A $10,000,000,000 telescope in your home

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Automatically translated from Spanish

I appreciate the use of the catalogues:

HyperLEDA. III. The catalogue of extragalactic distances
https://ui.adsabs.harvard.edu/abs/2014A%26A...570A..13M/abstract
http://leda.univ-lyon1.fr

Smithsonian Astrophysical Observatory
VizieR Online Data Catalog: Associated data in VizieRG.Landais, Laurent Michel, Pierre Ocvirk et al.
VizieR service DOI: 10.26093/cds/vizier
http://cds.u-strasbg.fr/vizier-org/licences_vizier.html

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1. Introduction.

Telescopes are those instruments that allow us to explore the sky far beyond what our eyes can see. There are rare people who have the possibility of looking through one of them do not do so and there are many who buy their own. There is also the possibility of renting these instruments, as an amateur or professionally, but as one can imagine, large telescopes are reserved for professional research projects and are still difficult to access. But the internet has made it easy to access observations made on any telescope of importance, we can't choose where to look but we can see exactly the same thing that those who do handle the telescope see. This is also true for the telescope par excellence: the Hubble Space Telescope (HST) and soon it will be for the James Webb (JWST),which after 10 years of retaso seems to be finally launched into space at the end of this year 2021. In the case of Hubble,the observations are made public a year after they have been made and are available to the researchers who requested them, but with the James Webb it seems that there will not be that waiting period and everyone will be able to dispose of them immediately,it is like having a telescope of3 billion dollars at home (HTS), and soon another $10 billion (JWST).

The observations of a telescope are specified in a series of data (photographs and spectra) that are recorded in the corresponding files that interested parties can download from the internet. Thefiles are construyen following a strict format so that anyone can extract the information they contain.

FITS is the standard format used in astronomy, supported by NASA and the International Astronomy Union. Although its name corresponds to the acronym Flexible Image Transport System is not a graphic format, it usually contains data that can be displayed as images but not necessarily. It is normal that it contains the data captured by the cameras of the telescopes or their spectrographs and it is required to be the original data with all its imperfections. Torepresent the data contained in an FITS is usually necessary orperform some previous tasks.

In image processing the essential element is the pixel, an image is a matrix of pixels and each pixel represents the color of a point in the image or more precisely the intensity of light at that point. In a black and white image the light intensity is a number that varies between 0 (no negative light intensity) and a maximum value. For color images the intensity of the light is expressed by three digits that are the intensity of each of the three basic colors (red, green and blue) varying those figures between 0 and a maximum value. There may be a fourth figure which is the degree of transparency of the image and some variants on basic colors and other issues that do not interest in this document. As for the maximum value, it is related to the amount of memory that is dedicated to each pixel,if one byte (8 bits) is dedicated the maximum value is 255 (2 raised to 8), if two bytes, the maximum is 65,536 (2 raised to 16), it is rare to use more memory for a pixel because 65,536 tones for a color is much more than the eye can distinguish.

The data of an astronomical observation are readings of electronic components called photoelectric certificates (CCD -coupled charge device-)that are responsible for transforming light energy (photons) into electrical energy,thesemeasurements,like those of any electronic device, haven a "noise" that varies,for example with temperature and can even be negative. Rregarding the maximum value of the readings, this depends on the brightness of the observed objects, the exposure time and other factors. The FITS files record this data as it is and if we want to represent them as an image we will have, at least, to eliminate the negative values and normalize them so that their values are between 0 and 255 (or between 0 and 65.536), it will also be frequent to establish a maximum dimension from which the maximum value is granted to all the data that exceed it, if it is not done, the brightest spots make those that are not so much so dark that they are not seen.

I mentioned that the FITS file collects the readings of the CCD as is, but it is not true, to these readings a series of corrections are applied in the telescope itself to take into account the physical characteristics of its instruments, this is a very important task that is part of the "art" of astronomers, but that today is fully automated by computer applications and FITS files usually inform of the processes applied to the data finally included in them so that we get an idea of the quality of these.

In this situation, to act as astronomers we can do without the telescope but not a computer application capable of exploring the FITS files, showing us their content and even carrying out some treatment of their data.

But before talking about the computer application we have to see how to get the FITS files, which leads us to take a step back, we have to know what a telescope records, here we are going to do it for the Hubble Space Telescope(HTS).

2. The Hubble Space Telescope (HST).

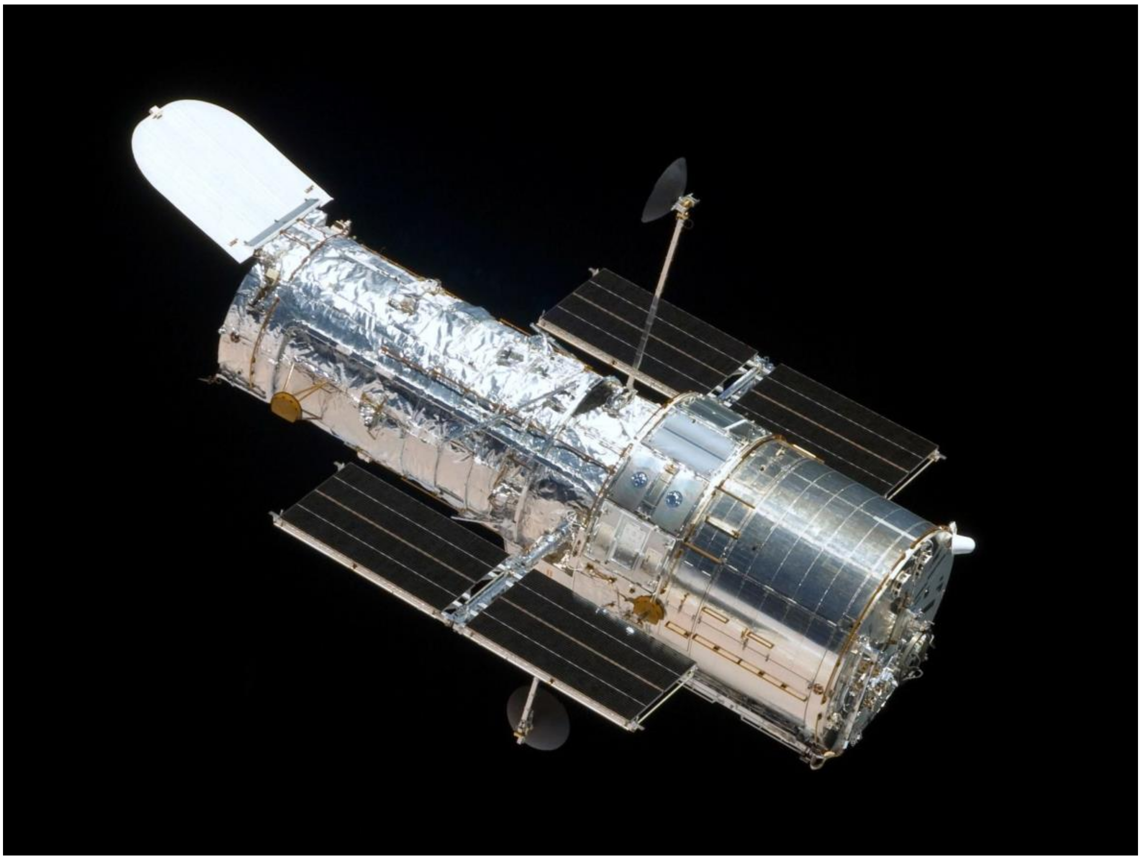


Figure 1. The Hubble Space Telescope.

2.1 Instruments.

Although instruments of extraordinarily complicated and precise technology are on board Hubble, the concepts on which they are based have been known for centuries:cameras and spectrómeters to record the light received by a mirror of 2.4 meters in diameter. In addition to solar panels and batteries to generate and store the electrical energy you need for the motors that allow you to guide it,among other things.

In the FITS files that NASA/ ESA puts at our disposal the instrument that captured the data is specified so it is very useful to know what they are (or have been, because some have been replaced in one of the five maintenance missions that have been carried out or are inactive due to breakdown),the acronymsof the instruments will give us a first idea of the content of the files. P For more details I recommend the website of the European Space Agency (ESA):

https://esahubble.org/about/general/fact_sheet/

2.1.1 Cameras.

WPF (WF/PC for planetarymode). Wide Field and PlanetaryCamera. It was the original camera of the telescope and funcionaba in the visible spectrum,as wide angle (WF) its field of view was 156x156 arcseg and as planetary(PC) 66x66 arcseg with a pixel size of 0.043 arcseg.

WPF2 (WPF2/PC for planetarymode). It replaced the original WPF in 1990 and was the most widely used instrument for over a decade. He took the most spectacular images that have transcended public opinion.

FOC. Faint Object Camera. It works in the visible and ultraviolet spectrum. Its resolution was seven times higher than WPF2.

WPF3. I replaced WPF2 in 2009. It works in the visible, ultraviolet and infrared spectrum.

ACS. The advanced camera for surveys (for its ability to map large areas of the sky in great detail -Advanced Camera forSurveys-) replaced the FOC. Angular cameradesigned for visible spectrum,although it also works in ultraviolet and near infrared and has the ability to perform spectra. I multiply by ten the power of the telescope. It has three channels, the WFC (Wide Field Channel), HRC (High-Resolution Channel) and SBC (Solar Blind Channel). THEY can be seen as ACS/WFC, ACS/HRC and ACS/SBC. Of these, most of the data you can find on the ACS comes from the WFC. HRC and SBC have more specific uses, and HRC is disabled due to breakdown.

2.1.2 Spectrographs.

NICMOS. It is aphotographic cameraand spectroscopic observations of astronomical targets at near-infrared wavelengths (Near Infrared Camera and Multi-Object Spectrometer).

COS. Cosmic Origins Spectrograph. It measures extremely faint levels of ultraviolent light emanating from distant cosmic sources, such as quasars in remote galaxies.

STIS. Space Telescope Imaging Spectrograph. Itis a versatile and "all-purpose" spectrograph that handles shiny objects well.

FGS. They areinterferometers (FineGuidance Sensors). Theyhelp the telescope to keep a stable target but also serve to measure the relative positions and brightness of stars,as well as the angular diameter of celestial objects.

There are redundancies between WFC3, ACS, STIS and COS as a mode of protection against degradation over time that these instruments will suffer.

When choosing between instruments, Table 1 can serve as a first reference.

Instrument	Wavelengthcoverage (nm)	Pixel size (arcsec)	Field of View (arcsec)
WFC3 UVIS	200 – 1000	0.04	162 × 162
ACS WFC	370 – 1100	0.05	202 × 202
ACS SBC	115 – 170	0.032	34 × 31
STIS FUV-MAMA	115 – 170	0.024	25 × 25
STIS NUV-MAMA	165 – 310	0.024	25 × 25
STIS CCD	250 – 1100	0.05	52 × 52
WFC3 IR	800 – 1700	0.13	136 × 123

Table 1. Comparison of some important factors of HTS instruments

There is an extensive and detailed documentation of the instruments, for example from thisto address:

https://hst-docs.stsci.edu/wfc3ihb/chapter-1-introduction-to-wfc3

We can know this all about WPF3.

2.1.3 Filters.

The instruments arecombined with certain filters to make the observations. The filters stand between the path of the light and the instrument and narrow the range of wavelengths to be observed. The filters will be found under the acronym: FnnnX,where F refers to filter, nnn is the wavelength and X can be: N, M, W, or X indicating that it is a narrow, medium, wide or extremely wide filter respectively.

At the address:

https://hst-docs.stsci.edu/wfc3ihb/appendix-a-wfc3-filter-throughputs

We can see in detail the 60 filters that can be put to the WPF3.

As an example, in Figure 1 we can see the % of light allowed by the F606W filter to pass according to the wavelength

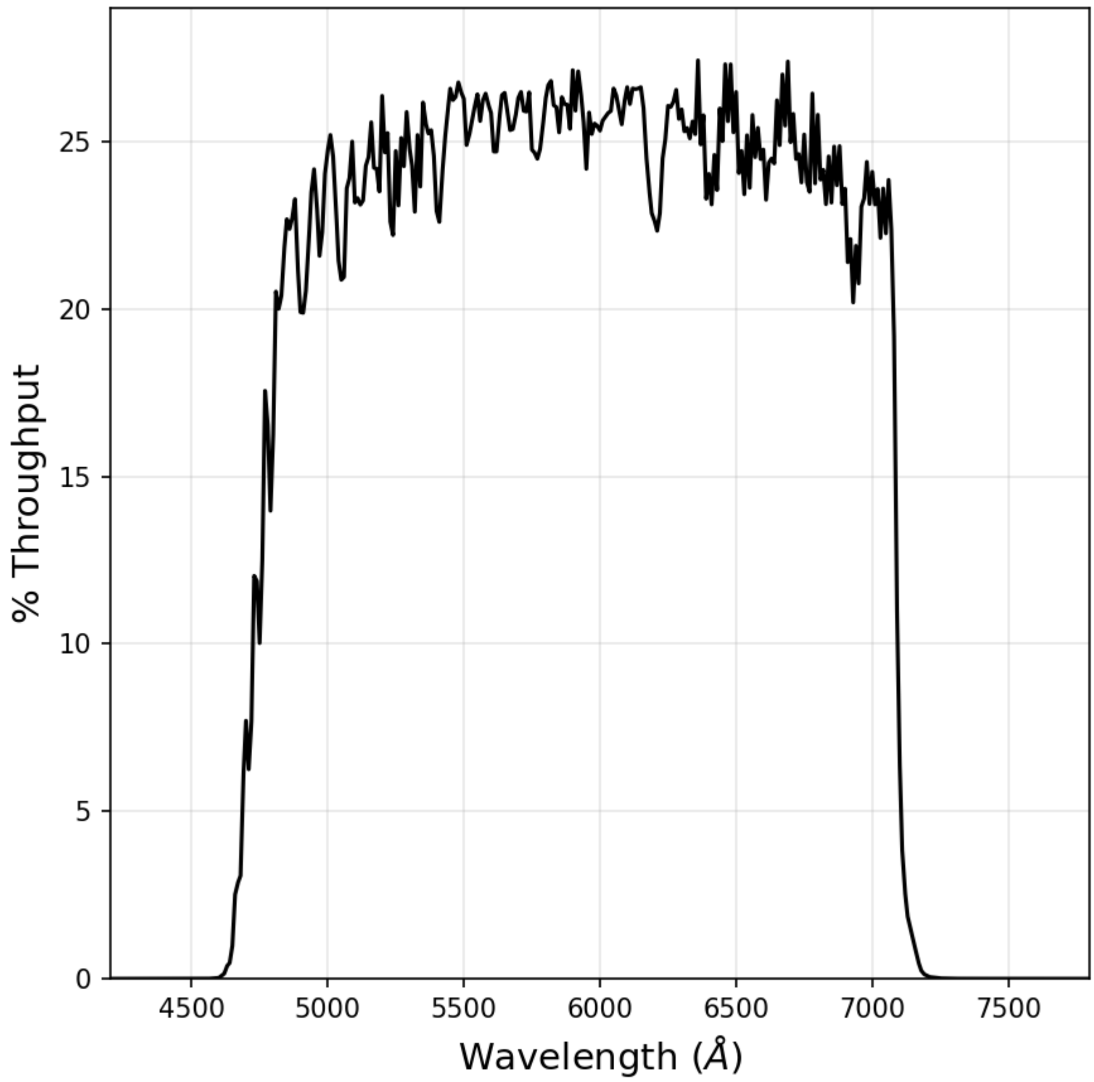


Figure 1. Filter F606W.

2.2 Download FITS files.

Once we have an idea of the HTS instruments, we will see how to obtain the FITS files that contain their measurements. The NASA website where you can download the HTS observations is at the following address:

https://hla.stsci.edu/hlaview.html

And it looks like this (Figure 2):

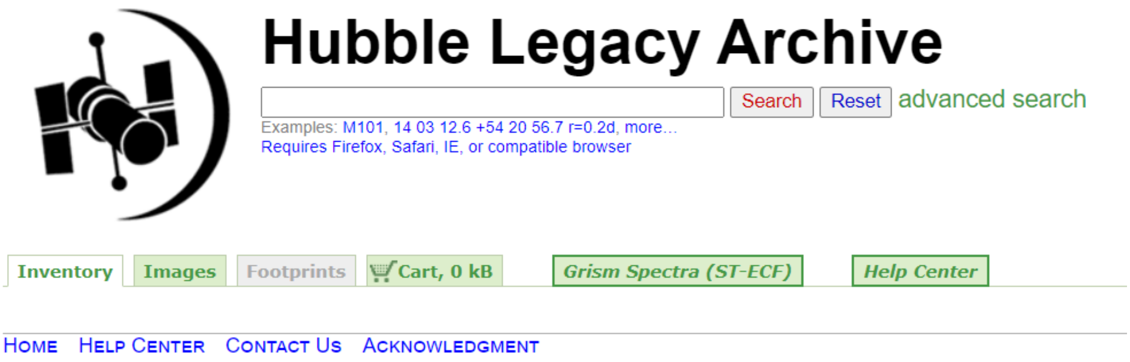
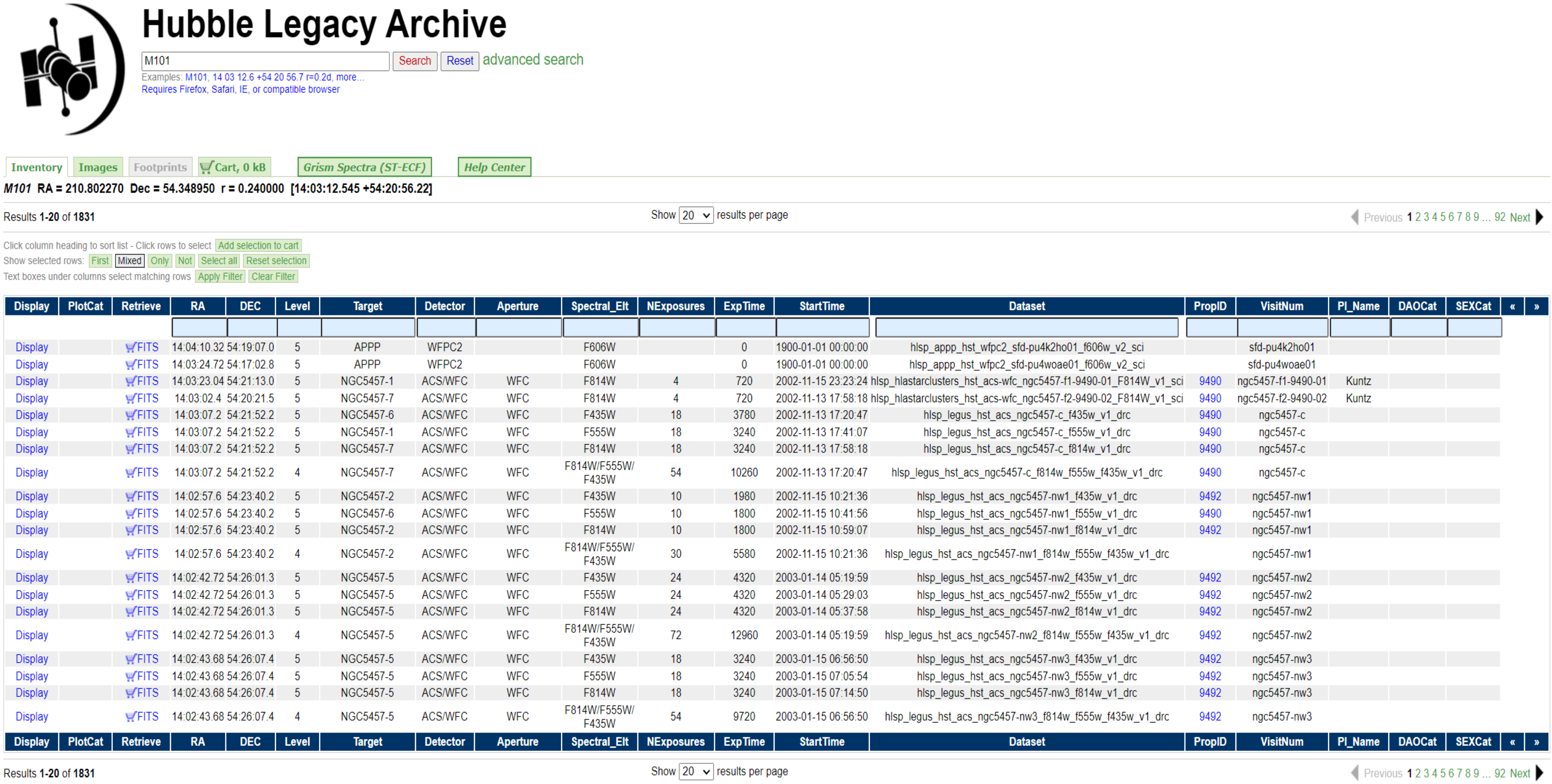


Figure 2. Downloading FITS files

Complications arise when the first search is made. If, as suggested in Examples,we write M101 and press the Searchbutton, a page appears (figure 3),which is the firstof 92 pages and in which we see only a part of all the columns that can be seen by the buttons located to the right of the header. The description of the columns is in Table 2:



Hubble Legacy Archive

M101 Search Reset advanced search

Examples: M101, 14 03 12.6 +54 20 56.7 r=0.2d, more...
Requires Firefox, Safari, IE, or compatible browser

Inventory | Images | Footprints | Cart, 0 kB | Grism Spectra (ST-ECF) | Help Center

M101 RA = 210.802270 Dec = 54.348950 r = 0.240000 [14:03:12.545 +54:20:56.22]

Results **1-20** of **1831**   Show 20 results per page   Previous **1** 2 3 4 5 6 7 8 9 ... 92 Next

Click column heading to sort list - Click rows to select   Add selection to cart
Show selected rows: First Mixed Only Not Select all Reset selection
Text boxes under columns select matching rows   Apply Filter Clear Filter

Display	PlotCat	Retrieve	RA	DEC	Level	Target	Detector	Aperture	Spectral_Elt	NExposures	ExpTime	StartTime	Dataset	PropID	VisitNum	PI_Name	DAOCat	SEXCat	«	»
Display		FITS	14:04:10.32	54:19:07.0	5	APPP	WFPC2		F606W		0	1900-01-01 00:00:00	hlsp_appp_hst_wfpc2_sfd-pu4k2ho01_f606w_v2_sci		sfd-pu4k2ho01					
Display		FITS	14:03:24.72	54:17:02.8	5	APPP	WFPC2		F606W		0	1900-01-01 00:00:00	hlsp_appp_hst_wfpc2_sfd-pu4woae01_f606w_v2_sci		sfd-pu4woae01					
Display		FITS	14:03:23.04	54:21:13.0	5	NGC5457-1	ACS/WFC	WFC	F814W	4	720	2002-11-15 23:23:24	hlsp_hlastarclusters_hst_acs-wfc_ngc5457-f1-9490-01_F814W_v1_sci	9490	ngc5457-f1-9490-01	Kuntz				
Display		FITS	14:03:02.4	54:20:21.5	5	NGC5457-7	ACS/WFC	WFC	F814W	4	720	2002-11-13 17:58:18	hlsp_hlastarclusters_hst_acs-wfc_ngc5457-f2-9490-02_F814W_v1_sci	9490	ngc5457-f2-9490-02	Kuntz				
Display		FITS	14:03:07.2	54:21:52.2	5	NGC5457-6	ACS/WFC	WFC	F435W	18	3780	2002-11-13 17:20:47	hlsp_legus_hst_acs_ngc5457-c_f435w_v1_drc	9490	ngc5457-c					
Display		FITS	14:03:07.2	54:21:52.2	5	NGC5457-1	ACS/WFC	WFC	F555W	18	3240	2002-11-13 17:41:07	hlsp_legus_hst_acs_ngc5457-c_f555w_v1_drc	9490	ngc5457-c					
Display		FITS	14:03:07.2	54:21:52.2	5	NGC5457-7	ACS/WFC	WFC	F814W	18	3240	2002-11-13 17:58:18	hlsp_legus_hst_acs_ngc5457-c_f814w_v1_drc	9490	ngc5457-c					
Display		FITS	14:03:07.2	54:21:52.2	4	NGC5457-7	ACS/WFC	WFC	F814W/F555W/ F435W	54	10260	2002-11-13 17:20:47	hlsp_legus_hst_acs_ngc5457-c_f814w_f555w_f435w_v1_drc	9490	ngc5457-c					
Display		FITS	14:02:57.6	54:23:40.2	5	NGC5457-2	ACS/WFC	WFC	F435W	10	1980	2002-11-15 10:21:36	hlsp_legus_hst_acs_ngc5457-nw1_f435w_v1_drc	9492	ngc5457-nw1					
Display		FITS	14:02:57.6	54:23:40.2	5	NGC5457-6	ACS/WFC	WFC	F555W	10	1800	2002-11-15 10:41:56	hlsp_legus_hst_acs_ngc5457-nw1_f555w_v1_drc	9490	ngc5457-nw1					
Display		FITS	14:02:57.6	54:23:40.2	5	NGC5457-2	ACS/WFC	WFC	F814W	10	1800	2002-11-15 10:59:07	hlsp_legus_hst_acs_ngc5457-nw1_f814w_v1_drc	9492	ngc5457-nw1					
Display		FITS	14:02:57.6	54:23:40.2	4	NGC5457-2	ACS/WFC	WFC	F814W/F555W/ F435W	30	5580	2002-11-15 10:21:36	hlsp_legus_hst_acs_ngc5457-nw1_f814w_f555w_f435w_v1_drc		ngc5457-nw1					
Display		FITS	14:02:42.72	54:26:01.3	5	NGC5457-5	ACS/WFC	WFC	F435W	24	4320	2003-01-14 05:19:59	hlsp_legus_hst_acs_ngc5457-nw2_f435w_v1_drc	9492	ngc5457-nw2					
Display		FITS	14:02:42.72	54:26:01.3	5	NGC5457-5	ACS/WFC	WFC	F555W	24	4320	2003-01-14 05:29:03	hlsp_legus_hst_acs_ngc5457-nw2_f555w_v1_drc	9492	ngc5457-nw2					
Display		FITS	14:02:42.72	54:26:01.3	5	NGC5457-5	ACS/WFC	WFC	F814W	24	4320	2003-01-14 05:37:58	hlsp_legus_hst_acs_ngc5457-nw2_f814w_v1_drc	9492	ngc5457-nw2					
Display		FITS	14:02:42.72	54:26:01.3	4	NGC5457-5	ACS/WFC	WFC	F814W/F555W/ F435W	72	12960	2003-01-14 05:19:59	hlsp_legus_hst_acs_ngc5457-nw2_f814w_f555w_f435w_v1_drc	9492	ngc5457-nw2					
Display		FITS	14:02:43.68	54:26:07.4	5	NGC5457-5	ACS/WFC	WFC	F435W	18	3240	2003-01-15 06:56:50	hlsp_legus_hst_acs_ngc5457-nw3_f435w_v1_drc	9492	ngc5457-nw3					
Display		FITS	14:02:43.68	54:26:07.4	5	NGC5457-5	ACS/WFC	WFC	F555W	18	3240	2003-01-15 07:05:54	hlsp_legus_hst_acs_ngc5457-nw3_f555w_v1_drc	9492	ngc5457-nw3					
Display		FITS	14:02:43.68	54:26:07.4	5	NGC5457-5	ACS/WFC	WFC	F814W	18	3240	2003-01-15 07:14:50	hlsp_legus_hst_acs_ngc5457-nw3_f814w_v1_drc	9492	ngc5457-nw3					
Display		FITS	14:02:43.68	54:26:07.4	4	NGC5457-5	ACS/WFC	WFC	F814W/F555W/ F435W	54	9720	2003-01-15 06:56:50	hlsp_legus_hst_acs_ngc5457-nw3_f814w_f555w_f435w_v1_drc	9492	ngc5457-nw3					

Display | PlotCat | Retrieve | RA | DEC | Level | Target | Detector | Aperture | Spectral_Elt | NExposures | ExpTime | StartTime | Dataset | PropID | VisitNum | PI_Name | DAOCat | SEXCat | « | »

Results **1-20** of **1831**   Show 20 results per page   Previous **1** 2 3 4 5 6 7 8 9 ... 92 Next

Figure 3. First page of results for M101 search

Columns Show all columns Restore original column order

Name	Unit	Datatype	Description
URL		char[*]	Link to data
RA	deg	double	RA (J2000)
DEC	deg	double	Dec (J2000)
Level		int	Processing level: 1=exposure 2=combined 3=mosaic 4=color 5=HLSP
Target		char[*]	Proposal target name
Detector		char[*]	Detector
Aperture		char[*]	Instrument aperture or slit
Spectral_Elt		char[*]	Filter or spectral element name
NExposures		int	Number of exposures combined in this image
ExpTime	s	double	Total exposure time
StartTime		char[*]	Start time of first exposure
Columns below are hidden - Drag to change			
Dataset		char[*]	Name of image: HST_propid_visit_detector_spectralelt_exposure
PropID		char[*]	HST proposal number (or "multi" for combined images)
VisitNum		char[*]	Visit number within proposal
PI_Name		char[*]	PI last name
DAOCat		char[*]	Processing status for DAOphot catalog
SEXCat		char[*]	Processing status for SExtractor catalog
Mode		char[*]	Data collection mode
DBCreationDate		char[*]	Date when this dataset was added to database
Source		char[*]	Source for this dataset (one of HLA, ECF, CADC, DADS, HLSP, HSTCACHE)
Wavelength	0.1nm	double	Characteristic wavelength for bandpass
Format		char[*]	Format of image
ReleaseDate		char[*]	Date when these data are made public (GMT)
NReleaseDate		long	Date when these data are made public (seconds since 1970)
Title		char[*]	Summary title
naxis		int[*]	Image size (pixels)
scale	deg/pix	double[*]	Pixel scale
naxes		int	WCS info
crpix	pix	double[*]	WCS info
crval	deg	double[*]	WCS info
cd_matrix	deg/pix	double[*]	WCS info
filename		char[*]	Filename (comma-separated list for color)
regionSTCS		char[*]	STC/S footprint region description

Table 2. Description of the columns in the results table.

The complication is to select the file, or files that interest usn. At least, we can see that for the first row, in the eighth column, it appears that the instrument (detector) is the WPF2 and that therefore it is a photograph,the observation was made with the F606W filter,guineapigor effect on the light received we have seen it in figure 1. Data such as right ascension, declination, number of exposures, etc. help us to understand what is in the file but not to imagine how it looks, to advance we will need the computer application, it is time to start with it and then we will resume the download of FITS files

3. Explore FITS computerapplication.

This part of the document describes an application that I have written to explore fits files,it is an application for the Windows operating system with the obvious name: Explore FITS.

To better understand how Explora FITS works, we must discuss some basic aspects of the FITS format.

A FITS file contains ano o o variors blocks (units),which are calledHDU (Headerand Data Unit). All THE ADDEDUs are preceded by a header where the values of a multitude of parameters are specified and comments can be included and then a data matrix can go,this matrix can be a table or an image.

The job of the application is to detect how many units are present in the file and for each of them show the header, parameters and the image or table that accompanies it.

In the case of tables there is not much to do, only visualize the columns of data for a series of rows,with oneexception: tosome spectrumfiles, such as those that can be obtained from the SDSS (TheSloan Digital Sky Survey)in Data Release 16 | SDSS,contain the spectrum data as tables within the FITS file, these tables contain tens of thousands of columns (even hundreds of thousands) that the application cannot display in a table. Formally the tables contain a small number of columns, but some of the columns are made up of tens of thousands of data. The application displays in those columns, the first and last data and the number of intermediate data that are not displayed. When these tables are exported if all the data is included, obtaining large files that, for example, cannot be treated in a spreadsheet because they exceed the capabilities of these applications. The file containing the high-quality spectra of the SDSS contains 8,646 spectra, each spectrum is a row of the table and each row has a length of 127,872 bytes, the FITS file occupies 1.02 Gb and if we export the table the resulting file occupies 2.23Gb.

Con the data matrices,if you want to visualize them as images you have to normalizethem to convert the data into pixels of an image, as mentioned above. The FITS format supports matrices of up to 999 dimensions, but Explora FITS only treats two-dimensional images (photographs) and although it contemplates three-dimensional blocks of data, it will consider that there are as many two-dimensional images as it indicates the third dimension. The two astronomical dimensions par excellence are right ascension (AR) and declination (DEC), so henceforth I will use AR as a synonym for dimension X and DEC instead of Yaxis.

For photographic images, it is very important specify the area of the firmament to the What Correspondsn, and for the images of spectra the range of wavelengths that Represent, in general, the range of variation of the value of the X, Y coordinates (which almost always they are the right ascension -AR- and the declination -DEC-).

The FITS format defines these coordinate variation ranges using a series of parameters in the HDU headers and allows you to do so in various ways. In all cases the header must include a reference element that is a point in the image (pixel x, pixel y), or more appropriately the two indexes of an element in the data matrix. In addition, you must include the actual values of the coordinates (AR and DEC) of that datum point. The simplest way to complete the information is to include another pair of values that are how much the X coordinate varies when moving a point to the right or left of the reference point and the same for the Y coordinate. With these three pairs of values we can calculate the coordinates of any point in the image (of any element of the data matrix), another more precise and therefore preferred way is to include a 2x2 matrix (CD) that allows to convert the pixel vector (inc px, inc py), with respect to the reference point, in coordinate variations (inc AR, inc DEC) with respect to the coordinates of the datum point.

| inc_AR | | CD11 CD12 | | inc_px |
| DEC inc_ | = | CD21 CD22 | x | inc_pand|

Equation 1. Calculation of the distance, in coordinates, to the reference point from the distance in pixels

The reverse CD array allows you to perform coordinate transformation into pixels.

Arrived here, it is time to start the application. The application consists of a set of files (chapter 6 of this document) that we will have downloaded fromtherepository:

https://github.com/labotecta/Explora-FITS

Weituamos these files in any folder of the computer, even in a USBmemory, because it does not need installation, what if it needs is that our PC has installed some Microsoft libraries, which is not a problem because if we run the application and they are not, it will ask us to install them and will facilitate the way to do it.

The executable file is the ExploraFits.exe and when opened it will show two windows on the screen (figure 4). One of themoccupies the entire screen and the other smaller, is located in the foreground, at the bottom right.

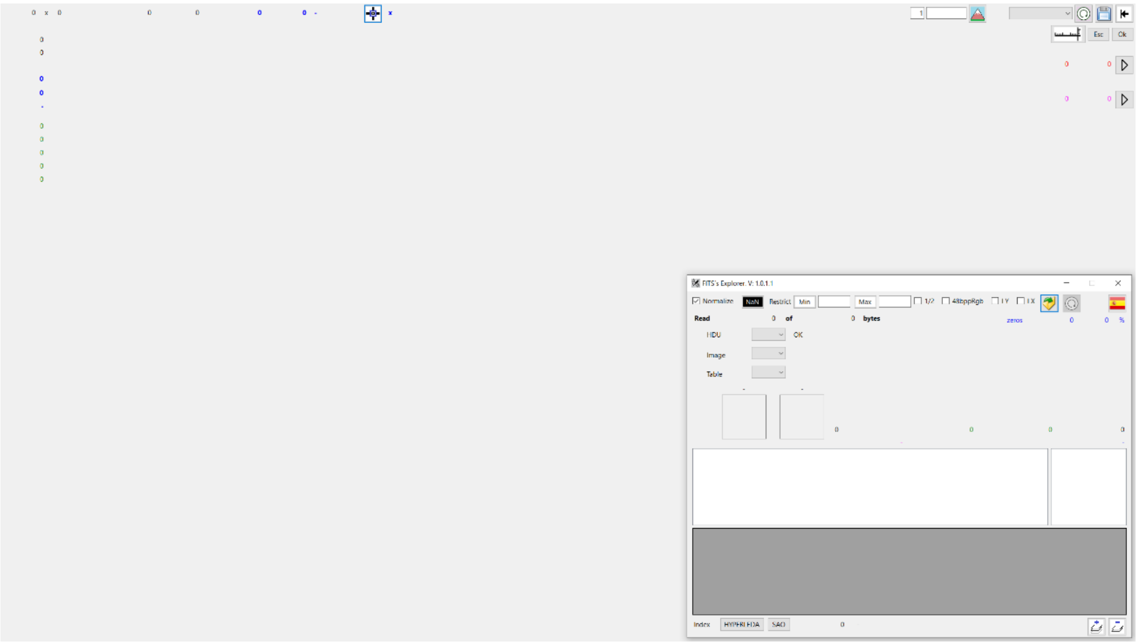


Figure 4. Explora FITS application windows

In the large window the images will be displayed and some actions will be carried out on them, especially the superposition of celestial objects contained in catalogs.

The small window (Figure 5) is where to start operations, such as selecting the FITS file to be processed and where the headers and tables contained in it will be displayed.

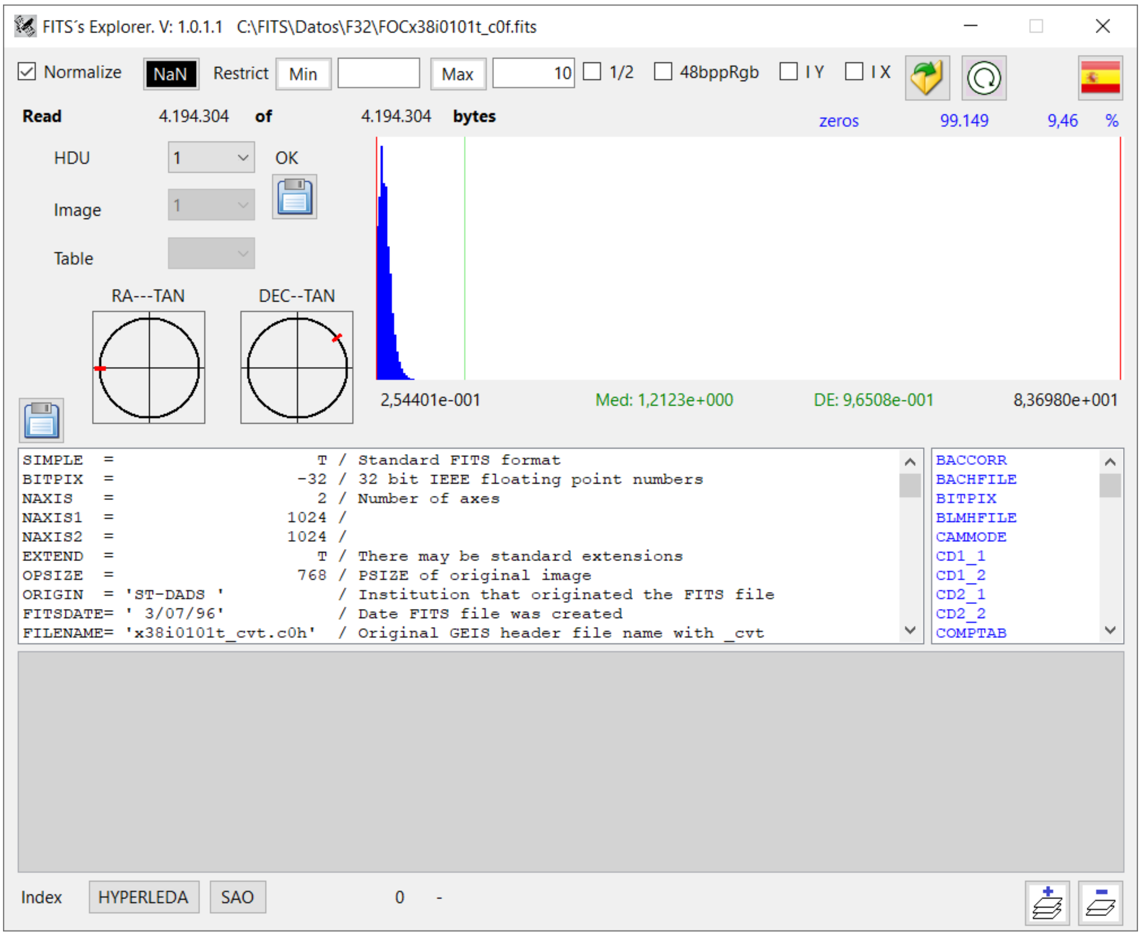


Figure 5. Main application window

3.1 Main window.

Figure 6 has marked 6 zones in the main window:

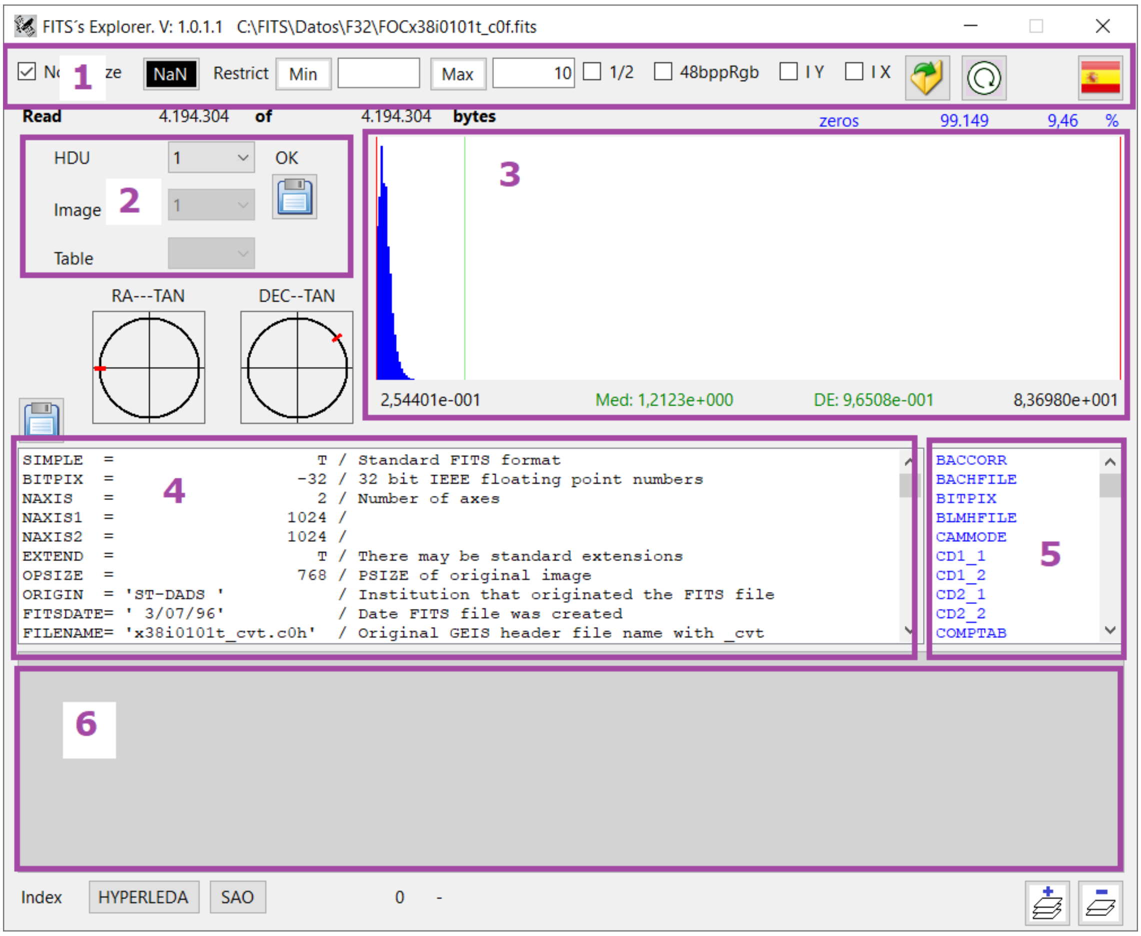


Figure 6. Areas of the main application window.

1. Reading the FITS file and basic parameters for the display of the images
2. Number of HDU blocks and their content. Allows you to select the HDU to work with.
3. Histogram showing the frequency of occurrence of values in the data matrix. Useful for normalizing images.
4. Headers included in each HDU
5. Alphabetically ordered list of all parameters included in the HDU header, clicking on them displays their value.
6. Table contained in the HDU, if it includes one.

The lower part is one more area that we will see at the end.

 The first thing is to open a FITS file using this button. The application will analyze it and create a list with the HDU it contains, it is the first drop-down list of zone 2, which has the HDU label on its left, in Figure 7 a case with 5 HDUs is shown

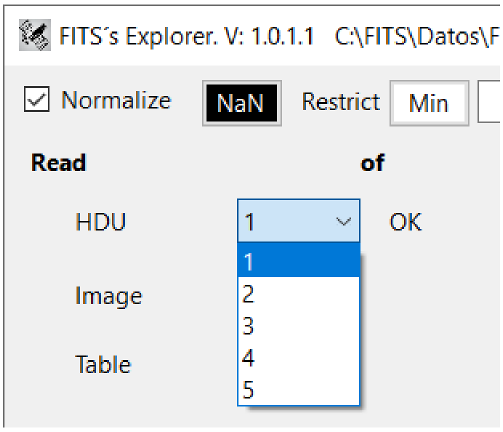


Figure 7. Drop-down list with the HDUs of the FITS file.

Immediately the HDU headers (zone 4) and the list of parameters (zone 5) figure 8 will be displayed.

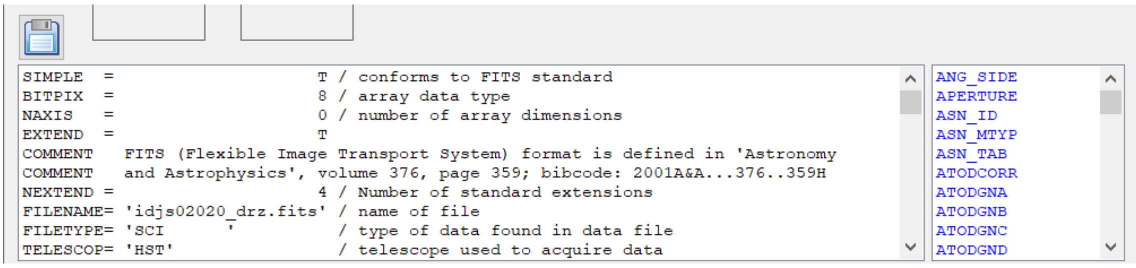


Figure 8. Headers and parameters of the HDU.

The button at the top left of the header list permiwill write these headers in a text fichero.

If the HDU contains a table it will be seen in zone 6 (Figure 9)

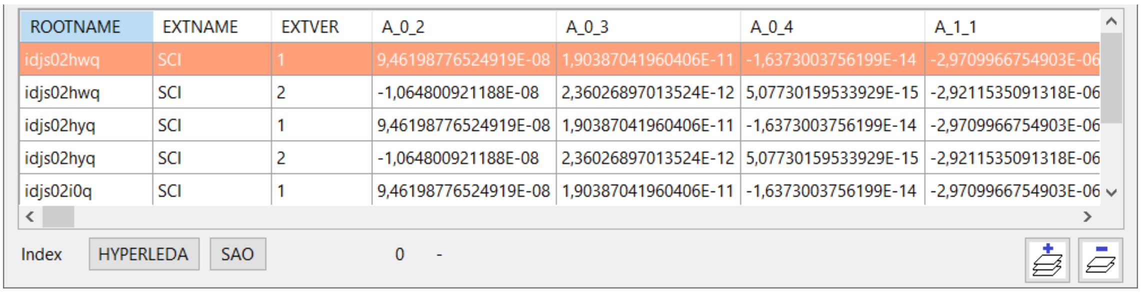


Figure 9. HDU table.

When you double-click a cell in the table, the contents of this cell are copied to the clipboard, except if it is a cell that contains more than fivevalues. Asalready mentioned, when a column contains several sub-columns only the first data, the last data and the number of intermediate data are displayed, in this case a file is requested in which the contents of all the sub-columnsof the cell will be copied, not only what is displayed. The data is copied vertically, a piece of data on each line of the output file.

 When there is a table in zone 2, the button that allows you to write the table to a text file is displayed to the right of the Table drop-down list (Figure 10).

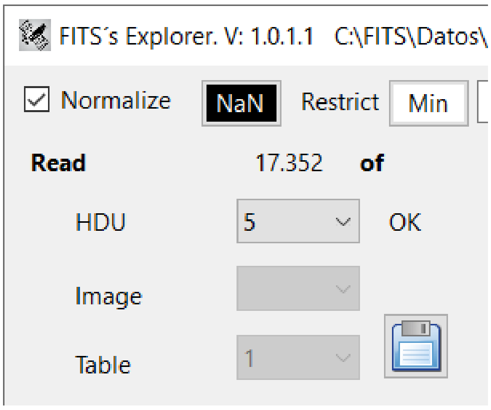
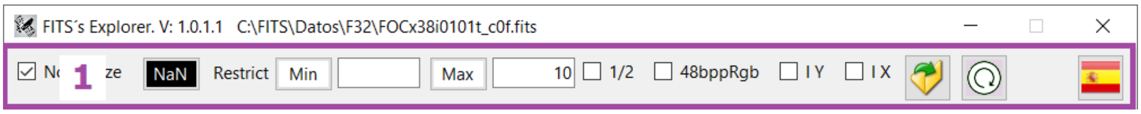
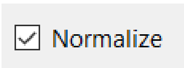


Figure 10. Tables can be written to a text file.

Si the HDU has an image will be drawn in the background window next to the relevant position data in the sky. The image is drawn according to the specifications of zone 1.





if this selector is checked the data is normalized between 0 and 255 to convert it to pixels taking into account the values in the s boxes to the right of the min and max buttons

These values are the dimensions that we want to impose on the data for visual purposes:all data with a value less than or equal to the specified minimum are considered zero and all values greater than or equal to the maximum are considered equal to 255, the rest of the values are normalized between the minimum and the maximum. The Min and Max buttons allow you to visualize in the image the data that we have made zero because they are lower than the minimum and those that are considered 255 because they are greater than the maximum. When the Min button is pressed, it has a red background and if the Max is pressed, it acquires a blue background, this indicates that when the image is drawn the pixels considered zero will be painted in red and those converted to 255 will be painted in blue. If you see one of these buttons press again, it will go to its normal state, white background, with which the converted data will be displayed according to the value to which it has been converted: the zero in black and the 255 in white.

The value that is specified for the minimum and maximum dimensions has an enormous significance in how the image is drawn and to help us see the best values we have the histogram of zone 3 that is commented on a little later.

NaN Color of pixels corresponding to unavailabledata. The readings of the instruments do not always provide values for all the data in the data matrix, the observed area does not have to be exactly rectangular, there are gaps between the CCDs of the cameras because it is impossible for the joints to fit 100%, it is a composition of images and for other reasons. A data not available is not the same as a zero data and when we draw the image we can paint it white, black or brown at our choice, by pressing the NaN button changes its background between those three colors.

☐ 1/2 ☐ 48bppRgb ☐ I Y ☐ I X If you mark the selector 1/2, instead of drawing the data you draw the root squareto them, this significantly attenuates the differences in value between them making you see points that would otherwise be obscured by the great contrast with the brightest. The IY button rotates the image on the Y axis and the IX button does the same on the X axis. If the selector is checked 48bppRgb the image will be drawn with 16-bit pixels, actually 13 bits, which are not bounded between 0 and 255 but between 0 and 8.192 which considerably expands the tones of the image. I discourage using it because it slows down operations drastically and its visual contribution is not appreciable.

 When any of the aforementioned parameters are modified, the image is not automatically redrawn (for large images it is a slow process) and once all the changes that are considered necessary are made, you have to press this button.

o Change the language of the application.

In addition to drawing the image,zone 3 shows a histogram that informs us of the distribution of values within the HDU data matrix used to draw the image (Figure 12).

Figure 12. Histogram of the distribution of data matrix values.

The histogram in Figure 12 tells us several things:

- The value specified as the minimum dimension affects 0.00% of the non-zero data (green).
- The value specified as the maximum dimension affects 0.15%of the non-zero data (green).
- The data matrix contains 99,149 zeros which are 9.46% of all data(in blue at the top right)
- The maximum value is 8.3698e+001
- The average of the values is 1.2123e+000
- The standard deviation of the data is 9.6508e-001
- The value in the source of accissas, 2.5441e-001 is not the minimum value of the data, it is the width of a bar of the histogram,the minimum value of histogram accissas is always 0.
- Below, in purple, the value 2.03521e+001 is shown that corresponds to the vertical line of the same color, the number 6 is the number of data that have that value (they are within the histogram of that position) and 99.99% is the percentage of data with a value less than or equal to that of the vertical line. The vertical line is marked when you click with the mouse on a place in the histogram.

 Similar to tables, when there is an image, the save to disk button is displayed in zone 2, to the right of the image drop-down list (Figure 13).

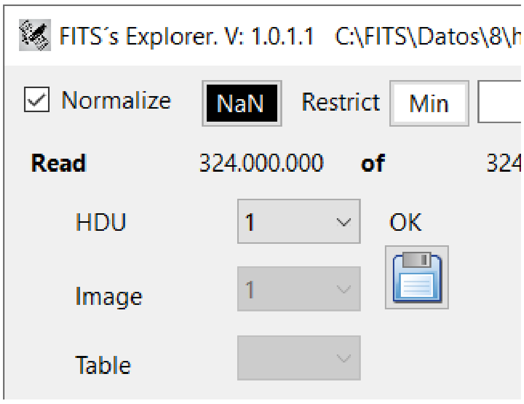


Figure 13. Export image data.

With this option, a binary file with the data matrix is exported (saved) in the same format (byte, int16, int32, float or double)as in the FITS file, only the data preceded by three int32 numbers that are the data type and the two dimensions of the matrix and six numbers in double precision with the following data aresaved:

- Pixels x, y of the reference point (CRPIX1, CRPIX2)
- Value of the X, Y coordinates of the datum point (CRVAL1, CRVAL2)
- Variation of the x coordinates, y when moving onepixelwith respect to the reference point (CDELT1, CDELT2).

The files exported as BIN, can be read and the application creates a FITS file with the essential headers.

To finish with the main panel, it must be said that the clocks in Figure 14 quickly show the angular coordinates of the displayed image.

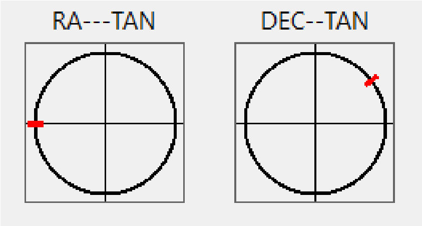
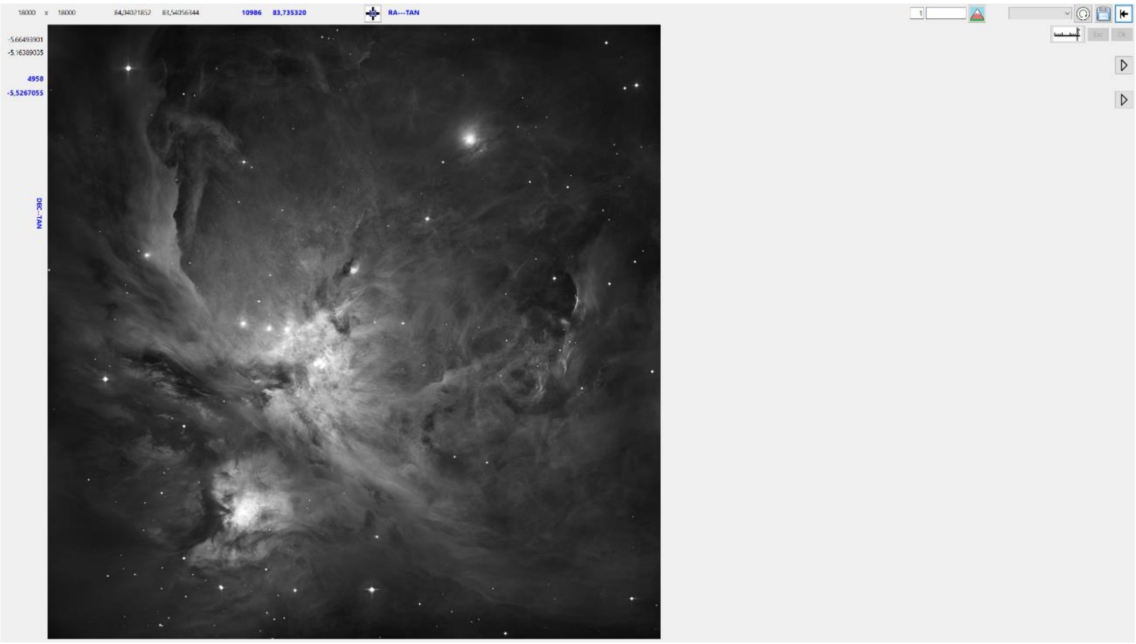


Figure 14. Angular coordinates of the image

3.2 Window where the image is drawn.

Now let's describe the window where the image is drawn (Figure15).



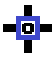
15. Window where the image is drawn

Figure 16. Image coordinates

In the upper left corner the dimensions are shown in the footers of the image, which in Figure 16 are 18000x18000.

Atthe top, to the right of the dimensions, you can see the range of variation of the Xcoordinate, usually the right ascension, in figure 16 varies between 84.04021852 (value in the left corner of the image) and 83.54056344 (value in the right corner of the image).

Then, in blue, the X position of the datum point in pixels and the value of the coordinate. In Figure 16: 10.896 and 83.735320.

 Follow the button that draws a blue square over the image marking the reference point.

Finally, horizontally, the X-axis label specified in the FITS file: RA---TAN (right ascension projected onto the TANgentplane).

Vertically, below the dimensions of the image, the range of variation of the Y coordinate. Figure 16 -5.66493901 and -5.16389035.

In blue, the Y position of the reference point in pixels and coordinate value, in Figure 16: 4958 and -5.5267055.

Below is the label of the Y axis specified in the FITS file: DEC---TAN (projected declination in the TANgenteplan).

When you click with the mouse on a point in the image, the position in pixels and values of the coordinates of that point, as well as the corresponding value of the data matrix is shown in green on the left (Figure 17).

Figure 17. Data for a point in the image

Spectra. Spectra images have a very small dimension on the Y axis, sometimes a single pixel, when the application detects an image this reduced lengthens it on the Y axis to improve the display. Figure 18 shows a spectrum that has dimension 1 on the y-axis.

18. Image of an elongated spectrum on the Y axis.

Figure 19 shows the top right of the window where the image is drawn.

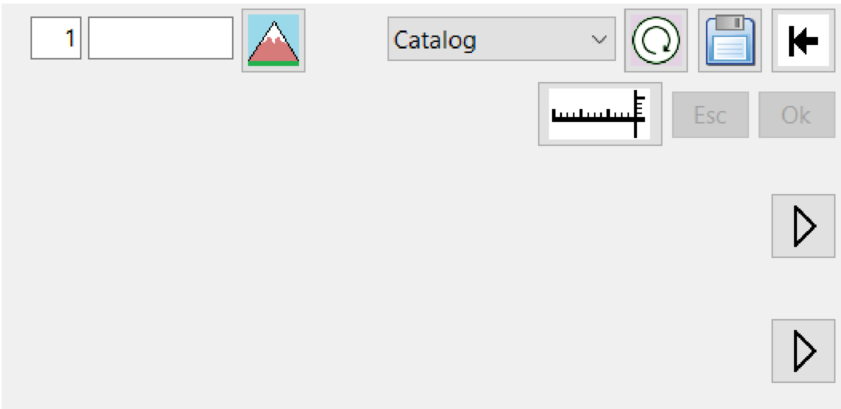


Figure 19. Tools in the panel where the image is drawn.

 This button allows you to bring to the foreground the main window that may be hidden behind the window where the image is drawn.

 Allows to save on disk the displayed image, regardless of the resolution of the screen of the PC where the application is running, the image is saved with the original dimensions of the FITS file, in figure 16 an image of approximately 1000x100 pixels is shown that is the maximum that allows the resolution of the PC with which it has been displayed, but when he saves it he will do it with the 18000x18000 pixels of the original image.

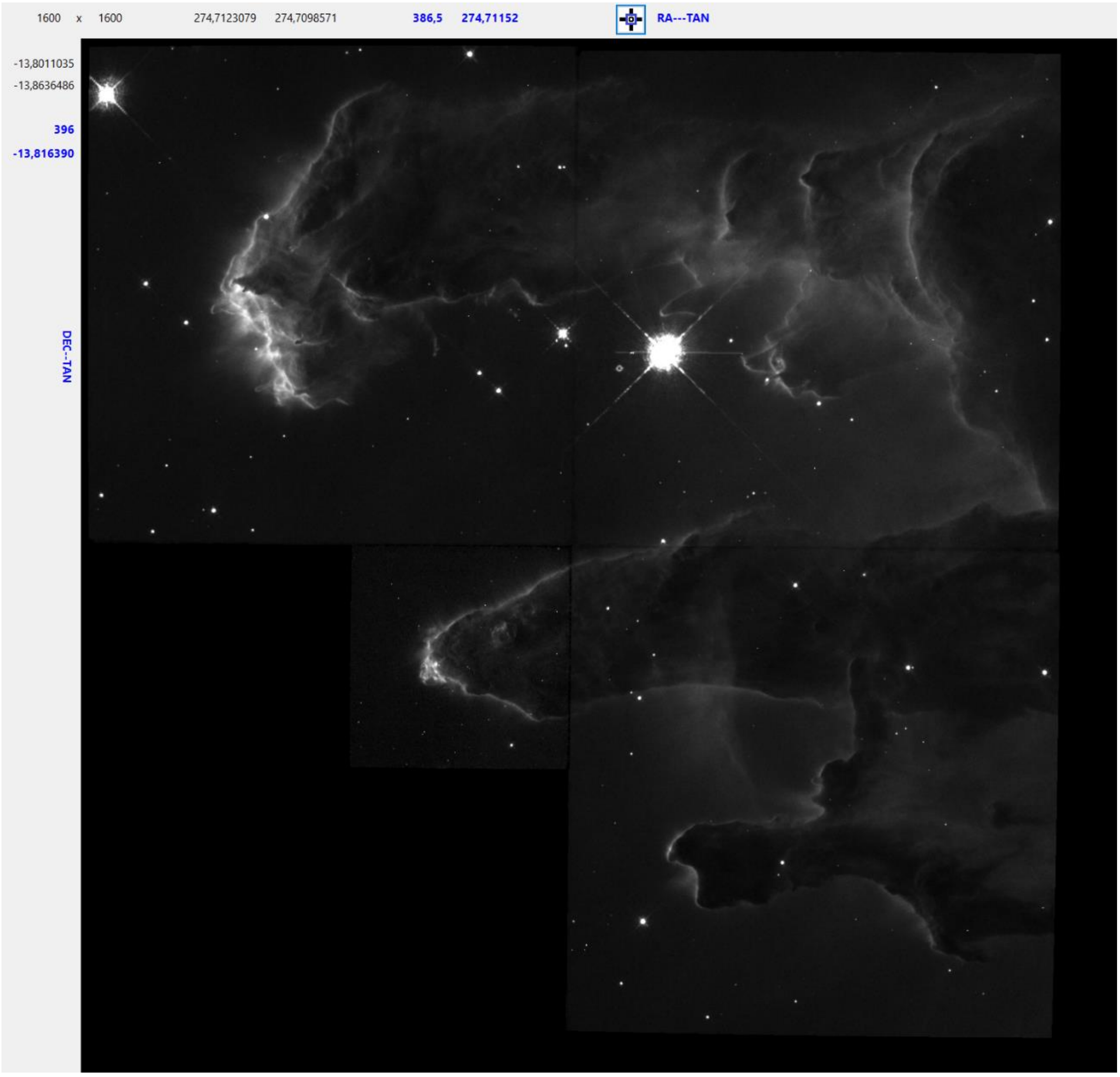
 Redraw the image. The application makes overlays of graphic elements on the image, such as the mark of the reference point and others that we will see later, which can be removed by redrawing the image.

The app can create a list of bright spots, or peaks of brightness. It will search the image for pixels with at least a certain brightness that are surrounded by pixels with a lower brightness. Understanding by brightness the value of the corresponding element of the data matrix. This threshold value is specified in the box immediately to the left of this button. To the left of the box for the threshold value, there is another box in which you can specify that the application instead of working with individual pixels does so with squares of several pixels on the side, a value of 3 corresponds to squares of 3 pixels on the side. The application works with the original data matrix and not with the displayed image that will be adapted to the resolution of the screen. The "peaks" found will be displayed as red squares in the corresponding places in the image.

It is enough that one of the pixels that surround a given one has a brightness higher than it for it to be discarded as a peak. If none is superior but there is one, or several, of the same brightness, the radius of the search circumference is increased until the pixel is discarded because r one appears with more brightness or is labeled as top because all have lower brightness.

When marking the peaks on the image, squares of different dimensions will appear indicating the radius to which it has been necessary to go. The list of brands can be written in a file, by means of the button that will be shown to the right of the button that we are commenting.

Figure 20 shows the 220 marks found by the application for an image of the pillars of creation. None of the marked objects are listed in the HyperLEDA catalog or the Smithsonian Astrophysical Observatory Star Catalog.


1600 x 1600
274,7123079 274,7098571
386,5 274,71152
RA---TAN
-13,8011035
-13,8636486
396
-13,816390
DEC--TAN

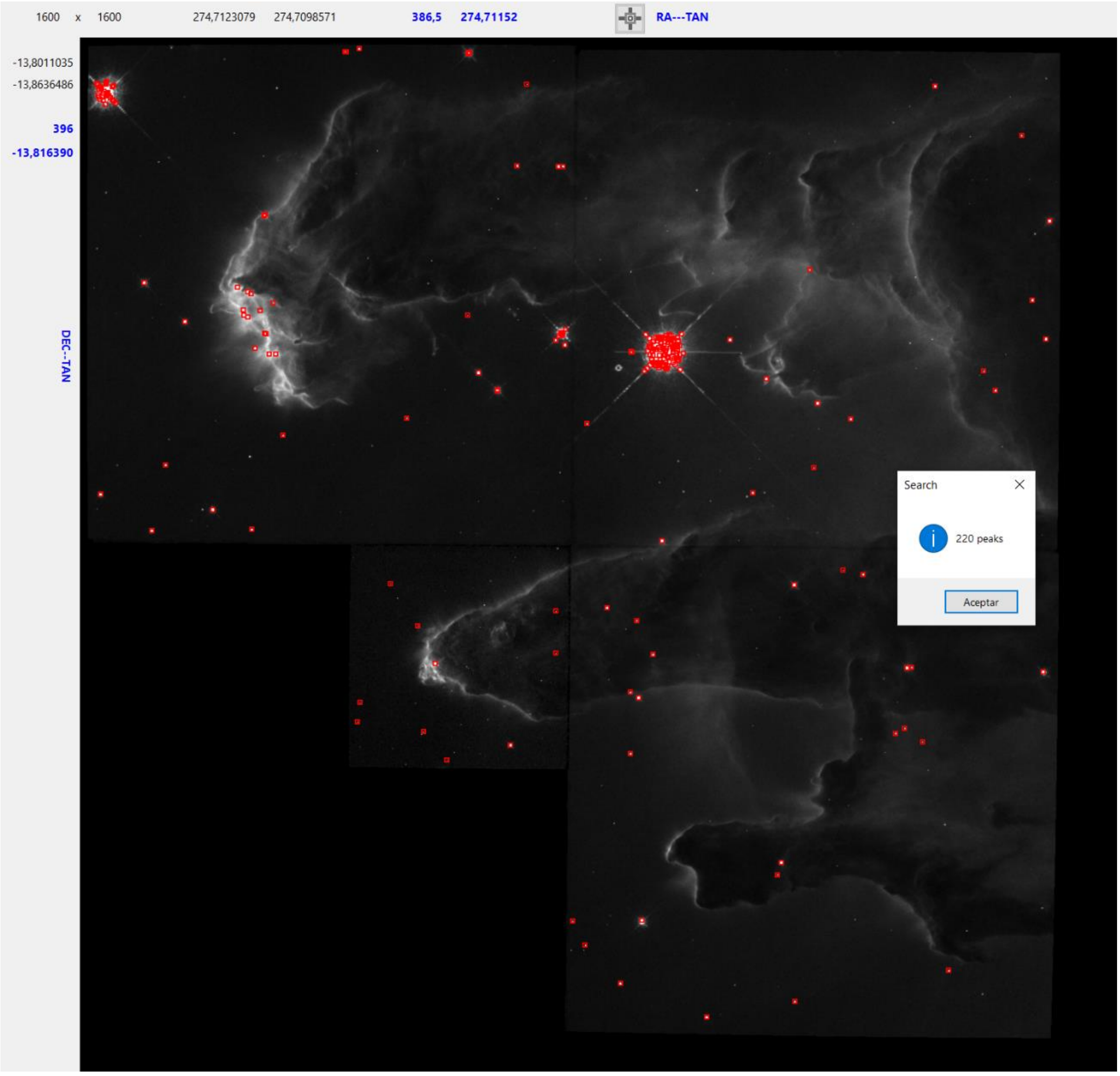
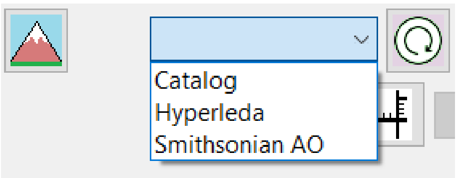


Figure 20. "Peaks" found in the image of the pillars of creation.



Catalogues. Two catalogs can be selected from this drop-down list:

- HyperLEDA.
- Smithsonian AO

<u>HyperLEDA database on galaxy physics.</u>

http://leda.univ-lyon1.fr

HyperLEDA is a database and collection of tools for studying galaxy physics and cosmology. The project, started in 1983, is currently maintained by a collaboration between the Lyon Observatory (France) and the Special Astrophysical Observatory (Russia).

The principle behind HyperLEDA is to collect measurements published in modern literature and surveys, and combine them into a unique homogeneous description of astronomical objects. This allows the researcher to compare objects located at very different distances. This approach is a continuation of the famous bright galaxy catalog series (RC1, RC2, RC3) from Vaucouleurs and co-workers. The result of homogenization is the Leda catalogue.

HyperLEDA is not only used by researchers, but also by sky lovers or amateur astronomers interested in learning more about galaxies, by students and by teachers. HyperLEDA is developed within the framework of the Virtual Observatory, an initiative aimed at facilitating the exchange and use of data on a global scale. All data and software are publicly available in open source for non-commercial purposes.

It contains data from more than five and a half million celestial objects.

Smithsonian Astrophysical Observatory Star Catalog (1990)

https://cdsarc.cds.unistra.fr/viz-bin/cat/I/131A

This catalog is based on an original binary version of the Smithsonian Astrophysical Observatory Star Catalog (SAO Staff 1966). The catalogue contains the SAO number; the ascension and declination J2000;annual proper motion and its standard deviation, photographic and visual magnitudes; spectral type; references to sources; the identifier Durchmusterung (DM) if the star appears in the Bonner DM (BD), Cordoba DM (CD) or Cape Photographic DM (CP); identification of components; The Henry Draper number (Extension) (HD or HDE).

It contains data from 259,000 stars.

When one of the catalogues is selected, the objects contained in the image are marked on the image,   whose coordinates are within the range of the coordinates of the image (Figures 21 and 22).

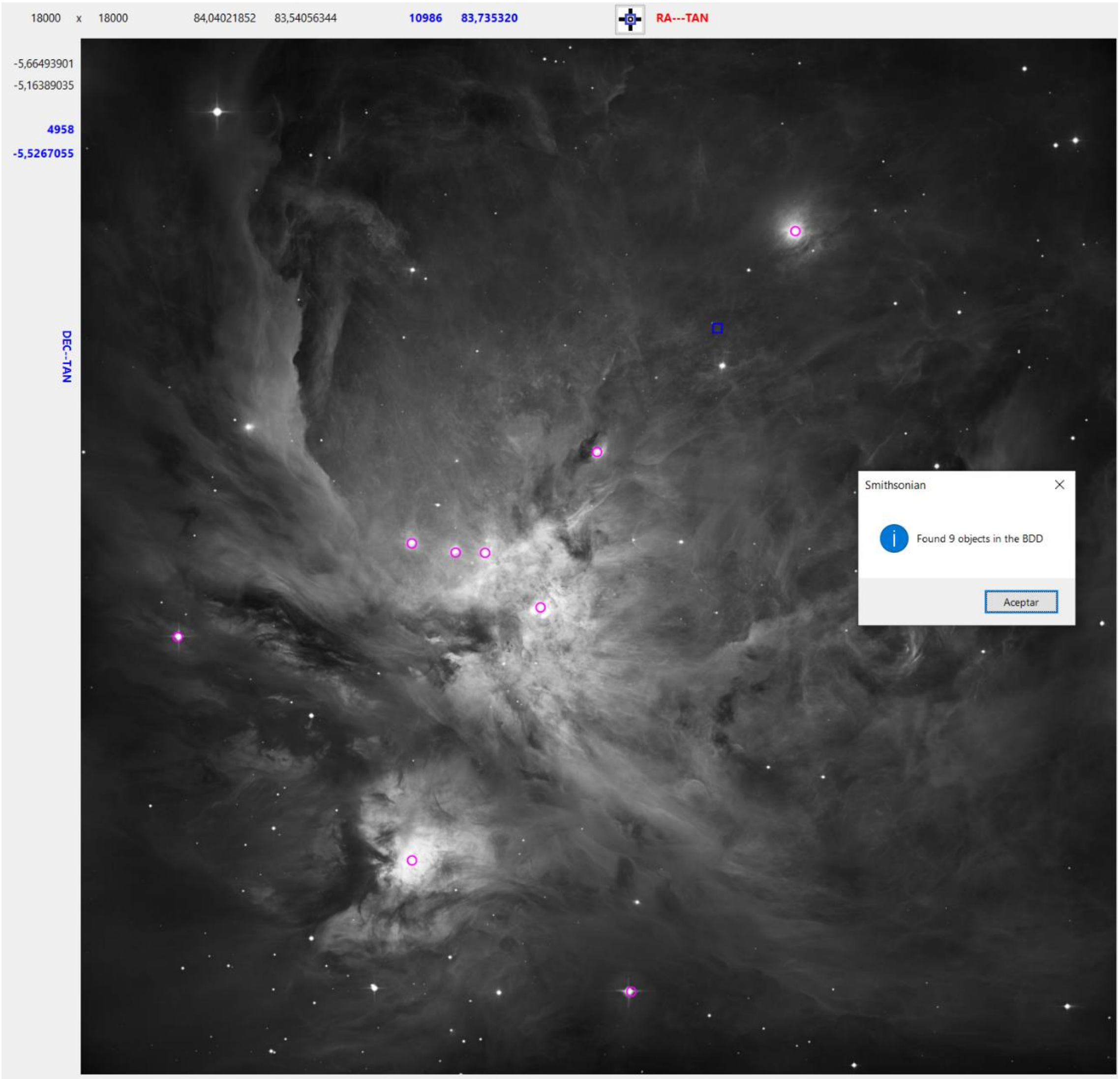


Figure 22. Objects from the Smithsonian Astrophysical Observatory catalog.

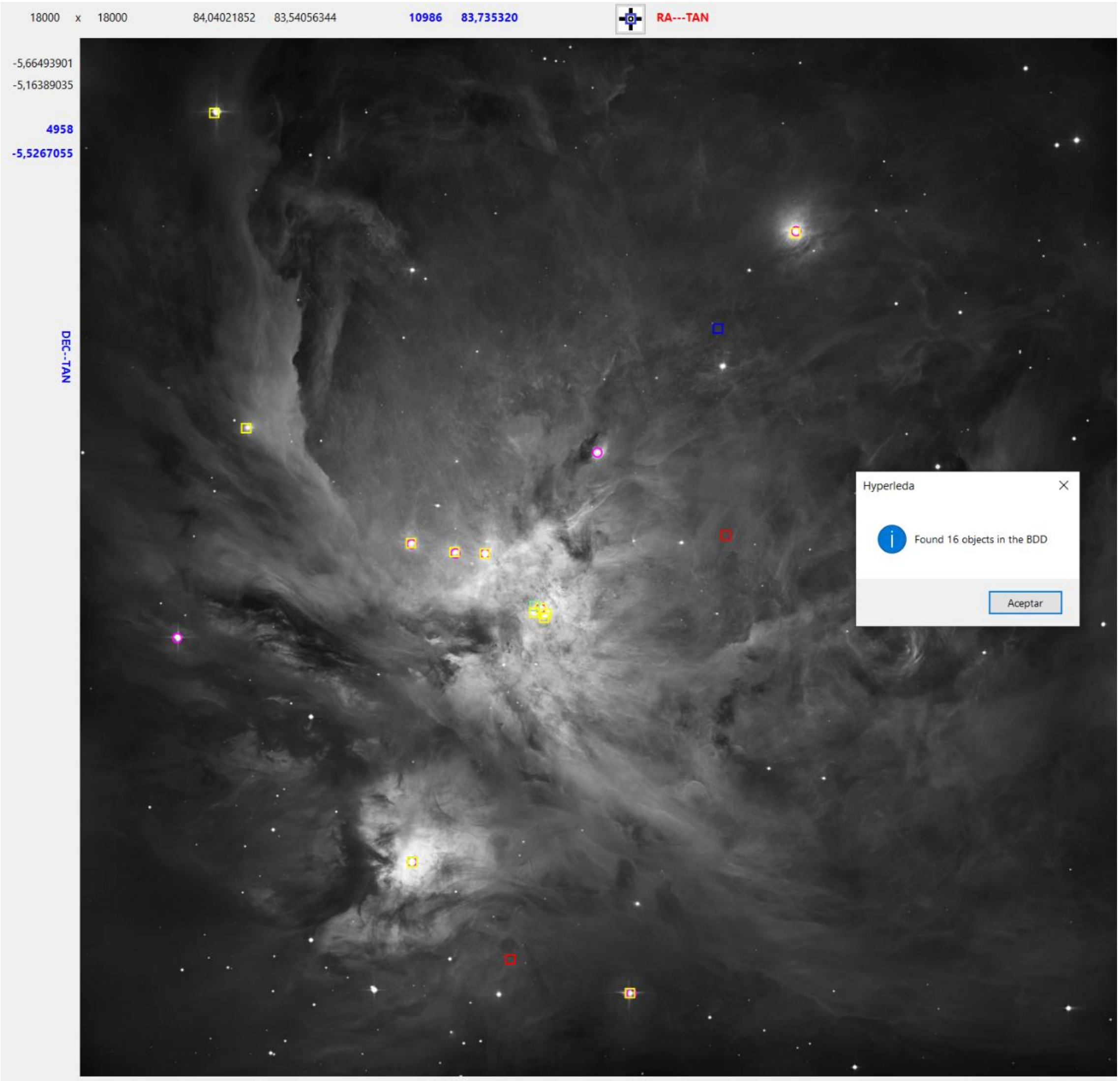


Figure 22. HyperLEDA catalogobjects.

Clicking with the mouse on one of these marks displays the name of the object and its coordinates (Figure 23). Information from HyperLEDA objects in red and purple from the Smithsonian Astrophysical Observatory.

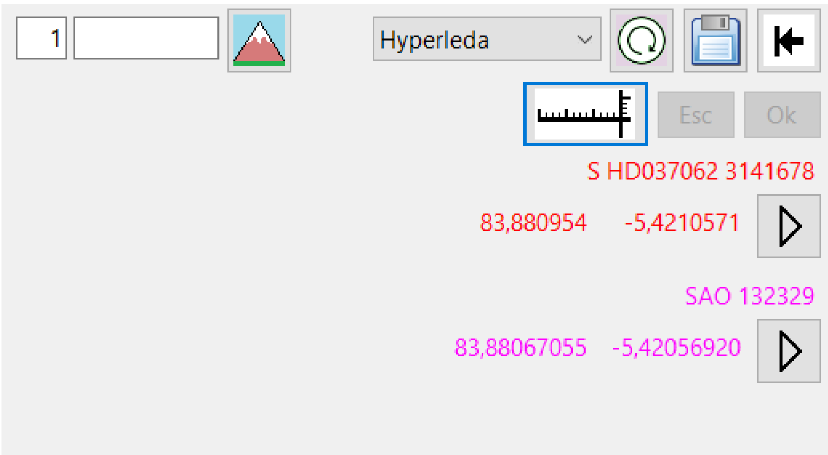
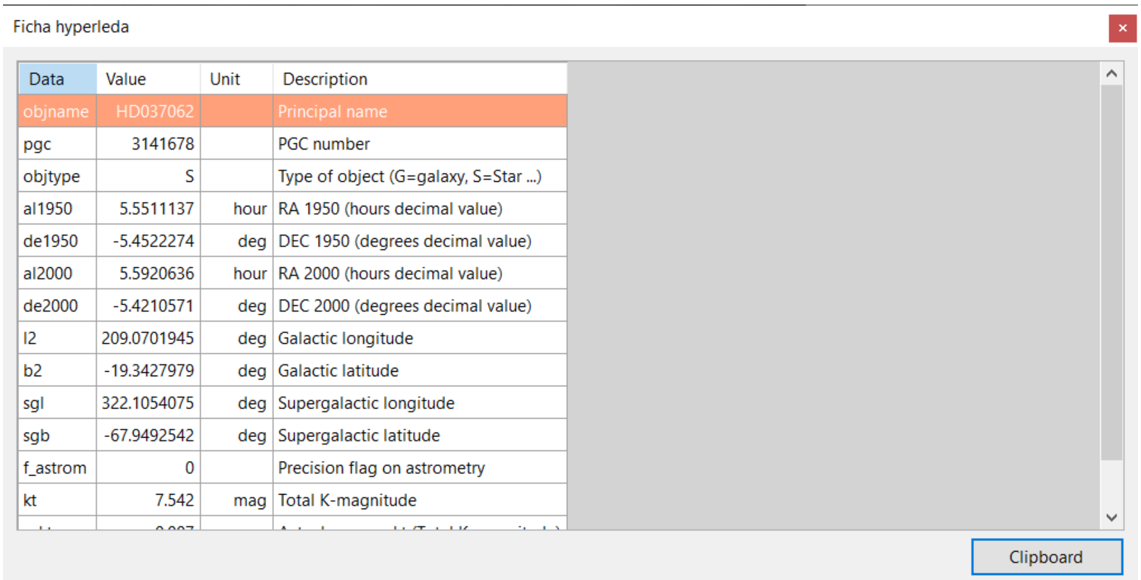


Figure 22. The name of the catalog object.

And if you then press the button:

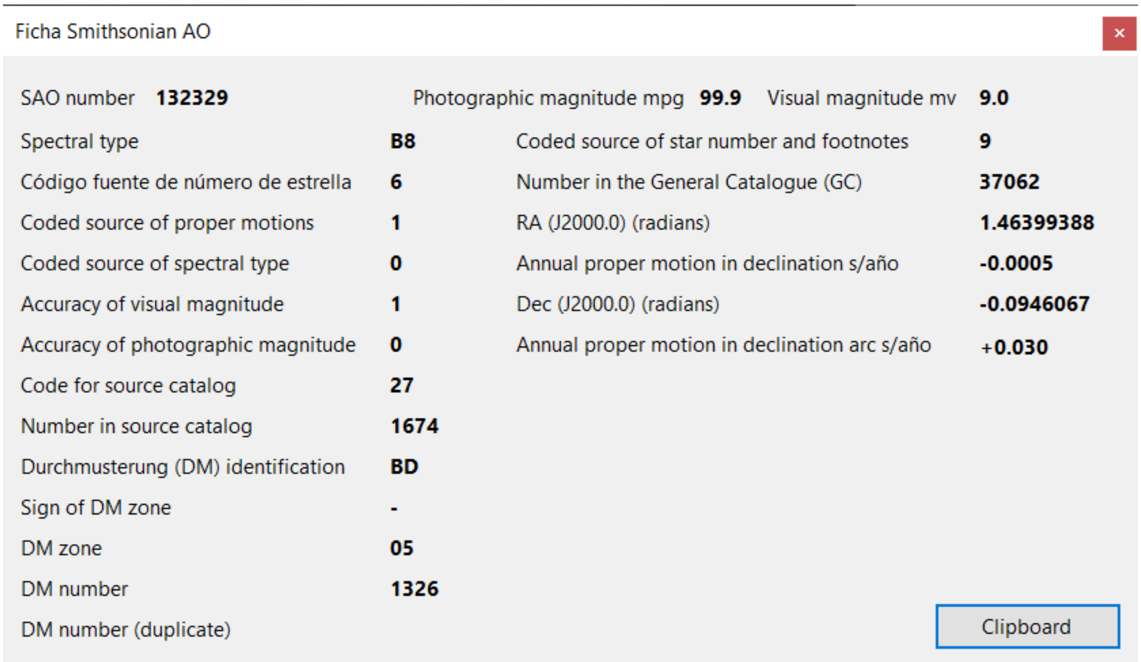
A tab is displayed with the catalog information about that object (Figures 24 and 25).


Ficha hyperleda

Data	Value	Unit	Description
objname	HD037062		Principal name
pgc	3141678		PGC number
objtype	S		Type of object (G=galaxy, S=Star ...)
al1950	5.5511137	hour	RA 1950 (hours decimal value)
de1950	-5.4522274	deg	DEC 1950 (degrees decimal value)
al2000	5.5920636	hour	RA 2000 (hours decimal value)
de2000	-5.4210571	deg	DEC 2000 (degrees decimal value)
l2	209.0701945	deg	Galactic longitude
b2	-19.3427979	deg	Galactic latitude
sgl	322.1054075	deg	Supergalactic longitude
sgb	-67.9492542	deg	Supergalactic latitude
f_astrom	0		Precision flag on astrometry
kt	7.542	mag	Total K-magnitude

Clipboard

Figure 24. Tab of an object in the HyperLEDAcatalog.

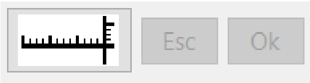

Ficha Smithsonian AO

SAO number **132329** Photographic magnitude mpg **99.9** Visual magnitude mv **9.0**

Spectral type	**B8**	Coded source of star number and footnotes	**9**
Código fuente de número de estrella	**6**	Number in the General Catalogue (GC)	**37062**
Coded source of proper motions	**1**	RA (J2000.0) (radians)	**1.46399388**
Coded source of spectral type	**0**	Annual proper motion in declination s/año	**-0.0005**
Accuracy of visual magnitude	**1**	Dec (J2000.0) (radians)	**-0.0946067**
Accuracy of photographic magnitude	**0**	Annual proper motion in declination arc s/año	**+0.030**
Code for source catalog	**27**		
Number in source catalog	**1674**		
Durchmusterung (DM) identification	**BD**		
Sign of DM zone	**-**		
DM zone	**05**		
DM number	**1326**		
DM number (duplicate)			

Clipboard

Figure 25. One-star file from the Smithsonian Astrophysical Observatorycatalog.



Scale images.

This function allows to determine the range of variation of the coordinates in an image that does not have them defined, usually an image in bmpformat, jpeg, etc. downloaded from the internet. To do so, it will rely on one of the catalogs.

 The application, in addition to reading FITS files, can read images in the usual graphic formats. To read them, the same button in the main window that we described is used to open a FITS file.

If a file with a graphic extension is opened, the application shows a small window that offers us the possibility of assigning parameters that allow the image to be placed in the sky (figure 26)

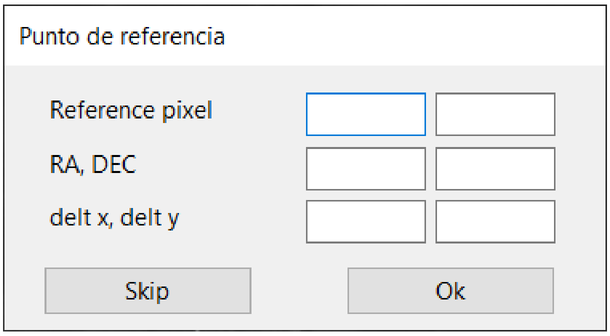


Figure 26. Parameters to position an image in the sky.

If we do not know this data, it can be omitted by pressing the button(skip). The application creates a FILE in FITS format with a single HDU and minimal headers.

When we press the button to scale images we are shown this same window and this time we will have to provide some approximate data:

- The pixels of a landmark of our choice.
- The right ascension and declination we think that pixel may have
- What we think varies the right ascension and declination when we move a pixel.

This information allows the application to provisionally assign coordinates to the vertices of the image that will be adjusted with the help of one of the catalogs.

By pressing the ok button of the salena of figure 24, it will inform us that we must provide at least two pairs of reference points and a maximum of 32. Each pair of points consists of a point where one of the catalog objects has been marked and a point in the image where that catalog object should actually be.

We close the message and select one of the catalogs to show us the objects of this that fall within the range of provisional coordinates that we have defined.

Then we click with the mouse on the brand of an object in the catalog and then click on the point of the image where the object should be, with this we would already have the first pair. We click on another of the marked objects and a new click on the point of the image where it should be, we already have the two pairs of points, the minimum required and we can press the button to the right of the "Esc" button that will show the number ofpairs marked, or add more pairs, a greater number of pairs produces a better fit as long as we are not wrong in some pair pointing out an incorrect position in the image for the catalog object. The application will make the coordinate adjustments, redraw the image and ask if it updatesr the FITS file that had been created when reading the image,we will not have another opportunity todo so, but if we do, the FITS file will be overwritten without the possibility of recovering it. We can select the catalog again to verify that the objects in it are located in the correct places in the image.

Let's see an example, we have the image of figure2 7 of which if we know its position in the sky which allows us to see how the application works. In the image we have marked the objects (stars) contained in the catalog of the Smithsonian Astrophysical Observatory.

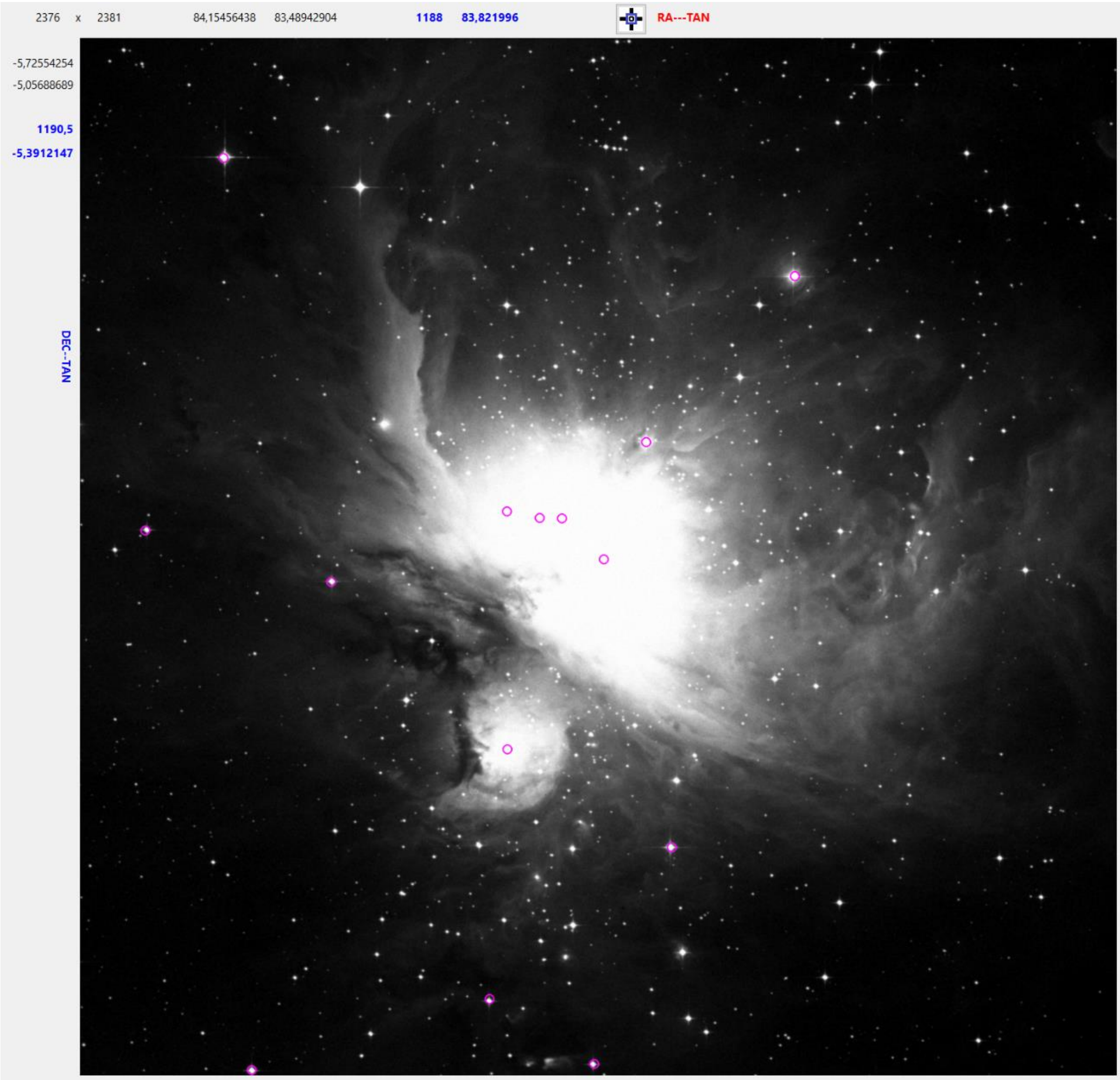
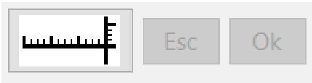


Figure 27. Orion in IR with objects from the Smithsonian Astrophysical Observatorycatalog.



We click on the scale button and the window of figure 28opens.

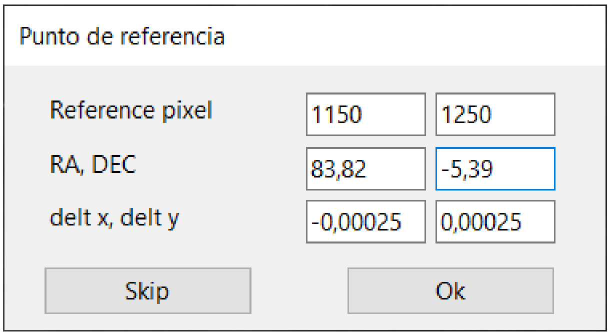


Figure 28. Approximate position of the image in the sky.

The values are a little different from the real ones, enough for the objects in the catalog to deviate from the correct positions of the image.

We press the "Ok" button with which the window closes and the application assigns to the image the positioning that is derived from the data entered. We select the catalog again and we will see that the objects no longer match the stars of the image (figure 29),we proceed to mark three pairs of points (object, image), in the image the letter "F" (or "D") is placed on the object and the "T" (or "H") at the point of the image to which it should go.

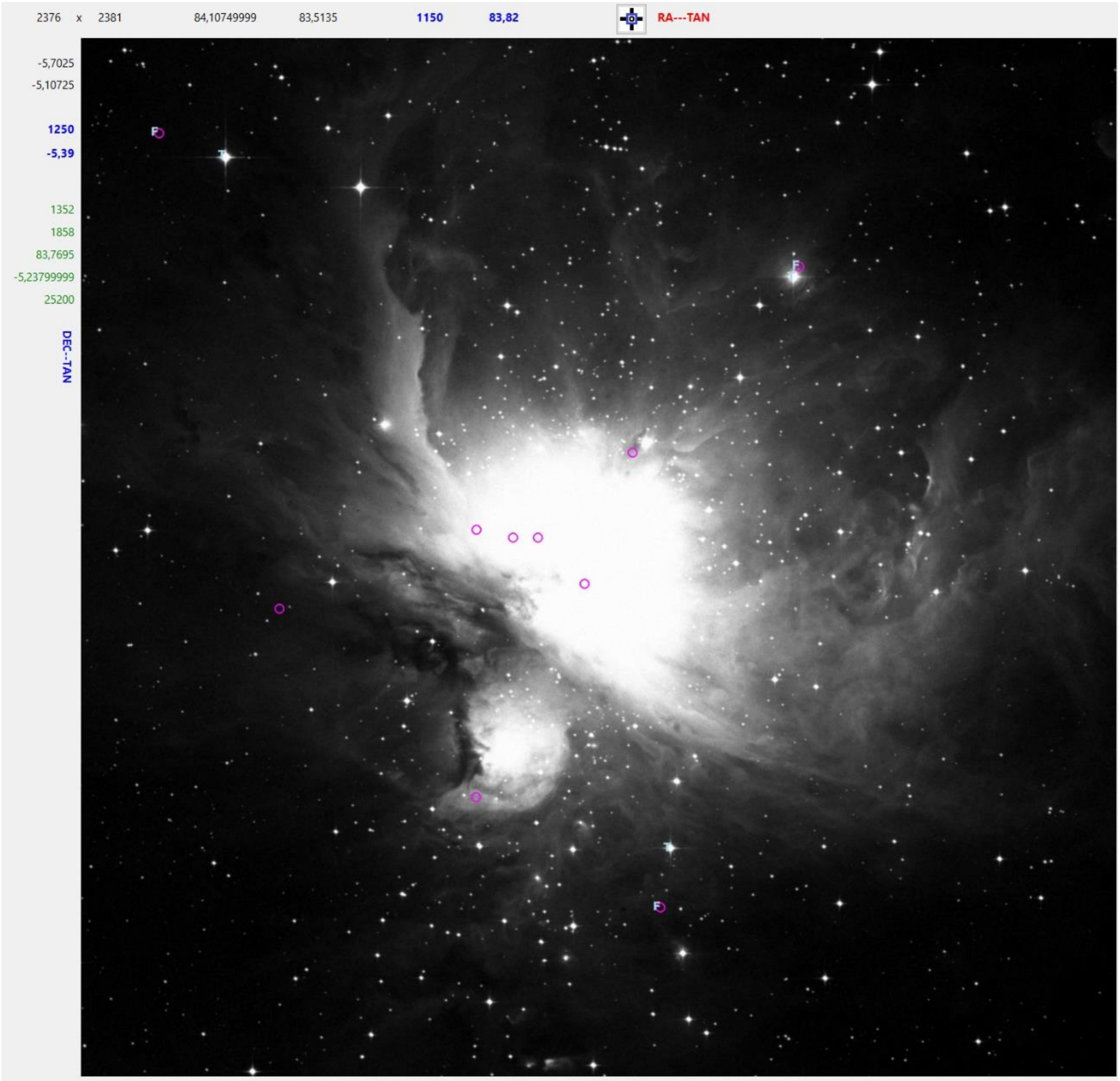


Figure 29. Objects in the catalog do not appear in the correct places in the image.

Press the button to the right of the scale button, which will contain a 3, because we have marked three points, and the application recalculates the positioning of the image. If we select the catalog again, we will see that the objects appear in the correct positions (figure 30).

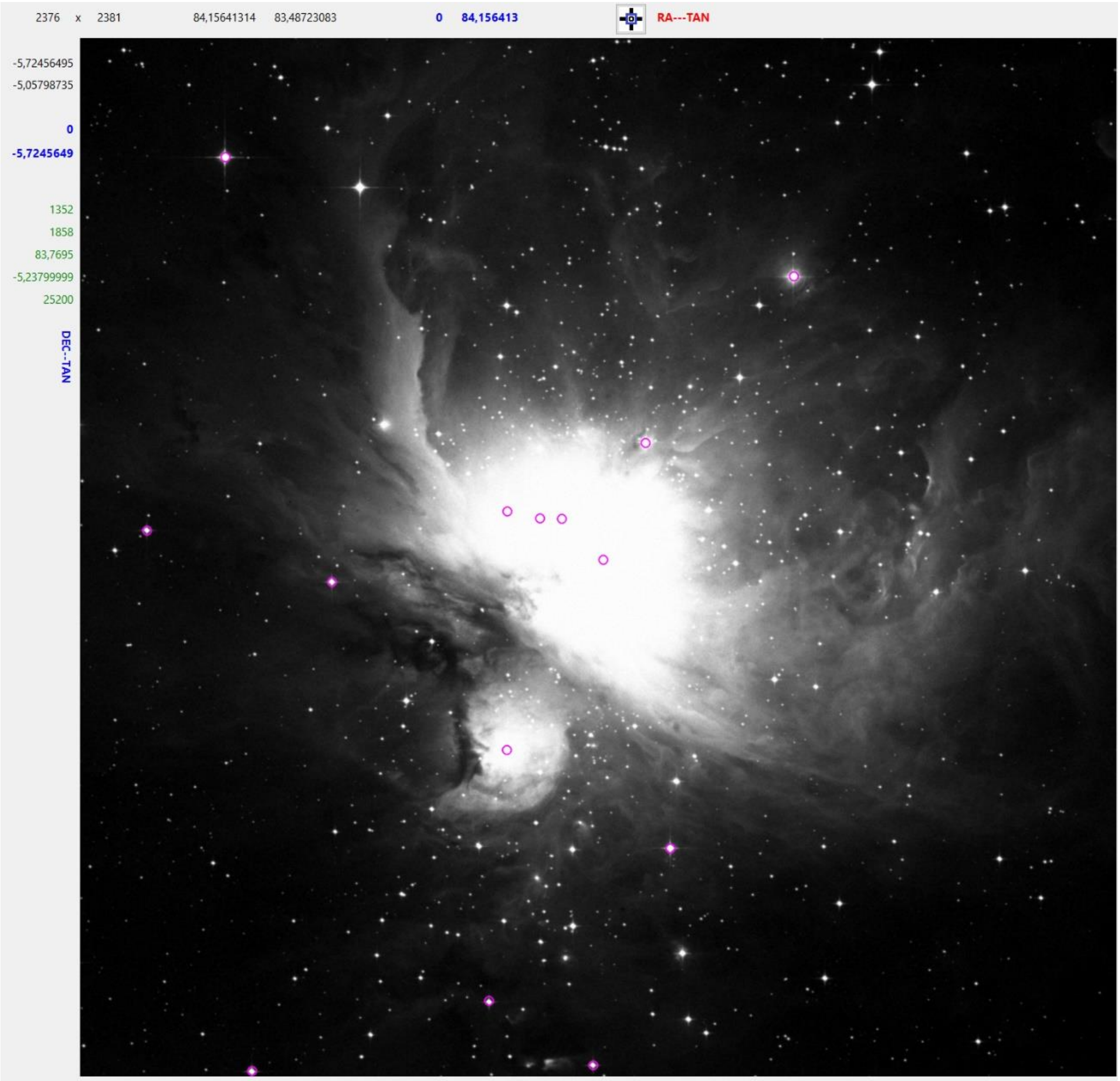


Figure 30. The image has been positioned correctly.

4. Download FITS files (parttwo).

In section 2.2 we already had a first approach to downloading the files containing the HTS observations. We just tested with the M101 object as the example on the download page itself suggests.

M101 is one of the last objects that Messier added to his catalog in 1781, it is a spiral galaxy that is known as the pinwheel and is best known for its number in the New General Catalog: NGC 5457. We can see it in Figure 31 obtained from the HTS observations

Figure 31. Galaxy M101 (NGC 5457).

In Figure 3 we saw that there are 1,831 FITS files related to this galaxy. Now that we have the Explora FITS application we can visualize some of them and let's start by downloading the first two that indicate in the column "Target" to the NGC5457 (those located in the third and fourth row of the search results).

1. hlsp_hlastarclusters_hst_acs-wfc_ngc5457-f1-9490-01_F814W_v1_sci.fits
2. hlsp_hlastarclusters_hst_acs-wfc_ngc5457-f2-9490-02_F814W_v1_sci.fits

Both are observations with the ACS/WFC camera and the F814W filter but it changes a bit the direction in which the telescope was pointing:

1. AR = 14:03:23.04 DEC = 54:21:13.0
2. AR = 14:03:02.40 DEC = 54:20:21.5

The file combines, for each one, 4 exposures of 720 seconds of exposure in total.

We start by opening the first one with our application and we see that it contains two HDUs, in the first there are only headers and there is no data, but in the second there is a block with a two-dimensional matrix of 5,700 x 5,700 data although the application shows a totally black image, which is explained if we look at the histogram with the distribution of values (figure 32)

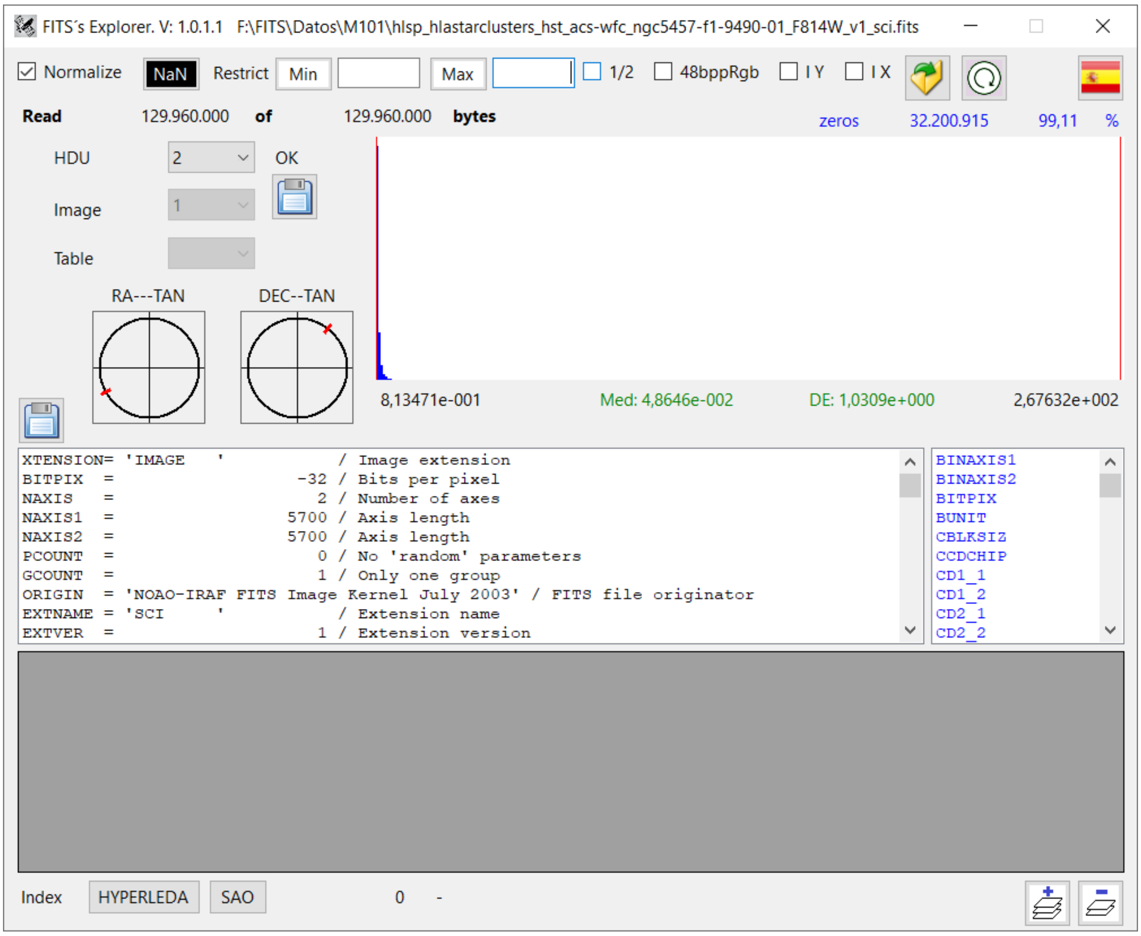


Figure 32. hlsp_hlastarclusters_hst_acs-wfc_ngc5457-f1-9490-01_F814W_v1_sci.fits

Some element of the data matrix reaches a value of 267, but the vast majority does not exceed 5 and the mean is 0.048646 with a standard deviation of 1. It is essential to limit the maximum value and we can start with the average value plus a standard deviation, that is, 1.05, with this we see the image in Figure 33.

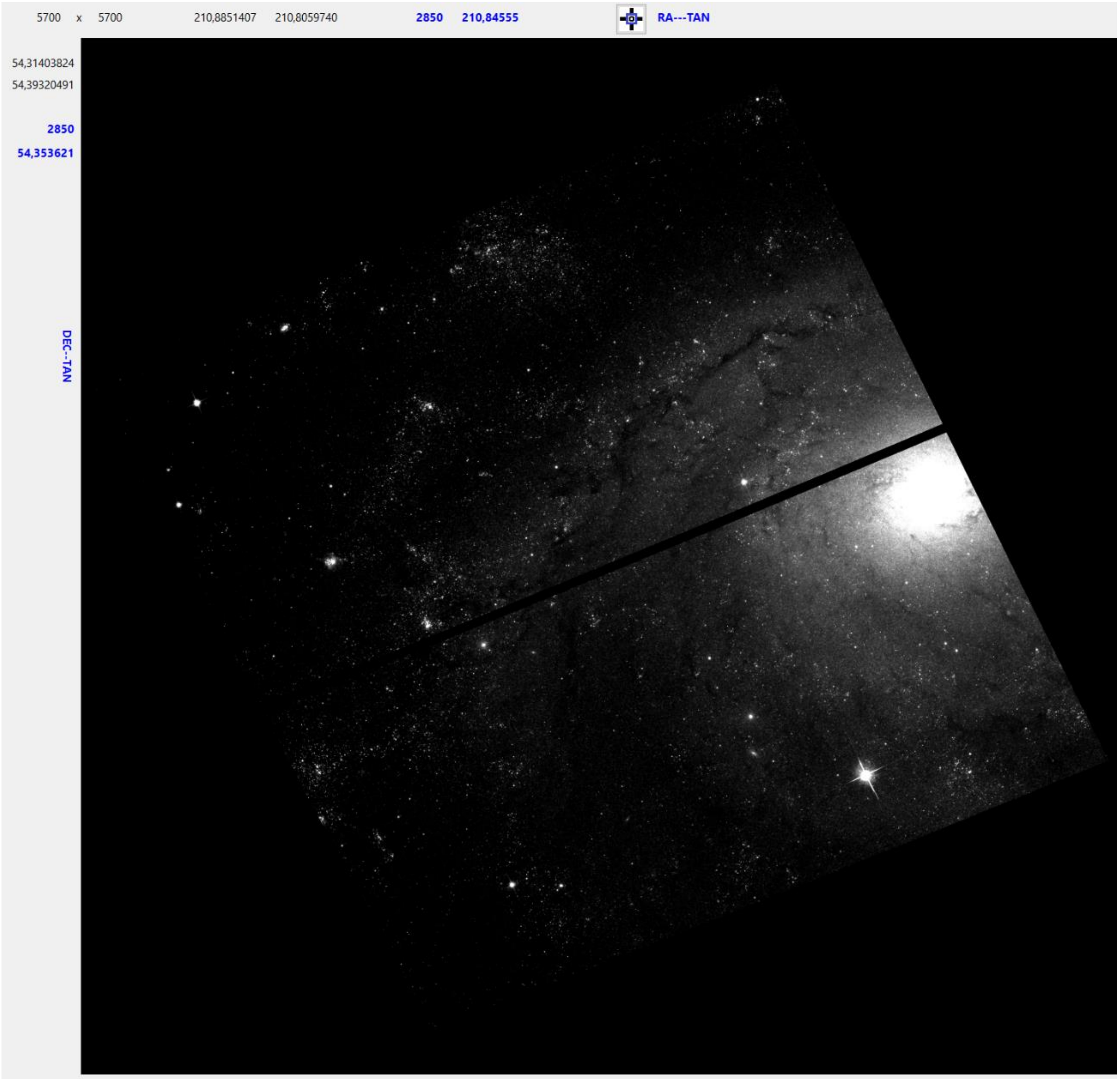


Figure 33. First normalized file with maximum dimension equal to 1.05

It is very different from the image in figure 30,but we can distinguish that it is a part of it in black and white. To see details that are obscured by the brightest points we reduce the maximum height to 0.5 (Figure 34)

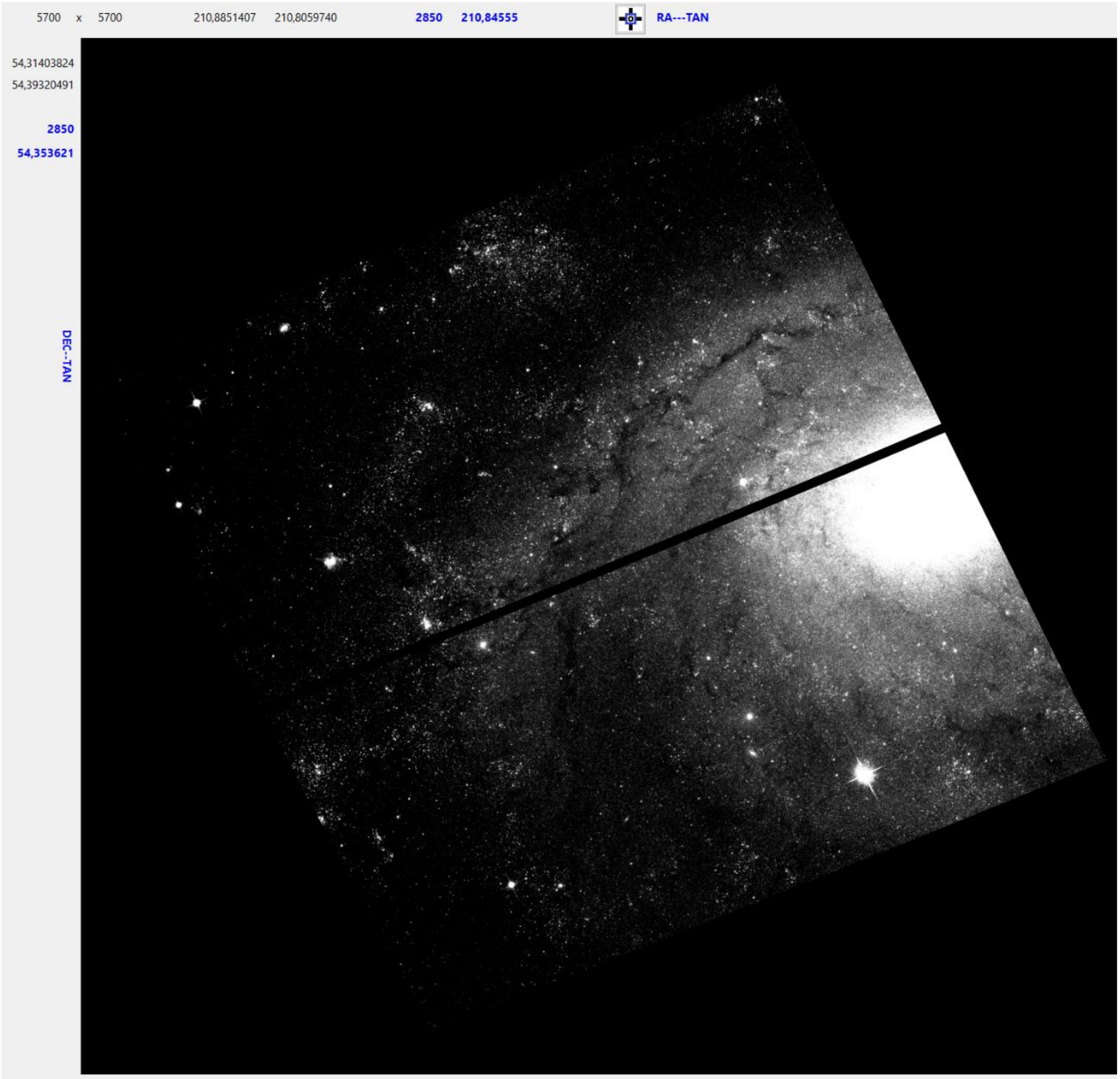


Figure 34. First normalized file with a maximum dimension equal to 0.5

If we open the second file that we have downloaded and proceed in a similar way we obtain the image of figure 34.

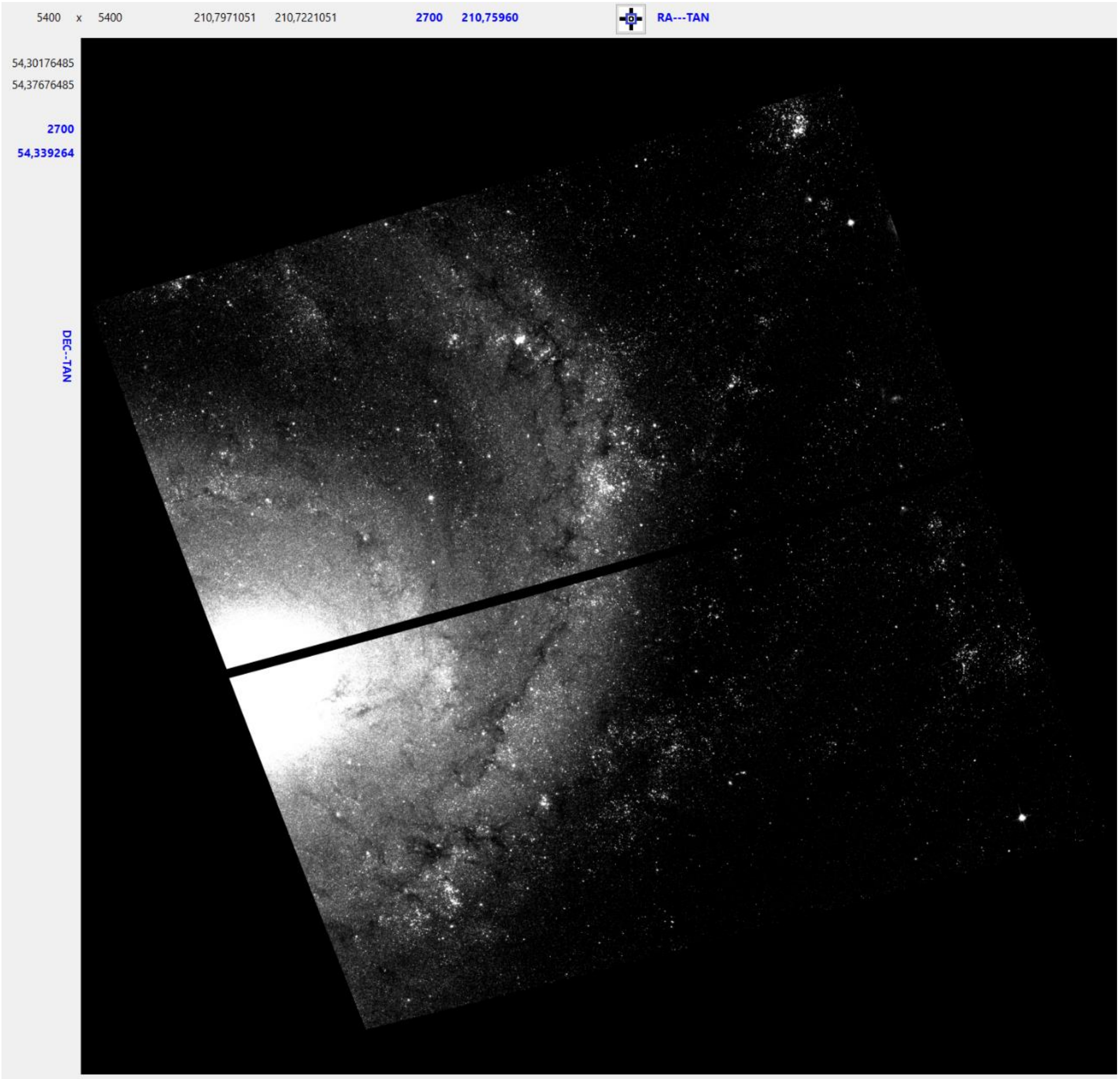


Figure 35. Second normalized file with maximum dimension equal to 0.5

More or less, the other half of the galaxy.

The resolution is so large that it must be taken into account when we use the catalogs. For example, if we ask HyperLEDA to show us what objects it has in the area of the first image,it finds a star at the bottom of the image and part of a galaxy almost on the left edge, but nothing from NGC5457.

For Image 2, HyperLEDA shows two objects,two small greensquares (Figure 36)

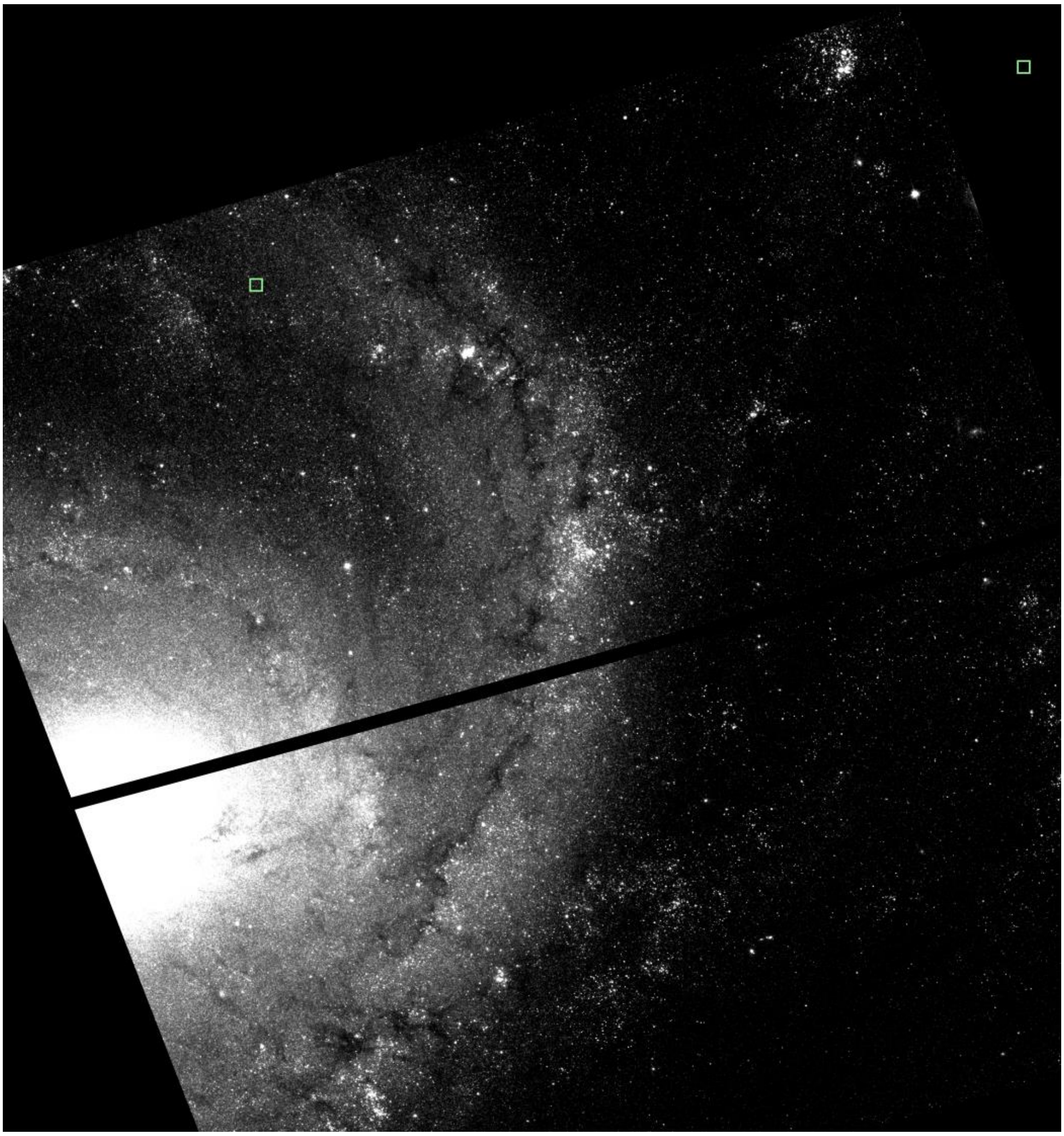
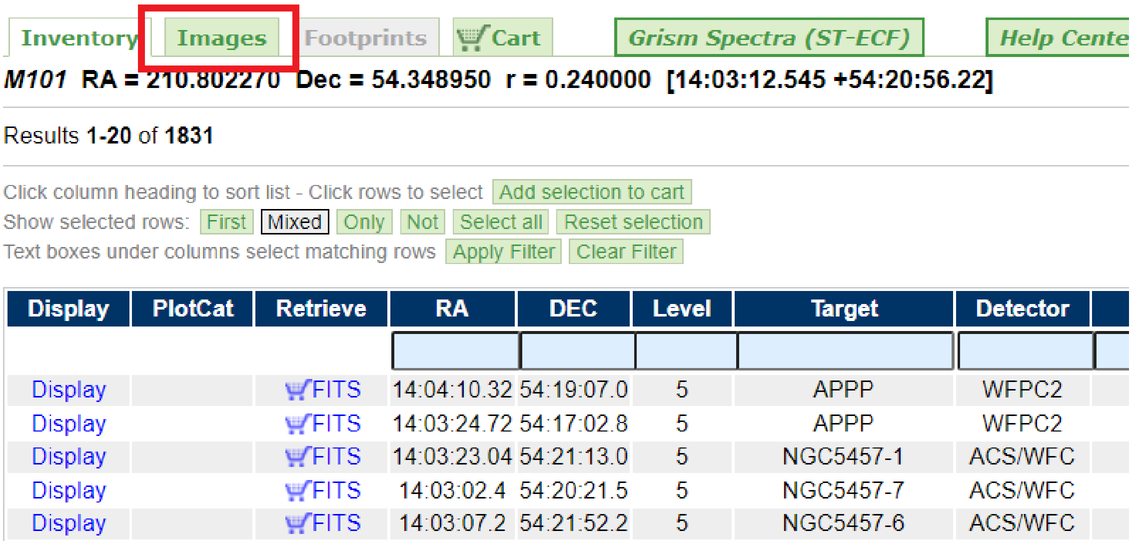


Figure 36. HyperLEDA objects in the area of the second image.

The object near the upper right is outside the range observed by the HTS and the other is precisely NGC5457, although it is shown far from the center of the galaxy, this may be due to the higher resolution of the HTS with respect to the ground telescope that provided the data collected by the HyperLEDAcatalog, for this telescope the difference between its measurement and the center of the galaxy may be below its resolution.

The images that we have obtained from the downloaded files are in black and white and for any other file with HTS observations the same will happen. To obtain color images, it is necessary to compose observations made with different filters, which as we saw limit the wavelengths recorded by the HTS instruments. If we have three observations of the same area of the sky but with three filters of different wavelength, to the one with the shortest wavelength we can assign the red color, to the one with the greater the blue and to the intermediate the green, which is what is done in those full-color images that are shown to the public opinion, without the need for the wavelengths of the filters to correspond to those of the three colors, or even of the visible spectrum.

The NASA page, in addition to downloading the files has a tab where it shows some images (figure 37)


Inventory | Images | Footprints | Cart | Grism Spectra (ST-ECF) | Help Cente

M101 RA = 210.802270 Dec = 54.348950 r = 0.240000 [14:03:12.545 +54:20:56.22]

Results **1-20** of **1831**

Click column heading to sort list - Click rows to select | Add selection to cart

Show selected rows: | First | Mixed | Only | Not | Select all | Reset selection

Text boxes under columns select matching rows | Apply Filter | Clear Filter

Display	PlotCat	Retrieve	RA	DEC	Level	Target	Detector
Display		FITS	14:04:10.32	54:19:07.0	5	APPP	WFPC2
Display		FITS	14:03:24.72	54:17:02.8	5	APPP	WFPC2
Display		FITS	14:03:23.04	54:21:13.0	5	NGC5457-1	ACS/WFC
Display		FITS	14:03:02.4	54:20:21.5	5	NGC5457-7	ACS/WFC
Display		FITS	14:03:07.2	54:21:52.2	5	NGC5457-6	ACS/WFC

Figure 37. Tab to view images of FITS files.

This possibility of seeing before downloading can avoid many useless downloads. In figure 38 we see the image that shows for the two files that we have downloaded.

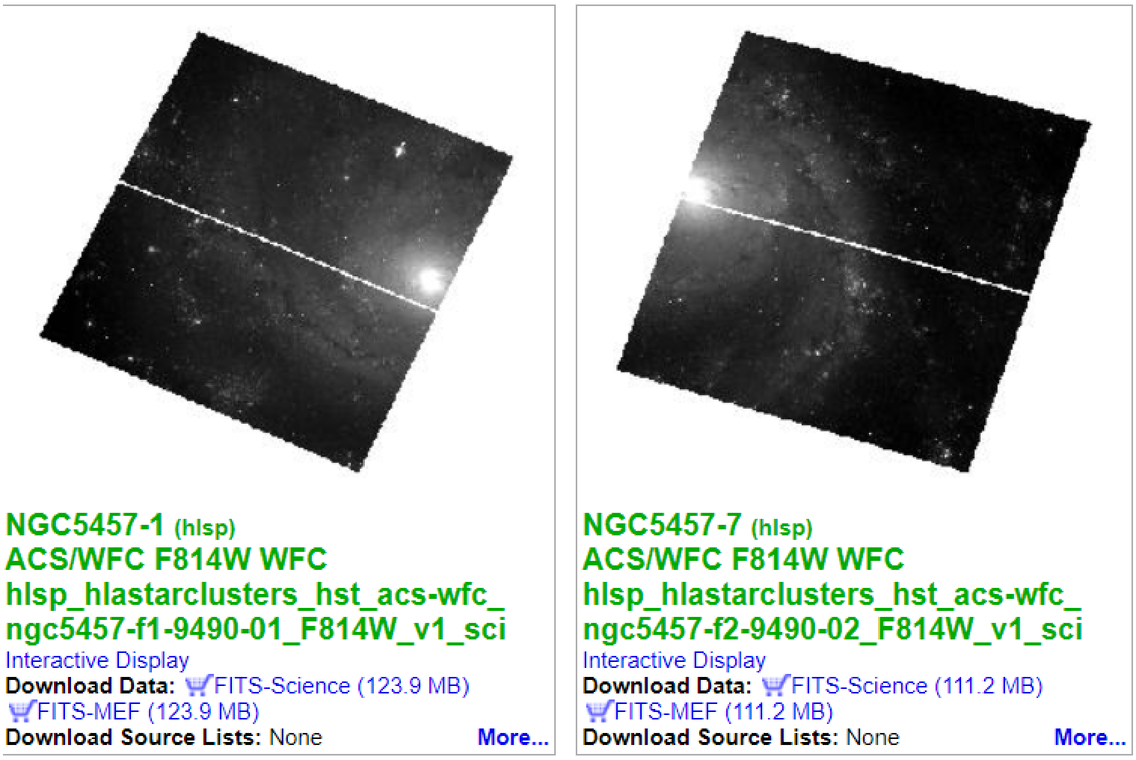


Figure 38. Images on the web

5. Auxiliary functions.

At the bottom of the main window (Figure 6) some buttons are shown (figura 39)

Figure 39. Auxiliary functions.

The HyperLEDA button is used to construct the indexes that your application needs to use the HyperLEDAcatalog. This catalogue can be downloaded at the website:

http://leda.univ-lyon1.fr/fullsql.html

In the form of CSV text (with separator ";"), this function creates a binary file with the right ascension and declination of each object and a pointer to the line of the object within the downloaded file.

The SAO button does the same as the previous one for the Smithsonian Astrophysical Observatorycatalog.

This button can "add" two or more data files, exported by the application (Figure 13). It is common that to reduce the "noise" of the images several corresponding to observations of the same area of the sky are superimposed. The points corresponding to real objects will add their brightness, but the points corresponding to noise will be distributed randomly and it is very unlikely that two images record noise at the same point, the result is that the noise loses importance with respect to real objects. The result will cover an area containing all the zones added together.

This button subtracts two images (files exported by the application itself), this allows to highlight differences between observations of the same area but at different times (possible supernovae) and also assess the noise level, for the same reason explained above, the light of the real objects will be canceled but not that of the noise. The result will cover the area common to the two subtracted areas.

6. Repository.

The application and related files, such as this documentation can be obtained from the repository:

https://github.com/labotecta/Explora-FITS

The application files are as follows:

- fieldsHL.txt

- ExploraFits.deps.json
- ExploraFits.dll
- ExploraFits.exe
- ExploraFits.pdb
- ExploraFits.runtimeconfig.json
- languages.txt

They can be in any folder, even on a USB stick

Catalog files are compressed into the **catalogs file.rar** in the **Catalogs** folder

In order for the application to use the HyperLEDA catalog, the following two files must be copied:

- HyperLeda_meandata_1631273210.txt
- indicesHL.bin

To the same folder where the application filesare.

To use the Smithsonian star catalogue you have to copy the following two files:

- indicesSAO.bin
- sao.txt

To the same folder where the application filesare.