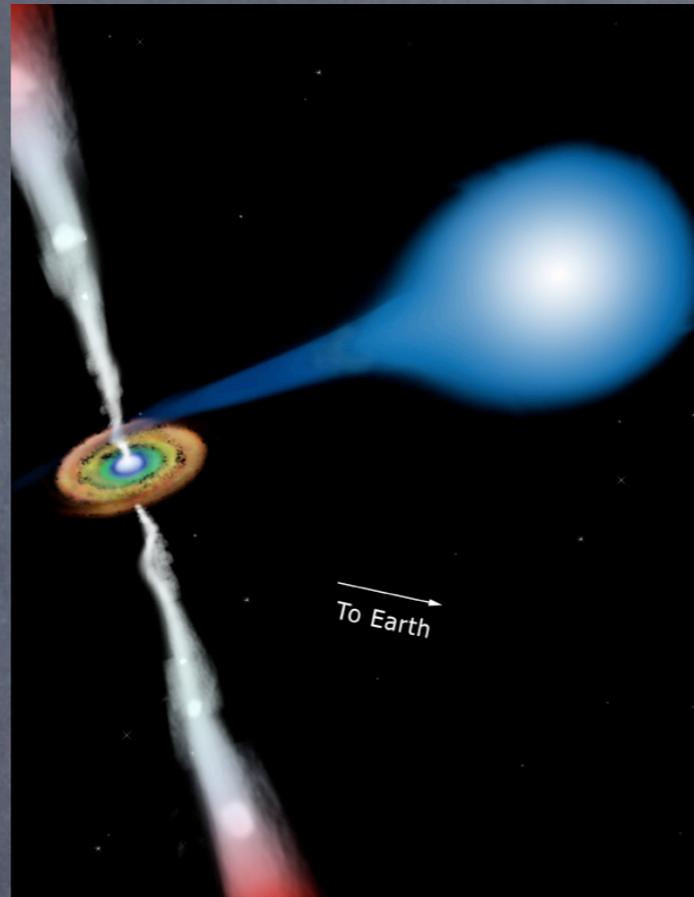


Modeling X-ray Spectra of the SS 433 Jets

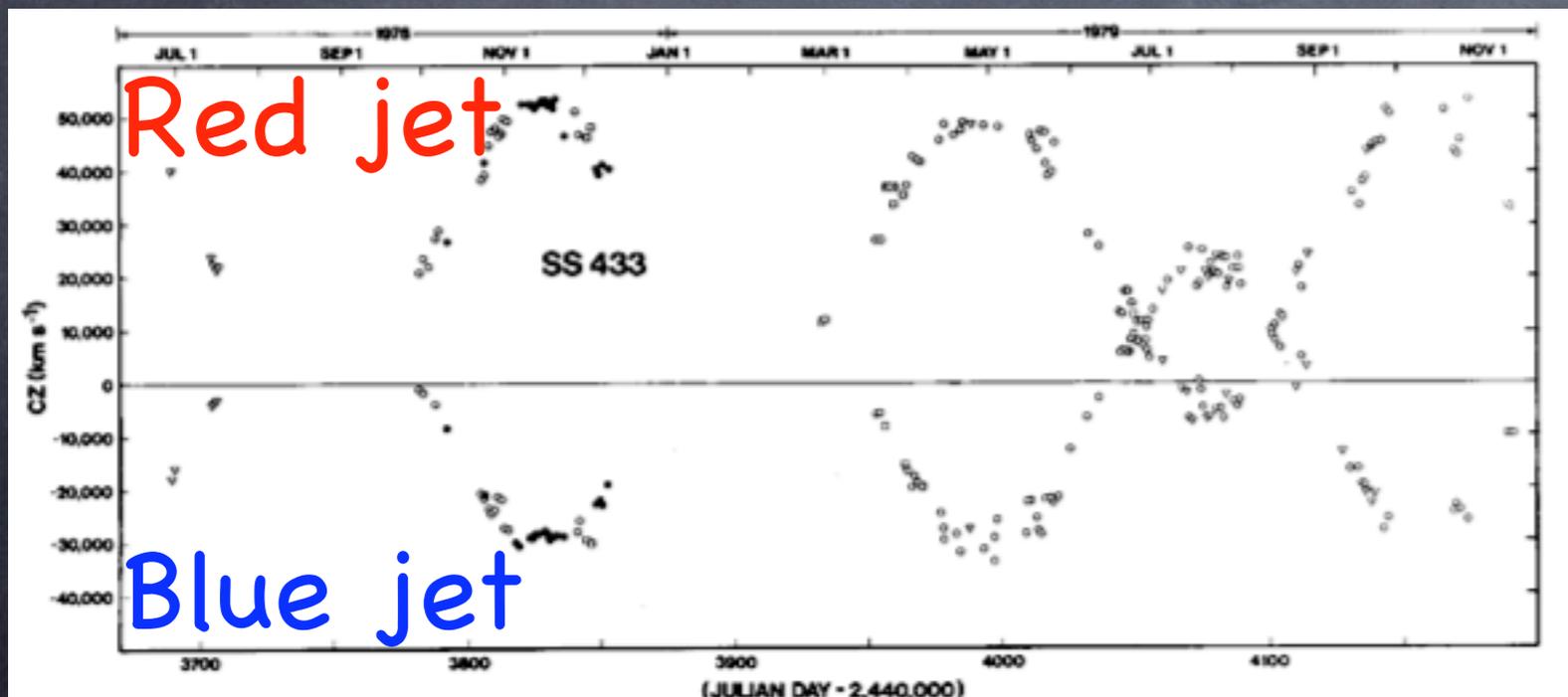


Herman L. Marshall, Claude R. Canizares,
Norbert S. Schulz, Sebastian Heinz, Mike Nowak
(MIT Kavli Institute)

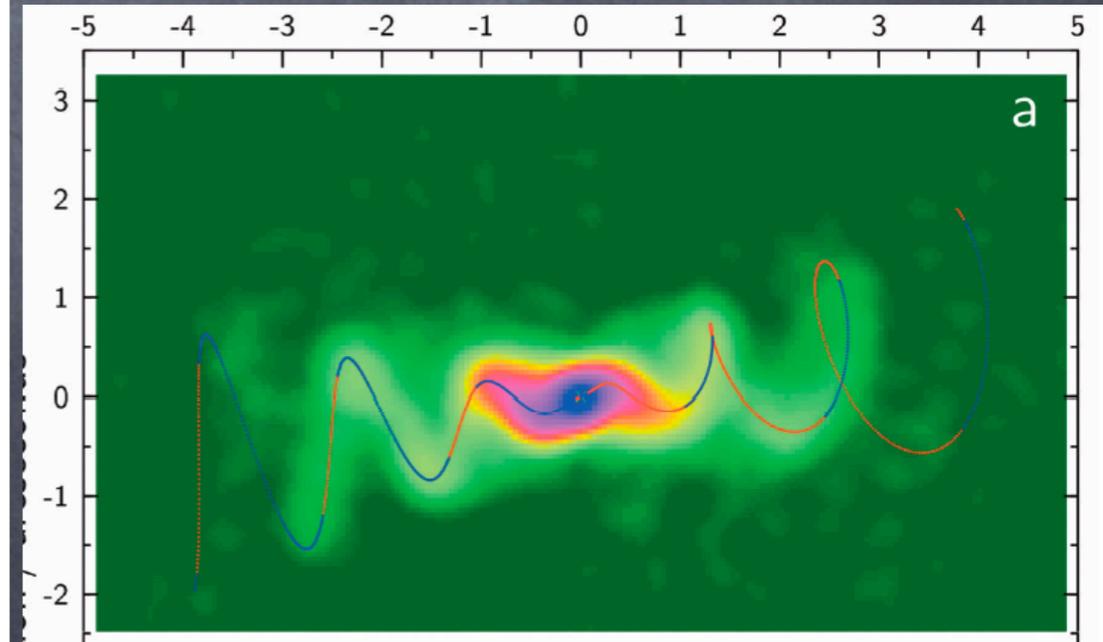
Todd Hillwig (Valparaiso), Amy Mioduszewski (NRAO)

SS 433 Background

- Periodically Doppler shifting H α HeI and H β
- Model: oppositely directed jets at 0.26 c
 - Precession period: 162 days $\frac{\lambda}{\lambda_0} = 1 + z = \gamma(1 \pm \beta \cos \alpha)$
 - Orbital period: 13.08 days
- Radio: verifies model and sets orientation
- Only jet known to contain baryons



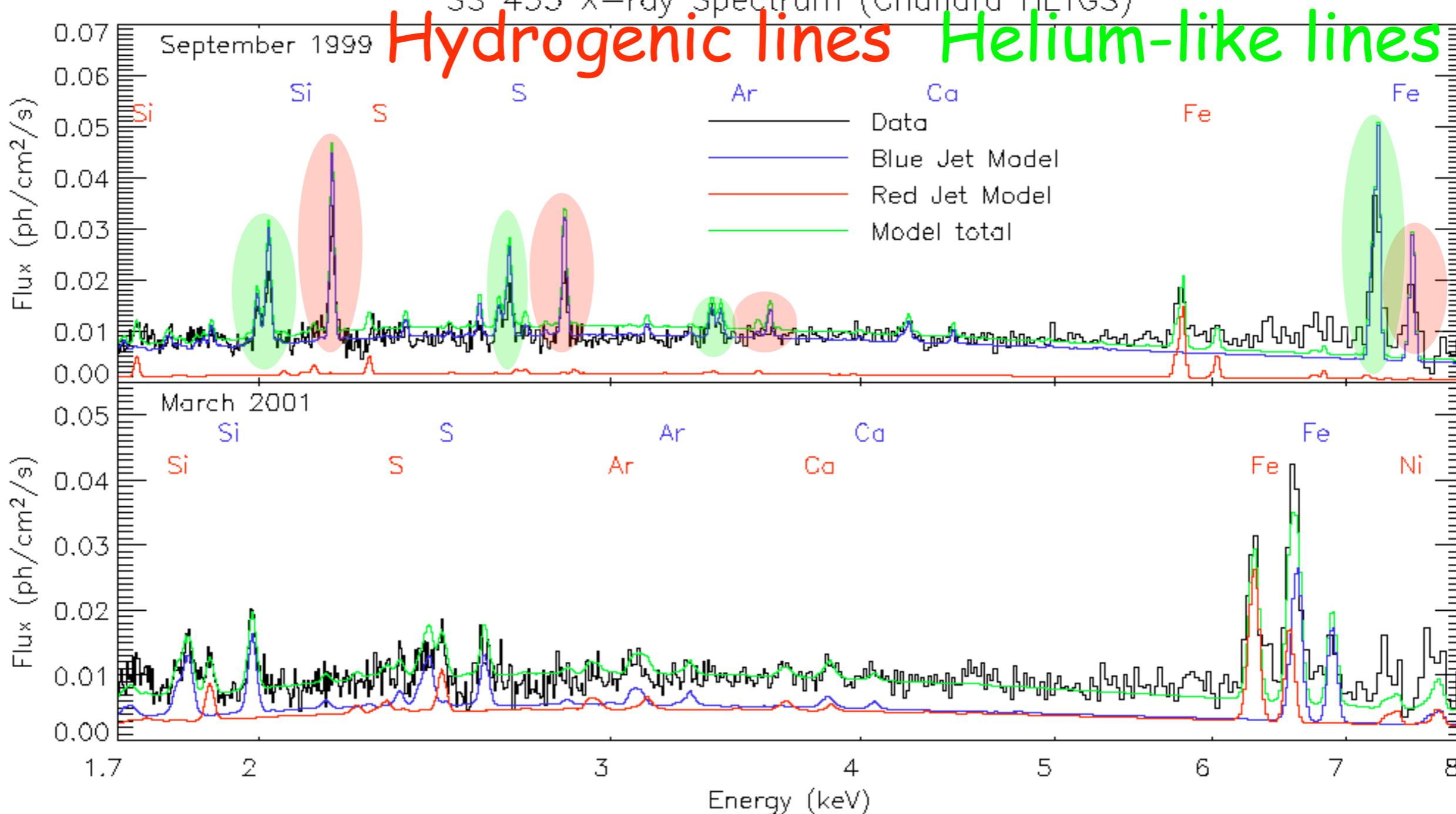
Margon et al. 1980



Blundell & Bowler 2005

Two HETGS Spectra

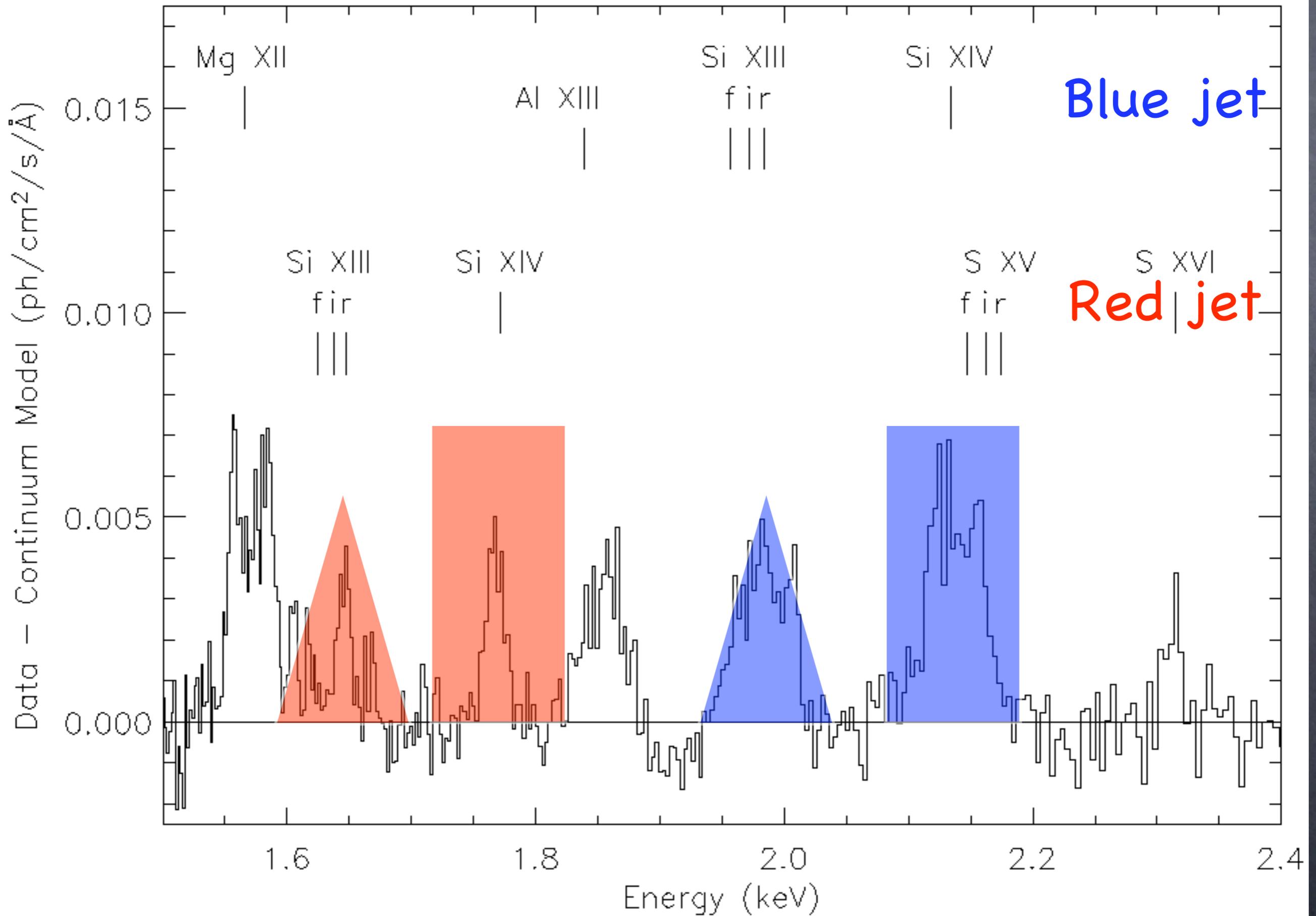
SS 433 X-ray Spectrum (Chandra HETGS)



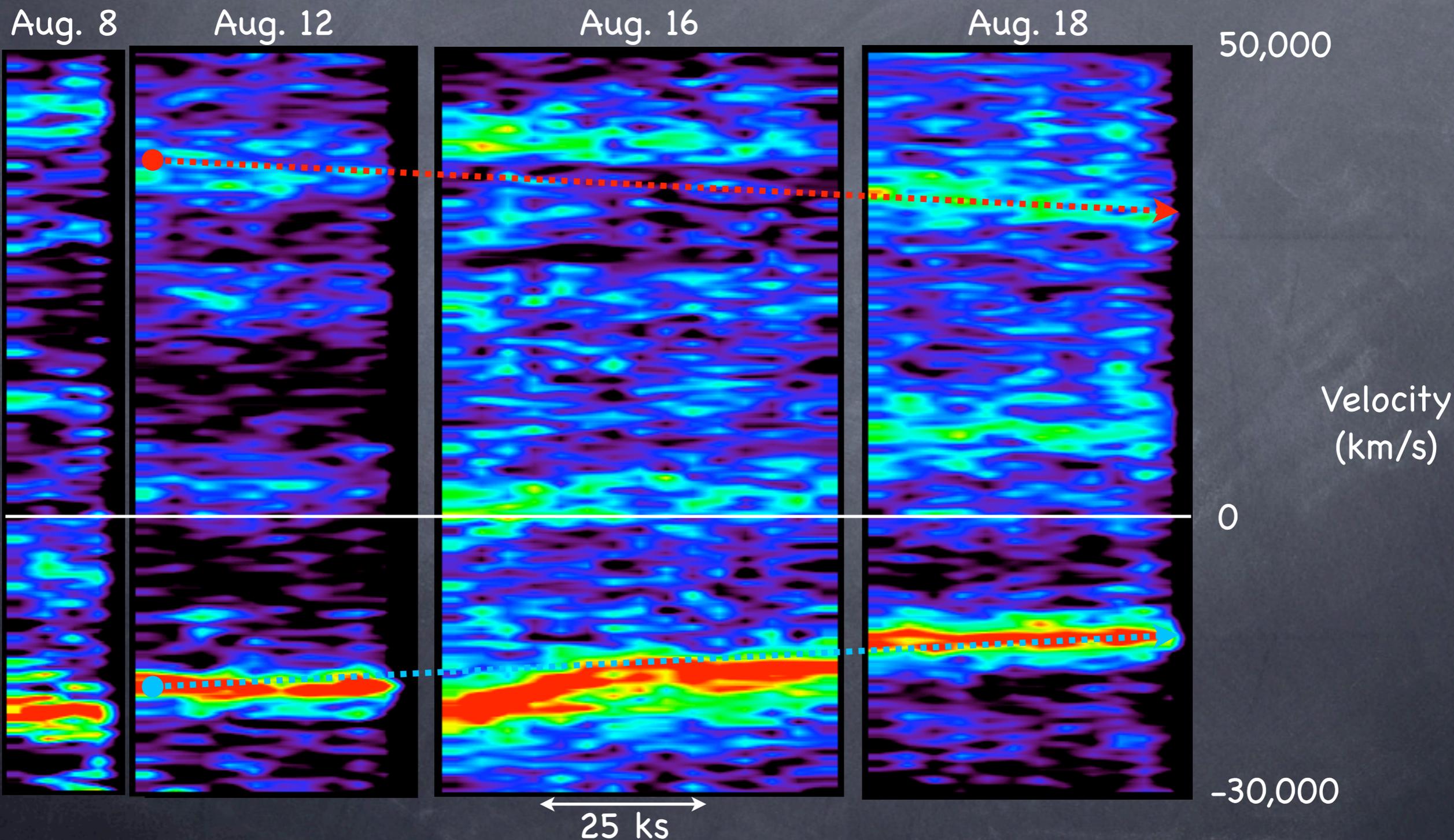
Jet Physics from Lines

- Line Doppler shifts
 - not in acceleration zone
 - all ions accelerated to same speed
- Line widths
 - not in nozzle or flaring zone
 - opening half-angle is constant at 0.75°
- Line strengths
 - collisionally heated plasma, $kT_b = 15 \text{ keV}$
 - EM(T), test cooling models
 - with continuum, get abundances
- Si XIII triplet: electron density $\sim 10^{14} \text{ cm}^{-3}$

SS 433 Aug 16, 2005 Chandra HETGS

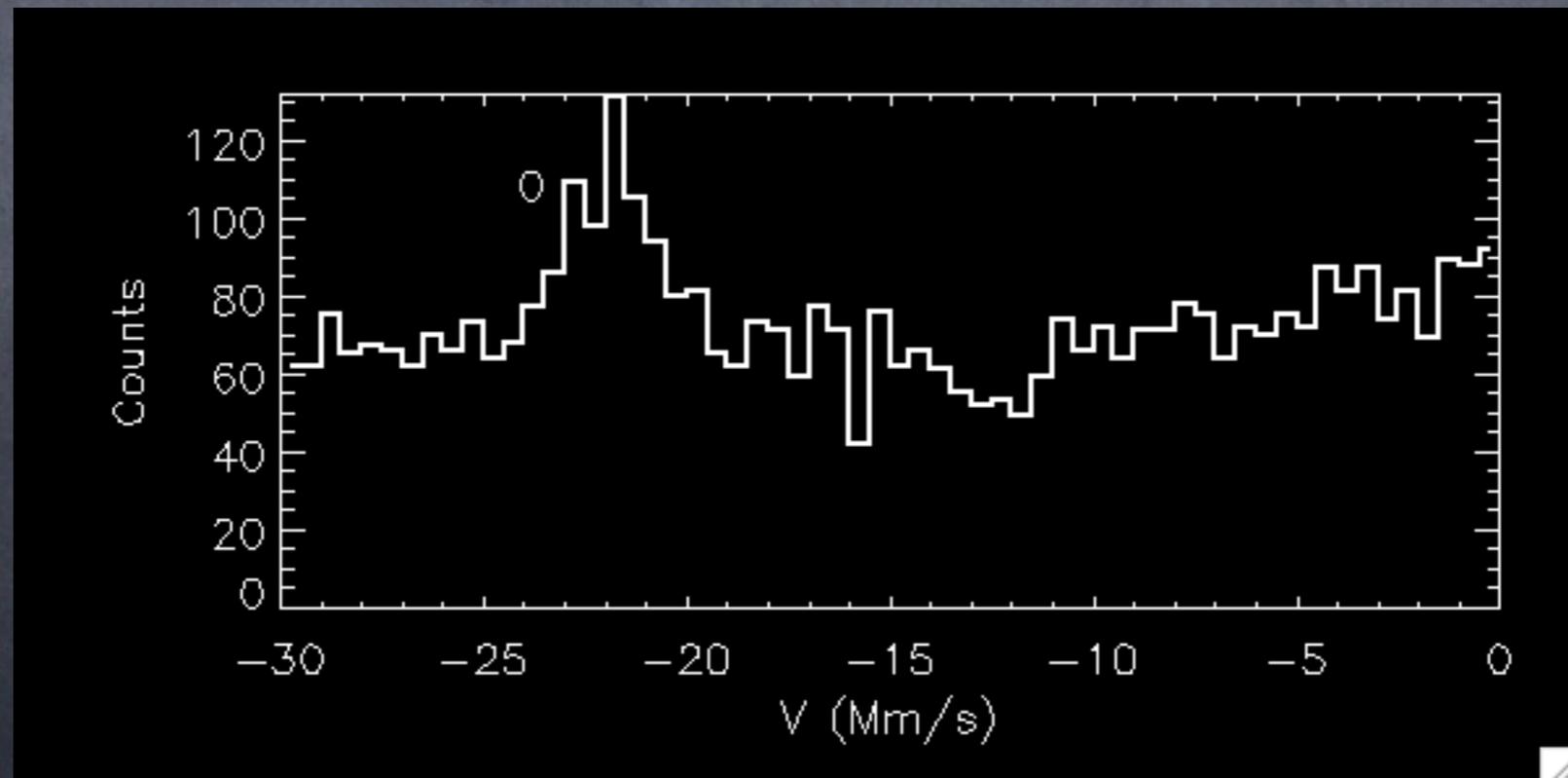


Trailed Spectra, 8/2005



Moving Lines Movie

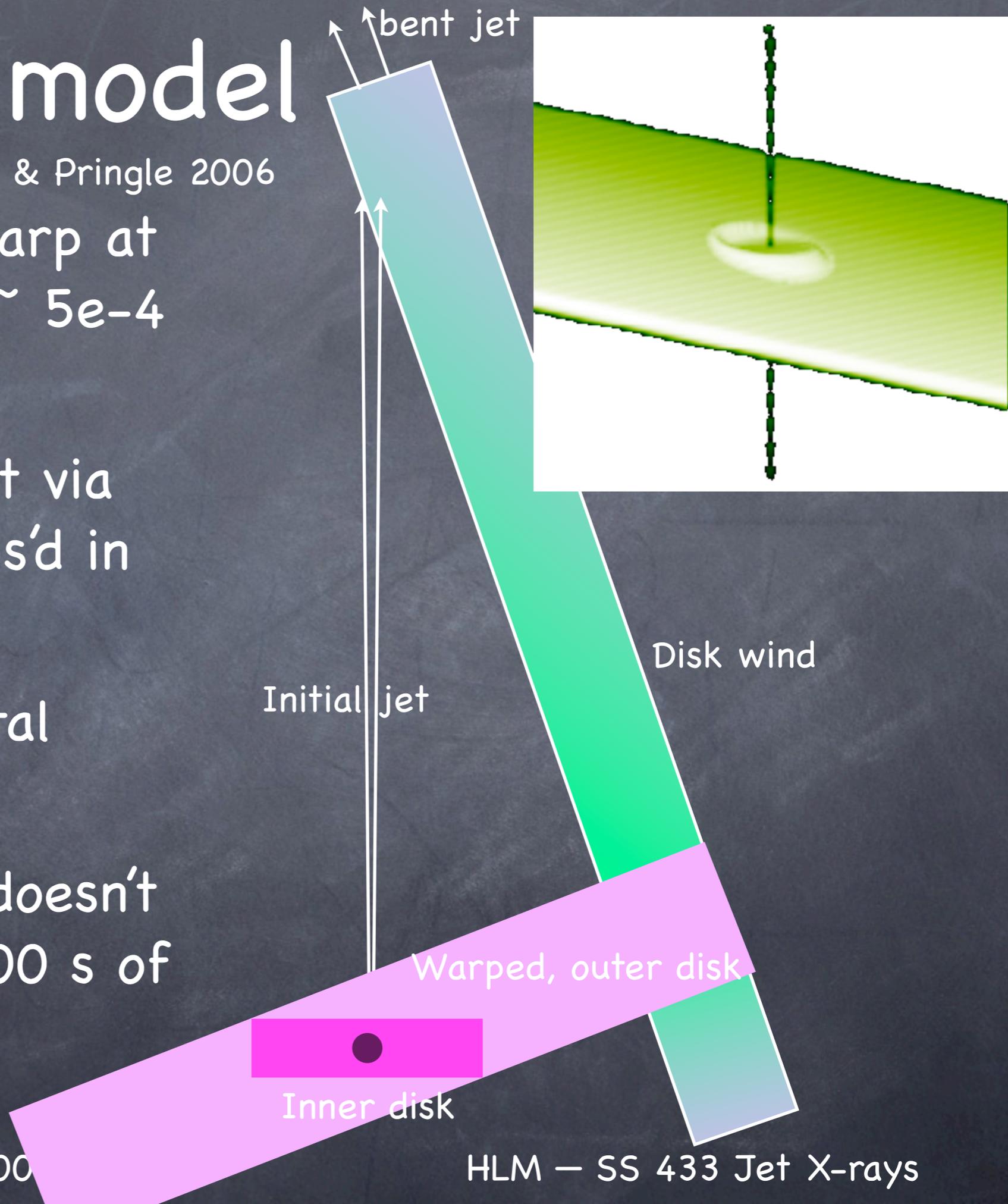
- Made by Doppler Shifting to rest frame
- Used many lines: Mg XII, Si XIV, Fe XV, etc.
- Time slices are 5 ks each
- Very little "trailing flux", observed in H α



Wind model

Begelman, King, & Pringle 2006

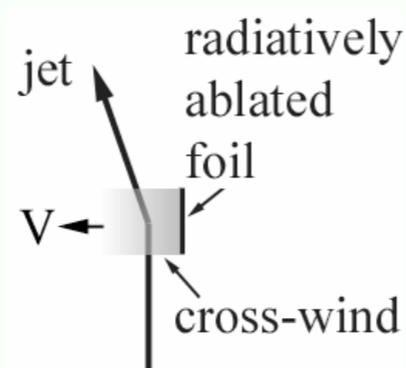
- Wind from disk warp at 1500 km/s, $\dot{m} \sim 5e-4 M_{\text{sun}}/\text{yr}$
- Wind can bend jet via oblique shocks (obs'd in lab experiments)
- At $r=10^{11}$ cm, orbital period = 5000 s
- Problem: red jet doesn't deviate within 2500 s of blue jet



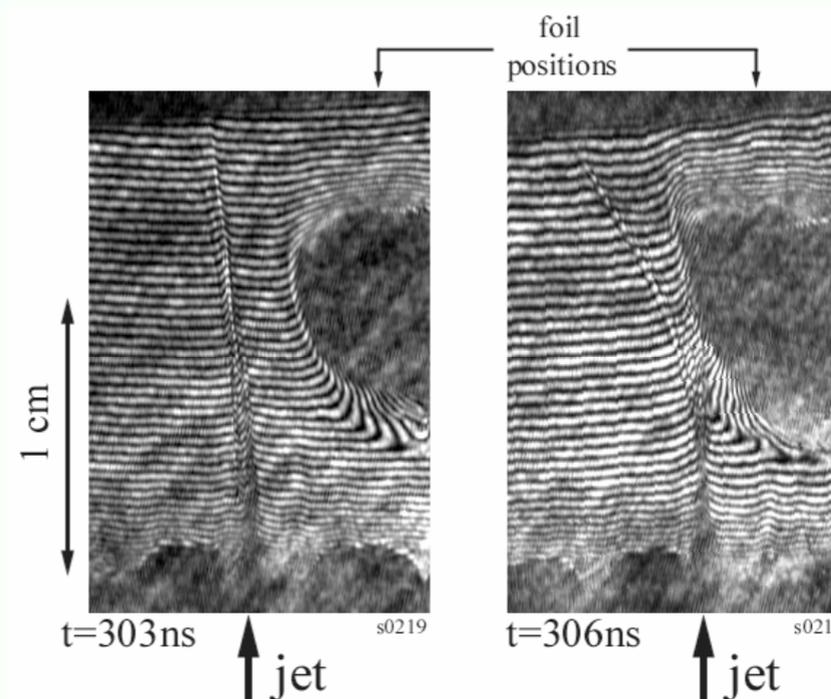
Jet Bending Experiment

Deflection of the jet in interaction with plasma cloud

The ram pressure of plasma ablated from CH foil deflects the jet



Higher wind ram pressure for closer foil position



Wind Velocity

$\sim 20 - 50 \text{ km s}^{-1}$

Wind Electron Density

$\sim 10^{17} - 10^{18} \text{ cm}^{-3}$

“Control” over wind parameters

- Ram pressure
- Direction
- Cooling Properties

Jet remains collimated after deflection by up to 30°

Lebedev et al., ApJ 2004
(accepted)

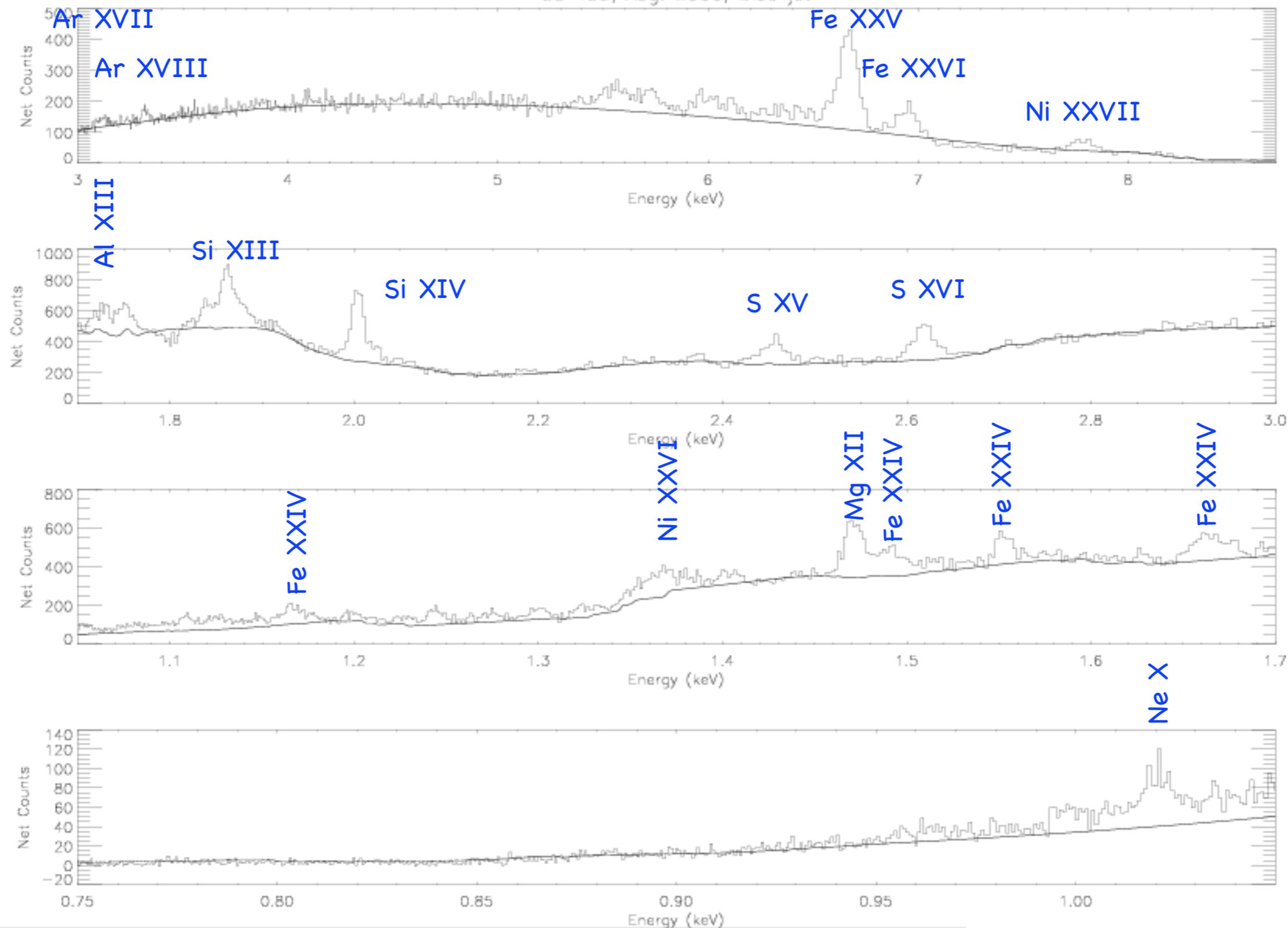


MIT Kavli Institute
for Astrophysics

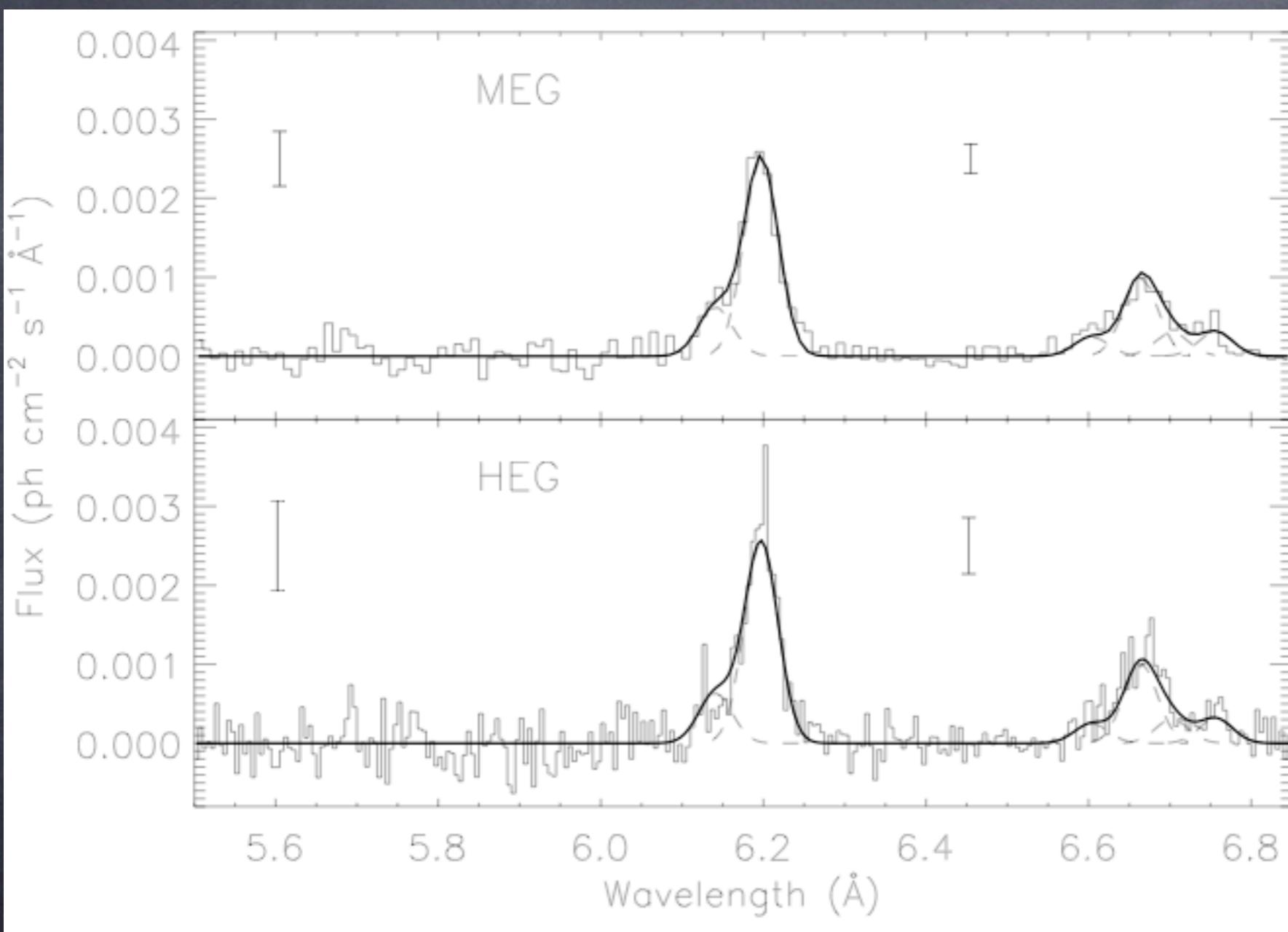
a

Blue-shift Corrected Spectrum

SS 433, Aug. 2006, Blue jet



Fits to Si XIV, Si XIII



Compare to Paper I

G: 0.61 ± 0.07
(30% lower)

R: 1.04 ± 0.23
(same)

$\sigma_v = 960$ km/s
(30% larger)

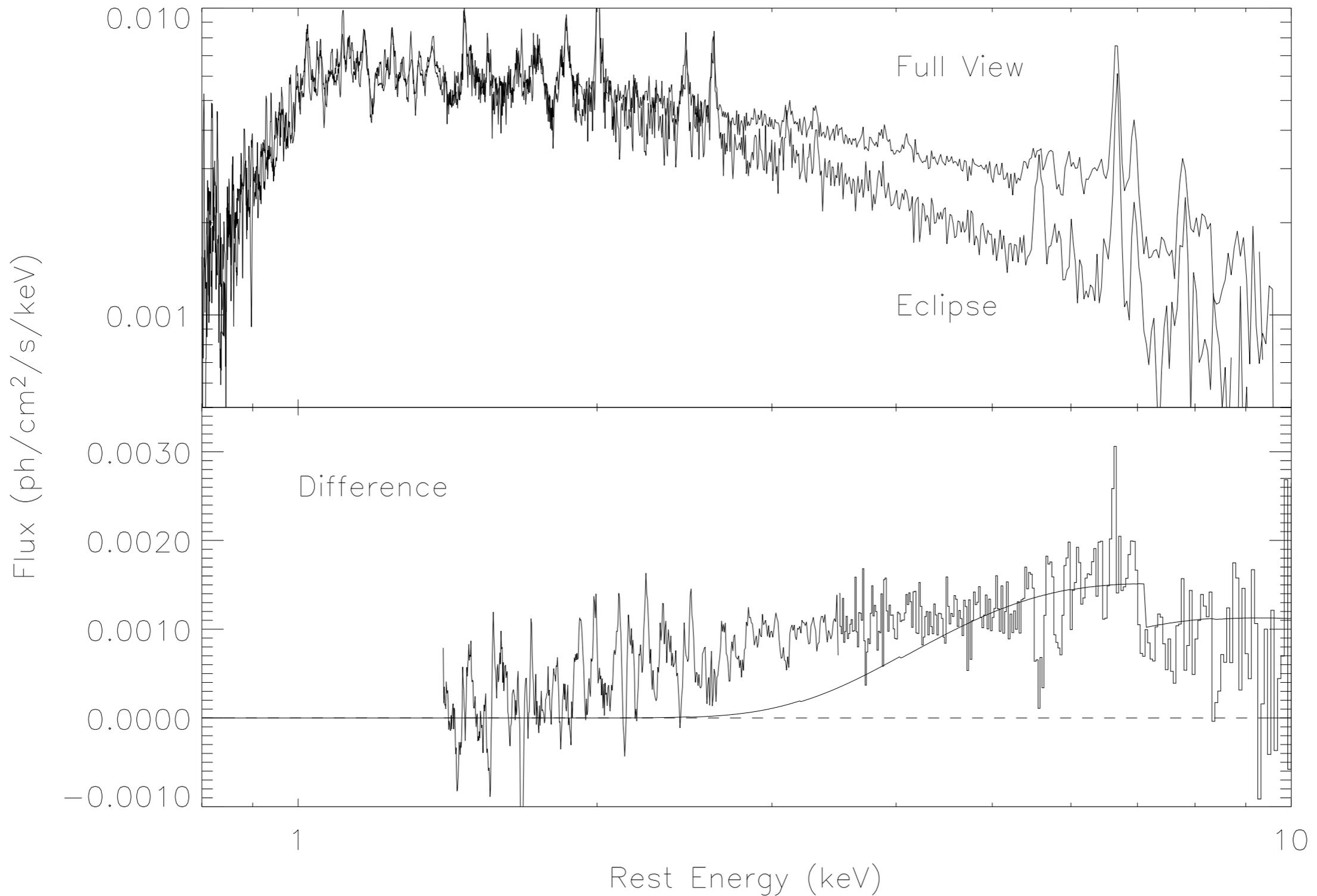
Si XIV, Si XIII
are 20% weaker

Offset line:

25% of main

$dv = 2000$ km/s

Eclipse Spectrum



Conclusions



Leroy

- Jet redirected on 0.3d time scale by 2°
 - Blue, red jets different
 - Due to local effects where jet is directed
- X-ray region cooling time < 5000 s
 - Consistent with radiative cooling of thermal plasma < 100 s
 - X-ray emission $< 4 \times 10^{13}$ cm (0.1 mas) from jet directing shocks that heat gas
 - VLBI shows jet slows by 15000 km/s before 6 mas from direction setting location
- Eclipsed region spectrum: hard, no lines