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"Pick-up Ion Instabilities at Planetary Magnetospheres"

Final Report

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This effort involved the analysis of low frequency waves as observed by the Galileo spacecraft near the Galilean moon, Io. Io is a significant source of material, especially SO_2, and various products of dissociation, and further these atoms and molecules are readily ionized. The initial velocity of the ions is essentially that of the neutral species, i.e., the Keplerian velocity. The plasma, on the other hand is co-rotating, and there is a differential flow of the order 57 km/s between the plasma and the neutral particles. Thus pick-up ion instabilities are likely to occur within the Jovian magnetosphere. Indeed, magnetometer observations from the Galileo spacecraft clearly show ion cyclotron waves that have been identified with a large variety of plasma species, such as O^+, S^{++} (which has the same gyro-frequency as O^+), S^+, and SO_2^+. Typically, however, the dominant frequency is near the SO_2^+ gyro-frequency.

The research effort was originally planned to be a team effort between Robert J. Strangeway as the Principal Investigator, and Debbie Huddleston, who was an Assistant Research Geophysicist at UCLA. Unfortunately, Dr. Huddleston took a position within Industry. The effort was therefore descoped, and Dr. Strangeway instead pursued a collaboration with Dr. Xochitl Blanco-Cano, of the Instituto de Geofísica, Universidad Nacional Autonoma de Mexico. This has proved to be a productive collaboration, with several papers and publications arising out of the effort.

The magnetic field oscillations near Io generally fall into two types: ion cyclotron waves, with frequencies near an ion gyro-frequency, and lower frequency mirror-mode waves. The ion cyclotron waves are mainly transverse, and frequently propagate along the ambient magnetic field. The mirror-mode waves are compressional waves, and they have essentially zero frequency in the plasma rest frame. One of the purposes of our investigation is to understand what controls the types of wave modes that occur, since both wave modes can be drive unstable by the pressure anisotropy associated with the pick up ions. The pick ion velocity is perpendicular to the ambient magnetic field, and is generally much larger than the thermal velocity, at least initially.

At its simplest, we found that the ion cyclotron waves are controlled by the parameters of the species in gyro-resonance with the wave. Thus, while the growth rates for the lower mass (higher gyro-frequency) pick-up ions are generally larger, we found that the heavier SO_2^+ ion cyclotron waves are generally preferred. This is because one of the effects of the wave instability is to diffuse the ions in pitch angle and energy. The lower mass ions therefore consist of both a ring of recently created pick-up ions, and a thermal background. This thermal background quenches the ion cyclotron instability. SO_2^+ is different, however. Being a molecule, the species can also dissociate. Our analysis suggests that the dissociation acts on a time scale comparable to or faster

than the velocity space diffusion time scale. There are consequently no thermal SO_2^+ ions to quench the instability.

We have also investigated the mirror-mode. This mode can at times grow more rapidly than the individual ion cyclotron waves. This is mainly because the mirror-mode can grow off the pressure anisotropy of all the species combined, whereas the ion cyclotron wave is dependent on the pressure anisotropy of the individual species with which the waves are in resonance.

Lastly, as part of this effort we have begun to investigate the instability for obliquely propagating modes. Galileo observations show that at times the ion cyclotron waves are significantly elliptically polarized, and further the wave vector is at a large angle to the field. Kinetic dispersion analysis shows that while the peak growth rate occurs along the field, significant growth can occur for oblique propagation. Depending on the group velocity of the waves, it is possible that obliquely propagating modes have higher advective growth rate, but this has yet to be determined.

Publications that Include Work Supported by this Grant:

1. Huddleston, D. E., **R. J. Strangeway**, J. Warnecke, C. T. Russell, and M. G. Kivelson, Ion cyclotron waves in the Io torus: Wave dispersion, free energy analysis, and SO_2^+ source rate estimates, *J. Geophys. Res.*, *103*, 19,887–19,899, 1998.

2. Russell, C. T., D. E. Huddleston, **R. J. Strangeway**, X. Blanco-Cano, M. G. Kivelson, K. K. Khurana, L. A. Frank, W. Paterson, D. A. Gurnett, and W. S. Kurth, Mirror mode structures at the Galileo-Io Flyby: Observations, *J. Geophys. Res.*, *104*, 17,471–17,477, 1999.

3. Huddleston, D. E., **R. J. Strangeway**, X. Blanco-Cano, C. T. Russell, M. G. Kivelson, and K. K. Khurana, Mirror mode structures at the Galileo-Io flyby: Instability criterion and dispersion analysis, *J. Geophys. Res.*, *104*, 17,479–17,489, 1999.

4. Huddleston, D. E., **R. J. Strangeway**, X. Blanco-Cano, C. T. Russell, M. G. Kivelson, and K. K. Khurana, Io-Jupiter interaction: Waves generated by pickup ions, *Adv. Space Res.*, *26(10)*, 1513–1518, 2000.

5. Russell, C. T., X. Blanco-Cano, and **R. J. Strangeway**, Ultra-low-frequency waves in the Jovian magnetosphere: causes and consequences, *Planet. Space Sci.*, *49*, 291–301, 2001.

6. Blanco-Cano, X., C. T. Russell, D. E. Huddleston, and **R. J. Strangeway**, Ion cyclotron waves near Io, *Planet. Space Sci.*, *49*, 1125–1136, 2001.

7. Russell, C. T., Y. L. Wang, X. Blanco-Cano, and **R. J. Strangeway**, The Io mass-loading disk: Constraints provided by ion cyclotron waves, J. Geophys. Res., 106, 26,233–26,242, 2001.

8. Blanco-Cano, X., C. T. Russell, and **R. J. Strangeway**, The Io mass-loading disk: Wave dispersion analysis, J. Geophys. Res., 106, 26,261–26,275, 2001.

Contributed Papers that Include Work Supported by this Grant

1. Volwerk, M., M. G. Kivelson, K. K. Khurana, D. E.Huddleston, **R. J. Strangeway**, Ion pickup and assymetries in Europas wake, *Eos, Trans. AGU, 79(45), Supplement*, F551, American Geophysical Union Fall Meeting, San Francisco, 1998.

2. Russell, C. T., **R. J. Strangeway**, M. G. Kivelson, K. Khurana, D. E. Huddleston, X. Blanco-Cano, L. A. Frank, W. Paterson, D. A. Gurnett, and W. S. Kurth, Mirror mode structures at the Galileo flyby, International Union of Geodesy and Geophysics, 22nd General Assembly, Birmingham, England, p. A.379, 1999.

3. Quest, K. B., V. Shapiro, K. Szego, **R. J. Strangeway**, Interaction of the solar wind with unmagnetized planets: Two-dimensional particle simulations, *Eos, Trans. AGU, 80(46), Supplement*, F873, American Geophysical Union Fall Meeting, San Francisco, 1999.

4. Blanco-Cano, X., C. T. Russell, **R. J. Strangeway**, Waves in the Jovian magnetosphere, *Eos, Trans. AGU, 80(46), Supplement*, F876, American Geophysical Union Fall Meeting, San Francisco, 1999.

5. Blanco-Cano, X, C. T. Russell, and **R. J. Strangeway**, The Io mass loading disk: Ion cyclotron waves generation, *Eos, Trans. AGU, 81(19), Supplement*, S289, American Geophysical Union Spring Meeting, Washington, DC, 2000.

6. Blanco-Cano, X., C. T. Russell, **R. J. Strangeway**, M. G. Kivelson, and K. K. Khurana, Galileo observations of ion cyclotron waves in the Io torus (abstract), 33rd COSPAR Scientific Assembly, Warsaw, Poland, 2000.

7. Russell, C. T., X. Blanco-Cano, **R. J. Strangeway**, and Y. L. Wang, Evidence for a disk-shaped neutral source cloud at Io (abstract), 33rd COSPAR Scientific Assembly, Warsaw, Poland, 2000.

8. Russell, C. T., X. Blanco-Cano, and **R. J. Strangeway**, The fluctuating magnetic field of the middle magnetosphere of Jupiter (abstract), 33rd COSPAR Scientific Assembly, Warsaw, Poland, 2000.

9. Blanco-Cano, X., C. T. Russell, **R. J. Strangeway**, M. G. Kivelson, K. K. Khurana, Waves in the Io torus, *Eos, Trans. AGU, 81(48), Supplement*, F795, American Geophysical Union Fall Meeting, San Francisco, 2000.

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PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THIS ADDRESS. RETURN COMPLETED FORM TO THE CONTRACTING OFFICER.

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Olwin, Keith R.	NAG5-6965	Olwin, Keith R.	NAG5-6965	a. INTERIM [ ] b. FINAL [X]

b. ADDRESS (Include ZIP Code)	d. AWARD DATE (YYYYMMDD)	b. ADDRESS (Include ZIP Code)	d. AWARD DATE (YYYYMMDD)	4. REPORTING PERIOD (YYYYMMDD)
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Olwin, Keith R.	Departmental Research Associate		12/5/01