Black Hole Grand Unification:

Modelling and measuring SEDs from microquasars to quasars

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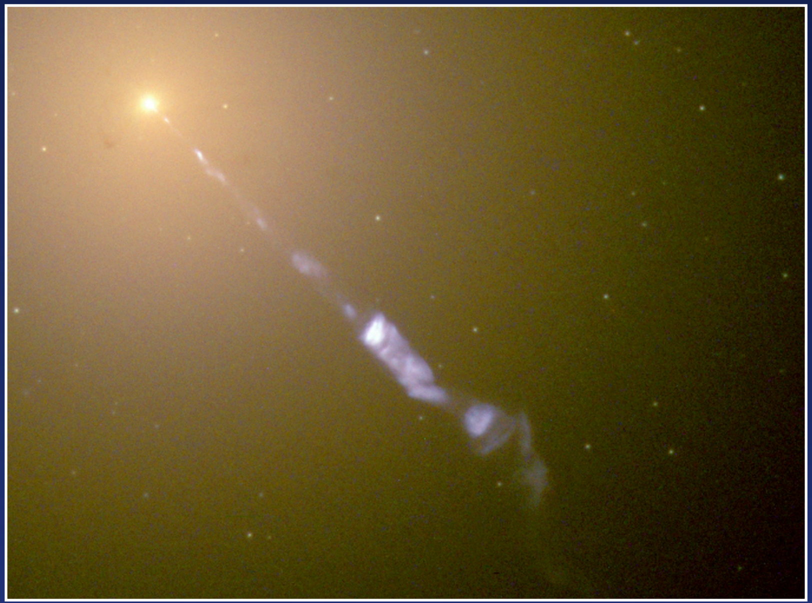
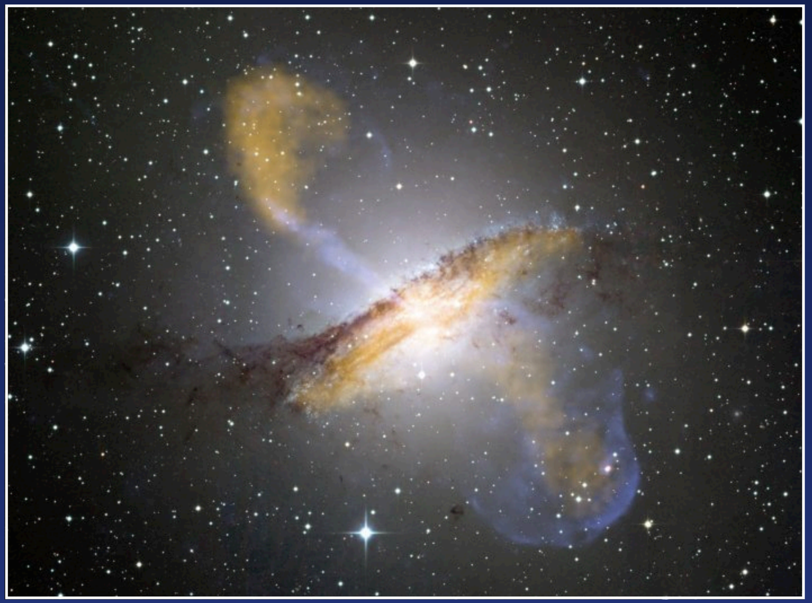


M87
Credit: STScI/AURA and NASA/ESA



Cen A
Credit: ESO

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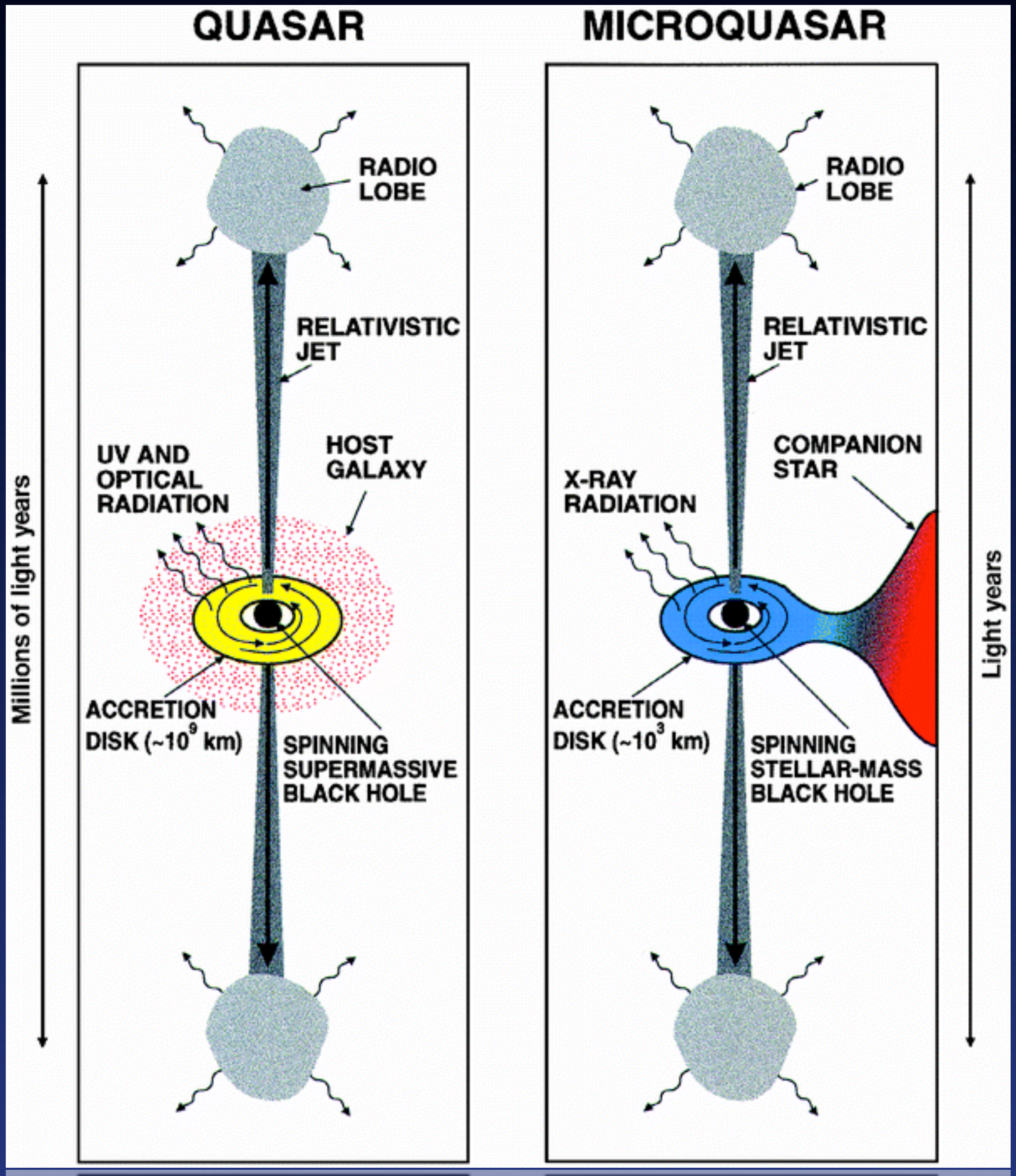
Universität Erlangen-Nuremberg

Black Hole Universe

The Project

- Main purpose: Shed light on how Active Galactic Nuclei (AGN) evolve over time
- In particular, determine if states states found in X-ray Binaries (XRBs) map onto AGN states, accounting for:
  - ☑ Selection Effects
  - ☑ Scaling Relations
- Find out if correcting for BH mass is enough to explain AGN behaviour, or are e.g. environment/evolution/BH spin important?

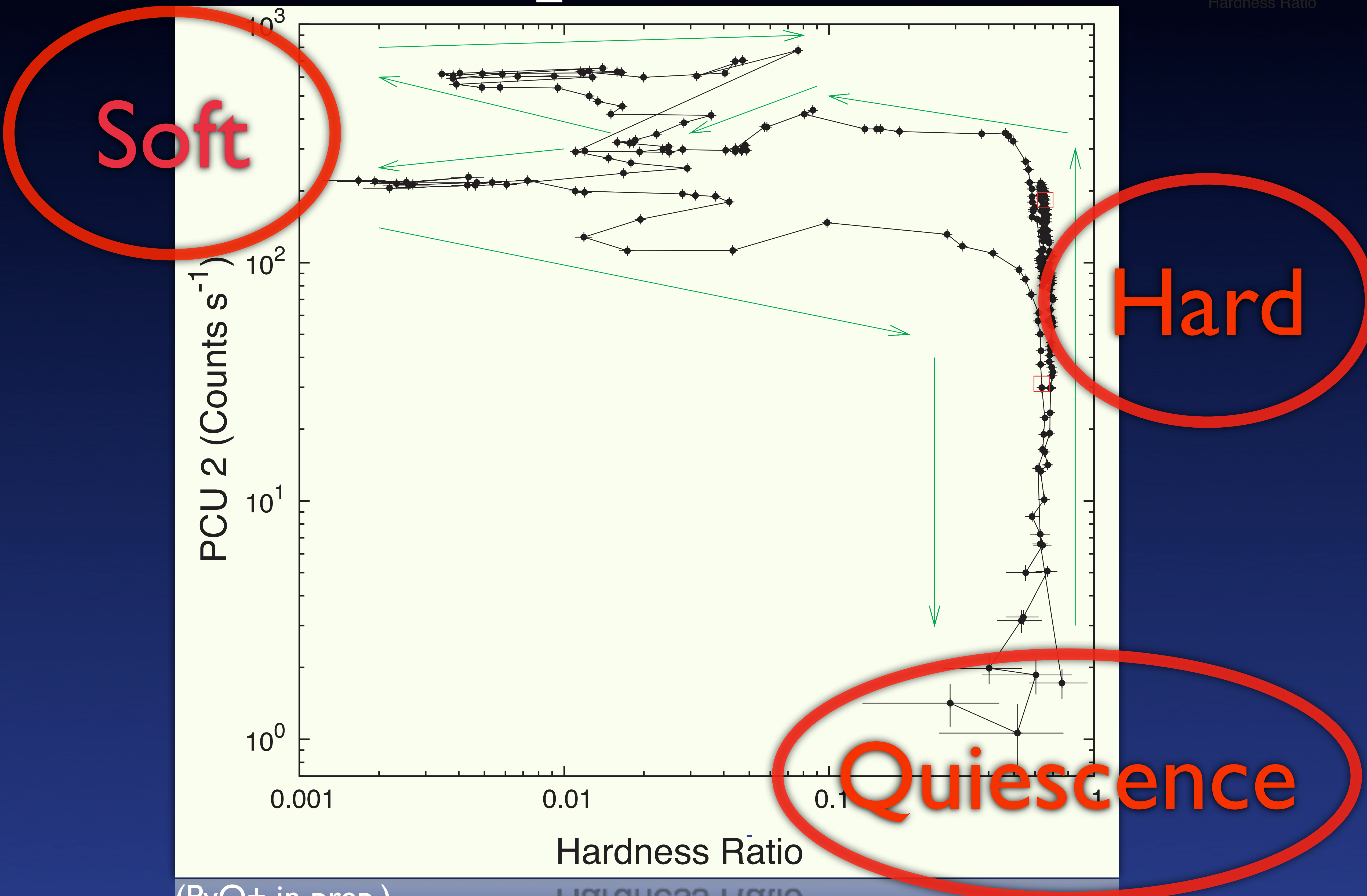
Mass-Scaling?



(Mirabel & Rodiguez 1998)

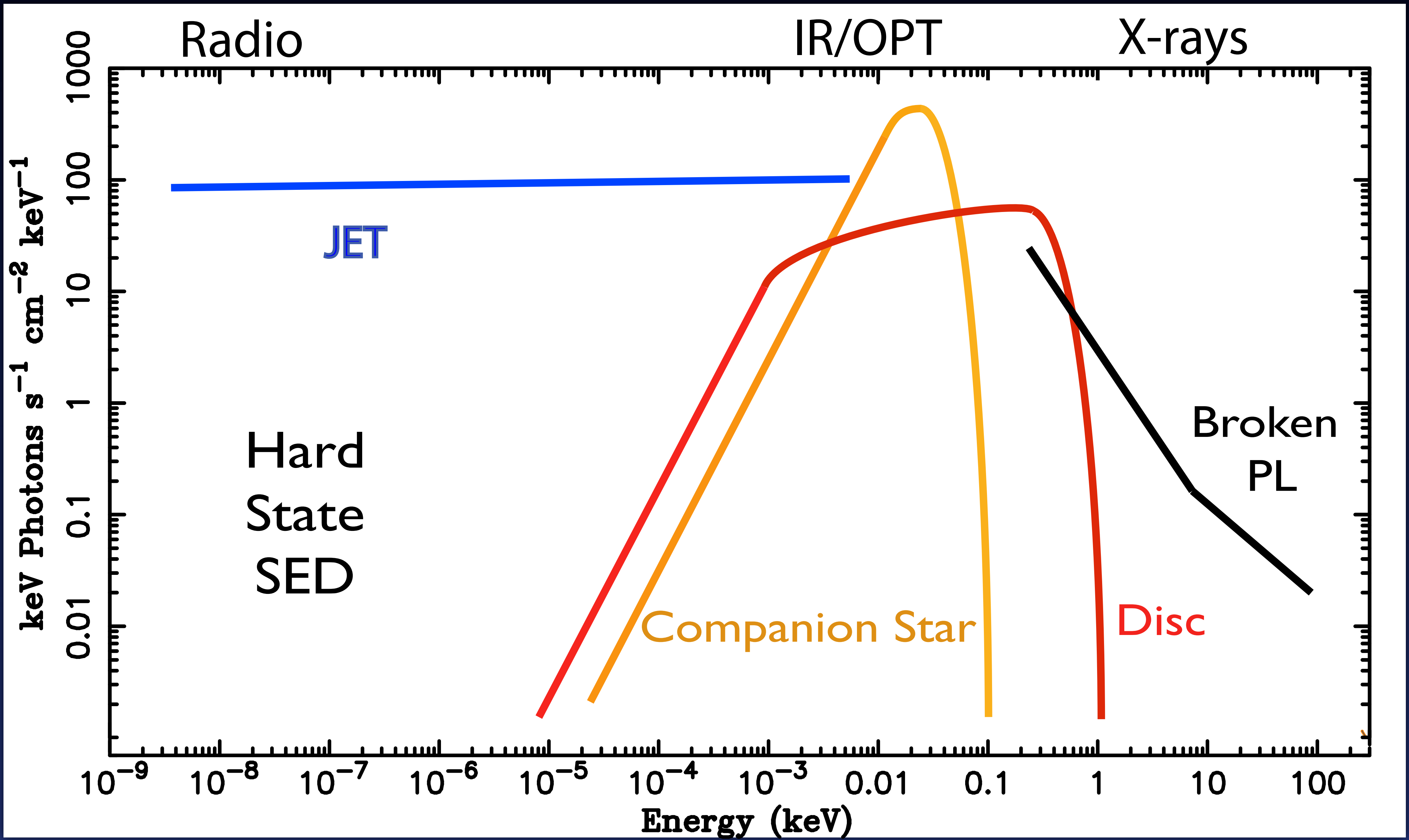
	XRBs	AGN
Mass (M_{sol})	few	$\sim 10^6$ - 10^9
Geometry	AU/Pc	$\sim 10^6$
Disc peak	X-ray	UV/Opt
Timescale	days/ months	millions of years

Microquasar HID

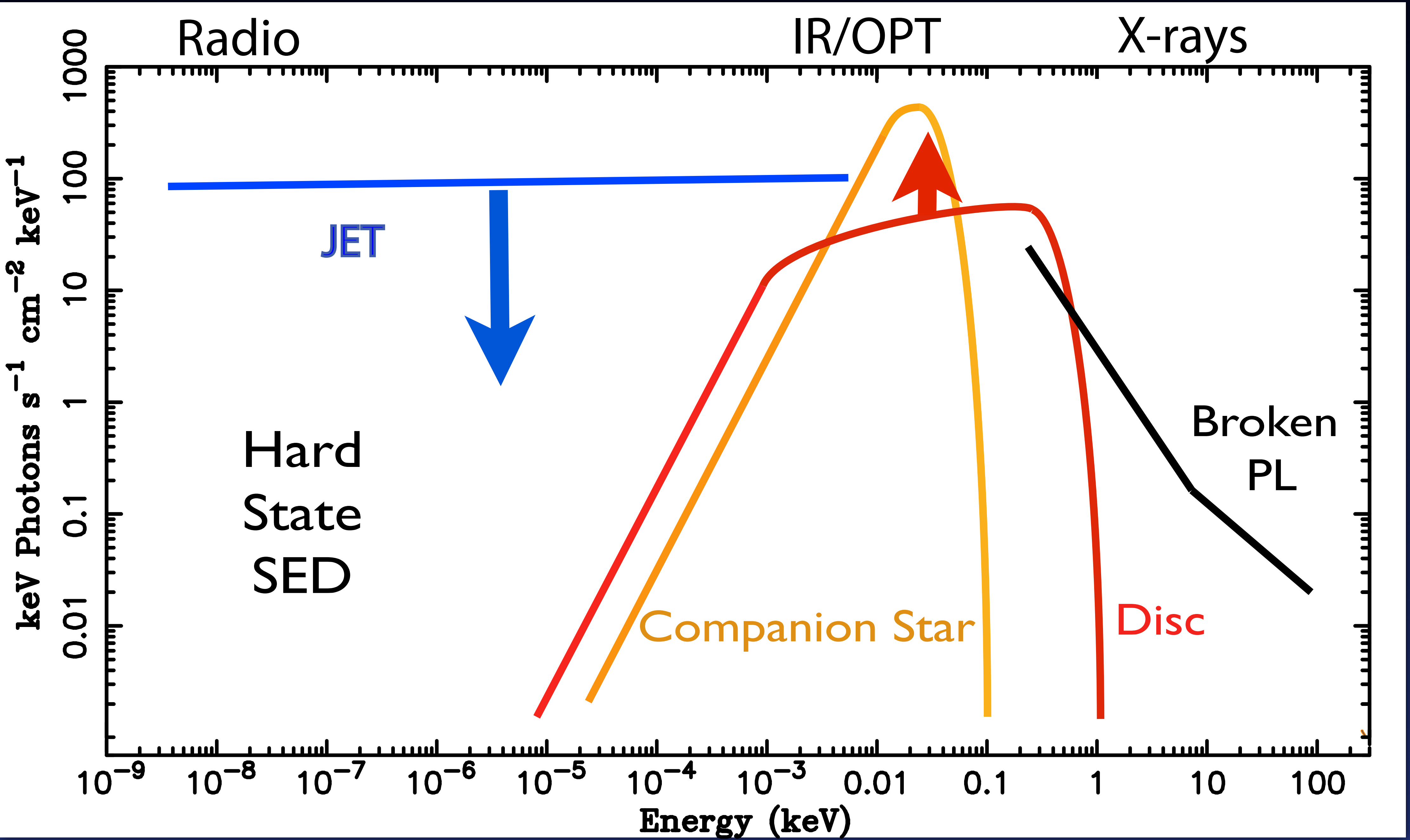


(PvO+ in prep.)

Hard State SED



Soft State SED

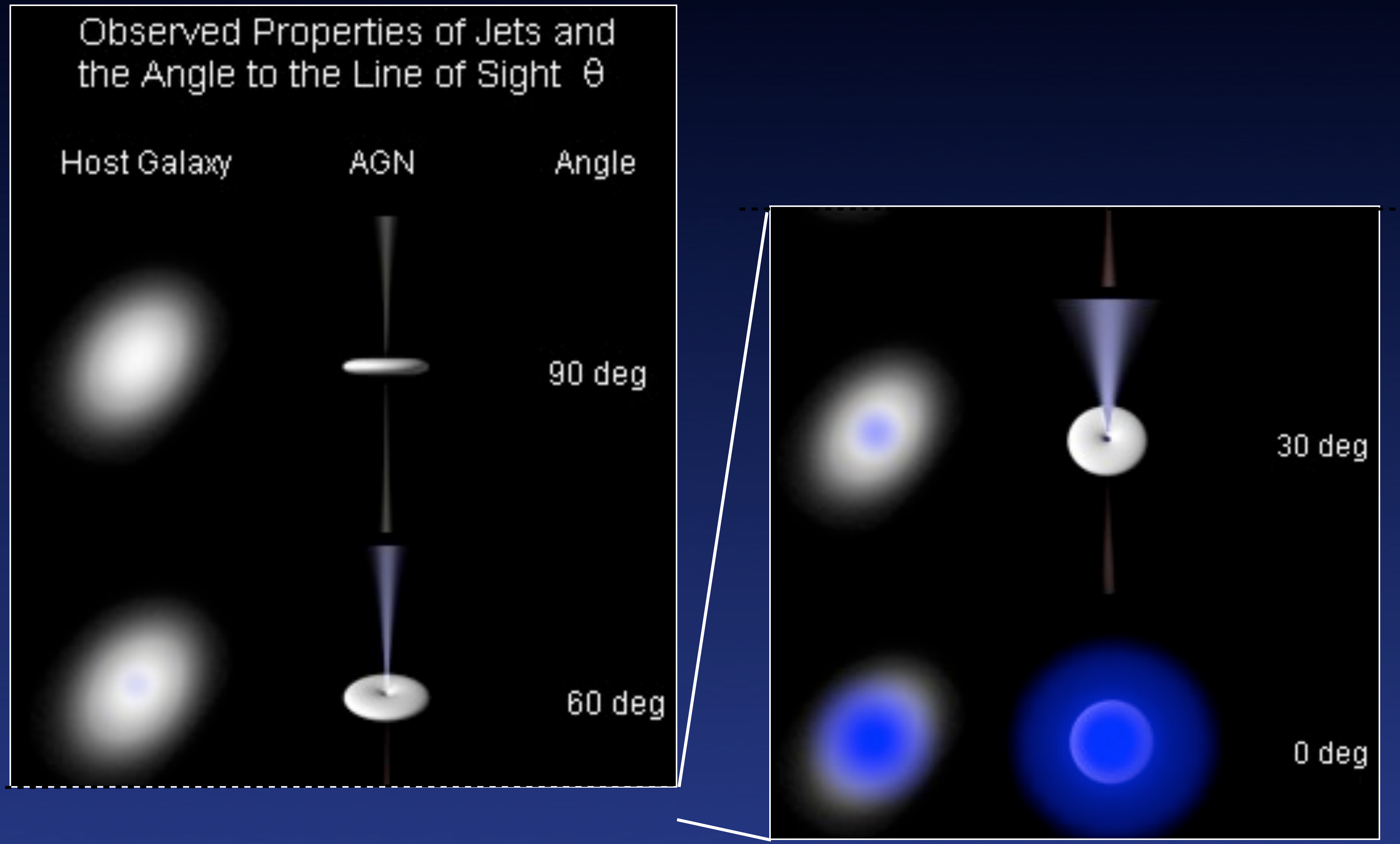


The AGN Zoo

Optical Luminosity

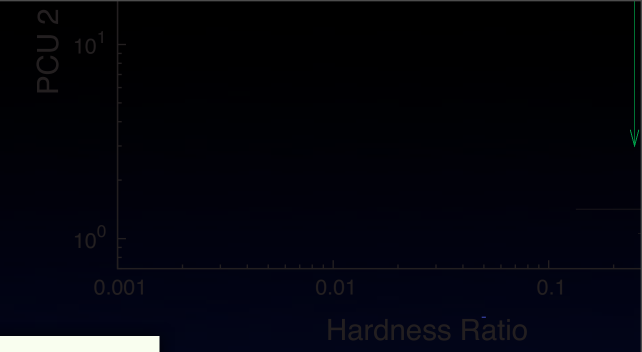
	optical spectrum	radio loud
LINERs	narrow lines	no
Seyferts I Seyferts II	narrow/broad lines narrow lines	no
quasars	narrow/broad lines	~10%
BLAZARS (BL Lac) Radio Galaxies	flat spectrum/faint broad some narrow/broad	yes

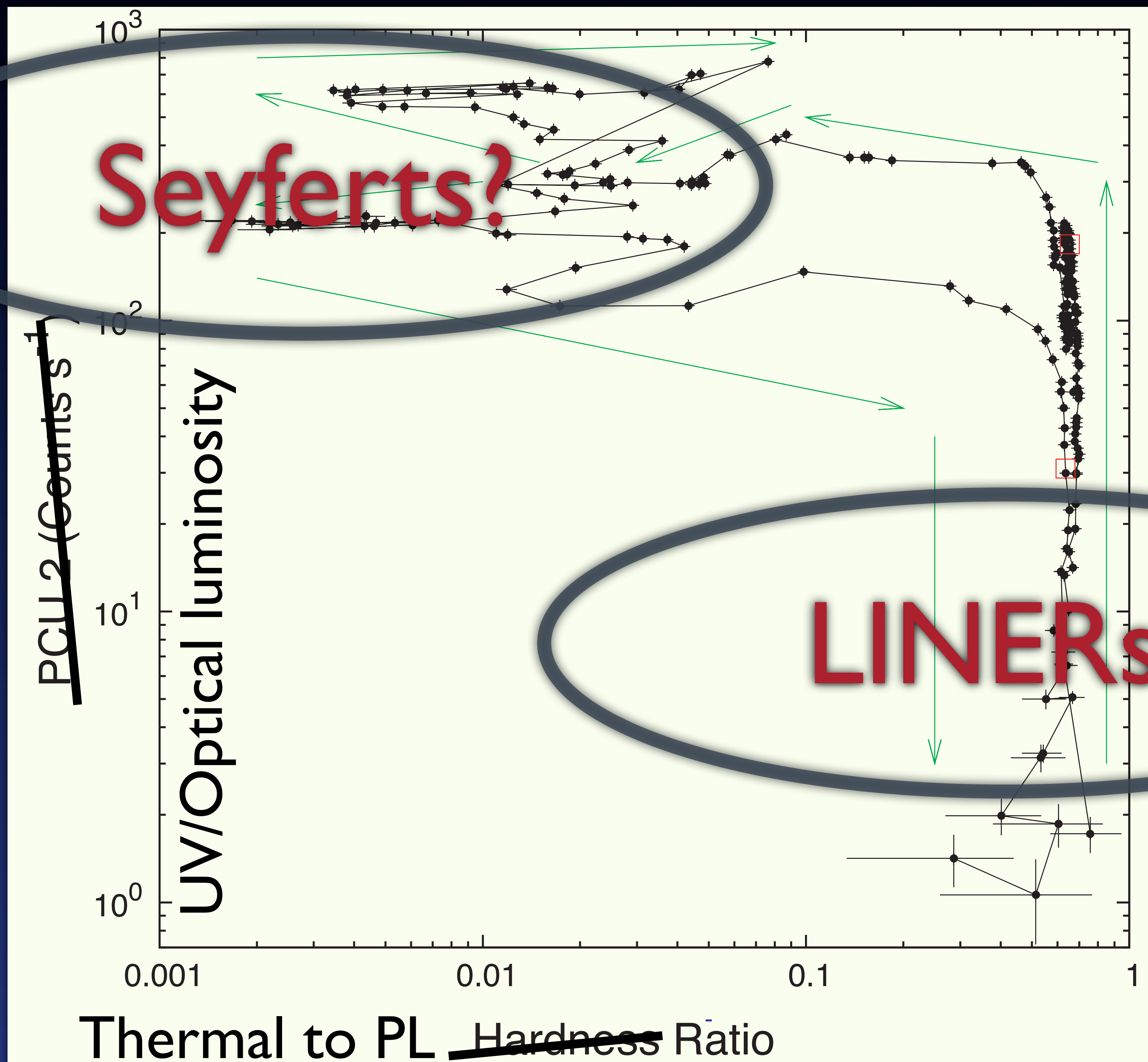
AGN unification



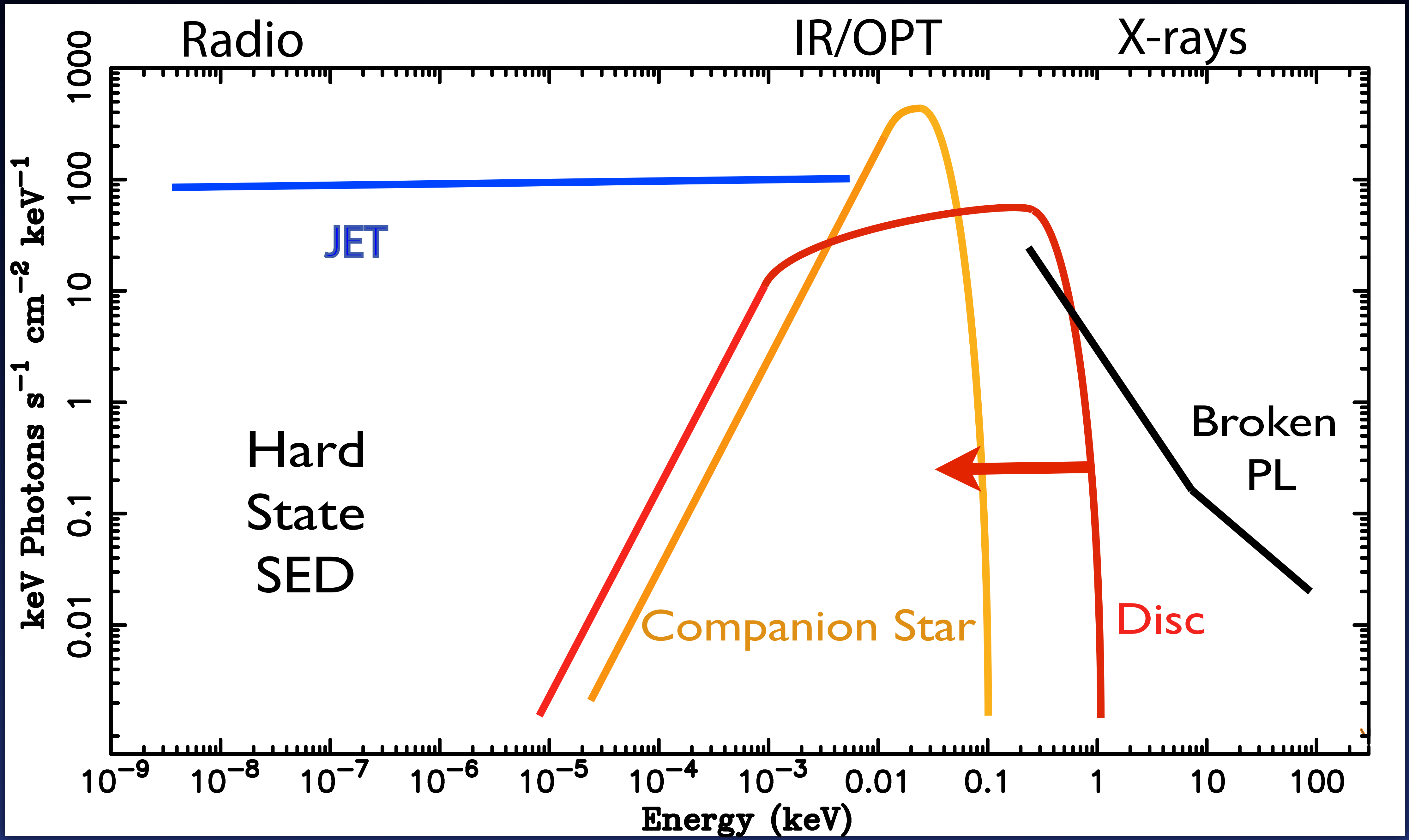
Credit: Ron Kollgaard

AGN HID?


PCU 2
10^1
10^0
0.001
0.01
0.1
Hardness Ratio

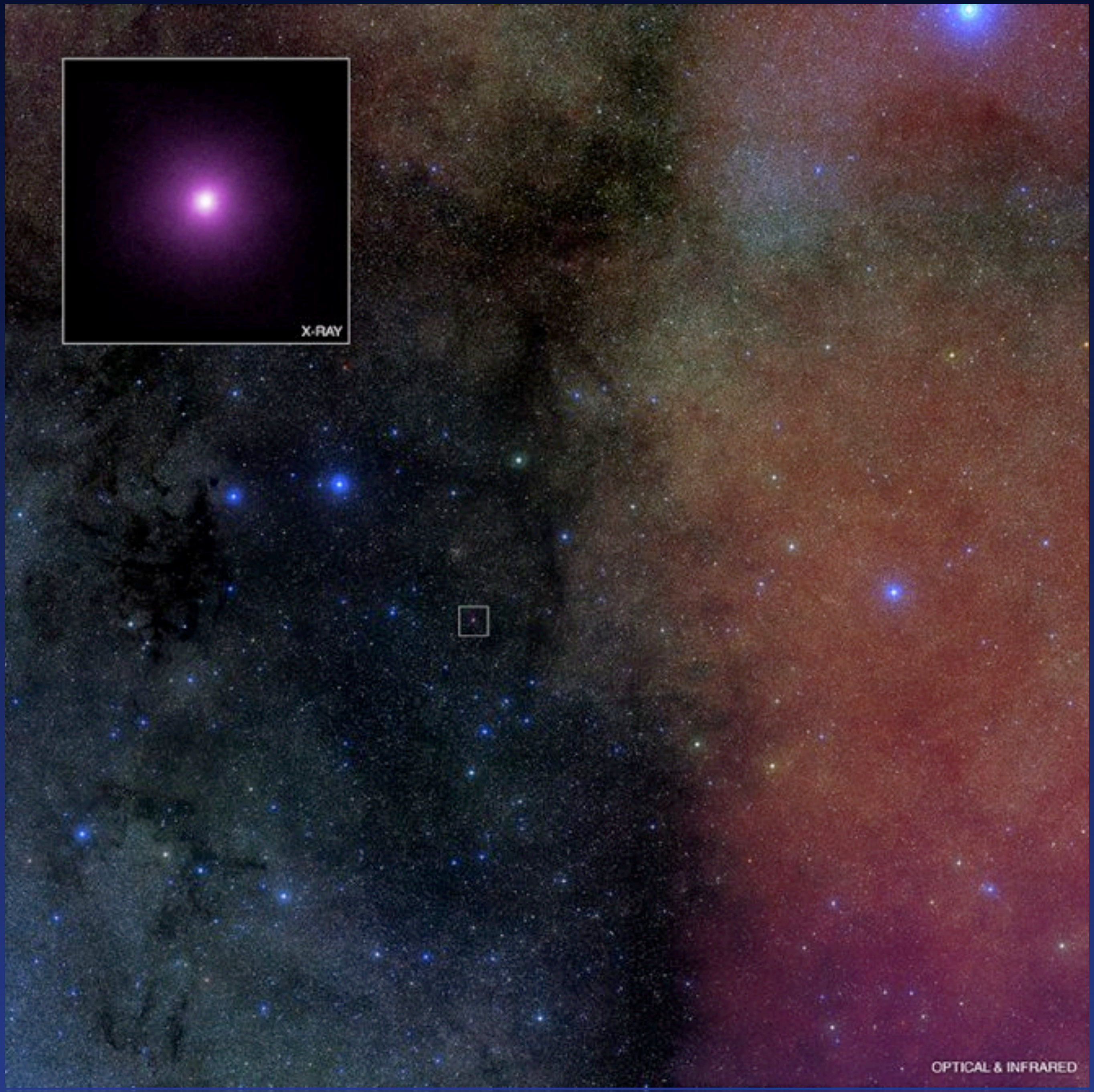

Seyferts?
LINERs?
UV/Optical luminosity
PCU 2 (Counts s^{-1})
10^3
10^2
10^1
10^0
0.001
0.01
0.1
1
Thermal to PL Hardness Ratio

AGN SED?



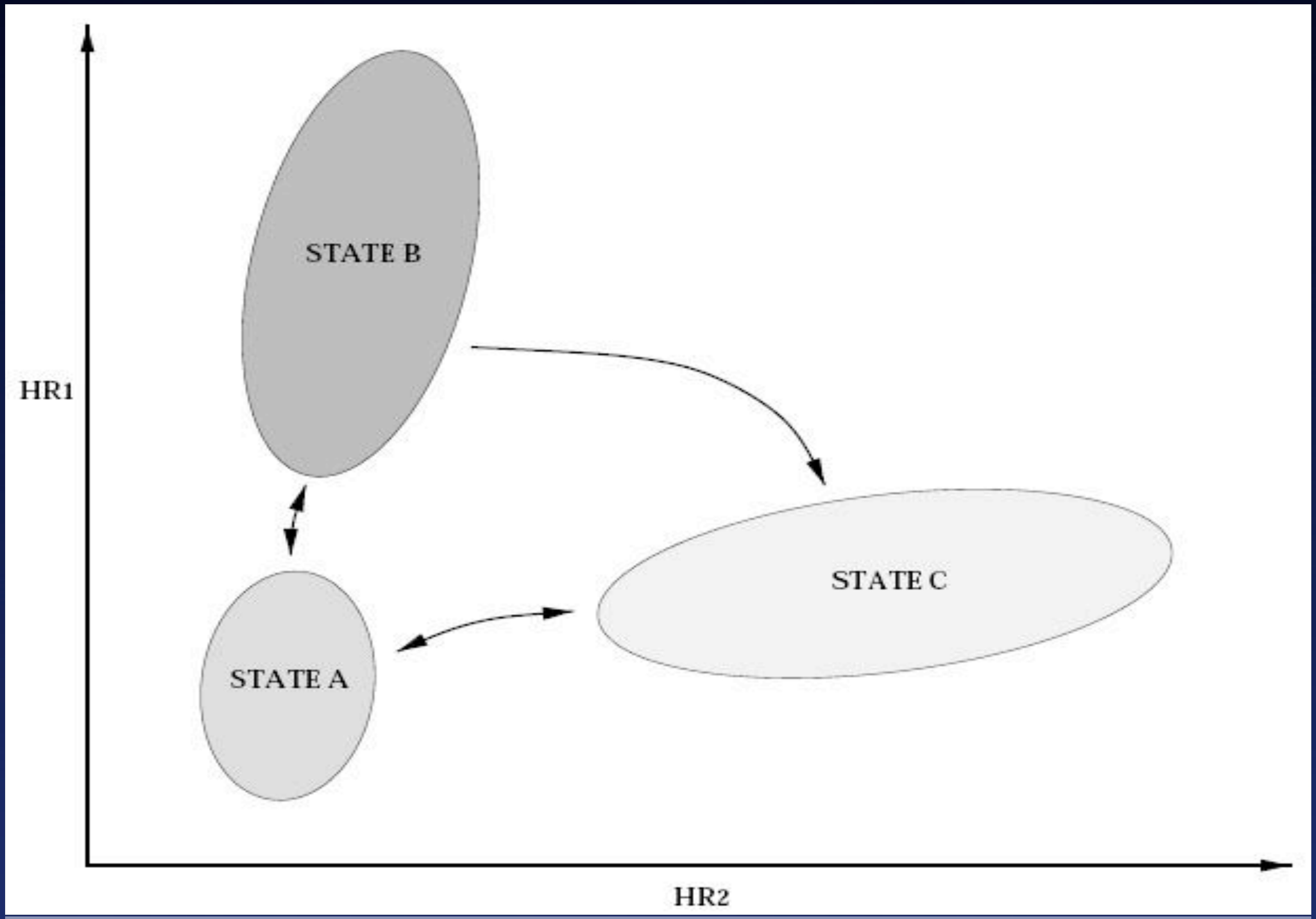
Radio
IR/OPT
X-rays
JET
Hard
State
SED
Companion Star
Disc
Broken
PL
keV Photons s^{-1} cm^{-2} keV^{-1}
0.01
0.1
1
10
100
1000
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1
10
100
Energy (keV)

I. microquasar GRS1915+105



Credit: X-ray (NASA/CXC/Harvard/J.Neilsen); Optical & IR (Palomar DSS2)

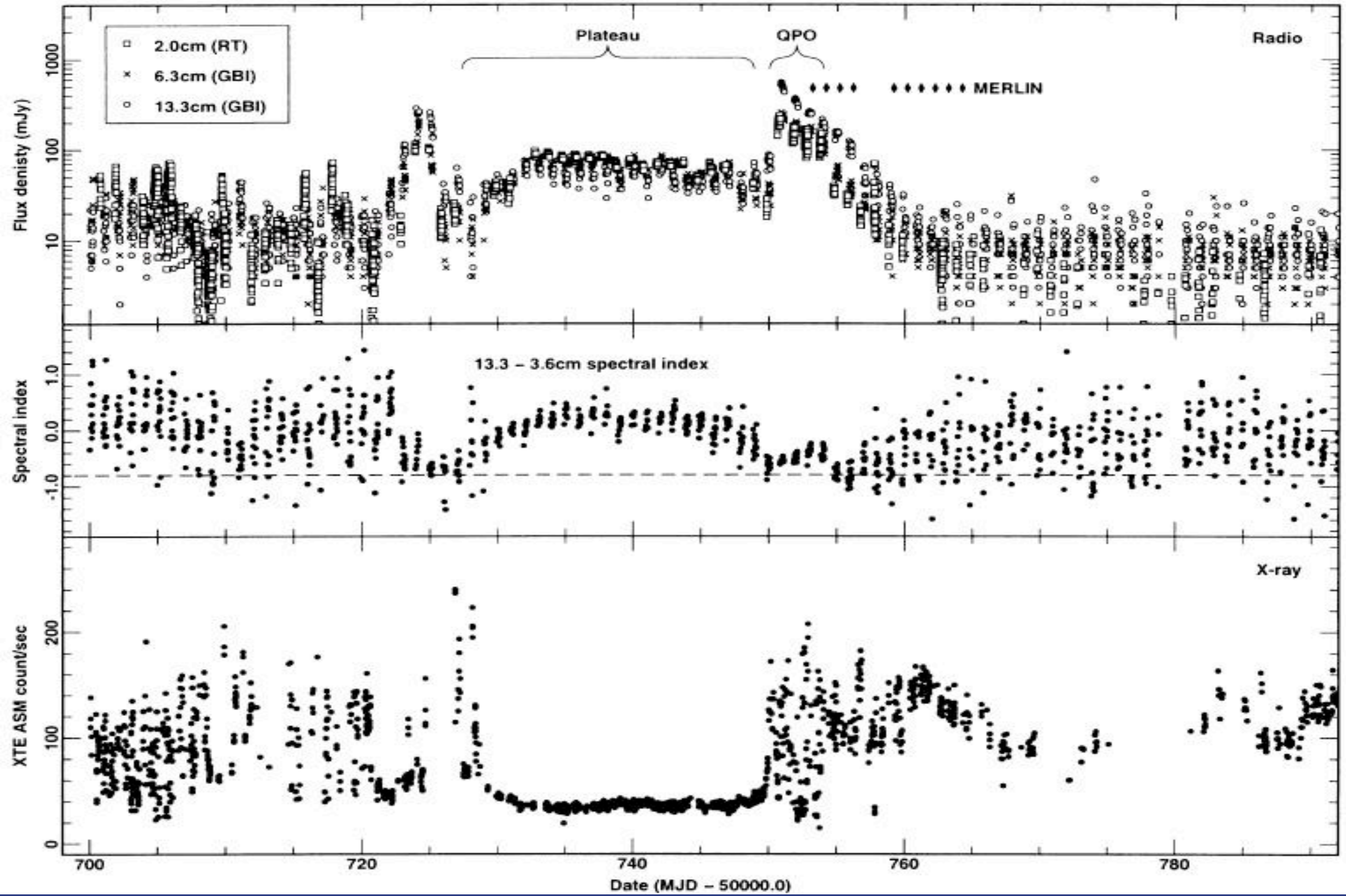
GRS1915+105 states



Belloni+ (2000) identified 12 classes using three basic states (A, B, C)

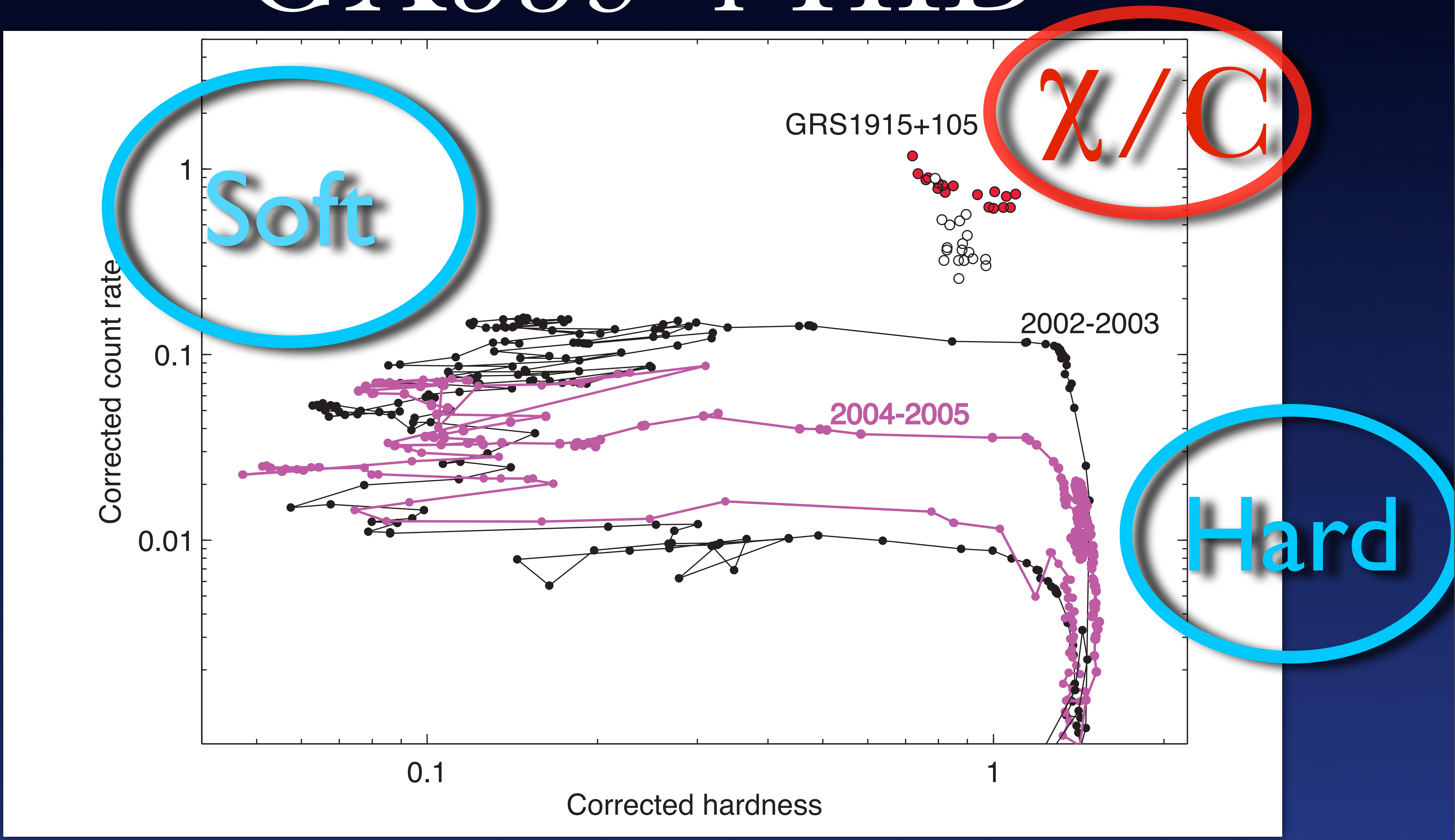
Class χ: The plateau state

(Fender+ 1999)



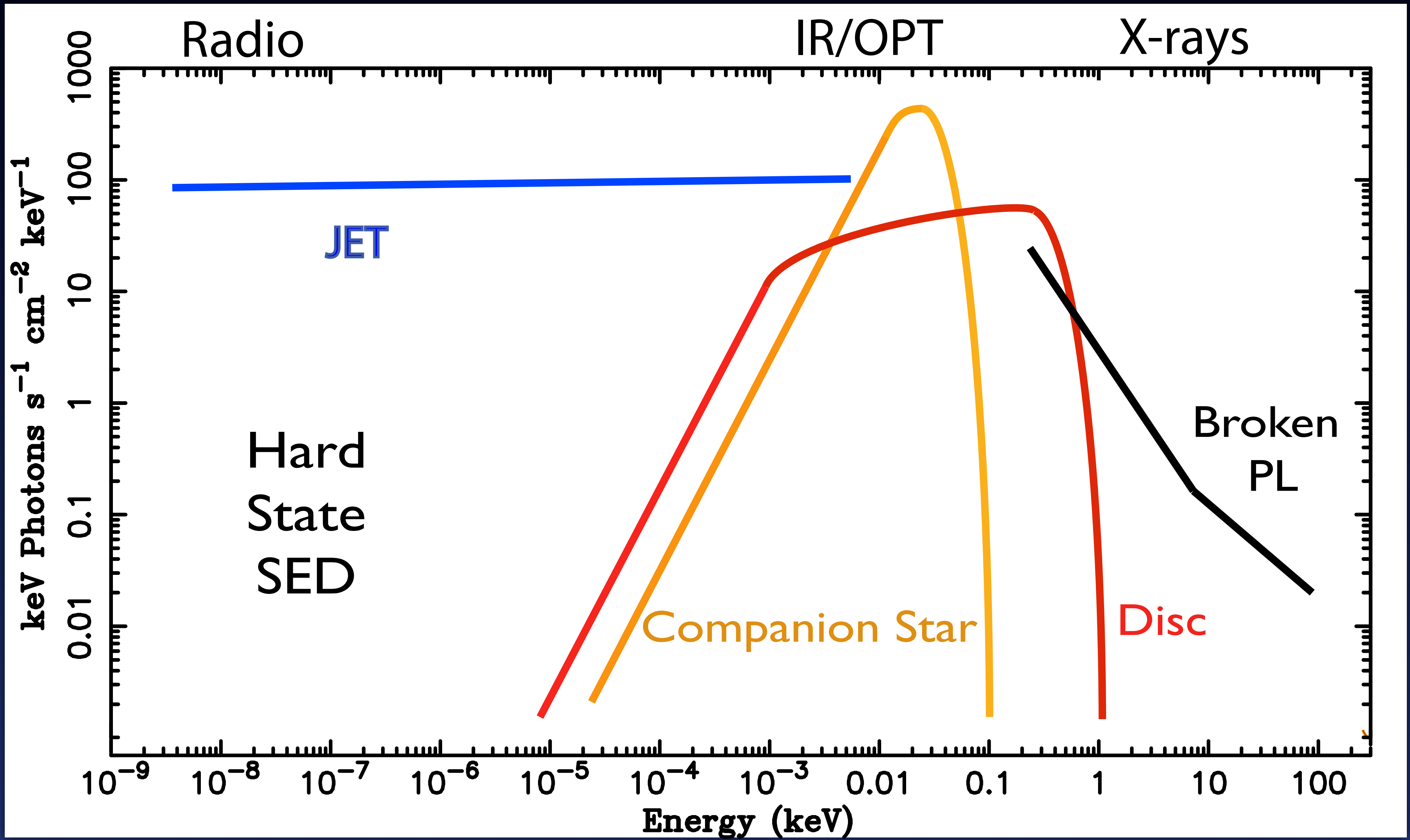
Does this state resemble a hard state?

GRS1915+105 and GX339-4 HID



Adapted from Belloni (2009)

Hard State SED



- Need self-consistent model to explain broadband data: Markoff, Nowak, Wilms 2005

Jet model merits

☑ Successfully explains XRB observations:

- GX339-4 (Markoff+. 2003, 2005; Maitra+ 2009)
- XTE J1118+480 (Maitra+ 2009)
- Cyg X-1 (Markoff+ 2005)
- GRO J1655-40 (Migliari+ 2007)
- A0620-00 (Gallo+ 2007)

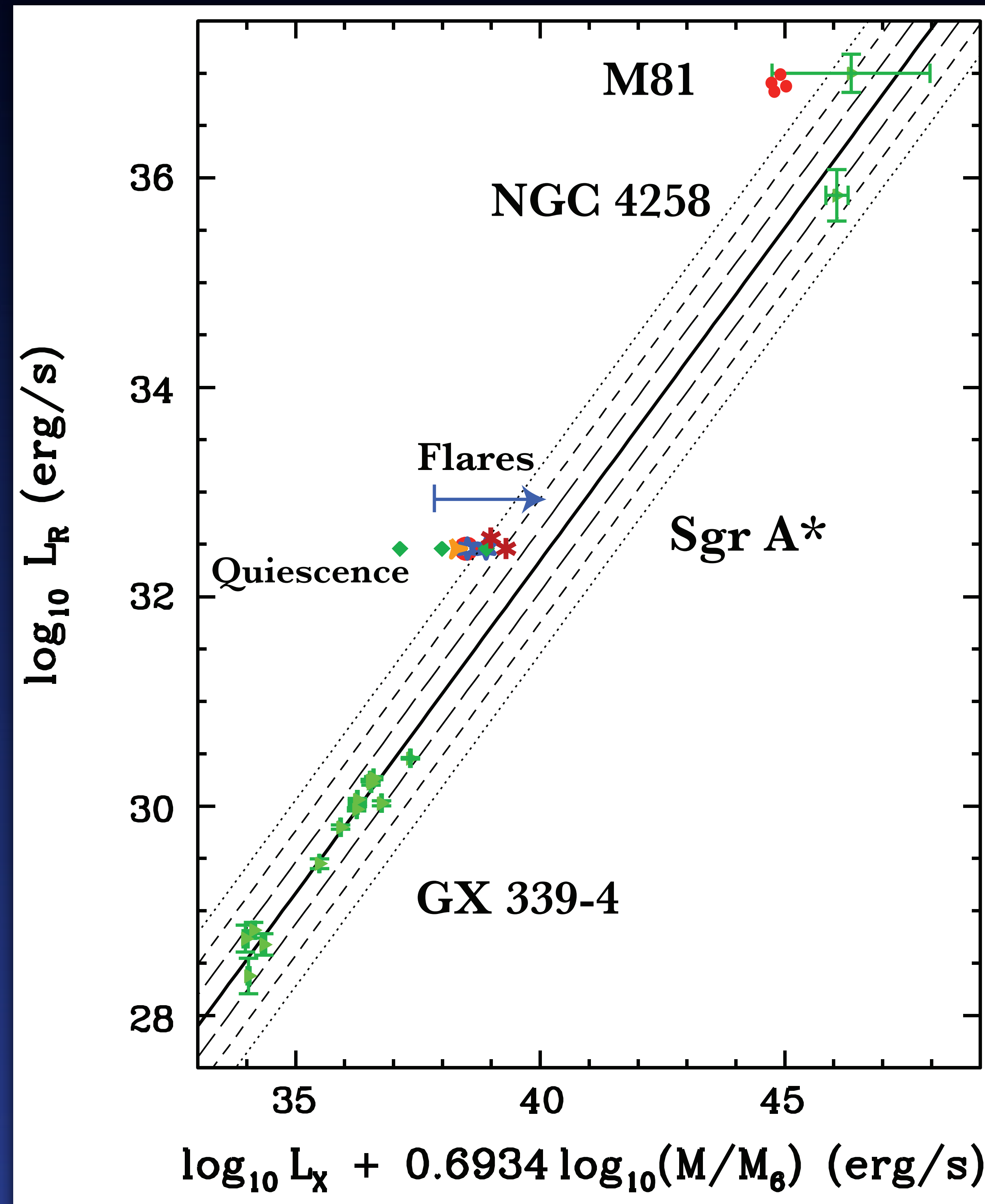
☑ and Supermassive BH observations:

- M81* (Markoff+ 2008)
- SGR A* (Markoff+ 2007)
- NGC 4258 (Yuan+ 2002, Reynolds, Nowak, Markoff+, in prep)

Fundamental Plane

(Merloni+ 2003; Falcke+ 2004)

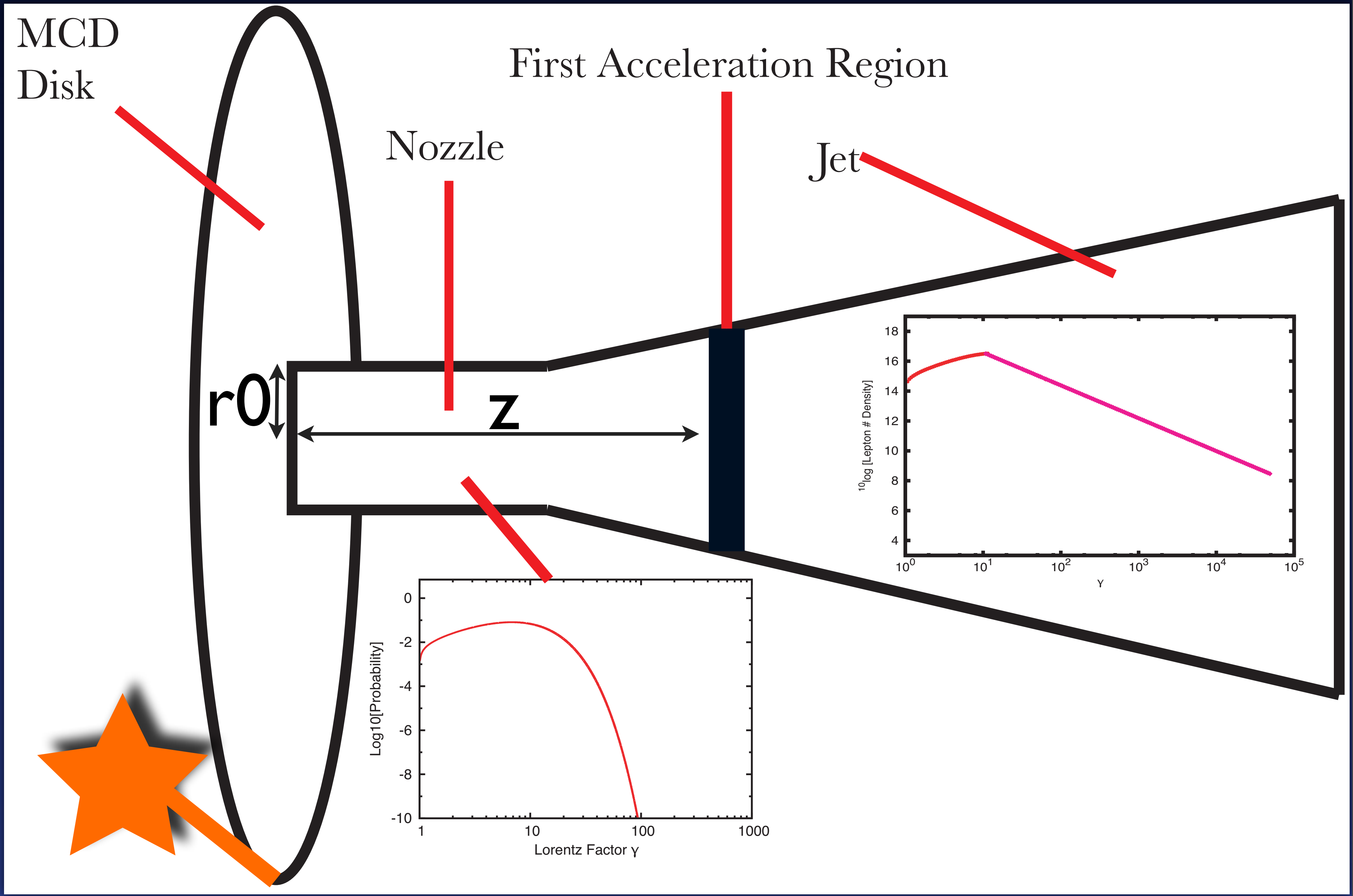
- Correlations found between
  - Radio luminosity
  - X-ray luminosity
  - Black hole mass



(Markoff 2009)

Jet parameters and (Markoff et al. 2005) structure

- jet luminosity
- magnetic dominance (U_B/U_e)
- jet base-radius (r0)
- electron temp.
- acceleration region distance (z)
- particle distribution index (pdi)



Additional modeling

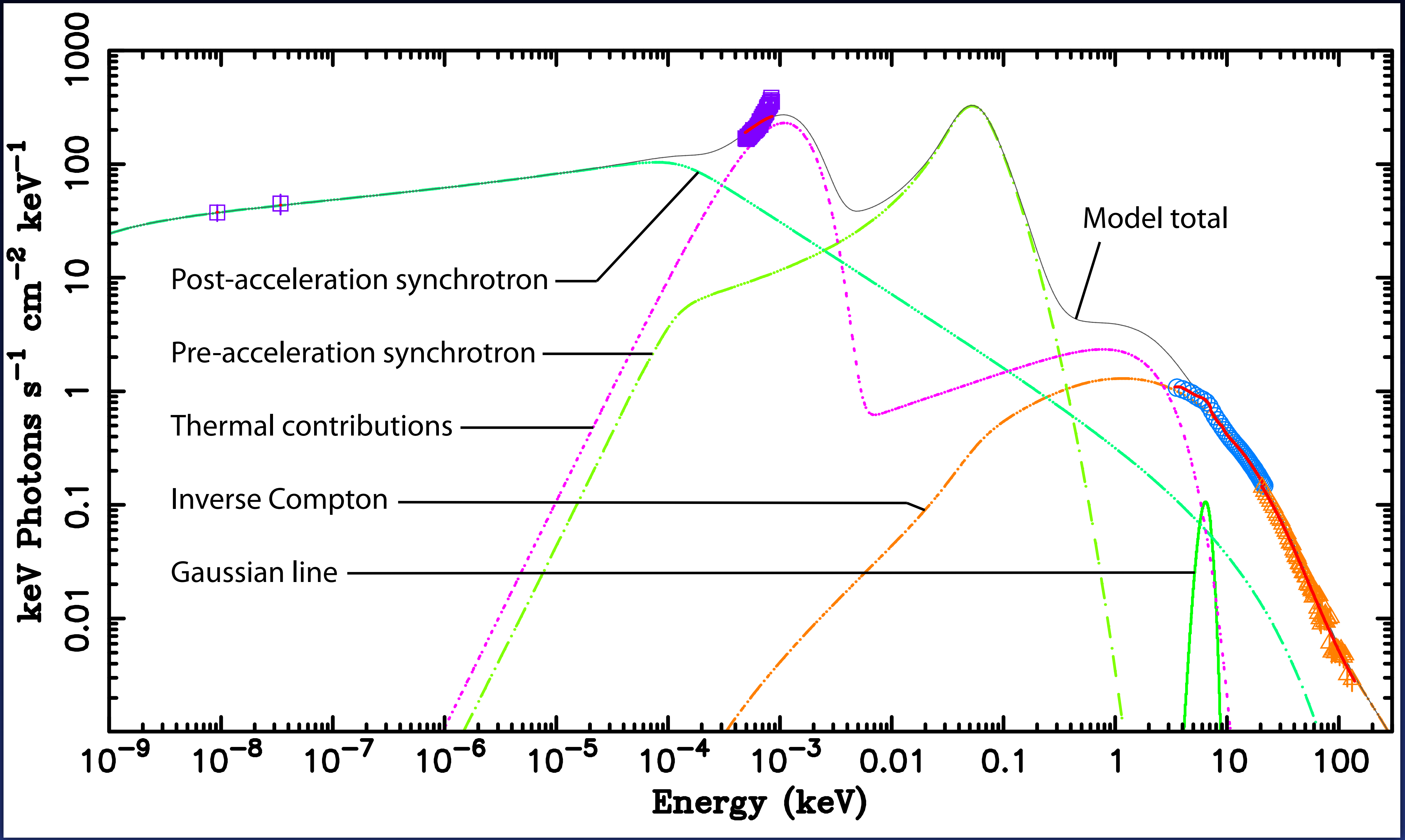
- Gaussian @ ~6.4 keV
- Smeared edge
  (Ebisawa 1991)
- Compton reflection from the disk
  (Magdziarz & Zdziarski 1995)

Literature Values

parameter	value	units	ref.
column dens.	4.7	10^{22} cm^{-2}	Chaty+ 1996
distance	11	kpc	Fender+ 1999
inclination	66	degrees	Fender+ 1999
mass	14	M_{sol}	Greiner+ 2001
donor temp.	4455	K	Alonso+ 1999

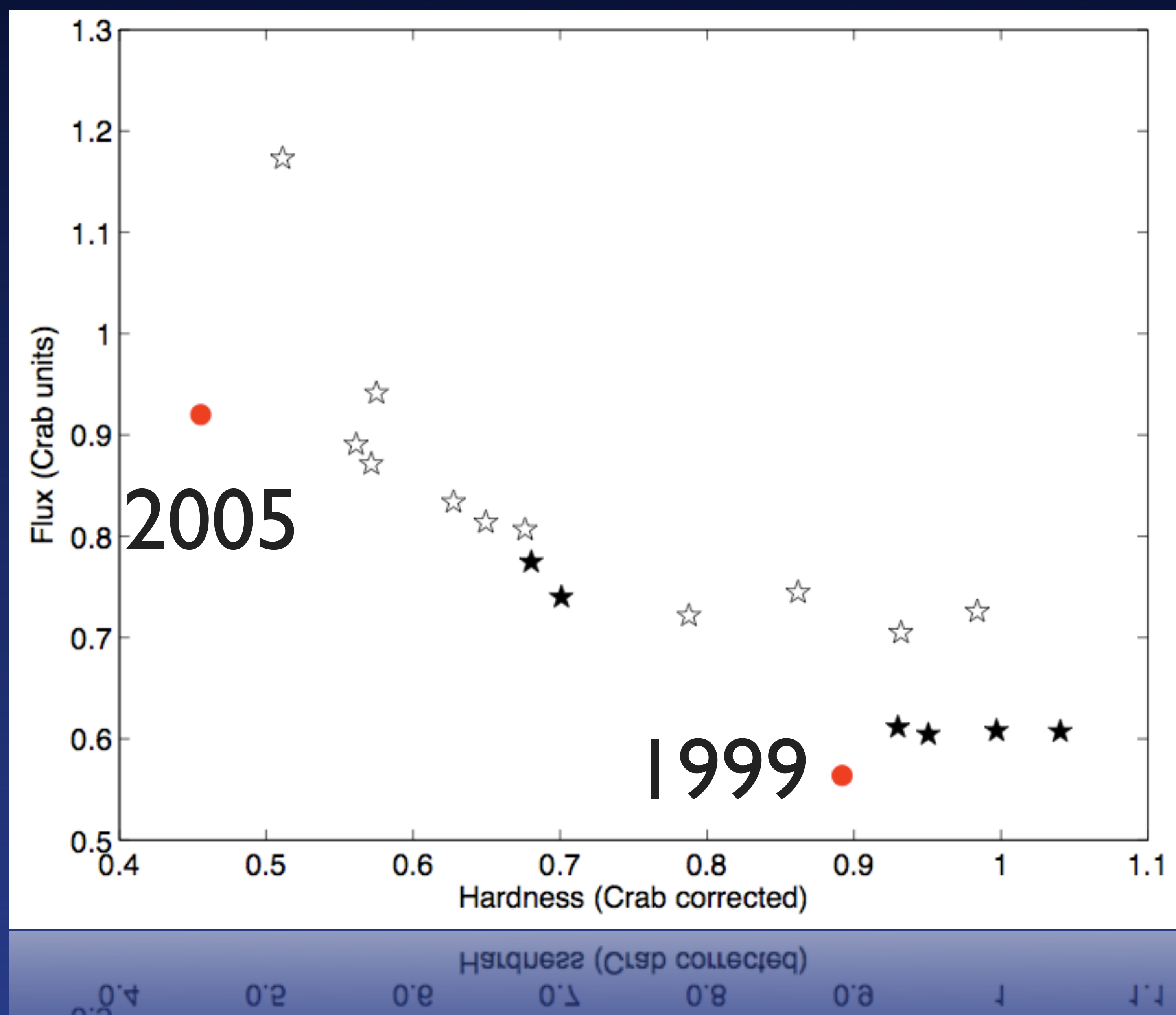
Fixed physical parameters used for fitting

Example result



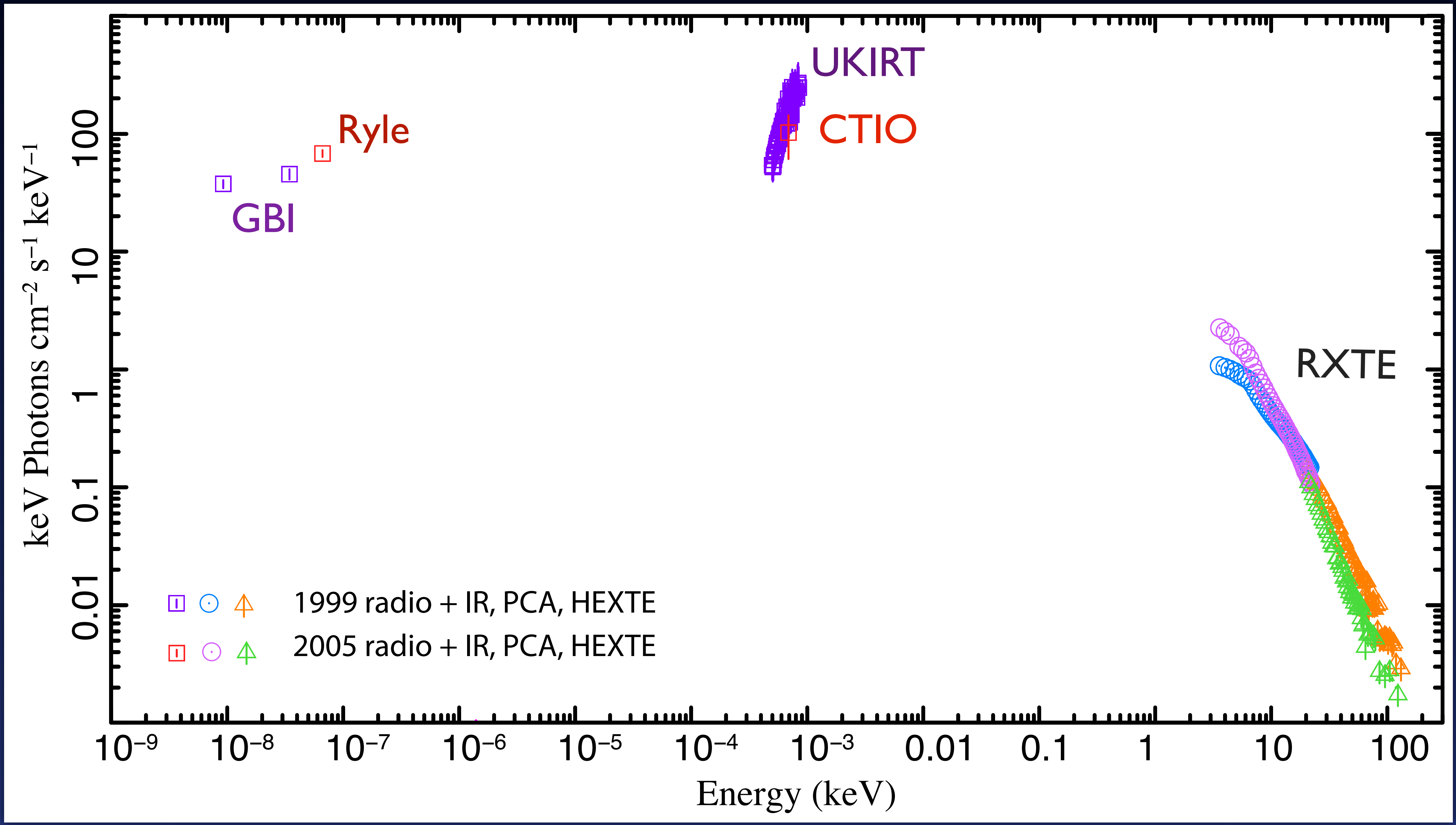
Observations

1999 observation is much harder and is of lower X-ray luminosity then 2005



(PvO, SM+, 2010; Figure courtesy of T. Belloni)

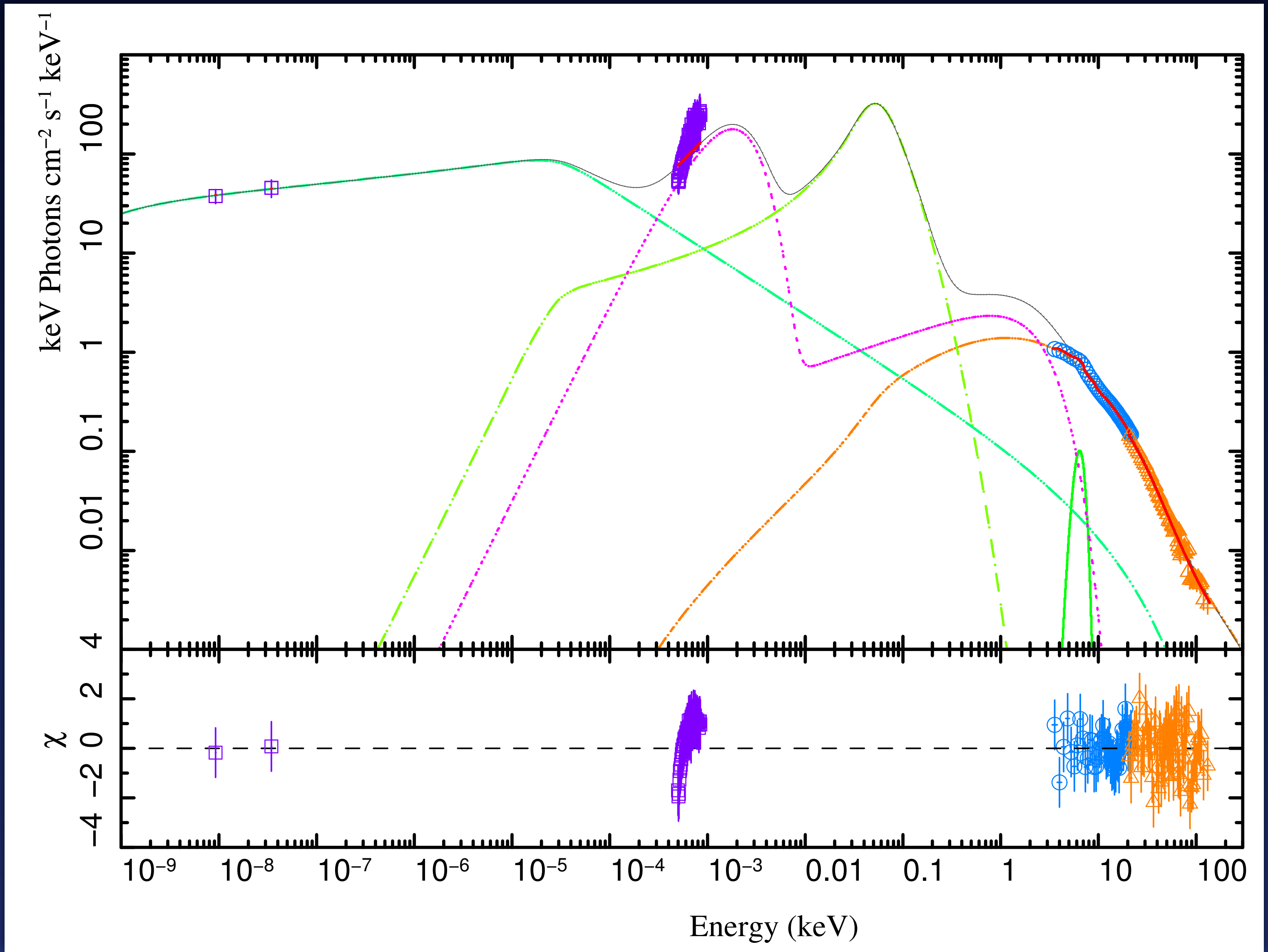
1999/2005 observed SEDs



1999

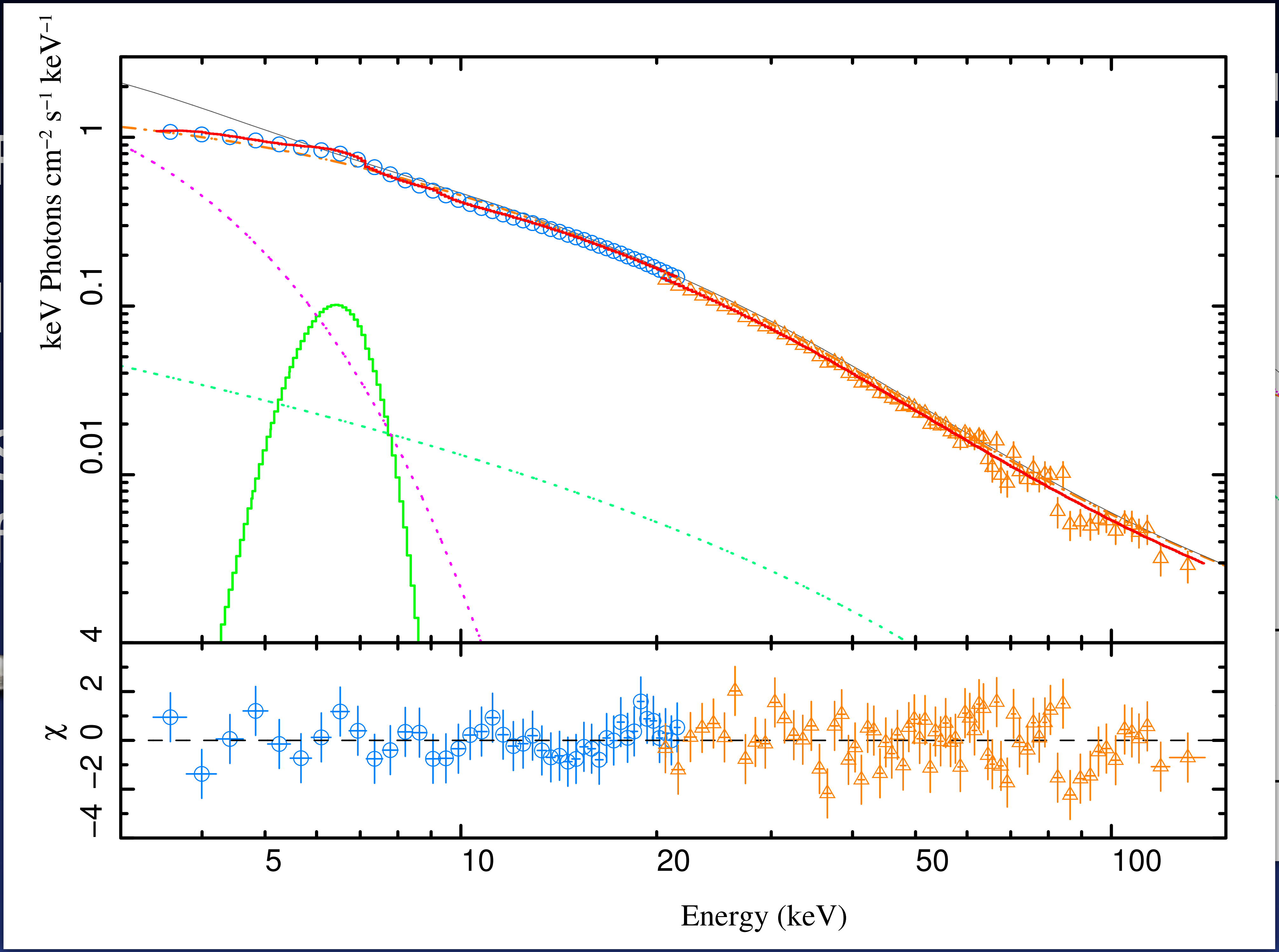
(PvO, SM+ 2010)

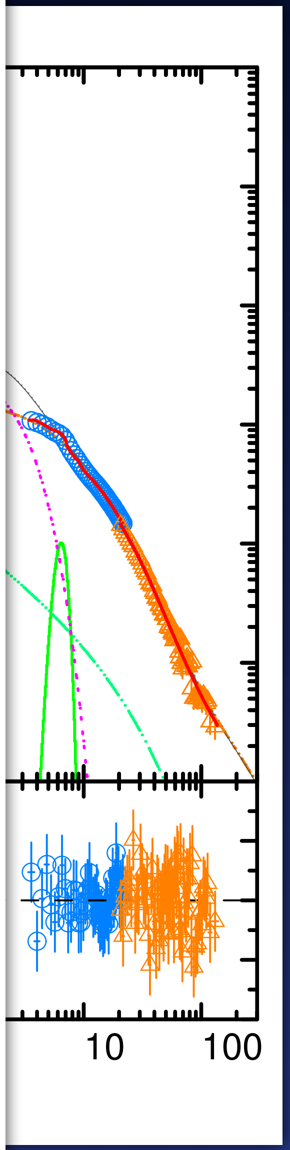
- Radio from GBI
- IR from UKIRT
- Statistically good fits obtained
    - definite trend discovered



1999

+ 2010)


keV Photons cm^{-2} s^{-1} keV^{-1}
1
0.1
0.01
4
2
0
−2
−4
χ
5
10
20
50
100
Energy (keV)


10
100

plateau state vs. hard state

Similar to canonical HS

parameter	units	canonical	GRS1915+105
jet base radius	r_g	3.5-20.2	20.4
electron temp	10^9 K	20-52.3	9.2
pdi		2.1-2.9	2.3

Distinct from canonical HS

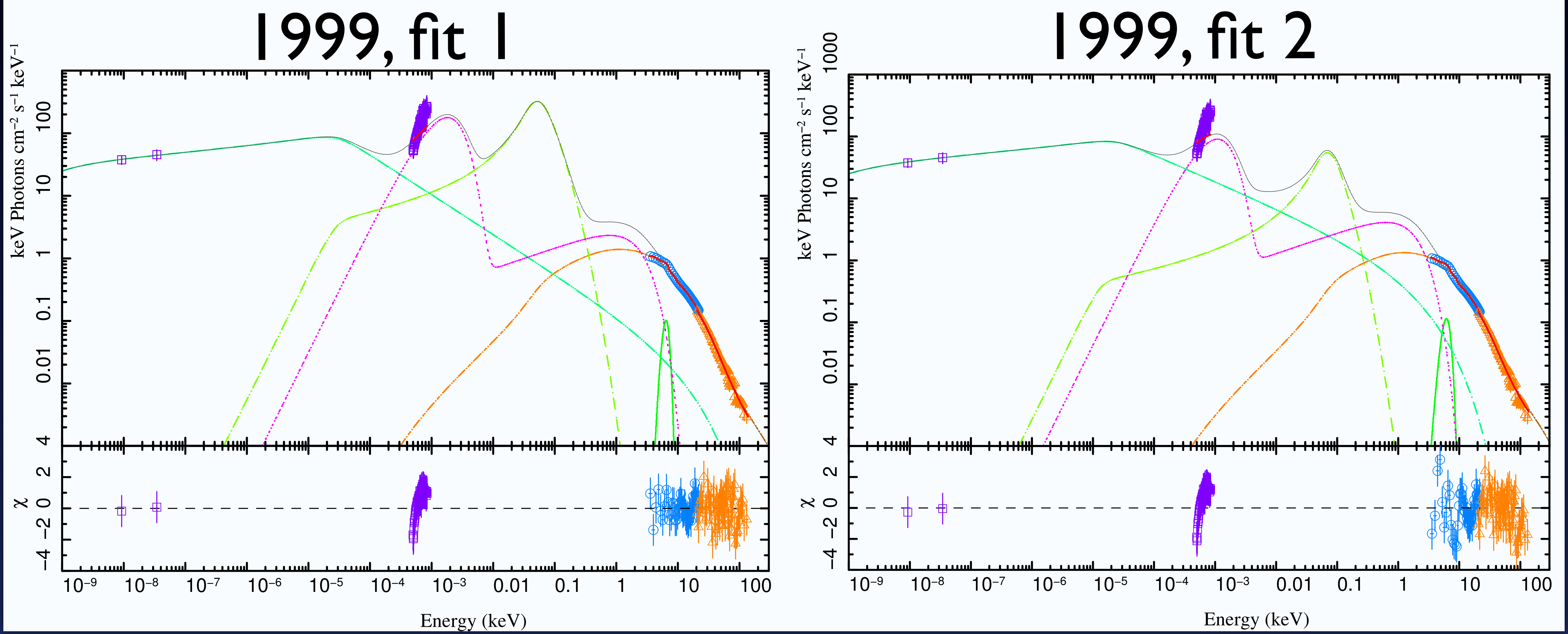
parameter	units	canonical	GRS1915+105
U_B/U_e		1.1-7	692
dist. to acc. region	10^3 r_g	0.007-0.4	30
jet luminosity	L_{Edd}	0.00034-0.07	0.48

(Markoff+ 2008)

(Polko+, in press)

1999, fit 2

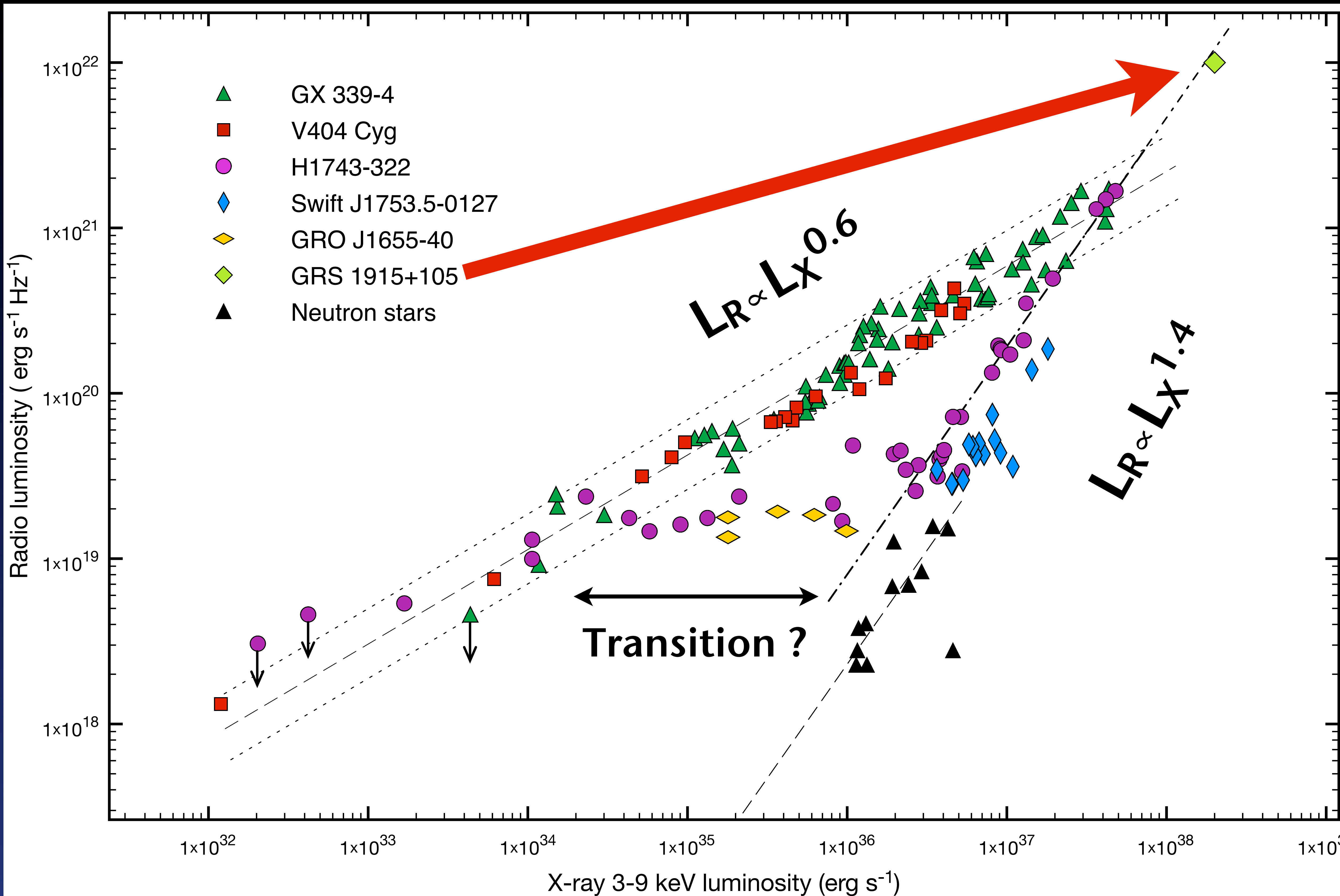
(PvO, SM+ 2010)



parameter	units	canonical	1999 I	1999 II
U_B/U_e		1.1-7	692	29
jet luminosity	L_{Edd}	0.00034-0.07	0.48	0.99
pdi		2.1-2.9	2.3	1.8

Conclusions

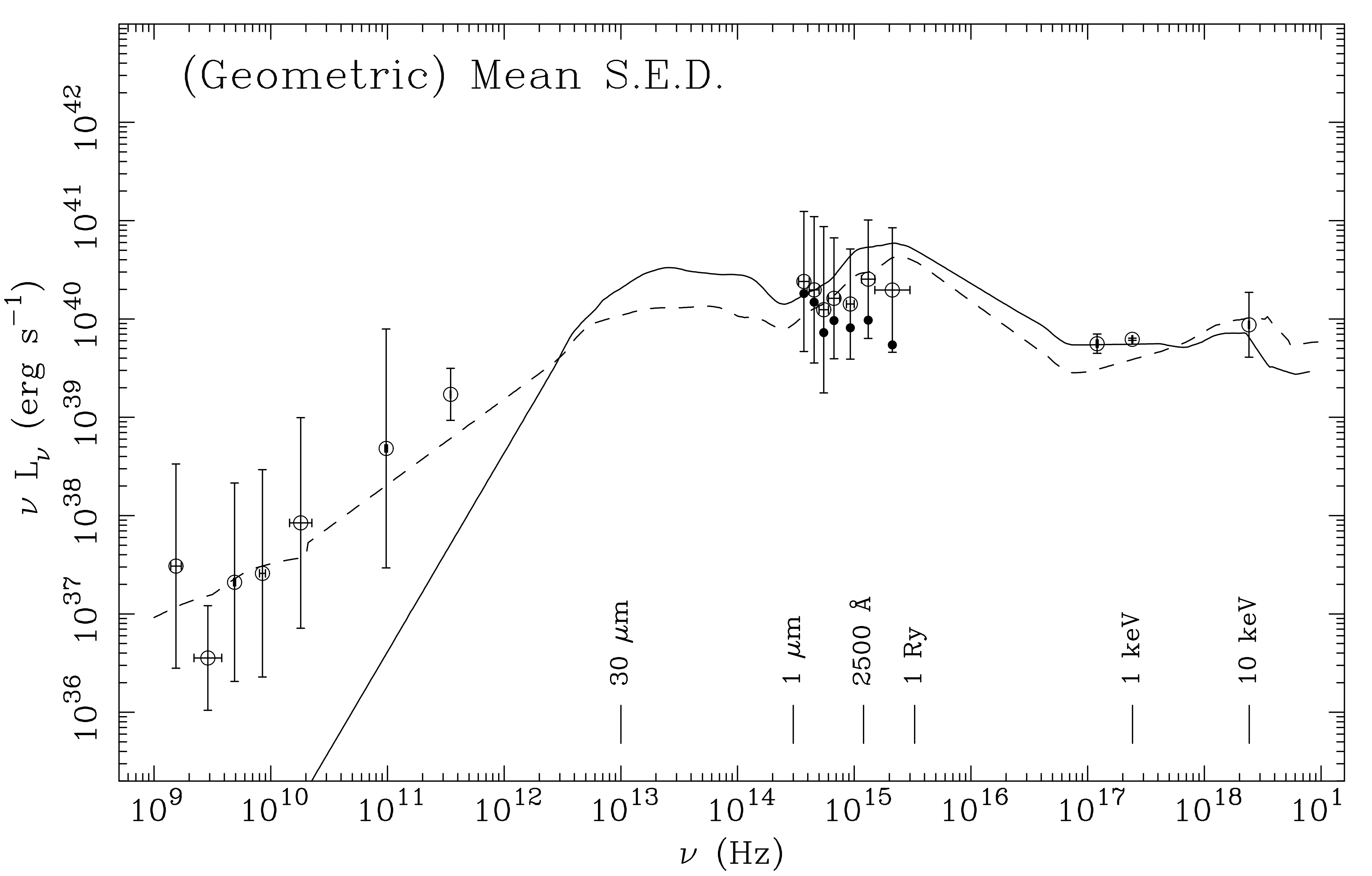
- ☑ 1999 appears well-approximated by outflow model, but with extreme results
- ☑ Plateau state is very extreme compared to the 'canonical' hard state => radiatively efficient track? (Coriat+ in prep.)



(Coriat+, in prep.)

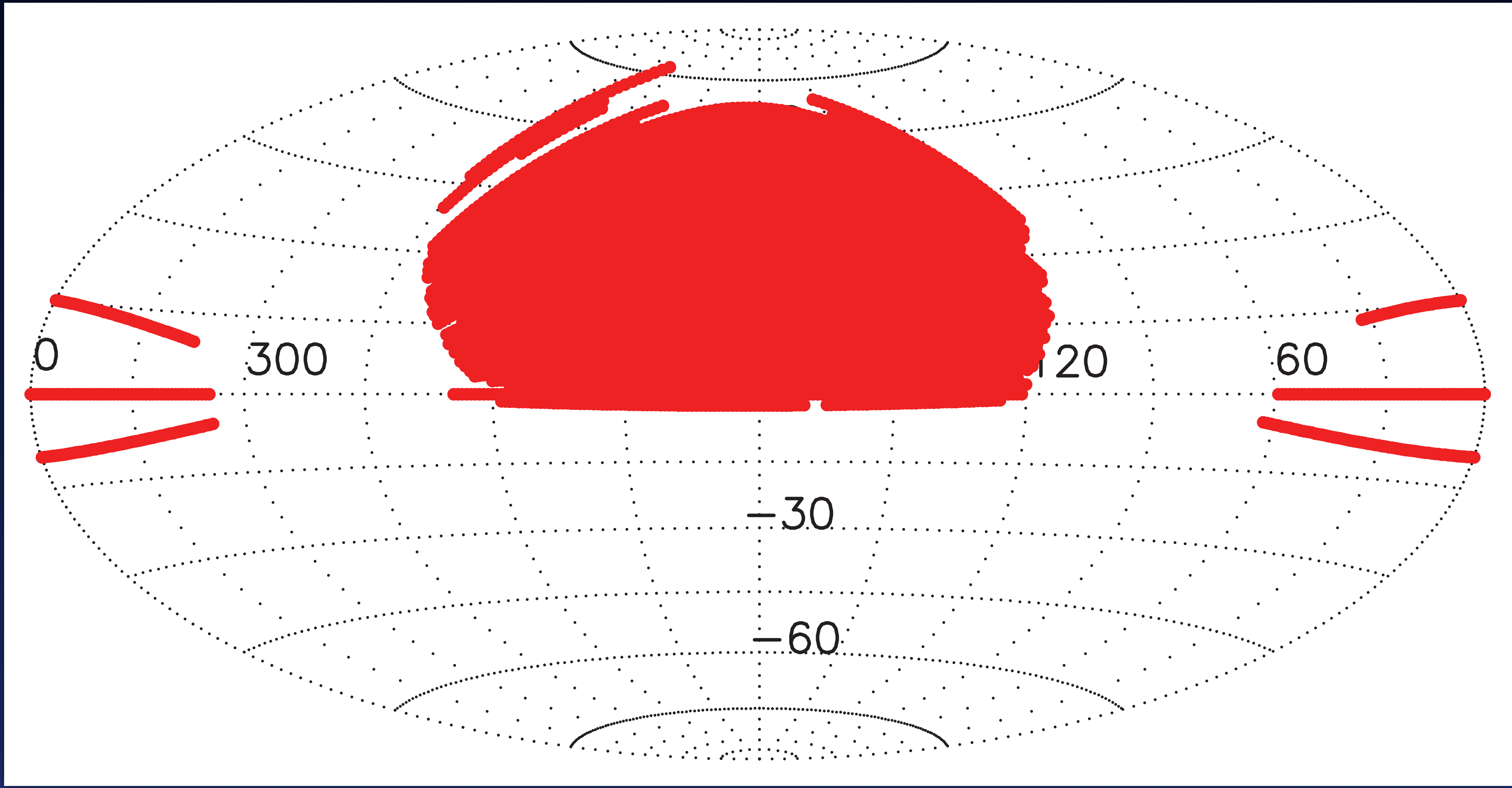
Radio vs. X-ray luminosity

II. Constructing AGN SEDs



(Eracleous+ 2010)

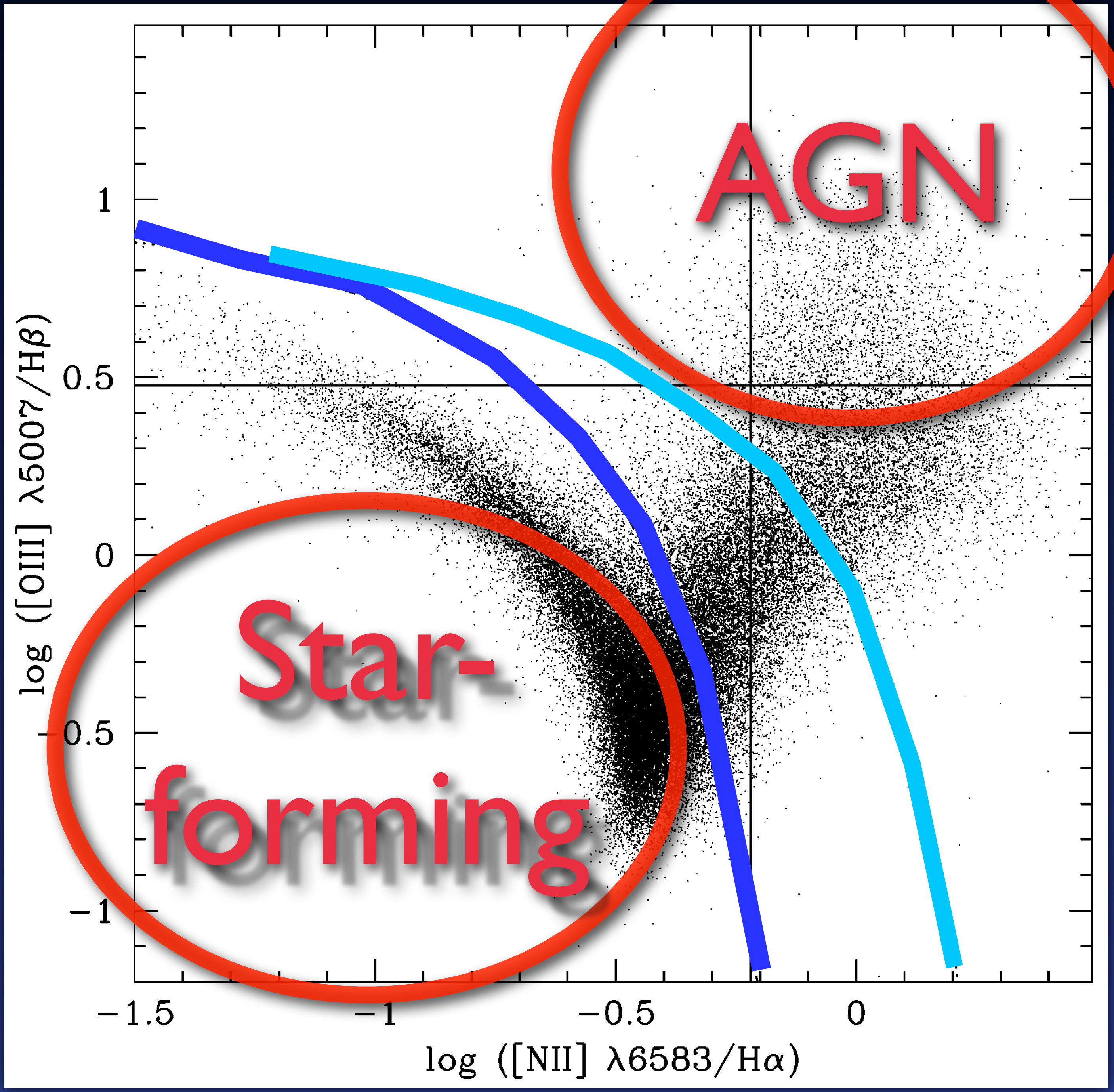
Optical: SDSS DR7
Radio: >30 yrs of VLA



SDSS comprises spectroscopy of nearly 10^6 galaxies, mainly located in northern hemisphere

Finding the AGN: BPT diagrams

- Baldwin, Phillips & Terlevich (1981) devise first (empirical) classification scheme, using optical line flux ratios, to remove star-forming regions that also ionise those lines
- Main lines OIII/Hβ, NII/Hα, SII/Hα, OI/Hα



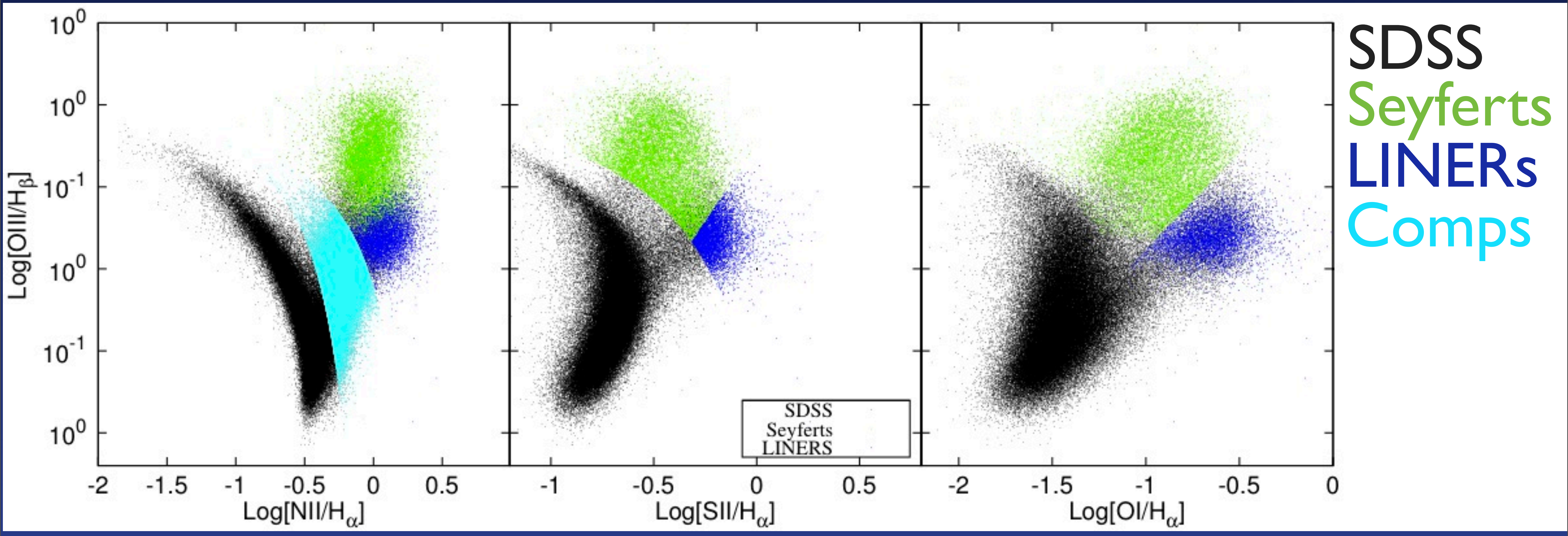
(Kauffmann+ 2003)

AGN classification

- Kewley+ 2001: first theoretical scheme, based on stellar synthesis, photo-ionization and shock models to get 'maximum starburst line'
- Kauffmann+ 2003: move extreme starburst line semi-empirically, fitting ~22,600 SDSS spectra(DR1)
- Kewley+ 2006: SDSS DR4; 567,486 galaxies, 85,224 galaxies

Kewley+ 2006 classification

- Main lines OIII/Hβ, NII/Hα, SII/Hα, OI/Hα with S/N > 3.0 and redshift 0.04<z<0.1
- Very conservative



Creating our sample

- Get BH mass from velocity dispersion using M-σ relation (Tremaine+ 2002)
- Want sample with restricted mass range but wide range in accretion rates to get SED templates as function of accretion rate
  - [x] data mining: 8.5<Log[BH Mass]<9.0
  - [x] proposals: 9.0<Log[BH Mass]<9.5

Matching SDSS DR7 with VLA observations

- ~10^5 VLA observations and SDSS AGN
- Use only higher frequency VLA to isolate core emission (X/C band, 8/5 GHz)
- Sources may not be centre of FOV; these are likely targeted sources (remove centre 10% in area)

Matching SDSS DR7 with VLA, results

	X band obs	sources	n_{AGN} in mass range
AGN (Sy/LINERS)	1568	367	27
composites	2478	599	7

	C band obs	sources	n_{AGN} in mass range
AGN (Sy/LINERS)	6468	895	44
composites	12539	1614	21

- Using Kauffmann 2003 classification
- Mass range: 8.5<Log[BH Mass]<9.0

Future work/next steps

- Reduce radio data with automated script (James Miller-Jones, Martin Bell)
- Add multi-wavelength data:

BAND	Project
Optical	SDSS
Radio	eMerlin & eVLA
UV	SWIFT/GALEX
IR	SPITZER

- Propose for high-quality data set: eVLA, eMERLIN?