The STEREO Electron Spikes and the Interplanetary Magnetic Field

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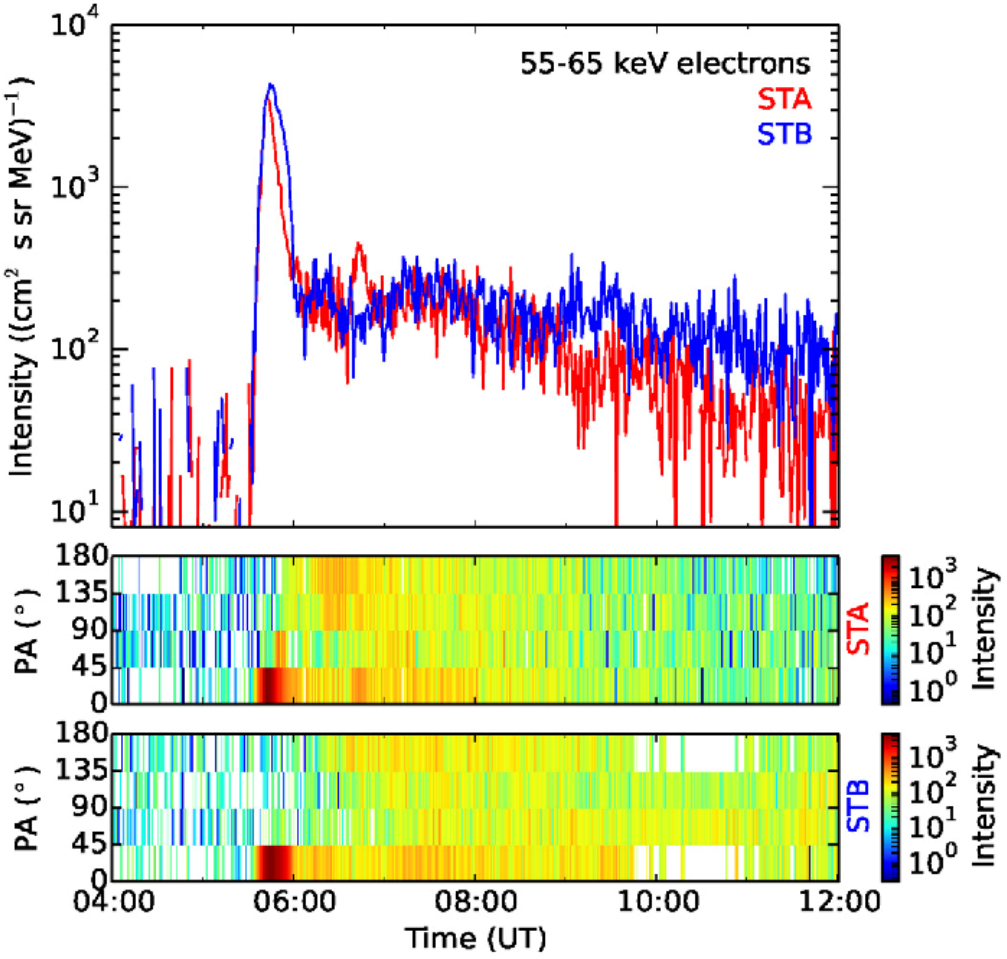
Observations reported by Klassen etal, (2015)



May 2, 2014

Outline

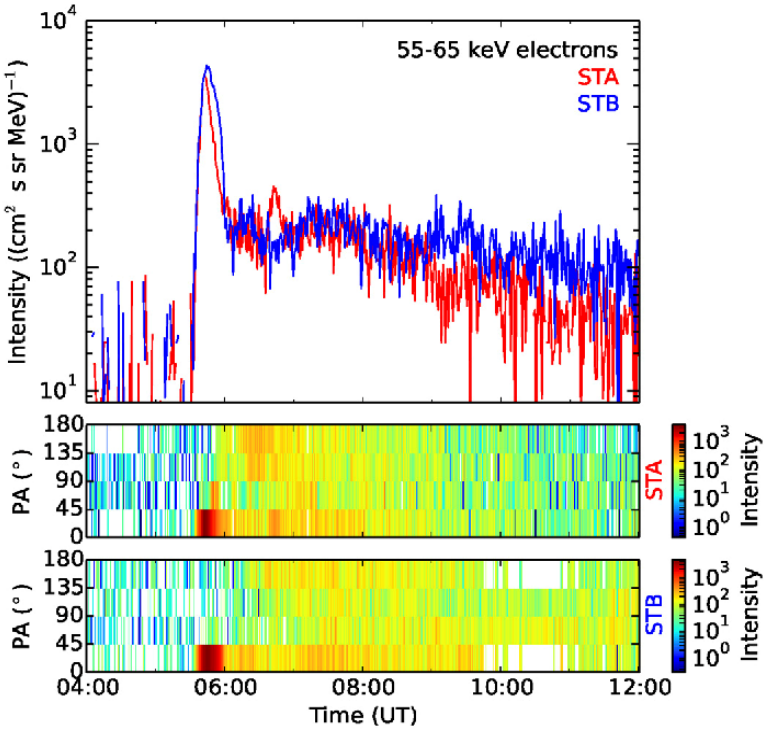
- Observational background
  - Electron Spikes reported by Klassen etal.
- General considerations
  - Interplanetary Magnetic Field
  - Spacecraft longitudinal separation
  - Field line mixing or random walk
  - Flux Tube expansion
- Interpretation of the observations.

- Klassen etal, (2015) discussed observations of two spike events of 55-65 keV electrons which occurred very nearly simultaneously (within 2.2 minutes)at STEREO A and STEREO B, which at the time were separated in longitude by **38 degrees**.

- These authors associated the spikes with a flare at the Sun near the footpoint of the nominal Archimedean spiral magnetic field line passing through STEREO A. They discussed various interpretations.

- The spike at STEREO A was **delayed by 2.2 minutes** from that at STEREOB. The transit time for these particle along the spiral interplanetary magnetic field is much larger ≈15-20 minutes.

- We discuss here these observations in terms of a model in which the electrons, accelerated at a small flare, propagate, without significant scattering, along magnetic field lines which separate as a function of radial distance from the Sun. The separation is a consequence of flux-tube expansion and field-line random walk.



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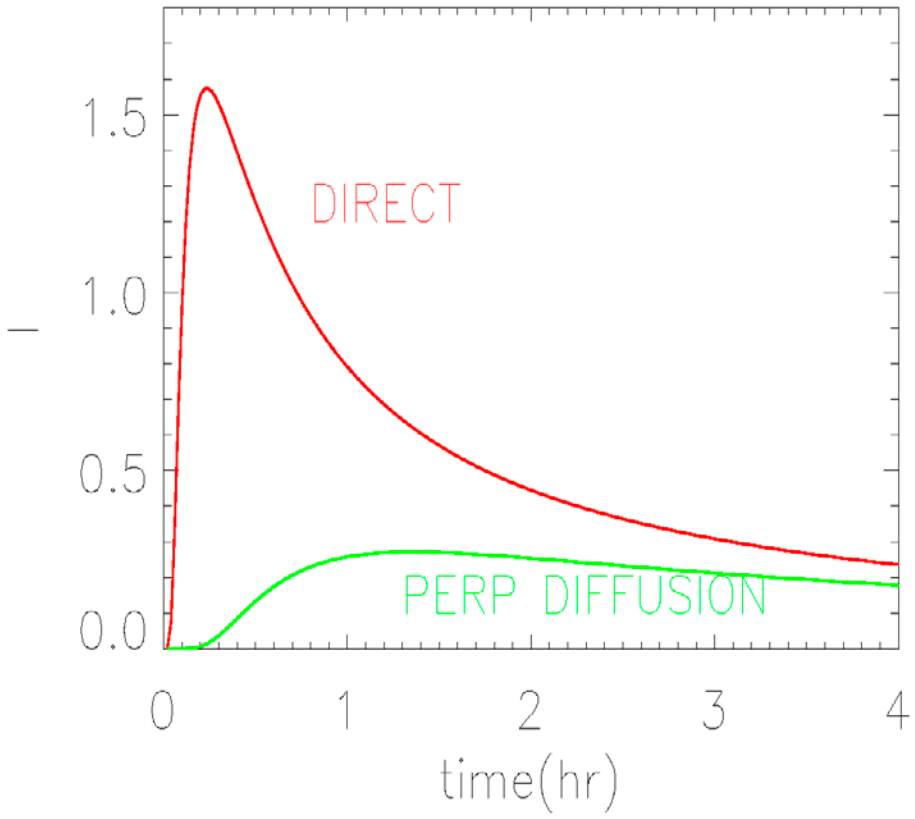
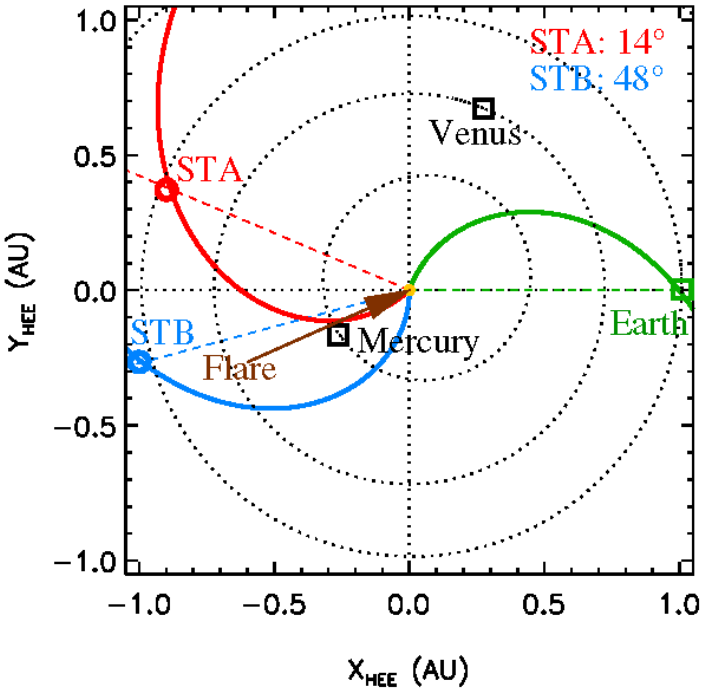


It is not plausible that the observations were the result of perpendicular diffusion.



The spacecraft angular separation is significant.

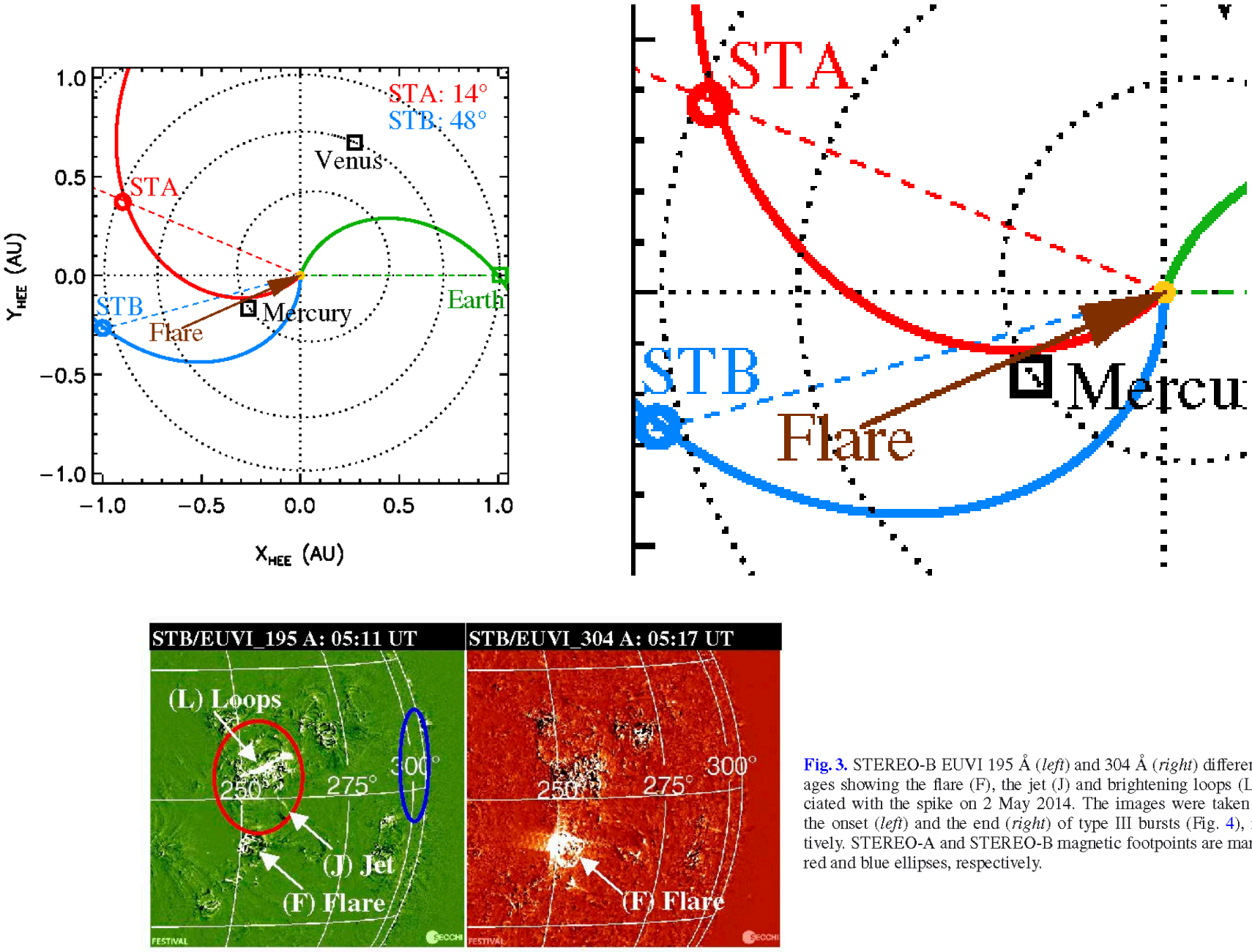
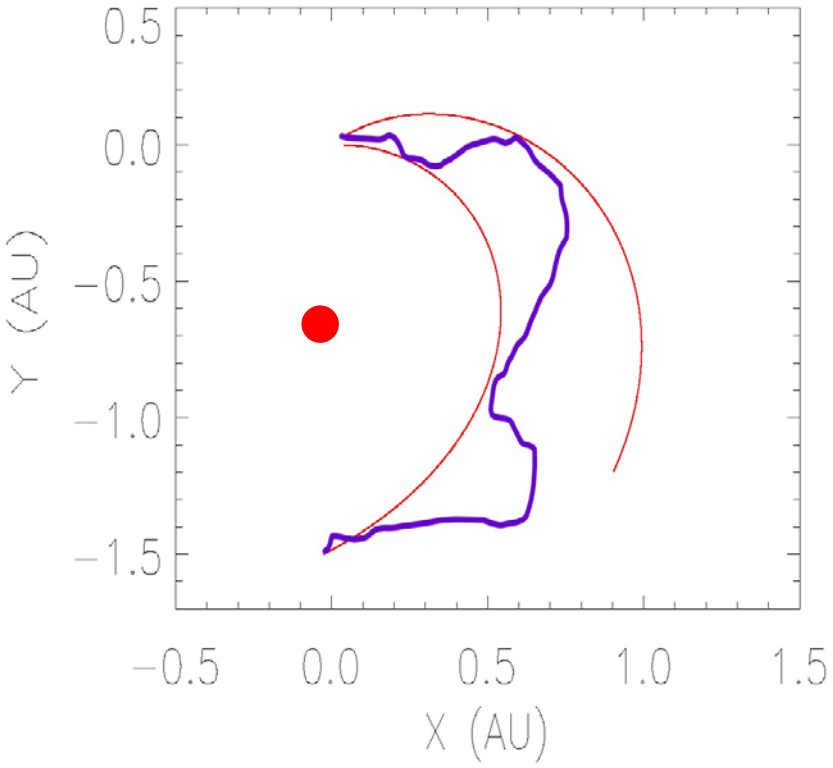
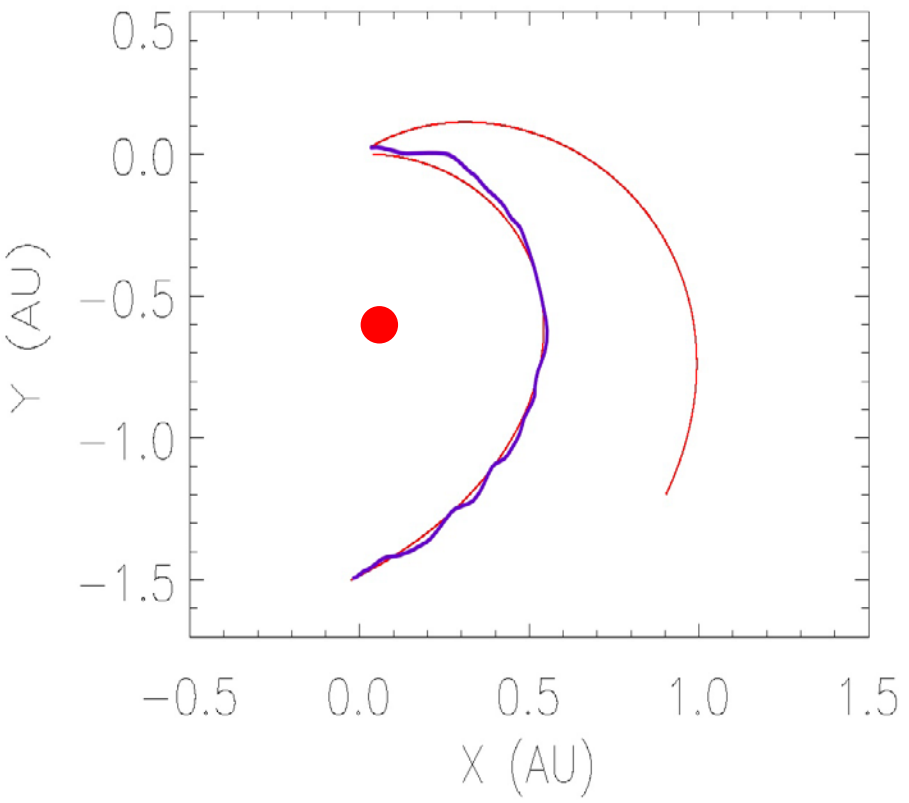


Fig. 3. STEREO-B EUVI 195 Å (*left*) and 304 Å (*right*) difference images showing the flare (F), the jet (J) and brightening loops (L) associated with the spike on 2 May 2014. The images were taken during the onset (*left*) and the end (*right*) of type III bursts (Fig. 4), respectively. STEREO-A and STEREO-B magnetic footpoints are marked by red and blue ellipses, respectively.

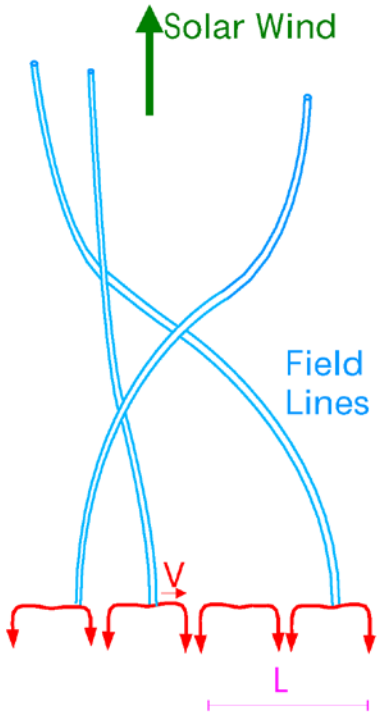


One possible cause of the field-line separation is the supergranulation in the solar photosphere, which causes the field lines to random walk or mix.

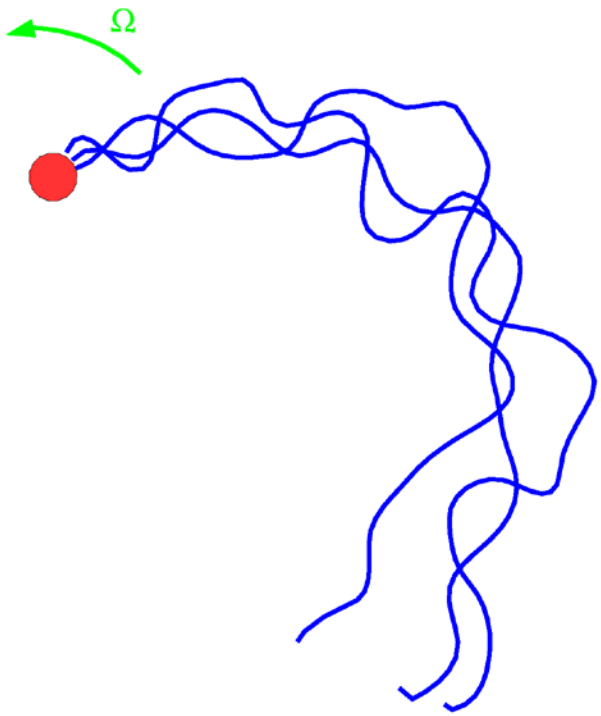


Or it is possible that the separation is caused by the divergence of magnetic field in flow of the solar wind to 1 AU. This is called flux tube expansion, or FTE.

Supergranulation and Field–Line Random Walk



Field–Line Random Walk, or Mixing



Consider whether the field line random walk alone is sufficient.

From Jokipii and Parker, Ap. J., 1969. They interpreted the time profile as a result of rotation of a ~ steady longitudinal profile past Pioneer 6.

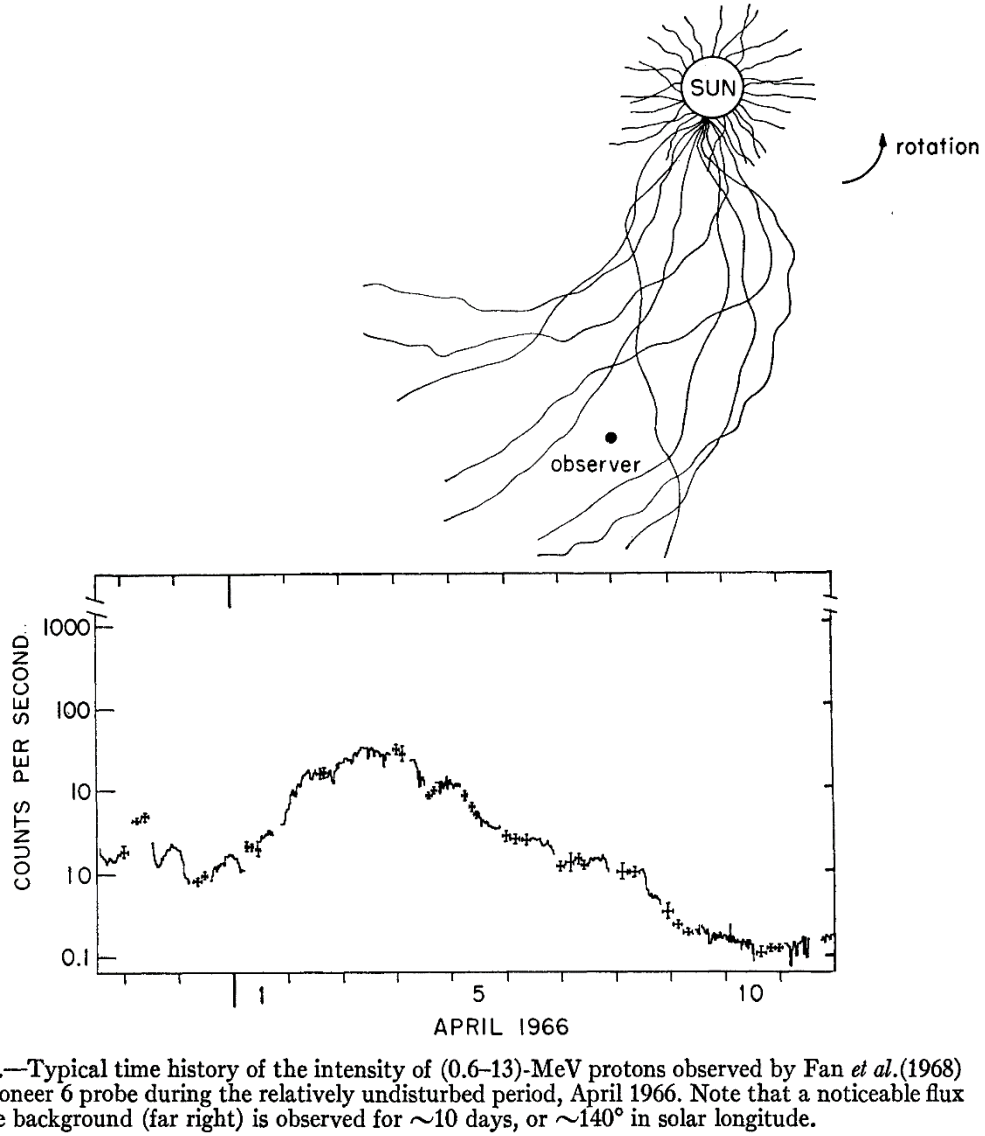


FIG. 5.—Typical time history of the intensity of (0.6–13)-MeV protons observed by Fan *et al.*(1968) on the Pioneer 6 probe during the relatively undisturbed period, April 1966. Note that a noticeable flux above the background (far right) is observed for ~10 days, or ~140° in solar longitude.

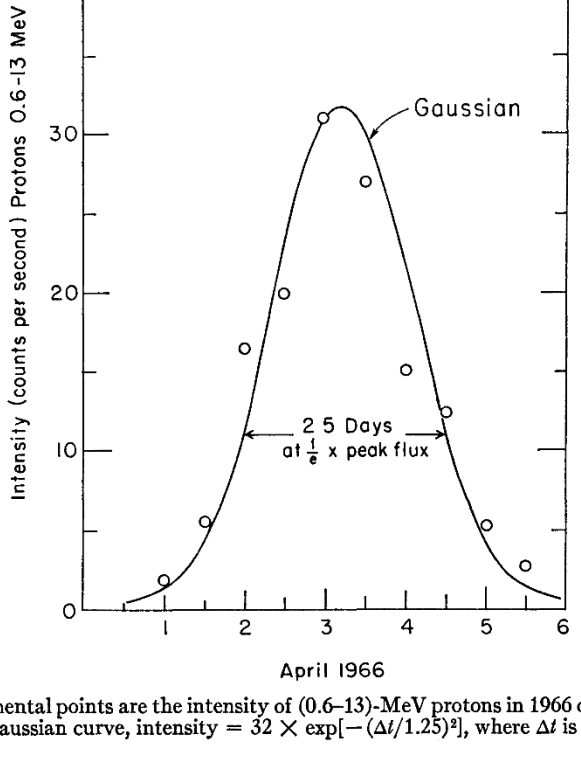
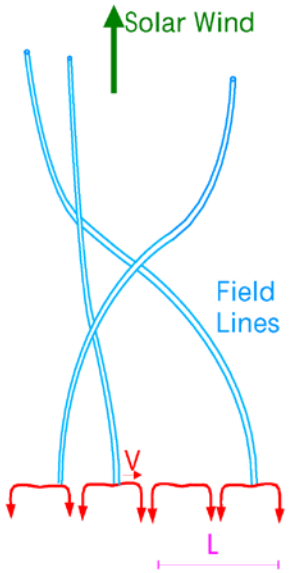


FIG. 6.—Experimental points are the intensity of (0.6–13)-MeV protons in 1966 observed by Fan *e* (1966). *Solid line*, Gaussian curve, intensity = $32 \times \exp[-(\Delta t/1.25)^2]$, where Δt is time from maxim intensity in days.

Supergranulation and Field– Line Random Walk



Consider whether random walk at the Sun can account for the effects at STEREO at 1 AU.

Observed supergraulation parameters:

$L \approx 30,000 km$

$V \approx 0.5 km / sec$

$< (\Delta x)^2 > / \Delta t >= w \times L / 2 \approx 1.5 \times 10^{14} cm^2 / sec$

$or < (\Delta \theta)^2 >^{.5} \approx [(< (\Delta x)^2 > / \Delta t >)^{.5}) / r] \times \tau$

$where \ \tau = 1AU / V_w$ is the time for the solar wind to flow to the spacecraft

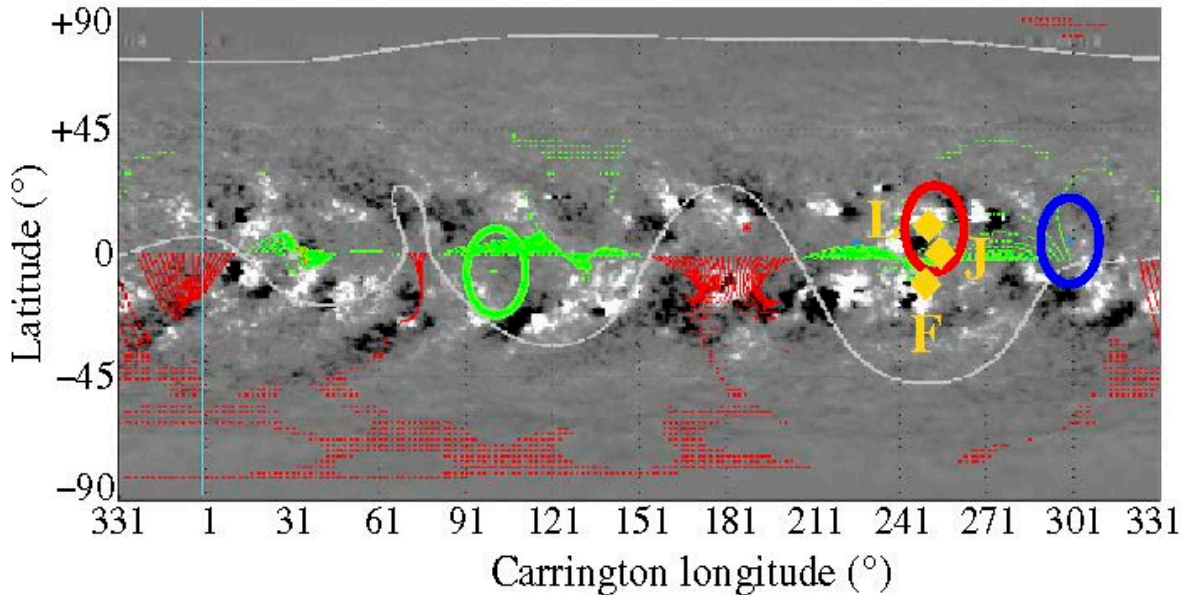
Putting in the parameters yields

$< (\Delta \theta)^2 >^{.5} \approx 9^o \ or \ full \ width = 18^o$ << 38^o (consistent with Jokipii and Parker (1969)

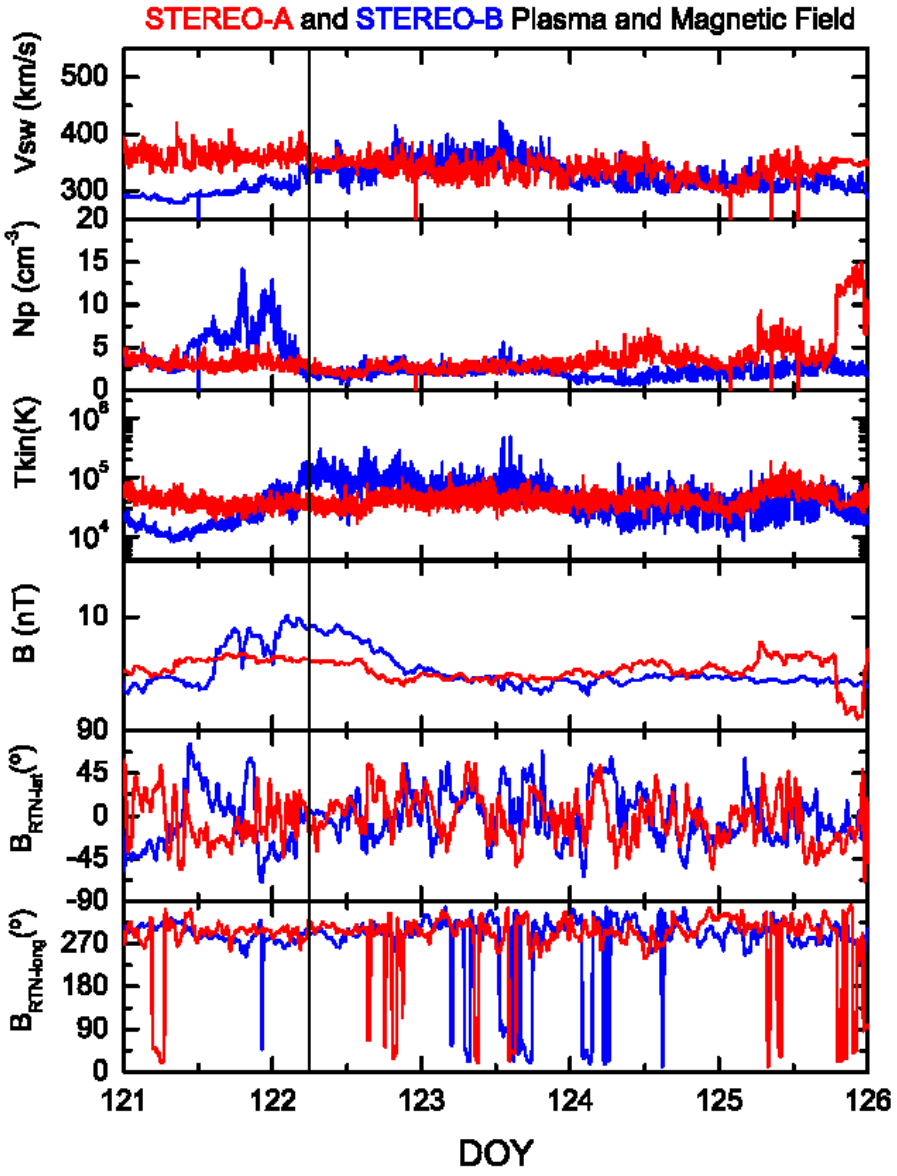
which is too small to account for the events.

→ **The field line random walk alone cannot account for the effects.**

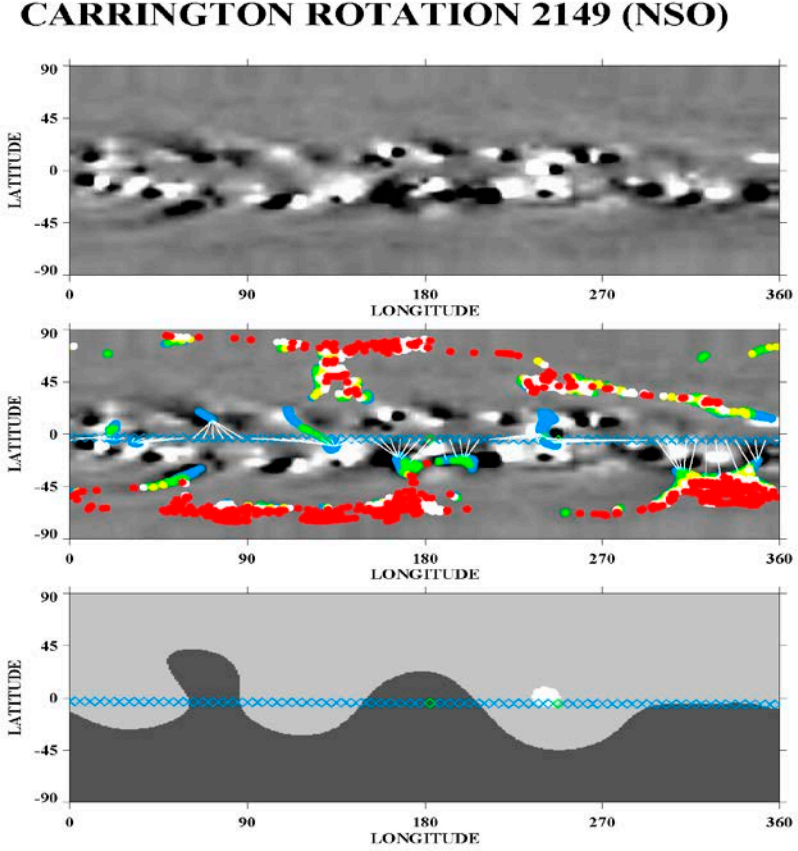
Consider instead evidence from the solar surface magnetic field.

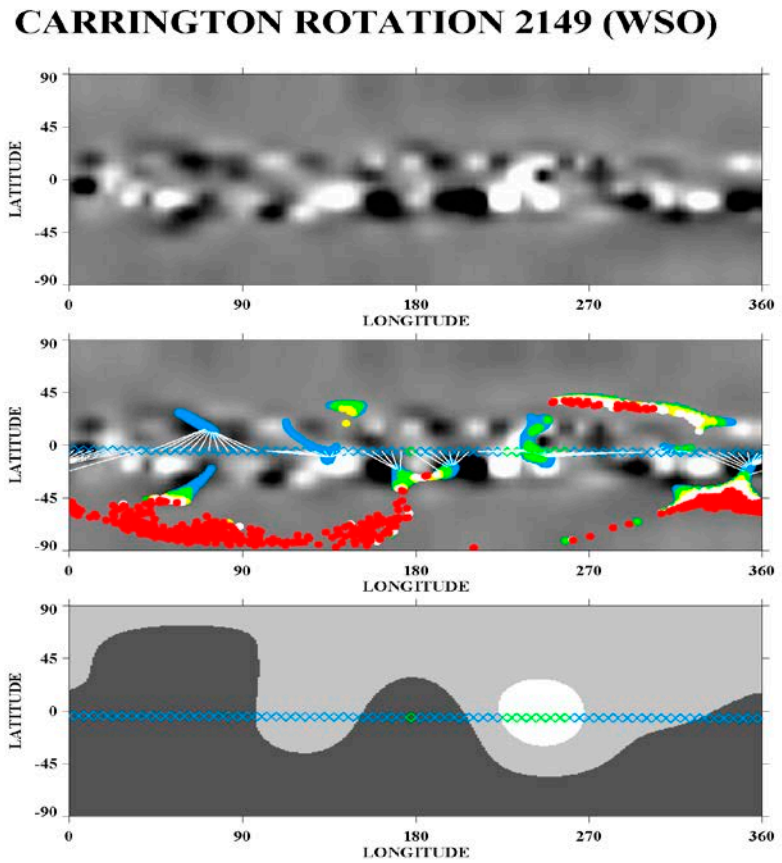


Gong measurements showing open magnetic fields connecting to the ecliptic plane. Green are outward and red are inward. Ellipses are footpoints of STEREOA (red) and STEREOB (blus). Yellow diamonds indicate source candidates. One therefore expects an outward field at the STEREO spacecraft.



Vertical line marks the spike time. Clearly, the field is outward.





In the Carrington maps, the two spacecraft would be located about 180 deg to the right of the May 2 longitude, which centers them around 250 deg longitude.

At about 250 deg longitude, there is a region of positive polarity (white) with a blue open field patch located in it. The field lines from that patch expand in longitude, stretching out along the ecliptic track by almost 90 deg. The ST-A and ST-B spacecraft locations are both intercepted by those field lines from the open field region at about 250 deg longitude. This strongly support for the idea that the electrons originated in the vicinity of that coronal hole and were guided out to the two spacecraft by the diverging field lines.

So flux tube expansion clearly occurs. It alone could account for the observations.

But it is established observationally that the random walk also occurs. So it is likely that both effects were probably at work.

The bottom panel shows the source-surface field at 2.5 R with the ecliptic superimposed. Region of strongest positive magnetic field lies at about 250 deg longitude. The results are essentially the same regardless of whether we use the WSO figure or the NSO figure.

- The near simultaneity of the spikes at the two spacecraft is a natural consequence of this picture. We interpret the divergence of the magnetic field lines as a consequence of *both* field-line random walk and flux-tube expansion.

- The field-line random walk in the absence of flux-tube expansion produces an rms spread of field lines significantly *less than that* which is required to produce the observed divergence.

- We find that observations of the solar wind and its source region at the time of the event can account for the observations in terms of propagation along separating and random-walking interplanetary magnetic field-lines.

Summary and Conclusions

- The near-simultaneous Stereo electron events provide a valuable probe of solar-wind structure.
- The observations show that the flare, which is quite limited in area, is connected to magnetic-field lines which, at 1 AU are separated by 38^{o}.
- Simple longitudinal diffusion cannot account for the sharpness of the spikes.
- The random walk of magnetic-field lines can be shown to be inadequate to account for the 38^{o} spread required.
- Longitudinal expansion of the solar wind, which is consistent with the observations, is apparently the cause.