A 1972 PREDICTION OF URANIAN RINGS BASED ON THE ALFVÉN CRITICAL VELOCITY EFFECT*†

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(Received 15 August, 1977)

Abstract. It is speculated from an empirical point of view that there may be yet unobserved matter around the planet Uranus inside the orbit of Miranda. Such matter, if any, is likely to be emplaced in the form of rings.

A recent paper by Alfvén and Arrhenius (1972) has drawn attention to the fact that the Moon may not have been Earth's original satellite, but a captured planet. The Earth may have had its own satellites which were 'swept up' by the Moon during the process of capture. The existence of such satellites may be conjectured on the basis of Figure 1, which shows the quantity M_c/R_{orb} (M_c = mass of the central body, R_{orb} = orbital radius of the secondary body) for the secondary bodies (planets around the Sun or satellites around the planet) in the solar system plotted as a function of M_c. The figure shows that all the secondary bodies are formed in three bands. Whenever a band is located sufficiently above the surface of the central body, the formation of secondary bodies takes place by the accretion of swarms of small grains that encircle the central body and act as the precursors of the secondary bodies. The physical basis of this diagram has been discussed in the above reference. We shall discuss below the specific case of formation of secondary bodies around planets.

In the region close to the planet, the small grains cannot coalesce together to form larger bodies (satellites) because of the disruptive tidal forces due to the planet. There may instead be the formation of rings in this region. This region extends to a distance R from the planet, called the Roche limit, and is given by

$$\frac{R}{R_p} = 2.44\left(\frac{\varrho_p}{\varrho}\right)^{1/3},$$

where R_p is the radius of the planet and ϱ_p and ϱ are the average density of the planet and the density of the grains respectively. If for ϱ we use the average density of the

* In December, 1972, this paper – exactly as it is presented here, but with the title 'On the Possibility of Existence of a Ring of Uranus' – was submitted to another scientific journal in the relevant field and was rejected. After the discovery of the Uranian rings, the same journal was requested to reopen the question of publication. This was done, and the paper was again rejected. The author has provided *The Moon and the Planets* with proof of the original submission.

† Paper dedicated to Professor Hannes Alfvén on the occasion of his 70th birthday, 30 May 1978.

The Moon and the Planets **18** (1978) 339–342.

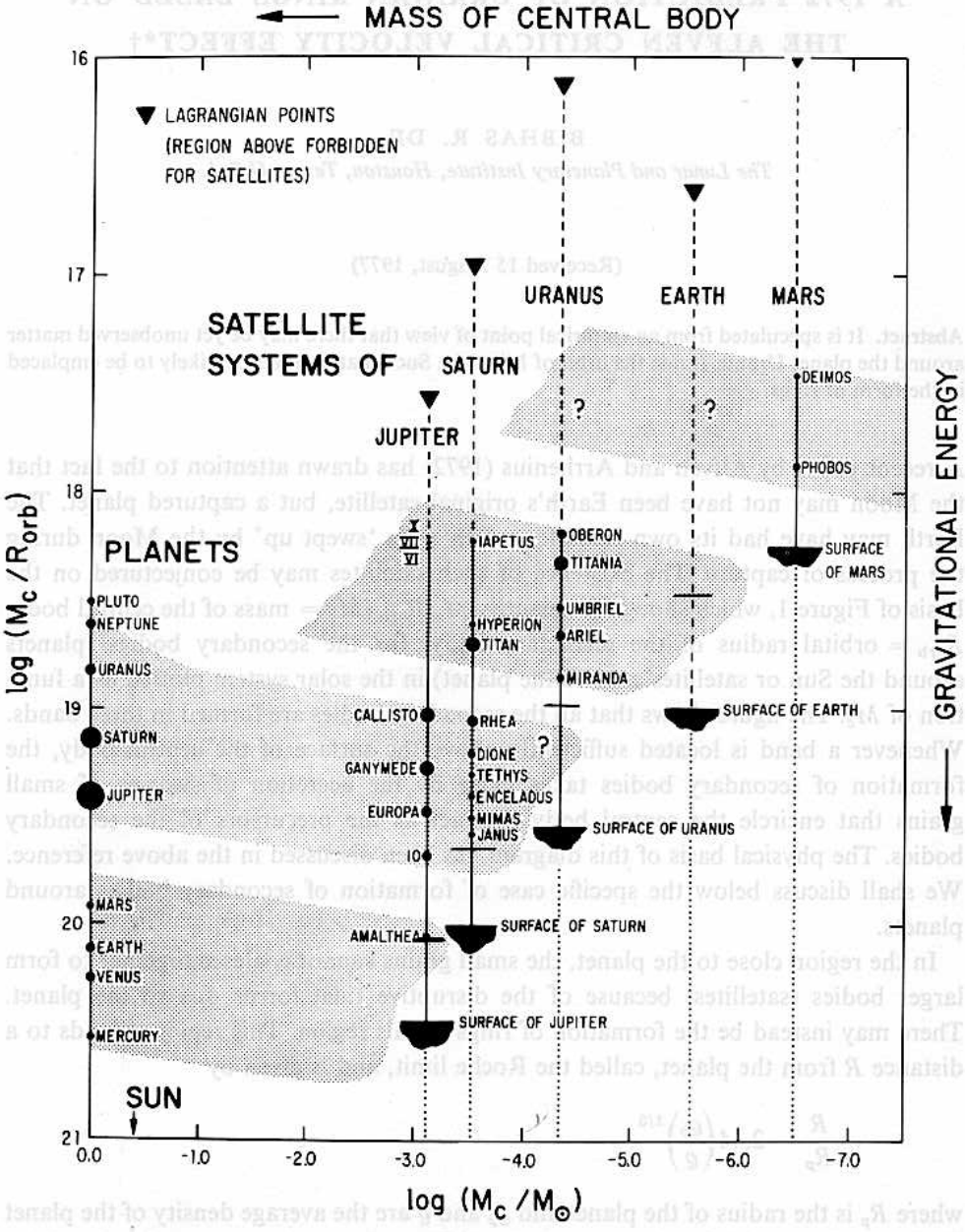

Fig. 1. Structure of planet and satellite systems in terms of gravitational energy and mass of central body. Secondary bodies are generated within three shaded bands. (It is possible that the existence of the Martian satellites indicates a fourth band.) Whenever a band is located sufficiently above the surface of the central body, formation of secondary bodies takes place. The horizontal bars represent the Roche limits in the case that the secondary bodies have the same density as the central body. Inside the Roche limit small grains cannot accumulate to form large secondary bodies because of tidal disruptive forces. Instead, the grains may form a ring system, such as the Saturnian rings (from Alfvén and Arrhenius, 1972).

planets, we can calculate the Roche limits. Even if ϱ differed from the average density of the planet by a factor of 2, the position of the Roche limit changes only by a factor 1.26 and hence our discussion is not affected very much. In Figure 1 these Roche limits are indicated by horizontal bars. We observe the following features of this diagram:

In the case of Saturn, the shaded band extends into the Roche region and we have formation of rings. The outer border of the ring system is located at about 2.3 R_{Saturn}. The possibly captured satellite of Saturn, Phoebe, at about 217 R_{Saturn} probably never came close enough to Saturn to disturb this ring system appreciably.

On the same basis it is also possible that the Earth, Jupiter and Uranus may also have formed rings in the past. But the Earth has captured the massive 'planet' Moon, which probably came close to the Roche limit (Gerstenkorn, 1969) during the process of capture. Thus the Moon is likely to have swept up all the matter in the ring, or perhaps caused some of the matter to fall down to the Earth. In the case of Jupiter, we note that the satellite Amalthea has formed just on the edge of the Roche region. This would have formed out of much of the matter that would otherwise form the ring. However, it is still possible that some particles remain in orbit around Jupiter within its Roche limit.

In the case of Uranus also, we expect a ring system on the basis of our diagram. Uranus has no captured satellites, and its satellite system shows a striking regularity – all the five satellites moving in almost circular orbits, showing that this system has not been perturbed at all by outside influences. The innermost Uranian satellite, Miranda, is far away from the Roche limit. Thus it seems that if Uranus had formed a ring system by the same general processes as Saturn, it would survive to this day. The Roche limit of Uranus is about 2.44 R_{Uranus} or about 5.7×10^9 cm, and the ring system should be located within this region. Whether or not such a ring will be observable is a question difficult to answer from theoretical arguments.

It seems reasonable on the basis of the above discussion to conclude that the most likely place for the existence of another ring in the solar system is around Uranus.

Note added in July, 1977

The physical basis of Figure 1 is the now well-known and experimentally verifiable critical velocity phenomenon of plasma physics. For detailed discussions of this basis see, for example, Alfvén and Arrhenius (1976) and De *et al.* (1977). The critical velocity phenomenon itself was *predicted* by Alfvén on the basis of the diagram in Figure 1 long before the technology necessary to verify the phenomenon became available.

Rings around Uranus – inside the Roche limit – were observed on 10 March, 1977, by Elliot *et al.* (1977) and Millis *et al.* (1977). At the same time, a new satellite of Uranus – at an orbital distance of about 5.3×10^9 cm – was observed by Bhattacharyya and Kuppuswamy (1977).

I have left the text of the present paper untouched so that the paper stands exactly

as it stood in 1972 when I was a graduate student of Professors H. Alfvén and G. Arrhenius.

Note Added in Proof:

S. K. Bhattacharyya and M. K. V. Bappu (*Nature*, **270**, 503, 1977), on the basis of close examination of the Kavlura photoelectric record, have suggested the existence of four broad 'Saturn-like' rings of Uranus.

Acknowledgement

The Lunar and Planetary Institute is operated by the Universities Space Research Association under Contract No. NSR 09-051-001 with the National Aeronautics and Space Administration. This paper constitutes the Lunar and Planetary Institute Contribution No. 308.

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