

# Measurements of Wide Tycho Double Stars in Orion

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**Abstract:** About 25 TDS objects in Orion with separation of 1.5" or larger remained at the beginning of 2016 in the WDS catalog without confirmation while 10 are listed as confirmed. Several of the so far unconfirmed objects have now been successfully observed while most of the remaining objects are to be suspected as being bogus as the evidence suggests single stars. The number of confirmed TDS objects of this separation range in Orion is greater than in the other constellations we have studied so far.

## Introduction

At the beginning of 2016, McPhee joined Chris Thuemen's "Double Star Imaging Group" with an equipment portfolio that Knapp thought potentially able to resolve TDS objects with separation less than 1.5". McPhee was contacted for a test run with objects with somewhat larger separation as a starter. So far, unconfirmed TDS objects with separation 1.5" or larger are to be found ample in all constellations. In Orion, 20 such objects were selected plus TDS3407 as one already confirmed object as reference. These are listed in Table 1.

## Further Research

A single image was taken by Knapp for most of the selected objects with the iT27 using a 3s exposure time, but a few were missed due to ongoing bad weather along with Orion fading in altitude quickly. The RA/Dec coordinates resulting from plate solving with UCAC4 reference stars in the 10.5 to 14.5mag range were used to calculate Sep and PA using the formula provided by R. Buchheim (2008). Err\_Sep is calculated as  $\text{SQRT}(dRA^2 + dDec^2)$  with dRA and dDec as aver-

age RA and Dec plate solving errors. Err\_PA is the error estimation for PA calculated as  $\arctan(\text{Err\_Sep}/\text{Sep})$  in degrees assuming the worst case that Err\_Sep points in the right angle to the direction of the separation means perpendicular to the separation vector. Mag is the photometry result based on UCAC4 reference stars with Vmags between 10.5 and 14.5mag. Err\_Mag is calculated as square root of  $(dVmag^2 + (2.5 * \text{Log}_{10}(1 + 1/\text{SNR}))^2)$  with dVmag as the average Vmag error over all used reference stars and SNR is the signal to noise ratio for the given star.

Knapp also checked 2MASS J-band images for evidence proven to be helpful down to 1.5" separation depending on delta\_m.

Additionally, McPhee observed a number of the objects visually and also took some photographic images for visualisation.

The results are given in Table 2.

## Images for Visualization

Figure 1 is of some of the TDS objects imaged by McPhee. Figure 2 shows 2MASS images for two objects.

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Figure 1. McPhee's images for some of the measured objects

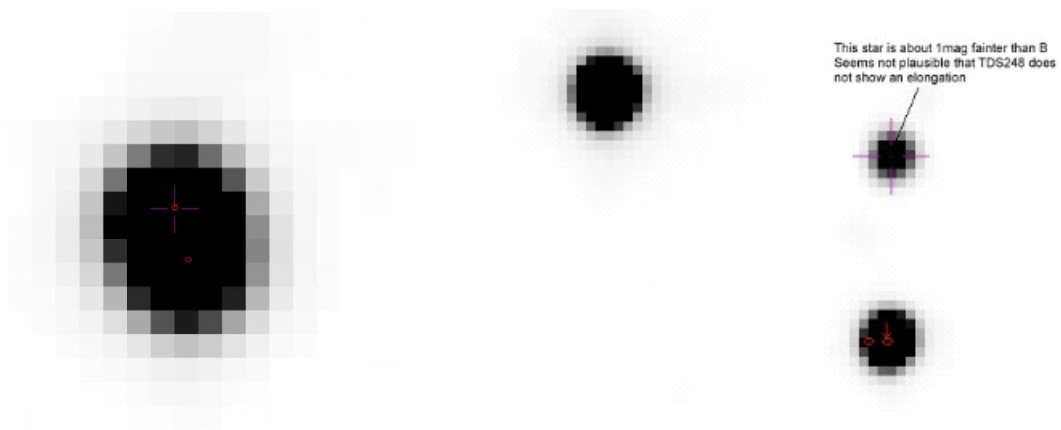


Figure 2. 2MASS J-band for TDS3010 and TDS248 with TDSC positions

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*Table 1. WDS catalog data (based on Fabricius et al. 2002) at the beginning of 2016 for the selected unconfirmed TDS objects in Ori with separation of 1.5 arcseconds or larger*

Name	Comp	WDS ID	RA	Dec	Sep	M1	M2	PA
TDS185	AB	05366-0625	05:36:37.810	-06:25:30.3	1.5	10.14	12.10	195
TDS211	AB	05591+1846	05:59:08.690	+18:45:36.6	1.8	10.18	11.94	181
TDS241	AB	06207+0857	06:20:39.380	+08:57:04.7	2.1	9.49	11.27	92
TDS248	AB	06244+1128	06:24:23.640	+11:27:42.2	2.0	9.40	11.82	94
TDS2965	AB	04474+0907	04:47:23.540	+09:06:55.7	1.5	10.59	11.62	332
TDS3010	AB	04561+0555	04:56:03.281	+05:54:51.3	2.2	11.54	12.22	194
TDS3160	AB	05220+0319	05:22:00.780	+03:18:50.2	1.5	9.50	11.72	219
TDS3167	AB	05228-0804	05:22:46.370	-08:04:21.2	1.7	11.63	12.01	138
TDS3407	AB	05535-1025	05:53:29.821	-10:24:33.8	2.3	11.73	11.88	80
TDS3443	AB	05569+1859	05:56:51.250	+18:58:51.1	2.0	11.30	12.38	154
TDS3535	AB	06044+1257	06:04:26.849	+12:57:11.9	2.2	11.14	12.03	206
TDS3542	AB	06053+2028	06:05:16.810	+20:27:58.9	1.7	10.27	11.89	274
TDS3545	AB	06055+1742	06:05:27.460	+17:41:32.7	2.1	11.26	11.97	217
TDS3550	AB	06057+2039	06:05:44.330	+20:39:13.5	1.7	10.80	11.70	138
TDS3562	AB	06069+1428	06:06:52.739	+14:27:42.4	2.2	9.66	12.08	323
TDS3613	AB	06115-0343	06:11:29.320	-03:43:20.6	2.1	11.50	11.51	179
TDS3661	AB	06149+0822	06:14:53.899	+08:22:02.3	2.1	11.66	11.97	38
TDS3669	AB	06153+1740	06:15:18.060	+17:39:41.2	1.7	9.85	11.71	231
TDS3674	AB	06156+0706	06:15:34.190	+07:05:30.7	1.5	11.78	12.26	94
TDS3679	AB	06158-0145	06:15:50.941	-01:45:18.5	2.0	11.09	11.89	143
TDS3684	AB	06161+0935	06:16:04.649	+09:35:09.2	2.6	11.22	11.31	159

### Summary

The veracity of several objects from this study remains unresolved due to inconclusive results. While a few objects were missed, 4 double stars out of 17 were confirmed. Compared with the TDS record in other constellations (see Knapp, Gould 2016), this was a rather positive result. Next observing season should witness completion of this project. Imaging upgrades by one of the authors (McPhee) allowing for resolution of TDS objects below 1.5" separation is in progress—this should allow a more detailed analysis of these objects within the constellation of Orion.

### Acknowledgements

The following tools and resources have been used for this research:

- Washington Double Star Catalog as data source for the selected objects
- Mark McPhee's equipment: Telescope: 381mm Dobsonian reflector (Obsession brand) with 1732mm focal length. Camera: Nikon D5100 DSLR. Located in Bee Cave, Texas. Elevation 280m
- iTelescope: Images were taken with the iT27: 700mm CDK with 4531mm focal length. CCD:

FLI PL09000. Resolution 0.53 arcsec/pixel. V-filter. Located in Siding Spring, Australia. Elevation 1122m

- AAVSO VPhot for initial plate solving
- AAVSO APASS providing Vmags for faint reference stars (indirect via UCAC4)
- UCAC4 catalog (online via the University of Heidelberg website and Vizier and locally from USNO DVD) for counterchecks and for high precision plate solving
- Tycho Double Star catalog for counterchecks
- Aladin Sky Atlas v8.0 for counterchecks
- SIMBAD, Vizier for counterchecks
- 2MASS All Sky Catalog for counterchecks
- URAT1 Survey (preliminary) for counterchecks
- AstroPlanner v2.2 for object selection, session planning and for catalog based counterchecks
- MaxIm DL6 v6.08 for plate solving on base of the UCAC4 catalog
- Astrometrica v4.8.2.405 for astrometry and photometry measurements

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Table 2: Astrometry and photometry results for the selected TDS components in Ori. Date is the Bessel epoch in 2016 and N is the number of images used for the reported values. iT in the Notes column indicates the telescope used with number of images and exposure time given (Specifications of the used telescopes: See Acknowledgements).

Name		RA	Dec	dRA	dDec	Sep	Err Sep	PA	Err PA	Mag	Err Mag	SNR	dVmag	Date 2016	N	Notes
TDS 185	A	05 36 37.805	-06 25 30.46	0.15	0.14	-	0.205	-	-	10.322	0.100	236.21	0.10	.155	1	1
	B	-	-							-	-	-				
TDS 241	A	06 20 39.373	08 57 04.75	0.18	0.17	-	0.248	-	-	9.644	0.070	150.50	0.07	.160	1	2
	B	-	-							-	-	-				
TDS 248	A	06 24 23.628	11 27 42.06	0.18	0.20	-	0.269	-	-	9.165	0.100	202.34	0.10	.160	1	3
	B	-	-							-	-	-				
TDS2965	A	04 47 23.575	09 06 55.40	0.22	0.15	-	0.266	-	-	10.278	0.090	170.85	0.09	.155	1	4
	B	-	-							-	-	-				
TDS3010	A	04 56 03.219	05 54 50.60	0.16	0.17	2.100	0.233	181.221	6.342	11.611	0.091	85.40	0.09	.155	1	5
	B	04 56 03.216	05 54 48.50							12.136	0.092	64.42				
TDS3160	A	05 22 00.744	03 18 49.85	0.17	0.17	-	0.240	-	-	9.259	0.100	332.23	0.10	.155	1	6
	B	-	-							-	-	-				
TDS3167	A	05 22 46.366	-08 04 21.10	0.15	0.14	-	0.205	-	-	12.227	0.071	93.59	0.07	.155	1	7
	B	-	-							-	-	-				
TDS3407	A	05 53 29.840	-10 24 33.96	0.18	0.20	2.029	0.269	81.496	7.555	11.572	0.082	57.15	0.08	.160	1	8
	B	05 53 29.976	-10 24 33.66							11.626	0.082	54.36				
TDS3443	A	05 56 51.214	18 58 50.83	0.17	0.19	-	0.255	-	-	11.160	0.091	96.33	0.09	.160	1	9
	B	-	-							-	-	-				
TDS3535	A	06 04 26.841	12 57 11.83	0.17	0.19	-	0.255	-	-	11.144	0.131	77.08	0.13	.160	1	10
	B	-	-							-	-	-				
TDS3545	A	06 05 27.460	17 41 32.49	0.21	0.17	-	0.270	-	-	11.453	0.091	74.08	0.09	.160	1	11
	B	-	-							-	-	-				
TDS3550	A	06 05 44.334	20 39 13.41	0.19	0.17	-	0.255	-	-	10.705	0.114	35.78	0.11	.172	1	12
	B	-	-							-	-	-				
TDS3562	A	06 06 52.715	14 27 42.29	0.24	0.20	-	0.312	-	-	9.593	0.080	136.32	0.08	.160	1	13
	B	-	-							-	-	-				
TDS3613	A	06 11 29.315	-03 43 20.80	0.15	0.14	2.050	0.205	172.025	5.716	11.383	0.061	107.52	0.06	.160	1	14
	B	06 11 29.334	-03 43 22.83							12.191	0.062	62.15				
TDS3661	A	06 14 53.997	08 22 03.69	0.15	0.16	-	0.219	-	-	12.617	0.072	63.72	0.07	.160	1	15
	B	-	-							-	-	-				
TDS3674	A	06 15 34.186	07 05 30.74	0.15	0.16	-	0.219	-	-	11.501	0.091	103.07	0.09	.155	1	16
	B	-	-							-	-	-				
TDS3679	A	06 15 50.932	-01 45 18.45	0.14	0.16	1.851	0.213	142.586	6.553	10.885	0.110	106.60	0.11	.160	1	17
	B	06 15 51.007	-01 45 19.92							11.233	0.111	101.91				
TDS3684	A	06 16 04.636	09 35 09.14	0.14	0.16	2.675	0.213	158.593	4.545	11.004	0.071	101.50	0.07	.160	1	18
	B	06 16 04.702	09 35 06.65							11.289	0.071	87.43				

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### Table 2 Notes

1. iT27 1x3s. No resolution, not even hint of an elongation. Check 2MASS J-band image not conclusive, primary might be too bright for any hint of the faint companion. But measured magnitude no good match with calculated combined magnitude. McPhee: appears to be a single star (289x). Bogus assumed.
2. iT27 1x3s. Star disk slightly deformed but no serious hint for a double, primary might be too bright for resolution with iT27. Measured magnitude no good match with calculated combined magnitude. 2MASS J-band image also negative. McPhee: no elongation detected at any magnification (173x, 231x, 266x). Bogus assumed.
3. iT27 1x3s. Star disk slightly deformed but no serious hint for a double, primary might be too bright for resolution with iT27. Measured magnitude would be rather good match with calculated combined magnitude. Check 2MASS J-band image negative. McPhee: no elongation detected at any magnification (173x, 231x, 266x). Inconclusive result.
4. iT27 1x3s. Star disk with no distinctive elongation. Measured combined magnitude would be rather good match with calculated combined magnitude. Check 2MASS J-band image negative. McPhee: a single star at 173x, but appears extended or pointy at 231x. Stars appear to be closer than 1.5" or the magnitude of secondary is fainter than 11.6 despite WDS listing data being similar to TDS 3550. Overall result is inconclusive.
5. iT27 1x3s. Overlapping star disks, distinctive elongation/rod - but measurements due to overlap probably somewhat imprecise. Check 2MASS J-band image positive. McPhee: resolved at 173x with magnitudes and position angle matching WDS data; second, separate observation confirms resolution at 289x. Confirmed.
6. iT27 1x3s. Star disk slightly deformed but no serious hint for a double, primary might be too bright for resolution with iT27. Measured magnitude would be rather good match with calculated combined magnitude. Check 2MASS J-band image negative. McPhee: appears to be a single star (289x). Inconclusive result.
7. iT27 1x3s. No resolution, not even hint of an elongation. Check 2MASS J-band image negative. McPhee: no elongation detected at any magnification (173x, 231x, 266x). Bogus.
8. iT27 1x3s. Distinctive rod. Sep bit smaller as WDS catalog listed, else data rather confirmed. Listed in WDS catalog with confirmation. Check 2MASS J-band image positive. McPhee: resolved at 173x to two evenly matched stars with correct pa. Image confirms duplicity. Confirmed.
9. iT27 1x3s. Star disk slightly deformed but no serious hint for a double. Measured magnitude would be rather good match with calculated combined magnitude but check 2MASS J-band image also negative. McPhee: no elongation detected at any magnification (173x, 231x, 266x). Bogus assumed.
10. iT27 1x3s. Star disk slightly elongated, but not distinctive - rather tracking problem. Calculated combined magnitude no good match with measured magnitude. Countercheck 2MASS J-band image: Obviously single star. McPhee: possibly rod shaped (extended) at 173x and 289x; seems to be too close to be 2.2". Image does not show any elongation. Bogus assumed.
11. iT27 1x3s. Star disk slightly elongated, but not distinctive - rather tracking problem. Calculated combined magnitude not good match with measured magnitude. Countercheck 2MASS J-band image: Obviously single star. McPhee: conflicting data at 173x (possibly resolved) and 289x (single star) during separate observing sessions. Image does not show any elongation. Bogus assumed.
12. iT18 1x3s. Star disk slightly elongated, but not distinctive - rather tracking problem. Calculated combined magnitude no good match with measured magnitude. Countercheck 2MASS J-band image: Obviously single star. McPhee: doubtful duplicity at 173x; possible hints of elongation in correct p at 231x; suspected elongation at 289x. Image does not show any elongation. Bogus assumed.
13. iT27 1x3s. Star disk slightly deformed but no serious hint for a double. Measured magnitude would be rather good match with calculated combined magnitude but check 2MASS J-band image distinctive negative. McPhee: no elongation at 173x; possibly extended (pointy) at 231x; possibly elongated at 266x. Bogus assumed.
14. iT27 1x3s. Clear elongation. Check 2MASS J-band image positive. McPhee: suspected elongation at 173x, but magnitude seems a bit low at 11.5 and separation is too tight for 2.1"; elongation suspected at 266x with averted vision and confirmed at 289x. Image confirms duplicity. Confirmed.
15. iT27 1x3s. No resolution, not even hint of an elongation. Check 2MASS J-band image negative. McPhee: single star at 173x and magnitude seems too faint for a pair of magnitude 11.7, 12 stars; appears to be a single star at 289x, but hard to tell because the system is very faint. Overall result not fully conclusive, but rather bogus assumed.
16. iT27 1x3s. Hint of elongation obviously tracking error. Check 2MASS J-band image also negative. McPhee: possible elongation at 173x; potential rod shape at 171x; most likely extended at 289x as seen with averted vision. Bogus assumed.
17. iT27 1x3s. Clear elongation/rod. Check 2MASS J-band image also positive. McPhee: just resolved at 173x; definitely elongated in correct pa at 289x. Confirmed.
18. iT27 1x3s. Clear elongation/rod. Check 2MASS J-band image also positive. McPhee: easily split at 289x with stars displaying correct pa. Image confirms duplicity. Confirmed.

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