Next Generation Space Telescope
Ad-Hoc Science Working Group
Design Reference Mission Proposal

A Survey of the Trans-Neptunian Region

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Scientific category: SOLAR SYSTEM
Instruments: OPT/CAM, NIR/CAM
Days of observation: 22

Abstract

Since the first discovery in 1992, limited ground-based surveys have found about 70 Trans-Neptunian objects (TNOs, also known as Kuiper Belt objects). Most known TNOs are relatively close (heliocentric distances from 30 to 45 AU), and with R magnitudes of 20 to 24 are thought to be from 100 to 800 km in diameter. At R = 23.5 the surface density of KBOs is about 1 per square degree, with the density of objects on the sky increasing rapidly at fainter magnitudes. NGST will be able to obtain the first global look at the Kuiper Belt, mapping its overall structure by determining its thickness, its azimuthal variation, and its radial extent. The unique sensitivity of NGST will permit deep searches (to R = 30.5) which should yield of order 500 new objects per field. Imaging a set of fields spaced uniformly around the ecliptic will determine the resonance structure imposed on the belt by the gravitational effects of Neptune. At each longitude, fields at several ecliptic latitudes will map the inclination distribution of the belt, testing competing theories for the formation and orbital evolution of the giant planets. The greater depth obtainable with NGST will allow detection of 100 km radius objects, if they exist, at distances >200 AU, and 5 km-radius objects at 50 AU. Such a survey can be accomplished in approximately 500 hours of observing time, and is likely to identify 40,000 new objects. Longer integrations (18,000 sec) in selected ecliptic fields will permit the TNO population to be characterized down to $R = 31.5$, corresponding to a typical 2 km radius comet at 40 AU. We can thus probe our own Kuiper Belt at distances comparable to the sizes of the dust disks seen around some young stars, while carrying out a census of actual comet progenitors in the inner belt.

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
ECLIPTIC FIELDS	0,1,2...23	ecliptic	R=30.5	OPT/CAM R3	3
±10 DEG FIELDS	ditto	±10	R=30.5	OPT/CAM R3	3
±20 DEG FIELDS	ditto	±20	R=30.5	OPT/CAM R3	3
±30 DEG FIELDS	ditto	±30	R=30.5	OPT/CAM R3	3
±40 DEG FIELDS	ditto	±40	R=30.5	OPT/CAM R3	3
±50 DEG FIELDS	ditto	±50	R=30.5	OPT/CAM R3	3
DEEP-1	tbd	ecliptic	R=31.5	OPT/CAM,NIR/CAM R3	1
DEEP-2	tbd	ecliptic	R=31.5	OPT/CAM,NIR/CAM R3	1
DEEP-3	tbd	ecliptic	R=31.5	OPT/CAM,NIR/CAM R3	1
DEEP-4	tbd	ecliptic	R=31.5	OPT/CAM,NIR/CAM R3	1
				Grand total days	22

EXPLANATION: This is a moving target program (although non-sidereal tracking is not necessary). Thus, there are 3 visits to each target field, spaced over a week of time. In each observing session 6 fields (in the ecliptic and at ecliptic latitudes ranging from ±10° to ±50°) are imaged with 6 sequential 500-second exposures, for a total of 36 500-sec exposures. All fields in one 'visit' have roughly the same ecliptic longitude, located either +77° or −84° from opposition at the time of the first exposure set. These 6 fields are repeated 3 and 7 days later. The process is then repeated for the next ecliptic longitude, starting $\sim$ 15 days later. Choice of northern or southern latitudes will be made based on Galactic confusion, etc.

Thus, the total time of 3 days for each latitude represents the acquisition of each field for 3000 seconds, repeated 3 times, and for 24 different longitudes (with a 20% duty-cycle overhead).

Scientific Objectives

Beyond the orbit of Neptune, at the fringes of the known solar system, lies the Edgeworth-Kuiper Belt: a flattened disk of icy planetesimals thought to be left over from the formation of the solar system 4.5 billion years ago. The Kuiper Belt is also the hypothesized source of prograde, Jupiter-family comets, as opposed to the randomly-inclined near-parabolic comets which come from the much more distant Oort cloud. In recent years, this region has begun to yield its secrets to the first tentative probings with instrument/detector combinations powerful enough to find the first few tens of objects (see Jewitt *et al.* 1996, Jewitt *et al.* 1998 and Gladman *et al.* 1998 for recent surveys, and Dones (1997) for a review of the origin and dynamical evolution of the Kupier Belt).

The dynamical structure of the Belt is clearly quite complex, with at least 3 components: (1) a dynamically cold disk of presumably primordial planetesimals, (2) a set of objects trapped in mean-motion resonances with Neptune (especially the ‘plutinos’ in the 2:3 resonance), and (3) a ‘scattered disk’ of objects that have encountered Neptune in the past and are in scattered orbits with high inclinations and eccentricities (eg., the unusual object 1996 TL66 with $a = 84.5$ AU and $e = 0.59$, discovered at perihelion by Luu et al. [1997]). The distribution of the objects between these populations is heavily influenced by how the outer planets formed (Dones 1997). The plutinos are believed to have been captured as Neptune and its family of resonances migrated outwards, due either to interactions with Jupiter and the ejection of planetesimals into the Oort cloud or to torques associated with the protoplanetary disk. A currently unsolved puzzle, however, is the apparent lack of TNOs in the strong 1:2 resonance at 48 AU. Passage of resonances thru the Belt can also lead to the excitation of eccentricities and inclinations. Thus the distribution of orbital inclinations (and hence ecliptic *latitudes*) and heliocentric distances will tell us much about how and when the outer planets migrated radially as they formed. The distribution of objects as a function of ecliptic *longitude* will reveal the resonance structure imposed on the belt by Neptune; the plutinos, for example, are at perihelion $\pm 90^\circ$ from Neptune, and thus likely to be found preferentially near these locations).

The purpose of this program is to conduct a large-scale survey of the overall structure of the belt to observe the variation of the sky density of Kuiper Belt objects as a function of ecliptic latitude and longitude, while also examining selected ecliptic fields to great depth to probe the size distribution of the smallest TNOs. The luminosity function of the Kuiper Belt (the number of objects per sq. deg. brighter than a given magnitude) increases rapidly, with the cumulative number of objects increasing by a factor of 4–6 for each fainter magnitude (Gladman *et al* and Jewitt *et al* give somewhat different estimates); there is one object per sq. deg. at $R \approx 23.3$. Thus, looking in the ecliptic to a magnitude of $R = 30.5$ (or $K \approx 28.5$) should yield $\sim 10^5$ objects per sq. deg., or ~ 500 Kuiper Belt objects per 4’×4’ NGST field. This provides good statistics with which to observe the azimuthal variation of the Belt, and also examing fields at 10°, 20°, 30°, 40° and 50° ecliptic latitude will reveal the drop-off in the sky density caused by the inclination distribution.

At $R = 30.5$, or $K \approx 28.5$, NGST will detect objects as small as 5 km in radius at 50 AU, enabling us to see Halley-sized objects in the presently-known Kuiper Belt. The typical-size TNO (100 km radius, albedo 0.04) will be detectable out to distances of ~ 220 AU, assuming the population extends that far. To date, no objects have been actually detected beyond 50 AU, although one object has a semimajor axis of 84.5 AU and there are good theoretical reasons to believe that the "scattered disk" must extend far beyond this distance (Levison & Duncan 1997).

Bibliography

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NGST Uniqueness/Relationship to Other Facilities

Only NGST has the capability for imaging point-source Kuiper Belt objects fainter than $R \approx 28$. Current and forseeable ground-based searches with large-format CCD arrays are capable of a large-area survey, but are limited to $R \sim 26.5 - 27$ for full-night integrations even on 8-10 meter size telescopes. HST and WFPC2 were used by Cochran et al. (1995) to carry out a very narrow angle survey down to $V = 28.8$, or $R \approx 28.3$ for typical TNO colors. NGST will be able to survey significant regions down to $R = 30.5$, as well as carry out more limited pencil-beam surveys to $R = 31.5$. The latter will enable for the first time observation of objects the size of real short-period comets (radii of $2-3$ km) out to distances of $40 - 50$ AU, while the broader survey will permit the spatial distribution of the largest objects to be mapped well beyond 100 AU.

Observing Strategy

In the basic survey, the ecliptic will be uniformly sampled in ecliptic longitude and latitude in a set of pencil beam fields (each 4'×4' in size). Ecliptic longitudes will be sampled at 15° intervals around the sky, with one field centered very near the location of Neptune. At each longitude, single fields at 0°, ±10°, ±20°, ±30°, ±40° and ±50° will be selected, avoiding bright sources or star clusters, and a set of 18 exposures of each will be acquired, in 3 groups of 6 scheduled at 3–4 day intervals. By observing at elongations of $77 - 84°$ from opposition, the apparent geocentric motion of objects in the Kuiper Belt beyond 40 AU is reduced to ≤ 70 mas per 1000 sec, permitting essentially untrailed images in individual exposure times up to 500 sec without tracking. A sequence of 6 such exposures will permit the identification of TNO candidates from their slow motion, the rejection of nearby asteroids and fixed sources (stars and galaxies) and should yield an SNR of 4.55 at I for $R = 30.5$. With 6 different latitude fields per visit, the total number of exposures is 36 for each longitude, repeated 3 and then 7 days later.) Simulations indicate that this 1-week time baseline should be sufficient to allow the determination of the orbital inclination, orbital node, and heliocentric distance of the TNOs discovered. (More analysis is needed to establish whether or not semimajor axes and eccentricities can be estimated separately.)

Note that a specific ecliptic longitude is available for imaging only twice per year, and within a window of ~ 7 days long. Longer-term follow-up for better orbital determination is thus unfortunately not feasible, at least without moving-target tracking capability. Wherever possible, we will choose fields which contain known Kuiper Belt objects ($R \sim 23$, typically). This will not only provide a direct test of the image-stacking algorithm (a major difficulty with recent HST observations of TNOs, due to HST's own orbital parallax), but may yield rotational periods and lightcurves for the bright TNOs. The latter can provide estimates of these objects' shapes.

A more limited but deeper 4-color pencil-beam survey will be conducted in selected ecliptic fields, accumulating a total integration time of 18,000 sec (5 hrs) on each field in each filter. The fields will be selected at $\sim 77°$ from opposition to minimize the dispersion in geocentric motion. In 18,000 sec at R, I, J and K for example, this deep survey should go to $R = 31.5$ and $K = 29.5$ with SNRs of 3.7 and 5.9, respectively, which is satisfactory for object identification in the stacked exposures. This is equivalent to a 2 km radius TNO at 40 AU, 10 km objects at 85 AU and 100 km objects at 280 AU. These fields will provide size distribution and color information, but probably no useful orbital data.

Special Requirements

THIS IS A MOVING TARGET SURVEY, AND AS SUCH THE TIMING OF THE OBSERVATIONS IS CRITICAL. Each chosen field must be imaged during a relatively small window during the year, when it is located within the $77 - 84°$ elongation range from opposition so as to prevent trailing losses. The fields must then be repeated on 2 further epochs, spaced at $3 - 4$ day intervals following the first acquisition. Since fields of low background object density are preferable, all fields must be chosen in advance for particular dates of observation. This program will therefore be a challenge for NGST scheduling, if not tracking.

THIS DRM PRPOSAL ASSUMES THE LAGRANGE POINT OR EARTH DRIFT-AWAY ORBIT. If the 1×3 AU orbit is chosen, the times and intervals of observation must be changed since the object's apparent motions will be different. Observing at 3 AU allows the significant advantage that the objects will move more slowly (since the apparent motion is dominated by the reflex motion due to the observing platform).

Minimum FOV:	$4'$ at 0.7 μm
Maximum time until replanned science followup:	4 days
Minimum obs time with same orientation:	7 days
Maximum tracking blur:	15 mas

■ Precursor/Supporting Observations

PRECURSOR: All potential target fields will be deeply imaged ($R \sim 26$) from the ground (eg., at the Palomar 5-meter telescope) to ensure that the density of background objects is acceptably low.

SUPPORTING: Several ground-based telescopes will be ready to perform follow-up observations on the brightest of the objects discovered by the NGST survey. However, the small field size means that in an average set of 6 fields at the same ecliptic longitude, the brightest object that would likely be discovered is $R \sim 25$, and thus would not be easily recovered from the ground with small telescopes. However, deep integrations (in the manner described by Gladman *et al.* 1998) could be conducted from the ground one month later on the most promising of the fields. This might permit recovery — and thus provide much more detailed orbits for — the brightest ($R < 26$) few objects per field.