PLASMA WAVES ASSOCIATED WITH MASS-LOADED COMETS

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Why Study Plasma Waves at Comets?

- Plasma waves and instabilities are integrally involved with the plasma "pickup" process and the mass loading of the solar wind (thus the formation of ion tails and the magnetic tails)
- Anisotropic plasmas generated by solar wind-comet interactions (the bow shock, magnetic field pileup) cause the generation of plasma waves which in turn "smooth out" these discontinuities.
- The plasma waves evolve and form plasma turbulence
- Comets are perhaps the best "laboratories" to study waves and turbulence because over time (and distance) one can identify the waves and their evolution. We will argue that comets in some ways are better laboratories than magnetospheres, interplanetary space and fusion devices to study nonlinear waves and their evolution.

Proton Cyclotron Waves: ICE
28 Million Km Away from Comet Halley

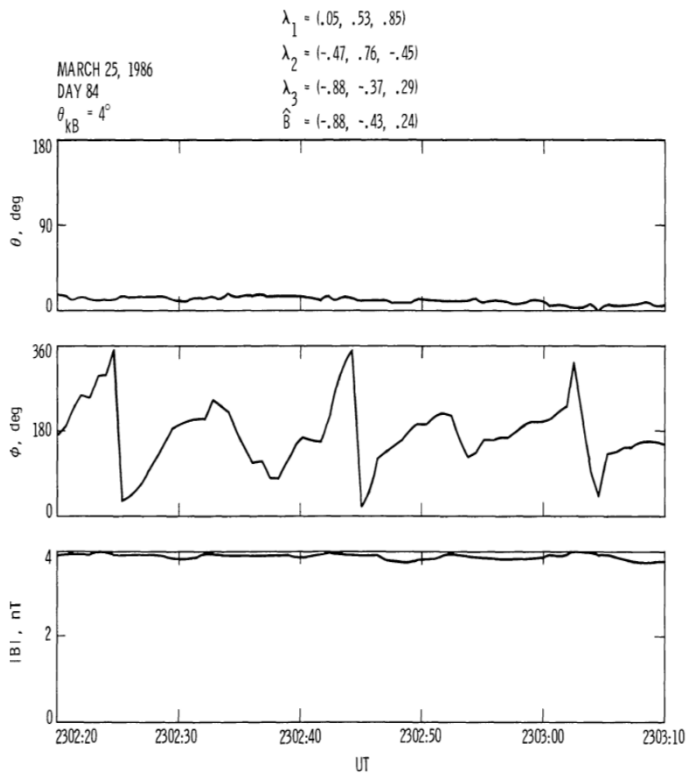
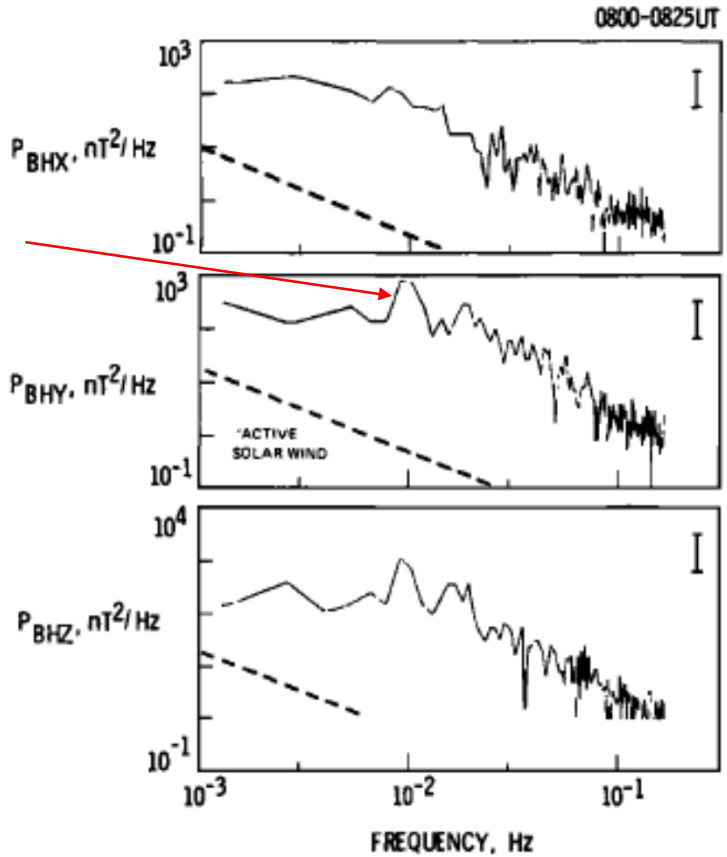


Fig. 5. An example of an electromagnetic cyclotron wave in the solar wind

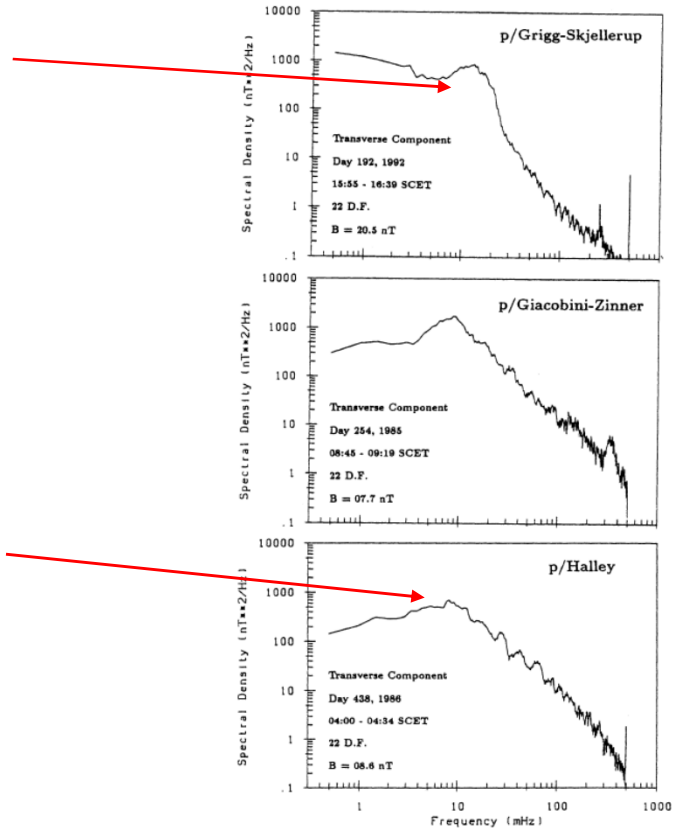
Tsurutani et al. 1987 A. A.

Cometary (Giocobini-Zinner) Plasma Waves Can Be Used as Mass Spectrometers

The peak in the spectrum of the wave power spectral density (or "pump frequency" identifies H_2O^+ group ions as the source.



Comets Halley and Grigg-Skjellerup Power Spectra Indicate H_20 Group Ion Pickup



Glassmeier, Tsurutani and Neubauer, Terrapub, 1997

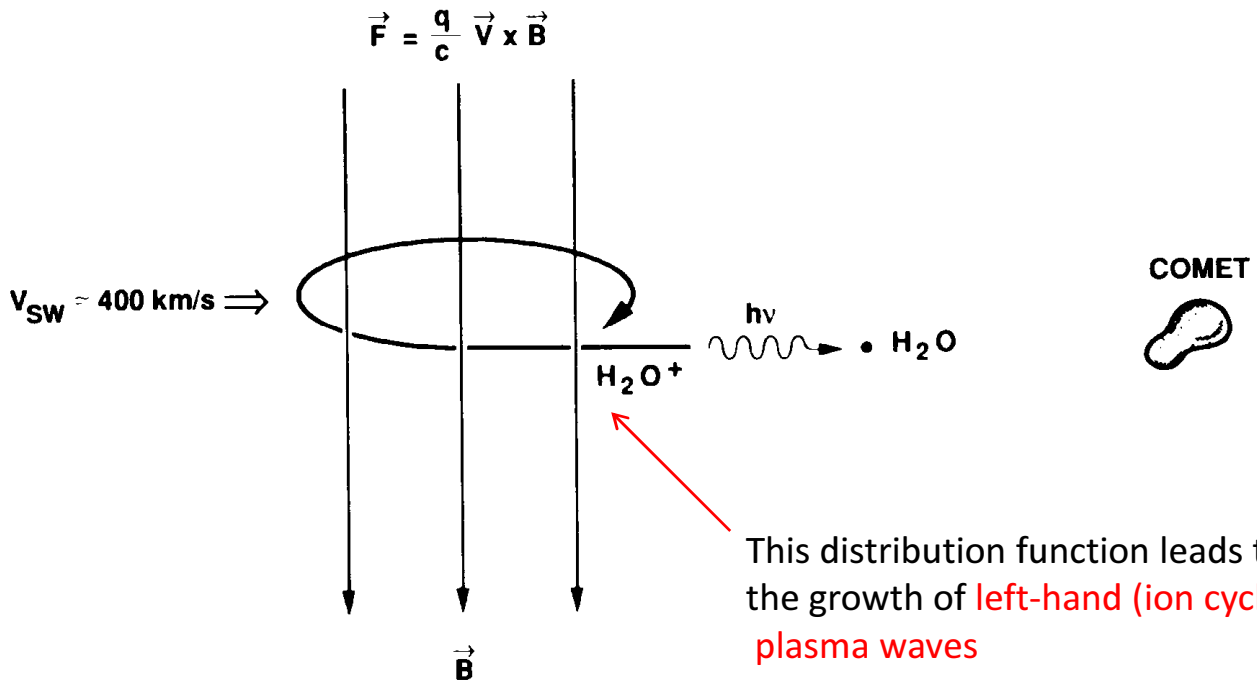
SOURCES OF PLASMA WAVES AT COMETS

1. Pickup of Cometary Ions by the solar wind: different cyclotron resonant plasma instabilities depending on the magnetic field direction and plasma β.

2. Plasma temperature anisotropies generated by compression (shocks) or magnetic field draping.

3. Current systems (radiative waves)

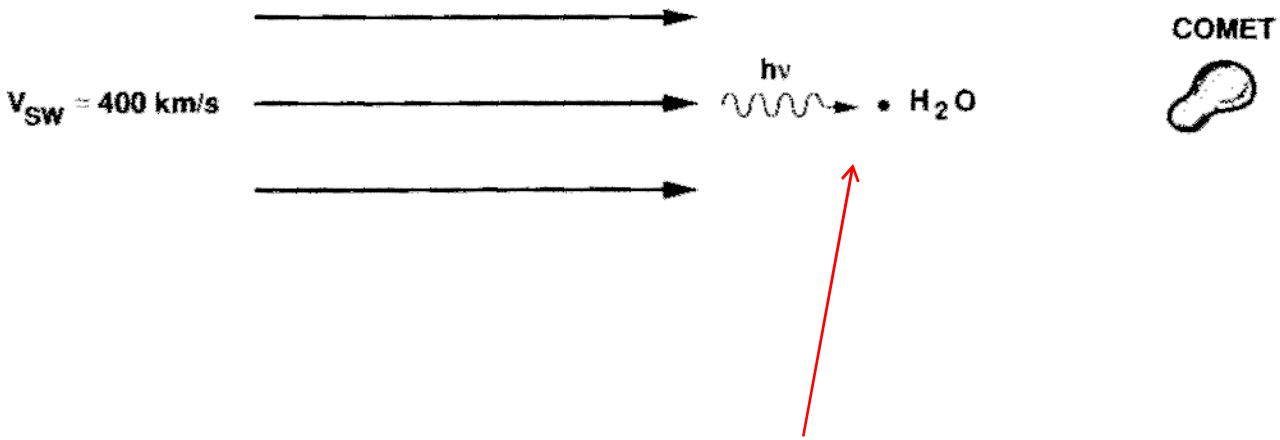
Ion Pickup for Perpendicular Magnetic Fields: Mass Loading



This distribution function leads to the growth of left-hand (ion cyclotron) plasma waves

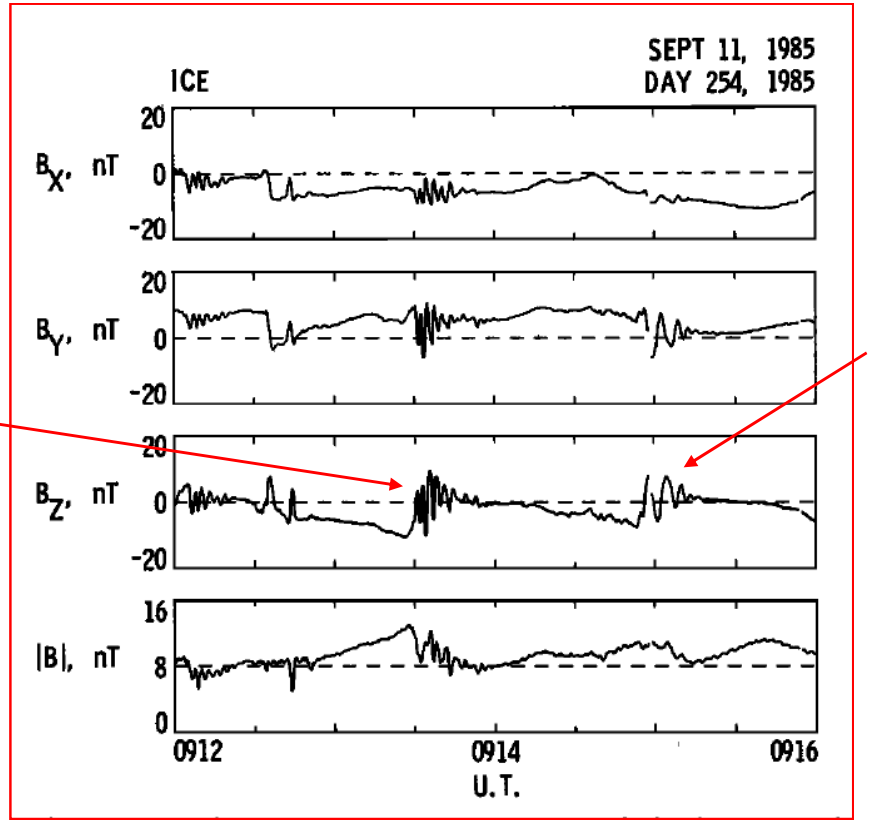
Tsurutani, AGU monograph 1991

ION BEAM INSTABILITY



This distribution function (a high velocity beam) leads
to growth of right-hand magnetosonic waves, then mass loading

Comet GIACOBINI-ZINNER: ICE SPACECRAFT

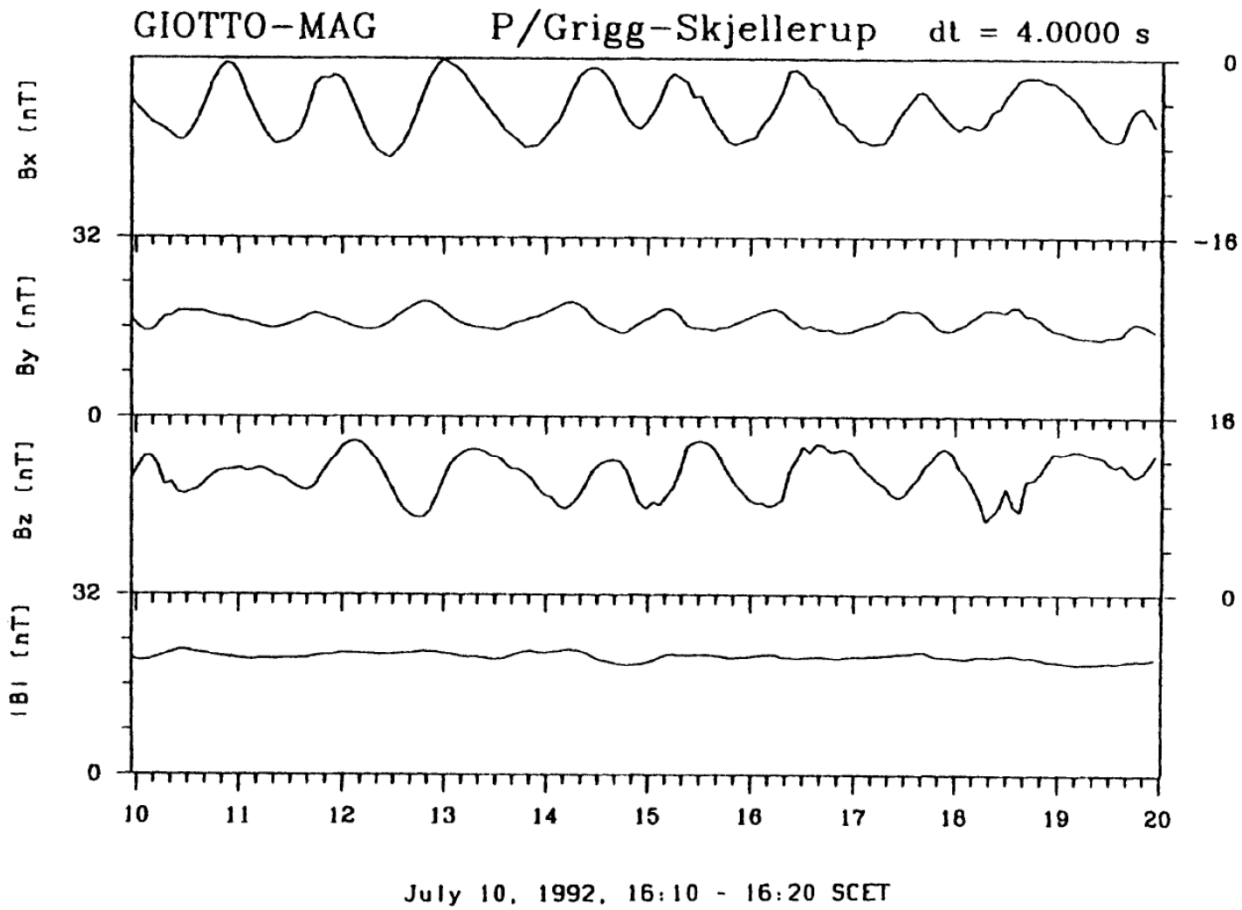


Phase-steepened resonant magnetosonic waves

The high frequency component Is due to "wave breaking" leading To the development of turbulence

Tsurutani and Smith 1986 GRL

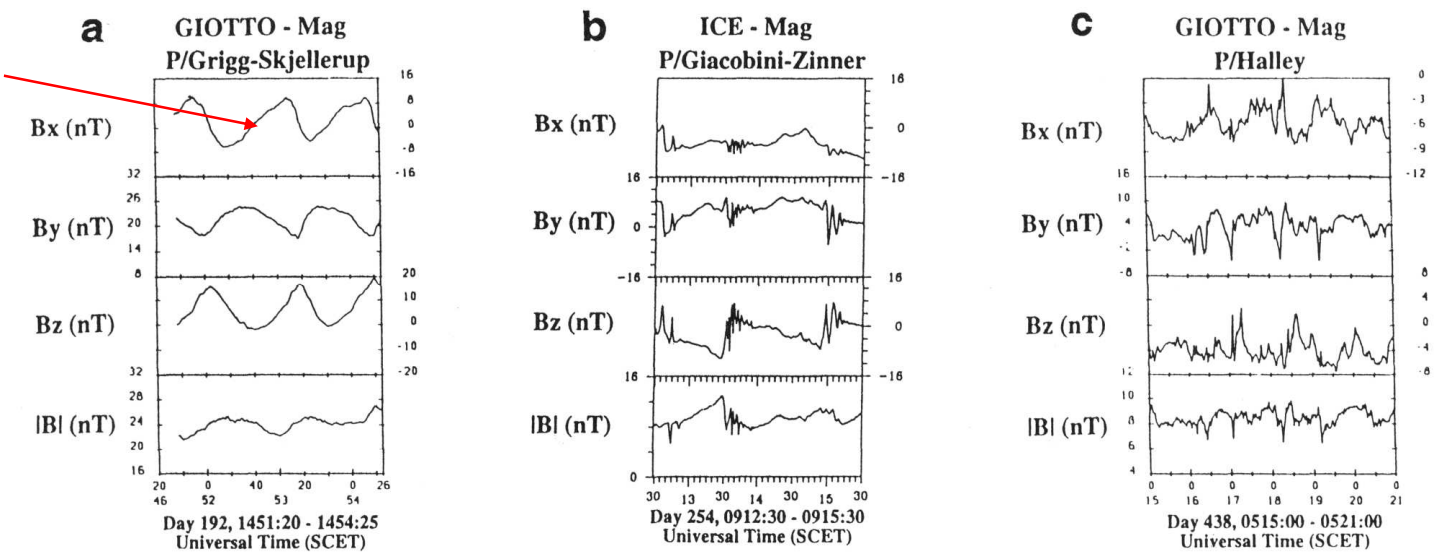
Left-Hand Cyclotron Waves at Comet Grigg-Skjellerup: Giotto



Neubauer et al., A. A., 1993

Comparative Cometary Waves

Phase steepening of LH waves



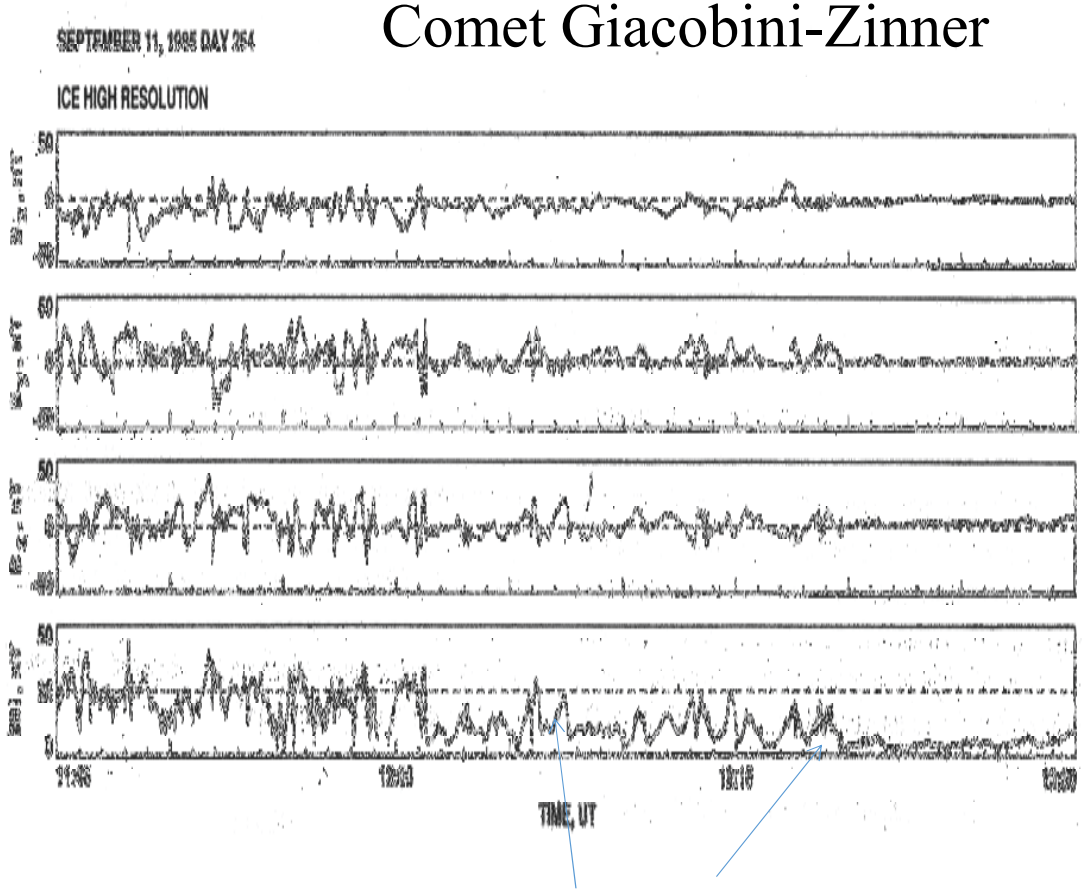
Left-hand polarized

Right-hand polarized

Turbulence

Tsurutani, Glassmeier, Neubauer, GRL 1995

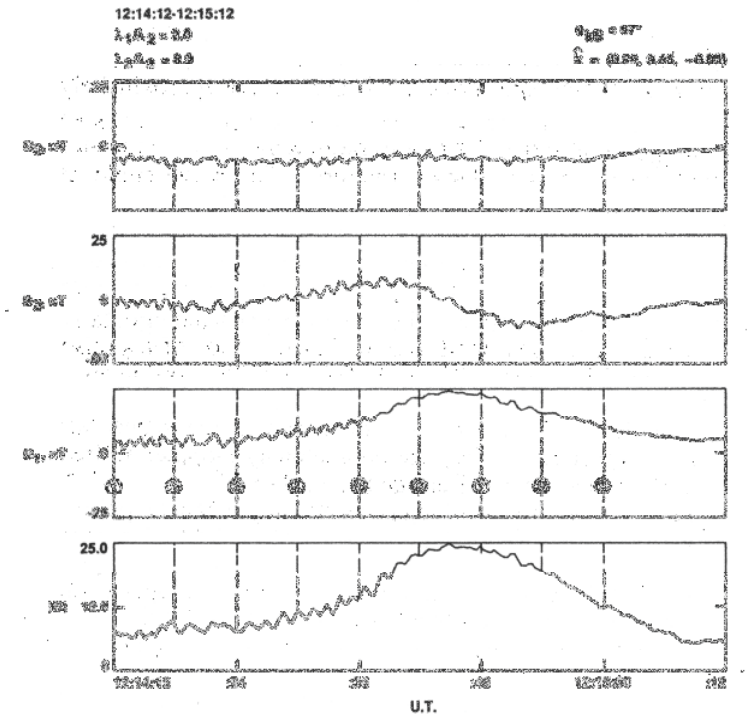
Comet Giacobini-Zinner

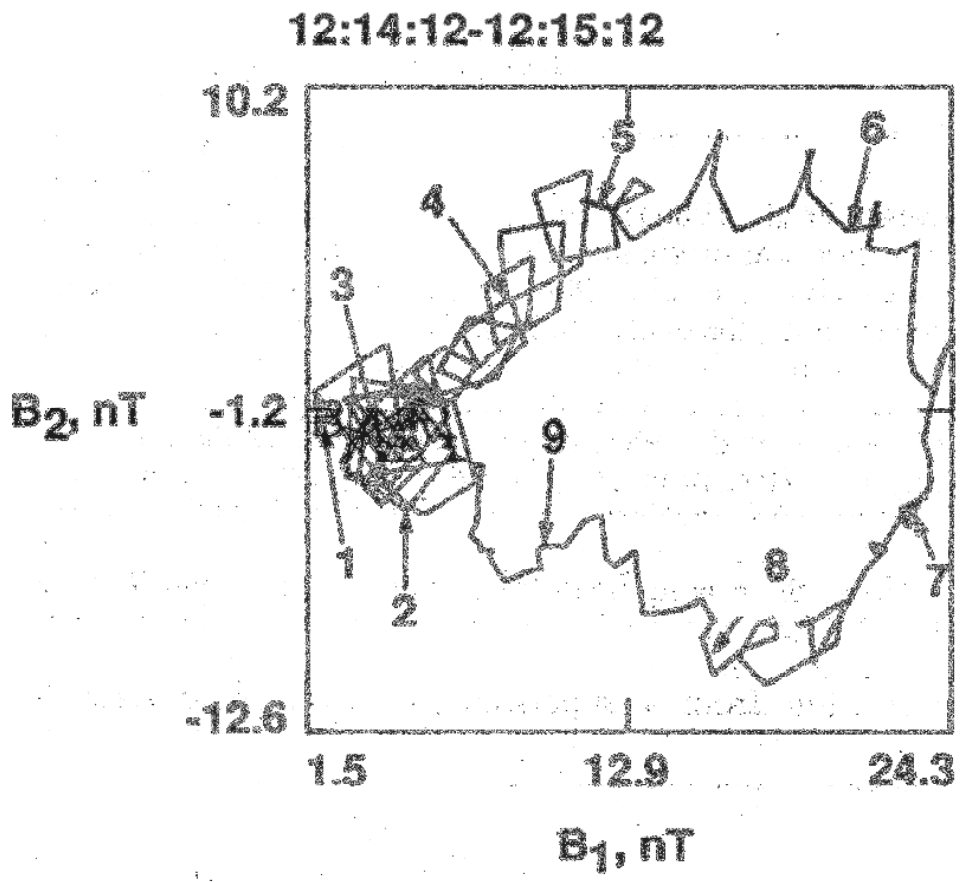


Magnetic pulses/SLAMS at a quasiparallel shock. Important for dissipation?

Tsurutani et al. GRL 1990

A High Resolution Examination of a Cometary SLAM

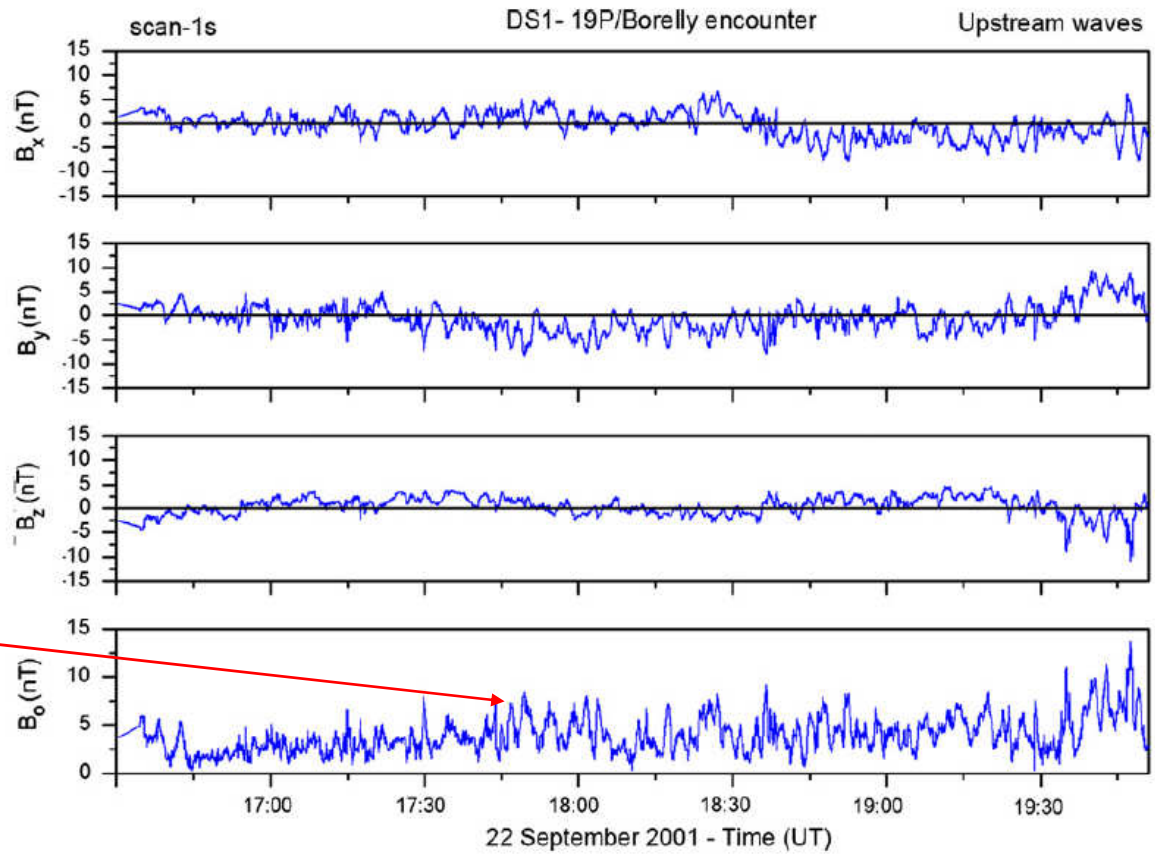




Right-hand circularly polarized in the plasma frame

COMET BORELLY (DS-1)

Nothing but SLAMS



SLAMS

Tsurutani et al., PSS, 2013

Mirror Mode Detection at Comet Halley: Giotto

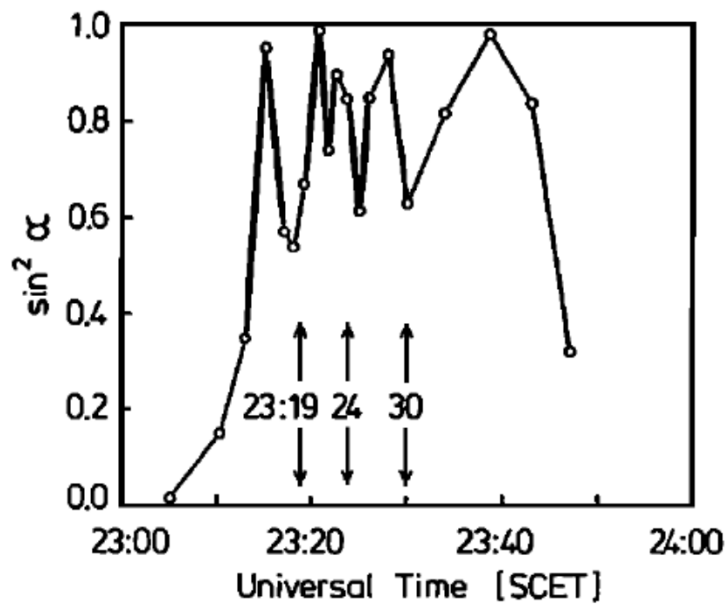
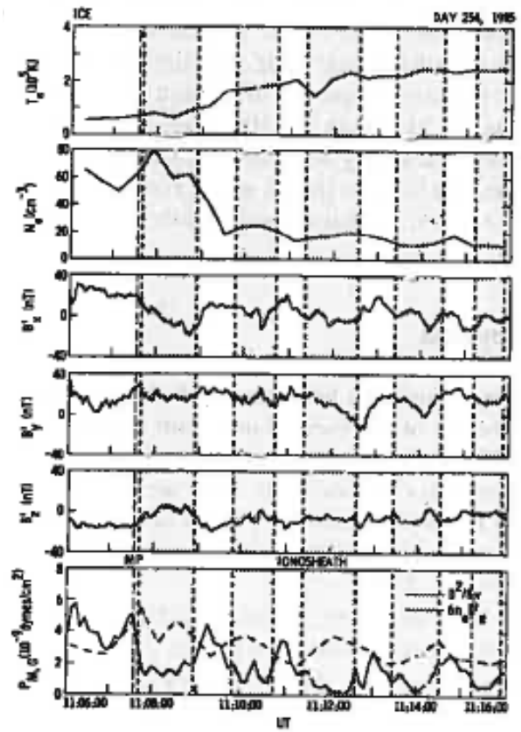


Fig. 8. Variation of the angle α between the solar wind flow velocity and the interplanetary magnetic field.

Glassmeier et al. JGR 1993

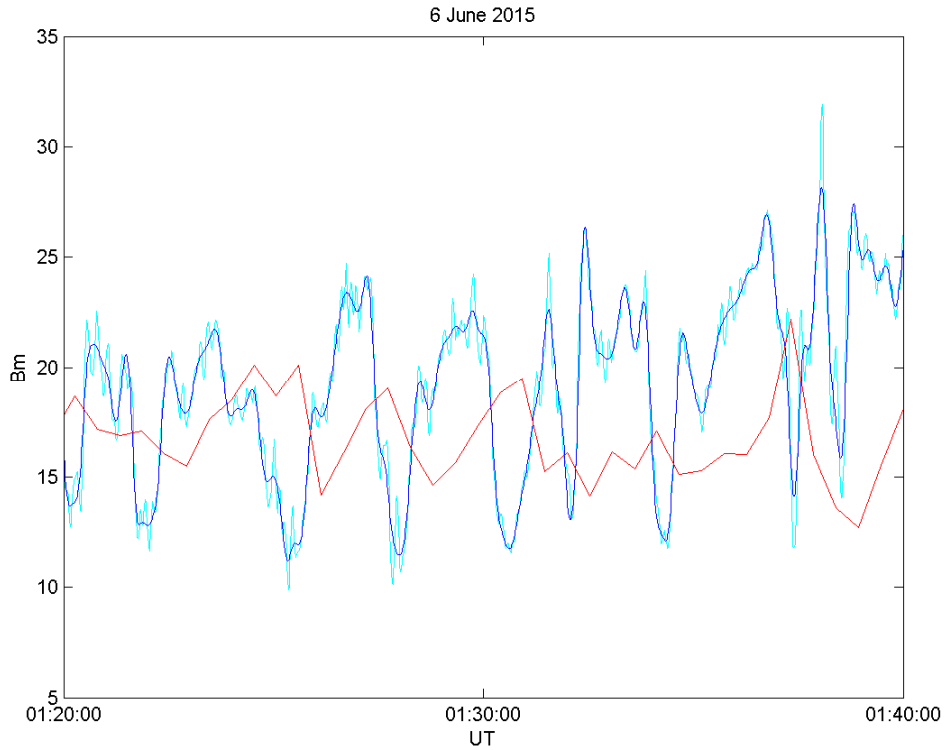
COMET GIACOBINI-ZINNER MIRROR MODES

Again, only a few mirror mode cycles



Tsurutani et al. NPG 1999

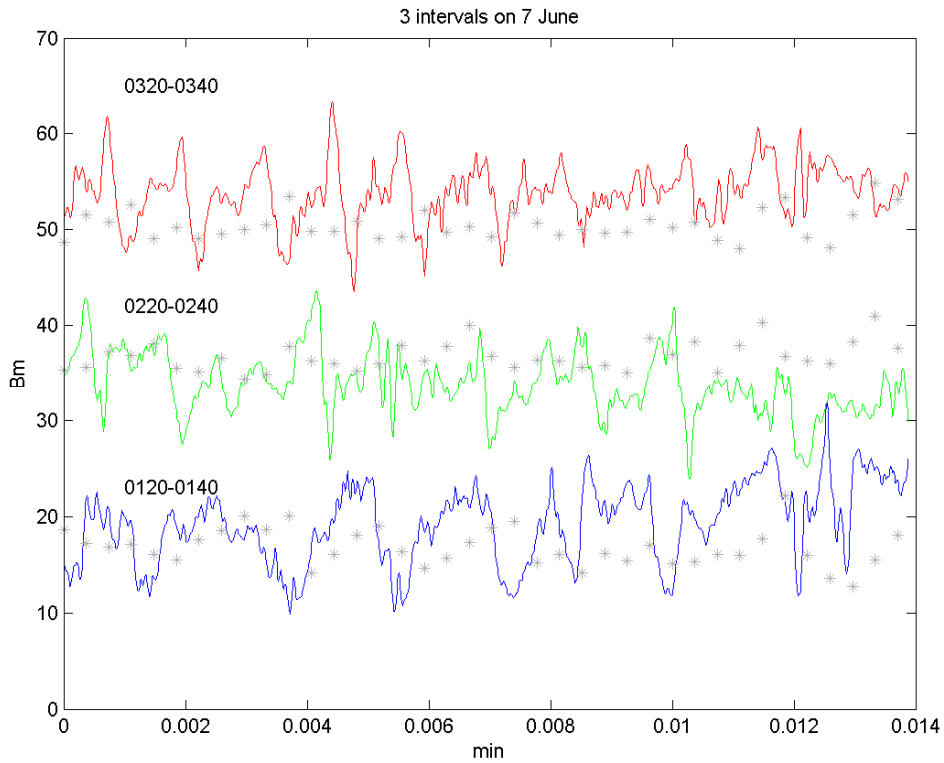
Mirror Modes Everywhere at Comet C.-G.: Rosetta



Volwerk et al. A.G. 2015

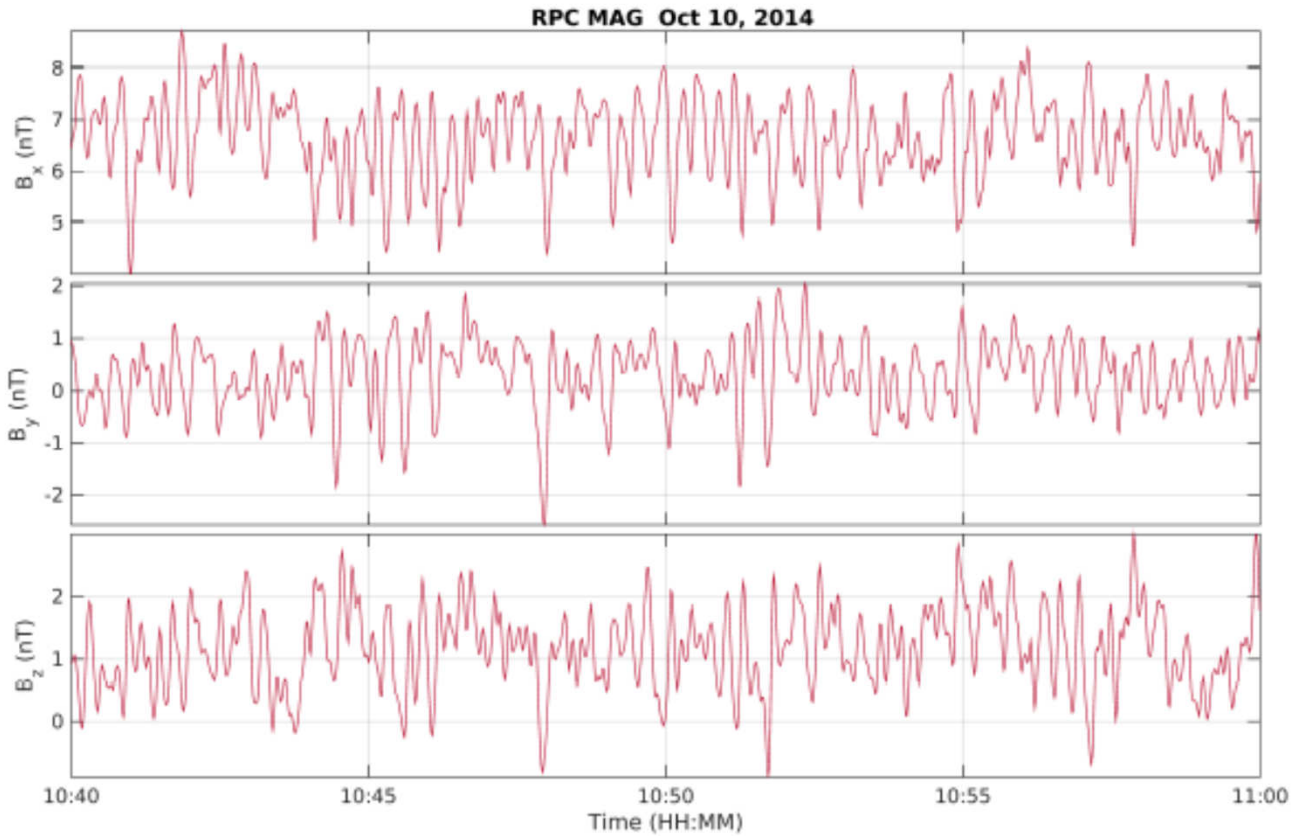
Three Intervals of Mirror Modes

Examples of wave-wave coupling? MM nonlinear development?



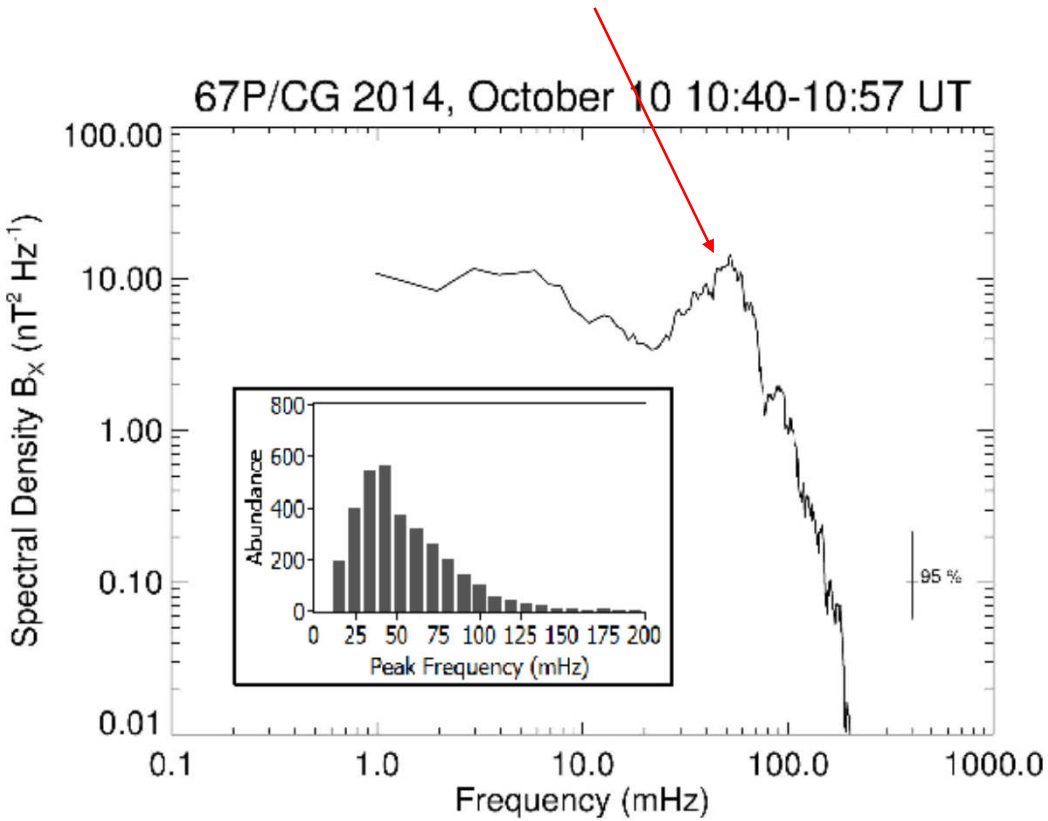
Volwerk et al. AG 2015

A New Type of Cometary Wave: Rosetta



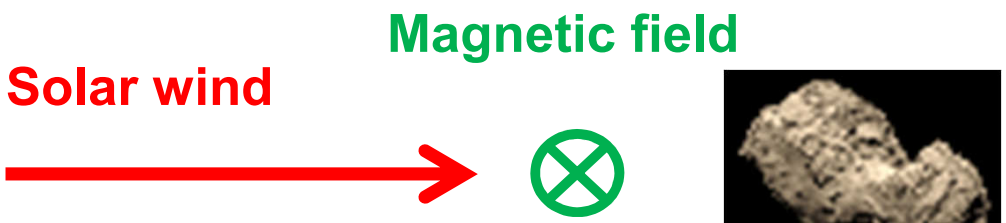
Goetz et al., 2015

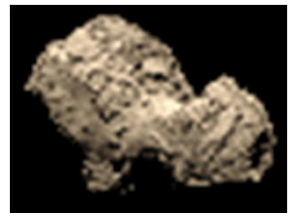
~40 mHz Magnetic Oscillations



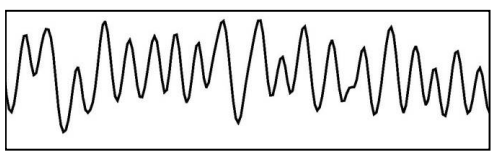
Richter et al., 2015 A.G.

Cross-Field Current Instability





Initial pick-up ion motion represents electric current, driven unstable:

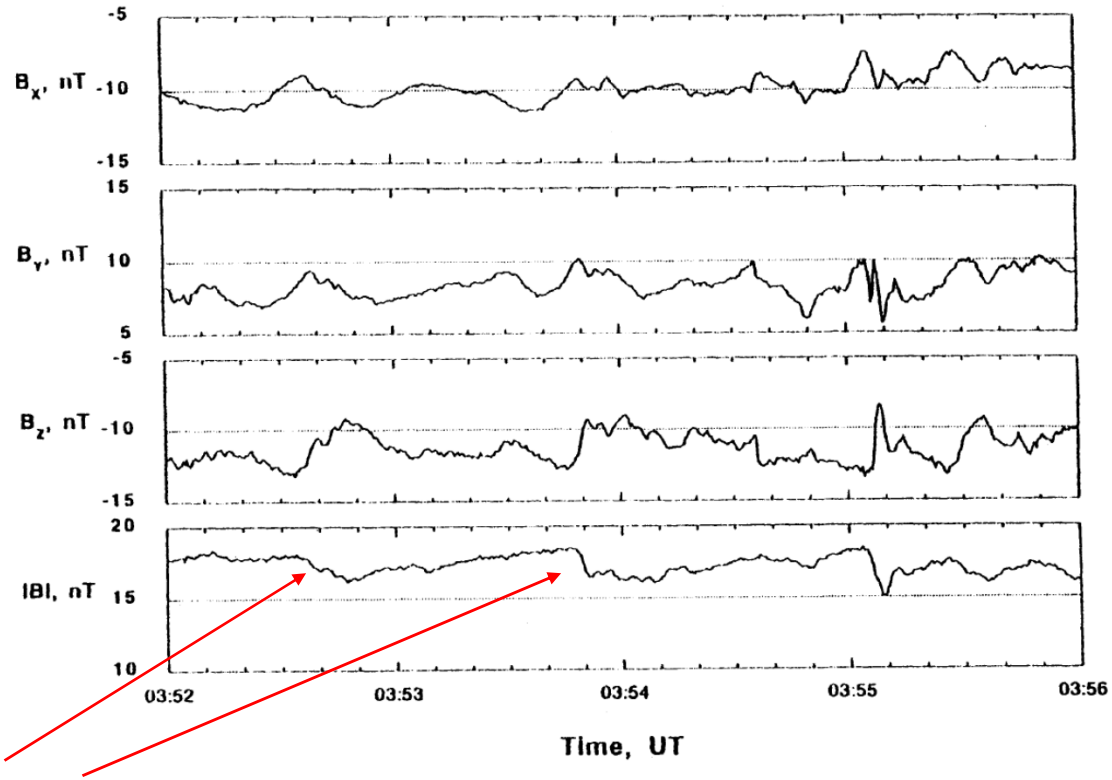


RPC-Mag measurement

Dispersion relation	$\omega \approx k_{\parallel} \cdot v_{newborn}$
Newborn ion velocity	40 km/s (measured)
Newborn ion flux	10^{10} m^{-2} s^{-1} (measured)
Wave number	$6 \cdot 10^{-6}$ m^{-1} $(\nabla \times B)$
=> Frequency about 38 mHz	

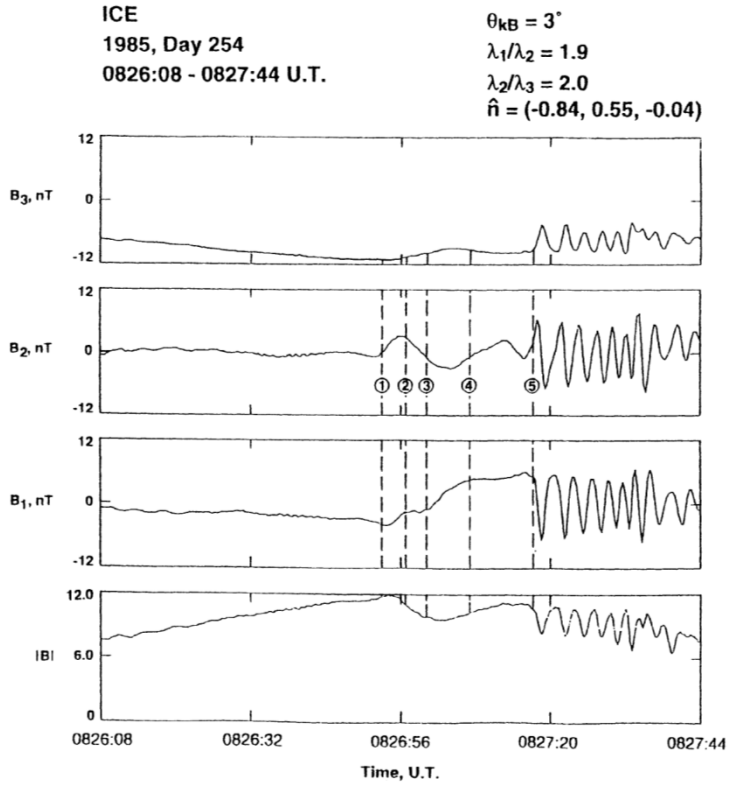
Glassmeier, 2015

One Example of Wave Evolution:
Magnetosonic Waves Start Out Like Waves At the Beach



"Beach-like waves"

A Complex Magnetosonic Wave Splitting into Parts?



Tsurutani, Glassmeier, Neubauer 1997

Thank You For Your Attention