AE Ursae Maioris

Project results and evaluation

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Class: ASTR 104, honors section

General purpose of the project: to observe a whole cycle of the short period pulsating variable AE UMa, and obtain a light curve.

General information about the object: AE UMa is a 12-mg pulsating variable of the δ Phe type pulsating variable, with a large (~0.6 mg) amplitude and short (2 hours) period.

Specific purpose of this project:

1. to improve the precision of the measurement from a previous projects overall ±0.03 mg, through (a) more careful image taking and evaluation, (b) the use of a broadband filter instead of no filter.
2. to ensure the students properly understand what they are doing,
3. to find the main source of error and suggest improvement.

Instrument used: the University of Mississippi's 12-inch Meade SCT, mounted on a Paramount mount, with an Astro-Physics 0.63x focal reducer; an SBIG ST-10ME CCD camera with Astrodon red broadband filter. The pixel size is 0.78 as, significantly oversampled compared to the ~ 3 as FWMH.

Comments on the instrument's quality:

1. the filter is not standard R-band, only close to it, with 60 nm irregular bandwidth, centered on 650 nm.
2. There is significant coma on the images, on the order of 5 as.
3. There is significant vignetting (~ 20% at the edges of the image), and various flats usually show a ~ 1% variation among themselves.
4. Guiding has not been used (because automatic timing of the images is not possible with CCDops while guiding). This results in drift, which introduces systematic photometric error through the inaccuracy of the flats. Our educated guess is that this effect is the main source of systematic error, in the amount of 0.01-0.02 mg.

Images taken: on the photometric night of April 7/8, 2008, we took 100 images of the variable and the field around it. The starting time of the images were separated by 90 seconds, exposure length $t = 60$ sec. The total time covered was 149 minutes, cf. the period of 120 min. Red filter was used, T=-25°C, airmass changed from m=1.04 to m=1.36. To minimize drift, we adjusted the aim many times between exposures. We used autograb and a series setting for autodark. We took two flats with the same filter on April 15, 2008.

General processing: We flat-fielded the images with the arithmetic average of the two flats. We aligned all images with CCDsoft's "align a folder of images" utility. We inserted an inventory into each image with CCDsoft, which resulted in a ***.src file, containing the data of each source on each image. For source extraction, we used CCDsoft's default settings. We also checked each image visually, to detect any failed images (we did not find any).

Photometric processing:

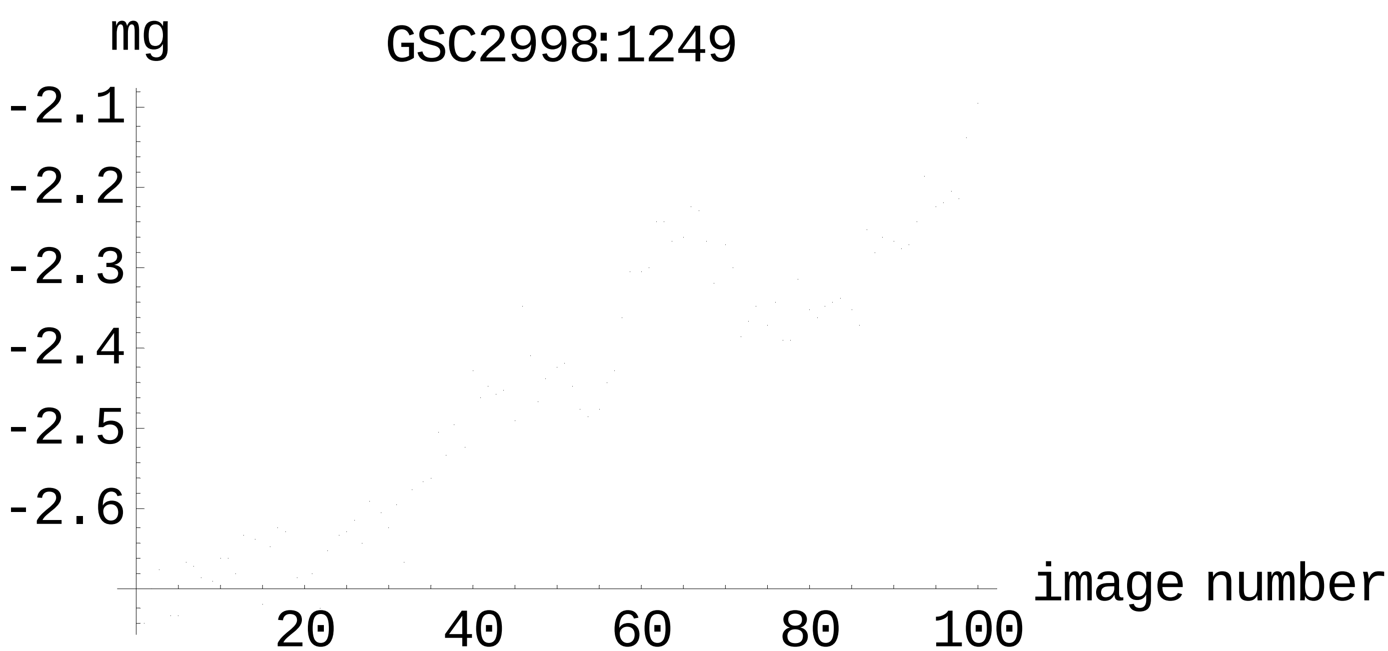
1. We wrote a Mathematica program (Processing1.nb), which reads in each of these ***.src files, extracts the data for each star on each image, and saves them in one large array ("Sources.m"). This program is fairly easy to follow; we inserted detailed comments.

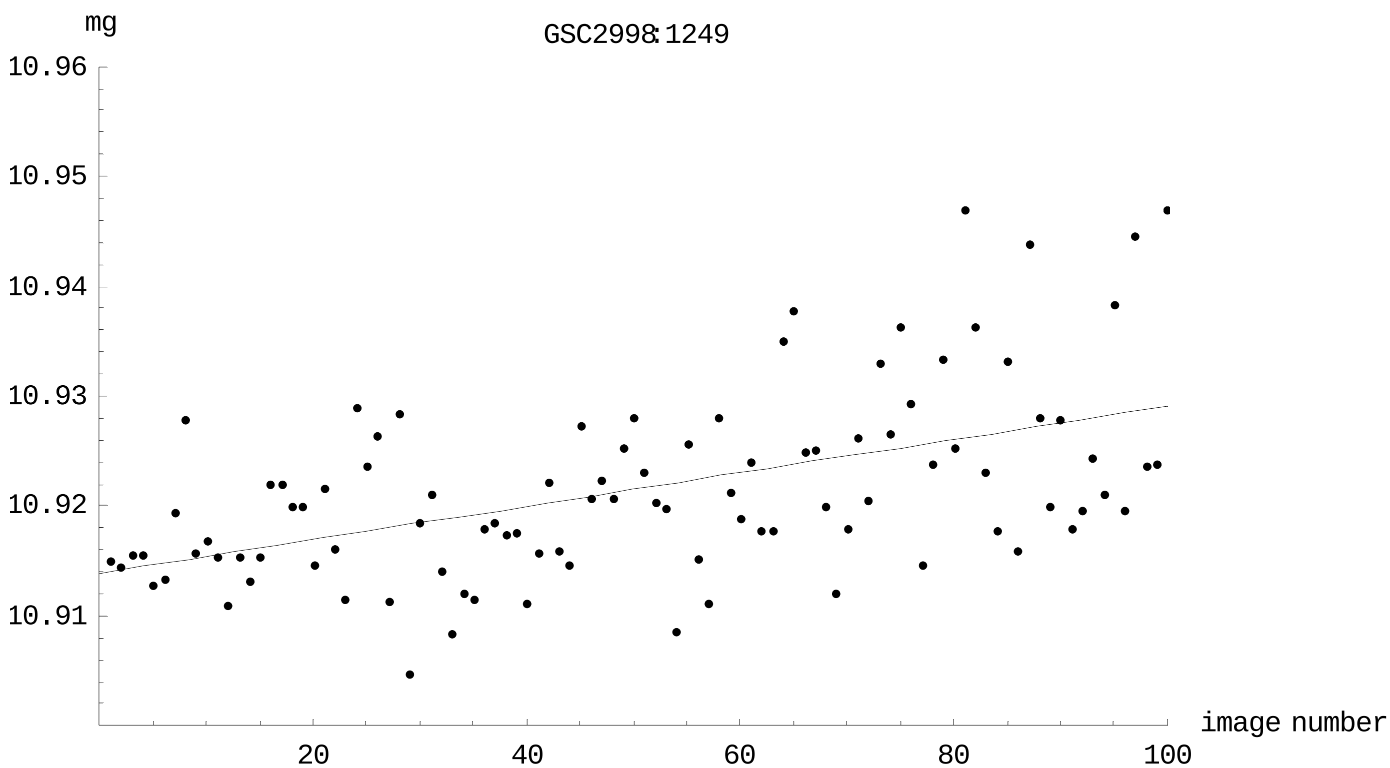
2. Next we wrote another Mathematica program (Processing2.nb), which reads in the data in Sources.m, and plots the light curves of the variable and four more stars (GSC2998: 1249, 1166, 963, and 215), three approximately equal in brightness (~ 11.5 mg) to the variable, one fainter (~ 13 mg).

The light curves provide uncalibrated magnitudes. There is a tendency for each comparison star to get fainter, by about 0.6 mg. we do not think this could be fully due to airmass, because that would mean a red extinction of 2.0 mg per unit airmass, incredibly high. We suspect a change in air transparency during the 2.5 hours of observation.

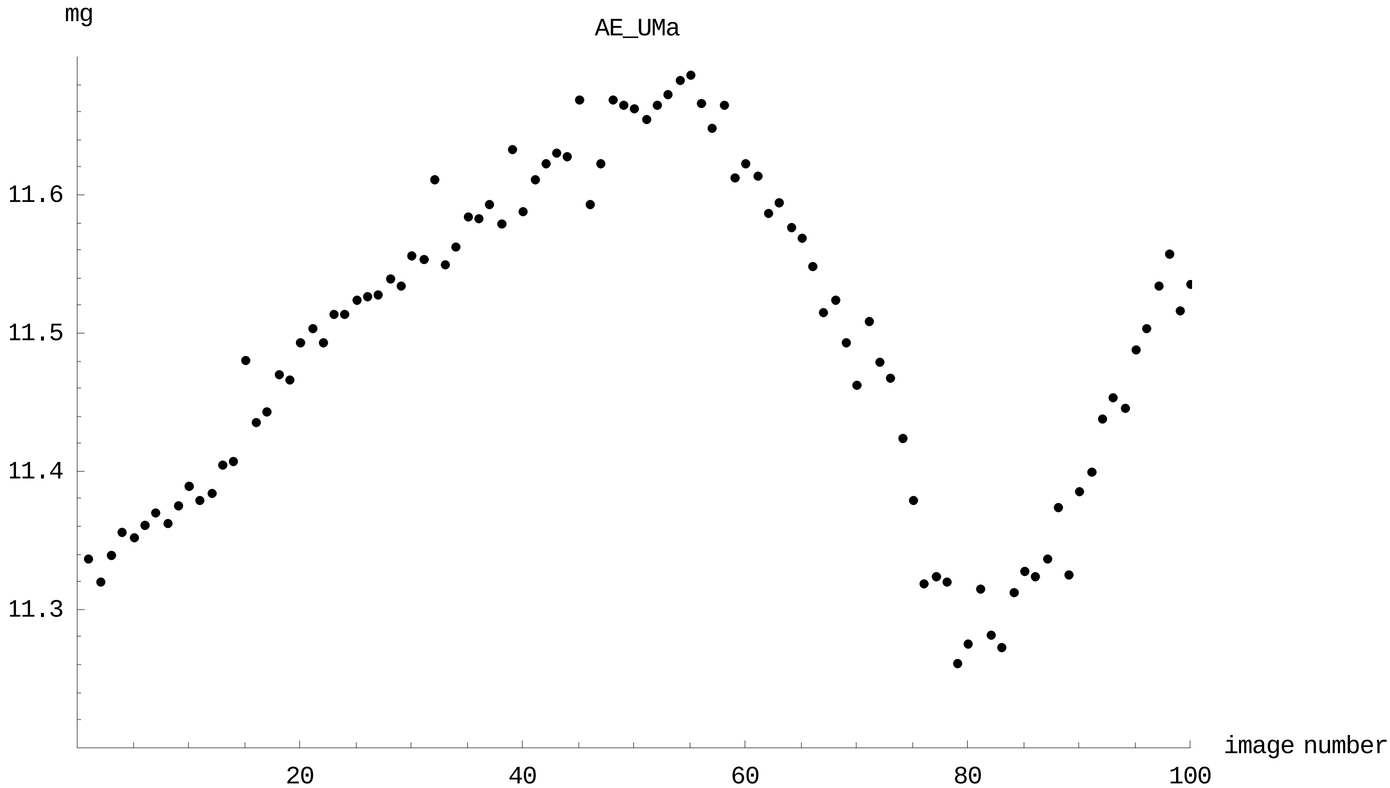
We used the average of three comparison stars to determine a baseline magnitude for each image, which we subtracted from the brightness of the variable. As an educated guess, we added + 11.2 mg to the result. (This can be taken as the definition of our red instrumental magnitude.)

We found that, after this adjustment (a technique called relative photometry), the comparison stars change their brightness much less. There is a random component from statistical error, $\sigma = 0.01$ mg, and also a linear change in the amount of ~ 0.01 mg / 2.5 hours. The linear change varies from star to star, so our guess for its cause is the difference in the spectrum of stars (recall that we are using broadband filters).


mg
GSC2998:1249
-2.1
-2.2
-2.3
-2.4
-2.5
-2.6
image number
20
40
60
80
100


mg
GSC2998:1249
10.96
10.95
10.94
10.93
10.92
10.91
image number
20
40
60
80
100

The light curve of the variable after the adjustment is shown in the image below.

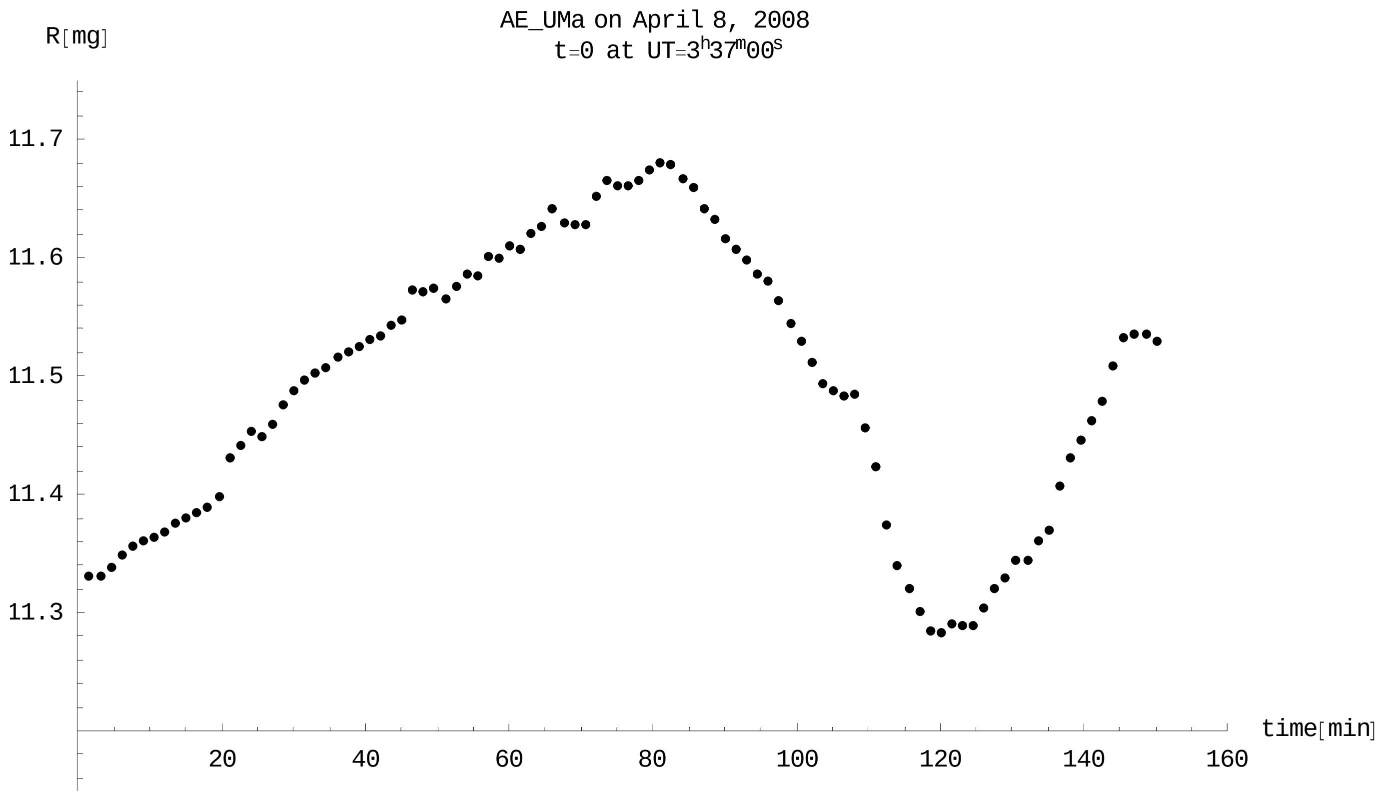


There is a significant scatter from point-to-point. To smoothen this, we used a sliding average according to $f_n = (1\text{-}2\zeta)\ f_n + \zeta\ (f_{n-1} + f_{n+1})$, (except at n=1 and n=100), and experimented with various values of $0 < \zeta < 1$. The best compromise between too little smoothing and too many artificial features turned out to be ζ=0.33. We also converted the image number to time. (Notice that the equidistance of times was not a requirement, but still, it has greatly simplified the processing.)

We do not have enough information to decide whether the small dips on the light curve are real or not.

In order to determine the pulsation period, we also superposed the curve onto itself with a time delay. Experimenting with various amounts of time delays, we found the best match at t= 120 ± 2 min, which agrees (within the error bars) with the period quoted in the General Catalog of Variable Stars.

Finally, we analyze the sources of expected statistical error. The background is (116.5 ± 11 ± 5) ADU/pixel; the second error is a highly unsure guess of the variation of the background from location to location on the image, with a characteristic linear size of ~ 100 pixels.



The total light of the star is seen to be contained within the closest ~ 1000 pixels, although star size is about ~ 10 pixels FWMH. We measured the total amount of starlight to be ~ 200,000 ADU. This means that the expected electron noise is ± 450 ~ ± 0.002 mg, negligible. Similarly, in order to explain the ~ 1% error by the statistical fluctuation of the background, it should add up to ± 2,000, which would have required $(2000/11)^2 \sim 20\times20$ pixels. However, given that a significant part of the star stretches out way beyond the FWMH due to coma, is conceivable that the dominant statistical error is coming from the incorrectness of the brightness evaluation of a non-Gaussian shaped star. It is also possible that different settings of CCDops's source extractor might have provided smaller statistical error. In any case, the systematic error is not smaller that this statistical error, so we do not think it is worth trying to reduce it much.

A comment of the students' performance: The initial preparation and the observation were done as well as they could be, excepting some delays. In the evaluation process, there was a significant lack of communication between the instructor and the student. This fact explains why the students' report does not properly explain all the details that were discussed above, and that in their graphs, the brightness change of the comparison stars has not been subtracted. Consequently, their light curve does not indicate periodic change at all.