RECENT PROGRESS IN THE MEASUREMENT OF JUPITER'S DECAMETRIC RADIO SOURCE PARAMETERS BY THE MODULATION LANE METHOD

K. Imai*, F. Reyes†, T. D. Carr†, and A. Lecacheux‡

Abstract

The modulation lanes in the dynamic spectra of Jupiter's decametric emission were discovered by Riihimaa in 1968. We have developed a model to explain the production of the modulation lanes. By using our model the precise Jupiter's radio source locations and beam parameters can be measured. This new remote sensing tool is called as the modulation lane method. We made a statistical analysis of Io-B and Io-A source modulation lanes observed by wideband spectrographs at Oulu, Florida, and Nancay. Using the modulation lane method it is possible to make precise measurements of the value of the cone half-angle of the hollow-cone emission beam and the System III source locations for the Io-B and Io-A sources. The averaged values of measured cone half-angles at 23 MHz were 60° for Io-B and 65° for Io-A. The measured typical ranges of source System III longitude are 124° to 226° for Io-B and 142° to 192° for Io-A. These results show that the active radio regions of Io-B and Io-A are sharing the same source System III longitude. Based on these new results, we are able to show for the first time a more realistic view of the location and beaming of Jupiter's radio sources using 3D computer graphics.

1 Introduction

The Jovian decametric radiation is emitted in the X mode at frequencies approximately equal to the local electron cyclotron frequencies (f_c) from auroral-zone source regions in the lower magnetosphere of Jupiter (see, for example, Carr et al. [1983], and references therein). Most of the emission originates from localized sources within a relatively narrow sector of longitude in the northern auroral zone (although there is probably also a less active source region in the southern auroral zone). Radiation from the localized sources is

* *Department of Electrical Engineering, Kochi National College of Technology, Kochi 783-8508, Japan*
† *Department of Astronomy, University of Florida, Gainesville, FL 32611-2055, USA*
‡ *Observatoire de Paris, LESIA, UMR CNRS 8109, 92195 Meudon, France*

emitted into similar thin-walled hollow-cone beams having relatively wide opening angles, the cone axis in each case being tangent to the magnetic field at the source. Since they are fixed to the magnetic field at the individual source locations, these hollow-cone beams corotate with Jupiter. Radiation from the sources can be received at terrestrial observatories only when some part of the leading or trailing sides of the hollow-cone beams are aligned with Earth. Radiation from the northern auroral zone appears in two regions of central meridian longitude (CML) that are referred to as the Source B and Source A regions. Whether the radiation is of Source B or A depends on which side of the hollow-cone beams is aligned with Earth. The occurrence probabilities and intensities of these emissions are enormously increased if the magnetic flux tube within which the source lies was recently activated by having been swept across the Jovian moon Io as a result of the corotation of the field with Jupiter. The Source B and Source A emissions that have thus been greatly stimulated by Io are referred to as Io-B and Io-A emissions.

A number of attempts have been made over the years to establish accurately the radio source geometry and hollow-cone emission beam dimensions by modeling. The development of the new beam modeling method employing modulation lane measurements by Imai et al. [1992a, 1992b, 1997, 2001, 2002] has provided results of higher precision and repeatability that was possible with previously used methods. Our latest results are presented in this paper.

2 Modulation Lane Method

The modulation lanes in Jupiter's decametric radiation, which were discovered by Riihimaa [1968], are groups of sloping parallel strips of alternately increased and decreased intensity in the dynamic spectra. Extensive systematic observations of modulation lanes have been made in the frequency range 21 to 23 MHz by Riihimaa [1970, 1974, 1978]. The frequency-time slopes of the lanes can be either positive or negative, depending on which of the Jovian sources is being observed.

In the Imai et al. model for the production of modulation lanes, the lanes are assumed to be a manifestation of interference fringes from the line source consisting of the points along the axis of the Io-activated flux tube that are emitting at the different local values of f_c. The fringes are produced as a result of the passage of the multi-frequency radiation through an interference grating. This grating is a planar grid of almost equally spaced field-aligned columns of enhanced plasma density, perpendicular to the ray-paths toward Earth, located near the sub-Earth point on Io's orbit. Radiation from each of the frequencies emitted by the line source produces a set of interference fringes when it is scattered by the plasma-enhanced columns. These sets of fringes are inclined with respect to the Jovian equator. The rotation of Jupiter sweeps the inclined interference patterns for the different frequencies across Earth, producing the modulation lanes in the observed dynamic spectra.

In our modeling we have made the usual assumption that the emitted frequency is very close to the local electron cyclotron frequency ($f_c = 2.8\ B$). In order to compute the slope of the modulation lane (SL) we consider two points on the active flux tube from which radiation is being emitted at the frequencies f_h and f_l, where f_h is the higher. Define the positive x direction to be perpendicular to the line of sight to Earth and parallel to the Jovian equator, in the direction of increasing System III (west) longitude. Let the x coordinates of the above two points be x_h and x_l, respectively. Since $(x_h - x_l)$ is negative for Io-B and positive Io-A, the slope of the frequency versus time curve (SL) is positive for the former and negative for the latter. The slope equation is written in the form $SL = -(v_c - v_s)\ (f_h - f_l)/(x_h - x_l)$ where v_c and v_s are the velocities of the plasma column and the radio source respectively.

The procedure for determining the cone half-angle of the beam model is as follows. The values of System III longitude (λ_{III}) and Io orbital phase (ϕ_{Io}) are determined from the Universal Time of the modulation lane event. Next, a value of longitude lead angle of the source ahead of Io (α) is assumed. To calculate the longitude of the intersection of the active magnetic flux tube with the equatorial plane (θ), all the three previous values are entered in the formula $\theta = 180° - \phi_{Io} - \alpha + \lambda_{III}$. Starting at the equator and using the value of θ, we traced a magnetic field line toward the northern hemisphere. The location of the source (at a given frequency) is defined by the point along the magnetic field line at which the local gyrofrequency matches the observed frequency. Once the location of the source is found, we determine the cone half-angle (β) as the angle between the direction tangent to the magnetic field line at the source and the direction to the Earth as seen from the source.

For a given value of θ, the slope of the modulation lane (SL) for the appropriate frequency range can be calculated. Several of these slopes are computed for different values of α until a good match between the slope defined by the observational points and the one generated by our model is obtained. By using this procedure we are able to obtain the source System III longitude (θ) and the cone half-angle (β).

3 Source Longitudes and Cone Half-Angles of Io-B and Io-A

The observations used for the determination of source and beam parameters of Io-B source were made by Riihimaa at Aarne Karjalainen Observatory of the Department of Astronomy, University of Oulu, Finland, in 1987 and 1988, at frequencies between 20 and 32 MHz [Riihimaa, 1993]. The antenna system consisted of an array of two crossed log periodic polarimetric antennas from which, the right-hand (RH) and left-hand (LH) circularly polarized components of the radiation were obtained. The received radiation was processed and recorded by an analog acousto-optical radio spectrograph, providing frequency and time resolutions of about 70 kHz and 150 ms, respectively.

From these data we plotted 40 frequency versus time curves delineating modulation lanes representative of different sections of four selected Io-B storms. Figure 1 shows θ and β versus CML as calculated from the lead angle values at the frequency of 23 MHz for four Io-B storms. The plot of θ as a function of CML shows a clear linear increase. The interpretation of this linear increase is that the location (longitude of the intersection of the active magnetic flux tube with the equatorial plane) is continuously changing with

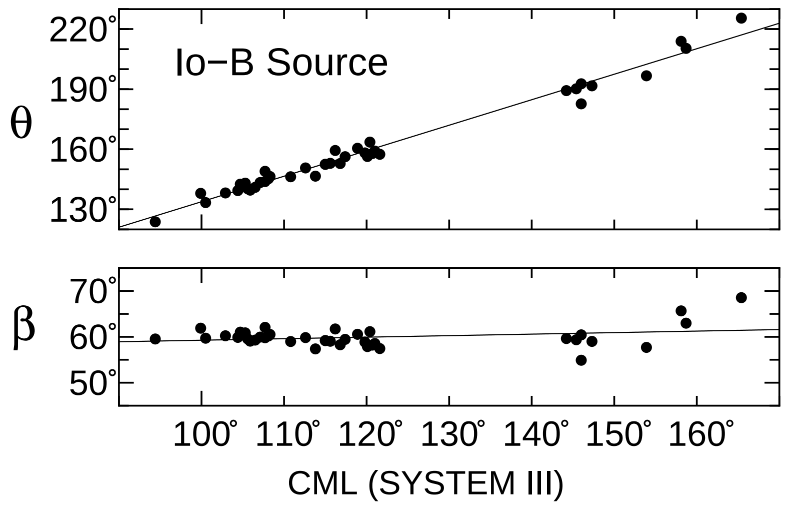


Figure 1: Plot of the derived parameters at the frequency of 23 MHz, longitude of the intersection of the active magnetic flux tube with the equatorial plane (θ) and cone half-angle (β) versus CML (System III longitude of Earth) for the four Io-B storms observed in 1987 and 1988. The thin lines are the linear fit to the derived values.

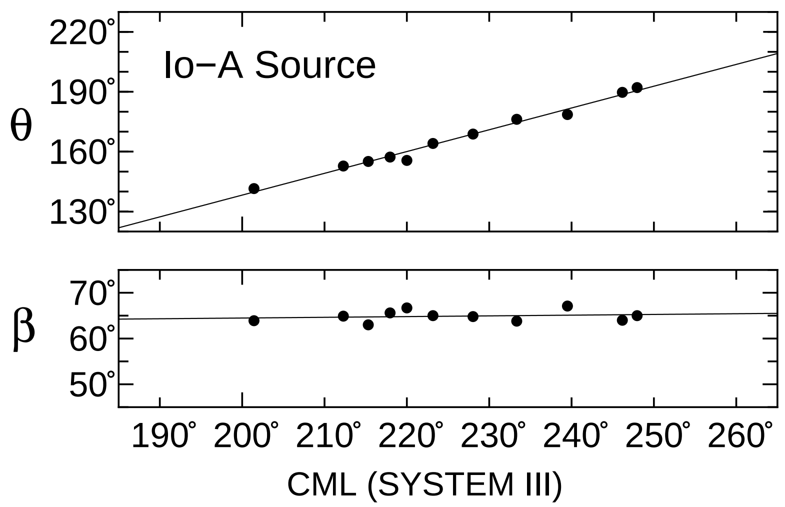


Figure 2: Same as Figure 1 but for the five Io-A storms observed in 2004 and 2005.

the rotation of Jupiter. The plot of cone half-angle (β) shows that this parameter remains constant at an average value of 60°.

For the determination of the source and beam parameters of the Io-A source, we made use of more recent data obtained with the new University of Florida Radio Observatory (UFRO) radio spectrograph. This recently installed radio spectrograph, operated at UFRO for Jupiter and solar radio observations, was made possible by resources provided by the NASA Radio JOVE education program (`http://radiojove.gsfc.nasa.gov/`). The antennas used with the radio spectrograph consisted of two 8-element conical log spiral N-S oriented linear arrays, one RH and the other LH circularly polarized. The UFRO spectrograph has the unique capability of being accessible on the Internet continuously in real time. The frequency and time resolutions are 30 kHz and 100 msec respectively.

Although Riihimaa provided an abundant of data for the modeling of Io-B modulation lane events, there was a deficiency of that of Io-A events. Observations of Jupiter during 2004 and 2005 made with the log spiral array and the new radio spectrograph at UFRO enabled us to eliminate the deficiency of Io-A modulation lane data. Figure 2 shows θ and β versus CML as calculated from the lead angle values at the frequency of 23 MHz for 11 modulation lane data points of five recorded Io-A storms. The plot of θ as a function of CML shows a clear linear increase as in the case of Io-B source. The plot of cone half-angle (β) shows an average value of 65°. This value is consistently higher by 5° respect to the value of the Io-B source. Since the longitude range of the Io-A source overlaps the range of Non-Io-A source, our data could have a contamination of emission from both sources. Therefore our results cannot be conclusively applied to the Io-A source alone.

In summary, the measured ranges of source System III longitude (θ) are 124° to 226° for Io-B and 142° to 192° for Io-A. These results show that the active radio regions of Io-B and Io-A are sharing the same source System III longitude.

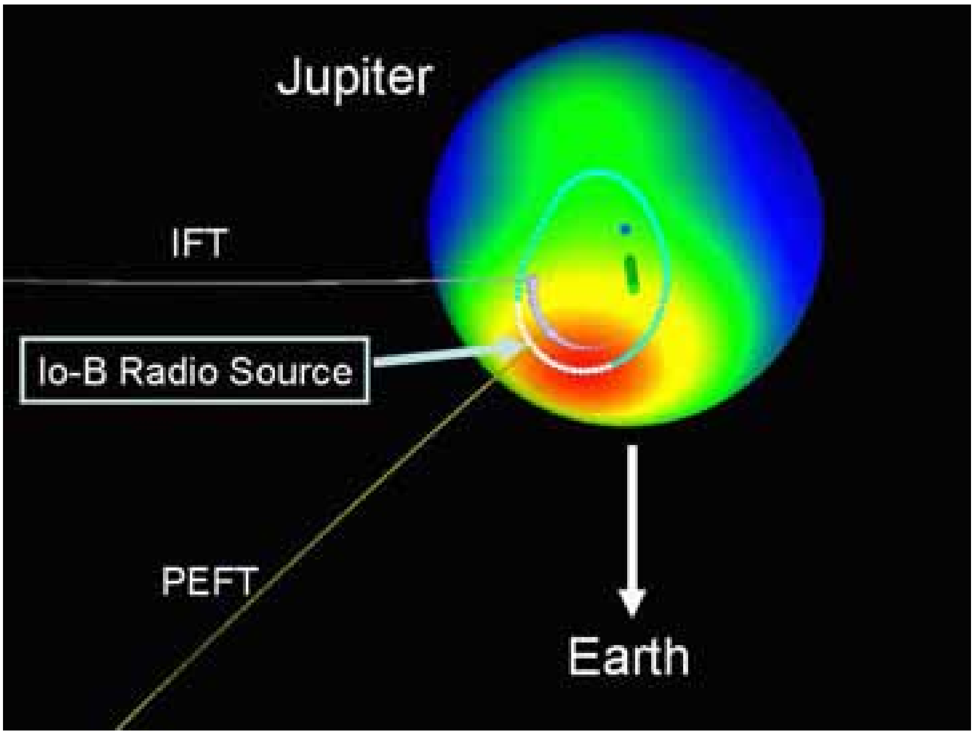
4 Improved Geometrical Visualization

By using the modulation lane method we have gained new information about the locations and beaming of the Io-B and Io-A sources. Based on the results of the location of the Io-B and Io-A sources obtained with the modulation lane method and the VIP4 Jupiter's magnetic field model [Connerney et al., 1998], we have been able to produce 3D computer graphic (CG) images of the source location and the geometry of the emission cone.

Figure 3, upper and lower panels show views from two different angles of the active radio region (white sector of the ring) where the Io-B source is located. We have extended the ring beyond the active region to cover 360° showing the location of hypothetical sources at 20 MHz (See Figure 5). We have also plotted the trail of the location of the foot of the active flux tube passing through the location of the 20 MHz sources. The upper panel shows a view from above Jupiter's north pole. The lower panel shows a view from the Jovian equator; the emitting cone has been added to this last view.

Figure 3: (plate, next page) Upper panel: View of the Io-B source from above the north pole. Geometrical parameters are CML(System III)=140°, Io Phase=90°, Source System III Longitude=185°, and Lead Angle=45°. Lower panel: View of the Io-B source with emitting cone (60° cone half-angle) from the Jovian equator.

Figure 4: (plate, following page) Same as Figure 3 but for the Io-A source. Geometrical parameters are CML(System III)=210°, Io Phase=225°, Source System III Longitude=150°, and Lead Angle=15°.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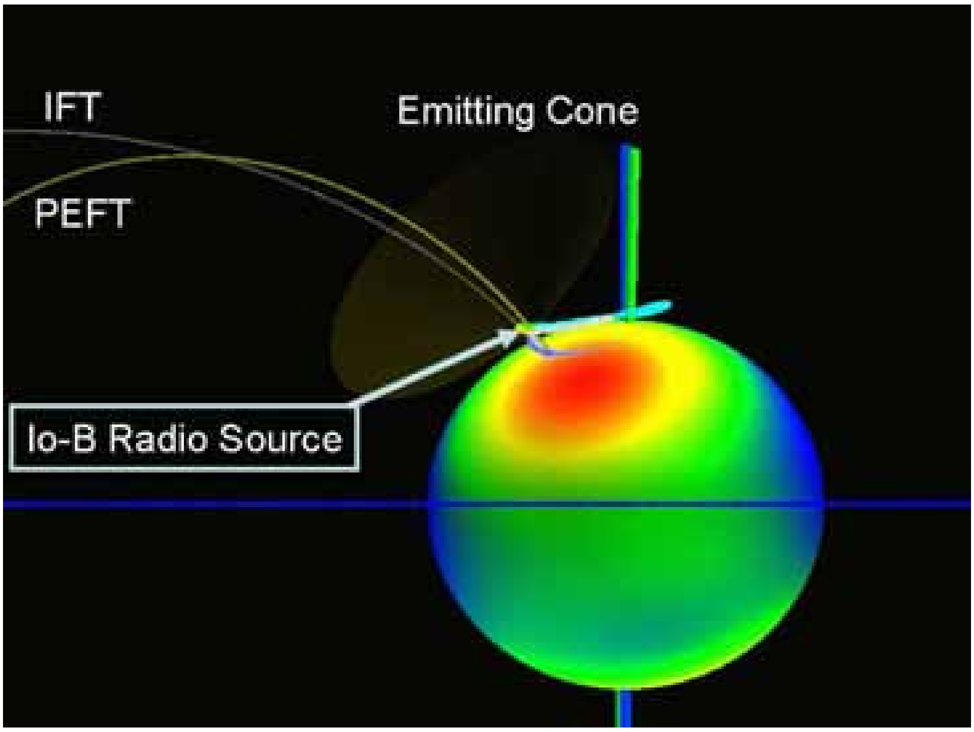
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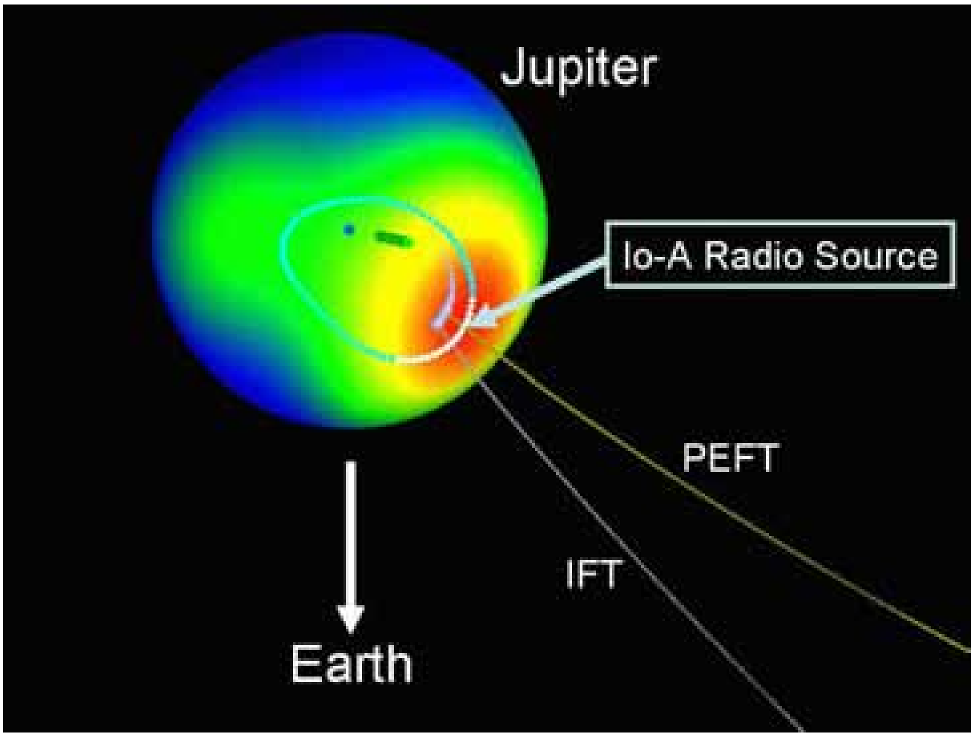
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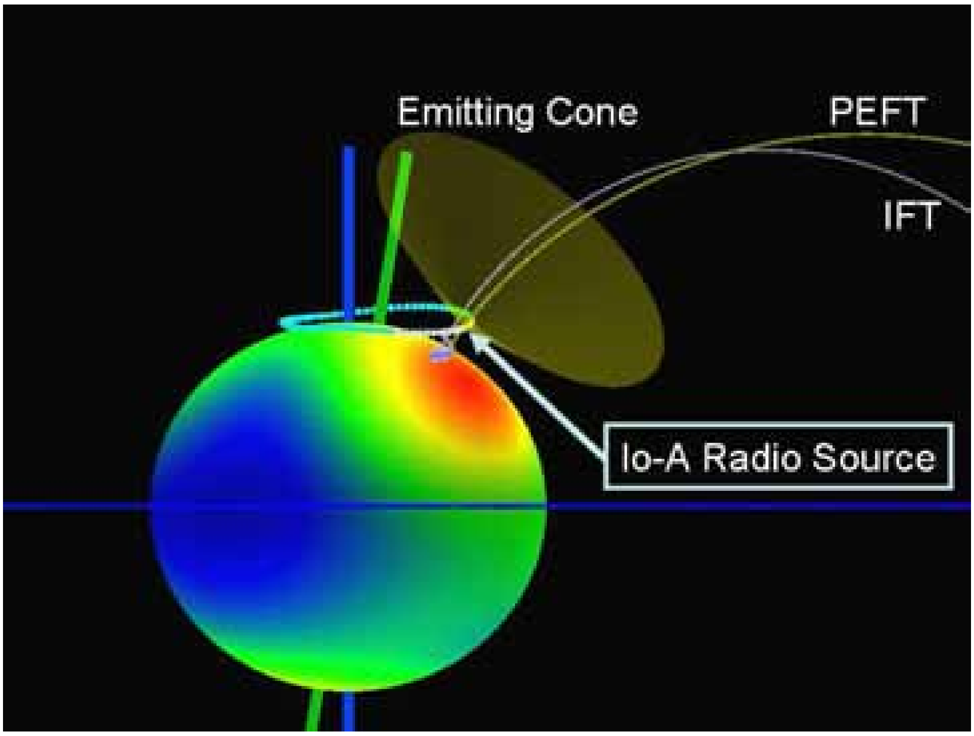
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Io-A Radio Source

Figure 4, upper and lower panels show the same views but for the Io-A source. We have generated images of the rotation of the sources and the emission cone using a series of CG images. The animations can be displayed at the web site (`http://jupiter.kochi-ct.jp/cg/`).

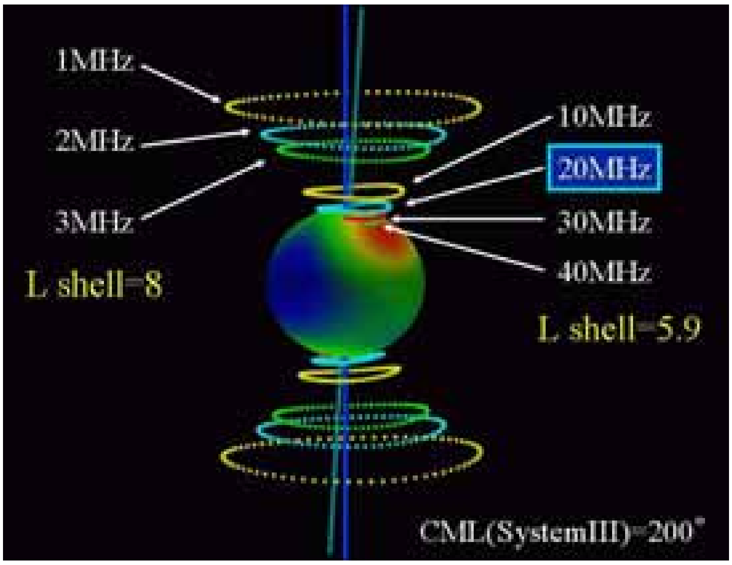

Figure 5: Locations of the points in Jupiter's magnetosphere where the electron cyclotron frequencies correspond to 10 – 40 MHz for the L shell value of 5.9 based on the VIP4 Jupiter's magnetic field model; the location of the points at 20 MHz (this paper) has been used as reference. The locations of the points corresponding to the frequencies of 1, 2, and 3 MHz but for the L shell value of 8 are also plotted.

5 Conclusion

By the use of the modulation lane method we have been able to obtain improved values for the longitude of the location and the emitting cone geometry of the Io-B and Io-A sources. We found that the active radio regions of these two sources share the same range of System III longitude. Based on our results we are able to show for the first time a more realistic view of the location and beam geometry using 3D CG images. Our results can provide a very important piece of information in the investigation of the mechanism responsible for Jupiter's decametric radio emission.

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