# *In situ* observations of EMIC waves and associated plasma properties in the inner magnetosphere: Comparisons of two events

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## Abstract

Electromagnetic ion cyclotron (EMIC) waves, which are normally induced by anisotropic distributions of energetic $H^+$, play an important role in the overall dynamics of the Earth's magnetosphere, contributing to the loss and energization of particles. In this study, two EMIC wave events and associated plasma properties are examined and compared against each other. The 30 Mar. 2002 event occurred in the main phase of a mild storm, while the 22 Nov. 2003 event took place in the recovery phase of a rare super-storm. During both events, *in-situ* observed plasma conditions were favorable to the occurrence of the EMIC instability and also indicated the resonant interactions of particles with the waves. However, in the former event they are consistent with linear theory but in the latter one they are not. The possible reason is that in one case Cluster detected the wave near its source region but in the other case the observed wave had propagated for a while and already experienced a polarization reversal.

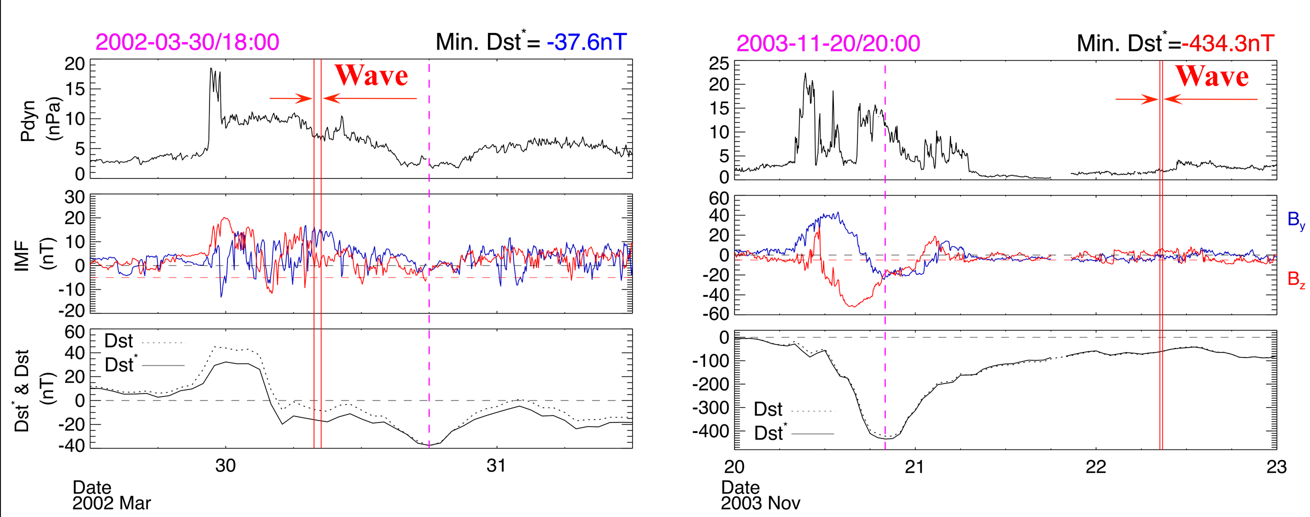
## Motivation

1. To investigate the causes, effects, and differences of the two EMIC wave events observed by Cluster in the inner magnetosphere, which could cause pitch-angle scattering and loss of relativistic $e^-$.

2. To extend the case and statistical studies of EMIC wave-associated $He^+$ heating events in the outer magnetosphere [*Zhang et al.*, 2010; 2011].

3. To follow up the case studies of the 30 Mar. 2002 wave [*Pickett et al.*, 2010] and the 22 Nov. 2003 wave [*Engebretson et al.*, 2007].

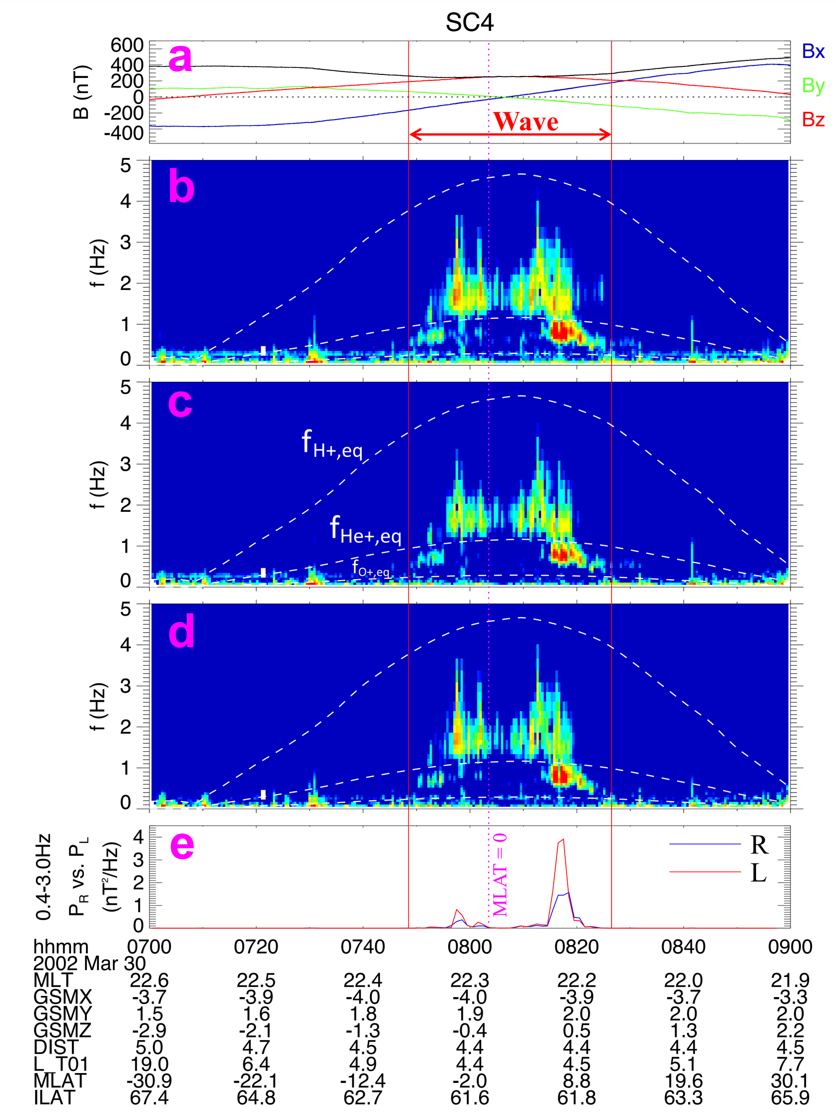
## Solar Wind/Geomagnetic Condition



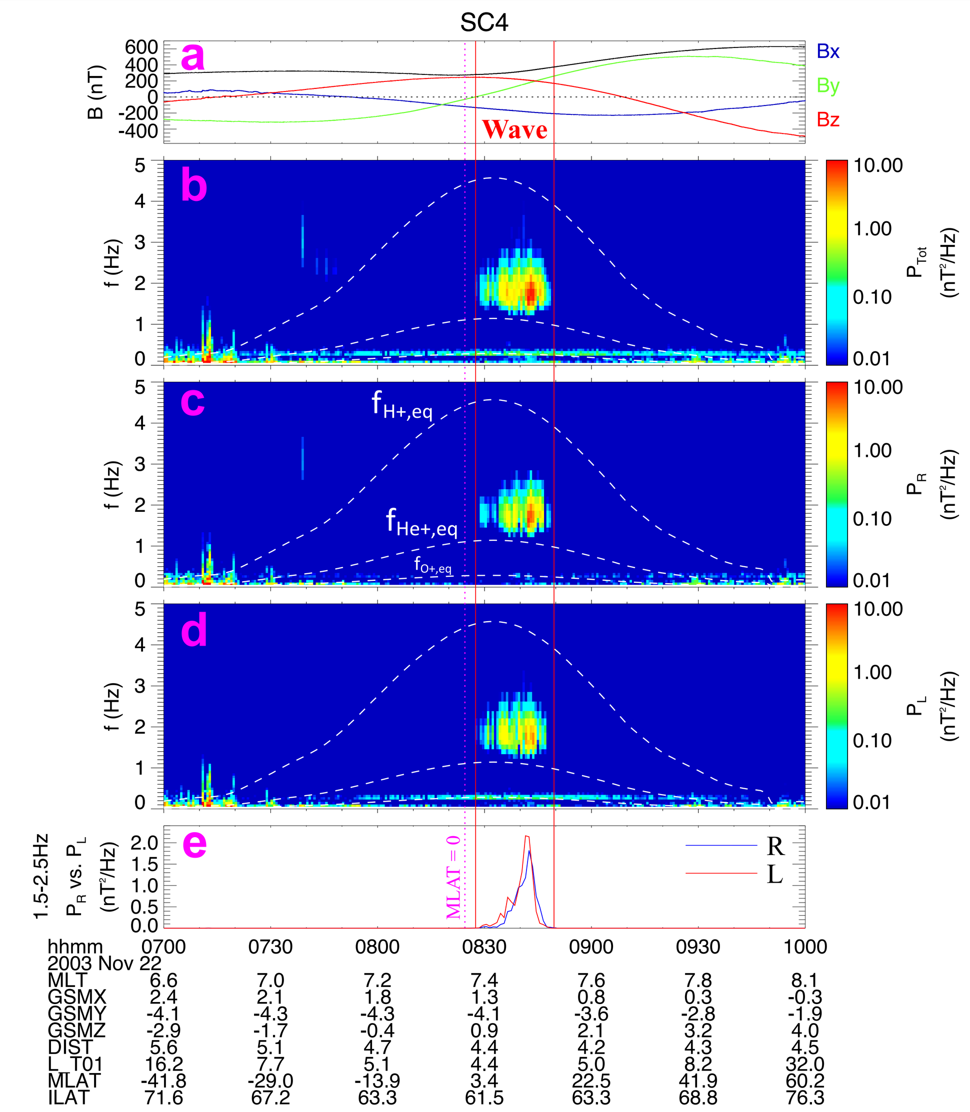

❖ Wave on 30 Mar. 2002 [left panel]: Observed in the main phase of a weak storm. During the wave period,
- Avg. $Pdyn$ = 7.0 nPa
- Avg. IMF $B_y$ = 12.8 nT
- Avg. IMF $B_z$ = 1.6 nT
- Avg. $Dst$* (pressure-corrected $Dst$) = -16.3 nT

❖ Wave on 22 Nov. 2003 [right panel]: Observed in the recovery phase of a super-storm. During the wave period,
- Avg. $Pdyn$ = 1.8 nPa
- Avg. IMF $B_y$ = -1.8 nT
- Avg. IMF $B_z$ = 3.5 nT
- Avg. $Dst$* = -61.1 nT

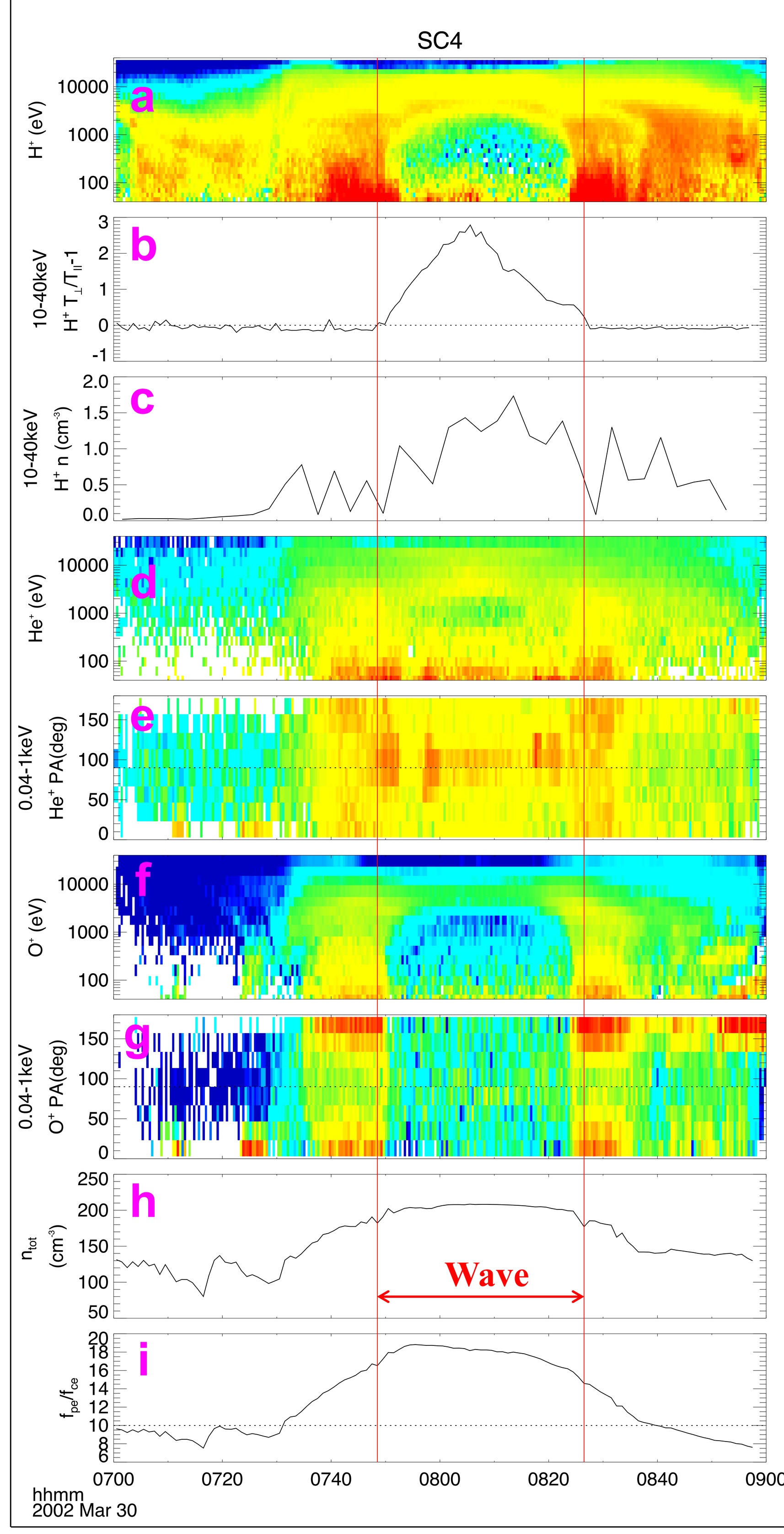
## Magnetic Field & Wavelet Analysis



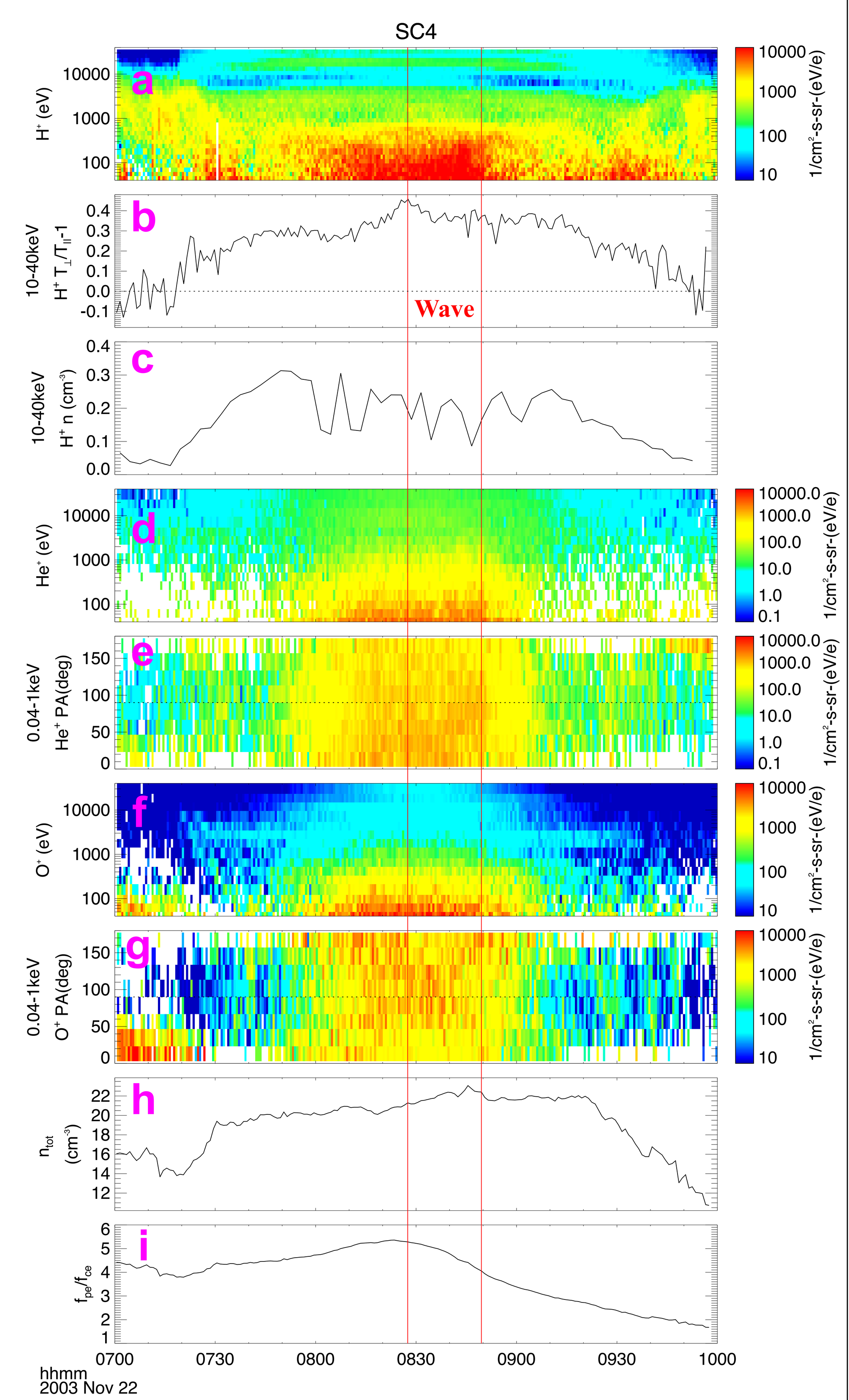
a —
b — Total wave power
c — Right-hand polarized wave power
d — Left-hand polarized wave power
e — Average wave power in the frequency range of wave activity



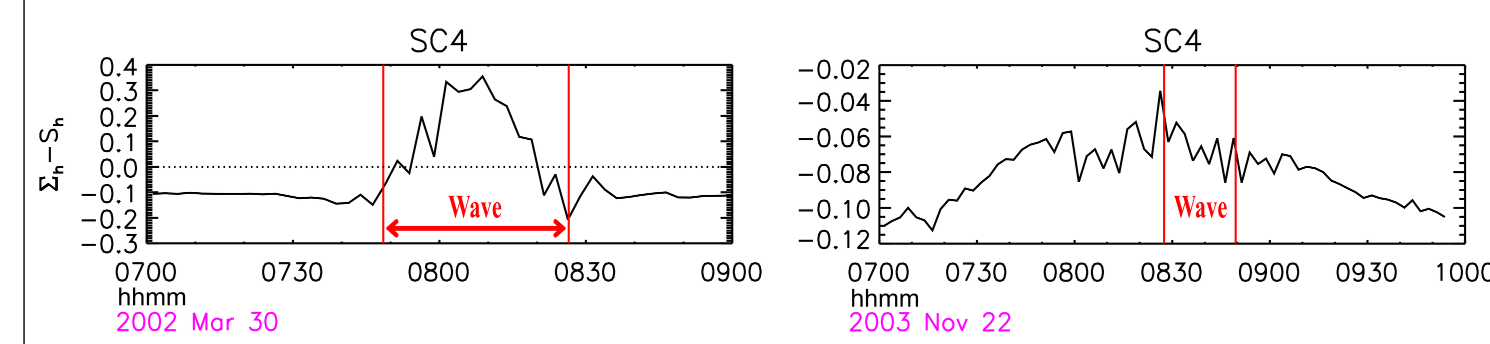
## Plasma Data



a — $H^+$ spectrograms
b — Hot $H^+$ anisotropy
c — Hot $H^+$ density
d — $He^+$ spectrograms
e — Cool $He^+$ pitch angle distribution
f — $O^+$ spectrograms
g — Cool $O^+$ pitch angle distribution
h — Total ion density (= $n_e$)
i — $e^-$ plasma/gyrofrequency ratio



## Comparison with Linear Theory




❖ Linear Theory: EMIC wave activity can occur only if $\Sigma_h - S_h > 0$ [*Gary et al.*, 1994], where $\Sigma_h$ is the observational EMIC growth parameter and $S_h$ is the EMIC instability threshold.

❖ $\Sigma_h - S_h > 0$ around the center of the event on 30 Mar. 2002 [left panel]. However, $\Sigma_h - S_h < 0$ during the 22 Nov. 2003 event [right panel].

## Summary & Discussion

| | 30 Mar. 2002 | 22 Nov. 2003 |
|---|---|---|
| **Geomagnetic Condition** | Main phase of a small storm | Recovery phase of a super-storm |
| **Location** | L~4.4, MLT~22.3, MLAT~0° | L~4.4, MLT~7.4, MLAT~3.4° |
| **Region** | Equatorial plasmapause | Above the equatorial plane |
| **Wave Frequency** | Around $f_{He+,eq}$ | Below $f_{He+,eq}$ |
| **Total Wave Power** | up to 50 $nT^2/Hz$ | up to 8 $nT^2/Hz$ |
| **Wave Polarization** | Left-handed | Nearly linear |
| **Hot $H^+$ Anisotropy** | up to ~3 | up to ~0.5 |
| **Hot $H^+$ Density** | up to 1.7 $cm^{-3}$ | up to 0.3 $cm^{-3}$ |
| **$He^+$ Heating** | Strongly | Mildly |
| **$O^+$ Heating** | Slightly | N/A due to RB $e^-$ contamination |
| **$n_{tot}$** | up to 200 | up to 23 |
| **$f_{pe}/f_{ce}$** | up to 18 (> 10) | up to 5 (< 10) |
| **Theory Consistency** | Yes | No |
| **Explanation** | Newly generated Close to the wave source region | Propagated & polarization reversed Away from the wave source region |

● **Future Work:** 1) create lists of all Cluster-observed EMIC waves & associated plasma properties; 2) understand discrepancies between observations & wave theories/modeling.

## References

Gary, S. P., et al. (1994), *JGR*, *99*(A12).
Pickett, J. S., et al. (2010), *GRL*, *37*(L09104).
Engebretson, M. J., et al. (2007), *PPS*, *55*
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Zhang, J.-C., et al. (2011), *JGR*, under review.

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