USING COMPUTER-GENERATED IMAGERY (CGI) FOR SCIENCE AND OUTREACH ON MISSIONS: NEW HORIZONS' ENCOUNTER WITH THE PLUTO-CHARON SYSTEM AND (486958) 2014 MU_{69}.

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Introduction: Visualization has always been important for understanding the universe in which we live, from the earliest cave paintings and petroglyphs to the most sophisticated computer models today. In modern space missions, visualizations are important to understand the science results by both the scientists involved and the general public. In this presentation, we will discuss how NASA's *New Horizons* mission used computer-generated imagery (CGI) to create images and animations used both internally for the mission team and for public engagement. Note that a related abstract [1] discusses hand-drawn art used by the *New Horizons* mission.

Pluto-Charon (and Friends) Encounter: One of the first animations created during the Pluto encounter in July 2015 was a movie of the flyby. This was important not for science, but for the mission as an education and public outreach (EPO) product. The final animation was created using a predicted spacecraft trajectory, a real Pluto-Charon system with accurate rotation and orbital data, and early basemaps based on approach imagery. Published in late August 2015 (6 weeks after the flyby), the animation has gotten over 600,000 views on YouTube. Recently, for the MU_{69} flyby, *Queen* guitarist Brian May released a single with an associated music video that used the flyby animation for 7% of the music video's duration. As of the time of this writing, the music video has been posted for 8 days and garnered nearly 1 million views on YouTube.

Once better data were returned, higher resolution movies and fly-arounds of Pluto to show certain landforms (in particular, the mountains around Sputnik Planitia) were generated. Similarly, an animation flying over Charon and highlighting key features was created (see still in Fig. 1). These animations were used extensively by the mission team in their science talks at the 2016 LPSC and later conferences.

Separately, still images were also released based on *New Horizons* data, such as Figure 2, which was released in color shortly after the original black-and-white version. While analytics are not nearly as easy to estimate for still images as they are for YouTube postings, the image has become iconic, currently ranking as the 11th unique Pluto surface image in an anonymized Google image search, and appearing throughout digital and print media (such as featured in *The New York Times*, postcards from the Lunar & Planetary Institute, information sheets from NASA, and featured five times in the NOVA special *Beyond Pluto*). In retrospect, the rendering was never intended to go so far, for it was created quickly (a few minutes), as opposed to several days' effort for the Pluto flyby animation. If nothing else, this demonstrates that one cannot predict the reach of a product.

MU_{69} Encounter— Flyby Visualization: The nature of the MU_{69} encounter led the team to consider additional tools that could be useful for deriving science. In particular, uncertainty in the position of MU_{69} relative to the time-of-flight and the flyby geometry led us to create the system in 3D software along a movable track with an accurate star field background and trajectory to better understand where MU_{69} was in space. However, that model ended up not being needed because of the accuracy of the navigation.

MU_{69} Encounter— Shape Model: Instead, efforts in the week surrounding the MU_{69} encounter turned to an accurate shape model. There are many applications for a shape model beyond a simple EPO tool: Navigation reconstruction, light curve modeling and analysis, topography, dynamics modeling, and geophysics modeling, among many others.

Two potential workflows were considered: Starting with primitive spheres in 3D software and modeling MU_{69} completely within software; or beginning with a clay-sculpted model and scanning it, then refining that through alignment with real images (limb fits), preliminary photoclinometry, and preliminary stereo. This work was to be preliminary to a more robust solution described in [4], though that more robust modeling takes significantly more time and could not be used by the team nearly as quickly.

While all components had been practiced or used in the recent past, when the first flyby images were received, the data fidelity and the observed shape ruled out several paths. First, the convergence angle of early downlinks was only ~5–10°. Combined with somewhat low signal-to-noise and a ~few-pixel smear, both photoclinometry and stereogrammetry performed independently by four team members resulted in a shape indistinguishable from our initial ellipsoid. Sculpting in 3D software was also difficult because only the limb was constrained, for on-disk topography was masked by the ≈12° phase angle. Therefore, software-based modeling using a physical model as a starting point was our workflow.

The modeling process is described in detail in another abstract [2]. In brief, the model was hand-sculpted and then scanned. The resulting file was heavily edited to smooth and remove artifacts from both the sculpting and scanning process. It was further modified to correctly orient the apparent spin axis relative to Celestial North and the Solar System's barycenter. Various polygon simplifications were then calculated for different purposes (*e.g.*, the navigation team preferred on the order of thousands of vertices, while 3D animation software for photorealistic rendering could handle millions of vertices).

MU$_{69}$ Encounter— Light Curve for EPO: One of the first public applications of our CGI for the MU$_{69}$ encounter was to illustrate what the mission PI, S.A. Stern, publicly termed, "Ultima's first puzzle:" Why the light curve appeared to not vary within our ability to detect it. It was known from occultations over a year prior that the overall shape was likely bilobate, a close binary, or extremely elongated, such that unless the pole was aimed within a few degrees of the approaching spacecraft, there should be a significant lightcurve because the cross-section on the sky varied. However, none was detectable upon approach.

When the first sub-kilometer pixel scale images were received on January 01, 2019, and the body was shown to be a contact binary, we could explain the lightcurve: An ellipsoid with the measured dimensions [3] should present a lightcurve with order 10% variation, depending on the orientation; however, two spheres slightly occulting each other with the mutual pole near the approach asymptote would have a lightcurve varying on the order 0.1–1%. To easily explain this to the public (and better understand it on the team), a simple animation was created and rendered that was released at the press conference the following day (Fig. 3). It subsequently was shared in news stories and social media around the world, and some influencers (individuals with large social media followings) indicated it was one of their favorite components of the press briefing.

This demonstrates the utility of such visualization tools which can be made more quickly in Hollywood-style 3D animation software that can create such animations often more quickly than tools more geared towards scientific analysis. It also demonstrates the positive reaction from the public for such visualizations to explain mysteries that have been solved.

Summary: This abstract has discussed a few examples of still and animated CGI renderings used by the *New Horizons* team for internal science and external public engagement. As the general public continues to hunger for visual media, and as mission teams continue to produce varied datasets that can be difficult to synthesize through traditional means, we expect CGI to continue its important role in conveying data and science results to all involved.

References: [1] Keane (this conference). [2] Kinczyk *et al.* (this conference). [3] Bierson *et al.* (this conference). [4] Porter *et al.* (this conference).

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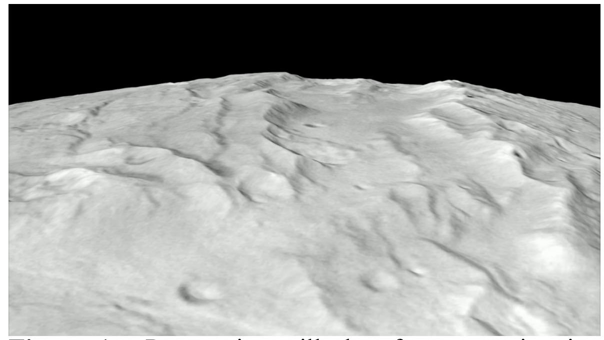

Figure 1: Perspective still shot from an animation highlighting features on Charon. This still is looking approximately East and is focused on the large tectonic rift region. It was made using an early topography solution and has 1.5× vertical exaggeration.

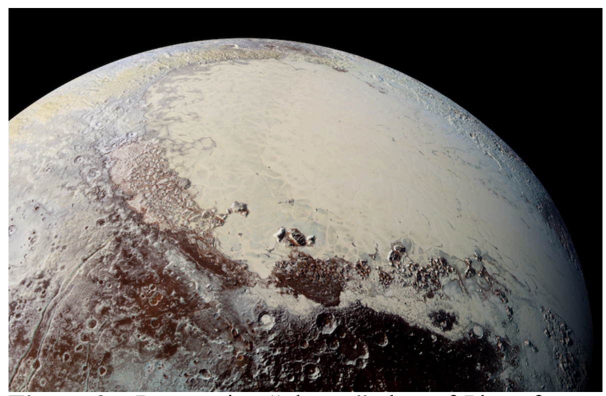

Figure 2: Perspective "glamor" shot of Pluto featuring almost all key terrains. This rendering by the primary author has been used extensively in media.

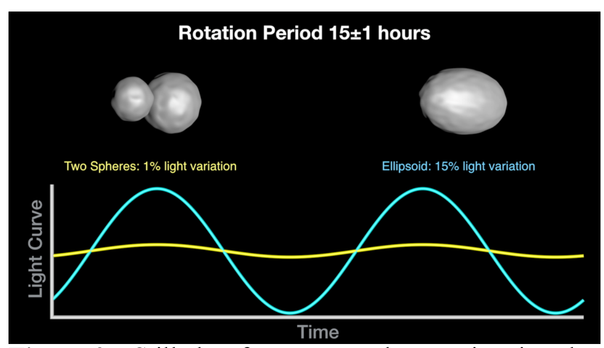

Figure 3: Still shot from press release animation that shows a simplified, modeled light curve from two spheres versus an ellipsoid. Significant specular reflection was added to help illustrate the point, even though it was a non-physical reflection model.