SWIFT OBSERVATIONS OF THE EJECTA OF ASTEROID 596 SCHEILA.

D. Bodewits[1], M. S. Kelley[1], J.-Y. Li[1], W. B. Landsman[2], and M. F. A'Hearn[1], [1]Dept. of Astronomy, U. Maryland, College Park, MD 20742, [2]NASA GSFC, Astrophysics Science Division, Mailstop 667, Greenbelt, MD 20771

Introduction: Early December 2010, an unexpected dust cloud was discovered around the asteroid 596 Scheila. We report on observations using the UV-Optical Telescope (UVOT) onboard the Swift gamma-ray observatory. While asteroids have long been believed to be inert objects, several asteroids have recently been observed to develop cometary features such as a coma and or dust tail [1]. Some asteroids are repeatedly active over periods as long as weeks or even months, most famously 133P/Elst-Pizzaro. Other asteroids are only active in what appears to be a short-lived burst.

The processes underlying asteroidal mass loss are poorly understood. Two main ejecta processes have been suggested: cometary-like outgassing of volatiles, and inter-asteroidal collisions. A combination of these two scenario's has also been suggested, as collisions may expose icy content otherwise buried beneath the surface [2].

596 Scheila is a T-type main belt asteroid with a diameter of 113 km that was discovered by A. Kopff in 1906. It was reported that on Dec 11.44, 2010 UT the asteroid had increased by m_v = 0.8 [3]. Inspection of archival Catalina Sky Survey observations showed that the asteroid's activity was triggered between Nov 11 and Dec 3rd 2010, when it first appeared as an extended source [3].

Observations: Swift is a multi-wavelength observatory equipped for rapid follow-up of gamma-ray bursts. Its UVOT has a 30 cm aperture that provides a 17 × 17 arcminute field of view with a spatial resolution of 2.5 arcsec. Seven broadband filters allow color discrimination, and two grisms provide low-resolution ($\lambda/\delta\lambda$ = 100) spectroscopy in the optical/UV band (1700 – 6500 Å).

Swift–UVOT observed 596 Scheila on December 14 and 15. On both days, we used the V (λ_c 5468 Å, FWHM 750 Å) and UVW1 (λ_c 2600 Å, FWHM 700 Å) filters. Additionally, on Dec 15th we used the UV grism to search for gaseous emission lines. While we successfully detected the asteroid in all our exposures, an internal reflection of background and stray light at the center of the detector hampers the interpretation of the UVW1 observations from Dec 14th. On Dec 15th, we avoided this problem by introducing an offset in the pointing of the telescope so that this ring did not coincide with the asteroid's position. We did not attempt any tracking, resulting in some smearing due to the apparent motion of Scheila.

Results: The images obtained on Dec. 15th 2010 using the V and UVW1 broadband filters are shown in Fig. 1. The images were carefully registered, binned, and logarithmically stretched to allow inspection of the morphology of the ejecta. Both panels span about 4'4" x 3'8", corresponding to approx. 400,000 x 312,500 km. It is of note that the background noise in the UVW1 filter appears worse than it is; the bottom left corner of the image is part of the reflection doughnut

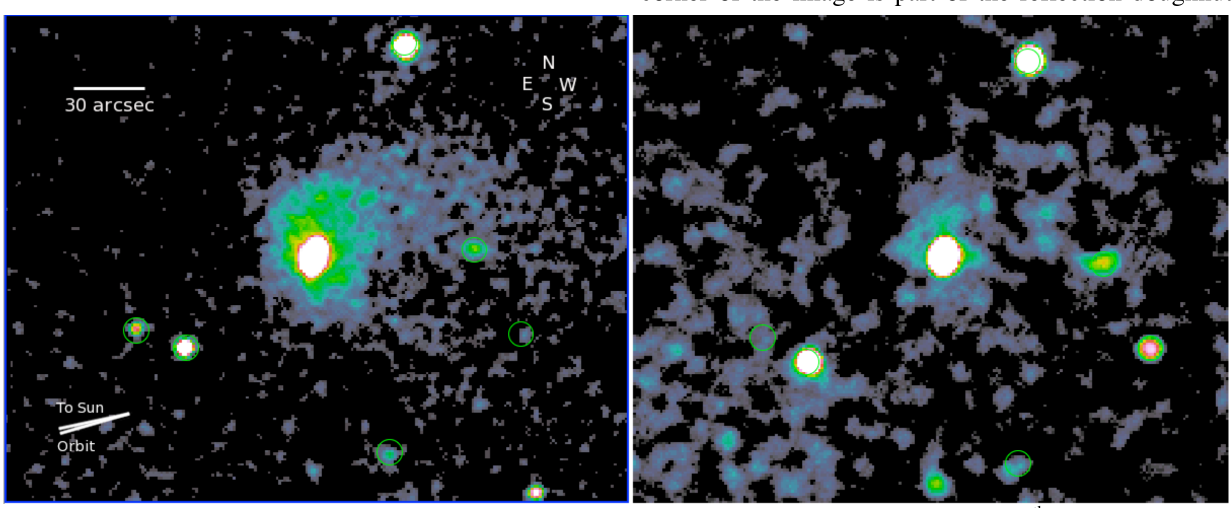

Fig. 1: Swift UVOT images obtained with the V (**left**) and UVW1 (**right**) filters on Dec 15th 2010 UT. The physical scale and orientation is the same in both frames. Both images are scaled logarithmically, but stretched and smoothed separately to enhance the ejecta surrounding the asteroid. The images were compared with archival DSS images to identify known background objects (indicated by green circles). The noise in the bottom left corner of the UV image is part of the internal reflection ring. As Swift did not track the asteroid, it appears slightly elongated in the northward direction. The ejecta moves in the anti-solar direction (west-northwest).

mentioned above. We used archival DSS images to identify background sources and indicated those in both panels. The projected directions to the Sun and the orbital motion almost coincide and are indicated by white lines.

We have a clearly resolved detection of the ejecta in both filters. In the V-band, the morphology seems to consist of two plumes; a Northern and a (fainter) Southern plume. The Northern plume is consistent with ejecta moving away from the asteroid and then being pushed in the anti-solar direction by solar ration pressure. We see no evident explanation for the morphology and direction of the Southern plume. The sunward extent of the dust cloud is ~30", corresponding to 2.6 x 10^4 km at the asteroid. This is distance where dust particles are turned around due to solar radiation, and it can be used to estimate the grain ejection velocity. Using the relations and assumptions from [2] we find $v_d = 57\sqrt{\beta}$ m/s, where β is the ratio of the radiation pressure acceleration to the local gravity in units of microns. This velocity is an order of magnitude larger than those reported for 133P ($1.5\sqrt{\beta}$ [2]) and P/2010 A2 ($1.1\sqrt{\beta}$ [4]), as is its escape velocity.

Aperture photometry on the broad band images yield $m_v = 14.3$ and $m_{uv} = 16.5$ for the the asteroid, and $m_v = 14.9$ and $m_{uv} = 16.7$ for the ejecta cloud within 45". Our measurements of the asteroid's brightness are in good agreement with its predicted brightness (m_v = 14.21, [5]). Within the uncertainties of our measurement, the ejecta has the same color or is slightly redder than the nucleus. Using the formalism from [6] it is possible to estimate the total mass of dust around the asteroid. For this, we assume no phase correction, an albedo of 0.1, and an apparent solar V-band magnitude of -26.74 to find a reflection cross section of ~10^9 m^2. Further assuming a power law distribution of spherical particles, we find that during our observations there was 4 x 10^7 kg of dust around the asteroid. To put this in perspective, this is a much larger mass than found around active centaurs (10^4 – 10^6 kg, [6]), comparable to the mass released by P/2010 A2 (LINEAR) (5 – 40 x 10^7 kg; [4,7], but small compared to the total amount of dust and gas excavated by the Deep Impact probe colliding with 9P/Tempel 1 (10^7 – 10^9 kg, [8]).

Spectroscopy: Figure 2 shows the asteroid's spectrum extracted from a rectangular region 13 pixels wide, along with a scaled solar spectrum (green). Only the part of the spectrum above 2800 Å is shown as at lower wavelengths, the spectrum was contaminated by a background star.

Scheila's spectrum appears significantly reddened compared to the Sun. Extrapolating the slope of the optical reflection spectrum published in the Small Main-belt Asteroid Spectroscopic Survey we would

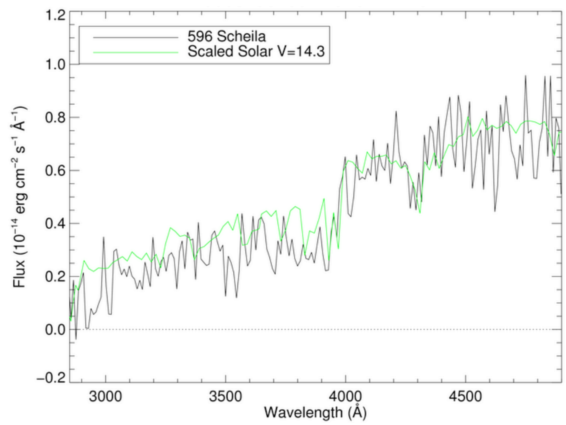

Fig. 2: Spectrum of 596 Scheila (black), compared to a solar spectrum with integrated m_v = 14.3 (green). The spectrum shows no evidence for the presence of gaseous volatiles typically present in cometary comae.

expect the reflectivity to drop by approximately 40% between 4500 Å and 3000 Å. Scaling the solar spectrum yields a best fit of $m_v = 14.3 \pm 0.1$, in excellent agreement with our broadband observations.

While the spectral grasp of the grism encompasses the emission features of several gaseous species that are abundant in comets (e.g. OH, CN, C_2, C_3, NH, CO_2^+ [9], there is no evidence of any gaseous emission feature in the spectrum of 596 Scheila. Most cometary fragment species observed in optical/UV wavelenghts have lifetimes in the order of 10^5 s at 1 AU, corresponding to about 11.1 days at the heliocentric distance of the asteroid (3.1 AU). While there were no detectable amounts of gas around the asteroid during the Swift observations on Dec 15th, gas released when the ejecta event set off (before Dec 3rd) initially may have dissipated.

Conclusions: The observed activity has not permanently increased the asteroid's brightness. We found no evidence of any of gases that are typically associated with cometary activity. Approximately 4 x 10^7 kg of dust was released with a high ejection velocity of 57 m/s (assuming 1 micron sized particles). The ejecta has the same color as the asteroid, suggesting that the ejecta currently does not contain any ice, which would result in blueing. While the observations hint at impact excavation, collisions between asteroids should be sufficiently rare that a collision on both P/2010 and 596 Scheila seems implausible.

References: [1] Hsieh & Jewitt (2006), *Science, 312,* 561. [2] Hsieh et al. (2004), *ApJ*, *127*, 2997. [3] Larson et al. (2010), *CBET*, *2583*. [4] Moreno et al. (2010), *ApJ 718*, L132. [5] JPL/Horizons. [6] Jewitt (2009), *AJ, 137*, 4296. [7] Snodgrass et al. (2010) *Nature, 467*, 814. [8] Küppers et al. (2005), *Nature, 437*, 987. [9] Bodewits et al. (2011) *AJ, 141*, 12.