In Search of DAL 45: Observing on the Edge with a 4 Inch Refractor

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Abstract: We discuss our effort to observe and measure DAL 45, a faint component of the Delta Cephei system first measured in 2008 by James Daley.

Over the course of the last year and a half my interest (S. Smith) in double stars has been the recording of photographic images of these captivating systems. As a member of the Double Star Imaging Group on Yahoo (http://groups.yahoo.com/neo/groups/double_star_imaging) I have met and collaborated with others interested in creating a visual record of double star systems through photography and sketching.

This particular adventure began in November 2013 when I began to photograph the well known and colorful double star Delta Cephei (STFA 58) first catalogued in 1800 by Giuseppe Piazzi. It easily lived up to its billing as a premier visual double and I was able to record the blue and gold A-C pair which shares the field of view with the triple system H IV 31 located just 6 arcminutes to the west. It wasn't until I began processing the image and checking the WDS data on the system that I became aware that Delta Cephei has 4 additional & very faint companions ranging between 13 to 14 magnitude. The information on this multiple system (from the Stelle Doppie website) is reproduced in Figure 1.

I wasn't too surprised that in my initial exposures, with the exception of F, several of the fainter companions (B D & E) weren't captured as my ISO settings and exposure times weren't set with 14 magnitude stars in mind. In the case of a multiple system with a great variation in separations and magnitudes, as is the case of Delta Cephei, some trial and error is usually involved to find the right combination of exposure & ISO to capture all of the components in a single exposure.

My typical imaging train consists of an Olympus E-PL1 micro four-thirds format camera shooting through a Sky-Watcher 100mm f9 ED refractor, all mounted on a Celestron AVX GoTo Mount. The camera has a 17.3 x 13mm Live MOS sensor (4032 x 3024 pixels - 12 MP) which equates to a 4.3 um square pixel size. The camera wasn't chosen as being particularly suitable for astro-imaging but was simply what I had on hand and has served me well, producing some very nice images.

In theory my 4" refractor has a resolution of 1.2 arc-sec (the Rayleigh Limit) and a limiting visual magnitude of approximately 12. From past experience I knew that at prime focus with photographic exposures

NAME	CST	SAO	COORD 2000	DISCOV#	COMP	FIRST	LAST	OBS	PA	SEP	MAG1	MAG2	D MAG
Del Cep	Cep	34508	22292+5825	BU 702	AB	1878	2012	10	282	21.80	4.21	13.00	8.79
del Cep	Cep	34508	22292+5825	STFA 58	AC	1800	2012	87	191	40.60	4.21	6.11	1.90
	Cep		22292+5825	DAL 45	AD	1999	2008	3	38	108.50	4.20	13.90	9.70
	Cep		22292+5825	FOX9037	AF	1921	2012	4	49	37.40	4.21	13.50	9.29
	Cep		22292+5825	DAL 45	DE	2008	2008	1	23	1.40	13.90	14.00	0.10

Figure 1: WDS Data on Delta Cephei as presented in Stelle Doppie

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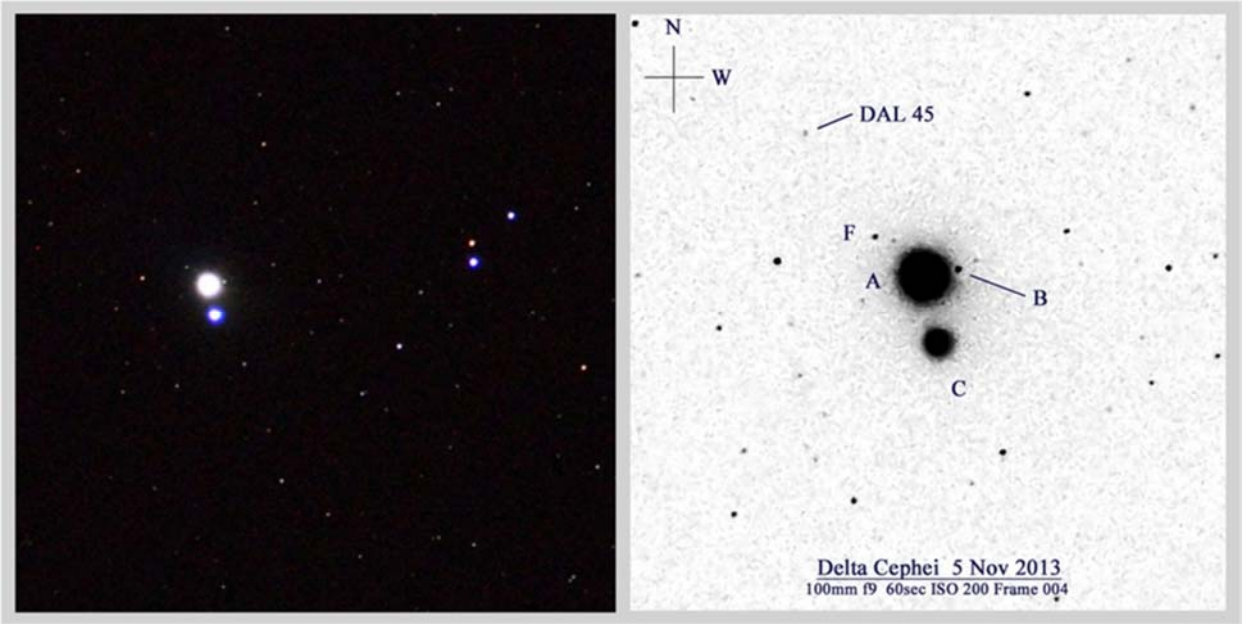

Figure 2: (Left) Delta Cephei and nearby triple H IV 31 - (Right) Components of Delta Cephei

up to one minute my setup was capable of capturing stars down to about the 14th magnitude. At prime focus the system gives very good resolution, on the order of 1.0 arc-sec per pixel based on star-drift timing across the field of view but resolving separations below 4 arc-sec are problematic depending greatly on the relative brightness of the components. I knew that the search for the faint components, particularly DAL 45, would be pushing the capabilities of my scope & camera to their limits.

I resolved to re-visit Delta-Cephei at the first opportunity and this came several nights later. I took several 60 sec exposures at various ISO settings and a cursory review though the viewfinder of the camera showed that several of the faint components were showing up. When processing, everything looked promising – the 13th magnitude B component was peeking through the glare of the 4th magnitude primary just 22" away, and 13.5 magnitude F at twice that distance was plainly visible, confirming that the limiting magnitude of my system was above the tabulated values of the stars I was looking for. But components D & E, the stars that make up the 13.9 magnitude subsystem of DAL 45, were buried in the noise. It appeared faintly on only one of the five frames (see Figure 2) and much fainter than expected especially when compared to F, supposedly only 0.4 magnitude brighter.

I sent the photo off to John Nanson, author of the Star-Splitters Double-Star Blog, who is also a contributor to the Imaging Group, for his opinion and between the two of us we began to run down the particulars of DAL 45.

As can be surmised from its name DAL 45 was the 45th double star discovery of James Daley, a prolific observer and measurer of double stars with 51 double star discoveries currently to his name. Daley is also accomplished in astronomical photometry and provided magnitude measurements for both A-D & D-E which along with his astrometric measures were published in the July 2009 issue of the Journal of Double Star Observations (JDSO). Daley used a 8" medial (folded) refractor to make his measurements and noted that D was a "new component" and DE is a "neat close pair for a CCD".

The WDS database actually contains two entries for AD that predate Daley**'s** 2008 measures. The first was in 1999, the result of the 2 Micron All-Sky Survey (2Mass) which mapped and measured stellar and extended objects at near-infrared wavelengths. The second referenced measurement of AD was in 2003 and again appears to have been the result of another Sky Survey, this time taking the UCAC4 catalog and matching with it all the double stars in the Washington Double Star Catalog to obtain astrometry and photometry measurements. The results were published in the "Double Stars in the USNO CCD Astrographic Catalog" by Hartkopf., Mason, et al.

Since both AD and the DE pair were given the DAL 45 designation along with the fact that Daley noted that "D is a new component" it can be inferred

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that the previous two measures were added to the database subsequent to Daley's measures and what appeared to be a single star (D) was not associated with Delta Cephei prior to 2008.

Searches of the SIMBAD & ALADIN databases produced sky survey photos, one of which is reproduced below in Figure 3, which show DAL 45 shining rather prominently in a field of stars reaching down past magnitude 18 and seemed to belie the difficulty I was having trying to capture it in my photos - it appears noticeably brighter and nearly equal in magnitude to F in comparison to its much dimmer appearance in my photo (Figure 2).

During 8 separate observing sessions spread over two months, 43 photos were taken of the Delta Cephei system. An object appearing to be in the correct location to be DAL 45 appeared in only 8 of them, but it was enough to remove all doubt that the object in the image was real and not sensor noise or some photographic artifact.

Because of the unexpected faintness, John and I measured the A-D distance and PA for the object. John used the measuring tools available on the ALADIN Sky Atlas website to measure the Sky Survey photo, which produced a position angle of 40.9 degrees and a separation of 110". I used AutoCAD on the photo in Figure 2, which resulted in a position angle of 37.8 degrees and a separation of 108.5" (see Figure 4), which were in good agreement with the WDS values and convinced us that the object in my photos was in fact DAL 45.

Two of my photos were sharp enough to show some hint of elongation rather than just a single faint star and were subjected to further processing. At prime focus the image of DE occupied an area of only about 4 x 6 pixels. In an effort to enhance the images which have a native image density of 314 pixels per inch, they were re-sampled in Adobe Photoshop using the Bicubic function up to 2512 pixels/inch; an 8 fold increase, resulting in an image scale of about 0.13 arc-sec/pixel.

One image stood out in that after the processing the object resembled a pair of stars in a figure-8 or "Kissing" orientation at what appeared to be near the tabulated PA and separation values. I am sure the faint and nearly equal magnitudes of the two stars along with good seeing were working in my favor to get this

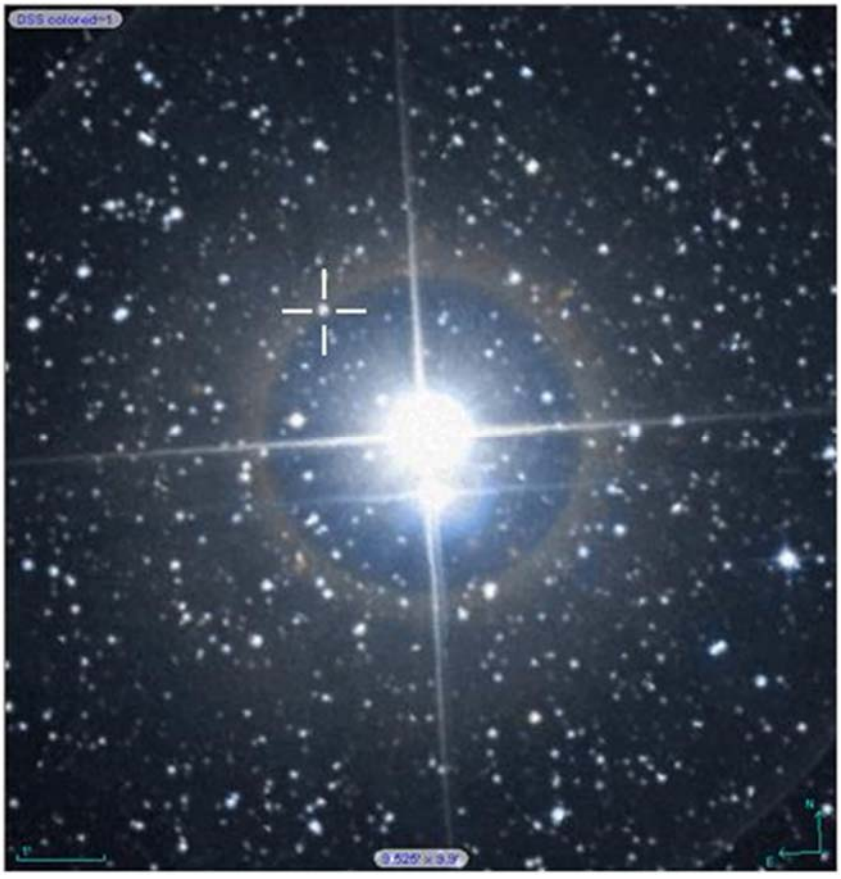

Figure 3: DSS Survey Photo of Deta Cephei - DAL 45 centered in crosshairs

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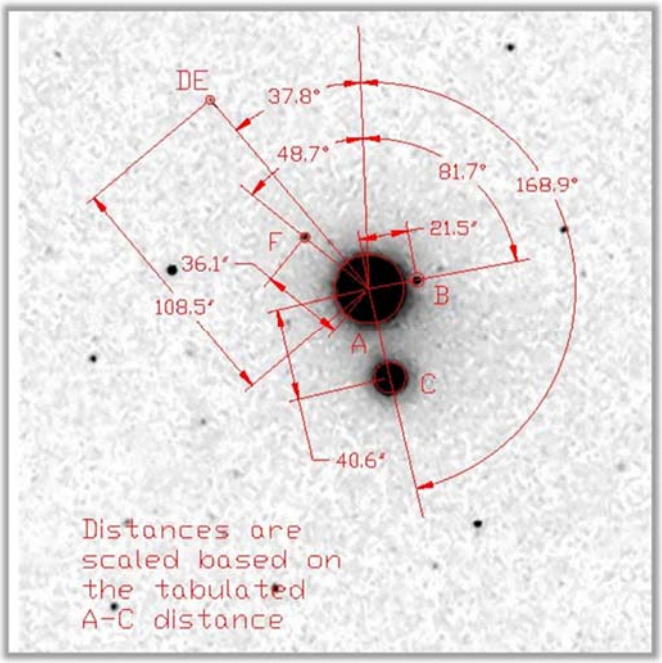

Figure 4: AutoCAD measures of Delta Cephei components, including DAL 45 (DE)

"Lucky Day" image of the pair.

One aspect of the enlarged photo that struck us immediately was the apparent unequal brightness of the pair. According to Daley's measurements the components were nearly a matched set (magnitudes 13.9 & 14.0) with the southernmost (D) being the brighter of the two. It is tempting to speculate that perhaps the difficulty I had in capturing the pair was in part due to a dimming of one of the components, but it also could be simply a byproduct of the extreme processing used on the tiny image. In any event I was not able to capture enough images with sufficient clarity to confirm or refute Daley's measurements, but this could be an interesting project for someone with an imaging system with better resolution to check out.

This enhanced image was imported into AUTOCAD and measured (results shown in Figure 5), which was further assurance that this was indeed DAL 45. Due to the significant under-sampling of the image (a deviation of even a fraction of a pixel in the resampling process or setting the origin of the measurement points could significantly change the results) the Position Angle and Separation measures cannot be considered as definitive but do show what detail can be teased out of digital images using relatively simple imaging devices and software.

As final confirmation I wanted to measure the combined magnitude of the DE pair since it was the fainter-than-expected image that prompted all of my previous efforts. For this I turned to the software package, IRIS, a freeware astro-imaging software package developed by Christian Buil that provides functions for astronomical image manipulations and photometric measurements.

The measuring process involved choosing several reference stars from the selected frame and taking photometric brightness (or intensity) readings for each. The relative intensity values along with the known magnitudes of the reference stars can then be used to calculate the magnitude of an unknown star using the relationship:

$$M_2 = M_1 + 2.5 \log_{10}(I_1 / I_2)$$

Where M_1 = known magnitude of reference star 1, M_2 = unknown magnitude of Star 2, and I_1 / I_2 = measured photometric intensities of stars 1 and 2.

Six reference stars in close proximity to DAL 45

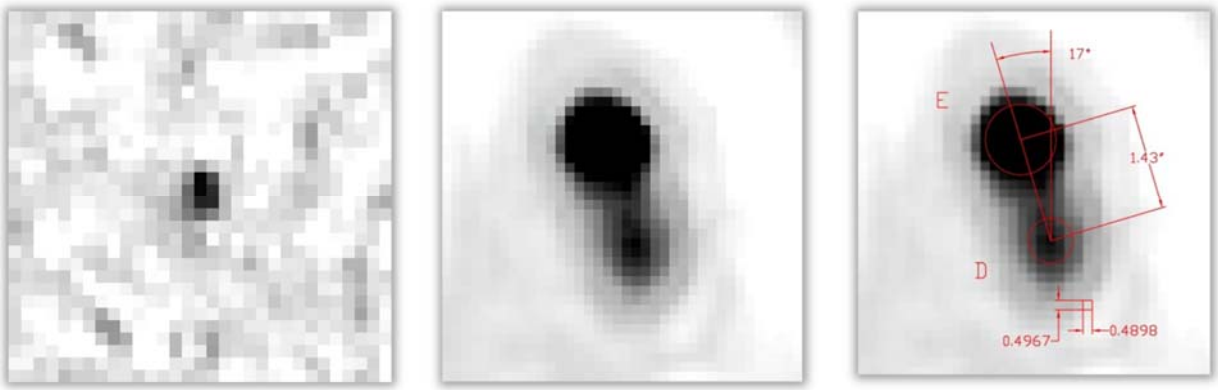

Figure 5. DAL 45 at original resolution of 1.0 arc-sec/pixel (left) and the same image (middle & right) resampled (8x) and processed to enhance the image (~0.13 arc-sec per pixel)

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were located on the photographic frame using the ALADIN Sky Atlas program and the UCAC4 Star Catalog. The selected reference stars (shown in Figures 6 and 7) have visual magnitudes close to the tabulated values of DAL 45 in order to reduce any possible effects of non-linearity of the camera sensor when recording such faint objects.

The measured photometric intensity for the combined image of Dal 45 (D + E) was 978. The measured photometric intensities of the reference stars and the resulting calculated magnitudes for DAL 45 are shown in Table 1.

Not surprisingly, and confirming the visual impression from the photographs, the calculated 14.4 magnitude is a half magnitude fainter than Daley's 13.9 magnitude value and nearly a full magnitude fainter than F and explains the difficulty I was having in photographing this system. As a further check on the accuracy of these measurements, the magnitude of each of the reference stars was checked against the other 5 reference stars using the same methodology with the results shown in Table 2.

The standard deviation of the tabulated magnitudes versus the calculated magnitudes was only 0.21, which lends confidence to the reference magnitudes and the intensity measures used in the comparison. So the lower magnitude estimate from my measurements for DAL 45 seems to be both real and significant. Table 3 is a summary of the various magnitude measurements of DAL 45 and show the variation in the measured magnitudes which are in part, no doubt, due to the differences in the photometric bandpass filters used in the measurements. Not surprisingly my measure seems to align best with the UCAC4 measure since my unfiltered exposures can be assumed to be most sensitive to the V band and that I used the UCAC4 catalog values as the source for my standard reference magnitudes.

So in the end DAL 45 ended up being much more challenging than expected – according to my measurements with a combined magnitude of 14.4 and a separation of 1.43 arc-sec it will present a challenge to just about any amateur telescope no matter the aperture. James Daley used an 8 inch refractor with 4 times the light gathering power of my 4 inch scope to make his original measurements and I am surprised at the detail I was able to collect using my modest 4 inch refractor and some amazing software, but for now will leave it to more capable instruments to further observe and measure this system.

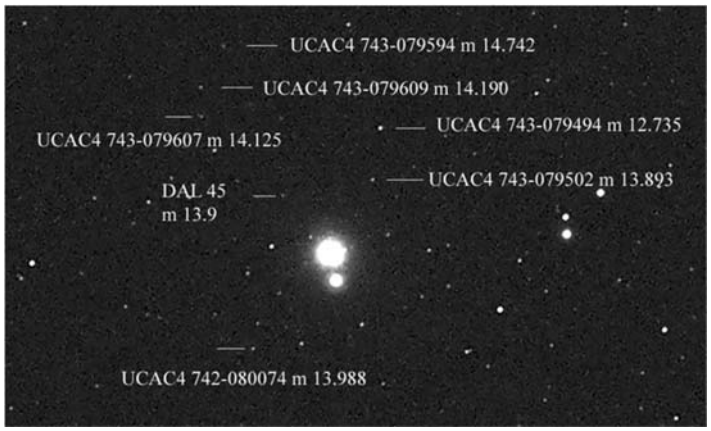

Figure 6. Photometric Comparison Stars

Table 1. Photometric Data Used For Calculating the Magnitude of DAL 45

Comparison Stars (UCAC4)	UCAC4 V Mag	Photometric Intensity	Calculated DAL 45 Mag
742-080074	13.998	1630	14.393
743-079494	12.740	4517	14.242
743-079502	13.900	1987	15.510
743-079594	14.742	1149	14.140
743-079607	14.125	1401	14.421
743-079609	14.190	1073	14.683
		Average =	14.398
		Std Dev =	0.176
		Std Mean Err =	0.072

Table 2. Photometric Data for Checking the Magnitude of the Calibration Stars

Comparison Stars (UCAC4)	UCAC4 V Mag	Avg Calculated Magnitude	Magnitude Difference
742-080074	13.998	14.004	0.006
743-079494	12.740	12.928	0.188
743-079502	13.900	13.766	-0.134
743-079594	14.742	14.400	-0.342
743-079607	14.125	14.434	0.309
743-079609	14.190	14.163	-0.027
		Avg Difference =	0.000
		Std Dev =	0.211
		Std Mean Err =	0.094

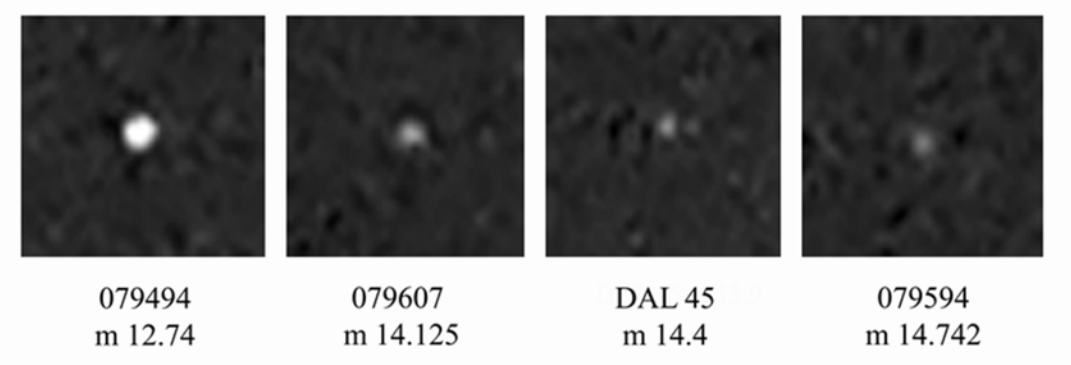

Figure 7. Closeup - DAL 45 & Comparison Stars

Table 3. *DAL 45 – Historical Magnitudes*

Source	Date	DE Magnitude	Comments
2MASS	1999	11.94	F mag - Avg of 3 frames
UCAC4	2003	14.44	V-R mag
J. Daley	2008	13.90	B-V mag
S. Smith	2013	14.40	V (Unfiltered)

Postscript 1-31-14

Just prior to submitting this article I discovered that an additional 4 components were added to the listing for Delta Cephei (FYM 115 G thru J) ranging in magnitude from 12 to 13.5. For now DAL 45 still remains the most elusive member of the Delta Cephei family.

References

"*Ludwig Schupmann Observatory Measures of Large Δ m Pairs*", Daley, J., 2009, JDSO, 3, 149-154.

"*Double Stars in the USNO CCD Astrographic Catalog" (UC_2013b),* Hartkopf, W.I., Mason, B.D., et. al., Astronomical Journal 146, 76, 2013.

"*Washington Double Star Catalog",* Mason, Brian., 2013, http://ad.usno.navy.mil/wds/

Web Sites

2MASS Point Source Catalog. 2003 all-sky release (TMA2003) http://www.ipac.caltech.edu/ 2mass/ releases/allsky/

ALADIN Sky Atlas: http://aladin.u-strasbg.fr/ aladin.gml

Double Star Imaging Group: http://groups.yahoo.com/ neo/groups/double_star_imaging

IRIS - Astronomical Images Processing Software, Version 5.59. www.astrosurf.com

SIMBAD Astronomical Database: http://simbad.u-strasbg.fr/simbad/

Stelladoppie WDS Interface: http:// stelledoppie.goaction.it/index2.php?section=1