SS 433 Jets: Fraternal or Identical Twins?

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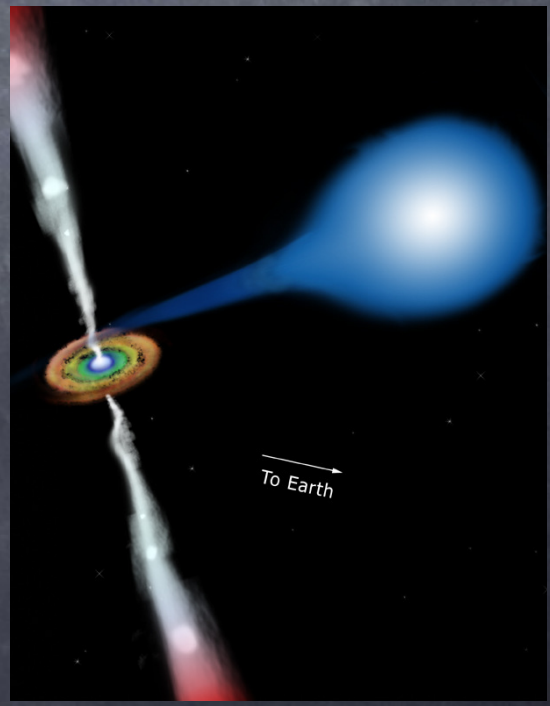
QuickTime™ and a
Video decompressor
are needed to see this picture.

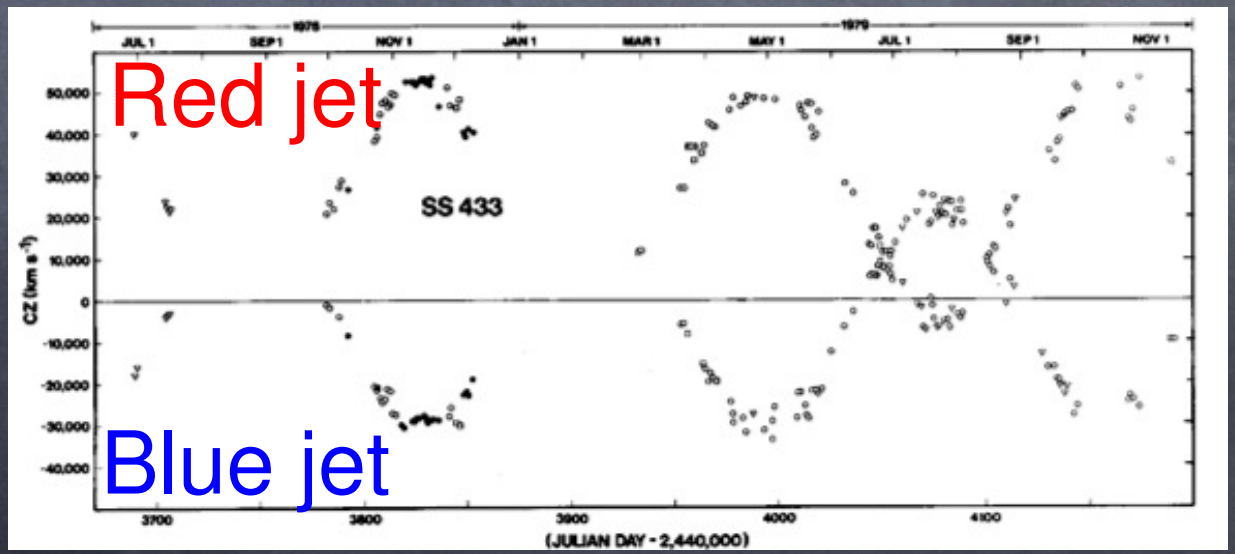


SS 433 Background

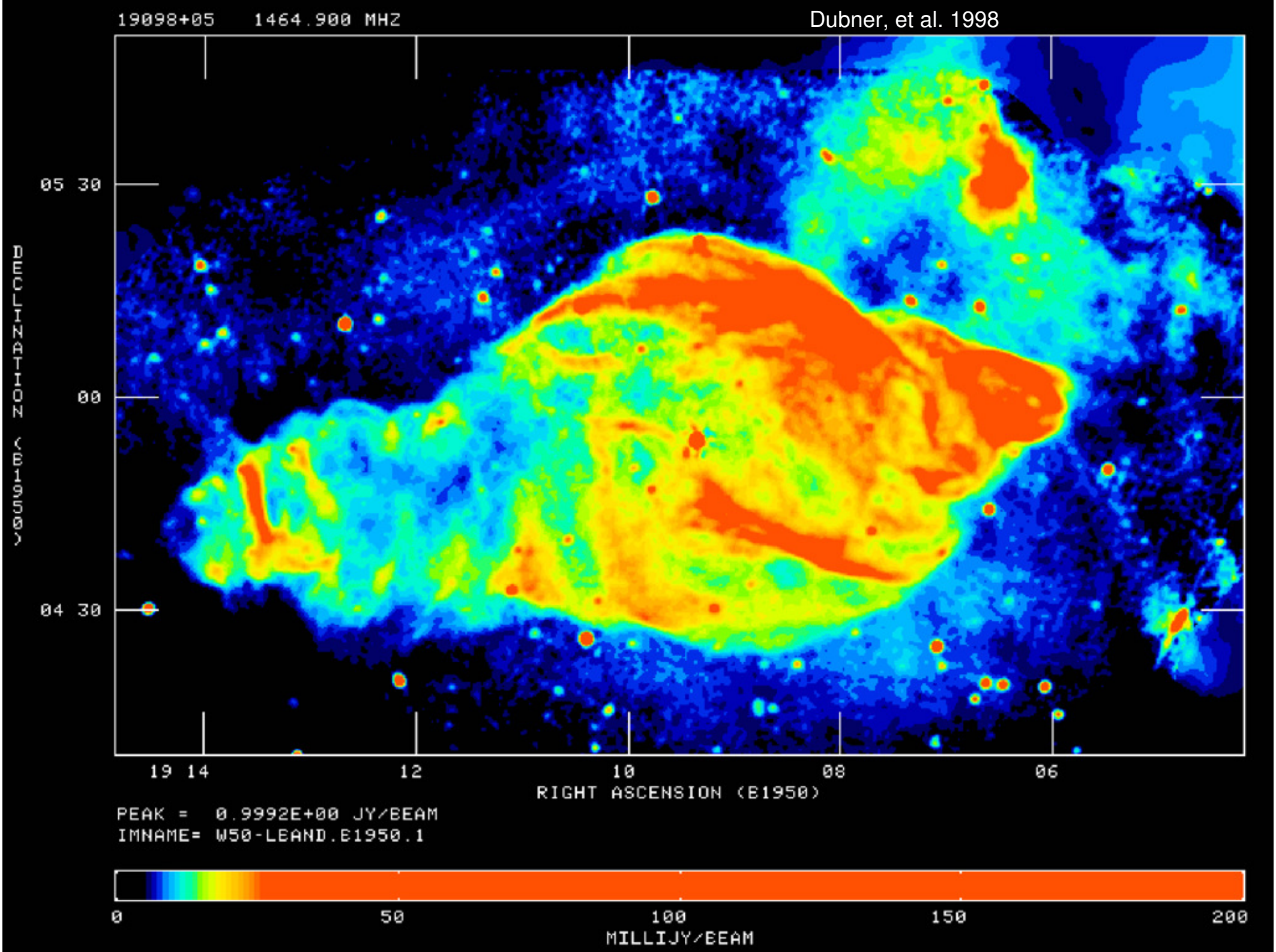
- Periodically Doppler shifting Hα HeI and Hβ
- Model: oppositely directed jets at 0.26 c
  - Precession period: 162 days
  - Orbital period: 13.08 days

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

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



Margon et al. 1980


19098+05 1464.900 MHZ
Dubner, et al. 1998
05 30
00
04 30
DECLINATION (B1950)
19 14
12
10
08
06
RIGHT ASCENSION (B1950)
PEAK = 0.9992E+00 JY/BEAM
IMNAME= W50-LBAND.B1950.1
0
50
100
150
200
MILLIJY/BEAM

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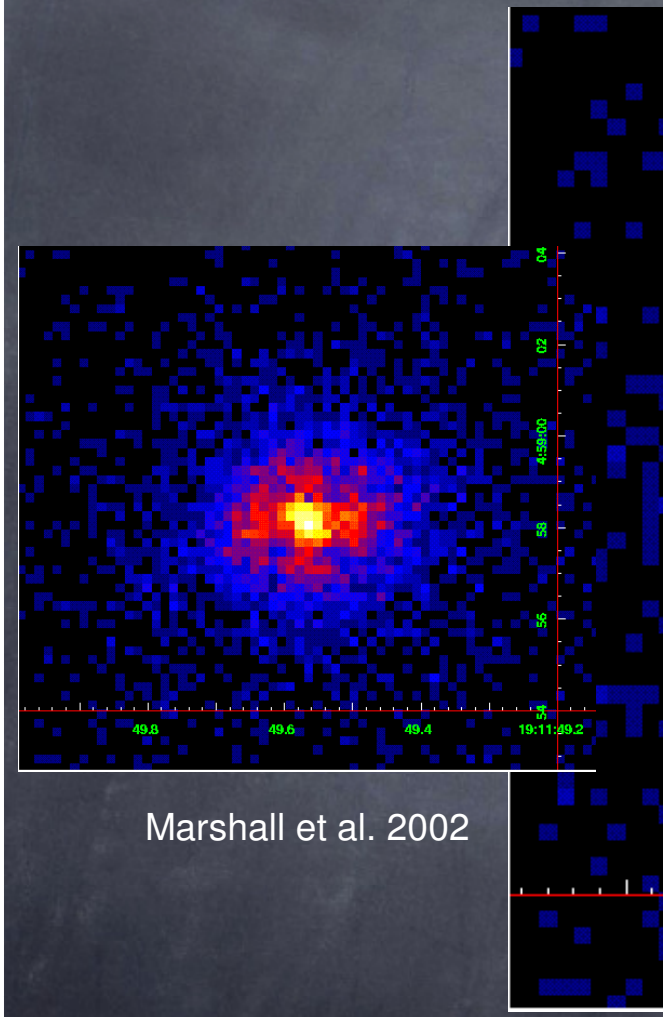
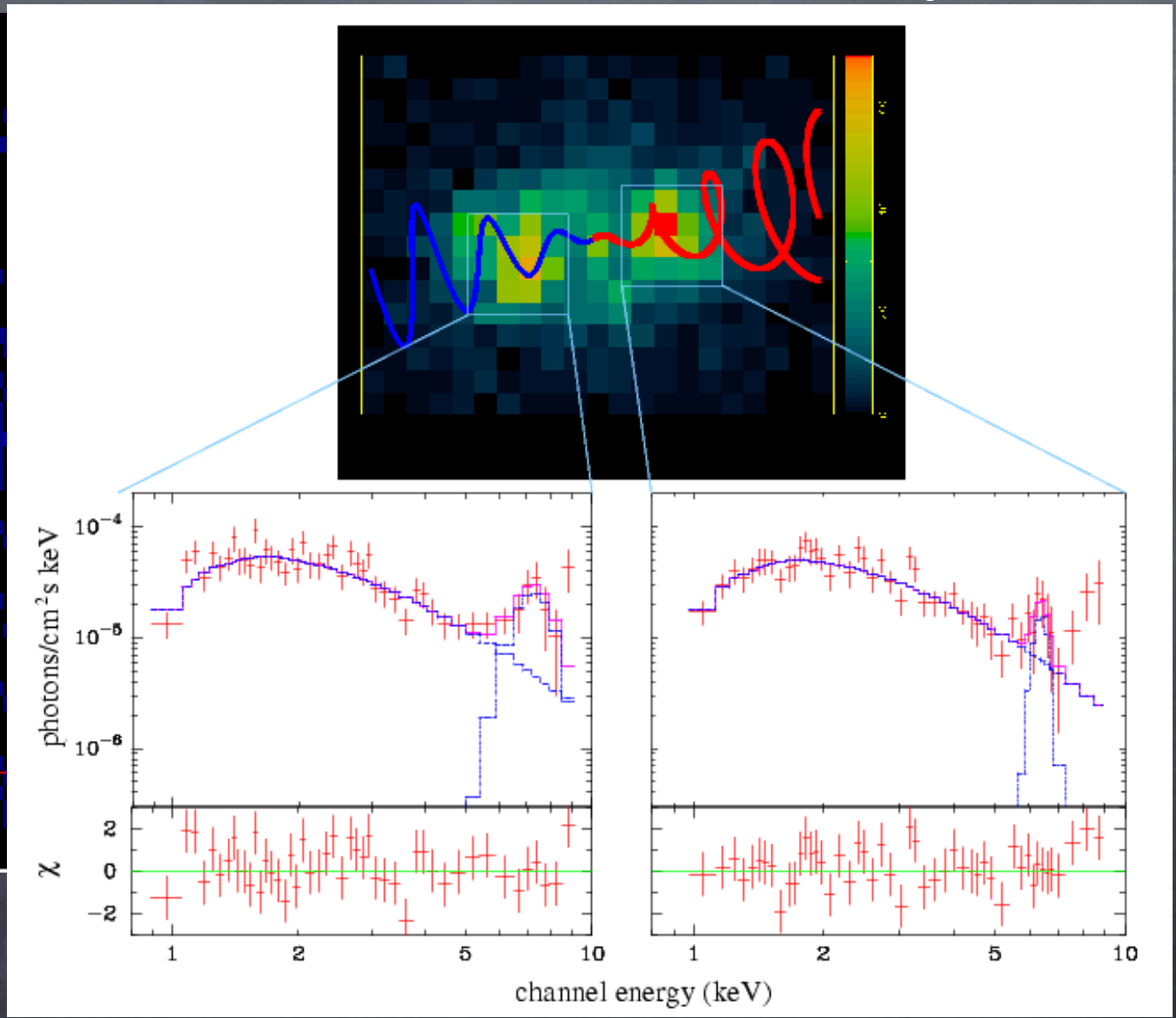
Migliari et al. 2003



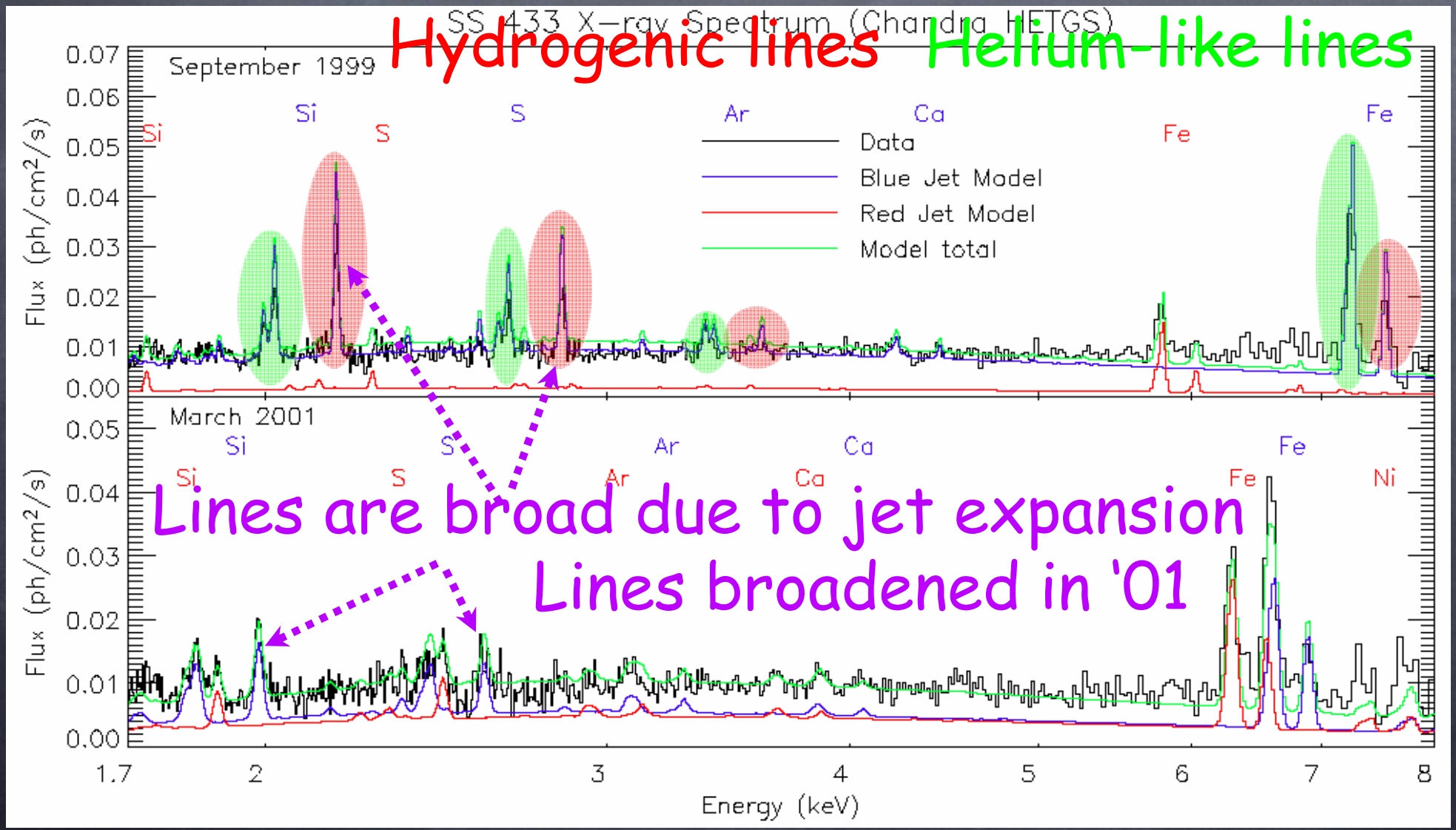
Marshall et al. 2002



Recent SS 433 X-ray Spectroscopy

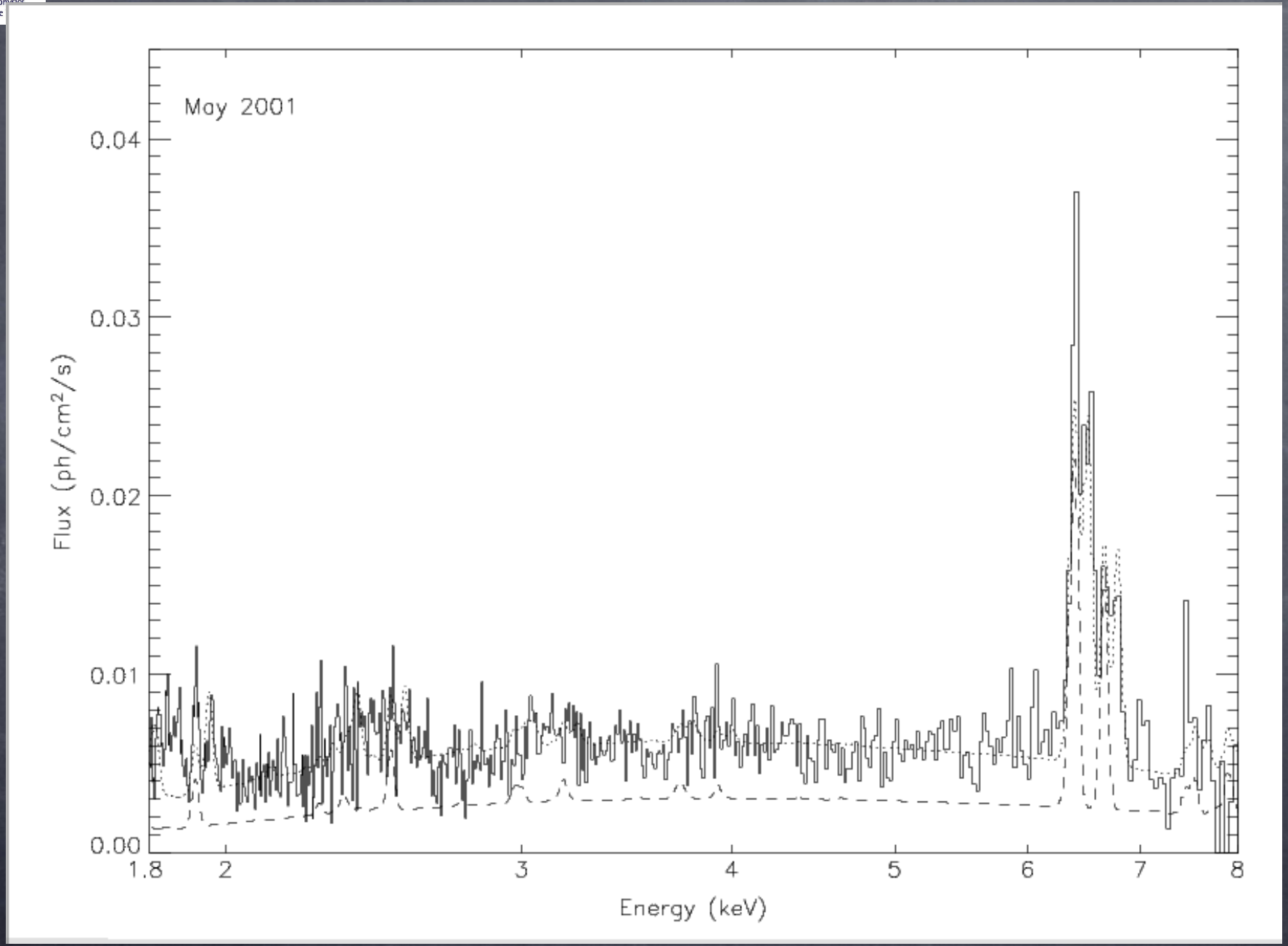
- Kotani et al. (1996, ASCA): Doppler shifted lines of a few ions (e.g., Fe XXV, Fe XXVI)
- Marshall et al. (2002, HETGS): 30 bright, narrow lines, extended emission ~ 5” across
- Migliari et al. (2002, ACIS): extended jets are thermal
- Namiki et al. (2003, HETGS): very weak lines
- Brinkmann et al. (2005, XMM EPIC): several phases, high abundances, extra component
- Lopez et al. (2005, HETGS): Fe lines in eclipse, lines weak in another observation

Two HETGS Spectra

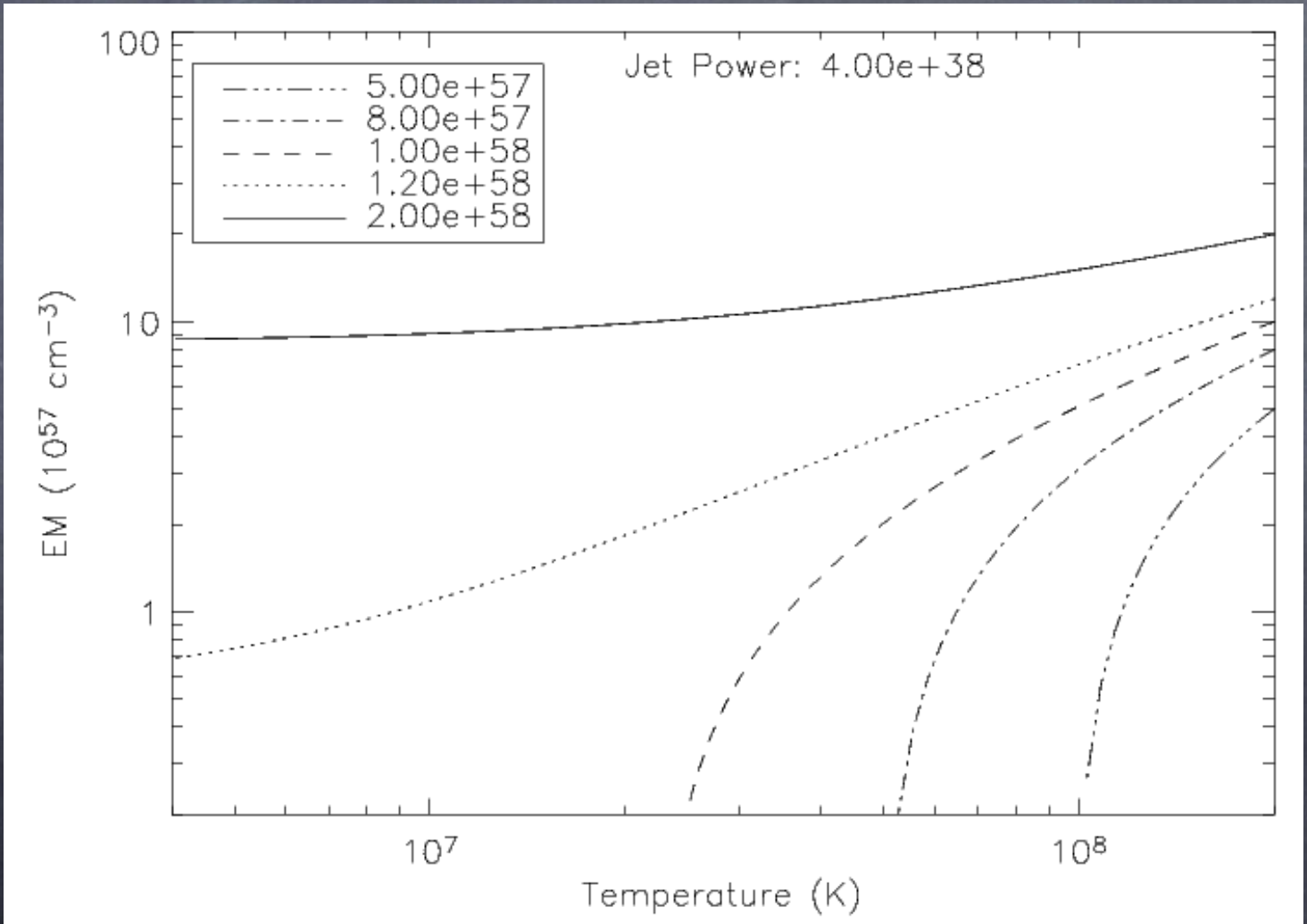


Jet Physics from Lines

- Line Doppler shifts
  - not in acceleration zone
  - all ions accelerated to same speed
- Line widths
  - not in nozzle or flaring zone
  - opening angle is constant at 0.5°
- 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}


May 2001
0.04
0.03
0.02
0.01
0.00
Flux (ph/cm²/s)
1.8
2
3
4
5
6
7
8
Energy (keV)

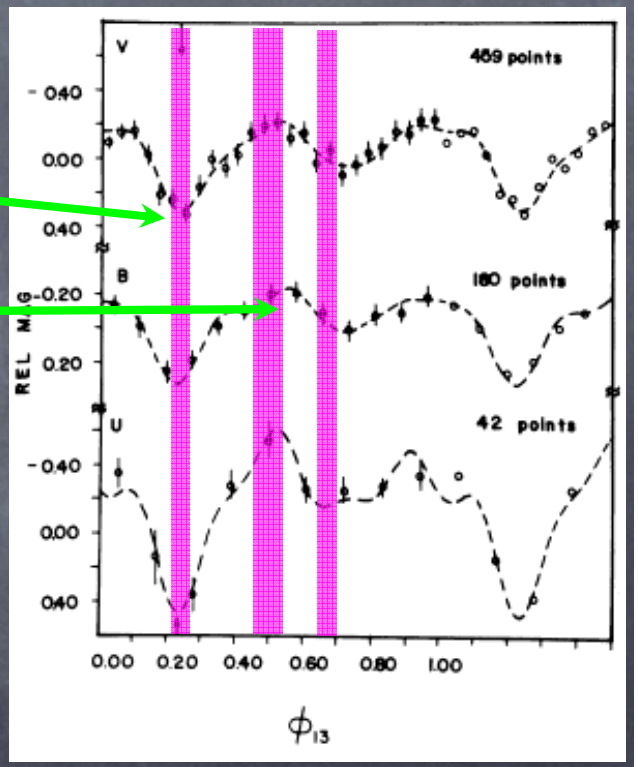
Radiative Cooling: Varying EM_i changes EM(T)



2005 Campaign

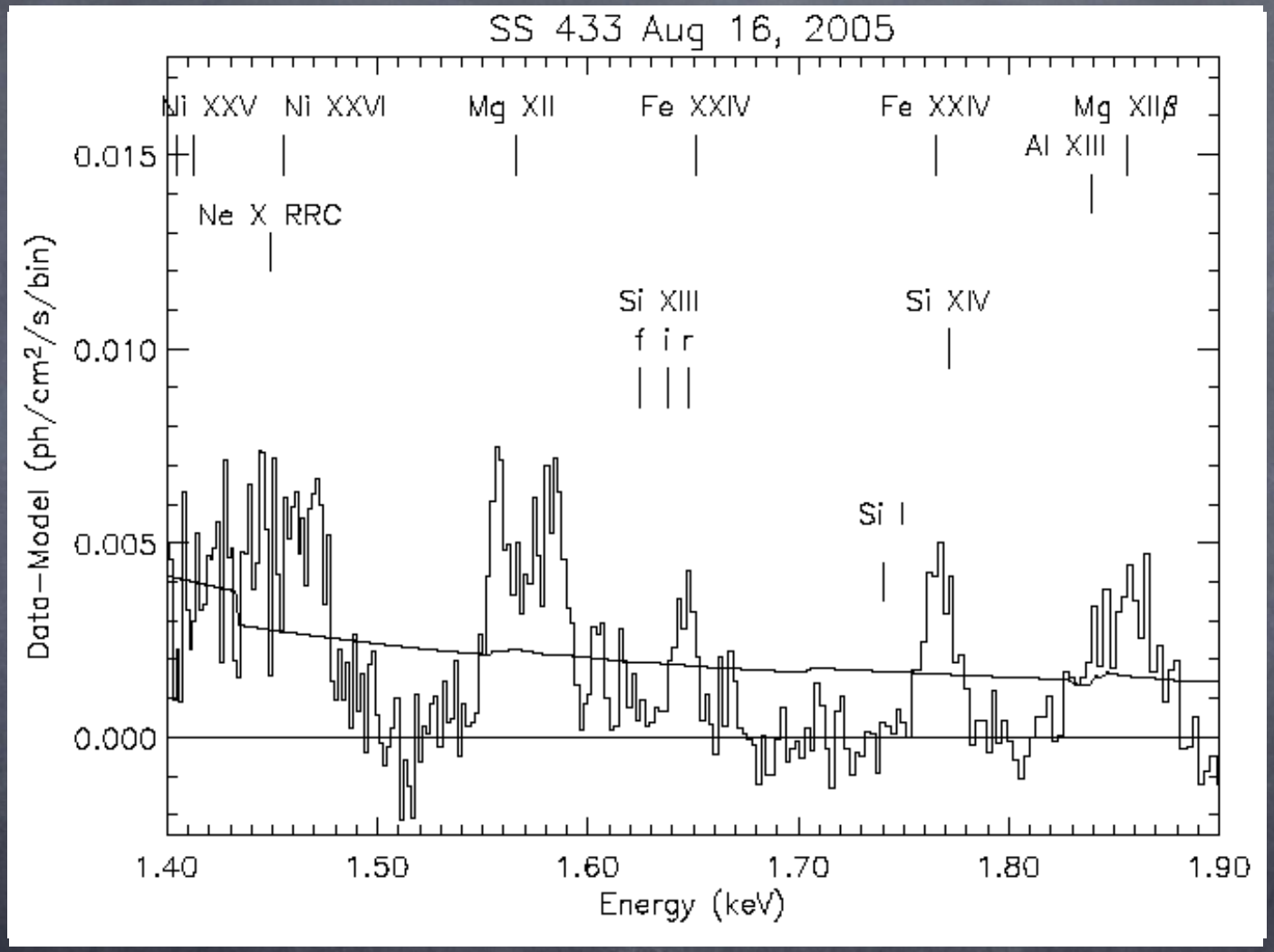
- 200 ks HETGS over 2 week span (PI: Canizares)
  - "Trigger" ensured bright lines
  - Aug. 12: 50 ks during eclipse
  - Aug. 15-18: 120 ks non-eclipse
- Simultaneous observations
  - optical spectroscopy (Hillwig)
  - VLA, VLBA imaging (Mioduszewski, Rupen)
  - RXTE (Marshall)

(Leibowitz et al. 1984)



Orbital Phase

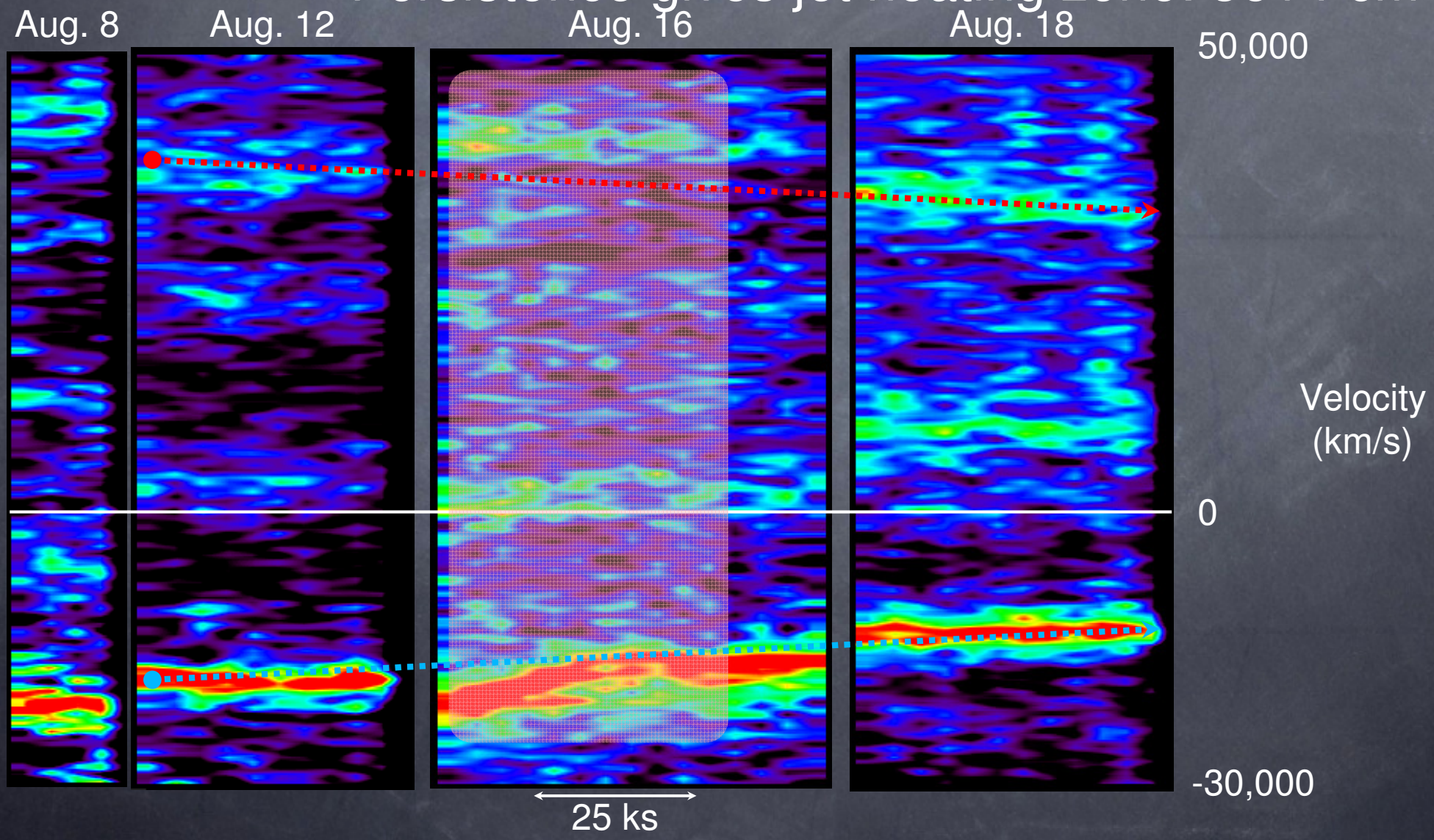
Non-Eclipse, Part 1



- Mg XII and Si XIV in blue jet: double peaked

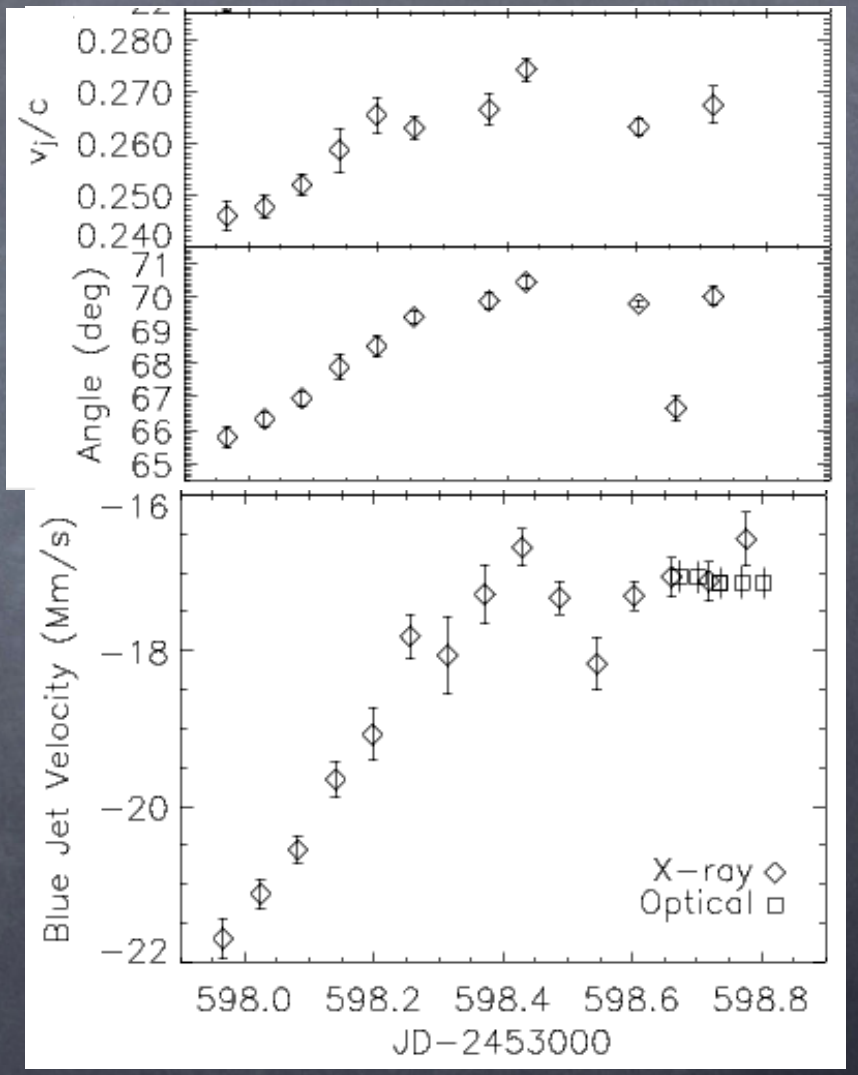
Discrete Precession

- Precession variations: episodic torquing
- Persistence gives jet heating zone: 3e14 cm



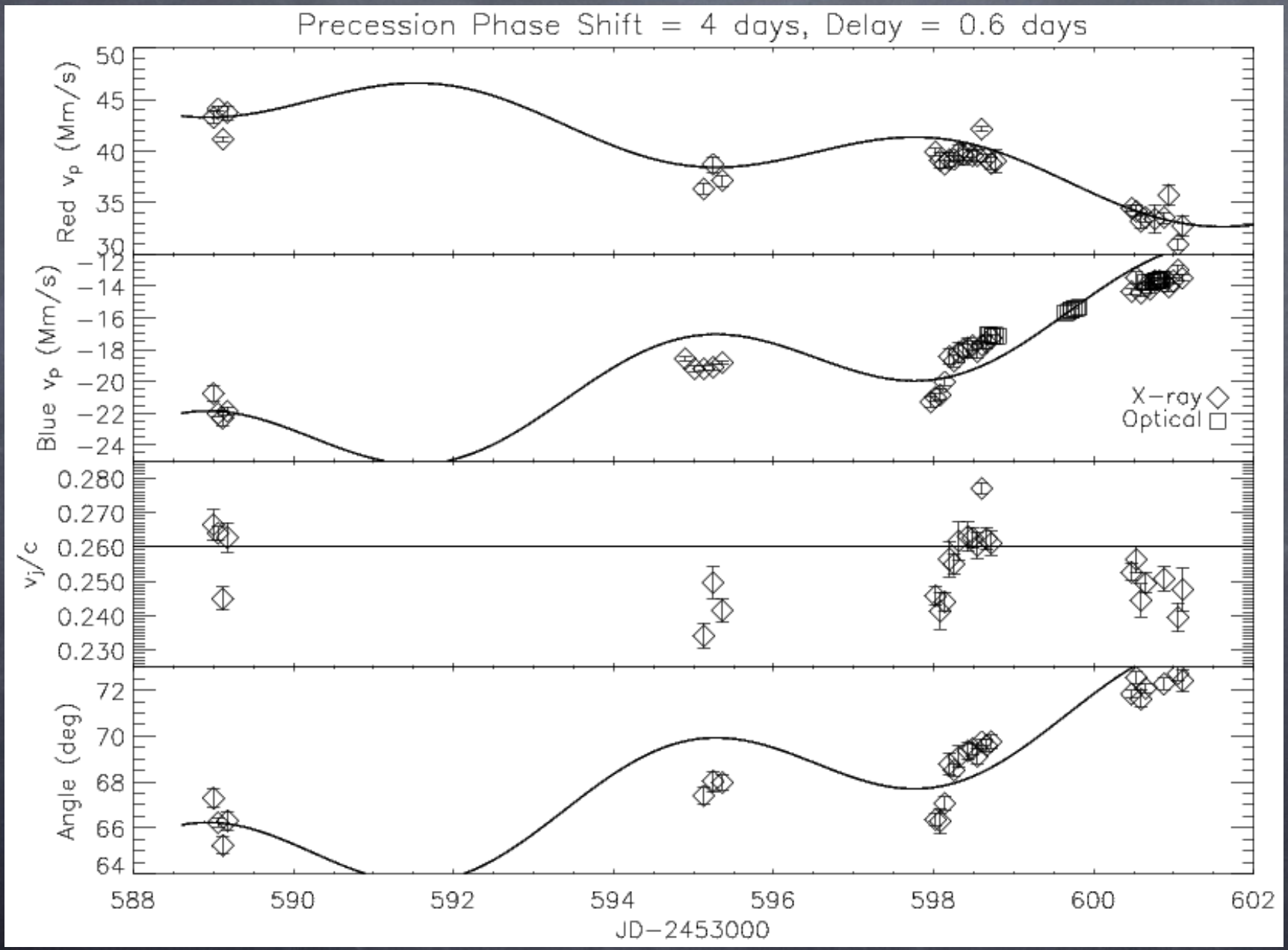
Optical and X-ray Doppler Shifts

- No deceleration from X-ray to optical emission regions
- Delays relative to disk
  - Optical: 0.6d
  - X-ray: 0.4d
- Red v. Blue
  - interp. as jet base change --> angle, speed both change
  - Environmental effect?



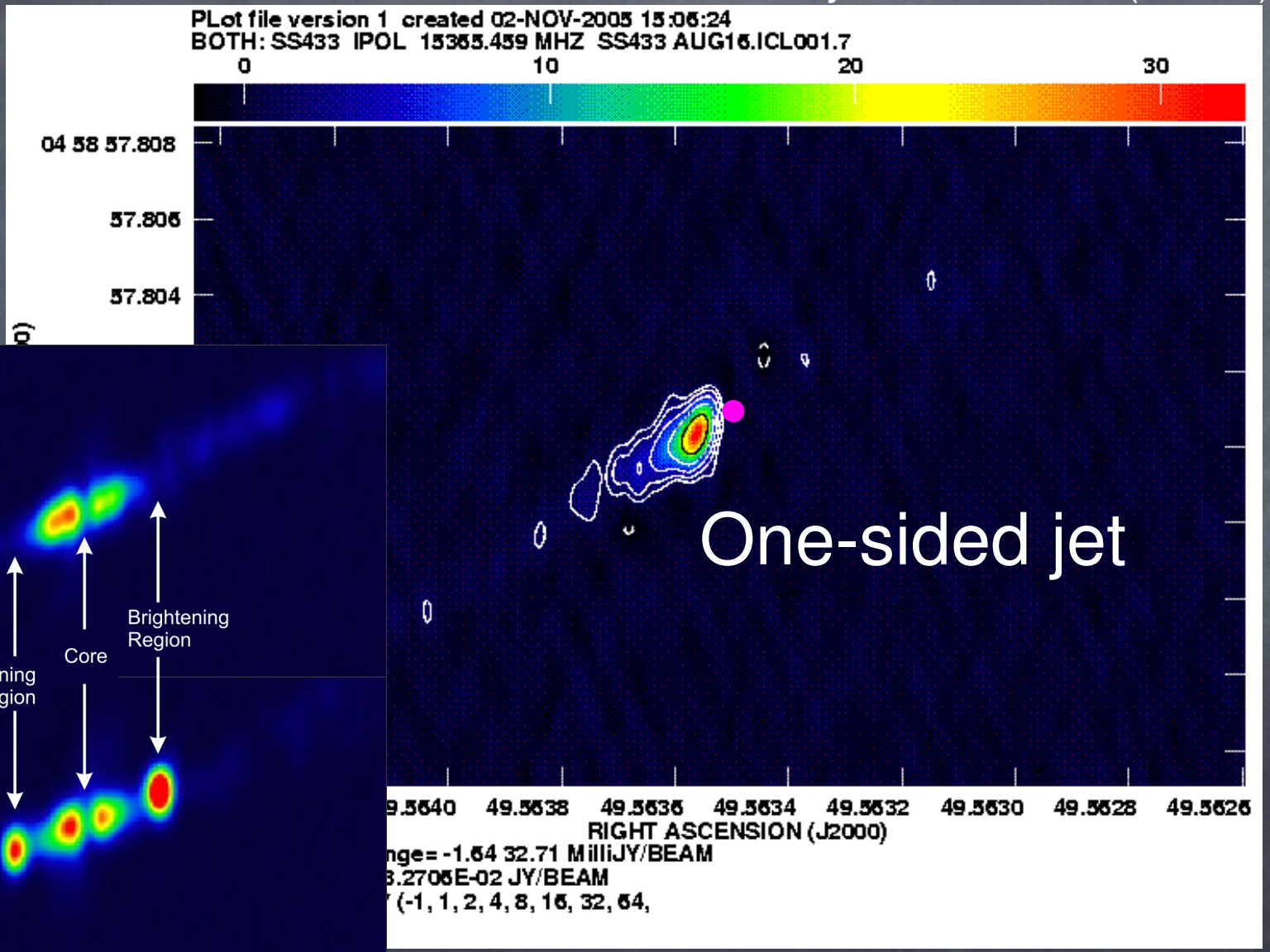
Optical data from Todd Hillwig (Valparaiso)
HETGS of SS 433

Tracking Doppler Shifts



Joint VLBA Data

Radio data from Amy Mioduszewski (NRAO)



Preliminary Results 1

- X-ray region cooling time < 5000 s
  - Length < 4e13 cm
  - Consistent with radiative cooling
  - Con-X could resolve cooling time
- Part of jet persists over > 50 ks
  - Larger than cooling time --> reheating
  - Related to spatially resolved jets?
  - Extended region scale ~3e17 cm

Preliminary Results 2

- X-ray jet starts ~2e14 cm from core
  - Optical and X-ray Doppler shifts match
  - Starts off disk: base obscured? detached?
  - Identical but different aging?
- Acceleration or redirection on 0.3d time scale
  - Amplitude is larger than “nodding” effect due to companion torque
  - Identical but different neighborhoods
- Jet can appear one-sided
  - Not just different Doppler boosting
  - X-ray and radio data agree
  - Fraternal

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More to come!

- Detailed modeling of line strengths
  - compare radiative and adiabatic cooling
  - He-like triplets: density estimates
- Eclipse modeling
  - compare EM(T)
- Red vs. Blue — intrinsic or environmental?
- Comparison to VLBA
  - jet direction
  - knot ejections matching speeds
- Torque estimates