



A Universe of Data

Jonathan McDowell

Smithsonian Astrophysical Observatory



21st century astronomy has seen amazing new telescopes on Earth and in space

But the new discoveries we're making are not just because of better telescopes – there's a whole new way of using them

First I'll introduce the Chandra space telescope and tell you a little about its discoveries

Then I'll explain the challenges and possibilities of astronomy in the digital age, where the software systems are as important as the space technology.

Part 1

Chandra reveals the
invisible universe

In 1999 NASA launched the Chandra X-ray Observatory into space to study the invisible energetic universe



Today, the Chandra space telescope continues to return amazing images of the cosmos – but not just images. I'll share some Chandra discoveries and then explore how astronomers use space data to unravel the stories of the heavens



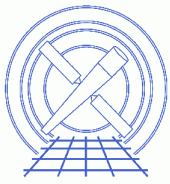
MAP of DEEP SPACE NETWORK



DSN control at Jet Propulsion Lab Pasadena, CA



Chandra science center Smithsonian Observatory, at Harvard (Cambridge, MA)



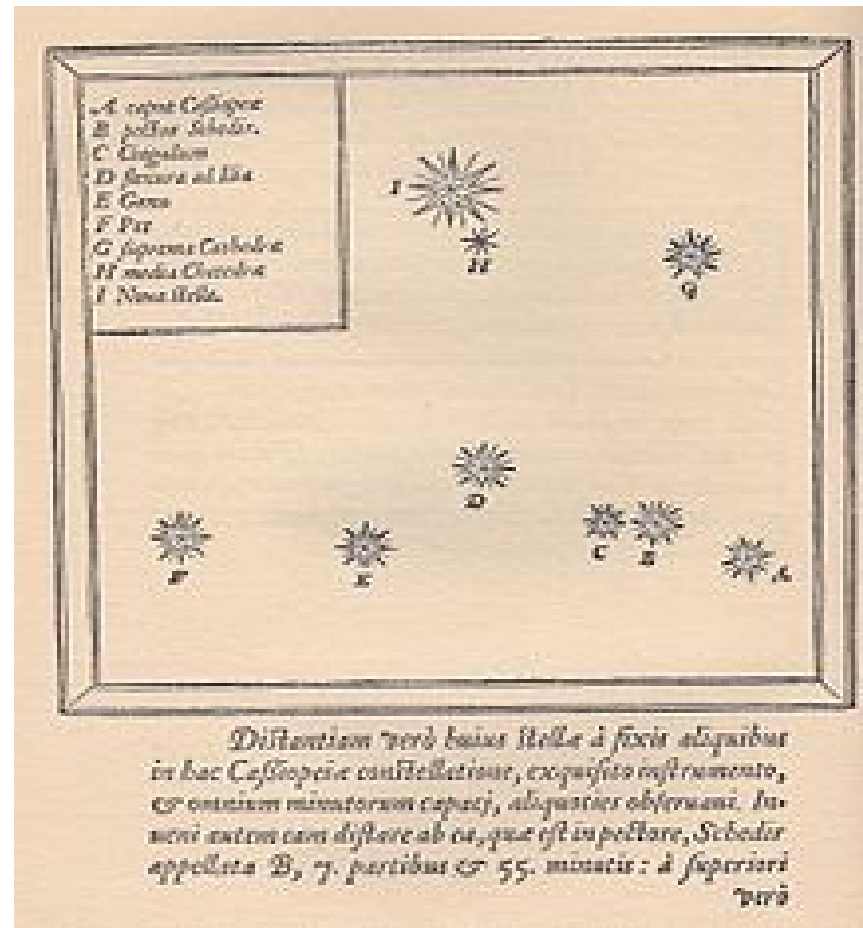
Chandra mission control Near MIT in Cambridge, MA

SAO operates Chandra on behalf of NASA

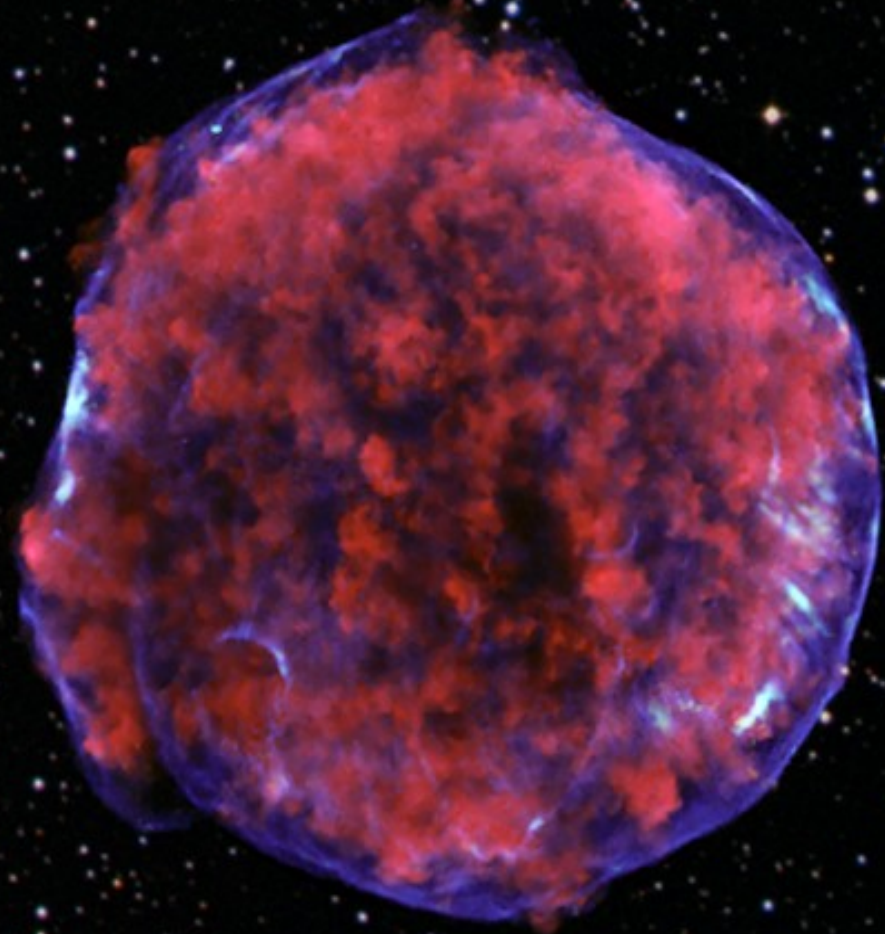
Let's visit the constellation Cassiopeia

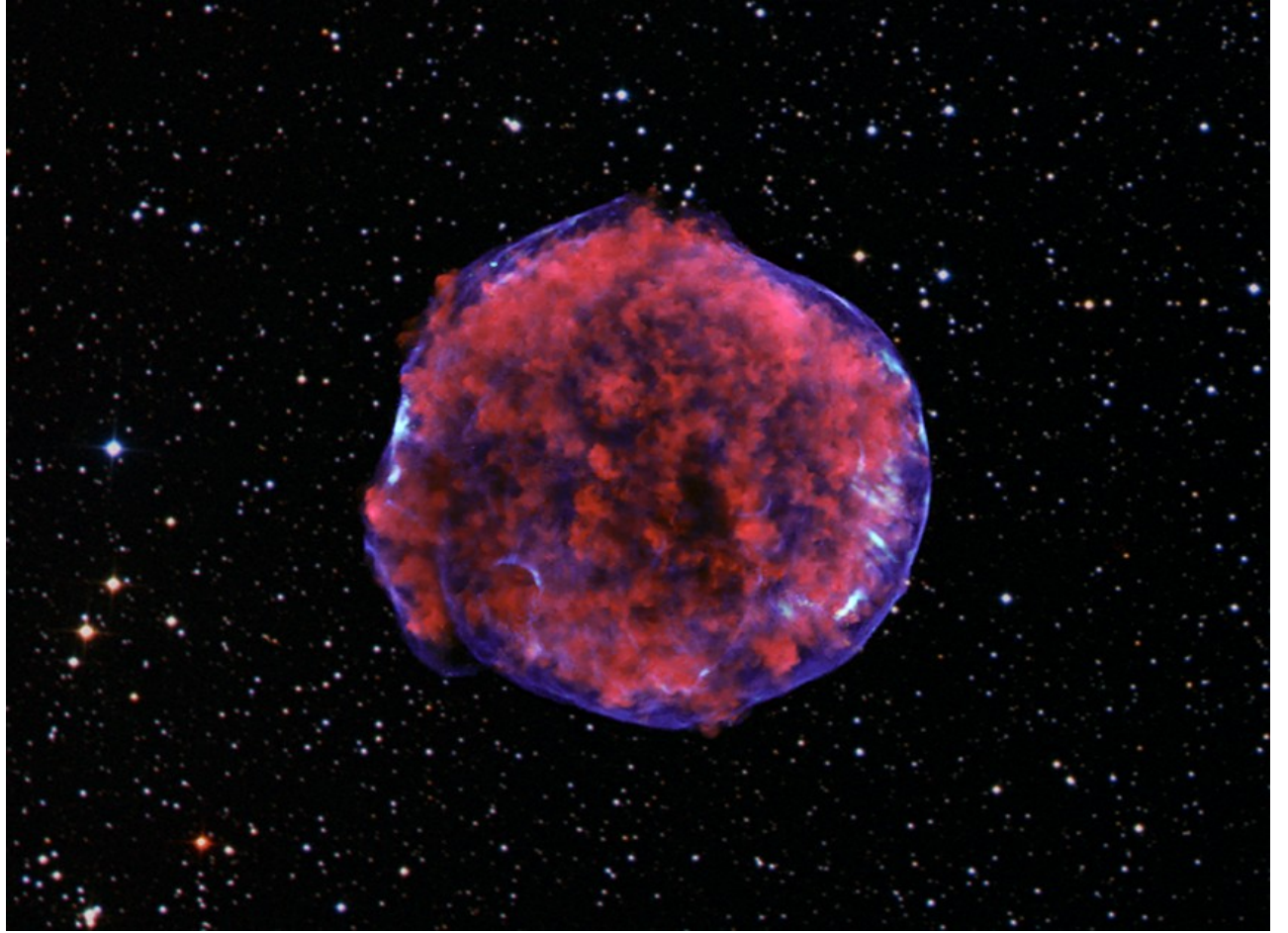
In 1572, Danish astronomer Tycho Brahe recorded a 'new star' in the constellation Cassiopeia

It was visible to the naked eye until 1574, slowly fading from view..







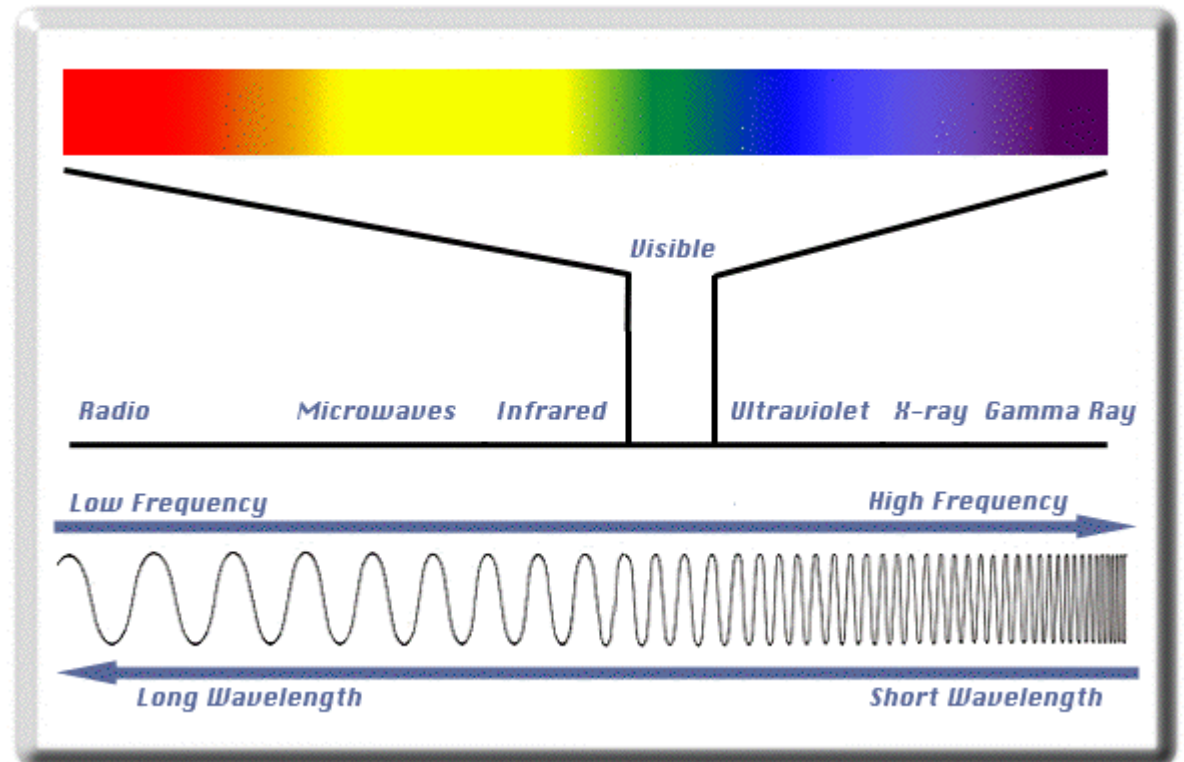


Credit:
Kris Eriksen et al, 2011 Ap J Letters 728, L28

The rainbow we all know is a sequence of colors from red through green and blue to violet – how our eyes make us perceive the different WAVELENGTHS or FREQUENCIES of light

Color in light is exactly the same as 'pitch' in sound waves

- blue is higher pitched light than red
- you can think of the invisible kinds of light like 'infrared' and 'x-ray' as different musical keys, many octaves away from the visible 'key' of light that we see





Digression: What's an X-ray?

A lot of people are familiar with, but confused by, medical X-rays

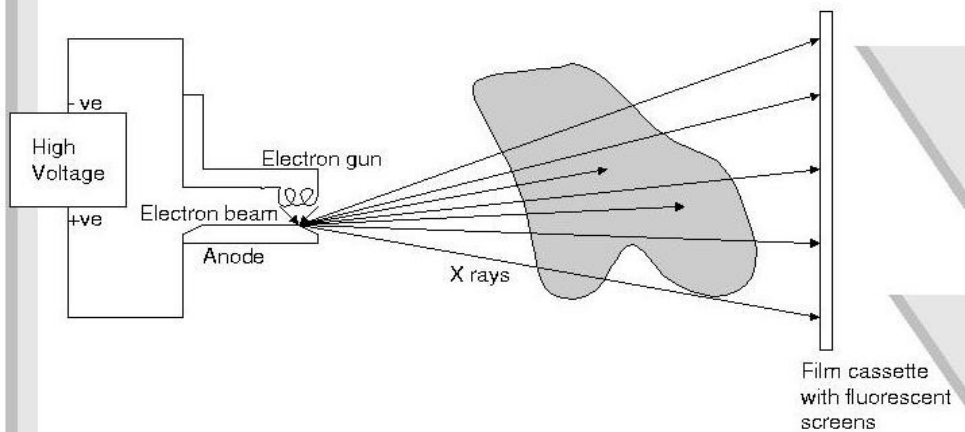
The photo at left is a picture of an X-ray light bulb, photobombed by someone's hand

The X-rays are the light bit. The dark areas are where there aren't any X-rays because the hand has blocked them.

X-ray bulb
= star, galaxy

Hand
= interstellar
gas and dust

X-ray
camera



In X-ray astronomy we are usually taking a picture of the “light bulb” (the star making the X-rays) and not interested in the “hand” (stuff blocking the X-rays between the star and us)



Visible-light photons are like raindrops

- each one is 'small' (has a small amount of energy)
- there are lots of them, but don't do any damage



X-ray photons are like hailstones

- each one is 'big' – lots of energy
- there are many fewer of them
- but each one packs a wallop

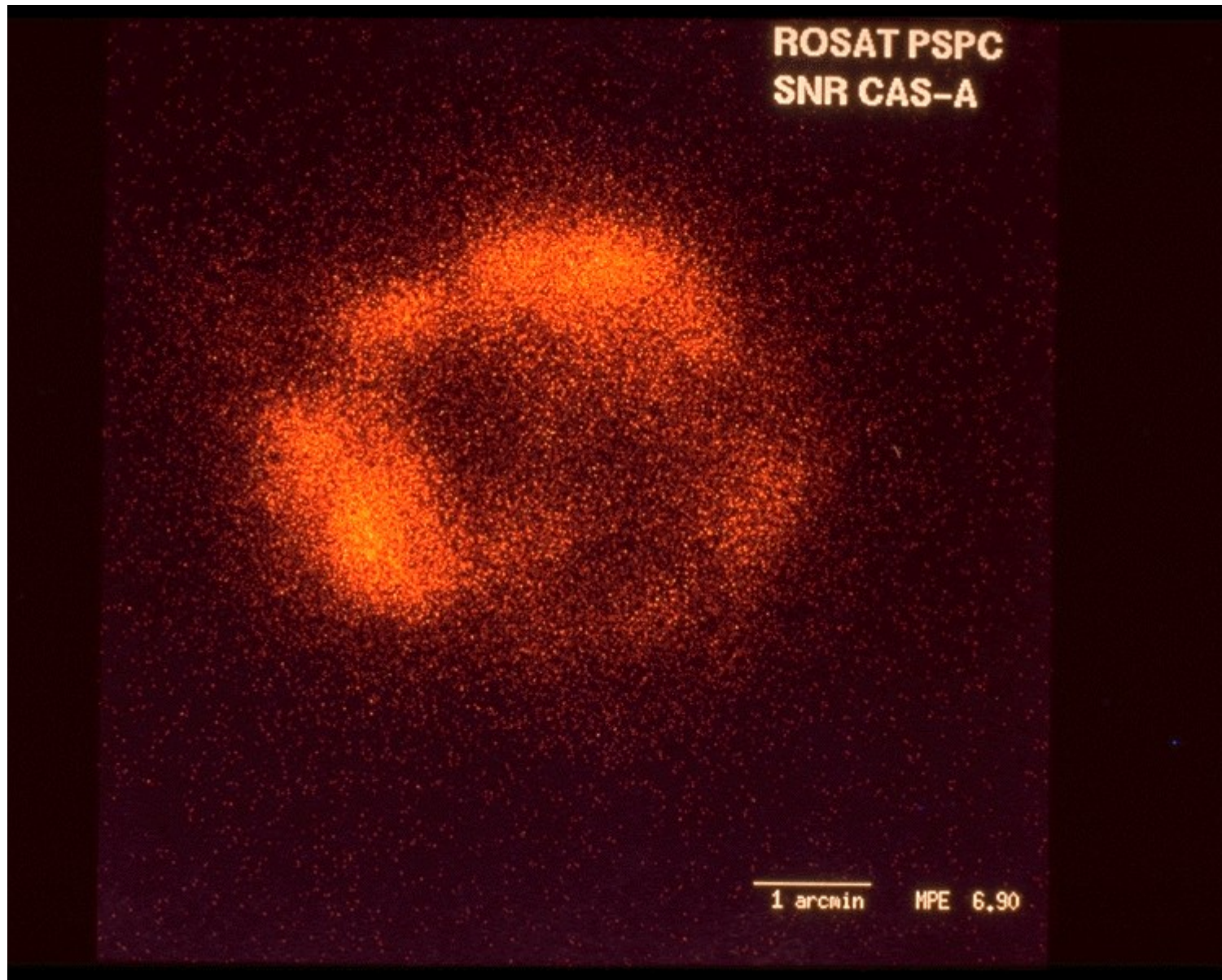
If you up the INTENSITY (number of photons) in a beam of light you increase the total energy you get but not the energy per 'packet'

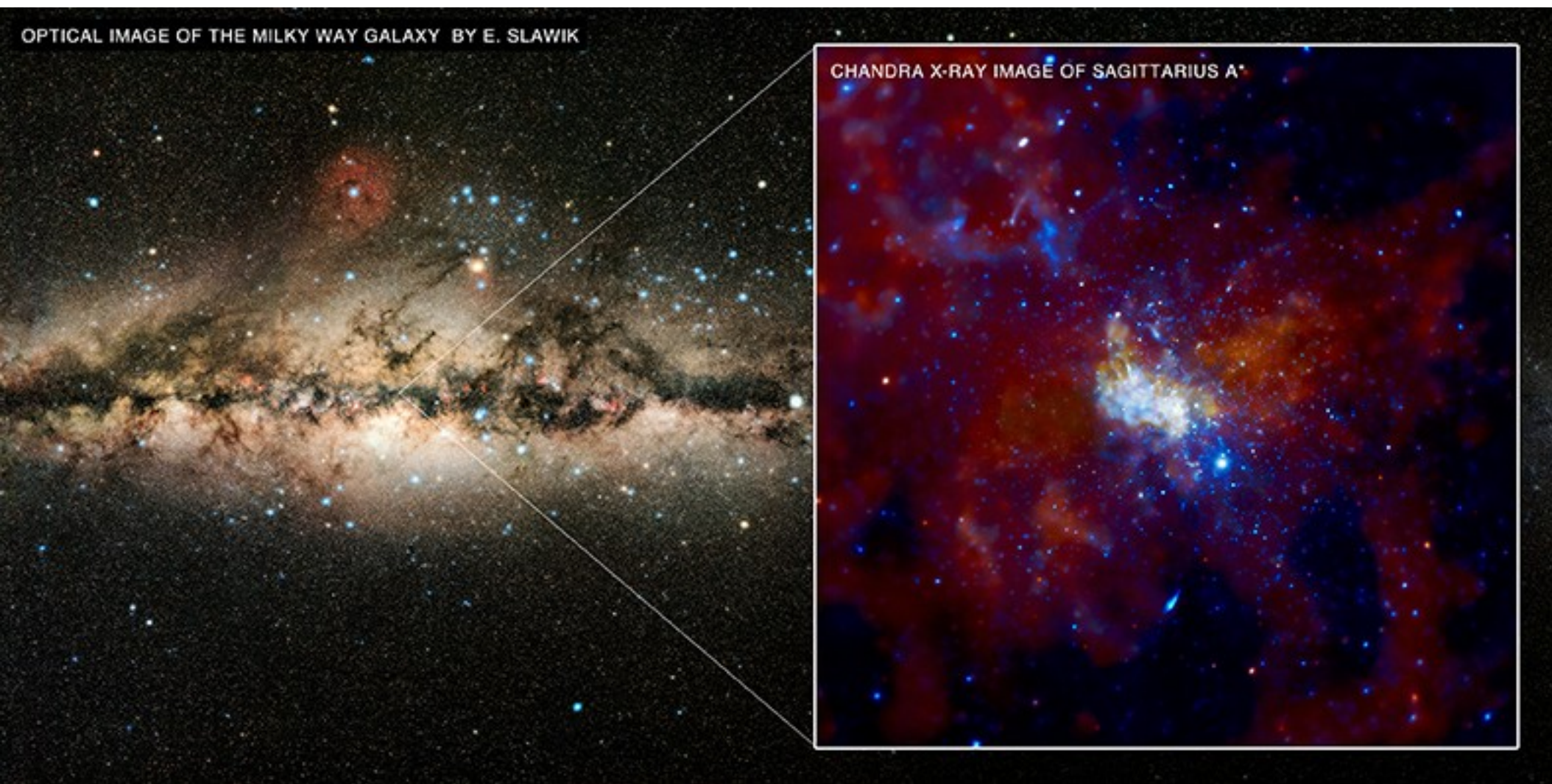
If you want to get a tan (or worse) you have to increase the energy per photon, not just the number of photons.

We have a word for the energy of a photon: “COLOR” (well, “COLOUR” but I'll defer to the local sensibility)



Milky Way galaxy: Supernova remnant (X-ray)
This was the best X-ray picture before Chandra

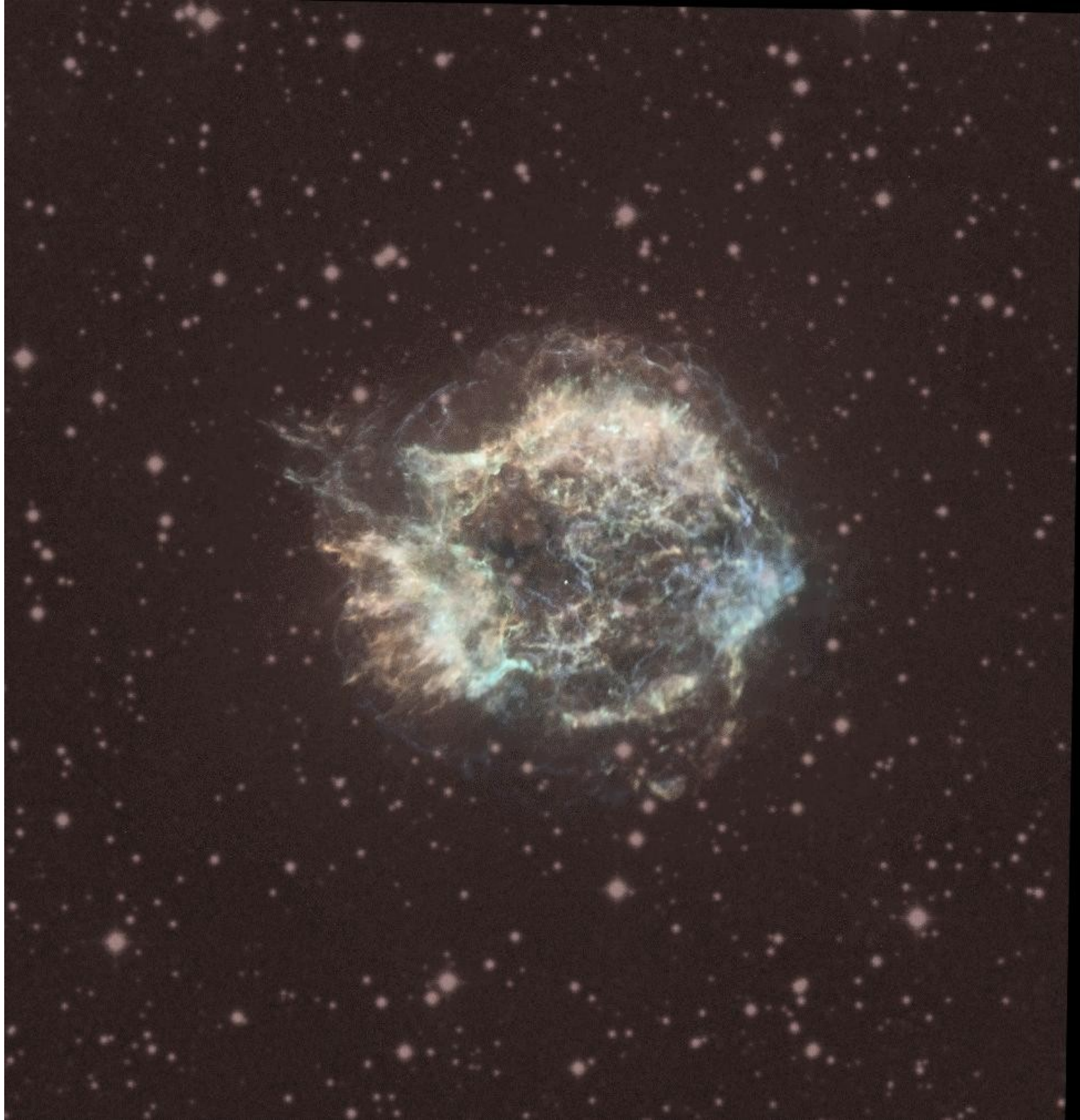




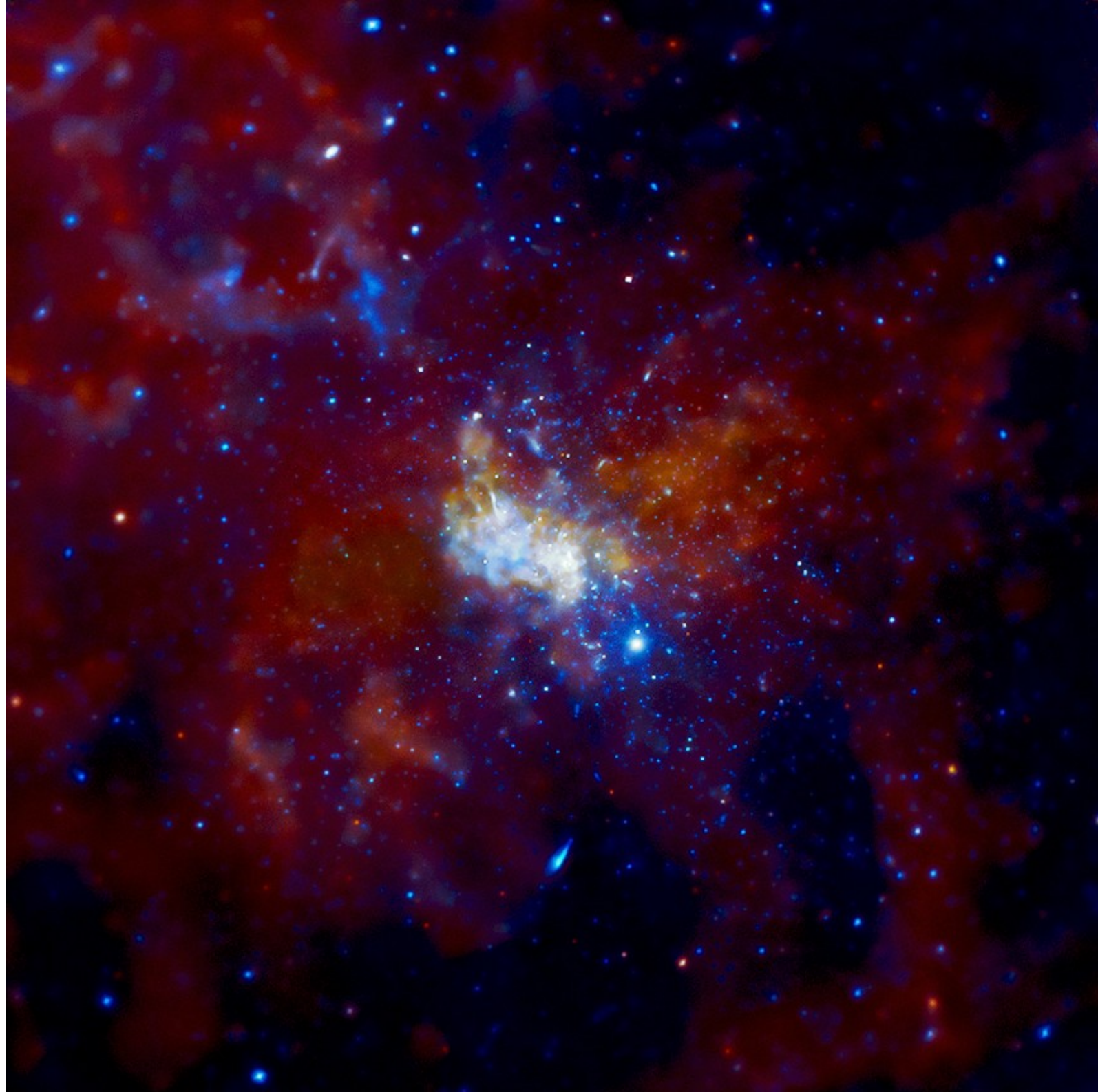
OPTICAL IMAGE OF THE MILKY WAY GALAXY BY E. SLAWIK

CHANDRA X-RAY IMAGE OF SAGITTARIUS A*

Milky Way Galaxy: Galactic Center

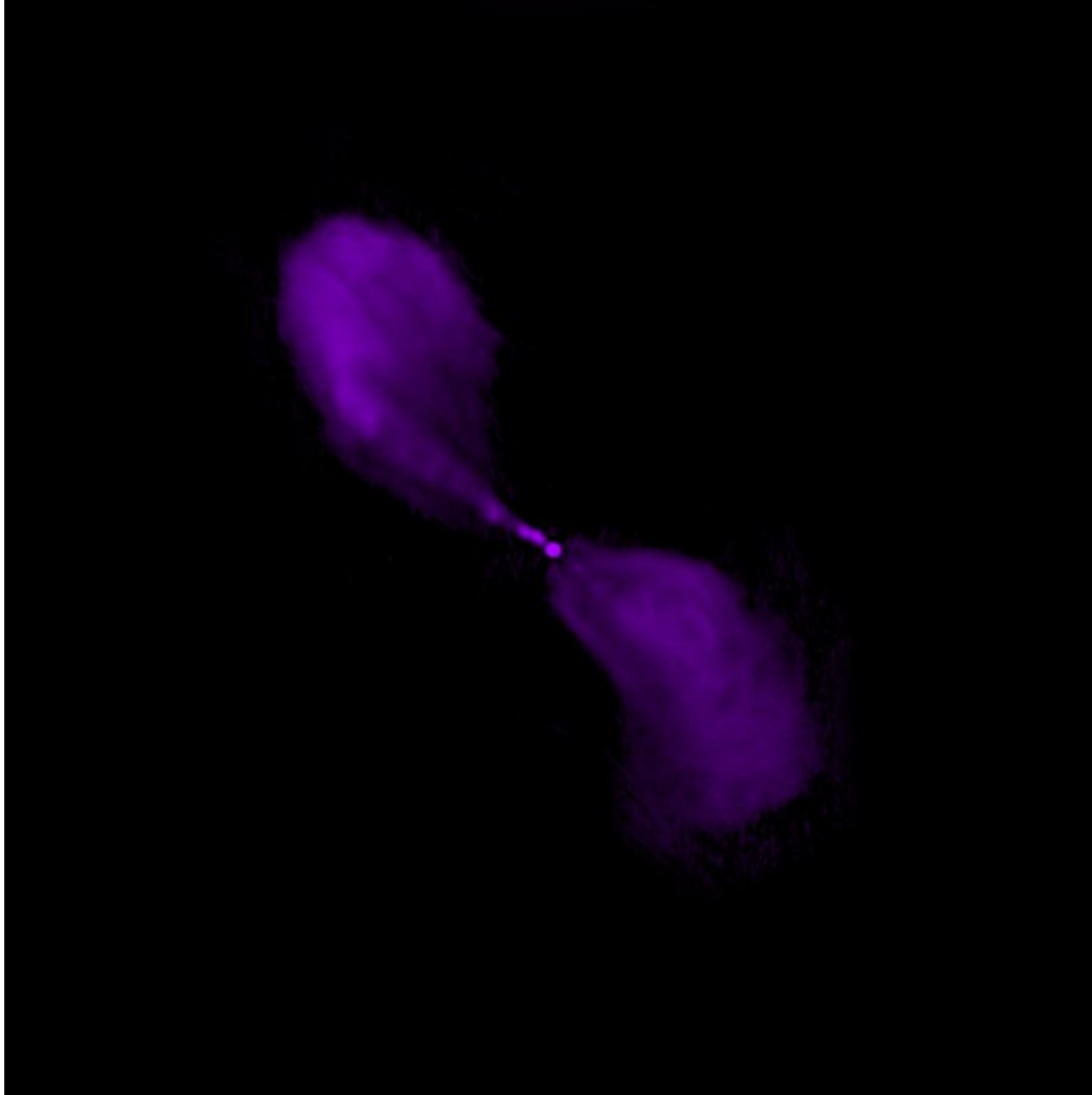






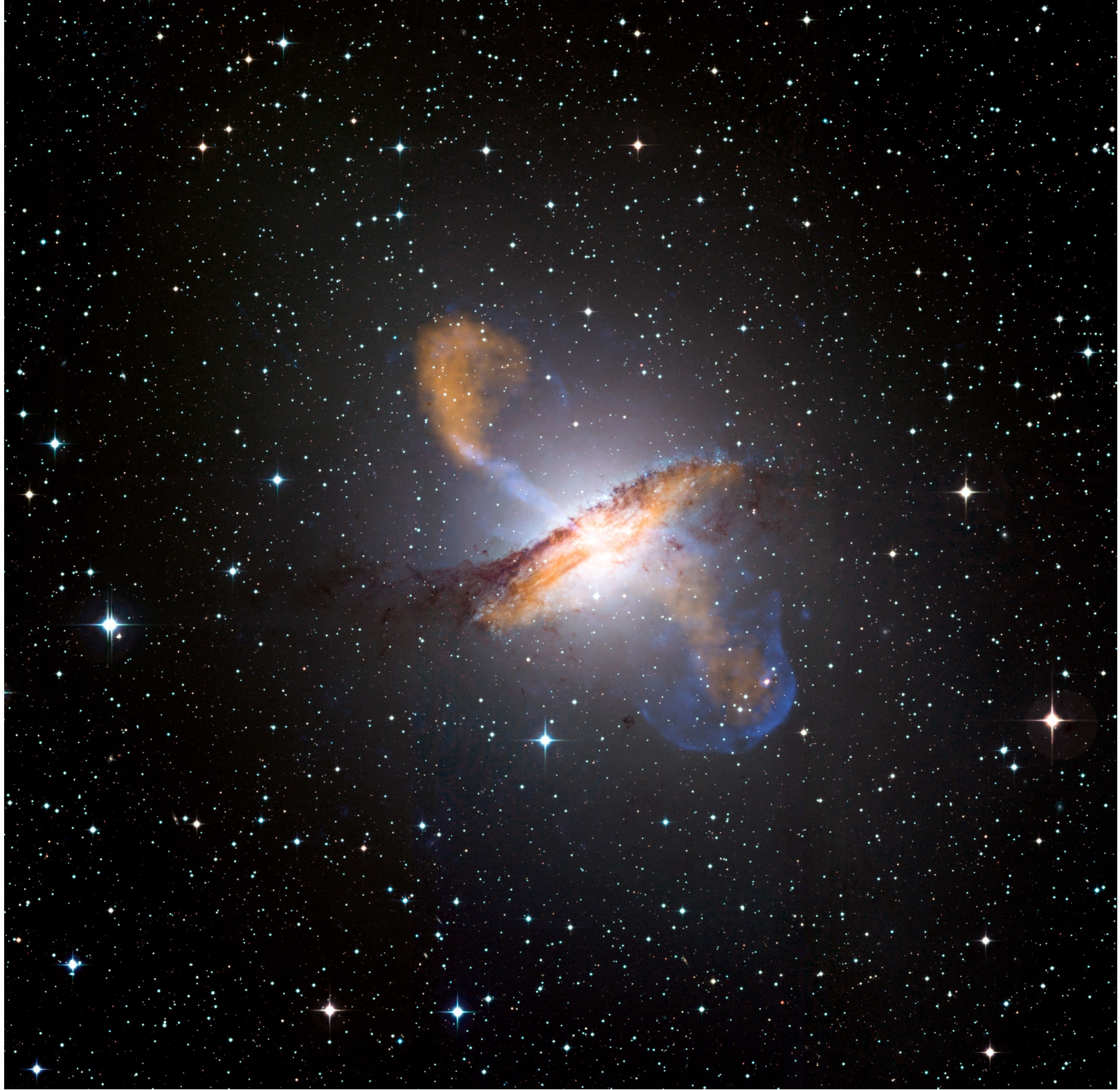


Galaxy Centaurus A (NGC 5128) - 12 million light years away



Extragalactic Universe: Active Galaxy (X-ray)



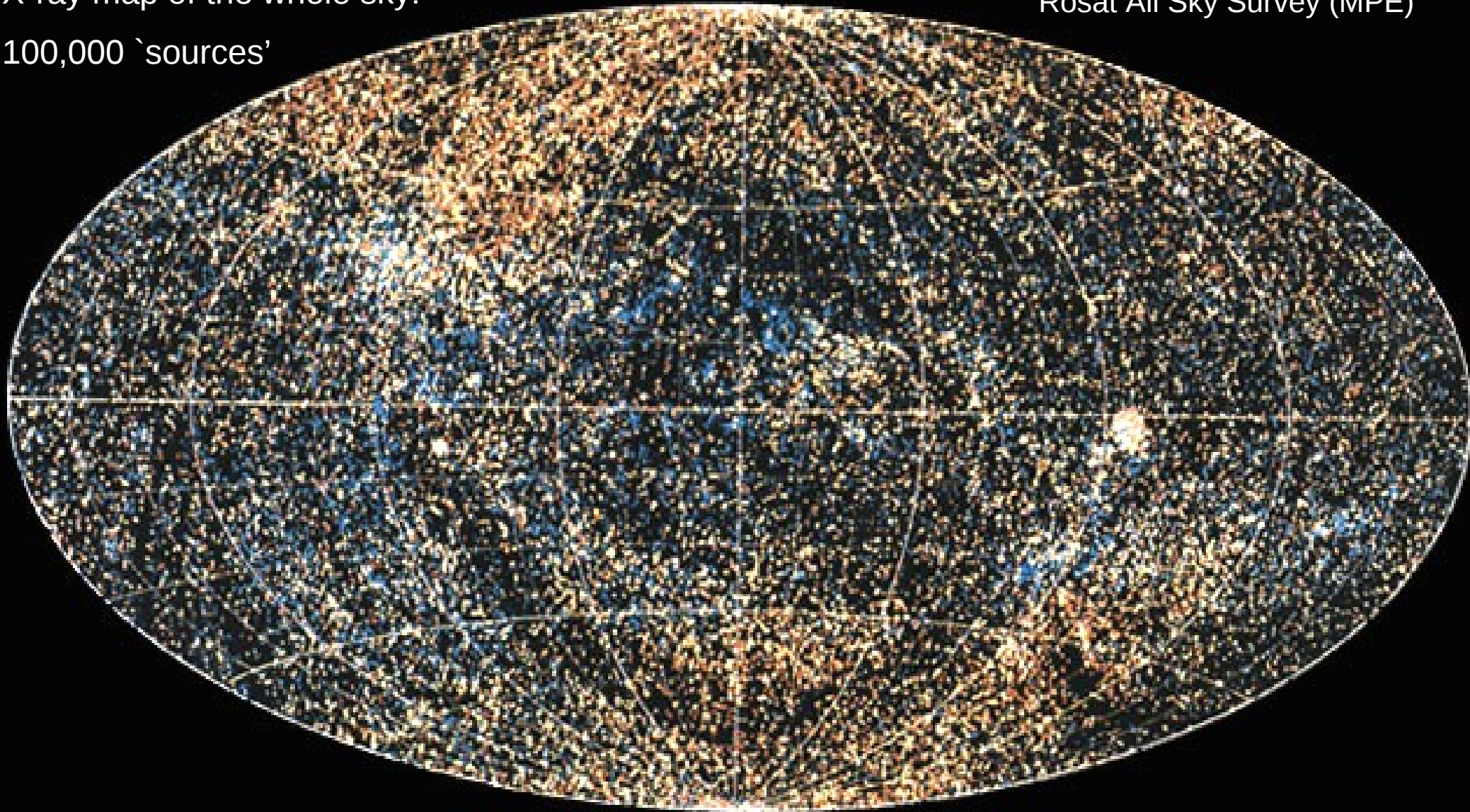


Powerful sources of X-rays

X-ray map of the whole sky:

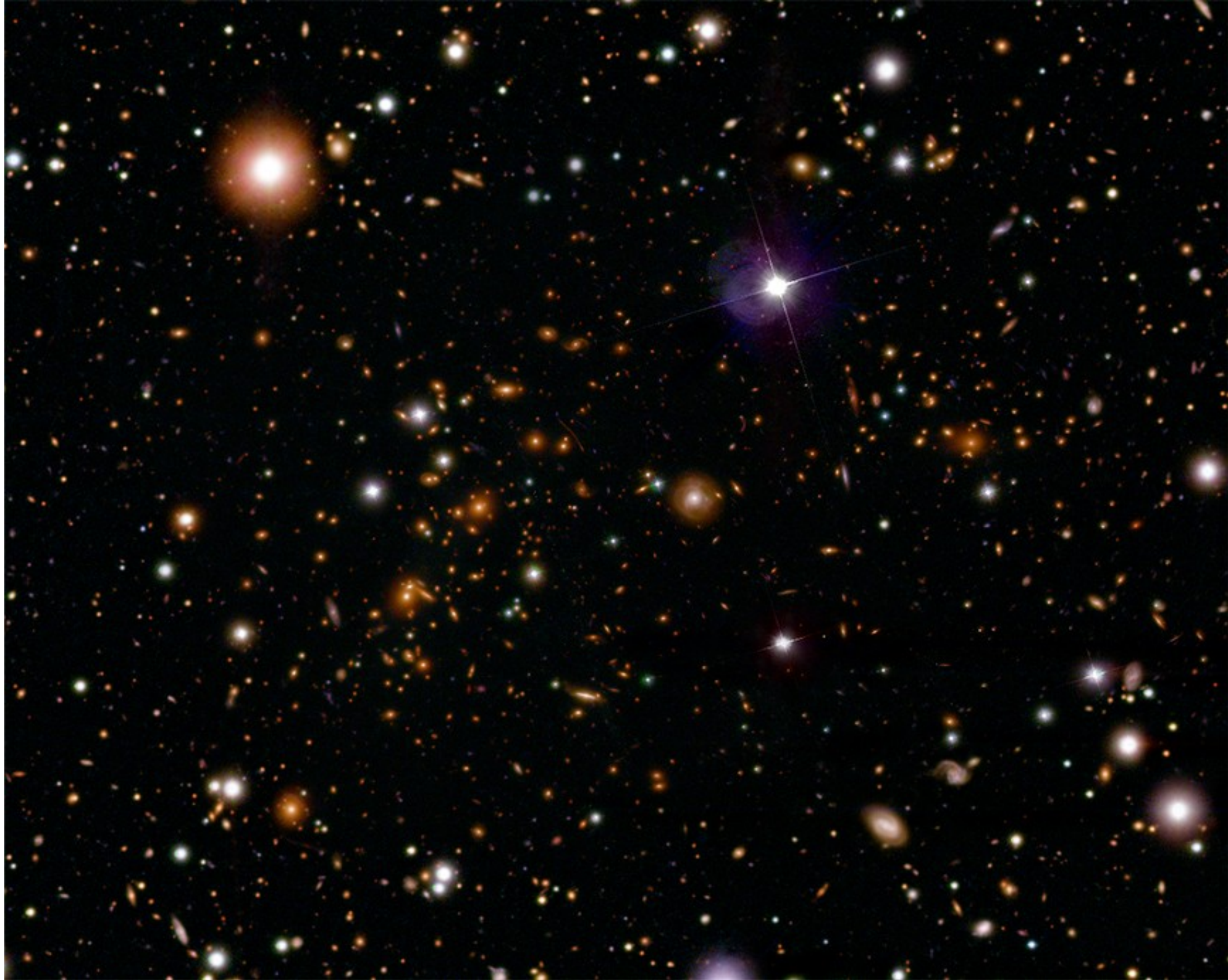
Rosat All Sky Survey (MPE)

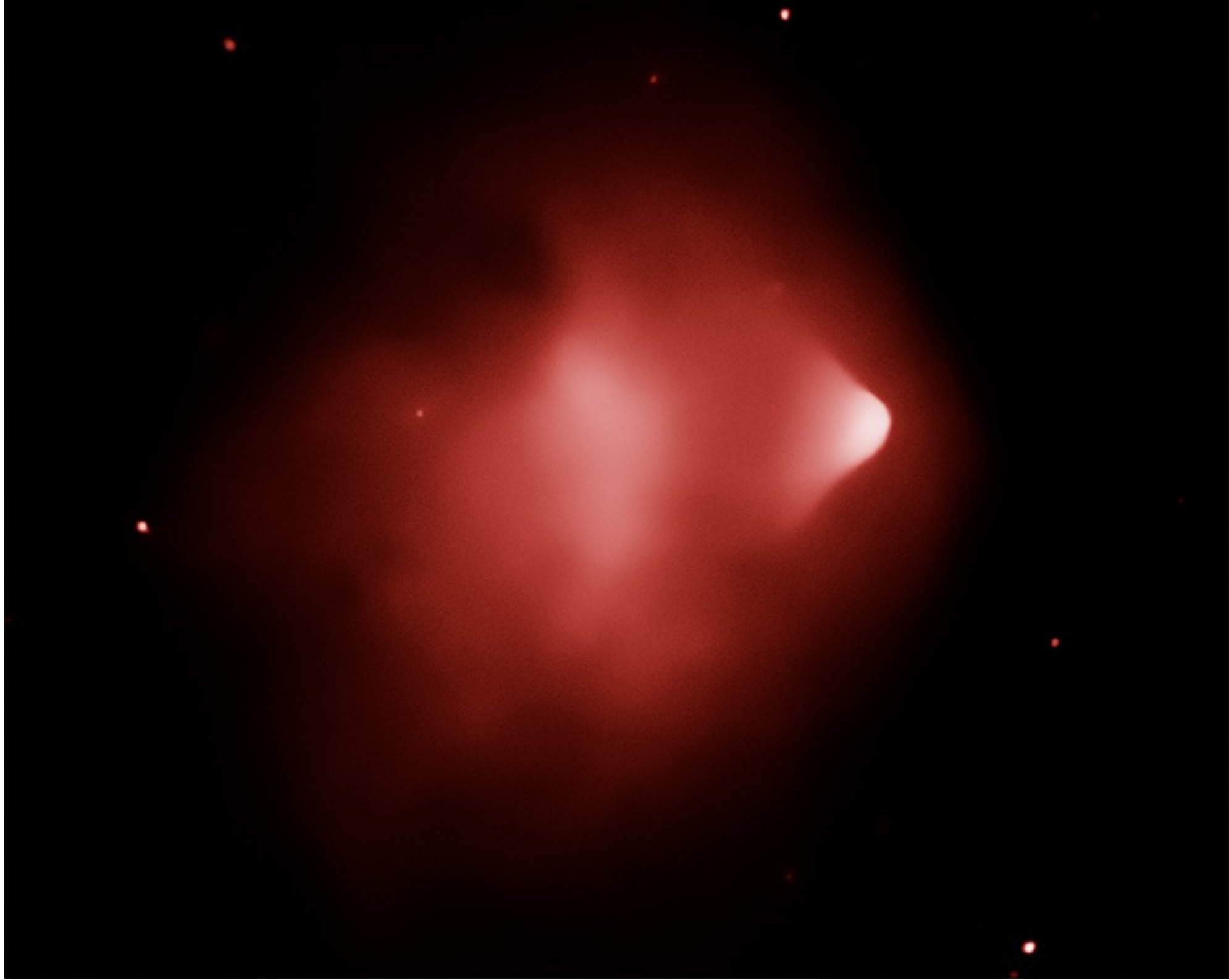
100,000 `sources`

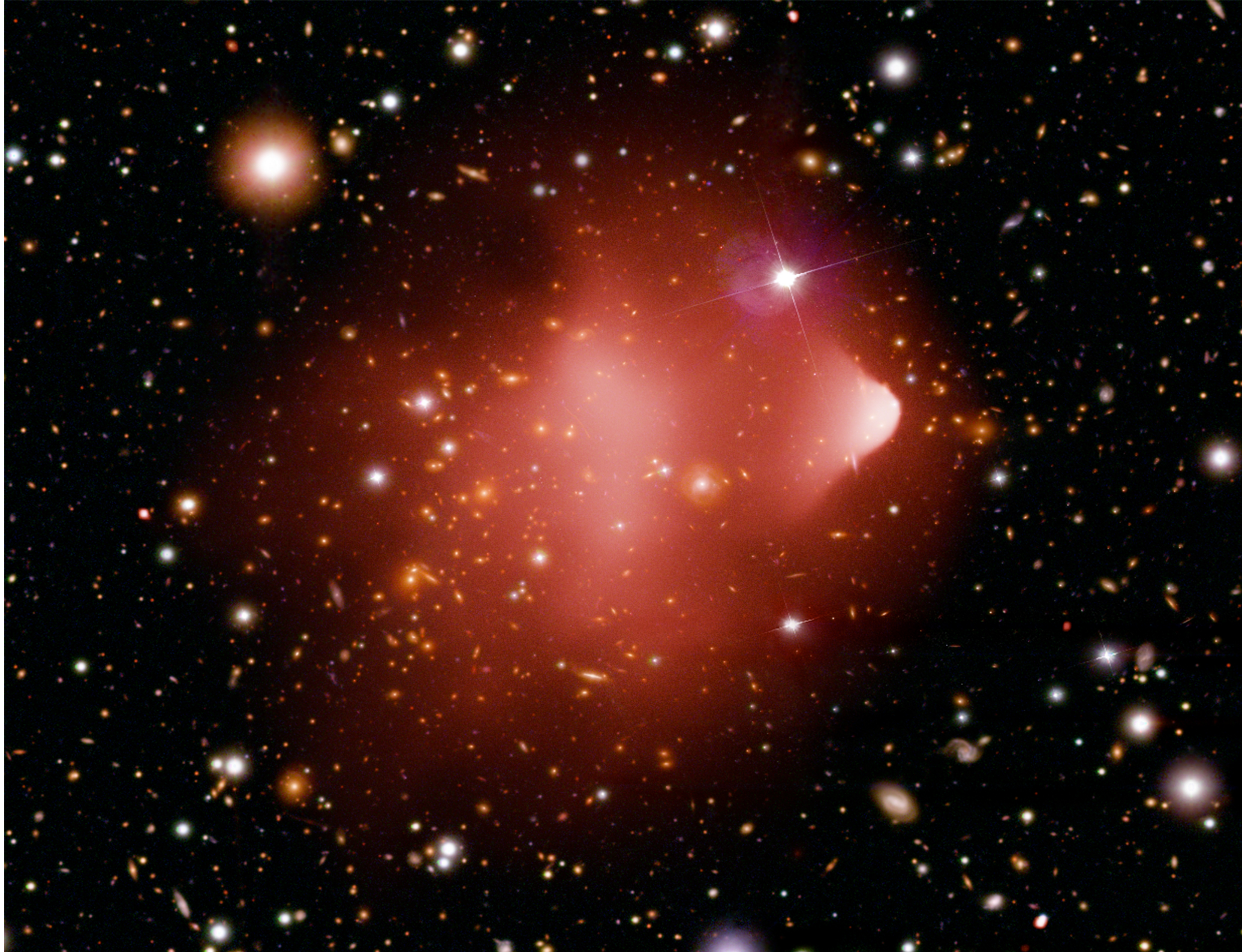


A power source entirely different from the nuclear fusion that drives the Sun and stars

...and much more efficient







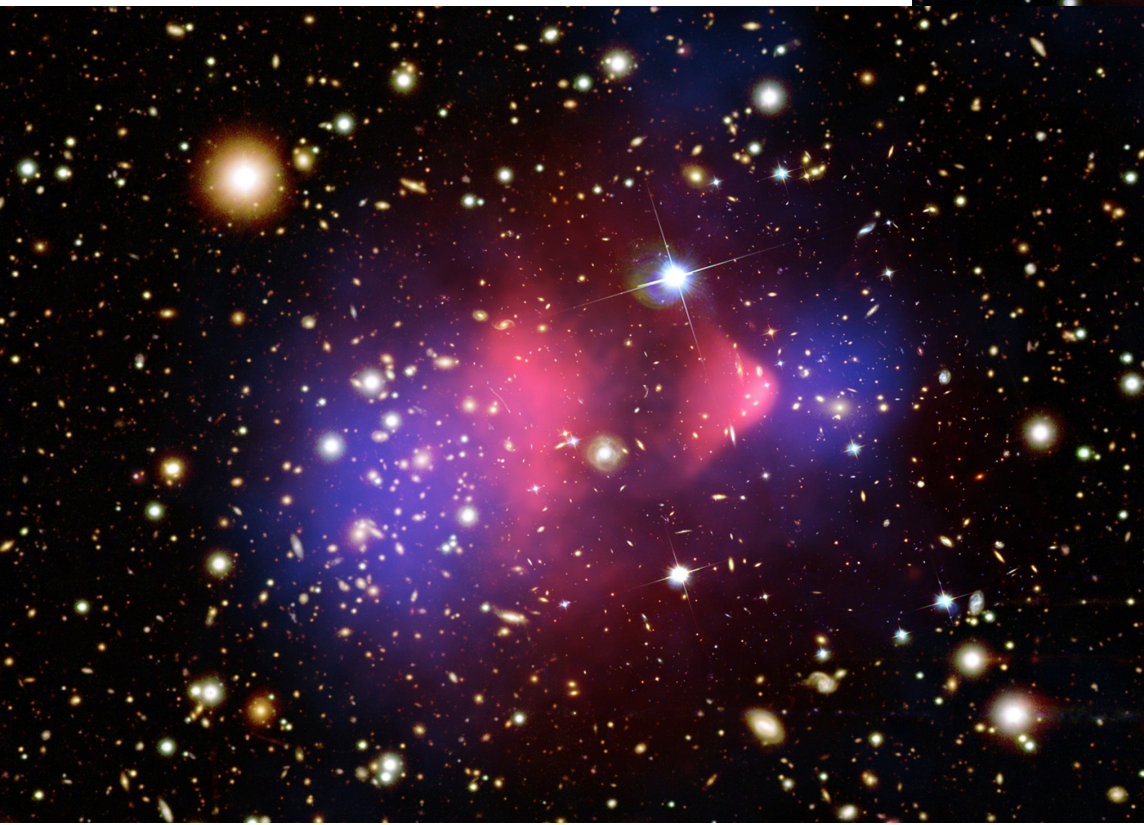
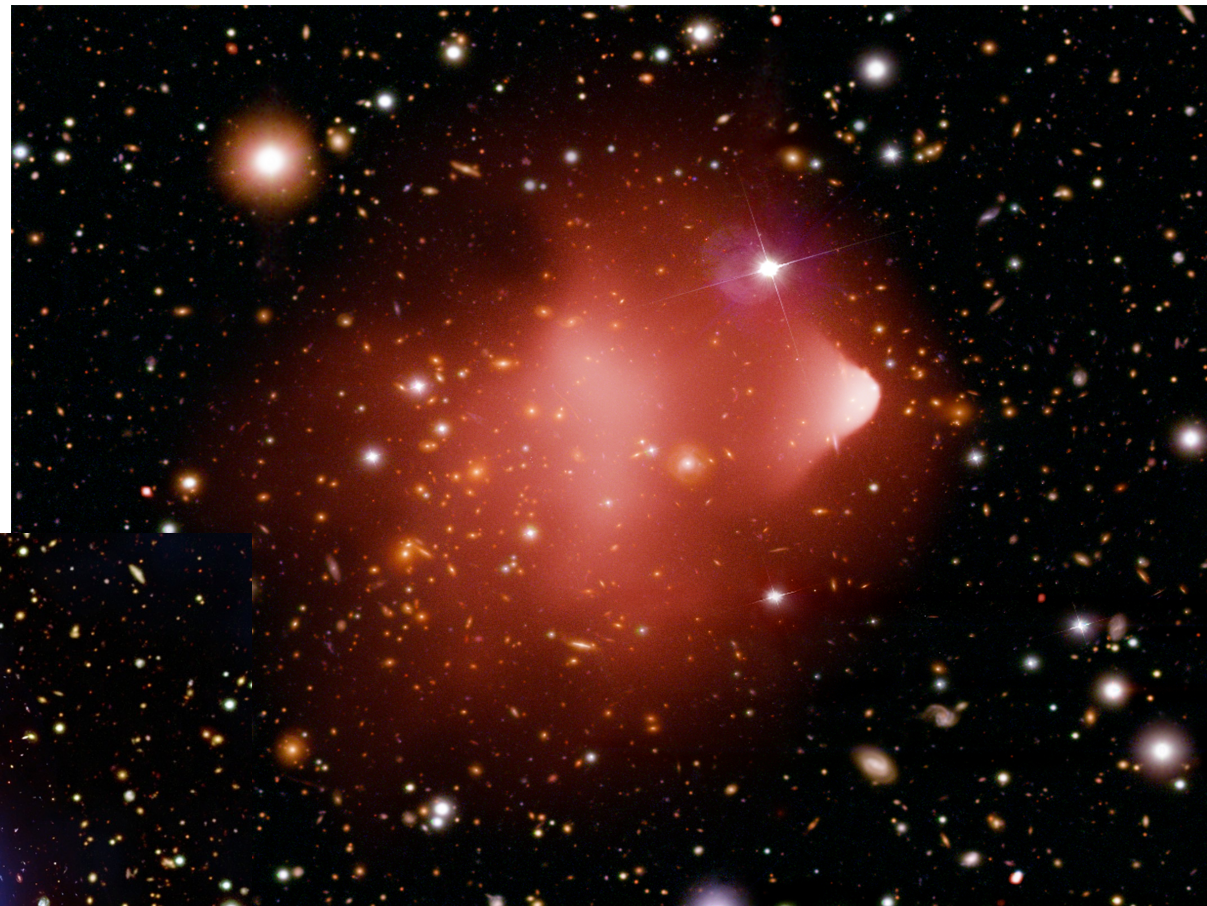
The Bullet Cluster, 1E0657-56

Two clusters in collision: studying this object let us measure the dark matter

Right: what we see directly in X-rays (red) and optical

Below: blue shows the matter distribution we infer

Extragalactic universe:
Cluster of galaxies (X-ray, visible and dark-matter model)



Distance: 3.3 billion light years

Size: 3 million l.y.

Data: Maxim Markevitch et al.

Part 2

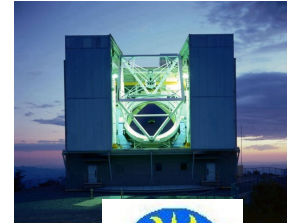
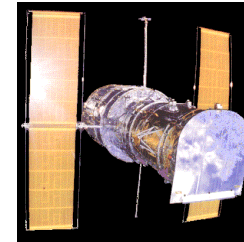
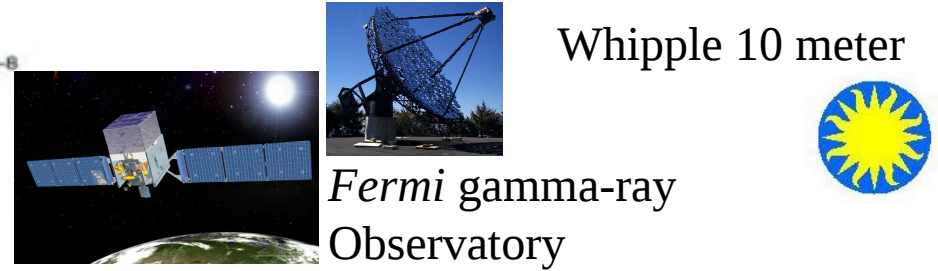
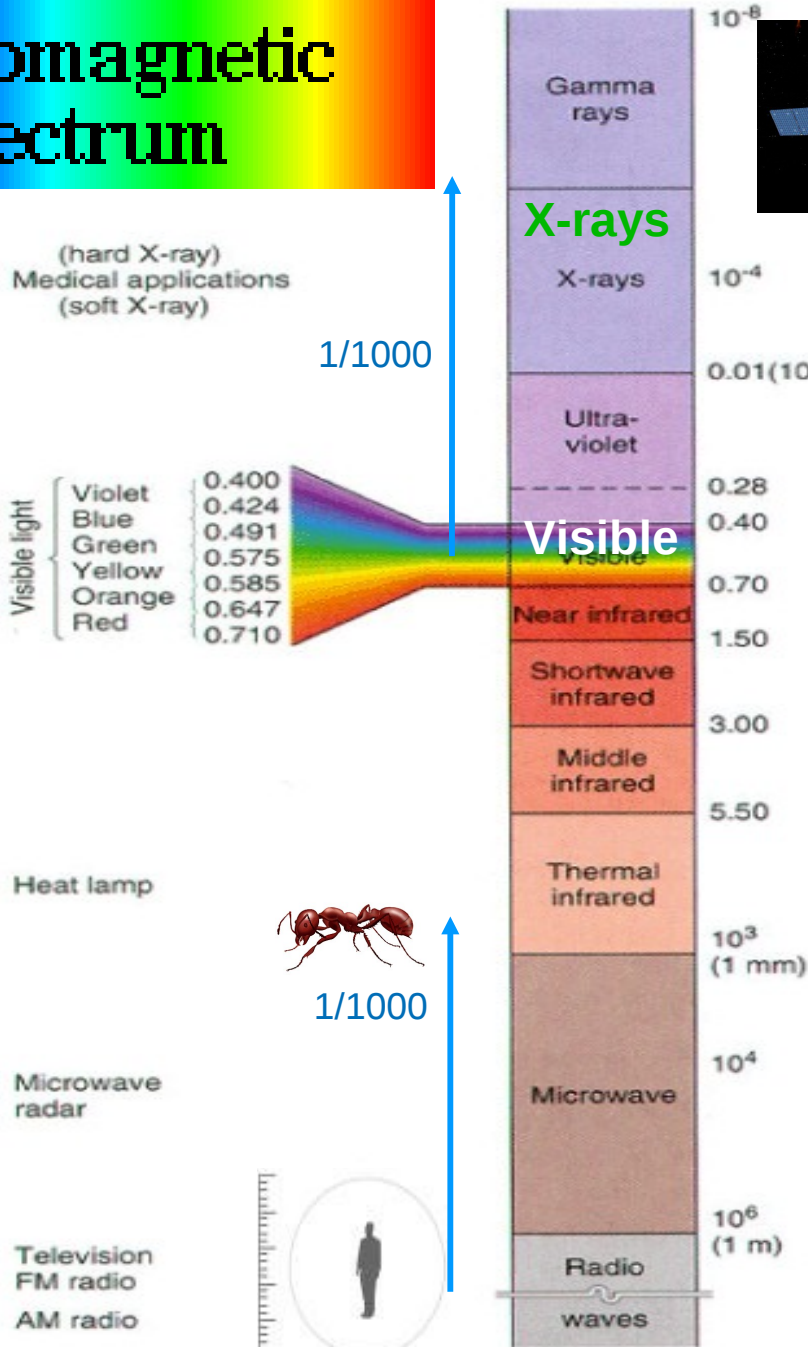
A Universe of Data

How do we take these amazing space pictures?
How do we make scientific measurements with them?

We are now in the era of multiwaveband astronomy

Electromagnetic Spectrum

10⁵ range of wavelength in astronomy



Beyond the Pretty Picture

When? Timing



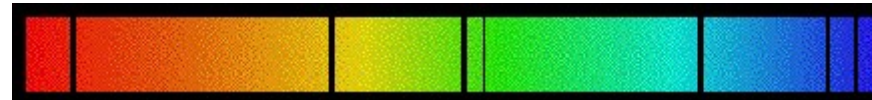
Where? Astrometry



How Bright? Photometry



What Color? Spectroscopy

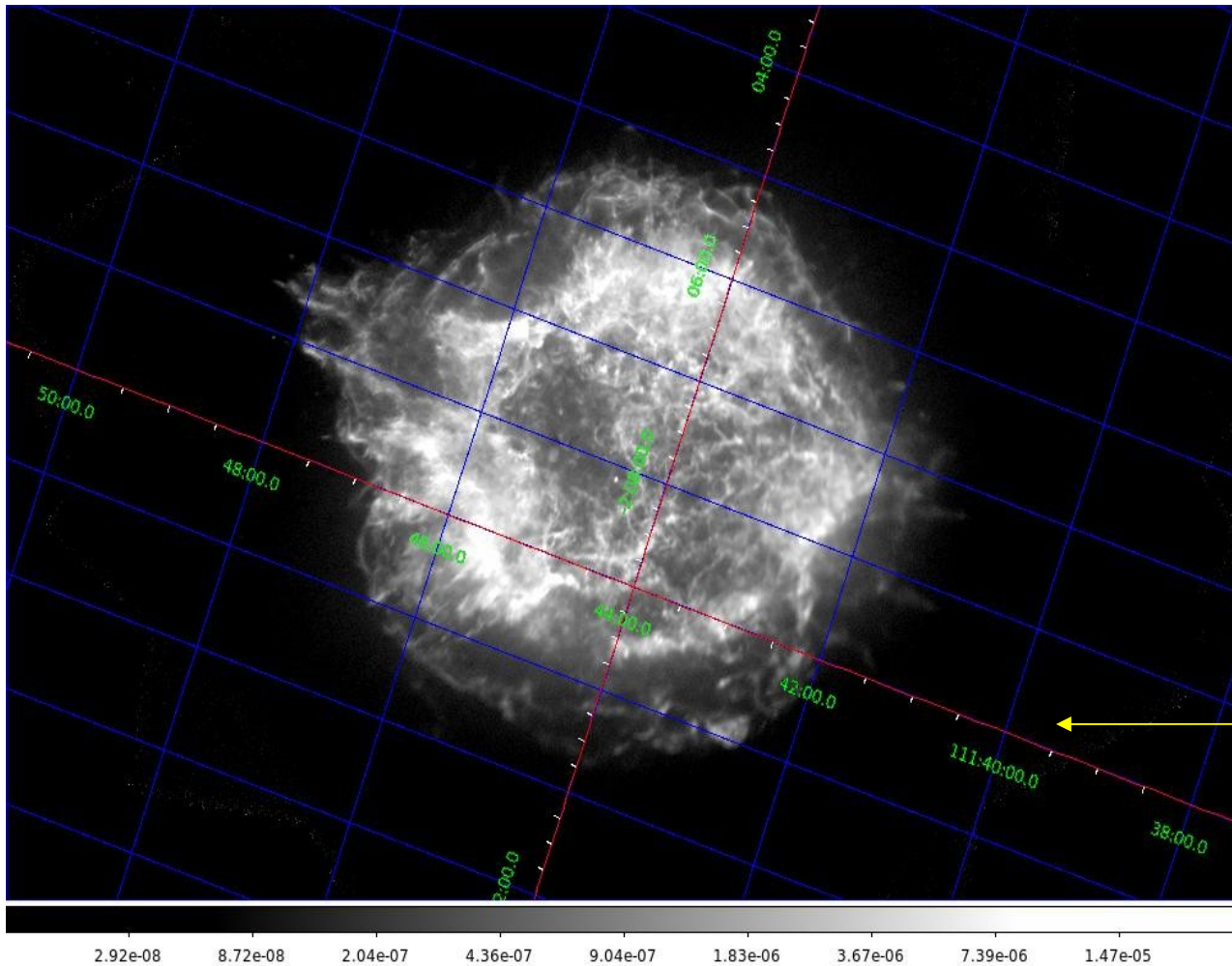


and

How am I being fooled?

- the camera is lying to me
bad pixels, sensitivity changes...
instrument background...
- the software is lying to me
processing artifacts
calibration issues
mismatched data
- the universe is lying to me
Are these two objects touching each other or just in the same direction?

Different Kinds of Data 1 - Images



HEADER

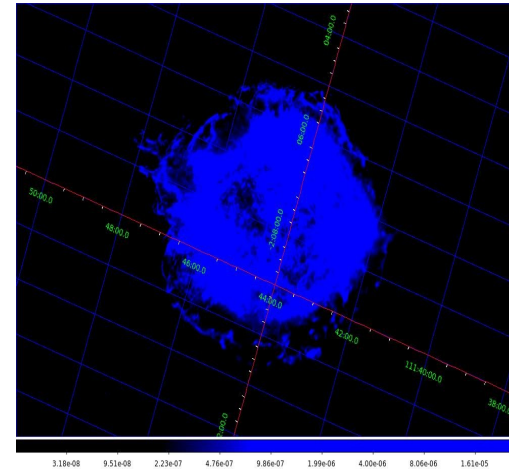
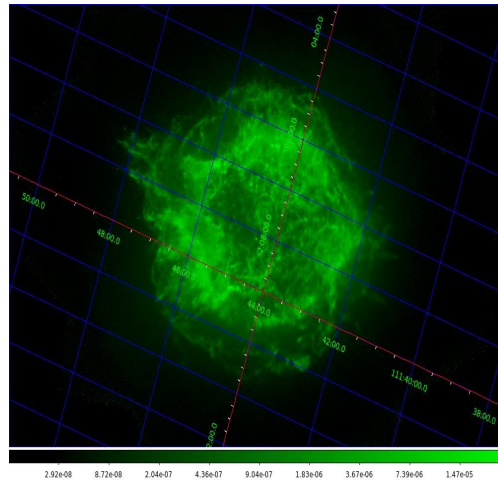
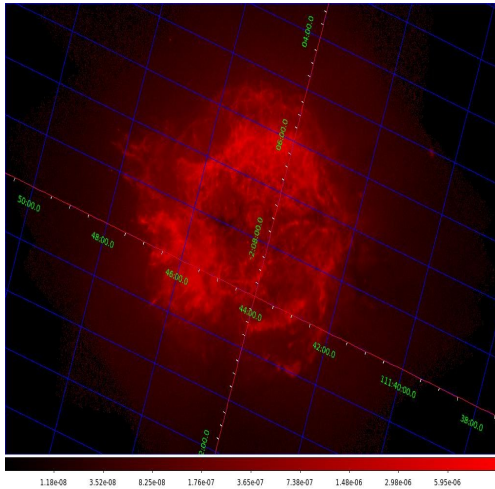
Date and time
Wavelength range
Which telescope and where
etc etc etc

Galactic latitude and
longitude grid

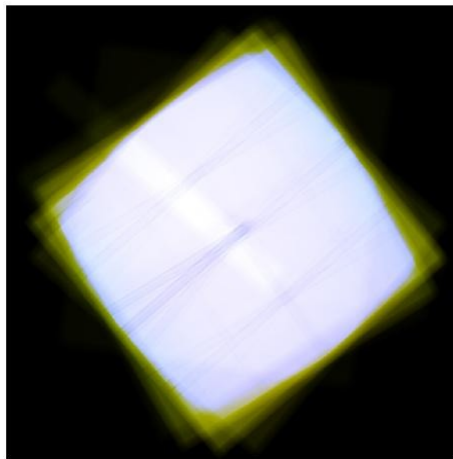
Need 3 of these
("red", "green", "blue")
for a color image

Calibrated brightness in milliwatts/sq m
- how bright is it in this particular wavelength range

Different Kinds of Data 1(b) – Lots of Images



Data images in different color ranges

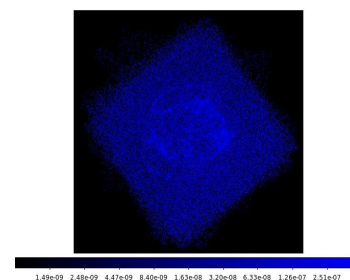
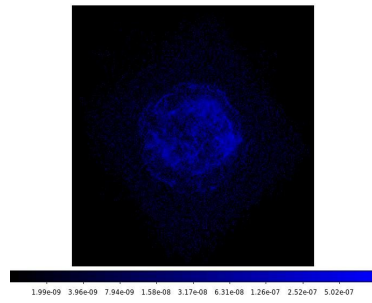
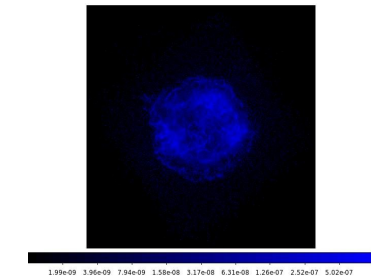
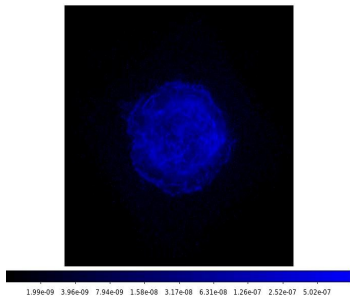
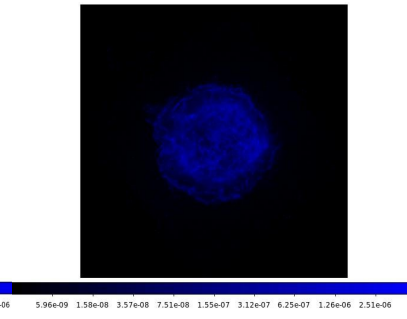
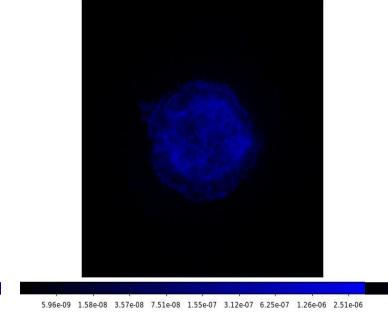
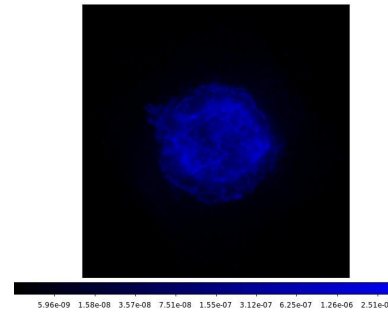
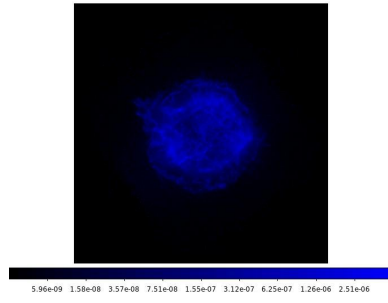
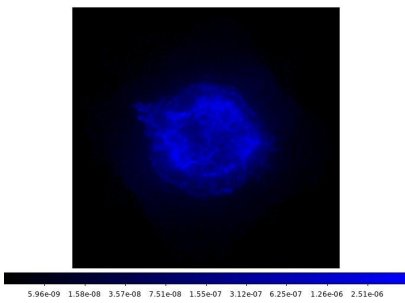
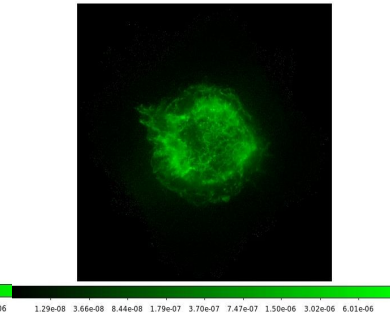
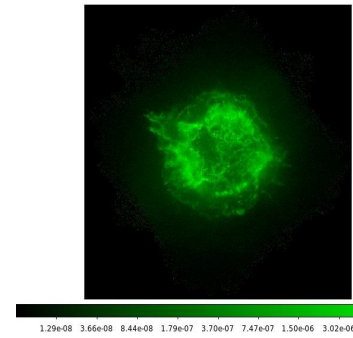
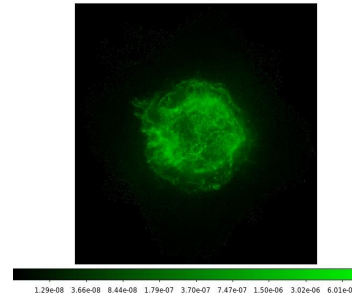
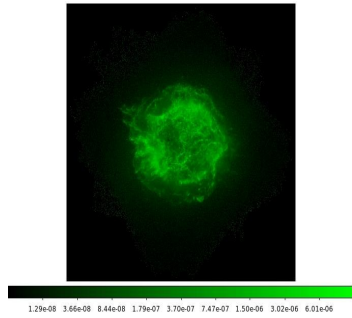
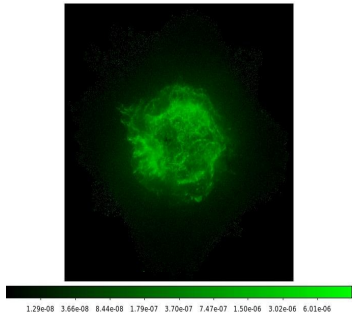
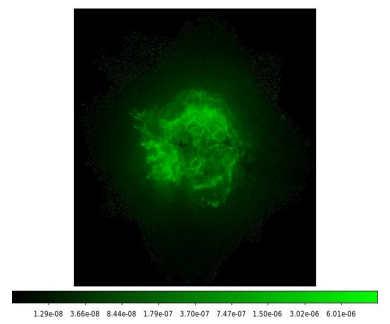
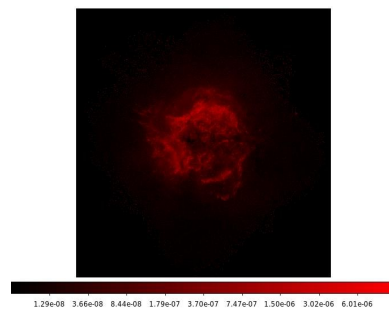
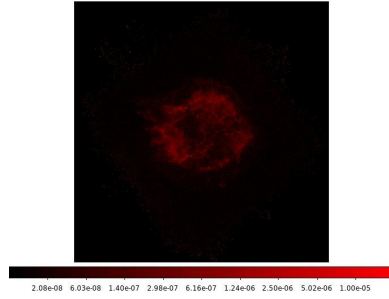
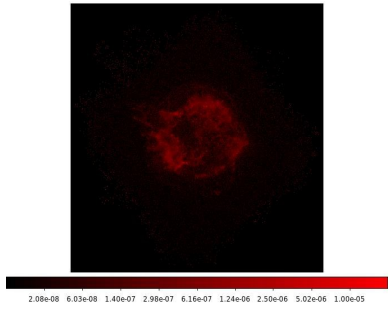


Also:

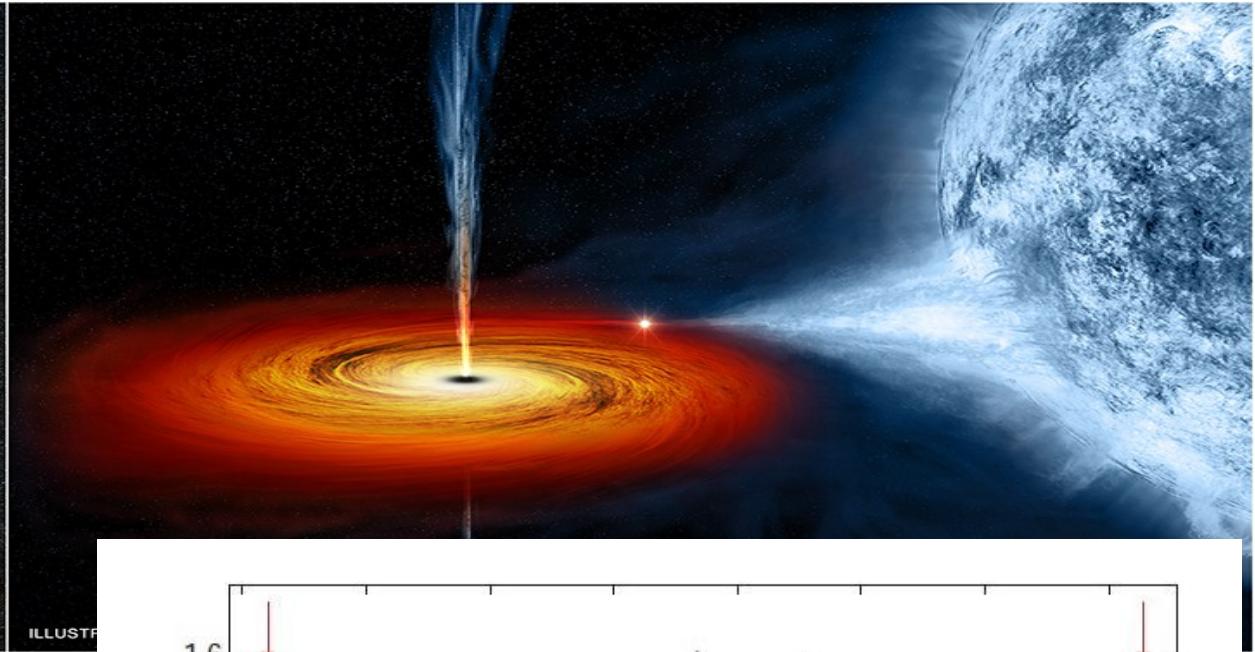
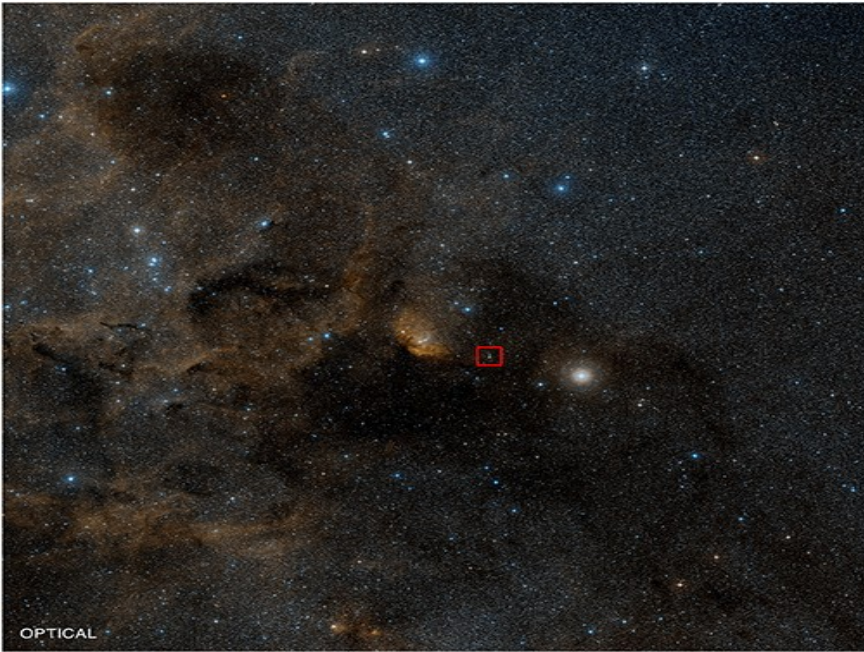
- sky background images
- bad pixel maps
- color 'gain' maps

different problems with the camera,
different calibration maps to fix them

Camera sensitivity
- different for different colors



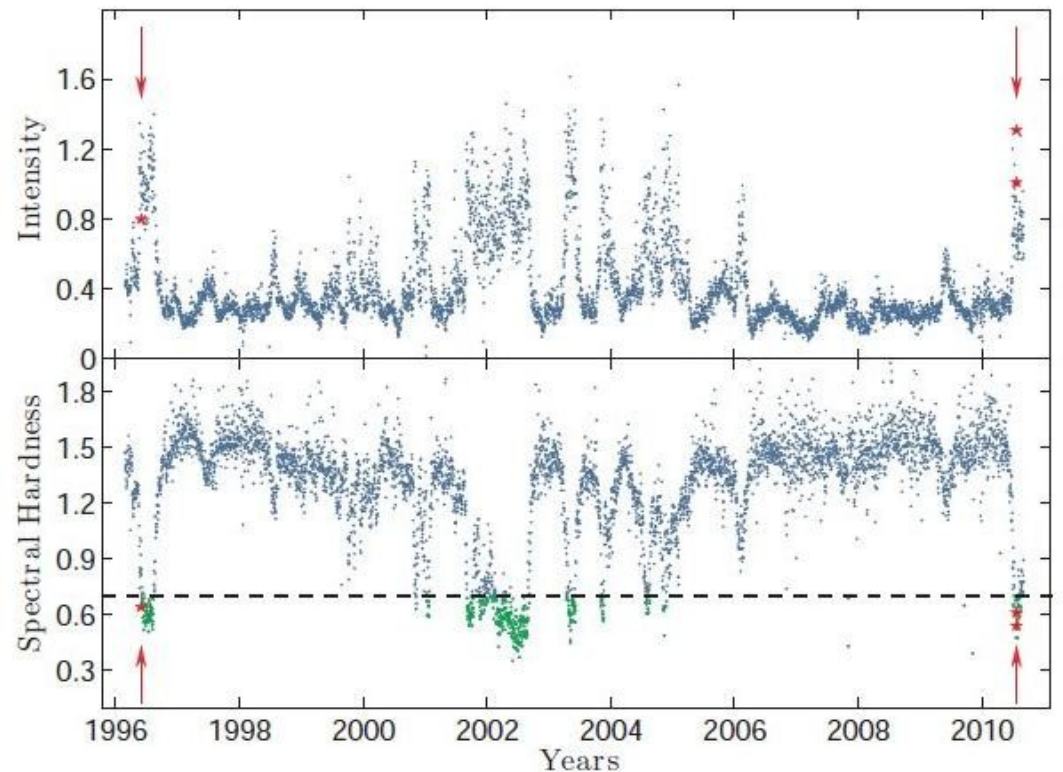
Different Kinds of Data 2- Light Curves

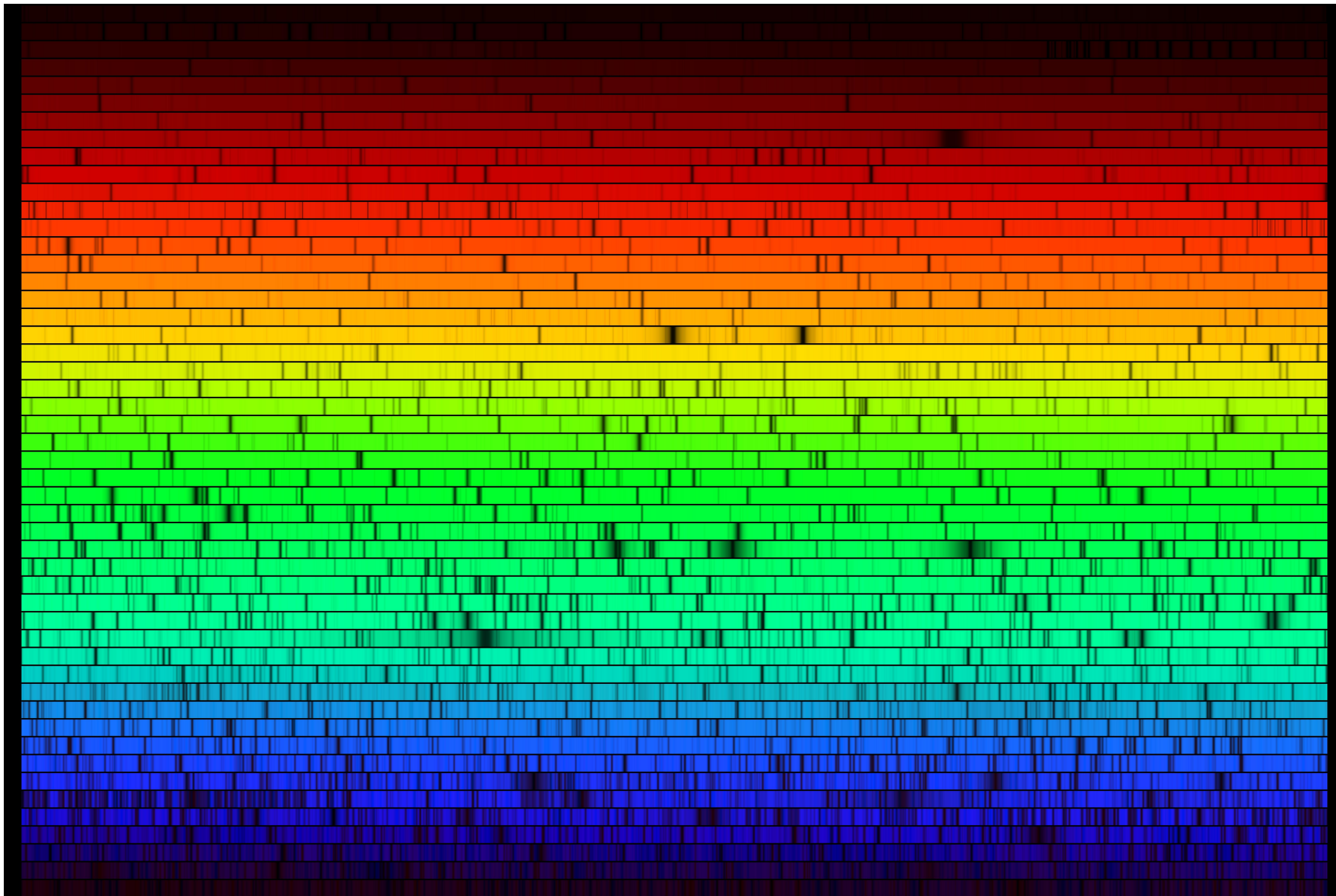


Cygnus X-1
A massive blue star slowly being eaten
by its companion black hole
When the stream from the blue star hits
the material swirling around the hole
X-rays are produced

The Rossi XTE satellite monitored the
brightness of Cyg X-1 over 14 years

Data: Gou et al 2011, ApJ 742, 85

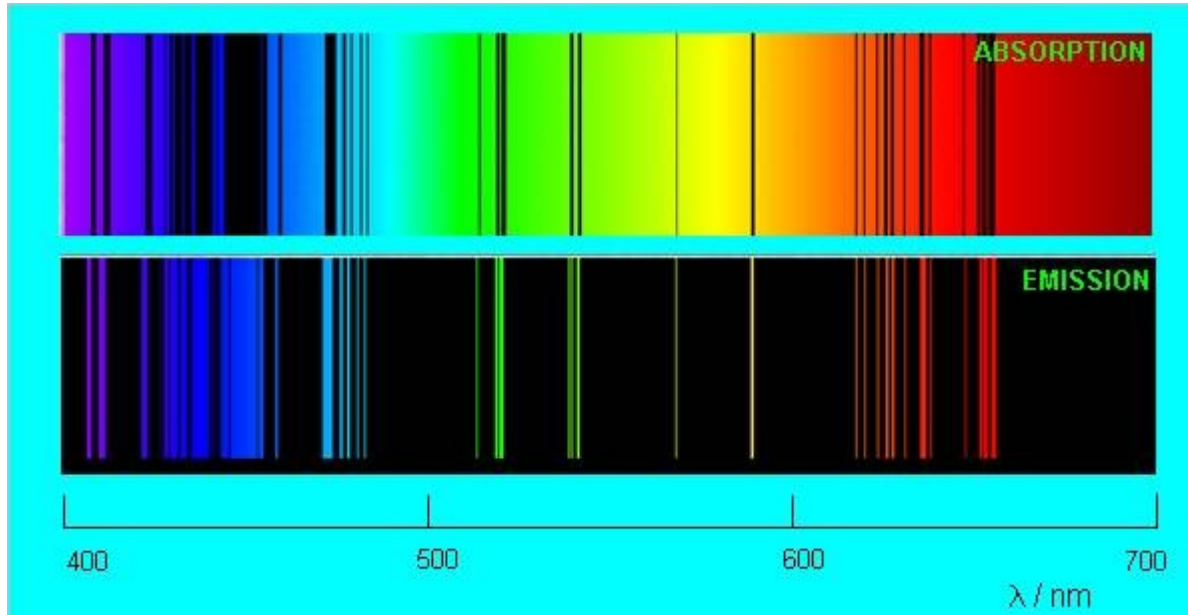




Solar spectrum, 2960-13000 Angstroms

Data: Bob Kurucz et al (SAO); Image: Nigel Sharp. NOAO; Telescope: KPNO-McMath

What we can learn from a spectrum:



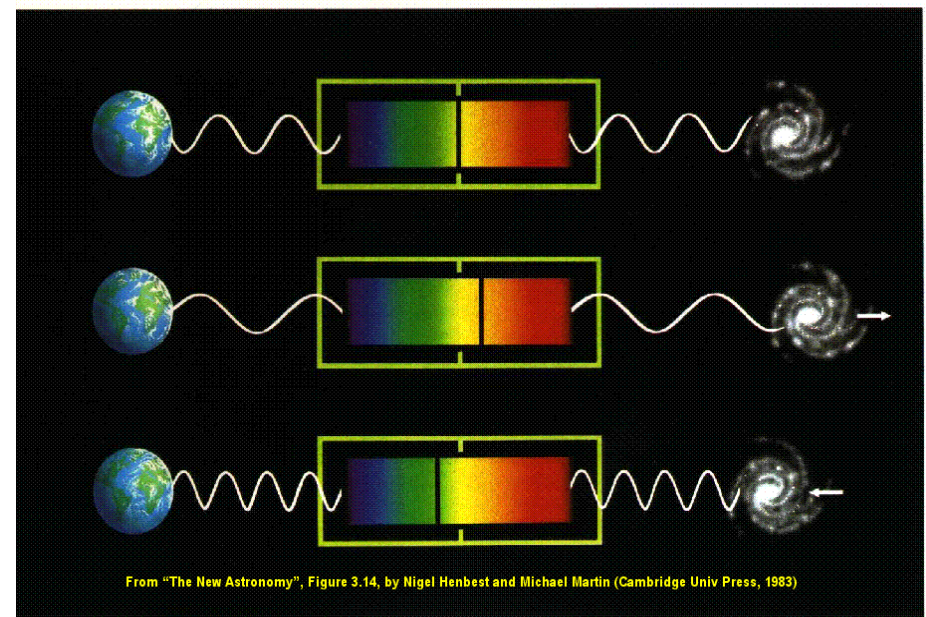
What is the light source made of?

- this is the “fingerprint” of sodium

What are the physical conditions like?

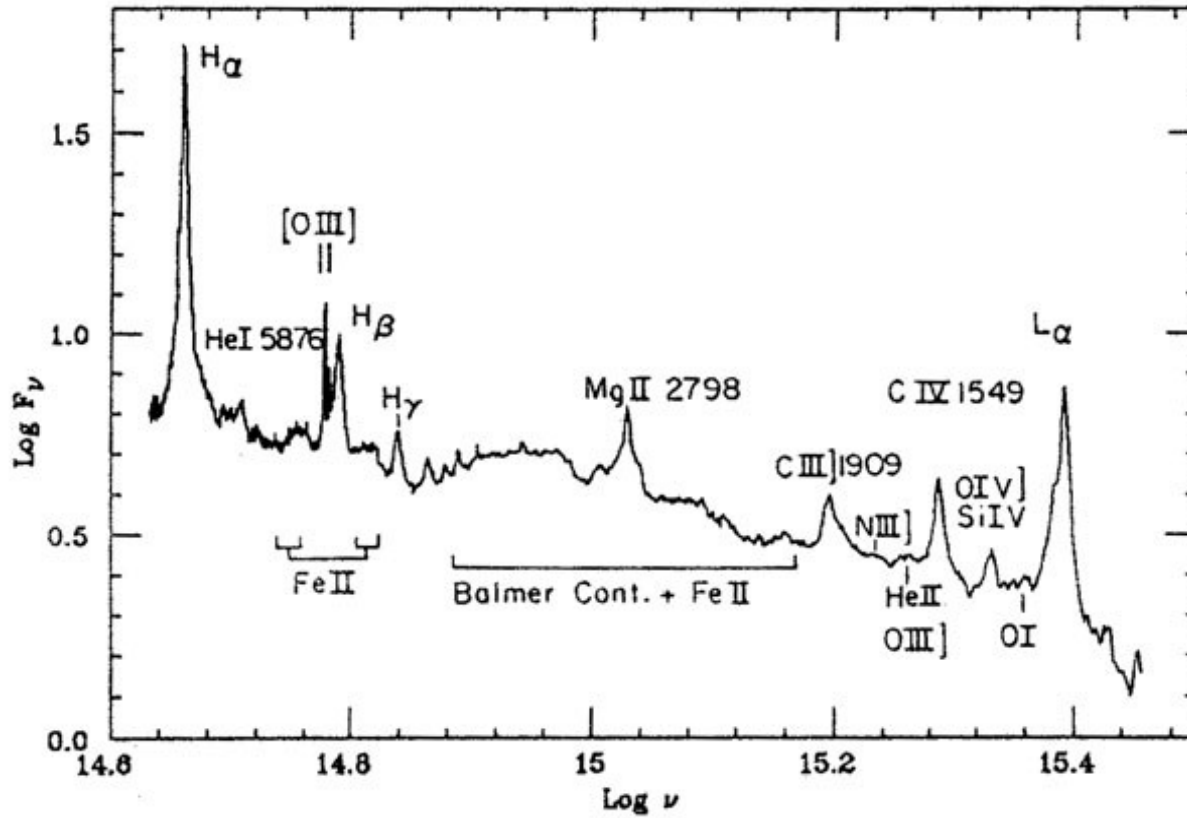
- relative brightness and thickness of different lines indicates temperature and density

How fast is it moving?
“Doppler Shift” stretches or squeezes the spectrum:
read off the speed



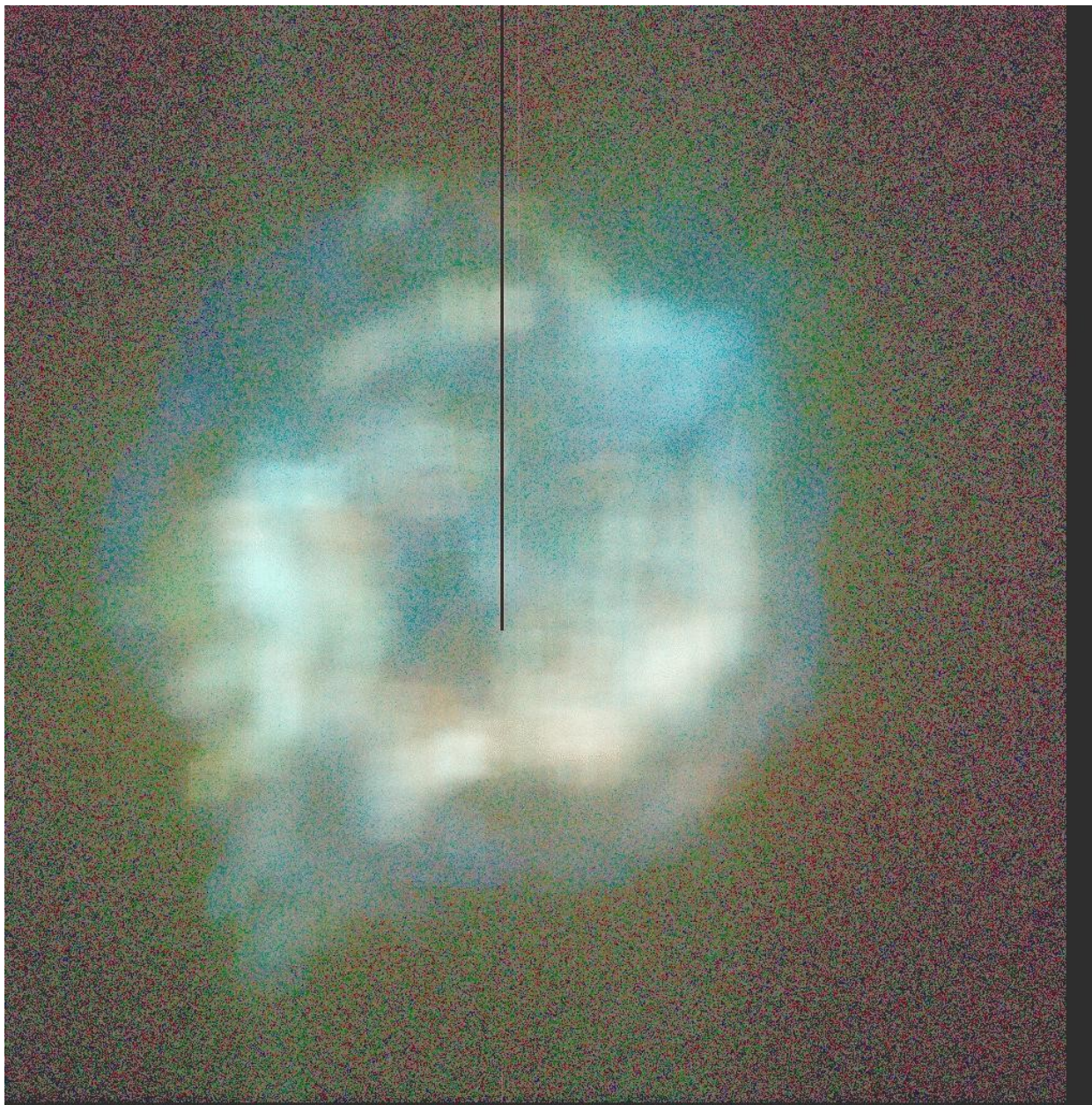
Different Kinds of Data 3 - Spectra

Brightness
↑



Red Blue Ultraviolet

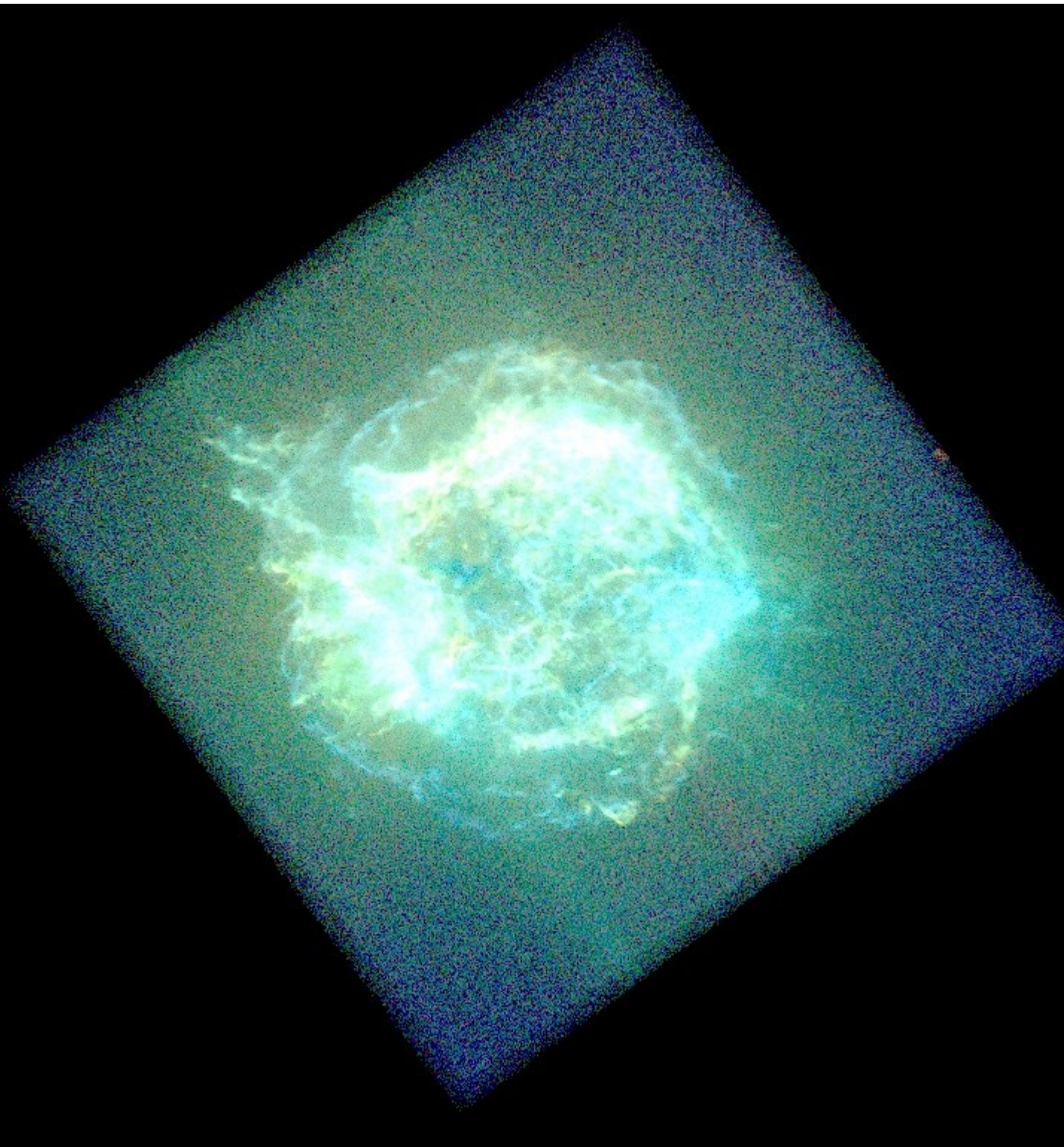
Data; J. Baldwin via NED IPAC (Caltech)



Observation 114
S. Holt, 2000
Downloaded from
public archive for
reanalysis

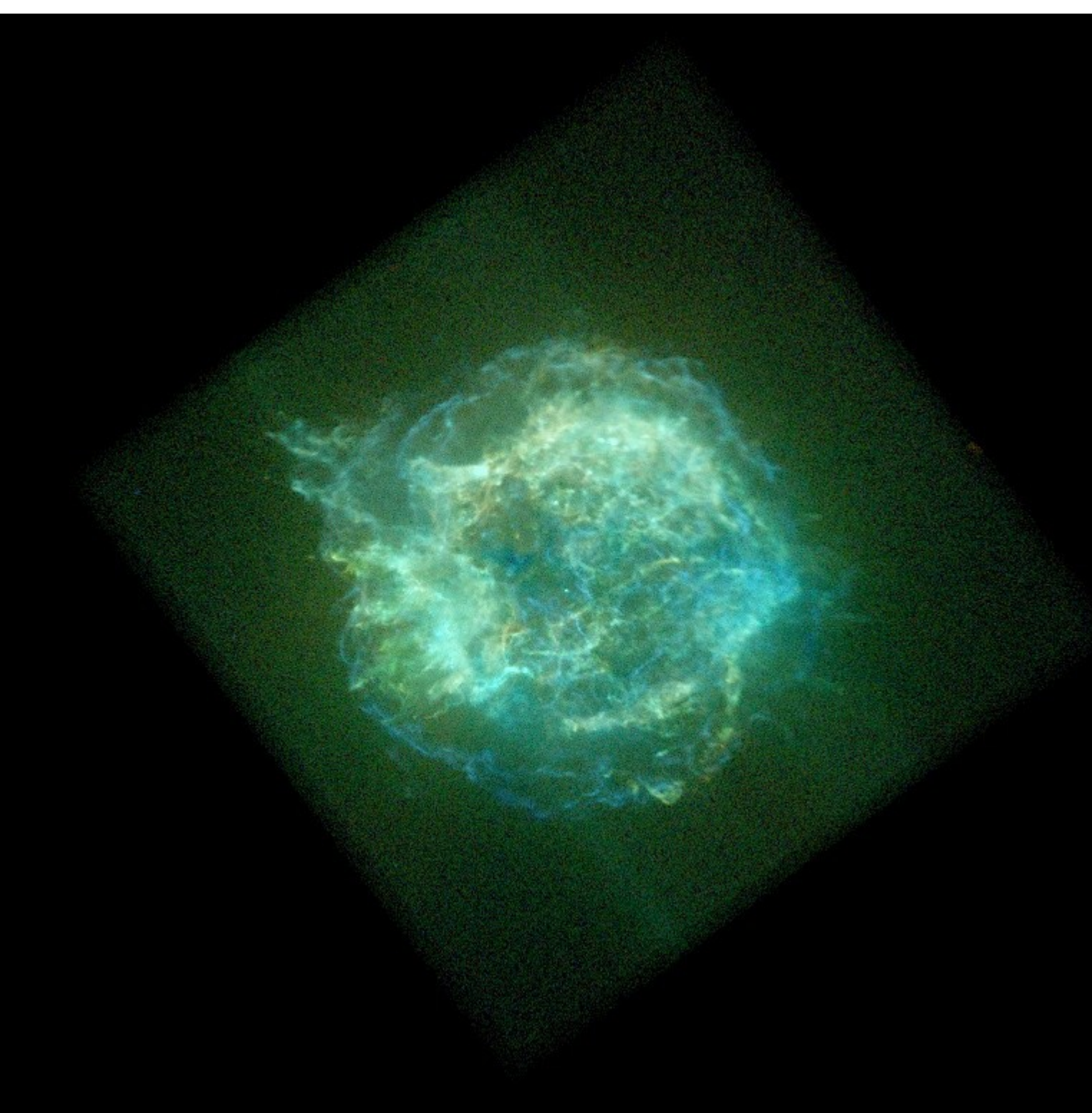
Our first image, as the spacecraft takes it

wrong (and unknown) way up
blurry
lots of background noise

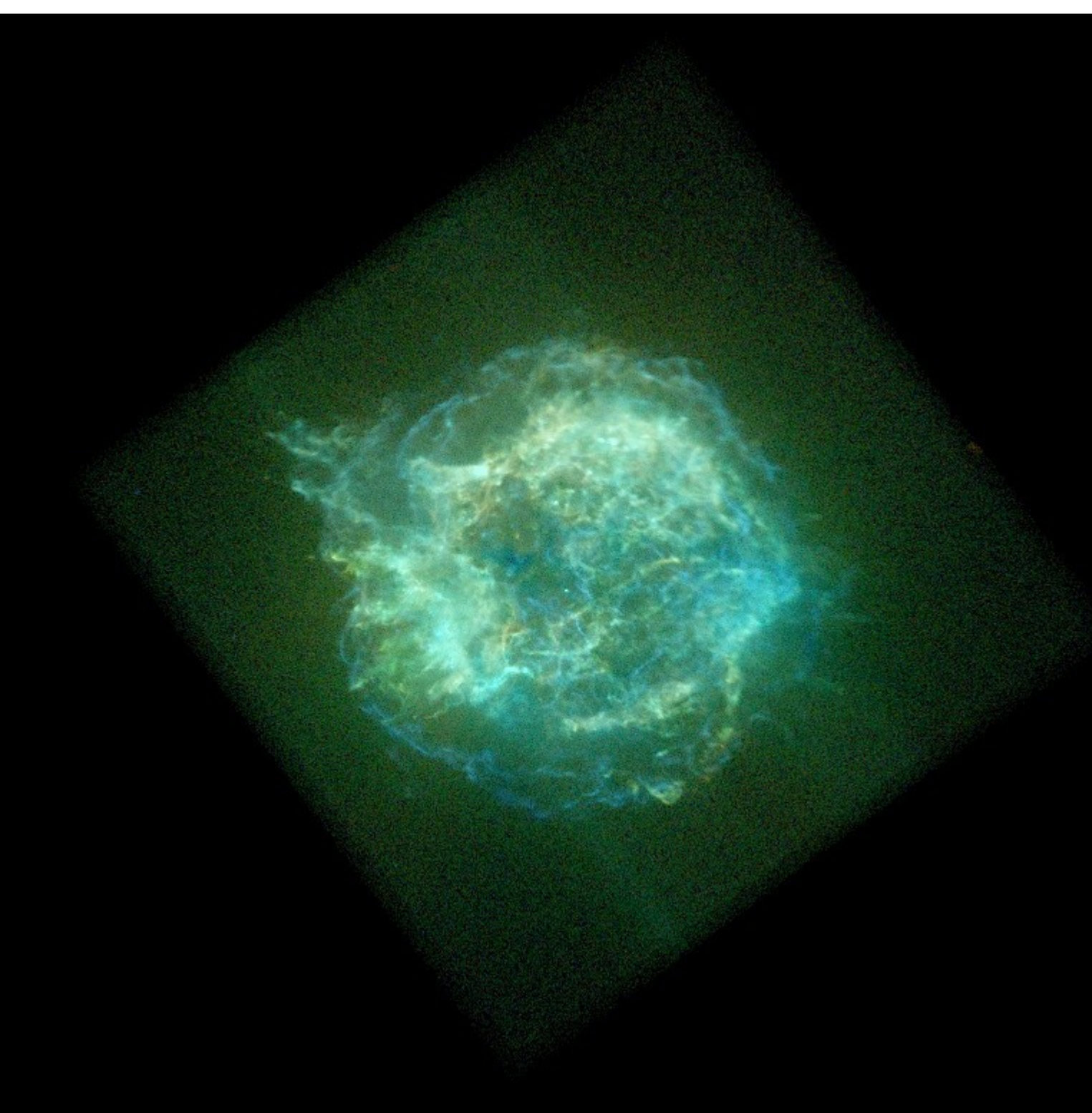


Correct for
telescope
motion

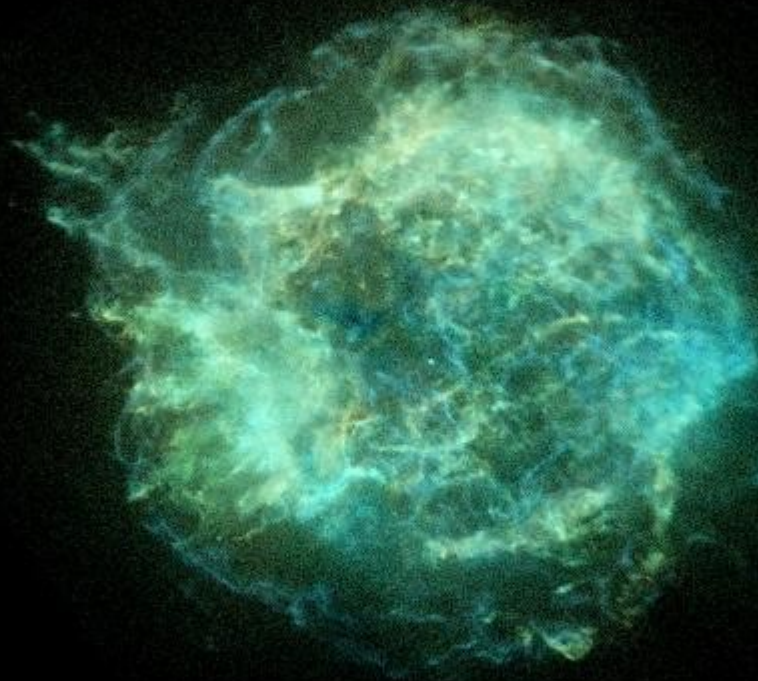
Remove bad
energy ranges

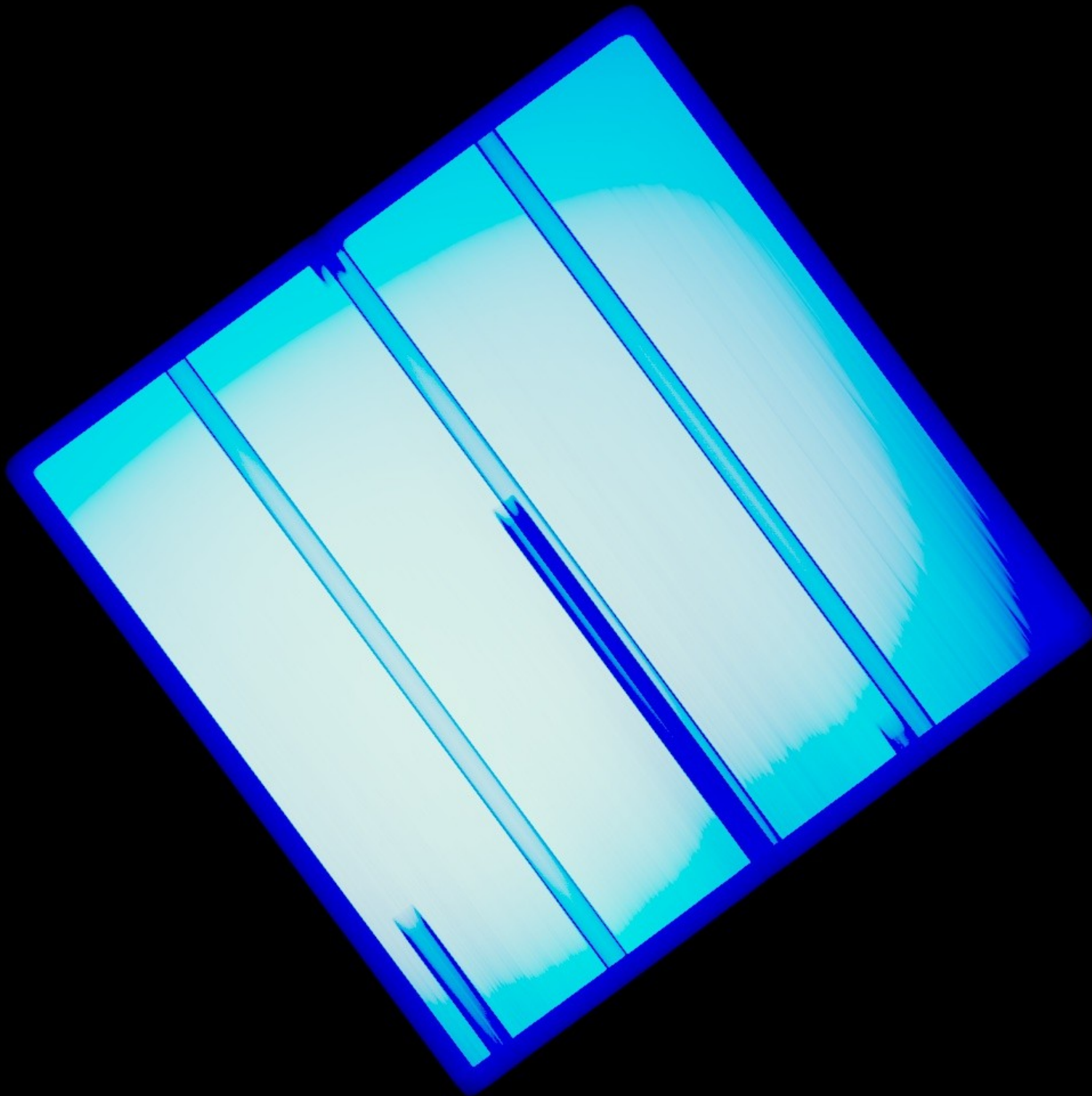


Remove bad
energy ranges



Remove bad 'grades'
(probable cosmic rays),
bad time intervals
(solar flares)

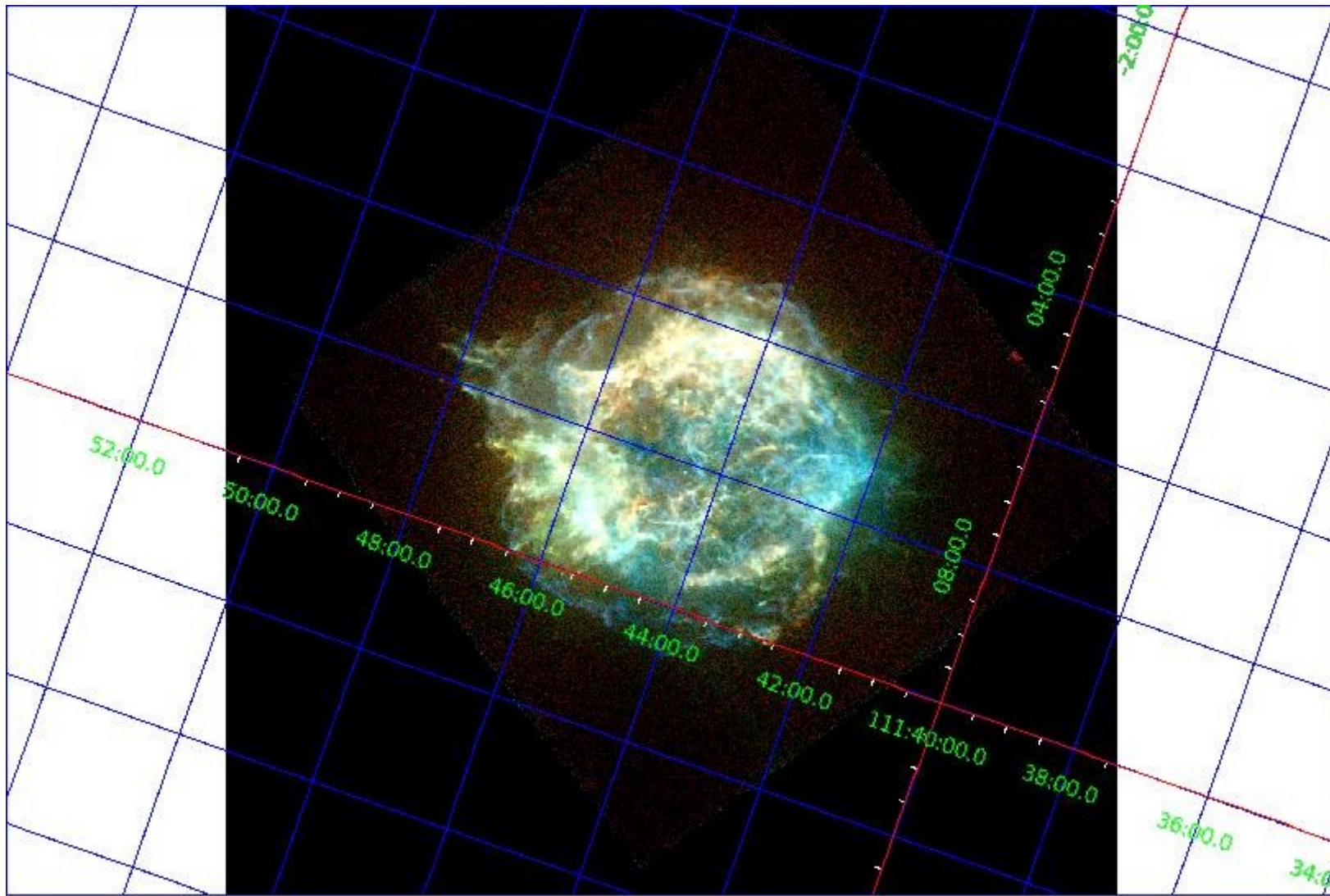




Correct for
detector
sensitivity

Correct for
detector
sensitivity

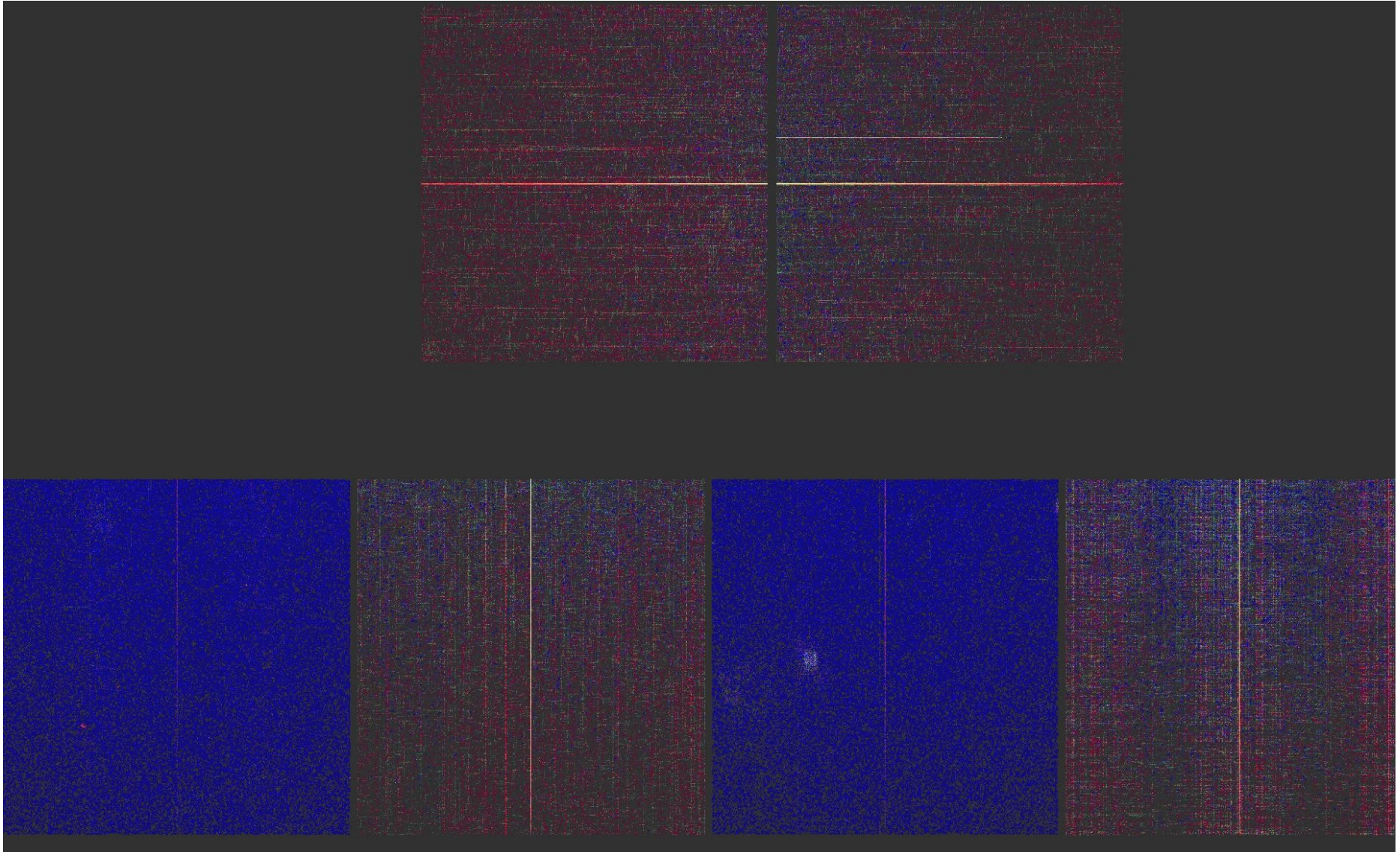




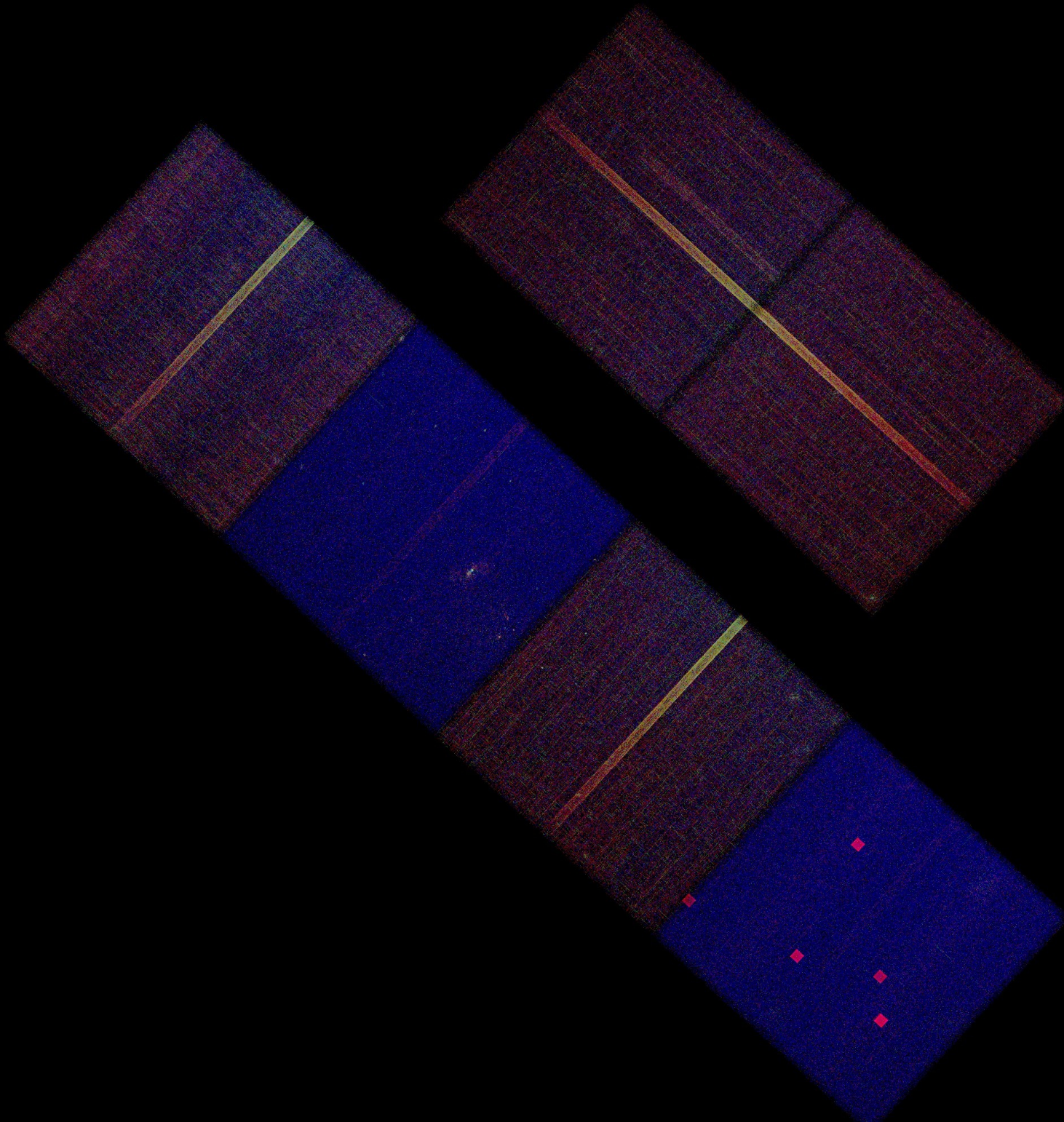
5.54e-08 1.66e-07 3.88e-07 8.28e-07 1.72e-06 3.47e-06 6.97e-06 1.40e-05 2.80e-05

Latitude
and
longitude
grid
etc.

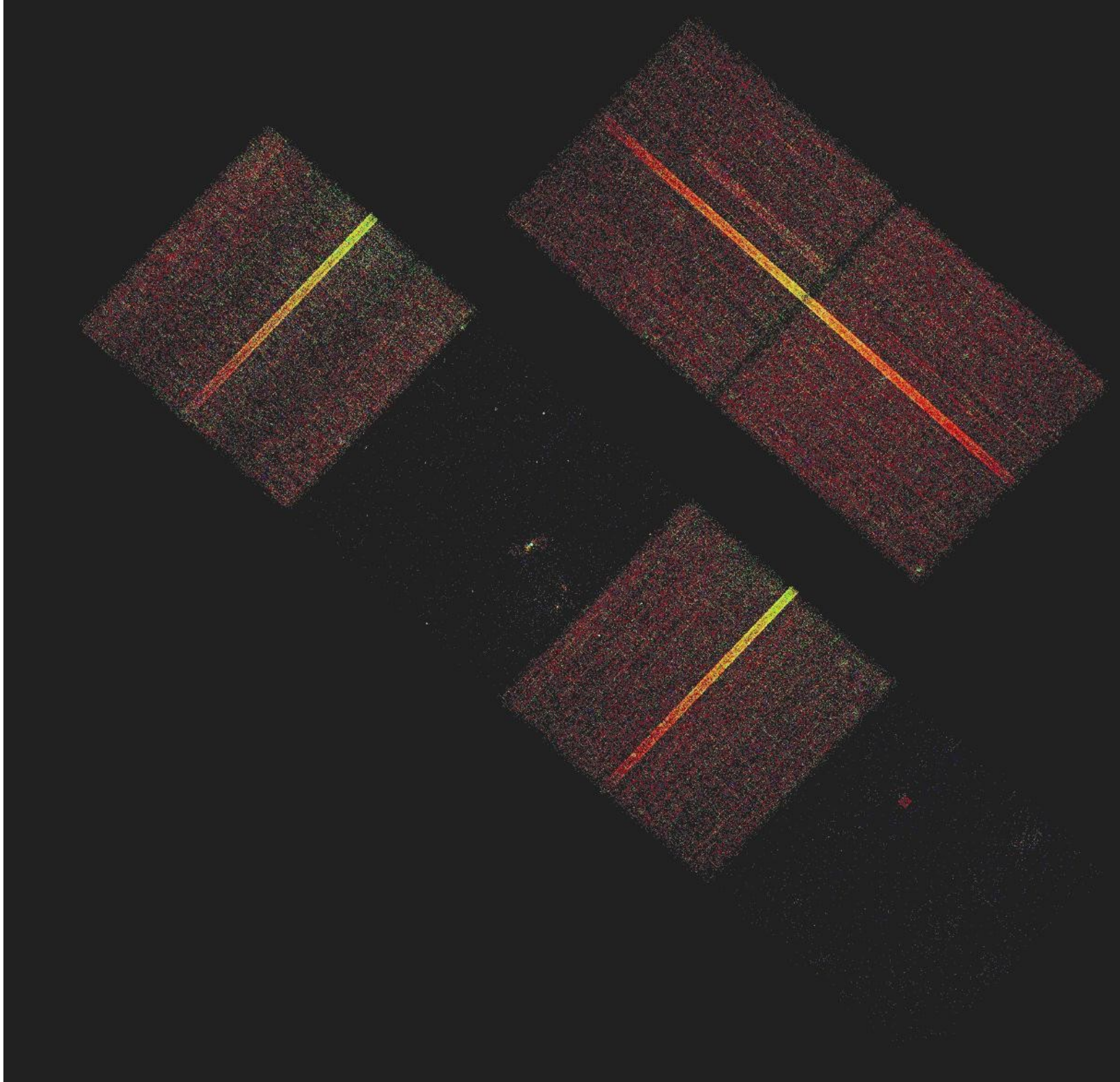
And now, to the constellation Serpens...



Our first image, as the spacecraft takes it
wrong way up
blurry
lots of background noise, bad columns - not obvious if we have got anything!



Corrected
for
telescope
motion



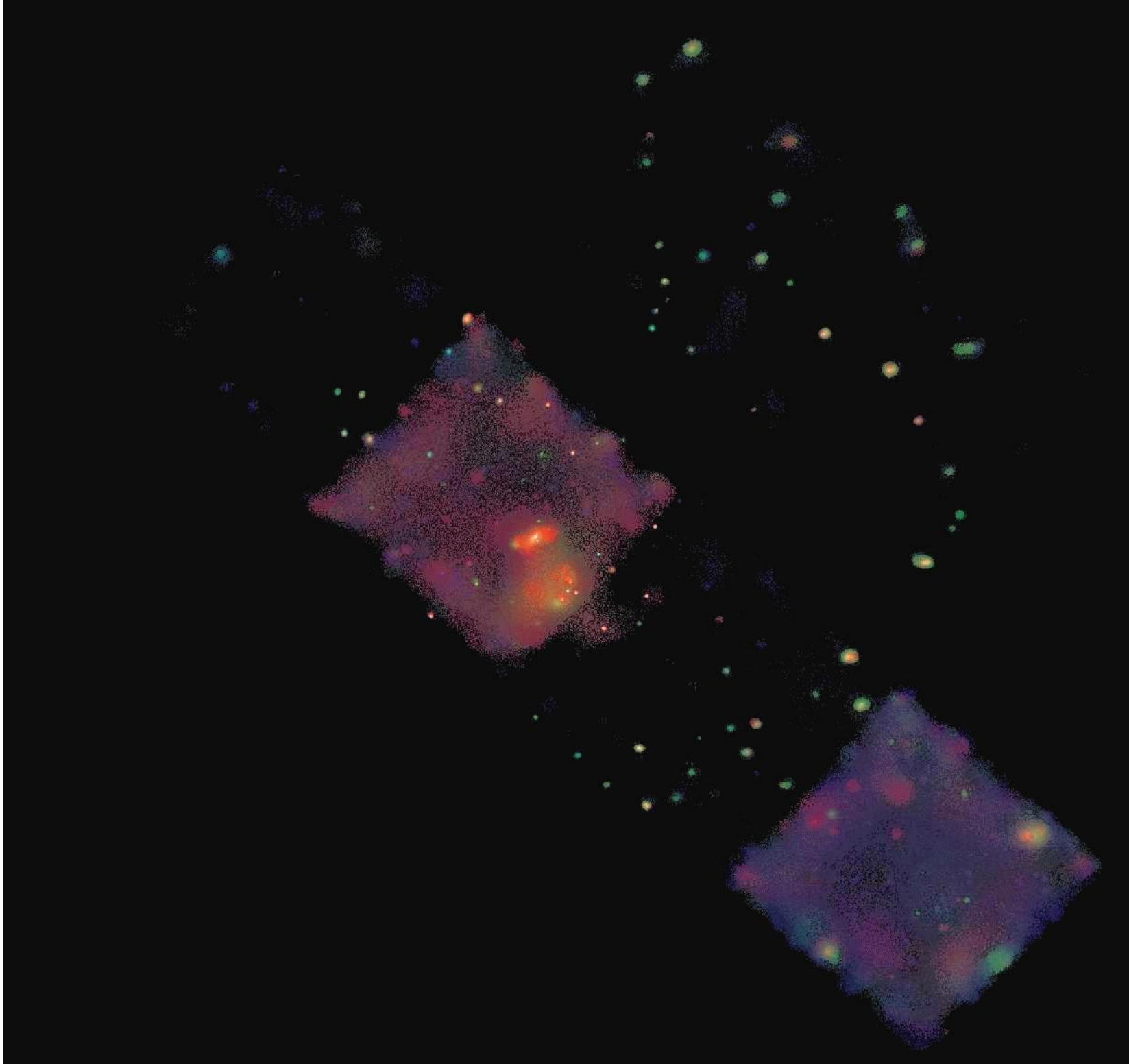
Clip out bad color ranges – removes some bad pixels and some of the cosmic ray background



Get rid of bad
columns, pixels

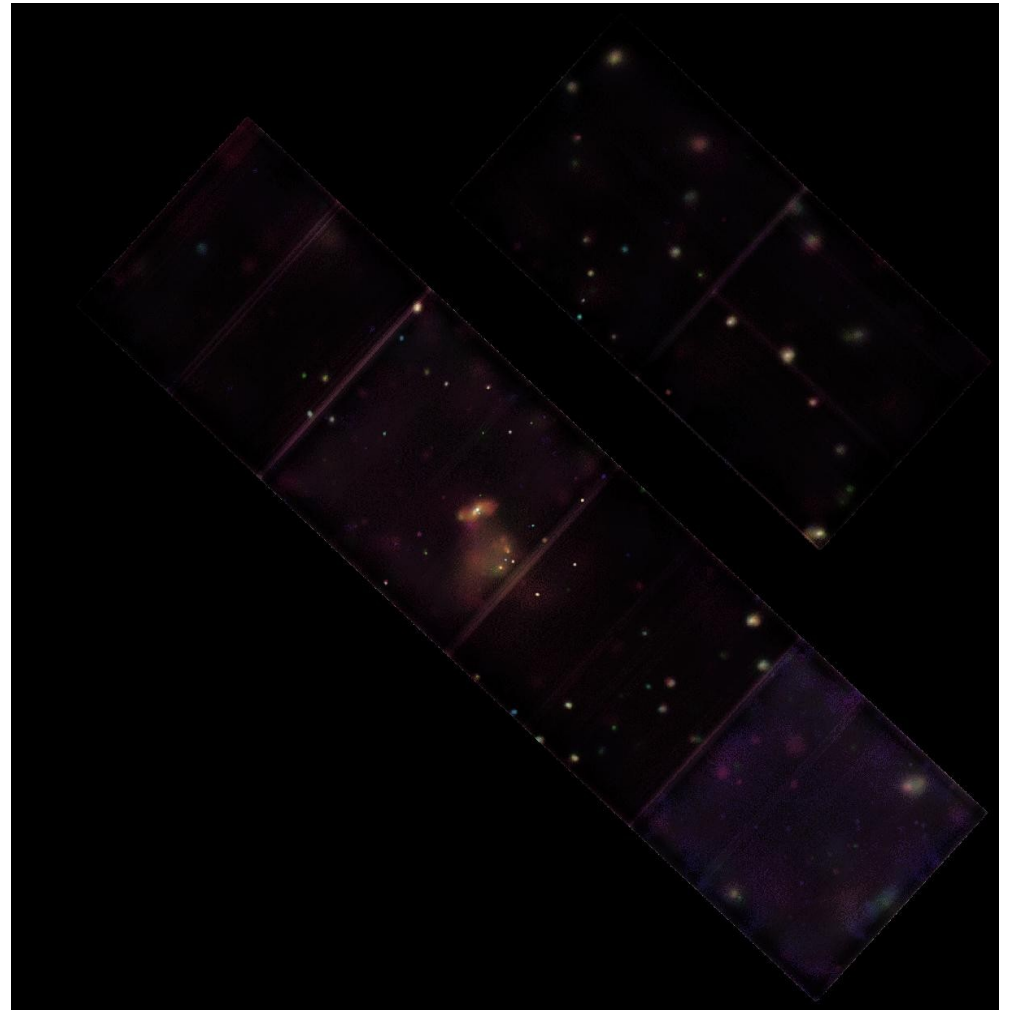
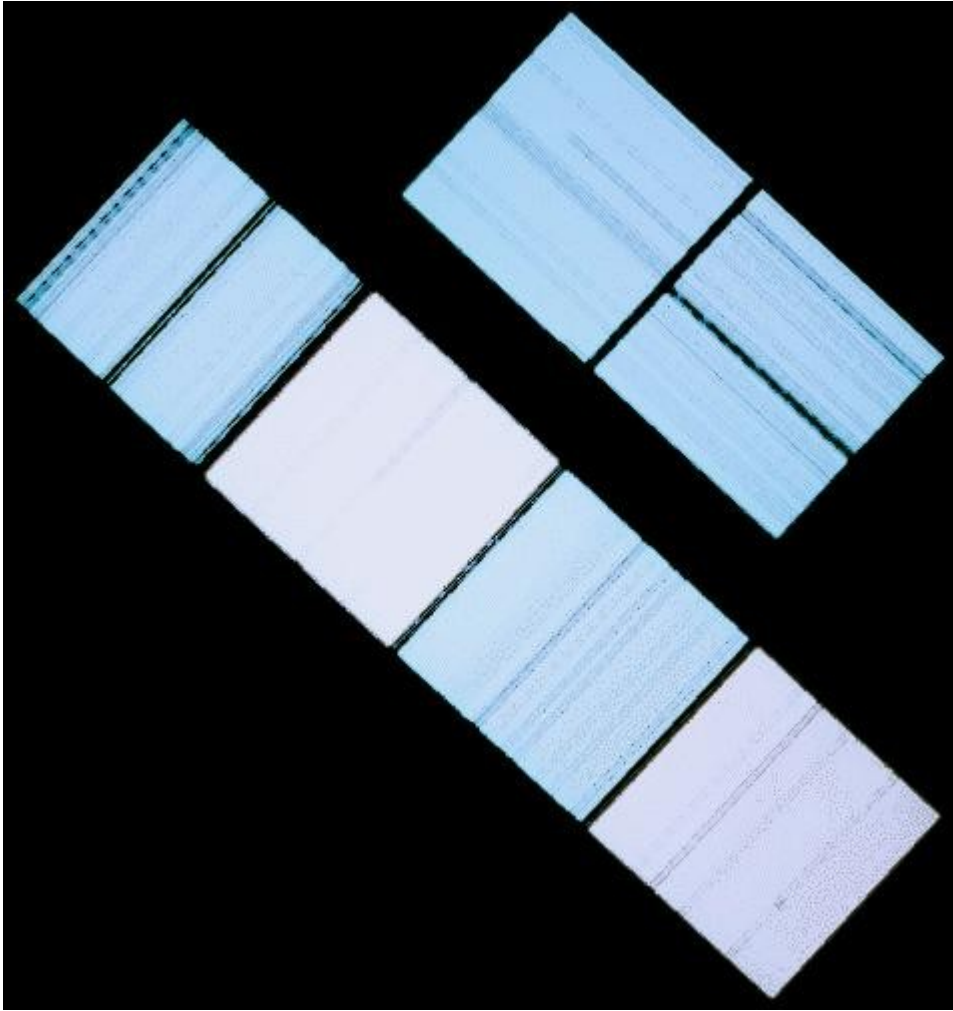
Get rid of some
more cosmic
rays (“grade
filtering”)

Get rid of bad
time intervals



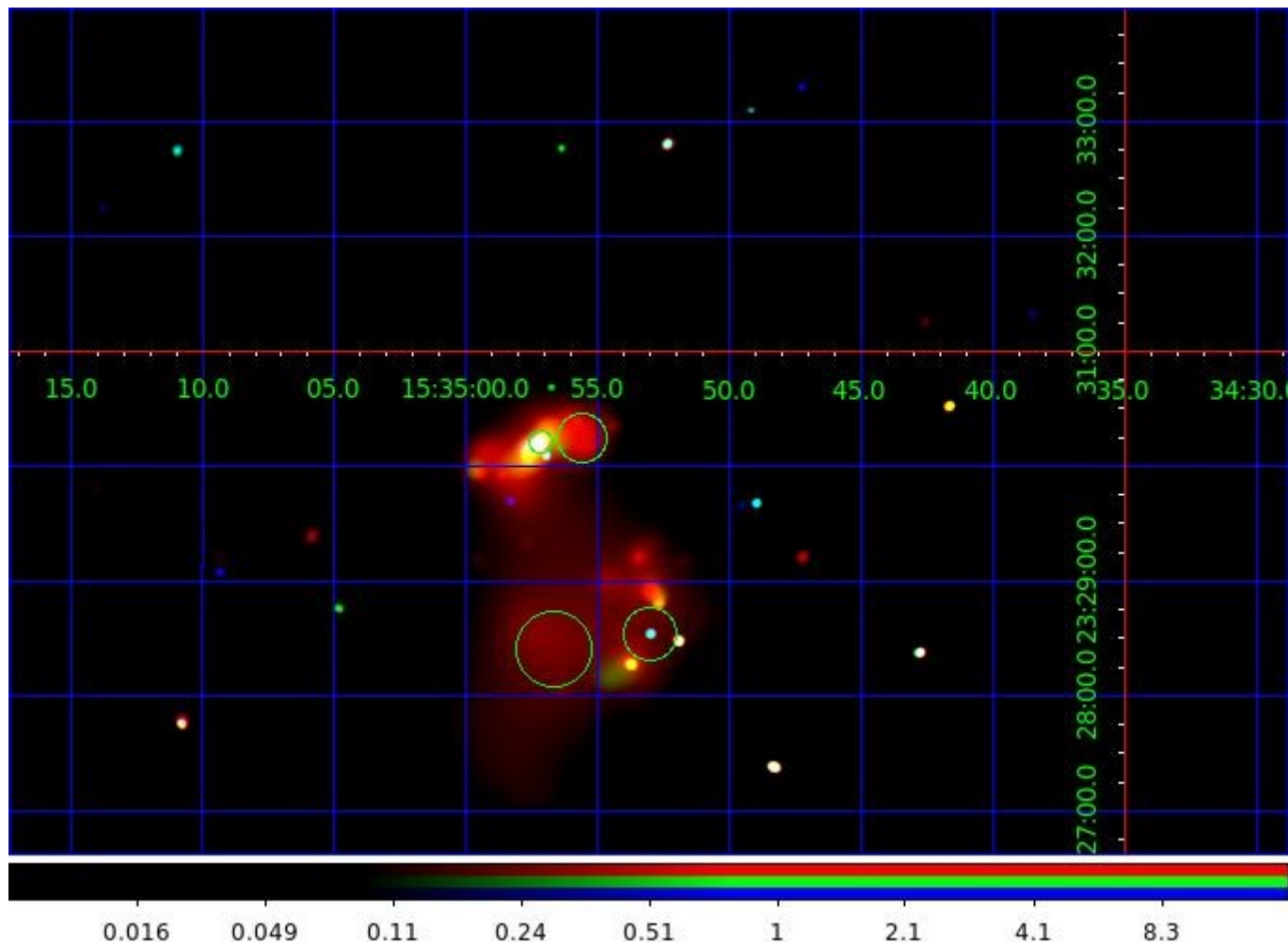
Adaptive
Smoothing:
desperately try and
compensate for the
fact that we have
only a handful of X-
rays.

Now we correct for the varying exposure across the image caused by imperfections in the camera and the observing process



Isolate the region of interest





Put on the coordinate grid

Find the galaxies you are interested in

Define circles to isolate them

Now we can look at the light from those regions and play the spectrum game:

- how hot? what's it made of? How fast is it moving?

Papers: Clements, McDowell, et al 2002 – Astrophysical Journal 581, 974

McDowell, Clements, Lamb et al 2003 – Astrophysical Journal 591, 154

Part 3

Astronomy Data in the New Millenium

Historical Digression

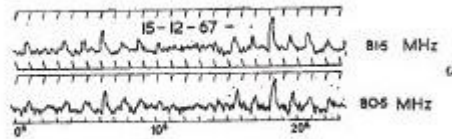


Fig. 1. a. A record of the pulsating radio source in strong signal conditions (receiver time constant 0.1 s). Full scale deflexion corresponds to

In the 1960s it was almost all done by hand...
 photographic plates
 light tables

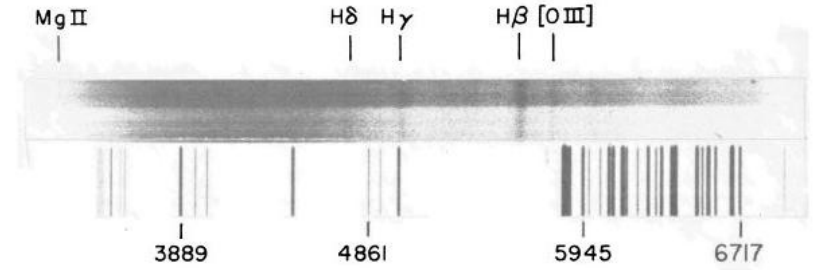


FIG. 2.—Spectrum of the quasi-stellar object 3C 273B, 400 Å/mm original, 103a-F, January 23, 1963. The comparison spectrum is H + He + Ne. Exposure over the upper half of slit was three times that over the lower half. Redshifted emission lines of H and [O III] are indicated; also the barely visible line of Mg II, confirmed on denser exposures.

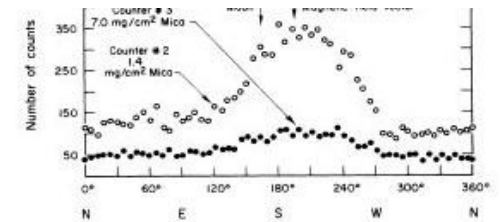


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

even lower back-lobe level.

From a combination of the above, we compute the remaining unaccounted-for antenna temperature to be $3.5^\circ \pm 1.0^\circ$ K at 4080 Mc/s. In connection with this result it should be noted that DeGrasse *et al.* (1959) and Ohm (1961) give total system temperatures at

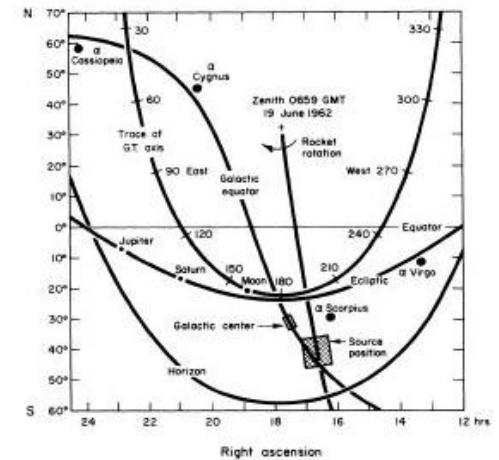
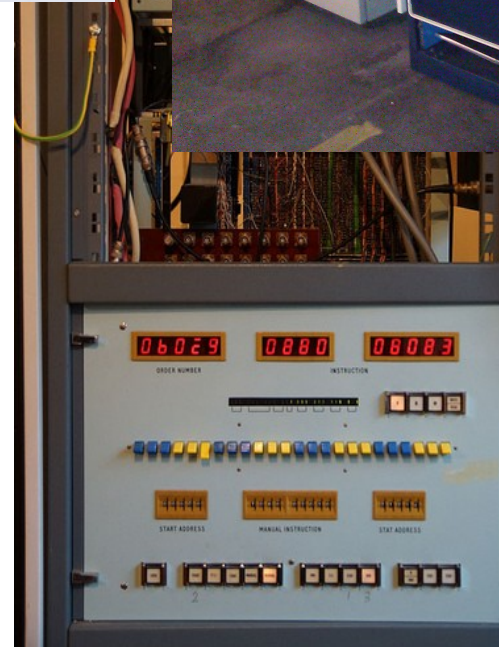


FIG. 2. Chart showing the portion of sky explored by the counters.

In the 1970s we introduced computer controlled telescopes
Data was written to magnetic tape, or photographic plates digitized by primitive
scanners

Each telescope and camera had its OWN software – and was usually used by only one
or a few astronomers. The software often only ran on ONE computer (not one TYPE
of computer!)



In the 1980s the first generic software systems appeared

FIGARO by Keith Shortridge (1982, Caltech then AAO)

IRAF by Doug Tody (1984 at NOAO)

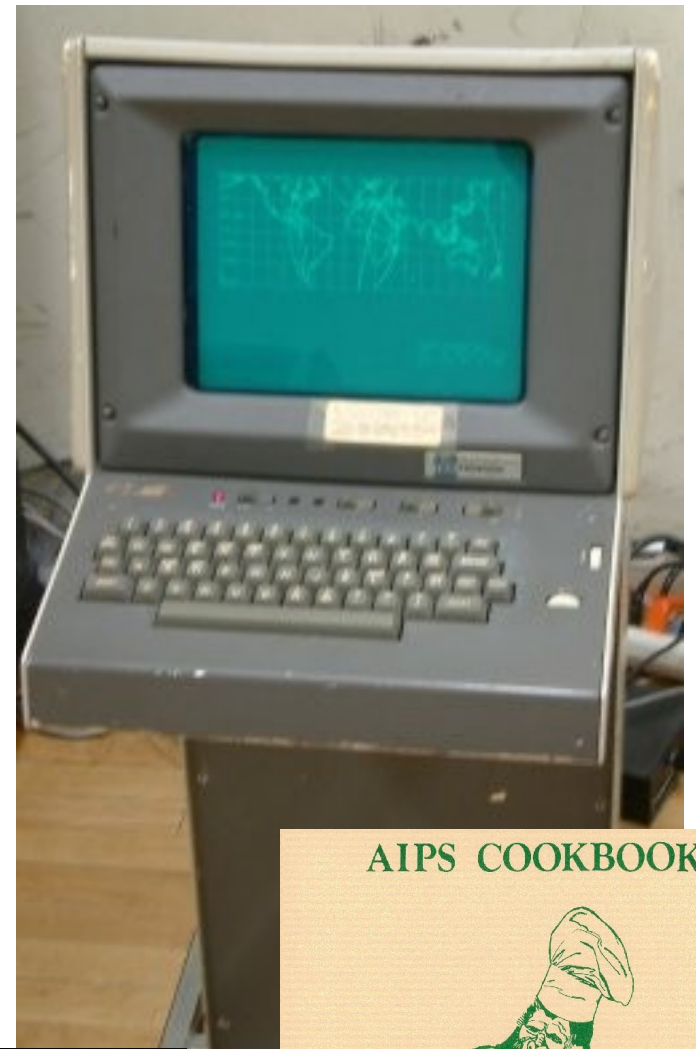
AIPS by Eric Greisen et al (1980 at NRAO) for radio astronomy

XSPEC by Rick Shafer, Keith Arnaud (c.1986) for X-rays

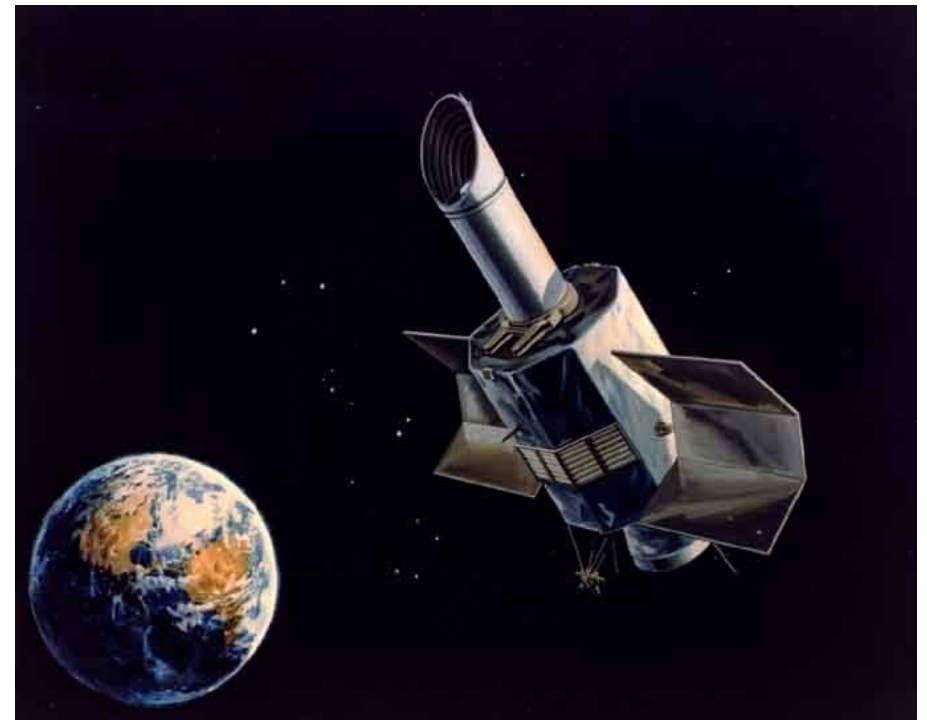
IDL (David Stern, commercial package) especially for analysis of IUE satellite data, late 1970s

Now astronomers could spend time using software instead of writing it

(Imagine if every time you needed to write a letter, you first had to invent your own equivalent of Word..)



Another crucial change in the late 1970s and early 1980s:
the public archive and the beginnings of the move to open source/open data



HEAO-2 1978-80
IUE 1978-1996



With HEAO-2 (Einstein) and IUE, astronomers (“Guest Observers”) across the world could request data from the telescope and come to mission control to analyse it
This drove us to standard 'data products' and formats,
and user-friendly software

Public data archives and archival research

- in the late 1980s and early 1990s it became practical to download science data over the internet.
- That forced us to be a lot more detailed in describing what the data is, so that astronomers who didn't make the observation can do something with it without making mistakes
- We even went back and read the old data tapes from old missions – gathering mold in warehouses – reformatted them and wrote the files to CD-ROM, put them online
- Expertise for different wavebands ended up in special centers

Today members of the public can download space telescope data and software for free

- learning how to use the software may be a bit more tricky!



Pasadena, California: IPAC, for Infrared Astronomy

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RADAR Estimation Page * IRSA

Back Forward irsa.ipac.caltech.edu/applications/wise/#id=Hydra_wise_wise_1&DoSearch=true&size=0.00555556&band=1,2,3,4 Home

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IRSA NASA / IPAC Infrared Science Archive

IRSA Mission Archive Search Related Data Archives Tools & Services Help

Searches History Preferences Help Plot Layers Background Monitor

MESSIER 051; Type=OVERLAPS; Region=0.0056 deg; Product Level=3a; alisky-4band

View Options: [Grid Icon] [List Icon]

Coverage Multi-Color Details

IRAS:IRIS 100 3x

Atlas (Level 3)

Prepare Download [1] of 1 (1 - 4 of 4) as Text Save Add filters

<input type="checkbox"/>	band	coadd_id	date_obs1	mid_obs	date_obs2	numfms
<input checked="" type="checkbox"/>	1	2029p469_ab41	2010-06-09 00:37:40.579	2010-06-11 09:47:10.619	2010-06-19 14:38:20.519	218
<input type="checkbox"/>	2	2029p469_ab41	2010-06-09 00:37:40.579	2010-06-11 09:47:10.619	2010-06-19 14:38:20.519	218
<input type="checkbox"/>	3	2029p469_ab41	2010-06-09 00:37:40.579	2010-06-11 08:12:00.594	2010-06-19 13:03:21.499	206
<input type="checkbox"/>	4	2029p469_ab41	2010-06-09 00:37:40.579			



Compact sources catalog, the Early Sunyaev-Zeldovich Cluster Sample, and the Early Cold Core Sample.

<http://irsa.ipac.caltech.edu/>

Baltimore, Maryland: MAST, for UV/Optical Astronomy

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MAST HST

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Barbara A. **MIKULSKI ARCHIVE OF SPACE TELESCOPES**

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HST Home About HST Getting Started Registration Archive Status HST Search HSTonline Search

HST Target Search

HST Abstract Search

FAQ

Search & Retrieval

MAST Services

Daily Data Reports

Please take [The 2012 MAST User Survey](#).

Hubble Space Telescope

Hubble Space Telescope (HST) is an orbiting astronomical observatory operating from the near-infrared into the ultraviolet. Launched in 1990 and scheduled to operate through 2010, HST carries and has carried a wide variety of [instruments](#) producing imaging, spectrographic, astrometric, and photometric data through both pointed and parallel observing programs. MAST is the primary archive and distribution center for HST data, distributing science, calibration, and engineering data to HST users at large. Over 100 000 targets are available for

- ### News
- November 02, 2012:**
HLA DR7 is available
 - October 10, 2012:**
CLASH team delivers catalogs and scale 30mas images for RXJ1532.9+3021
 - September 28, 2012:**
Swift UVOT data now available at MAST
 - September 11, 2012:**
High-Level Science Products for RXJ2129+0005 delivered by the CLASH Team
 - August 30, 2012:**
CLASH Team delivers data

- ### Missions
- Hubble
 - Hubble Legacy Archive
 - HSTonline
 - DSS
 - GALEX
 - JWST
 - KEPLER
 - SwiftUVOT
 - XMM-OM
 - BEFS (ORFEUS)
 - Copernicus
 - EPOCH
 - EUVE
 - FUSE
 - GSC
 - HPOL
 - HUT
 - IMAPS (ORFEUS)
 - IUE
 - TUES (ORFEUS)
 - UIT

View History Bookmarks Tools Help

Hubble Legacy Archive (M101)

hla.stsci.edu/hla/view.html#images/filter/terText%3D%24filterTypes%3D[query_string=M101&posfilename=6poslocalnai...]

Hubble Legacy Archive

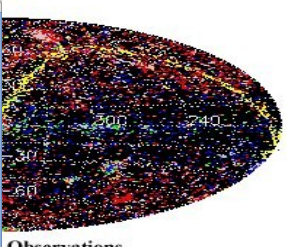
M101 Search Reset advanced search

Examples: M101_14 03 12.6 +54 20 56.7 r=0.2d more... Requires Firefox, Safari, IE, or compatible browser

Images Footprints Cart, 0 kb Grism Spectra (ST-ECF) Help Center

210.802270 Dec = 54.348950 r = 0.240000 [14:03:12.645 +54:20:56.22]

of 1463 Show 20 results per page



Observations

1st images Add selection to cart

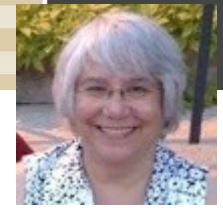
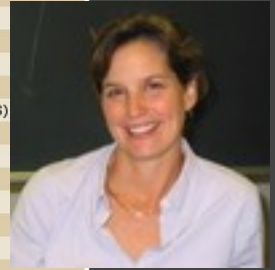
Rows: First Mixed Only Not Select all Reset selection

pp_hst_wfpc2_2ho01_f606w_v2_sci
Interactive Display
Download Data: FITS-Science (23.5 MB)
Download Source Lists: None

APPP (Hisp) WFPC2 F606W
hisp_appp_hst_wfpc2_sfd-pu4woae01_f606w_v2_sci
Interactive Display
Download Data: FITS-Science (13.4 MB)
Download Source Lists: None

M101-OUTER-A (combined) PC F602N WFALL-FIX
hst_05210_01_wfpc2_f602n_pc
Interactive Display
Download Data: FITS-Science (2.4 MB)
Download Source Lists: None

M101-OUTER-A (combined) WFPC2 F602N WFALL-FIX
hst_05210_01_wfpc2_f602n_wf
Interactive Display
Download Data: FITS-Science (9.8 MB)
Download Source Lists: FITS-MEF (7.4 MB), DAOPhot (plot), SExtractor (plot)



Greenbelt, Maryland: HEASARC, for High Energy Astronomy



NASA National Aeronautics and Space Administration
Goddard Space Flight Center
Sciences and Exploration

HEASARC Home Observatories Archive Calibration Software

NASA's HEASARC

High Energy Astrophysics Science Archive Research Center

About the HEASARC Resources for Scientists FAQ/Help Site Map



Guest Observer Facilities & Science Centers

AGILE	ASCA
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COBE	CGRO
Chandra	EUVE
Fermi	GALEX
HETE-2	INTEGRAL
MAXI	HuSTAR
ROSAT	RXTE
Suzaku	Swift
WMAP	XMM-Newton

NASA Archives

ADS	AstroGravS
EOSDIS	ExoArchive
HORIZONS	IRSA
KOA	LAMBDA
MAST	HEXSci
NEED	ISSDC
PDS	SDAC
SPDF	SSC

Try **Xamin**, the New HEASARC Discovery and Retrieval System

A faster, more powerful way to access data in HEASARC

The High Energy Astrophysics Science Archive Research Center (HEASARC) is the primary archive for NASA's (and other space agencies') missions dealing with electromagnetic radiation from extremely energetic objects in the universe. The Legacy Archive holdings contain extreme-ultraviolet and ground-based

telescope have made the most accurate measurement of the extragalactic background light in the universe and used it to establish the total number of stars that have ever shone, accomplishing a primary Fermi mission goal.

- [Updated IRAM Plateau de Bure Interferometer Observation Log](#) (01 Nov 2012)



Cambridge, Mass: Chandra Observatory

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Chandra X-ray Observatory



CXC Home Proposer Archive Data Analysis

Instruments & Calibration NASA Archives and Centers

CXC → CDA

File Edit View History Bookmarks Tools Help

Chandra Data Archive (Eta C...

Chandra Footprint Service

Eta Carinae Search Reset Search Options

Examples: Eta Carinae, 10 45 03.591 -59 41 04.26 (= \pm 0.24)
Requires Firefox 3, Safari 4, IE8, or compatible browser

Footprints Image Inventory Preview Images/Download Data Help FAQ

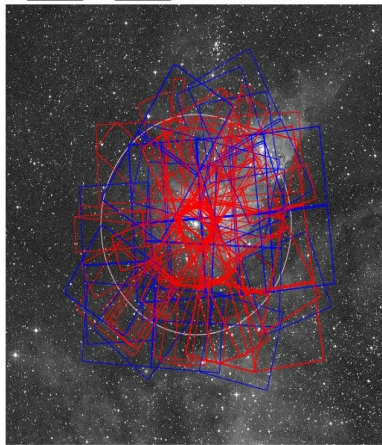
Eta Carinae RA = 161.264962 Dec = -59.684517 r = 0.200000 [10:45:03.591 -59:41:04.26]

Instrument: RA [161.675] DEC [-59.297] Search Radius (deg): 0.2

ACIS-I ACIS-S HRC-I HRC-S

Footprints to display:
 All Public Observations
 CSC Coverage ?

Show OSS Image:
Get VO Table ?



Results 1-20 of 57 Show [20] results per page

Click column heading to sort list - Click rows to select
Download Selected ObsIDs

Show selected rows: First Mixed Only Not Reset selection

Text boxes under column headings allow specifying a filter to be applied to columns Apply Filter Clear Filter

ObsID	Target	Observation Date	RA	DEC	Proposal ID	PI Last Name	Instrument
50	ETA CARINAE	1999-09-06T19:48:00	10 45 03.61	-59 41 03.1	1200093	Calibration	ACIS-I

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RADAR Estimation Page Chandra Data Archive: Obser...

cda.harvard.edu/chaser/ Reload Stop Google Home

Chandra X-ray Center Observation Search

Search

Target Name Resolve Name RA/Long/ Dec/Lat/ Radius 10 arcmin

Name Resolver SIMBAD/NED Coordinate System Equatorial J2000 Equinox 2000

Observation ID Sequence Number Proposal Number

Proposal Title PI Name Observer Name



Start Date Public Release Date

Exposure Time (ks) Approved Time (ks) Avg. Count Rate (hr)

Status Arch Obs Sch Uno Untr


Instrument ACIS ACIS-I HRC HRC-S

Customize Output: Sort Order Display Coordinate System

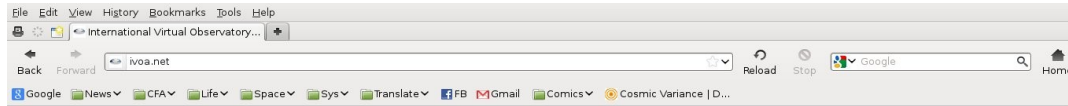
GO GTO TOO DNT

Type Observing Cycle



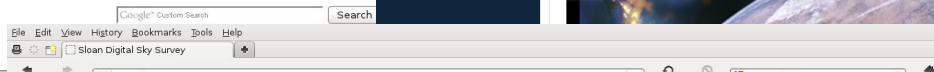
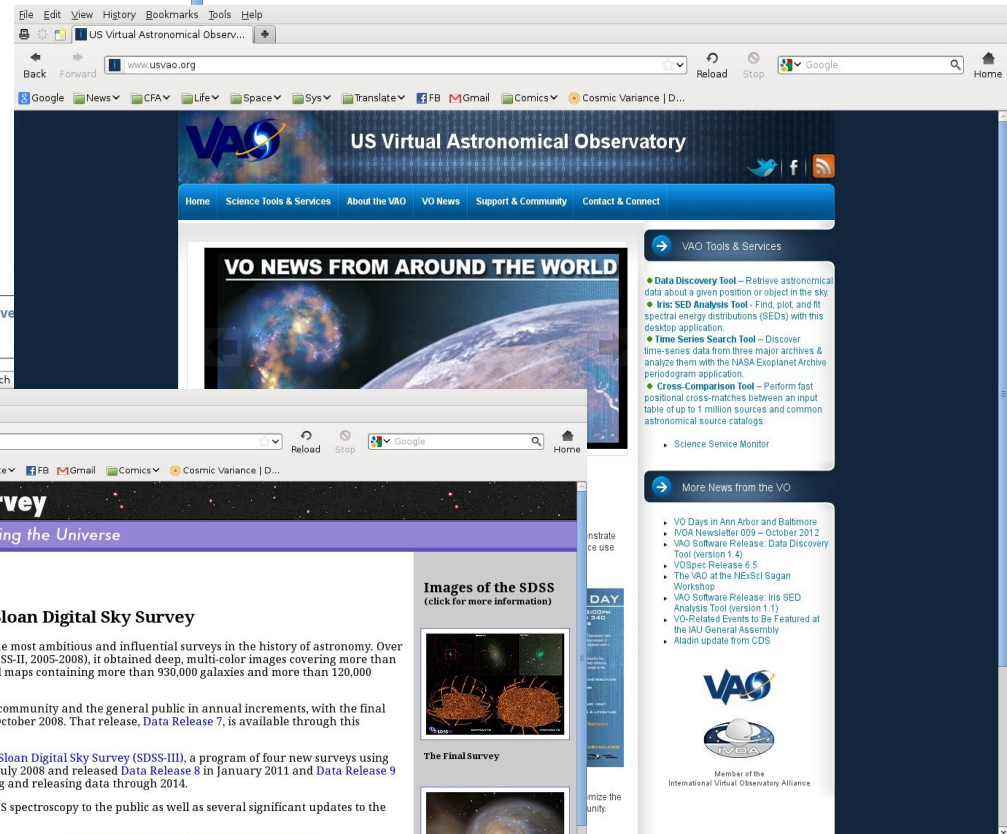
The 21st Century Challenge: Tying It All Together

How do I find all the data for one particular galaxy? Easily combine Hubble, Chandra, ground-based images?



International Virtual Observatory Alliance

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Sloan Digital Sky Survey

Mapping the Universe

The Sloan Digital Sky Survey

The Sloan Digital Sky Survey (SDSS) is one of the most ambitious and influential surveys in the history of astronomy. Over eight years of operations (SDSS-I, 2000-2005; SDSS-II, 2005-2008), it obtained deep, multi-color images covering more than a quarter of the sky and created 3-dimensional maps containing more than 930,000 galaxies and more than 120,000 quasars.

SDSS data have been released to the scientific community and the general public in annual increments, with the final public data release from SDSS-II occurring in October 2008. That release, Data Release 7, is available through this website.

Meanwhile, SDSS is continuing with the Third Sloan Digital Sky Survey (SDSS-III), a program of four new surveys using SDSS facilities. SDSS-III began observations in July 2008 and released Data Release 8 in January 2011 and Data Release 9 in August 2012. SDSS-III will continue operating and releasing data through 2014.

Data Release 9 contains the first release of BOSS spectroscopy to the public as well as several significant updates to the cumulative SDSS archive.

Data Release 8 contains all images from the SDSS telescope - the largest color image of the sky ever made. It also includes measurements for nearly 500 million stars and galaxies, and spectra of nearly two million. All the images, measurements, and spectra are available free online. You can browse through sky images, look up data for individual objects, or search for objects anywhere in the sky based on any criteria.

The SDSS used a dedicated 2.5-meter telescope at Apache Point Observatory, New Mexico, equipped with two powerful special-purpose instruments. The 120-megapixel camera imaged 1.5 square degrees of sky at a time, about eight times the area of the full moon. A pair of spectrographs fed by optical fibers measured spectra of (and hence distances to) more than 600 galaxies and quasars in a single observation. A custom-designed set of software pipelines kept pace with the enormous data flow from the telescope. The two key technologies that enabled the SDSS, optical fibers and the digital imaging detectors known as CCDs, were the discoveries awarded the 2009 Nobel Prize in Physics.

During its first phase of operations, 2000-2005, the SDSS imaged more than 8,000 square degrees of the sky in five optical bandpasses, and it obtained spectra of galaxies and quasars selected from 5,700 square degrees of that imaging. It also obtained repeated imaging (roughly 30 scans) of a 300 square degree stripe in the southern Galactic cap.

With new financial support and an expanded collaboration including 25 institutions around the globe, SDSS-II carried out three distinct surveys:

- The Sloan Legacy Survey completed the original SDSS imaging and spectroscopic goals. The final dataset includes 230 million celestial objects detected in 8,400 square degrees of imaging and spectra of 930,000 galaxies, 120,000 quasars, and 225,000 stars.

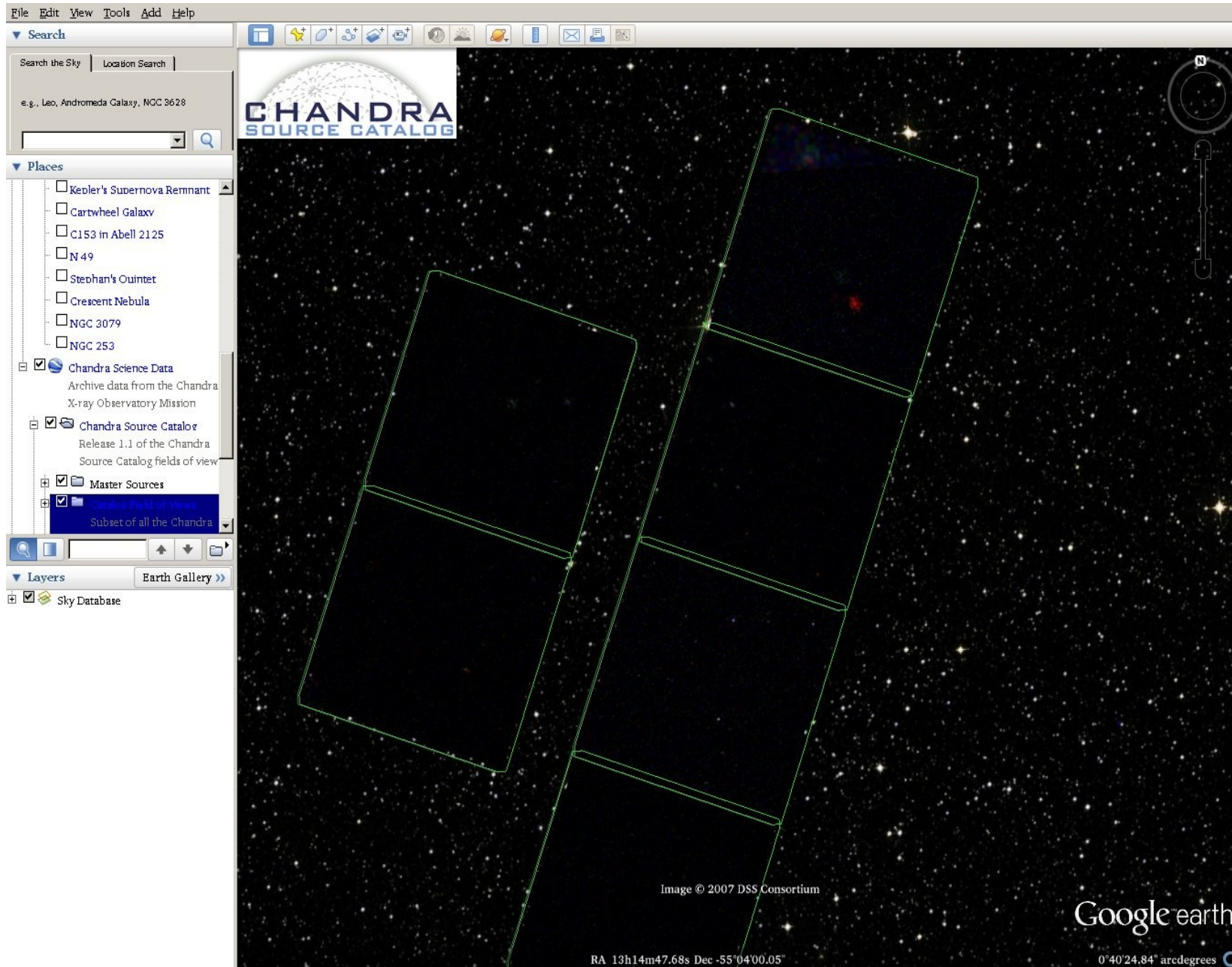
Images of the SDSS

(click for more information)

The Final Survey

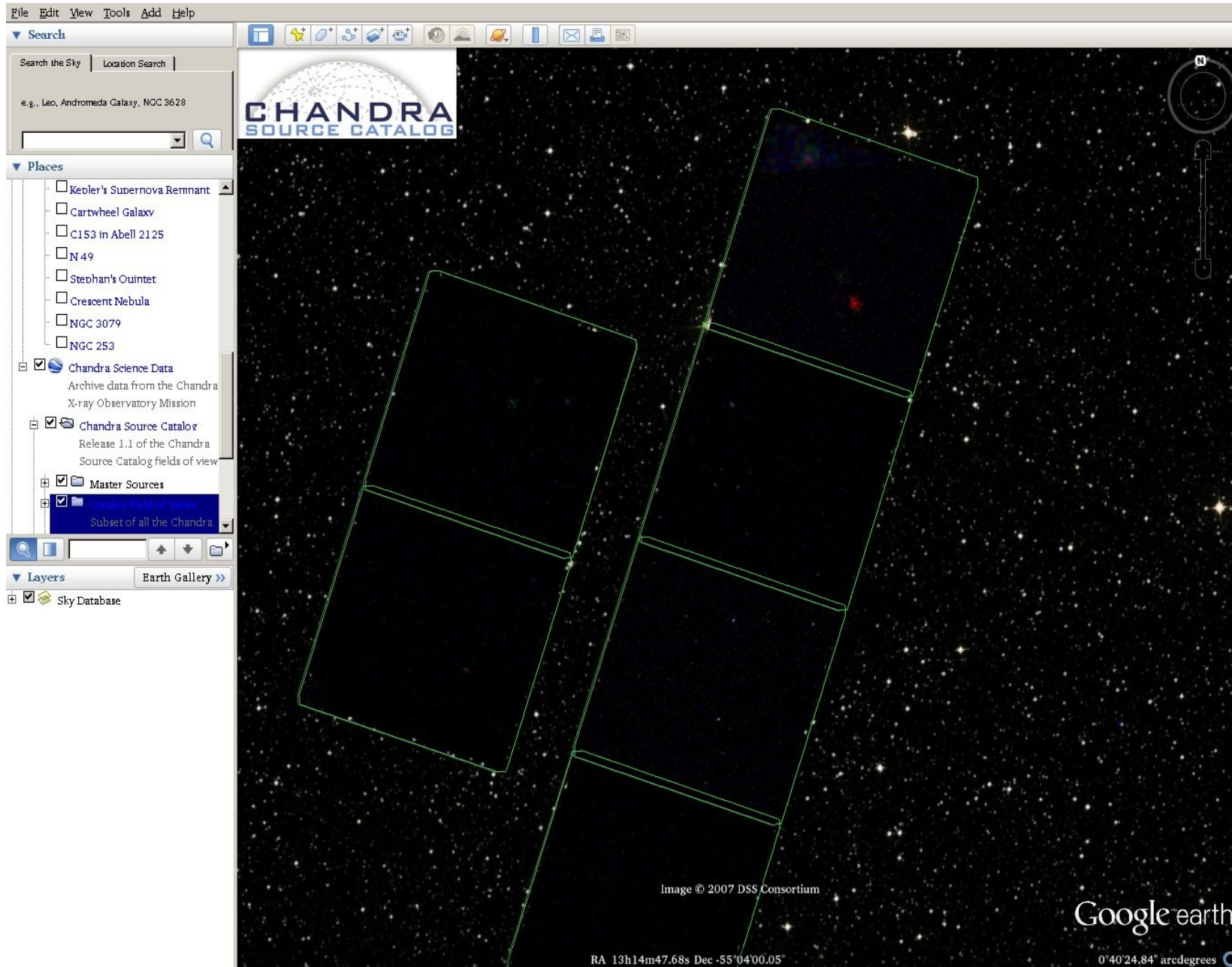
The Whirlpool Galaxy (M51)

Outreach tools with real data: Sky in Google Earth



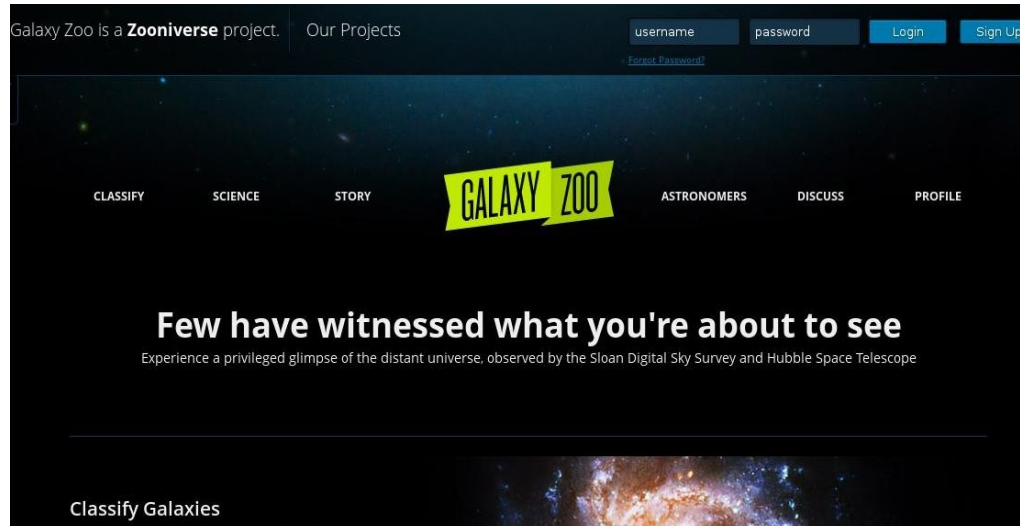
see also Microsoft's World Wide Telescope

Outreach tools with real data: Sky in Google Earth



see also Microsoft's World Wide Telescope

Citizen Science, Galaxy Zoo and the 'Zooniverse'



1999: SETI@home program borrows your unused computing resources

2007: Kevin Schawinski, Chris Lintott and others enlist the public to help classify galaxies on line – using spare human-brain compute power instead of spare digital CPUs: “Galaxy Zoo”

Is it a spiral or an elliptical?
Face or edge on?

Crowd-sourced science resulting in many published papers; on-line forum (Alice Sheppard et al) builds community

2012: Multiple projects including searching for extrasolar planets in Kepler light curves (“Planet Hunters”) and classifying cancer cells (Cell Slider)



How it all works: a space telescope team

Idea for experiment - astronomer anywhere in the world

Proposal planning - astronomer uses our software to see which camera is best for the experiment, how long they'd have to observe for

Proposal selection - 'peer review' by panel of experienced astronomers

Observation scheduling and planning - when is it best done? Which guide stars to use? What camera configuration?

Making the observation - flight control team sends up commands, retrieves the data

Making the calibration - Chandra's calibration team makes its own special observations throughout the year, updates our knowledge of the telescope

Data processing - go from raw data to science data with times, locations, brightness, color

Archiving - add lots of 'curation' information and stuff the data in the archive

Data analysis - astronomer gets the data from the archive, uses our software to turn the data into 'science'

Publication - astronomer writes up a paper and gets it peer-reviewed for the Astrophysical Journal, Monthly Notices of the Royal Astronomical Society, or another major journal

Astrometry: Where precisely is it on the sky?

Question: how can I find this object again?
What is its 'latitude and longitude'?

You can't just use Earth longitude – a star or galaxy rises and sets as the Earth spins. So we use a 'celestial longitude' (called 'right ascension' for historical reasons) that doesn't turn with the Earth.

Normal latitude is fine as a celestial latitude (but we call it declination also for historical reasons)

So we embed some data in the picture:

- what latitude and longitude is the middle of the picture?
- how many degrees across is the picture?
- more subtly, how do you map the sphere of the sky onto the flat picture? You probably know the 'Mercator projection' from atlases – we use a variety of different projections and we have to make a note of which one we used this time

Photometry: How bright is it?

Question: how bright is this object?
That's really two questions...

How bright does it appear to be to us? Is it blinding like the Sun, or super faint and needs a big telescope to see it?

How bright is it 'really'? That depends on how far away it is... the stars you see at night don't look as bright as the Moon but they are much, much further away, they only look faint because of their distance.

I'm going to ignore this second, harder question – once you know how bright it looks, you can figure out how bright it really is if you know the distance, but how we measure the distance to things in space is a tough problem and a whole other talk!

Even capturing exactly how bright each star and galaxy looks isn't easy. This is a process known as 'photometry'.

The multicolor universe: What kind of light?

The human eye sees different colors than a camera

Different filters can pick out different colors

An infrared or x-ray camera sees entirely different colors invisible to the human eye

A red-colored star may be brighter than a blue one when measured in a red filter, but the other way around in a blue filter

The nebula from an exploding star may be incredibly faint seen in any visible light colors, but really bright seen with an X-ray telescope.

It's all in the timing: when did I take this image?

In ancient times we thought the skies were unchanging, but actually things change on all timescales from microseconds to gigayears.

We obviously don't want to label our data in Eastern Daylight Time – astronomy's an international subject, someone in Japan might be studying the same object. So you'd think we'd put things in Greenwich Mean Time.

We sort of do, but... astronomers are the most persnickity people when it comes to calendars and watches. It turns out that GMT (or Universal Time) is tied to the spin of the Earth, which slows up and down as the continents slide around the core.

So instead we sometimes use Terrestrial Time, which is basically atomic clock time and is about a minute off from GMT

But wait! Einstein discovered that time isn't absolute – it runs at a different rate when you move fast (like the Earth does around the Sun) and when you go uphill in a gravity field (like the Earth does around the Sun!) So sometimes we use a Barycentric Time that corrects by a few milliseconds to account for Earth's motion around the sun.

So not only do we label our data with the time, but we must be careful to say what kind of time we used and where we measured it!