Bachelor Thesis

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Stellar activity in the open cluster Messier 39

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1.Abstract

An image series taken at the Observatory 'Lustbühel' in Graz of the open cluster Messier 39 was analysed, searching for flare events. During a period of 3,75 hours 120 images have been taken (in the year 2012). M39 is a relatively young cluster with its member stars all being around the same age and spectral types of B and later. 54 stars of membership probability over 66% were characterised, and the images were analysed, searching for indications of stellar flares. Due to several reasons no flares could be found.

2.Introduction

This thesis describes the process of analysing a series of images (taken at the "Observatorium Graz Lustbühel") of the open star cluster "Messier 39" (M39) and searching the data for stellar flares. The theoretical basis, a brief explanation of a flare, how it can be detected and how the refinement of the images work, is then explained. Following that, the whole procedure of reducing, preparing and analysing the data is described, while also explaining the purpose and the tools that are being used for each step. Finally, the results are presented and then discussed.

3.Theoretical Basis

3.1. (Solar) Flares and flare detection

Solar flares are eruptions of radiation, resulting from realignments of magnetic arcs on the surface of the sun. Upon a realignment of said magnetic arcs, energy is being released (Hanslmeier, 2015) amongst others in the form of electromagnetic radiation (Haisch, 1991). Flares can last from about 10 to 90 minutes (Hanslmeier, 2015). It is not directly evident that stellar flares are triggered by the same effect as flares on the sun, but the resulting light curves are similar (Pettersen, 1989). Because a flare is characterised by a sudden release of radiation, it is identifiable by observing its light curve, which is the variation brightness over an extended period of time. A sudden increase in a star's brightness could therefore be an indication for a flare. This can be recognized by a peak in a time-brightness diagram (as shown in the figure below). In this particular case the brightness value of each star can be extracted from the time series taken by the telescope over the course of multiple hours. A graph can now be created similar to the one below. To examine the data, the graphs for every star are created and then manually searched for flares.

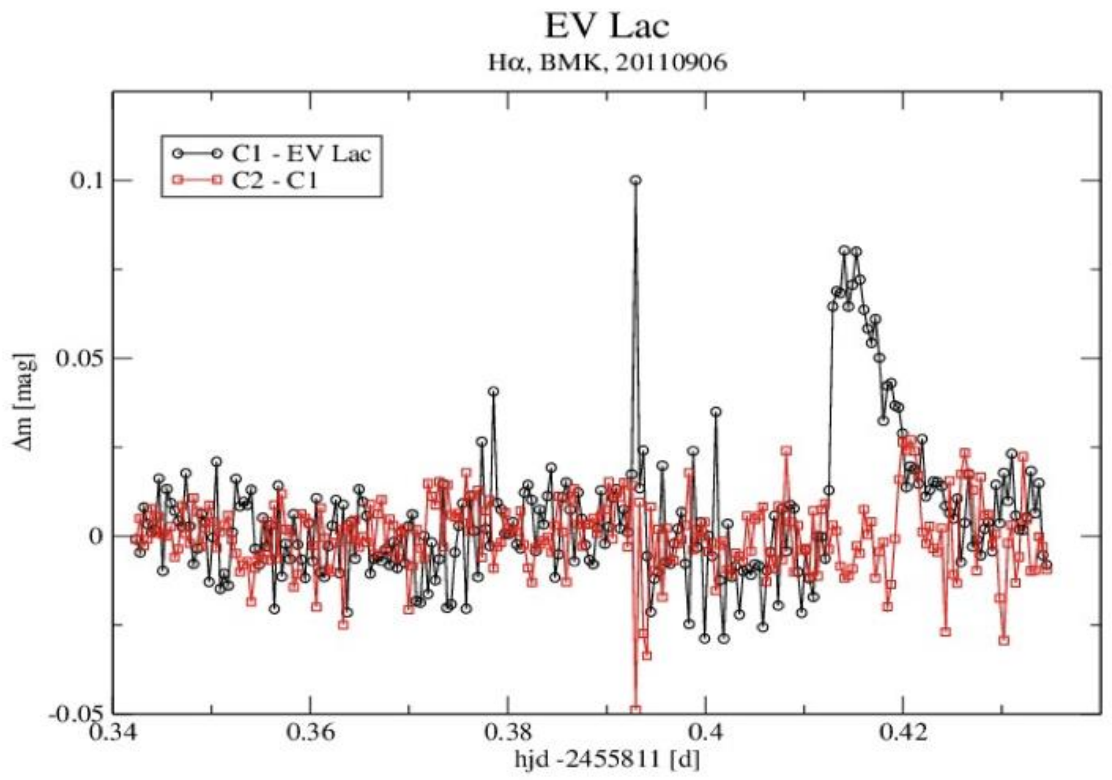

Figure 1: Stellar flare detected by the BMK (Greimel) on the star "EV Lacertae", spectral type M4[1]. The black line shows the delta-mag of the target star with a comparison star, whereas the red line shows the delta-mag of two comparison stars.

The flare in the figure above the flare is identifiable by the rapid increase of the black line and longer decay time of the difference in magnitude (=Δm).

3.2. Telescope

Following is a detailed description of the telescope and the filter that was used.

[1] http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=EV+Lac

The telescope that was used is the so called “Ballistische Messkammer” (BMK) by Zeiss. It is a refractor and features a diameter of 30cm, a focal length of 75cm resulting in an f-ratio of f/2.5. The field of view of the telescope with the mounted CCD camera is 2.75°x1.83°. The CCD camera is a Santa Barbara Instrument Group (SBIG) STL_11000M, featuring a Kodak KAI-11000M chip with 4008 x 2672 pixels.

Multiple filters can be applied to the telescope to block out certain wavelengths. In this case a V-band filter is used. Its maximum transparency lies at around 540nm (Hanslmeier, 2015).

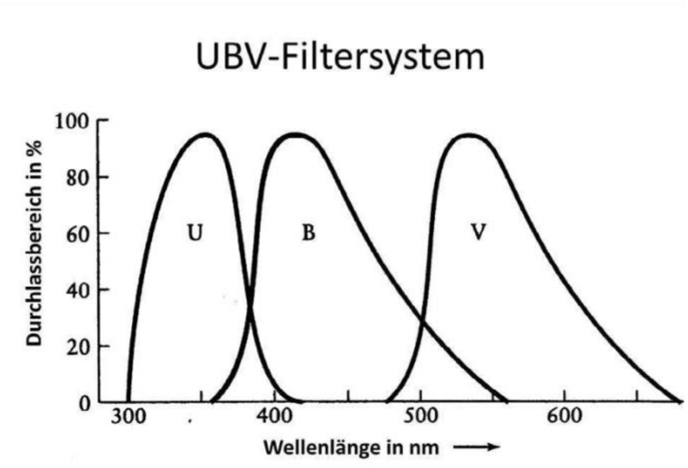

Figure 2: UBV-Filtersystem (Hanslmeier, 2015)

In the optical regime U, B or V filters should be used for flare detection since flare amplitudes are prominent at these wavelengths (AAVSO, 2010). However, U and B filters do not work with the BMK and therefore a V-filter was being used.

3.3. Messier 39

The star cluster Messier 39 was chosen as the object of interest by the observatory because of the following factors. One being the age of the open cluster which is estimated around 360 ± 120 million years (M. Manteiga, 1991), as for younger member-stars flare detection is more probable. Another one being the spectral type of the stars, of which there are no types earlier than B9 (Johnson, 1953). In general flaring has been reported from B stars to K and M stars (small dwarf stars) (Pettersen, 1989). Especially the latter are in an earlier stage of evolution and as mentioned above show increased flare activity (Mirzoian, 1990), hence being generally suitable for flare research. The distance of M39 is approximately 275 $\pm$ 30 parsecs, which equals 897 lightyears (Johnson, 1953).

The figure below shows the colour-magnitude-diagram of all stars in the field of M39 (Platais, 1994) in white and those with a membership probability above 66% in red.

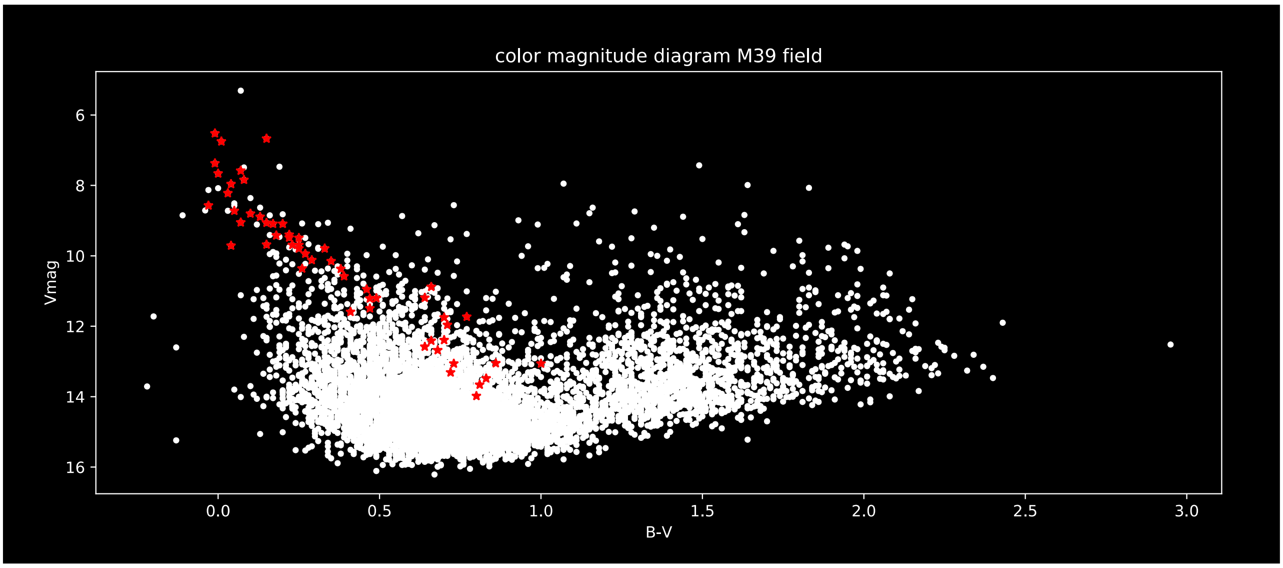

Figure 3: Colour magnitude diagram of M39 with data from Platais (Platais, 1994)

As one can see the member stars form a main-sequence. The spectral range of the member stars goes from early A- to early K-stars.

4. Process

4.1. Raw Data

In a timeframe of 3,75 hours from 22:22:00.205 until 02:07:27.602 o'clock, 120 images had been taken at the observatory on 24th may of 2012. Object of interest was the open cluster M39 or "NGC 7092". The exposure time was 80 seconds. All 120 frames were saved as .FIT files (Flexible Image Transport System, a file type commonly used for images in astronomy, formatting images in arrays, which simplifies further steps). The following image shows the field of view of the BMK.

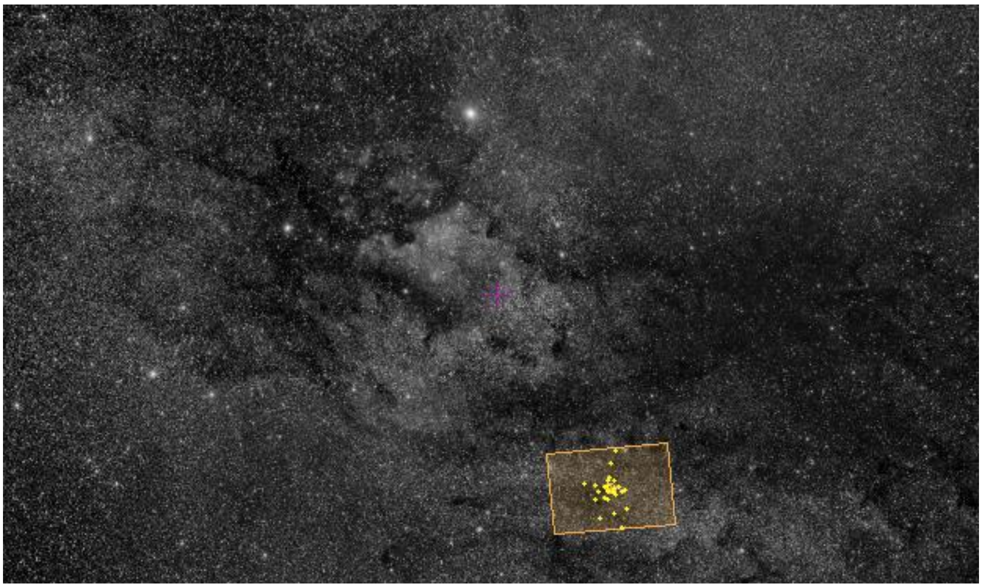

Figure 4: Field of view of the BMK (yellow rectangle), member stars highlighted in yellow, original image from astrometry.net[2], showing the night sky close to the Cygnus constellation, center at RA:316.369° DEC: 45.814°

4.2. Data reduction

The data (i.e. the raw images) are untreated and contain noise (i.e. unwanted and interfering signal), created by the electronics of the sensor, as well as impurities in the field of view of the telescope (e.g. dust particles). To remove distortions in the optical path and to remove artefacts from pixel-to-pixel variations, a bias subtraction and a flatfield correction are applied.

For the bias subtraction a so-called bias frame is needed. This is an unexposed picture, which means that no light from the outside is captured. A constant voltage is applied to every pixel. In theory the bias frame should be uniform. In practise the brightness of each pixel varies slightly because of the imperfections of the electronics. Every individual brightness value of the bias frame is now being subtracted from every corresponding value of the raw image. In the following figure the imperfections are clearly visible.

[2] http://nova.astrometry.net/user_images/2336498#annotated

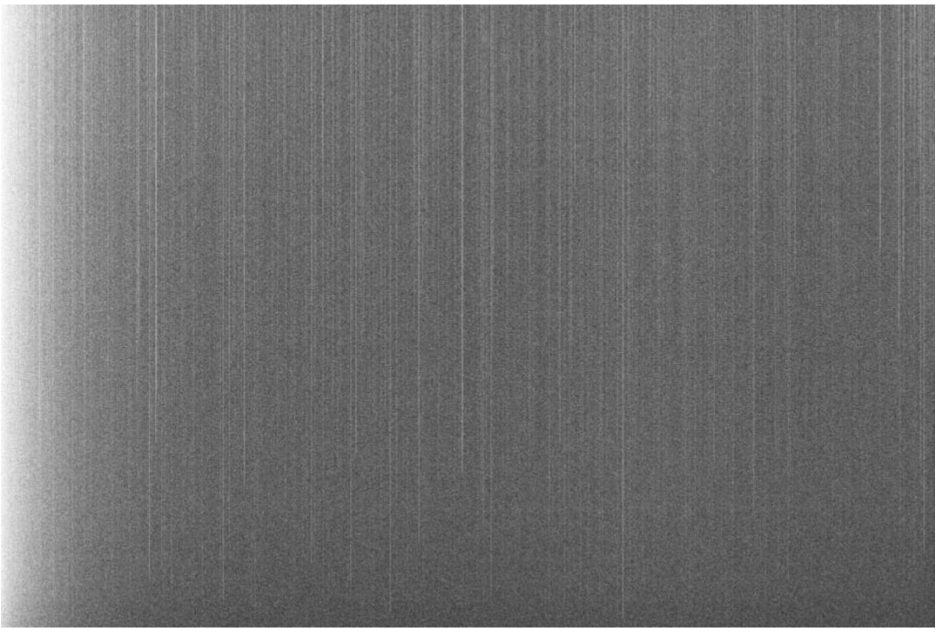

Figure 5: Bias frame (BMK)

Following that the flatfield correction is applied. The flatfield picture is a picture taken during daytime of the blue sky or during sunset and should therefore have constant brightness values. But the sensitivity of each pixel varies slightly, creating the distinctive flatfield. After subtracting the bias frame from the raw image, the result is divided by the flatfield frame (Hainaut, 1996). This ultimately is applied to all 120 frames that now can be further analysed.

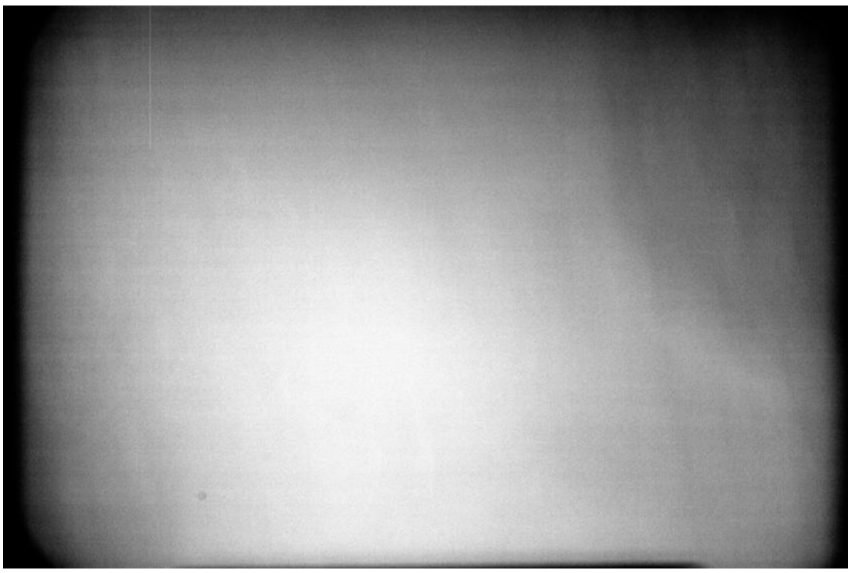

Figure 6: Flat field (BMK)

4.3. Locating the data

Although the location of the observed object is known, the individual frames have not yet been assigned their respective coordinates. For further analysis it is necessary to know the exact coordinates of each star. This is important, in order to make it possible to identify all the stars that correspond to the cluster, and to take the same star in each of the 120 frames and examine it in detail.

To append every picture with its coordinates the service "astrometry"[3] was used. The service is able to analyse any picture of the night sky that is uploaded and cross-references it with a data base to locate the input data. After uploading the first image (.FIT file), it is scanned and identified by the software. When the process is finished a new image (.FIT file) - now calibrated with the coordinates - can be downloaded. At first, only the first picture of the series was calibrated. After analysing the first frame and identifying the M39 member stars all consecutive frames have been analysed using a script.

4.4. Identifying member stars

To identify the M39 member stars in the picture series, the service "VizieR"[4] was used, which provides easy access to a huge number of astronomical catalogues. With VizieR the catalogue "Proper Motions, UBV-Phot. & Spectral Class Region 7092" (Platais, 1994) was selected. Applying the membership probability of >= 66%, 54 probable member-stars of M39 were found using the catalogue. That means those 54 stars have a probability of at least 66% to belong to the cluster according to the research done by Platais. A table containing the 54 coordinates as well as V- and B-band magnitude was generated. The table can be found in the appendix.

[3] http://nova.astrometry.net/
[4] http://vizier.u-strasbg.fr

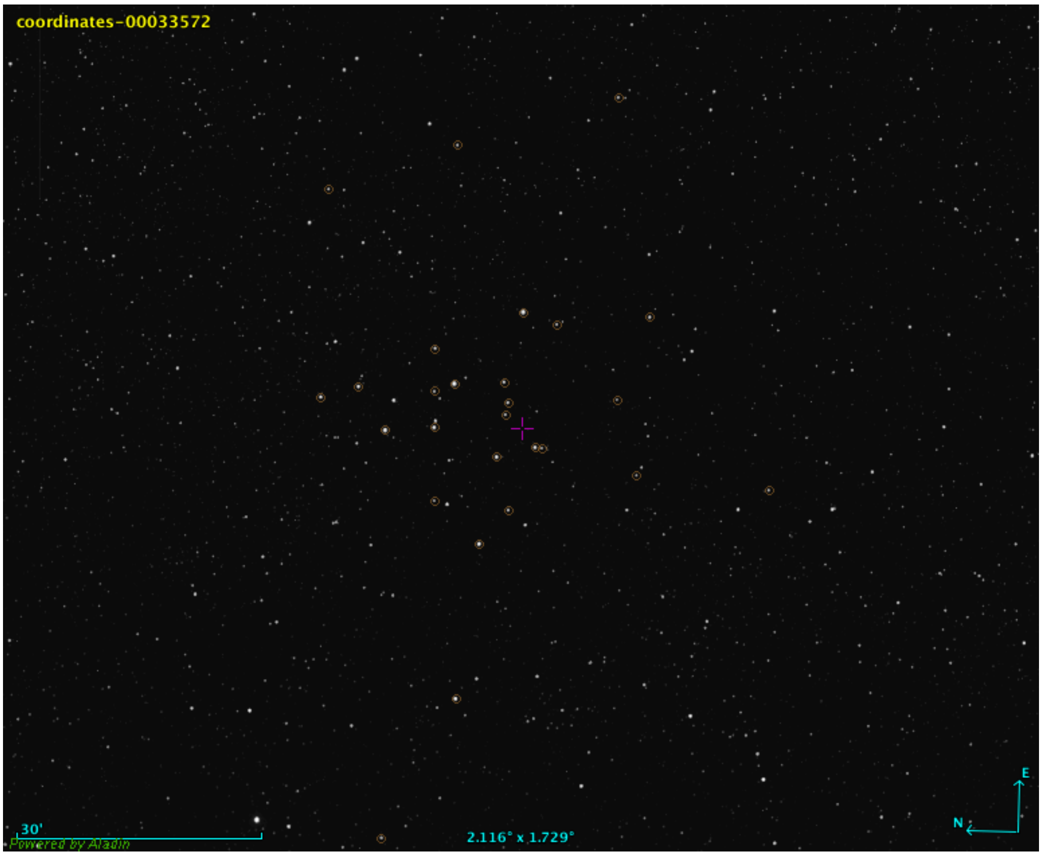

Figure 7: Member stars encircled (BMK), (generated with aladin)

4.5. Generating light curves

The last step is to generate a light curve for every star. As previously mentioned, all 120 frames were given their respective coordinates. To extract the target fluxes the software "Sextractor"[5] (short for source extractor) was used, which is able to identify a set of pixels as an object (e.g. a star) and also assign it its coordinates. It then prepares a vector that contains flux and magnitude values, and at the end the coordinates of every object it identified. This is done for every image.

Sextractor identifies every object in the image which results in a high number of detected sources. Every output file hence has to be scanned for the 54 member-stars. For a fixed star, coordinates do not stay exactly the same in those tables generated by the software, making it a little more complicated to scan the vectors for the member-stars. Very small changes in

[5] https://www.astromatic.net/software/sextractor

coordinates of the extracted target stars occur from frame to frame, as the observation conditions change from frame to frame. Therefore, the central coordinates of the extracted sources show small variations in right ascension and declination. Due to not being able to simply search through the vector for the exact coordinates of the 54 member-stars (because the coordinates are varying slightly from frame to frame), a python script was written which takes the coordinates of a member star and calculates the distance to the coordinates of each of the 15000 objects in a frame. The object with the smallest distance to the member star is identified as the member star itself. Its flux/magnitude values were appended to a new list. Repeating this process for every member-star and every frame creates 120 lists that contain the brightness values for every member-star in the time frame of 120 images or 3,75 hours. With these lists it is now simple to create a diagram that displays the time (120 steps) on the x-axis and the magnitude (brightness) on the y-axis.

To correct for fluctuations (due to e.g. earth's atmosphere or clouds) in the overall picture the magnitude of a member-star is subtracted by the magnitude of a star that does not belong to the cluster M39. These stars are referred to as "comparison stars".

5.Results

In this chapter a few of the diagrams are shown to give a brief overview of the analysed data. All light curves were created using a python script.

Three comparison stars (CS) have been selected. A collection of all graphs is presented in the appendix. The titles of the graphs show the number of the star and its coordinates as well as the number of the comparison star and its coordinates.

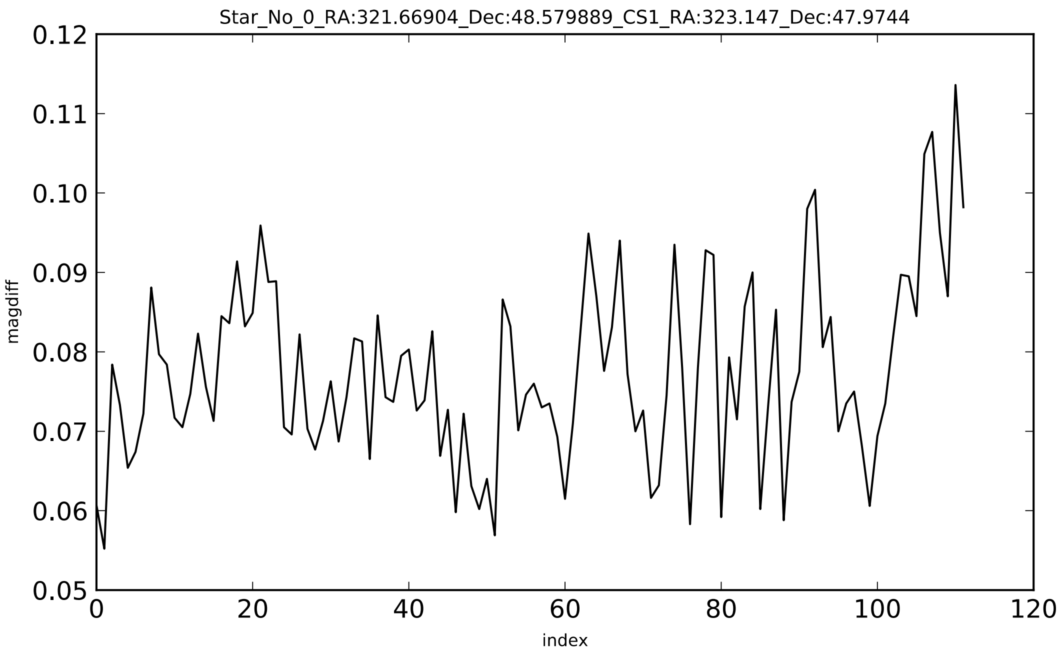

Figure 8: Light curve for star 0 with comparison star 1

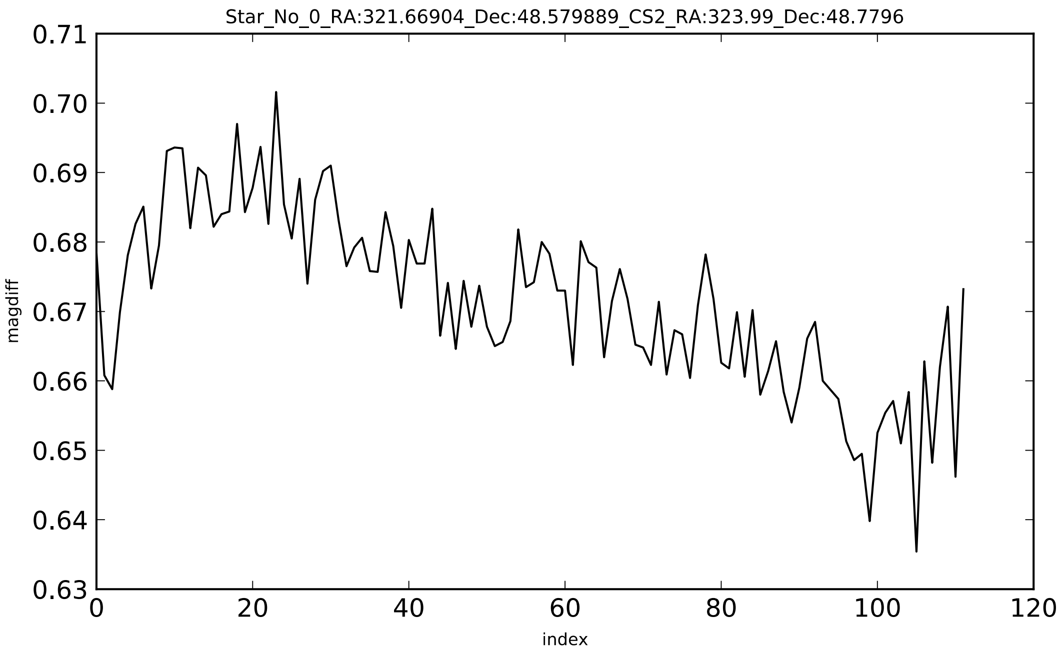

Figure 9: Light curve for star 0 without comparison star 2

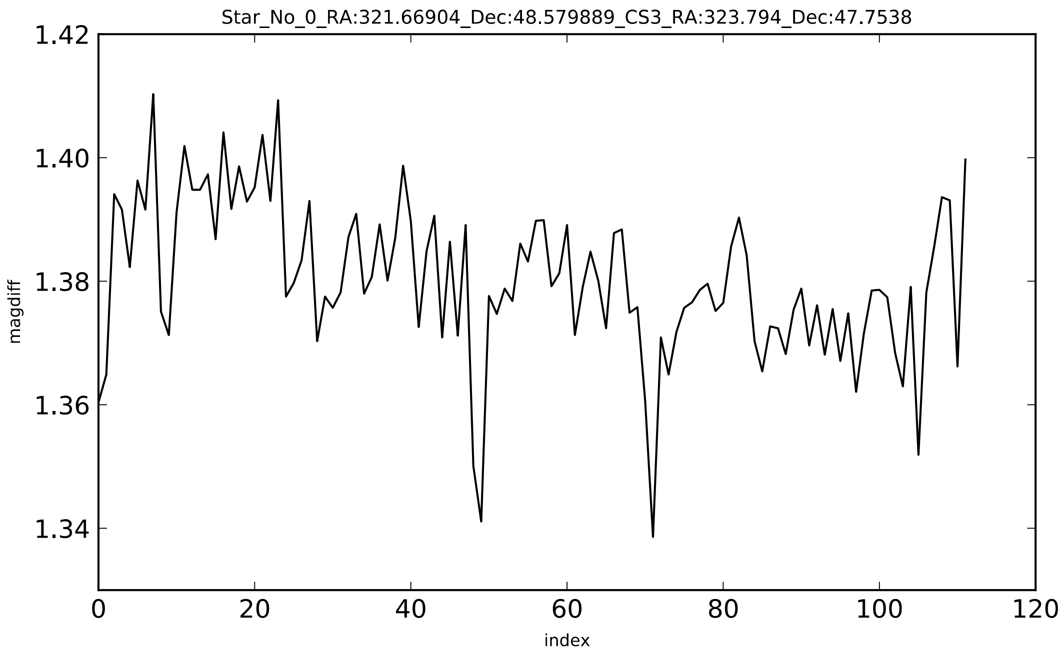

Figure 10: Light curve for star 0 with comparison star 3

Figure 8 to Figure 10 show the differences between the three comparison stars.

Besides a few slight differences, all other diagrams look similar in terms of noise and distribution of the measured values. None of the diagrams show a sign of a stellar flare. The results will be further discussed in the following chapter.

6.Discussion

As evident in the diagrams, a stellar flare, which can be seen in Figure 1, cannot be detected. Not finding any flares in the data can be due to multiple causes, which will be discussed in detail in the following chapter.

6.1. Unwanted Signal and its sources

The data is subject to a lot of noise which manifests itself in huge fluctuations of the brightness values, which would be much lower without the noise. Those fluctuations consequently make it more difficult to identify a pattern like a flare. Even though a bias subtraction and a flatfield correction have been applied, there is still noise that can't be eliminated. This is also related to the low integration time and a typically moderate seeing at the observing site of about 2 arcsecs.

While decreasing overlying unwanted signal, subtracting the comparison stars further increases certain noise-levels, because both stars have noise-levels on their own. Despite being subtracted, the corresponding noise-levels of each dataset add together.

As already mentioned the bias subtraction and flatfield correction cannot eliminate all the noise created by the electronics of the camera. Thermal radiation of the detector or small malfunctions of the amplifiers that are working while the data is read out from the sensor (Hainaut, 2005), are a few examples for noise sources originating in the electronics.

Not all the light passes all the way from the star to earths' atmosphere, the lenses and optics of the telescope, and ultimately to the sensor. This increases random noise levels, since not all the light is able to reach the sensor and is therefore not detected (Keele University Astrophysics Group). Random artefacts can also occur when certain pixels are hit by cosmic rays.

The observatory is located at the border of the city of Graz, and therefore exposed to a lot of light pollution. This means some of the brightness of the city's lights at night, is partly being captured by the sensor resulting in another source of noise.

6.2. Probability of Stellar Flares

It cannot be predicted when a stellar flare will happen. Flares are also not always high magnitude events and can be so dim as to be unable to be detected (AAVSO, 2010). This makes it difficult to randomly capture a stellar flare. A possible way to increase the probability of detecting a stellar flare is increasing the length of the observation (in this case almost 4 hours), as well as increasing the number of observations on the same target. Decreasing the length of the intervals between individual pictures would likewise increase the probability since flares can be relatively short, as mentioned above.

7.Conclusion

Finally, it is important to note that the BMK at the observatory Lustbühel is a relatively small telescope with a diameter of only 30cm. The biggest telescopes on earth feature diameters of up to 10 meters, which yield very precise and low noise data, but are understandably not used for time consuming observations like this. However, observing time at the BMK is reserved for the scientific staff of the night-time astronomy division of the IGAM at the University of Graz and therefore monitoring is possible. It is also possible to observe more uncommon targets with this telescope, like in this case, Messier 39.

8.List of references

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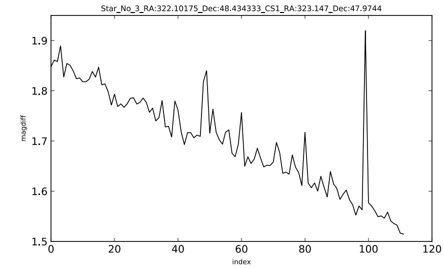
9.List of figures

10. Appendix

List of all M39 member stars (membership probability over 66%):

Number	**RA [°]**	**Dec [°]**	**Membership probability [%]**	**V magnitude**	**B - V**
0	321.67	48.58	97.00	9.79	0.25
1	321.88	48.32	72.00	12.41	0.66
2	322.06	47.96	74.00	13.31	0.72
3	322.10	48.43	97.00	7.58	0.07
4	322.40	48.35	80.00	11.19	0.64
5	322.58	48.39	97.00	7.37	-0.01
6	322.64	48.00	80.00	11.96	0.71
7	322.64	48.30	69.00	9.06	0.15
8	322.68	48.33	97.00	9.09	0.17
9	322.71	48.48	95.00	10.37	0.38
10	322.71	48.48	73.00	11.75	0.70
11	322.73	48.43	70.00	11.20	0.49
12	322.75	47.80	91.00	9.79	0.33
13	322.78	48.64	77.00	12.68	0.68
14	322.79	48.07	98.00	10.15	0.35
15	322.83	48.62	72.00	10.95	0.46
16	322.83	48.45	88.00	9.94	0.27
17	322.85	48.36	94.00	7.84	0.08
18	322.86	48.15	77.00	13.06	1.00
19	322.88	48.26	96.00	10.12	0.29
20	322.88	48.28	96.00	7.96	0.04
21	322.89	48.61	75.00	13.05	0.86
22	322.91	47.72	69.00	10.88	0.66
23	322.93	48.58	97.00	6.75	0.01
24	322.93	48.47	77.00	13.48	0.83
25	322.94	48.48	98.00	7.66	0.00
26	322.98	48.34	98.00	9.49	0.25
27	323.01	48.33	98.00	8.89	0.13
28	323.02	48.11	98.00	10.58	0.39
29	323.03	48.72	98.00	8.57	-0.03
30	323.05	48.48	92.00	9.71	0.04
31	323.06	48.64	97.00	8.22	0.03
32	323.07	48.44	96.00	6.52	-0.01
33	323.08	48.34	97.00	8.72	0.05
34	323.08	48.20	75.00	12.39	0.70
35	323.11	49.18	78.00	11.49	0.47
36	323.13	47.81	77.00	11.73	0.77
37	323.17	48.13	78.00	13.66	0.81
38	323.18	48.48	98.00	9.05	0.07
39	323.25	48.23	97.00	9.69	0.23
40	323.28	48.05	97.00	8.80	0.10
41	323.29	48.30	98.00	6.67	0.15
42	323.31	47.71	76.00	13.98	0.80
43	323.44	48.52	79.00	11.59	0.41
44	323.48	48.56	89.00	9.09	0.20
45	323.49	49.20	70.00	9.40	0.22
46	323.67	48.70	97.00	9.68	0.15
47	323.81	48.44	97.00	9.48	0.22
48	323.81	48.32	81.00	11.21	0.47
49	323.89	48.76	87.00	10.36	0.26
50	323.95	48.11	96.00	9.42	0.18
51	323.99	48.88	76.00	12.58	0.64
52	324.11	48.04	71.00	13.06	0.73
53	324.29	48.56	97.00	9.69	0.25

CS 1: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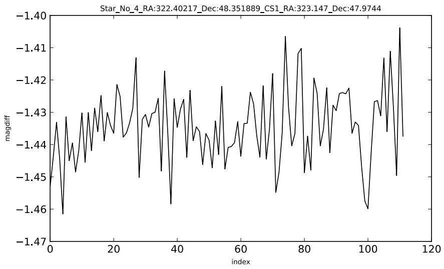
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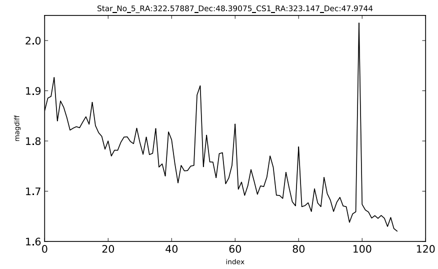
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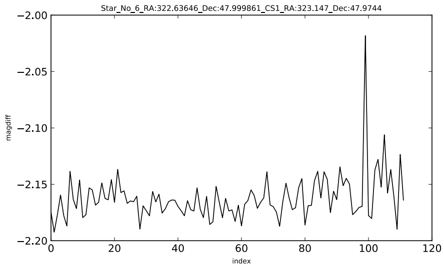
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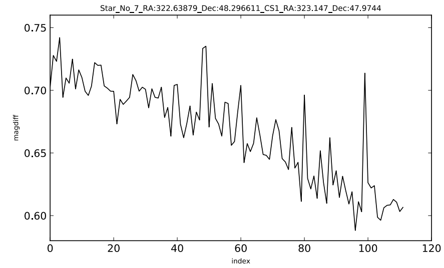
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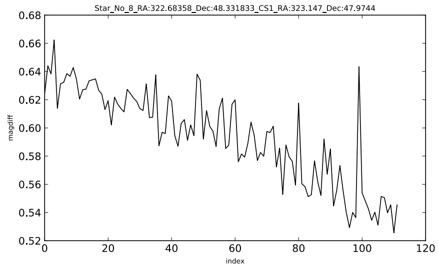
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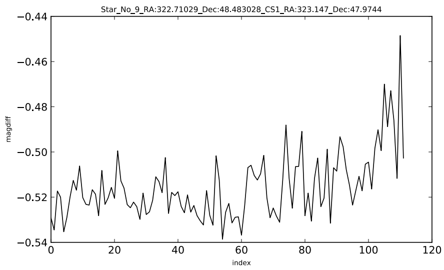
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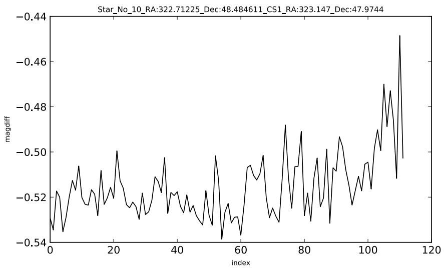
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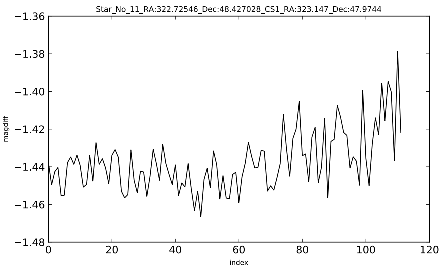
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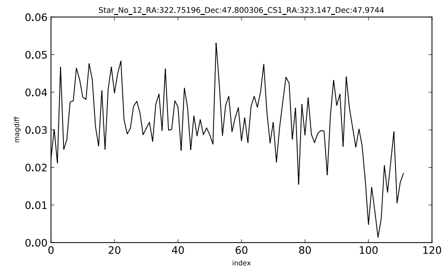
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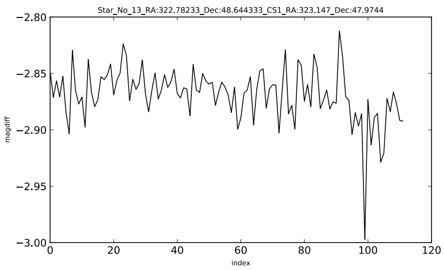
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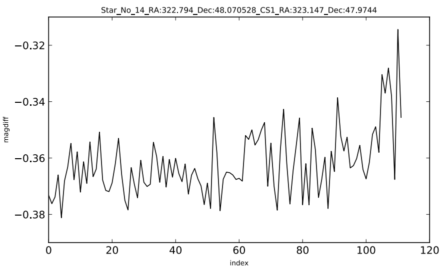
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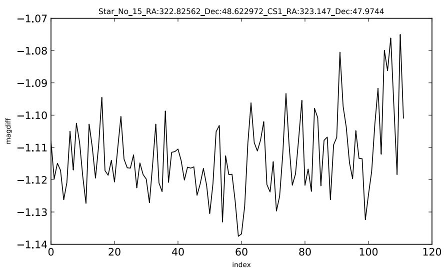
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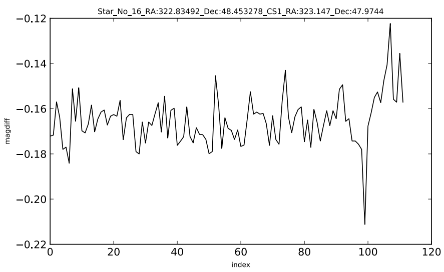
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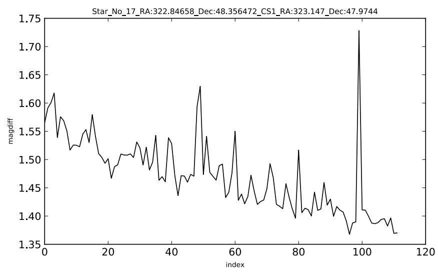
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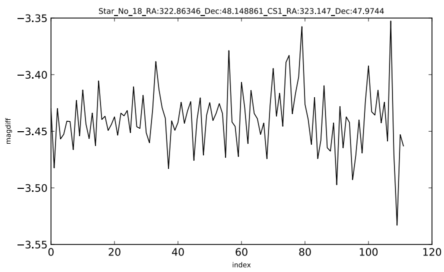
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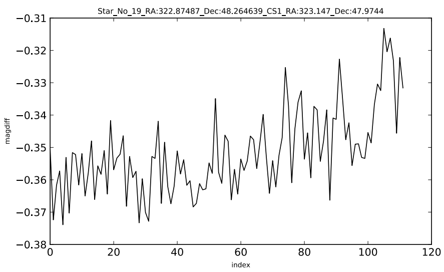
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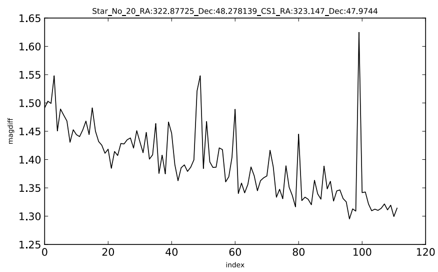
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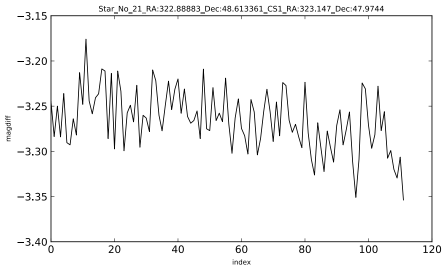
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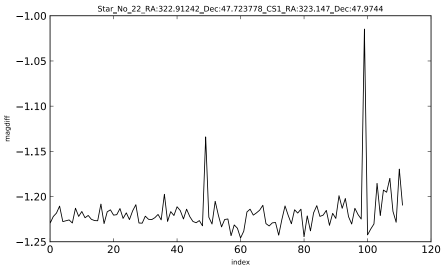
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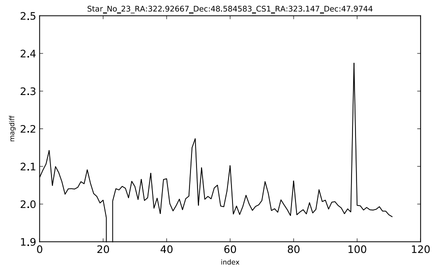
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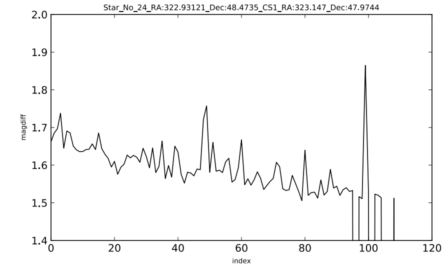
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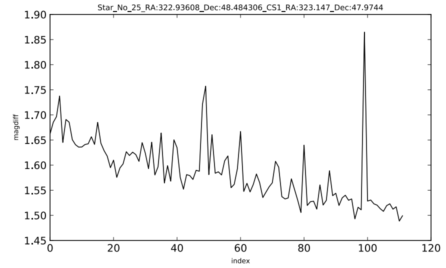
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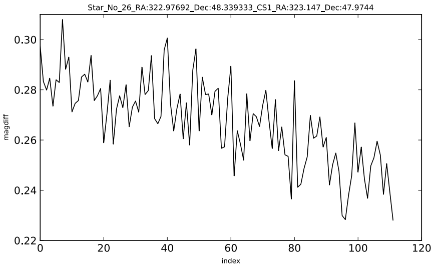
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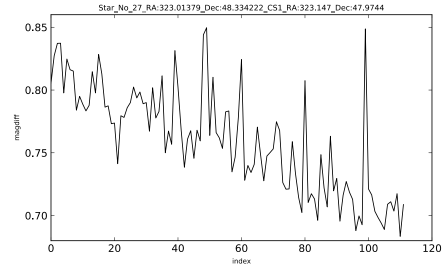
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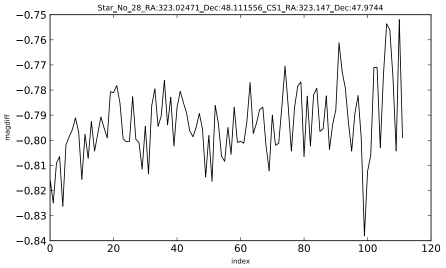
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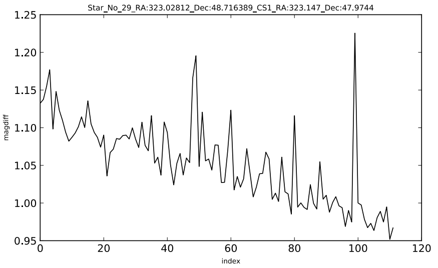
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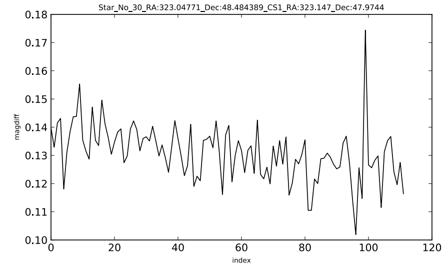
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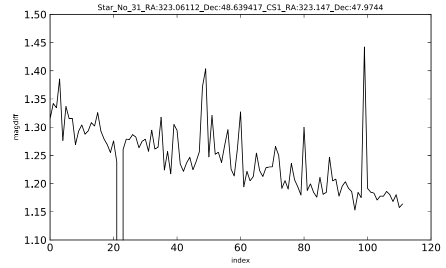
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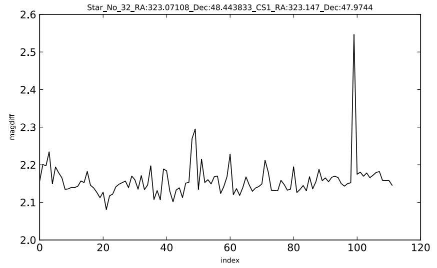
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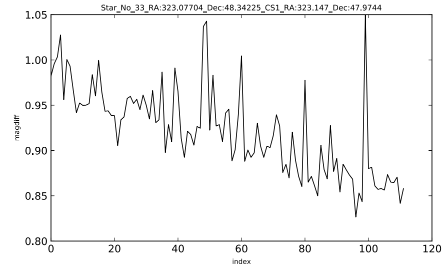
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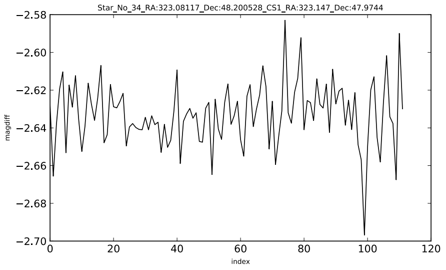
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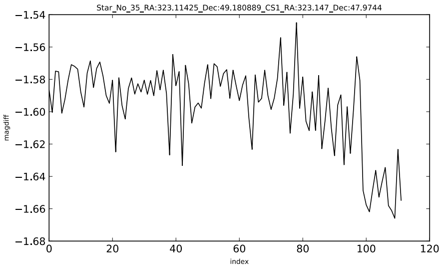
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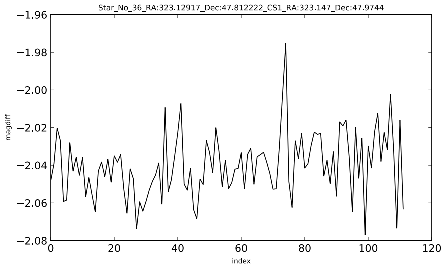
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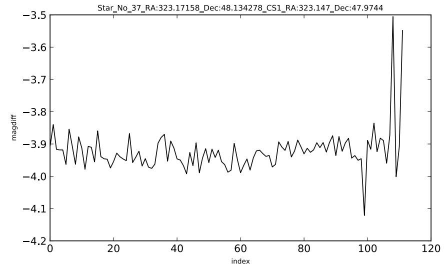
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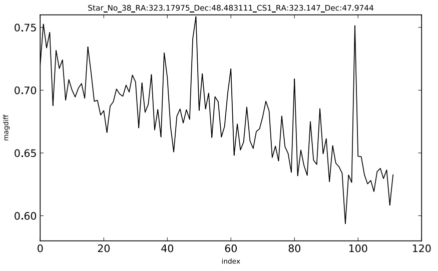
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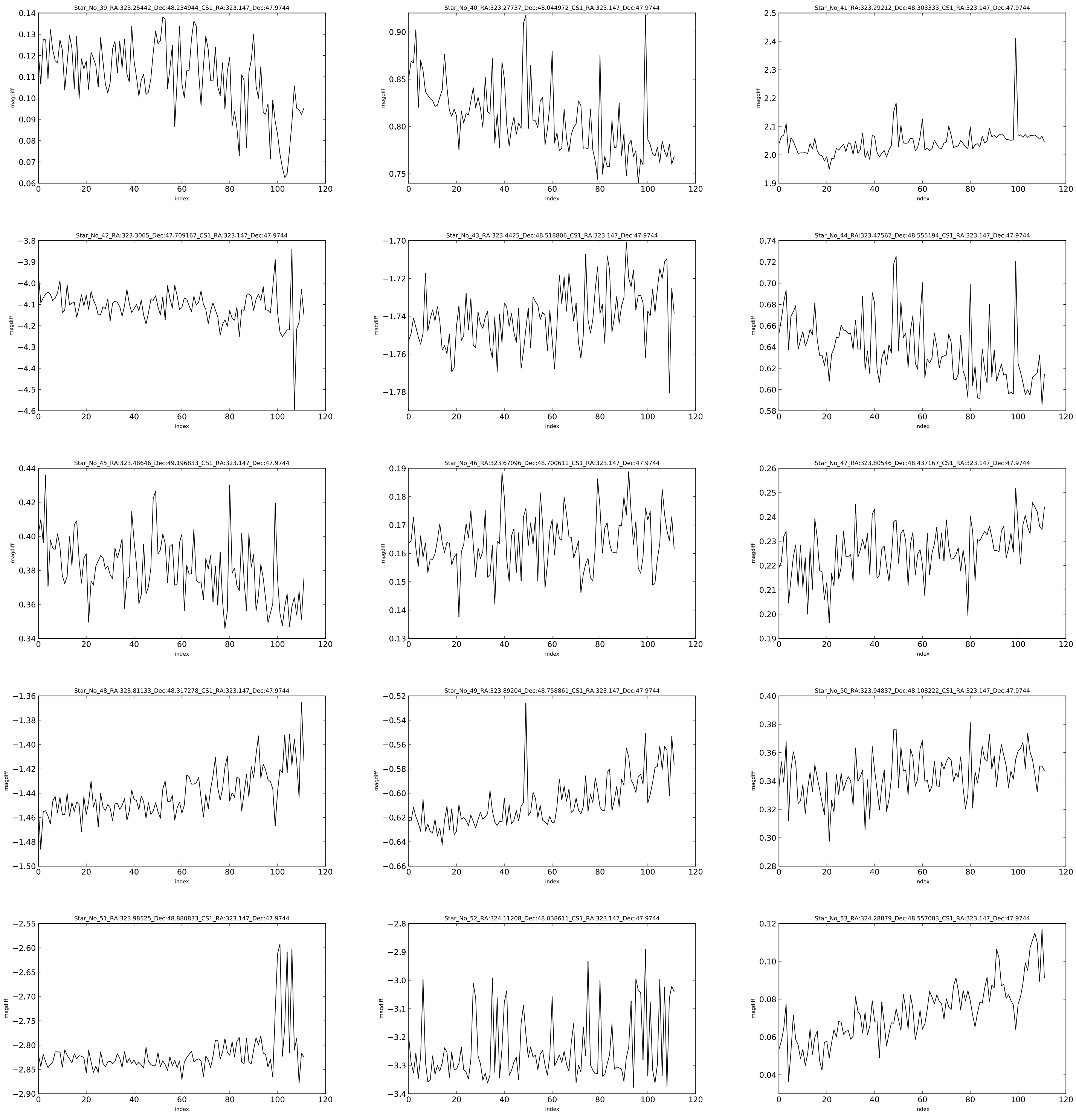

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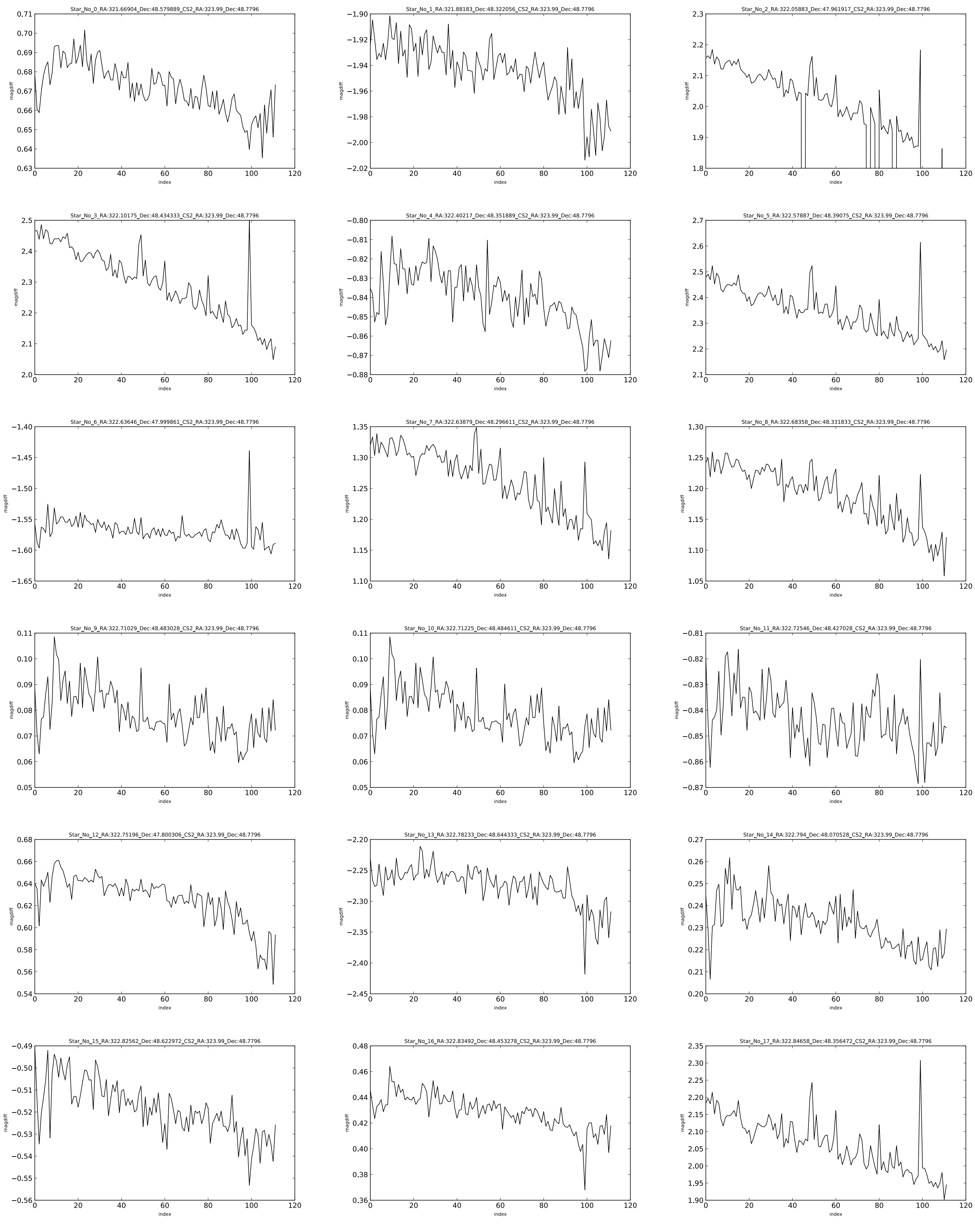

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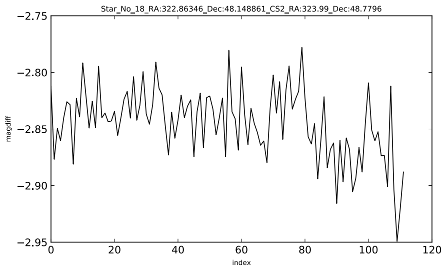
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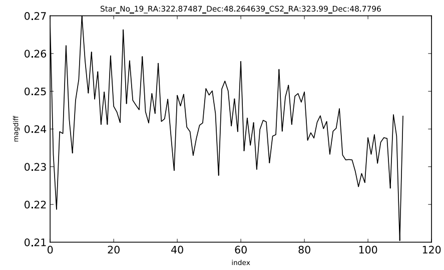
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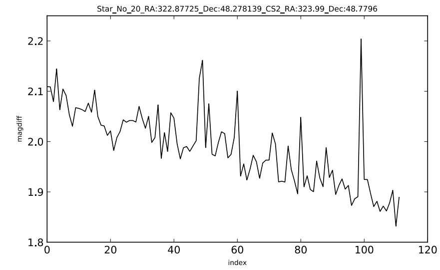
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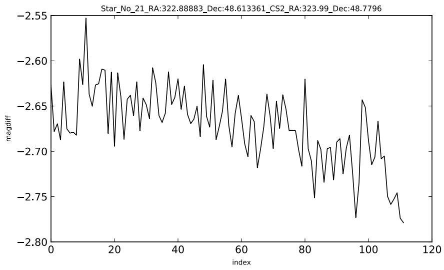
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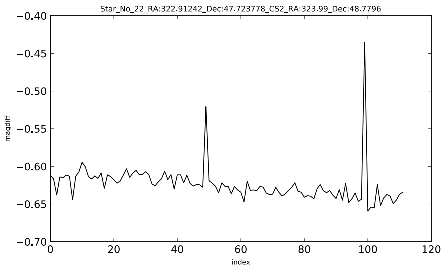
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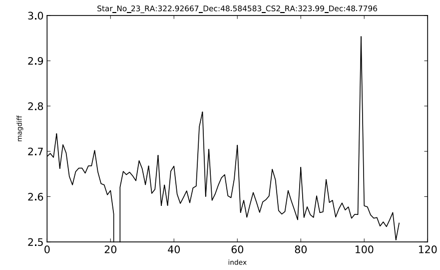
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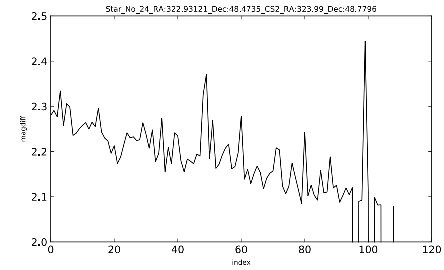
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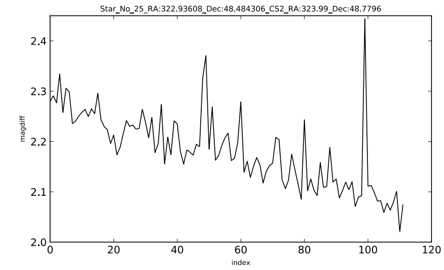
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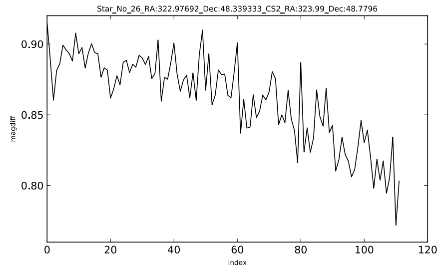
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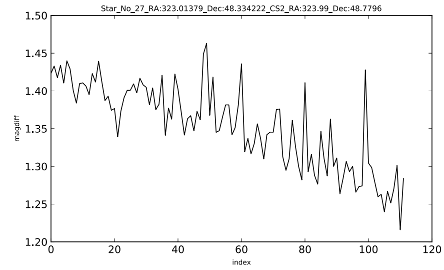
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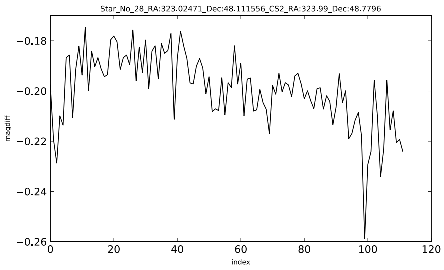
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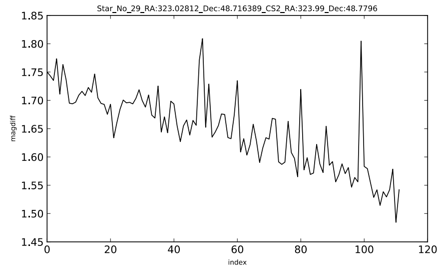
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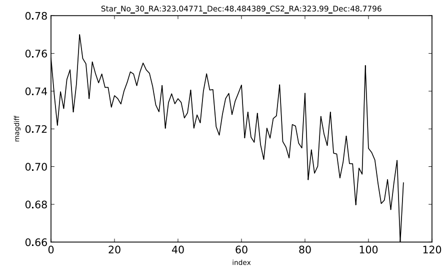
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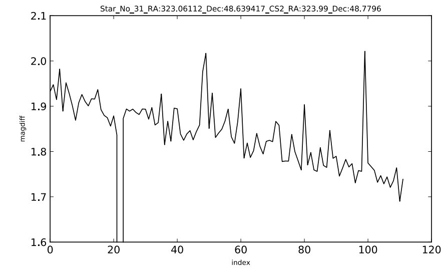
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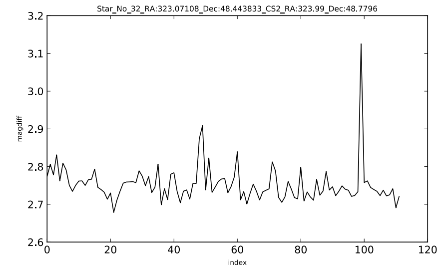
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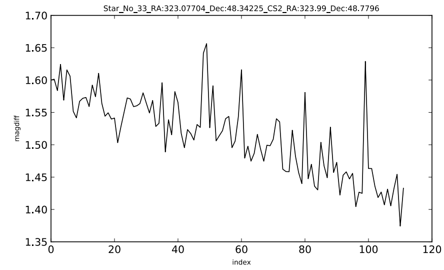
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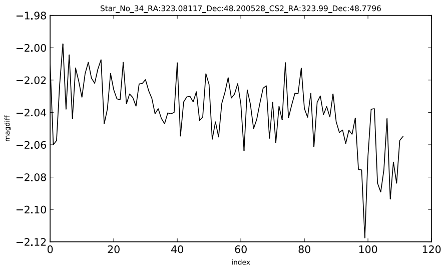
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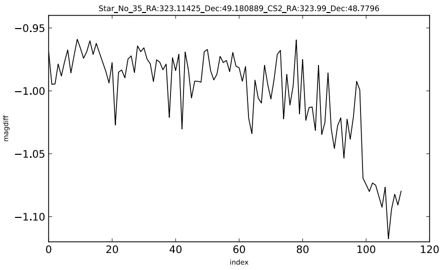
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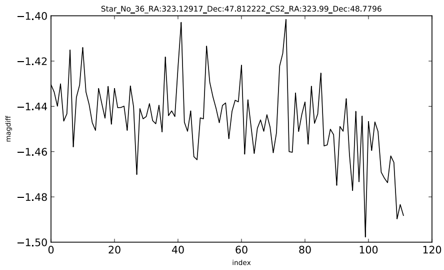
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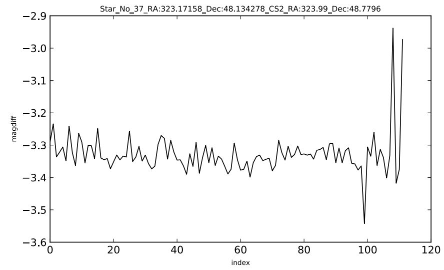
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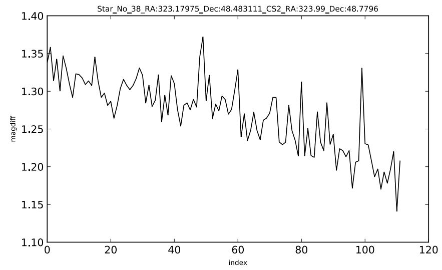
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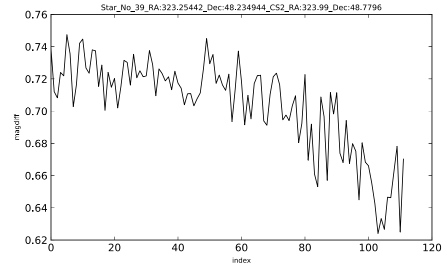
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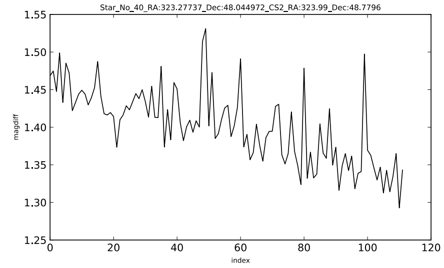
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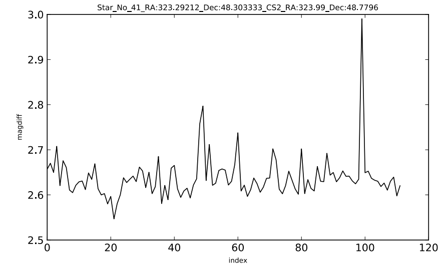
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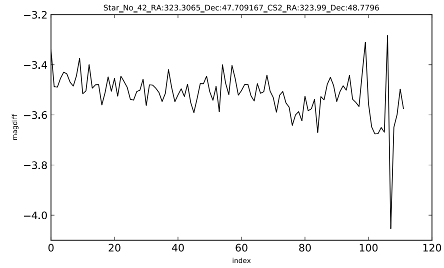
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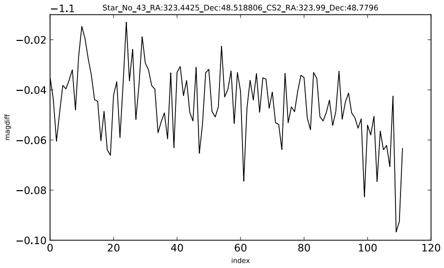
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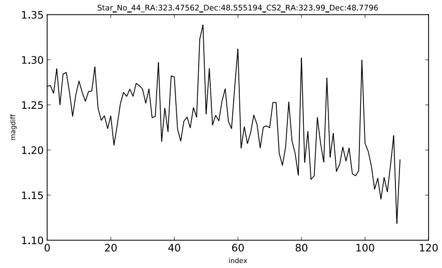
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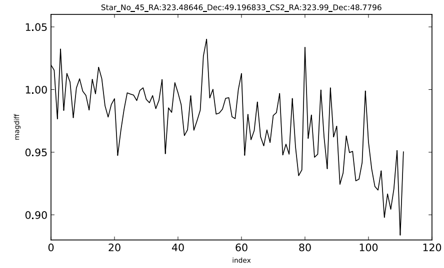
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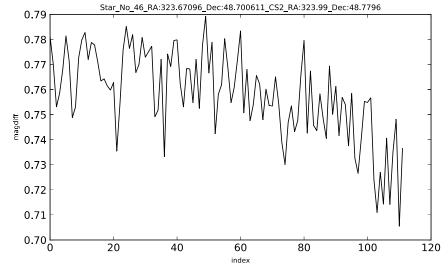
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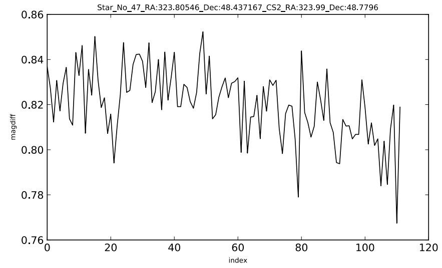
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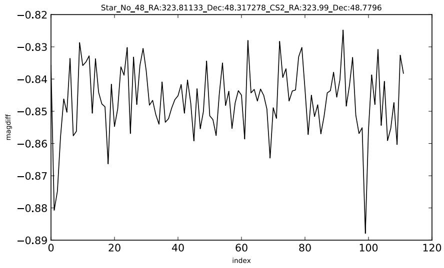
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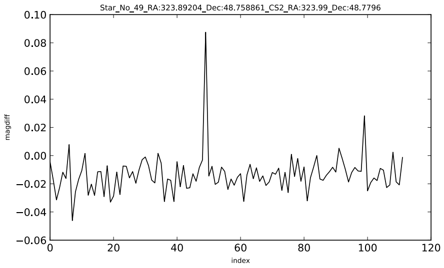
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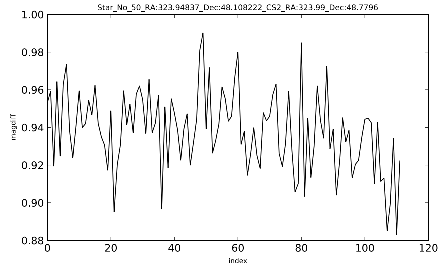
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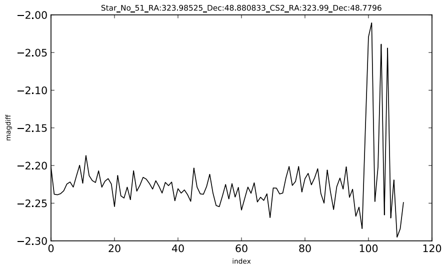
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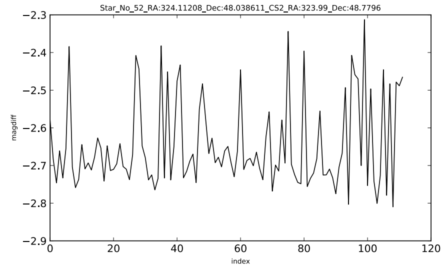
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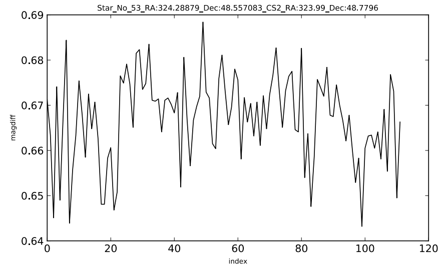
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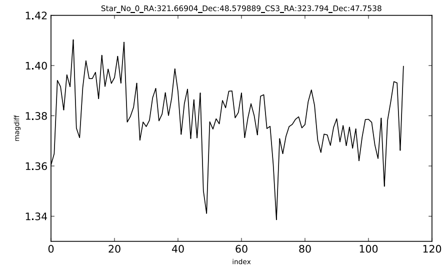
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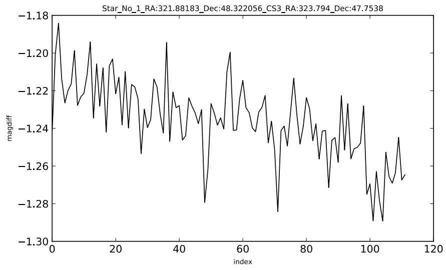
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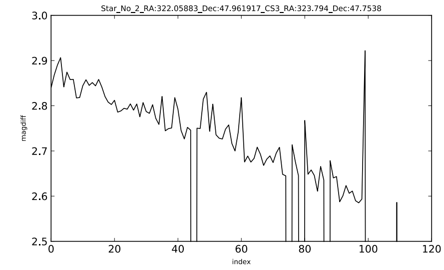
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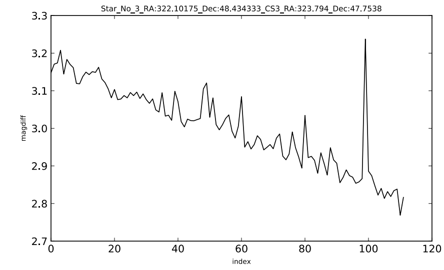
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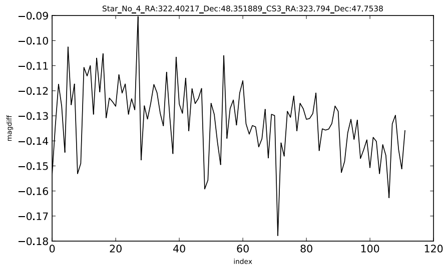
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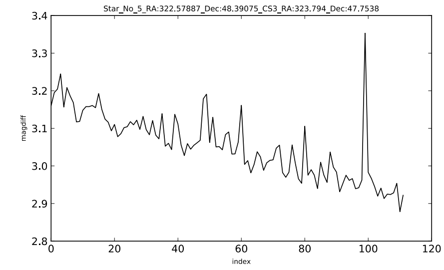
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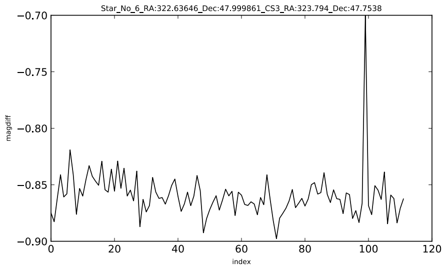
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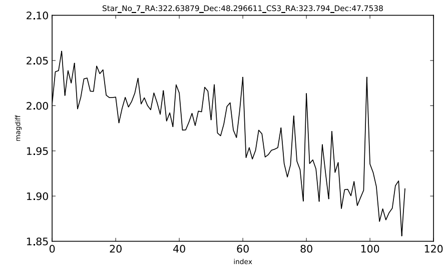
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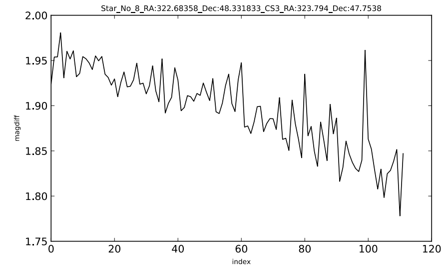
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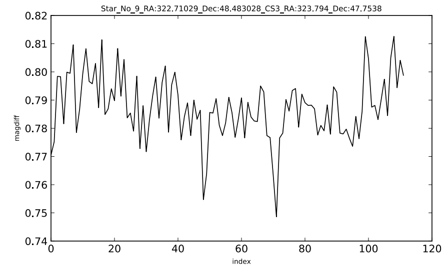
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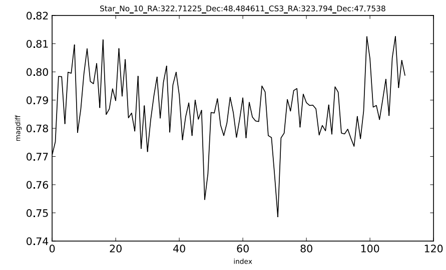
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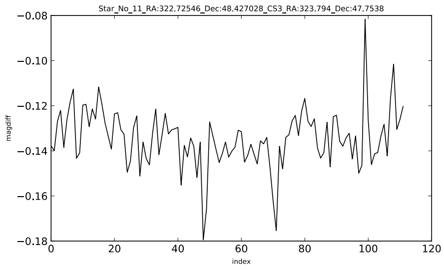
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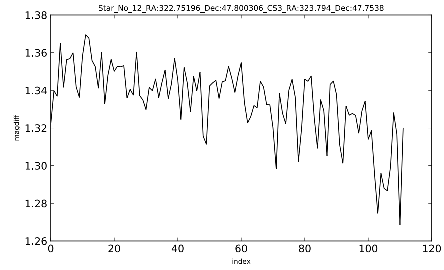
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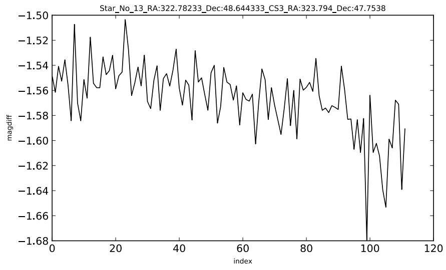
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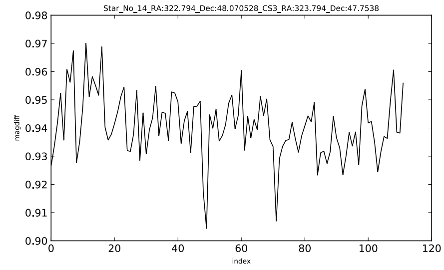
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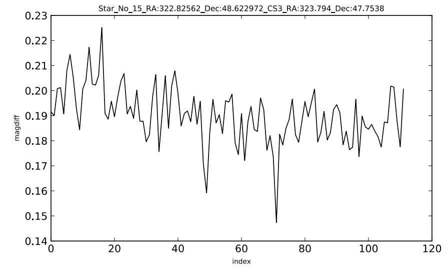
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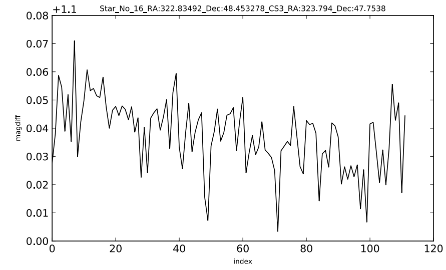
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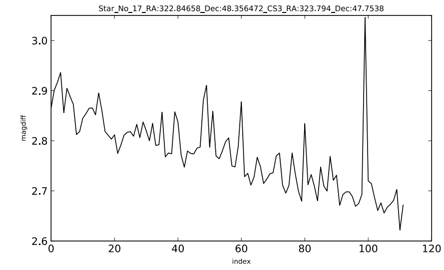
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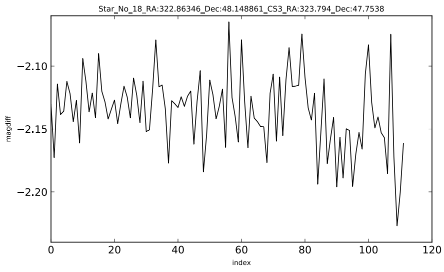
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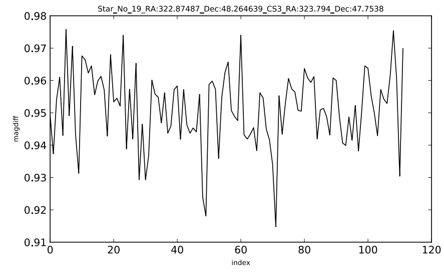
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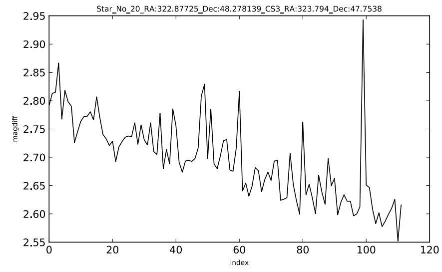
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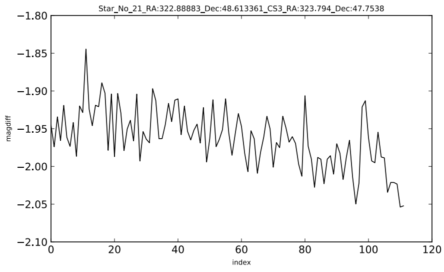
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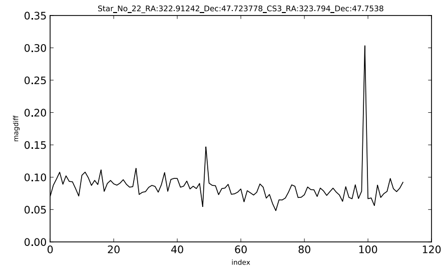
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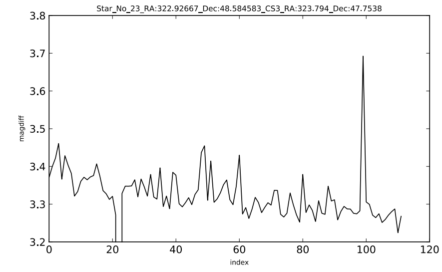
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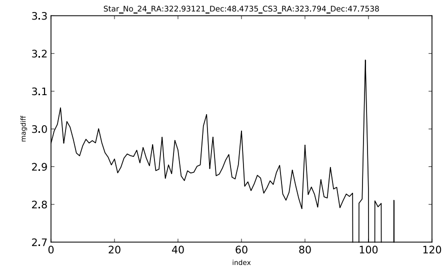
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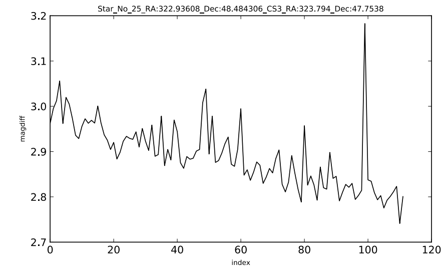
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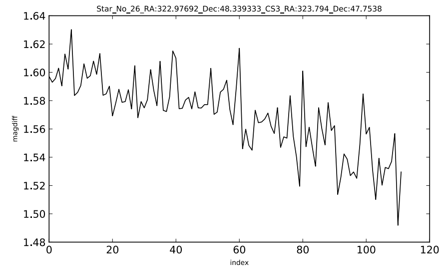
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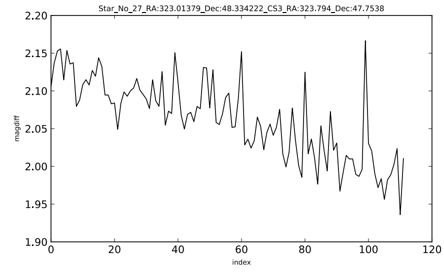
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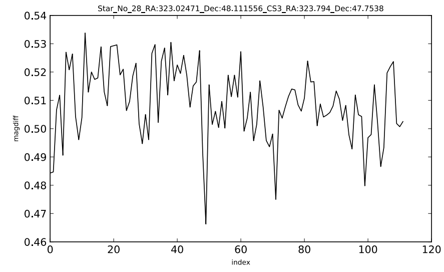
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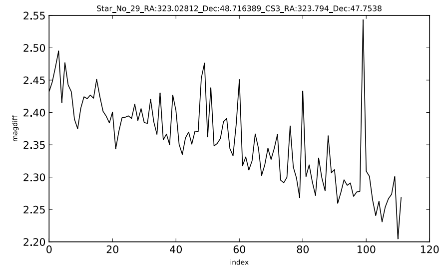
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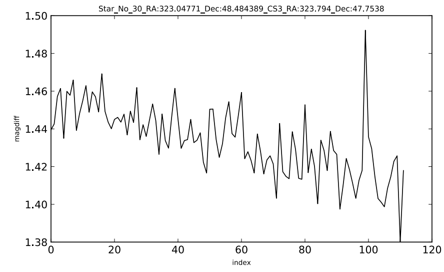
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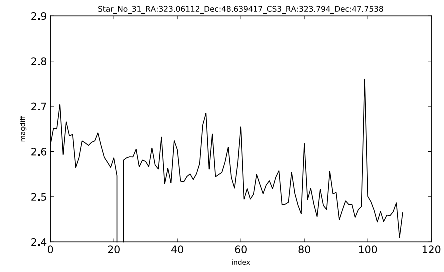
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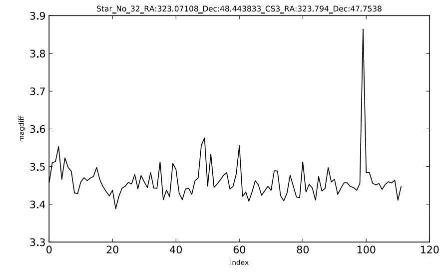
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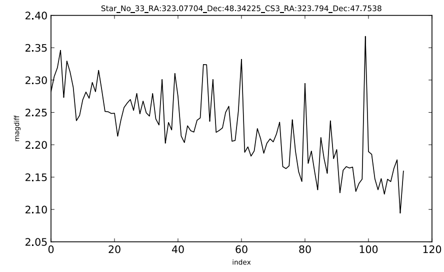
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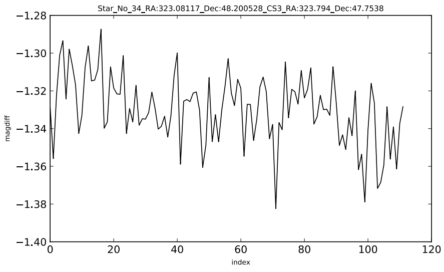
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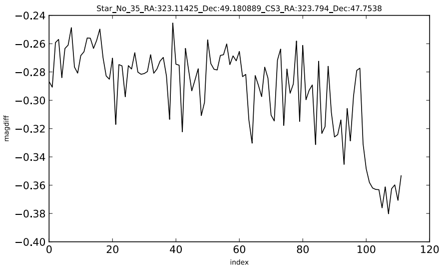
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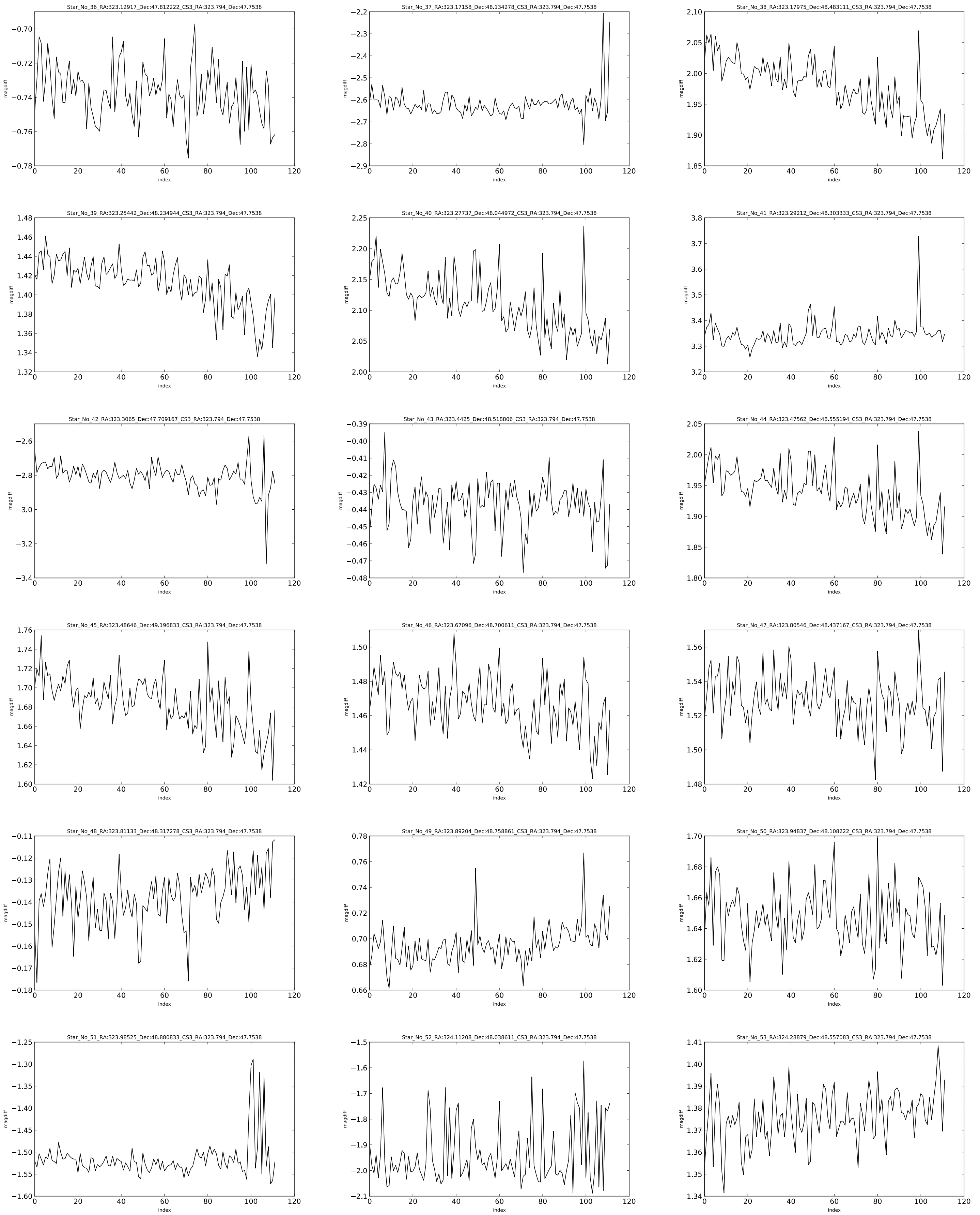
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