RADAR FOLLOW-UP OF SPACEGUARD DISCOVERIES: IMAGING AND ASTROMETRY

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Radar is a very powerful groundbased technique for post-discovery reconnaissance of NEOS and is likely to play a central role in investigating these fantastic worlds during the foreseeable future. Delay-Doppler measurements are orthogonal to optical angle measurement, t ypically have a fractional precision between 1 0^-5 and 1 W-9, and consequently are invaluable for refining orbits and prediction ephemerides. A single radar detection secures the orbit well enough to prevent "1oss" of the object, shrinking the object's instantaneous positional uncertainties by orders of magnitude with respect to an optical-only orbit. The availability of radar measurements could be the difference between knowing that an object witt pass "within several Earth-Moon distances of Earth" in a few decades and knowing that it will "hit the Earth." During the past decade, observations of newly discovered NEOS have revealed errors from -100 km to -100,000 km in pre-radar range predictions.

The same measurements also provide otherwise unavailable information about the target's physical properties -- size, shape, rotation, multiplicity, and surface characteristics. Measurements of the distribution of echo power in time dela y (range) and Doppler frequency (radial velocity) constitute two-dimensional images that provide spatial resolution as fine as 10 meters. With adequate orientational coverage, such images can be used to construct geologically detailed three-dimensional models, to define the rotation state precisely, and to constrain the object's internal density distribution. Moreover, radar wavelengths are sensitive to near-surface bulk densit y and structural scales larger than a few centimeters. For comets, radar waves can see through optically opaque comas and can also reveal large-particle clouds. Even modest delay-Doppler resolution of echoes can dramatically shrink the cost and risk of a spacecraft mission to a near-Earth object, by reducing or eliminating the need for on-board optical navigation. The strongest radar imaging experiments can be as informative as the cheapest NEO flybys now under consideration.

The world's two primary facilities used for planetary radar astronomy are the NAIC Arecibo Observatory in Puerto Rico and the NASA Goldstone Solar System Radar (part of the Deep Space Network) in California, Arecibo is being upgraded and by 1996 will be more than 20 times as sensitive as Golds tone, see twice as far, and cover three times as much volume as Goldstone. The more fully steerable Goldstone instrument, with a solid angle window twice the size of Arecibo's and an hour-angle window at least several times wider than Arecibo's for any given target, will serve a complementary role, especially for newly discovered objects, With the Evpatona-Effelsberg observations of Toutatis in Dec. 1992 and the Golds tone-Evpatoria and Golds tone-Kashima observations of 1991 JX in June 1995, asteroid radar astronomy has become an international endeavor.

Discovery apparition geometry often is exceptionally favorable to radar reconnaissance. but such windows rarely last more than a week or two. The optical-astrometric time base needed to secure a newly discovered NEO's orbit (and to identify the date of subsequent radar opportunities) is generally at least several months. That is, the radar-targeting decision usually must be made long before the orbit estimate is good enough to guarantee recovery or to identify future close approaches accurately. Minimal reconnaissance of a new NEO requires at least one block of time, probably at least two hours long, on one of a handful of possible dates. to be scheduled with extremely short notice (typically on the order of a few days to a few weeks), However, Arecibo is primarily a national center operated primarily for visitors engaged in passive radio astronomy and ionospheric physics, and Goldstone's primary responsibility is spacecraft telemetry. At each site, the total radar astronomy usage has averaged less than 5%; an increase to more than 10% is unlikely under current institutional constraints. Moreover, each site has limited tolerance for frequent disruption of schedules to accommodate new targets of opportunity. Current anticipations are that most of the NEO follow-up work possible with Arecibo and Goldstone will not be done. Neither Arecibo nor Goldstone were designed primarily as planetary radars.

At Vulcano, let us begin to discuss prospects for a radar telescope that would be optimized for NEOs. A plausible design might consist of two fully steerable 100-m antennas, one for transmitting and one for receiving. The cost of this system would be comparable to the cost of a Discovery mission or one launch of the Spare Shuttle. This radar would do flyby-level science (delay-Doppler imaging placing thousands of pixels on the target. over enough orientations to allow three-dimensional reconstruction of the shape in geological detail) of thousands of the optically discoverable NEAs, as well as several-hundred-pixel imaging of a few hundred mainbelt asteroids and excellent comet science. The cost of this project would be large, but the return on this investment would be extraordinary. Which of the industrial nations will seize the opportunist y to design and build a dedicated NEO radar telescope?