CRLS Astrophysics Lecture Series: Imaging basics (DS9+HST)

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Week 1

Goals

In next week's workshop, we'll learn how to work with astronomical images. We'll download images taken by the Hubble Space Telescope and use them to create color pictures of astronomical objects. The aim of this meeting is to prepare for next week's workshop by reviewing some basic concepts in modern astronomy. To work with astronomical images, we first need to understand what they are and how they are made.

Outline

Work through the following sections. In each section, read and discuss the various articles. Use the provided questions to guide your reading and discussion, but bring up your own questions as well. Write down shared questions that you will want to bring up during next week's workshop. It's OK if you don't understand every webpage listed below. Some of these are for the general public, but some are professional pages for astronomers (such as the ACS and WFC3 filter pages). See what you can make of these webpages and write down any questions that come up.

1. The electromagnetic spectrum

   What is the EM spectrum? What part of it is visible to our eyes? What part is visible to astronomers? Using which kinds of telescopes? Pay attention to the units used to describe the EM spectrum: what are nanometers, microns, and Angstroms?

   https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

2. Astronomical images

What is an astronomical image? How are astronomical images made? Describe, without going into too much detail, what happens to the light from a star once it enters a telescope. When reading about how telescopes work, pay close attention to CCDs (charged couples devices) – why are they important, and how to they work (just the basic idea, no need to go into technical details)? What are filters? What do RGB and CMYK stand for?

https://imagine.gsfc.nasa.gov/science/toolbox/images1.html

https://www.spacetelescope.org/projects/fits_liberator/improc/

https://mcdonaldobservatory.org/research/instruments/charged-coupled-devices

https://mcdonaldobservatory.org/research/instruments/ubvri-filters

3. The Hubble Space Telescope

The Hubble Space Telescope (HST, for short) is just one of many telescopes at our disposal, but arguable our most famous. Read about some of its cameras (specifically, ACS, WFPC2, and WFC3) and take note of what you've just read: what part of the EM spectrum is covered by each camera? What filters does it have? What do you think is the difference between "broad" and "narrow" filters? What is F555W? What does this name mean? Why do we say that HST has amazing resolution? What does resolution mean?

http://hubblesite.org/the_telescope/hubble_essentials/

http://science.howstuffworks.com/hubble.htm

http://hubblesite.org/the_telescope/nuts_.and._bolts/instruments/

http://hubble.stsci.edu/the_telescope/nuts_.and._bolts/res101.php

http://www.stsci.edu/hst/wfc3/documents/handouts/wfc3_brochure_200801.pdf

http://www.stsci.edu/hst/acs/documents/handbooks/current/c05_imaging2.html

http://www.stsci.edu/hst/wfc3/ins_performance/filters/

http://www.stsci.edu/hst/wfc3/documents/handbooks/currentIHB/c06_uvis06.html

Summary questions

After reading and discussing the various websites and articles, you should be able to answer the following questions. Don't worry if different people have different answers – there's more than one way to answer these questions. What's important is that you feel comfortable answering them and debating your answers.

1. If I want to make a color astronomical image, how many filters should I use?
2. What parts of the spectrum do the following filters cover? F606W, F160W, F275W.
3. If I wanted to create an RGB color image from those filters, what would their order be?
4. Would that color image be representative of what our eyes can see?
5. If I want my color image to reflect what my eyes would see, which HST filters should I use? What are their central wavelengths?
6. What are some of the differences between ACS, WFPC2, and WFC3?

Week 2

Goals

During the second meeting, we will use SAO DS9 to manipulate astronomical images (fits files) and create multicolor images from Hubble Space Telescope (HST) data. To do this, we will first learn how to use DS9 (in a very basic fashion), after which we will learn how to search the Hubble Legacy Archive (HLA; https://hla.stsci.edu/). At the end of this workshop, students will be able to download images, both in DS9 and HLA, and create multicolor images on their own. SAO DS9 is a free software that can be easily downloaded and installed at home. HLA is free to use as well.

Outline

SAO DS9 should have already been installed on the computers used in this workshop. The installation instructions are at: http://ds9.si.edu/site/Download.html On either PCs or Macs, there should now be a DS9 icon.

Part I: SAO DS9 basics

First, we will learn the basics.

1. File: Open one of the images already on the computer: File → Open: find the directory with the file, and select one of the .fits files inside.
2. Scale: The image may appear completely black. We need to re-scale it. Scale → ZScale (also check that Linear is selected). Let's play with the scaling some more. Click on "Scale → Scale Parameters" and a new window will appear. Slide the green slider to the right and watch how the scaling changes to highlight the brighter parts of the image. Slide it to the left, and fainter portions will appear.
3. Frame: Let's open another image. Click on "Frame → New Frame." The window will look blank again. Load another image, preferably of the same object but in another filter. The scaling should be the same as the previous image, but we can make sure that it's once again set to ZScale and Linear.
4. Frame: To see both images side by side, click on "Frame → Tile Frames." Then, in Frame → Frame Parameters, choose Tile → Columns.
5. Choosing which image to work in: We can switch between the images with the TAB button or by clicking on them with the mouse.
6. Panning: Once we're in an image, we can use the center button on the mouse to pan around the image. Another option is to click "Edit → Pan". Now we can use the left-mouse button to pan around the image.
7. Zooming: On the buttons just above the image pane, click "zoom," then click on "zoom in" and "zoom out." Notice that this only affect one of the images, not all of them. To lock the images so that panning or zooming in one image will do the same in all the other images:
8. Lock: Click "Frame → Lock → Frame → Image". Now, the images are locked.
9. Color: Assigns a color scheme to the pixels, based on their number count (how many photons landed in that pixel). Play with the different color schemes. Note "Invert Colormap" and "Reset Colormap."

10. Analysis: Let's download an image from one of the image servers. Click on "Analysis → Image Servers → SAO-DSS." A new window will pop up with a search bar. Type in the name of an object, e.g., M101. Play with the scaling and colormap.

Part II: Making multicolor images

Let's clear all of our open windows: Frame → Delete All Frames. You have several images already waiting to for you – let's use them first before we learn how to download data from the Hubble Legacy Archive. Let's choose the images titled "NGC 2442" - there should be three of them. Open each one in a separate frame, and look at them in parallel (Frame → Tile Frames). Make sure to lock them (Frame → Lock → Frame → Image / WCS) and that they all have the same scaling (Scale → ZScale and Linear) and color (Color → Reset Colormap). Notice how the object looks different in each filter.

Why do the images look different in each filter? Different astronomical objects, such as stars, supernovae, and nebula, emits different amounts of light in different parts of the spectrum. So, if we're looking at a nearby galaxy, for example, the bluer filters will be more sensitive to light from young, blue stars, while the redder filters will be more sensitive to old, red stars.

Now, let's combine the three images into a color image.

First, we need to work in an RGB frame. Click on "Frame → New RGB Frame." A new, small window will pop up that says "red, green, blue." The check box next to "red" will be pressed. Open the image (File → Open) corresponding to the reddest filter. It will appear completely red. Now, click on the check box next to "green" and open the image corresponding to the green filter. Repeat for the bluest filter (make sure to press the check box next to "blue" first).

You should now have a color image. To see only the color image, click on "Frame → Single Frame."

The image may not be quite so pretty yet. You may need to play with the scaling of each of the component colors to get the balance you want just right. Open the Scale Parameters window (Scale → Scale Parameters). Choose "Graph → Current Range" and either move the red and green markers, or type in the values you want.

HST images are in units of counts/s, meaning they're already scaled by the exposure time. So, to keep the same ratio between the three images, try to increase or decrease the scaling limits by known factors (e.g., a factor of 2). Otherwise, your color balance could quickly get weird. To reset everything, simple choose "Scale → ZScale" in each color (i.e., by clicking the check box next to each color and repeating).

Save image: to save any image we make, click "File → Save Image → JPEG". Give the file a name and make sure you notice where you're saving it (look at the bar at the top of the new window). Once you click "save", another window will come up with a slide bar: drag it all the way to the right (to 100%) to make sure you save the image at the highest quality.

Save RGB image: you can also save color images in .fits format, so that next time you use DS9, you can immediately open the color image, without needing to go through Part II over again. Click on "File → Save As → RGB Image" and follow the prompts.

Part III: Downloading data from the Hubble Legacy Archive

We will use the HLA to search for data on specific objects, such as nearby galaxies (M51, for example) or globular star clusters (e.g., M2). After inputting the name of the object into the search tab, HLA will output a table that lists the available images of that object. We will use the following tabs:

- Level: this shows how processed the image is. The higher the number, the more polished the image. Level 2 images are fine. Level 5 images are the cleanest, but also heaviest images. They take a longer time to download and work with.

- Detector: tells us which instrument was used. We will only use imaging cameras: WFPC2, ACS, and WFC3.
- Spectral_Elt: the filter in which the image was taken. It's usually best to use wide-band filters (e.g., F555W). For multicolor images, we need to make sure that there are at least 3 images with different wide-band filters that we can use. Don't use images with filter combinations (e.g., F450W/F555W/F814W), as those have already been combined by the HLA.
- ExpTime: the exposure time of the image (how long the telescope's shutter was open). We'll stay away from images with 0 exposure time.
- RA and DEC: these are the coordinates of the center of the image. When choosing three images to combine, we want to make sure that they all have the same center.
- Display: clicking the link will open up a new window with a preview of the image. We can use this to make sure that we want to download this image.

Once we've chosen three images to download, click on the rows, so that they become highlighted in dark green. Then, above the table, press the button marked "Add selection to cart." Above this button, the tab labeled with a shopping cart will turn yellow. Clicking on it will take us to the checkout window, where we can simply press the "Fetch HLA data" button. A zip file with our images will begin to download.

Extract the files into a folder (easiest to do by double-clicking the zip file you just downloaded, then dragging the files inside into a folder of your choice).

Now that you have your own images, go back to Part II and use them to create your own color images.