

National Science Olympiad

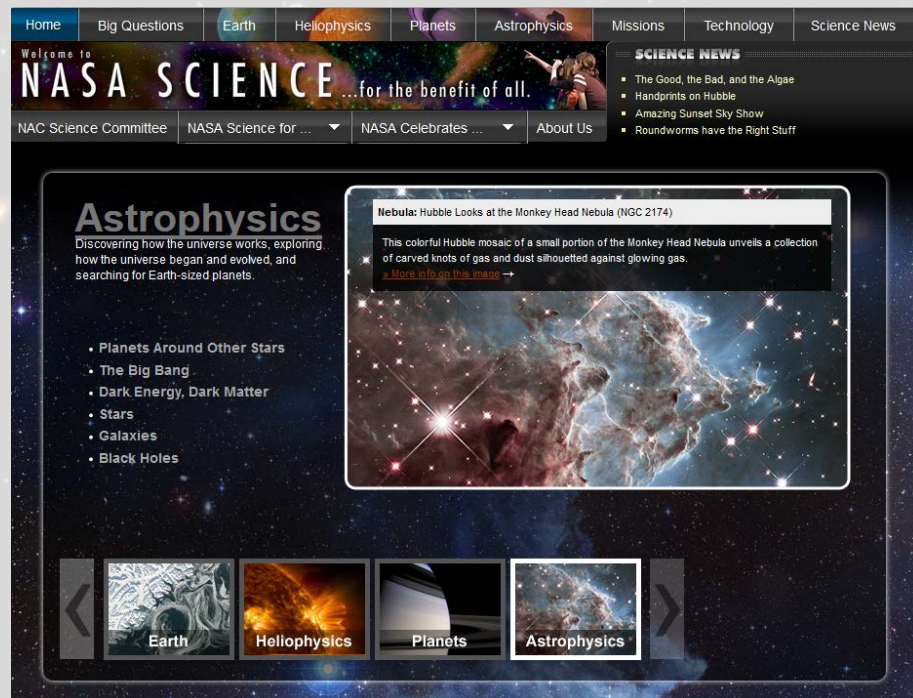
Astronomy 2020 (Division C)

Star and Galaxy Formation and Evolution

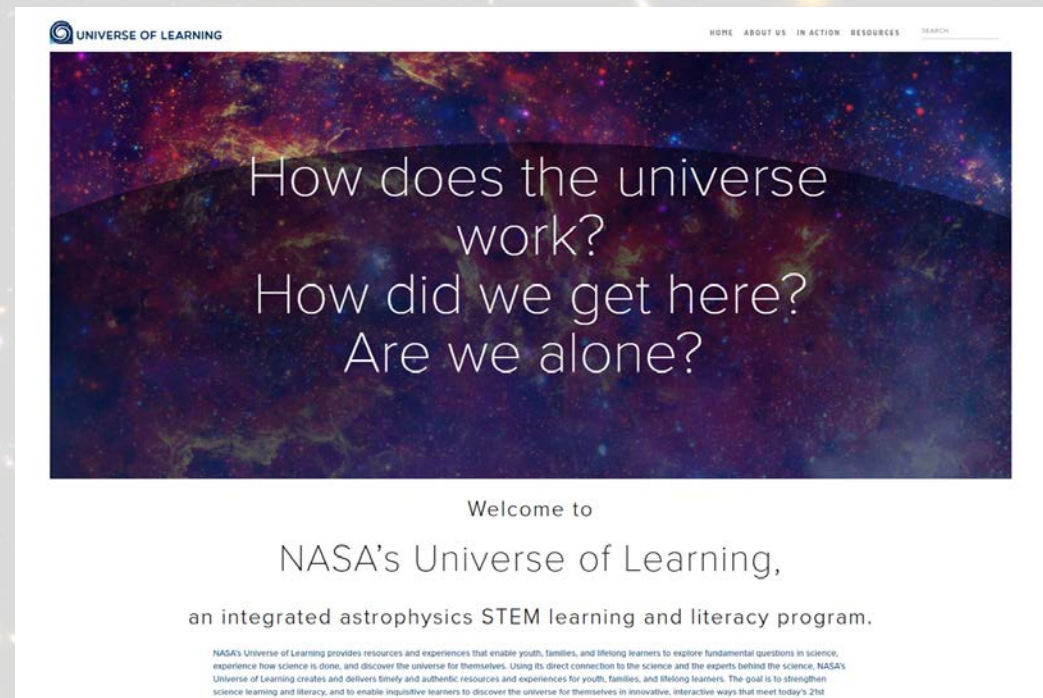
Supported by NASA Universe of Learning STEM Literacy Network

NASA Astrophysics Division/CXC/NSO

<https://www.universe-of-learning.org/>



The screenshot shows the NASA Science website interface. At the top, there is a navigation bar with links for Home, Big Questions, Earth, Heliophysics, Planets, Astrophysics, Missions, Technology, and Science News. Below this is a header section with the text "Welcome to NASA SCIENCE ...for the benefit of all." and a "SCIENCE NEWS" section listing articles such as "The Good, the Bad, and the Algae", "Handprints on Hubble", "Amazing Sunset Sky Show", and "Roundworms have the Right Stuff". The main content area features a "Astrophysics" section with the text "Discovering how the universe works: exploring how the universe began and evolved, and searching for Earth-sized planets." and a list of topics including Planets Around Other Stars, The Big Bang, Dark Energy, Dark Matter, Stars, Galaxies, and Black Holes. A featured article titled "Nebula: Hubble Looks at the Monkey Head Nebula (NGC 2174)" is displayed with a colorful Hubble mosaic image and a description: "This colorful Hubble mosaic of a small portion of the Monkey Head Nebula unveils a collection of carved knots of gas and dust silhouetted against glowing gas." Below the main content is a carousel of images with labels for Earth, Heliophysics, Planets, and Astrophysics.



The screenshot shows the NASA's Universe of Learning website interface. At the top, there is a navigation bar with links for HOME, ABOUT US, IN ACTION, RESOURCES, and SEARCH. The main content area features a large image of a nebula with the text "How does the universe work? How did we get here? Are we alone?" overlaid. Below the image is the text "Welcome to NASA's Universe of Learning, an integrated astrophysics STEM learning and literacy program." At the bottom, there is a small text block: "NASA's Universe of Learning provides resources and experiences that enable youth, families, and lifelong learners to explore fundamental questions in science, experience how science is done, and discover the universe for themselves. Using its direct connection to the science and the experts behind the science, NASA's Universe of Learning creates and delivers timely and authentic resources and experiences for youth, families, and lifelong learners. The goal is to strengthen science learning and literacy, and to enable inquisitive learners to discover the universe for themselves in innovative, interactive ways that meet today's 21st-century needs."

Chandra X-Ray Observatory

<http://chandra.harvard.edu/index.html>

<http://chandra.si.edu/edu/olympiad.html>

The screenshot shows the Chandra X-Ray Observatory website homepage. At the top, it features the Chandra logo and the text "NASA's flagship mission for X-ray astronomy." Below this is a navigation menu with links for Home, About Chandra, Education, Field Guide, Photo Album, Press Room, Resources, Multimedia, Podcasts, Blog, and Research. A search bar is also present. The main content area features a large illustration of a black hole with the headline "GW170817: Gravitational Wave Event Likely Signaled Creation of a Black Hole". Below the illustration are sections for "Learn About" (with links to Chandra, Light, Solar System, Supernovas, and Black Holes), "Latest" (with a podcast link), and "Explore" (with links to Chandra Images in 4K, 3D Files and Resources, Chandra Infographics, and The Science of X-ray Technology). A "Scientific User Support" section is also visible, listing links for CXC Science, Archive, Proposer, and Physics of the Cosmos.

The screenshot shows a page from the Chandra X-Ray Observatory website dedicated to the National Science Olympiad Astronomy Event - 2019. The page features a large video player with a play button and a small inset photo of a woman, identified as the Astronomy Event Supervisor 2019. The video title is "National Science Olympiad Astronomy Event - 2019 State Directors & Event Supervisors Guide Stellar Evolution in Normal & Starburst Galaxies". Below the video player, there is a section for "National Science Olympiad Astronomy 2019 (Division C) Stellar Evolution in Normal & Starburst Galaxies". The page also includes a "Science Olympiad Astronomy and Reach for the Stars Webinars" section with a paragraph of text describing the organization's goals and the support provided for the event.

2020 Rules [DRAFT]

1. **DESCRIPTION**: Teams will demonstrate an understanding of **Star and Galaxy Formation and Evolution**

A TEAM OF UP TO: 2

APPROXIMATE TIME: 50 minutes

2. **EVENT PARAMETERS**: Each team may bring one of the following options containing information in any form and from any source:

- i. a computer/tablet and a three-ring binder; or,
- ii. two computers/tablets, of any kind.

2020 Rules [DRAFT]

b. If three ring binders are used they may be of any size and the information contained should be attached using the available rings. The information or pages may be removed during the event. Sheet protectors and laminated sheets are allowed.

c. Each team may bring two calculators of any type (stand alone or computer app)

d. Participants using computers/tablets as a resource should have all information stored so that it is available to them offline. However; teams may be accessing a dedicated NASA image analysis website to answer JS9 questions. For JS9 questions, supervisors must provide an alternative (e.g. proctor-supplied computer or screen shots) for teams that did not bring a laptop/tablet.

2020 Rules [DRAFT]

3. **THE COMPETITION**: Using information which may include Hertzsprung-Russell diagrams, spectra, light curves, motions, cosmological distance equations and relationships, stellar magnitudes and classification, multi-wavelength images (gamma-ray, X-ray, UV, optical, IR, radio), charts, graphs and **JS9** imaging analysis software, teams will complete activities and answer questions related to:

a. Stellar and galactic evolution including stellar classification, spectral features and chemical composition, luminosity, blackbody radiation, color index and H-R diagram transitions, neutron stars, stellar mass and supermassive black holes, Type Ia supernovas, galactic structure and interactions, **quasars, active galactic nuclei (AGNs), galaxy clusters and groups of galaxies**, gravitational waves, **gravitational lensing, dark matter and energy, warm hot intergalactic medium (WHIM), and the Cosmic Microwave Background (CMB).**

2020 Rules [DRAFT]

b. Use Kepler's laws, rotation and circular motion to answer questions relating to the orbital motions of galaxies; **use the distance modulus, Type Ia supernovas, Hubble's law and redshift to answer questions about Hubble's constant and the recessional velocities and distances to galaxies.**

c. Identify and answer questions relating to the content areas outlined above for the following objects: **SN UDS10Wil, NGC 2623, GRB 150101B, JKCS 041, MACS J0717.5+3745, MACS J1149.5+2223, Bullet Cluster (1E 0657-56), H1821+643, The 3 Quasars (152156.48+520238.5, 153714.26+271611.6, 222256.11-094636.2), GOODS-S 29323, H2356-309, PSS 0133+0400 & PSS 0955+5940, GW151226, M87, 3C 273**

Deep Sky Objects

AGN/Quasars

- 3C 273
- NGC 2623
- M87
- The 3 Quasars
(152156.48+520238.5,
153714.26+271611.6,
222256.11-094636.2)

WHIM

- H1821+643
- H2356-309

Galaxy Clusters

- Bullet Cluster (1E 0657-56)
- MACS J0717.5+3745
- MACS J1149.5+2223
- JKCS 041

Early Universe

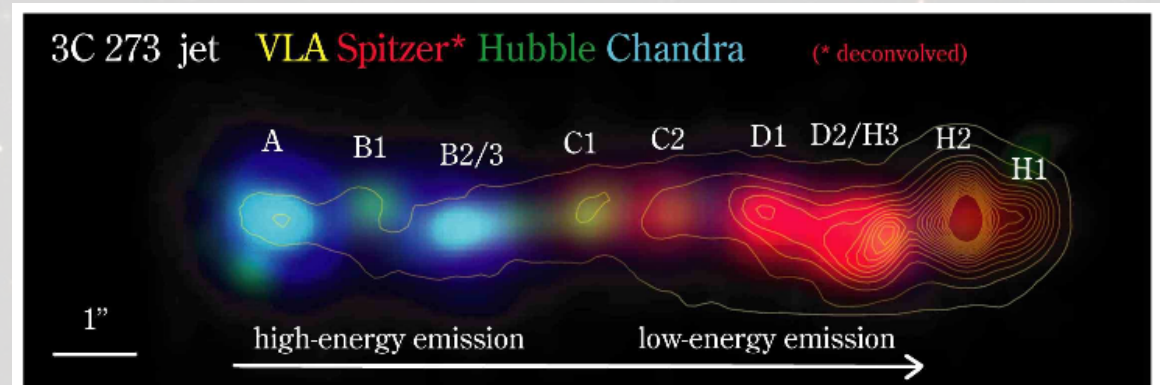
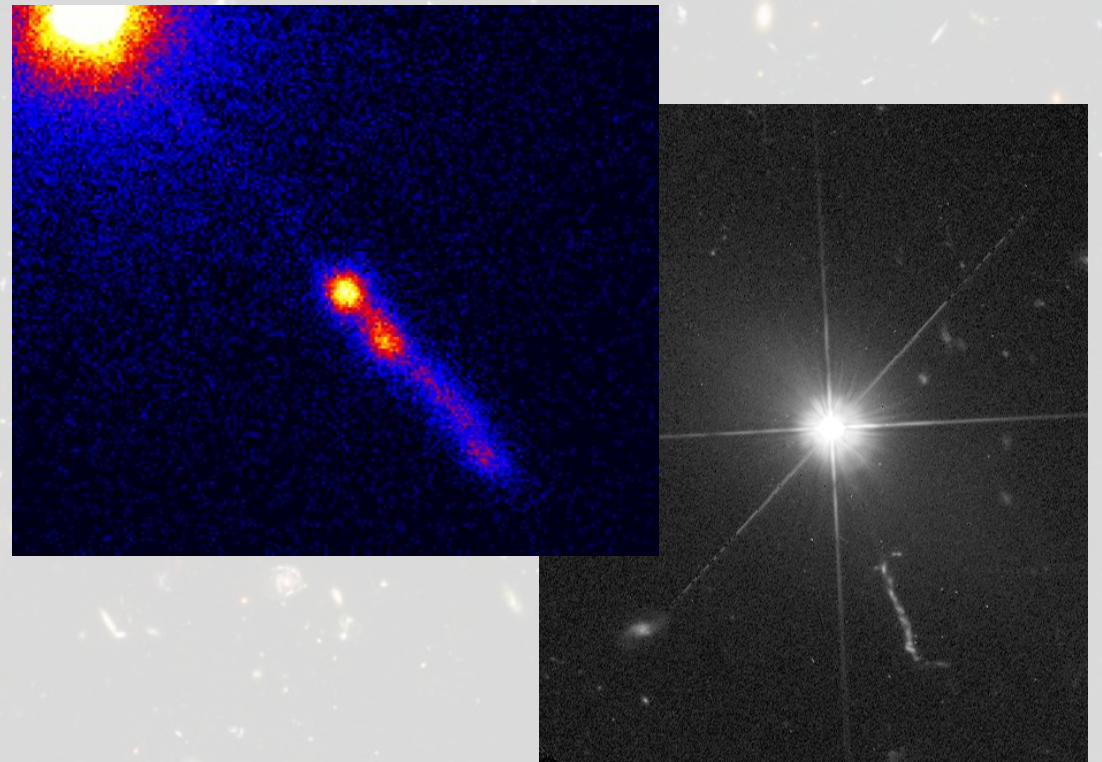
- SN UDS10Wil
- GOODS-S 29323
- PSS 0133+0400 & PSS 0955+5940

Gravitational Waves

- GW 151226
- GRB 150101B

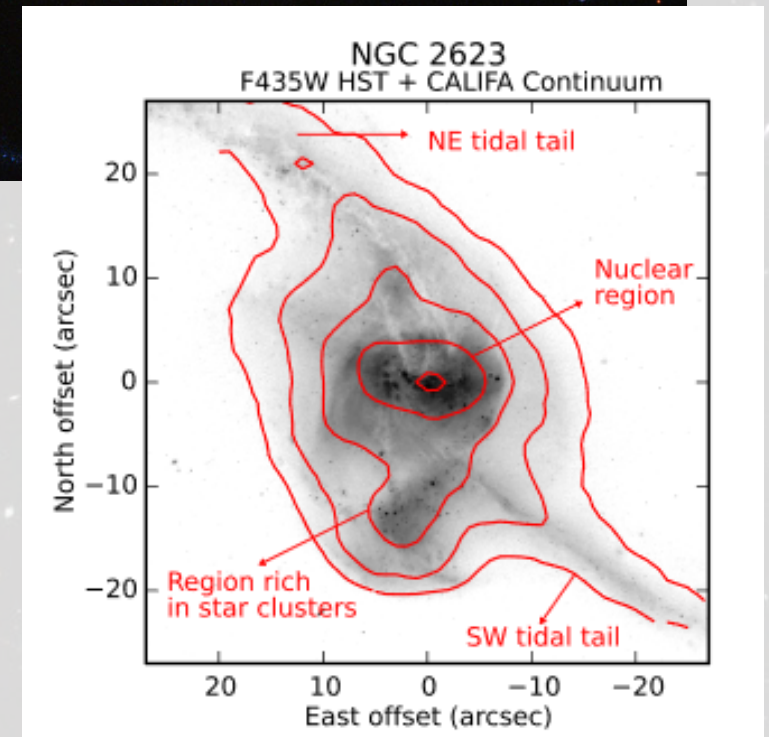
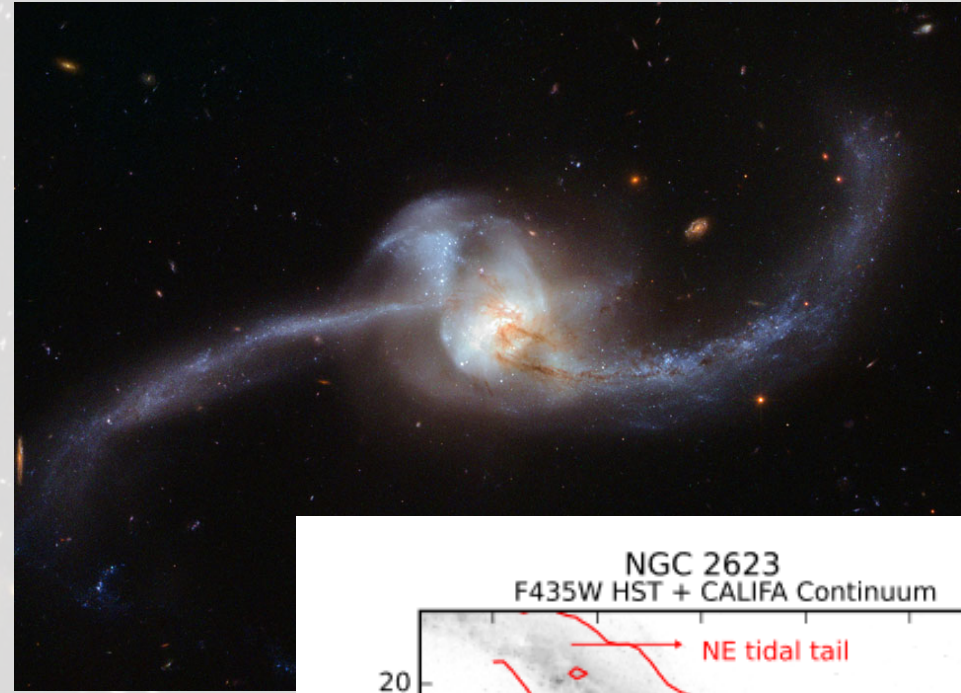
3C 273

- First quasar discovered, in 1959 (quasi-stellar radio source)
 - Observable at many wavelengths
 - Brightness varies over months – must be smaller than light-months in size
- Central supermassive black hole
 - Accretion disk
 - Jet of material ejected perpendicular to disk



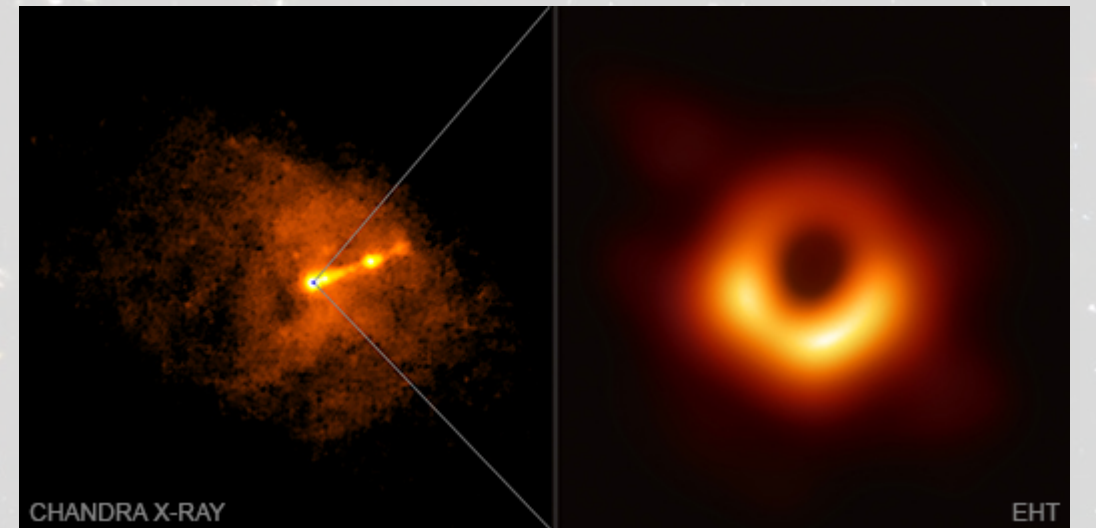
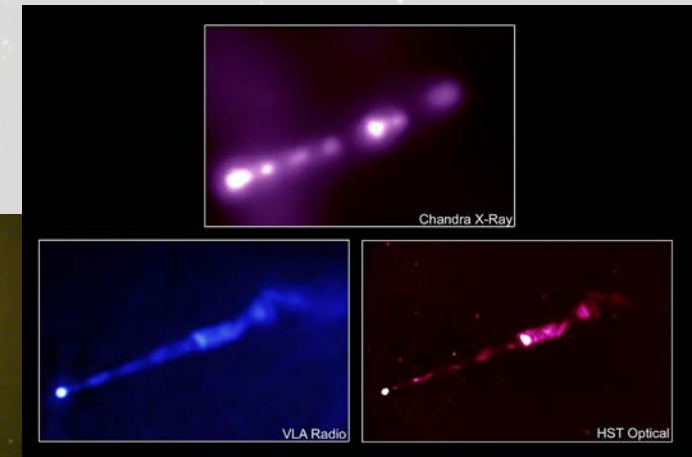
NGC 2623

- Merging galaxies
 - Star formation (seen in blue) triggered by compression of gas
 - Material flung out in tidal tails
- LIRG (Luminous InfraRed Galaxy)
 - Lots of star formation – bright in IR since dust absorbs visible light
 - AGN (Active Galactic Nucleus) hidden behind dust



M87 (aka Virgo A)

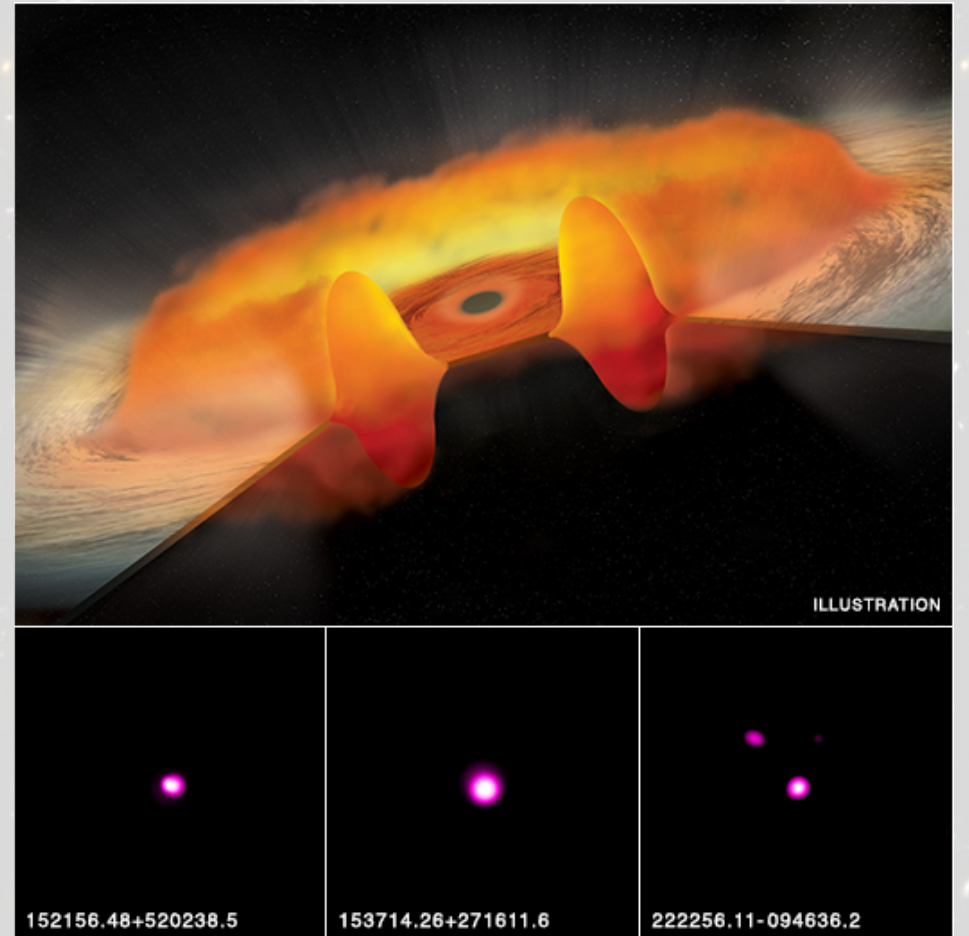
- Giant elliptical galaxy in the nearby Virgo Cluster
- Supermassive black hole surrounded by hot gas
 - Imaged by the Event Horizon Telescope!
- Jet appears to move faster than speed of light (relativistic effect)
 - Suggests all active galaxies are the same, just viewed differently



The 3 Quasars

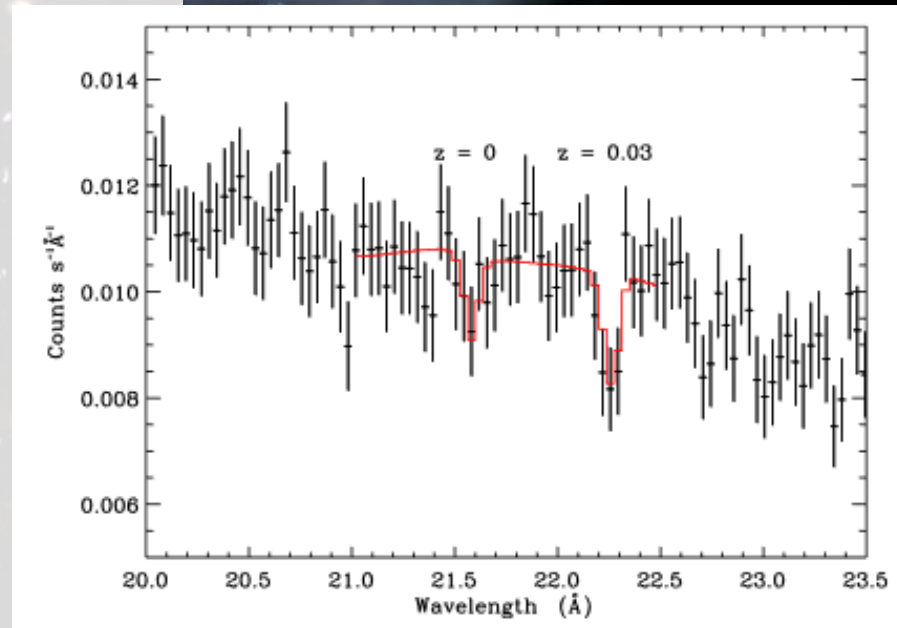
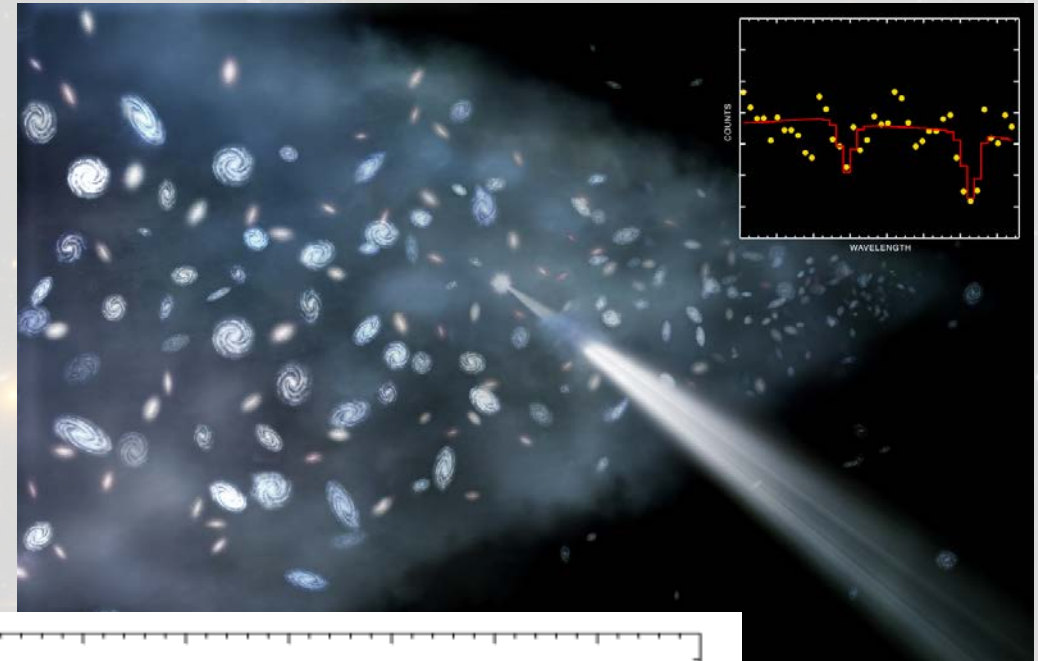
(152156.48+520238.5, 153714.26+271611.6, 222256.11-094636.2)

- “Thick disk” quasars
 - Disk puffs up due to lots of material flowing towards black hole
 - Weak in UV and X-ray due to absorption from disk
- Black holes growing very rapidly
 - Fast enough to explain high masses of early black holes?



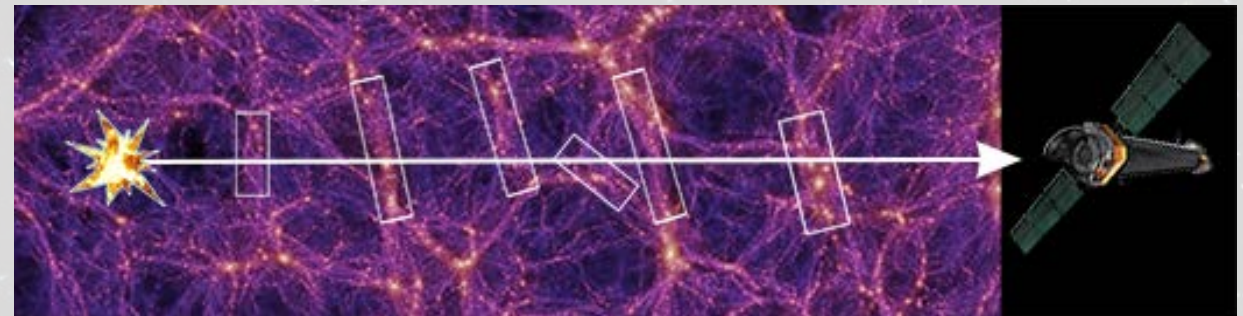
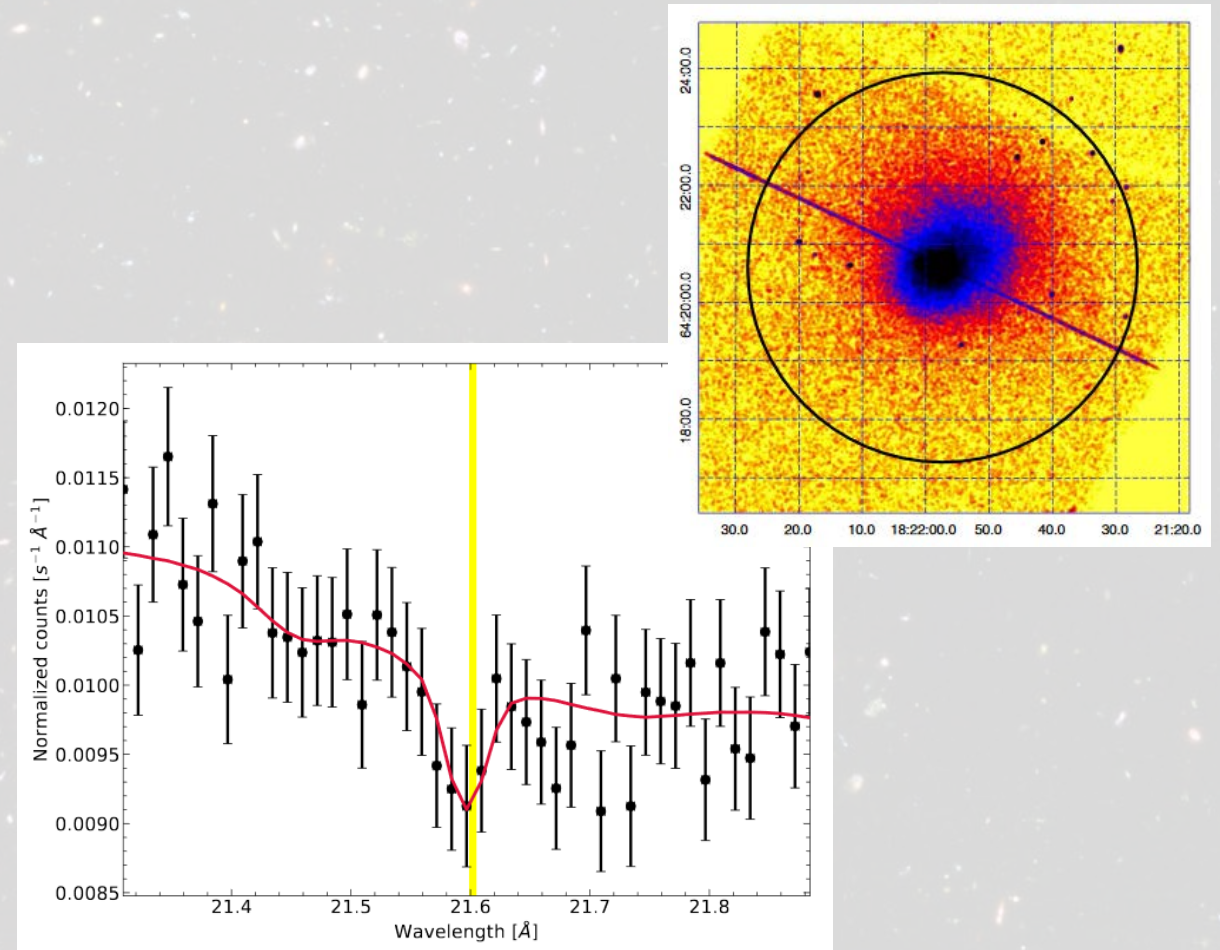
H2356-309

- Quasar beyond the Sculptor Wall of galaxies
 - Blazar – jet pointed directly at us!
- Evidence for WHIM (Warm Hot Intergalactic Medium)
 - Possible this is the “missing matter” in the nearby universe
 - Hard to detect because it is hot and diffuse, but large quantities will absorb noticeably



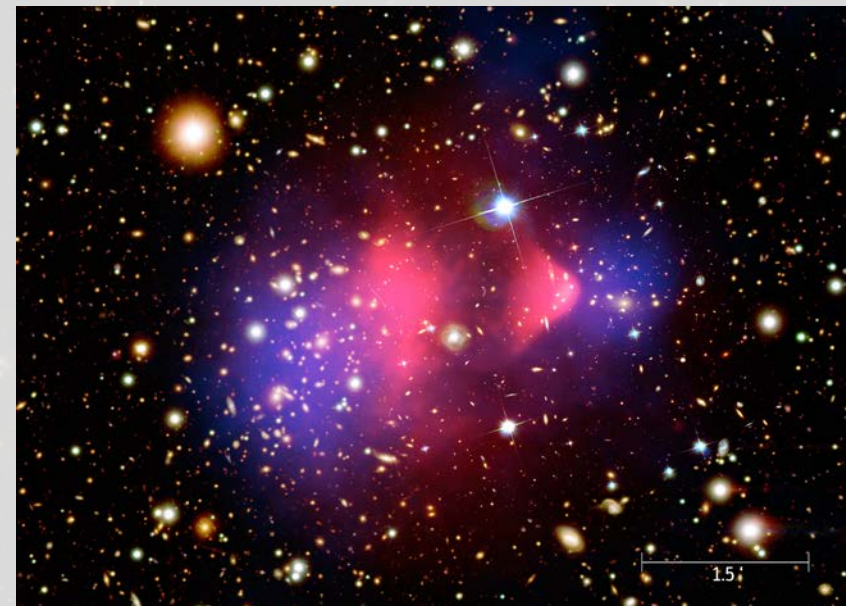
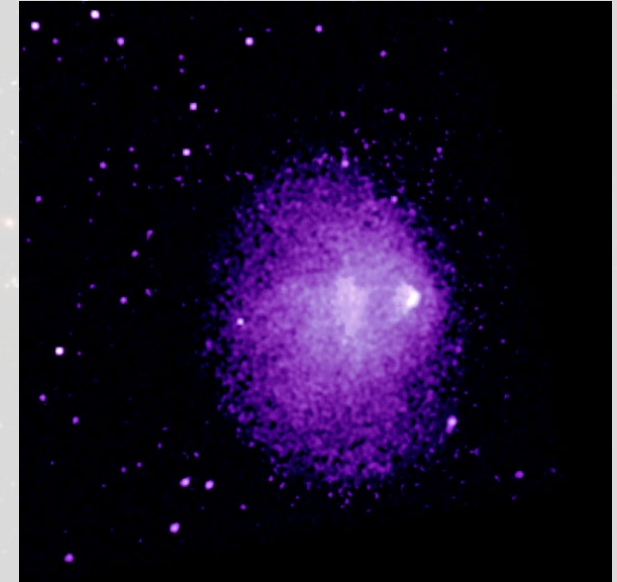
H1821+643

- Quasar at the center of a cooling-core galaxy cluster
 - Center is cooler than edges because it is denser and emits more energy
- Used to detect WHIM
 - Filaments of WHIM between the quasar and us absorb x-rays
 - Very weak absorption, so have to stack many observations



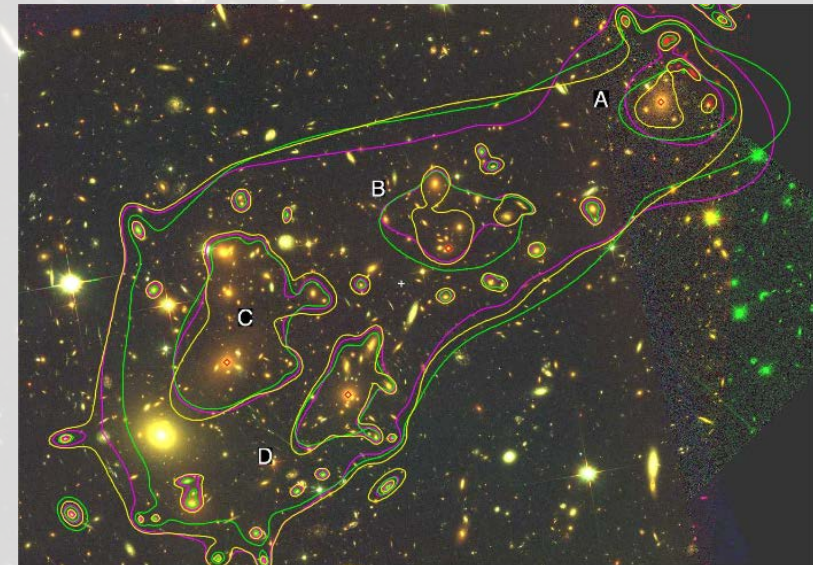
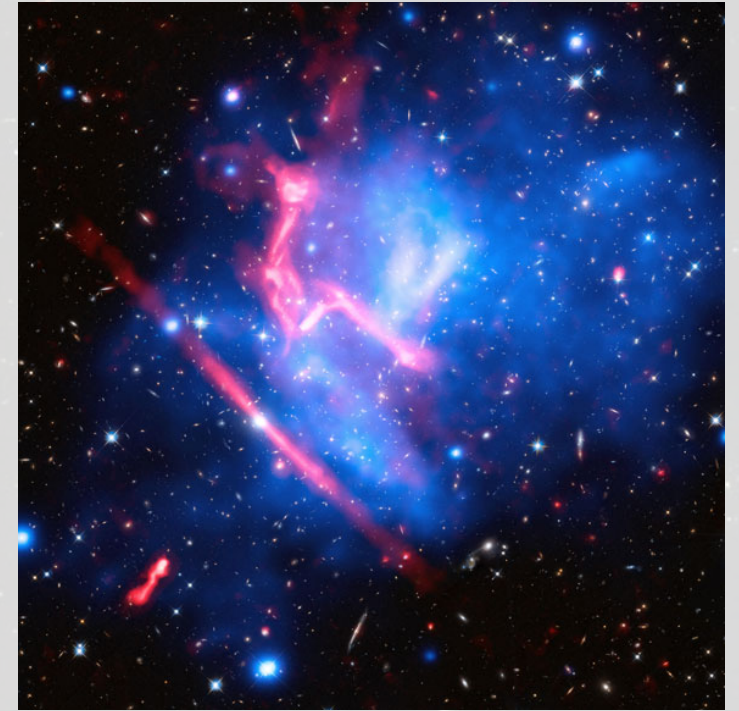
Bullet Cluster (1E 0657-56)

- Galaxy cluster merger
 - X-ray emission from colliding gas (hot!)
 - Dark matter doesn't collide though...
- Evidence of dark matter
 - Mass distribution is different from VISIBLE mass distribution
 - Gravitational lensing of background galaxies



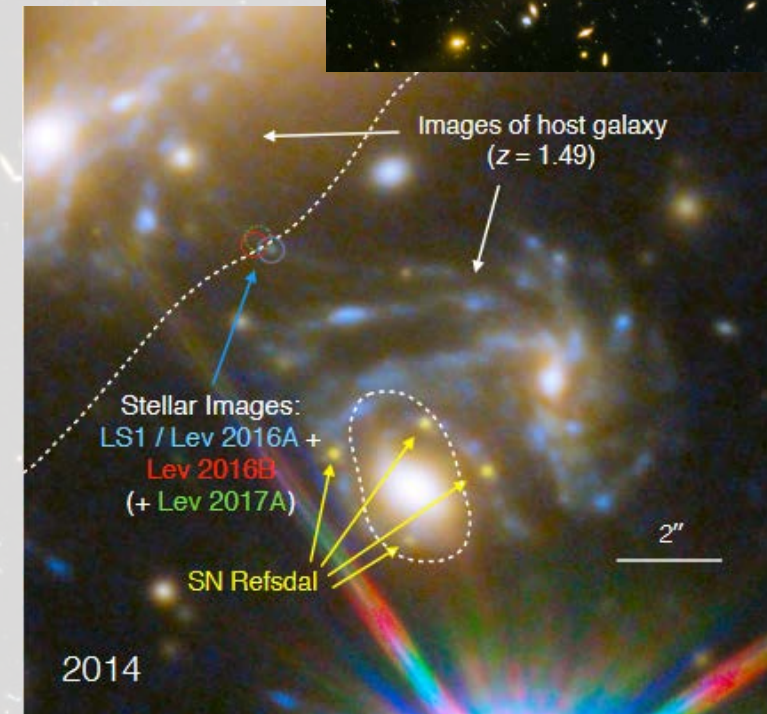
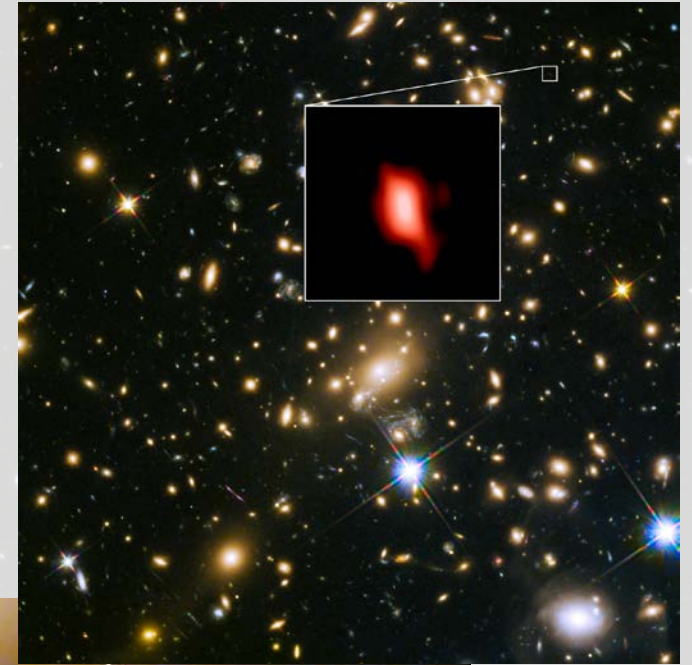
MACS J0717.5+3745

- Complex colliding galaxy cluster
 - 4 subclusters – determined by positions of visible galaxies vs their gas
 - Lots of x-rays from superheated gas
- Mass distribution determined based on gravitational lensing
 - Lensing also brightens background galaxies, allowing them to be studied



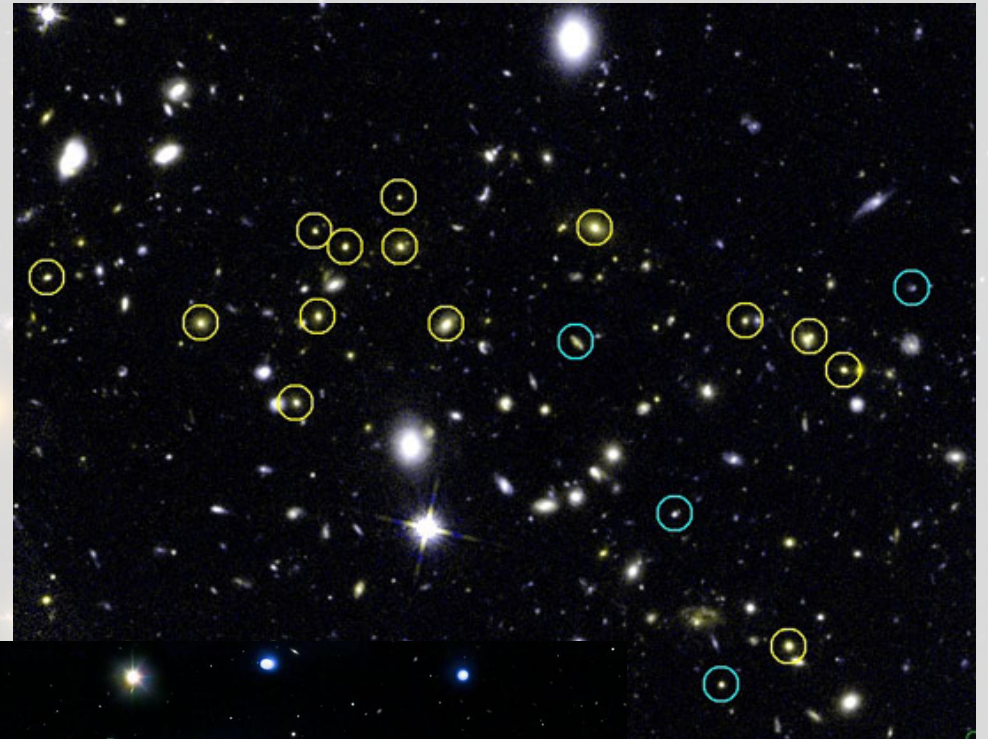
MACS J1149.5+2223

- Massive galaxy cluster
- Powerful gravitational lens
 - Distant galaxy at redshift $z \approx 9.6$ – when universe was only 500 million years old
 - MACS J1149 Lensed Star 1 (“Icarus”) – furthest star ever found, distance of 14.4 billion ly
 - SN Refsdal – first supernova with multiple lensed images



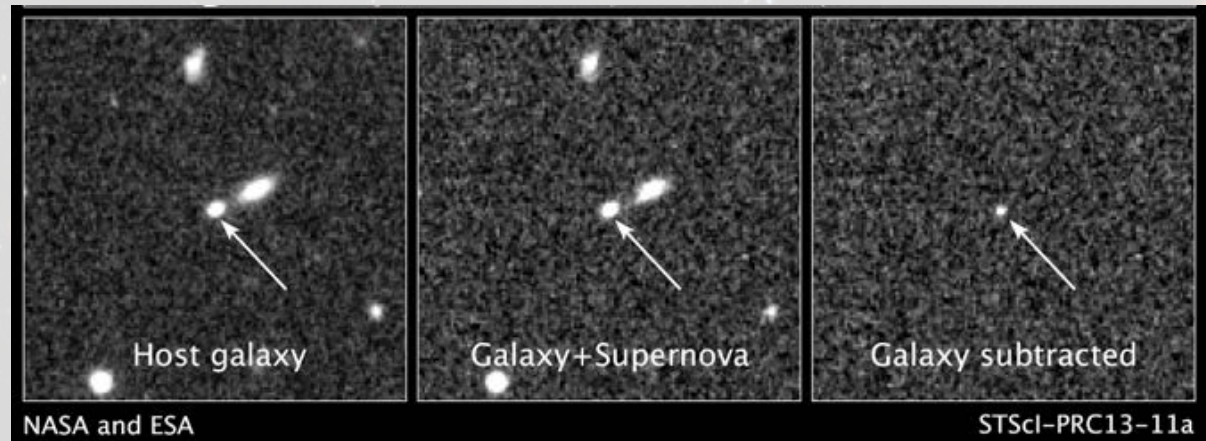
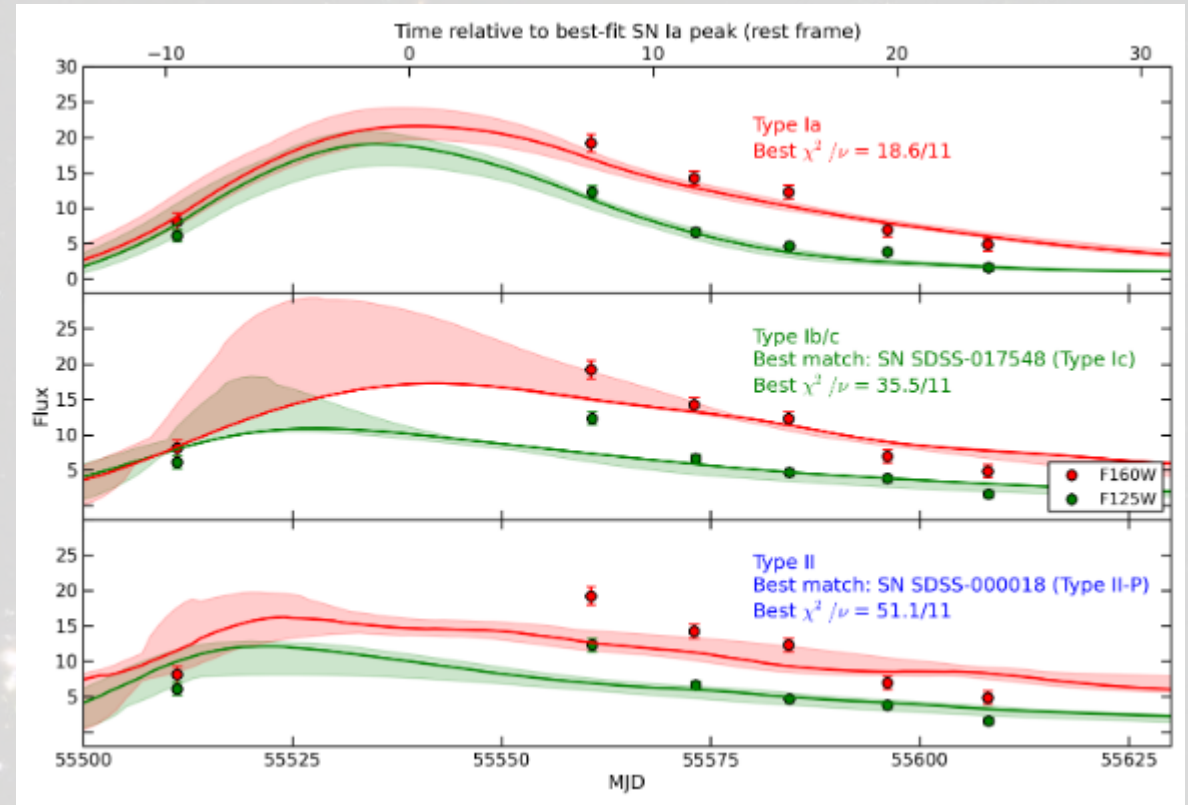
JKCS 041

- Most distant (and oldest!) galaxy cluster
 - Redshift $z \approx 1.9$ (distance of about 10 billion ly)
- Example of early star formation in the universe
 - Many massive galaxies already stopped forming stars
 - Do galaxies grow primarily due to collisions in clusters?



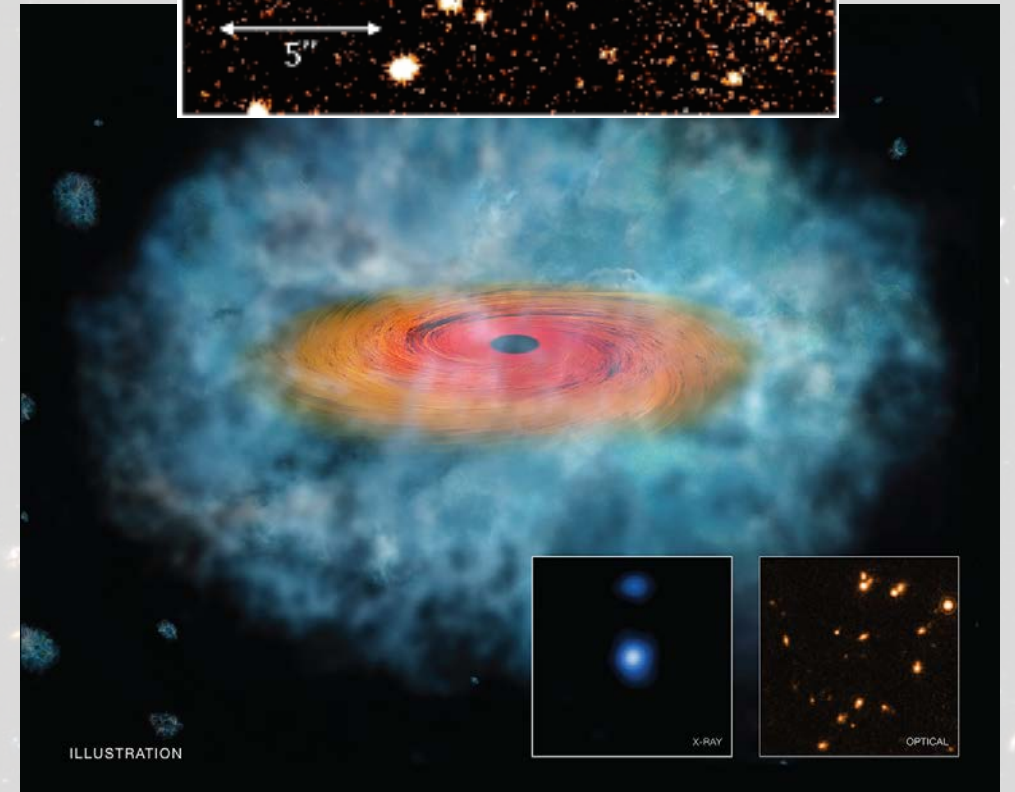
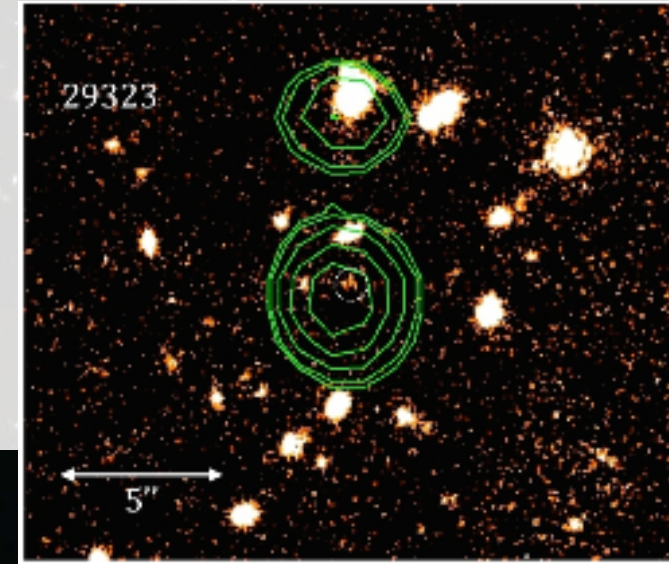
SN UDS10Wil

- Furthest Type Ia SN discovered
 - Redshift $z = 1.914$, universe was $\frac{1}{1+z} \approx \frac{1}{3}$ of current size
- Hubble CANDELS survey – searching for faint, distant supernovae
 - Have they changed between now and the early universe?



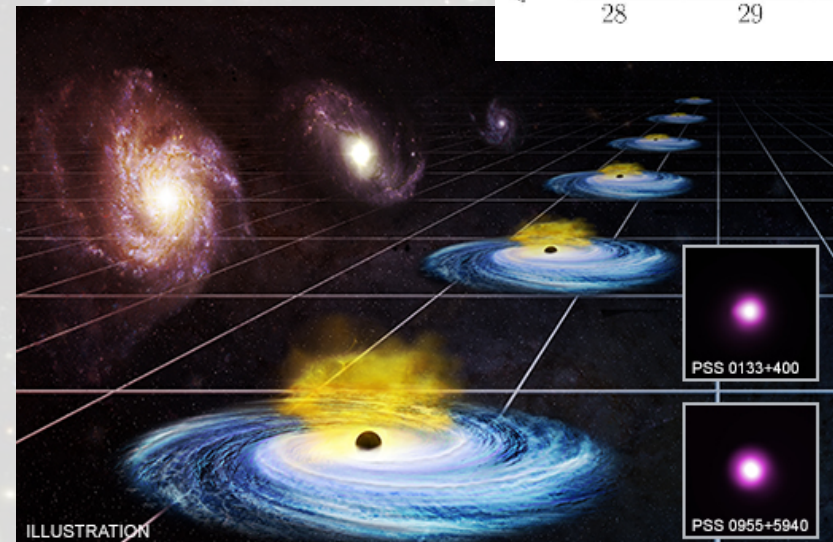
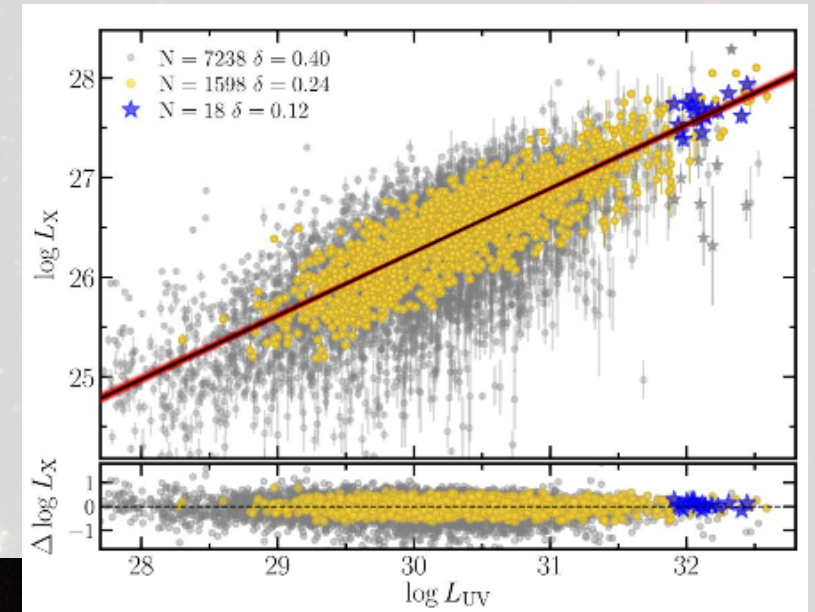
GOODS-S 29323

- Early supermassive black holes may have collapsed directly from large gas clouds
 - Matter can fall straight in instead of spiraling around in a disk
- Searched Hubble surveys for objects matching predictions
 - Very “red” (infrared-bright) because disk absorbs and re-emits light



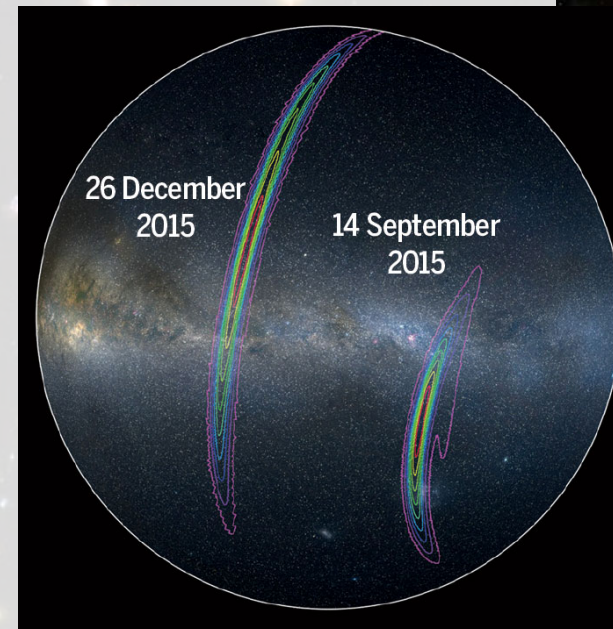
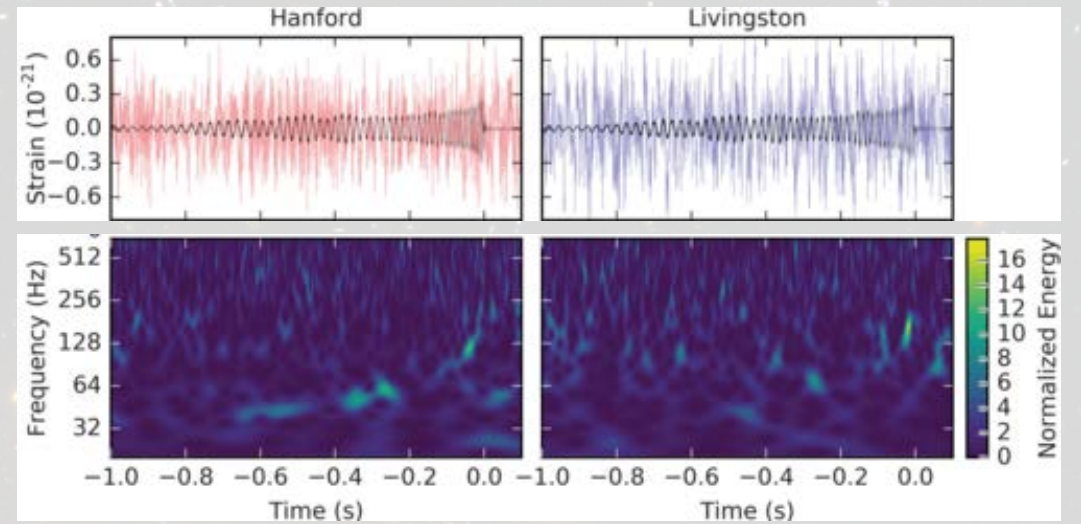
PSS 0133+0400 and PSS 0955+5940

- Quasars 10 billion ly away – very luminous
 - Used as “standard candles” based on relationship between UV and X-ray flux
- Track expansion of the universe over time
 - Dark energy (driving expansion) may be increasing...



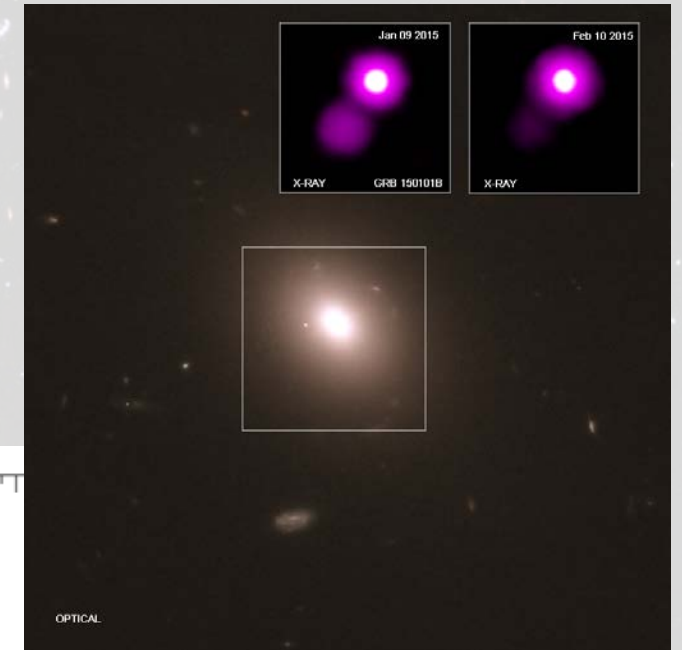
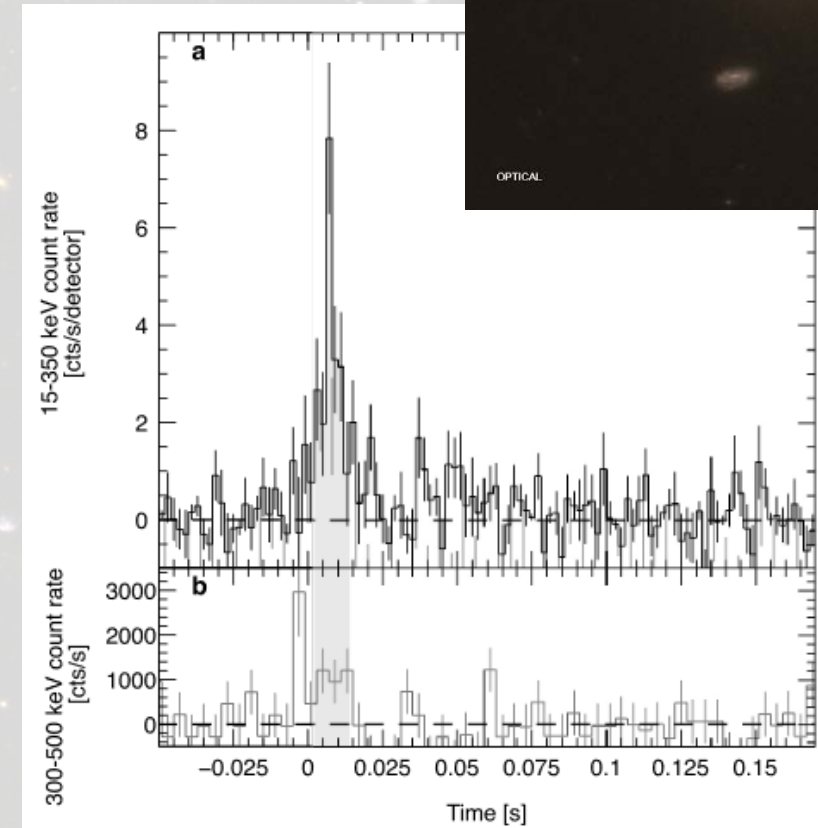
GW 151226

- 2nd confirmed gravitational wave event (December 26, 2015)
 - Found by LIGO (+ VIRGO)
 - General Relativity still works!
 - Location hard to constrain
- Merger of two black holes
 - $M_{\text{final}} = 20.8 \text{ Msun}$, less than combined mass before merger (turned into energy)

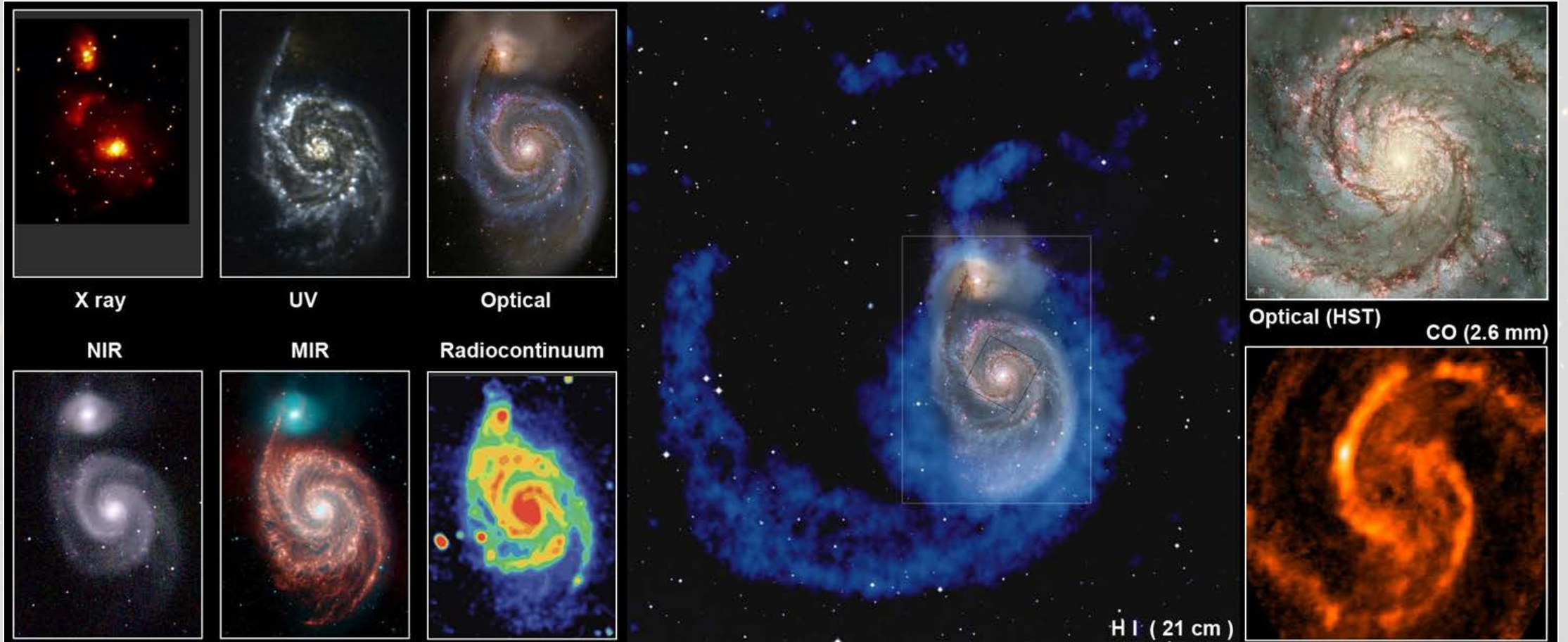


GRB 150101B

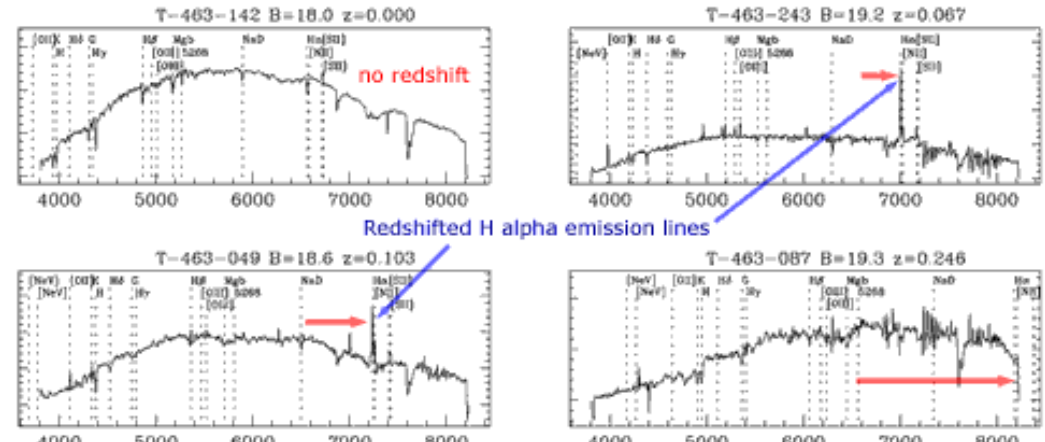
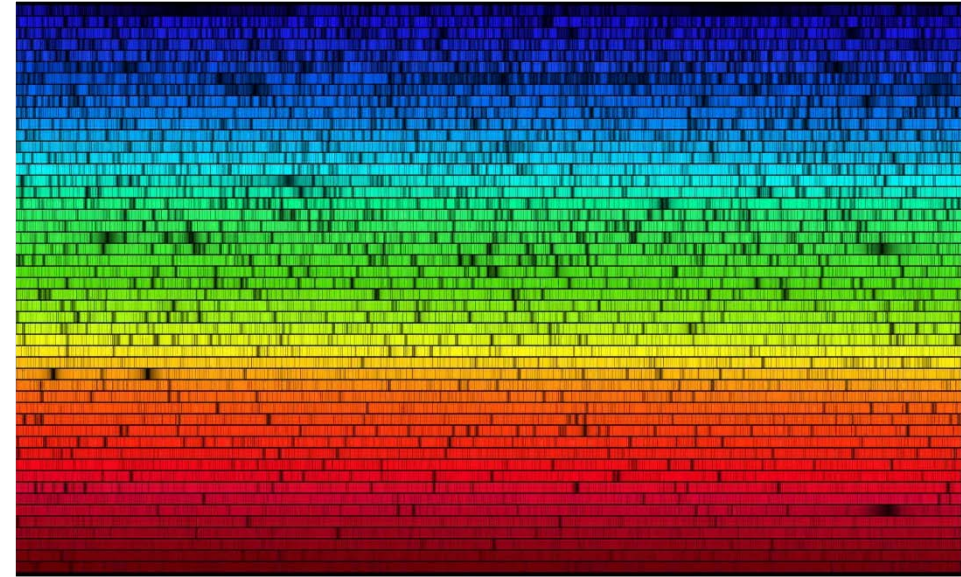
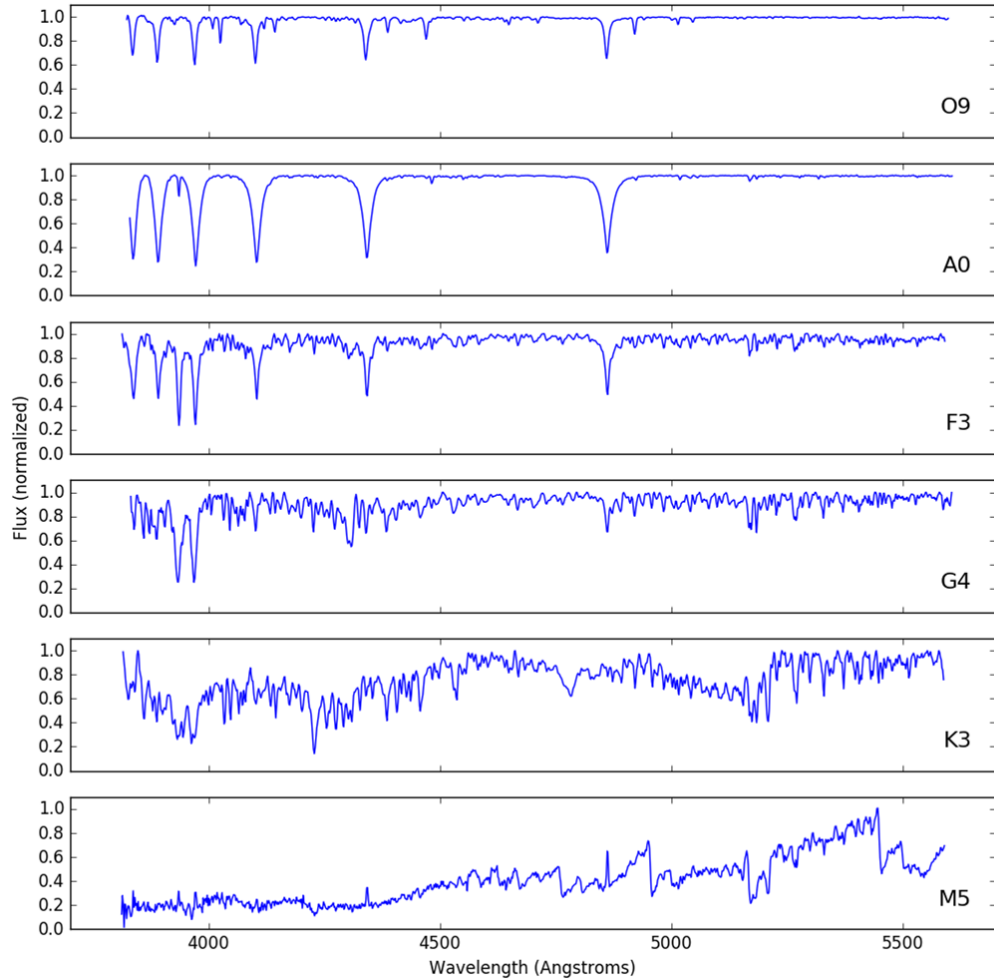
- Short gamma-ray burst (< 0.1 sec!)
 - Detected by Fermi (gamma-ray)
 - Fast follow-up by Swift, Chandra, Hubble, and more!
- Similar to GW 170817
 - Known neutron star + neutron star merger (kilonova)
 - Observed in gravitational waves (LIGO) and multiple wavelengths



Multi-Wavelength Observations



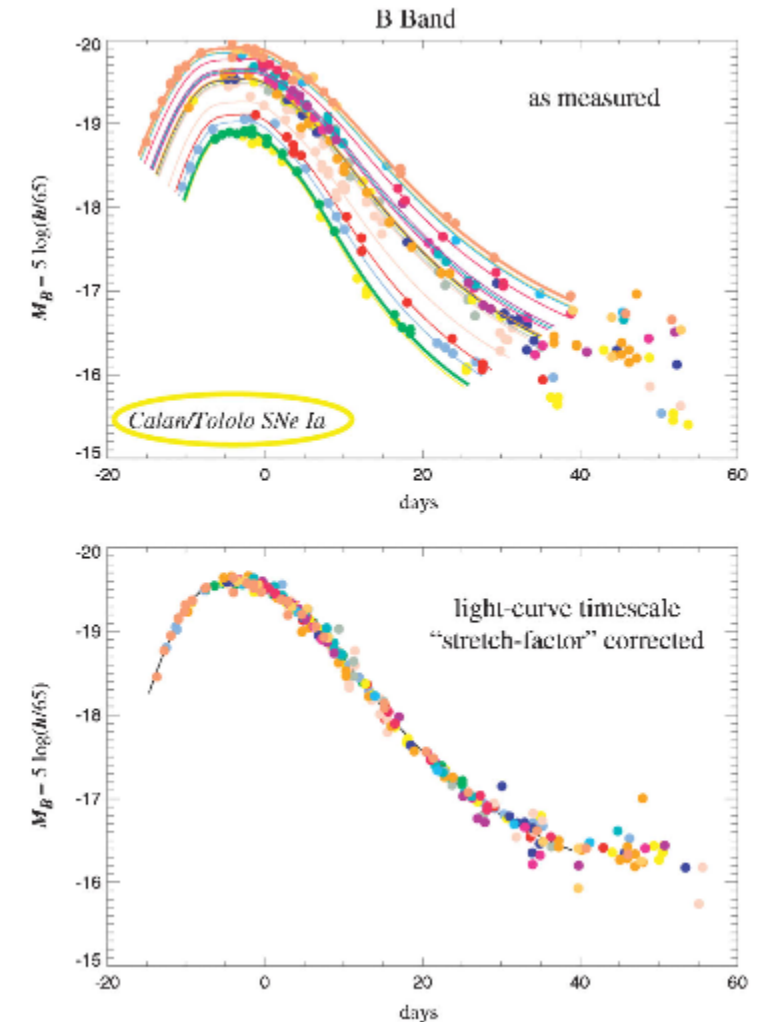
Spectra



Galaxy Spectra Showing Different Redshifts

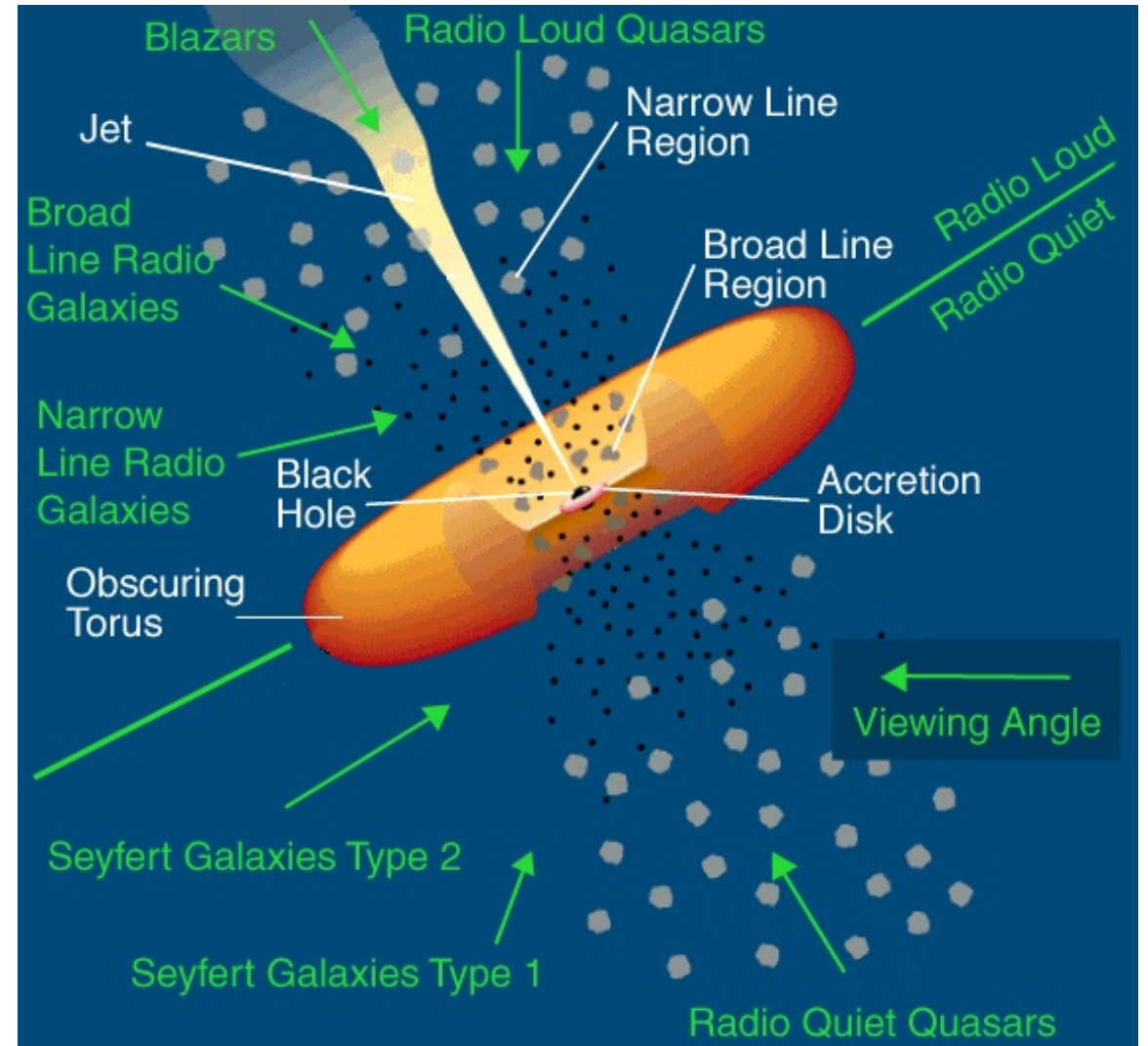
Type Ia Supernovae

- From white dwarf with mass > 1.4 solar masses (Chandrasekhar Limit)
- “Standard candle” for measuring distance because they are all the same brightness (well... maybe)
 - Slow mass transfer from binary companion, mass = 1.4 solar masses
 - Collision with another white dwarf, mass = ???



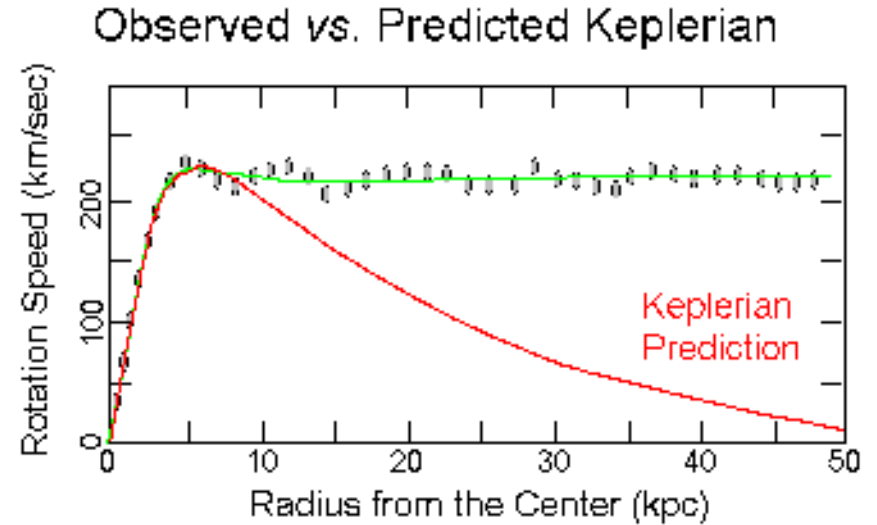
AGNs & Quasars

- Bright across many wavelengths, often variable
- Unified Model – all AGNs/quasars are similar, just viewed from different angles
 - Disk of matter accreting onto a supermassive black hole
 - Sometimes (but not always) produces a narrow jet



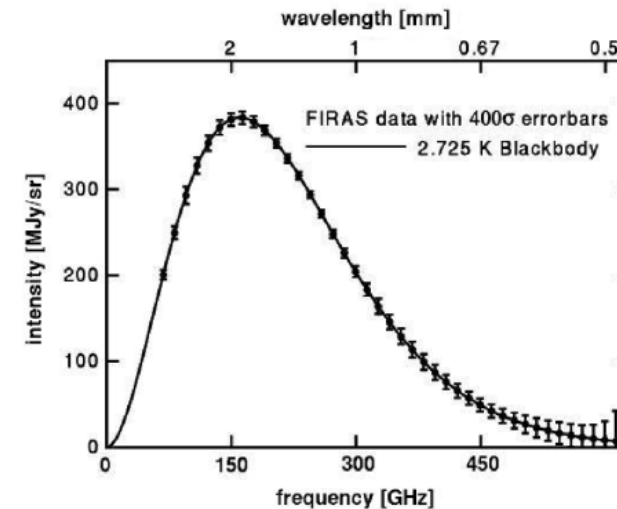
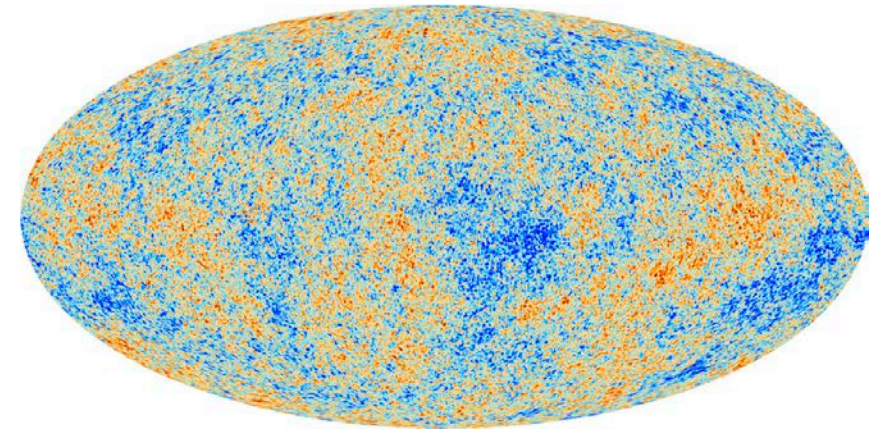
Dark Matter

- Several times more mass than “normal” matter
- Galactic orbital velocities should follow Kepler’s Law
 - Instead, rotation curves are flat
- Gravitational lensing
 - Mass bends light paths
 - Strong lensing (multiple images or arcs) vs. weak lensing (shape distortion)



Cosmic Microwave Background

- Era of Recombination
 - When universe was ionized, photons couldn't travel far without interacting with matter
 - Recombination of electrons + nuclei – no longer ionized, photons go free
- Almost perfect blackbody
 - Temperature at recombination, redshifted by expansion of the universe
 - Primordial fluctuations



Basic Equations & Relationships

Distance Modulus:

$$m - M = 5 \log_{10} \left(\frac{d}{10} \right)$$

Type Ia supernova: $M \approx -19.6$

Astronomical Units:

$$1 \text{ pc} = 3.26 \text{ ly} = 3.08 * 10^{16} \text{ m}$$

$$1 \text{ degree} = 60 \text{ arcmin} = 3600 \text{ arcsec}$$

Small Angle Formula: $d = \frac{\alpha D}{206,265}$

Inverse Square Law: $\frac{L_1}{L_2} = \frac{r_2^2}{r_1^2}$

Circumference, Area, Surface Area,
and Volume of a Sphere

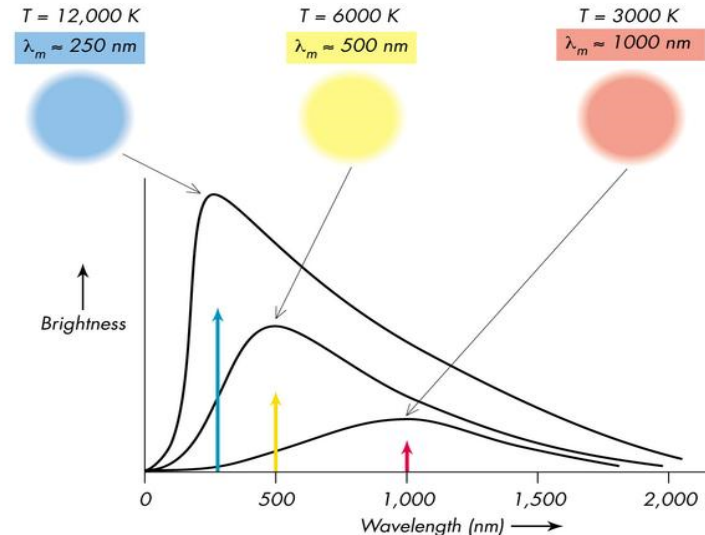
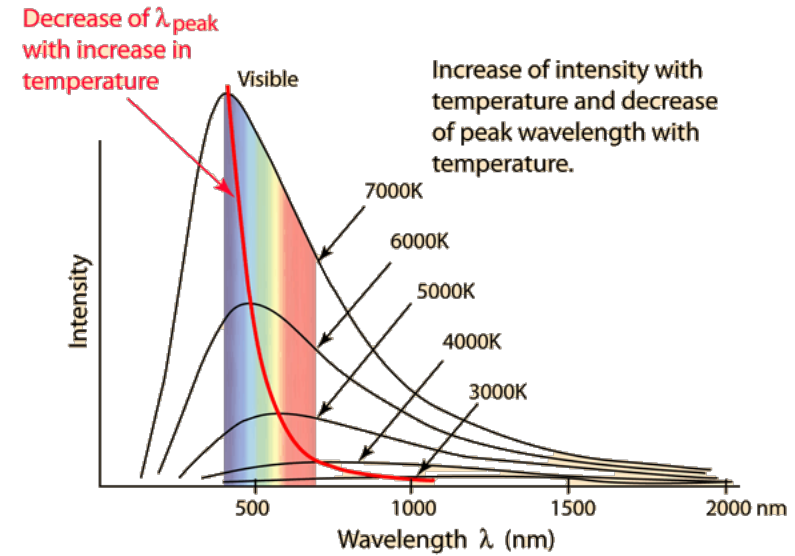
Radiation Laws

Blackbody – described by Planck's Law

$$\text{Wien's Law: } \lambda_{max} = \frac{2.9 \cdot 10^6 \text{ nm} \cdot \text{K}}{T}$$

$$\text{Stefan-Boltzmann Law: } L = A\sigma T^4$$

$$\text{LRT: } \frac{L_1}{L_2} = \left(\frac{R_1}{R_2}\right)^2 \left(\frac{T_1}{T_2}\right)^4$$



Orbital Motion

Kepler's Third Law:

$$(M_1 + M_2) = \frac{a^3}{P^2}$$

(in solar masses, AU, years)

$$(M_1 + M_2) = \left(\frac{G}{4\pi^2} \right) \frac{a^3}{P^2}$$

(in meters, kilograms, seconds)

Circular Motion:

$$v = \frac{d}{t}$$

$$a = \frac{v}{t}$$

$$P = \frac{2\pi r}{v}$$

$$F_c = ma_c = \frac{mv^2}{r}$$

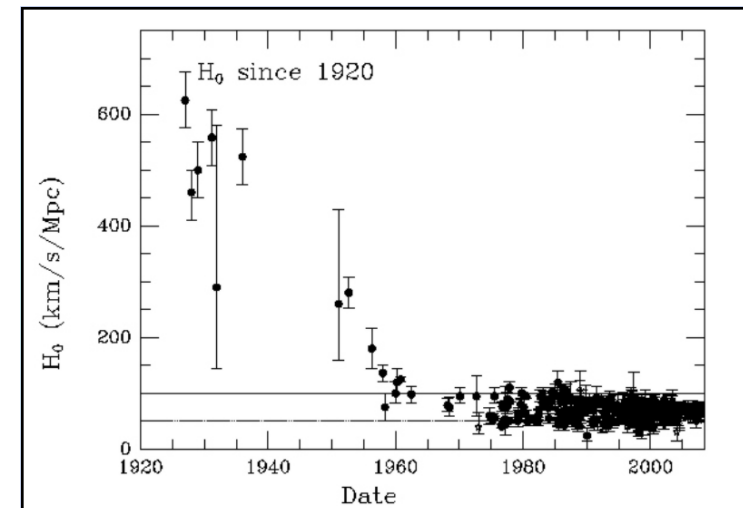
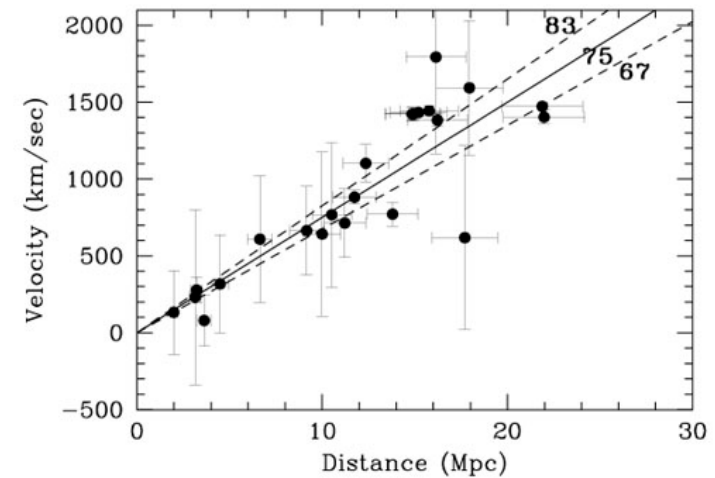
Hubble's Law & Hubble's Constant

- All galaxies recede from us due to expansion of the universe
- For nearby galaxies, peculiar motion (due to gravity, etc.) is more important

$$v_{rec} = H_0 d \quad (H_0 \approx 70 \frac{km/s}{Mpc})$$

$$\text{Age of universe} \approx \frac{1}{H_0}$$

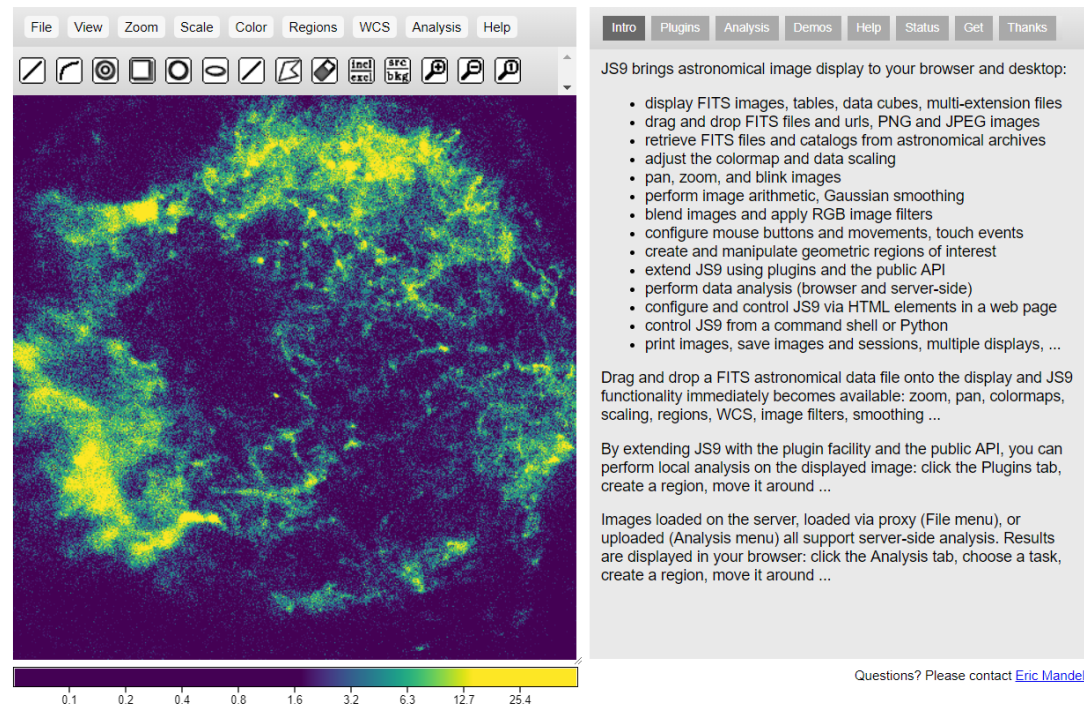
Hubble Diagram for Cepheids (flow-corrected)



JS9

<https://js9.si.edu/>

JS9: astronomical image display everywhere



JS9 brings astronomical image display to your browser and desktop:

- display FITS images, tables, data cubes, multi-extension files
- drag and drop FITS files and urls, PNG and JPEG images
- retrieve FITS files and catalogs from astronomical archives
- adjust the colormap and data scaling
- pan, zoom, and blink images
- perform image arithmetic, Gaussian smoothing
- blend images and apply RGB image filters
- configure mouse buttons and movements, touch events
- create and manipulate geometric regions of interest
- extend JS9 using plugins and the public API
- perform data analysis (browser and server-side)
- configure and control JS9 via HTML elements in a web page
- control JS9 from a command shell or Python
- print images, save images and sessions, multiple displays, ...

Drag and drop a FITS astronomical data file onto the display and JS9 functionality immediately becomes available: zoom, pan, colormaps, scaling, regions, WCS, image filters, smoothing ...

By extending JS9 with the plugin facility and the public API, you can perform local analysis on the displayed image: click the Plugins tab, create a region, move it around ...

Images loaded on the server, loaded via proxy (File menu), or uploaded (Analysis menu) all support server-side analysis. Results are displayed in your browser: click the Analysis tab, choose a task, create a region, move it around ...

Questions? Please contact [Eric Mandel](mailto:eric.mandel@si.edu)



Resources

National Science Olympiad

<http://www.soinc.org>

Chandra (x-ray)

<http://chandra.harvard.edu/>

Hubble (visible)

<http://stsci.edu/hst/>

Spitzer (infrared)

<http://www.spitzer.caltech.edu/>

Fermi (gamma-ray)

<https://fermi.gsfc.nasa.gov/>

Swift (x-ray/UV)

<https://swift.gsfc.nasa.gov/>

Nat'l Radio Astronomy Observatory

<https://public.nrao.edu/>

Astronomy Picture of the Day

<http://apod.nasa.gov/astropix.html>

Event Information

National Event Supervisors:

Donna L. Young (dlyoung.nso@gmail.com)

Tad Komacek (tkomacek@gmail.com)

Rules Clarifications available at soinc.org under Event Information

1. Read the Event Description for content and allowable resources.
2. Use the webinar (Chandra) and/or powerpoint (NSO) for an overview of the content topics and deep sky objects.
3. Use the Astronomy Coaches Manual (NSO) as a guide for background information.

Event Information

4. Use the resources listed in the event description for images and content.
5. Youtube has many related videos.
6. Invitationals.
7. Tests from invitationals and sample state tests will be posted on the NSO website for teams to use for practice.
8. The scioly.org test exchange (https://scioly.org/wiki/index.php/2019_Test_Exchange).
9. ASTRO 101 introductory college courses.
10. Scientific papers. Most useful parts: abstract, introduction, figures. Don't worry if you don't understand everything!