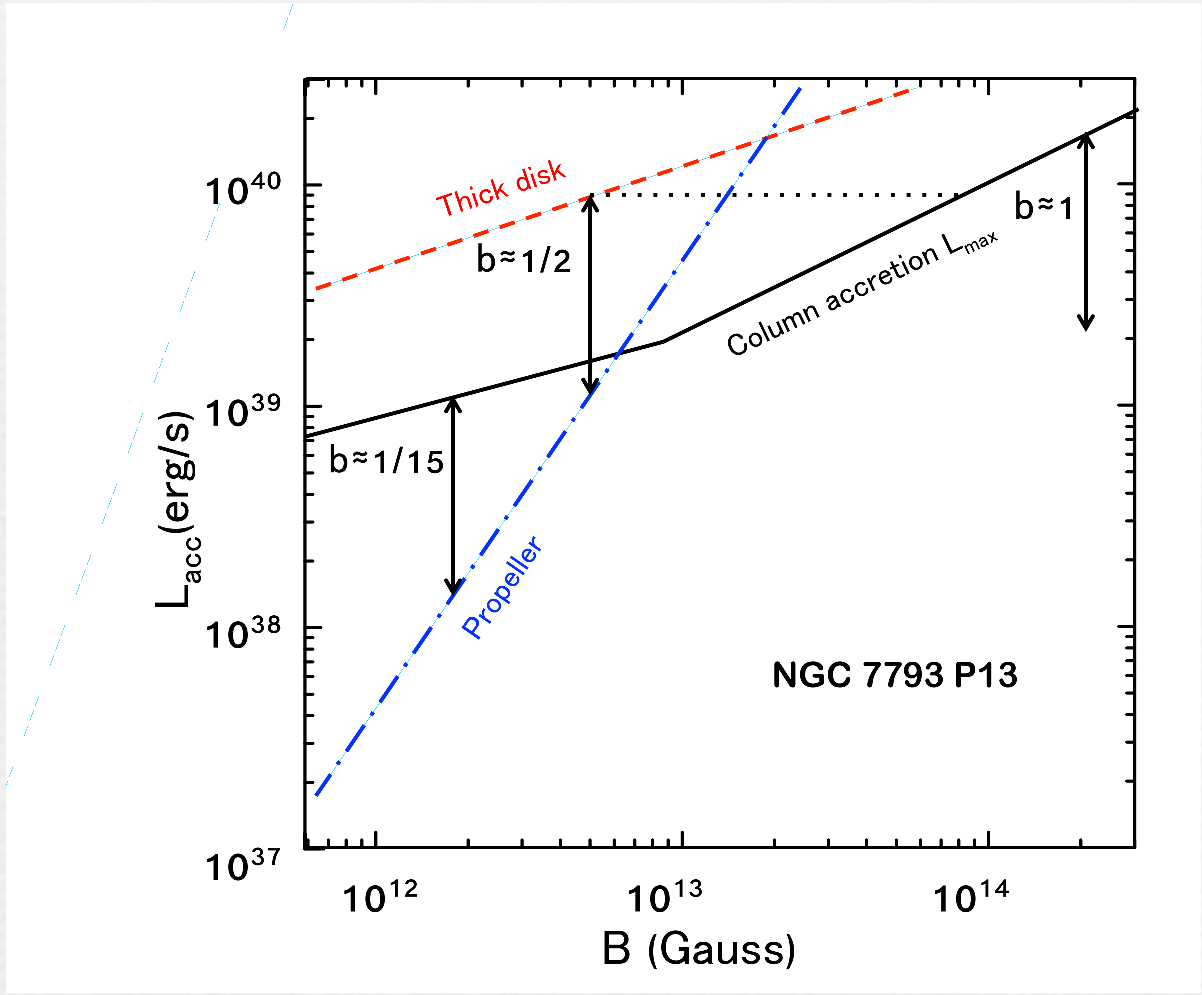



NGC 7793 P13; Israel et al. 2017

# Neutron star ULXs

- Ultra-luminous state of NS
  - show low BB temperature; variability; spectral curvature
- ULX Pulsars seems to require high magnetic fields/ accretion rates
- There could be BH ULXs out there, but the IMBH argument is typically weak now given the NS ULXs

Column accretion onto the NS poles

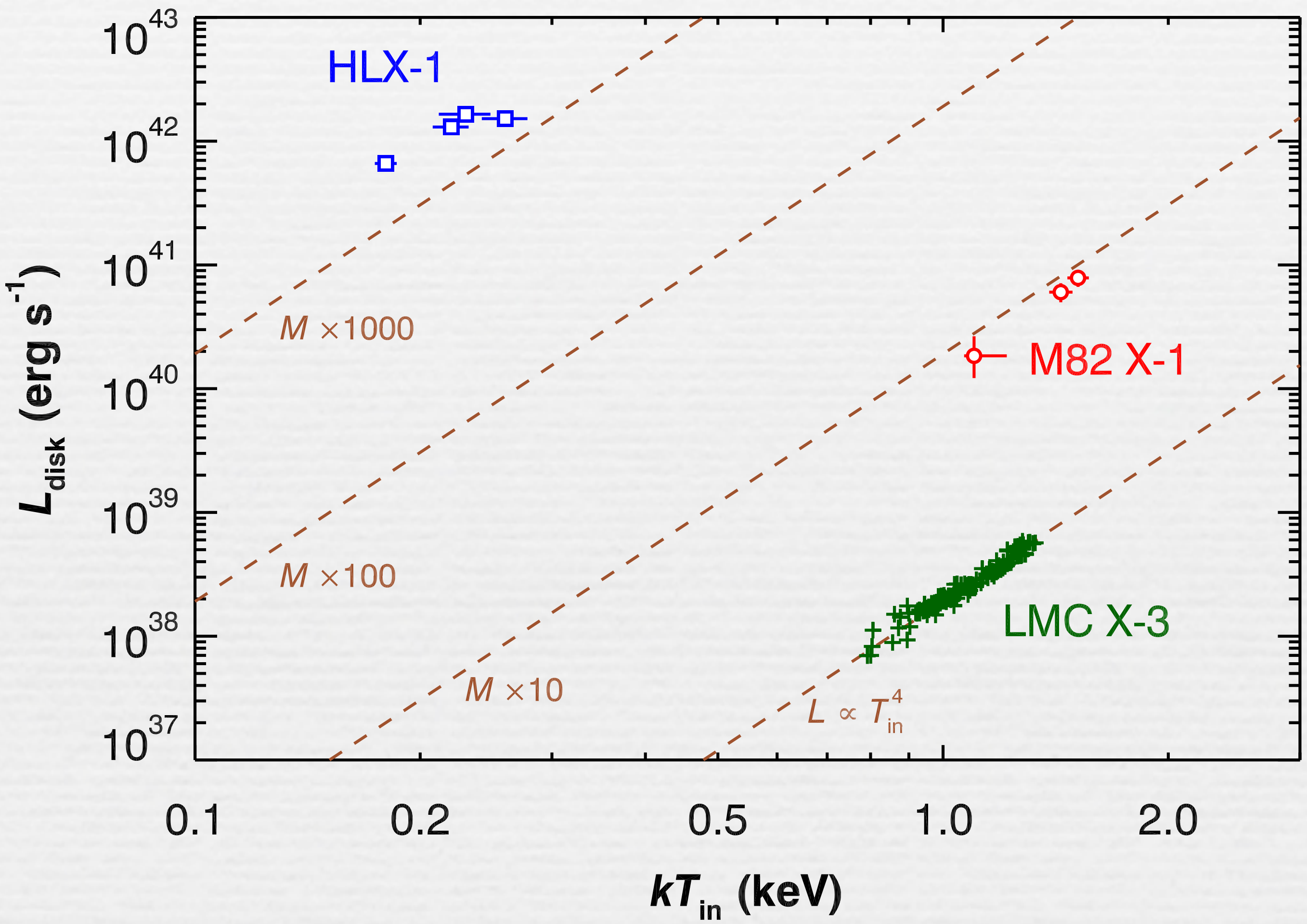



NGC 7793 P13; Israel et al. 2017

see theory talk how to unify with black holes

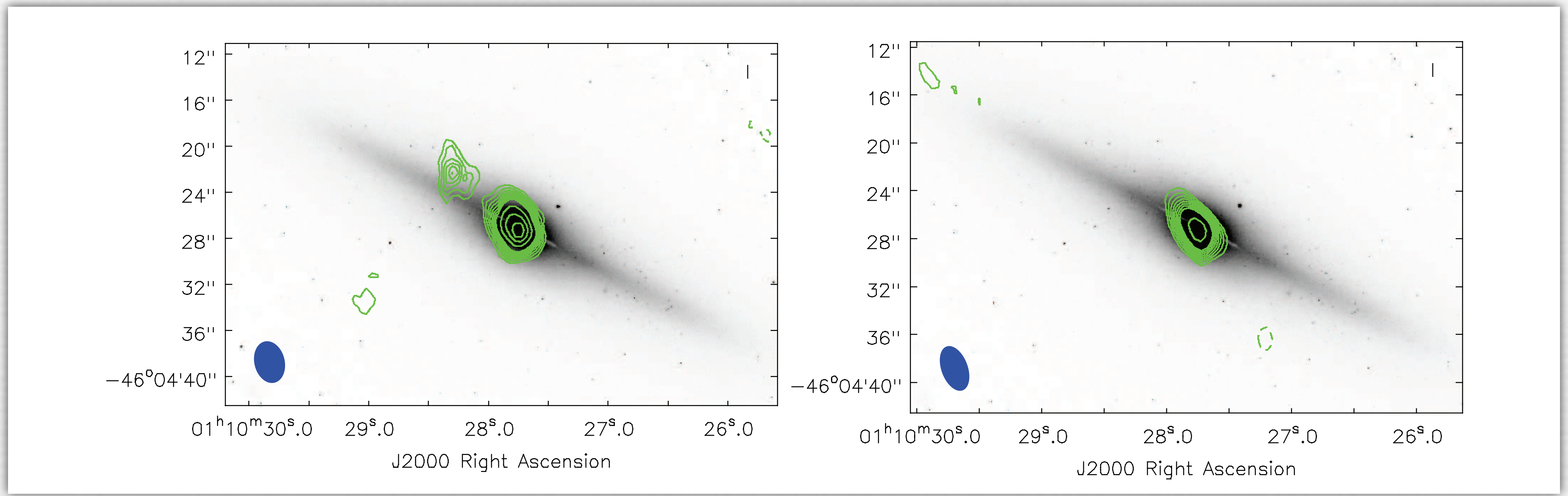
# Space for BHs

- One source: HLX-1 does show luminosities so high: unlikely a neutron star
- H-alpha line velocities relative to nucleus and rotational velocity suggest it may the stripped down remnant of a dwarf galaxy, i.e. a galactic nucleus at the low mass end




Kaaret et al. ARAA 2017

# HLX-1




- ATCA Images of HLX-1
- Clear variability in the radio band consistent with compact jet emission

In the context of unification this can be viewed as a small supermassive black hole if it is the remaining nucleus of a dwarf galaxy

Webb et al. 2014; Cseh et al. 2014

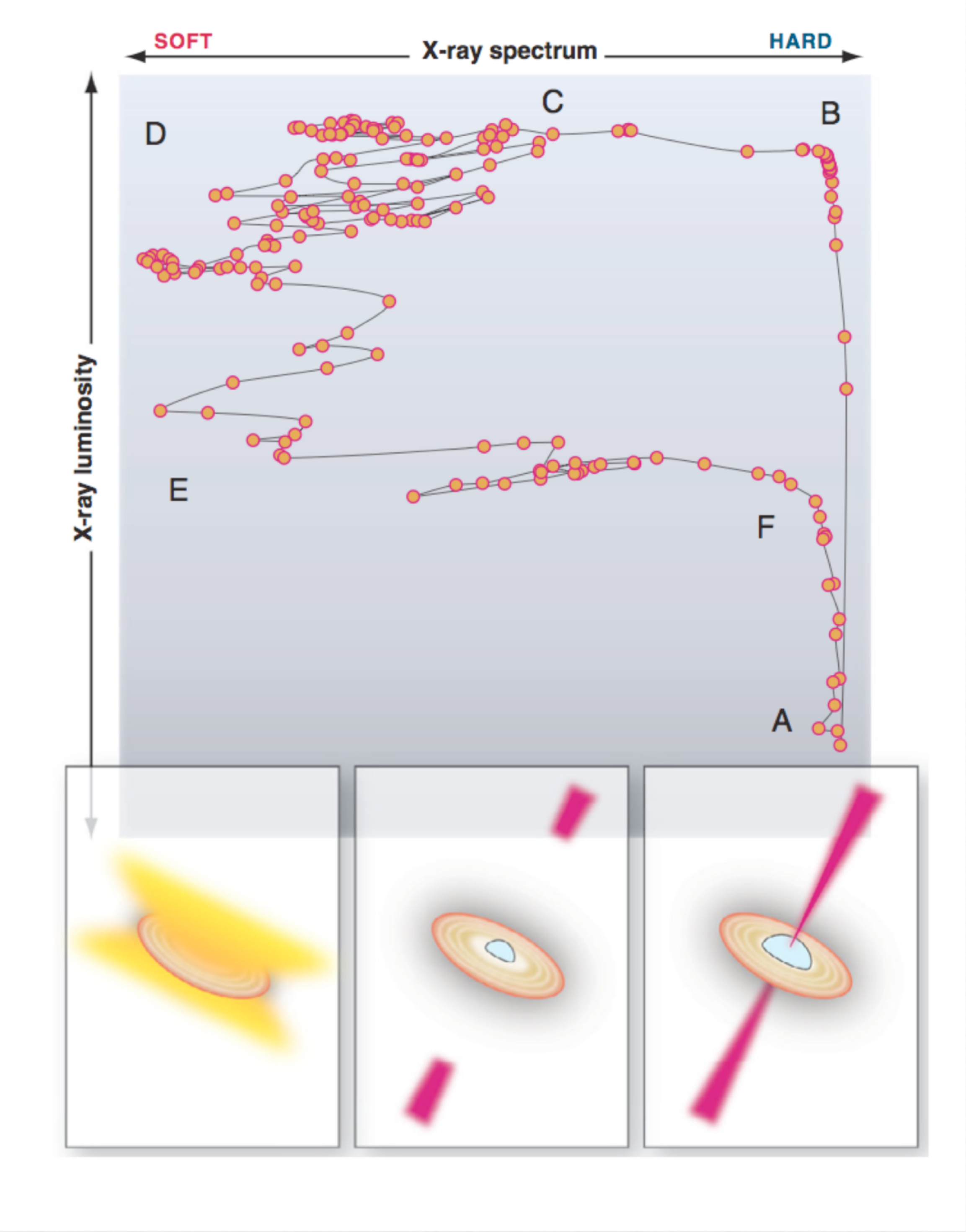
# Unification CV-BH-NS-AGN: Observation or Accretion onto compact objects

Elmar Körding

Radboud University Nijmegen

# The aim

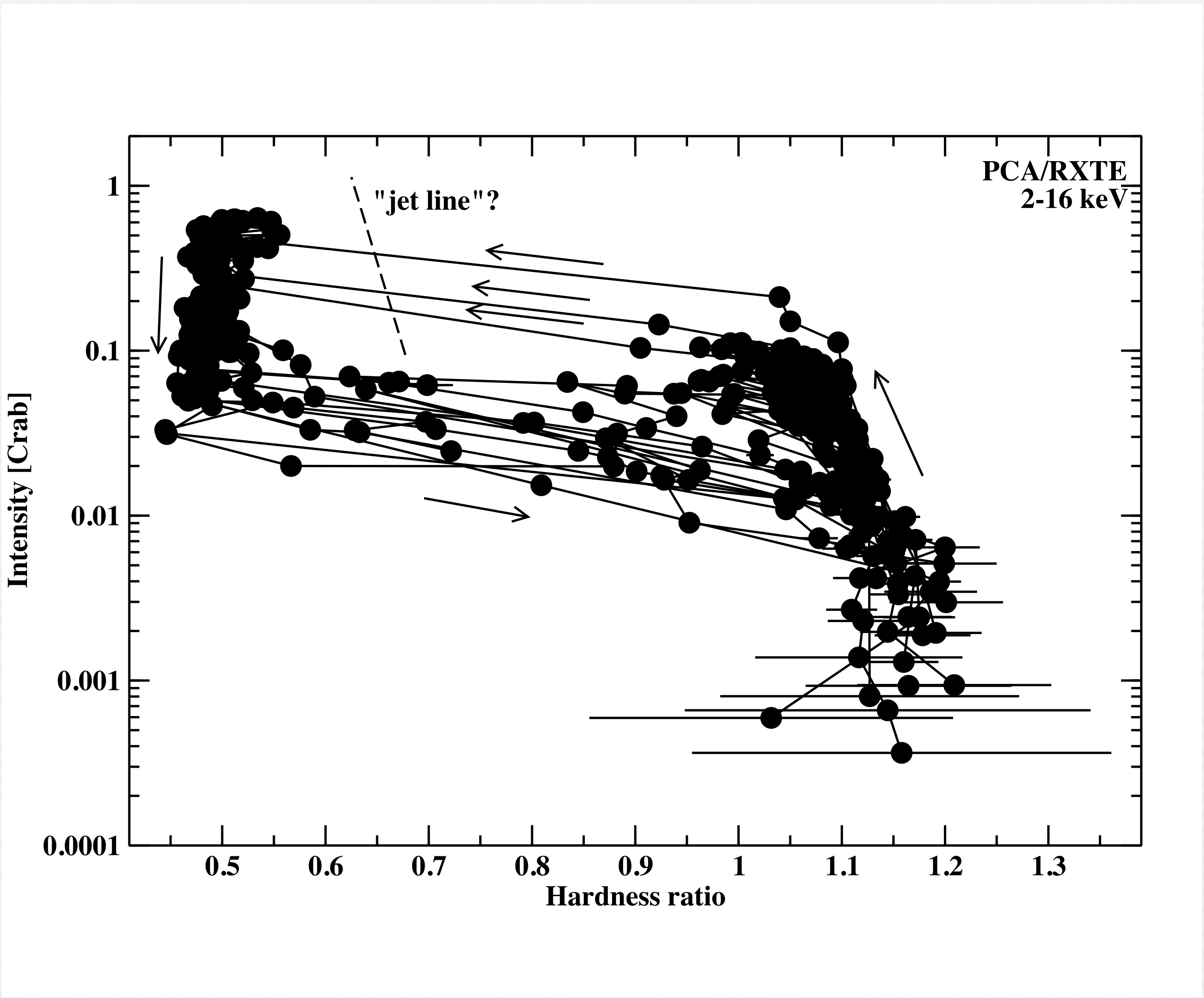
- Empirical model for discs and jets as a function of accretion rate
    - Clear spectral states
- Can this picture be scaled to other non-magnetic source classes?
- These phenomena are created inside a small radius of ~100 $R_G$
    - scaling may be possible




Fender, Gallo 2014; Talk by Rob

# Neutron stars: Aql X-1

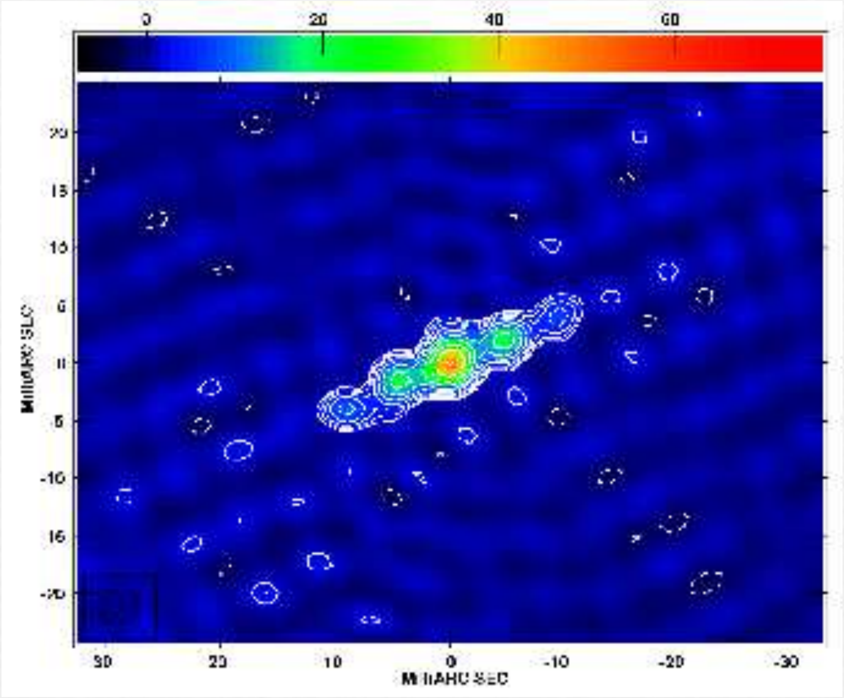
- Aql X-1 similar HID compared to BH XRBs
- Similarities for NS and BH XRBs not too surprising as stellar radius same order of magnitude as ISCO of a corresponding BH

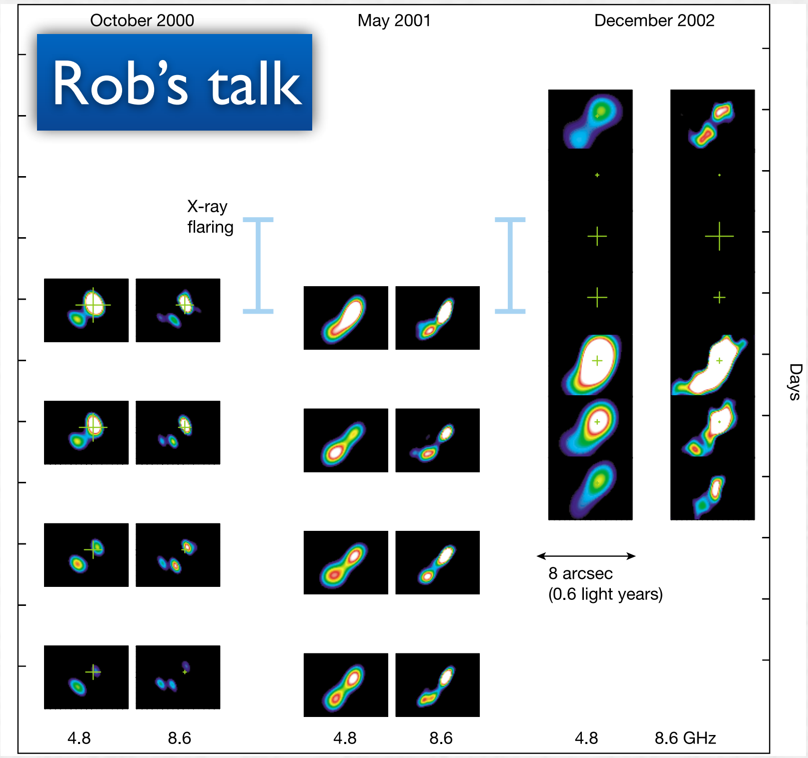



Tudose et al. 2009

# NS show relativistic jets

- Radio jets imaged: from mas scale to arc minutes,
  - from compact jet (albeit not stable) to ejections events
- Superluminal components
- Very similar behaviour as seen in black hole XRBs

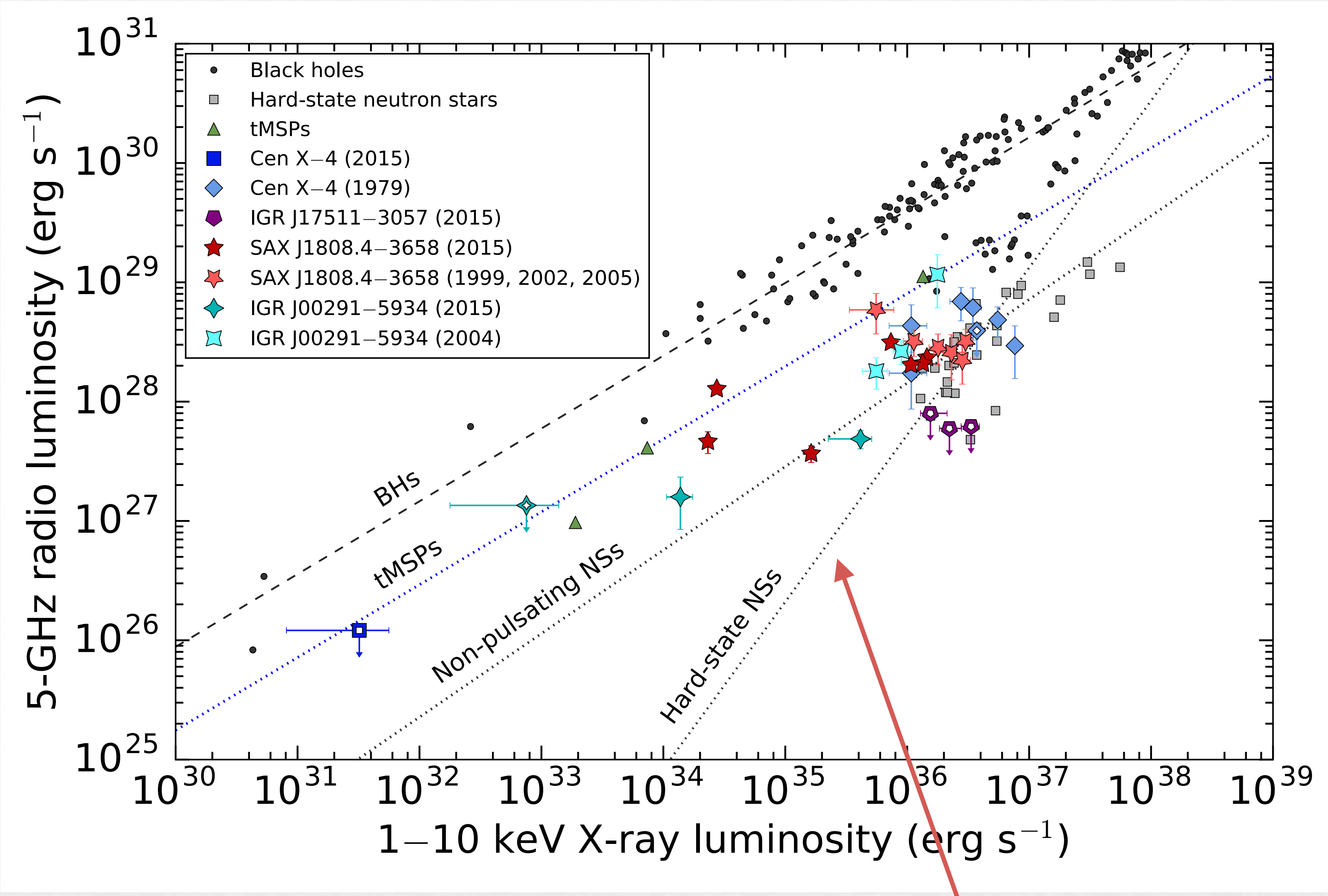



Miller-Jones et al. 2011; Fender et al. 1998; Fender et al. 2004 + many others

# Radio/X-ray correlation

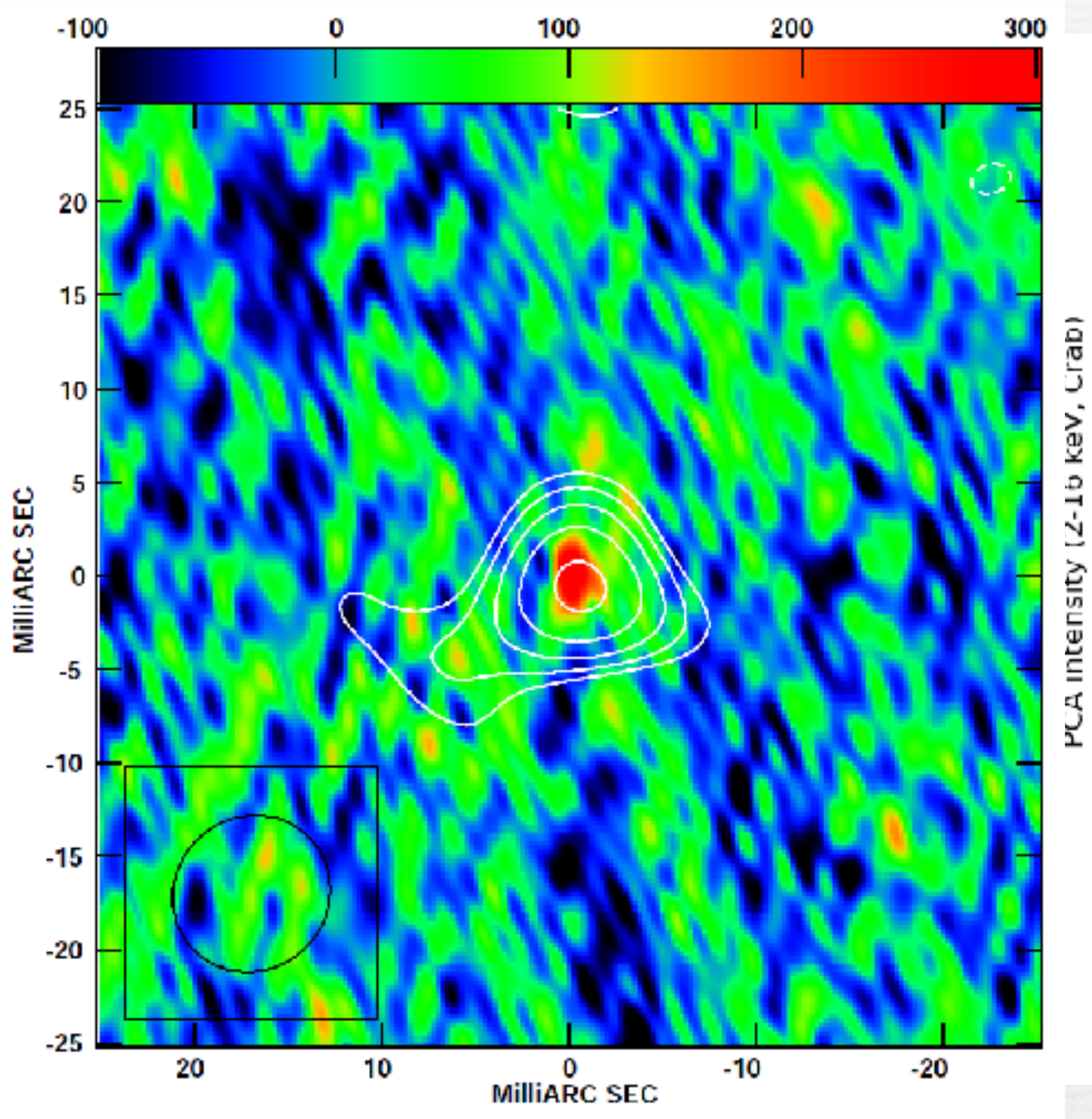
- Radio/X-ray correlation found in NSs and BH systems.
- NSs seem to show less radio emission for a given X-ray flux
- Some NS XRBs may show a similar correlation index than BHs. How is this possible?

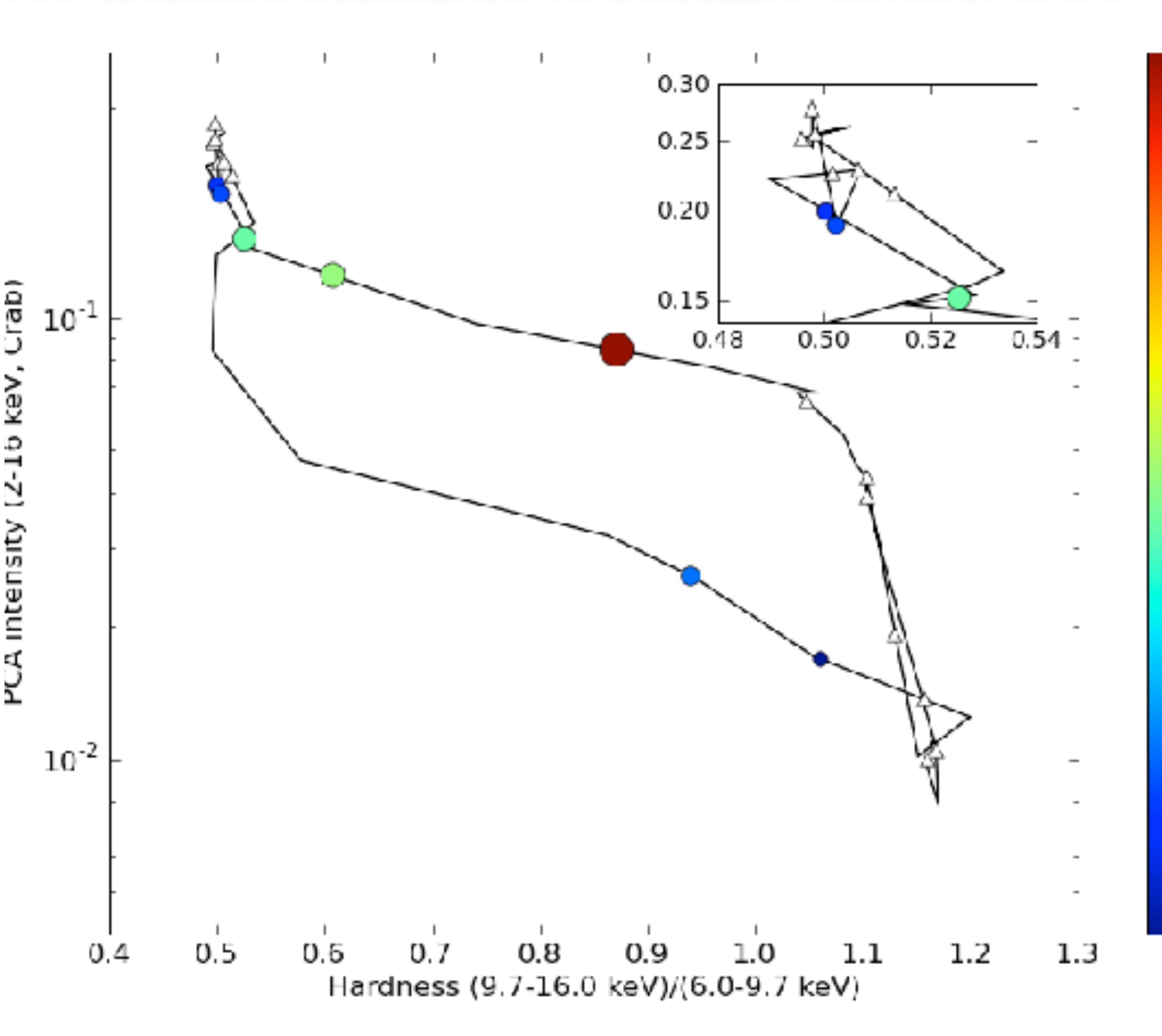



The hard state branch might still be the main branch for well behaved "hard" state NS XRBs, see poster by Nina Gusinskaia

Tudor et al. 2017

# XRB Monitoring of the neutron star Aql X-1

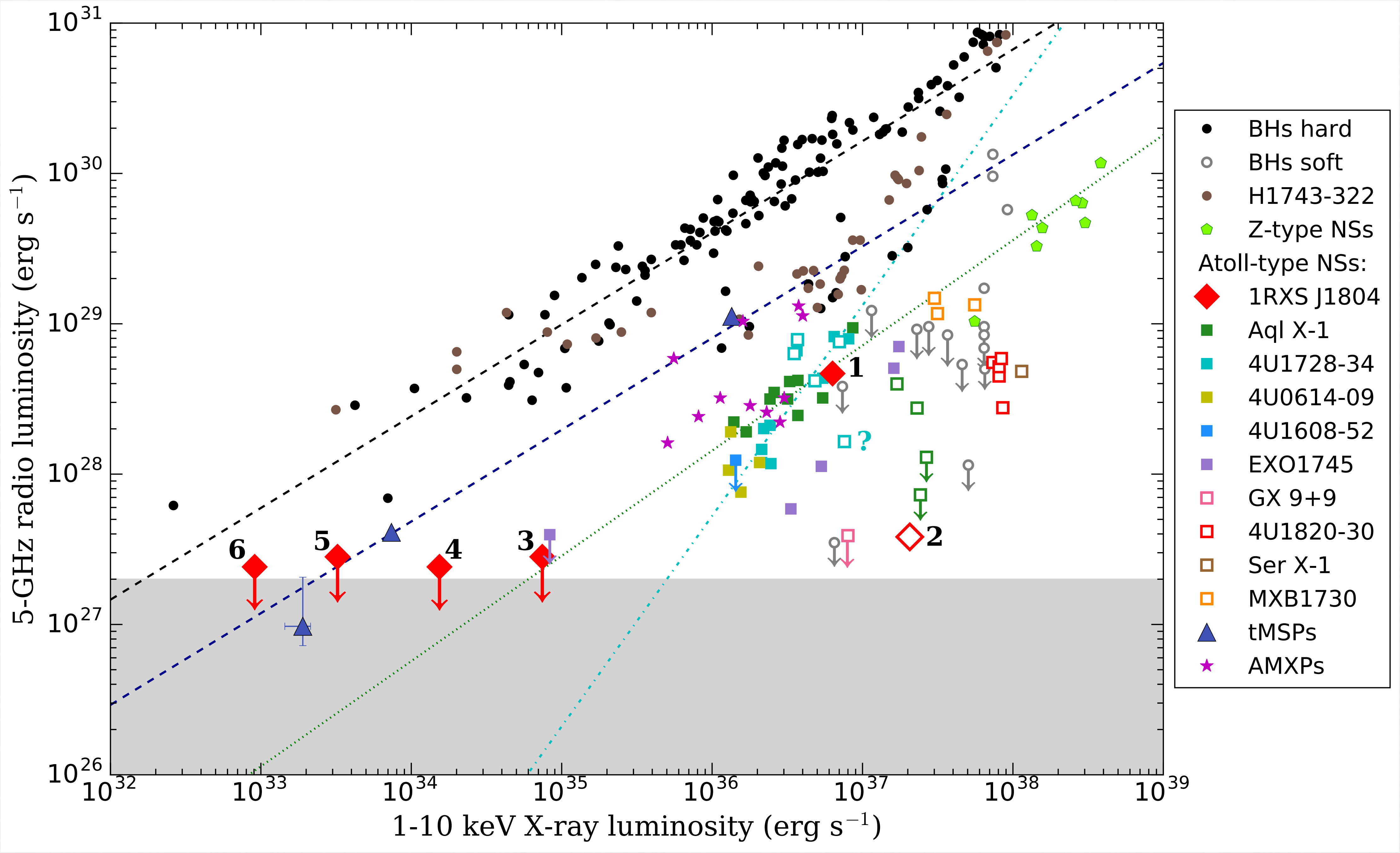



Radio jet quenched when going into the hard state as in black holes

Miller-Jones et al, 2010

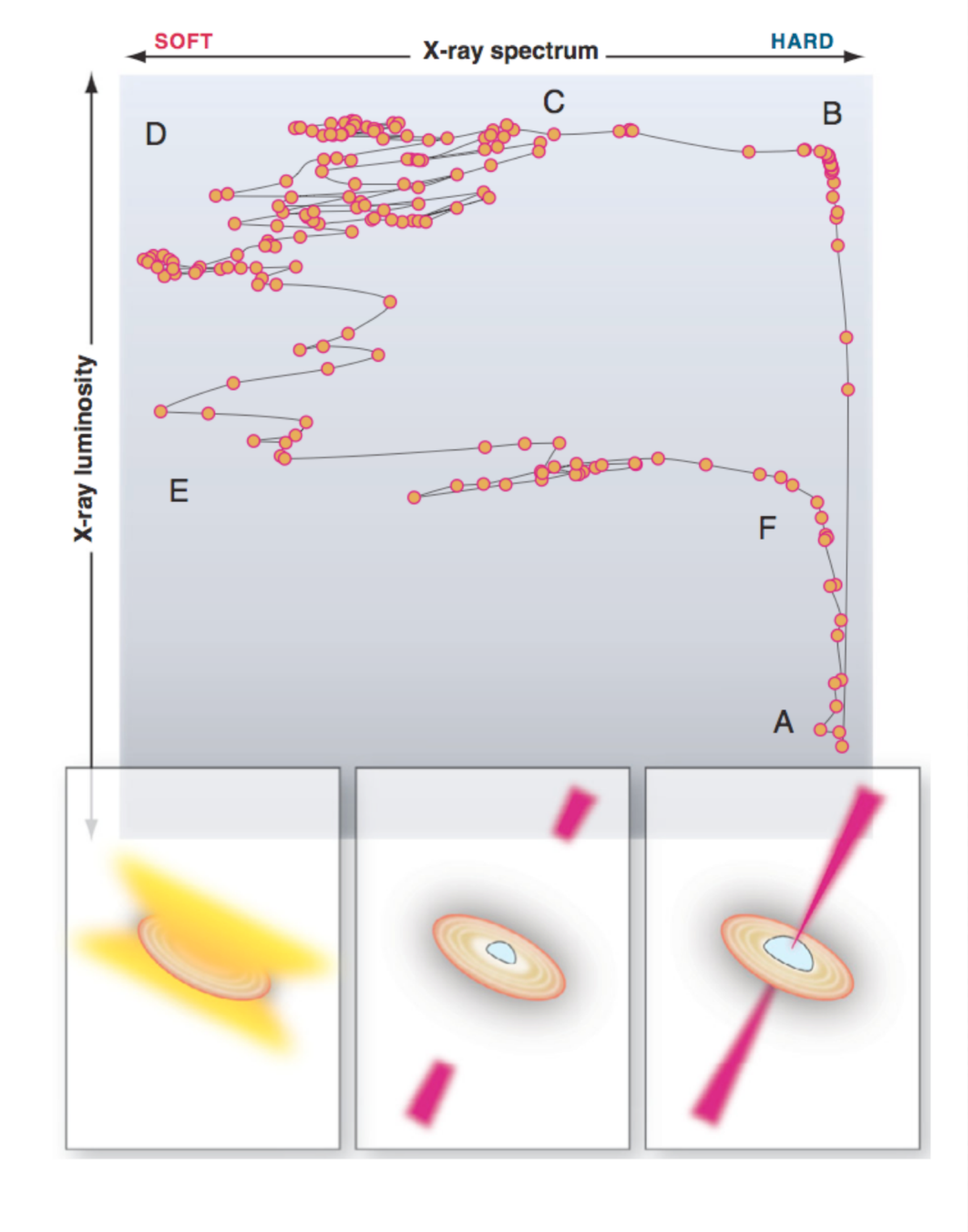
# Jet quenching II




Gusinskaia et al. 2017

# Neutron star empirical model:

- Similar HID
- Jet coupling seems similar; maybe less quenching in some sources
- Hard state scaling can be understood
- BH like XRBs: ADIOS type discs?



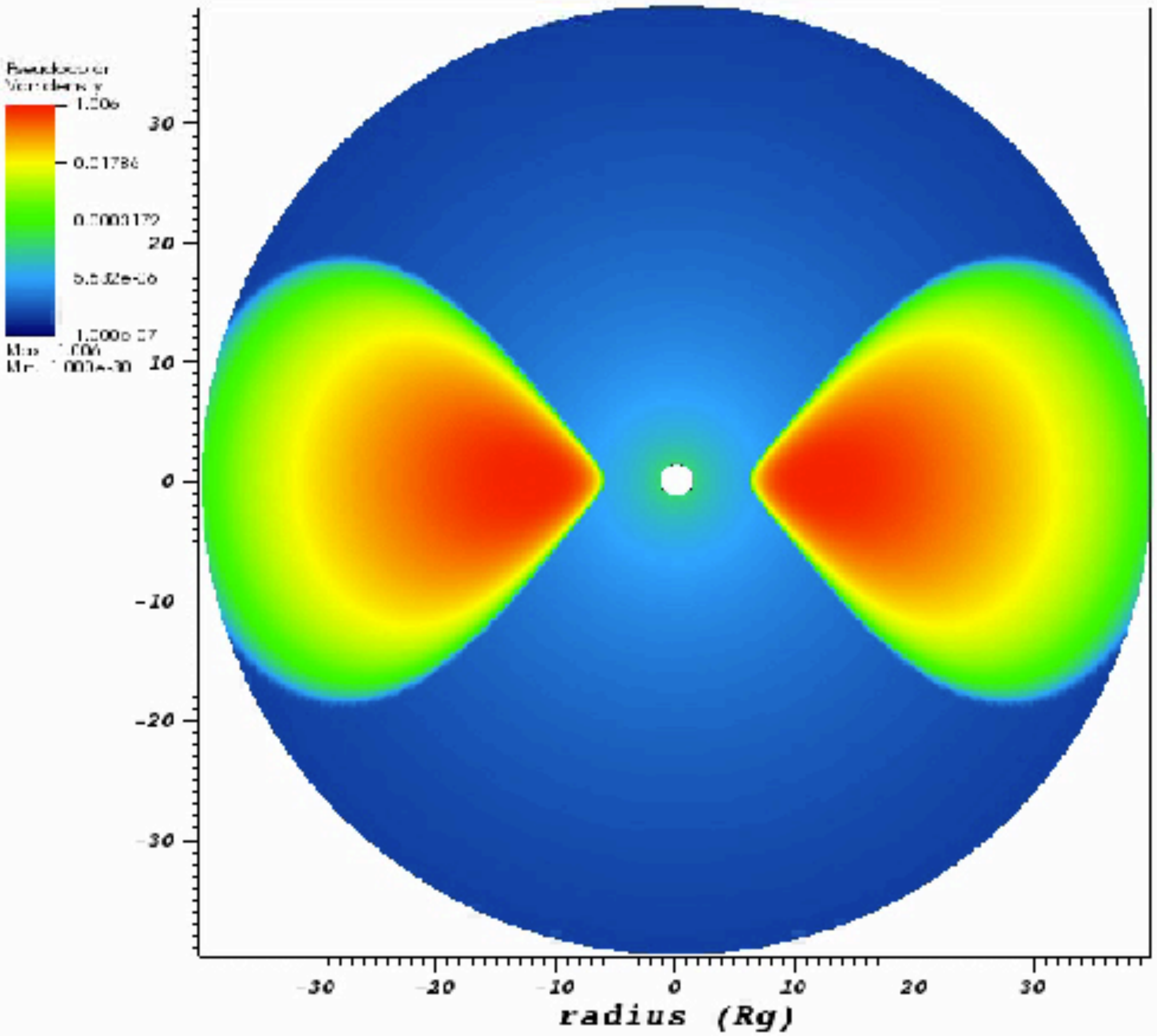

Fender, Gallo 2014; Talk by Rob

# Black holes: No hair theorem

A black holes only has

- Mass
  - Changes over 8 orders of magnitude
- Spin
  - Changes energetics by a factor 6
  - Energetically minor importance
- Charge
  - Not important

# Mass scaling



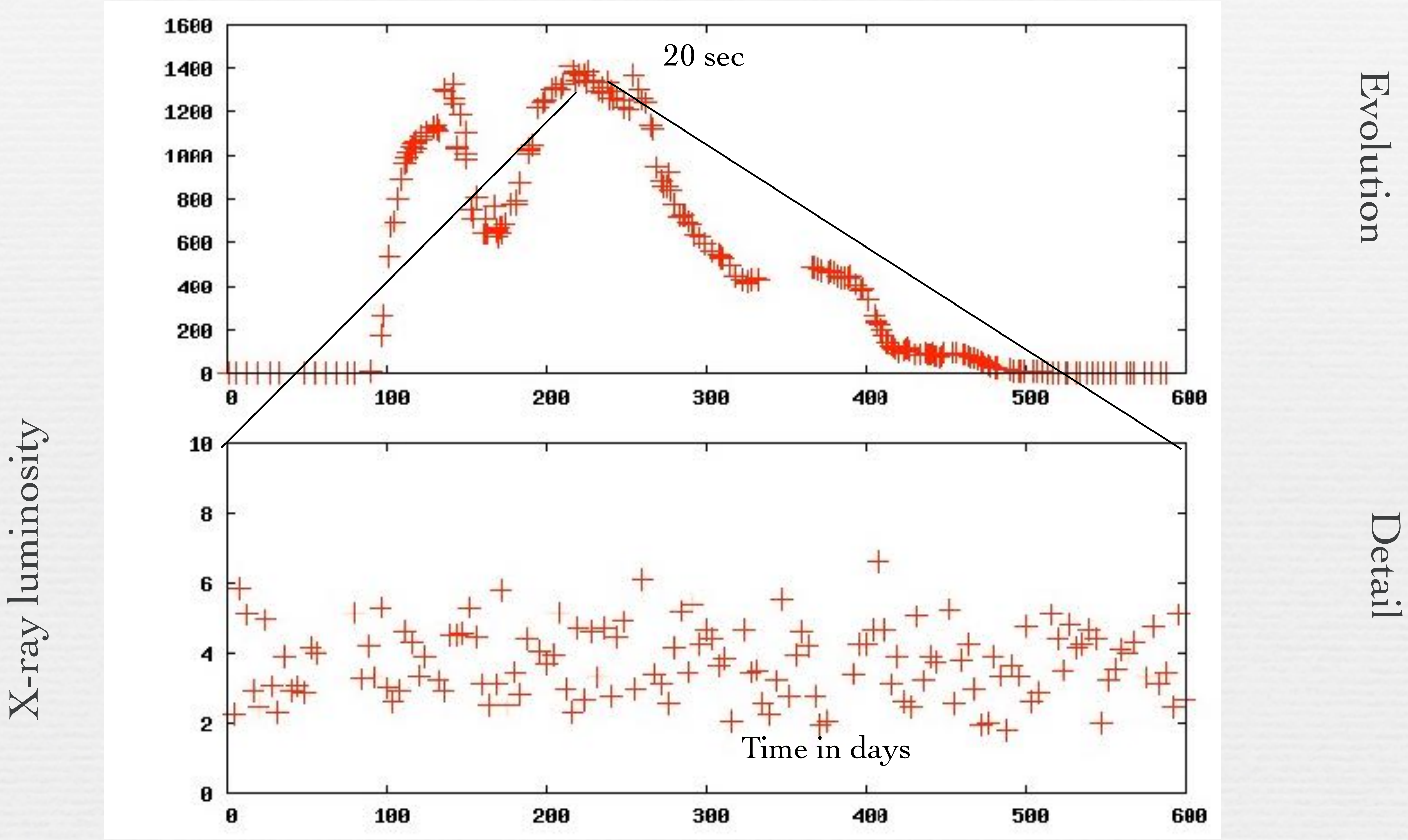

- Often one sets GM=1 and expresses densities in fractions of BH mass, time also measured in M
- Without radiative transfer and microphysics accreting discs are basically scale invariant
- Theory expects that accreting BHs are scale invariant in first order approximation

S. Dibi based on Harm2D, Gammie et al. 2003

# Complementarity X-ray binary - AGN

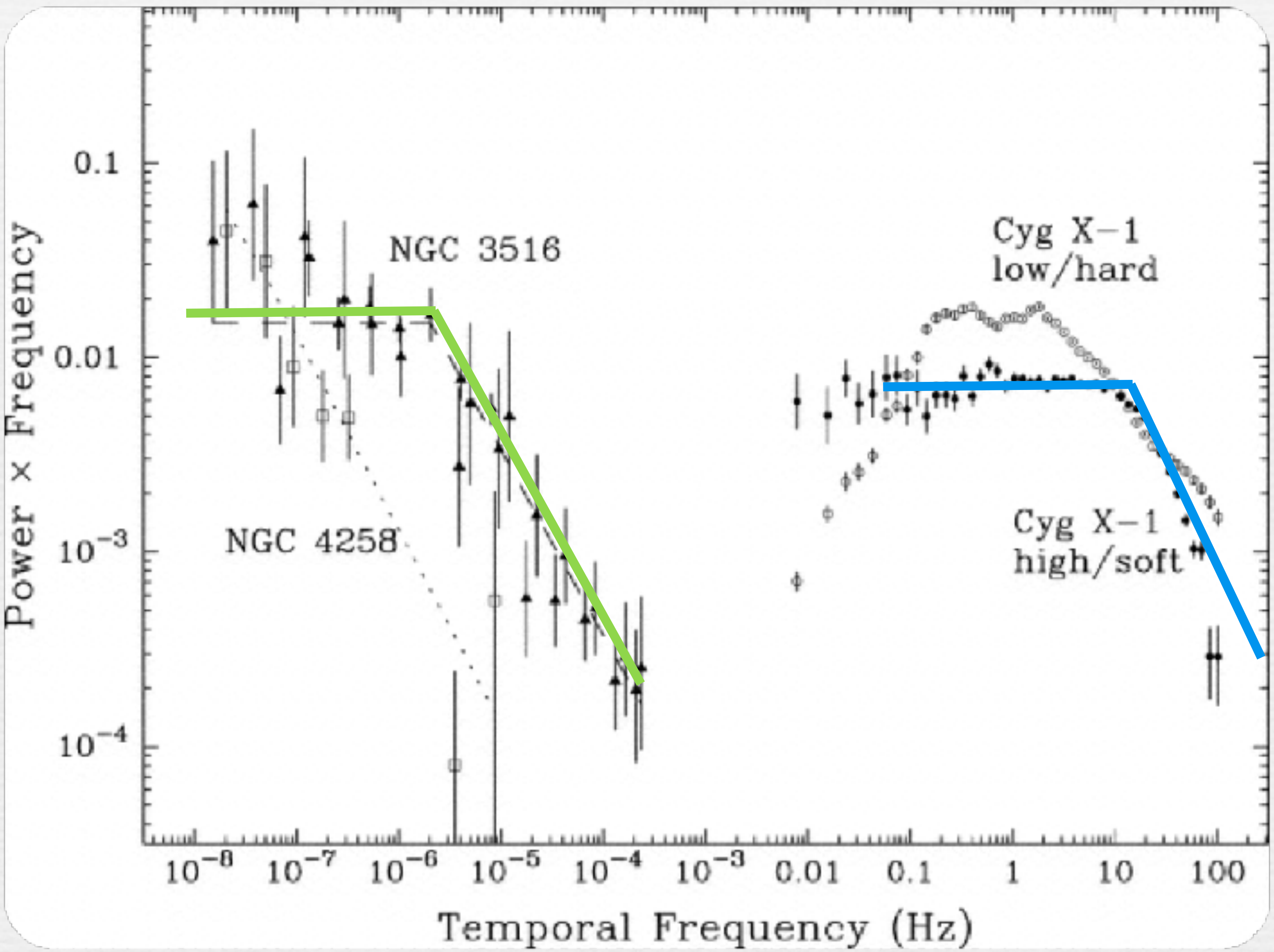
X-ray binary: GX 339-4

AGN: ARK 564



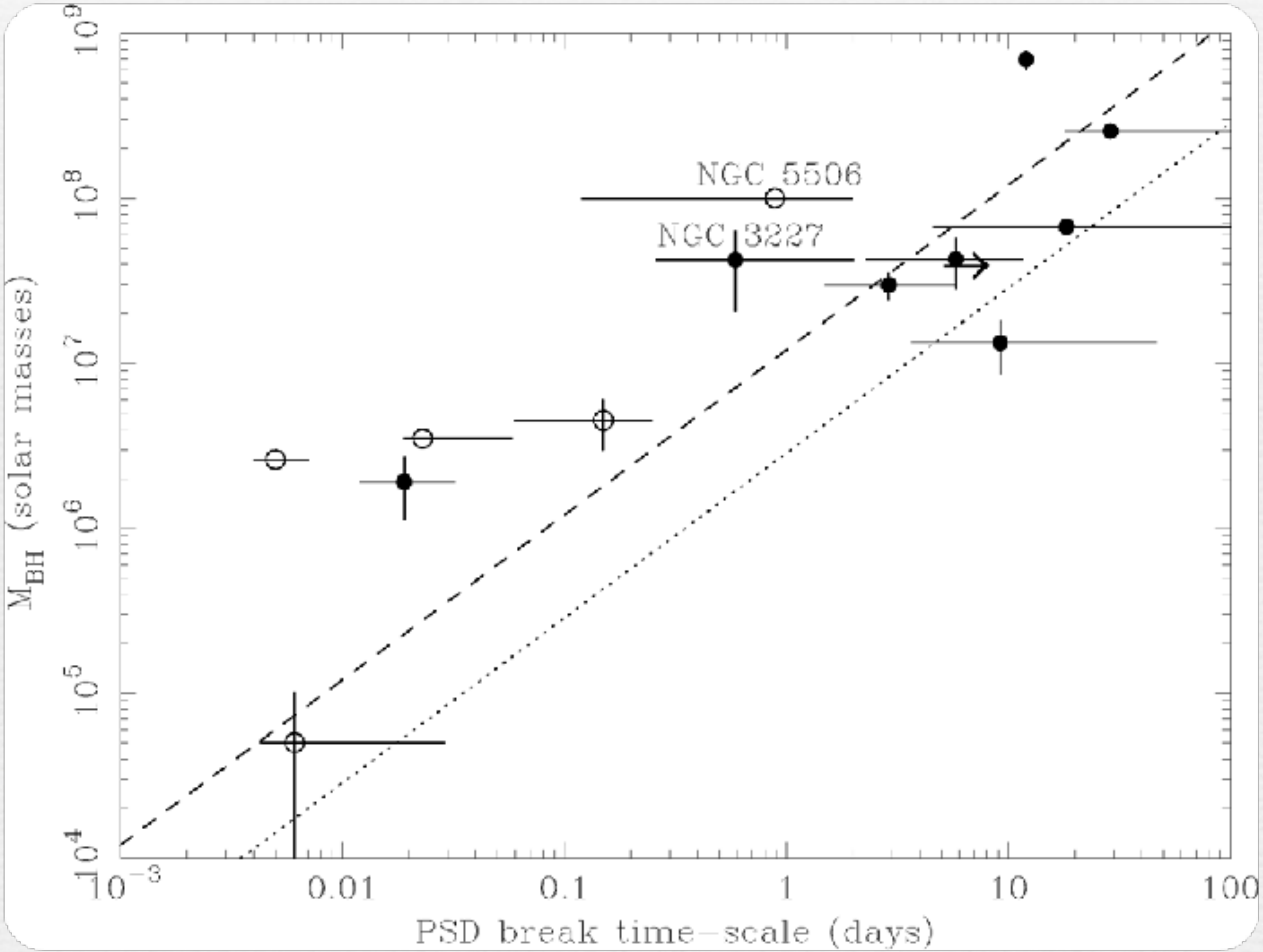

- In AGN one observes shorter dynamical timescales (relative to BH mass) than in XRBs
- XRBs and AGN probe different regions in the parameter space of accreting black holes

# Power spectral densities



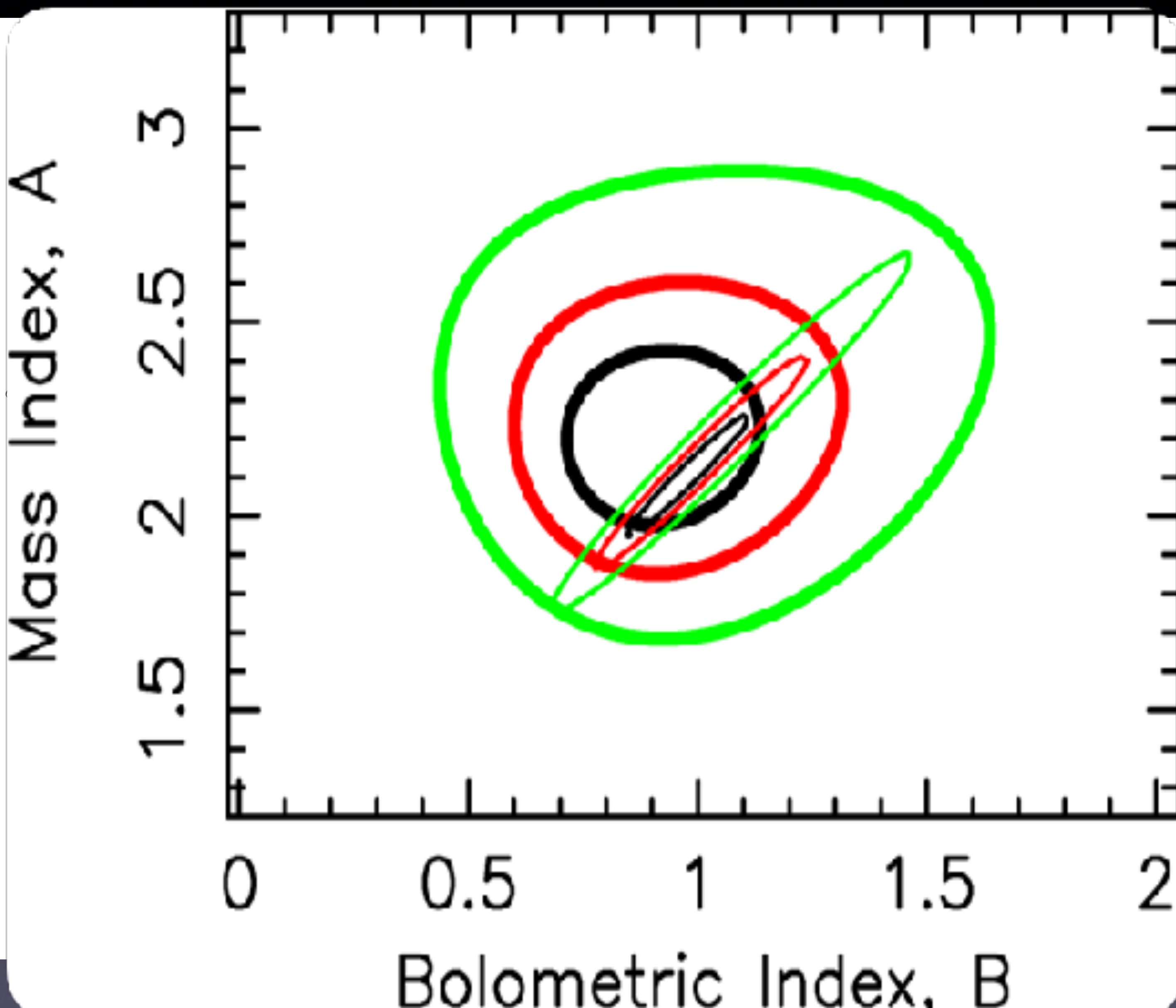

Markowitz et al. 2002

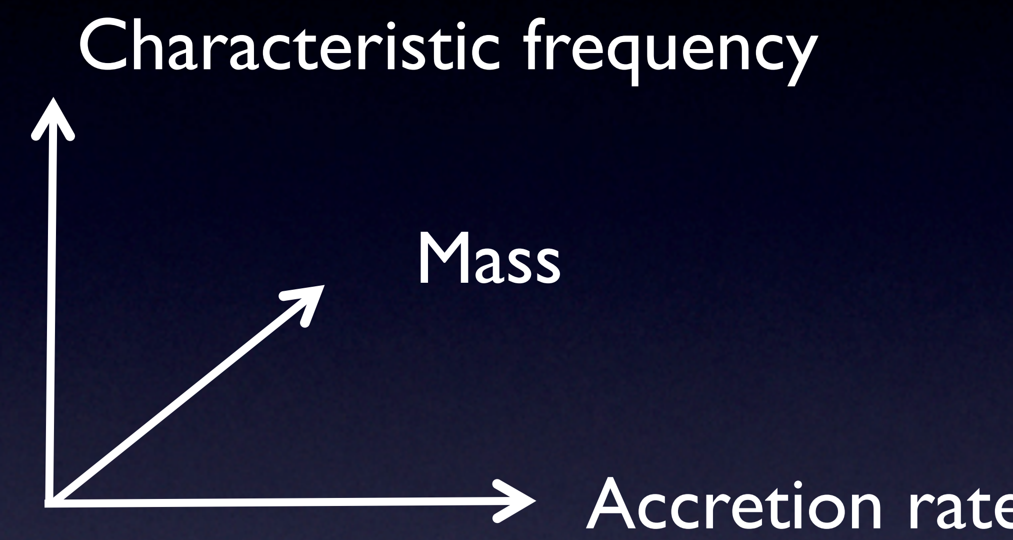
# Timescales as a function




Uttley, McHardy et al

# Connecting X-ray binaries and AGN: The variability plane

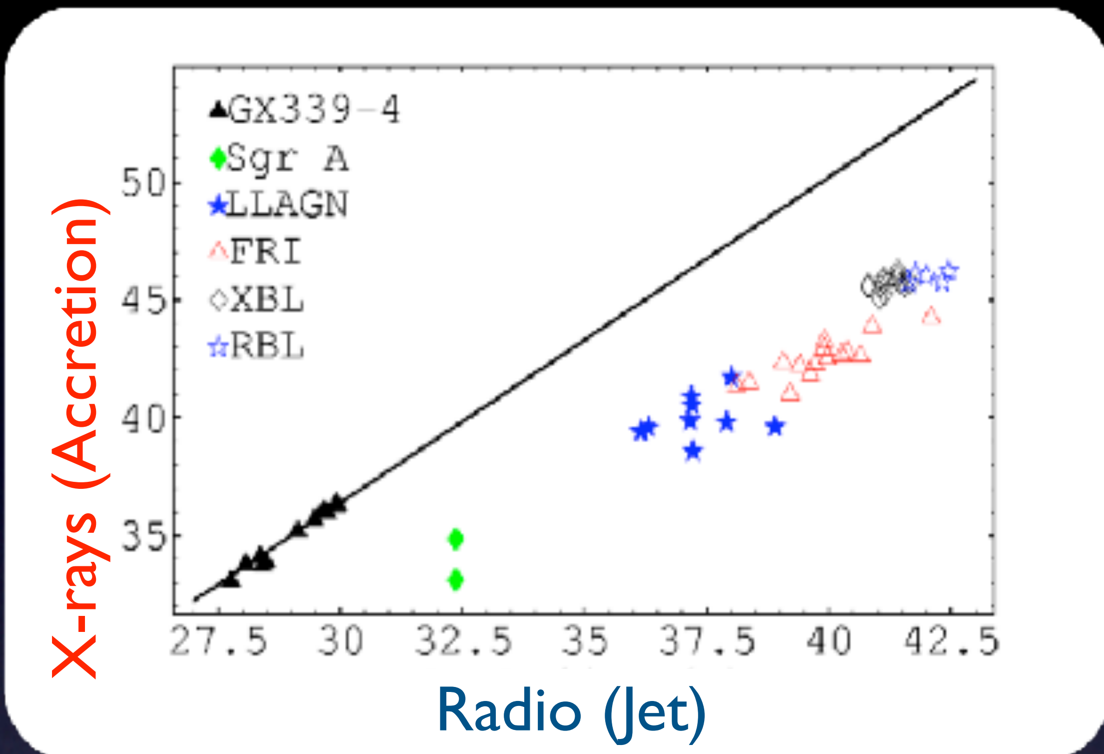


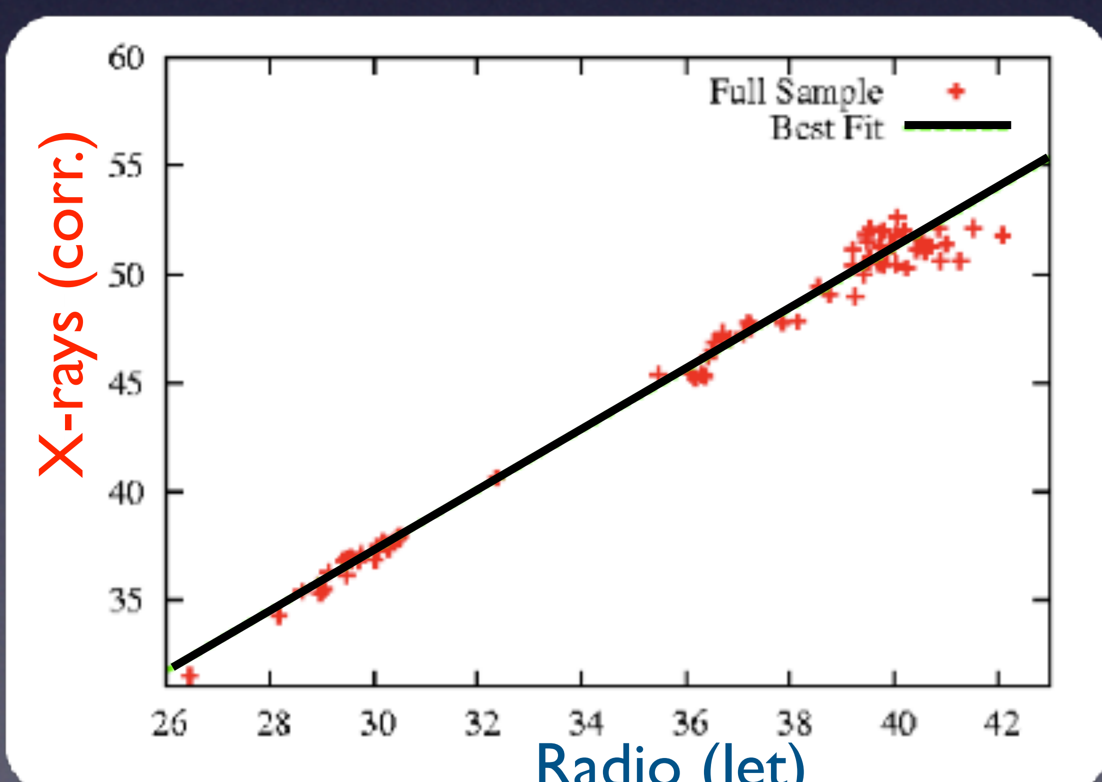




- $\nu M \propto \frac{\dot{M}}{M}$
- Accretion discs are scale invariant

McHardy, Körding et al. Nature 2006, Körding et al. 2007

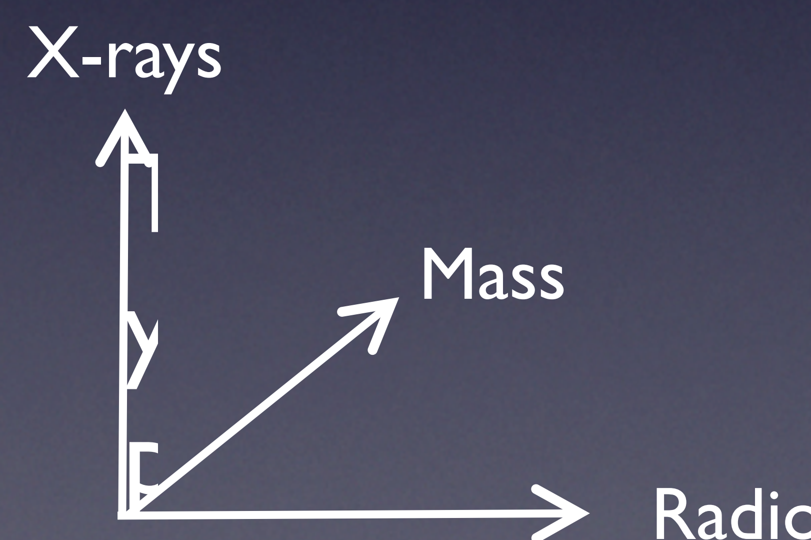
# Moving towards AGN: The fundamental plane of accreting black holes





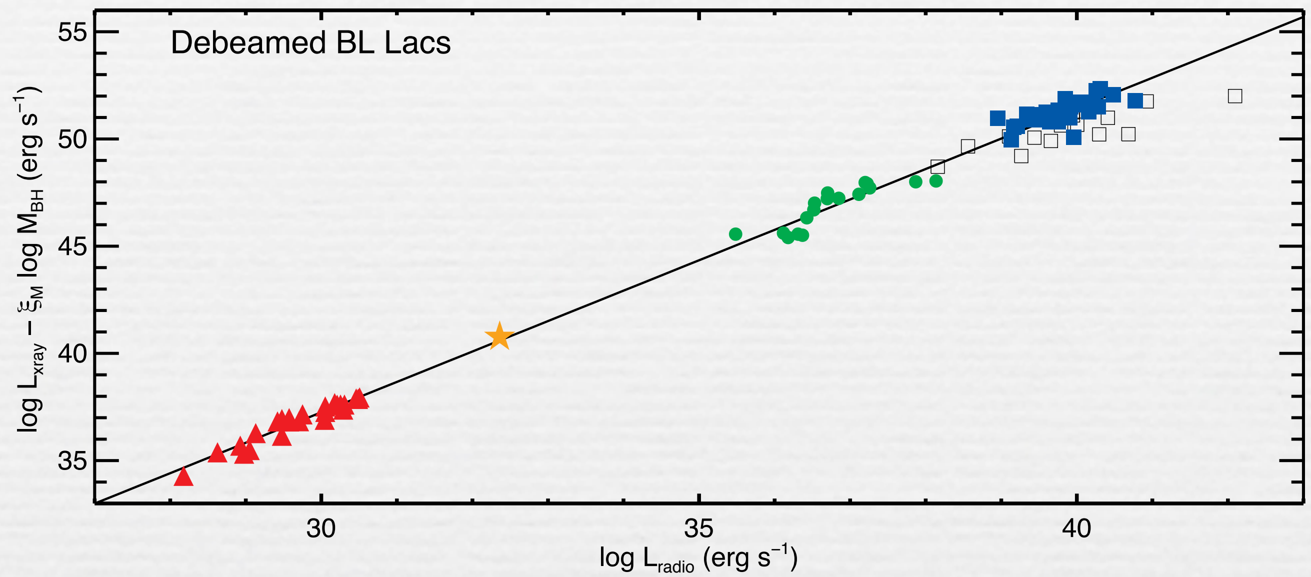
Edge-on projection of the plane



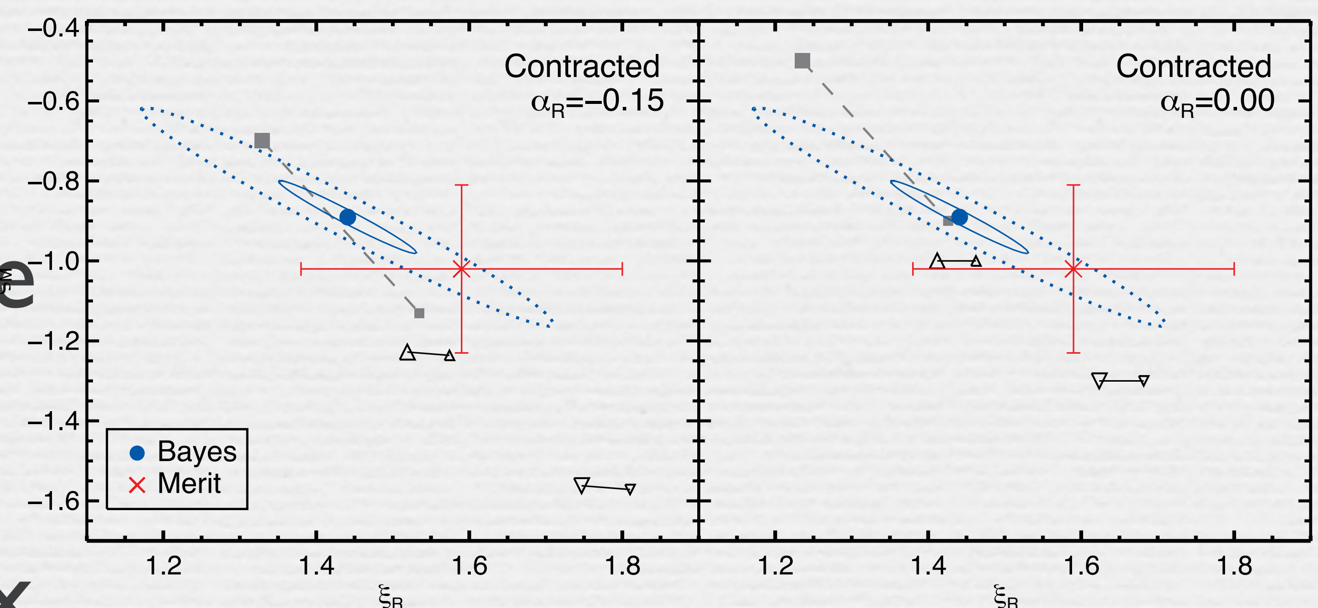

Merloni et al. 2003, Falcke, Körding, Markoff 2004, Körding et al. 2006

# Beyond the back of the envelope

- Bayesian analysis of fundamental plane provides good constraints on fit parameters, small intrinsic uncertainty




- Fit parameters can be used to estimate the radiative efficiency of the X-ray emitting region

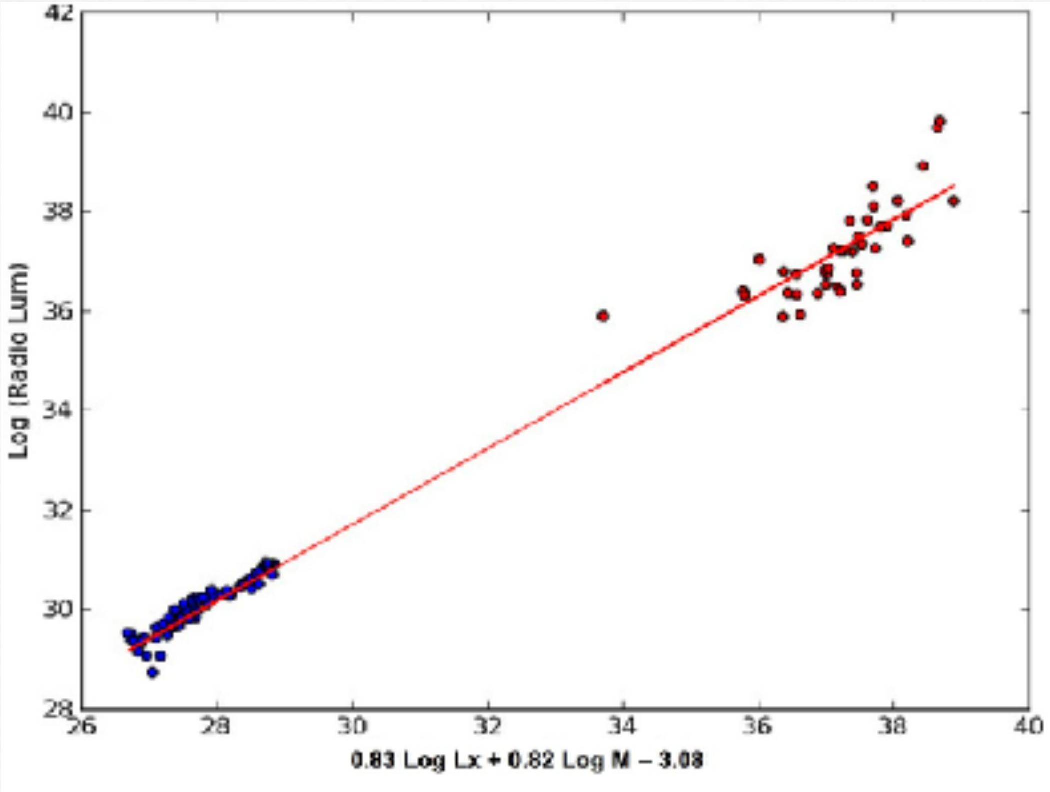


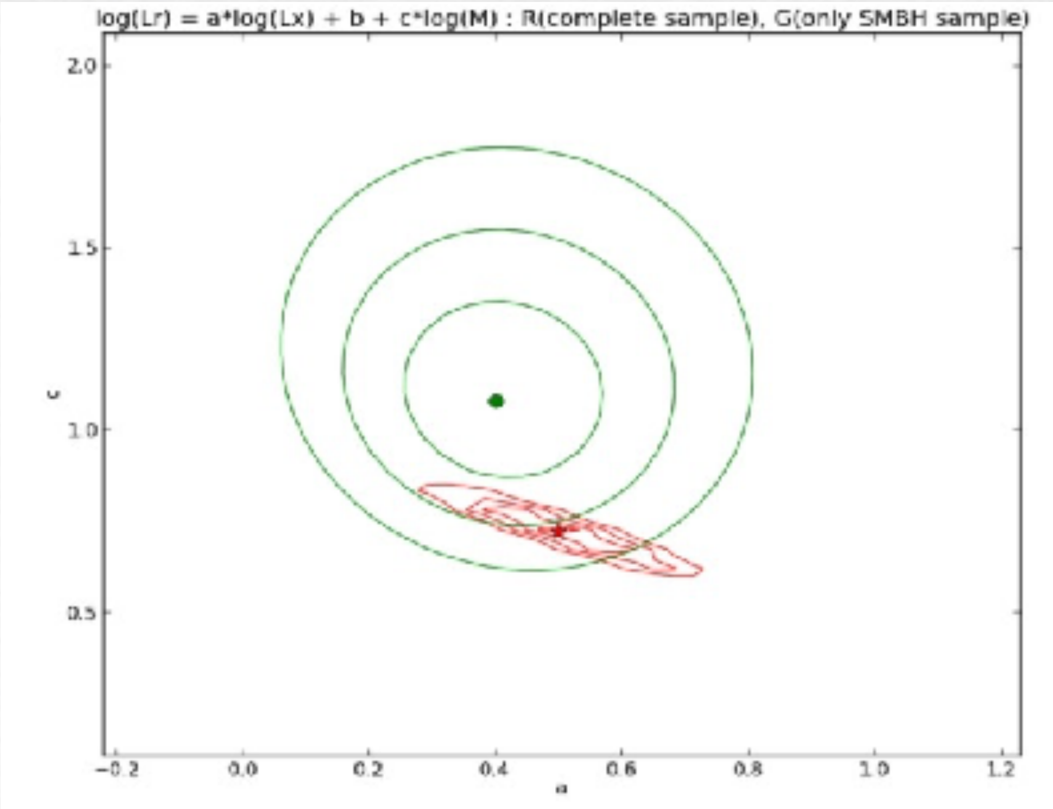

- Intrinsic scatter 0.07 dex to 0.11 dex

Plotkin et al. 2012

# An optical fundamental plane

- OIII/X-ray correlation allows construction of an optical FP
- One obtains the same FP
- FP is visible for AGN alone
- open FP studies to large samples

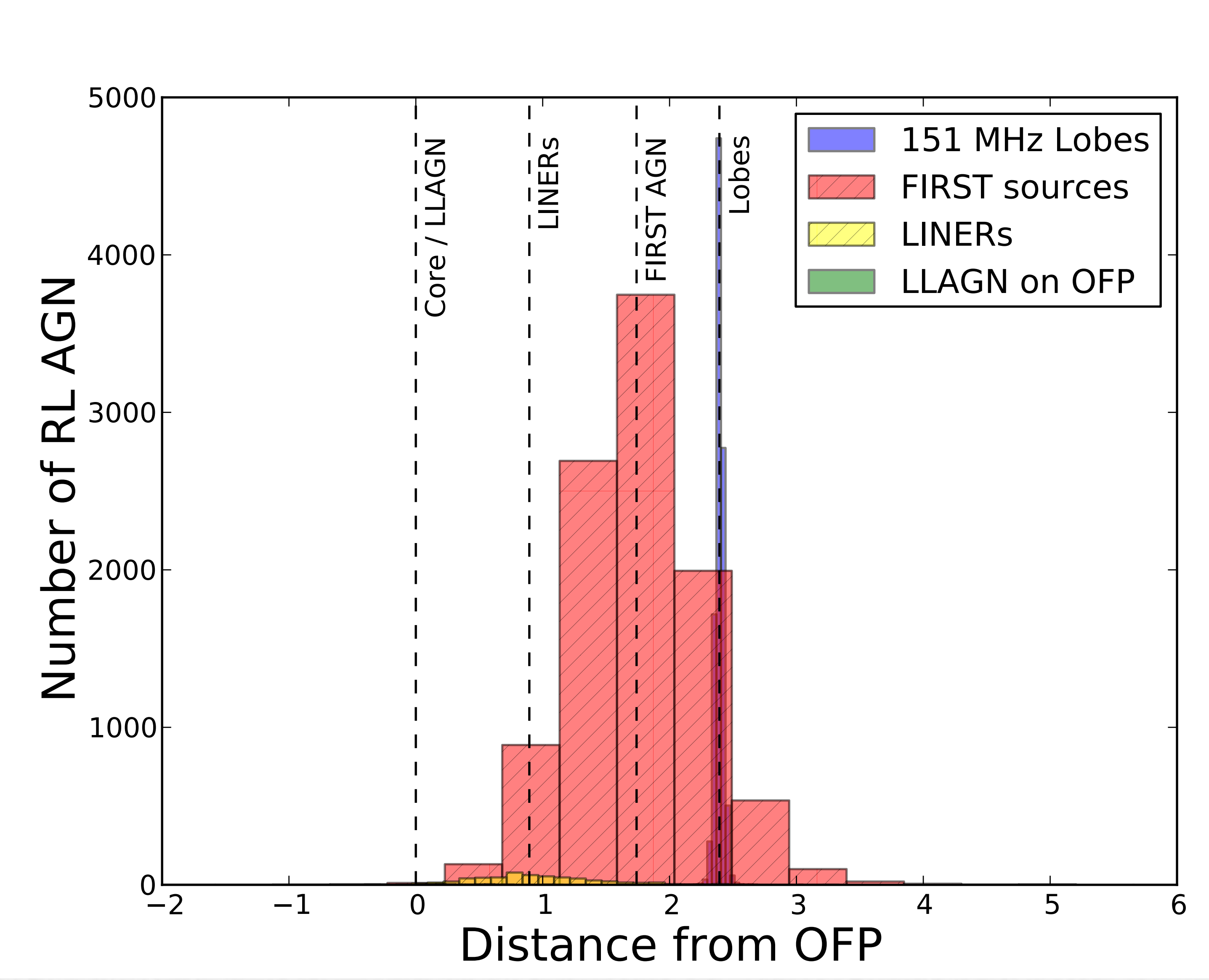



Saikia et al. MNRAS 2015

# Projection perpendicular to the FP

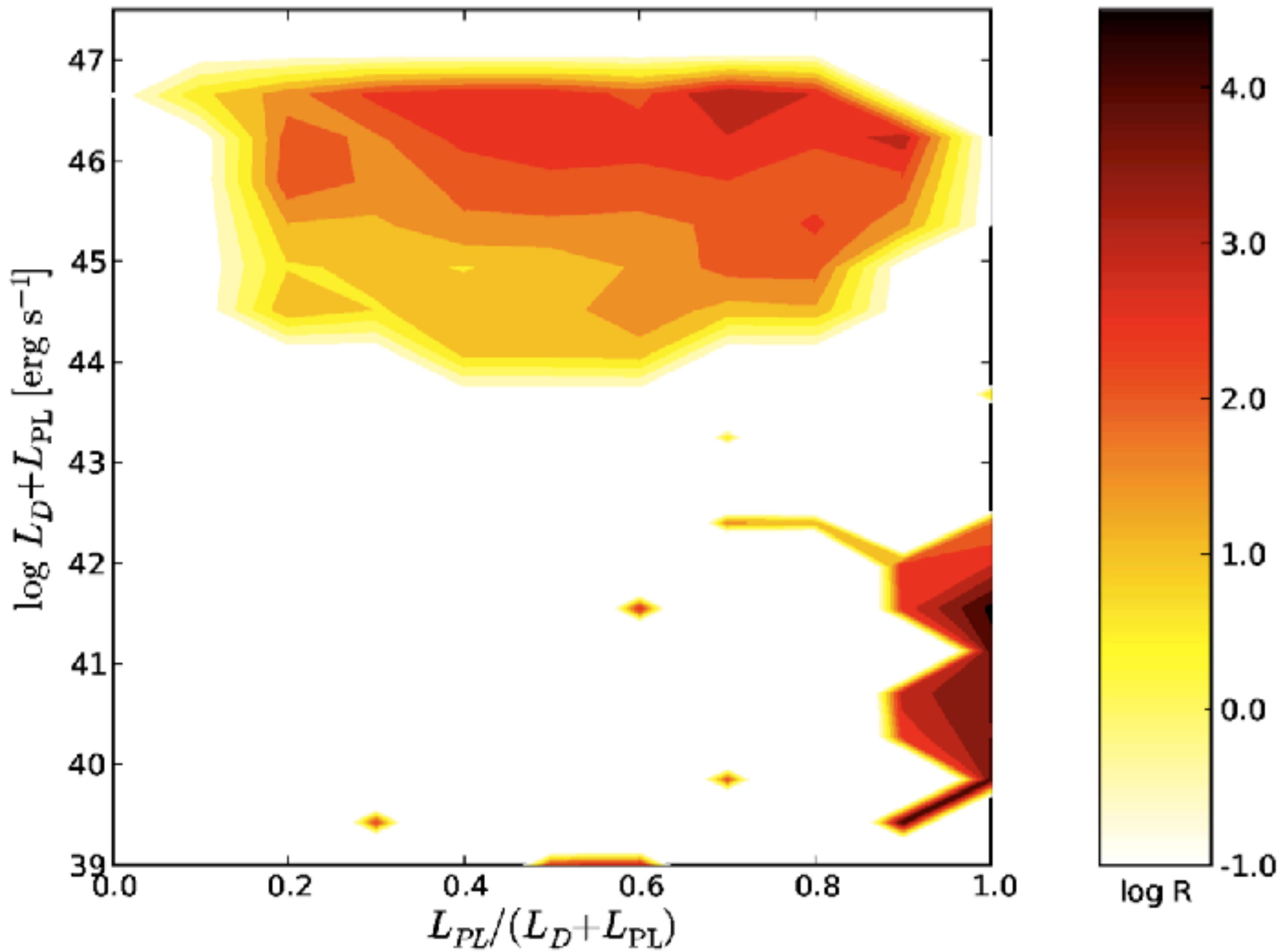
- “compact” FIRST sources are in agreement with the FP + beaming
- LINERS are still significantly above the plane, albeit nearer to it
- Majority of sources between FP prediction expected lobe flux. I.e. at 1.4 GHz one predominantly measures extended emission




Saikia et al. in prep

# Generalised HID for AGN

SDSS broad line quasars + low luminosity sample of Ho



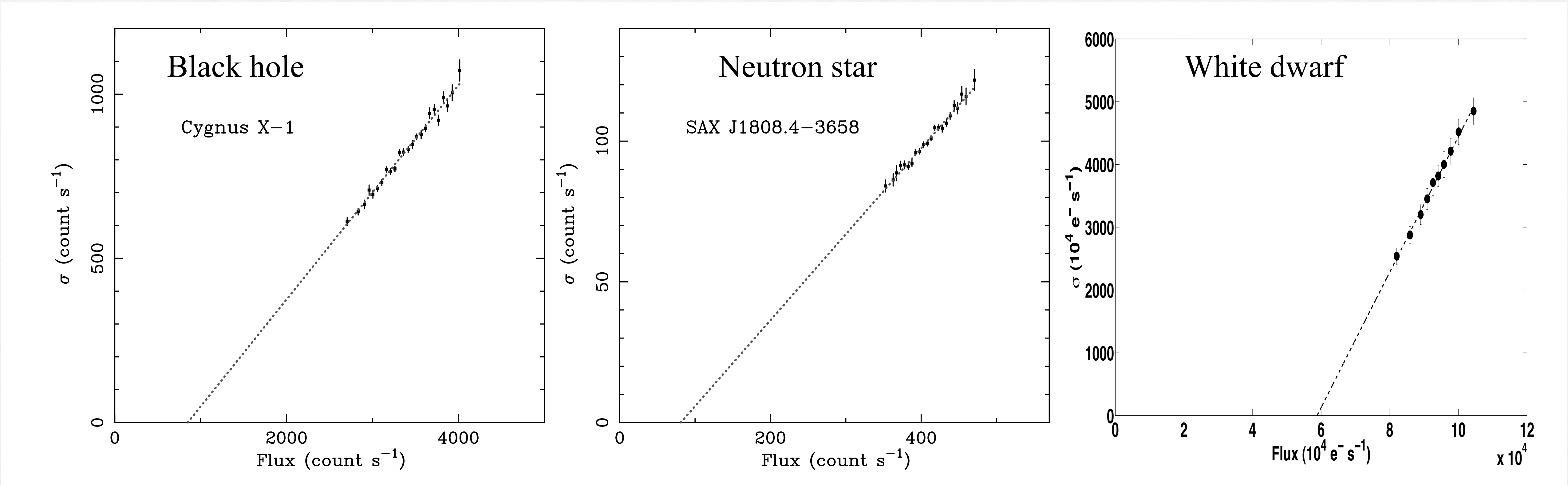

See talk by Jiri Svoboda for a modern update!

Koerding, Jester, Fender 2006

# Cataclysmic Variables

- Accreting white dwarfs
  - Dwarf novae : low average accretion rates
  - Nova like stars: high average accretion rate

# RMS flux relation

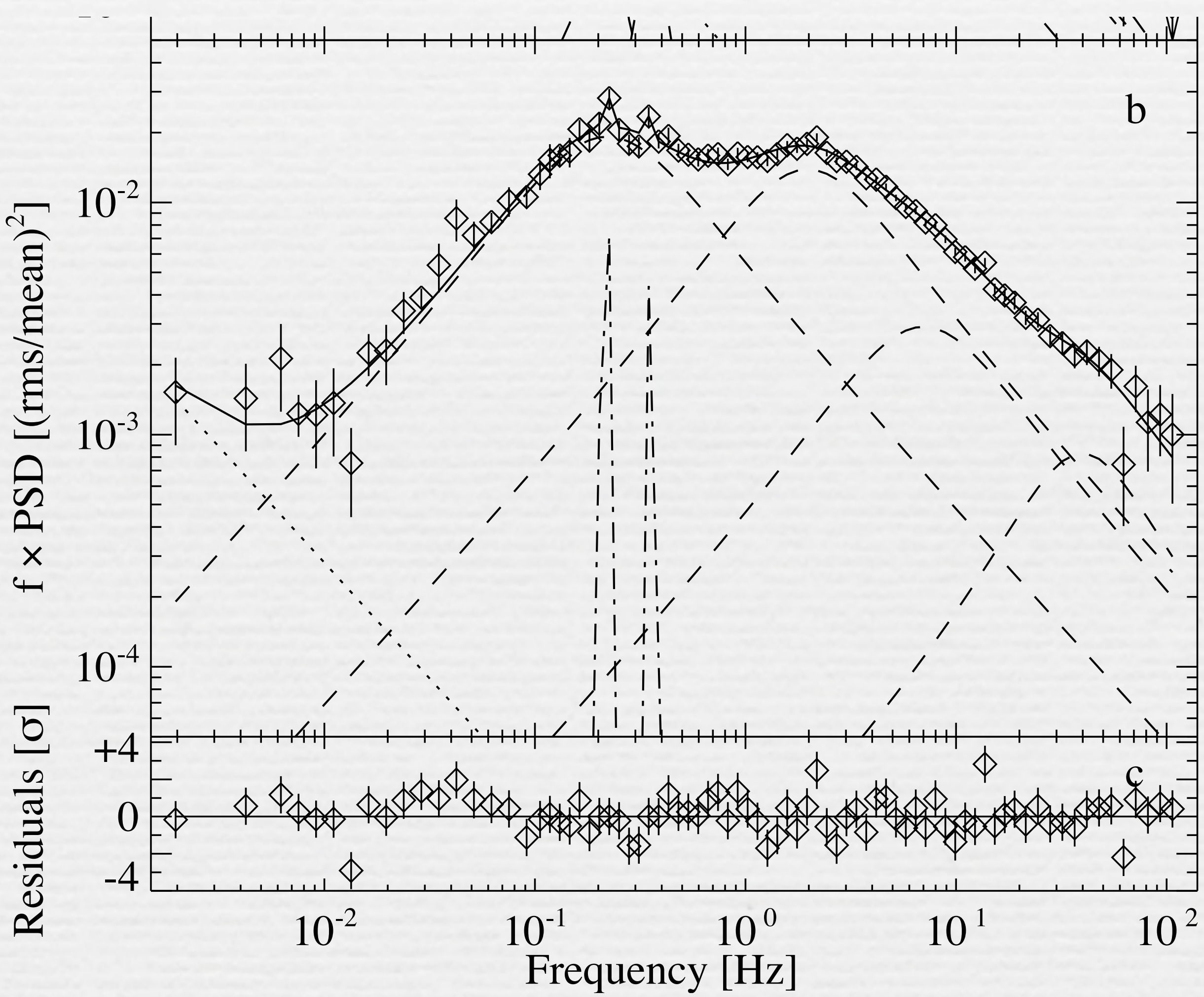



- The rms/flux relation found in BH and NS binaries is also present in accreting white dwarfs (Phil's talk)
- there exists a non-linear coupling between the different frequencies
    - e.g. propagating fluctuations model (Lyubarskii 1997)

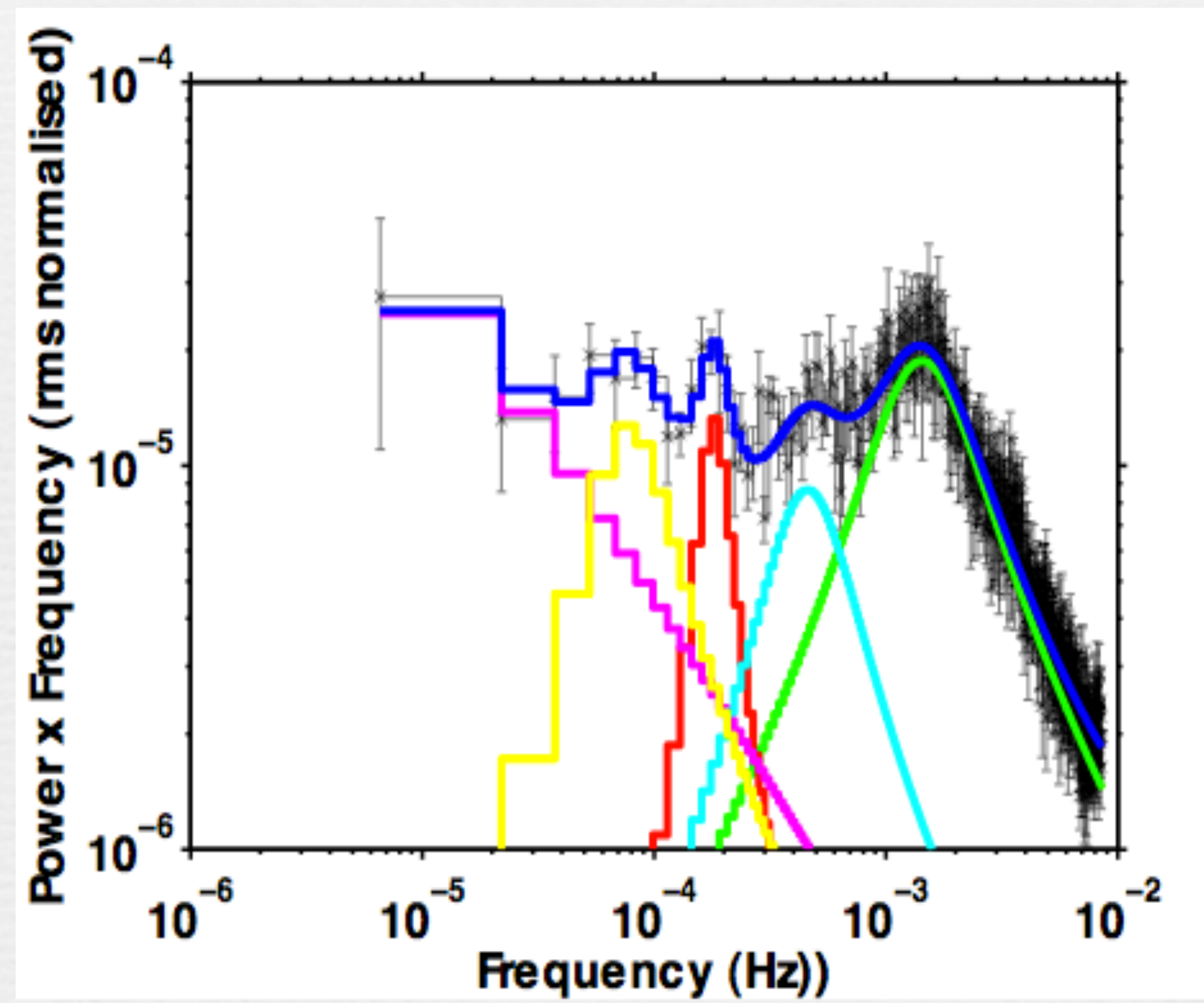
Scarinigi, et al. 2011

# Power spectral density

BH Cyg X-1



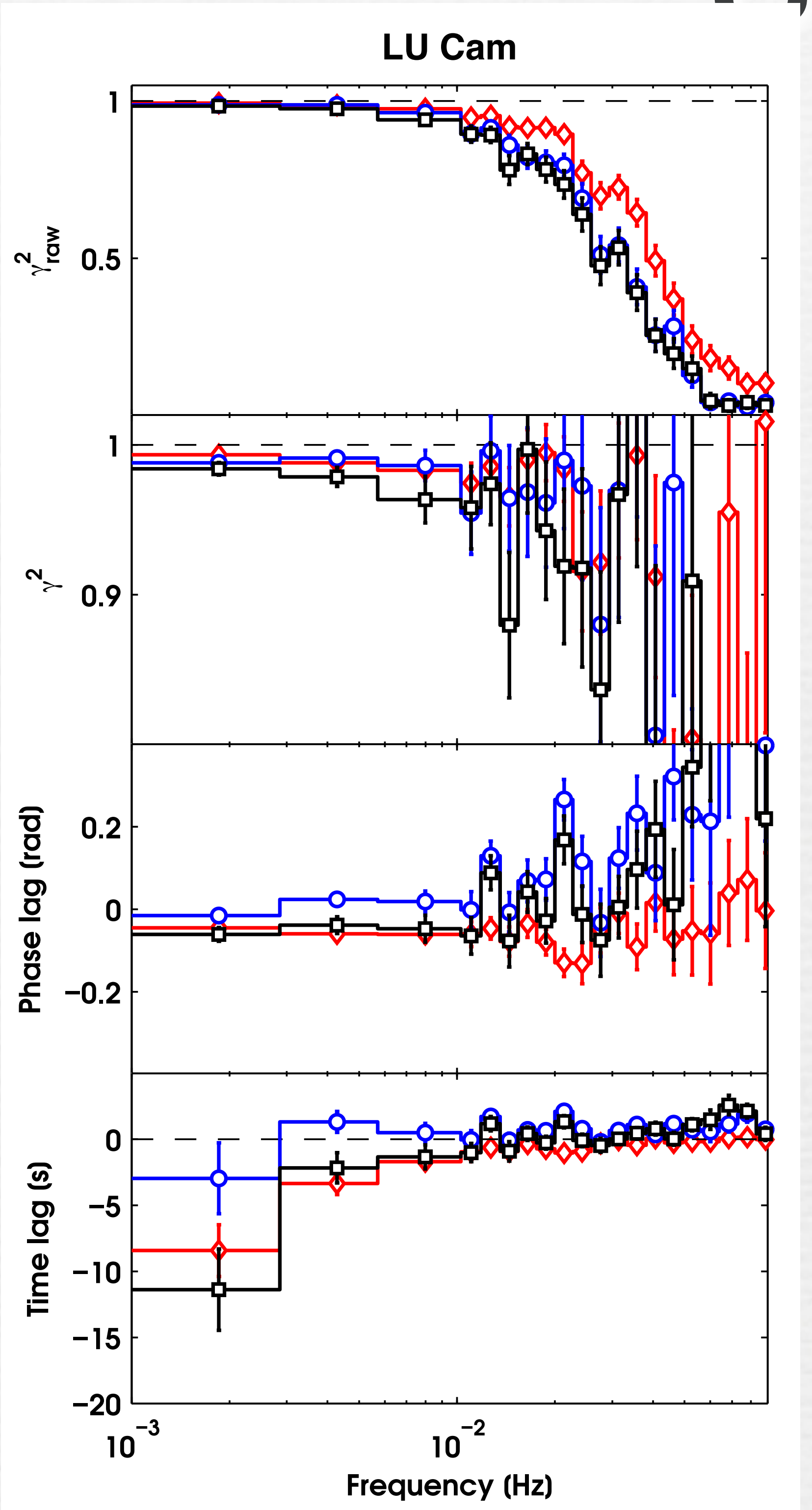

WD MV Lyr




Scarinigi, et al. 2012

# Fourier resolved time lags

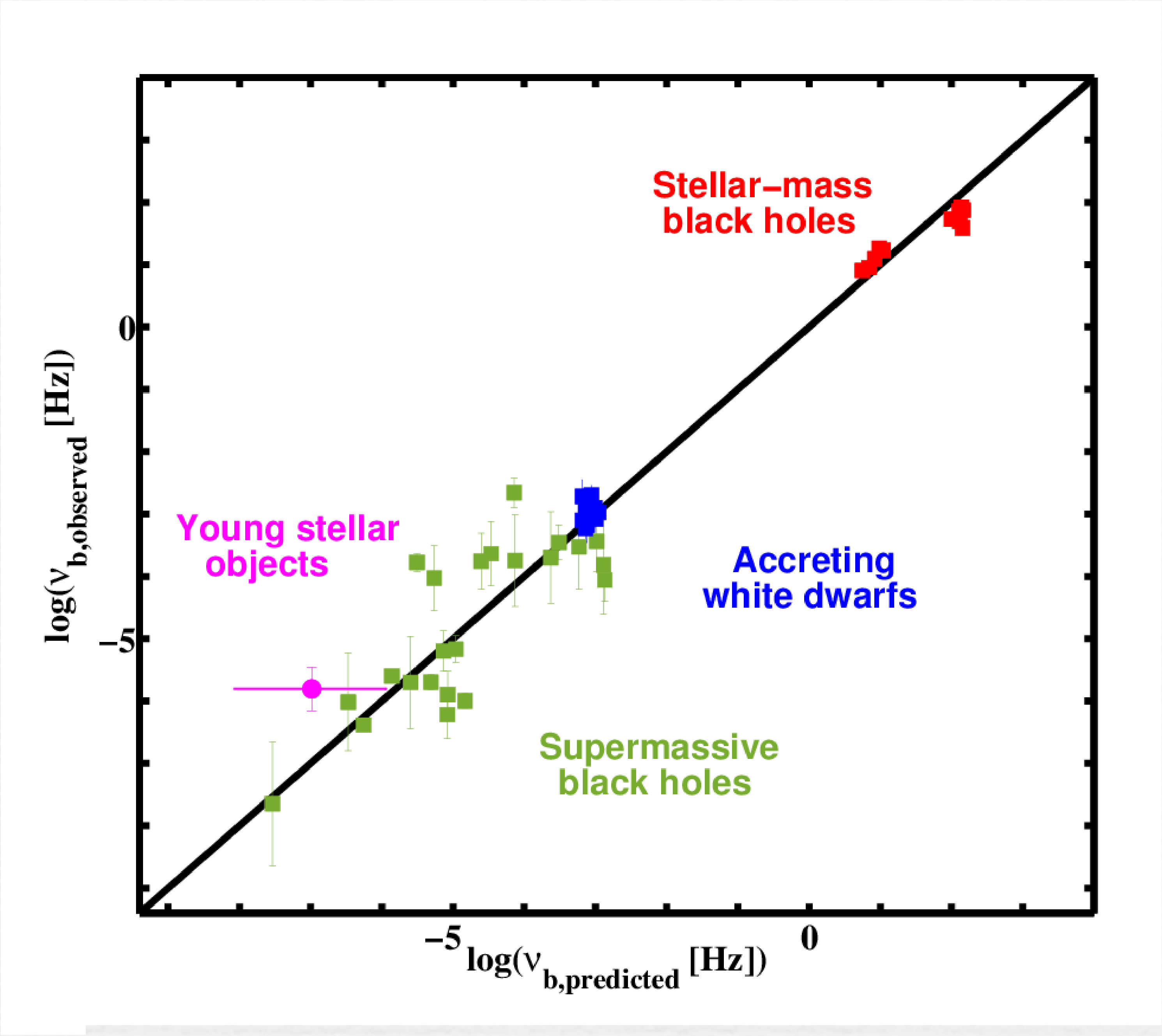
- Accreting white dwarf systems do show Fourier resolved time lags like XRBs/AGN
- Typically soft lags, but some indications for hard lags as well




Scarinigi, et al. 2013

# WDs fit the variability scaling relations; model-dependent

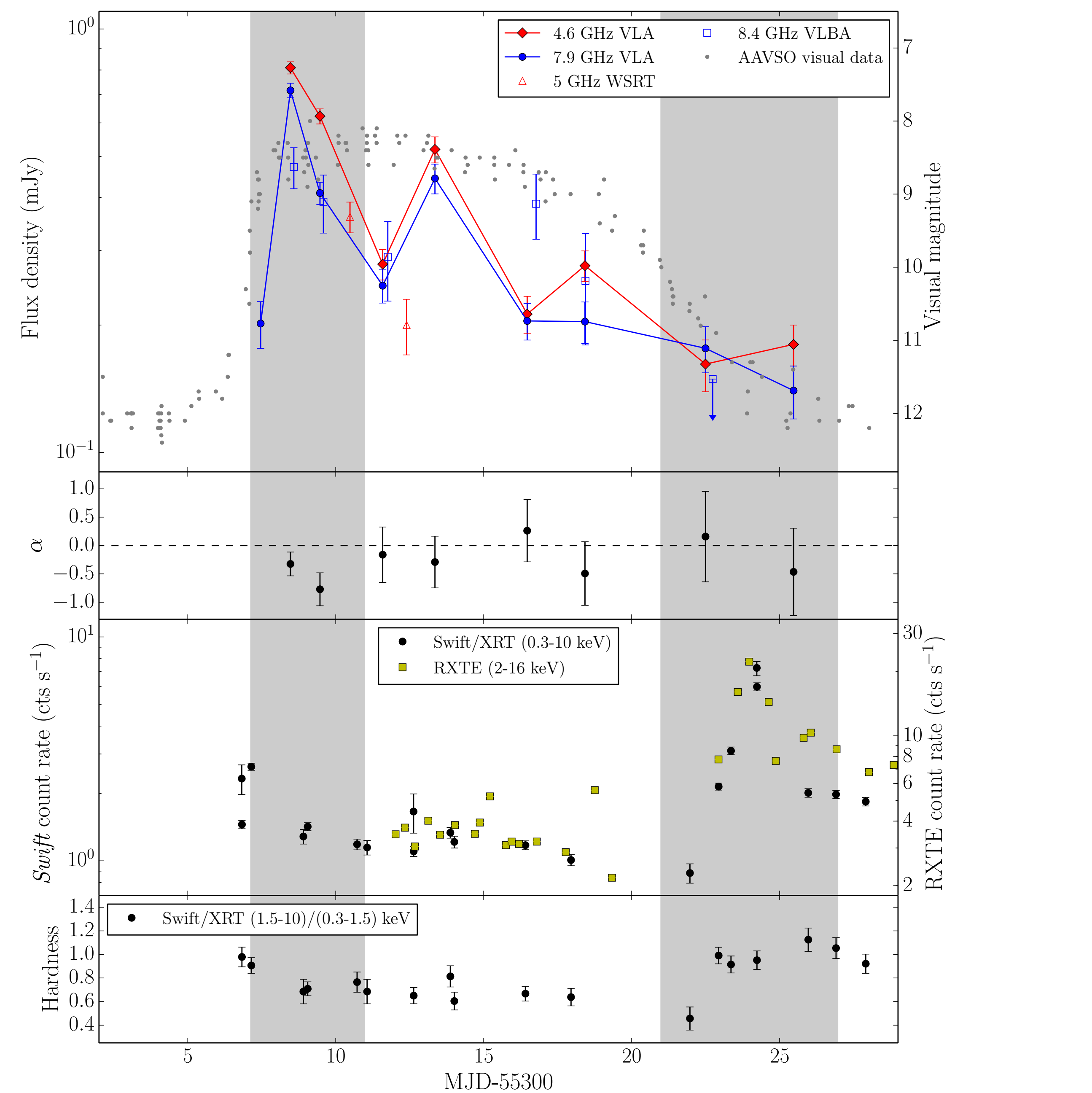
- Pretorias & Warner find a DNO/QPO extension to the PBK relation.
- If one accounts for the WD radius the variability timescales follow the black hole scaling relations




Warner et al. 2003; Scaringi et al. 2015

# Dwarf novae are radio emitters

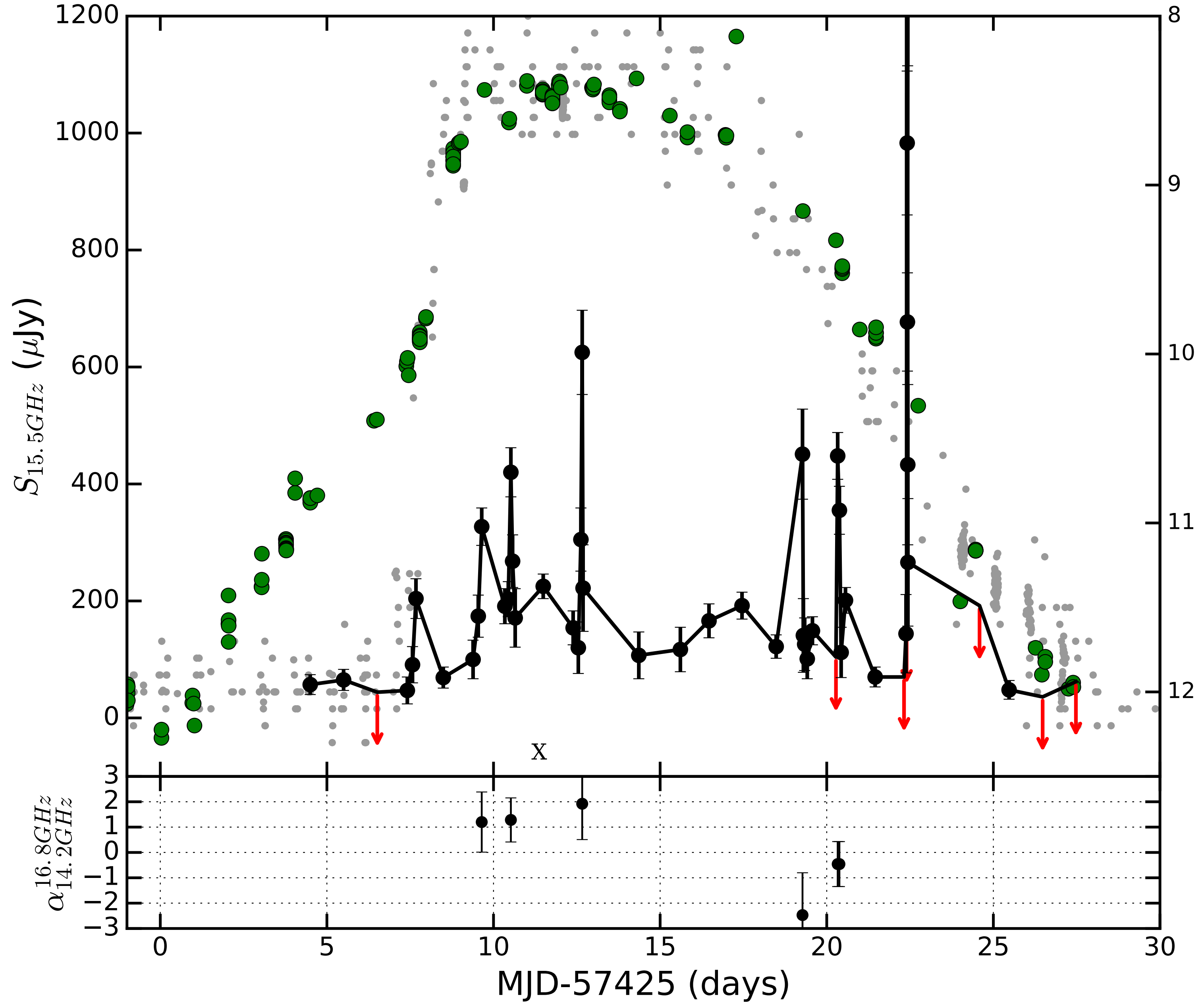
- CVs show a radio flare near the onset of the outburst
- Jets?
- Flux in agreement with extrapolation from XRBs
- Might be direct analogue of XRBs jets, but we have only imaged a jet at 4 sigma; needs to be confirmed (Talk of James)




Koerding, et al. 2008, Russell et al. 2016, …

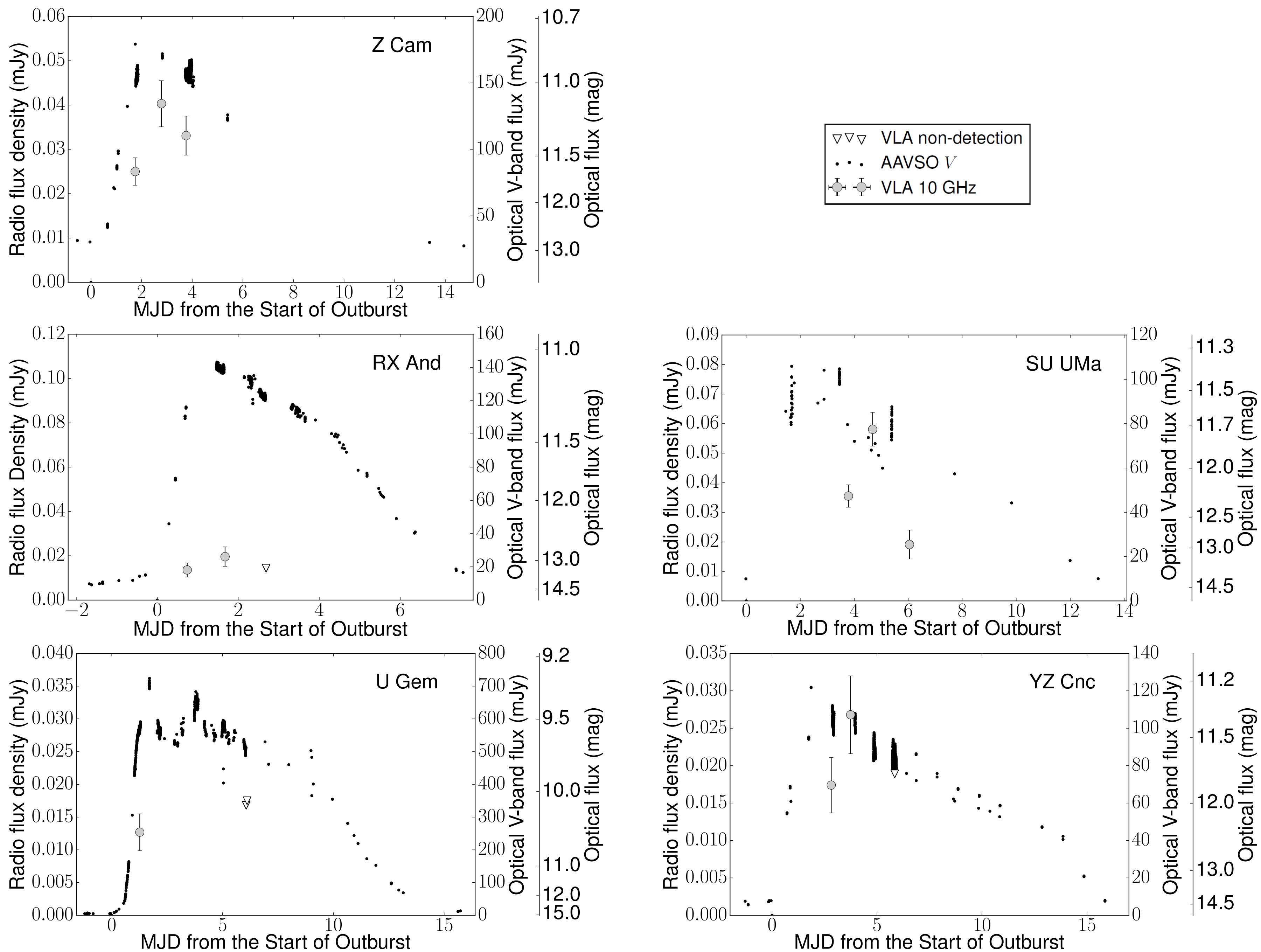
# Dwarf novae have two major flares: beginning & end

- Mooley et al. find that SS Cyg can be highly variable throughout the outburst.
- Big flare near the end, flare at the beginning missed. Similar to what is seen in XRBs.
- In combination: like in XRBs, we see one large flare at the onset and one flare in the late decline ('hard state')




Mooley et al. 2017

# All observed DN show radio emission




A typical CV@300 pc is around 15 **μJy**

Copejans et al. 2016

# Nova Like CVs

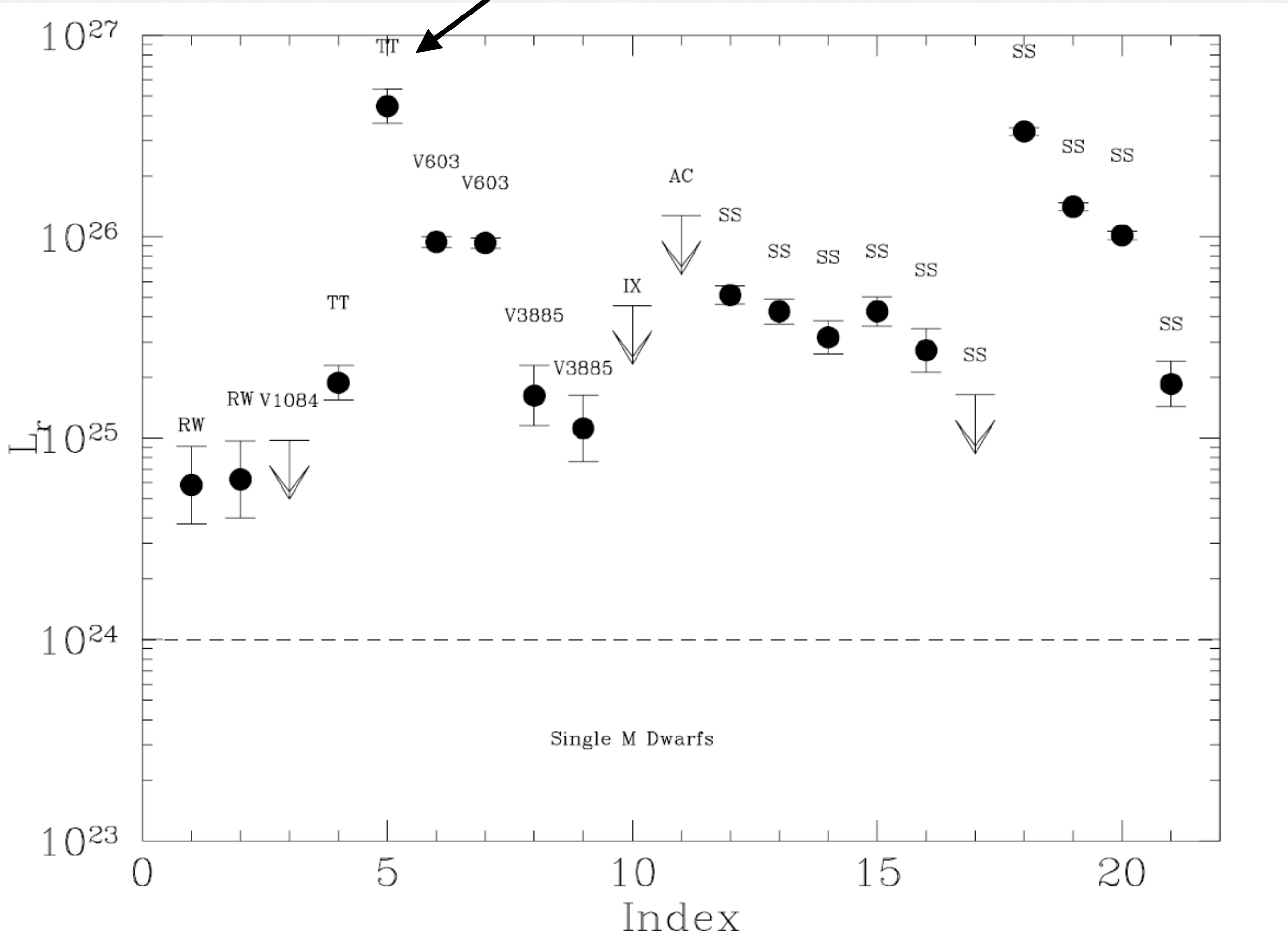
- Analogy XRBs - CVs: strongly accreting CVs should next to always show radio emission like Z-sources

- 5 nova-like CVs observed 4 detected

- Non-detection furthest away

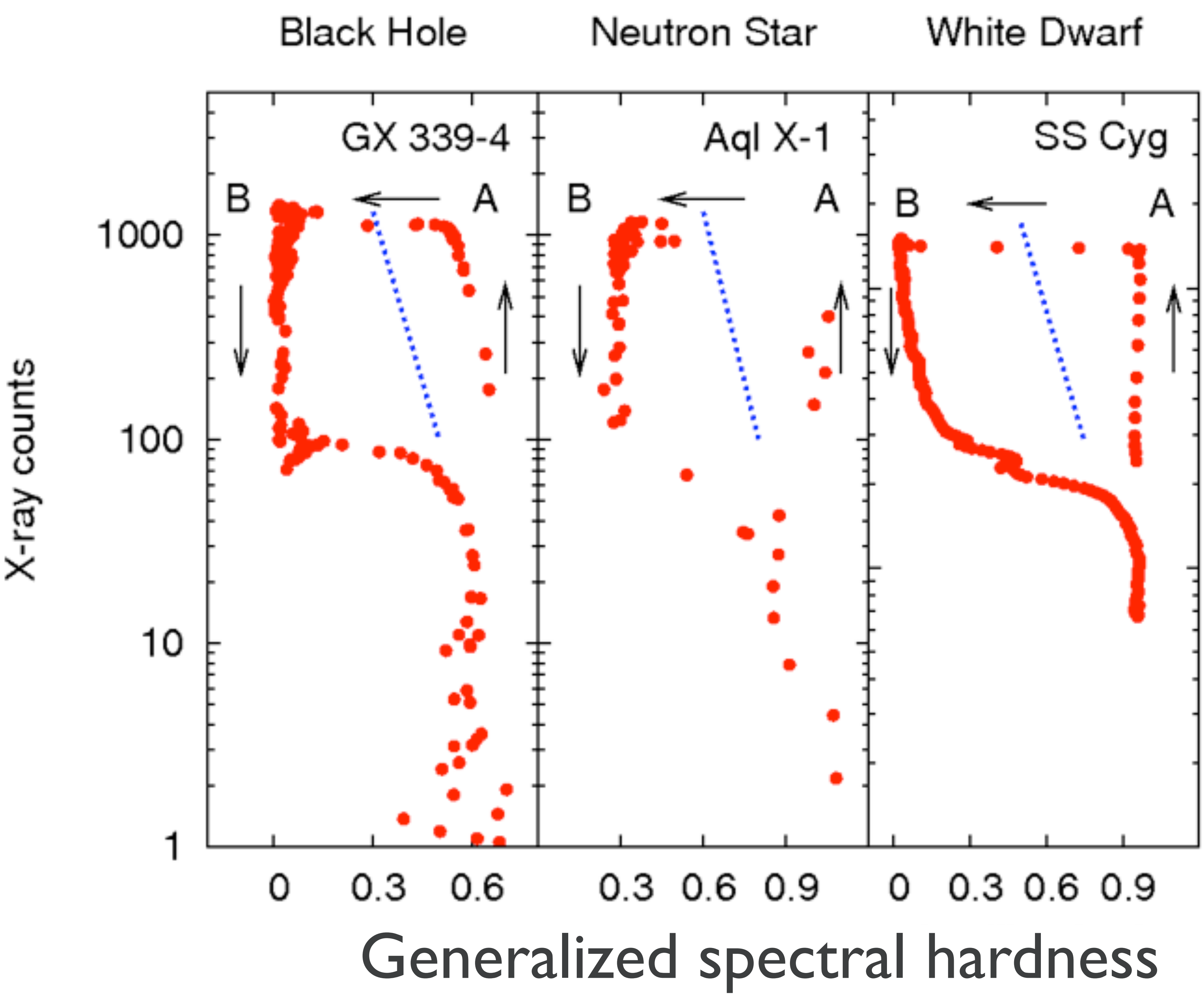
- CP flare cannot be due to a synchrotron jet…..

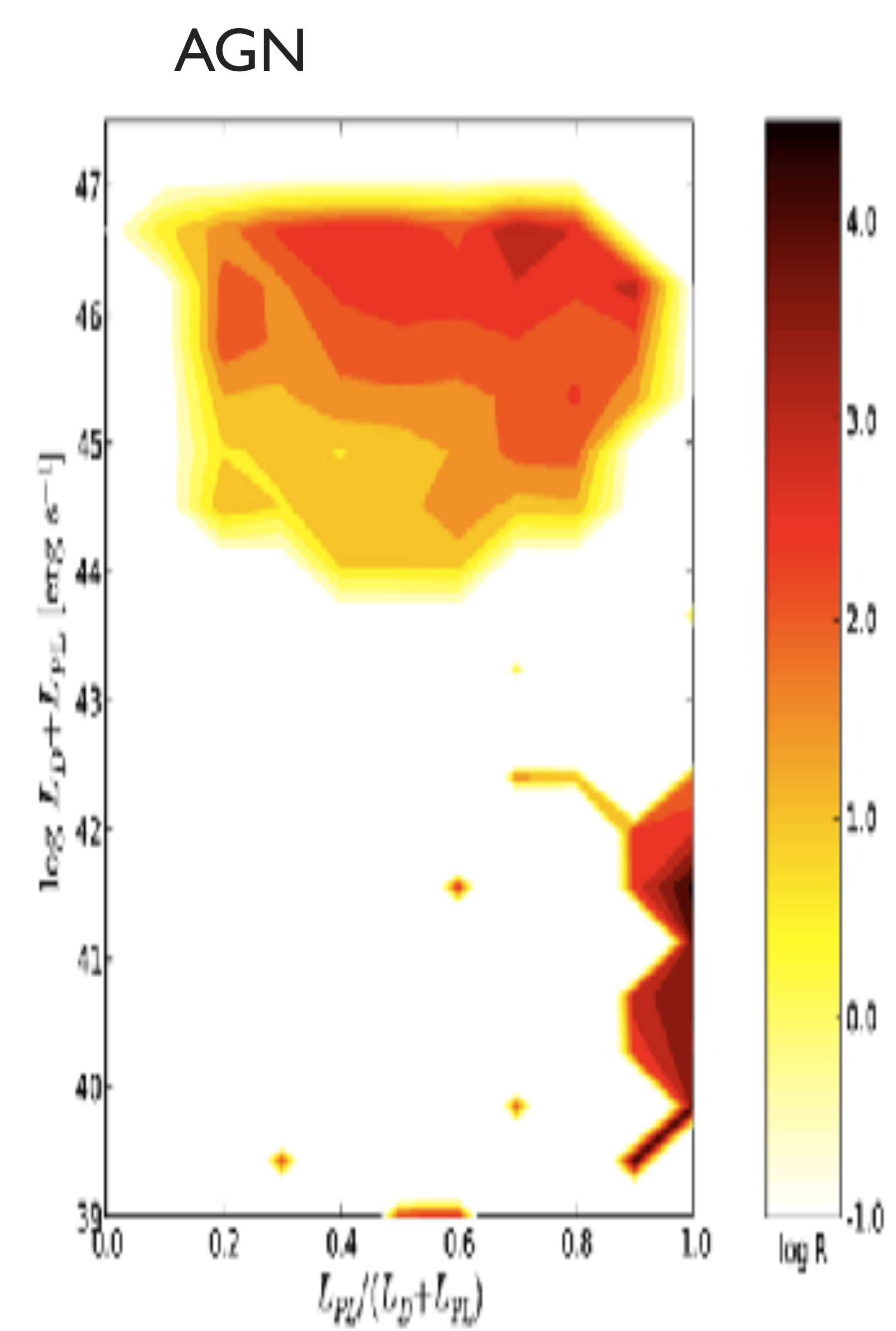
Shows CP




Deanne Coppejans et al.

# Accretion states of compact objects

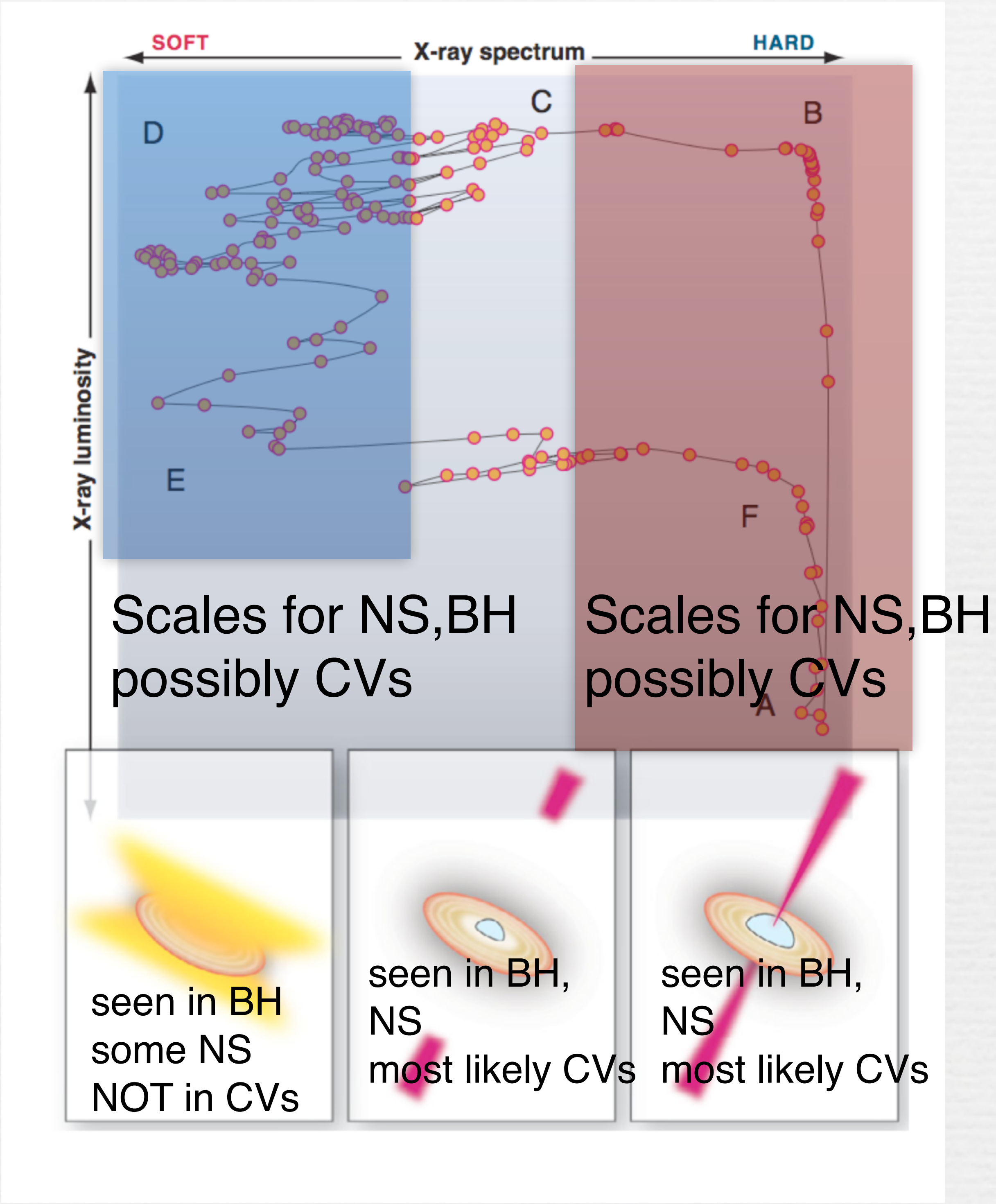



Körding et al., Science 2008, Körding, Jester, Fender 2006

# CV-BH-NS-ULX-AGN Unification

- ULXs can be high magnetic field neutron stars
- HID seen for NS, stellar and supermassive BHs
- CV Jet not imaged, but likely given the flat spectrum + outburst cycle
- some CVs have radio emission not originating in jets




Fender, Gallo 2014; Talk by Rob