Direct Observation of High-speed Reconnection Outflows with SOHO/SUMER, TRACE and RHESSI

Tongjiang Wang

Catholic University of America and
NASA's Goddard Space Flight Center

Linhui Sui CUA and NASA's GSFC

Jiong Qiu Montana State University

Introduction

- **Magnetic Reconnection**

  Energy release mechanism for flares and CMEs

- **Observational Evidence**

  — Separation motion of flare ribbons in Hα

  — Cusp-shaped soft X-ray flare loops (Tsuneta et al. 1992)

  — Loop-top hard X-ray sources (Masuda et al. 1994)

  — Double RHESSI X-ray coronal sources (Sui & Holman 2003)

♣ Signature of reconnection inflow by EIT (Yokoyama et al. 2001)

♣ Signature of reconnection outflow:

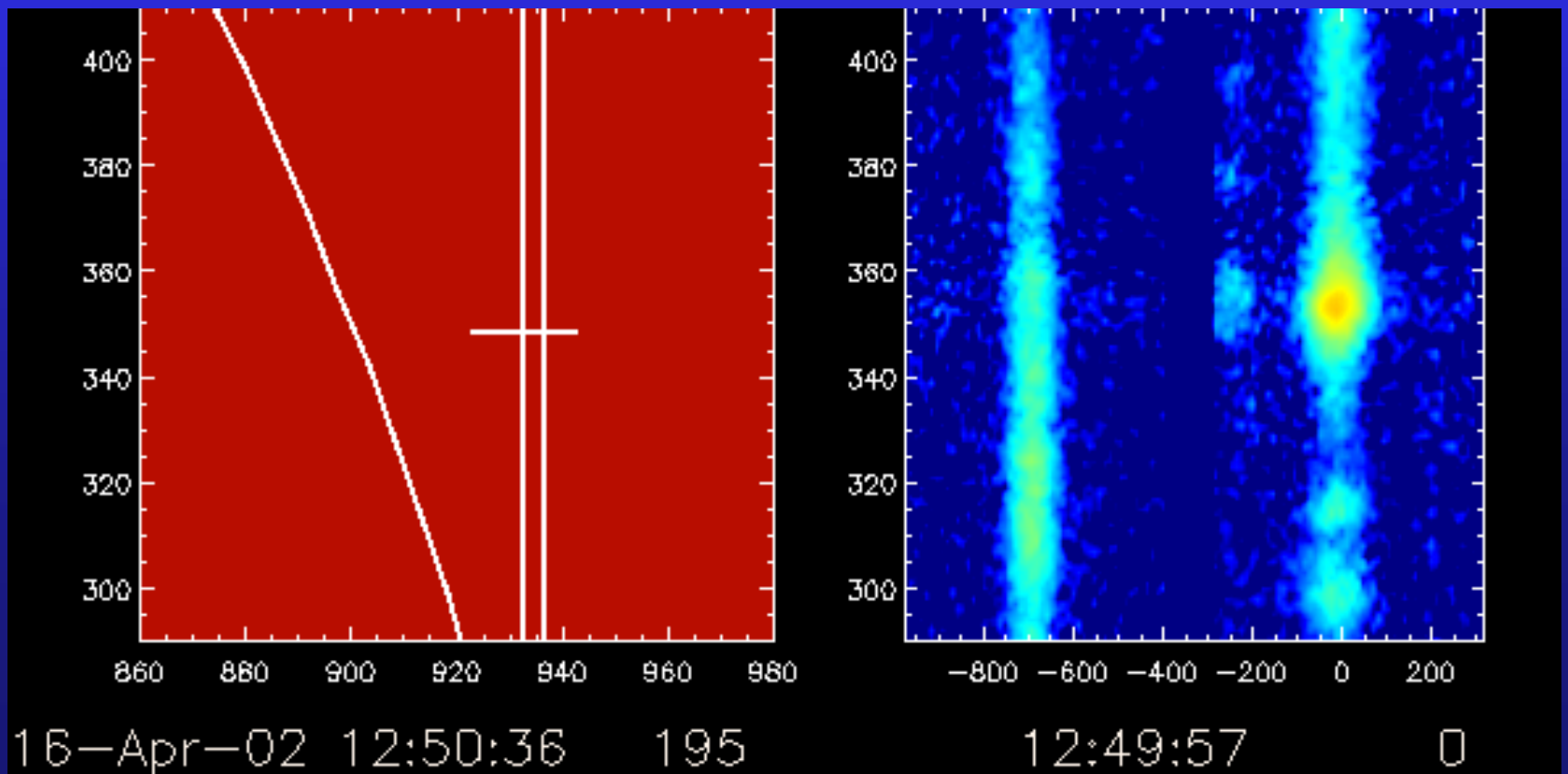
Plasma blob ejections in soft X-rays (Shibata et al. 1995)

Dark downward flows in X-ray and EUV (McKenzie & Hudson 1999)

Observations

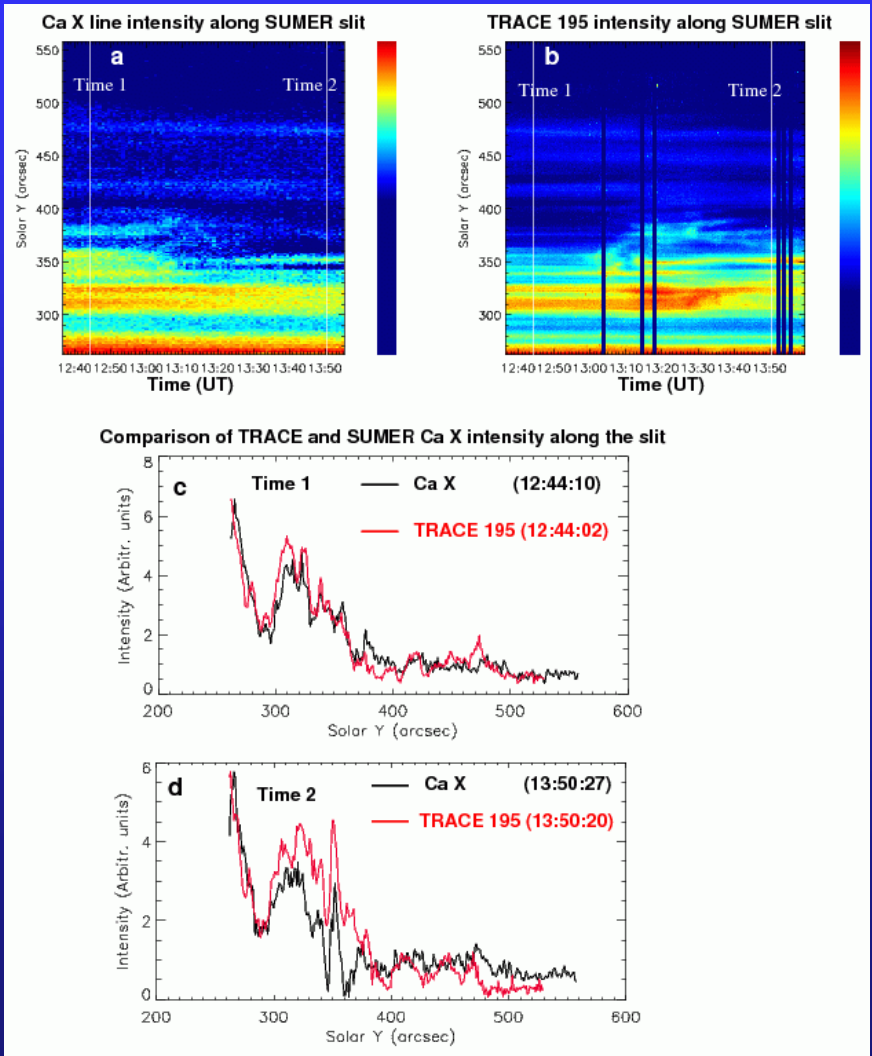
- **GOES M2.5-class flare on 2002 April 16, peaked at 13:15 UT**
  - — TRACE 195 A EUV images
  - — RHESSI hard X-rays
  - — SOHO/SUMER spectra

TRACE difference images **Ca x** **Fe XIX**

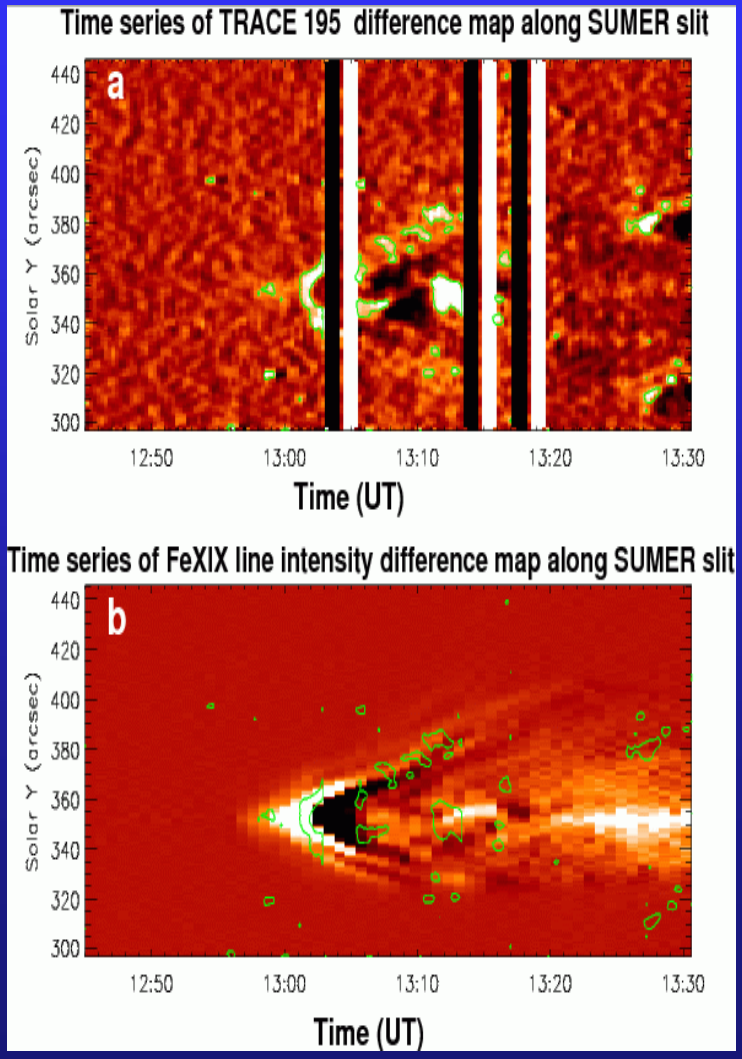


Coalignments between SUMER and TRACE

Coalignment in Y direction (along slit) within ~ 1 arcsec



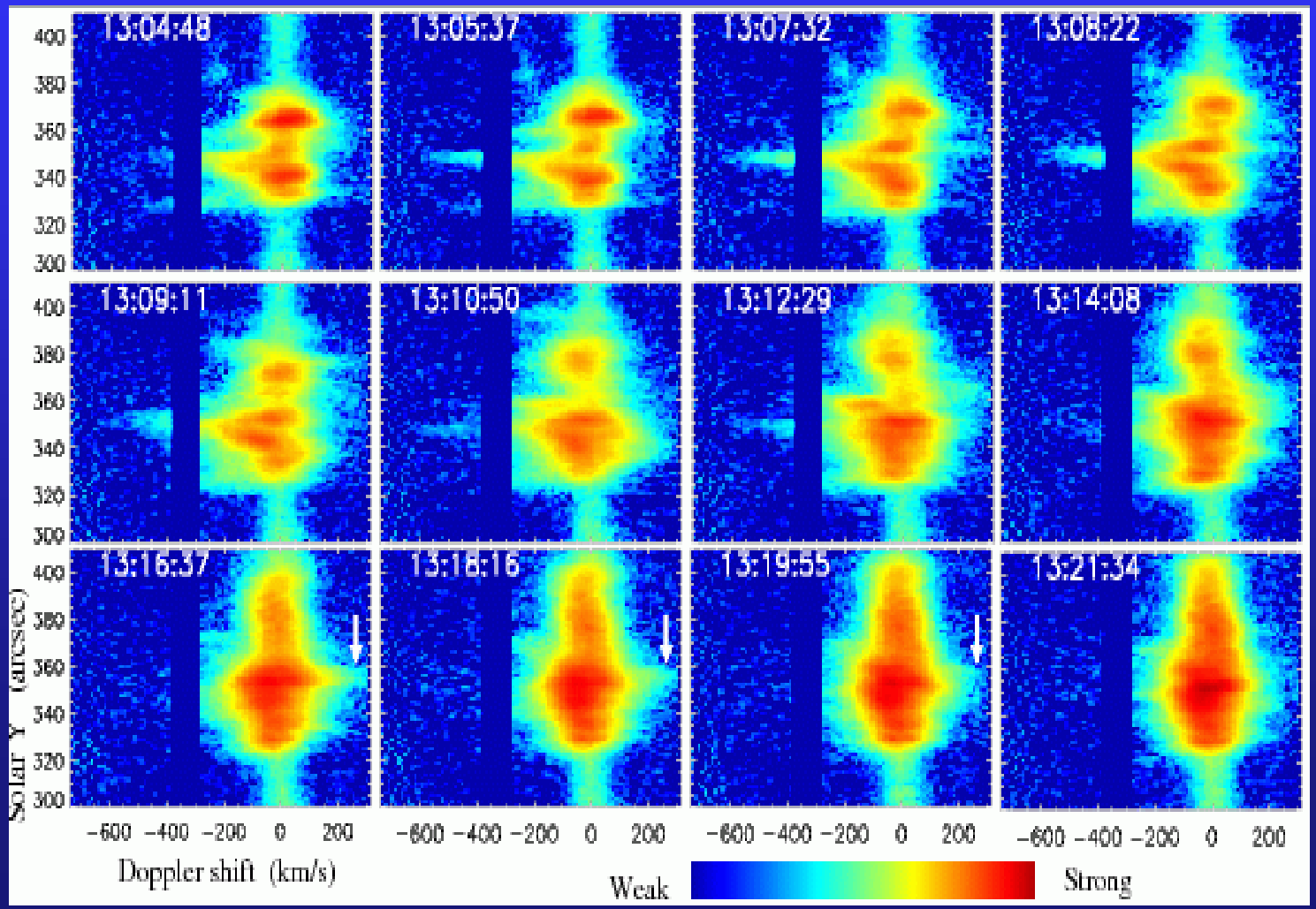
Coalignment in X direction within ~ 2-3 arcsec



Results: upflow and downflow of plasma jets

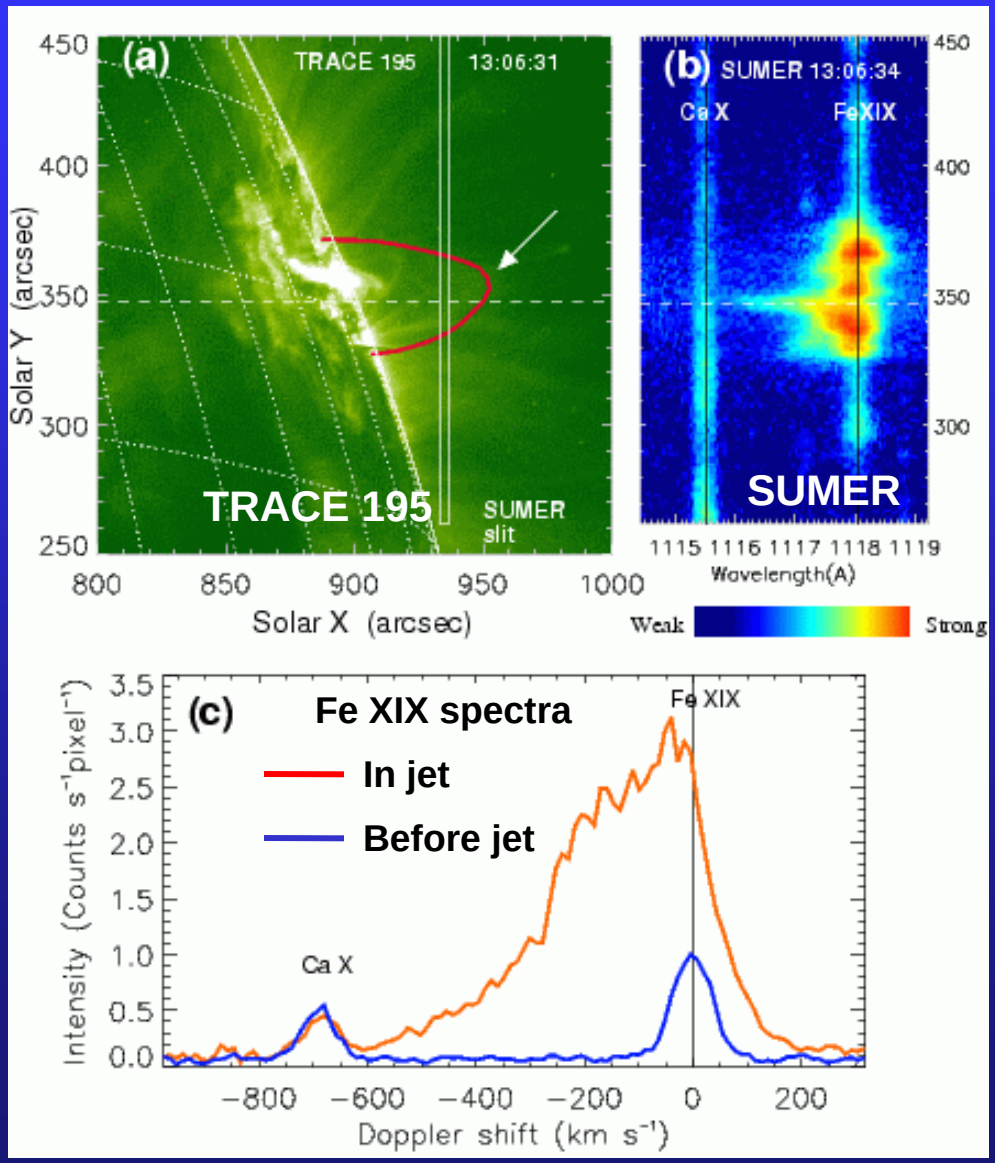
Upper two rows: an upflow with blueshift up to ~600 km/s

Bottom row: a downflow with redshift up to ~300 km/s



- Life time : upflow ~ 8 min downflow ~ 7 min
- Width of jet ~ 6 arcsec

Results: hot high-speed upflow in Fe XIX



- During flare impulsive phase
- Following eruption of a hot loop
- Life time ~ 8 minutes
- Narrow width ~ 6 arcsec
- Doppler shift up to 600 km/s

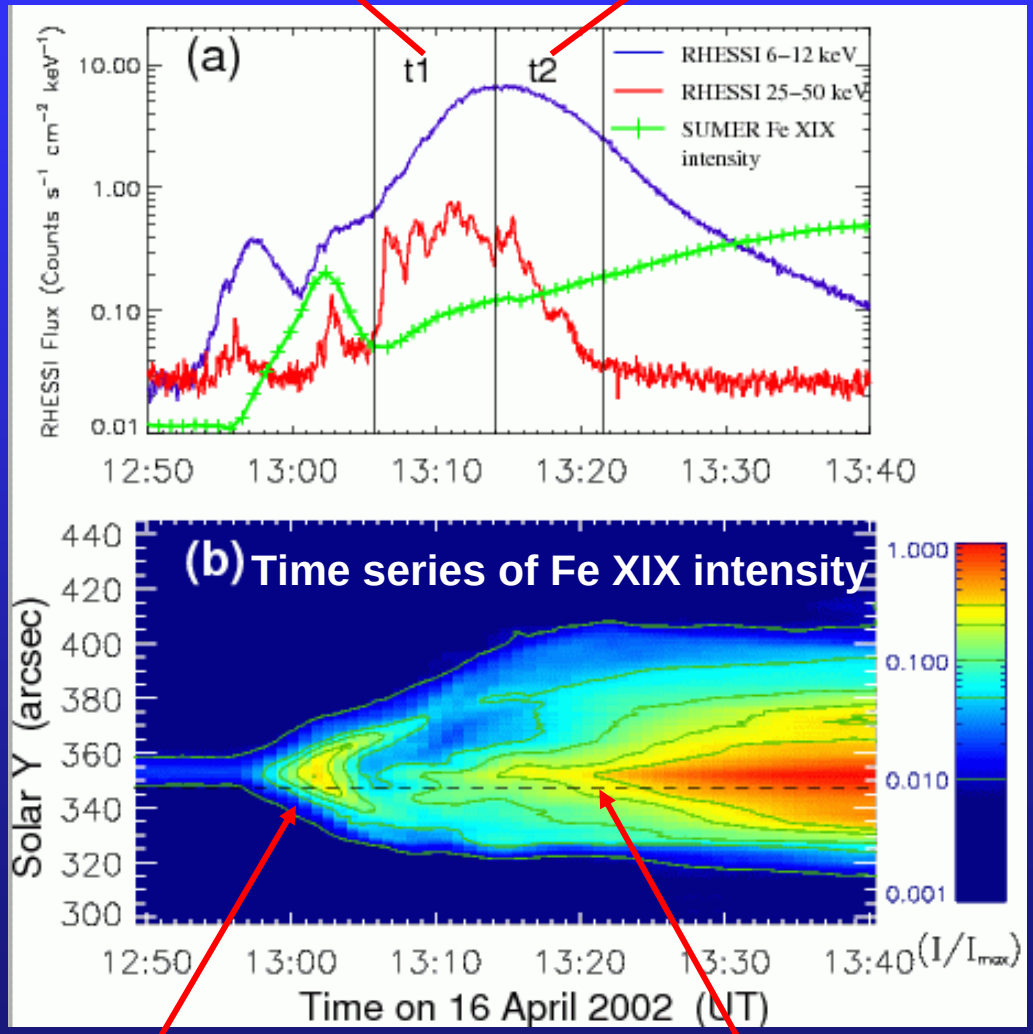
V_{upflow} ~ 1800 – 3500 km/s

If considering the projection effect

Results: Time correlation of jets with hard X-ray peak

Time for upflow

Time for downflow



- High-speed jets are coincided in time with main hard X-ray peak
- High-speed jets occur in an interval with low Fe XIX emission, following an erupting loop, and
- preceding the apparently-growing cusp-shaped flare loops

Sign of erupting hot loop (flux rope)

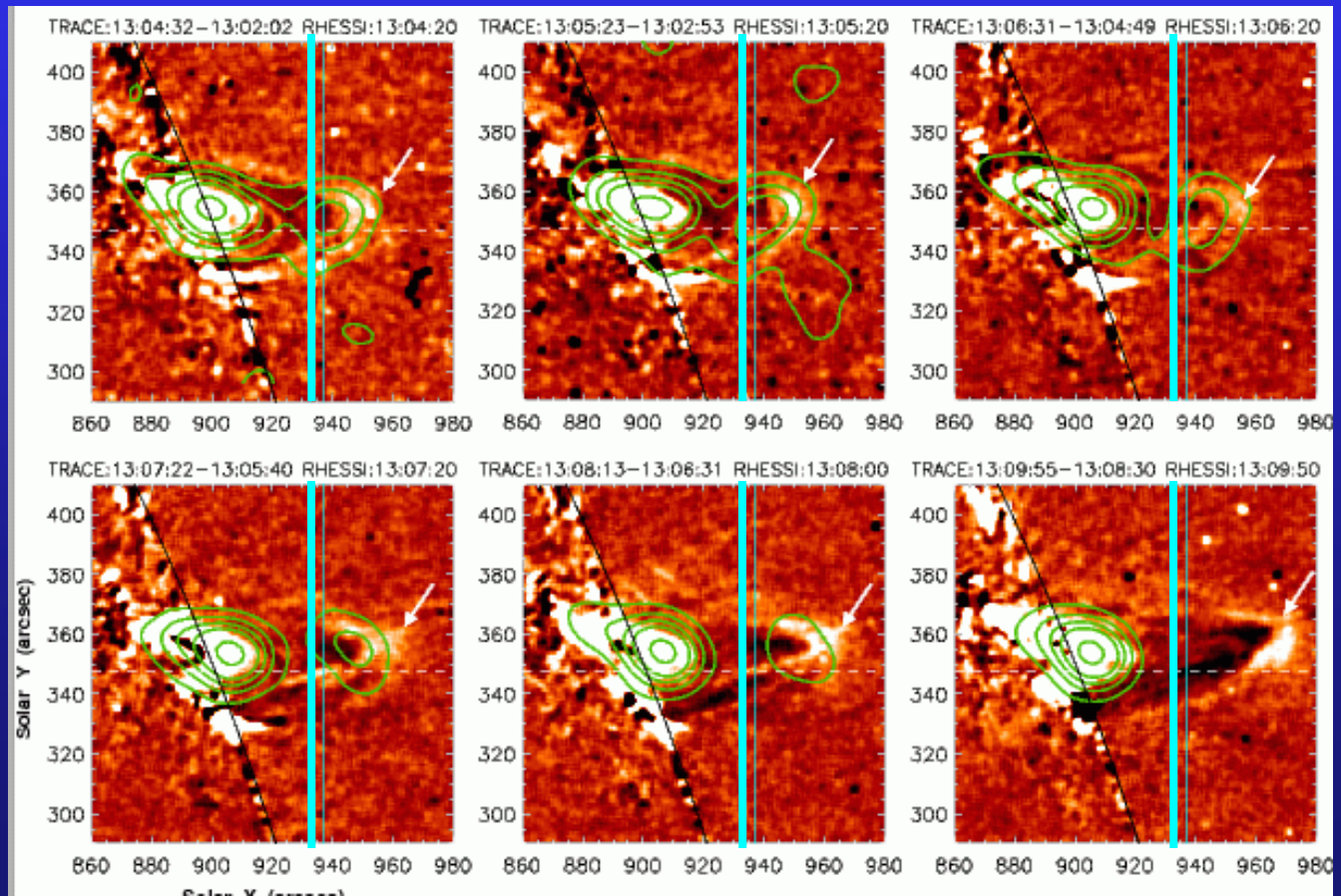
Sign of cusp-shaped post-flare loops rising across the slit

Results: location of high-speed jets at the magnetic reconnection region

— RHESSI Double hard X-ray sources with opposite temperature gradients

(Sui & Holman 2003; Sui 2004; Sui, Holman & Dennis 2004;)

– High-speed jets were seen after the top of TRACE loop and RHESSI X-ray source passed through the SUMER slit



TRACE: difference images

RHESSI: green contours

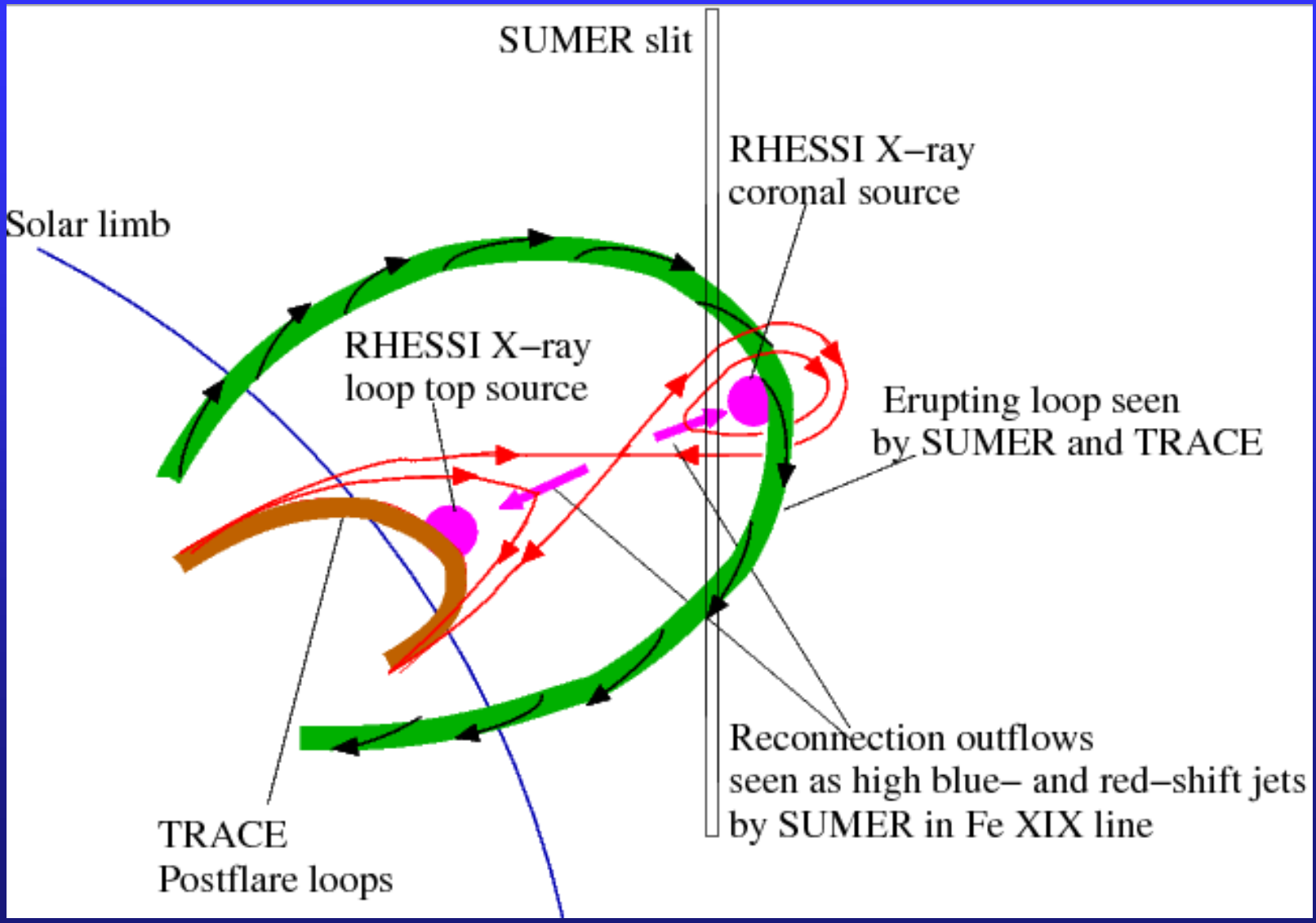
SUMER slit: vertical line

Speed of outwards moving TRACE loop:

V ~ 45 – 75 km/s

(Goff et al. 2005)

Discussions: Interpretaions

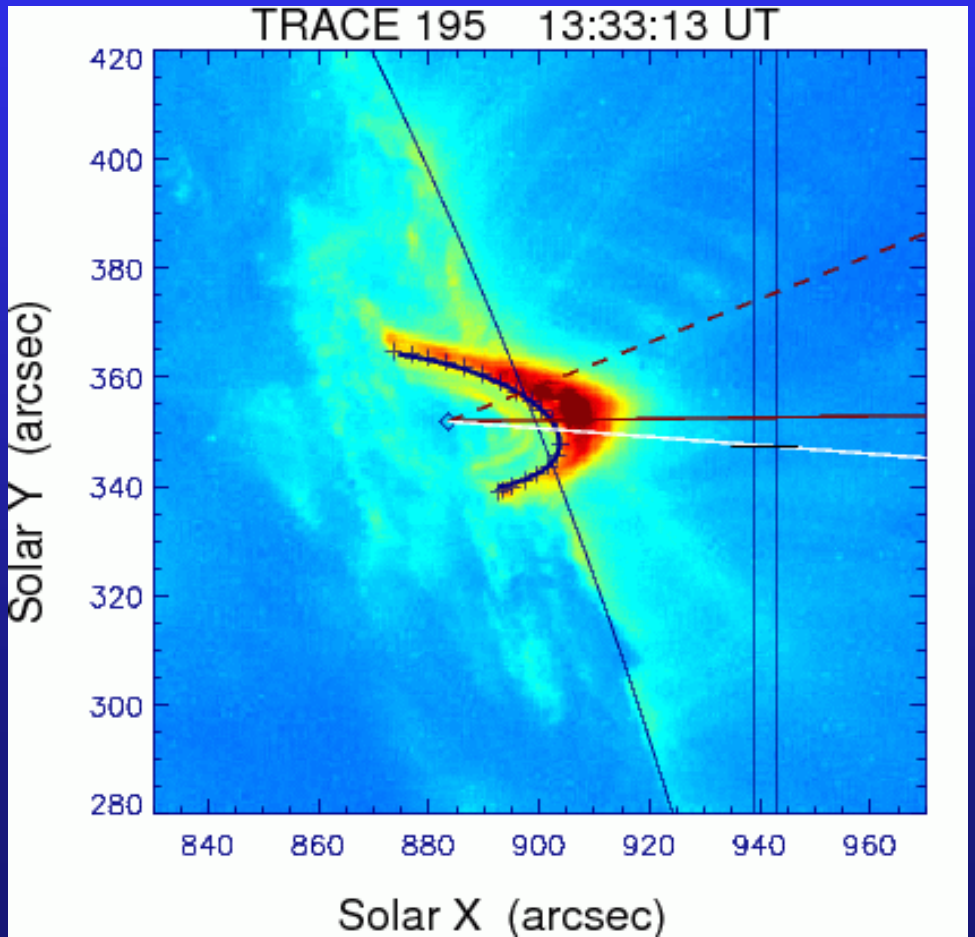


Discussions

- **Estimate of the true jet speed** by considering the projection effect

  The angle of jets to LOS ~ 70 – 80 degs, so V_{jet} ~ 1800 – 3500 km/s

  for $V_{Doppler}$ ~ 600 km/s typical Alfven speed in the corona



- **Estimate of magnetic field** near the reconnection site,

V_{Alfven} ~ 3000 (B/20 G) / (Ne/2e8 cm^{-3})$^{1/2}$ km/s

Given Ne ~ 5 × 10^8 cm^{-3} and
V_A ~ V_{jet} ~ 1800 – 3500 km/s

obtain B ~ 19 – 37 G

Conclusions

- Spatial relationship of high Doppler-shift flows with the reconnection region and temporal correlation of the flows with hard X-ray peak provide direct evidence of high-speed magnetic reconnection outflows in the current sheet in the corona.

- The observations lend strong support to the magnetic reconnection theory and the bipolar reconnection model of solar eruptive events (flares and CMEs)

Wang et al. 2007 ApJ Letter, 661, L207

Movie dowload:

http://solar.physics.montana.edu/wangtj/outflow_mov.gif

Guidance to prospective Hinode/EIS observation for magnetic reconnection in solar flares

1. Locate reconnection region (or current sheet) with imaging obs.

Using coordinated RHESSI, high-cadence Hinode/XRT and TRACE 195 A observations to detect the erupting flux rope, coronal source, and cusp-structure etc.

2. Detect reconnection inflow and outflows with EIS

Using sparsely, high-cadence (~ 1 min) EIS raster scanning.

strong coronal lines, e.g. Fe X - Fe XII to detect Doppler shift of reconnection inflows and measure coronal density near reconnection region

Hot lines, e.g., Fe XIV- Fe XVII to detect possible erupting hot flux rope

Flare lines, Ca XVII, Fe XXIII, Fe XXIV with enough wide windows to detect high Doppler shifts of reconnection outflows

2” slit, exposure time of 2 s, step size 6”, 10 pointing positions, FOV 60” x 100”

3. Target: near-limb ARs better with sigmoid feature in XRT