ORIGIN OF THE EDGEWORTH-KUIPER BELT ARCHITECTURE: EVIDENCE OF DYNAMICAL SCULPTING BY AN OUTER PLANET. P. S. Lykawka[1], and T. Mukai[1], [1]Kobe University, Dept. of Earth and Planetary Sciences, Kobe, Japan – patryk@dragon.kobe-u.ac.jp.

Introduction: Trans-Neptunian objects (TNOs) represent the relics of the primordial planetesimal disk that originated the solar system. These bodies orbit at semimajor axes a>30AU in the Kuiper belt [1]. Ongoing detection of TNOs has revealed a surprisingly complex orbital distribution [2-4], which challenges models of Kuiper belt formation [3-6]. Four main classes of TNOs have been identified: resonant, scattered, detached, and classical [2,7]. Resonant TNOs are locked in resonances with Neptune. Scattered TNOs originated from gravitational scattering by Neptune [8]. Detached TNOs, located beyond 48AU (with perihelion q>40AU), never encounter Neptune for longer than 4Gyr [7]. Classical TNOs are non-resonant objects that orbit around 37–48AU and exhibit intriguing excitation in eccentricities, e, and inclinations, i; these bodies are subdivided into two populations with different physical properties [3,4,6]. Other important constraints include the Kuiper belt outer edge at ~48AU [3,4] and the belt's small total mass, which is only ~1% of that required for TNOs to grow via accretion [1,9].

Model: We propose that the orbital history of a massive body (the outer planet or planetoid) with tenths of the Earth's mass (ME) can explain the Kuiper belt orbital structure. The past existence of large populations of such massive bodies is presently evidenced in the solar system [3,10]. We performed simulations using many thousands of disk planetesimals (e<0.001; i<0.2°) under the gravitational influence of the four giant planets and the planetoid. Two orbital symplectic integrators were used [11,12]. We focussed on planetoids with medium mass, M_P=0.3–0.7ME. The giant planets were initially within ~17–20AU, before planet migration, whilst the planetoid was placed on a giant planet-encountering orbit. Planet migration was implemented as described in previous studies [5].

In our scenario, the outer planet evolved on a scattered orbit over several tens of Myr, stirring the outerskirts of the planetesimal disk before planet migration. Later, the giant planets migrated to their current orbits, whilst the planetoid was transported outwards by a combination of gravitational scattering by Neptune and resonant interactions with the latter, in particular r:1 resonances (e.g., 6:1). Because these resonances commonly trap objects in Kozai resonance (KR), the outer planet probably exhibited KR behaviour, decreasing e_P and increasing i_P. This effect was implemented in the code. At the end, the outer planet acquired a distant and stable inclined orbit (>100AU; q_P>80AU; 10–40°).

Main accomplished results: 1) All identified resonant populations and their orbital and resonant properties. This includes Neptune Trojans, resonant TNOs in distant resonances (>50AU) and TNOs in KR; 2) Formation of scattered and detached TNOs, including analogues of Eris, 2004 XR_{190}, 2000 CR_{105}, and Sedna. The fractions of detached to scattered populations, 0.7–2.5, agree with intrinsic estimates based on observations [2,6]; 3) Classical TNOs and their dual nature of physically distinct cold (i≤5°) and hot (i>5°) populations; 4) Orbital excitation of classical TNOs with final e and i distributions remarkably similar to observed values; 5) The Kuiper belt outer edge, including the abrupt decrease in number density of TNOs beyond 45AU and the intrinsic lack of low-e objects in the same region; 6) Loss of ~99% of the initial Kuiper belt's total mass through the combination of dynamical depletion and enhanced collisional grinding, both of which were enabled by a large fraction of planetesimals that acquired excited orbits at early stages; 7) Neptune's current orbit at 30.1AU for extended planetesimal disks (50–60AU); 8) Possible existence of a resident outer planet within the solar system. This object could be as bright as very large TNOs (e.g., Eris).

Conclusions: Our model accounts for the Kuiper belt's orbital structure, its outer edge, the loss of ~99% of its initial total mass, among other features. We conclude that the observed orbital excitation in the 40–50AU region and the truncation near 48AU probably represent fossilized signatures of the outer planet's perturbation during its early scattered orbit, while the detached population, and perhaps TNOs with i>40°, resulted from the planetoid's perturbation over billions of years (current signatures). In summary, the scenario presented here can explain all main characteristics of Kuiper belt architecture with unprecedented detail and offers insightful observationally testable predictions.

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