PLANETARY DEFENSE EXERCISES WITH REAL ASTEROIDS: 2012 TC4 AND 1999 KW4.

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We conducted the first planetary defense exercise using a real asteroid with coordination support from the NASA Planetary Defense Coordination Office [1]. The target of this global, community-led exercise was 2012 TC4, an ~10 m diameter asteroid that made a close pass by the Earth on 2017 October 12 at a distance of about 50,000 km. The goal of the TC4 observing campaign was to recover, track, and characterize 2012 TC4 as a hypothetical impactor in order to exercise the global planetary defense system involving observations, modeling, prediction, and communication. Here we summarize some lessons learned during the campaign that would be helpful for improving global preparedness for future impact scenarios. For astrometric observations, we noted along-track residuals when we remeasured observations from 2012 opposition to support the recovery attempts and refine the ephemeris. We identify the cause of this error to timing information when the data were collected (1-3 seconds error) and the rate of motion of the object. Providing GPS-based time signals for observers, especially citizen scientists, would be one way to overcome this issue in the future. Characterization studies were affected by technical issues at the NASA Infrared Telescope Facility (IRTF) that prevented spectral observations during the closest flyby although data collected under suboptimal weather days prior was adequate for basic taxonomic classification. NASA IRTF remains a single point of failure in the NASA Planetary Defense capabilities and deploying instruments similar to SpeX on IRTF on other 6-8 meter class facilities would mitigate this risk. In addition, interpretation of the spectral data were limited by the lack of adequate laboratory spectra of meteorites slabs. 2012 TC4 has a diameter of ~10 meters suggesting a surface devoid of regolith. Existing laboratory spectral databases are based on meteorite powders that mimic surfaces of larger NEOs (>1 km). Laboratory spectral studies of meteorites would help better interpret spectra of small NEOs in the future. We also performed probabilistic impact risk assessments for hypothetical impactors based on the 2012 TC4 observing campaign. Risk assessments were calculated at several epochs before and during the close approach; incorporating new information about 2012 TC4 as it became available. Across the epochs, we found that only irons caused significant damage for smaller sizes similar to the actual size of 2012 TC4 (H = 26.7). For larger sizes (H = 21.9), however, hydrous stones caused the greatest damage, anhydrous stones caused the least damage, and irons caused moderate damage. We note that the extent of damage depends on composition in different size regimes and, after astrometry; size is the most important physical property to determine for an incoming object.

Building on the experience of the 2012 TC4 obsering campaign, we recently conducted a second exercise targeting near-Earth asteroid 1999 KW4, which made a close pass by the Earth in May and June of this year. The TC4 campaign was an end-to-end test of the NASA's planetary defense system, whereas the KW4 campaign was focused almost entirely on characterization of the target. Although, the KW4 exercise did include probabilistic impact risk assessments using real measurements from the target asteroid. Experience with and results from the characterization and modeling campaign for 1999 KW4, a non-contact binary, may yield benefits in the preparation for the DART mission to the Didymos binary. Participation in this second global exercise was coordinated primarily, though not exclusively, through the International Asteroid Warning Network (IAWN). Observations included photometry, spectroscopy, and radar. We will summarize here early results of the 1999 KW4 characterization campaign.

References: [1] Reddy V. et al. 2019. *Icarus* 326:133-150.