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High-Resolution Radar Imaging of Potentially Hazardous Near-Earth Asteroids

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Ground-based radar imaging is an important tool to characterize potentially hazardous near-Earth asteroids (NEAs). Radar observations provide extremely accurate trajectory predictions and information on NEA shapes, spin states, and surface properties. Radar imaging also can provide constraints on objects' masses and densities – either from radiation pressure perturbations to their trajectories or from the mutual orbits of multiple-component NEA systems.

Currently, the most sensitive astronomical radar in the world is the ~900 kW S-band planetary radar on the Arecibo Observatory 305-m antenna, which can provide images of NEAs with resolution as fine as 7.5 m in line-of-sight distance. Arecibo currently observes roughly 70 NEAs per year.

Since 2010, the Deep Space Network's ~450 kW X-band Goldstone Solar System Radar transmitter on the 70-m DSS-14 antenna has provided images with resolution as fine as 3.75 m for NEAs passing within < 10 lunar distances of Earth (e.g. Fig. 1, [1]). DSS-14 currently observes roughly 30 NEAs per year.

As of 2015, radar imaging resolution a factor of two finer, 1.875 m, is possible for selected objects. A new 80 kW C-band transmitter has been installed on the 34-m DSS-13 antenna, as part of the DSN Aperture Enhancement Project [2]. Although primarily designed for spacecraft telecommunications, this transmitter can also be used for high-resolution radar imaging of objects passing within a few lunar distances. We expect to use DSS-13 to observe a few NEAs per year.

The DSS-13 transmitter must operate in a bistatic mode, transmitting with one antenna and receiving with another – particularly Arecibo or the Green Bank Telescope, but potentially any large radio telescope with an appropriate receiver. Both the Arecibo and DSS-14 transmitters can also be operated bistatically. Bistatic observations can provide higher resolution than Arecibo

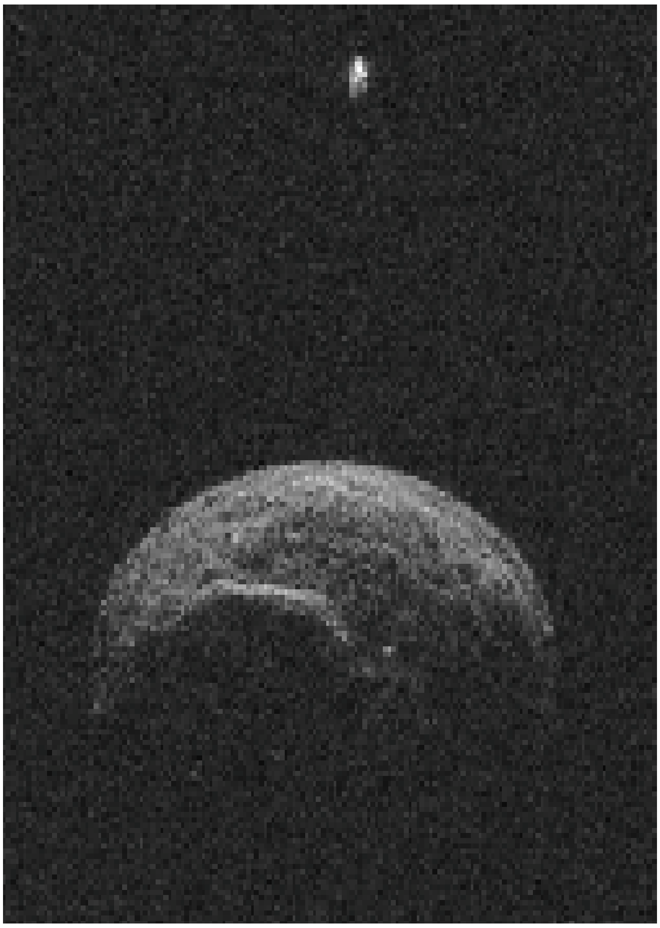

Fig. 1: Bistatic radar image of the binary near-Earth asteroid 2004 BL86, obtained with DSS-14 and GBT on 2015 January 27. Round-trip time delay of the radar signal, equivalent to distance from Earth, increases from top to bottom with resolution 25 ns / 3.75 m per pixel. Doppler frequency, equivalent to line-of-sight velocity, goes from left to right with resolution 0.1 Hz per pixel. BL86 Alpha, the primary, is oblate and ~325 m in diameter. BL86 Beta, the satellite, is ~70 m across. 10-m-scale boulders or blocks; a large raised area near one pole; and an equator-aligned ridge are visible on BL86 Alpha. [1]

Table 1: Relative Sensitivity of Monostatic and Bistatic NEA Radar Observations

Transmit Antenna	Receive Antenna	Relative Sensitivity	Relative Range Limit
DSS-14 (450 kW X-band)	DSS-14	1	1
	DSS-13	0.20	0.7
	GBT	2.2	1.2
	Arecibo	4.7	1.5
Arecibo (900 kW S-band)	Arecibo	21	2.2
	GBT	6.1	1.6
	DSS-13	0.4	0.8
DSS-13 (80 kW C-band)	DSS-28	0.006	0.2
	GBT	0.066	0.5
	Arecibo	0.14	0.6
DSS-43 (100 kW S-band)	Parkes	0.010	0.3
(400 kW S-band)	Parkes	0.039	0.4
DSS-34,-35, or -36 (notional DSS-13 clone)	Parkes	0.016	0.4

Relative sensitivity of radar observations of NEAs with different combinations of transmit and receive antennas; referenced to single-station monostatic observations using DSS-14. "Relative range limit" gives the relative distance at which each combination of antennas would be able to detect a target with a given size, spin state, and radar albedo in a given integration time. Monostatic observations with Arecibo are the most sensitive; observations transmitting with DSS-14 or DSS-13 can provide finer range resolution. The S-band transmitter on the Canberra DSS-43 antenna can transmit up to 400 kW, but is currently limited to < 100 kW in regular operations.

and higher sensitivity than DSS-14 can obtain when operated in a single-station mode (Table 1). For each potential NEA radar target, we consider telescope availability and the target object's trajectory, size, and spin state to decide which combination of transmit and receive stations to use.

Previous bistatic radar projects with 3.75-m resolution have included imaging campaigns on the NEAs 2005 YU55 [3], Toutatis [4], Duende [5], 2014 HQ124 [6], and 2004 BL86. 2004 BL86 was imaged with DSS-14, DSS-13, GBT, and Arecibo in 2015 January; and is a binary asteroid system (Fig. 1). Possible results for future high-resolution radar projects include measuring the size distributions of boulders and other surface features on small NEAs; and imaging the reconfiguration of asteroids' surfaces due to tides during extremely close Earth flybys.

We plan proof-of-concept radar observations with the existing S-band transmitter on the 70-m DSS-43 antenna at the Canberra Deep Space Network Complex and the 64-m Parkes antenna in late 2015. Further in the future, a copy of the DSS-13 C-band transmitter could be installed on one of the 34-m antennas at Canberra. Radar observations with Canberra and Parkes would observe targets in the far southern sky, which current radar facilities cannot see. They would also facilitate rapid radar follow-up of newly discovered potentially hazardous asteroids, preventing those objects from being lost.

References:

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