2003 EL61 – a TNO by Moonlight

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Readers might perhaps be interested in this lightcurve of the interesting Trans Neptunian Object 2003 EL61, which remarkable for its large size combined with short rotation period of just 3.9 hours. The lightcurve may not look pretty – but the observations were made with a 30 cm telescope just one night before full moon. In individual frames the object is barely detected, at just 2 sigma above the sky background. Not surprisingly, photometric analysis of the images presented a severe challenge!

A total of 532 images were obtained on the night of 31 March-April 1, using a 30 cm Meade SCT, and unfiltered Starlight Xpress MX916 CCD camera at Lymm, Cheshire. The exposure time was 30 seconds

Photometric processing of the images is done with my own software – called LYMM – which has been developed over the last six years. The main features are:

1. When the images are dark and flat corrected, and simple star search routine is executed, which writes a list of all stars above some threshold, in each image, to a file.

2. The user selects several stars to act as fiducial stars, and the software then carries out pattern recognition to compute the offsets and rotations (relative to the first image) of all images in the series

3. Once the offsets and rotations are known, the positions from all the frames can be combined to provide more precise star positions. This usually involves averaging the positions after removing the offsets and rotations; but for very faint objects it may be preferable to obtain positions from a set of stacked frames.

4. Steps 2 and 3 are iterated – since better positions yield better image alignment data and vice versa. Also, I finish the iterations using positions obtained from PSF fitting, rather than from centroids, since PSF positions have been found to be more accurate, especially for fainter objects.

5. How one proceeds depends on whether the target is moving, and how faint it is. For fixed targets (variable stars!), having obtained accurate positions, one can now carry out photometry.

6. For brighter asteroids – i.e. bright enough to provide good positions in individual frames – the software fits curves to the x and y pixel coordinates as a function of time. One can then perform photometry, using the curves to provide a set of smoothly varying positions which are unaffected by noise. But

for an object such as 2003EL61, which is barely detected in individual frames, a more sophisticated approach is required.

7. For 2003EL61, groups of 50 or so frames from the start and end of the series were stacked, and the position obtained by visual inspection. These start and end positions, together with average times for the stacks of frames, were used to define an approximate model which describes the motion.

8. The software is now used to stack successive batches of, say, 30 frames. In each set of stacked frames, the position of the target is determined by PSF fitting (actually, the shape of the PSF is taken from a brighter star in the field, and only the position determined for the faint target). The position, and an average time for the stacked frame, are written to a file.

9. If the initial model was in fact correct, the positions from the sets of stacked frames will not show any further motion; if the initial model was wrong, then the motion shown by these positions can be used to correct it. The software does just this to obtain a model which describes the motion of the target— even if the target is practically invisible in individual frames.

10. We are now ready to carry out photometry of the target and field comparison stars. Rather than use aperture photometry, a technique called *optimal extraction* is used, which provides an estimate of the flux with the highest possible signal to noise (lowest error). Optimal extraction has been shown to provide higher signal-noise than aperture photometry, and I find it to work particularly well on faint objects (see note 2).

11. Photometry is performed on the individual frames and the results transferred to an Excel spreadsheet. The flux from the target is normalised to (an) arbitrary field star(s), and then successive groups of 20 measures averaged to plot the lightcurve shown.

The motion of 2003 EL61 is of course very slow, and this helps us in two ways. First, we can describe its motion over several hours by a linear model. Second, the motion during an individual 30 second frame is negligible, and so for all practical purposes the object PSF can be assumed to be identical to that of the field stars; this second assumption permits the use of optimal extraction.

Note that LYMM requires the object position (or path) to be determined accurately *before* doing photometry; it *never* updates the target position immediately prior to photometry, based on the information in that particular frame.

Subsequently, more observations of 2003 EL61 were obtained at higher signal to noise on three dark, moonless nights. Analysis of all these data is continuing.

Notes:

1) Optimal extraction was originally developed for spectroscopy, but was extended by Prof Tim Naylor (University of Exeter) to work with two-dimensional CCD images.

He found it to provide a roughly 10% gain in signal to noise over aperture photometry, even when the aperture size was optimised for the target. This is consistent with my own experience.

2) For more information about the LYMM software, visit www.lymmobservatory.net. You can download the software free of charge, along with example image files and a 34-page manual. The optimal extraction procedure in LYMM follows the method described in Tim's paper, although all the coding was done by me.