Shock Heating by the SS 433 Relativistic Jets

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(MIT Kavli Institute)

and
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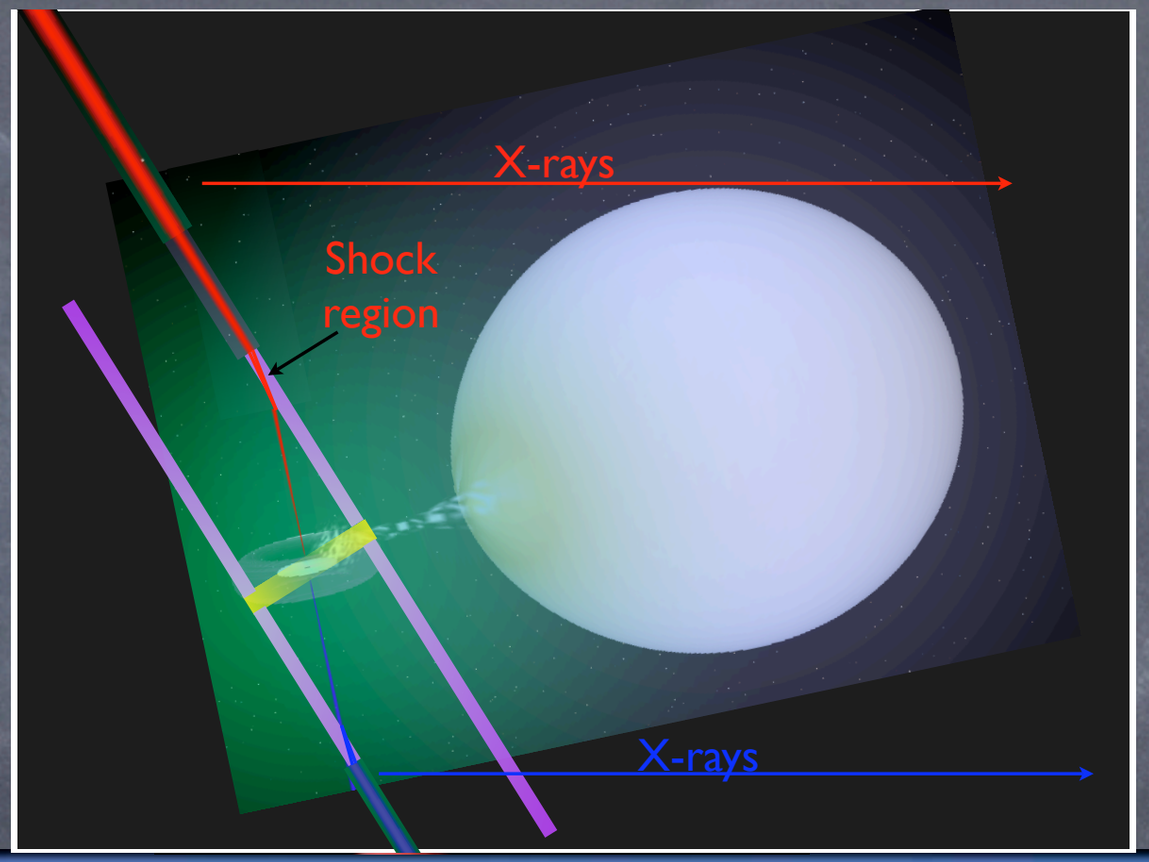

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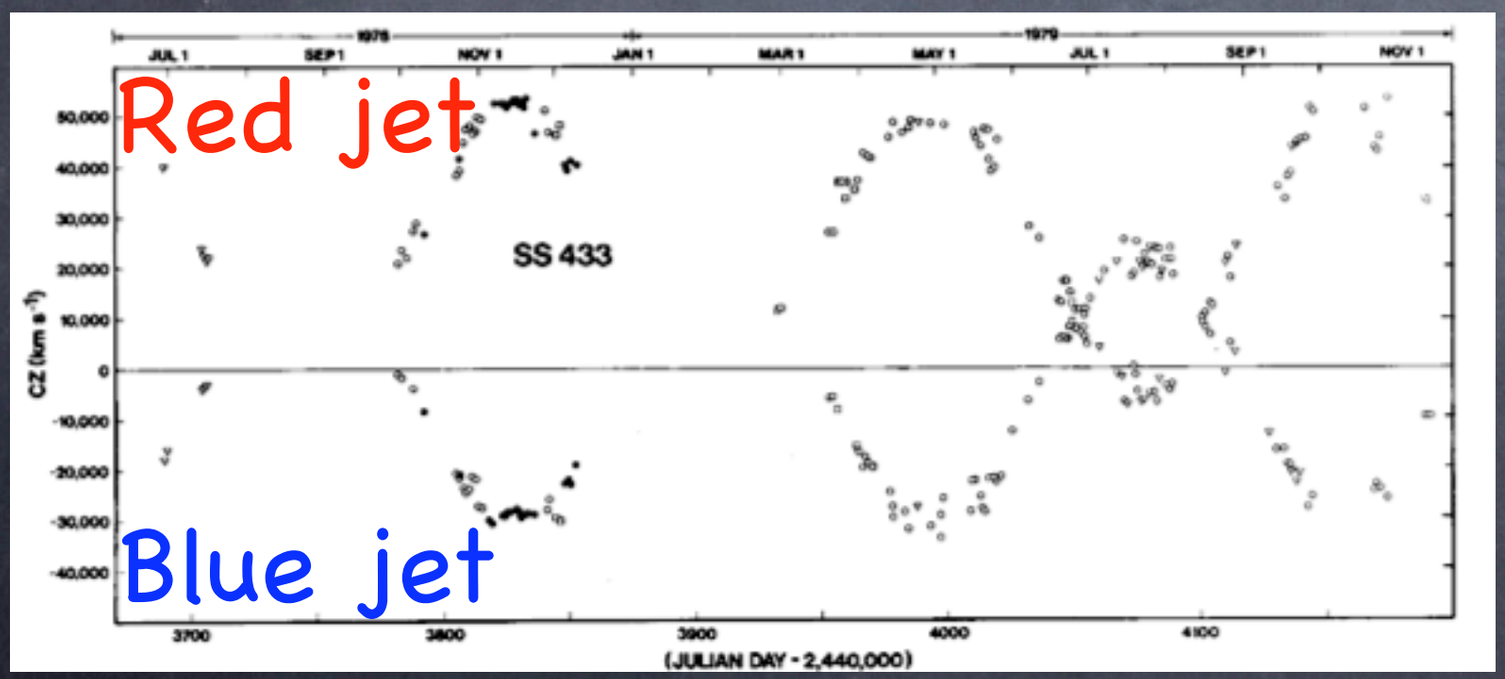
SS 433 Background

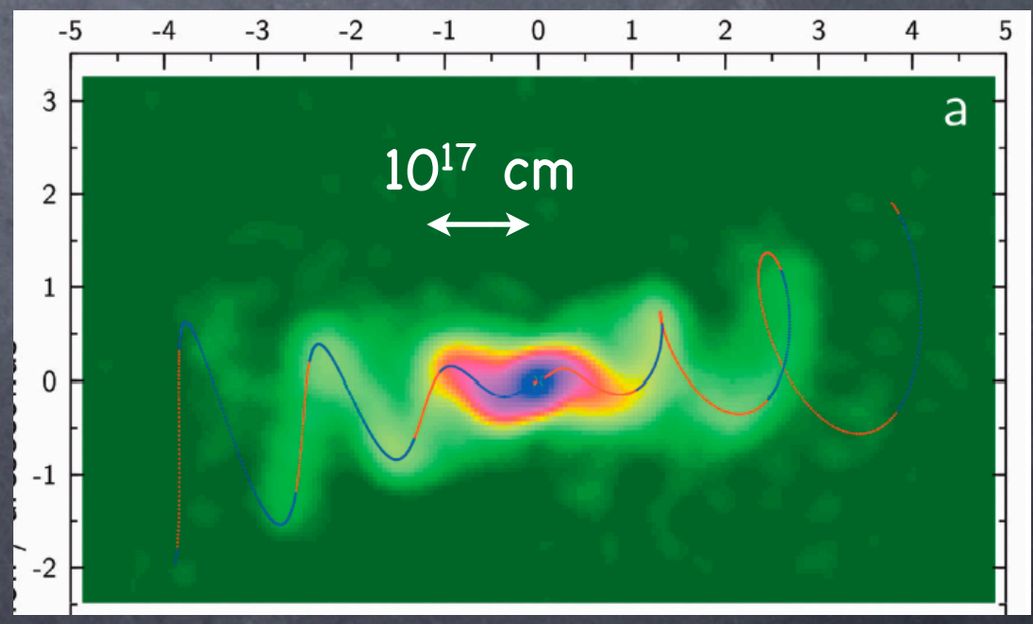
- Periodically Doppler shifting Hα HeI and H β
- Model: oppositely directed jets at 0.26 c
  - Precession period: 162 days
  - Orbital period: 13.08 days

$$\frac{\lambda}{\lambda_0} = 1 + z = \gamma(1 \pm \beta \cos\alpha)$$

- Radio: verifies model and sets orientation
- Only jet known to contain baryons



Margon et al. 1980



Blundell & Bowler 2005

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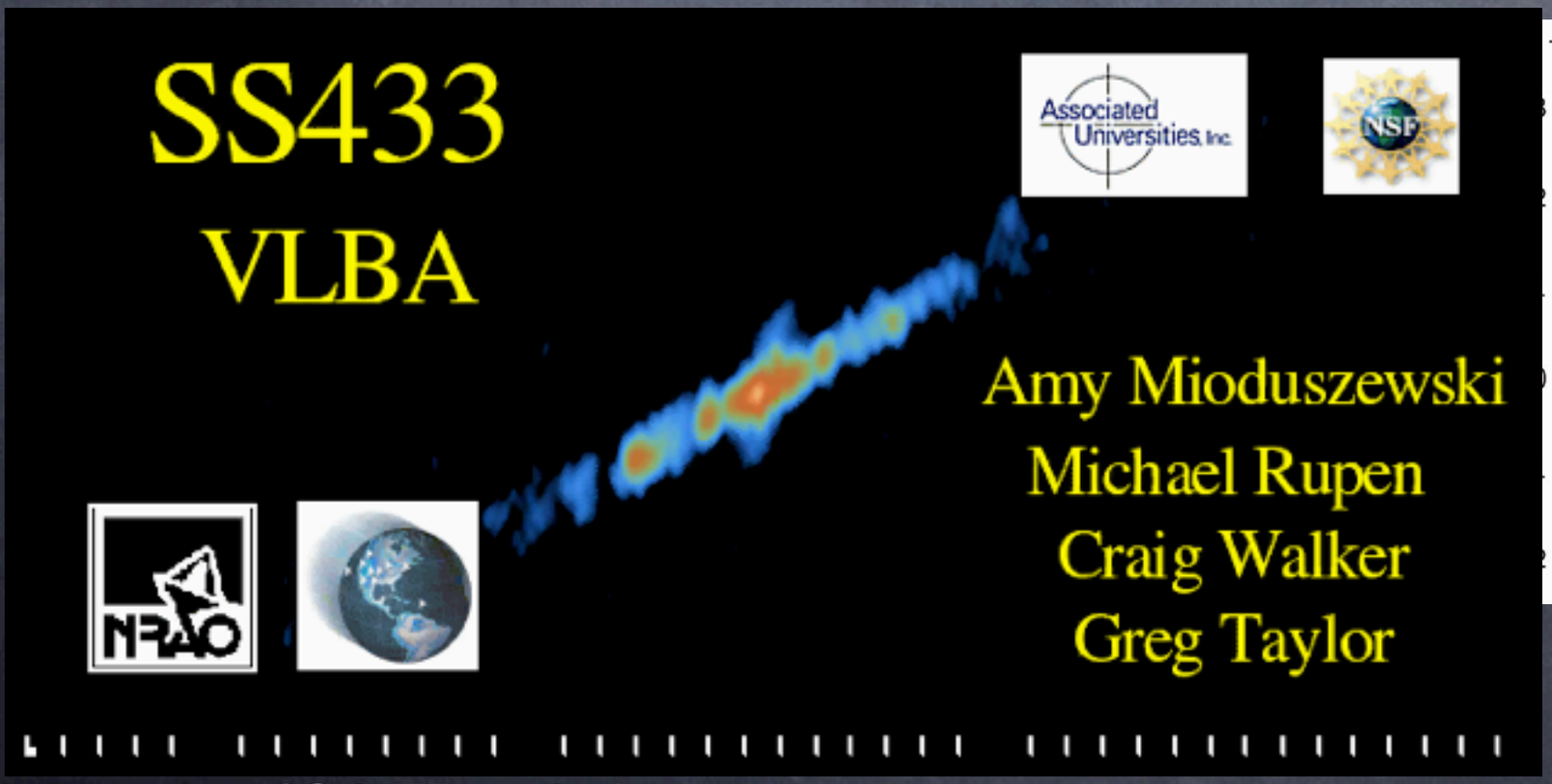

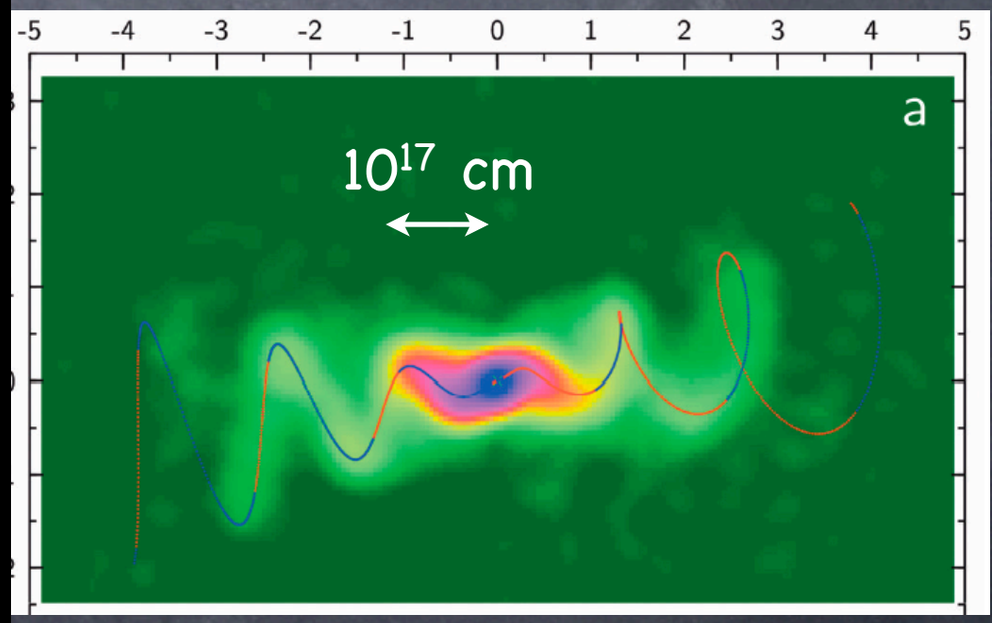

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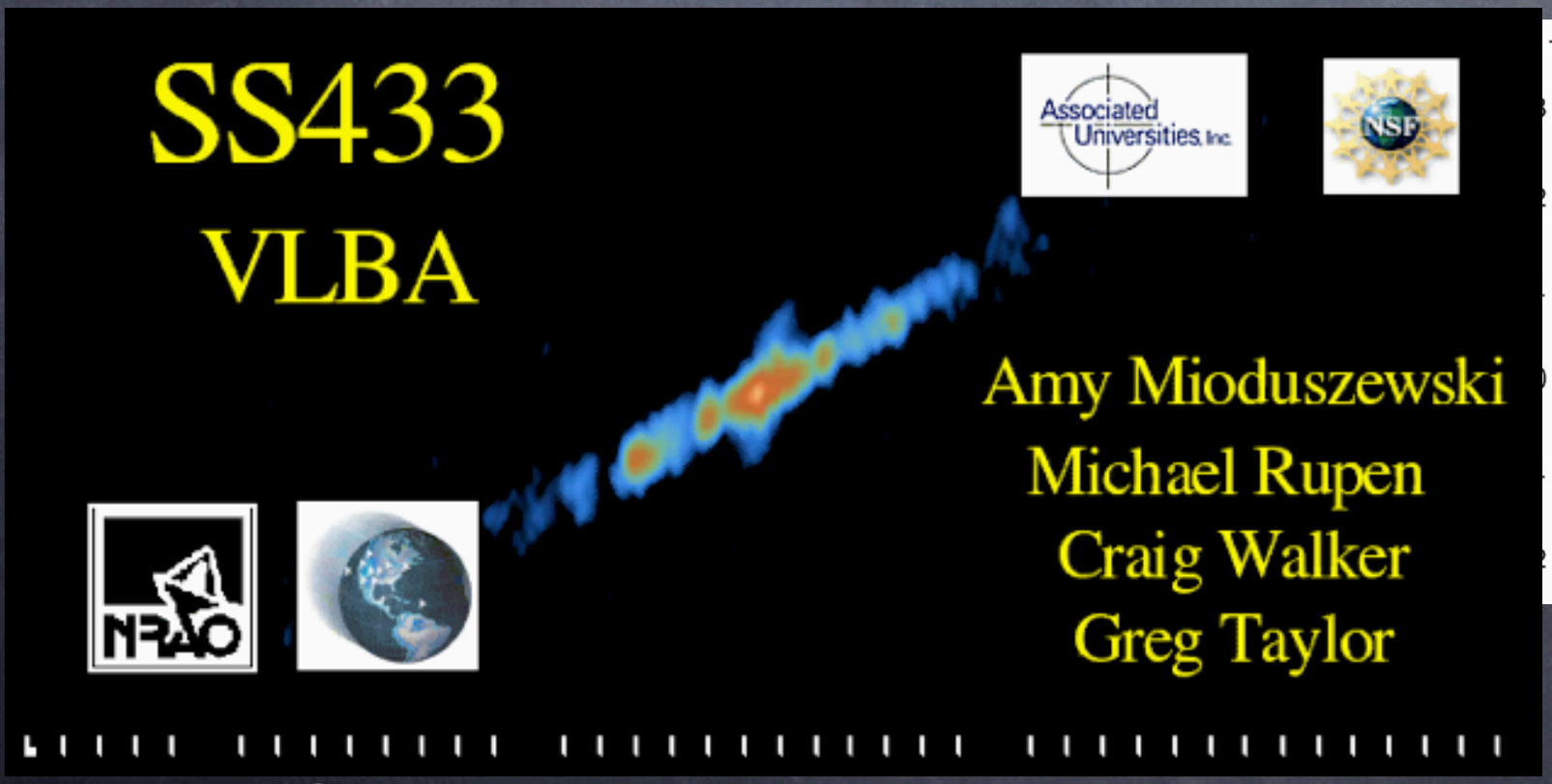

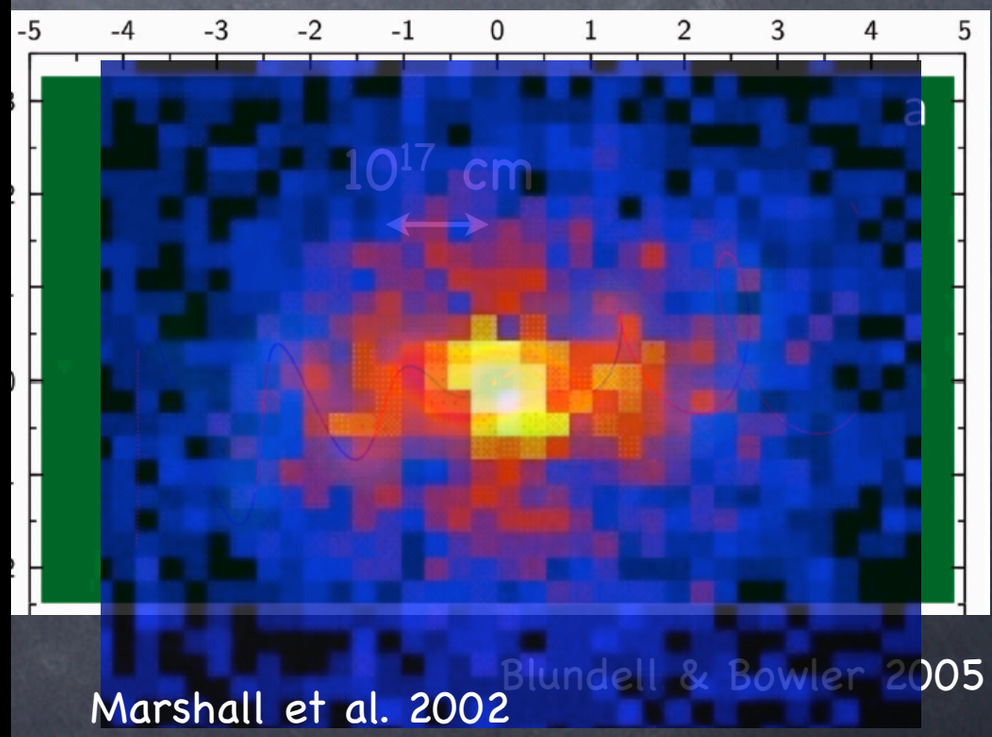

Marshall et al. 2002

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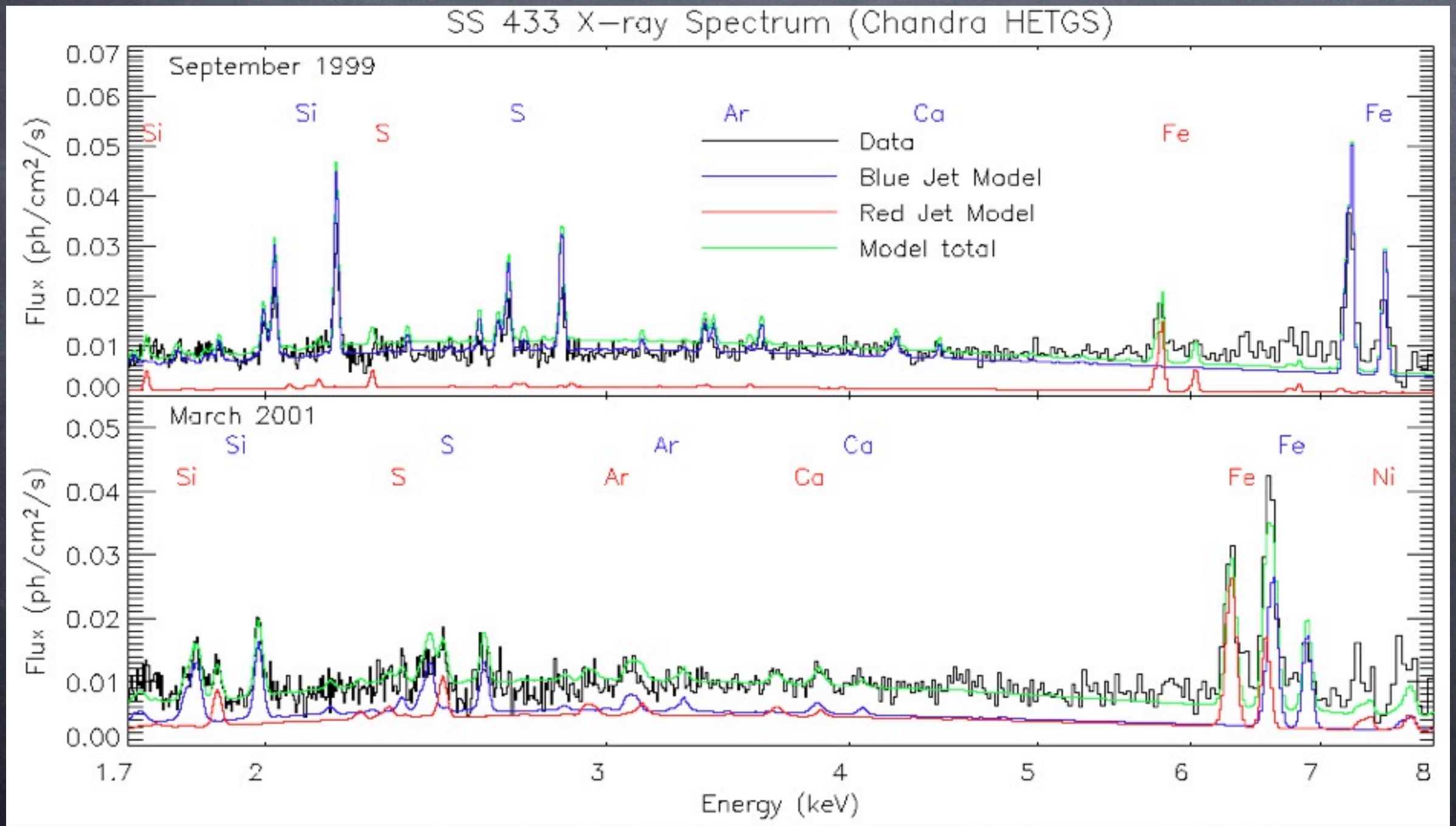
Some Questions

or: Why is SS 433 so different?

- What sets the jet speed of 0.26c?
- What causes the jet precession?
  - not the compact object
  - BH spin misaligned with inner disk?
- Why and how are baryons included in jet?
  - no other jets have them (so far!)
- A model to consider (Begelman, King & Pringle '06):
  - fixed jet redirected by disk wind
  - wind arises from outer, warped disk

Two HETGS Spectra



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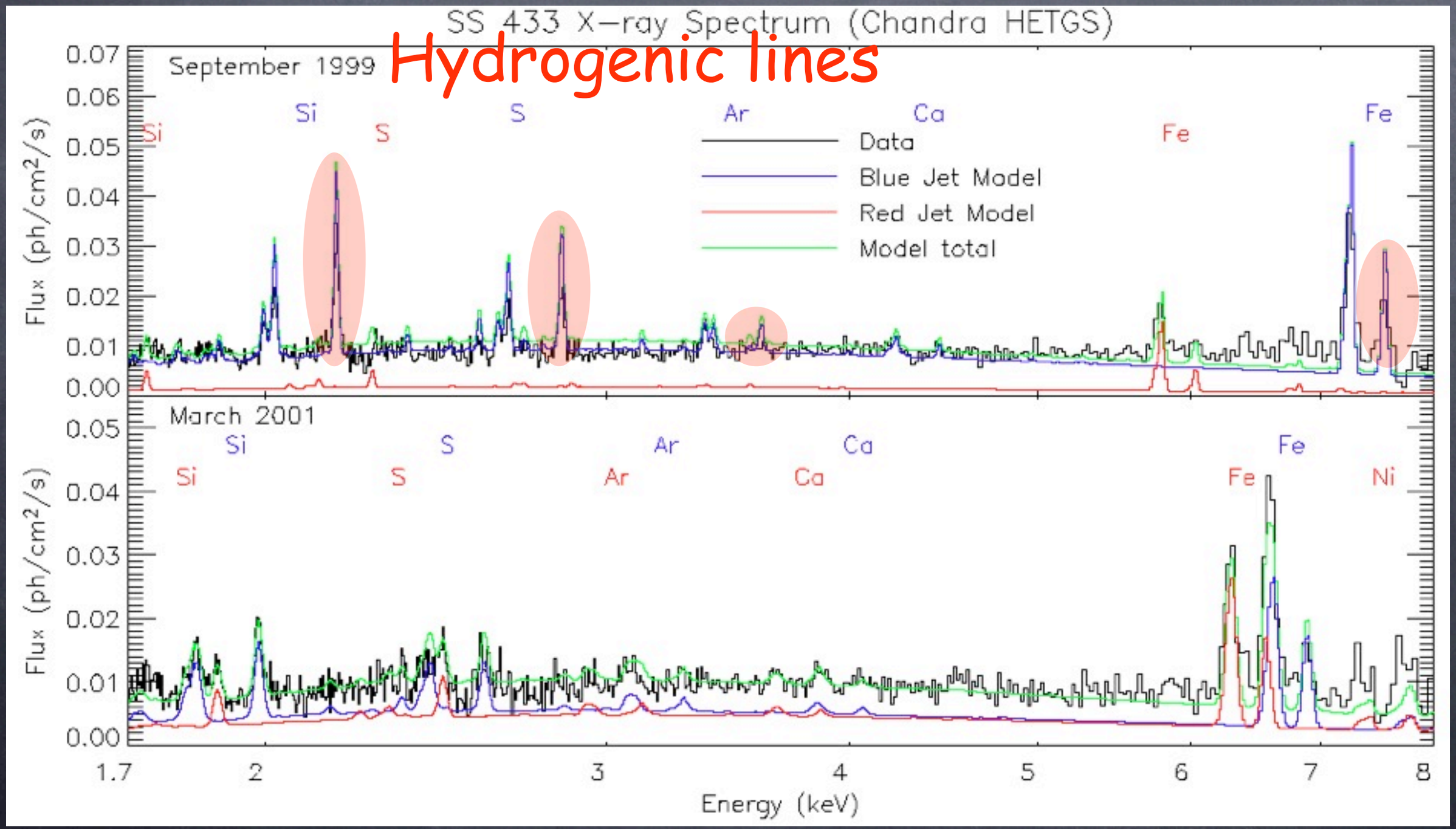

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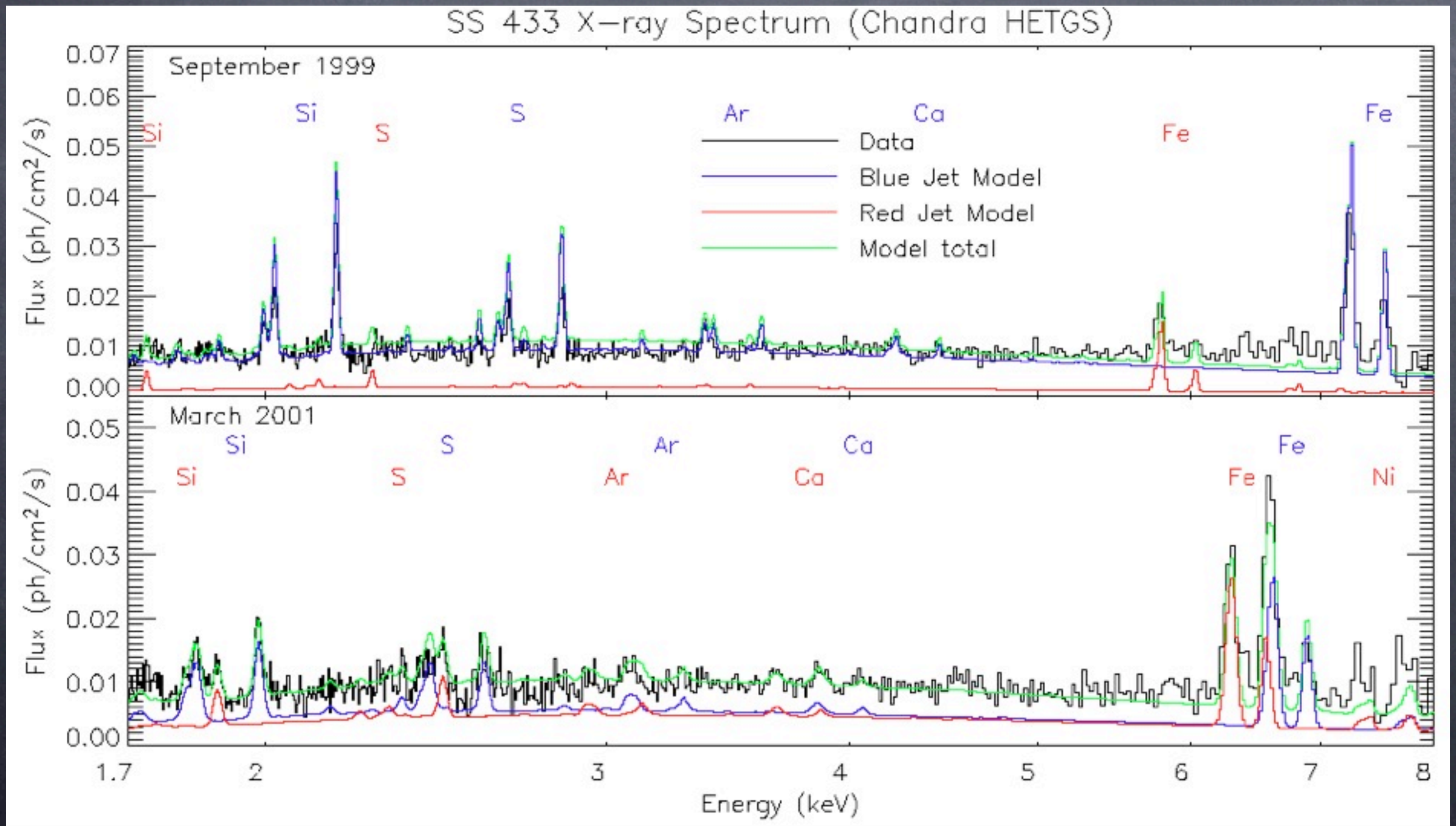

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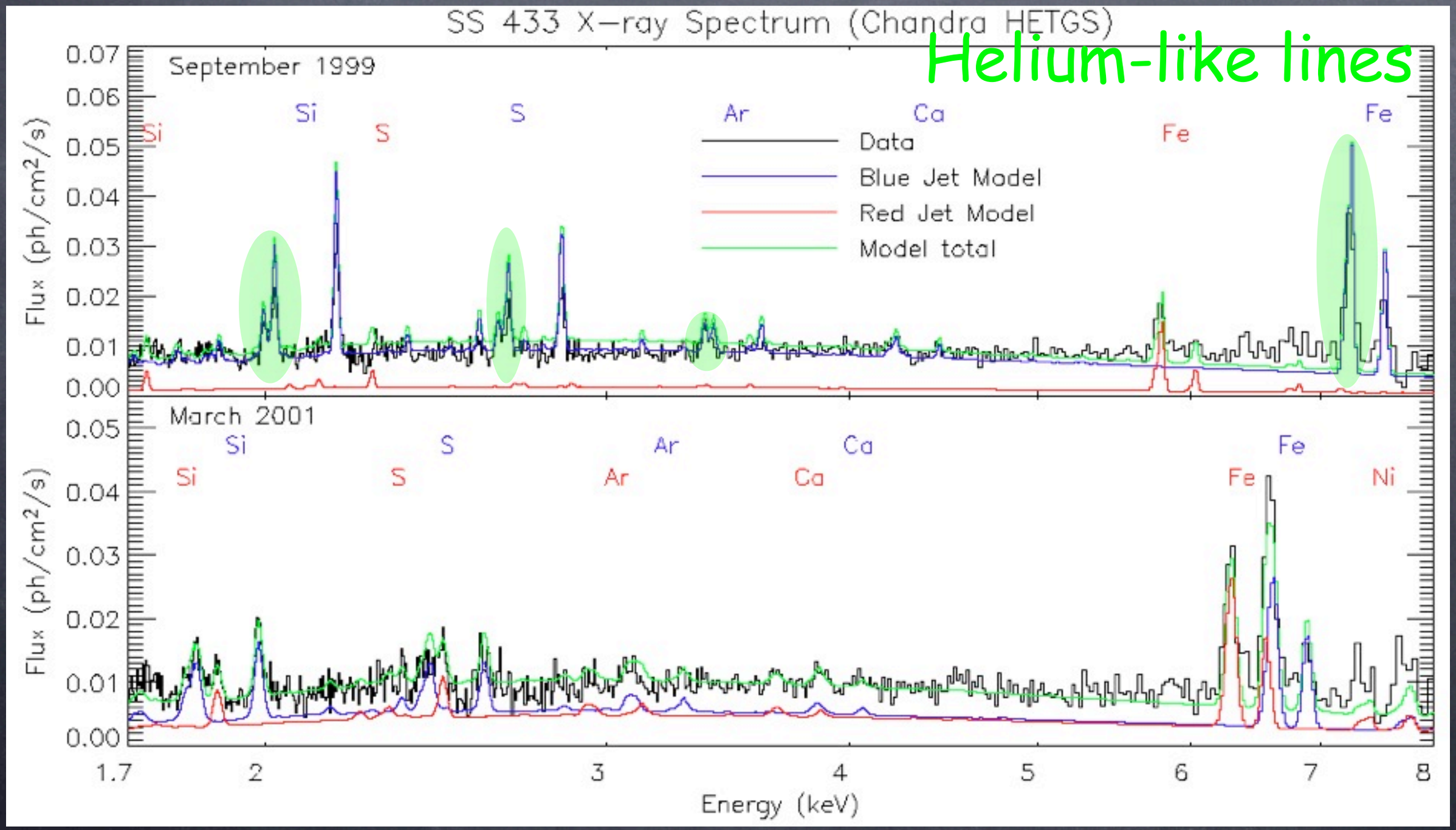

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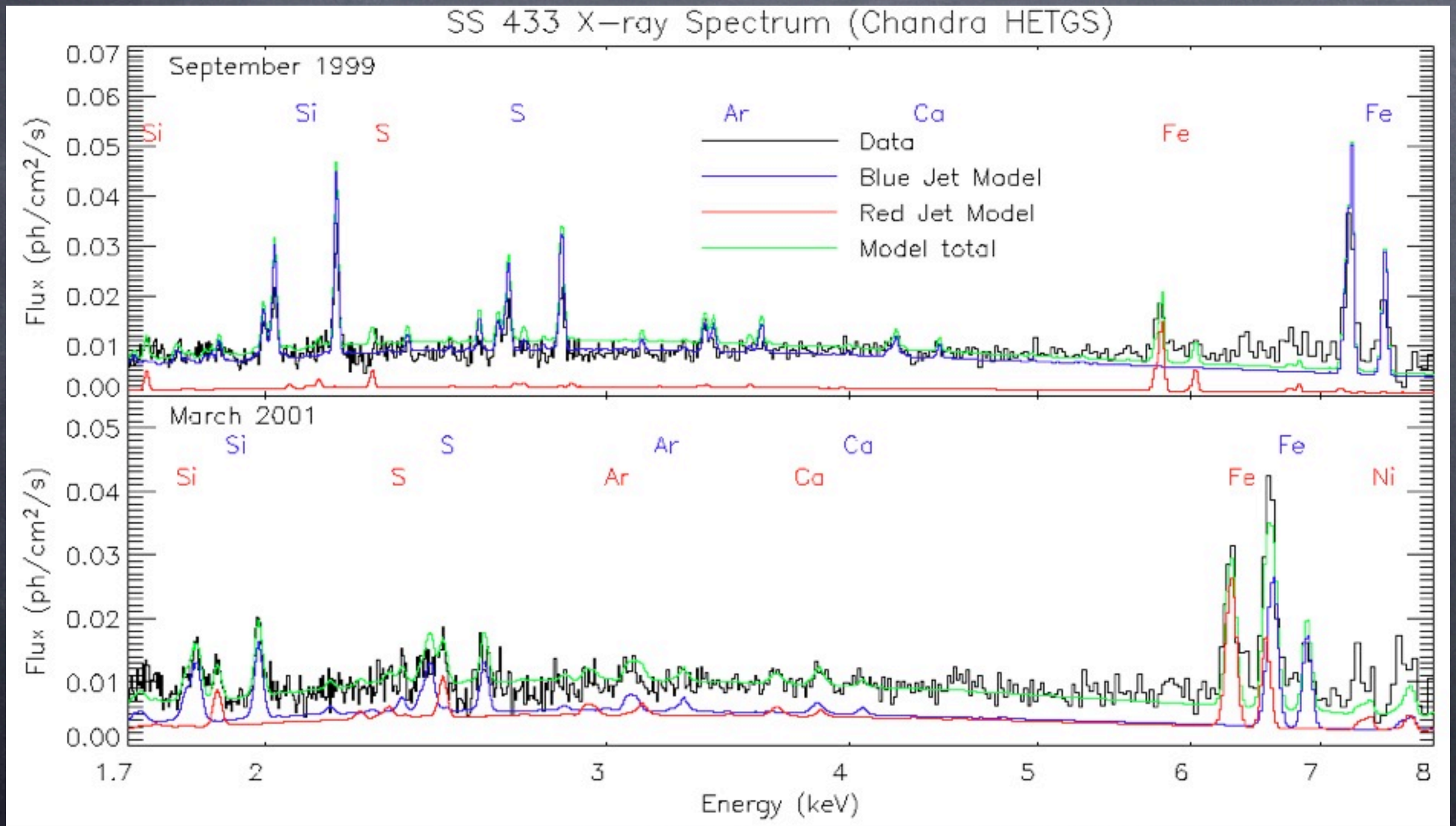

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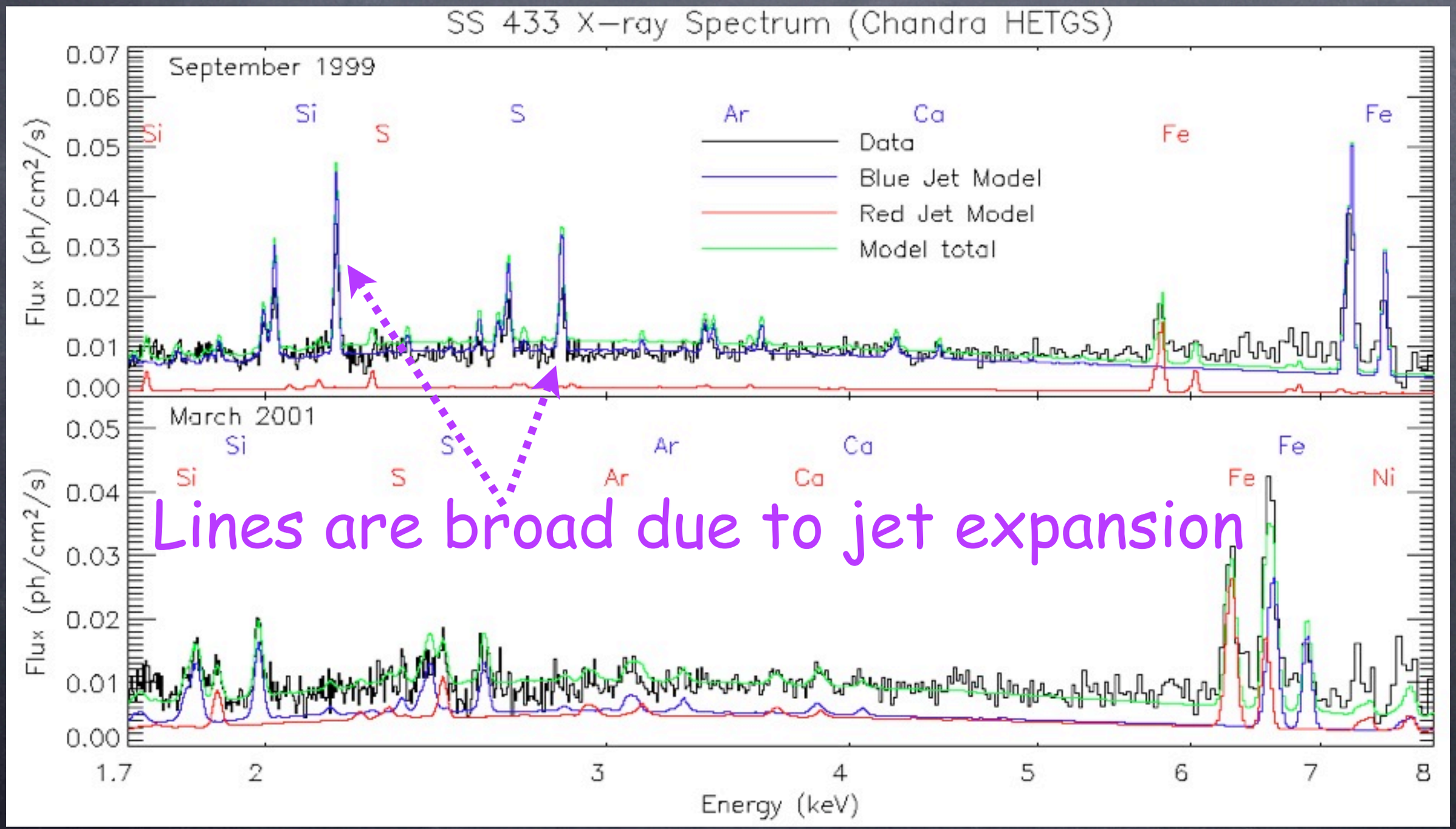

Lines are broad due to jet expansion

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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 keV
  - EM(T), test cooling models
  - with continuum, get abundances
- Si XIII triplet: electron density ~ 10^{14} cm^{-3}

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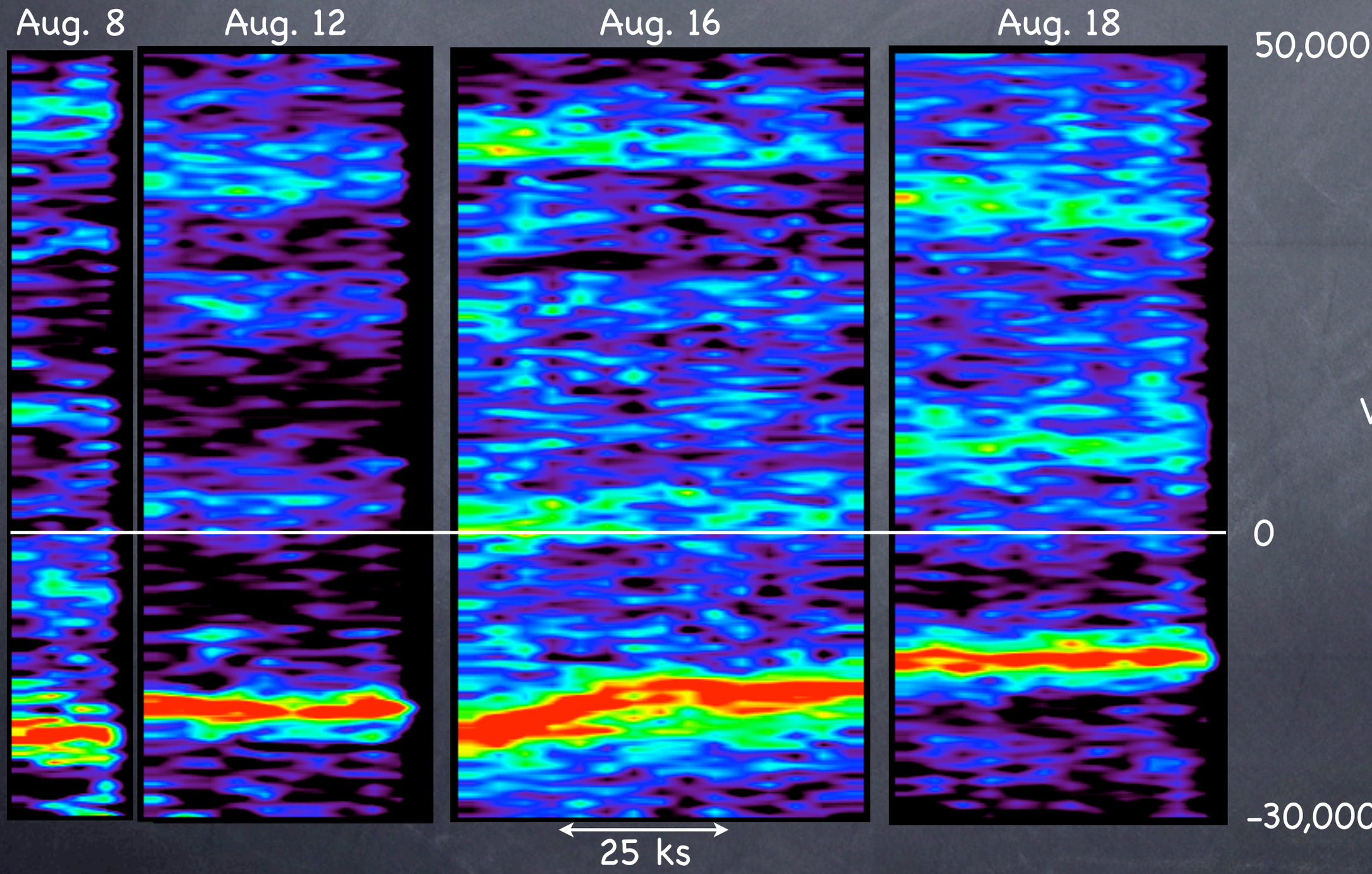
Trailed Spectra, 8/2005

- Made by Doppler Shifting to rest frame
- Used many lines: Mg XII, Si XIV, Fe XV, etc.



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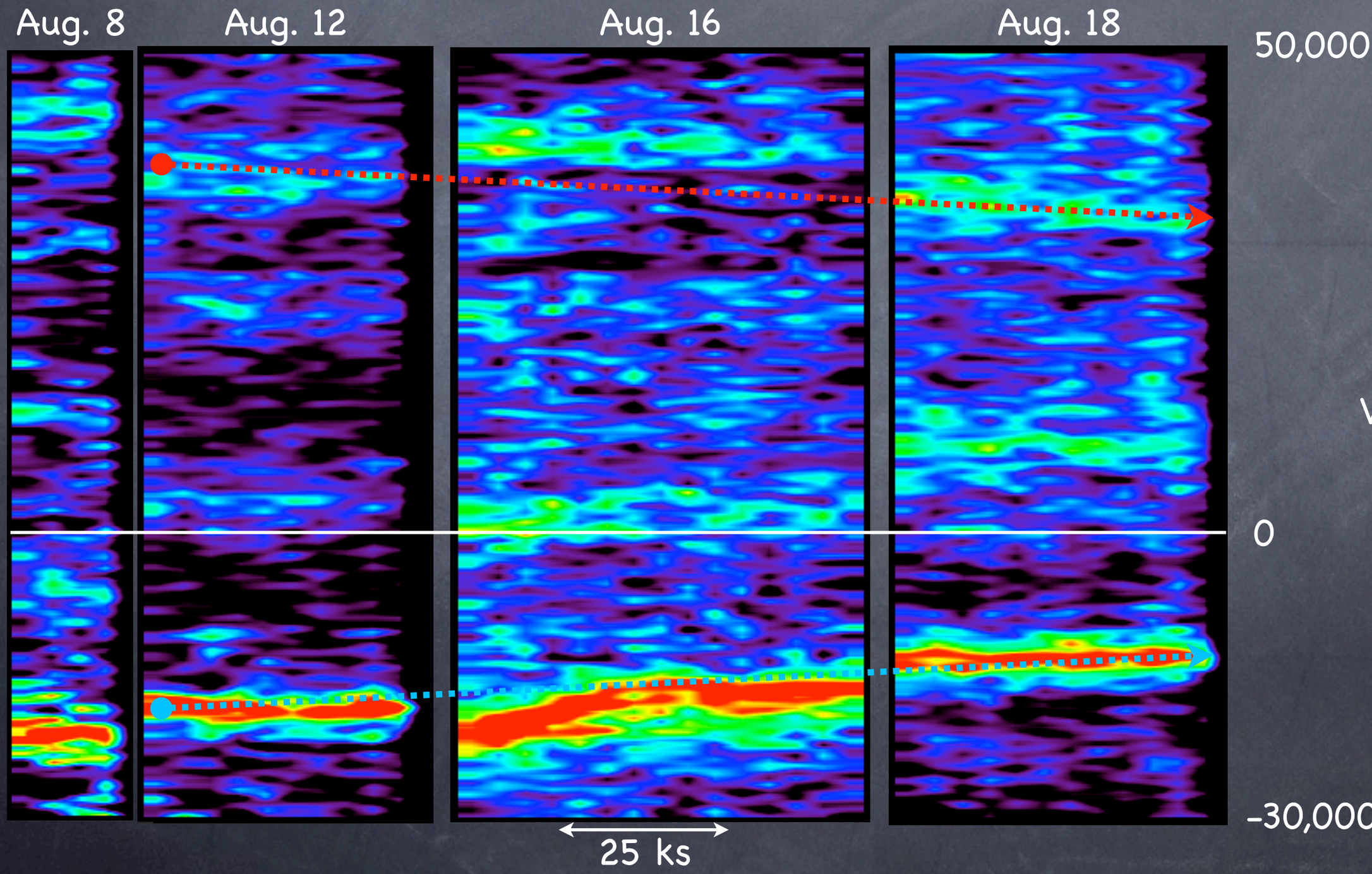

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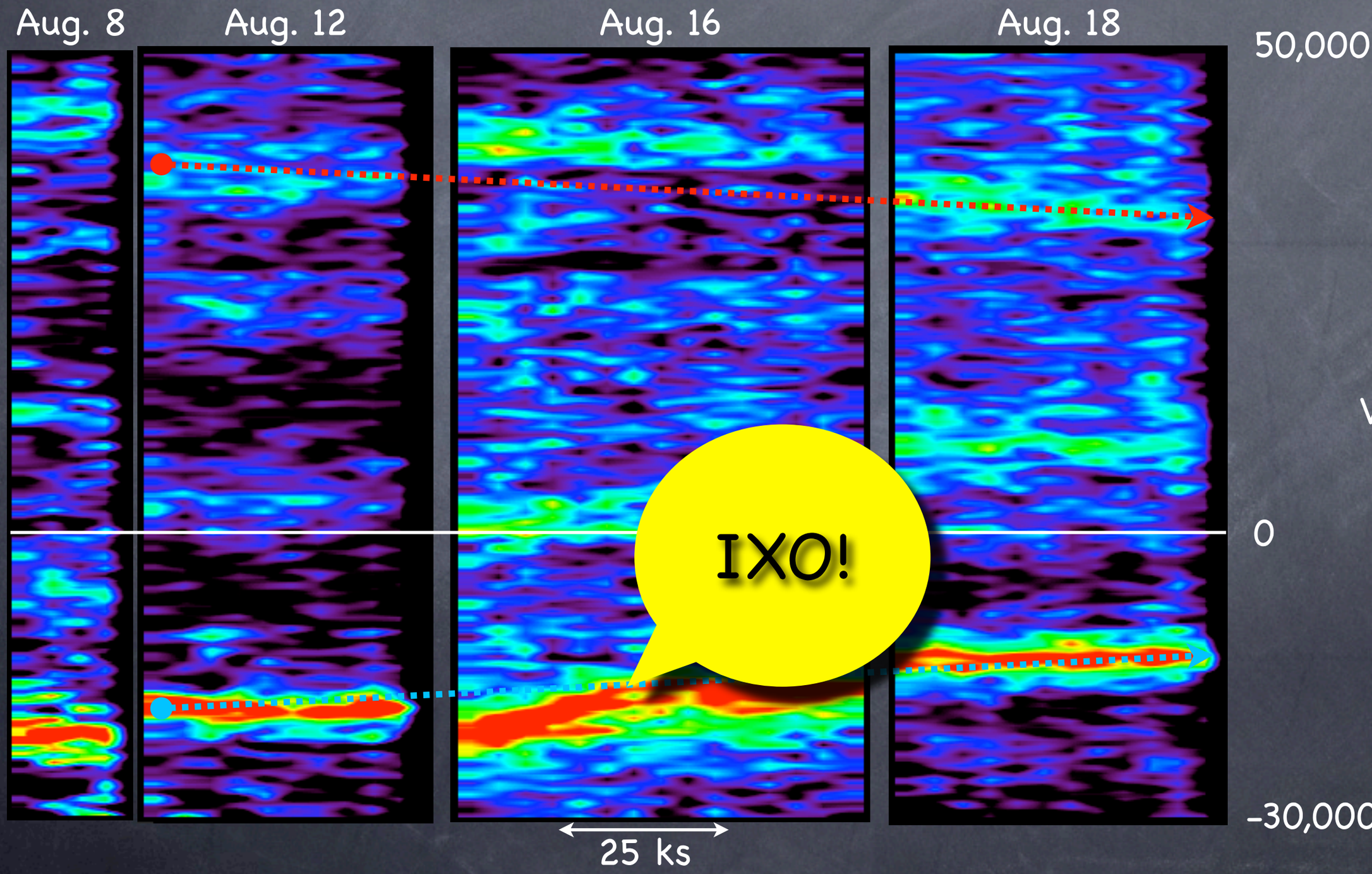

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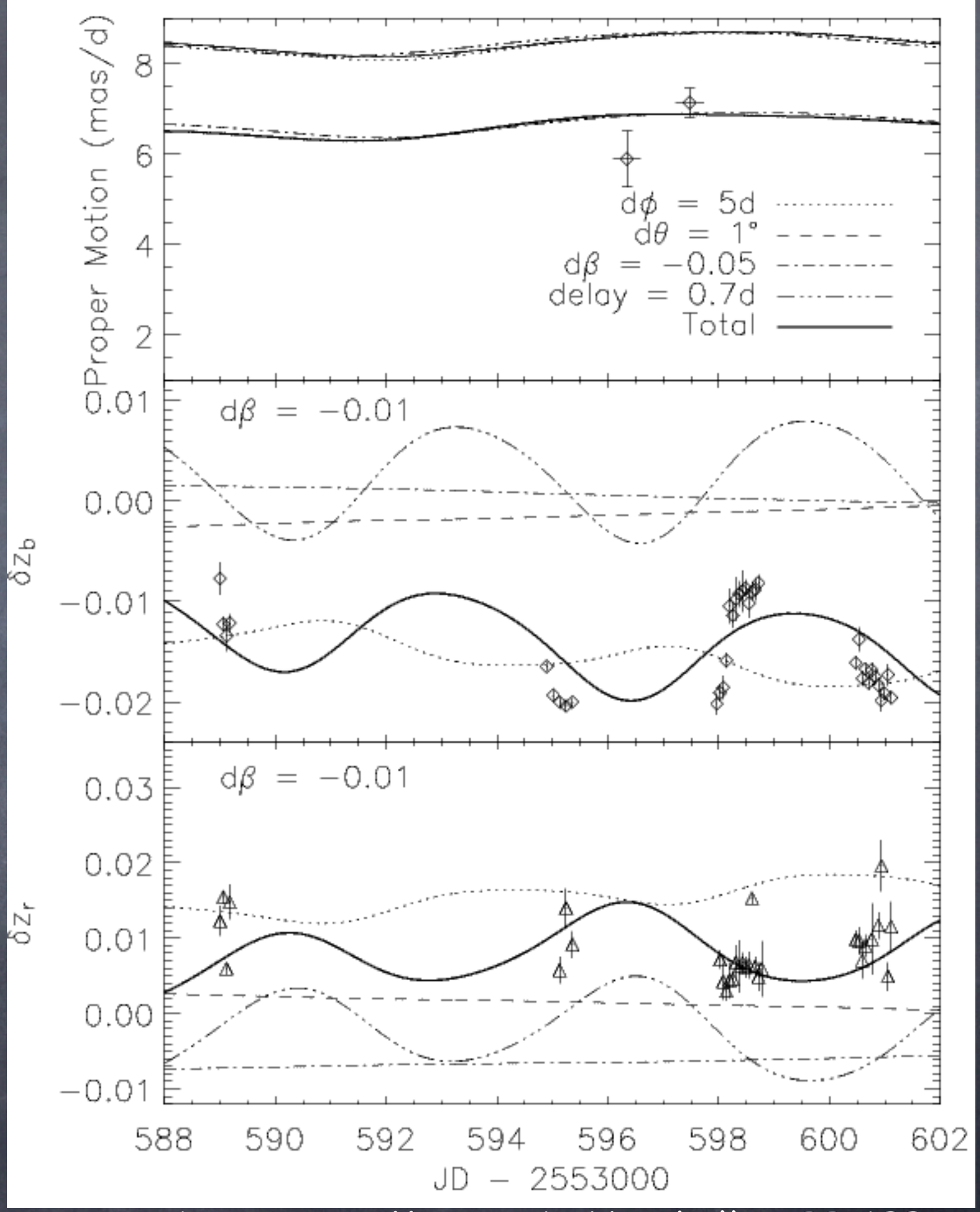
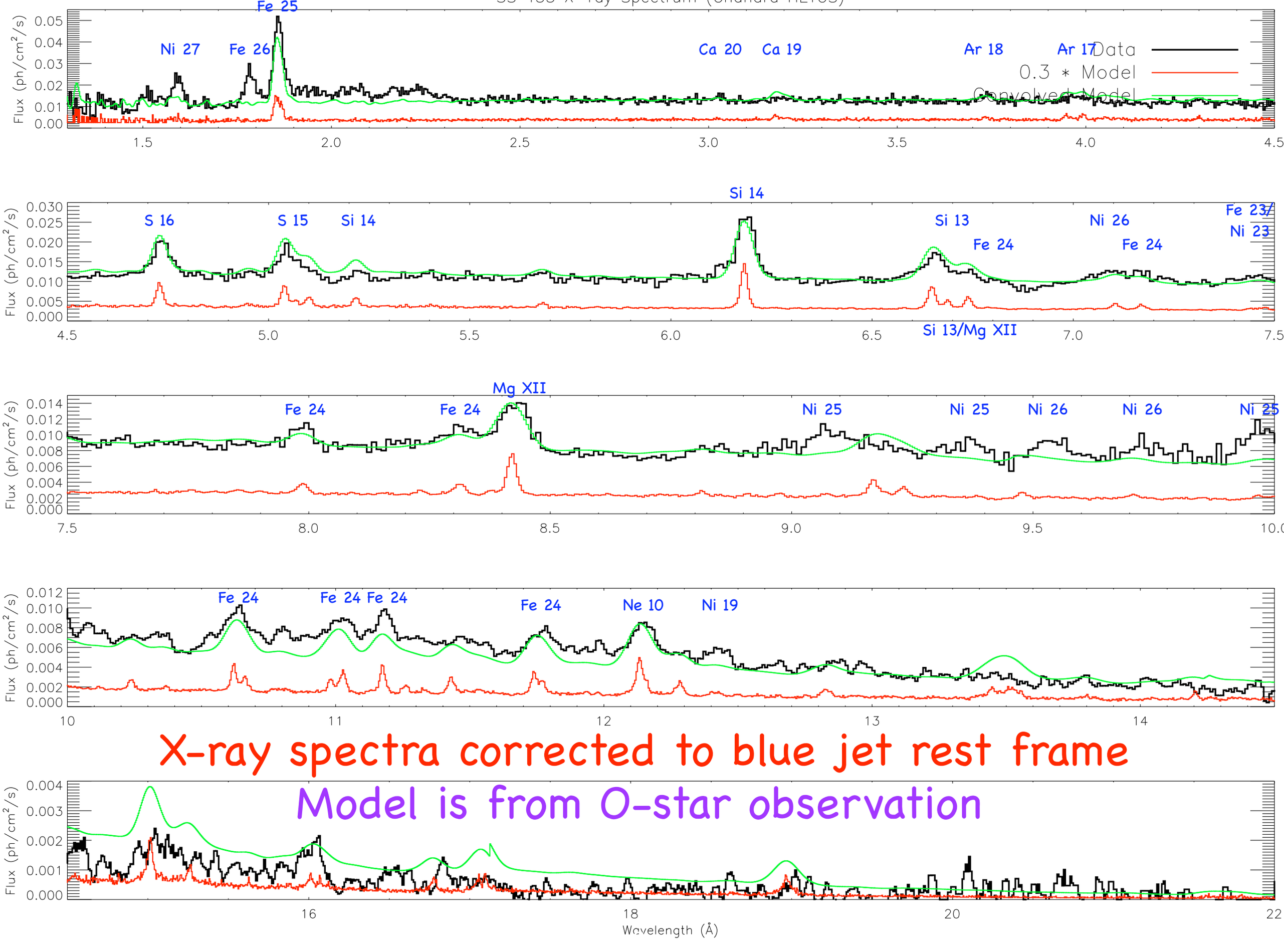
Modelling Doppler Shifts with Kinetic model

- Start with kinetic model from optical emission line data (update from Blundell & Bowler)
- Perturb kinetic model by small changes in speed, angle
- Proper motion rate requires slower jet speed not allowed by X-ray redshift residuals
- Additional short-term ϕ deviations are required

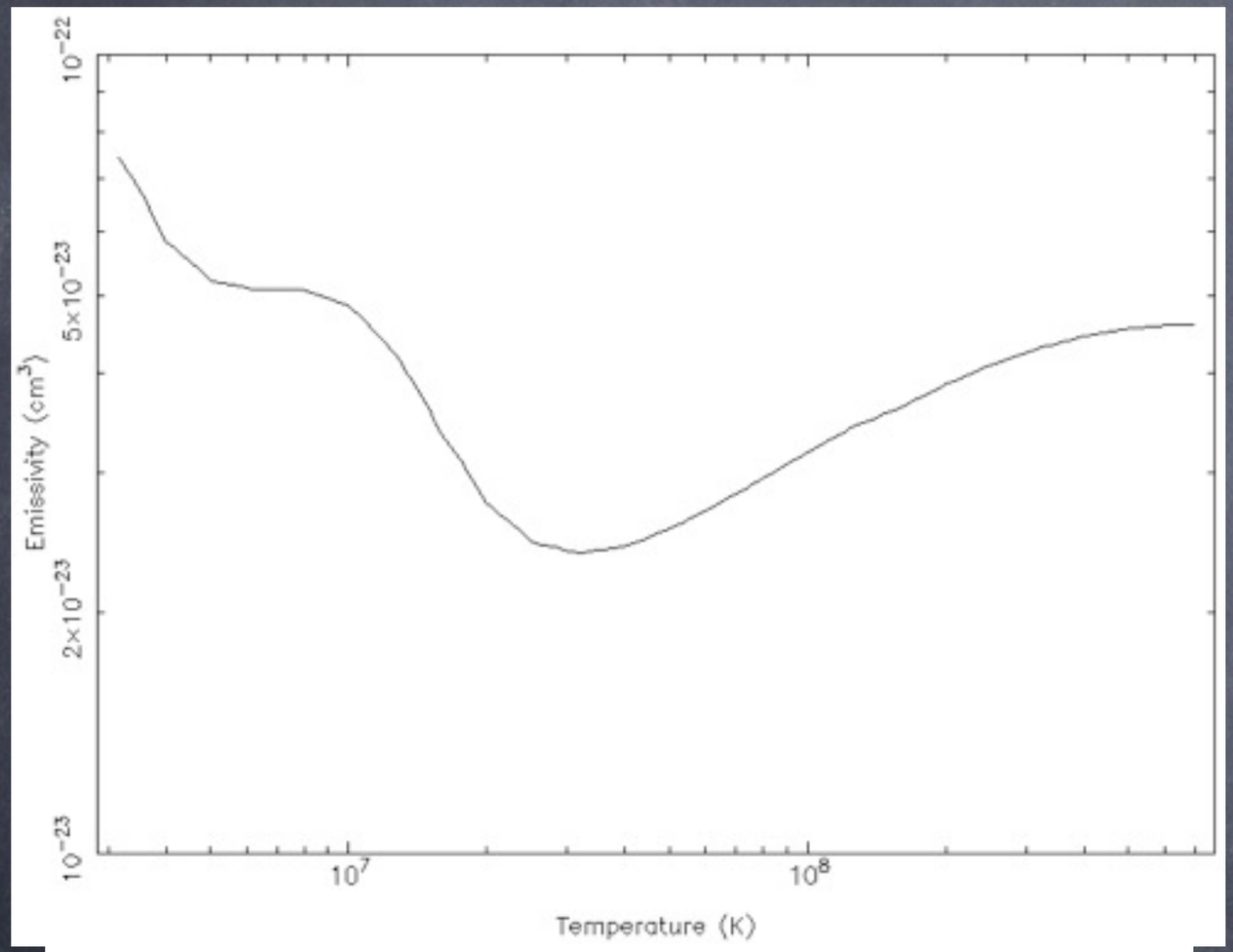


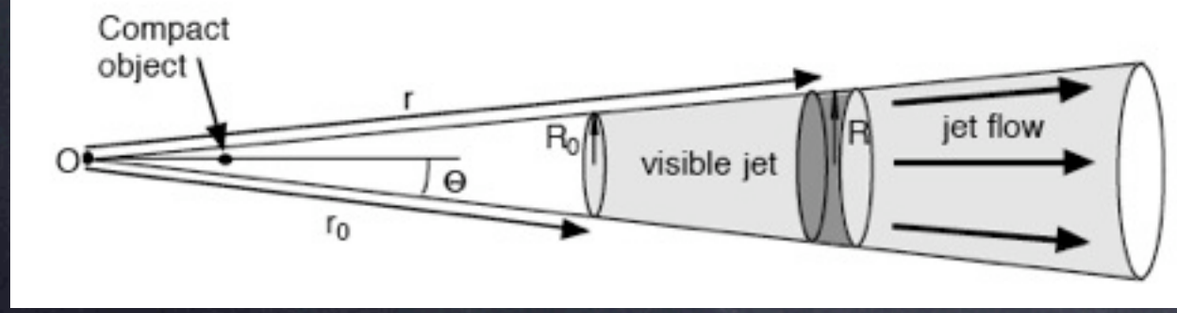


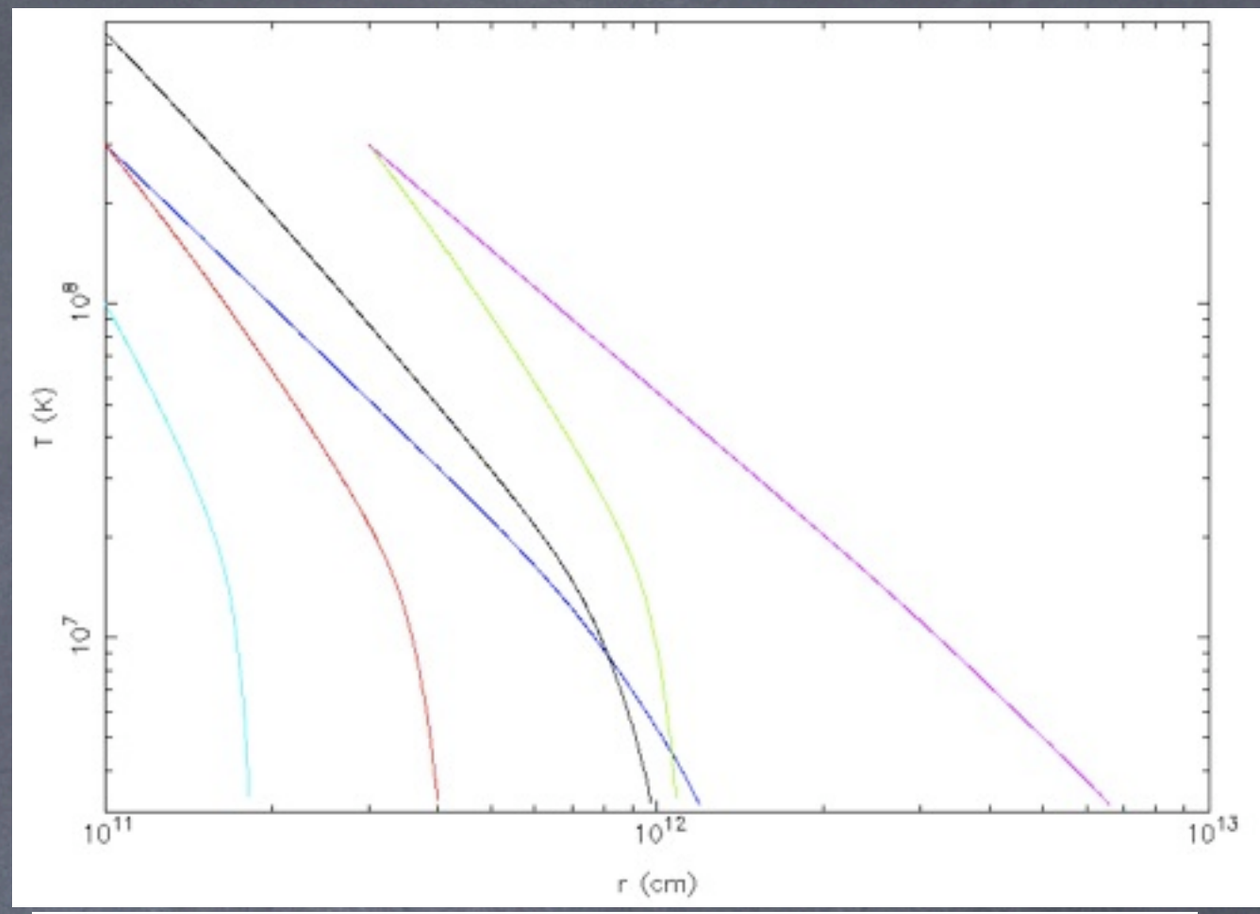
X-ray spectra corrected to blue jet rest frame

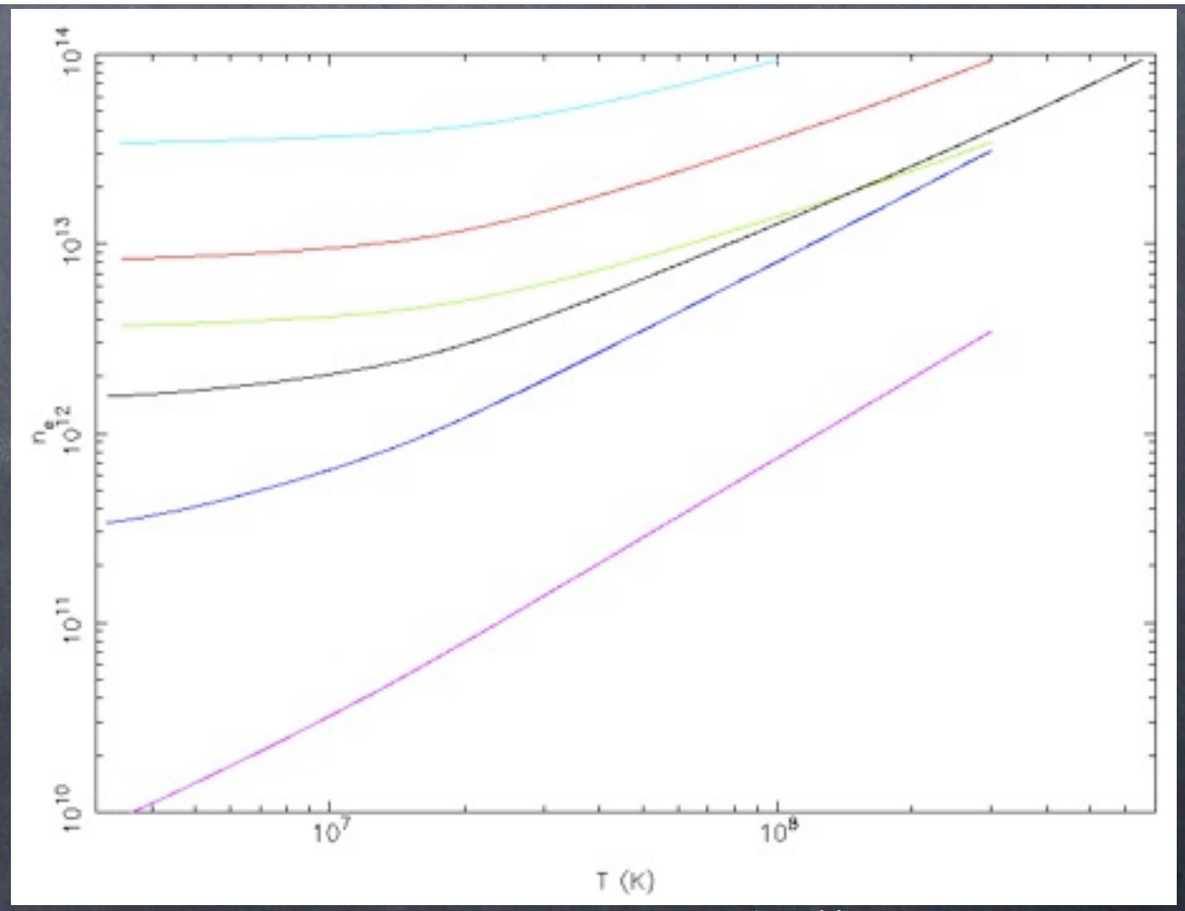
Model is from O-star observation

Jet Cooling Model









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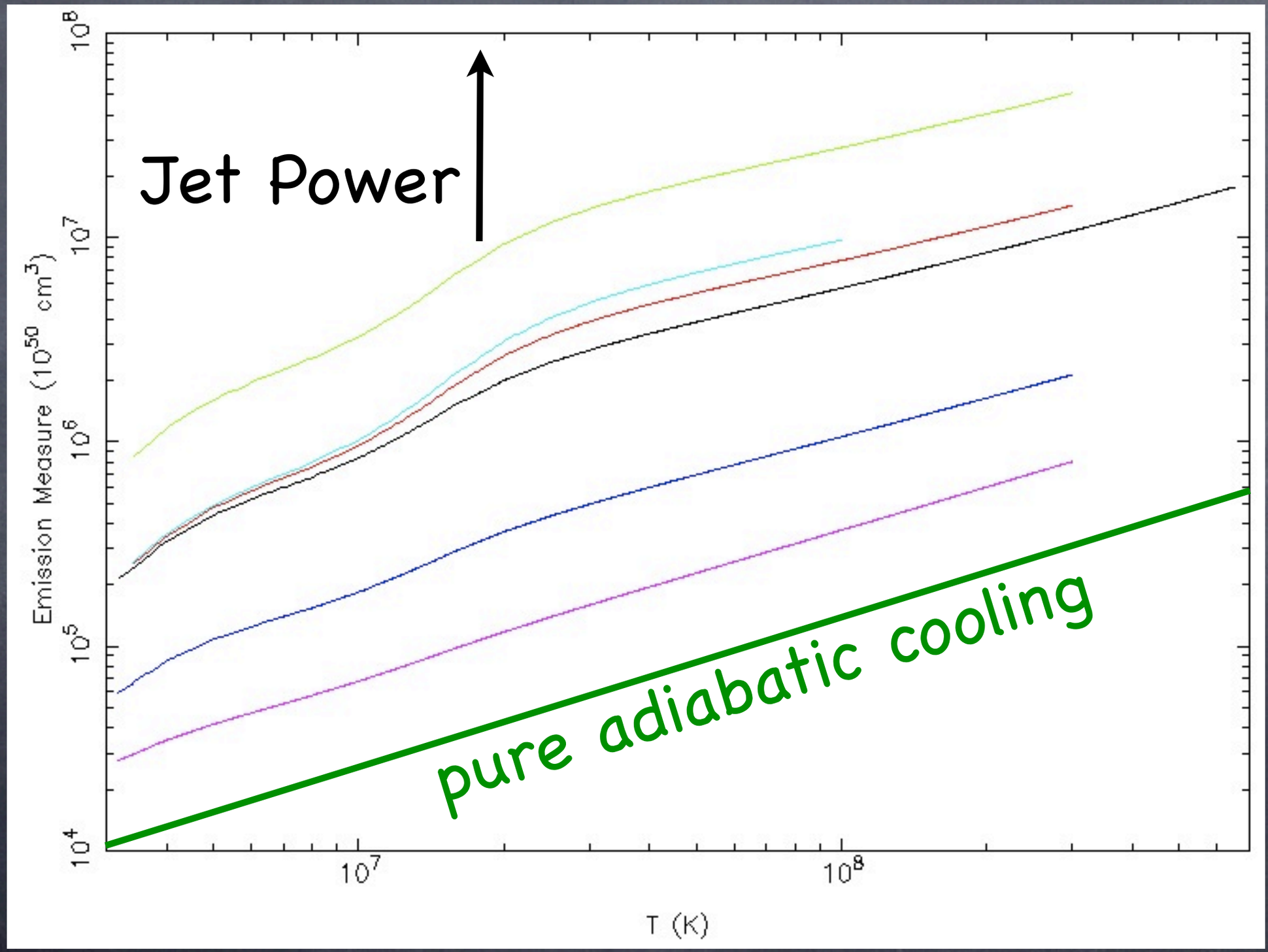
Spectral Modeling



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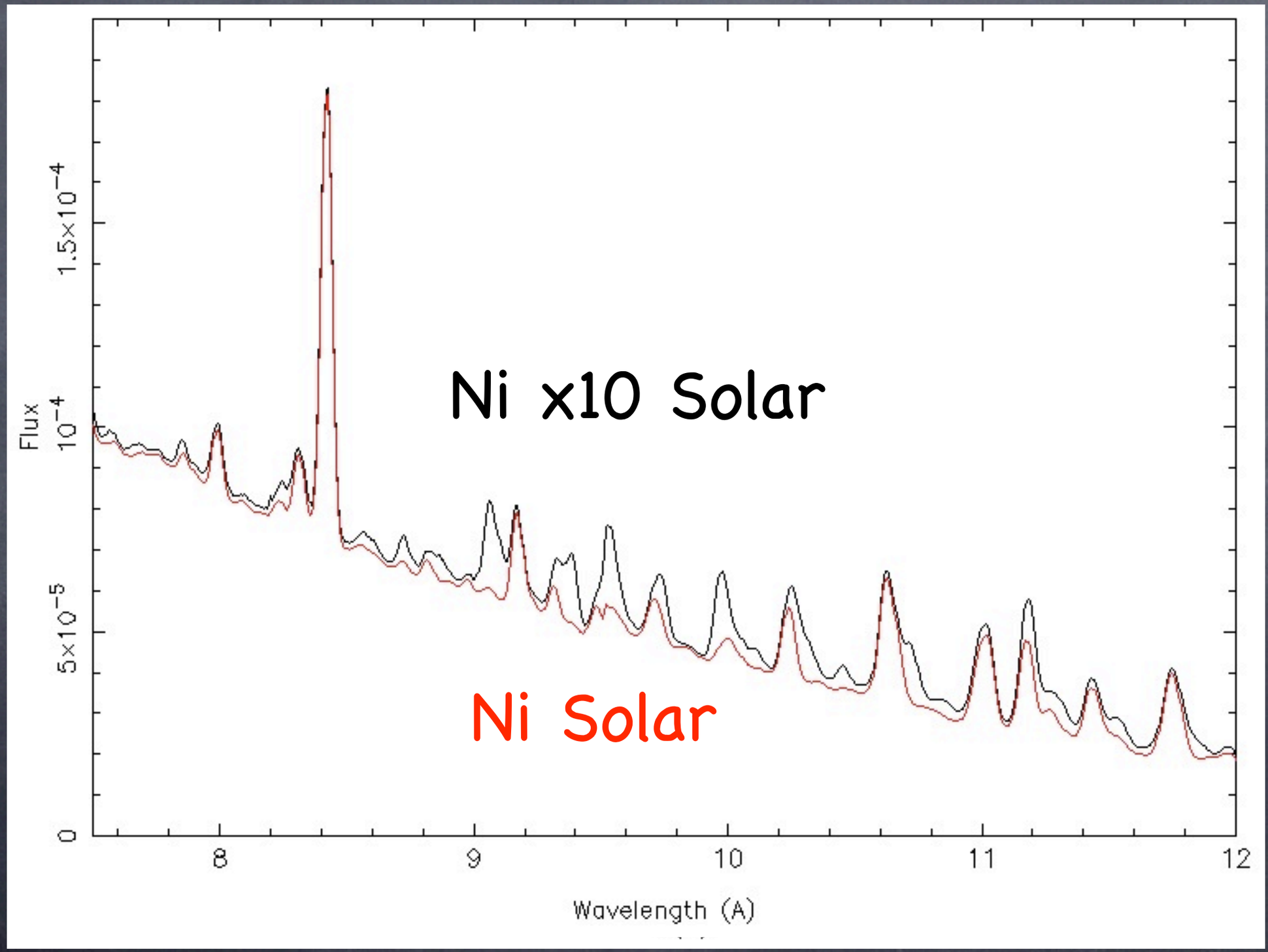

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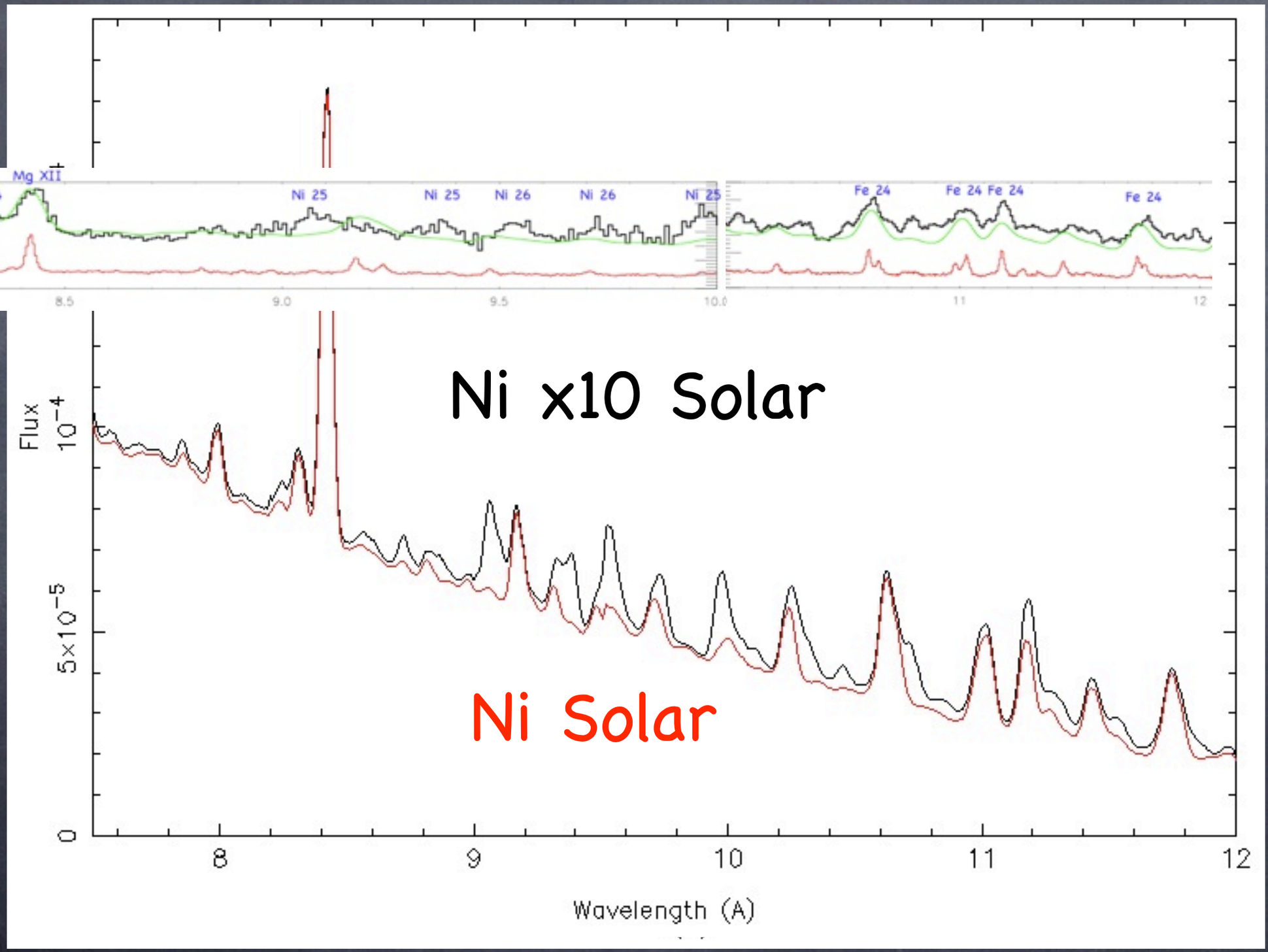
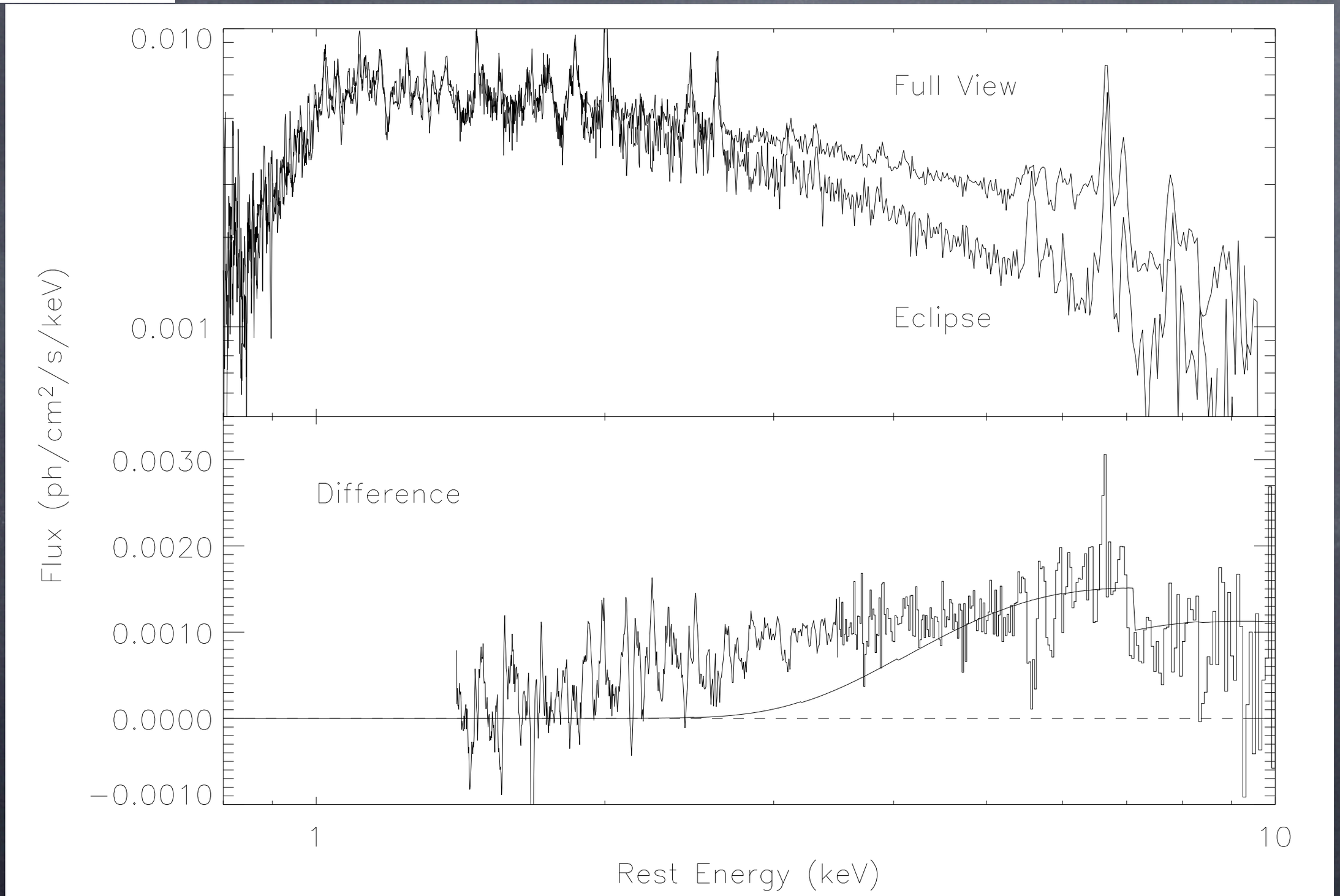


Eclipse Spectrum



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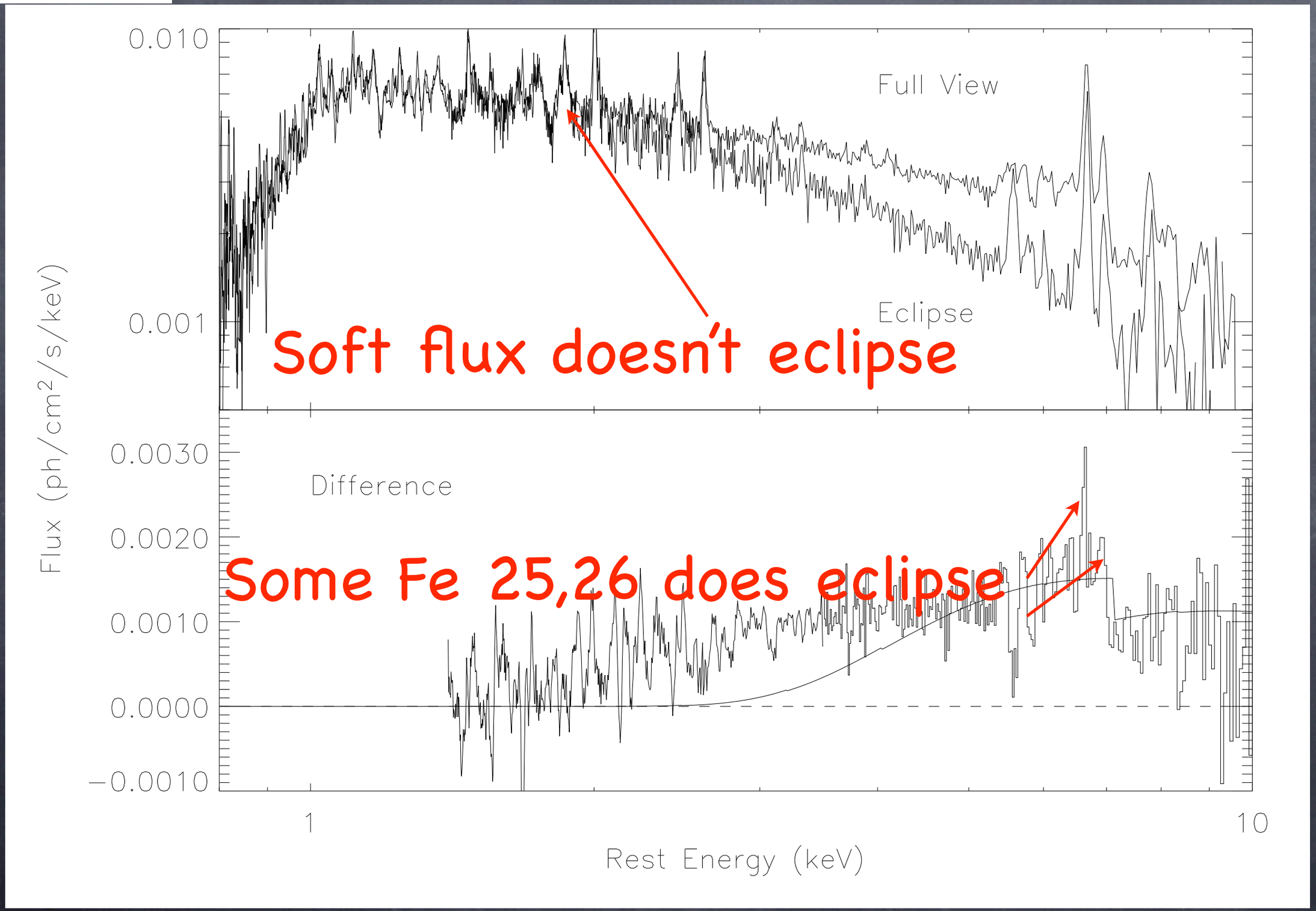
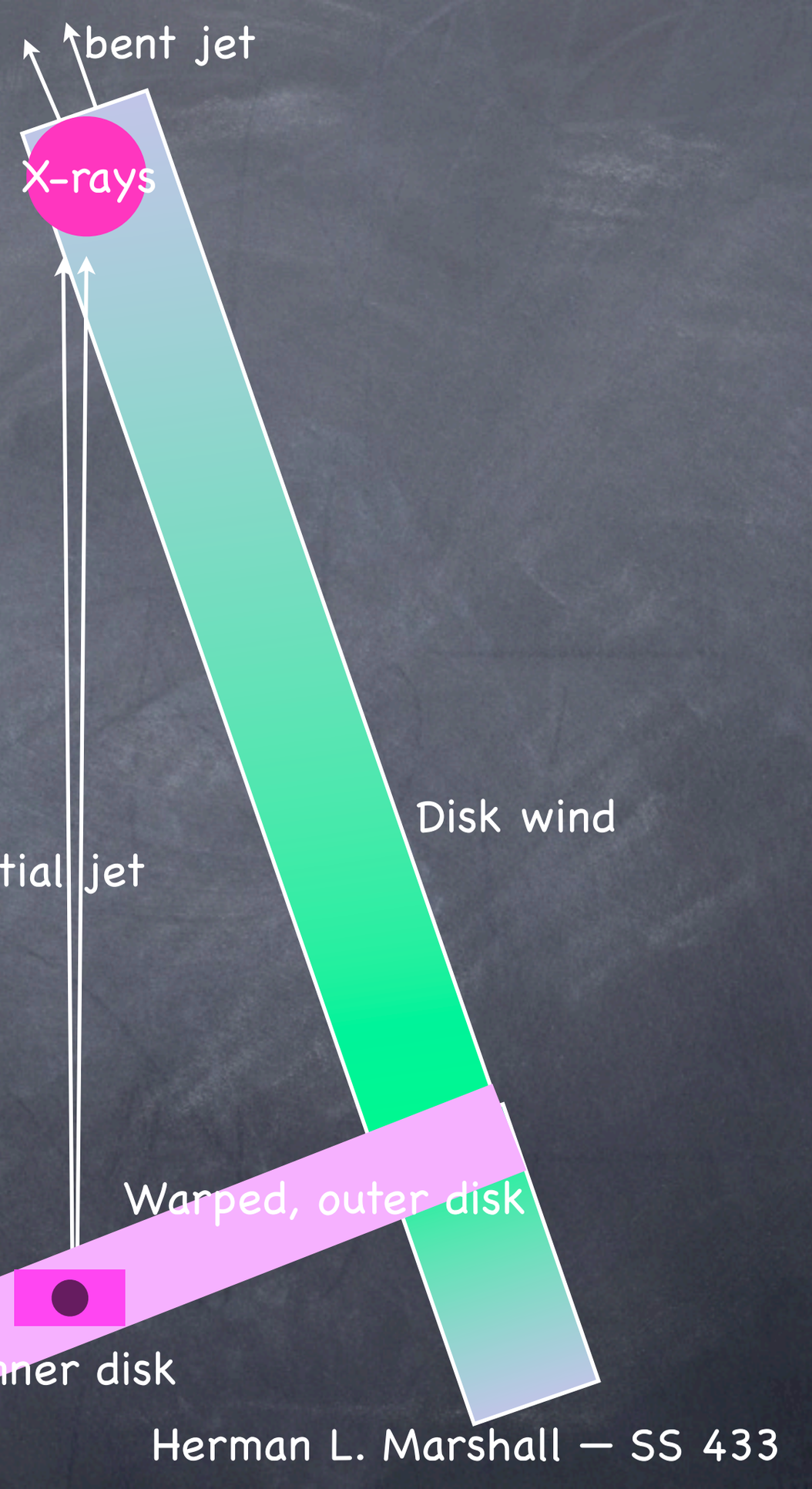


Wind model

Begelman, King, & Pringle 2006

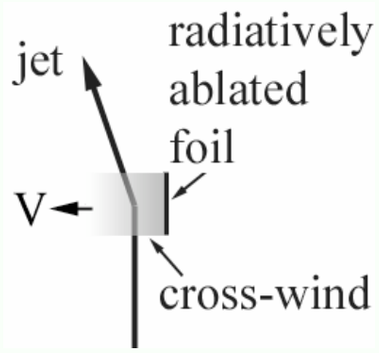
- Wind from disk warp
  - v_{wind} ~ 1500 km/s,
  - mdot ~ 5e-4 Msun/yr
  - $r=10^{11}$ cm (~ R_{disk})
- Wind bends jet via oblique shocks (obs'd in lab experiments)
- X-rays at shocks ~ 10^{12} cm from jet origin



Jet Bending Experiment

Deflection of the jet in interaction with plasma cloud

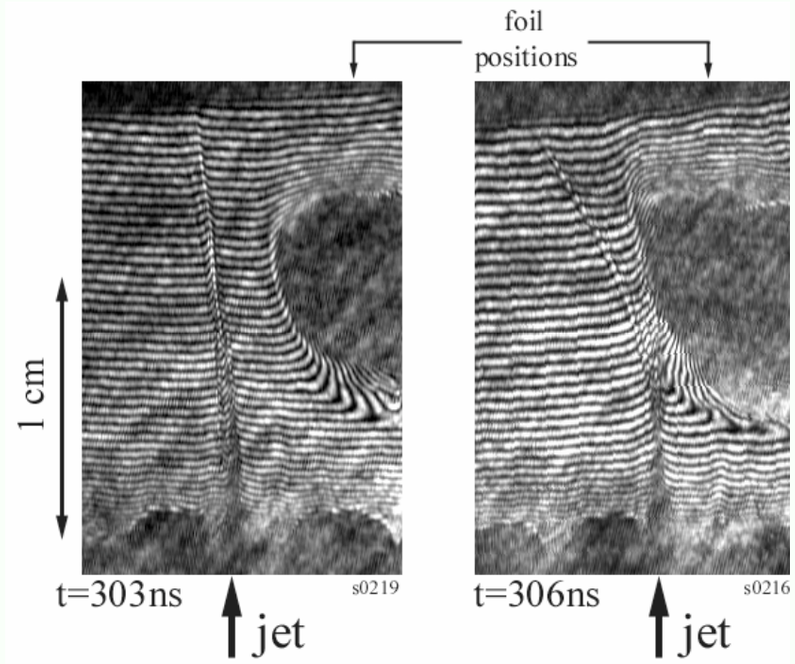
The ram pressure of plasma ablated from CH foil deflects the jet



Wind Velocity
~ 20 – 50 km s^{-1}
Wind Electron Density
~ 10^{17} – 10^{18} cm^{-3}

"Control" over wind parameters
- **Ram pressure**
- **Direction**
- **Cooling Properties**

Higher wind ram pressure for closer foil position



Jet remains collimated after deflection by up to 30^0

Lebedev et al., ApJ 2004 (accepted)

Jet maintains speed after deflection

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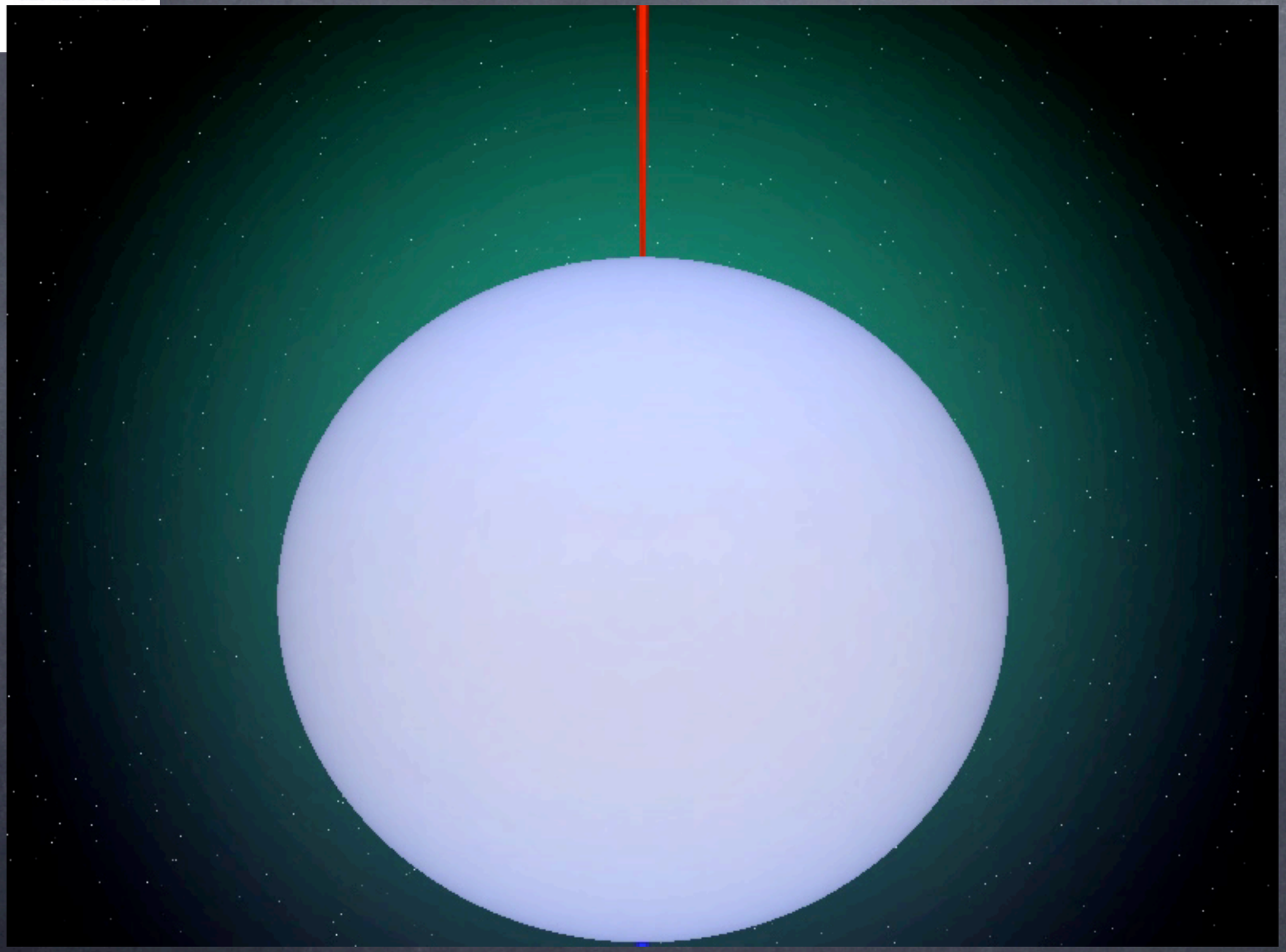

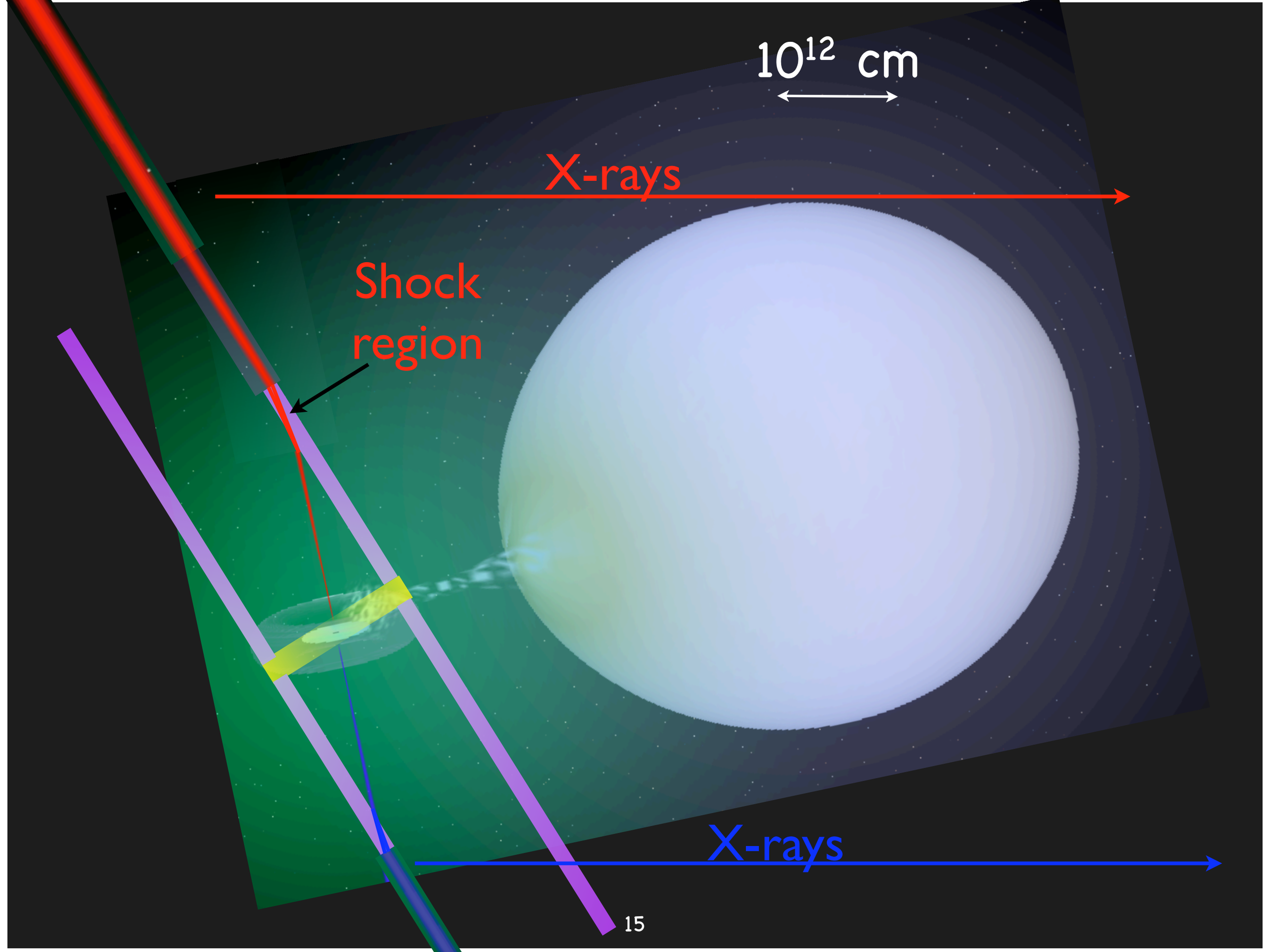
10^{12} cm
X-rays
Shock
region
X-rays

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Conclusions

- X-ray region cooling time < 5000 s
  - Radiative cooling of thermal plasma < 10 s
  - X-ray emission < 4 x 10^{13} cm (0.05 mas) from shocks that redirect jet and heat gas (IXO!)
  - spectral fit: r_{min} = 5 x 10^{11} cm, L_{jet} = 3 x 10^{39} erg/s (L_x ~ 10^{35})
- Jet redirected on 0.2d time scale by 2°
  - Blue, red jets different
  - Perturbed by local effects where jet is directed
  - --> supports a redirection model
- Eclipsed region spectrum: hard, weak Fe XXV line
  - Most of jet is not eclipsed; > 2 x 10^{12} cm from disk
  - Supports redirection model (or internal shocks)
- Ni overabundance, enhanced metals --> gas from companion "coated" with SN products

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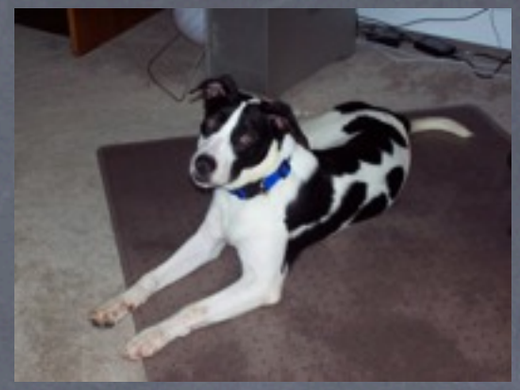

Leroy

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