PULSATIONS IN THE GIRAFFE

Studies on RR Lyrae star : AH Cam
or
How can we study a RR Lyrae star's variability ?

Le Luec Antoine, Buchet Samuel and Gautreau Dylan

2011-2013

Abstract

Our project is a study on RR Lyrae stars. We decided to study this type of star because they are close to our planet since they are in our galaxy. On top of that they have short pulsation periods. Therefore, we can study a complete pulsation period in a single night. Jean-François Le Borgne, an astrophysicist of the astrophysics laboratory in Toulouse (IRAP), helped us in the progression of our project. He urged us to study AH Cam, a star which he is studying himself, so we studied the star with him and took part in the scientific research auround it. Our work is based on the ways we can study an RR Lyrae star and phenomenans linked to it. We have done several observations by night, then we processed our data to study its variability.

Thanks

We would like to thank Mr. Le Borgne for his help during the whole project.

Jean François Le Borgne :

Astrophysicist

Works in the observatory of Toulouse (IRAP)

Website : `http://www.ast.obs-mip.fr/rubrique53.html`

Moreover, we would like to thank all the physics teachers from the school who attended our oral presentation and read our report.

We also would like to thank Mrs. Tinelli and Xoe Lichu who helped us to translate our report.

Finally, we would like to thank Mr.Rives and Mr.Guibert who helped us to achieve this project.

Table of contents

The bibliographic references are noted in between square brackets

1 The stars : general notions

1.1 The stars

Stars are celestial objects which are composed of hydrogen and helium. We can find different kinds of stars classified in different categories depending on their luminosity expressed in magnitude and their size : the O,B,A,F,G,K and M stars. They represent an important topic in the astronomical field. There are various methods to study them. For example, the spectroscopy which consists in analyzing the emission spectrum of a star in order to know its composition. Another method called photometry enables us to measure the evolution of the luminous flux.

1.2 Variable stars

Variable stars are stars of which brightness fluctuates. There are several types of variable stars classified in two categories : intrinsic variables and extrinsic variables.

Extrinsic variables are stars of which brightness fluctuates because of an external element from the star. This fluctuation can be caused by an eclipse of the star. Indeed, the star can be eclipsed by any astronomical object, like exoplanets, or another star in binary stars case, or else by violent and punctual physical events as in the case of cataclysmic variable stars.

Intrinsic variables are stars of which brightness fluctuates because of internal events. They are classified in three categories. Rotating variable stars which have a non-spherical form or have a non-uniform luminous surface. The rotation of these stars means a variation of the brightness according to the observated area of the star. Moreover, eruptive variable stars' luminosity changes because of eruptions on their corona or their chromosphere. Finally, pulsating variable stars are stars of which brightness fluctuates because of the expansion or the compression of their external layer. This is the kind of star we decided to study.

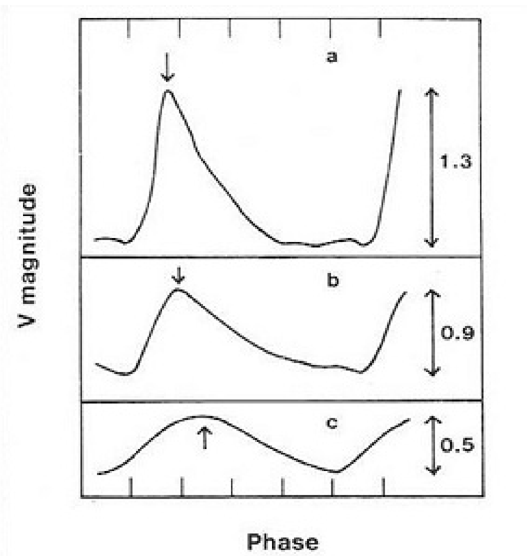

Figure 1 – Light curves of RRa, RRb and RRc stars [1].

Pulsating variable stars are classified into categories in accordance with their size and their pulsation period.

We had to choose which of these variables could be exploited the most efficiently. We chose the RR Lyrae variables which can be observed with our limited resources. Furthermore, the pulsation period of this kind of variable varies from 0.2 to several days. Therefore, most of these stars can be observed in one night. They are A or B stars which are blue stars. According to current knowledge, we know that few RR Lyrae stars are in a multiple star system. There are several kinds of RR Lyrae : the RRa, the RRb and the RRc. [2]

2 Our star : AH Cam

This data has been extracted from the database of the software "Skychart" [3].

Feature of the studied star :

- Name : GCV AH Cam (GCV catalog)
- Apparent Magnitude[1] : fluctuates between 11.31 (maximum) and 12.33 (minimum)
- As most of RR Lyrae stars, AH Cam has a blue color
- Astrometric coordinates J2000 :
  - Déclination : +55° 30' 00"
  - Right Ascension : 04h 06m 38,9s

FIGURE 2 – One of the images in negative shot by the CCD camera of the telescope. We can see on this picture the star AH Cam between the two "lines"

Despite appearances, AH Cam isn't a double star. It's just an optical illusion. Because of the star next to AH Cam, we can see, on our data, an increase of the brightness of AH Cam compared to tis actual brightness.

3 Acquisition

We spent the night of acquisition at the place of a physics teacher Mr Rives. He was present as well as Mr. Guibert, to help us for our first time. Those nights were hard because of the cold. The temperature dropped to -10,1°C and it was hard to observe the whole night, the weather was unsteady.

We made this acquisition with Mr. Rives' telescope, a Celestron C8 telescope, an equatorial mount CGEM Celestron and a CCD camera SBig ST7-XME.

Before we could take our pictures, it was necessary to set up the equipment. First, we had to set up the telescope, orienting the tripod to the North. The positioning of the telescope to the North isn't easy, in fact, we had to be as precise as possible for the slightest mistake leads to difficulties to find a star from its coordinates. After that, we had to install the mount and the tube at the same time by stabilizing the telescope with the counterweight. Next, we had to install the CCD camera. Finally, we had to connect the mount and the CCD camera to the computer and to launch our acquisition software.

1. Magnitude : unit of measurement of the irradiance of celestial objects. There are two types of magnitude: the apparent magnitude and absolute magnitude. They correspond respectively to the brightness (the flux) that we receive on Earth and to the one emitted by the star, seen at a reference distance (10 parsecs).

Nevertheless, orientating the telescope to the North was not enough to find our star. Actually, before setting our star's coordinates, we had to fine-tune the mount with the most luminous stars, thus making it easier to find it. After, we just had to set our star's coordinates and to re-focus if we needed to.

After fine-tuning the telescope, the mount automatically followed our star with a second CCD camera oriented on another star, that serves as a guide star. However, the turbulences, the light absorption by the atmosphere or the filter can make the star less visible, the result is the interruption of the auto guiding. Thus, we had to check, all night, if the mount was still following the star guide. Furthermore, to take a picture, we needed 90 seconds of acquisition followed by 15 seconds for the realignment and to change the filter. There is a considerable time between the two pictures.

FIGURE 3 – The three of us frozening out at night beside M.Rives' telescope

To take the pictures, we used four Astronomik type 2 filter. A green filter (from 450 to 650 nm), a blue filter (from 350 to 650 nm), ared filter (from 550 to 700 nm) and finally a luminance filter which includes the three other filters (from 400 to 700 nm). During the night, our main work was to check if the mount followed our star guide.

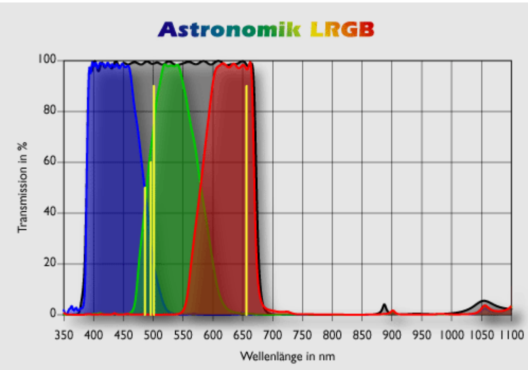

FIGURE 4 – Curves which indicate the filter transmission function of the wavelength [4].

Despite our efforts, the telescope's mount were misaligned during the night because of focus' problems. This made us lose some measures because the realignment we had to took a lot of time.

We also faced up to the formation of frost on the closing plate of the telescope. To remedy this problem, we had to use a hairdryer , what is not a so trivial step, because we had to heat the telescope slowly and uniformely not to break it by a gap snap of temperature. In addition, because of a sky which was not transparent enough, we couldn't take the measures with all the filters during all the nights. Indeed, when we took measures with the blue filter, we lost the signal of the star guide (the star followed by the telescope), so we chose to work only with the luminance filter on the night of 10th February.

We did another night of acquisition on 20th February. The only problem at night was the arrival of clouds at about 4.AM, that 's why we had to cut short our night. Fortunately, the use of data done durind the daybreak allowed us to see that we had the brightness peak !

4 Preprocessing

Before using our pictures, it was necessary to make them scientifically workable by removing the maximum number of elements which alter the image. In the field of astronomy, this step is called preprocessing. [5]

This is done through a series of corrections on our pictures to clean them. We had to take some specific shots to realise this preprocessing with Iris. But, we had to do the Median [2] of these different shots, to use them during preprocessing. In addition, before preprocessing, we had to adapt our shots. In fact, our photographs recorded by .fit format had no sign encoding data on 16 bits, that's why pixels can take data included between 0 and 65535. But, the software IRIS uses in memory encoding pictures signed on 16 bits, with pixels which have have data included between -32768 and 32767. Our data appear saturated with the software IRIS. The order *convertsx* allowed us to increase each pixel by 0.5 to be usable by the software.

2. Median : Calculation of the median of the brightness of pixels from a series of images, so as to eliminate nonsensical values.

Preprocessing takes place in several steps :

First step : The first step is to substract the offset, in other words, to delete defaults on the pictures linked to the CCD sensor (cold and hot pixels). To do this step, we had to realize a series of pictures with close shutter and with an exposure time as short as possible.

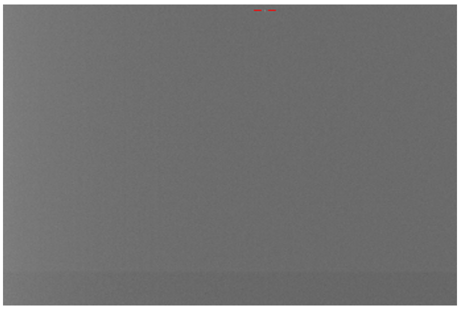

FIGURE 5 – Offset : to highlight the defaulting pixels

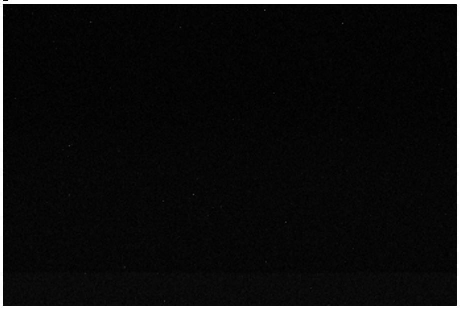

FIGURE 6 – Dark : disturbance of the CCD sensor

Second step : The second step is substraction of the "Dark". It consists in deleting the dark signal of the picture. As a result, we have to cool the CCD sensor, to -35°C to decrease the dark signal. To realise this "dark", we had to realize a series of pictures with close shutter, using the same exposure time as for our pictures.

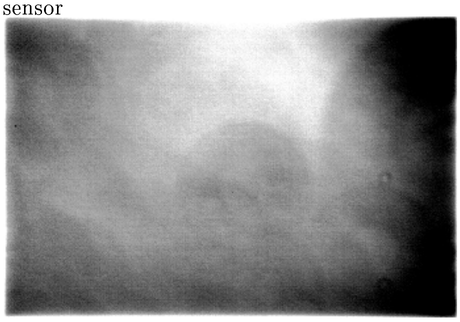

FIGURE 7 – Flat-field : default of the optical assembly

Third step : The last step consists in deleting the flat. In other words it consists in removing the defaults linked to the vignetting [3]. This time, we had to realize a series of pictures, using an exposure time as short as possible. It's a hard task when , you've got to maintain a white panel before the telescope when you're tired.

We used approximately 12 pictures of offset, 10 pictures of dark et 30 pictures of flat. Next the preprocessing is preformed in a specific order following this equation :

$$Prepocessed\ picture\ = \frac{untreated\ picture - offset\ \ - (dark - offset)}{flat - offset}$$

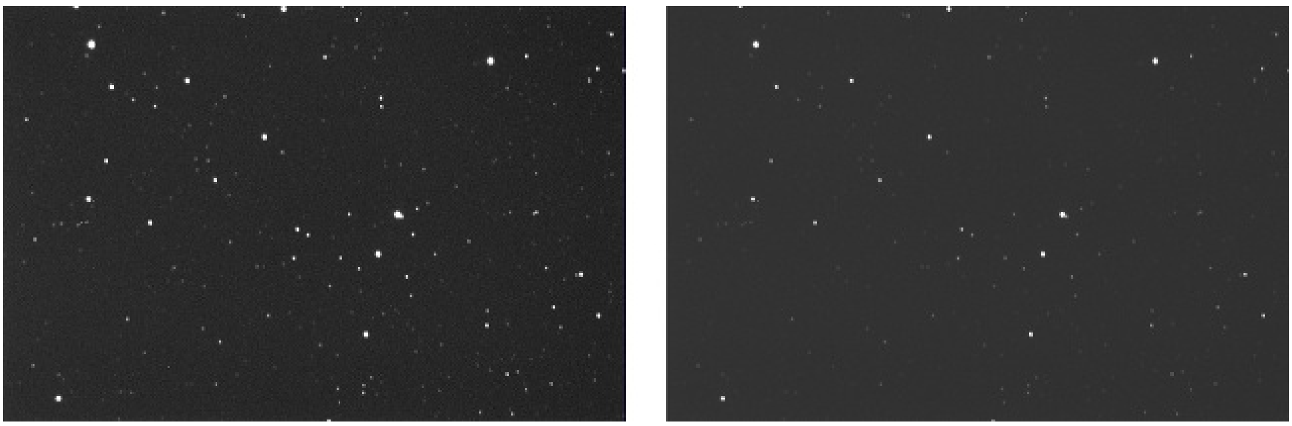

FIGURE 8 – Comparison between raw image (left) and preprocessed picture (right). The preprocessed picture has no defaults and can be exploited.

3. Vignettage : darkening of the image at the edges caused by the optics used.

5 Processing : photometry and creation of the light curve

5.1 Alignment of the images

Once our pictures were preprocessed, we had to proceed to alignment. This step is important because the frame must automatically follow the observed star, this one will never be shot exactly at the same place on screen between two consecutive shots. The process, which, once more, is automated by Iris, consists in modifying the position and the orientation of the pictures to put the star in the same position on each shot. Nevertheless, the alignment is a difficult step because if the stars are less bright in some pictures, this technic can cause a data loss. Fortunately, this has happened only for a few pictures during the alignment of our AH Cam shots.

5.2 Photometry

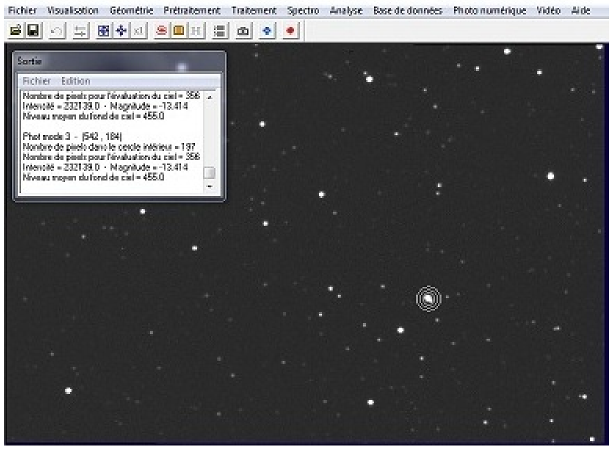

Figure 9 – Use of the photometry of opening with 3 concentrics circles, here centered around AH Cam, in the right side of the picture.

After the alignment of our shots, we had to realize the photometry. This process consists in measuring the bright of each pixel in a part of the picture which we want to analyse. To do that, we used an Iris function called "opening photometry". This function proposes many options to measure the luminous flux from a star from the picture's pixels.

We have chosen a method which consists in using 3 concentric circles of different sizes. This option allows to automatically subtract the sky's background to the luminous flux of the star by measuring it in the crown formed between the second and the third circle. This alternative allows us not to calculate the luminous flux of a star close to our star, which is included on the sky's background. The crown formed by the first and the second circles is thus an intermediate crown in which no measure is done. To get the luminous flux of a star, we simply have to give the radius of each circle after defining the parameters of the sofware Iris and to point the circle's centers to the star with the mouse. This procedure is set again for all the interesting stars, to create a bright curve. Nevertheless, this step only allowed us only to retrieve the coordinates in pixels of the stars. In fact, if we had used this process to get directly the luminous flux, we would have had to repeat the procedure 4 times for each picture. To put it in a nutshell we would have had to do this approximately 2400 times ! Fortunately, Iris was here to help us. In fact, it proposes a function called "automatic photometry" which allowed us to get the luminous flux of each star for all the pictures of a night from the coordinates of the studied stars, by reusing the circles of the photometry of opening. The software calculated the luminous flux for the same position on each picture, hence the necessity of a very accurate alignment of the shots.

IRIS created in this way a *.lst file containing the brightness data for each picture with the date in Julian Days [4] and for each star.

4. Julians Days : Dating system corresponding to the number of days elapsed since 1 Jan. -4712 at 12 pm (conventional date). So a Julian Day begins at noon.

5.3 Creation of the light curve

To exploit our data, we should import their in a board. We have use the board software of LibreOffice. This software allow us to import directly the data in .lst build by Iris. In addition we proceed of few adjustments before obtain our light curve.

First, we had to configure the data importation to put the columns side by side in the spreadsheet. To clarify the data, we added a line at the top of each column to write the caption. Then, before proceeding to the calculation, we had to replace the dot in each column by a comma. Indeed, IRIS uses dots instead of commas to write decimal numbers.

When we drew AH Cam's light curve, the result was not satisfactory so, we had to do something else before getting AH Cam's light curve. (Figure 10).

We can see that the light of references stars, which should be invariable, decays over time. This declination comes from atmospheric absorption. This absorption is increased when the sun rises.

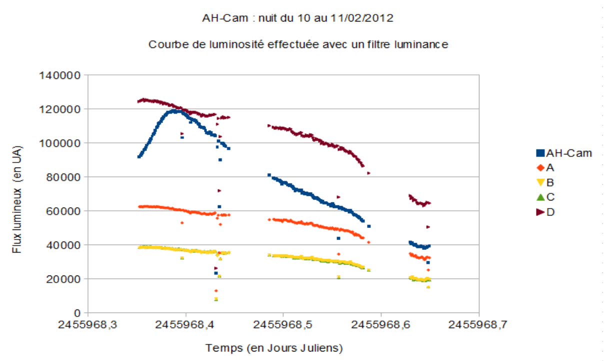

FIGURE 10 – Light curve of AH Cam and references stars, called here A,B,C,D in absolute value

Indeed, the light from the star has got a thicker atmospheric layer to cross. Besides, some points on the curve seem nonsensical. This can be caused by a number of phenomena.

The phenomena acting on all the stars are deleted while the pulsation of our star remains noticeable.

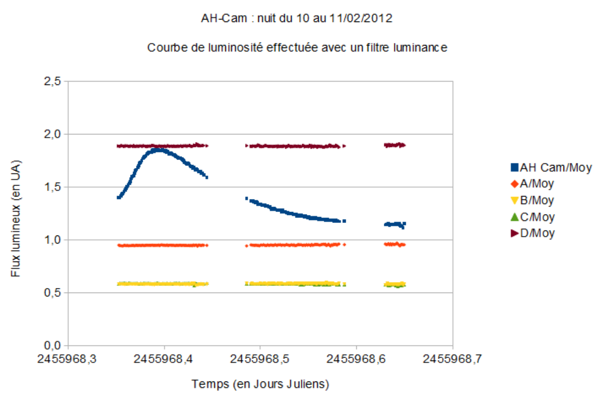

FIGURE 11 – Light curve of AH Cam and references stars, called here A,B,C,D, in relative values. The light average is called ABCD.

To obtain the result, we calculated the average of the luminosity of each reference star, it's called "Super Star". Then, we did the quotient between the luminosity of each star and the "Super Star". This step allowed us to get the luminous flux of the star(variable) compared to the references stars which are invariable. Thus we obtained light curves of our star in relation to the references stars. We can see that AH Cam is a variable star compared to the references stars which are invariable.

6 Data processing

6.1 Establishment of the maximum

6.1.1 Choice of a software

Once the light curve plotted, we must determine when the star is at the maximum of its brightness. Therefore, we must use an interpolation software. We had the choice between several softwares : Xcas, Généris, Polyreg, Libre Office's spreadsheet or Sine Qua Non. However most of them gave us an inaccurate polynomials. Moreover, they didn't take into account polynomials higher than second degree, or they didn't gave the equation (with Sine Qua Non).

We finally chose Polyreg which allowed accuracy and support big numbers.

6.1.2 Use of Polyreg

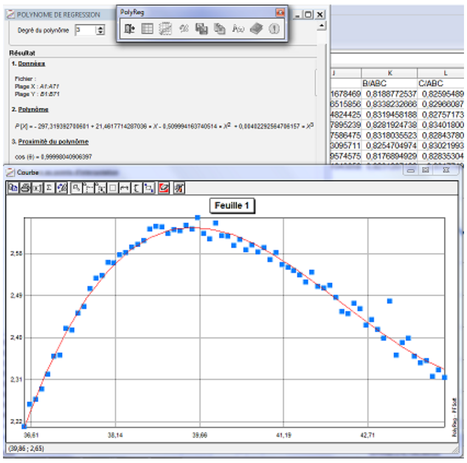

FIGURE 12 – Example use of Polyreg with a third degree polynomial, and values close to the maximum light.

When we used all the values from the light curve, the polynomial's degree was too high to determine the maximum by ourselves and the polynomial curve wasn't as congruent as our light curve. But, as we were only interested in the top of the curve, we focused on the values close to it for a more accurate interpolation.

The only thing that prevented us from doing the interpolation was the Julian Days value. Its integral part was too big for Polyreg which is limited by the length of the numbers. So it was necessary to reduce this number, firstly by removing the integral part of this number (which represent daytime) and to multiply the result by one hundred. It was also necessary to determine which polynomial degree was the most representative in the curve.

At last, we have chosen the third degree since it gave us the most congruent equation to our light curve. However, the second or the fourth degrees seemed to give better results. Actually, the polynomial degree depends on the number of point used, because with more or fewer points, the curve shape changes a lot.

So, thanks to Polyreg, we have determined a polynomial with a representative curve very similar to the top of the light curve. For this, the correlation coefficient of the curve must be very close to one.

6.1.3 Determining the maximum

To determine the date of the maximum, we have to calculate the derivative of the third degree polynomial. So, we use the determinant which gives us the variation of this function. This allowed us to find the maximum of the function, which matchs the the star maximum brightness.

This step can become very hard with the numbers used, because with our calculator, they lose their precision. As a consequence, we made a spreadsheet which gave us the variation between the two roots of a second degree polynomial. However it gave us a wrong result. We spent one hour looking for the error. The reason was that we forgo the of parentheses ! Finally, we obtained nine dates in Julian Days (cf Tables). Indeed, we have done the preprocessing separately so that our values differ.

Member	Luminance	Green	Blue	Red	Average
Antoine	2455961,4241	2455961,4234	2455961,4234	2455961,4231	2455961,4235
Dylan	2455961,4258	2455961,4233	2455961,4248	2455961,4248	2455961,4247
Samuel	2455961,4237	2455961,4240	2455961,4249	2455961,4256	2455961,4245
Average	2455961,4245	2455961,4235	2455961,4244	2455961,4245	2455961,4243

TABLE 1 – Maxima calculated by everyone on 03/02/2012, with a precision of $\pm 0,0001$ for each value.

Member	Luminance
Antoine	2455968,3971
Dylan	2455968,3963
Samuel	2455968,3968
Moyenne	2455968,3967

TABLE 2 – Maxima calculated by everyone on 10/02/2012, with a precision of $\pm 0,0001$ for each value.

Member	Luminance	Green	Blue	Red	Average
Antoine	2455978,3492	2455978,3495	2455978,3487	2455978,3488	2455978,3491
Dylan	2455978,3497	2455978,3498	2455978,3485	2455978,3499	2455978,3495
Samuel	2455978,3494	2455978,3491	2455978,3486	2455978,3503	2455978,3494
Average	2455978,3494	2455978,3495	2455978,3486	2455978,3497	2455978,3493

Table 3 – Maxima calculated by everyone on 20/02/2012, with a precision of $\pm 0,0001$ for each value.

6.2 Heliocentric correction

After finding the moment of maximum [5] in Julian Days, we had to convert it in Heliocentric Julian Days (HJD [6]) in order to have the same reference as the other scientists for the maximum moment. In fact, the Earth position during the observation would have disrupted our values so that we couldn't compare them with scientists's data who didn't do their observations at the same place and at the same time. So we need a universal reference : here the center of the Sun for the heliocentric correction, to refer to values measured by an observer situated at the center of the Sun. (voir Fig. 13).

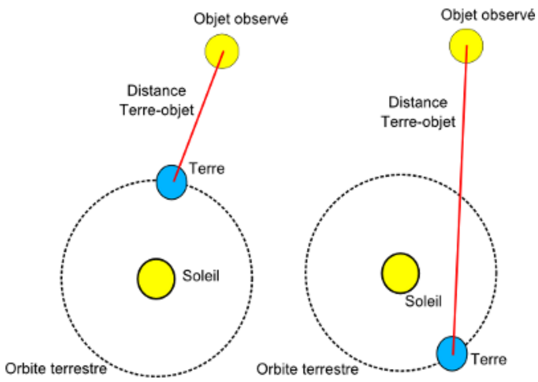

Figure 13 – Focus on the lag of the light in terms of observation date.

To convert Julians Days into Heliocentrics Julians Days, we have to take into account the difference between the time needed for the light to reach the Earth and the time needed to reach the Sun.

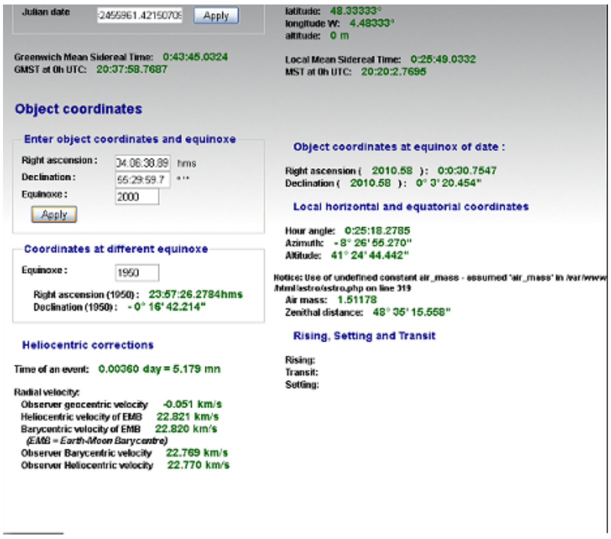

Figure 14 – Worksheet used to calculate the heliocentric correction [6].

Indeed, the distance between AH Cam and the Sun doesn't change, or it changes a little, because these two stars are in the same galaxy. However, the distance between AH Cam and the Earth changes. In fact, during one year, the Earth rotates over the Sun. The delay of the light depends on the Earth's position relatively to the Sun, so it depends on the date.

To perform this calculation, we tried to make a program, with Mr.Le Borgne's help (cf annexes L.2 et L.3), but it was too difficult and the result wasn't satisfying. Moreover, we also tried to understand heliocentric correction's formula found on the web. Unfortunately, we didn't find much information about this. So Mr.Le Borgne suggested we use the worksheet of his website (see figure 14). This allowed us to calculate out O-C saving time. Nevertheless we have tried to understand the calculation of this correction.

6.3 Calculation of the O-C

O-C means "Observed minus Calculated". The O-C calculation allows us to compare the observed moment of maximum "O" of a light curve to the moment of maximum calculated for the same night "C". This maximum can be planned knowing the period (P) and another maximum, called reference

5. Moment of maximum : Moment when the maximum brightness is present. It corresponds to a time unit (here the Julian day).

6. HJD : abbreviation for Heliocentric Julian Day, a Julian Day system applied to the sun.

maximum (JJO). JJO and P form the "elements". We prefer to use an old maximum as a reference so that all scientists would agree about its date.

Thus, to calculate a maximum, we start to calculate the number of periods (or cycles) elapsed since the JJO (called E). For this, we have to subtract the JJO's date to the maximum observed date.

For example, we take the maximum determined for AH Cam on 03/02/2012, with a luminance filter. Its value is 2455961,4245 HJD : that's the maximum observed. Then we look for the number of days elapsed since the JJO, which is 2438729,458 HJD, according to Midi-Pyrénées Observatory's website.

Therefore we execute the following calculation : $2455961,4245 - 2438729,458 = 17231,9665$ days elapsed.

To obtain the number of cycles, we just divide by the period, which is of 0,3687346 for AH Cam : $17231,9665/0,3687346 = 46732,71$ cycles elapsed.

As we need an integral number of cycles to calculate the O-C, we take a round of this value for E, i.e. in this example 46733 cycles.

Now, we have all the elements to calculate the maximum planned. Indeed, it just consists in executing the following calculation : $JJO + P \times E$. Therefore, $P \times E$ will give us the number of cycles elapsed since JJO and, adding this number to JJO, we obtain a date of the maximum planned. For our example : $2438729,458 + (0,3687346 \times 46733) = 2455961,5320618$. The moment of maximum as calculated is $2455961,532 \pm 0,001$ days. By precaution, we keep as many significant digits as professional scientists.

To finish, we substract this maximum calculated from the maximum observed and we obtain the dfference between them : our O-C value. For our example, This results : $2455961,4245 - 2455961,532 = -0,108 \pm 0,001$ days. It means that the maximum arrived 0,108 days ahead of the maximum planned.

So we have a gap between the maximum planned and the maximum observed, which shows that the phenomenon doesn't have a stable period, otherwise the O-C would be zero. Therefore we can suppose that another phenomenon affects the light curve progress of our star.

We can summarize this by the following calculation :

$$O - C = JJH - (JJO + P \times E)$$

With :
- *JJH : the date in Heliocentrics Julians Days of the maximum observed*
- *JJO : the date in Heliocentrics Julians Days of the Origin Julian Day (reference) (for our calculations : 2438729,458 days)*
- *P : the average period of the star light in days which is 0,3687346 for AH Cam*
- *E : the number of cycles elapsed since the maximum reference date (JJO) which is obtained with :* $E = \frac{JJH - JJO}{P}$

Here are the results of our O-C for each night obtained with the luminance filter, but these results don't vary much from those obtained with color filters :

Member	Night from 3 to 4 February	Night from 10 to 11 February	Night form 20 to 21 February
Antoine	-0,108	-0,141	-0,145
Dylan	-0,106	-0,142	-0,144
Samuel	-0,108	-0,141	-0,144
Average	-0,108	-0,141	-0,144

TABLE 4 – O-C calculated individually for each night, with an accuracy of $\pm 0,001$ for each value. Once again, our values differ since we have all done our preprocessing and our interpolations so that our values of maximum differ, so our O-C values differ too.

7 Interpretations

7.1 The Blazhko effect

The Blazhko effect concerns about 40 to 50 % of RRab stars. It was discovered in 1907 by Sergei N. Blazhko (1870-1956). It consists in a modulation in amplitude and period of the star's light curve.

Currently, we don't know the cause of the Blazhko effect. Some "tracks" could have been explored thanks to Kepler satellite since the study of this phenomenon needs a regular sampling and because on earth, the sun light is a considerable obstacle. Three main hypothesis have been mentionned. This effect could be due to the magnetic field of the star which would rotate in a different direction to incandescent helium's rotation. However, this hypothesis is unlikely. For a while, the hypotesis of a polarized light has been mentionned, but has been quickly excluded. Finally, the hypothesis which is the most likely is the one which supposes the presence of resonances between the various types of variations which affect the star.

As it is previously stated, the Blazhko effect will impact the brightness peak which will fluctuate in time and in amplitude.

7.2 Comparison with professional data

To check if our measures were correct, we had to compare them to those of professionals. To do this, we made the O-C graph as a function of the time with professionals' data and we added our measures to it.

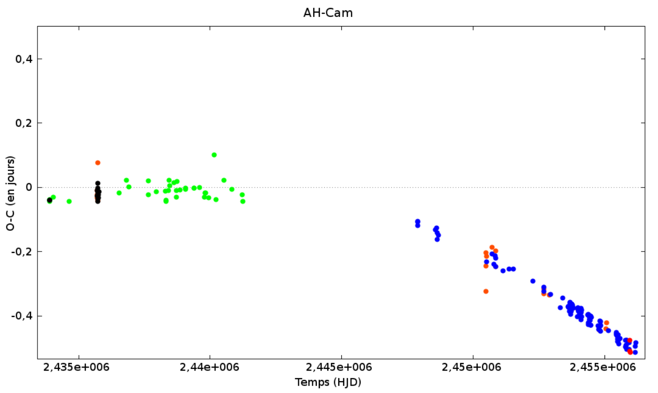

FIGURE 15 – O-C graph with *period shift* [7]. Colors meaning : green : photographic ; orange : visual ; blue : ccd ; black : unknown. Our measures are in red color in the bottom right-hand corner.

We had to consider the various possibilities with which this graph could be made. Indeed, we could calculate the O-C with several elements defined by various scientists, which did not lead to the same graph. Moreover, it is possible to use an option *period shift*, which consists in removing a period in the calculation because the shift due to the blazhko effect is too important.

There are also many methods of acquisition, depending on the wavelength and the sensor (visual, photoelectric, CCD or photographic), and of the determining of maxima (by interpolation or other methods). But they don't seem to affect the O-C graph progression on a long period, according to figure 15.

If we compare our data only with this graph, we could not verify their accuracy exactly. Indeed, we can see our measures in the scatter plot in the bottom right-hand corner, and it enable us to know that our measures are in line with the decrease of the period. Those measures are different from those given in Table 4 because the option "period shift" is enabled. However, we can't see the variation of O-C due to the Blazhko effect because the graph scale is too big and we can't see the variation of period.

Thus, we had to make this graph with greater precision. So, we selected data on a short interval, and wich didn't take into account the

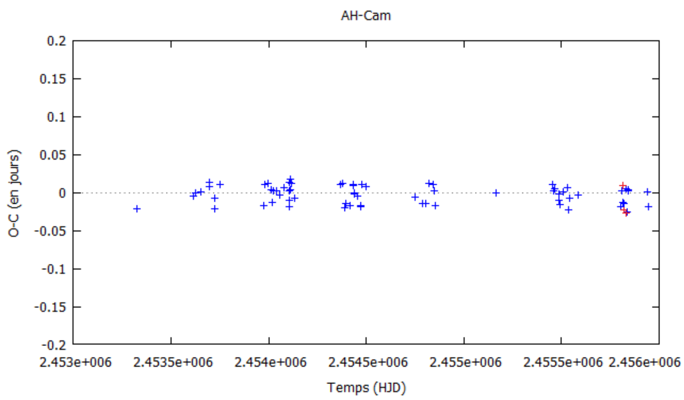

FIGURE 16 – O-C graph obtained on a short period (between 2453000 HJD and 2456000 HJD). So, this graph enables us not to take in account the period decrease. Our measures are in red.

decrease period (Fig. 16). Indeed, on this interval, the period has a value determined by the professionals of 0,368716 day, and we consider that it does not decrease on such a short interval [8].

This graph enables us to see that our points are not aberrant because they are in accordance with the progression of professional's ones by being in the scatter plot. Therefore, they seem to correspond.

Then, we sent the result of this graph to Mr Le Borgne so that he could verify our measures and they seemed correct to him. So it encouraged us to continue.

After, he advised us to make the O-C graph as function of the Blazhko phase [7] to confirm their validity.

So we made this graph so as to observe the periodic progression of the maxima in time.

For this graph too, some data were not obtained with a CCD camera but with a visual or photographic observation, and some maxima were determined thanks to an average curve of measures made on a long period (several months) and they were not individual maxima. So we had to sort those measures.

Then, we calculated the moment of the Blazhko phase which corresponded to each of our maximum moments as well as those of professionals. To calculate this Blazhko phase, we have to know the Blazhko period, that is the time taken by the Blazhko effect to return to its starting point, and to choose any maximum of reference but which remains the same.

Next, we do the following calculation and we keep only the decimal part of the result : $\frac{HJD-JD_{ref}}{T_{Blazhko}}$

With :

- *HJD : the date in Heliocentric Julian Days of the maximum concerned*
- *JD_{ref} : the date in heliocentric Julian Days of the maximum of reference*
- *$T_{Blazhko}$: the Blazhko period in days*

However, we didn't know the Blazhko period. We had found a value of 10,9 days in the American documentation [9] but this period didn't enable us to obtain a scatter plot which would look like a curve (see Fig. 17).

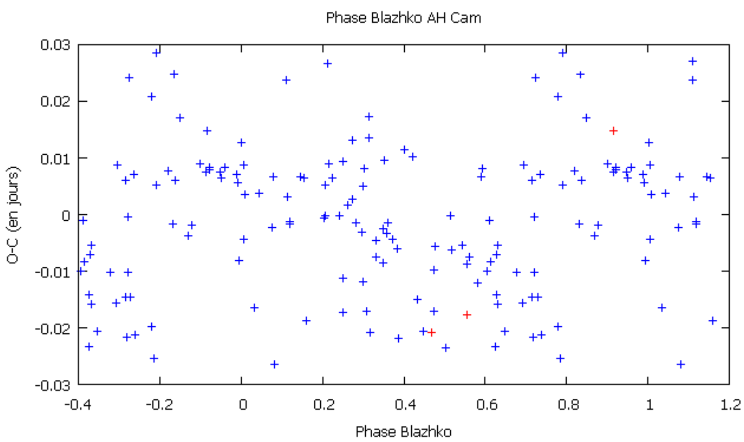

Figure 17 – Representation of O-C as a fonction of Blazhko phase obtained with a Blazhko period of 10,9 days. Our measures are in red.

This graph does not reveal a real signal of the phenomenon because we observe a diffuse scatter plot. So it's not workable. We deduced that the Blazhko period of 10,9 days may be wrong.

So, we tried reveal a curve. To do that, we processed by trial and error in order to find a Blazhko period which good results. But the period change to the nearest hundredth gave us completly diferents results (see Fig. 18).

7. Blazhko phase : This phase is in fact the advancement of the Blazhko period.

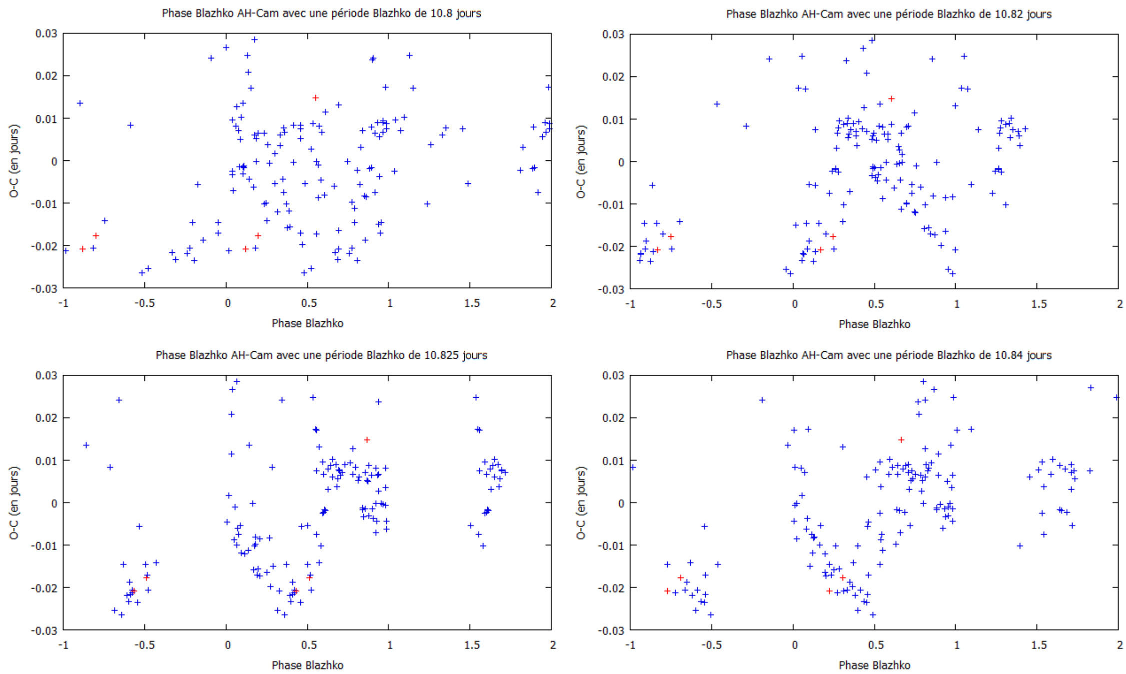

Figure 18 – Representations of O-C as function of Blazhko phase obtained with various Blazhko period. Our measures are in red.

So, after many tries, we evaluated this period at 10,83 days. This gave us the following graph :

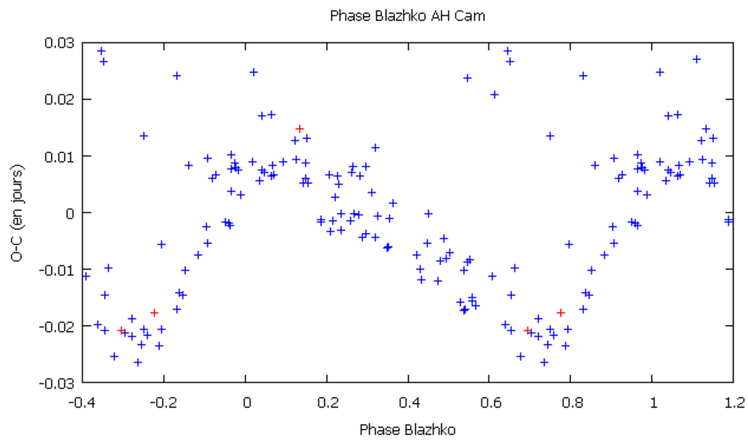

Figure 19 – O-C graph as a function of Blazhko phase obtained with a Blazhko period of 10,83 days. Our measures are in red.

So we obtain a real curve which shows us the progression of the Blazhko effect and our points correspond to this progression. So we can think that our measures are in accordance with those of professionals. Besides, Mr Le Borgne published them on the professionals' database.

We shared this result with Mr Le Borgne who answered that he had published the period one work before with a value of 10,8289 days [10]. So our estimation was very close to the result and very close to the moment of publication ! Moreover, the shape of our curve is very similar to the one of the scientists (see figure 21).

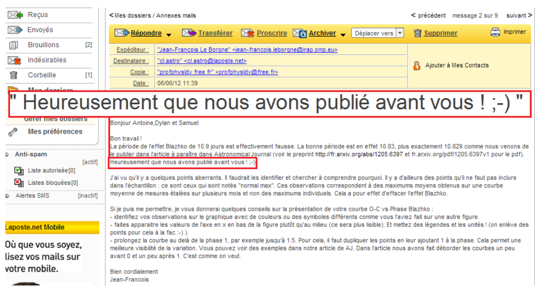

Figure 20 – Mr Le Borgne's mail about AH Cam's Blazhko period

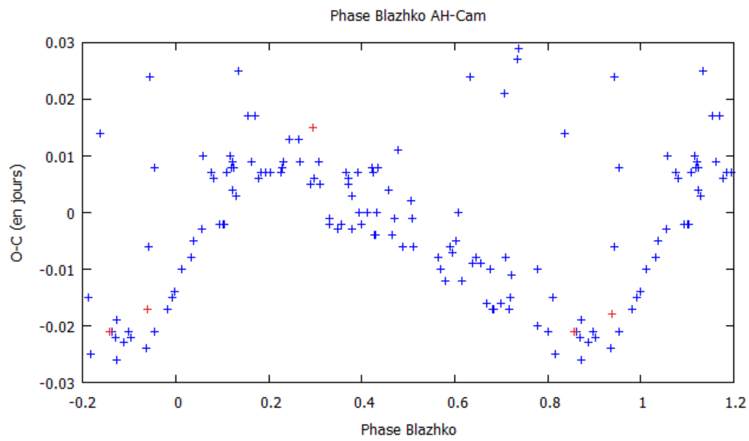

Figure 21 – Representation of O-C as a function of Blazhko phase with the Blazhko period determined the professionals. Our measures are in red.

All of this enabled us to shape our search and to validate our measures. So we were even more eager to realise the sequel of our project.

7.3 Animation which represents the evolution of AH Cam's light curve

We also tried to represent the Blazhko effect with a morphing software. Indeed, thanks to the O-C, we had been able to grade our curves to bring out this effect significantly. To make this animation, we firstly attempted to use our three curves only, but the result was meaningless. So we asked Mr.Le Borgne if he could send us some data so that we could have more curves to show a full Blazhko cycle. He accepted and sent us more than 5000 measures that we had to sort so as to keep only those which represented an almost full period and mainly with what interests us : the maximum.

Then, we calculated the pulsation phase for each measure in order to have corresponding curves since this pulsation phase represents the proportion of an average period on which each measure is located. Thereby, all of our curves were located beside a reference period. This enabled us to see the light curve in a period, and so, it enabled us to bring out the Blazhko effect on AH Cam. We also put our curves in phase Blazhko's order so as to see this cycle.

However, we met some difficulties. Indeed, since the period of AH Cam fluctuates, the pulsation phase changes too and so we can see a slight shift for some curves. Furthermore, we abandoned the idea of using a morphing software because the result was less significant than with an animation.

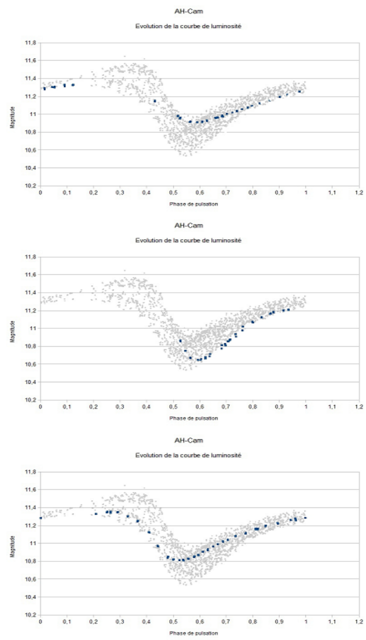

Figure 22 – Pictures taken from the animation at three differents moments

7.4 Decrease of the period

With the O-C study, we faced a new problem.

In the two cases, explained below, a period decrease corresponds to an O-C decrease since maxima appears increasingly early. Here, each period of the function represent, schematically, a pulsation period of the star.

In this first case (figure 23), the period's modification is due to a punctual event, and this event will lead to a period decrease. In this case, the O-C graph will take this shape, considering linear regressions of the two exact parts. So we could see two distinct part of lines.

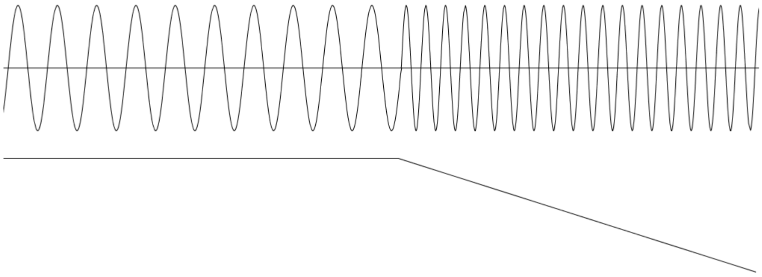

Figure 23 – Curves representing the effect on the period of a linear rupture on the O-C graph (above) and the linear rupture on the O-C graph (below).

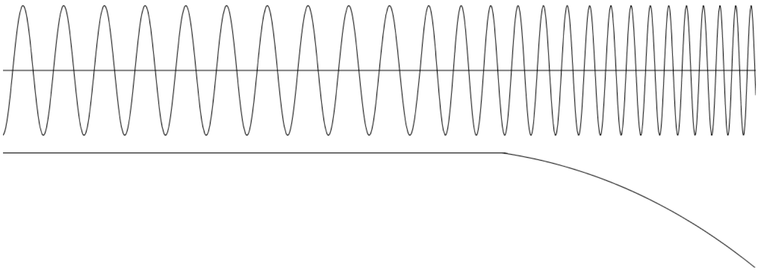

Figure 24 – Curves representing the effect on the period of a parabolic rupture on the O-C graph (above) and the parabolic rupture on the O-C graph (below).

In this second case (figure 24), the period's modification is due to an event which can come back cyclically for some RR Lyrae. Here, the period may accelerate and slow down alternately. In the case of an acceleration, we will be able to observe a line and then a parabolical decrease in the O-C graph, but without a clear rupture in this case.

Comparing the O-C graph of AH Cam (see Fig. 15) to those two cases, we will be able to determine how our star evolve.

At the sight of figure 15, we could tend to think that the first case is the right one. Yet, according to Mr Le Borgne, it's the second case which would be validated. The only problem is that the part of the graph wich could enable us to decide is missing. However, we can see a slight curve on the blue part. So we have to do the maximum number of observations in a future time to solve this problem.

You can see the same kind of variation in most RR Lyrae as for SW And (Figure 25).

This modification of period could be due to the evolution of the combustion of the star to the stage of helium combustion that involves changing the internal structure of the star like some RR Lyrae. Therefore, a change in temperature and radius occurs which causes a variation in the period.

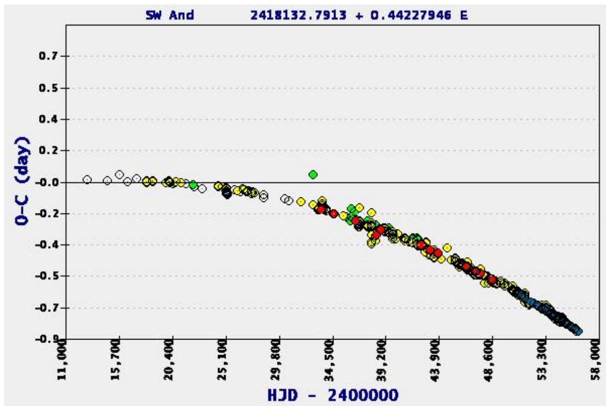

Figure 25 – O-C graph SW And. Colors meaning : green : photographic ; yellow : visual ; red : photoelectric ; blue : ccd ; no color : unknown

So, we need more measurements to determine whether the evolution of O-C is parabolic or if it is a linear rupture. Therefore, our measures participate in helping scientists answer to this question and it's also why we must continue to study this star.

7.5 Study of the star's color

7.5.1 Time-related study

We calculated the date of the maximum of brightness for the pictures taken with each filter. Since this date was not different for each filter, we deduced that the variations of brightness were simultaneous for the colors. So the colors are synchronized. For our measures from the night of the 2012-02-03 for example, we have on average :

- for the luminance : a maximum at 2455961,4245 JD
- for the green filter : a maximum at 2455961,4235 JD
- for the red filter : a maximum at 2455961,4244 JD

– for the blue filter : a maximum at 2455961,4245 JD

We can still notice a slight variation between the average of the green filter and those of the others. However, this difference is probably due to measurement error. Anyway, it doesn't seem logical since the variation happens from the red to the blue, or conversely, the green is just an intermediary. Whereas in this case, only the green changes while the red and blue stay unchanged.

7.5.2 Amplitude study

Then, we wondered whether the Blazhko effect had an effect on the star's color, not in time, but in amplitude. So we calculated the quotient between the various light curves performed with filters, that is to say the quotients B/G, G/R and B/R for each night for which we had colors curves (B, G and R correspond respectively to the Blue, the Green and the Red).

Thanks to these curves, we had been able to say that the color balance of the star fluctuates firstly during pulsation of the star. So, it comes in contradiction with what is stated in the previous paragraph. Indeed, we note that the quotient B/R at the peak brightness is higher than 1, which means that the star is "more blue than red" and the trend is reversed out of the area of the peak, so at the minimum of brightness, for all nights.

We could also affirm that the Blazhko effect had an influence on the color of the star by comparing the curves of the two nights. We can see a difference between curves B/R of the 2012/02/03 and B/R of the 2012/02/20. This difference is noticeable at the peak of brightness, indeed, we see firstly that the two curves do not have the same shape, and then we observe different values. To verify this hypothesis more precisely, we calculated the ratio of these two curves and noticed that it was not constant. So this hypothesis is verified.

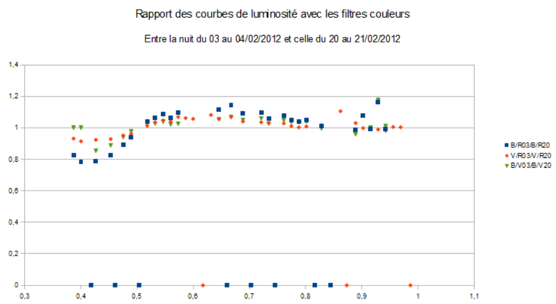

Figure 26 – Curves of the ratio of light's ratio between the nights of 2012/02/03 and of 2012/02/20

According to Mr.Le Borgne, we have clearly shown that the Blazhko effect had an influence on the color of the star. But according to him, it is necessary, to ensure that our data is really workable, to establish another procedure. That is to say it's necessary to trace the curves in magnitude difference instead of in flux ratio : for example, $B - G = -2,5 \times \log 10(\frac{signal\ B}{signal\ G})$ Moreover, it's necessary to put the curves B-G from each night on the same graph, and also for G-R and B-R. Then, we have to trace the curves (B-G)(2012/02/03)-(B-G)(2012/02/20), as for the other nights.

However, we have not been able to perform this study in difference of magnitude due to lack of time and lack of resources.

8 Conclusion

This project enabled us to gain a lot of knowledge about the study of stars. It also showed us that it's difficult to study the variability of a RR Lyrae star, even more with amateur equipment.

During this project, we determined some characteristics of the star we studied. First, we estimated its pulsation period at about 8 hours. Then, thanks to the O-C, we verified that AH Cam is submitted to the Blazhko effect. Moreover, we determined, only one week later than the scientists, that the Blazhko period wasn't 10.9 days but 10.83 days.

We also showed that the temperature variation is not late or in advance relative to the maximum. So the pulsation period is directly related to a change in the star's color and therefore in its temperature. The star is hotter during the peak brightness. We can detect a small influence of the Blazhko effect on the color of the star at the peaks of brightness.

A priori, the evolution of the period of AH Cam is regular and evolves progressively to an advance of one period which corresponds to an acceleration. This change is not due to a sudden effect.

Finally, we participated in scientific research, which really motivated us, and our data has been published on the website : `http://rr-lyr.ast.obs-mip.fr/dbrr/dbrr-V1.0_08.php?AH%20Cam` and also on Mr Le Borgne's web page : `http://rr-lyr.ast.obs-mip.fr/Gwenchlan-project/gwenchlan-V1.0_2.1.php?AH%20Cam`

Of course, we have to thank again Mr.Le Borgne without whom we would not have discovered all this knowledge and Mr.Rives, who enabled us to complete this project by guiding us in the field of astronomy, even if he discovered at the same time as us notions about the variable stars.

However, this project is not finished. We must continue our research since there are missing values to determine how the period of the star really evolves. It is also important to study AH Cam and other RR Lyrae to understand the Blazhko effect, on which we learned that it influences the color of the star. We also need to complete the study of color, by tracing the curves in magnitude difference. So this is a subject of continuous study, which has its place in scientific research.

Bibliography

[1] Cor Caroli Obesrvatory. `http://www.obscorcaroli.eu/rr_lyrae.html`.

[2] R. Scuflaire. Étoiles variables, 1999-2000. Document used for the information about variable stars.

[3] Developer : Patrick Chevalley. "cartes du ciel" software. License GPL (General Public License). Official website : `http://www.ap-i.net/skychart/`.

[4] RVB Astronomik filters for CCD trichromy. `http://www.optique-unterlinden.com/catalogue/produit/m/13/p/AS010`. Website for the picture about the filters.

[5] Tutorial about IRIS usage. `www.astrosurf.com/buil/iris/iris.htm#tutorial`. Used for the learning of Iris.

[6] Mr. Le Borgne's calculation web page. Web adress : `http://rr-lyr.ast.obs-mip.fr/astro/`.

[7] GEOS RR-Lyr database. `www.rr-lyr.ast.obs-mip.fr`. Database about RR Lyrae stars.

[8] GEOS RR-Lyr database. `http://rr-lyr.ast.obs-mip.fr/Gwenchlan-project/gwenchlan-V1.0_2.1.php?AH%20Cam`. Mr. Le Borgne's data for a period shorter and not taking into account the decrease of the period.

[9] Horace A. Smith and Al. Ah-cam : A metal-rich rr lyrae star with the shortest known blazhko period. *The Astronomical Journal*, page 12, February 1994. The information which interess us about the Blazhko period is on page 12, on the top of the right column. Available at this web address : `http://adsabs.harvard.edu/abs/1994AJ....107..679S`.

[10] Jean François Le Borgne and Al. The all sky geos rr lyr survey with the tarot telescopes. analysis of the blazhko effect. *The Astronomical Journal*, page 8, Mai 2012. The information which interess us about the Blazhko period is on page 12, in the top of the right column and on page 8, in the third line of the table. Available at this web address : `http://fr.arxiv.org/pdf/1205.6397v1`.