# STEREO Contributions to the Understanding of Interplanetary Field Enhancements

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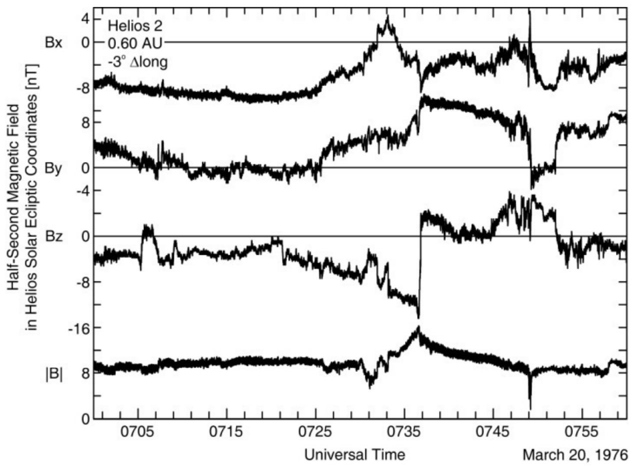
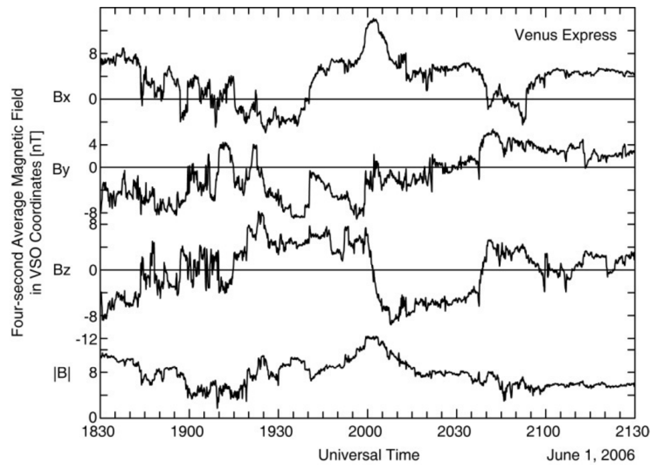
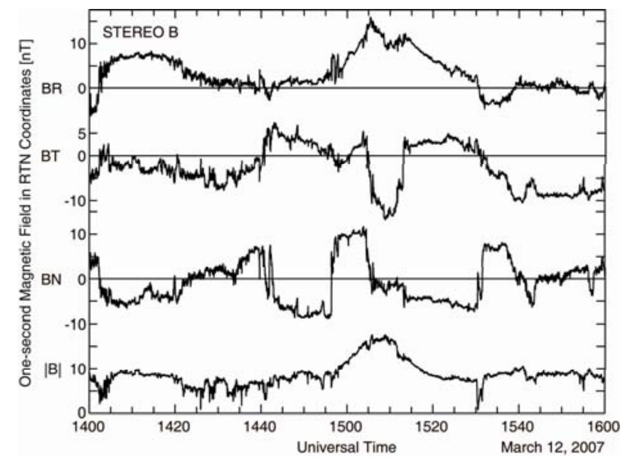
# What is an Interplanetary Field Enhancement?

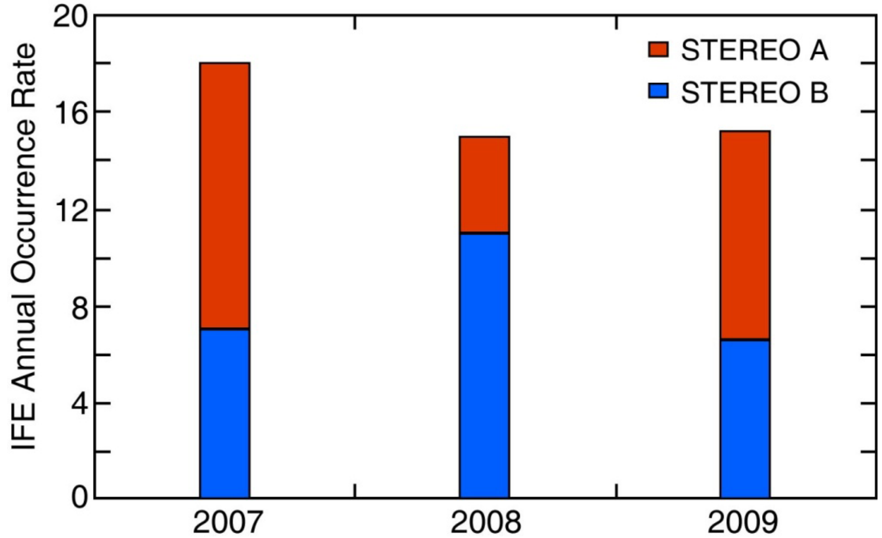


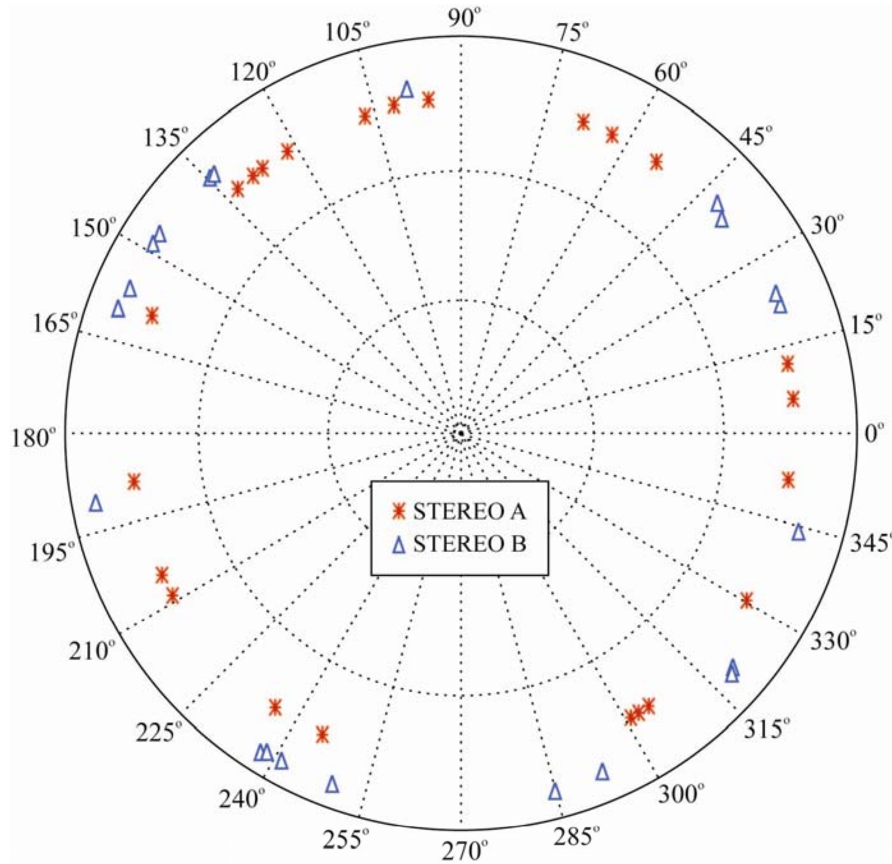




- An IFE is a smooth enhancement in the magnetic field often rising to a cusp-shaped maximum. There is usually a thin current sheet near the center.
- IFEs are seen throughout the inner solar system from Helios near 0.3 AU to Ulysses near 5 AU. They have been detected on ISEE 1, 2, 3 in the 1970s to STEREO currently.
- There is no shock front associated with them and they have no obvious draping signature.
- They appear in a variety of sizes and can create large transverse disturbances.

# STEREO Observations of IFEs: Rate and Location

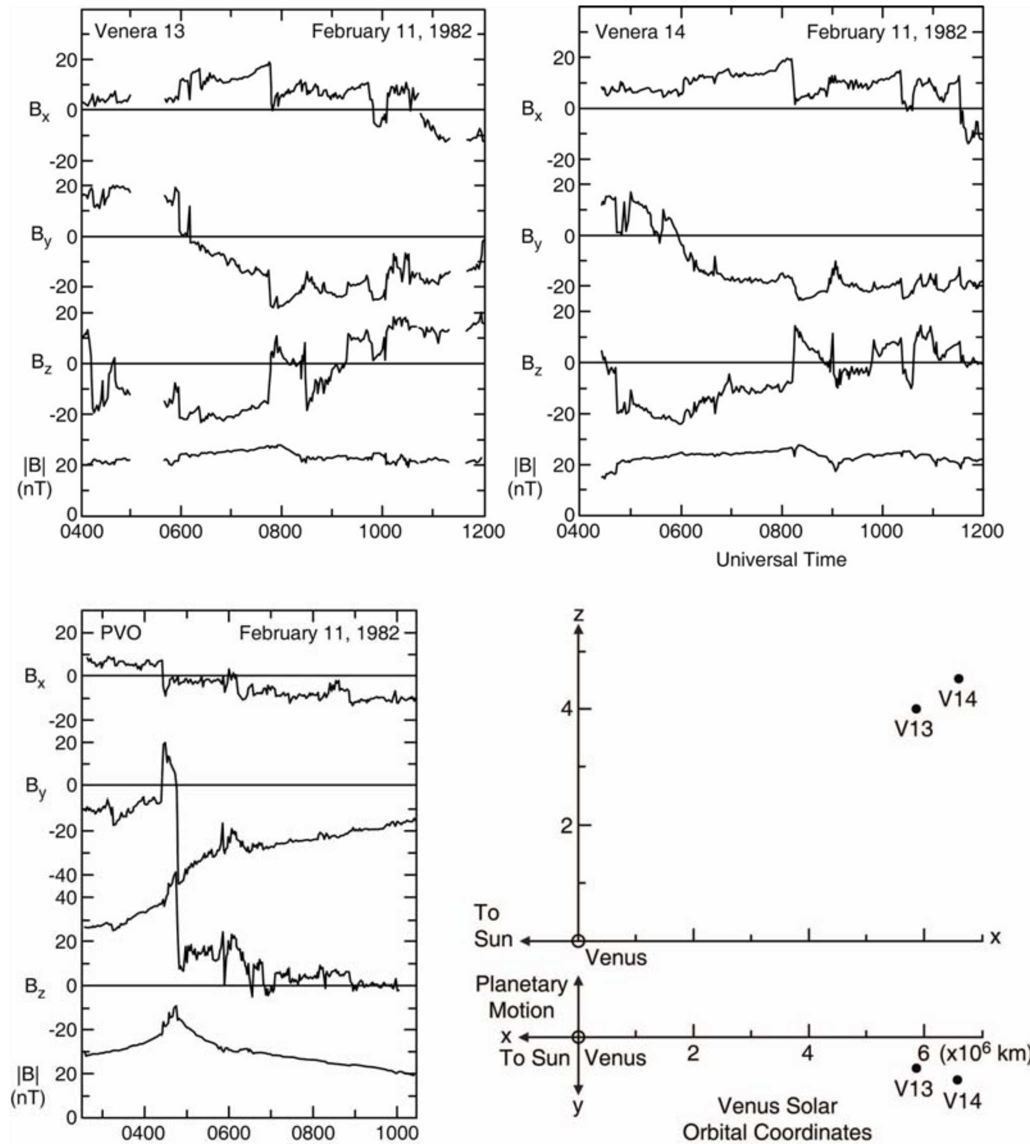


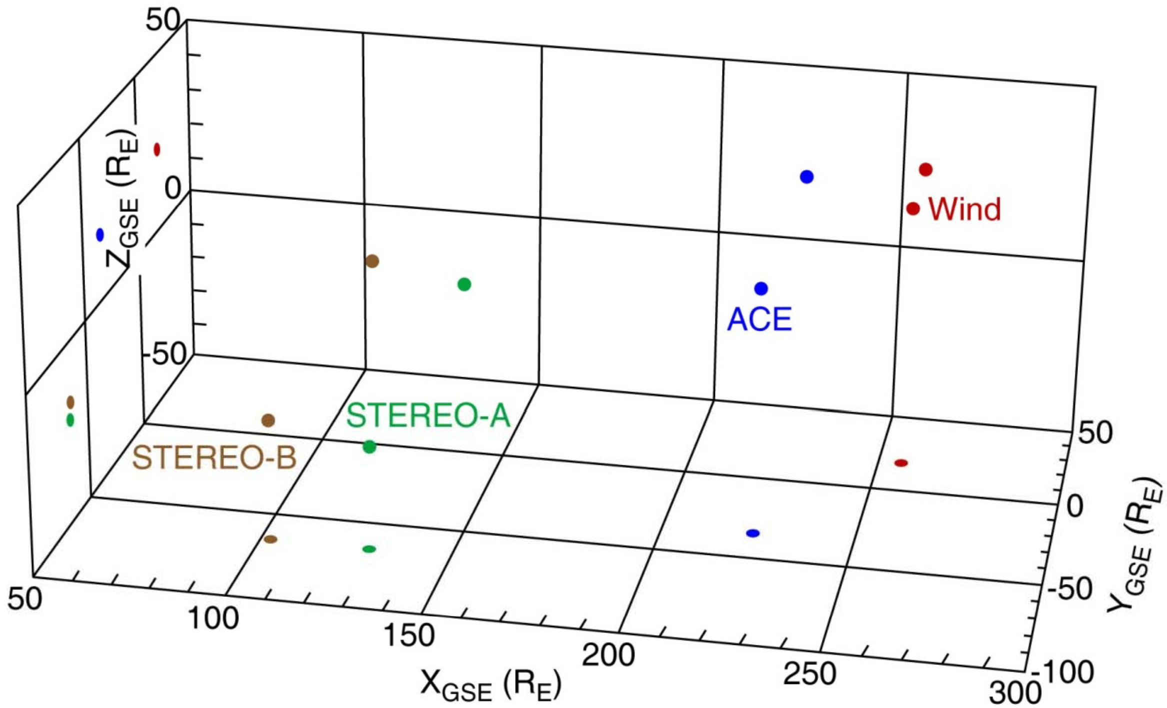

- IFEs can be as short as several minutes and as long as many hours. In this study, we examined IFEs lasting over 10 minutes.
- Each STEREO spacecraft observes about 8 IFEs of these per year.
- IFEs are seen all around the ecliptic plane but do appear to be more frequent at certain longitudes.

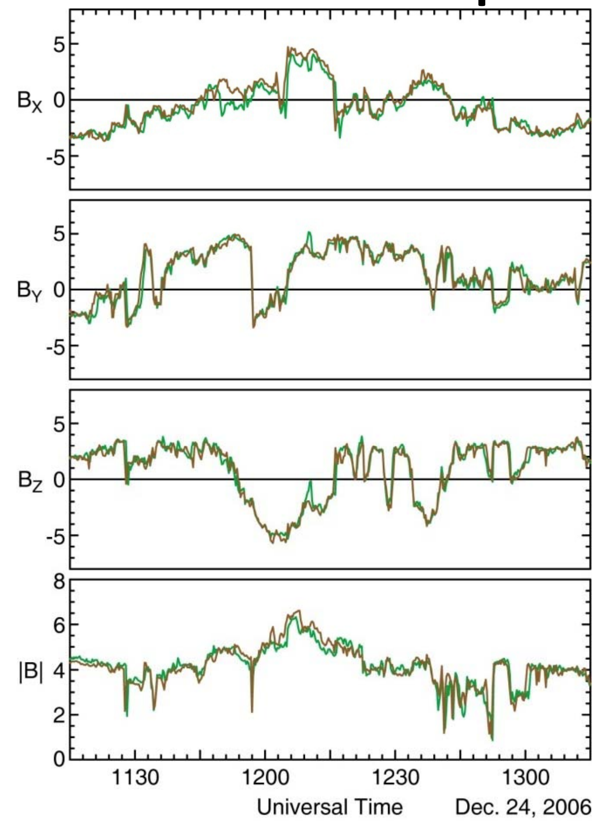
# IFE Motion and Size

- With a single spacecraft, you cannot tell the speed of a disturbance. Is it orbiting the Sun? Is it moving outward from the Sun?
- The largest IFE seen by PVO at Venus was later seen by Venera 13 and 14 later on the same day 7 Mkm downwind and 4 Mkm above Venus' orbit.
- The magnetic signature was weaker and the current sheet qualitatively the same.
- This suggests that the disturbance is moving nearly at the solar wind speed and has dimensions of nearly 7 million km.



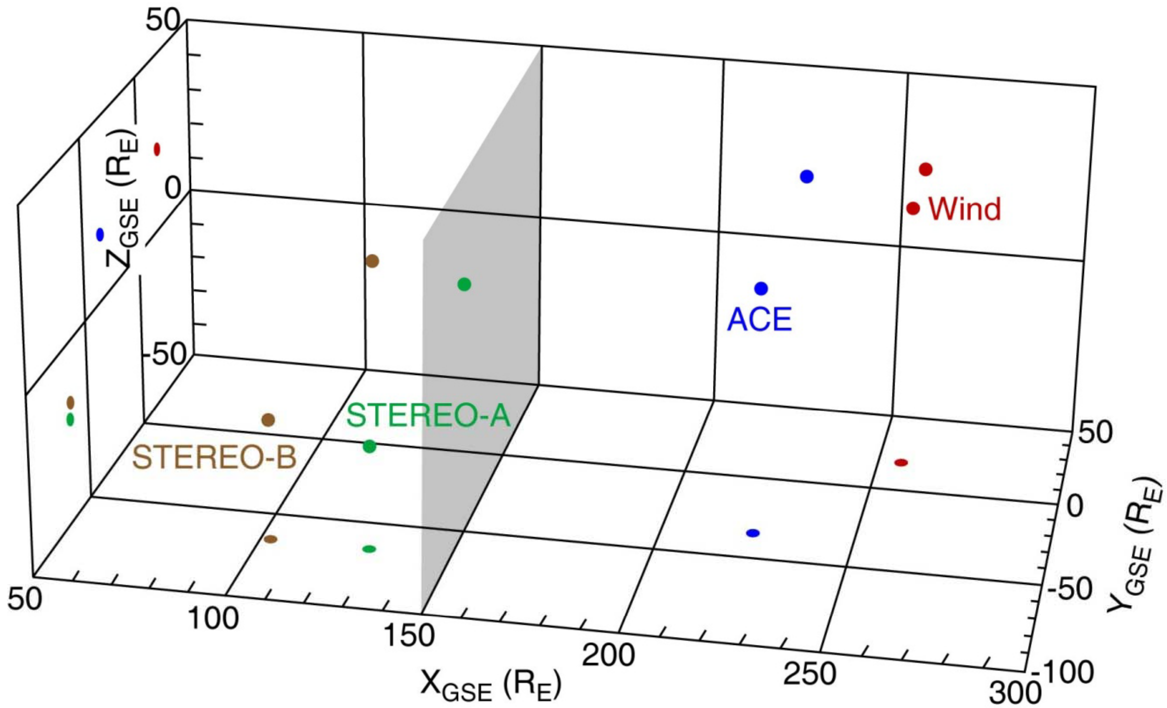
# STEREO Contribution: IFEs move at Solar Wind Speed

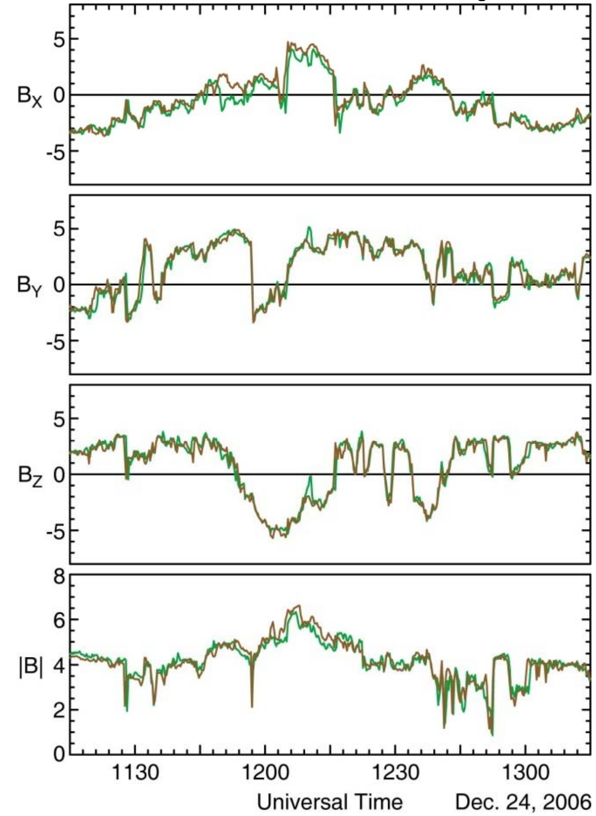



- Before they left the Earth, the two STEREO spacecraft saw an IFE when they were aligned with the solar wind flow. Simultaneously, Wind and ACE saw it.
- The delay time between the four spacecraft and their relative positions prove that the disturbance is moving out from the Sun at the solar wind speed.

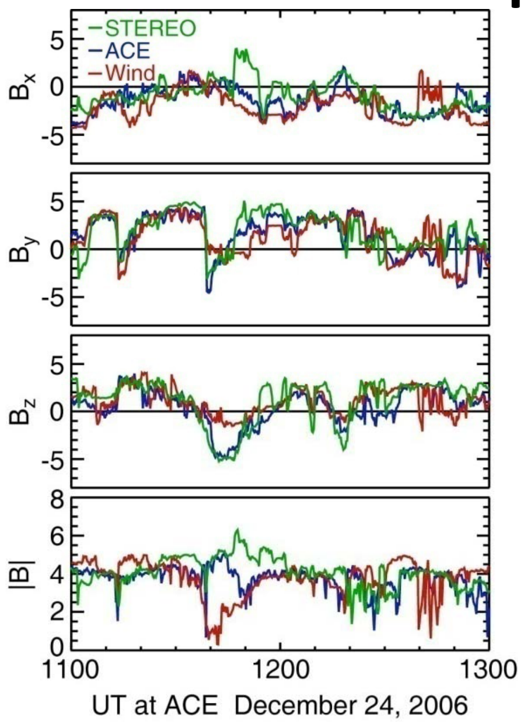
# STEREO Contribution: IFEs move at Solar Wind Speed

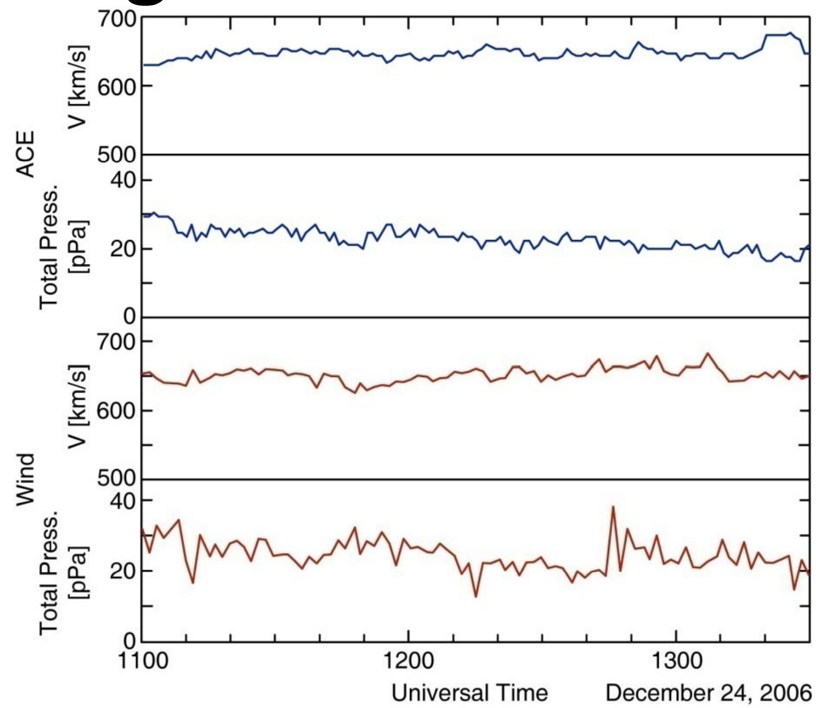



- Using the time of arrivals at the four spacecraft and then mutual separations we can solve for the orientation of the plane of constant phase and its speed.
- The solution is a plane perpendicular to the solar wind vector moving with the solar wind.

# STEREO Contribution: Spatial Structure and Plasma Signature

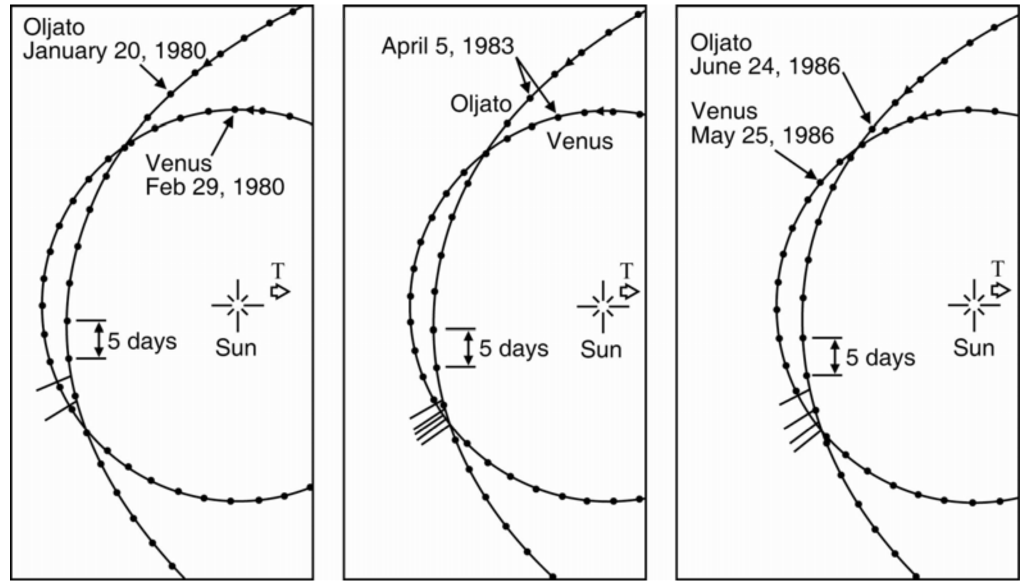


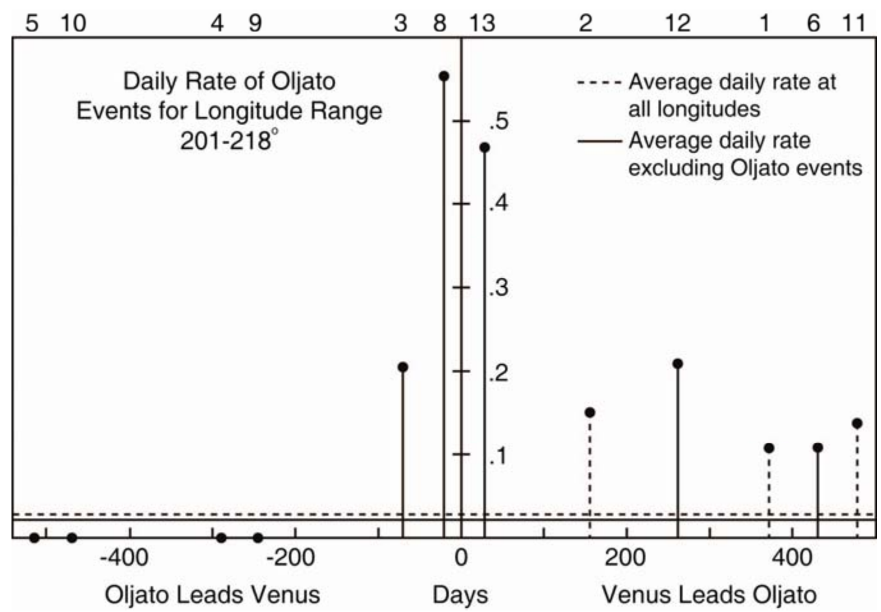




- We can use the orientation of the phase front and the speed measurement to stack the magnetograms from the four spacecraft. The field strength differs at the four locations but it is clear that the same feature is being seen, just different aspects of it. There is also large scale coherence in the vector components.
- We do not have plasma data from STEREO at this time but we do have WIND and ACE data. We see no change in the speed upon passage of these structures. And the sum of the plasma and magnetic pressures remain constant as well.

# Association with Dust: PVO Evidence

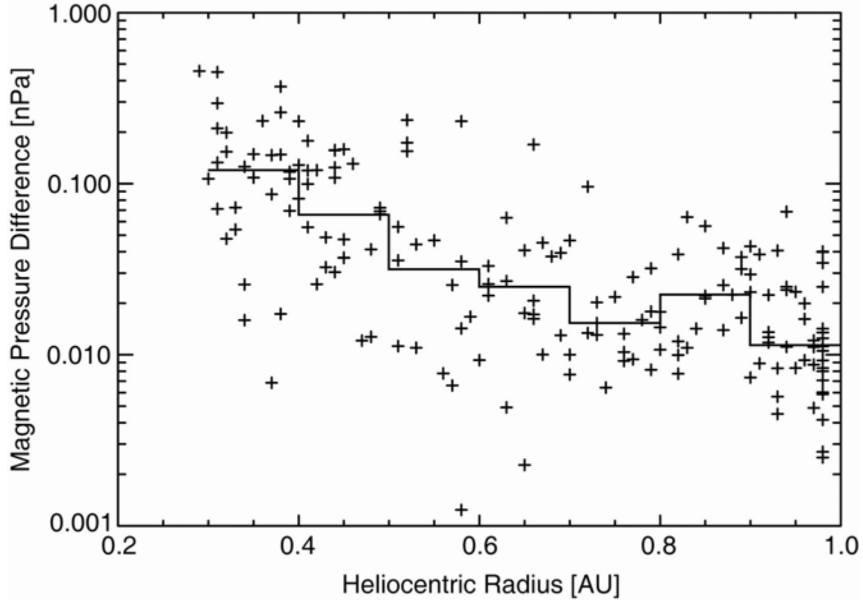
- The asteroid 2201 Oljato cuts through Venus' orbit plane just inside Venus orbit.
- Near this intersection on three successive apparitions IFEs were found, and not on years when the asteroid was not near conjunction.
- Thus it was hypothesized that charged dust was being picked up by the solar wind to make this disturbance.
- Thus the disturbance may be signaling the presence of mass and the pressure gradients a means to accelerate that mass.

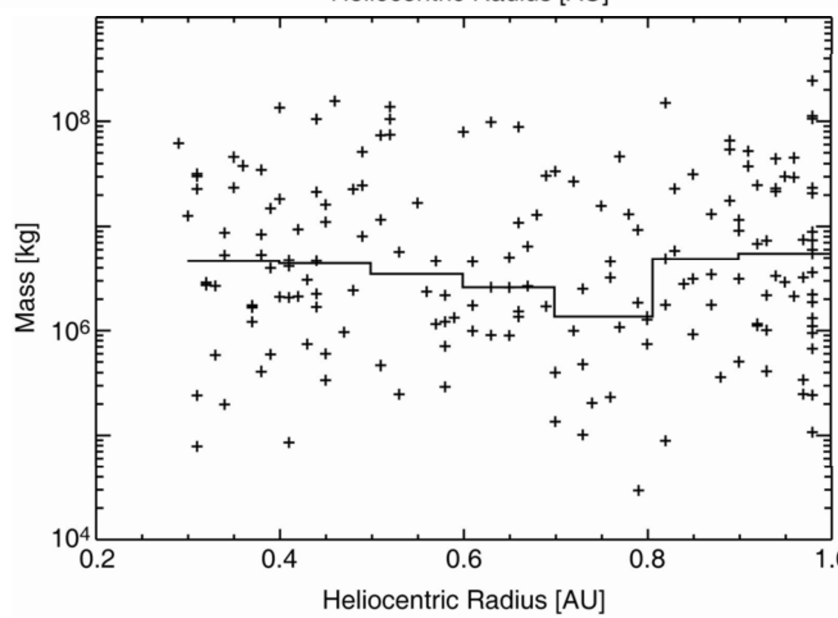


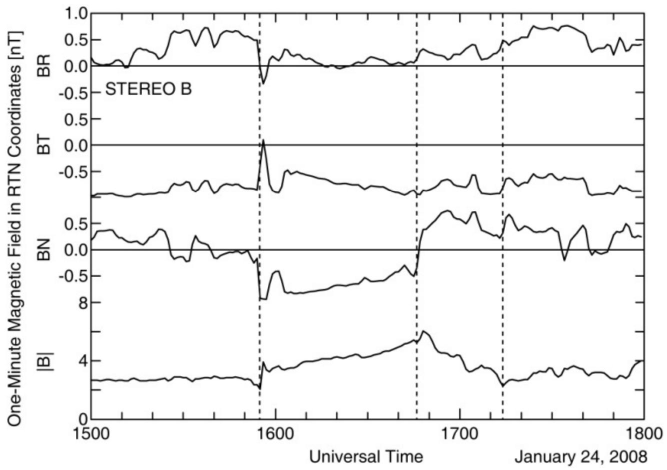
# Weighing an IFE

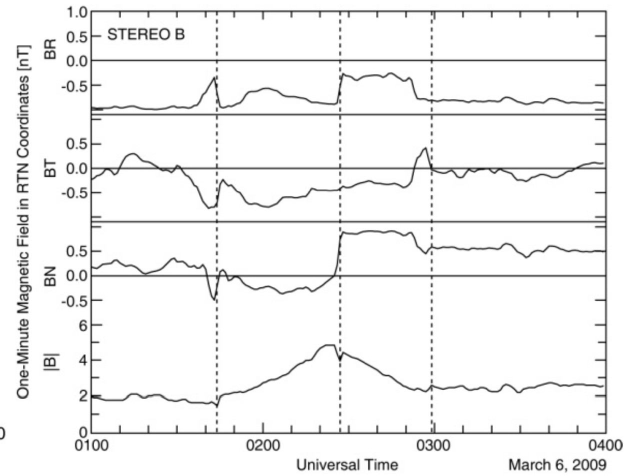
- We can weigh the mass inside an IFE with several simplifying assumptions:
  - The magnetic forces do all the work.
  - The time for the disturbance to cross the spacecraft gives the size of the cross section orthogonal to the flow.
- The initial magnetic gradient is taken to be the pressure on the dust particle; the trailing gradient is the pressure on the plasma. The total force is this pressure times the area of the IFE.
- Since we see no acceleration or deceleration, the force must be that needed to lift the particle at constant speed out of the gravitational potential well of the sun. This force allows us to find the mass of the particle.
- Applying this to the Helios data set obtained over a range of disturbances. We calculate (on the top) the magnetic pressure difference from the center to the edge of the IFE. It falls as $R^{-2}$ approximately.
- If we convert this to mass, we get nearly a constant number. This is reassuring but the mass in a median IFE is quite large, about $4 \times 10^6$ kg. This is the mass of a rock 10m on a side.

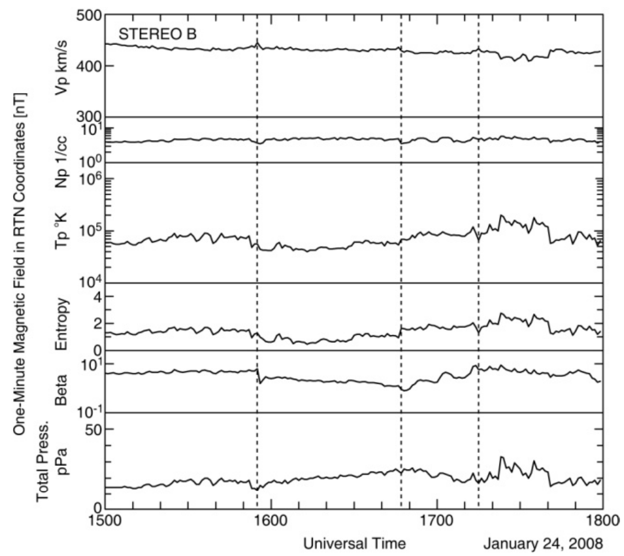


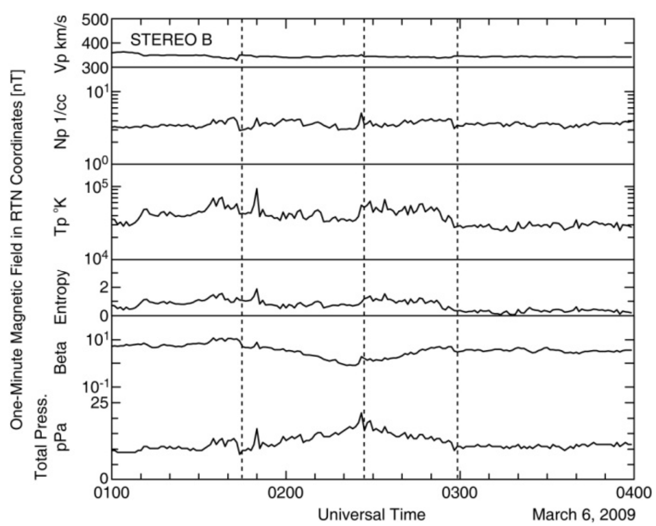



# IFEs are Pressure-Balanced Structures



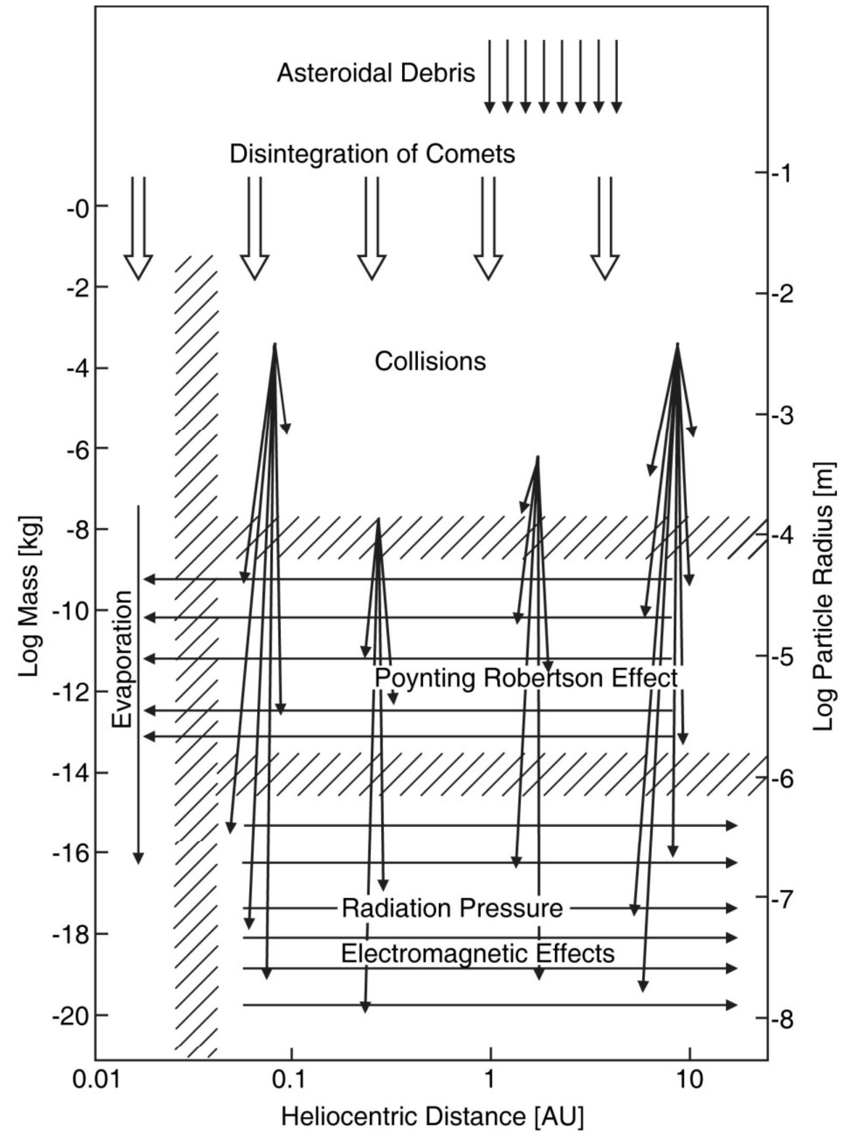




- If the magnetic pressure associated with these field signatures were not compensated by the plasma, the total pressure rise here would be dramatic but we can hardly see a rise.
- For some reason, the plasma is compensating for the magnetic pressure rise and very little pressure is being applied to the mass to lift it away from the Sun. The true mass is below our limit of detection, about $10^6$ kg.
- A micron-sized dust particle weighs about 4 pg. This is the largest sized particle we might expect to be accelerated by the solar wind to such high speeds. This presents us with a dilemma.

# What Causes IFEs?

- Observables
  – IFEs are associated with sources of dust.
  – IFEs move with the solar wind speed.
  – IFEs have dimensions of over $10^6$ km.
- Interferences
  – IFEs have masses of less than $10^5$kg.
  – Solar wind will not accelerate particles of mass greater than about 4 pg.
  – Is there a way of accelerating up to $10^{19}$ pico gram particles?
- Dust Production
  – Dust is produced by collisions between comets, asteroids and meteoroids.
  – A collision could release a large number of particles in a small region of space.
  – Initially those particles would be within each other's Debye spheres and could interact coherently.
  – Perhaps each IFE is the charged dust remnant of a collision with friable material in the solar wind.
  – Eventually the structure would dissipate as the particles drifted apart.



# Summary

- IFEs have been associated with dust producing objects.
- IFEs move with the solar wind speed implying that any entrained dust is small in size.
- Paradoxically, the IFE is macroscopic in scale, about $10^6$ km across exerting a magnetic force capable of moving many tons of material away from the Sun.
- The answer to this paradox is that the magnetic pressure is balanced by a region of low plasma pressure. Thus the magnetic field cannot act as a scale to measure the IFE mass.
- The Debye length in the solar wind is about 10m. The inter-particle distance in the debris cloud would be much smaller than the Debye length even when the structure evolved to the macroscopic scales observed.
- The only hypothesis that seems consistent with all the observables is that we are seeing the interaction with a cloud of submicron sized dust particles produced by interplanetary collisions of meteoroids.