# Small-scale Magnetic Reconnection Eevents in the Sun

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## ABSTRACT

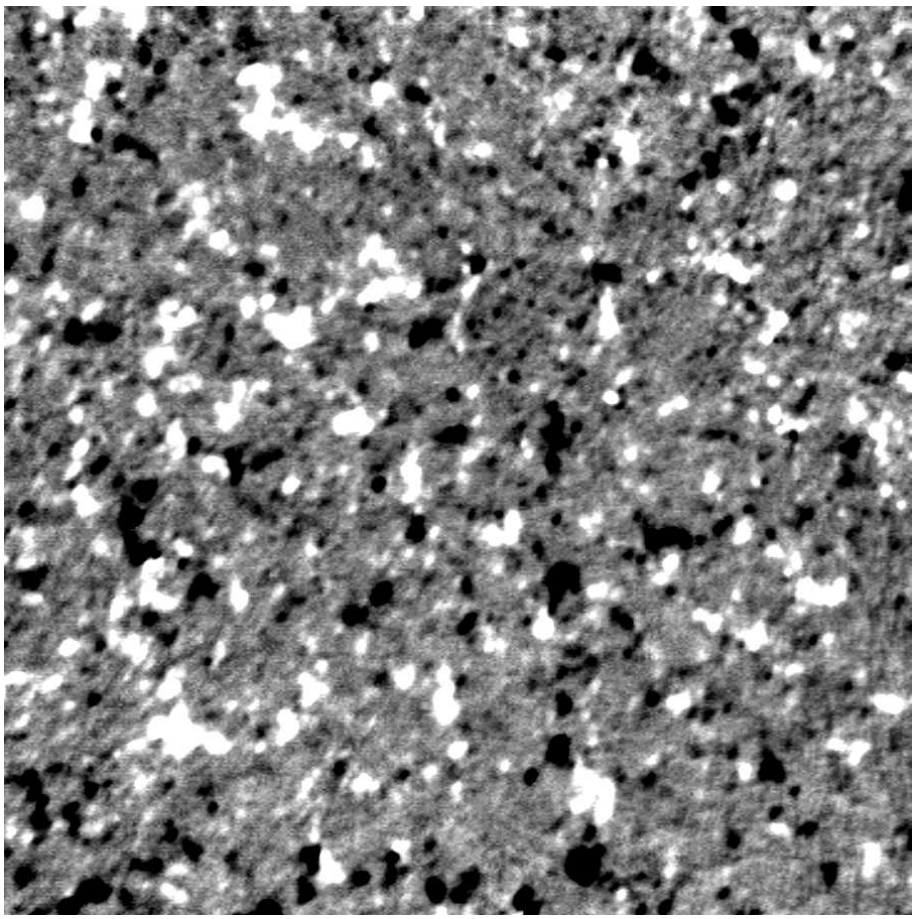
Magnetic reconnection appears to be a promising solution for mass, momentum, and energy problems in the solar chromosphere and corona. There has been increasing observational evidence that magnetic reconnection ubiquitously occurs in the quiet Sun as well as in active regions. The study of small-scale reconnection events is expected to extend our knowledge on large-scale reconnection events – e.g., flares and prominence eruptions – down to unresolved-scale reconnection events – e.g., nanoflares. I give a brief review of our recent observational results on this interesting topic, which include UV explosive events, chromospheric upflow events, and mini-filament eruptions in the quiet Sun, and microflares EUV jets, and H alpha surges in active regions. I emphasize the importance of understanding the physics of flux cancellation and the two kinds of (slow and fast) magnetic reconnection in future studies.

# 1. The Case for the Study

- **Fundamental Problems in the Solar Upper Atmosphere**
  - **Mass Supply**
    - **solar wind**
    - **UV downflow**
    - **mass inside loops (such as post-flare loops)**
    - **mass in the prominence**
  - **Mass Support and Acceleration**
    - **large pressure-scale height of chromosphere**
    - **solar wind**
    - **prominence eruption**
    - **coronal mass ejection**
    - **jets**
  - **Heating**
- **Magnetic reconnection is a posssible solution for these problems of**
  - **Mass**
  - **Acceleration**
  - **Heating**
- **Why do we study small-scale reconnection events?**
  - **a bridge between flares and nanoflares**
  - **maybe potentially important, but not well understood**
  - **numerous, small, short-lived and simple**

## 2. Candidates for Magnetic Reconnection Events

- **Photospheric Magnetograms**
  - **Flux Distribution**
    - **all scales and mixed polarity**

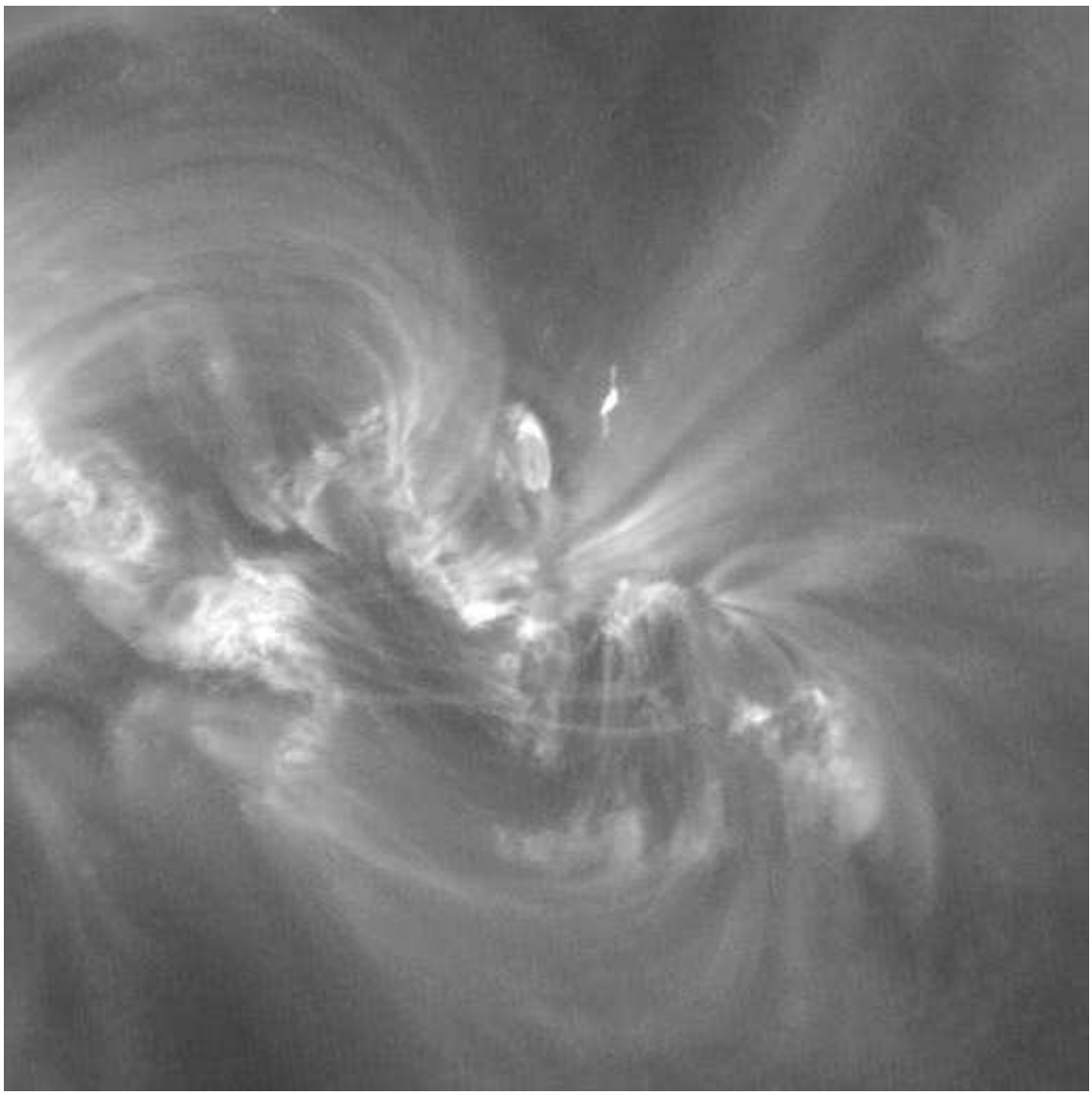


  - **Flux Evolution**
    - **emergence, transverse motion, <u>cancellation</u>**

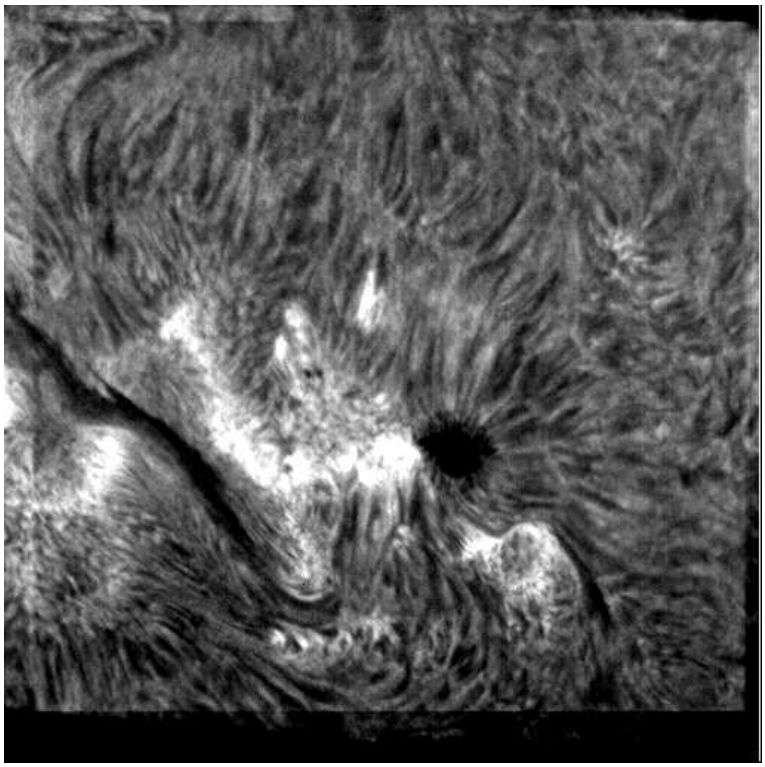
- **Transient Brightenings**
  - **Flares**
  - **X-ray Bright Points**
  - **Microflares**
  - **Blinking**
  - **Nanoflares**
- **Jets and mass ejections**
  - **Coronal Mass Ejection**
  - **Prominence eruptions**
  - **Mini-filament eruptions**
  - **Surges**
  - **X-ray/EUV Jets**
  - **Macrospicules**
  - **UV explosive events**
  - **Spicules**
  - **H$\alpha$ upflow events**

## 3. Small-scale Reconnection Events in an Active Region

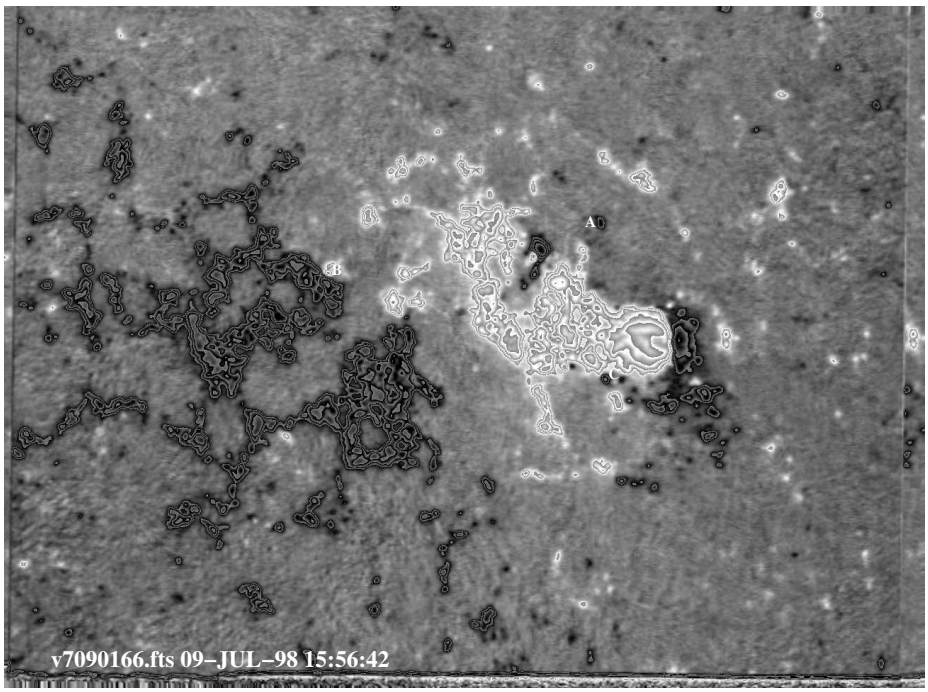
- **Ref: Chae et al. 1999, ApJ Letters, in press**
- **Cooridinated TRACE and BBSO Observations of NOAA 8264 on 1998 July 9**
  - **TRACE Fe XII 195**



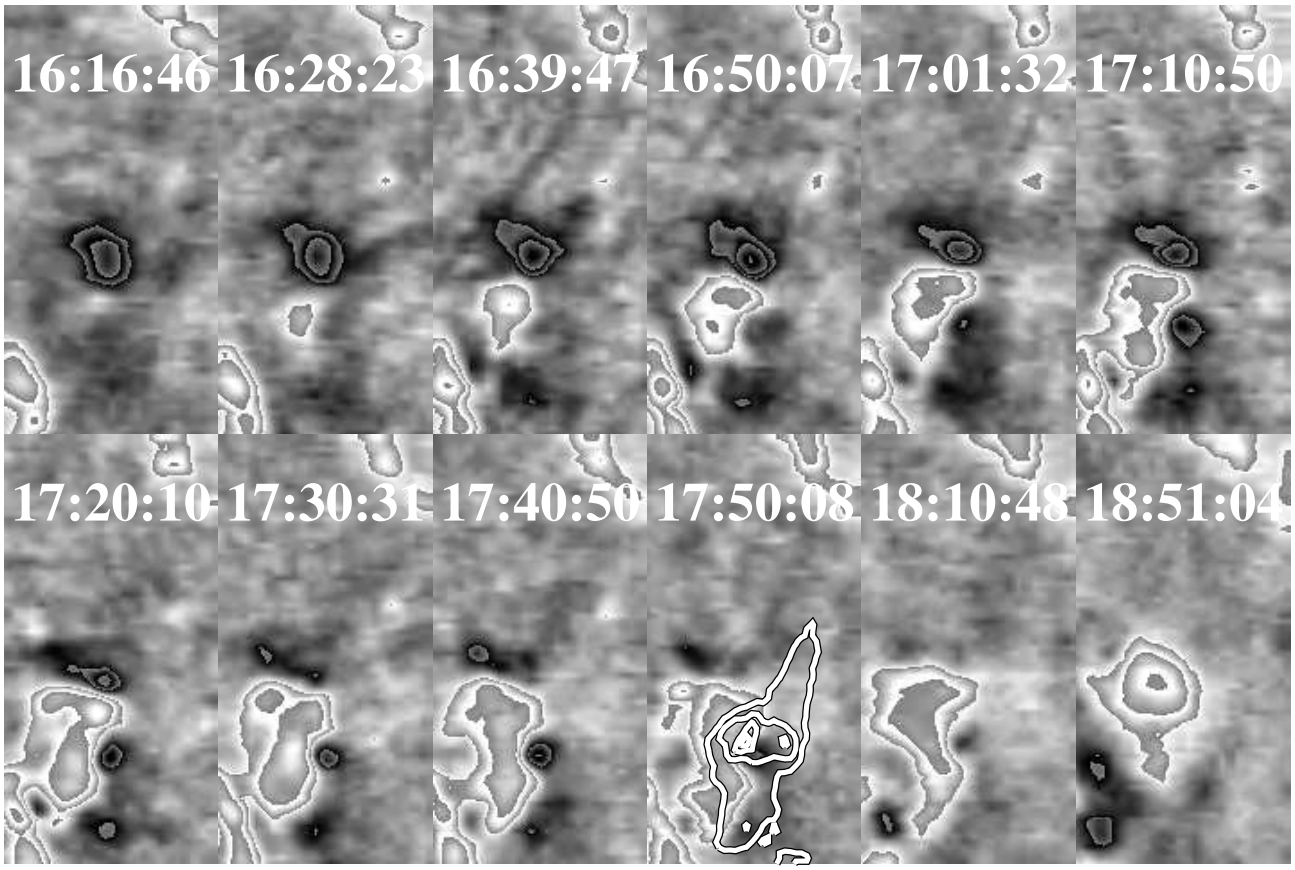
– **BBSO H$\alpha$ centerline**



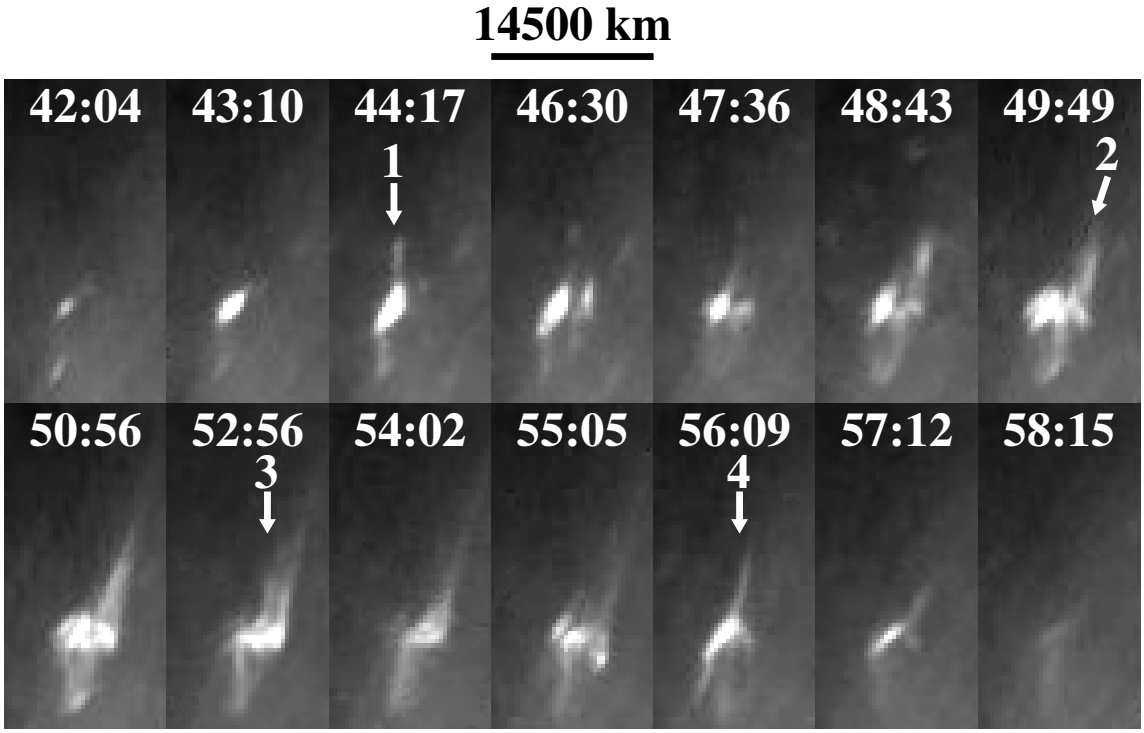
– **BBSO Magnetogram**



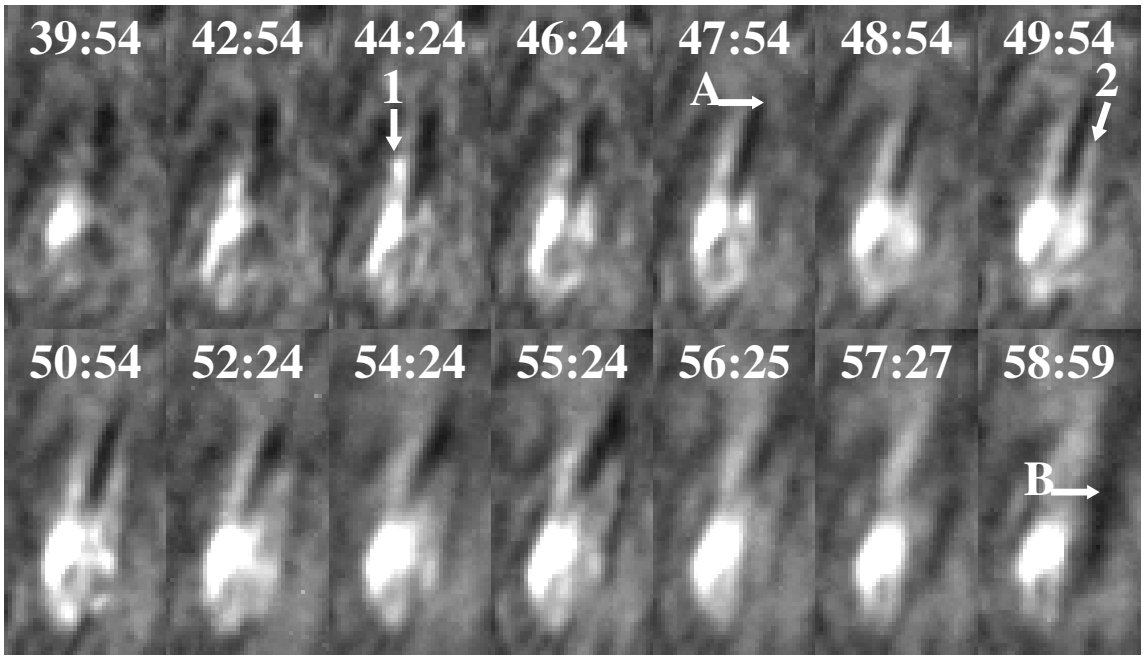
- **Magnetic Flux Evolution: emergence and cancellation**



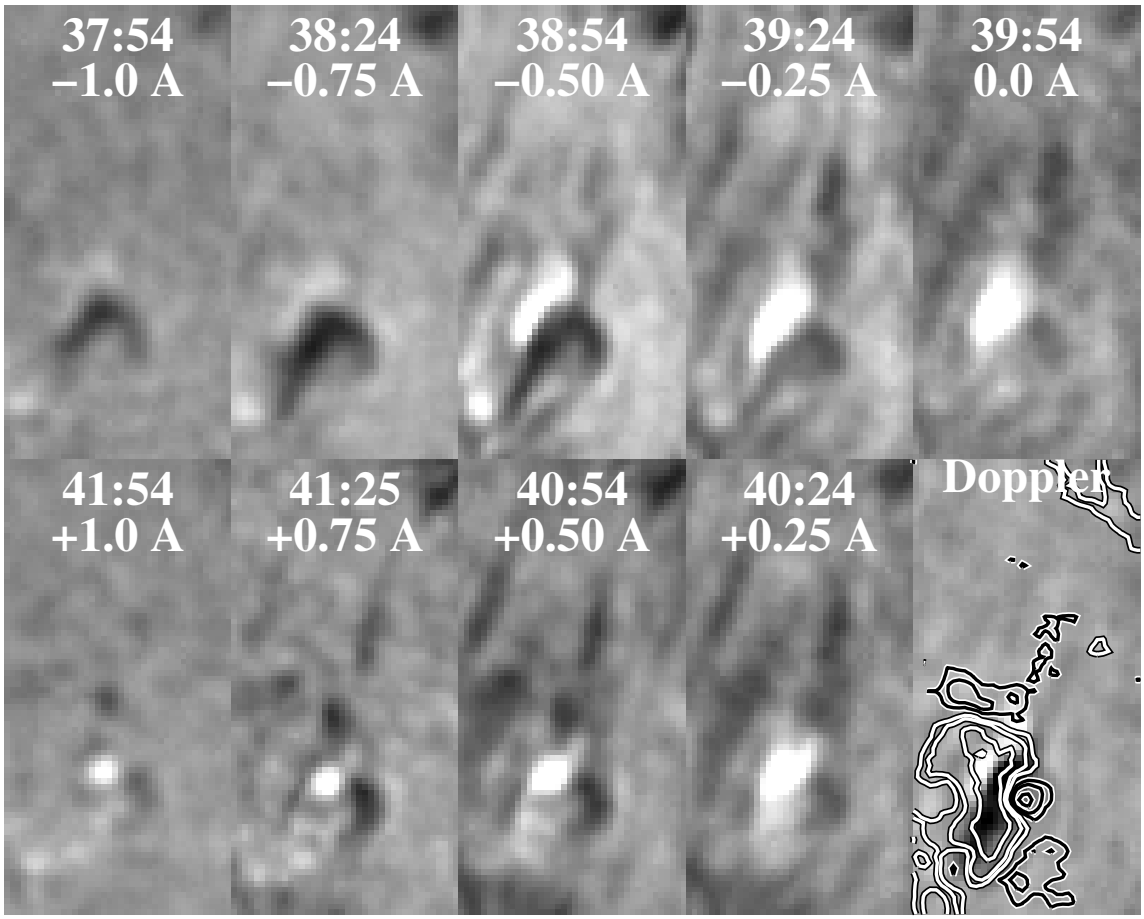
- **EUV Microflares and Jets**




- **H*alpha* Jets and Surges**



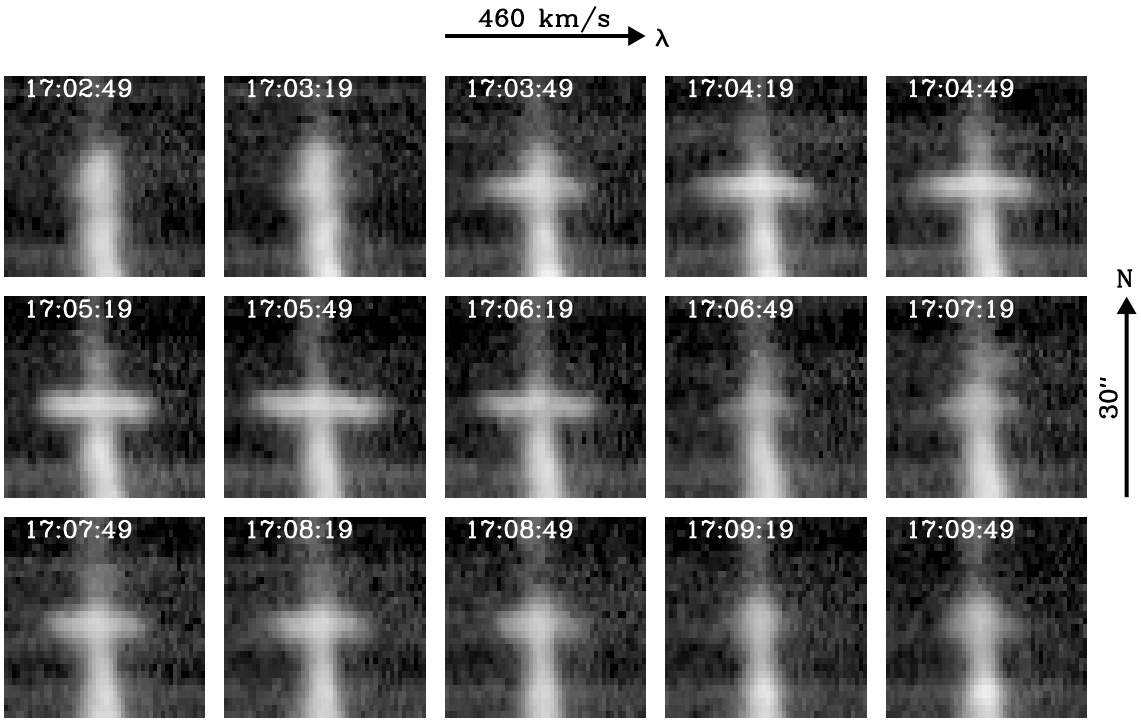
- **An Erupting Mini-Filament**

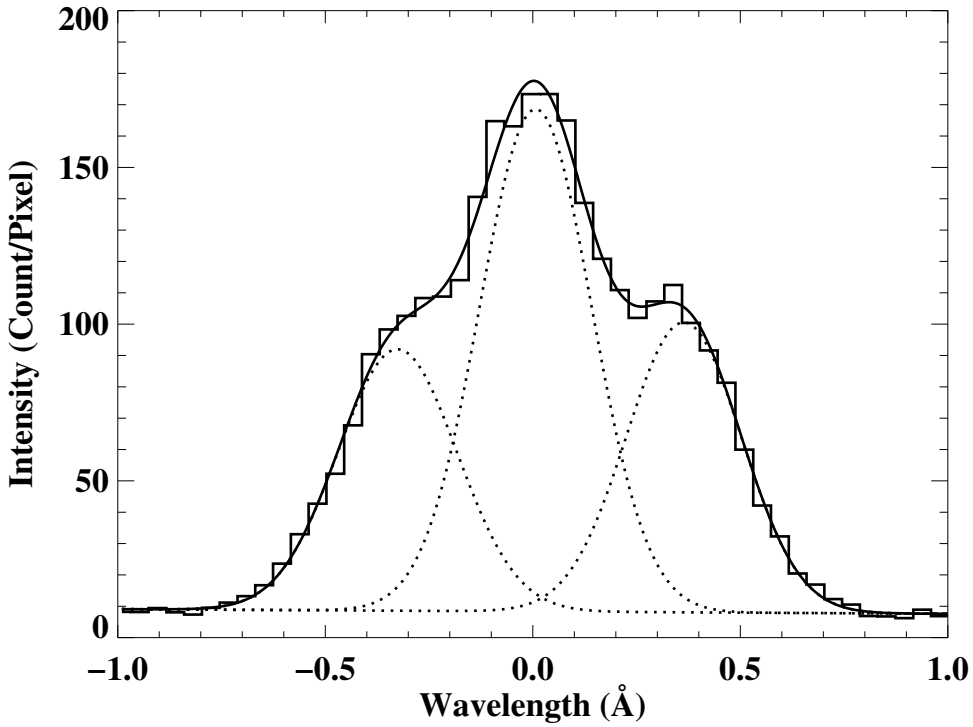


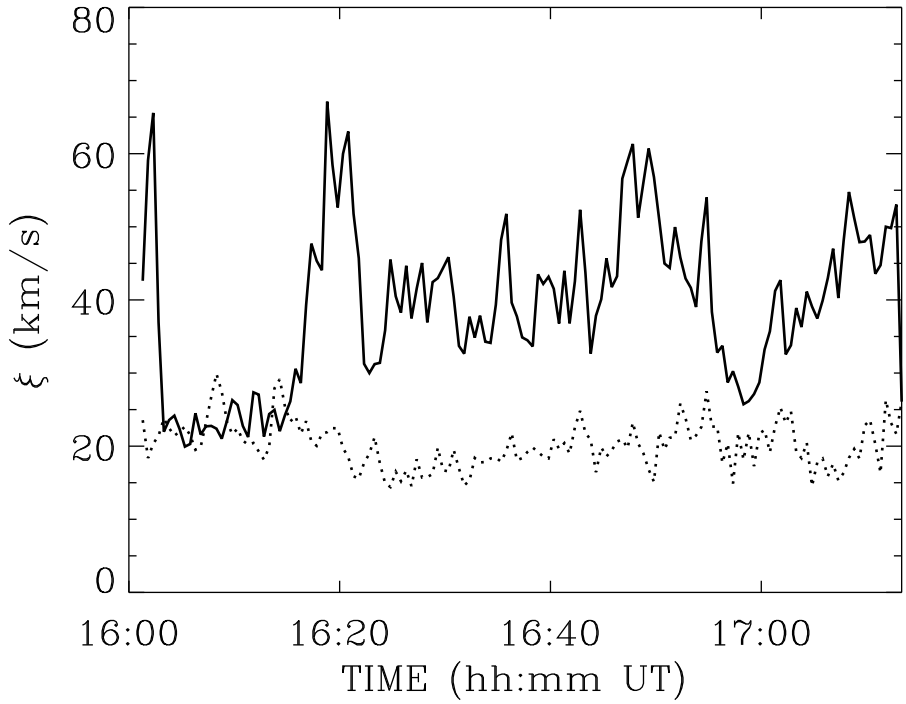

- **Discussion**
  - **Yohkoh X-ray Jets and TRACE EUV Jets**
  - **EUV Jets and H$\alpha$ Surges**
  - **Flux cancellation and erupting mini-filament**
  - **Consistent picture of flux cancellation, erupting min-filament, microflares, EUV jets and H$\alpha$ surges?**

## 4. Small-scale Reconnection Events in the Quiet Sun

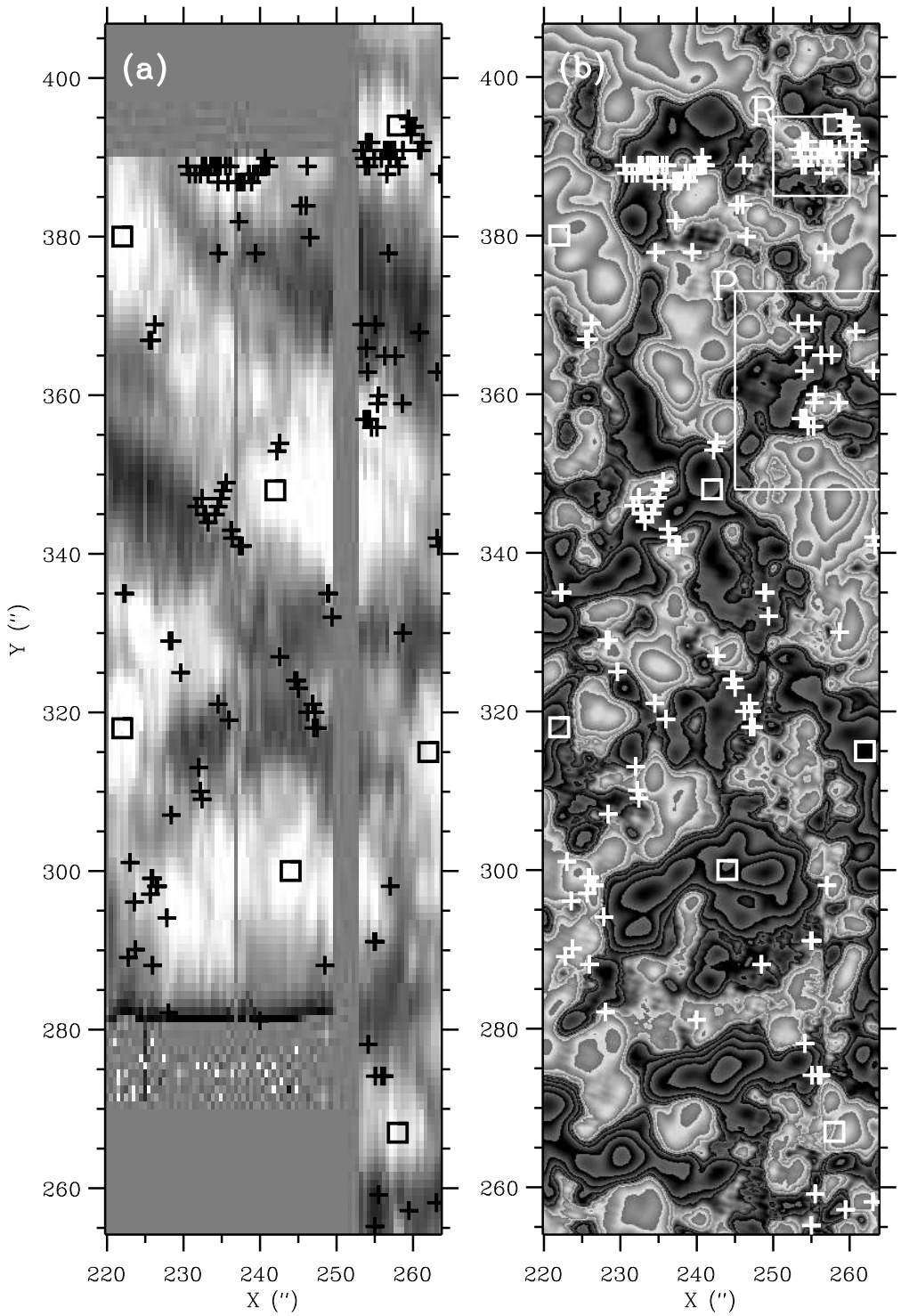
- Reference
  - Wang et al. 1998, Sol. Phys. 178,493
  - Chae et al. 1998, ApJ, 497, L109
  - Chae et al. 1998, ApJ, 504, L123
  - Chae 1998, 19th Sac Peak Workshop
  - Lee, Chae & Wang, 1999, in preparation
- Coordinated SOHO and BBSO Observations of a Quiet Area on 1997 August 26
- UV Explosive Events
  - discovered from HRTS experiments
  - dynamical characteristics

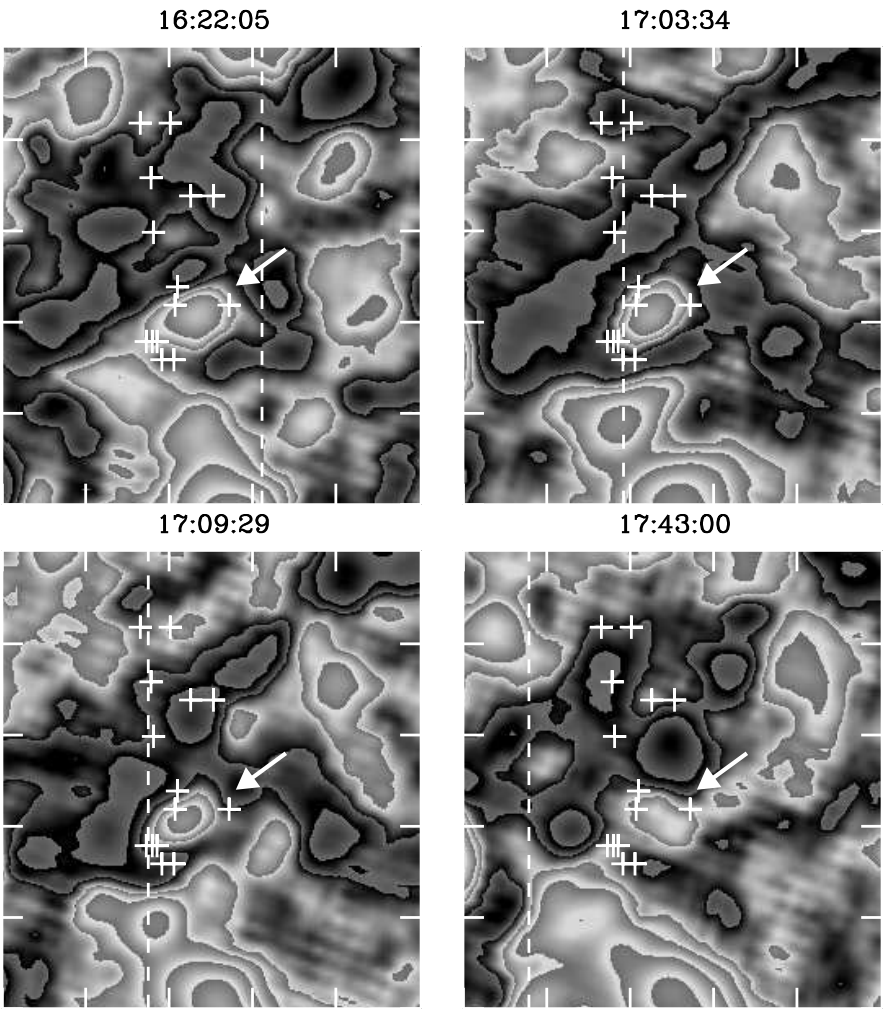



200
150
100
50
0
Intensity (Count/Pixel)
−1.0
−0.5
0.0
0.5
1.0
Wavelength (Å)

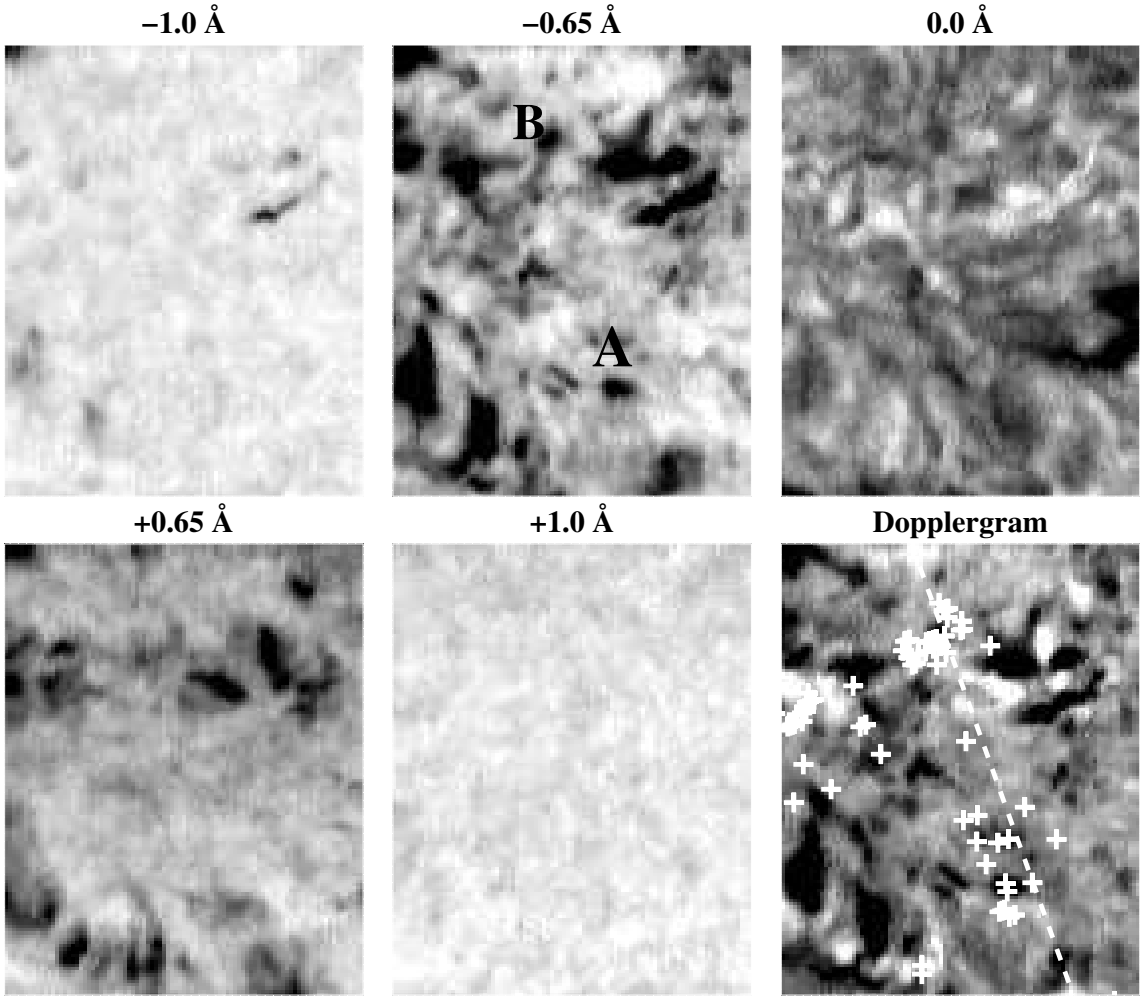

80
60
40
20
0
ξ (km/s)
16:00
16:20
16:40
17:00
TIME (hh:mm UT)

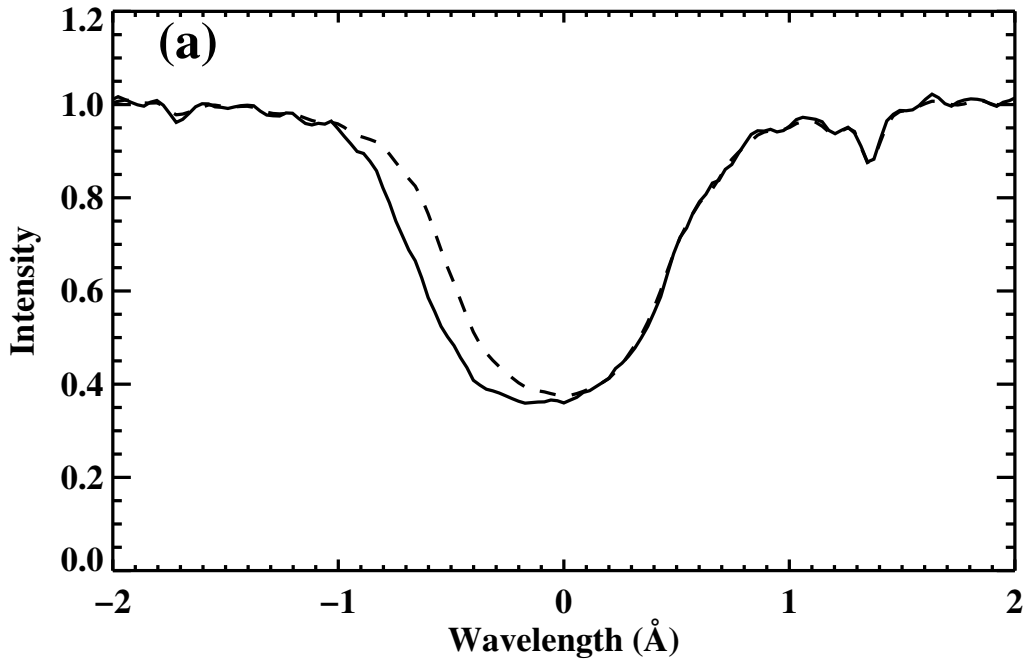
– correlation with flux cancellation




16:22:05
17:03:34
17:09:29
17:43:00

- **H$\alpha$ uplfow events**
  - **History**
    - **Title 1966 PhD Thesis. "upgoing features with 2 min life time"**
    - **Wang et al. 1998 "H$\alpha$-1.0 jets"**
    - **Chae et al. 1998b, "H$\alpha$ upflow events"**
  - **Dynamical Characteristics**




(a)
Intensity
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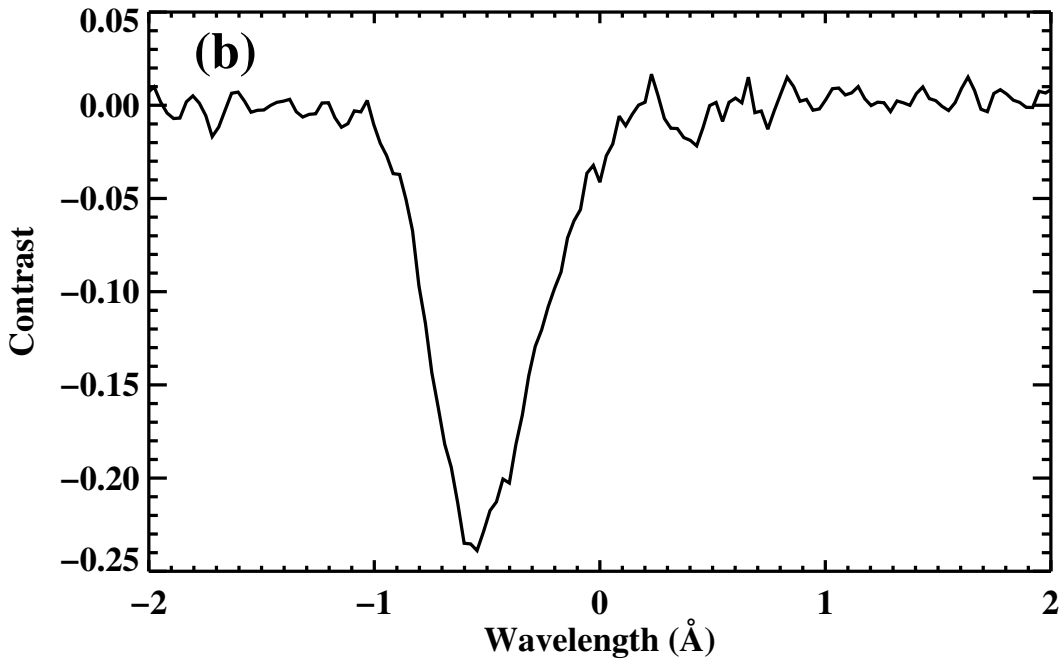
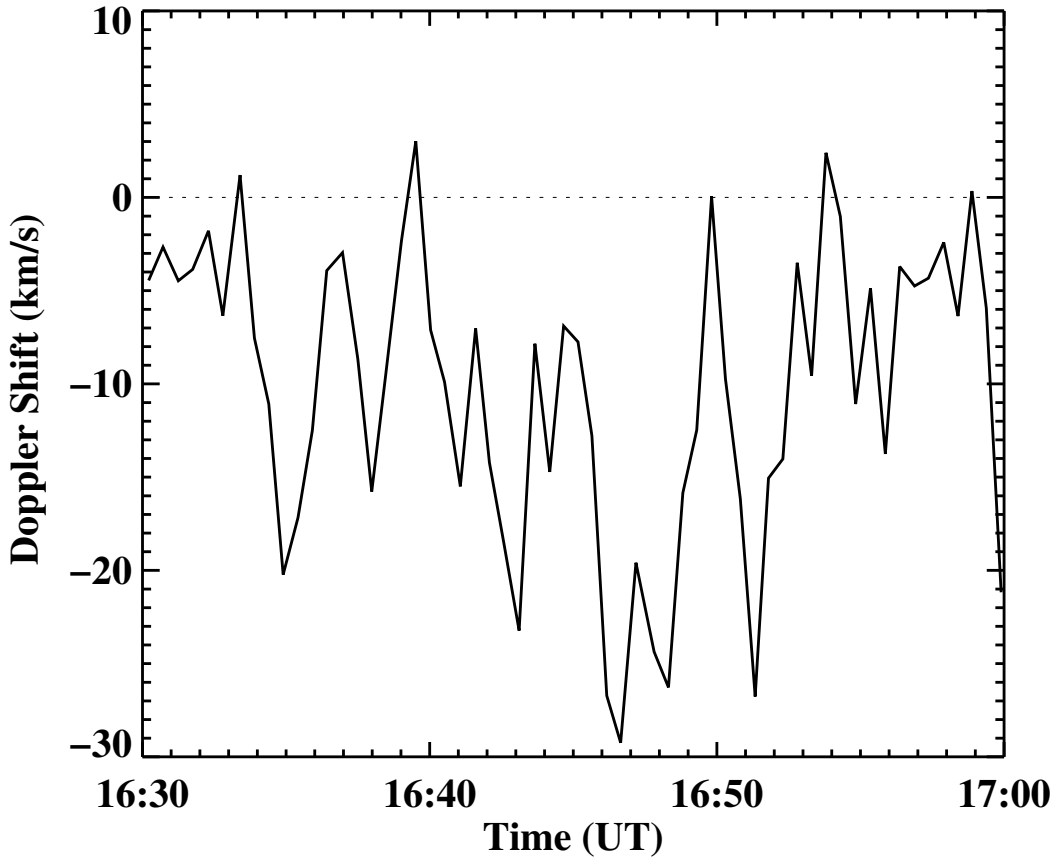
1.0
0.8
0.6
0.4
0.2
0.0
−2
−1
0
1
2
Wavelength (Å)


(b)
Contrast
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
−2
−1
0
1
2
Wavelength (Å)

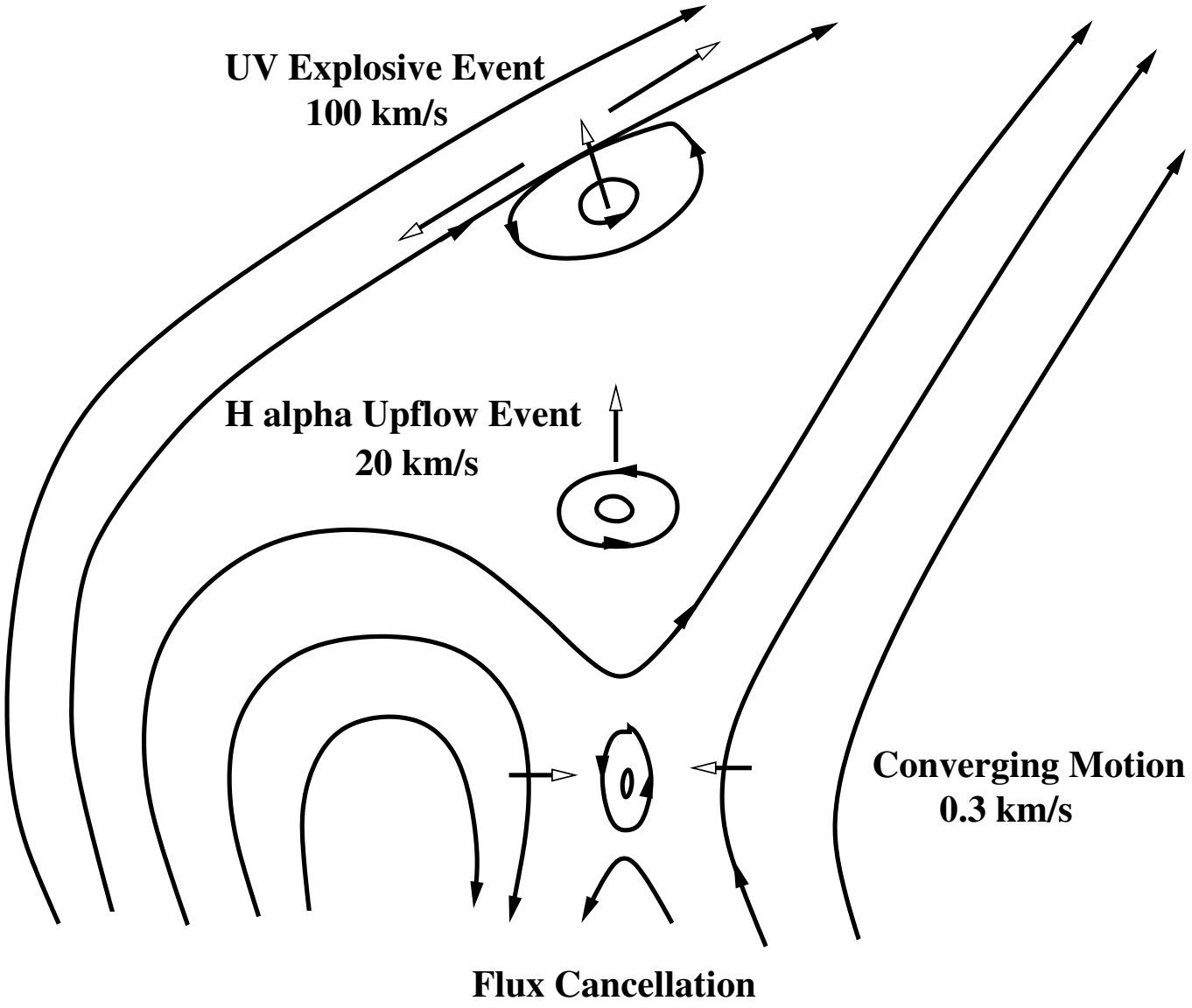



– associations among flux cancellation, H$\alpha$ upflow events, and UV explosive events

• **Comparison of UV Explosive Events and H$\alpha$ Upflow Events**

| Parameter | Explosive event | Upflow event |
|---|---|---|
| Size | 1500 km | 1500 km |
| Lifetime (FWHM) | 60 s | 60 s |
| Bulk motion | 100 km $s^{-1}$ | 20 km $s^{-1}$ |
| Nonthermal motion ($\xi$) | 35 km $s^{-1}$ | $<$ 10 km $s^{-1}$ |
| Temperature | $10^5$ K | $10^4$ K |
| Electron density | $7 \times 10^{10}$ $cm^{-3}$ | $3 \times 10^{10}$ $cm^{-3}$ |
| Mass density | $1{\times}10^{-13}$ g $cm^{-3}$ | $1{\times}10^{-13}$ g $cm^{-3}$ |
| Global birthrate | 600 $s^{-1}$ | 200-500 $s^{-1}$ |

- **A Two-step Magnetic Reconnection Model**
  - **The Picture**



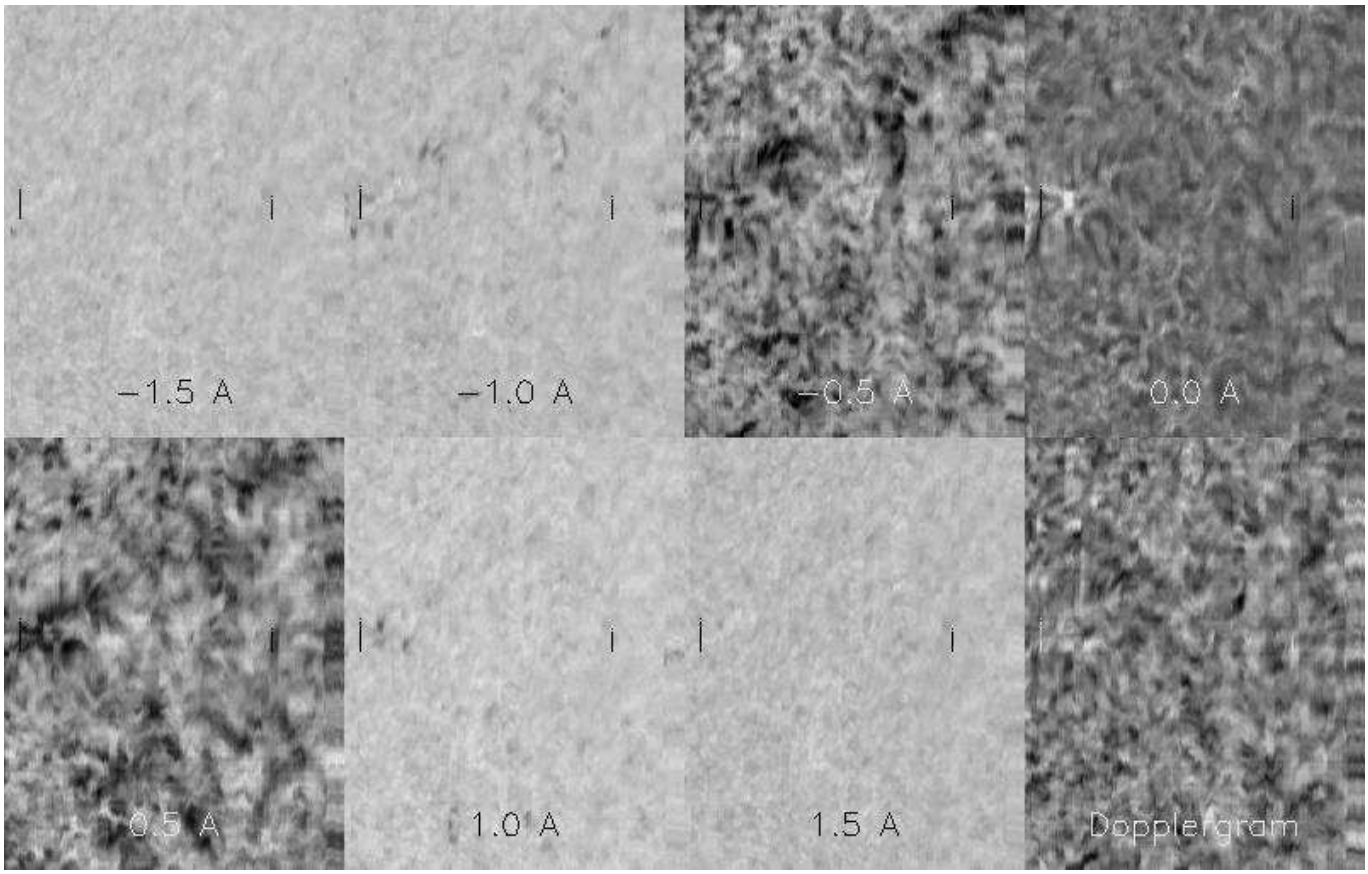
- **Two kinds of Magnetic Reconnection**
  - **first reconnection: temperature minimum region, slow, O-type neutral points**
  - **second reconnection: upper chromosphere/transition region, fast, X-type neutral points**
- **Condition for Slow Reconnection**
  - **Low electrical conductivity $\Leftarrow$ cool atmosphere**
  - **Slow driving speed**

$$\alpha \equiv \frac{w}{h}\frac{v_{\rm A}}{v_{\rm in}} > \alpha_c$$

$$w = \frac{c^2}{4\pi\sigma v_{\rm in}}$$

- **Physical Consequences of the Model**
  - **possible to explain the mass source for the UV downflow**
  - **H$\alpha$ upflow events: very tiny erupting filaments?**

## 5. Summary and Ongoing Research

- **Summary**
  - dynamical features are frequently associated flux cancellation
  - cool and hot plasma ejections often come together
- **Future Research Directions**
  - Investigating the physics of flux cancellation
    - temporal evolution of flux in cancelling regions
    - correlation between Doppler and magnetic signals at flux cancelling regions
    - dynamic features associated with flux cancellation, e.g. mini-filament eruptions
  - UV Explosive Events
    - thermal evolution
    - dependence of birth rates on temperature
    - relation to blinker
    - relation to coronal heating
  - Extensive studies of H$\alpha$ upflow events
    - detail structure and time-evolution
    - correlations with flux cancellation
    - UV bright points
  - Interpretational efforts
    - 3-dimensional generalization of the two-step reconnection model
    - Alternative models?
    - Unifying models for both the quiet Sun and active region events?
  - And more?

## New H$\alpha$ Spectral Data