High X-ray Spectroscopy of V404 Cygni in Near Eddington Outburst

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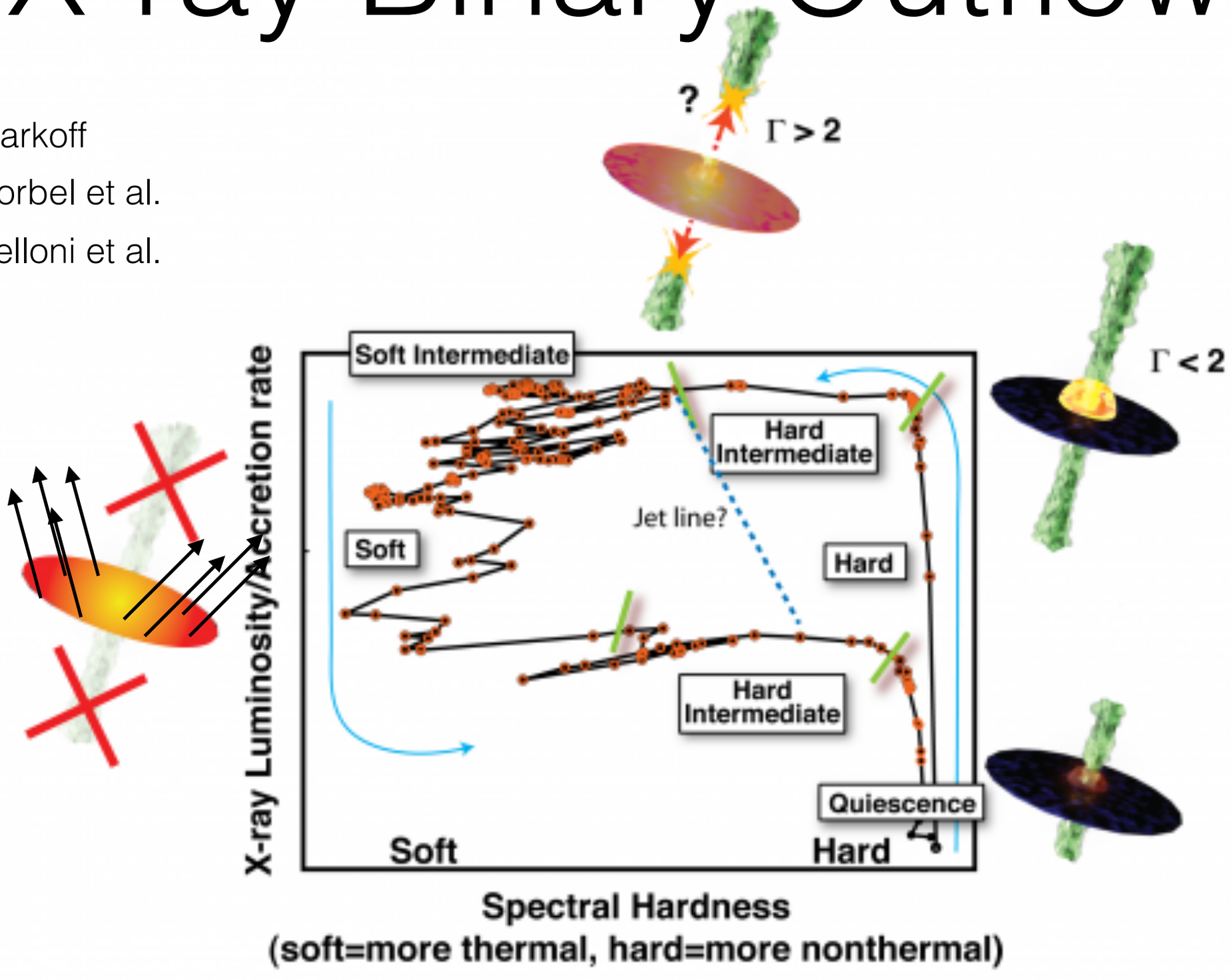
THANKS!!!!!

- Thank you Belinda Wilkes and the Chandra team for observing this ToO, V404 Cyg during this extremely bright outburst!!!

- Thank you Herman Marshall, David Huenemoerder, and the Chandra Calibration team for your Help and Advice!!!

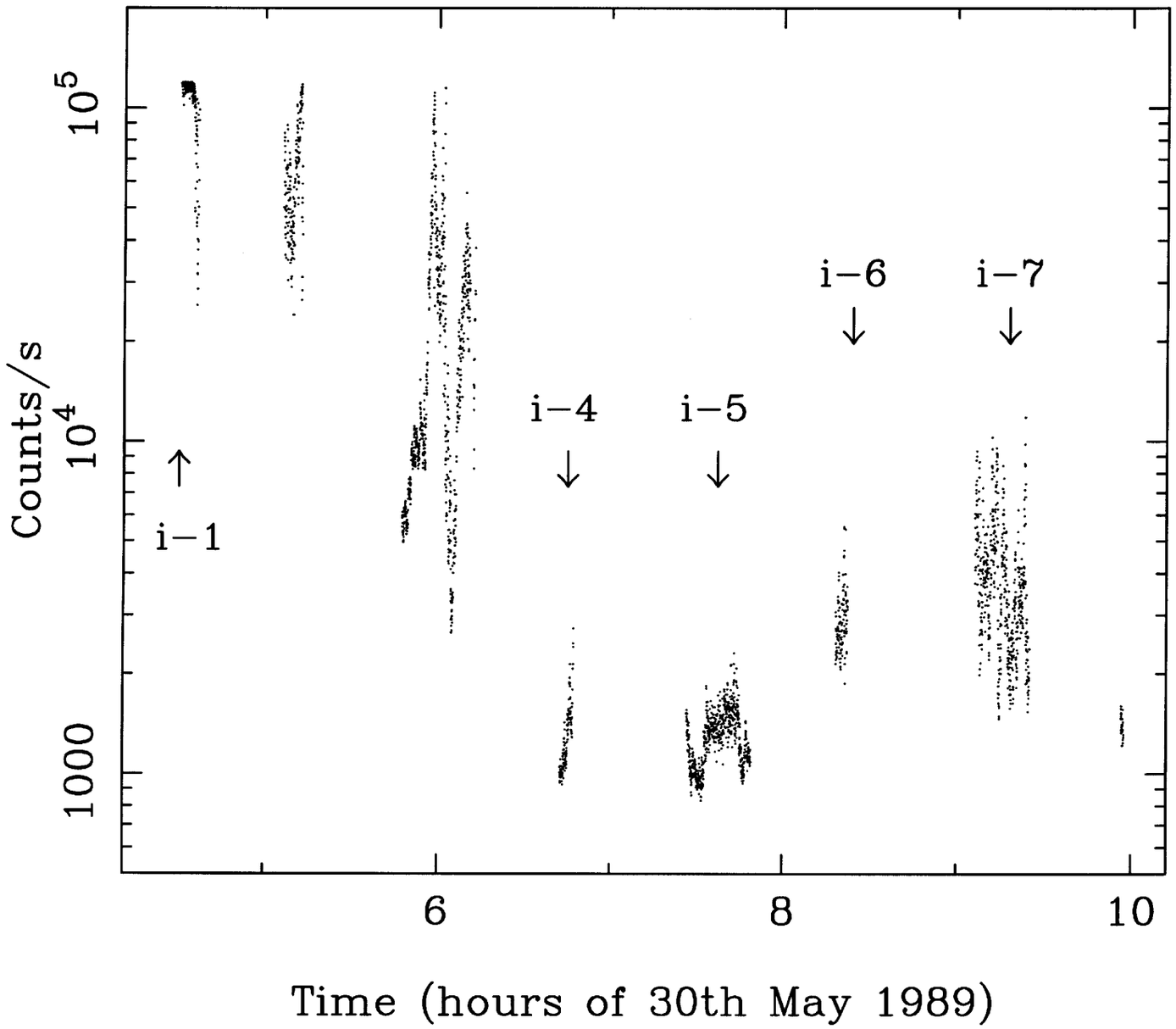
X-ray Binary Outflows

- Markoff
- Corbel et al.
- Belloni et al.



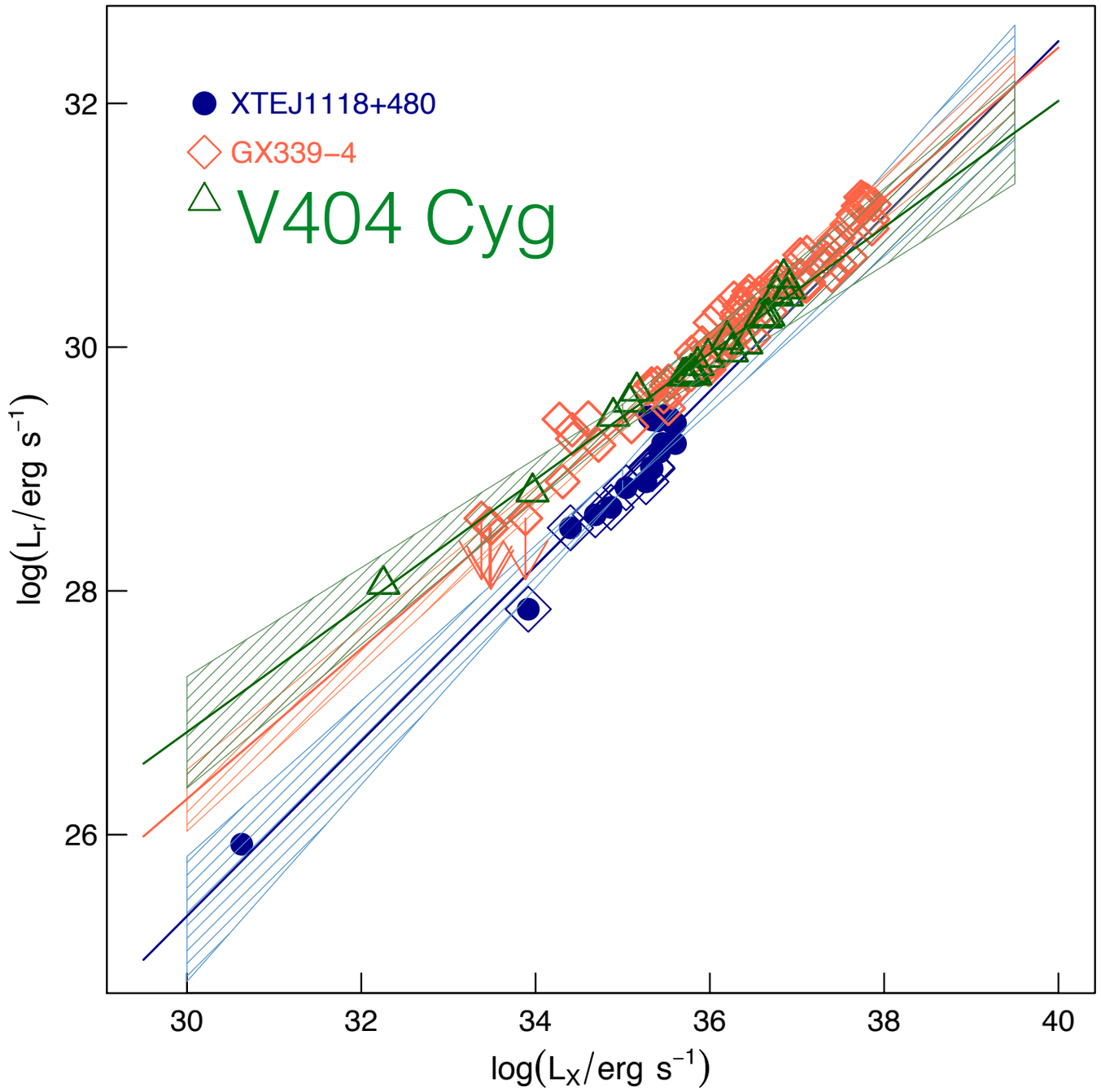
May1989 Outburst

- Zycki et al. 1999
- Ginga Observations
- Strong X-ray variability
  - both intrinsic and absorption
  - Not clear how long the outburst lasted ~ a few days to weeks

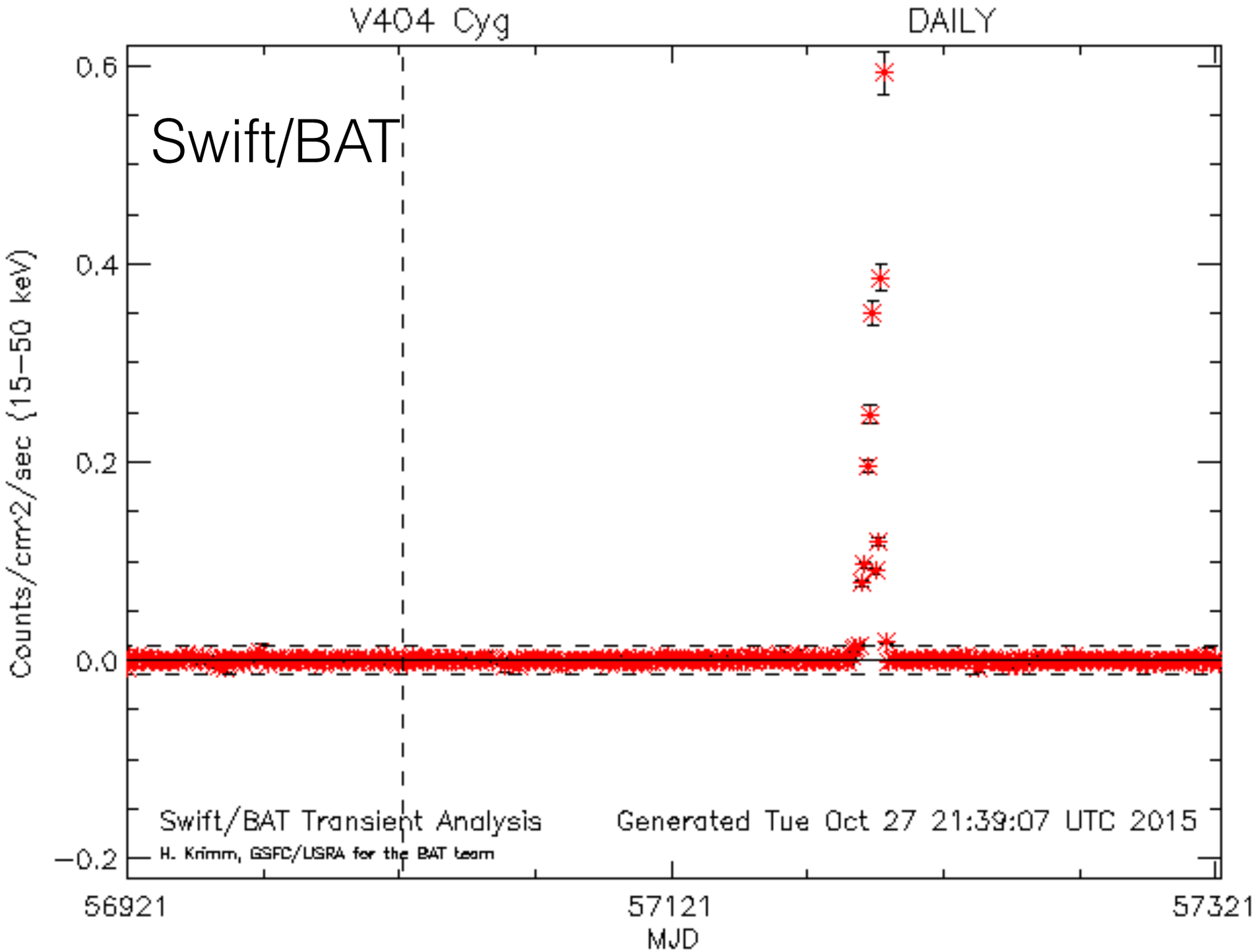


Into Quiescence

- Gallo et al. 2014
- V404 1989 Outburst into Quiescence
- Falls on “Fundamental Plane of Black hole Activity”
  - Radio emission has an exponential dependence on X-ray emission, even at low X-ray luminosity

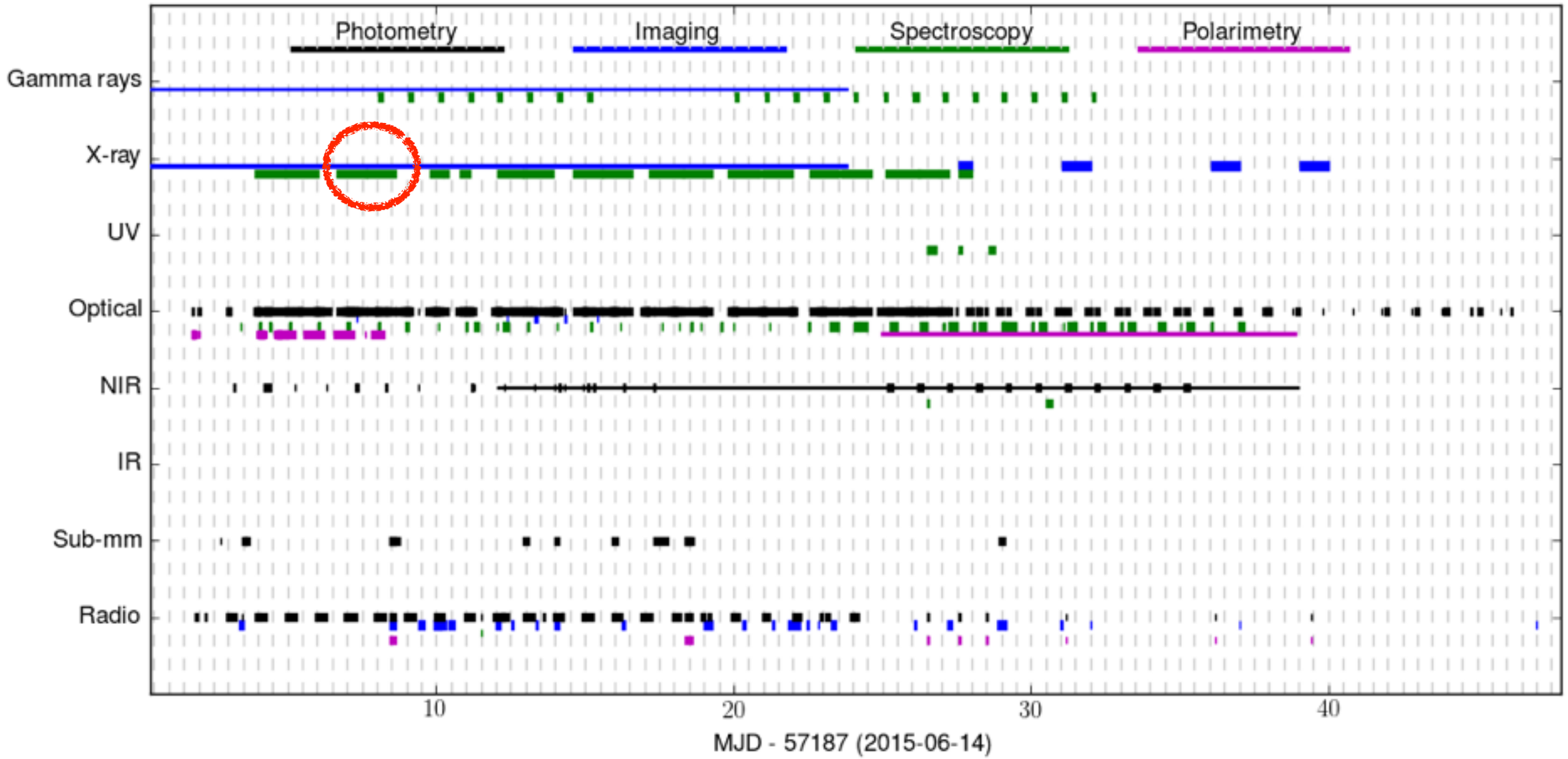


June 2015 Outburst

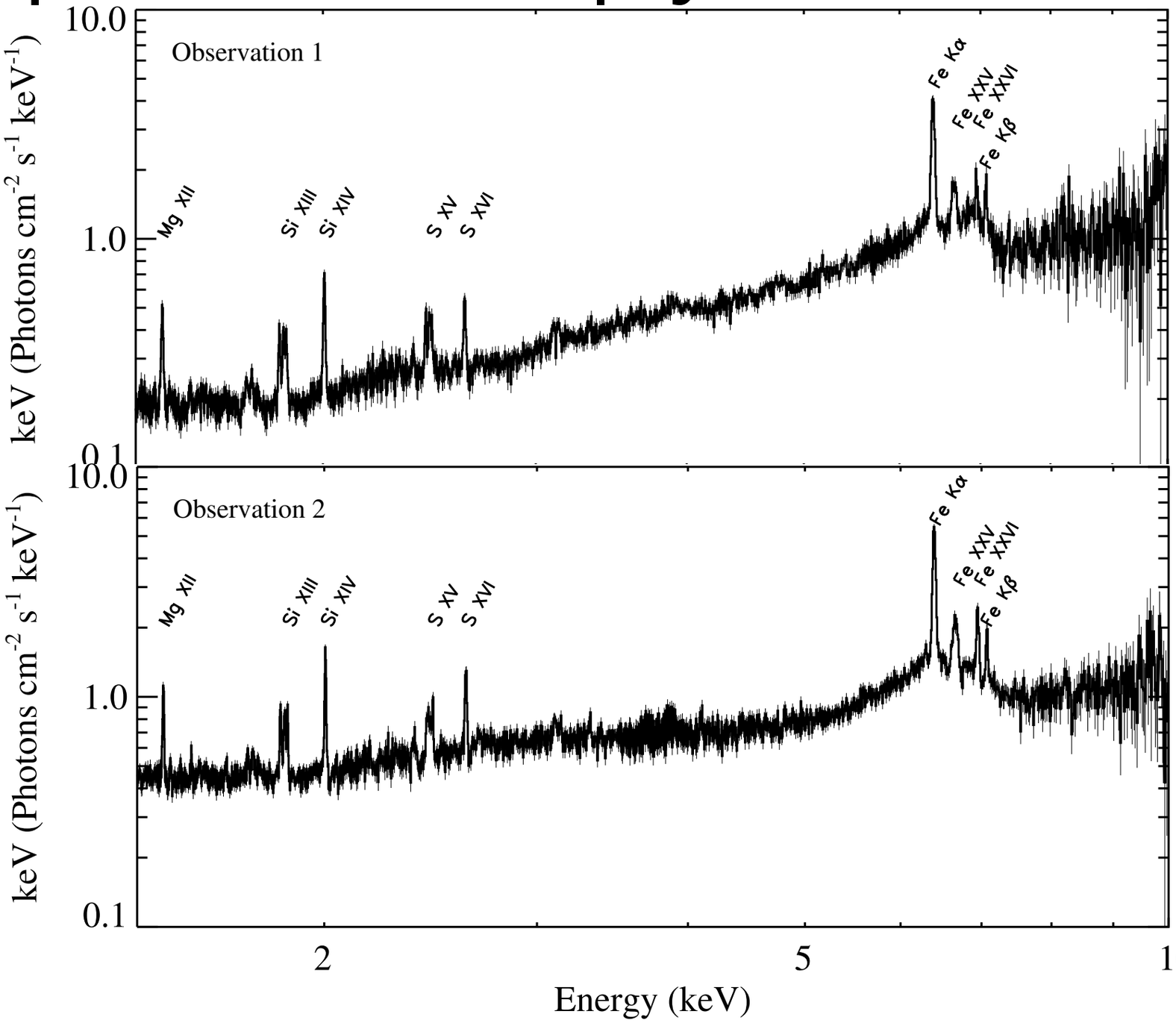


June 2015 Outburst

http://deneb.astro.warwick.ac.uk/phsaap/v404cyg/data/



Chandra HETG Spectroscopy of V404 Cyg



June 22, 2015
21 ksec

<F> = 9.5x10^{-9} ergs/s/cm^3

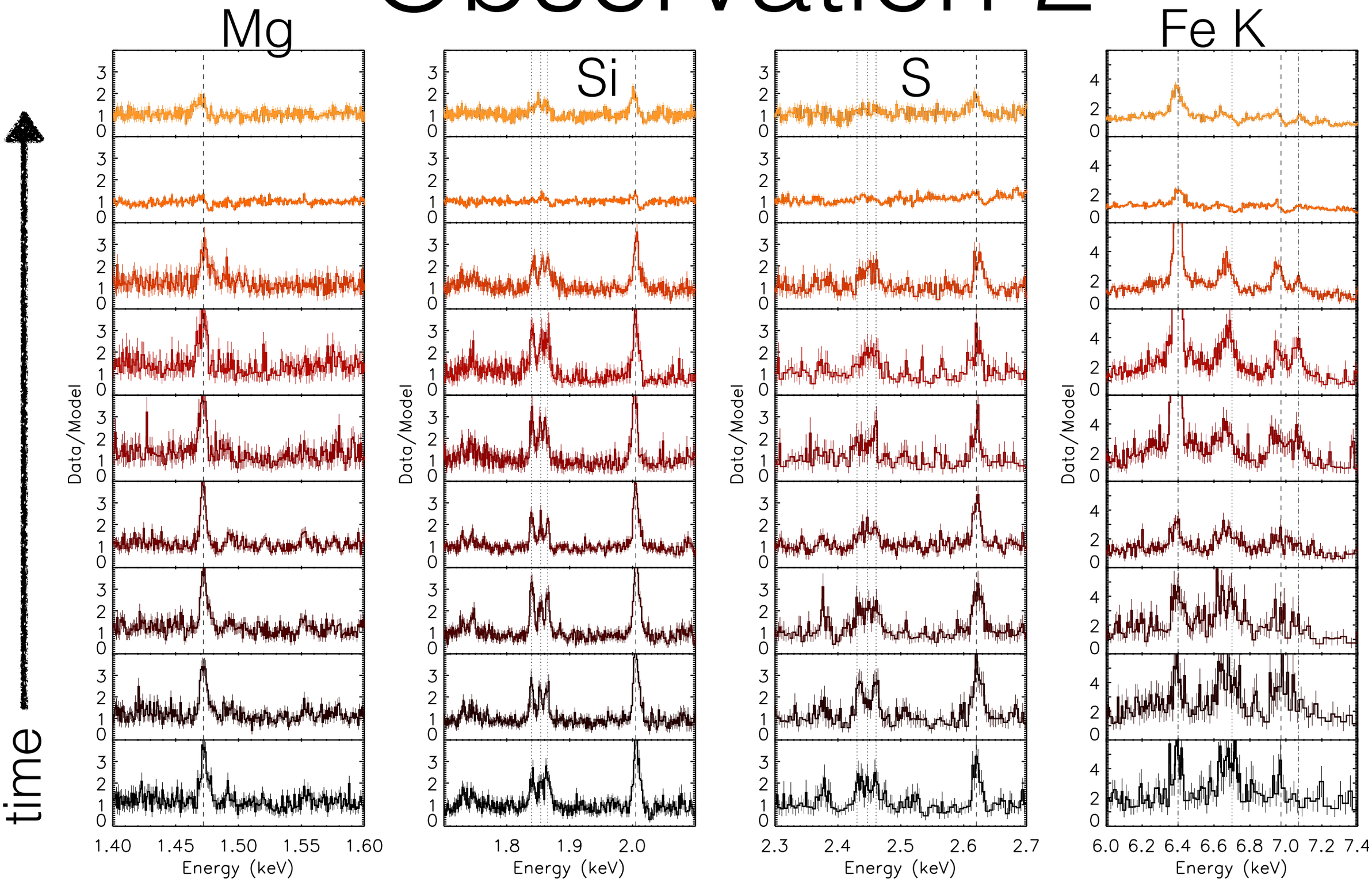
<L> = 6.5x10^{36} ergs/s

June 23, 2015
25 ksec

<F> = 1x10^{-8} ergs/s/cm^3

<L> = 8.9x10^{36} ergs/s

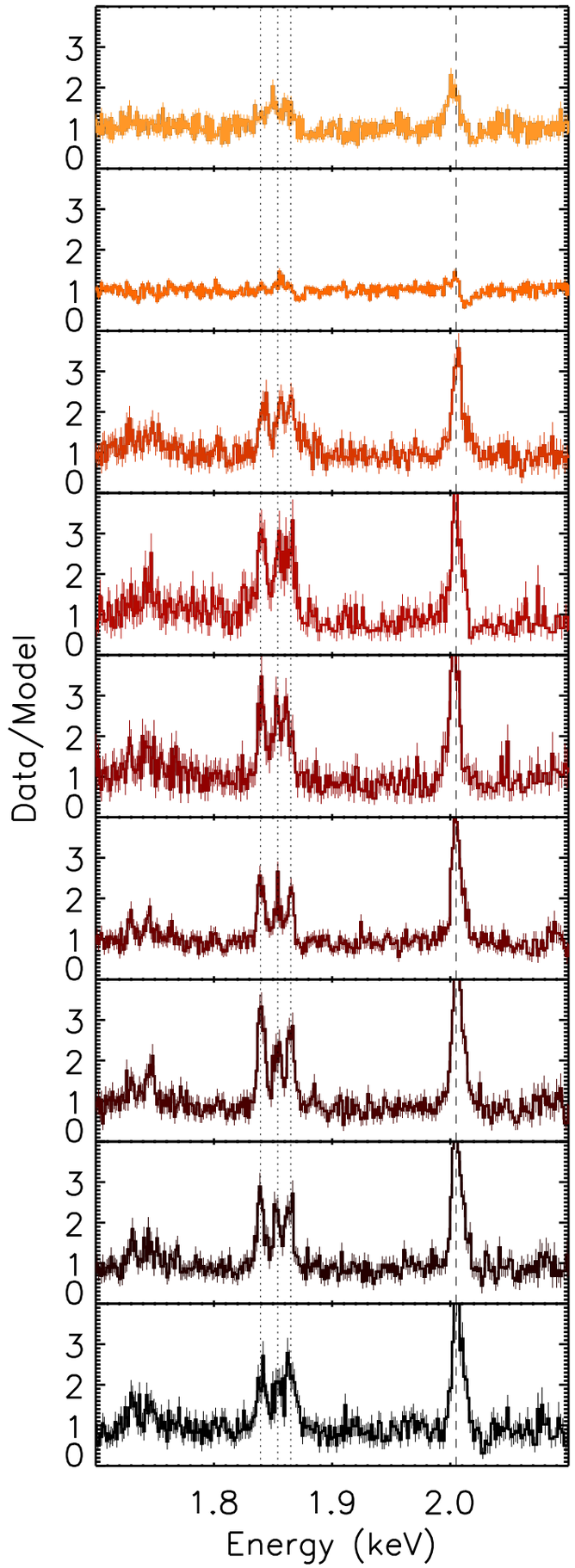
Observation 2



He-like Triplet

- i/f ~ 1
  - if collisionally excited n~3x10^{13} cm^{-3}
  - If photoexcitation from strong UV field is important
    - r= 4x10^{11} cm
- r/(f +i) ~ 0.5 is intermediate between collisional and photoionized cases
  - Could be Photoionized, but with T > T_{eq} = 7x10^{5} K

    or
    - Some of r intensity is P Cygni emission -> supported by the blue-shifts and larger line widths
- Outer Disk - orbit of binary separation is r~2x10^{12} cm



Emitting Region Density and Size

$N_H = n\,r \quad \sim \quad 3\text{x}10^{22} \quad cm^{-2}$

EM = Emission Measure = $n^2V = 4\pi n^2 r^3 \sim 2\text{x}10^{58} \ cm^{-3}$

$\xi = L/nr^2 \sim \ 1000$

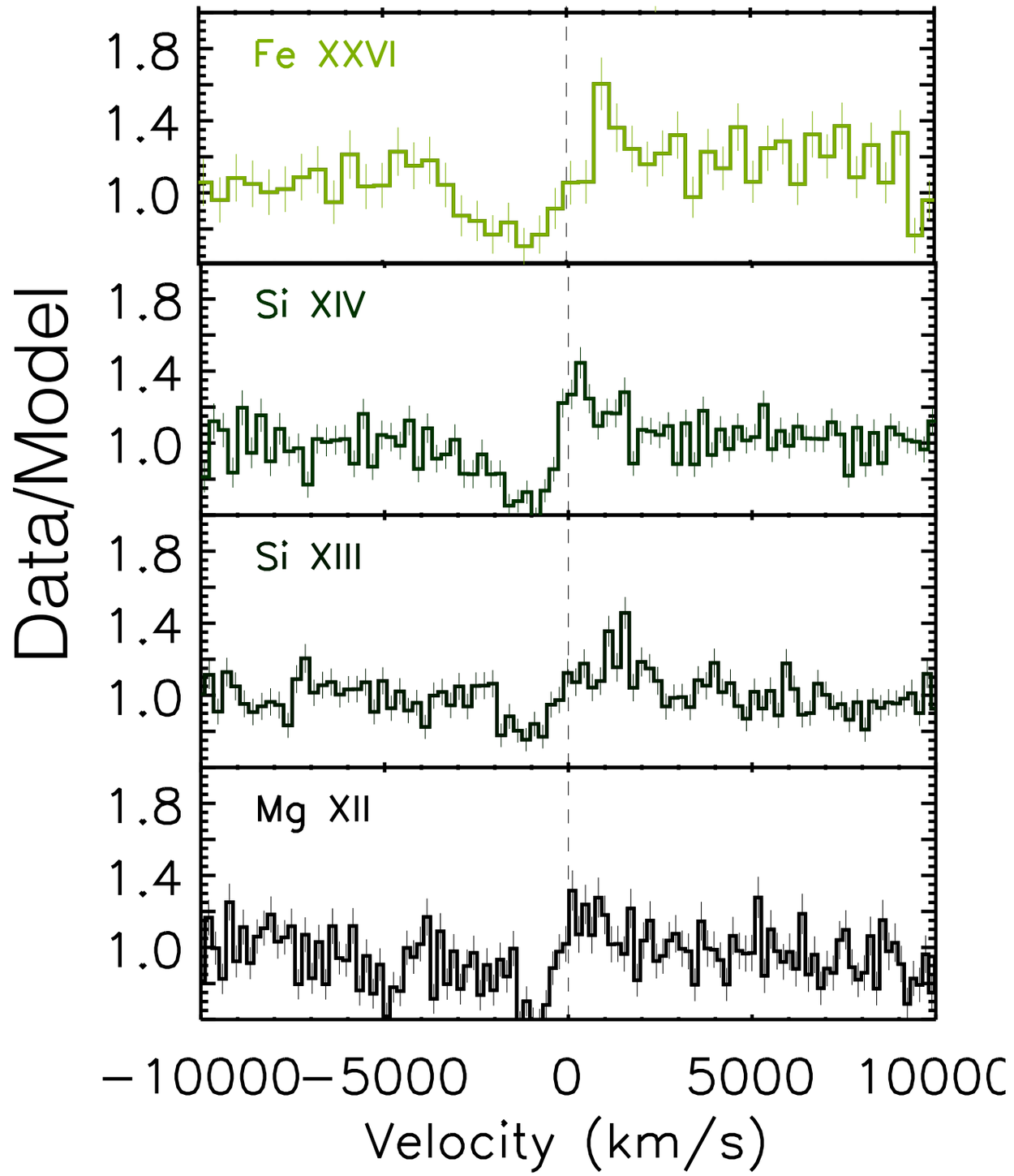
$r \ = \ nr^2/nr \ = \ L/\xi nr \ = \ n^2r^3/(nr)^2 \ = \ EM/2\pi N_H^2$

$r \ \sim \ 3\text{x}10^{12}$ cm ~ binary separation -> outer disk

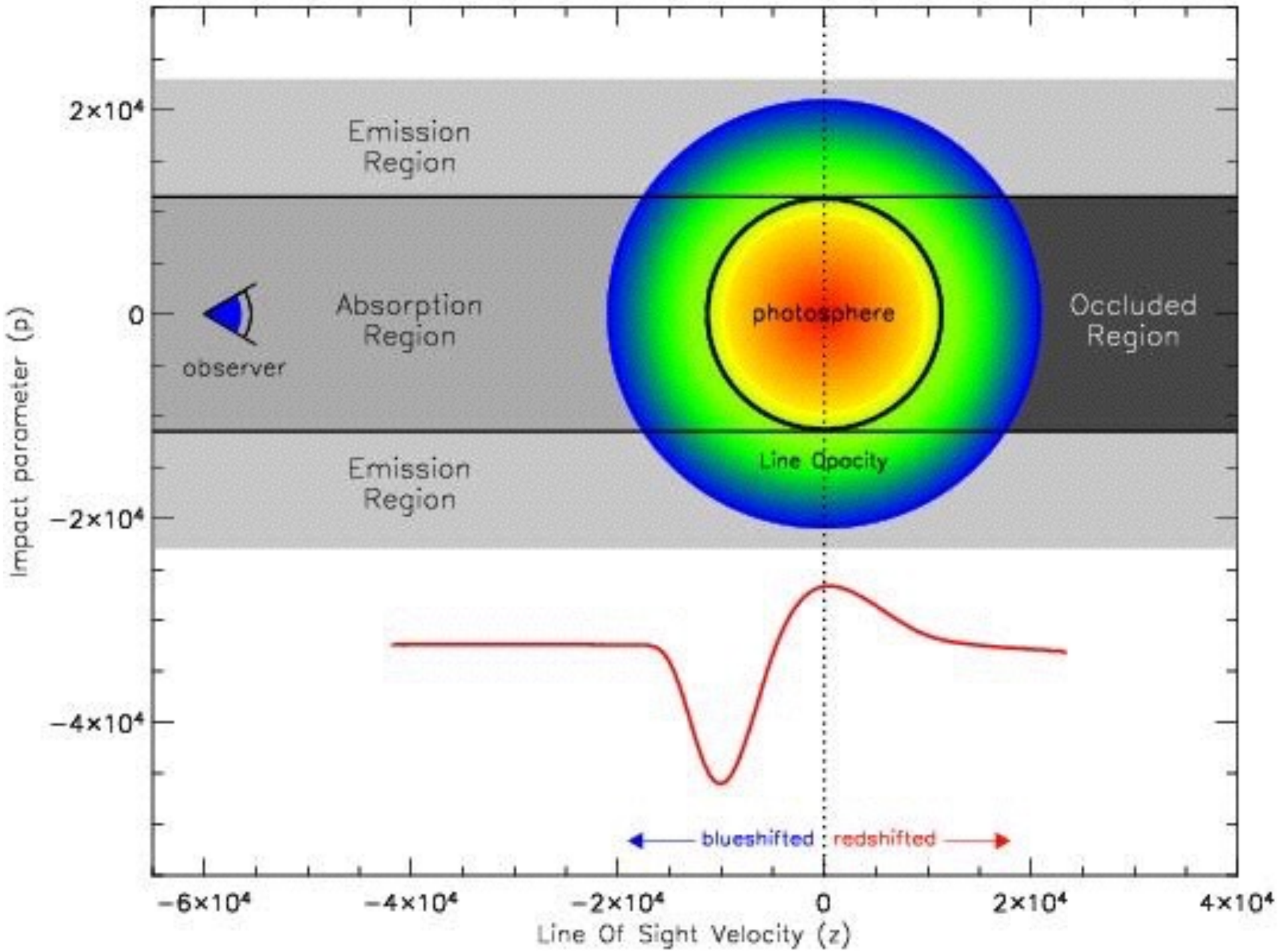
$n \ \sim \ 3\text{x}10^{10} \ cm^{-3}$

P-Cygni Profiles

- Highest Fluxes
  - >0.1 L_Edd
    - Absorption increases to >4000 km/s in the highest ionization lines
- Earlier in the outburst Optical P-Cygni Profiles were detected with velocities of ~4000 km/s

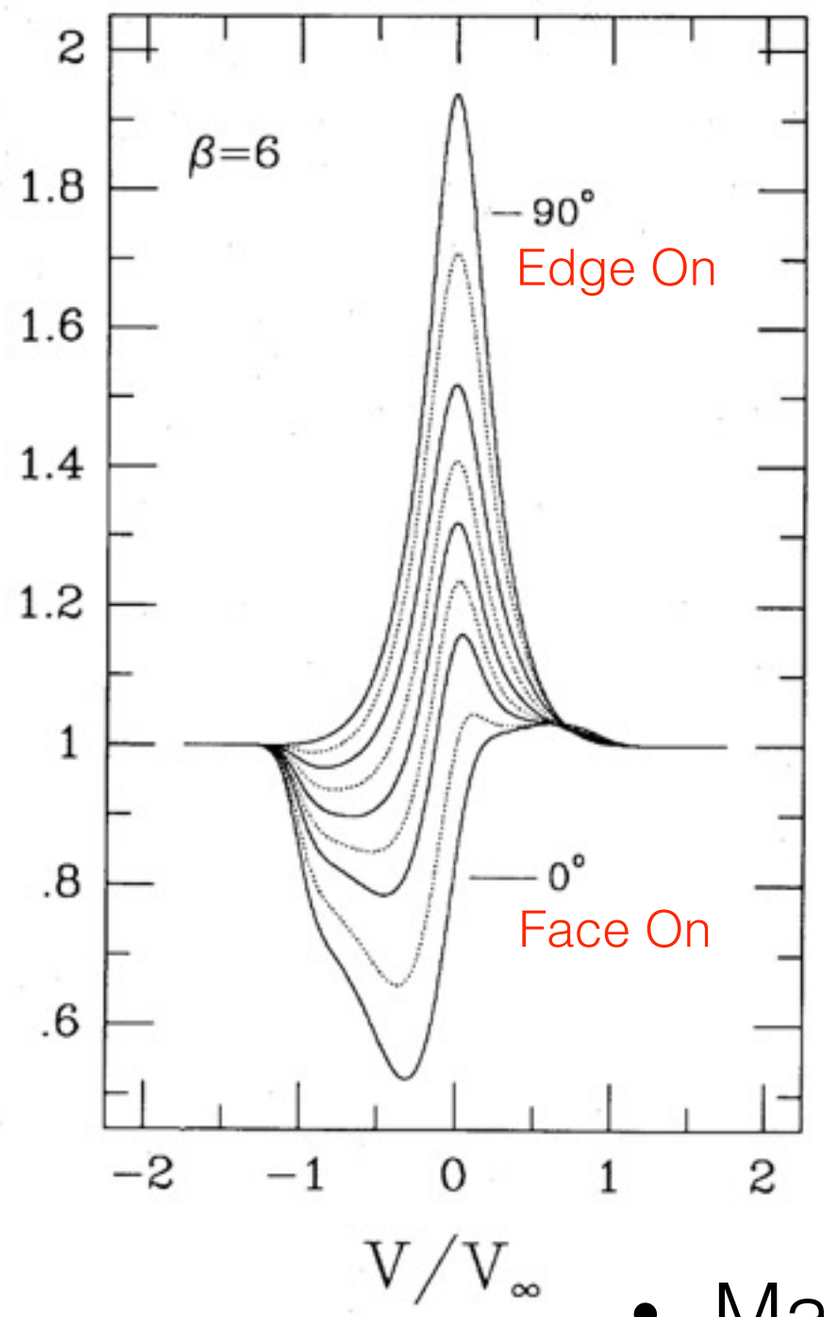


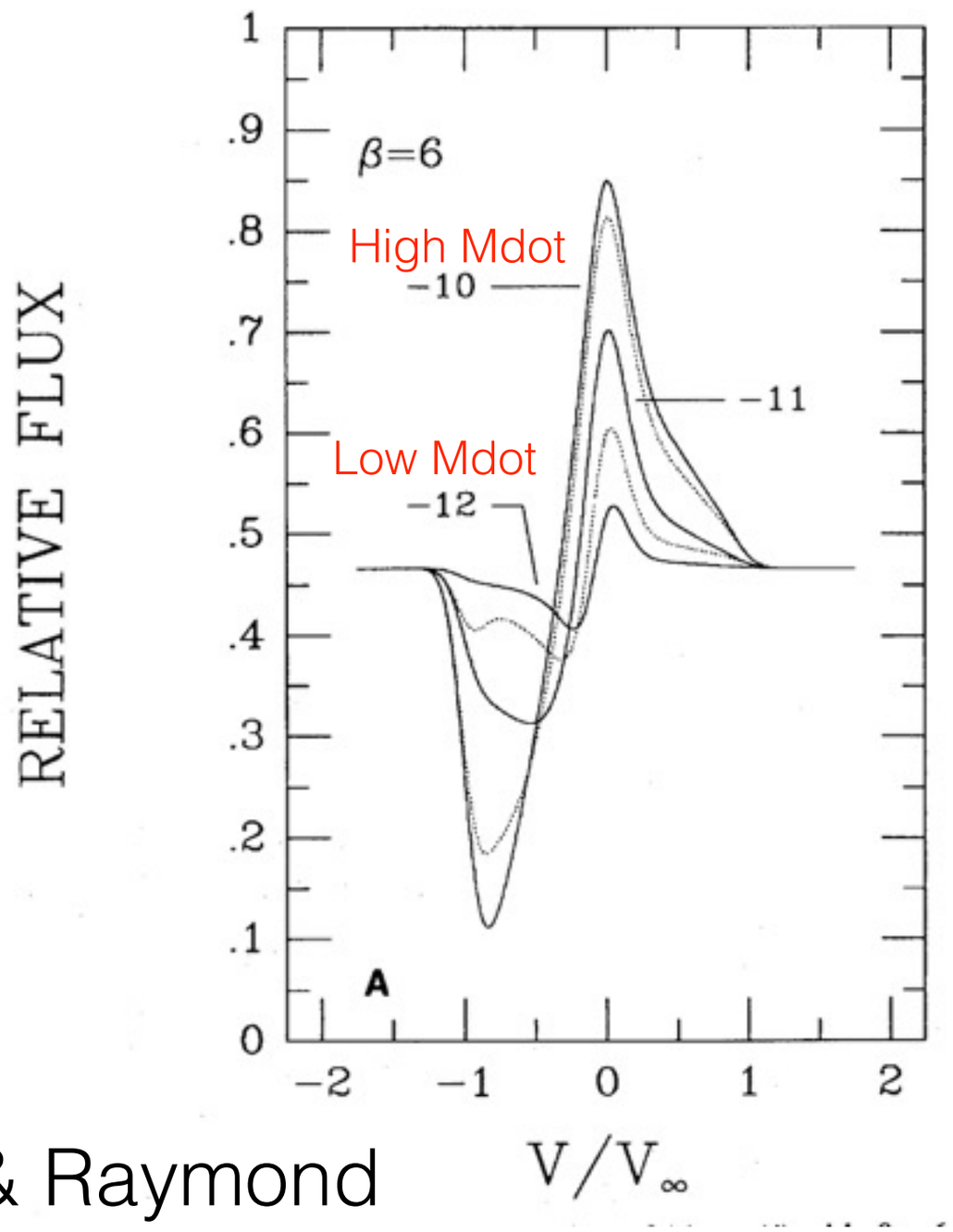
P-Cygni Geometry



Morrison et al. - astrobites

Disk Wind Profiles



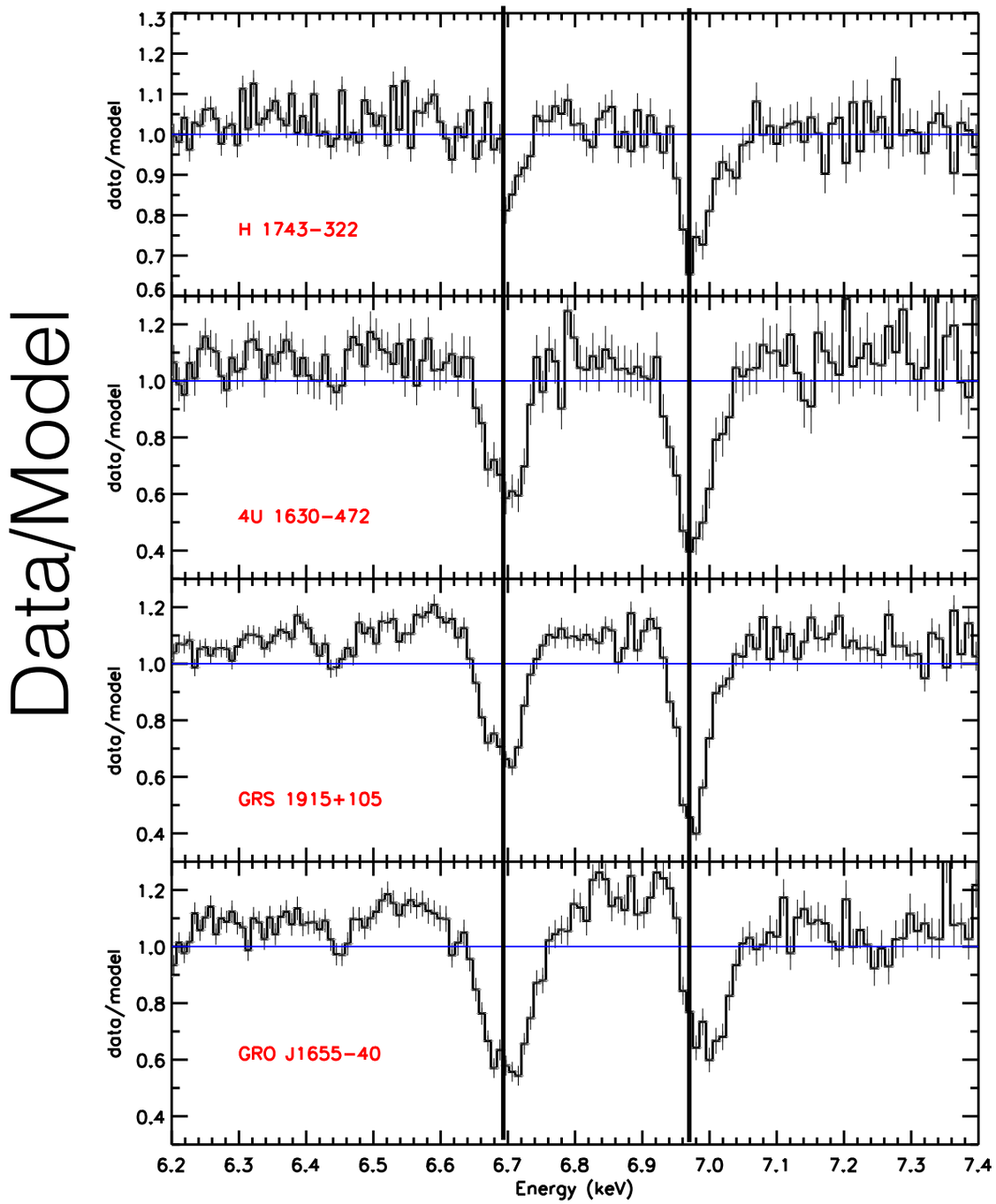


- Mauche & Raymond

Depends strongly on inclination, Mdot, velocity law

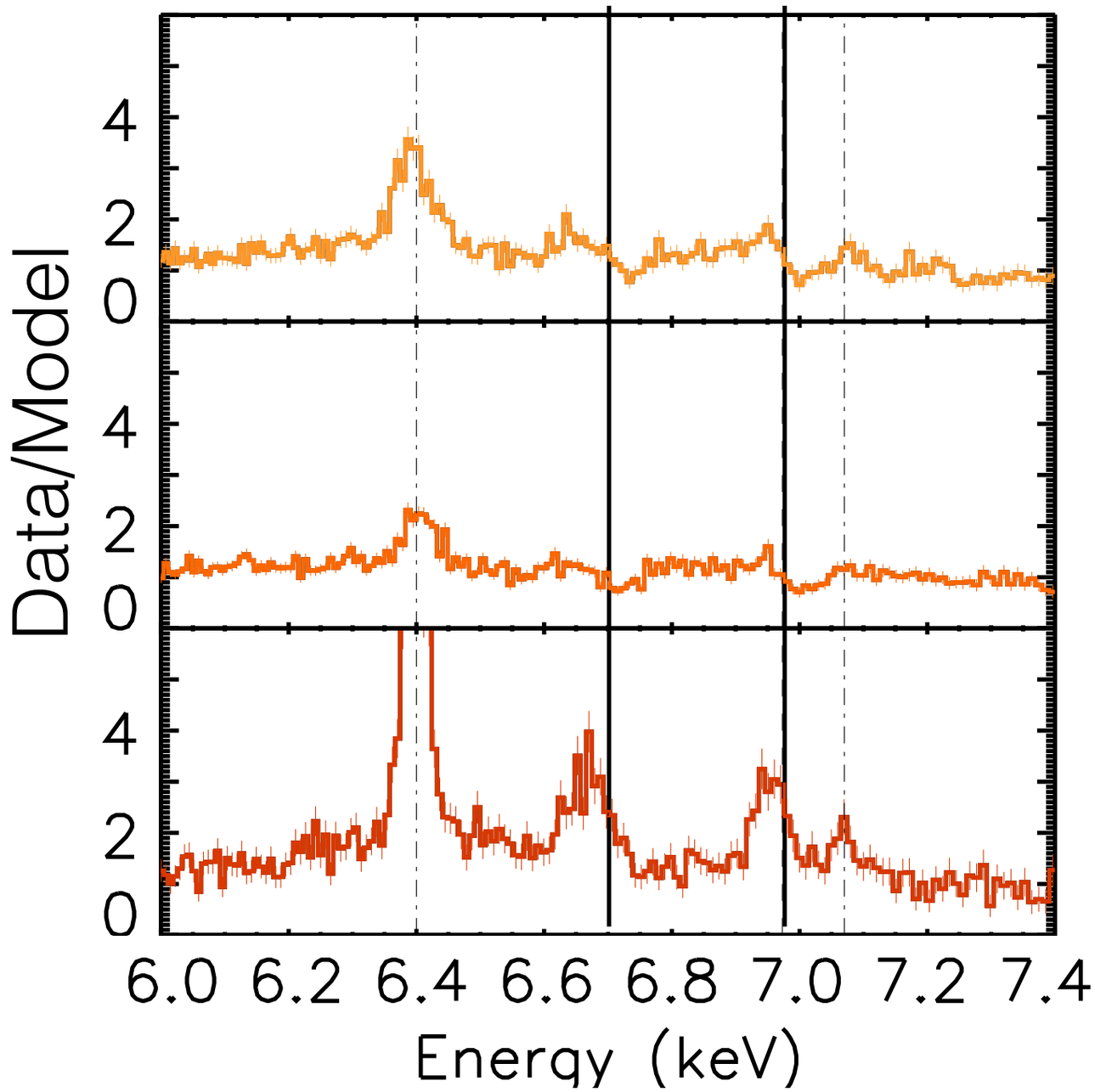
Wind Profiles

"Typical" X-ray Binaries

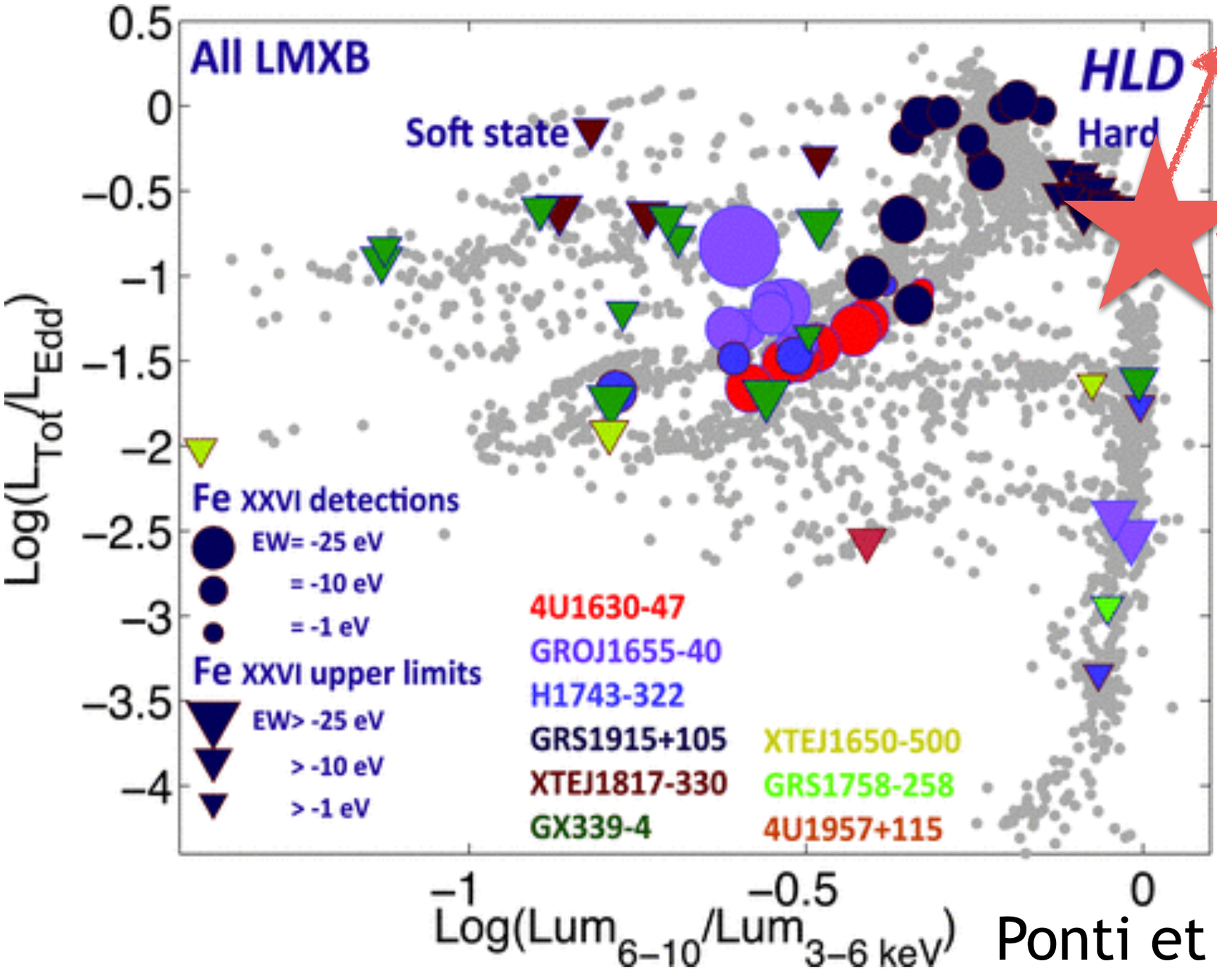


Miller et al. 2015

V404 Cyg



Typical X-ray Binary Winds



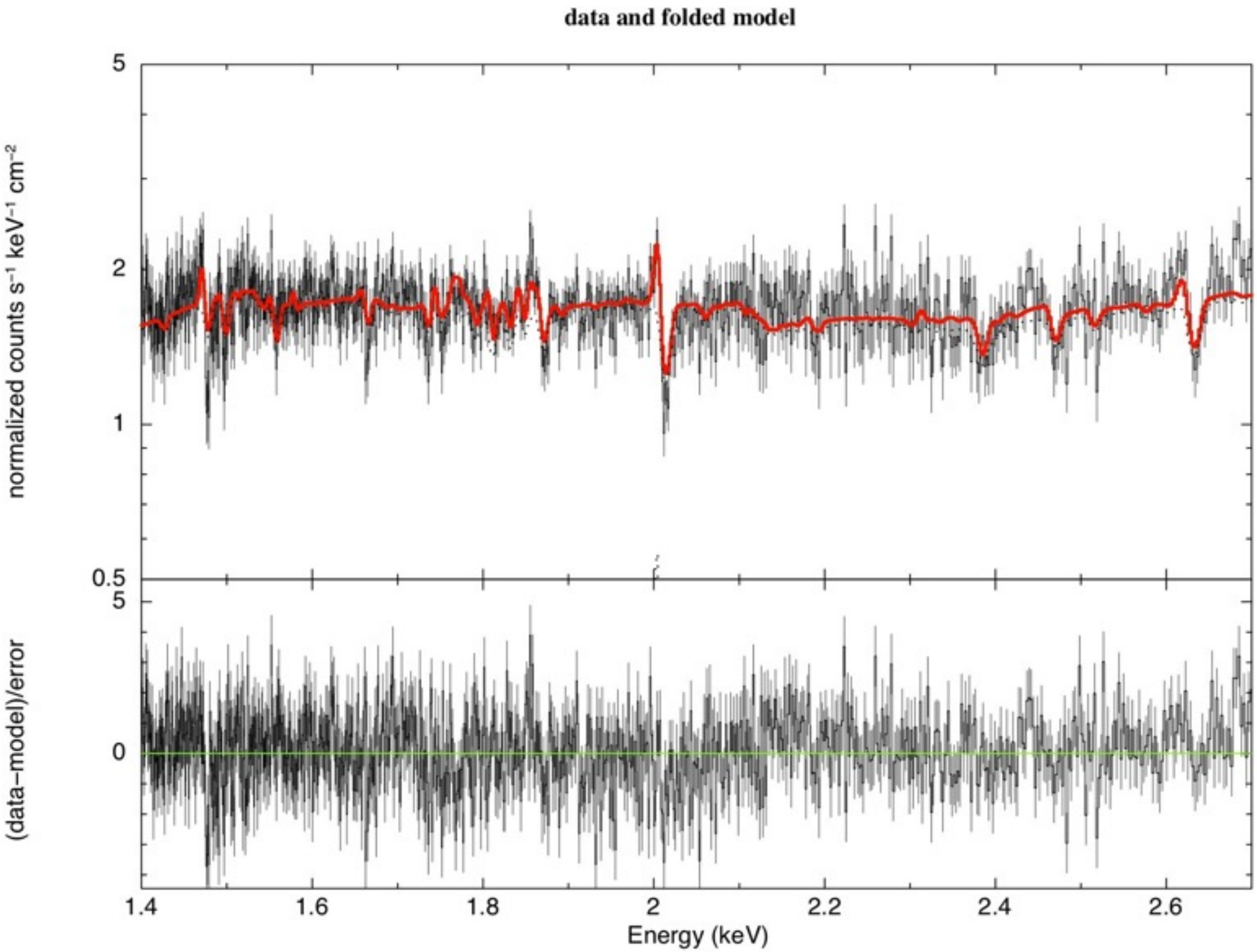
Ponti et al. 2012

V404 Cygni Wind Parameters

- Covering fraction is HUGE, compared to other X-ray binaries
- V_wind = 4000 km/s, xi= 3 (Si/S ratios)
- $\xi = \frac{L_{ion}}{nr^2}$
- $\dot{M}_w = \Omega\mu\frac{L}{\xi}V_w$ = 3x10^{20} g/s = 5x10^{-6} M_{solar}/year
- $L_w = \frac{1}{2}\dot{M}_w v_w^2$ = 2x10^{37} ergs/s
- $L_w/L_{bol} = \frac{\Omega\mu v_w^3}{2\xi}$ = 0.06 $\dot{M}_w/\dot{M}_{acc} = 30$

Preliminary X-Star models

- Good fit for ~low energy ions
- Super Solar Abundances
- n=10^10 cm^-3
- resonant scattering into our line of sight
- UV emission
- Two Components
  - First
    - log xi = 1.8
    - N_H = 1.3x10^21 cm^-2
    - z_abs = -0.002
  - Second
    - log xi= 4.35
    - N_H = 3x10^20 cm^-2
    - z_abs=-0.004

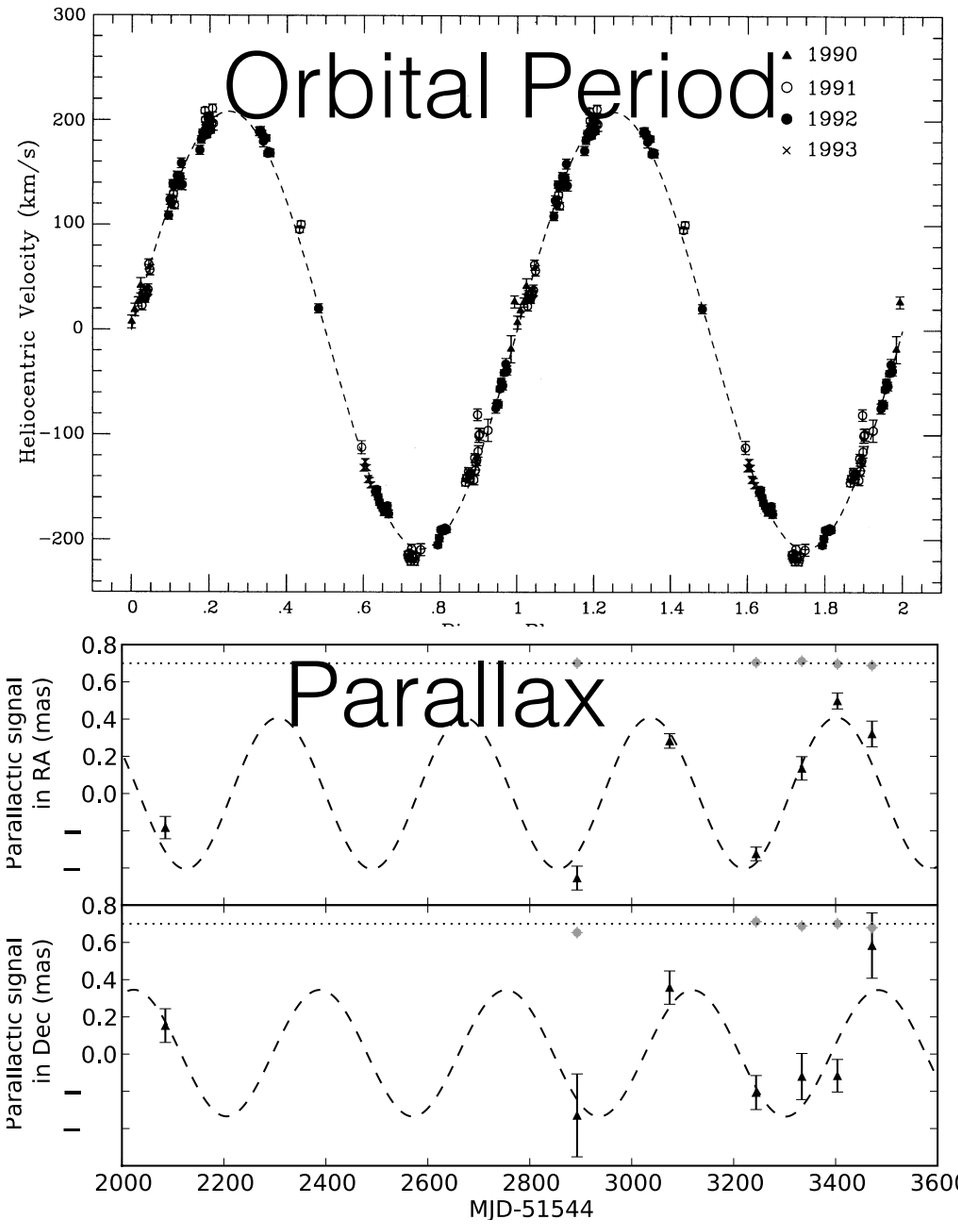


Conclusions

- V404 Cyg underwent a outburst in June of 2015 that likely reached and/or exceeded its Eddington limit
- Strong Variability
- Variable X-ray Emission and Absorption lines
- Emission lines are located in the outer disk (10^12 cm) with a density of ~10^10 cm^-3
- P-Cygni Profiles are observed at the highest flux flares
    - Dense but Fast wind (>4000 km/s)
- Mass Outflow rate exceeds the Mass Accretion Rate observed in the X-rays
- Future Work
        - Accelerated Disk Wind Models
        - Physical Modeling of the Spectral Evolution within each epoch
        - Broad Fe K alpha Line Evolution

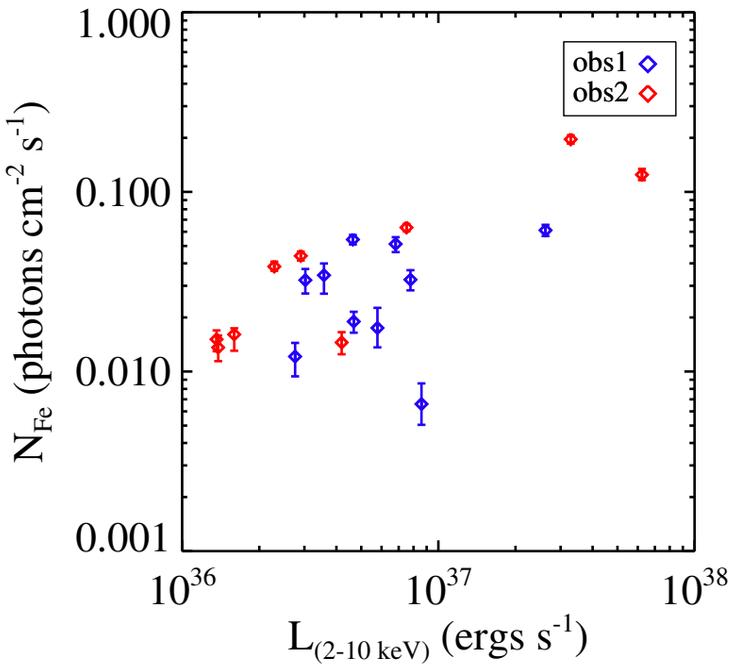
V404 Cygni

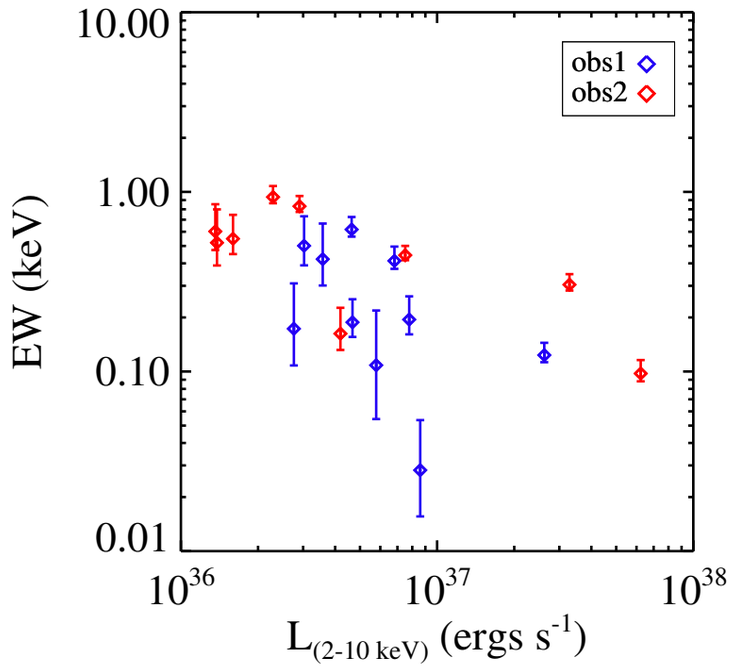
- Distance - 2.39+/-0.14 kpc - Parallax
- Mass: $9^{+0.2}_{-0.6}$ M_solar (8-12 M_solar)
  - **Black Hole**
- $L_{Edd} = 1.1 \times 10^{39}$ ergs/s
- inclination: 67^{+3}_{-1} degrees
- Donor Star - F0-F5 (low mass)
  - **Roche-lobe overflow**
  - Super Solar Abundances (1.7xFe_solar)
  - Orbital Period 6.4714 days
  - orbital separation $r \sim 2 \times 10^{12}$ cm

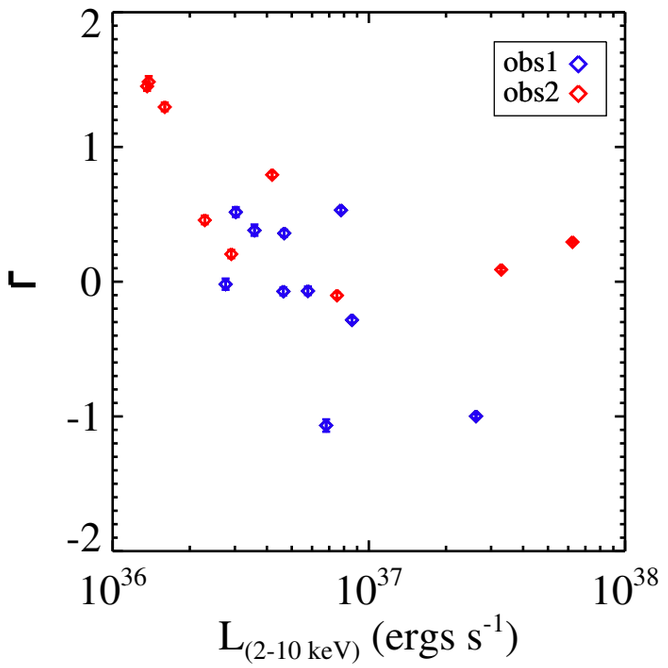


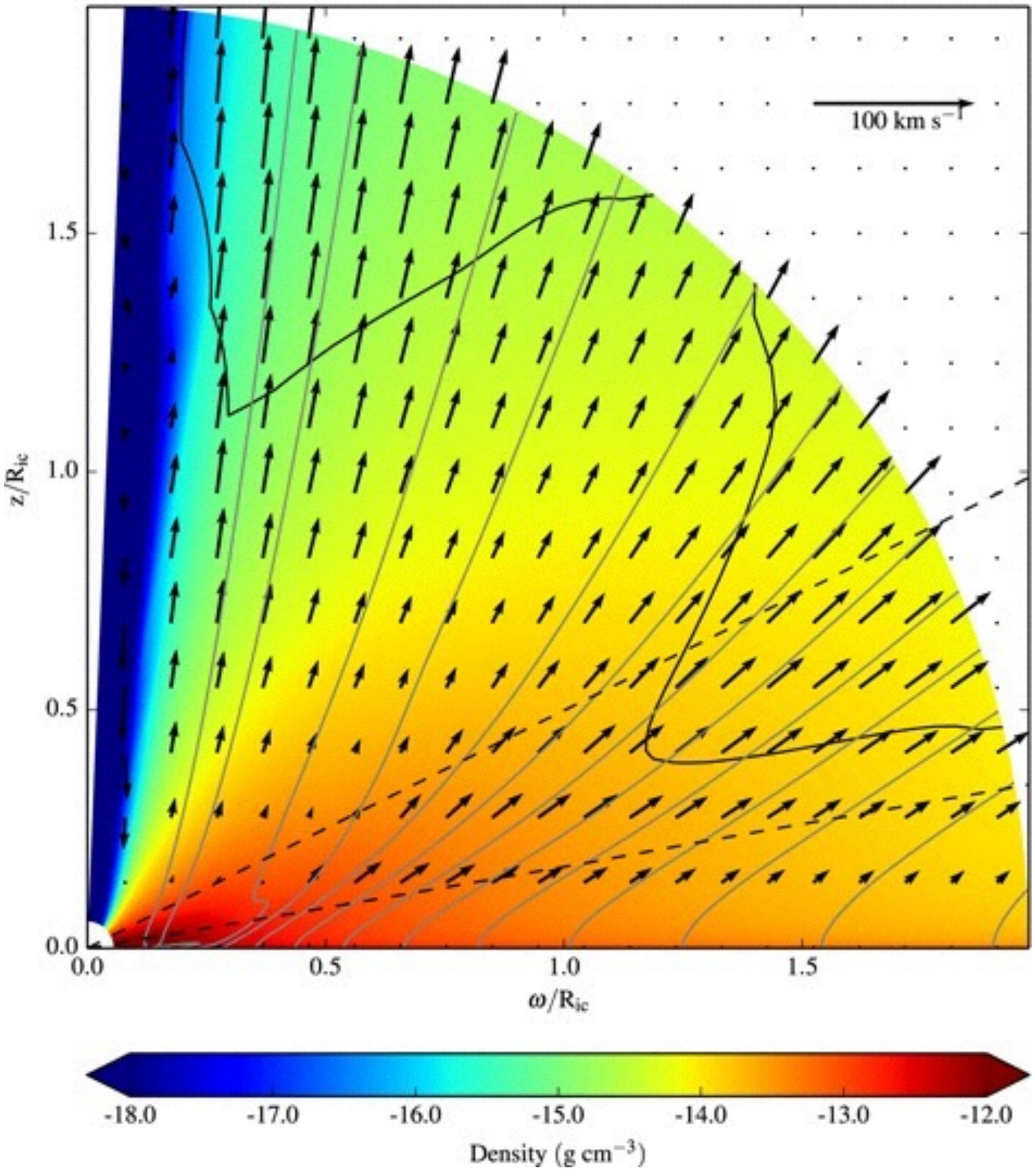
Casares & Charles 1994, Casares & Jonker 2014, Sanwal et al. 1996, Khargharia et al. 2010, Miller-Jones et al. 2009

Narrow Fe K alpha Line





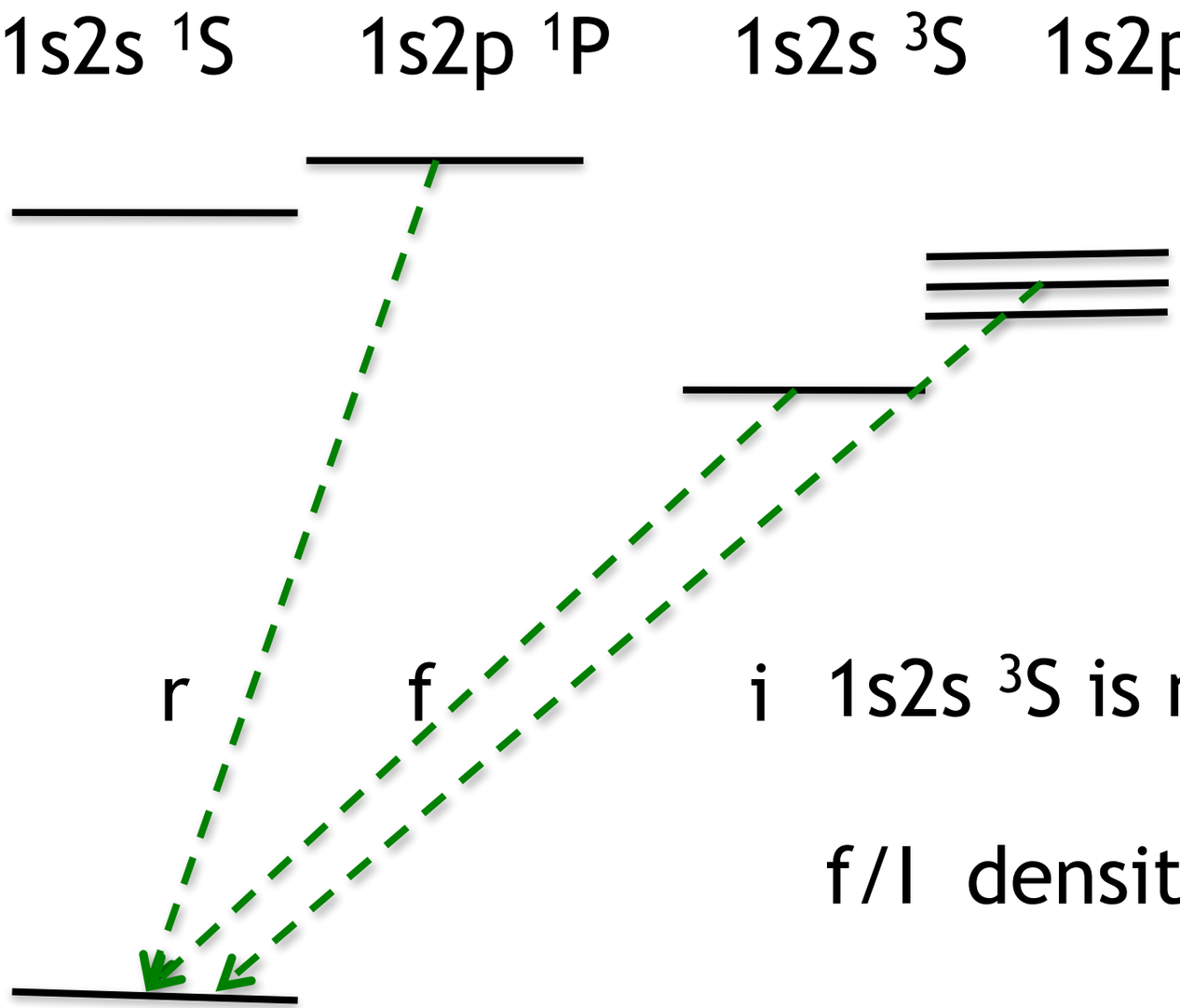




Thermally driven wind

Higginbottom & Proga

He-like Ion Structure



i 1s2s ^{3}S is metastable

f/I density or radiation flux

r/(f+i) recombination vs collisional excitation

P-Cygni Profiles from Disk Winds

- HL Cma
- UV profiles of C IV
- Dwarf Nova in Outburst
- Lines vary with inclination, M-dot and velocity structure
- Mauche & Raymond