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MAGNETOSPHERIC RESEARCH
AND THE HISTORY OF THE SOLAR SYSTEM

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Abstract

The aurora is due to a cosmic plasma penetrating into the Earth's ionosphere. Studies of the aurora have given us some knowledge of cosmic plasmas. More important are in situ measurements in the magnetospheres and the solar wind. Combined with plasma experiments in the laboratory they begin to give us a reasonably good picture of the basic properties of plasmas. As more than 99% of the universe consists of plasma this gives a new foundation for astrophysics.

Extrapolation of magnetospheric results makes it necessary to revise the evolutionary history of interstellar dusty clouds and the formation of stars, including the sun and the "solar nebula", out of which our planetary system derived.

The formation of planets and satellites can also be approached by an extrapolation backwards in time of magnetospheric results.

A combination of these two methods makes it possible to reconstruct certain events 4-5 billion years ago with an accuracy of a few per cent. This reconstruction is essentially based on the Pioneer and Voyager measurements of the highly structurized Saturnian rings. These can be regarded as a time capsule which has registered decisive processes leading to the formation of our solar system.

#1 Aurora and Cosmic Plasmas

When a cosmic plasma penetrates into the ionosphere, aurorae are produced. The aurora is not only one of the most beautiful phenomena in nature, it is also scientifically important because it gives us an understanding of basic properties of cosmic plasmas: when observed locally it is rapidly changing in an erratic way. Indeed, we cannot predict its appearance from one minute to the next. At the same time, its large-scale properties are regular: it is essentially confined to the auroral zone, which is governed by the earth's magnetic field, it is associated with an electric current system which produces magnetic storms, etc.

#2. In Situ Measurements

Space research, especially in situ measurements in the magnetospheres and solar wind, has demonstrated that cosmic plasmas basically have the same properties. As most of the universe is filled with plasma, this means that when we observe aurorae we may get interesting information about the cosmos in general.

#3 Extrapolation in Space and Time

We have now learned how to transfer information, to "translate" plasma phenomena observed in the laboratory to the magnetospheres. There is good

reason to continue the translation into still more distant regions, such as interstellar clouds (see Figure 1). This paper will be devoted to attempts to make a similar translation backwards in time: we use our knowledge of plasmas today to reconstruct those events 4-5 billion years ago by which the solar system presumably was formed.

#4. Evolution of Interstellar Clouds

It is likely that long before the planets/satellites were formed, the matter they now consist of was part of a dusty interstellar cloud of about the same type as we observe today. By extrapolating what we know from magnetospheric studies about the general behavior of plasmas in space and combining this with our present increasingly sophisticated observations of interstellar clouds, we have a fair chance of understanding the evolution of such clouds, and the formation of stars like the sun and the formation of the "solar nebula" which surrounded the sun. (The scenario will be rather different from what has been generally believed before the new phase in cosmic plasma physics.) This evolution was governed by a combination of mechanical and electromagnetic forces. The physics of dusty plasmas is essential (see Table 1).

#5. Plasma-Planetesimal Transition

The same holds for the first phase of the evolution of the solar nebula up to a very important event, viz., the transition from plasma to "planetesimals". By planetesimals we mean small bodies like asteroids of widely different sizes (microns to millimeter, meters, kilometers or megameters), which are formed from the dusty plasma. The planetesimals later aggregate to planets. This evolution is ruled exclusively by mechanical forces.

TABLE 1: FORMATION OF PLANETS/SATELLITES FROM INTERSTELLAR CLOUDS

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	Electro-Magnetic Transfer of Angular Momentum Critical Velocity
	Plasma-Planetesimal transition	2/3 Contraction Cosmogonic Shadow Effect Rosseland Field
Planetesimals	Accretion of Planetesimals to Planets	Mechanical Effects Plasma Processes not Important
Planets Satellites	Formation of Satellites around Planets occurs by a Repetition in Miniature of these Processes (starting with formation of nebula around planet).	

The plasma-planetesimal transition was not one event which took place at a certain instant: it was a series of small-scale transitions of individual cloudlets. Each transition was a rather rapid and irregular process -- like an aurora -- but a long sequence of such processes over millions of years gave a highly regular result -- like the secular regularity of the aurora -- and for the same reason: it was largely regulated by the magnetic field.

When planets had been formed, similar processes -- first electromagnetic-mechanical, and later purely mechanical -- produced satellites around some of the planets.

#6. Information Stored in Saturnian Ring and Asteroid Belt

In two cases the planetesimal state is conserved -- at least to some extent -- for the following reasons: the Saturnian ring is inside the Roche limit, which means that tidal effects from Saturn prevent the planetesimals from accreting to satellites. The other case is the asteroidal belt, where the density is extremely low, with the result that the formation of a planet (or several planets) is still in an early phase. These two specimens of the planetesimal phase are crucial to our attempts to reconstruct the evolutionary history of the solar system, because they give detailed information of an intermediate process: the plasma-planetesimal transition (compare Table 1).

#7. Two-Thirds Contraction

Theoretically, we have reason to suppose that this transition should be associated with a contraction by a factor of 2:3 (a factor which is determined by the geometry of the magnetic field in analogy to the auroral regularity). We know from observations of the Jovian and Saturnian magnetospheres that satellites carve "holes" (actually produce toroidal empty regions) in the

plasma (see upper curve in Figure 2). If this process were active already at cosmogonic times, we should expect that, for example, the satellites of Saturn should absorb plasma, which after the 2:3 contraction should be found as a "cosmogonic shadow" at 2:3 of the distance of the satellites (see Figure 2).

Figure 2, lower curve, shows that at 2:3 of the distance of Mimas we find Cassini's division, the most pronounced dark region in the ring (see Figures 1 and 2). Further, at 2:3 of Janus (the co-orbital satellites) we find a minimum, which in the density curves (Figure 2) is very pronounced, but (because of insufficient contrast) is not always clearly visible in the photograph (Figure 3). A further comparison shows cosmogonic shadows, characterized by a 2:3 contraction, in four cases in the Saturnian ring (see Table 2).

A similar study of the asteroidal belt shows three similar cases of "shadow" effects, so we have no less than seven cases which clearly show the cosmogonic shadow effect (see Table 2).

Comparing the observed contraction ratio with that which is theoretically predicted we find an agreement within a few percent. A further analysis demonstrates that this means that we can reconstruct events at the plasma-planetesimal transition, which must have taken place 4-5 billion years ago, with remarkably high accuracy. In other words, the Saturnian ring should be considered as a fossil from cosmogonic times (which is preserved because in the ring the diffusion is negative).

#8. Cosmogonic Geology

Geologists can reconstruct early events by a study of ancient rock structure. Similarly, we can use Saturnian ring information to reconstruct parts of the evolutionary history of the solar system. And the asteroidal

TABLE II

Cosmogonic shadows		
Saturnian ring from Holberg's data		
	<i>a</i>	<i>F</i>
Mimas	3.075	0.646
Co-orbitals	2.510	
Shepherds	2.349	0.63
	2.310	
Cassini Center	1.984	0.655 (0.650-0.660)
Outer B	1.945	
Holberg min	1.58	0.635
Inner B	1.525	
Inner C	1.235	
Average $0.642 \pm 2\%$ (Theoretically, a 4% correction should be applied to the contraction ratio 2:3)		
Asteroidal region		
Jupiter	5.18	0.676
Main belt		
outer limit	3.50	0.674
High density		
outer limit	3.22	0.683
High density		
inner limit	2.36	0.667
Main belt		
inner limit	2.00	
Theoretical value		

(Alfvén, 1981b)

belt is a similar fossil from which we can get essential information about the early state of the planetary system.

#9. Conclusion

What has been said above has far-reaching consequences for our understanding of the evolutionary history of the solar system. We shall only mention a few of them.

The formation of the planetary system and the formation of the satellite systems were basically similar processes.

The evolution of an interstellar cloud to planets-satellites was governed by electromagnetic and mechanical effects up to the plasma-planetesimal transition, and later exclusively by mechanical effects.

The formative plasma processes were similar to the auroral processes in the sense that they consisted of a long series of apparently erratic local phenomena which, however, follow certain large-scale patterns, so that the integrated result was a smooth build-up of the present structure of the solar system. There is no evidence for large-scale turbulence or dramatic processes (as has been assumed in pre-space age theories).

A further development of this approach can be expected to lead to a more detailed theory of the formation of planets and satellites and hence connect with geology, paleobiology and related sciences.

Extrapolation backward in time will give us important information about the structure of the solar nebula and the formation of the sun, and hence connect with galactic astronomy in general.

Further, the possibility of an accurate determination of 4-5 billion-year-old events will give us information of cosmological significance; e.g., to what extent, if any, the physical constants have varied.

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Figure Captions

Fig. 1 Magnetospheric research has matured to such an extent that it is possible to treat essential parts of the evolutionary history of the solar system as an extrapolation of magnetospheric research. Laboratory experiments also form an important basis for this.

Further, extrapolation from both magnetospheric and laboratory results contribute to a revision of our view of interstellar clouds, and hence influence also the way in which we approach cosmogony.

The transfer of information from one field to another is shown in the figure.

Fig. 2 Production of cosmogonic shadows

Upper curve is an example (Fillius and McIlwain, 1980) of how under present conditions Saturnian satellites may carve "holes" in the plasma around Saturn.

We compare this with the density profile of the Saturnian ring shown by the lower curve (from Holberg 1980, 1983; compare Esposito et al, 1983). Extrapolating to cosmogonic conditions, we assume that analogous phenomena produced similar holes. Shrinking the distances by 2:3, we can explain the Cassini division as the "cosmogonic shadow" of Mimas, the minimum at 1.58 as the shadow of Janus (because of insufficient contrast not clearly visible in the figure), the cut-off between B and C rings as the shadow of the F ring and A ring, and the inner border of the C ring as the shadow of the outer limit of the B ring. Compare Table 1 and also the whole list of references.

Fig. 3 Photograph of the Saturnian ring showing some of the "cosmogonic shadows." Such shadow effects explain the bulk structure of the ring system.

IMPORTANT FIELDS OF PLASMA PHYSICS

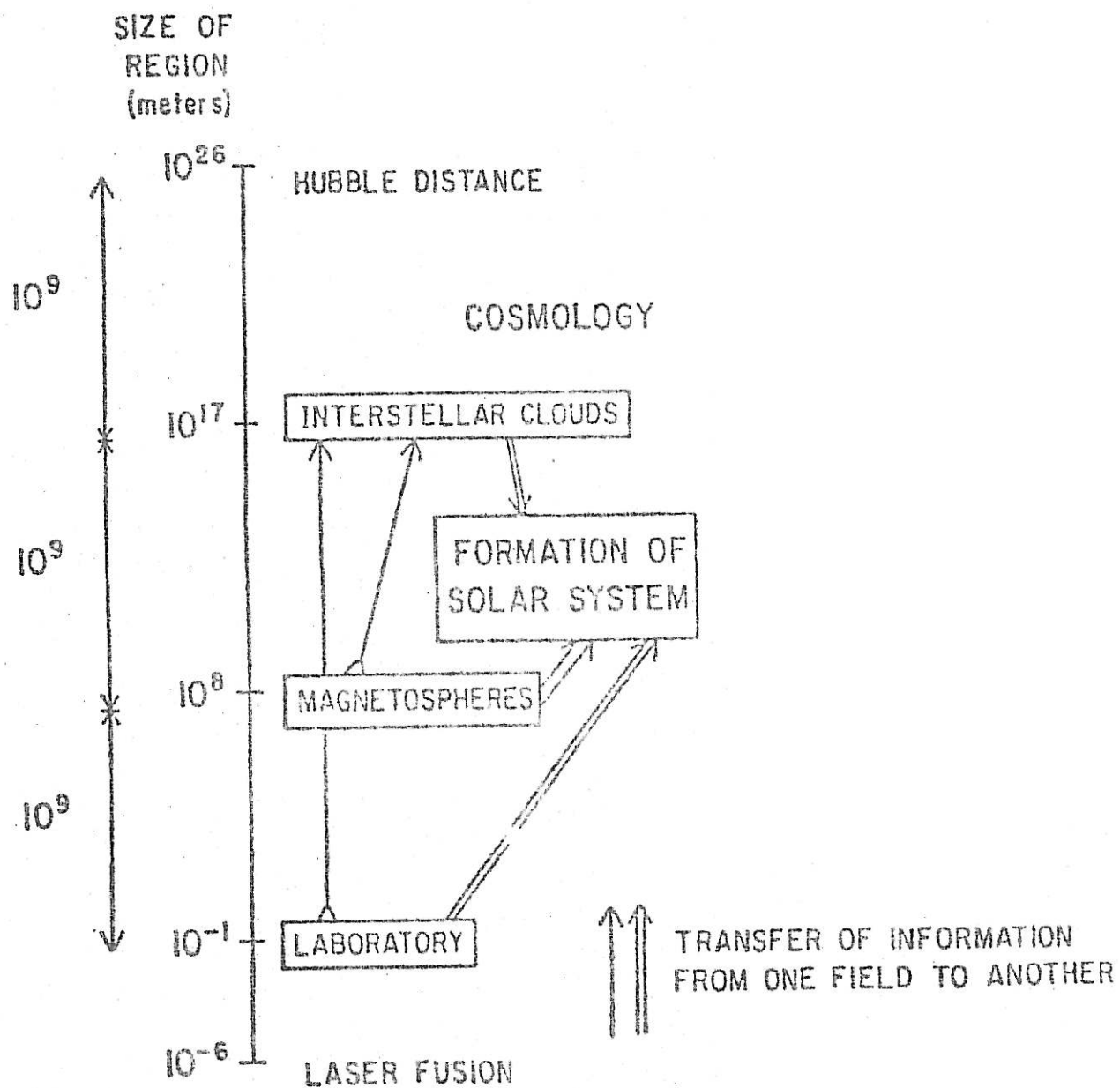


Fig. 1

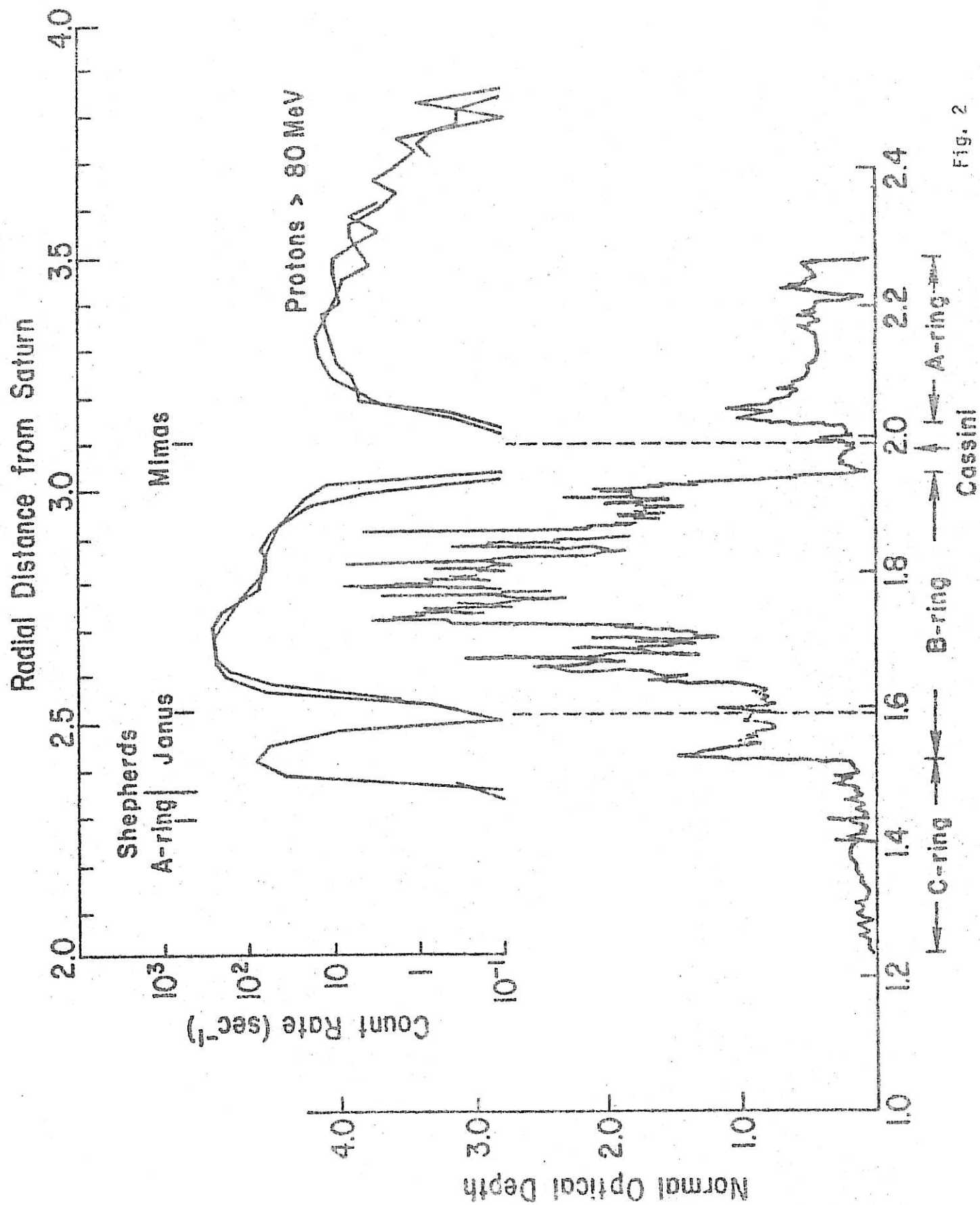
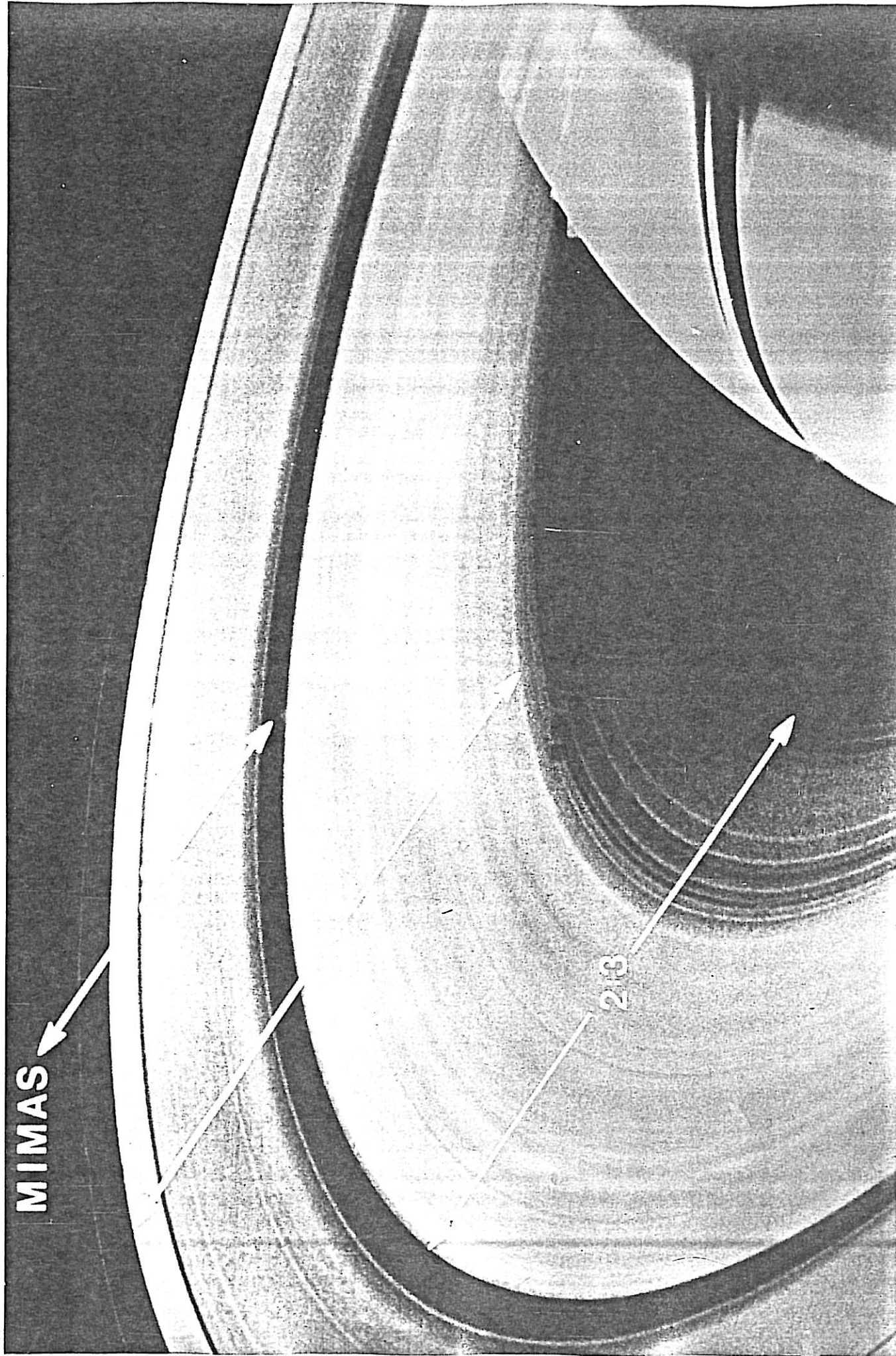


Fig. 2

MIMAS

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Fig. 3



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Key words: Asteroid belt, Cosmic plasmas, Cosmogony, Magnetospheres, Planetesimals, Saturnian rings, Solar system history