Model of the Plasma Universe

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***Abstract*—This paper is a review of a number of publications during the last ten years about those changes in our views of the cosmic environment that are the result of advances in plasma physics. To a large extent, these originate from new observational material that space research has supplied.**

An attempt is made to construct a model of the "plasma universe" which is claimed to be an alternative to the traditional "visual universe" based mainly on observations in the visual octave. Besides the Hubble expansion there is also a "knowledge expansion," which means that knowledge originating from plasma experiments in the laboratory is spreading to the magnetospheres and, it is predicted, sooner or later will also penetrate astrophysics in general.

As an example of the usefulness of this model, it is applied to cosmogony, and a review is given of new results from an analysis of the Saturnian rings. The recent reconstruction of certain cosmogonic events with an accuracy better than 1 percent is reviewed and developed.

I. Impact of Space Research on Cosmic Physics

TRADITIONALLY, our knowledge about our cosmic environment has been based on the radiation we receive in the visual octave (Fig. 1). Space research has now made it possible to also observe cosmic X rays and gamma rays. The universe as seen in these wavelength regions is drastically different from our visual universe. As these wavelengths derive mainly from plasma processes, this means that beside the "visual universe" we now can also observe the "plasma universe."

The following figures show typical differences. Fig. 2 shows that the sun seen in X rays is shockingly different from our visual pictures of it.

The general time scales of the visual and plasma universe are also often different. Whereas our night sky gives an impression of calmness—the moon moves with a time period of one month, planets with periods of years or centuries—gamma-ray bursts (Fig. 3) change their output by orders of magnitude in seconds or milliseconds; i.e., ten orders of magnitude more rapidly.

Also, those radio waves that derive from synchrotron radiation in a plasma give us a picture of the plasma universe that does not resemble the visual night sky very much (Fig. 4). As a complement to our traditional views of the universe, which are primarily based on visual observations, a motivation exists to try to find the properties of the "plasma universe." (The claim that "the plasma universe is >99 times more important than the conventional universe" is meant as a challenge of the usual view

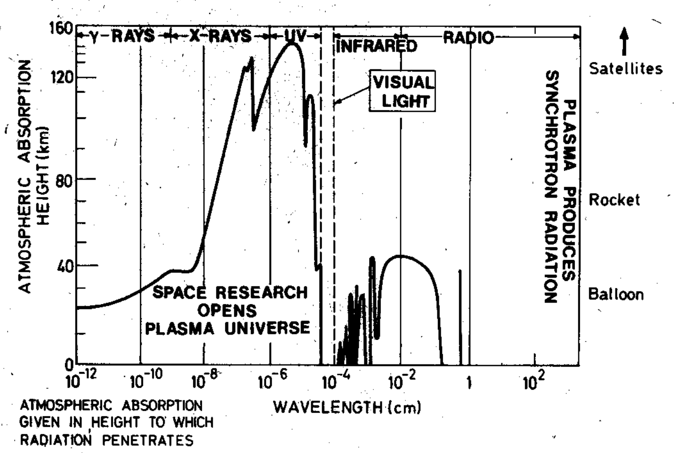

Fig. 1. Spectrum of the plasma universe. Atmospheric absorption given in height to which radiation penetrates. As we now can eliminate atmospheric absorption, we can observe our cosmic environment also in X rays and gamma rays, wavelengths which are mainly produced by plasma phenomena. Traditionally all our knowledge of the universe was derived from observations in the visual octave, later supplemented by radio observations. The space age has made it possible to see not only this "visual universe" but also the "plasma universe."

that our picture of the universe should be based exclusively on the latter).

Fig. 5 shows the relations between the plasma universe and the visual universe.

II. Model of Plasma Universe

Fig. 6 is an attempt to construct a *model of the plasma universe*. Plasma experiments in the laboratory (size 10^{-1} m) and ionosphere, and *in situ* measurements in the magnetospheres (10^8 m), have clarified that plasmas have properties that are drastically different from what was earlier generally supposed [1]–[3]. There is reason to believe that many of the results from laboratory and magnetospheric investigations can be extrapolated further out to plasmas in interstellar ($\sim 10^{17}$ m) and intergalactic regions ($< 10^{26}$ m) [4].

As there are good reasons to suppose that the *basic* properties of plasmas are the same everywhere, we can depict this extrapolation as a "knowledge expansion" which started from laboratory research. With the advent of the space age, which made possible *in situ* measurements in the magnetospheres (including solar magnetosphere ≡ heliosphere ≡ solar wind region), the knowledge expansion increased in strength and is now on its way to reach out as far as spacecraft go.

It is very important that it proceed further out. Indeed, astrophysics will be changed very much when (sooner or

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Fig. 2. The sun seen in X rays looks drastically different from the visual sun.

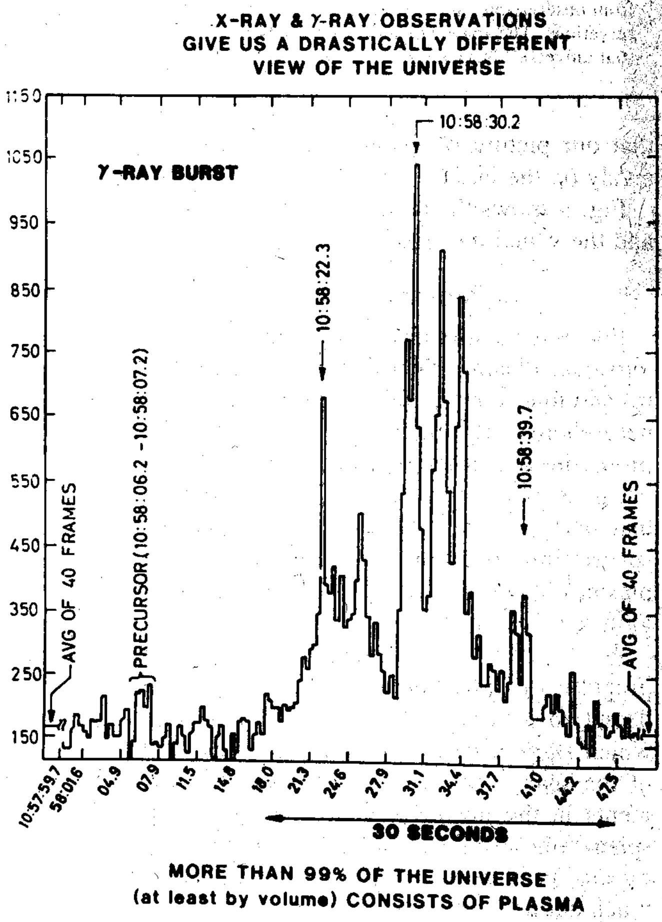

Fig. 3. A majestic calmness characterizes the visual night sky. The planets move with periods of years, if not centuries (only the moon has a period of one month), but the plasma universe as observed in X rays and γ-rays shows variations by orders of magnitude, with time constants of seconds, if not milliseconds as in the γ-ray burst shown.

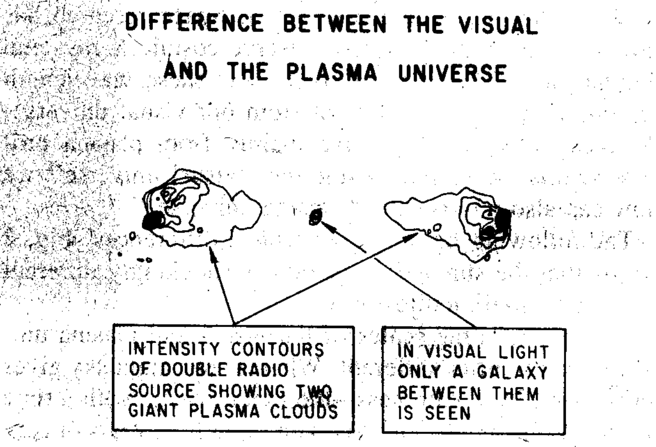

Fig. 4. A double radio source is a very strong emitter of synchrotron radiation produced in giant magnetized plasma clouds. Nothing is seen in visual light at the place of the clouds, but there is often a galaxy halfway between them.

PLASMA UNIVERSE (FROM X-RAY, γ-RAYS and RADIO)
IS DRASTICALLY DIFFERENT FROM CONVENTIONAL UNIVERSE FROM VISUAL

- UNIVERSE CONSISTS TO >99% OF PLASMA
- HENCE PLASMA UNIVERSE IS >99 TIMES MORE IMPORTANT THAN CONVENTIONAL UNIVERSE
- MOREOVER THE X-RAY & γ-RAY REGION COVERS TEN TIMES MORE OCTAVES, 1000 TIMES MORE BANDWIDTH THAN VISUAL UNIVERSE

Fig. 5. As a complement to our traditional views of the universe, which are primarily based on visual observations, a motivation exists to find the properties of the "plasma universe." (The claim that "the plasma universe is >99 times more important than the conventional universe" is meant as a challenge of the usual view that our picture of the universe should be based exclusively on the latter.) When better instruments for observing the plasma universe in X rays and gamma rays are developed, we may get more information from these than from visual observations.

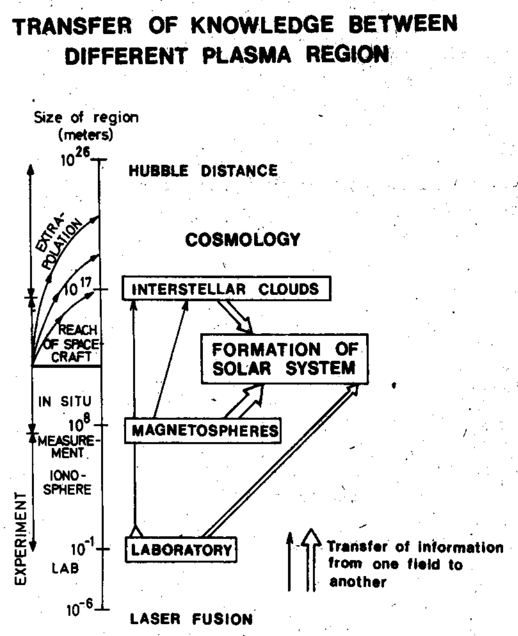

Fig. 6. Plasma universe. It is assumed that the *basic* properties of a plasma are the same everywhere. When the knowledge resulting from laboratory and magnetospheric research is combined with direct observations of interstellar and intergalactic plasma phenomena, we can predict that a new era in astrophysics is beginning, largely based on the plasma universe model.

PLASMA UNIVERSE

HAS A CELLULAR STRUCTURE

MAY CONTAIN ANTIMATTER

IS **NOT** CREATED BY CONVENTIONAL BIG BANG

IS PENETRATED BY A NETWORK OF CURRENTS WHICH
TRANSPORT ENERGY OVER LARGE DISTANCES
PRODUCE DOUBLE LAYERS WHICH ACCELERATE PARTICLES TO VERY HIGH ENERGIES

IT ALLOWS NEW APPROACHES TO THE ENERGY RELEASE IN
DOUBLE RADIO SOURCES
QSO:s, SIEFERTS, ETC.

THE PLASMA IS OFTEN DUSTY

CRITICAL VELOCITY PHENOMENON OFTEN IMPORTANT AND

ALLOWS A NEW APPROACH TO COSMOGONY
(= ORIGIN OF SOLAR SYSTEM)

Fig. 7. Properties of the plasma universe as extrapolated from laboratory and magnetospheric phenomena.

later) the knowledge expansion reaches interstellar and intergalactic regions.

Extrapolation of laboratory and magnetospheric research demonstrates that the plasma universe has properties that differ from those of the traditional visual universe in many respects. A survey of these is given in [1] and briefly summarized in [2]. The list in Fig. 7 is restricted to those properties that are essential for the following.

III. Electric Currents in Interstellar Clouds

There are good reasons for the general view that stars and solar systems are born out of an interstellar cloud of dusty plasma. However, the theory of the origin and evolution of such clouds and the formation of stars and solar nebula is a field that must now be revised for the following reasons.

In situ measurements in magnetospheric plasmas (including the solar wind) have caused drastic changes in our views of the properties of cosmic plasmas. What was considered sacrosanct ten or even five years ago is now hopelessly obsolete. This theoretical paradigm transition, which is summarized in Table I, has penetrated as far out as *in situ* measurements are made, i.e., as far as spacecraft have traveled. Outside this limit the paradigm transition has not yet taken place. Plasmas in interstellar space are still being treated according to the old paradigm. This means in reality that the present theories of interstellar clouds and of the formation of stars and solar nebulas are based on the tacit assumption that the basic properties of cosmic plasma change at the outer reach of spacecraft.

It is obvious that astrophysics cannot remain in this unstable state (indeed, a "universal instability" in plasma physics!). The new paradigm will sooner or later be extended to interstellar space. It will cause a revolutionary change in our view of the evolution of interstellar clouds, in the following respects.

1) According to No. 2 in Table I, cosmic plasmas cannot be described by the magnetic field picture alone. This must be supplemented by an electric current description. Astrophysicists are often reluctant to accept the existence and importance of electric currents in interstellar space, but none of them claims that the magnetic fields are curlfree. As a noncurlfree magnetic field means electric currents, they implicitly accept that interstellar space is penetrated by electric currents. However, there is an immense difference between an implicit acceptance and an explicit description of the phenomena in terms of electric currents. The latter description calls immediately for models of the circuits in which the currents flow, and models of the dynamos that produce the currents. Such currents may transfer energy from one region to another, sometimes over distances comparable to the size of the whole galaxy. (With regard to the circuit description, it has been objected that "there are no wires in space." But "circuits" do not necessarily mean an aggregate of simple linear elements. Especially in the "computer age," circuits often contain nonlinear elements, e.g., as given in Boström's circuit of a magnetic substorm [5]).

2) As soon as electric currents are introduced explicitly, attention is focused on the pinch effect. In the pressure equation

$$\nabla(p + B^2/2\mu_0) - (B\nabla)B/\mu_0 = 0$$

the second term represents the pinch effect. If this is neglected, the sum of gas pressure p and magnetostatic pressure $B^2/2\mu_0$ should be constant. In astrophysics there seems to be a general belief that this is usually the case. As soon as we accept that there are currents in space, this

TABLE I

Magnetospheric research is causing a paradigm transition in geophysics and astrophysics for the following reasons:

No. 1.	*Electric double layers* are realized to be very important.
No. 2.	The often misleading 'magnetic merging' theories of energy transfer should be replaced by an electric current description, including the circuits in which the currents flow.
No. 3.	Homogeneous models often are found to be misleading and should be extensively replaced by inhomogeneous models.
No. 4.	It is realized that inhomogeneities are produced by *filamentary currents*
No. 5.	and by *surface currents*, dividing space into *cells*.
No. 6.	It is concluded that space in general has a *cellular structure*.
No. 7.	The introduction of the current-circuit description makes it impossible to neglect the pinch effect term in the pressure equation $\nabla(p + B^2/2\mu_0) - (B\nabla)B/\mu_0 = 0$.
No. 8.	It is doubtful whether large-scale *turbulence* is of importance in diffuse media.
No. 9.	In a space plasma, electric currents may produce chemical separation.
No. 10.	In dusty plasma, gravito-electromagnetic effects are often important.
No. 11.	The 'critical velocity' is often decisive to the interaction of neutral gas and magnetized plasma. Cosmological consequences will not be discussed here.

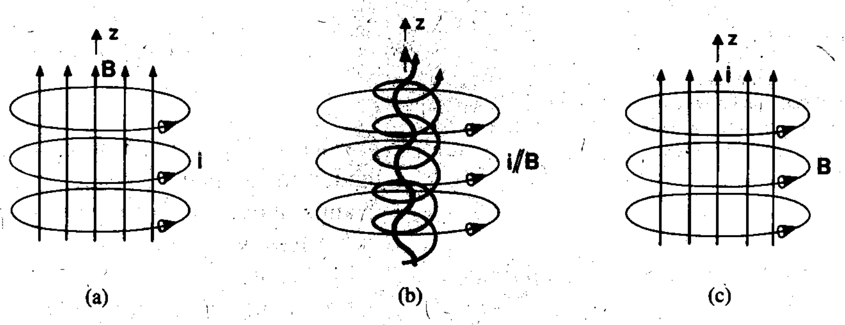

Fig. 8. Three special cases of stationary and cylindrically symmetric current i and magnetic field B configurations. (a) A toroidal current and an axial magnetic field leading to a force opposing contraction. (b) A force-free configuration with i and B parallel. (c) The Bennett pinch with an axial current and a toroidal magnetic field. Electromagnetic effects aid and even start contraction.

is not valid. In a typical Bennett pinch both the pressure and the magnetic field are large inside the pinch but small outside. A typical simple Bennett pinch is produced when

$$\frac{\mu_0}{4\pi} I_z^2 > 2Nk(T_e + T_i)$$

(I_z = current, T_e, T_i are electron and ion temperatures, N = number of particles per unit length). Fig. 8 illustrates three typical cases of stationary and cylindrically symmetric currents i and magnetic line B configurations. In most treatments of the evolution of an interstellar gas cloud, it is assumed that electromagnetic forces oppose the contraction, as in Fig. 8(a), whereas they just as well may assist or cause the contraction, as in Fig. 8(c). The intermediate case (Fig. 8(b)) may be a first approximation of a model of filamentary currents (e.g., [1, p. 95]).

3) According to No. 3 in Table I, homogeneous models of plasmas are now increasingly replaced by inhomogeneous models. When a new field is opened, it is natural to approach it by making homogeneous models, in the belief that these will in any case be a reasonable first-order approximation to a final theory. In plasma physics we have the sad experience that this is very often not true. When a field has matured to such an extent that it is obvious that homogeneous models are no longer sufficient, it is often evident that inhomogeneous models give a drastically different description of the phenomena. The homogeneous model was of no use. Instead, it led the modeling into a dead end from which it often is very difficult to turn back because a powerful establishment committed to the homogeneous model has already been formed. Dessler [6] has drawn attention to one of many cases when such an establishment has delayed progress by decades.

4) According to No. 4, there is often an association between electric currents and observed filaments. Examples of this in our close vicinity are auroral rays associated with filamentary currents, the filamentary structure of the solar corona, and the filamentary currents in the ionosphere of Venus [7]. In interstellar clouds, there are often observed filamentary structures (especially in contrast-enhanced photographs). Such observations support our conclusion that interstellar space, and not the least interstellar clouds, are penetrated by a network of electric currents (cf. [1, ch. II]).

Concerning clouds in which no filamentary structure is observed, it is an open question whether this depends on an absence of them or the inadequacy of observational methods to detect them. From the general picture of the new paradigm, the latter interpretation seems to be preferable.

As stated above, sooner or later the new paradigm will also penetrate the field of the evolution of interstellar clouds. The theory of interstellar clouds should be treated as an extrapolation of magnetospheric research.

Very much work will be required for this transaction, and it is difficult to predict in detail what the result will be. As a reasonable guess as to what a future model of the formation and evolution of interstellar clouds should be, we may suggest the following.

a) Electric currents in "void" interstellar space assist gravitation in collecting matter by the pinch effect, so that interstellar clouds are formed.

b) These develop under the combined action of mechanical and electromagnetic forces. The volume occupied by currents may constitute a very small fraction of the total volume, so that the plasma regions are not evident in the averages of measurements with insufficient resolution. Still, a network of filamentary currents may be decisive to the evolution of the clouds. It is correct to treat the evolution of an interstellar cloud independent of its surroundings *only* if there is no current connecting it with the surroundings.

c) As stated above, the general belief that electromagnetic forces oppose the contraction of a cloud is not necessarily correct. Pinch effects may contribute to the contraction and, indeed, cause a collapse of clouds with a mass that is orders of magnitude smaller than the Jeans mass.

d) A "stellesimal" star formation out of a dust cloud seems possible (cf. [1, ch. V]).

One of the many problems that will appear in a new light is the cosmogonic problem. In the remainder of this paper we shall discuss the application of the plasma universe model to cosmogony.

IV. Application to Cosmogony

The sun is supposed to be formed from a dusty interstellar cloud by processes discussed above. It has a certain mass, spin, and magnetization. Residuals from the cloud form cloudlets which fall in towards the sun and, according to the plasma cosmogony, they are emplaced in those regions where they reach the critical velocity. Angular momentum is transferred from the sun. These processes are governed by plasma effects, of course in combination with mechanical effects. The result is a state of partial corotation (Fig. 9). According to the "hetegonic principle" satellites and planets were formed by basically the same processes [8]–[14]. Hence, we can study essential features of planetary formation through a study of the Saturnian satellite system. This is convenient because of the remarkably accurate observations of this satellite system by Voyager.

The next process is when the plasma becomes deionized and forms planetesimals. This plasma-planetesimal transition (PPT) is associated with a contraction by a factor Γ, which should be approximately $\Gamma = 2:3$, but some secondary effects are expected to reduce this value by a few percent.

PLASMA COSMOGONY

FORMATION OF SUN FROM INTERSTELLAR CLOUD
RESIDUALS FALL IN

FIRST PROCESSES GOVERNED BY PLASMA PROCESSES
EMPLACEMENT OF PLANETARY MATTER
TRANSFER OF ORBITAL MOMENTUM

PLASMA PLANETESIMAL TRANSITION (PPT)
ASSOCIATED WITH CONTRACTION 2:3

LAST PROCESSES GOVERNED BY MECHANICAL PROCESSES
ACCRETION OF PLANETESIMALS TO PLANETS

SATELLITE FORMATION BY REPETITION OF SAME PROCESS
IN MINIATURE

Fig. 9. Application of the plasma universe model to plasma cosmogony.

The planetesimals aggregate to planets. Around some planets the same processes are repeated in miniature, which leads to the formation of satellite systems. The cosmogony of these is similar to the cosmogony of the planetary system. We shall here study the formation of the Saturnian system, especially the rings. The results we obtain are applicable to the formation of planets [2], [8]–[14].

V. Structure of the Saturnian Rings

The present structure of the Saturnian Rings and innermost satellites is seen in Fig. 10. Fig. 11 shows the basic mechanism behind the partial corotation [8], [9, sec. 17.2]. Before the PPT, a plasma element (or a charged grain) is acted upon by the gravitational pull F_g from the central body and centrifugal force F_c. Moreover, there is an electromagnetic force F_E, which prevents the plasma element from moving perpendicular to the field lines. For geometrical reasons we have $F_c = \frac{2}{3} F_g$ and $F_E = \frac{1}{3} F_g$ (see [8], [9], and Fig. 11). At the PPT, F_E is cancelled. As F_c alone cannot compensate F_g, the result is a contraction by a factor $\Gamma \approx \frac{2}{3}$ (a small correction decreases Γ to about 0.63–0.65). Fig. 12 demonstrates that if the Saturnian satellites Mimas and Janus have swept the plasma close to their orbits, the PPT contraction displaces these empty regions to smaller Saturnocentric distances, thus producing what we call "cosmogonic shadows." If the Saturnocentric distances of Mimas and Janus are scaled down by a factor $\Gamma = 0.64$, the regions which they have swept before the PPT coincide with the Cassini division and pronounced minimum in the inner B ring. Before the spacecraft missions to Saturn, confirmation of the cosmogonic shadow effect had already been found in four cases, so that the bulk structure of the Saturnian rings could be explained by these cosmogonic effects. (Similar confirmation of the 2:3 fall down is found in the asteroidal belt [12].) Two of these cases are demonstrated in Fig. 12.

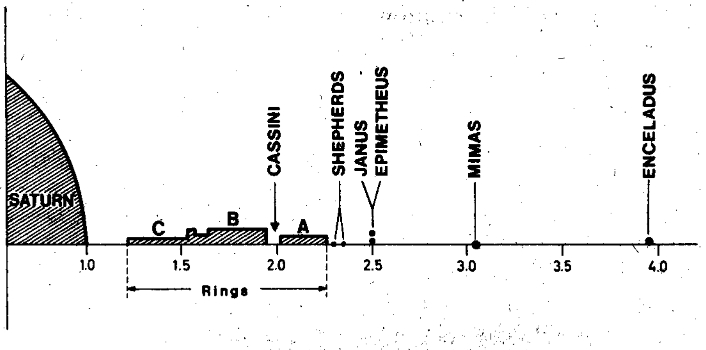

Fig. 10. Saturnian rings and the innermost satellites.

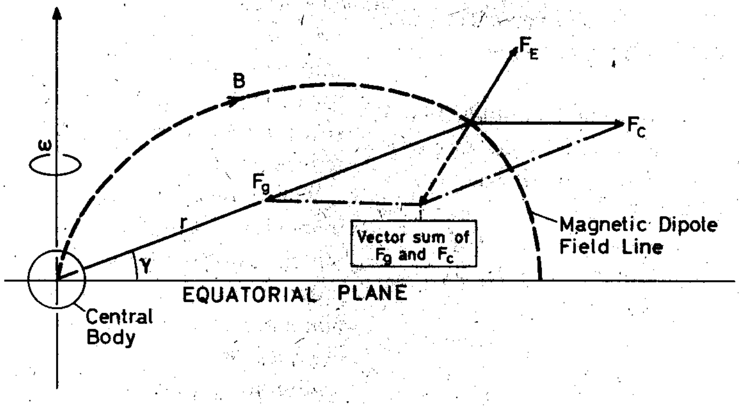

Fig. 11. Partially corotating plasma. The gravitation of the central body on a plasma cloud or grain is balanced to 2:3 by the centrifugal force and to 1:3 by electromagnetic forces. When at the PPT the latter disappear, the partially corotating medium contracts by a factor $\Gamma = 2:3$.

Fig. 13 shows the diagrams of the A, B, and C rings; more detailed diagrams are depicted in Figs. 14–16. It has been believed for a long time that the outer limit of the A ring is given by the Roche limit, which probably is correct (Fig. 14). It is limited inwards by the Cassini division which has a double ringlet in its interior. A tentative explanation is given in Fig. 17. The primary shadow of Mimas should be at the void at 1.993 between the two ringlets. In the region 2.00–2.02 there is a void which we identify with the outer secondary shadow in Fig. 17, outside which there should be a region of increased density which we identify with the 2.02–2.05 maximum. Inside the primary maximum there is a secondary shadow 1.95–1.99, and further inwards a maximum. However, the Mimas 2:1 gravitational resonance at 1.94 and the beginning of the dense B ring make the structure more ambiguous.

The Encke division at 2.21 and Keeler division at 2.26 are difficult to explain either by resonances or cosmogonic shadow effects. A suggestion by Cuzzi [15] that Encke is produced by a tiny satellite seems attractive, but a similar explanation is necessary for the Keeler division.

Fig. 15 shows the B ring; the densest ring of Saturn. The primary shadow of Janus produces a void at 1.59, surrounded by a double ringlet at 1.58 and 1.60. Outside the doublet there is a secondary shadow at 1.60–1.64 followed by a maximum at 1.65. Inside there is a secondary shadow 1.56–1.58, and still farther inside a maximum at 1.55. All this agrees reasonably well with the idealized Fig. 17. Most of the ring is characterized by large fluc-

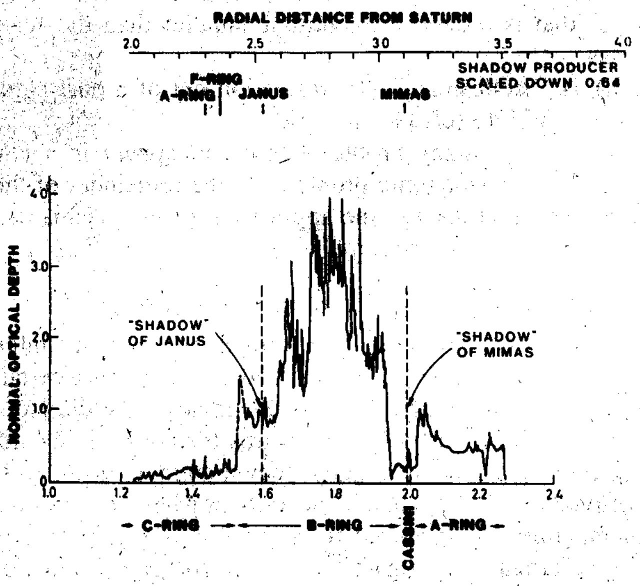

Fig. 12. Mimas and Janus (or the jetstreams out of which they are formed) sweep the regions in which they move so that they are free from plasma. At the PPT contraction these empty regions are scaled down by the factor Γ. This explains why there is a void region (the Cassini division) and a similar low-density region at 1.60. The Saturnocentric distances of these correspond to $\Gamma = 0.65$.

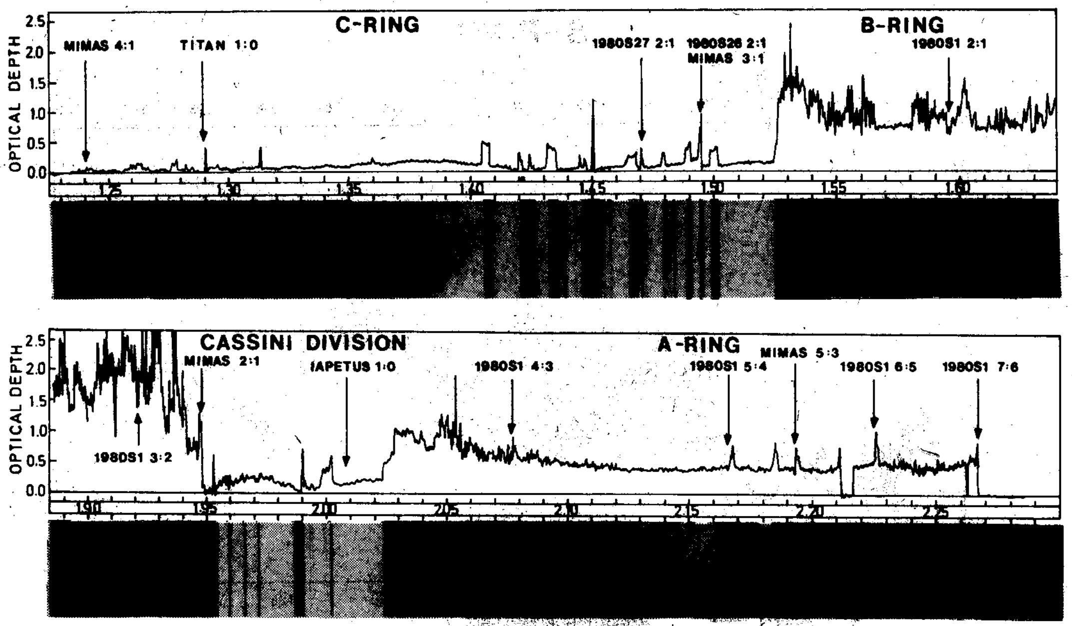

Fig. 13. The *A*, *B*, and *C* rings of Saturn.

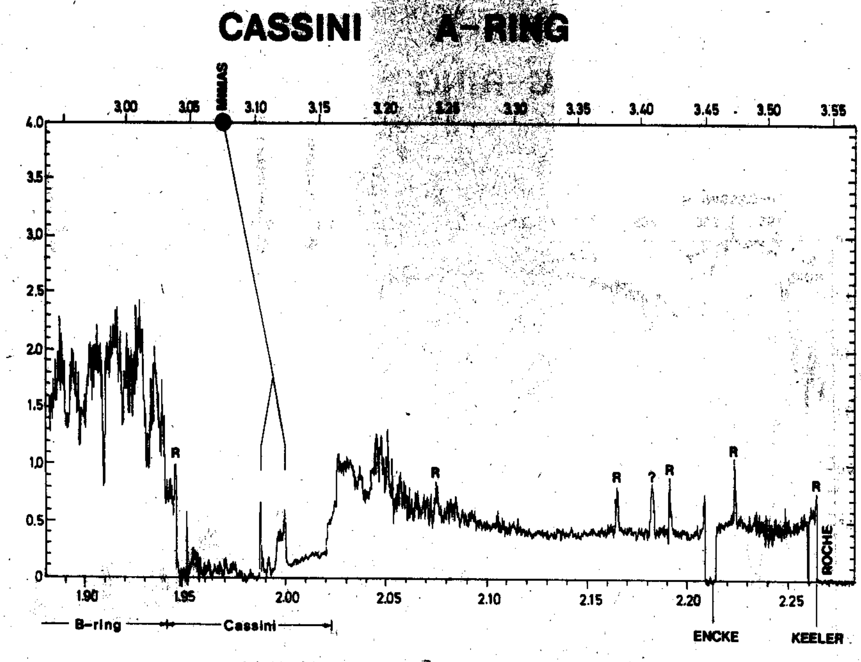

Fig. 14. The *A* ring and Cassini's division.

tuations which probably are not due to cosmogonic effects. There are no satellites that should give shadows in this region.

A remarkable discovery of the Voyager missions was that the Cassini division was not empty. There were two ringlets near its center. Holberg [16] pointed out that in the density minimum at the inner part of the *B* ring there was a similar doublet.

Preliminary attempts to understand this led to the conclusion that the primary cosmogonic shadow of a satellite should be identified with the density minimum between the two ringlets of the doublet. However, the density gradient caused by the shadow and associated electric fields produce one secondary shadow on each side of the primary shadow by changing the fall-down ratio. This means that the total result should be as shown in Fig. 17. It seems to give a first approximation of the general structures of the Cassini division and Holberg minimum.

VI. The *C* Ring of Saturn

With this as a background we shall now analyze the detailed pattern of the *C* ring. The *C* ring consists of a number of ringlets separated by almost void regions. This makes it of special interest. The *A* and *B* rings are sometimes approximated as uniform discs. This cannot possibly be done with the *C* ring.

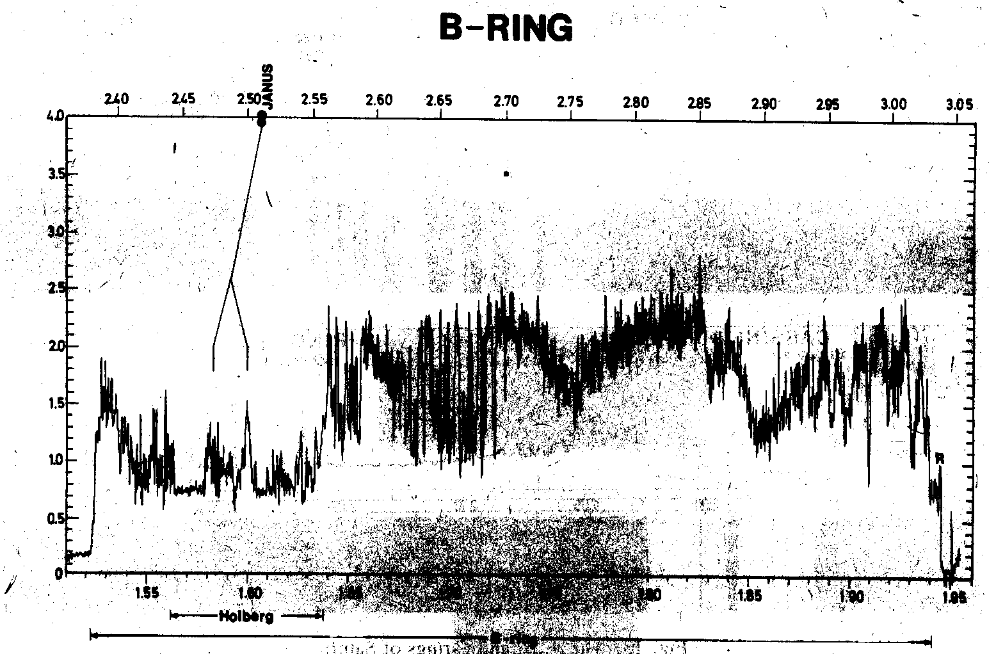

Fig. 15. The opacity of the B ring with Holberg's minimum. Five-point average.

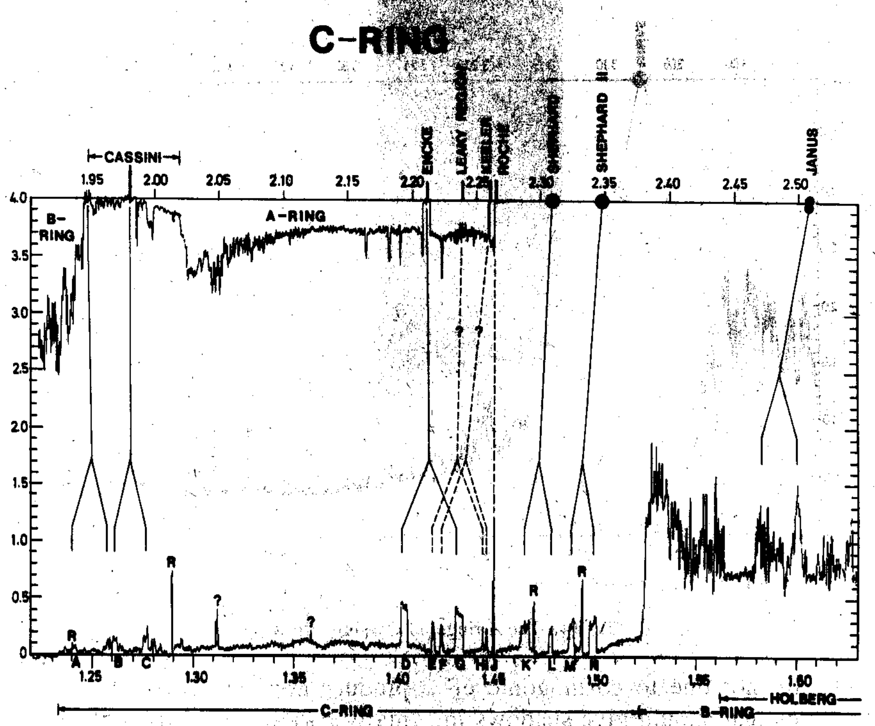

Fig. 16. The opacity of the C ring and the inner part of the B ring.

Fig. 16 shows that some of the ringlets are sharp peaks (marked R) which have been identified as caused by gravitational resonances with some of the satellites. Beside there are a number of ringlets with drastically different structures. The density maxima are rather flat and they are much broader than the resonances. It is reasonable to assume that these might have been caused by the same mechanisms that produced the shadows of Mimas and Janus. If we do this we find that *all of these* maxima can be identified with cosmogonic shadows caused by the shadow producers which are shown at the upper scale [14].

There seems to be a third kind of maxima which is very wide and low, as shown at 1.358 and 1.375 (Fig. 16). Some of the photographs show very faint ringlets deriving from these.

The cosmogonic shadow can be regarded as signatures of the processes we have summarized. Table II shows how

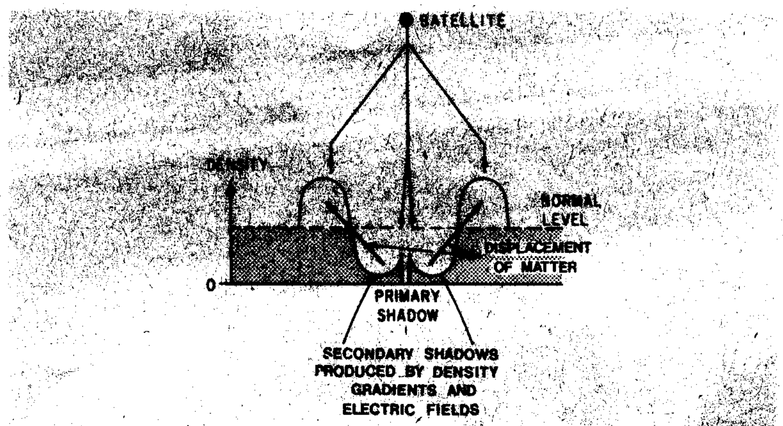

Fig. 17. Cosmogonic shadows. The primary shadow is supplemented by one secondary shadow inside and one outside the primary shadow. These are presumably produced by changes in the contraction ratio due to the density gradient caused by the primary shadow. A similar effect makes "antishadows" also double.

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
Eccentric 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

the Γ values agree within less than 1 percent. Fig. 18 is a picture of the Saturnian rings which shows the identifications. It should be studied in detail together with Figs. 13 and 16.

VII. CONCLUSIONS

1) With the model of the plasma universe as a background, it is possible to understand much of the complicated structure of the Saturnian *C* ring. This shows how useful the plasma universe model is.

2) Figs. 16 and 18 and Table II demonstrate that it is possible to reconstruct certain cosmogonic events with an accuracy of better than 1 percent. This makes possible a new approach to the evolutionary history of the solar system.

3) As cosmogony is a key problem in astrophysics, planetology, geology, paleobiology, etc., the results will be relevant to a number of sciences.

This paper is a summary of the publications that are quoted in the references. Further references may be found in them.

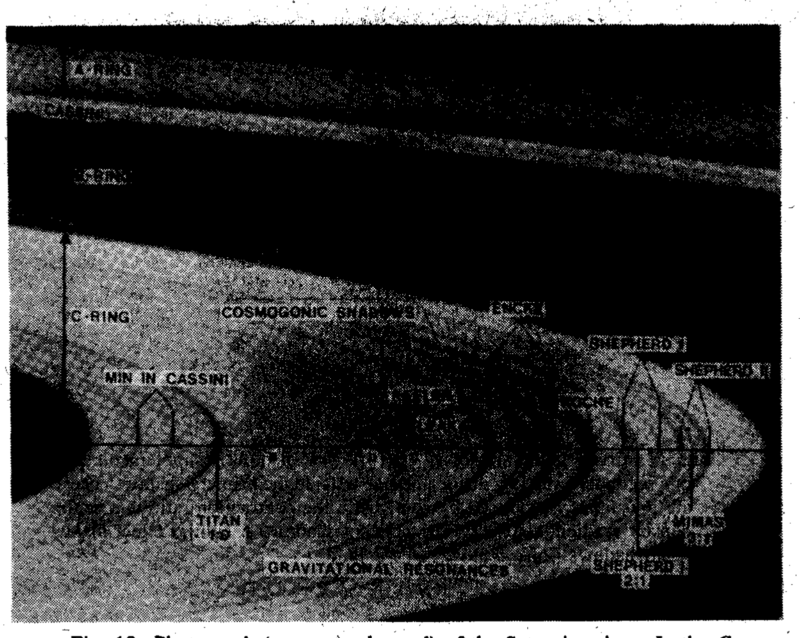

Fig. 18. Photograph (contrast enhanced) of the Saturnian rings. In the *C* rings, there are sharp gravitational resonances, which are shown by lines downwards. *a* is unidentified, but its sharpness indicates that it is a gravitational resonance. According to Fig. 16, the density does not vary very much between *a* and Encke, but because of the contrast enhancement, the small variations show up as weak diffuse ringlets at *b* and *c*. All other markings in the *C* ring can be identified as cosmogonic shadows.

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