Title: A naked-eye optical transient

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Abstract:

A previously unknown optical transient has been observed in the constellation Bootes. The transient flared to brighter than 5th magnitude, which is comparable to the visual magnitudes of the nearby stars π Bootes and o Bootes. This article describes the relative astrometry and photometry work we have done regarding the transient, which we provisionally designate Tr Boo.

Introduction: To be written.

Discovery:

The constellation Bootes was observed from Brampton, Ontario, Canada (79.7667 W, 43.6833 N) by J. Sandal on the evening of 2012 September 25 (MJD 56195; UTC 2012 September 26) using a Sony DSC-W570 18.2 Mpix handheld camera. These observations reveal an unknown object flaring to brighter than 5th magnitude, comparable in brightness to π Bootes and o Bootes (hereafter pi Boo and omi Boo). The transient was between 20 and 30 degrees above the horizon at the times of observation.

There are two photographs taken that night indicating the existence of the transient. Image DSC1875 had an exposure time of 2 seconds, and stars in it possess a slightly elongated point spread function. Image DSC1861 had an exposure time of 0.125 seconds in which stars appear as complicated trails due to camera motion. Information on the two images is given in Table 1 below.

Table 1

Image Name	UTC of Observation	Exposure Time	Pixel Scale (arcsec/pixel)
DSC1861	2012-09-26 00:17:54	0.125 sec	146.49±1.94
DSC1875	2012-09-26 00:45:50	2 sec	85.27±2.25

A third photograph (DSC1864), taken in between the other two at 00:23:14 (UTC), does also show the transient to be present. However, its poor PSF and low resolution of about 300 arcseconds per pixel makes it useless for detailed analysis. All we can conclude from it is that the transient is not brighter than pi Boo in that image.

Tr Boo and its neighbors, pi Boo and omi Boo are approximately equally spaced in a straight line on the sky with pi Boo in the middle, as seen in Fig.1.

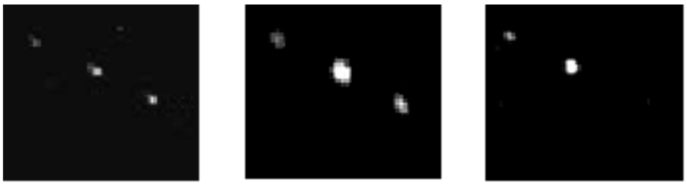

Fig.1 Figure showing omi Boo, pi Boo and Tr Boo in our two images side by side (DSC1861 on the left and DSC1875 in the middle), rotated and magnified to the same scale, with north up and east to the left. The right image of the same region is from the Palomar Observatory Sky Survey blue plate (right), magnified to the same scale.

The two pictures taken at different time with different rotation angles of the camera relative to the sky has shown that Tr Boo has an unchanged position relative to pi Boo and omi Boo, which excludes the possibility that Tr Boo is a reflection of Arcturus. To be more specific, if Tr Boo is caused by the reflection effect, then the reflection would have appeared at a different location on the sky when the camera was rotated.

We used the IRAF (Image Reduction and Analysis Facility) tasks "rotate" and "magnify" to transform the two images to the same scale and orientation. We then centered on pi Boo and blink the two images; the position of Tr Boo is the same within the uncertainties on each image.

All sky camera searches:

We searched for the transient around omi Boo and pi Boo on images from the all sky camera operated by The Liverpool Telescope Project (Steele et al. 2004) on the island of La Palma. We scrutinized images taken between 19:41:14 and 20:05:14 on September 25th 2012 (UTC), which is several hours before the transient was observed in Toronto. Because of moonlight, we have to smooth, shift and combine several images together before seeking around Bootes for the transient. Nevertheless, we did not find any object around omi Boo and pi Boo, which probably because the images were taken before the transient really happened.

We also examined images from the all sky camera archives at the Kitt Peak National Observatory and MMT Obervatory (Pickering 2004). The earliest available images are from approximately UTC 02:00. They do not show the transient, but the limit on its brightness is only V>2.2 from Kitt Peak (fainter than alpha CrB) and worse on the lower-resolution MMTO images.

Scrutiny of the Liverpool all sky camera images taken the next night (UTC September 26th between 19:40:13 and 20:04:15) also show no sign of the transient.

Position Measurement:

An approximate astrometric solution could be obtained for image DSC1875 using nova.astrometry.net (see Figure.2); however, examination of the astrometric solution revealed it to have unacceptably large position residuals for pi Boo and omi Boo, and thus an unacceptably large uncertainty on the position of the flare object.

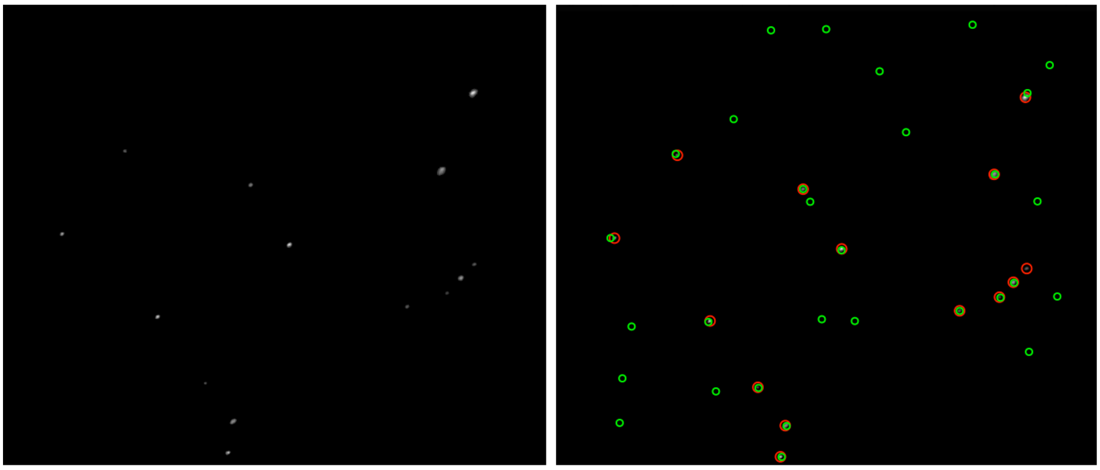

Fig.2 The astrometric solution of image DSC1875 using nova.astrometry.net. The image on the left hand side is the original version of DSC1875; the image on the right hand side is the red-green overlay output image, wherein the red-green overlay circles represent the consistency of catalog objects (green) with objects on the image (red). The single red circle near the right edge is Tr Boo, the object of interest.

In image DSC1861, the stars have the shape of a seeing disk trailed in a complicated pattern due to camera motion. We used the IRAF task "imedit" to isolate only the sharpest part of each object trail. Fig.3 shows image DSC1861 before and after this processing.

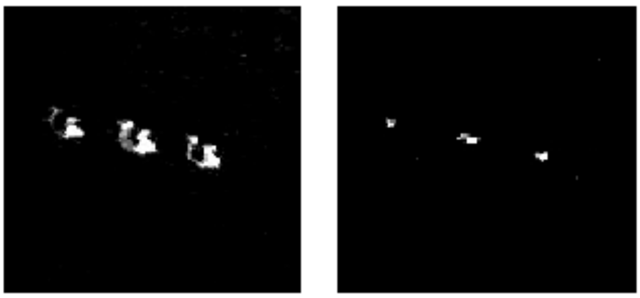

Fig.3 Image on the left is the original DSC1861 image; the trailed pattern is obvious. The image on the right is the processed DSC1861 image wherein the trailed patterns have been removed.

We calculate the coordinates of Tr Boo via a local linear transformation between pixel and equatorial coordinate systems, which assumes the two coordinate systems are locally Cartesian-like, with the equatorial system having only a rotation angle and a scale relative to the pixel system.

Under this approximation, the linear transformation between two sets of coordinates can be shown by the formula below:

$$\begin{cases} a = s(x\cos\theta + y\sin\theta) \\ d = s(-x\sin\theta + y\cos\theta) \end{cases} \qquad (1)$$

wherein x and y represent the coordinates in pixels, a and d stand for distances in degrees on the sky along the right ascension axis and declination axis respectively, s is the scale factor and θ is the rotation angle of equatorial coordinates relative to pixel coordinates.

For the sake of simplicity, we set pi Boo as the origin of both coordinate systems. The coordinates of omi Boo in pixels and degrees relative to pi Boo are shown below:

Table 2

Name	x/pixel	y/pixel	α/degree	δ/degree
pi Boo	0	0	0	0
omi Boo	27.32	11.9	1.082683	0.545945

Based on the coordinates above, we can calculate the scale factor and rotation angle.

The scale can be calculated by dividing the distance between pi Boo and omi Boo in degrees by distance in pixels.

In this approach θ is solved by search method after substituting omi Boo's coordinates into eq.1.

An alternative to calculate s and θ is to utilize the IRAF task "geomap" with the parameter "fitgeo"="rscale". Both the results of these two methods are shown below:

Table 3

Method	s degrees/pixel	θ degrees
IRAF "geomap" task	0.040690	356.77728
Linear Transformation	0.040661	356.79242

We used the IRAF results in this work. The coordinates of Tr Boo in degrees can thus be converted once we obtain the appropriate value of s and θ by using eq.1, which are shown in Table 4.

Table 4

	RA/degrees	DEC/degrees	RA	DEC
DSC1861	219.1299±0.0122	15.8928±0.0122	14:36:31±0:03	+15:53:34±0:44

DSC1875	219.1417±0.0237	15.8300±0.0237	14:36:34±0:06	+15:49:48±1:25
Average	219.1317±0.6750	15.8795±0.6517	14:36:31.6±0:02.7	+15:52:46.2±0:39.1

Based on the coordinates above, the discrepancy in the coordinates is 0.45 sigma in right ascension and 4.47 sigma in declination between the two images.

Candidate Identifications:

No known variable star is listed in the General Catalog of Variable Stars (Samus et al. 2010) within one degree of the transient. There are 3 stars that may be responsible for the transient when we search for candidates on SIMBAD centered on the calculated coordinates within a radius of 5 arcminutes. Information on these 3 candidates, plus one other identified in the SDSS, are listed below in Table 5.

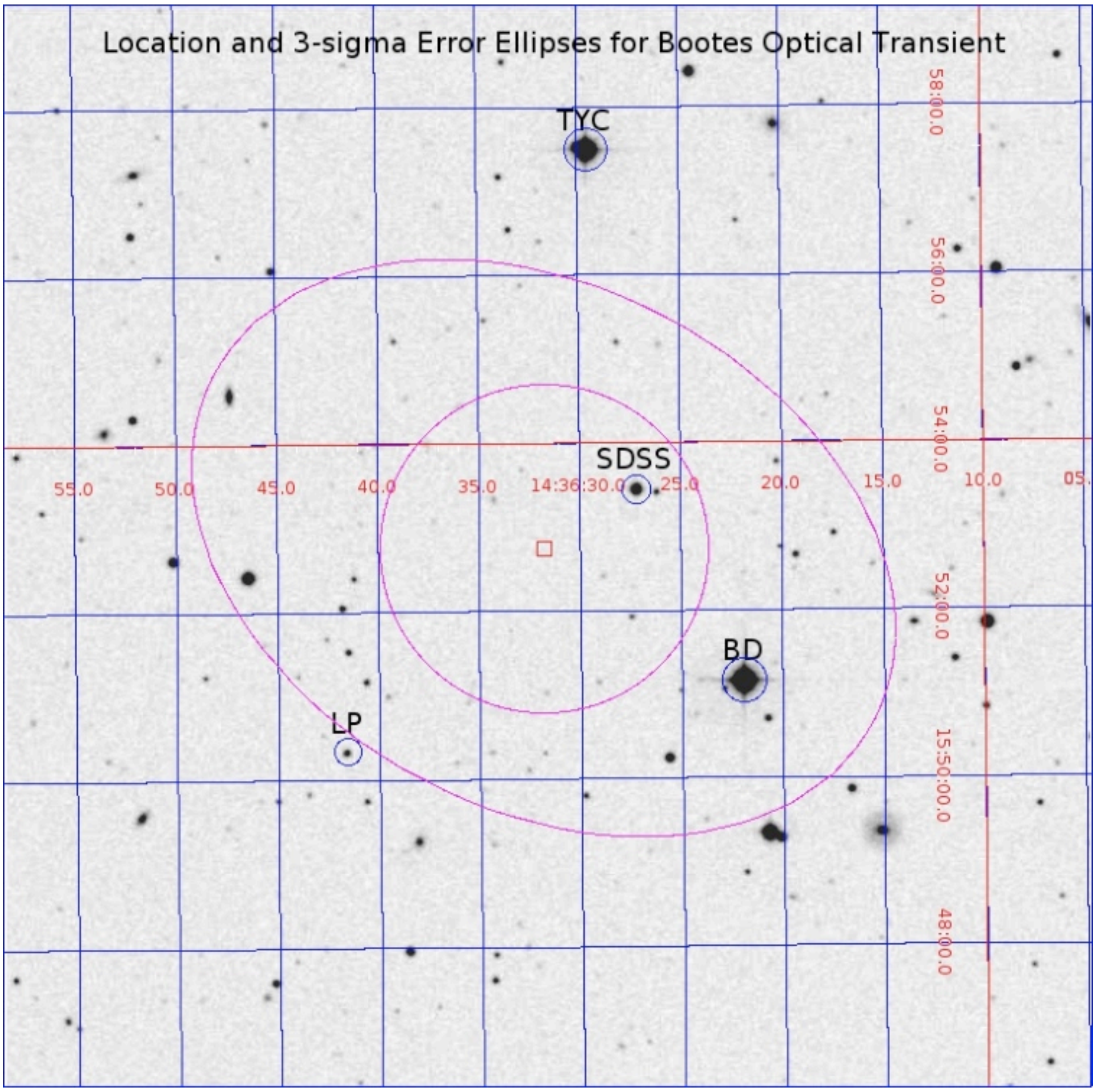

Fig.4 This finding chart shows the POSS-II F plate (approximately R band) of the area. The red box shows the weighted average position of Tr Boo. The magenta circle shows the 3-sigma random uncertainty on its position. The magenta ellipse incorporates both the 3-sigma random uncertainty and the 3-sigma systematic uncertainty on its position, added together linearly (not in quadrature). The four objects discussed in the text as possible counterparts are labeled by their IAU prefix.

Table 5

Object	Magnitude	Distance(arcsec)	Distance(sigma)	RA	DEC
Tr Boo	4.70	0	0	14:36:33.40	+15:52:46.20
SDSS J1436+1553	13.99	98.38	2.52	14:36:27.19	+15:53:26.83
LP 440-48	15.96	187.83	4.80	14:36:41.59	+15:50:20.20
BD +16 2671	11.49	191.18	4.89	14:36:21.97	+15:51:09.47
TYC 1477-341-1	12.03	288.65	7.38	14:36:29.56	+15:57:29.50

Objects labeled in Table 5 are shown in a finding chart of the area around Tr Boo in Figure 4.

Photometry:

The transient Tr Boo was of similar brightness to omi Boo but not as bright as pi Boo (a blended binary with V=4.53). In the next section we discuss our derivation of a peak observed apparent magnitude of 4.7.

We used the databases of the CRTS (Catalina Real-time Transient Survey; Drake et al. 2009) and the ASAS (All Sky Automated Survey; Pojmanski 1997) to search for photometry of the objects above.

The object SDSS J143627.19+155326.8 (ASAS 143627 +1553.5) was taken into consideration because of its relative proximity to Tr Boo. The CRTS database shows that this object has an unchanged magnitude around 14.0, consistent within the errors with the result given by the ASAS.

The object LP 440-48 has a magnitude of 15.9 in the CRTS, with no sign of variability. It is not found in the ASAS.

When comparing the photometry results from the CRTS and ASAS on the objects BD +16 2617 and TYC 1477-341-1, there emerged a large discrepancy. There is no conspicuous change in their magnitudes in the light curves given by ASAS, but the CRTS results suggest three to four magnitudes of variability. The CRTS photometry data for these objects are untrustworthy because the objects are often saturated in the CRTS.

We searched for variable objects within a radius of 3 arcmin of every object in Table 5. We found one object (CSS J143625.1+155102) with apparent variability due to its proximity to a much brighter star. There is no useful data available in the ASAS for this object.

We examined cutouts of the CRTS images at the transient's location (kindly provided by A. Drake), but found no evidence for an uncatalogued variable object in them.

Examination of the POSS-I and POSS-II plates within a 6 arcminute radius of the transient's coordinates did not reveal any objects with dramatic variability. (Note that the POSS-I O plate has at least six point-like features within a 6 arcminute radius which are spurious, as they do not correspond to the positions of any objects in the SDSS images of the region.)

Examination of GALEX images of the field did not reveal any objects with unusual ultraviolet-optical colors. The star BD is much brighter in the UV than TYC, but both stars have UV-optical colors consistent with expectations for stars with their optical colors. The star LP is not detected by GALEX, and the star SDSS is barely detected.

Examination of the HEASARC X-ray and gamma-ray satellite databases did not reveal any X-ray sources near the position of the transient.

Note that if this transient was a flare from any of these objects, it would be a flare of amplitude approximately 7 to 11 magnitudes.

Magnitude Calculation:

The calculation of the magnitude of the transient is based on the two DSC images mentioned above and one combined image from Liverpool all sky camera. The combined image is made of 10 Liverpool all sky camera images taken between UTC 19:51:14 and 20:00:03 on September 25th 2012. Because omi Boo is the faintest object detected on the combined image, the magnitude of the transient is larger than omi Boo's magnitude. This magnitude limit is shown in Fig 5 with an error bar extending off the plot.

Magnitudes of the transient on DSC images is the average of the magnitudes relative to pi Boo and omi Boo, which also shown in Fig 5. To be more specific, calculations of averaging flux in B and V band of pi Boo and omi Boo were done before converting flux back to magnitude. Magnitudes of Tr Boo relative to pi Boo and omi Boo were calculated by contrast the magnitudes from IRAF and SIMBAD, based on the fact that the difference in magnitudes between Tr Boo and other object (pi Boo, for example) is constant, and Tr Boo's magnitude is the average of magnitude relative to pi Boo and omi Boo, shown in Table 6.

Image	UTC	Magnitude
Liverpool	2012-09-25 19:51:14-20:00:03	Larger than 5
DSC1861	2012-09-26 00:17:54	4.6926±0.1784
DSC1875	2012-09-26 00:45:50	4.6926±0.1784

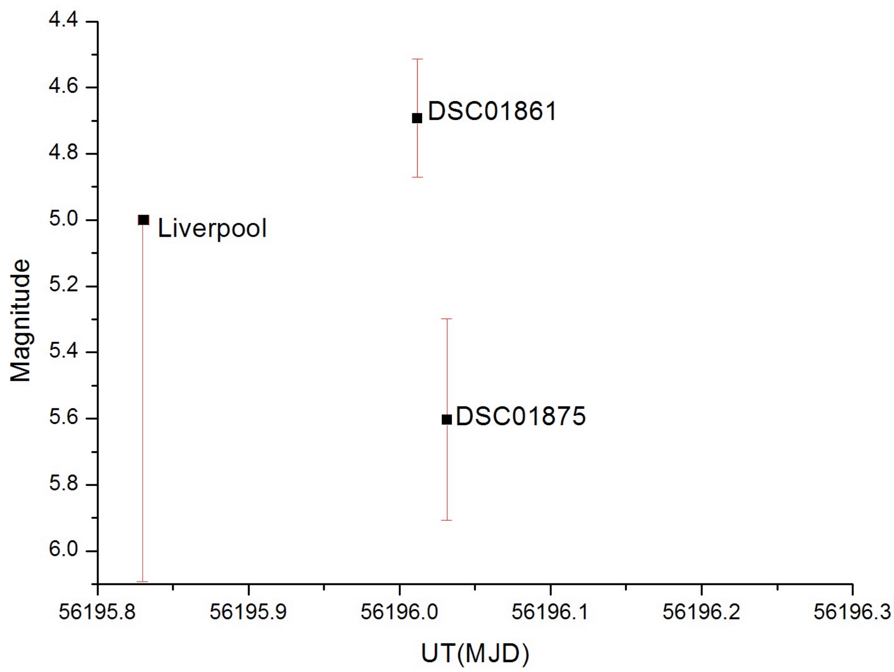

Fig 5. The magnitude of the transient at three different times. Note that the downward error bar on the Liverpool point means the transient's magnitude can be any value larger than 5.

Conclusion: to be written.

Acknowledgements:

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