Spectropolarimetric Insight into Plasma Sheet Dynamics of a Solar Flare

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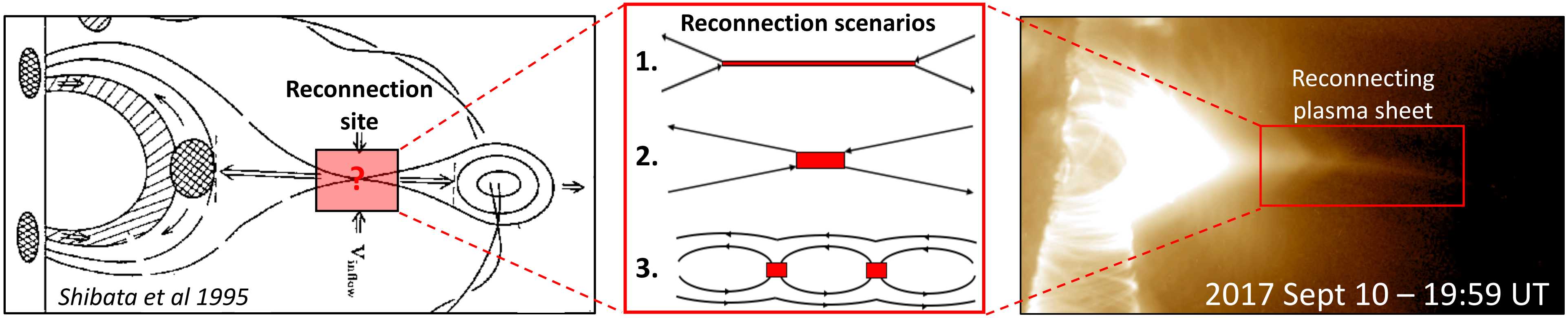
Magnetic reconnection is a fundamental process in plasma physics, responsible for energy release in the standard solar flare model. Many models of reconnection exist, but their complexity makes it difficult to account for all observed features of solar flares. Key models include -

1. **Sweet-Parker reconnection** - magnetic reconnection along an entire current sheet of oppositely orientated field lines. However, the energy release rate is far slower than that observed in flares.
2. **Petschek reconnection** - reconnection along a small fraction of the sheet, with a configuration sustained by slow shocks. It is unclear whether such a configuration can be sustained during a flare.
3. **Tearing mode / plasmoid instability** - If the sheet's length greatly exceeds its width, the current sheet collapses/reconnects in certain locations to produce plasmoids or 'magnetic islands'. These plasmoids continue to break down to progressively smaller scales in a turbulent cascade.

Fig 1.



Shibata et al 1995

In this study, we use CoMP spectropolarimetry to probe the nature of reconnection within the plasma sheet (heated plasma around the reconnecting current sheet) of the off-limb 10 Sept 2017 flare.

Linear Spectropolarimetry

1. Plasma in the corona is atomically polarised due to anisotropic radiation from the solar disk, with a fraction dependent on local thermal and magnetic conditions.
2. Consequent emitted radiation is imprinted by this environment, polarised by the same dependency.
3. Depolarisation can occur via collisions, if density is high enough.

CoMP is a 20cm coronagraph, measuring intensity and linear polarisation (Stokes *I*,*Q*,*U*) of infrared Fe XIII 1074.7 nm and 1079.8 nm lines. Linear polarisation of these lines is given by -

$$\boxed{P = \sqrt{Q^2 + U^2}/I \propto 3\cos^2\theta_B - 1}$$

where θ_B is the angle between the magnetic field and incident solar radiation, (θ_B= 0 for a radial field).

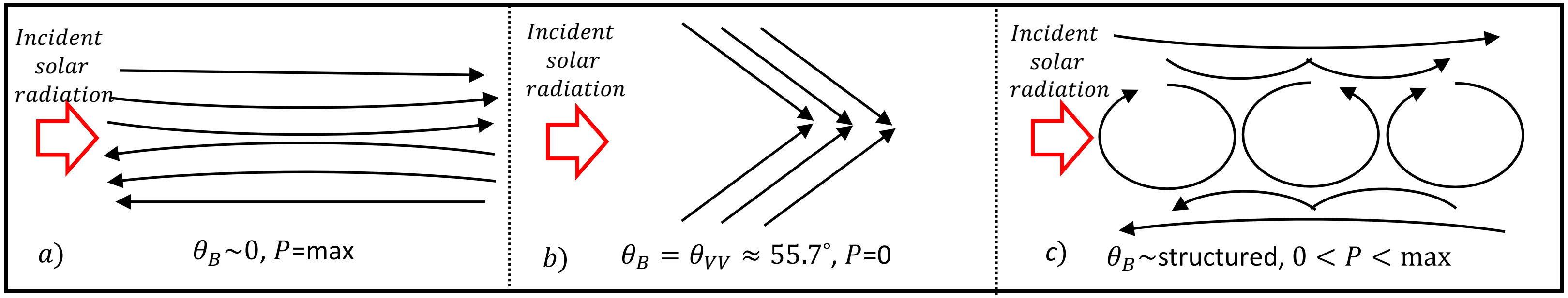


***Fig 2.** Cartoons depicting the P values of simple magnetic configurations.*

The above cartoon shows 3 scenarios of θ_B.

1. For a radial field (θ_B= 0), *P* is maximum (with a max value dependent on density and line properties).
2. For a field at the 'van Vleck' angle (~55.7˚), *P = 0*.
3. If, for a given pixel, there is a variation in θ_B in the LOS or POS, then *P* will be somewhere between 0 and the maximum value.

CoMP *P* can therefore probe the level of θ_B variation within the plasma sheet of the 10 Sept 2017 flare.

10 Sept 2017 - CoMP Data

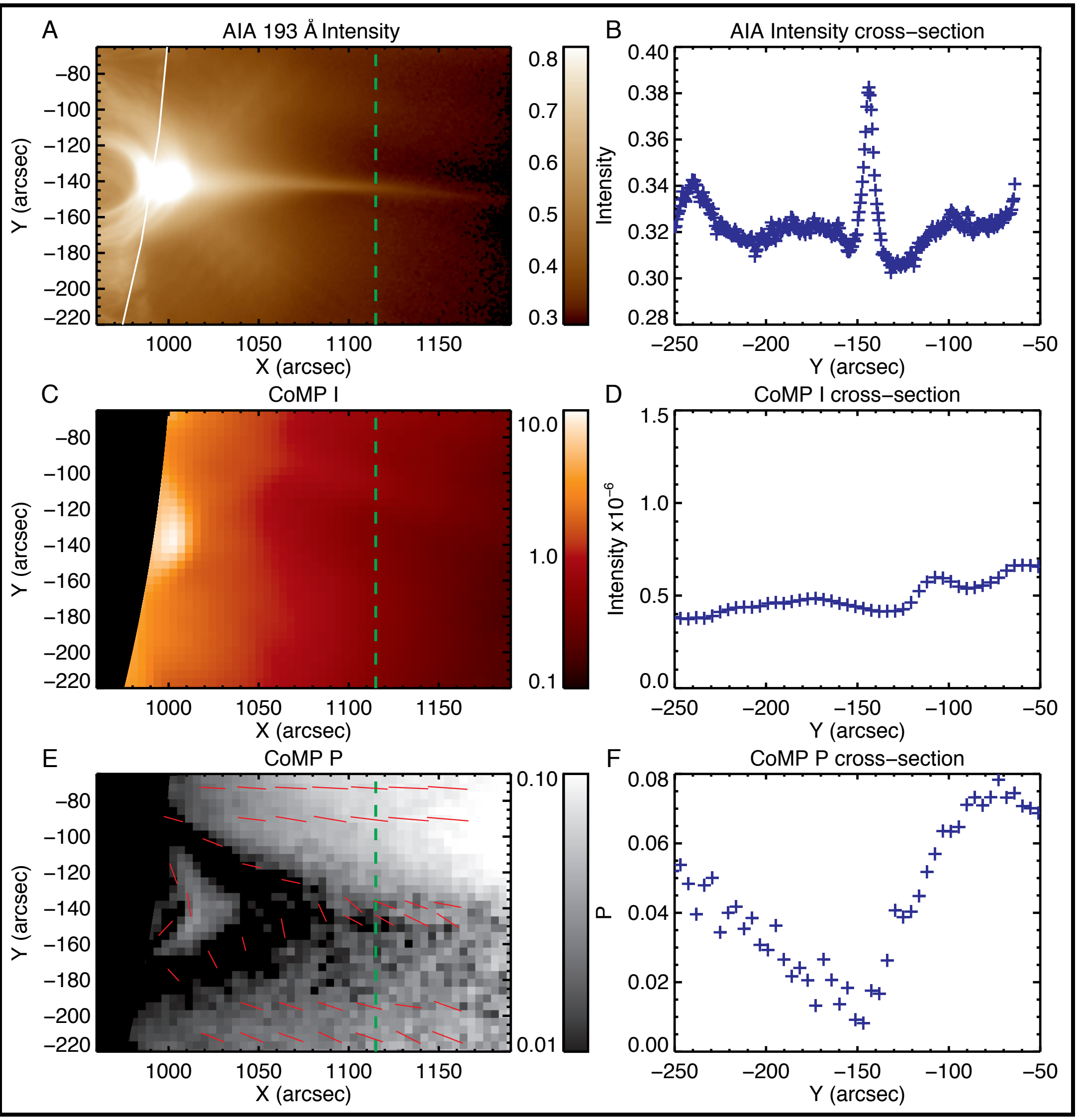


***Fig 3.** A) AIA 193 A intensity. B) AIA 193˚A cross-section. C) CoMP 1074.7 nm I D) CoMP 1074.7 nm cross-section of I. E) CoMP 1074.7 nm P. Red lines are polarisation vectors. F) CoMP 1074.7 nm cross-section of P.*

CoMP observations are available at 20:00 - 20:10 UT on 10 Sept 2017, 4 hours after flare onset. Despite no signature in CoMP intensity (Fig. 3C), we see a clear low linear polarisation structure (Fig. 3E). This includes

1. A small dark structure peaking over the occulting disk, aligned with the flare loops.
2. Larger dark 'triangle' structure, aligned with the fainter EUV separatrix.
3. A dark horizontal feature, emanating from the top of the dark triangle. Taking a cross-section through this, we see a broad and gradual decline in linear polarisation to a minimum of P = 0.01, at the same location as the plasma sheet in EUV observations.

Features 1 and 2 can be explained by depolarisation due to high density, and a field tracing the ‘van Vleck’ angle. Low P in the plasma sheet cannot be a result of this, so must be due to unresolvable magnetic substructure.

Why is Polarisation so Low? - Simulations

To determine whether low polarisation in the plasma sheet can be a result of unresolvable magnetic structure, we use Coronal Line Emission (Judge & Cassini, 2001) code to synthesise CoMP P for basic magnetic configurations. From these simple empirical simulations, we find -

1. A Sweet-Parker current sheet configuration is inconsistent with observed polarisation.
2. Randomly orientated field can reduce polarisation to 0.01-0.03, within the realm of observations.
3. Small-scale (unresolvable) plasmoids can destroy polarisation to the value of 0.01 observed.

Conclusions

- Unresolved magnetic structure is capable of destroying polarisation to levels observed by CoMP in this event, (French et al 2019).
- Observations are consistent with current theory and models of current-sheet instabilities. This is also supported by non-thermal velocity measurements at this time, (French et al 2020).
- The future is bright with DKIST. Cyro-NIRSP will observe the same Fe XIII lines with much higher resolution.

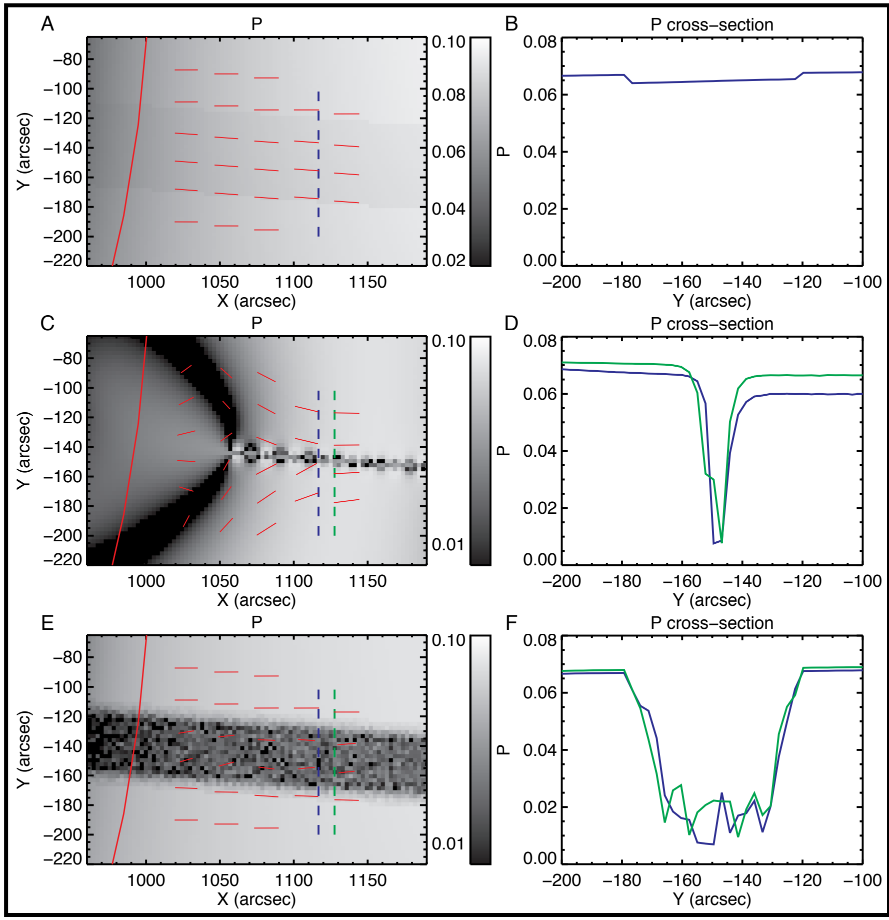


Fig 4. *Maps and cross-sections of P for plasma-sheet models. Models show: AB) Laminar plasma-sheet.*
CD) LOS line current potential field model, combined with a sub-surface dipole. This represents unresolvable plasmoid reconnection within the current-sheet.
EF) Nonphysical plasma-sheet with a randomly orientated field, analogous to plasma turbulence.