Multi-wavelength Studies of Interchange Reconnection on the Sun

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Panel Review - 28 June 2007

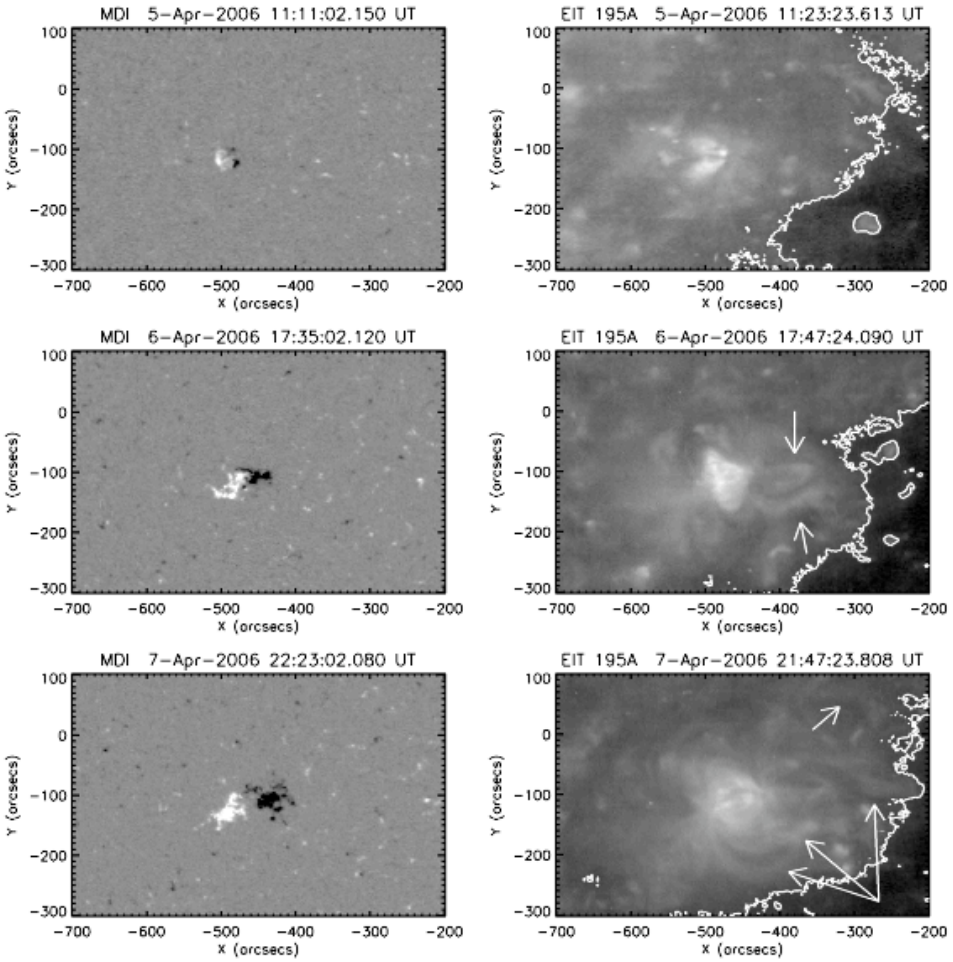
Outline

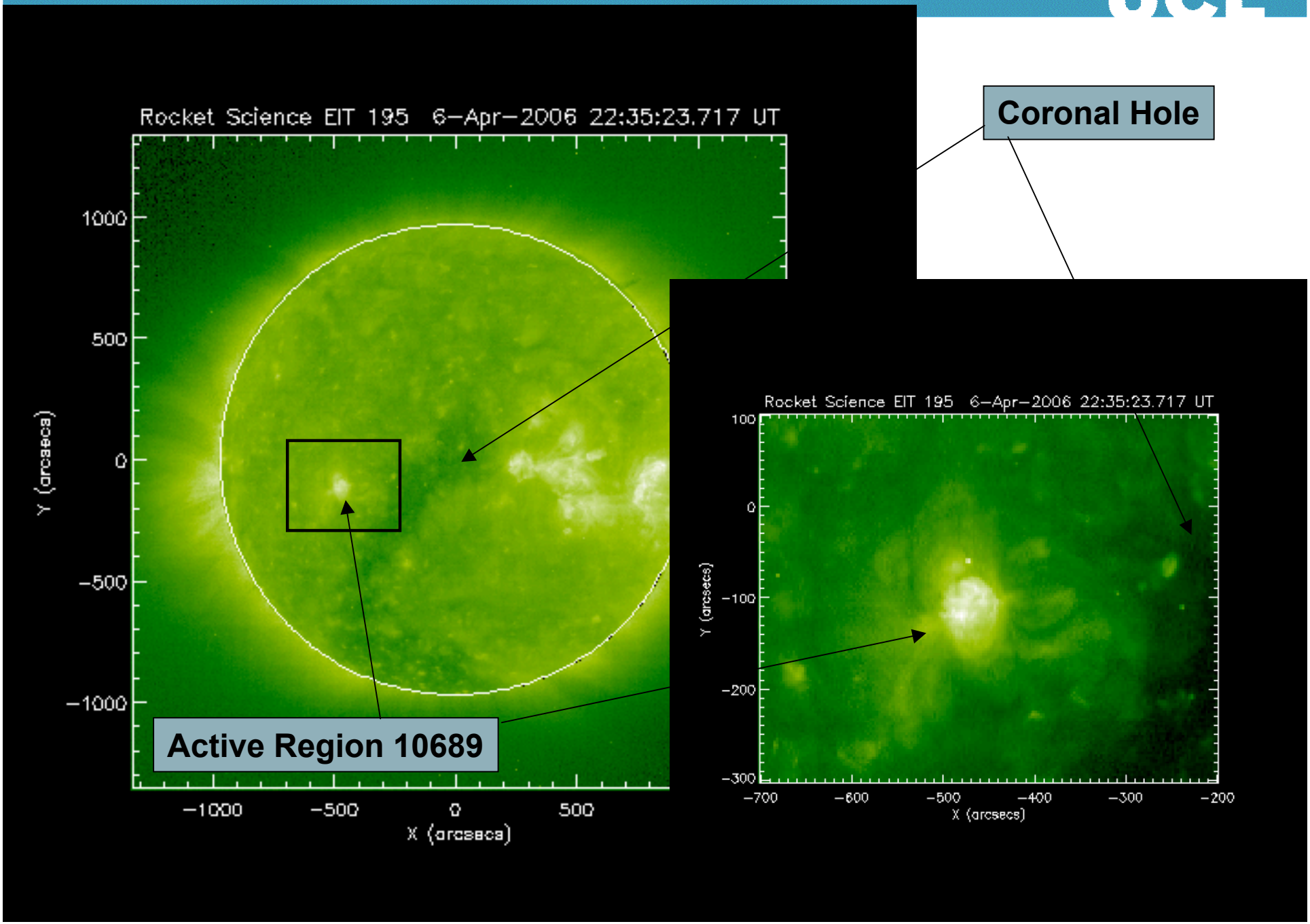
1. 1st Project Results - Evidence for Interchange Reconnection between a Coronal Hole and an Adjacent Emerging Flux Region - accepted by AN on 23 April 2007.

2. 2nd Project Initial Results - Coronal jets (Culhane, Harra, Baker, et al 2007 - submitted to PASJ on 3 June 2007).

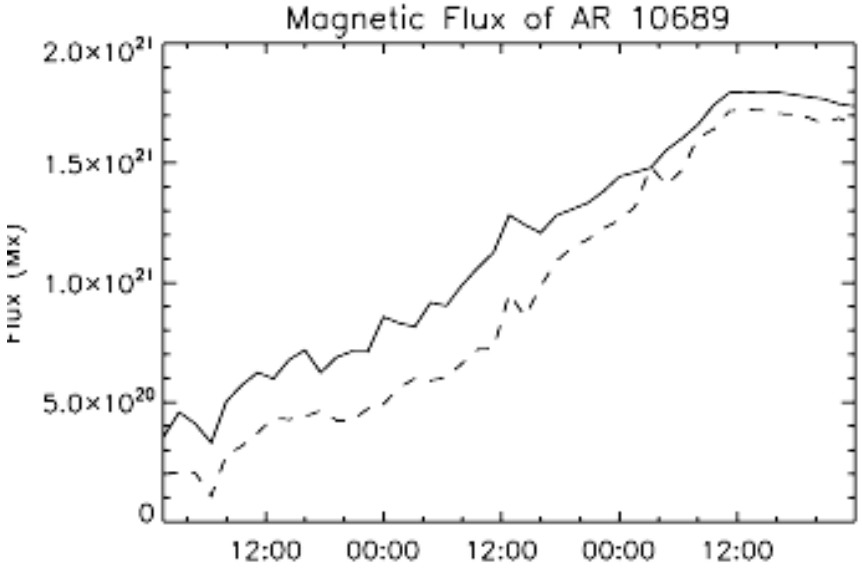
3. Thesis Plan

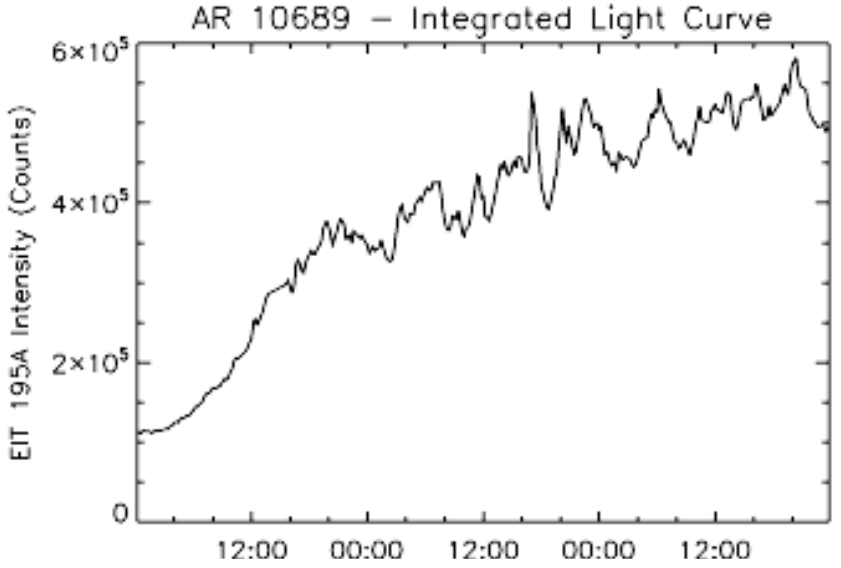
1st Project - Observational Evidence for Interchange Reconnection

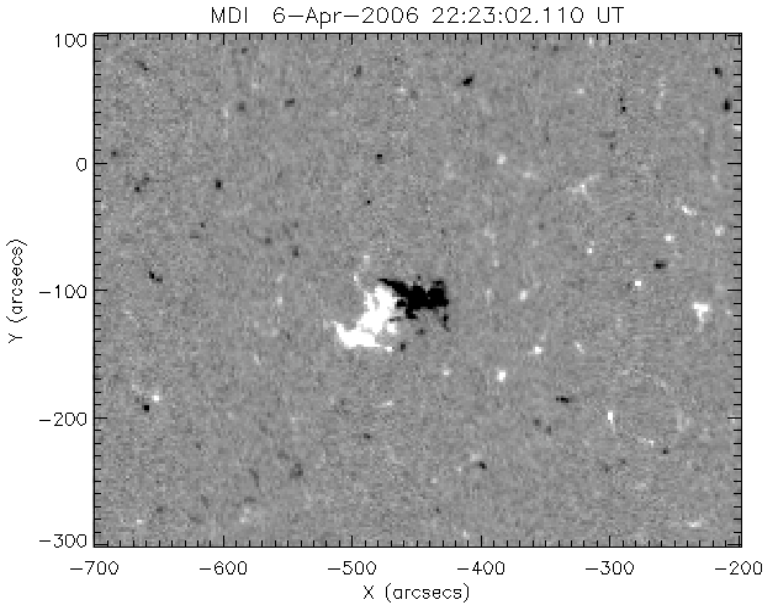


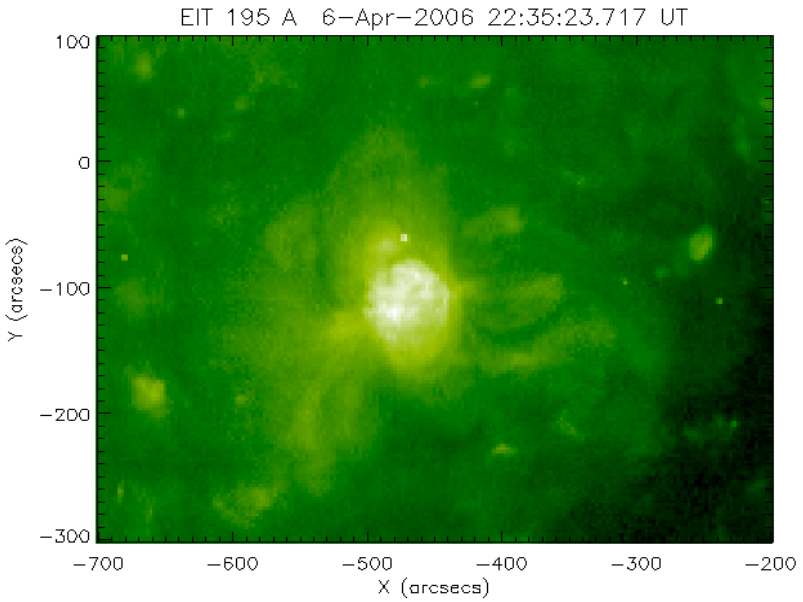

Rocket Science EIT 195 6-Apr-2006 22:35:23.717 UT
Coronal Hole
Active Region 10689
Y (arcsecs)
X (arcsecs)
1000
500
0
-500
-1000
-1000
-500
0
500
Rocket Science EIT 195 6-Apr-2006 22:35:23.717 UT
100
0
-100
-200
-300
-700
-600
-500
-400
-300
-200
Y (arcsecs)
X (arcsecs)

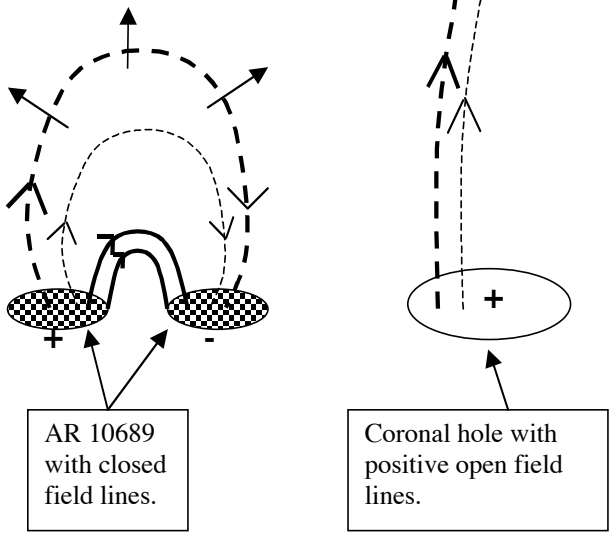
AR 10689 Magnetic Flux and EUV Intensity Evolution

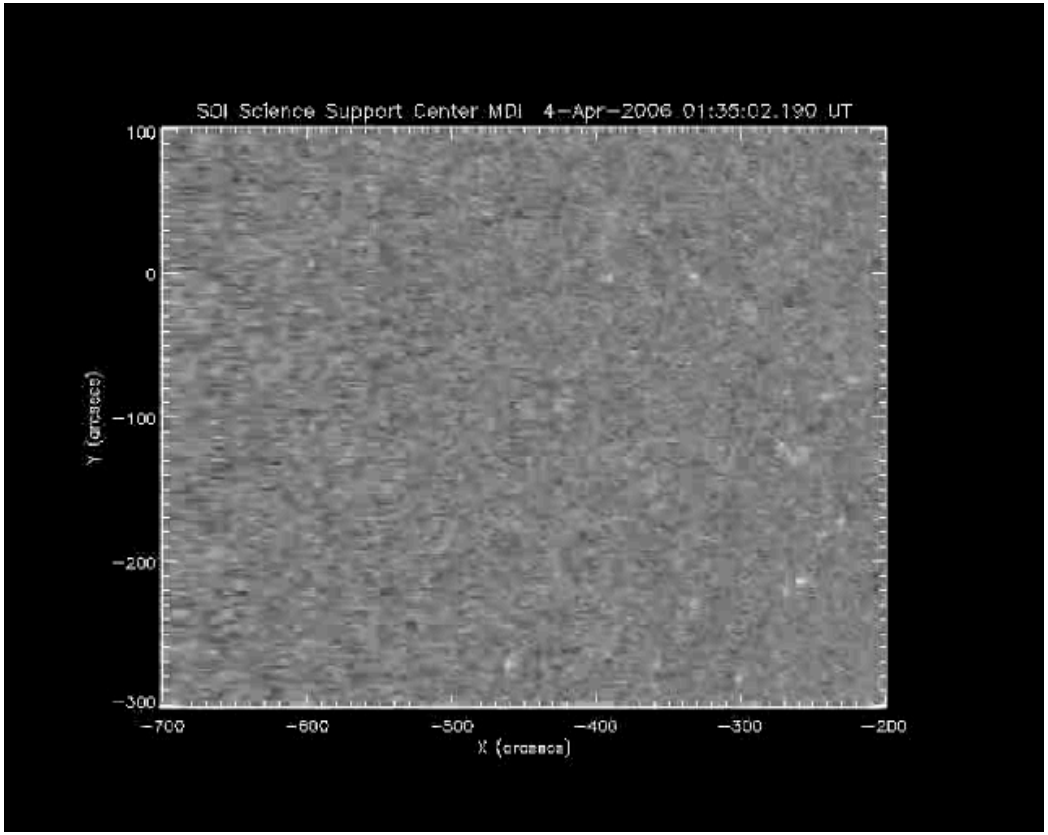








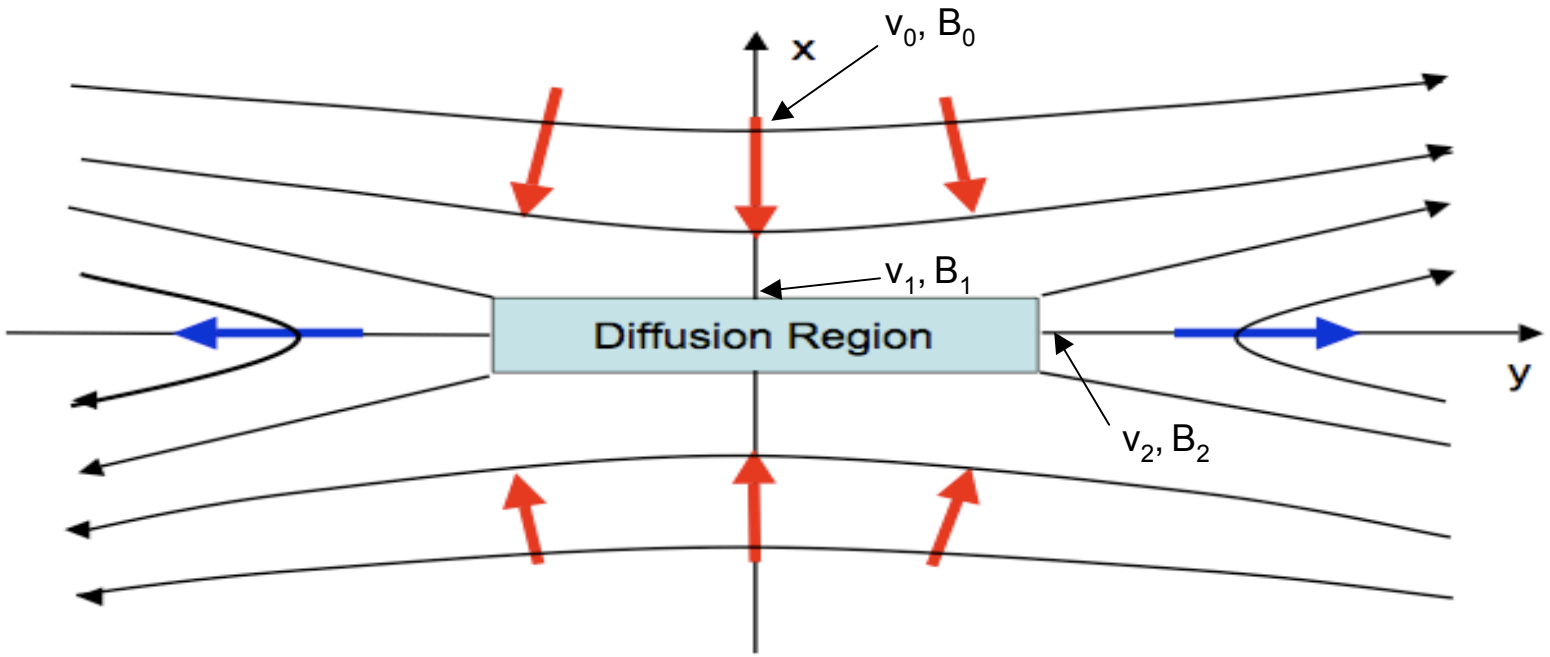




Active region AR 10689 emerges with a favorable magnetic field line orientation for interchange reconnection with the open field lines of the nearby coronal hole.

(SOHO/MDI full-disk magnetograms)

Magnetic Reconnection - 1



Inflow →
Outflow →

$$B_1^2 / 8\pi + p_1 = p_{nl} = B_2^2 / 8\pi + p_2$$

External inflow speed = v_0

Inflow speed = v_1

Outflow speed = v_2

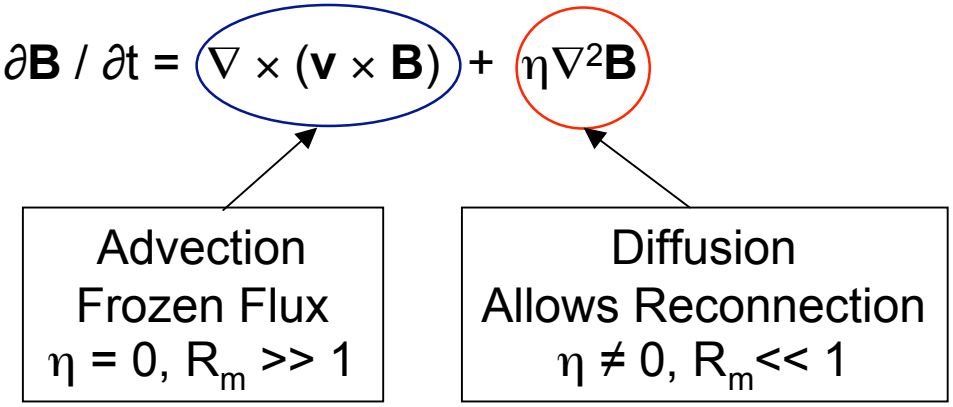
$$\beta = p_{th} / (B_1^2 / 8\pi)$$

$$E_0 = 1/c\ v_1 B_1 = 1/c\ v_2 B_2 = j_{nl} / \sigma$$

Sources: *Physics of Solar Corona - M. Aschwanden (Springer, 2005)*
Solar and Stellar Magnetic Activity - C. Schrijver & C. Zwaan (CUP, 2004)

Magnetic Reconnection - 2

Induction Equation: $\partial \mathbf{B} / \partial t = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$



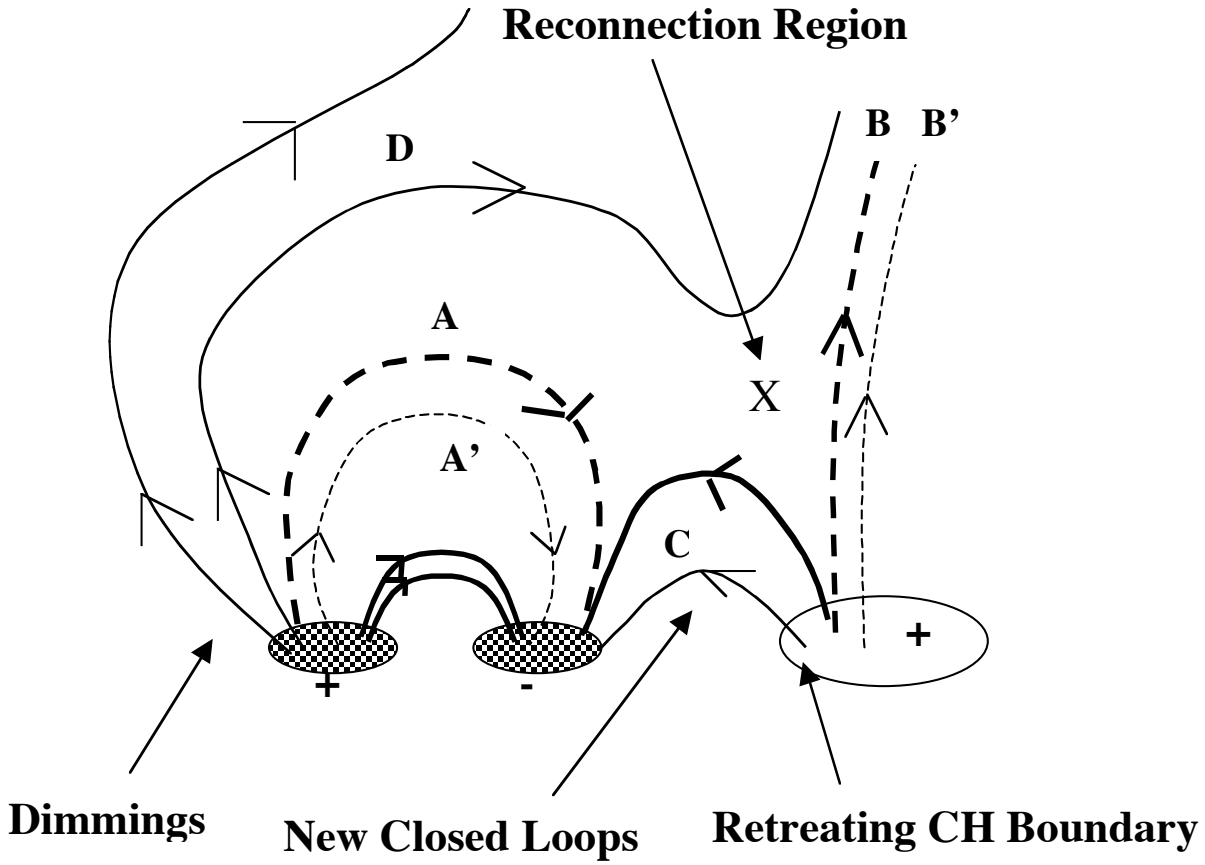
Dimensional form: $B / t = vB / L + \eta B / L^2$

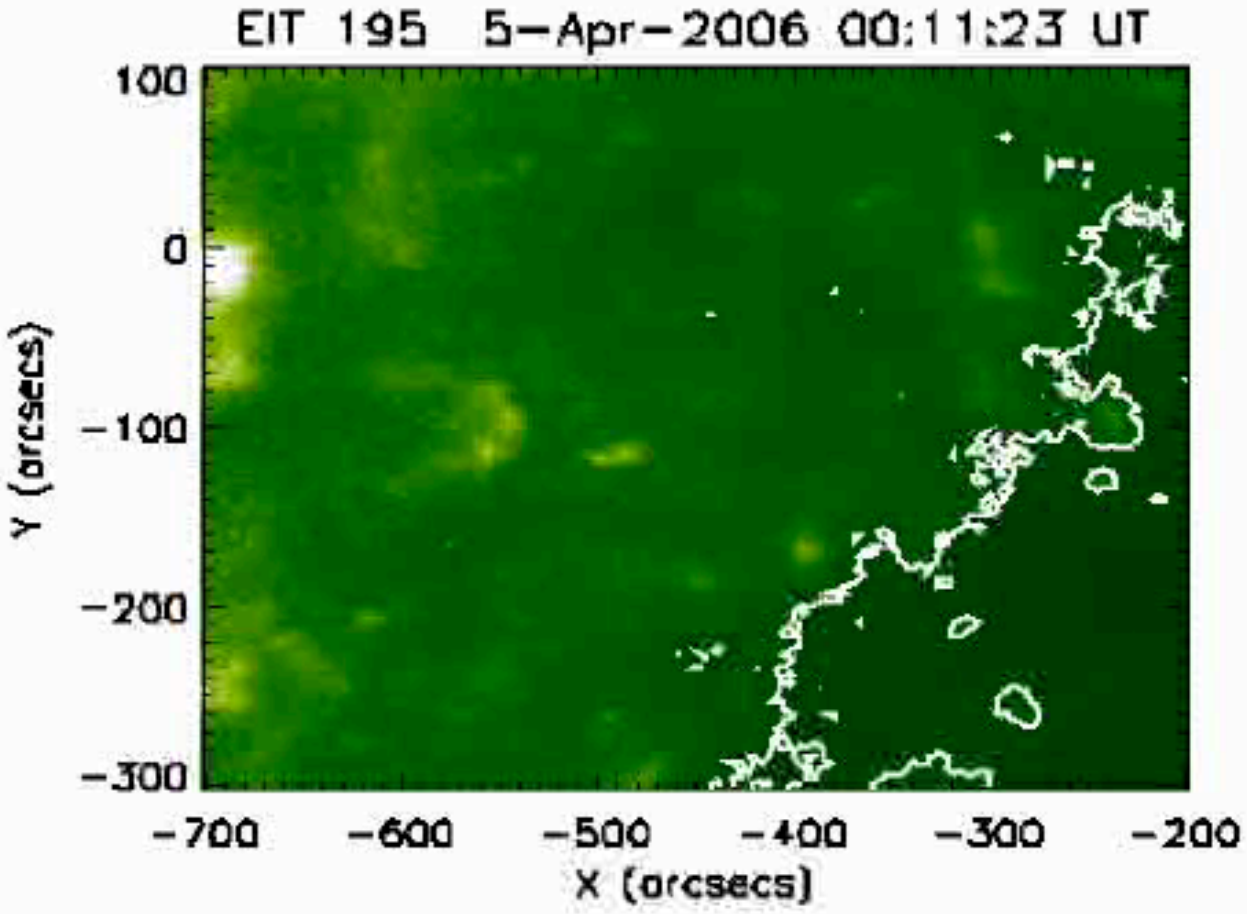
Magnetic Reynolds number R_m = advection/diffusion = vL / η

Ohmic diffusion time scale $t_d = L^2 / \eta = L / vR_m$

Definitions:
-Ohmic magnetic diffusivity $\eta = c^2 / (4\pi\sigma)$ where σ is electric conductivity
-L is scale length

Interchange Reconnection

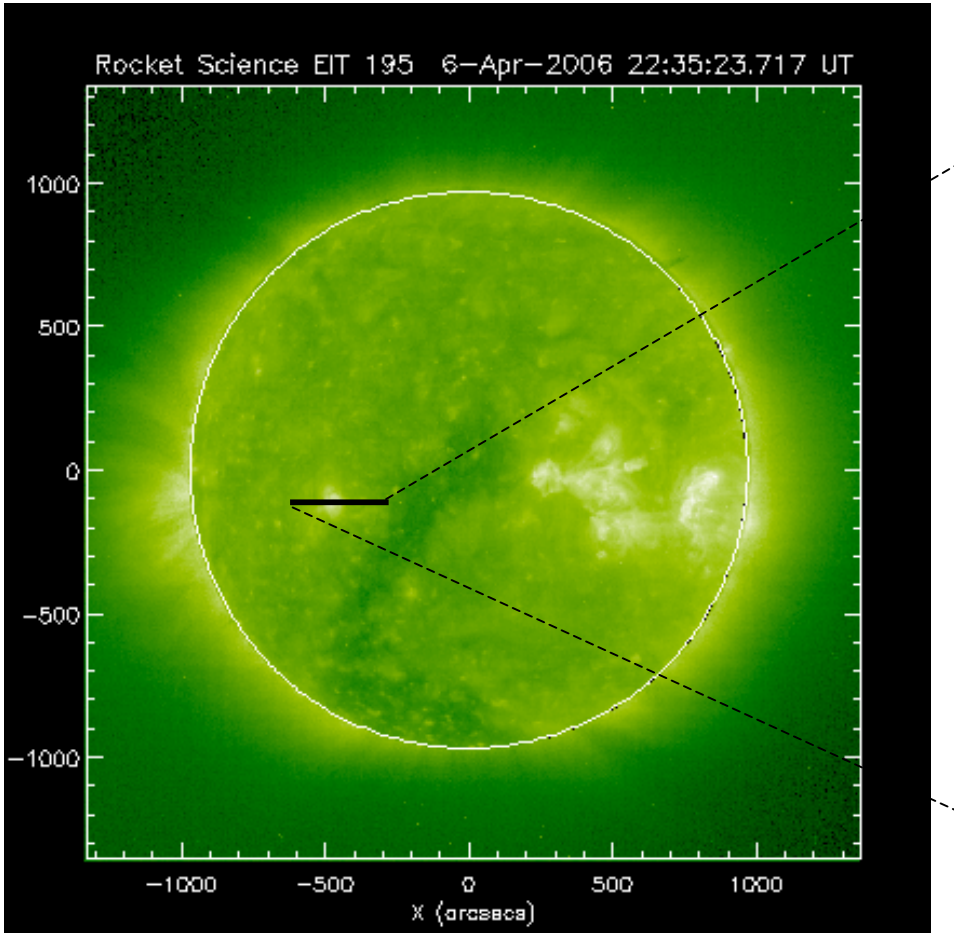


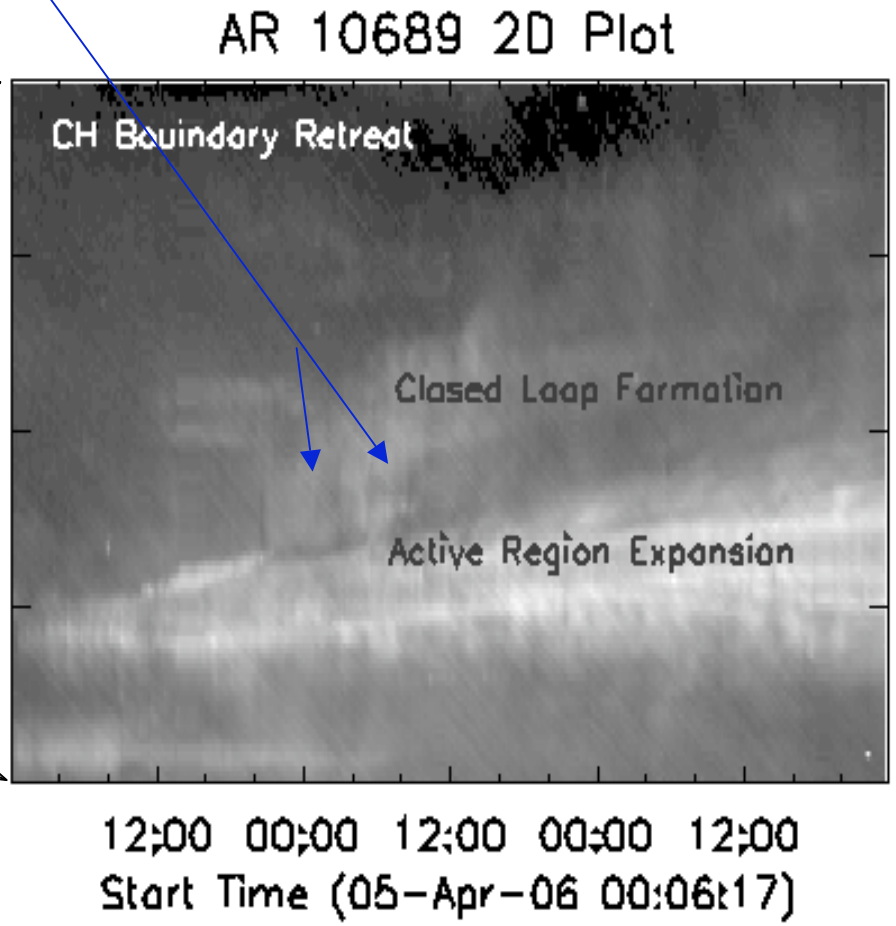


Evidence for interchange reconnection:

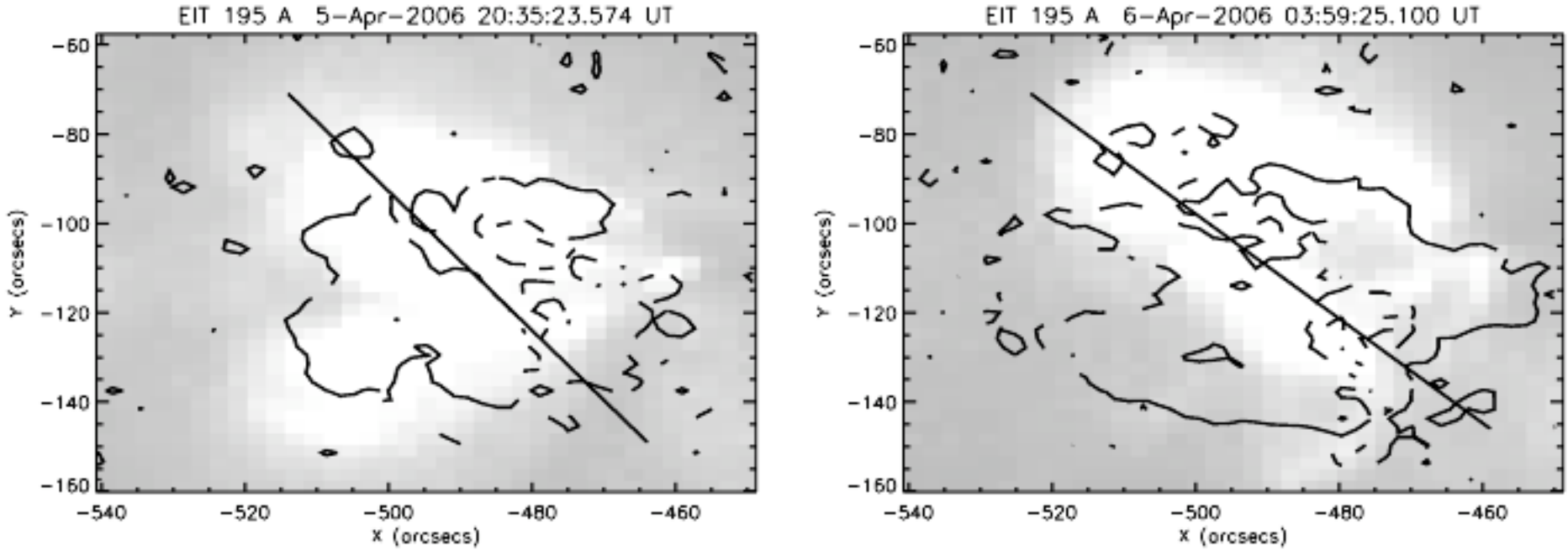
- Formation of new closed loops towards the coronal hole.
- Coronal hole shrinkage and boundary retreat.

Intense loop formation

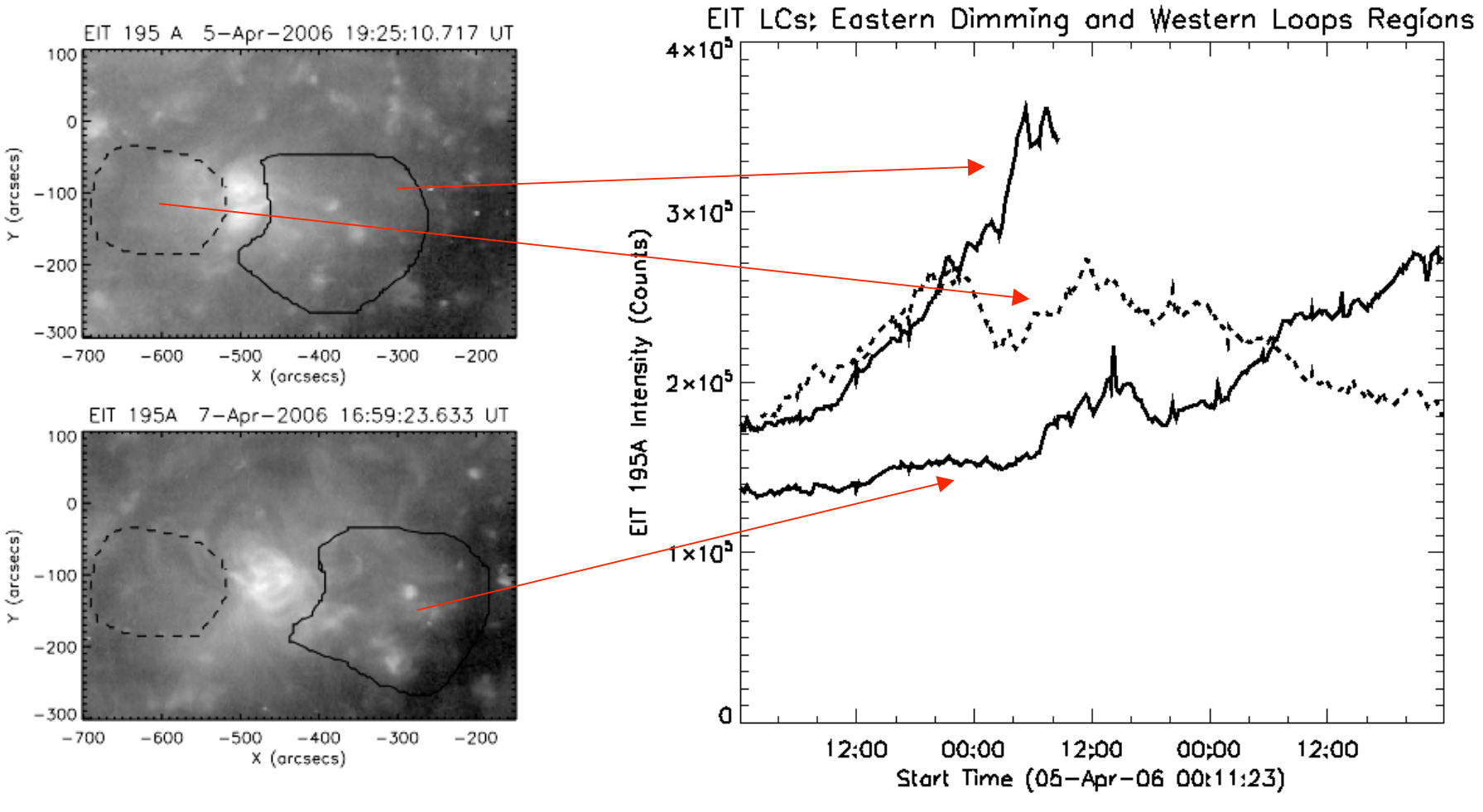




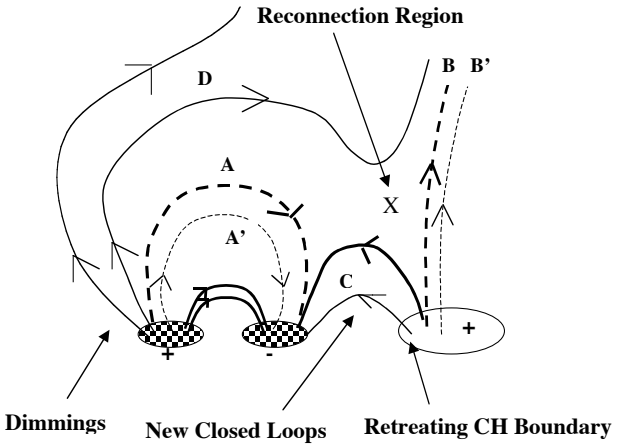
Evidence: Dimming on the far side of the active region.

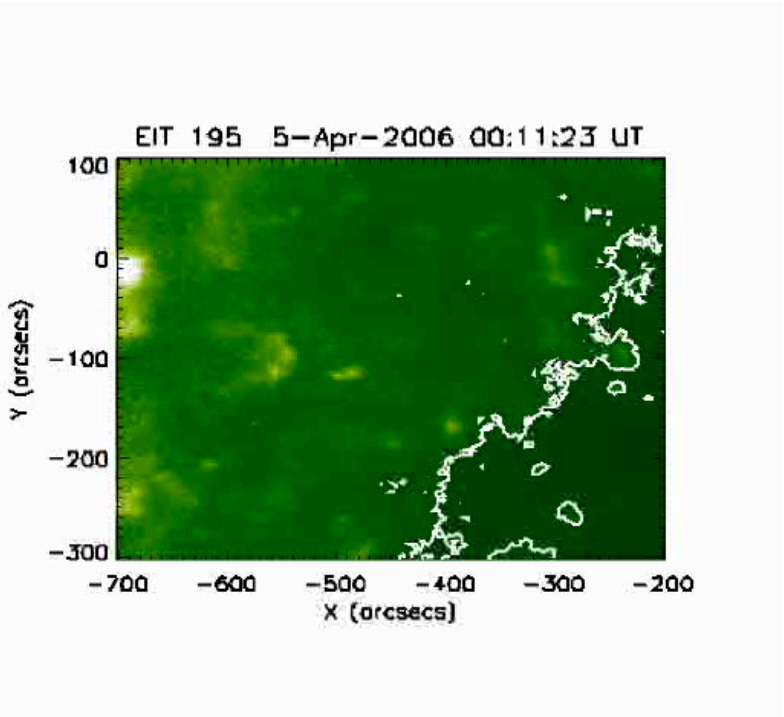


Light Curves: Eastern Dimming and Western Loop Regions



Conclusions:



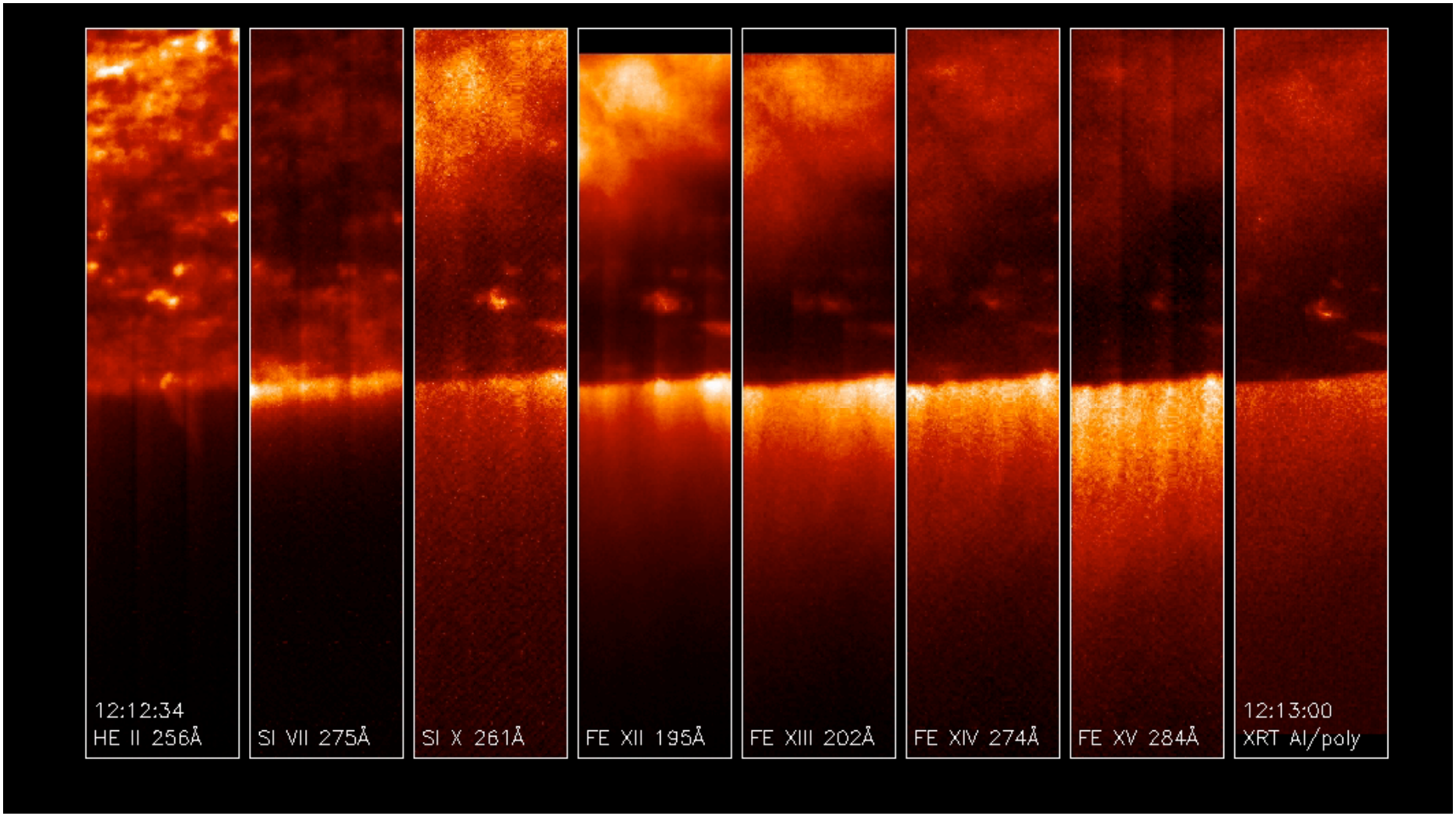


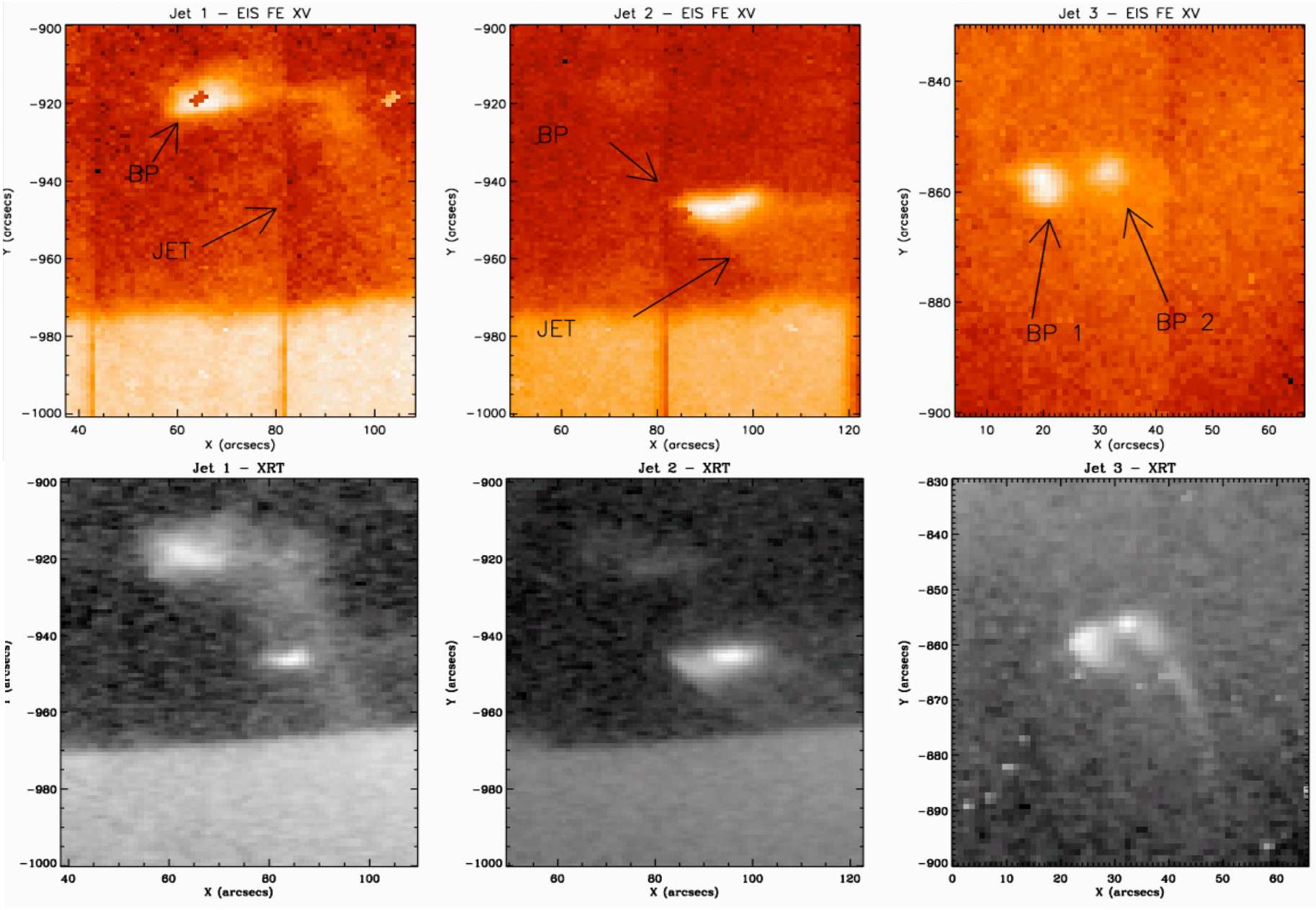
Evidence for interchange reconnection between emerging active region and coronal hole:

- Formation of **new closed loops**.
- **Shrinking** of the coronal hole.
- **Dimming** of the corona on the far side of the active region.

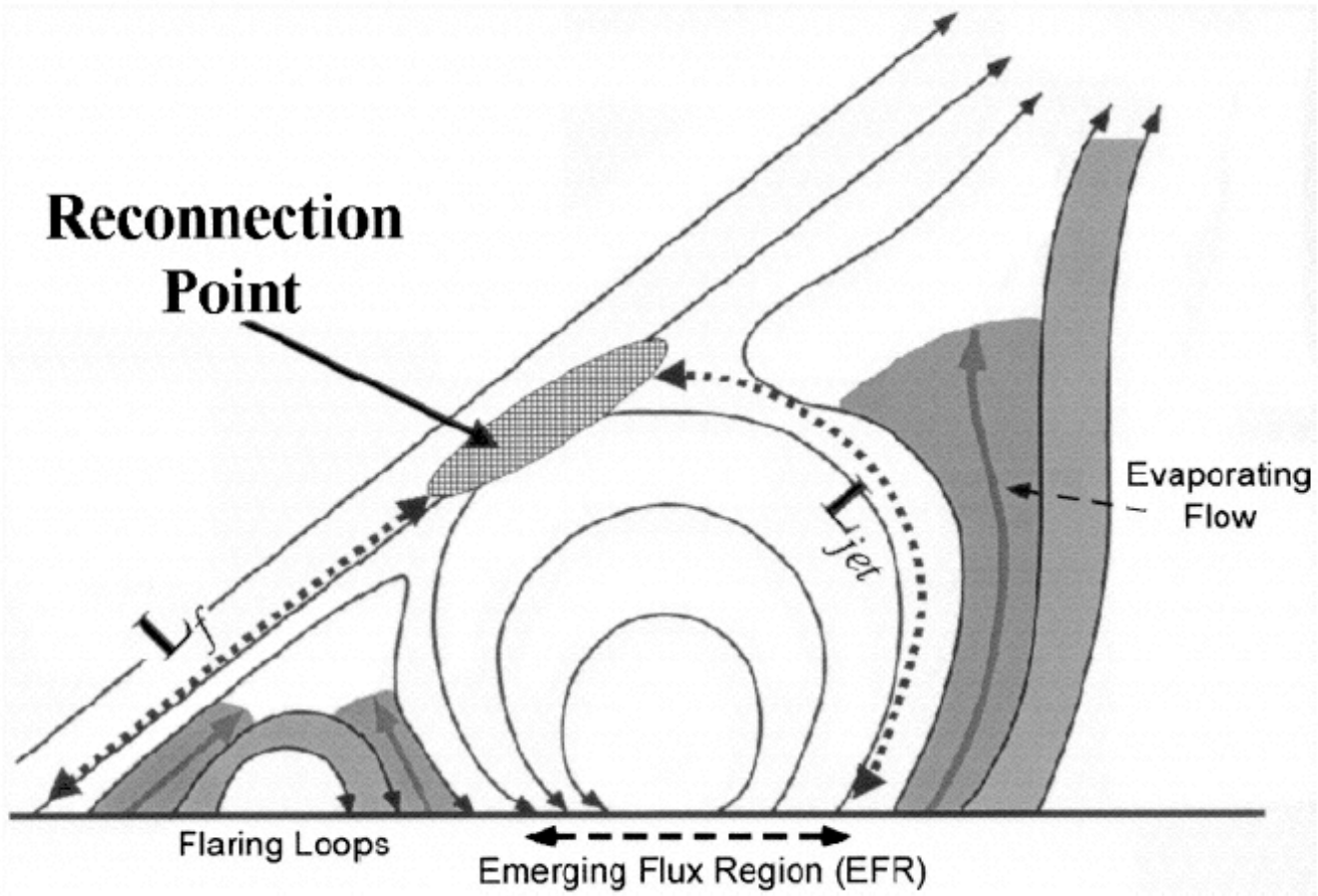
Taken together these observations provide strong evidence for the emerging active region - coronal hole interaction predicted from the model.

2nd Project - Coronal Jets




Jet 1 – EIS FE XV
BP
JET
Jet 2 – EIS FE XV
BP
JET
Jet 3 – EIS FE XV
BP 1
BP 2
Jet 1 – XRT
Jet 2 – XRT
Jet 3 – XRT
X (arcsecs)
Y (arcsecs)

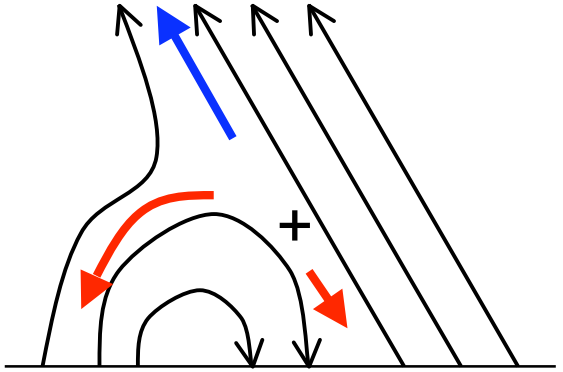
Interchange Reconnection 1

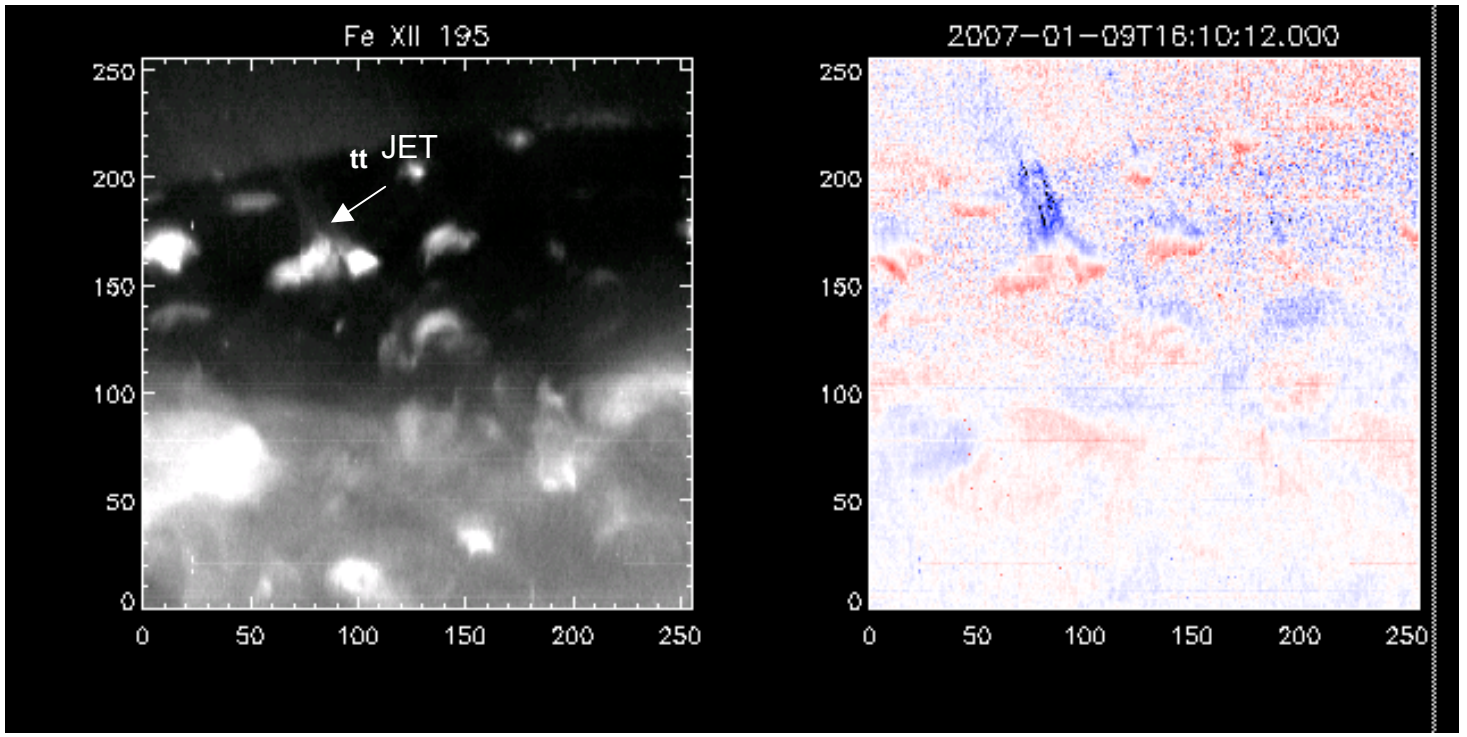


Shimojo and Shibata ApJ 542, 1100 (2000)

Interchange Reconnection 2

Kamio et al., 2007
(Submitted PASJ)

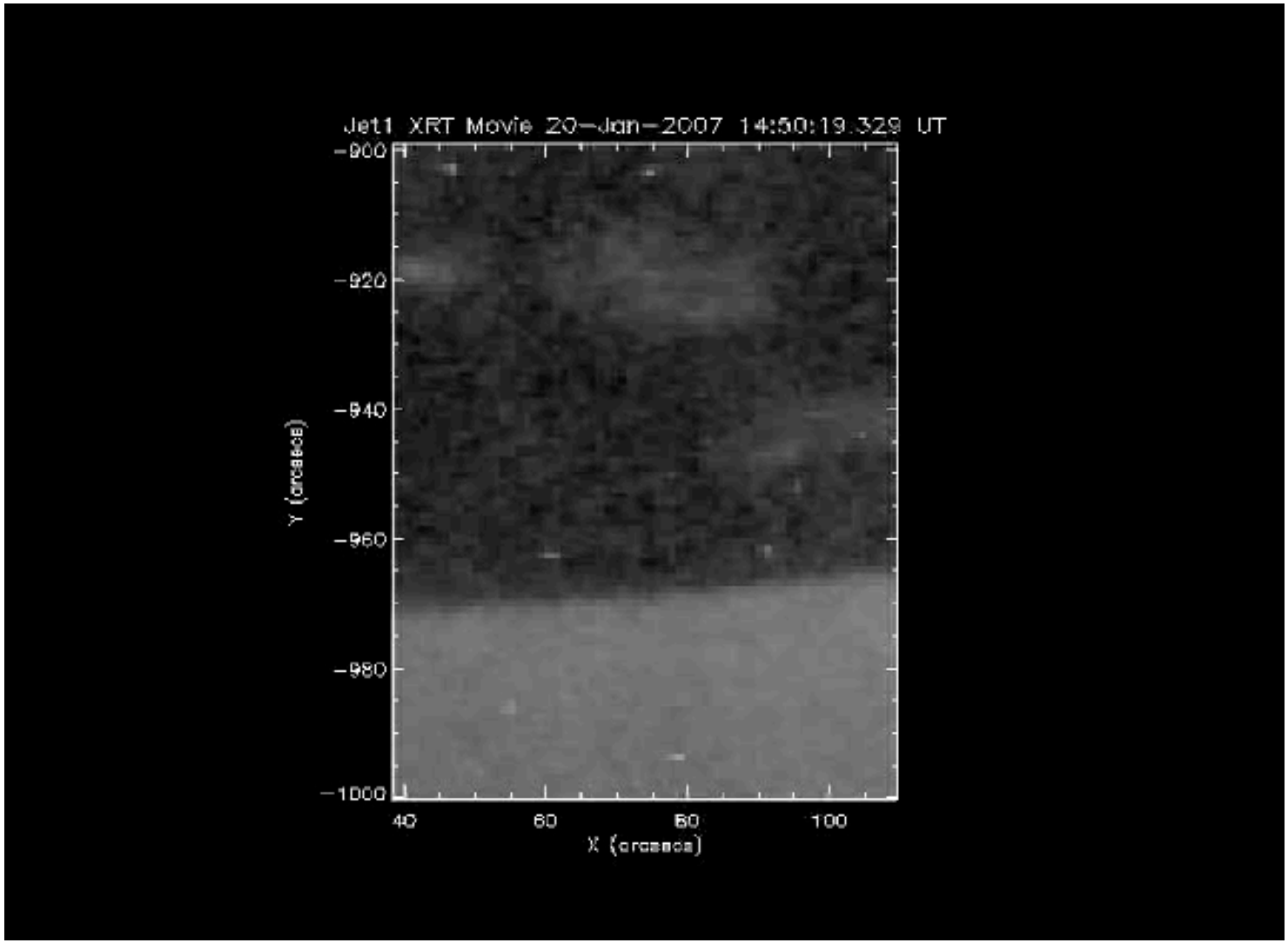




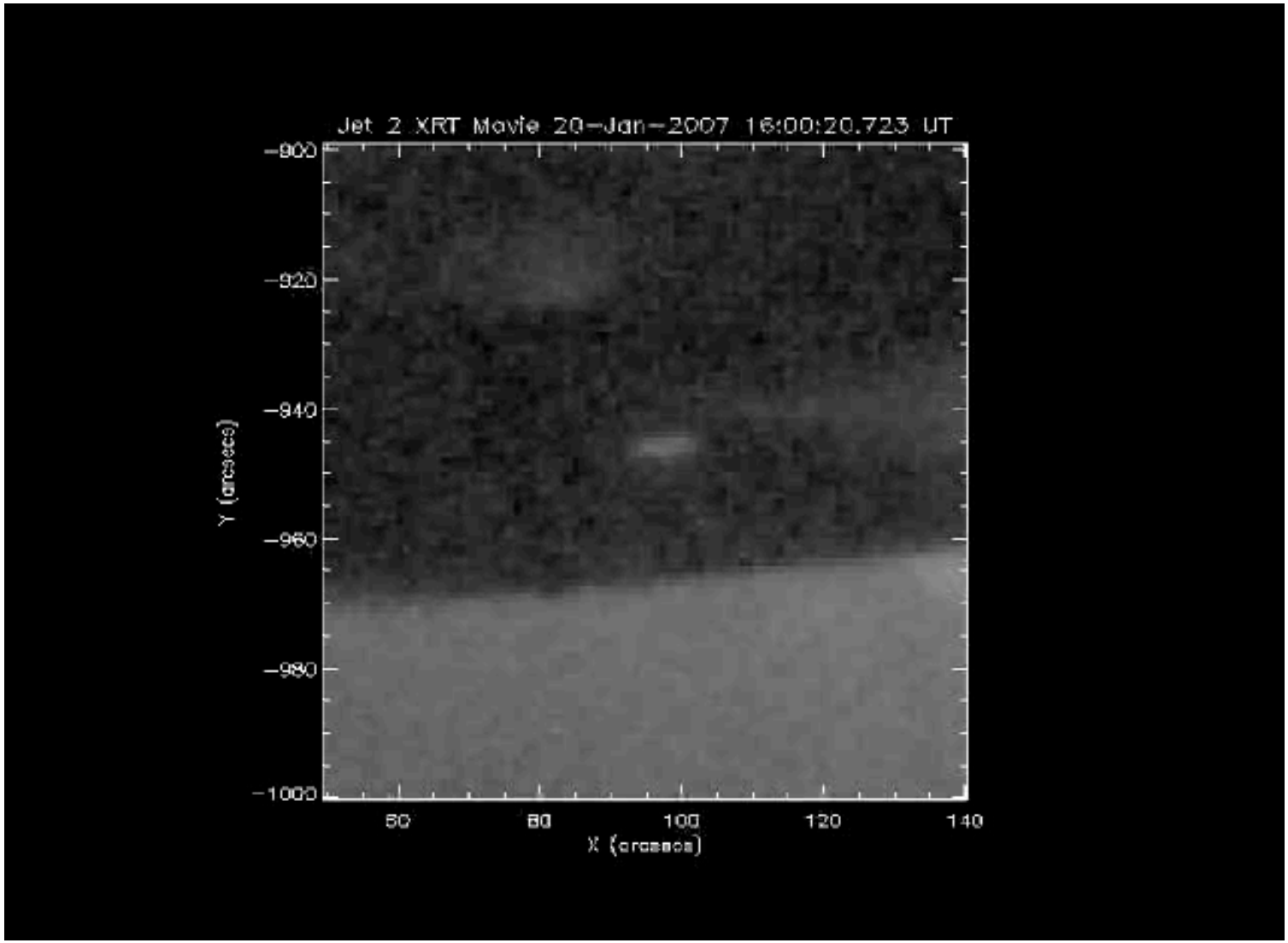
Fe XII Intensity

Fe XII Velocity

Jet 1 XRT Movie



Jet 2 XRT Movie



Jet 3 XRT Movie

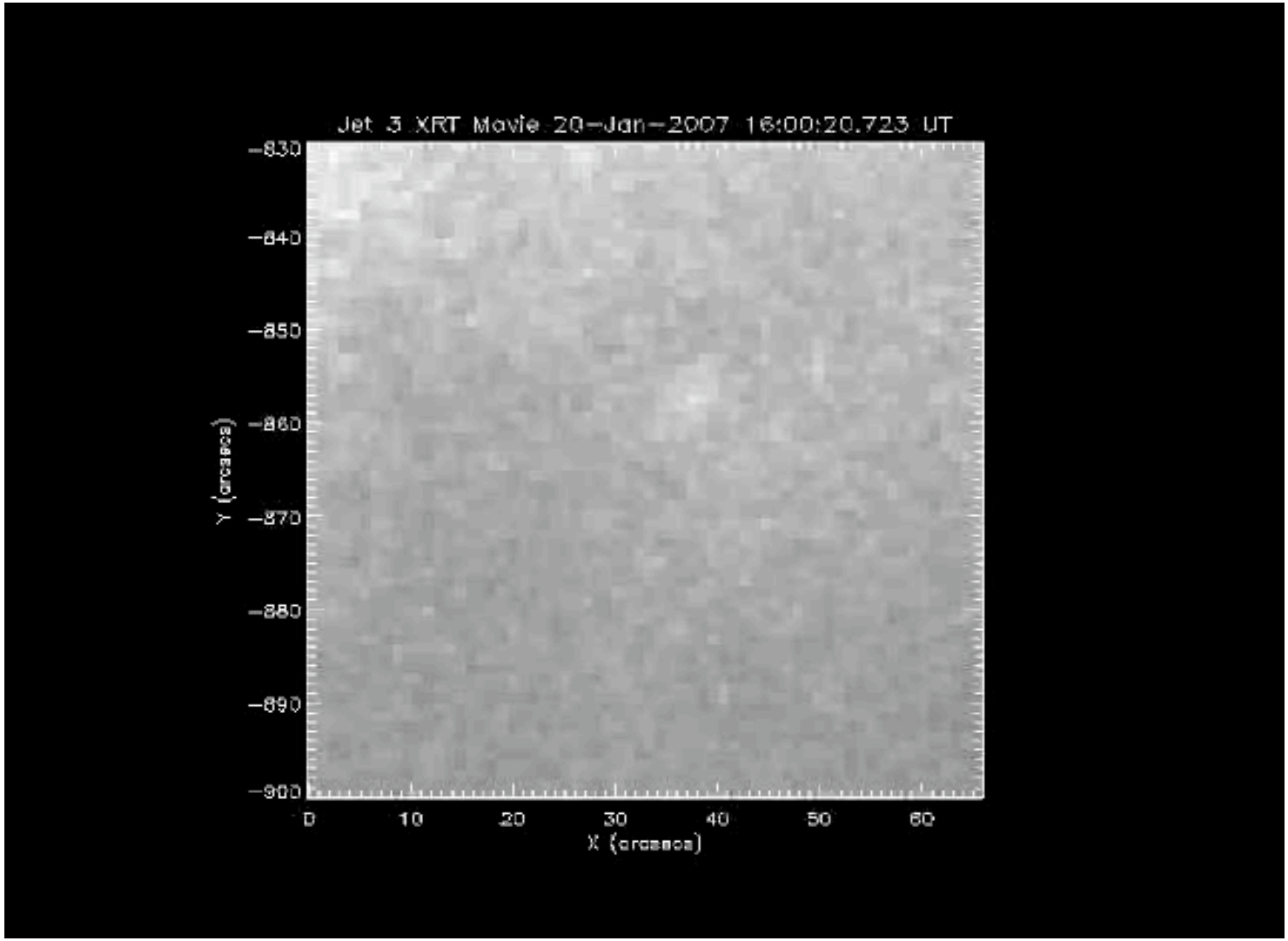
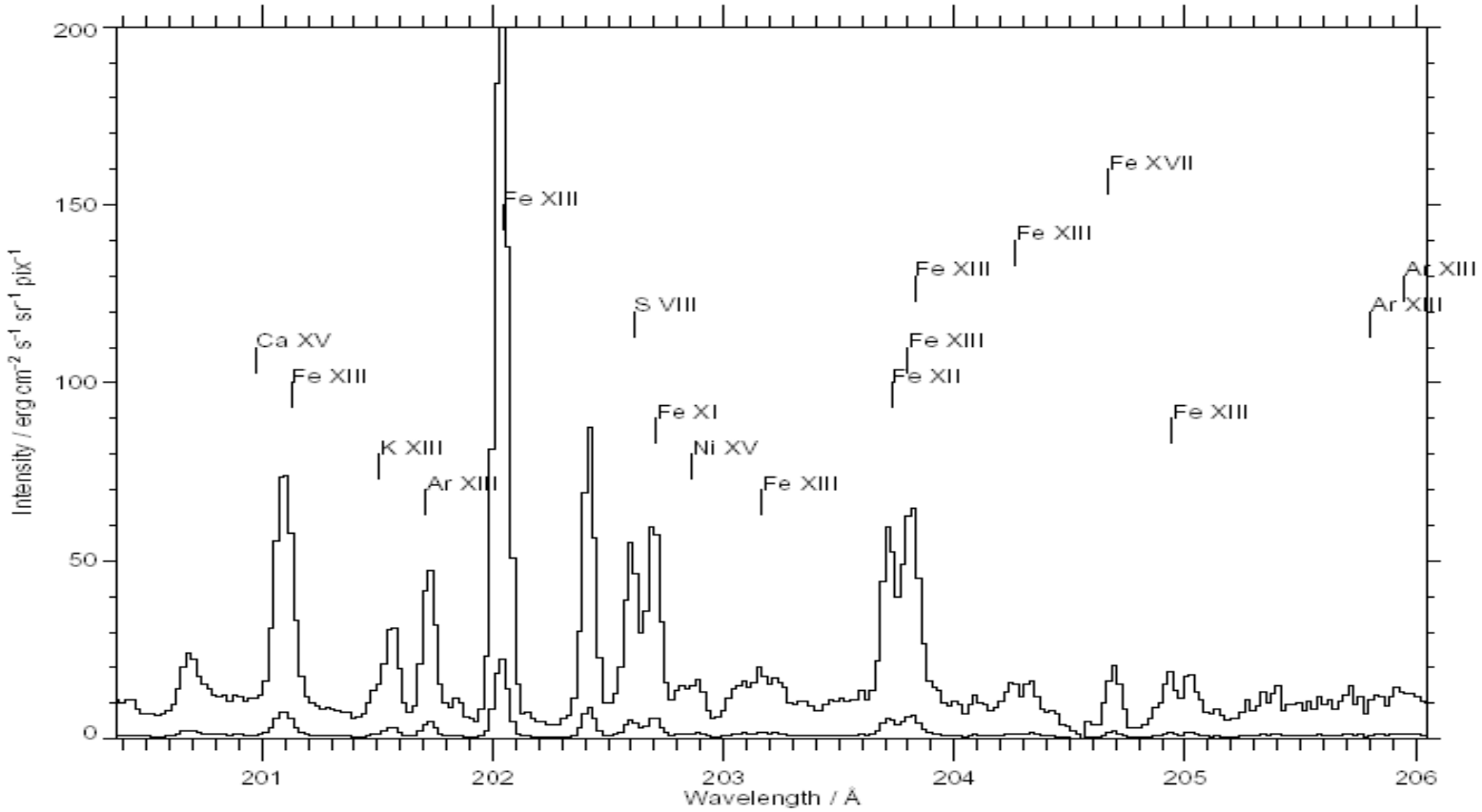


Table of Lines
Used in EIS Study

Ion Species	*λ (Å)*	*T (MK)*	*Other Lines in 40 arc sec slot (AR, QS)*
He II	256.32	0.079	Si X, Fe XII, Fe XIII, Ni XVI, S XIII
Si VII	275.35	0.63	Si VII lines
Si X	261.04	1.26	No other lines
Fe XII	195.12	1.26	Fe VIII, Ni XVI, Ni XV
Fe XIII	202.04	1.58	Ar XIII,
Fe XIV	274.20	2.00	Si VII
Fe XV	284.16	2.00	Al IX
Fe XI	188.23	1.26	Fe XI, Fe XII
Ca XVII	192.82	5.01	Fe XI, OV
Fe XVI	262.98	2.51	No other lines
Fe X	184.54	1.00	Ar XI, Fe XI
Fe VIII	185.21	0.40	Ni XVI
Si X	258.37	1.26	Si IX
Fe XIV	264.79	2.00	Fe XVI

Culhane, Harra, Baker et al *PASJ* (submitted 2007)

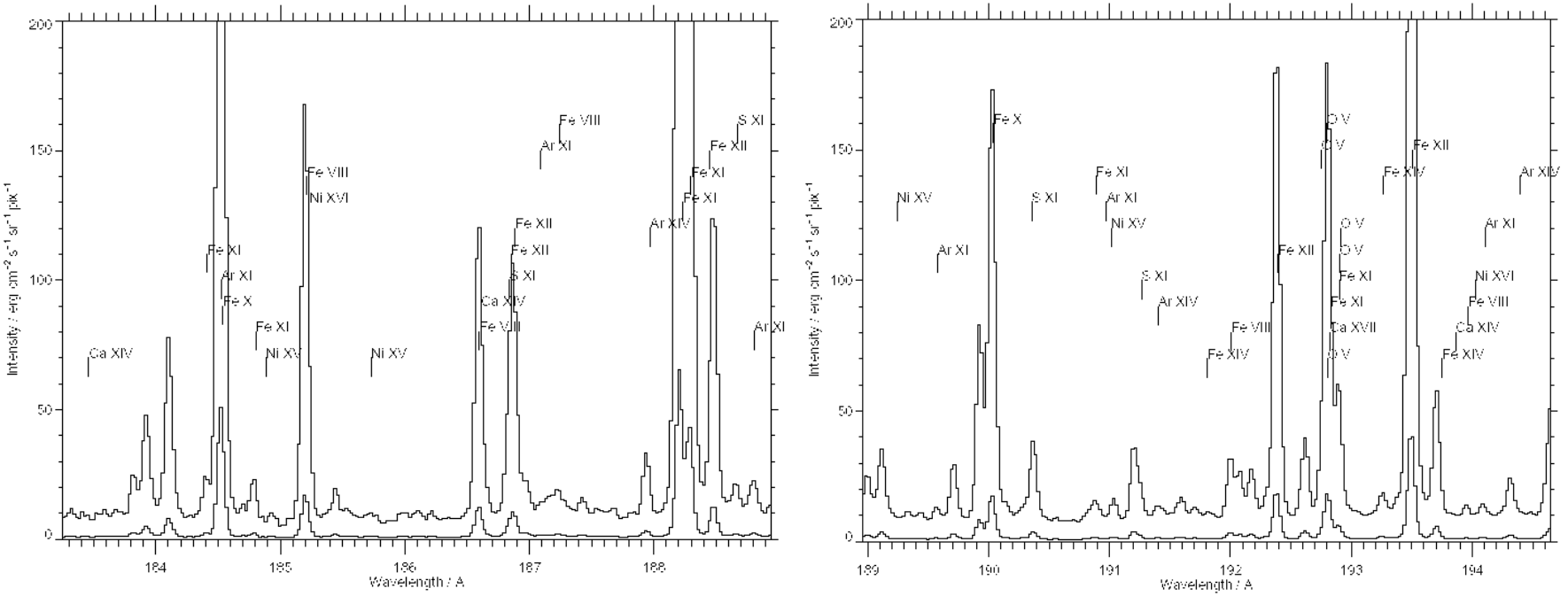
Quiet Sun Spectrum - 1



Wavelength Range

Fe XIII @ 202.0 A ± 0.46 A

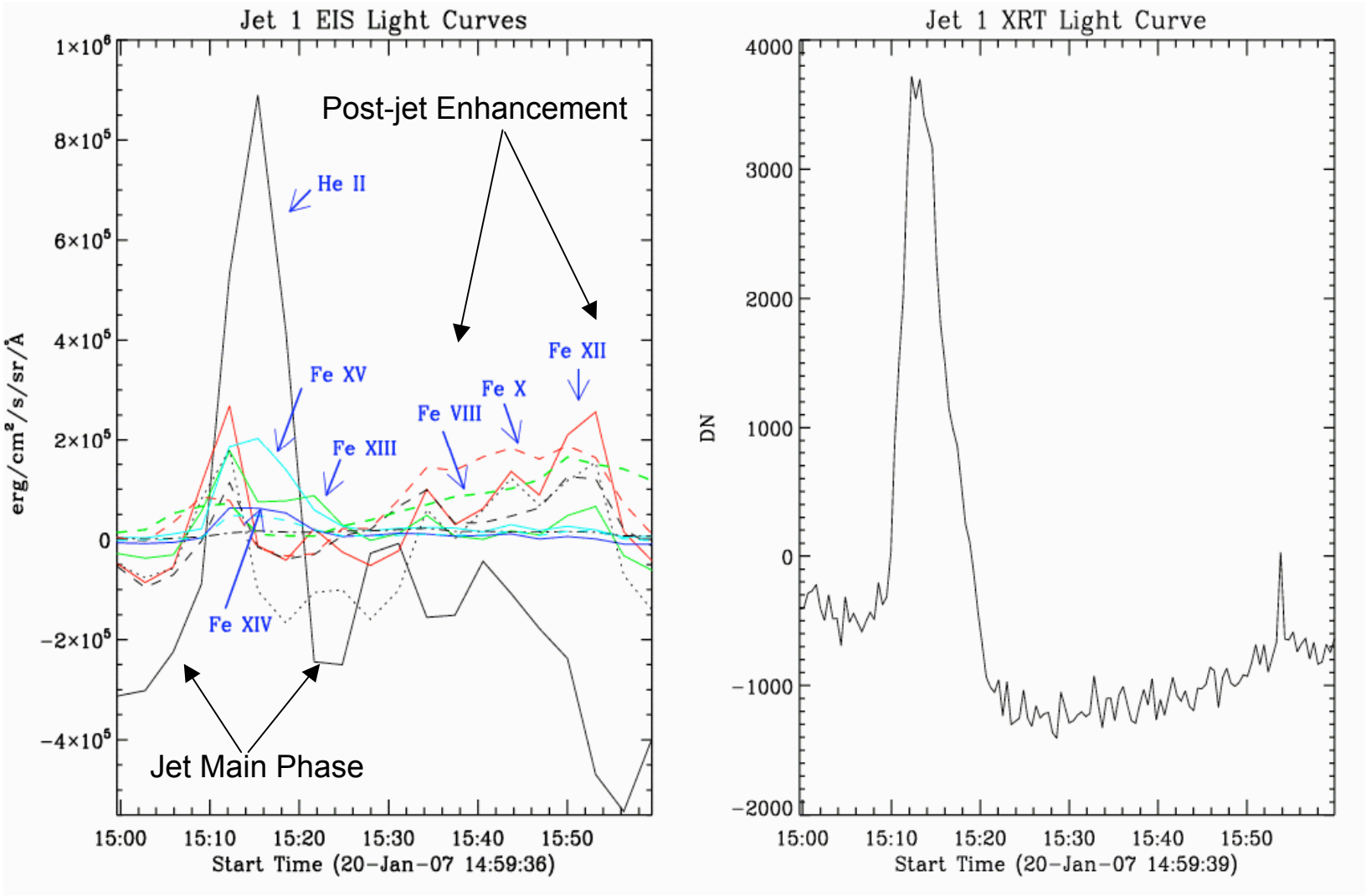
Quiet Sun Spectrum - 2



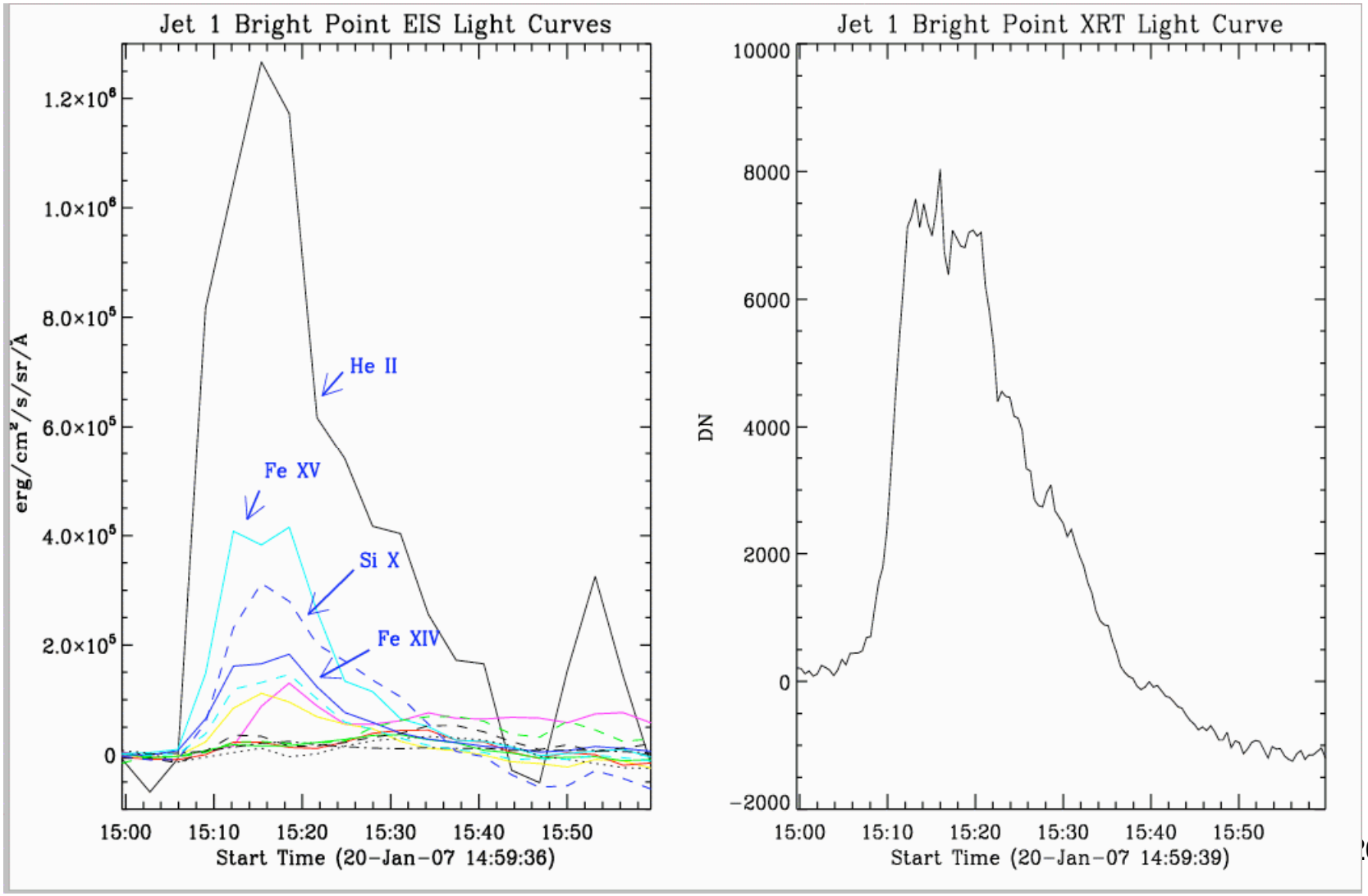
Fe XI @ 188.2 A

Wavelength Range
Ca XVII @ 192.8 A ± 0.46 A

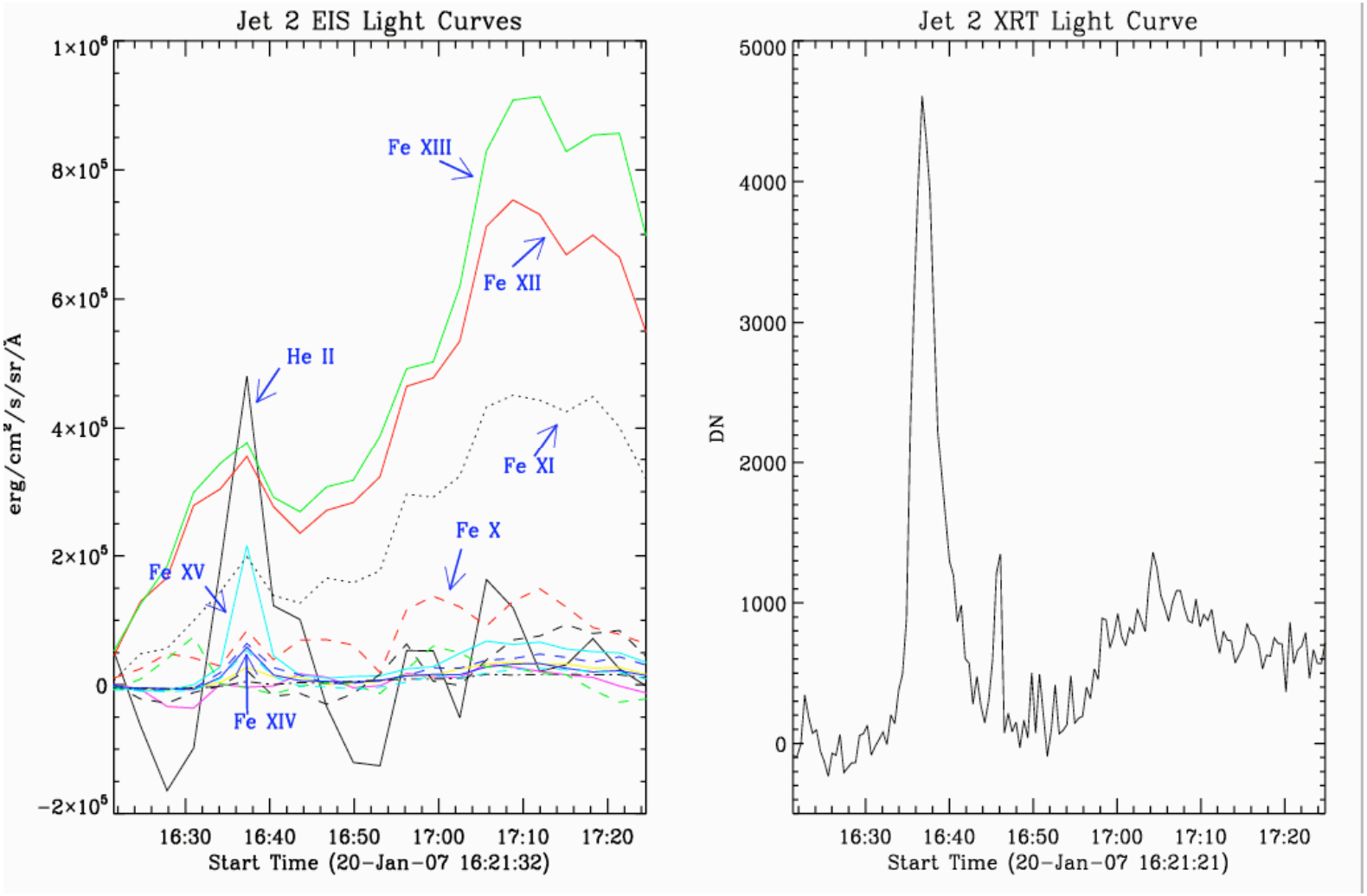
Jet 1 Light Curves



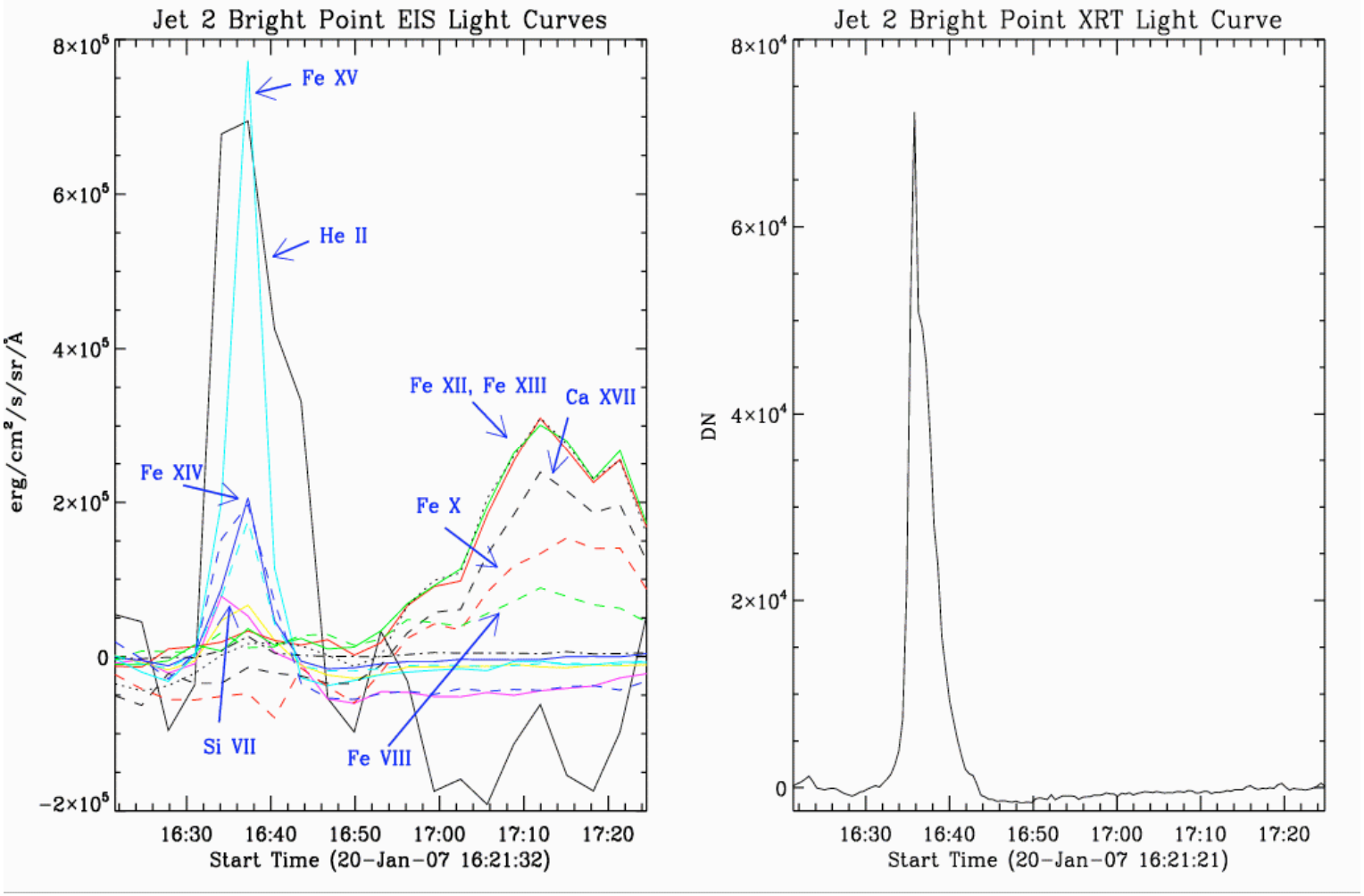
Jet 1 Bright Point Light Curves

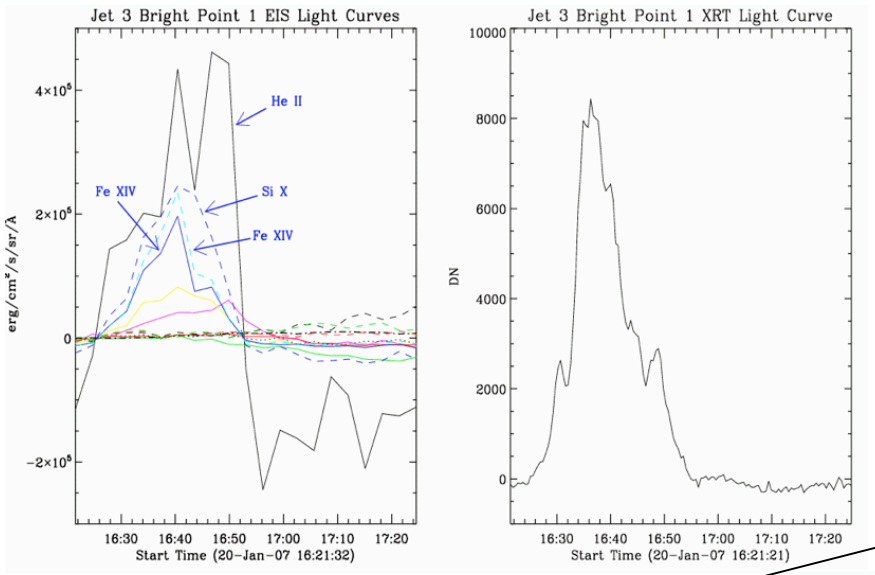


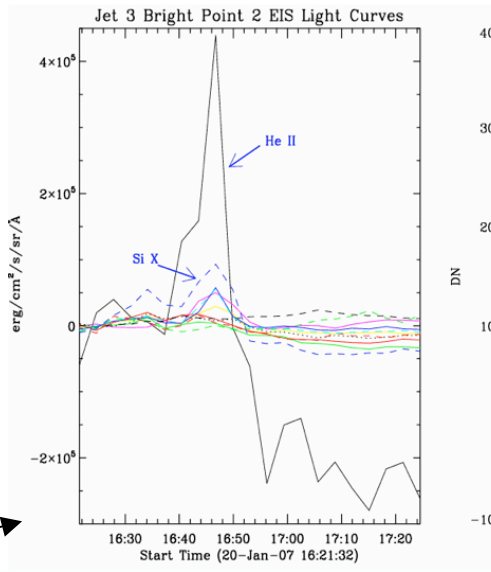
Jet 2 Light Curves

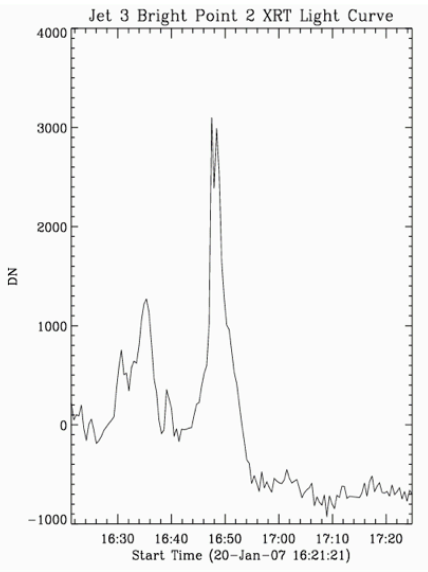


Jet 2 Bright Point Light Curves

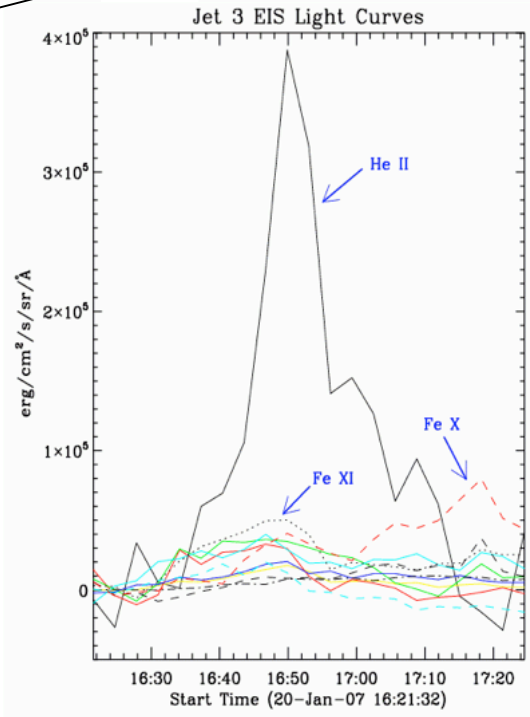


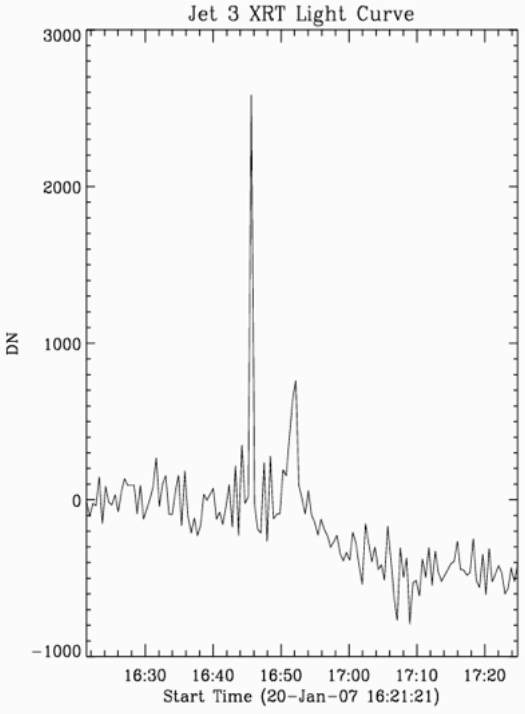






Jet 3 BP EIS & XRT LCs





Jet 3 EIS & XRT LCs

Summary of Preliminary Results

- All jets and bright points show impulse behavior.

- Jets and bright points have coincident start and peak times in EIS and XRT light curves.

- Bright points look hotter than their associated jets based on the temperature of the spectral lines in which they appear.

- Post-jet increases in intensity appear cooler than the jets which they follow.

Plausible Explanation for Post - Jet Enhancement??

Accelerated jet plasma falls back towards the Sun along open field lines and re-enters the contour region of the light curves.

•Hot jet plasma has velocity significantly below escape velocity.

	Jet 1	Jet 2	Jet 3	Escape
Speed (km/sec)	360	150	63	618

•Assuming thermal conduction along the magnetic axis of the jet, the plasma is cooled by the time it returns to the contour region.

•Near vertical trajectory of plasma jet - low plasma beta regime and near vertical open field lines of the coronal hole.

Thesis Plan

1. First Project - June to December 2007
   - Expand to multi-wavelength, multi-case study for major journal. Include 3 examples of emerging flux near a CH and 2 possible examples within a CH. Use Hinode and STEREO instruments.
   - Submit EIS observing plan designed to capture plasma outflow during formation of dimming regions on far-side of AR.
2. Second Project - Concurrent with 1st project and into 2008
   - Expand and develop the work done on coronal jets using Hinode vector magnetograms and spectrographic data.
   - Submit EIS observing plan to obtain Doppler velocity of jets in equatorial CH. We have an ongoing running observation program for this project.
3. Years 2 to 4
   - Collaboration with theoreticians/modelers.
   - Improve programming skills.
   - Work in Japan and/or the detector group during 4th Year.