[21.01] The Kuiper Belt Survey of the GEST Mission

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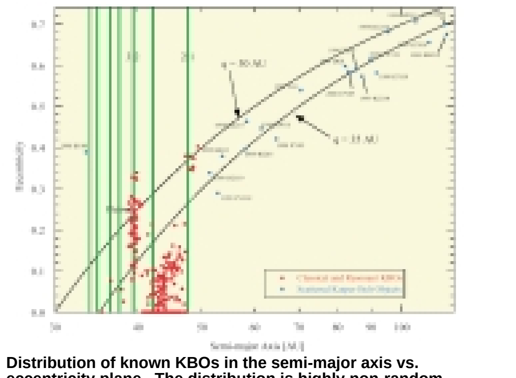
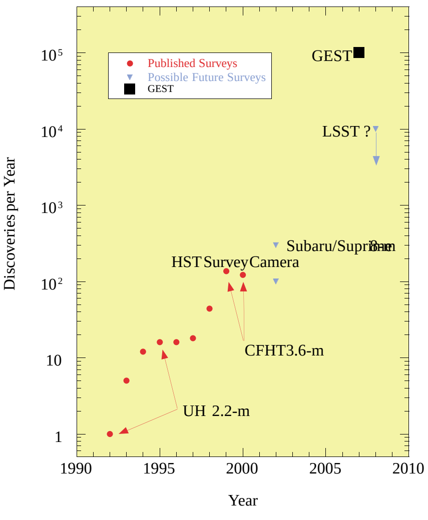
A secondary science goal of the proposed Galactic Exoplanet Survey Telescope (GEST) is to discover ~100,000 new Kuiper Belt Objects (KBOs). Using a fraction of each season when GEST's primary target, the Galactic bulge, is not visible, GEST will survey ~1200 square degrees of sky near the ecliptic plane down to a limiting red magnitude of R ~26.5. GEST's KBO survey will be repeated at specific weekly, monthly, and yearly intervals to permit orbit determination. GEST will also do a deep KBO survey which aims to detect KBOs as faint as 29th magnitude in a single 1 square degree field.

The number of KBOs that GEST will discover exceeds the number of known KBOs by a factor of ~300 and the number of KBOs expected from other proposed telescopes by a factor of 10. This will enable the measurement of the number of KBOs in the more distant mean motion resonances, the measurement of the radial extent of the Kuiper Belt, and the measurement of the relative abundances of the classical, resonant and scattered KBO populations.



Distribution of known KBOs in the semi-major axis vs. eccentricity plane. The distribution is highly non-random. Excess numbers of objects appear trapped in the 3:2 mean motion resonance at 39.4 AU. The scattered KBOs are preferentially found at larger semi-major axes. They are distinguished by having perihelia near q = 35 AU, implying that their orbital evolution has been controlled by weak scattering against Neptune.



Number of known Kuiper Belt Objects as a function of the date. Red symbols show surveys already published. Blue symbols show anticipated future surveys with the HST, the prime focus camera of the Japanese 8-m SUBARU telescope, and the all-sky Large Synoptic Survey Telescope advocated by the Decadal Review. The GEST wide survey will detect 1 to 2 orders of magnitude more KBOs than any other planned survey. It beats existing surveys by about 3 orders of magnitude in discovery rate.

The Kuiper Belt: History and Current Problems

It is well established that stars grow through centripetally flattened accretion disks, and that these disks are also the sites of planet formation. In fact, planet formation proceeds most efficiently in the denser, inner portions of circumstellar disks, where orbital periods are short and collisions between planetesimals are frequent. Growth in the outer portions of disks occurs more slowly, leading to a ring of mid-sized objects whose collisional growth timescales may rival the main sequence lifetime of the central star. Our own solar system provides the clearest example. The primordial accretion disk inside about 30 AU has been completely dissipated by planet formation and the accompanying strong gravitational perturbations from planets have ejected all original planetesimal bodies. Beyond 30 AU, however, elements of the disk survive in the recently discovered Kuiper Belt (Jewitt and Luu 2000, Protostars and Planets IV). This is a disk-like assemblage containing 1010 bodies (with radii greater than 1 km) beyond Neptune whose larger members are survivors from the era of planetary growth. Other stars show evidence for long-lived circumstellar disks that are likely analogs of our own Kuiper Belt.

The Kuiper Belt is important to planetary astronomy in several ways.

- First, it is the long-sought source of the short-period comets (Fernandez 1980, MNRAS; Duncan, Quinn and Tremaine 1988, ApJL).
- Second, in the dynamics of its members, the Kuiper Belt holds a fossil record of conditions and processes from the earliest days of the solar system.
- Third, the Kuiper Belt plays a bridging role in the comparative study of the solar system with planetary systems surrounding other stars.

For these reasons, the discovery of the Kuiper Belt in 1992 has provoked an incredible surge of observational and theoretical interest in the contents and properties of bodies at the outer edge of the solar system (see also Canizares 1998, COMPLEX Report). As a result of nearly a decade of intense observational effort from ground-based telescopes, a number of outstanding science questions exist about the Kuiper Belt.

1. About 30% of the known Kuiper Belt Objects (KBOs) are trapped in mean motion resonances with Neptune (these are the so-called Resonant KBOs; the non-resonant objects are known as Classical KBOs). One likely trapping mechanism involves radial migration of Neptune in response to torques exerted on it by sling-shot interactions with the nearby planetesimal disk (Fernandez and Ip 1984, Icarus; Malhotra 1995, AJ). These interactions were responsible for the ejection of comets to the interstellar medium and the population of the Oort Cloud. The parameters of Neptune's migration, including the total distance moved and the rate of migration, can in principle be extracted from the relative populations of different mean motion resonances and from the distributions of inclinations of trapped KBOs. Unfortunately, the KBO sample is sufficiently small and biassed against detection of KBOs in more distant resonances (e.g. the 2:1 resonance at 47 AU) that firm estimates of the migration parameters have not been derived.

2. The known KBOs are mostly larger than about 100 km in diameter. These objects must have accreted in an environment where the velocity dispersion among planetesimals was small compared to the escape velocity (about 0.1 km/s). The current velocity dispersion among KBOs is near 1.5 km/s. Therefore, some process has pumped the velocity dispersion of the KBOs since formation. A number of hypothesis have been advanced. Resonance sweeping should pump inclinations (Malhotra 1995, AJ), but it fails to explain the broad inclination distribution of the non-resonant KBOs as do long-term interactions with Neptune (Holman and Wisdom 1993, AJ). Earth-mass planets scattered through the Kuiper Belt by Neptune could have excited the velocity dispersion (Morbidelli and Valsecchi 1997, Icarus) but would have inflicted severe damage on the resonant populations (Malhotra 2000, Protostars and Planets IV). Passing stars, perhaps members of a dense cluster from which the sun formed, can play a similar role (Ida et al. 2000, ApJ). We possess insufficient information, in the form of well sampled distributions of the orbital elements of KBOs, to decide among these possibilities.

3. About 20 so-called Scattered KBOs have been discovered. These orbit beyond the classical Kuiper Belt, forming a populous swarm of objects with perihelia near 35 AU and high orbital eccentricities. The prevailing hypothesis for their origin is that they are bodies originally strongly interacting with Neptune, whose perihelia have been diffusively raised to the point where the dynamics is now almost decoupled. Amazingly, recent observations suggest that these objects may outnumber the rest of the Kuiper Belt while recent models suggest that the Scattered KBOs (rather than the classical or resonant KBOs) may be the source of the short-period comets. The situation is unclear, because the number of known SKBOs remains small (see top figure).

4. The radial extent of the Kuiper Belt is observationally not well constrained. Ground-based observations (top and bottom figure) show an edge at 50 AU but there is reason to think that the Kuiper Belt extends to much larger distances (Jewitt et al. 1998, AJ). We know that the surface density of the observed Kuiper Belt is too small to permit accretion: about 99% of the initial mass from the 30 AU to 50 AU region has been lost (Kenyon and Luu 1999, AJ). The surface density of the Belt might rise towards primordial levels at large distances, perhaps a factor of 100 larger than the region observed. Distant KBOs suffer from an inverse fourth power dependence of the scattered intensity on distance, and are too faint for detection from the ground.

GEST will probe the Kuiper Belt to exciting new depths

GEST is a proposed Discovery Mission which is designed to discover about 100 of earth sized planets via the gravitational microlensing technique (see poster 32.10 and astro-ph/0003102). Kuiper Belt science would be conducted during the 4 months of each year when the solar elongation of the galactic bulge is too small to permit micro-lensing observations. The GEST science divides into two surveys.

1. The GEST Large Survey
Observations of 600 close-packed ecliptic fields will be obtained to limiting red magnitude 26.5, and repeated at specific weekly, monthly and yearly intervals to permit orbit determination. A majority of the detected objects would be too faint for routine follow-up from the ground, requiring repeated observations from GEST. At 26.5 mag, the surface density of KBOs is ~83 per sq. deg., giving about 166 new objects in each 2 sq. deg. field of view of GEST. The Large Survey would be conducted at solar elongation angles near 100 deg., corresponding to the stationary points of KBOs. This minimizes trailing losses due to the finite proper motions of KBOs. The objective of the Large Survey is to detect 100,000 KBOs and obtain photometry and astrometry sufficient for orbital element determination. This is approximately a factor of 1000 times the number of KBOs presently having well-determined orbital elements. The unprecedented size of the Large Survey KBO sample will permit high signal-to-noise ratio measurements of:

a) the relative populations of the different dynamical types of KBO (resonant objects vs. classical objects vs. scattered objects) and their orbital element distributions, needed for comparison with evolutionary dynamical models (figure to right).

b) the luminosity function and hence the size distributions of the KBOs, differentiated according to dynamical type, for constraints on the growth process (Kenyon and Luu 1999)

c) the relative populations of the mean-motion resonances, providing key constraints on models of Neptune's migration.

d) the radial distribution out to ~75 AU.

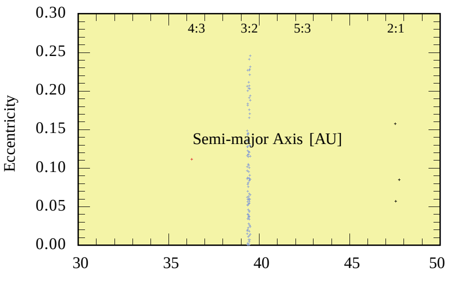
About 2000 of the 100,000 KBOs will be brighter than 24th mag., and hence within easy reach of study from the ground. Positions and orbital elements of these brighter objects will be made publicly available in near real-time (through the WWW and by traditional channels including notification of the Minor Planet Center) in order to facilitate ground-based physical observations not possible from GEST.

2. The GEST Deep Survey
The objective of the Deep Survey is to probe the faintest members of the Kuiper Belt and to assess the structure of the Belt at large distances. Accumulated images of a single 2 sq. deg. field to 29 mag. will yield about 6000 KBOs if the presently determined luminosity function applies at faint magnitudes. These images would be obtained in a series of short integrations then shift-and-add combined according to motion vectors calculated from the allowable orbits of KBOs. The Deep Survey will be sensitive to the Kuiper Belt "Wall", if such exists, and probably many more than 600 objects may be detected. As with the Large Survey, observations will be repeated at pre-selected intervals so that the orbital elements of the KBOs can be determined. Deep Survey objects will enable:

a) Measurement of the size distribution of objects in the classical Kuiper Belt down to cometary nucleus sizes (e.g. the nucleus of Halley's Comet has absolute red magnitude 13.7 and would appear at 29.1 mag at 35 AU). Assessment of the small body population is important in the context of the Kuiper Belt's role as the source reservoir of the short-period comets, and vital to understanding the role of collisions in the modern-day Kuiper Belt.

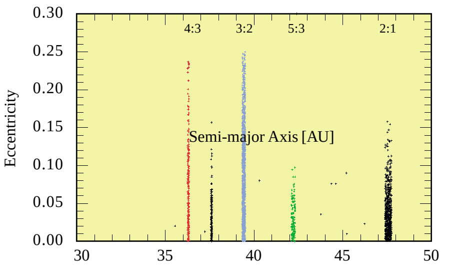
b) Detection of 100 km scale KBOs to about 150 AU. About 40,000 KBOs larger than 100 km diameter are expected inside 50 AU but none have been detected beyond this distance. This observation will have important bearing on the question of the radial extent and outer edge of the Kuiper Belt.

Testing Models Now

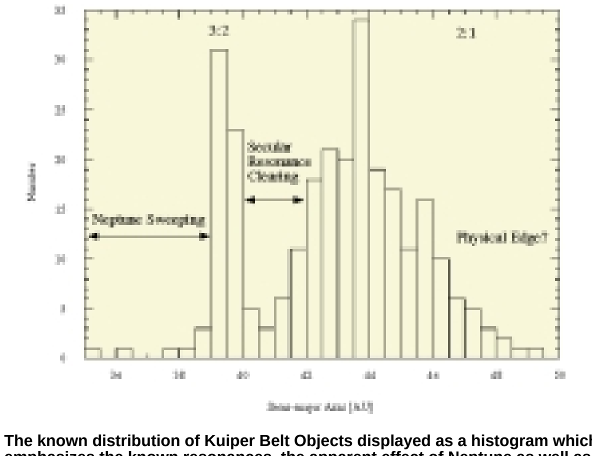


A plot of semi-major axis vs. orbital eccentricity for 100 Kuiper Belt Objects drawn from a Monte-Carlo simulation. Resonant structure in the belt is evident mainly in the well-populated 3:2 resonance at 39.4 AU.

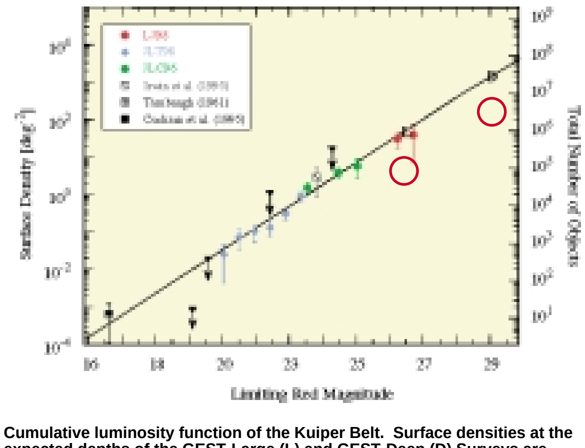
Testing Models With GEST



Same as above but for 100,000 objects, drawn from the model to simulate the GEST wide survey. The full resonant structure of the belt is now apparent and can be used to explore the dynamical evolution of the KBOs in detail. Note that, since 1000,000 points overcrowd the plot, we have used one symbol to denote 50 objects in the second panel.



The known distribution of Kuiper Belt Objects displayed as a histogram which emphasizes the known resonances, the apparent effect of Neptune as well as the apparent edge of the belt due to the lack of any known, distant KBOs.



Cumulative luminosity function of the Kuiper Belt. Surface densities at the expected depths of the GEST-Large (L) and GEST-Deep (D) Surveys are marked.

SUMMARY

GEST Large Survey observations of the Kuiper Belt will provide:

- Detections and orbits of 100,000 Kuiper Belt Objects (KBOs), a factor of 300 improvement on the currently known population
- Measurements of the population ratios of dynamical resonances with which to constrain the migration history of the outer planets
- Determination of the dynamical structure and radial distribution of the Kuiper Belt to at least 200 AU

GEST Deep Survey observations will provide

- A sensitive probe of the hypothesized density wall beyond which the density of KBOs returns to primordial values
- The size distribution of KBOs down to cometary nucleus size scales and a direct assessment of the source population of the short-period comets