



UNIVERSITY OF
CAMBRIDGE

DIS MPhil : Lecture 12

Exploring the Low
Surface Brightness
Universe

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Outline of this block

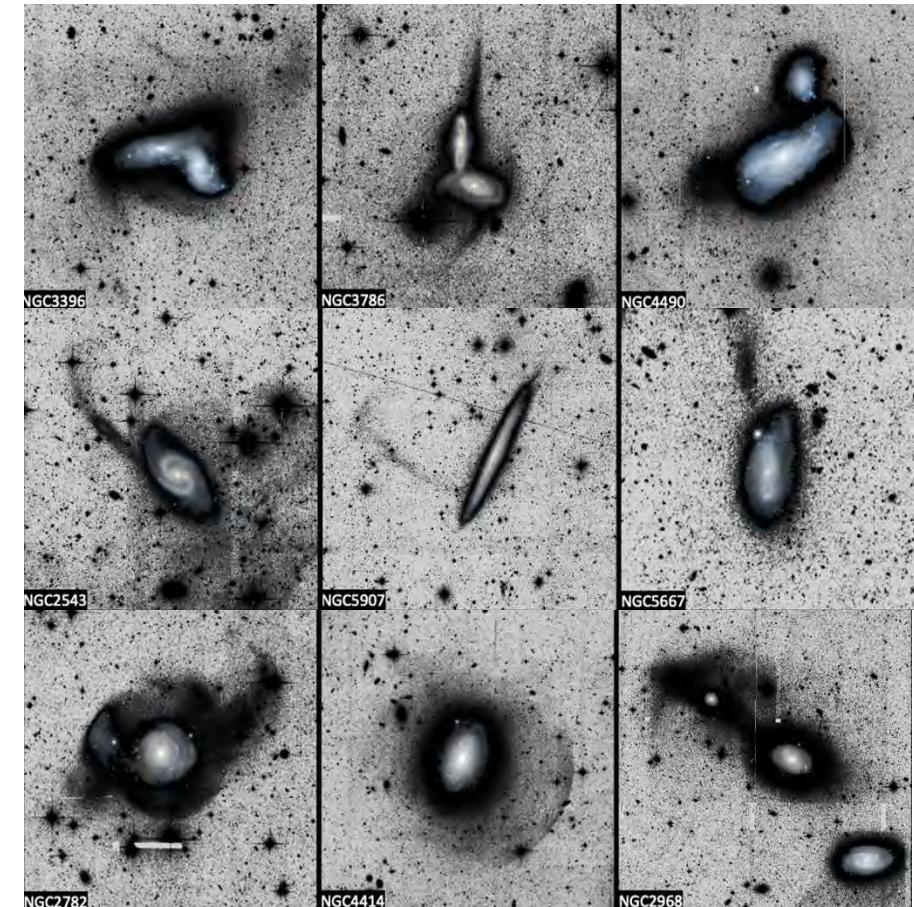
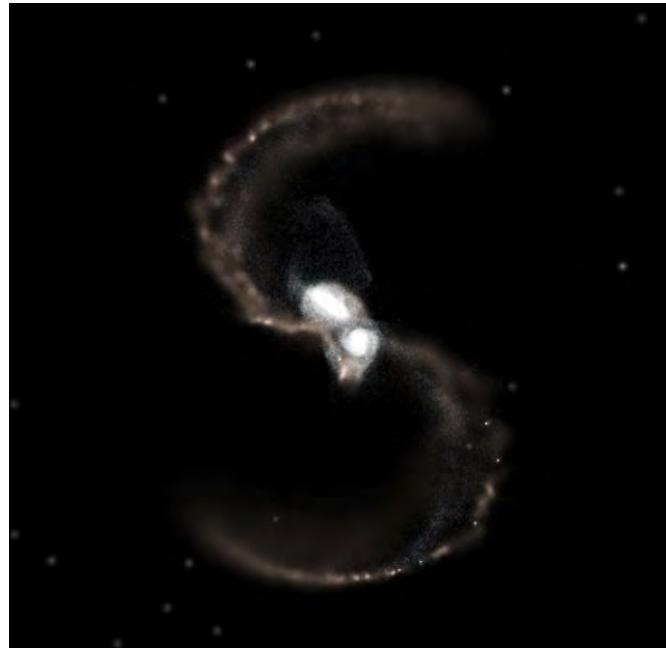
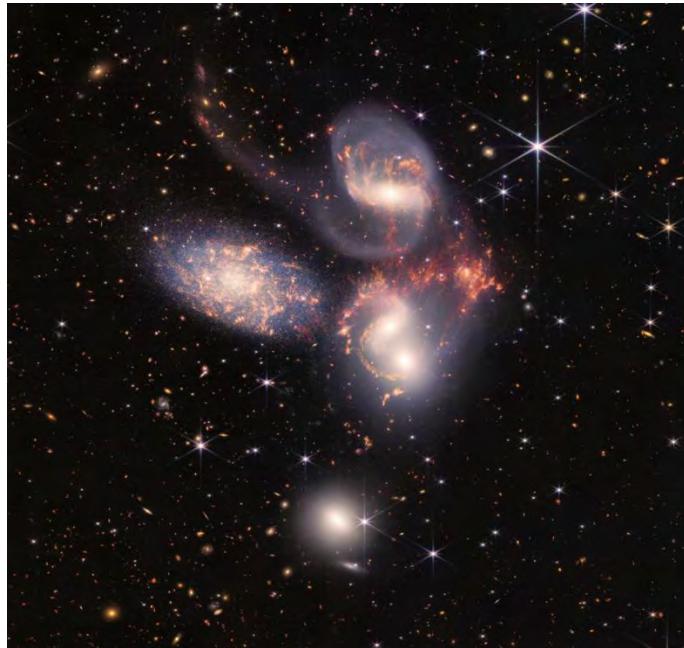
Block C: Low Surface Brightness Universe & image analysis

- 1.28/02/2025: Galaxies in the Local Universe:** Introduction to models of galaxy formation and evolution. Galaxy mergers and tidal features. Tidal features in the Local Group and beyond.
- 2.04/03/2025: Exploring the LSB Universe:** Deep astronomical imaging and data processing techniques. The LSB Universe. Hunting for tidal features in the LSB realm.
- 3.07/03/2025: LSB features and galactic evolution:** LSB features as probes of galactic evolution. Ongoing and future surveys. Machine learning for LSB features.
- 4.11/03/2025: Hands-on session:** explore astronomical images and catalogues with Aladin, DS9, Topcat, Python

Recap of Lecture 11

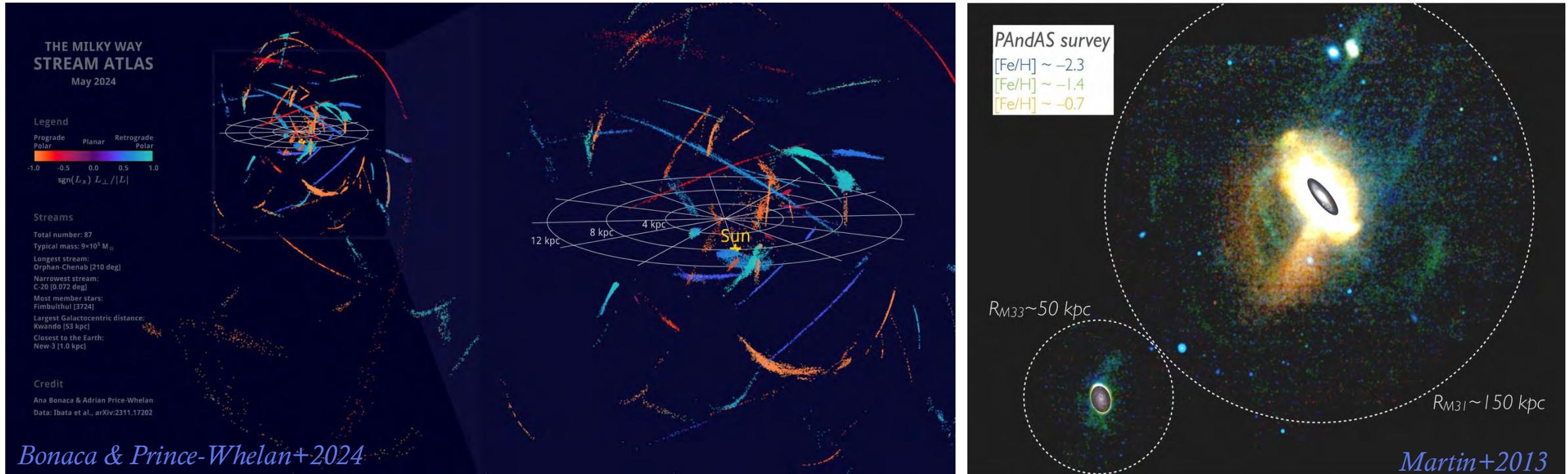
- Hierarchical build-up of galaxies through **mergers** and gas accretion
- The **environment** strongly shapes galactic evolution
- Mergers leave behind **tidal features** which hold the clues of the late galaxy assembly

Sola+2022



Recap of Lecture 11

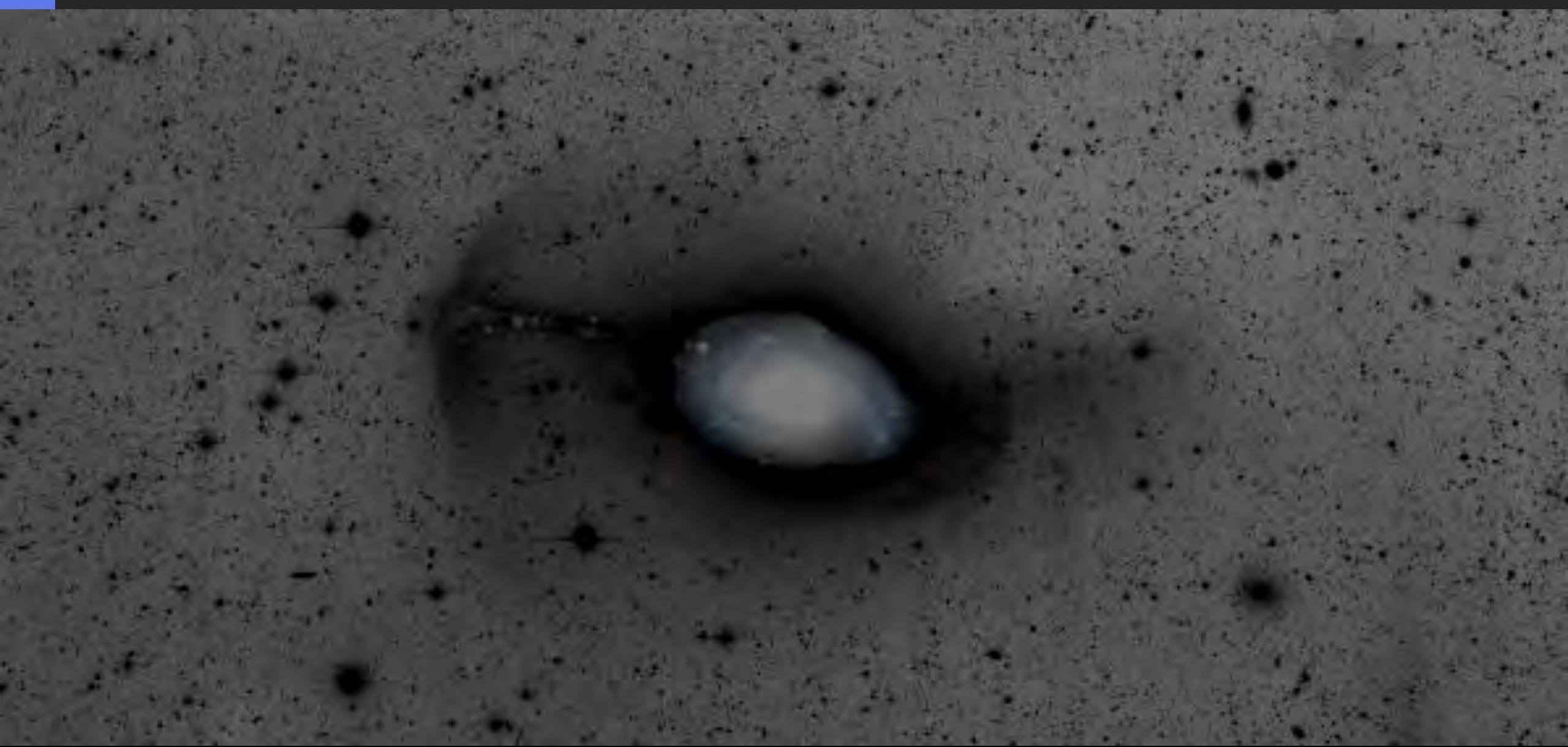
- Tidal features are **faint = low surface brightness**
- In the Local Group, they are disclosed by stellar count



Outline: Lecture 12

- Astronomical images + catalogues
- Image processing to reveal the LSB Universe
- Finding tidal features in deep images

Astronomical images



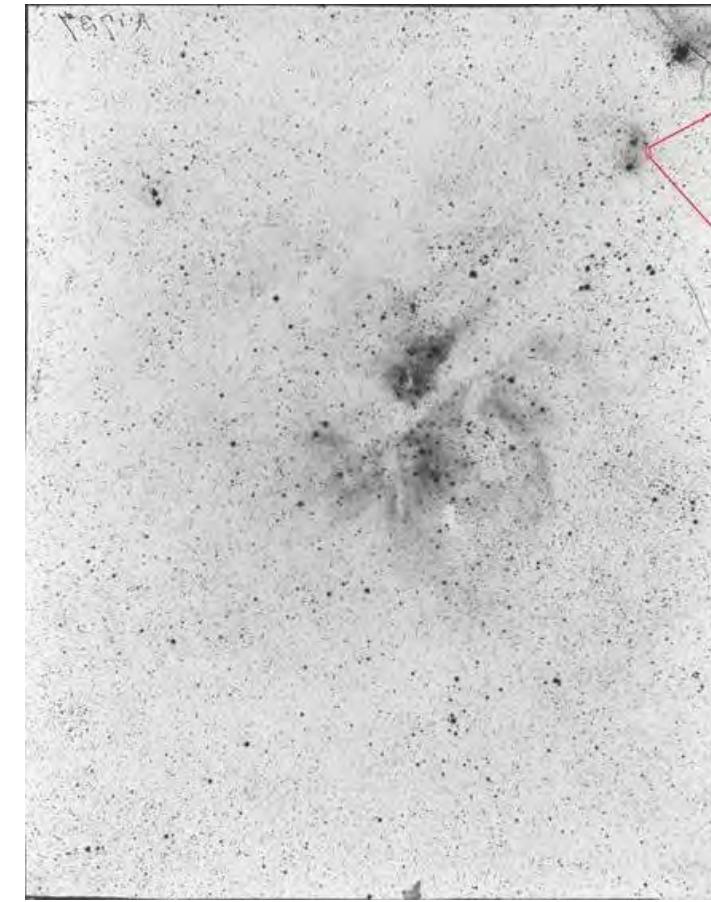
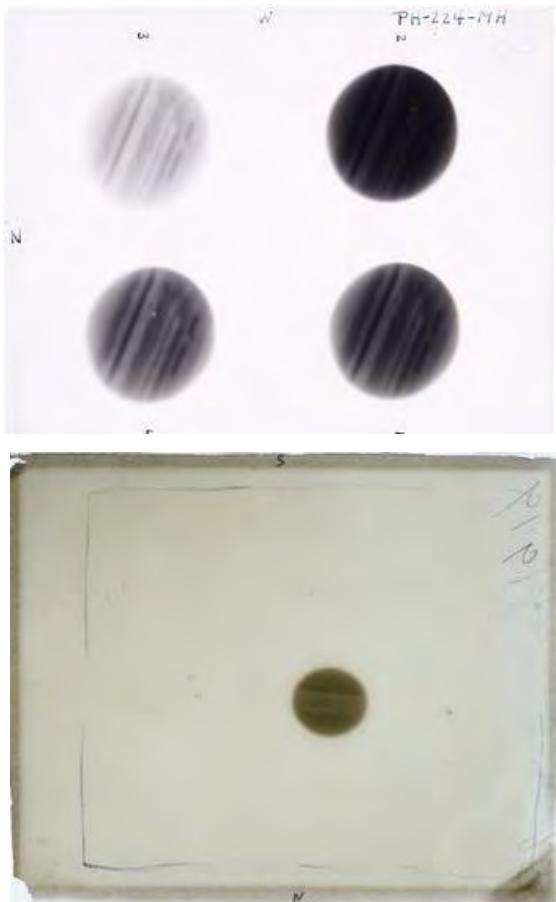
Celestial globes

- Celestial globes: apparent position of stars on the sky



Photographic plates

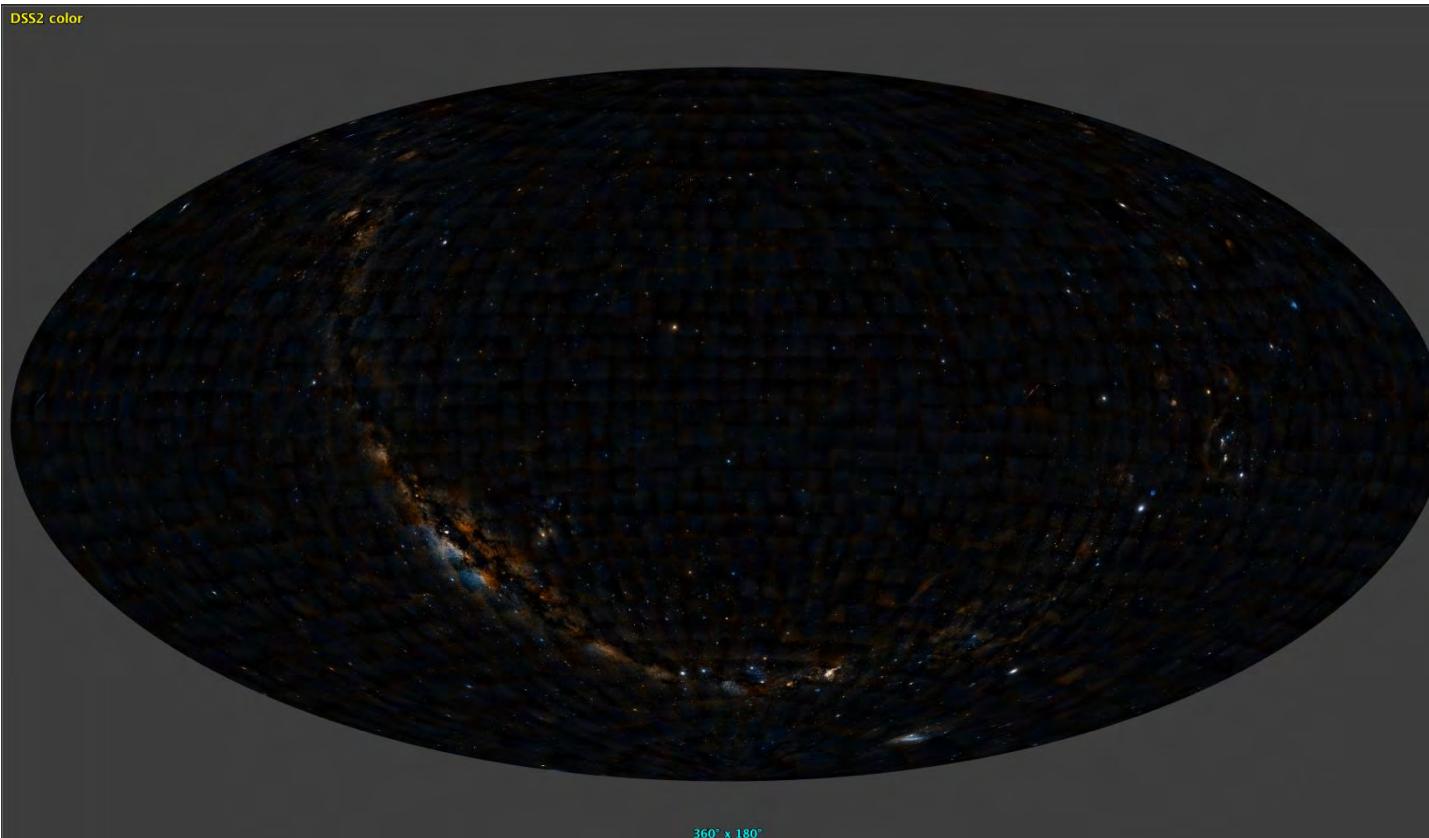
- 19th century - 1980s: pictures of celestial objects on glass plates: **photographic plates**



©Harvard College
Observatory

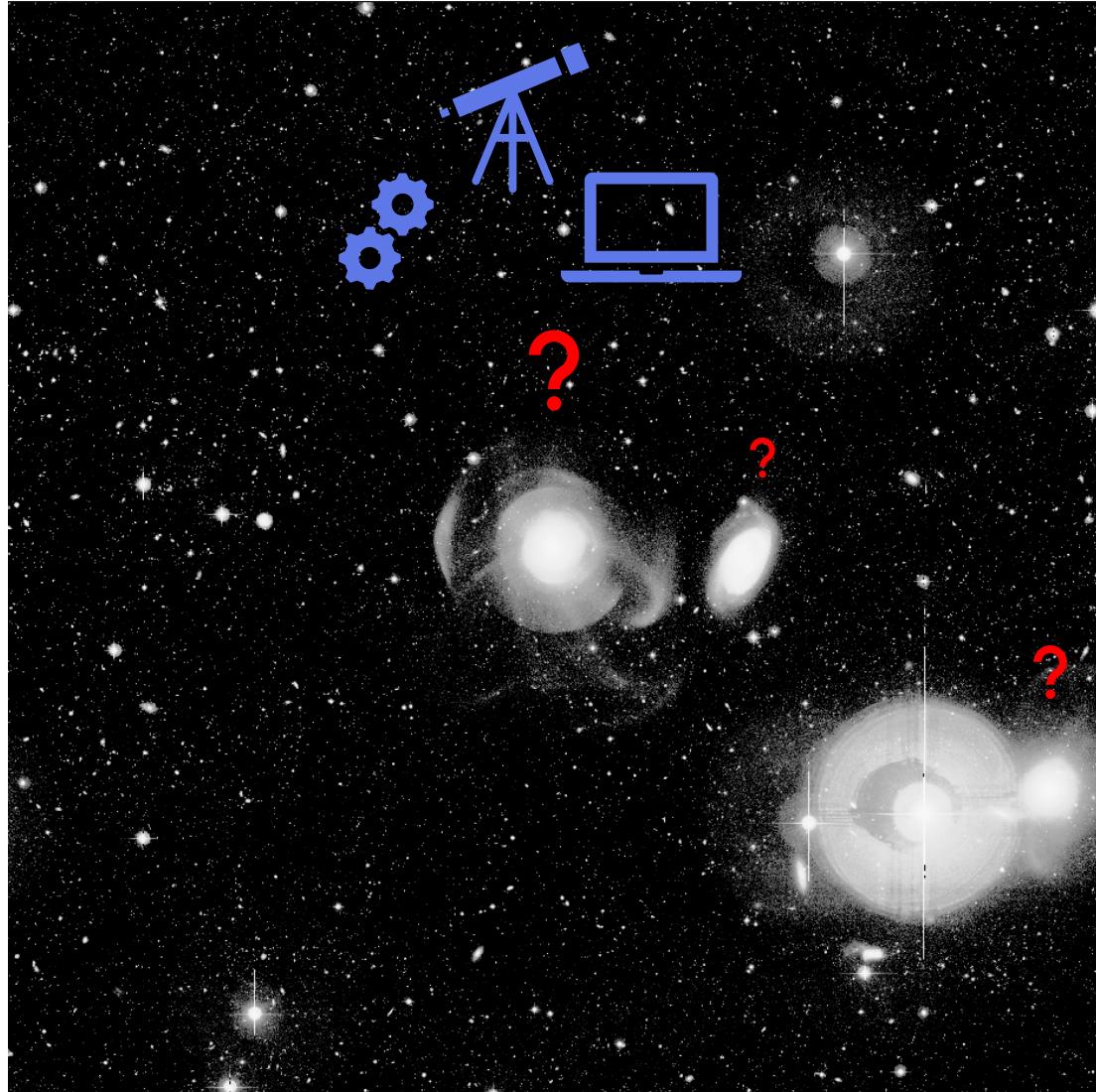
Digitalising photographic plates

- DSS: Digitized Sky Survey: digital version of photographic plates of the entire sky obtained at Palomar and UK Schmidt telescopes



- >1980s: CDD cameras, numerical images

Back to basics: what is an image made of ?



You got amazing
images



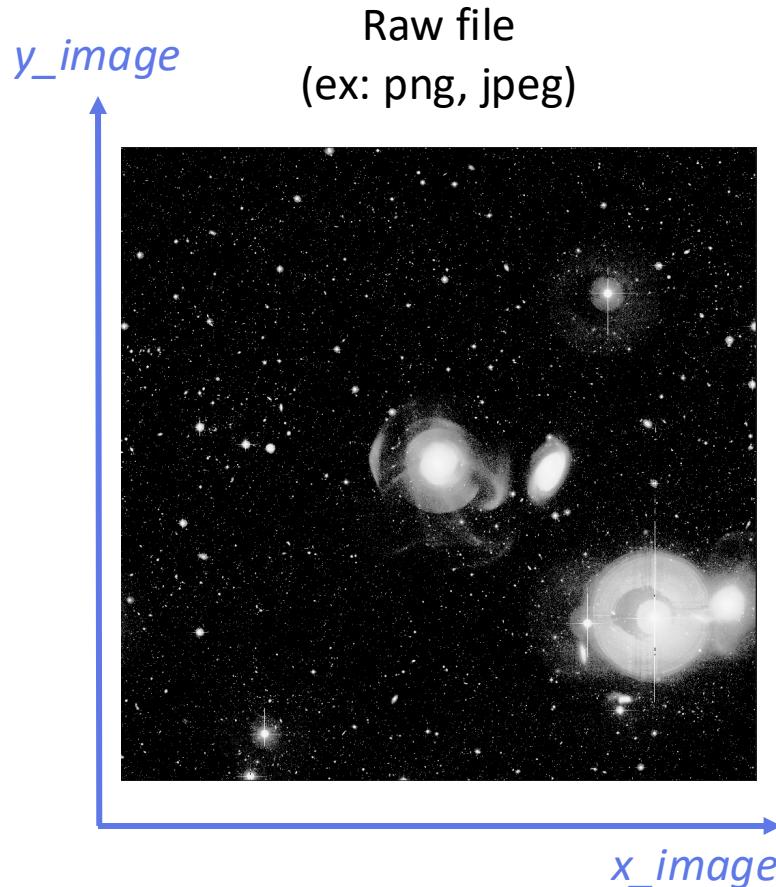
Actually, they're
useless



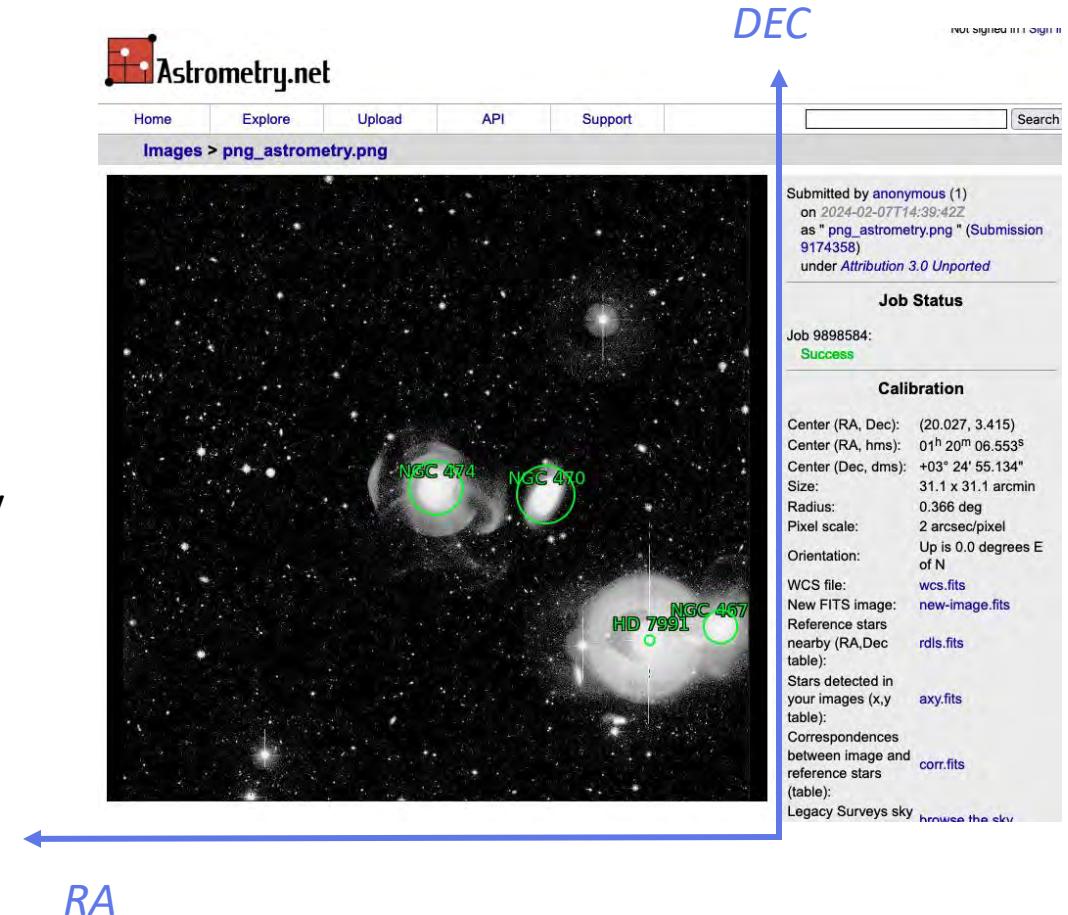
Unless you have
astrometric
calibration



Astronomical images: pixels and what else?



Astrometric calibration
 $(x,y)_\text{image} \rightarrow (\text{RA},\text{DEC})_\text{sky}$



Astronomical images

- Different formats of images: png, jpeg, tiff...
- Not appropriate for astronomical data: compression, small resolution, limited number of data channels
- ► **FITS** (Flexible Image Transport System) format widely used:
 - Can store multiple channels for multi-wavelength observations or 3D cubes
 - Metadata containing photometric and spatial calibration information
 - Unlimited metadata
 - Higher resolution
 - Huge dynamical range
- FITS = **data + header**

Headers

- Headers contain all the important metadata, especially the **WCS** (World Coordinate System) used to transform (x,y) pixels to (RA,Dec) in the sky
- Syntax: KEYWORD = value / Comment

Number of axes and number of pixels per axis

Pixel/world transformation + units and projection



```
BITPIX = -32 / file does conform to FITS standard
NAXIS = 2 / array data type
NAXIS1 = 3333 / number of array dimensions
NAXIS2 = 3333
EXTEND = T / FITS dataset may contain extensions
COMMENT = FITS (Flexible Image Transport System) format is defined in 'Astronomy
          and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
PC1_1 = 1679.8333333333 / Pixel coordinate of reference point
PC2_1 = 1697.5 / Pixel coordinate of reference point
PC1_2 = -0.00015480691944 / Coordinate transformation matrix element
PC2_2 = 0.00015480691944 / Coordinate transformation matrix element
CDELT1 = 1.0 / [deg] Coordinate increment at reference point
CDELT2 = 1.0 / [deg] Coordinate increment at reference point
CRVAL1 = 'deg' / Units of coordinate increment and value
CRVAL2 = 'deg' / Units of coordinate increment and value
CTYPE1 = 'RA---TAN' / Right ascension, gnomonic projection
CTYPE2 = 'DEC--TAN' / Declination, gnomonic projection
CRVAL1 = 20.02594502 / [deg] Coordinate value at reference point
CRVAL2 = 3.419933103 / [deg] Coordinate value at reference point
CDELTA1 = 180.0 / [deg] Native longitude of celestial pole
```

Headers

- All these are non-mandatory keywords. Read the comment to understand what they mean

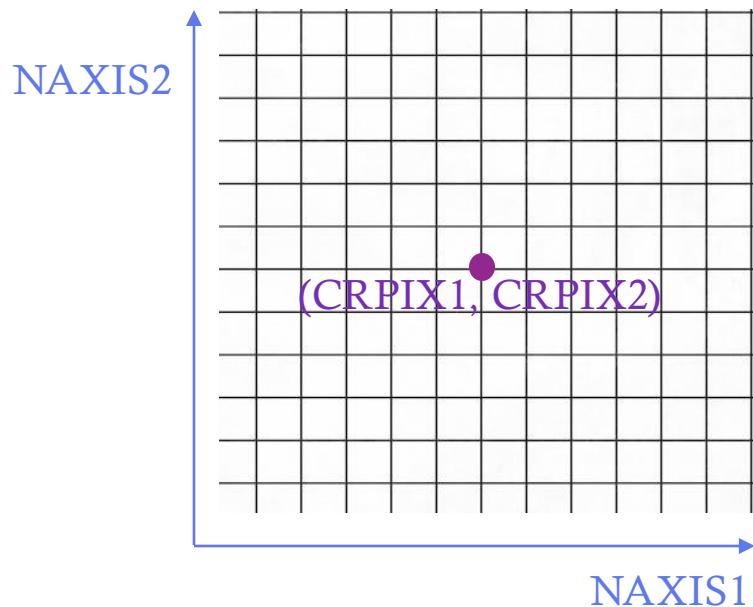
```
LONPOLE =           180.0 / [deg] Native longitude of celestial pole
LATPOLE =           3.419933103 / [deg] Native latitude of celestial pole
DATEST = '1858-11-17' / ISO-8601 fiducial time
MJDREFI =           0.0 / [d] MJD of fiducial time, integer part
MJDREFF =           0.0 / [d] MJD of fiducial time, fractional part
FRAME = 'ICRS' / Equatorial coordinate system
COMMENT FITS (Flexible Image Transport System) format is defined in 'Astronomy
and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
CROPCENTER =           / WCS information
EQUINOX =           2000.0 / [yr] Equinox of equatorial coordinates
CROPCENTER =           / Crop information
FILE = '/home/eli/point_montage/sola/MATLAS/NGC0474.l.r.Mg004.fits'
PIXELRANGE = '9733:19733,8486:18486' / Range of pixels used for this output.

/ Versions and date
DATE = '2020-06-30T11:36:11' / file creation date (YYYY-MM-DDThh:mm:ss UT)
CFITSIO = '3.43' / CFITSIO version.
WCSLIB = '5.18' / WCSLIB version.
GLSL = '2.4' / GNU Scientific Library version.
GNAUTINFO = '0.11.49-f0539' / GNU Astronomy Utilities version.
DUNIT = '' / data unit type
EXTNAME = 'DATA' / extension name
```

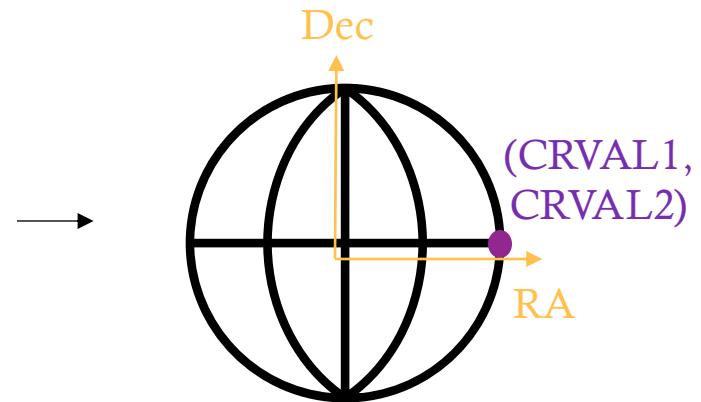
Minimal header

Other notation: PC_{i,j} with CDELT = 1" is equivalent to CD_{i,j}

```
SIMPLE = T
BITPIX = 8
NAXIS = 2
NAXIS1 = 4096
NAXIS2 = 4096
CTYPE1 = 'TAN'
CUNIT1 = 'degree'
CRVAL1 = 180
CRPIX1 = 2048
CD1_1 = -0.00038197186341489
CTYPE2 = 'TAN'
CUNIT2 = 'degree'
CRVAL2 = 0
CRPIX2 = 2048
CD2_2 = 0.00038197186341489
END
```



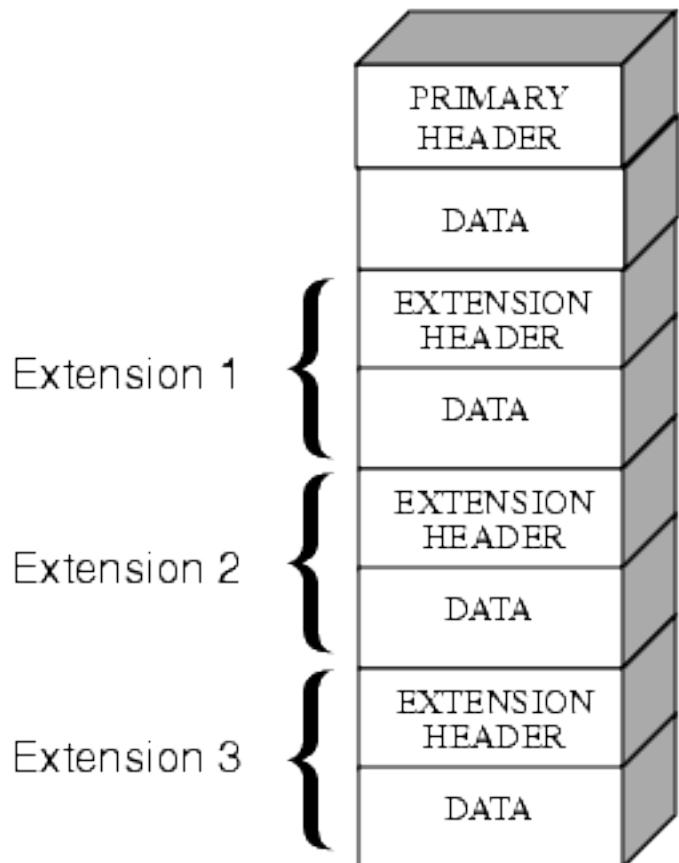
$$\begin{pmatrix} \text{CD1_1} & \text{CD1_2} \\ \text{CD2_1} & \text{CD2_2} \end{pmatrix} \text{ Encodes pixel size + transformations}$$



Multiple extensions

- FITS can store several extensions

Q? Explain this header !



```
BITPIX = -32 / conforms to FITS standard
NAXIS = 3 / array data type
NAXIS1 = 1825
NAXIS2 = 1825
NAXIS3 = 3
NCDIMNS = 3 / number of array dimensions
NCDIMNS = 3 / Number of coordinate axes
CRPIX1 = 913.0 / Pixel coordinate of reference point
CRPIX2 = 913.0 / Pixel coordinate of reference point
CRPIX3 = 0.0 / Pixel coordinate of reference point
CDL_1 = -0.0001666666666667 / Coordinate transformation matrix element
CDL_2 = 0.0001666666666667 / Coordinate transformation matrix element
CDLT_1 = 1.0 / [deg] Coordinate increment at reference point
CDLT_2 = 1.0 / [deg] Coordinate increment at reference point
CDLT_3 = 1.0 / Coordinate increment at reference point
CUNIT1 = 'deg' / Units of coordinate increment and value
CUNIT2 = 'deg' / Units of coordinate increment and value
CTYPE1 = 'RA---TAN' / Right ascension, gnomonic projection
CTYPE2 = 'DEC---TAN' / Declination, gnomonic projection
CRVAL1 = 8.008776 / [deg] Coordinate value at reference point
CRVAL2 = -64.2533874 / [deg] Coordinate value at reference point
CRVAL3 = 0.0 / Coordinate value at reference point
LONPOLE = 180.0 / [deg] Native longitude of celestial pole
LATPOLE = -64.2533874 / [deg] Native latitude of celestial pole
MJDREF = 0.0 / [d] MJD of fiducial time
RADESYS = 'ICRS' / Equatorial coordinate system
COMMENT grz data
COMMENT data from ls-dr9
END
```

https://www.stsci.edu/hst/wfpcc/Wfpcc_dhb/intro_ch23.html

Image visualisation tools: DS9

- SAOImageDS9 (ds9) <https://sites.google.com/cfa.harvard.edu/saoimageds9>



```
NGC0474_rebin3.r.fits[DATA]
S9601 = T / file does conform to FITS standard
S9602 = -32 / array data type
S9603 = 2 / number of array dimensions
S9604 = 3333
S9605 = 3333
S9606 = T / FITS dataset may contain extensions
S9607 = FITS (Flexible Image Transport System) format is defined in 'Astronomy
        and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
S9608 = 2 / Number of coordinate axes
S9609 = 1679.833333333 / Pixel coordinate of reference point
S9610 = 1697.5 / Pixel coordinate of reference point
S9611 = -0.00015480691944 / Coordinate transformation matrix element
S9612 = 0.00015480691944 / Coordinate transformation matrix element
S9613 = 1.0 / [deg] Coordinate increment at reference point
S9614 = 1.0 / [deg] Coordinate increment at reference point
S9615 = 'deg' / Units of coordinate increment and value
S9616 = 'deg' / Units of coordinate increment and value
S9617 = 'RA---TAN' / Right ascension, gnomonic projection
S9618 = 'DEC---TAN' / Declination, gnomonic projection
S9619 = 20.02594502 / [deg] Coordinate value at reference point
S9620 = 3.419933103 / [deg] Coordinate value at reference point
S9621 = 180.0 / [deg] Native longitude of celestial pole
S9622 = 3.419933103 / [deg] Native latitude of celestial pole
S9623 = '1858-11-17' / ISO-8601 fiducial time
S9624 = 0.0 / [d] MJD of fiducial time, integer part
S9625 = 0.0 / [d] MJD of fiducial time, fractional part
S9626 = 'ICRS' / Equatorial coordinate system
S9627 = FITS (Flexible Image Transport System) format is defined in 'Astronomy
        and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
S9628 = / WCS information
S9629 = 2000.0 / [yr] Equinox of equatorial coordinates
S9630 = / Crop information
S9631 = '/home/eli/point_montage/sola/MATLAS/NGC0474.1.r.Mg004.fits'
S9632 = '9733:19733,8486:18486' / Range of pixels used for this output.
S9633 = / Versions and date
S9634 = '2020-06-30T11:36:11' / file creation date (YYYY-MM-DDThh:mm:ss UT)
S9635 = '3.43' / CFITSIO version.
S9636 = '5.18' / WCSLIB version.
S9637 = '2.4' / GNU Scientific Library version.
S9638 = '0.11.49-f0539' / GNU Astronomy Utilities version.
S9639 = '' / data unit type
S9640 = 'DATA' / extension name
```

Image visualisation tools: Aladin

- **Aladin** (CDS): interactive sky atlas to visualize astronomical images or full surveys, query catalogues and entries from the Simbad database, Vizier service and other archives

The screenshot shows the Aladin Sky Atlas website. At the top is a dark header with the CDS logo and links for Portal, Simbad, VizieR, Aladin, X-Match, Other, and Help. Below the header is a large banner with the text "Aladin Sky Atlas". On the left is a vertical navigation menu with links for Overview, Aladin Desktop, Aladin Lite, Information, and a link to "en français". The main content area has a title "Overview" and a paragraph describing Aladin as an interactive sky atlas. It includes two sections: "Download Aladin Desktop on your machine" with a thumbnail image and "Preview with Aladin Lite in your browser" with another thumbnail image.

Overview

Aladin is an interactive sky atlas allowing the user to visualize digitized astronomical images or full surveys, superimpose entries from astronomical catalogues or databases, and interactively access related data and information from the *Simbad* database, the *VizieR* service and other archives for all known astronomical objects in the field.

 Download **Aladin Desktop** on your machine

 Preview with **Aladin Lite** in your browser

The *Aladin* sky atlas is available in two modes:

- *Aladin Desktop*, a regular Desktop application
- *Aladin Lite* a Javascript Web application.

Image visualisation tools: Aladin

Catalogues

Tools

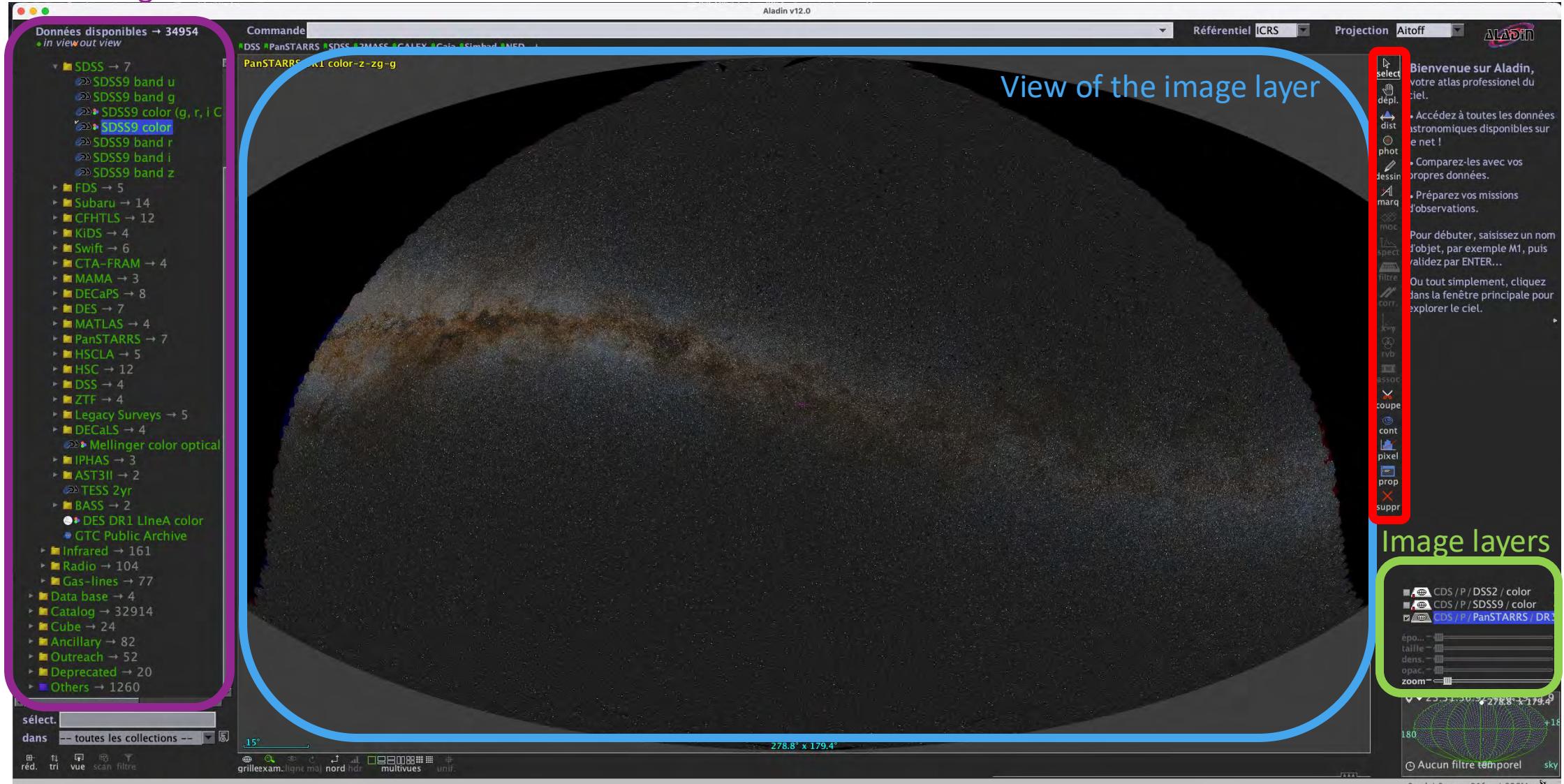


Image visualisation tools: Aladin



Image visualisation tools: others

- Plenty of other softwares

FITS Image Software Packages for image viewing, analysis, and format conversion

The following software packages display or manipulate the relatively simple class of FITS data files that containing 2-dimensional images, often of celestial objects in the night sky. It should be noted that FITS is a very general data format that is used for many different types of astronomical data sets, so these packages are not necessarily capable of reading every type of FITS file. Developers of new image display programs should be aware of the [special requirements](#) for effectively displaying FITS images.

FITS Image Viewers

- [Image viewers for PC and Macs](#) - an extensive listing of commercial and freeware image processing software compiled by the Astronomy Education Committee.
- [Aladin](#) - Interactive Sky Atlas
- [APPlot](#) - Astronomical Plotting Library in Python is a Python module aimed at producing publication-quality plots of astronomical imaging data in FITS format.
- [Aperture Photometry Tool](#) - interactive software tool for visualizing and performing aperture photometry measurements on astronomical images.
- [ASTAP viewer, image stacker, plate solver](#) This program, available as an executable on Windows, Macs and most varieties of Linux, supports 8, 16, and 32 bit integer images and also 32-bit floating point, including images using FITS compression. Users can determine the astrometric properties of images, stack and display them; including blind solving of the astrometry of each image using the GAIA database.
- [AstroImageJ](#) - processing, modeling and plotting astronomical image data in one package based upon the ImageJ Java library.
- [Avis FITS Viewer](#) - a FITS viewer for Windows. Only reads 8 and 16 bit FITS images. Converts to RAW, TIF, TGA, BMP, and JPEG formats
- [Carta FITS Viewer](#) - an image visualizing tool designed for professional researchers to support very large files (GB to TB size) from ALMA, VLA, and SKA pathfinders. Supports FITS, CASA, and HDF5 data formats.
- [CCDLAB](#) - a FITS image viewer and data reducer for Windows platforms based upon the JPFITS FITS file interface. [Features](#) include functionality for manipulating the image data and header keywords, batch processing, general image reduction, source detection, and automatic or manual World Coordinate solutions.
- [Clearsky viewer](#) - a javascript library for viewing a FITS image. Features include multiple regions of interest, stats, contrast, magnifying glass and more.
- [ds9 \(SAOImage\)](#) - astronomical visualization application from SAO
- [FITS Liberator](#) - a plug-in for Adobe Photoshop for manipulating FITS format images. Also works with Photoshop Elements 2. Includes a short introduction to [astronomical image processing](#).
- [Fits4Win2 Viewer](#) (shareware with free beta version) - a FITS viewer for Windows. Works as an extension to Windows Explorer and includes support for viewing thumbnail images of FITS files.
- [FitsPlug v2.0](#) (shareware with free beta version) - a FITS plug-in for Adobe Photoshop for Windows
- [FITView](#) - FITS image viewer from NRAO
- [fv](#) - FITS file viewer and editor (supports FITS images and FITS tables)
- [GAIA](#) - an image display and analysis tool from the U.K. Starlink Project. It is a derivative of the ESO SkyCat tool
- [Ginge](#) - a Python toolkit for visualizing 2D pixel data in NumPy arrays. Supports FITS format data.
- [giv](#) - A cross platform (posix and Windows) image viewer designed especially for scientific vision and computational geometry. Supports interactive brightness and contrast adjustment of 2D images and 3D cubes in various data formats, including FITS. Also supports drawing vector graphics on top of the image.
- [GLnemo2](#) - an interactive 3D visualization program for n-body snapshots which supports 2D and 3D FITS data, as well as other data formats. GLnemo2 is open source, multi-platform (linux, MacosX, windows), and uses qt5 API and openGL hardware acceleration.
- [Gluevis](#) - a Python library designed for professional researchers to explore relationships within and between related datasets.
- [ImageJ](#) - a public domain, Java-based image processing program developed at the National Institutes of Health. ImageJ was designed with an open architecture that provides extensibility via Java plugins and recordable macros. It supports 8-bit and 16-bit integer and 32-bit floating point images and RGB color images.
- [ImageTOOLs](#) (shareware, with a free trial period) - a FITS image viewer for Windows. Supports 16 and 32 bit integer FITS images. It can convert to or from other image formats such as TIFF, JPG, BMP, and Photoshop PSD, and can create AVI animations from a sequence of images. Also supports some image processing tasks such as bias subtraction and flatfielding
- [JS9](#) - next generation astronomical visualization from SAO for both desktop and web applications.
- [KStars](#) - KStars is free, open source, cross-platform (Linux, OSX, Windows) Astronomy Software. It provides an accurate graphical simulation of the night sky, from any location on Earth, at any date and time. KStars FITS Viewer tool supports grey scale and color (3D Cube) across all bit depths. It can display captured images from INDI cameras and video cameras.
- [Libviso](#) - a fully demand-driven, threaded image processing library with no image size limits and with good support for colour. Reads and writes FITS images, as well as TIFF, JPEG, PPM, PNG, and other file formats. Has interfaces to C, C++ and Python, and a command-line interface that can be called from shell scripts.
- [MicroObservatory Image 2.0](#) - astronomical image display program works with FITS and GIF images on PCs and Macs. Can also perform mathematical image processing operations on multiple images.
- [PhAst](#) - A flexible IDL tool to display and analyze FITS images. It can calibrate raw images, provide astrometric solutions, and do circular aperture photometry. PhAst allows the user to load, process, and blink any number of images. Requires either an IDL license, or installation of the (free) IDL Virtual Machine.
- [QFileView](#) - An image viewer for 1-D, 2-D, and 3_D FITS images. It is written in C++ and uses the Qt widget library. Binary executables for Microsoft Windows, Linux, and Mac OSX, as well as the source code, are available.
- [RSpec](#) - A Windows software package with many spectroscopic analysis features that can process 2D FITS Images and 1D tables. Can remove background, rotate, extract and process profiles. 30-day free trial version available.
- [Siri](#) - an astronomical image processing tool specially tailored for noise reduction and improving the signal/noise ratio of an image by stacking multiple exposures. Siri provides a large set of dedicated algorithms which can be run manually or in automated processing scripts. This free beta-release software runs on Linux, Windows or macOS.
- [SkyCat](#) - ESO tool combines image visualization and access to catalogs
- [SpacePixels](#) - SpacePixels is an astronomical image (FITS) manipulation tool supporting object detection (asteroids, comets, spacecraft, ...). It is intended to be an easy-to-use tool for amateur astronomers. The input to SpacePixels is a set of aligned and calibrated images which can be generated by stacking software such as Deep Sky Stacker. It can stretch and blink (animate) a set of FITS images to visually detect moving objects. It can solve for the astrometric coordinates within an image, and has batch processing capabilities to process multiple images. This is an alpha-release of the software, with more features planned.
- [Tria](#) - an advanced image processing suite for Windows platforms (only), including deconvolution, image registration, and noise filtering functions. Supports FITS, TIFF, BMP, JPEG, PNG, and WMF image formats.
- [kv](#) (shareware) - interactive image manipulation program for X Window systems
- [xINDI](#) - xINDI is a suite of native astronomical software tools for MacOS X built around INDI standard. It consists of binary INDI distribution wrapped into INDI Server application, INDI Control Panel application and FITS Viewer. The viewer is based on CFITSIO library and supports all standard monochromatic and color FITS image formats. It shows both an image (zoomed and stretched automatically, but manual correction of black and white point is available) and the image metadata.

https://fits.gsfc.nasa.gov/fits_viewer.html

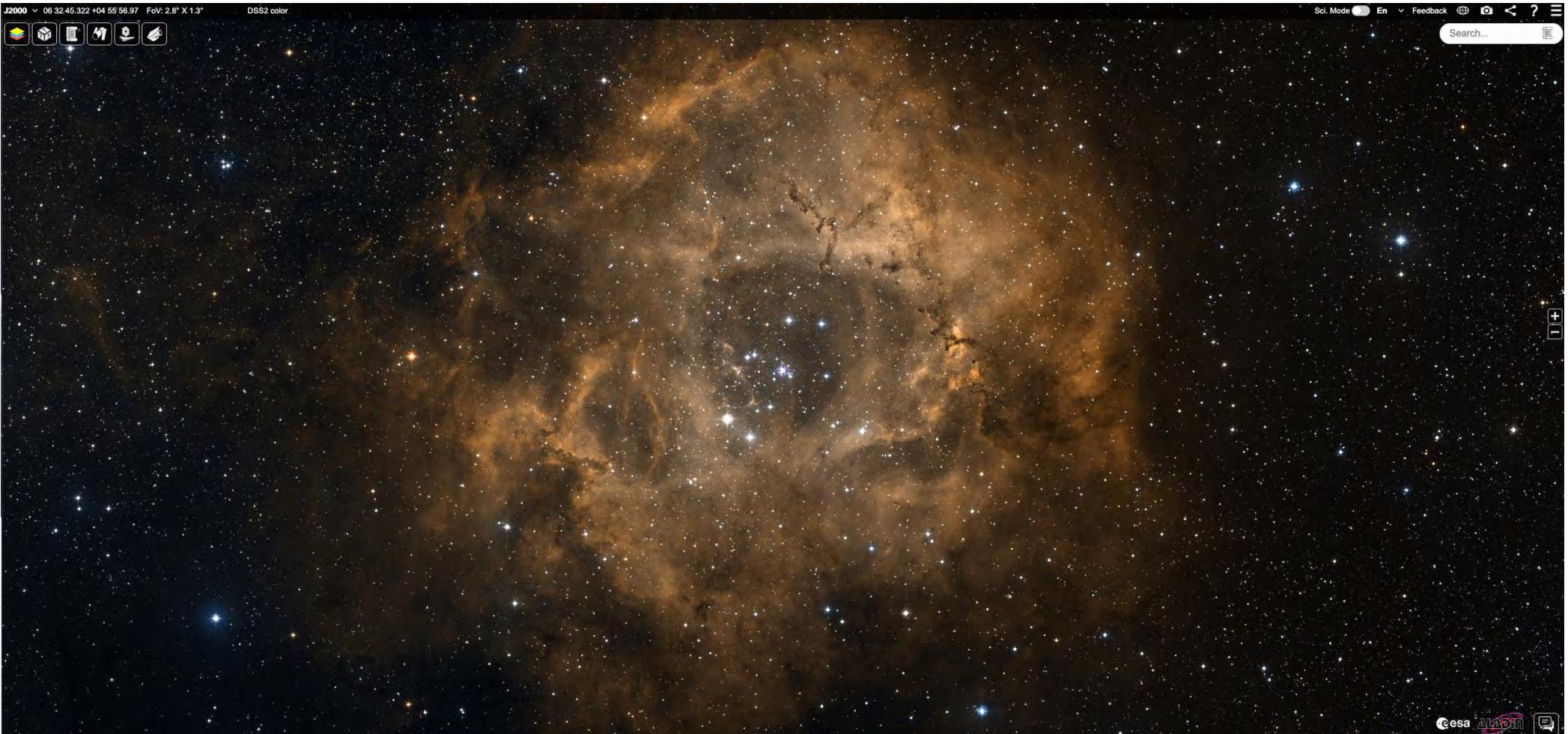
Survey specific viewers

- DESI Legacy Imaging Surveys

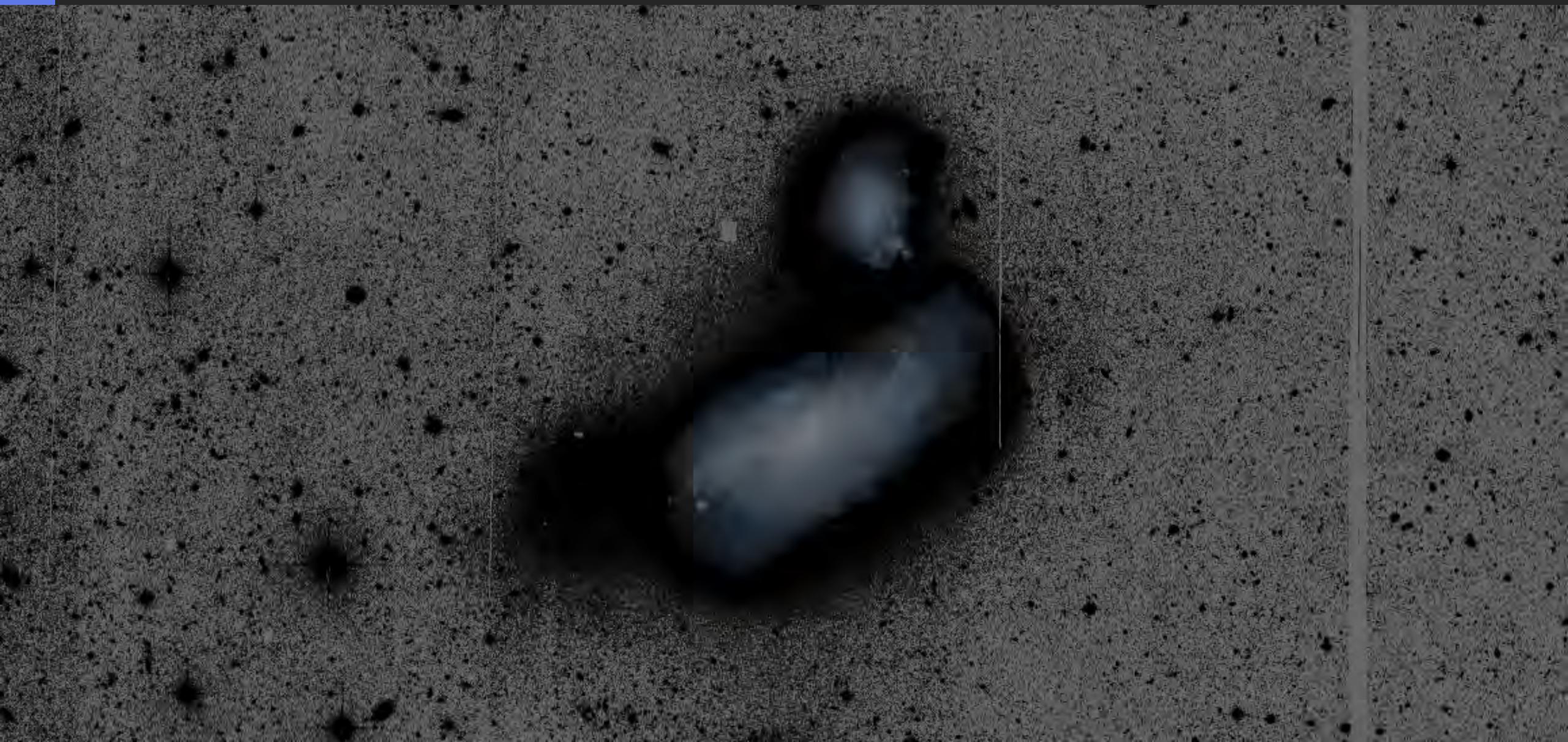


Survey specific viewers

- ESA sky (relies on Aladin)



Catalogues



Catalogues

- **Catalogues**: collection of astronomical objects, identified by a name/ID, position, type...
 - Impossible to manually go through all of them
 - **Databases and services** to access these catalogues: Vizier, Simbad, Gaia, NED, LEDA, SDSS...
 - Accessible through APIs, SQL, TAP, ...

Welcome to the Gaia ESA Archive	
<p>Gaia is a European space mission providing astrometry, photometry, and spectroscopy of nearly 2000 million stars in the Milky Way as well as significant samples of extragalactic and solar system objects. The Gaia ESA Archive contains deduced positions, parallaxes, proper motions, radial velocities, and brightness measurements. Complementary information on multiplicity, photometric variability, and astrophysical parameters is provided for a large fraction of sources.</p>	
	
<h2>Top Features</h2> <ul style="list-style-type: none">  Gaia Mission News, Gaia alerts, information, and resources on the Gaia mission for the scientific community. 	<ul style="list-style-type: none">  Gaia DR3 Direct access to Gaia DR3 papers, known issues, tools, auxiliary data, etc.  Gaia FPR Direct access to all information of the Focused Product Release.  Download Direct bulk download of Gaia data in ECSV format.
<ul style="list-style-type: none">  Software Tools Software tools for resampling of spectra, calibration of data, etc. 	<ul style="list-style-type: none">  Auxiliary Data Small data sets related to calibration, photometric pass bands, exoplanets, asteroids, etc.  Citation How to cite and acknowledge the use of Gaia data and where to find DOIs.  Partners Partner data centres after serving Gaia data.

VizieR

Portal Simbad VizieR Aladin X-Match Other Help

VizieR home · Photometry viewer · Query VizieR using TAP · X-match tables · Query images/spectra
The VizieR service is now hosted by CDS domain (cds.unistra.fr). Please, modify your configuration for the new domain.

Search Criteria

Preferences max: 50 HTML Table All columns Compute Directories CDS, France

Find catalogs among 24649 available:

Expand search

Catalog, author's name, word(s) from title, description, etc.
e.g.: AGN, Veron, I/239, or b2cdec...

► Search for catalogs by column descriptions (UCD)
► Search for catalogs containing additional data

Search by Position across 27710 tables

Target Name (resolved by [Session](#)) or Position: Target dimension:
 2 arcmin 2 arcsec Box size
NB: The epoch used for the query is the original epoch of the table(s) Radius Box size



More about VizieR sort by popularity date

Tools related to VizieR

- Catalogue collection : Search VizieR catalogues available via various services (FTP, VizieR, TAP,...)
- CDS Portal : Access CDS data including VizieR, Simbad and Aladin using the CDS portal
- Spectra, images in VizieR : Search Spectra and Images in VizieR
- Photometry viewer : Plot photometry (sofi) including all VizieR
- TAP viewer : query VizieR using ADQL (SQL extension dedicated for astronomy)
- CDS cross-match service : fast cross-identification between any 2 tables, including VizieR catalogues, SIMBAD

→ Cite/acknowledge VizieR catalogue
→ Rules of usage of VizieR data

Wikipedia

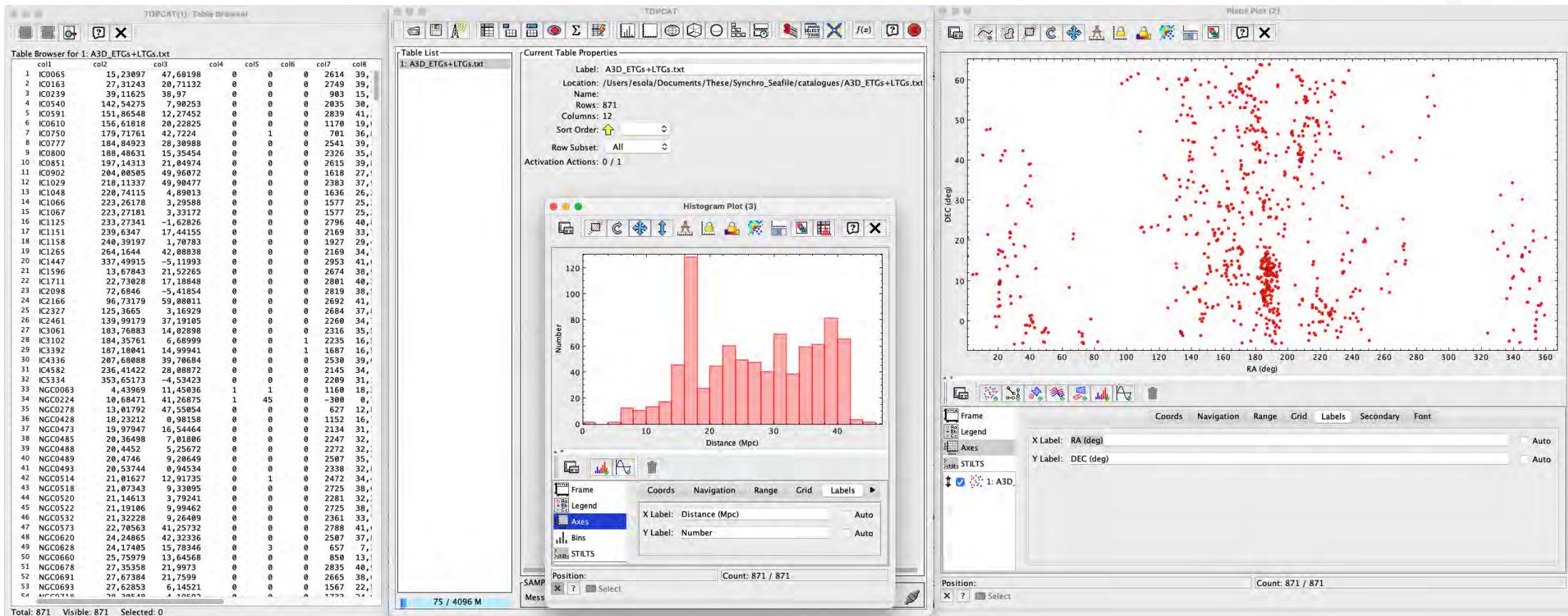
Catalogue visualisation tools

- Many softwares/services/platforms to open/read/access/catalogues
- **TOPCAT** widely used. Many tools (tables, plots, cross-match)



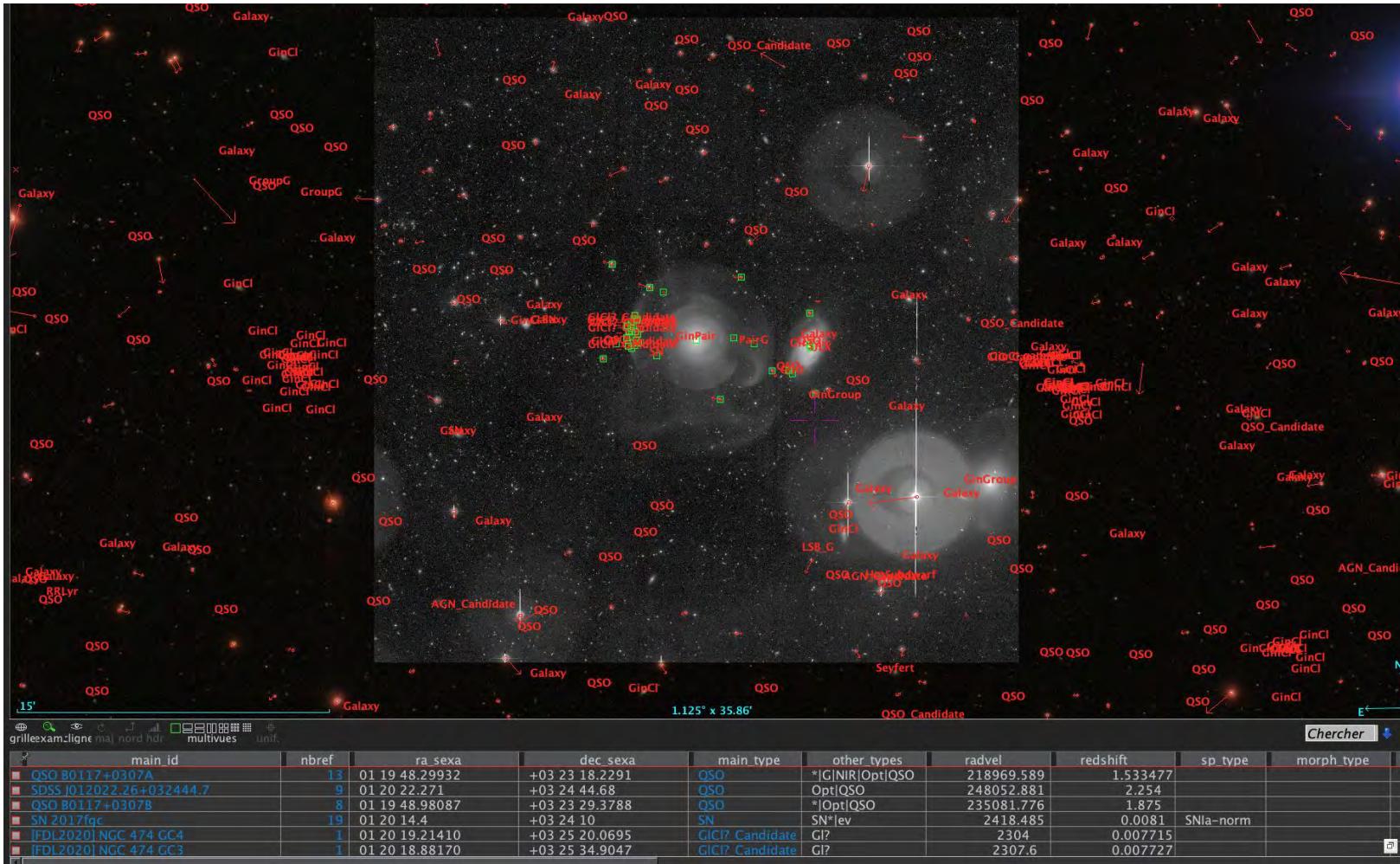
Tool for Operations on Catalogues And Tables

Does what you want with tables



Catalogues and Aladin

- Overlay information from catalogues in Aladin from Simbad, NED, Gaia, your own tables



Cross-matching catalogues

- **Cross-match:** identify the same celestial objects from several catalogues

Q? How ?

Name	RA	Dec	Photometry
NGCXXX	0	30	18
NGCYYY	145	42	22
...
PGCZZZ	22	25	14

Cat A: 15 million rows

Name	RA	Dec
AbellABC	89	11
UGCXX	145	42
...
NGCYYY	145	42
PGCCDE	145	41.8

Cat B: 169 rows

- **By identifier:** easiest, most obvious
 - ... but almost never possible. Even the well-known objects have several identifiers.
- **By coordinates:** yes, but need to define a cross-match radius

Cross-matching catalogues

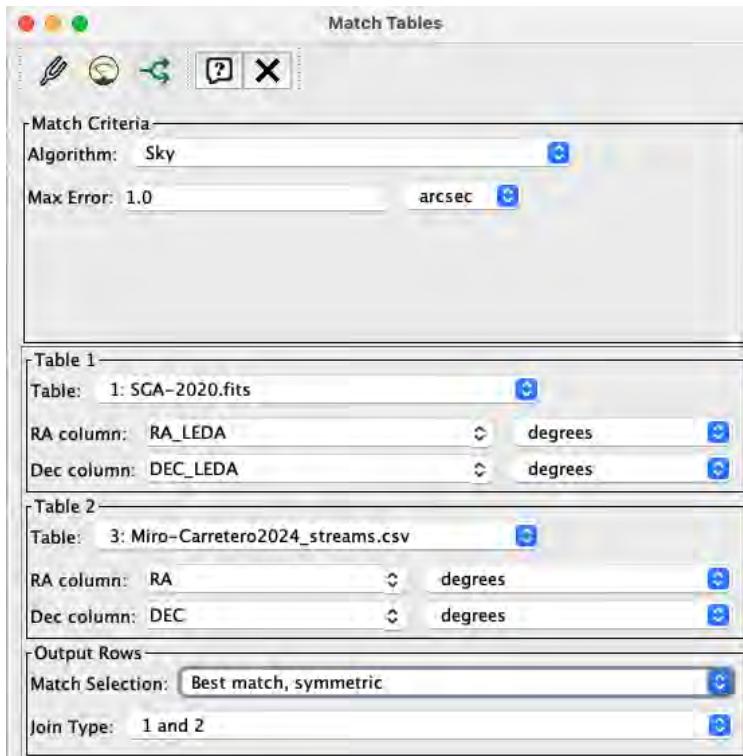
- **Need to specify:**
 - Cross-match radius
 - Cross-match type: one-to-one, one-to-many, ...
- **Need to tackle:**
 - Duplicates
 - Not the same precision in the coordinates
 - Not the same coordinate reference frame
 - Even more complicated for transients/high proper motion objects?
 - All other problems you didn't think about at first

Name	RA	Dec	Photometry
NGCXXX	0	30	18
NGCYYY	145	42	22
...
PGCZZZ	22	25	14

Name	RA	Dec
AbellABC	89	11
UGCXX	145	42
...
NGCYYY	145	42
PGCCDE	145	41.8

Cross-matching catalogues

- You can make your own cross-matching algorithms (e.g. using astropy functions)
- Use more efficient tools: TOPCAT cross-match, CDS X-Match service, many more...



Topcat cross-match interface

The screenshot shows the 'CDS X-Match Service' interface. The top navigation bar includes links for CDS, PORTAL, SIMBAD, Vizier, ALADIN, X-MATCH, OTHERS, HELP, and ? . The main menu has tabs for 'X-match' (which is selected), 'Tables management', and 'Documentation'. The central part of the page is titled 'Choose tables to cross-match' and contains two input fields for table names: 'e.g. VII/260/dr7qso, or select in list' and 'e.g. VII/233/xsc, or select in list', each with 'VizieR', 'SIMBAD', and 'My store' buttons. Below this is a 'Show options' button and a large orange 'Begin the X-Match' button. The bottom section is titled 'Visualize and manage your cross-match jobs' and shows a table titled 'List of X-match jobs'. The table has columns for 'Table 1', 'Table 2', 'Options', 'Begin', 'Status', and 'Actions'. A note says 'No job in list'. At the bottom right, it says 'For the selected job(s):' with a 'Delete' button.

<http://cdsxmatch.u-strasbg.fr/>

By the way, how do you know an object's name?

- Q? How do you link an object's name to its coordinates ? Or how do you recover the many different identifiers of a same object?
- Search NED or SIMBAD databases !

NED NASA/IPAC Extragalactic Database

Home Search Objects Literature Services Tools Information

Home > Search Objects > By Name

Detailed Information for a Named Object

Object Name: NGC4254

Search Options Go

Results for object MESSIER 099 (NGC4254)

Overview Cross-IDs (44) Coordinates (115) Redshifts (55) Distances (15) Classifications (58) Galactic Extinctions Notes (21) Diameters (12)

Photometry & SED (291) Spectra (25) Images (124) References (990) External Links Survey Coverage

POSS-II F (North), AAO-SES/SERC-ER (South), Red image
View in IRAF Finderchart
Image Credit: Caltech or AAO/ROE

Selected data and derived quantities for MESSIER 099. More information in the tabs above.

Cross-identifications Essential note

MESSIER 099; NGC 4254; UGC 07345; VCC 0307; CGCG 098-144

Coordinates for Fiducial Position

Equatorial (J2000)	Galactic				
RA, Dec	RA, Dec [Deg]	Unc Semi-major,minor ["]	Unc PA [deg]	Reference	Lon, Lat [deg]
12h16m49.6340s, +14d24m59.377s	184.706809, 14.416494	0.08000, 0.07925	90	2013wise.rept....1C	270.431332, 75.189769

Fiducial Redshift & Derived Quantities ($H_0 = 67.8 \text{ km/sec/Mpc}$, $\Omega_{\text{matter}} = 0.308$, $\Omega_{\text{vacuum}} = 0.692$)

	Reference	cz (CMB) [km/s]	Hubble Distance (CMB) [Mpc]	Mean Distance [Mpc]
z (Heli)	cz (Heli) (km/s)	2005ApJS...160..149S	2737 ± 23	40.36 ± 2.85
				15.193 ± 0.528

Classifications

Object Type	Morphology	Reference	Activity Type	Reference	Other
G	SA(s)c	1991RC3.9.C...0000d			SA(s)c;LINER HII

NGC4254

other query modes : Identifier query Coordinate query Criteria query Reference query Basic query Script submission TAP Output options Object types Help

Query : NGC4254

submit id

M 99 -- HII Galaxy

Other object type: M99 (J, G [2014ApJS...EVCC,...], Rad (BVE,GRB,...), X (2E,IRXS), IR (ALFALFA,HIPASS), IR (IRAS,PSCe), GIC (CAINNS), GIG ([OM2007]), AG7 (2020MNRAS...), zmm (JCHSE), Opt (SDSS))

ICRS coord. (ep=J2000): 12:16:17.196 +14:41:44.9 (Infrared) [] C 2980842...131...11835

FK4 coord. (ep=J2000): 279.431828 +75.189835 []

Gal coord. (ep=J2000): 7.4589 (0.022) C 209863...131.11635

Radial velocity / Redshift (cz): 2148 [km/s] / 0.000008 (0.000018) / cz 3427.83 [km/s]

Vizier ID: 2418 [3J / emission] 0.000008 (0.000018) / cz 3427.83 [km/s]

Morphological type: SA C 2013MNRAS...480...5900

Angular size (arcmin): 5.13 ± 4.47 (Opt) D 2003A&A...412...45P

Fluxes (11):

Filter	Type	Value
U	Optical	10.45 [0.09] D 2007ApJS...173...1856
B	Optical	10.44 [0.08] D 2007ApJS...173...1856
V	Optical	10.43 [0.08] D 2007ApJS...173...1856
R	Optical	7.4589 [0.022] C 209863...131.11635
I	Optical	7.251 [0.022] C 209863...131.11635
K	Optical	6.929 [0.031] C 209863...131.11635
u (AB)	Optical	12.32 [0.041] C 2009ApJS...182...543A
g (AB)	Optical	10.43 [0.031] C 2009ApJS...182...543A
r (AB)	Optical	11.471 [0.032] C 2009ApJS...182...543A
i (AB)	Optical	10.669 [0.032] C 2009ApJS...182...543A
z (AB)	Optical	10.344 [0.032] C 2009ApJS...182...543A

Notes:

- See GALEX UV data in GALEX data
- See also Spectred ratio flux densities.

Hierarchy : number of linked objects whatever the membership probability is (see description here) :

parents : 6 children : 1875 siblings : 6440 Display criteria : All

Identifiers (49) :

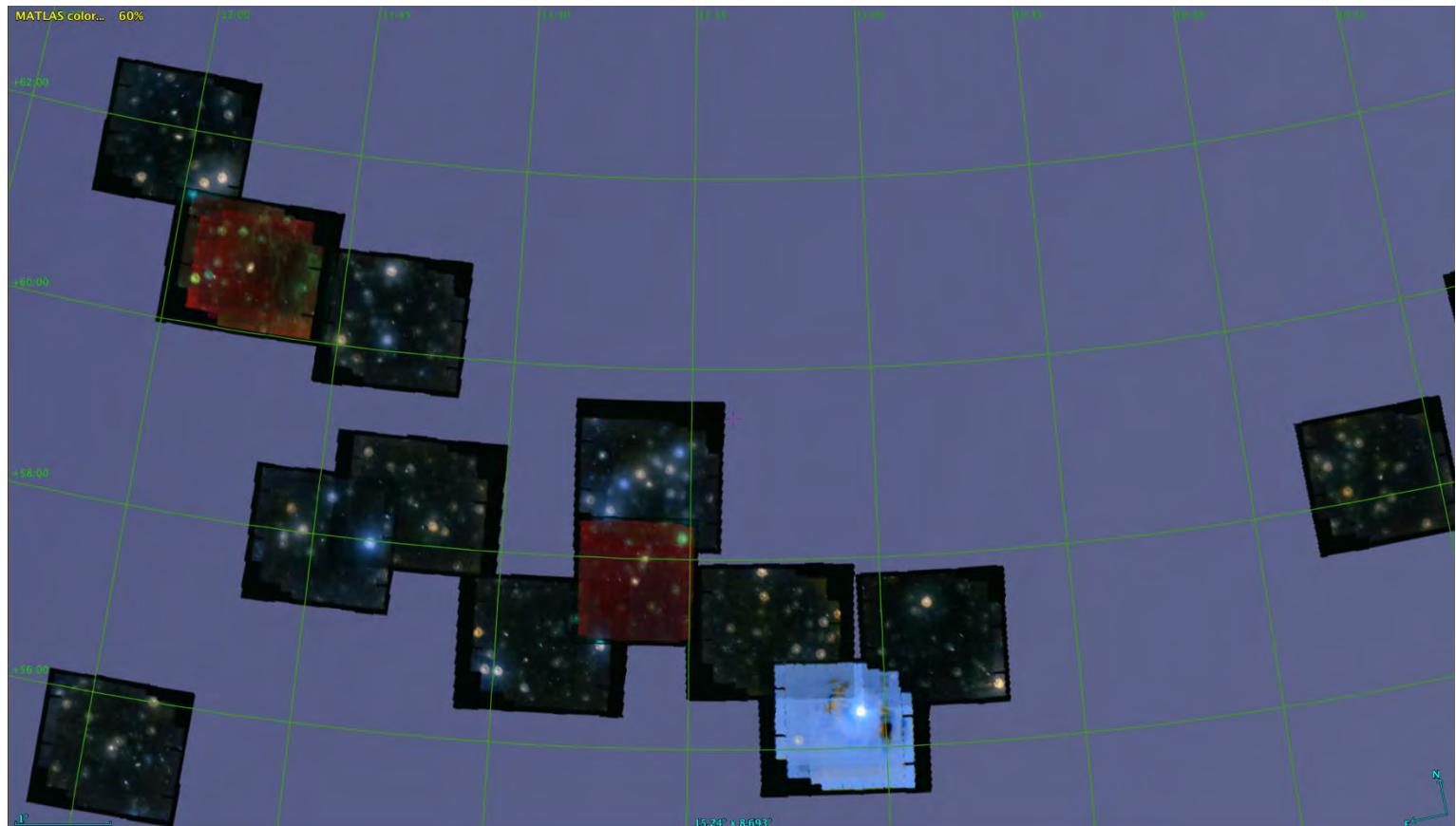
An access of full data is available using the icon Vizier near the identifier of the catalogue.

Identifier	Description
JCHSE J121649.6+142502	
LDA 39578	
ZMASK J12184962+1424593	
NGC+03-1199	
2E 2658	
2E 1216+1442	
CAINNS J121849.56+142459.4	
IRXS J121849.6+142459.2	
PSCS1 857 G270.45+75.20	[BEC2010] HRS 18Z
PSCS1 145 G270.36+75.19	[CAR05] IRAS F12163+1441
PSCe Q12162+1441	[CHM2007] HDC 792 J121849.62+1424593
IRXS J121849.6+142459.4	[CHM2007] LDC 984 J121849.62+1424593
SDSS J121849.58+142459.4	[DC78] UGC 7345
UGC 7345	[DS98] 308
UGC 121849.6+142459.1	[N98c] 121616.9+1441446
VCC 387	[N98b] M4254

Linking catalogues and images

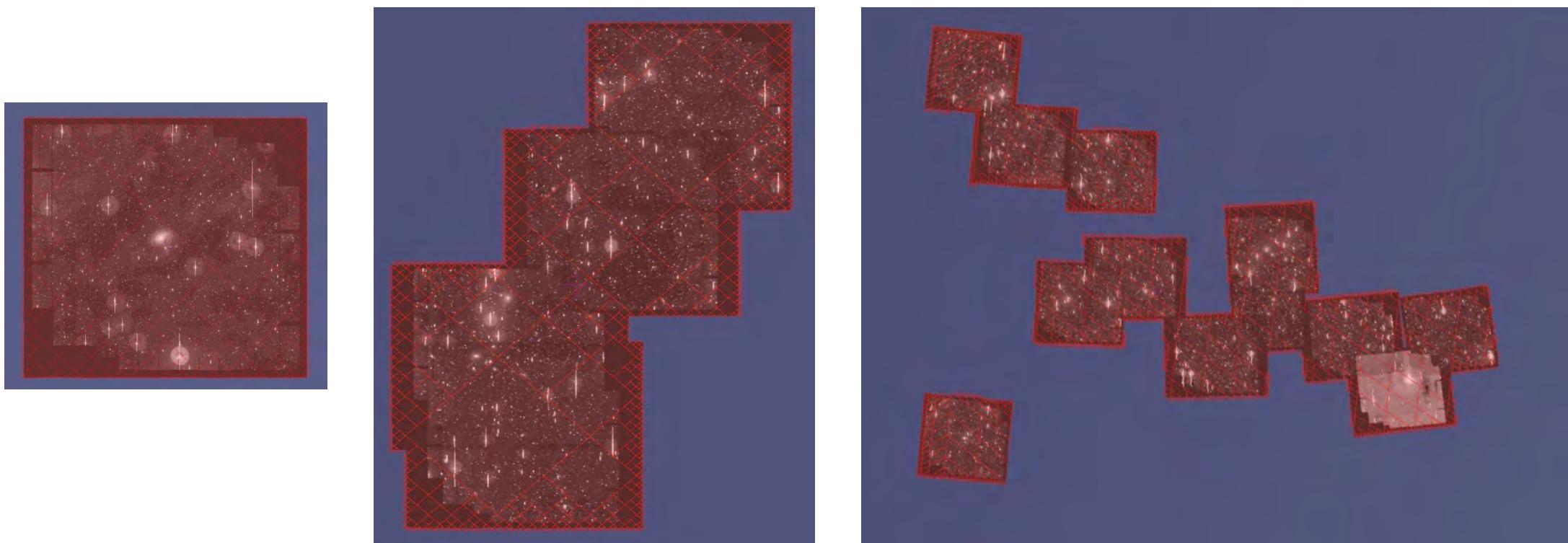
- **Q?** How do you know which objects of your catalogue are available in your set of images ?

Name	RA	Dec	Photo metry
NGCX XX	0	30	18
NGCY YY	145	42	22
...
PGCZZ Z	22	25	14



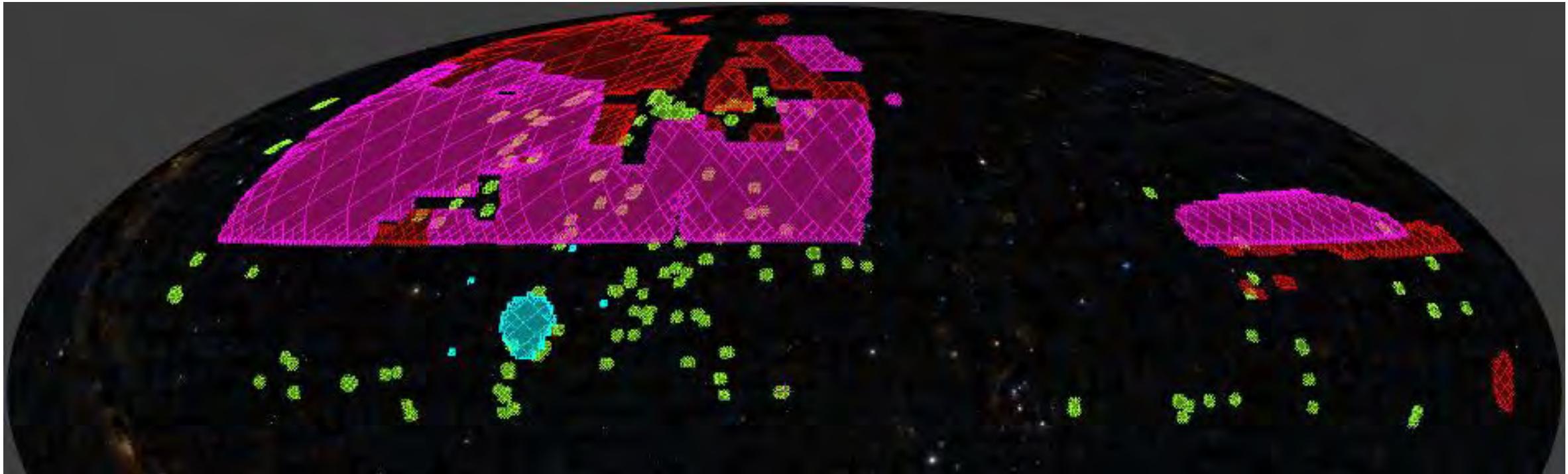
Multi-Order Coverage Maps (MOCs)

- **Multi-Order Coverage** (MOC) maps: representation of the spatial extent (= footprint) of an image on the sky. Developed by the CDS.
- Fast and easy representation of very complex footprints



MOC of some MATLAS images

Multi-Order Coverage Maps (MOCs)



Spatial footprint (MOC) of CFIS (red/pink), MATLAS (green) and NGVS/VESTIGE (blue)

- Fast and easy **intersection between MOCs and catalogues**
 - Many operations on MOCs (intersection, union)
- + Space-Time MOCs (STMOCs) useful for e.g. transients, objects over many observing times

Be ready for the last lecture !

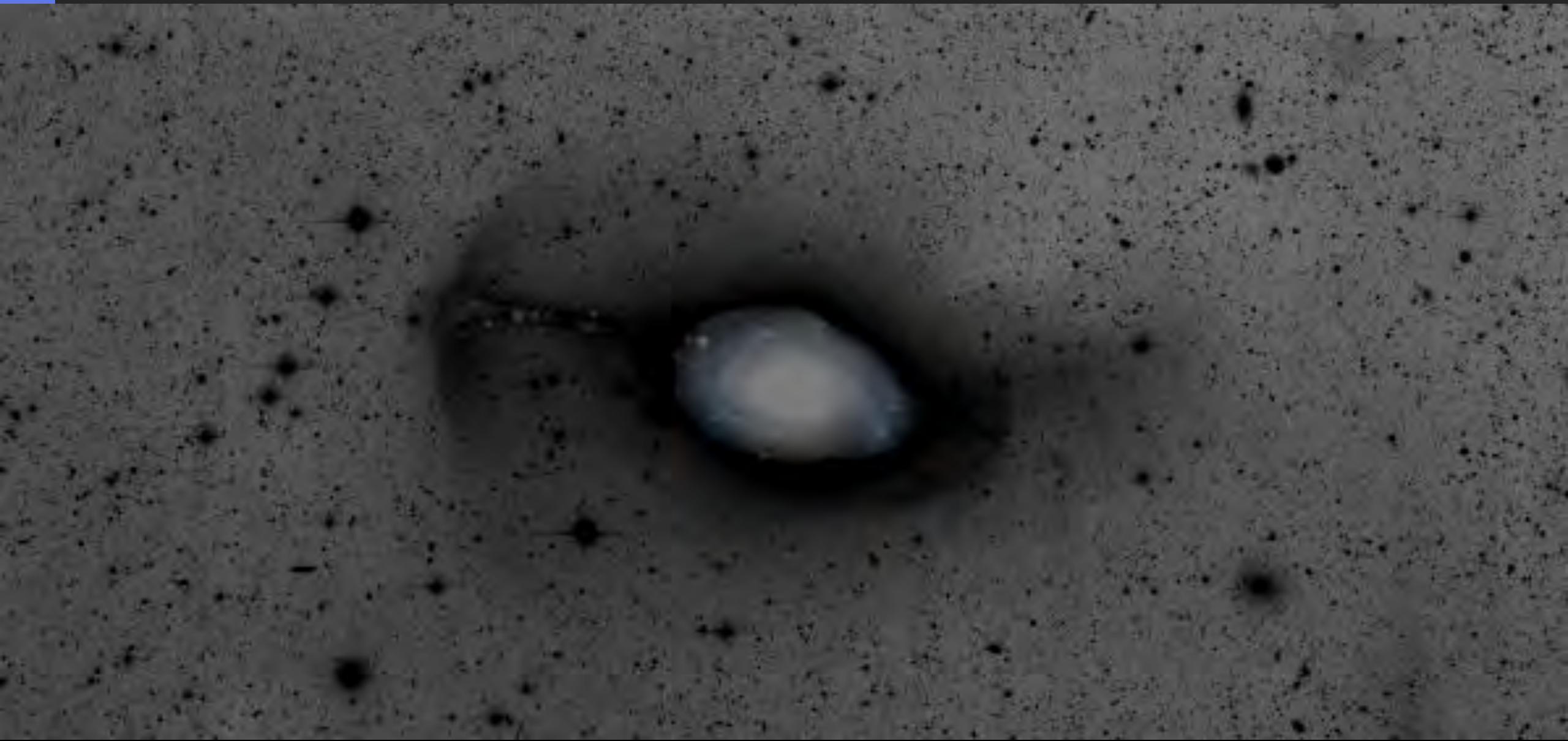


WikiCommons

Install SAOImage
DS9, **TOPCAT** and
Aladin desktop
(at least look up at
Aladin Lite online)

Look up at **NED** and
SIMBAD

Back to the LSB Universe: image processing



Reminder: deep images

- Tidal features are faint, low surface brightness



NICGO747P MASTAAR Simage (SB <
2859 mag arcsec⁻²)

Image processing

- What's wrong in the images below ?

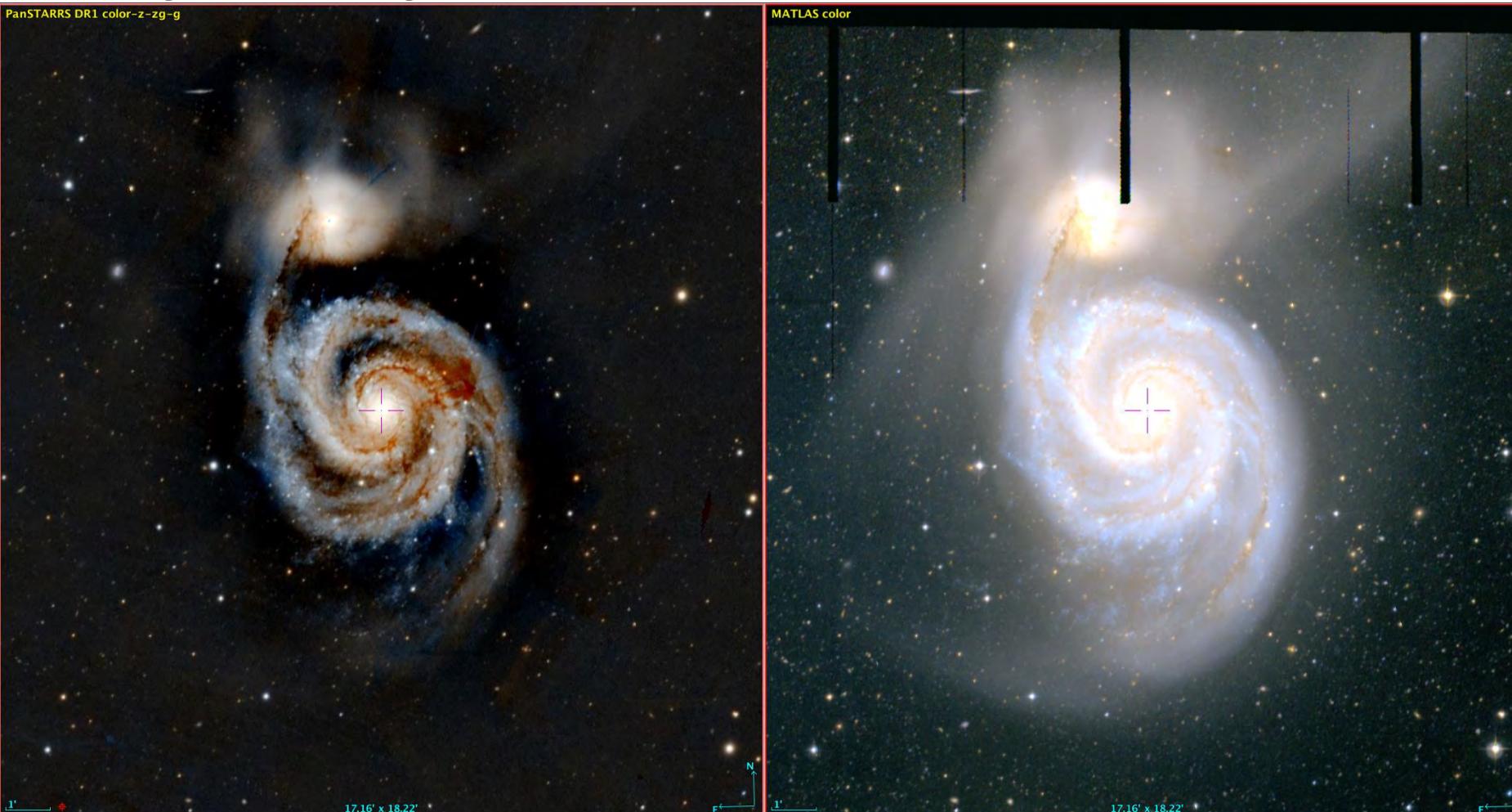


Image processing

- What's wrong in the images below ?



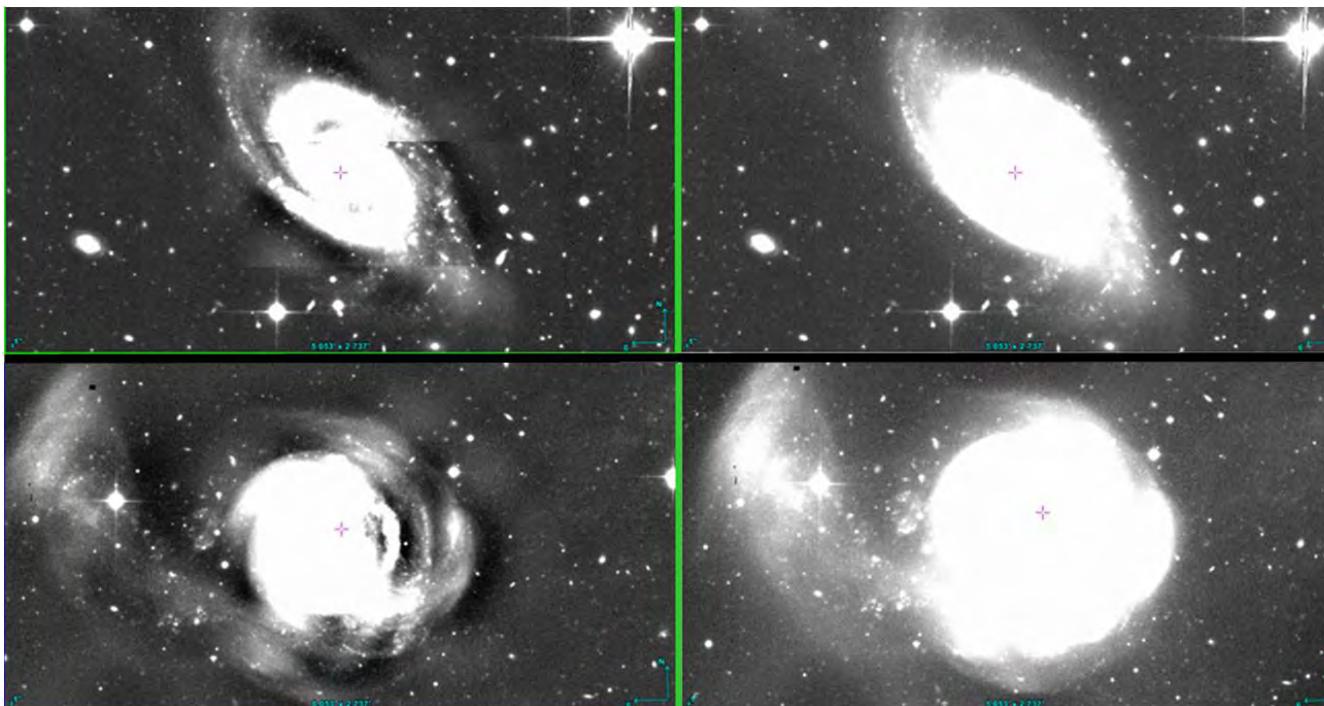
Image processing

- What's wrong in the images below ?



Image processing

- **Over-background subtraction:** standard pipelines are usually oriented for point-source like science (cosmology, galaxy evolution...) i.e. small objects that require a precise and local estimate and subtraction of the background.
- ... but our objects are very faint and extended ! Traditional pipelines consider the galaxy outskirts as background and ends up **destroying** the LSB signal.



► **Very careful background subtraction must be performed to preserve the LSB signal !!**

Image scaling

Huge dynamical range: need non-linear transformations to reveal the faint outskirts even in LSB-compliant processed images

'Linear' scaling

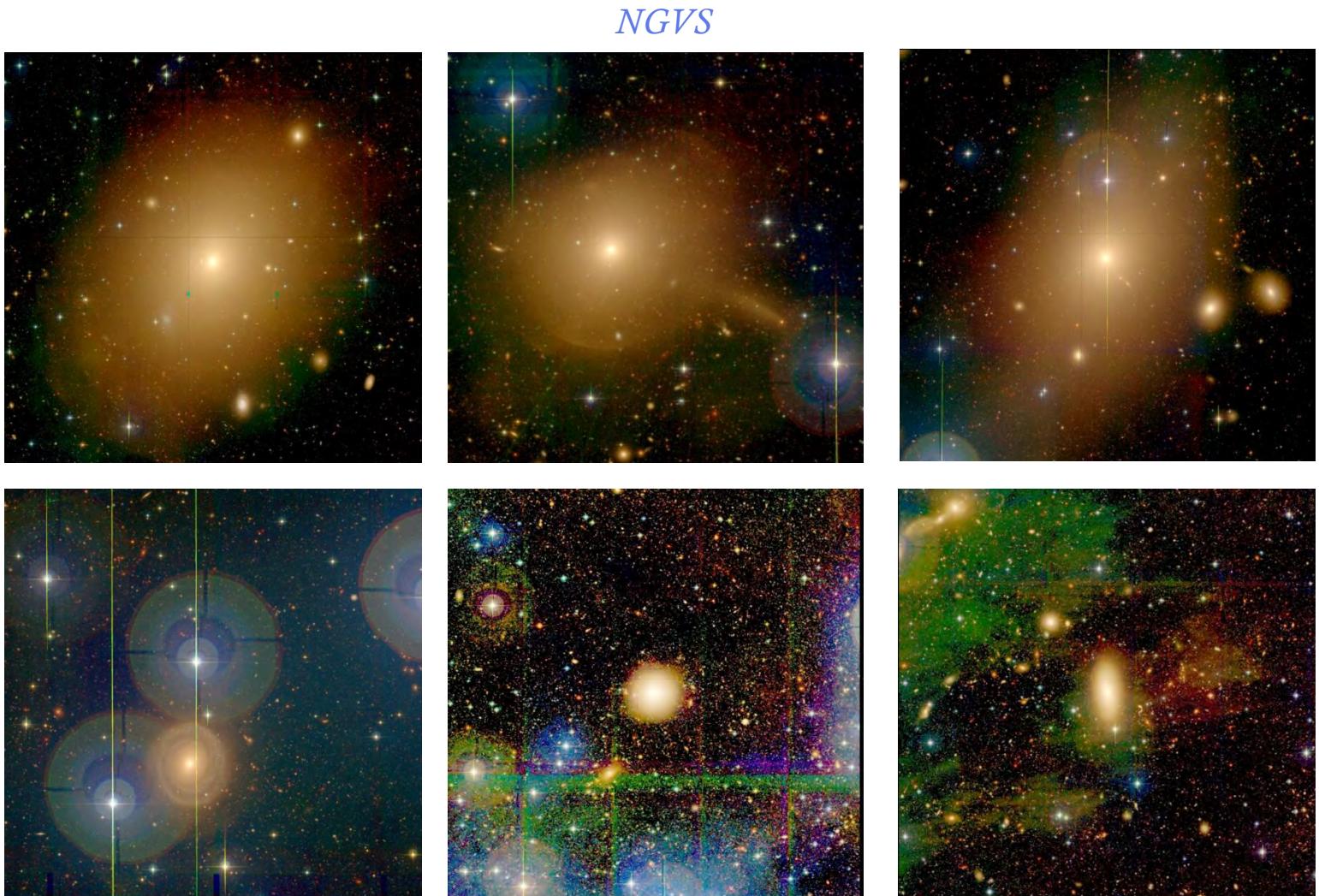


'Asinh' scaling



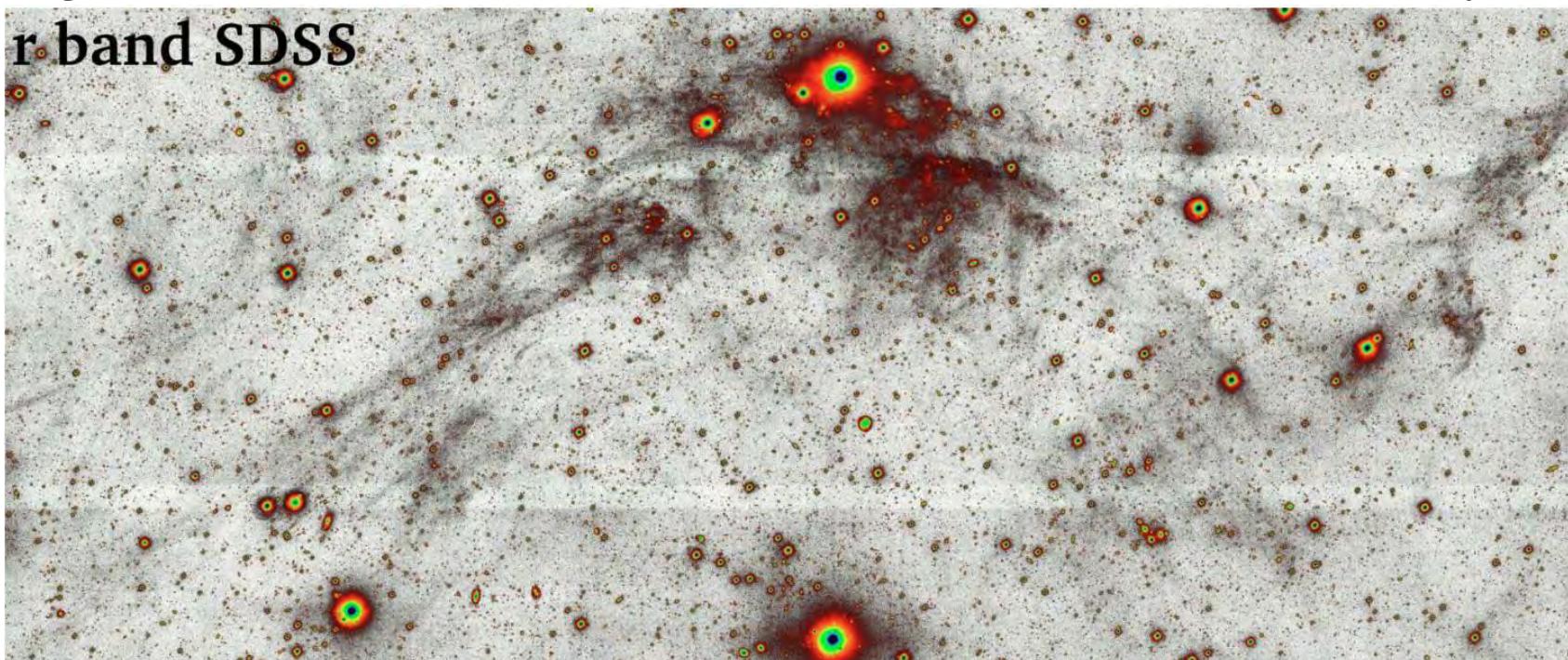
Deep images

- Deep images reveal many **stellar features**:
 - Stellar haloes
 - Tidal features
 - Intracluster light
- But also **contamination sources**:
 - Artefacts
 - Internal reflections
 - Cirrus



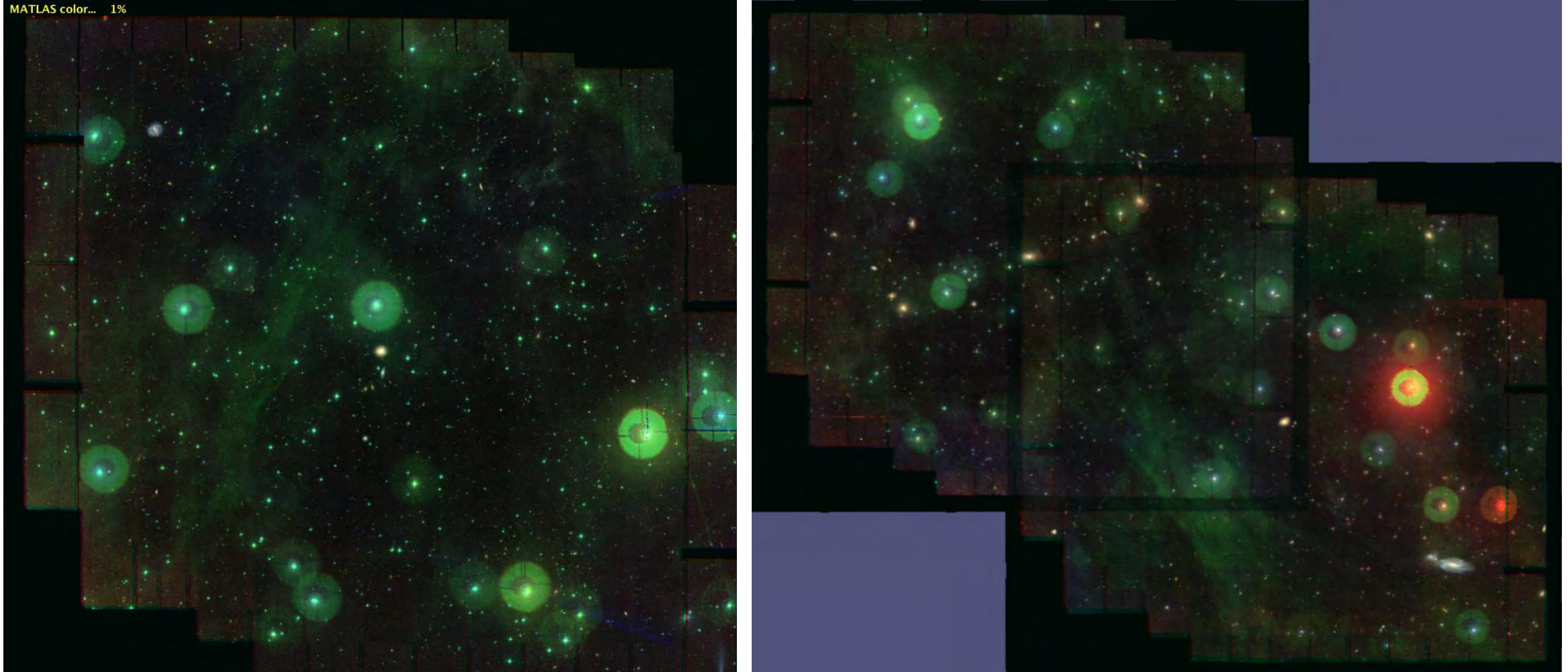
Galactic cirrus

- Cirrus: dust clouds in our Milky Way, emit in infrared, reflect in optical and UV
- Filamentary, fractal shape, LSB : hinder the observation of tidal features and/or can be confused with them !
- Big challenge to detect, characterise and remove them, no clear solution yet

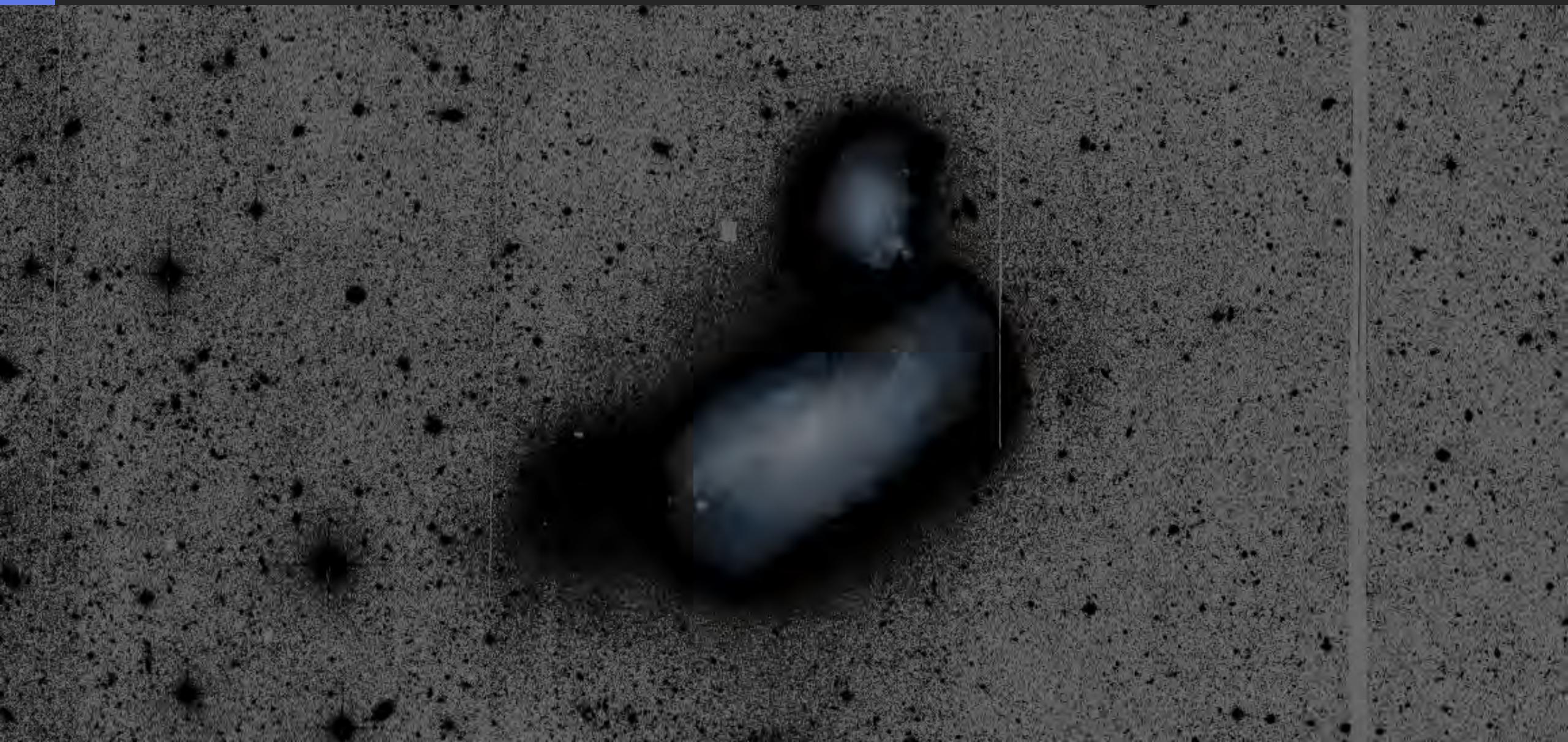


Román+2020

Galactic cirrus

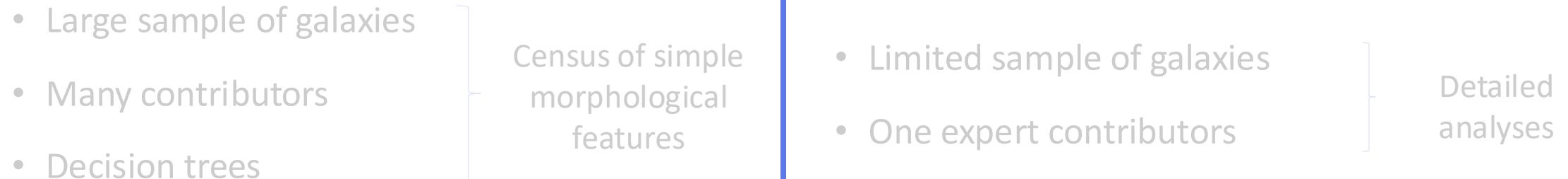


Deep images and tidal features



Deep images and tidal features

- Once the deep images are available, how to characterise tidal features ?
- Several approaches: **visual (largely used)**, automated methods, machine learning



- Our approach:** obtain detailed analyses of LSB features on hundreds of galaxies with few contributors

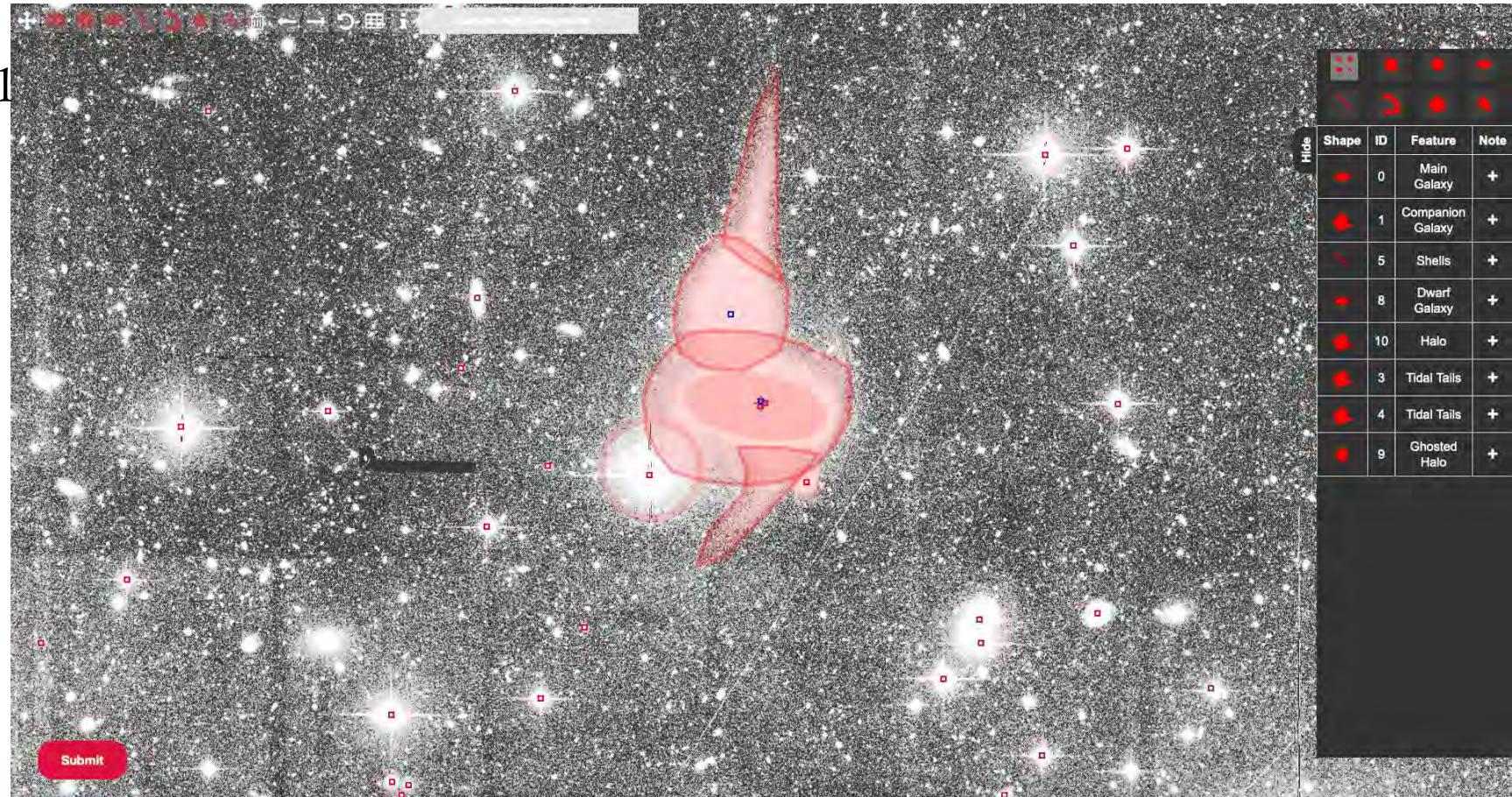
Jafar: an annotation tool for LSB structures

- Development of Jafar ([Sola+2022,2025](#)) an **online** tool (*with F. Richards*) to easily annotate and classify LSB structures in deep images
- Based on CDS Aladin Lite



Goals:

- **Draw** with precision the **shapes** of LSB structures
- A few expert contributors
- Obtain **quantitative** results about LSB structures



Interface of the annotation tool

Jafar: an annotation tool for LSB structures



The screenshot shows a web interface for the Jafar annotation tool. At the top, there is a navigation bar with links: Home, Surveys, Tutorial, and test. Below the navigation bar, a large button labeled "Welcome on the deep-imaging annotation server" is visible. To the right of this button is a vertical sidebar containing links: My annotations-observations, My annotations-simulations TNG50, Results and analysis, and Logout. The main content area is titled "Low Surface Brightness structures". It contains three paragraphs of text. The first paragraph discusses the study of galaxy morphology and its relation to galaxy evolution. The second paragraph explains what Low Surface Brightness (LSB) structures are and why they are difficult to detect. The third paragraph mentions the Canada-France-Hawaii Telescope (CFHT) survey and the MATLAS survey.

Home Surveys Tutorial test

Welcome on the deep-imaging annotation server

My annotations-observations
My annotations-simulations TNG50
Results and analysis
Logout

Low Surface Brightness structures

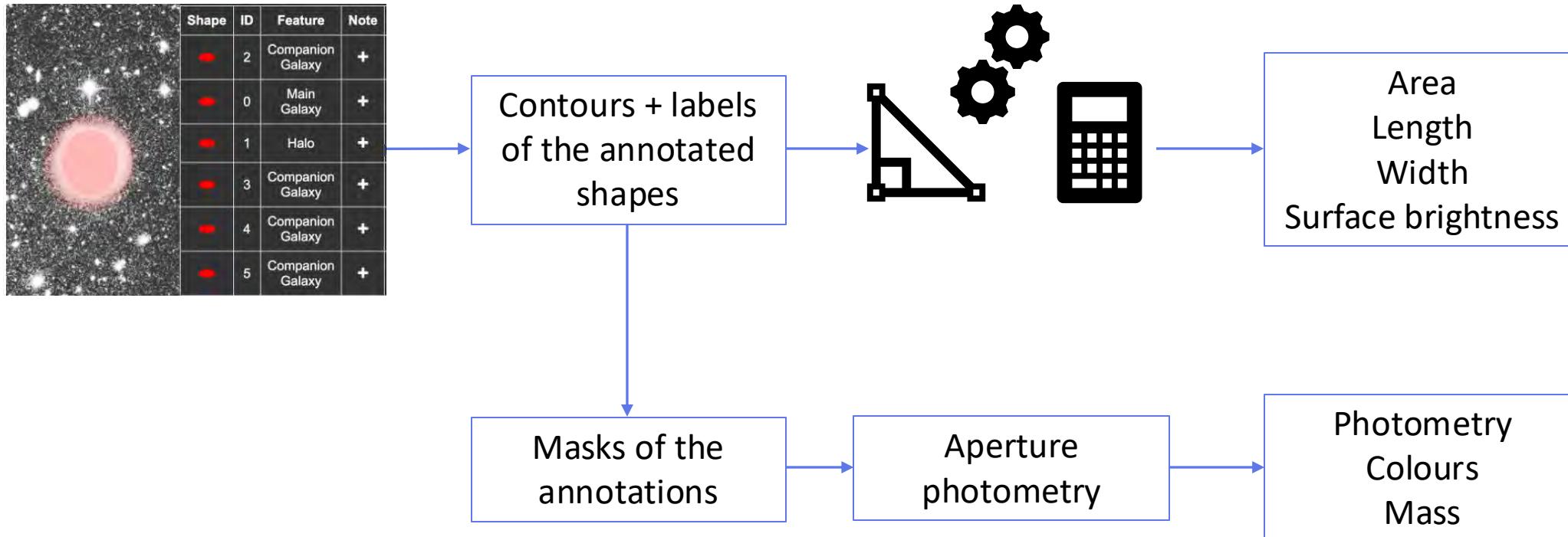
The study of the **morphology of galaxies** is essential to constrain models of galaxy evolution. Indeed, in the standard model, galaxies are formed through successive mergers with galaxies and other phenomena such as dark matter accretion or continuous process of cold gas. Vestiges of these past interactions between galaxies remain today, and they are very important as their shape and number informs us about the past merging history of a galaxy, and may change its apparent morphology.

However, these structures, these collisional debris, are very faint so their detection is complicated. They are called **Low Surface Brightness (LSB) structures**, as their flux per unit area is low. That is the reason why they have not been studied much outside the Local Group, until the use of powerful enough telescopes made their studies possible.

In particular, the **Canada-France-Hawaii Telescope** (CFHT) provided deep enough images of some galaxies that were studied with the **MATLAS** survey: many LSB structures around elliptical galaxies were discovered and classified. More recently, **CFIS** (Canada-France Imaging Survey) is a large CFHT program aiming at mapping a large part of the Northern hemisphere (5,000 square degrees) with deep images, where MATLAS only

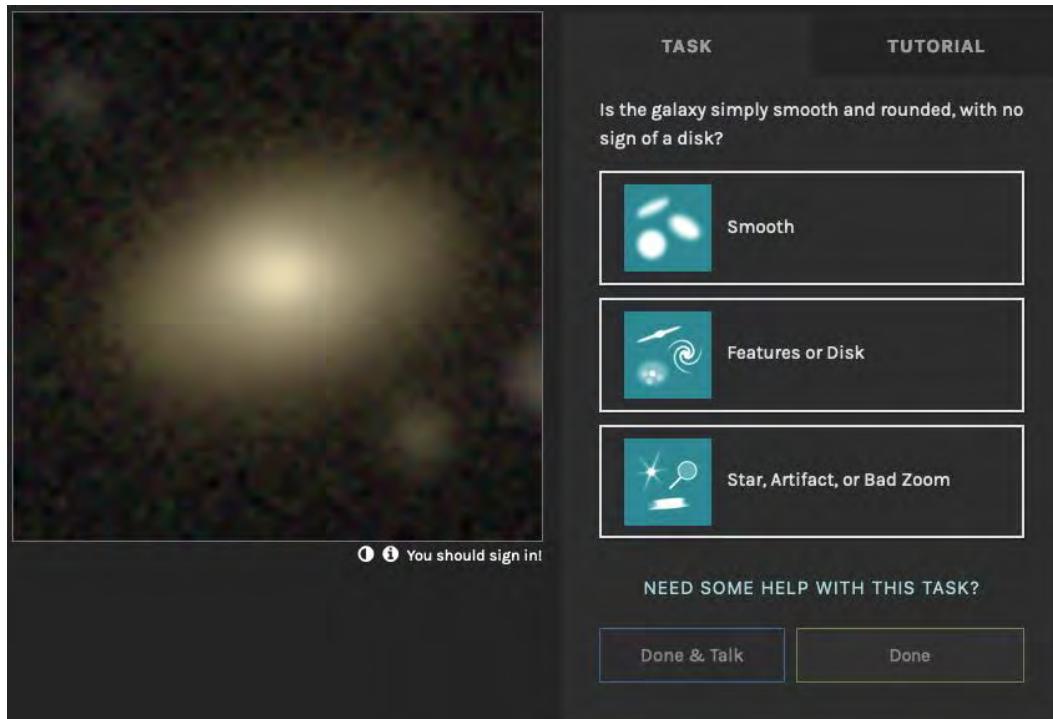
Analyses

- Need to take into the annotations of **several users**
- **Quantitative** measurements from the annotation database + **automated aperture photometry**



What about citizen science ?

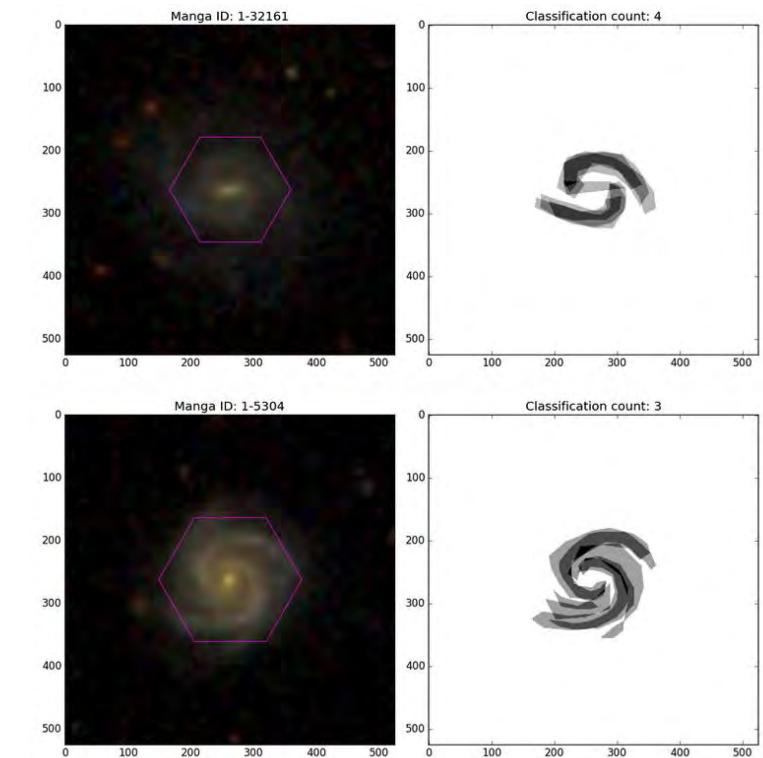
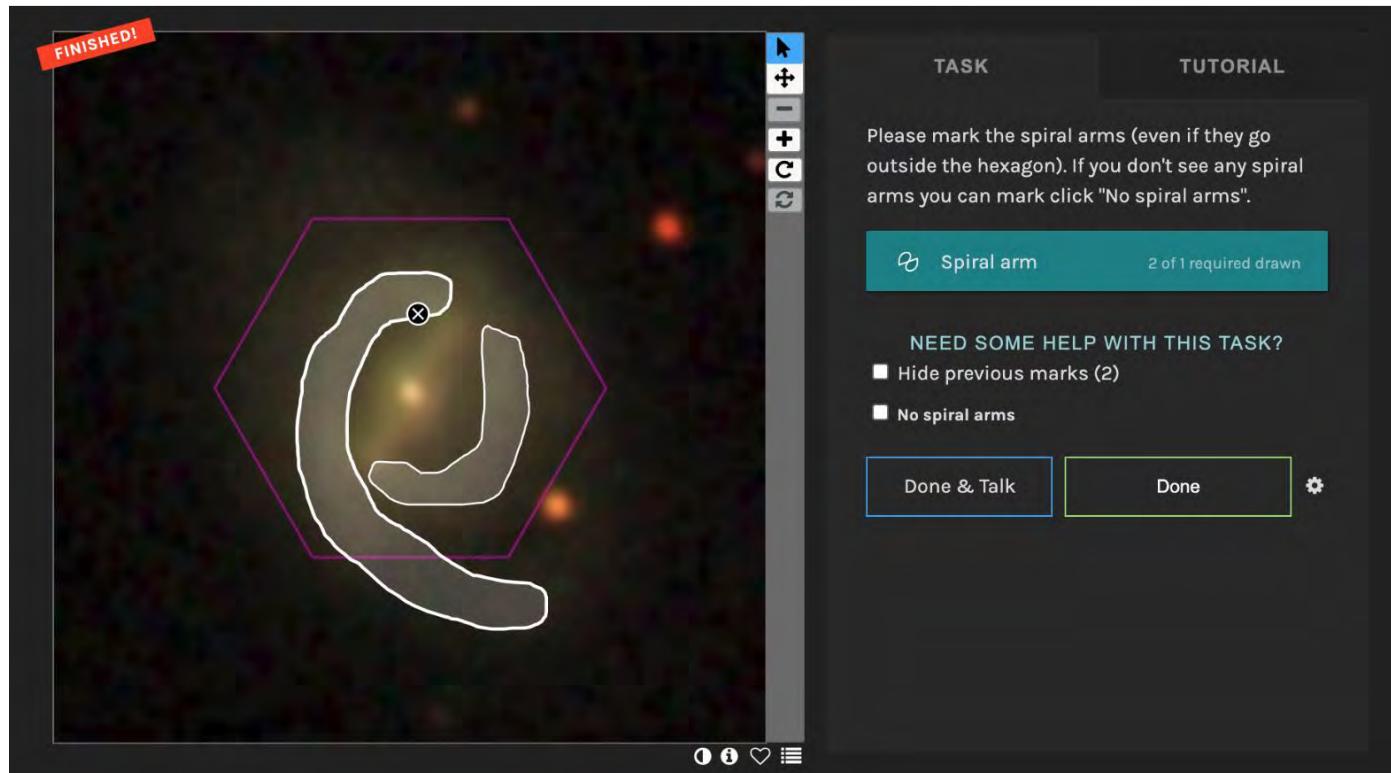
- Why not use the help of the general public for this task ? **Citizen scientists**
- A crowd of citizen scientists can classify hundreds of thousands of galaxies for simple tasks.
- Galaxy zoo is a great example: +60 million classifications about galaxy morphology



Example of the Galaxy Zoo interface

What about citizen science ?

- Galaxy Zoo 3D: recently added the possibility to draw polygons: used to count the number of spiral arms or the shape of the bar



Citizen science projects

- Zooniverse: extension to many different fields of science, largest and most popular platform but many others exist (e.g., NASA..)

The screenshot shows the Zooniverse homepage with a teal header bar. Below it, a teal navigation bar has tabs for "Active" (which is selected), "Paused", and "Finished". A welcome message reads: "WELCOME! WE'RE SO GLAD YOU'RE HERE. Thank you for your interest in helping real research. Here we've gathered a few projects we could really use your help on right now. For more options just scroll down to browse all of our active projects." It also encourages users to check out the "Talk" section. Below this, four project cards are displayed: "SEABIRD WATCH" (with a bird icon), "WHALE CHAT" (with a whale icon), "REDSHIFT WRANGLER" (with a cartoon character icon), and "VOYAGES IN TIME" (with a clock icon). At the bottom, there's a "SCROLL DOWN FOR EVEN MORE" button, followed by a row of discipline icons: ALL DISCIPLINES (selected), ARTS, BIOLOGY, CLIMATE, HISTORY, LANGUAGE, LITERATURE, MEDICINE, and NAT. A search bar at the bottom left says "Most Recently Launched" and a name input field at the bottom right says "Name:". The Zooniverse logo is in the bottom right corner.

Citizen science projects

- Tidal feature identification: Galaxy Cruise project to classify the shapes of interacting galaxies



Fig. 1. GALAXY CRUISE's classification screen. Participants classify the target at the center, and then 'sail' to the next target. Passport stamps, souvenirs and other features are available to motivate the participants.

public. We thus choose to adopt the simplified classification scheme. Some interacting galaxies show significantly distorted shapes and their original morphology can be difficult to infer. In such a case, the participant can choose 'not sure'. When a target galaxy is too close to a nearby bright star and a fair classification

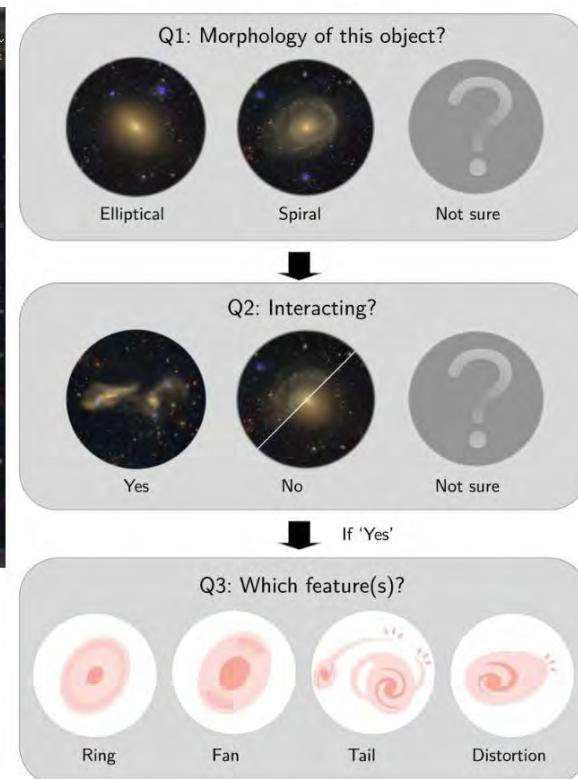


Fig. 2. GALAXY CRUISE's classification scheme. The first question is whether a galaxy is spiral or elliptical. The second question asks if the galaxy is interacting or not. If yes, the participant can choose observed feature(s).

Tanaka+2023

Then, why not use citizen scientists ?

- Highly specialized task: requires previous training and knowledge
- Subtle disentanglement between tidal tails and streams
- **Segmentation** and not just identification !
- Very time consuming
- ▶ Limited team of a few expert contributors
- But our manual approach is not possible for future surveys to come where thousands of galaxies will be studied.
- Need automated methods and **machine learning** approaches !

TO BE CONTINUED !

Summary

- Astronomical data: **images + metadata** (headers): FITS format very common
- Online databases, images and catalogues can be queried: e.g., Aladin, Simbad, NED, ...
- Useful tools to manipulate catalogues, e.g., Topcat
- **Deep** images require careful processing to reveal the LSB Universe
- Tidal features in deep images are mostly discovered visually.... but automated methods exist and will become necessary, including Machine Learning !

- **Next lecture (07/03/2025): LSB features and galactic evolution:** Machine learning to disclose faint features. LSB features as probes of galactic evolution. Observations vs simulations. Ongoing and future surveys.

Be ready for the last lecture !



Install **DS9**, **TOPCAT** and **Aladin** desktop
(at least look up at Aladin Lite online)

Look up at **NED** and
SIMBAD

+ bring your computer