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AND THE EARLY HISTORY OF THE SOLAR
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VOYAGER SATURNIAN RING MEASUREMENTS AND THE EARLY HISTORY OF THE SOLAR SYSTEM

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Abstract

The mass distribution in the Saturnian ring system is investigated and compared with predictions from the plasma cosmogony. According to this theory, the matter in the rings has once been in the form of a magnetized plasma, in which the gravitation is balanced partly by the centrifugal force and partly by the electromagnetic forces. As the plasma is neutralized, the electromagnetic forces disappear and the matter can be shown to fall in to $2/3$ of the original saturnocentric distance. This causes the so called "cosmogonic shadow effect", which has been demonstrated earlier for the astroidal belt and in the large scale structure of the Saturnian ring system.

The relevance of the comogonic shadow effect is investigated for parts of the fine structures of the Saturnian ring system. It is shown that many structures of the present ring system can be understood as shadows and antishadows of cosmogonic origin. These appear in the form of double rings centered around a position a factor 0.64 (slightly less than $2/3$) closer to Saturn than the causing feature. Voyager data agree with an accuracy better than 1%.

1. INTRODUCTION

A theory for the evolutionary history of the Solar System taking account of plasma effects was published ten years ago in two monographs by Alfvén and Arrhenius (1975,1976). Since then plasma research has produced a drastic change in our views of cosmic plasmas, a summary of which has been given in Alfvén, Cosmic plasma (1981). Further observational results have demonstrated to what extent cosmogony depends on the new in situ measurements in the magnetospheres. A survey of this has recently been published (Alfvén, 1984). According to table I the evolution of the solar system passes through three phases: 1) a primeval dusty plasma which condenses to 2) planetesimals, which accrete to 3) planets and satellites.

The transition from 2) to 3) does not take place in the Saturnian rings (inside the Roche limit) or the asteroidal belt (because of extremely low smeared out density). This makes these two regions of special interest to cosmonogy, because the plasma-planetesimal transition (PPT) can best be studied in these two regions.

We are here treating exclusively the massive rings, which are believed to consist of grains and boulders with a size of mm - 100 m. The rings consisting of mirror sized particles which have masses which are 10^{10} - 10^{20} times smaller obey gravito-electrodynamic effects and have been treated by Mendis et al. 1982 and others.

It is expected theoretically that the PPT should be associated with a general contraction by a factor $\Gamma = 2/3$, which because of certain secondary effects should be corrected downwards by a few percent. This transition is clearly visible in four cases in the Saturnian rings and in three cases in the asteroidal belt. With these seven cases the importance of a PPT of the theoretically predicted type seems to be clearly established.

The recent detailed measurements made by the Pioneer and Voyager missions have shown a wealth of fine structure in the Saturnian ring system. Many of the newly discovered ringlets have been identified as gravitational resonances. However, a large number remains, which might be of cosmogonic origin. If the cosmogonic theory is applied to this fine structure, the effects of density gradients must be taken into account. While the bulk structure of the Saturnian rings can be treated without introduction of such effects they should be important for the fine structure.

The present paper is therefore written with a dual purpose: on one hand, it is meant to test the cosmogonic theory by an investigation of whether it can explain the newly discovered fine structure, particularly the many isolated ringlets in the C ring. On the other hand, it is an attempt to determine how the theory should be developed in order to include the effects of density gradients. To this purpose, the fine structure (where one might expect density gradients to play a role) is studied in detail in a search for patterns, which could indicate in what direction the earlier model should be developed.

A brief review of the theory, and its application to the bulk structure of the ring system, is given in Sections 2 to 4. In Section 5, the observational material from the C ring is studied in detail, and an attempt is made to determine in what way the predictions of the earlier theory are modified by density gradients. Section 6, finally, contains a summary and discussion of the results.

2. THEORETICAL BACKGROUND

The transition from the plasma state to planetesimals has been studied in a number of papers (e.g. Alfvén, 1984; Alfvén and Čech, 1984). This analysis starts with an investigation of the equilibrium of a very thin dusty plasma which rotates around a uniformly magnetized central body with the axis of magnetization and the rotational axis coinciding. The magnetization is supposed to be so strong as to compel the guiding centres of the

electrons, ions and charged dust grains to move parallel to the magnetic field. The pressure forces are assumed to be negligible in the force balance. In the direction along the magnetic field a (dusty) plasma element is therefore acted upon only by gravitation and the centrifugal force. Because these forces make different angles with the magnetic field, the case of force balance along the magnetic field gives a situation where only $2/3$ of the gravitational force is balanced by the radial component of the centrifugal force. The factor $2/3$ follows from the geometry of a dipole field. The remaining third of the gravitational force is balanced by electromagnetic forces. This state of equilibrium with respect to forces parallel to the magnetic field is called partial corotation.

If the electromagnetic forces in partial corotation are cancelled instantaneously (e.g. by recombination for the case of ions), the centrifugal force cannot keep equilibrium with gravitation. The result is that the matter in the considered plasma element starts to move in an ellipse with an eccentricity $e = 1/3$ and a semi-major axis $a = 3/4 a_0$, where a_0 is the central distance of the place of recombination. The ellipses will intersect the equatorial plane at $a_p = 2a_0/3$. Collisions between the grains and/or with a thin layer of dust which rapidly will be formed in the equatorial plane, will circularize the orbits of the grains by inelastic collisions, so that they all will move in circles at $r = a_0$, with $\Gamma = 2/3$.

Hence circularization of the orbits will lead to a contraction of the plasma by a factor $\Gamma = 2/3$ at the transition to neutral matter.

3. PREDICTIONS OF THE THEORY

According to this model, the matter which today exists at a given central distance a_1 in the Saturnian ringlet system once was in the form of a partially corotating plasma at a distance approximately $3a_1/2$. During the formation of the ring system, the matter in the plasma phase would continually be swept up at

positions where rings and satellites are under formation, with the following two important consequences:

(1) Since a partially corotating plasma moves with a velocity below the Kepler velocity, the angular velocity of the sweeping-up matter is reduced. It is therefore displaced towards the central body (in our case Saturn). This effect has been estimated to reduce the final fall-down factor by a few percent from the value $\Gamma = 2/3$.

(2) There should be some kind of anticorrelation between the present-day density at any central distance a_0 and the density at the distance Γa_0 , in the form of "shadows" and "antishadows" as described below.

3.1 Cosmogonic shadows

If a satellite (or an embryo of a satellite, or a jet stream accreting to a satellite) is located at a central distance a_0 , it will deplete the plasma in a magnetic flux tube with the L-value a_0 . This is a phenomenon which is well known from spacecraft measurements of the Jovian and Saturnian magnetospheres. After the PPT this depleted region will be found at Γa_0 and there produce an empty region in the equatorial disc. We call this depleted region the cosmogonic shadow of the satellite. Also the mini-satellites of which the Saturnian rings consist will produce such shadows. Hence any ring or ringlet will also produce its own shadow.

3.2 Cosmogonic antishadows

In a similar way, the gaps in the ring system, e.g. the Encke division at $R/R_S = 2.21$ (see Figure 6), should correspond to regions where plasma is not swept out. The fall-down of this plasma with a factor Γ should give rise to rings in an otherwise empty region; we call such rings cosmogonic antishadows.

4. THE BULK STRUCTURE OF THE SATURNIAN RING SYSTEM

The Saturnian ring system, with the inner satellites, is schematically illustrated in Fig. 1. The "first order" theory, as outlined above, gives a good explanation of the bulk structure. This is illustrated in Fig. 2, in which the density of the rings (actual opacity) is plotted. At the top of the figure the inner satellites are represented but with their Saturnocentric distances reduced by a factor $\Gamma = 0.64$. It is obvious that the Cassini division can be interpreted as the cosmogonic shadow of Mimas, the Holberg minimum at $R/R_S = 1.6$ as the cosmogonic shadow of Janus (with Epimetheus) and the rapid fall in intensity at the border between the B and the C ring as the combined effect of the Shepherds and the A ring. Furthermore, the inner edge of the C ring corresponds to the shadow of the rapid rise in density between Cassini and the B ring. Gravitational disturbances from the satellites produce resonances which are clearly visible (see Holberg, 1982), but small compared to cosmogonic shadow effects.

5. THE FINE STRUCTURE OF THE SATURNIAN RING SYSTEM

For a study of the fine structure of the rings, we have used UVS ring occultation data supplied on magnetic tape by J.B. Holberg, University of Southern California. The Holberg data seem to agree with the curves of Esposito et al (1983).

The figures represent plots of the normal optical depth τ versus the radial distance from Saturn.

Some figures contain averaged data, where the averaging has been done in the following way:

$$\tau_{\text{aver}} = \alpha \ln \frac{1}{n} \sum_{i=1}^n w_i \exp(\tau_i / \alpha)$$

where $\alpha = -0.4803$ and w_i is a weighting factor. This weighting factor is computed to weight the points according to a Gaussian

distribution around the central point $i = (n+1)/2$. The width of the Gaussian is such that \pm one standard deviation, $\pm 1 \sigma$, corresponds to the radial averaging distance given in each figure. Points beyond $\pm 3 \sigma$ are discarded. The average is a running average, i.e. there are as many data points in the averaged data sets as in the original data set.

5.1 Effect of density gradients

The fine structures we will discuss here are the shadows of satellites and the antishadows from holes in the ring system. In the plasmaphase, each such structure is bordered by density gradients, transverse to the magnetic field. Such gradients are generally associated with electric fields. Both the pressure term ($\text{grad } p$) and the electric fields would influence the force balance in the partial corotation. This would in turn change the fall-down ratio Γ from the value $\Gamma = 2/3$ obtained from the original theory, which neglected density gradients.

Since a theory for the effect of these density gradients is not yet developed in detail, we will here analyze the observational material from the simple assumption that the regions with inwards and outwards directed density gradients influence the fall-down factor in opposite senses. In each structure in the plasma phase - either a gap swept out by a satellite, or a ring of plasma left by a hole in the ring system - there will be one region where the density gradient is directed inwards, and one where it is directed outwards. Every shadow and antishadow should therefore be expected to split up into some approximately symmetric structure, the shadow profile, around the central Γ value expected in the absence of gradients.

In our analysis of the observational material, we will therefore search for such symmetric structures at the location where we expect shadows and antishadows to fall. This will serve both our purposes with this paper: the aspect of test of the theory lies in the existence of symmetric structures at the expected

locations, while the aspect of development lies in the identification of the shape of the shadows and antishadow profiles, which should be explained by a further development of the theory.

5.2. Cassinis division and Holbergs minimum

Cassinis division and Holbergs minimum have earlier been proposed to be the shadows of Mimas and Janus (Alfvén, 1983). They are shown in Figures 3 and 4. It is true that there are considerable differences between them, but this is not unexpected because the shadow-producing objects are different; the volume ratio of Mimas/Janus (with Ephimetheus) is about 50 and the latter is a double satellite. The Holberg minimum is broader than Cassini, which may have some connection with this. Further, in the B ring there is obviously a population superimposed on the population we study. This is shown by the fact that the density in the Holberg minimum never approaches zero as it does in the Cassini. This unknown population in the B ring -- let us call it the X population -- may also be the reason why the B ring is much more erratic than the A ring.

However, the main impression is the mutual similarity. In both cases there is a central double peak. In Cassini the outer peak is broader, but the inner one is higher, while in Holberg the situation is reversed. The peaks are in both cases surrounded by voids, which are rather symmetric in Holberg while in Cassini the outer one is somewhat narrower.

In our first approximation we disregard these rather small differences. Hence both Cassinis division and the Holberg minimum can approximately be represented by the same symmetric structure:

1. Two peaks, centered around $\Gamma = 0.64$, with a separation $D = \pm 0.008 R/R_S$ from the central position.
2. Surrounding voids, with a width $W = 0.03 R/R_S$ in both directions from the central position. We will call these the inner and outer voids.

This means that the effect of density gradients change the simple shadow to a triple shadow. This can also be expressed by saying that in the center of a broad minimum there are two ringlets left. Indeed, one of the most astonishing discoveries of the Voyager mission was that in the middle of the Cassini division there was a double ringlet. Holberg pointed out that in the minimum at $R/R_S = 1.6$ there is a similar double ringlet, a remark which was of decisive importance for the development of the cosmogonic theory.

5.3 The C ring

Contrary to the A and B ring, the C ring consists of a number of isolated ringlets separated by low-density regions or voids. It is obvious that at least the outermost and innermost parts of it are very far from homogeneous disks.

The outer part of the C ring (outside $R/R_S = 1.40$) is the most complicated region of the ring system. There are sharp gravitational resonance peaks identified by Holberg, and two other peaks, at $R/R_S = 1.311$ and 1.658 , which, to judge from their appearance, are probably due to resonances. Further, there is a remarkable eccentric ring at 1.45 , which has been studied in detail by Esposito et al (1983), but has not been identified. Moreover, there are a large number of well-defined maxima, which clearly differ from the resonance peaks; they have flat tops and constitute rectangles with steep sides.

We will now investigate to what extent the shadow profile we found for Cassini's division and Holberg's minimum can explain also the details in the C ring.

5.4 The shadows of the Shepherds

Fig. 5 is the basis for the discussion in sections 5.4 to 5.6. Both the upper and the lower curves show the present-day Saturnian ring system. The upper curve is reversed, and the scale is reduced by a factor 0.64 for convenient identification of shadows and antishadows. The rings which have been identified as resonances by Holberg et al (1982) are marked by R's.

The main impression of the C ring is the absence of matter; this can be understood basically as the shadow of the A ring. However, this shadow would extend only out to $R/R_S = 1.45$, while the inner edge of the B ring is located at $R/R_S = 1.52$. Between these values we expect the shadows of the Shepherd satellites to fall.

From the shape of Cassini's division and Holberg's minimum, we expect the outer Shepherd (Shepherd II) to produce a double ring, at the outside of which there is a void region. It seems reasonable to identify the double ring with the maxima M and N (at $R/R_S = 1.488$ and $R/R_S = 1.499$) and the outer void with the low density region $R/R_S = 1.50-1.52$. This structure is similar to the transition from the Cassini division to the A ring. In fact, this similarity was discovered by Holberg, who pointed it out during a seminar discussion. Numerical values for this shadow are $\Gamma = 0.636$, peak separation $D = \pm 0.006 R/R_S$, and outer void width $W = 0.03 R/R_S$.

The inner void of Shepherd II is superimposed on the shadow of Shepherd I. This satellite produces a similar double ring (peaks K and L in Fig. 5, at $R/R_S = 1.465$ and $R/R_S = 1.477$). Numerical values for this shadow are $\Gamma = 0.637$ and $D = \pm 0.006 R/R_S$. The outer void of Shepherd I is overlapped by the Shepherd II shadow; the low density region between $R/R_S = 1.427$ and

$R/R_S = 1.488$ may therefore be considered as a combination of the inner void of Shepherd II and the outer void of Shepherd I. In a similar way the inner void of Shepherd I should be the empty region $R/R_S = 1.449-1.465$, which extends in to the outer edge of the expected shadow of the A ring.

Close to the shadows of the Shepherds are also two resonances, which we disregard here. The satellite Atlas (at $R/R_S = 2.276$) with a volume of only a few percent of the Shepherds is considered to be too small to be included. It may contribute to making K different from L.

5.5. Shadows of the A ring (inside $R/R_S = 1.45$): Antishadows

The A ring is dense enough to give a shadow inside $R/R_S = 1.45$ which makes the density of the C ring in the shadow region close to zero. However, there are "holes" in the A ring, which should give rise to antishadows. The extremely void Encke division (at $R/R_S = 2.214$) is one of the outermost (compare Fig. 6). Inside $R/R_S = 1.40$ the density curve in the C ring is very smooth (except for gravitational resonance peaks), which it should be since the A ring, which casts its shadow here, has no "hole" inside the Encke division. The density has an almost constant low value. The reason why it is not exactly zero may be that the A ring during the early stages of ring formation was somewhat "leaky". When we reach the Cassini division we note that there are two regions where the density is close to zero, viz., at $R/R_S = 1.953$ (which is named the Maxwell gap) and at $R/R_S = 1.980$. Following the arguments in these notes we should expect these minima, and Enckes division, to produce antishadows in the C ring.

The main difference between shadows and antishadows is that the density gradients (in the plasma phase) are directed outwards (away from the hole swept out by the satellite) in the former case, and inwards in the second. From this we may guess that holes may also produce doublets so that we obtain a double

ringlet for each hole.

The three expected antishadows, from the Encke division and the two minima in the Cassini division, are all easily found, as illustrated in Fig. 5. The double rings are all remarkably symmetrical and also centered very well around $\Gamma = 0.64$. No expected ring is missing. Numerical values of the Γ values and the rings separations are given in Table I.

Close to the antishadow peaks D and G from the Encke division lie four small peaks (E, F, H and I in Fig. 5). If these are antishadow doublets, one should expect the same ring separation D as in the neighbouring Encke antishadow. This means that E and H would be the antishadow of one gap, and F and I the antishadow of another. These gaps would have to lie in the outer A ring, between the Encke division and the Roche limit. Figure 6 shows the details of this region; indeed, there are two places where the density does go down to zero, viz in the Keeler division at $R/R_S = 2.26$ and in a "leaky region" around $R/R_S = 2.24$ where some readings go down to close to zero. It is possible that these minima were more pronounced in the early stages of the formation of the Saturnian rings, and that the four peaks are antishadows from that period.

5.6. Peak at $R/R_S = 1.449$

Inside the region of shadows produced by the Shepherds but outside the antishadows produced by the holes in the A ring there is a very strong peak at $R/R_S = 1.449$. A detailed analysis by Esposito et al (1983) has shown that this constitutes an eccentric ringlet. Although there are other eccentric ringlets, this is unique due to its strong eccentricity. Its position does not agree with any identified resonance. If we look for a signature which might cause a cosmogonic shadow effect at this location, the only possible choice seems to be the Roche limit, which gives a Γ value of 0.640.

There is not yet any detailed theoretical motivation why the Roche limit should cause a shadow consisting of an eccentric ringlet, but a Γ value so close to the other Γ values indicates that this might be the case. (According to Holberg the fall in intensity at $R/R_S = 2.265$ may be sharpened by a resonance effect, but this does not mean that the ringlet at $R/R_S = 1.449$ is a direct resonance effect).

6. DISCUSSION

The theory for the PPT is not yet developed enough to give detailed predictions in a case like the Saturnian ring system. In order to explain the ring system, it has to be supplemented with a few ad hoc hypotheses (e.g. the reduction of Γ by a few percent from $2/3$ to 0.64 , and the splitting of the shadows and the antishadows into double rings). These hypotheses might be motivated qualitatively, but are not yet proven.

Seen as a test of the cosmogonic theory, the result of this work is therefore "semi-statistical": the number of features that are explained should in some sense be compared to the number of assumptions that are needed to explain them:

1. The sweeping-up of corotating plasma reduces the Γ value from $2/3$ to $\Gamma = 0.64$.
2. Density gradients influence the shape of shadows and the antishadows in such a way that they are split up into the structures described in section 5 (symmetric double rings, for the case of shadows surrounded by voids).
3. There is a "X population" in the B ring superimposed on the population we study here.

The most crucial test of the theory lies in the possible absence of rings. The presence of rings that are not explained by the theory is not so crucial. Such rings could either be unidentified resonances, or antishadows from gaps in the early

Saturnian ring system, which have later been filled in.

From the assumptions listed above follow definite predictions about the ring system. Taking the ring and the satellite systems as they exist today, there are four cases of expected shadows, and three (or perhaps five) of expected antishadows. The most striking feature around their expected "shadow location" at $\tau = 0.64$ is that in all seven cases we find a central void flanked by two peaks. The central position between the peaks is at $\tau = 0.64 \pm 1\%$ (in the five cases in the C ring, $\pm 0.5\%$).

The good agreement between the τ values is difficult to ascribe to arbitrary selection. Indeed, the shadows of every satellite in the relevant region are identified. Also, the antishadows of every zero value in the A ring and Cassini are identified. Further, excepting the resonance peaks identified by Holberg and the peaks at $R/R_S = 1.312$ and $R/R_S = 1.358$, which are sharp maxima similar to the resonance peaks (see especially Fig. 7), every pronounced peak in the C ring is identified with a cosmogonic effect.

The symmetry between the double peaks in the C ring is also encouraging (see Fig.5). Of the seven proposed ring pairs (A-left hump of B, right hump of B - C, D-G, E-H, F-I, K-M, L-N) all except the pair K-M are virtually identical, both in height and width. The most striking example of this is the two antishadows of the Encke division (see Fig. 8).

This agreement between theory and observation seems too remarkable to be a coincidence, particularly since the existence of a fall-down factor a few percent below $2/3$ was proposed before the detailed measurements of the Pioneer and Voyager missions were made.

Measurements in radio wavelengths at the same Voyager mission reported by Rosen 1985 also gives τ values close to 0.64 with the same accuracy as in the present work. However, there are also differences. One of the most conspicuous is the absence of the Holberg minimum in the radio data.

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8 FIGURE CAPTIONS

- Fig.1 Saturnian rings and the innermost satellites.
- Fig.2 Voyager measurements of opacity plotted as a function of the saturnocentric distance. At the top: the innermost Saturnian satellites and the A ring with saturnocentric distance scaled down by a factor $\Gamma = 0.64$.
- Fig.3 The opacity of the A ring and Cassini's division. Five point average.
- Fig.4 The opacity of the B ring with Holberg's minimum. Five point average.
- Fig.5 The opacity of the C ring and the inner part of the B ring. Five point average.
- Fig.6 Outermost part of the A ring in high resolution. It shows the Roche limit at 1.212, and the dramatically sharp Encke division. Further there is the Kieler gap at 2.260 where the density also goes down to zero, although it is much thinner than Encke.
Between the two gaps there is a region around 2.24 where the density at some points goes down to very low values (although never to zero). This region may be "leaky", so that plasma from it may fall down.
- Fig.7 The innermost part of the C ring in high resolution. Note that the unidentified peak at 1.31 is similar to the identified resonances.
- Fig.8 The Encke division (upside down and scaled down by $\Gamma = 0.64$) compared with the two peaks (D and G) in its antishadow. These two peaks are remarkably similar, and their breadth is similar to the projected Encke division.

TABLE 1

Formation of planets/satellites from interstellar clouds (compare Alfvén 1984)

State of matter which is located at present in planets/satellites	Evolutionary process	Main evolutionary mechanism
Dusty plasma	Evolution of interstellar cloud formation of Sun and solar nebula	Gravitation Pinch effect
	Evolution of solar nebula	Critical velocity Electro-magnetic transfer of angular momentum
	Plasma-planetesimal transition	2/3 contraction cosmogonic shadow effect
Planetesimals	Accretion of planetesimals to planets	Mechanical effects but plasma processes not un- important
Planets Satellites	Formation of satellites around planets occurs by a repetition in miniature of these processes (starting with formation of nebula around planet)	

TABLE II. COSMOGONIC SHADOWS AND ANTISHADOWS

Peak separations and saturnocentric distances in units R/R_S

STRUCTURE (ANTISHADOW DOUBLETS OR SHADOW CENTRAL PEAKS)	PEAK SEPARATION 2 D	CAUSE (GAPS OR SATELLITES)	Γ VALUE
A 1.240 B 1.262	0.022	Maxwell Gap 1.953	0.640
B 1.262 C 1.276	0.014	Zero point in Cassini 1.980	0.641
D 1.405 G 1.432	0.027	Encke 2.214	0.641
E 1.419 H 1.443	0.024	Leaky Region 2.240	0.639
F 1.423 I 1.445	0.022	Keeler 2.262	0.634
Excentric ringlet J 1.449		Roche 2.265	0.640
K 1.465 L 1.477	0.012	Shepherd I 2.310	0.637
M 1.488 N 1.499	0.011	Shepherd II 2.349	0.636

SATURN WITH MASSIVE RINGS AND INNERMOST SATELLITES.

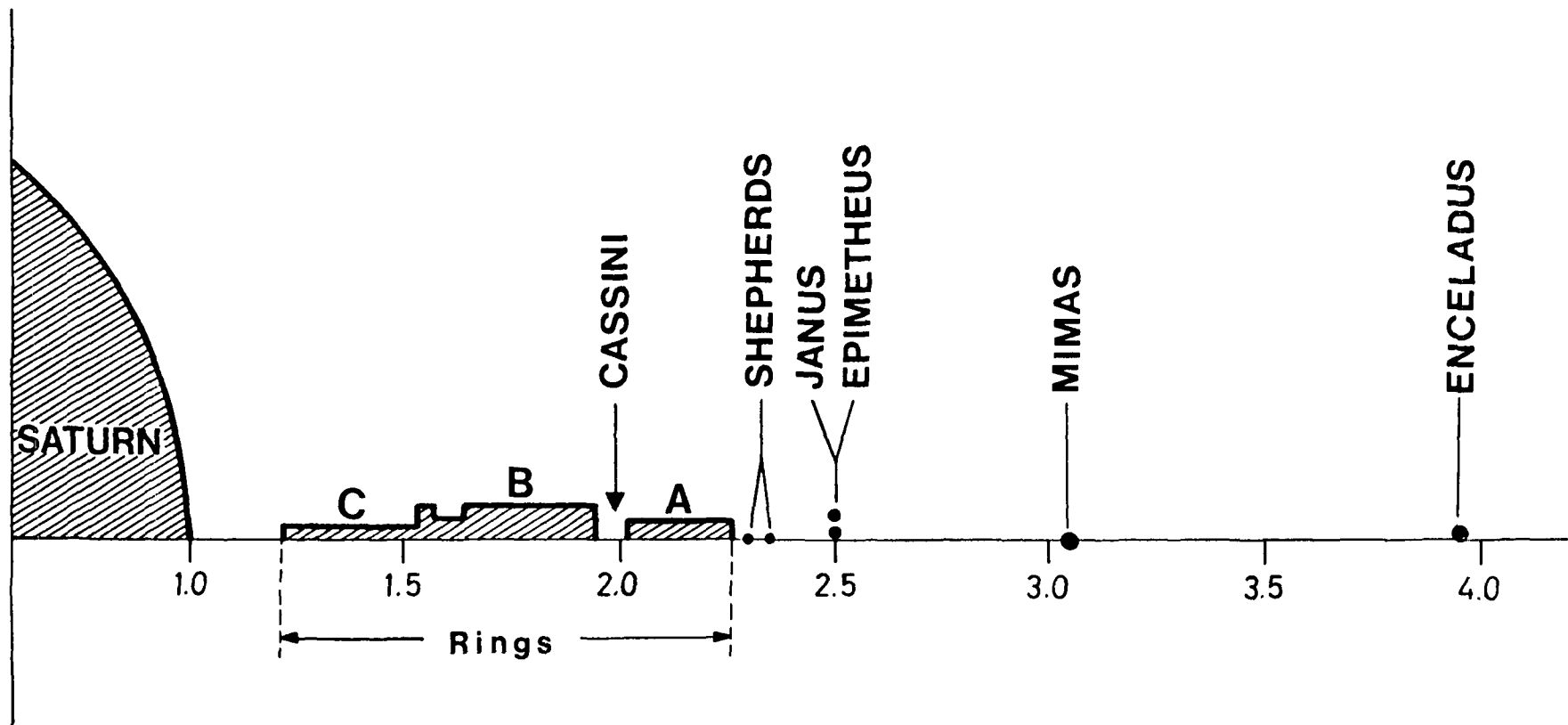


Fig.1 Saturnian rings and the innermost satellites.

VOYAGER 2 UVS - SATURNIAN RING OCCULTATION

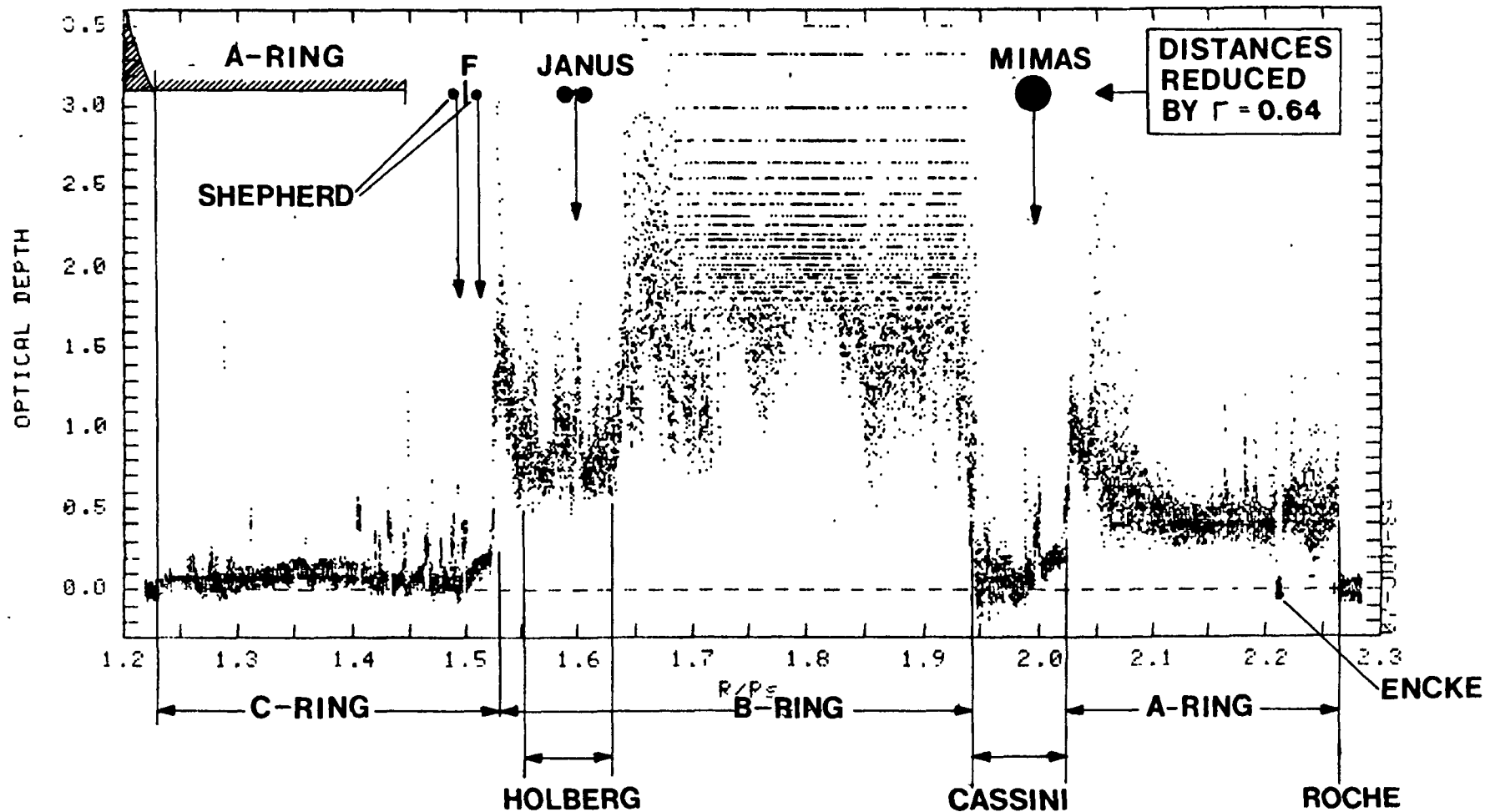


Fig.2 Voyager measurements of opacity plotted as a function of the saturnocentric distance. At the top: the innermost Saturnian satellites and the A ring with saturnocentric distance scaled down by a factor $\Gamma = 0.64$.

CASSINI A-RING

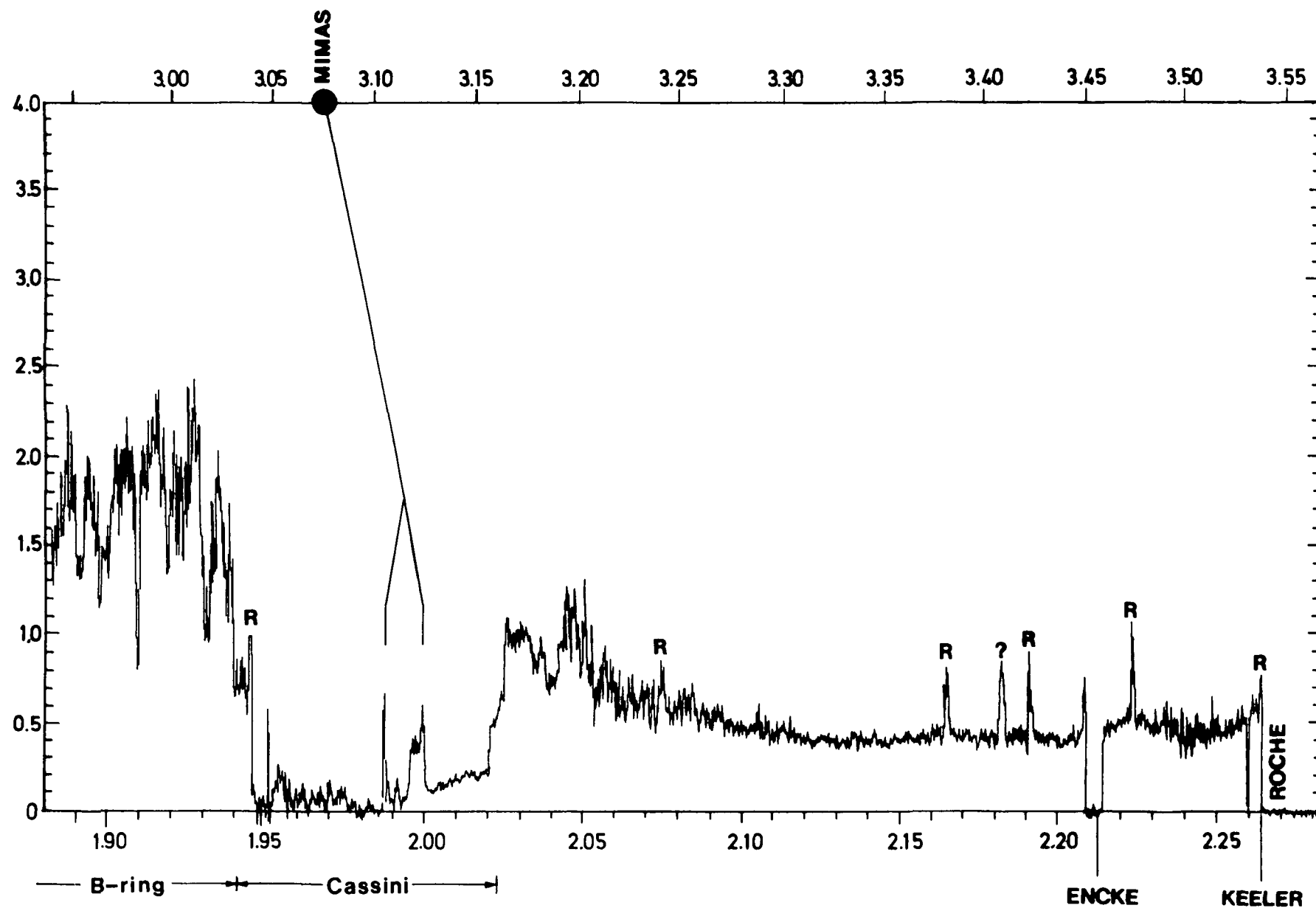


Fig.3 The opacity of the A ring and Cassini's division. Five point average.

B-RING

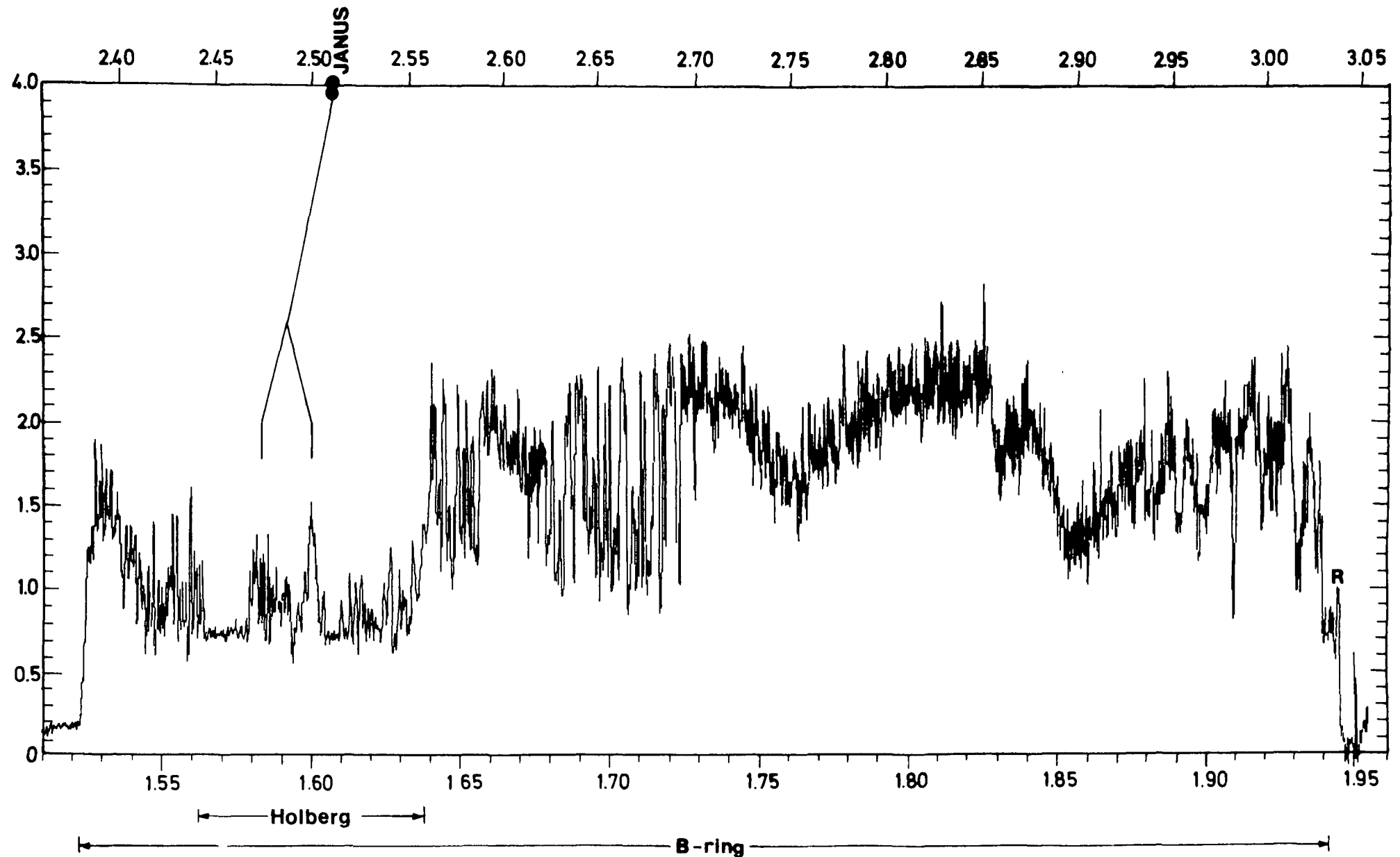
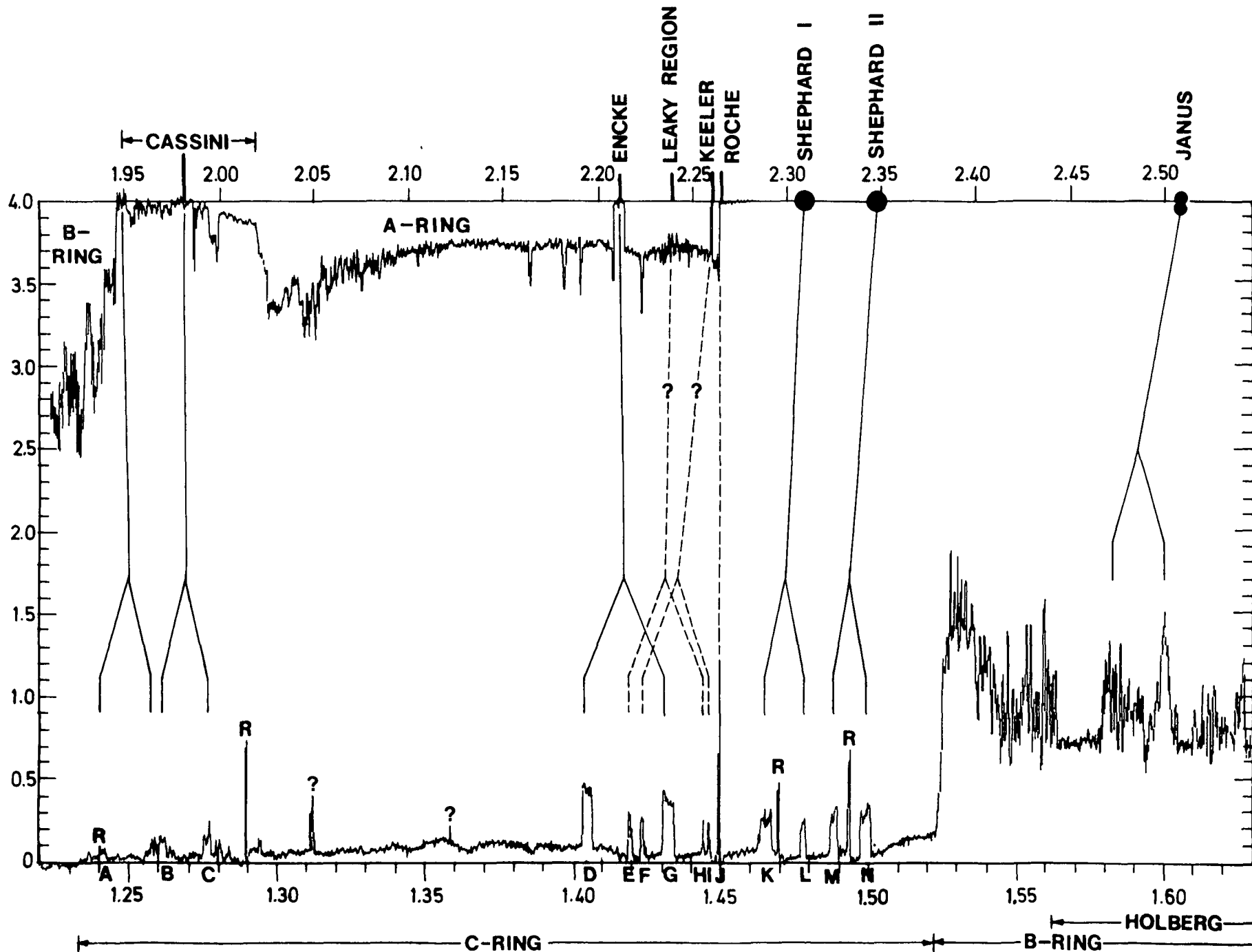


Fig.4 The opacity of the B ring with Holberg's minimum. Five point average.

C-RING

Fig.5 The opacity of the C ring and the inner part of the B ring. Five point average.



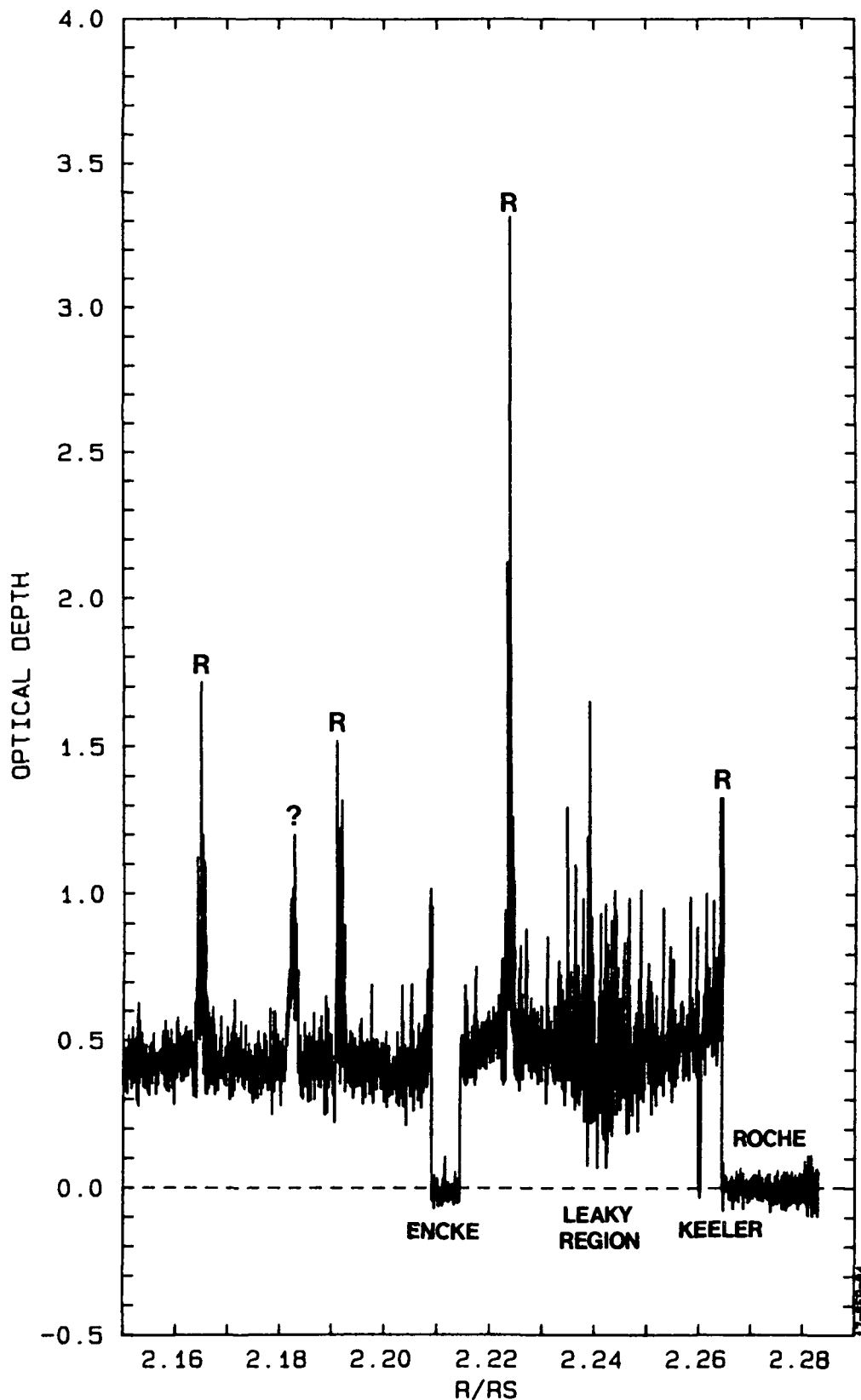


Fig.6 Outermost part of the A ring in high resolution. It shows the Roche limit at 1.212, and the dramatically sharp Encke division. Further there is the Kieler gap at 2.260 where the density also goes down to zero, although it is much thinner than Encke.

Between the two gaps there is a region around 2.24 where the density at some points goes down to very low values (although never to zero). This region may be "leaky", so that plasma from it may fall down.

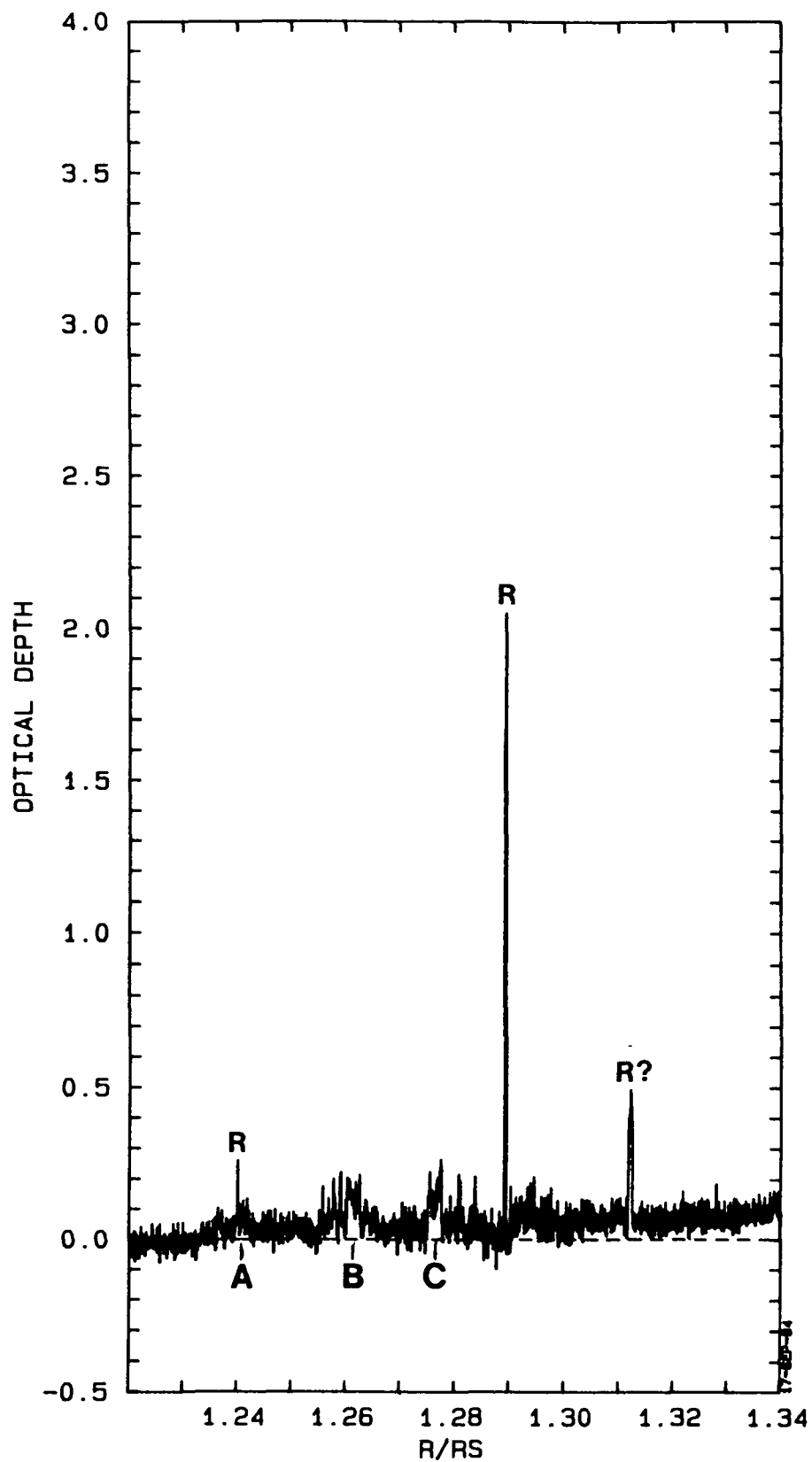


Fig.7 The innermost part of the C ring in high resolution. Note that the unidentified peak at 1.31 is similar to the identified resonances.

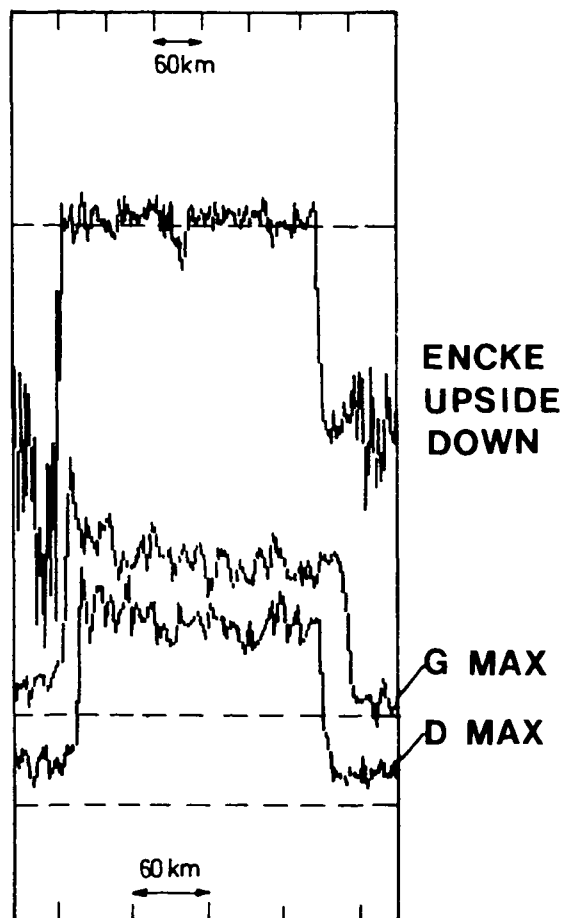


Fig.8 The Encke division (upside down and scaled down by $\Gamma = 0.64$) compared with the two peaks (D and G) in its antishadow. These two peaks are remarkably similar, and their breadth is similar to the projected Encke division.

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VOYAGER SATURNIAN RING MEASUREMENTS AND THE EARLY HISTORY OF THE
SOLAR SYSTEM

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The mass distribution in the Saturnian ring system is investigated and compared with predictions from the plasma cosmogony. According to this theory, the matter in the rings has once been in the form of a magnetized plasma, in which the gravitation is balanced partly by the centrifugal force and partly by the electromagnetic forces. As the plasma is neutralized, the electromagnetic forces disappear and the matter can be shown to fall in to $2/3$ of the original saturnocentric distance. This causes the so called "cosmogonic shadow effect", which has been demonstrated earlier for the astroidal belt and in the large scale structure of the Saturnian ring system.

The relevance of the comogonic shadow effect is investigated for parts of the fine structures of the Saturnian ring system. It is shown that many structures of the present ring system can be understood as shadows and antishadows of cosmogonic origin. These appear in the form of double rings centered around a position a factor 0.64 (slightly less than $2/3$) closer to Saturn than the causing feature. Voyager data agree with an accuracy better than 1%.

Key words: Cosmogony, Magnetospheres, Planetesimals, Saturnian rings, Solar system history.