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Trans-Neptunian Region Architecture: Evidence for a Planet Beyond Pluto

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Trans-Neptunian objects (TNOs) represent the relics of planet accretion in the primordial planetesimal disk, and therefore they carry precious information about the origin and evolution of the solar system. We investigated the trans-Neptunian region structure (at semimajor axes a beyond 30AU) by using theoretical methods, in particular extensive computer simulations (4-5Gyr) using tens of thousands of particles and statistical analysis of physical properties (absolute magnitudes, albedos and sizes). After taking into account several observational and theoretical constraints, we developed a model to explain the origin and evolution of the trans-Neptunian belt (or Edgeworth-Kuiper belt) (a=30-48AU) and scattered disk (typically a beyond 48AU) by considering a hypothetical outer planet (or planetoid) with tenths of Earth masses (ME) orbiting beyond Pluto. The main results are:

1) Large TNOs have higher albedos (greater than 0.04), possibly caused by icy frosts of CH_4, CO or N_2. Thus, any sufficiently distant planetoid should be ice-rich, and at most moderately reflective because of the long-term exposition to space weathering and the local very low temperatures;

2) Objects have stable orbits at a beyond 42AU for near circular orbits. This is in contrast with the lack of TNOs beyond ~45AU, and the absence of low-eccentricity (e) objects beyond about 50AU (the so-called trans-Neptunian belt outer edge). Since Neptune's or mutual gravitational perturbations cannot explain these features, an extra perturbation seems likely;

3) There are five dynamical classes of outer solar system bodies: Centaurs, resonant, classical, scattered and detached TNOs. In particular, scattered TNOs are strongly affected by r:1 resonances (2:1, 3:1, etc.) coupled with the Kozai mechanism during their evolution in the scattered disk. Lastly, resonances alone cannot explain the origin of detached TNOs so that an extra perturbation appears to be necessary;

4) Long-term resonant TNOs in the scattered disk should have originated from sweeping resonances over a previously excited trans-Neptunian belt. This requires a primordial planetesimal disk extending to 47-50AU and a perturbation mechanism operating during the early solar system, before planet migration;

5) An outer planet (0.3-0.5ME) in a distant orbit in the scattered disk (currently near a r:1 resonance) can explain the ancient trans-Neptunian belt excitation, the formation of an outer edge at ~50AU, the entire TNO resonant population, the formation of detached TNOs and many other features in a self-consistent way. Noteworthy, the results match very well up-to-date observations. The best constraints obtained from the model for the planetoid are: a_P=100-150AU, q_P greater than 80AU, i_P=30-50 degrees, albedo=0.1-0.3, and apparent magnitude m_P=15~17mag at perihelion.

In summary, based on well established mechanisms, such as giant planet scattering, a large population of planetary-sized planetesimals in the past, planet migration, and resonance sweeping capture, our model with the existence of a massive planet beyond Pluto successfully describes the trans-Neptunian region architecture with an unprecedented level of details and predictability.