The Solar Wind Interaction with Vesta and Ceres Implications for their Magnetic Moments

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Solar Wind Interaction with Atmosphereless Bodies
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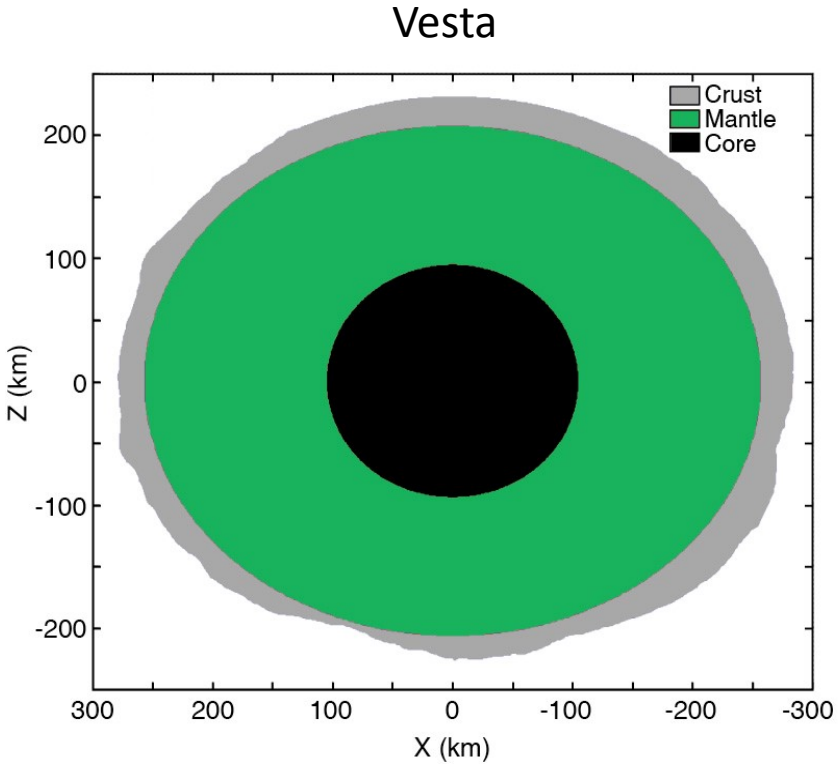
Why Might Vesta Have an Intrinsic Magnetic Field?

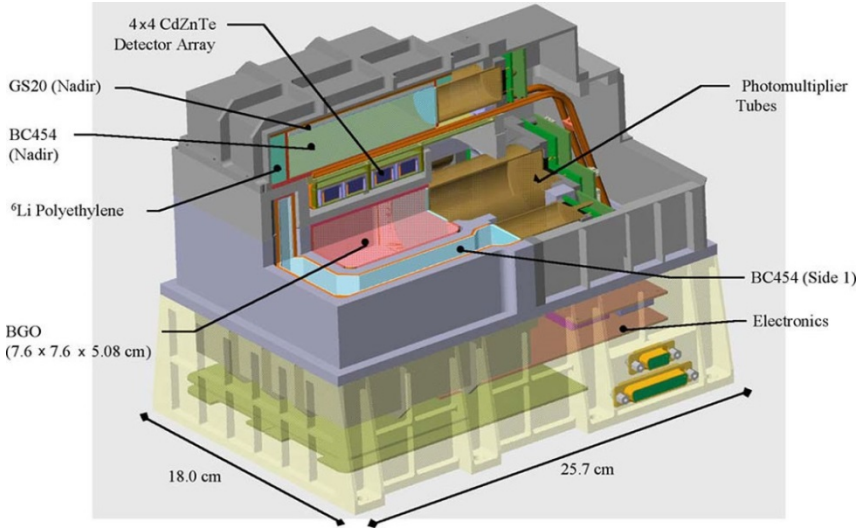
- Vesta was long expected to have an iron core based on the HED meteorites.
- But Vesta does not necessarily have a strong magnetic field today.
- Because Dawn lost its magnetometer during mission development, we needed to find ways to detect a magnetic field without a magnetometer.
- One possible approach (if the Vesta field were very strong) was to use the gain of the GRaND instrument by looking at the output of its electron multiplier tube that had a magnetic sensitivity.



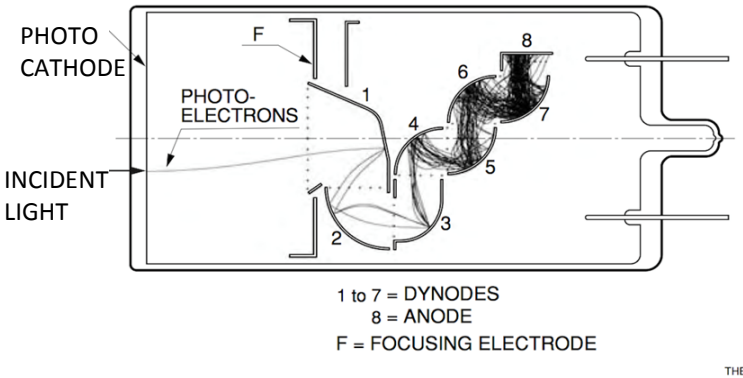
How to Determine if a Body in the Solar Wind Has a Magnetic Moment

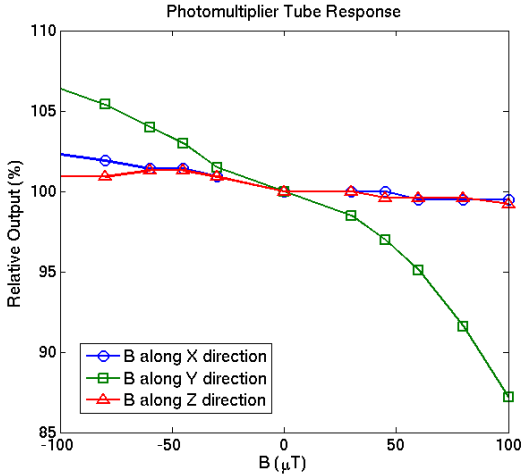
- Best way: Use two magnetometers on a boom
- Next best: Use one magnetometer on a boom
- Much poorer: Use a sensor that has some response to a magnetic field. Success depends on strength of field and sensitivity of sensor
- Even poorer: Use energetic particles reflected by body. Success depends on ability of body to strongly deflect solar wind.

  Qualitative only but may be more sensitive
- Lesson: Always carry a magnetometer on planetary missions especially if the target has never been visited before



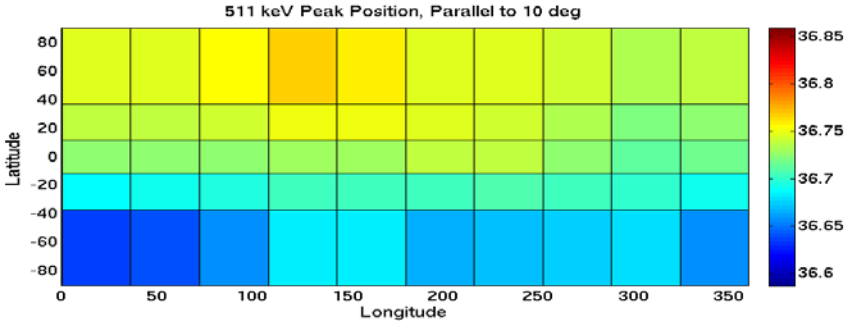
Sensitivity of Photomultiplier Tube to Magnetic Effects

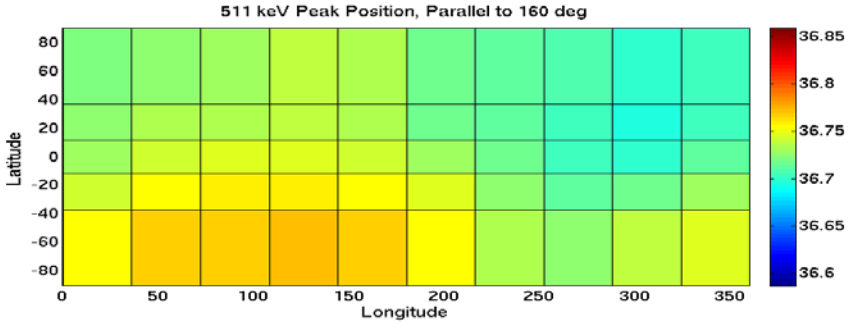


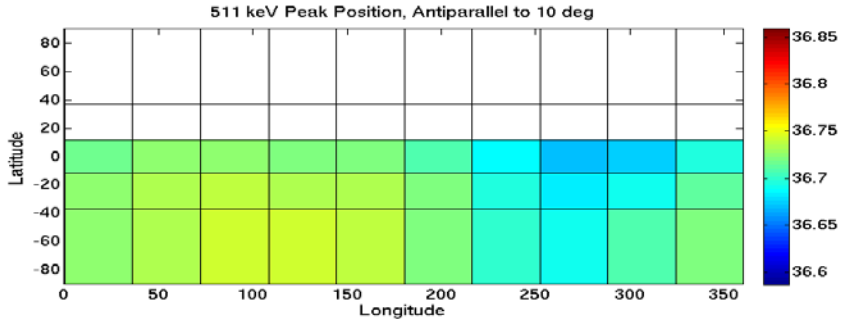


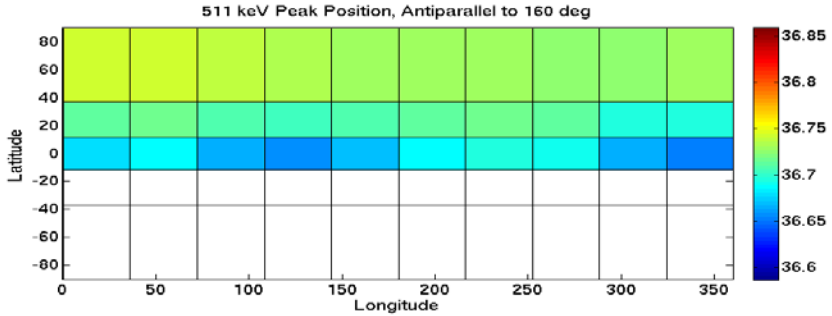
- Magnetic force deflects moving electron away from anode decreasing energy detected for a particular gamma ray energy.
- Sensor designed to work on surface of Earth so field must be microteslas at Dawn to be detected.
- Difference in reading along –Y and +Y directions could provide estimate of Y- component of field. Little sensitivity in X and Z axes.
- The Z-axis is pointed to Vesta and the spacecraft rotates about Z while orbiting and mapping.
- So we made maps separately for all orientations of the spacecraft, and then compared (differenced) antiparallel orientations.
- Compared energy of 0.511 MeV peaks (electron-position annihilation) for shifts.

MAPS



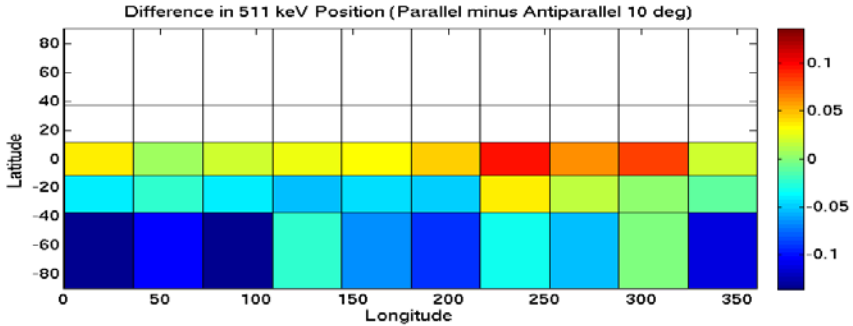


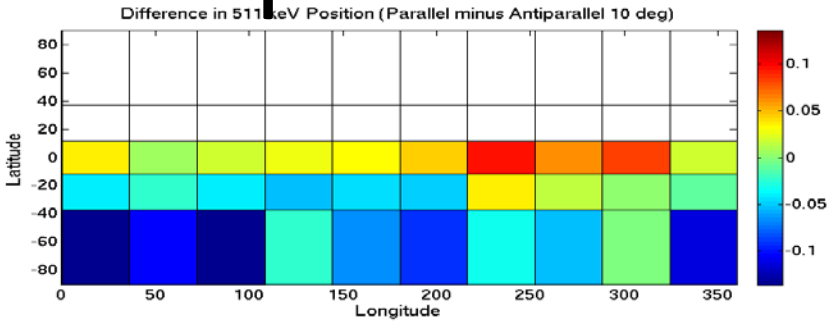


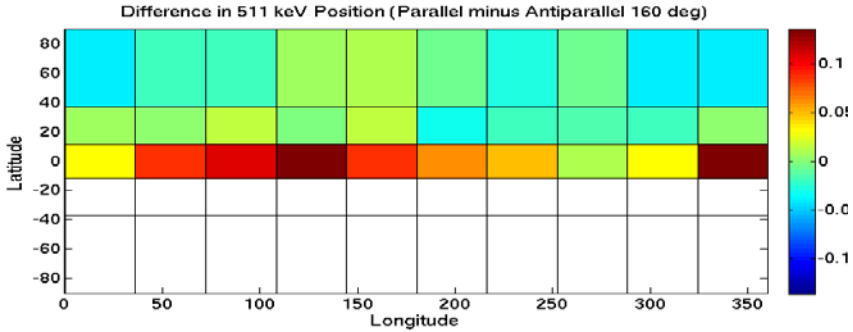


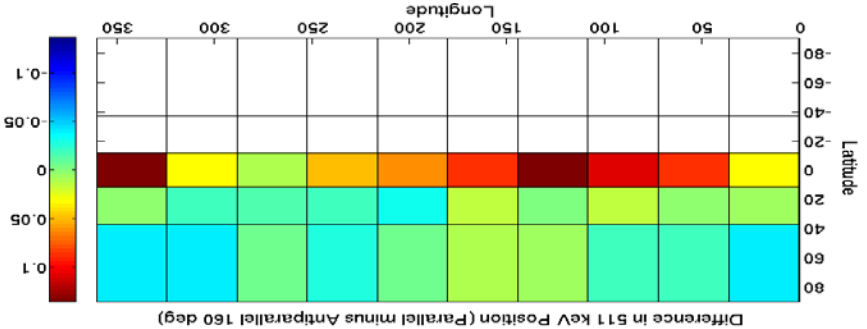
- Only the 10deg rotation about Z and the 160deg rotation produced maps with sufficient coverage parallel to the sensitive axis and antiparallel to make a useful comparison.

Difference Maps





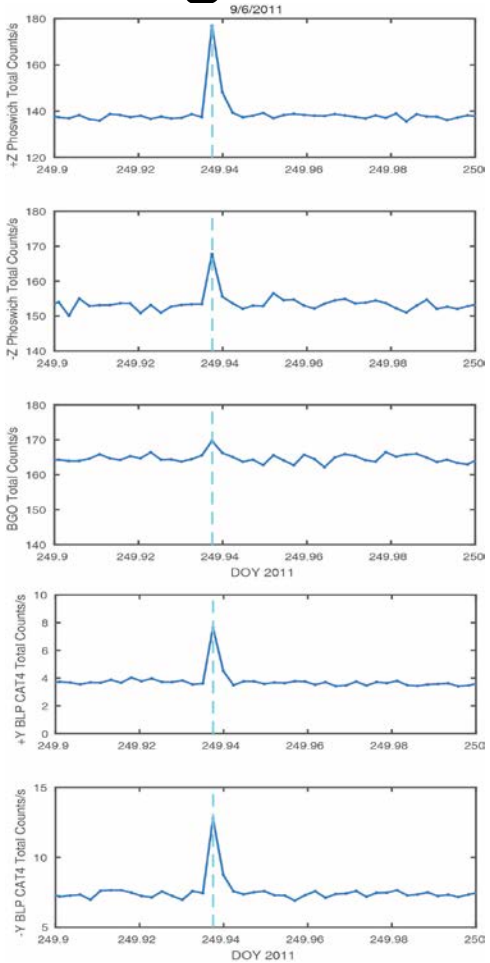


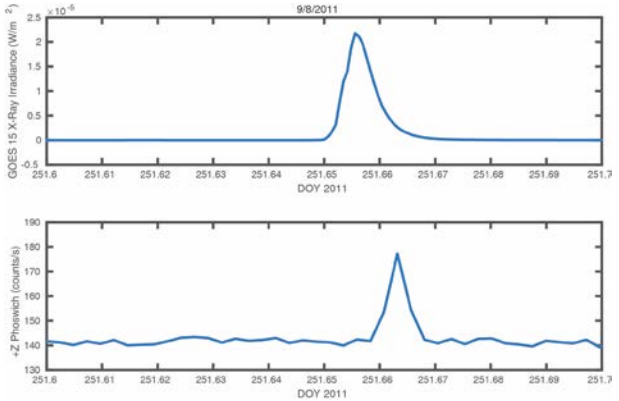


- When we subtracted the antiparallel (y-direction) maps, we were left with only the two left-hand maps. These overlap along the 0° latitude pixels.
- These two stripes are anticorrelated or have maximum correlation when shifted 180°! This could happen if instead of magnetism, the geometry of the spacecraft and instruments controlled the count rate!
- The bottom panel on the right turns the bottom left map upside down. In this position, it correlates well with the top right map. Thus the magnetic-oriented data correlates more poorly than data obtained without magnetic ordering.

What Energetic Events are Seen on Dawn@Vesta

Solar X-rays on Different Dawn Sensors





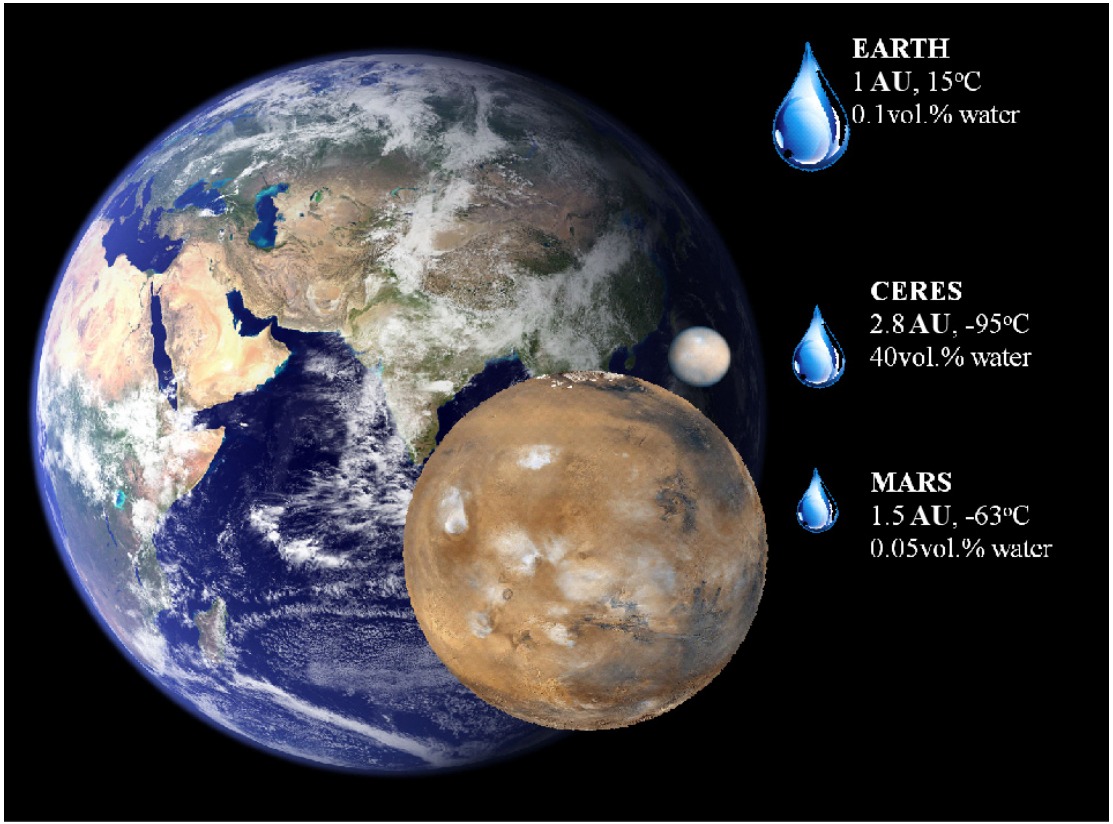
Solar X-rays at Earth and Dawn

- Dawn at Vesta saw X-ray events from the Sun and galactic gamma ray bursts.
- Their times of arrival are those expected from the relative orientations of Vesta and the Earth and their sources (on Sun or in galaxy).
- No energetic events originated at Vesta.

Summary of Vesta Magnetism Study

1. Magnetic field on Vesta too small to affect photomultiplier gain. Orientation of spacecraft relative to Vesta affects signal.
2. All energetic “particle” detections are due to photons from Sun or galaxy. None from Vesta.
3. Vesta does not “stand off” the solar wind and form a bow shock or we would observe fast Fermi electrons.
4. Planetary magnetic field must be too weak to stand off magnetic field above surface of Vesta. $M_{vesta} \leq 10^{9} Tm^{3} \leq 10^{-7} \times M_{Earth}$

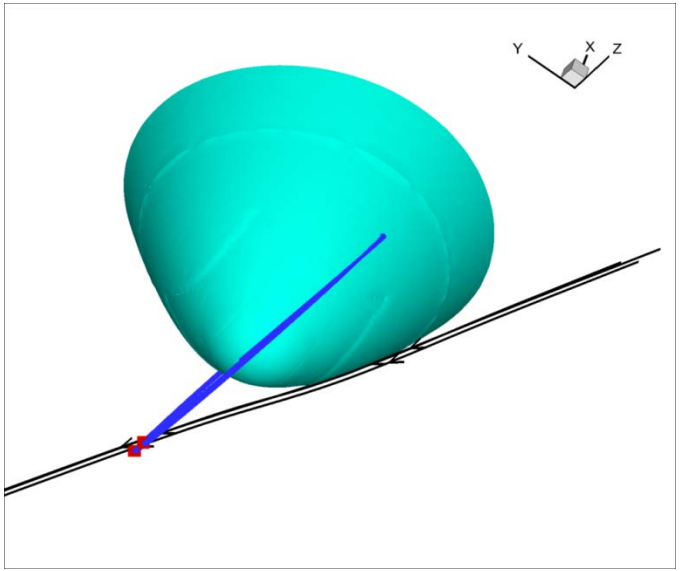
In contrast to Vesta, Ceres is a very wet planet



This gives us another way to have a magnetic field

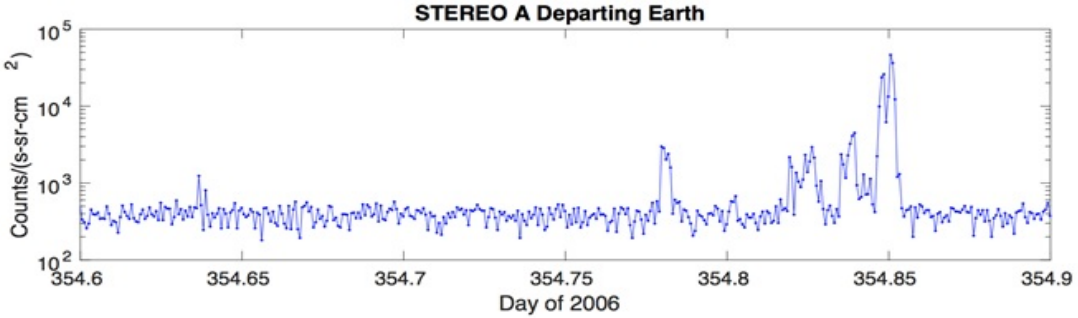
Fermi Accelerated Electrons from Bow Shocks

- The Earth's bow shock is an effective accelerator of electrons by the fast Fermi mechanism.
- The point where the field line is tangent to the shock surface moves quickly across the shock surface and produces a moving mirror that accelerates the electrons from solar wind energies to energies that could be detected by GRaND.
- While we did not see fast Fermi electrons at Vesta, we have seen them at Earth with STEREO and at Ceres with Dawn.
- Dawn is at 10 $R_{ceres.}$



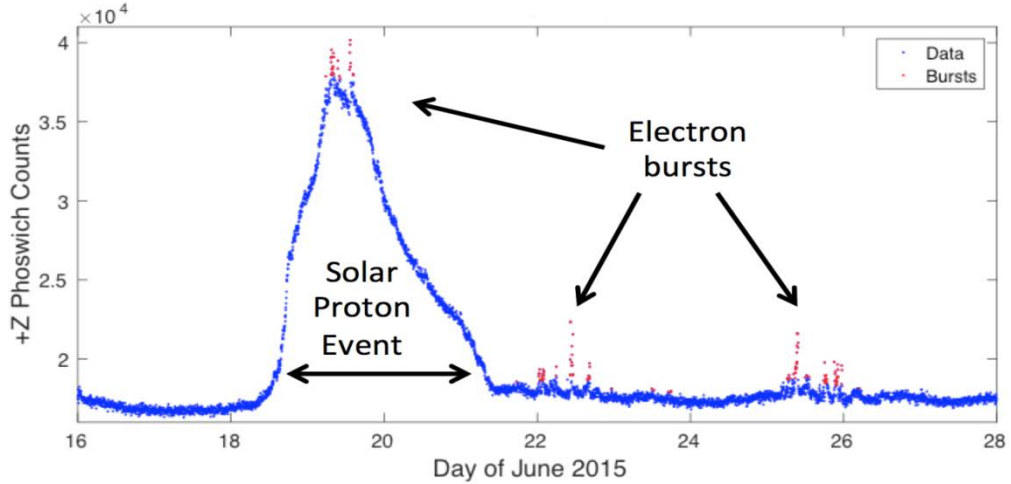
Idealized Symmetric Shock (May be more localized)

Earth Foreshock Energetic Electrons



- Here STEREO is 100 RE from Earth or about 6 times the shock stand off distance.
- The magnetic field direction moves around and when it is tangent to the shock (somewhere), fast Fermi electrons are accelerated sunward along the field line.
- The statistics of these connections varies with distance and the peak fluxes weaken with distance but the “appearance” remains the same.

Arrival at Ceres



- Soon after Dawn arrived at Ceres it twice saw “fast Fermi” accelerated electrons from a temporary bow shock supported by a H_2O exosphere that deflected the solar wind.
- Here during the second of those two occasions we see the signature of the SEP event and the fast Fermi electron acceleration when the detector is orientated toward the expected location of the shock tangent point. These bursts look very similar to those at Earth. The bursts lasted a week consistent with the slow loss of the water exosphere.

Magnetic Moment from Fast Fermi Electrons at Ceres

1. Fast Fermi electrons were observed on only 2 occasions: a distant observation on arrival during a SEP event and for a week after a large SEP event.
2. Our interpretation is that the SEPs release a water atmosphere that becomes ionized and creates an induced magnetosphere that produces a bow shock.
3. At all other times we see only x-ray flare photons from the Sun and gamma ray bursts from the galaxy. The x-ray photon fluxes appear to be weaker than at Ceres due to distance and phase of the solar cycle; the gamma ray bursts are typical gamma ray bursts.
4. There seems to be no significant Ceres magnetic moment. It is also $\leq 10^9 Tm^3$.

Summary

- Even without a high precision magnetometer we are able to search for evidence of magnetic fields at the asteroids Vesta and Ceres.
- We used a coarse magnetically sensitive component in the GRaND instrument but found no strong field.
- We then looked for reflected fast Fermi electrons and found none, implying not even a “weak” field capable of deflecting solar wind at Vesta.
- At Ceres we did see such reflected electrons but they were only present for a short period after the arrival of clouds of Solar Energetic Protons that produced a water exosphere.
- Ceres is wet and can produce an induced magnetosphere but it seems also to have no measurable intrinsic magnetic field.