Improved spin-state and shape models of near-Earth asteroid (4179) Toutatis from the 2012 radar observations

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(4179) Toutatis is one of the best-characterized objects in the near-Earth population. It is near to a 4:1 orbital resonance with the Earth, and makes close approaches at four-year intervals for 20–28 years before going out of phase for several decades. Toutatis has been imaged by radar at Arecibo and/or Goldstone during each flyby since 1992.

Previous radar observations have shown that Toutatis is irregular, bifurcated, $\approx$ 4.5 km long, with an unusual non-principal-axis spin state (Ostro et al. 1995; Hudson & Ostro 1995; Hudson, Ostro & Scheeres 2003). Arecibo radar images from the 2008 close approach showed that Toutatis is dramatically affected by gravitational tidal torques. During each orbit, Toutatis' spin state changes by up to 0.1% of the asteroid's total rotational angular momentum (Takahashi, Busch & Scheeres 2013).

In December of 2012, Toutatis approached within 0.0463 au (6.93 million km) of the Earth. This was the last approach within 0.1 au until 2069. We conducted an extensive campaign of radar observations with Goldstone and with elements of the Very Large Array. Radar images were obtained on 16 days between December 4 and December 22. They bracket both the closest approach by the asteroid to the Earth and the *Chang'e 2* spacecraft flyby of the asteroid on December 13 (Huang et al. 2013; Xiaoduan et al. 2013).

The radar images on December 12 and 13 had range resolution of 3.75 m/pixel and show a wealth of surface features, many previously unseen, including radar-bright spots that we interpret as decameter-scale boulders. Some can be linked to features visible in the *Chang'e 2* images. The spacecraft and 2012 Goldstone images reveal that previous radar-derived shape models accurately reproduced Toutatis' dimensions and global shape, but both the big end and the joint are actually more angular than previously realized.

Toutatis' non-principal-axis spin state allows us to determine its moment-of-inertia ratios, which constrain the asteroid's internal structure. We have constructed an improved model of Toutatis' changing spin state, covering 1992 to 2012 and including gravitational torques from the Sun, Earth, Moon, and Jupiter. Other torques, such as excursions due to YORP, are not significant compared to the uncertainties in Toutatis' orientation.

We are updating the Toutatis shape model based on the 2012 radar images. The new radar-derived model more accurately represents the angularities in Toutatis' shape. The 2012 images provided far better views of all of Toutatis' surface and especially the big end than were obtained during previous flybys, and updates to the SHAPE software (Magri et al. 2007) allow us to avoid biases that made the earlier Toutatis shape models artificially rounded.

References: Huang et al. 2013. Scientific Reports 3, 3411; Hudson & Ostro 1995. Science 270, 5233, 84–86; Hudson, Ostro, & Scheeres 2003. Icarus 161, 346–355; Magri et al. 2007. Icarus 186, 152–177; Ostro et al. 1995. Science 270, 5233, 80–83; Takahashi, Busch, & Scheeres 2013. AJ 146, 95; Xiaoduan et al. 2013. Icarus 229, 348–354.