Determination of Light Variations of NEAs by the Pill Aperture Photometry

Paweł Koleńczuk[1]

1. Institute Astronomical Observatory, Faculty of Physics, Adam Mickiewicz University in Poznań, Słoneczna 36, 60–286 Poznań, Poland

Near-Earth Asteroid photometry is struggling with the problem of their observed high speed in the sky during approaching Earth what causes image stretching of an asteroid and/or stars on a CCD frame. In this work we analyze the efficiency and usefulness of the pill aperture photometry from the TRIPPy package to obtain the optimal S/N ratio.

1 NEAs photometry problems

Photometry of Near-Earth Asteroids (NEAs) is struggling with the problem of their observed high speed in the sky μ when approaching Earth. When the telescope follows the sidereal motion, the image of the asteroid is stretched on the CCD frame, and when it follows the asteroid, the images of the stars are stretched (leave the trails). The other approach is to follow the asteroid motion, which allows to keep the asteroid longer in the field of view and allows to take the instrumental brightness measurements of the asteroid using a circular aperture (example Fig. 1).

However, the problem of reducing the influence of atmosphere transparency remains. Typical differential photometry using circular apertures does not give good results. The shape of the circular aperture does not reflect the shape of the trail profile. A suitably large circular aperture covers a large area of the sky background, unnecessarily decreasing the signal-to-noise ratio S/N. Some photometric software packages offer elliptical apertures. However, their shape is also not perfectly matched to the obtained images, moreover, by using different aperture shapes for the asteroid and comparison star, the different part of the image profile of the objects can be cut off (Koleńczuk, 2019).

2 Potential solutions to the problems

There are a few possible solutions to the problems mentioned above:

1. Creating of star trails can be prevented by doing very short exposures. However, then the S/N ratio decreases and with faint asteroids on risks that the accuracy of photometric measurements will be too low.

2. Telescope following at speed 0.5μ. Then the trail length of the stars and asteroids is the same, so the same apertures can be used. However, since each pixel contributes to noise, the S/N of the asteroid is smaller than its circular equivalent (Fig. 1).

3. The ideal solution is to use an aperture that accurately reflects the shape of the object's profile. We keep optimal S/N (no unnecessary sky background

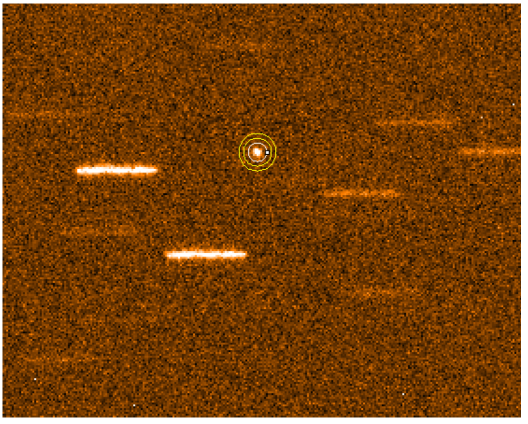

Fig. 1: The image of asteroid 2015 AK_{45} (in aperture) with telescope following asteroid.

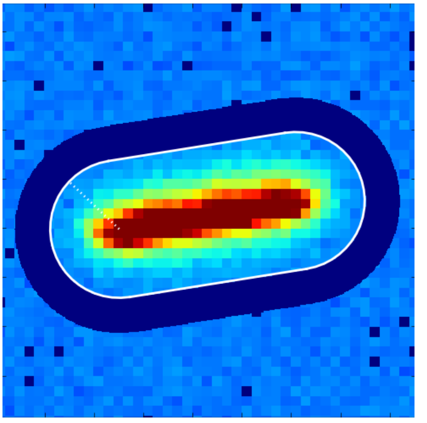

Fig. 2: Pill aperture including trail of star displayed with TRIPPy.

area), just like using a circular aperture for a circular object profile. This aperture shape, called the pill by its authors, was made available in the TRIPPy package (Fraser et al., 2016)[1].

3 Pill aperture photometry

The shape of the pill aperture (white border, Fig. 2) can be described as two semicircles with radius r connected with a rectangle of length l equal to trail length (Fraser et al., 2016). Circular and pill aperture with r radius contains the same part of the object profile so differential photometry using different shapes of apertures is possible. Our goal was to check the efficiency of photometry using circular aperture for asteroid and pill aperture for comparison star.

4 Observation data and methods

I used CCD frames from Tomasz Kwiatkowski's observation of four NEAs. The asteroids were observed with a clear filter using 1 and 2 m telescopes of the global web system LCOGT. One of the asteroids was observed for three nights, the rest of them were observed for one night. The telescope was following the asteroid, which resulted in the trail length of 1.32–14.92 $FWHM$. To do the differential photometry, stars with similar spectral types to the Sun from the PanSTARRS catalog were used and that allowed transforming the differential brightness to the standard system. The trail length was determined from the equation $l = \mu t$, where t is the exposure time, and the proper motion μ was determined using the JPL HORIZONS ephemeris service[2] (Koleńczuk, 2019).

[1] package available from: `https://github.com/fraserw/trippy/releases/tag/0.4`
[2] `https://ssd.jpl.nasa.gov/horizons.cgi#top`

5 Results

The lightcurves obtained by differential photometry were compared with the instrumental results. Both lightcurves show agreement for observations of the 2015 HQ_{11} asteroid (Fig. 3, top panel) in photometric night conditions (small changes in atmospheric transparency). In the case of worse weather conditions (e.g., Fig. 3, bottom panel), the amplitudes of the differential lightcurves are smaller than amplitudes of instrumental lightcurve. Such results are characteristic of correctly done differential photometry, thus the effectiveness of the method using circular and pill aperture was confirmed (Koleńczuk, 2019).

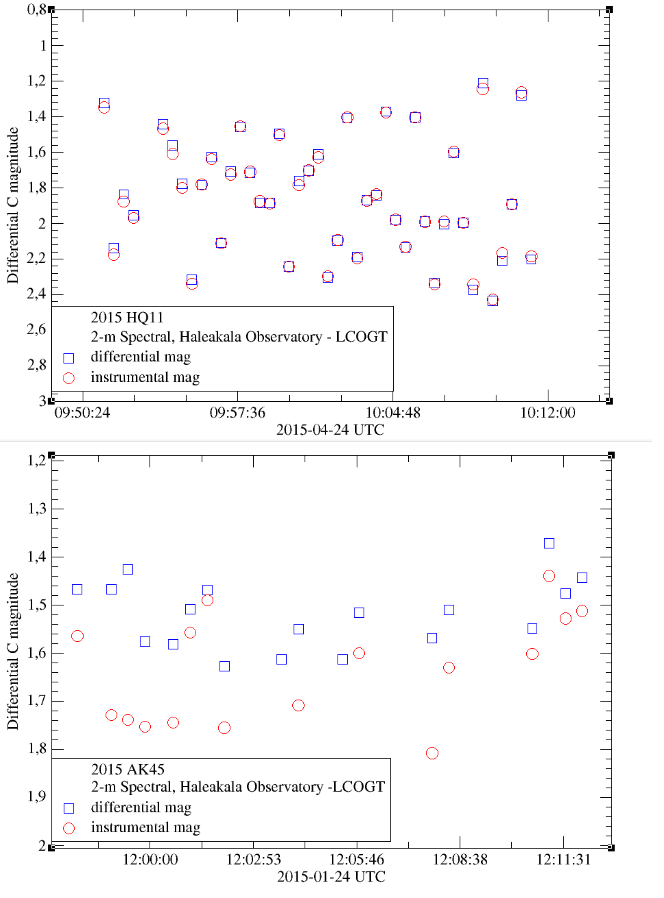

Fig. 3: Comparison of differential (blue squares in the plots, circular apertures for the asteroids + pill apertures for the comparison stars) and instrumental (red circles in the plots, circular apertures for asteroids) photometry. Top panel: observations of 2015 HQ_{11}, photometric night. Bottom panel: observations of 2015 AK_{45}, transition of cirruses. The instrumental lightcurves were shifted vertically for comparison. The plots were made on the basis of Tomasz Kwiatkowski's observations with a clear filter on the 2-m LCOGT telescope at Haleakala Observatory.

6 Conclusions

Observation of NEAs with following asteroid and photometry using circular (asteroid) and pill aperture (comparison stars) provides the highest possible S/N. The use of the pill aperture is not limited to asteroid photometry. Note that the problem of the observed high speed in the sky also applies to artificial Earth satellites. Pill aperture can also eliminate the problem of star and quasar photometry during unexpected movement telescope, e.g., in a sudden gust of wind (Koleńczuk, 2019).

References

Fraser, W., et al., *AJ* **151**, 6, 158 (2016)

Koleńczuk, P., Master's thesis (2019)