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An outer ring to Saturn and an orbit to Janus

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[Plate 1]

New results emerging from observations of Saturn in 1979–1980, when the rings were seen edge on, are reported.

I report here some of the new results that emerged from recent Satern observations in late 1979 and early 1980, around the rare period when the rings are seen edge-on. Then, these rings appear as a tiny lineament on both sides of the disk. The last edge-on opportunity, which occurred in 1966, enabled estimation of the thickness of the Saturn rings as 2.4 ± 1.3 km (Focas & Dollfus 1968; Dollfus 1979), and discovery of a tenth satellite of Saturn, of magnitude 14, very close to the outer edge of ring A (Dollfus 1967); this new object was recognized by I.A.U. with the designation Janus (I.A.U. 1967).

Observation of a new ring around Saturn

In 1966, our effort to discover a faint ring of Saturn which could extend outside the known rings was unsuccessful. W. A. Feibelman (1967) from Allegany Observatory suspected on longer exposures a tenuous spike of light which he attributed to an outer ring, but this was later questioned (Michaux 1975; Smith *et al.* 1975).

For the 1979–1980 observations, I improved my 1966 technique to reduce the lights scattered by the planetary disk, by designing a fully coronographic system, the Corfoc (*coronographe focal*) instrument, which S. Brunier and I adapted to the Meudon 100 cm and Pic-du-Midi 107 cm telescopes in France (cf. Dollfus & Brunier 1980).

On 1 November 1979, we had the first evidence, with the Corfoc at Pic-du-Midi, of the existence of an outer ring (E ring) extending up to 3.6 equatorial radii (R_{eq}) from Saturn's centre. Figure 1, plate 1, reproduces a negative of the discovery plate, in which the lineament extending outwards of the classical rings is seen on both sides, but more intensely above the east limb. We confirmed this observation on 29 January 1980 on new plates which were taken with the Meudon telescope; the outer ring extended up to 7 R_{eq} at the west limb, with structures in the lineament (figure 2, plate 1) and was fainter at the east limb (Dollfus & Brunier 1980*a*). In both cases, the visual magnitude of a 1″ segment of the lineament was *ca.* 16.5–17 in the yellow.

Then we proceeded to record the E ring several times and with increasing success. Figure 3, plate 1, reproduces a plate taken on 3 March 1980, ten days before the opposition, when the phase angle was $-1.2°$; the high contrast of the lineament illustrates the steep increase of brightness of the E ring seen edge-on when the phase angle approaches zero. These observations and others that followed were published by Dollfus & Brunier (1980*b*) and communicated on 14 March 1980 to the French Academy of Sciences.

Around the period of opposition, the outer ring so enhanced was recorded by several other observers in the U.S.A. and in France. Continuing our survey after the opposition with the Corfoc instrument, we recorded the ring fading away up to May 1980. Photometric calibrations of the plates are suitable for producing the light curve of the outer ring lineament.

Figure 5, plate 1, is a print of one of our plates taken at Pic-du-Midi at 23 h 17 min on 22 March 1980 with 8 min exposures; this plate is impressive because all the satellites that usually superimpose their images upon the faint E ring line happened to be either aligned with the Saturn disk or out of the field; note the unsymmetrical behaviour of the E ring which displays more extension along the east limb and more brightness at the west limb.

On each observation date, in our collection of images, these features behave differently; they include tenuous beads or gaps, almost disappearances at one edge or the other, gradient changes, etc. We conclude that the so-called E ring is not, strictly speaking, a disk in the sense of the classical A, B and C Saturn rings, but rather a complex and changing flat structure with arms, streamers or segments. Comparison with structures of spiral galaxies comes to the mind.

The E ring is subjected to the gravitational and sweeping effects of the satellites, as it extends beyond the orbit of Dione. The E ring extends entirely outside the distance to Saturn at which tidal stress produced by the gravity gradient of the planet could break up a solid body, as computed by Roche; it lies at distances at which the simple Roche model implies accretion processes to form satellites. The outer ring could possibly be the visualization of remnant storage of small debris which could be produced by ejecta from meteoroid impacts on Saturn satellites, and eliminated by effects such as the Poynting–Robertson forces which act towards decreasing their distances to Saturn. The apparently complex and variable structures of the E ring that seem to emerge from our observations are of importance for understanding the physics of rings and should be kept in mind when dynamical models are developed.

Reobservation and orbit determination of Saturn satellite Janus

Another result from our telescopic work with Corfoc is the reobservation and orbit determination of Janus, the tenth satellite of Saturn, discovered with the first coronographic design in 1966. While the 1966 plates were merely used at the time as evidence for the existence of the body, a final orbit determination was premature, the more so when it appeared 11 years later that there are not one but two satellites in very similar orbits, the two faces of Janus (Fountain & Larson 1978)! But now, in addition to our 1980 observations and the satellite measurements reported by several other observers, we analysed our eight 1966 Janus plates by measuring the satellites' positions referenced by their mutual locations. All the 1966 measurements, taken alone, produced a period of around 0.694 day. It was also made clear that the object observed twice by Fountain & Larson in 1966, and attributed by them to a new satellite with a period of 0.6938 day, and provisionally designated 1966 S2, corresponds to a reobservation of Janus, respectively 2.0 and 3.5 revolutions after the discovery date. Conversely, the other object seen by Fountain & Larson, tentatively attributed by them to Janus, is the new satellite, which is in an orbit similar to that of Janus. These two satellites were reobserved at length by many people in 1980, as reported in the I.A.U. circulars under the provisional designations 1966 S2, 1980 S1 and 1980 S3. Figure 4, plate 1, reproduces one of our Corfoc observations

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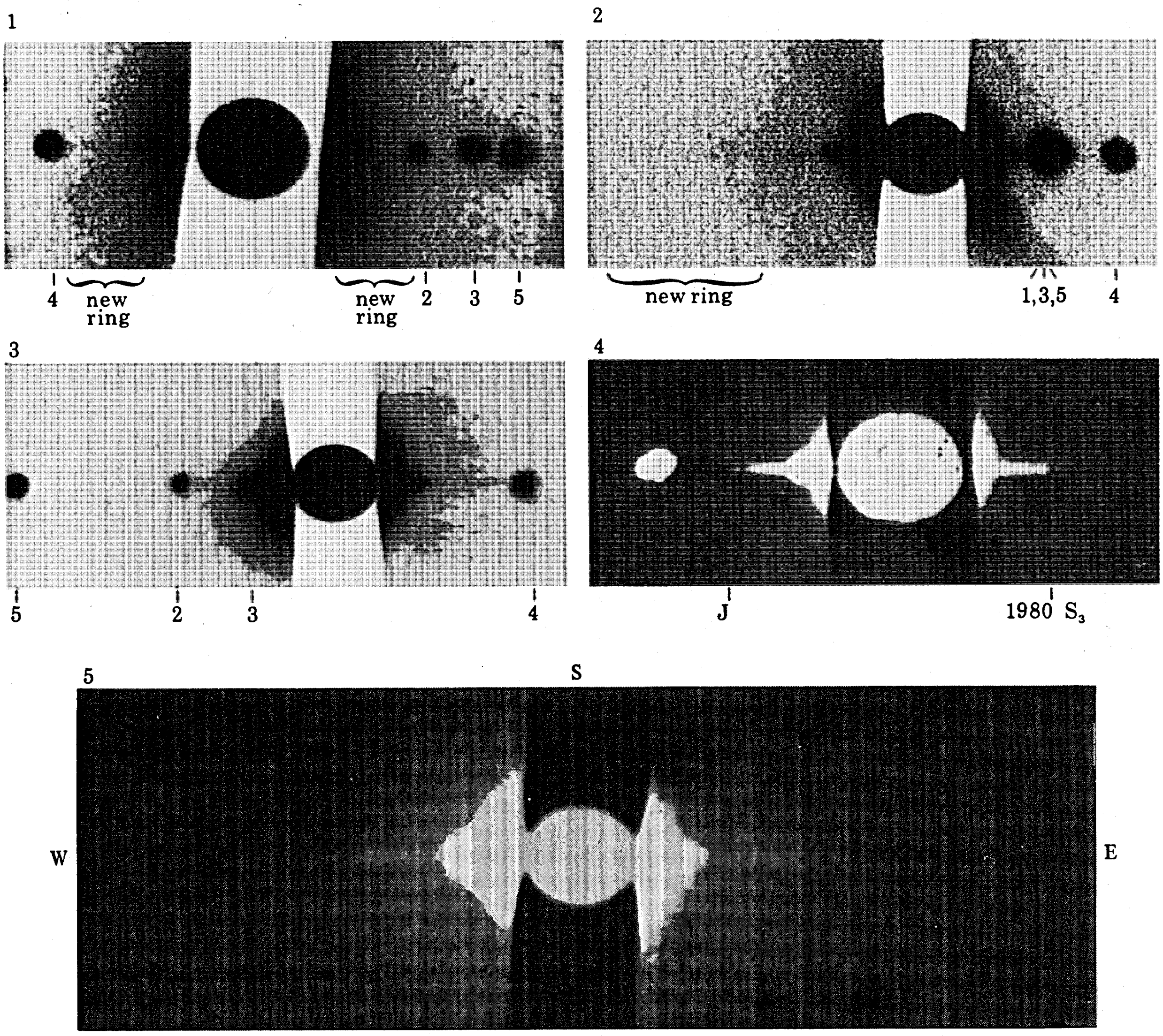

FIGURES 1–5. Saturn outer ring and inner satellites, Pic-du-Midi and Meudon observations with a focal coronograph: 1, November 1979; 2, 29 January 1980; 3, 3 March 1980; 4, 23h 57 min on 23 March 1980; 5, 23h 17 min on 22 March 1980, 107 cm reflector, Pic-du-Midi, CORFOC plus blue filter. (Photographs by A. Dollfus and S. Brunier.)

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on 23 March 1980, when the two satellites were seen at the same time, both of them completely detached from the A ring lineament, respectively at the east and west sides. Magnitude considerations enabled us to recognize that it is the brighter, 1980 S1, that is to be identified as Janus. To date, position measurements of Janus include sequences for four distinct nights in 1966 and more than 20 nights in 1980. From their analysis (Dollfus 1980), it emerges that Janus has an exactly equatorial and practically circular orbit with a semi-major axis of 151500 km or 2.525 R_{eq}. Between 17 h on 15 December 1966 and 21 h on 23 March 1980 Janus experienced an integer number of revolutions of around 6988 orbits, which gives a period of 0.69468 day. An uncertainty of one or several orbits remains, however, in the integral number of revolutions. In addition, large libration effects are superimposed.

The fainter counterpart of Janus, provisionally designated 1980 S3, gravitates in almost the same orbit. In March 1980, this companion was leading the major satellite by 190° in longitude; this value was 224° in December 1966. This smaller object is solicited by Janus to librate in a 'horseshoe' mode between its two Lagrangian points L4 and L5, and this effect protects the two bodies against collisons. In addition, the perturbations by the other satellites, dominated by the 2:1 resonance with Enceladus, are very strong. The overall celestial mechanics problems involved, as well as the cosmological implications, are of importance.

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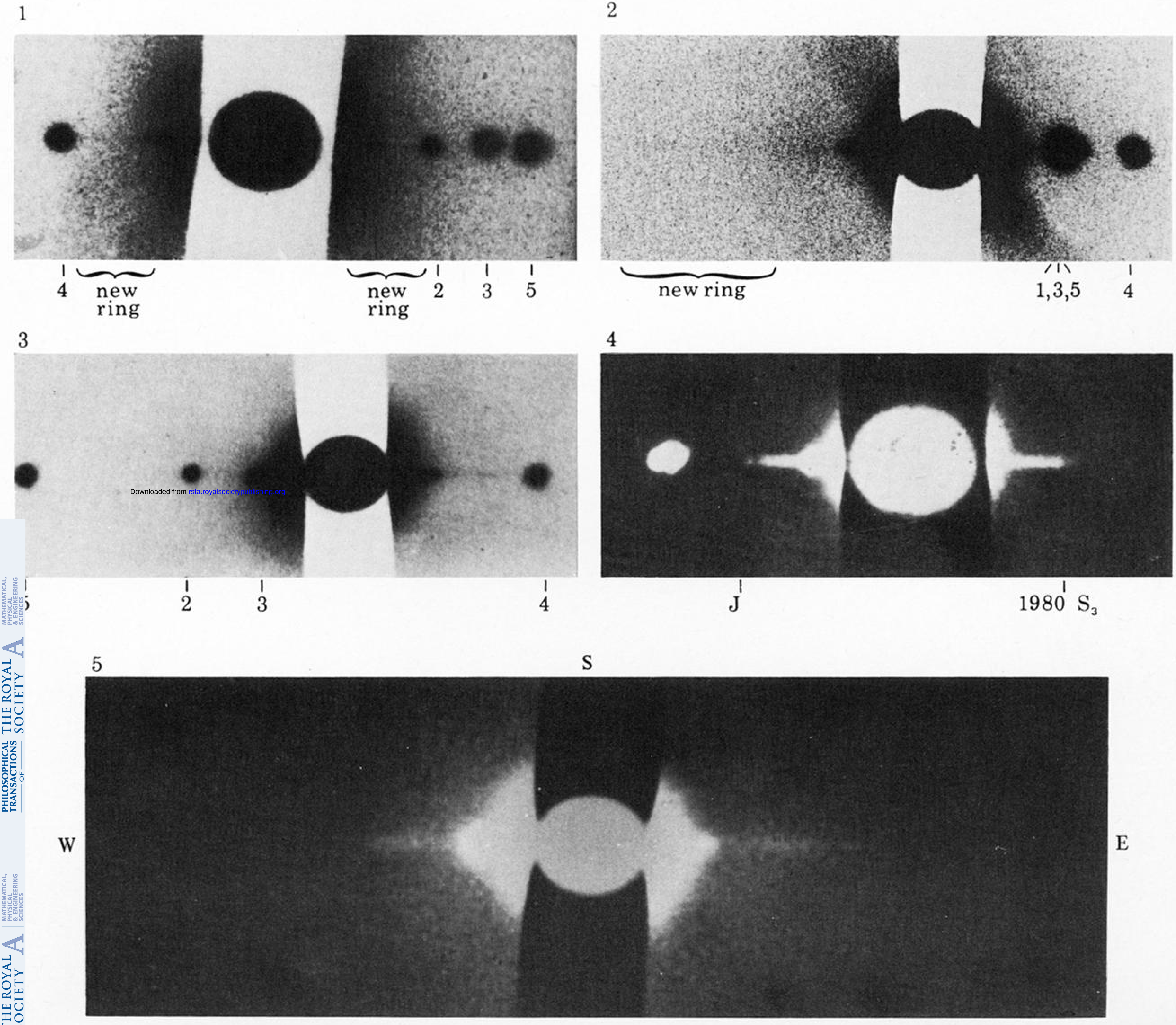

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