A STUDY OF THE OUTERMOST RING OF SATURN

M. S. BOBROV

Astronomical Council of the U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.

Abstract. The attention is called to the fact that the discovery by Feibelman (1967) of the rarefied outer ring of Saturn is confirmed by the observations of Kuiper (1972). It is proposed to designate this object as E-ring (exterior) in order to avoid confusion with the innermost, also rarefied, D-ring observed by Guérin (1970) and earlier by Barabashov and Semejkin (1933). The effects of the interaction of E-ring with inner Saturn's satellites are briefly discussed. The conclusion is drawn that in cosmogonic time scale these effects are small. It is also shown that the optical thickness of E-ring is lower than 1/20000; the available photometric estimations of the geometric thickness of A- and B-rings need not be corrected for the light scattering and absorption by E-ring.

1. The Existence of the Ring

Now it appears unquestionable that outside the well-known ring system of Saturn there is one more ring, broader than others but extremely rarefied. It is very faint and may be detected only near the edgewise position of the ring system.

I should like to remind that the first photographs showing this object were taken by Feibelman (1967). Figure 1 displays his drawing from the negative taken on November 14, 1966, and the microdensitometer trace along the path crossing the new ring.

For several years Feibelman's result was not confirmed by any other observer. Recently Kuiper (1972) reported that he has also found the outermost ring of Saturn

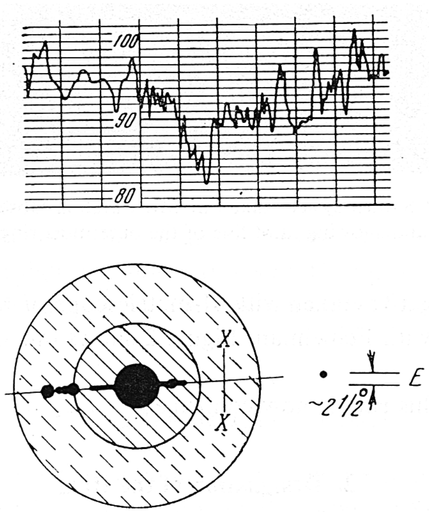

Fig. 1. Below: Aspect of Saturn, 14 November, 1966. Top: Microdensitometer trace along path $X-X$. The central dip corresponds to the location of the visible thin line of the outermost ring (Feibelman, 1967).

Woszczyk and Iwaniszewska (eds.), Exploration of the Planetary System, 465–470.

https://doi.org/10.1017/S0074180900025705 Published online by Cambridge University Press

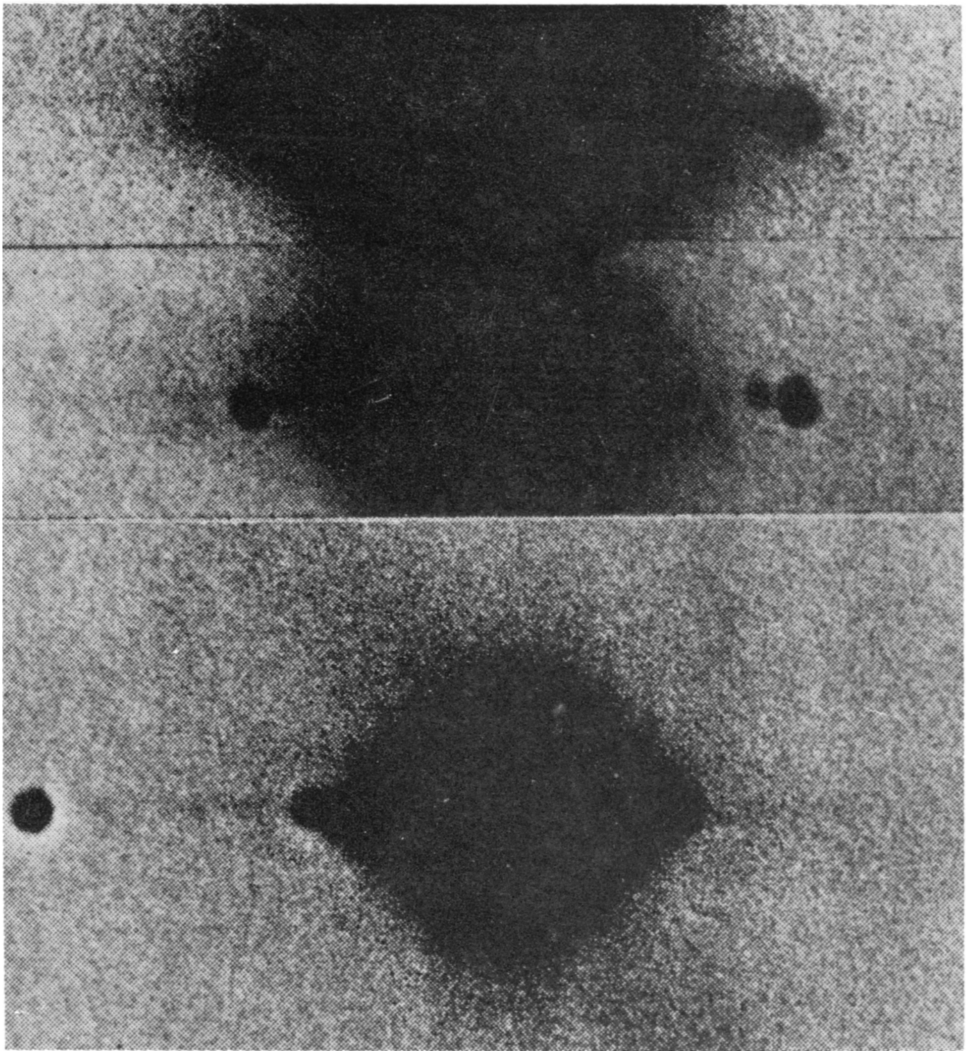

Fig. 2. Some negatives of Saturn system taken at Mt. Catalina Observatory in December 1966 – January 1967 and showing faint line of the outermost ring (Kuiper, 1972).

when examining his negatives taken with 61-in. telescope of Mt Catalina Observatory nearly simultaneously with Feibelman. Figure 2 shows one of the negatives taken by Kuiper.

So the existence of this ring is now confirmed.

2. Designation of the Ring

In old literature and in Feibelman's paper it is called D-ring. Some years later Guérin (1970) reported on the discovery of another ring of Saturn, inside of the known ring system, and called it also 'ring D'. Since that time the majority of authors designate Feibelman's ring as 'D′-ring'.

This is not convenient and may lead to misunderstanding. Possibly it would be more reasonable to keep the designation 'D' for the innermost ring, as the ring immediately following A-, B- and C-rings, and for the outermost ring to introduce the new designation 'E-ring' (exterior).

Moreover, D-ring cannot be considered as a new object. About forty years ago Barabashov and Semejkin (1933) revealed the presence of fine rarefied matter in space between C-ring and Saturn's ball. Figure 3 displays the photometric cross-section

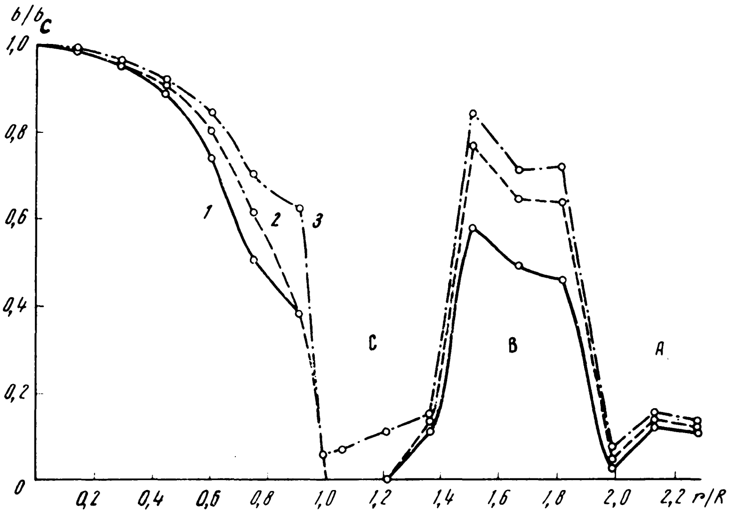

Fig. 3. Photometric cross-section through the disk and rings of Saturn along the major axis of the rings; r – the distance from the center of the system, R – radius of Saturn's disk, b – brightness in a given point of cross-section, b_c – brightness in the center of the disk. Curves 1, 2, 3 correspond to the data obtained with red, yellow, and blue filters, respectively. Blue curve shows the presence of rarefied matter between C-ring and limb of the planet. All data are corrected for seeing and diffraction effects using the method of artificial planet (Barabashev and Semejkin, 1933).

through the rings and disc of Saturn according to observations of these authors. It may be seen that in blue light the intensity inside C-ring is not zero. This fact was formulated by the quoted authors as "the continuation of the ring system down to Saturn's atmosphere."

3. E-Ring and Saturn's Satellites

E-ring is so wide that the orbits of some inner satellites of Saturn lie inside it. According to Feibelman, E-ring spreads out to the orbit of Enceladus, according to Kuiper – even to Dione. An interesting problem is arising from the effects due to interaction of the ring matter with the satellites.

Evidently the interaction must lead to secular diminution of the excentricities and inclinations of the satellites' orbits. But actually Mimas and Tethys have inclinations 1°.5 and 1°.1, respectively; Mimas has also noticeable eccentricity (0.02). These facts indicate that even in cosmogonical time scale the interaction effects are small.

4. E-Ring and Photometric Estimations of the Ring System Thickness

Due to observations of Focas and Dollfus (1969) and Kiladze (1969) we have now for the first time photometric estimations of physical thickness Z_0 of Saturn's rings (1–3 km). The estimations are based on measurements of light flux Φ per unit length of the image of nearly edgewise rings.

In Figure 4 the observed values of Φ are plotted as a function of Earth's elevation angle B above the ring plane. One may see practically linear course for both branches of photometric curve (for bright and dark sides of the rings, respectively). This is consistent with the simple ring model – a plane-parallel homogeneous sheet of diffusely reflecting particles (for details see Bobrov, 1972).

But using the plane-parallel model we neglect the fact that the bright rings are surrounded by ring E. Let us show that such neglection does not introduce significant errors into photometric estimations of physical thickness of the bright rings.

The observations of E-ring in 1966 were carried out during the period of very small B when the rings' structure along the normal to their major axis could not be resolved by telescope, i.e. the rings were the linear light source. For such source a good photometric characteristic is the above-mentioned magnitude Φ – the light flux per unit length (in the case under consideration Φ is a function of the distance of a given photometric cross-section from the center of Saturn's disk). All the observations show that for sections crossing only E-ring the values of Φ are much lower than for sections crossing both E- and A-ring:

$$\Phi_E \ll \Phi_{AE}. \tag{1}$$

This result follows from the examination of Figure 1 and 2 ,as well as from the fact that Focas and Dollfus (1969) and Kiladze (1969) did not obtain the image of E-ring even at extremely small values of B. In particular, on December 17, 1966, only a few hours before the ring-plane crossing by the Earth, no trace of E-ring was detected. The ratio of light fluxes from the dark side of B-, A- and E-rings and from the edge of A-ring was

$$\Phi_{\text{dark BAE}}/\Phi_{\text{edge A}} = 13/87 \tag{2}$$

(Bobrov, 1970). Hence taking into account that Equation (1) is also valid for the periods of dark side visibility, and that

$$\Phi_{\text{dark AE}} \approx \Phi_{\text{dark BAE}} \tag{3}$$

we may write

$$\Phi_{\text{dark E}} \ll \Phi_{\text{edge A}}. \tag{4}$$

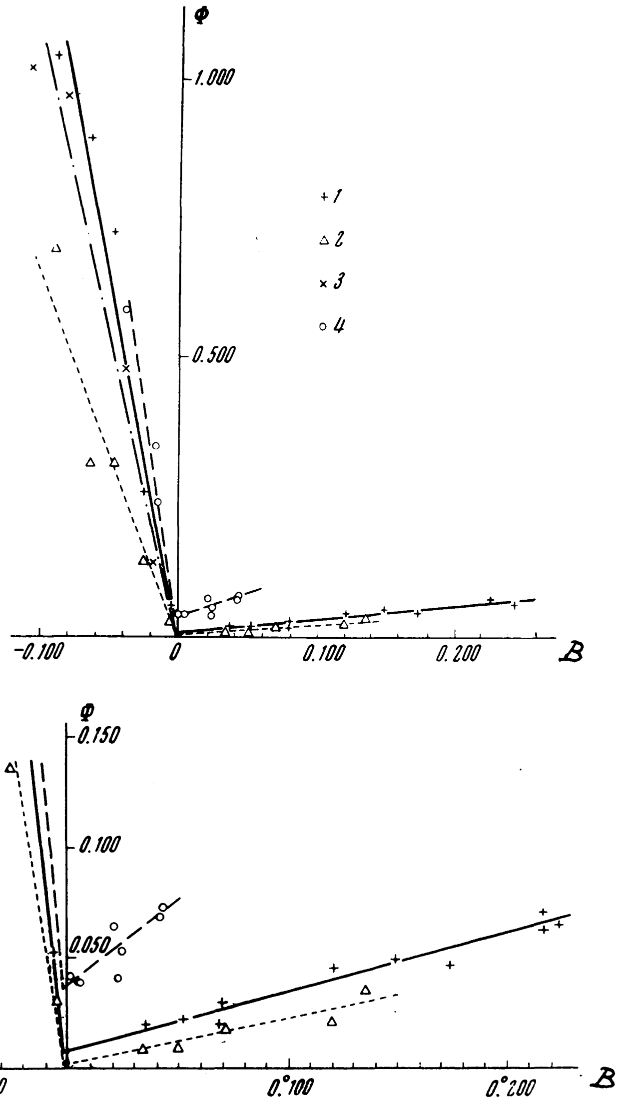

Fig. 4. Light flux Φ, per unit length of the rings, plotted as a function of the elevation angle B of the Earth above the ring plane. Data of observations near the moments $B = 0$. 1 and 2 – October–November, 1966, blue and red light, respectively (Kiladze, 1969); 3 – December 1966, blue light (*ibid.*), 4 – December, 1966, yellow light (Focas and Dollfus, 1969). Within the accuracy of measurements the course of Φ (B) is linear.

Since the Z_0 estimation was, in the end, based on the measured values of $\Phi_{\text{edge A}}$, Equation (4) means that the influence of the light flux from E-ring on the ring thickness estimation was small.

E-ring may also cause another effect: absorption of the light of the bright rings. In assumption that B-, A- and E-rings have equal or comparable physical thickness, there will be absorption of the light falling on the edge of A-ring and being reflected by this edge to the Earth. If the thickness of E-ring is much greater than that of the bright rings there is also absorption of the light from the northern or southern side of the bright rings. However, the observations made in 1966 did not reveal such effects. Indeed, the linear course of $\Phi(B)$ in cross-sections 0.66 R_A and 0.85 R_A (where R_A is the outer radius of A-ring) took place down to very small B (see Figure 4). In particular, Focas and Dollfus (1969) observed down to $B_{min}=0\overset{\circ}{.}003$; the path of the light ray inside E-ring in that moment was Z_0 cosec $10\overset{''}{.}8=2\times10^4 Z_0$, but it did not cause any appreciable absorption.

Furthermore these data permit to estimate the upper limit of the E-ring optical thickness, τ_{OE}. As it follows from the absence of absorption, τ_{OE} cosec $B_{min}<1$. Substituting the numerical data, we obtain

$$\tau_{OE} < \frac{1}{20000}. \tag{5}$$

Thus the optical thickness of E-ring is extremely small.

The final conclusion is that within the accuracy of 1966 photometric measurements the influence of the reflecting and absorbing properties of E-ring on the estimations of rings' physical thickness is negligible.

References

Barabashov, N. P. and Semejkin, B. E.: 1933, *Astron. Zh.* **10**, 381.
Bobrov, M. S.: 1970, in A. Dollfus (ed.), *Surfaces and Interiors of Planets and Satellites*, Section 7, Academic Press, London, p. 429
Bobrov, M. S.: 1972, *Astron. Zh.* **49**, 424.
Feibelman, W. A.: 1967, *Nature* **214**, 793.
Focas, J. H. and Dollfus, A.: 1969, *Astron. Astrophys.* **2**, 251.
Guérin, P.: 1970, *Sky Telesc.* **40**, 88.
Kiladze, R. I.: 1969, *Abastumansk. Obs. Bull.*, No. 37.
Kuiper, G. P.: 1972, AAS Meeting, invited paper on 'Origin of the Solar System'.