Waves associated with interplanetary shocks driven by stream interactions.

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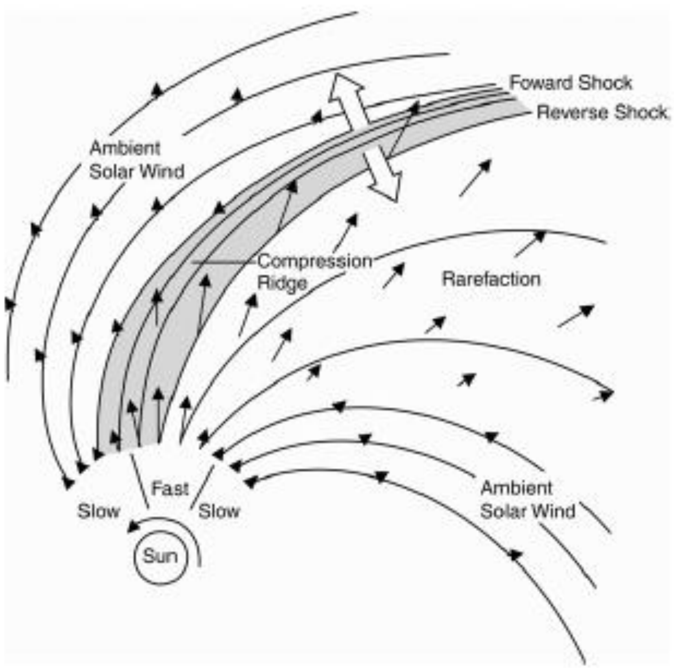
Questions:

1.- How often do we see proton excited waves at IP shocks?
2.- what are their properties, and dependence on shock parameters, $\theta_{Bn,}$ M_{ms}?

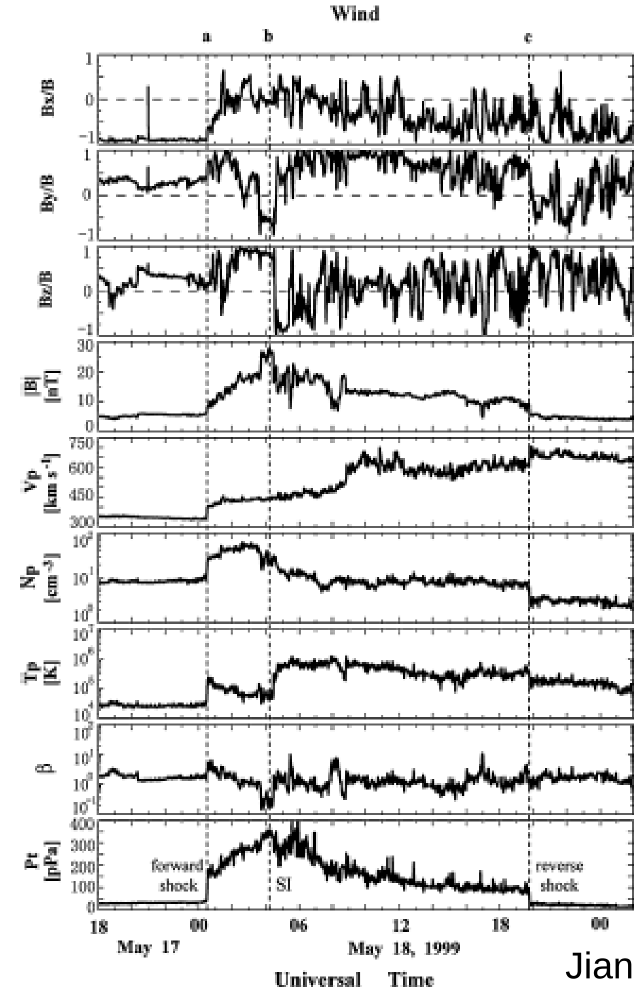
Outline of talk:

-Stream Interaction Shocks observed by STEREO A and B, 2007-2009
-Quasi-Perpendicular shock profiles and waves
-Quasi-Parallel shock profiles and waves
- Summary

During solar minimum most interplanetary shocks are produced by stream interactions:



CIR/SIR sketch



Jian et al., 2006

Observation of CIR/SIR

- Because the magnetic and velocity structure is not co-aligned with the rotational axis, fast streams collide with slow streams as the Sun rotates.

- As streams move outward in the solar wind, the interaction regions steepen, the Alfvén and sonic speeds drop, and shocks form.

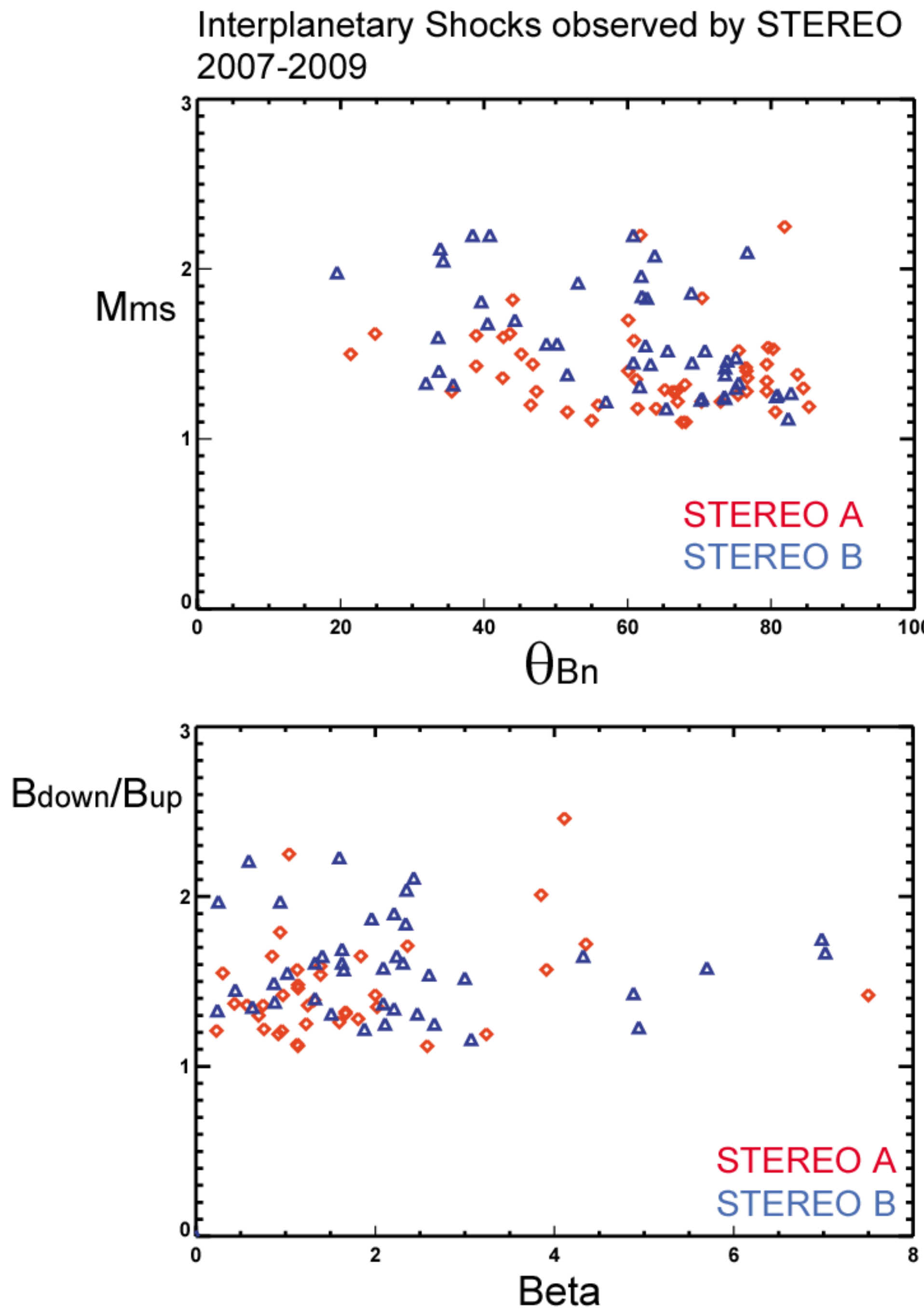
STEREO shocks:

- SIRs produce weak shocks near the Sun and strong shocks far from the Sun. Beta of the plasma remains "high" everywhere.

- During 2007-2009 STEREO spacecraft have observed around 100 low-moderate Mach number (M_{ms} 1.1~2.5) shocks.

- Most of these shocks are quasi-perpendicular (θ_{Bn} > 45°), with only 20 quasi-parallel (θ_{Bn} < 45°), shocks.

- Plasma beta is up to 7.5



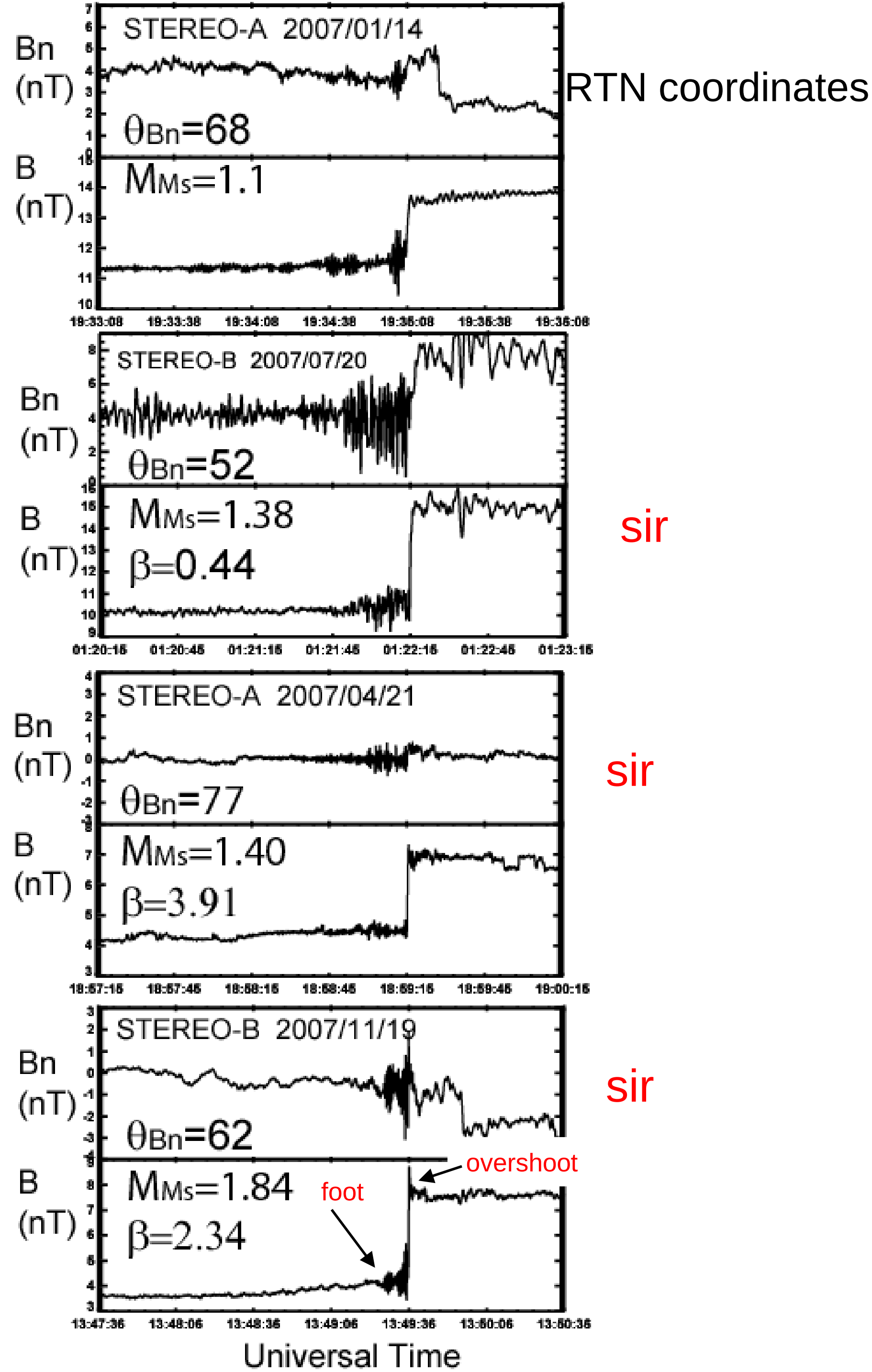
Quasi-Perpendicular Shocks

- Whistler precursors are found upstream of quasi-perpendicular shocks. In all cases the shock profile is sharp and well defined.

- When the Mach number is low this precursor is more prominent and can extend further upstream.

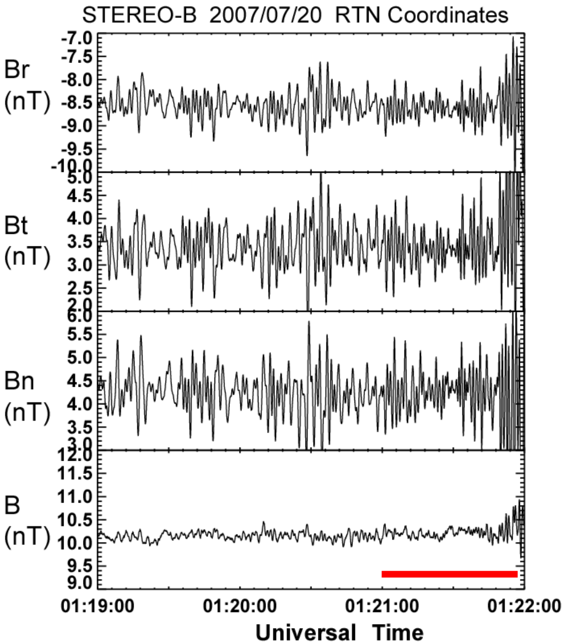
- As Mach number increases, the shock profile changes and starts to develop a foot and overshoot associated with ion reflection and gyration.

- Note that a whistler precursor can be superposed on the foot region, so that the shock has characteristics of both, subcritical and supercritical shock.

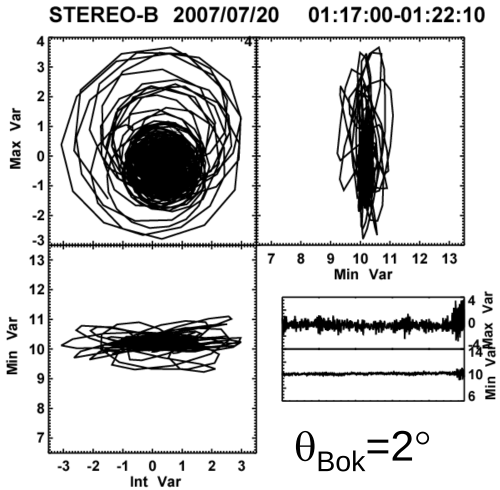


Quasi-Perpendicular Shocks Upstream Waves

Transverse whistler

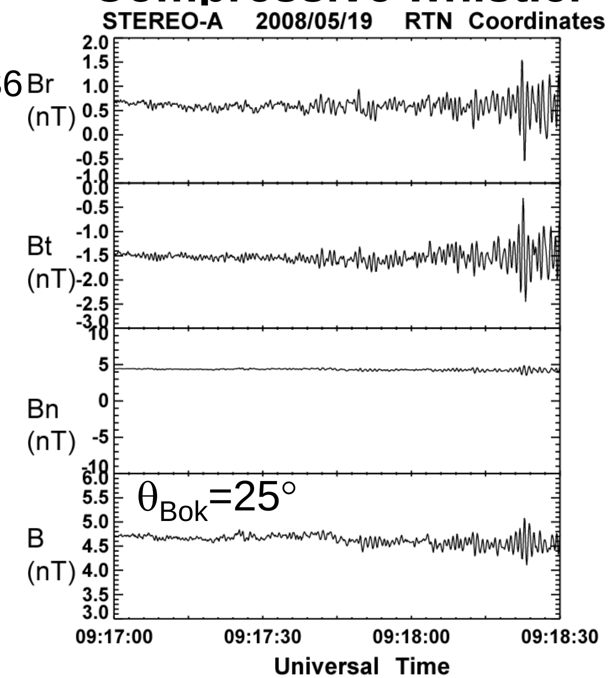


θ_{Bn}=52
M_{ms}=1.38
β=0.44



θ_{Bn}=77
M_{ms}=1.36
β=1.14

Compressive whistler



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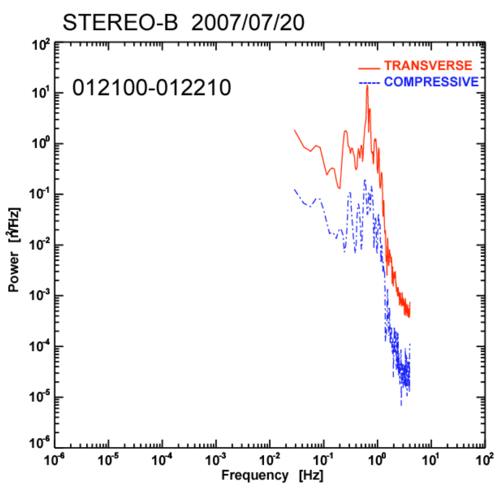
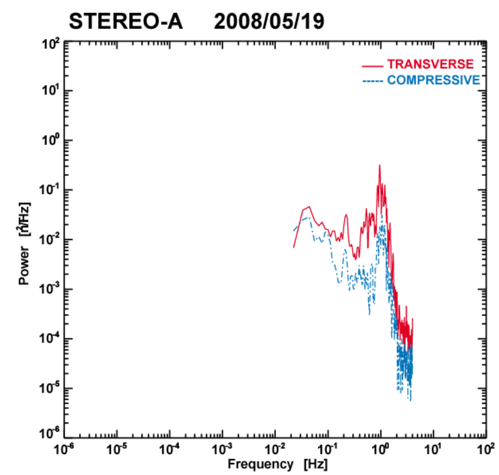


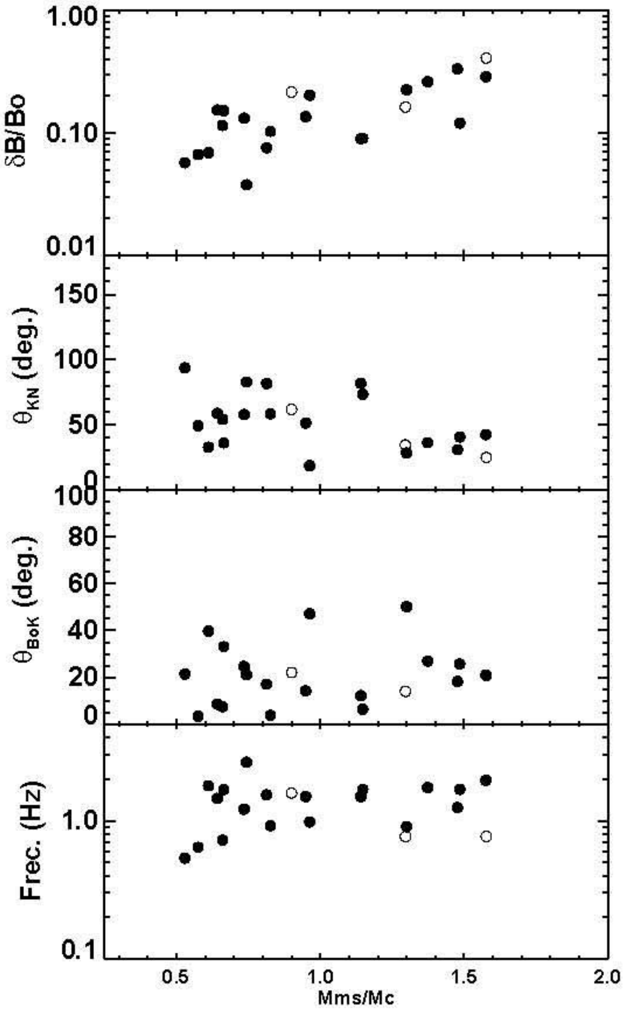
- Upstream whistlers propagate over a range of angles to the IMF and occur over a broad range of plasma conditions.
- Oblique propagating whistlers show a large compressive component.



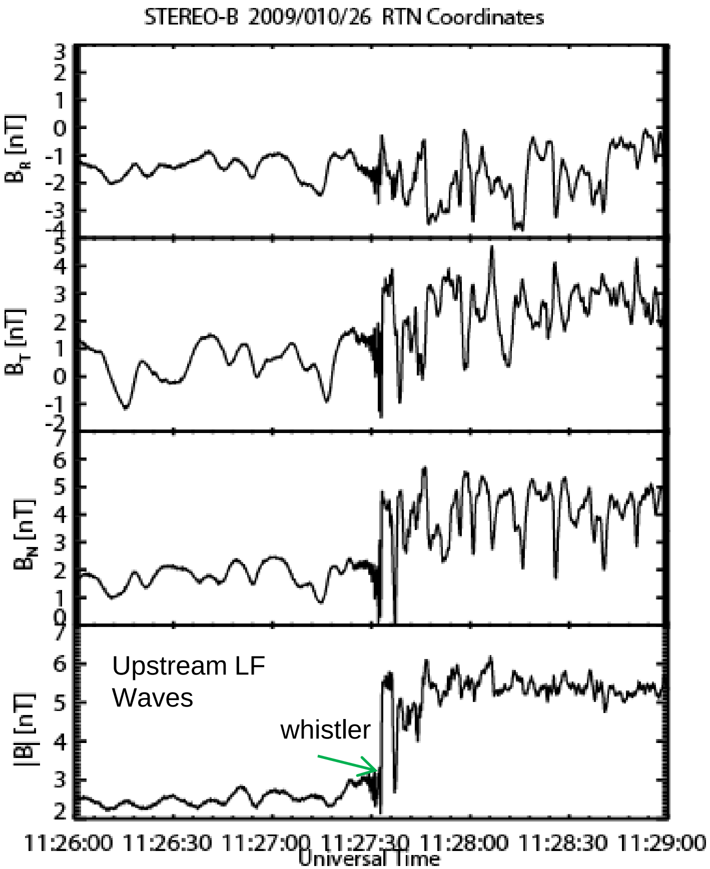
Summary upstream whistler properties

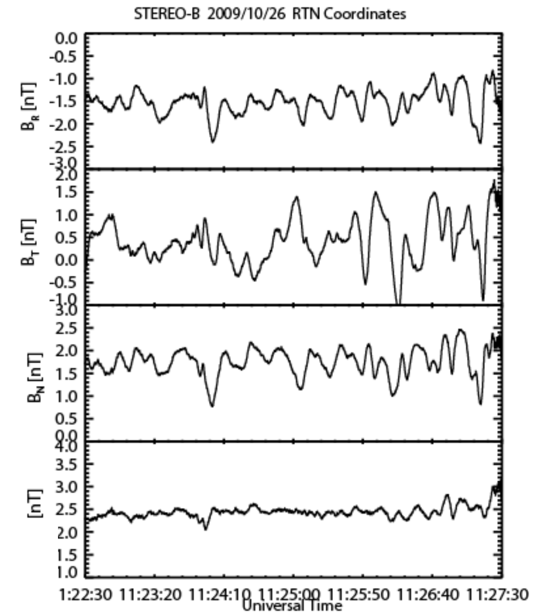
-Amplitude increases with Mach number
-θ_{kn} tends to be large
-In the majority of the cases $\theta_{Bok} < 30°$
-Waves frequency, f~1 Hz (s/c frame).

Shock generated?
Electron generated?

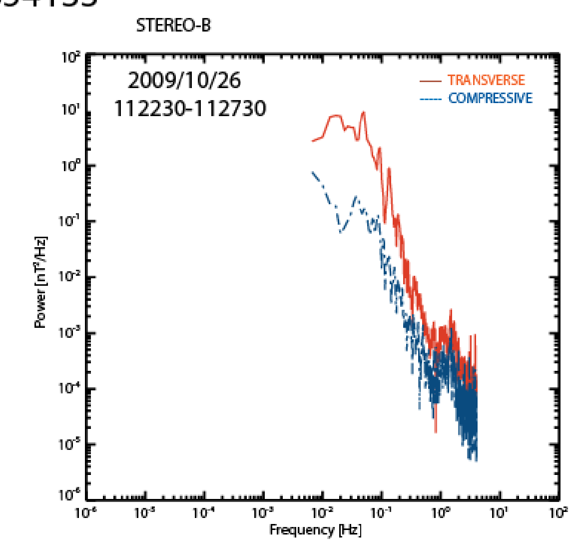


In a few cases, quasi-perpendicular shocks(θ_{Bn}=68, Oct 26, 2009) have an upstream region with low frequency, f ~0.01-0.1 Hz waves , which resemble fluctuations upstream of quasi-paralel shocks…



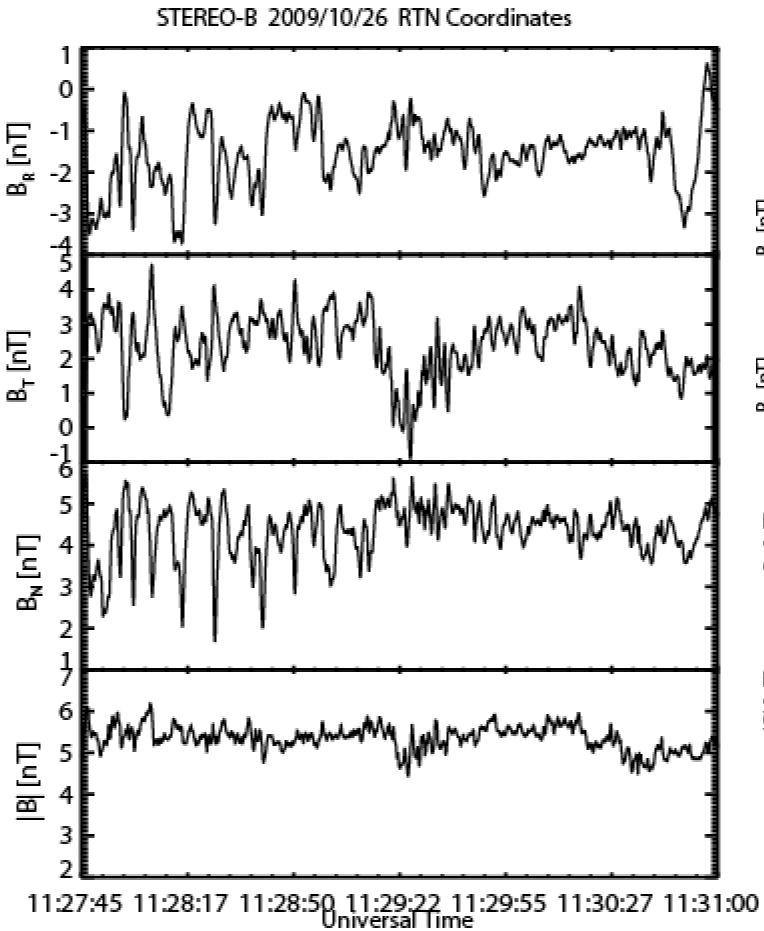


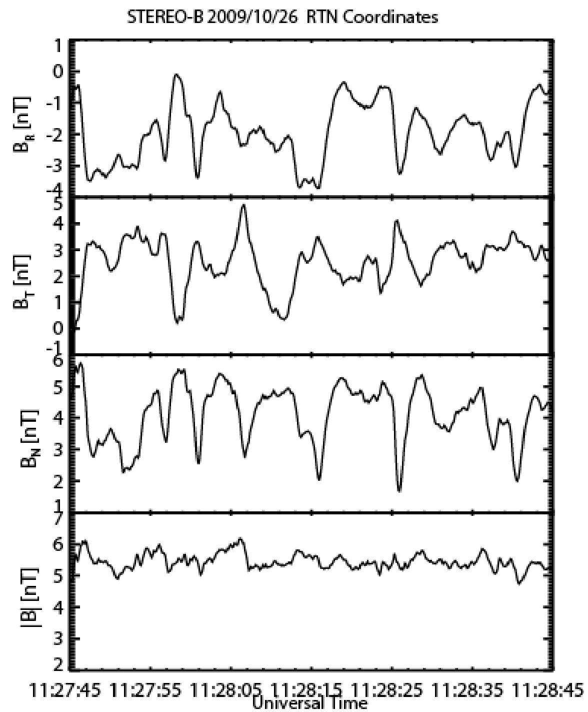
$\Theta_{B_{ok}}$=9.67644
$\Theta_{B_{oi}}$=84.4538
Int/Min=9.9654133

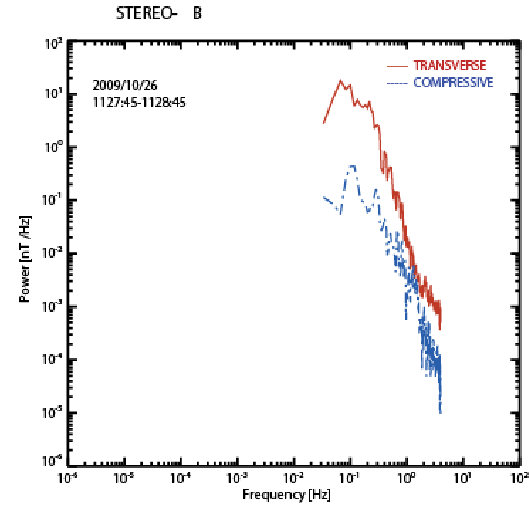


Krauss-Varban et al. (2008) hybrid simulations: dilute ion beams upstream of oblique IP shocks can generate upstream compressive fluctuations that can impact the shock and change θ_{Bn} locally, leading to more backstreaming ions and more wave particle interactions.

Enhanced downstream waves, quasi-perp (θ_{Bn}=67)

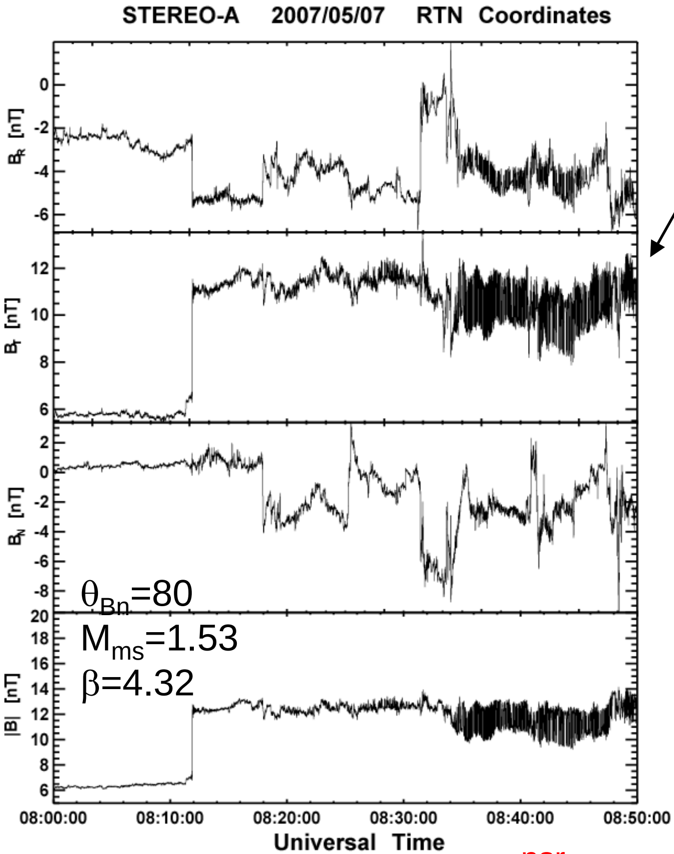






Waves downstream of quasi-perp shocks

Mirror mode storms



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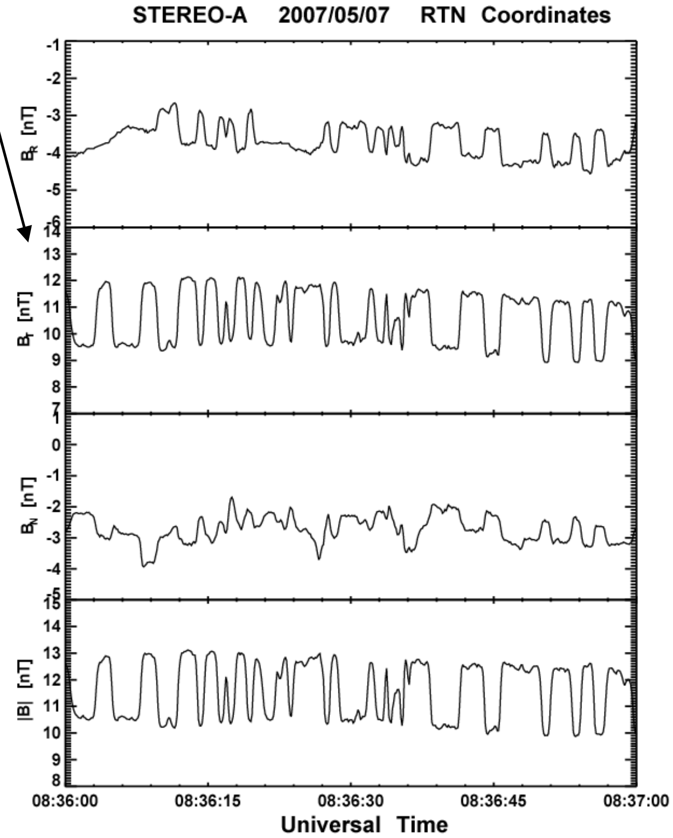
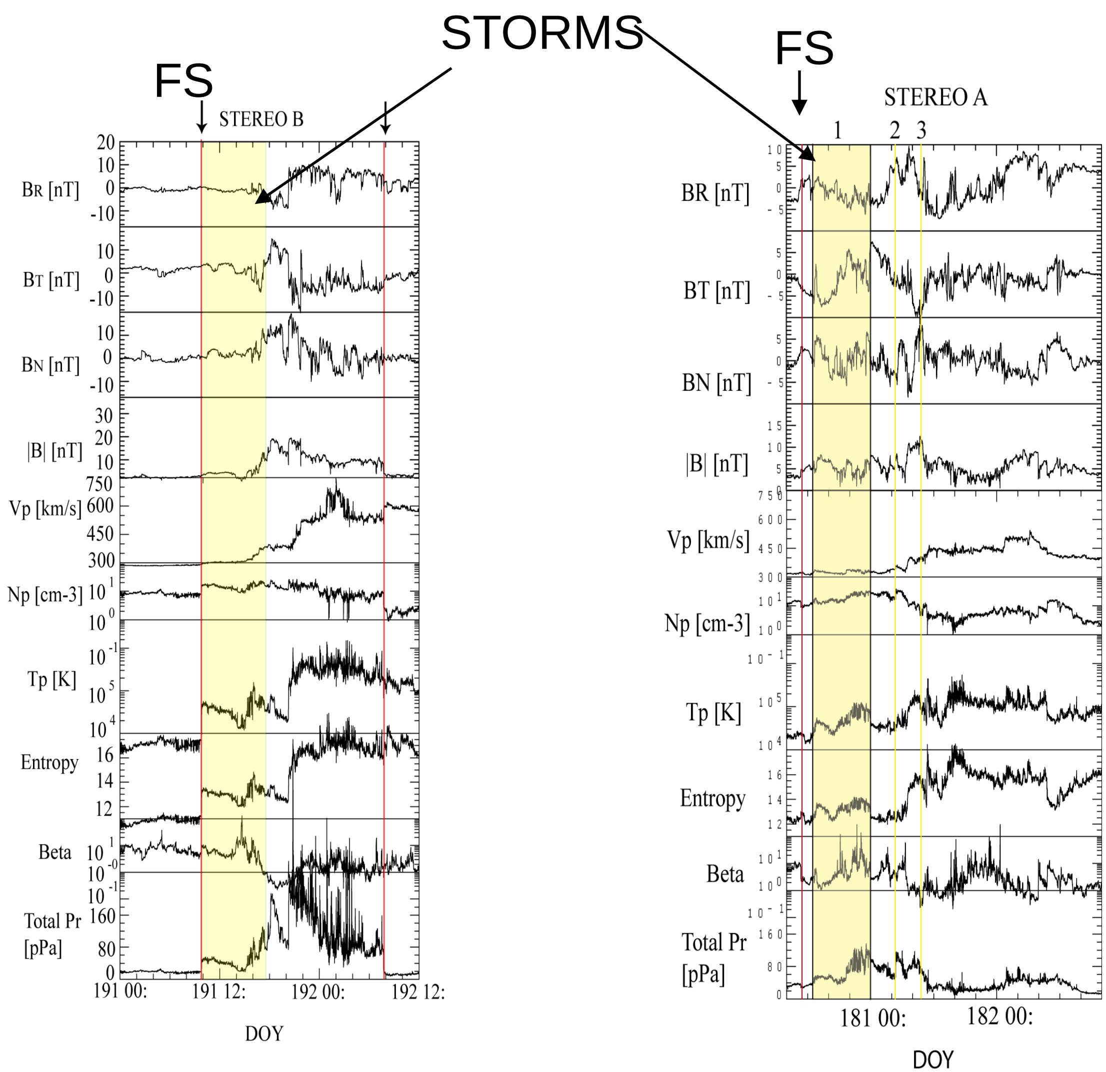
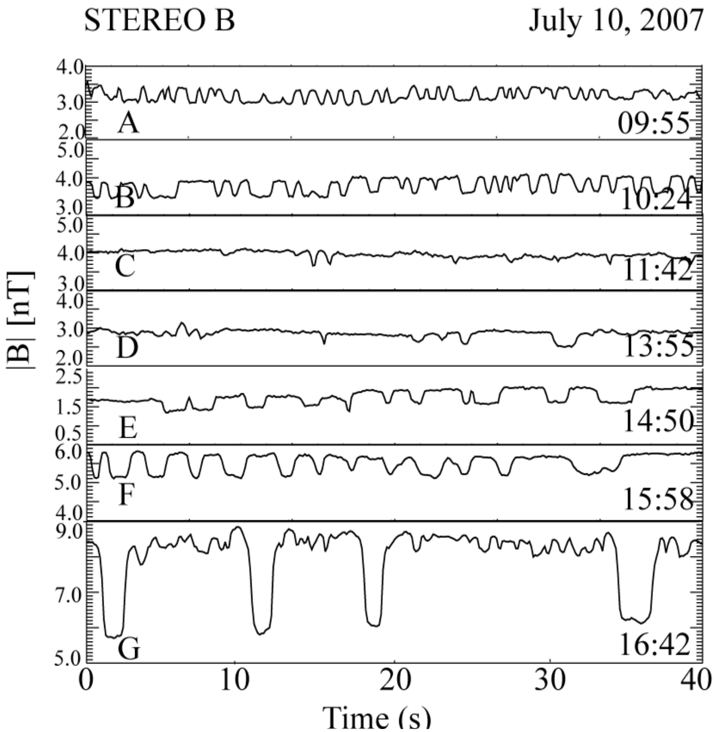
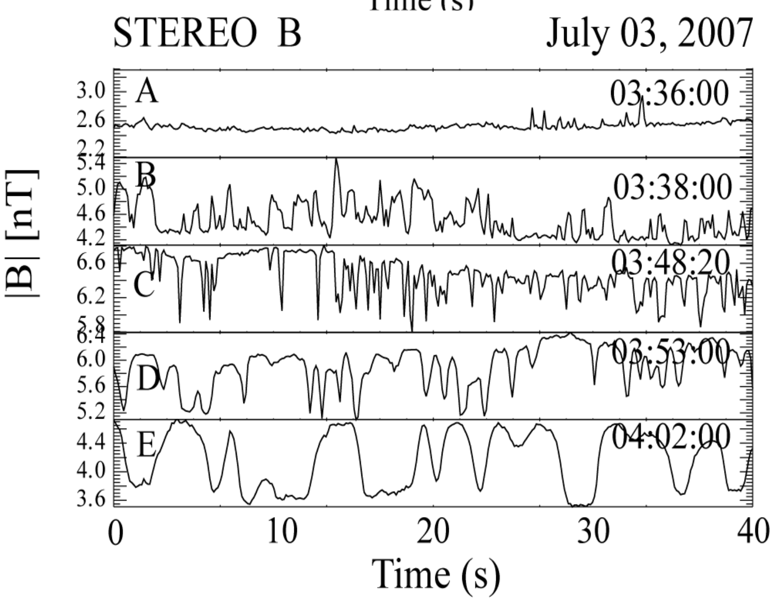


Mirror mode storms are observed downstream of quasi-perpendicular shocks. They can appear with the “typical” mirror mode drop shape, or as peaks in the field magnitude.

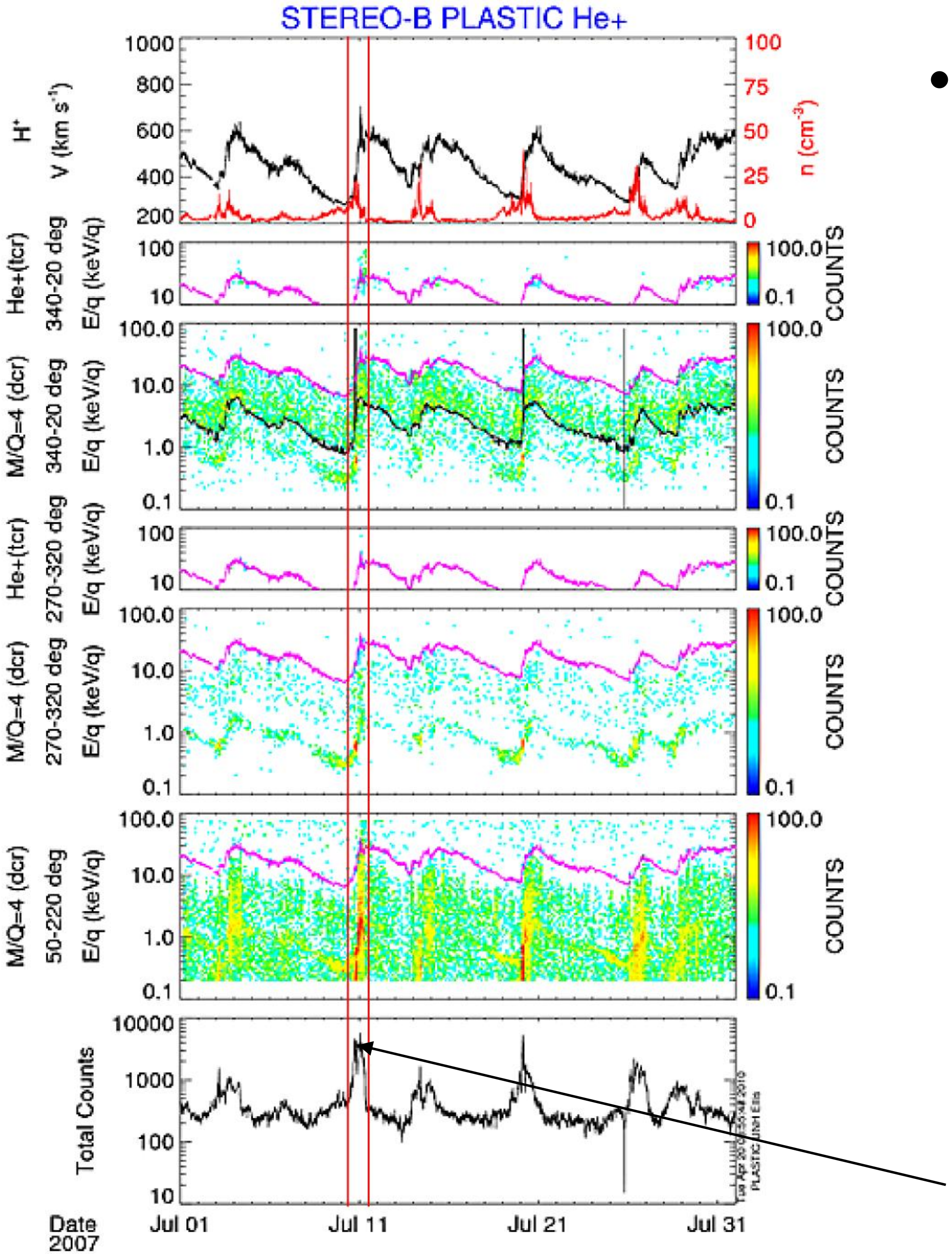
- Mirror mode storms (YELLOW) have been frequently found downstream of forward SIR shocks, and also inside the SIR (not close to the FW shock)







- Mirror mode structures inside the storm follow an evolutionary pattern. They appear first as small amplitude peaks which may sometimes grow in amplitude and disappear. Then holes are observed becoming large amplitude structures.
- This is in agreement with mirror mode observations in planetary magnetosheaths (Earth, Jupiter, Saturn).
- We believe the shape of the structures is controlled by the combination of β plus temperature anisotropies (Gènot, et al., 2009).



- Mirror mode events are related to Helium suprathermal events observed by PLASTIC.

Helium suprathermal tail event inside a SIR in the same period where mirror mode storms where found. Red lines mark the edges of the SIR.

In this event the mirror mode storm lasts 8 hours!

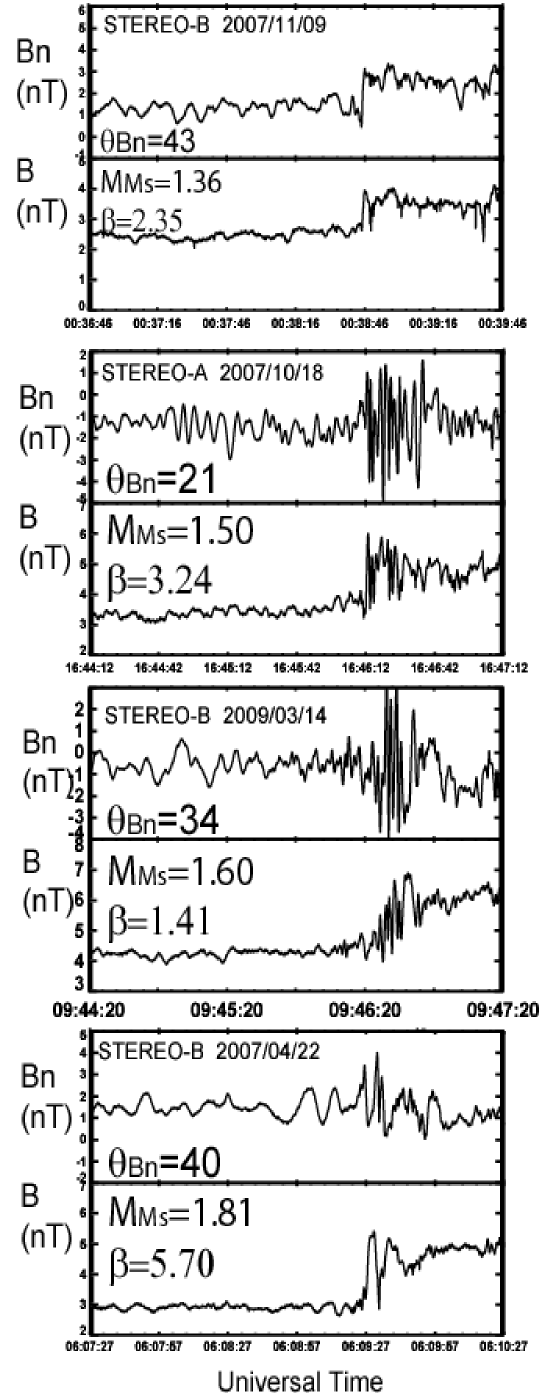
-Helium presence may be important for mirror mode growth overcoming ion cyclotron waves growth rate.

Quasi-Parallel Shocks

- Shock transition is not as sharp as in the quasi-perpendicular case

- The upstream spectra is formed by higher frequency waves that appear as whistler trains whose characteristics can be slighlty modified probaby by reflected and/or leaked ions, and lower frequency almost circularly polarized waves which may be locally generated.

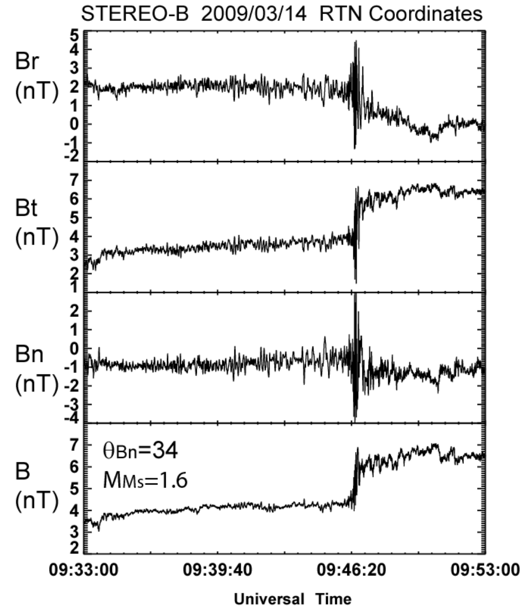
Studying particle distributions would give us insight on wave origin

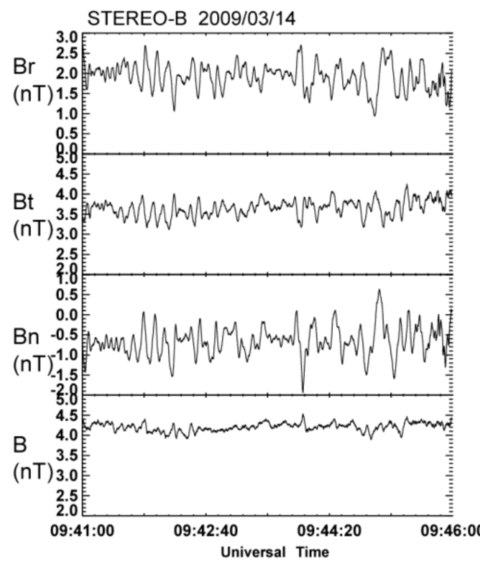


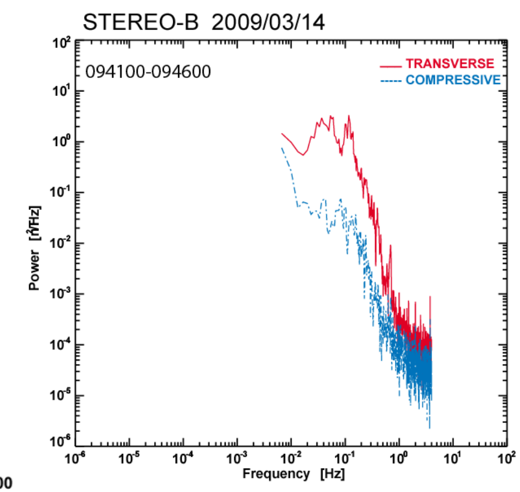
Waves upstream of quasi-parallel shocks

- A double peak spectra is commonly found. Most of these waves are transverse and propagate at small (<10°) angles to the background field, B_o.

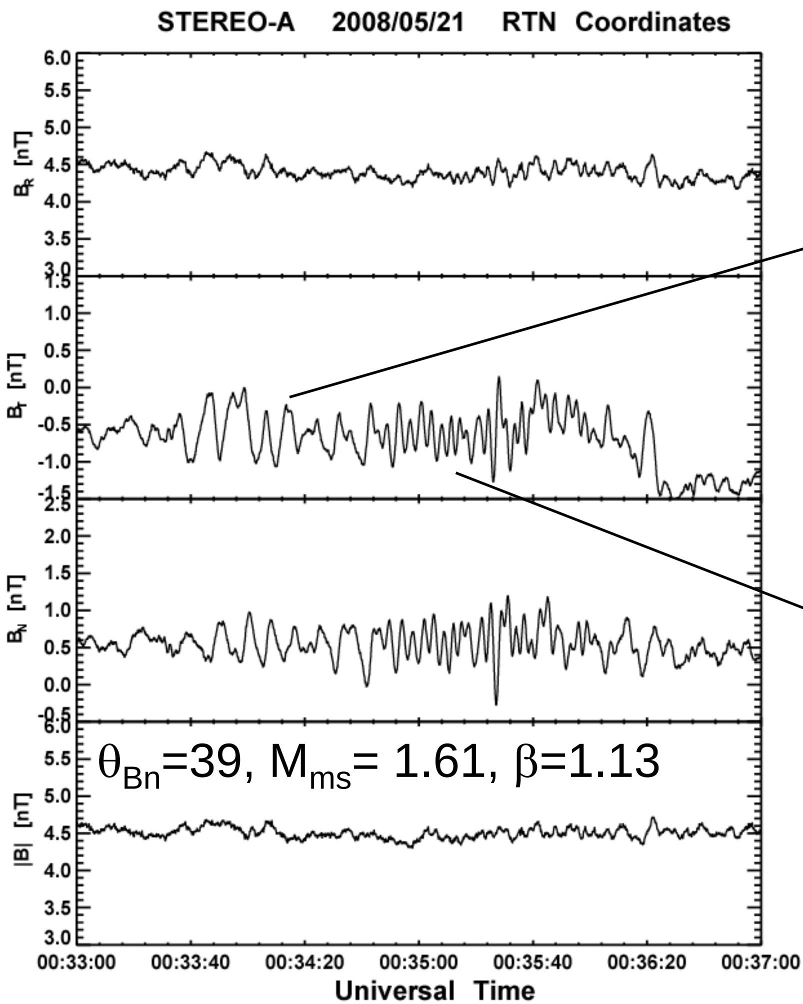
- This is in contrast to waves in planetary foreshocks, where most fluctuations are very compressive.

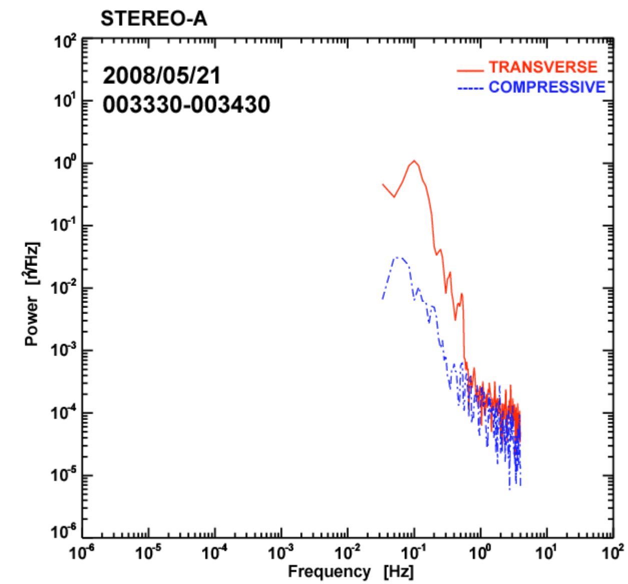


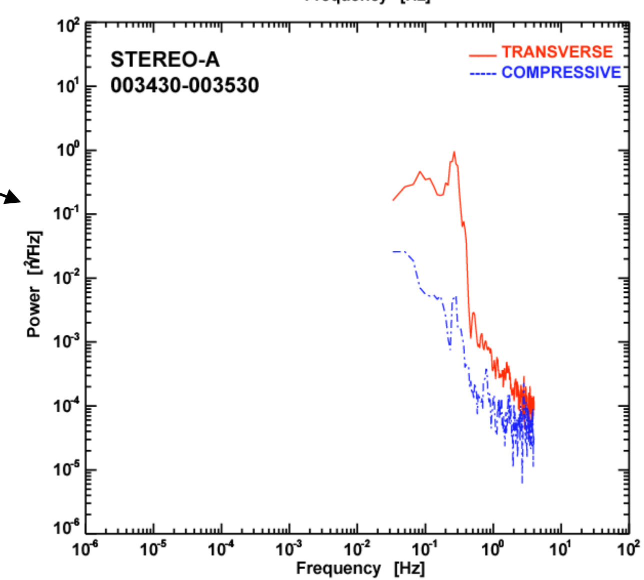




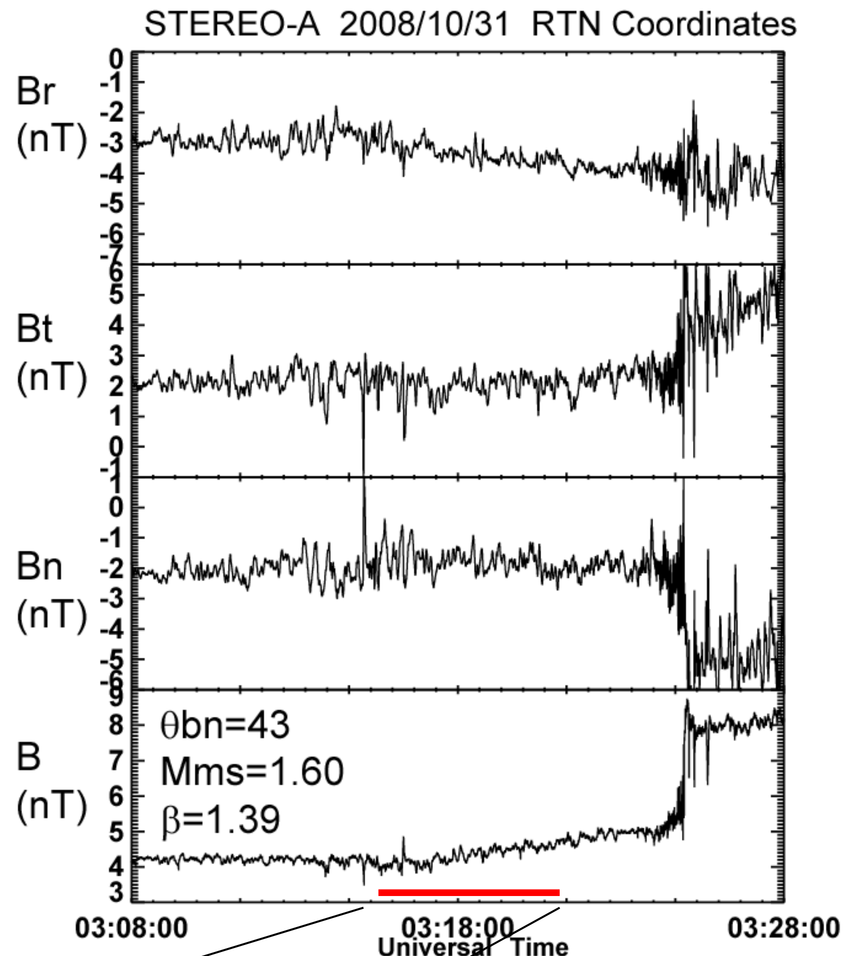
It is probable that the high frequency component is related to whistler precursors which have been modified in the foreshock by backstreaming ions. The lower frequency waves may be generated locally via a beam driven instability

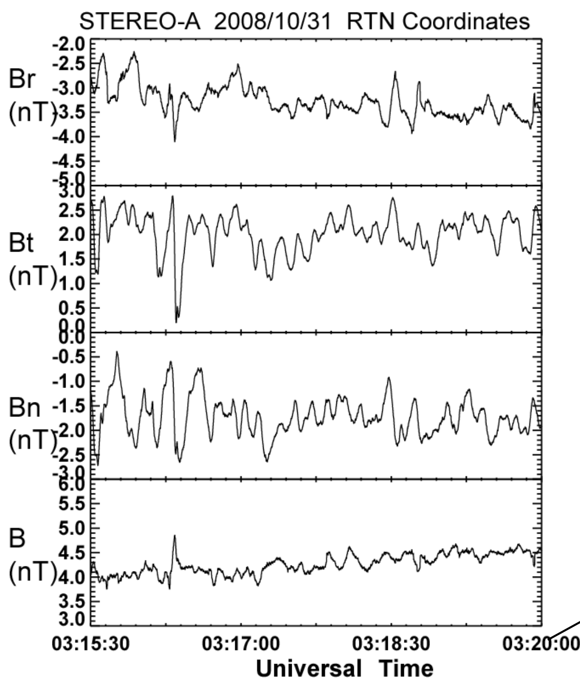






• Although most of the waves upstream of the quasi-parallel foward shocks observed to date by STEREO are transverse, there is evidence that some steepening may take place forming "shocklets" in few regions:

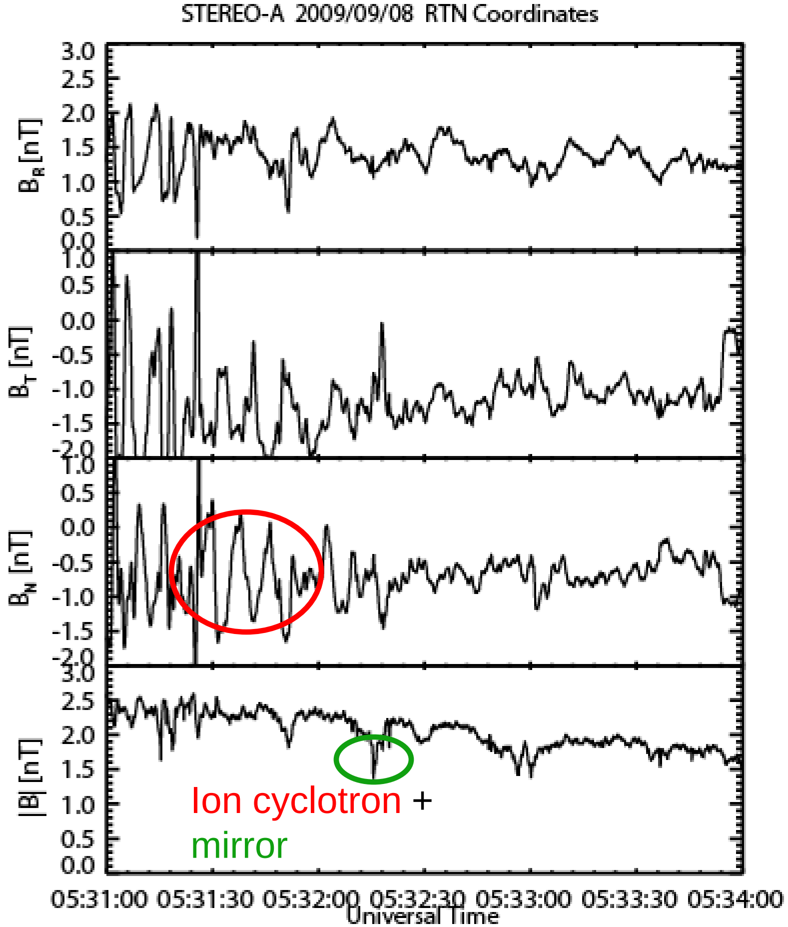


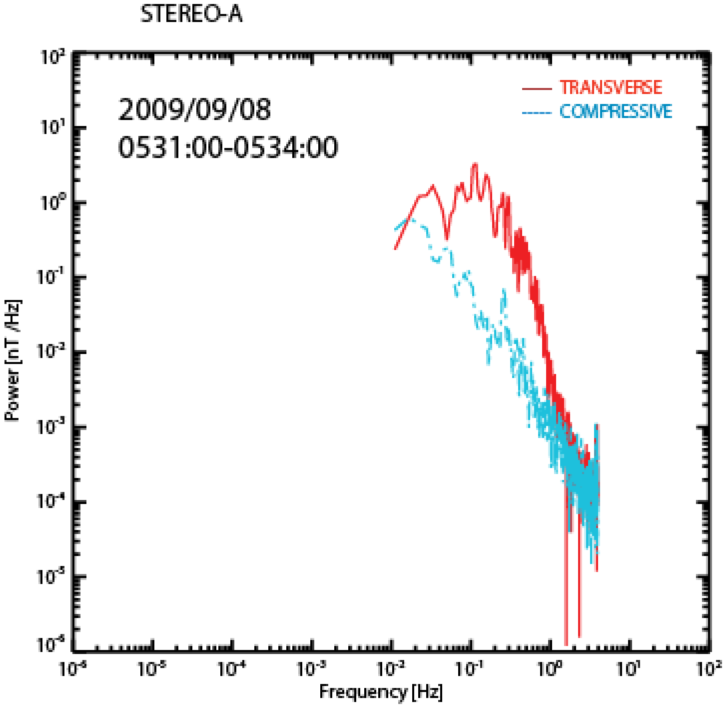


In this case the ion foreshock extended 2.7 x 10^5 Km.

Evidence of shocklet-like structures were found by Wilson et al. (2009) upstream of IP shocks observed by WIND

Waves downstream of quasi-par shocks, θ_{Bn}=32, M_{ms}=1.87





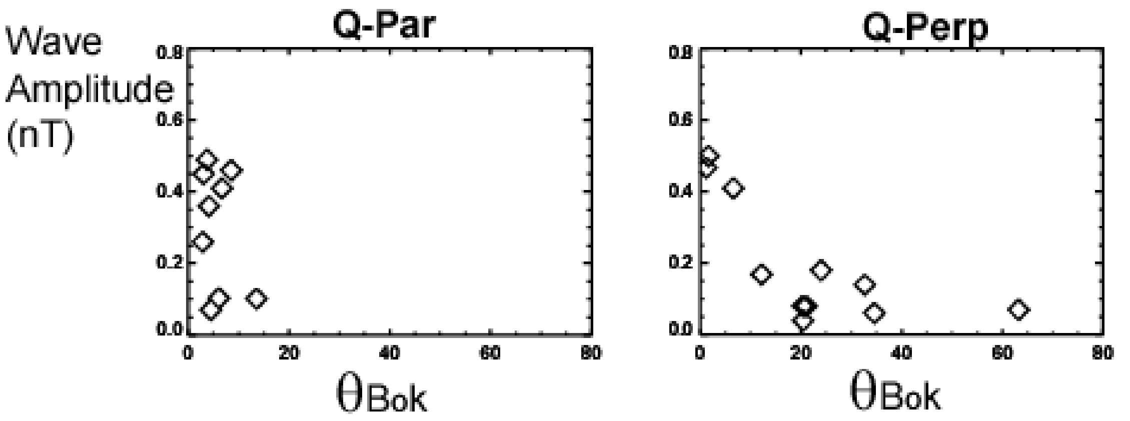
$\Theta_{B_{ok}}$=36.7305

$\Theta_{B_{oi}}$=74.6917

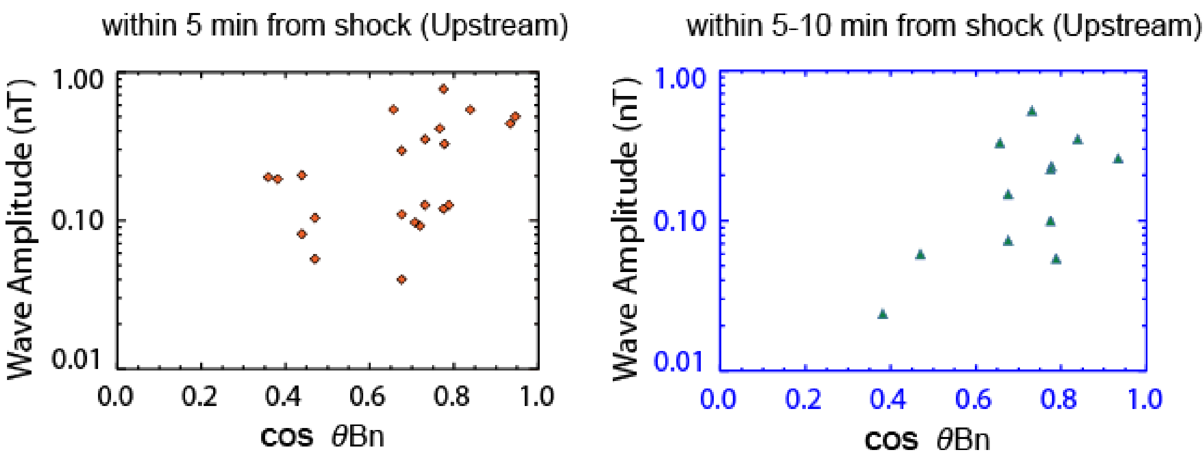
Int/Min=2.1315249

Wave amplitude observed upstream from shocks

- Waves upstream from quasi-parallel shocks propagate at small angles to B_o. This is in contrast to whistler precursors associated with quasi-perpendicular shocks, which can propagate obliquely. Whistler amplitude drops with θ_{Bok}.

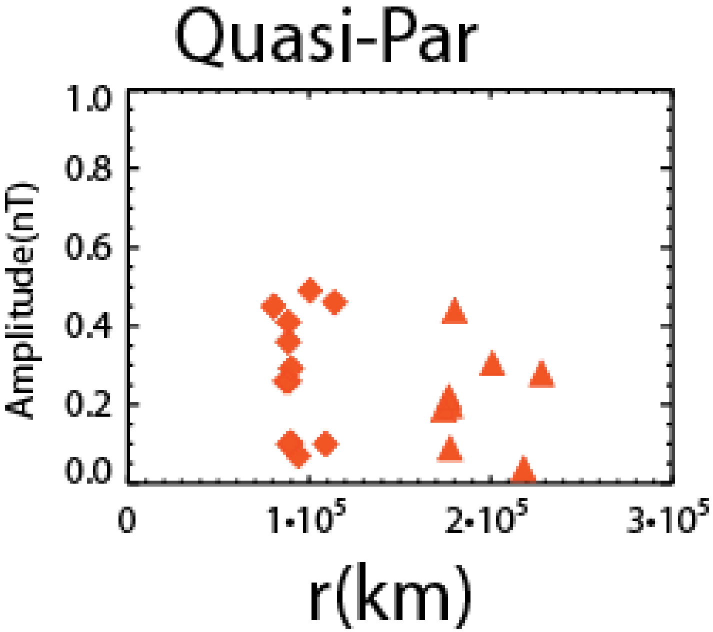


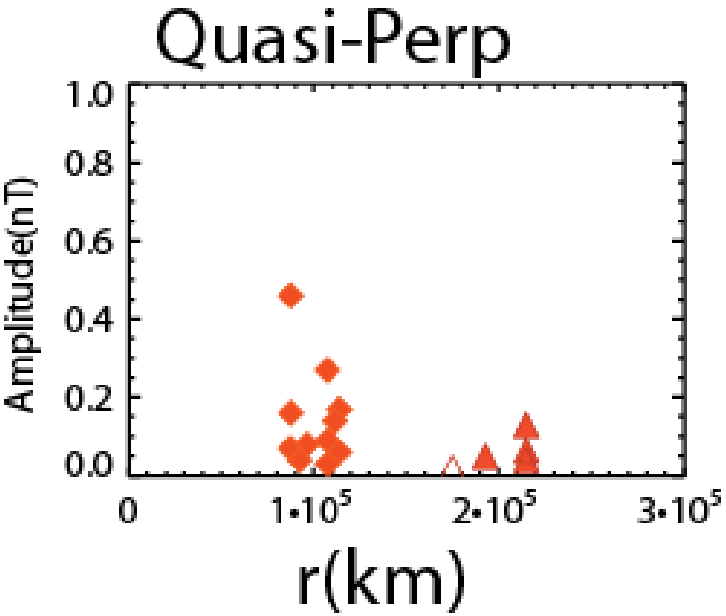
- Wave amplitude changes with θ_{Bn} and distance from shock



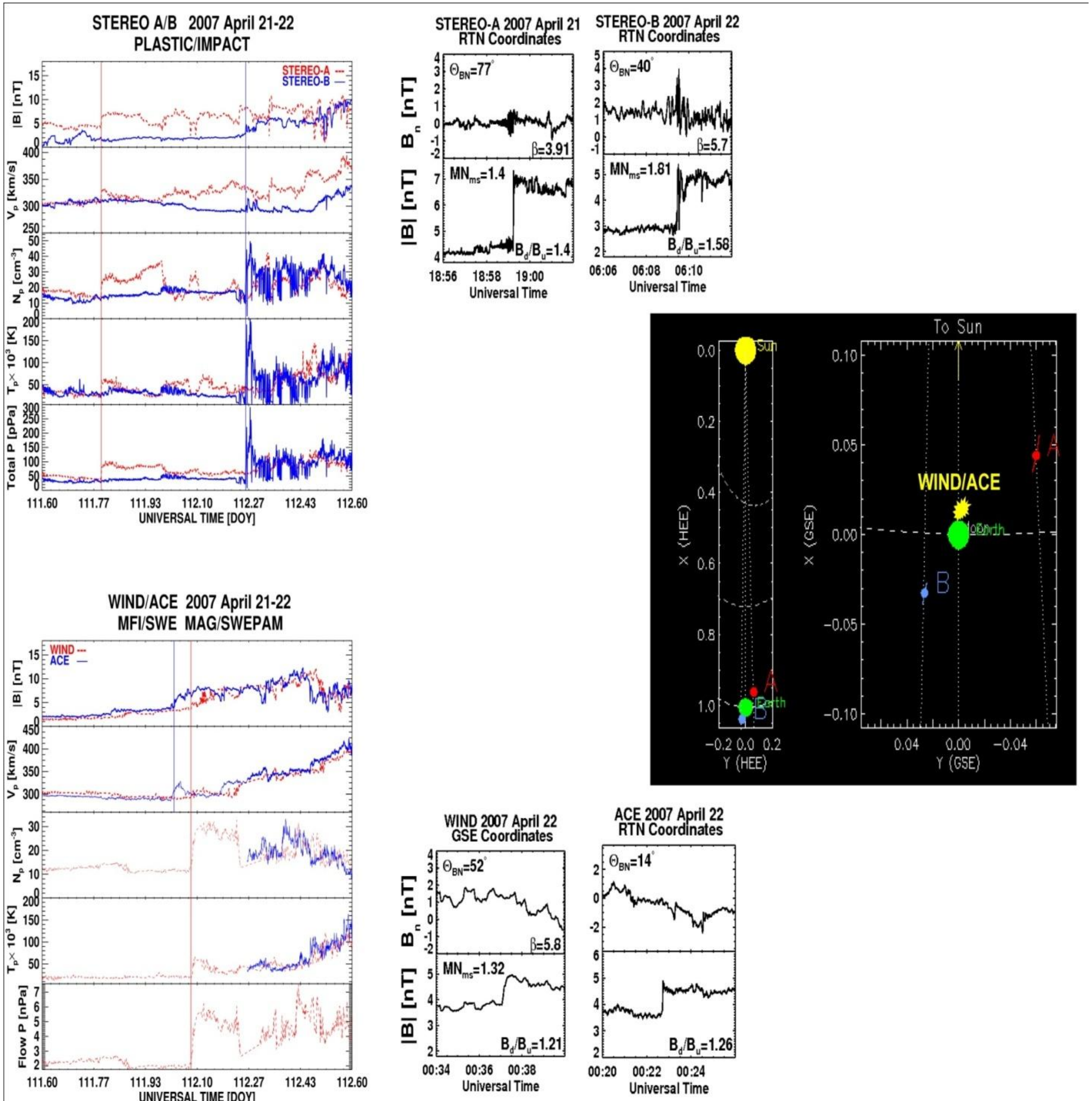
Mms=1.5-2.08

Large Foreshock extensions, up to ~30 R_E





No time to go into details on shock changes of geometry with helio-longitude and consequences on wave spectra



Conclusions

- STEREO observations during the extended solar minimum have provided a good opportunity to study interplanetary shocks with low to moderate Mach numbers (M_{ms} 1.1~2.5) generated by stream interactions.

- Most shocks are quasi-perpendicular and accompanied by whistler precursors.
- While some shocks are laminar, with a well defined transition, other show features like a foot and overshoot combined with whistler precursors. This tells us that there is not a sharp separation between subcritical and supercritical shocks.
- Whistler characteristics are variable, some propagate at small angles and are non-compressive circularly polarized. Others propagate at oblique angles and show a compresive component.
- Mirror mode storms have been observed downstream from quasi-perpendicular shocks.

- Quasi-parallel IP shocks are preceeded by foreshocks, where a mixture of waves exists. In contrast to planetary foreshocks, most of these waves are non compressive, but there are a few regions where steepened shocklet-like structures develop. Wave spectra seems to be formed by both, whistler waves and locally generated lower frequency fluctuations.
- Upstream wave amplitude drops for quasi-perpendicular shocks, but this drop is not as dramatic as for Earth's bow shock.

Future work

- Comparison of wave spectra with shock acceleration models.
- Origin of mirror mode storms. Helium related?
- Ion distributions, wave origin.

- Models need to take into account the fact that wave characteristics are variable as well as the shock structure.

- Similar studies for ICME shocks