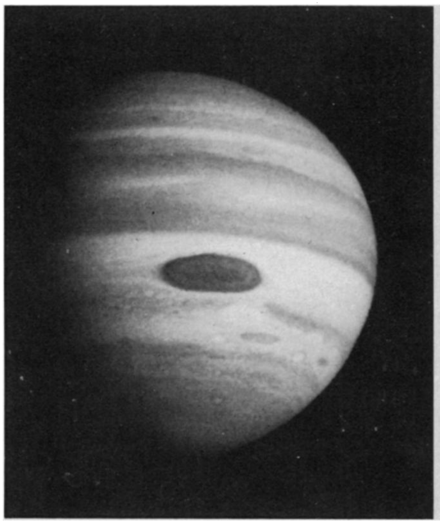
The Three-Star Solar System—



Jupiter and Saturn, the odd planets that didn't quite make it as stars.

The sun is definitely top banana in the solar system but, if recent theories of the evolution of Jupiter and Saturn are right, we very nearly missed having a multiple-star system

BY DIETRICK E. THOMSEN

Elementary astronomy instruction makes, or used to make, a sharp distinction between stars and planets. "Stars shine by their own light; planets shine by reflected light." Numerous textbooks and high-school teachers have delivered a sentence something like that. As in some other cases of textbook certainties, modern astronomy has to respond to that statement with "yes and no."

Take the two largest "planets" in our solar system, Jupiter and Saturn. For the earth and the inner planets the business about shining by reflected light is true. In the earth's case, says J. B. Pollack of NASA's Ames Research Center in Mountain View, Calif., there would be an exact balance between energy received from the sun and energy reradiated "except one place in the fourth decimal" were it not for a slight excess of heat produced by decay of radioactive elements in the earth's interior. Observation shows that this is not true for Jupiter and Saturn by a long way. Jupiter radiates 1.9 times the amount of energy it gets from the sun and Saturn a whopping 2.6 times.

Both ground-based and Pioneer space probe observations indicate that the chemical composition of the two biggest planets is more starlike than planetary, consisting mainly of helium, hydrogen and other light substances. (Uranus and Neptune also appear to share this light density; Pluto seems an anomaly for its position.) In fact, at the time the Pioneer 10 results were announced (SN: 9/21/74, p. 186), SCIENCE NEWS called Jupiter "the planetless planet."

Beyond the raw data that Jupiter and Saturn are chemically more reminiscent of the sun than of the terrestrial planets and that they have important internal heat sources, Pollack asks whether they are in "a more profound sense like stars." The profound sense he means is evolutionary. The resemblance to stars could be coincidental and arise from different causes. Did Jupiter and Saturn evolve like stars? Study convinces Pollack that one can hypothesize evolutionary tracks for Jupiter and Saturn that are very like those of stars and that lead to the planets' present state. He discussed these at the most recent meeting of the American Astronomical Society. At one point he goes so far as to speak of Hertzsprung-Russell diagrams, the traditional representation of evolutionary sequence for stars, for Jupiter and Saturn.

It might at first seem impossible that the history of the two bodies could be deduced from what we know of their present condition, says Pollack. After all, in the case of the moon we have not merely indirect data, but actual concrete samples of the surface to analyze in our laboratories, and it is still very difficult to untangle the moon's early history. "With a gas ball the situation might seem almost hopeless."

But there are several important clues from Jupiter and Saturn's present behavior that can help justify starlike evolutionary tracks. They fall under three general categories: the internal heat and excess radiation from the two planets; the properties of the satellite systems of the two planets, especially the mean densities and clues to the chemistry of the satellites; and the present characteristics of the masses and radii of the two planets.

Observations from aircraft five years ago showed that both Jupiter and Saturn radiated excess amounts of energy for simon-pure planets. The excess is about the same amount as or more than what each planet absorbs from the sun. Thus, the explanation used for the earth's minuscule excess, radioactive decay in the interior, is insufficient by orders of magnitude. Students of Jupiter have proposed a number of possible explanations, but, says Pollack, most can be dismissed. In his view the only source of the correct order is gravity. This gravitational effect—which is a very starlike thing by the way, being the major source of energy build-up in infant stars—could come in three varieties. It could be heating from contraction of Jupiter going on now; it could be heat from a reservoir generated by contraction in the past, or it could result from a fall in interior temperature that makes helium immiscible in hydrogen so that the two separate, generating energy as they do.

The satellite systems of the two planets are rather curious, especially Jupiter's. Jupiter's collection of orbiting bodies, which now counts up to 14, looks very much like a miniature solar system inside the big one. The inner planets of the solar system (Mercury, Venus, Earth, Mars, asteroids) are rocky, dense, terrestrial; the outer ones (Jupiter, Saturn, Uranus, Neptune) are low in density and have a chemical composition more like that of the sun. Pluto is an anomaly.

It happens that Jupiter's Galilean (four largest) satellites show a similar progression. From inner Io to outer Callisto, the mean density of the satellites falls off in a systematic way as the distance from Jupiter increases. Furthermore the densities of Ganymede and Callisto are too low to be entirely rocky. They seem to have a large proportion of water ice. Theorists of the solar system tend to suppose that the temperature in the nebula out of which the planets condensed was responsible for the differences in composition: The heavier, more refractory elements condensed where the temperature was hotter, near the sun, the lighter elements in the cooler regions. Perhaps something similar happened in the Jupiter satellite system.

The Saturn satellite system is not so neat. The inner satellites have low density

(Almost)

and a lot of water ice. Titan has a lot of methane—a possible clue to the temperature of its formation, Pollack says. And last but not least are the rings, unique in the solar system. They appear to be made of chips of water ice.

The third general clue is the masses and compositions. The composition of both Jupiter and Saturn is much like that of the sun, and one is led to speculate that they can be treated evolutionarily like low-mass stars. The basic history of such a star is that it collapses gravitationally from a large radius to a much smaller one and is heated up until the various cycles of nuclear burning begin. The star then enters the main sequence in which nuclear burning produces its energy and maintains its size. Finally the fuel is used up, and the star undergoes further contraction (sometimes explosively) to a white dwarf, neutron star or black hole.

If you treat Jupiter like a star evolutionarily, you can get a number of things. You get a set of model atmospheres that predict very well the pressures at different levels in Jupiter's present atmosphere and fit nicely with the spectrum of thermal emission. Study of the thermodynamics of the matter in the interior under these assumptions yield regions where hydrogen becomes a metallic fluid. Jupiter's magnetic field may be generated by currents in such a fluid.

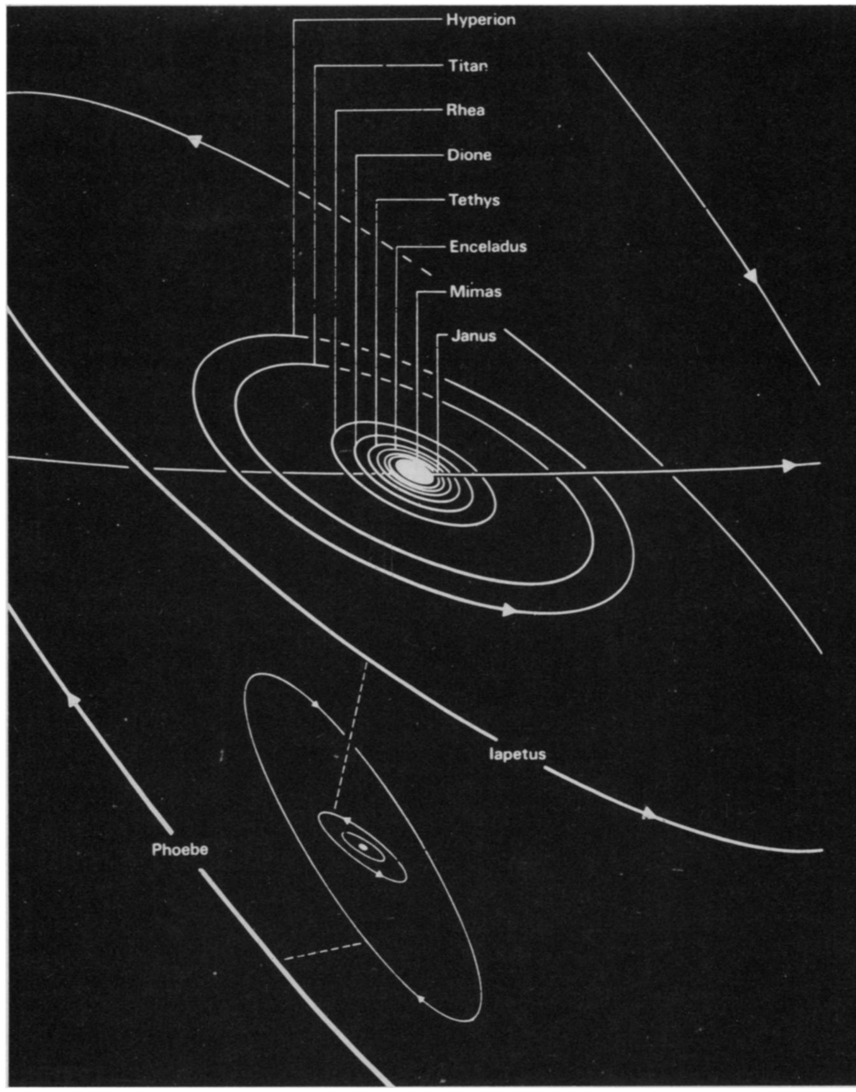
And finally, there emerges a Hertzsprung-Russell diagram for Jupiter, in which the early stages behave like a pre-main sequence star, and the late ones rather like a white dwarf. What's missing is the main sequence. Jupiter never got hot enough to initiate deuterium burning. Eventually, too, Jupiter's contraction reached a state of electron degeneracy, in which electrons refused to be further crowded together, and contraction halted. Jupiter's excess heat, Pollack concludes, comes from a reservoir generated by past contraction.

Saturn tended to evolve faster than Jupiter, generating less heat by contraction. The immiscibility of hydrogen and helium under certain conditions seems to have much to do with Saturn's heat source. Also, Saturn's starlike evolutionary track does not come down to present conditions of temperature and radius as neatly as Jupiter's does. There are small discrepancies in Jupiter's case and larger ones in Saturn's that seem to indicate either the presence of rocky cores (more likely for Saturn) or some uncertainty in the theoretical inputs.

Jupiter, evolving slowly, generated enough heat to control the composition of at least its inner satellites, just as the sun's heat controlled the formation of the inner planets, and that accounts for the resemblance between the two systems. Saturn, evolving faster, never generated enough heat to excercise this control. In fact, near Saturn at the crucial time it was still cold enough for water ice to form. The ice never coalesced into a single body because it was within the Roche limit, and tidal forces exerted by Saturn prevented coalescence. Yet Saturn was contracted enough at the time and had strong enough gravity to hold the rings in orbit.

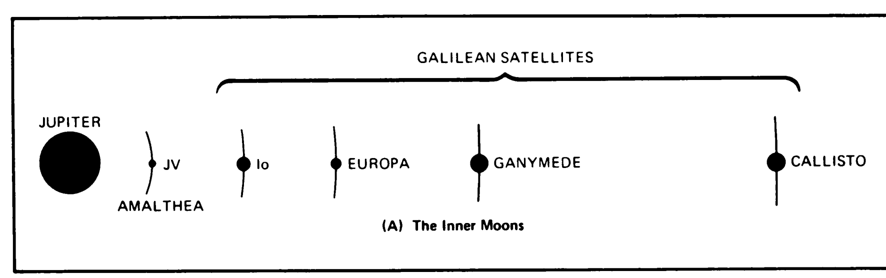
Why do the other planets have no rings? In Jupiter's case, it was too hot for water ice within its Roche limit during the critical time for ring formation. Uranus and Neptune, which are in many ways similar to Jupiter and Saturn, have no rings because presumably they evolved even faster. (Calculations for them have not been reported.) Any water ice formed near Uranus or Neptune was swept away before their gravity could form it into rings.

So there appears to be a hierarchy in the solar system. Bismarck, viewing Europe as orbiting around Berlin, once remarked that the Bavarians were nature's link between humanity (meaning the Prussians) and the Austrians. Following Pollack we can conclude that Uranus and Neptune are probably nature's link between the failed stars Jupiter and Saturn, and the more truly planetlike planets including our own. □



Rand McNally's Atlas of the Universe, Mitchell Beazly Publishers

Chemical composition of Saturn's satellites shows little influence of the planet.



NASA

Jupiter's heat seems to have influenced densities of the four Galilean satellites.