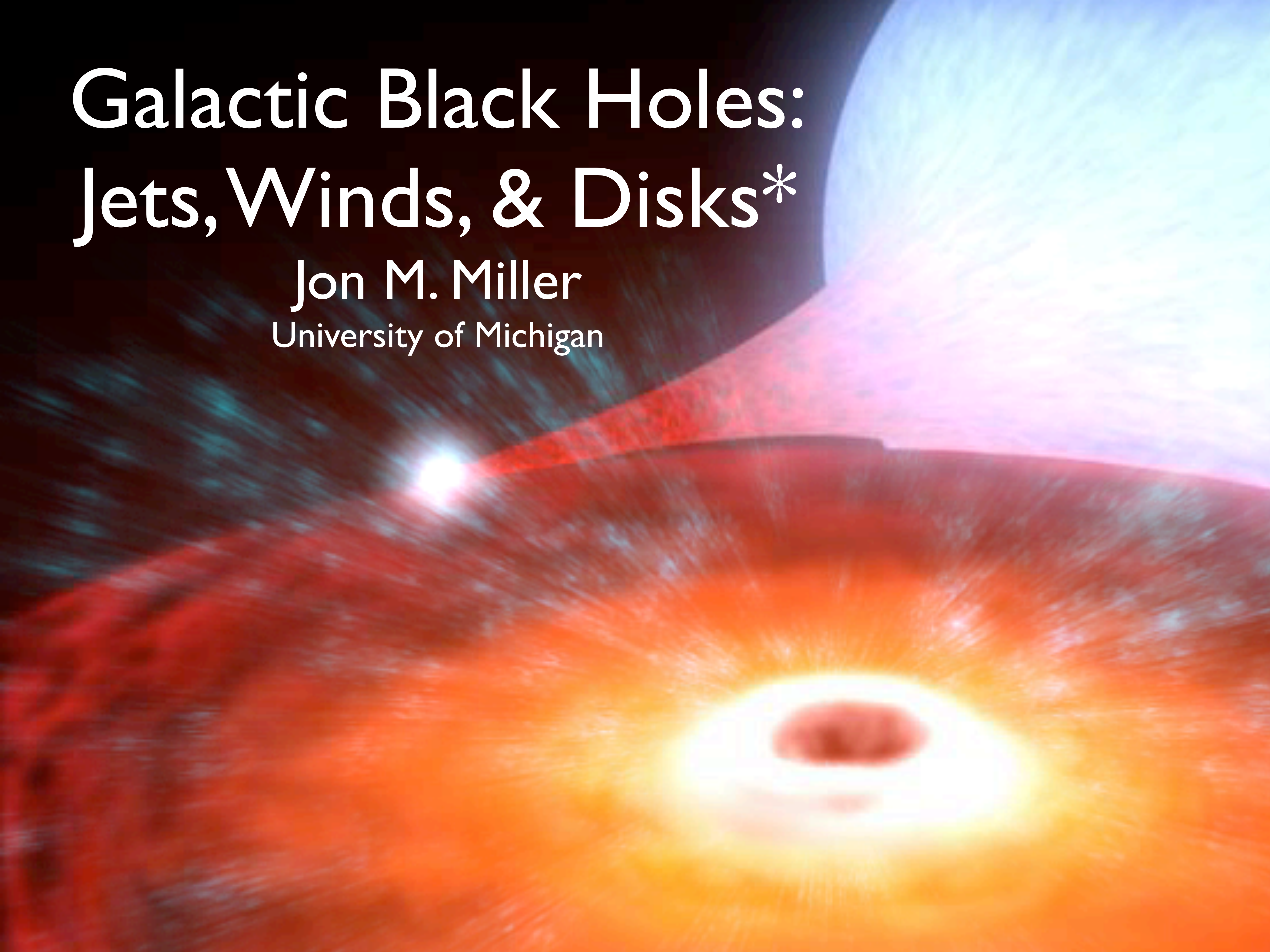
Galactic Black Holes: Jets, Winds, & Disks*

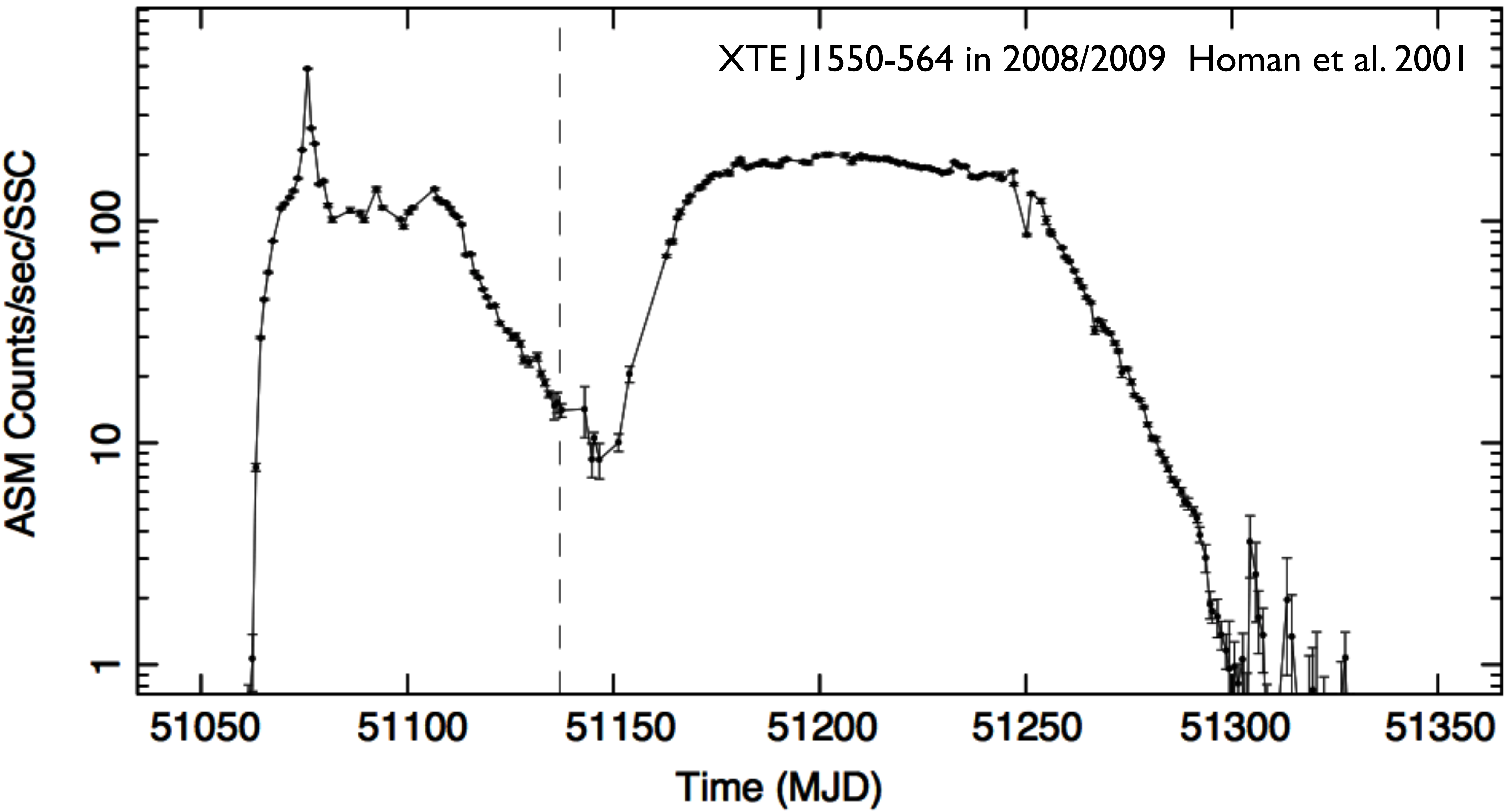
Jon M. Miller
University of Michigan



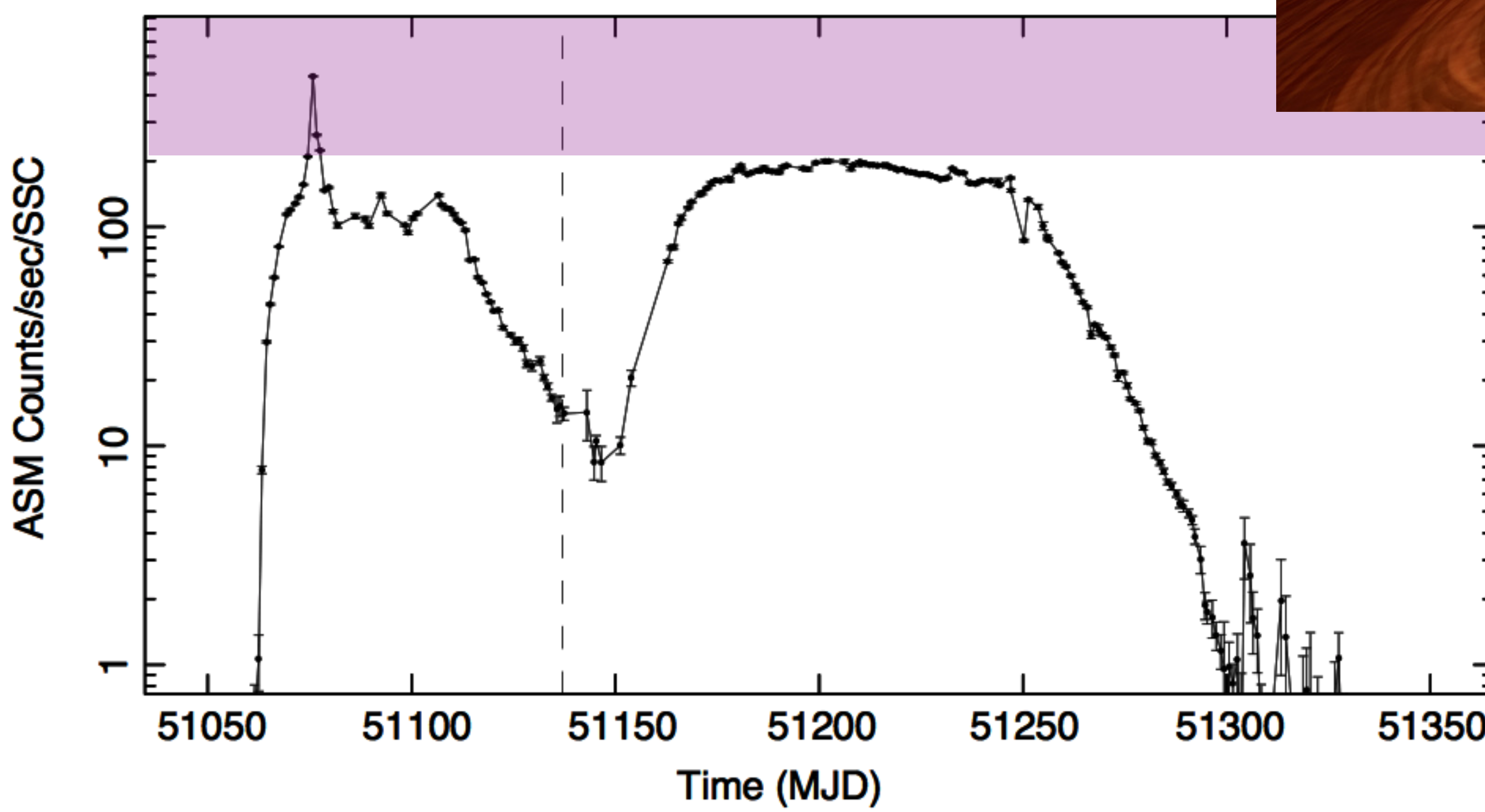
A matter of resolution

- Chandra's contributions to persistent jets, and discovery of transient jets.
- Chandra's discovery of disk winds, including relationships with jets, and consequences.
- A quick look to the future.

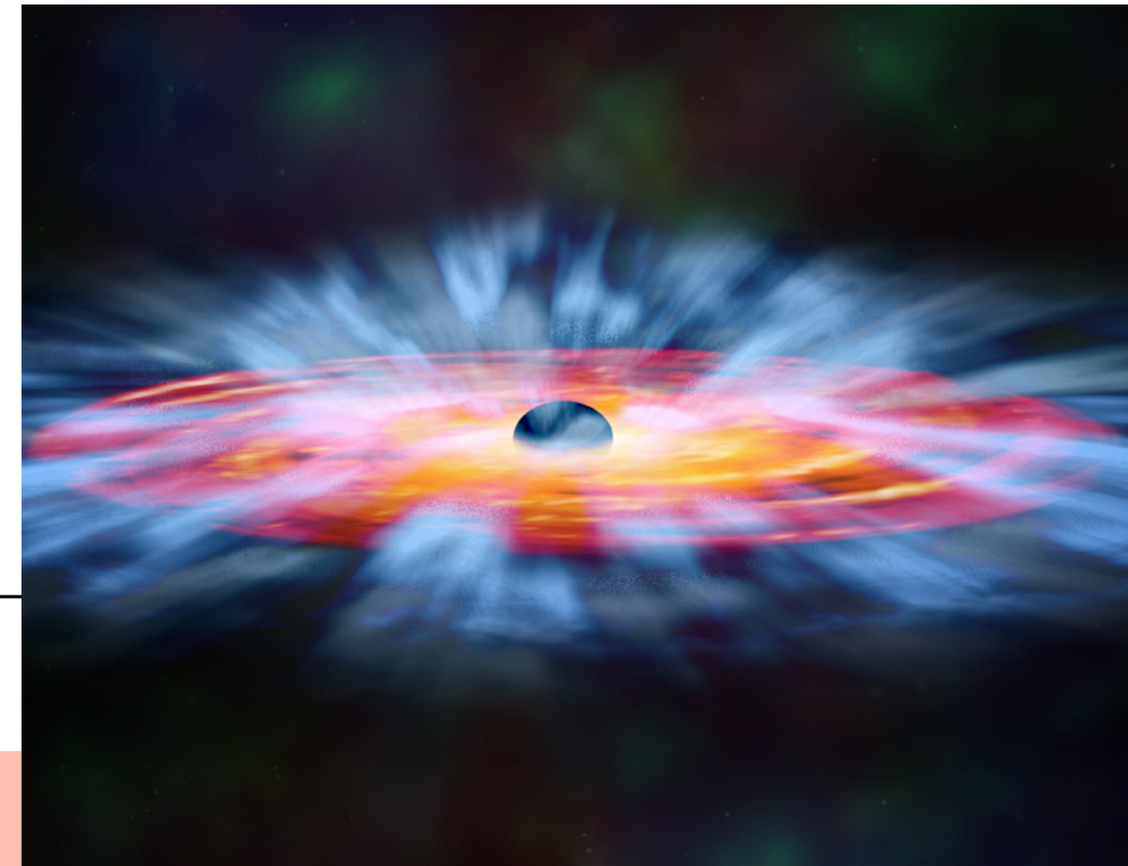
“AGN for the impatient”

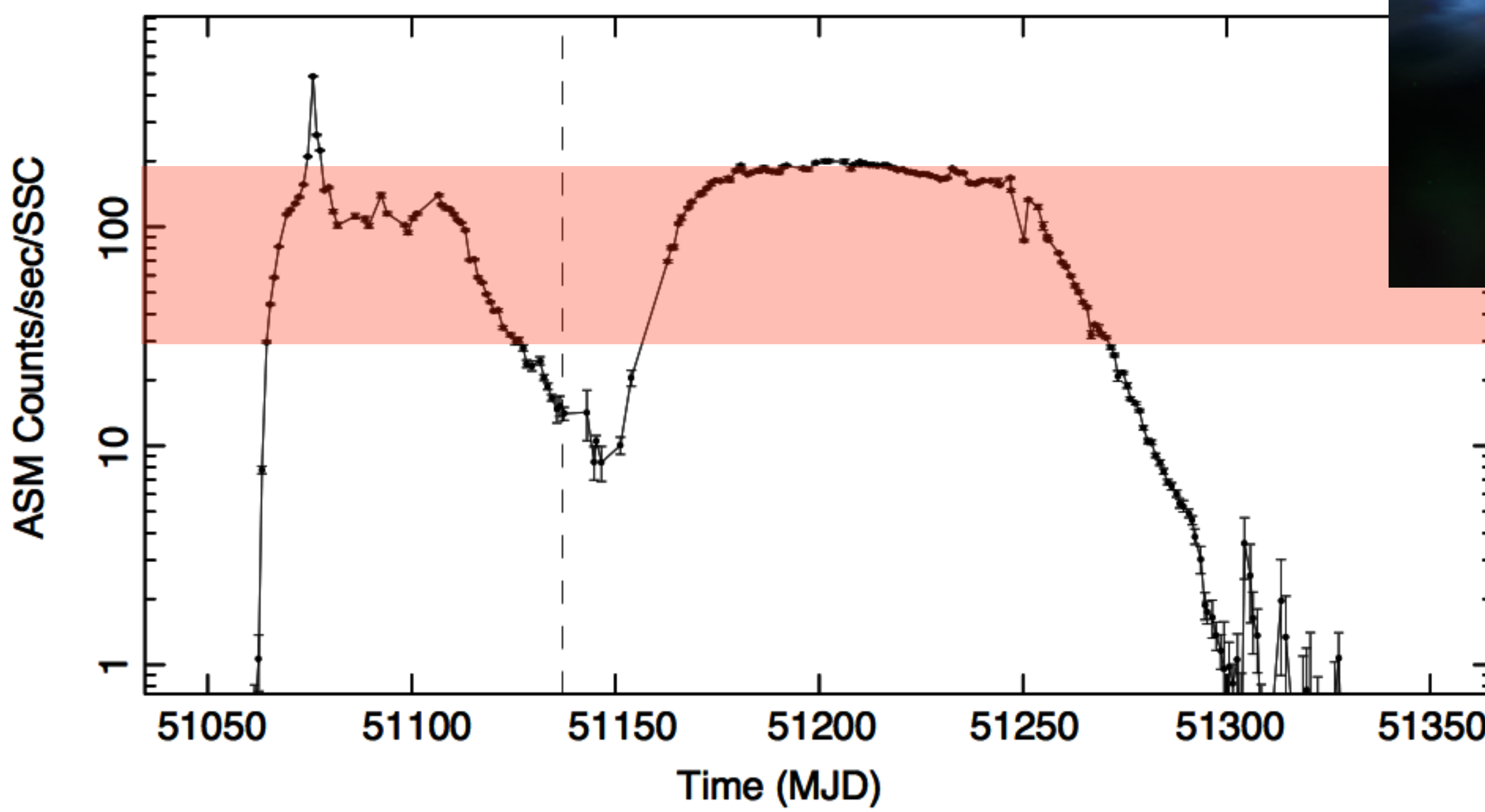


“Quasars for the impatient”

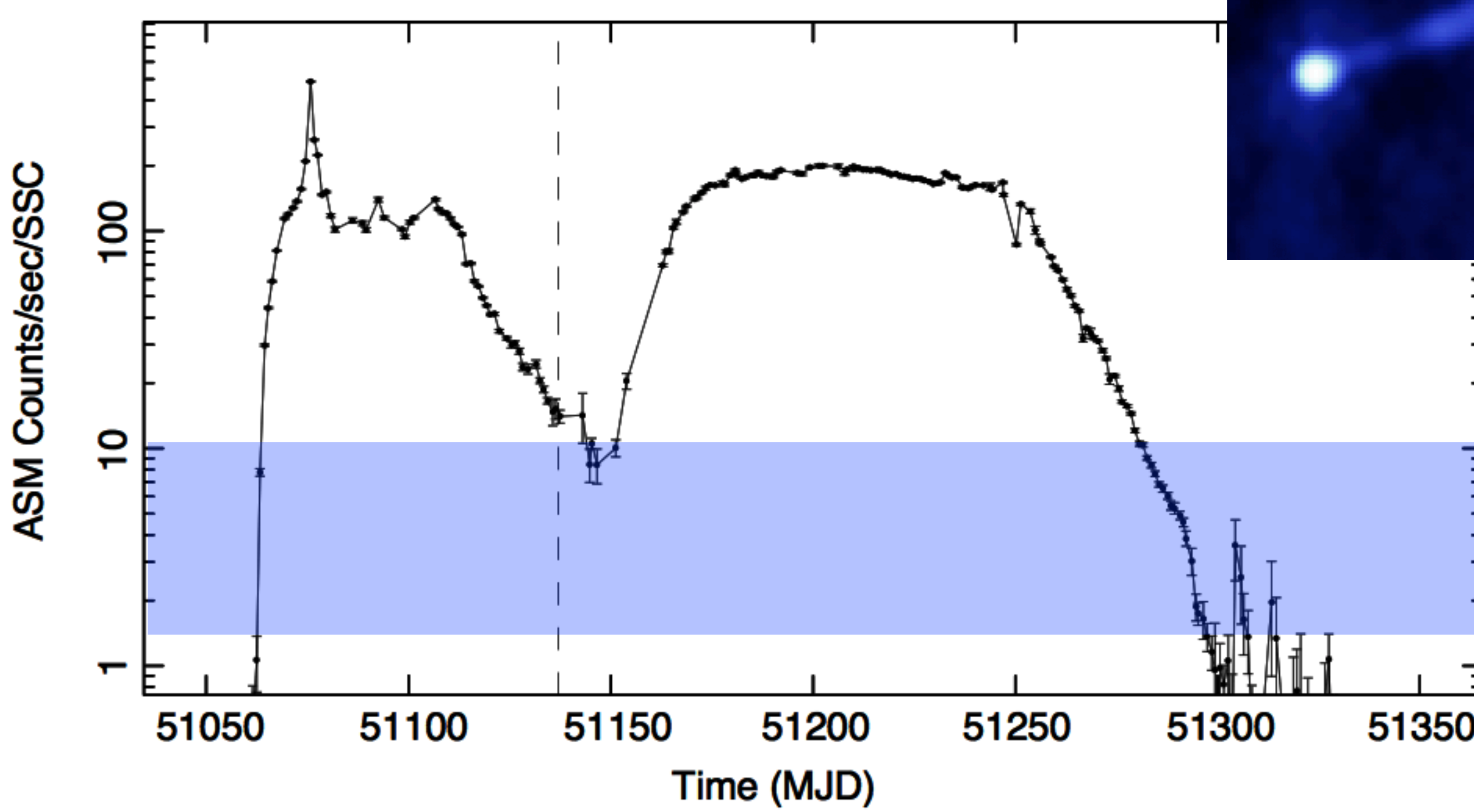


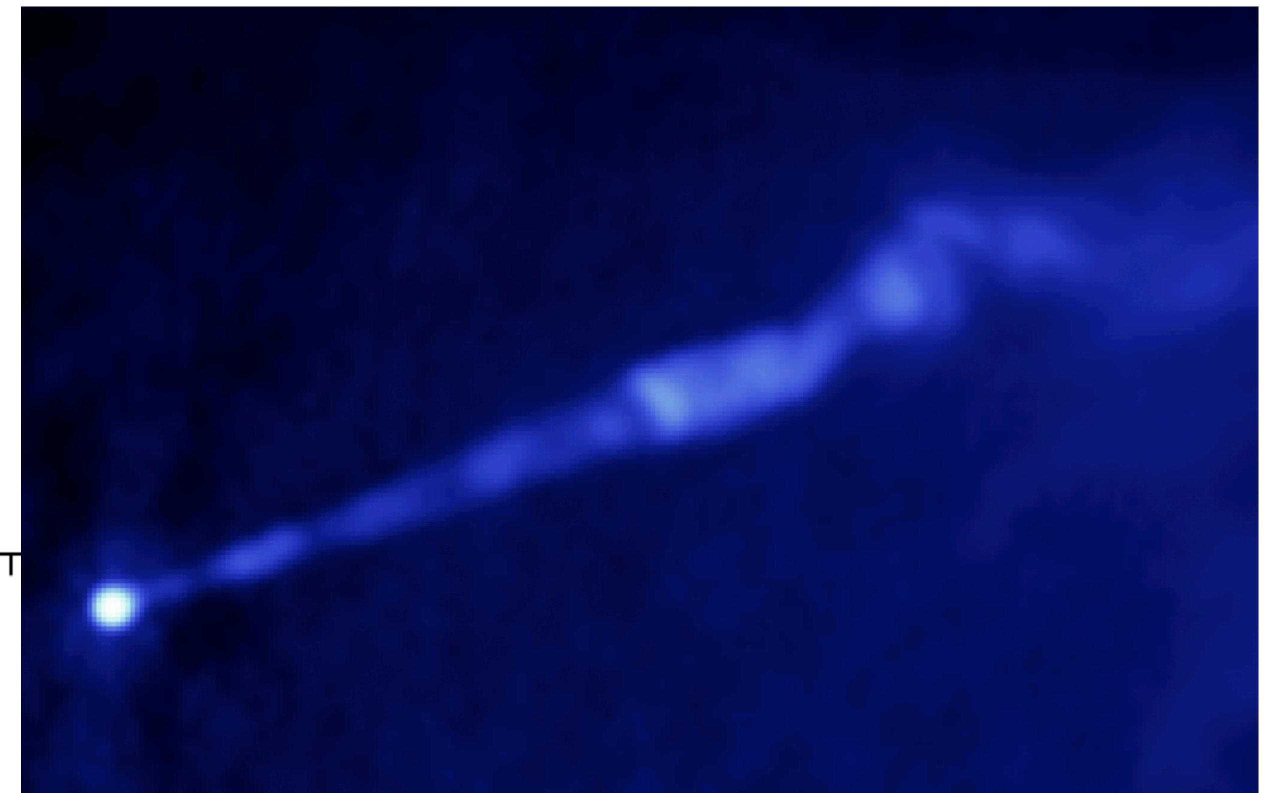
“Seyferts for the impatient”





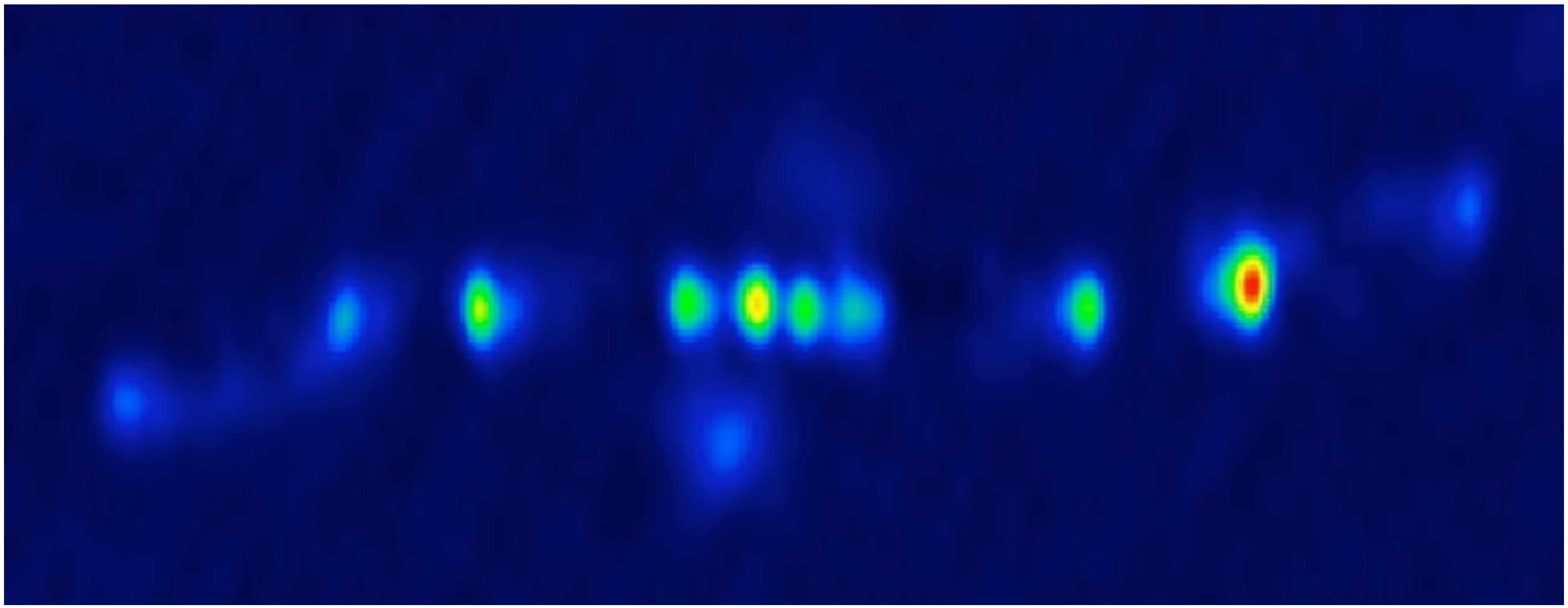
"LINERS for the impatient"





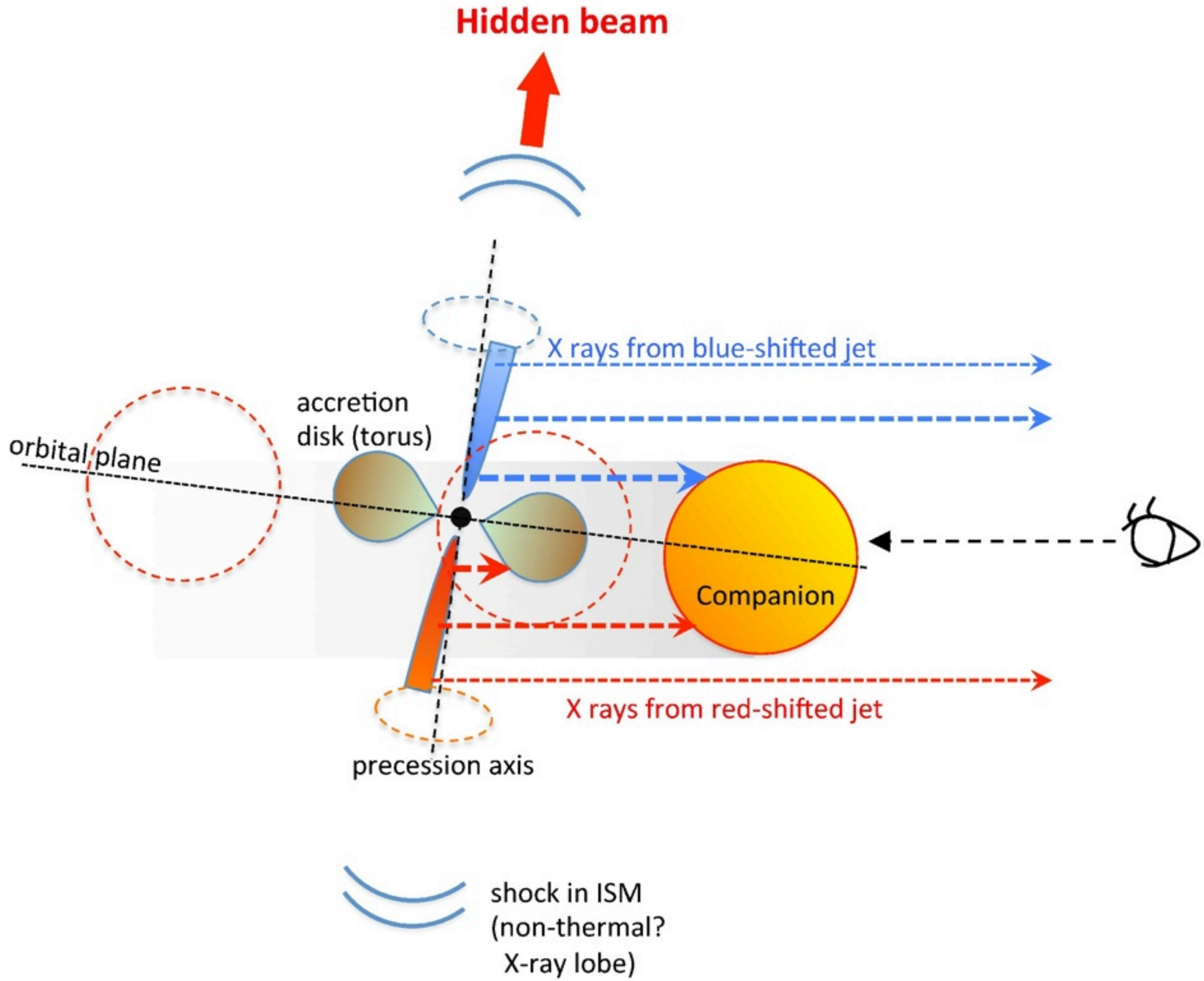
Jets

SS 433



Mioduszewski et al., VLBA

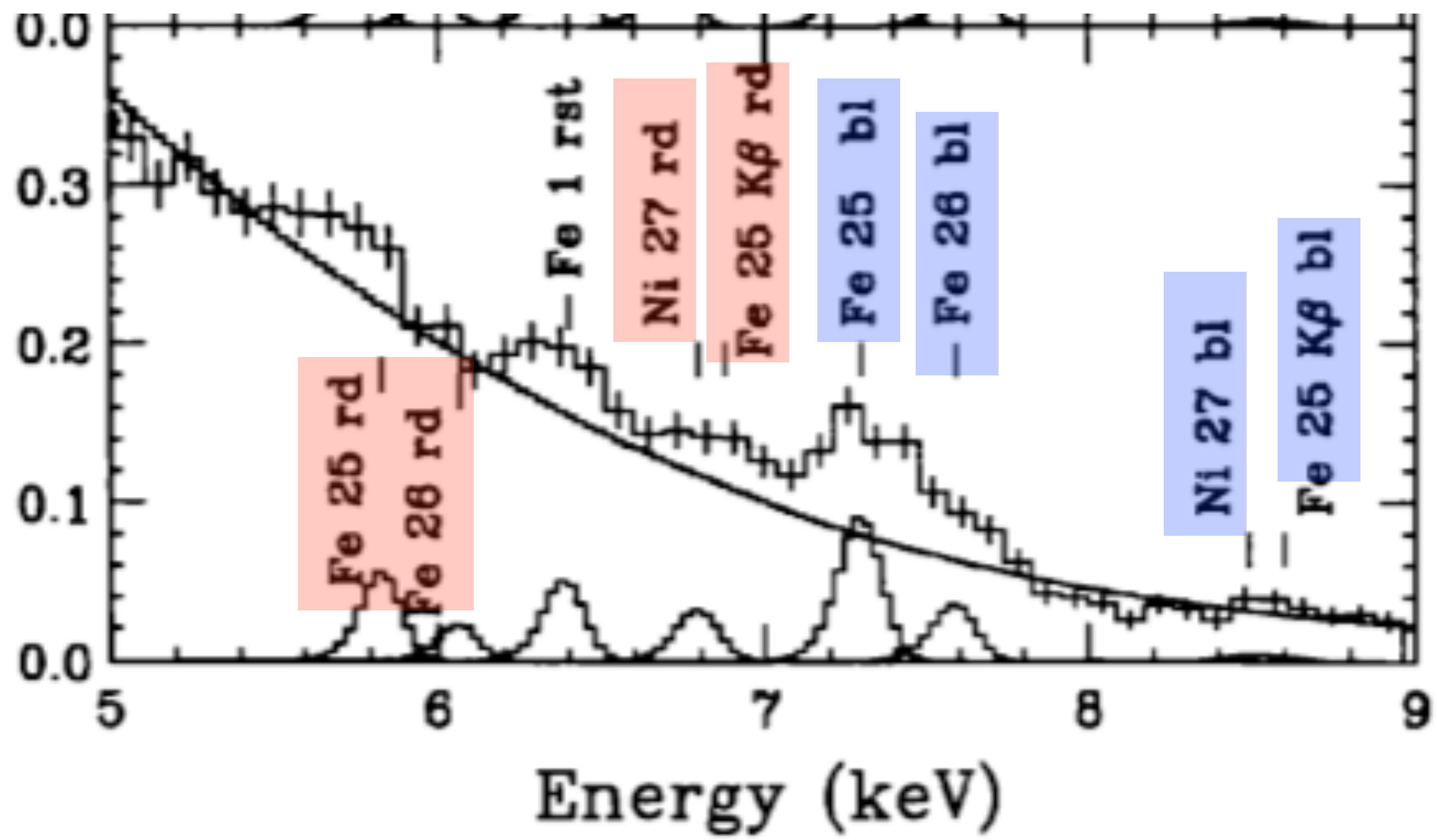
- Precessing *baryonic* jets.
- Blobs move outward at 0.27c.



Hidden beam
X rays from blue-shifted jet
accretion
disk (torus)
orbital plane
Companion
X rays from red-shifted jet
precession axis
shock in ISM
(non-thermal?
X-ray lobe)

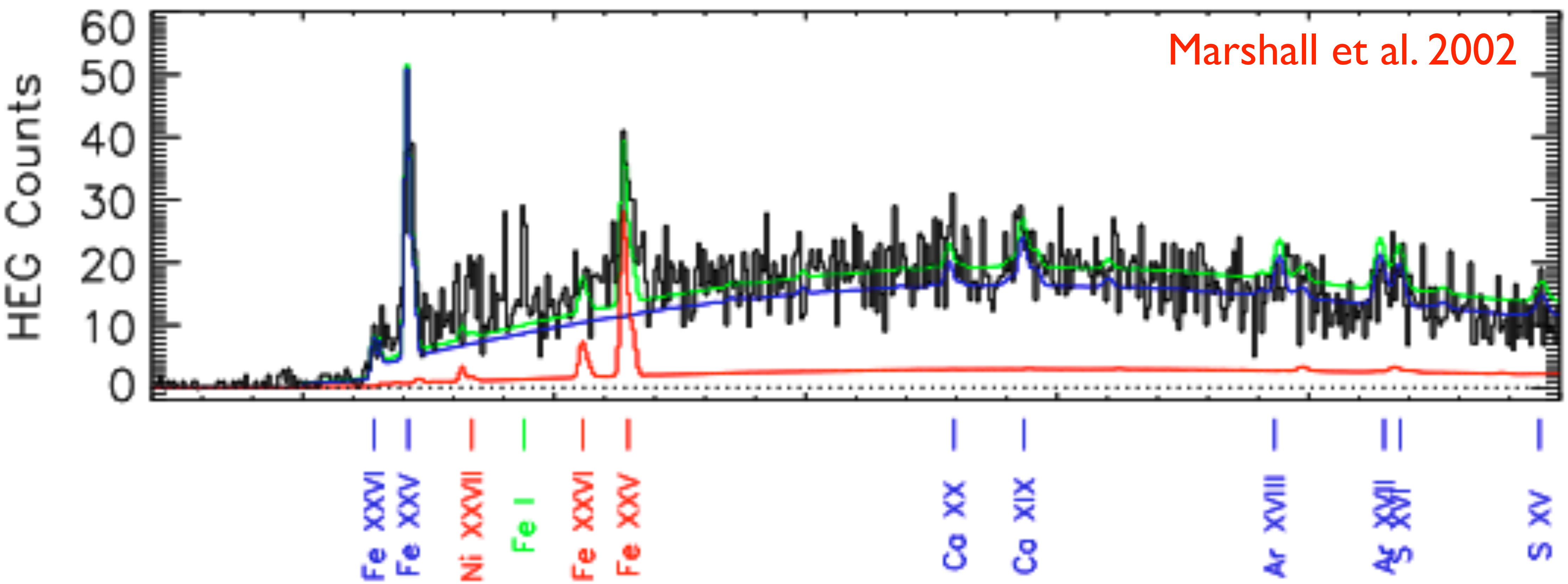
SS 433 with ASCA

Kotani et al. 1996



- CCD resolution blends the lines.
- Probably getting it right, but ambiguous.
- Very difficult to estimate T, density.

SS 433 with Chandra



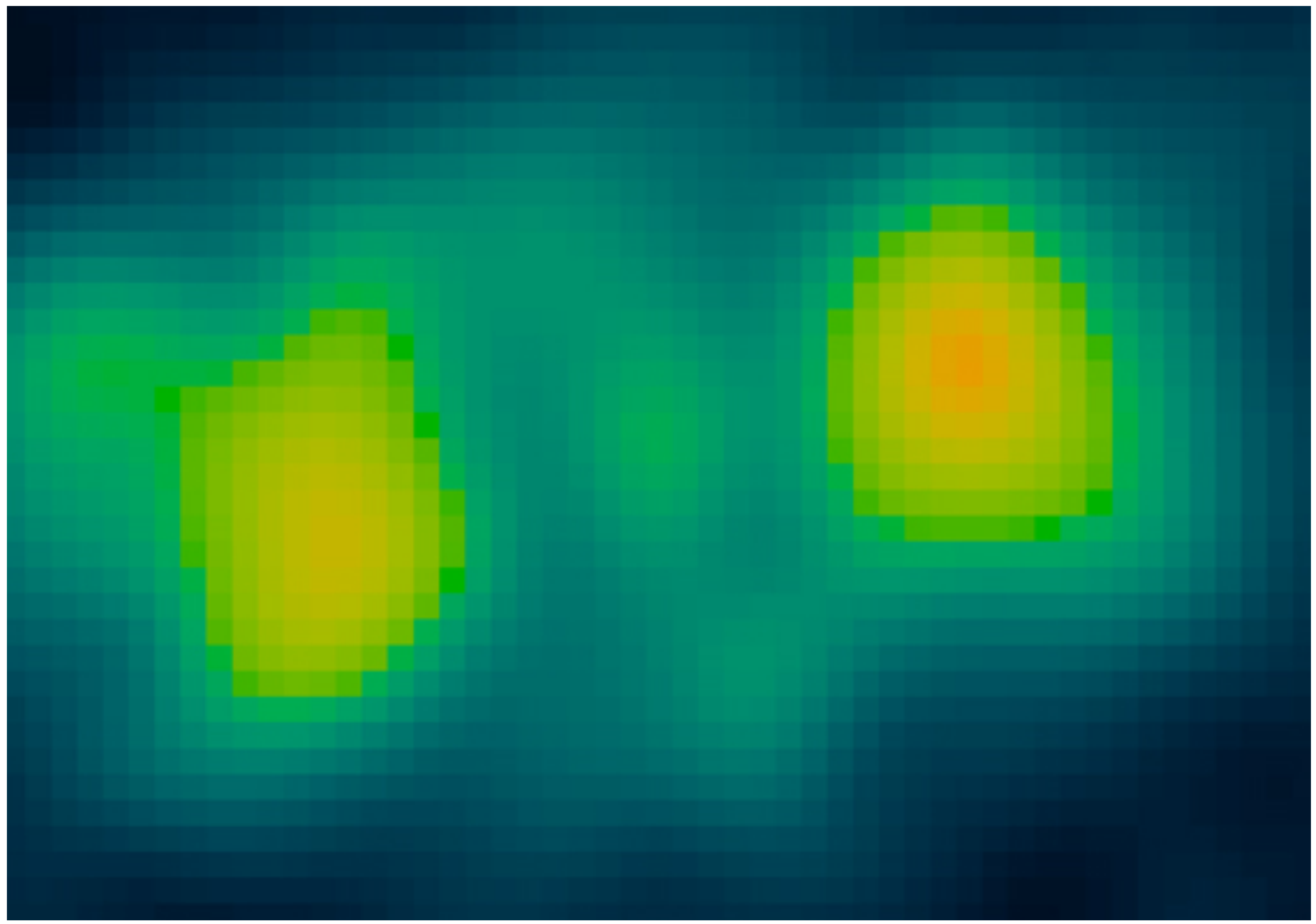
- Narrow lines are separated, sorted into red/blue jets.
- He-like triplets are readily detected -> T, density.

By the numbers...

Marshall et al. 2002

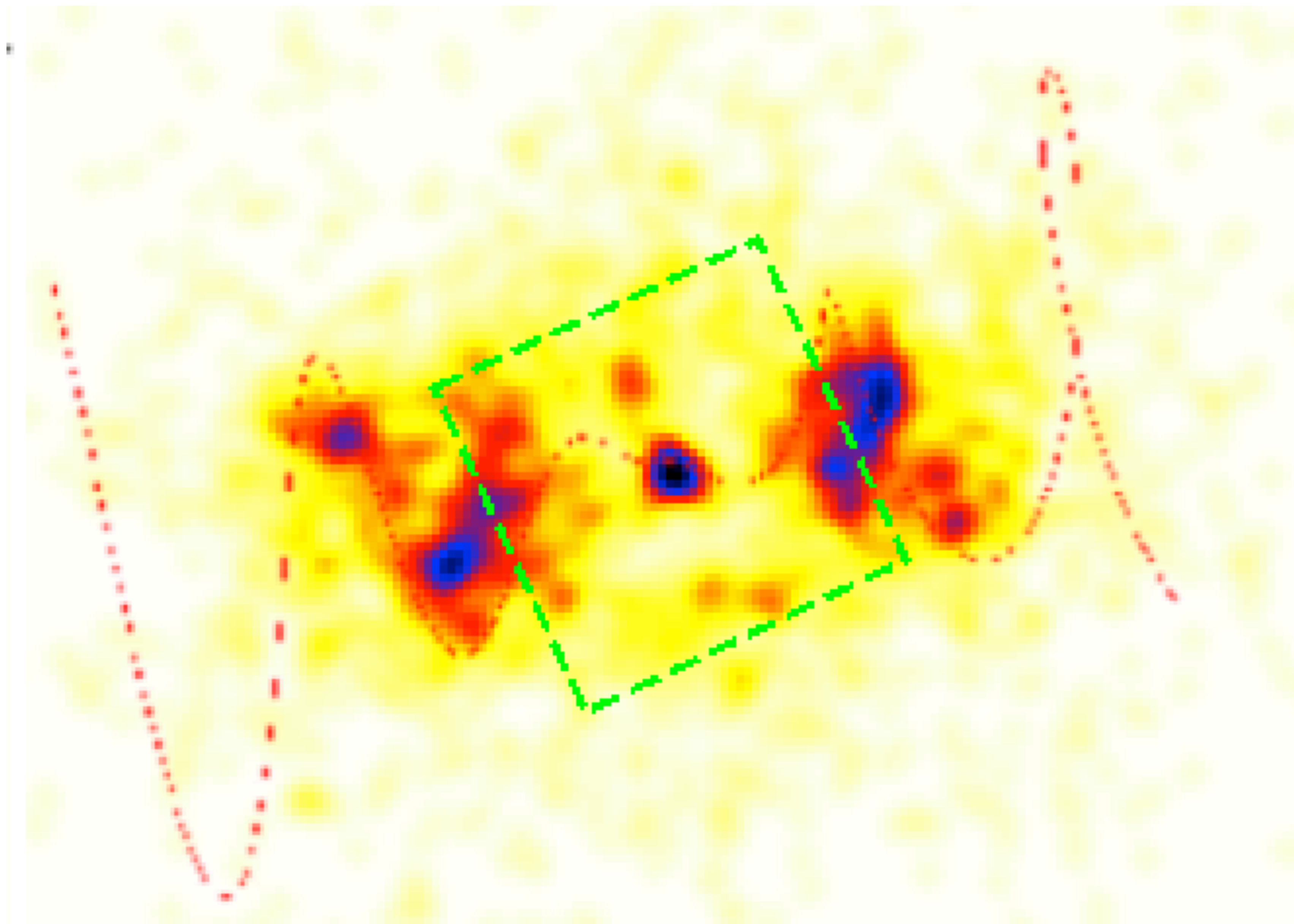
- $n = 10^{14}\ cm^{-3}$ (Si XIII He-like triplet).
- $T = 10^{5-8}$ K.
- v = 0.27c.
- M-dot_out = 10^{-7} Msun/yr.
- L_{kin} = ~~$3.0*10^{38}$ erg/s.~~ --> $1*10^{39}$ erg/s (Marshall et al. 2013)
- $L_{rad} \sim 3.0*10^{35}$ erg/s.

Chandra resolves SS 433



Migliari & Fender 2002

Now with edser ...



M. Reynolds, Miller, et al. 2015

Baryons in the relativistic jets of the stellar-mass black-hole candidate 4U 1630-47

María Díaz Trigo, James C. A. Miller-Jones, Simone Migliari, Jess W. Broderick & Tasso Tzioumis

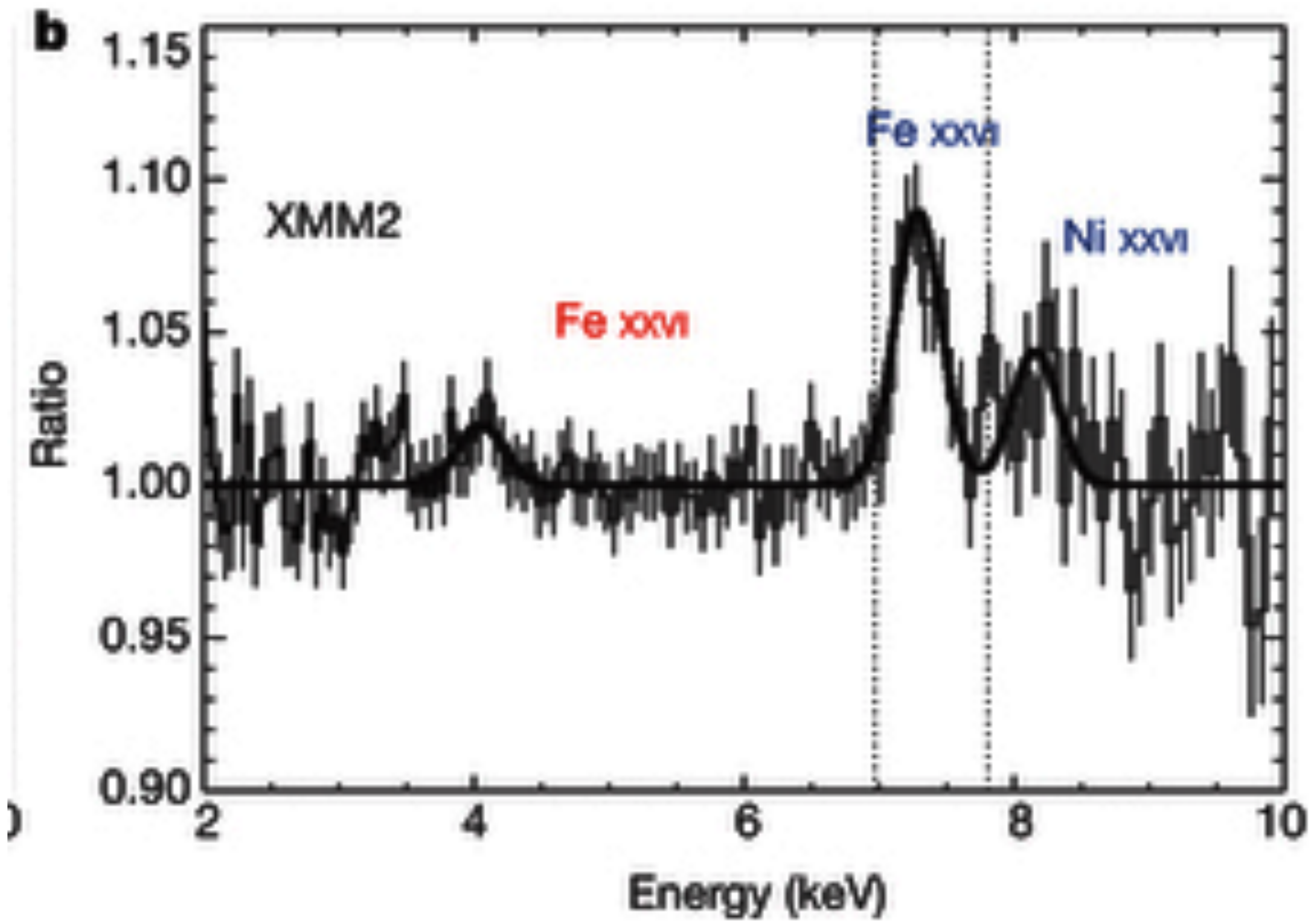
Affiliations | Contributions | Corresponding author

Nature **504**, 260–262 (12 December 2013) | doi:10.1038/nature12672
Received 01 May 2013 | Accepted 16 September 2013 | Published online 13 November 2013

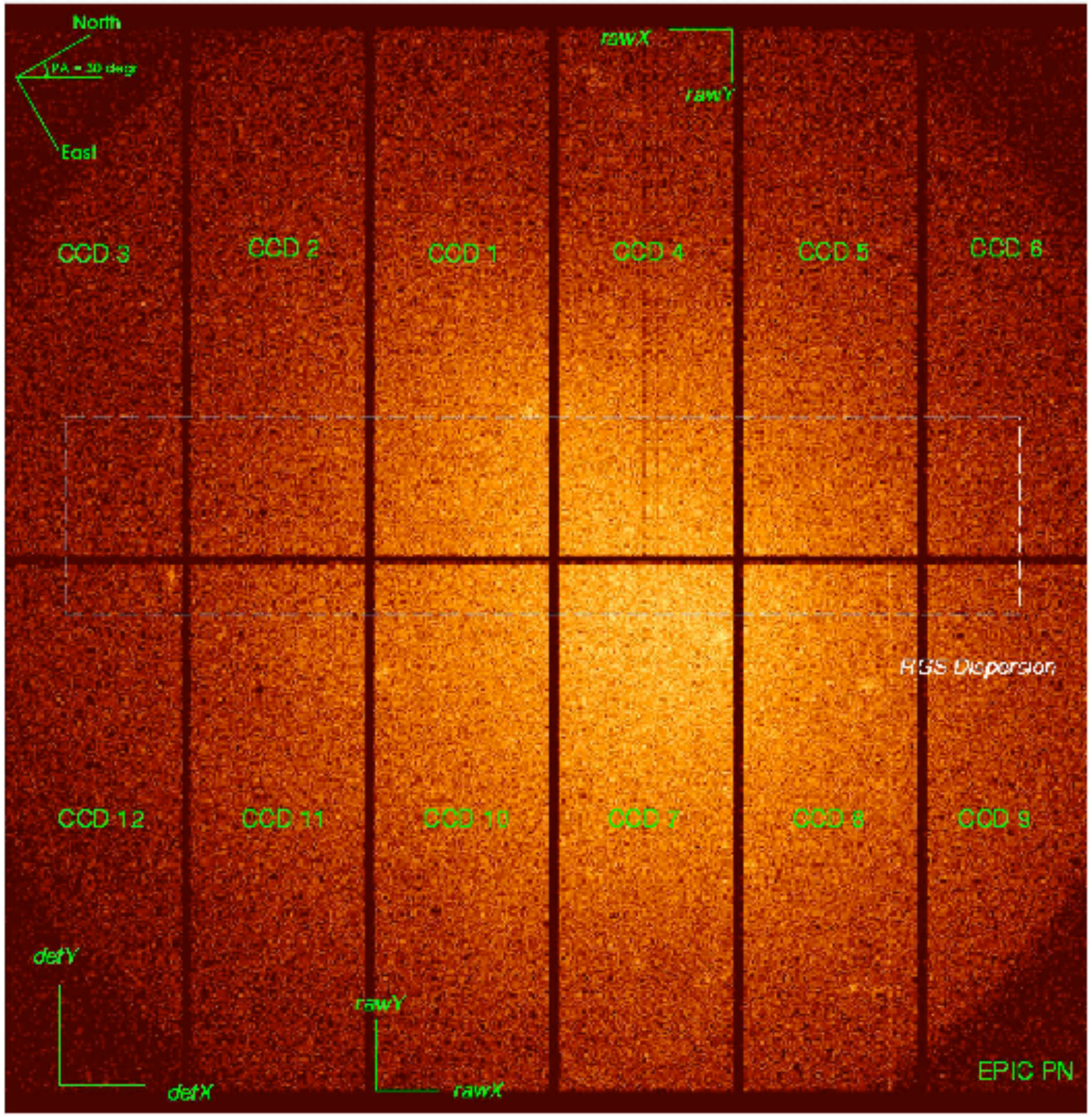
Citation | Reprints | Rights & permissions | Article metrics

Accreting black holes are known to power relativistic jets, both in stellar-mass binary systems and at the centres of galaxies. The power carried away by the jets, and, hence, the feedback they provide to their surroundings, depends strongly on their composition. Jets containing a baryonic component should carry significantly more energy than electron–positron jets. Energetic considerations[1, 2] and circular-polarization measurements[3] have provided conflicting circumstantial evidence for the presence or absence of baryons in jets, and the only system in which they have been unequivocally detected is the peculiar X-ray binary SS433 (refs 4, 5). Here we report the detection of Doppler-shifted X-ray emission lines from a more typical black-hole candidate X-ray binary, 4U 1630-47, coincident with the reappearance of radio emission from the jets of the source. We argue that these lines arise from baryonic matter in a jet travelling at approximately two-thirds the speed of light, thereby establishing the presence of baryons in the jet. Such baryonic jets are more likely to be powered by the accretion disk[6] than by the spin of the black hole[7], and if the baryons can be accelerated to relativistic speeds, the jets should be strong sources of γ-rays and neutrino emission.

Atomic lines [?]



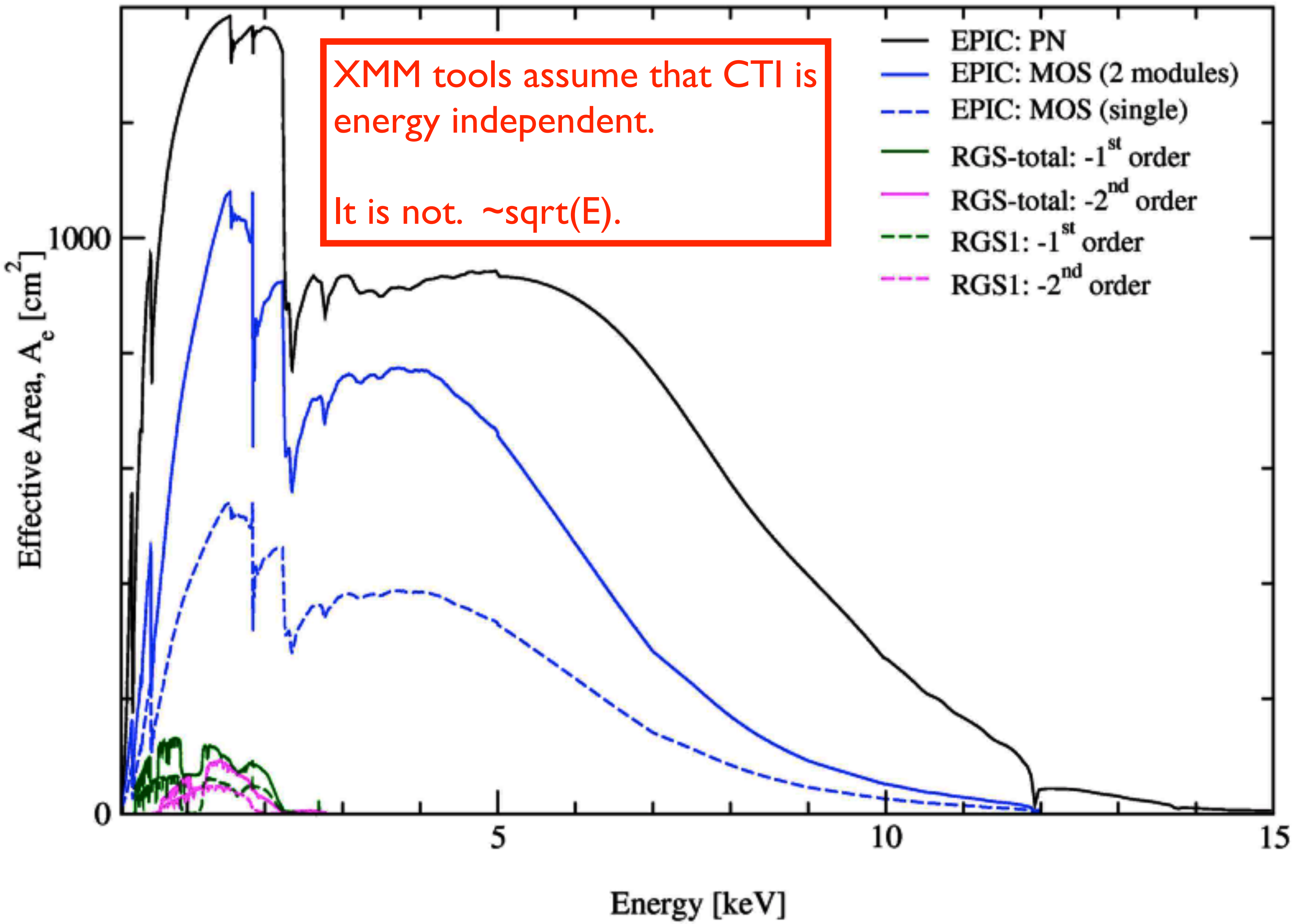
XMM EPIC-pn



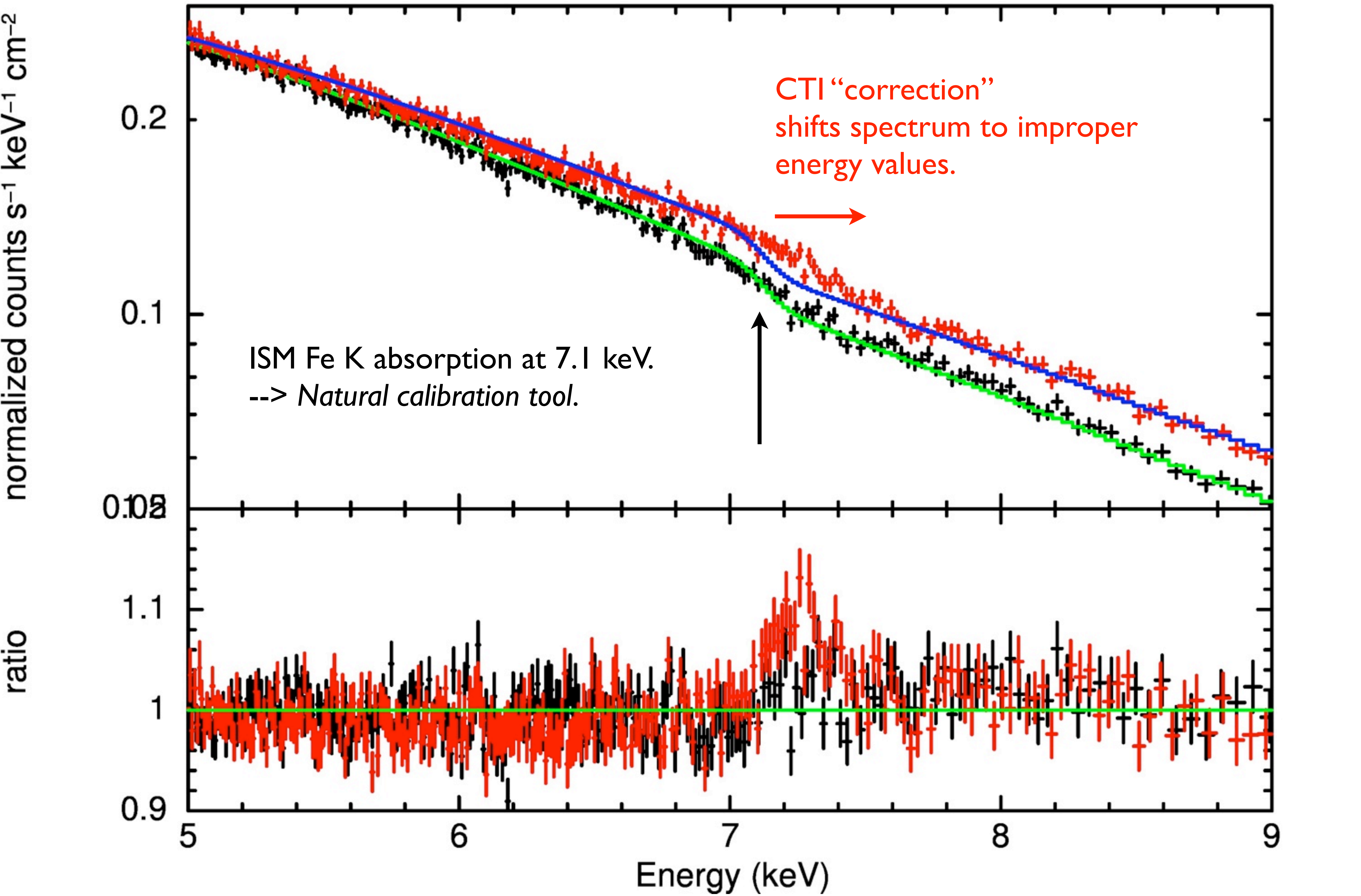
Charge-transfer inefficiency (CTI) occurs when charge gets trapped as it is clocked toward the read-out.

Registered energies are affected because only a fraction of the charge cloud is recorded.

XMM EPIC-pn

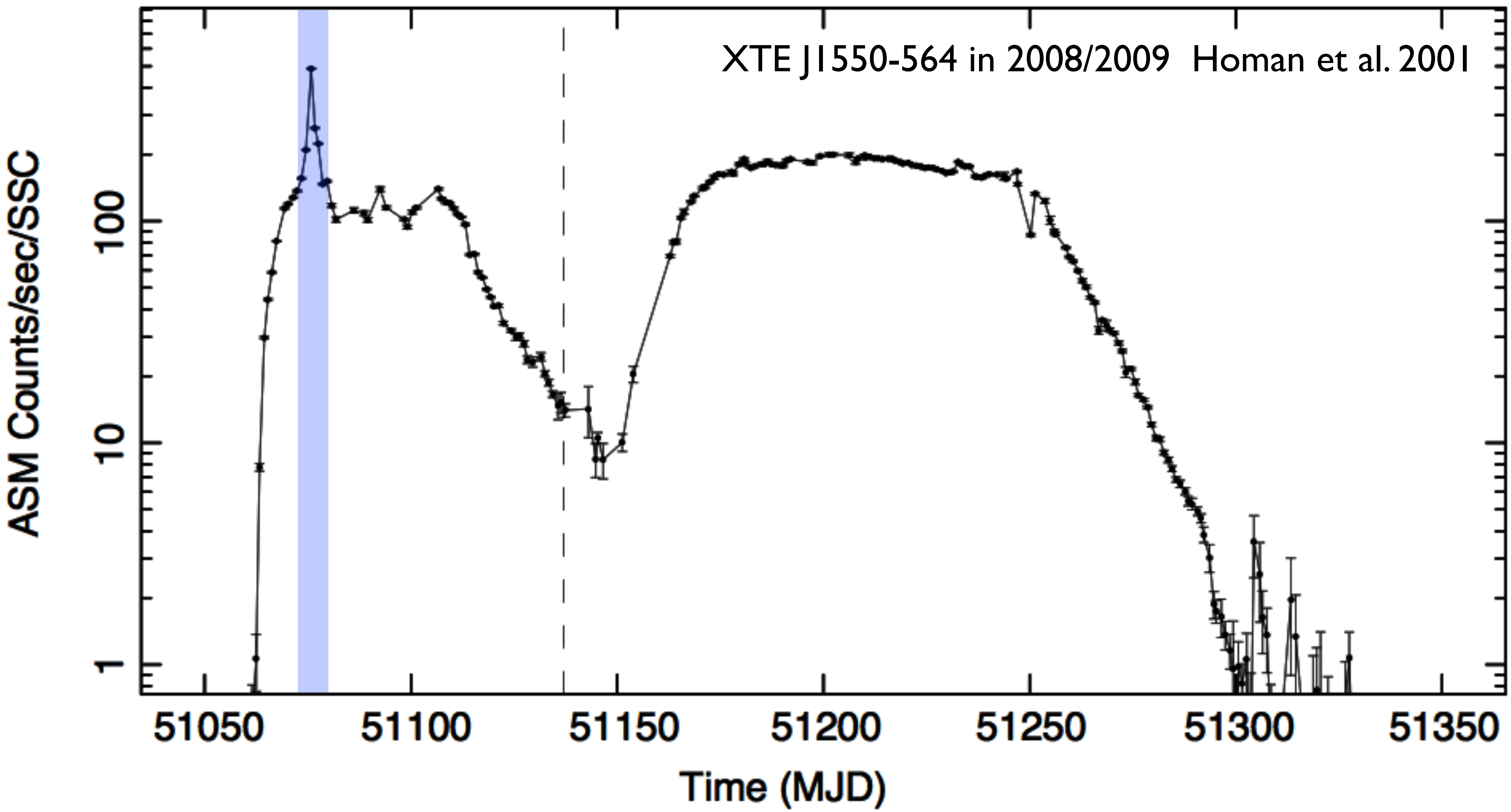


XMM tools assume that CTI is energy independent.
It is not. ~sqrt(E).
EPIC: PN
EPIC: MOS (2 modules)
EPIC: MOS (single)
RGS-total: -1st order
RGS-total: -2nd order
RGS1: -1st order
RGS1: -2nd order
1000
0
5
10
15
Effective Area, Ae [cm2]
Energy [keV]



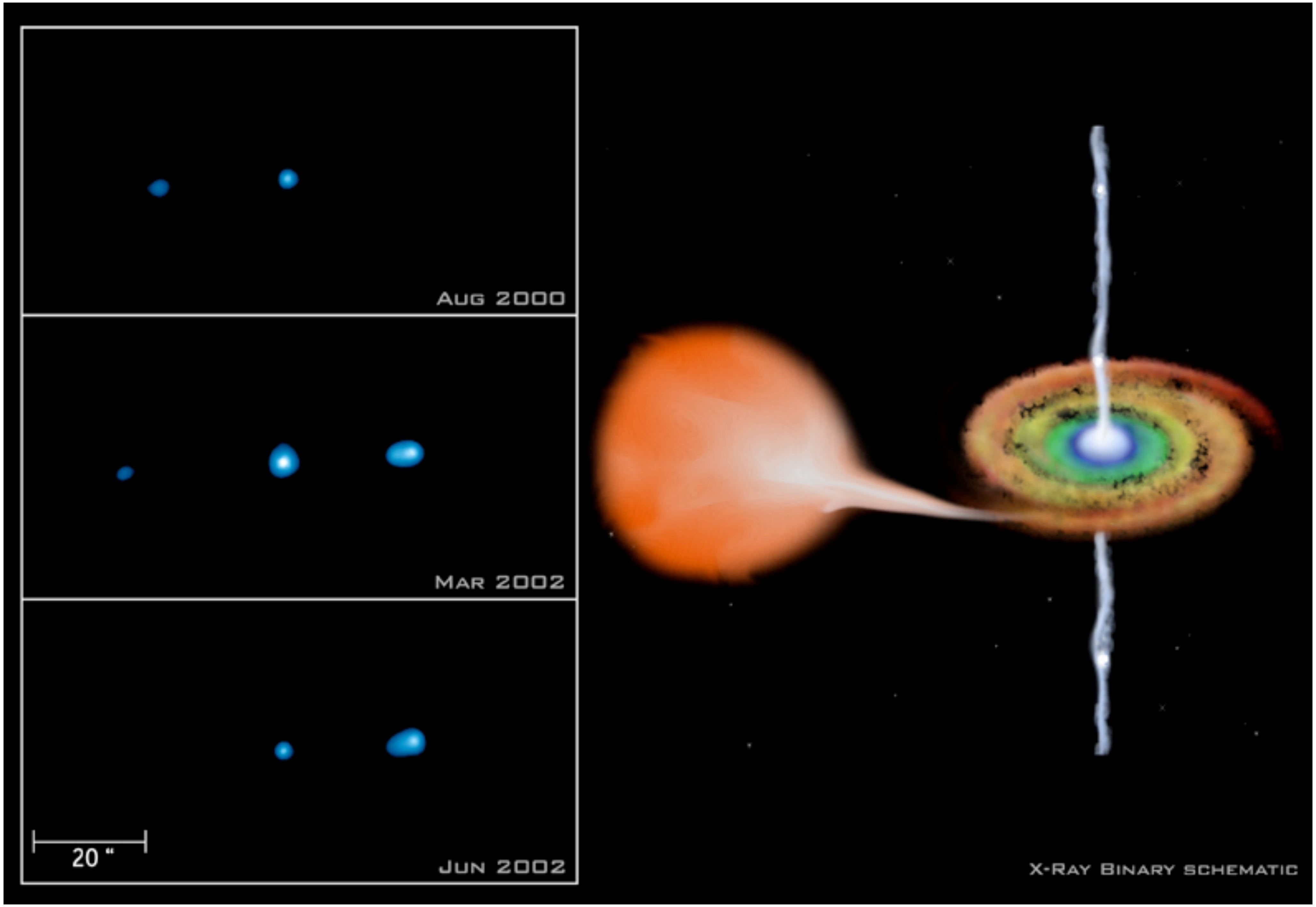
normalized counts s^{-1} keV^{-1} cm^{-2}
0.2
0.1
0.05
CTI "correction"
shifts spectrum to improper
energy values.
ISM Fe K absorption at 7.1 keV.
--> *Natural calibration tool.*
ratio
1.1
1
0.9
5
6
7
8
9
Energy (keV)

“Quasars for the impatient”



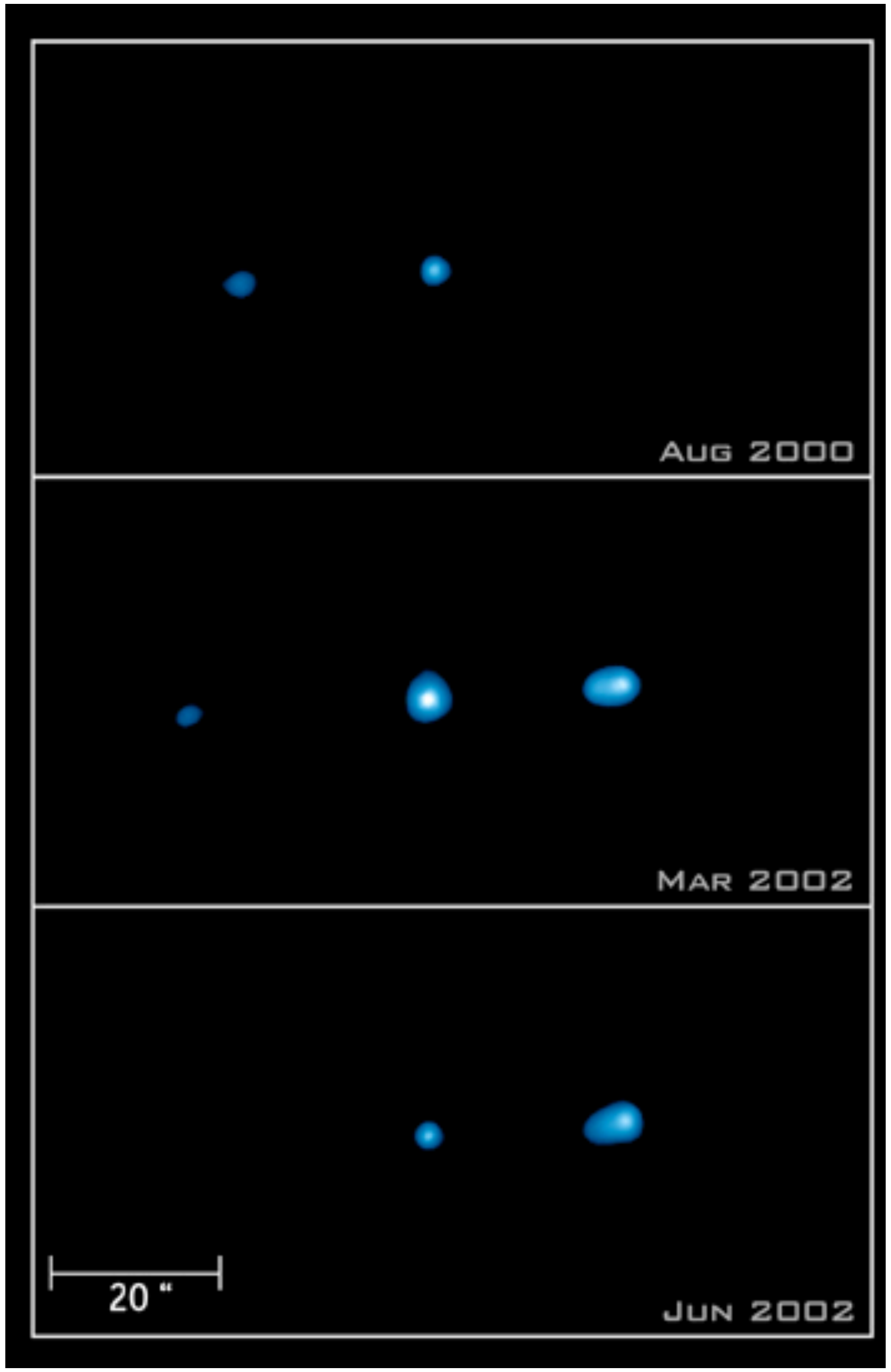
Cannonball Jets

Corbel et al, Tomsick et al., Kaaret et al. 2002



Cannonball Jets

Corbel et al, Tomsick et al., Kaaret et al. 2002



Shocks from swept-up ISM.

Requirements:
1) huge outburst
2) high inclination
3) sufficient ambient ISM

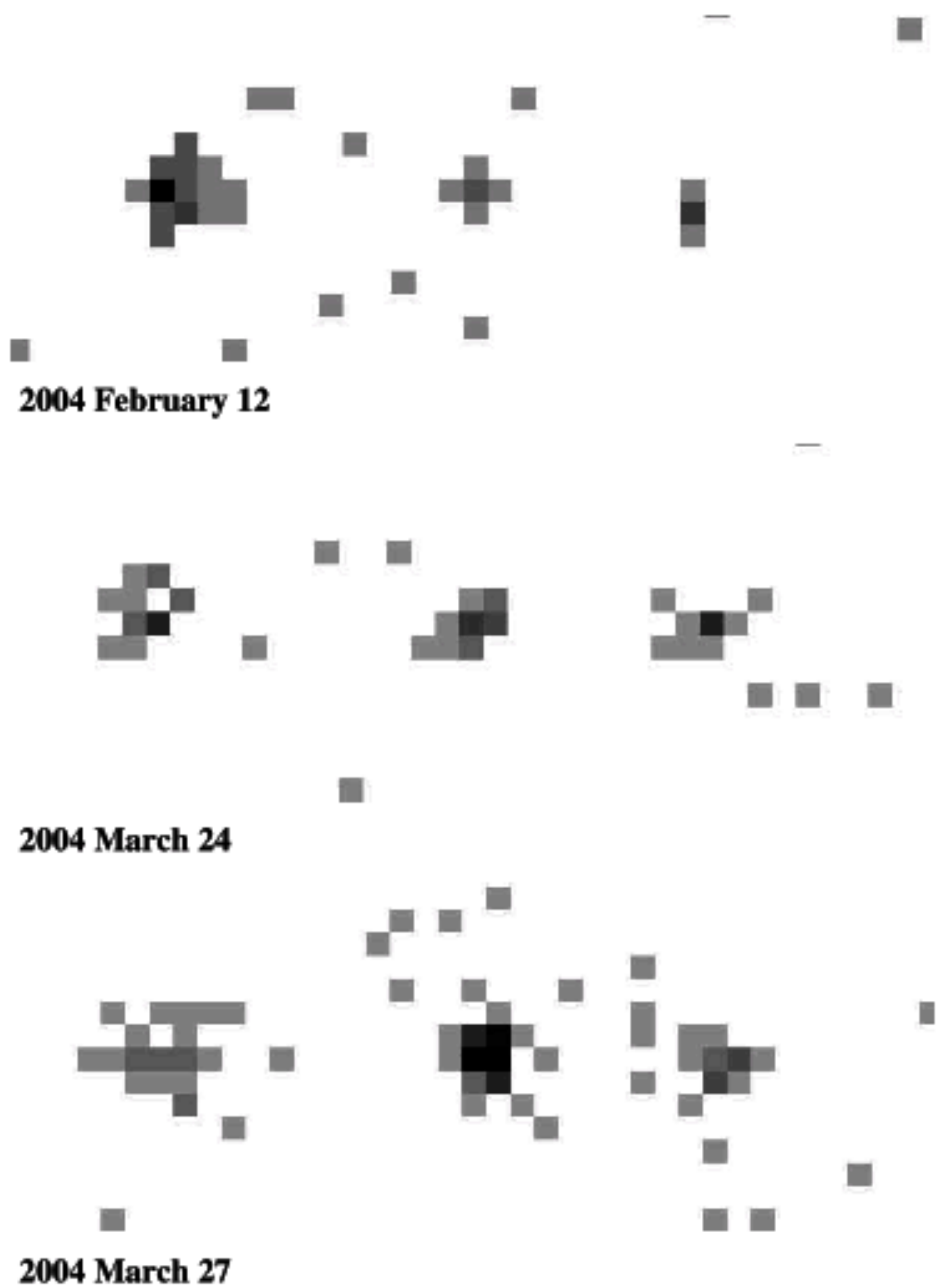
θ_{open}= 7 degrees

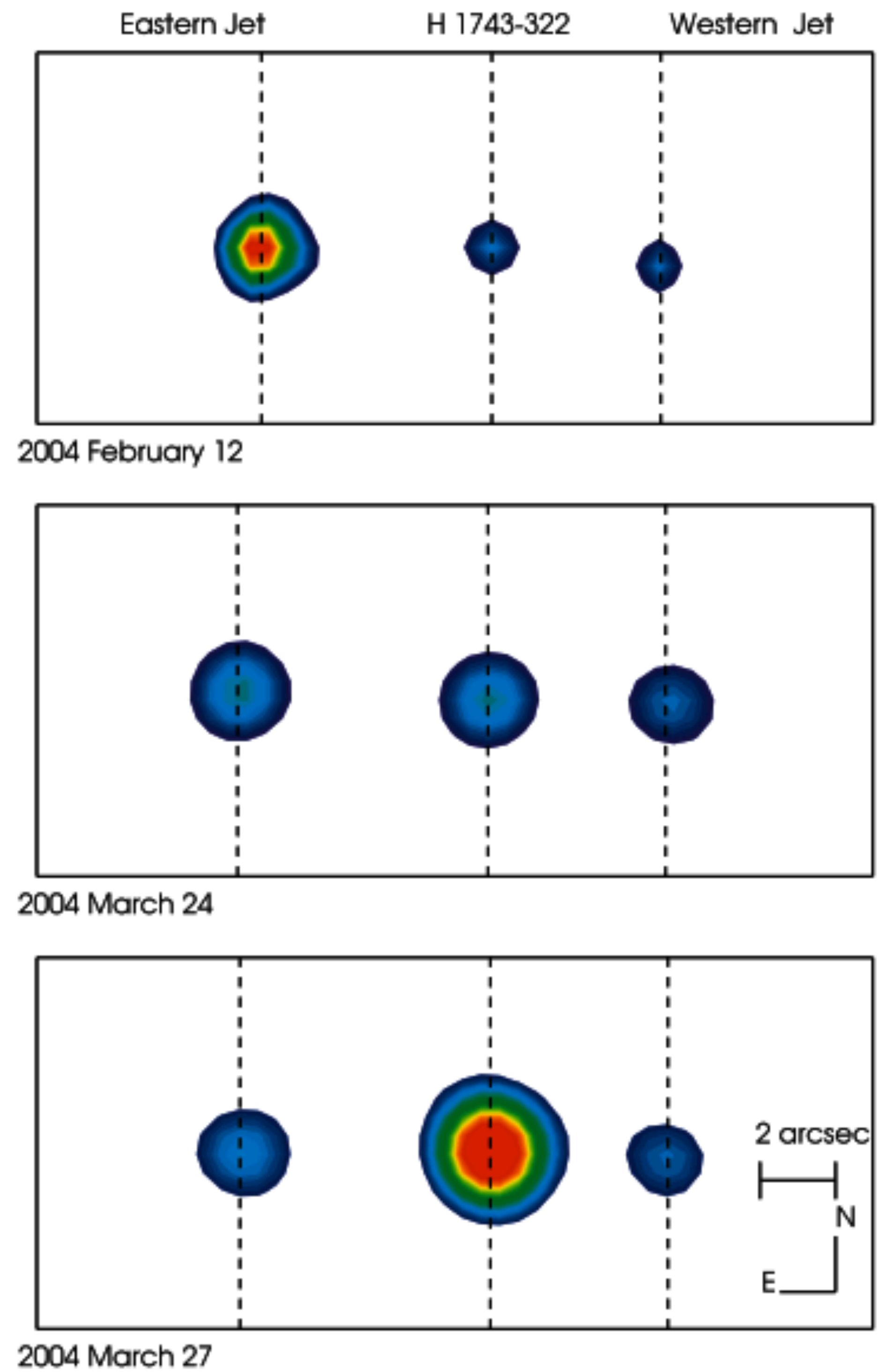
v/c = 0.93 (d = 7.6 kpc)

Collimated at 10^{12} GM/c^2
M87: 10^9 GM/c^2

H 1743-322

Corbel et al. 2005

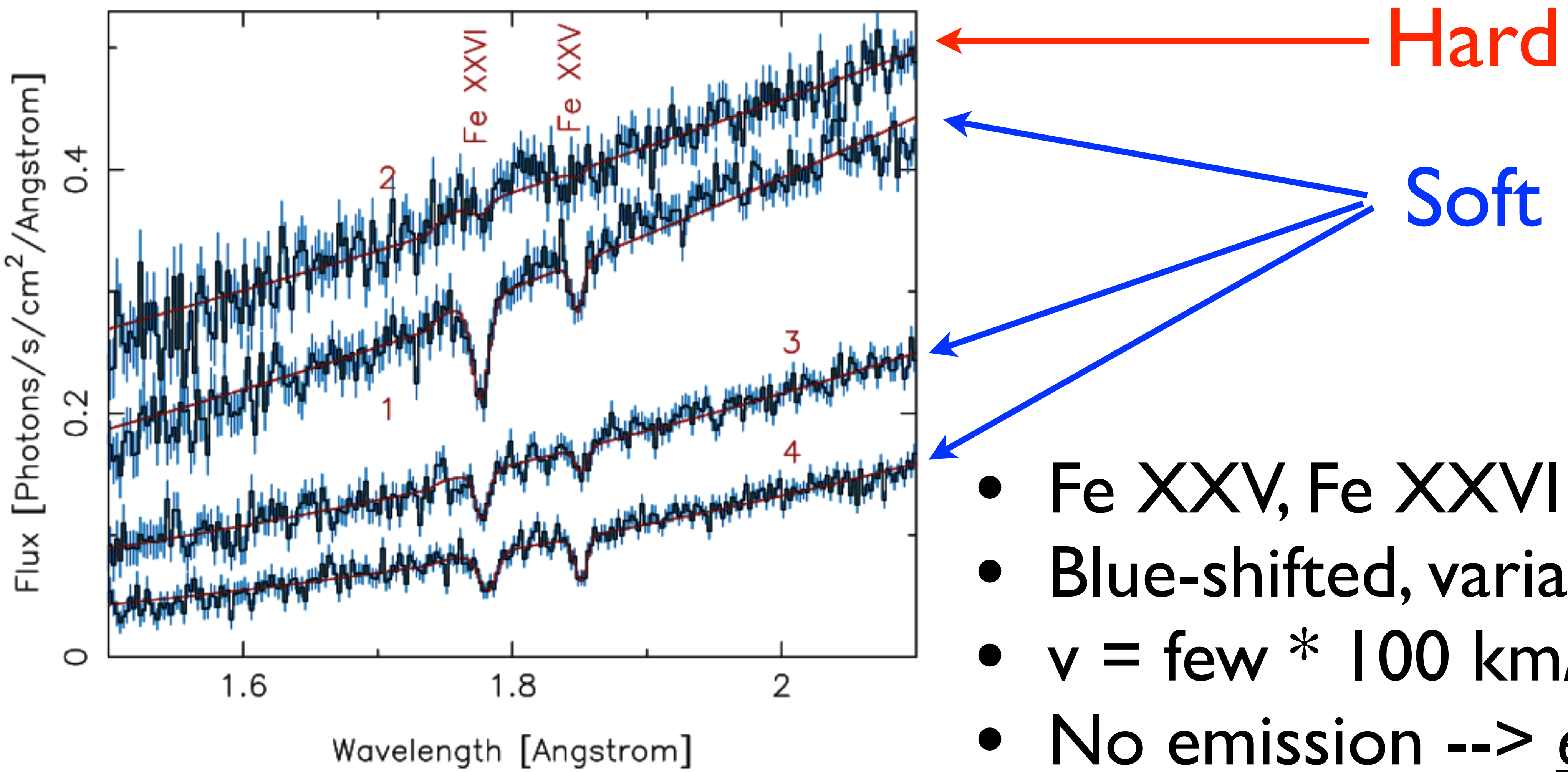




Winds

H 1743-322

Miller et al. 2006

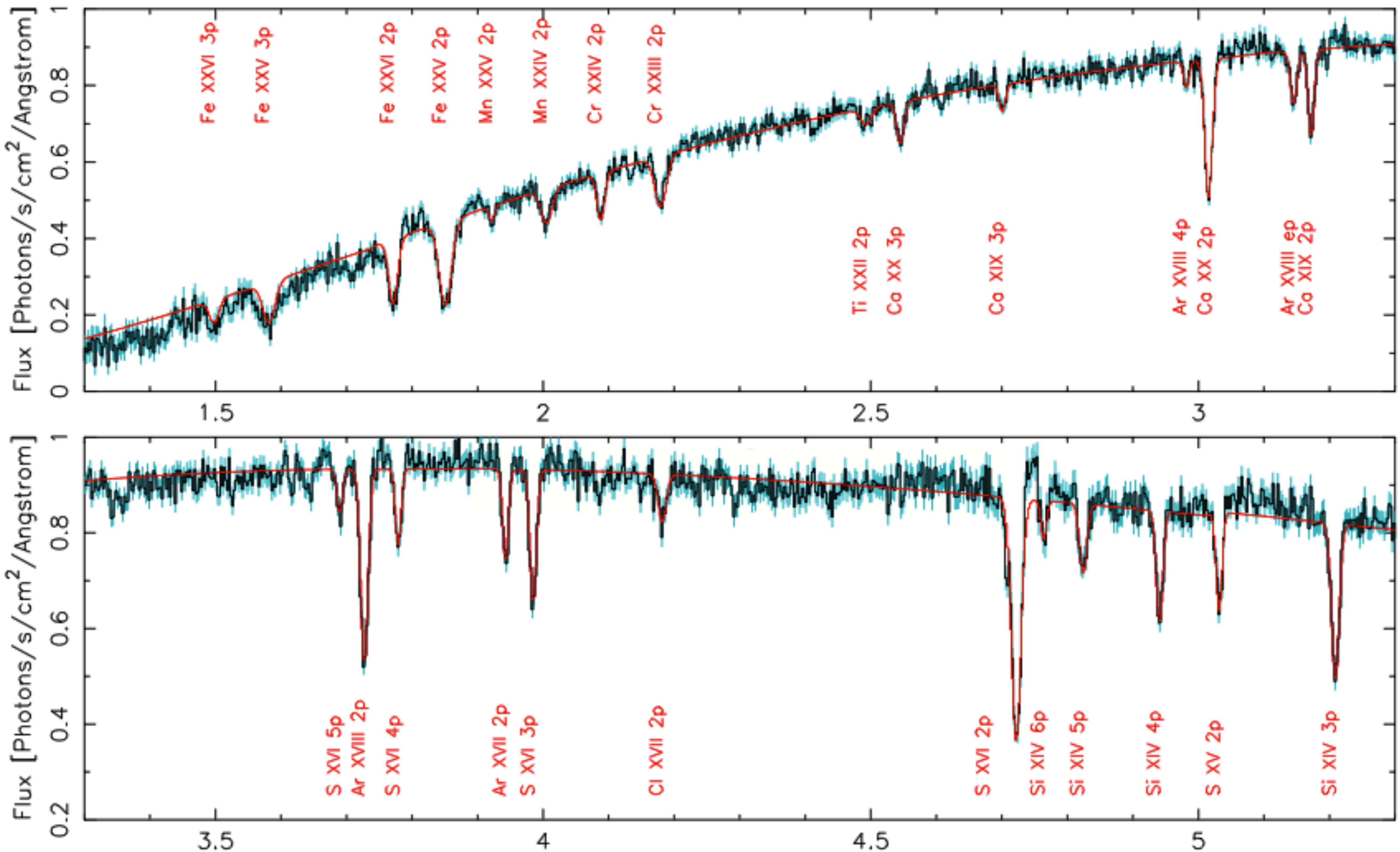


- Fe XXV, Fe XXVI absorption.
- Blue-shifted, variable.
- v = few * 100 km/s.
- No emission --> *equatorial.*
- Only present in disky states.

-> *Disk winds.*

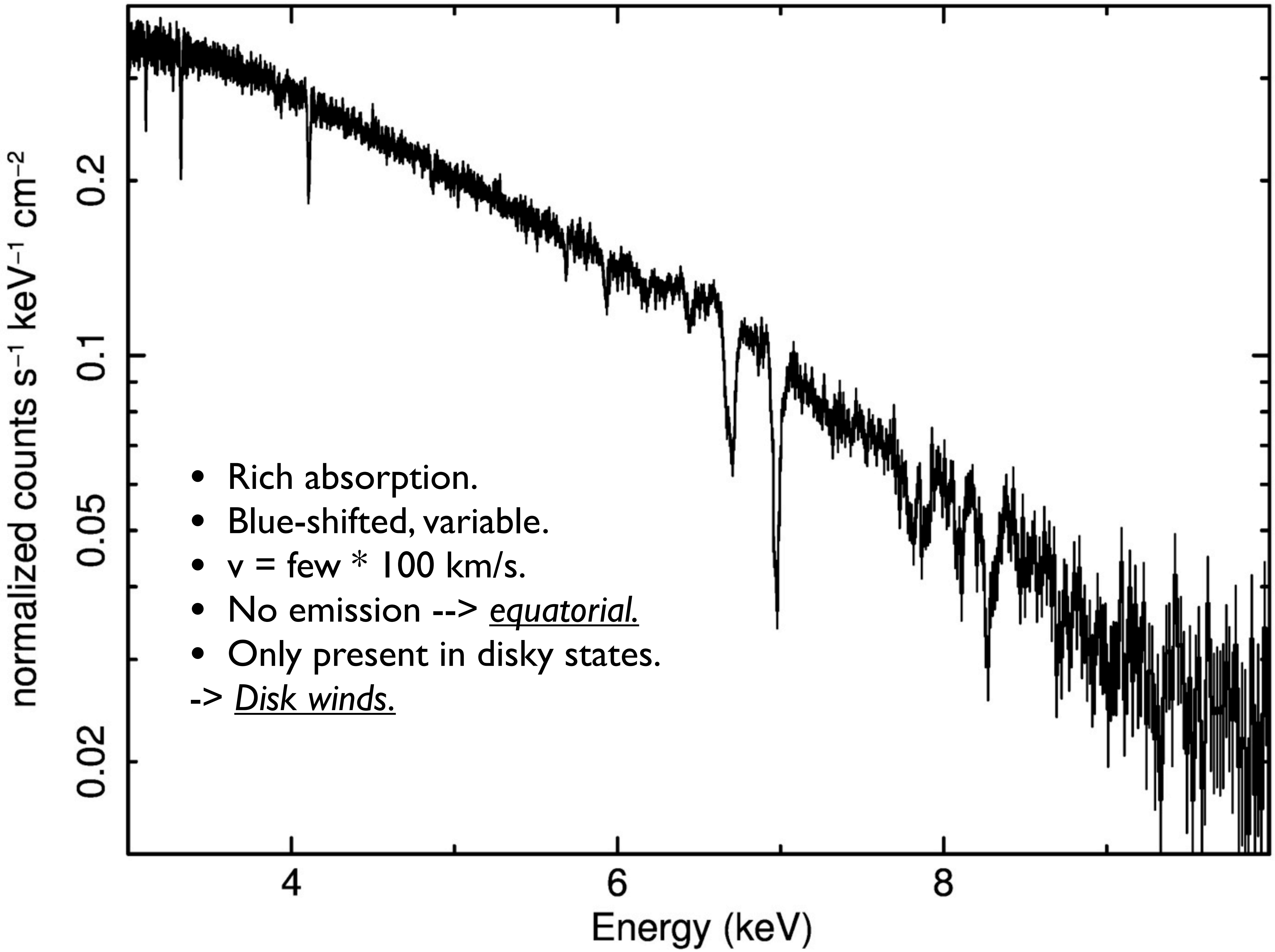
GRO J1655-40

Miller et al. 2006, 2008



GRS 1915+105

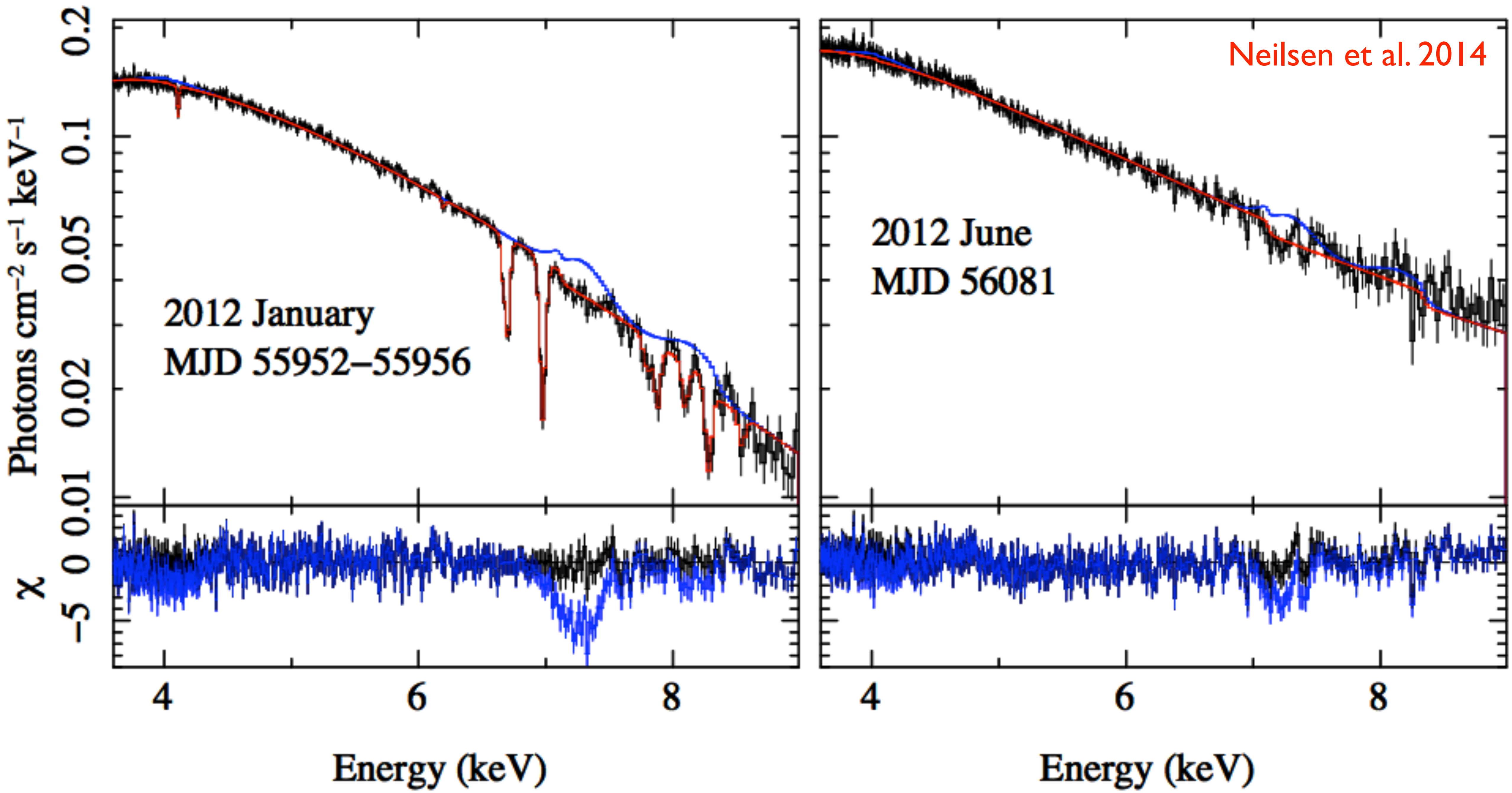
see Ueda et al. 2009



- Rich absorption.
- Blue-shifted, variable.
- v = few * 100 km/s.
- No emission --> *equatorial.*
- Only present in disky states.

-> *Disk winds.*

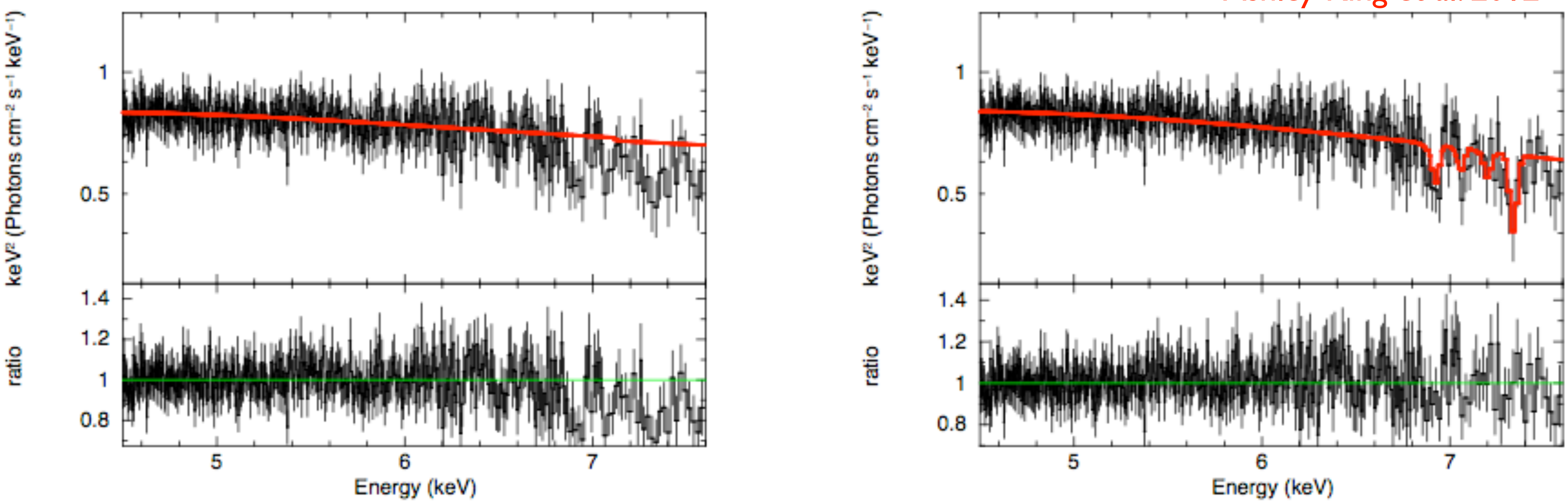
4U 1630-472



- Strong, variable, blue-shifted Fe XXV, XXVI lines.
- No jet emission in a phase similar to the XMM "detection."

IGR J17091-3624: UFOs

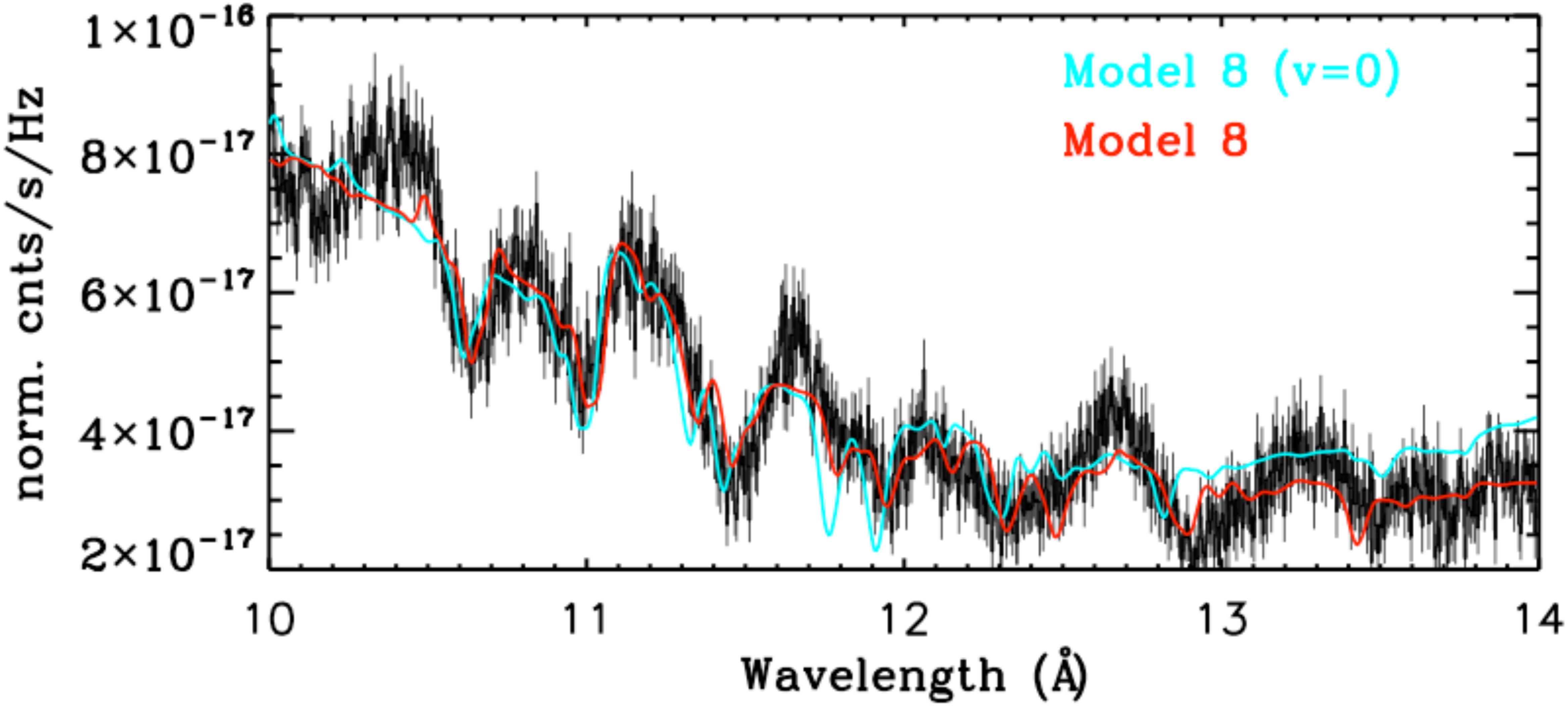
Ashley King et al. 2012



- Confident detections, 5σ. Unlike UFOs in Sy1s.
- Two-component UFO: v =10,000 km/s, 15,000 km/s.
- Commensurate with   r = 1000 GM/c^2.
- *Perhaps an micro-BALQSO, except* log (ξ) > 3.

MAXI J1305-704: Failed Wind ?

Miller et al. 2013



- Density-sensitive Fe XX, XXI, XXII lines detected.
- Photoionization modeling (XSTAR): r ~ 500 GM/c^2 (4000 km).
- z_1 = 0.003 ~ redshift for gas in Keplerian orbits at 500 GM/c^2.
- z_2 = 0.05 ~ redshift for gas in free-fall at 500 GM/c^2.

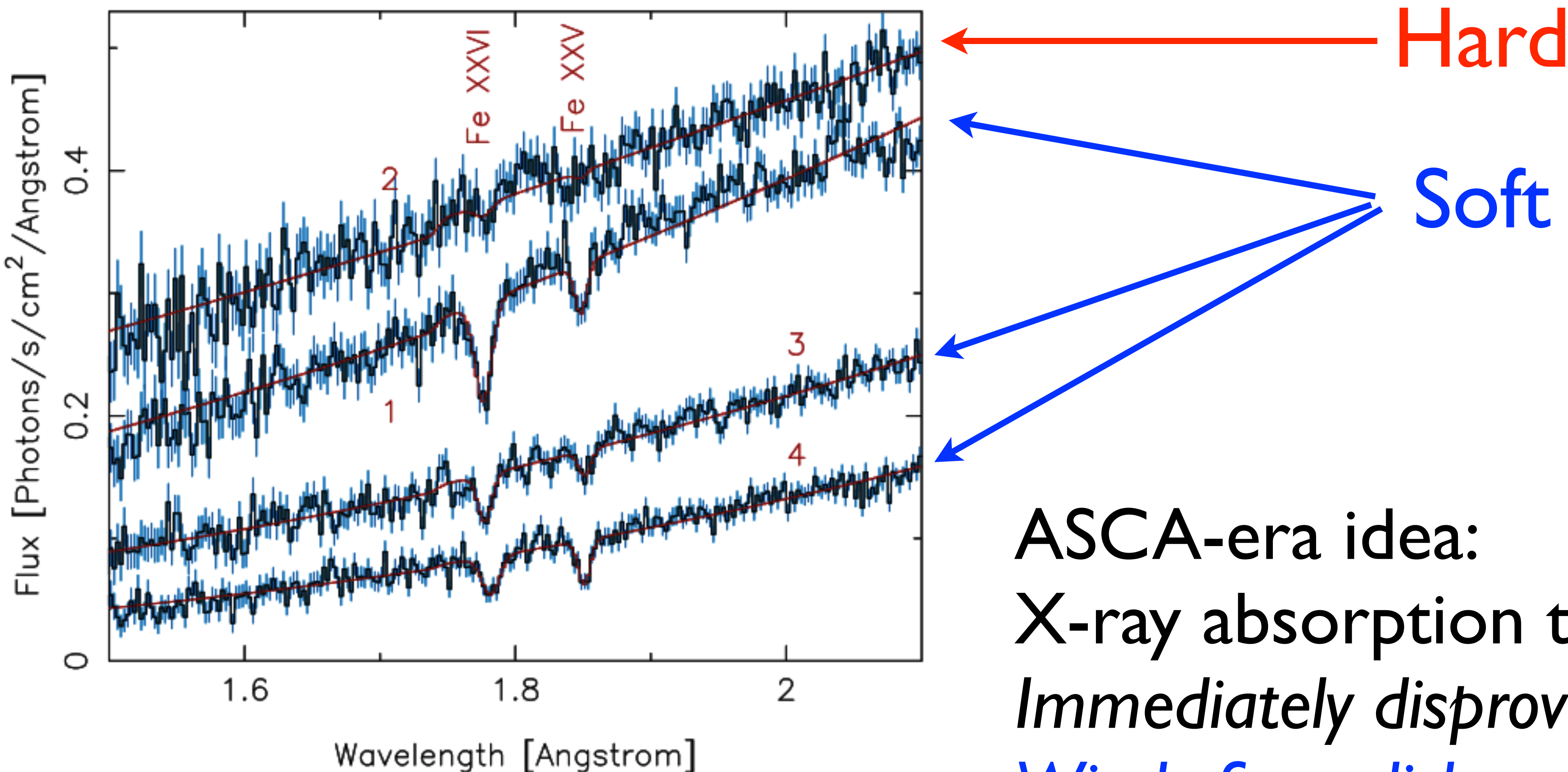
Implications

- Stellar mass black hole winds have broadly similar gas/photionization properties (N, ξ, v).
- *The mass loss rate is 10-100+ % of the accretion rate.*
- And, the losses occur in the highest- M-dot state.
- Binary evolution models that assume conservative mass transfer are wrong.
- Winds might have an important relationship with the basic process of disk accretion.

Winds and Jets

H 1743-322

Miller et al. 2006



ASCA-era idea:

X-ray absorption tied to jets.

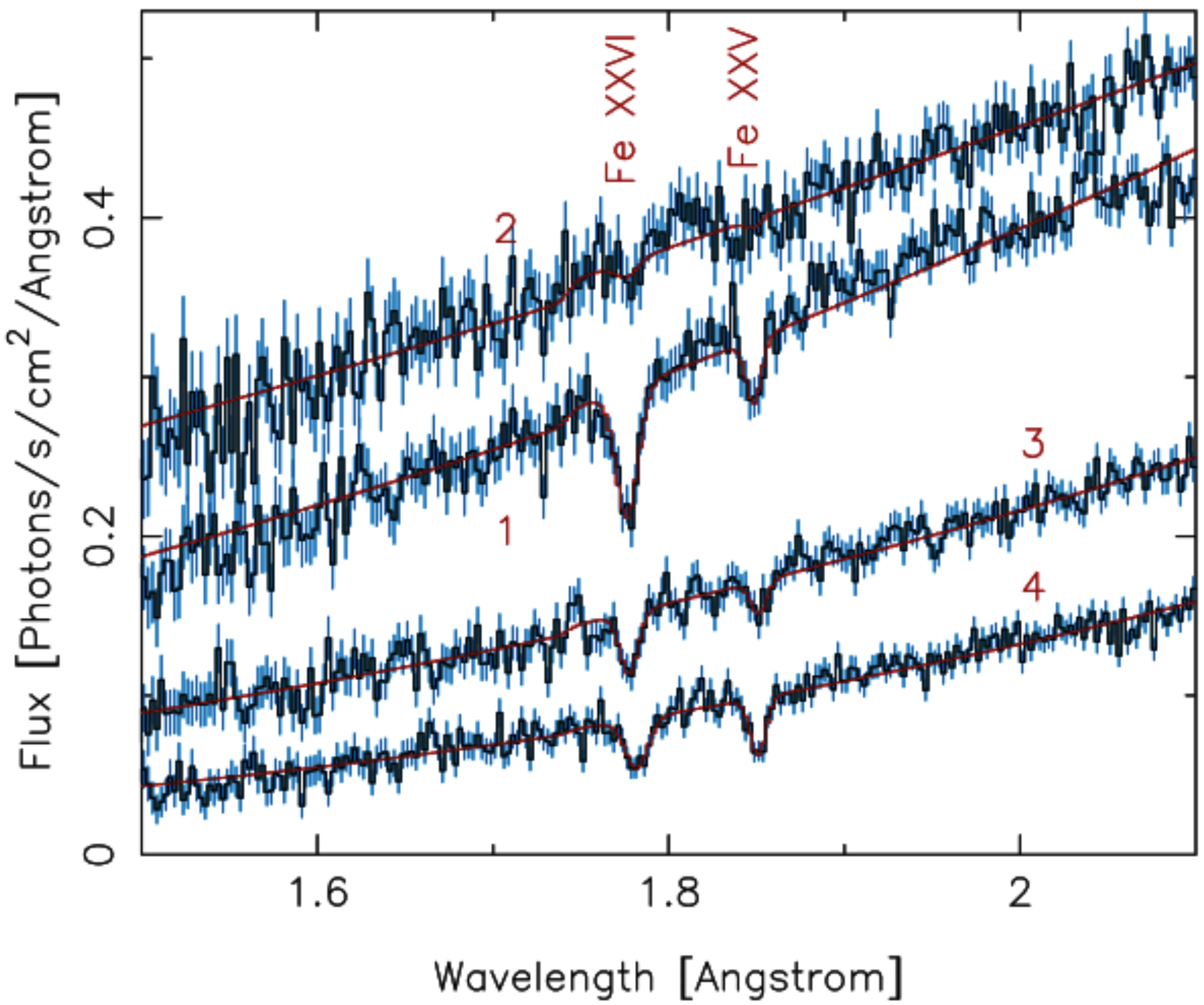
Immediately disproved.

Winds from disk states.

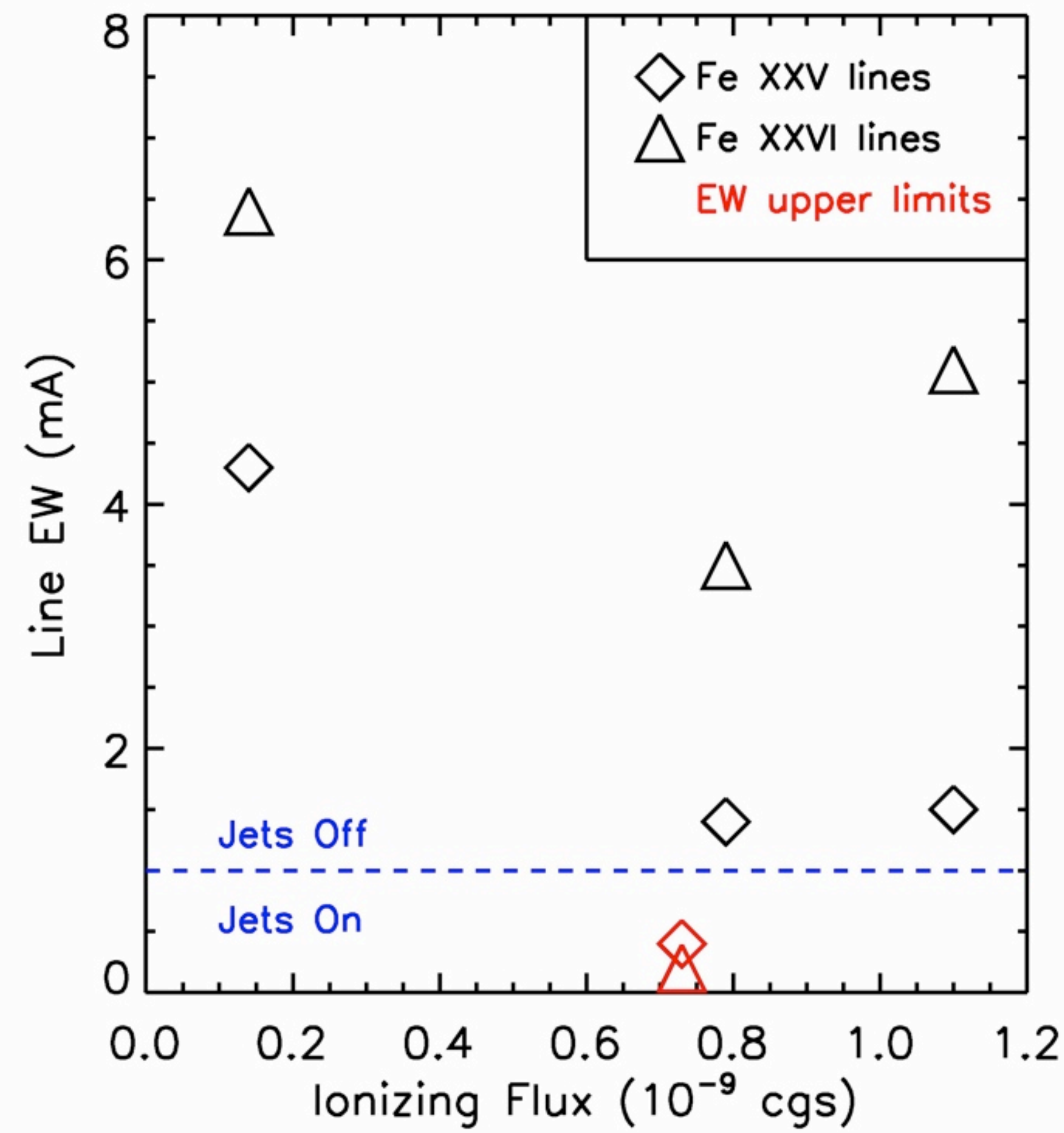
Jets from hard coronal states.

Winds or jets, not both

Miller et al. 2006



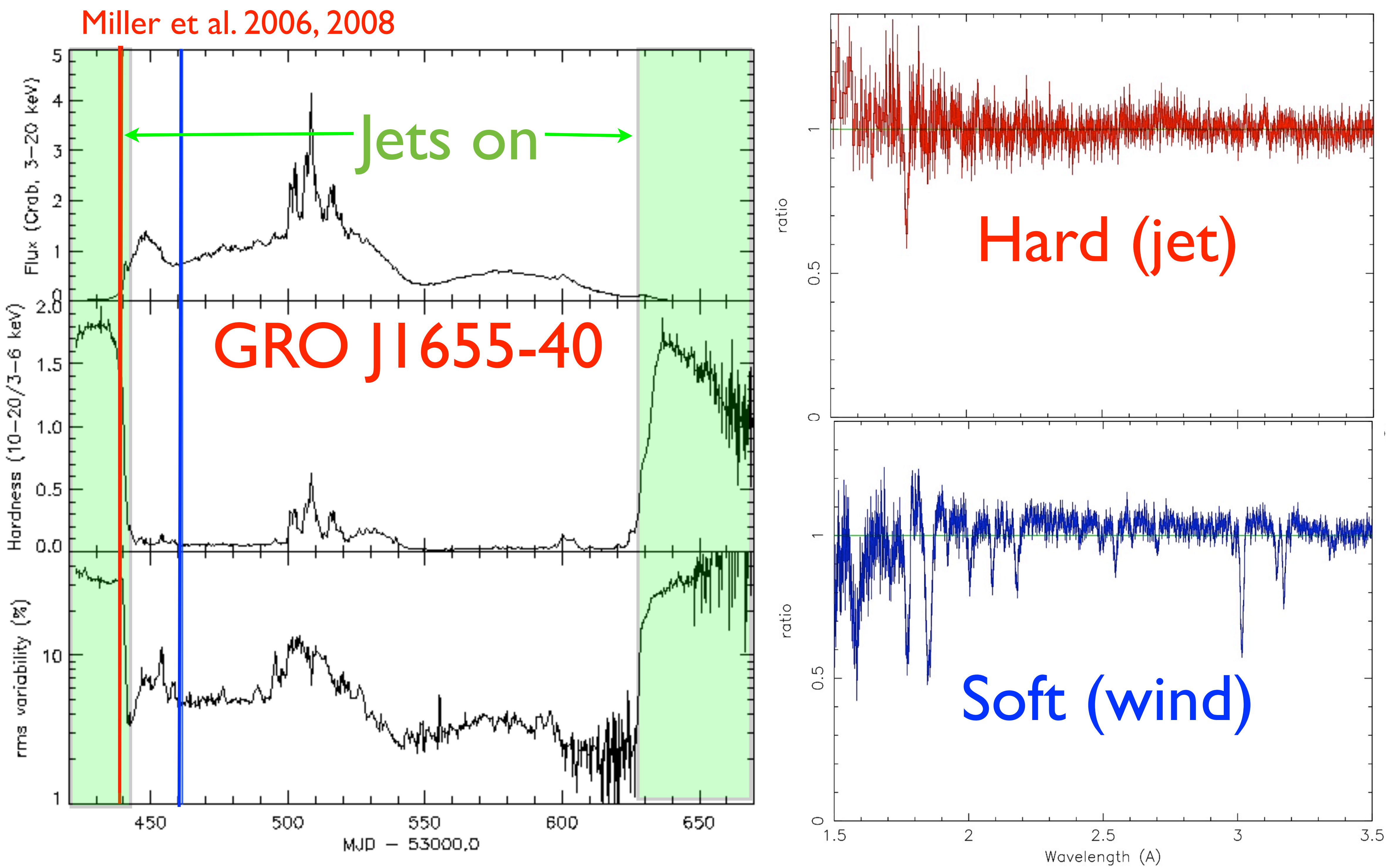
Miller et al. 2012



Winds really shut off,
not an ionization effect.

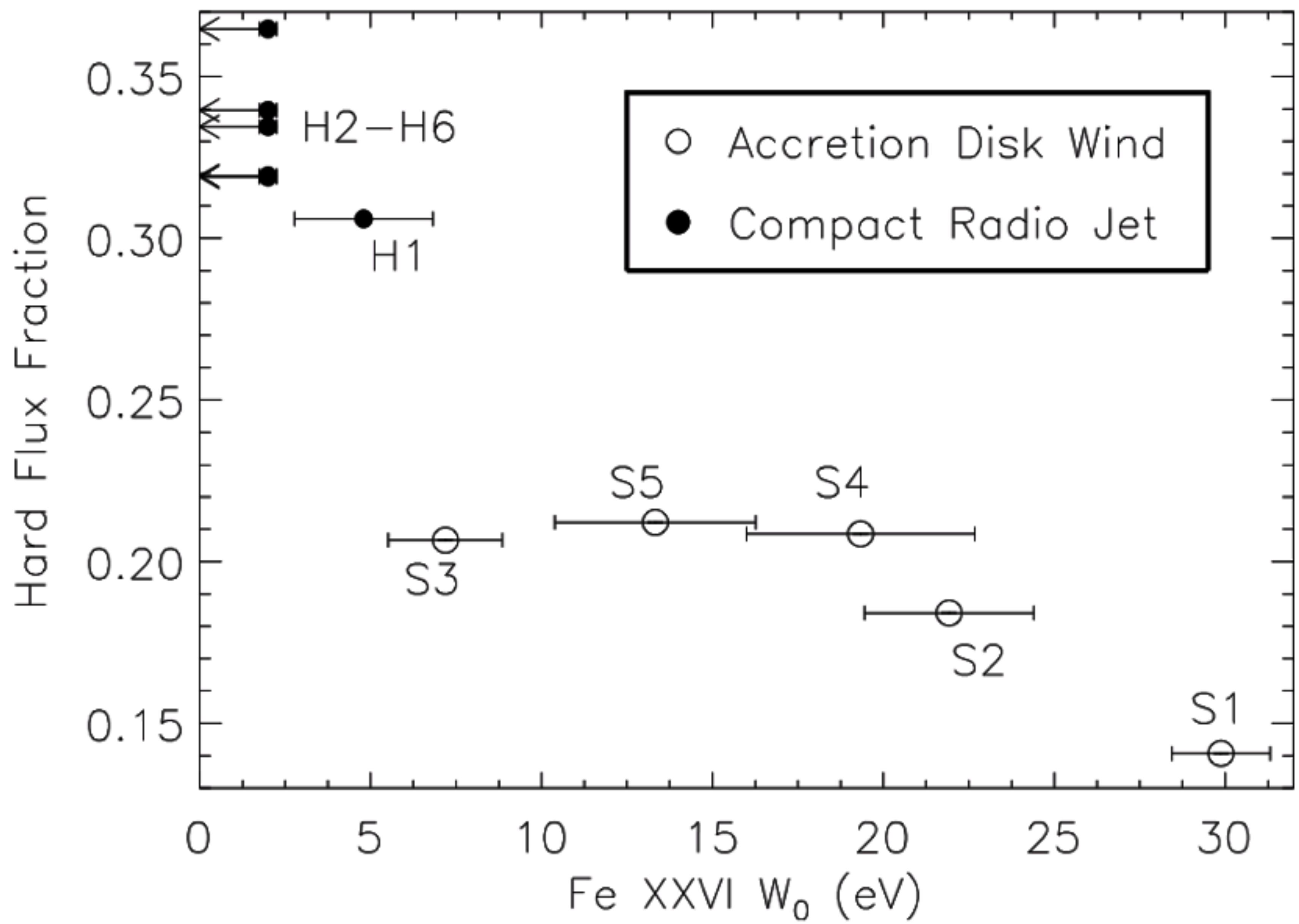
Winds or jets, not both

Does the disk flip its outflow mode? Toroidal/Poloidal B?



GRS 1915+105

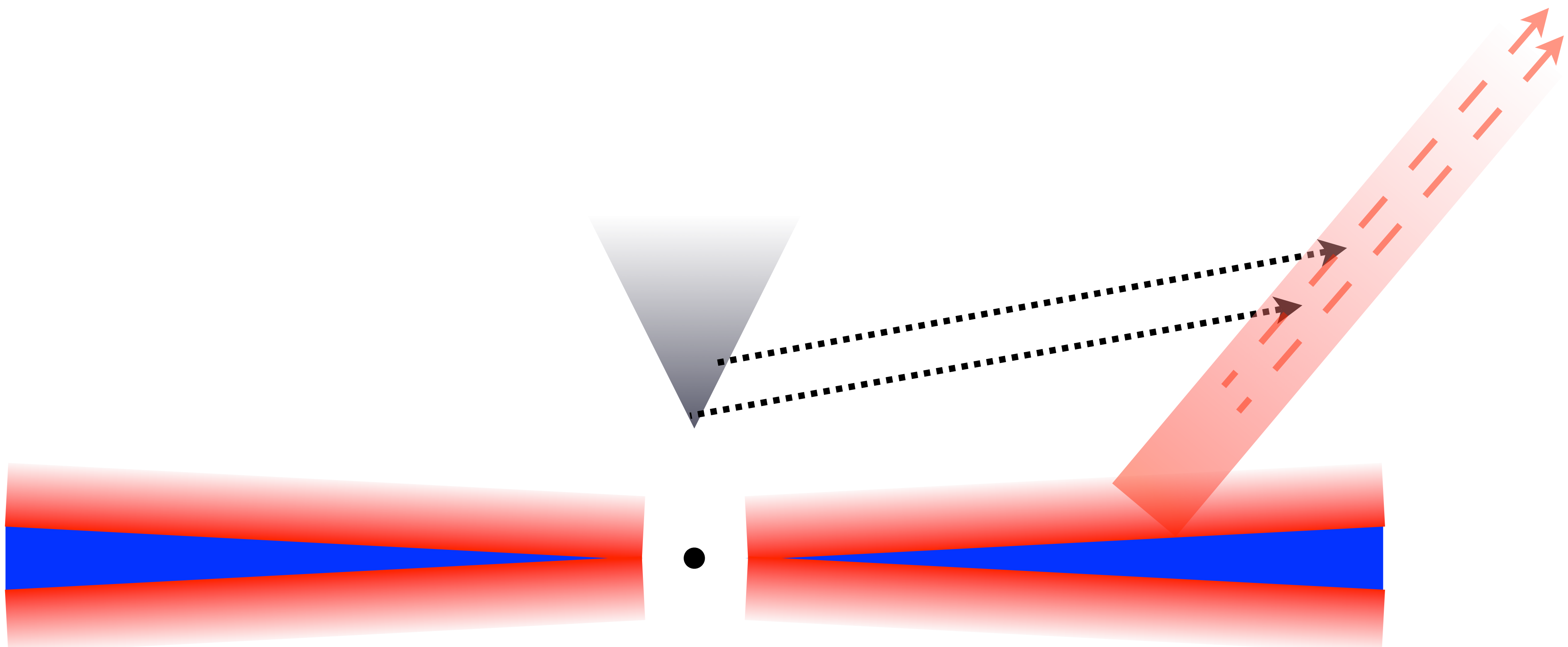
Neilsen & Lee 2009



Winds really are state-dependent, tied to disks.

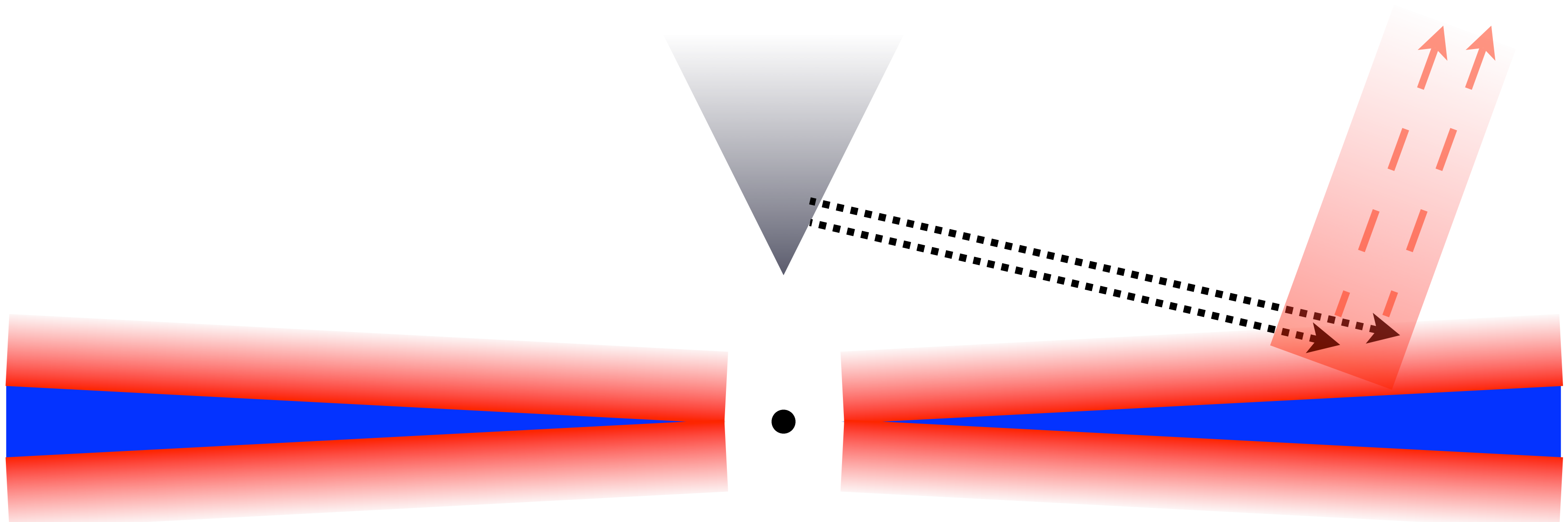
Driving mechanisms

Radiative driving



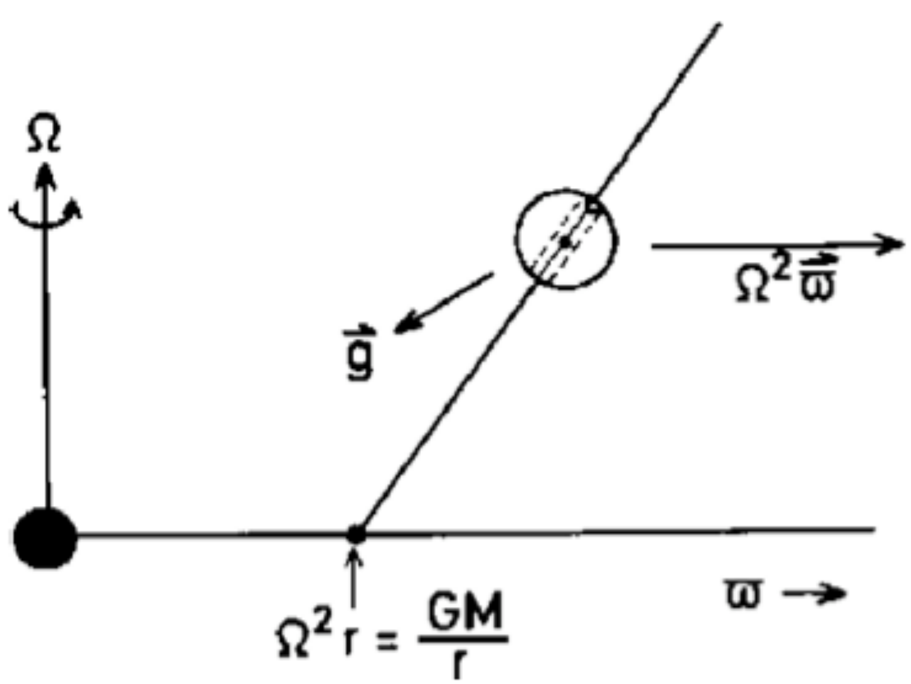
- Cross section of some transitions spikes in UV.
- Radiation particularly effective at driving gas then.
- This is important in O stars, CVs, some AGN.
- *Requires low ionization*: $\log(\xi) < 3$.

Thermal driving

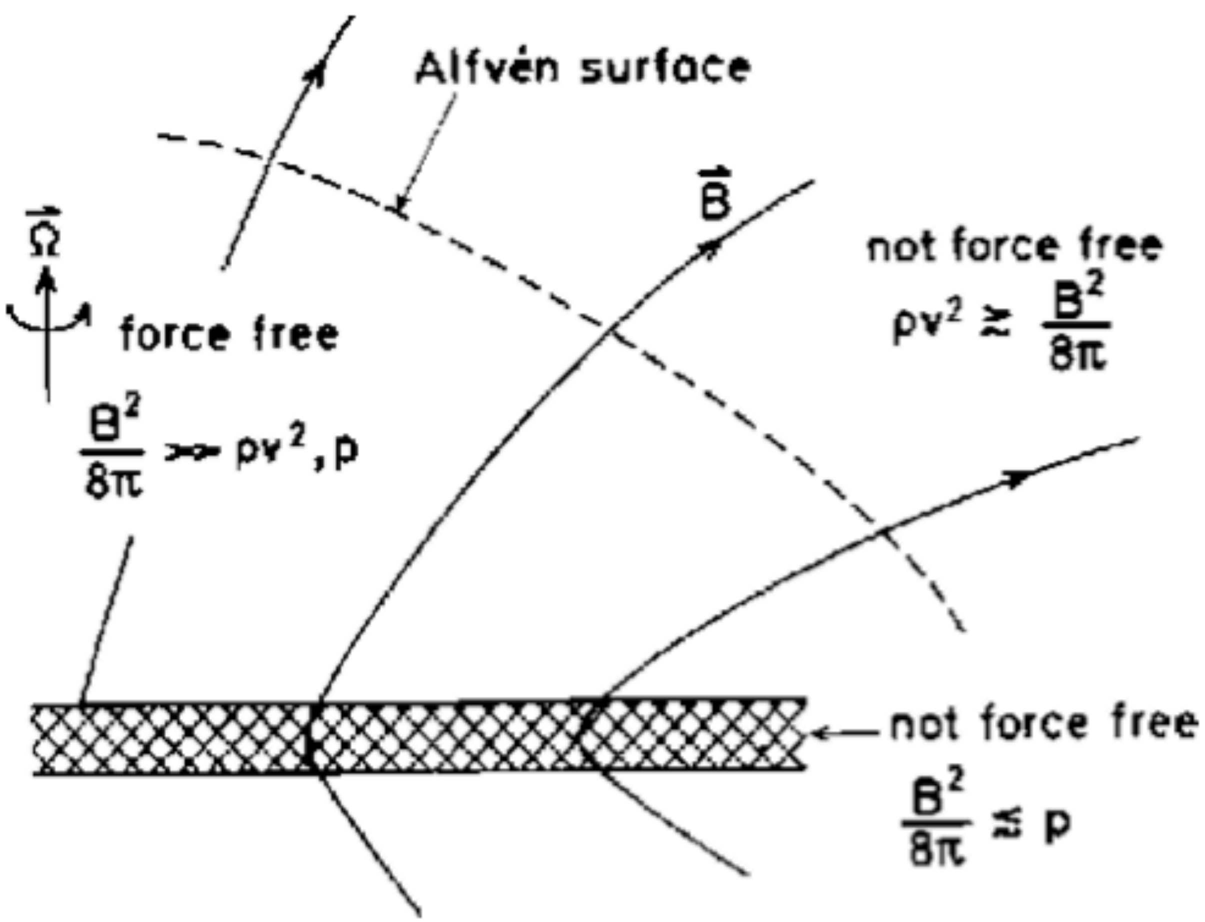


- Both escape temperature and irradiation fall with R.
- At some R, Compton heating causes $T > T_{esc}$.
- Wind: $R > R_C = 10^{10} (M_{BH}/M_o)/T_{C,8}$ cm (BMS 1983)
- $R > 0.1 R_C$ (Woods 96)

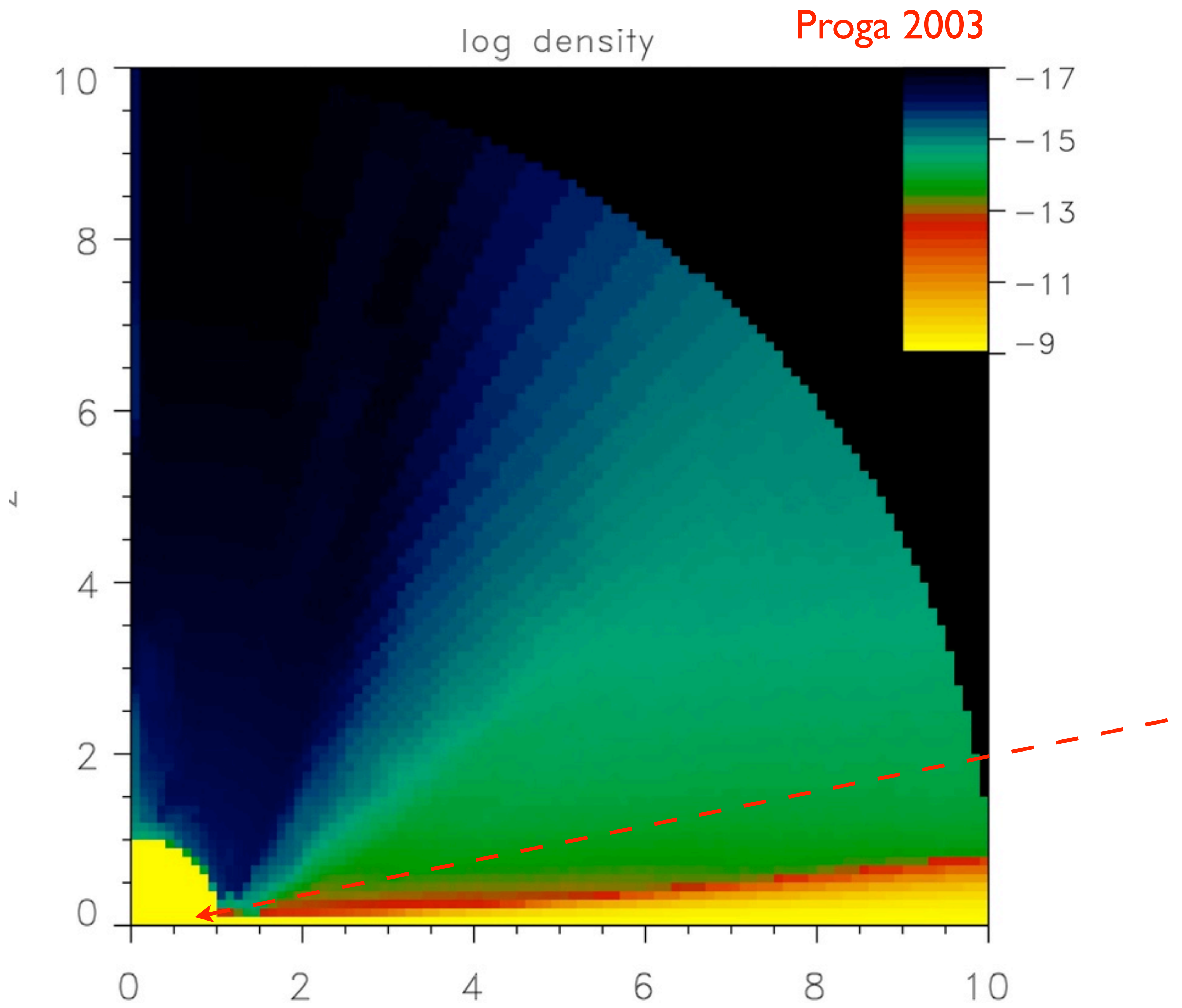
Magnetocentrifugal winds/jets (Blandford & Payne 1982)



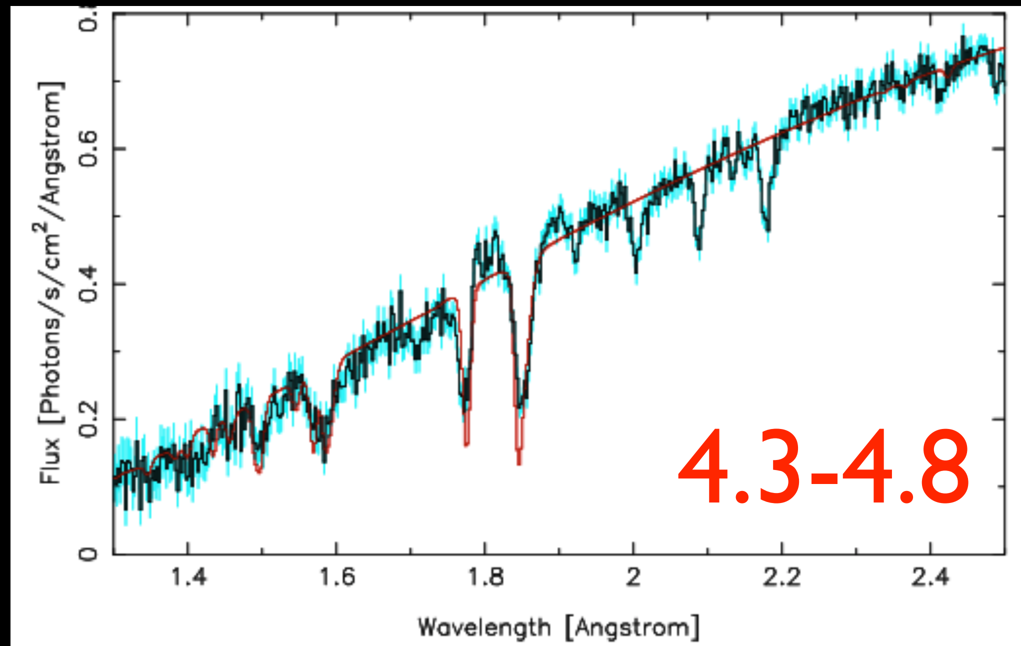
Spruit 1996



Magnetic Pressure from MRI

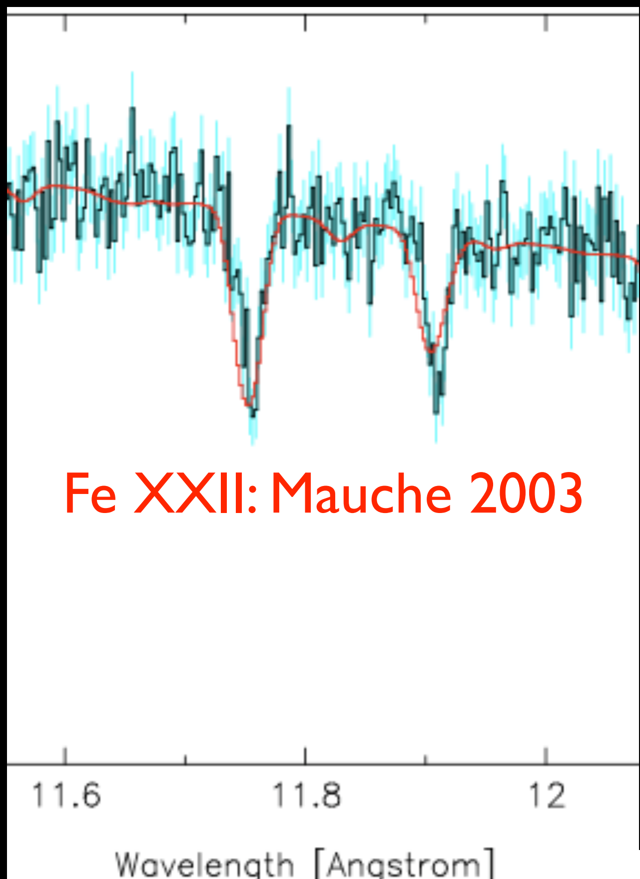


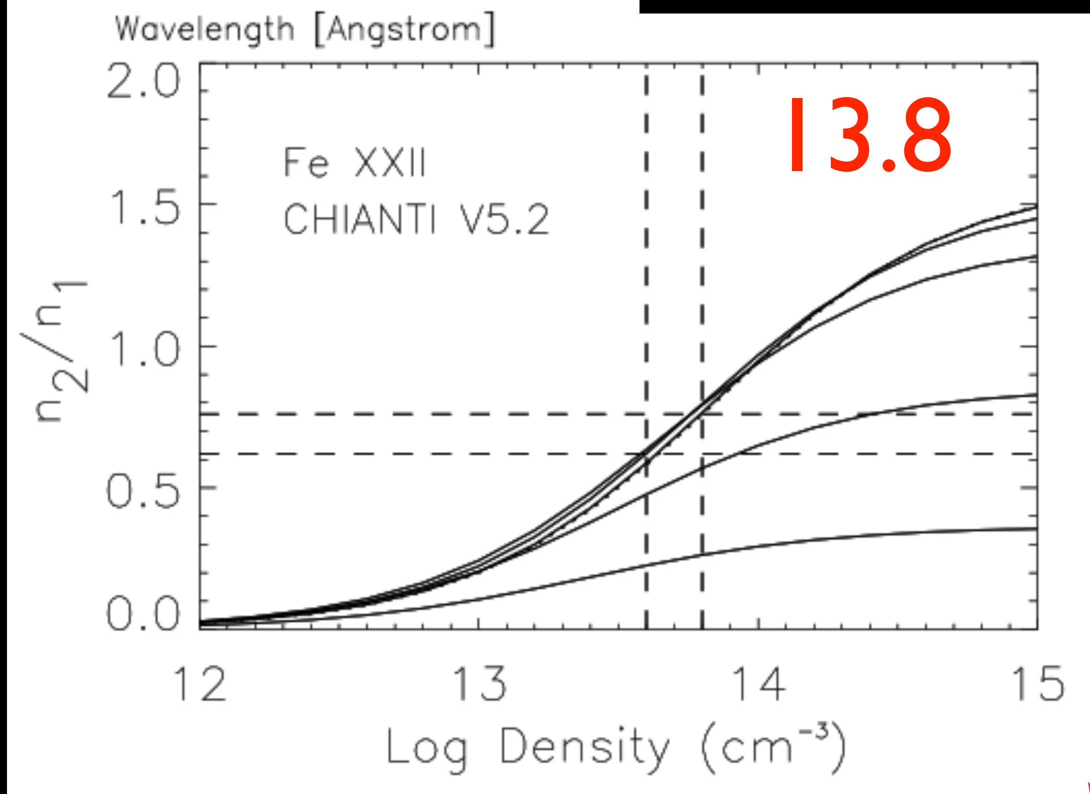
GRO J1655-40

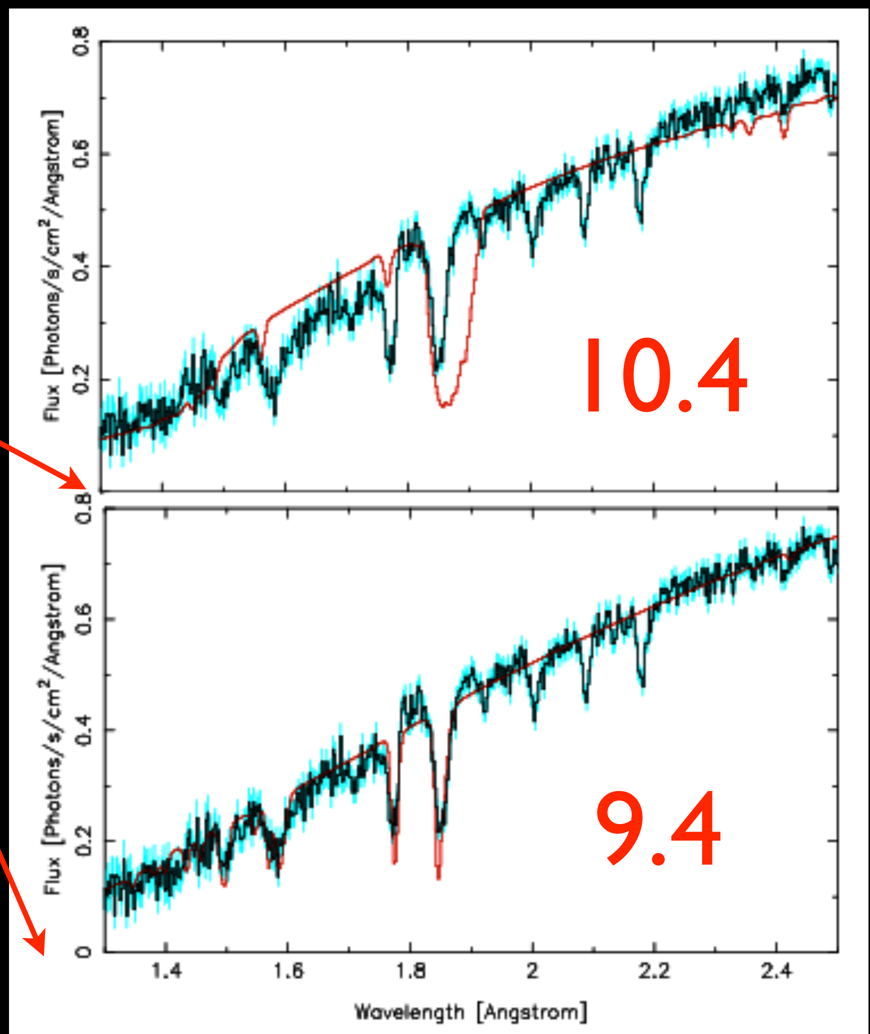


5.0 E+37 erg/s

$$\xi = \frac{L_X}{nR^2}$$





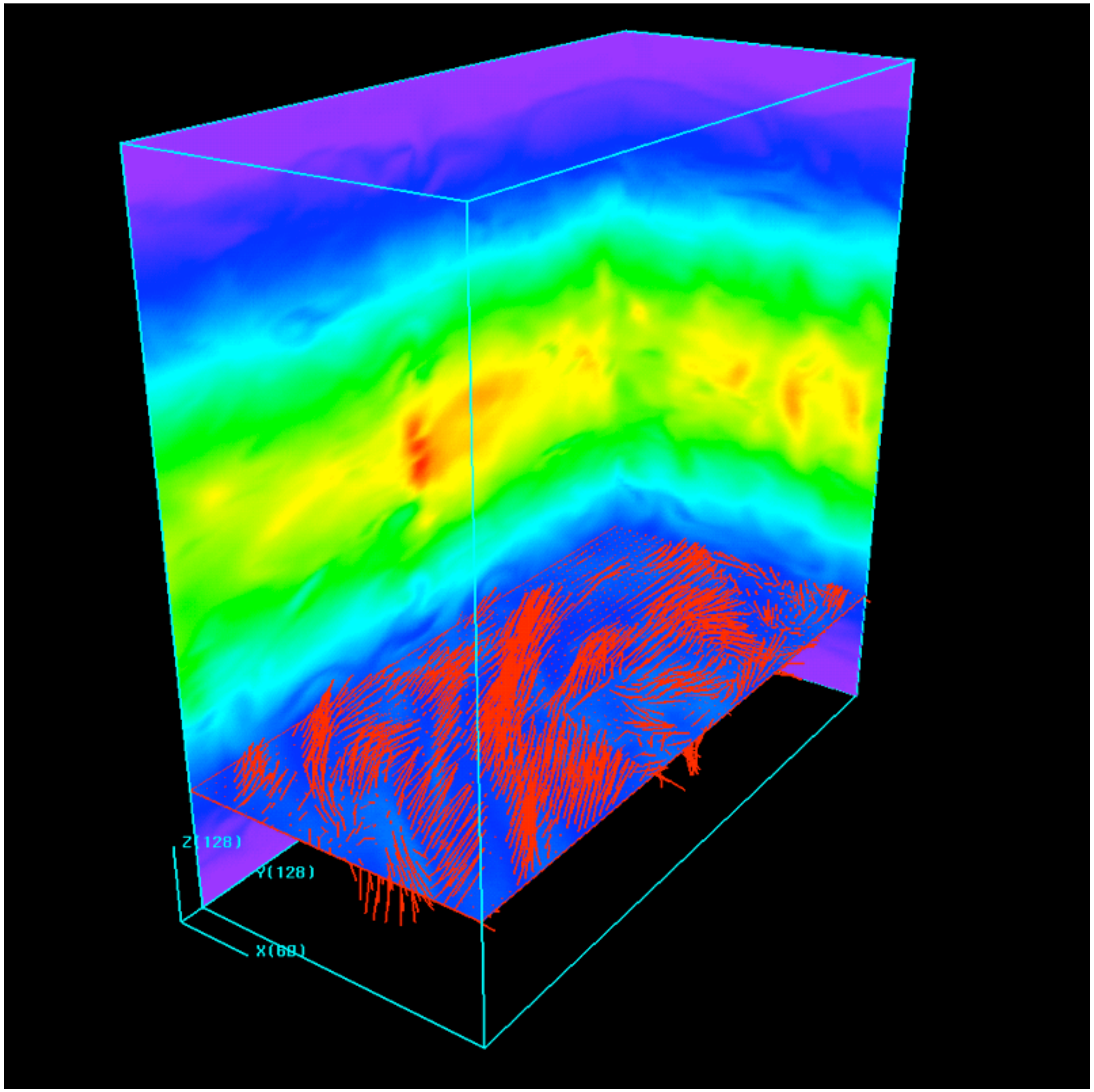


Results

Best-fit	Thermal
• $\log(n) = 13.8\text{-}14.0$	
• $\log(N) = 23.1\text{-}23.6$	
• $\log(\xi) = 4.3-4.8$	
• $\log(r) = 9.4-9.7$	$\log(r) = 11.7$, maybe 10.7
• $\log(\delta r) < 9.7$	
• M-dot = 10^{-2} g/cm^2/s	M-dot = $6 * 10^{-6}$ g/cm^2/s

Luketic et al. 2010 also rules out thermal driving.

Can B do it?



KE flux: 3-6*10^{14} erg/cm^2/s

VE flux: 8*10^{16} erg/cm^2/s

Miller & Stone 2000

Blaes 2007

--> Magnetic energy flux more than enough to supply the KE flux needed.

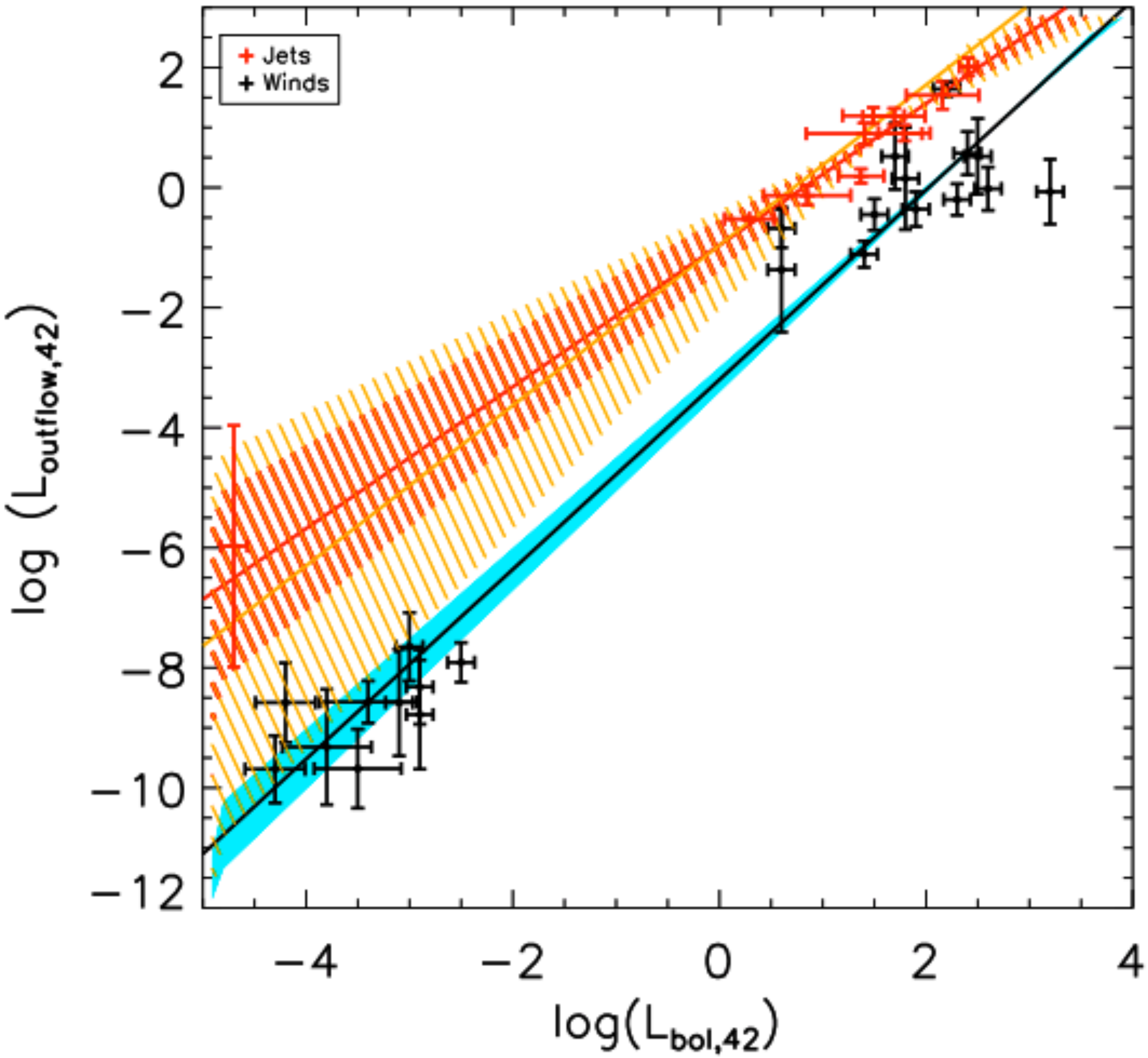
Proga 2003

More broadly ...

- Stellar mass black hole winds have broadly similar gas/photionization properties (N, ξ, v).
- Suggests similar density values as well.
- Similarly small launching radii, r ~1000 GM/c^2, then possible for all sources.
- GRO J1655-40 certainly requires magnetic driving. May point to basic disk physics.
- State dependence = wind/jet dichotomy inconsistent with thermal driving.
- Perhaps magnetic driving generally plays a role for highly ionized disk winds.

Winds and Jets, across M.

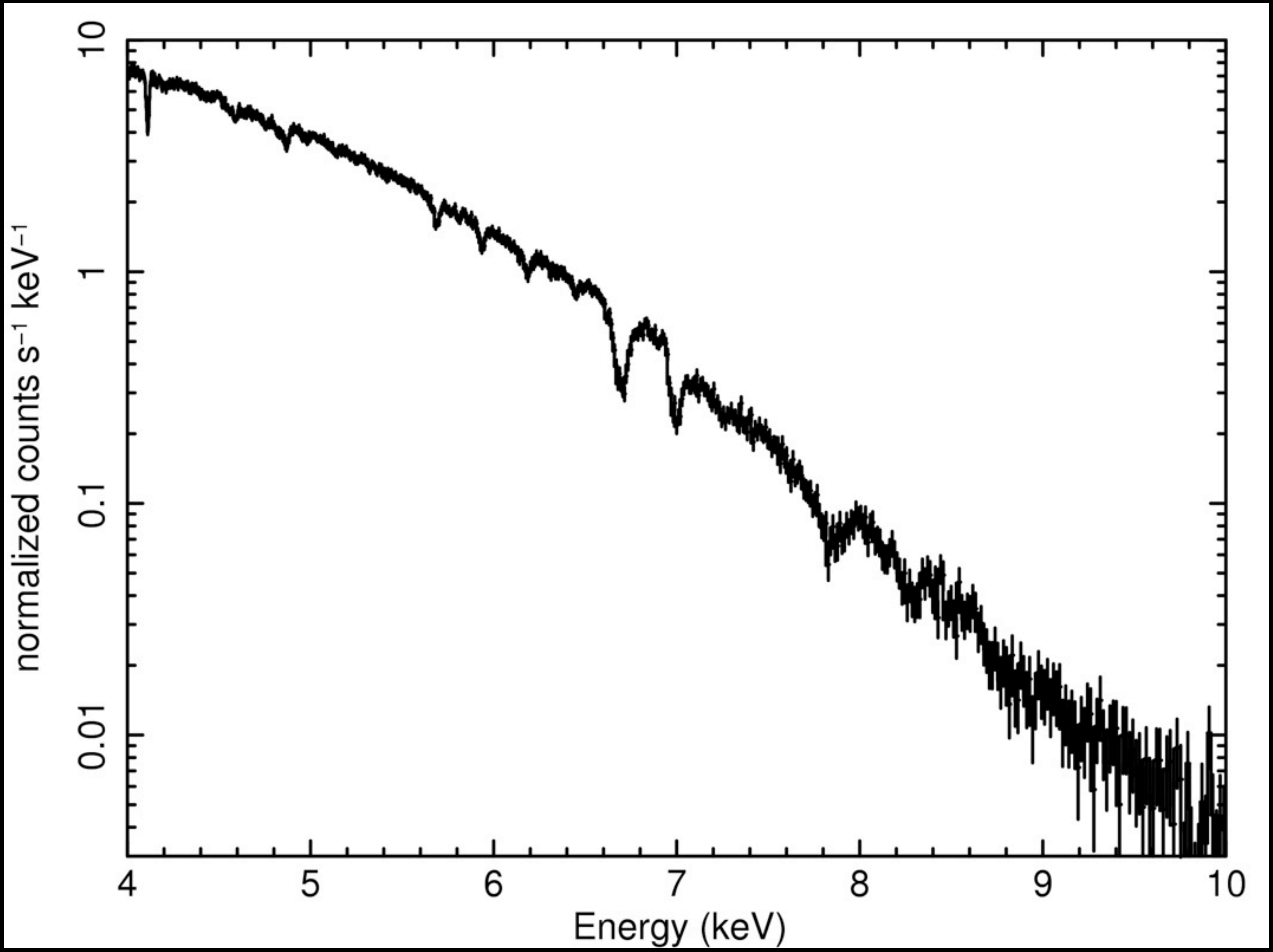
Ashley King et al. 2013



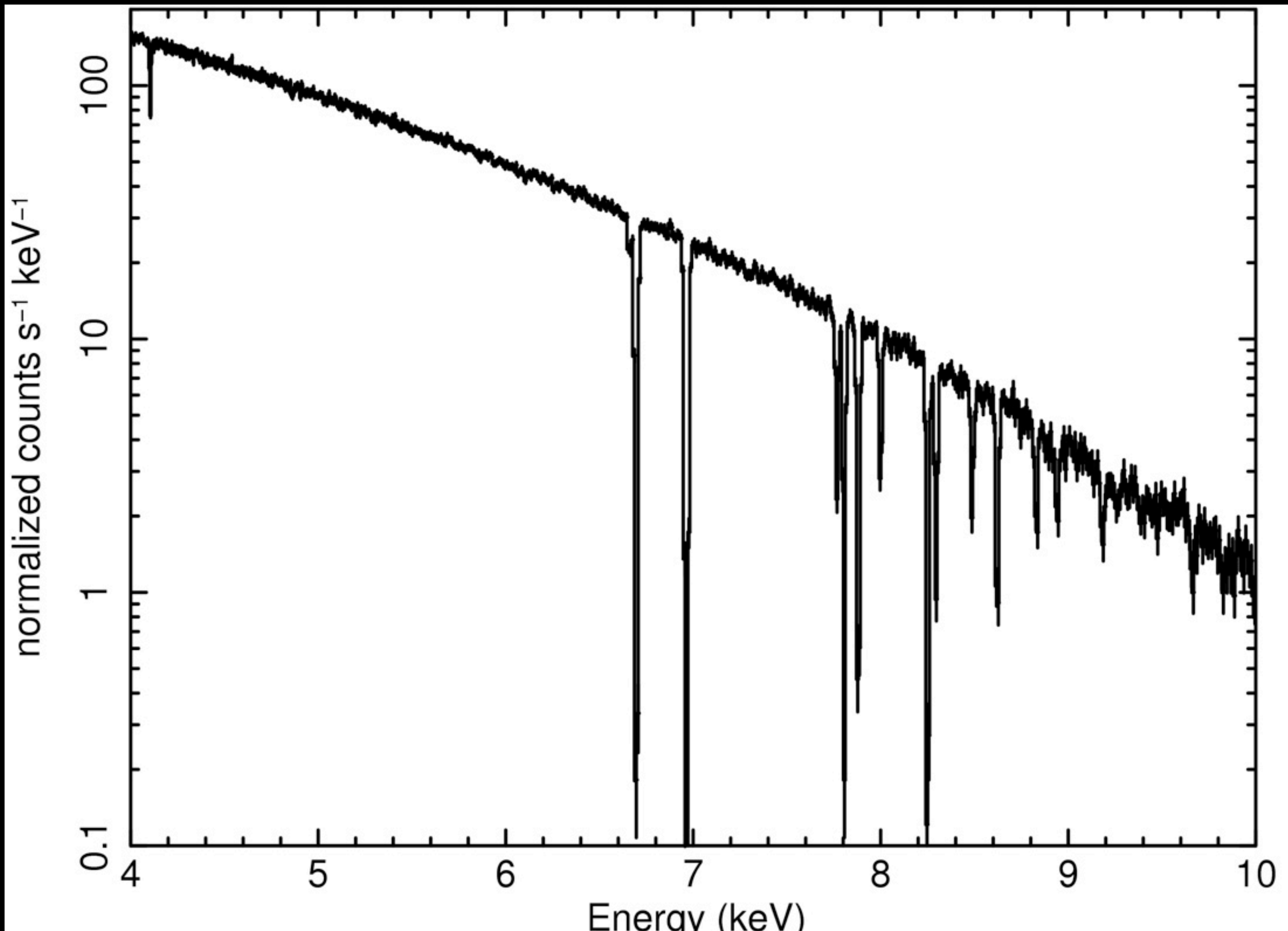
The Future

- Chandra has imaged jets, discovered disk winds, and studied their relationship.
- The overall effect is to strengthen and deepen the similarities between binaries and AGN.
- *Chandra is the only mission that can image jets from binaries in X-rays.*
- *Chandra will continue to be the best mission for spectroscopy for E < 4 keV, even in the Astro-H era.*
- *Need to keep observing transients, and partner with NuSTAR, Astro-H, VLA, ALMA.*

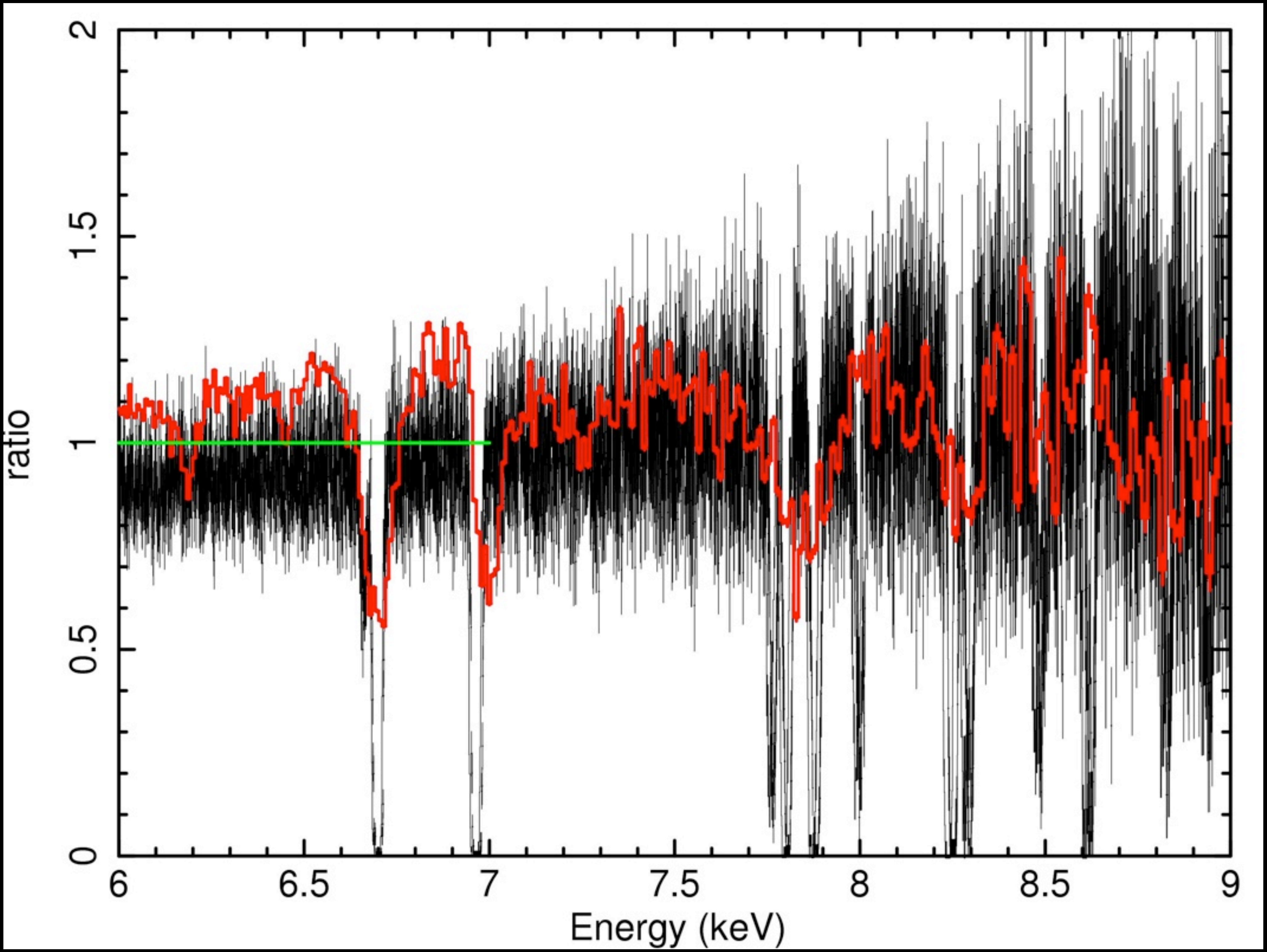
GRO J1655-40: Chandra



Astro-H SXS, 50 ksec



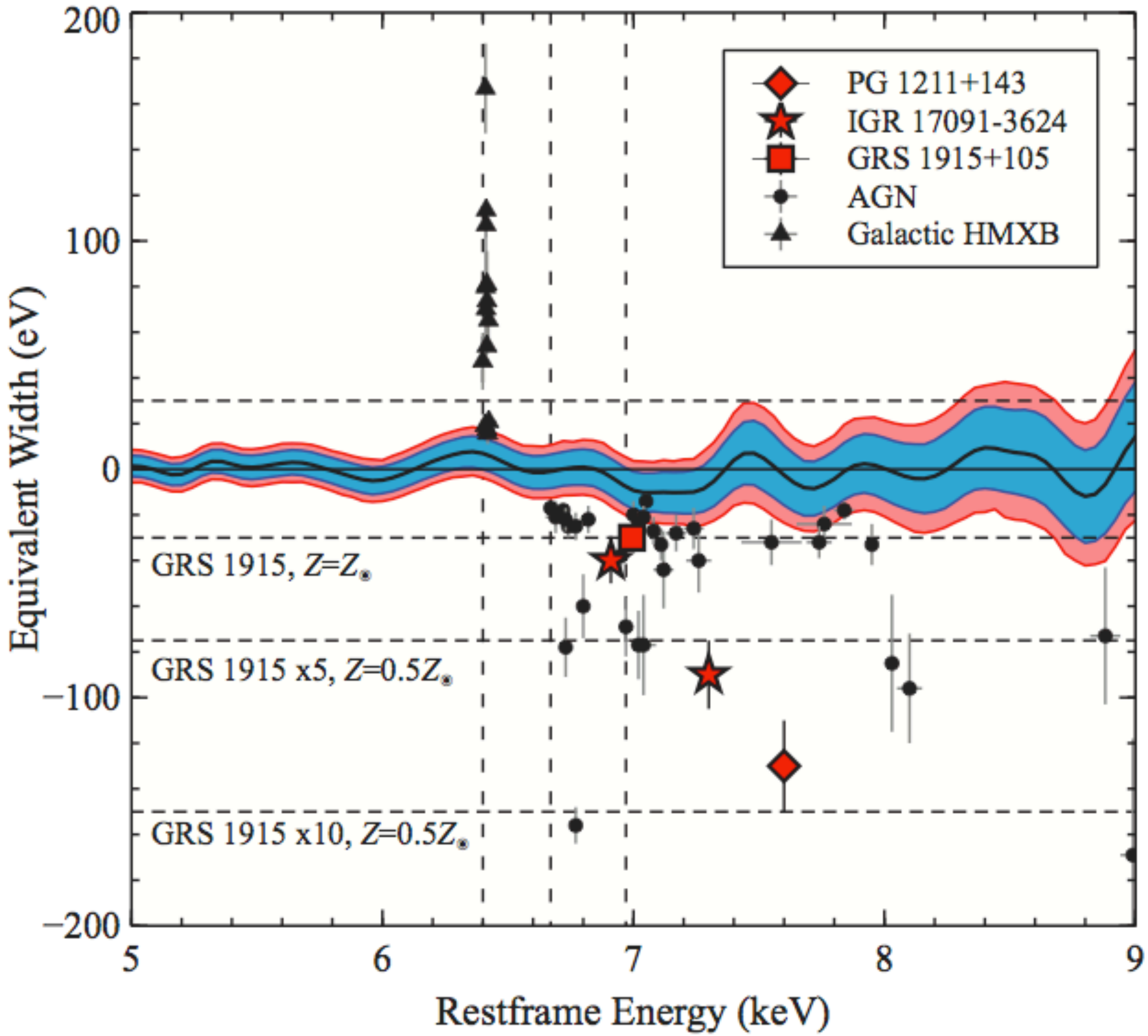
Astro-H vs Chandra



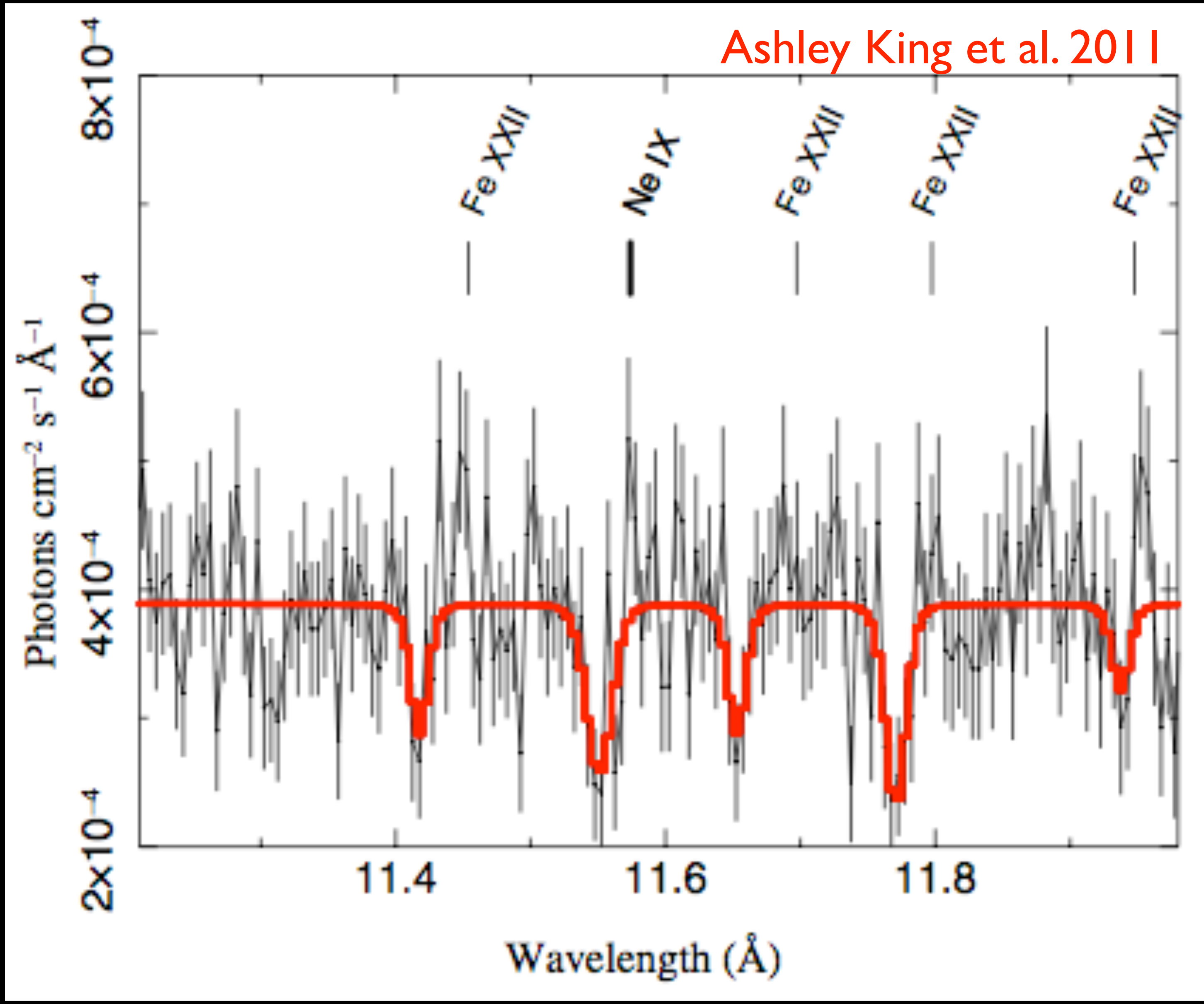
extra slides

Ho IX Line Limits

Walton et al. 2013

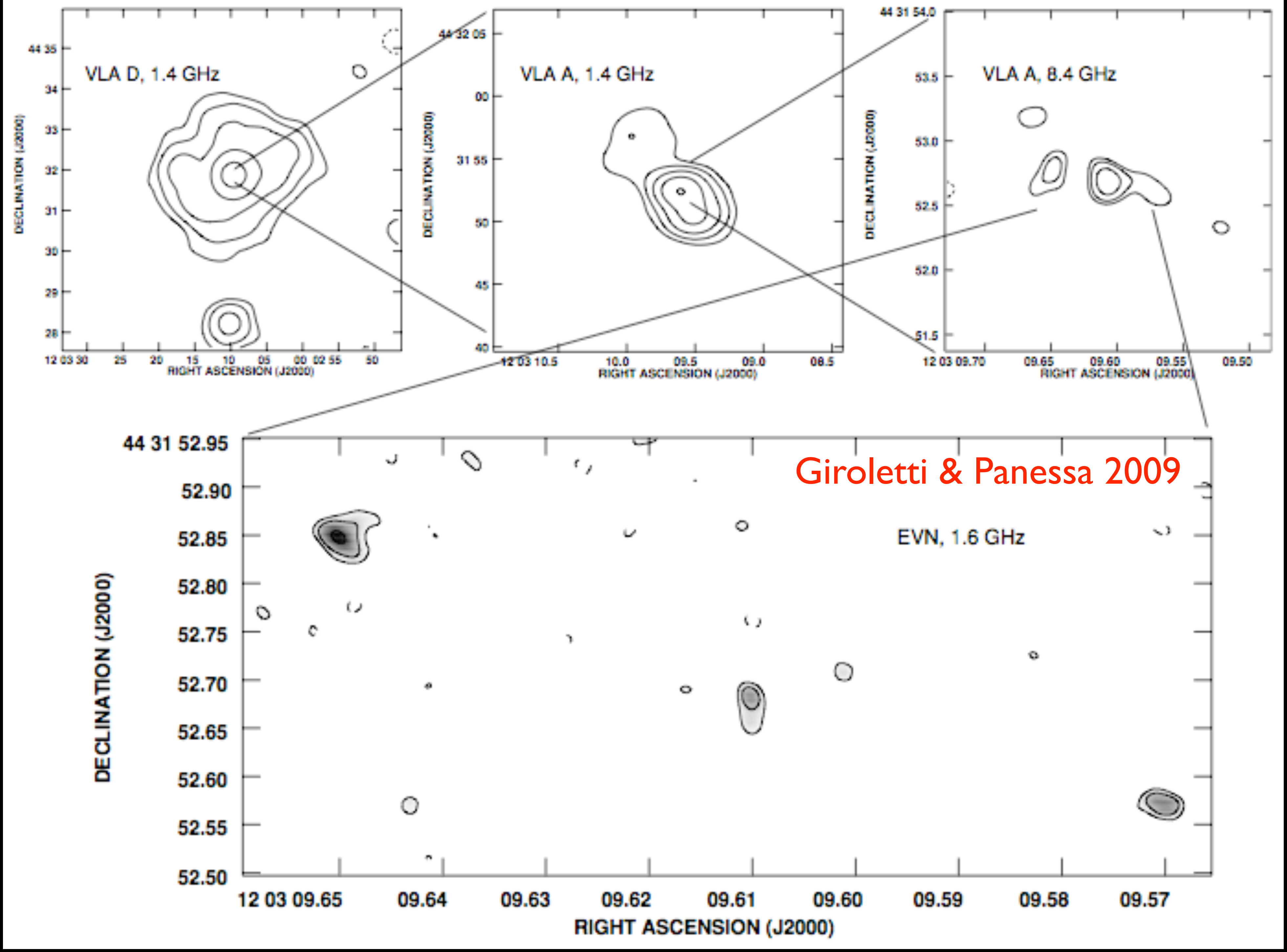


NGC 4051



Variability: n > E+8 (Krongold++ 2007).
Fe XXII: n < few E+12 (King et al. 2011).

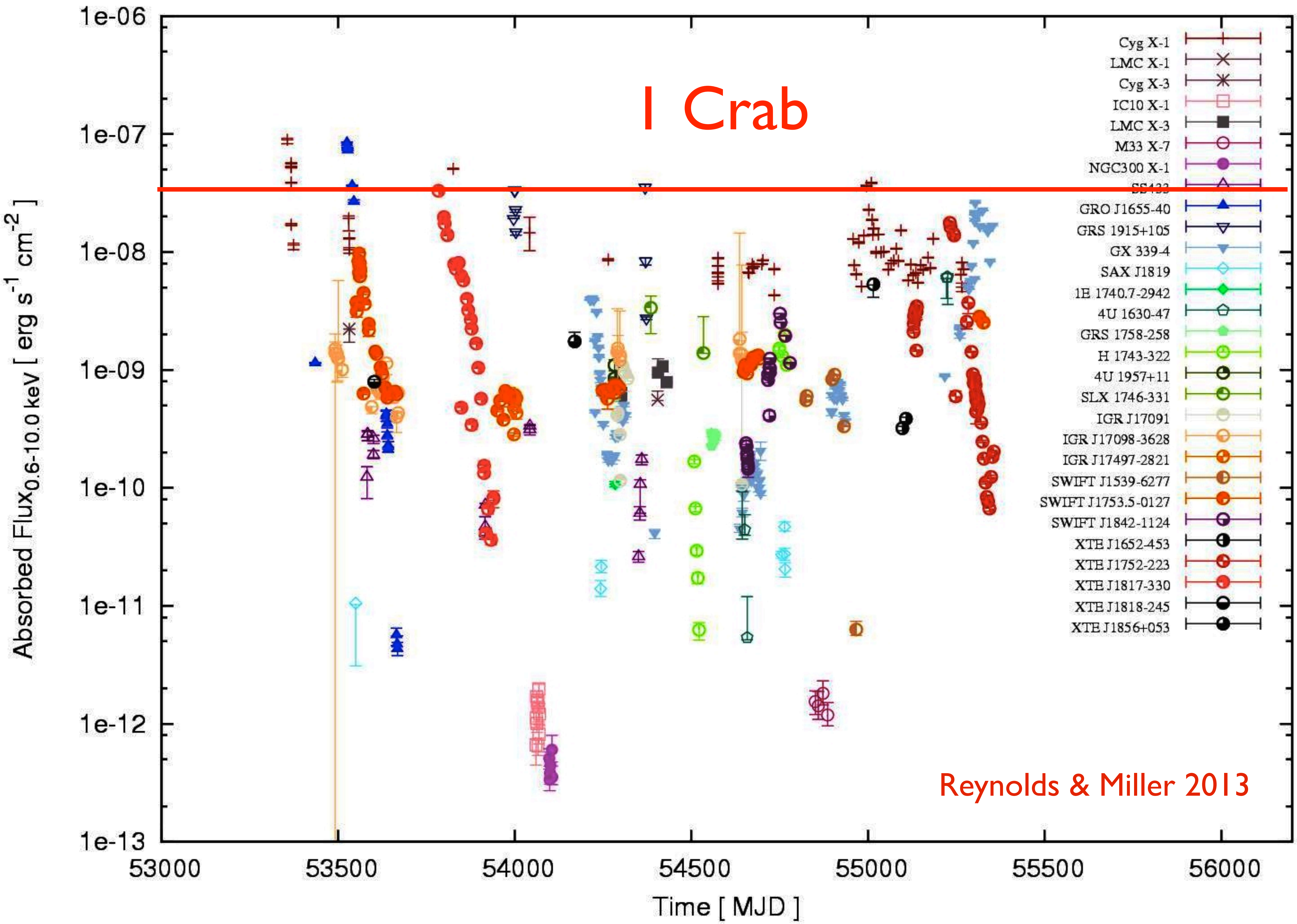
NGC 4051



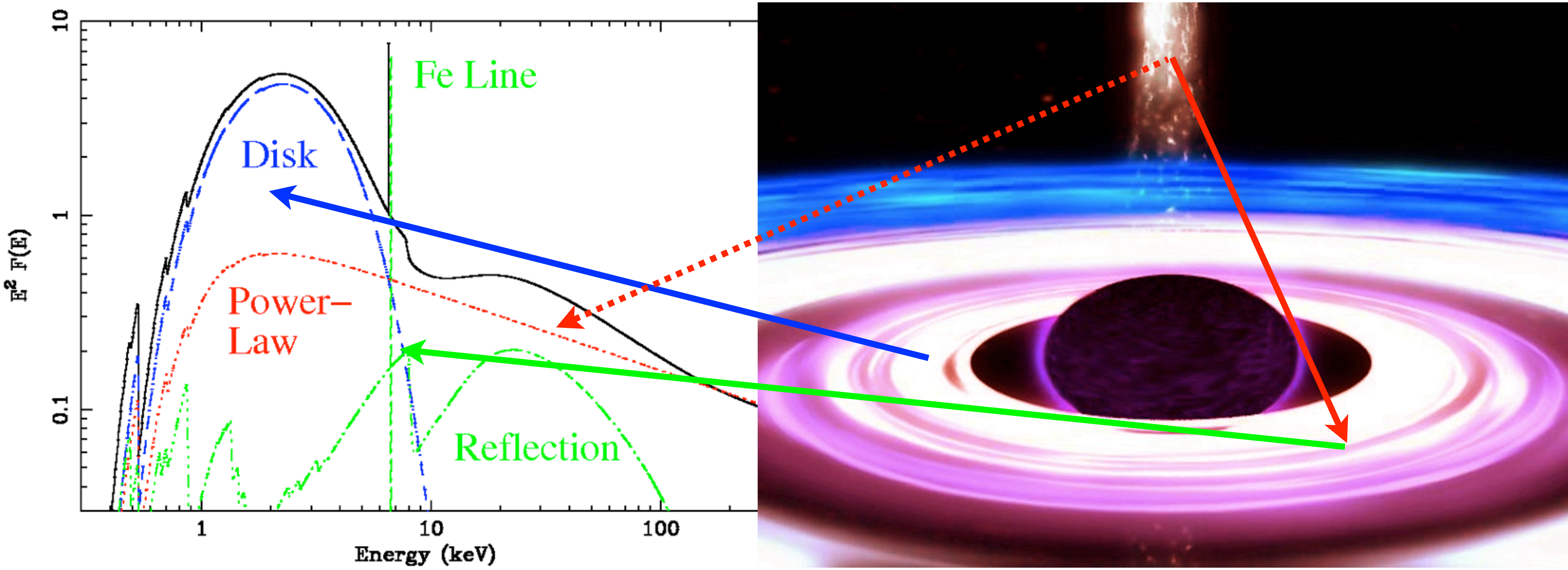
Giroletti & Panessa 2009

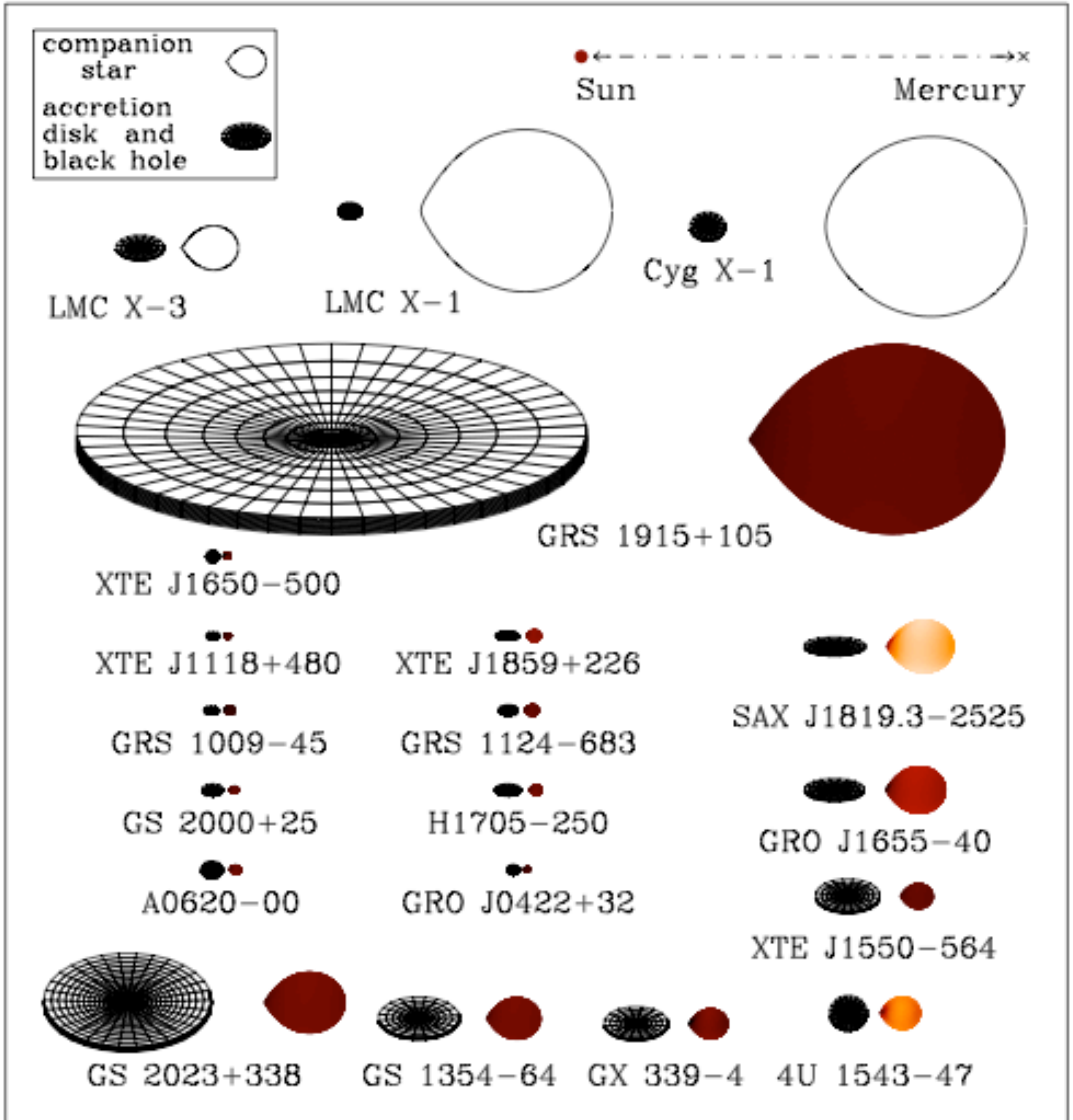
- Radiation pressure
    - Force multiplied in certain UV transitions.
    - Clearly important in AGN, especially BALQSOs.
    - Only effective for $\log(\xi) < 3$.
- Thermal driving (e.g. Begelman ++ 1983)
    - Raise disk surface to the local escape velocity.
    - Can drive modest winds from outer disk.
    - Likely always present at some level. Unless...

Outbursts (Swift)



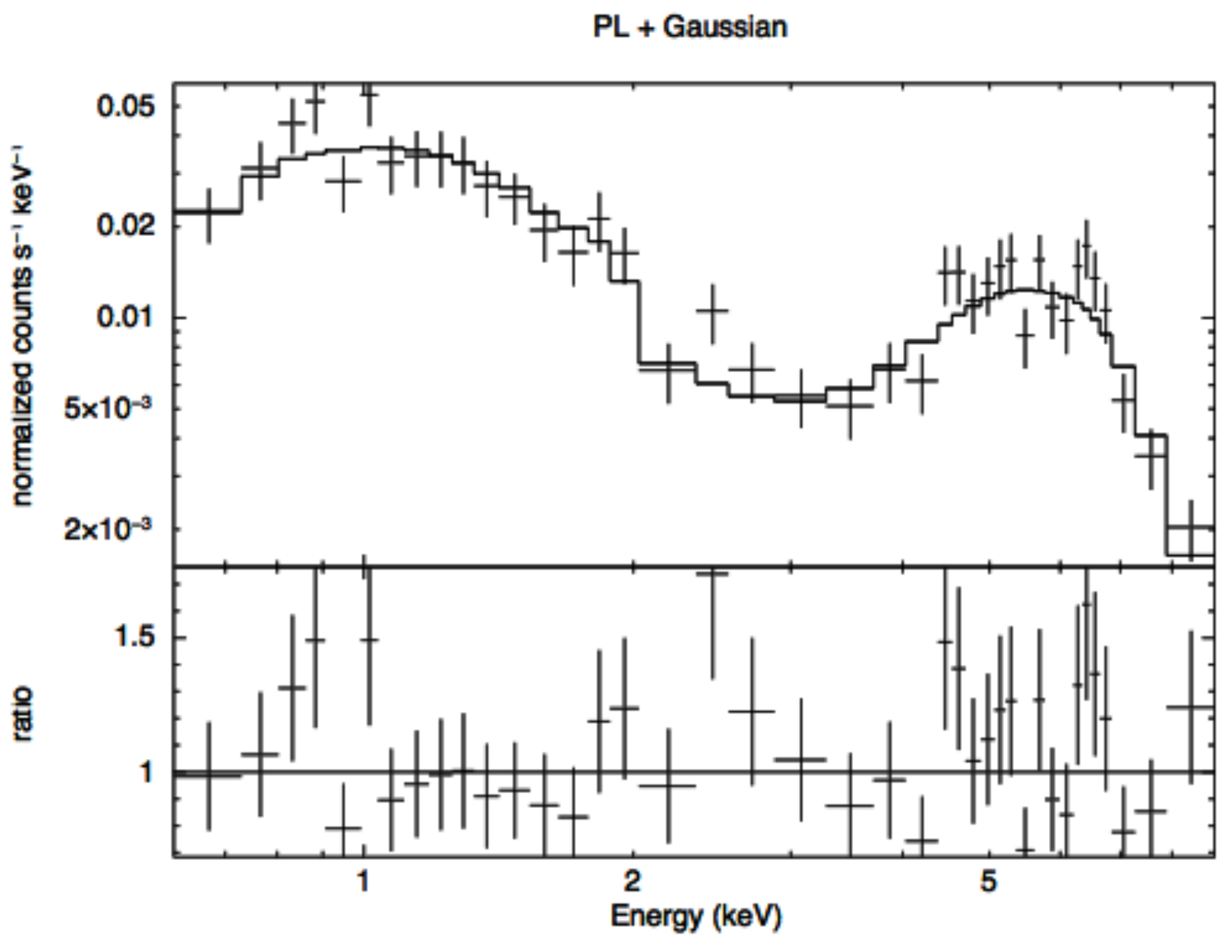
Spectra <--> Geometry

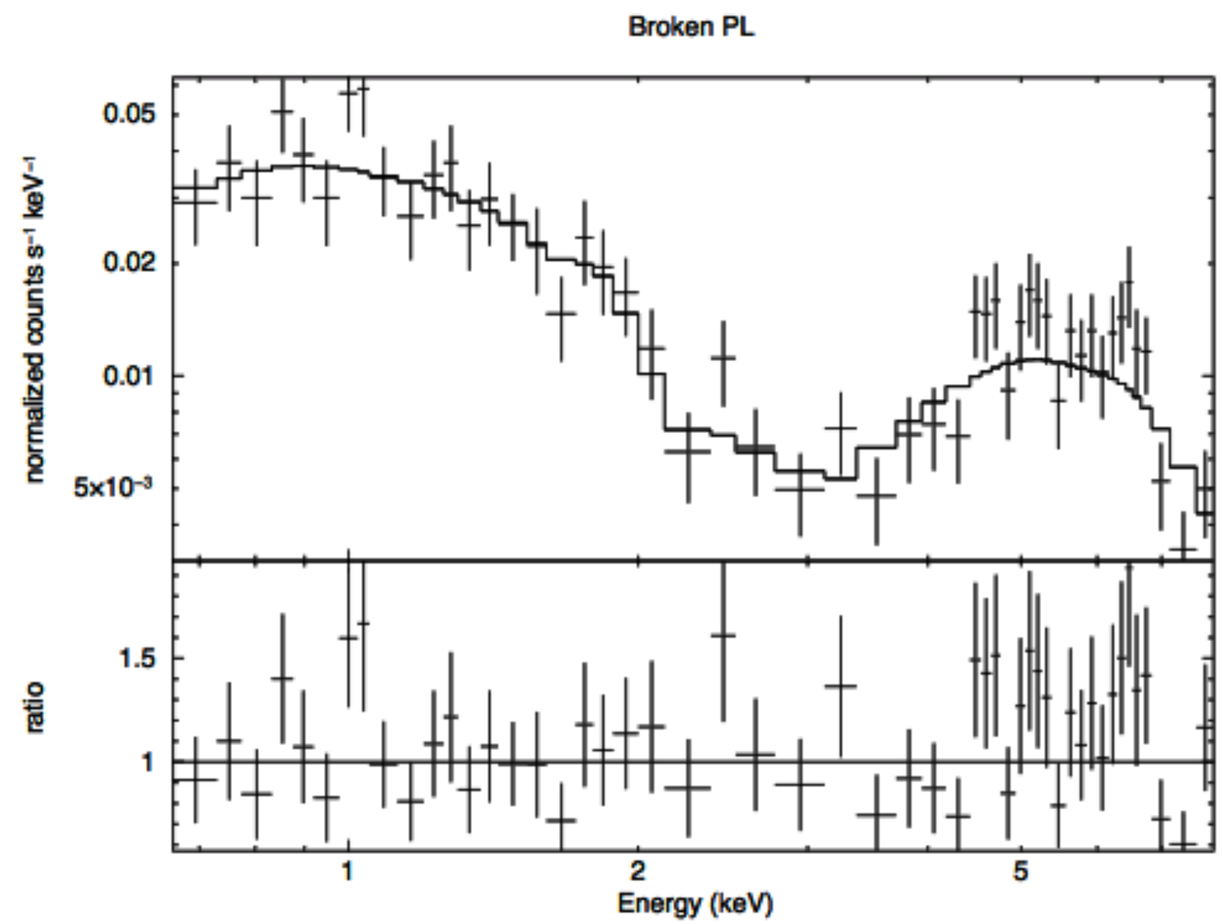




companion star
accretion disk and black hole
Sun
Mercury
LMC X−3
LMC X−1
Cyg X−1
GRS 1915+105
XTE J1650−500
XTE J1118+480
XTE J1859+226
SAX J1819.3−2525
GRS 1009−45
GRS 1124−683
GS 2000+25
H1705−250
GRO J1655−40
A0620−00
GRO J0422+32
XTE J1550−564
GS 2023+338
GS 1354−64
GX 339−4
4U 1543−47

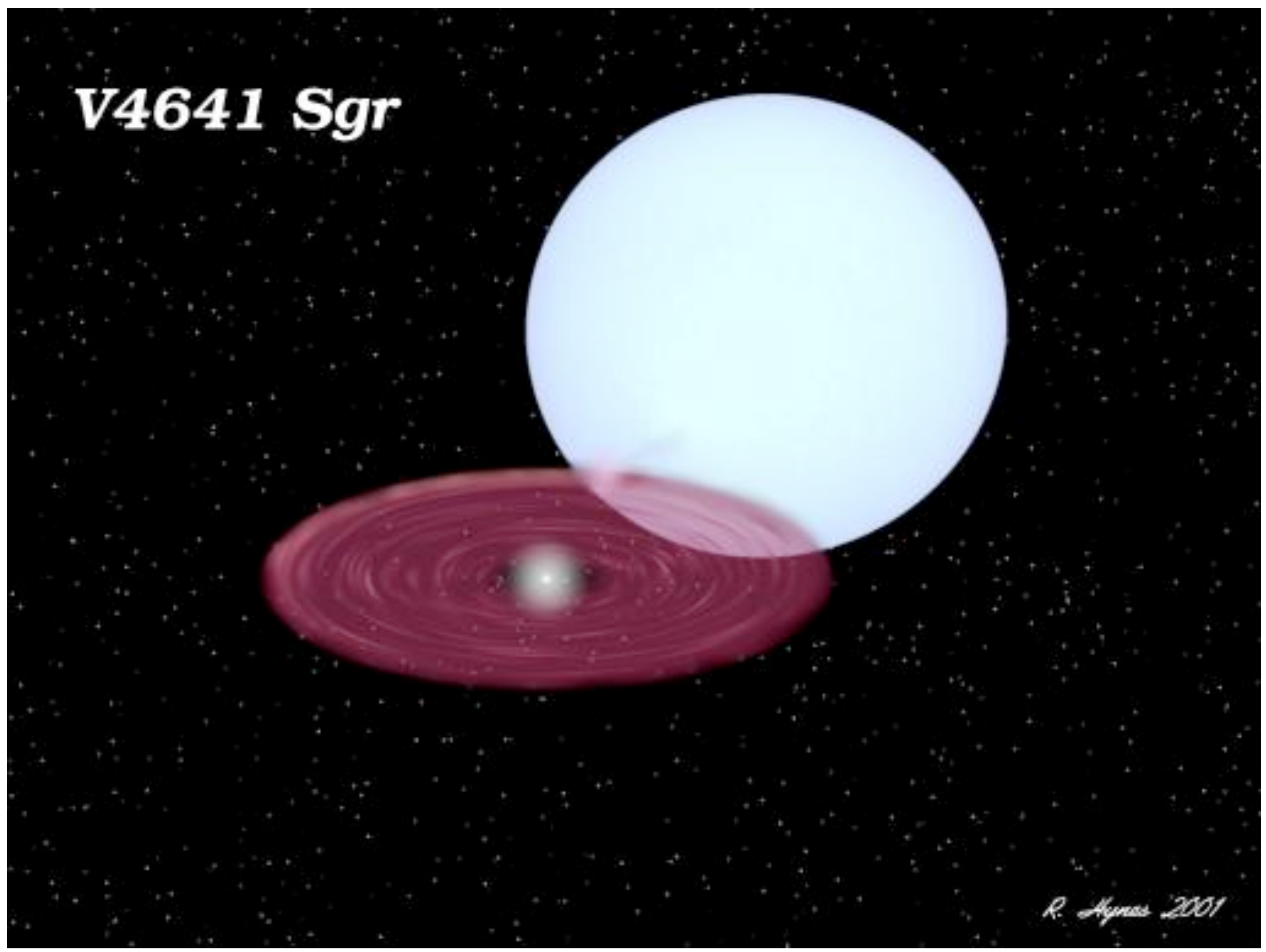
Baryonic jets in V4641?





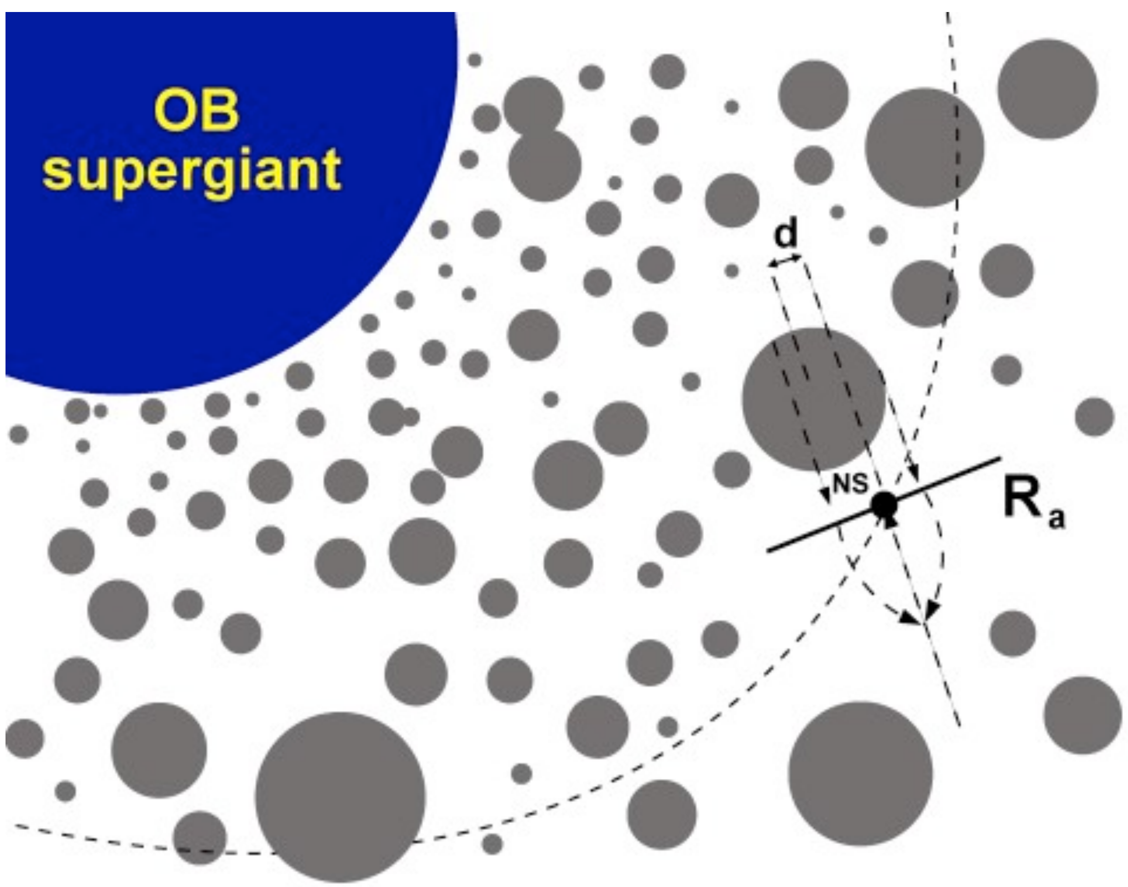
Gallo, Plotkin, Jonker 2014

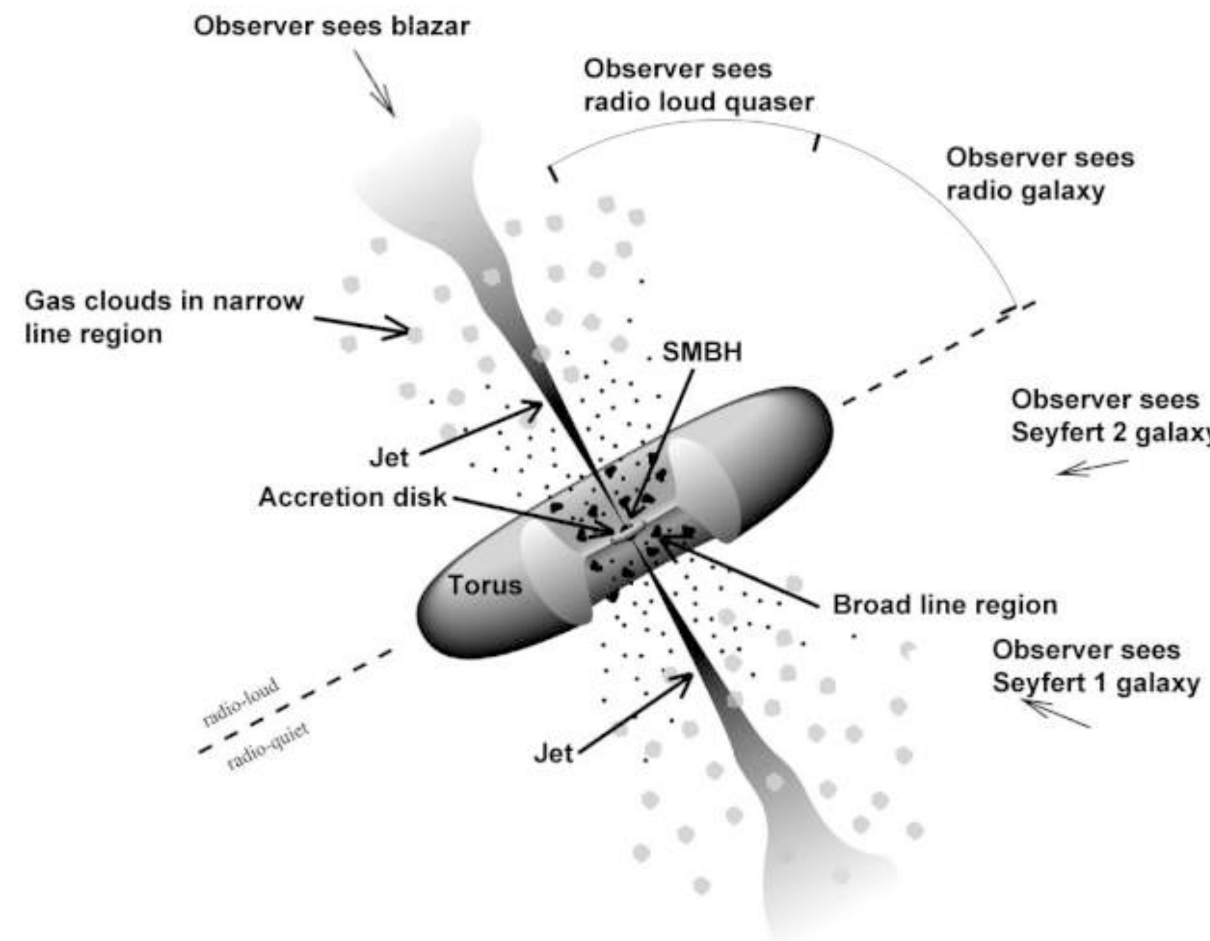
Baryonic jets in V4641?



V4641 Sgr has a B-type companion.

Baryonic jets in V4641?

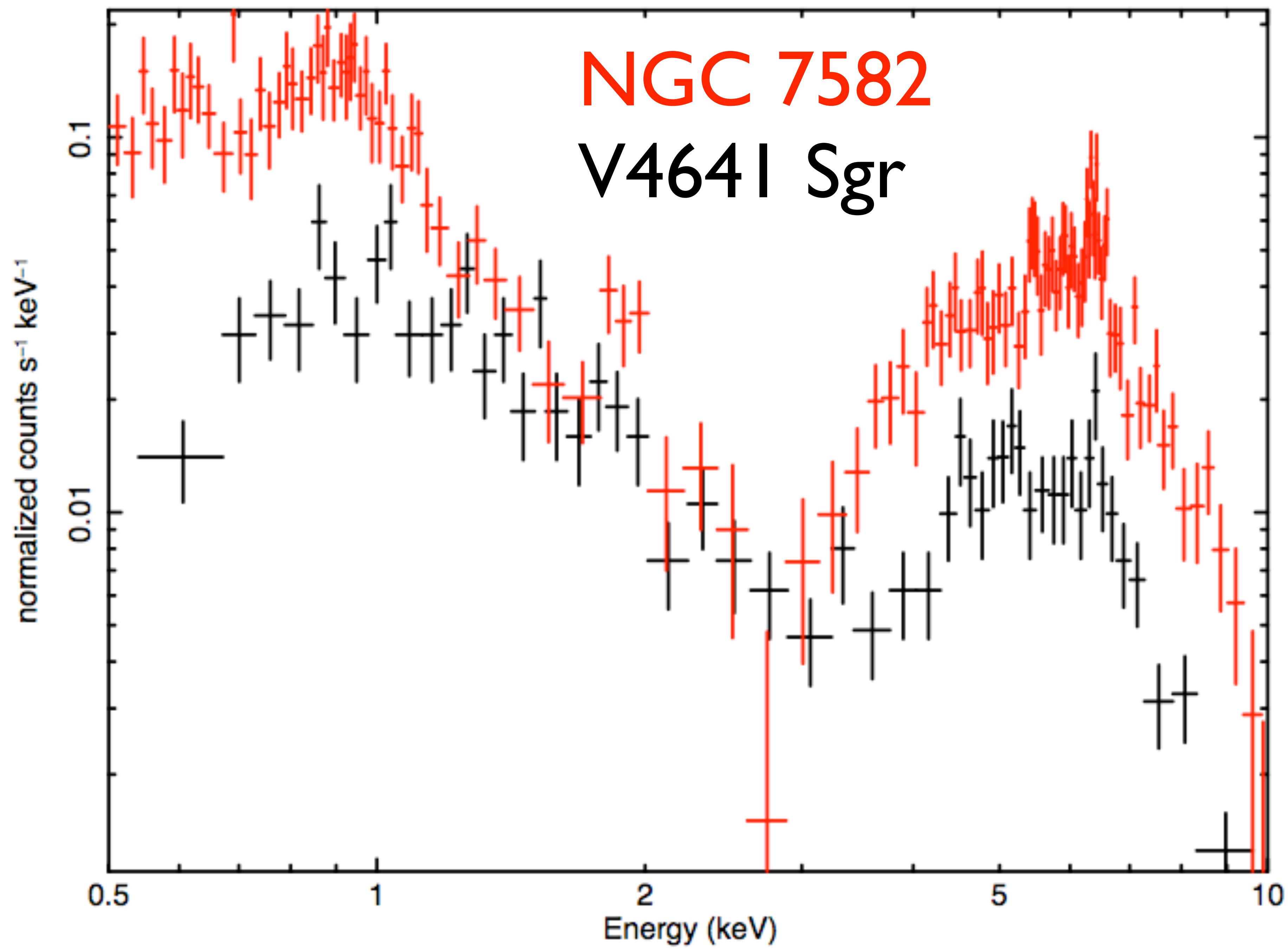




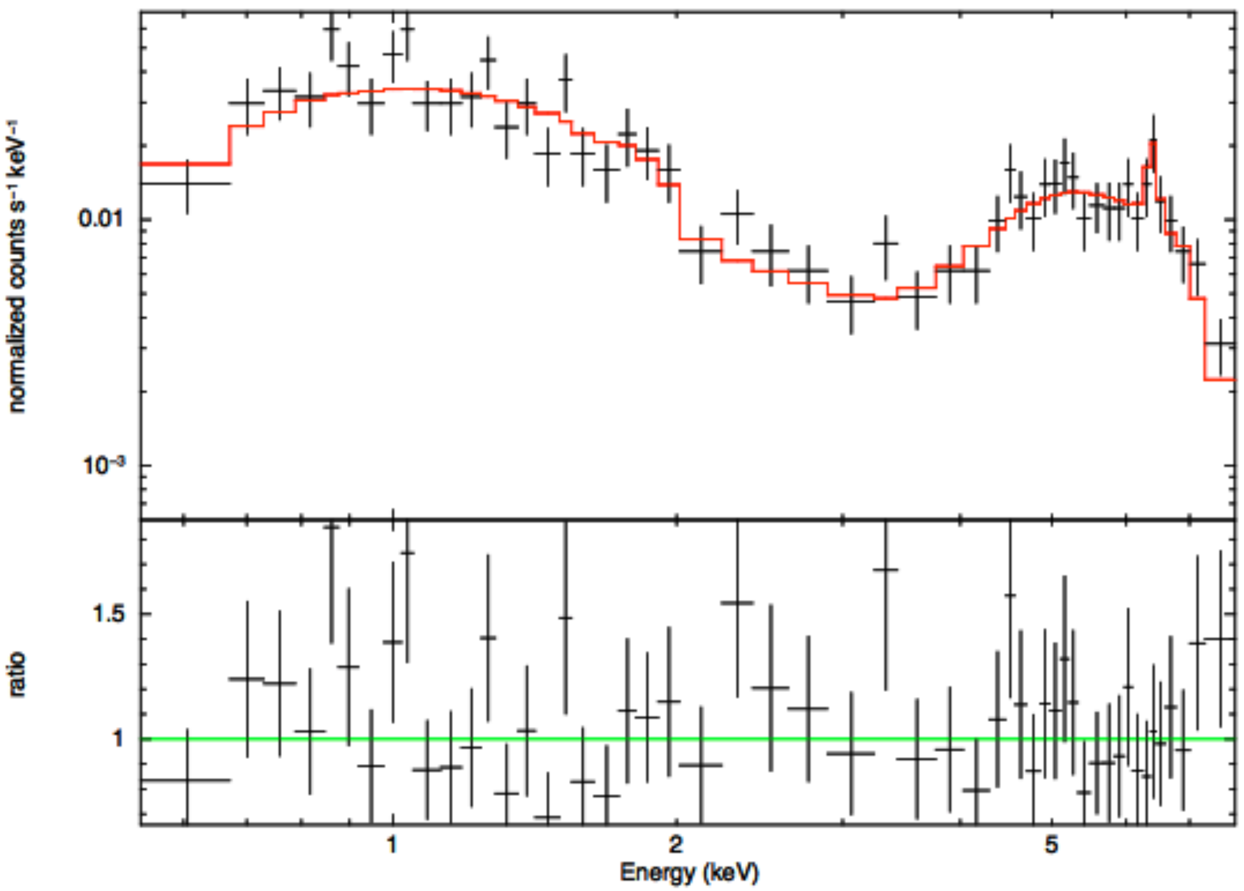
Clumps in massive companion winds causes obscuration, like that seen in a Seyfert-2.

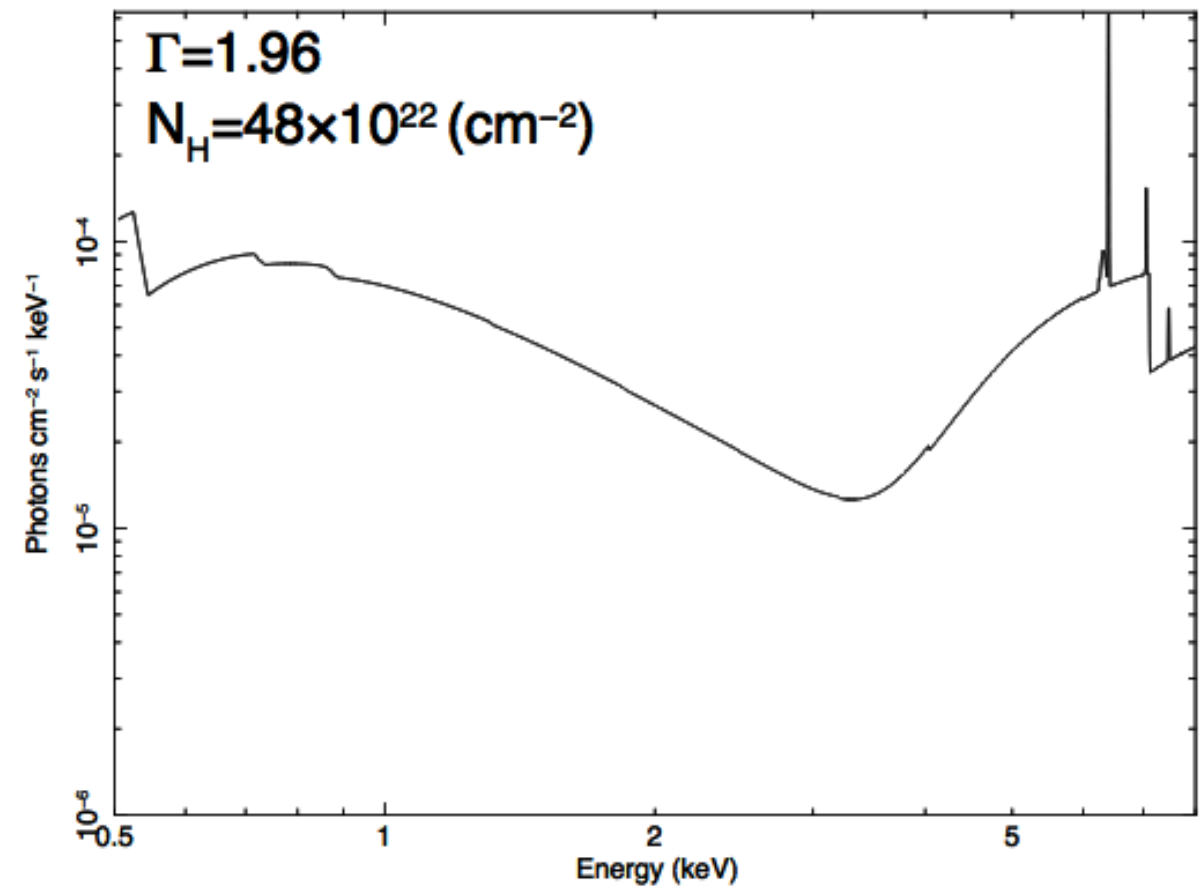
Baryonic jets in V4641?

Morningstar et al. 2014



Baryonic jets in V4641?





Morningstar et al. 2014