Jets in accreting objects: black hole and neutron star binaries

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Outline

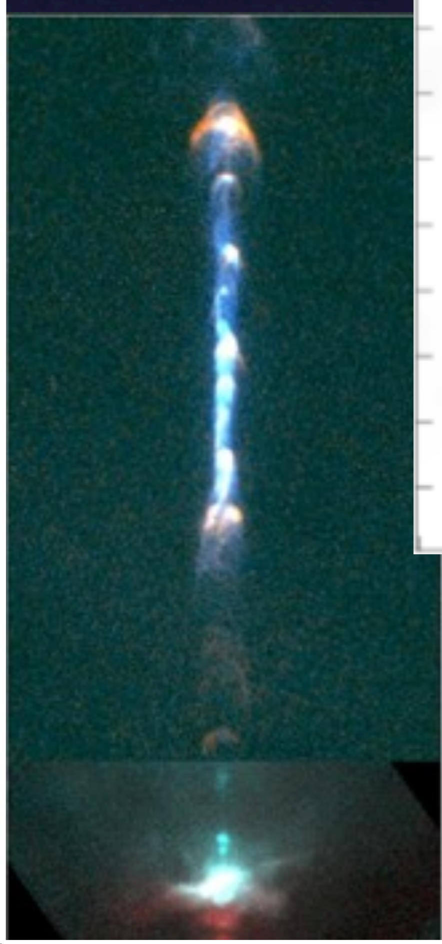
- The jet depends on the accretion state
  - Radio/X-ray correlation
    - Black holes
    - Neutron stars
  - Accretion rates and jet powers
    - efficient and inefficient accretion flows
  - Towards non-relativitic objects: White dwarfs
- Spin powered jets?
- Summary

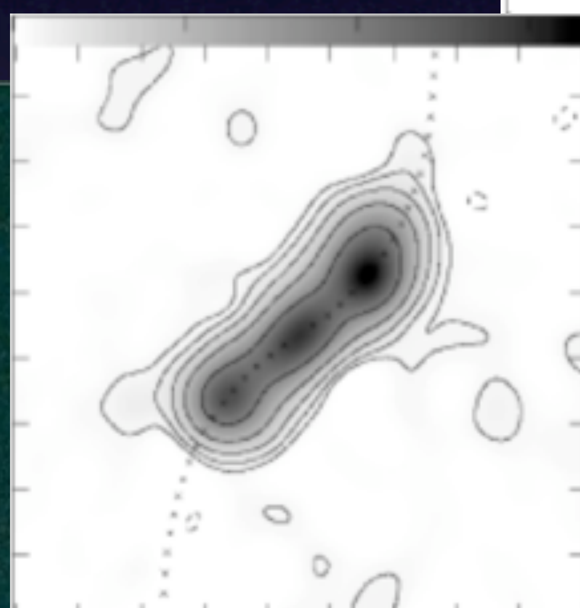
Accretion and jets

Jet power

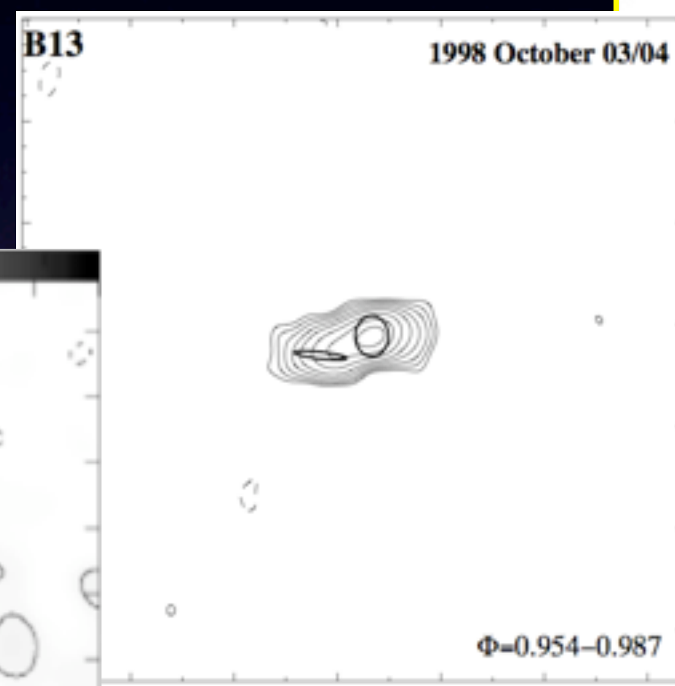
Images in the radio regime:
One would expect points, but ....

Young stellar objects (optical)

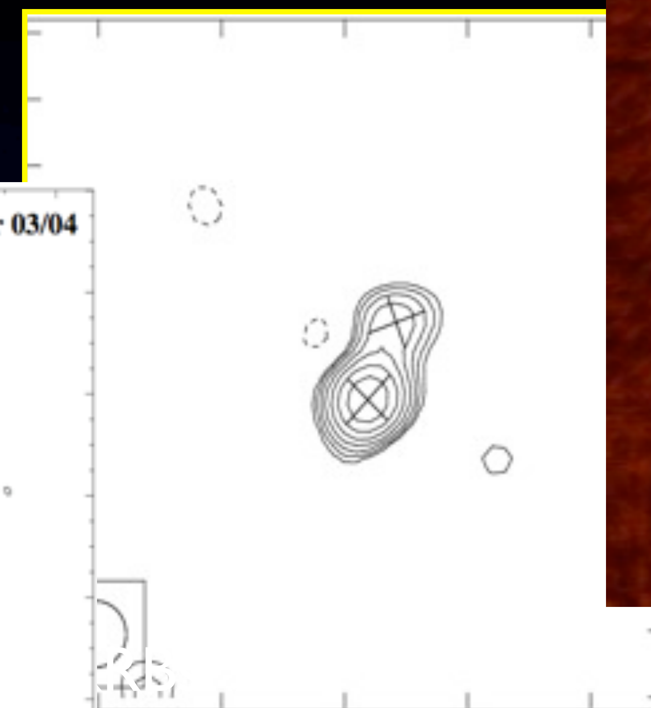




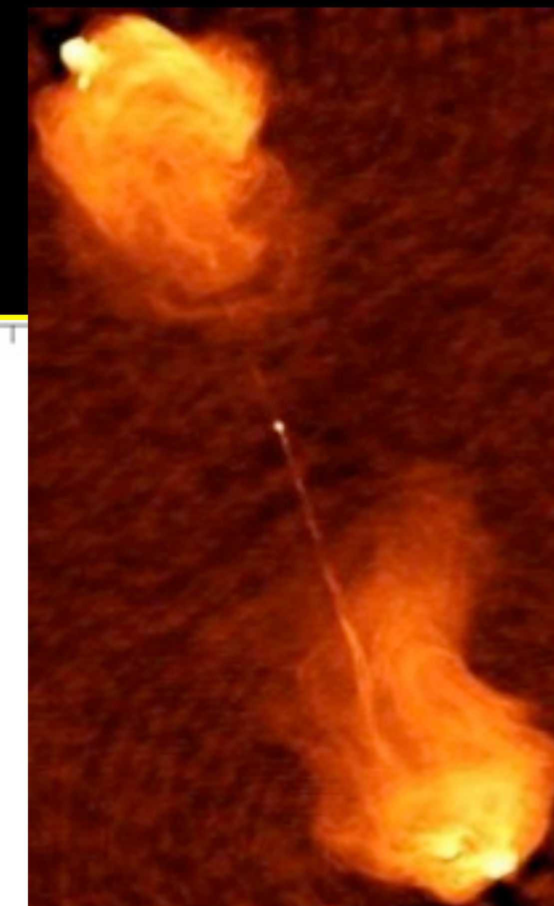
White dwarfs



Neutron stars



Stellar black holes



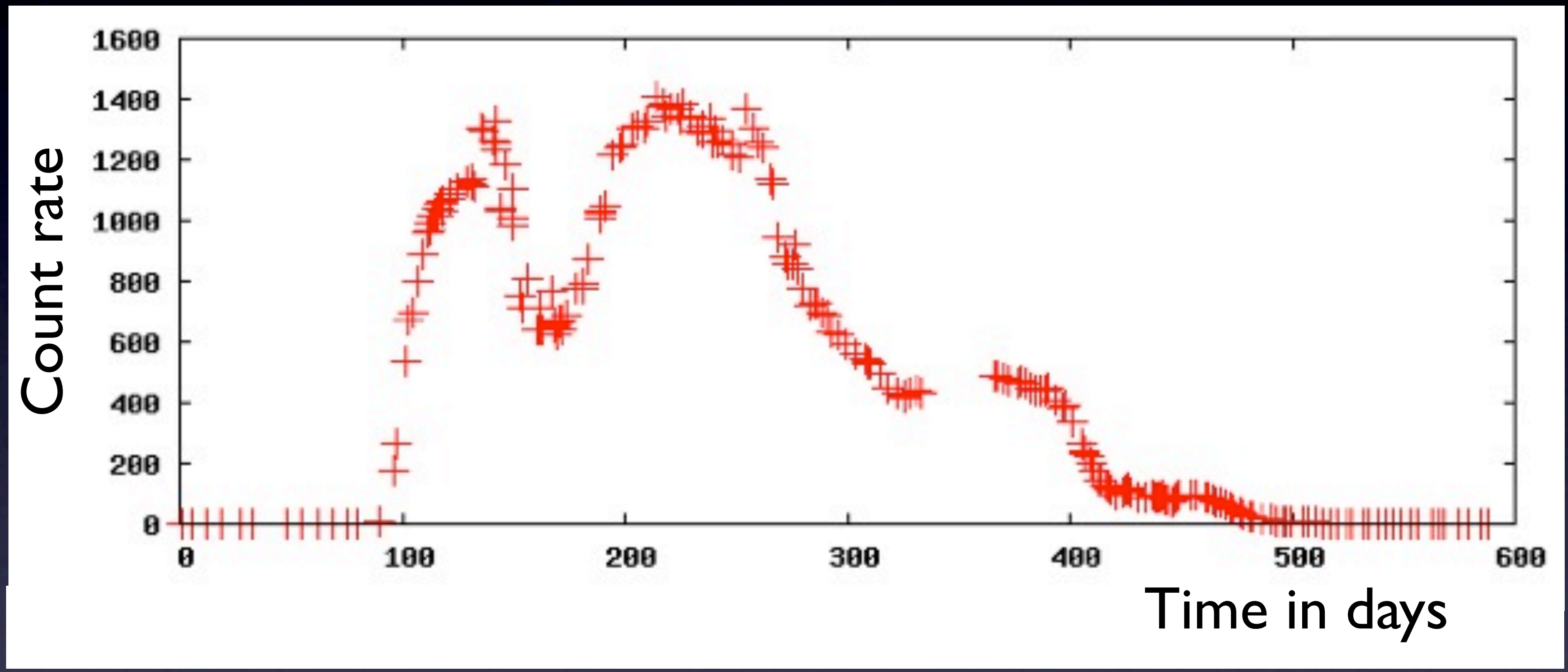
Supermassive black holes (AGN)

Accretion power

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

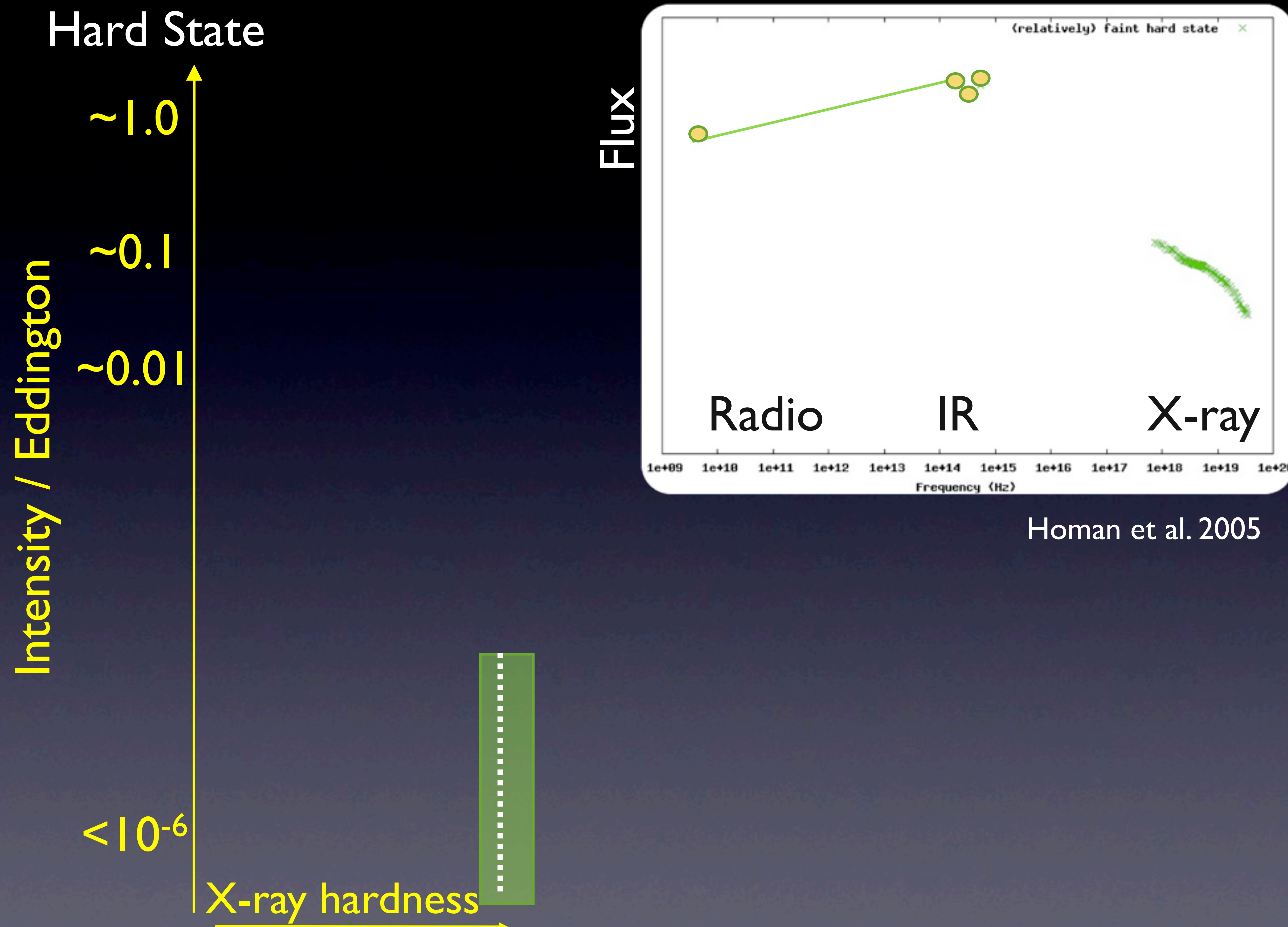
Accretion states in black hole X-ray binaries

X-ray binary
GX 339-4
black hole of
mass 10 M_{sol}

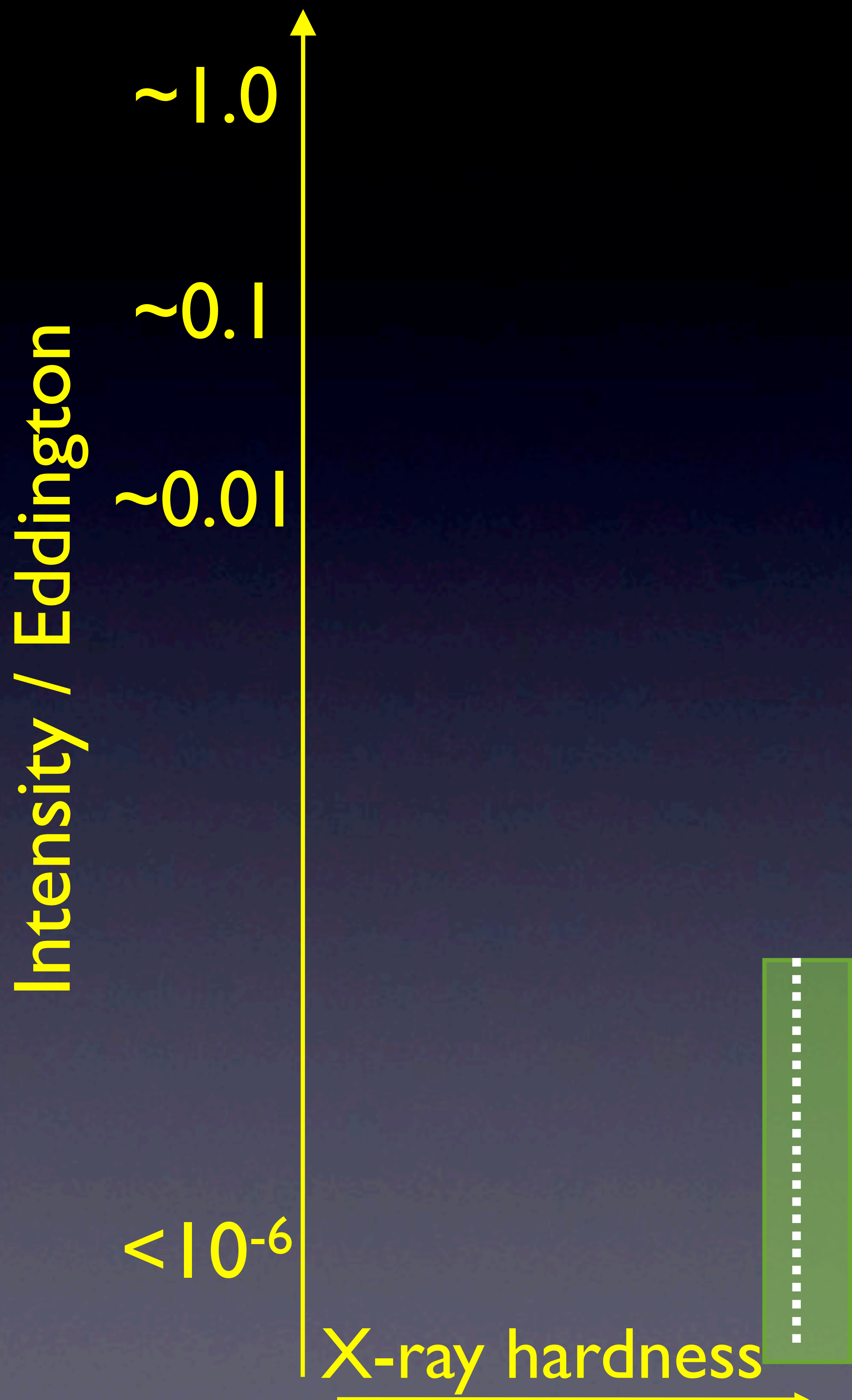


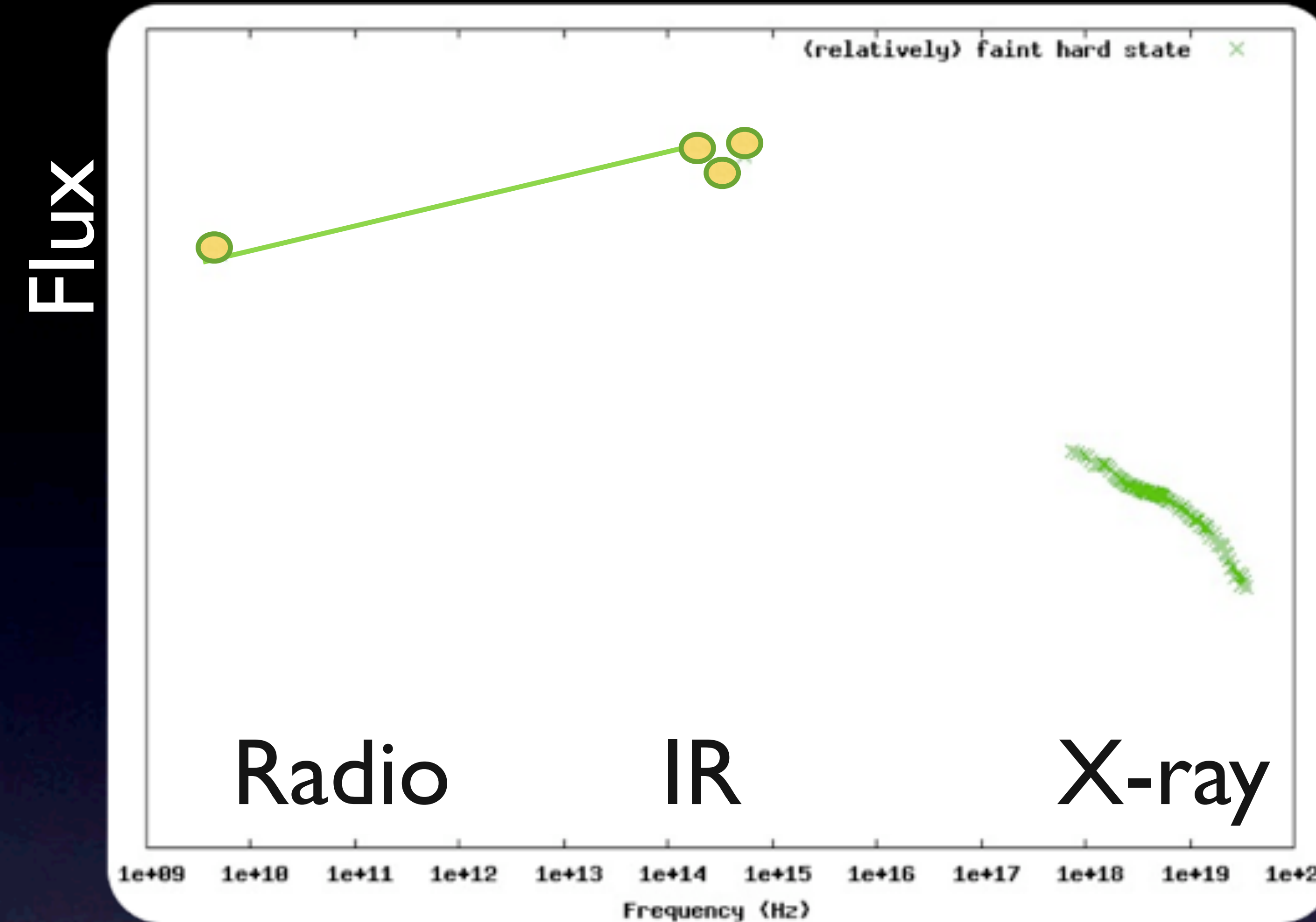
- All basic parameters of the black hole stay fixed: mass, inclination, orbital period etc., except the accretion rate.
- Study of the accretion disc/jet system under evolution of the accretion rate

Hard State

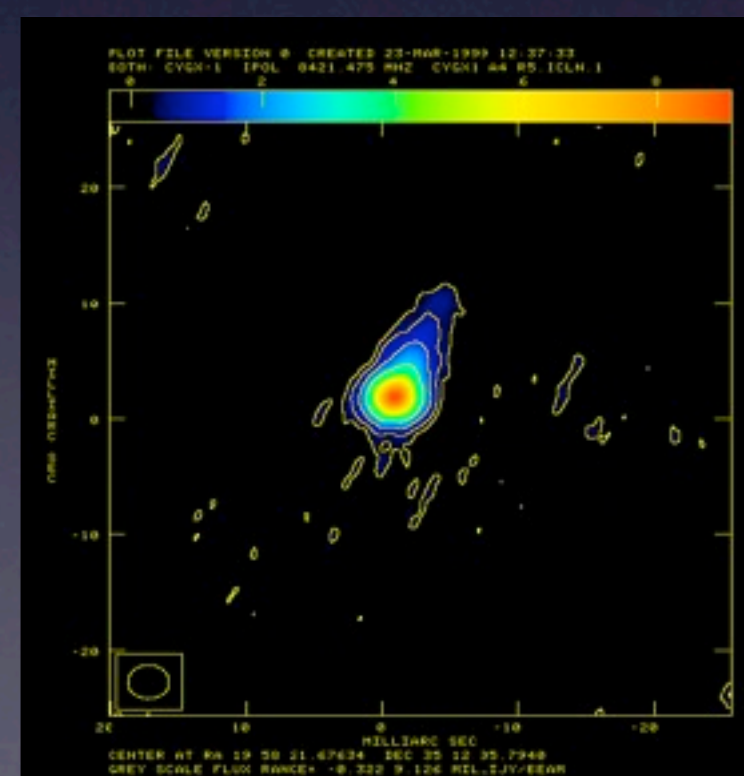

~1.0
~0.1
~0.01
<10^-6
Intensity / Eddington
X-ray hardness
Flux
(relatively) faint hard state
Radio
IR
X-ray
1e+09 1e+10 1e+11 1e+12 1e+13 1e+14 1e+15 1e+16 1e+17 1e+18 1e+19 1e+20
Frequency (Hz)
Homan et al. 2005

Hard State





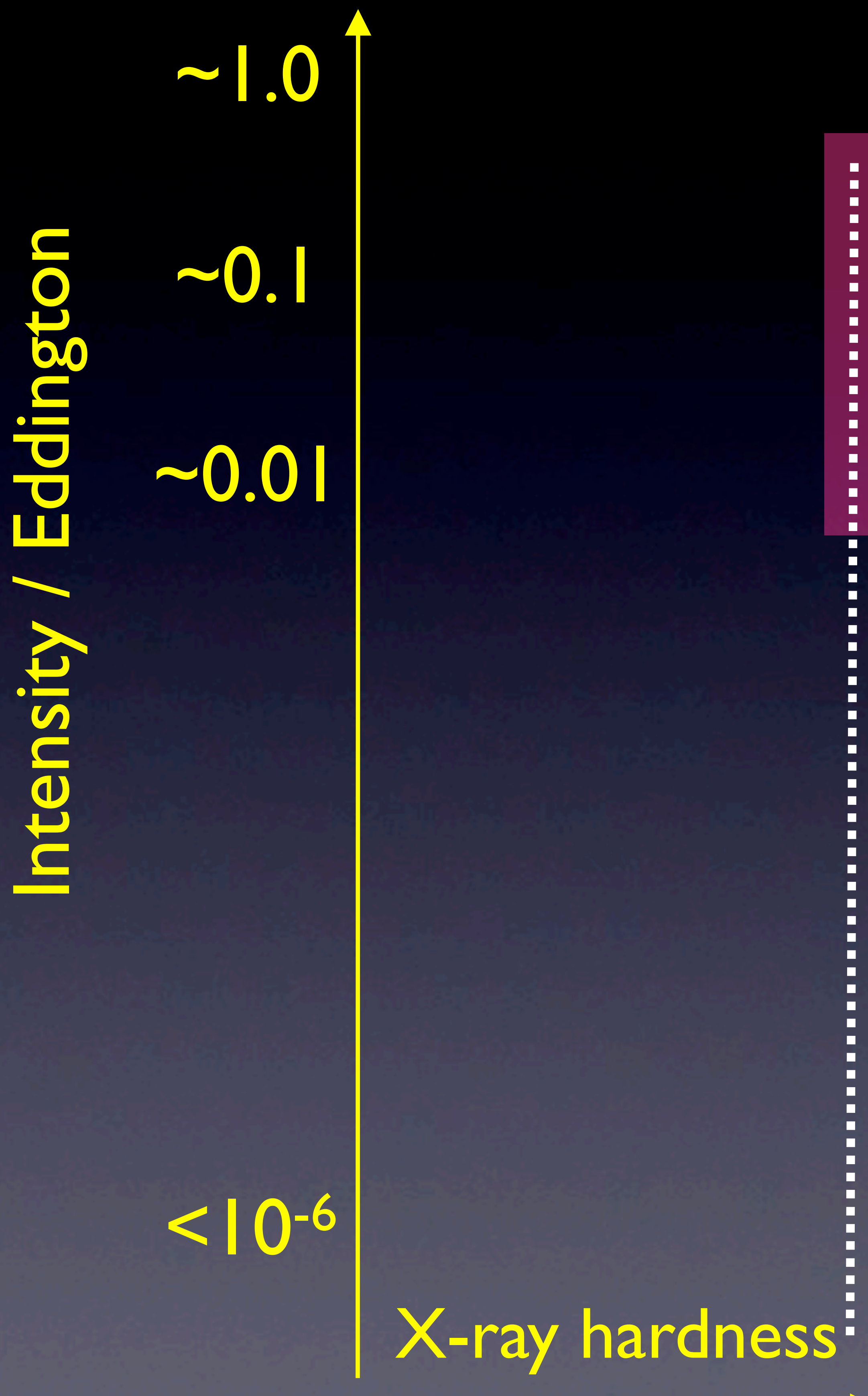
Homan et al. 2005

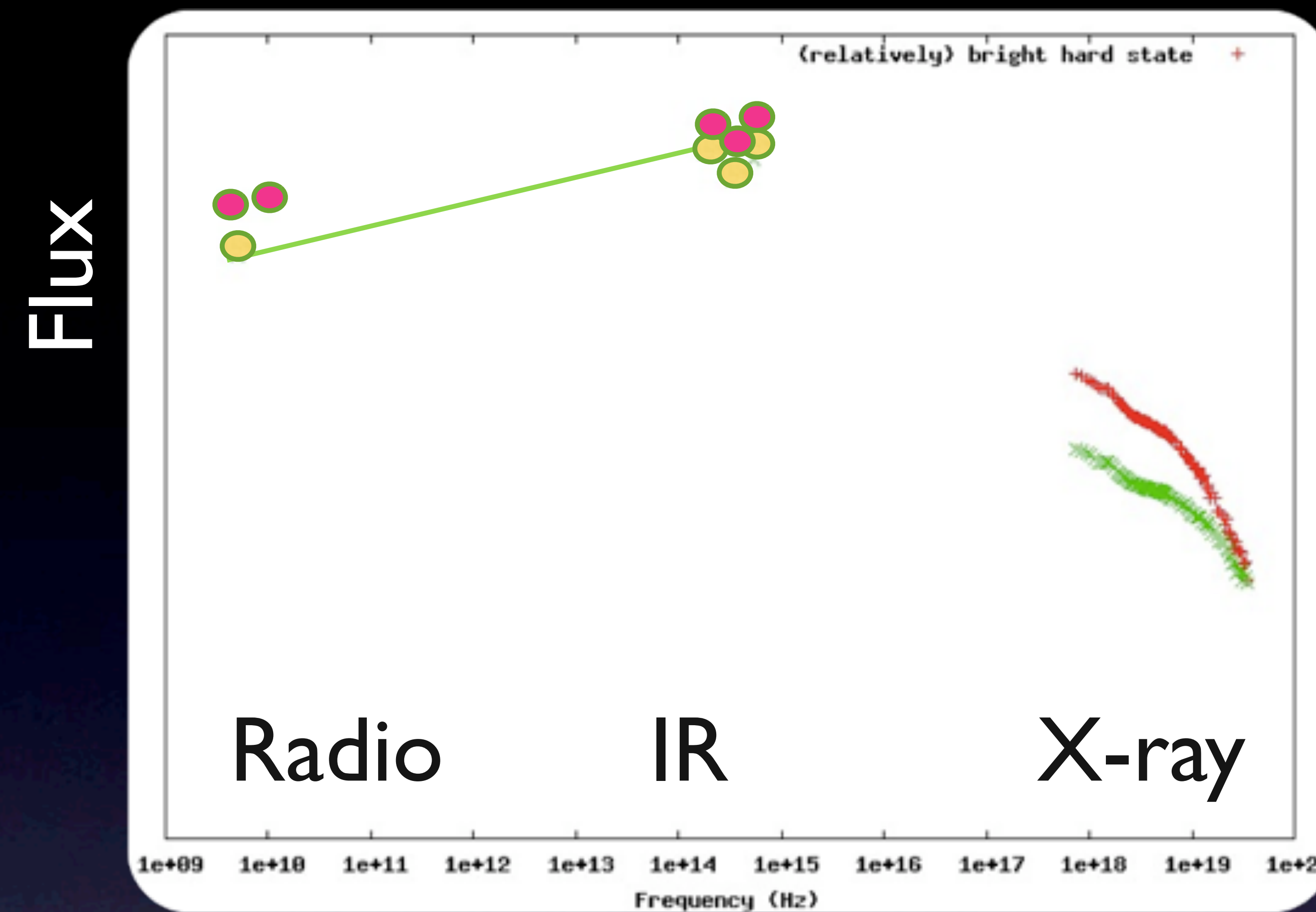


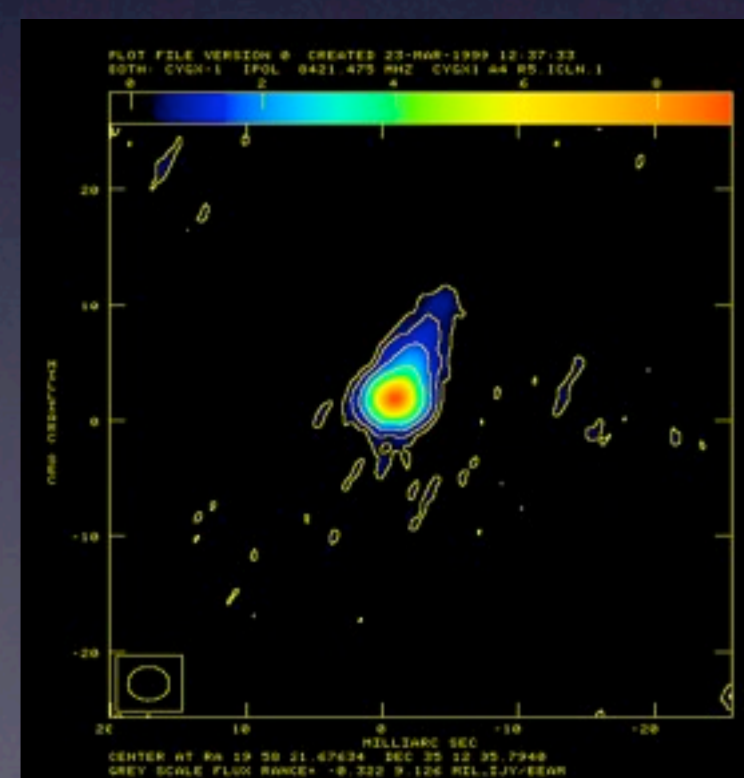
Compact steady jet

Stirling et al. 2001

Hard State



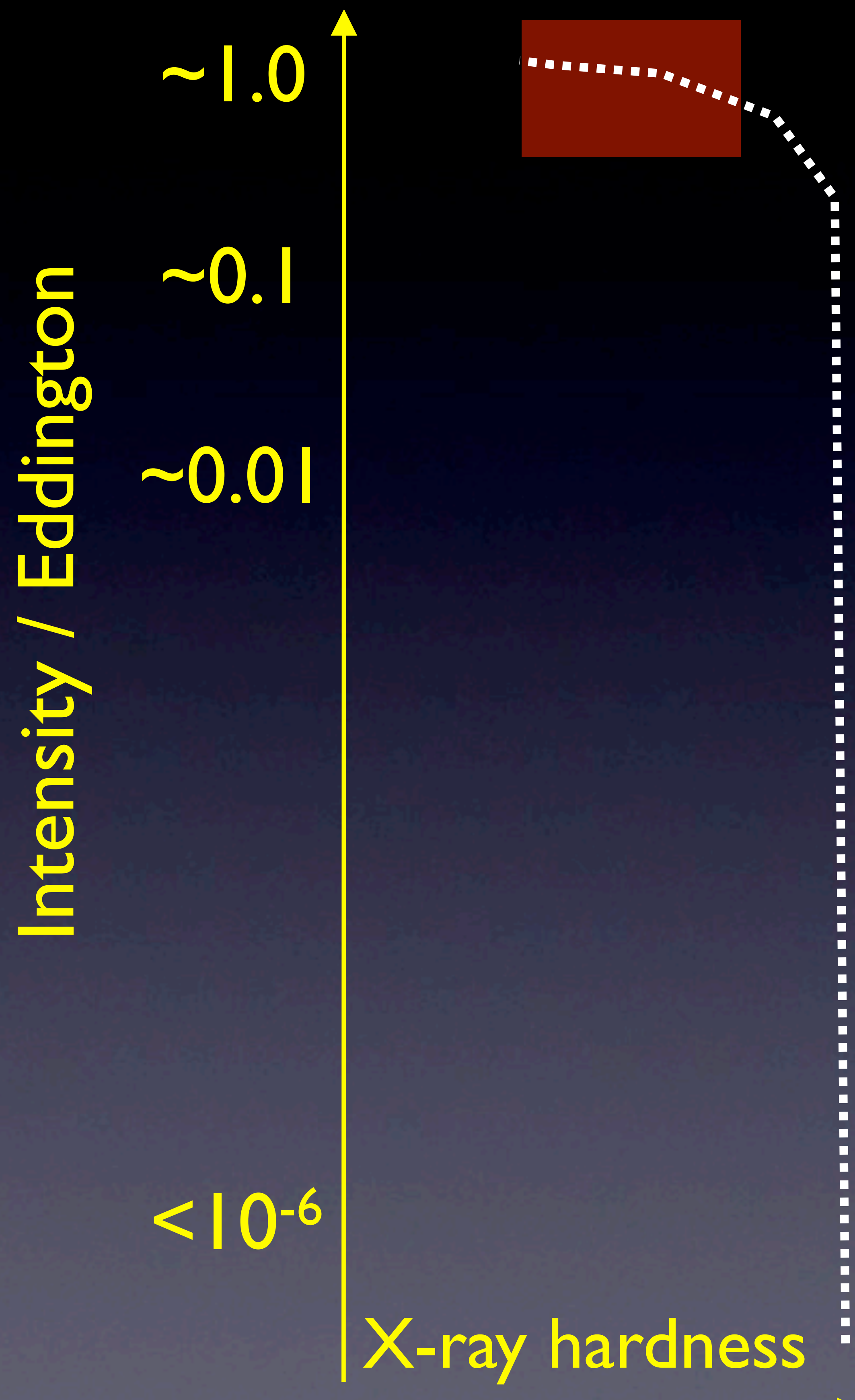


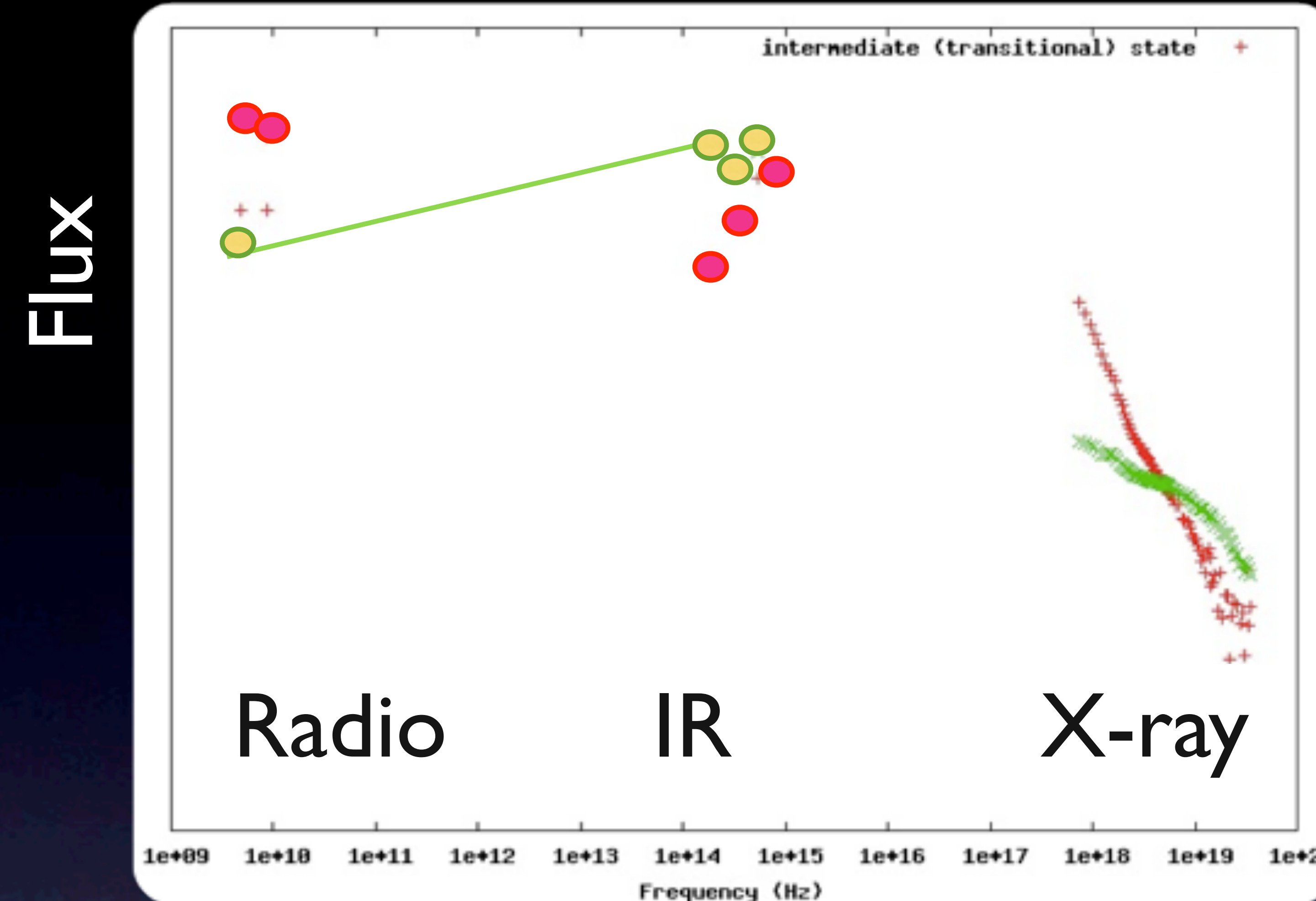


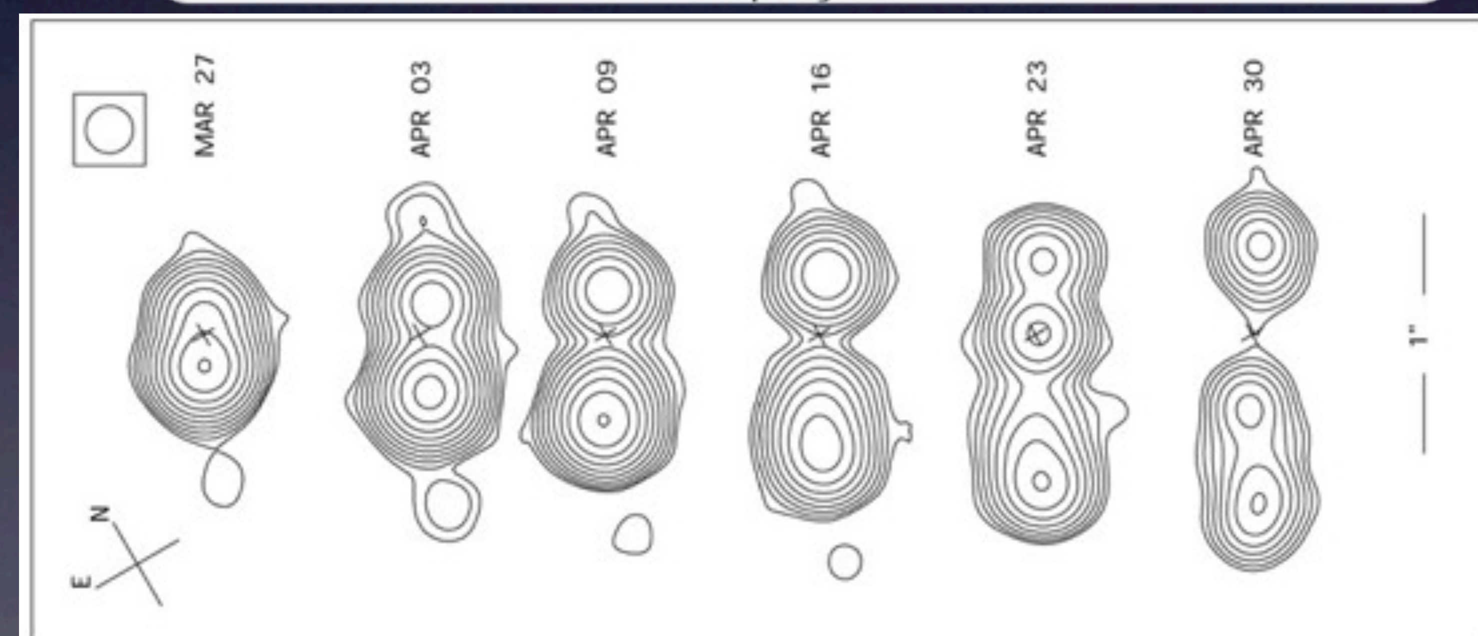
Compact steady jet

Stirling et al. 2001

Intermediate State



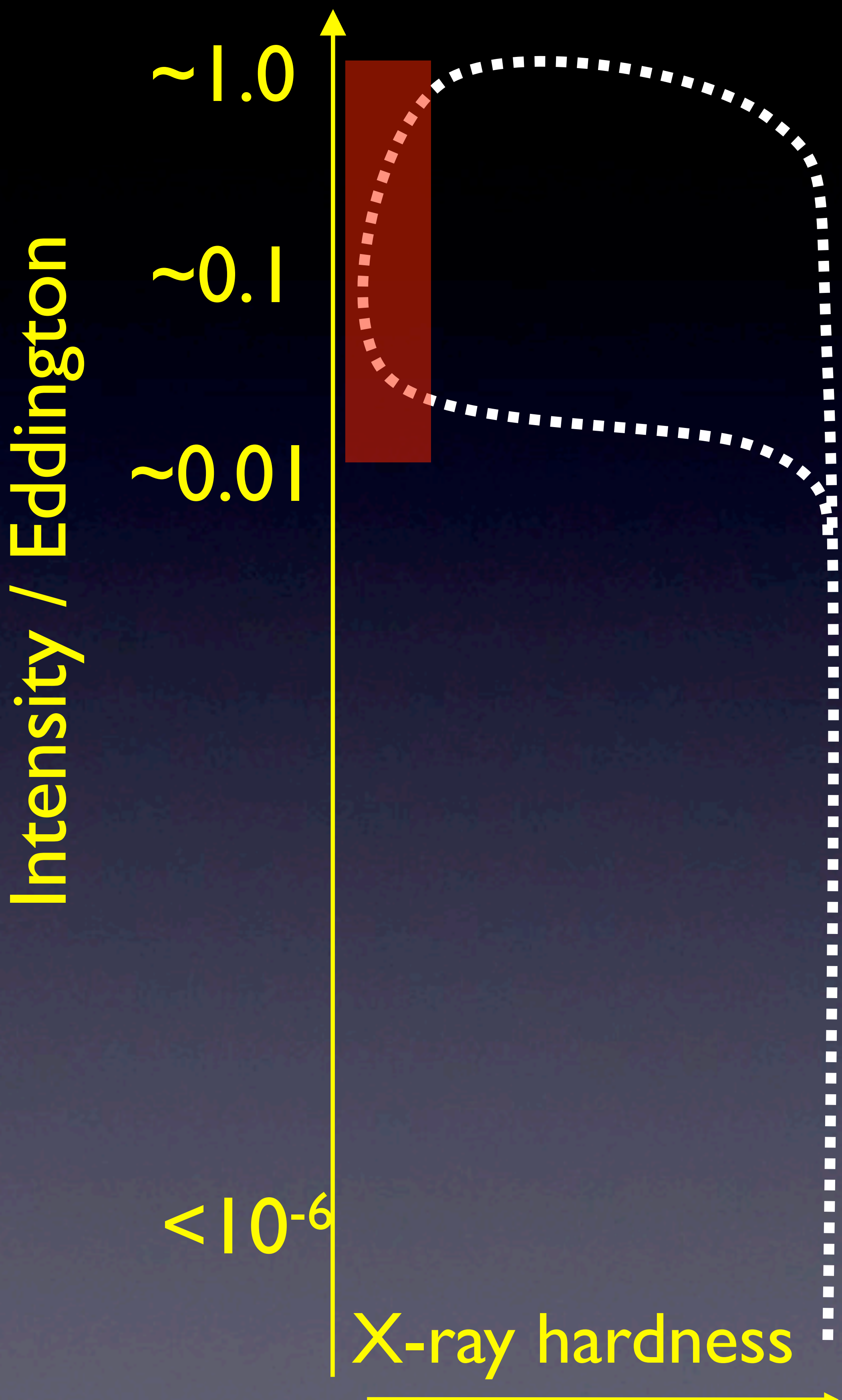


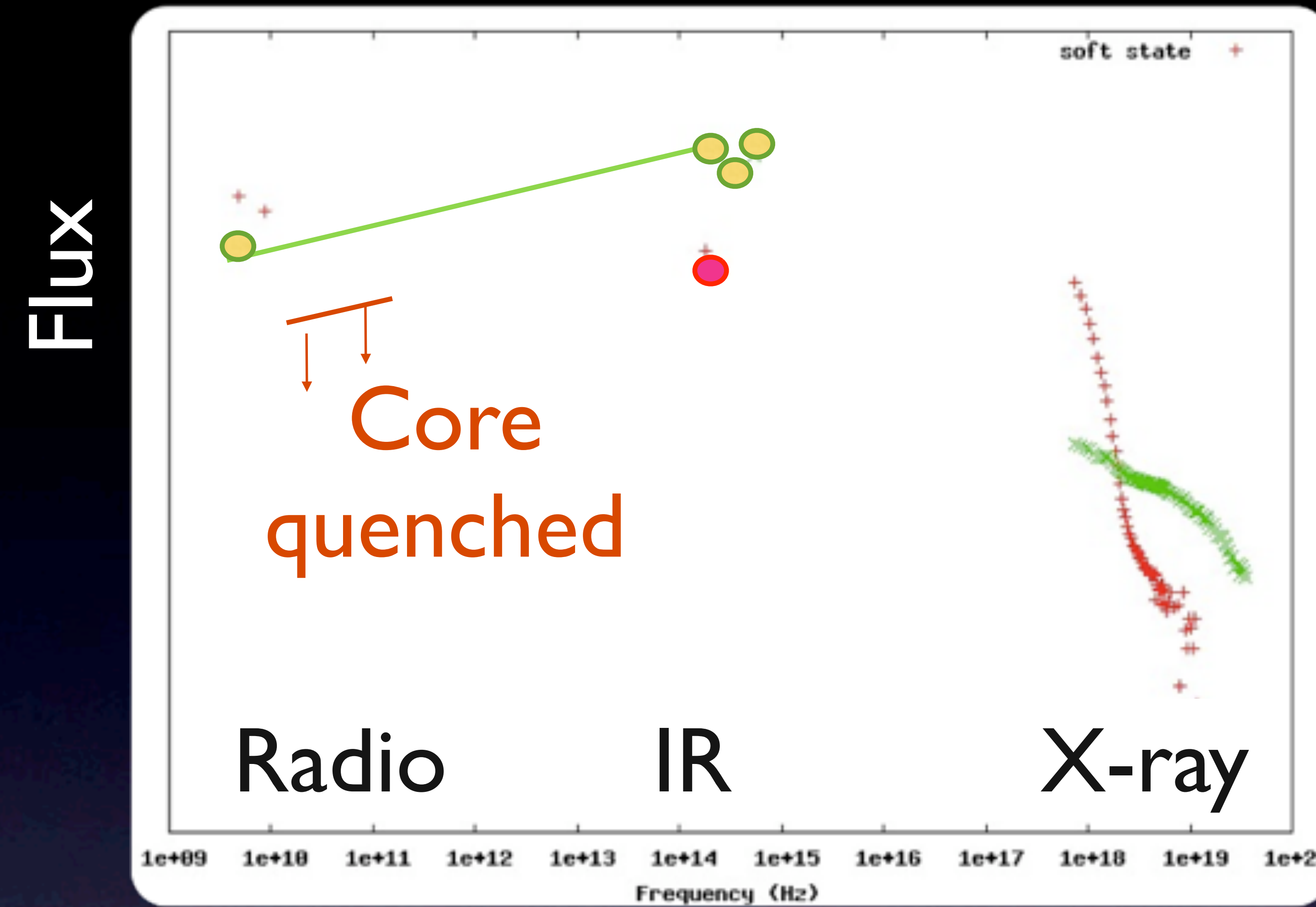


Unsteady jet. GRS 1915+105

(Mirabel et al. 1994)

Soft State

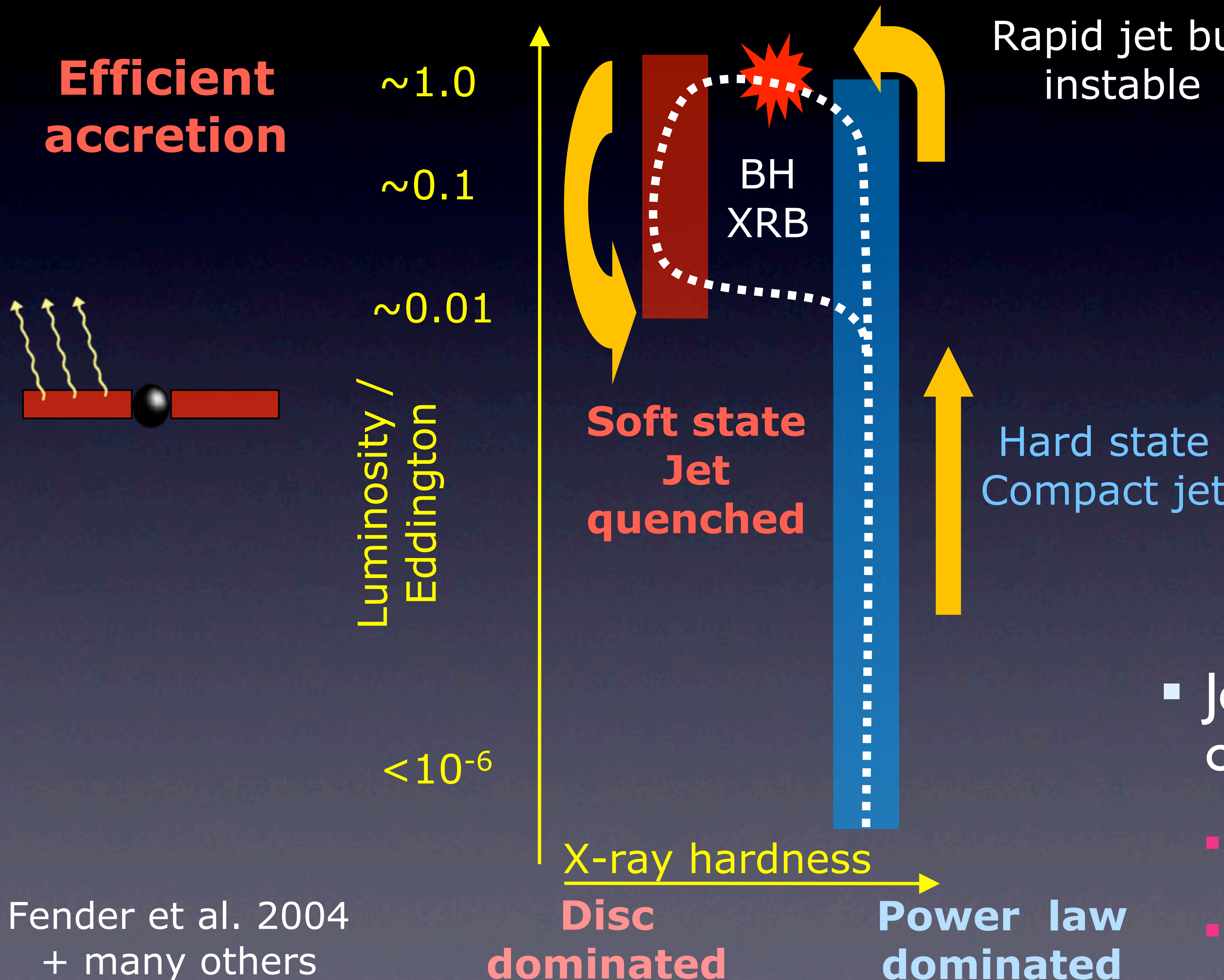


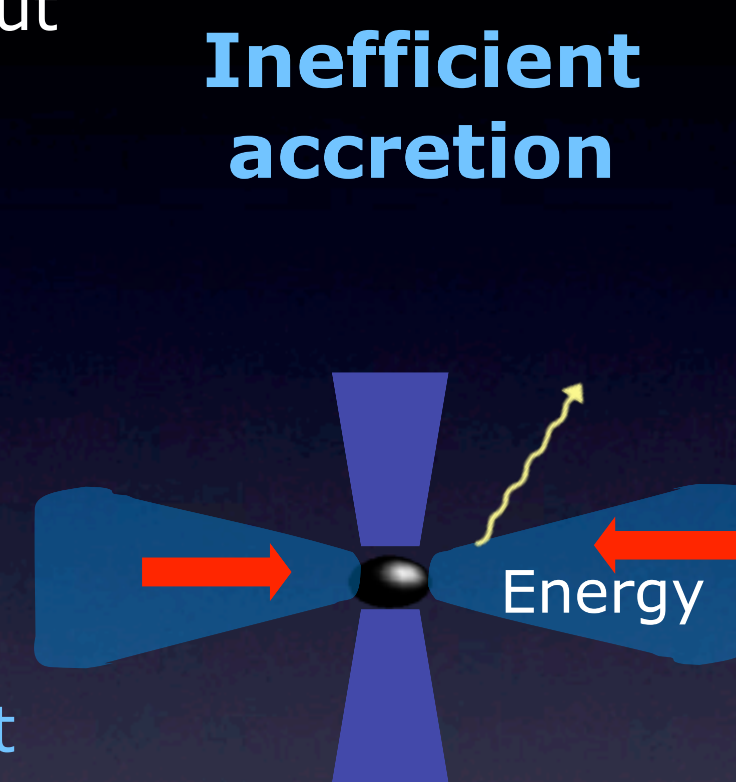


Jet quenched

Nothing
to see here
Move along

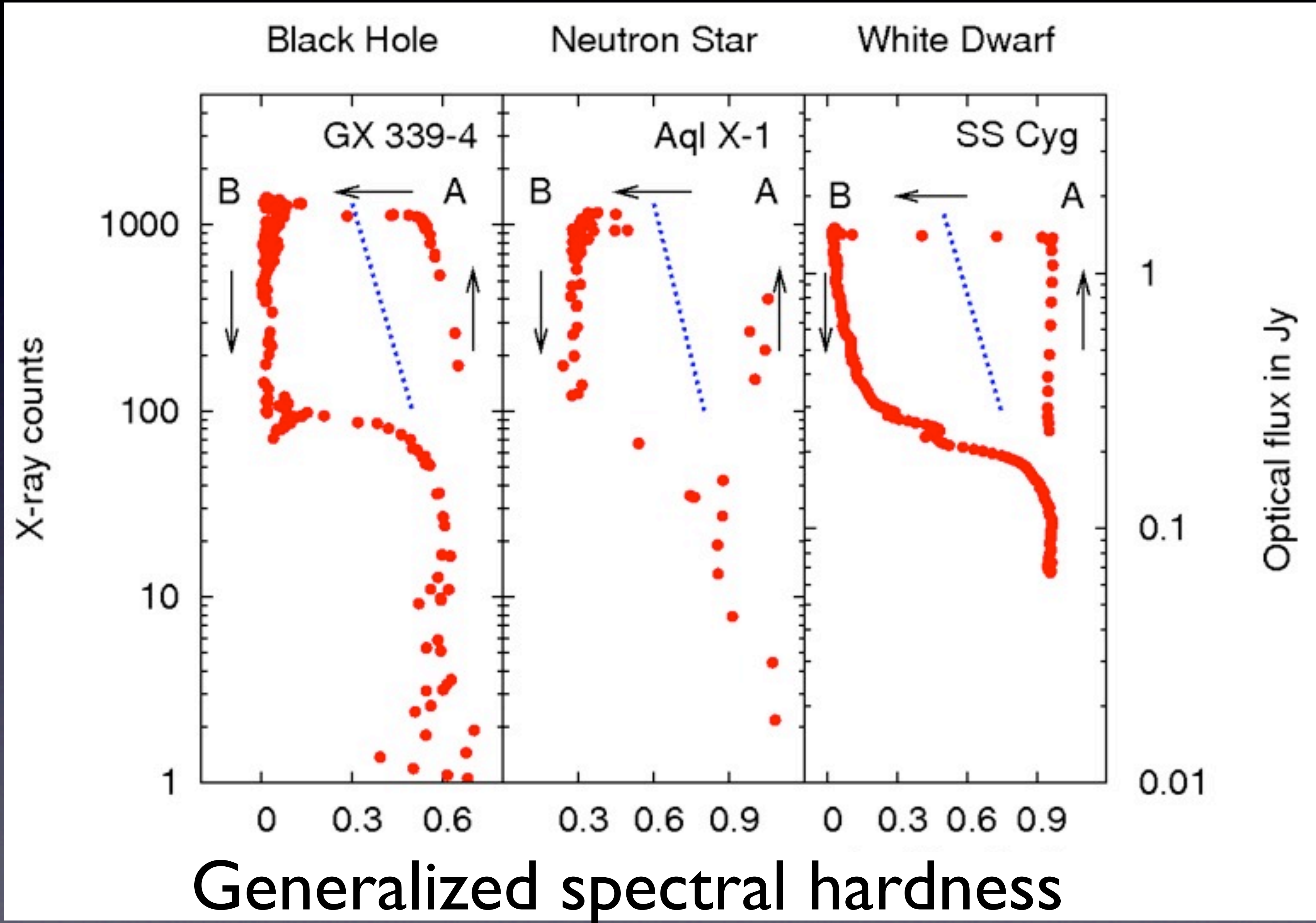
Disc/Jet coupling in XRBs





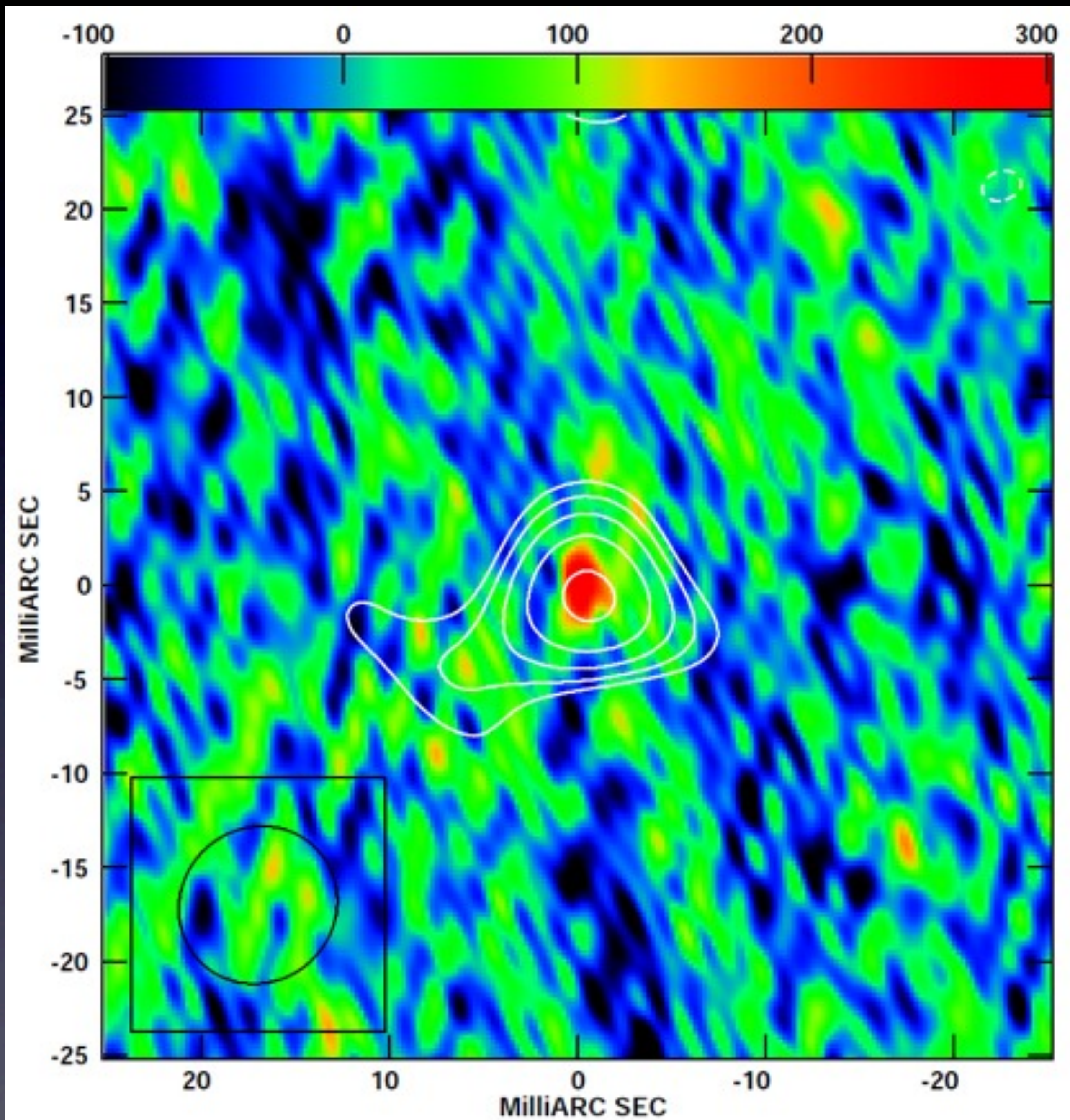
- Jet power depends on
  - Accretion rate
  - Accretion state

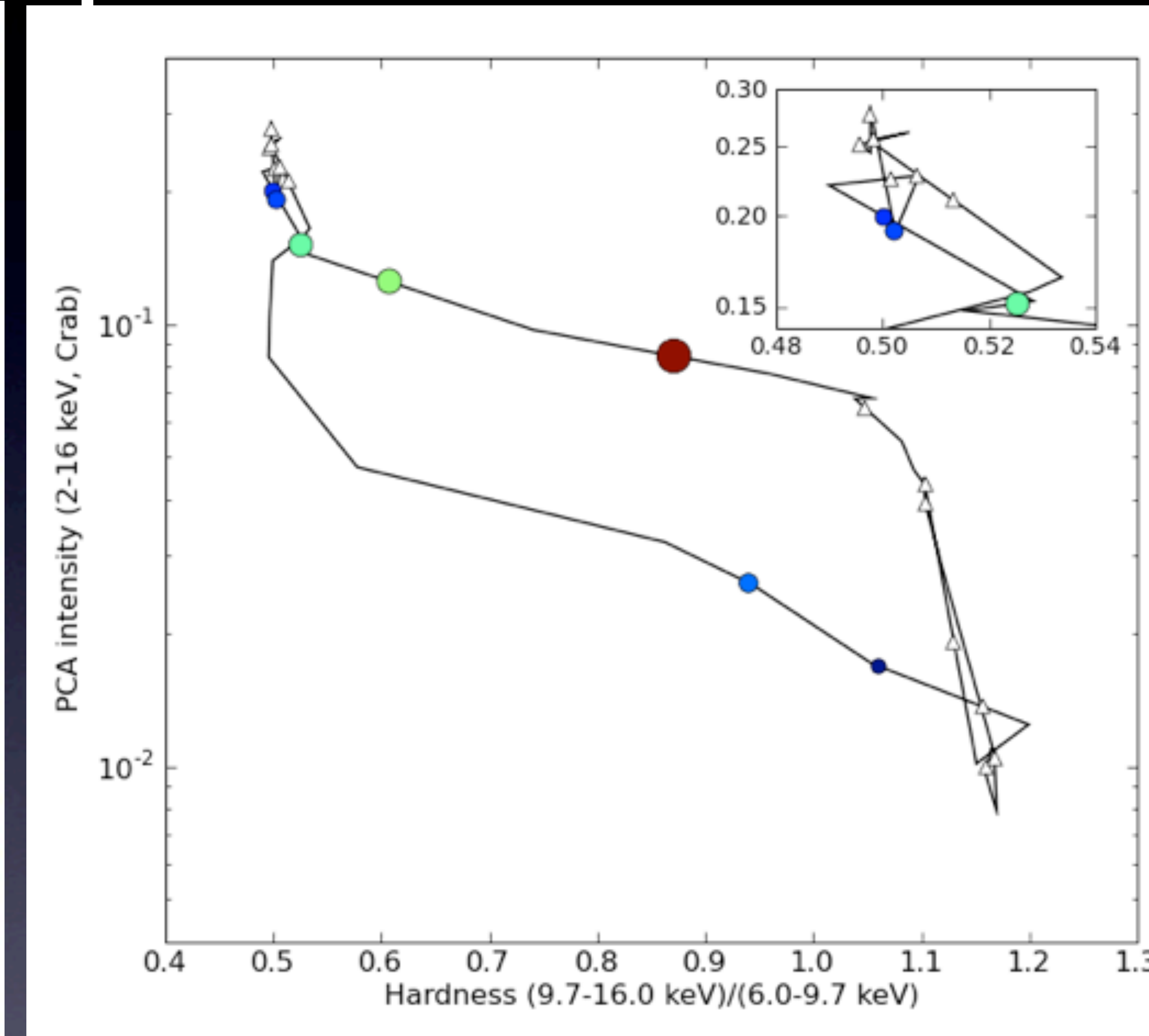
Accretion states in stellar accreting objects



Körding et al., Science 2008

XRB Monitoring of the neutron star Aql X-1

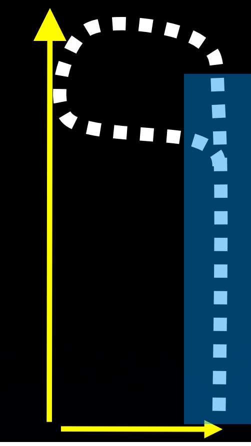




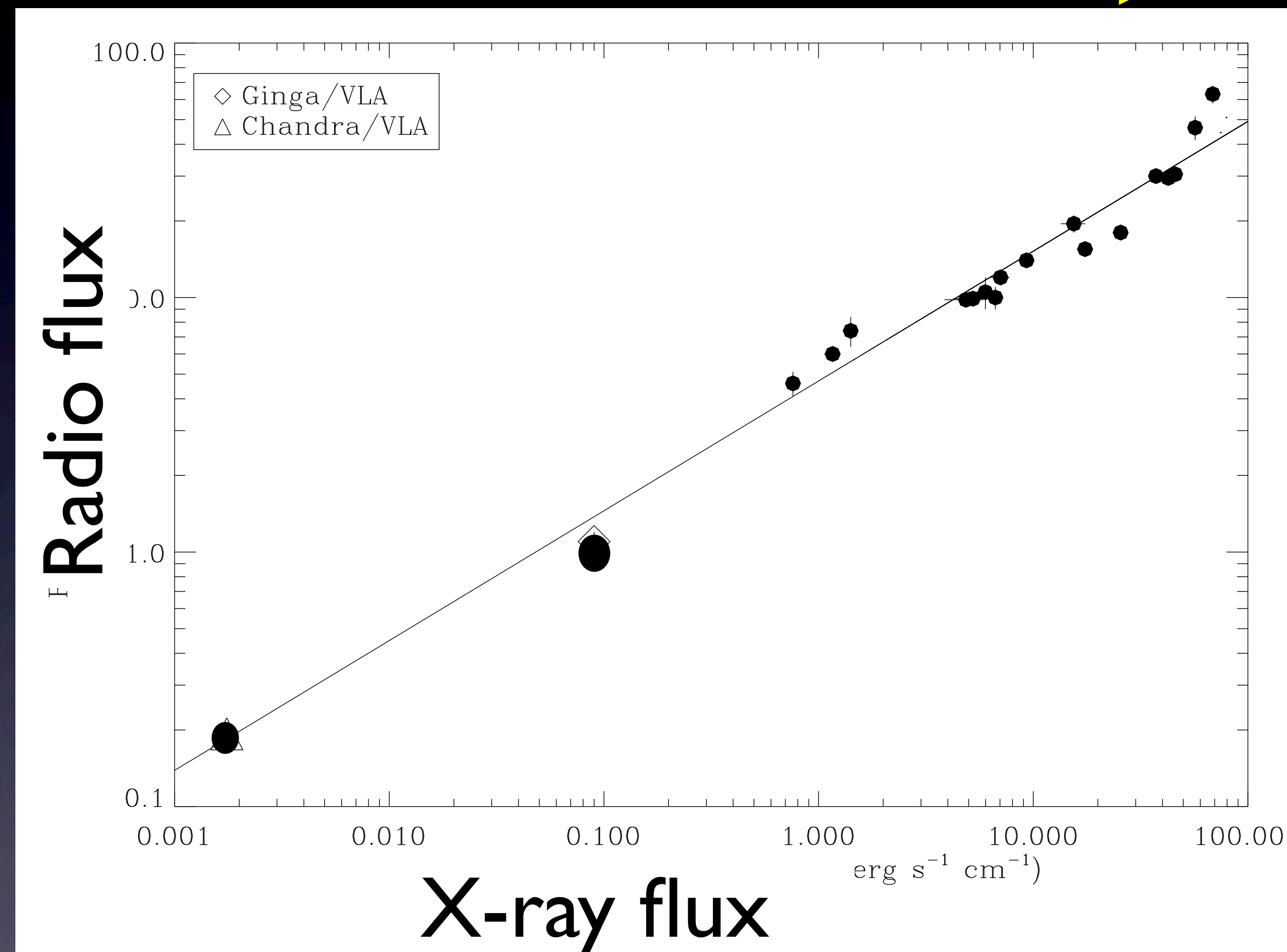
- Radio jet quenched when going into the soft state as in black holes

JACPOT, Miller-Jones et al.

Radio X-ray correlation



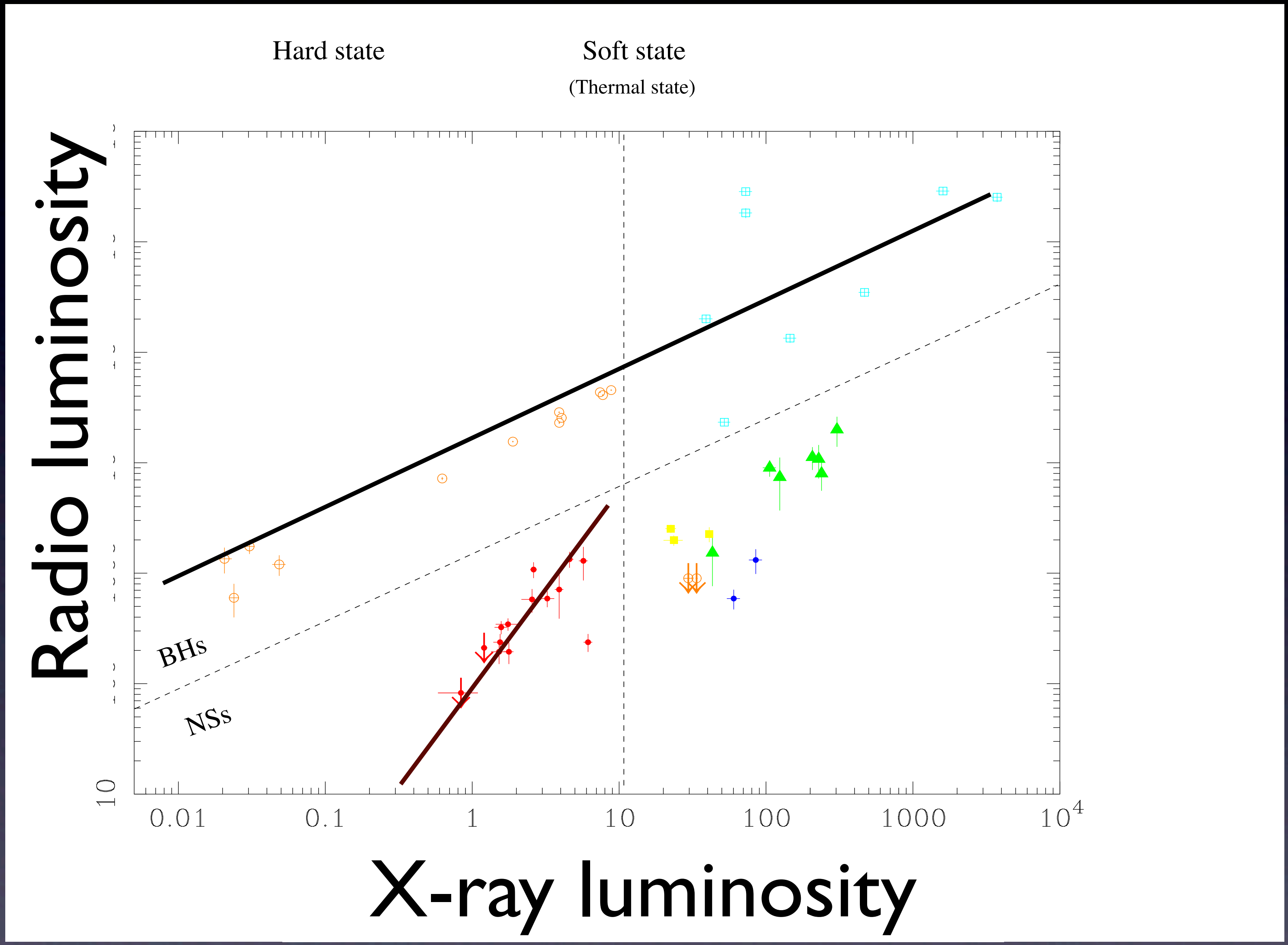
- Tight correlation between X-rays and radio emision (e.g., V404 5 orders of magnitude)
- Radio: Jet
  X-rays: Corona or base of the jet



Gallo et al., 2003, Corbel, EK, Kaaret 08

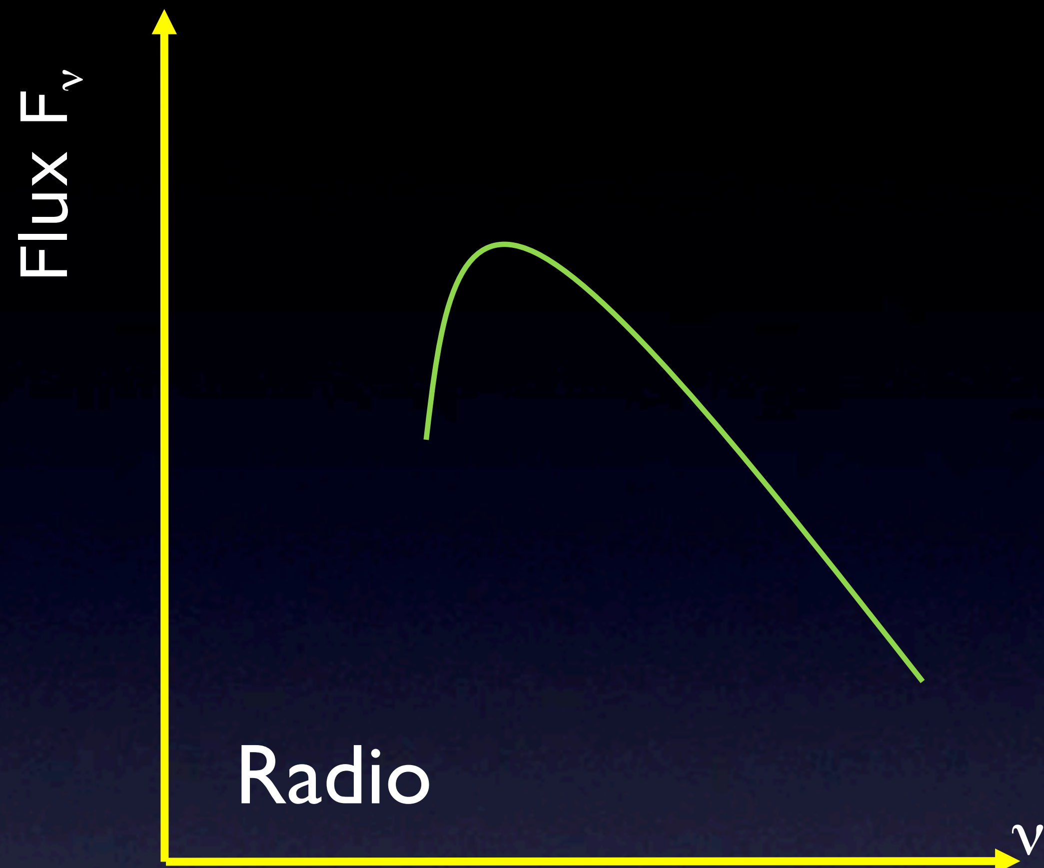
The neutron star case

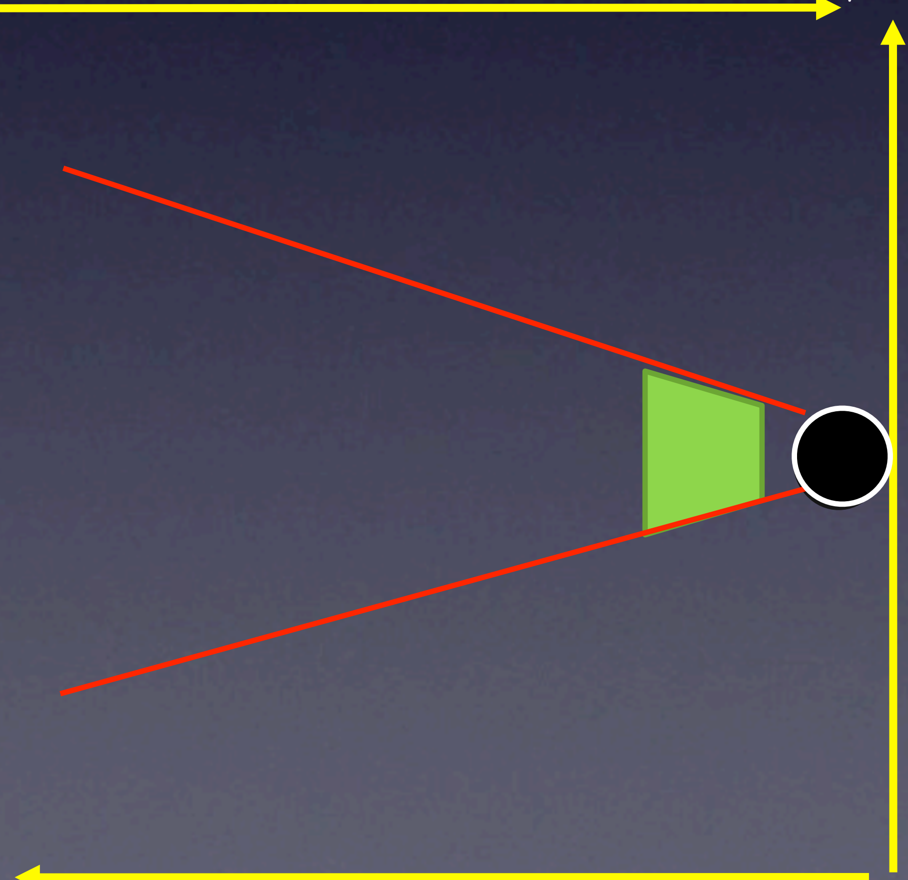
- Neutron stars also show correlated radio/X-ray fluxes
- Slope and normalization different (NS have 1.4 vrs 0.6-0.7 for BHs)
- Neutron stars a less radio loud for a given X-ray flux



Migliari et al. 2005

Steady spectrum of a scale invariant jet





- Conical jet
- Superposition of self-absorbed synchrotron spectra at different positions of the jet yields a flat spectrum

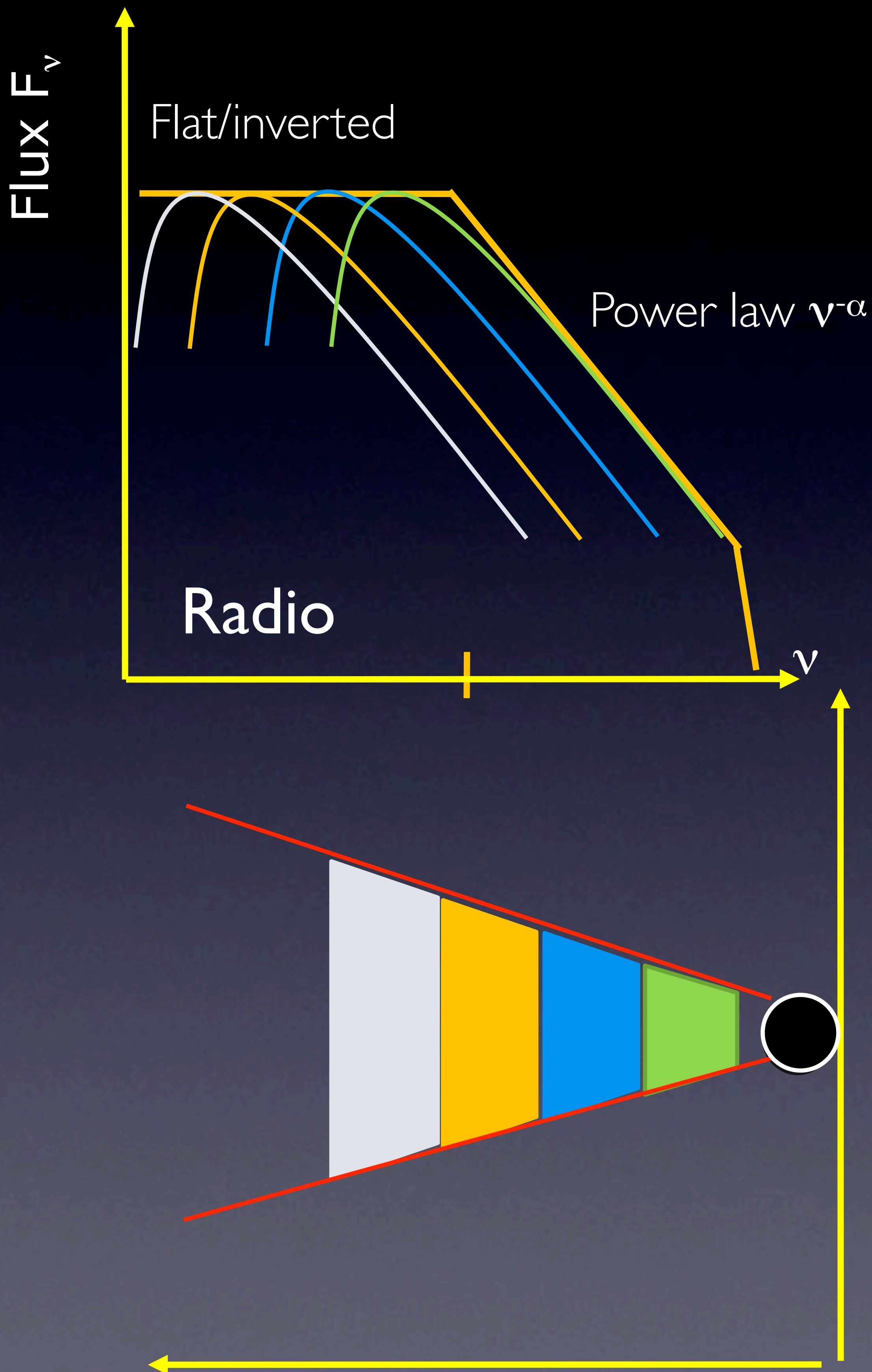
$$F_\nu \propto P_{\rm Jet}^{1.4} \propto \dot{M}^{1.4}$$

- Flat spectrum flux does not depend on mass, only on power

- Most other components depend on mass, e.g., disc
  - Multi-wavelength needed

Blandford & Koenigl 1979, Falcke et al. 1995

Steady spectrum of a scale invariant jet



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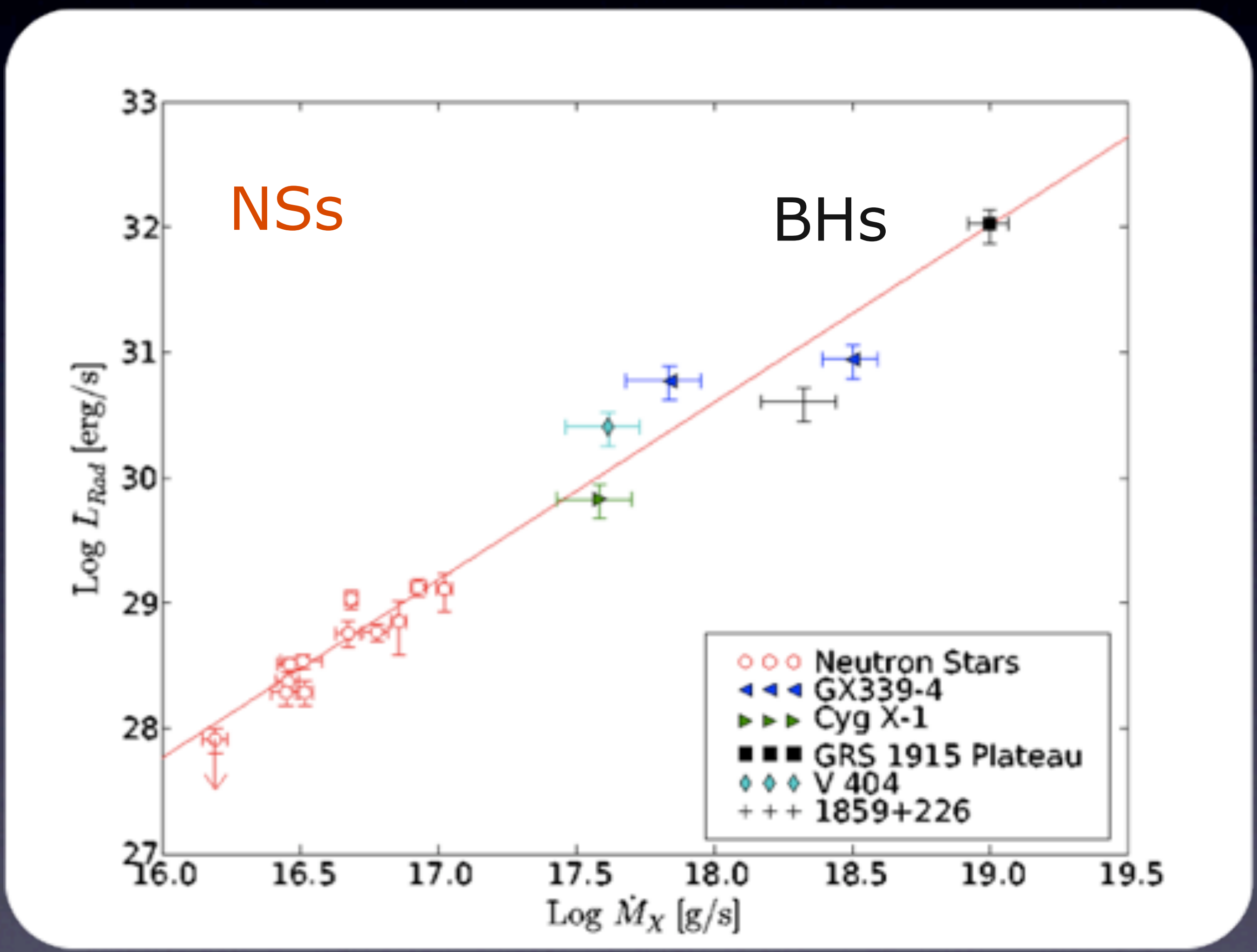
Empirical evidence for this model



Plot shows objects with known accretion rate

- Radio luminosity follows the analytical prediction

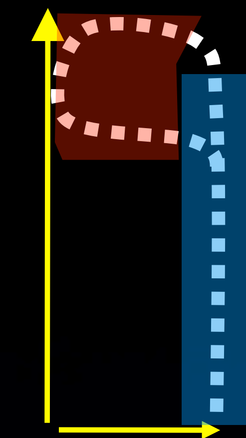
$$L_{\mathrm{Rad}} \propto \dot{M}^{1.4}$$

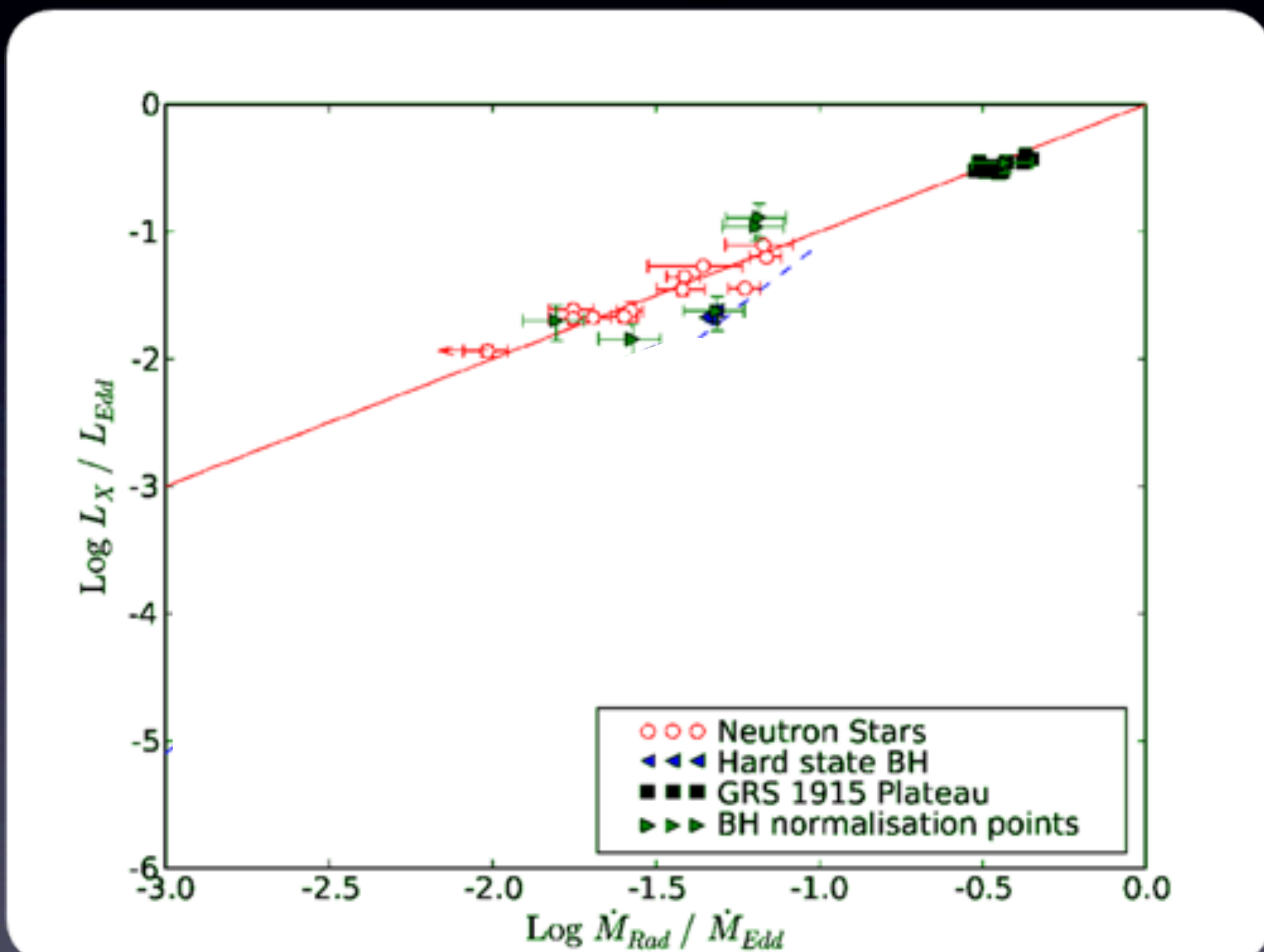
- Difference of radio luminosity between neutron stars and black holes may be a factor 2.5 (without boundary layer)
- Jet power for a given accretion rate similar for black holes and neutron stars (Spin powered jets? No)
- Radio can be used as a tracer of the accretion rate

$$\dot{M} = \dot{M}_0 \left(\frac{L_{5\mathrm{GHz}}}{10^{29}\,\mathrm{Js}^{-1}} \right)^{1/1.4}$$

Körding et al. 2007

Inefficient accretion flows for black holes





- Accretion rate measured via radio luminosity
- Neutron stars + intermediate state black holes:

$$L_X \propto \dot{M}$$

  efficient accretion disk

- Hard state black holes:

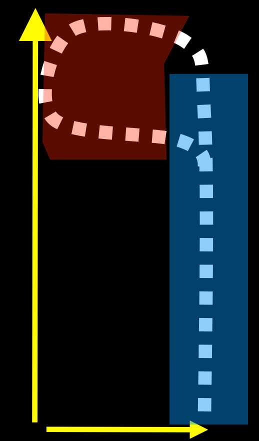
$$L_X \propto \dot{M}^2$$

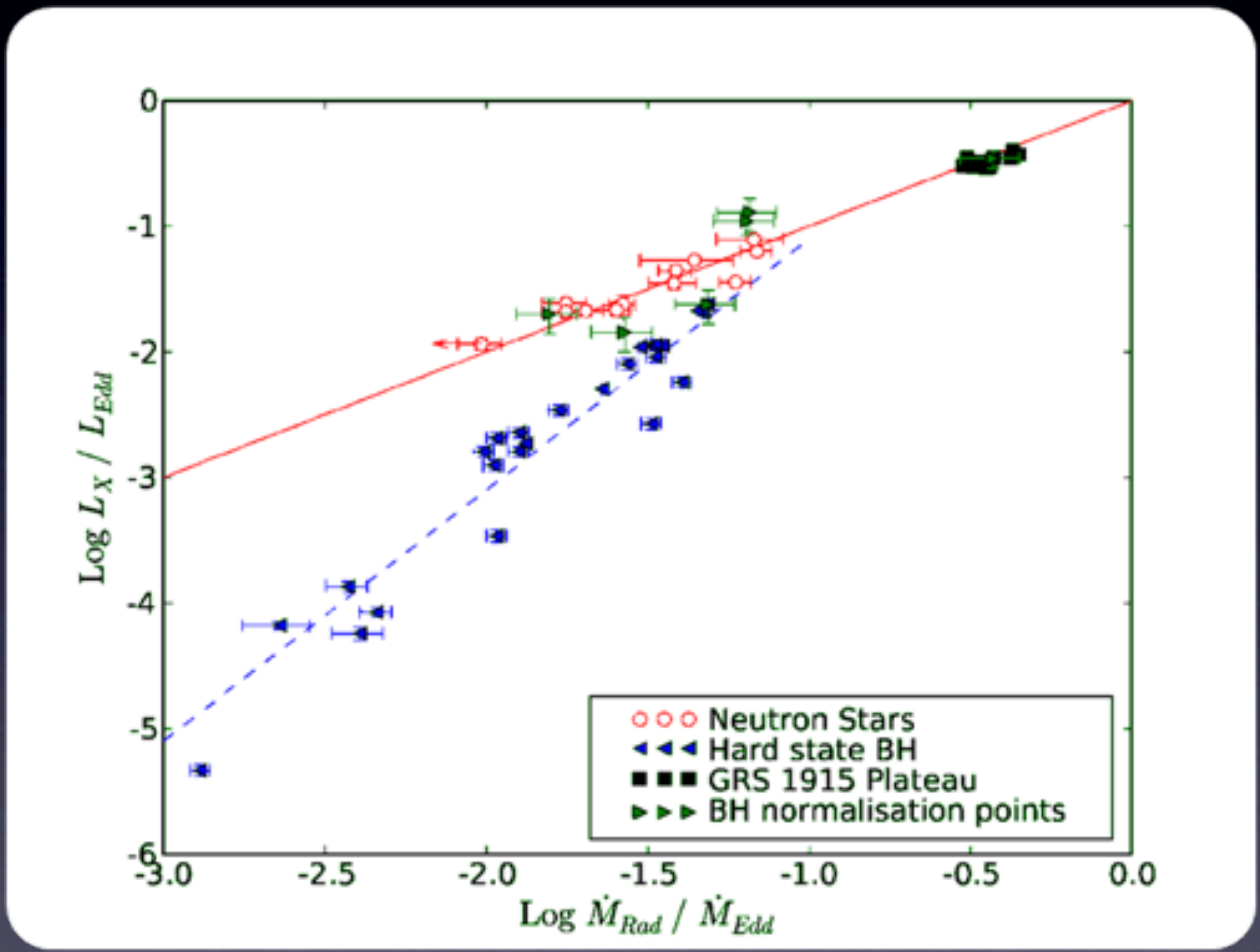
  inefficient flow as expected

- Radio/X-ray correlation (Gallo et al.) translates to quadratic scaling

Körding et al. 2007

Inefficient accretion flows for black holes





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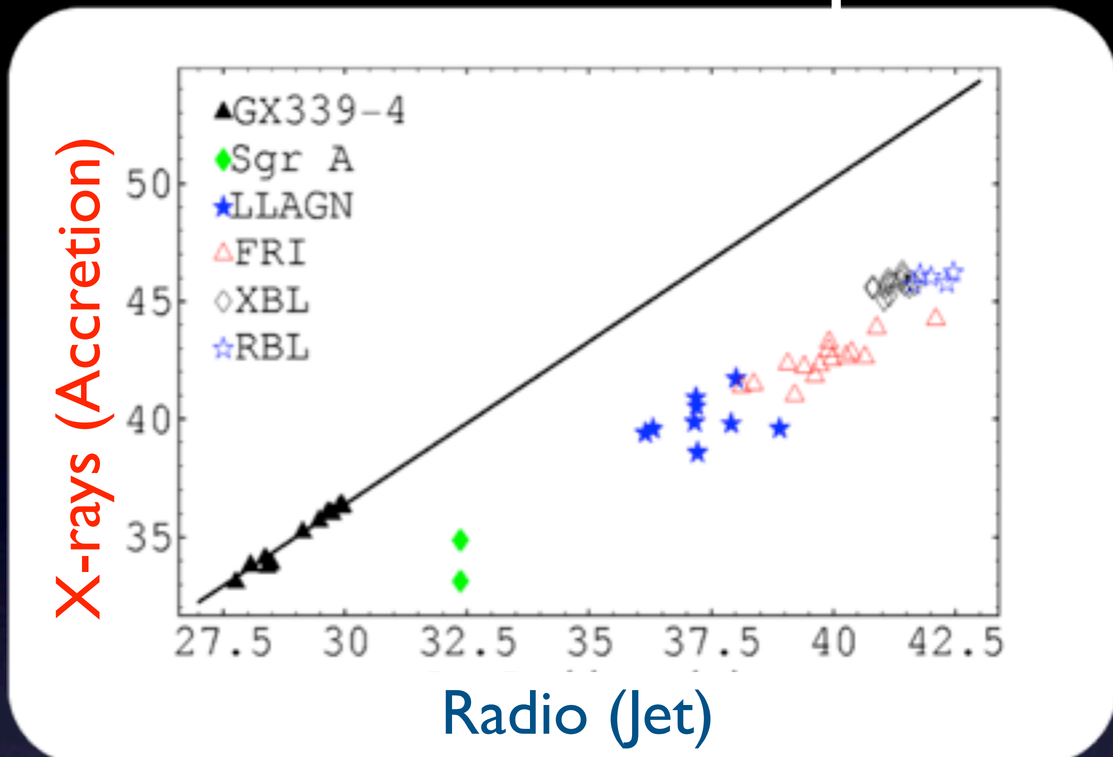
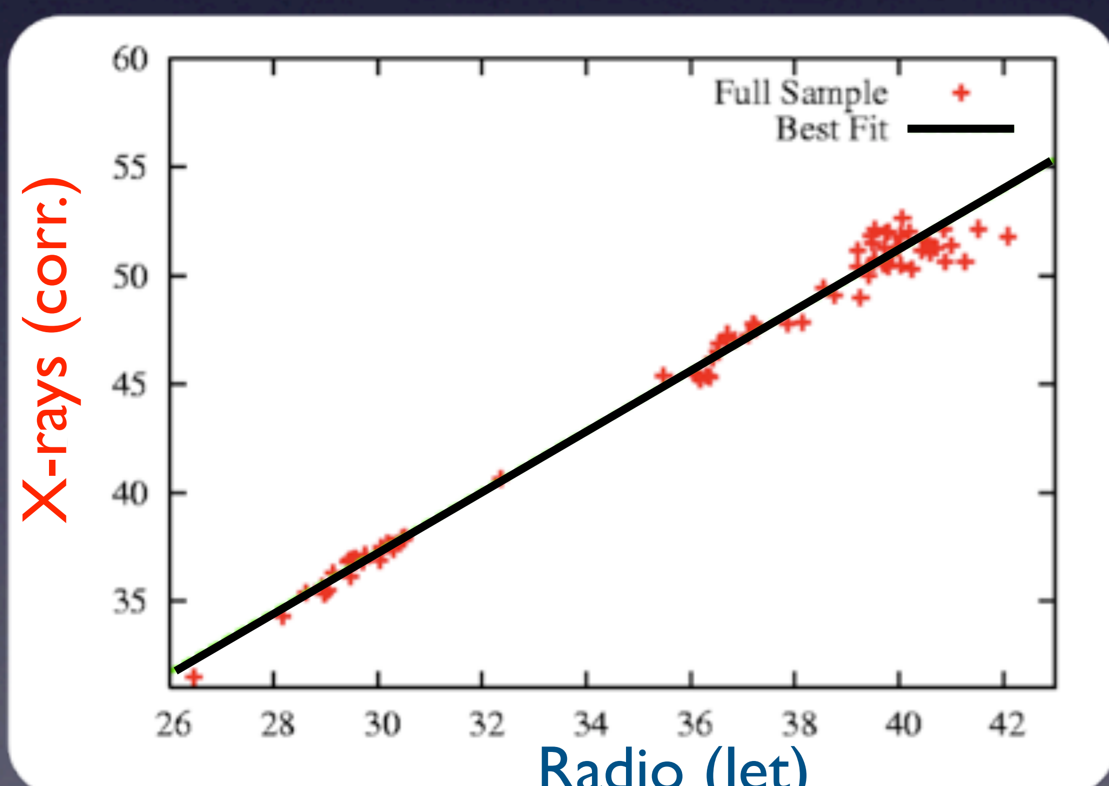
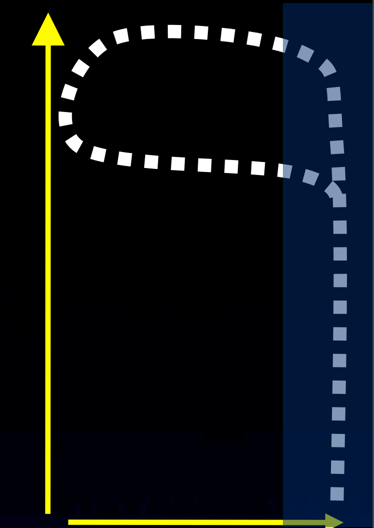
Körding et al. 2007

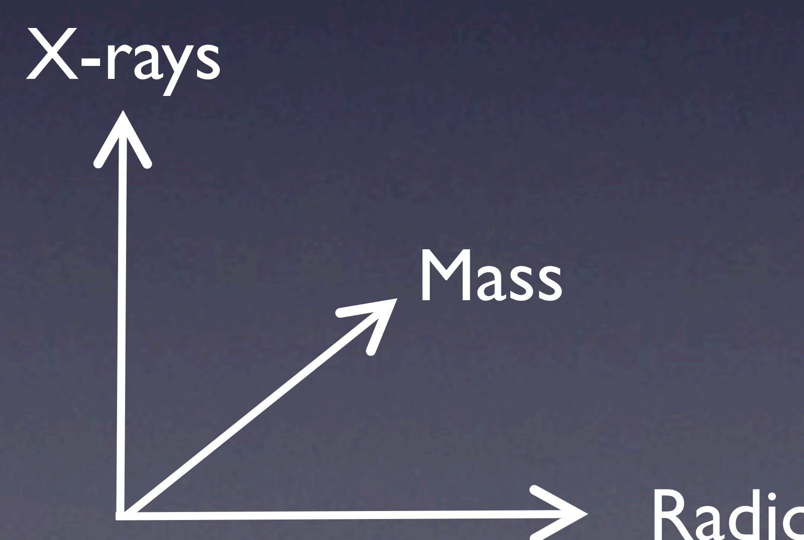
Connecting X-ray binaries and AGN:
The fundamental plane of accreting black holes





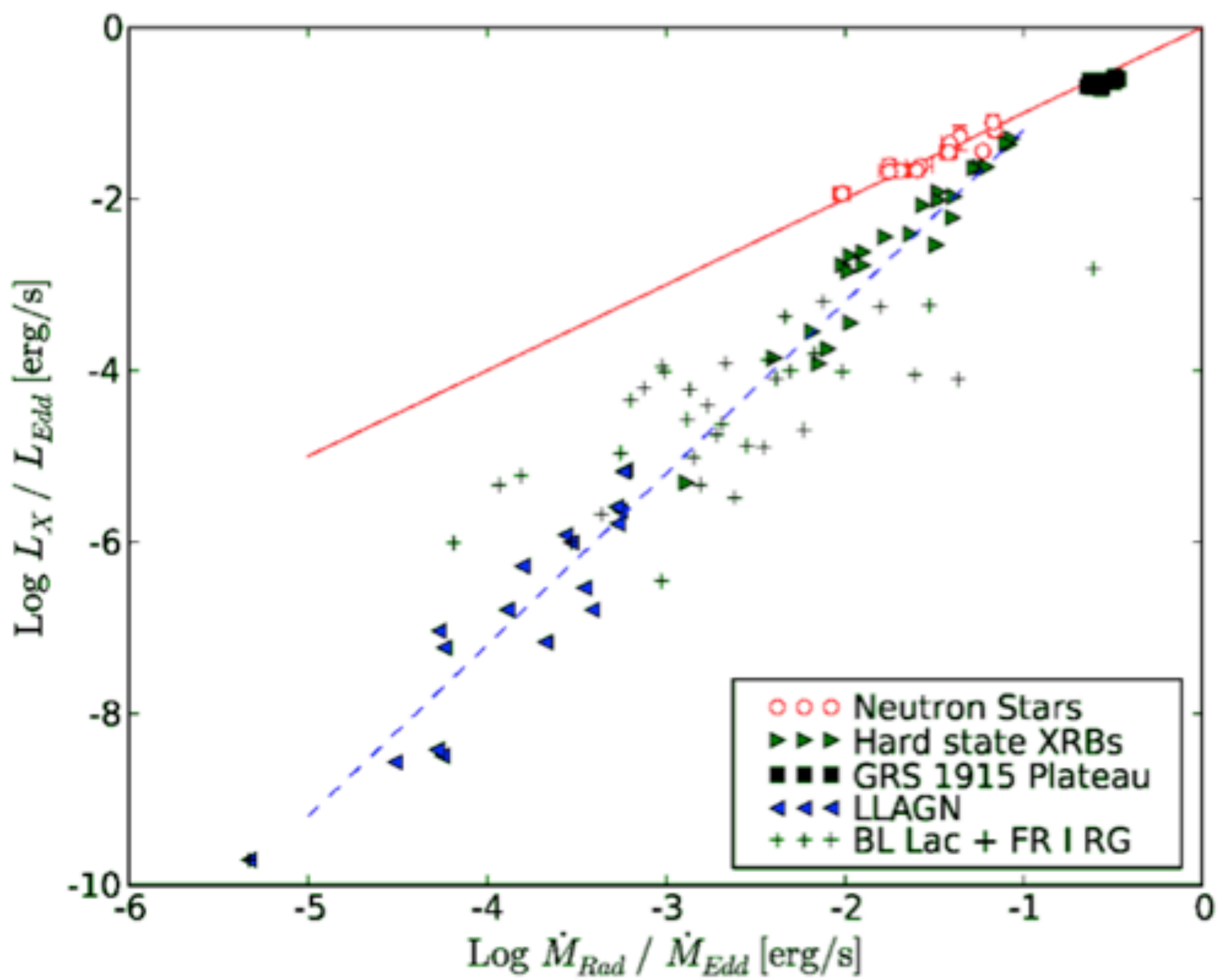


Edge-on projection of the plane



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

Inefficient accretion in AGN



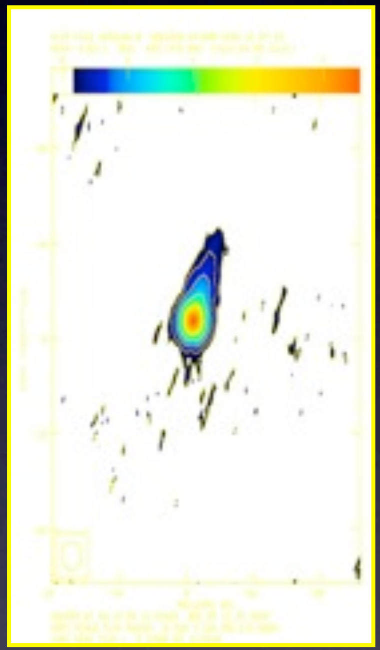
Fundamental plane can be reformulated using accretion measure:

$$\frac{L_X}{L_{Edd}} \propto \left(\frac{\dot{M}}{\dot{M}_{Edd}}\right)^2 M^{0.1}$$

Körding et al. 2007

Gallo et al. 2005

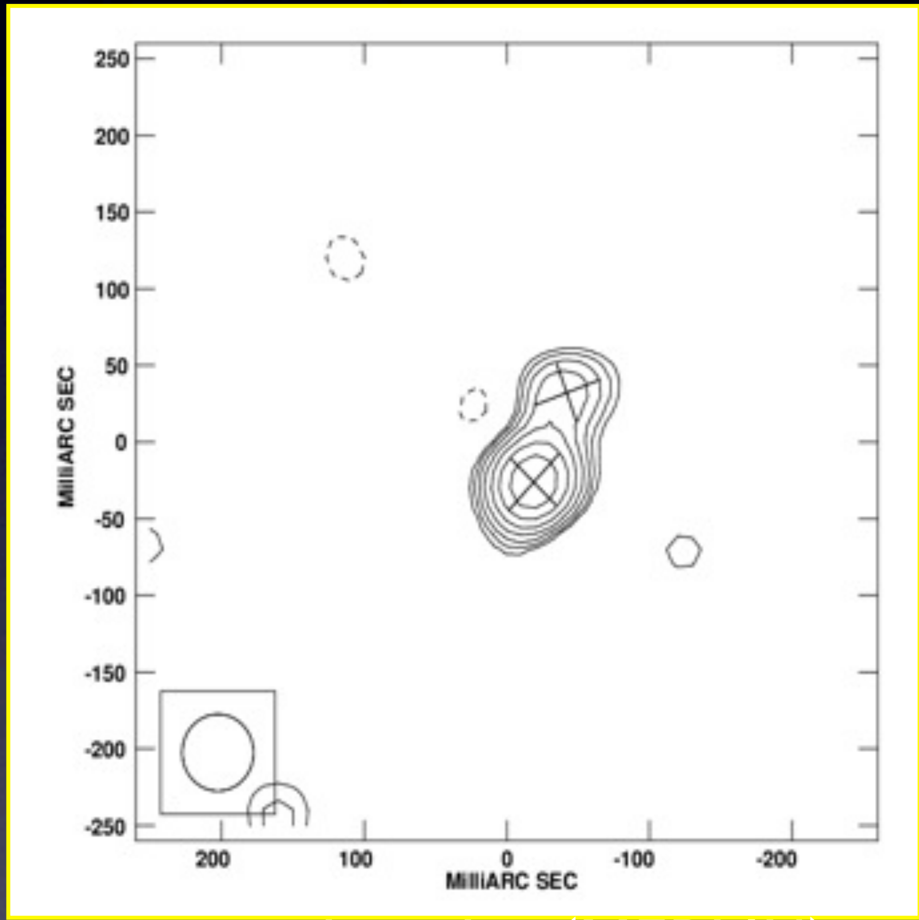
Jet power limit from Cyg X-1



15 mas steady jet (VLBA)

- Accretion measure yield upper limit on the total jet power!
- Lower limit from the jet inflated “Bubble” for Cyg X-1 and other measures of kinetic jet power. This gives: $P_j = \frac{1}{2}\eta \dot{M} c^2$

Jet power limit from Cyg X-1



70 mas transient jet (MERLIN)

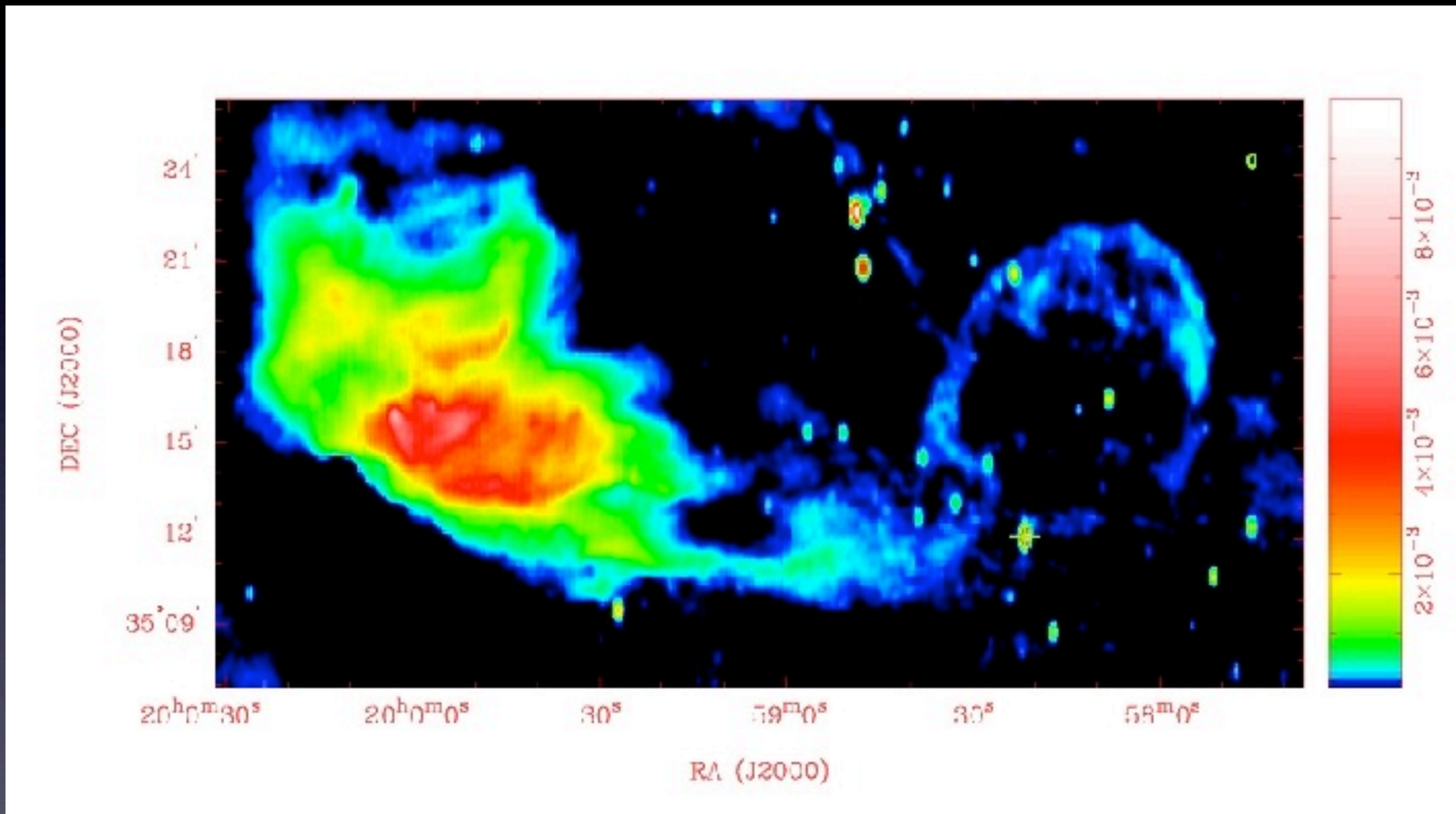
- Accretion measure yield upper limit on the total jet power!
- Lower limit from the jet inflated “Bubble” for Cyg X-1 and other measures of kinetic jet power. This gives:

$$P_j = \frac{1}{2}\eta \dot{M} c^2$$

Gallo et al. 2005

Jet power limit from Cyg X-1

5-arcmin jet-blown bubble (WSRT)



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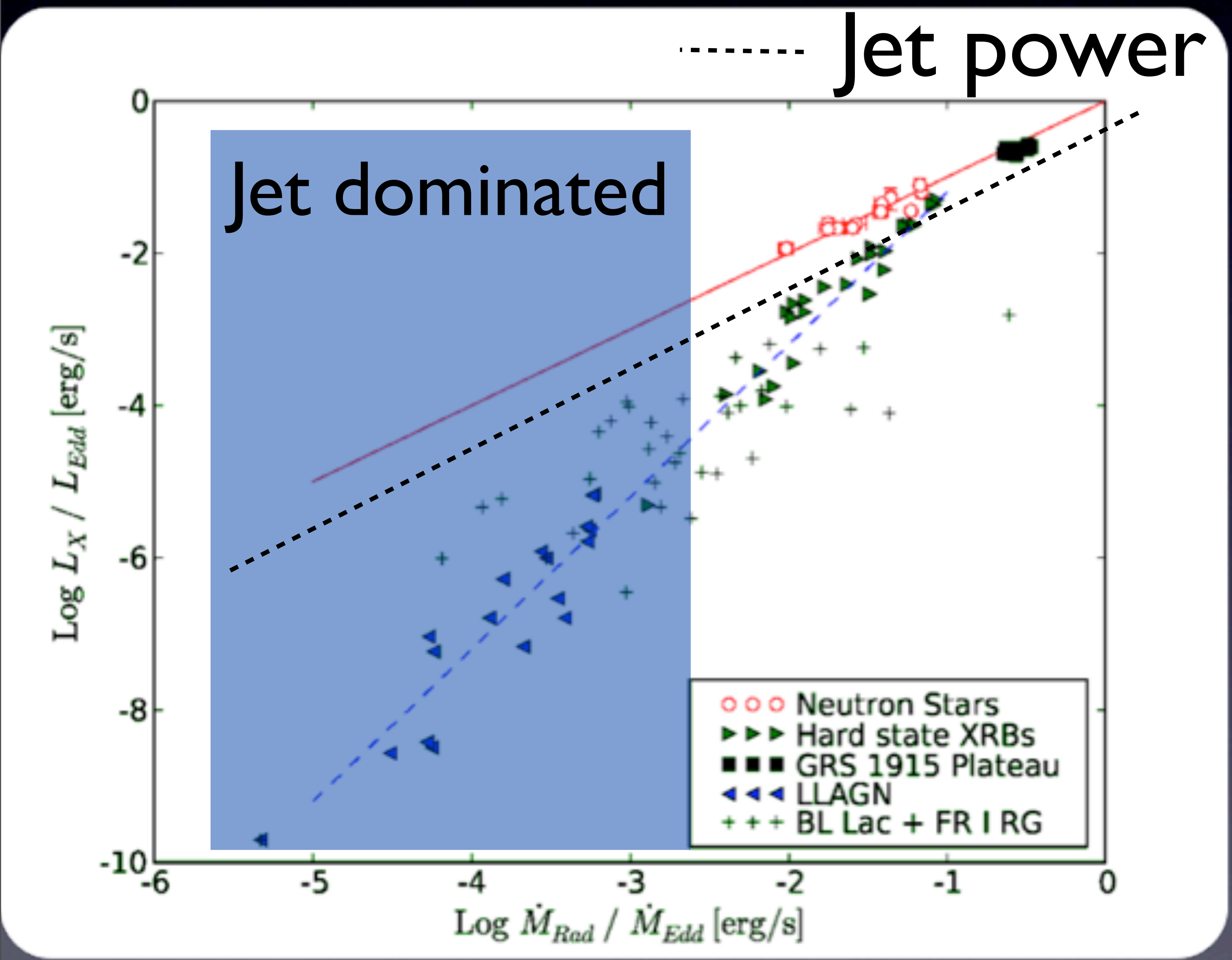
Jet dominated accretion flows



- At low luminosities the jet power completely dominates the radiated power
  - Radiated power depends quadratically on the accretion rate:

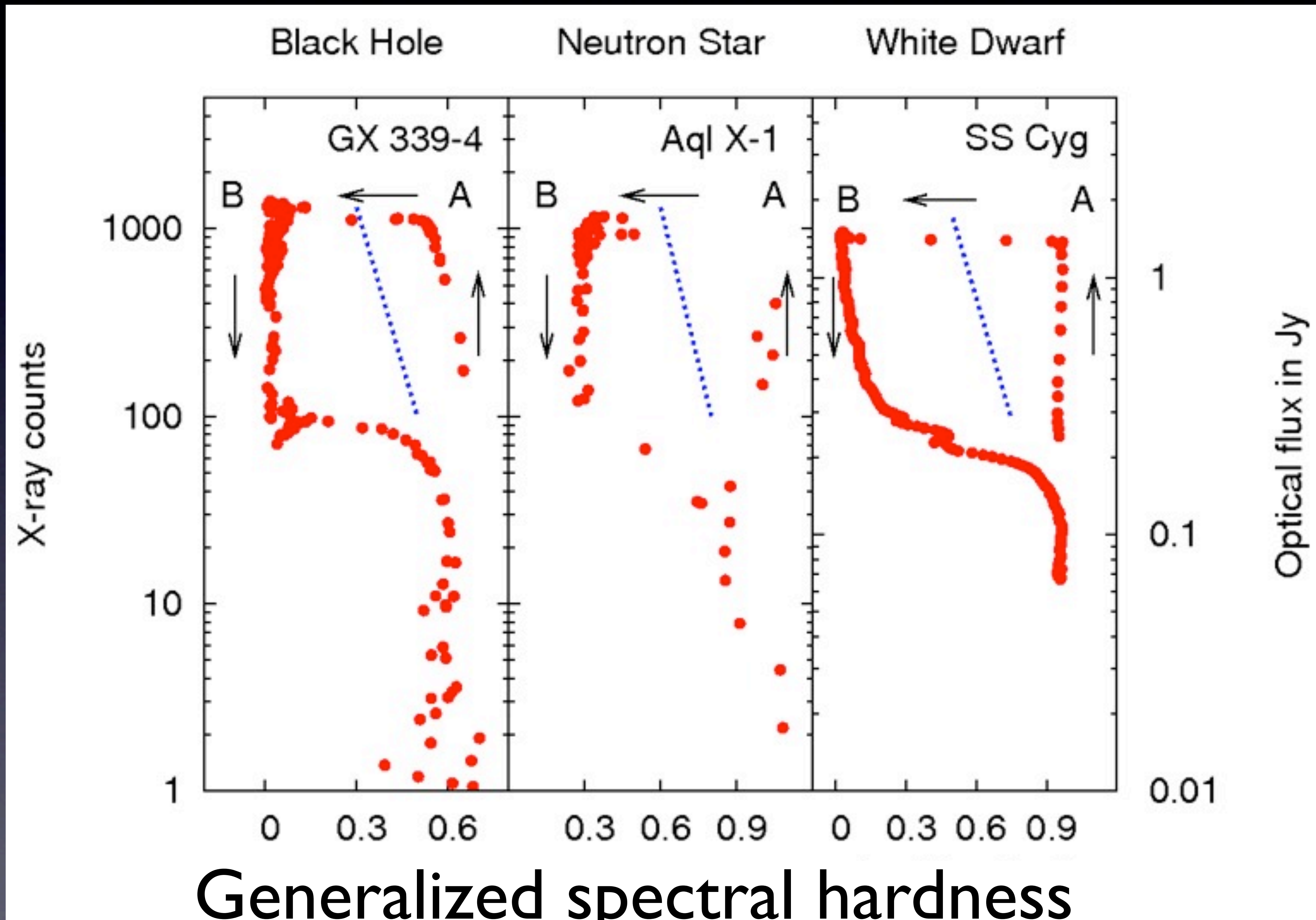
$$\frac{L_X}{L_{Edd}} \propto \left(\frac{\dot{M}}{\dot{M}_{Edd}}\right)^2 M^{0.1}$$

  - Jet has a linear dependence:

$$P_J = \frac{1}{2}\eta \dot{M} c^2$$

Körding et al. 2007

Accretion states in stellar accreting objects

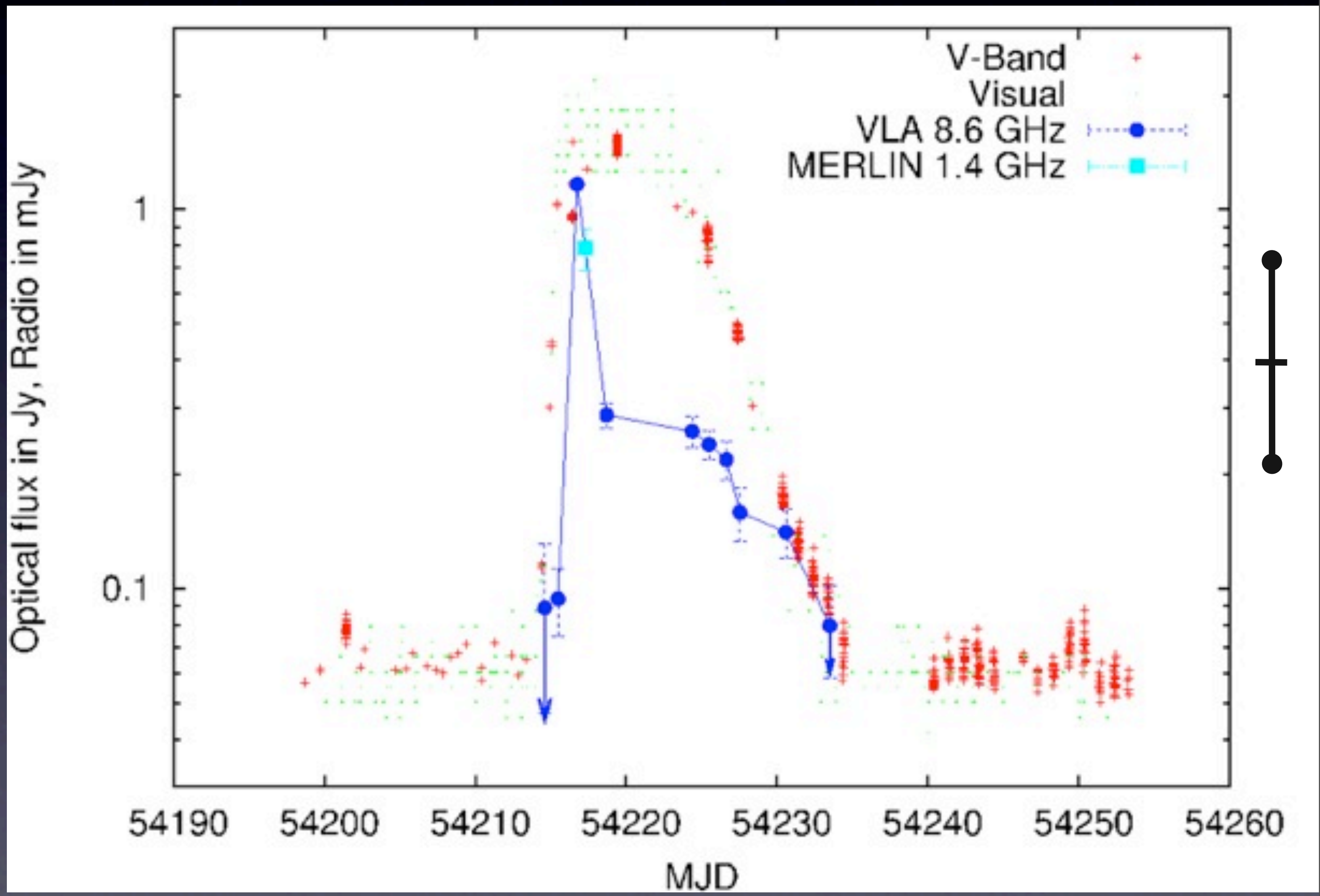


Körding et al., Science 2008

Application: Cataclysmic variables have jets

- Cataclysmic variables (a type of accreting white dwarfs) have been used as a counterexample to universal jet emission
- Through analogy with X-ray binary evolution: Reproducible and variable radio emission (a tracer of the jet)

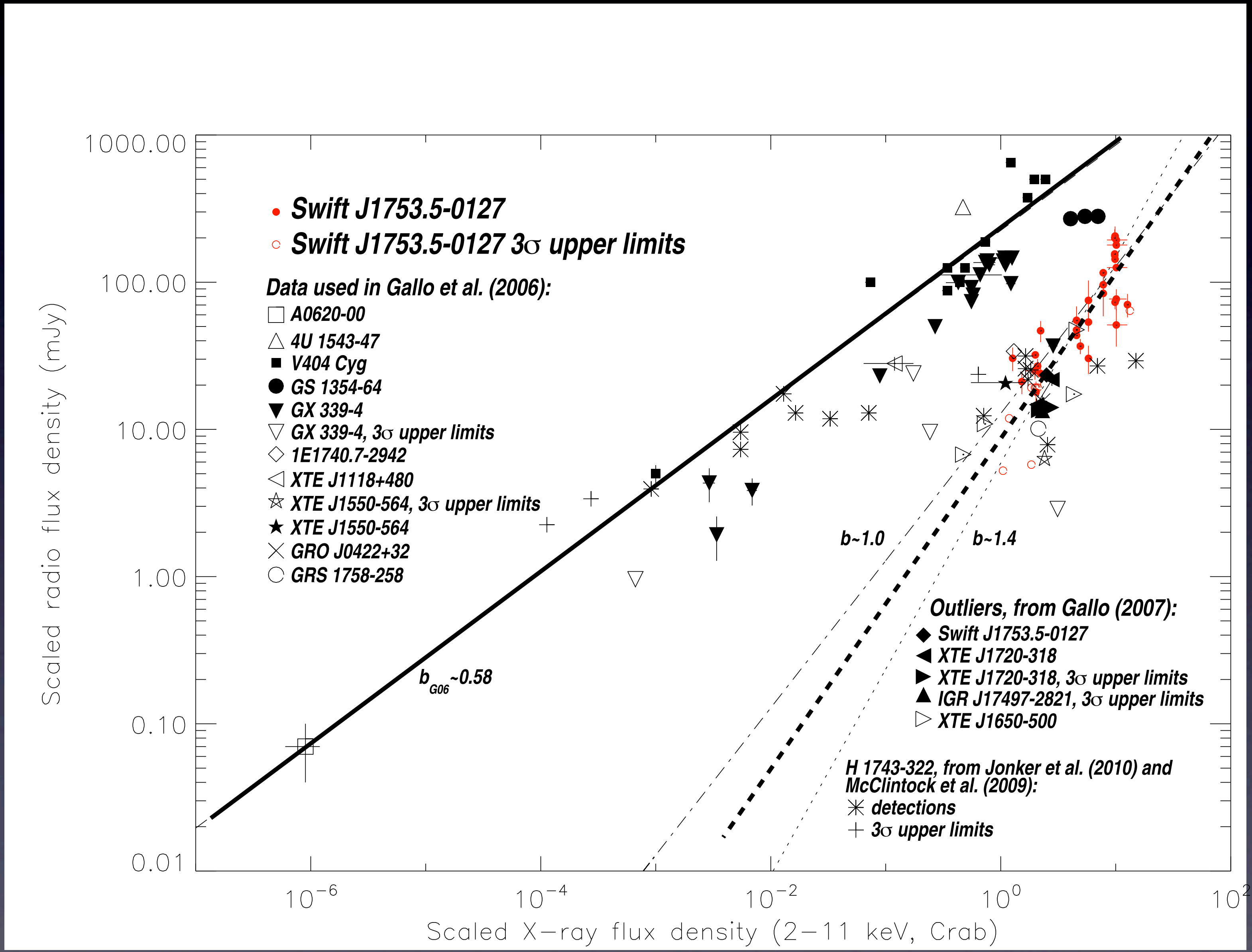
Light-curve of the cataclysmic variable SS Cygni



Optical: AAVSO (Templeton) Radio: Körding, Rupen, Knigge, Fender, Dhawan, Science 2008

Back to black holes

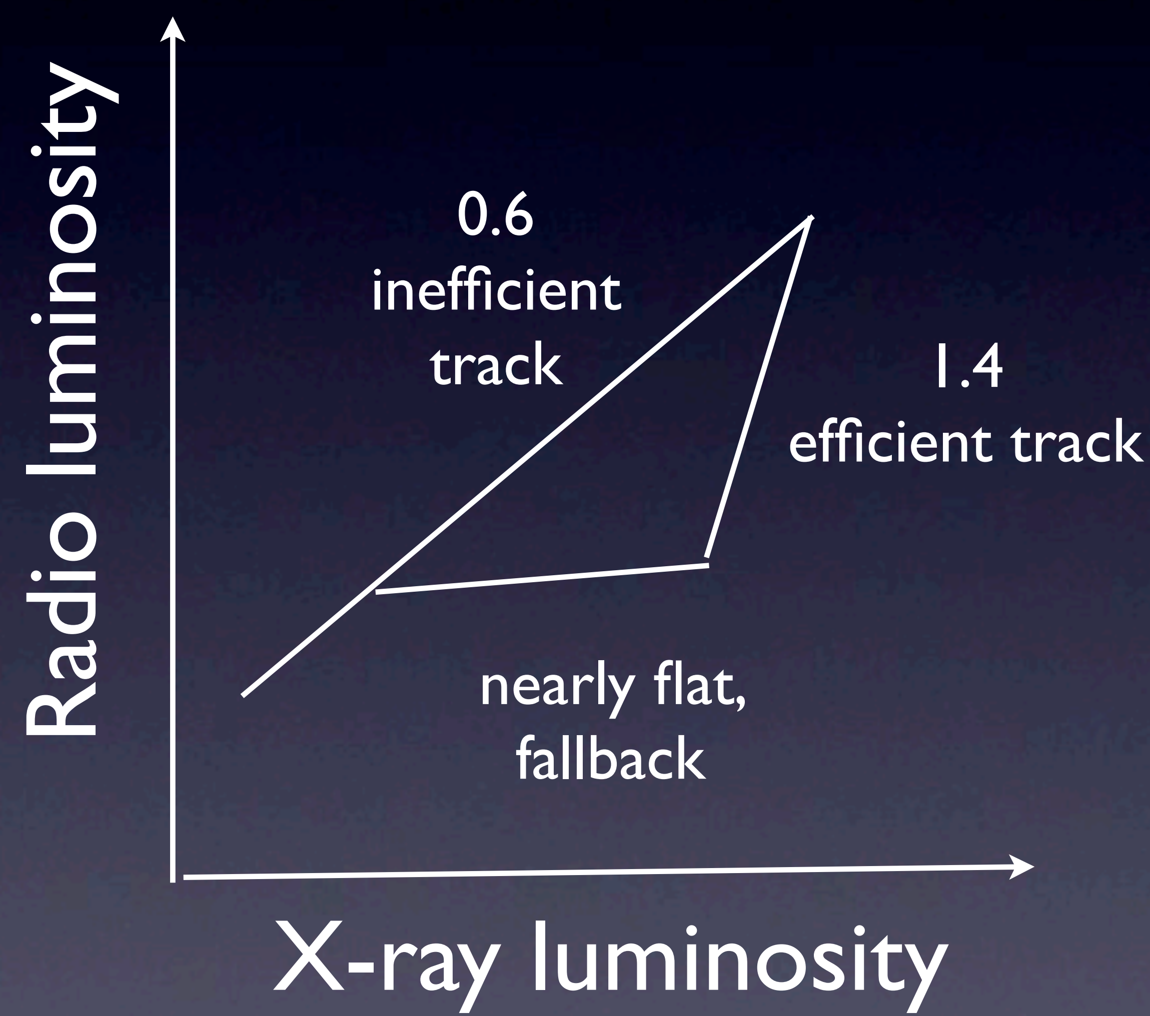
- Radio/X-ray correlation does not have a single track
  - one track with 0.6
  - one consistent with slope1.4 (like the neutron stars)



Soleri et al 2010, Coriat et al. 2010

Efficient hard state black holes?

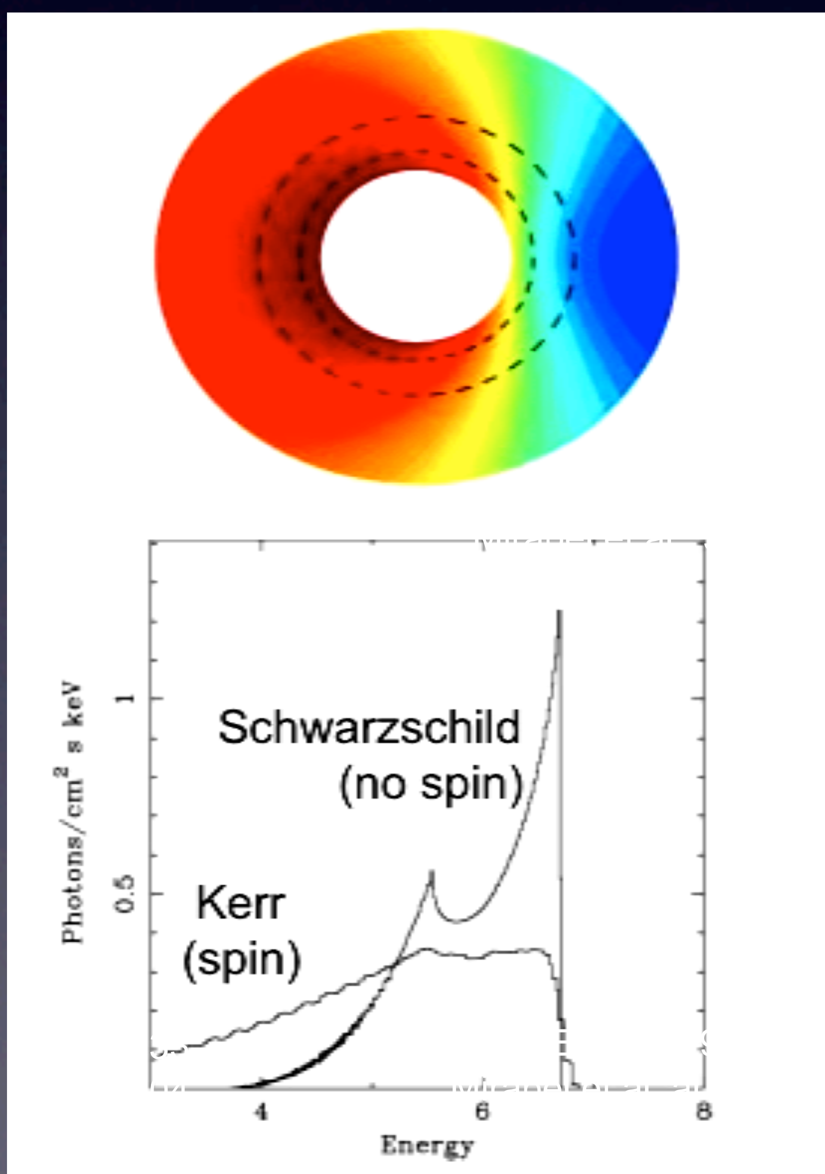
- Slope of 1.4 expected if one has an efficiently accreting object (like neutron stars)
- Hard state objects are thought to be inefficient accreters!
- But - if true - why are there inefficient and efficient black holes?



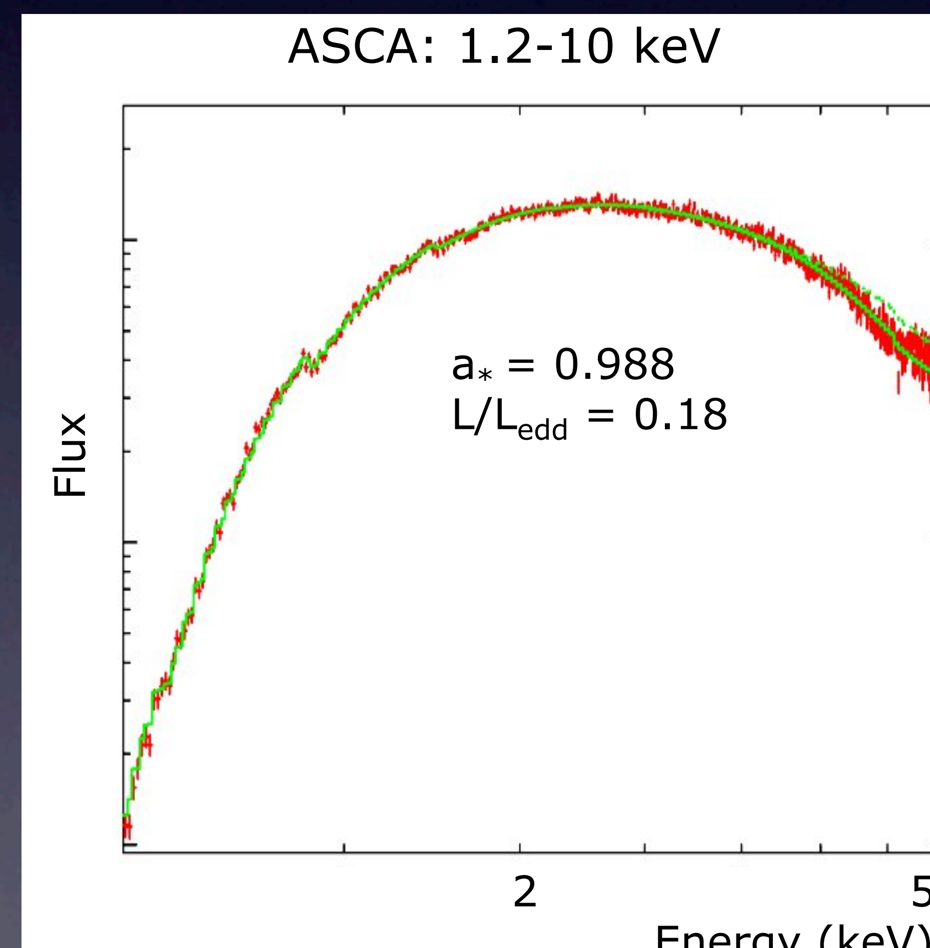
Black hole spins:

Two techniques:

relativisic lines



Accretion disc fitting

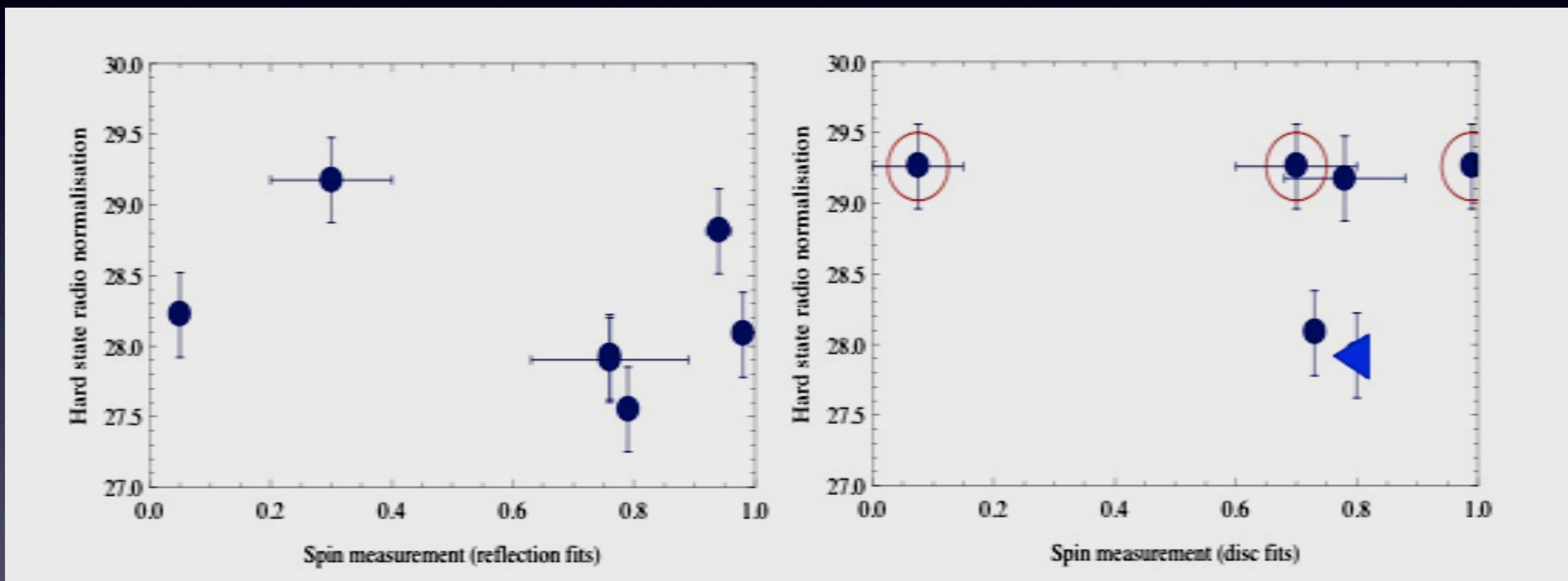


compare talk by R. Narayan

Jet power dependence on spins I

Compact Jet

"radio normalization": measure of the jet power after the effects of accretion rate taken out

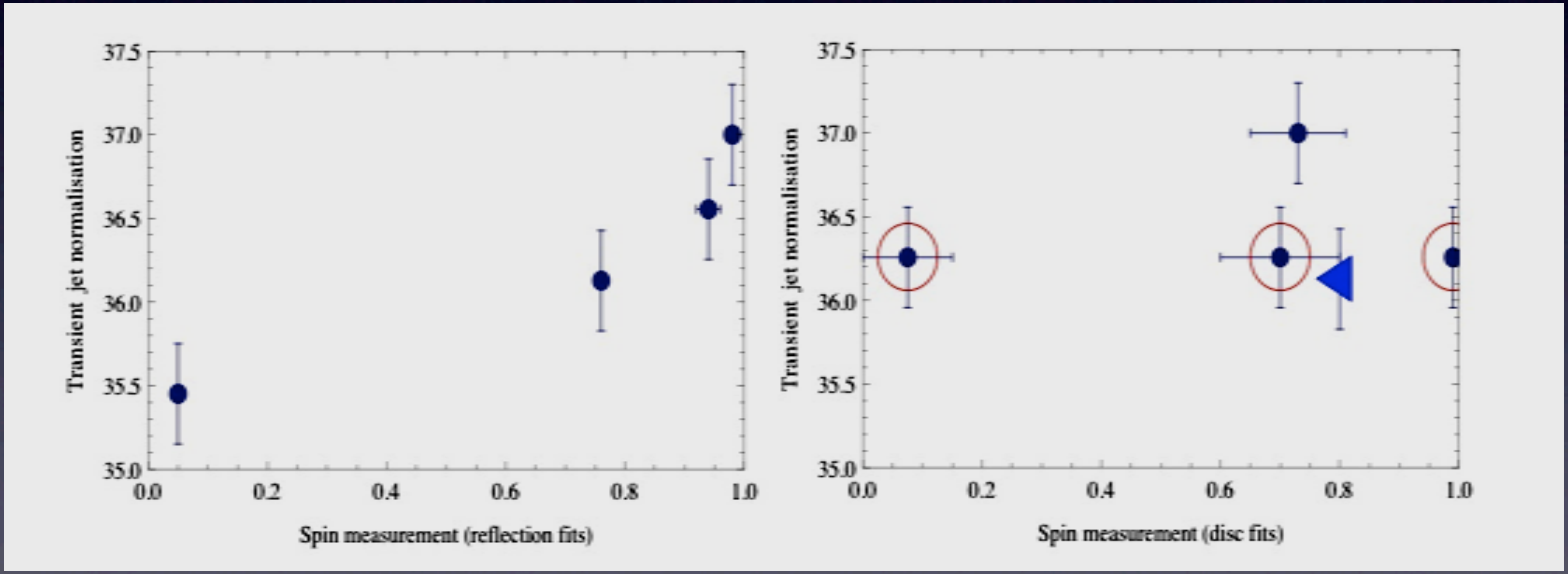


Reflection fits   Disc fits

Fender, Gallo, Russell 2010

Jet power dependence on spins II

Rapid ejections



Reflection fits Disc fits

Fender, Gallo, Russell 2010

Spinning black holes power jets?

1. One or more methods used for measuring spin are in error
2. One or more methods used for measuring jet power /velocity are in error
3. Jet power and/or velocity are not related to BH spin! (at least its not the dominat factor after accretion rate and mass)
   - Also supported by the fact that NS and BH produce the same jet power for a given accretion rate (EK et al. 2006)

Fender, Gallo, Russell 2010

Summary

- Jets are an important aspect of accretion in general
- The main parameters of jets and accretion are the accretion rate and accretion state as well as the mass and size of the compact object
- Are spins not important at all or are we unable to estimate them?
- For most of the parameter space and the majority of all sources one finds inefficient accretion which is dominated by the jet power