Unsolved Problems of Magnetospheric Physics
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Some outstanding problems in radiation belt and wave physics

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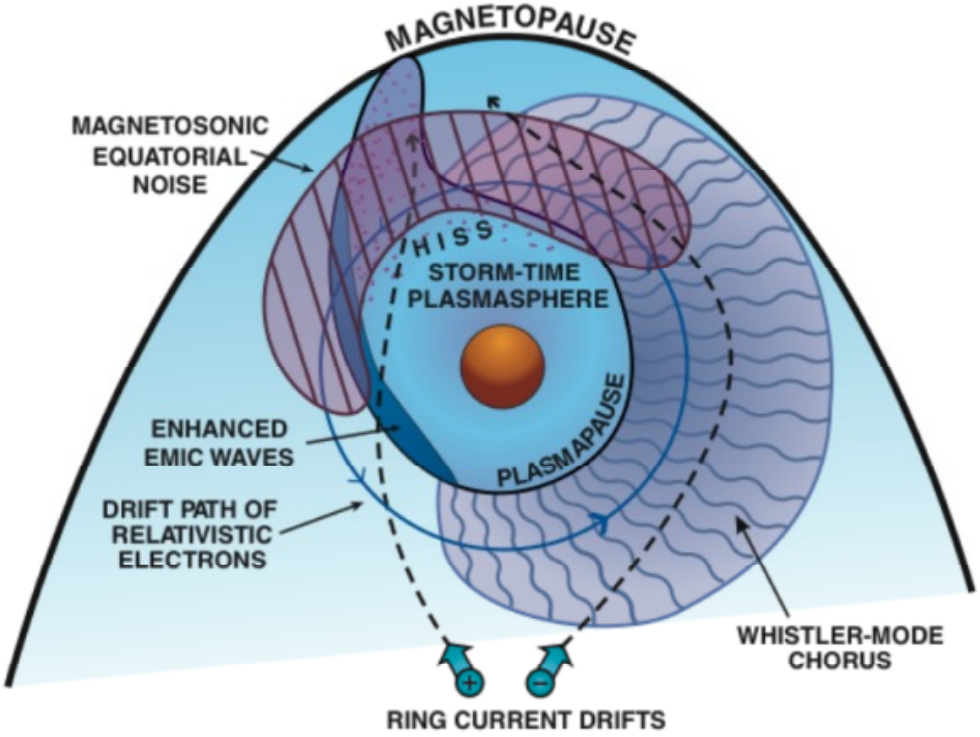
The 50,000 ft view

- Since energetic space plasmas are basically collisionless, the dynamics have to come from *adiabatic breaking*! (i.e., waves)
- That leaves us with only 2 problems:
  1. What is the nature of the *wave-particle interactions*?
  2. What is the nature of the 'waves'?



Thorne [2010] GRL "frontiers" review

Outline

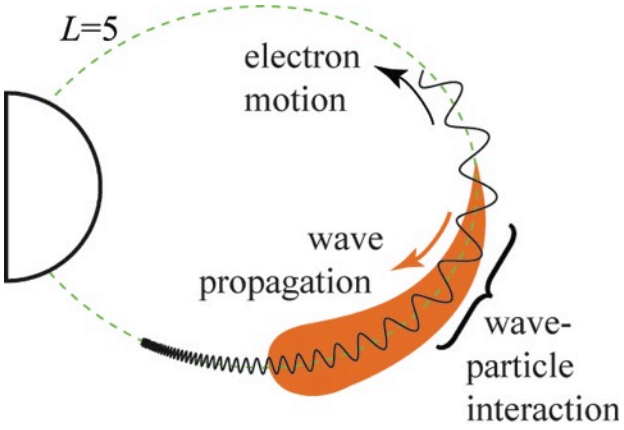
What is the nature of wave-particle interactions?

1. Nonlinear effects
2. Wave generation

What is the nature of the 'waves'? i.e., translation of microphysics to macrophysics

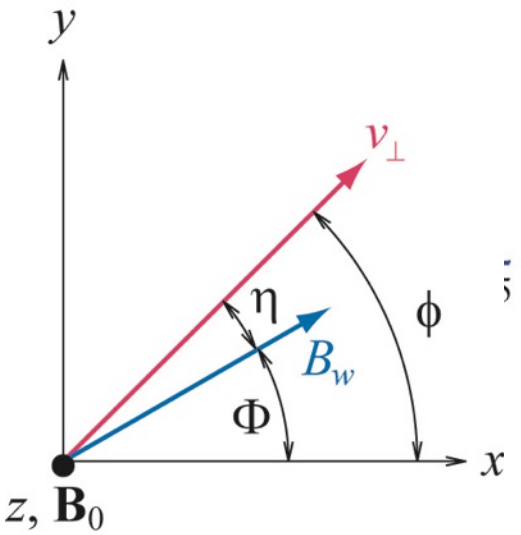
3. System science
4. Dropouts

1. Nature of w-p interactions: nonlinear effects



$$\frac{d\mathrm{p}}{dt} = q\left(\mathrm{E_w} + \frac{\mathrm{p}}{m_e\gamma} \times \left[\mathrm{B}_0(\lambda) + \mathrm{B_w}\right]\right)$$

Example simple case: field aligned wave, non-relativistic particles



wave

$$\frac{dv_{\|}}{dt} = \left(\frac{qB_w}{m}\right) v_\perp \sin\eta - \frac{v_\perp^2}{2B}\frac{\partial B}{\partial z}$$

adiabatic

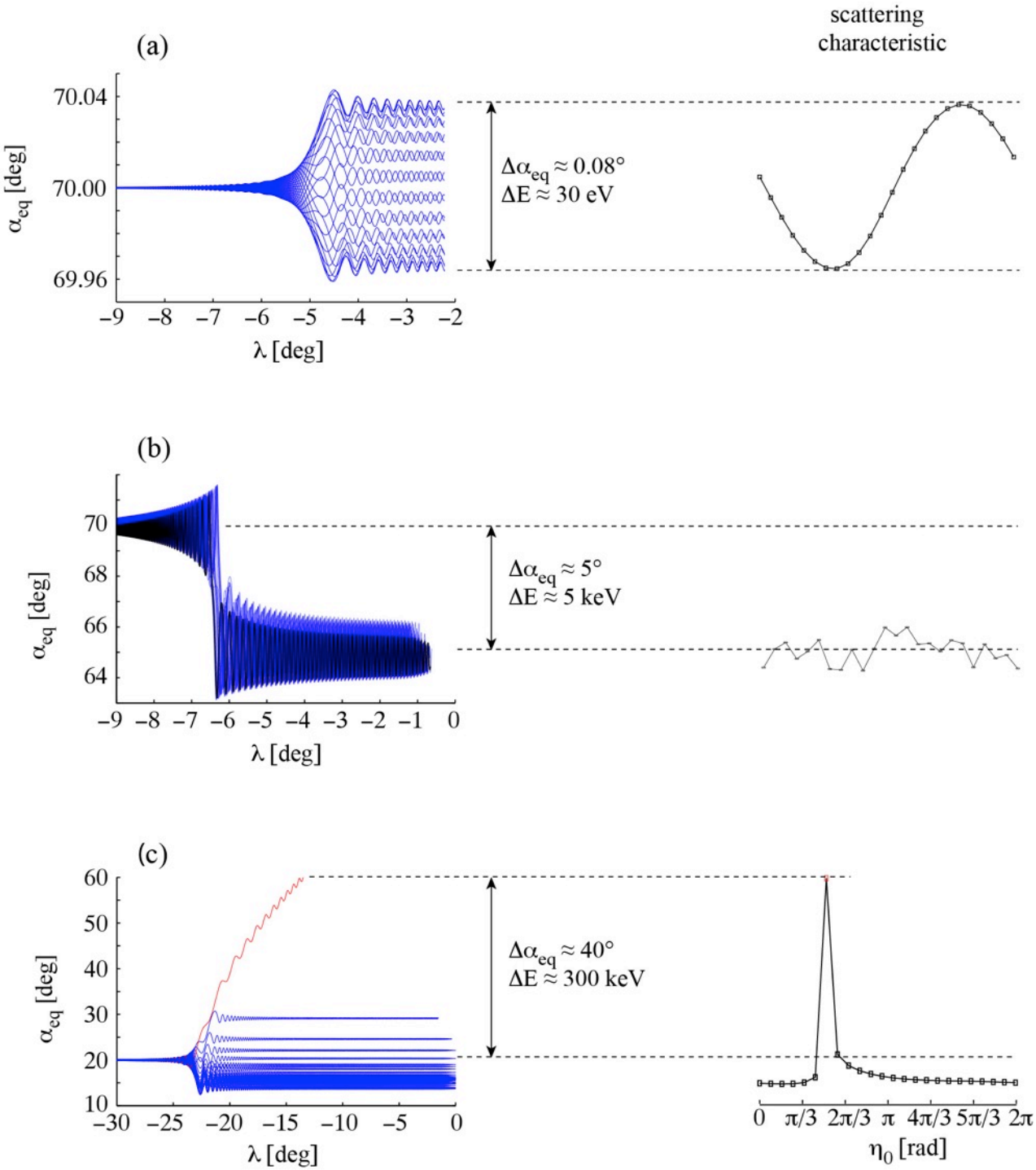
$$\frac{dv_\perp}{dt} = -\left(\frac{qB_w}{m}\right)\left(v_{\|} + \frac{\omega}{k}\right) v_\perp \sin\eta + \frac{v_\perp v_{\|}}{2B}\frac{\partial B}{\partial z}$$

$$\frac{d\eta}{dt} = \Omega - \omega - kv_{\|}$$

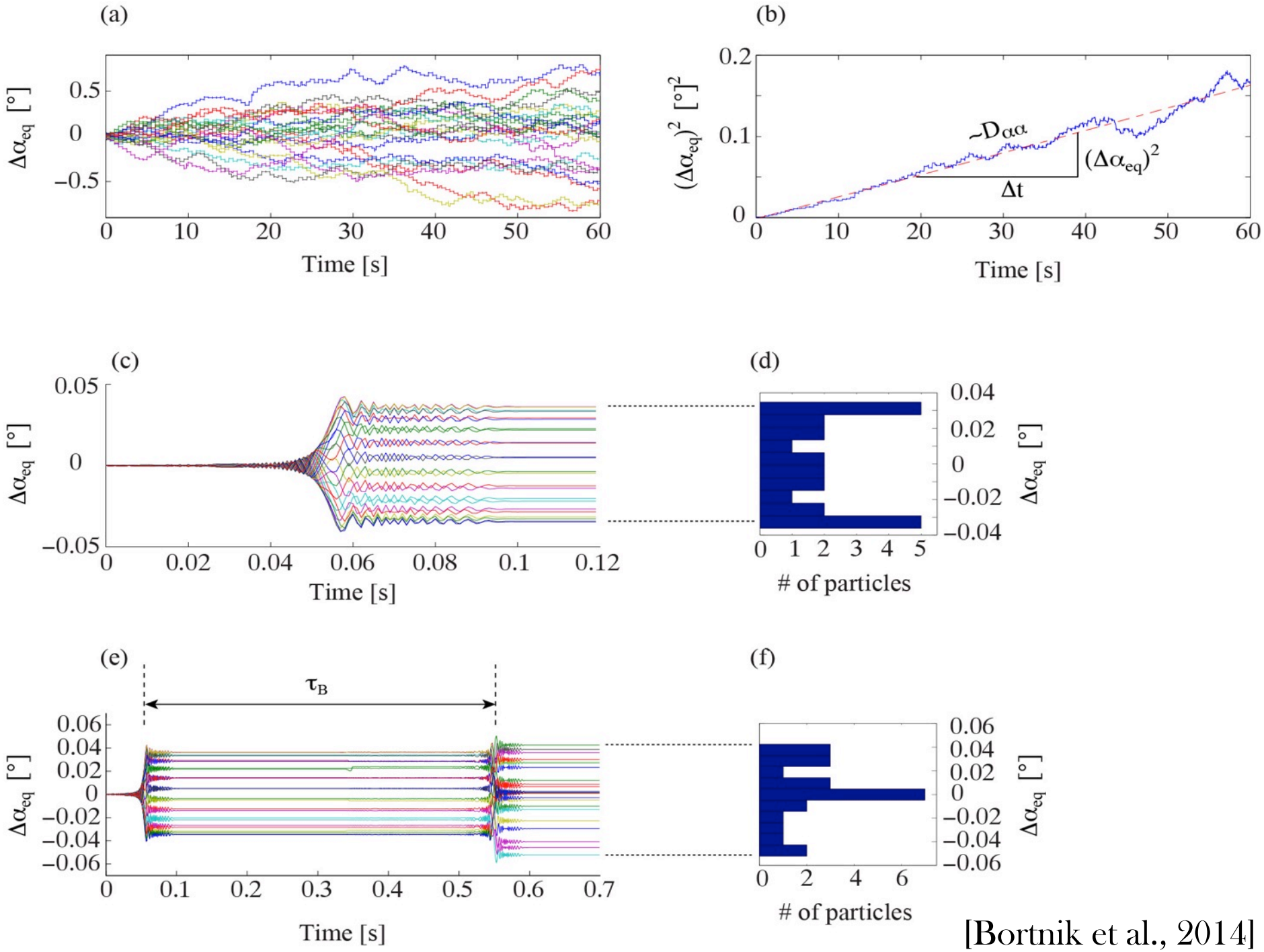
phase

Three representative cases

(a) small amplitude, ~1 pT wave
(b) Large amplitude ~1 nT waves
(c) Large amplitude, oblique, off-equatorial resonance



Bortnik et al. [2008]



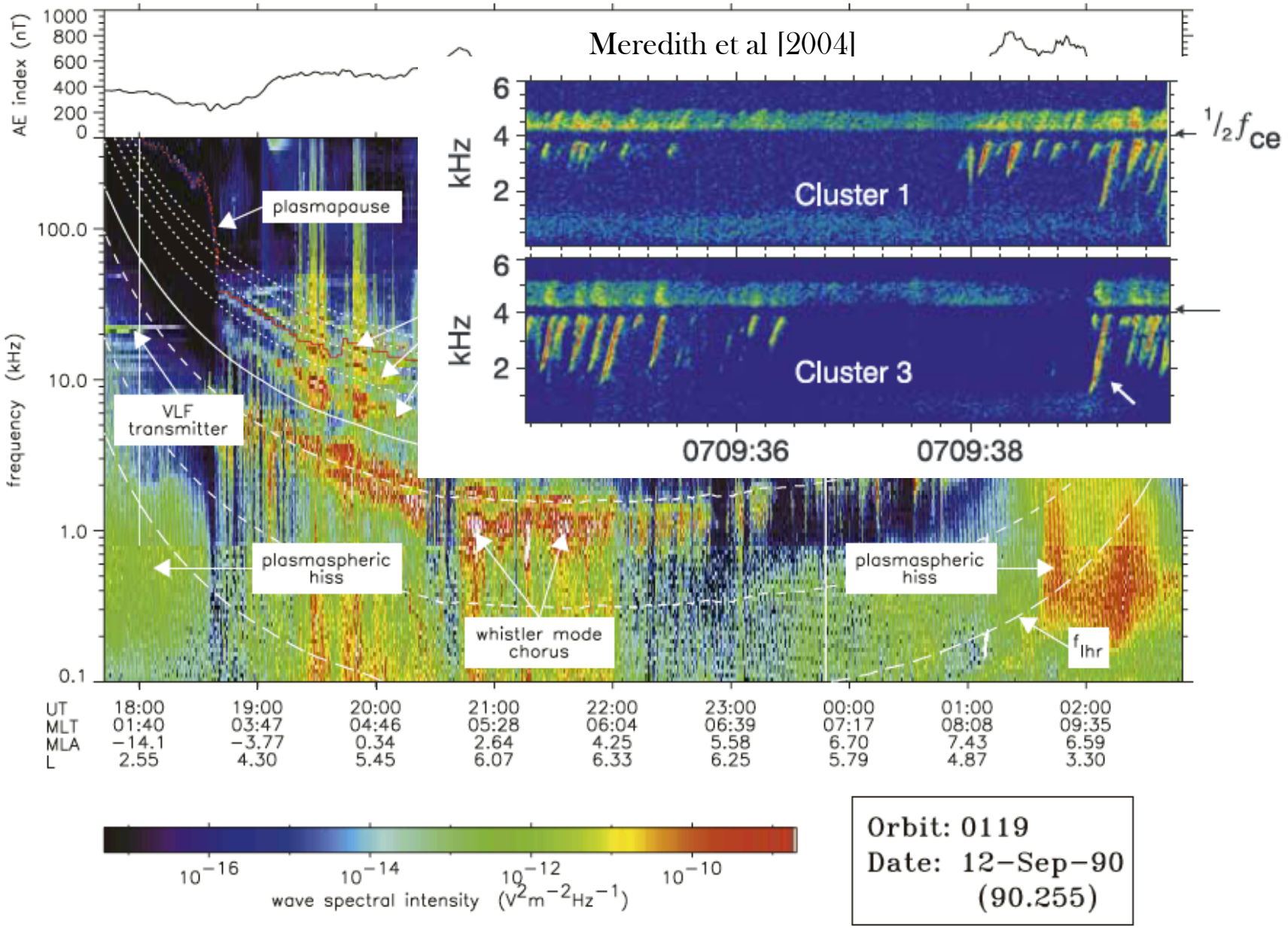
[Bortnik et al., 2014]

Topic #1. Problems

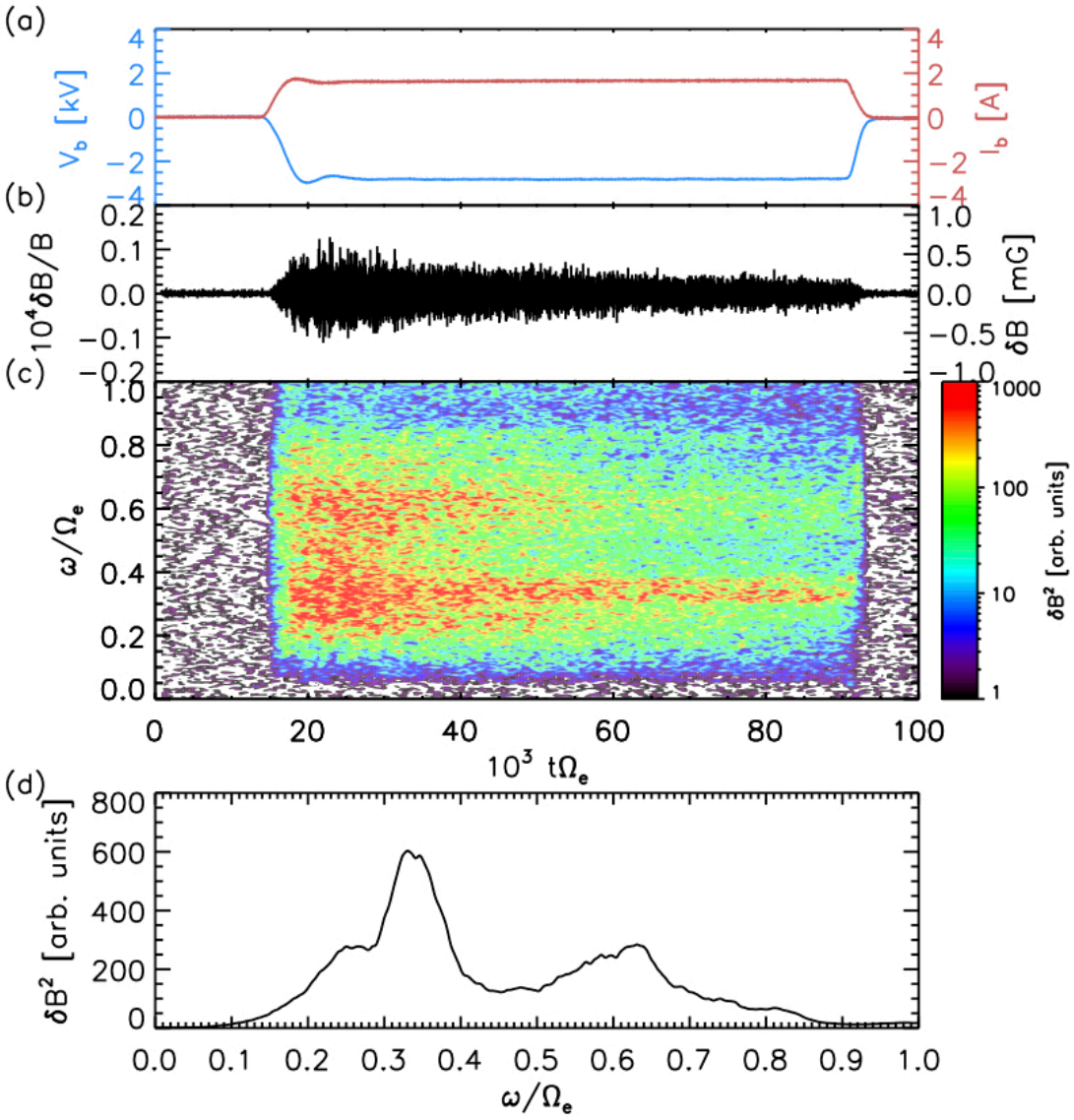
What is the nature of wave-particle interactions? Nonlinear effects

1. When are w-p interactions: linear, accelerating, decelerating? Chorus can do all 3 things ALONE!
2. Amplitude, coherency, and spatial dependence– need to specify this to get the proper ratios
3. What is the real timescale of radiation belt acceleration at different energies? E.g., John Foster, acceleration ~1hr much too quick for QL diffusion.

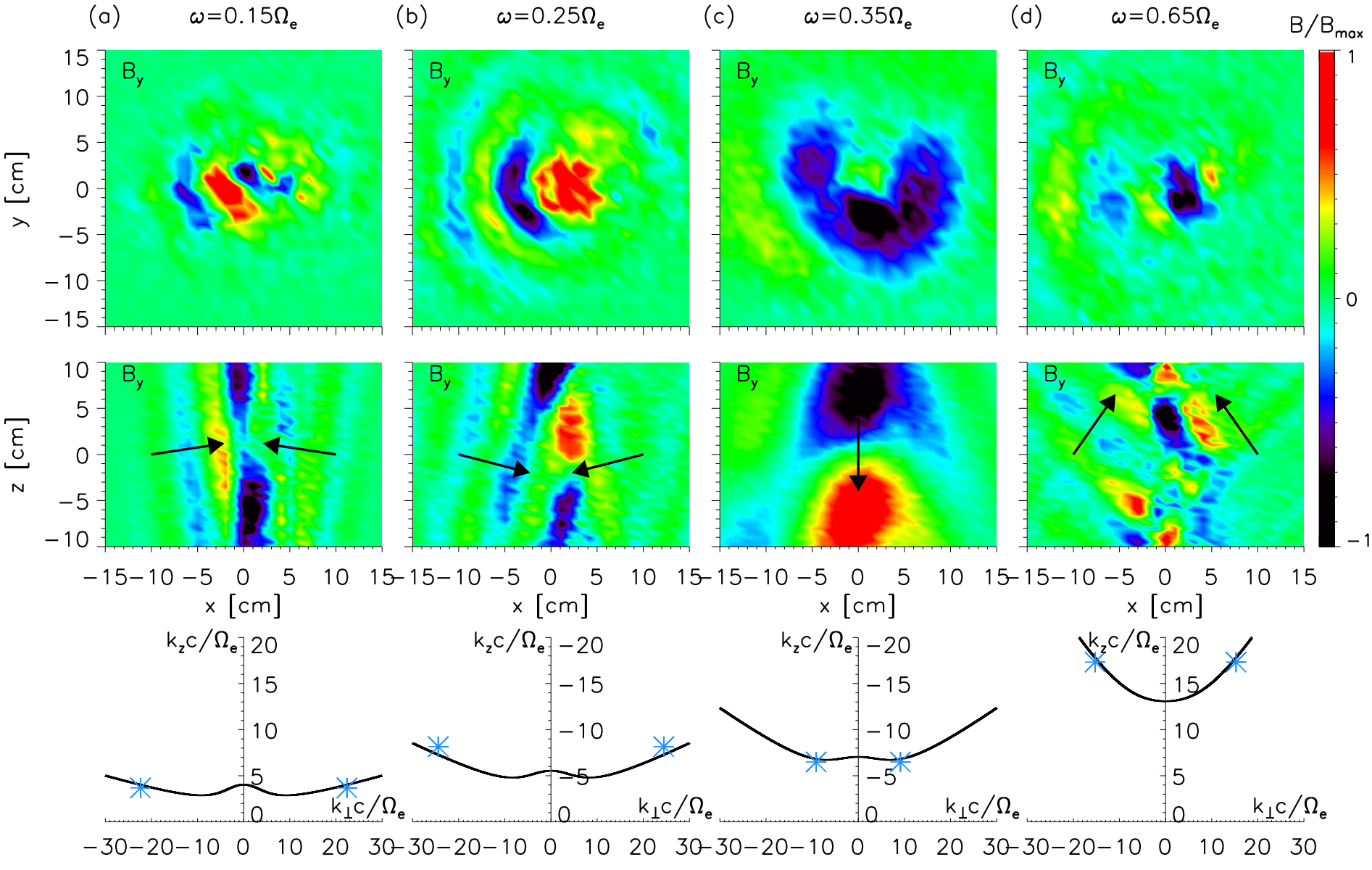
Topic #2: wave generation



Growing chorus waves in the lab



Growing chorus waves in the lab



0.15 fce

0.25 fce

0.35 fce

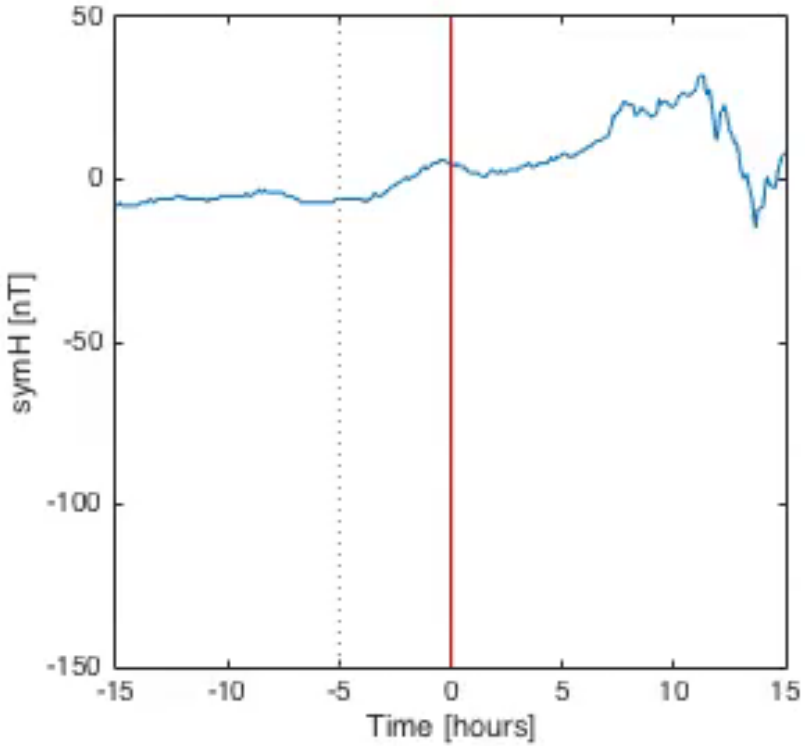
0.65 fce

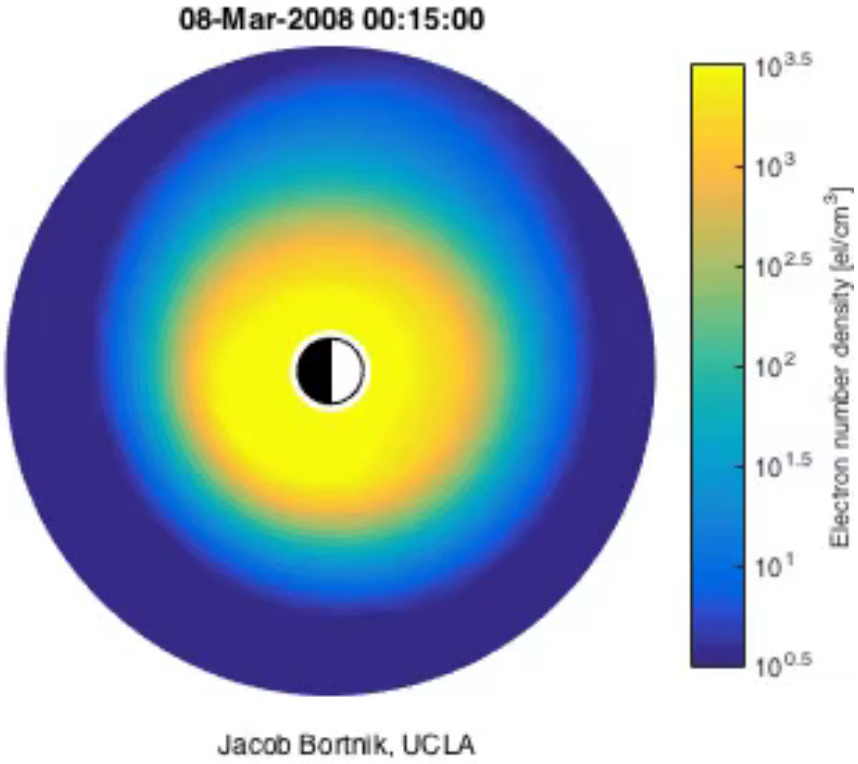
Topic #2. Problems

What is the nature of wave-particle interactions? Wave excitation

1. Based on a specified distribution f(v), can we predict the wave properties?
   - Wave mode: whistler-mode, ion cyclotron, electrostatic …
   - Start frequency, stop frequency, intensity, wave normal angle
   - Coherence, subpackets
2. Propagation characteristics
   - Growth/damping
   - Connection with other waves: chorus-hiss

Topic #3: What is the nature of the waves? System science





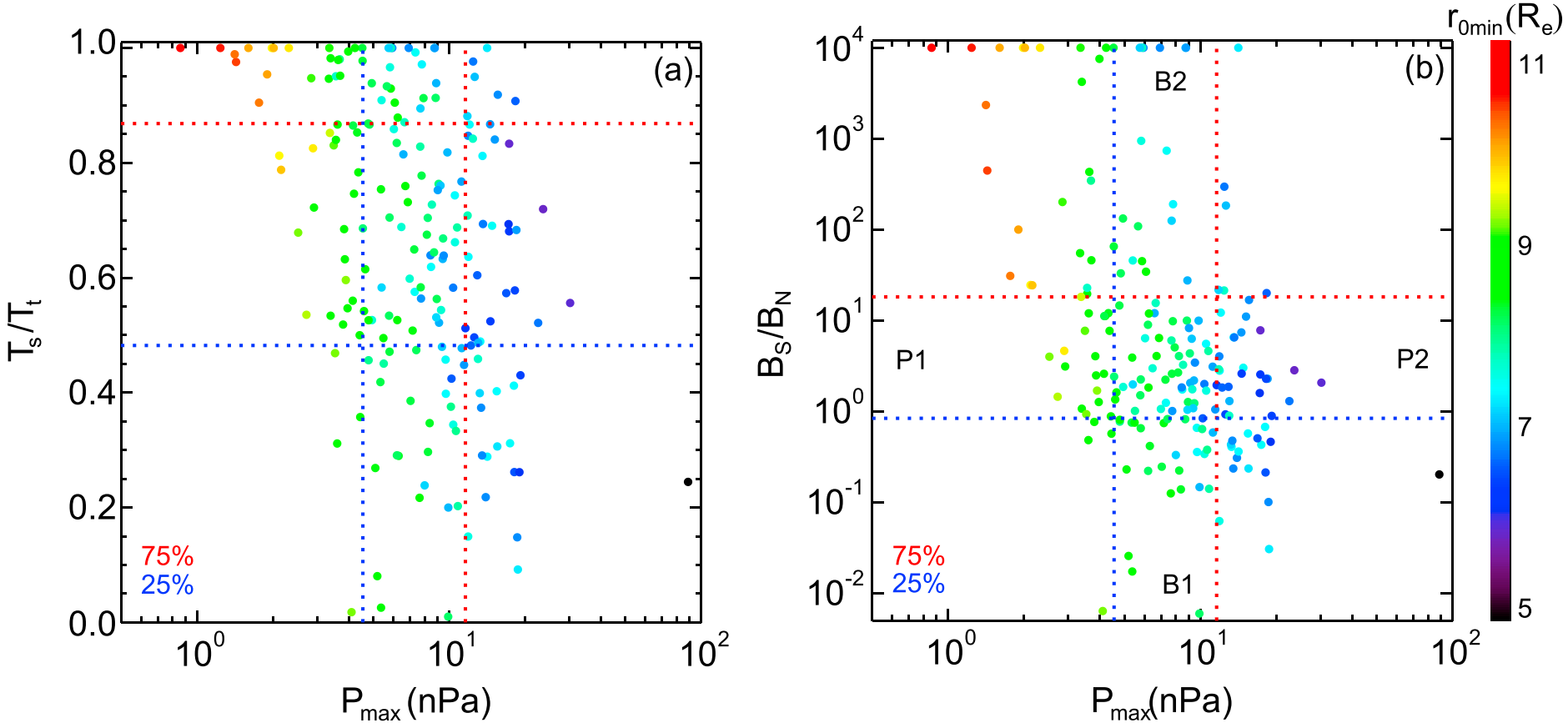
Use THEMIS density data (from S/C potential) June 2008 – Oct 2014, TH-A, D, E in 5-min cadence (~10^6 samples) regress on 5-hour history of sym-H.

Topic #3. Problems

What is the nature of the waves? System science

1. Goal: Given a set of sparse measurements of some quantity Q, at location r and time t, we want to reconstruct Q over all r at any t Based on a specified distribution f(v), can we predict the wave properties?
   - Input conditions in physical models
   - Specification for space weather
   - 'Insight discovery' in physical processes
2. The good news: there is LOTS of data! That's great
3. The bad news: data is generally not intercalibrated … not too glamorous but very useful

Topic #4: dropouts



Gao et al. [2015]

Topic #4. Problems

What is the nature of the waves? Dropouts

1. What is the cause or radiation belt dropouts?
   - This is a problem for models!
   - There are 3 boundaries: L, pitch-angle, E
2. Are there 2 different 'kinds' of magnetopause shadowing?
   - Opening up drift paths by compressing magnetopause boundary
   - Stripping field lines by dayside reconnection

Summary

Since space plasmas are collisionless, dynamics can only be produced by 'loss of adiabaticity', i.e., waves. That leaves 2 broad questions:

What is the nature of wave-particle interactions?

1. Nonlinear effects
2. Wave generation

What is the nature of the 'waves'? i.e., translation of microphysics to macrophysics

3. System science
4. Dropouts

Back ups