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Methane planets and the mass-radius diagram

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The multitude of newly discovered exoplanets are too far away to be studied in the same detail as the planets of our own solar system. Many planets have measured masses and radii, and their mean densities can be compared to those expected for different simple compositions (see, e.g. Seager et al. 2007). Clearly, different mixtures of materials can give similar density distributions and as a result, the mass and radius of a planet do not give a unique composition. It turns out that even if we limit the composition to one species, the mass-radius relation can show complex structure. To illustrate this, we consider planets composed of pure CH_4.

The complications arise because CH_4 is expected to undergo dissociation at high pressure. *Ab initio* calculations (Gao et al. 2010) suggest that CH_4 dissociates to C_2H_6, C_4H_{10}, and finally carbon + hydrogen at progressively higher pressures. We have modeled isothermal planets composed initially of pure CH_4. We assume that if the planet is massive enough so that the central pressure exceeds the dissociation pressure of CH_4, a diamond core is formed and the hydrogen released diffuses through the intermediate CH_4 shell to form an H_2 atmosphere. This leads to a sharp discontinuity in the mass-radius relation for such planets.

A further complication arises from the fact that within a narrow range around the transition mass there can be multiple solutions ranging from a pure CH_4 planet to those with diamond cores, CH_4 shells, and hydrogen atmospheres of different masses. Methane planets thus provide an example of the instability first noted by Ramsey (1950) and Lighthill (1950). As a result, even for a given composition the mass-radius diagram is non-unique, making the characterization of extrasolar planets even more challenging.

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