

Characterizing and Evaluation NEO Surface and Interior Properties and Binary Configurations

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Introduction

A fundamental outstanding issue in NEO studies, from both a scientific and engineering perspective, is our need to better understand, in detail, the surface and internal structural properties of these objects. From a planetary science perspective, the remotely-sensed characteristics and physical properties of the surfaces of NEOs (and inferred internal structures) connect them with known classes of meteorites and help us address processes of planetesimal origin and thermal and collisional evolution of these objects. From an engineering perspective, knowledge of the surface and internal structural properties of NEOs will be necessary in designing spacecraft technologies and stand-off/surface operations techniques for scientific exploration, resource utilization, and impact hazard mitigation.

A primary goal of future NEO investigations should be to characterize the physical, optical, chemical, and mechanical nature of the regolith or surface particulates (if any), and the strength and cohesiveness of the upper layers of these bodies. In particular, can mitigation devices adhere to an NEO? How will the surface respond to attempts to push or pull the object, or ablate its surface? What range of internal structures can we expect among NEOs, and will mitigation or resource utilization efforts modify such structures?

Closely related to the problem of characterizing surface and internal structural properties of NEOs is the fact that at least 15% of the NEO population are binary

objects (double bodies or bodies with satellites); even more NEOs may resemble contact binaries. Many binary asteroids on planet-crossing orbits may be by-products of recent tidal disruption events, where the parent object is pulled into two or more components during a close flyby with a terrestrial planet. Such encounters also may have played a role in determining the gross shapes and spins of many other, non-binary, objects (e.g., Geographos, also the 2029 close pass of Apophis). Other near-Earth binaries may have been delivered as binaries from the main belt, produced there by collisional processes.

In either case, binaries are valuable scientific targets. But such objects are also a challenge for deflection missions. Can binary pairs be deflected from impact trajectories as a single gravitational entity? There are also issues of binary impact into Earth: what would be a typical (projected) separation during encounter, and the effects on altering the type of devastation to be expected. Would the typical separation be such that it appears as simply one impact? Or would there be spatial or temporal separation of impact effects beyond what might otherwise be expected for a single impactor? For example, could a double impact into the ocean cause unexpected water-wave interference effects, magnifying the expected size of a tsunami?

Bridging the two issues of the properties of surface materials and the binary nature of some NEOs is the concept of surface blocks as failed satellites. The surfaces of Eros and Itokawa are dominated not by craters but by boulders. Whether or not some of these may

be reaccreted satellites, the boulders nevertheless testify to at least transitory debris that has existed in the vicinity of NEOs. Debris stirred up around an object by a spacecraft operating on or near the surface of an NEO may pose a hazard for continued near-surface and surface operations on or around the object.

Here we address the needs to understand these issues involving surface/interior structures and binaries through theoretical and modeling research as well as ground-based and space-based investigations.

In Situ Surface Property Investigations

Here we discuss a selection of priority in-situ surface property studies that bear directly on the engineering capabilities and requirements for working on and near the surfaces of NEOs.

Elemental and Mineralogical Composition.

Determining the elemental and mineralogical composition of NEOs and connecting these compositions to those of known classes of meteorites is a scientific priority. From an engineering/operational perspective, knowing the composition of the surface of an NEO is important in setting at least zeroth-order expectations for the mechanical properties of the surface (see next subsection) and how we might interact with it. The surfaces of primitive NEOs with easily volatilized materials might evolve into very porous, fairy-castle structures with little cohesive strength. High iron content chondritic material might offer the option for magnetic bonding of vehicles or surface equipment to the surface rather than the more conventional notions of harpoon-like anchors. Nickel-iron alloys present radically different challenges from those involving essentially rocky materials.

On the surface of an NEO with a lander/penetrator, we can do more to determine elemental, molecular, isotopic, and mineralogic composition to correlate with known chondritic compositions than is possible from remotely-sensed, 'astronomical'-style observations. To accomplish that correlation, we need to make in situ measurements with sufficient precision to match the classic laboratory discriminators used to classify primitive meteorites into carbonaceous, ordinary, and enstatite subgroups (see Kring et al. 1995 LPI Tech. Rep. 95-05, for a review).

Candidate instruments on a lander/penetrator sufficient to this end include gamma ray spectrometers (GRS), Alpha-Proton-X-ray instruments (in combination), and RAMAN spectrometers. The GRS should provide sufficient chemical information to distinguish chondritic from achondritic material and, ideally, specific groups of chondritic and achondritic material. An alternative to the GRS is a mass spectrometer, if sufficiently large sample mass can be homogenized and ionized. This would likely require a mechanical device and/or lasers. Another alternative instrument involves laser-induced breakdown spectroscopy, but thus far elemental abundances are only reproducible with such instrumentation to within ~10%. The RAMAN device should be able to identify surface mineralogy, although there are limits in its ability to identify the specific composition of minerals (e.g., the amount of Fe in pyroxene and olivine). A near-IR spectrometer may also be needed.

The specific mix of instrumentation needs to be determined in the context of particular asteroid targets and with the latest estimates of mass and power for the instruments. In particular, the GRS may be particularly massive. Finally, a magnetometer may be

useful. Nobody “expected” any magnetic signature for any whole asteroid, but did expect highly localized magnetic fields (since meteorites exhibit that). What has been found so far is exactly the opposite, so expectations should not be weighed heavily. Related, a very simple, no moving parts instrument for helping to distinguish between chondritic compositions might be some sort of magnetic susceptibility probe. When combined with density/porosity measurements this technique has been very useful in the laboratory for re-classifying previously mis-classified meteorites. For a surface ‘lander’ this could be a simple, small, and low-power option.

Mechanical Strength and Cohesion. NEOs can be expected to display a wide range of surface mechanical properties. At some small size (perhaps below the ~150-m diameter size where material strength and gravity trade for dominance in determining impact strength, and where the monolith to rubble-pile structure transition may lie) objects must exist as shards of essentially regolith-free rock, resembling the intact (or nearly so) blocks that make up the very largest size fraction of the regoliths on Eros and Itokawa. The largest NEOs may retain much finer regoliths; the ‘ponds’ on Eros (see next subsection) are consistent with filling of topographic lows by particulates ranging from fine dust to centimeter-scale gravel.

This range of possible mechanical strengths poses a significant challenge for the design of autonomous spacecraft intended to have significant interaction with NEO surfaces. Can spacecraft expect to securely anchor themselves to NEO surfaces for operations requiring substantial force to be applied to the object?

How ‘fluffy’ can the surface be expected to be? On the one hand, a fine mixture of impact-comminuted rocky debris might be expected to behave almost as a fluid in the effectively zero-g environment of a very small NEO. On the other hand, thermal cycling of the surface, micro-seismic effects of small and near-continuous impacts, and various yet-to-be understood annealing processes might act to settle and sort and cement the surface into a more compact structure. The final image in NEAR-Shoemaker’s final descent to Eros’ surface reveals a strange, cm-scale ‘canyon’ in the fine material at the edge of a pond, indicating that some fine grain annealing process is at work at least on that asteroid. On the other hand, Deep Impact’s collision with a comet has suggested that the surface resembled ‘talcum powder’.

In situ investigations and instrumentation for documenting and understanding the morphology of whatever regolith or particulate population exists on NEOs, the variation of the existence and properties of that regolith with NEO size, and the processes governing the formation and evolution of that material are a top priority for any NEO ‘lander’ or very near-surface spacecraft.

A small, surface imaging camera would allow for near-field imaging of regolith properties and documentation of sample composition analyses. A microscopic imager, similar to those on the arms of the MER rovers, would allow examination of the finest regolith features. The imager(s) should provide geologic context and elucidate structural components in the asteroid, on macroscopic scales down to at least ~1 mm. The general undisturbed appearance of the regolith and any scuff marks made in it by the ‘lander’ as it touches the surface in coming to rest can be

used to estimate coherence and compliance of the surface as is being routinely done by observing tracks marks and trenches made by the wheels of the MER rovers on Mars.

A simple compliance probe could be used to contact and/or penetrate the surface while measuring the mechanical resistance. This would quantify the compressive strength of the surface in a manner not possible through simple morphological examination via image analysis.

Electrostatic Charging. The surfaces of airless bodies like asteroids are subject to positive electrostatic charging by photoemission of electrons from the sunlit, UV-illuminated surfaces. Dust particles on these surfaces likewise become positively charged and are subject to mobilization by the charging process itself and by other mechanisms like impact cratering (at all scales, especially continuous microcratering), mass wasting events caused by cratering and tidal encounters with terrestrial planets, and diurnal and seasonal thermal cycling. The smooth surfaces and correlation with topographic lows subject to significant diurnal lighting variation of the 'ponds' on Eros are consistent with dust having migrated to these areas.

The dust-size fraction of regoliths on NEOs, if present, is created through impact processes and is not likely to be subject to substantial subsequent mechanical and/or chemical weathering such as that which rounds small grains on Earth. These small grains can thus be expected to have shapes that will be highly irregular and sharp, more closely resembling volcanic ash than beach sand.

When electrostatically charged, this abrasive dust presents a particularly troublesome engineering challenge for any surface or

very-near-surface spacecraft operations. The Apollo astronauts all experienced various problems with lunar dust. During their technical debriefing after returning home to Earth, the Apollo 12 crew reported that although they did their best to keep equipment clean, merely moving around got dust all over everything. "I got quite concerned with not only the wear and tear on the suits but the effect of dust on the suits", Pete Conrad recalled. "On our final hookup back on the LM ECS system for ascent, it was all we could do to get our wrist locks and suit hose locks to work. They obviously were beginning to bog down with dust in them... there's no doubt in my mind that with a couple more EVAs something would have ground to a halt."

The moving parts of any automated equipment operating on the surface on an NEO for exploration or deflection operations can likewise be expected to have to operate under such conditions.

Characterizing the microscopic texture and electrostatic charging properties of the finest fraction of NEO regoliths and the charging mechanisms and properties of dusty plasmas around and on NEO surfaces should be a priority for in-situ investigation.

Plasma density and electric field mapping instrumentation can be as simple as a few Langmuir probes deployed from a few places around the spacecraft. By changing the electrode potentials and measuring the change in current they draw, plasma and electron densities can be determined. By using multiple such probes around the spacecraft, vertical and horizontal electric field variations can be mapped, yielding clues to dust transport mechanisms. Very sensitive dust detectors (e.g., an optical transmissometer for measuring accumulation of dust on spacecraft surfaces)

would quantify dust transport efficiency and constrain dust transport models that depend on changing solar illumination.

Interior Structure Investigations

Small body mass determination traditionally comes through spacecraft tracking, and object volume is determined through shape modeling based on data from the imaging system(s). The object bulk density then is obtained.

We need the NEXT STEP in trying to learn about interiors beyond such simple and rather non-useful kinds of constraints. This means investigations and instrumentation to determine the details of internal structure that lead to the object's bulk density and its overall strength: the nature of interior porosity (e.g., uniform microporosity or macroscopic void spaces in a megaregolith structure); size distribution of interior rubble fragments; existence and degree of non-gravitational cohesion between interior components and the nature/origin of that cohesion; etc.

Two techniques for addressing these issues that are likely to be most practically applied in the near future are radar tomography and seismic studies.

Radar tomographic sounding of interiors.

Deep imaging of the interiors of asteroids is possible because low-frequency radio waves can penetrate the regolith and rock of an NEA until reflected by structural or compositional boundaries within the interior or attenuated by a sufficient pathlength through the object. Analysis of these reflections and absorption characteristics allow for a 3D reconstruction of the interior structure. The Deep Interior and ISHTAR missions are or were pursuing this technique

for detailed reconnaissance of the interior structure of NEOs.

Active and passive seismic missions.

Spacecraft-deployable seismometers with reasonably small masses (<0.5 kg) exist that can detect accelerations as small as 10^{-9} g and ground motions as small as 1 nm. For comparison, the typical surface accelerations for moonquakes are of order 5×10^{-9} g, and the terrestrial background seismic 'noise' is around 2×10^{-8} g.

The engineering and operational challenges of employing these instruments for seismic studies on NEOs, of course, are determining how to couple, in effectively zero-g and to an unknown surface, the energy of an acoustic or explosive pulse into the subsurface and the related problem of coupling the receiving sensors. Penetrators may work in soft surfaces, vacuum-curable adhesives might work on bare rock surfaces that prove too hard to drill into, and magnetic pads might work on the surfaces of iron-rich objects. No matter the surface, the seismic noise produced by diurnal thermal cycling of the surface will likely prove to be a limiting factor in detectability of acoustic returns from the interior.

The 13 April 2029 close pass of 99942 Apophis offers a unique scientific opportunity that we should take full advantage of. During this close pass (about 5.7 Earth radii, within geostationary distance!), tidal torques will measurably alter the asteroid's spin state and may well cause surface and/or internal structural deformations that would be detectable by seismometers emplaced on or within the object. Nature is doing the energetically difficult part of an active seismic sounding mission for us – we simply need to wire the asteroid for sound and passively listen!

Binary Asteroids and Orbiting Debris

Another aspect of NEO properties that has become increasingly important is the potential (about one chance in 5, or more) that any given NEO may turn out to be a binary. That is, it may be composed of a primary with one (or even more) small satellite, or it may be two bodies of nearly equal size, or it may be a contact binary, a double system that has components now in contact, presumably due to the tidal decay of a close binary pair. Recent estimates are that at least 15% of NEOs are pairs (not including contact binaries). This fraction is so large that the implications must be addressed in any serious survey, characterization, or mitigation program.

Our understanding of binaries is far from complete. NEOs are elusive targets for all types of investigations, but particularly those that seek to determine the binary fraction of NEOs. The targets are small (and faint), they are relatively close to Earth for only short times, they often do not return to good viewing circumstances for several years (unlike, e.g. main-belt asteroids, which have roughly the same observing circumstances every 16 months or so), and they are generally moving very fast across the sky when they are observable (meaning they are hard to follow and the window of observability is short).

Certain properties of an asteroid may be revealed through the presence of a binary that may not otherwise be discernable, at least without a spacecraft mission. For example, the bulk density may be determined and hence a guess at the gross internal structure (rubble pile or solid) may be made. Spin and total angular momentum, as well as pole orientation, may be inferred,

which are likely to affect approach trajectory, the orbit, and landing sites of any mitigation spacecraft.

Study of binaries can help us assess the likelihood that any NEO is binary and that its nature may affect the degree of hazard to Earth posed by an individual NEO, and it allows evaluation of the special problems binaries pose to mitigation of a hazard. Therefore, we think that study of binaries should be a major component of any NEO characterization program. We argue here that the resources are currently not adequate to do justice to this important aspect of hazard evaluation.

Special problems in mitigation of binaries

Binaries pose additional complexities on the already difficult problem of mitigating a hazard. Instead of moving one object, two must be moved. We expect that a binary could be moved as a single gravitational entity, provided it is done slowly enough. Most scenarios for moving an asteroid are inherently slow anyway, but some are not. And there may not be the luxury of time. We do not yet know whether NEO binaries are formed in near-Earth space by tidal disruption, or whether they are delivered from the Main Belt as already-formed binaries. Suggestions favoring the latter come from recent determinations that, at the small end of the main-belt size distribution, the binary fractions are closer to 20% (and similar to the NEO binary fraction), than they are to the binary fraction of large main-belt binaries (about 2%), although this may be entirely coincidence. If it can be shown that NEOs binaries come from the Main Belt pre-made, then at least we know that binaries can be moved as a pair. How this would affect our choice of mitigation scenario is not clear, but it needs study. The location and timing of a nuclear charge for

mitigation will clearly be dependent upon whether the system is binary and on the binary characteristics. The nuclear option may even be ruled out in the case of a binary.

Operating a spacecraft in the vicinity of a binary or multiple-body system (or in the presence of orbiting debris) would be hazardous. Aside from the danger of impact, navigational complexities of operating in a binary gravitational environment will present another risk to a mission, and would undoubtedly force restrictions on orbits and activities. If the bodies are rubble piles, and are of significant size, there may be tidal distortions of the bodies on one another. If the tidal bulge changes with time, it will affect the types of mitigation possible or make them more complex. It is also possible that the presence of a companion may affect any plan to de-spin an asteroid before attempting to maneuver it (e.g. pushing through the CM, as envisioned by some tugboat scenarios). We also have to consider whether the body will make a close pass to Earth before a mitigation mission, an event that could cause tidal stripping of the binary and/or changes in the separations or shapes of the bodies. We should also study whether the body has recently had a close pass to Earth.

So it is imperative that we search for binaries, that we learn whether any identified hazardous NEO is a binary, and in evaluating options, we need to keep in mind the possibility of a binary. Even with these steps, it may not be enough. It is entirely plausible that we will not know if an NEO is binary until a spacecraft arrives (maybe the companion is too close or too small to detect from Earth). If we have enough time for a reconnaissance craft, we will know the answer before final mitigation design, but

we will have lost valuable time. If the NEO appears to be single from Earth, and if there is not time for reconnaissance, then the mitigation strategy must be one that is adaptable to both single and binary systems. The mitigation craft must arrive at the NEO prepared to search for and detect possible companions, and characterize them. This will be in addition to dealing with the hazard as either a single or double object. In the case that the mitigation solution is the same for either case, then it may come down to a matter of real-time implementation. This will markedly affect the planning and logistics of the mission. Any limitations on our knowledge from ground-based study will be mapped directly into complexity and cost of contingencies of a mission. There is also the possibility that a binary could *give us* additional options to mitigate a hazard. In our thinking, we should remain open to clever ways to leverage a binary “misfortune”.

The binary impact hazard

Efforts should also be directed specifically at the study of the effects of a binary impact as distinguished from impact of a single object. There is substantial evidence, from the crater records of the Moon, Mars, Venus, and Earth, that double impacts occur. Some of these studies were done long before any binary NEO was found and suggested similar binary fractions as the telescopic data are now showing. We know that a typical crater diameter is ~10 times the size of an impactor, and that double craters are seen to be separated by a few crater diameters, thus the separations on impact are of the same order as the separations in observed binaries, some 10-100 asteroid radii. Although detected NEO binaries generally have separations closer to the small end of this range (~10), the Hill stability limit for objects at about 1 AU from

the Sun is about 100 radii. There is also a bias toward detection of closer binaries in the two techniques responsible so far for NEO binary detection – radar and lightcurve analysis. Recent work [Walsh and Richardson, *Icarus* 180, 201 (2006)] shows that tidal disruption may also create wide binaries. Although none have been found, wide binaries may lend themselves well to detection by direct imaging, once technical problems are overcome.

The evidence is clear that such double impacts occur. What special effects might be caused by a double, rather than a single, impact? Of course, the region in the immediate impact zone may be significantly affected, spreading the effects of a direct hit from a region, in the case of a 1 km impactor, of 10 km to over 100 km. If the impact were into ocean, the possible scale of the water disturbance may render the tsunami wave from the short-wavelength regime expected of a single impact [and hence less destructive, see Melosh, *LPSC* 34, 2013 (2003)], to now a longer wavelength disturbance more similar (and destructive) to earthquake tsunami waves. The effects of a double impact into ocean water, with separations of the order of tsunami wavelength and possible wave interference effects, should be studied to again re-examine the threat due to impact tsunamis. There may also be differences in the ejecta plume and the effect on the atmosphere.

Binary measurements and techniques

Aside from a spacecraft encounter (where it is *still* difficult to search for small satellites), we can search for and study NEO binaries in several ways. The two techniques that have delivered all of the known NEO binaries are radar and lightcurve analysis. A third technique, direct imaging, particularly by

ground-based adaptive optics (AO) has not yet detected NEO binaries, although the number of attempts has been limited.

The radar technique uses large radio dishes to beam a signal toward an object and study its return (reflected) signature. The advantages of radar are that it can discern very close binaries and see very small objects, even tens of meters in size. One of the limitations is that, because it uses a 2-way signal, the effective return power goes as the distance to the object to the 4th power. Thus, small objects must be reasonably close to Earth for study. Further, the largest dish (Arecibo) is fixed in pointing and can only study objects within a certain range of the local zenith.

The second method, detailed analysis of lightcurves, has shown that binaries can be detected by looking for double-period lightcurves --- the first period being the rotation of the primary, and the second due to occultation/eclipse events due to the presence of a secondary. The technique is sensitive to a relatively large secondary that orbits an asynchronously rotating primary. A huge advantage of this technique is that it does not require the largest astronomical facilities in the world, but can be done with modest-sized telescopes. One drawback is that it can only detect binaries in the right geometry --- they must be eclipsing --- and so is sensitive only to systems where our line of sight is roughly in the plane of the binary orbit. Therefore, there is a selection effect against wide binaries. Direct imaging has the advantage that it could detect wide binaries and much smaller companions (relative to the primary), and can do so quite rapidly. A drawback is that it needs the largest telescopes with AO, which are not currently configured to be compatible with rapidly moving objects.

Among the measurable quantities, all of interest to mitigation, include object sizes, separations, shapes in some cases (and hence possible clues on tidal distortion), densities and possibly inference of interior composition and structure. In some cases, using radar, reflex speed of the primary can be determined and this can result in knowledge of the secondary mass. We could also learn the amount of angular momentum of the system tied up in orbital motion vs. primary spin, which is another quantity that may be measured. Of fundamental importance is the composition of the bodies. A spectrum from normal ground-based spectroscopy will show only a “combined” spectrum. If the bodies are of different taxonomic types, we may not be able to uniquely determine individual compositions for planning mitigation. Using AO, we may be able to acquire spectra of the individual objects. However, the separations of known NEOs are so close that AO cannot resolve the pairs, except at closest approach. If wider pairs are prevalent (we don’t know yet), then AO will provide relief. Finally, space-based imaging may also be useful sometime in the next decade, but right now the crippled state of HST leaves it unable to image NEOs.

Proposed concepts for the binary “problem”

The main problem to overcome in making a detailed, reliable survey of binary fraction and binary characteristics in NEO space is inadequate telescope time devoted to the problem (and also inadequate resources for data reduction, analysis, and interpretation). This must be overcome if we are to retire or at least understand many of the problems posed by binaries in mitigation of the NEO hazard. There must be sufficient funding from NASA to support the needed augmentations in effort in the observational, theoretical, and modeling studies proposed

here. In addition, there must be an urgency passed on to the relevant observational facilities that the NEO observations are crucial not only to science, but perhaps to the very existence of our civilization. We cannot put off for decade after decade a threat that knows no schedules or budgets, but instead looks at the Earth as a gambler sees a Roulette table. We suggest that there are three domains of study needed: (1) the ground-based survey for binaries and the detailed characterization of those objects, as a group and as individual objects; (2) a plan for a detailed reconnaissance mission to be implemented on very short time scale should a threat be detected; and (3) planning of a detailed mitigation mission with a credible deflection strategy that takes into account the reasonably good chance that the target will be binary. The “live” reconnaissance mission should be preceded by one or more trial reconnaissance missions to other objects that will be able to gather the data required to support a mitigation effort and to learn how to operate in a difficult environment. We suggest the first such mission be to a binary (we have already done flyby, rendezvous, and landing on a single NEO in the NEAR mission). We must start planning all of these as soon as possible, but making significant progress on domain 1 is the foundation for the other two, and it is closest to being realized. It is an issue of money and priority.

We propose the following steps to lay the groundwork for a proper characterization of NEO binaries, allowing for realistic reconnaissance and mitigation missions to be developed. First, we must increase the amount of money and large telescope time devoted to NEOs. The large radio telescopes at Arecibo and Goldstone are largely dedicated to other tasks. It is our understanding that getting scheduled on these facilities is very competitive and

planetary science activities are not given high priority. Increasing the dedication of radar facilities to NEOs is vital. Lightcurve studies of NEOs, as for any other objects, are particularly time consuming. An enhanced network of telescopes, remotely controlled, and distributed strategically around the Earth, would offer the best hope for fast-turnaround detection of close binaries. Our group at SwRI has experience in photometric lightcurve measurements on faint bodies and also has experience in remotely-operated telescopes that have been shown to be feasible by detection of binaries in the Main Belt. Collaboration with existing teams, particularly that of P. Pravec in Europe, would be most beneficial. We do not have a cost estimate for this concept, but we expect it would be relatively modest, perhaps \$0.5M per facility.

We also propose that NASA find a way to direct some portion of (at least the US) large-telescope assets toward this effort. At the present time, NASA shares a portion of the Keck telescopes, and the US has a significant interest in the Gemini telescopes. We believe that with a commitment from

NASA, we could bring the AO systems on Keck, Gemini (North and South), and the ESO Very Large Telescope (VLT) in Chile into a mode compatible with fast-moving NEOs. The main problem is that the AO systems, which typically feedback small motion increments to the telescope now get confused with objects moving more than a certain speed. Further, the AO systems tend to pick up and track, instead of the target asteroid, any brighter object that comes into the field. We have already made inroads at each of these facilities to solve these problems. But the scientists and engineers at these facilities are not paid to make specialized upgrades and we as astronomers are not funded to do engineering. And any changes to the systems that would be only of use to, say, asteroid observers, are of low priority, because the majority of use is for galactic and extra-galactic research. Specifically, funding the needed changes to have operating AO systems on these large telescopes, and getting more observing time devoted to NEO and NEO/binary work, would permit rapid survey of many NEOs that are currently not accessible.