

# ULYSSES AND CASSINI AT JUPITER: COMPARISON OF THE QUASI-PERIODIC RADIO BURSTS

M. L. Kaiser\*, W. M. Farrell\*, M. D. Desch\*,  
G. B. Hospodarsky†, W. S. Kurth†, and D. A. Gurnett†

## Abstract

We report on the observations of quasi-periodic radio bursts observed by Cassini/RPWS during the December 2000 flyby interval. Comparison with similar observations during the 1992 Ulysses flyby show that the morphology appears much more complicated such that nearly any periodicity can be observed from nearly any location at any given time.

## 1 Introduction

During retrospective data analysis of the Voyager Plasma Wave Science (PWS) [Scarf and Gurnett, 1977] data from the 1979 flybys of Jupiter, Kurth et al. [1989] discovered low frequency (5–12 kHz) drifting bursts which they called 'Jovian type III' bursts because of their similarity in appearance (although on a dramatically different time scale) to Solar type III bursts. Figure 1a shows an example of these bursts. In addition to their general appearance, the bursts seemed to come in groups of a few bursts separated by 2–3 minutes with these groups separated from one another by about 15 minutes.

MacDowall et al. [1993] provided a more detailed description of the Jovian type III bursts based on the Ulysses/URAP [Stone et al., 1992c] observations during the 1992 Jupiter flyby. They preferred to rename the bursts to quasi-periodic or 'QP' bursts since the term 'type III' denotes a particular type of mechanism (based on Solar type IIIs). They confirmed the basic 15-min (QP-15) periodicity found by Kurth et al. [1989] and found an additional category of 40-min (QP-40) periodic bursts (Figure 1b), observed exclusively on the Ulysses outbound trajectory near the dusk meridian and at high southern latitudes. Perhaps the most surprising observation concerning the QP-40 bursts was their correlation with in situ observations of MeV electrons by the Ulysses COSPIN instrument [Simpson et al., 1992], as shown in Figure 2.

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\*NASA/Goddard Space Flight Center Greenbelt, MD 20771, USA

†Department of Physics and Astronomy, University of Iowa Iowa City, IA 52242, USA

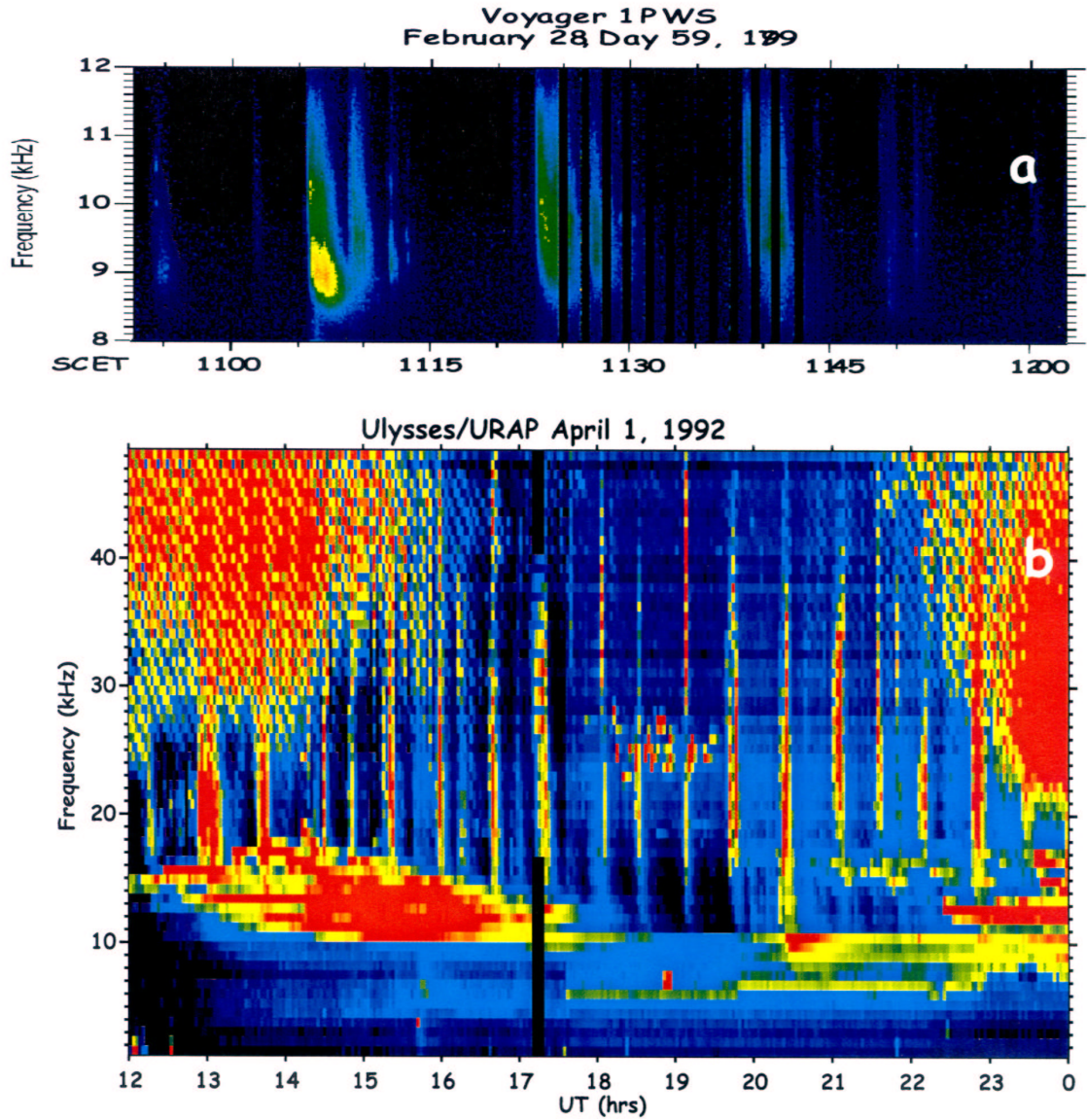


Figure 1: (a) One of the 'discovery' panels from Kurth et al. [1989] showing the overall 15-min periodicity and the embedded shorter duration bursts. (b) A 12-hr dynamic spectra from Ulysses/URAP taken nearly two months after closest approach to Jupiter. Ulysses was some  $900 R_J$  distant from Jupiter at  $\sim 18$  hr local time and  $36^\circ$  S. latitude. The broadband bursts separated by  $\sim 40$  min dominate the data.

MacDowall et al. [1993] also showed that the occurrence of Jovian QP bursts was associated with Solar wind enhancements; in particular, their occurrence was loosely correlated with Solar wind speed. It is likely, however, that the speed correlation is a proxy for some other Solar wind parameter, such as the magnetic field orientation, whose properties are difficult to propagate to Jupiter from the spacecraft. The terrestrial analog of QP bursts (LF bursts), for example, was found to be highly correlated with the IMF orientation [Desch et al., 1996].

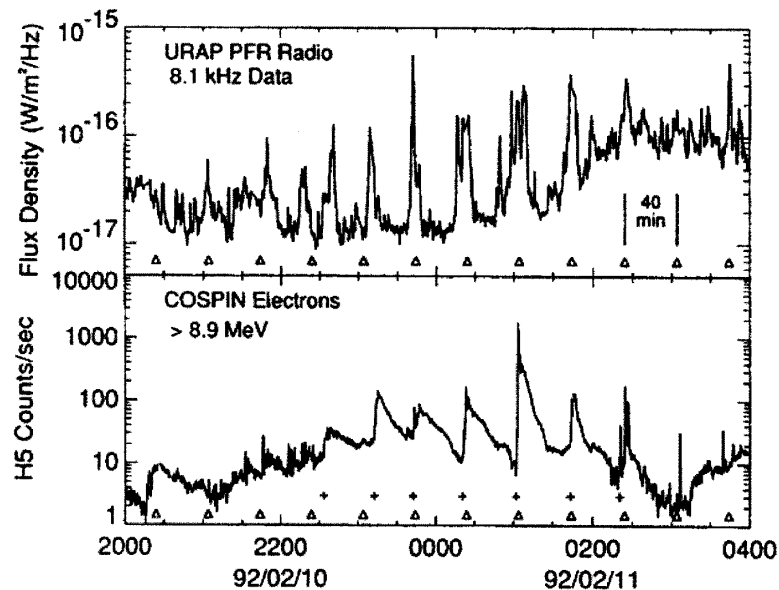


Figure 2: A comparison between the Ulysses/URAP data and the Ulysses/COSPIN data during an interval when Ulysses was still within the Jovian magnetosphere on its outbound trajectory at high Southern latitudes (from MacDowall et al. [1993]).

However, despite the nearly two years of Ulysses/URAP observations of QP bursts, their origin and/or the cause of their periodicities has remained elusive. Desch [1994] showed that the type III-like shape of the QP bursts could be caused by propagation effects through the Jovian magnetosheath from an initial broadband pulse, but offered no suggestion as to the origin of the pulses. In December 2000 the Cassini spacecraft flew past Jupiter on its way to rendezvous with Saturn in 2004. During the several months surrounding the flyby, the RPWS radio and plasma wave science instrument [Gurnett et al., 2001b] was able to observe the QP bursts. It was hoped these new observations would yield a solution to the vexing origin of the QP bursts. We report here on the observations obtained during the Cassini flyby interval and compare them with those obtained by Ulysses.

## 2 Observations

Cassini and Ulysses (and the Voyagers) all followed similar trajectories inbound to Jupiter near the equatorial plane and near the late morning to noon meridian. However, the outbound trajectories were drastically different, with Cassini staying near the equatorial plane near 21 hr local time, while Ulysses was near the dusk meridian at  $38^\circ$  South latitude, as shown in Figure 3. Only for a brief interval of time did Cassini pass through the outbound local time zone of the Ulysses trajectory. The sensitivity of Cassini/RPWS in the frequency range of the QP bursts is less than that of Ulysses/URAP owing to the significant difference in antenna lengths (10-m versus 72-m). Nevertheless, RPWS was

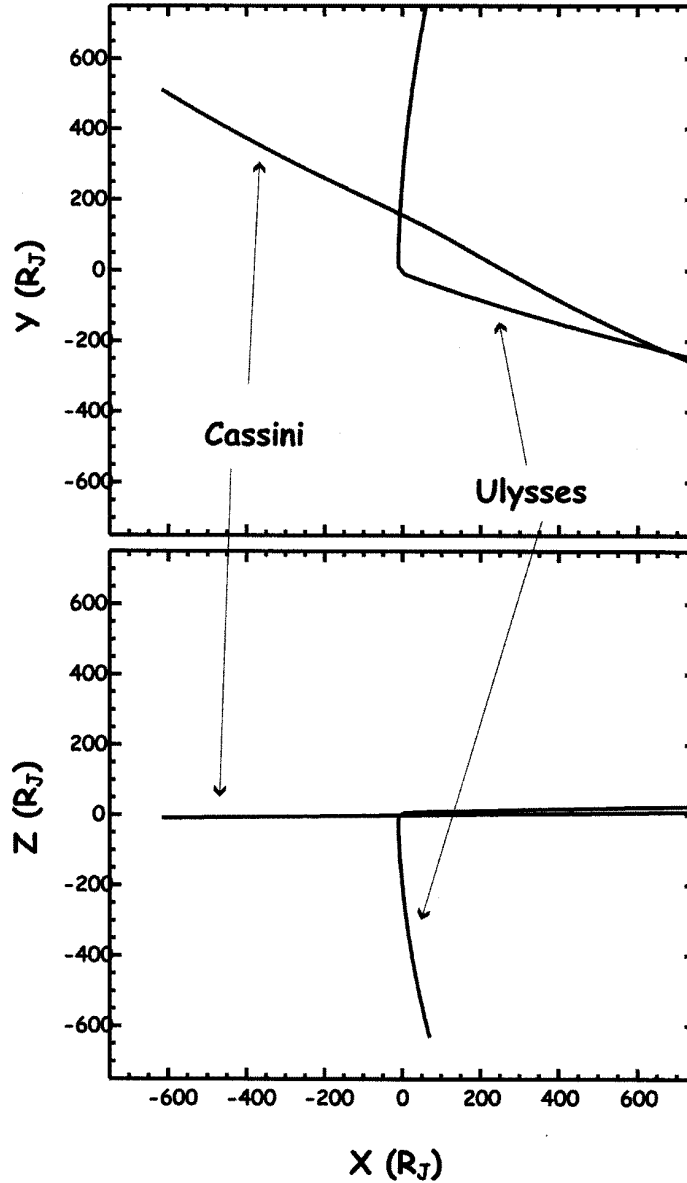


Figure 3: Jovicentric X–Y and X–Z projections of the Cassini and Ulysses flyby trajectories.

able to observe the QP bursts for many months prior to and following the Dec. 30, 2000 closest approach.

Figure 4 shows several examples of the observations obtained during the inbound portion of the trajectory (left column) and outbound portion (right column). Upon cursory inspection, it is obvious that the rather simple picture of QP–15s inbound, QP–40s outbound presented by MacDowall et al. [1993] based on Ulysses/URAP does not exist for the Cassini era.

For the inbound examples, panel (a) shows a rather commonly observed pattern of QP

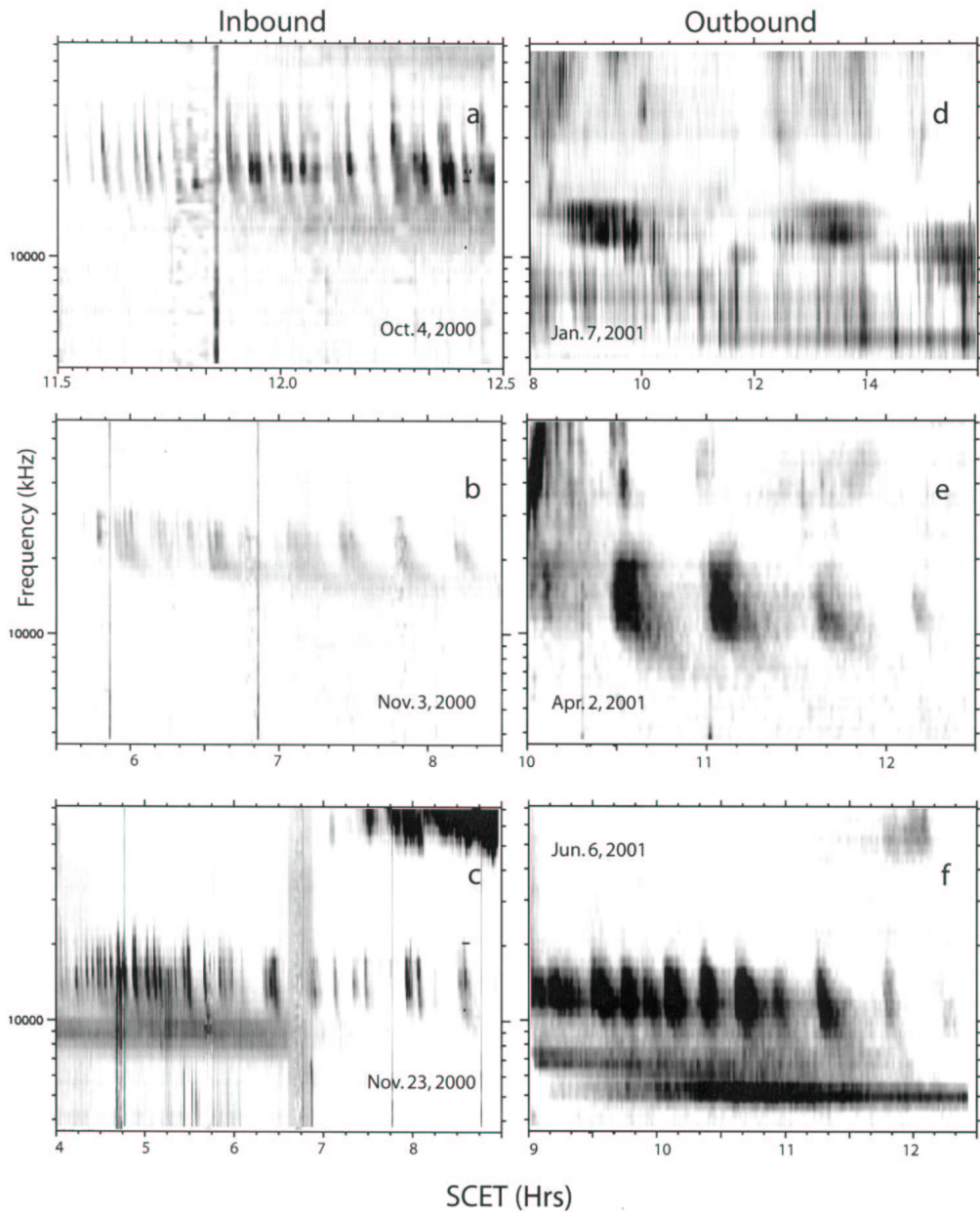


Figure 4: Examples of QP bursts observed by Cassini/RPWS. (a) At a distance of  $1150 R_J$  at 10.6-hr local time. (b)  $760 R_J$  at 10.7-hr local time. (c)  $505 R_J$  at 11-hr local time. (d)  $175 R_J$  at 18.5-hr local time. (e)  $1215 R_J$  at 21.4-hr local time. (f)  $2140 R_J$  at 21.2-hr local time.

bursts where the spacing between bursts is sometimes only  $\sim 2$  min or less. Ulysses/URAP would not have even recognized bursts at this short spacing because the standard sampling rate was 144-s. Furthermore, the 'periodicity' is very difficult to perceive, with spacings between bursts ranging from  $< 2$  min to 8–9 min. Panel (b) shows an interval somewhat similar to the Voyager example shown in Figure 1a. There is an overall 'periodicity' of  $\sim 22$ – $23$  min but with each of these major bursts composed of many bursts with much

shorter spacing, most evident between 6 and 7 hrs. Again, Ulysses/URAP would have been 'blind' to the sub-bursts. Panel (c) shows a several hour-long set of bursts with a particularly wide and seemingly random set of spacings between bursts.

Panel (d) shows QP bursts observed after closest approach as Cassini was passing through the dusk meridian. It was at this local time that Ulysses/URAP first started observing QP-40s and it has been unknown whether their appearance was a function of local time or latitude, since Ulysses was very far south. At first glance, panel (d) seems to show many bursts with random spacing between them. However, power spectral analysis of the panel, where intensity is taken into account, reveals that the main periodicity is, indeed 40-min. Although an exhaustive survey has not been completed, we believe this is the first time during the flyby that Cassini clearly detected 40-min bursts even though they are not nearly so dominant in the dynamic spectra as Figure 1b. On the outbound leg after panel (d), 40-min bursts were occasionally observed, but they certainly were not exclusive or special in any way. Panels (e) and (f) show additional examples from the outbound leg with pseudo-periodicities of 20–30 min.

### 3 Discussion and conclusions

The Cassini/RPWS observations of QP bursts reveal a much more complicated morphology than that reported by [MacDowall et al., 1993]. They reported a dichotomy between predominantly 15-min periodicities observed in the equator plane near local noon and 40-min periodicities observed exclusively near the dusk meridian at high Southern latitudes. Although detailed histograms of bursts separation intervals like Figure 3 of MacDowall et al. [1993] have not been done for Cassini/RPWS, it is our impression that the histograms would be much broader and with a large peak at the 1–2 min level. Ulysses/URAP did not report this short-interval peak due to its comparatively long sampling rate (144-s). These Cassini/RPWS findings are also in agreement with (unpublished) Galileo/PWI [Gurnett et al., 1992] observations. Given the fact that Ulysses/URAP is more sensitive than Cassini/RPWS in the low frequency range, these observed differences then suggest that the emission mechanism involved in the QP bursts was different during the interval 2000–2001 (and, perhaps, 1995–2001 taking the Galileo/PWI results into account) as compare to 1991–1992.

Observations by Cassini similar to those of Figure 2 are not available, probably due to the fact that Cassini only marginally entered the Jovian magnetosphere during its flyby. However, other periodic events were reported. Chandra x-ray observations made just prior to Cassini closest approach revealed pulses of 40-min duration emanating from inside the auroral ovals, north and south [Gladstone, private communications, 2001]. However, detailed comparison with Cassini/RPWS shows no direct correlation between the x-ray and radio bursts; indeed, RPWS was observing QP bursts with a smaller spacing between bursts at the time Chandra was observing 40-min x-ray pulses. Also, the Cassini/MIMI experiment [Krupp, private communications, 2001] reported quasi-periodic 40-min electron bursts during one excursion into the magnetosphere, but again no direct correlation with the radio bursts exists.

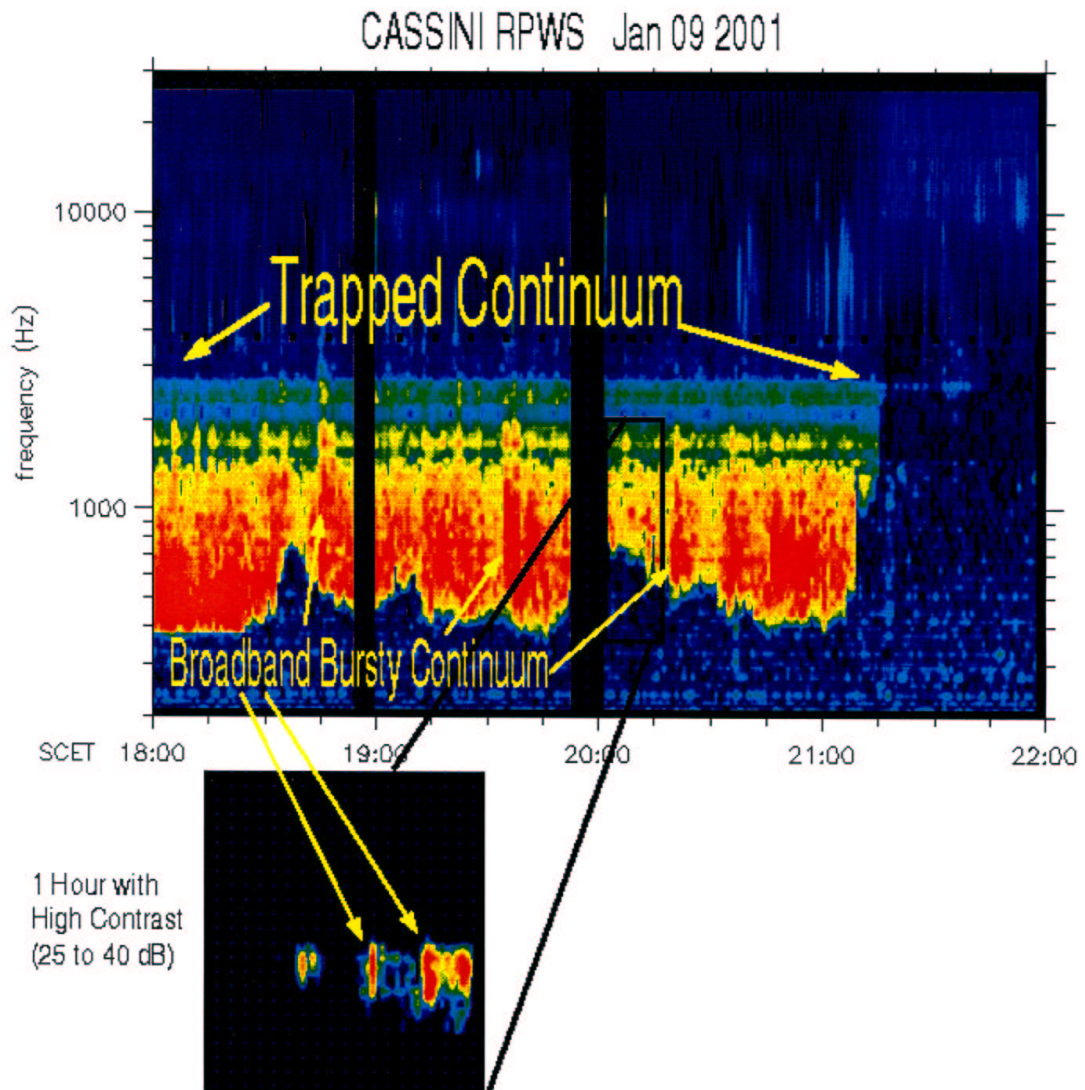


Figure 5: Semi-periodic behavior observed by Cassini/RPWS in trapped continuum emission.

We are intrigued by the observations of 40-min bursts in both radio and x-ray because certain Solar flares also manifest quasi-periodic radio and x-ray behavior [Aschwanden et al., 1994] that may be a clue to the Jovian mechanism. Although the Solar and Jovian periods are very different, seconds vs. minutes, respectively, the non-stochastic injection of energetic particles, possibly due to explosive reconnection events, may be similar. In both cases, the particle acceleration into a magnetic structure can be stabilized by phase locking with an MHD wave if both periods are close to each other. In the Jovian case the MHD period would have to be much longer than in the Solar case, and probably represents some resonant mode associated with a high latitude field structure.

Besides periodic activity in the x-rays and particles, the trapped Jovian continuum emission also displayed unexpected periodic structure, this observed during the short 2-day

period of time when Cassini entered the deep magnetic tail region (1/9/01–1/10/01). Specifically, the continuum emission appeared to have two distinct components, as shown in Figure 5: A diffuse emission of approximately the same intensity observed ubiquitously throughout the deep tail region, and a broadband "bursty" component appearing as episodes of quasi-periodic impulsive events extending from the local plasma frequency to about 10 kHz. The low frequency continuum bursts each lasted a few minutes and tended to reappear quasi-periodically on time scales of 1–30 minutes. Further, the bursts tended to be more intense than the diffuse component by about 10 dB or so.

Quasi-periodic broadband bursts in the continuum emission are difficult to explain. In general, continuum emission is intrinsically narrow banded, generated near the edge of the Io torus at locations where the local electron plasma frequency is approximately equal to odd-half harmonics of the electron cyclotron frequency (see review by Kurth [1992]). In essence, the region emits a set of narrow tones into the low-density magnetospheric cavity. After multiple reflections from the moving magnetopause, the intrinsically narrow banded tones broaden into a diffuse component appearing as the homogeneous continuum emission. However, there is currently no known mechanism to explain the observed discrete, temporally sharp, broad banded event in the continuum emission like those observed by Cassini. It is unclear whether the broad banded events result from a quick variation at the continuum source itself, or whether they are a propagation phenomenon, this occurring between the source and Cassini.

Quasi-periodic broadband structure in the continuum is worthy to mention here, since, like the x-rays and particle events, they too may be tied to the mechanism responsible for the higher-frequency QP bursts. The similar many-minute periodicity in each case suggest a common source for all the different observations.

More detailed analysis of the Cassini observations is in progress, but based on these preliminary findings, it seems unlikely that the basic questions concerning the origin of the QP bursts and the cause of the periodicities will remain unchanged. The next spacecraft that will make observations of QP bursts will be, again, Ulysses when it makes a pass through the Jovian northern hemispheric latitudes (albeit at a distance of  $\sim 1$  AU) in 2003–4. Perhaps by the time of the PRE-VI meeting, progress toward an explanation for the QP bursts will be at hand.

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