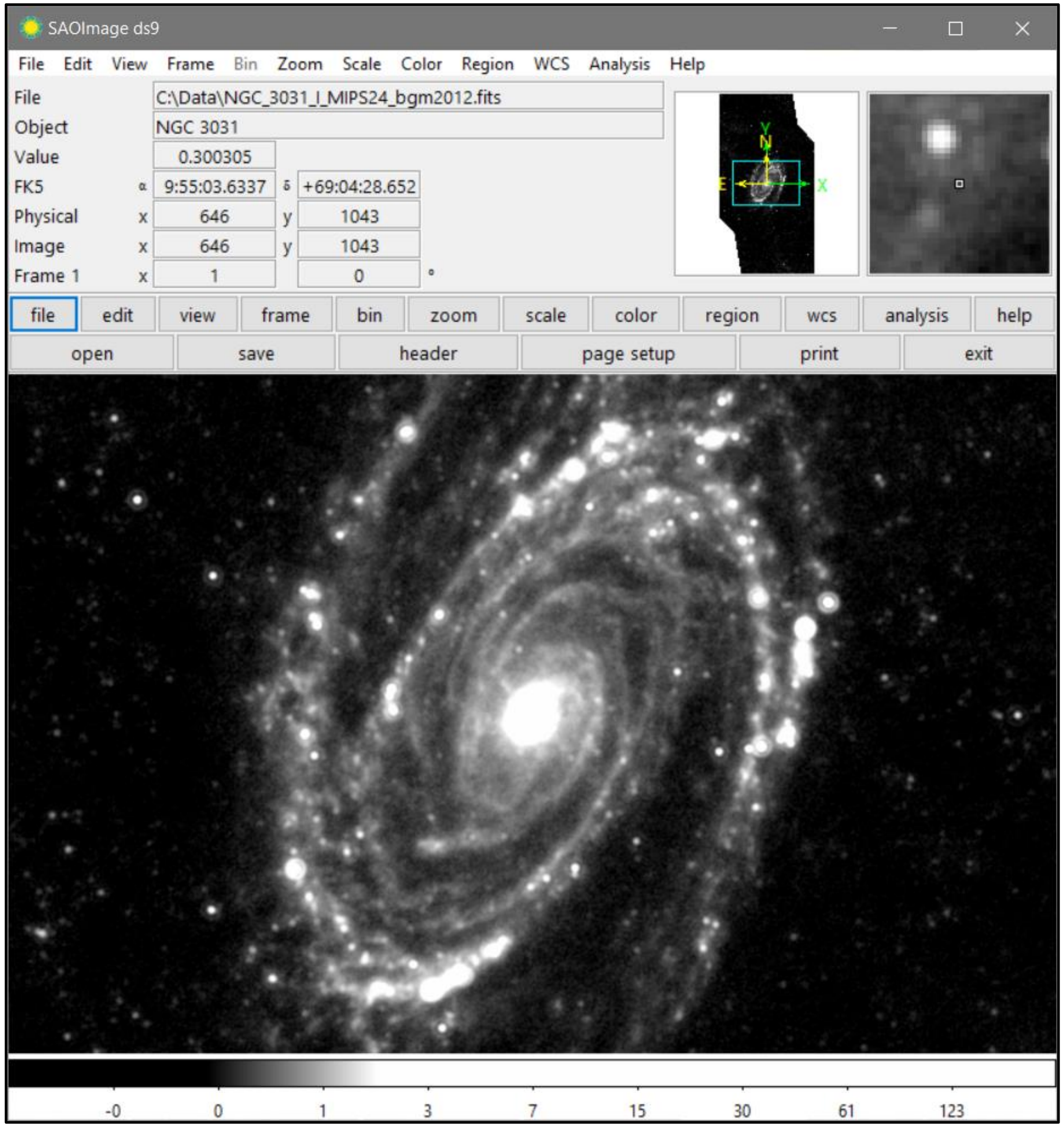
Introduction to Astronomy Images and the DS9 Image Viewer



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Contents

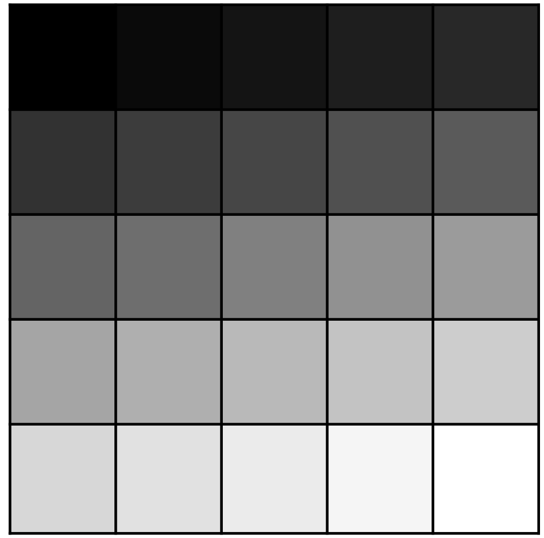
Introduction to Astronomy Images

Images are stored in computers as arrays of numbers.

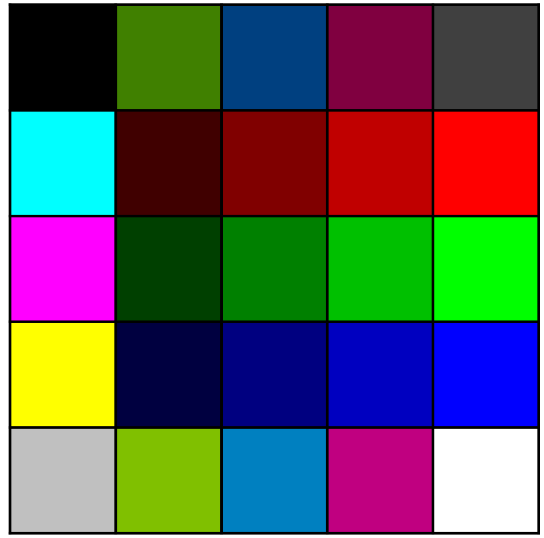
Black-and-white images can be described by a single array of numbers describing the pixel brightness.

Colour images are typically described by 3 arrays of numbers describing the intensity of the red, green, and blue colours in a pixel (which add together to form other colours that we can see).

0	10	20	30	40
50	60	70	80	90
100	110	128	145	155
165	175	185	195	205
215	225	235	245	255



0 0 0	64 128 0	0 64 128	128 0 64	64 64 64
0 255 255	64 0 0	128 0 0	192 0 0	255 0 0
255 0 255	0 64 0	0 128 0	0 192 0	0 255 0
255 255 0	0 0 64	0 0 128	0 0 192	0 0 255
192 192 192	128 192 0	0 128 192	192 0 128	255 255 255



The FITS format is used by professional astronomers to store images and other data.

FITS images have two advantages over other file formats:

- Data can be stored as any type of real number.
- Data can represent anything, including physical measurements.

Multiple frames of data can be stored in a single file.

Data can be stored in multiple dimensions.

FITS images need to be viewed with special programs, but they can be converted to other formats like jpg, gif, or png.

FITS files contain headers that may contain various information about the files.

FITS image viewers can be used to look at this information.

This information could include the following:

- Image creation information
- Coordinate information
- Data units
- Data processing history

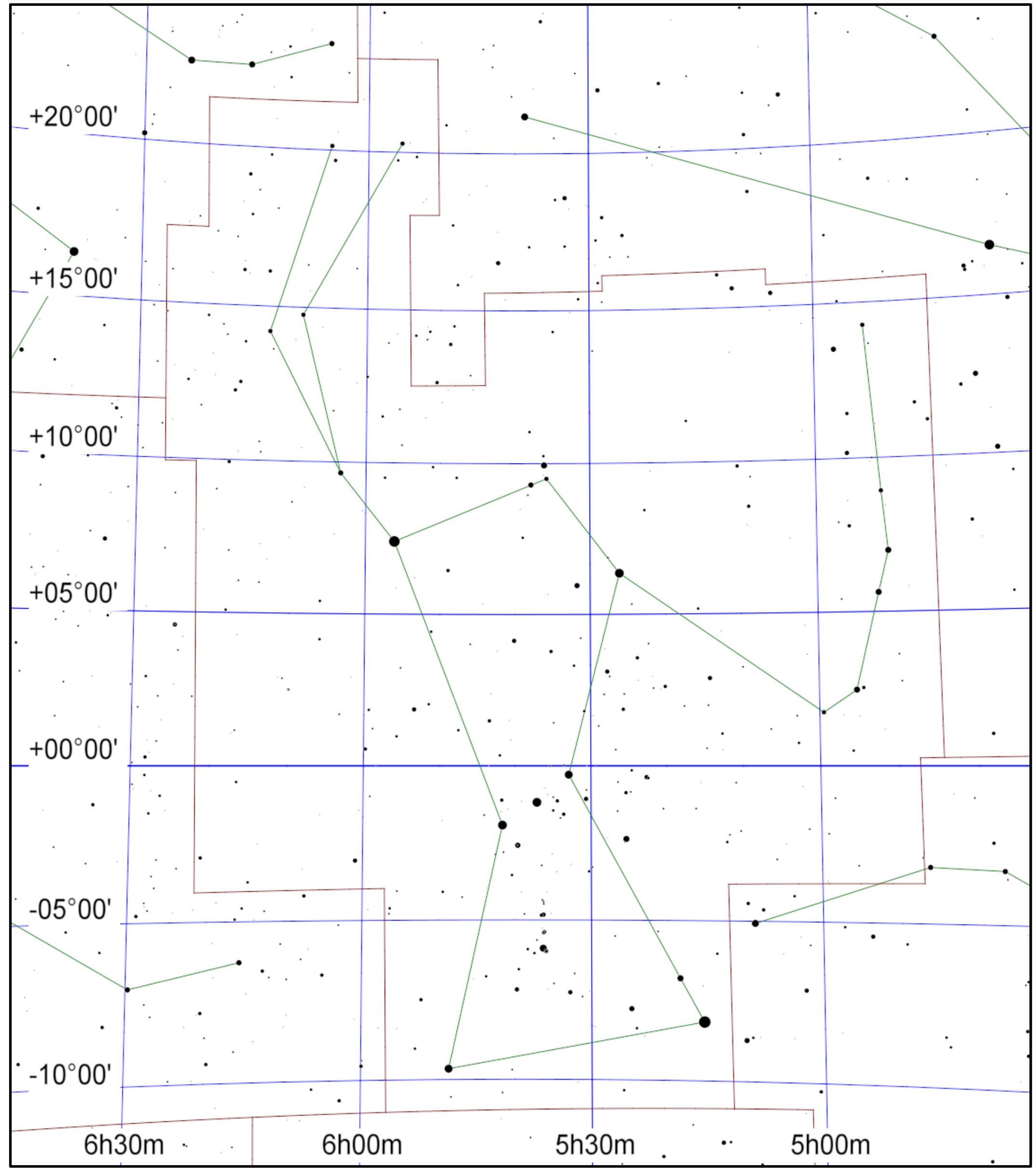
```
SIMPLE  =                    T / Written by IDL:  Fri Jul  4 18:30:41 2014
BITPIX  =                  -32 / IEEE single precision floating point
NAXIS   =                    2 /Number of data axes
NAXIS1  =                  720 /Length of data axis 1
NAXIS2  =                 1080 /Length of data axis 2
DATE    = '2012-03-21'         /File creation date (yyyy-mm-dd)
OBJECT  = 'NGC 3031'           /Title of the dataset
TELESCOP= 'Spitzer '           /Telescope name
INSTRUME= 'MIPS    '           /Instrument name
CHNLNUM =                    1 /MIPS channel number (1=24um,2=70um,3=160um)
WAVELEN =          2.36800E-05 /Wavelength of the observation (m)
FREQ    =          1.26689E+13 /Frequency of the observations (Hz)
AORKEY1 = '5554688 '           /Spitzer AOR key 1
AORKEY2 = '5554944 '           /Spitzer AOR key 2
AORKEY3 = '7864576 '           /Spitzer AOR key 3
RA      = '09:55:33.1'         /Right ascension (hh:mm:ss)
DEC     = '+69:03:55.0'        /Declination (dd:mm:ss)
EQUINOX =              2000.00 /Equinox of RA and DEC
PLTSCALE=              1.50000 /Plate scale (arcsec/pixel)
CTYPE1  = 'RA---TAN'           /Quantity represented by axis 1
CTYPE2  = 'DEC--TAN'           /Quantity represented by axis 2
CRPIX1  =              361.500 /Reference pixel on axis 1
CRPIX2  =              540.500 /Reference pixel on axis 2
CRVAL1  =        148.888220800 /Value at reference pixel on axis 1
CRVAL2  =        69.0652947000 /Value at reference pixel on axis 2
CD1_1   =   -0.000416666666667 /Transformation matrix element
CD1_2   =              0.00000 /Transformation matrix element
CD2_1   =              0.00000 /Transformation matrix element
CD2_2   =    0.000416666666667 /Transformation matrix element
ZUNITS  = 'MJy/sr  '           /Current units of data
JANSCALE=               0.0454 /Conversion from MIPS units to MJy/sr
BACK_SUB=                    T /Indicator for background subtraction (T/F)
BACKGRND=                20.10 /Background value at CRPIX1,CRPIX2 in ZUNITS
BCKNOISE=               0.0438 /Background RMS noise in ZUNITS
COMMENT
COMMENT   Processed by George J. Bendo using the MIPS DAT 3.10.  When using
COMMENT   this image for any purpose, please reference the following paper:
COMMENT           Bendo G. J., Galliano F., & Madden S. C.
COMMENT           MIPS 24-160 micron photometry for the Herschel-SPIRE Local
COMMENT               Galaxies Guaranteed Time Programs
COMMENT           2012, MNRAS, 423, 197
COMMENT   Additional information about the image or the data processing can
COMMENT   be found in this paper.
COMMENT
END
```

Astronomers use right ascension and declination to identify locations in images.

Right ascension is the equivalent of longitude, but it is measured in hours instead of in degrees.

Declination is the equivalent of latitude.

Other latitude and longitude coordinate systems (defined relative to the galaxy or the Solar System) are also used.



The sizes of astronomical objects as they appear in the sky are measured as angles.

The entire sky can be thought of as a sphere with a diameter of 360 degrees (although we only see half the sky from the Earth's surface).

Each degree is divided into 60 arcminutes (often written with the symbol ′). Each arcminute is divided into 60 arcseconds (often written with the symbol ″).

For reference, both the Sun and the Moon as seen from Earth appear about 0.5 degrees or 30 arcminutes in size.

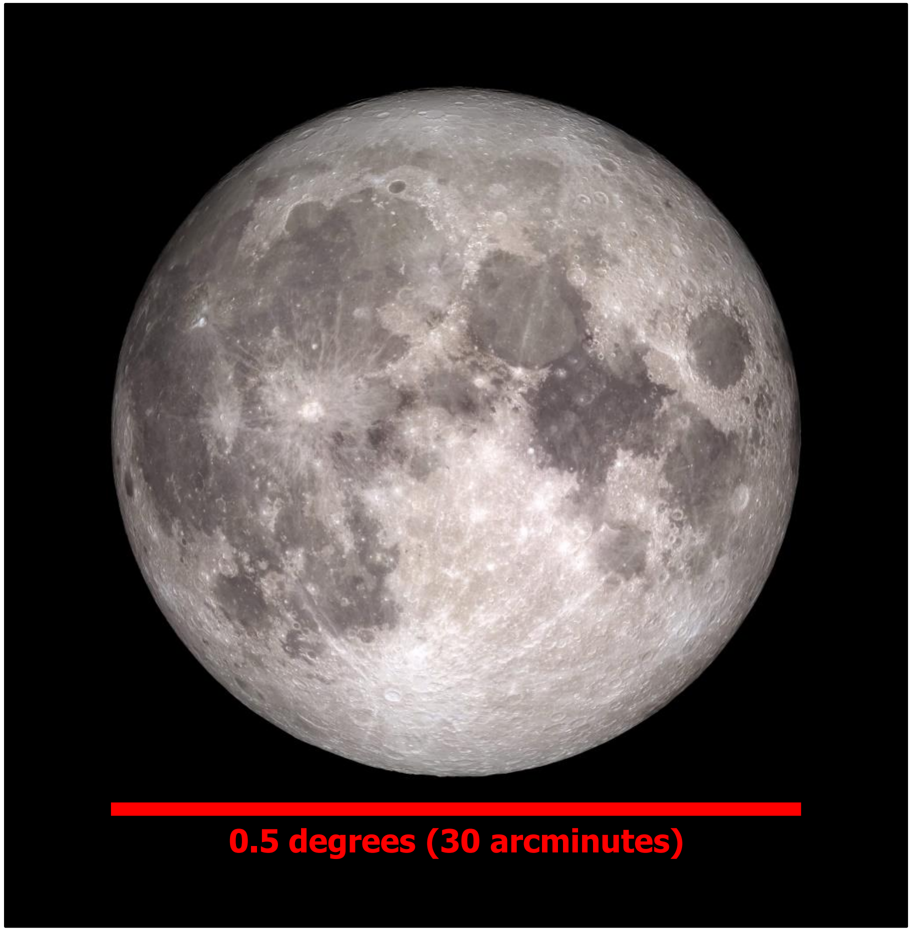
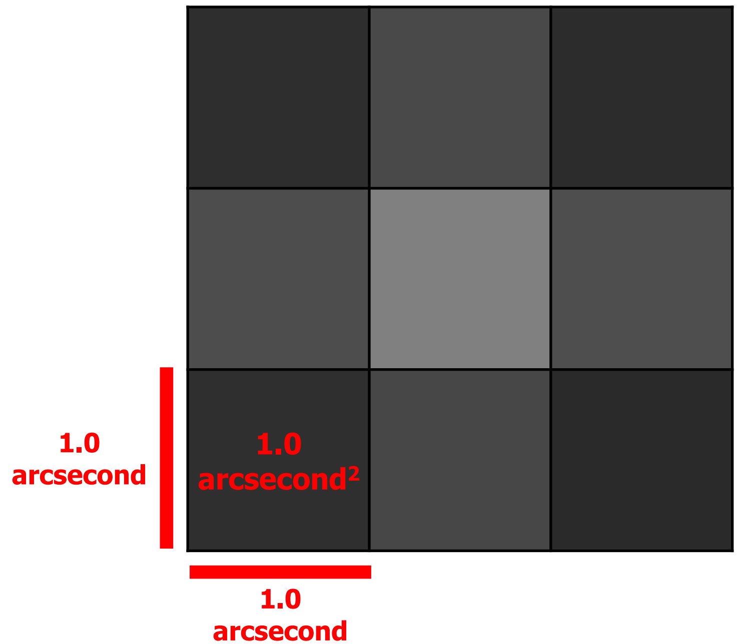


Image Credit: NASA/GSFC/Arizona State University

The pixel sizes in astronomical images can also be described in terms of angles. Their sizes are usually described in terms of arcseconds.

Areas on the sky are expressed as the square of the angular measurements. The two most common angular areas are arcsecond^2 and steradians (radian^2).



Astronomy images are often stored in a variety of units, including the following:

- Instrument units (photons, electrons/s, volts, etc.)
- Magnitudes
- Flux units (W/m^2, $erg/s/cm^2$)
- Flux density units, which is flux divided by the range of wavelengths or frequencies observed (such as Jy (10^{-26} $W/m^2/Hz$))
- Any of the above divided by angular area
- Velocity (km/s)

Completely arbitrary units can also be used.

In images where the data are in flux or flux density units, it is possible to measure the amount of light from an object by adding the values of the pixels that cover the object.

However, the light from most objects, including stars, is usually spread over multiple pixels.

In the example on the right, if the pixel values are in Jy, then the total amount of light from the central 3×3 pixels, which contains a simulated star, is 0.152 Jy.

0.001	0.001	-0.001	0.000	0.001
0.000	0.005	0.020	0.004	-0.001
-0.002	0.022	0.050	0.023	0.000
-0.001	0.006	0.019	0.003	-0.002
0.000	0.001	-0.001	0.001	0.000

In images where the data are in intensity units (which is equivalent to flux divided by area) or surface brightness units (which is equivalent to flux density divided by area), it is possible to measure the average brightness of a region by taking the average of the pixel values.

In the example on the right, if the pixel values are in Jy/arcsec^2, then the average surface brightness is 0.0278 Jy/arcsec^2.

0.040	0.029	0.025	0.015	0.008
0.031	0.045	0.030	0.019	0.013
0.025	0.033	0.041	0.023	0.018
0.021	0.036	0.039	0.033	0.021
0.018	0.034	0.040	0.032	0.025

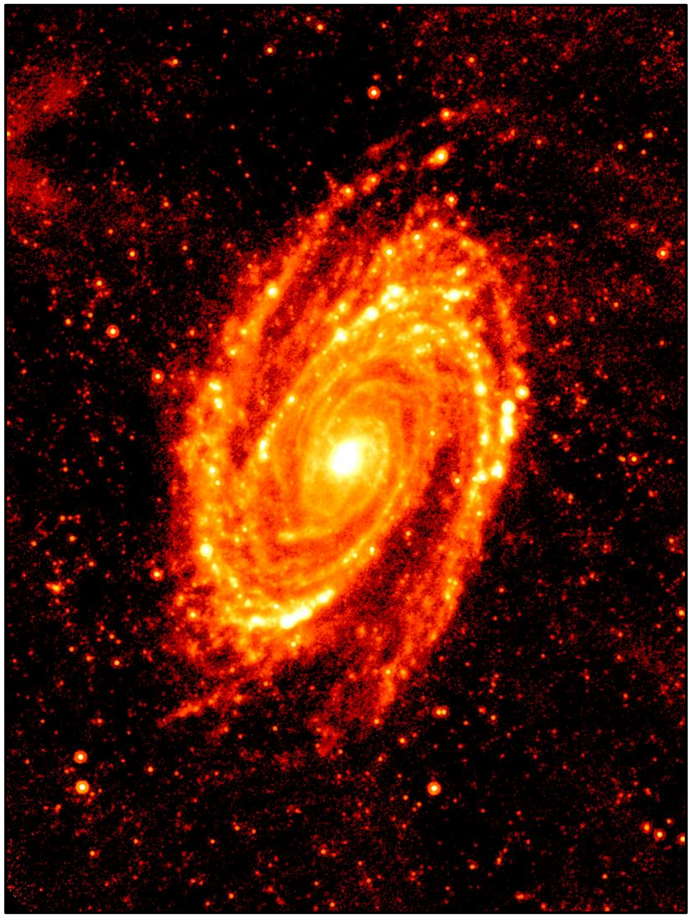
Pixel values in flux or flux density units can be converted to intensity or surface brightness by diving by the pixel area.

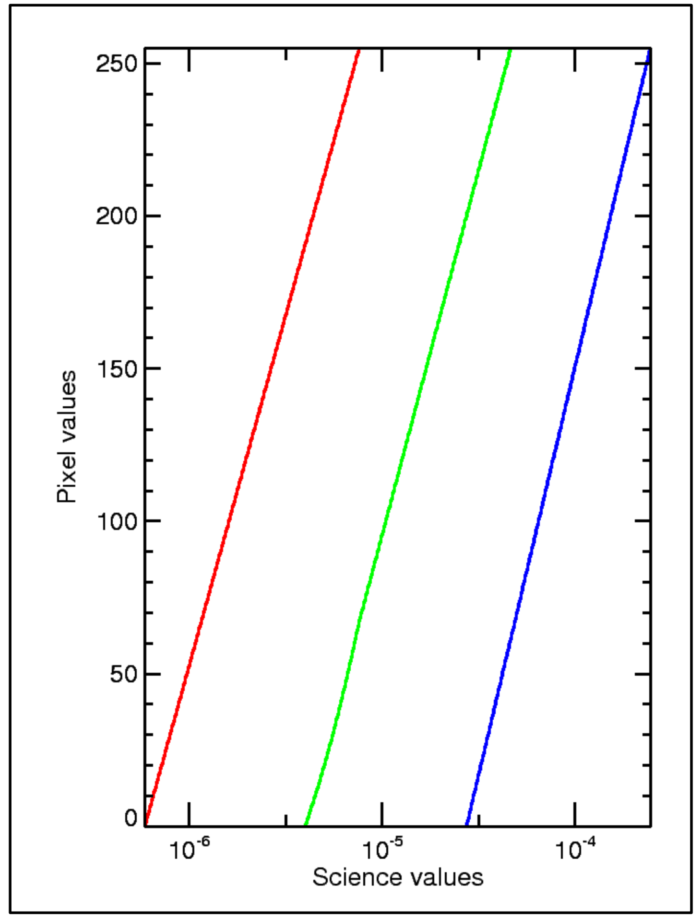
Pixel values in intensity or surface brightness units can be converted to flux or flux density by diving by the pixel area.

Astronomy images can be coloured in one of two ways.

False-colour images use different colours to show different brightnesses.

To make the images, pixels in monochrome FITS image are mapped to a new colour table where the red, green, and blue pixel values vary from 0 to 255.

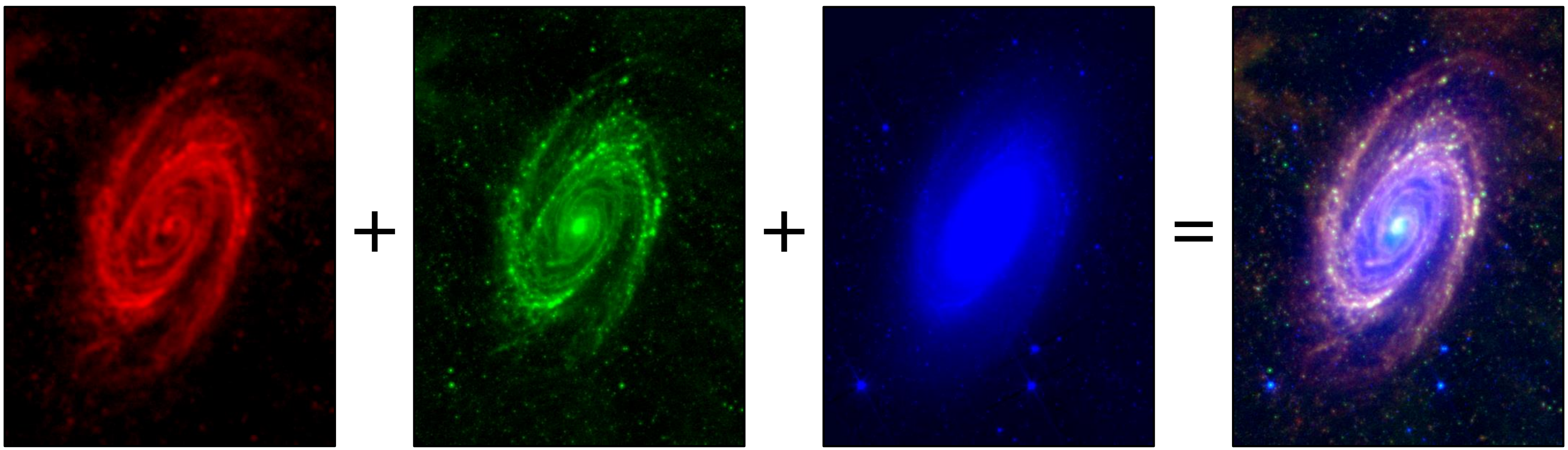




In representative colour images, each colour represents a different wavelength of radiation.

The first step in making these images is to convert monochrome images in two or three bands into red, green, or blue images where the pixel values vary from 0 to 255.

The different images are then added together.



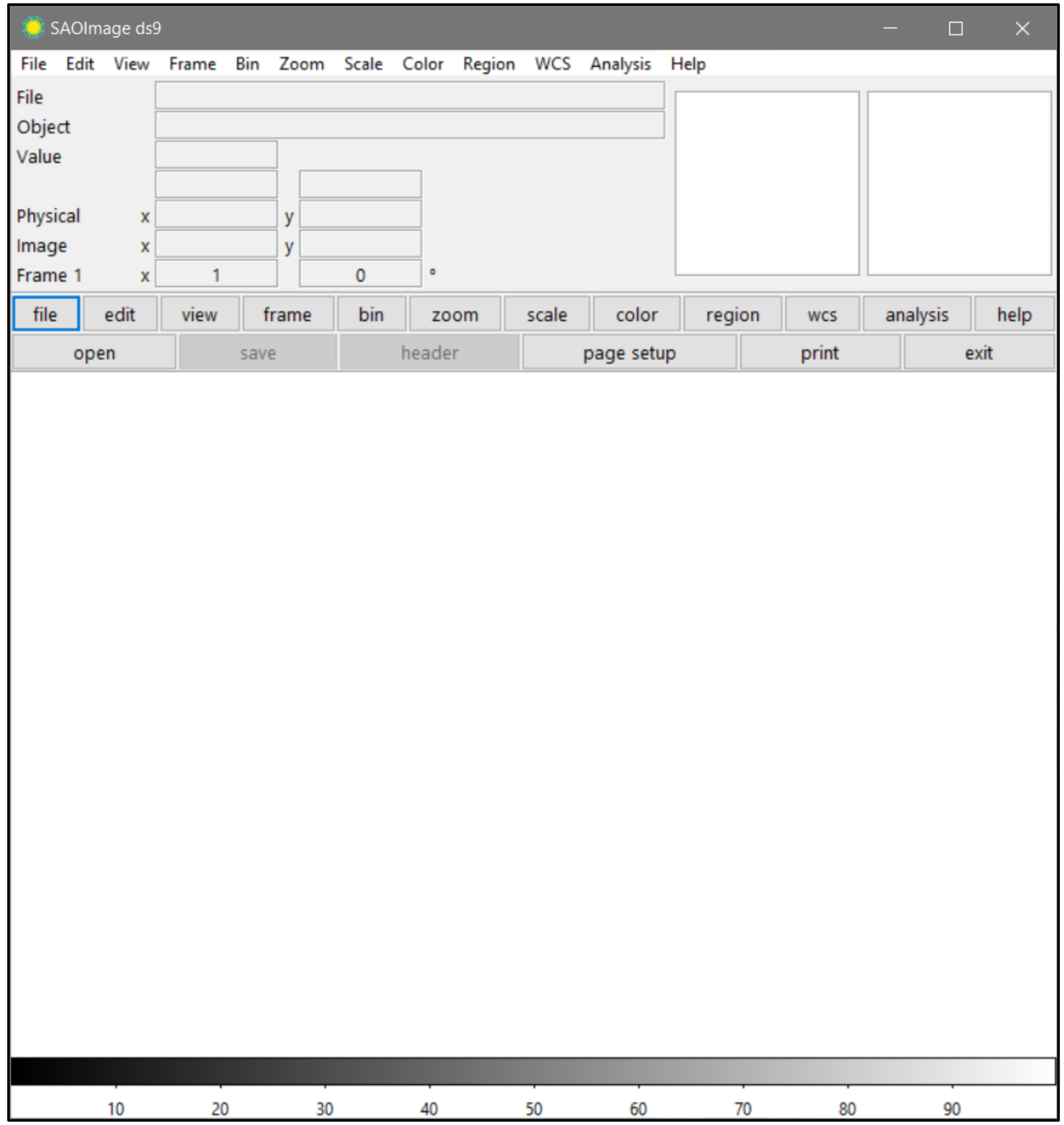
DS9 Quick Start Guide

DS9 is one of the most commonly-used FITS image viewing programs.

The program can be downloaded from http://ds9.si.edu . Windows, Mac, and Linux versions are available.

For this demo, we will work with an image of the galaxy M81 from http://ned.ipac.caltech.edu/uri/NED::Image/fits/2012MNRAS.423..197B/NGC_3031:I:MIPS24:bgm2012, which you will need to download beforehand.

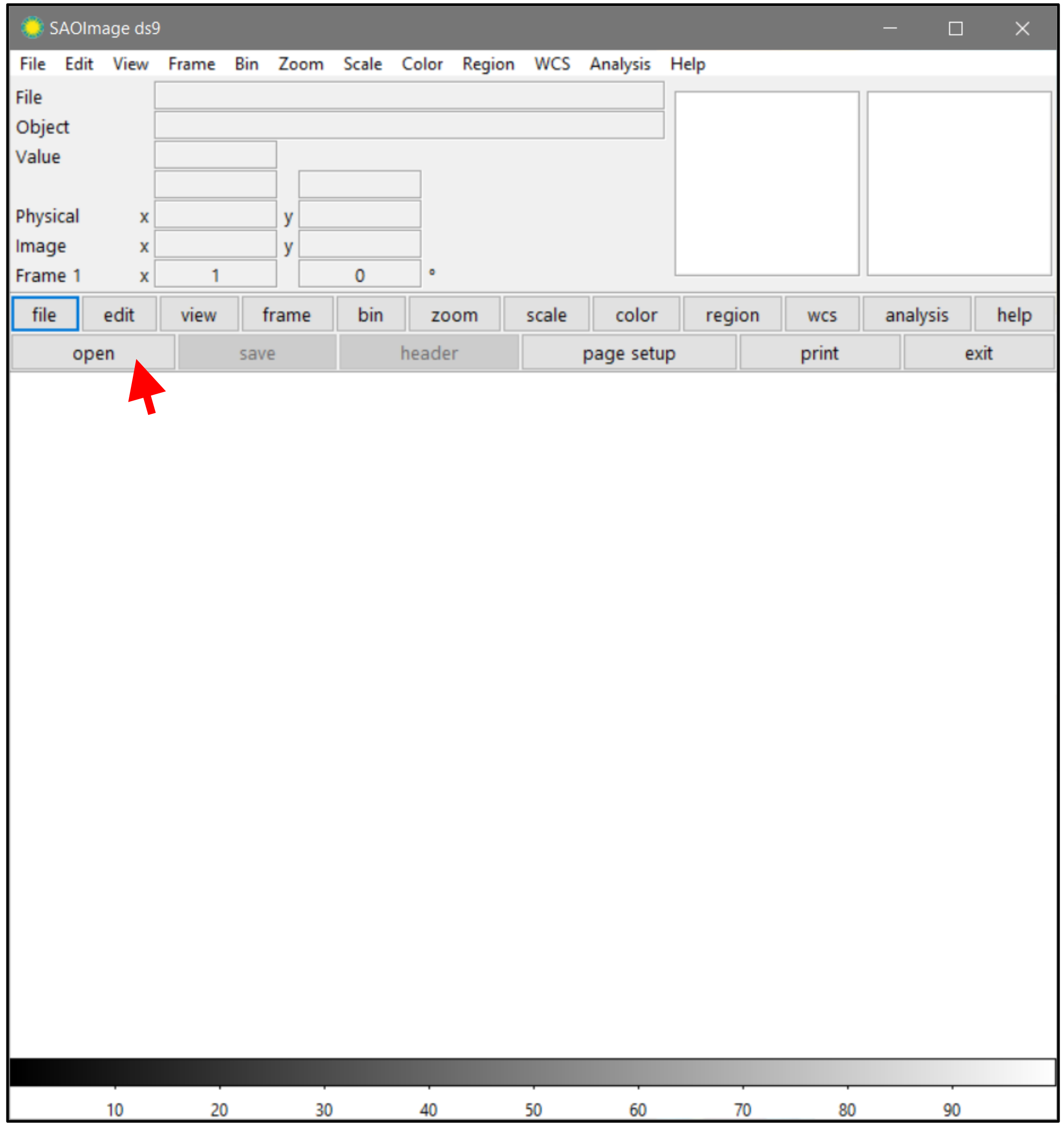
(On Mac computers, you may need to change the end of the filename to ".fits" to get the files to work with DS9.)



DS9 has both a text menu bar and a button bar.

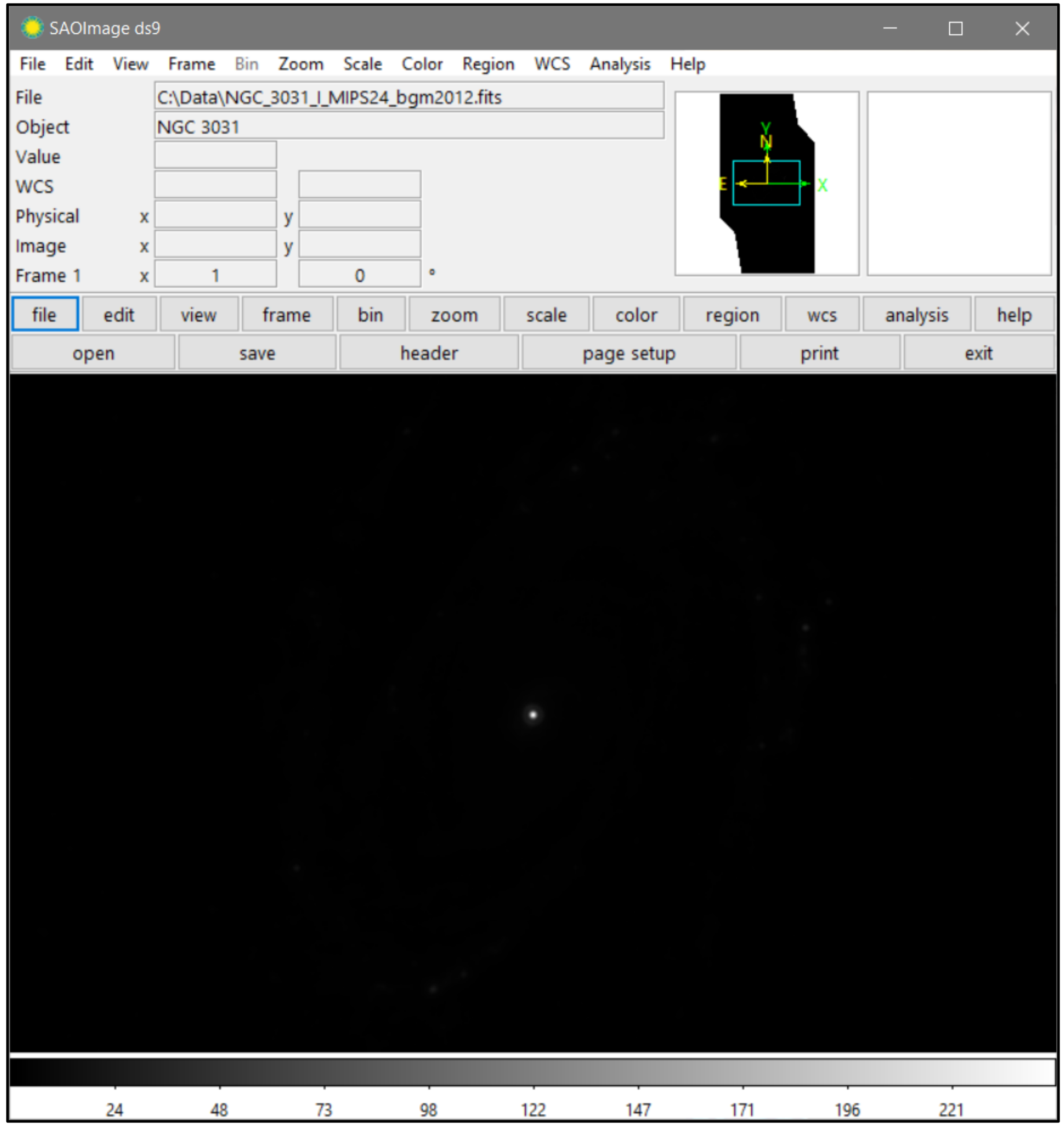
The button bar has commonly-used options and functions. The text menu bar contains all options.

To get started, open the image of M81 by clicking on File, then clicking on Open (in either the text menu bar or the button bar), and then clicking on the file.



When the image is open, it will probably look similar to this.

The galaxy looks like a dot. Some other parts of the galaxy are visible, but they look faint.

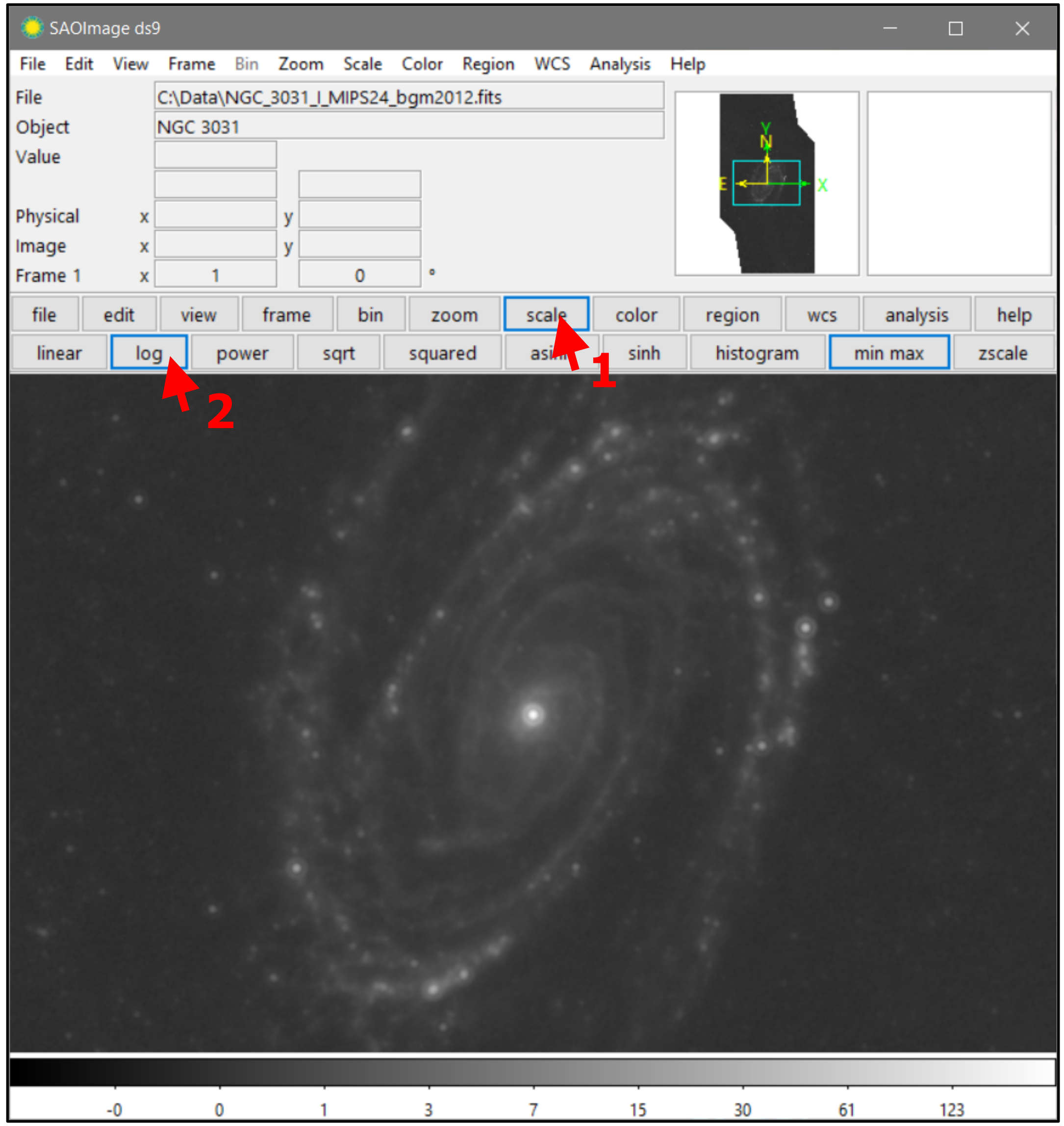


Next, click on Scale.

After this, click on log.

The emission from the entire galaxy is now visible.

(With some images, clicking on Scale in the menu bar and then selecting 99.5%, Zscale, or Zmax sometimes produces better results.)

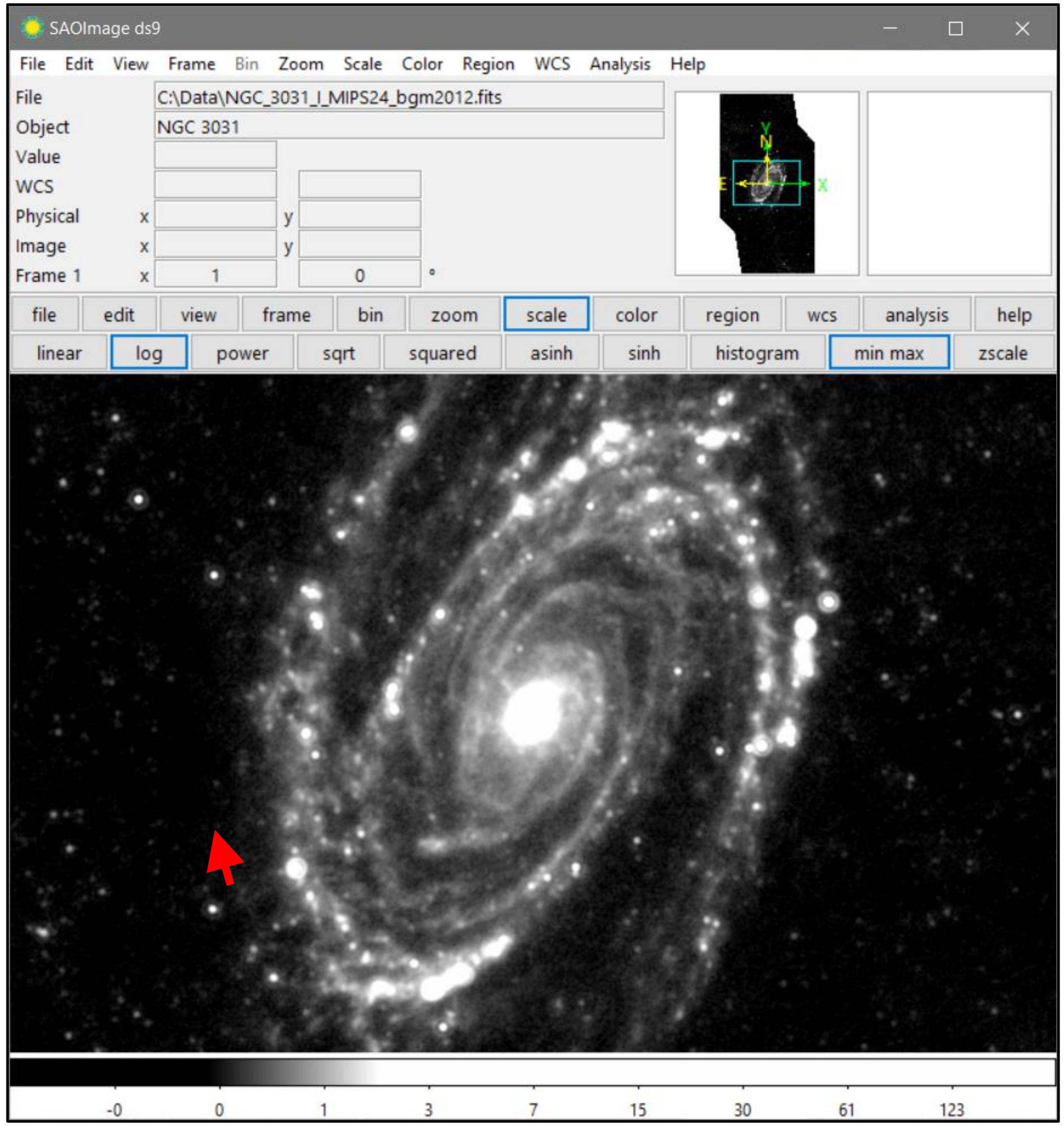


Next, do the following:

- Move the cursor to the image window.
- Hold the right mouse button down.
- While holding the right mouse button down, move the curson within the image window.

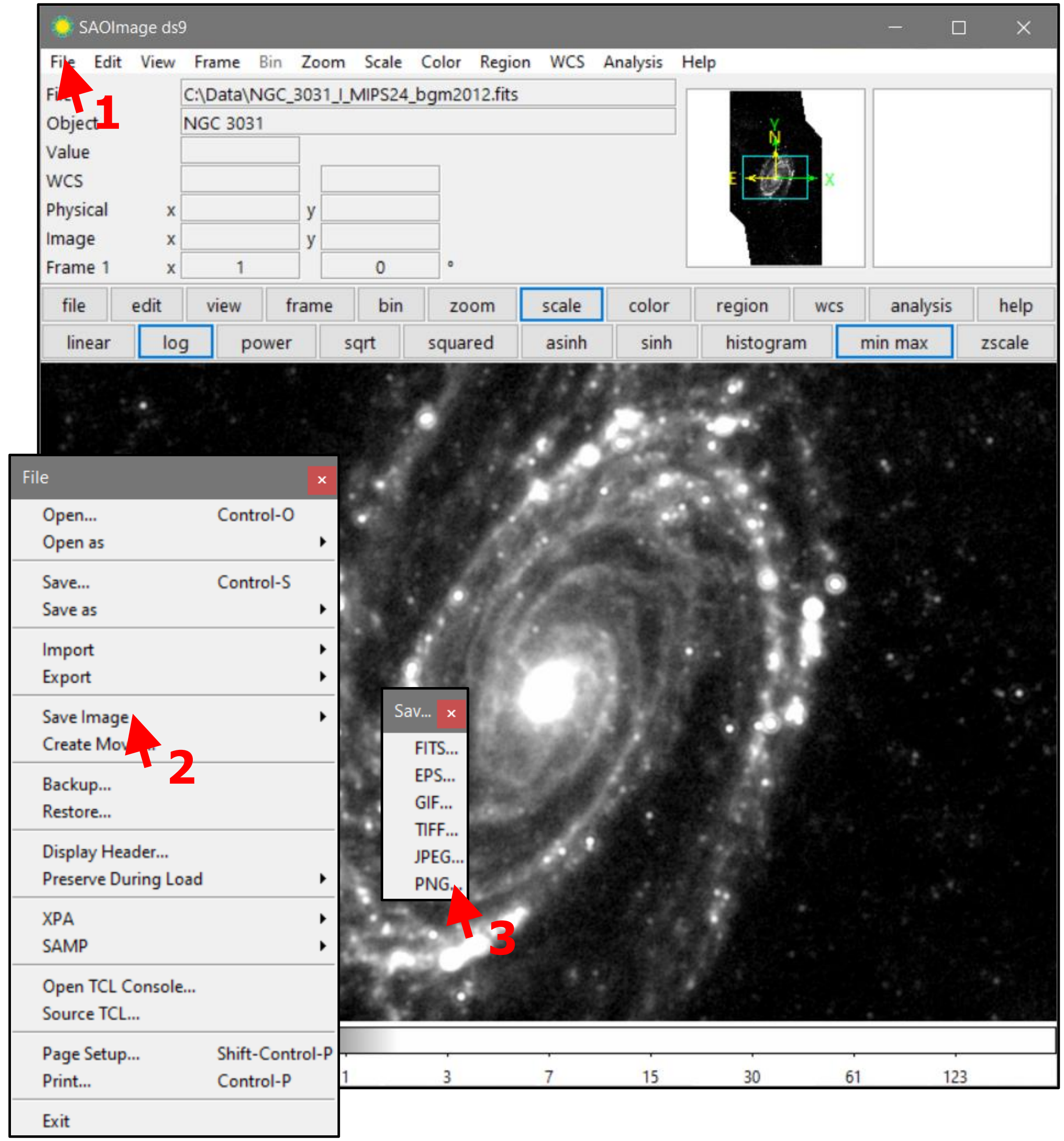
This will change the brightness and contrast of the image. M81 itself and lots of background galaxies are now clearly visible.

Follow these steps in the future to quickly display images with ds9.



To save the image in another format (jpg, png, etc.), do the following:

- Click on File in the menu bar, which will open a menu.
- Select Save Image, which will open a new menu.
- Select an image format. (JPEG and PNG are the best choices.)
- In the windows that appear after selecting the image format, input a filename, and adjust any other image settings.

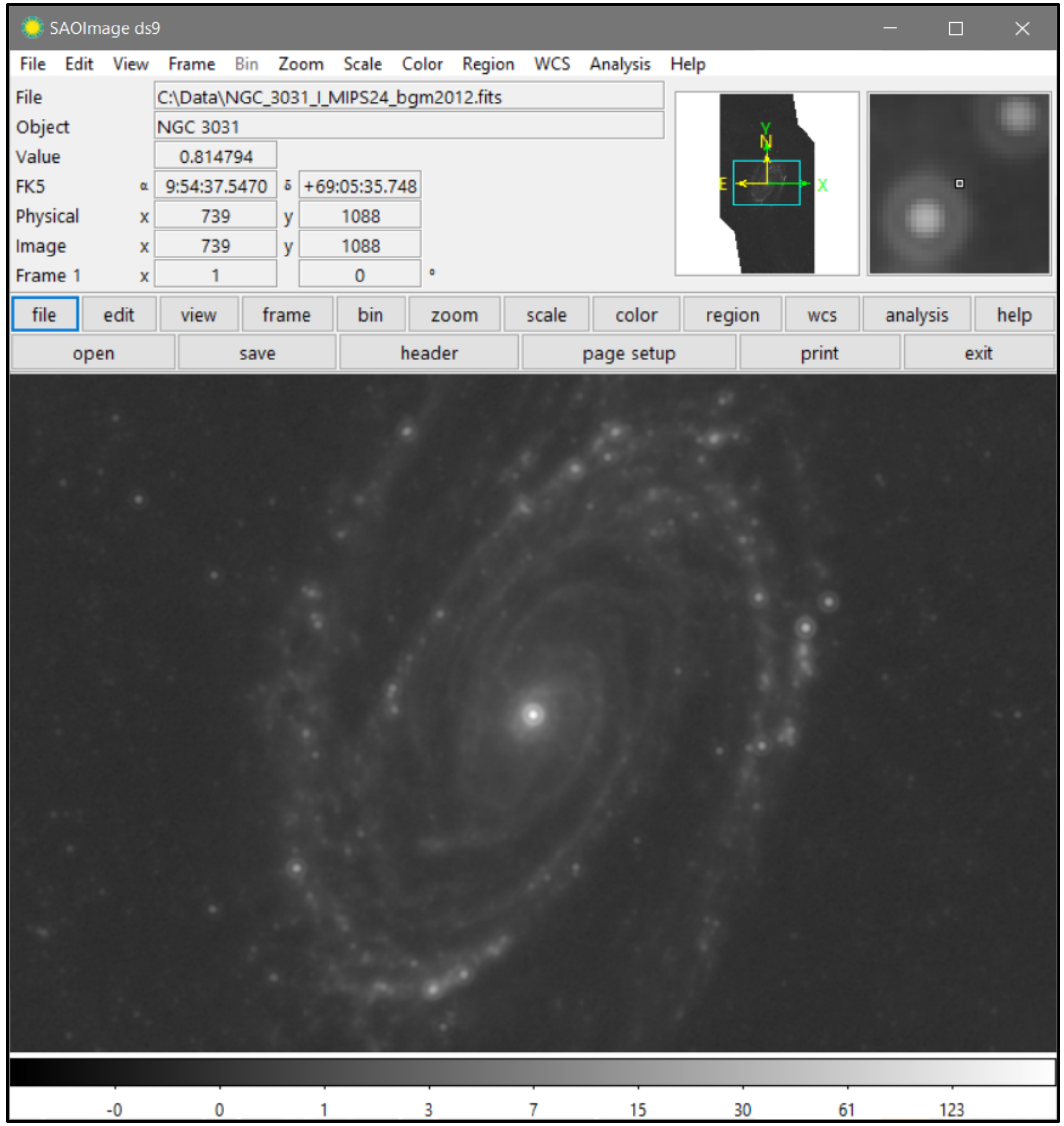


DS9 Overview

DS9 has many different ways to display and analyze FITS images.

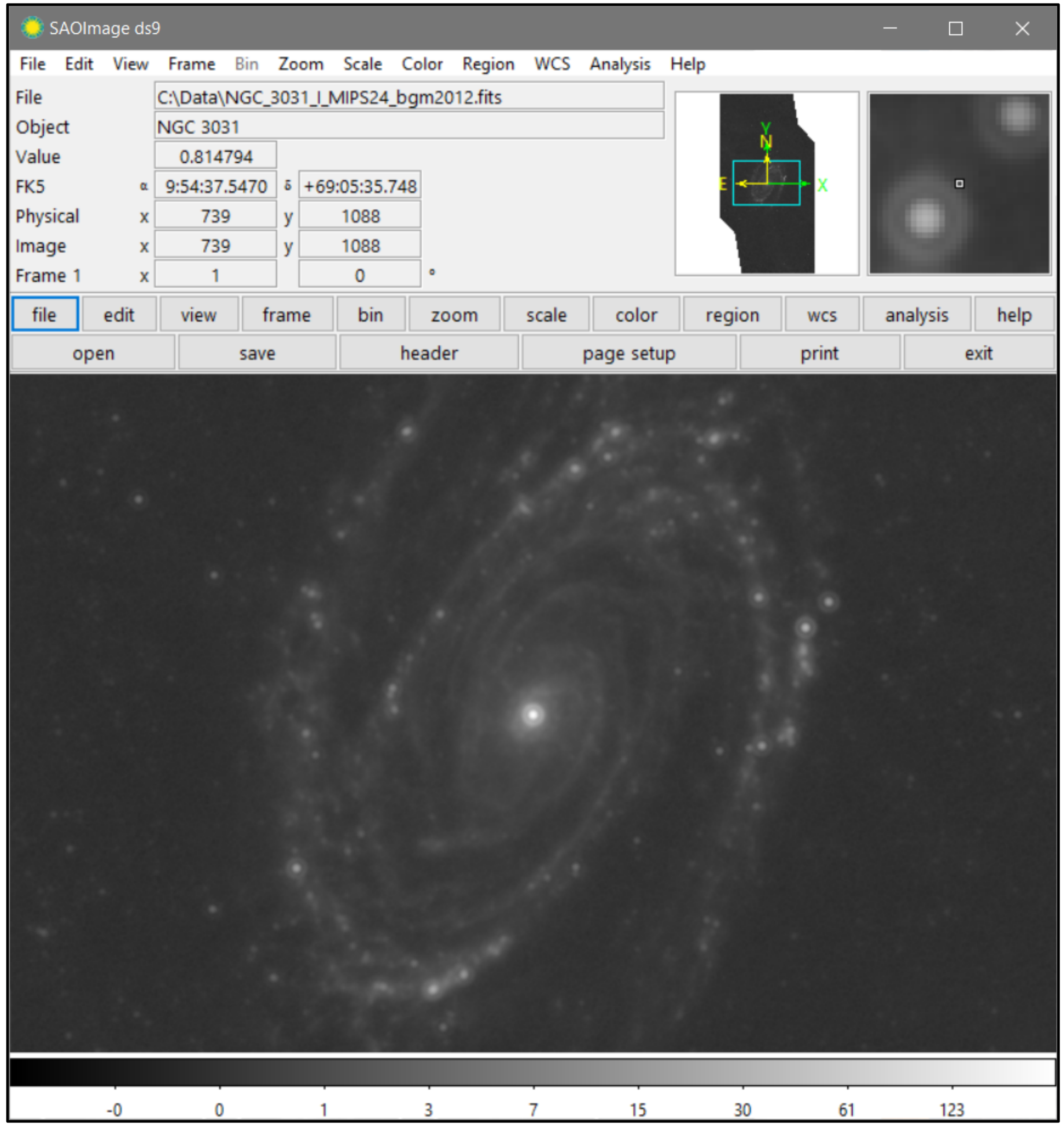
It is not an image editing tool. Except for a couple of functions, it does not actually change the images.

However, it can be used to change the appearance of the FITS images and to export them to other image formats.

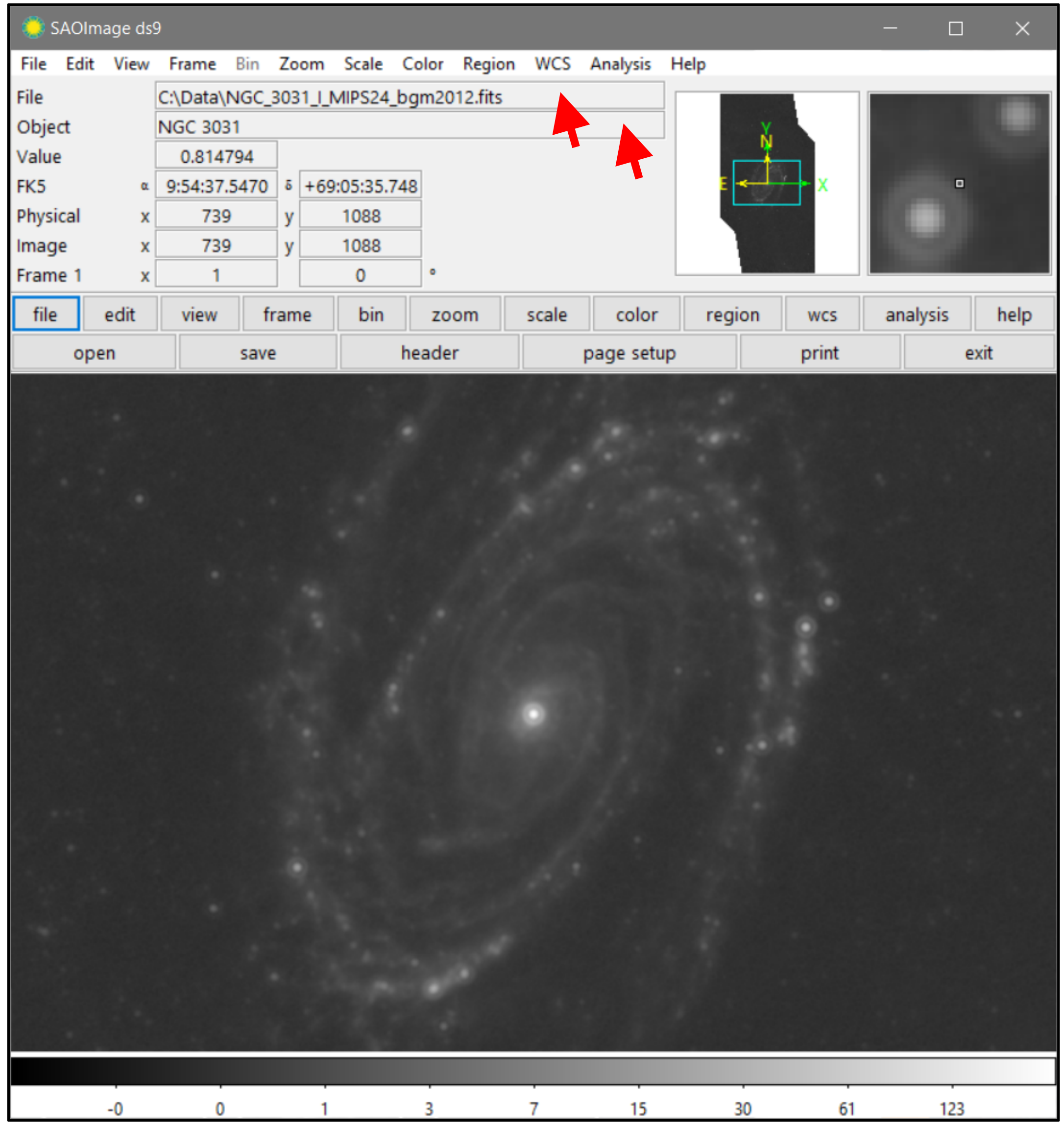


To begin with, it is useful to explain all of the things in the window.

Between the menu and button bars is a list of text information and two image panels on the right.



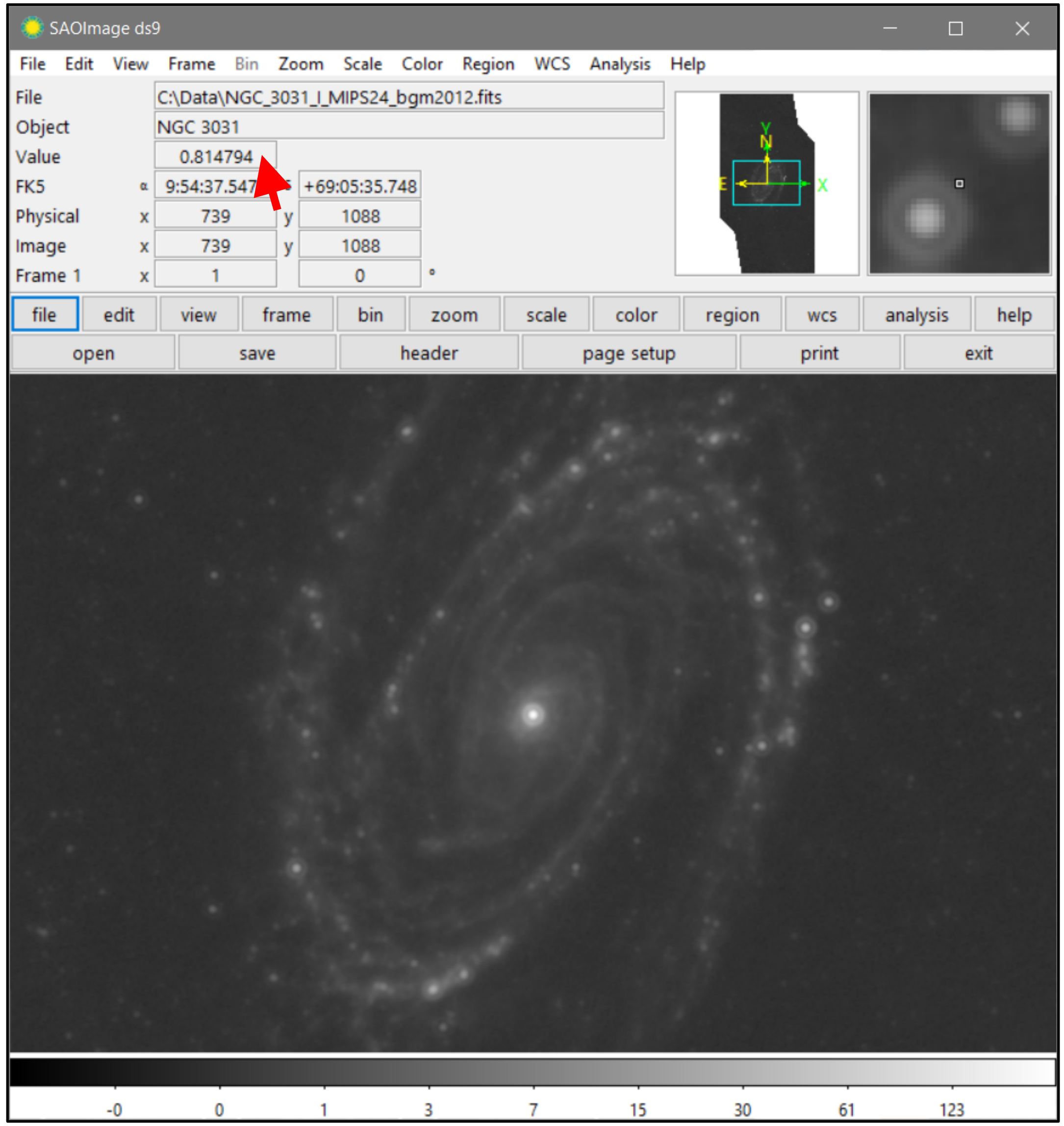
The top two lines of the text information list the file name and the object name (if the header contains a keyword named “OBJECT”).



The third line list the pixel value at the location of the cursor (when the cursor is in the image window).

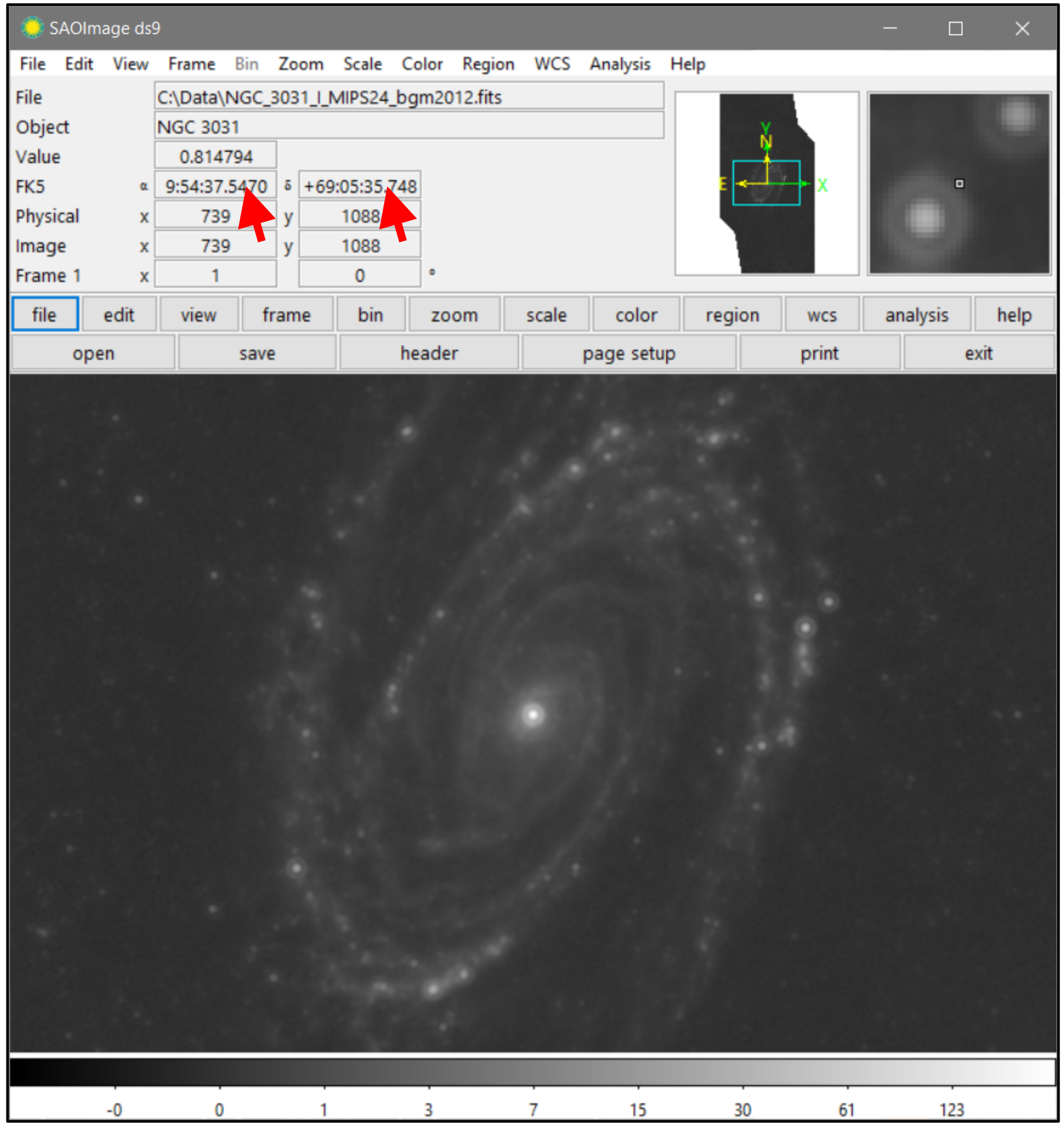
Although this value could be completely arbitrary, the pixel will probably represent a scientific measurement.

The measurement is usually the amount of light or energy measured within that pixel by a telescope, but it could also represent other quantities (velocity, temperature, etc).



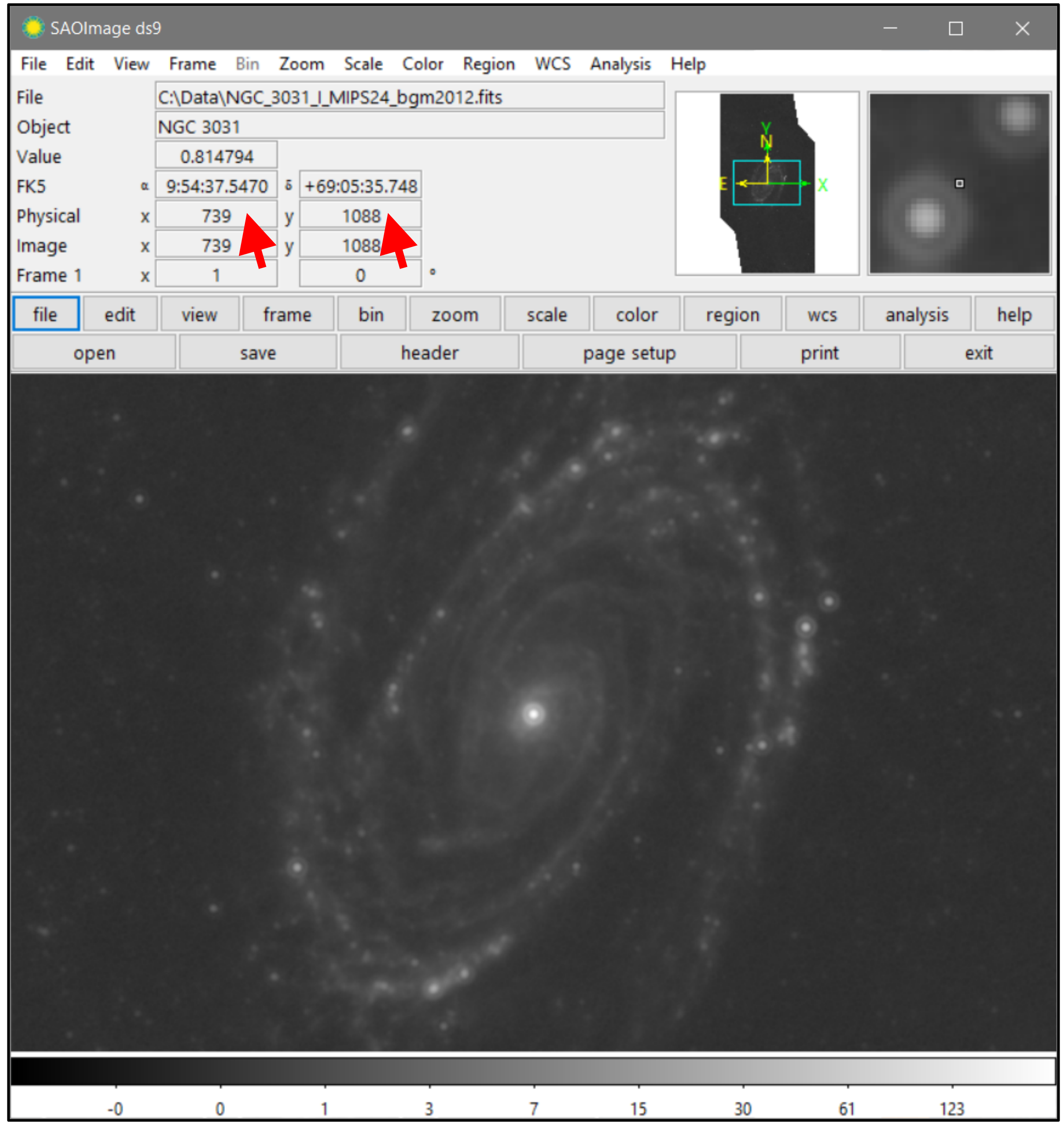
The fourth line labelled "WCS" shows the coordinates at the position of the cursor in astronomical coordinates (or the World Coordinate System).

In the default system (labelled "FK5"), the first number is right ascension, and the second number is declination.

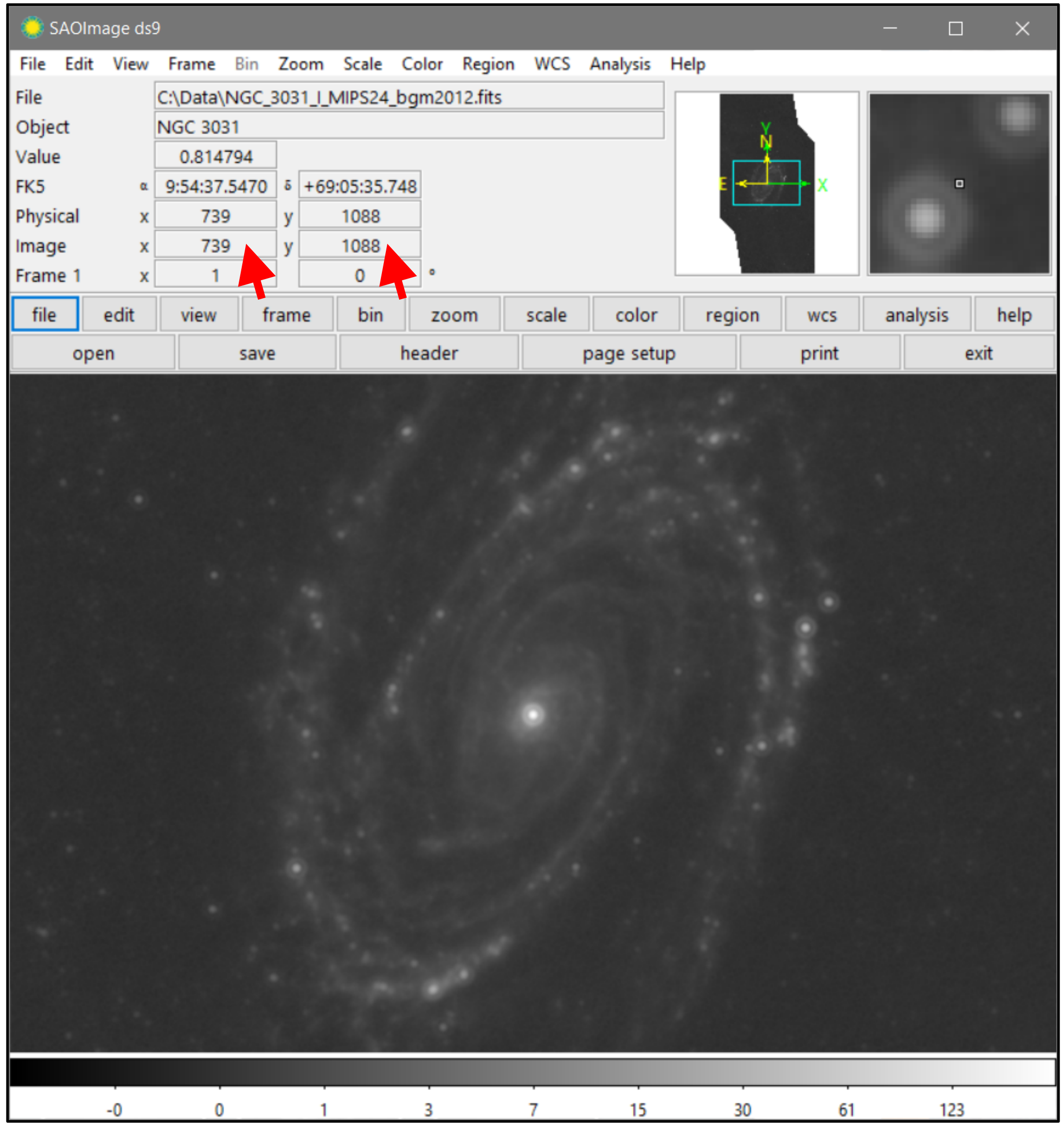


The fifth line labelled “Physical” shows the coordinates at the position of the cursor in terms of the physical location on the astronomical detector used to make the image.

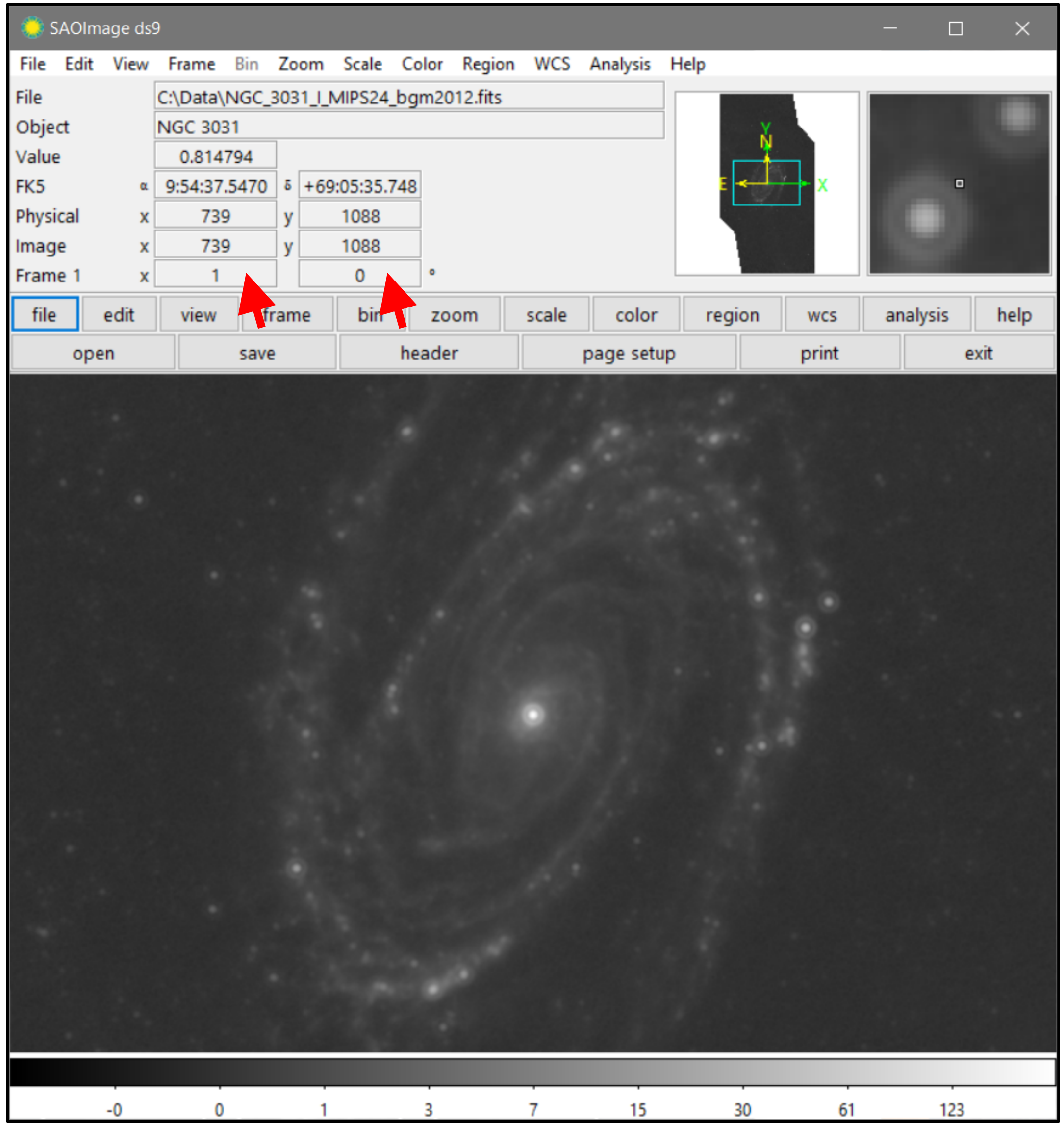
For most FITS images, either the image does not contain the correct information needed to display physical coordinates properly, or this type of physical coordinate system is not applicable, so you can ignore it.



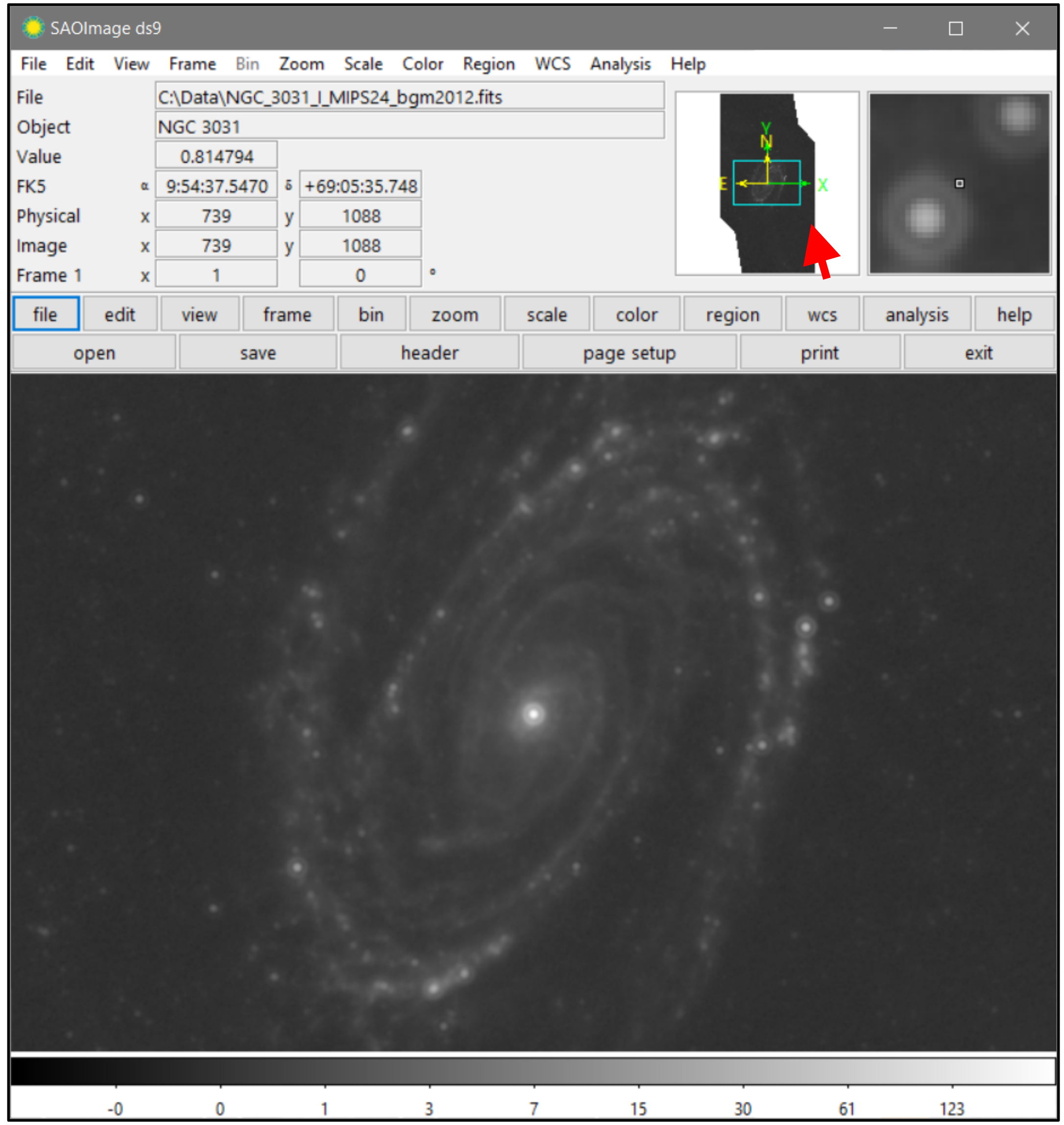
The sixth line labelled “Image” shows the coordinates at the position of the cursor in terms of pixels.



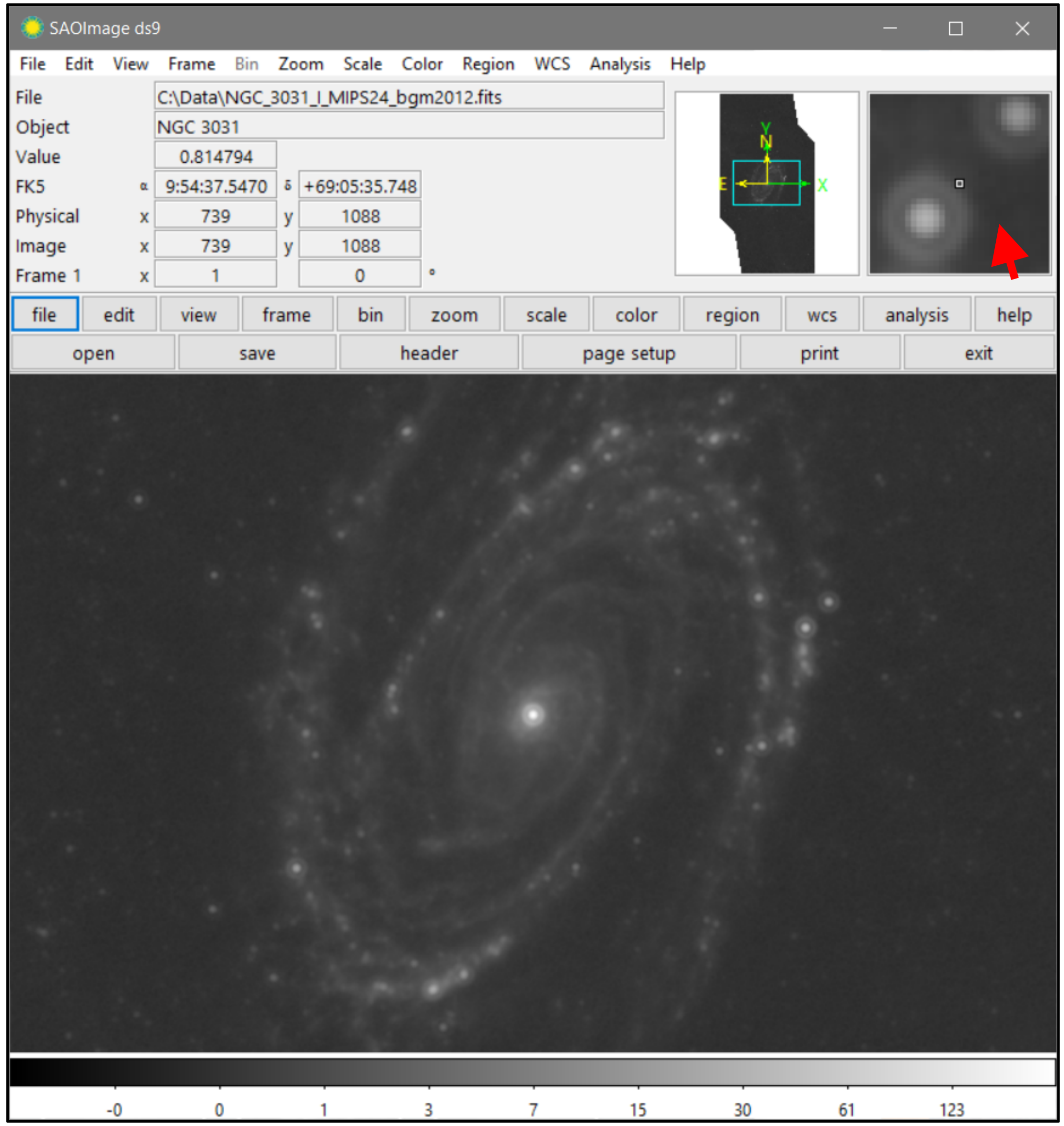
The bottom line shows the magnification of the image on the left and the rotation angle of the image.



The first panel to the right of the text information shows the entire FITS image as well as the part that is displayed in the image window below.

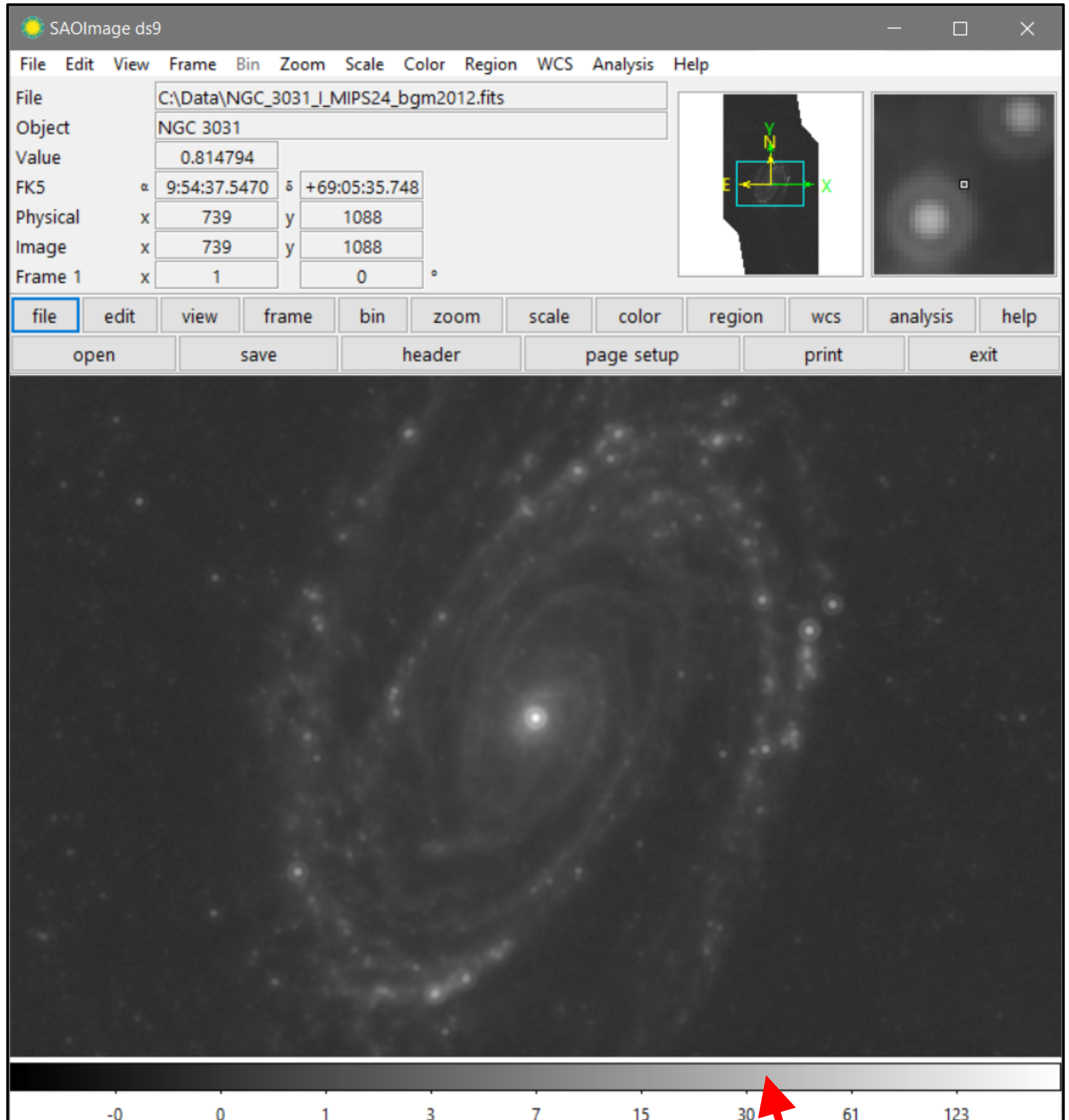


The second panel to the right of the text information shows the a magnified view of the region around the location of the cursor.



The colour bar is displayed at the bottom of the window. This shows the correspondence between the pixel values and the colour used to display those pixels.

The number range looks odd when anything other than "Linear" is used as an option under "Scale", so it's best to ignore this.



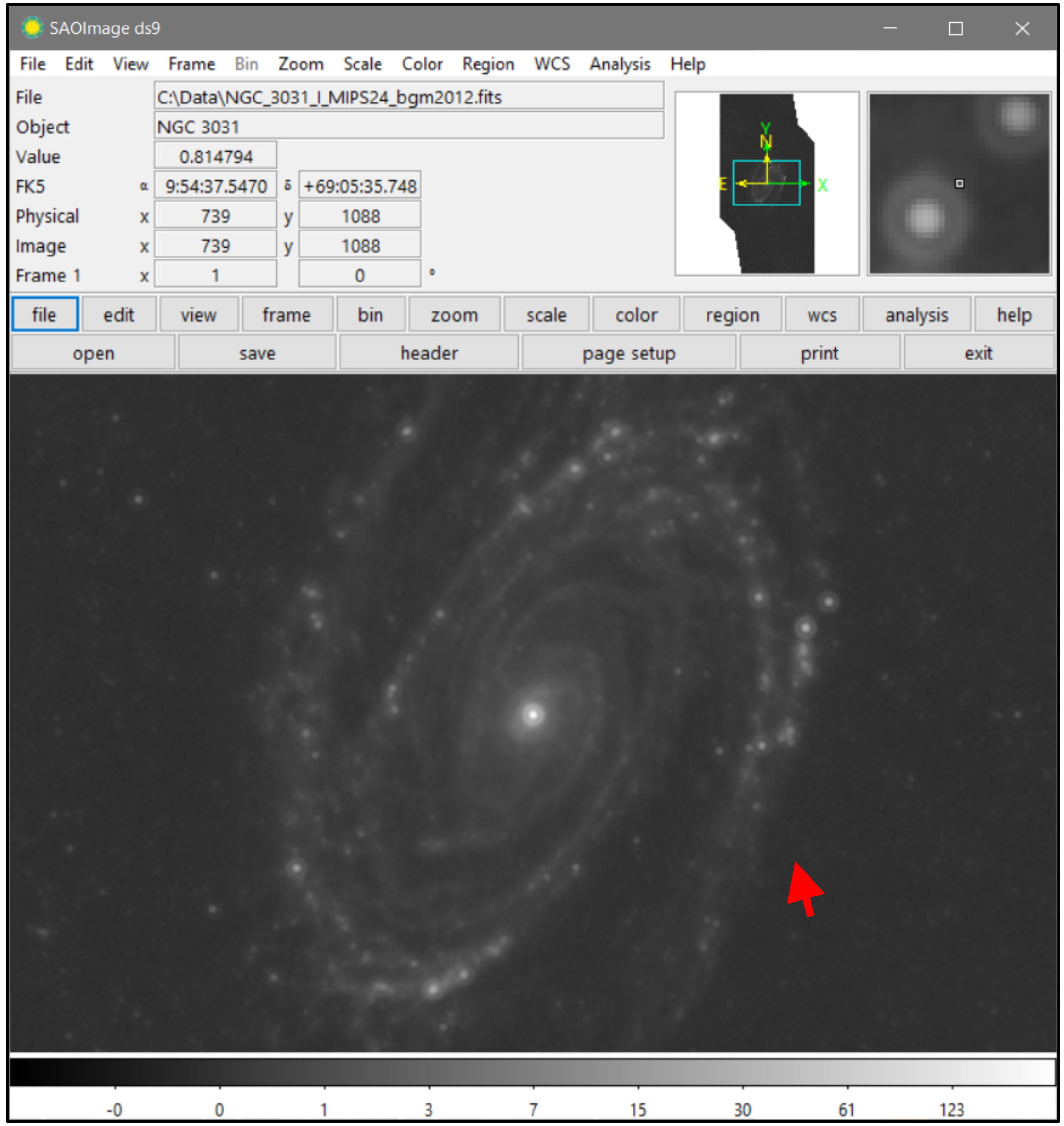
When the cursor is in the image window, the mouse buttons do the following:

Left mouse button: (the function set using the edit menu)

Middle mouse button: Center

Right mouse button: Change the brightness/contrast

Scroll wheel: Zoom



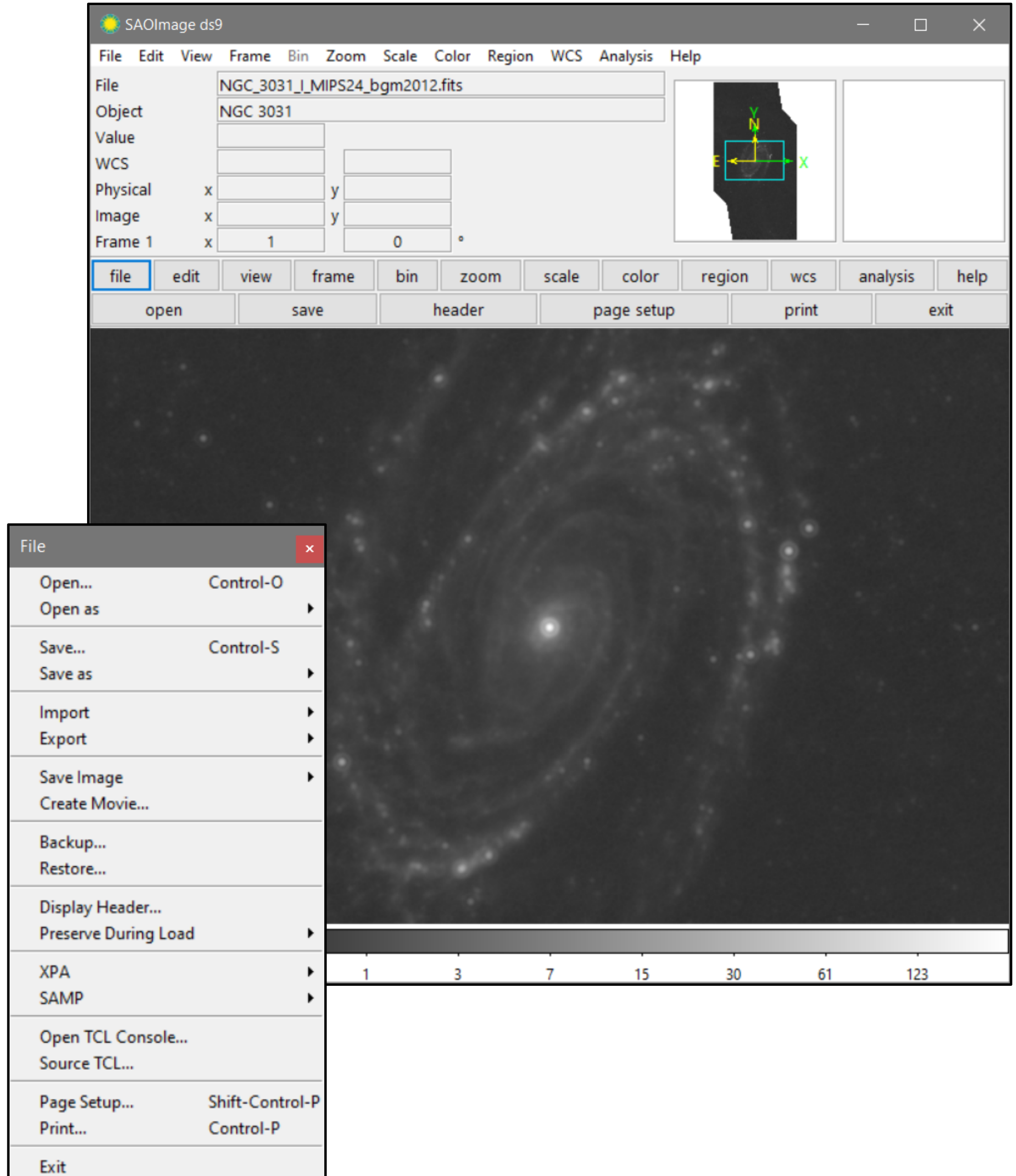
File

The file menu can be used to not only open FITS images but to save them in other formats (as gif, jpg, png, etc).

The file menu can also be used to display the image header.

The file menu has two didfferent options for saving images in different formats.

- Use “Save” to save what appears in the window (or an RGB image) in a different format.
- Use “Export” to save an entire image to a different format.

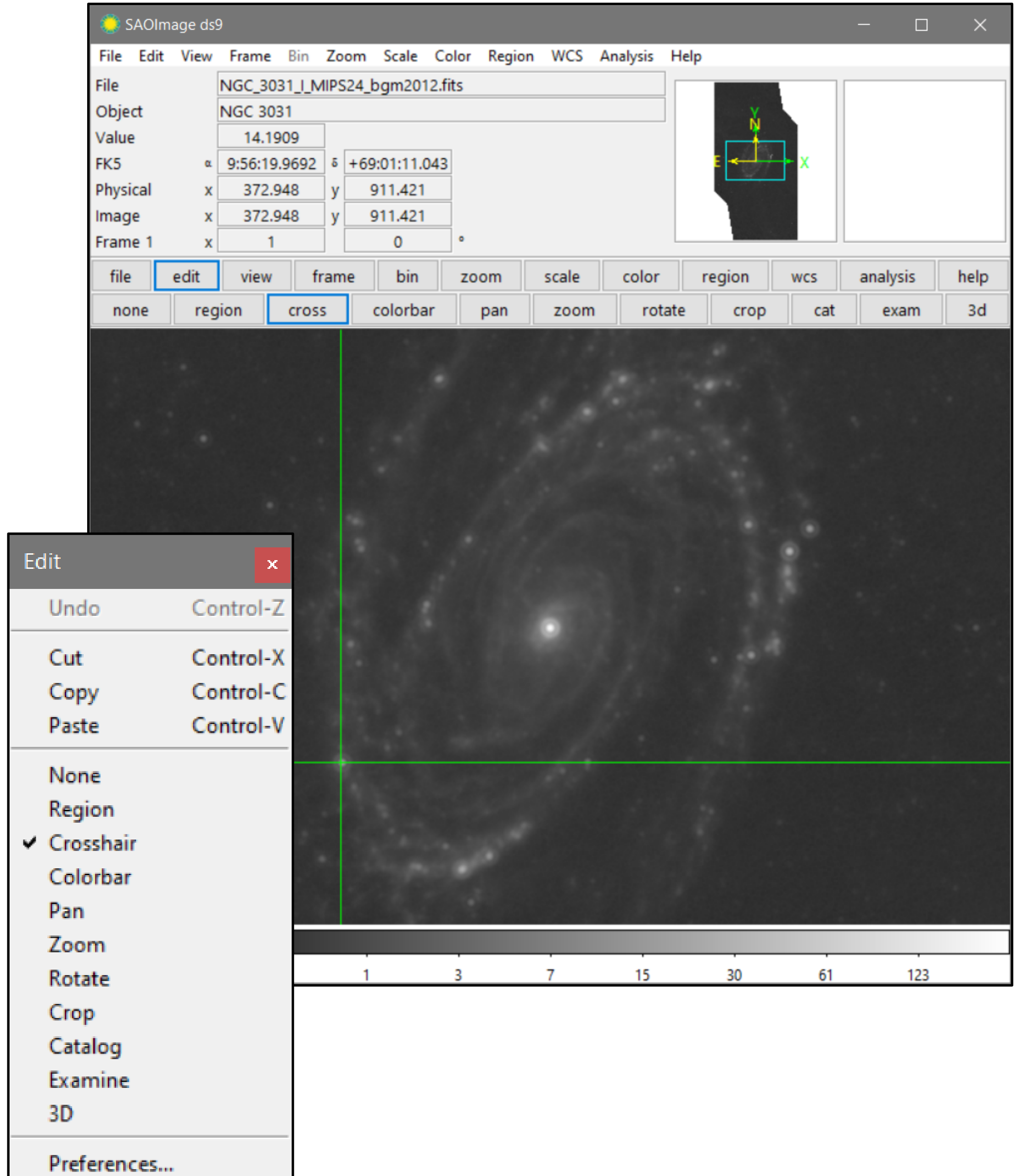


Edit

The edit menu can be used to change what happens when left-clicking in the image. This includes:

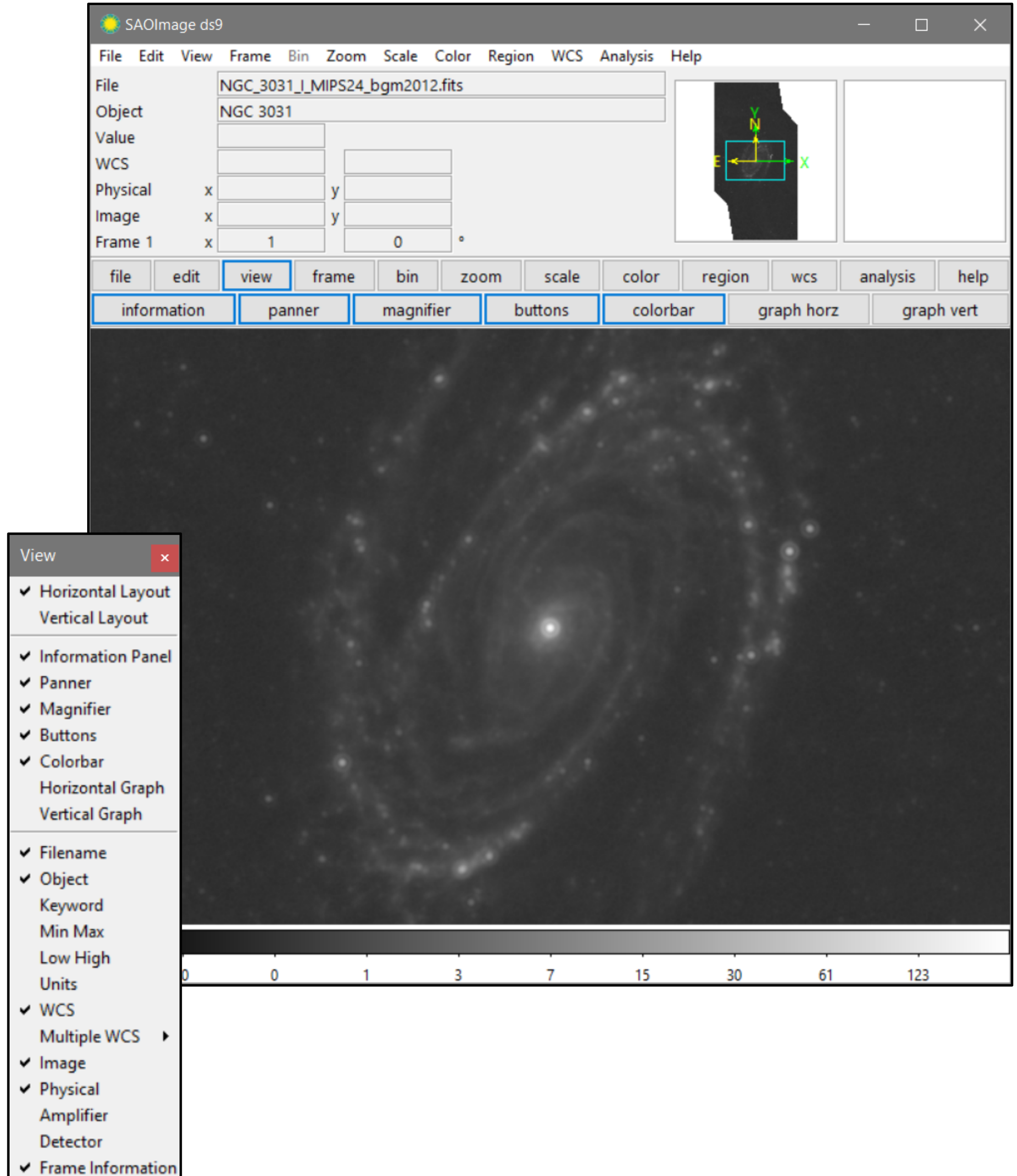
- Draw a region
- Move crosshairs
- Change the colour bar (the same as right-clicking)
- Pan (the same as middle-clicking)
- Zoom
- Rotate

Preferences for DS9 can be set using this menu.



View

The view menu can be used to change the appearance of DS9.

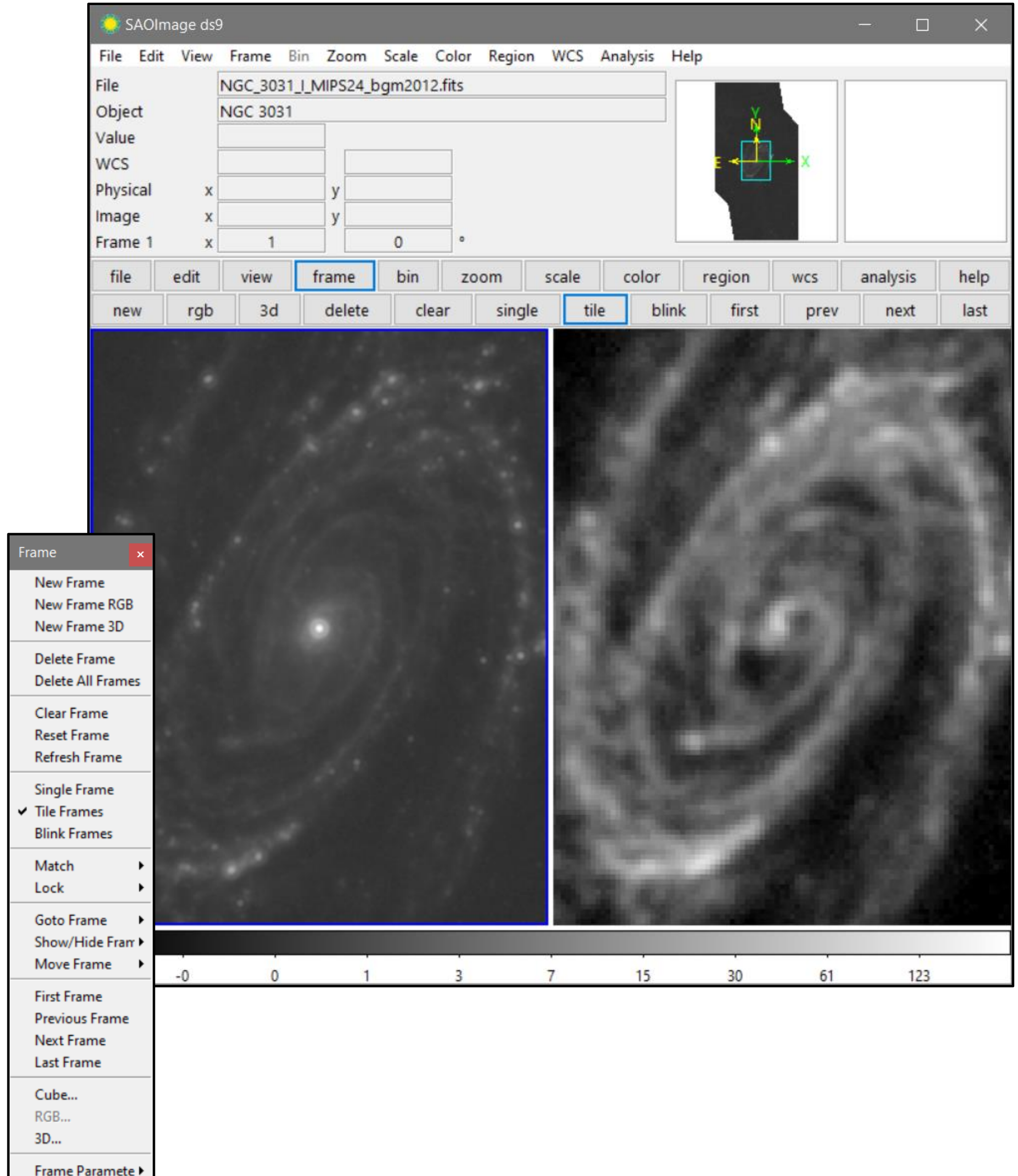


Frame

The frame menu can be used to display multiple images side-by-side

The frame menu can also be used to blink between images (which is good for spotting asteroids and supernovae).

It can also be used to align images to the same coordinate system (using the options under “Match”).

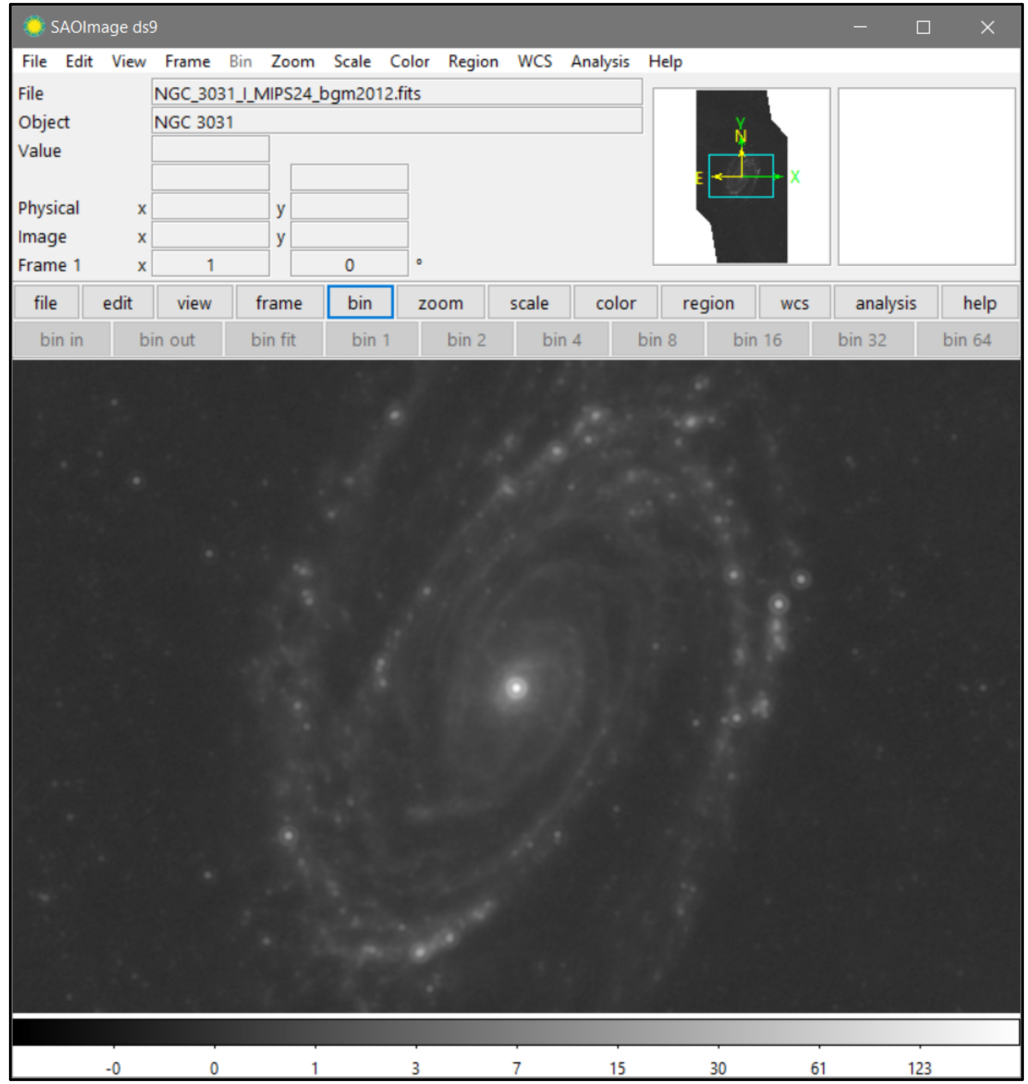


Bin

The bin menu features options for combining the values within pixels in an image into larger pixels. This changes the resolution of the image.

The options in this menu are disabled for most images. The menu is mainly meant to provide advanced display options for some types of X-ray data. Unless you are working with such data, you can ignore this menu.

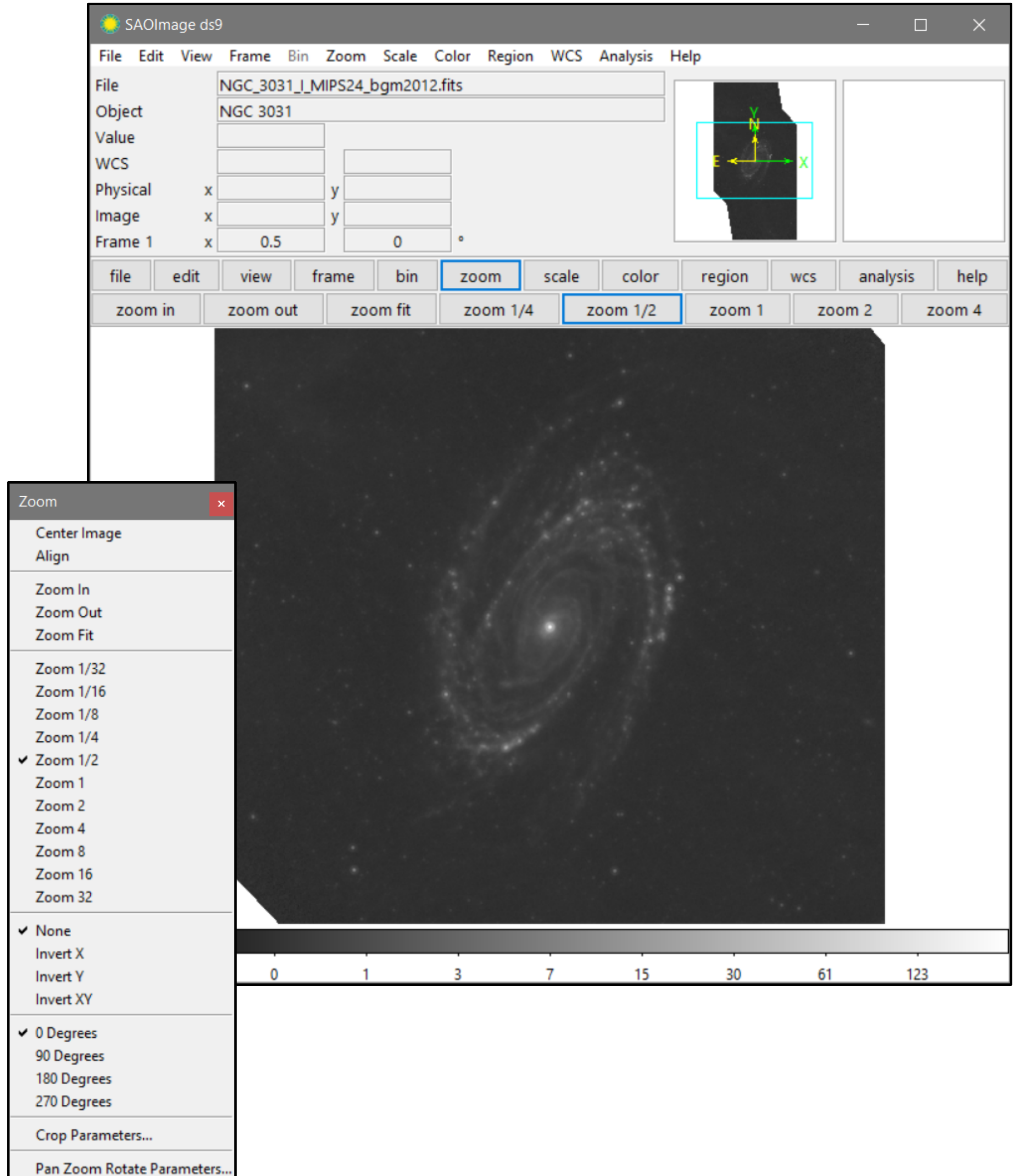
The Analysis menu has a Block submenu that can also be used to combine pixels together.



Zoom

The zoom menu can be used to zoom in or out of images.

It can also be used to flip and rotate images and to recenter an image.

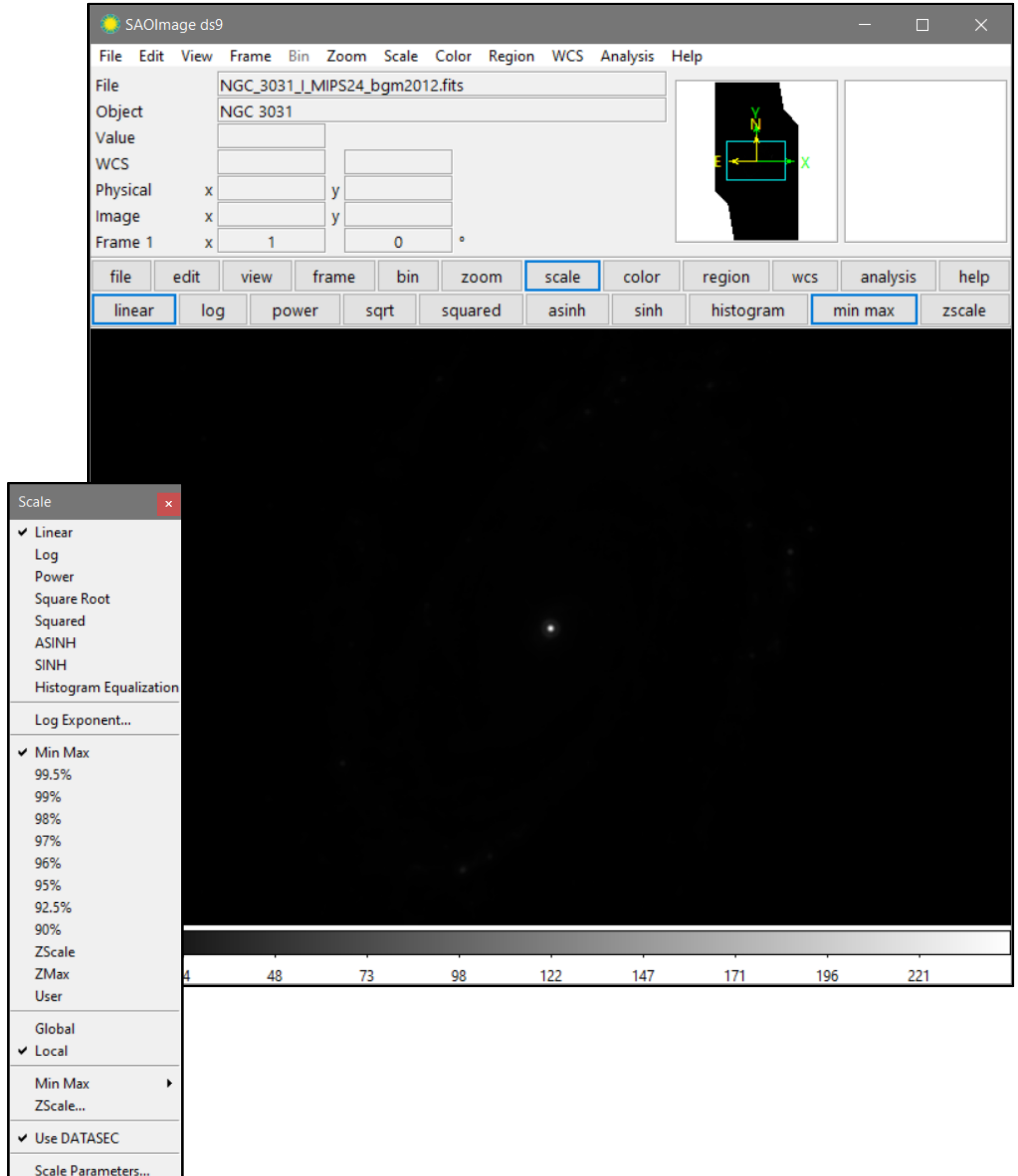


Scale

The scale menu is used to change how the science values for the individual pixels are converted into brightness on-screen.

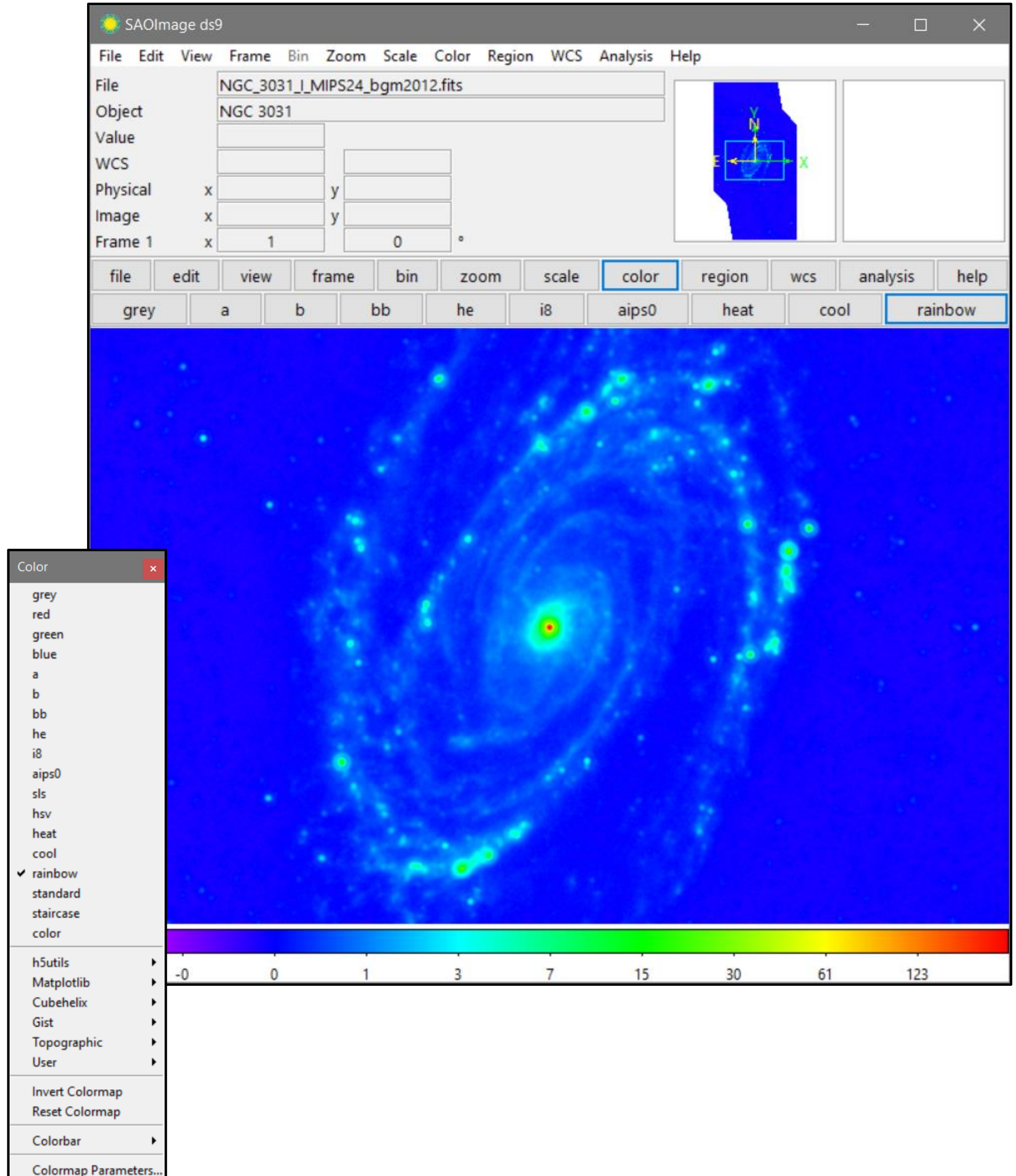
One set of options describe the math function used to convert between science values and display brightnesses. “Log” usually works best.

The other set of options describe the range of pixels to use for setting the scale. The default is “Min Max”, which usually works. Try “99.5%”, “Zscale”, or “Zmax” if the default does not work.



Color

The color menu can be used to add false colour to images. This is usually nicer than the default grey colour.



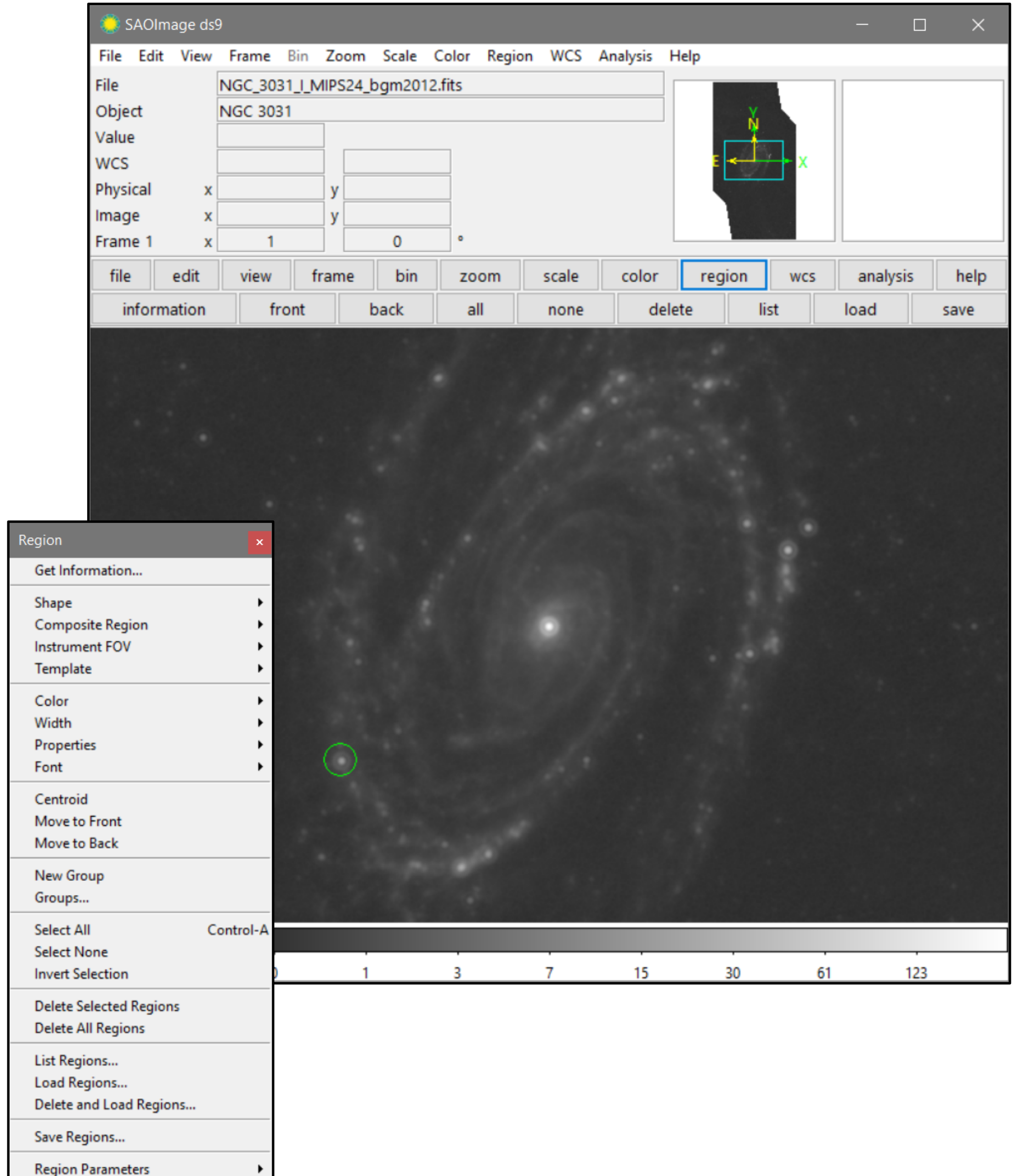
Region

The region menu can be used when "Region" is selected in the edit menu.

The menu can be used to change the shape and appearance of regions.

The menu can also be used to display region information (which can also be done by double-clicking on a region).

Regions can also be saved and loaded using this menu.



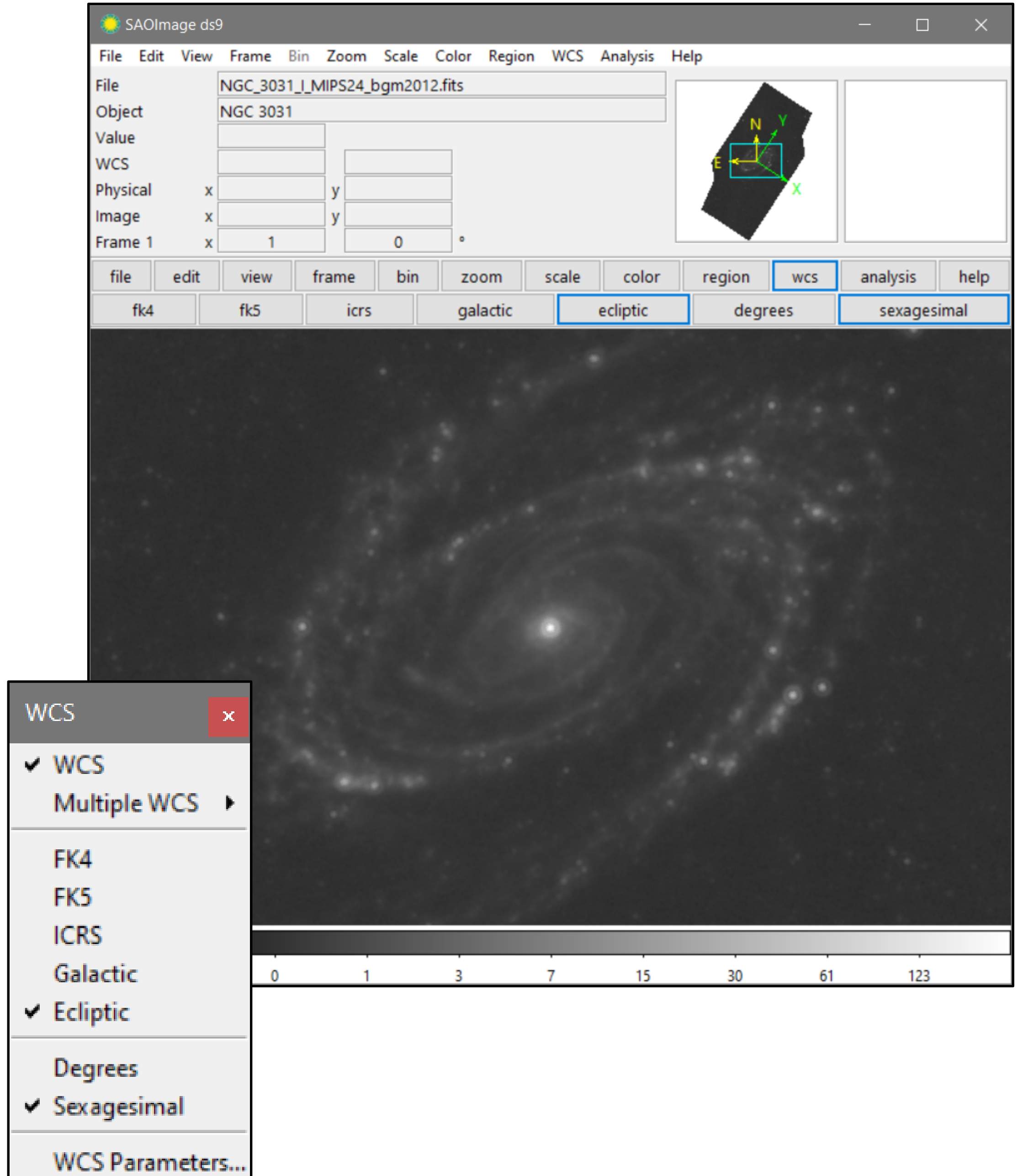
WCS

The WCS menu can be used to shift the image to other coordinate systems.

The default is "FK5", which is the "modern" coordinate system of right ascension and declination. "IRCS" is very similar.

The "Galactic" coordinate system displays images in a coordiante system where the plane of the Milky Way is the equator.

The "Ecliptic" coordinate system displays images in a coordinate system where the path of the Sun in the sky is the equator.



Analysis

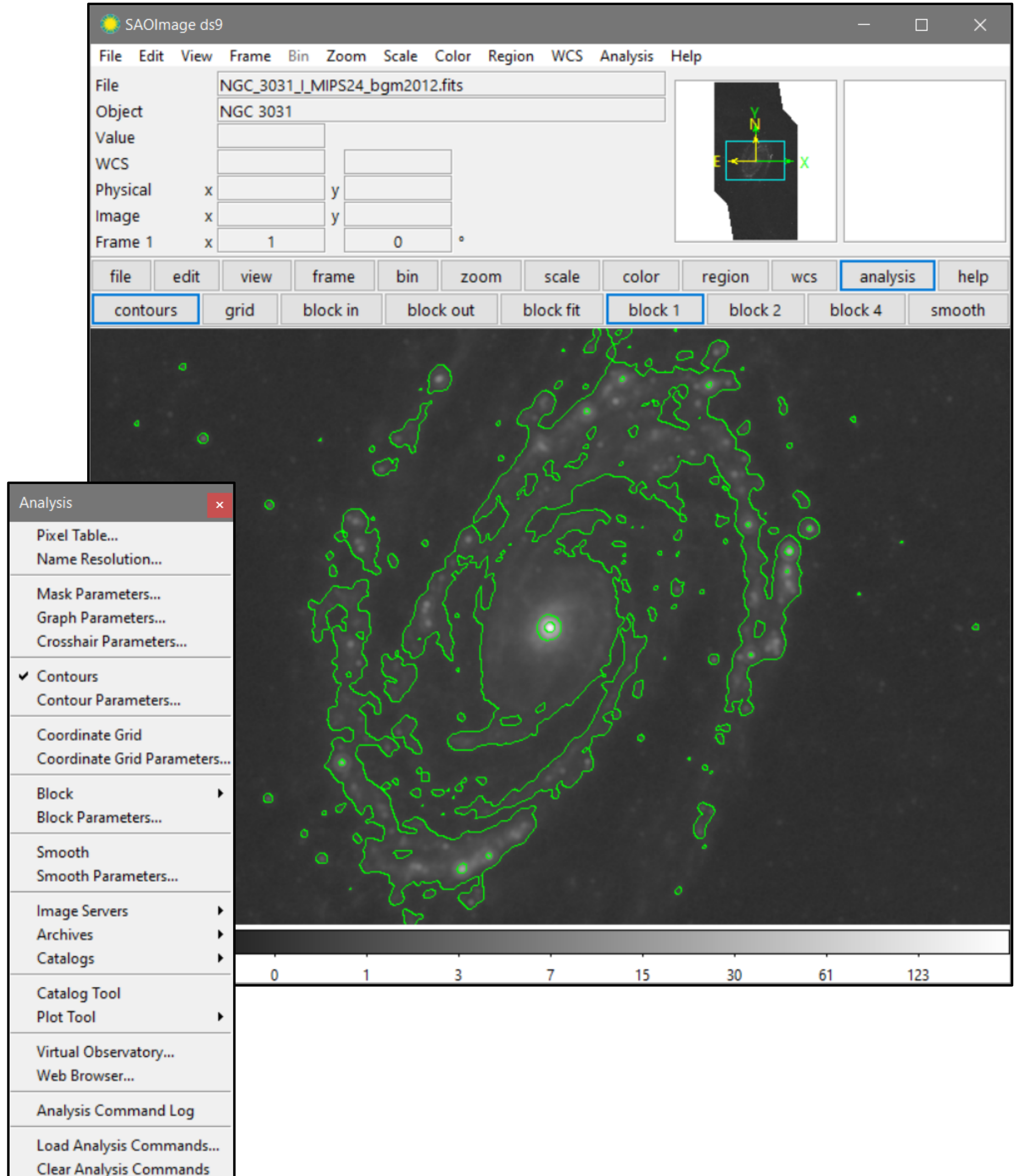
The analysis menu has multiple tools.

The “Image Server” and “Archive” tools can be used to retrieve additional images (although some of these aren’t very good).

The “Catalog” tool can be used to show all the sources from an astronomical catalogue that also appear in the image.

The “Block” and “Smooth” options change the appearance of images.

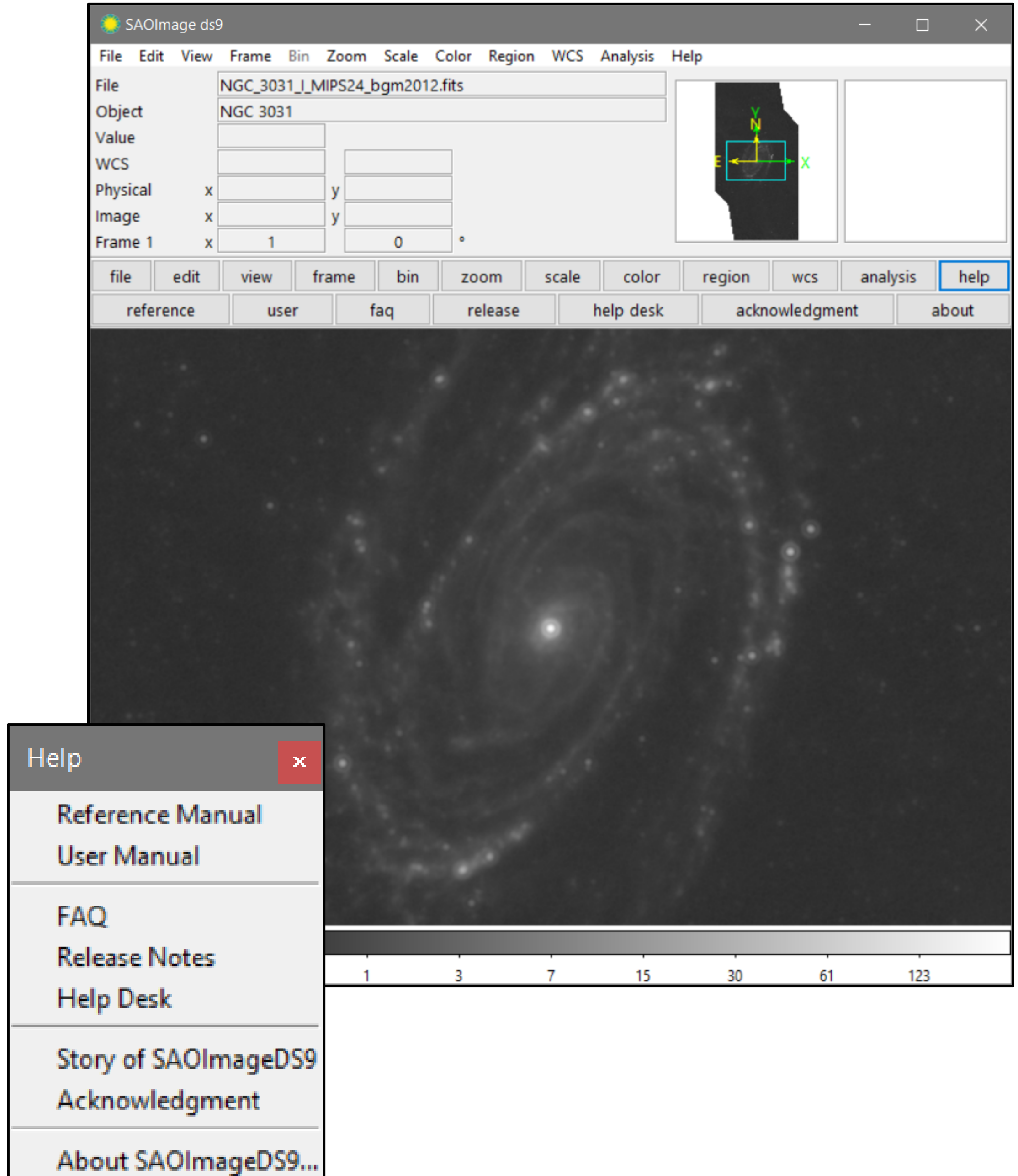
Many other tools are also available.



Help

The help menu provides information on everything in DS9.

The “Story of SAOImage DS9” page explains why this program is named after a Star Trek series.



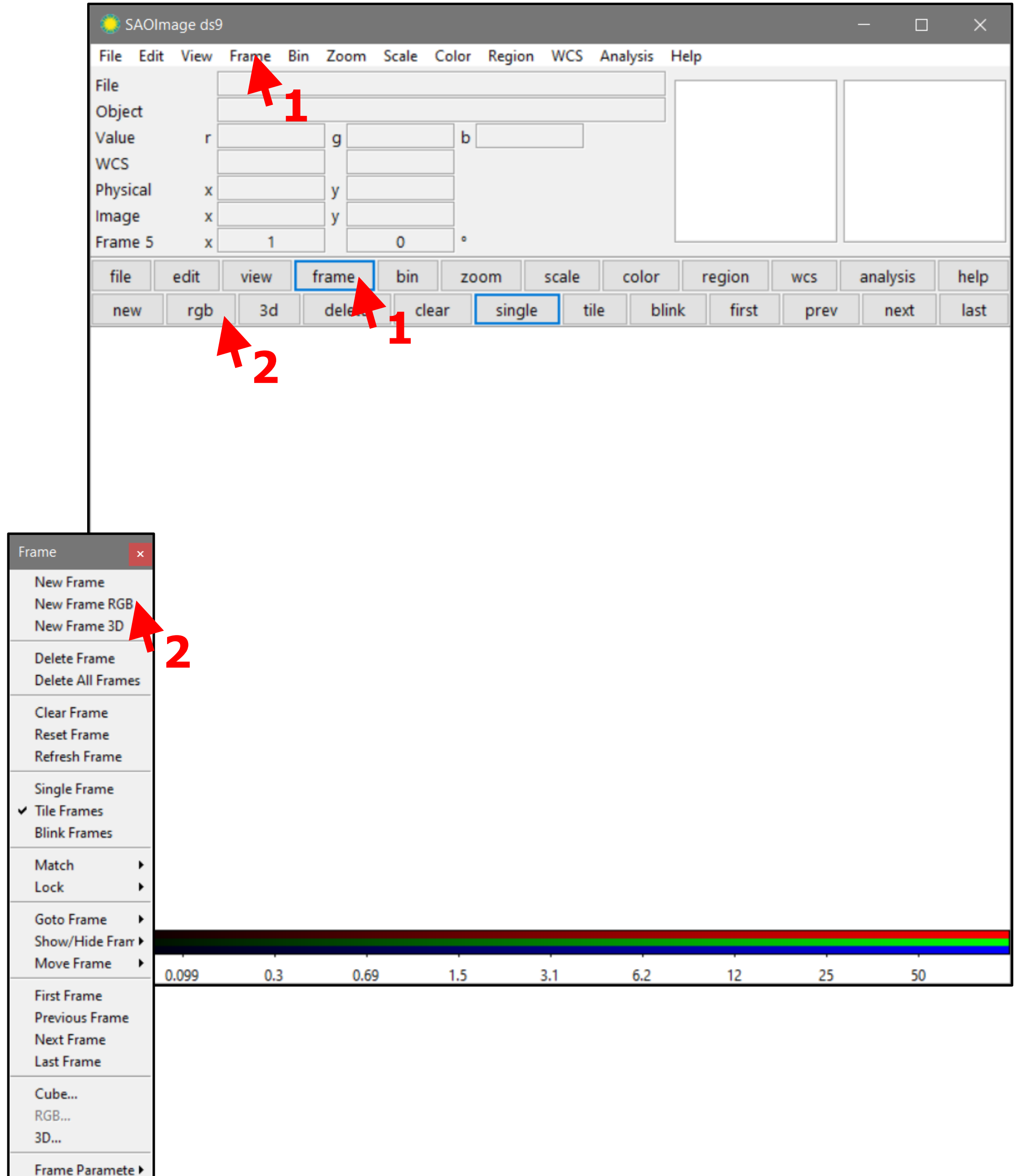
DS9 Special Tricks

Creating Representative Colour Images

False-colour images can be created by opening any fits image and then choosing a colour scheme from the color menu.

To create representative colour images takes more work.

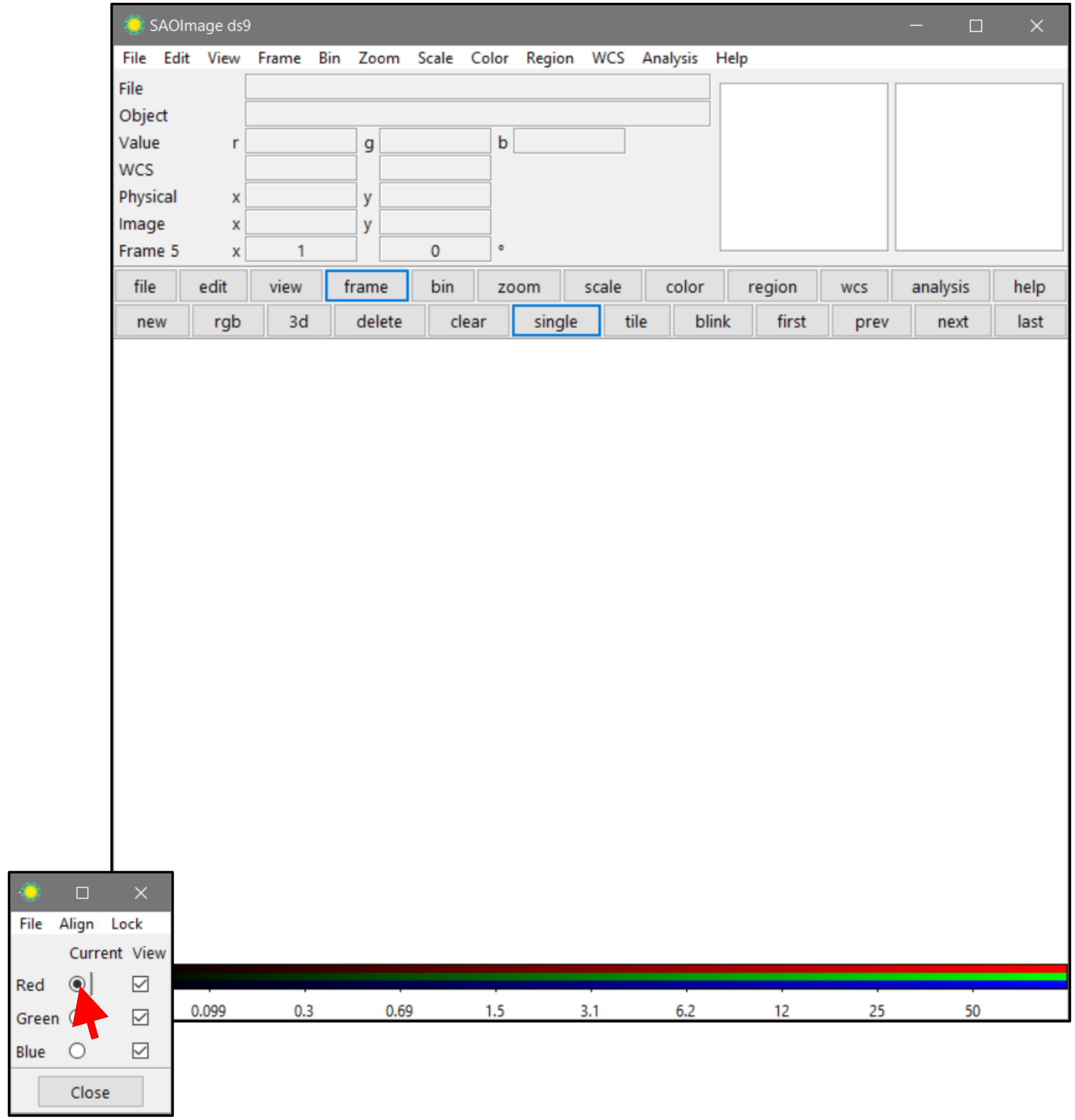
To begin with, go to the frame menu and select "New Frame RGB" or click on the frame button and then select "rgb".



After doing this, a new window with the title RGB will appear, and a new blank frame will appear in the window.

Make sure the diamond next to Red in the RGB window is selected.

This means that you can load a FITS image to be the red channel in your representative image. You can also change its appearance when this diamond is selected.



Open a FITS image to represent the red channel.

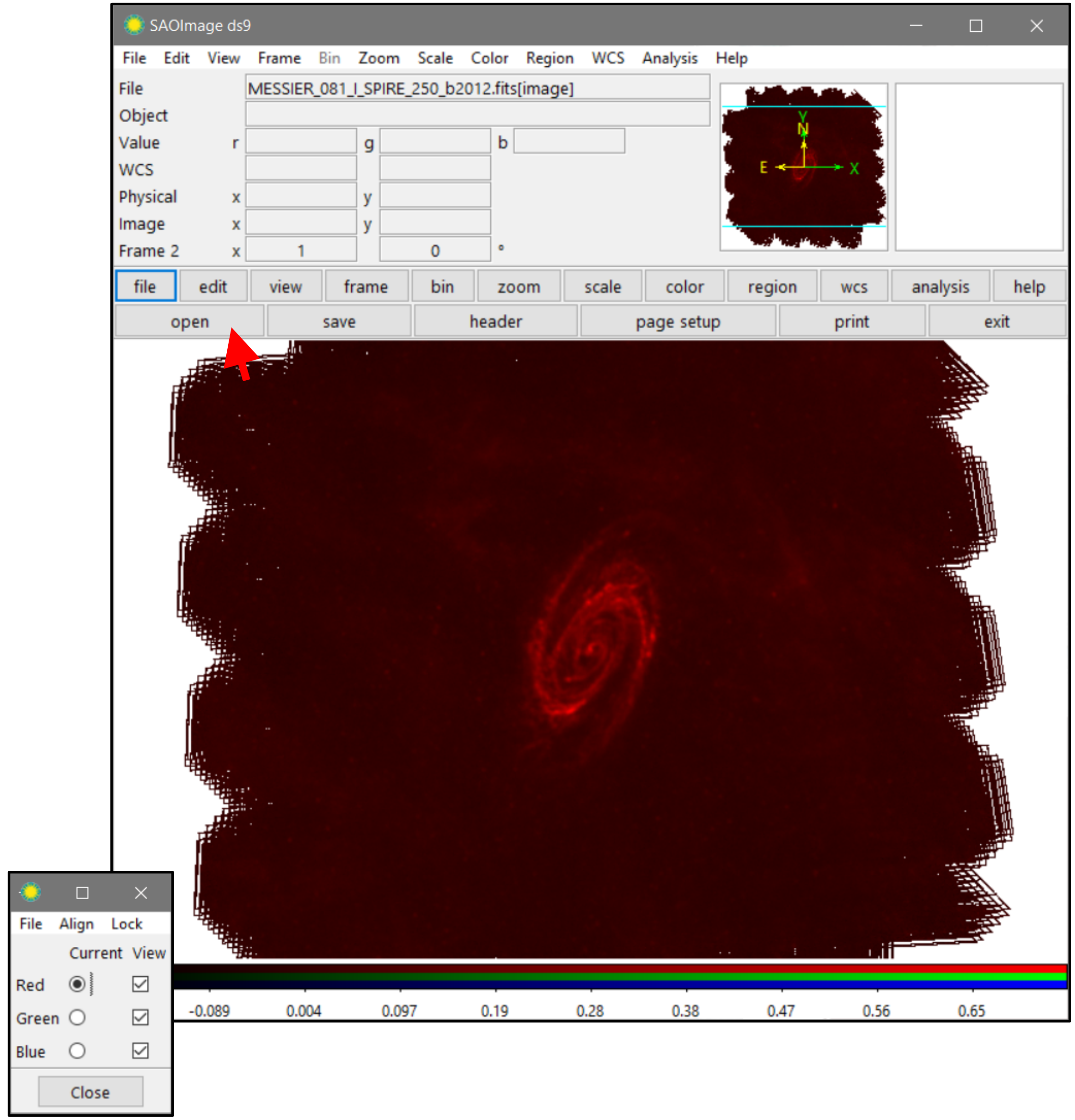
(Astronomers often like to show the data with the longest wavelength as red.)

The example shown here uses the following files:

- Red: http://ned.ipac.caltech.edu/uri/NED::Image/fits/2012MNRAS.419.1833B/MESSIER_081:I:SPIRE_250:b2012

- Green: http://ned.ipac.caltech.edu/uri/NED::Image/fits/2012MNRAS.423..197B/NGC_3031:I:MIPS24:bgm2012

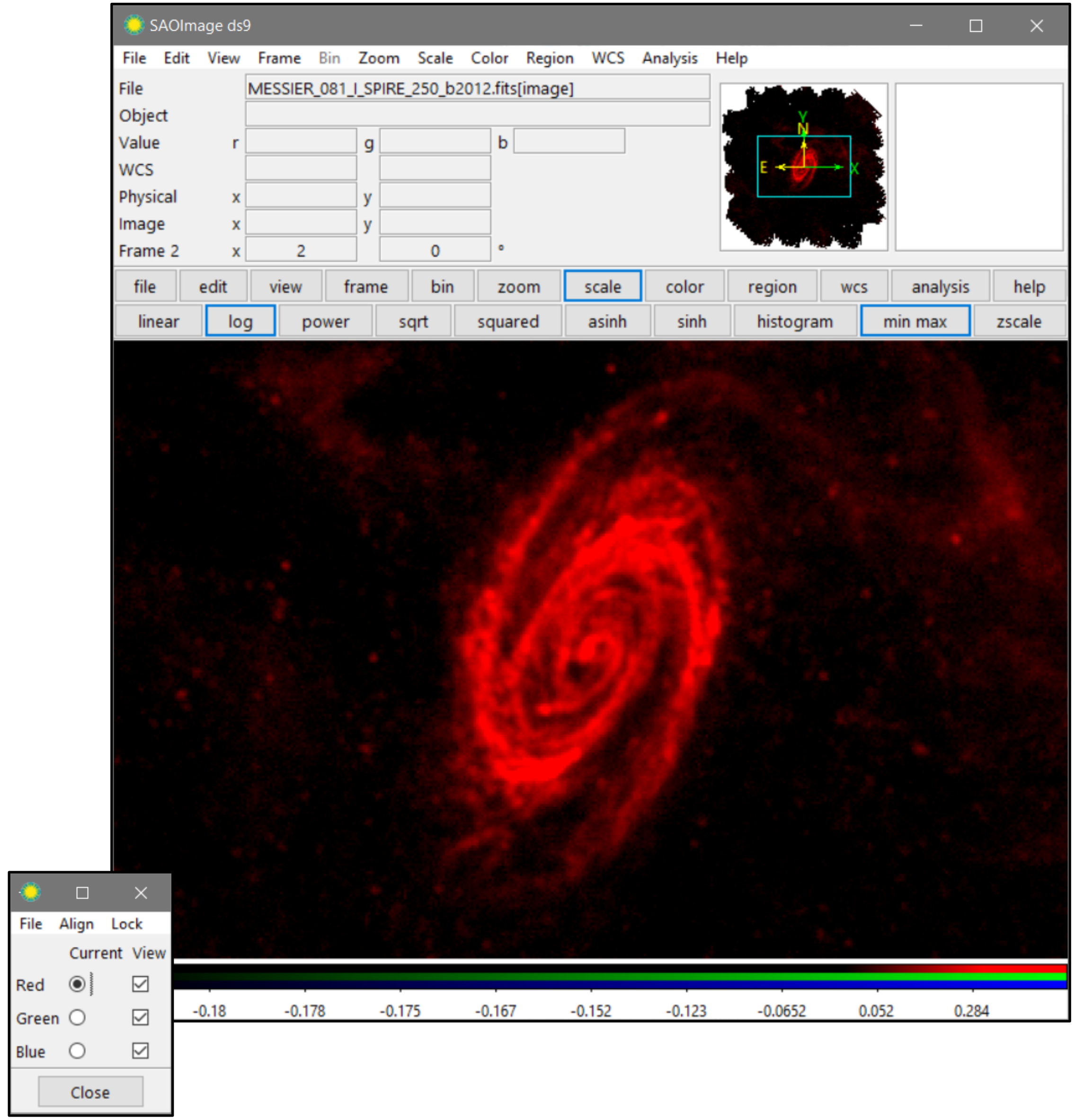
- Blue: http://ned.ipac.caltech.edu/uri/NED::Image/fits/2003PASP..115..928K/NGC_3031:I:IRAC_3.6:kab2003



Adjust the red image so that it looks the way you want it to look.

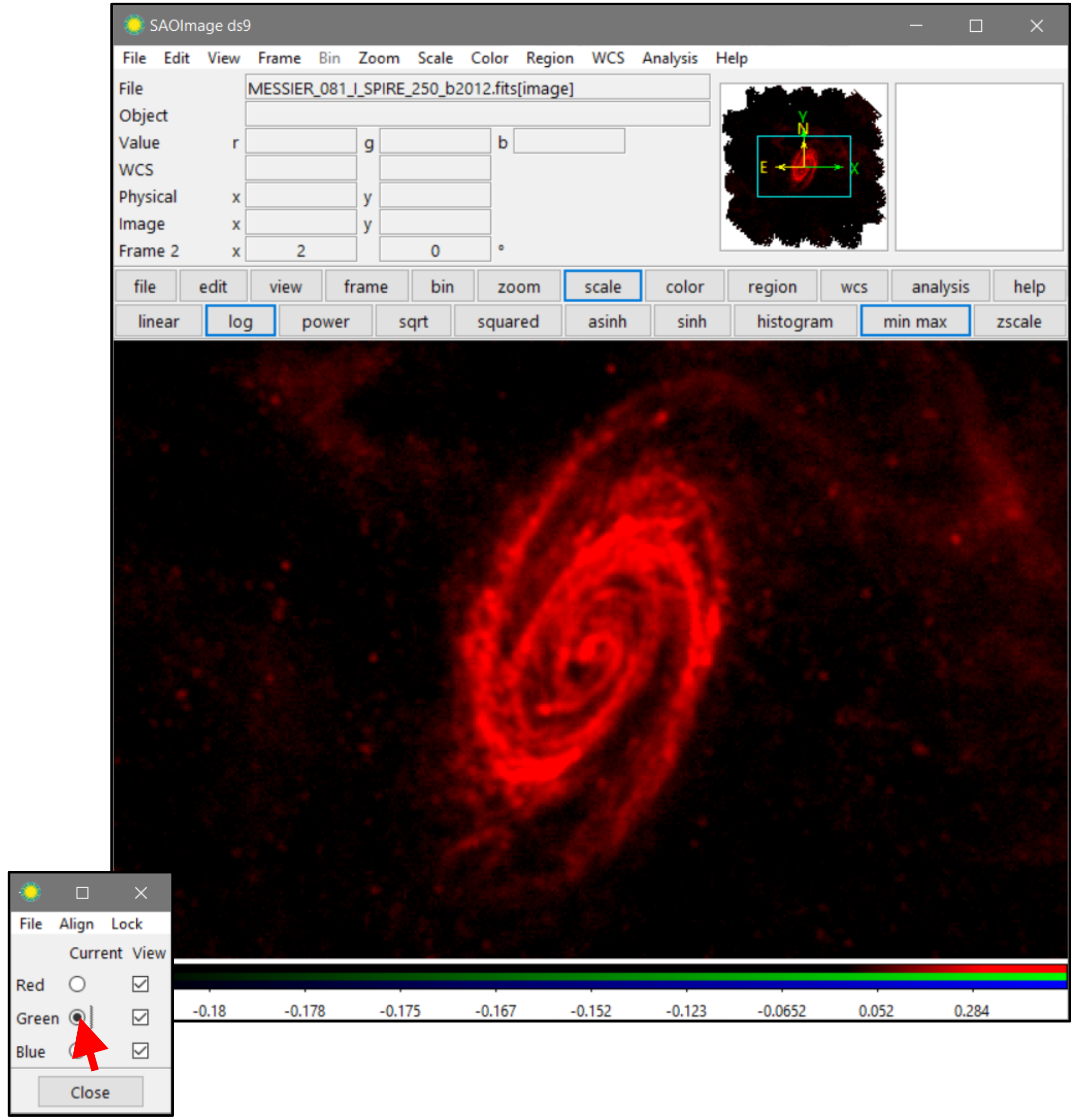
This includes the following:

- Changing the scale to log (or making other scale changes if necessary)
- Changing the brightness and contrast
- Changing the zoom
- Re-centering the image

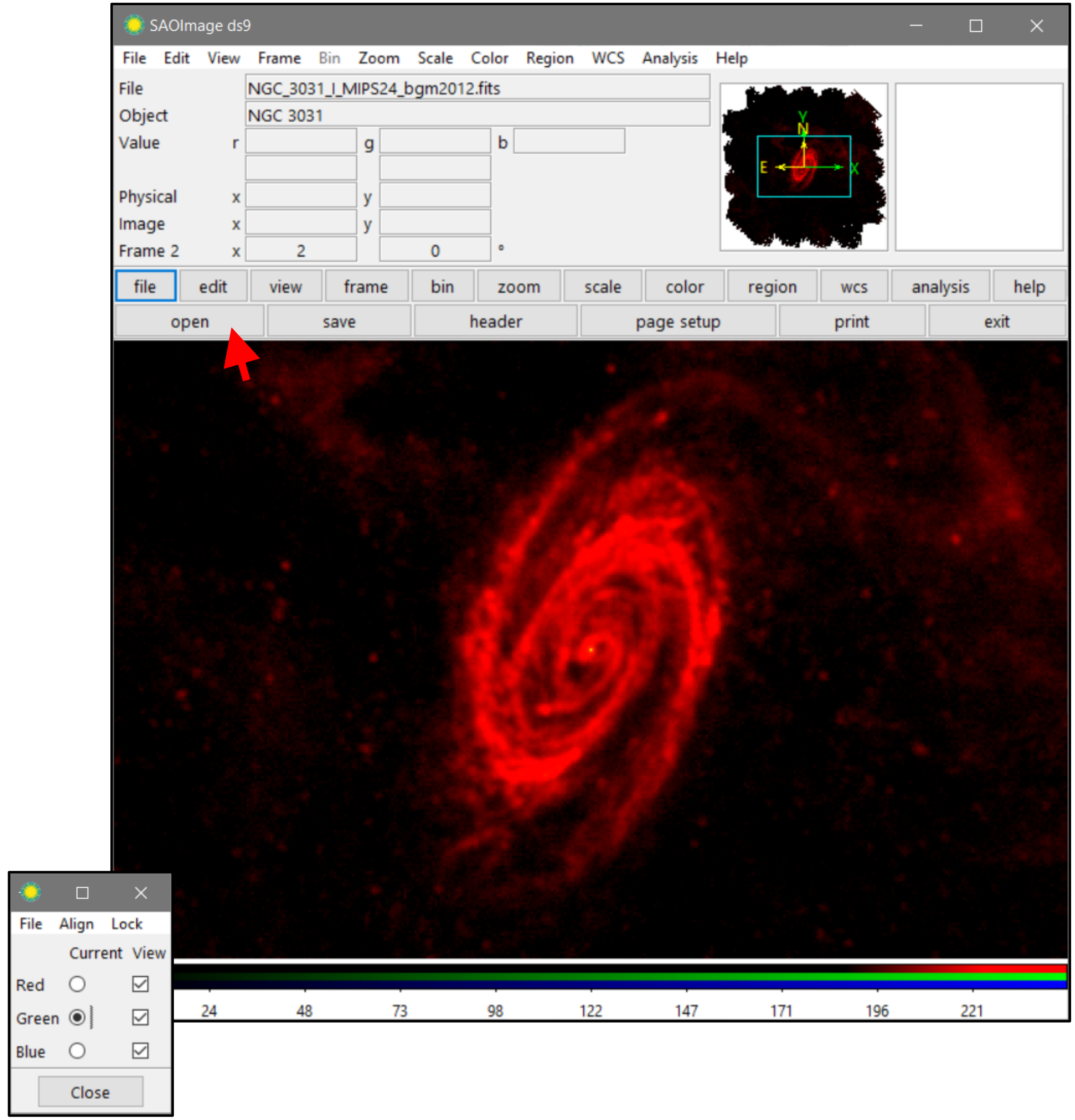


Next, select the diamond next to “Green” in the RGB window.

You can now load an image as the green channel in your image.

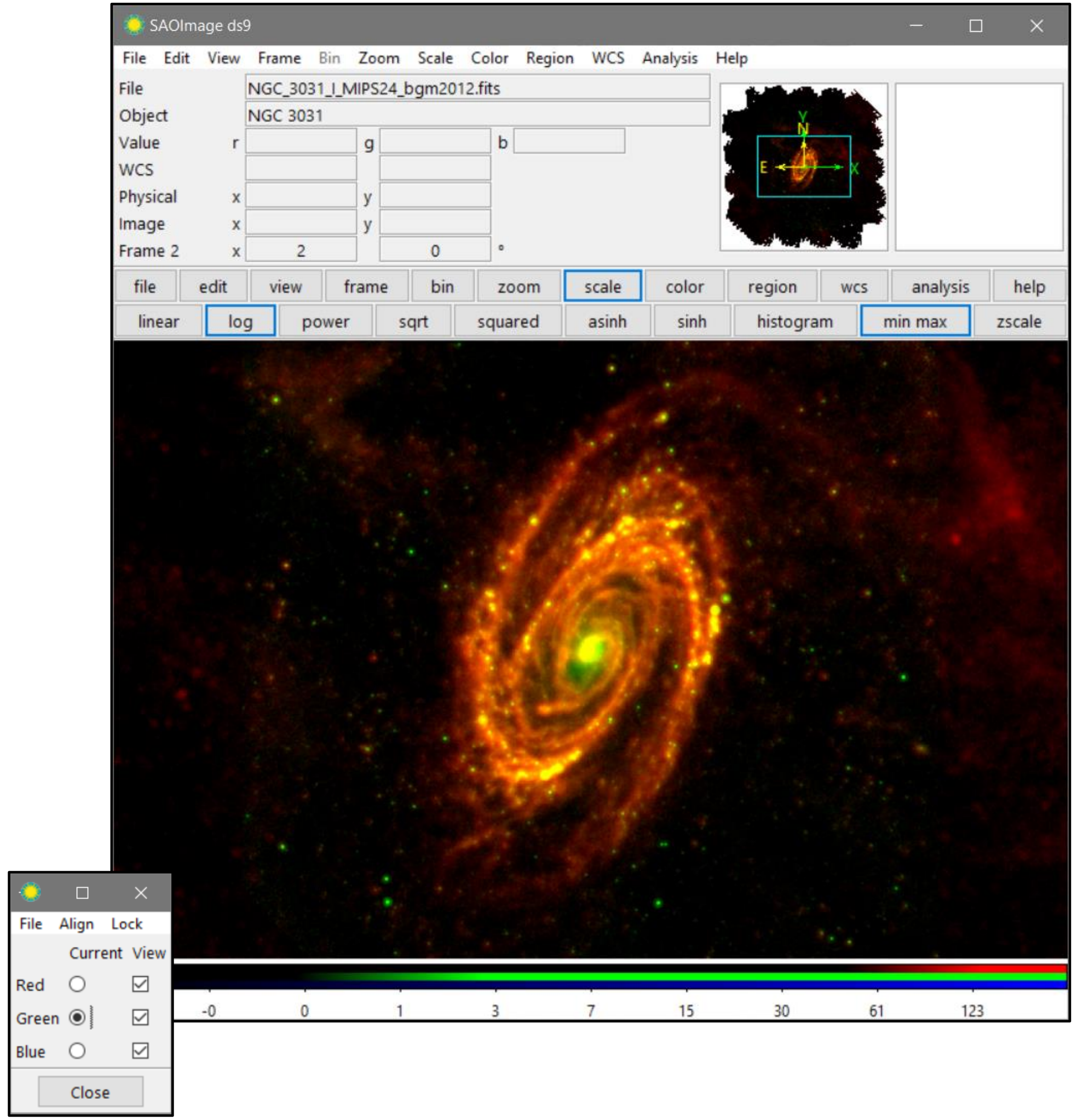


Open a FITS image to represent the green channel. If you are using the example in this demo, you may hardly be able to see the image at first.



Adjust the scale and the brightness/contrast in the green channel so that it looks the way you want it to look.

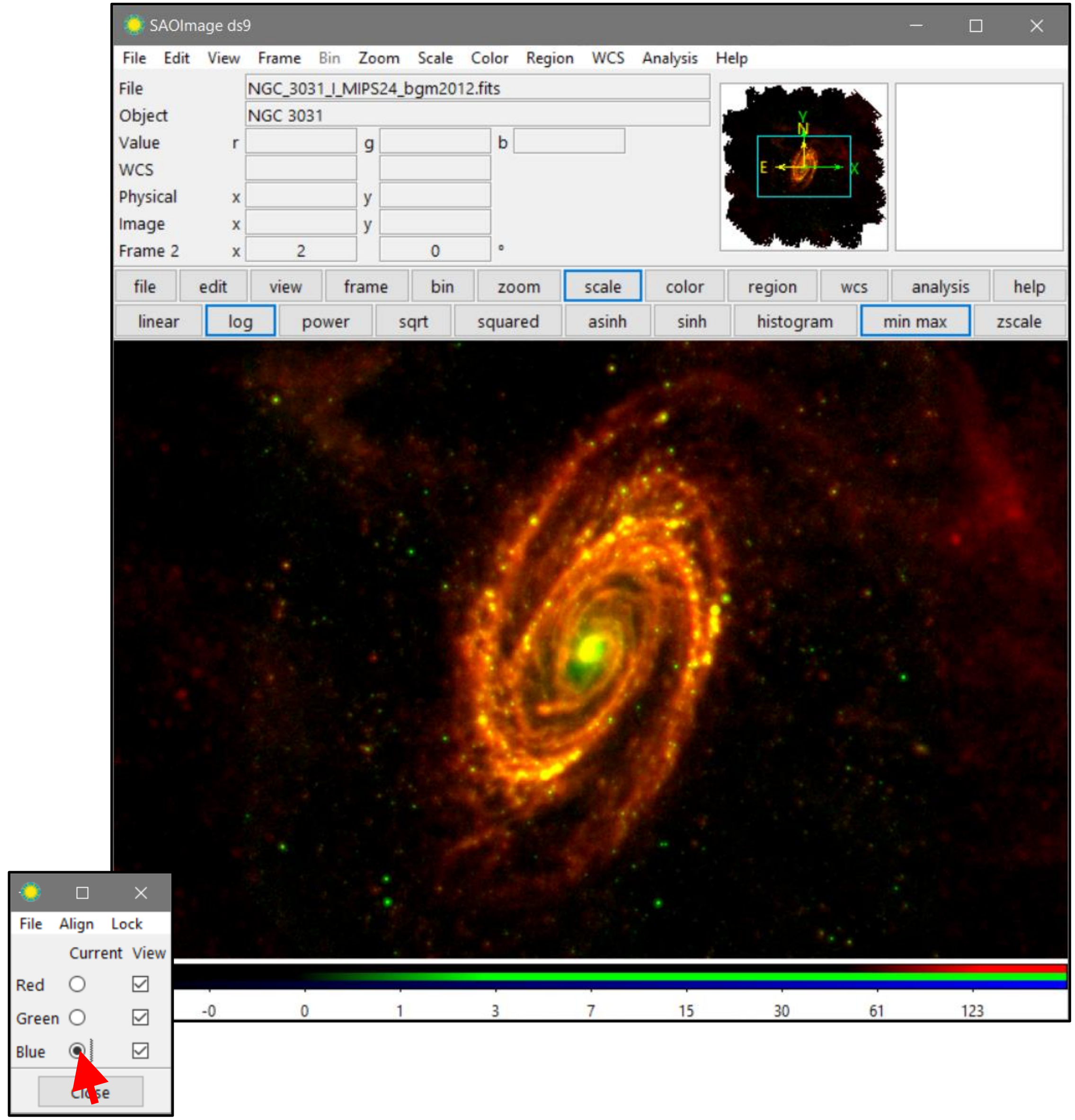
Parts of the image with emission from both the red and green channels will look yellow.



Next, select the diamond next to “Blue” in the RGB window.

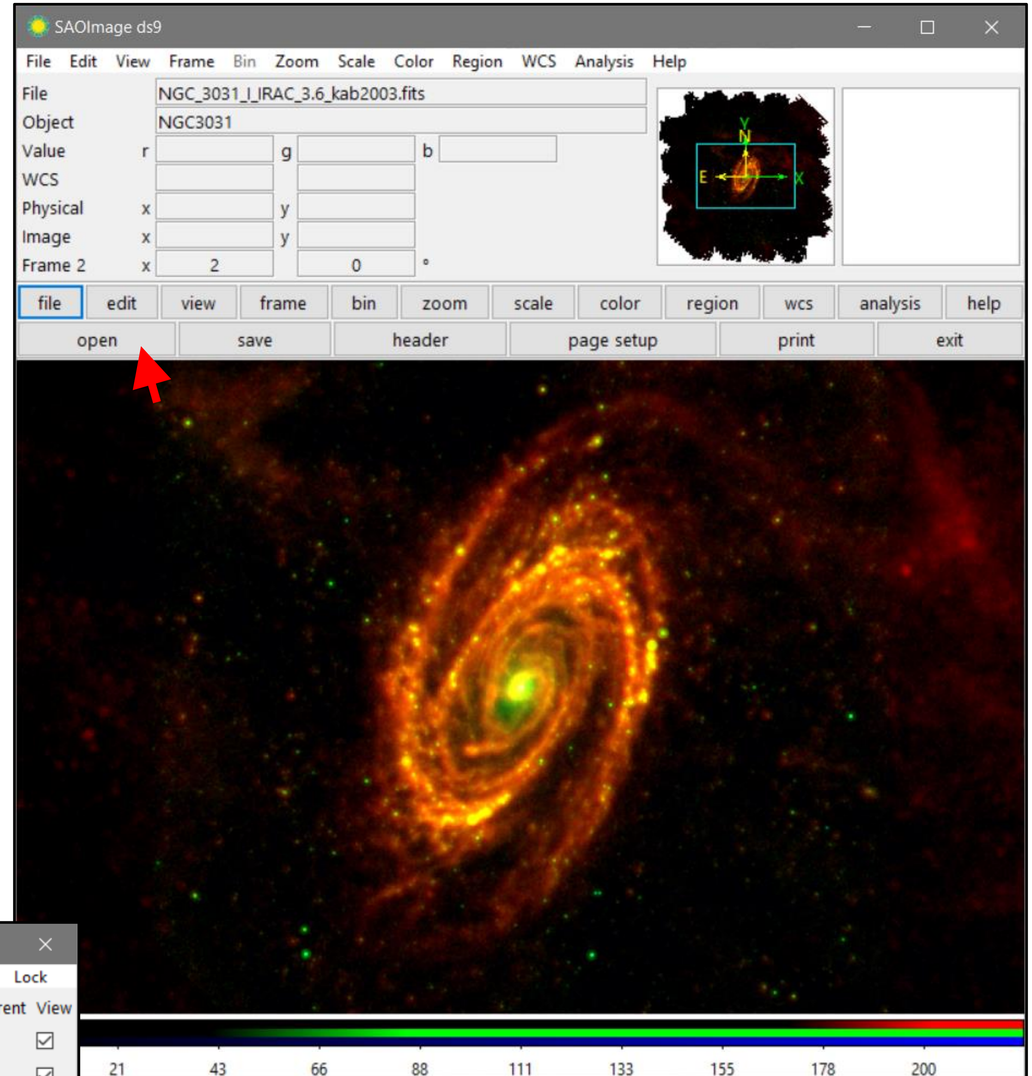
You can now load an image as the blue channel in your image.

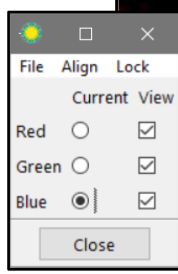
(Astronomers often like to show the data with the shortest wavelength as blue.)



Open a third image to be the blue channel. Again, the example image used here is hardly visible.

(Astronomers often like to show the data with the shortest wavelength as blue.)



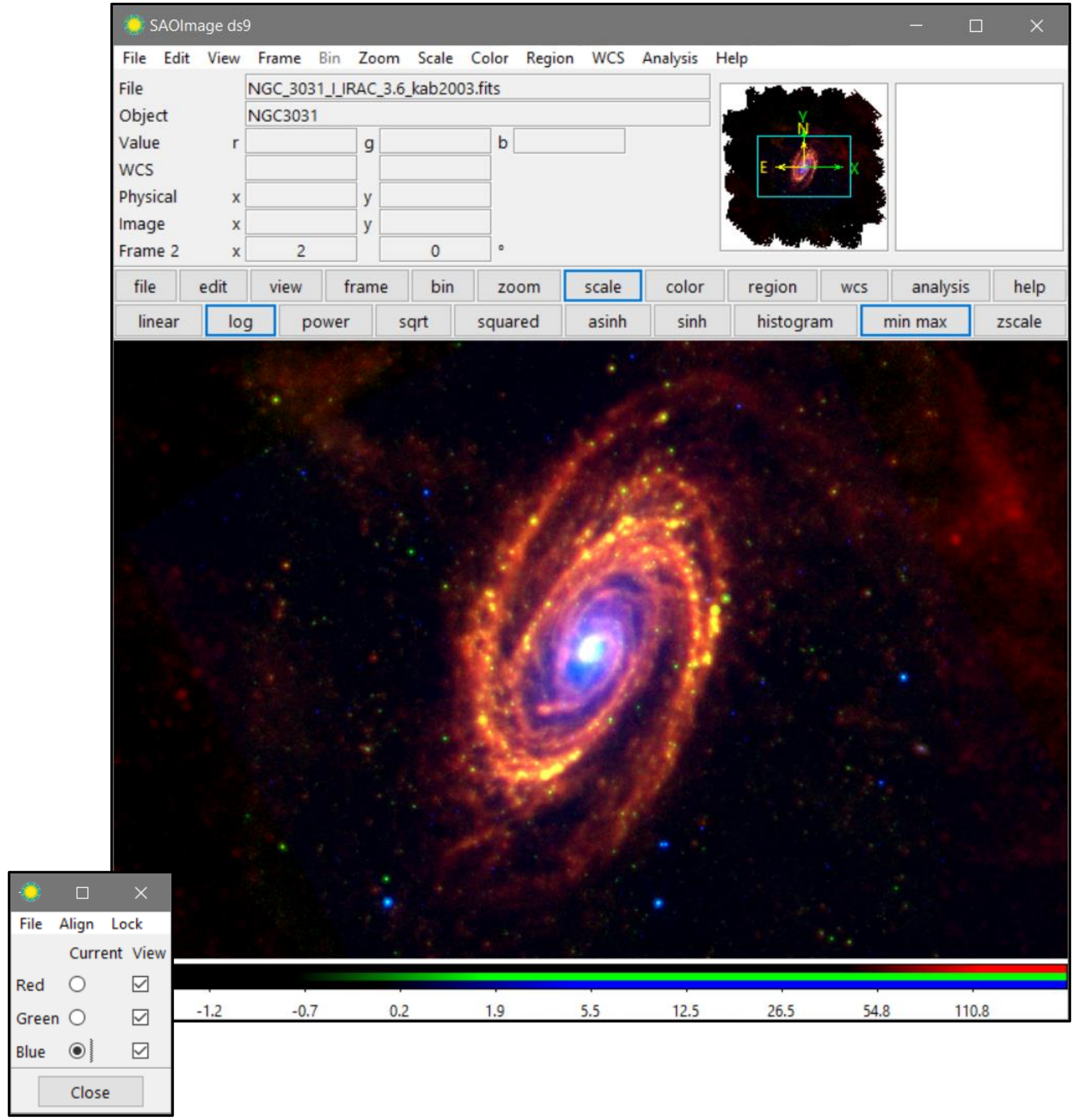


Adjust the scale and the brightness/contrast in the blue channel so that it looks the way you want it to look.

Parts of the image with emission from both the red and blue channels will look magenta.

Parts of the image with emission from both the green and blue channels will look magenta.

In places with emission from the red, green, and blue channels, the image will look white.

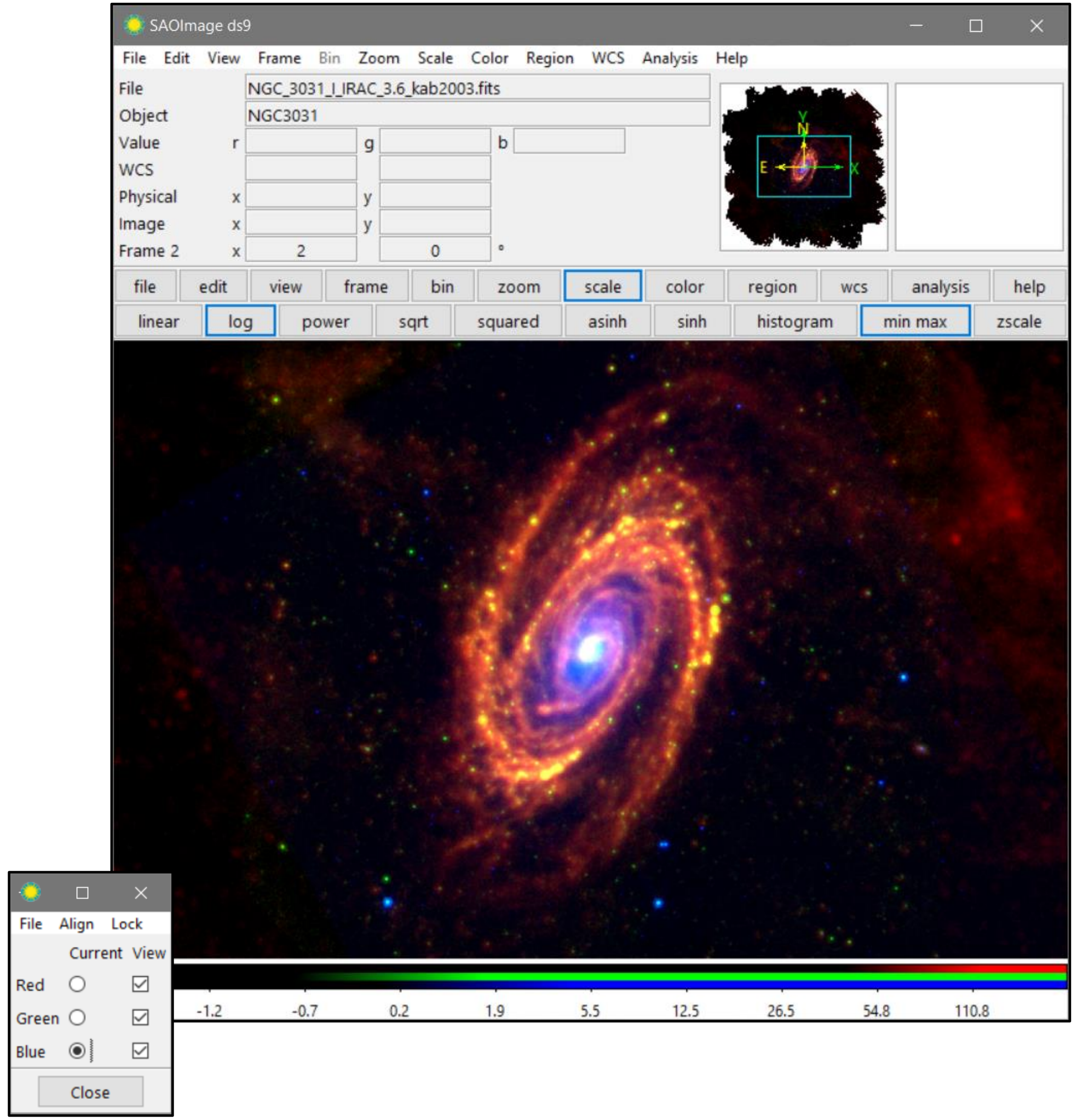


You can change the centering and zoom at any time.

If you want to change the colour scale or brightness /contrast for any colour channel, you can do so after first selecting that channel in the RGB window.

You can also replace the image in any channel by opening a new image (but you will probably have to readjust the brightness and contrast of the new image).

Unfortunately, it is not possible to save the image in another format with DS9. To save the image, use an image editor to take a screenshot of DS9.

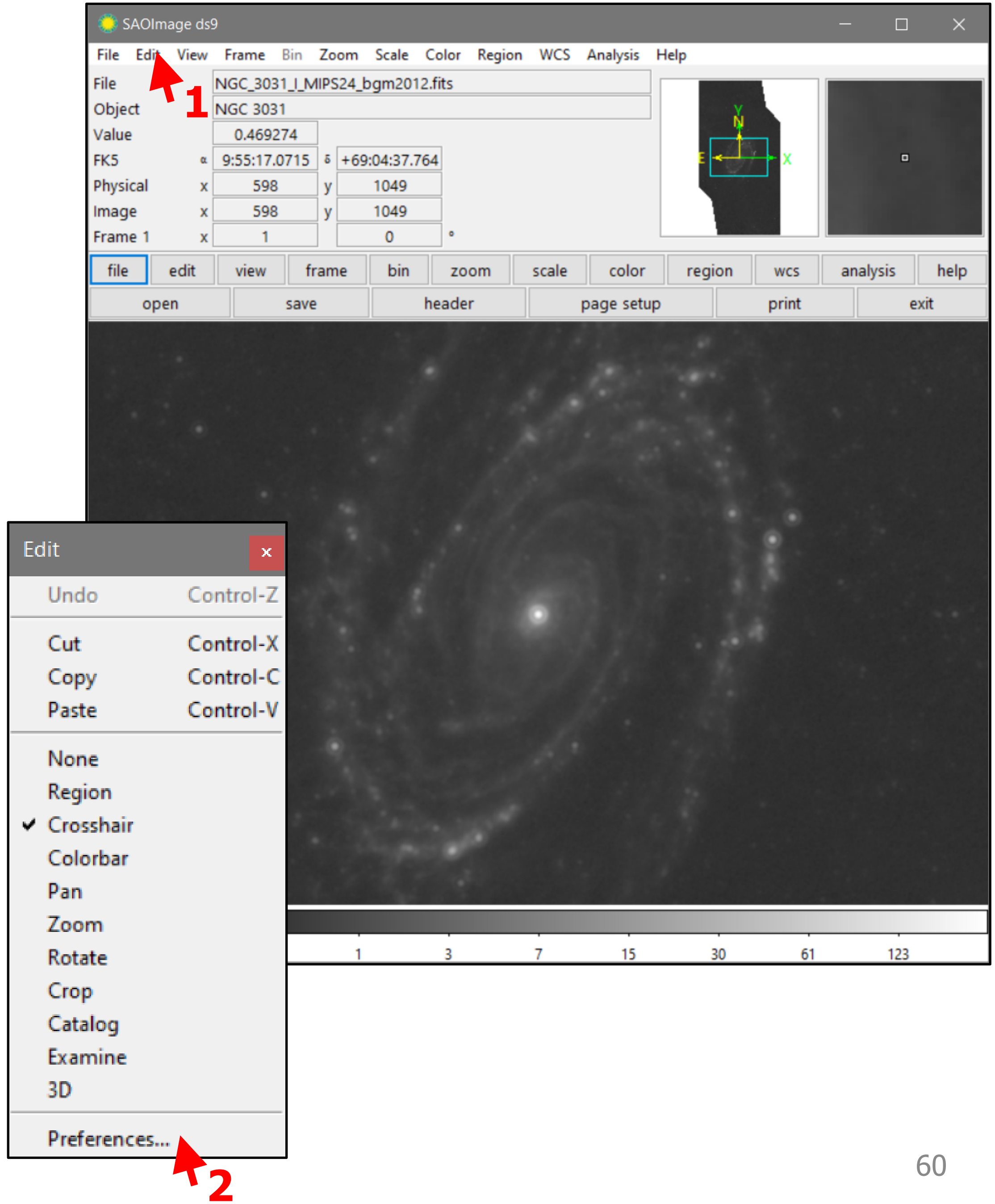


Set DS9 Default Settings

It can be annoying to repeatedly set the scale to “log” every time you start DS9.

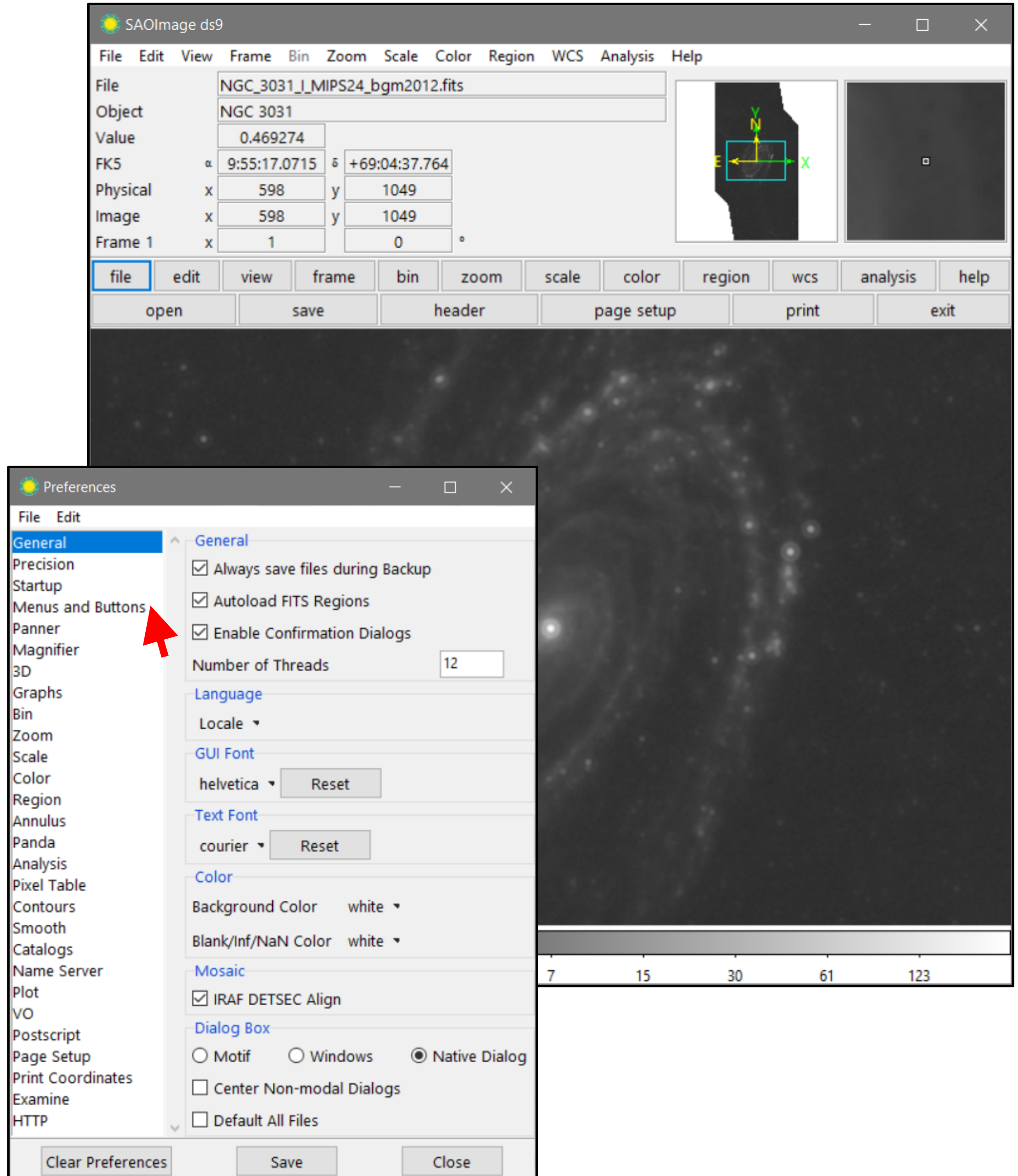
You may also want to do something like set a favourite false colour scheme. (I like “sls”.)

You can set this as a default by going to the edit menu and selecting “Preferences…”. (On Mac computers, “Preferences” is found under “SAOimage DS9” in the menu bar.)



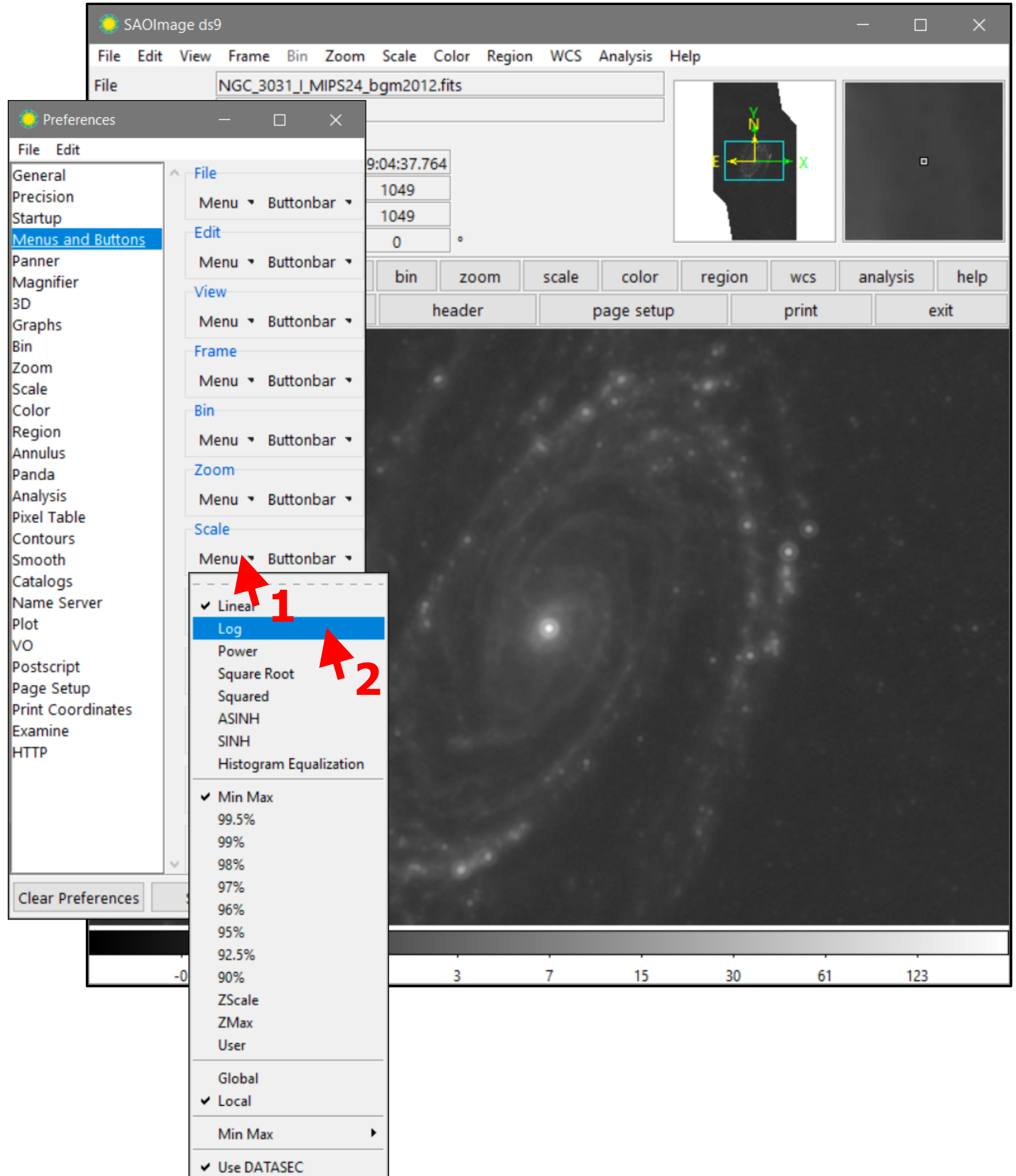
A new Preferences window will appear with lots of options.

To set the default settings, go to “Menus and Buttons”.

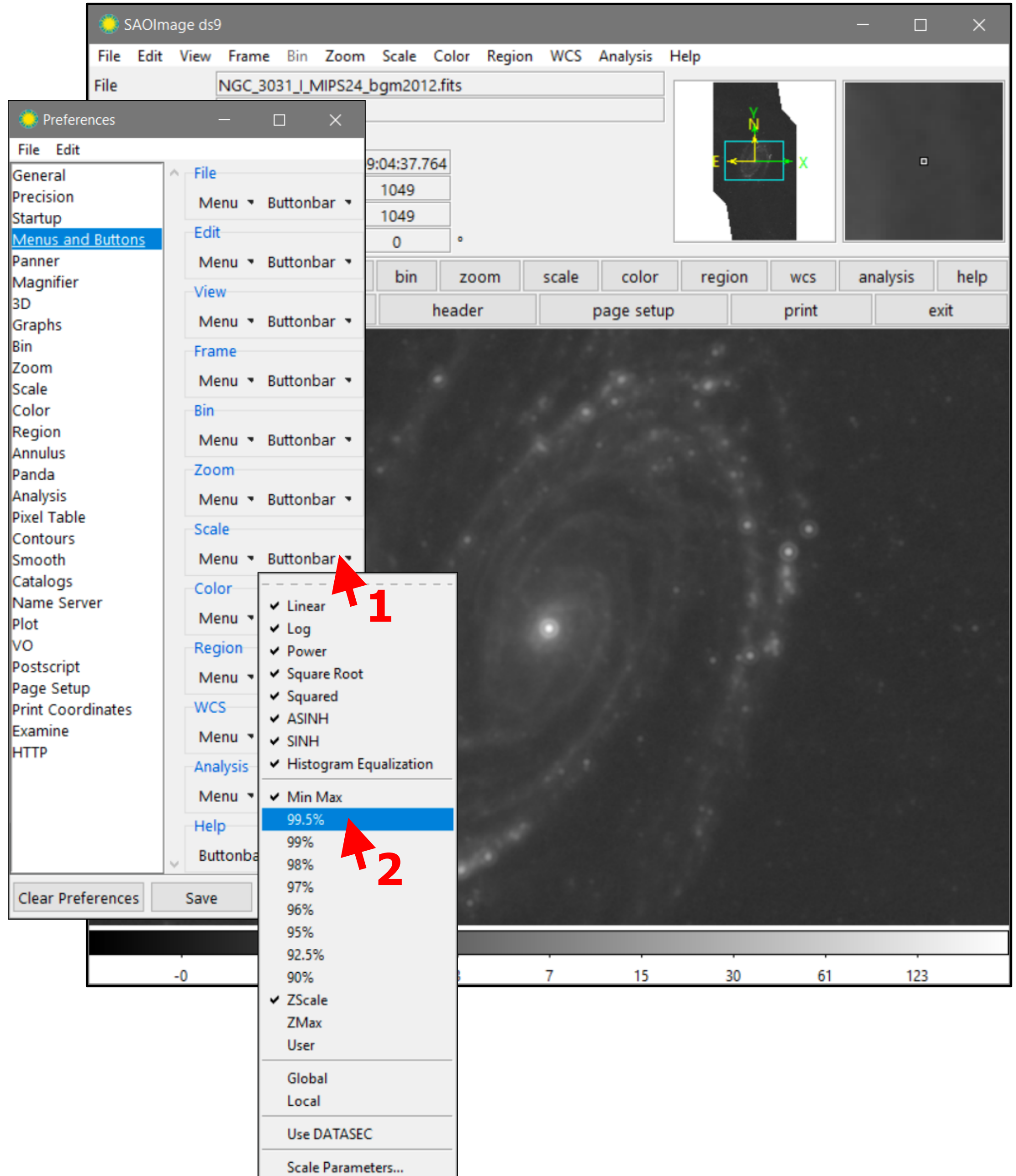


You will now see a list representing each item in the main menu.

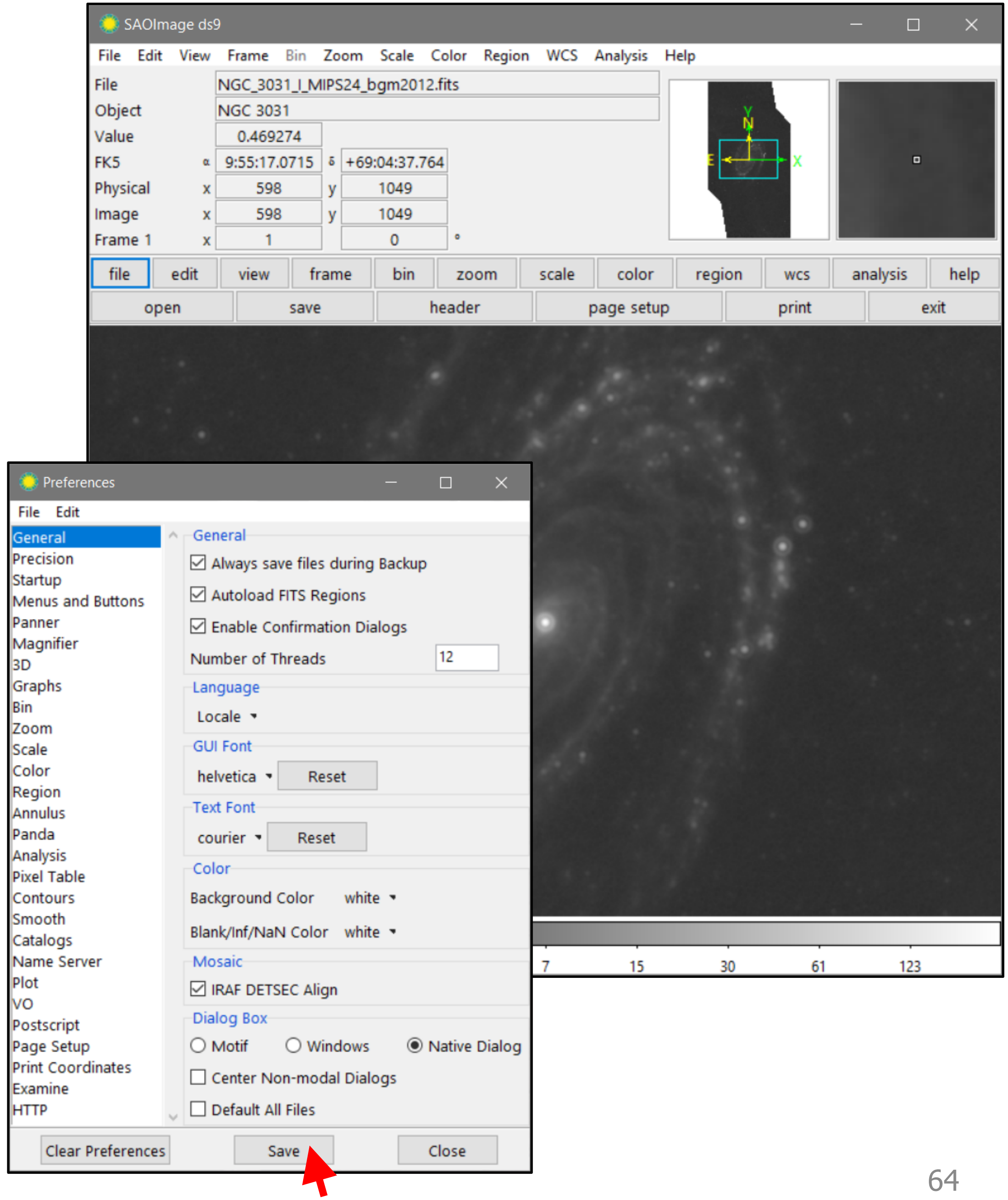
If you click on one of the boxes labelled “Menu”, a menu will appear where you can set the default settings for that menu.



If you select one of the boxes labelled "Buttonbar", you can change the buttons that appear in the main DS9 window.



When you are done, be certain to save your preferences.

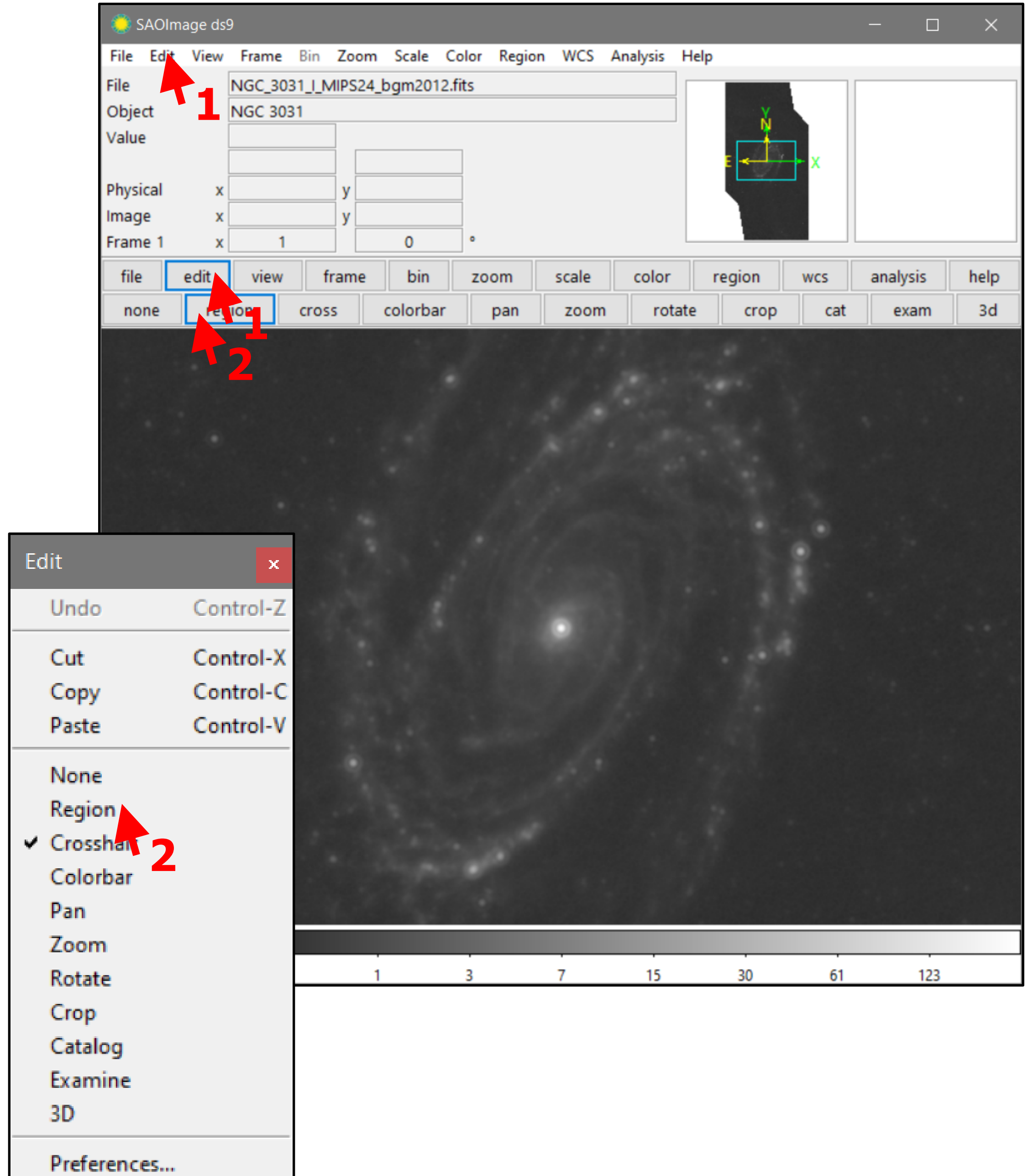


Make Science Measurements with Regions

As stated earlier, you can draw regions when "Region" is selected in the edit menu.

These regions can be used to measure the amount of light from objects in the image.

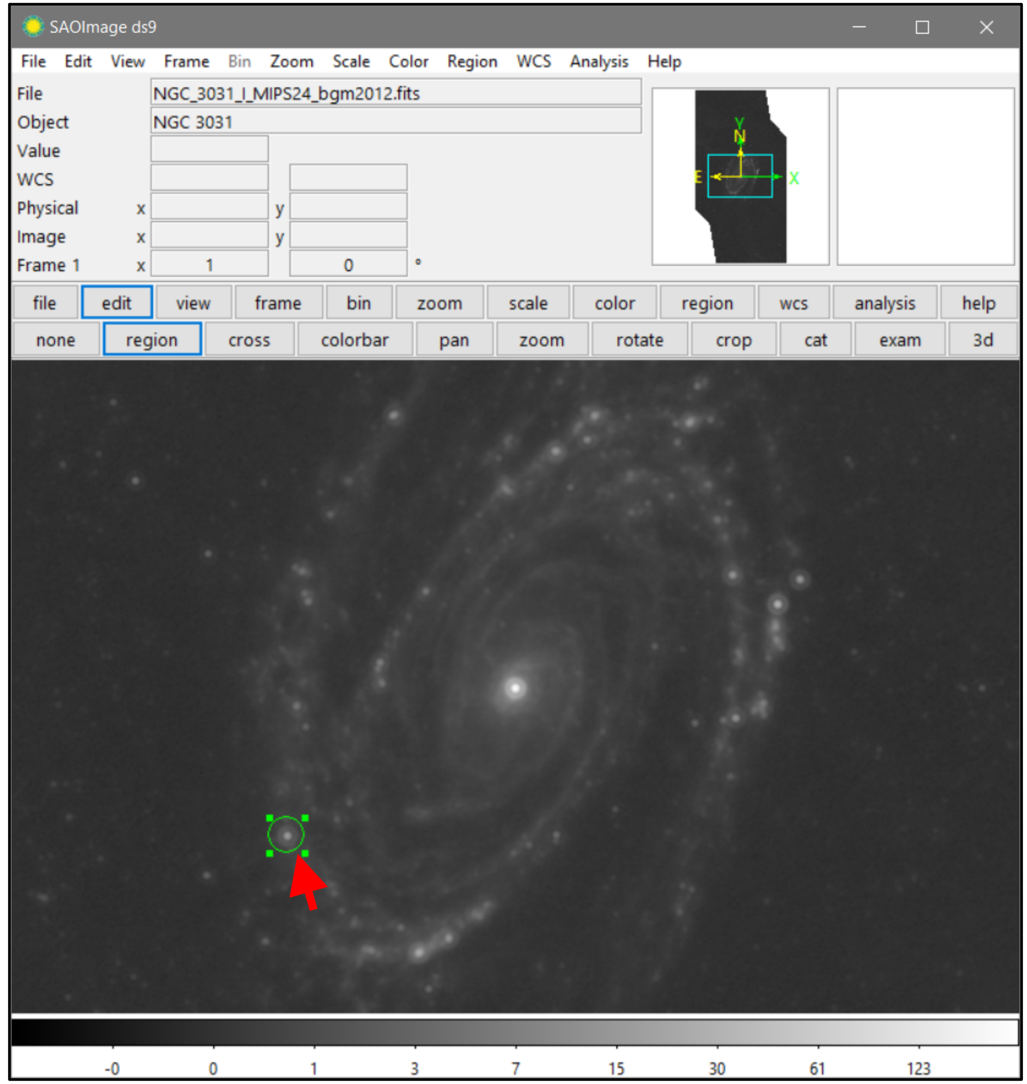
To begin, go to edit in either the menu or button bar and select "Region".



Next, left click in the image. A circle will appear.

When the circle is selected, it will have little green boxes around it. You will be able to move and resize the circle when it is selected.

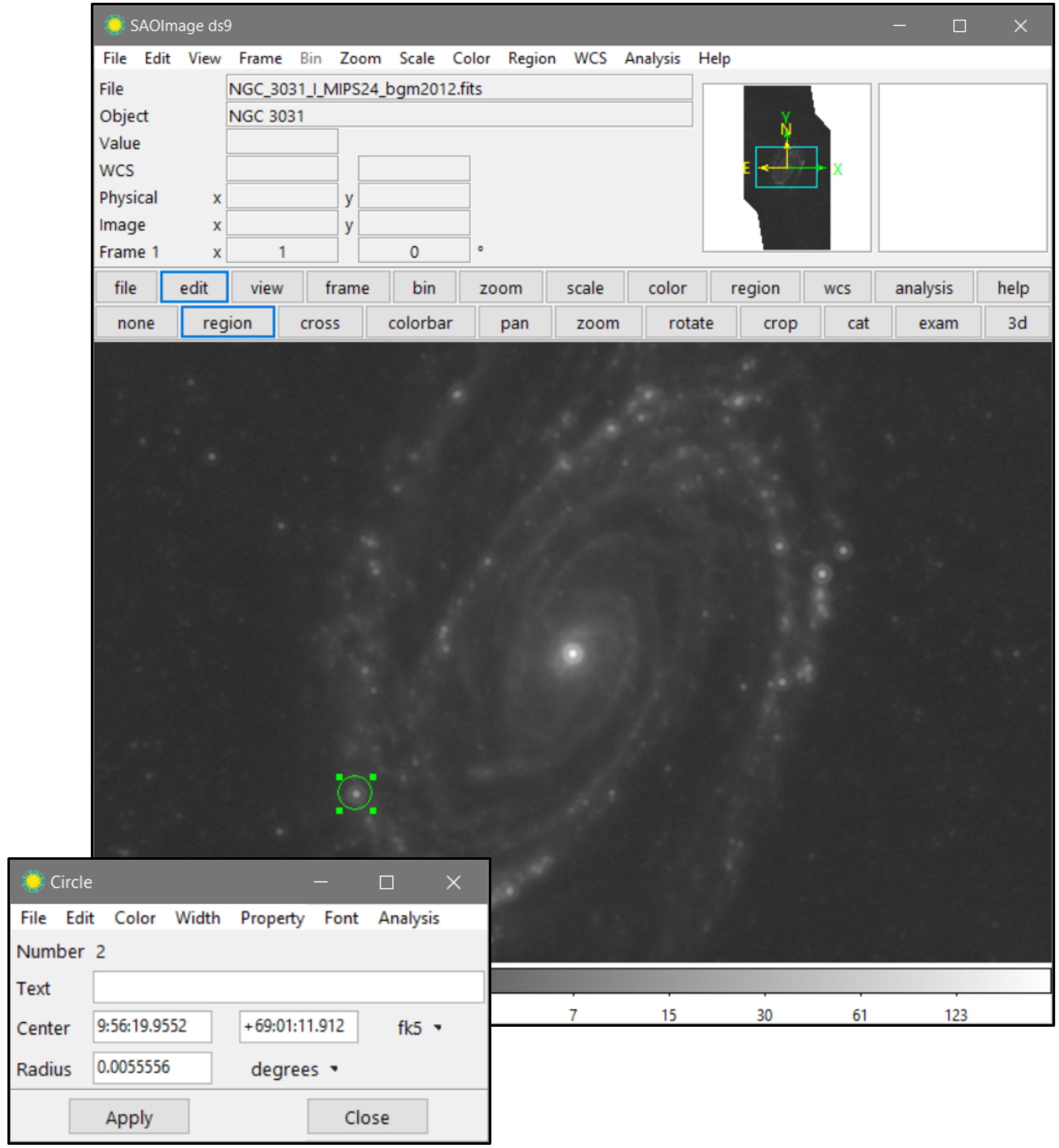
You can change the colour, shape, and line thickness of this region using options in the "Region" menu.



If you double-click on the circle, an information box with appear with the coordinates and size of the circle.

You can also open this window by selecting the region in the image and then selecting “Get Information” from the region menu.

You can put the circle in a specific position or set it to a certain size if needed.

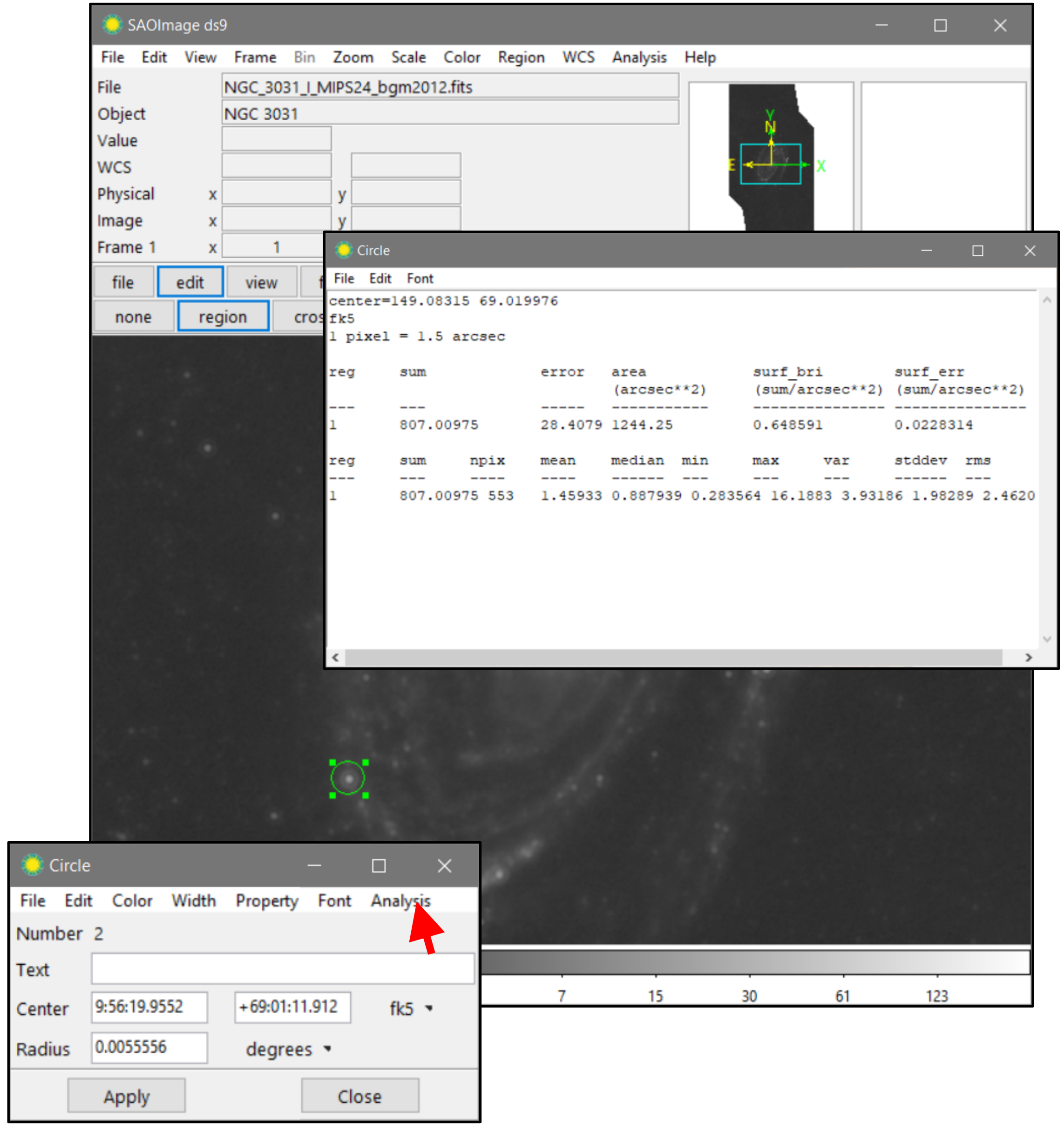


If you click on “Analysis”, a new window with statistical information appears.

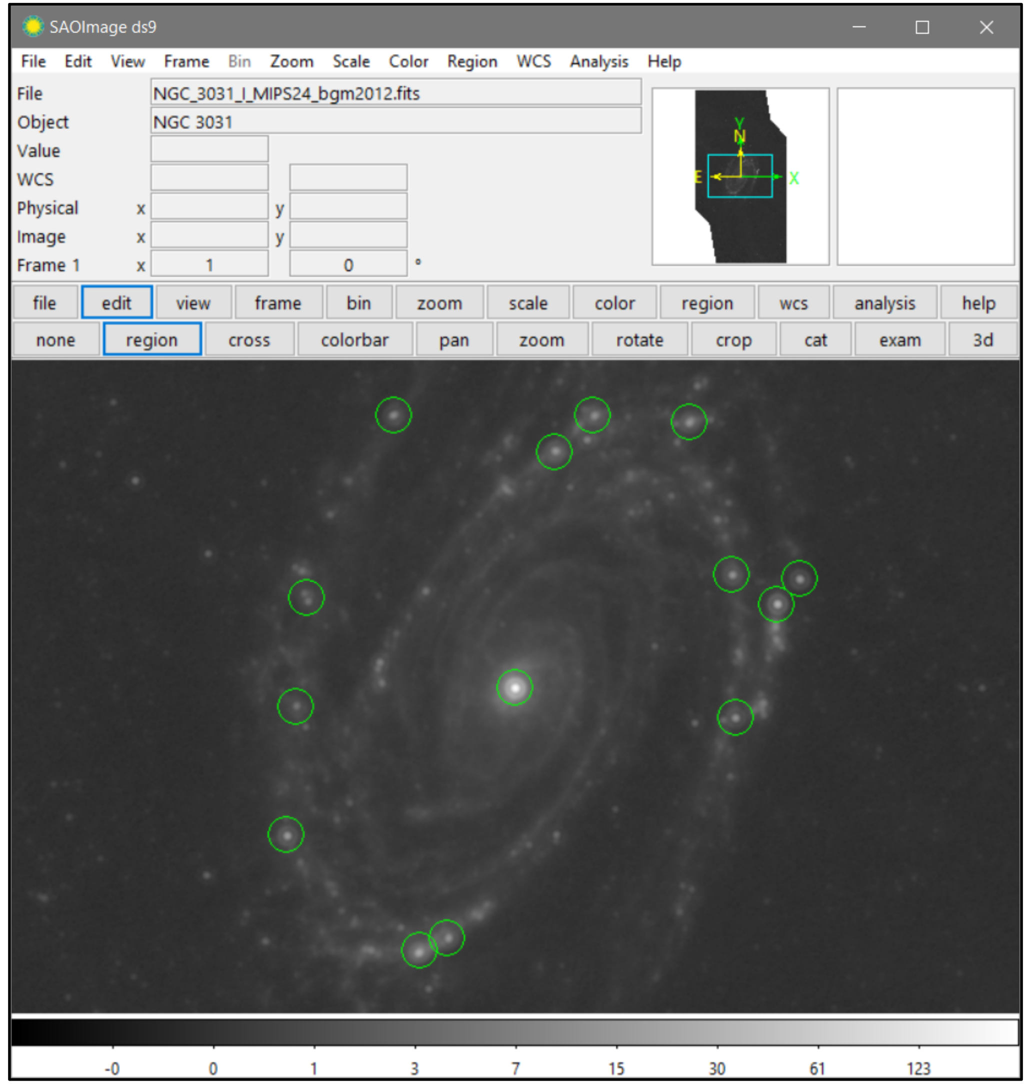
If the data are in flux units (like Jy or number of photons), you can use the sum as the signal from the source.

If the data are in surface brightness units (like MJy/sr or Jy/arcsec^2), you can use the mean or median as the signal from the region (For point sources, you should convert the sum to flux units by multiplying by the area within the circle).

If the image is in other units, you will need to look up how to convert the data to something useful, like Jy.



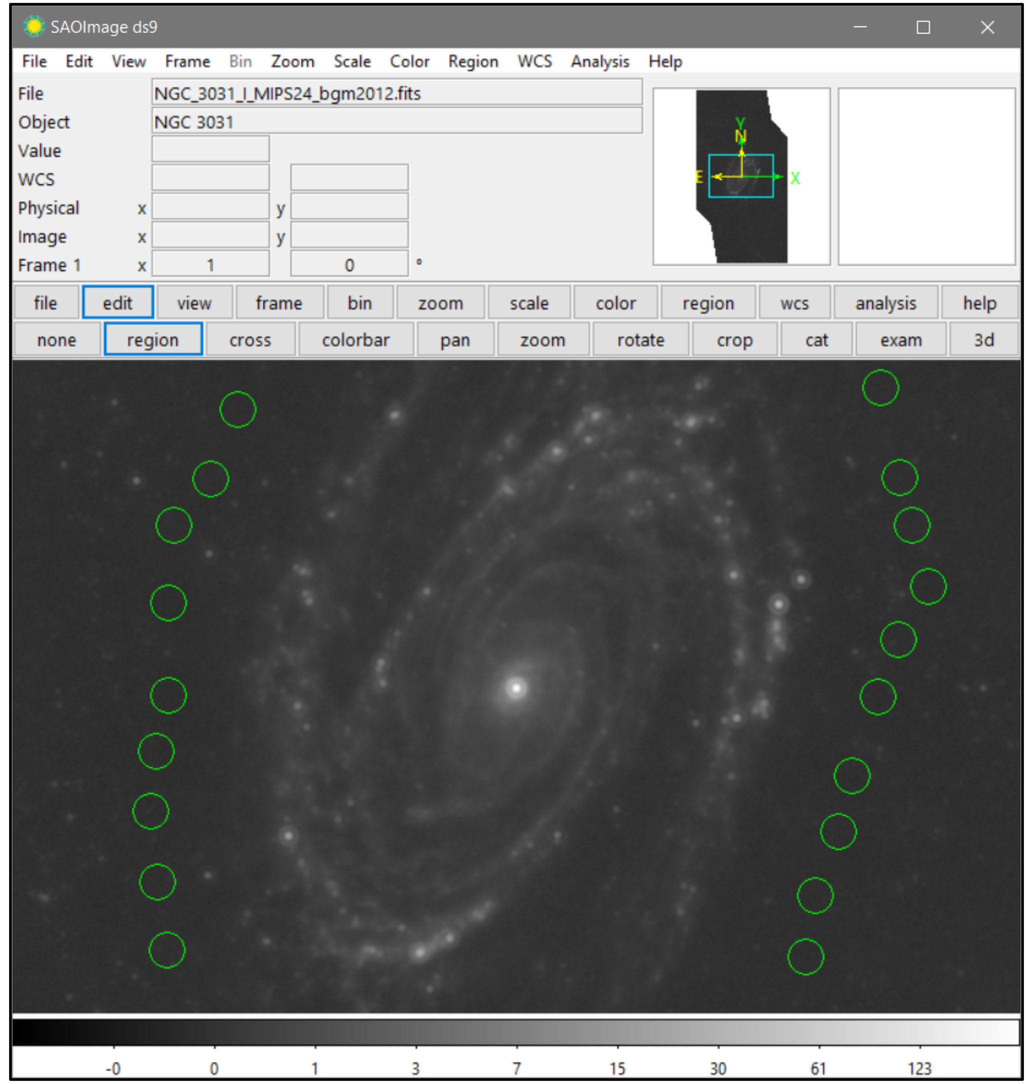
You can measure the signal from multiple regions to perform statistical analyses.



Most images also contain background emission. In other words, the sky is not completely black.

To measure this background emission, use multiple circles as the same size that you used on your sources. The average flux in these circles will be your background emission.

Subtract this background from your science target measurements to get the real signal from the science targets.



Useful Information

Websites with Example FITS Images

These websites are good places to find images to use while getting familiar with either FITS images or DS9.

- Chandra X-ray Observatory
  http://chandra.harvard.edu/photo/openFITS/
- FITS Support Office
  http://fits.gsfc.nasa.gov/fits_home.html
- George Bendo's Webpages: Science Image Gallery
  http://www.jb.man.ac.uk/~gbendo/Sci/Pict/pict_main.html
- Hubble Space Telescope
  http://www.spacetelescope.org/projects/fits_liberator/datasets_archives/

Websites with Professional FITS Image Archives

Professional astronomers use these websites to store and distribute their data, including FITS images. Many of these websites expect people to search for images of specific objects; a list of example objects is presented after this list of websites.

Some of these data may come in compressed formats such as tar, gzip, or bzip2. These files can be uncompressed in Windows using PeaZip (http://www.peazip.org/) or 7-Zip (http://www.7-zip.org/). Mac and Linux computers have software built in to uncompress these files.

It might also be necessary to add ".fits" to the ends of files to make them work in DS9.

- ESASky
  http://sky.esa.int/
- GALEX View *(requires Adobe flash)*
  https://galex.stsci.edu/GalexView/
- Herschel Database in Marseille
  http://hedam.lam.fr/
- Herschel User Provided Data Products
  http://www.cosmos.esa.int/web/herschel/user-provided-data-products
- Mikulski Archive for Space Telescopes (MAST) Portal
  https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html
- NASA/IPAC Infrared Science Archive
  http://irsa.ipac.caltech.edu/images.html
- NASA/IPAC Extragalactic Database
  http://ned.ipac.caltech.edu/
- PanSTARRS-1 Image Access
  https://ps1images.stsci.edu/cgi-bin/ps1cutouts

Websites with Professional FITS Image Archives (continued)

- Sloan Digitized Sky Survey
  https://dr12.sdss.org/fields
- Spitzer 24-160 Micron Data for the Herschel-SPIRE Local Galaxies Guaranteed Time Programs
  http://www.jb.man.ac.uk/~gbendo/exchange/SpitzerData/spitzerdata_main.html
- UKIRT InfraRed Deep Sky Surveys
  http://wsa.roe.ac.uk:8080/wsa/getImage_form.jsp

Interesting Objects

Star Forming Regions

- 30 Doradus
- IC 434 (Horsehead Nebula)
- M16 (Eagle Nebula)
- M20 (Trifid Nebula)
- M42 (Orion Nebula)
- Sgr B2

Planetary Nebulae

- Helix Nebula
- M27 (Dumbbell Nebula)
- M57 (Ring Nebula)
- M97 (Owl Nebula)

Supernova Remnants

- Cassiopeia A
- M1 (Crab Nebula)

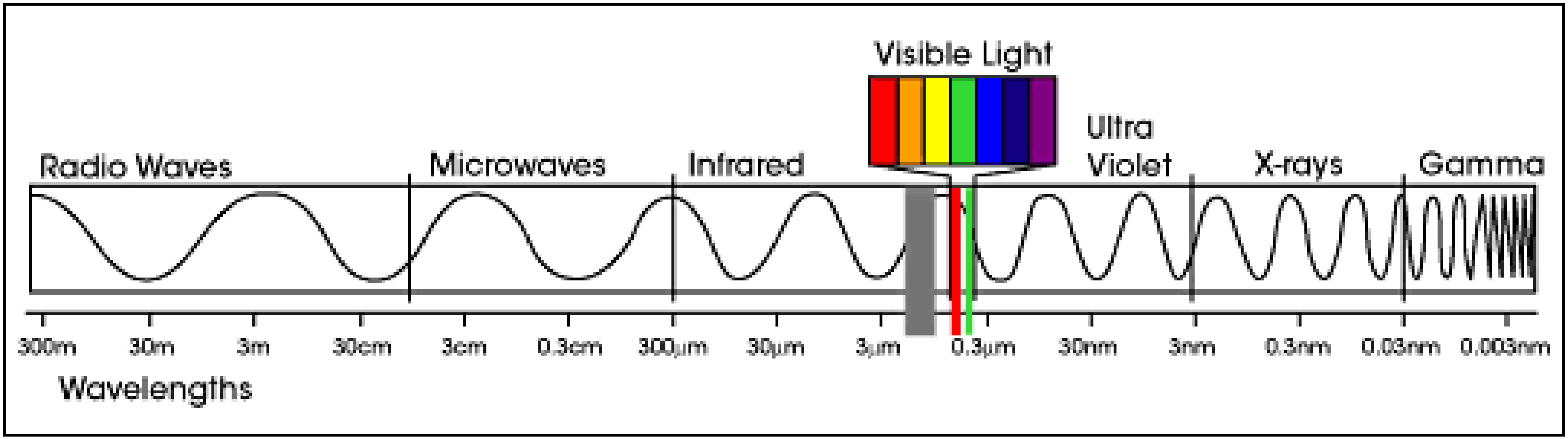
Globular Clusters

- 47 Tuc
- M5
- M13
- M15
- Omega Centauri

Galaxies

- Centaurus A
- M51 (Whirlpool Galaxy)
- M63
- M74
- M81
- M83
- M87
- M101
- M104 (Sombrero Galaxy)
- NGC 253
- NGC 300
- NGC 2403
- NGC 6946

Electromagnetic Spectrum



Electromagnetic Spectrum

Band	Wavelengths	Emission Sources
Radio	>3 mm	▪ Supernovae ▪ AGN ▪ Atomic interstellar gas (hydrogen 21cm spectral line)
Millimetre	1 mm – 4 mm	▪ Ionized interstellar gas ▪ Molecular interstellar gas (CO spectral line)
Submillimetre	250 μm – 1 mm	▪ Cold interstellar dust ▪ Molecular interstellar gas (CO spectral line)
Far-infrared	50 μm – 500 μm	▪ Cold interstellar dust
Mid-infrared	5 μm – 50 μm	▪ Hot interstellar dust ▪ Large interstellar carbon molecules (PAHs)
Near-infrared	780 nm – 5 μm	▪ Old stars
Optical	380 – 780 nm	▪ Old stars (red wavelengths) ▪ Young stars (blue wavelengths) ▪ Warm ionized interstellar gas (Hα line, Hβ line, other spectral lines)
Ultraviolet	10 nm – 380 nm	▪ Young stars
X-ray	10 pm – 10 nm	▪ Hot ionized interstellar gas ▪ X-ray binary stars ▪ AGN
Gamma-ray	> 50 pm	▪ Gamma ray bursts ▪ AGN