OUTER RINGS OF SATURN

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ABSTRACT

A two component model of a possible ring structure at about 12.5 Saturn radii is presented here which can explain the shapes of the immersion and emersion occultation profiles obtained during the occulation of SAO 158913 by Saturn's magnetosphere on March 24, 1984 and March 25, 1984. The four sharp features may be due to micron sized dust grains confined close to the equatorial plane. The extended wings associated with the sharp features may be due to extended ionic and molecular belts stretching far above and below the equatorial plane of the planet Saturn.

THE magnetosphere surrounding the planet Saturn has been known to be quite extensive; the three deep space probes Pioneer XI and Voyagers 1 and 2 have all observed characteristic variations of ion densities and energies in this region[1-6]. Recent observations of occultation of a star by Saturn has yielded clear indications of the presence of absorbing clouds about 12.5 Saturn radii away, close to the equatorial plane. In the present paper results of further critical analysis of the occultation data obtained at Kavalur (Longitude: $-5^h 15^m 19.^s6$, Latitude: $+12^\circ 34'.58$, Height 725 mts.) are presented which throw new light on the physical nature of this circumplanetary matter.

Following the publication of Voyager results, Lazarus *et al*[7] suggested the presence of fine particulate matter in the region of ion density irregularities. Possibilities of detection of such clouds were investigated by Mink[8] who calculated the detailed circumstances of several occultation events when the planet Saturn would drift across some stars. Occultation passages of the star across symmetrical zones in the circumplanetary region during March 24 and 25, 1984 were observed photoelectrically from Kavalur[9,10]. Details of the circumstances and observing equipment have been given in the earlier paper[10].

Two independent scans of the region 12–14 Saturn radii away from the planet centre could be obtained during the events; one on the west side of the planet on March 24 and one on the east side, next day (figure 1). Several interesting features of the extinction light curves suggest a complex structure; these features are discussed below.

Although different wavelength bands were used for the two scans, the general shapes of the light curves were remarkably similar. Large variations in the extinction magnitudes in two spectral bands have been noticed which allow certain interesting speculations regarding the nature of the absorbing clouds. Table 1 summarizes the results of extinction measurements. Observations on the immersion side in white light show a maximum optical depth of 0.71 whereas through blue filter the maximum optical depth as observed next day is only 0.14. Such a variation cannot be explained by a symmetrical model of absorbing clouds.

The extinction of the star beam had occurred at regions symmetrically around the planet's centre. The period during which the extinction was observed was about 40 min on either side of the planet. A close examination of the light curve reveals that the four features which are symmetrical with reference to the Planet's centre, may be ascribed to a concentric system of ringlets in a simplistic model. General feature of these regions are shallow wings culminating in deep central minimum (figures 1, 2). Two of them are quite broad, lasting more than a couple of minutes and have more than one minima embed-

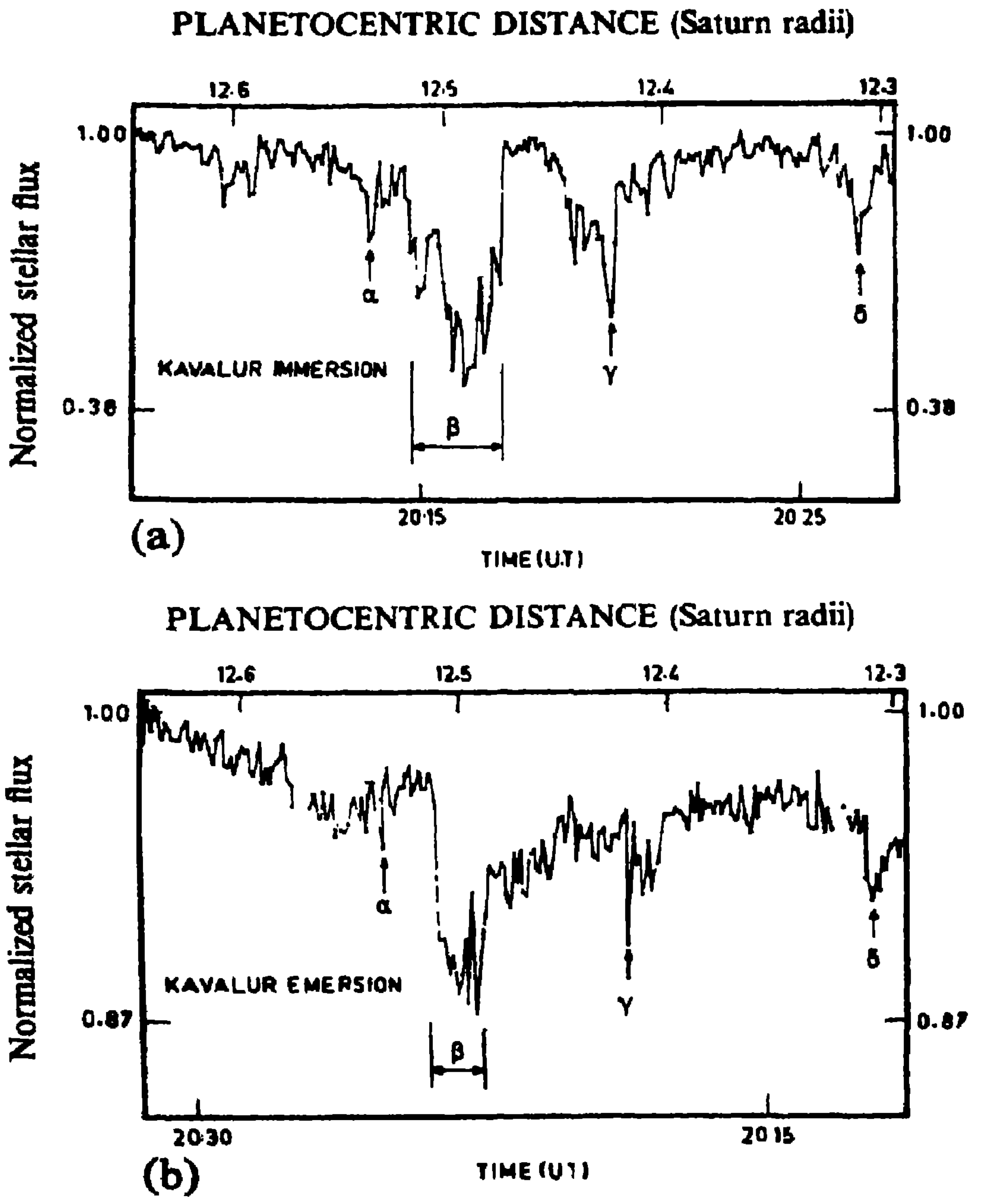

Figure 1. Light curves (a) Immersion on 24 March 1984 (b) Emersion on 25 March 1984, reversed for direct comparison. Each point corresponds to photon counts summed over an interval of 5 seconds.

Table 1 *Optical depth measurements*

Event	Wave-length band	Maximum Optical depth	Overall Optical depth
Immersion 24 March 84 Kavalur	White	.71	.06
Emersion 25 March 84 Kavalur	Blue	.14	.08

Table 2a *Observed timings of the events*

	Immersion – Filter: Clear		Emersion – Filter: Blue	
Event	Observed Timings UT ± a	Duration Sec.	Observed Timings UT ± a	Duration Sec.
Zone	20:11:02.5	420	20:27:20.0	425
Spike	20:13:37.5	≃2	20:24:47.5	≃2
Zone	20:15:57.5	170	20:21:57.5	220
Spike	20:16:44.0	≃2	20:22:49.0	≃1
Zone	20:20:02.5	210	20:17:47.5	110
Spike	20:20:02.5	<1	20:18:25.0	<1
Zone	20:26:25.0	105	20:11:57.5	60
Spike	20:26:36.0	≃2	20:12:09.0	≃3

a = $\pm 5^s$ for the zones, a = $\pm 1^s$ for the spikes.

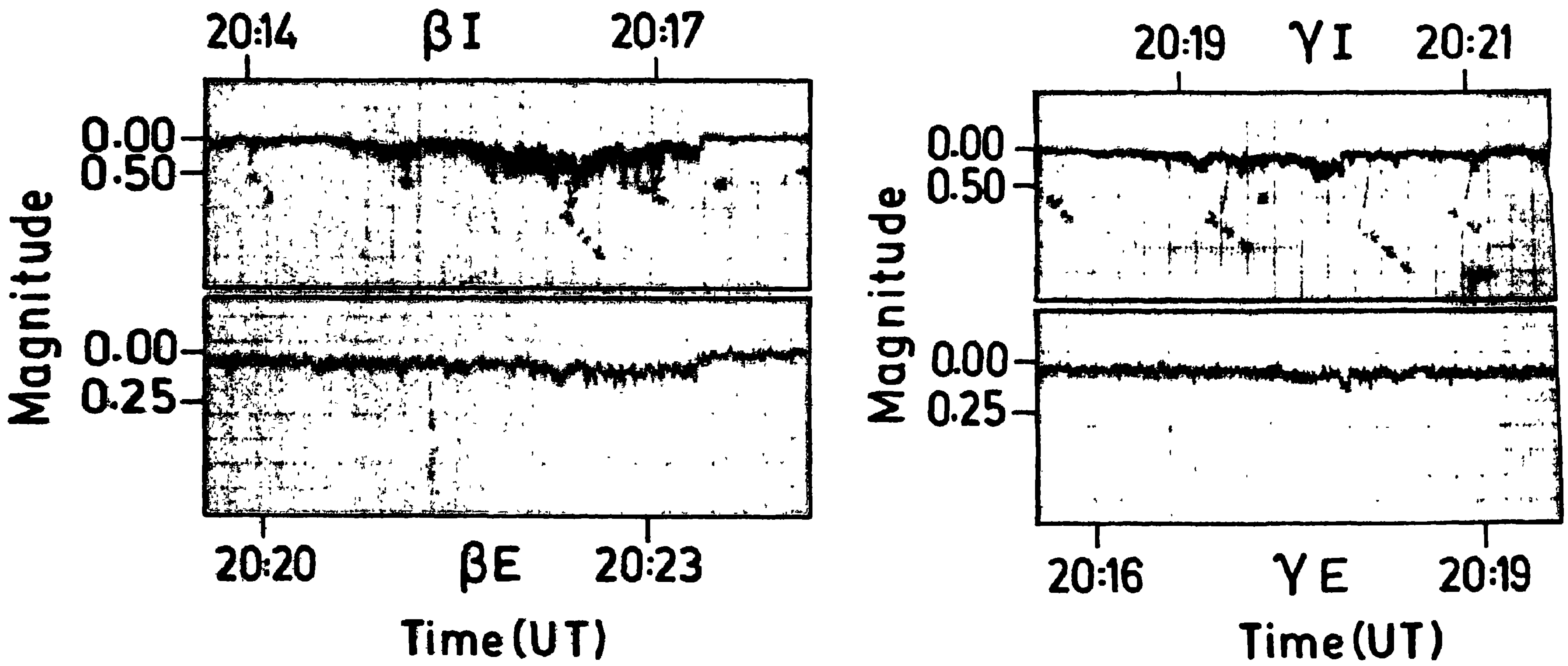

Figure 2. Strip chart recorder tracings showing the dips due to (a) zone β and (b) zone γ. The top figure in each case shows the immersion light curve and the bottom one the emersion light curve. Unlike figure 1 the time axis of emersion light curve is not reversed. Sharp edges on the inner side during immersion and on the outer side during emersion can be clearly noticed on both the curves II(a) and II(b).

Table 2b *Planeto centric distance, width and optical depth of the features*

Event	Immersion			Emersion		
	Planetocentric Distance RS	Width Km	Optical depth	Planetocentric Distance RS	Width Km	Optical depth
Zone	12.5790	7283	.05	12.5756	7565	.07
Spike	12.5344	≃42	.11	12.5307	≃41	.03
Zone	12.4942	2948	.37	12.4805	3916	.12
Spike	12.4808	≃37	.44	12.4957	≃21	.06
Zone	12.4237	3641	.15	12.4067	1958	.10
Spike	12.4237	≃17	.31	12.4178	≃18	.05
Zone	12.3137	1821	.10	12.3036	1068	.11
Spike	12.3106	≃40	.31	12.3069	≃62	.04

ded therein. The other two are relatively thin with the total duration lasting about a minute with one prominent minimum each. The appearance of these features was in a time sequence (table 2a) which unambiguously point to a concentric set of rings. We have designated these by the letters α, β, γ and δ; the details of their calculated widths and optical depths are given in table 2b. The optical depths have been calculated from the magnitudes of the dips below the immediate continuum. The planetocentric distances of the maximum extinction points have been calculated following the method of Elliot *et al*[11]. These are shown alongside in figure 1. It may be noticed that the planetocentric arrangements of these rings are almost perfectly symmetrical. In the absence of timings of occultation events by planet body or any of the known rings to correct for the uncertainty in the relative position of the star and the planet, we find that the planetocentric distances of the four spikes on either side agree even better (in the least square sense) if a correction of $\Delta\alpha = -0^s.0102$ and $\Delta\delta = 0.0$ is applied to the planet position.

Minor variations in the shape within the broad features may, however, be noticed on the two sides of the planet. The minimum light points are not exactly central in the features, and some assymmetry may be seen in the wings. These coupled with the noticed differences in optical depths of the absorbing material indicate that there are large azimuthal variations along the ring plane.

We have also estimated the total extinction over the entire 40 min period and find that the large variations noticed in selected portions of the light curve are considerably reduced in the computation. These integrated optical depths are given in table 1. This suggests the possibility that although the structure is basically symmetrical, other dispersing factors have added to the observed assymmetries.

We have to keep in view that the region in which these absorbing clouds are located are traversed by strong Saturnian magnetic field. Also the deep space probes have detected ionized plasma in the planet's magnetosphere[3]. We also know that the structure of planetary magnetosphere is distorted along the direction of the solar wind. The occulting regions on the two sides of this planet are located in such a way that assymmetries in the distribution of ionised plasma or even fine particles cannot be overruled. The heavier particles are likely to be contained in equatorial planetocentric orbits which may be responsible for the spikes α, β, γ and δ, but the gas and fine dust can extend far out of the equatorial plane giving rise to the broad shallow zones α, β, γ and δ. One feature noticed in our records may be explained if we assume slight assymmetry in the density distribution above and below the equatorial plane of the ring.

This feature is illustrated in figure 2. The wings of the two broad zones β and γ have clearly assymetric profile. On the immersion side inner regions of the rings are sharp while the outer ones in the entire region, whereas the bulk of the extinction is effected by selective absorption by ions and molecules and perhaps by fine dust particles. Such a model can explain the majority of features observed during this particular event.

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