

Automatic Cartography of the Deep Sky under Iris

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1 Introduction

This document describes a number of functions available in the software Iris (V5.52 and later) making it possible to assemble mosaic images of the deep sky automatically, especially raw images acquired with a Digital camera. These are specialised tools which are provided to allow a series of RAW images to be processed into a final mosaic in a cartographic projection of choice. The images targeted are more particularly those carried out with photographic optics of short focal length, ideally between 50 mm and 200 mm focal length. The envisaged applications include creating wide field images of the celestial sky for aesthetic and educational purposes, as well as the inter-comparison of images acquired on different dates (possibly with different instruments) in order to facilitate the detection of variable stars, novae or new comets.

These functions are written to allow bulk processing of large batches of survey type images. The functions call user defined text files which contain a list of parameters that guide the function operation. It is a matter of writing these script files using a basic text editor (using Notepad in Windows for example). Essentially, the whole operation rests on three macro commands which can be launched from command console of IRIS as follows :

1. SV1 : Carries out complete processing of the RAW digital camera files, followed by optical distortion correction and finally astrometric reduction.
2. SV2 : This command takes the images of the preceding stage and geometrically transforms them into a defined cartographic project and coordinate system, then assembles them into a single image.
3. SV3 : This command makes it possible to draw a list of coordinates in the cartographic representation created from the preceding stage, and to draw the trajectory of a mobile object or to delimit the contour of the constellations.

2 Initialisation

First of all it is necessary to carry out some adjustments in IRIS. Open the **Settings** dialog box as shown in figure 1 (**File** menu). In this example the TYCHO-2 catalogue shall be used. This catalogue is recommended here taking into account the "large-field" of the exploited images. It offers an ideal density of stars, very precisely positioned, while being a complete catalogue of relatively reduced size. This catalogue contains 2.5 million stars down to approximately magnitude 12 and can be downloaded on the Web. In the example the catalogue is placed in the directory `c:\tycho\data` of the hard disk (see figure 2). See Web address at the end of the section for download TYCHO-2.

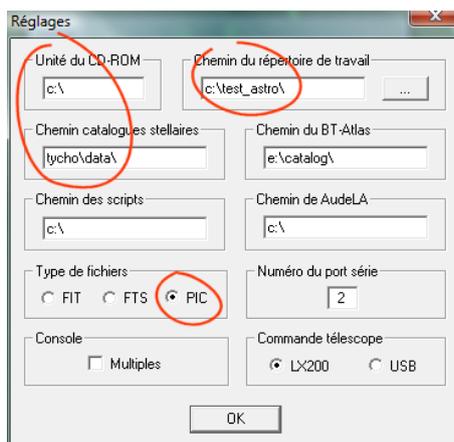


FIG. 1 – The dialog box showing IRIS settings. It is important to select the format PIC and to define the path designating the place of the hard drive where the images are to be processed (the *Working directory*), as well as the location of the star catalogue that will be used during the Astrometric reduction.

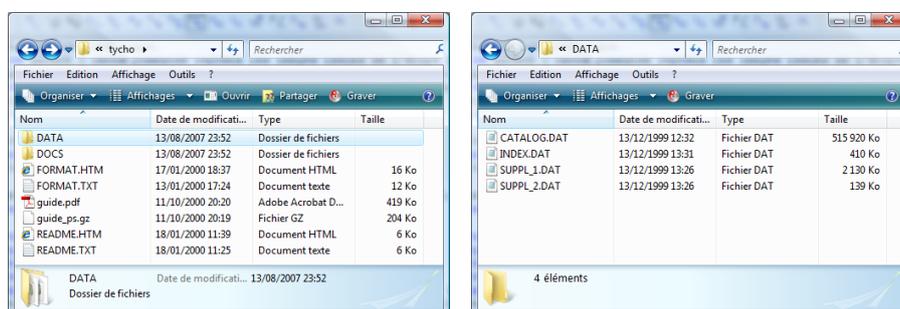


FIG. 2 – The location of the catalog TYCHO-2 on the hard disk in this example.

The second adjustment is to set the digital camera definition. Click on the camera icon on the toolbar to display the dialog box. Adjusting the camera (see figure 3) and select the type of digital camera for which the raw images will be processed.

At this stage you can verify the correct settings of stellar catalogue. Display a digital stellar sky map, it is the more simple. From the menu **Data base** run the command **Display a sky map**. See the figure 4 example. It is important to run one once this checking procedure is you change the catalog name.

It is possible also to use the SKY2000 catalog for moderate focal length lens (50 mm - 100 mm) (download the 5.52a version of Iris and upper). See the configuration example given in figure 5.

You can download the SKY2000 catalog here (6.7 Mb) :

<http://astrosurf.com/buil/iris/zip/sky2000.zip>

You can download the TYCHO-2 catalog here (168 Mb) :

<http://astrosurf.com/buil/iris/zip/tycho.zip>

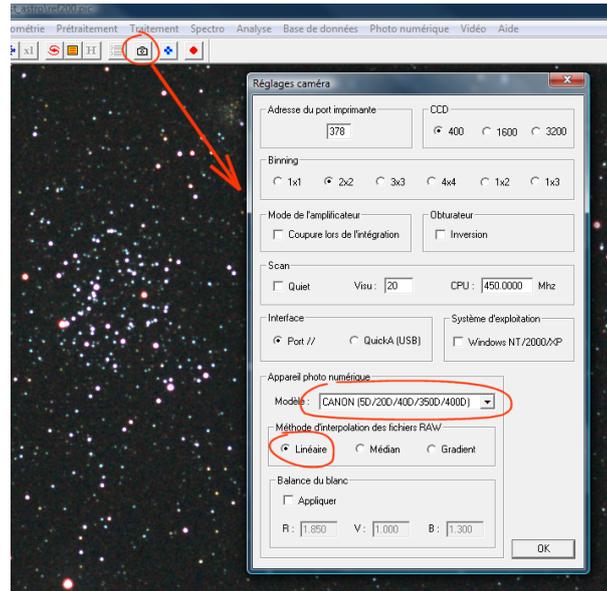


FIG. 3 – Select the type of camera used (here the canon EOS 40D is used). It is recommended to select the *Linear RAW interpolation* method. The stellar images are less fine with this option, but it also minimizes the risk of artifacts and preserve the photometric quality of the original RAW images.

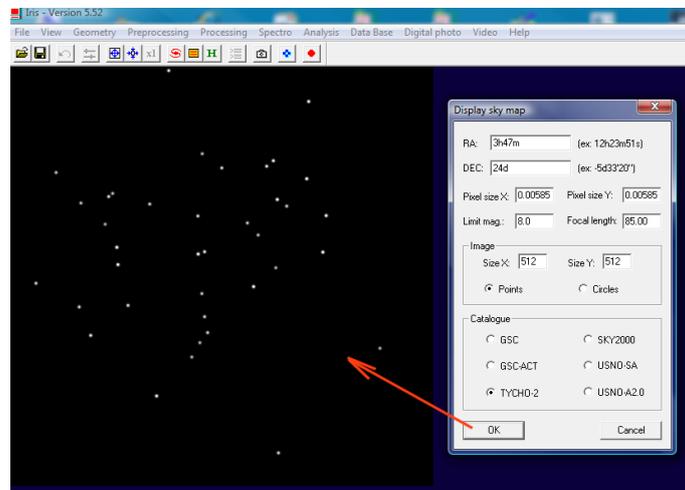


FIG. 4 – Display of the Messier 45 field by using TYCHO-2 data (equatorial coordinates $\alpha=3h47m$ et $\delta=24^\circ$). The size of the output image (512 by 512) is here arbitrary. If you re-run the sky map command, you can before erase the actual image, for example by using the console command `>FILL 0`.

3 SV1 : Pre Processing and astrometric reduction

We develop an example to demonstrate the operation of the **SV1** function. Here 4 images in the region of the cluster Messier 35 are taken with a Canon 40D camera equipped with a Canon 85mm f/1.2 lens with aperture set to f/2. Each individual image is a 30 seconds exposure with gain set to ISO 100. The exposures are made from an urban area. In the working directory the RAW files to be processed (CR2 extension) are named IMG_1237.CR2, IMG_1238.CR2, IMG_1239.CR2 et IMG_1240.CR2 (see figure 6).

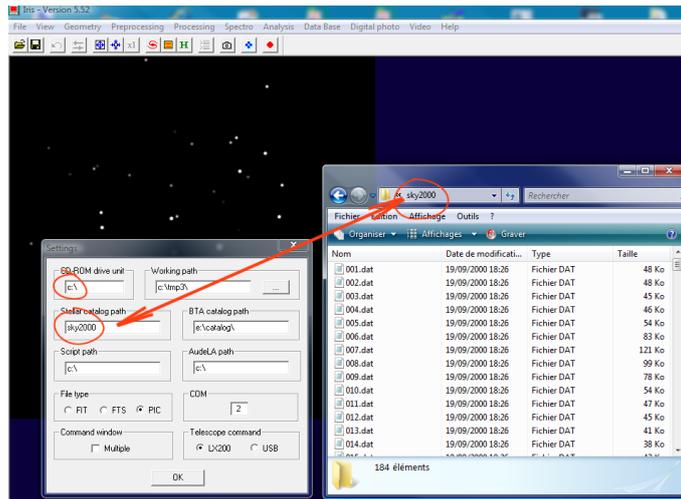


FIG. 5 – Example of configuration of the software for use the SKY2000 catalogue.

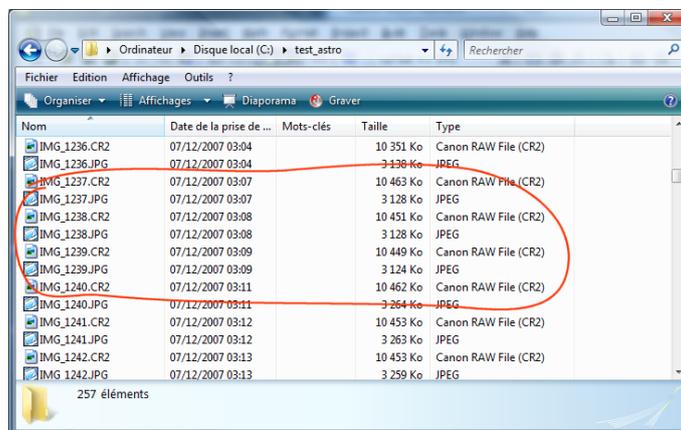


FIG. 6 – The list of the files to be processed in the working directory. RAW files here are accompanied by a JPEG. The latter are not essential.

A number of elements must be brought together to run the **SV1** command. Firstly, it is necessary to obtain the master offset (or bias) frame, dark frame and flat-field images. These master images are essential for carrying out serious pre-processing of the RAW images. The way to achieve these master calibration images is not discussed here, all the details are given pages http://astrosurf.com/buil/iris/tutorial3/doc13_fr.htm and <http://astrosurf.com/buil/iris/roadmap/helpfr.htm>.

In this example the master calibration images are in the working directory and are named **OFFSET**, **FLAT85** and **DARK** (see figure 7). Also a map of hot pixels is stored in file **COSME.LST** as generated with the command **FIND_HOT** (typically adjust the parameter threshold of this command to identify the 20 to 200 most intense pixels in the image **DARK**). Also determine the approximate size of the pixels of the sensor in millimeters and the focal length of the lens, also in millimeters. The real focal length is often not strictly that advertised by the manufacturer and discrepancies can reach a few percent. For simplicity, the focal length is assumed 85.0 mm and the pixel size parameter is adjusted to meet the correct image scale (arcsec per pixel). For the Canon 40D it is taken that the pixel size

0.00585 mm pixel (the true dimension must be in the range of 5.8 microns). The impact of this value is not critical but it is recommended to keep the same value focal length and pixel size for all images made with the same lens/camera combination.



FIG. 7 – From left to right, the image OFFSET, image DARK, image FLAT85.

Also the approximate equatorial coordinates of the center of the image are required (the accurate values will be found automatically by the software during the execution of the **SV1** command). An easy way to find the centre coordinates is to plot a cross-hair at the centre of the image and then compare this to a planetarium program (see figure 8). For example from the IRIS console :

>CENTER

A precision of a few minutes of arc on the co-ordinates of the centre is completely acceptable. In this example the following centre coordinates are adopted : RA=6h07m and DEC=24d17'.

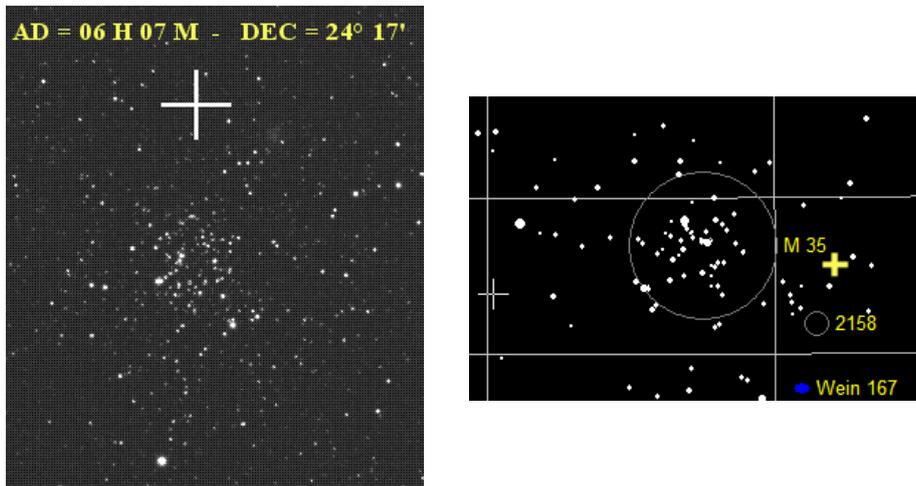


FIG. 8 – A the left, a part of image IMG_1237.CR2, towards its center (the cross is generated with command **CENTER**). On right-hand side, a chart of the same field generated with the Megastar software (obviously any other planetarium software is suitable). The approximate co-ordinates of the center are obtained by comparing these two images.

It is now necessary to use a text editor (i.e. Windows Notepad is perfect) to write a small script file that contains a list of instructions for the **SV1** command to execute. These instructions specify the images names and parameters required for processing. The first line of this file, which must start with the character "@", contains the name of the master calibration images and the parameters of the astrometric reduction chosen. This line contains 13 columns (or 13 fields if one prefers), separated by at least a white. Here is their full description :

- Field 1 : Mandatory character @.
- Field 2 : Filename of the master *offset* image.
- Field 3 : Filename of the *dark* frame (this image should contain only the signal of darkness i.e thermal signal, which means that the offset signal has been removed, therefore the median value should be about 0). The integration time employed to carry out the dark file must be the same one as that employed for the science frames made of the sky that are being processed here.
- Field 4 : Filename of the *flat-field* image (a true image of flat field thus, with the offset signal removed).
- Field 5 : Filename of the cosmetic defects list (it contains the list of the hot points typically created from the **FIND_HOT** command. If there are no defects of note then an empty text file may be specified here.
- Field 6 : Size of window to be used for 3 zones stellar registration (this operation ensures that the stars in the image sequence are correctly aligned). Refer to http://astrosurf.com/buil/iris/tutorial2/doc10_fr.htm for more information on this method. A size from 200 to 350 pixels is in general a good choice (see also **Stellar registration** command of **Processing** menu).
- Field 7 : Flag specifying whether color or black and white processing is to be performed. If this field is equal to 0, then the process delivers at the end an image with 48-bit color. If this field is equal to 1, then the result is a black and white image (the summation of the red, green and blue channels of the digital camera RAW file, prior to any white balance being performed). For faster processing, Black and White mode is useful (it requires less computer resources). This is useful if the aim is for new object detection.
- Field 8 : Right ascension of the centre of the image in the format hours, minutes, seconds. For example, following syntax's are acceptable 9, 9h, 9H, 9h30m, 9H30M34.3S.
- Field 9 : Declination of the centre of the image in the format degrees, minutes, seconds. For example, following syntax's are acceptable 9d, 9D, 9d30', 9D30' 34.3", 9d30' 34.387".
- Field 10 : Focal length in millimetres of the camera lens/telescope.
- Field 11 : Pixel size in millimetres.
- Field 12 : Orientation of north in the starting images. The possibilities are up, down, right and left.
- Field 13 : The generic name of the resultant image after processing. Iris adds an index to this name, which increments by one each time a line starting with the character @ is met.

In this example the first line of the command file will thus be written (with 48 bit color processing) :

@ offset dark flat85 cosme 200 0 6h07m 24d17' 85.0 0.00585 left t85_

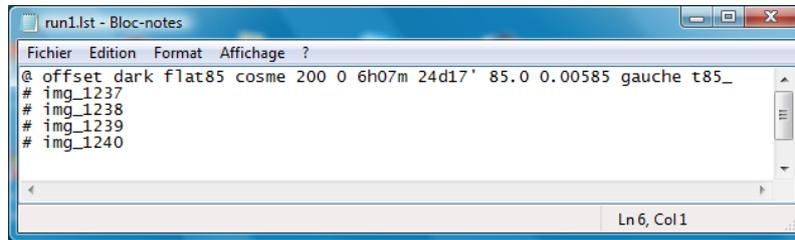
The filename of the resultant output image will have the name *t85_1.pic* (to the generic name t85_, Iris adds index 1 and completed by the .pic extension). The image will be color since the field number 7 has a zero value.

Following this first line, the successive lines contain the name of the images to be processed (a line per image). The first character of a line image is a mandatory #, followed by at least one space, then name of the file. In this example :

img_1237
img_1238
img_1239

img_1240

Note that the name of the files can be preceded by a path if the images are not in the working directory. The final script file is then given in figure 9. This file may be given any name but must have the extension .lst. For example here RUN1.LST.



```
run1.lst - Bloc-notes
Fichier  Edition  Format  Affichage  ?
@ offset dark flat85 cosme 200 0 6h07m 24d17' 85.0 0.00585 gauche t85_
# img_1237
# img_1238
# img_1239
# img_1240
Ln 6, Col 1
```

FIG. 9 – Contents of the script file to be used in conjunction with command **SV1**. Script file contains a list of instructions for processing and astrometric reduction.

To run the processing, open the IRIS command console and enter :

>SV1 RUN1

note : do not include the lst extension for run1.lst

The processing carried out is complex, and according to the speed of the computer, the number of images concerned and the size of the files, it can take several minutes to several tens of minutes per image. Here is a summary description of the operations carried out :

1. The decoding (or development) of RAW images.
2. The complete pre-processing (subtraction of the offset, the dark, division by the flat-field, correction of the cosmetic defects). This processing is in conformance with the Pre-processing dialog box under the Digital Photo menu option. Note however, that optimization of the thermal signal is not carried out. It is therefore necessary that the dark image (or thermal signal) is acquired under conditions close to those of the images to process (or adjusted before).
3. Registration of the images using the three zone method (the software evaluates the translation, the rotation and the scaling between the individual images).
4. Addition of the images of the sequence.
5. The evaluation of the background of the sky and the subtraction of this sky to the composite image (uses a method with two passages, first of all a polynomial adjustment, then a local estimator, which corresponds to the menu commands **Remove Gradient (Polynomial Fit)** and **Remove Gradient (Local Estimator)** (**Processing** menu).
6. The precise evaluation of the optical distortion by comparing the position of stars in the image and the catalogue (Iris calculates the A1, A2 and A5 coefficients of an odd polynomial of the fifth order describing the distortion).
7. Correction of the optical distortion by modifying the image geometrically.
8. The astrometric reduction (the connection between the (x,y) pixels coordinates and celestial coordinates).
9. The geometrical transformation of the image in a gnomonic reference frame with north at top (gnomonic : central projection of the objects on a tangent plane to the celestial sphere)

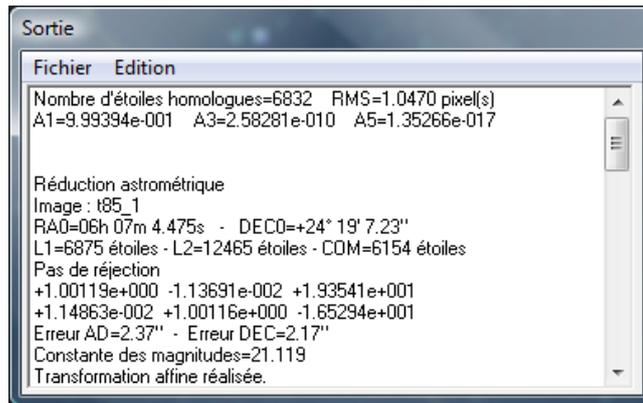


FIG. 10 – Data output at the time of the correction of the geometrical distortion of the images and at the time of the astrometric reduction.

At the end of the process, the last processed image is in memory and displayed (and also saved in a file in the working directory, under the name `t85_1.pic` in this example). The output window also displays key elements of calculation, as shown in figure 10. This displays the number of stars homologous between the star catalogue and those found in the image in the course of astrometric processing. These stars are exploited for the calculation of the optical distortion. The coefficients $A1$, $A3$ and $A5$ are also displayed. At this stage, a value close to unity for the $A1$ coefficient is a sign that the ratio between focal length of the lens and the size of the pixels is correctly selected. It is indeed the case here with an error of 10^{-3} , which is very satisfactory. The choice of pixel size at 0,00585 mm and a focal length of 85.0 mm is thus the good choice.

The software gives also the equatorial co-ordinates of the centre actually used for the astrometrical reduction (the tangent point). Then the number of stars found in the image ($L1$), the catalogue of stars ($L2$) and stars at the end of the accounts employed for the astrometric reduction (COM). This is then followed by parameters which define the transformation equation to make the image conform to the specified scale (focal length/pixel size) and to the image with north at the top. RMS error of the reduction is given in arc second. Lastly, the photometric magnitude constant is given. All the astrometrical parameters are saved in the header of the calculated image (in this case `t85_1.pic`). These can be view by using the command `INFO_ASTRO`. For example :

```
>LOAD T85_1
>INFO_ASTRO
```

The result is displayed in the output window as shown in figure 11.

The processed image, which is the sum of 4 images starting from RAW images and then reduced astrometrically, is shown in figure 12.

Important care was taken in the processing of the sky background to remove all gradients. This makes the image very flat and neutral, which is not like the original RAW which was made in a very light polluted sky (see figure 13).

Iris arranges the processed image so that the sky background has blue, green and red levels set as close as possible to a value of 0 (this can be verified by moving the cursor across the image and noting intensity values). This outcome is particularly useful for applying white balance to the image, i.e. to multiply RGB channels by coefficients so that a naturally white star appears indeed with this color in the image. Taking into account the co-

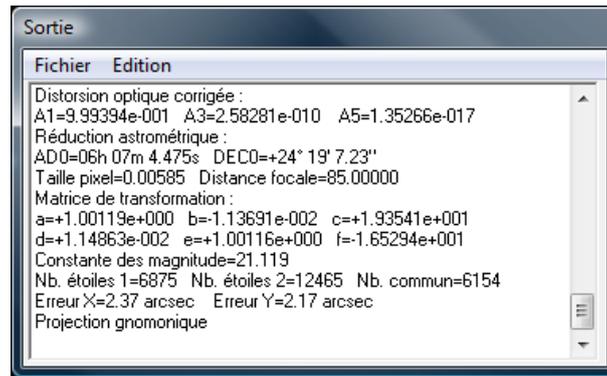


FIG. 11 – The result of the command **INFO_ASTRO**. To erase the astrometric data of the image, run the command **RESET_ASTRO**.

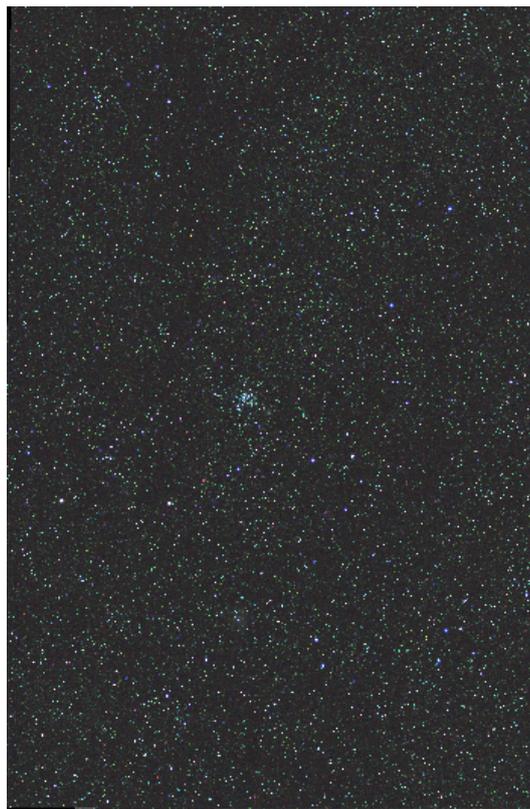


FIG. 12 – The image of the field of the cluster Messier 35 (very reduced in this representation). To note that north is now in top and that the sky background has a very neutral color in spite of severe light pollution.

lor temperature of the lamp used to perform the flat-field (here a slide light box), the white balance is applied by multiplying the red channel by 2.00, the green channel by 1.00 and the blue channel by 1,35 (command **RGB Balance** under **Digital Photo** menu - this is shown in figure 14). The colors of stars then are correctly restored, and simultaneously, since the level of the background is zero, the color of the sky remains neutral.

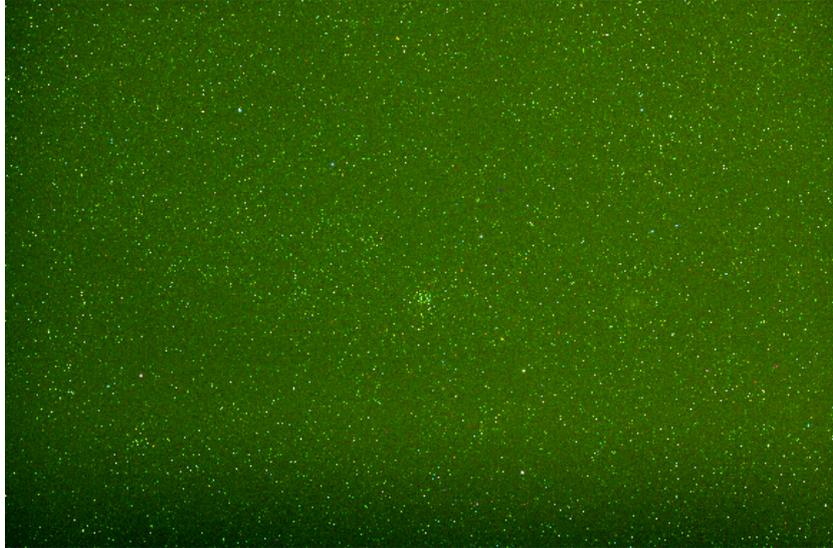


FIG. 13 – One of RAW image before any processing. The green color is typical of an unprocessed RAW file. It means that the sensor used is manifestly more sensitive in the green channel compared to the red or blue channels. Note the presence of optical vignetting.

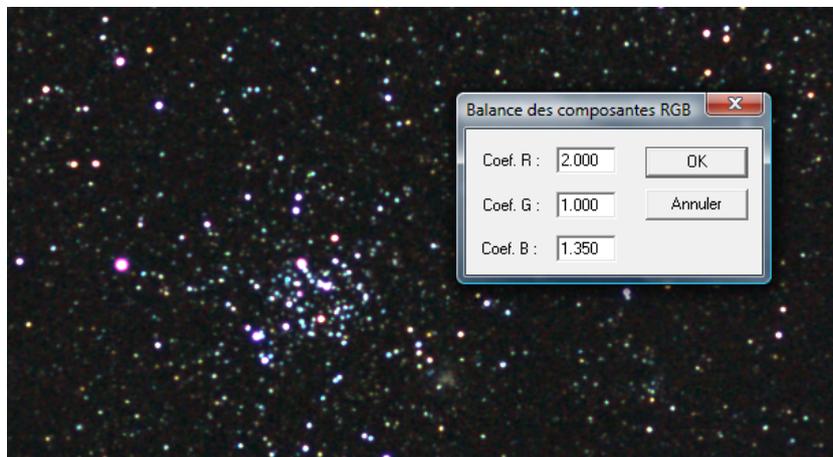


FIG. 14 – Applying white balance to image t85_1.

Now try this operation : a star is bounded by a small selection box using the mouse. Then right clicking the mouse and run the command **Compute**. The equatorial coordinates of the stars are returned - see the figure 15.

To locate in the image the open cluster NGC 2158, at the coordinates $\alpha = 6\text{h}07\text{m}26\text{s}$ and $\delta = +24^{\circ}05'48''$, it is possible to draw intersecting lines of Right ascension and Declination at the level of the object. Proceed by selecting **Draw Coordinate Circles** from the **Analysis** menu. The fields are already pre-filled with data from the header of the image. Check that the gnomonic projection is selected. Enter the coordinates $\alpha = 6\text{h}07\text{m}26\text{s}$ and $\delta = +24^{\circ}05'48''$. Click **OK**. Figure 16 shows the result.

As a check, or for educational purposes, it is possible to superimpose the astrometrically reduced image with the star catalog TYCHO-2. Use the **Display a Sky Map** command

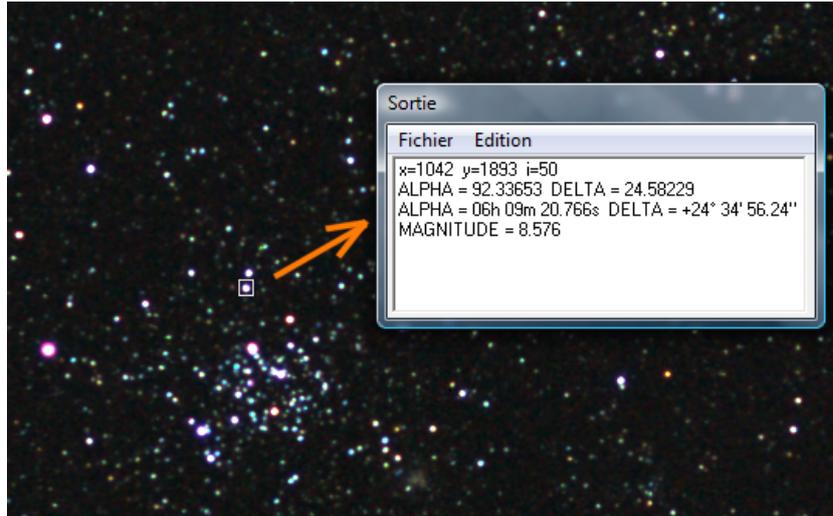


FIG. 15 – Once the image is reduced astrometrically, it is easy to find the precise co-ordinates of all the objects in the image (either from the context menu, or using the commands **COMPUTE** and **REC2SKY** from the console).

from the **Database** menu. In the example of figure 17 TYCHO-2 stars are shown in the form of small circles. The coordinates specified are those of the centre of the image which are calculated at the end of the astrometric reduction (normally these fields are pre-filled).

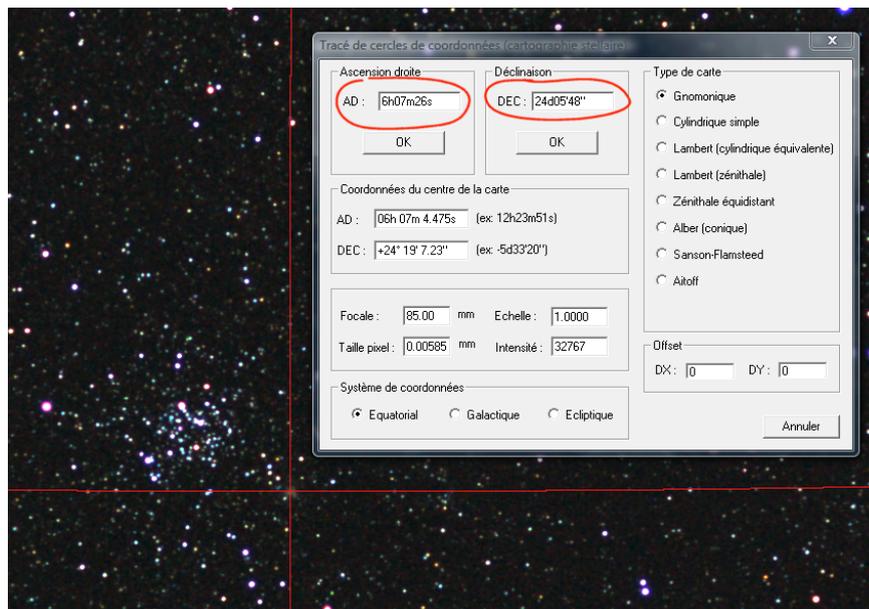


FIG. 16 – The cluster NGC 2158 is located by drawing coordinate RA and DEC circles.

The great strength of using a script file with the **SV1** command is the possibility of processing sequences of images without intervention. Figure 18 shows that it is possible to define a very long sequence of images. Here the images processed 3 by 3 for produce output sequence $t1, t2, t3, \dots$

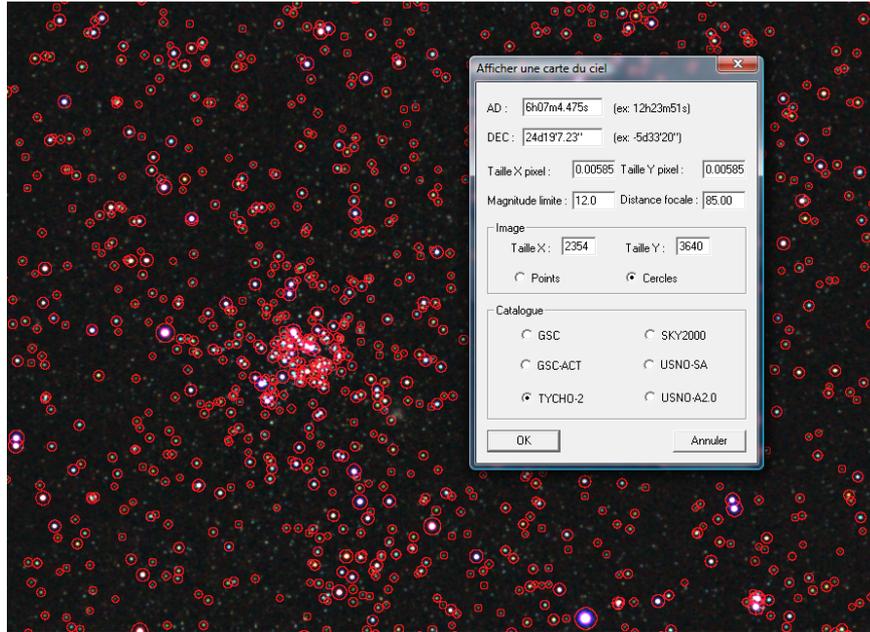


FIG. 17 – Plotting of the stars from Tycho-2 in the astrometrically reduced image.

```

astro1.list - Bloc-notes
Fichier Edition Format Affichage ?
@ offset dark flat cosme 250 1 8h00m 00d 85.0 0.00585 gauche t
# img_1738
# img_1739
@ offset dark flat cosme 250 1 8h30m 00d 85.0 0.00585 gauche t
# img_1741
# img_1742
# img_1743
@ offset dark flat cosme 250 1 9h00m 00d 85.0 0.00585 gauche t
# img_1744
# img_1745
# img_1746
@ offset dark flat cosme 250 1 8h30m -10d 85.0 0.00585 gauche t
# img_1747
# img_1748
# img_1749
@ offset dark flat cosme 250 1 8h00m -10d 85.0 0.00585 gauche t
# img_1750
# img_1751
# img_1752
@ offset dark flat cosme 250 1 7h30m 20d 85.0 0.00585 gauche t
# img_1756
# img_1757
# img_1758
@ offset dark flat cosme 250 1 7h30m 10d 85.0 0.00585 gauche t
# img_1759
# img_1760
# img_1761
@ offset dark flat cosme 250 1 7h30m 00d 85.0 0.00585 gauche t
# img_1762
Ln1, Col1

```

FIG. 18 – Example of script file for the SV1 command. This file defines the tasks require to process a set of contiguous images that constitute a panorama. Note that the images are here processed in black and white 16 bits (column 7 has value 1).

SV1 generates in the working directory a file called LOG.DAT which contains logging information of the processing stages (see figure 19). Information in the logging file includes the order number in the sequence, the image name, image path on the disk, equatorial coordinates of image center, the number of stars found in the image, the number of stars found in the catalogue, the number of stars matched, the RMS error reduction in right ascension and declination and the photometric magnitude constant for the V Band (approx). If the re-

duction fails for some of the images then this is reported in the LOG.DAT file. It is therefore recommended to examine this file before going further.

Line	File Name	Time	RA	Dec	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
31	c:\test_astros\t31.pic	07h 31m 38.456s	+30° 11' 1.38"		5028	7004	4414	2.49	2.35	21.398	
32	c:\test_astros\t32.pic	07h 29m 56.964s	+50° 11' 4.28"		4332	5378	3822	3.32	2.15	21.420	
33	c:\test_astros\t33.pic	06h 59m 50.960s	+50° 10' 27.24"		5224	6685	4601	3.41	2.22	21.425	
34	c:\test_astros\t34.pic	06h 29m 43.693s	+50° 09' 39.55"		5543	7539	4878	3.42	2.28	21.435	
35	c:\test_astros\t35.pic	05h 59m 36.877s	+50° 08' 52.43"		5547	8002	4947	3.52	2.33	21.442	
36	c:\test_astros\t36.pic	05h 29m 29.826s	+50° 07' 57.33"		5668	7904	4899	3.58	2.30	21.477	
37	c:\test_astros\t37.pic	05h 27m 33.988s	+60° 08' 26.25"		4875	6595	4319	4.52	2.35	21.452	
38	c:\test_astros\t38.pic	04h 57m 23.686s	+60° 07' 29.41"		4919	6340	4301	4.64	2.40	21.461	
39	c:\test_astros\t39.pic	04h 27m 13.118s	+60° 06' 28.71"		4898	6548	4360	4.32	2.16	21.461	
40	c:\test_astros\t40.pic	04h 29m 9.363s	+50° 07' 6.64"		5287	7142	4512	3.38	2.46	21.495	
41	c:\test_astros\t41.pic	05h 31m 11.365s	+30° 06' 43.96"		6086	9363	5208	2.74	2.39	21.509	
42	c:\test_astros\t42.pic	04h 32m 18.939s	+00° 02' 34.08"		3757	4570	3279	2.10	2.18	21.382	
43	c:\test_astros\t43.pic	05h 02m 18.796s	+00° 03' 31.91"		4811	6524	4249	2.22	2.23	21.372	
44	c:\test_astros\t44.pic	05h 02m 3.050s	+10° 02' 43.92"		4690	5703	3967	2.15	2.17	21.434	
45	c:\test_astros\t45.pic	04h 32m 1.949s	+10° 01' 19.42"		3334	3455	2710	2.14	2.18	21.387	
46	c:\test_astros\t46.pic	04h 32m 28.473s	-09° 59' 2.09"		3030	4340	2780	2.09	2.21	21.285	
47	c:\test_astros\t47.pic	05h 02m 27.773s	-09° 58' 4.21"		3740	5368	3435	2.18	2.23	21.283	

FIG. 19 – An example of LOG.DAT file.

4 SV2 : Cartographic Projection

The command **SV2** functions act to the same principle as **SV1**, starting from a text script file containing a list of tasks to exercise. The goal is to follow astrometric reduction by projecting the images in a defined cartographic coordinate system, then by carrying out the assembly of the individual images into a single image (mosaic operation).

The stellar cartography functions of Iris are described with some details at this address : http://astrosurf.com/buil/iris/new550/new550_us.htm

However, here is a brief review of some basic principles and definitions.

The purpose of a cartography (or map) projection is to represent a curved surface on a plane, for example representing spherical coordinates (right ascension and declination of the celestial sphere for example) in a planar coordinate system (x, y). In Iris, there is an intermediate step, using the **SV1** command. The image is reduced to a mapping known as gnomonic, near to how an observer actually sees the sky (projection of the sphere on a tangent plane at the centre of the image). It is from this elementary projection that new projections are carried out corresponding to sky charts of various projections.

There is a great choice of cartographic projections. This profusion of choices translates to the fact that there is not one projection which can simultaneously preserve the lengths, surfaces, angles and the shapes initially defined on the surface of the celestial sphere.

The different classes of projection are shown in figure 20 and can be divided into the following :

- Azimuth Projection. They are particularly suitable to visualize the polar areas of the sphere. The meridian lines (axis of the right ascensions) converge towards a central point and the circles of declination are concentric relative at this point.
- Conical Projection. This type is of interest for representing the intermediate declination zones. The meridian lines converge towards a point outside the map and the declination lines appear in the form of arc's or circles.
- Cylindrical Projection. This type is ideal for representing the equatorial zone. This projection can be visualised by wrapping a sheet around around the sphere, tangent at the equator. The grid of coordinates is then rectangular.

Charts of hybrid projection also exist.

Projections are associated with particular geometrical characteristics. The more noteworthy projections include :

- Equal-Area or Equivalent, by definition the areas are preserved. This property is very important in astronomy because it preserves the photometry of areas. The projections most employed in astronomy are thus "equivalent". One can use them in addition since it is necessary to represent a statistical distribution in a chart.
- Conformal, by definition the angles around a point are preserved (as well as the forms locally). These projections are important for navigation, but of a minor interest in astronomy.
- Equidistant, by definition the distances are preserved. It is the type more used for the construction of charts of the Earth (they make it possible to reach directly the linear distance between two points).

A map cannot be at the same time be equivalent and conformal, nor in conformal and equidistant. In front of the multiplicity of projections it is necessary to make choices which meet a definite need as well as possible. There are a number of practical projections for astronomy, for example the equivalent cylindrical projection known as of Lambert or the equivalent conical projection known as of Albert. In the example of figure 21 a projection known as Aitoff (Hammer-Aitoff to be more precise) will be used as it is often used to show a global view of the heavens, with a relatively reduced deformation.

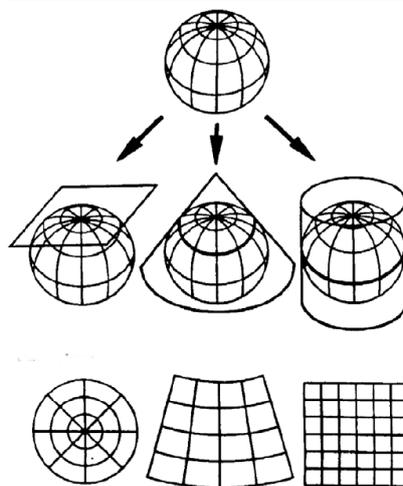


FIG. 20 – Various methods of projecting a sphere. From left on the right, an azimuth projection, a conical projection and a cylindrical projection. Below the impact of the coordinate grids.

In the example taken below a total of 12 contiguous zones of the sky is acquired using a lens of 85 mm focal length (Canon 85 mm f/1,2L, aperture set to f/2) and Canon 40D camera. In fact, these zones overlap slightly so that as to be continuous in the final assembled image. The step adopted between each zone is 30 minutes in right ascension and 10 degrees in declination. At the time of observation, the large axis of the camera is directed along the axis of the declination. For each zone 3 images of 30 seconds exposure was made.

In all $3 \times 12 = 36$ images are required to be processed. The area of the sky covered includes part of the constellations of the Auriga, Gemini and Monoceros. At the beginning the **SV1** command is called to process the images, as well as stack and perform the necessary geometric astrometric reduction. Figure 22 shows the standard contents of the file used as

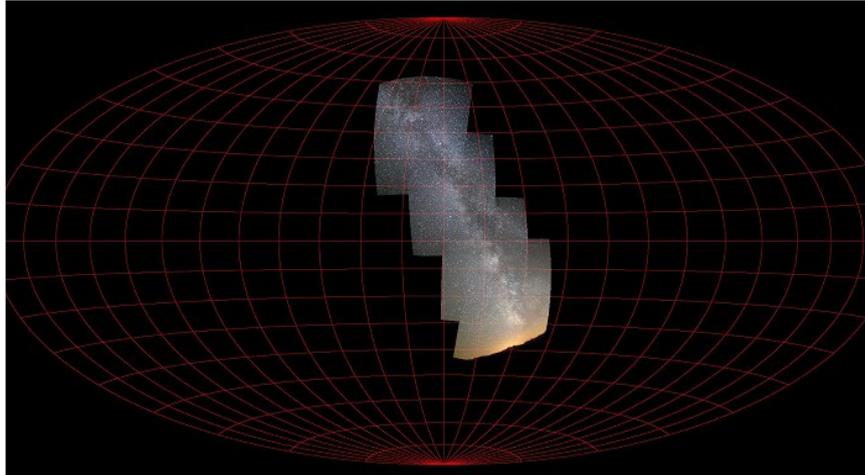


FIG. 21 – The Hammer-Aitoff projection, with its characteristic oval form. It is a type of projection known as pseudocylindric. A small portion of the sky is represented in this global frame.

an argument to the **SV1** command. As a result 12 processed images of the zones are created with generic names *t1.pic*, *t2.pic* ...

```

astro1list - Bloc-notes
Fichier Edition Format Affichage ?
@ offset dark flat cosme 250 0 4h30m 20d 85.0 0.00585 gauche t
# img_1448
# img_1449
# img_1450
@ offset dark flat cosme 250 0 5h30m 20d 85.0 0.00585 gauche t
# img_1451
# img_1452
# img_1453
@ offset dark flat cosme 250 0 6h00m 20d 85.0 0.00585 gauche t
# img_1454
# img_1455
# img_1456
@ offset dark flat cosme 250 0 6h30m 20d 85.0 0.00585 gauche t
# img_1457
# img_1458
# img_1459
@ offset dark flat cosme 250 0 6h30m 30d 85.0 0.00585 gauche t
# img_1460
# img_1461
# img_1462
@ offset dark flat cosme 250 0 6h00m 30d 85.0 0.00585 gauche t
# img_1463
# img_1464
# img_1465
@ offset dark flat cosme 250 0 5h30m 30d 85.0 0.00585 gauche t
# img_1466
# img_1467
# img_1468
@ offset dark flat cosme 250 0 5h30m 40d 85.0 0.00585 gauche t
# img_1469
# img_1470
# img_1471
Ln 29, Col 31

```

FIG. 22 – The text file used by the **SV1** command.

Examination of the output file LOG.DAT shows that the photometric magnitude constant in the output images is approximately 21.5 (for this particular example). This value should be noted because it will be useful later.

The command **SV2** makes it possible to project these images in the coordinate system selected, then automatically assemble the individual image in a single mosaic image.

It is first of all necessary to choose the cartographic projection type, the scale of the chart and the celestial coordinates which will be at the centre of image. Another important problem to solve is that overall pixel dimensions of the final map. It is guessed that a total representation of the sky on an original scale of our images will be of gigantic proportions. This will be unmanageable. The key is to reduce the scale of the image and/or showing only

one part of the sky. In the present example a mixture of both will be adopted : The size of the original images is reduced by a factor 2 and a section of the sky just large enough to cover the final 12 image mosaic is selected.

To proceed with the example, select **Stellar Map Projections** from the **Analysis** menu. Enter the parameters values as shown in figure 23.

The focal length and pixel size should be checked to ensure they conform with the imaging setup used. The Aitoff projection is selected. A scale factor of 0.5 is adopted so that the sizes of the images in the chart are half the original size. Note that the Aitoff is the item #7 in the proposed projection list.

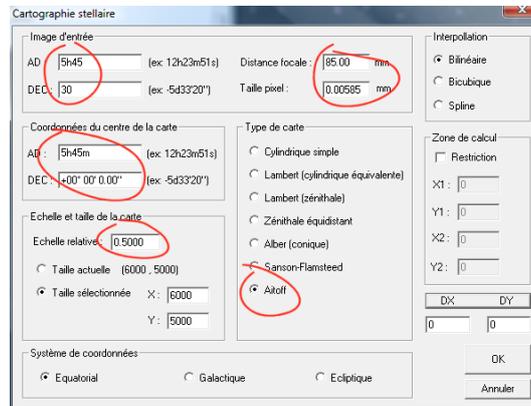


FIG. 23 – Values required in **Stellar Map Projections** Dialog box.

The center of the projection (central point of the future sky map) is at equatorial coordinates RA=5h45m and DEC=30d, based on the average position on the sky of the acquired images. However, an Aitoff projection is basically equatorial, i.e. the software expects that the centre of the chart contains the celestial equator (with a Aitoff projection it is mandatory to specify 0° declination for the centre of the chart projection). Taking into account the scale of the images, if the centre of the chart is indeed RA=5h45m and DEC=0°, then the point RA=5h45m coordinates and DEC=30° is located very high in the chart. To see the images it will be necessary to adopt very large dimensions for the final projected image (which will be mostly black, since the effective observed images will occupy only a small area of the projection). To solve this problem Iris can add values to the X and Y axes so as to shift the desired centre into the centre of the representation, while carrying out a correct equatorial projection (i.e. the centre calculation is still made at coordinates RA=5h45m, DEC =0°, the shift is applied after). The button **DX DY** in the **Stellar Map Projection** dialog box makes it possible to calculate this shift. Enter the coordinates desired for the centre of the mosaic, i.e. RA=5h45m DEC=30° and then click on button **DX DY**. Iris gives the shift in the text windows just below the button, which in this case will be DX = 0 pixels and DY = -3760 pixels, which we rounded here to DY = -3800 pixels.

The dimension of the final projected mosaic image must be sufficient to cover the desired field. Taking into account the scale factor, a dimension of 6 000 by 5 000 pixels proves to be sufficient in this case (it may be necessary to perform successive tests or do some elementary calculations beforehand to arrive at these dimensions). Without any image scaling the output image would be 12 000 by 10 000 pixels, requiring a very powerful computer setup!).

At this point all the necessary is available to create a script file to be used by the command **SV2**. This is a text file starting with the character "@" which defines the parameters

of cartographic projection. It is necessary to define 13 fields, separated by at least a space. Here is the description of these fields :

- Field 1 : Mandatory character @.
- Field 2 : The type of projection, identified by a number (refer to **Stellar Map Projections** dialog box, the number is the order in which they appear in this list, i.e 1 = Cylindrical Equal Spacing, 7=Aitoff).
- Field 3 : The right ascension of the centre of projection (it is not necessarily the centre of the image viewed in the final analysis because of the introduction of an X-Y shift in fields 10 and 11). The format is HMS.
- Field 4 : the declination of the centre of projection (it is not necessarily the centre of the image visualized in the final analysis because of the introduction of an X-Y shift in fields 10 and 11). The format is of type DMS.
- Field 5 : the declination of the tangent point at the time of a conical projection. The format is of type DMS.
- Field 6 : the scale factor of the final image.
- Field 7 : the type of Coordinate System used. Put 0 for an equatorial Coordinate System, 1 for a galactic Coordinate System (the galactic equator takes the place of the usual celestial equator), 2 for an ecliptic Coordinate System (practical to represent the plane of the solar system, the position of planets and asteroids).
- Field 8 : horizontal size of final image in pixels.
- Field 9 : vertical size of final image in pixels.
- Field 10 : X shift in pixels.
- Field 11 : Y shift in pixels.
- Field 12 : The photometric magnitude constant for the final image. The reason is so that each image of the sequence is corrected photometrically so as to match the specified constant. This makes it possible to carry out mosaics starting from images acquired with different exposure times, or more simply, with conditions of transparency of the sky variables. For example, if the constant initial magnitude is 21.2 for one of the images of the sequence and if one aims at a constant magnitude of 21.5 in the mosaic, then the level of all the pixels of this image is multiplied by coefficient 1.3182 (see definition of magnitude). If one does not wish to see the intensity of the images modified then it is necessary to give a zero value to this field.
- Field 13 : the generic name of the output image.

A line starting with character # identifies the name of an image file to load. This filename follows character # on the same line. There is a line per image.

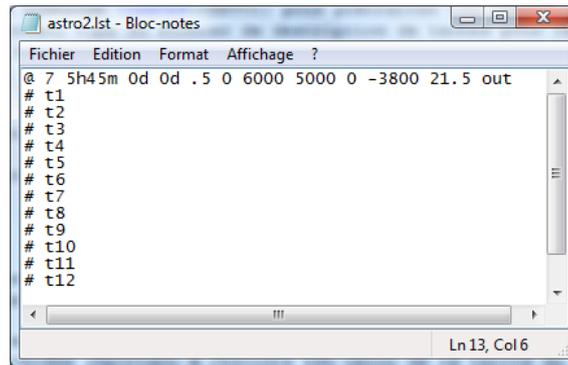
The operations carried out consist of applying cartographic projection to the images, then fusion of all the images into a single image (to generate for example a mosaic covering a vast area of the sky).

Figure 24 gives the contents of the script file for this example. As there is only one sequence to process, there is only one output file (i.e *out1.pic*). Note that the signal of all images is equalised such that they all have a photometric magnitude constant of 21.5 (a signal of one digital count corresponds to the stimuli produced by a star magnitude 21.5 in the V band). The selected precise value is somewhat arbitrary. Here it is chosen as the typical constant based on all the individual images of the sequence.

Save the script file under the name RUN4.LST (for example), then from the command console type :

```
>SV2 RUN4
```

Attention, the processing time can be long (several tens of minutes, ... several hours). Be patient ! Test with a small number of images first.



```
Fichier Edition Format Affichage ?
@ 7 5h45m 0d 0d .5 0 6000 5000 0 -3800 21.5 out
# t1
# t2
# t3
# t4
# t5
# t6
# t7
# t8
# t9
# t10
# t11
# t12
Ln 13, Col 6
```

FIG. 24 – Script file for the command **SV2** as used in this example.

Figure 25 shows the final resulting image in negative high contrast view and very reduced. The 12 zones were assembled satisfactorily. Note that there is an absence of join artifacts on the boundaries of the individual images, which is the sign of satisfactory processing of the sky background gradients (it should this be recalled that these images are acquired in urban environment, with a limiting magnitude in the eye ranging between 2 and approximately 3 !).

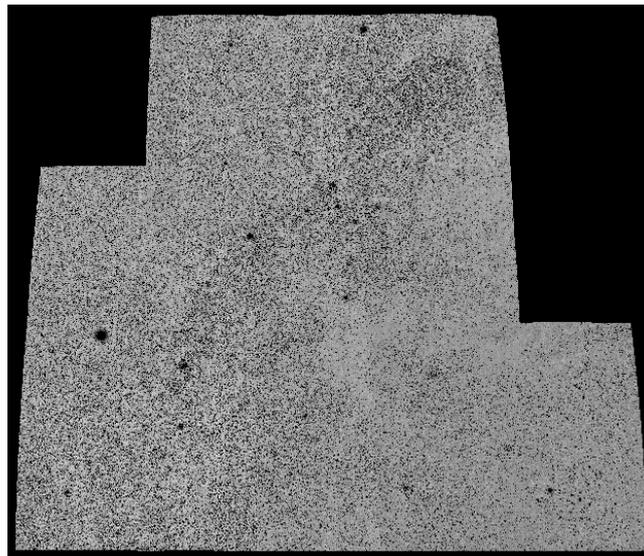


FIG. 25 – The 12 individual fields gathered into a single image. This final image here is converted into black and white and is displayed with a strong contrast.

In the resulting image OUT1.PIC the sky background was set to 500 for all 3 channels. The goal is to facilitate visualization. To return the background sky to 0 (for applying white balance for instance) it is matter of using the offset command :

>OFFSET -500

It is perfectly possible to use the astrometric information tools, for example **INFO_ASTRO** (figure 26), **Compute** command of contextual menu, or **Draw Coordinate Circles** command (see figure 27).

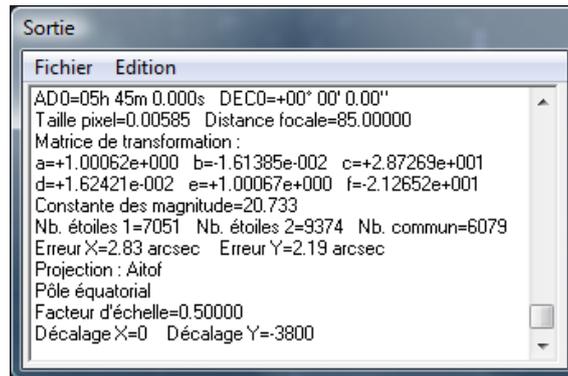


FIG. 26 – Astrometrical and cartographic information available after the execution of command **SV2**.

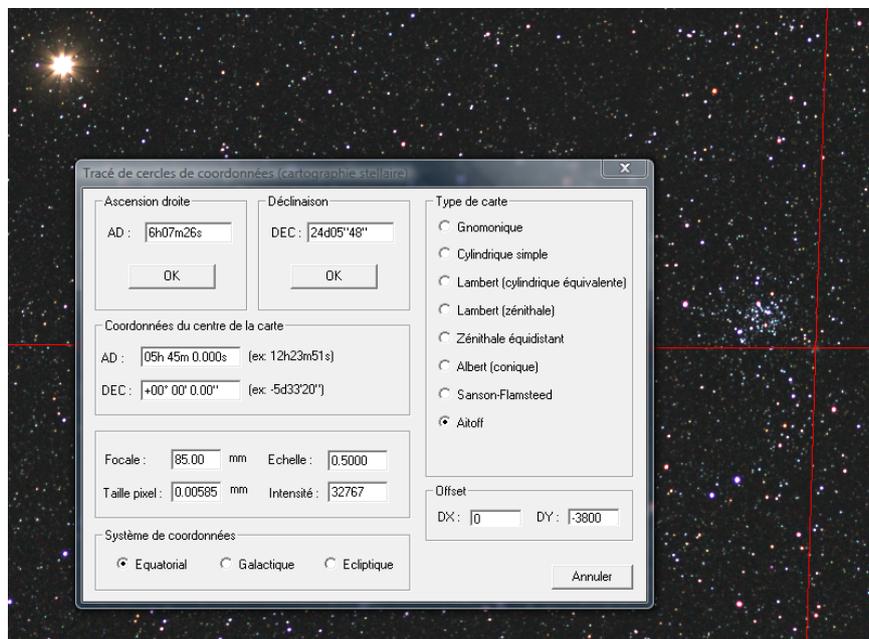


FIG. 27 – Grid coordinates tool for the Aitoff projection. The object shining in top left is the planet Mars. Note that the coordinates of the center of the chart entered are those specified in the script file for command **SV2** (enter also the DX and DY values).

It is perfectly possible to combine the construction of several cartographic projections starting from the same script file as illustrated in figure 28. The second produced image (name OUT2.PIC) is defined in a galactic coordinate system. In this case, the centre of the chart corresponds to the galactic longitudes and galactic latitudes, given in degrees, minutes and seconds. In the example, selected galactic longitude at the centre of the chart is $L = 185^\circ$. Figure 29 shows the result.

One very useful application of cartographic projections is the capacity to compare data taken at different dates or/and with different instruments. This constitutes a genuine tool for making discoveries.

In the example of figure 30, images of the same field (near cluster Messier 35) are projected with the same cartographic projection but acquired with very different photographic optics. The processing is nearly identical for these 4 images with the only difference being the scale factor. For example for the focal length of 200mm, if the scale factor is set at 1.0 exactly, the scale factor adopted for the 50mm lens will be 4.0 (200 mm / 50 mm = 4). For the 85mm and 135mm focal length lenses, the scale factor would be 2.3529 and 1.4815 respectively. No other parameters need to be modified ; the superposition of images is thus easy and also very precise.

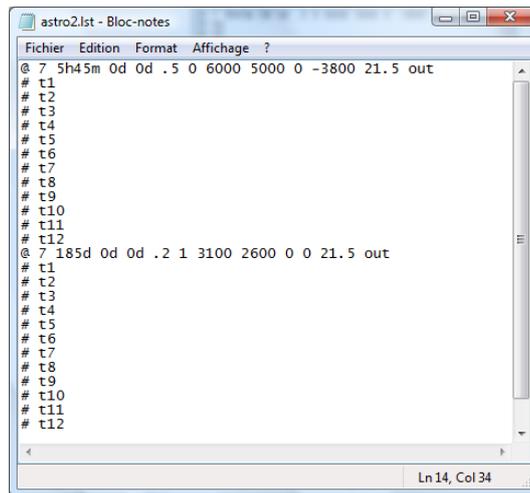


FIG. 28 – Script file used with **SV2** which generates two projections from the same sequence of images, one equatorial, the other one galactic.

5 SV3 : Graphic Layout

Command **SV3** reads a data file making it possible to draw points, lines or of the circles in the cartographic image. The positions of these points, lines and circles are defined in equatorial coordinates (or galactic coordinates). Command **SV3** can be used to delimit fields, to trace the limits of the constellations, or to draw the trajectory of a mobile object directly in the image (comet, asteroid,...).

To trace great arc circle between two points of equatorial coordinates (RA1, DEC1) and (RA2, DEC2), write a line in the file commencing with the letter "L" (Line). The format of the parameters is

L AD1 DEC1 AD2 DEC2 R G B

with *R*, *G* and *B* intensity of the layout respectively in the red , green and blue channels in pixel intensity (a number between 0 and 32767).

For example :

L 3H45M23S 56D21'22" 3H46M49S 54D18'02" 32767 20000 10000

To trace a Right Ascension circle, use the following format :

A AD R G B

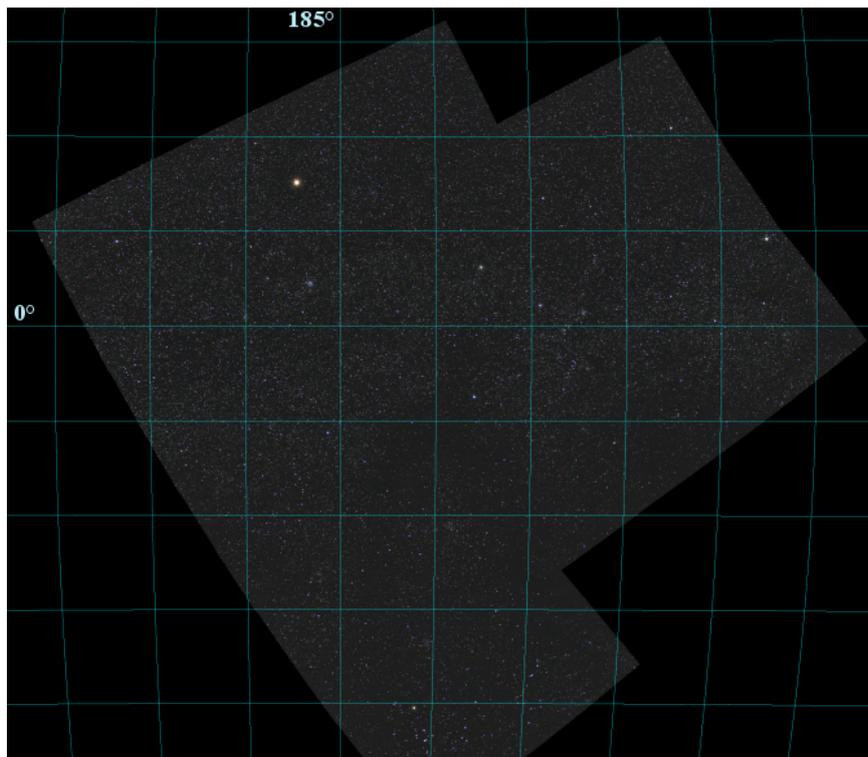


FIG. 29 – The 12 zones projected in the galactic coordinate system. The plane of the Galaxy is defined by the horizontal line marked 0° .

where *RA* is the right ascension, and R, G and B the intensity of the circle.

To trace a Declination circle, use the following format :

D DEC R G B

where *DEC* is the declination, and R, G and B the intensity of the circle.

To trace a small circle of diameter *DIAMETER* in pixels around a point of coordinates (*RA*, *DEC*) use the following syntax :

C AD DEC R G B DIAMETER

This last item is very useful to mark in the image the position of already known or suspected variable stars. A list of these stars is available from site of the AAVSO at the following address <http://www.aavso.org/vsx/>. The typical data from the VSX used by **SV3** are shown in figure 31. The result of execution of the **SV3** command against this data file in the image is shown in figure 32.

Lastly, to trace a point with coordinates (*AD*, *DEC*), use the format

P AD DEC R G B

As example creating a file *RETI.LST* with contents as defined in figure 33 and launching **SV3** against it, i.e

>SV3 RETI

gives the result shown in figure 34.

An application of this could, for example, be the tracing of a comet trajectory to check for the presence of a suspect object in a field. Figure 35 shows an example with the image reduced astrometrically showing comet 8P/Tuttle observed on December 17.8, 2007 with a

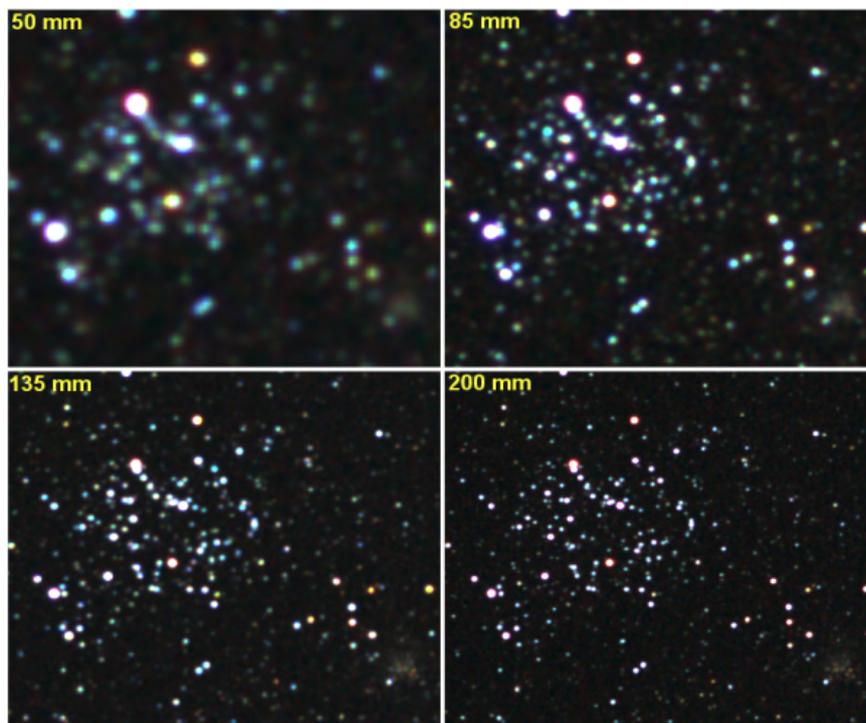


FIG. 30 – The field of Messier 35 cluster photographed with a Canon 40D equipped successively with optics of focal length 50 mm, 85 mm, 135 mm and 200 mm. For the first 3 focal lengths the aperture was set at $f/2$. For the 200mm focal length, the aperture was set at $f/2.8$. Each image is a composite of 4 exposures of 30 seconds at ISO 100. The Aitoff projection was select as the common coordinate system for these images. The effect of the special resolution with respect to focal length is clearly visible.

Fichier	Edition	Format	Affichage	?
C	5h26m57s	21d52'41"	1000	3000 300 14
C	5h26m59s	22d57'46"	1000	3000 300 14
C	5h27m5s	21d35'25"	1000	3000 300 14
C	5h27m10s	29d55'16"	1000	3000 300 14
C	5h27m15s	26d43'3"	1000	3000 300 14
C	5h27m18s	23d6'24"	1000	3000 300 14
C	5h27m18s	23d6'25"	1000	3000 300 14
C	5h27m24s	28d40'46"	1000	3000 300 14
C	5h27m38s	32d12'33"	1000	3000 300 14
C	5h27m50s	22d59'23"	1000	3000 300 14
C	5h27m52s	22d38'0"	1000	3000 300 14
C	5h28m13s	30d12'33"	1000	3000 300 14
C	5h28m14s	24d33'48"	1000	3000 300 14
C	5h28m21s	29d28'13"	1000	3000 300 14
C	5h28m29s	18d34'24"	1000	3000 300 14
C	5h28m41s	21d41'24"	1000	3000 300 14
C	5h28m51s	29d48'38"	1000	3000 300 14
C	5h28m51s	32d25'22"	1000	3000 300 14
C	5h28m52s	32d28'39"	1000	3000 300 14

FIG. 31 – The list of variable and suspect variable stars in a field within 15 degrees centred around Messier 35 (from VSX data).

Canon 40D equipped with 85 mm focal length lens closed $f/2$ (3 exposures of 30 seconds). Figure 34 shows an extract of the data file containing ephemeris data for the comet.

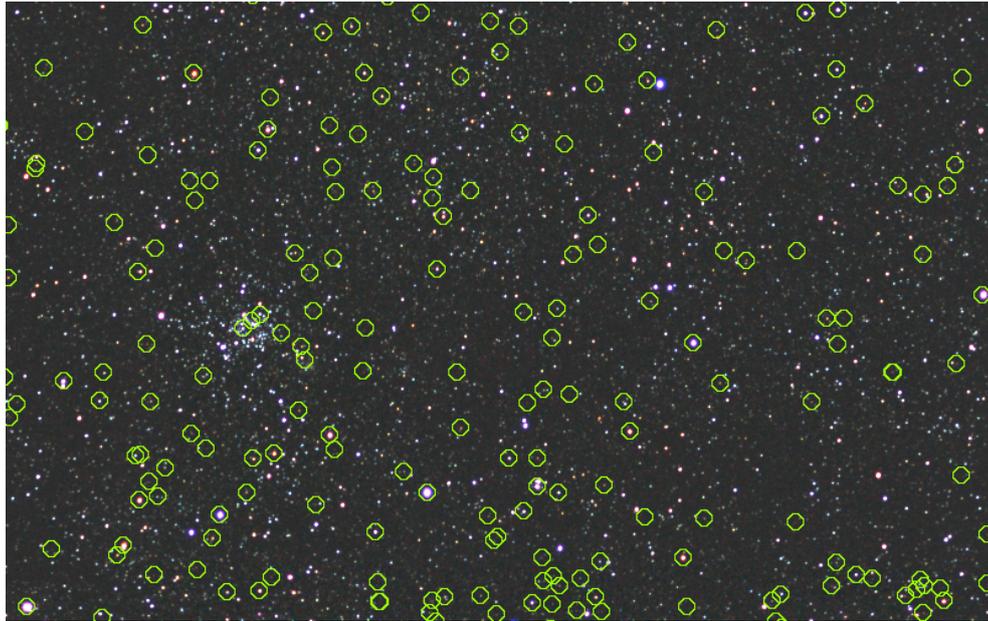


FIG. 32 – The position of variable stars in the field of Messier 35. Some positions correspond to quite identifiable stars in the field, others correspond to objects too faint for the optics used. This identification is a key stage before announcing for example the presence of a new variable object.

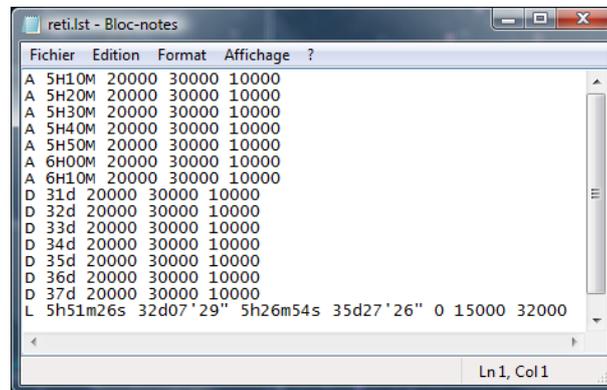


FIG. 33 – Example data file to be used with **SV3**. Here there is a network of coordinates grid as well as a line to be traced between stars HD39045 and HD35519 (a great circle between these two objects).

6 SV0 : Preprocessing only

The command **SV0** is a subset of the command **SV1** that insulates preprocessing section of the latter. **SV0** can be useful to carry out some checks, analyze the operating principle of command set **SV1**, **SV2**, **SV3** and allows the possibility of process your DSLR with a high degree of automation. The constitution of the description file is usual. For example, the file may be of the form shown in figure 37.

For run the processing (for example) :

>SV0 ASTRO0

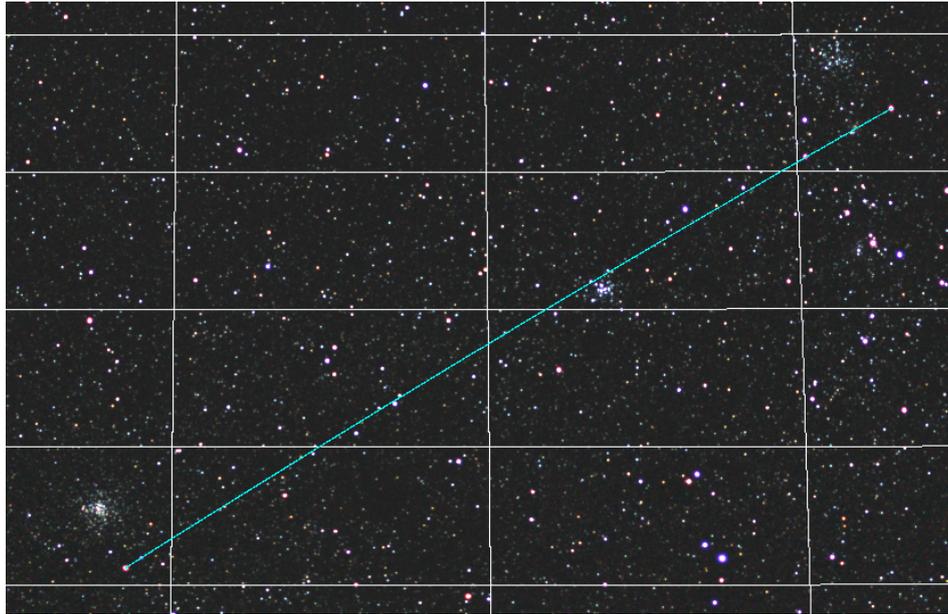


FIG. 34 – The result of the execution of command **SV3** with **RETI.LST** as parameter file (the zone represented corresponds the centre of the constellation of Auriga).

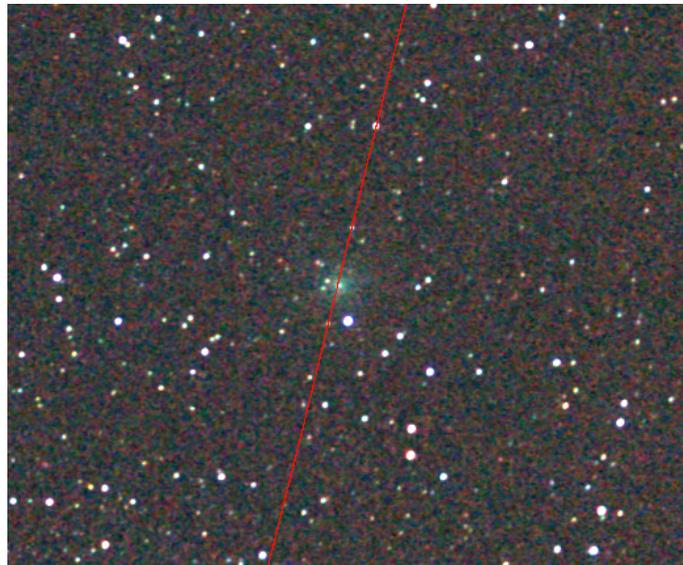


FIG. 35 – Crop of an image showing the field of the comet 8P/Tuttle the 17.8/12/2007. The comet is the diffuse object of green-blue color, easily detected on some 30 seconds exposures (Canon 40D + 85 mm f/2 lens). Superimposed on the image is the theoretical trajectory of comet extracted from ephemeris.

In the example software preprocesses images `img_2658`, `img_2659`, `img_2662`, `img_2663`, `img_2664` and then add those five images, which gives the image `t1`. He did the same for the next sequence images for give the image `t2`, and so forth. The description of the command line beginning by the `@` character is :

- Field 1 : Mandatory character `@`.
- Field 2 : Filename of the master *offset* image.

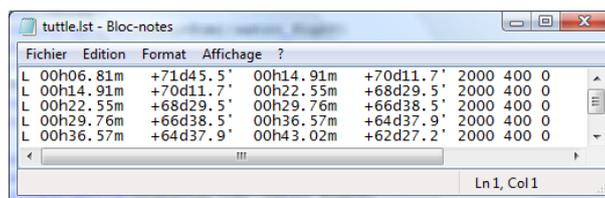


FIG. 36 – The file used to trace the trajectory of the comet 8P/Tuttle.

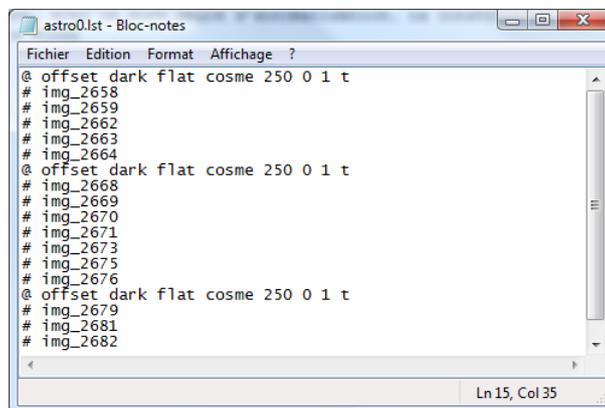


FIG. 37 – Exemple of task file for the command **SV0**.

- Field 3 : Filename of the *dark* frame (this image should contain only the signal of darkness i.e thermal signal, which means that the offset signal has been removed, therefore the median value should be about 0). The integration time employed to carry out the dark file must be the same one as that employed for the science frames made of the sky that are being processed here.
- Field 4 : Filename of the *flat-field* image (a true image of flat field thus, with the offset signal removed).
- Field 5 : Filename of the cosmetic defects list (it contains the list of the hot points typically created from the **FIND_HOT** command. If there are no defects of note then an empty text file may be specified here.
- Field 6 : Size of window to be used for 3 zones stellar registration (this operation ensures that the stars in the image sequence are correctly aligned). Refer to http://astrosurf.com/buil/iris/tutorial2/doc10_fr.htm for more information on this method. A size from 200 to 350 pixels is in general a good choice (see also **Stellar registration** command of **Processing** menu).
- Field 7 : Flag specifying whether color or black and white processing is to be performed. If this field is equal to 0, then the process delivers at the end an image with 48-bit color. If this field is equal to 1, then the result is a black and white image (the summation of the red, green and blue channels of the digital camera RAW file, prior to any white balance being performed). For faster processing, Black and White mode is useful (it requires less computer resources). This is useful if the aim is for new object detection.

- Field 8 : Flag to choose if you flattens the sky or not. If the value is 0, evaluation of the sky is not done. If the value is 1, the sky is estimated and subtracted of the images produced.
- Field 9 : The generic name of the resultant image after processing. Iris adds an index to this name, which increments by one each time a line starting with the character @ is met.