

Physics of Dust Pickup in the Solar Wind: Contributions by STEREO

C.T. Russell, L.K. Jian, J.G. Luhmann, D.R. Weimer

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Conventional Wisdom about Dust Pickup in Solar Wind

- With few exceptions, researchers treat only the effect of the solar wind on dust and ignore the effects of the dust on the magnetized plasma.
- Many treat the $-\mathbf{V} \times \mathbf{B}$ electric field as the ultimate force accelerating particles, rather than an agent that transfers momentum from the solar wind plasma to the charged dust particles.
- Very few appreciate that the correlated magnetic field perturbations in the dust pickup process implicate the magnetic field as a partner with the electric field in this process.
- Very few people consider the Debye length as an important scale length in this problem.

Phenomena Probably Associated with Dust Pickup

- Interplanetary Field Enhancements
 - Cusp-shaped field enhancements
 - Strong central current sheets
- Discordant current sheets in ICME
 - Strong current sheets totally out of place inside an ICME
- Non-compressive current sheet storms
 - Many thin current sheets that are not accompanied by a field dip

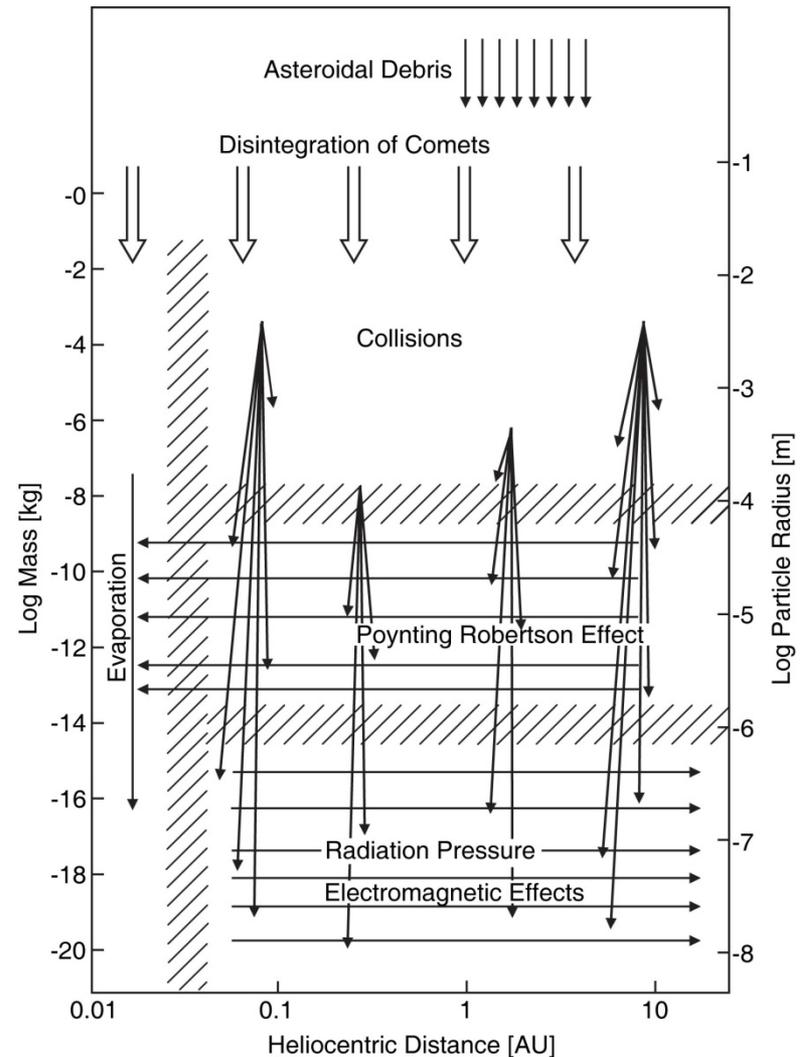
Outrageous Possible

Consequences of Dust Pickup

- Compressionless current sheet storms evolve by dissipating energy in current sheet, heating plasma and making D-sheets. Could all magnetic structures at 1AU originate as dust pickup?
- Alfvénic turbulence is ubiquitous in solar wind. Is this also just a manifestation of dust pickup?

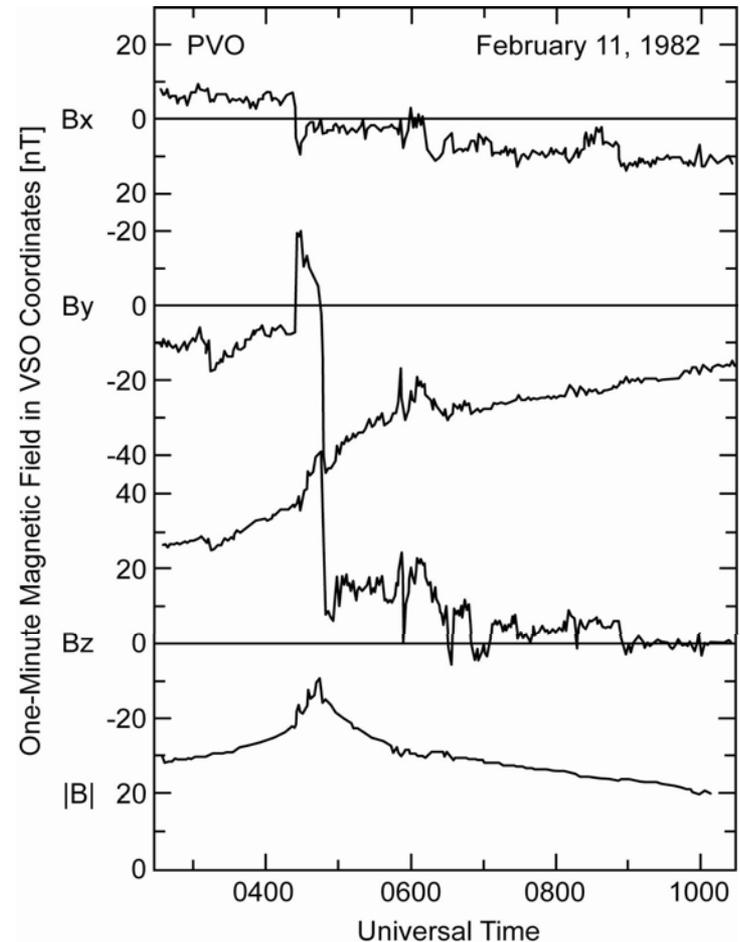
The Conventional Wisdom of Dust Transport in the Solar System

- Comets and asteroids supply dust.
- The transport of dust is very size-dependent.
 - Poynting-Robertson effect drives dust inward.
 - Light pressure and electromagnetic effects drive dust outward.



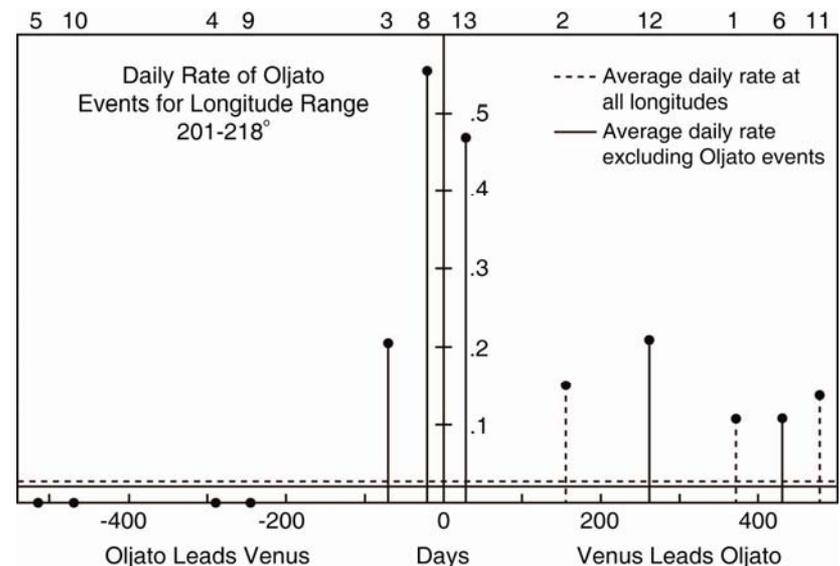
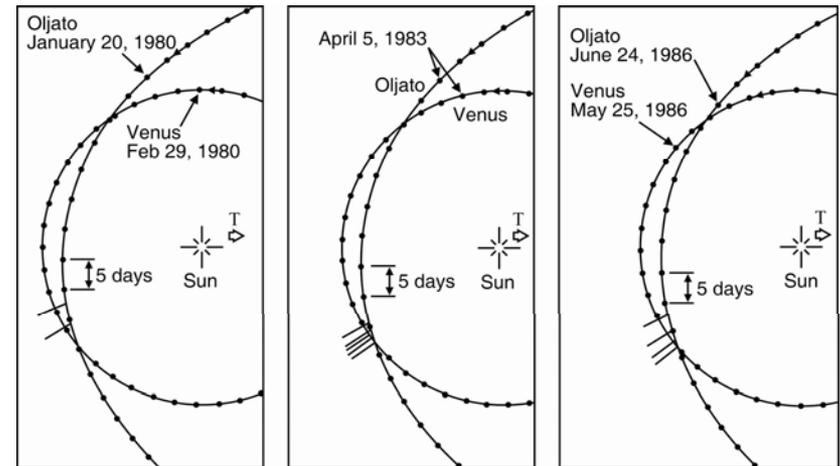
What is an Interplanetary Field Enhancement?

- IFEs are disturbances in the IMF that have a cusp-shaped magnetic enhancement and strong current sheets in their central region.
- They have been associated with charged dust pick up by the solar wind when an association was found during apparitions of asteroid 2201 Oljato with the PVO magnetometers 25 years ago.
- They occur throughout the inner heliosphere, but weaken at greater heliospheric distances.



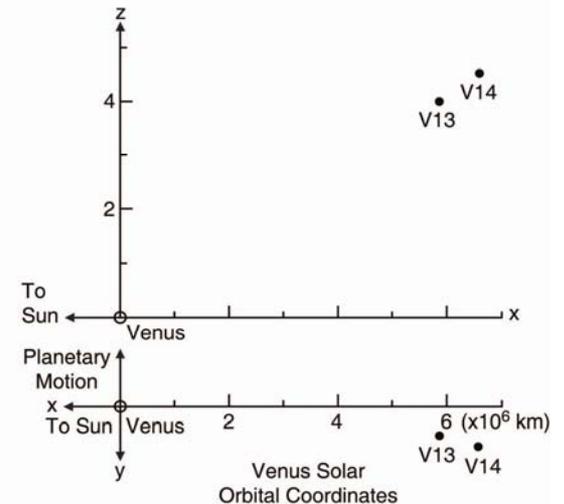
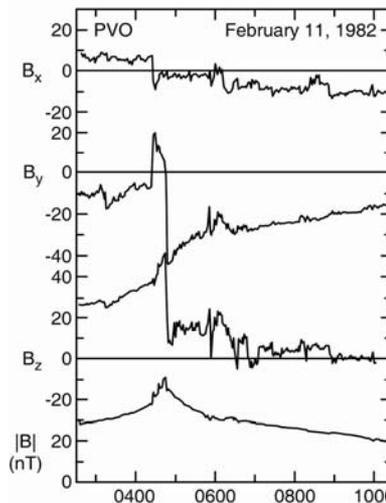
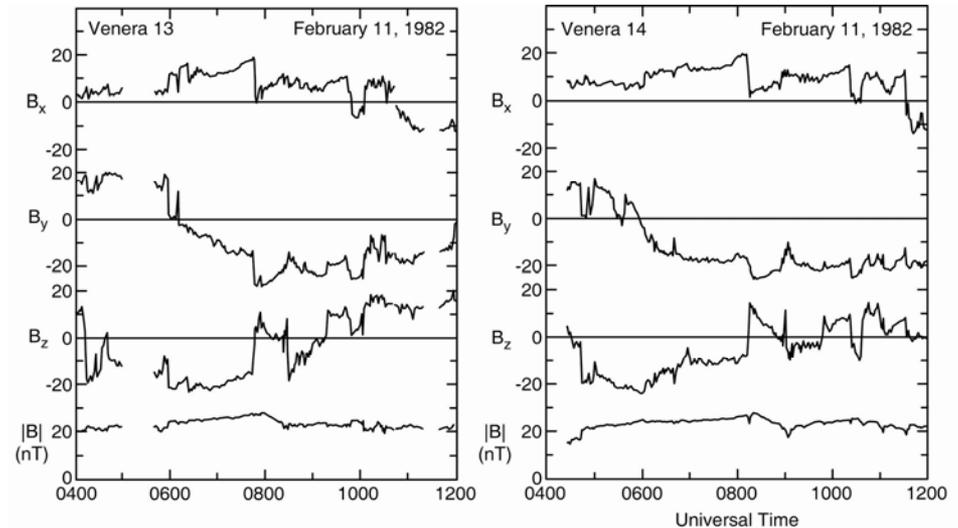
What Causes an Interplanetary Field Enhancement?

- The most compelling evidence that IFEs are produced by charged dust is provided by three successive passes of the asteroid 2201 Oljato through the inner solar system.
- Oljato crosses Venus' orbital plane just inside Venus' orbital distance.
- When Venus is down wind from this point, it sees IFEs whether Oljato is ahead of this point or behind.
- The closer Oljato is, the more events are seen.
- Most events seen are not associated with known bodies.



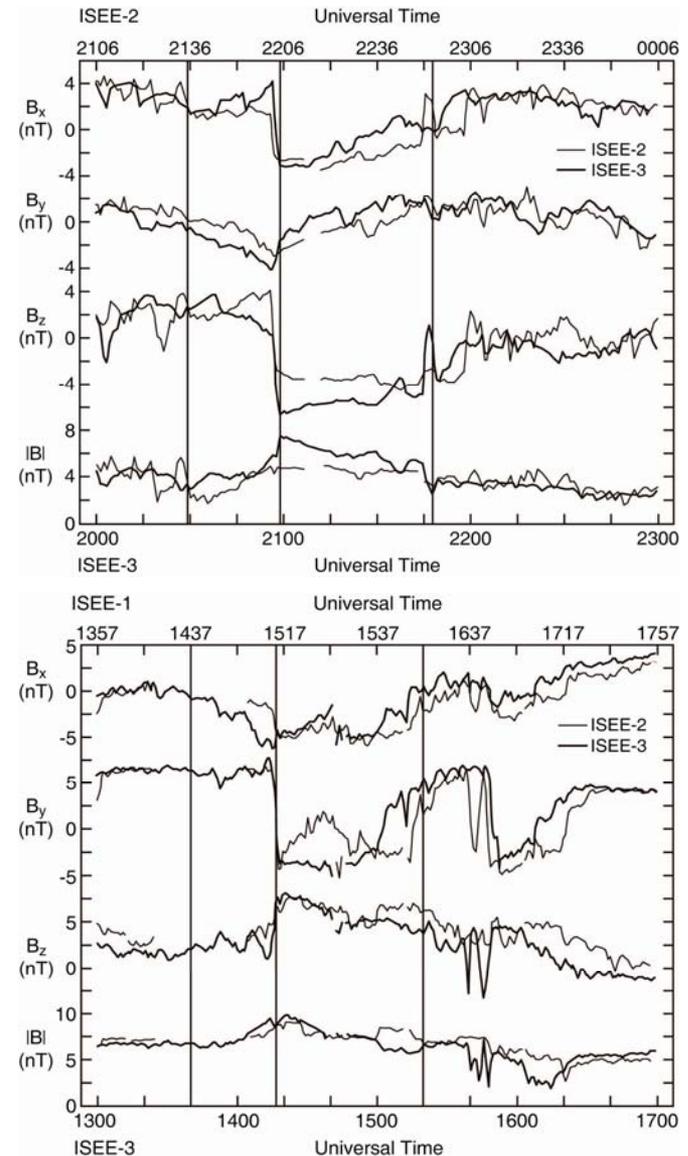
IFE Motion and Size

- With a single spacecraft, you cannot tell how disturbance is moving.
 - Co-orbiting with asteroid?
 - Radially outward from Sun.
- The largest IFE seen by PVO was also seen by two other spacecraft, Venera 13 and Venera 14 later on the same day, but 6 million km down wind and 4 million km above Venus' orbit.
- The magnetic signature is weaker and the current sheet signature is only qualitatively the same.
- This gives an idea of the size of the disturbance and its speed.
 - It probably is moving outward.
 - If so, then it is moving at the solar wind velocity.
 - It is about 7 M km from beginning to end.
 - It is at least 8 M km from one side to the other.

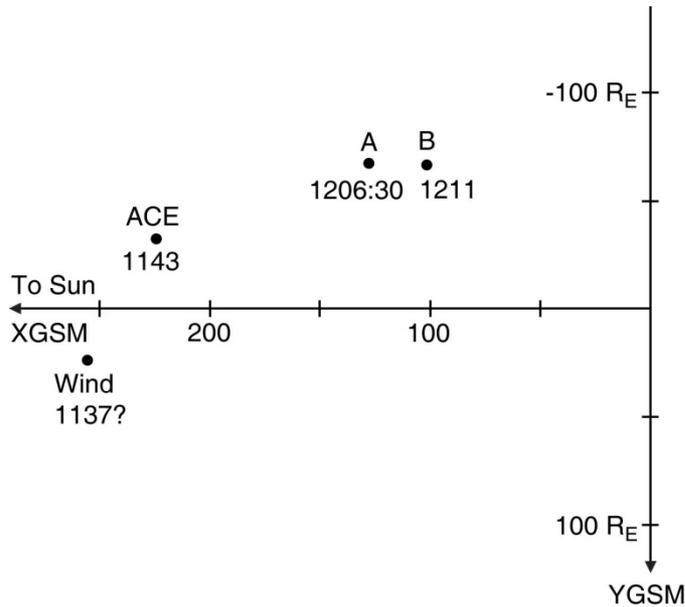


Behavior at 1AU

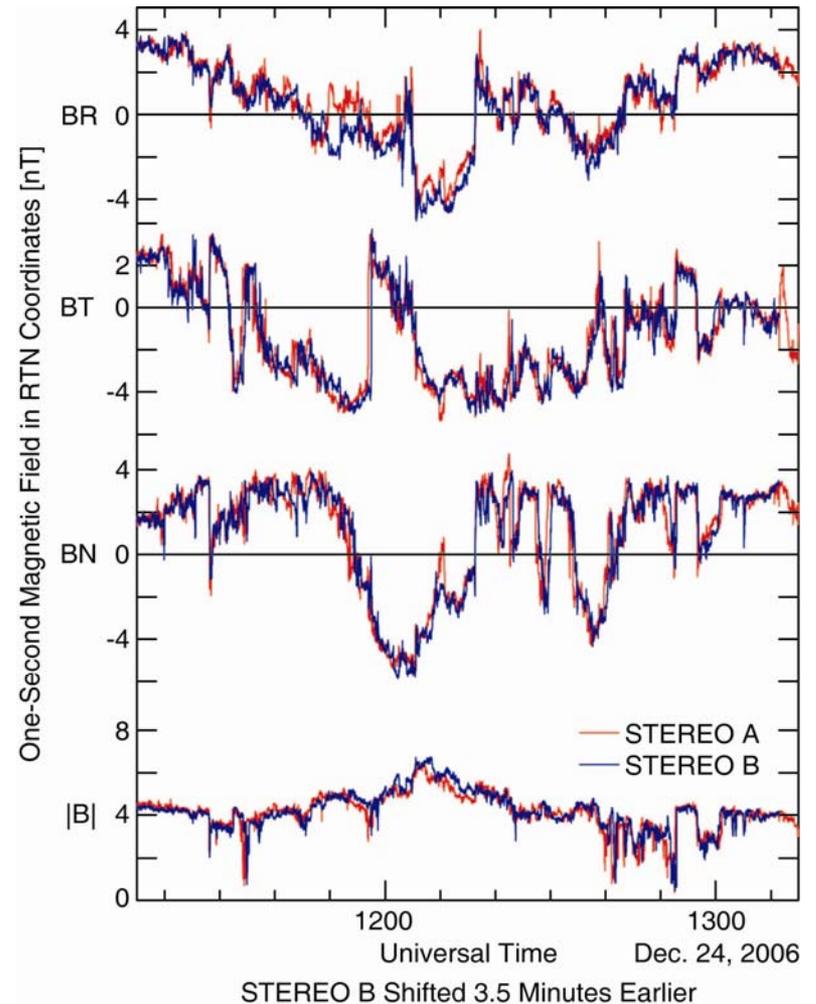
- IFEs are seen in Earth orbit. ISEE-3 and either ISEE-1 or ISEE-2 were able to see the same IFEs on occasion.
- At Earth, the spacecraft farthest from the Sun always was the last to see the disturbance, again consistent with outward propagation, but not firm proof of it.
- As in the previous example, spacecraft to the side of a strong IFE record a weaker signature in the total field, but the current sheets are similar.



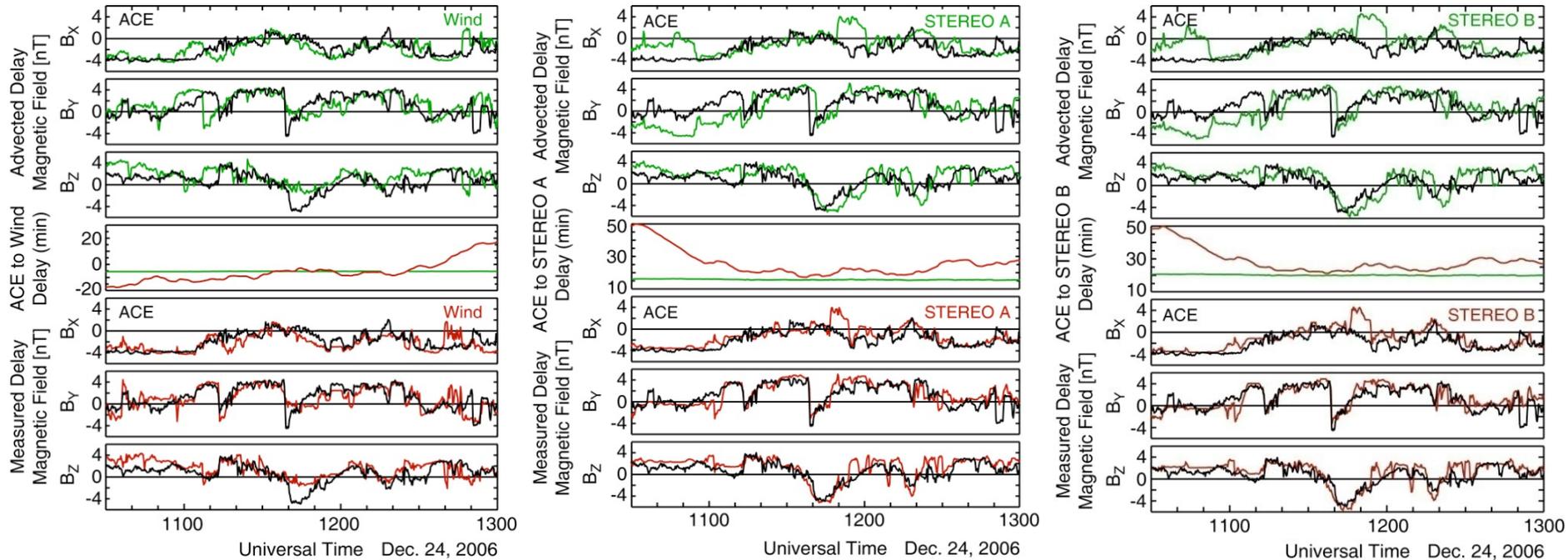
IFE of December 24, 2006, at STEREO, Wind, and ACE



- Before they left the Earth, the two STEREO spacecraft saw an IFE at the same time as Wind and ACE saw it.
- Here, we superpose the two STEREO field measurements with a 3.5-minute delay, which is consistent with the solar wind time delay from A to B.

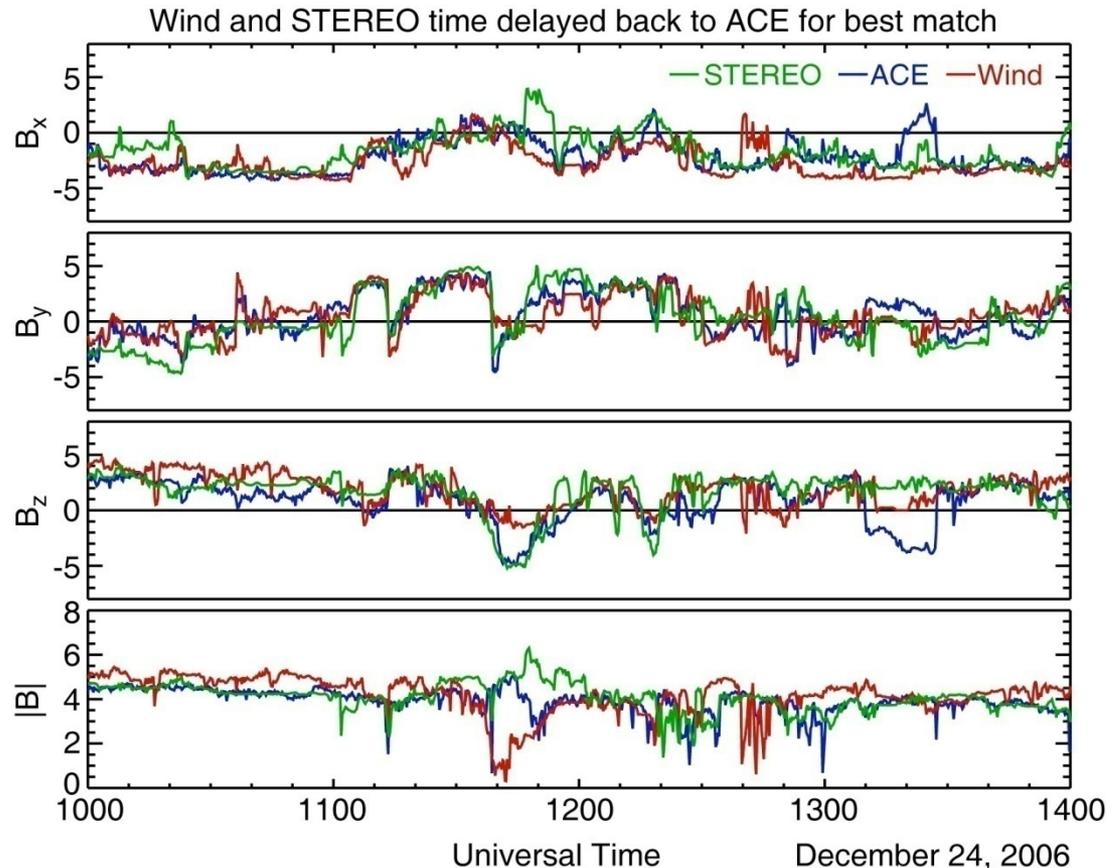


Multi-Spacecraft Observation of an IFE



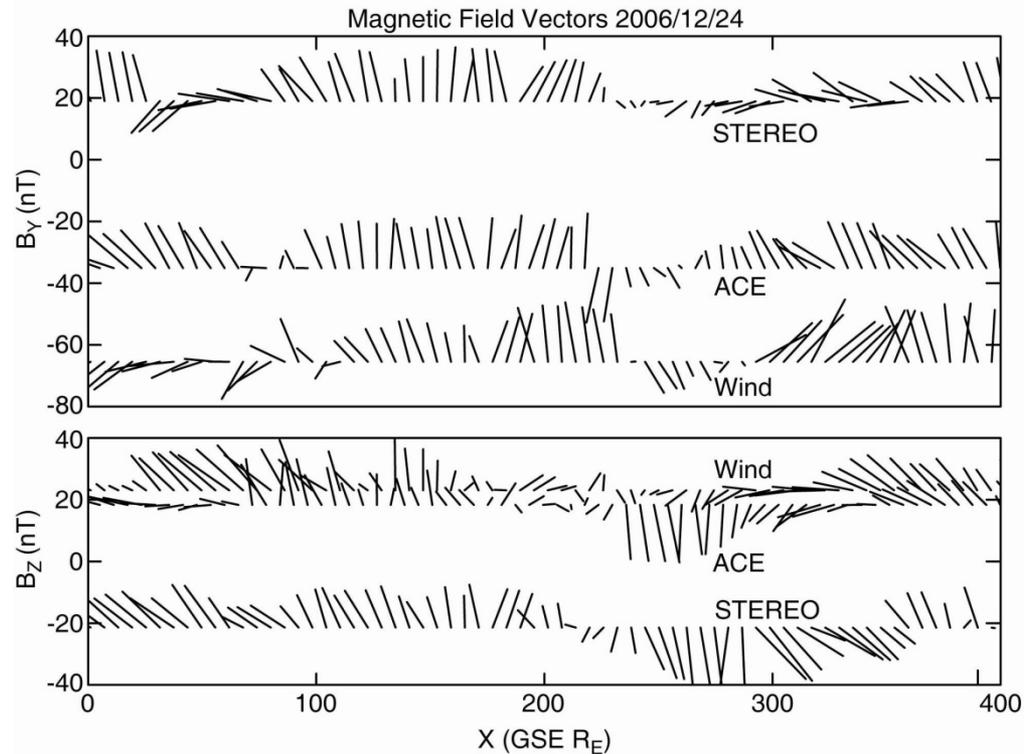
- Using the magnetic field data, we have calculated the delay times dynamically and compared with solar wind delay times.
- The delay times show that the structure is being carried radially out from the Sun at the solar wind velocity.
- Thus, we believe some dust particles are accelerated up to the solar wind velocity.

Spatial Variation of IFE Signatures



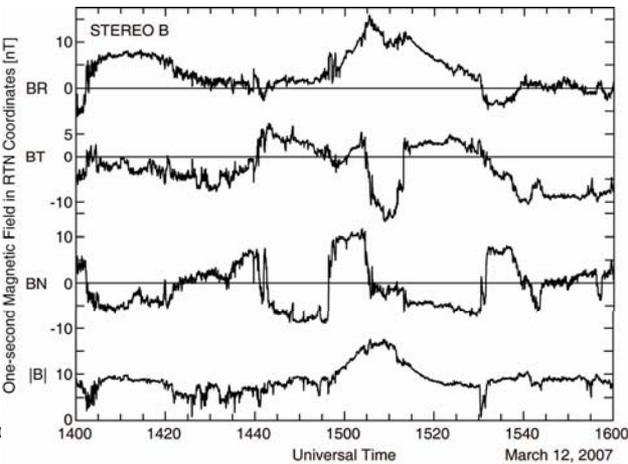
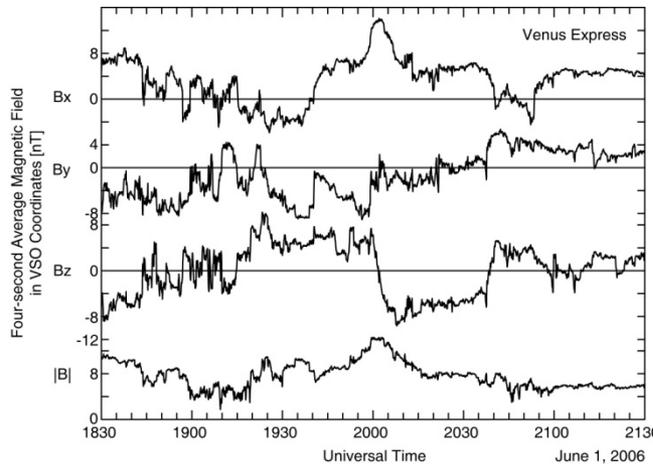
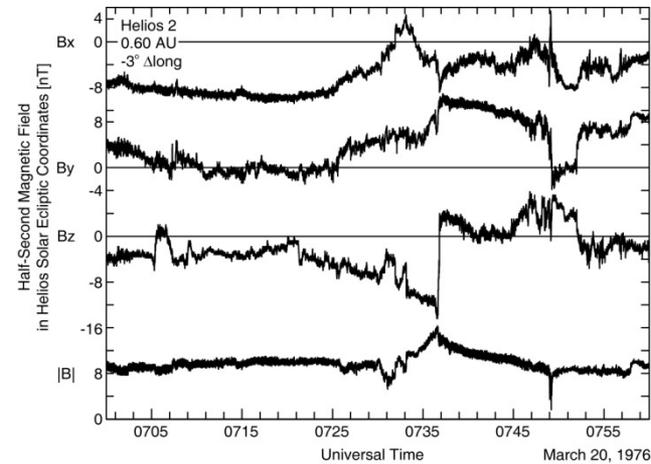
- Strong cusp-shaped field is seen only near center of the disturbance.
- To the side of the region of cusp-shaped field, the increase becomes more rounded and smooth. Further away, it may become negative.
- Current sheets and the field components seem to be coherent over larger distances.

Magnetic Field Variation Through an IFE

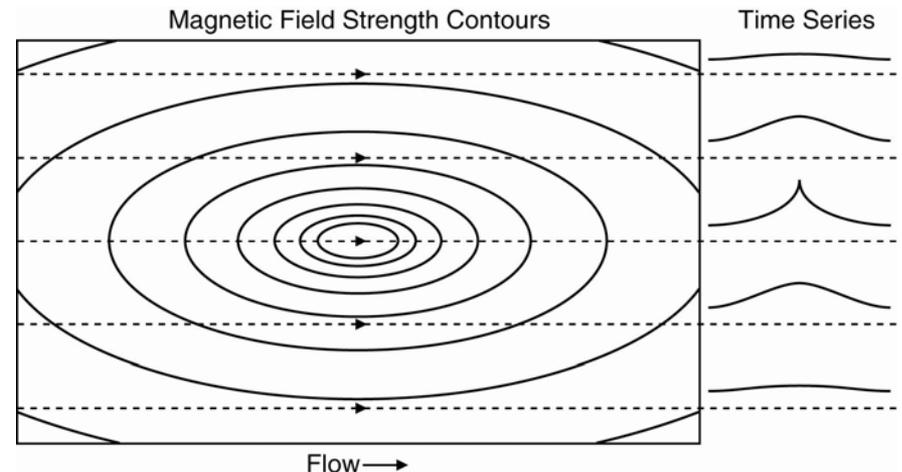


- If we plot the field variation as arrows in two dimensions, we can see how the field varies as a function of distance across the flow.
- Even though the profile of the magnetic field strength changes drastically across the structure, the vector field pattern shows great coherence in both the XY and XZ planes.

Interpreting the Magnetic Signatures of IFEs

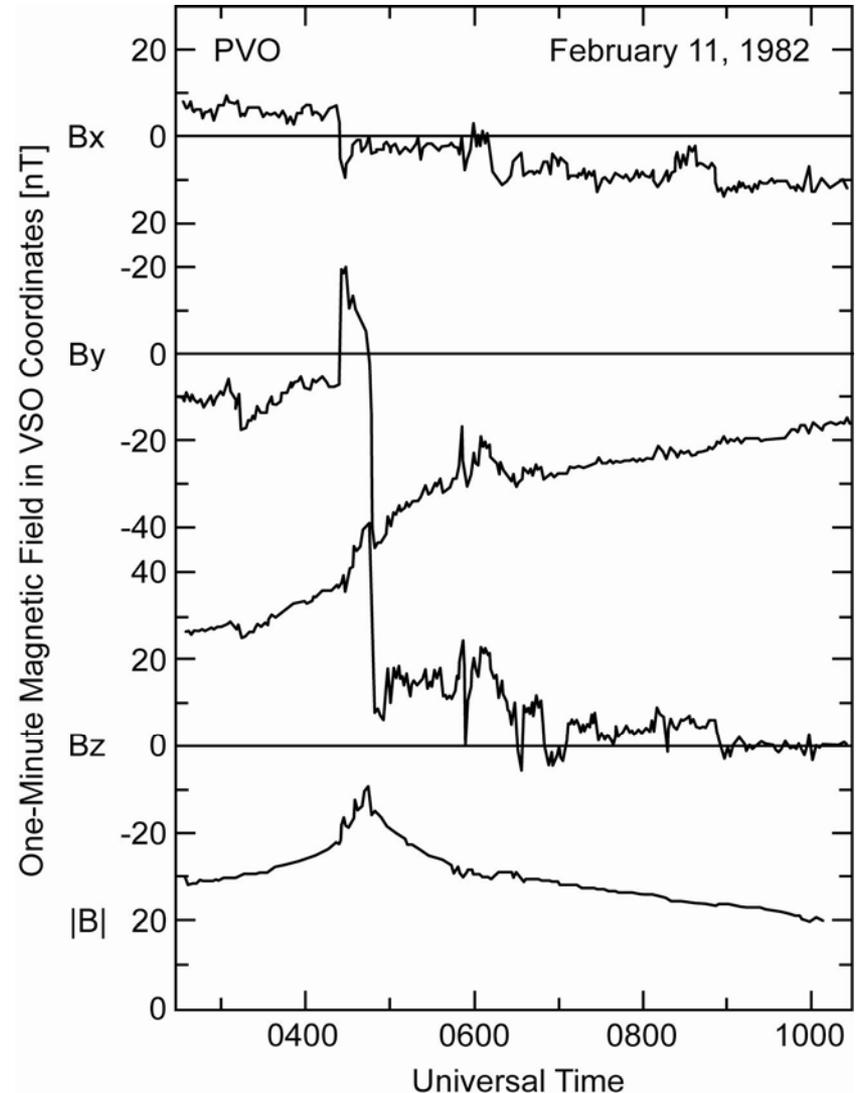


- The varied shape of IFE magnetic profiles may depend on their impact parameters.
- Sharply peaked events pass through the center and rounded, smooth profiles when they pass to the side.



Physics of the Interaction

- The cusp-shaped magnetic field in the central region of the IFE is magnetic force moving the particle out of the Sun's gravitational potential well.
 - The outward force is pushing the charged dust particle away from the Sun.
 - The inward magnetic force is pushing against the outward moving plasma.
 - The magnetic pressure is the agent for transfer of momentum from the plasma to the dust.
- The distorted field perpendicular to the flow is caused by momentum balance in this direction.
 - The dust particle has inertia concentrated in a small region.
 - To balance the sideways motion of the dust requires a much, much larger motion of the plasma that pulls the magnetic field far to one side of the dust particle.



Conclusions

- Dust is being accelerated to great speeds in the solar wind. This has been seen near Jupiter and Saturn before, but could have been planetary in origin.
- This fast dust is probably responsible for many of the dust hits on STEREO.
- We do not see IFEs when these dust strikes are seen, so IFEs may be rarer larger events.
- It is important to understand this pickup process.
 - It may produce a hazard to space exploration.
 - It may explain many phenomena that presently are a mystery, such as the source of the Alfvénicity of the solar wind.