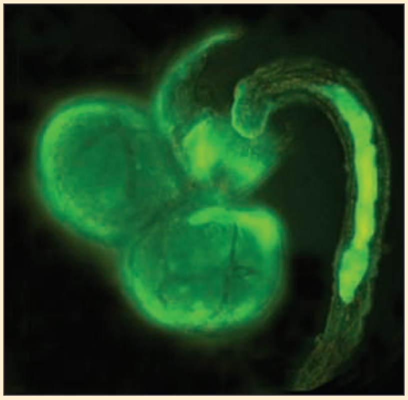
A **Life cycle of a polyembryonic wasp**

A female wasp deposits her eggs into a caterpillar host egg.

The wasp larvae undergo clonal proliferation within the caterpillar host.

Larvae develop either precociously into soldiers (left) or normally (right).

B **Caught in the spiteful act**



A soldier wasp larva ingests its fluorescently labeled victim.

In a companion study (*3*), the investigators shed light on the mechanism of this kin recognition faculty. They reveal that the key element is the extraembryonic membrane surrounding each larva during its development in the caterpillar host. They show that attack rates correlated negatively with kinship when the membrane was present, but not when the membrane was removed. In addition, by transplanting membranes between larvae they were able to fool the soldiers, whose attack rates correlated negatively with the kinship of the membrane donor but not with the larva encased inside. Mechanisms of kin recognition are unstable because deceptive variants arise that signal strong kinship to everyone; such variants can become common. However, the importance of the membrane in protecting larvae from host immune attack means that rare variants are intrinsically favored and that common variants are disadvantageous, providing a robust, honest signal of kinship. This may be true for many endoparasites, rendering such species masters of kin recognition.

One potentially puzzling result is that manipulation of resource availability by starving the host caterpillars did not influence the level of aggression exhibited by the wasp soldier caste (*2*). Possibly because competition is always local, resource availability does not influence how soldiers vary their relatedness-dependent behavior. Alternatively, soldier larvae may not be able to assess the intensity of competition for resources, either because doing so is difficult or because natural variation in competition is negligible and there has been no need for this faculty to evolve. Future work on how local competition for resources relates to soldier aggression could benefit from explicit theoretical modeling, as well as alternative methods for varying the scale of competition such as selection experiments (*9*) or comparative studies across species and populations. Nonetheless, the existence of an aggressive soldier caste among parasitic wasps provides evidence that spite does exist in the real world, as Hamilton predicted it would.

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PLANETARY SCIENCE

Looking into the Giant Planets

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Images of Jupiter and Saturn from telescopes and space probes only show the outermost layers of these giant planets. Learning about their interiors, which consist mostly of hydrogen (H) and helium (He) and make up over 90% of the planetary mass in the solar system, is more challenging. Recent model studies (*1*–*3*) show how new measurements from the Cassini spacecraft—now in orbit around Saturn—could lead to a better understanding of the interior of Saturn and, by extension, all giant planets.

The most important input into giant planet models is the equation of state—that is, the relation between pressure and density—of hydrogen. Uncertainties in the equation of state translate directly into uncertainties in the estimated size of the "heavy element" (elements more massive than He) cores of the giant planets and the abundances of elements in their hydrogen-rich envelopes (*1*). Two groups have measured the shock-induced compressibility of deuterium, a heavy isotope of H, but there is a 50% discrepancy between their data sets (*4*, *5*). As Saumon and Guillot (*1*) show in a recent paper in *The Astrophysical Journal*, this uncertainty profoundly affects inferences about the composition of the planets and the sizes of their cores. These quantities must be known before we can understand the process of giant planet formation and properties of the early solar system.

The authors created static models of Jupiter and Saturn that match all available constraints, including mass, radius, oblateness, rotation period, atmospheric temperature, and gravitational moments for each planet. They also used a wide range of possible equations of state for H to allow for the disparate experimental data sets. According to their model, Jupiter's core is 0 to 11 Earth masses. Saturn's core is likely larger, between 9 and 22 Earth masses. (For comparison, Jupiter is 317.8 Earth masses and Saturn 95.2 Earth masses.) Overall, Jupiter is enriched in heavy elements by a factor of 1.5 to 6 relative to the Sun, and Saturn by a factor of 6 to 14. The most striking of these results is that we cannot be sure whether Jupiter has a core.

The greatest uncertainty in the structure of Jupiter comes from unsatisfactory understanding of liquid metallic H at Mbar pressures. In contrast, for Saturn, poor knowledge of its gravitational moments, which describe how the planet's mass responds to its rotation, is the main obstacle. Gravitational moments are determined by measuring small accelerations of a spacecraft as it passes near a planet. During Cassini's 4-year mission, error bars on the low-degree gravitational mo-

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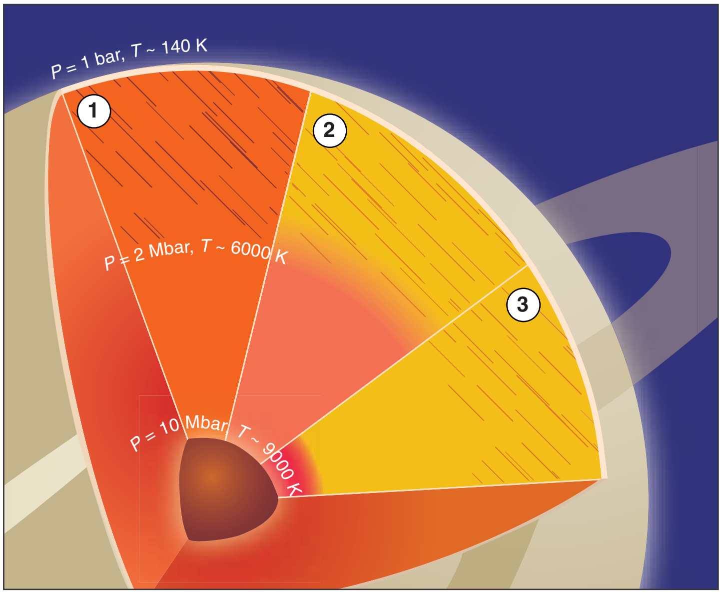
ments J_4 and J_6 should be reduced by factors of at least 50 and 20, respectively. These measurements will lead to much tighter constraints on Saturn's core mass and heavy-element enrichment. In a possible extended mission, additional moments could be determined for the first time (*6*).

Jupiter and Saturn both emit nearly twice as much energy as they receive from the Sun. This intrinsic flux is carried through each planet by convection in their fluid interiors. Both planets are thus likely to be adiabatic and well mixed in most of their interiors. A simple cooling model for a fully convective homogeneous Jupiter, radiating energy left over from its formation 4.55 billion years ago, gives a current luminosity that closely matches the measured value. In contrast, Saturn is over 50% more luminous than this model predicts (*7*). Saturn must possess a substantial additional internal energy source that is much smaller, or nonexistent, in Jupiter.

The gradual sinking of He could be such an additional energy source (*8–10*). If He phase-separates deep within a giant planet from the previously homogeneous mixture, this He could form stable droplets. The droplets, being denser than their surroundings, could fall to deeper layers of the planet and exchange their gravitational potential energy for thermal energy through viscous dissipation (*9*). The visible atmosphere would also be depleted in He, because it is connected with deeper layers through convection.



Three views of the interior of Saturn. Orange represents the protosolar He/H ratio. A yellower orange indicates less He, and a redder orange more He. Brown is the ice/rock core. The hashed regions indicate that H is liquid molecular, whereas in the unhashed regions it is liquid metallic. **(1)** Saturn at an age of ~1.5 billion years, before the onset of He phase separation. **(2)** The current Saturn according to a previously proposed H-He phase diagram (*11*). **(3)** The current Saturn according to a phase diagram derived from new evolutionary models (*2*).

Quantum mechanical calculations (*11*) put the onset of this phase separation at pressures above 2 Mbar and temperatures below 8000 K—conditions found in the interiors of gas giant planets. Consequently, the picture has emerged that Saturn has been differentiating for the past 2 to 3 billion years, whereas Jupiter, whose interior is warmer than Saturn's, has either not begun to differentiate, or has begun to do so only relatively recently. However, many details are still unclear.

Measurements of the atmospheric He abundance of Jupiter and Saturn support the view that differentiation is currently under way in both planets. The envelopes of Jupiter and Saturn are thought to have the protosolar He/H ratio of 0.096 ± 0.004 (by number). However, the Galileo entry probe gave a lower ratio of 0.079 ± 0.002 in Jupiter's atmosphere (*12*). Indirect measurements from Voyager, which used an inversion technique on infrared spectra of Saturn, put the ratio in Saturn's atmosphere at 0.055 to 0.080 (*13*). These data support the idea that He is "raining down" in both planets, but likely to a greater extent in Saturn. The deeper layers of the planets must contain the He missing from the visible atmosphere.

To test calculated H-He phase diagrams and place constraints on the temperature/pressure range of the He immiscibility region, for which there are no experimental data, Bill Hubbard and I recently coupled detailed evolutionary models of Saturn to high-pressure phase diagrams of He-H mixtures (*2*). We found that the original H-He phase diagram calculation (*11*) is likely incorrect. Evolutionary models of Saturn that use this phase diagram are 30% less luminous than the actual planet. We propose a new ad hoc phase diagram, guided by more recent molecular dynamics calculations (*14*).

The proposed phase diagram allows immiscible He to rain down further in Saturn's interior (to the core), liberating more gravitational potential energy. With this phase diagram, the current Saturn model agrees with all available constraints: At an age of 4.55 billion years, it matches the planet's known luminosity and has an atmospheric He abundance that matches the Voyager-derived value. The predicted shape of the H-He phase diagram can be tested by computer simulations and perhaps by future high-pressure shock experiments. The model indicates that He phase separation cannot be Saturn's only additional energy source if the planet's current atmospheric He/H ratio is greater than 0.063.

He phase separation can be accommodated into the evolution of Saturn, but Jupiter's smaller atmospheric He depletion remains unexplained. Can a H-He phase diagram be devised that allows both Jupiter and Saturn to reach their measured luminosities and atmospheric He abundances? This problem will continue to be addressed by planetary scientists during the Cassini mission. A more accurate determination of Saturn's He abundance would shed considerable light on the evolution of Saturn, Jupiter, and extrasolar giant planets like them (*3*). Cassini does not have a Saturn entry probe, but it could provide a better indirect measurement. The spacecraft will obtain many atmospheric pressure-temperature profiles over a range of latitudes and infrared spectra to wavelengths of 1 mm (*15*).

Saturn and Jupiter serve as calibrators for theories of the formation and evolution of all giant planets. In addition, both planets are vast natural laboratories with which to study He and H under high pressure. Further progress will require advanced computational modeling of the behavior of H/He mixtures, continued experiments on these elements under intense pressure, and accurate and precise determinations by the Cassini spacecraft of Saturn's gravitational moments and atmospheric He abundance.

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