EFFECTS OF A GIANT IMPACT ON URANUS.

W. L. Slattery, Los Alamos National Laboratory, and W. Benz and A. G. W. Cameron, Harvard-Smithsonian Center for Astrophysics.

People usually regard the 97 degree tilt of the Uranus rotational axis, which gives the planet a retrograde spin, as perhaps its most distinguishing feature. We discuss here a series of giant impacts on the planet, a majority of which can induce a rotation rate in Uranus of at least the present value, starting with a non-rotating Uranus. Since a giant impactor can strike Uranus at an arbitrary angle with respect to the ecliptic plane, the probability of producing a retrograde spin is about 50 per cent. Thus the more interesting quantity is the rotation rate (or period, which we will use hereafter), and not the inclination of the rotation axis. It is significant, however, that the regular satellites of Uranus orbit in the plane of its equator in the same direction as its spin. If they had been formed prior to the giant impact, and the giant impact had tilted the spin axis by more than 90 degrees, then the equatorial bulge would have tended to pull the satellite orbits around so that they travelled in a direction opposite to the planetary spin. Thus it appears likely that we should look for conditions in the giant impact which leave condensable material in orbit in the plane of the collision, which will become the equatorial plane.

We do not know when the giant impact might have occurred, but we think it would have been early in the life of the solar system, late in the general planetary accumulation process. For this reason we can use present-day models of Uranus only as a general guide, since the precollision Uranus was probably hotter than now, and it may have been more thoroughly mixed, with rock and iron dissolved in a convective atmosphere. However, we have followed conventional planetary structures by giving both the protouranus and the impactor an iron core surrounded by a rock (dunite) mantle. The impactor was given an atmosphere composed of the ices H_2O, NH_3, and CH_4 in relative solar proportions. The atmosphere of the protouranus was composed of these ices with an additional 2 $M_\oplus$ of hydrogen and helium mixed into them.

Simulations of possible giant impacts were made with the 3D smooth particle hydrodynamic (SPH) code that we have used to study giant impacts on the protoearth and on protomercury (1–4). We used 5000 particles in the protouranus and 3000 particles in the impactor. Equations of state (EOS) came from a variety of sources. For iron and dunite we used tabular versions of the ANEOS EOS as previously described (4). For H_2O, CH_4, H_2, and He we used tabulated relations in the SESAME EOS library (5), which themselves were collections from many sources. We did not have an EOS for NH_3, so the solar proportion of ammonia was divided between water and methane.

Many numerical simulation runs were made, varying the mass of the impactor between 1 and 3 $M_\oplus$ (but keeping the sum of the impactor and protouranus masses equal to that of Uranus today), and varying the angular momentum in the collision. The velocity at infinity in all the simulations was set at 5 km/sec.

A summary of all the simulations is shown in the figure. A horizontal line is drawn at the present value of the Uranus rotational period, 17.24 hours. The angular momenta on the abscissa are in units of 10^{43} gm cm^2/sec. The large range in collisional angular momenta corresponds to a small range of planetary rotational periods because part of the impactor can sometimes escape from the system following the collision. A low angular momentum collision leads to core impact and absorption of the impactor. Higher values of the angular momentum will lead to an atmospheric passage which slows down the impactor, which then rises to a height of several planetary radii, with its core tidally sheared and separated from the atmosphere, to be followed by an infall that absorbs most of the impactor core in the core of protouranus.

Most of the collisions leave ice in orbit. The energy released by the impact heats the protouranus so much that the ice in orbit will be in gaseous form in the temperature field of

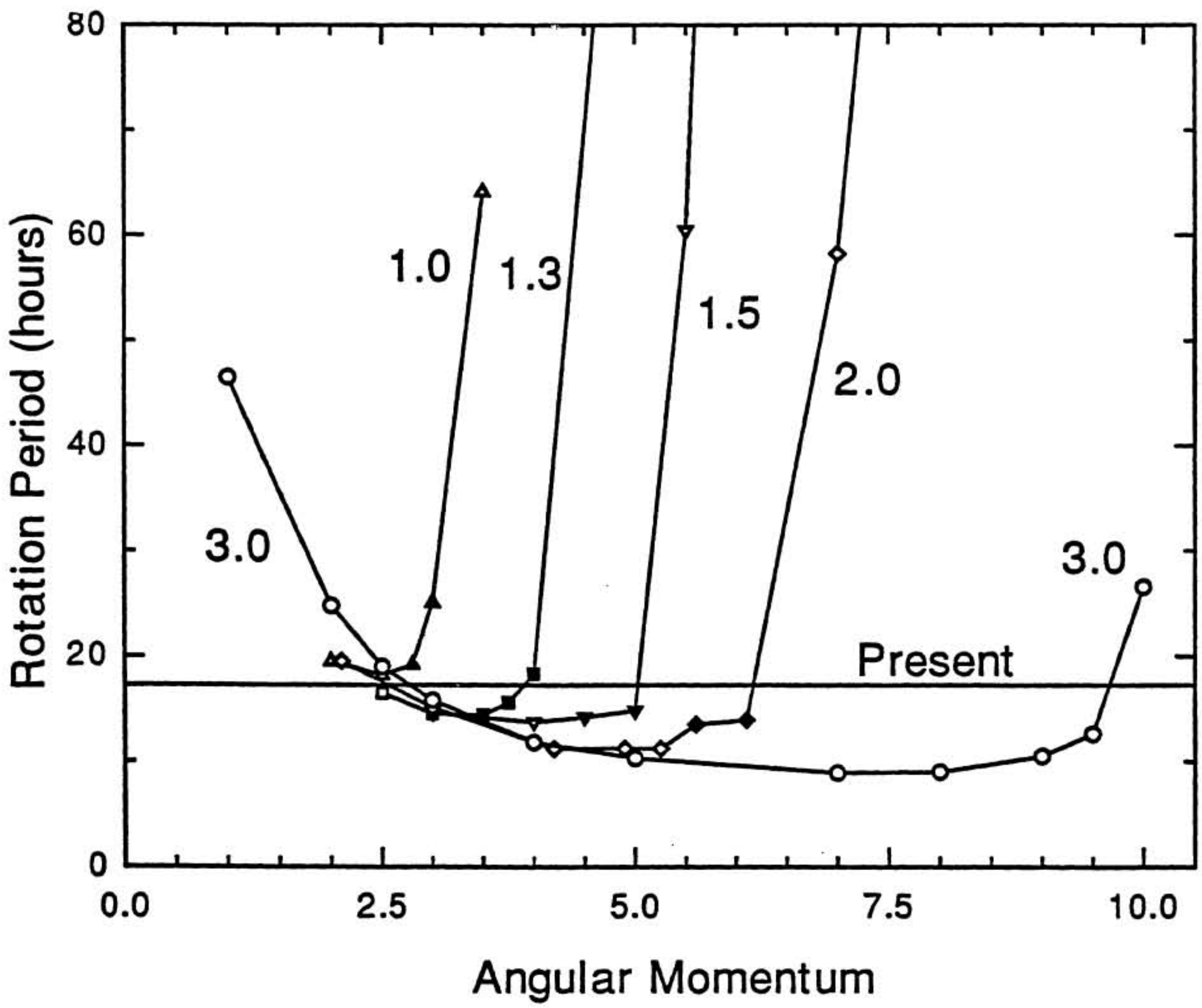
© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

the atmospheric radiating surface. Some of the collisions also leave some rock in orbit, also as vapor. These collisions are shown by filled symbols in the figure.

None of the simulations with an impactor mass of 1 $M_{\oplus}$ leaves Uranus rotating with a period as short as the present-day value, although some of them come close; this impactor mass can therefore be stated as a lower limit to the probable impactor mass needed. An impactor mass of 3 $M_{\oplus}$ succeeds over a wide range of collisional angular momenta in producing a Uranus rotation period shorter than at present, which we regard as acceptable, but in none of the cases is rock left in orbit. This is not necessarily fatal for the satellites, because an orbiting disk may capture significant amounts of rock-containing planetesimals that impact upon it; we are almost completely ignorant of the satellite accumulation conditions. However, for all impactor masses in the range 1.3–2 $M_{\oplus}$ there were collisions which both spun the planet fast enough and left rock and ice in orbit.

Thus the simulations have not selected a narrow range of giant impact conditions that would be needed to produce the observed Uranus system, but have proved to be quite permissive. We believe that the high temperature and mixing results of the collisions will be of interest to those trying to model the history of the system.

References: (1) Benz, W., Slattery, W. L., and Cameron, A. G. W. (1986) *Icarus*, **66**, 515–535; (2) Benz, W., Slattery, W. L., and Cameron, A. G. W. (1987) *Icarus*, **71**, 30–45; (3) Benz, W., Slattery, W. L., and Cameron, A. G. W. (1988) *Icarus*, **74**, 516–524; (4) Benz, W., Cameron, A. G. W., and Melosh, H. J. (1989) *Icarus*, **81**, 113–131; (5) Holian, K. S. (1984) Los Alamos report LA-10160-MS.



© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System