Alternative Evolution and Internal Structure for Jupiter and Saturn

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Simple, approximate models based on perturbations of the n=1 polytrope are used to identify some general properties of models for nearly-isentropic Jupiter-like planets where the total heavy element mass fraction is small. In these models, it is found that the radius is remarkably insensitive to the distribution of heavy elements and is effectively a measure of total heavy element enrichment (sum of core and envelope). The gravity harmonic J_2 and the normalized moment of inertia $\alpha=I/MR^2$ are almost entirely determined by the density structure outside the core, and this depends on the reduced core mass, defined to be the actual core mass minus the mass of hydrogen and helium that would occupy that region in the absence of the core. The actual core mass or its radius or composition cannot be well determined, even when there is perfect knowledge of the equation of state, thermal state and envelope enrichment by heavy elements. The central concentration of heavy elements is approximately determined, even when the actual core is more massive and contaminated with hydrogen and helium by mixing or erosion (double diffusive convection). At fixed J_2, the dependence of α on core structure is very small, and only exceeds the likely detection limit ~0.1-0.2% for very extended cores. Even though these results are obtained for a simple model, it is argued that they are semi-quantitatively applicable to realistic models. A perturbation scheme is presented for testing this systematically and for assessing the consequences of perturbations to the equation of state, compositional profile and temperature structure for the trade-off between reduced core mass and envelope enrichment.

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408.03 – Alternative Evolution and Internal Structure for Jupiter and Saturn

The internal structure of gas giant planets may be more complex than the commonly assumed core-envelope structure with an adiabatic temperature profile. Different primordial internal structures as well as various physical processes can lead to non-homogenous compositional distributions. A non-homogenous internal structure has a significant impact on the thermal evolution and final structure of the planets. Here we present alternative structure and evolution models for Jupiter and Saturn allowing for both adiabatic and non-adiabatic evolution. In convective regions we calculate the mixing of heavy elements by convection, as these planets evolve. We present the thermal and structural evolution of the planets accounting for various initial composition gradients, and in the case of Saturn, include the formation of a helium-rich region as a result of helium rain. We investigate the stability of the structure against convection, and find that the helium shell in Saturn remains stable and does not mix with the rest of the envelope. In other cases, convection mixes the planetary interior despite the existence of compositional gradients, leading to enrichment of the envelope with metals. We show that non-adiabatic structures (and cooling histories) for both Jupiter and Saturn are feasible, and the interior temperatures in that case are much higher that for standard adiabatic models. Moreover, we show that non-adiabatic evolution can suggest more than one mechanism to explain the current structures, including Saturn's high luminosity. We conclude that the internal structure is directly linked to the formation and evolution history of the planet. These alternative internal structures of Jupiter and Saturn should be considered when interpreting the upcoming Juno and Cassini data.

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408.04D – Tidal Response of Jupiter and Saturn from CMS calculationsTidal Response of Jupiter and Saturn from CMS calculations

The *Juno* gravity science system promises to provide observational data from Jupiter's gravitational field at an unprecedented precision. Meanwhile, recent *ab-initio* simulations on mixtures of hydrogen and helium allow for the construction of realistic interior models. The concentric Maclaurin spheroid (CMS) numerical method has been developed for efficient, non-perturbative, self-consistent calculations of shape and gravitational field of a rotating liquid body to this desired precision. Here we present a generalization of the CMS method to three dimensions and included the effect of tides from a satellite. We have identified a number of unexpected features of the static tidal response in the case where a planet's shape is dominated by the rotational bulge. In the general case, there is state mixing of the spherical-harmonic components of the response to the corresponding components of the rotational and tidal excitations. This breaks the degeneracy of the tidal love numbers k_{nm} with m, and introduces a dependence of k_{nm} on the orbital distance of the satellite. Notably for Jupiter and Saturn, the predicted value of k_2 is significantly higher when the planet's high rotation rates are taken into account: $k_2=0.413$ for Saturn and $k_2=0.590$ for Jupiter, accounting for an ~13% and 10% increase over the non-rotating case respectively. We have also done preliminary estimates for the off-resonance dynamic response, which may lead to an additional significant increase in k_2. Accurate models of tidal response will be essential for interpreting gravity observations from *Juno* and future studies, particularly for when filtering for signals from interior dynamics in the observed field.

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408.05 – Unfolding the atmospheric and deep internal flows on Jupiter and Saturn using the Juno and Cassini gravity measurements

In light of the first orbits of Juno at Jupiter, we discuss the Juno gravity experiment and possible initial results. Relating the flow on Jupiter and Saturn to perturbations in their density field is key to the analysis of the gravity measurements expected from both the Juno (Jupiter) and Cassini (Saturn) spacecraft during 2016-17. Both missions will provide latitude-dependent gravity fields, which in principle could be inverted to calculate the vertical structure of the observed cloud-level zonal flow on these planets. Current observations for the flow on these planets exists only at the cloud-level (0.1-1 bar). The observed cloud-level wind might be confined to the upper layers, or be a manifestation of deep cylindrical flows. Moreover, it is possible that in the case where the observed wind is superficial, there exists deep interior flow that is completely decoupled from the observed atmospheric flow.

In this talk, we present a new adjoint based inverse model for inversion of the gravity measurements into flow fields. The model is constructed to be as general as possible, allowing for both cloud-level wind extending inward, and a decoupled deep flow that is constructed to produce cylindrical structures with variable width and magnitude, or can even be set to be completely general. The deep flow is also set to decay when approaching the upper levels so