Chorus Temporal Structures, Wave-Particle Interactions, and Electron Precipitation (Microbursts)

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Chorus is a right-hand, circularly polarized planar electromagnetic wave which is generated by anisotropic ~5 to 100 keV energetic electrons.

Discussion of the following topics will be presented:

pitch angle scattering of microburst 10-100 keV electrons,

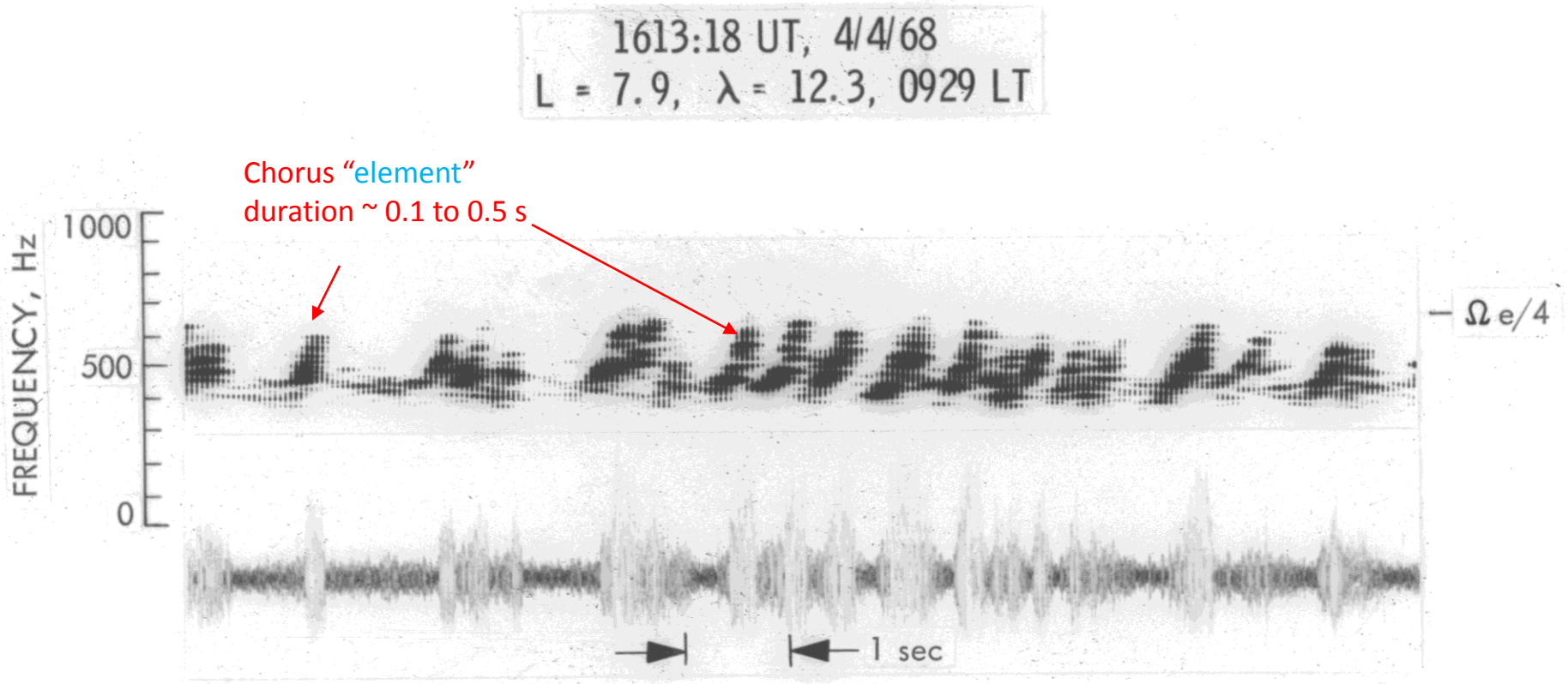
scattering of relativistic electrons,

microbursts are not detected in the midnight sector (observations),

microbursts may have substructures, and

5-15 s auroral pulsations.

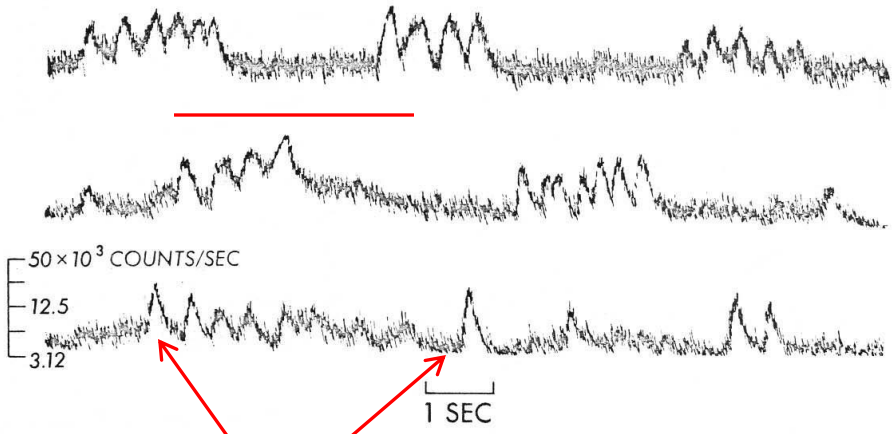
Dayside Rising Tone Chorus: OGO-5



Burton and Holzer JGR 1968

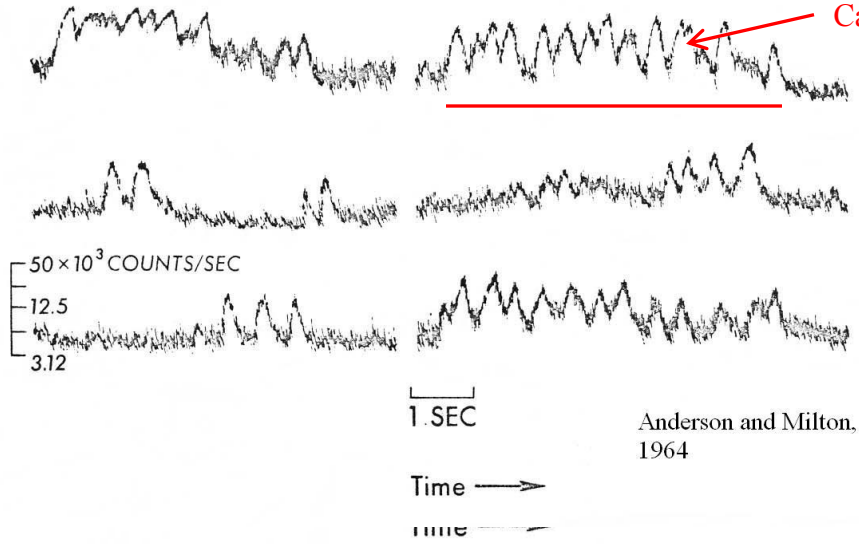
Bremsstrahlung "Microbursts": Balloon Detection

5-15 s betweeen combs



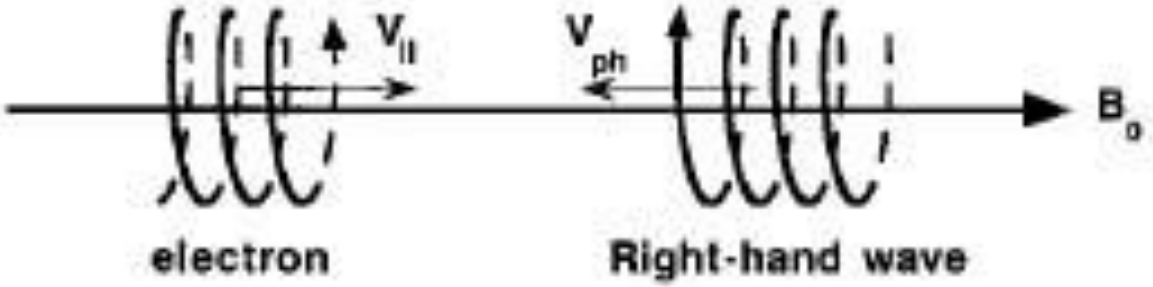
Note, the timescale of μBs are the same as chorus

Called "combs" for obvious reasons



Anderson and Milton, JGR, 1964

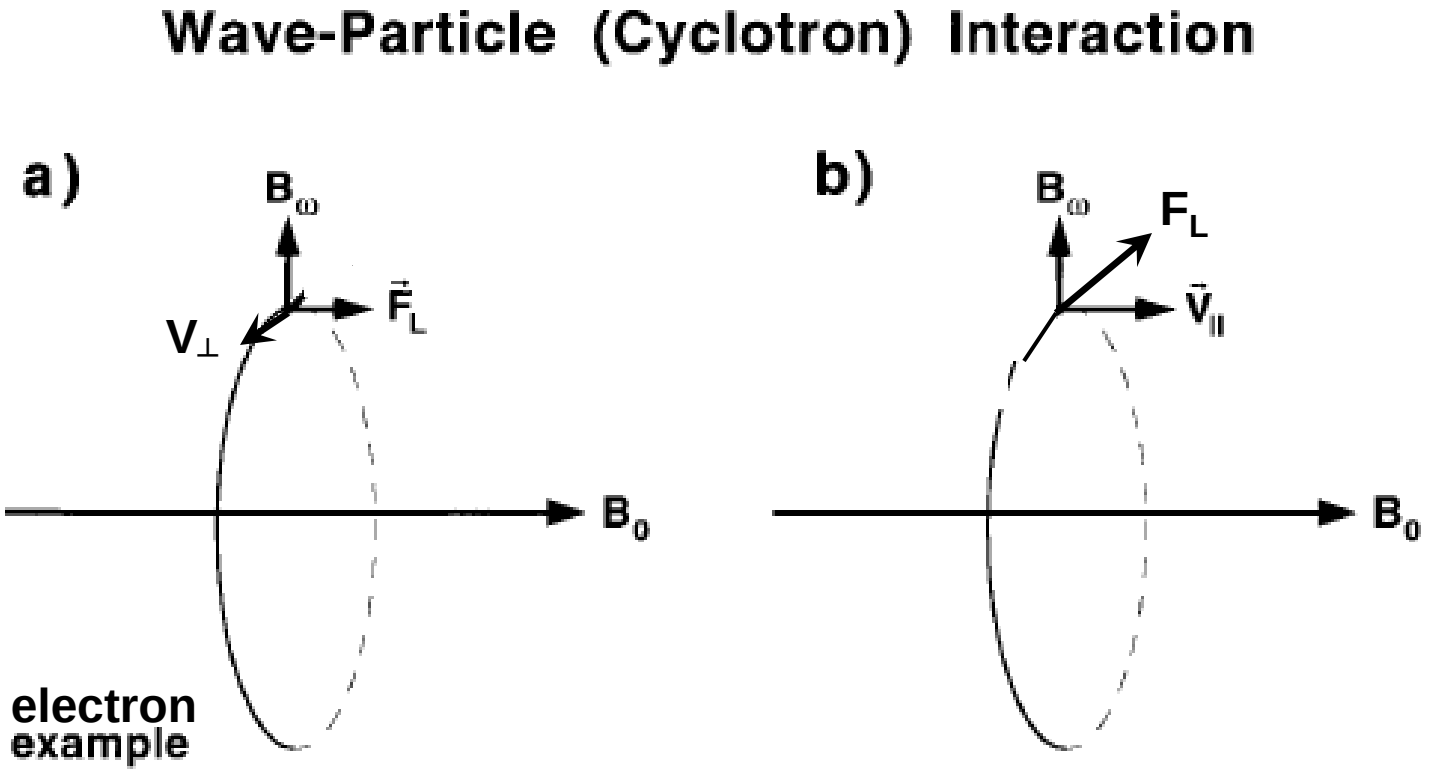
“Normal” Cyclotron Resonance: Doppler-shifted Cyclotron Resonance



$$\omega - \mathbf{k} \cdot \mathbf{V} = \Omega^{-}$$

Tsurutani and Lakhina, RG, 1991

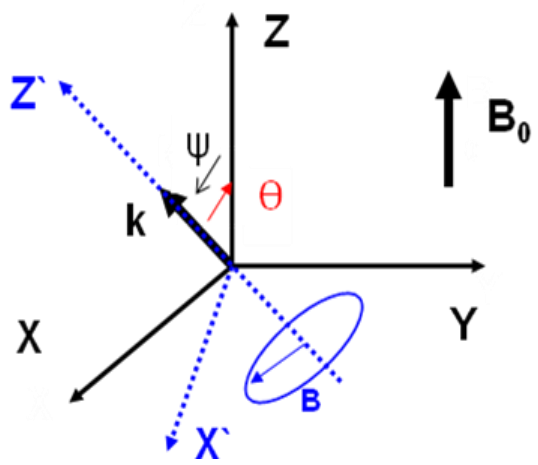
Pitch-angle scattering caused by Lorentz force between electron velocity and orthogonal wave magnetic field. Electric fields unimportant

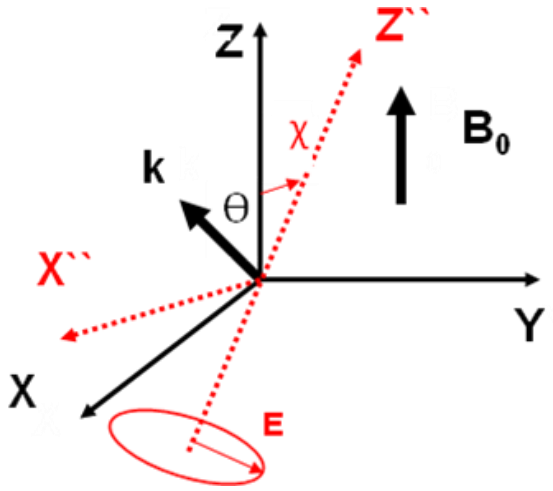


Tsurutani and Lakhina, RG 1997

From cold plasma theory

The background magnetic field B_0 is directed along the Z-axis and electromagnetic waves are assumed to propagate in the (XZ) plane. Here *k* is the wave vector.

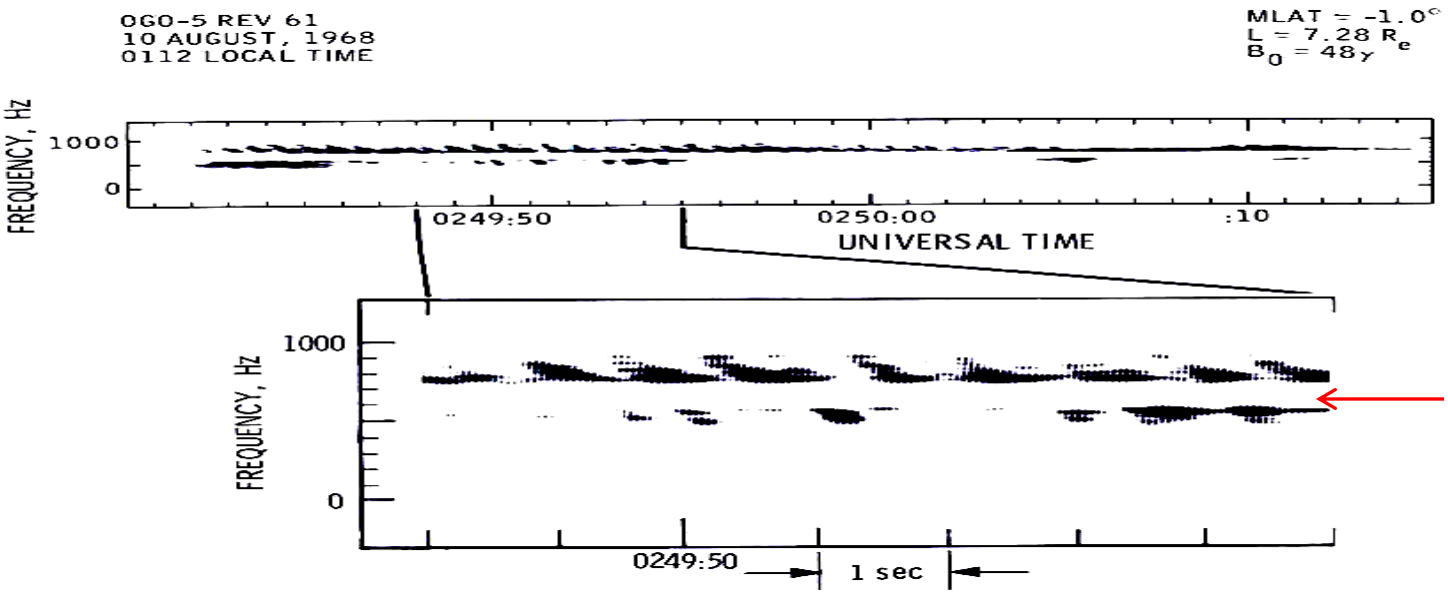




Important point: It is difficult to go from electric polarization and amplitude to magnetic. Assumptions have to be made.

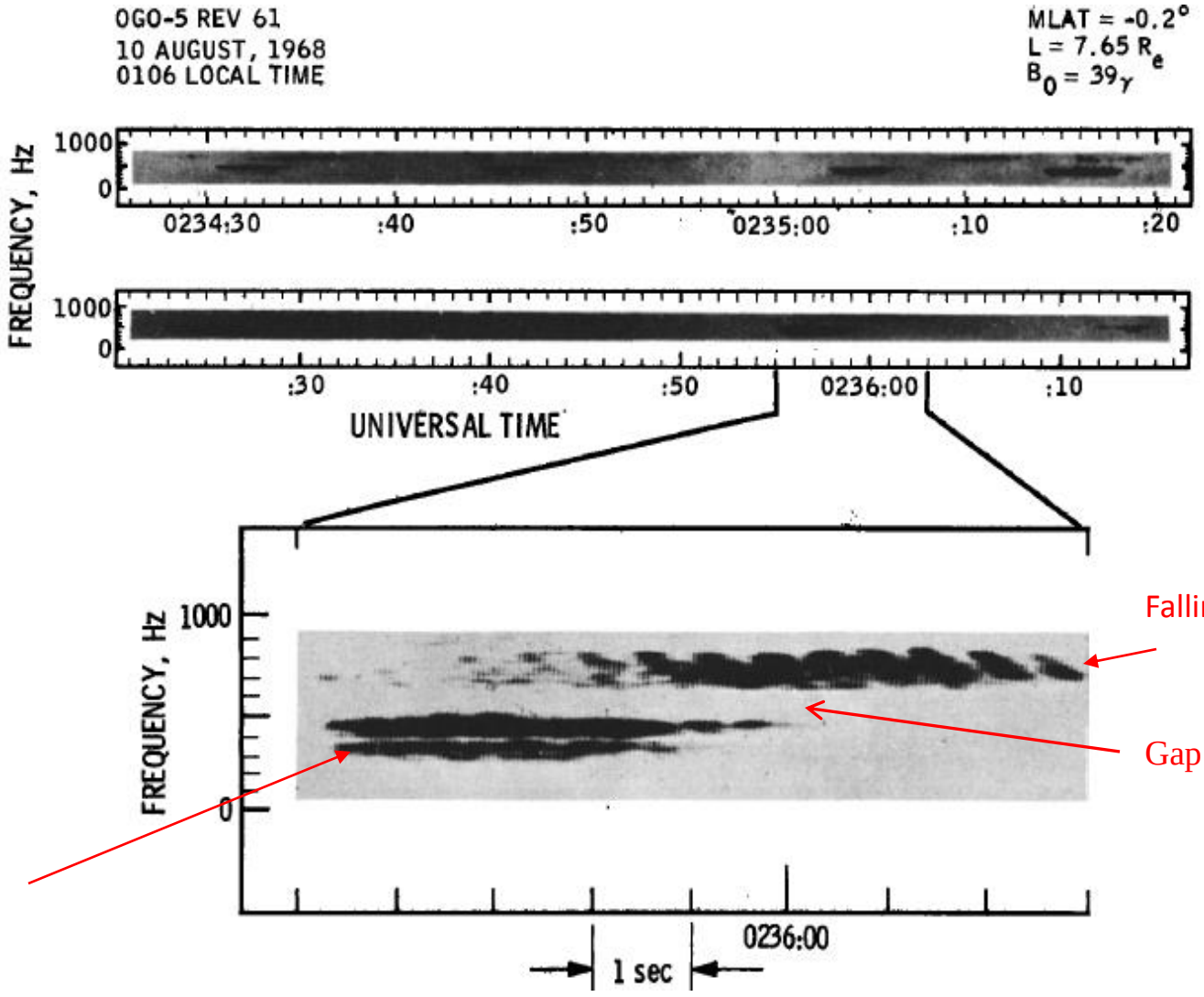
Verkhoglyadova et al., JGR 2009.

Nightside Chorus Example: Falling Tone Elements with a Gap at 0.5 f_{ce}



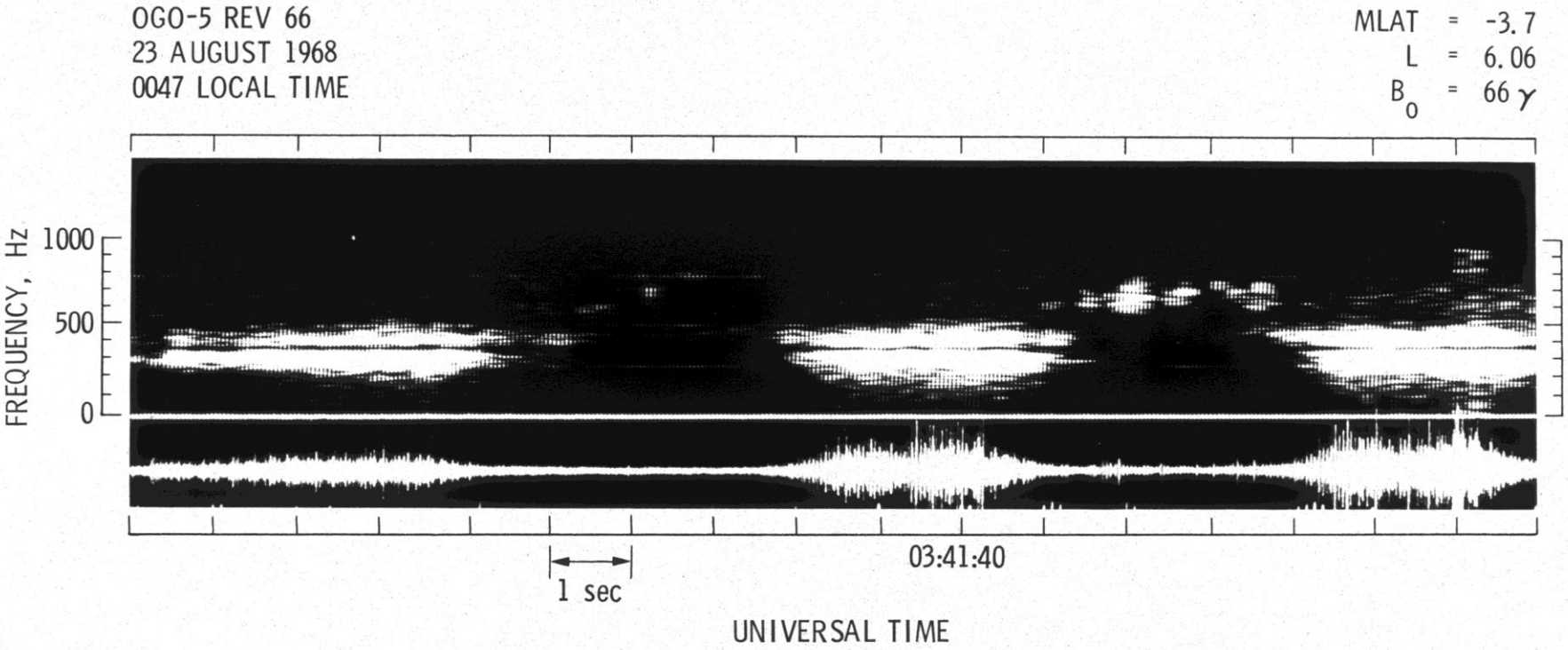
Tsurutani Smith, JGR 1974

5-15 sec hiss (lower band) and chorus (upper band) groupings



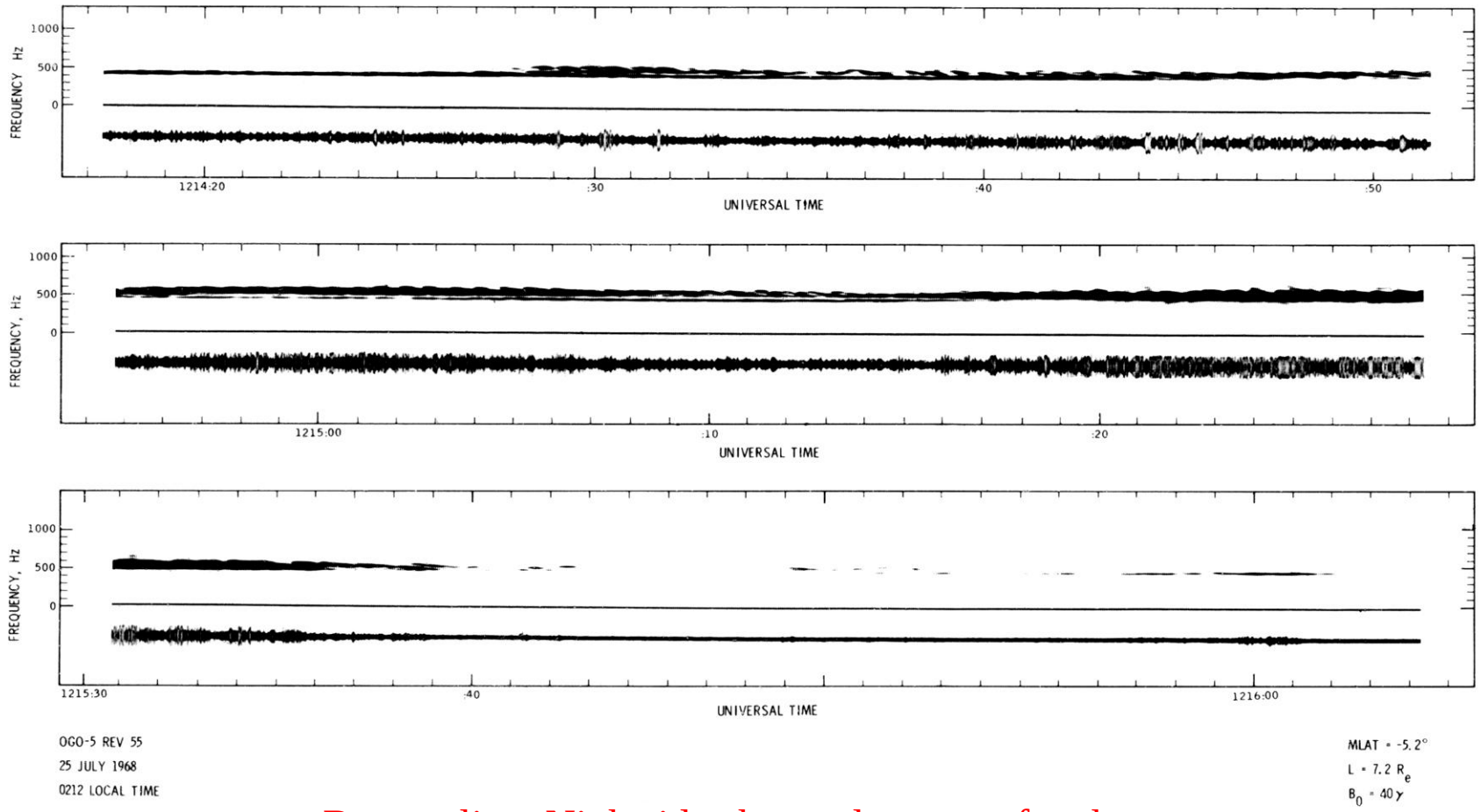
Tsurutani and Smith JGR 1974

Nightside Event: 5-15s Hiss Groupings



Tsurutani and Smith JGR 1974

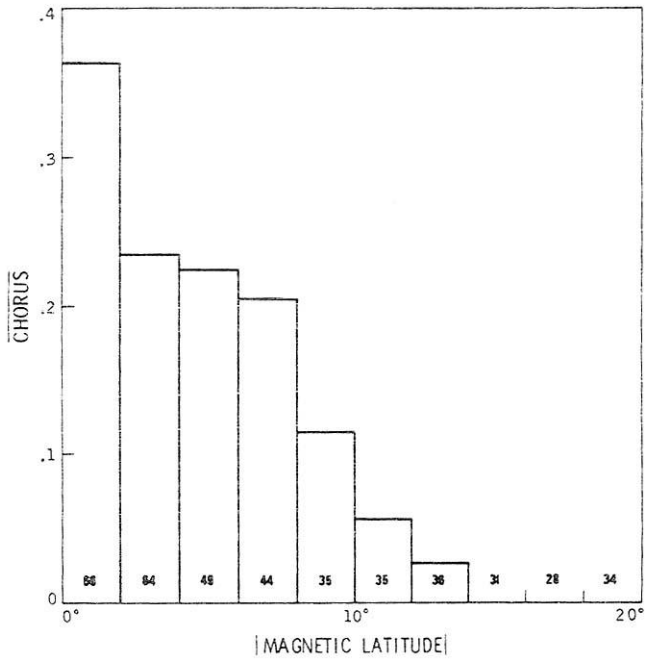
Horizontal Tones



Bottom line: Nightside chorus does not often have rising tone structures, thus electron precipitation occurs but should not exhibit < 1 s structures

Chorus is generated at the magnetic equator, as expected from K.-P. 1966

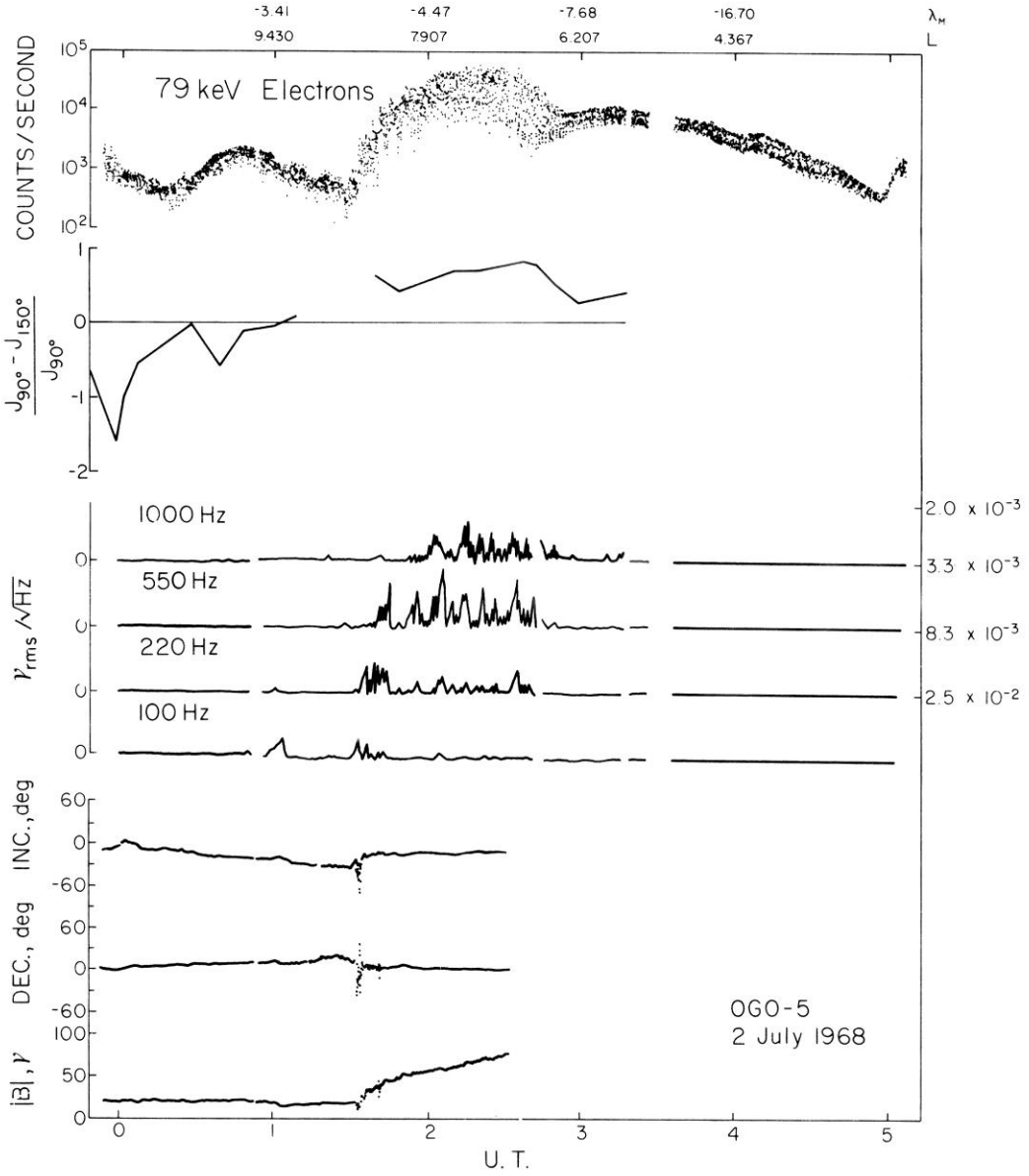
$$\omega - \mathbf{k} \cdot \mathbf{V} = \Omega^{-}$$



TS JGR 1974

Within 1°of equator: LeDocq et al. GRL 1998; Lauben et al, JGR 2002

Chorus due to Injection of $T_{\perp}/T_{||} > 1$ Anisotropic 10-100 keV Electrons: K-P

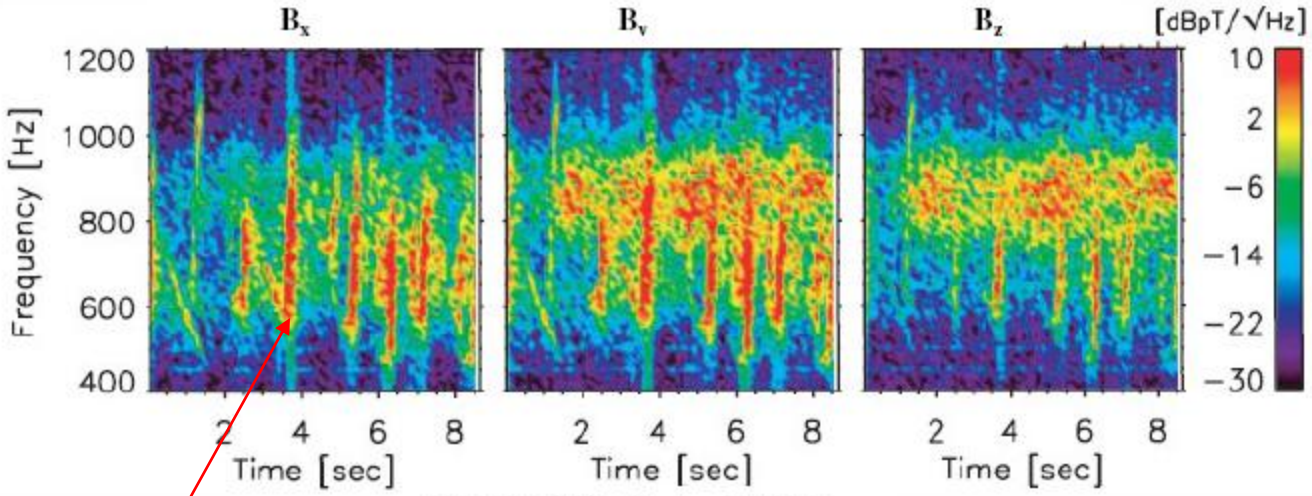


Tsurutani, West and Buck, Wave Inst. Spa Plas., 1979

Comments in TS, JGR 1974 Concerning 5-15 sec pulsations

"The dominant quasi-period of chorus bursts was approximately 5-15 s." "Variations of the ambient magnetic field strength were examined during quasi-periodic pulsation events; no apparent correlation between chorus pulsations and micropulsations was detected."

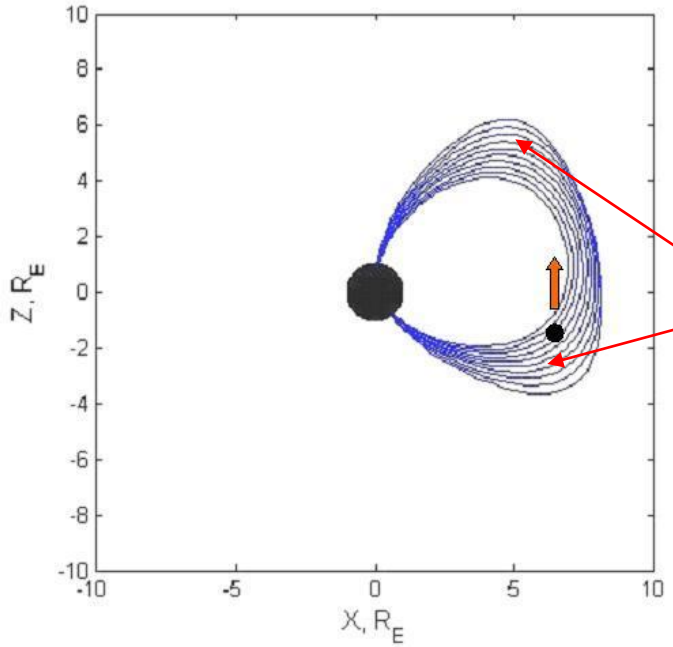
The Coroniti-Kennel mechanism (JGR, 1970) of electron loss-cone modulation in the equatorial plane can be discounted. Suggestion: micropulsations are made in the ionosphere.



Chorus "element"

Tsyganenko Model:
(P_{dyn} = 4 nPa, Dst = +2 nT)

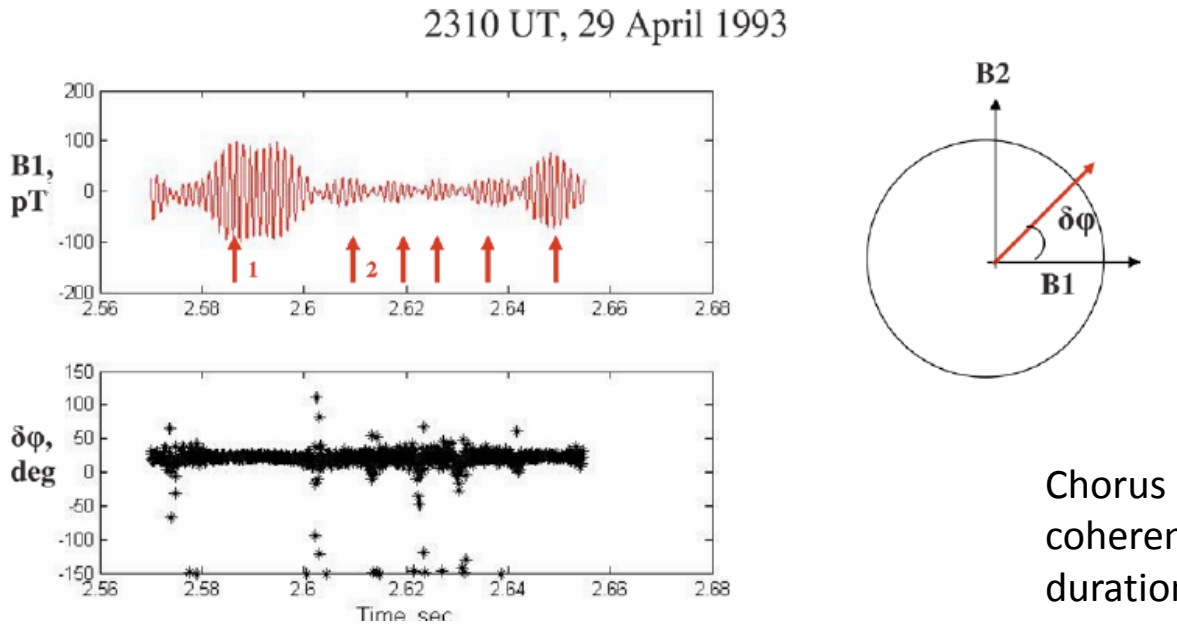
GEOTAIL OBSERVATIONS



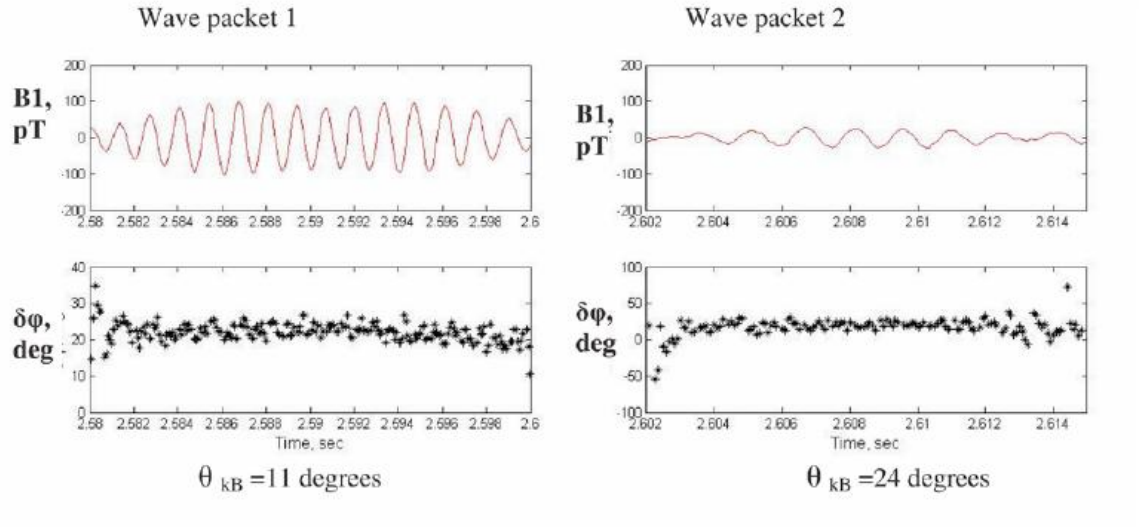
Minimum B pockets

Tsurutani et al., JGR, 2009

CHORUS FINE STRUCTURE: VERY LARGE AMPLITUDES



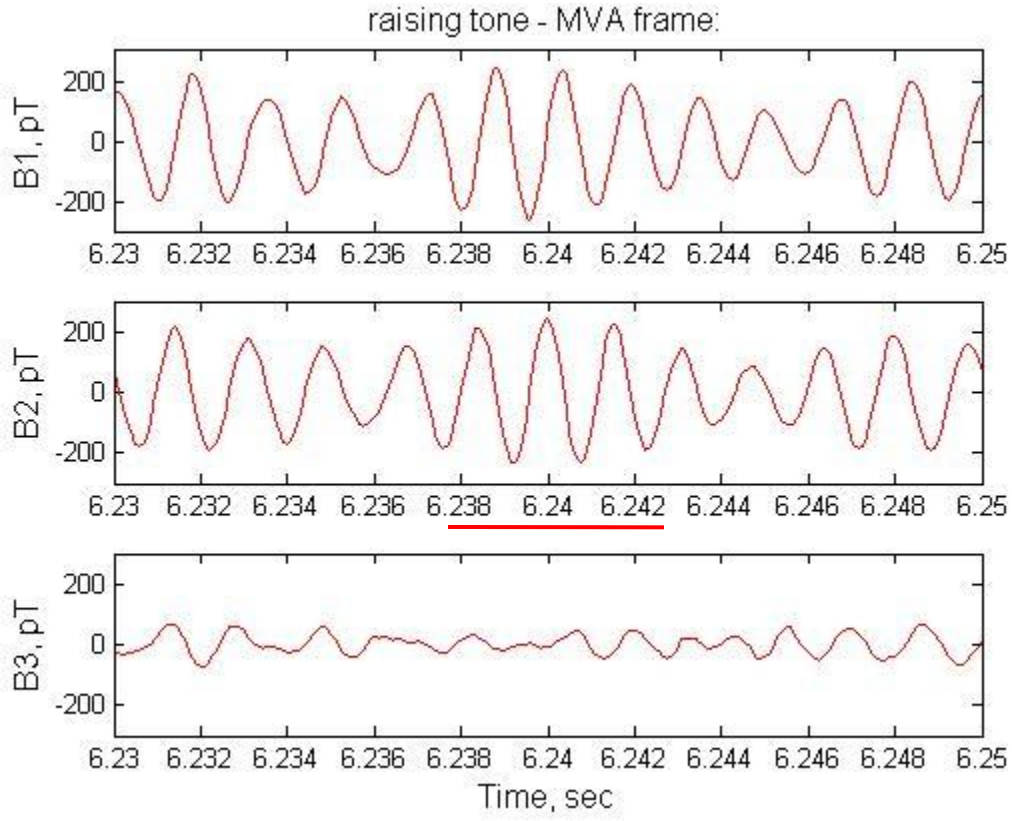
Chorus elements are composed of coherent subelements or packets with durations of ~ 0.5 to 1.0 x 10^{-2} s.



Santolik et al. JGR 2003;
Tsurutani et al. (JGR, 2008);
Verkhoglyadova et al. (EPS, 2009)

2311:45 UT, 29 April, 1993

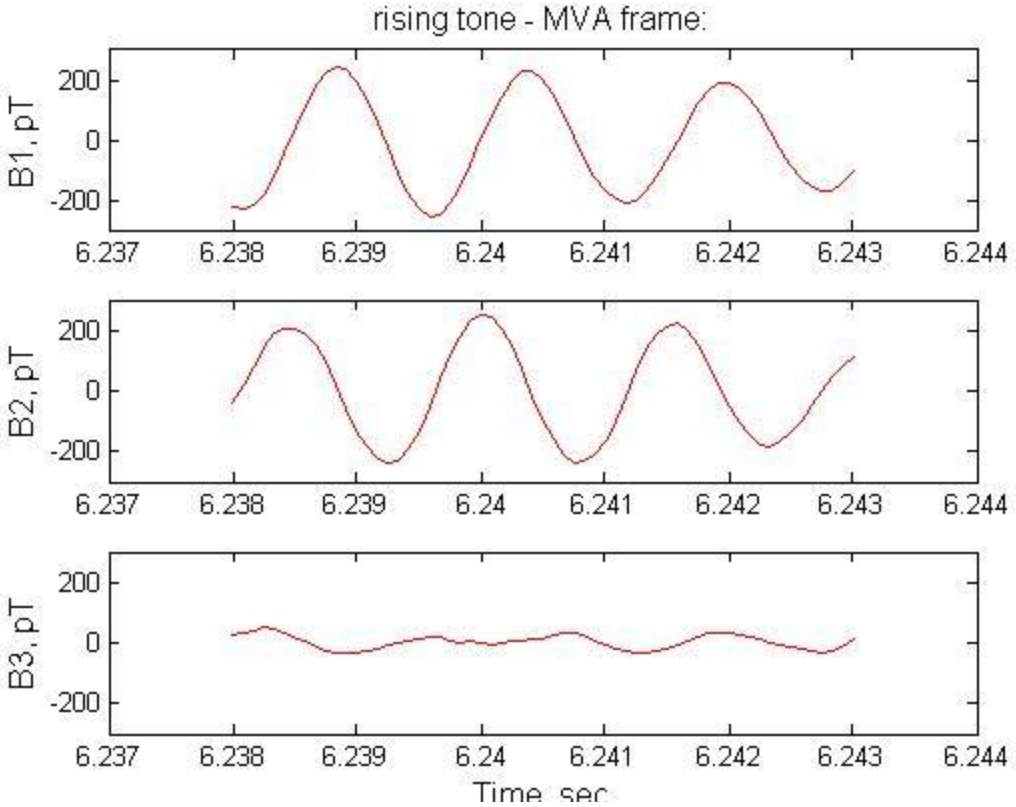
θ_{kB0}=20˚, Bω ~ ± 250 pT
Peak-to- peak



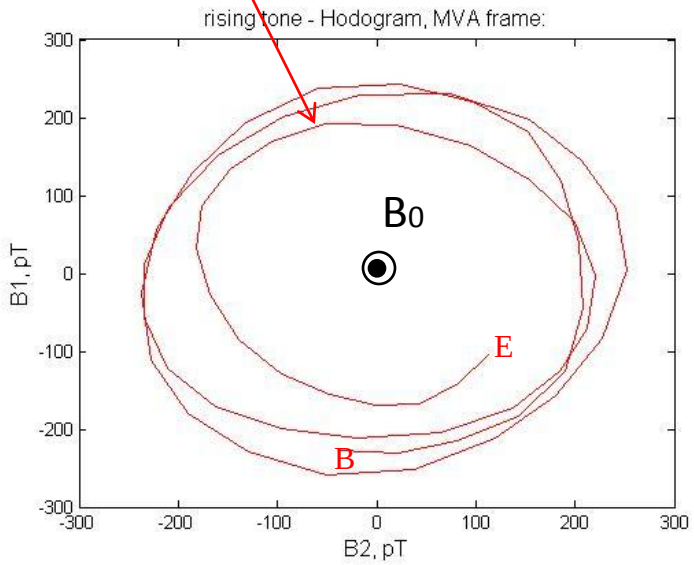
Wave is almost monochromatic.

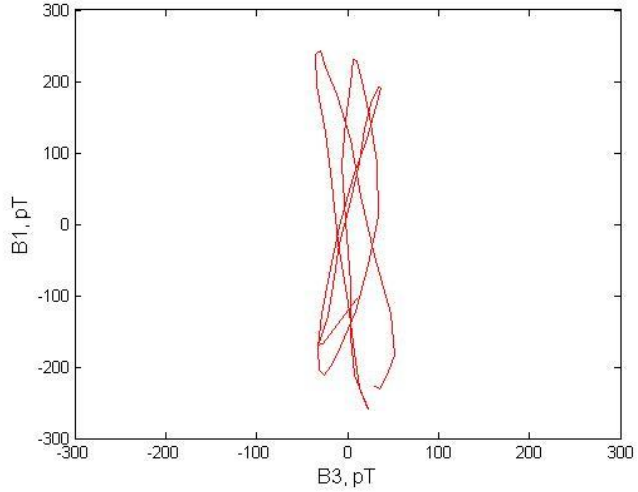
$\theta_{kB0}=15.7^{\circ}$

Circular polarization

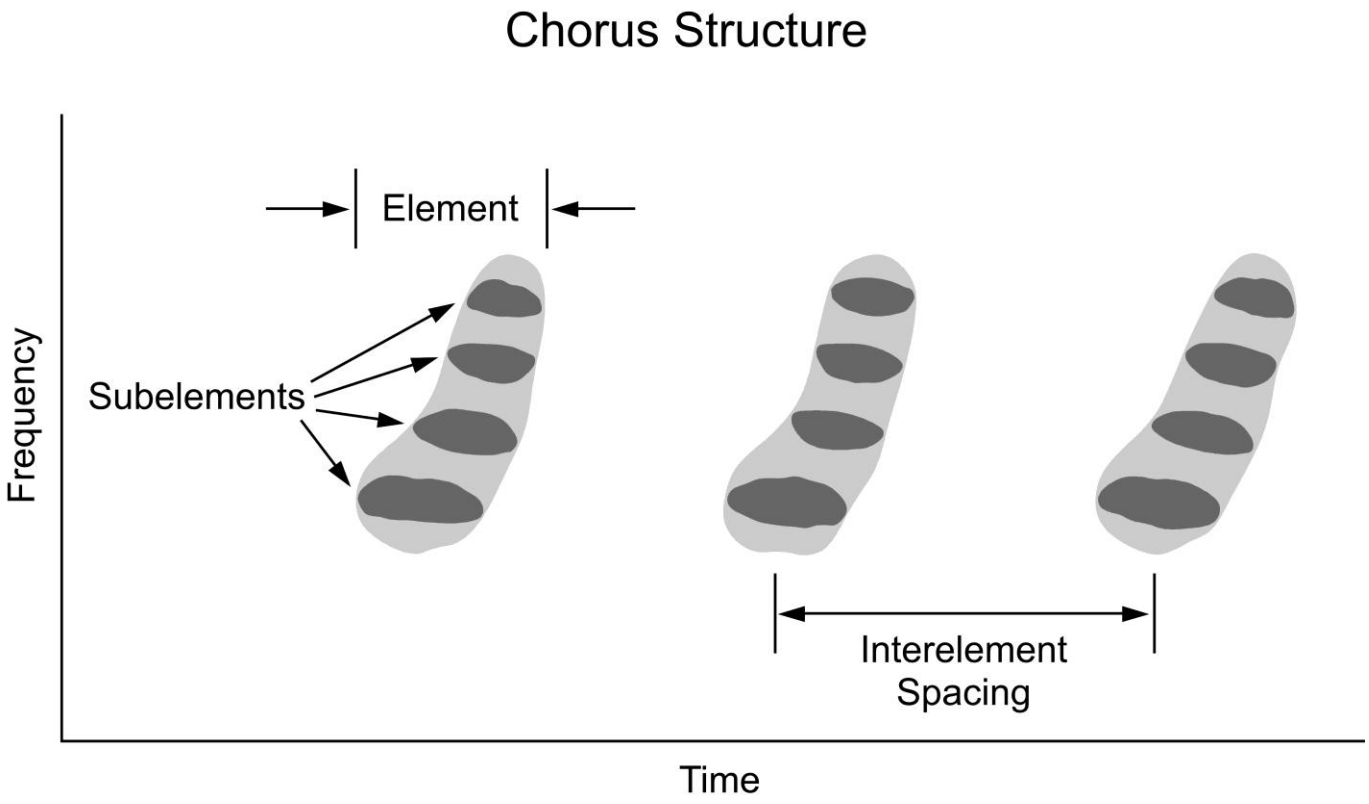


Chorus R-H polarized: whistler mode





Observed but Not Currently Theoretically Modeled



Cyclotron Resonant Energies

- Take the normal first-order cyclotron resonance (n = 1)

$$V_{\parallel} = V_{ph}(1 + [\Omega/\omega])$$

- $E_{\parallel} = \frac{1}{2}\, mV_{\parallel}^2 \sim$ 10 keV at top of the element frequency and 90 keV at the bottom of the element frequency.

Pitch Angle Diffusion

$D_{\alpha\alpha} = \Omega^{-} (B_{\omega}/B_{o})^{2} \eta$ (Kennel and Petschek, 1966; Tsurutani and Lakhina, 2001)

Assumes incoherent electromagnetic waves

For $B^{2} = 10^{-3}\ nT^{2}$ (Tsurutani and Smith, 1977)

$T \sim 1/ D_{\alpha\alpha} = 7.6 \times 10^{3}$ s (slow diffusion)

If one considers chorus subelements, B_{ω} is $\underset{\sim}{}$ 0.2 nT.

T = 200 s

Still too slow for microbursts!

Particle Pitch Angle "Transport" for Coherent Interactions with Parallel Propagating Chorus

$\Delta\alpha = (B_\omega/B_o)\,\Omega\,\Delta t$

Use Geotail numbers: f_ω = 800 Hz, B_ω = 0.2 nT, B_o = 125 nT, f_{ce} = 3500 Hz -> f_ω/f_{ce}=0.25

Assume duration of interaction is over a subelement, $\Delta t = \Delta t_\omega * (V_{ph}/V_{||})$= 0.003 sec, $V_{||}$=c/3, V_{ph}=c/10, one gets a pitch angle "transport" of

$\Delta\alpha = 7°$

As energetic electrons cross the magnetic equator, they will interact with several chorus subelements. Thus electrons near the loss cone will be transported into it.

This can explain the structure of microbursts!

Tsurutani et al., JGR 2009; Lakhina et al., JGR 2010

Pitch Angle Transport

- $D_{\alpha\alpha} = [B_{\omega}^2 \Omega / 4B_0^2 (\omega/\Omega + ½)] [1 + \omega \cos^2\alpha/\Omega - \omega]^2 \tau$

- Where τ = subelement time, ω = chorus frequency, B_0 = ambient magnetic field strength and Ω = electron cyclotron frequency.

Lakhina et al. JGR 2010

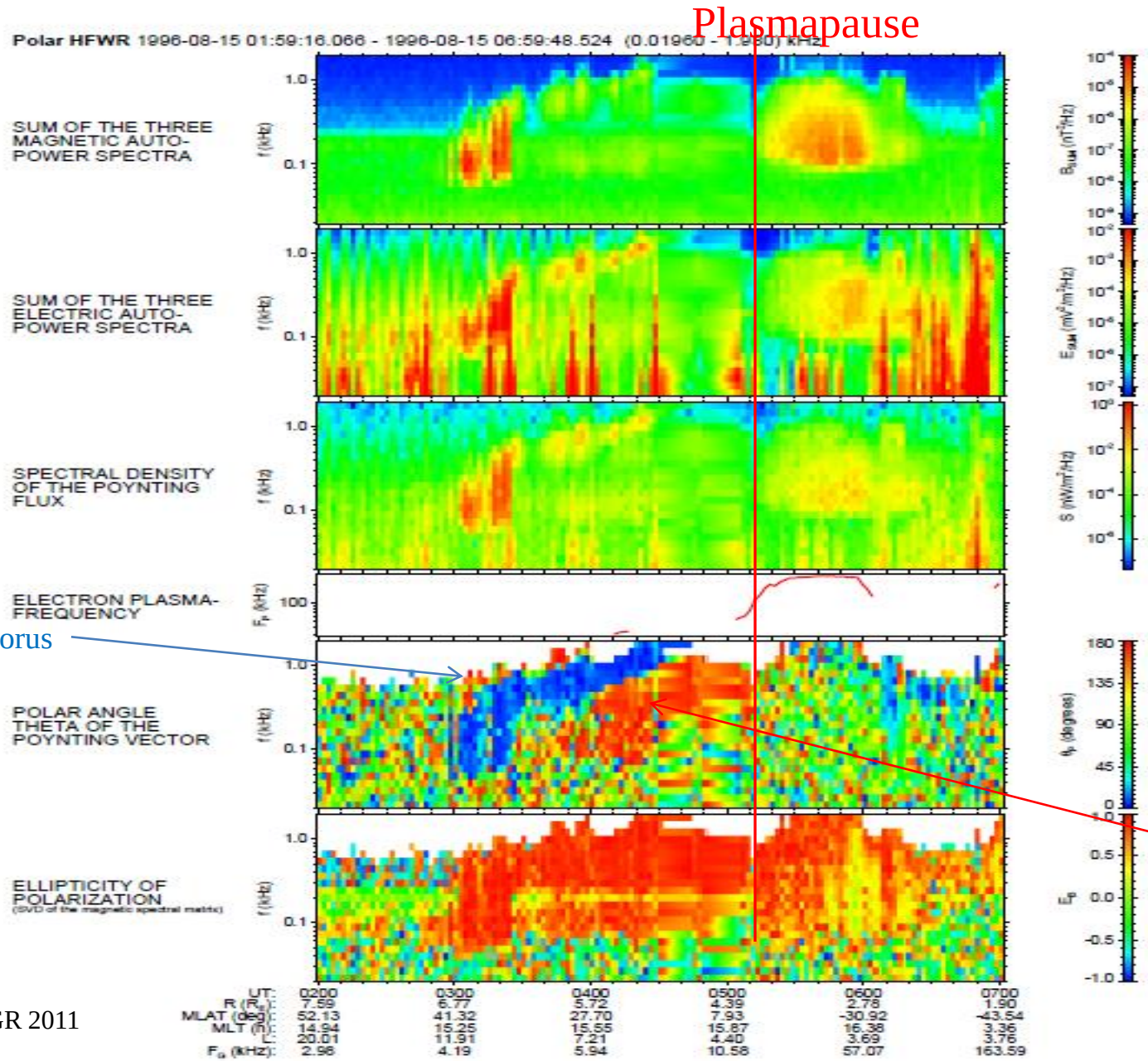
Power Law Subelement Time Durations

$P \alpha \tau^{-\beta}$ (empirically, $\beta = 1.5$ to 3.0, Santolik et al., 2007)

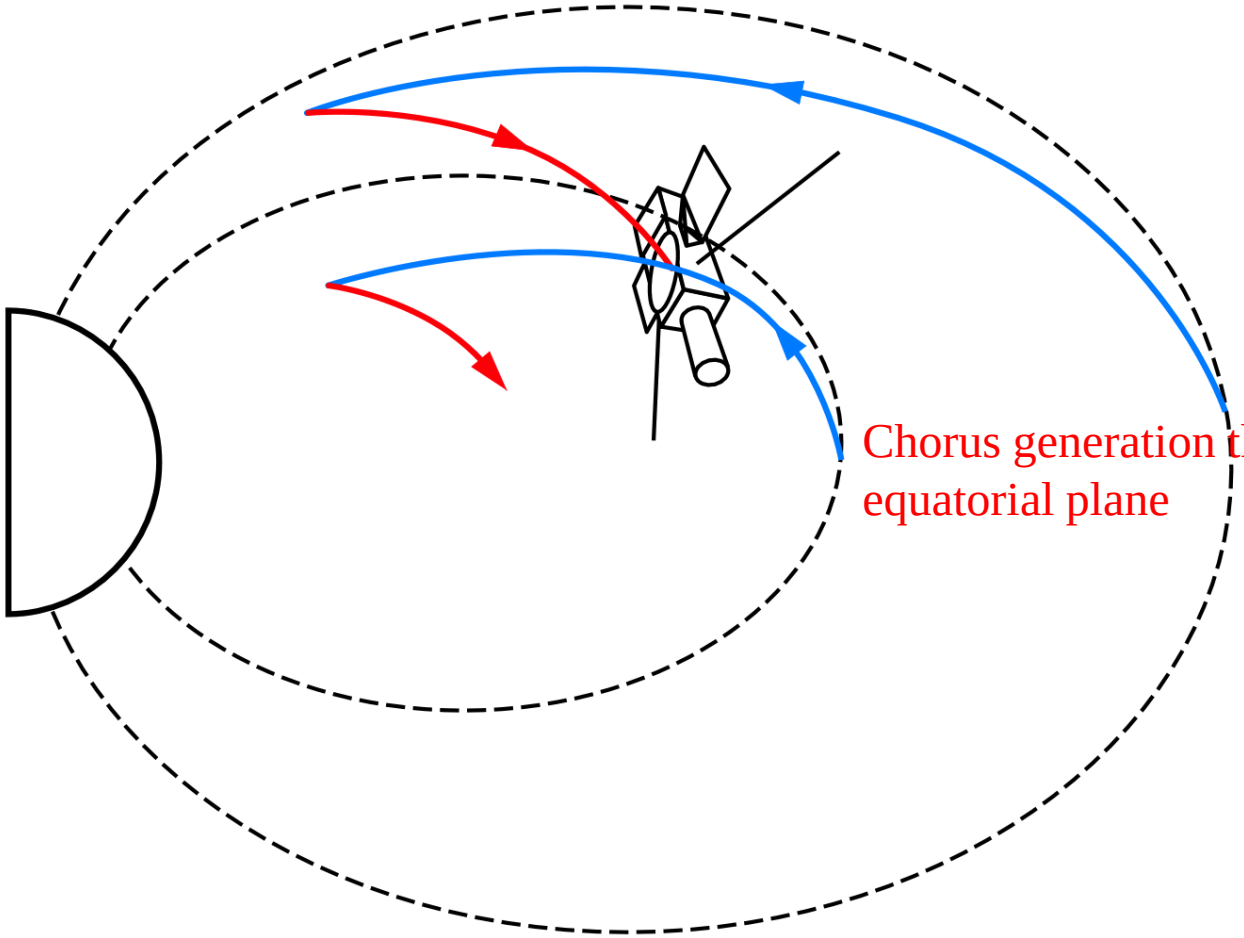
Then the maximum change in the average pitch angle $\Delta\alpha = \sim 2° - 20°$

and $< D > \sim 0.5$ to 8.5 s^{-1}

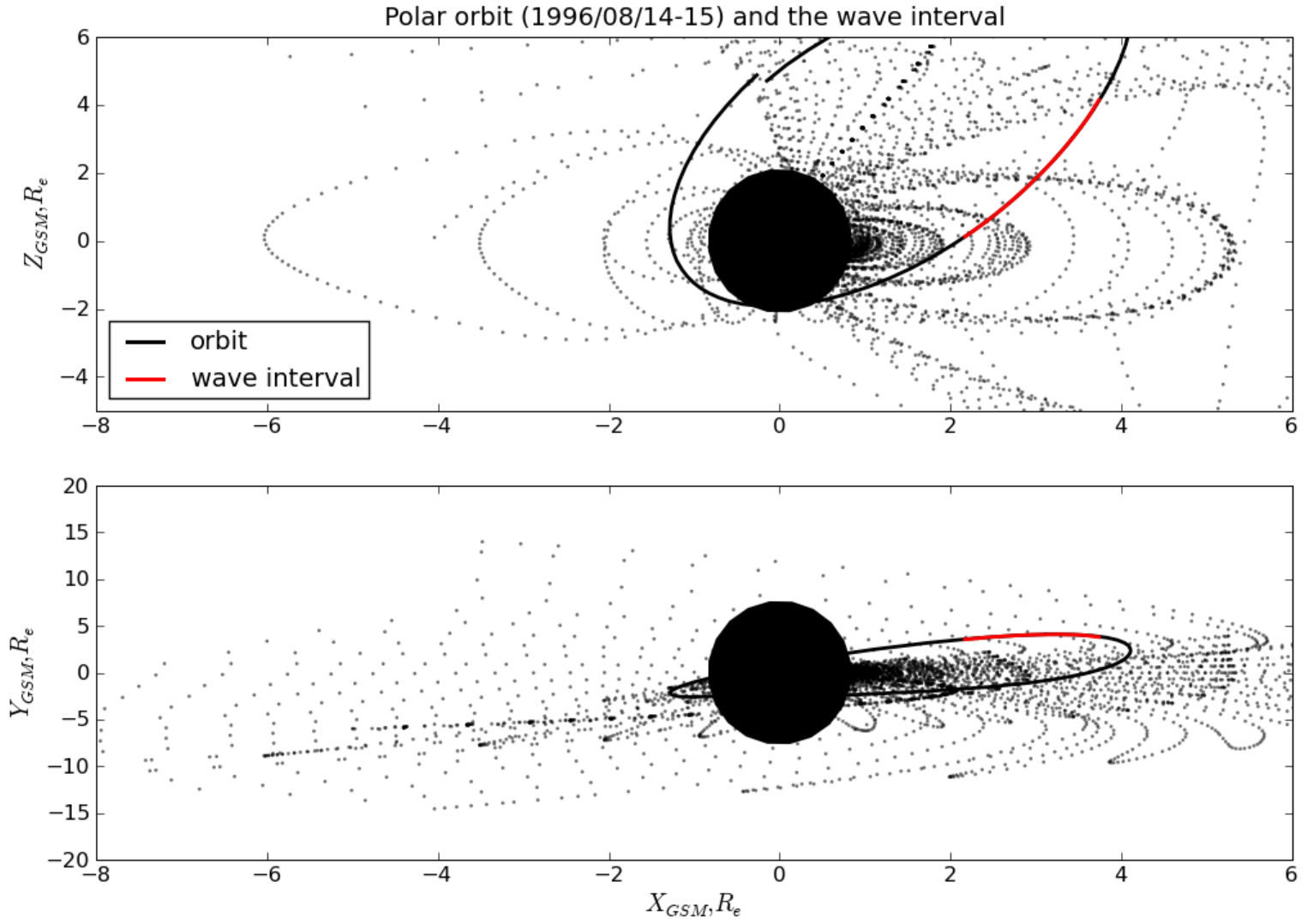
Overlapping Downgoing and Upcoming Outer Zone Waves are Common at Polar



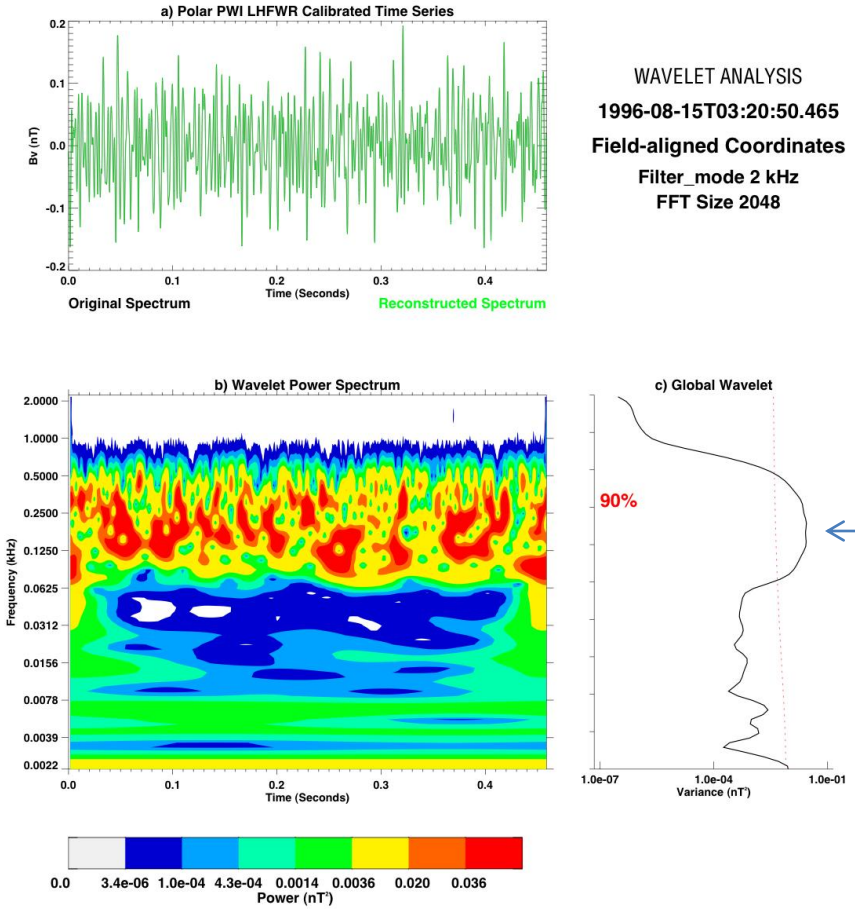
Tsurutani et al., JGR 2011


Chorus generation throughout
equatorial plane

The Polar Orbit



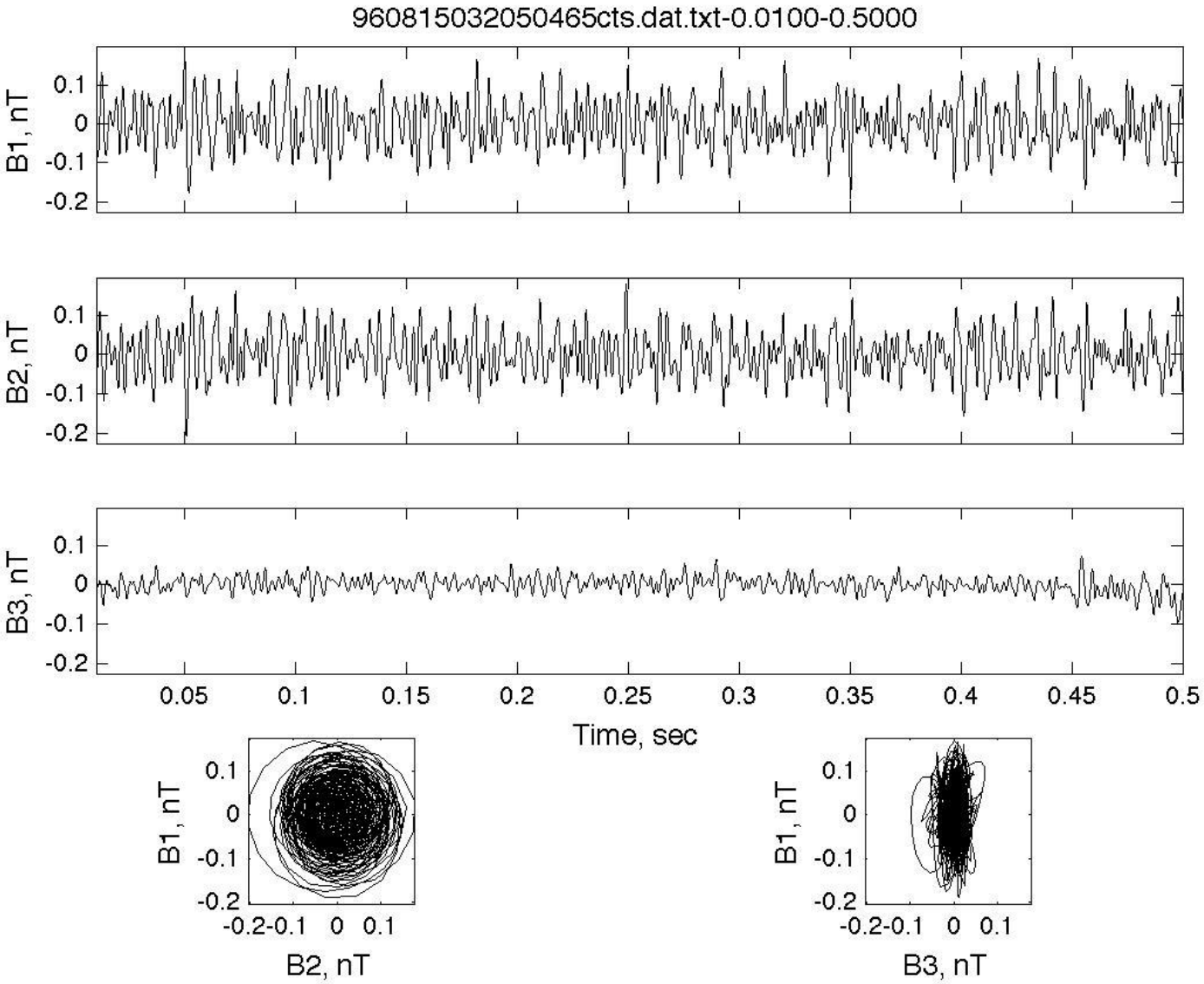
Downward Propagating Chorus



10^{-2} nT^2

Ulowa 101007

Downward Propagating Chorus

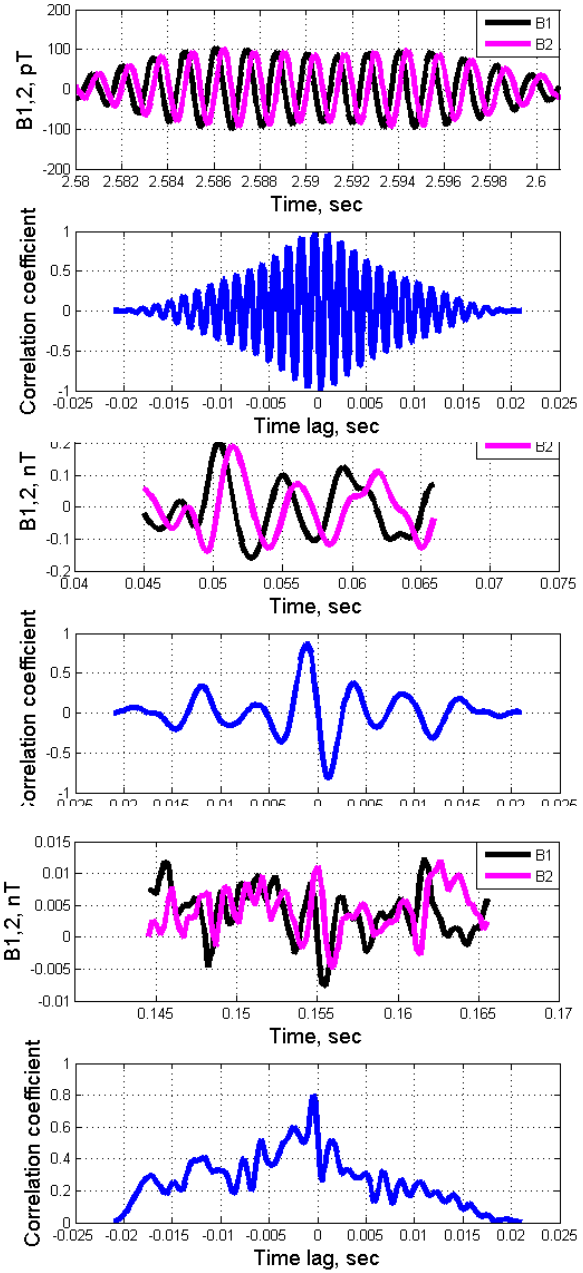


No subelements present!

Chorus in generation Region: Geotail

Downgoing Polar waves

Upcoming Polar waves



Tsurutani et al. JGR 2009

Conclusions: Chorus f-t structure and time scales

10-100 keV electron microbursts are created by coherent interactions at the mag. equator.

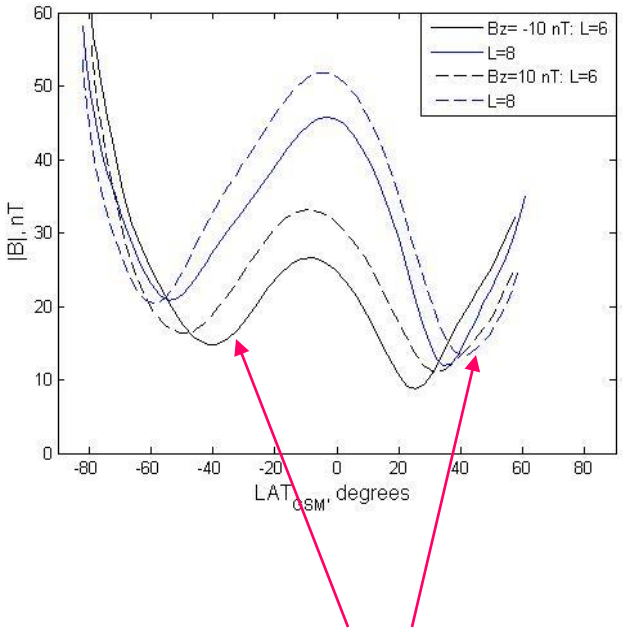
Relativistic microburst pitch angle scattering probably occurs off-axis by quasicoherent chorus (pitch angle transport by single cycle waves?).

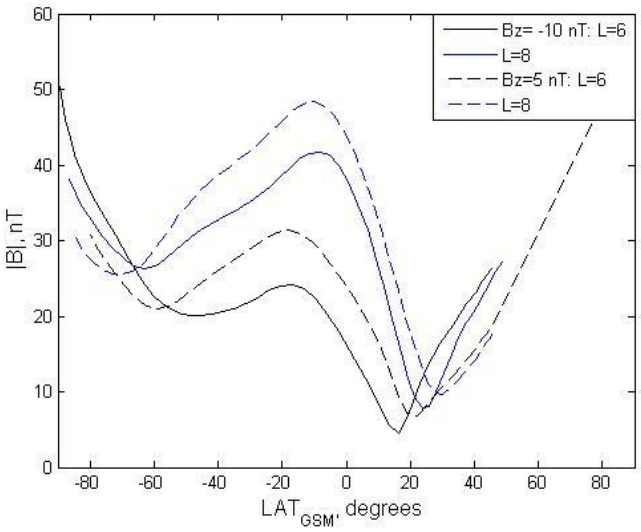
Microbursts are not detected in the midnight sector because of chorus temporal structure.

Microbursts should have substructures (scattering by subelements)

5-15 s chorus pulsations generated by thermal plasma triggering? Micropulsations might be an effect of particle precipitation into the ionosphere (W. Campbell)

Tsyganenko 04 Model





Minimum B Pockets

Verkhoglyadova et al. 2009

Open Questions for Further Research

How does chorus coherency vary with distance from the equator? How often does ducting occur and how does that affect coherency?

What causes falling-tone chorus?

Can microburst substructure be identified?

Thank You for Your Attention