

# Plasma Universe

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## Abstract

Traditionally the views on our cosmic environment have been based on observations in the *visual* octave of the electromagnetic spectrum, during the last half-century supplemented by infrared and radio observations.

Space research has opened the full spectrum. Of special importance are the X-ray- $\gamma$ -ray regions, in which a number of unexpected phenomena have been discovered. Radiations in these regions are likely to originate mainly from *magnetised cosmic plasmas*. Such a medium may also emit synchrotron radiation which is observable in the radio region.

If we try to base a model of the universe on the plasma phenomena mentioned we find that the *plasma universe* is drastically different from the traditional *visual universe*.

Information about the plasma universe can also be obtained by extrapolation of laboratory experiments and magnetospheric *in situ* measurements of plasmas. This approach is possible because it is likely that the *basic* properties of plasmas are the same everywhere.

In order to test the usefulness of the plasma universe model we apply it to *cosmogony*. Such an approach seems to be rather successful. For example, the complicated structure of the Saturnian C ring can be accounted for. It is possible to reconstruct certain phenomena 4–5 billions years ago with an accuracy of better than 1%.

## 1. Space research and the plasma universe

### 1.1. Impacts of space research on cosmic physics.

#### Terminology

For centuries or millennia our knowledge of the universe has been based on information received in the visual octave  $0.4\text{--}0.8\ \mu$  (see Fig. 1). During the last half-century the visual light astronomy has been supplemented by infrared and radio astronomy. During the last decade space research has opened the whole electromagnetic spectrum. This means that we now also receive information in the whole infrared region and the ultra-violet-X-ray- $\gamma$ -ray region.

In this paper we shall concentrate our attention on the X-ray and  $\gamma$ -ray regions. Most of the emissions in these wavelengths are likely to be produced by electrons with energies in excess of some hundred eV. We know that processes in magnetized plasmas, especially in connection with double layers and other magnetic field aligned electric fields, accelerate auroral electrons to some  $10^3$  eV. Further in solar flares basically similar plasma processes produce energies of  $10^9\text{--}10^{10}$  eV (C.P. III).<sup>\*</sup> Carlqvist's theory of relativistic double layers demonstrates that under cosmic conditions even much higher energies may be generated in magnetized cosmic plasmas [1].

Hence with some confidence we can assume that the X- $\gamma$ -rays we observe derive mainly from magnetized plasmas with electron energies in excess of some hundred eV. This

<sup>\*</sup> C.P. = Alfvén, H., Cosmic Plasma, Astrophys. Space Sci. Libr. 82, D. Reidel Publ. Co., Dordrecht, Holland (1981).

means that it seems legitimate to call the picture we get from these wavelengths "the high energy plasma universe".

As we shall see this picture is often drastically different from the traditional picture of the *visual universe* which is based on observations in visual light. This light derives from solid bodies (e.g., planets) but to a much larger extent from stellar photospheres which usually are in a state of low energy plasmas ( $\leq 10$  eV). Hence visual universe is not far from a synonym to low energy plasma universe, but for the sake of convenience we shall use the term visual universe. We shall compare this with the high energy plasma universe, a term which we shall shorten to *plasma universe*.

High energy magnetized plasmas do not only emit X-rays- $\gamma$ -rays but also synchrotron radiation which often falls in the radio bands. Hence *radio astronomy* also gives us information about the plasma universe.

### 1.2. Difference between plasma universe and visual universe

The following figures show a few typical differences. Figure 2 shows that the sun seen in X-rays is shockingly different from our visual picture of it.

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

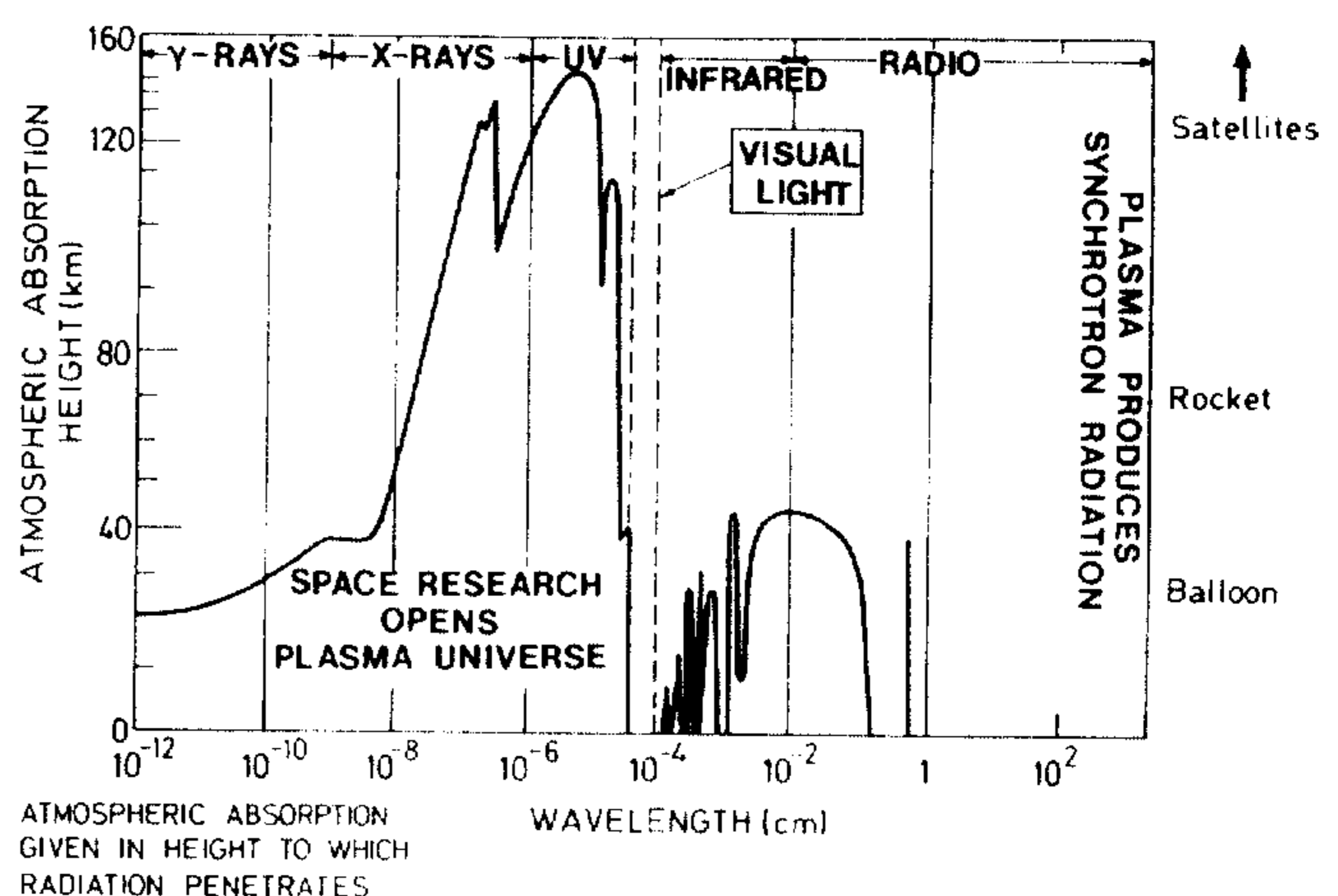


Fig. 1. As we now can eliminate atmospheric absorption we can observe our cosmic environment also in X-rays and  $\gamma$ -rays, wavelength which are mainly produced by plasma phenomena. Traditionally all our knowledge of the universe was derived from observations in the visual octave, later supplemented by radio observations and some infrared observations. Space age has made it possible to see not only this "visual universe" but also the "plasma universe".

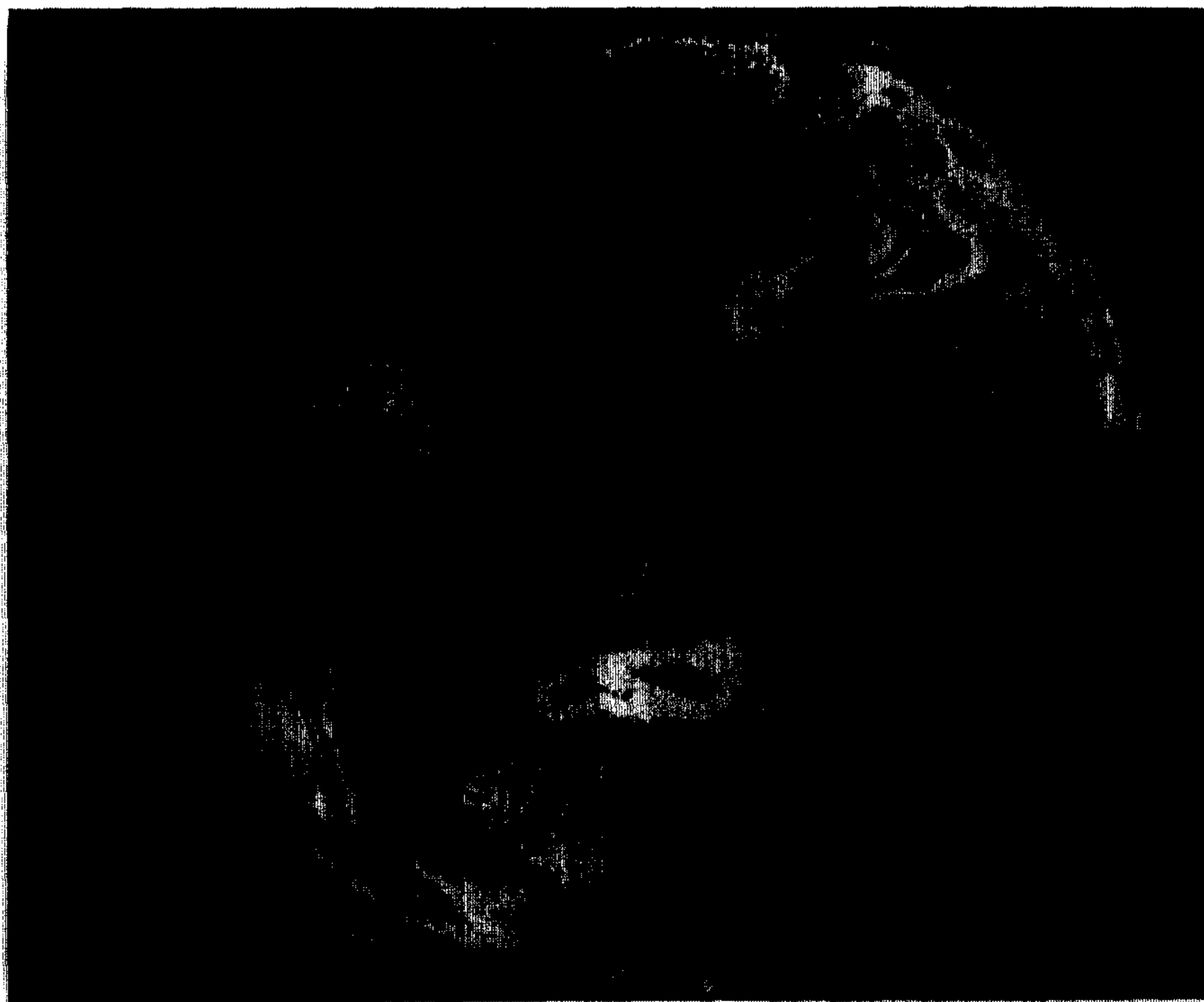


Fig. 2. The sun seen in X-rays looks drastically different from the visual sun. The large dark regions are "coronal holes".

**X-RAY &  $\gamma$ -RAY OBSERVATIONS  
GIVE US A DRASTICALLY DIFFERENT  
VIEW OF THE UNIVERSE**

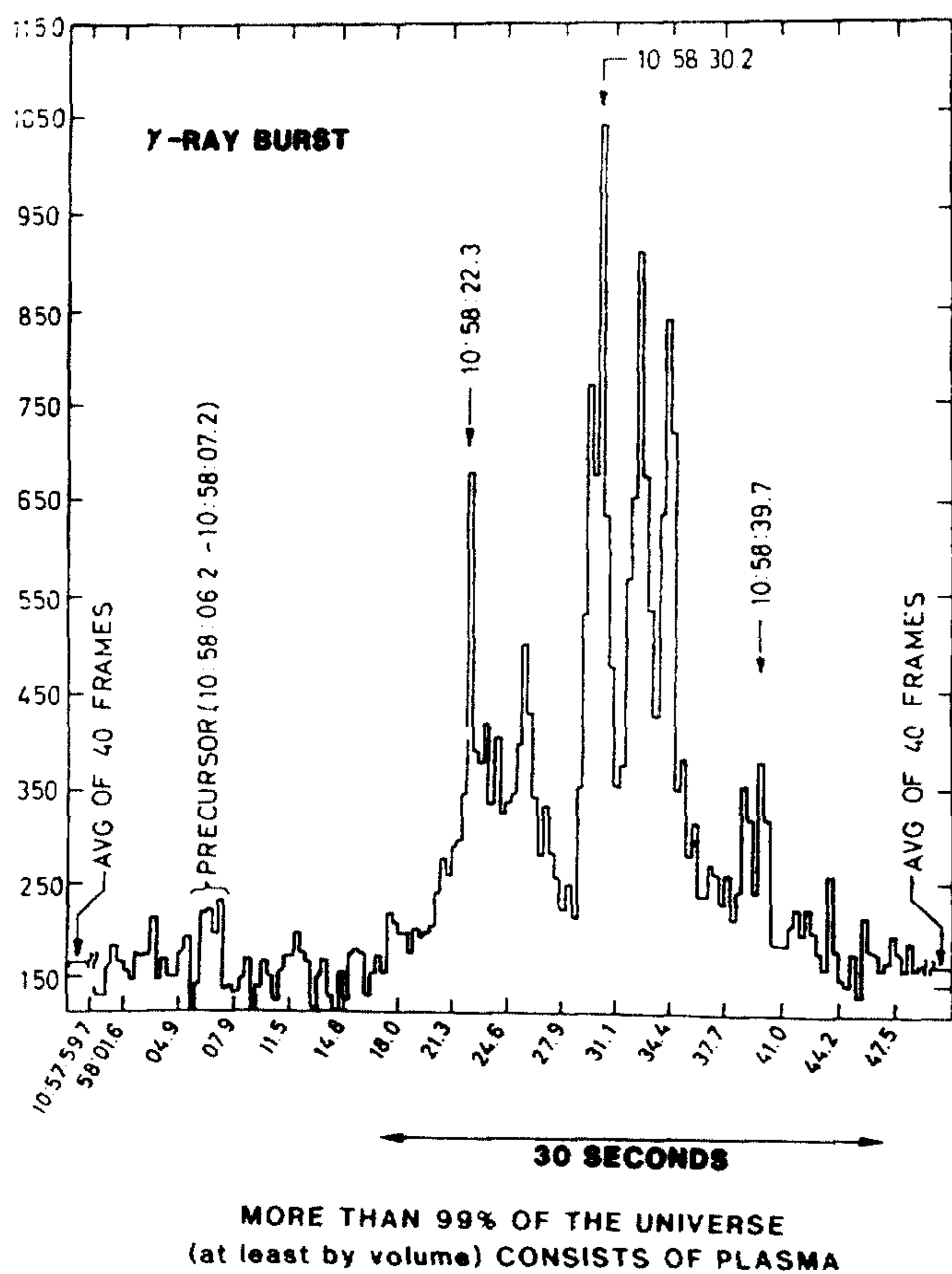


Fig. 3. A majestic calmness characterizes the visual night sky. The planets move with periods of years, if not centuries. (Only the moon has a period of one month.) But the plasma universe as observed in X-rays and  $\gamma$ -rays shows variations by orders of magnitude, with time constants of seconds,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

Also, those radio waves which derive from synchrotron radiation in a plasma give us a picture of the plasma universe which does not resemble the visual night sky very much (Fig. 4).

*1.3. Relations between the visual and the plasma universe*

The relation between the visual and the plasma universe is somewhat analogous to the relation between a visual and an X-ray picture of a man. The visual picture is — literally — superficial: you see his skin and not very much more. The X-ray picture reveals the structure of his whole body, it shows the skeleton and intestines, and gives us a better understanding of how his body works (Fig. 5a, b).

Similarly, the visual picture of our solar system gives us information about thin surface layers of the celestial bodies,

**DIFFERENCE BETWEEN THE VISUAL  
AND THE PLASMA UNIVERSE**

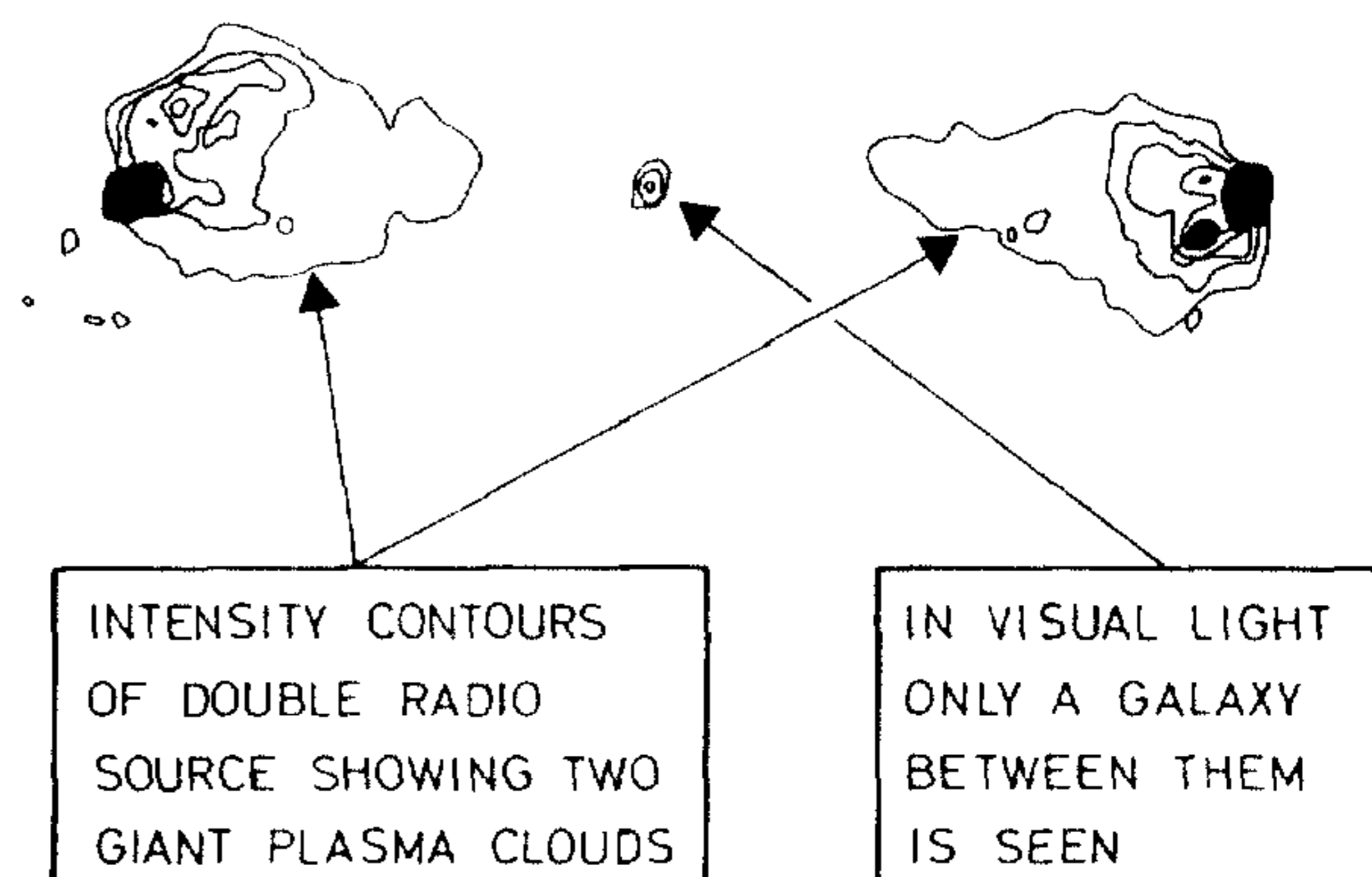


Fig. 4. A double radio source is a very strong emitter of synchrotron radiations produced in giant magnetized plasma clouds. Nothing is seen in visual light at the place of the clouds, but there is usually a galaxy halfway between them.



Fig. 5. X-ray pictures of a hand (a) and the belly (b) showing the spinal column and the elementary canal.

whereas plasma investigations tell us the structure of the interplanetary space, and — by extrapolation — how once the solar system was formed out of a dusty plasma (see Bg 6). Similarly, as most of the universe is likely to be in the state of a dusty plasma, the plasma universe is more basic than the visual universe. Further, the X-ray- $\gamma$ -ray regions cover 10 times more octaves and  $\gg 1000$  times more band width than the visual light, and when receivers in these wavelength regions have been adequately developed we can expect to obtain more observational data from them than from the single visual light octave.

There is still another good reason for concentrating our attention on the plasma universe: our views of the universe are traditionally based on visual observation and in order to compensate for the “generally accepted” but distorted views of the structure of the universe and how it has developed it is healthy to put much emphasis on the plasma universe.

#### 1.4. Model of the plasma universe

There is another, and perhaps even more important approach to the study of the plasma universe. There are good reasons to suppose that the *basic* properties of plasmas are the same everywhere (C.P. 1.2 and Bg 2\*). Hence *plasma experiments* in the laboratory or in the magnetospheres (including solar magnetosphere  $\equiv$  heliosphere  $\approx$  solar wind region) are relevant also for the understanding of distinct astrophysical regions. Similarly, passive *in situ* measurements from spacecraft in the magnetospheres give us important information about galactic, cosmogonic, and cosmological conditions. Figure 6 shows different plasma regions and the transfer of knowledge between them.

The same material as in Fig. 6 is used in Fig. 7 for constructing a picture of the plasma universe (in an essentially logarithmic scale).

We can depict the extrapolation mentioned above 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 the “*knowledge expansion*” increased in strength and is now on its way to reach out as far as spacecraft go.

\* Bg (2) means Background material No. (2).

It is very important that it proceed further out. Indeed, astrophysics will be changed very much when (sooner or later) the knowledge expansion reaches interstellar and intergalactic regions (Bg 2 and [2]).

### TRANSFER OF KNOWLEDGE BETWEEN DIFFERENT PLASMA REGION

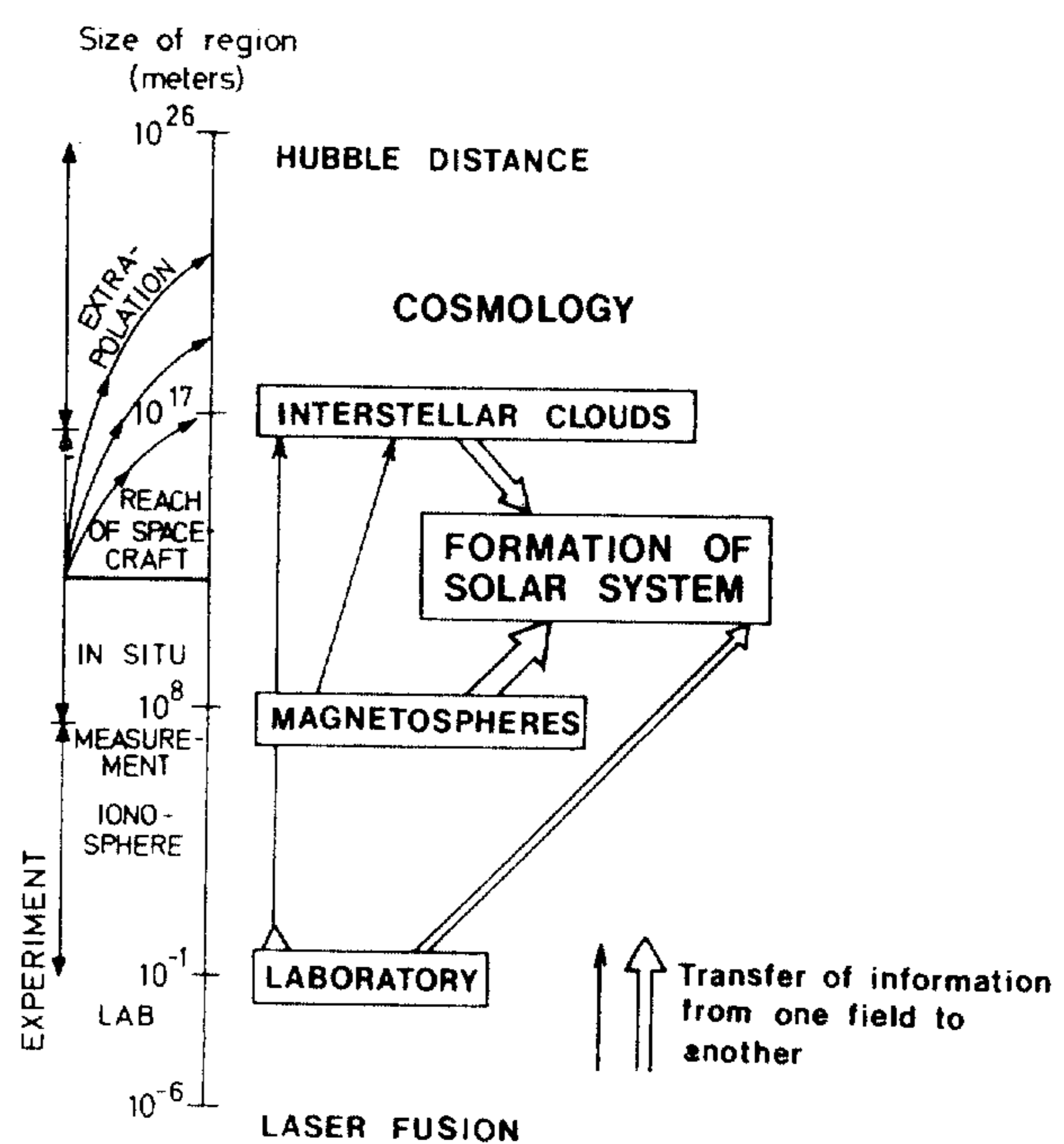


Fig. 6. Transfer of knowledge between different plasma regions. The linear dimensions of plasma vary by  $10^{27}$  in three jumps of  $10^9$

from laboratory plasmas	— 0.1 m
to magnetospheric plasmas	— $10^8$ m
to interstellar clouds	— $10^{17}$ m
Hubble distance	$10^{26}$ m

Including laser fusion experiments brings us up to  $10^{32}$  orders of magnitude. New results in laboratory plasma physics and *in situ* measurements by spacecraft in the magnetospheres (including the heliosphere) make sophisticated plasma diagnostics possible out to the reach of spacecraft ( $10^{13}$  m). Plasmas at larger distances should to a considerable extent be investigated by extrapolation. This is possible because of our increased knowledge of how to *translate* results from one region to another. See C.P. and Ref. [2]. The figure shows us an example of how cosmogony (formation of the solar system) can be studied by extrapolation from magnetospheric and laboratory results, supplemented by our knowledge about interstellar clouds.

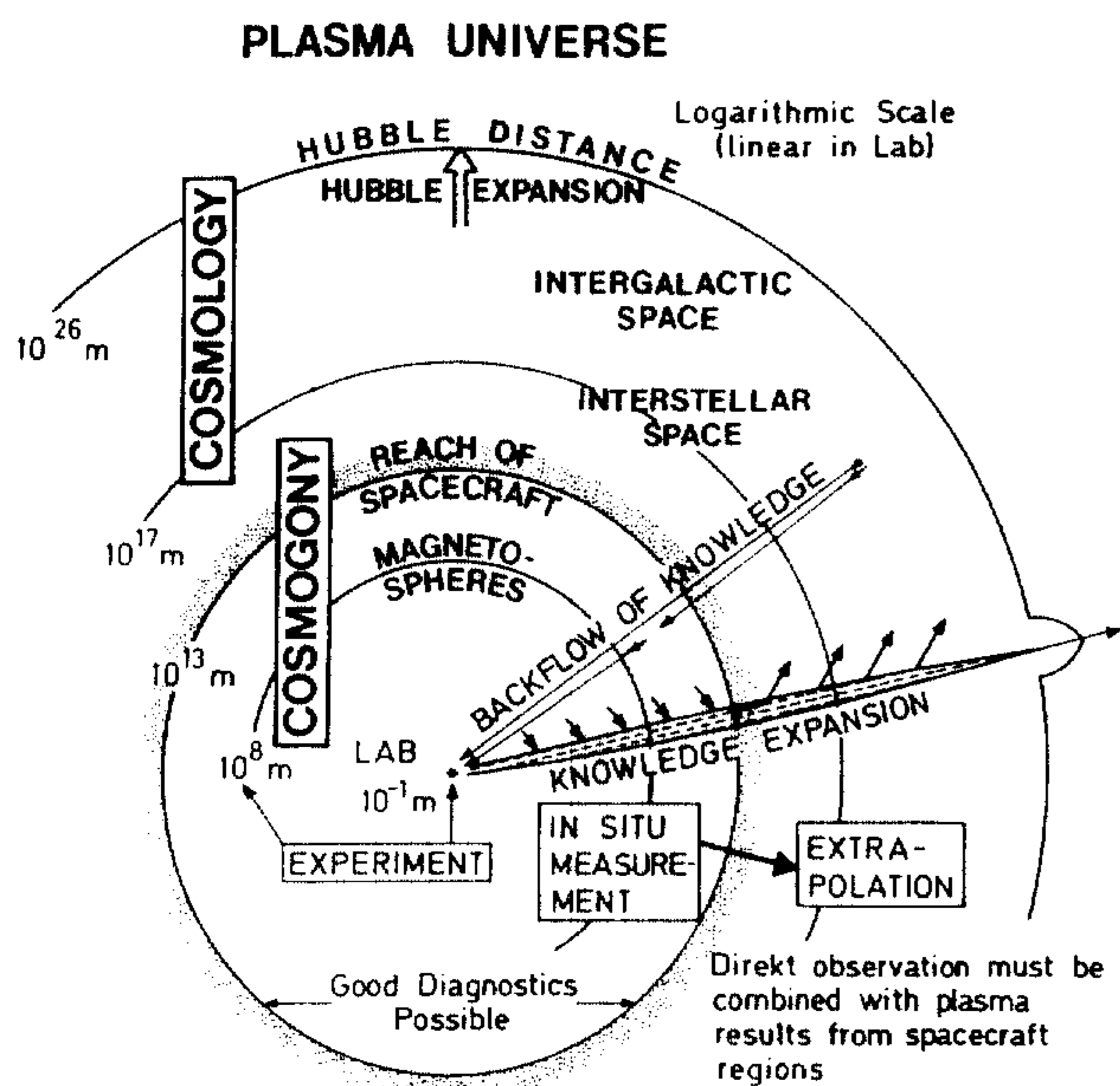


Fig. 7. Plasma universe. Contains essentially the same information as Fig. 6. Plasma research has been based on highly idealized models, which did not give an acceptable model of the observed plasma. The necessary "paradigm transition" leads to theories based on experiments and observations. It started in the laboratory about 20 years ago. In situ measurements in the magnetospheres caused a similar paradigm transition there. This can be depicted as a "knowledge expansion", which so far has stopped at the reach of spacecraft. The results of laboratory and magnetospheric research should be extrapolated further out. When this knowledge 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 (see C.P. and [2]).

Extrapolation of laboratory and magnetospheric research demonstrates that the plasma universe has properties which differ from those of the traditional visual universe in many respects. A survey of these is given in C.P., and briefly summarized in Bg (2). Important results are:

1.5. *Electric currents in interplanetary interstellar, and intergalactic space*

Space is divided by current sheaths into compartments. On the two sides of a current layer magnetisation, density, temperature and chemical composition may differ. Examples: the magnetopause which separates the solar wind and

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. 8. Application of the plasma universe model to plasma cosmogony. According to HAGA (Bg 3) the main processes were those listed here. According to the "hetegonic principle" satellites and planets were formed by basically the same processes. 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 the Voyager results (Bg 4, 5, 6, 8, 9, 10).

SATURN WITH MASSIVE RINGS AND INNERMOST SATELLITES.

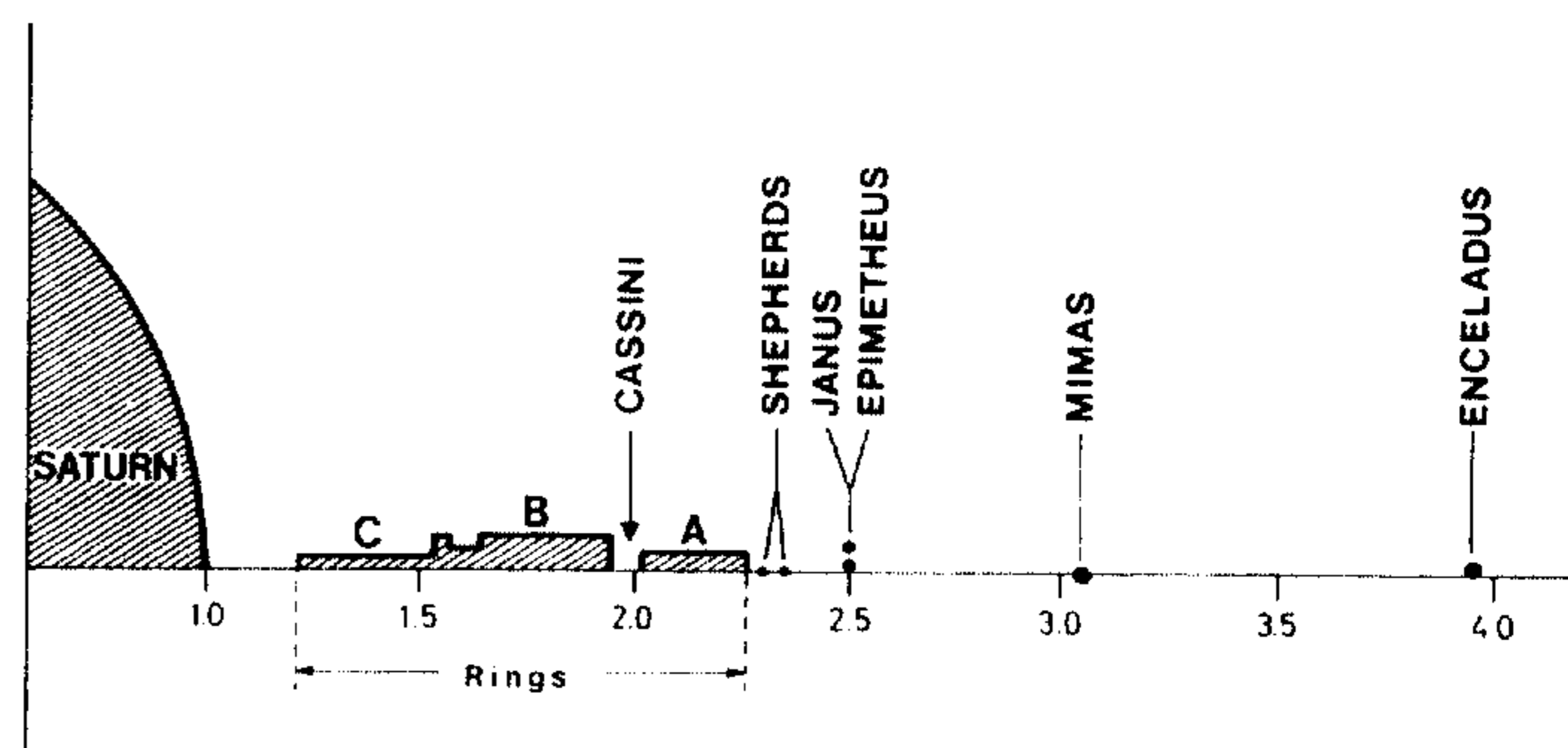


Fig. 9. Saturnian rings and the innermost satellites.

our magnetosphere, and similar phenomena around other planets. In interstellar and intergalactic space also the kind of matter may differ (koinomatter on one side, antimatter on the other, see C.P.VI).

Space is penetrated by a network of filamentary currents. Examples: Birkeland currents (magnetic field aligned electric currents) currents producing the filamentary structure of the corona, and similar currents in hydromagnetic "shock fronts".

The filaments are usually produced by the pinch effect. They transfer energy and momentum over large distances. The currents often produce electric double layers (C.P. II.6), in which charged particles may be accelerated to high, even very high, energies.

Such current layers and pinches may scatter radiation. Whether such effects are large enough to isotropize the 3 K radiation is an open question.

2. Applications

2.1. Application to cosmogony

One of the many problems that will appear in a new light is the cosmogonic problem. We shall here discuss the application of the plasma universe model to cosmogony (HAGA\* and Bg 9).

In these publications the sun is supposed to be formed from a dusty interstellar cloud by processes which we shall not discuss here. 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

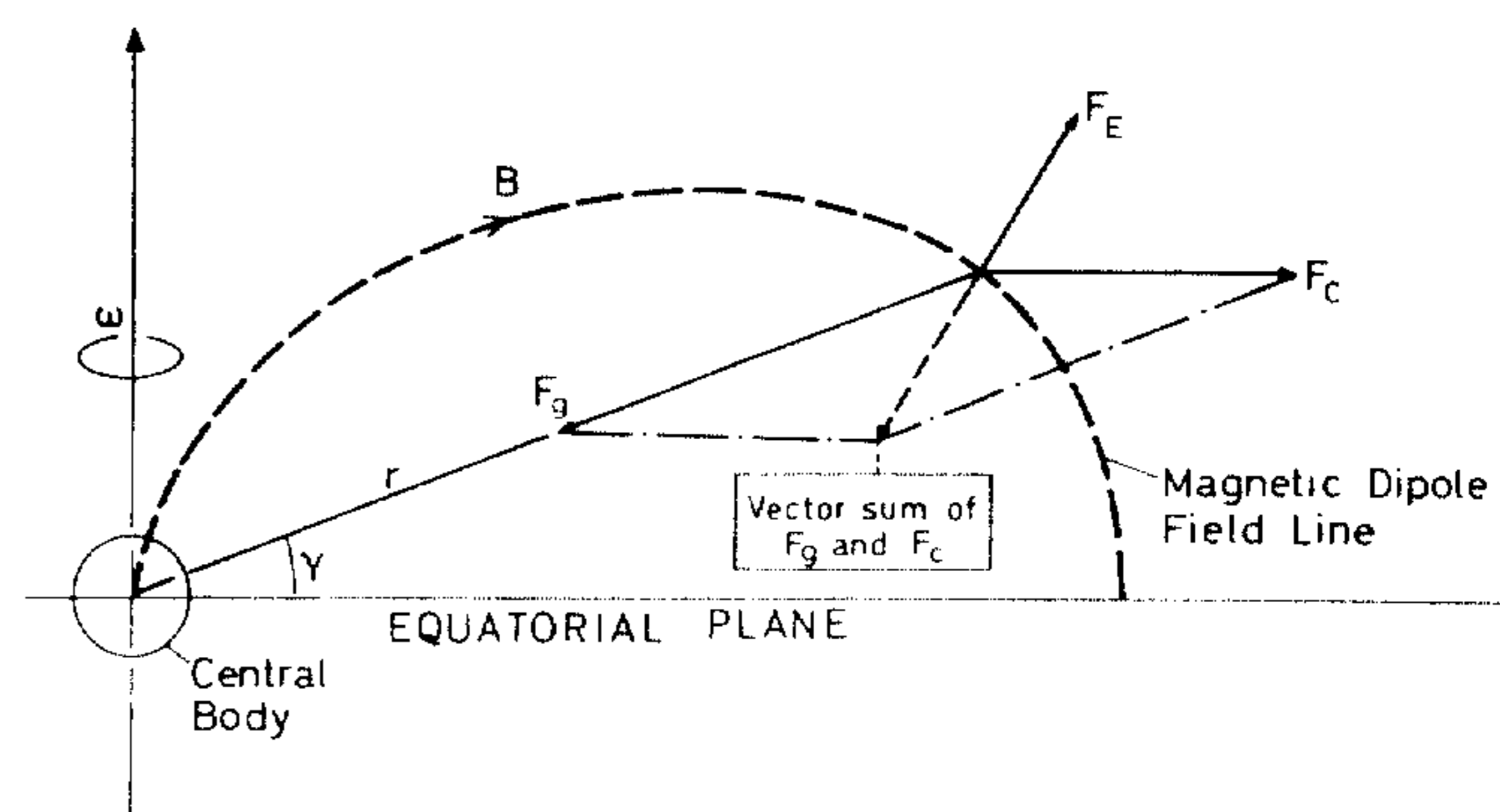


Fig. 10. Partially corotating plasma. The gravitation of the central body on a plasma cloud or grain is balanced to 2:3 by the centrifugal force and to 1:3 by electromagnetic forces. When at the PPT the latter disappear, the partially corotating medium contracts by a factor  $\Gamma = 2:3$  (a small correction brings down the  $\Gamma$ -value to 0.63-0.65) (see HAGA).

\* HAGA means two monographs by H. Alfvén and G. Arrhenius 1975 and 1976 (see Bg 3).

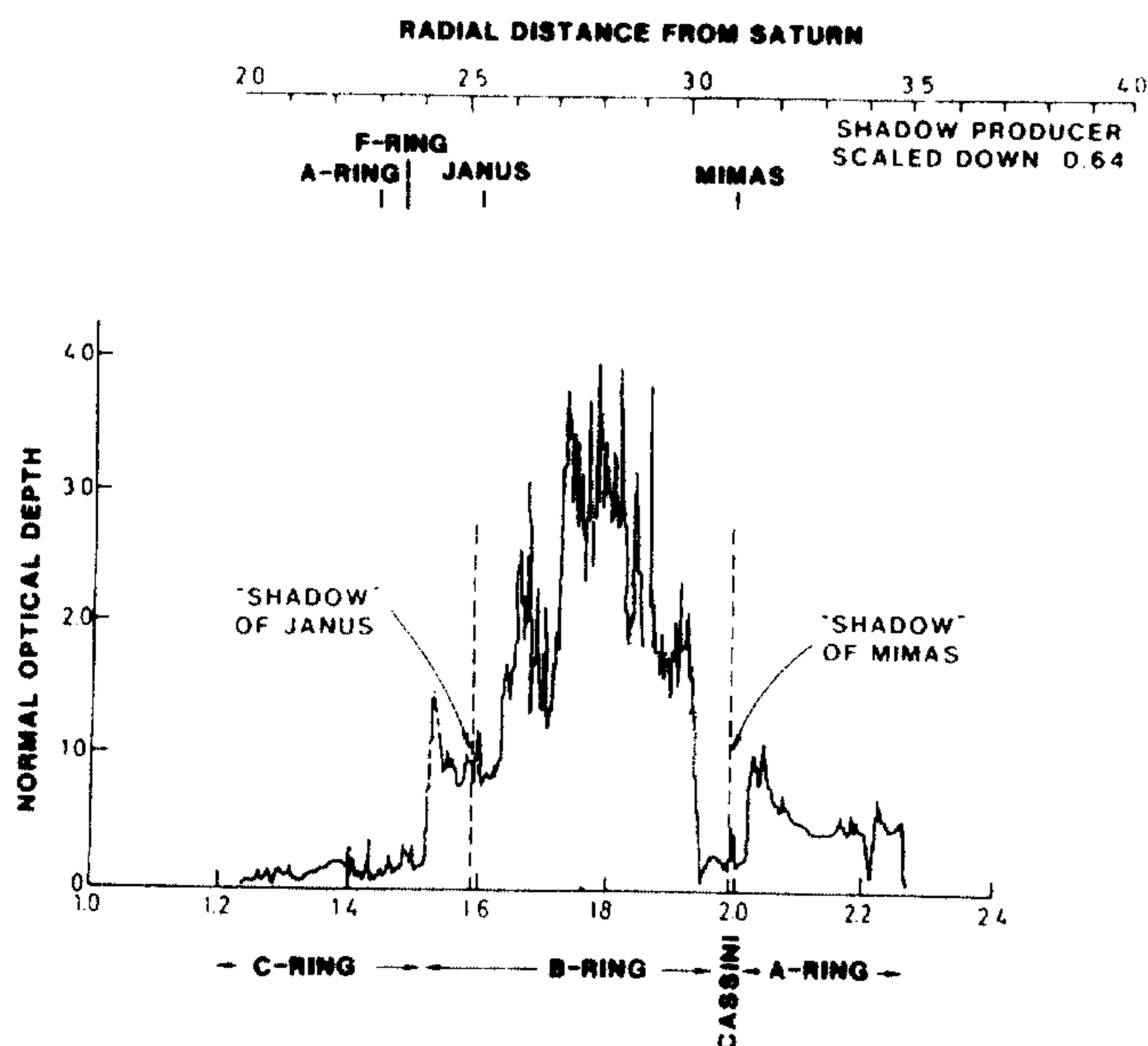


Fig. 11. Mimas and Janus (or the jetstreams out of which they are formed) sweep the regions in which they move so that they are free from plasma. At the PPT contraction these empty regions are scaled down by the factor  $\Gamma$ . This explains why there is a void region called the Cassini division, and a similar low density region at 1.60. The Saturnocentric distances of these correspond to  $\Gamma = 0.65$ .

are emplaced in those regions where they reach the "critical velocity". (When the relative velocity between a non-ionized gas and a magnetized has reached the "critical velocity" the kinetic energy of the relative velocity equals the ionisation energy (C.P.IV.6.). An unexpectedly strong interaction occurs. 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 [see Fig. 8 (table)].

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  $\Gamma$ , which should be approximately  $\Gamma = 2:3$ , but some secondary effects should reduce this value by a few percent.

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 (see HAGA).

2.1.1. *Structure of Saturnian rings.* The present structure of this is seen in Fig. 9. Figure 10 shows the basic mechanism of the contraction at the PPT (HAGA 17.2 and Bg 4, 5, and 9).

Before the PPT a plasma element (or charged grain) is acted upon by the gravitation pull  $F_g$  from the central body and the centrifugal force  $F_c$ . Moreover, because the plasma preferentially moves along the magnetic field lines, there is also an electromagnetic force  $F_E$ . In a dipole field we have for geometrical reasons  $F_c = 2/3F_g$ ;  $F_E = 1/3F_g$  (HAGA and Fig. 10). At the PPT,  $F_E$  is cancelled. As  $F_c$  alone cannot compensate  $F_g$ , the result is a contraction by a factor  $\Gamma \approx 2/3$  (a small correction decreases  $\Gamma$  to about 0.63–0.65). Fig. 11 demonstrates that if 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 satellites 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 a pronounced minimum in the inner B ring. Before the spacecraft missions to Saturn, confirmation of the cosmogonic shadow effect has already been found in four cases, so that the bulk structure of the Saturnian rings could be explained by these cosmogonic effects. (Similar confirmation

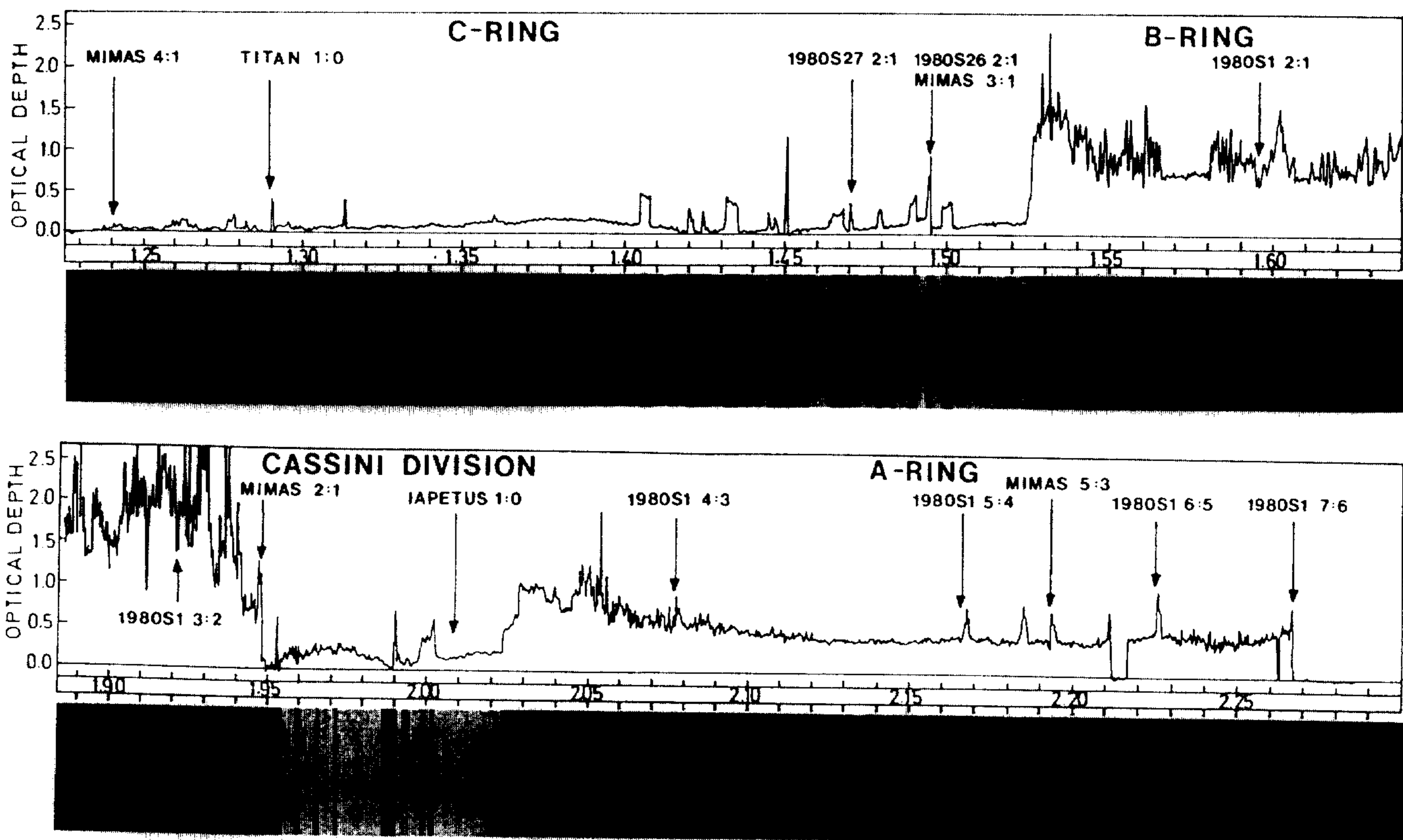


Fig. 12. Opacity of the A, B, and C rings. Below "photographic recording".

## CASSINI A-RING

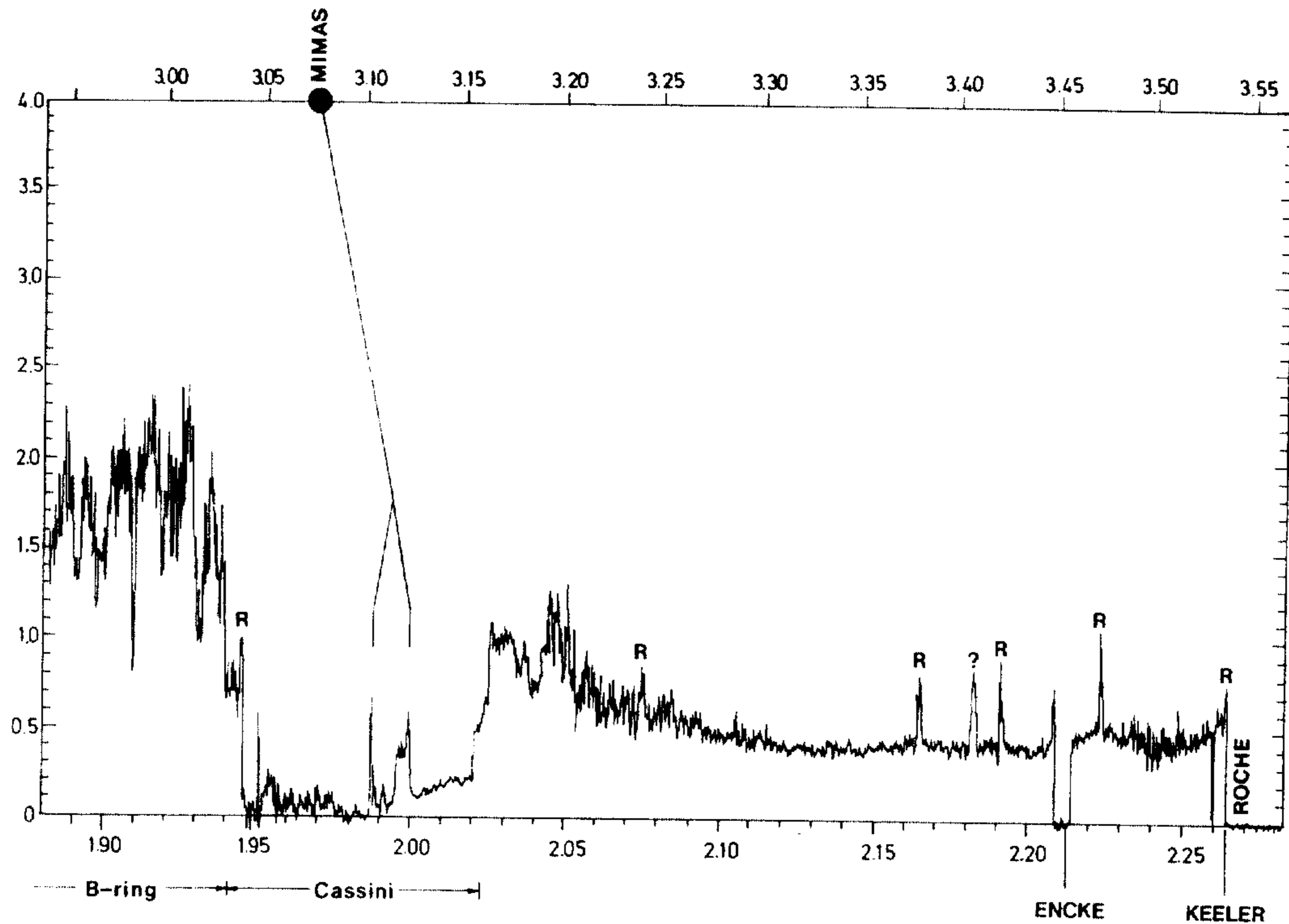


Fig. 12A. The A ring and Cassini's division. It has been believed for a long time that the outer limit of the A ring is given by the Roche limit, which probably is correct. It is limited inwards by the Cassini division which has a double ringlet in its interior. A tentative explanation is given in Fig. 13. The primary shadow of Mimas should be the void at 1.993 between the two ringlets. In the region 2.00 to 2.02 there is a void which we identify with outer secondary shadow in Fig. 14, 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 somewhat ambiguous. The Encke division at 2.21 and the Keeler division at 2.26 are difficult to explain either by resonances or cosmogonic shadow effects. A suggestion by Cuzzi that Encke is produced by a tiny satellite seems attractive, but a similar explanation is necessary for the Keeler division.

## B-RING

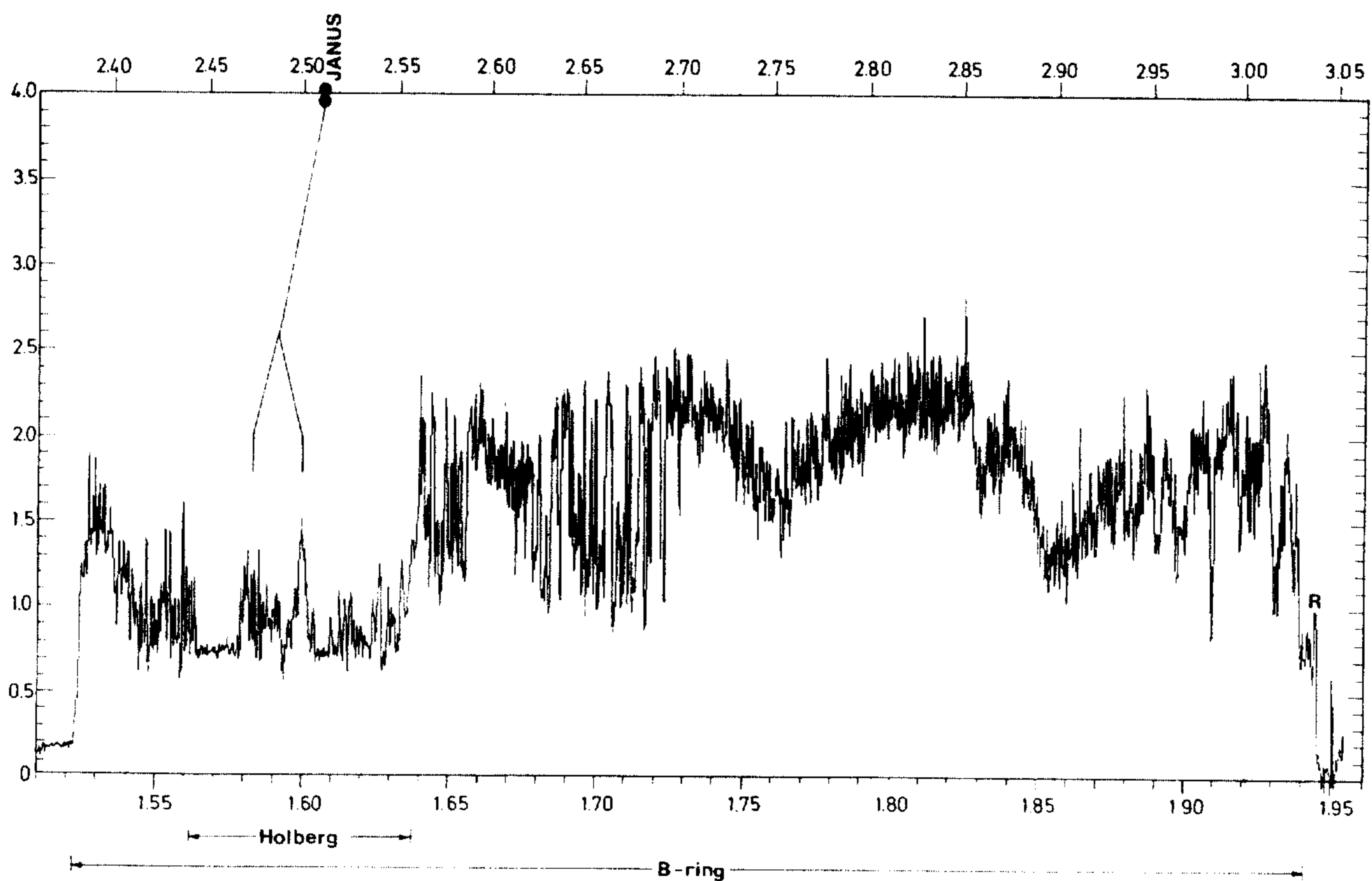


Fig. 12B. The B ring. The densest ring. The primary shadow of Janus produces a void at 1.59, surrounded by a double ringlet at 1.58 and 1.60. Outside the doublet there is a secondary shadow at 1.60-1.64 followed by a maximum at 1.65. Inside there is a secondary shadow 1.56-1.58 and still

further inside a maximum at 1.55. All this agrees reasonably well with the idealized Fig. 13. Most of the ring is characterized by large fluctuations which probably are not due to cosmogonic effects. There are no satellites which should give shadows in this region.

## C-RING

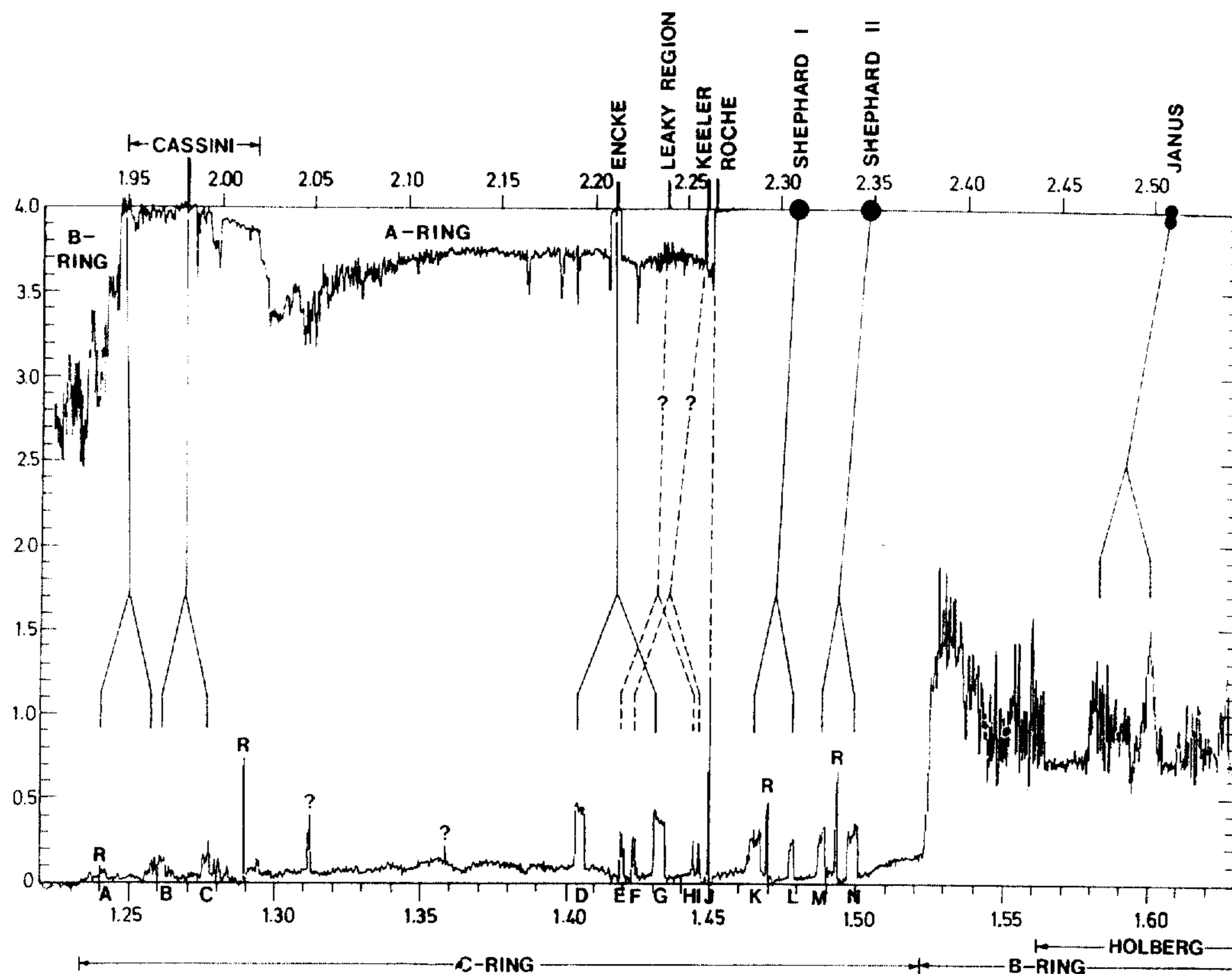


Fig. 12C. The C ring. There are three sharp maxima which are identified as gravitational resonances (cf. Fig. 12) and two other similar sharp maxima (at 1.31 and 1.36) which because of their sharpness are likely to be still unidentified resonances. In the region 1.35–1.40 there are some not very well

of the 2:3 fall down is found in the asteroidal belt; see Bg 7.) Two of these cases are demonstrated in Fig. 11.

Figure 12 shows the diagrams of the A, B, and C rings; more detailed diagrams are depicted in Figs. 12A, B, and C.

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

Preliminary attempts to understand this led to the conclusion that the primary cosmogony 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 may be as depicted in Fig. 13. It seems to give a first approximation of the general structures of the Cassini division and the Holberg minimum.

2.1.2. *The C ring.* With this as a background we shall now analyse 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.

The diagram 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 (see Fig. 12). Besides 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

structured density variations (but they show up in some strongly contrast-enhanced photographs like Fig. 14). All the rest of the structure of the ring seems to be explicable as produced by a superposition of cosmogonic shadow effect of the Shepherds and the A rings according to Fig. 13 (see Ref. [9]).

mechanisms as produced the shadows of Mimas and Janus. If we do this we find that all these maxima can be identified with cosmogonic shadows caused by the shadow producers which are shown at the upper scale (Bg 9).

There seems to be a third kind of maxima which are very wide and low, as shown at 1.358 and 1.375 (Fig. 12C). Some of the photographs show very faint ringlets deriving from these.

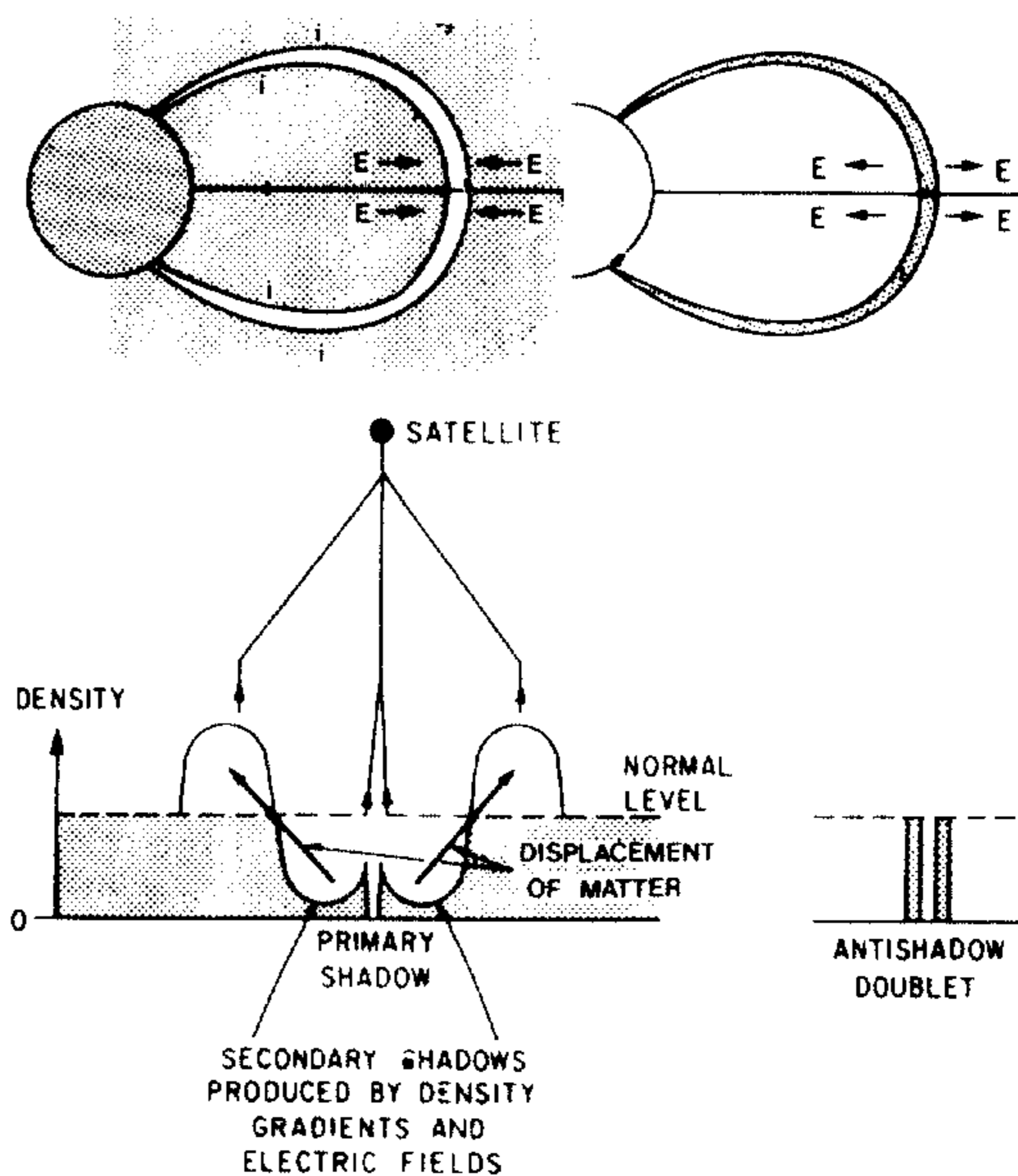


Fig. 13. Cosmogonic shadows. The primary shadow is supplemented by one secondary shadow inside and one outside the primary shadow. These are presumably produced by changes in the contraction ratio due to the density gradient caused by the primary shadow. A similar effect makes "antishadows" also doublet.

The cosmogonic shadows can be regarded as signatures of the processes we have summarized. Table I shows how the  $\Gamma$  values agree within less than one percent. Figure 14 is a picture of the Saturnian rings which shows the identifications.

There has been much discussion about gravity waves in the rings. It seems reasonable to approximate both the A ring and B ring as homogeneous discs in which such waves may proceed (but there is no convincing proofs that they affect the ring structure). However, the C ring consists of a number of distinct ringlets separated from each other by almost void regions. It seems unlikely that gravity waves are of any importance in the C ring.

2.1.3. *Conclusions. Accurate reconstruction of cosmogonic events.*

(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.

(2) Figure 12C and Table I demonstrate that it is possible to reconstruct certain cosmogonic events with an accuracy of better than 1%. 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, palaeobiology, etc., the results will be relevant to a number of sciences.

## 2.2. Other applications of the plasma universe model

A large number of other applications of the plasma universe model have been made, many of them before the term plasma universe was coined. Many of these are described in the "Background material". Of special interest are:

2.2.1. *Circuits.* Up to recently practically all descriptions of electromagnetic conditions in space have been based on pictures of magnetic fields. Electric currents have been accounted for as curl  $B$ . As has been clarified especially at the Symposium on Magnetospheric Currents [3] and the Double Layer in Astrophysics Symposium [4], this is erroneous,

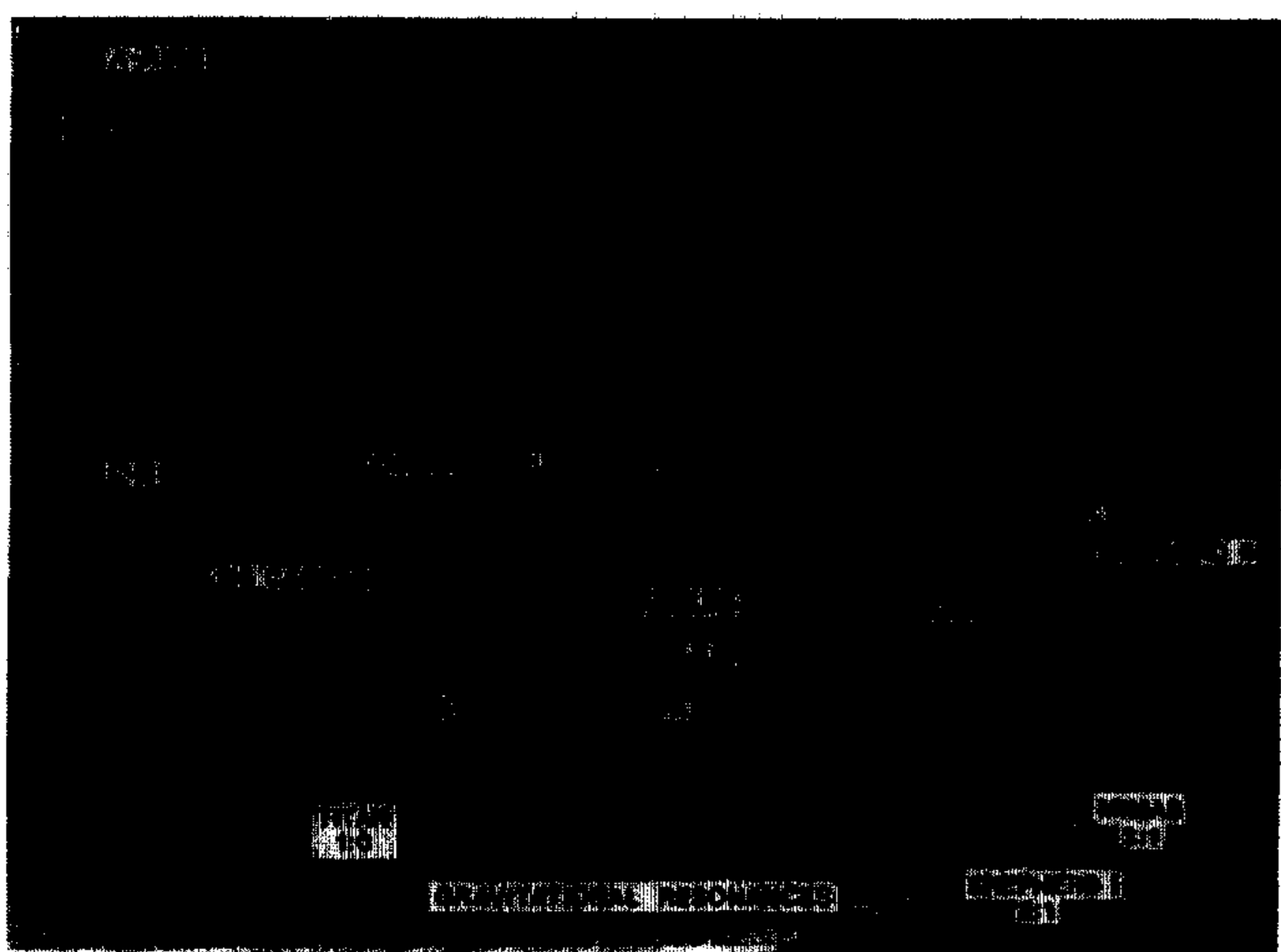


Fig. 14. Photograph (contrast-enhanced) of the Saturnian rings. Should be studied in detail in combination with Fig. 12 and Fig. 12C. In the C ring there are sharp gravitational resonances, which are shown by lines downwards on the photograph and are located at 1.290, 1.470 and 1.494 (a) (at 1.312) is unidentified but its sharpness indicates that it is a gravitational resonance. According to Fig. 12C the density varies only slowly between a and the inner Encke shadow at 1.406, 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. The outer components of the doublet from leaky region and Keeler are very small according to Fig. 12C — presumably because of closeness to Roche — and are not visible in the photograph.

because there are a number of essentially electrostatic phenomena which require that electric currents and the circuits in which they flow are *explicitly* introduced (see Bg 5).

Basically the same circuit can be used to account for the electromagnetic conditions in the auroral region, in the heliosphere, and in intergalactic space (C.P. III). The formation of the two giant plasma clouds in Fig. 4 are explained by a transfer of energy from the rotation of the central galaxy by means of the same circuit is transfers energy from plasma clouds in the magnetosphere to electric double layers in which it is accelerating charged particles to high or very high energies (C.P. Fig. III.8).

2.2.2. *Magnetosphere-ionosphere interactions — as a manifestation of the Plasma Universe.* As the universe almost entirely consists of plasma, the understanding of astrophysical phenomena must depend critically on our understanding of how matter behaves in the plasma state. *In situ* observations in near earth cosmic plasmas offer an excellent opportunity of gaining such an understanding [5]. The near earth plasma not only covers vast ranges of density and temperature but also a rich variety of complex plasma physical processes.

Hence an application of the plasma universe models makes it easier to understand the near earth processes. Vice versa, the study of near-earth processes gives us important information which can be applied to a better understanding of interstellar and intergalactic plasma phenomena.

2.2.3. *Cosmology.* In the plasma universe the big bang hypothesis will meet serious difficulties (see C.P. VI).

## 3. Conclusions

The transition from the geocentric to the heliocentric cosmology is usually attributed to the Copernican theory. This is only partially correct. Galileo's introduction of the telescope was probably more important, because it gave a large quantity of new observational material. In fact the heliocentric cosmology had been proposed 2000 years earlier by Aristarchus, but without telescope he could not prove it.

Spacecraft has given us an enormous wealth of new information. The purpose of this paper is to give a sketch of possible consequences of this for our views of our cosmic environment. It will require much work before we can construct a new picture of the universe which incorporates our new knowledge.

This paper is a summary of the publications which are quoted in the reference list. Further references are found in them.

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