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General Discussion (Results of Recent Space Missions)

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T. Gold, F.R.S. (*Centre for Radiophysics and Space Physics, Cornell University, Ithaca, New York 14853, U.S.A.*). There is a simple way of accounting for the accumulation of material to make discs or satellites around planets. At a time when still a significant amount of planetary material was in the form of grains or pieces, but not yet collected into the planets, collisions between such material must have been common. In collisions occurring near a planet, some of the collision debris may emerge with less than the velocity of escape from the planet, and therefore remain bound on a satellite orbit (unless it collides with the planet). As more such orbits of arbitrary inclination and eccentricity become populated, collisions between this bound material become important in reshaping the distribution of orbits.

Since each particle must have the plane of its orbit precess around the pole of the planet's spin (due to the planet's oblateness and the resulting quadrupole moment of its gravitational field) the long term mean of each particle's angular momentum is in the direction of the planet's spin, but the sense of the orbital motion need bear no relation to the sense of the planet's spin. Collisions will now collapse the cloud of particles eventually to the plane defined by the mean angular momentum, and, because of the precession, that will be the planet's equatorial plane.

However, since this argument does not have anything to say about the sense, it is quite possible that retrograde discs can be set up. The fact that a disc is in the equatorial plane of the planet has suggested a connection with the spin of the planet; but in this explanation it is a connection only with the oblateness, i.e. an effect dependent on the square of the spin, and therefore independent of sign.

The sense of the spin will become important, however, the moment any subsequent tidal or other frictional evolution of orbits is significant, and a prograde motion will then result in a longer lifetime than a retrograde one. If the majority of orbiting rings are found to be prograde, this might be taken to imply that frictional forces have been important. This means either that there are satellites of substantial mass in the system, so that their tidal interaction is important, or that magnetic or gas-dynamical effects have played a part in shaping the present configuration.

The preference that planetary spins show for prograde motion must be attributed to the circumstances applying at an earlier stage. The bulk of the planetary masses must have been collected up when the density of the solar nebula was much too high to allow any 'wild' orbits to be populated. The accretion process from the regular orbits appears to favour a prograde spin for the forming planet.

T. Gold, F.R.S. The manner in which a small satellite would be destroyed by tidal stress is interesting to discuss in detail. If tidal drag brings a satellite closer to its planet, it will eventually enter what is called the Roche Zone. This is that interval of distance from the planet in which a part, but not yet all, of the satellite will be subject to disruption.

Consider a satellite that is small enough to have a rather arbitrary shape, quite different from spherical; and suppose that it is made of rigid debris, broken up so that on the whole it has no tensile strength. This is probably a common situation. Such a body will lose its spin in the tidal régime and orient itself in synchronous rotation so that the minor axis of inertia, the long axis of the shape, lies in the radial direction to the planet. As it enters the Roche Zone, the surface material at the cap nearest to and farthest from the planet will be the first to experience a force directed away from the surface; if it is not held by a tensile strength, i.e. if it is loose debris for example, it will fall off. The long body axis will become shorter. The fallen-off material cannot reach any very different orbit, and its precise orbit has to be calculated with the full elaboration of the three-body problem involving even the non-spherical components of the planet and satellite fields. Collisions between the fallen-off material may cause some of it to reach orbits that were not directly accessible in the first place.

The satellite will become more nearly round as a result of this loss of material. As it comes closer to the planet, the process continues, and it may proceed until the initially largest body axis has become shorter than another. The body will then flip over, making the new longest axis the one oriented along the radius vector to the planet. In this way the body will be maintained in a near-spherical shape, but get smaller. Eventually it will reach the inner edge of its Roche Zone where even a sphere is pulled apart, and there it will disintegrate. We note that all the rings of Uranus are in just the region expected to be the Roche Zone for a density between that of rock and those of ices.

Relevant paper

Dermott, S. F., Gold, T. & Sinclair, A. T. 1979 *Astr. J.* **84** (8), 1225–1234.

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