

# Probing Neptune With Kepler

J.F. Rowe, M.S. Marley, J.J. Lissauer

**Science Goals Objectives:** There are two classes of solar system giant planets: the gas giants and the ice giants. Uranus and Neptune, with masses less than 18 Earth masses comprise a distinct class from Jupiter and Saturn, with masses greater than 95 Earth masses. The primary constituents of Uranus and Neptune are likely ices surrounding a rocky core with a relatively thin atmospheric veneer of hydrogen rich gas. The *Kepler* Mission has ably demonstrated that such Neptune sized planets are common—much more common than gas giants in fact—outside of the solar system. It is thus important to understand the interior structure of these worlds in order to better model their formation and evolution. Unfortunately our best data on the interior structure of these worlds comes from the gravitational harmonics measured during the single flybys of Voyager 2 about 25 years ago. Oscillations not only provide complimentary information but would be more sensitive to internal sharp boundaries.

The proposed, two wheel K2 mission will now observe fields along the ecliptic continuously up to 80 days. K2 presents an opportunity to obtain ultra-high precision, high duty-cycle, integrated disc photometry of Solar Systems such a Neptune to search for oscillations and seismically study an ice giant. Seismology is *by far* the most promising technique for constraining the core mass of a giant planet, independent of the uncertainties that plague interior model inversion.

**Methodology:** Oscillations of a giant planet change the size of the observable disk, thus altering the total reflected solar flux. From simple geometry alone a velocity of 50 cm/s with a frequency of 1 mHz changes the reflected flux at the several ppm level. Thus photometry has the potential to detect oscillations excited by turbulence from convection that pumps energy into random sound waves. Neptune's brightness at quadrature is comparable to that of the brightest stars that Kepler has monitored in its exoplanet search. It has been repeatedly shown that Kepler photometry for bright ( $V < 8$ ) stars can reach noise levels of better than 1 ppm in the Fourier domain on time-scales shorter than 30 minutes with a month of observations. There have been a number of searches for giant planet oscillations, primarily for Jupiter. Gaulme et al. (2011) reported the Doppler detection of jovian modes with peak amplitudes near frequencies of 1.2 mHz, a period of about 14 minutes. One of us (MM) carried out an exploratory computation of ice giant mode frequencies some years ago but did not publish the results, but as with Jupiter and Saturn expected periods are in the range of tens to hundreds of minutes. Thus short-cadence is necessary.

**Summary:** Observations of Neptune (or any giant planet) with Kepler have the potential to answer many long-standing questions regarding the interior structure of ice giants from detecting a core to understanding the compositional structure of the envelope. The clear detection of oscillation modes will of course energize a new generation of theorists to compute model frequencies for comparison with data. We thus urge that the inclusion of Neptune in any appropriate near- ecliptic star field observed by Kepler be seriously considered.