THE NEAR-EARTH ENCOUNTER OF ASTEROID 2005 YU55: VISIBLE AND NEAR-INFRARED SPECTROSCOPY.
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Introduction: Approximately once every decade a large near-Earth object (NEO) passes inside of the Moon's orbit. On November 8, 2011 at 23:28 UT the approximately 360m C-type asteroid 2005 YU55 passed inside of the Earth-Moon distance (=0.0025 AU) and reached a brightness of V~11 (Fig. 1). This fly-by enabled a host of novel investigations on an object typically too faint for extensive multi-wavelength observations. We employed a suite of visible through mid-infrared (0.4 - 22 μm) instruments as part of a multi-observatory campaign to understand the physical and chemical properties of 2005 YU55. These observations will contribute to the first-ever detailed study of a C-type asteroid less than 5 km in size and are relevant to JAXA's Hayabusa II mission and NASA's Dawn and OSIRIS-REx missions, all of which are scheduled to visit C-type asteroids. These data will complement other studies of 2005 YU55, including radar observations from Goldstone and Arecibo, and a light curve campaign that has determined a rotation period between 16 and 20 hours [1].

The goals of our spectroscopic campaign are to (i) robustly determine the composition of 2005 YU55, (ii) constrain the effects of phase angle (i.e. the Sun-asteroid-Earth angle) on the reflectance spectra of 2005 YU55, (iii) constrain the thermo-physical properties of 2005 YU55's surface, and (iv) determine whether 2005 YU55 displays any physical or chemical heterogeneity across its surface. Our mid-infrared (7-22 μm) observations are presented in a complementary abstract [2]. Here we focus on the contribution of visible (VIS, 0.5-1.0 μm) and near-infrared (NIR, 0.8-2.5 μm) data towards achieving these goals.

Observations and Data Reduction: Our observing campaign was scheduled for the two nights immediately following closest approach (UT Nov. 9 and 10). Visible spectroscopy was carried out at the Kitt Peak 2.1m telescope using the GCAM instrument with the #09 grating to produce spectra covering a wavelength range of 0.4 to 0.8 μm. Near-infrared spectroscopy was performed using SpeX [3] at NASA's Infrared Telescope Facility (IRTF) and TripleSpec at the Palomar 200" Telescope. Both NIR instruments produced spectra from approximately 0.9 to 2.5 μm. The use of multiple and sometimes redundant instruments increased phase angle coverage throughout the encounter and will allow for confirmation of detected variability in the measurements.

The highly non-sidereal motion of 2005 YU55 was the most challenging aspect of these observations. After acquiring the target at non-sidereal rates, guiding was achieved by applying pointing corrections based on a continual read-out of the slit viewing cameras available on all three instruments.

Reduction of the GCAM data will employ standard IRAF routines. Reduction of TripleSpec and SpeX data used the Spextool IDL package [4]. Solar analog stars HD217577, SA93-101, SA115-271, and HD12846 were used for telluric correction and removal of the solar component in the measured reflectance.

Composition: Figure 2 shows a series of spectra from TripleSpec taken between 2:00UT and 8:00UT on November 9, 2011. 2005 YU55 has a featureless red-sloped NIR spectrum with pronounced thermal emission at wavelengths beyond 2.0 μm. Initial analysis indicates variability in slope throughout the observing run, the cause of which is currently unclear

Based solely on NIR data 2005 YU55 is part of the C- or X-complex in the Bus-DeMeo taxonomy [5] and thus may have a chemical composition representative of the primordial solar nebula. Reduction of the visible GCAM data will provide further insight on taxonomy/composition. However, interpreting the mineralogy of asteroids with spectra largely devoid of absorption features (e.g. Fig. 2) is a long-standing problem related to spectro-compositional degeneracy. For example, at VIS/NIR wavelengths metallic and carbon-rich bodies can be spectroscopically indistinguishable [6]. Detection of a 3.0 μm hydrated mineral absorption feature can disentangle these compositions. We obtained data at 3 μm with SpeX and will ultimately be able to infer whether hydrated minerals are present on the surface of 2005 YU55. These 3-μm data will be presented at a future date. Detection of emission features in the mid-infrared due to Si-O stretching and bending modes may provide further insight on composition [2].

Phase Angle Effects: Ground-based photometry, spacecraft data and laboratory measurements suggest that phase and spectral slope are correlated [7,8,9,10,11]. However, this "phase reddening" is not well understood and has been difficult to spectroscopically confirm from the ground [12]. This is partly due to the many days or months typically needed to sample a wide range of phase angles on a single object. Comparison of spectra over such long intervals is complicated by variable observing conditions (e.g. weather, seeing). This is not the case for 2005 YU55. A range of phase angles from approximately 75° down to 16° were accessed during our two nights of observing. This could result in spectral variability up to 20% [8]. Further spectral modeling is required to determine if we have detected these effects.

Thermal Emission in the NIR: NEOs at heliocentric distances near 1 AU can have surface temperatures in excess of 300 K and produce significant thermal emission at NIR wavelengths (Fig. 2). Modeling this component can aid searches for thermal variability, indicating heterogeneous regolith depth or grain size across the surface. To date this variability has only been detected by spacecraft [10]. We will present results of spectral modeling (e.g. Fig. 3) to constrain the thermal properties of 2005 YU55 at various rotational phases. This spectral model fits both the continuum slope and thermal emission, and is based on the NEATM thermal model [13], with the exception that 2005 YU55's diameter is not a free parameter as it is well constrained at 360m from radar observations (M. Busch, private communication). Removal of the thermal emission reveals the spectrum of 2005 YU55 is similar to that of the C-type 175 Andromache (Fig. 3).

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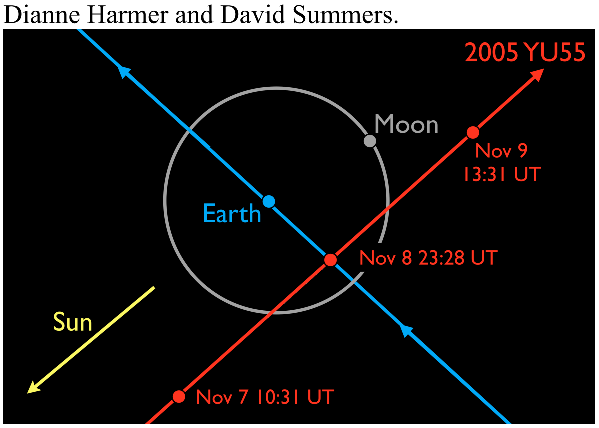

Figure 1: Geometry of 2005 YU55's close approach to the Earth. Orbital directions of the Earth (blue) and 2005 YU55 (red) are indicated with the arrows. The direction of the Sun and the orbit of the Moon are also shown. The location of 2005 YU55 is indicated at three different times during the encounter. Adapted from an image by J. Giorgini (JPL).

References: [1] Warner B. et al. (2012) *MPB*, submitted. [2] Lim L. F. et al. (2012) *LPS XLIII*, this volume. [3] Rayner J. T. et al. (2003) *PASP*, 115, 362-382. [4] Cushing M. C. et al. (2004) *PASP*, 116, 362-376. [5] DeMeo F. E. et al. (2009) *Icarus*, 202, 160-180. [6] Rivkin A. et al. (2000) *Icarus*, 145, 351-368. [7] Gradie J. et al. (1980) *LPS XI*, 799-815. [8] Luu J. and Jewitt D. (1990) *AJ*, 99, 1985-2011. [9] Clark B. E. et al. (2002) *Icarus*, 155, 189-204. [10] Abe M. et al. (2006) *Science*, 312, 1334-1338. [11] Cloutis E. et al. (2011) *Icarus*, 212, 180-209. [12] Bus S. J. et al. (2002) in *Asteroids III*, pp. 169-182. [13] Harris A. W. (1998) *Icarus*, 131, 291-201.

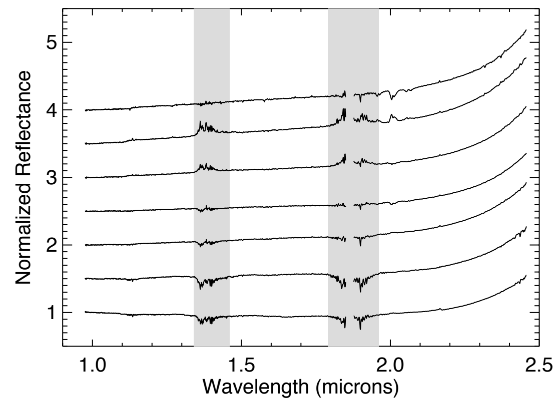

Figure 2: TripleSpec spectra of 2005 YU55 representing approximately one hour increments between 2:00UT (bottom) and 8:00UT (top) on Nov. 9, 2011. Spectra have been normalized and offset by multiples of 0.5 units. The grey bars represent regions of low atmospheric transmission where telluric correction is poor. Variation in spectral slope is seen throughout this time series of data.

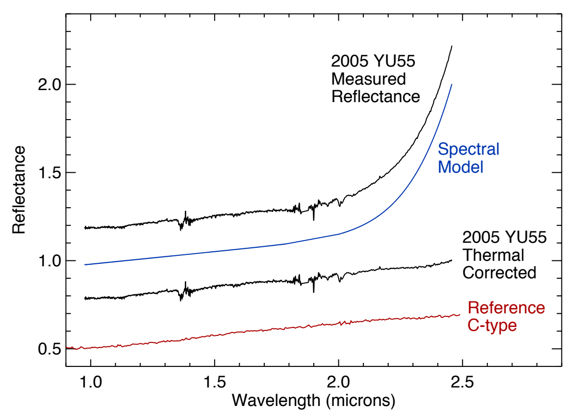

Figure 3: From top to bottom: reflectance spectrum of 2005 YU55, spectral model, spectrum with thermal component removed, and reference spectrum of C-type asteroid 175 Andromache from [5]. The spectra have been normalized and offset for clarity. The 2005 YU55 data correspond to the middle spectrum in Figure 2.