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"A Study of the Io-Associated Plasma and Neutral Sodium Cloud"

FINAL TECHNICAL REPORT

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We have obtained narrow-band interference filter images of the Io torus at the [SII] wavelengths of $\lambda\lambda6716,6731$ and at the wavelength of the [SIII] $\lambda9532$ emission. Our principal data sets were acquired on the nights of 10, 11, and 12 June 1983; 14 and 17 August 1983; and on 24, 25, and 26 June 1984. The purpose of these observations is to study the short term (day to day) temporal behavior of the torus and to gain a better understanding of the systematic morphology of the torus.

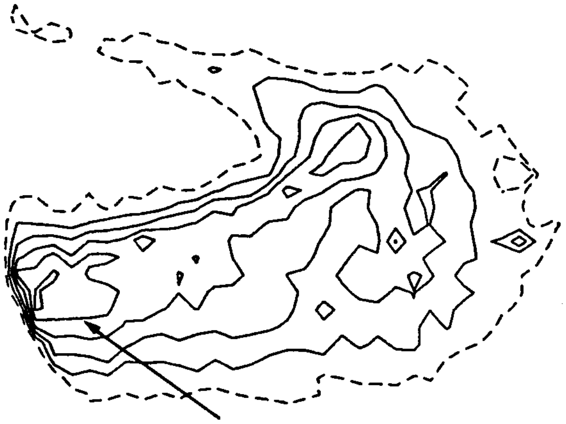
From these images we have obtained estimates of the electron and ion densities and ion temperatures as a function of longitude, latitude, radius from Jupiter, and time. Resulting from a knowledge of these quantities will be an increase in our understanding of the ion mixing ratios, the sources of ionization in the torus, the nature of temporal changes in the torus, and the cause of large-scale features in the torus. In addition, nearly simultaneous measurements of emissions from Io's neutral clouds will increase our knowledge of the ion-neutral interactions. We have constructed three-dimensional models of the torus in order to extract the desired information from the images.

From our analysis of images taken in 1983 and 1984 we have detected extremely sharp longitudinal variations in plasma density, measured subcorotational velocities in the torus plasma, confirmed the presence of an optical east-west brightness asymmetry in the ion emissions, and detected longitudinal variations in torus ion temperatures. Figure 1 shows two $\lambda6731$ "open ring" images of the western torus ansa taken with a temporal separation of 48 hours. North and west are respectively to the top and right of the figure. The outer-most contours in both images extend to a distance of ~5.5 R_j. At ~4 R_j the contours are cut off by the circular field of view of the camera. The ring ansa lies at a radial distance of 5.1 R_j. Jupiter is to the left outside the camera's field of view. In these images the northern arm of the emission ring lies in front of Jupiter and corresponds to lower magnetic longitudes than the torus ansa while the southern arm runs behind Jupiter and is at higher magnetic longitudes. The longitude of the torus ansa is labeled on each image.

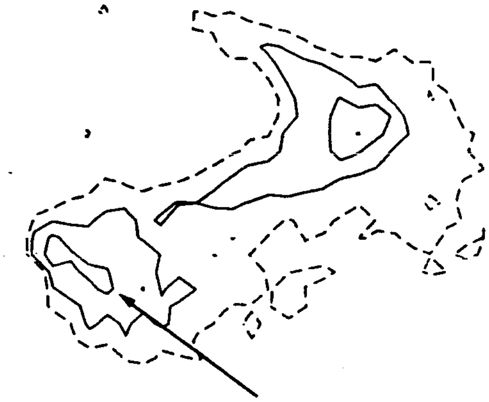
An arrow marks the location of a "knot" of bright emission on the southern arm of each image shown. From 6 hours of continuous observation previous to each of these images it is known that this "knot" corresponds to a longitudinal asymmetry in the torus. The longitudinal asymmetry is confined primarily to plasma beyond 5.5 R_j. A three-dimensional model of the torus has been constructed which fits the entire suite of images taken on June 12. Figure 2 shows the [SII] and [SIII] densities at 5.65 R_j, the radial distance at which the longitudinal asymmetry is most extreme. The density gradients in magnetic longitude are quite large. For "open-ring" images such as those shown in Figure 1 the longitudinal location of the density maximum can be determined to within 5 degrees with the help of the detailed model. The ansa longitudes of the images in Figure 1 differ by 21 degrees. This is evidence that within 2 days the longitudinal location of the density maximum shifted ~20 degrees towards higher magnetic longitudes. This shift corresponds to a subcorotational lag in the plasma of ~1%. Images in 1984 show evidence for ~2% subcorotational velocities. While it is clear from the current results that some portions of the torus near 5.7 R_j do undergo substantial subcorotational motions it has not yet been shown if these motions are confined to the regions of density maxima or whether the torus as a whole undergoes subcorotation. This question deals intimately with how plasma is injected into the torus since plasma loading of the field lines is responsible for subcorotation. Another question of great interest is what is the temporal variability of the subcorotation? Spectroscopic measurements by Brown indicate a range of 2-8% in the subcorotational motions. Is this variability real and over what time scales do these variations take place?

Another result of the modeling of the 12 June images is that the density maximum appears to be accompanied by a decrease in the ion temperatures in the torus. Figures 3 and 4 show the torus model compared to data from a single image. Figure 3 shows a radial (east-west) cut through an image of the torus taken close to the longitude of the density maximum at λ_{III}=224. The solid lines show the data and the dashed lines show the model intensities. The data in Figure 4 comes from the same image and shows a latitudinal (north-south) cut through the intensity maximum at ~5.7 R_j and the results of two model calculations utilizing different longitudinal variations of the ion temperatures. The short dashed line shows the intensities calculated assuming no longitudinal temperature variations. The radial ion temperature profile used was derived from fitting several images taken at longitudes well away from the longitude of the density maximum. The long dashed line shows the intensities calculated for a model in which the ion temperatures were assumed to vary as a function of longitude. Figure 5 shows the model radial temperature profiles away from the density maximum and at the maximum. The temperature profile was allowed to vary between these two extremes in the manner shown in Figure 6. For reference the [SII] ion densities are also plotted on Figure 6. The principal effect of the longitudinal variations of the ion temperature profile is to decrease the ion temperatures near the longitudes of the density maximum. It should be noted here that the assumed longitudinal temperature variations take place only between ~5.2 and 6.0 R_j. It is clear that the assumption of longitudinally invariant temperatures is a poor assumption compared to one which allows this variation. The conclusion is that at this time the density maximum was accompanied by a localized decrease in the ion temperatures. This is what one would expect under equilibrium conditions. In equilibrium the plasma heating is proportional to the plasma density but the plasma cooling is proportional to the square of the density. In equilibrium one therefore expects higher densities to be associated with lower temperatures. However, it is curious that the temperature minimum does not appear to be coincident in longitude with the density maximum, but at slightly higher longitudes. Since subcorotational motions cause the plasma to drift toward higher longitudes, the region of cooler plasma in the model may correspond to a region in the torus which has not yet experienced the plasma loading which was taking place in the region of the density maximum. The speed at which temperature equilibrium is reached may give us limits to the minimum length of time over which the observed maximum had existed before our observations were taken.

t39: [SII] λ6731, 10 June 1983

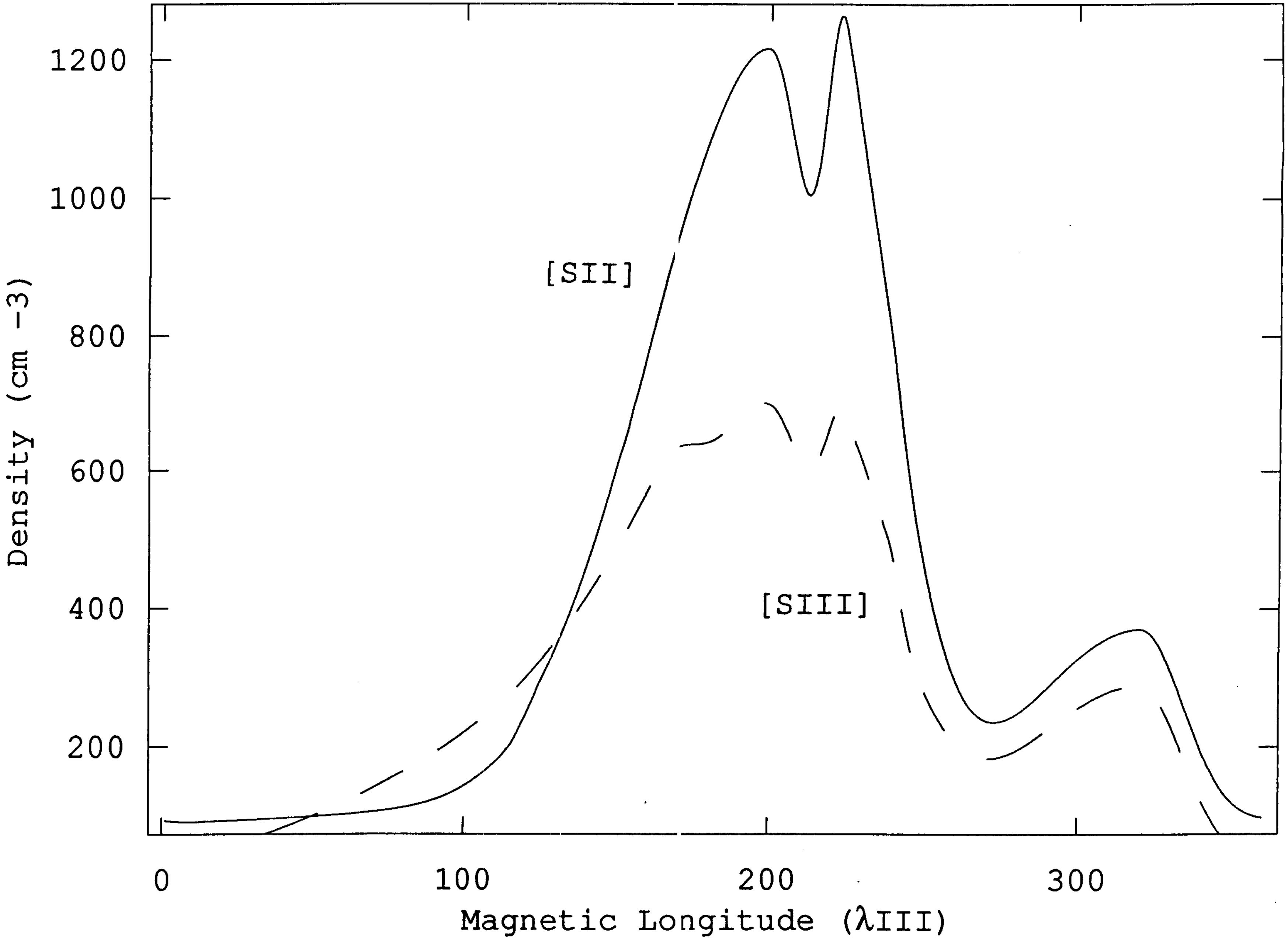


λIII= 264

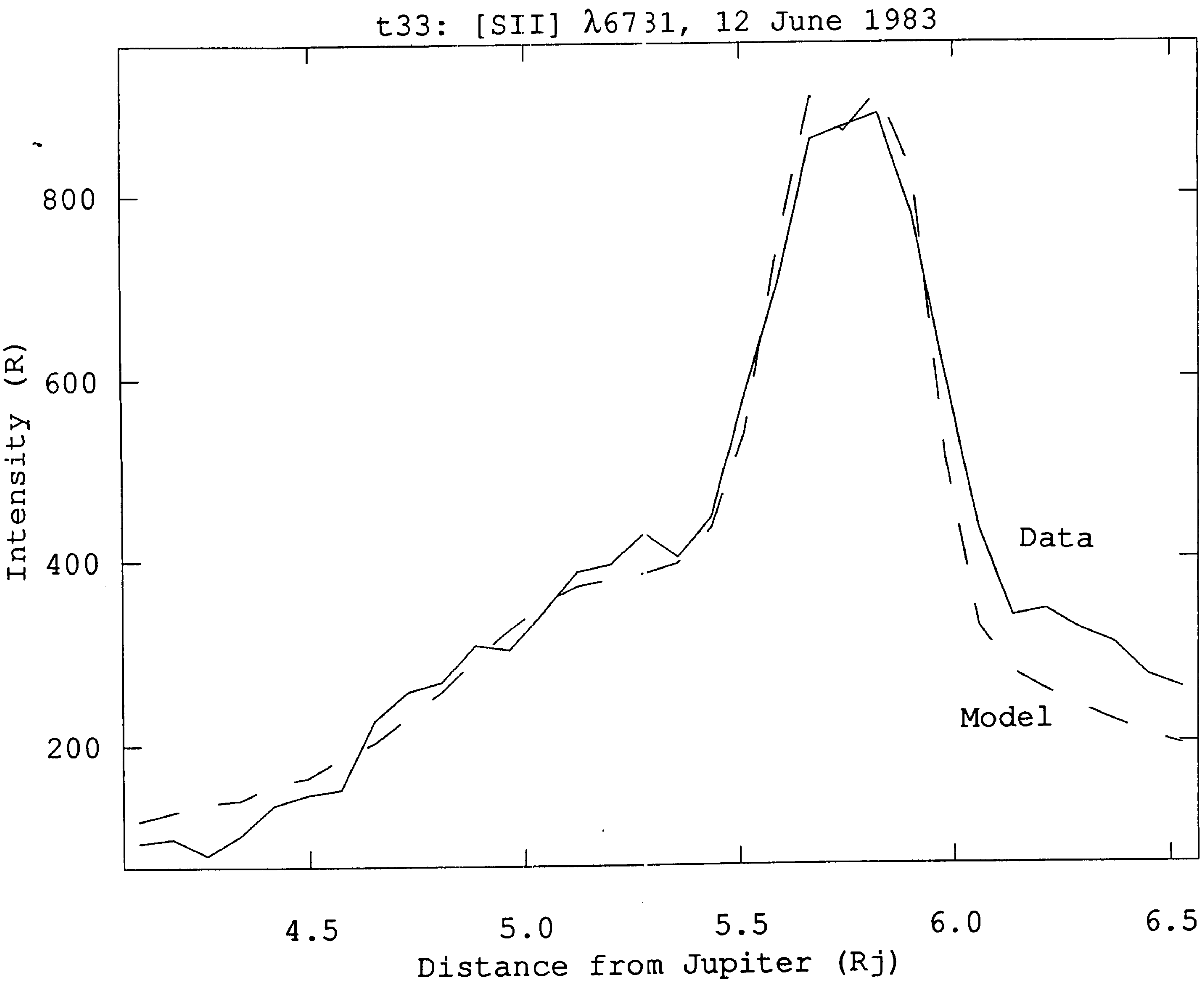


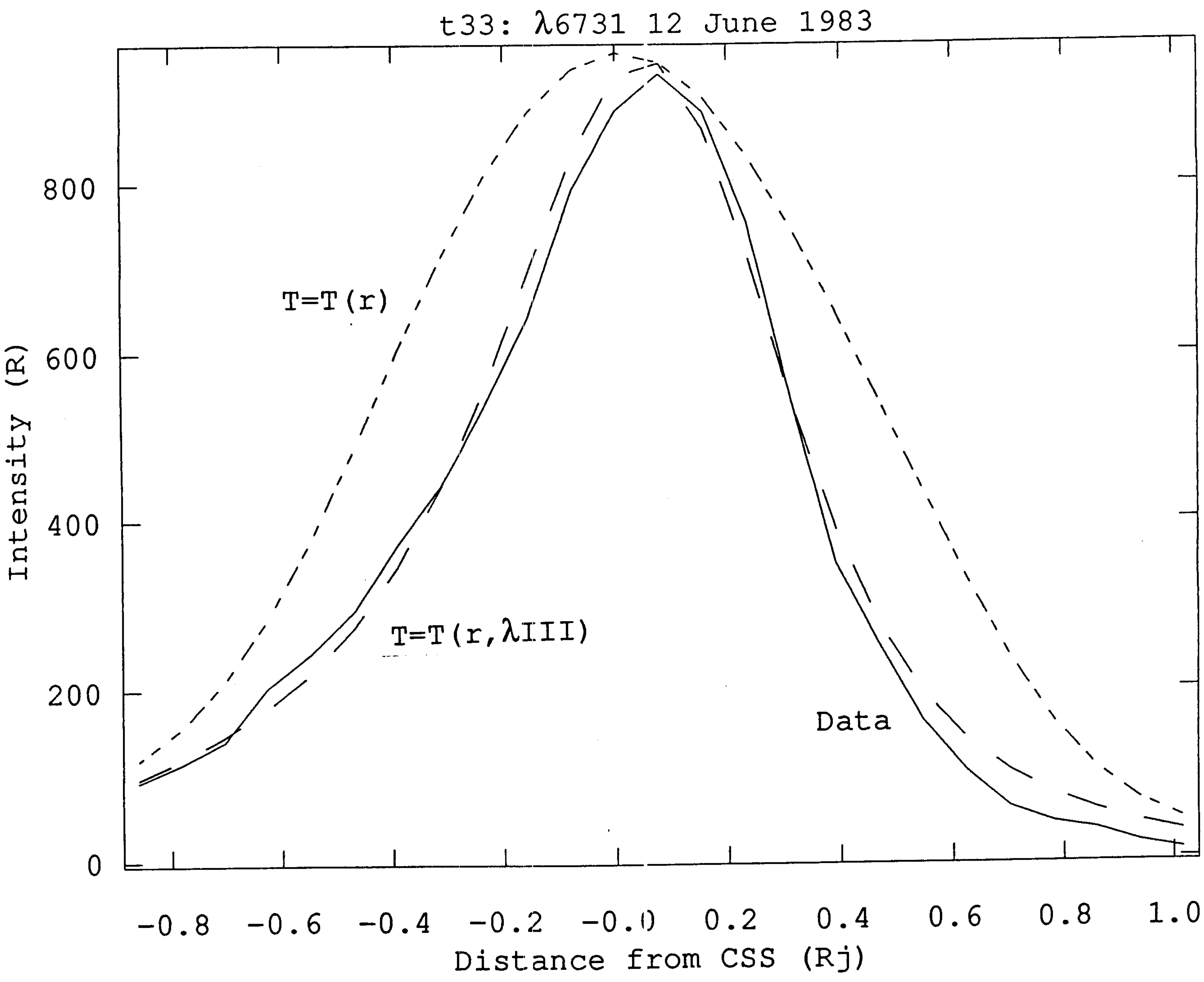
λIII= 285

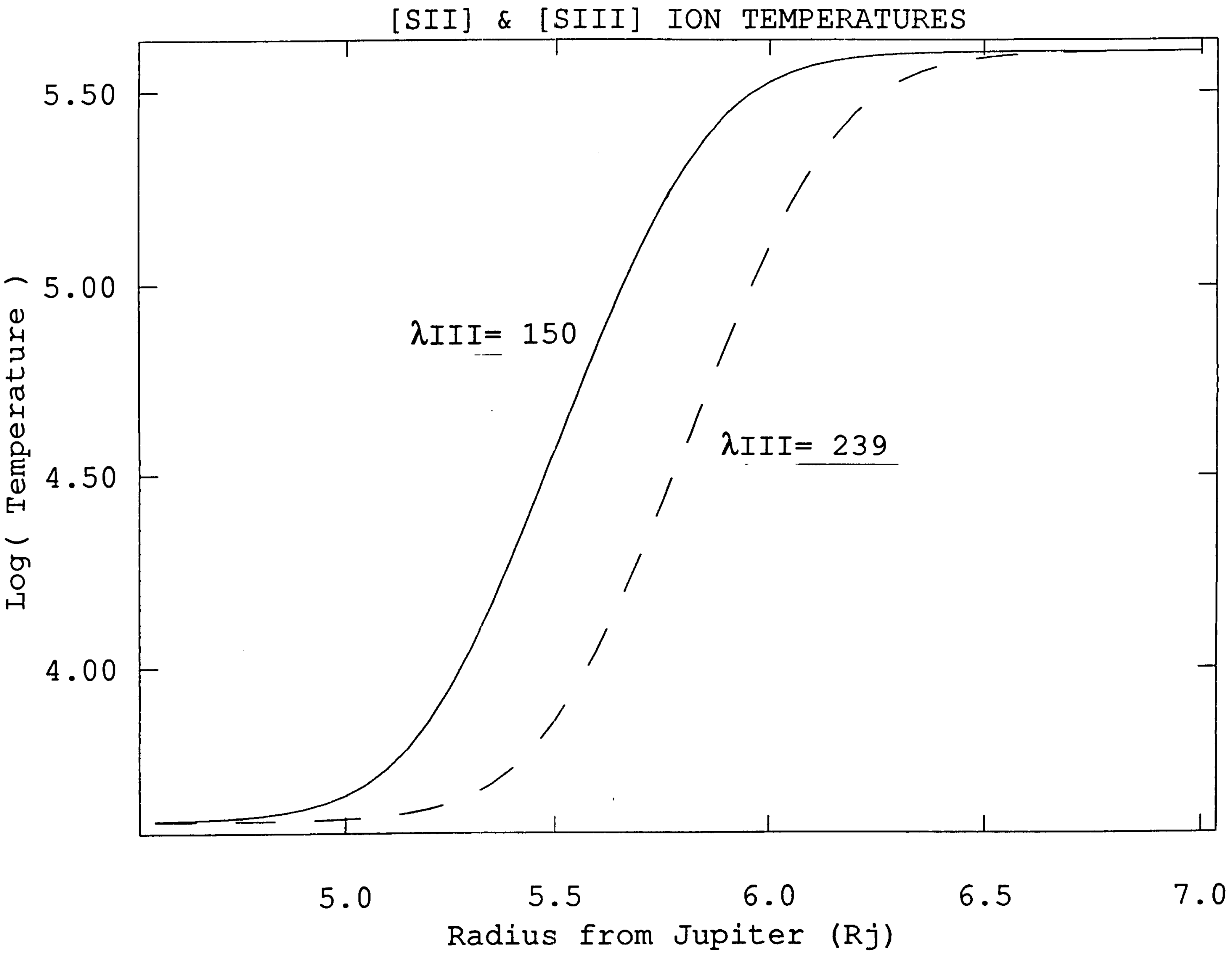
t50: [SII] λ6731, 12 June 1983

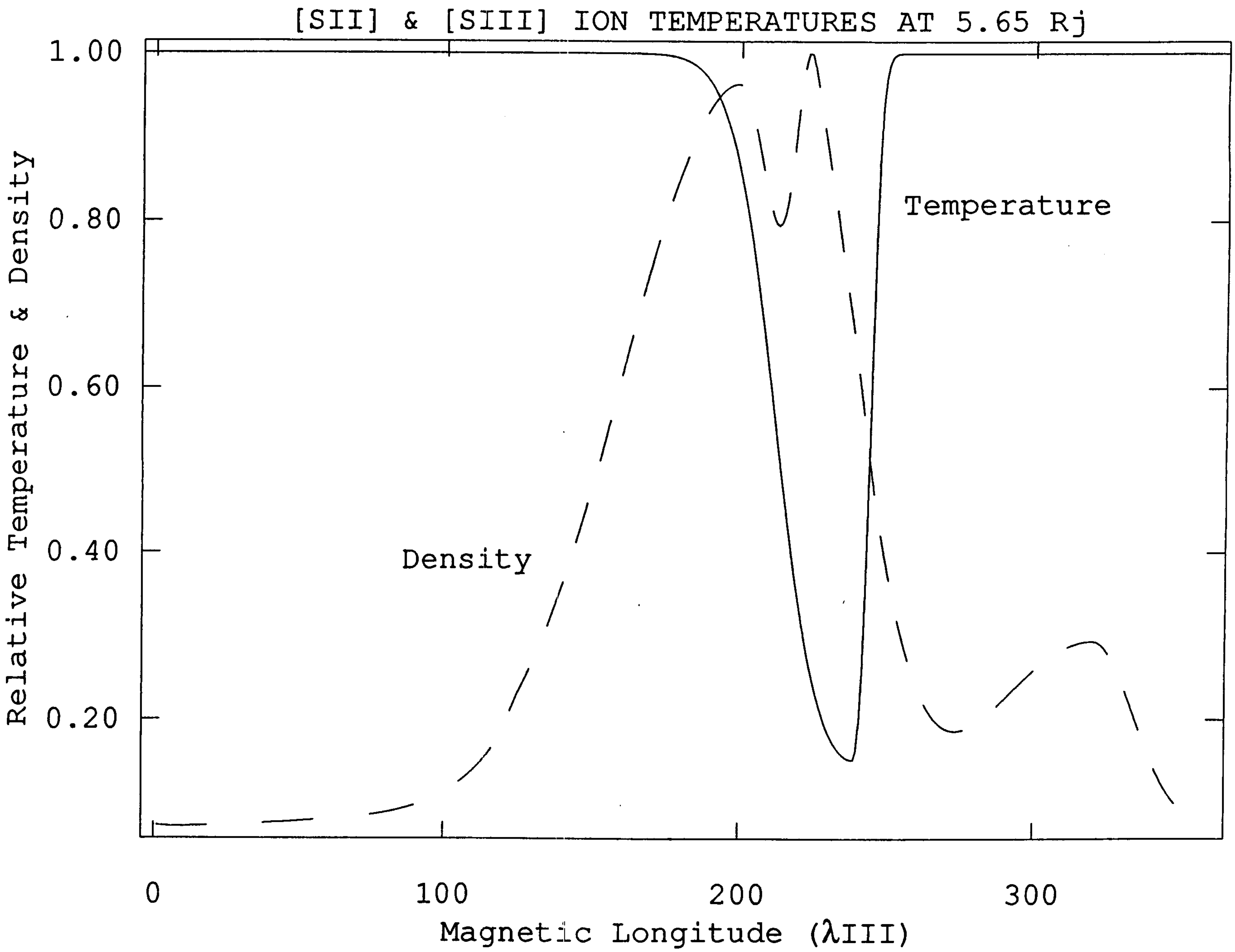


[SII] & [SIII] MODEL DENSITIES, 5.65 Rj


t33: [SII] λ6731, 12 June 1983
Intensity (R)
800
600
400
200
4.5
5.0
5.5
6.0
6.5
Distance from Jupiter (Rj)
Data
Model


t33: λ6731 12 June 1983
T=T(r)
T=T(r,λIII)
Data
Intensity (R)
0
200
400
600
800
-0.8
-0.6
-0.4
-0.2
-0.0
0.2
0.4
0.6
0.8
1.0
Distance from CSS (Rj)


[SII] & [SIII] ION TEMPERATURES
Log (Temperature)
5.50
5.00
4.50
4.00
λIII= 150
λIII= 239
5.0
5.5
6.0
6.5
7.0
Radius from Jupiter (Rj)


[SII] & [SIII] ION TEMPERATURES AT 5.65 Rj
Relative Temperature & Density
1.00
0.80
0.60
0.40
0.20
0
100
200
300
Magnetic Longitude (λIII)
Temperature
Density