Solar Wind 13

Coronal outflows from active region boundaries and CME-induced dimming regions

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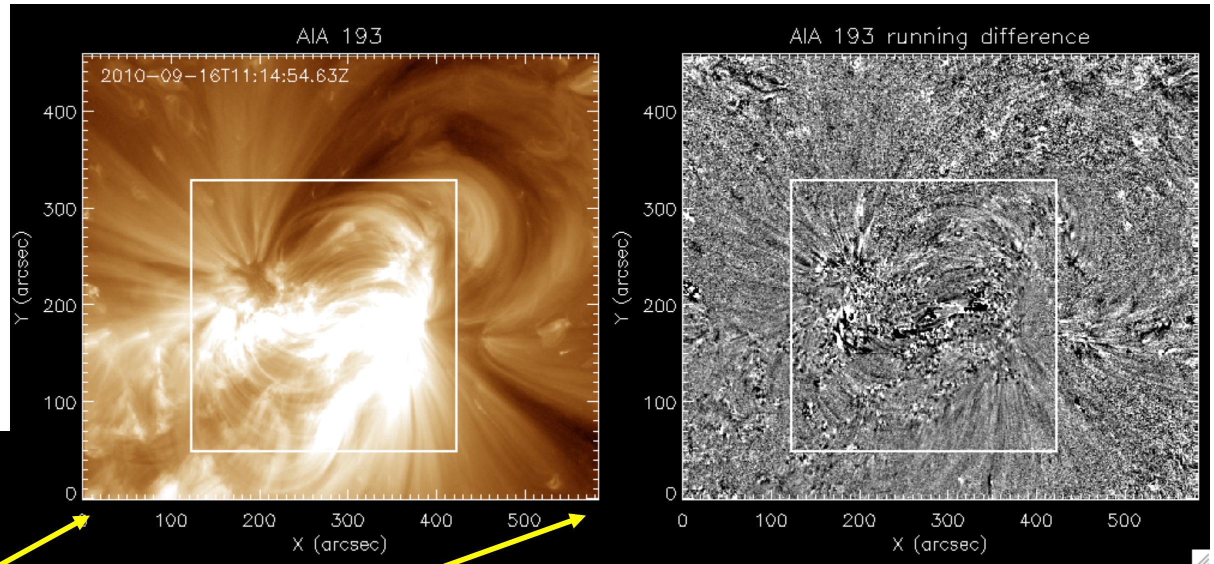
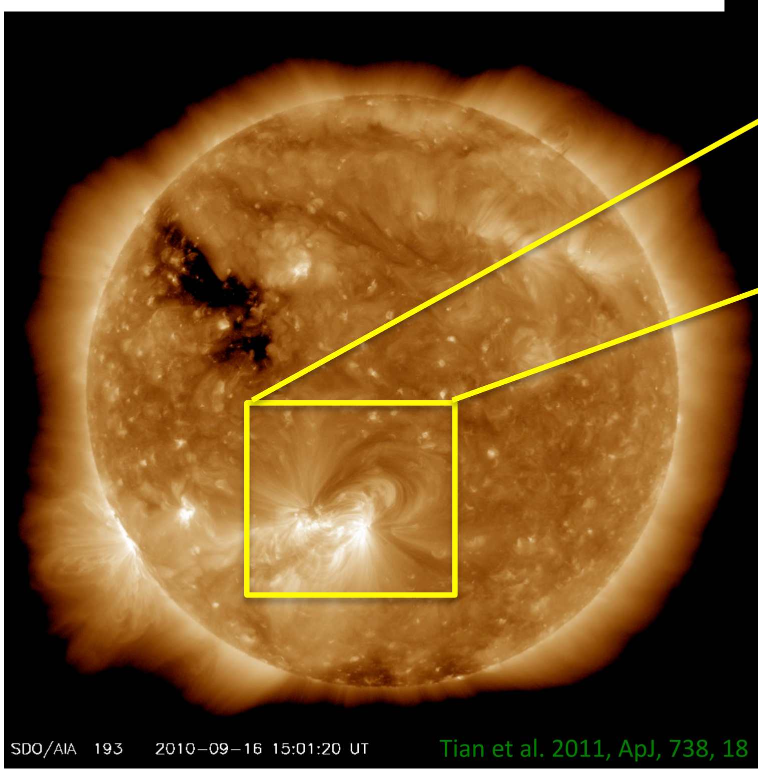
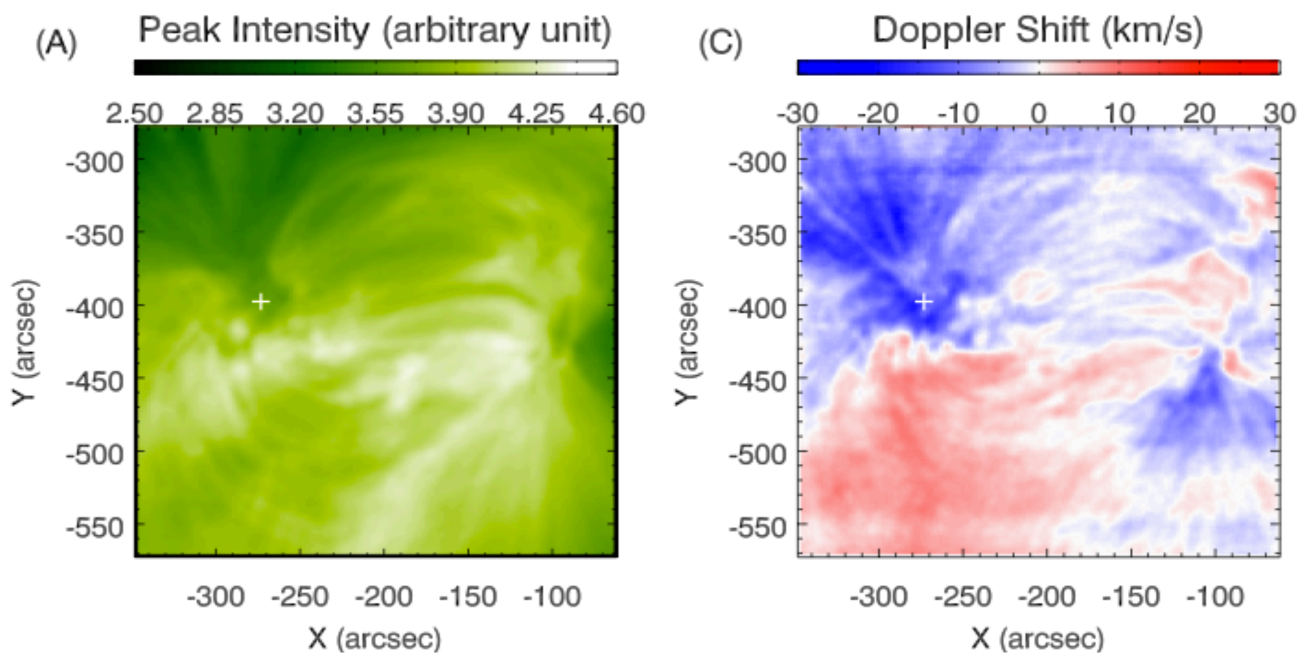
Upward propagating disturbances in imaging observations





- Upward propagating disturbances (PDs) at AR boundaries
  - Slow waves: De Moortel et al. 2002; Robbrecht et al. 2001; King et al. 2003; Marsh et al. 2009; Wang et al. 2009; Stenborg et al. 2011; Yuan & Nakariakov 2012; Krishna Prasad et al. 2012; et al.
  - Mass supply to the corona & solar wind: Sakao et al. 2007, et al.; McIntosh & De Pontieu 2009; He et al. 2010; Su et al. 2012; McIntosh et al. 2012; Tian et al. 2011, 2012

Blue shifts at AR boundaries

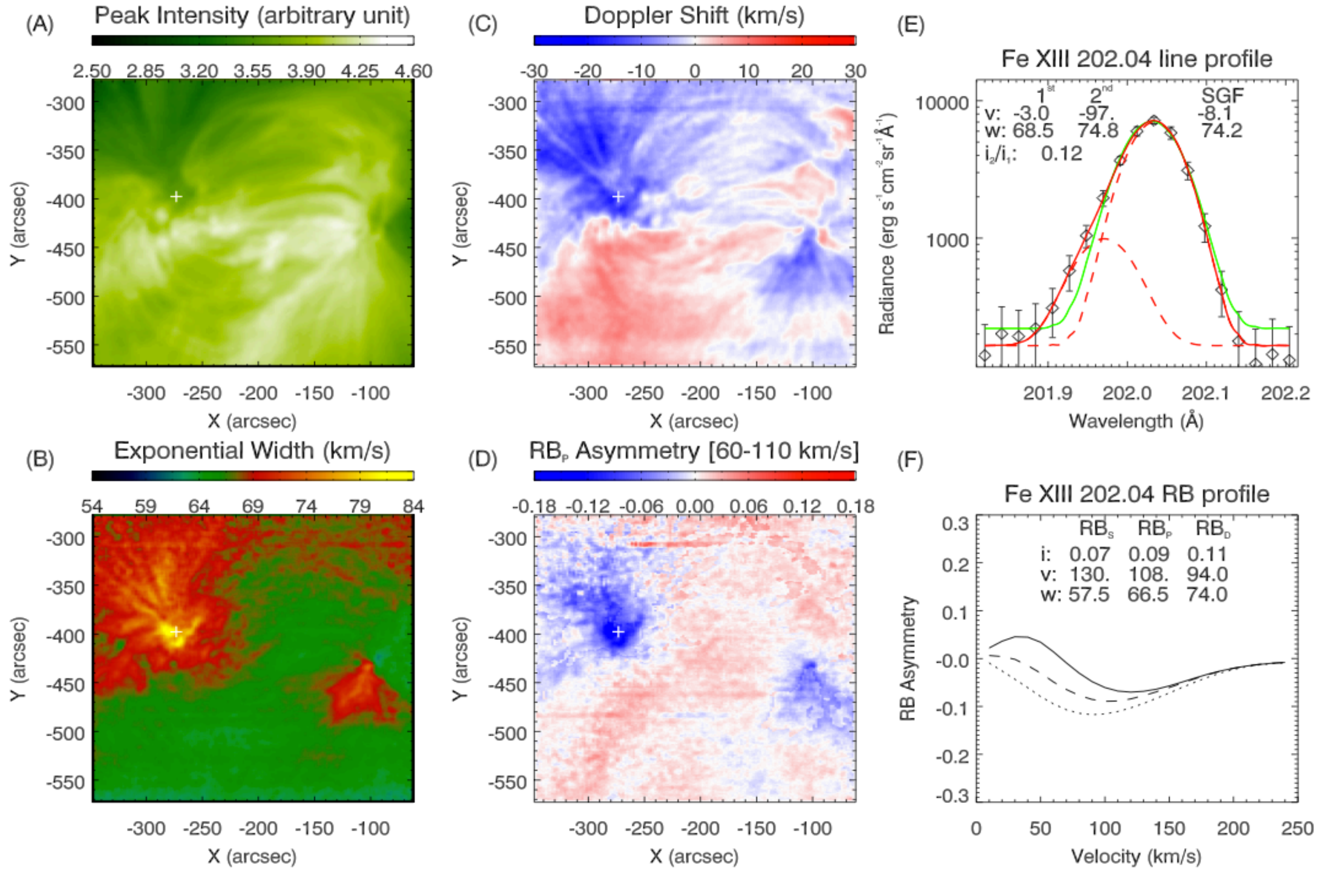


HINODE/EIS
Fe XIII 202.04 Å

- Compare blueshits & PDs (De Moortel 2009)
  - Same location: AR boundaries
  - Speed:
    PDs: ~100 km/s
    Blueshifts: ~20 km/s
  - Periodicity:
    PDs: quasi-periodic
    Blueshifts: no periodicity was reported

- SUMER & EIS observations of AR boundaries: ~20 km/s blue shift in coronal lines, SGF
  - Marsch et al. 2004, 2008; Del Zanna 2008; Tripathi et al. 2009; Murray et al. 2010; Young et al. 2011; Tian et al. 2011, et al.
- Origin of the slow solar wind?
  - Harra et al. 2008; Doschek et al. 2008; Brooks & Warren 2011, et al.

Blueward asymmetry of the line profiles

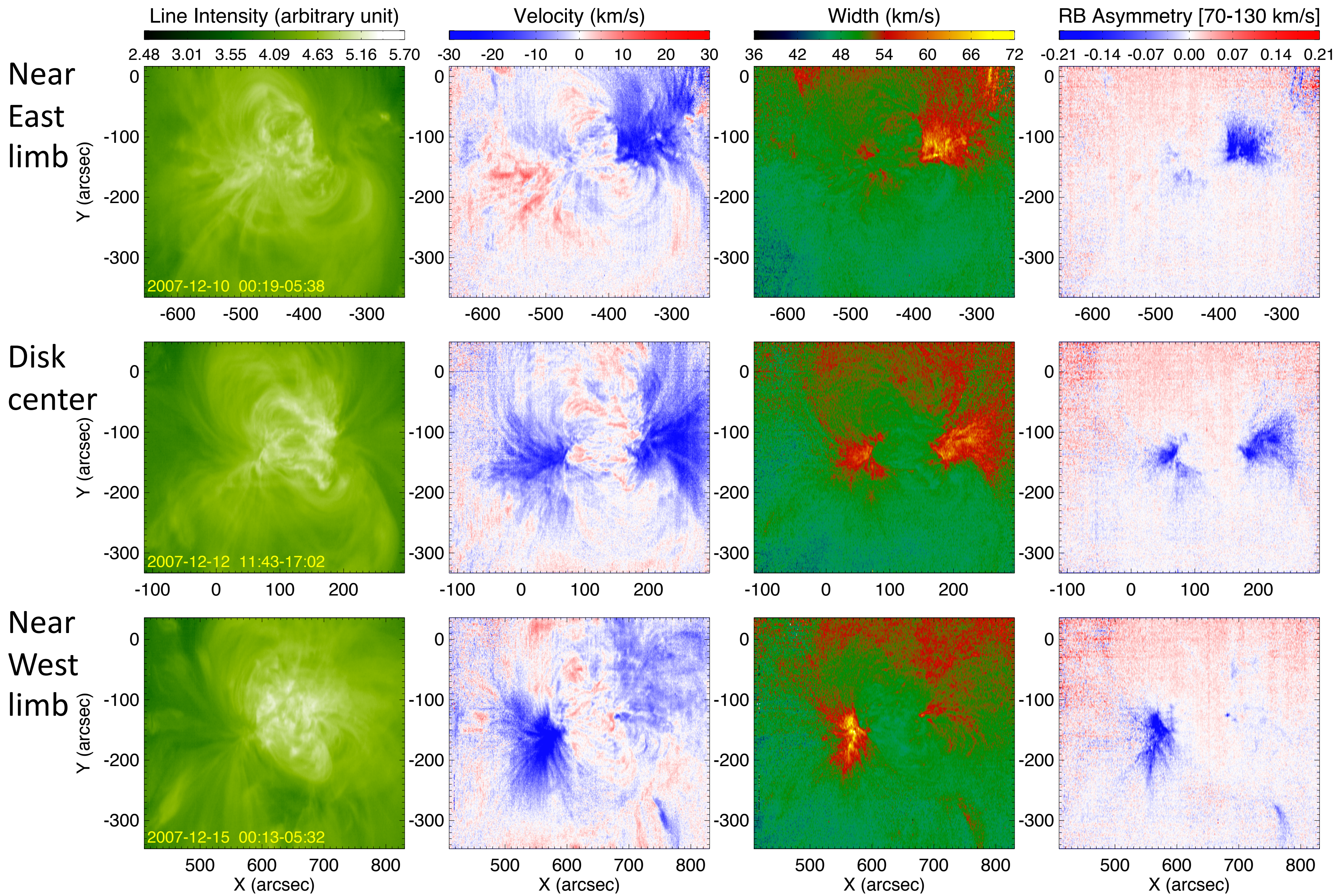


Tian et al. 2011, ApJ, 738, 18

- ❑ At least two emission components:
  - ➢ an almost stationary primary comp.
  - ➢ a weak high-speed (~100 km/s) 2nd comp.
- ❑ Blueshift of ~20km/s and enhanced line width are caused by the superposition of the two
  - ➢ SGF can not reflect the real physics
  - ➢ Previous results based on SGF, e.g., solar wind origin from AR edges at a speed of ~20 km/s, may need to be reconsidered
- ❑ It is the 2nd comp. that is associated with the PD!

- ❑ Blueward asymmetry of line profiles
  - ➢ Hara et al. 2008, De Pontieu et al. 2009, Peter 2010, Bryans et al. 2010, ; McIntosh & De Pontieu 2009; Tian et al. 2011; Martínez-Sykora et al. 2011, et al.

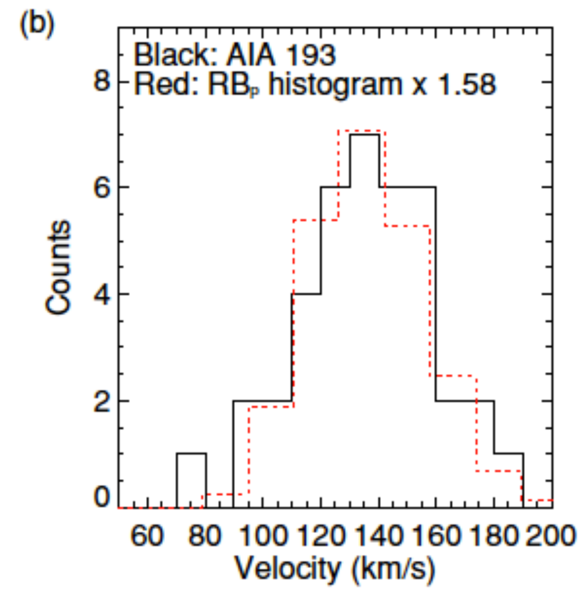
Profile asymmetry not caused by noise or blend

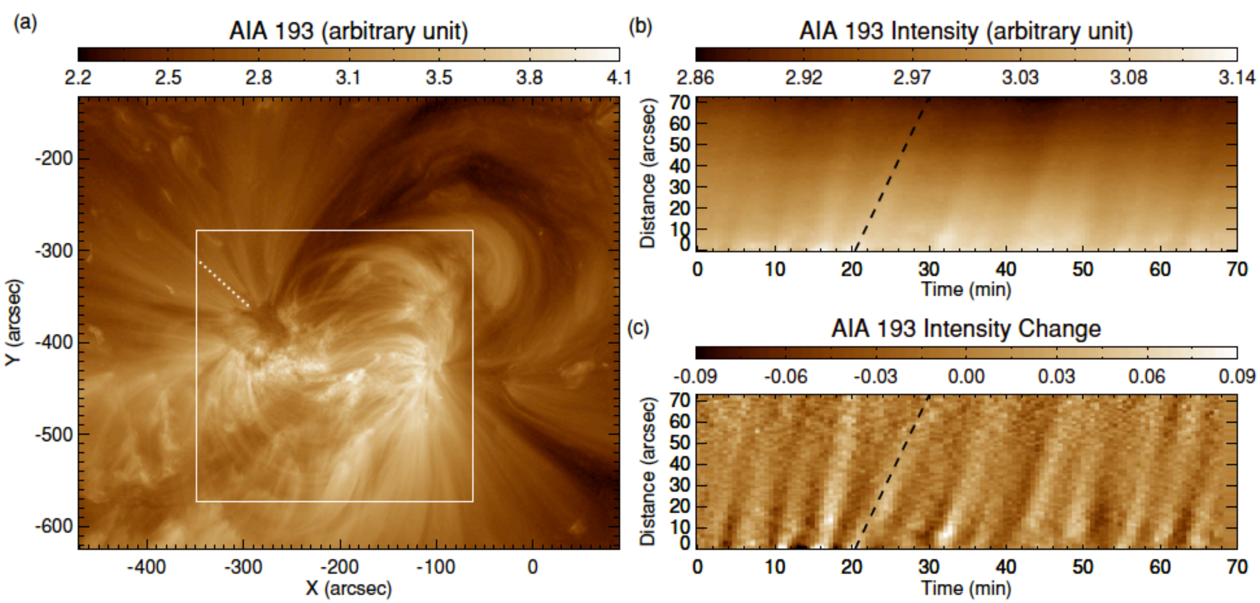


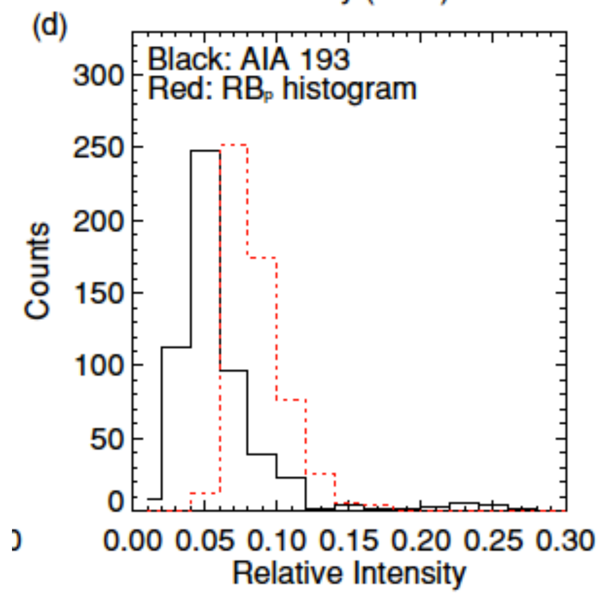
Tian et al. 2012, ApJ, 748, 106

Speeds of PDs are consistent with those of the 2nd component of line profiles

- ❑ Speed: ~100 km/s
- ❑ Intensity change: a few percent of the background intensity

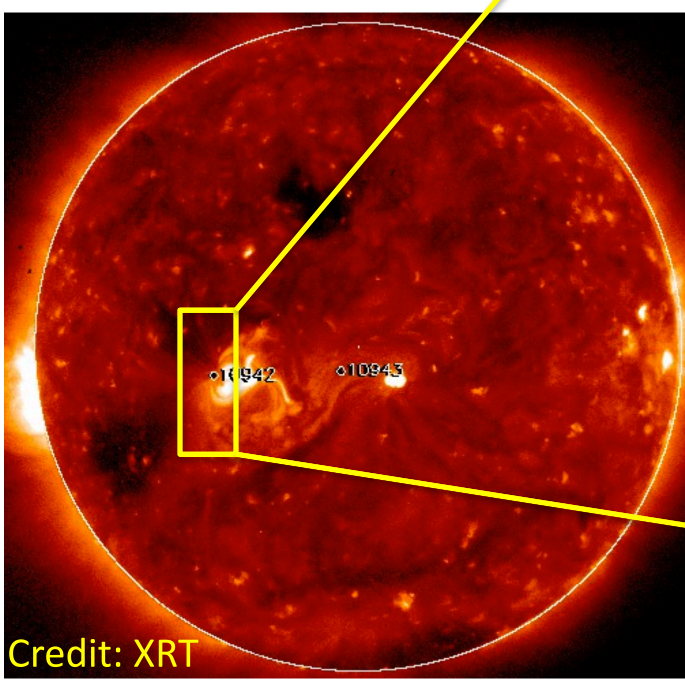


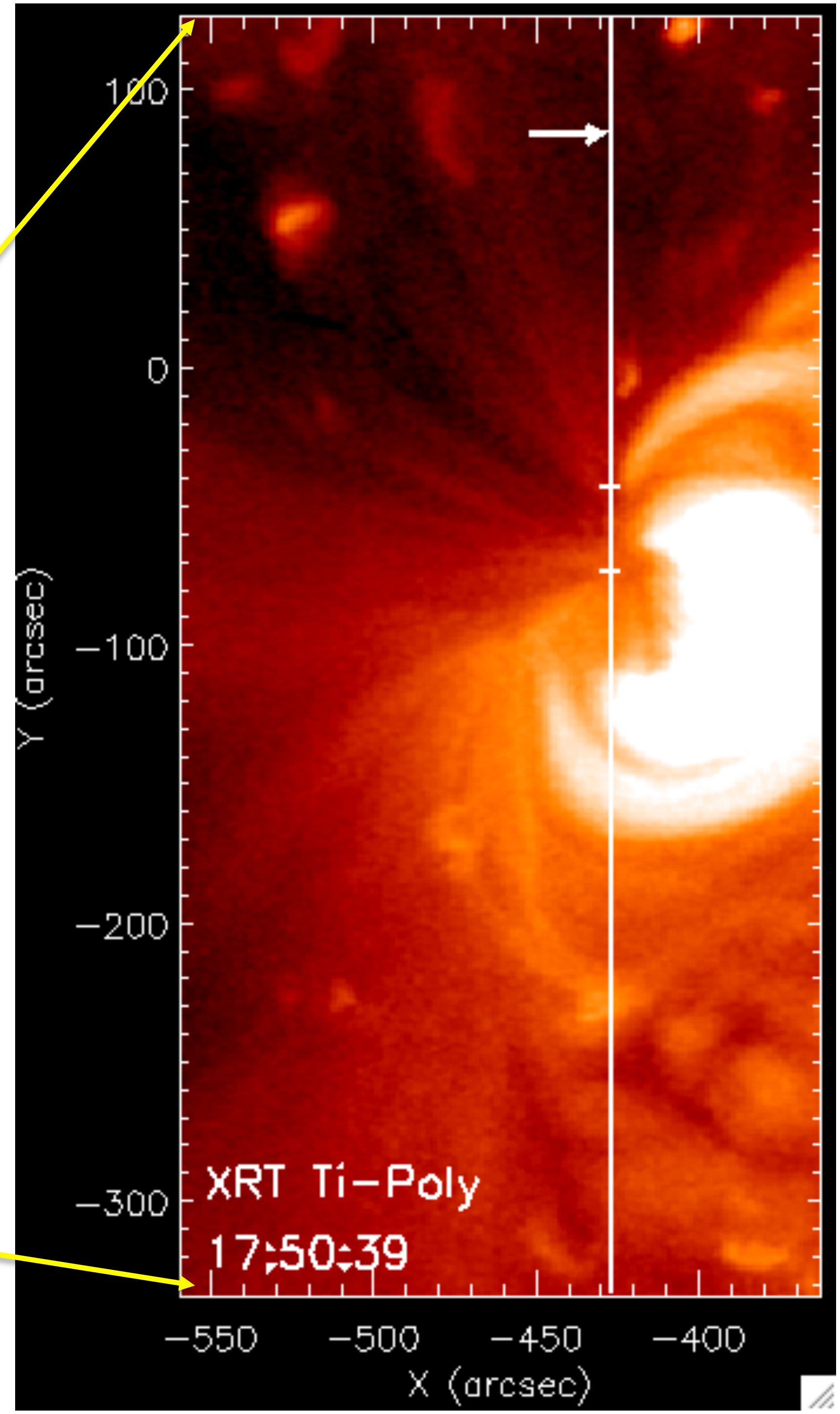




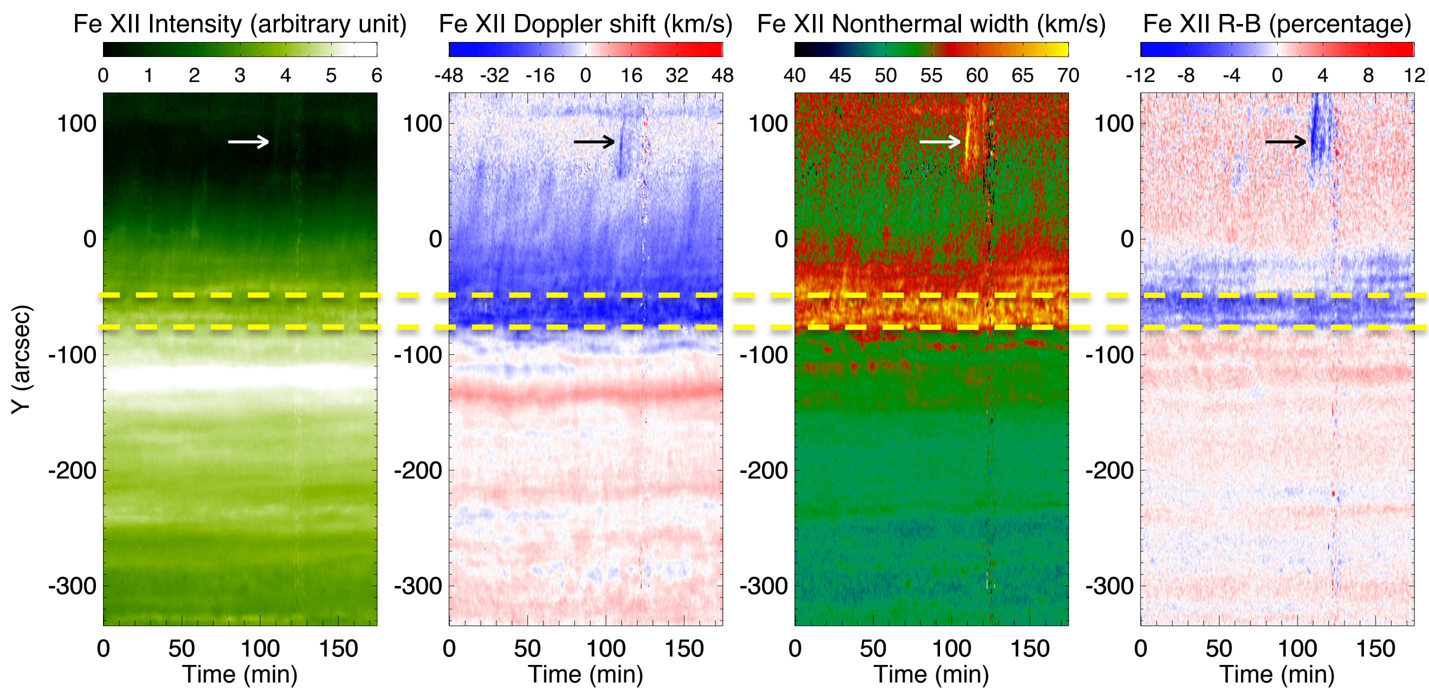
PDs observed by Hinode/XRT

- Relentless PDs at the weak-emission boundary (small coronal holes) of the AR



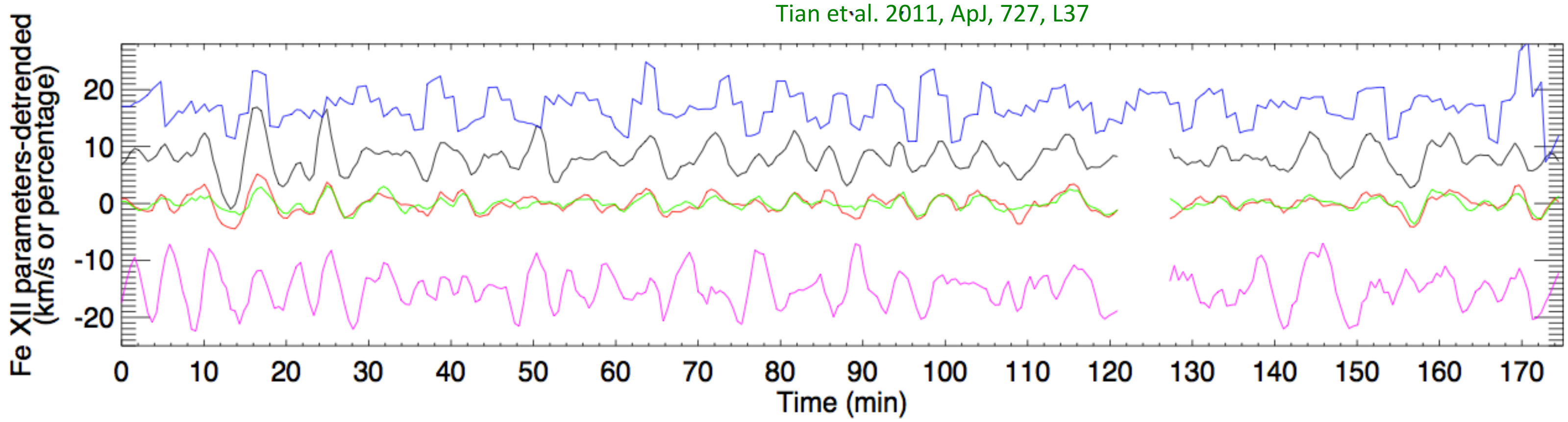


Coherent behavior of PDs and EIS line parameters



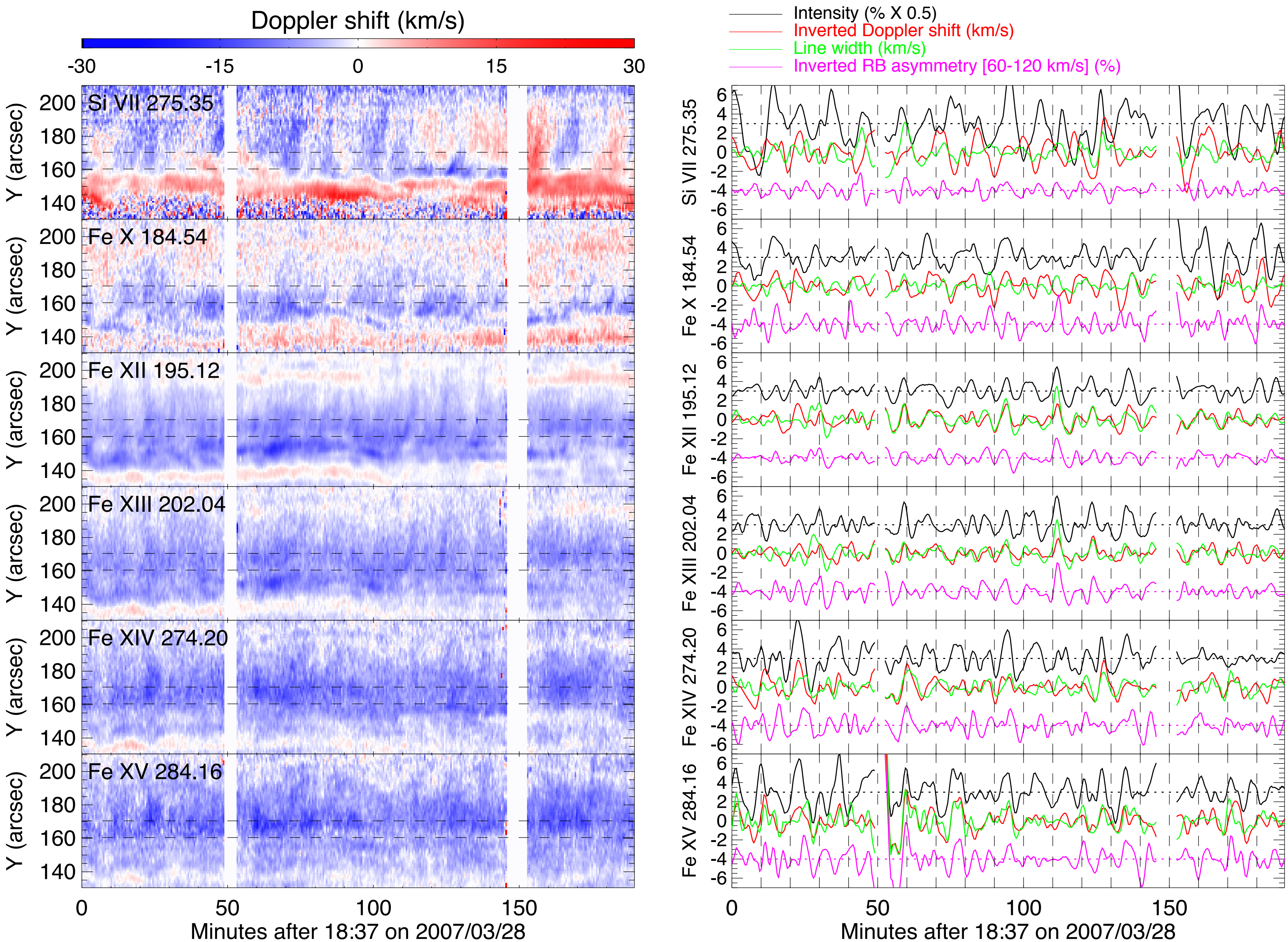
Tian et al. 2011, ApJ, 727, L37

black: intensity
red: Doppler shift (inverted)
green: line width
purple: R-B (inverted)
blue: XRT intensity



- Blueshfit & blueward asymmetry throughout the entire duration
- All line parameters show in-phase quasi-periodic (3-15 min) variation
- XRT intensity and EIS line parameters show similar oscillatory behavior, suggesting that PDs are responsible for the 2nd component

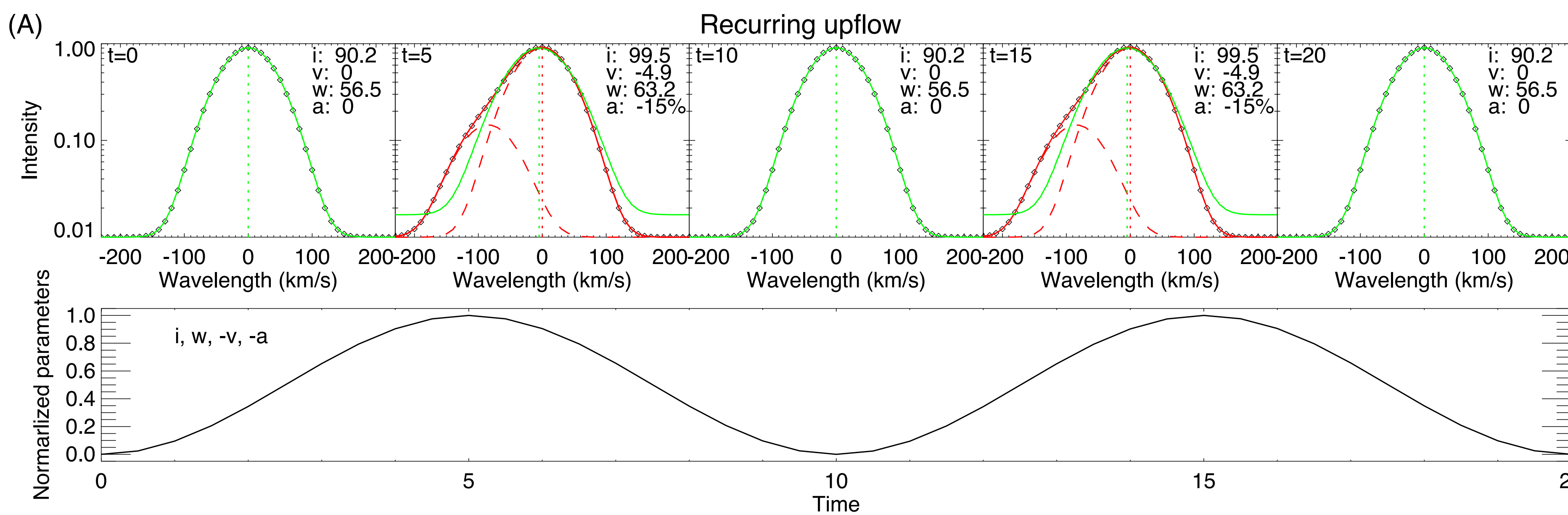
Another time series observation



Tian et al. 2012, ApJ, 759, 144

Interpretation

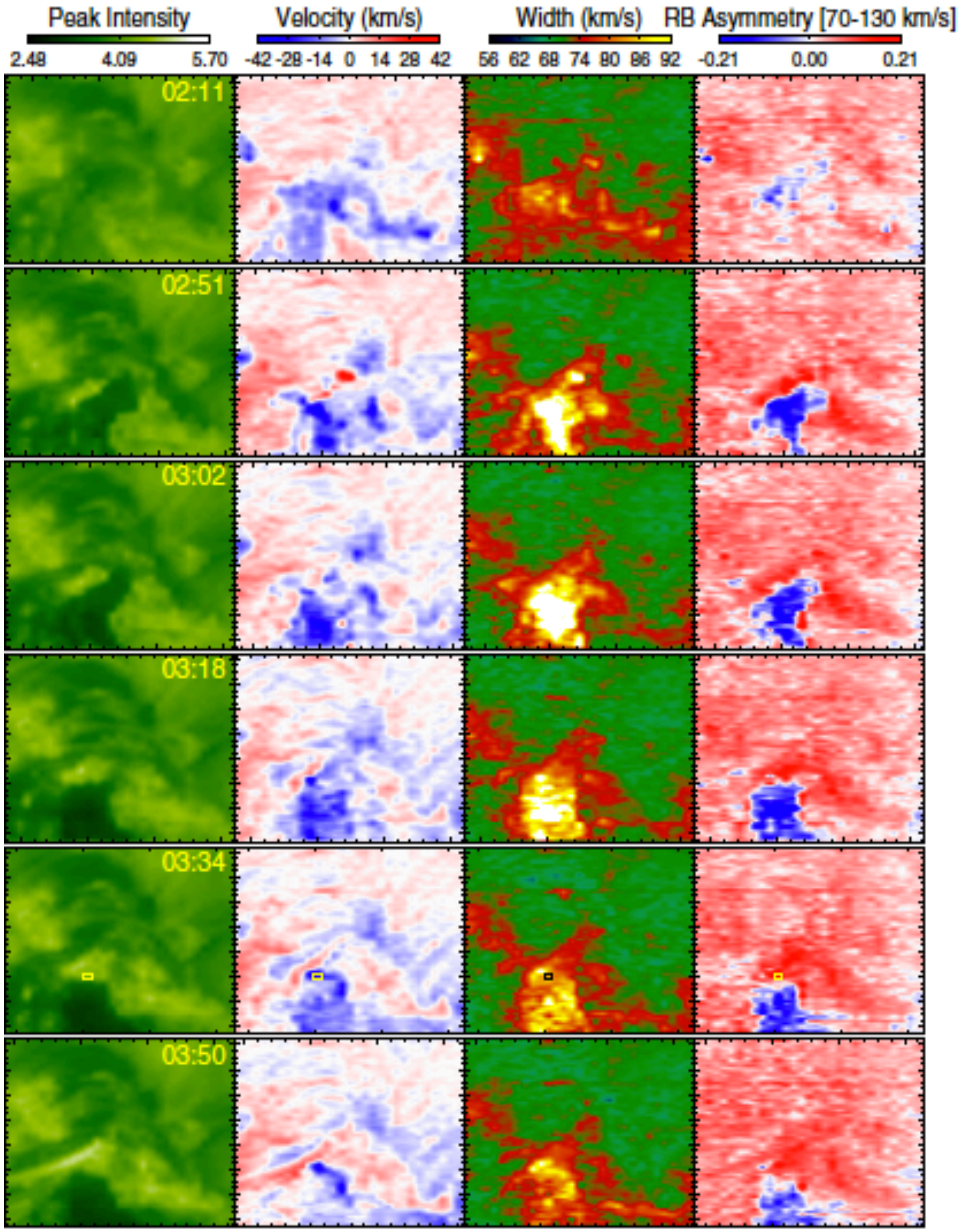
- ❑ Recurring high-speed upflows superimposed on the background corona: possible signature of episodic mass supply to the corona and slow solar wind
  - ➢ Blueshfit & blueward asymmetry almost all the time, no red shift and redward asymmetry
  - ➢ Coherent behavior of all line parameters, no frequency doubling in line width
- ❑ Nascent solar wind not continuous but intermittent?



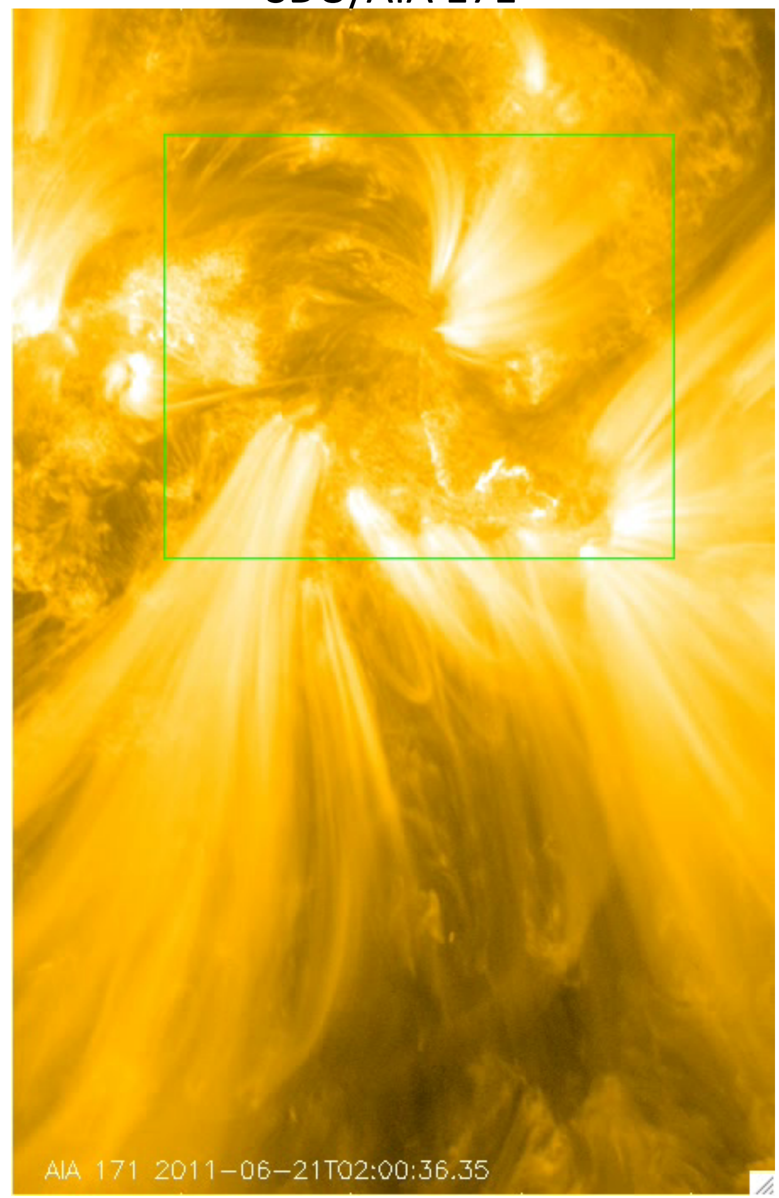
Tian et al. 2012, ApJ, 759, 144
De Pontieu & McIntosh, 2010, ApJ, 722, 1013

Dynamics in dimming regions (transient CHs)

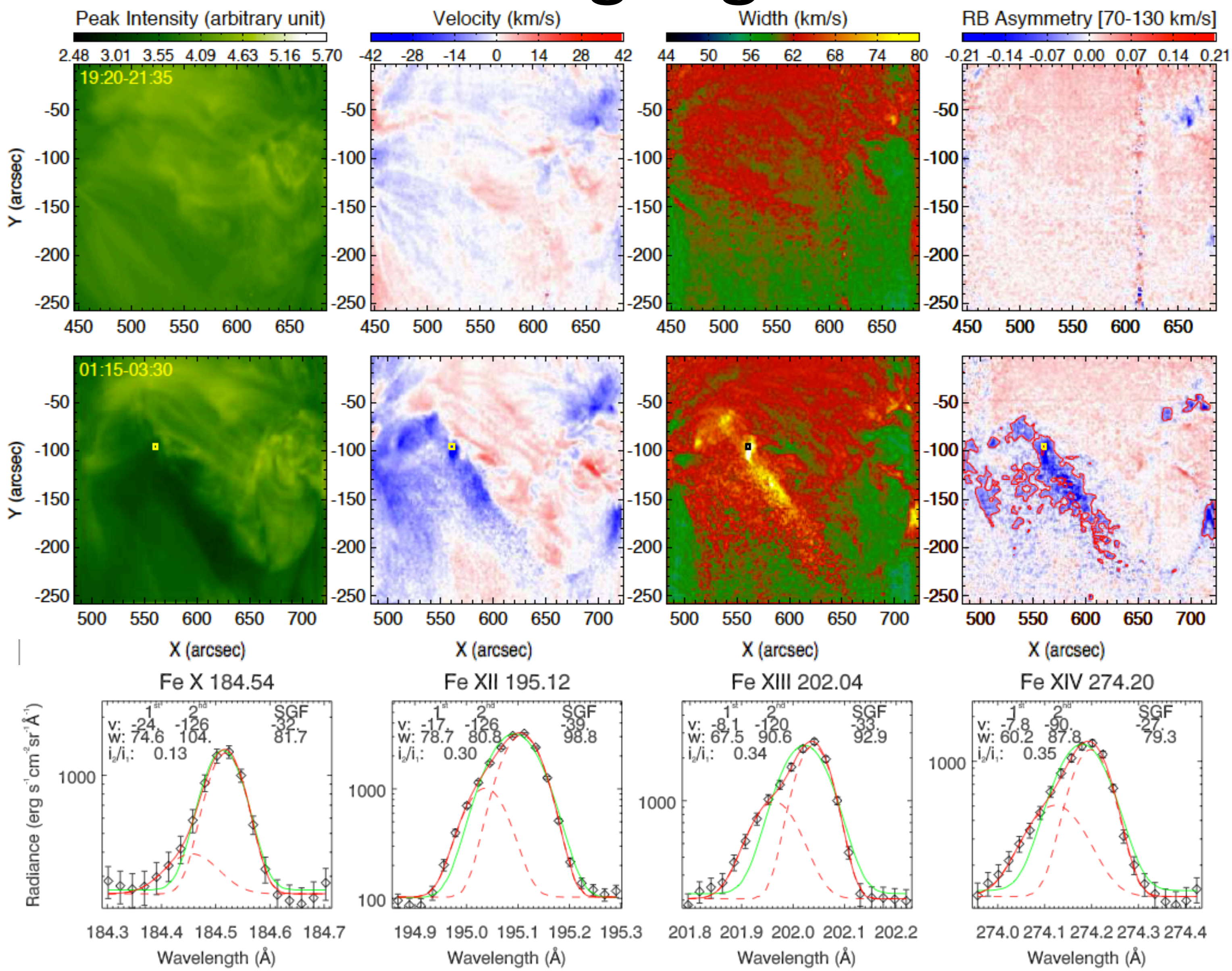
HINODE/EIS Fe XII 195



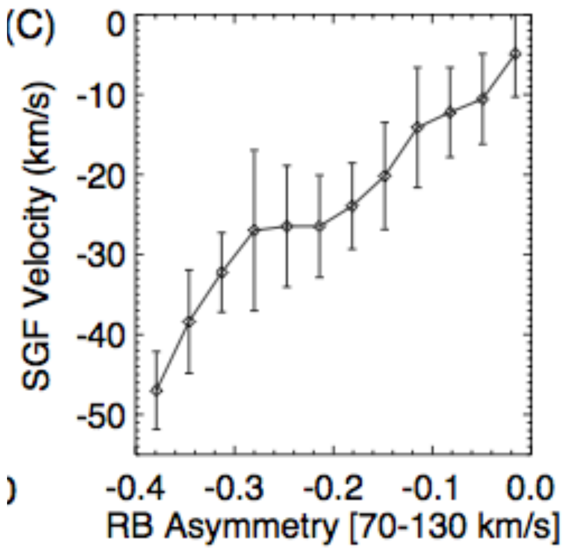
SDO/AIA 171

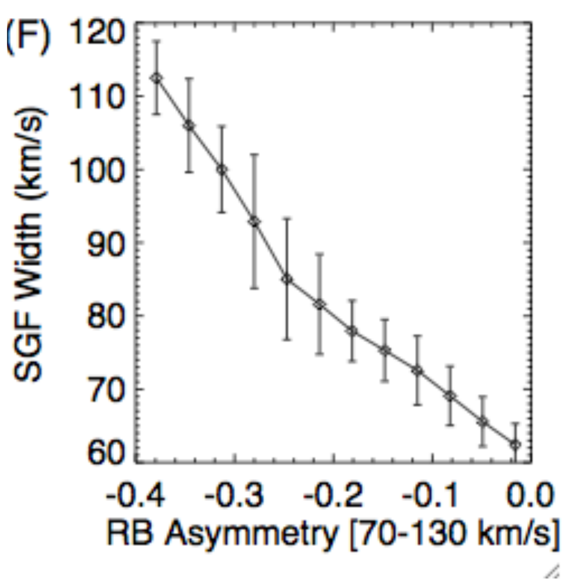


Blueward asymmetry of line profiles in dimming regions

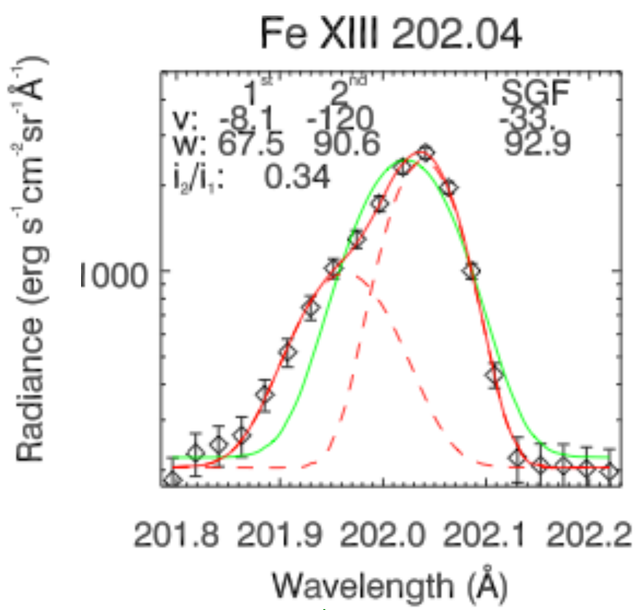


Two emission components in dimming regions





- Two emission components
  - ➢ A nearly stationary background
  - ➢ A weak high-speed (~100 km/s) component representing outflows
- Blue shift of 10-50 km/s and enhanced line width are caused at least partly by the superposition of the two components
- SGF can not reflect the real physics, assuming everything is moving at a uniform speed



Tian et al. 2012, ApJ, 748, 106

- A small portion of the plasma in the dimming region is flowing outward at a speed of the order of 100 km/s
- Mass flux density: 1.67×10^{-9} g cm^{-2} s^{-1} if using $\log(Ne/cm^{-3})=8$ and $v=100$ km s^{-1}, mass flux two orders higher than that of solar wind at 1 AU

Summary and open questions

- Through jointed imaging and spectroscopic observations, we have demonstrated that the PDs are responsible for the secondary component (blue wing enhancement) of line profiles. We think that they are likely to be dominated by quasi-periodic high-speed (~100 km/s, fine-scale jets) plasma outflows which may be an efficient means to supply mass into the corona and solar wind.
  - Can slow waves produce blue shift and blueward asymmetry? Verwichte et al. 2010
  - Why no blueward asymmetry at higher part of loops? Wang et al. 2012
  - Production mechanism? Martínez-Sykora et al. 2011; Su et al. 2012; McLaughlin et al. 2012, Démoulin et al. 2012
  - Can we trace them to the interplanetary space? Slemzin et al. 2012; Van Driel-Gesztelyi et al. 2012
  - Both waves and flows? Nishizuka & Hara et al. 2011; Ofman et al. 2012; Kiddie et al. 2012
- Similar blue wing enhancements have also been found in CME-induced dimming regions. If they are also episodic rapid outflows, they should play an important role in the refilling of the corona and possibly mass supply to the solar wind from transient coronal holes. Detailed time series observations may help us understand the nature of them.
  - Do they have the same nature?
  - How do they evolve as dimming occurs and recovers?
  - Are they signatures of the nascent solar wind from transient coronal holes?

Observational studies of mass supply to the solar wind and corona

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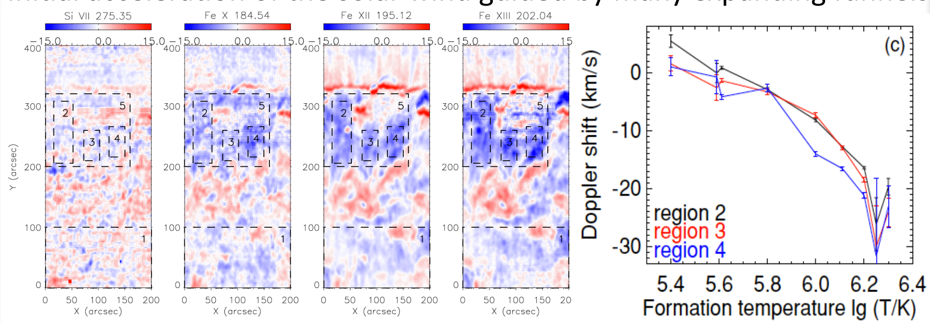
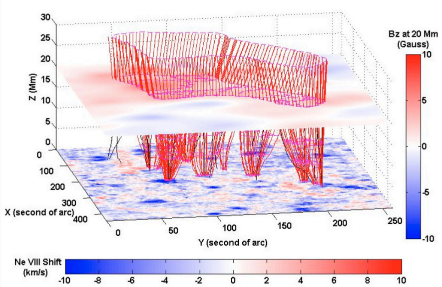
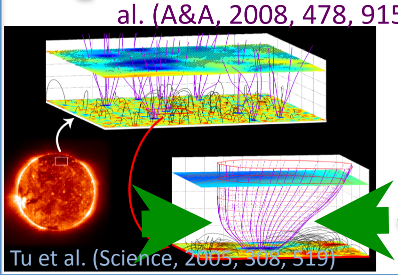
Initial acceleration of the solar wind guided by many expanding funnels



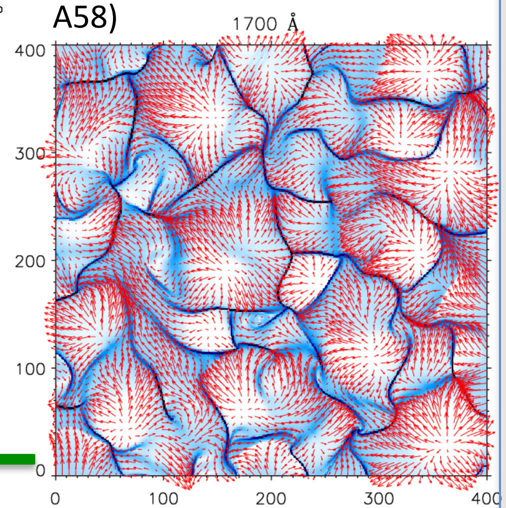
- Patches of significant blueshift on Dopplergrams of coronal lines.
- The blue shift increases with temperature, possibly indicating the initial acceleration of the fast solar wind. Tian et al. (ApJ, 2010, 709, L88)



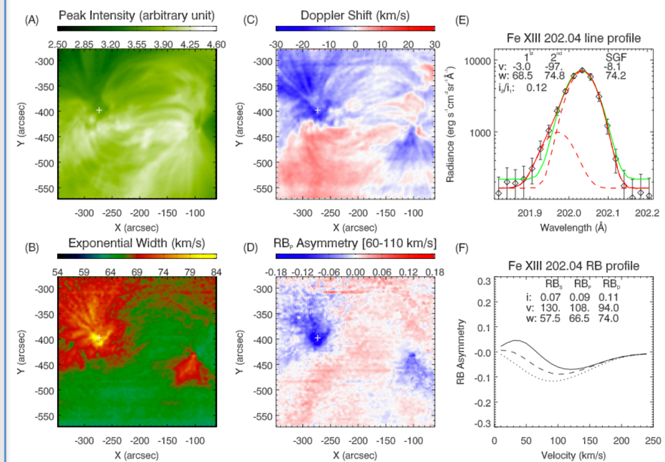
- Supports the scenario of solar wind outflow being guided by many expanding and gradually merging magnetic funnels. Tian et al. (A&A, 2008, 478, 915).



Feeding the solar wind through supergranule-scale horizontal flows in the chromosphere/TR. Tian et al. (A&A, 2010, 519, A58)



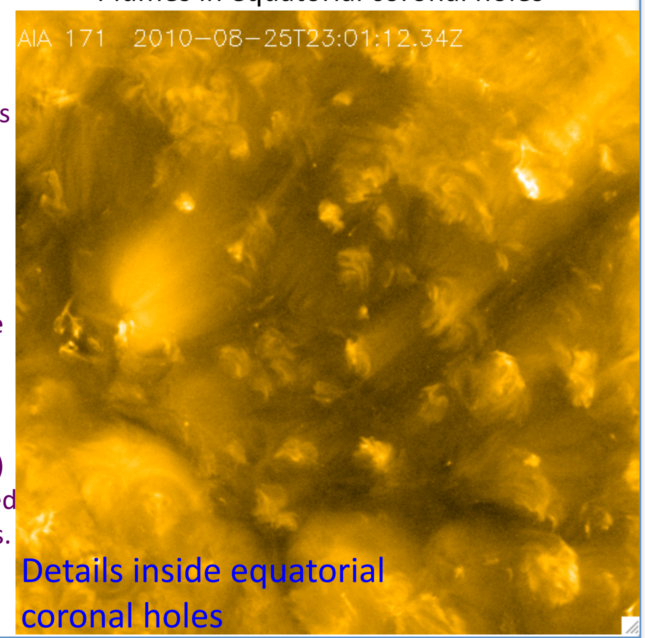
Episodic mass supply to the solar wind and corona



- High-speed outflows exhibit as an enhancement in the blue wing of the line profile. Tian et al. (ApJ, 2011, 738, 18)

Plumes in equatorial coronal holes

- Plume-like structures not only in polar CHs, but also in ECHs & QS
- Ubiquitous quasi-periodic upward propagating disturbances (possible signatures of episodic rapid upflows/jets) in both QS & CH
- Transverse (Alfvénic) waves clearly identified in some bright plumes. Tian et al. (ApJ, 2011, 736, 130)



Poster 1-26