From Rock Mechanics to Planetary Interior Dynamics

Chhavi Jain
Assistant Professor
Department of Space Planetary Astronomical Sciences and Engineering, IIT Kanpur

Brief Biographical Sketch

Dr. Chhavi Jain is an Earth and planetary scientist. She secured a PhD in Geophysics from Yale University and pursued postdoctoral training at Washington University in St. Louis, USA. Her research integrates experimental rock mechanics, geophysical and satellite observations, theoretical mineral physics, and computational fluid dynamics to develop more realistic and self-consistent models of the interior dynamics of a planet.

Abstract

Although rocks appear rigid on human timescales, they deform as highly viscous materials over millions of years. This slow deformation governs mantle convection, controls the thermal and mechanical evolution of planetary interiors, and ultimately shapes the surfaces of rocky planets. Understanding these processes therefore requires bridging laboratory studies of rock deformation with theoretical and computational models of planetary dynamics.

In this talk, I will discuss how my research combines rock mechanics, fluid dynamics, and numerical modeling to investigate the interiors of the Earth and other terrestrial planets. I will first present a new approach to analyze experimental data on the deformation of olivine, the dominant mineral of Earth's upper mantle, that produces more realistic constraints on mantle rheology and lithospheric strength. My results also highlight the significant uncertainties that remain in our understanding of the mechanical behavior of mantle rocks and the resulting implications for geodynamic models.

I will then show how rheology fundamentally controls the onset and style of thermal convection in planetary interiors. Using computational fluid dynamics, I investigated the nonlinear onset of convection in fluids with strongly temperature-dependent viscosity, demonstrating the existence of a new planform of convection – the localized convection planform – that can occur below the classical (linear) critical threshold. These results provide new insights into the onset and evolution of convection in planetary interiors.

Finally, I will illustrate how these concepts can be applied to a range of planetary bodies, including Mercury, Venus, and Pluto, to help address long-standing questions regarding interior dynamics and surface evolution. Together, these studies demonstrate how advances in rock mechanics and fluid dynamics can improve our understanding of the diverse evolutionary pathways of rocky planets.