Rotational properties of Quaoar using K2 Campaign 9 data

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1 Scientific justification

(50000) Quaoar is a large object in the classical Kuiper belt, one of the ancient and original populations in the trans-Neptunian region (Brown & Trujillo, 2004, Gladman et al., 2008, Lacerda et al., 2014). Due to its large size (∼1000 km) it is considered to be a very likely dwarf planet. It is a binary object, the orbital period of its moon Weywot is 12.438±0.005 d. Quaoar will be visible during the entire Campaign, at a brightness of $V = 18.9$ mag.

Light curve data obtained in 2003 showed a period of 8.84 h, but a double peaked lightcurve of 17.68 h provided a more probable fit (Ortiz et al., 2003, Thirouin et al., 2010). The average amplitude was ∼0.15 mag in these measurements. Rabinowitz et al. (2007) suggested a 8.84 h single peaked light curve, while Lin et al. (2007) presented *R* band results and proposed a 9.42 h single peaked light curve with a ∼0.3 mag amplitude. Multi-chord occultation observations of Quaoar (Braga-Ribas et al., 2013) provided an equivalent size of $R_{equiv} = 555 \pm 2.5$ km and a *V*-band geometric albedo of $p_V = 0.109 \pm 0.007$. Based on the 2-D occultation information and an assumed rotation period of 8.84 h, they estimated the body's true oblateness to $\varepsilon = 0.087^{+0.0268}_{-0.0175}$. In the framework of the "TNOs are Cool!" open time key program observations with the PACS and SPIRE photometers on board the Herschel Space Observatory provided size ($R = 530 \pm 19$ km, very close to the occultation value) and other properties via thermophysical modelling (Fornasier et al., 2013). In addition to the Open Time Key Program measurements Quaoar was also observed with the PACS camera of the Herschel Space Observatory in October, 2011, to obtain thermal light curves at 100 and 160 μm (PI: Esa Vilenius). Analysis of this data has not been published so far.

Here we propose Campaign 9 observations of (50000) Quaoar to obtain a rotational light curve in the optical band. The new K2 light curve will unambiguously determine the rotation period, both clarifying the single-peak period (8.84 or 9.42 h) and reveal whether the observed light curve is single or double peaked, in the latter case with a ∼18 h period. Quaoar has moved ∼15° along its orbit since 2003 and the position angle of the spin axis with respect to the line of sight changed accordingly. The comparison of the previous and current light curve amplitudes will constrain the possible spin axis orientations, an important parameter for the thermal emission models. The spin axis orientation is also constrained by the shape observed in the occultation measurements.

We are going to combine the new K2 light curve data with the unpublished Herschel thermal light curve observations and these together will clearly decide whether the light curve is caused by shape or by albedo variegations (see e.g. Lellouch et al., 2010, for a similar study on the dwarf planet Haumea). We will also be able to determine the main thermal characteristics of the surface (and also their rotational phase dependence) more precisely then from light curve average thermal data in Fornasier et al. (2013).

With all these information we will be able to set up the most complete internal structure and surface model to date for this large Kuiper belt object. We note that there are very few objects in the outer Solar System that had such a complete dataset (except Pluto after the New

Horizons mission). **Therefore Quaoar is a unique target for a benchmark study that will significantly improve our knowledge on the ~1000 km-size trans-Neptunian objects**. E.g. Quaoar is located very close to the CH_4 retention line, as presented in Schaller & Brown (2007) and Brown et al. (2011). The new surface model will allow us to place this object more precisely in this diagram, helping us to better understand the surface chemistry. Quaoar is a classical Kuiper belt object, bearing a ”red” surface, characteristic for many objects in its subpopulation. Crystalline water ice was also detected on Quaoar (Jewitt & Luu, 2004) indicating recent resurfacing, likely caused by cryovolcanism. The latest internal structure models of Quaoar (Shchuko et al., 2014) suggested a presence of subsurface oceans as a source of cryovolcanism, if some conditions were met. The combined Kepler-Herschel-groundbased data set will allow us to do a full 3-D characterisation of Quaoar and put much stronger constraints on the internal structure and the hypothetical cryovolcanic activity.

Overall, the observations of Quaoar can be one of the high points of the Solar System studies that K2 can deliver, in cooperation with other space telescope missions. **All future K2 TNO targets are smaller than 650 km, making Quaoar likely the last of its kind we can observe during the mission.**

2 Technical realisation

Quaoar will be visible in front of the Milky Way, just outside the Galactic Bulge itself, at Galactic coordinates $l \approx 12.8°$, $b \approx 4.5°$ at a brightness of 18.9 mag. Despite the dense background, we estimate that we can safely recover the light variations of Quaoar with K2. We developed a complete, state-of-the-art pipeline that can efficiently extract photometry for moving objects in the K2 data. We successfully detected rotational light curves of much fainter objects (2002 GV31: 23.0 mag, Pál et al. 2015) and with much lower amplitudes (2007 OR10: ±0.044 mag at 21.2 mag, Pál et al., subm.) than that of Quaoar. In both cases, the arc length was much shorter than the campaign length (13 and 12 days). The magnitude difference between Quaoar and its satellite, Weywot, is 5.6±0.2 mag (Brown & Suer 2007): we foresee an amplitude of < 0.005 mag for the phase variation of Weywot which is unlikely to be detectable with K2.

We propose to observe Quaoar for at least 30 days to safely recover the rotational light curve. According to our calculations, such an arc, positioned symmetrically around the stationary point, can be covered with approximately 1000 pixels. The target table lists the daily positions of Quaoar during the campaign, as seen by K2. **This proposal is submitted as a DDT as no regular proposal could have been submitted for K2 Campaign 9 targets.**

References: Braga-Ribas, F., et al., 2013, ApJ 773, 26; **Brown, M.E., & Trujillo, C. A.** , 2004, AJ, 127, 2413; **Brown, M.E., & Suer**, T.-A., 2007, IAUC, 8812; **Brown, M.E., et al.,** 2010, AJ, 139, 2700; **Fornasier, S., et al.**, 2013, A&A, 555, A15; **Jewitt, D.C. & Luu, J.,** 2004, Nature, 432, 731; **Lellouch, E., et al.**, 2010, A&A, 518, L152; **Ortiz, J.-L., et al.** , 2003, A&A, 407, 1149; **Pál, A., et al.,** 2015, ApJL, 804, 2; **Rabinowitz, et al.,** 2007, AJ, 133, 26; **Shchuko, O.B., et al.,** 2014, Planetary & Space Science, 104, 147; **Thirouin, A., et al.,** 2010, A&A, 522, A93