SS 433 Jets: Fraternal or Identical Twins?
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SS 433 Background

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

Margon et al. 1980

Red jet
Blue jet

Margon et al. 1980
MSSL Spectroscopy — 3/28/06

Marshall et al. 2002

Migliari et al. 2003

HETGS of SS 433
Recent SS 433 X-ray Spectroscopy

- Kotani et al. (1996, ASCA): Doppler shifted lines of a few ions (e.g., Fe XXV, Fe XXVI)
- 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

Hydrogenic lines  Helium-like lines

Lines are broad due to jet expansion
Lines broadened in '01
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 $\sim 10^{14}$ cm$^{-3}$
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)
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: $3 \times 10^{14} \text{ cm}$

Aug. 8  Aug. 12  Aug. 16  Aug. 18

MSSL Spectroscopy — 3/28/06

HETGS of SS 433
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)
Tracking Doppler Shifts
Joint VLBA Data

Radio data from Amy Mioduszewski (NRAO)

One-sided jet
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
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