(Introduction to) Getting Your Hands on Real Astronomy Data

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Outline

- Jumping right in: Citizen Science
- FITS vs. JPG, GIF, etc.: why this matters
- Crash course in astronomical images
  - Color, artifacts, resolution
- Astronomical archives: IRSA
- *Key ideas have a box.*

Will put up a web page at the end which has a copy of this talk and links mentioned here.

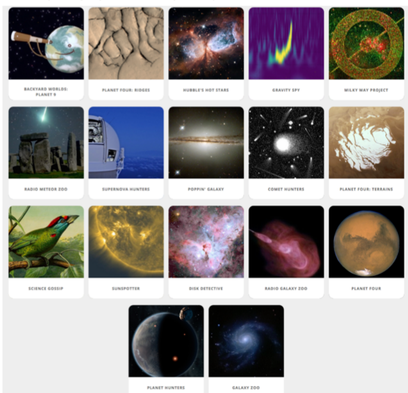
(Astronomical) Citizen Science

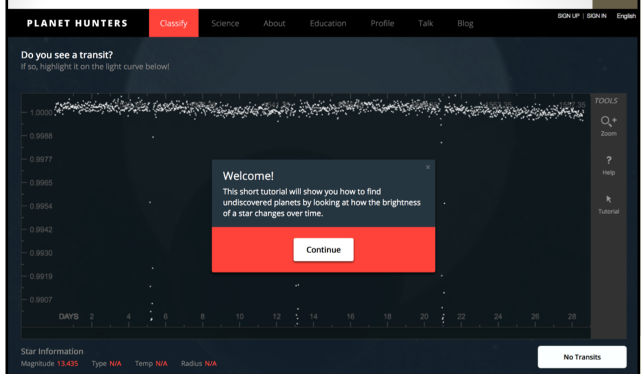
- Many, many programs out there.
- Most are :
  - Entirely web-based.
  - Require no special software (other than a web browser).
  - Require no deep astronomical knowledge.
- Some have lesson plans/labs/exercises.
- Some have hooks to go further when you are ready.

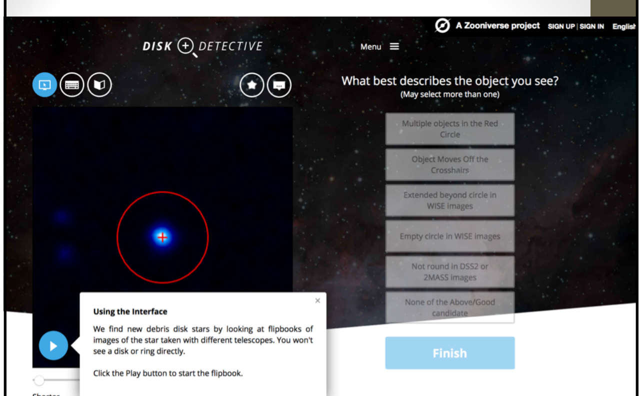
Many choices

- Zooniverse has a TON – go to the list of all Zooniverse projects, and scroll through the list!
- SETI at home – look for ET in radio signals
- International Observe the Moon Night – moon watching
- Globe at Night – light pollution
- Great World-Wide Star Count – also light pollution
- Stardust at Home – look for dust particles in aerogel
- Citizen Sky – part of AAVSO, variable stars
- Cosmo Quest – Mars, Vesta, Mercury, and Moon crater mapping
- *I'm sure I am missing some…*

Zooniverse "menu"

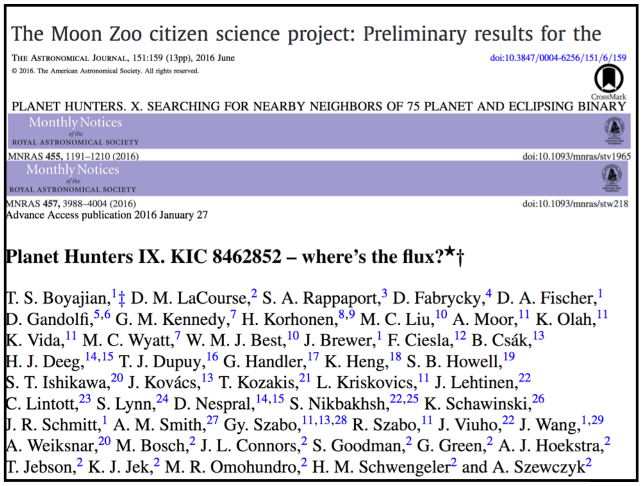






Nice things

- Zooniverse (and others) have tutorials to help you get started.
- Usually the tasks they are asking you to do are not difficult and can be easily explained via the tutorials.
- Kids can participate to the same degree as adults.
- ***You do not have to be perfect!*** Many people look at each item, and mistakes average out.
- Why are they going through this level of effort to get your help? Because the human eye is ***really*** good at identifying patterns, often way better than computers!
- You are contributing to real science!


The Moon Zoo citizen science project: Preliminary results for the

The Astronomical Journal, 151:159 (13pp), 2016 June doi:10.3847/0004-6256/151/6/159
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PLANET HUNTERS. X. SEARCHING FOR NEARBY NEIGHBORS OF 75 PLANET AND ECLIPSING BINARY

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **455**, 1191–1210 (2016) doi:10.1093/mnras/stv1965

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **457**, 3988–4004 (2016) doi:10.1093/mnras/stw218
Advance Access publication 2016 January 27

Planet Hunters IX. KIC 8462852 – where's the flux?★†

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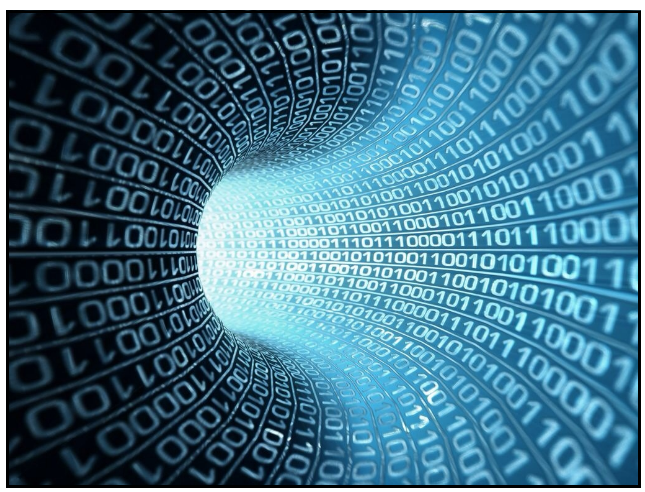
If that's the only thing you remember from this talk, and especially if you really get into these, then I've done my job…

However… maybe that just whets your appetite and you want more, more, more!!



Astronomical Archives

- It's really true that there are **more data** than professional astronomers can hope to completely mine, with more coming in **all the time**.
- (Professional astronomers often pull off the low-hanging fruit, but that doesn't mean there's no other fruit on the tree!)
- **Any facility that comes from public funding is supposed to have a publically accessible archive**. **These are your data**!
- NASA is super good about this. NSF getting there. Europe is catching up. Other countries (e.g., China) not so much…
- NASA data alone will keep you busy for quite a while.
  - Astronomical data ←
  - Moon, planetary data
  - Earth observing data

Astronomical Archives cont'd

- Archives designed for the professional astronomy community.
- Archives usually designed to be easily accessible .. And if the archive team has done their job, **you** should be able to get into it without trouble!
- However, you do have to "reach across the barrier" to become familiar with some conventions, jargon, etc. It's not going to be packaged up for you with a nice little ribbon!

Concept #1

Don't use MSIE
(Internet Explorer!)

Ditch MSIE

- Don't use it as your default browser.
- Go get Firefox or Chrome.
- MSIE is buggy and has security holes.
- Most astronomers use Mac or Linux machines, so are not using MSIE.
- Most archives are operating more or less on a shoestring. It takes a lot of resources to make sophisticated web-based tools work on MSIE. With very few astronomers using MSIE, that's a lot of resources to pour into something with little reward. Thus, MSIE support is often dropped, **so some archives won't work with MSIE.**

Concept #2

Image "mechanics"

Concept #2a: Bit depth

- All digital images are "ones and zeroes" – your computer just knows how to handle those ones and zeroes.
- Images from your digital camera (JPGs, GIFs) are typically "8 bits deep."
- That means that there are only 2 to the power of 8 (2^8=) 256 discrete levels of information for each pixel (per color plane).
- That usually doesn't matter for you (unless you are a graphic designer or web developer…or an astronomer).
- Astronomical images have a much greater **dynamic range**; they are at least 16 or even 32 bits deep -- that is, there are at least 2 to the power of 16 (2^{16}) or 65,536 and possibly (2^{32}=) 4.3 billion possible discrete levels of data for each pixel.
- That kind of detail gets lost when you save an image as a JPG. *The computer is compressing 65,000 levels into 256*.

Think of bit depth like this…

Array of thimbles

Can't get very much more than a dribble of water in each one. ("256 drops"!) Each overflows quickly! This is ok for images taken with your cell phone.

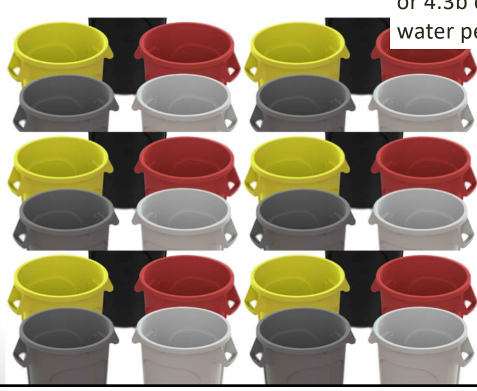
Teacups are bigger

Now can get more than a dribble of water in each one. But they still overflow easily!

Ooh! Trashcans are bigger still!

Array of trashcans!

LOTS of water in each one! (65k or 4.3b drops of water per can!)

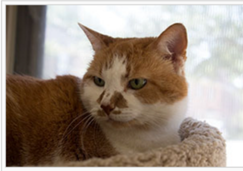


Concept #2a: Bit depth

- “8 bits deep” = Images from your digital camera (JPGs, GIFs) = 256 (=2^8) drops can fit in each bucket (pixel).
- “16 or 32 bits deep” = Astronomical images = 65,536 (=2^{16}) drops can fit in each bucket, or even 4.3 billion (=2^{32}) drops can fit in each bucket.
- [AND, in your camera, you have one array of buckets for each color (red, green, blue), but we will get to that momentarily!]
- The analogy is imperfect, but does ok. Higher numbers of pixels in your camera (e.g., comparing cell phone to “real” camera) usually refers to how densely the buckets are packed together and how many total buckets there are. How deep the buckets are = bit depth.
- Key concept: astronomical images can hold more information than JPGs or GIFs.

Concept #2b: Compression

- JPGs are “lossy compressed” – they compress the data such that the file takes up less disk space, but it actually loses information!
- Someone worked hard to collect all those photons .. Don’t lose information at the last step!
- (Loss-less compression is ok.)
- If you want to play with real astronomical images, you can’t be using JPG, GIF, PNG…



Low compression (high quality) JPEG

High compression (low quality) JPEG

Concept #2c: FITS files!

- **FITS = Flexible Image Transport System**
- Most professional astronomers use this format. Not compressed, no loss of information at all.
- FITS images consist of a plain text header and the binary image.
- The header usually contains “metadata” – information about the data: coordinates of the image; maybe things about, e.g., target, telescope, astronomer(s), observation date/time, wavelength, even data reduction steps.
- The binary image can be one plane or many planes of images. It can also be a table of data (like a spectrum, or literally a table).

FITS, cont’d

- Need to have software that can read FITS.
- Image J, MaxIm DL, …
- Photoshop (not free) has a free plugin (FITS Liberator).
- Astronomers like free software.
  - IRSA tools I will show you shortly.
  - ds9 (Google that with “Harvard” to find it).
  - Python tools.
  - …

Concept #3

Color in images

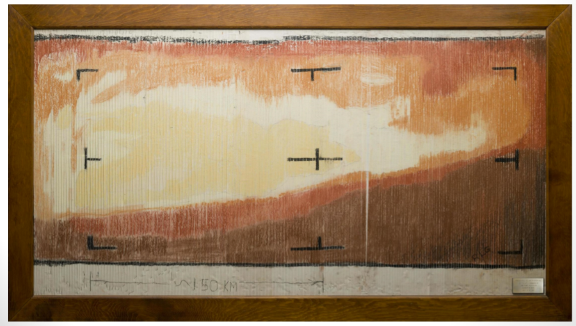
Concept #3a: Color images

- Ok, so we have our array of 'buckets' that have collected 'water' (light). How will we display those water levels?
- How will we represent the numbers on our screen?
- (*historical detour…*)

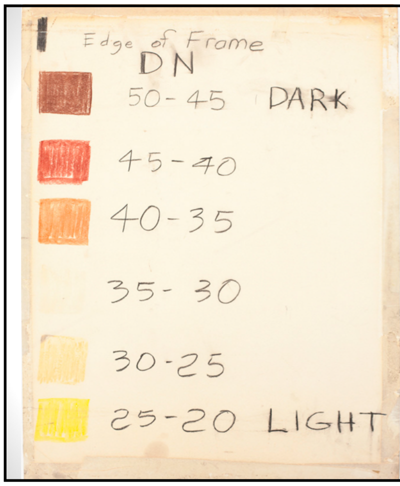
Mariner 4, July 15, 1965

First image from Mars

http://www.directedplay.com/first-tv-image-of-mars/



…print out the digits and color over them based upon how bright each pixel was.



- Brown/red color scheme, but didn't know Mars was red.
- Was looking for the colors that best represented a grey scale, **since that was what they were going to get anyway.**
- Could have been green or purple!

Hand-done Mars image (left) and actual Mariner data (right).

Color-by-number

0 1 2 3 4 5 6 7 8

Within an image, assign a number to a color.

What if have values more than 8?

Color-by-number

0-1 2-3 4-5 6-7 8-9 10-11 12-13 14-15 16-17

Now you can show data ranges from 0-17 (not just 0-8).

What color should 7.9 be?

Color-by-number

0-1 2-3 4-5 6-7 8-9 10-11 12-13 14-15 16-17

Now you have a more continuous spectrum of colors.

What if you have numbers >>17?

Color-by-number

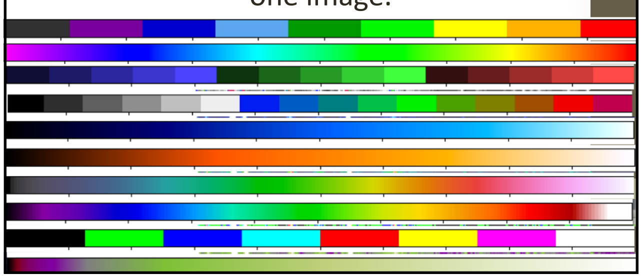
10^0 - 10^1 10^1 - 10^2 10^2 - 10^3 10^3 - 10^4 10^4 - 10^5 10^5 - 10^6 10^6 - 10^7 10^7 - 10^8 10^8 - 10^9

Now you can display a MUCH larger range of numbers!

But, you are still working with just one image. Values from that one image are displayed as a color.

Color Tables

Color tables describe the range of colors to which you are mapping the data values from one image.



Color Stretch

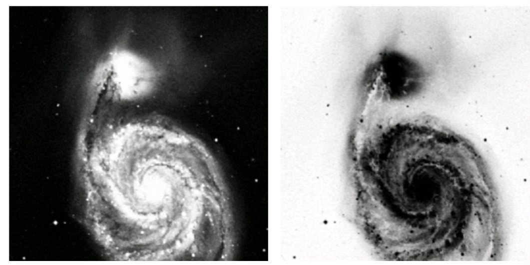
Color stretch describes how you translate the the range of data values to the range of colors from one image.

0	1	2	3	4	5	6	7	8
0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17
10^0 - 10^1	10^1 - 10^2	10^2 - 10^3	10^3 - 10^4	10^4 - 10^5	10^5 - 10^6	10^6 - 10^7	10^7 - 10^8	10^8 - 10^9

(I've demonstrated linear and logarithmic stretches here, but there are myriad others.)

One image

- One image can be represented as shades of grey. (or red pastels like Mars image!)
- Astronomical images in one filter are often shown in greyscale or reverse greyscale.
- This is the least distracting way to display details in the image!
- (Also uses less printer ink!)



Concept #3b: Color images

There is no such thing as a color image!

Whut?

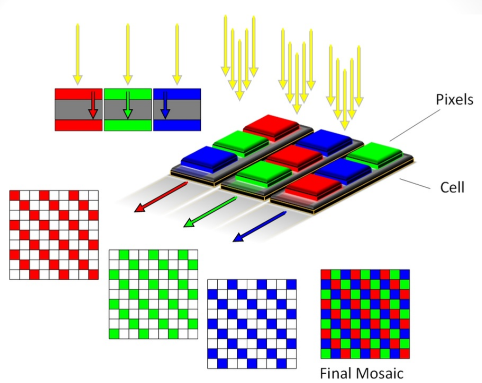
One image … to 3-color image!

- What if we took one image, and rather than scaling it to shades of black to white, did scales of black to red?
- Another image: black to green
- Another image: black to blue
- **Stack them up**: this is how you (your tv, your camera) construct a 3-color image!
- (faint in all 3=black; bright in all 3=white)

All color images ..

- ..**are made up of 3 (sometimes 4) separate images**.
- Photographs: 3 emulsions (R,G,B)
  - (RGB=red, green, blue)
- Digital cameras/TVs: 3 sets of pixels (R,G,B)
- Digital systems sometimes have c,m,y,k
  - (cyan, magenta, yellow, “key”=black)
- Astronomical images have filters!

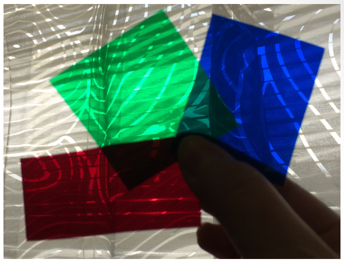
Demonstration of 3-color images from 1902



Astronomy

- You take an image in one filter....

Filters



- Kinda sorta like pieces of colored cellophane (here, theater gels).
- Only let in light over a narrow(er) range in wavelengths.
- It is not a coincidence that I picked red, green, and blue (R, G, B) here!
- Purpose: Make the light going through your telescope go through a filter before it hits your detector. Only record light that makes it through the filter.

Astronomy

- You take an image in one filter.
- You assign a color to an image from that filter.
- Repeat as necessary!
- Conventionally shortest wavelength is blue, longest wavelength is red.

- Assigning shades of color? Can do it ANY WAY YOU WANT.
- How you map the numbers to the colors matters for what details you bring out in the image.

"True color"

- Lots of astronomy public images describe things as 'true color' or 'false color'.
- What is "true color", really?
  - http://www.planetary.org/blogs/emily-lakdawalla/2015/12291508-two-epic-photos-of-earth.html
- "False color" makes it seem like we're hiding something.
  - But how do you make a "true color" IR image?
- "**Representative color**" is a better choice.

Common misconception

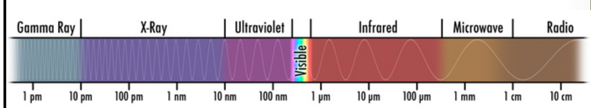
- Some people have the (incorrect) idea that astronomical images are obtained first, then broken into colors later.
- If you think of taking just one image and changing the color table, then yes, that works.
- But to make a color image, you need three images taken in different filters (like R, G, B).
- **You can't separate the photons after you record them**. You have to take 3 images in 3 filters, then combine them; you can't separate them afterwards.

Concept #4

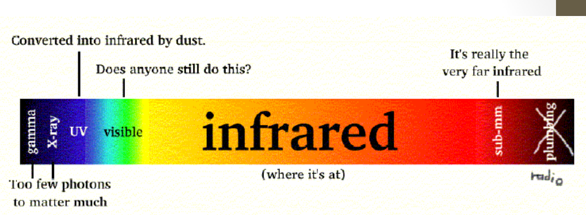
Astronomical data…

Concept #4a: multiple wavelengths!

- In astronomy, we're studying things we can never visit (or often even see from another angle).
- We have to take advantage of all the light we get from these things, even light that doesn't make it through the atmosphere to us!
- Lots of telescopes, data, **archives** from gamma rays through radio!



IPAC's Electromagnetic Spectrum



Slide from G. Rieke

Concept #4b: sky coverage, resolution

- Not every telescope looks at everything in the sky. (Some are surveys, many are not.)
  - In any given archive, your object may not have been observed. (yet?)
- Different telescopes may use different wavelengths of light (radio through gamma rays).
- Different telescopes have different pixel sizes, so a "pinpoint" of light may look like a pinpoint to one telescope but a much larger blob to another.
- (Also sometimes there are real astrophysical differences so what looks like a point source at one wavelength may legitimately be a blob at another wavelength.)

M16: Pillars of Creation

HST-WFPC2 (optical)

Hester & Scowen (Arizona State/ NASA), Nov 1995

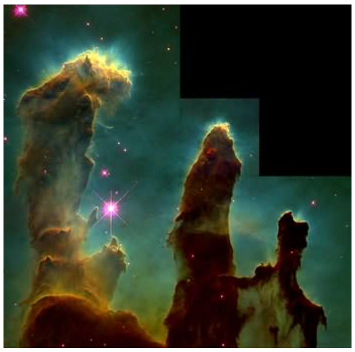
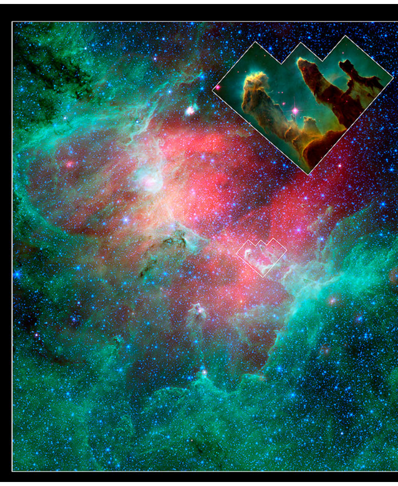


Image is ~1.2 arcmin square

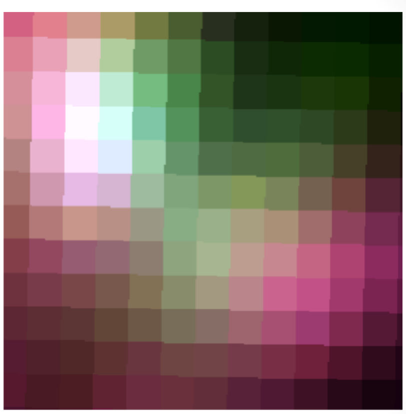
RGB image!

Blue=[O III] (5007 A); Green= Hα (6560 A); Red=[S II] (6731 A)

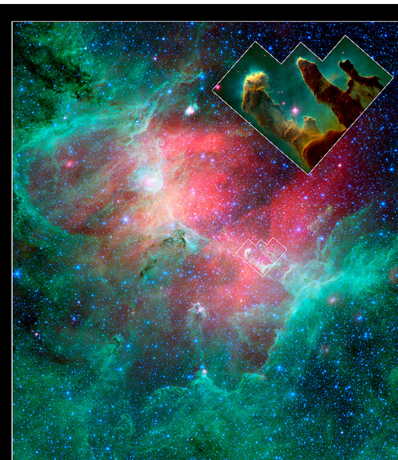


Spitzer : 4.5, 8, 24, and 70 microns *(cmyk image!)*

(Flagey et al. 2007)



IRAS : 12, 25, 100 microns



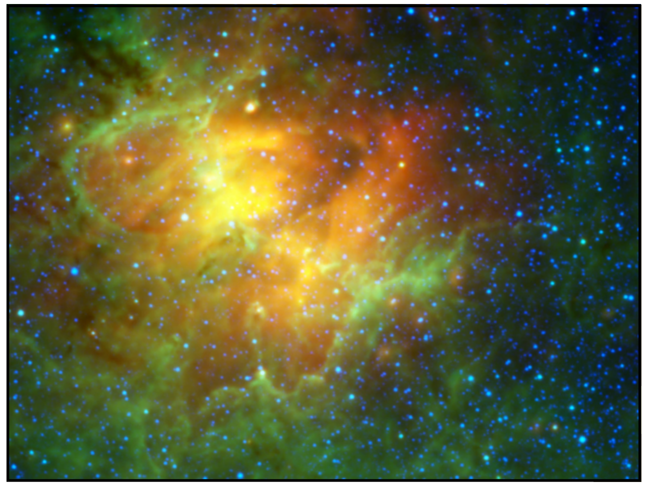
Spitzer : 4.5, 8, 24, and 70 microns

(Flagey et al. 2007)

Herschel : 70, 160, and 250 um.

Dust is ~10K (red) to ~40K (blue).

ESA/Herschel/PACS/ SPIRE/Hill, Motte, HOBYS Key Programme Consortium



Concept #5 (last one!)

Artifacts!

Concept #5: Artifacts

- You're working with real data.
- Not prettied-up for public consumption.
- There will be artifacts – that is, stuff that isn't really part of the sky – in the image.
  - It's part of how the telescope responds to light, or a plane flying through the image, or even a bit of dust.
- Many big images are actually composed of lots of smaller ones, knit together ("mosaic").
  - You may be able to see these tile boundaries.

Artifacts

- Neil deGrasse Tyson on Colbert: "**Excuse me. Just because you don't understand what you're looking at doesn't mean it's aliens**."
- If you find something that looks weird, DO NOT assume it's really in the sky. It is much more likely to be saturation effects, scattered light, a plane, resolution issues, just how the telescope responds to bright light … Read all the documentation and understand the possible artifacts … educate yourself, try to convince a friend that it's not artifacts.
- (Don't immediately email the archive's helpdesk that you've found evidence of alien life that the government has been hiding …)

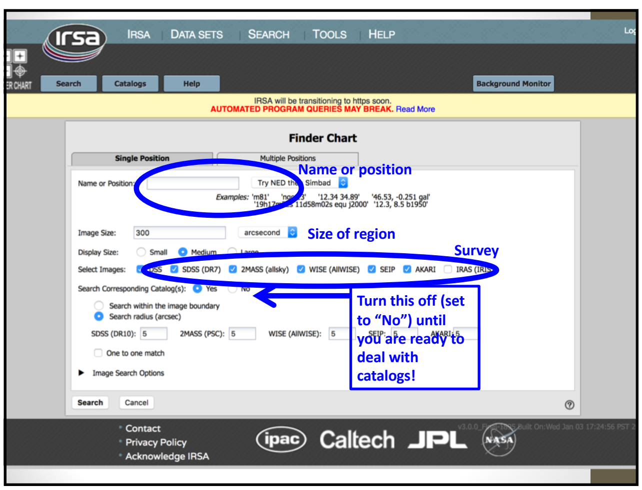
OK, now … real archives!

NASA Astronomical Archives

- IRSA (@Caltech) – Infrared & longer wavelengths
- Exoplanet Archive (@Caltech) – exoplanets
- NED (@Caltech) – galaxies
- MAST – Optical
- HEASARC – High energy
- ADS – Literature
- (Other US archives, plus Europe, Canada, …)

IRSA

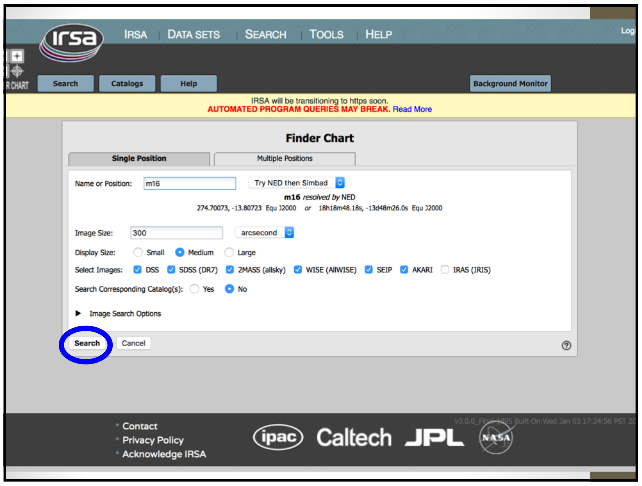
- IRSA = Infrared Science Archive = where I work!
- Physically at Caltech.
- *Running* towards petabytes of data!!
  - (1 PB=1024 TB=10^6 GB)
- All-sky surveys and pointed observatories. Big and small data sets.
- Many of the largest data sets in the same sort of interface.
- Going to point you towards Finder Chart because it gives you the same chunk of sky in several wavelengths from several different surveys all at once.
  - http://irsa.ipac.caltech.edu/applications/finderchart/

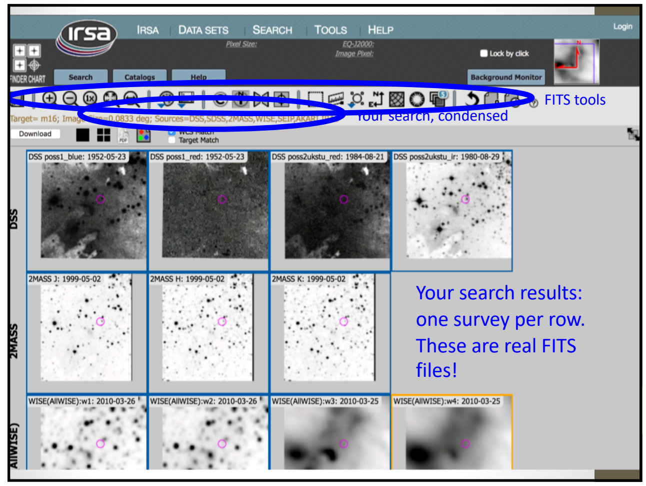


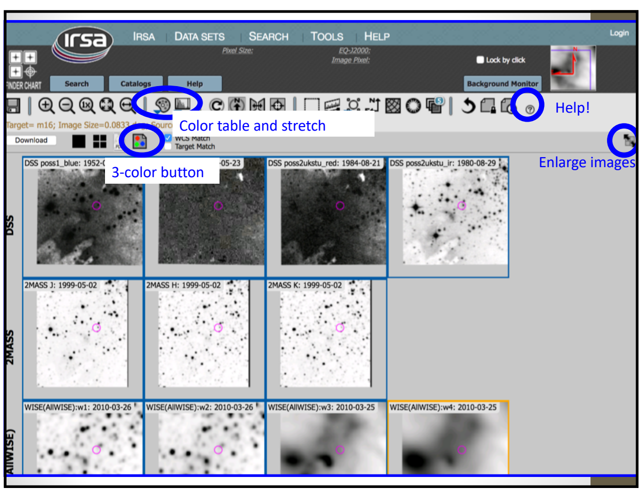
Bands

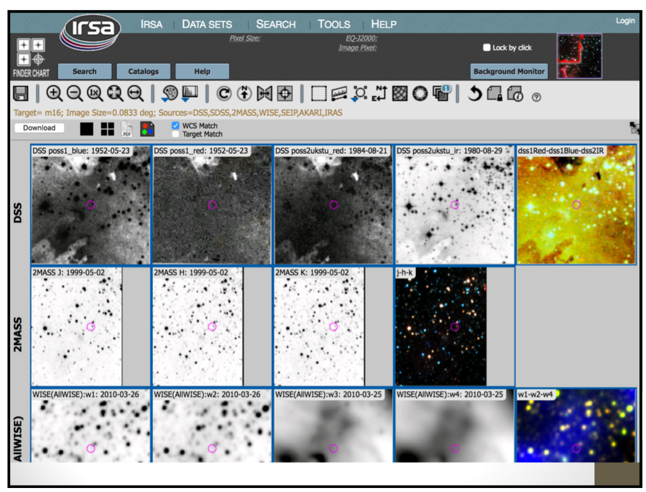
- ***Optical***: DSS (Palomar Observatory SS): blue, red, NIR
- ***Optical***: SDSS (Sloan Digital SS): *ugriz* (blue to NIR)
- ***Infrared***: 2MASS (2-Micron All SS): *JHK* (NIR, 1-2 microns)
- ***Infrared***: WISE (Widefield Infrared Survey Explorer): 3.5, 4.6, 12, 22 microns
- ***Infrared***: SEIP (Spitzer Enhanced Imaging Products): 3.6, 4.6, 5.8, 8, 24 microns
- ***Infrared***: AKARI (Japanese satellite): 60, 90, 140, 160 microns
- ***Infrared***: IRAS (Infrared Astronomy Satellite): 12, 25, 60, 100 microns

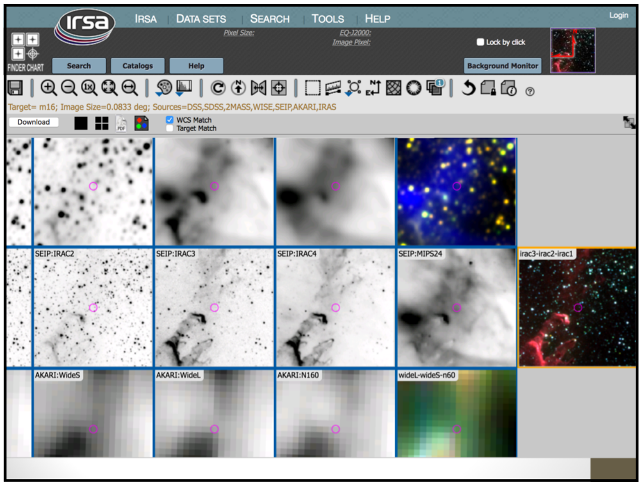
- Can also load in a FITS file from other IRSA holdings, off your disk, or off the web!

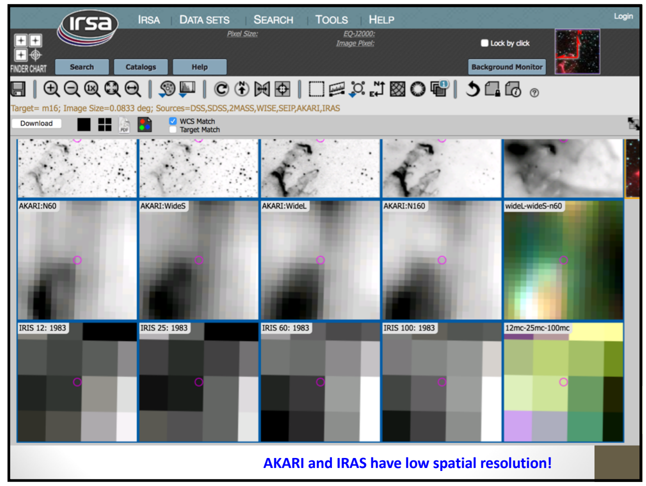

IRSA
DATA SETS
SEARCH
TOOLS
HELP
Search
Catalogs
Help
Background Monitor
IRSA will be transitioning to https soon.
AUTOMATED PROGRAM QUERIES MAY BREAK. Read More
Finder Chart
Single Position
Multiple Positions
Name or Position:
m16
Image Size:
300
arcsecond
Display Size:
Small
Medium
Large
Select Images:
DSS
SDSS (DR7)
2MASS (allsky)
WISE (AllWISE)
SEIP
AKARI
IRAS (IRIS)
Search Corresponding Catalog(s):
Yes
No
Image Search Options
Search
Cancel
Contact
Privacy Policy
Acknowledge IRSA
Caltech
JPL

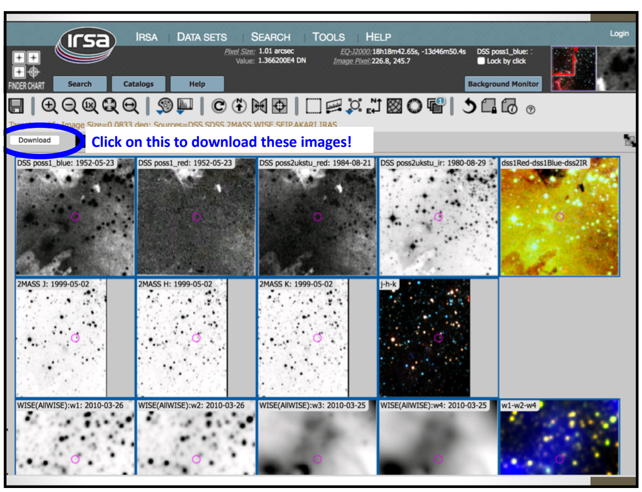

FITS tools
Your search, condensed
Your search results: one survey per row. These are real FITS files!
DSS
2MASS
AllWISE

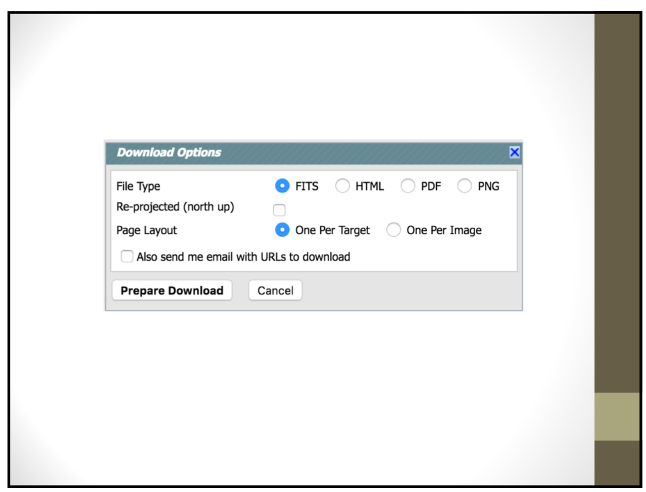

Help!
Color table and stretch
3-color button
Enlarge images
DSS
2MASS
AllWISE


DSS
2MASS
AllWISE


IRSA
DATA SETS
SEARCH
TOOLS
HELP
Search
Catalogs
Help
Background Monitor
Target= m16; Image Size=0.0833 deg; Sources=DSS,SDSS,2MASS,WISE,SEIP,AKARI,IRAS
Download
SEIP:IRAC2
SEIP:IRAC3
SEIP:IRAC4
SEIP:MIPS24
irac3-irac2-irac1
AKARI:WideS
AKARI:WideL
AKARI:N160
wideL-wideS-n60


AKARI:N60
AKARI:WideS
AKARI:WideL
AKARI:N160
wideL-wideS-n60
IRIS 12: 1983
IRIS 25: 1983
IRIS 60: 1983
IRIS 100: 1983
12mc-25mc-100mc
AKARI and IRAS have low spatial resolution!


Download
Click on this to download these images!
DSS poss1_blue: 1952-05-23
DSS poss1_red: 1952-05-23
DSS poss2ukstu_red: 1984-08-21
DSS poss2ukstu_ir: 1980-08-29
dss1Red-dss1Blue-dss2IR
2MASS J: 1999-05-02
2MASS H: 1999-05-02
2MASS K: 1999-05-02
j-h-k
WISE(AllWISE):w1: 2010-03-26
WISE(AllWISE):w2: 2010-03-26
WISE(AllWISE):w3: 2010-03-25
WISE(AllWISE):w4: 2010-03-25
w1-w2-w4


Download Options
File Type
FITS
HTML
PDF
PNG
Re-projected (north up)
Page Layout
One Per Target
One Per Image
Also send me email with URLs to download
Prepare Download
Cancel

Challenges to explore

- For your favorite object, what is bright and what is faint in each wavelength (image)? Is it the same things that are bright in each one?
- Go get a Messier object of each broad type (nebula, globular cluster, galaxy) and see what it looks like across these wavelengths. You may need to request different sizes of images! Which Messier objects look different and which look the same across these wavelengths?
- Go find images of something you imaged with your own setup. Can you make a 3-color image with your image as one of the color planes? (In order for this to work, the astrometry in the FITS header of your image must be good! Try http://astrometry.net if you need to fix your header.)
- IRSA's YouTube feed has several movies on Finder Chart and the other tools at IRSA. ☺

More interested in the planets?

- There is a HUGE, vibrant community of "amateurs" who play with NASA images of planets (Cassini, Juno, Mars rovers/spacecraft, …)
- Images are posted to these archives as soon as possible after downloading from the spacecraft; often you are looking at them at the same time the scientists are.
- Emily Lakdawalla (at the Planetary Society, http://www.planetary.org/) is a **huge supporter of/advocate for** this community, and has *many* tutorials on how to get access to and work with those images.

Summary

- A lot of data already out there. A lot available via web interfaces.
- You can do citizen science and really help out!
- You can poke around in the archives and get real data but you do need to know some basics:
  - FITS files not PNG, GIF, JPG.
  - You can change the scaling and color table to whatever you want to bring out whatever details you want.
  - Weirdness in the images = probably artifacts, not aliens ☺
  - Poke around in the web interface – you can't break anything, and you can learn some interesting things!
- Other archives too, and there is a rich community of people working with images from other planets in our SS.

For more information

This takes you to a web page that has links to all the stuff I talked about (plus a copy of the talk).

http://web.ipac.caltech.edu/staff/rebull/outr/datalinks.html

Do you know a high school educator who wants to get involved in real research? Ask me about NITARP, or go to http://nitarp.ipac.caltech.edu