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COSMOGONIC SCENARIO

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Abstract

A recent analysis demonstrates that the Saturnian C ring and essential features of the B and A rings agrees with the plasma cosmogony approach with an accuracy of about 1% or even better. This starts a transition of cosmogony from speculation to real science. Based on the monographs by Alfvén and Arrhenius on the evolution of the solar system a cosmogonic scenario is tentatively proposed. This outlines the evolution of an interstellar cloud and the formation of stars surrounded by solar nebulae under the combined action of gravitational and electromagnetic forces. Further, matter falling in from the solar nebula towards the sun is processed by newly clarified electromangetic processes and a plasma-planetesimal transition (PPT) occurs. Planetesimals accrete to planets and around some of them the same process in miniature leads to the formation of satellites. Also the origin of comets is discussed.

1. Cosmogony in a State of Transition

During the Fall 1984 och the Winter 1985, a series of lectures and discussions at the Seminars in Cosmic Plasma Physics at UC San Diego have been devoted to the evolutionary history of the solar system. The motivation was that cosmogony work reported here seems to lead to a transition from speculation to serious science. In part this is caused by in situ measurements in the magnetospheres, and the realization that essential parts of cosmogony should be treated as an extrapolation of magnetospheric research. A survey of this is given in H. Alfvén "Cosmic Plasma" (in the following referred to as CP) 1981 and in Alfvén 1984a. Further, observations of dust in interplanetary space, especially in the planetary rings, and the increased interest in comets is producing a new field of science, "gravito-electrodynamics" (Mendis et al., 1983). Moreover, radio and infrared, visual and ultraviolet observations of interstellar clouds and circumstellar discs give information on dust clouds, which are likely to be solar systems in formation. Finally, investigations of the detailed structure of the massive Saturnian rings have demonstrated that it is possible to reconstruct some of the cosmgonic processes -- which probably took place 4-5 billion years ago -- with an accuracy of a few percent (Alfvén, 1983, 1984a, 1984b). The most recent results demonstrate that in essentially the whole C ring and in important features of the A and B rings the accuracy is better than 1% (Alfvén, Axnäs, Brenning, Lindqvist, 1985). All this indicates that cosmogony is entering a new phase.

The theoretical discussion this fall and winter was to some extent based on the quoted monograph (Alfvén, 1981) which gives a survey of the "paradigm transitions" caused to a large extent by in situ measurements in the magnetosphere (see also Alfvén, 1984a). During the fall, Lyons and Williams (1984) published their monograph Quantitative Aspect of Magnetospheric Physics. This is excellent, also as a textbook in general cosmic plasma physics, and should be

read by all students in the field, including astrophysicists.
Several of the participants in the seminars have first-hand knowledge of space measurements, and a number of guest speakers have broadened our views. Part of the discussions were devoted to an update of Alfvén and Arrhenius, 1975, 1976 (referred to here as HAGA).

The present paper is an attempt to summarize what we believe to be the most important results of the seminars for the construction of a cosmognic scenario (Figure 1). As we are in a transition from speculation to science, large parts of the scenario must be speculative. To clarify all of the important problems would probably require the equivalence of 50-100 Ph.D. dissertations! We believe that in the present state a scenario should be useful for locating the fields of research which are most important for speeding up the transition. We do not claim the present scenario to be sacrosant, but we hope it to be a challenge to everybody to construct a better one.

2. "Primeval" Plasma

The solar system, including the sun, is likely to derive from an interstellar plasma cloud, the primeval plasma. As the basic property of a plasma seems to be the same everywhere, studies of plasmas in the magnetospheres and solar wind are valuable for clarifying the properties of the primeval plasma. As direct visual observations often give more of an intuitive feeling for a phenomenon than any package of computer data, we should look at the aurora (which is a cosmic plasma penetrating down to the ionosphere) and at the solar corona in order to get a general understanding of what a plasma in cosmos is like. From this we infer that the primeval interstellar plasma is penetrated by a complicated network of electric currents which, as in the plasma we observe in our neighborhood, often produces filaments with dimensions from a few Larmor radii or Debye length up to visible dimensions (see CP, especially Chapters II and IV:8). It is highly inhomogeneous, with parameters like density, magnetization, temperatures, and chemical abundances varying by orders of magnitude. This means that in some respects it is similar to the solar corona, which has a filamentary structure, with temperatures varying from more than 10^6 degrees to less than 10^4 degrees (in prominences). Interstellar plasmas are usually much cooler, and even if the average density of them is much smaller, there may be local very dense regions.

The plasmas we are mainly interested in are the dusty plasmas. Some of their properties have been studied in connection with planetary rings and cometary dust tails (see, e.g. Mendis *et al*. 1983; Horanyi and Mendis 1985). Still, we are just in the befinning of explaining their properties, especially when the dust content is very large.

A dusty plasma consists of electrons, ions, and dust grains ranging in size from macro-molecules upwards. The grains are normally electrically charged, e.g. by absorbing electrons or through photoelectric emission. Sometimes in regions where the kinetic temperature is low (<< $10{,}000^0$) there are also neutral atoms and molecules.

In combination with gravitation, the electromagnetic forces may produce interstellar clouds which are usually dusty. Because the grains have charge to mass ratios q/m which are much smaller than the valus for electrons and ions, the forces acting on dust grains differ so much from the forces acting on the plasma in general that the dust may accrete in certain regions, eventually forming dust balls and larger solid bidies. A scenario of this kind is discussed by Alfvén and Carlqvist, 1978). When these have reached a certain mass (perhaps 10^{23} kg) they may accrete the gaseous surrounding so that the mass increases more rapidly and a partially gaseous "stellesimal" accretion occurs, similar to the planetesimal accretion of planets. See the upper part of Fig. 1.

3. Sun and Solar Nebula

When the sun was produced it was probably surrounded by a vast, almost empty region, perhaps 10^2 AU or larger, which is enclosed in the rest of the "primordial" cloud out of which the sun was formed (see HAGA 1976, Chapter 16 and CP, Chapter V). This cloud may act as a cocoon, which protects the region in which the cosmogonic processes work from possible disturbances from outside.

Cloudlets of neutral atoms, molecules and dust with low q/m values fall in towards the Sun and are stopped when the velocity of their falls reaches the "critical velocity". This seems to account for the band structure of the solar system (HAGA 1976, Chapter 21).

Electric currents of the same type as observed in the auroral region transfer angular momentum from the sun to the dusty plasma accumulated in the bands, thus bringing the plasma into a state of partial corotation. When this state is reached a "plasma-planetesimal transition" (PPT) occurs. This process is of decisive importance to the present structure of the solar system. It can best be studied in those regions where the planetesimals have not accreted to bigger bodies. Such regions are the asteroidal belt (with very low average density!) and - for the similar processes around planets - the massive Saturnian Rings (inside the Roche limit!). All these processes occur in the gravitational field of the sun, which means that they are due to a combined action of electromagnetic and gravitational effects.

4. Planets (and Asteroids)

The planetesimals formed at the PPT aggregate to jet streams which eventually accrete to planets (see HAGA, Chapters 12 and 21). In the asteroidal belt the jet streams may be identified with some asteroidal families (HAGA, Fig. 3.4.6).

A future development of the asteroidal belt during billions or trillions of years may result in one or several planets in the asteroidal belt.

Gaseous planets may be formed from planetesimals like solid planets, but when the planetesimals have reached a certain size the gas in their surroundings is accreted in the same way as we have discussed in Section 2 for stellesimal accretion. This makes the gaseous planets intermediate between solid planets and stars.

5. Comets

Long-period comets and meteoroids are usually considered to be produced in the outer regions of the planetary system and perturbed into nearly parabolic orbits by celestial mechanics effects. There seems to be no decisive arguments against this view. An alternative theory using the same basic mechanism is the following (HAGA, Chapter 19).

The solar magnetic field can only transfer angular momentum out to a certain distance. The PPT outside this distance, for example in the cocoon, results in bodies with small and random angular momentum. Such bodies may be identified as comets and meteroids in almost parabolic orbits. The Oort cometary reservoir may be a residue of the cocoon. So it is more the location where comets are formed than the mechanism which forms them that is still in doubt. See right side of Fig. 1.

6. Satellites

When a planet is formed and has become magnetized it can process a surrounding dusty plasma in the same way as the Sun did, hence forming satellite systems. According to what in HAGA is called the "hetegonic pronciple", the basic cosmogonic processes forming satellites around a magnetized planet are the same as those forming planets around the sun. The left part of Fig. 1 shows "satellite formation by repetition in miniature" of the planet forming process. This means that instead of "Sun surrounded by Solar nebula" we should read "Planet surrounded by a similar nebula" and instead of "Plasma Planetesimal Transition" we should read "Plasma satellitesimal transition".

7. Gravito-Electrodynamic Focussing

It is obvious that a disintegrating comet may produce a meteor stream, and that collisions between asteroids may result in an asteroidal family. However, the planetesimal mechanism requires that the accretion of asteroids and comets should pass a jet stream phase, which for a comet, should look like a meteor stream (HAGA 1976, Chapter 14 and 19). In some cases these identifications encounter quantitative difficulties. If cosmogonic meteor streams were similar to the present ones it is not obvious how they were held together unless the proto-jet streams of comets at cosmogonic times were much denser than present meteor streams.

Mendis and his group have demonstrated that a collection of charged dust grains moving in relation to a plasma constitutes an electric current. Houpis and Mendis (1982) used this to explain the formation of ringlets in the Saturnian ring system. Generalizing this effect may give a solution for the difficulty mentioned above. Similar currents should also flow in other dusty plasmas, and may be essential for the focussing of jet streams. In principle, meteor streams and asteroidal families may be focussed by this mechanism (but this remains to be demonstrated quantitatively and generally).

8. The Saturnian Rings

The application of the theory of the PPT allows us to interpret essential features of the Saturnian rings such as

Cassini's division, the Holberg minimum, and the B-C ring limit as "cosmogonic shadow" produced at a 2:3 contraction associated with the PPT (Alfvén 1984a, 1984b). The most recent results (Alfvén, Axnäs, Brenning and Lindqvist, 1985) show that practically all those features of the C ring which are not due to resonances can be accounted for as cosmogonic shadows with an accuracy better than 1%. Moreever, essential features of the A and B rings seem to be due to the same mechanism.

Accepting the hetegonic principle we may conclude that the Saturnian results are representative of all cosmogonic magnetospheres. The surprisingly high accuracy (1%) demonstrates that at least certain parts of our scenario must be taken seriously. The fact that similar results are obtained for the asteroidal belt gives further support for this view.

If we accept these conclusions, the PPT must have occurred in an extremely quiet plasma. This requires that

(a) There was no appreciable turbulence. To cosmogonies based on turbulence this will present a difficulty.

(b) Unlike the present-day magnetospheres, cosmogonic magnetospheres were not disturbed by magnetic storms or deformed by solar wind. This requirtes that there was little or no solar wind impinging on the cosmogonic magnetospheres. If we consider a state when at least the heliographic equatorial region of interplanetary space was filled with dusty plasma, jet streams, etc., it is quite reasonable that near the equatorial plane solar perturbations could not penetrate very far from the Sun. However, the intense heating of the Sun and the regions close to the Sun which must be associated with the formative processes are likely to cause a solar wind (or solar gale), but this should be confined to high latitudes.

(c) If there are perturbations in interstellar space the cosmogonic magnetospheres must be protected from these. This means that the solar system in formation must be surrounded by a cocoon. This may be identified with a residue of the interstellar source cloud which we have discussed already. See Section 3 and Fig. 2.

9. Discussion

This scenario has a certain degree of instrinsic consistency. The same basic process produces both the planetary system and the satellite systems by a combination of four phenomena (a) critical velocity arrest, (b) angular momentun transfer by the auroral current system, (c) PPT, and (d) the planetesimal accretion.

None of these phenomena is yet accounted for by a theory which satisfies sophisticated theoreticians, but there are sem-empirical models which seem to be consistent with quite a few basic properties of cosmic plasmas (See CP). It may be possible to account for comets by the same processes - - without angular momentum transfer. The stellesimal formation of stars is basically the same as the formation of gaseous planets.

When we have become familiar with these plasma processes it is possible that the present structure of the solar system will appear as a straghtforward and unavoidable result of the properties of a "primeval" dusty plasma.

Acknowledgements

The list of speakers at the seminars included S.-I. Akasofu, C. Kennel, L. Lyons, W. Olson, R. Torbert, E.C. Whipple. This paper is an attempt to synthesize what the authors have interpreted as the most important contributions. We also wish to thank Dr P. Carlqvist for valuable criticism.

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11. Figure Captions

Fig. 1 Cosmogonic Scenario as direvied in Sections 3 - 6.

Fig. 2 Qualitative picture of the early state of a solar system in formation.

Fig. 3 Later state: Planetesimals are forming a disc in the equatorial plane where planets are accreted. The remnants of the solar nebula may act as a "cocoon", protecting the forming solar system from galactic dusturbances. During the formation large energy quantities must be released in the sun and its close environment. This should result in emission of solar wind, but only at high latitudes. Near the equatorian plane dust and gas forming planets will prevent major perturbations from reaching the regions where the formative processes occur.

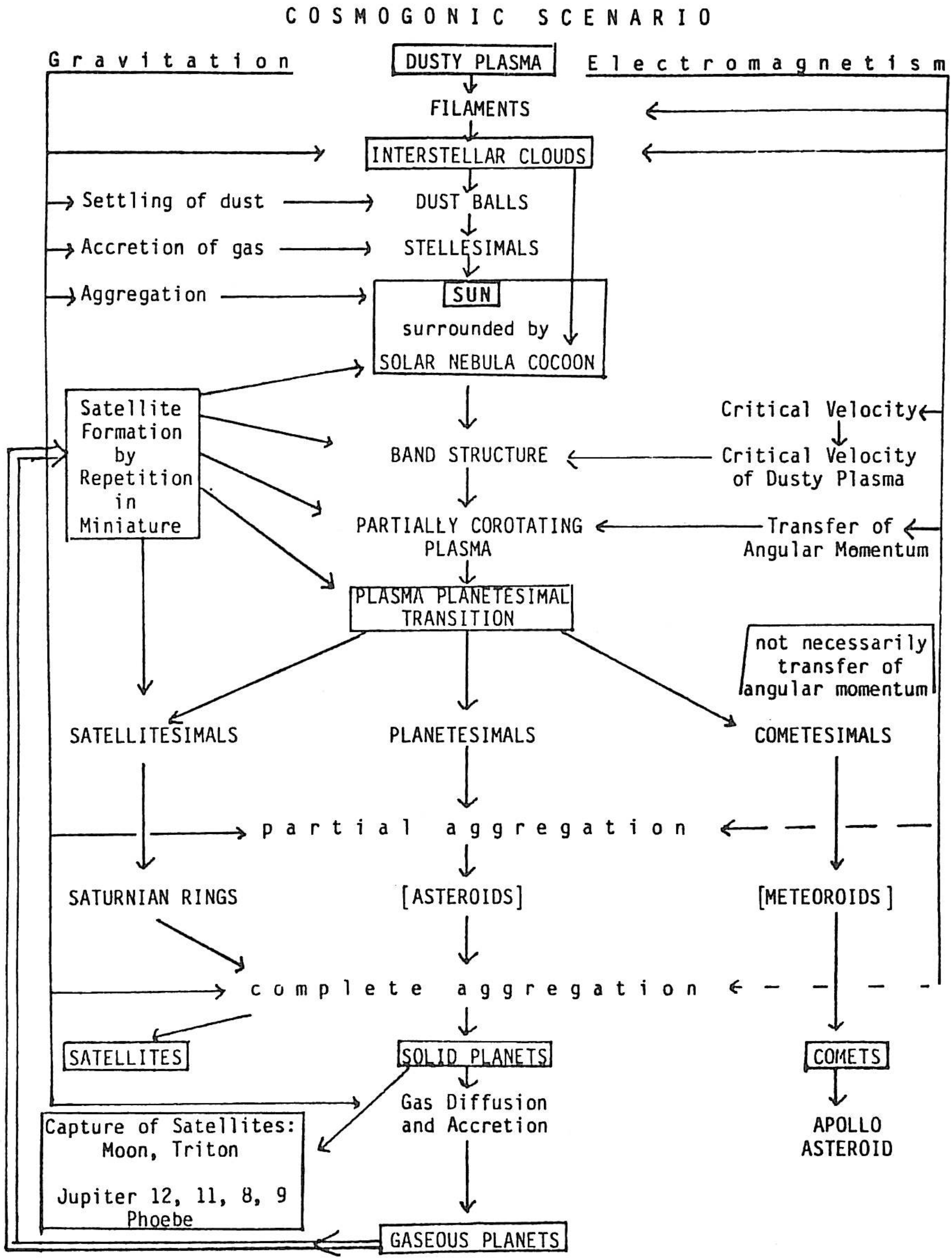
COSMOGONIC SCENARIO
Gravitation
DUSTY PLASMA
Electromagnetism
FILAMENTS
INTERSTELLAR CLOUDS
Settling of dust
DUST BALLS
Accretion of gas
STELLESIMALS
Aggregation
SUN
surrounded by
SOLAR NEBULA COCOON
Satellite Formation by Repetition in Miniature
Critical Velocity
BAND STRUCTURE
Critical Velocity of Dusty Plasma
PARTIALLY COROTATING PLASMA
Transfer of Angular Momentum
PLASMA PLANETESIMAL TRANSITION
not necessarily transfer of angular momentum
SATELLITESIMALS
PLANETESIMALS
COMETESIMALS
partial aggregation
SATURNIAN RINGS
[ASTEROIDS]
[METEOROIDS]
complete aggregation
SATELLITES
SOLID PLANETS
COMETS
Gas Diffusion and Accretion
Capture of Satellites: Moon, Triton
Jupiter 12, 11, 8, 9
Phoebe
APOLLO ASTEROID
GASEOUS PLANETS

Fig. 1

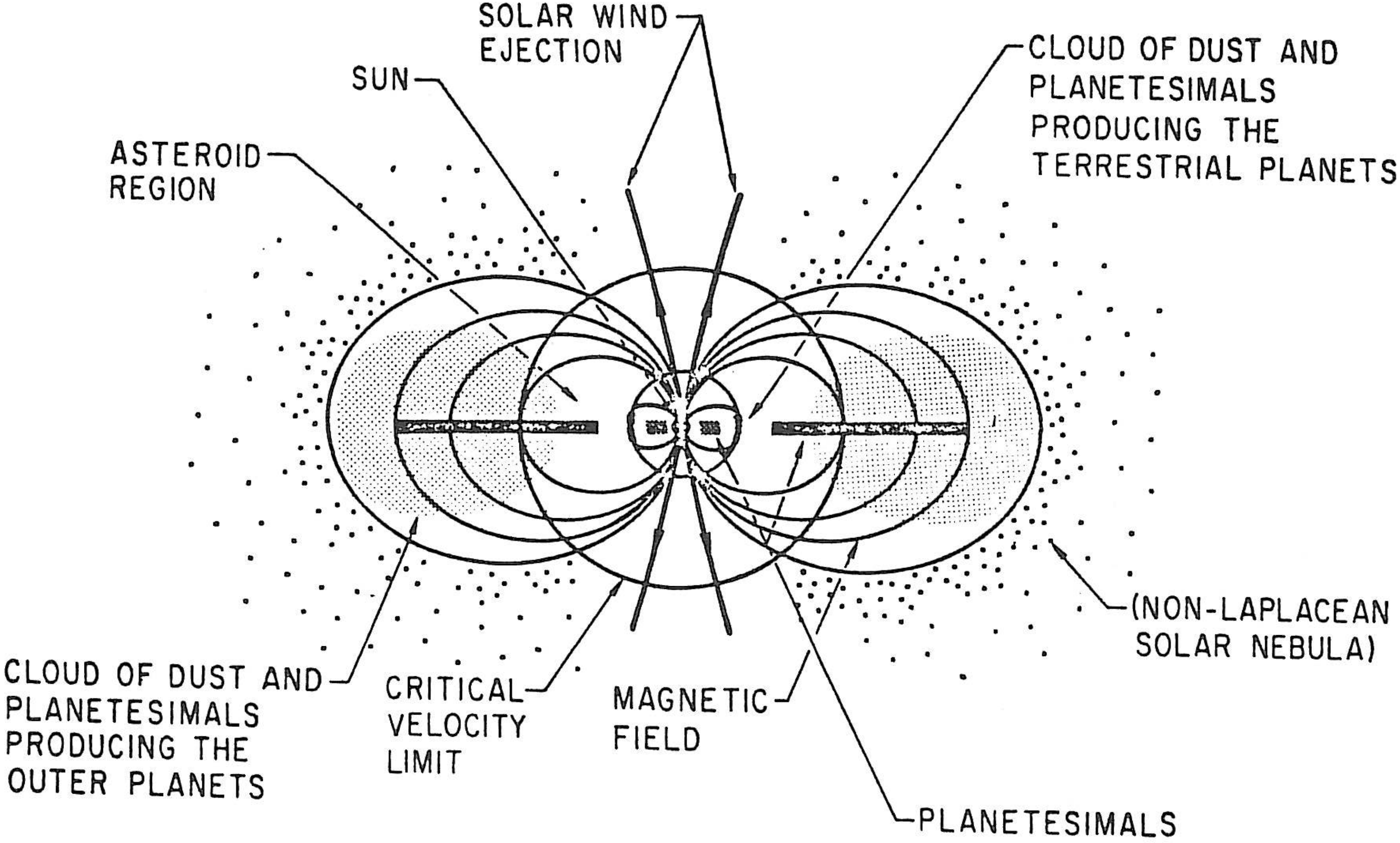
SOLAR WIND
EJECTION
SUN
ASTEROID
REGION
CLOUD OF DUST AND
PLANETESIMALS
PRODUCING THE
TERRESTRIAL PLANETS
(NON-LAPLACEAN
SOLAR NEBULA)
CLOUD OF DUST AND
PLANETESIMALS
PRODUCING THE
OUTER PLANETS
CRITICAL
VELOCITY
LIMIT
MAGNETIC
FIELD
PLANETESIMALS

Fig. 2

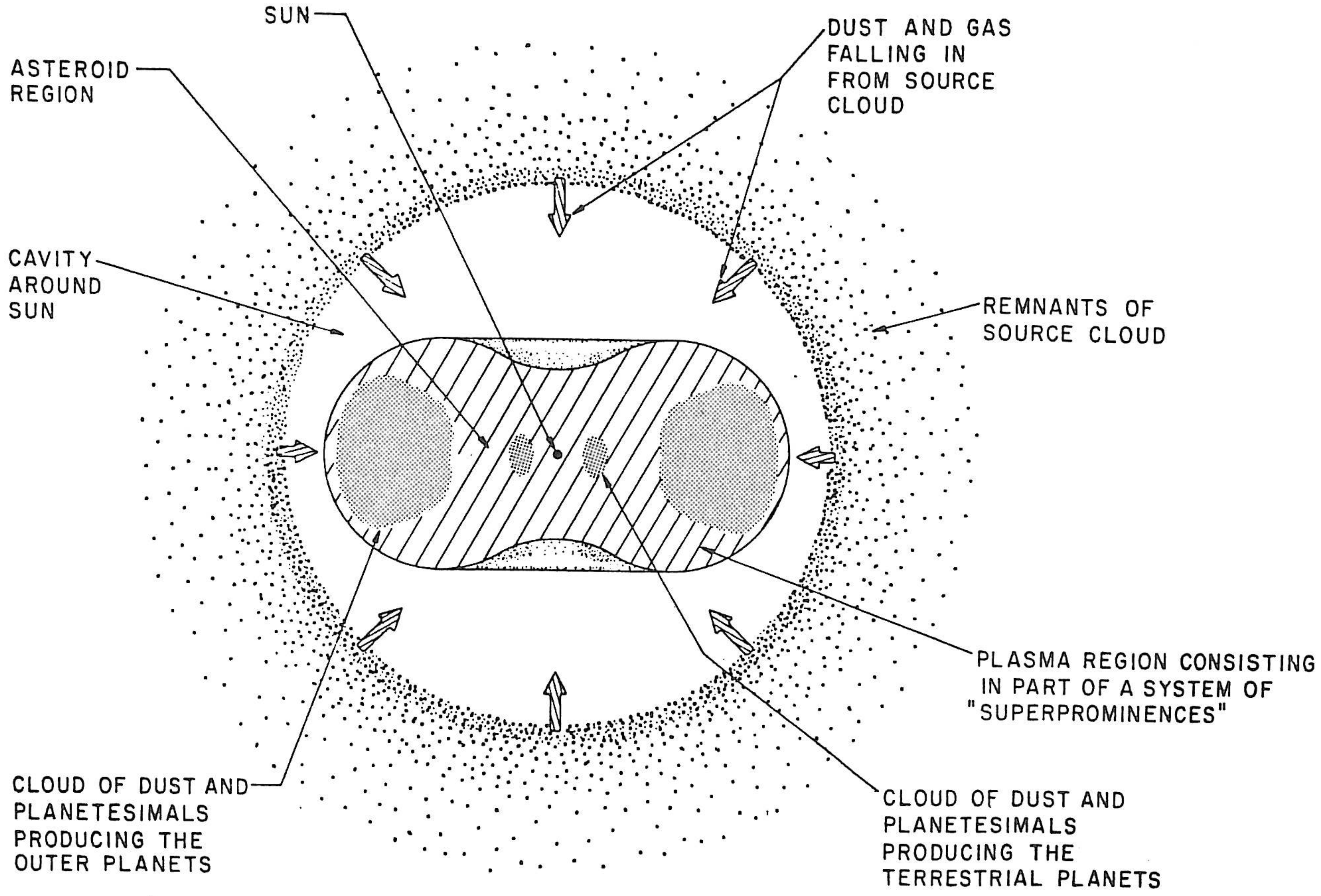
SUN
ASTEROID REGION
DUST AND GAS FALLING IN FROM SOURCE CLOUD
CAVITY AROUND SUN
REMNANTS OF SOURCE CLOUD
PLASMA REGION CONSISTING IN PART OF A SYSTEM OF "SUPERPROMINENCES"
CLOUD OF DUST AND PLANETESIMALS PRODUCING THE OUTER PLANETS
CLOUD OF DUST AND PLANETESIMALS PRODUCING THE TERRESTRIAL PLANETS

Fig. 3

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Key words: Origin of solar system, Plasma cosmogony, Formation of planets, Formation of satellites, Formation of comets, Absence of turbulence.