Goldstone Solar System Radar

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2nd NASA-SAAO virtual workshop: Asteroid Planetary Radar

Oct 27, 2014

Goldstone Solar System Radar – DSS14

- 70 m diameter antenna
- X-band (8560 MHz, 3.5 cm)
- transmit power of 440 kW

DSS-14

- Fully steerable antennae, covers 80% of the sky; tracking speed up to ¼ deg/sec

- Radiation clearance up to 20 deg above the horizon

- Radar observations of NEOs require orbital solutions with pointing better than 20 arcsec   (~100 arc sec beam width)

- DSS-14 can observe in monostatic mode up to RTT~5 sec (or ~2 lunar distances)

http://gssr.jpl.nasa.gov/

Recent Radar Observations at Goldstone

- Observed 89 NEOs in last 3 years (~400 observing hours/year)
- 50% were Potentially Hazardous Asteroids (PHA)
- 40% were Targets-Of-Opportunity (TOOs)
- 20% were Near-Earth Object Human Space Flight Accessible Targets Study (NHATS): http://neo.jpl.nasa.gov/cgi-bin/nhats

2014

- Goldstone discovered 3/10 radar binaries during 2012-2014
  - 2007 LE
  - 1998 QE2
  - 2013 WT44

- Radar astrometry: http://ssd.jpl.nasa.gov/?radar

*TOOs

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(251346) 2007 SJ	2014 JL25
2014 BA3	2014 KH39
(348306) 2005 AY28	2014 HQ124
2006 DP14	Comet C/2013 UQ4/Catalina
2014 BR57	(398188) 2010 LE15
2014 CU13	(285944) 2001 RZ11
(275677) 2000 RS11	(163132) 2002 CU11
2014 EP12	(333587) 2006 KM103
2013 WT44	2014 RC
(363599) 2004 FG11	2009 FG19
2003 HM	(68267) 2001 EA16
(304330) 2006 SX217	2011 TB4
2007 TV18	2014 SM143
2014 HO132	(2340) Hathor
2011 JR13	2014 RQ17
2013 WF108	2014 SC324
Comet 209P/LINEAR	

Radar modes used in asteroid observations

Continuous wave (CW)

- circularly polarized EM wave of constant amplitude and frequency
- asteroid rotation – Doppler dispersion
- OC and SC echoes
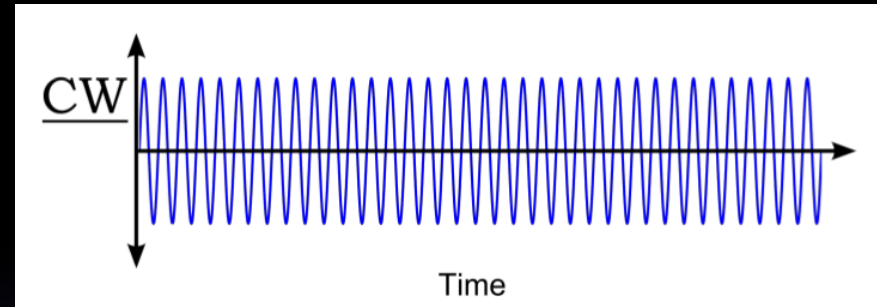
Binary Phase Coding (BPC)

- Time-coded waveform
- Echo power measured in both Doppler frequency and time-delay
- the phase of the carrier wave if modulated with pseudo-random code that repeats   (7.5 m res at Arecibo)
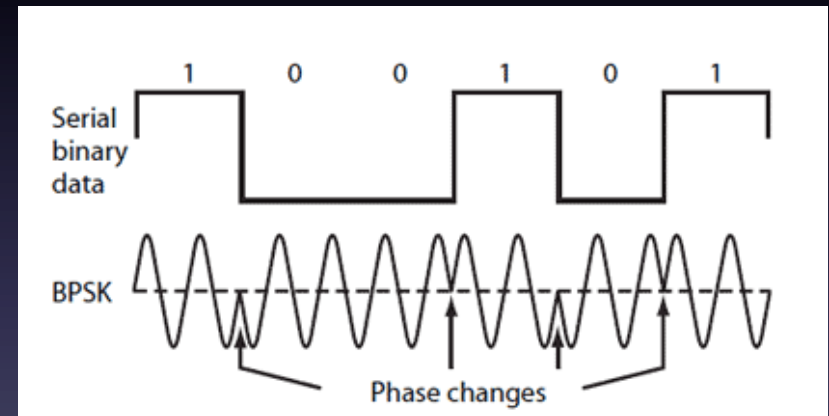

Linear Frequency Modulation (Chirp)

- delay-Doppler, Goldstone only (since 2010)
- the frequency of the carrier wave is modulated with a linear ramp signal   (3.75 m res at Goldstone)
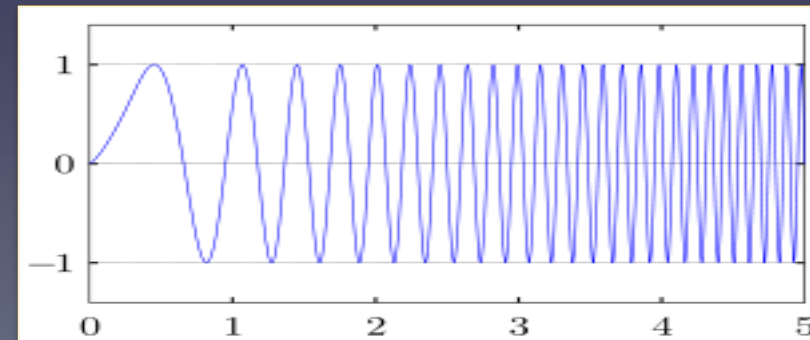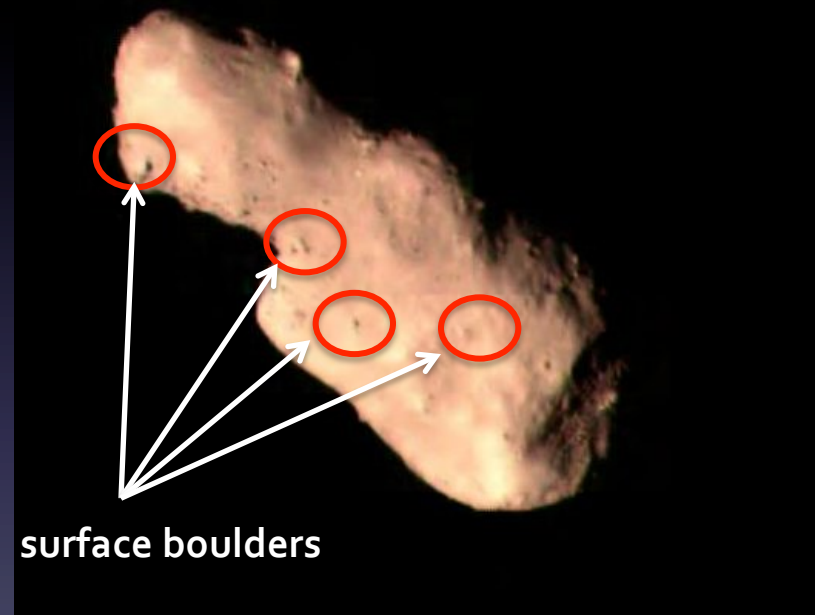
"Spacecraft" Goldstone
Radar Observations of (4179) Toutatis

Dimensions: 1.92x2.4x4.6 km, P1=7.35 days, P2=5.41 days

Distance from radar

surface boulder

Dec 12, 2012

Doppler increases

surface boulders
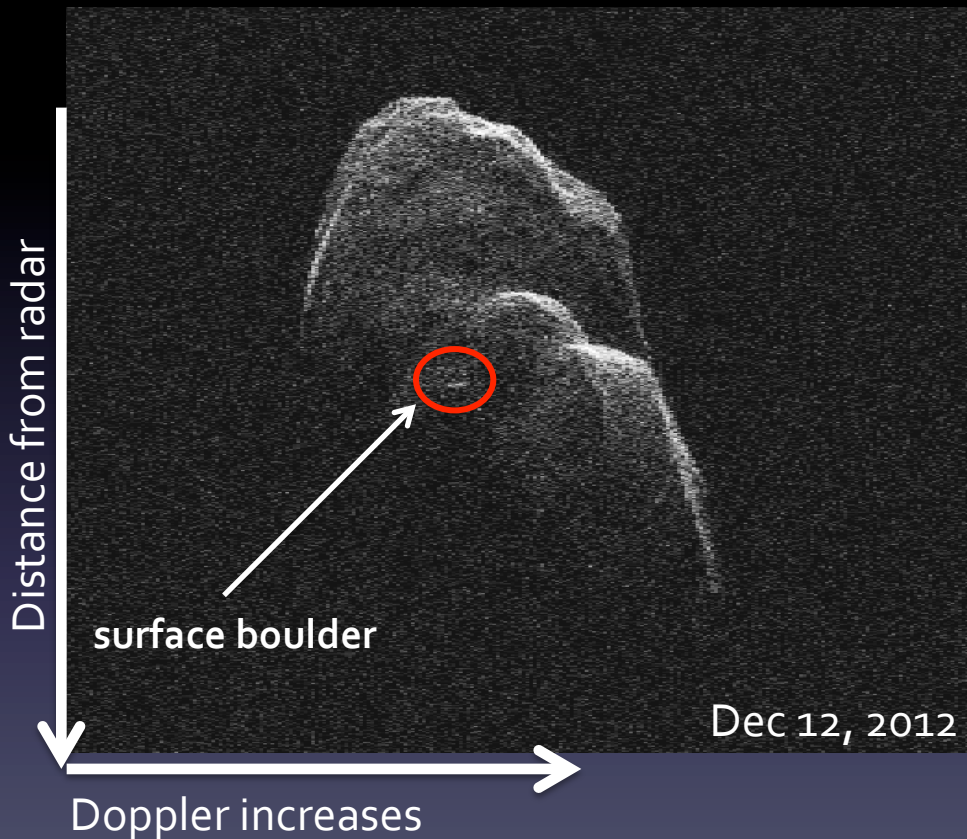
Goldstone DSS-14

- 3.75 m resolution, 0.047 AU (7 million km)
- ~65 hours of radar observations (13 hours with 3.75 m resolution)
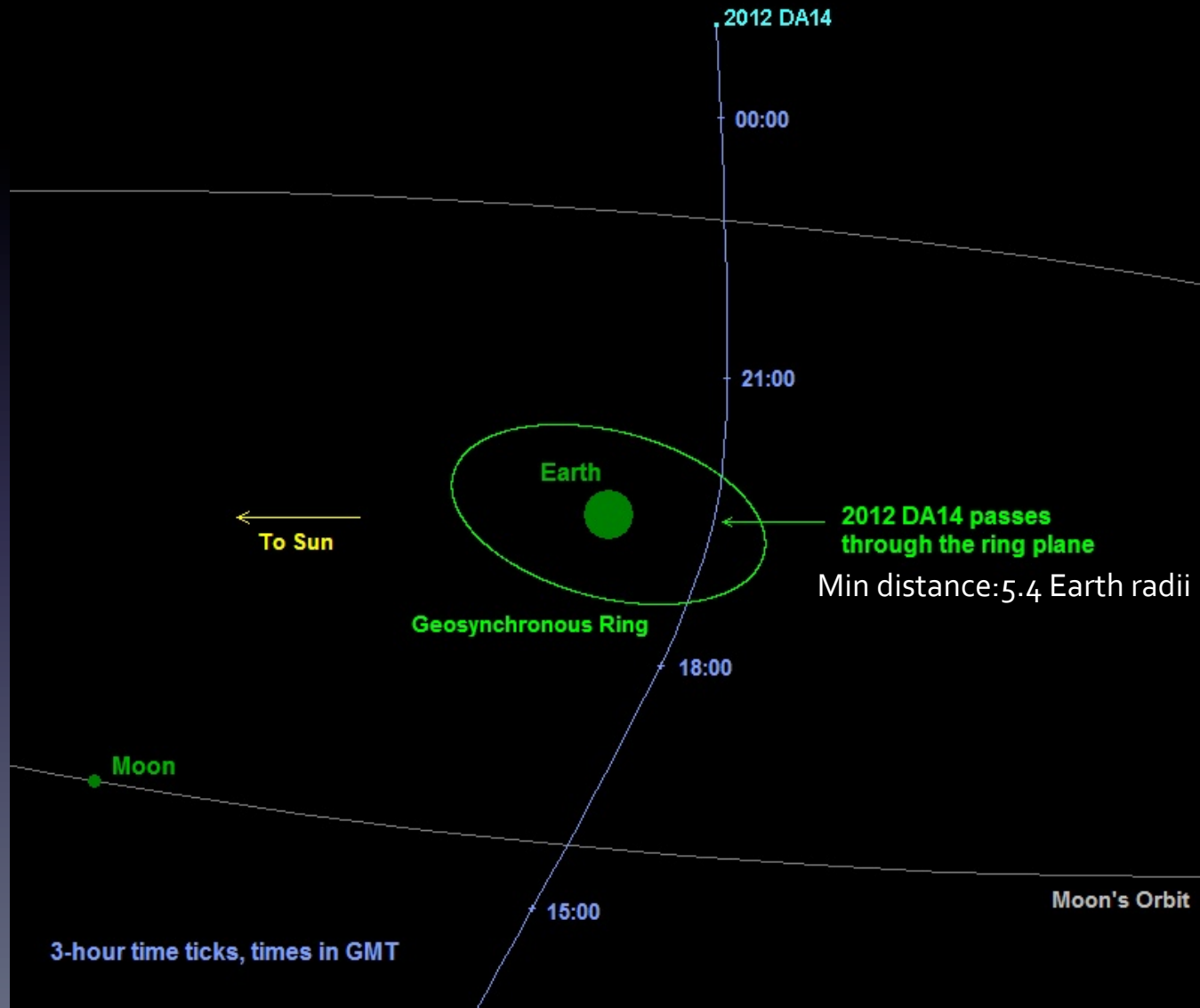
Chang'e 2 spacecraft

- 8 m resolution, closest image at 18.3 km (2 m res)
- 15 sec of high-resolution data
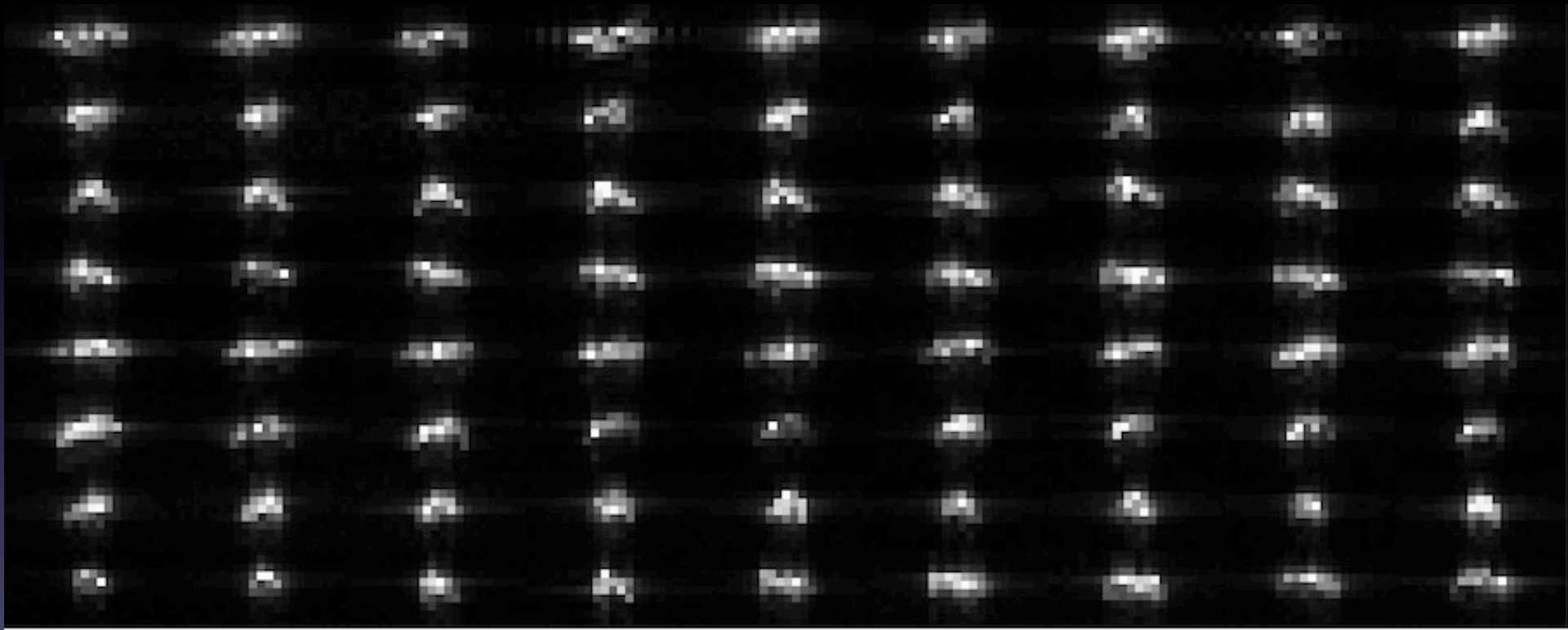
It came from the South: 2012 DA14!

Asteroid 2012 DA14: Close Approach to Earth, Feb. 15, 2013

The closest flyby of a ~40 m object that we know of to date

Goldstone Radar Images of 2012 DA14

Bistatic DSS-14 to DSS-13 sequence of radar images ~7.8 hours long


1.875 m/px (double-sample 3.75 m), 0.00625 Hz Doppler resolution

320 sec of data integration per frame

Target Of Opportunity: 2014 HQ124

- Discovered by NEOWISE at declination of -72 deg (A. K. Mainzer et al.) on Apr 23, 2014
- Closest approach at 3.2 lunar distances on Jun 8
- Astrometry reported by optical observers in New Zealand, Australia, and Chile was crucial!
- D~330 m (thermal modeling), ~20 h rotation period (lightcurves)
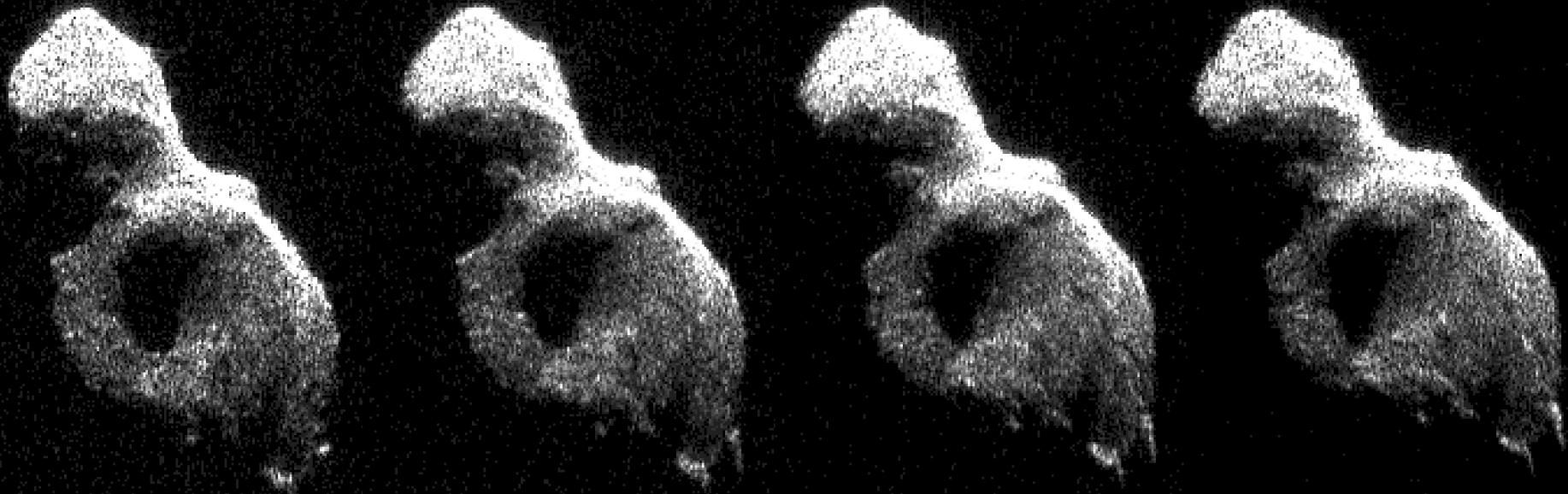
Benner et al., 2014
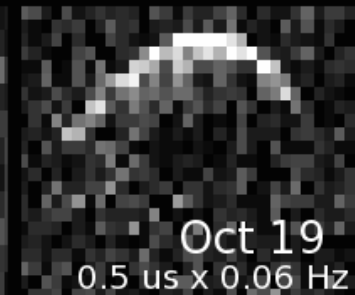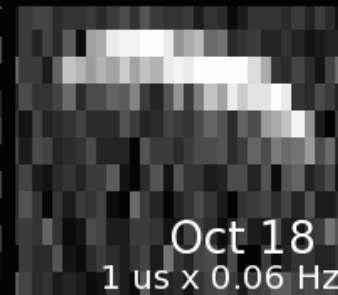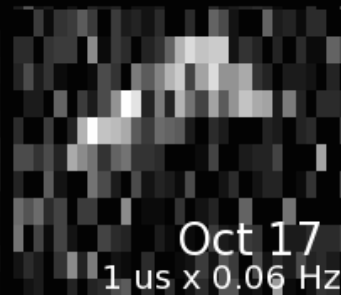
3.75 m resolution, 16 min of data / frame

Bistatic experiment DSS-14 to Arecibo, June 8 2014: echo fully resolved in Doppler and SNRs increased by 5-fold due to Arecibo's 305 m antenna

(214869) 2007 PA8
Goldstone Radar Images

Oct-Nov, 2012

Oct 16
1 us x 0.12 Hz

Oct 17
1 us x 0.06 Hz

Oct 18
1 us x 0.06 Hz

Oct 19
0.5 us x 0.06 Hz

Oct 28
0.125 us x 0.03 Hz

Oct 29
0.125 us x 0.03 Hz

Oct 30
0.125 us x 0.02 Hz

Oct 31
0.125 us x 0.02 Hz

Nov 2
0.05 us x 0.025 Hz

Nov 3
0.05 us x 0.025 Hz

Nov 5
0.025 us x 0.025 Hz

Nov 6
0.025 us x 0.025 Hz

Nov 8
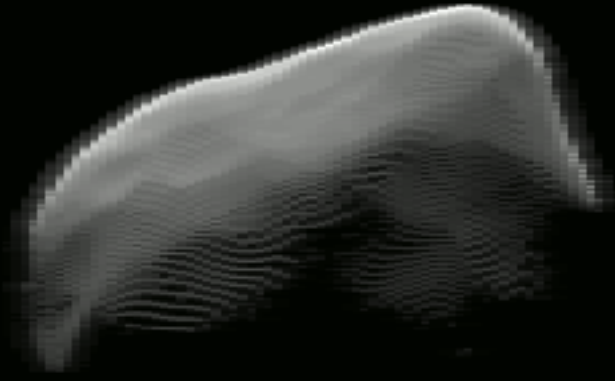0.05 us x 0.025 Hz

Nov 11
0.125 us x 0.02 Hz

Nov 12
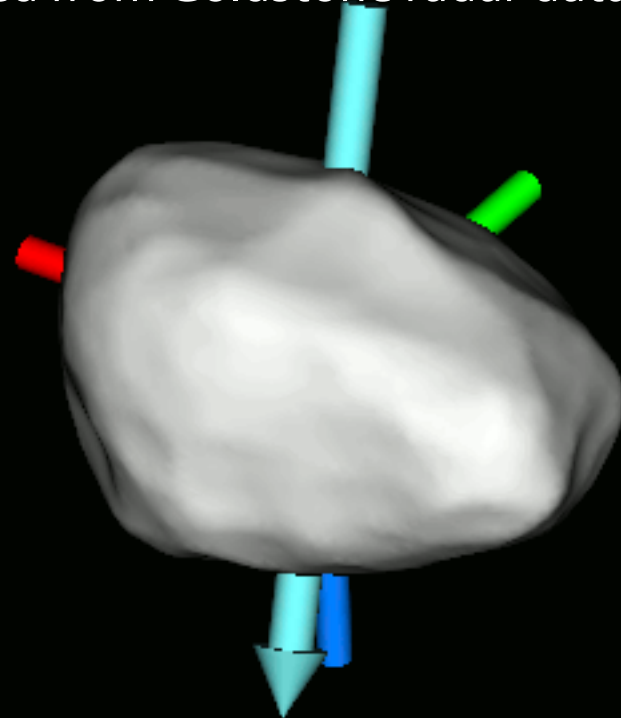0.125 us x 0.02 Hz

Nov 13
0.125 us x 0.02 Hz

From radar data to full physical characterization

2007 PA8 3-D shape model reconstructed from Goldstone radar data

Simulated radar echo

Plane-of-sky view

Principal axes:

X	1.82 ± 0.05 km
Y	1.33 ± 0.05 km
Z	1.14 ± 0.05 km

Equivalent diameter: 1.35±0.05 km

NPA rotation in short-axis mode:
P1=4.26±0.02 days
P2=20.55±3.75 days

Ratios of moments of inertia:
$I_l/I_s=0.582\pm0.058$,
$I_i/I_s=0.921\pm0.015$

Brozovic et al. (2014)

Future Plans for Goldstone

- More bistatic experiments with Arecibo
- Plans for bistatic experiments with the Green Bank Telescope (100 m antenna), 3-fold increase in SNRs; GBT will also be able to receive 40 MHz chirp (3.75 m)
- DSS-13 (34 m antenna) will soon have 80 MHz chirp (1.875 m) capability (TX power of 80 kW); bistatic experiments with GBT and Arecibo, also other 34m antennae at Goldstone

Outstanding Radar Targets in 2015

Jan 27: (357849) 2004 BL86
-3.1 lunar distances, D~500 m
-closest approach of the object this size that we know until 2027 (1999 AN10)
-as good if not better than 2014 HQ124
-visual magnitude of 9 for several hours!

Jul 19: 2011 UW158
-6.4 lunar distances, D~450 m

Backup

GSSR subsystem interfaces

M. A. Slade, L.A. M. Benner, and A. Silva, Proceedings of the IEEE, 2010