Observations of Large Amplitude, Monochromatic Whistlers at Stream Interaction Regions

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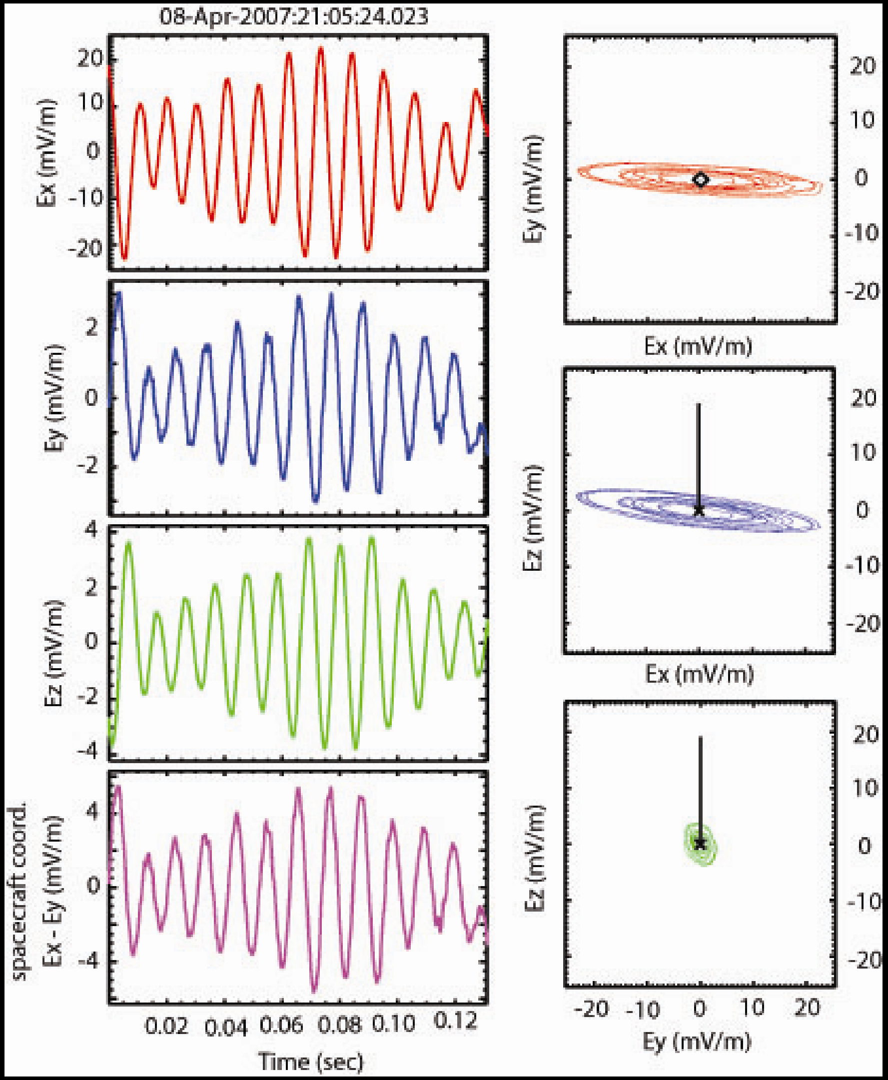
Introduction

- Whistler frequency range waves prevalent in solar wind near stream interfaces (Beinroth and Neubauer [1981], Lin et al. [1998]).
- Previous time-averaged spectral measurements, $E<0.1$ mV/m (e.g. Lin et al. [1998])
- Previous waveform measurements from Wind TDS of whistler waves at ICMEs. E~0.4 mV/m (Moullard et al. [2001]).
- Wave instabilities, in addition to collisions, maintains isotropy of core/halo electrons (Stverak et al. [2008])

Monochromatic waves

If whistler mode then largest in solar wind observed thus far. Waves only observable on STEREO TDS

Large amplitude (~100 mV/m), monochromatic whistler mode waves previously seen in magnetosphere on STEREO by Cattell et al. [2008].



STEREO FA coordinates

Wave groups

Automated search identified few thousand monochromatic waveforms in solar wind.

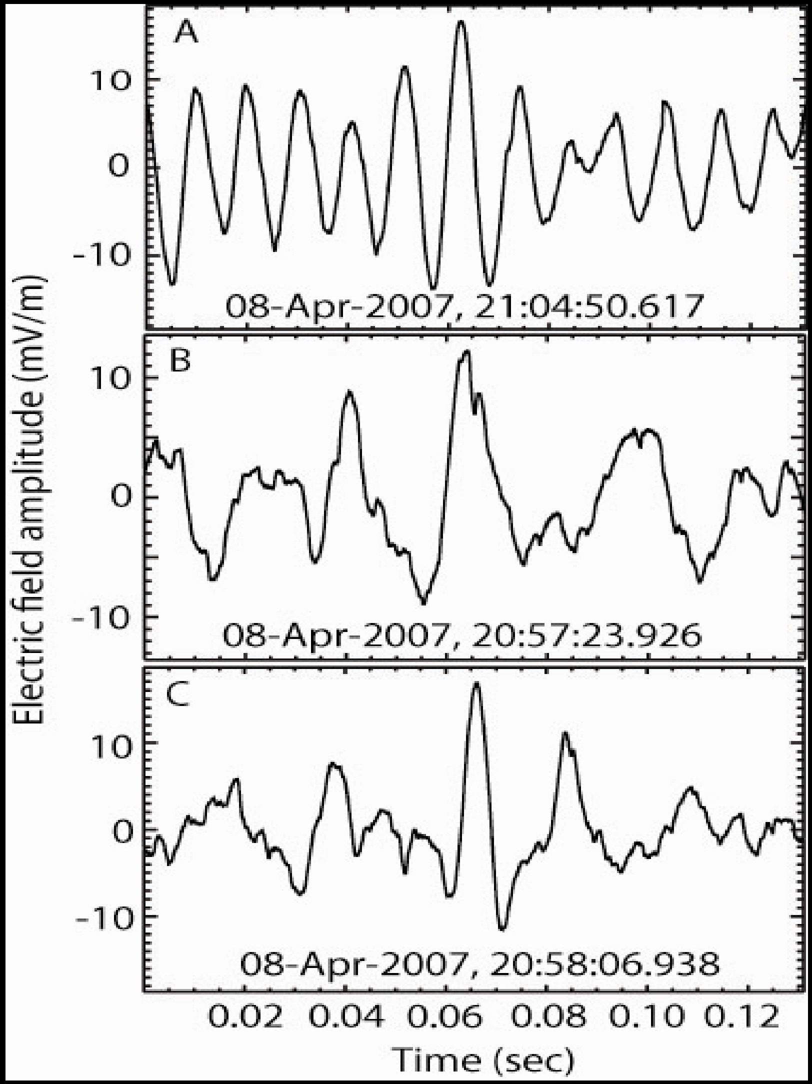
Often observed in groups of up to a few dozen that last from a few seconds to minutes.

Classified waves by eye into 3 types

These groups are found at SIRs and some shocks

a)	*STA*	*STB*
A-type	405	269
B-type	190	220
C-type	117	210
Total (w/ C)	712	699
Total (w/o C)	595	489

April 1st 2007 - April 30th 2009

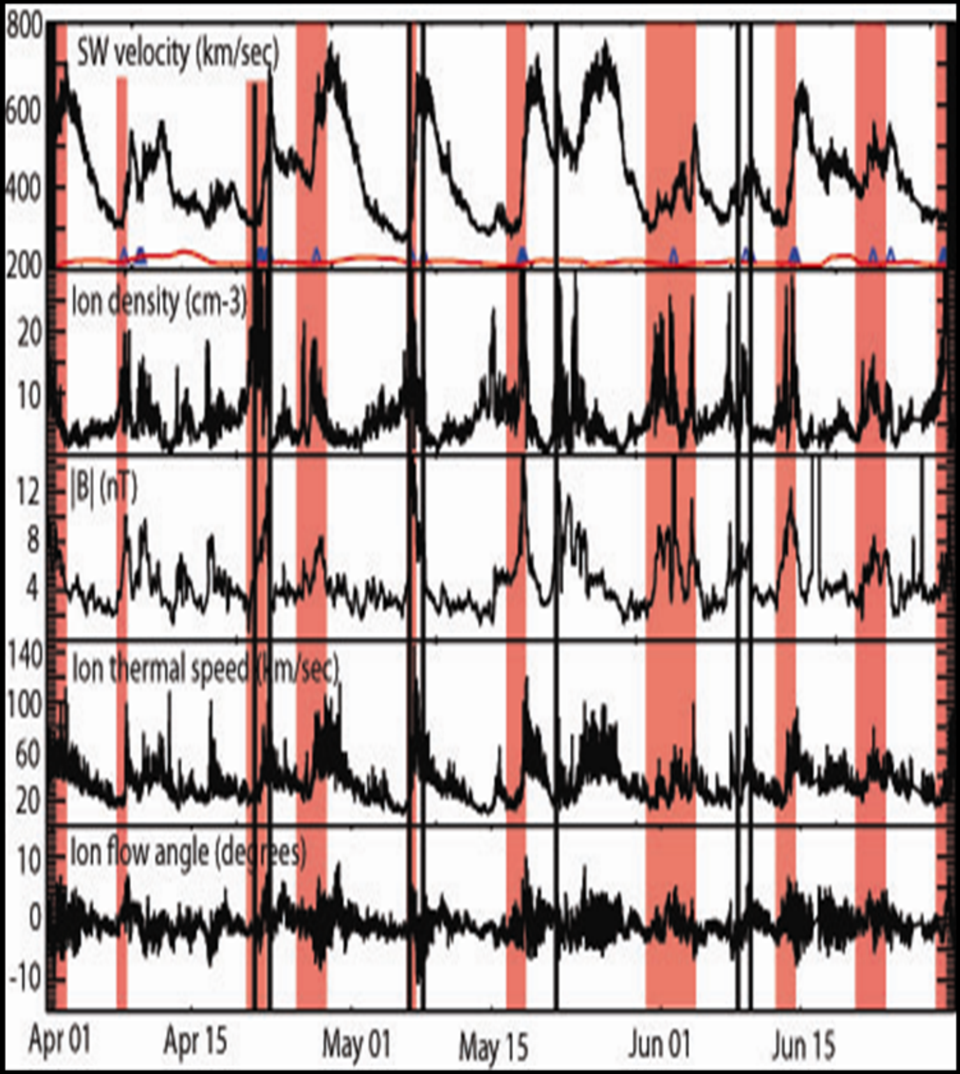


Seen at SIRs

Wave groups seen at >90% of Stream Interaction Regions and 20% of shocks (2007 data, list compiled by L. Jian)

Groups seen before and after stream interface

STA, 2007



STEREO PLASTIC AND IMPACT DATA

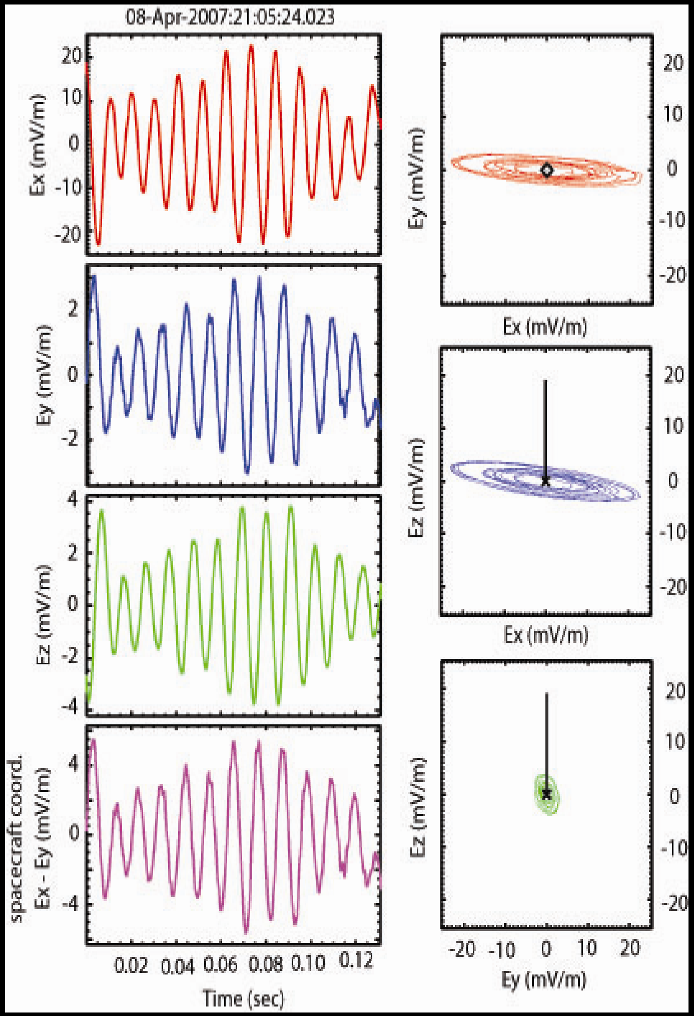
Dispersion estimate

- Use Doppler shift condition (f'=f-k*V) to restrict k-vec with following conditions:
  - Assume wave is whistler mode in plasma frame
  - Wave is RH polarized in spacecraft frame (from observations)
- Solve cold plasma dispersion relation with these restrictions

$$n^2 \simeq \frac{\omega_{pe}^2}{\omega(\Omega_e \cos\theta - \omega)}$$

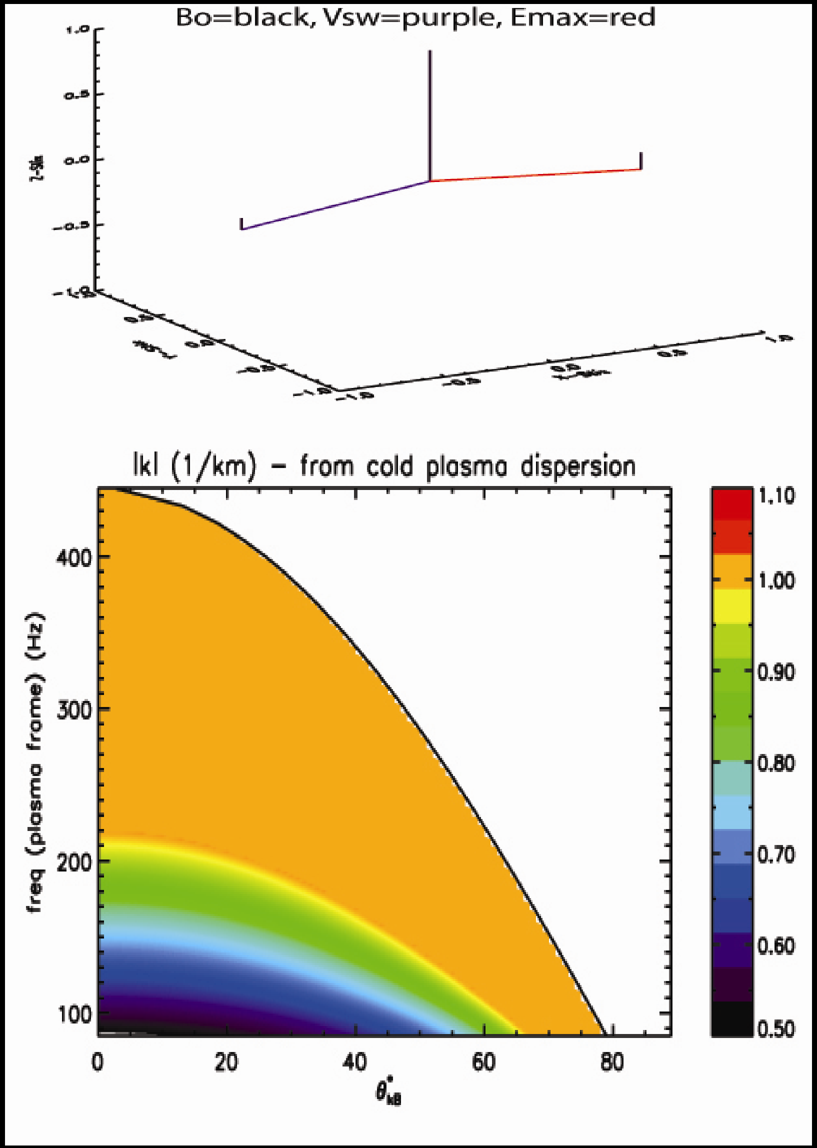
Dispersion test

- Vsw=368 km/s, |B|=14nT, Emax=21mV/m, fsc=85Hz, n=11cm-3
- Only 3 E-field components available for waves – 180 degree ambiguity in Emax direction



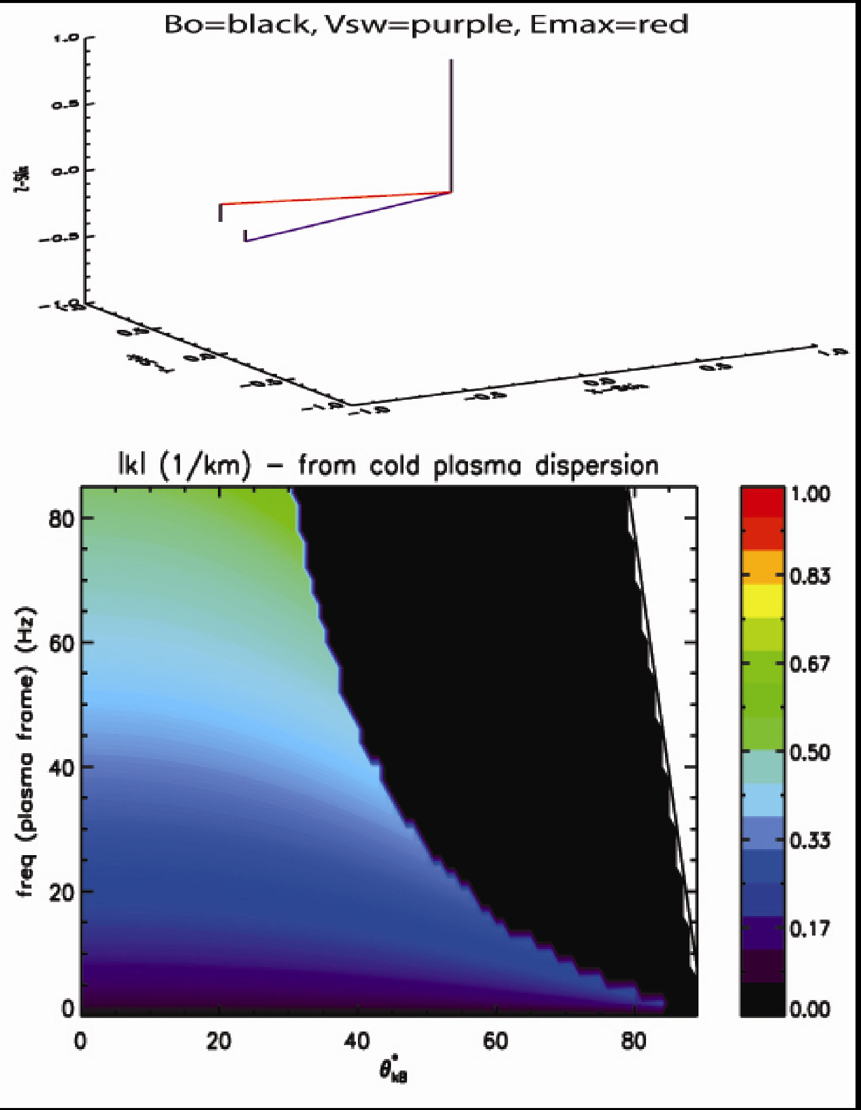
Dispersion test I

- Emax has component antiparallel to Vsw
- |k|~0.5-1 km-1
- Vp~600-1500 km/s
- Parallel resonance energies:
  - Cyclotron~0-100 eV
  - Landau~1-6 eV
  - Anomalous~0-200 eV



Dispersion test II

- Emax has component parallel to Vsw
- |k|~0.1-0.6 km-1
- Vp~100-1000 km/s
- Parallel resonance energies:
  - Cyclotron~100-1000 eV
  - Landau~1-5 eV
  - Anomalous~100-1000 eV



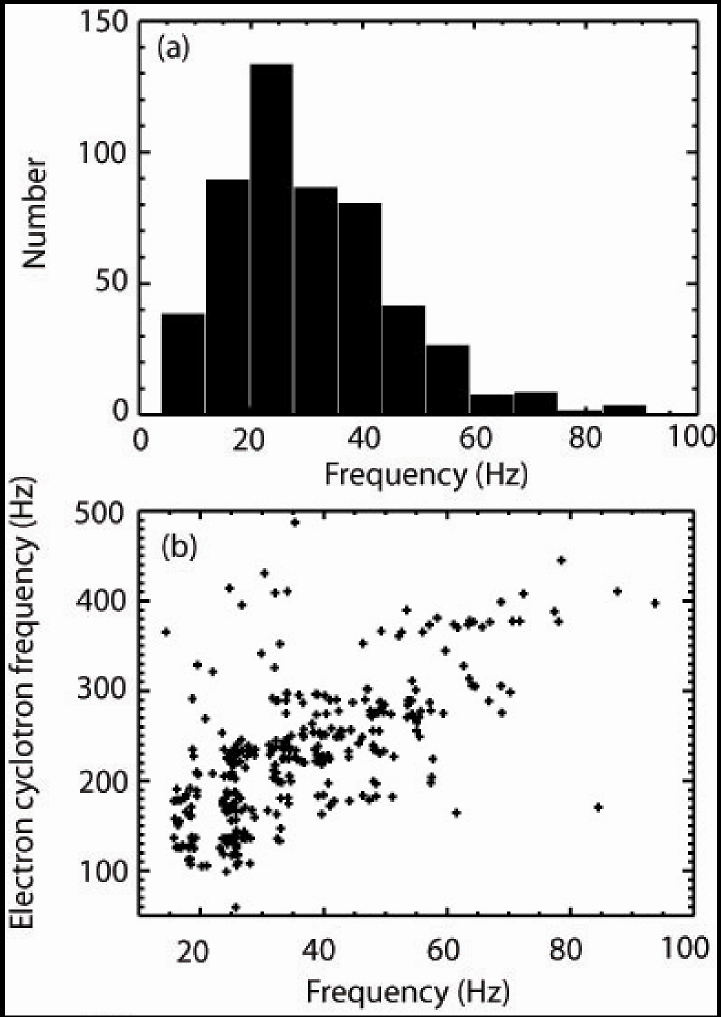
Waves most consistent with whistler mode

Observed frequencies (sc frame) in whistler mode range

Dispersion characteristics (plasma frame) consistent with whistler mode

Observed frequencies track cyclotron frequency

All A-type waves are RH polarized in spacecraft frame

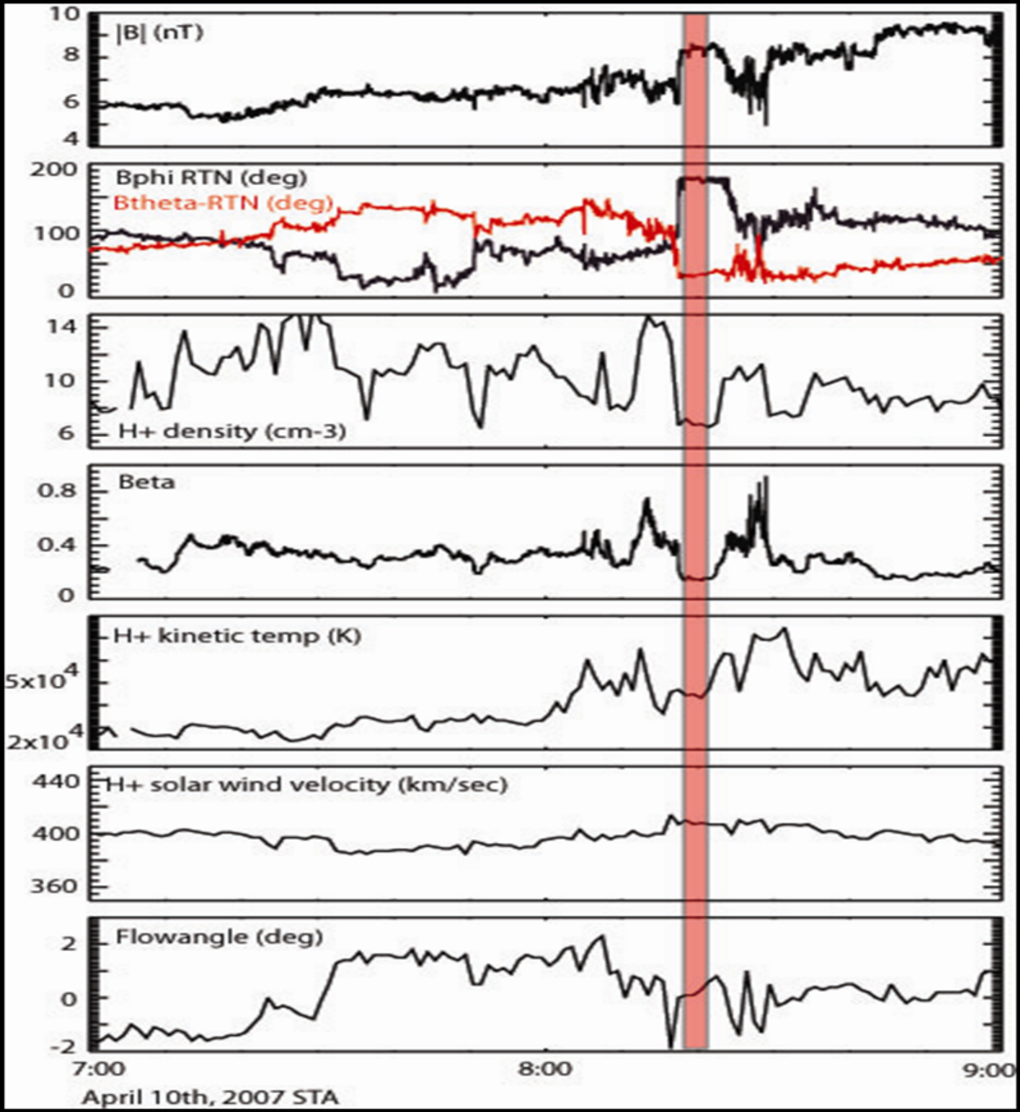


Local solar wind conditions

Apr10, 2007 STA

Locally: wave groups seen at mirror-like structures (Winterhalter et al. [1994]), in low beta regions

Possibly associated with steepened Alfven waves

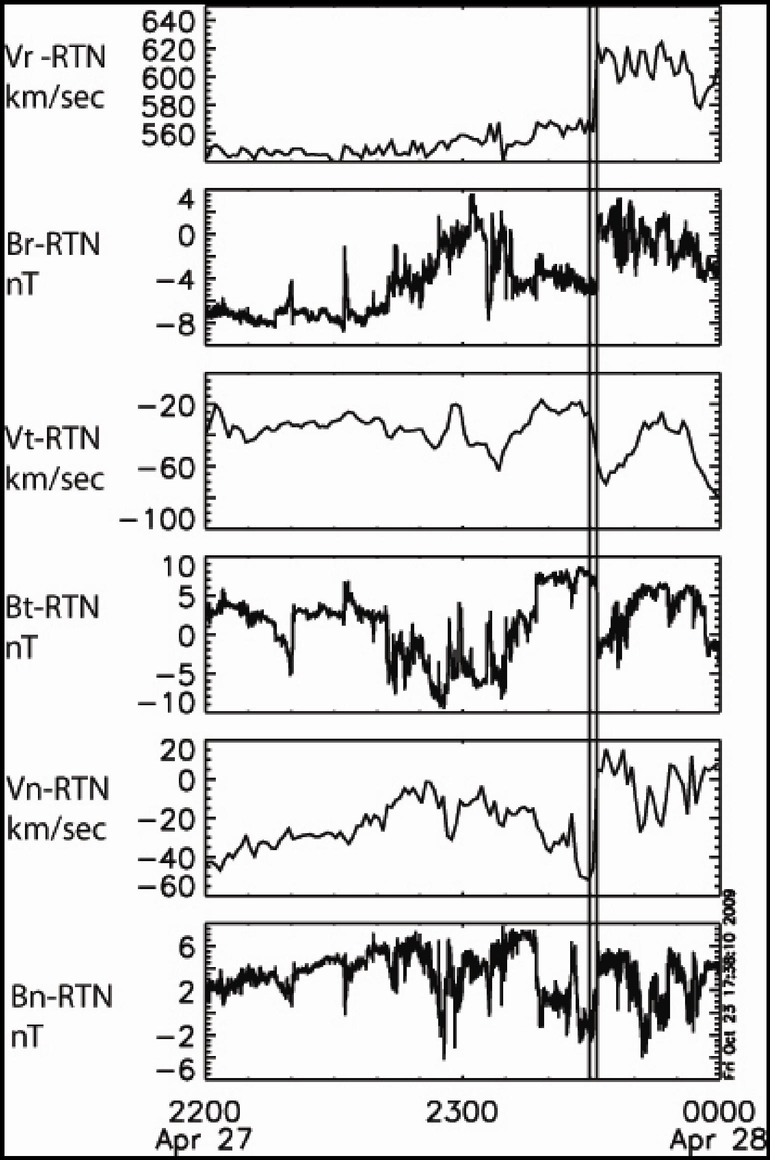


STEREO PLASTIC and IMPACT

Phase-steepened AW

Apr 27, 2007 STA

- $V_i \sim Bo_i$
- Can lead to formation of mirror-like structures via ponderomotive force (Tsurutani et al. [2002])



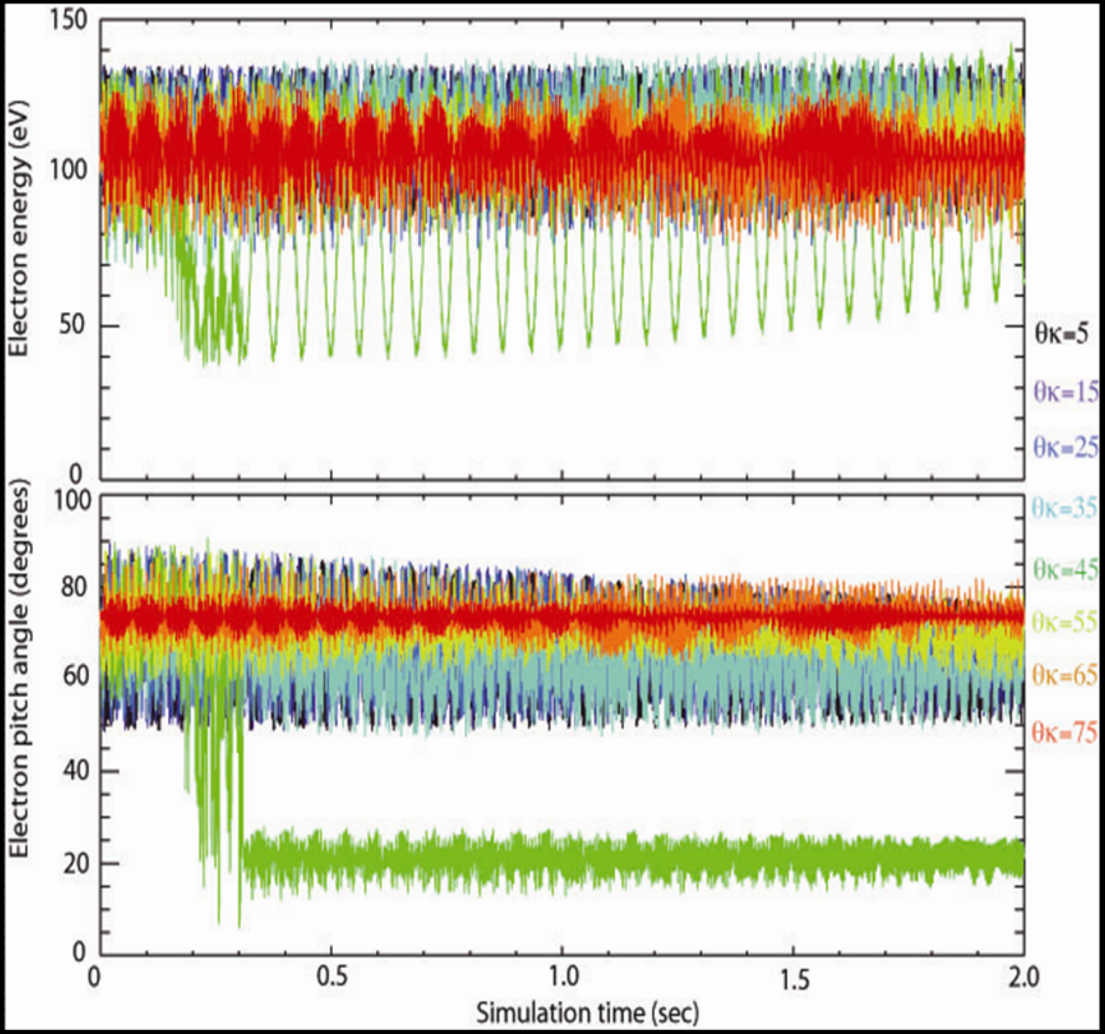
Whistler/electron interaction

Simulations in magnetic bottle geometry show that whistlers strongly interact with halo electrons

Electrons → 50,100,300 eV
Pitch angles from 5-85 degrees

Waves → 10mV/m, 50 Hz
Theta_kB from 5-85 degrees

E- scattered by tens of degrees and energized/de-energized by 50% in few tens of msec via Landau resonance



Plot from K. Kersten

Conclusions

- STEREO TDS has observed largest amplitude whistlers in solar wind, not observable in earlier instruments
- monochromatic and oblique with large electrostatic component
- Waves may interact strongly with halo electrons
- Associated with mirror-like waves, phase-steepened Alfven waves (rotational discontinuities)

Future work/Questions

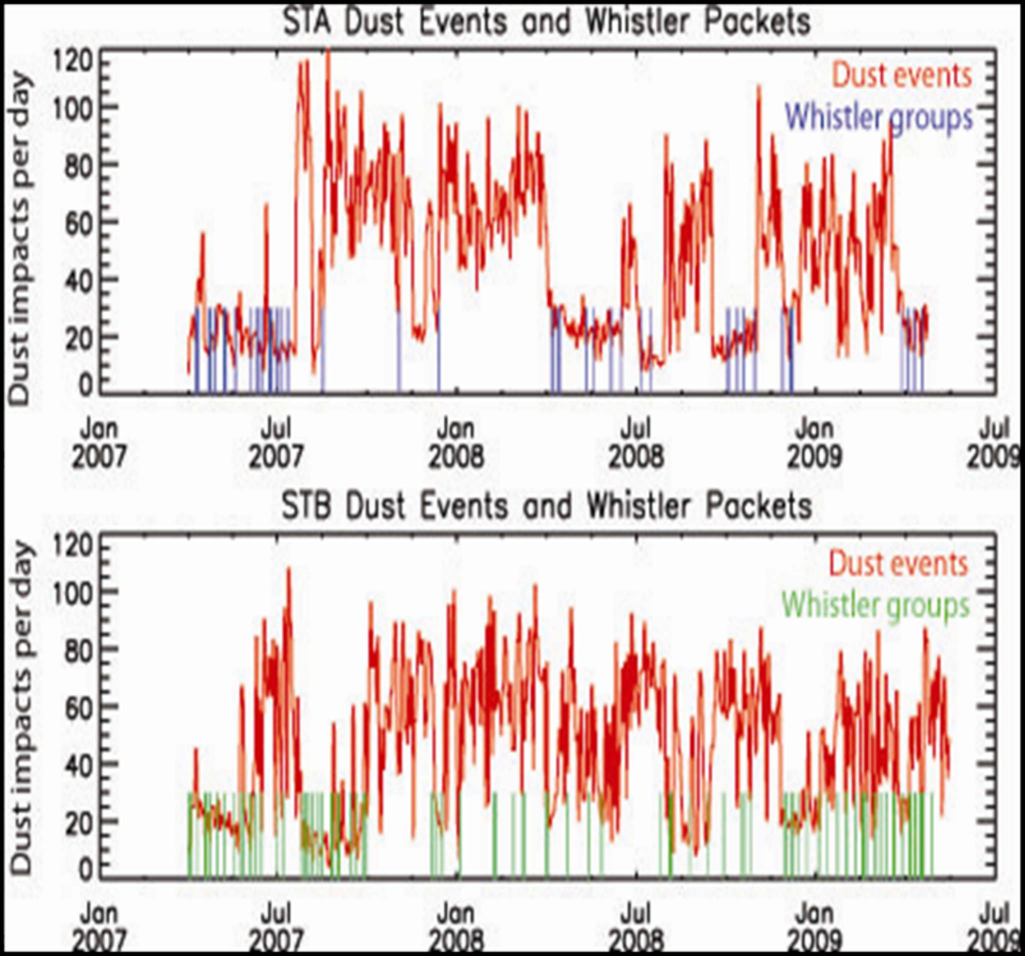
- Determine instability mechanism.
- Determine correlation with local plasma conditions (minute and hour timescales)
- Do whistlers significantly modify solar wind core or halo populations?
- Effect stability of mirror mode?

…extra slides

Dust contamination

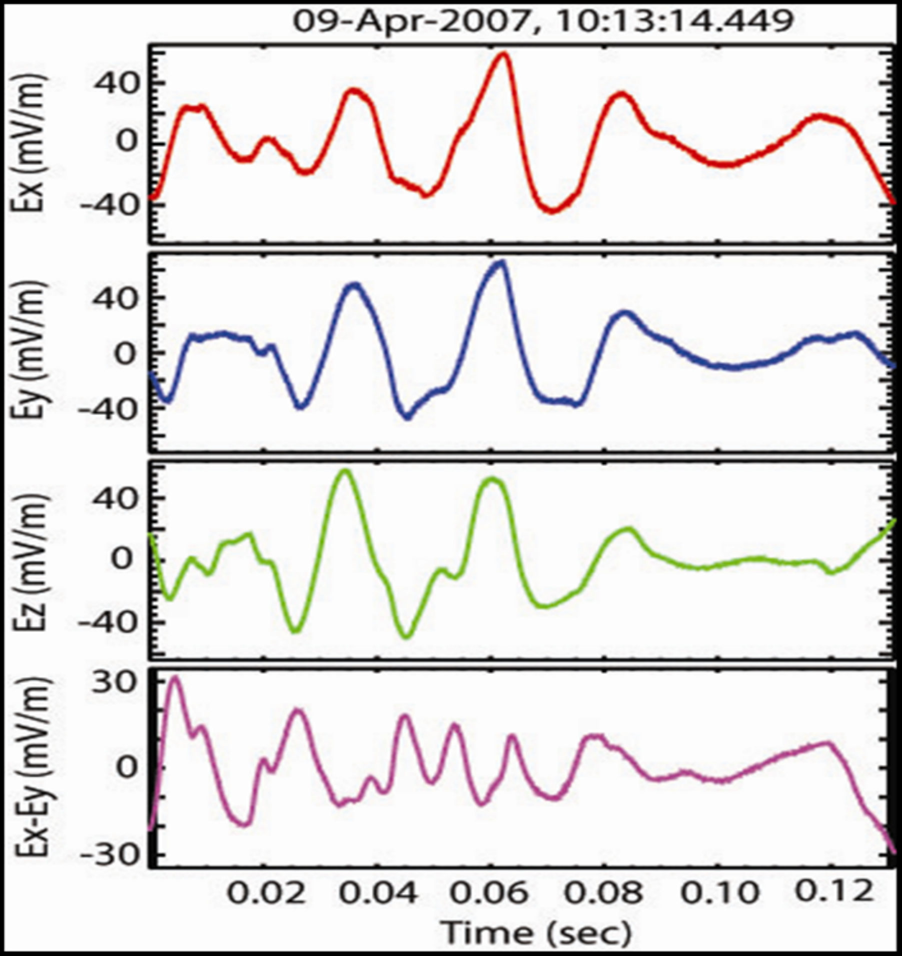
Large amplitude of dust impact causes STEREO TDS to prioritize dust impacts over smaller amplitude plasma waves.

Dusty regions contain enough dust impacts that other wavetypes are not transmitted to Earth.

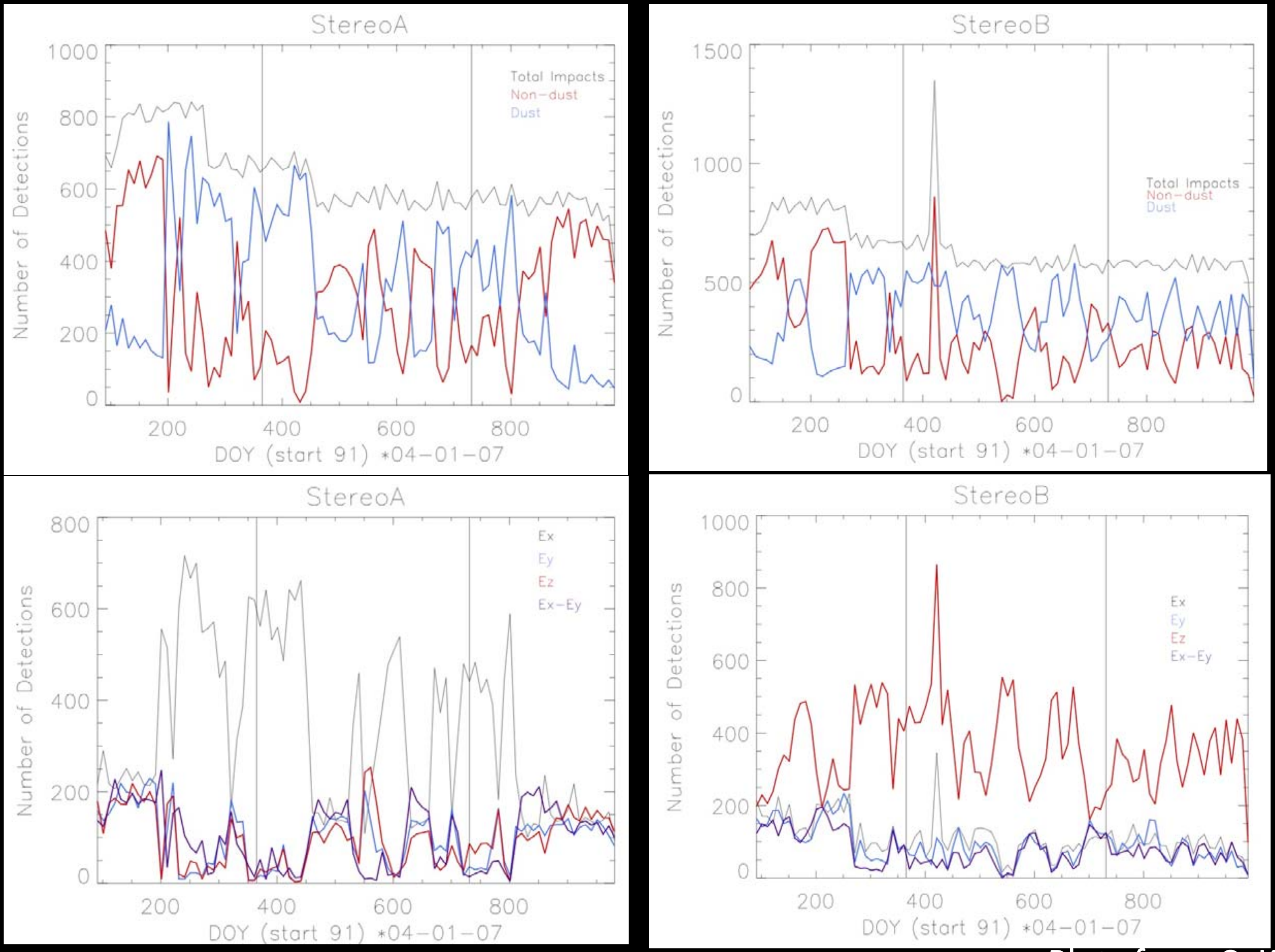


E-field and density II

Largest amplitude wave > 100 mV/m, modifies plasma density.



Dust source



Plots from C. Kuehl

Mirror-mode structures

- Perpendicular kinetic pressure bulge pushes away magnetic field and creates magnetic bottle structure until pressure balance is reached [Hasegawa 1969, Kivelson and Southwood 1996].
- Stability (bi-Maxwellian) when: $$p_\perp\left(1-\frac{T_\perp}{T_\parallel}\right)+\frac{B^2}{2\mu_o}=0$$
- Traditionally occur in high-beta plasmas
- Magnetic humps and troughs observed in solar wind [Winterhalter, 1994]
- Nonlinear effects less well understood, but can theoretically lead to magnetic humps as well as troughs [Baumgartel, 1999 → AW evolution, Hellinger, 2009 → nonlinear mirror instability]

Phase-steepened Alfven waves

- Alfven waves prevalent in fast solar wind [Belcher and Davis, 1971]
- Magnetic holes can form from dissipation of steepened Alfven waves [Tsurutani 2002, Lin 2009]
- Ponderomotive force heats plasma in perp direction which leads to mirror instability. [Tsurutani 2002b, 2005a, Dasgupta 2003]
- Nonlinear Alfven waves dispersive and compressive [Medvedev and Diamond 1996], [Medvedev et al. 1997], [Vasquez and Hollweg 1998, 2001]

Possible Instability Mechanisms

- Electron or ion beams may produce oblique whistlers
- Possible mechanisms:
  - Sentman 1983 – Oblique 1 Hz whistlers (mag) seen upstream of bowshock in association with e- beams.
  - Wong and Smith 1994 –Tperp/Tpar>1 e- beams that can create whistlers. High beam density and anisotropy leads to two simultaneous whistler modes, a parallel and oblique whistler.
  - Gurgiolo 1993 – gyrophase bunched ions.
  - Sauer (not published) – Isotropic super-Alfvenic electron beams may create the large amplitude oblique whistlers
  - Thorne and Tsurutani 1981 – lion roars can be generated by cyclotron res instability w/ temp anisotropy Tper/Tpar>1.
  - Treumann 2000 – Trapping in mirror cavity generates whistlers with narrow freq.
  - Chian 1999 – Whistler waves from parametric coupling to Langmuir waves in magnetic holes in the solar wind

Cyclotron (n=-1) Resonance energies

April 8th, 2007 STA at ~21:05:24.023