# 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/



https://www.universe-of-learning.org/
http://chandra.harvard.edu/index.html

# Chandra X-Ray Observatory

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

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


# 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

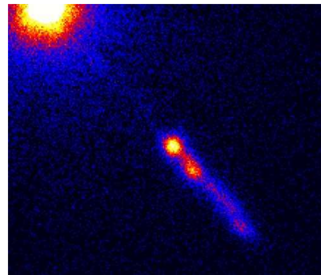
**Galaxy Clusters**
- Bullet Cluster (1E 0657-56)
- MACS J0717.5+3745
- MACS J1149.5+2223
- JKCS 041

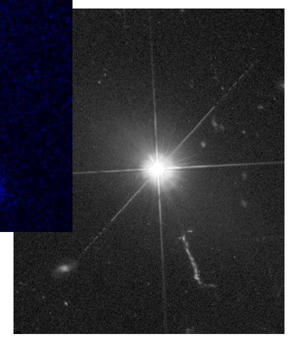
**Early Universe**
- SN UDS10Wil
- GOODS-S 29323
- PSS 0133+0400 & PSS 0955+5940

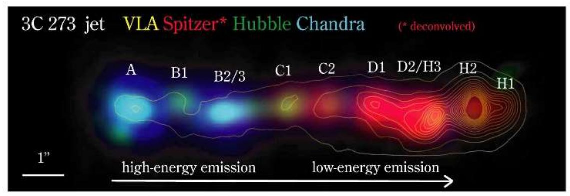
**Gravitational Waves**
- GW 151226
- GRB 150101B

# 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





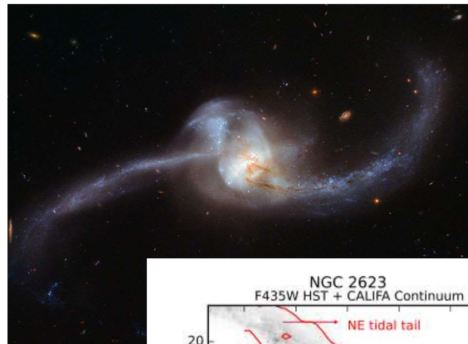


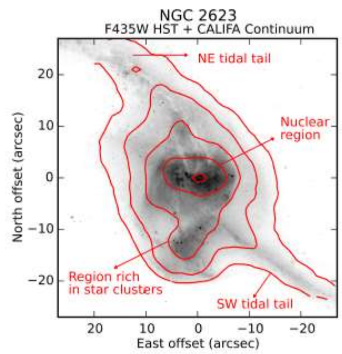

https://www.spacetelescope.org/images/potw1346a/
https://earthsky.org/space/1st-close-up-look-supermassive-black-hole-3c273
https://www.aavso.org/vsots_3c273

Advanced:
http://www.astro.caltech.edu/~george/ay21/eaa/eaa-3c273.pdf
http://adsabs.harvard.edu/full/1964ApJ...140....1G
https://arxiv.org/pdf/astro-ph/0605530.pdf

# 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



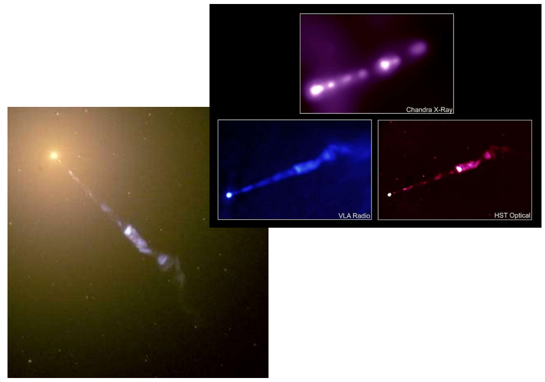


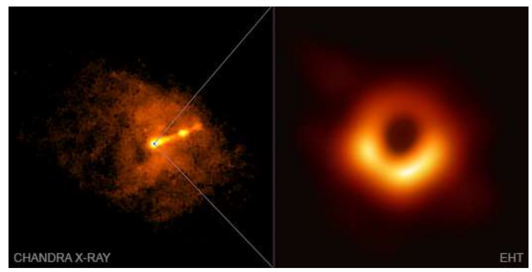

https://www.nasa.gov/image-feature/goddard/2017/hubble-unravels-a-twisted-cosmic-knot
https://apod.nasa.gov/apod/ap180110.html
https://www.spacetelescope.org/news/heic0912/

Advanced:
https://arxiv.org/abs/1706.01896
https://iopscience.iop.org/article/10.1086/533499/pdf

# 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



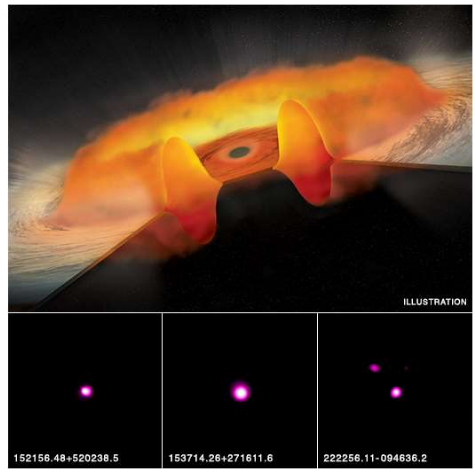

http://chandra.harvard.edu/photo/2019/black_hole/
https://www.nasa.gov/feature/goddard/2017/messier-87
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_museum/m87.html
https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA23122

Advanced:
https://www.messier-objects.com/messier-87-virgo-a/
https://en.wikipedia.org/wiki/Messier_87

# 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?

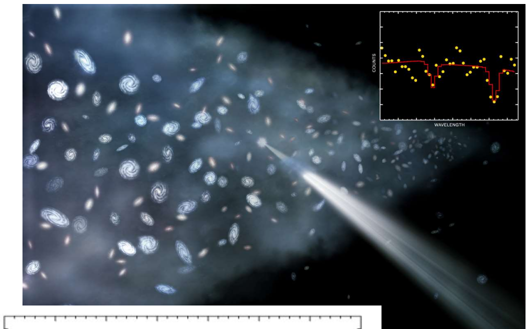


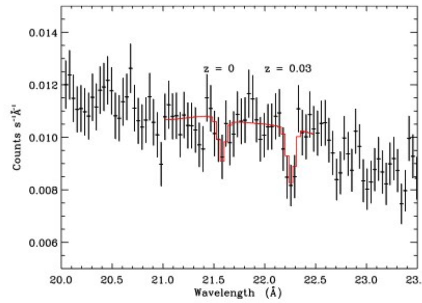

http://chandra.harvard.edu/press/15_releases/press_043015.html
https://www.youtube.com/watch?v=NWqafCnDvdg

Advanced:
https://arxiv.org/abs/1503.02085

# 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



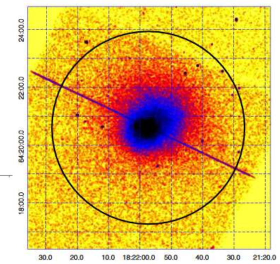


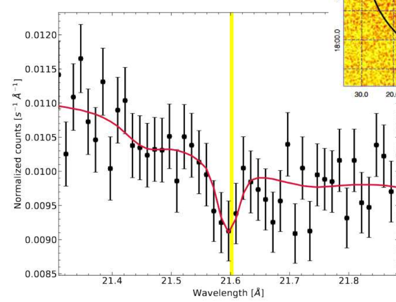

http://chandra.harvard.edu/photo/2010/h2356/
https://www.space.com/8386-huge-chunk-universe-missing-matter.html

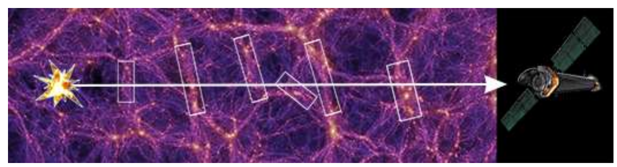
Advanced:
https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2006/01/
https://dspace.mit.edu/bitstream/handle/1721.1/63603/Canizares2.pdf?sequence=1&isAllowed=y

# 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





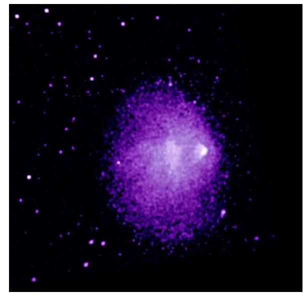



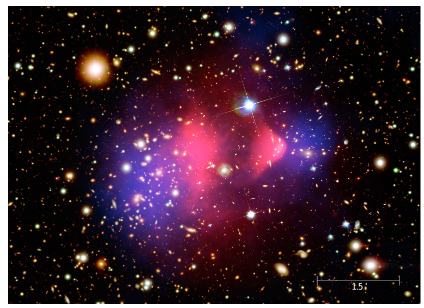
https://apod.nasa.gov/apod/ap000516.html
http://chandra.harvard.edu/photo/2019/whim/

Advanced:
https://iopscience.iop.org/article/10.1088/2041-8205/792/2/L41/pdf
https://arxiv.org/abs/1405.7522
https://arxiv.org/abs/1812.04625

# 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



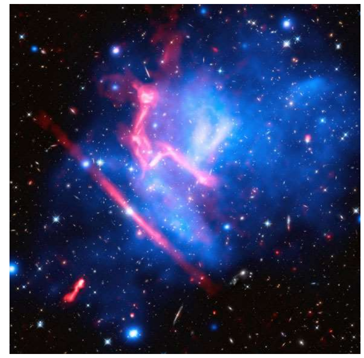


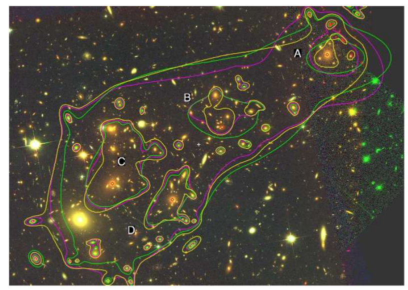
https://apod.nasa.gov/apod/ap170115.html
https://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/large_scale_structure/1E0657-56.html
http://chandra.harvard.edu/press/06_releases/press_082106.html

Advanced:
https://arstechnica.com/science/2017/09/science-in-progress-did-the-bullet-cluster-withstand-scrutiny/
https://astrobites.org/2016/11/04/the-bullet-cluster-a-smoking-gun-for-dark-matter/

# 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



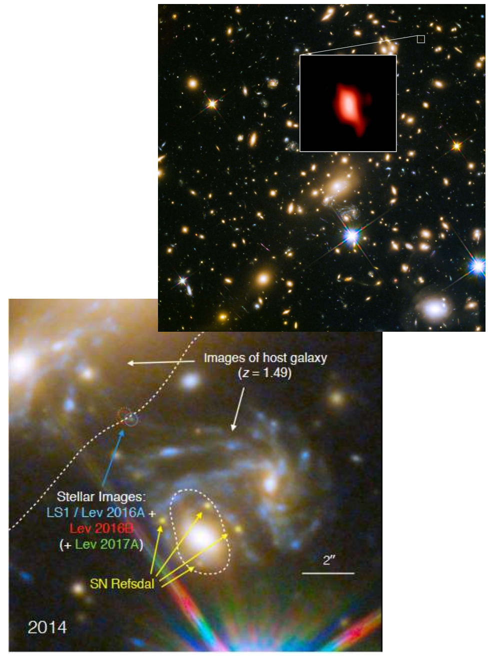



https://www.spacetelescope.org/images/opo0917a/
https://scitechdaily.com/three-datasets-produce-a-unique-new-view-of-macs-j0717/
http://chandra.harvard.edu/photo/2016/frontier/index.html

Advanced:
https://arxiv.org/abs/1512.04527
https://arxiv.org/abs/1510.08077

# 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

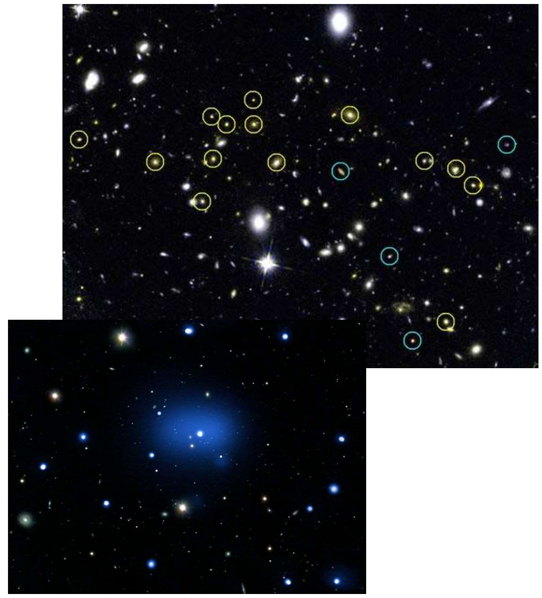



https://frontierfields.org/meet-the-frontier-fields/macsj1149/
http://hubblesite.org/news_release/news/2012-31
https://en.wikipedia.org/wiki/MACS_J1149_Lensed_Star_1
https://en.wikipedia.org/wiki/SN_Refsdal

Advanced:
http://www.mergingclustercollaboration.org/macs-j114952223.html
https://arxiv.org/pdf/1204.2305.pdf
https://arxiv.org/pdf/1706.10279.pdf

# 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?

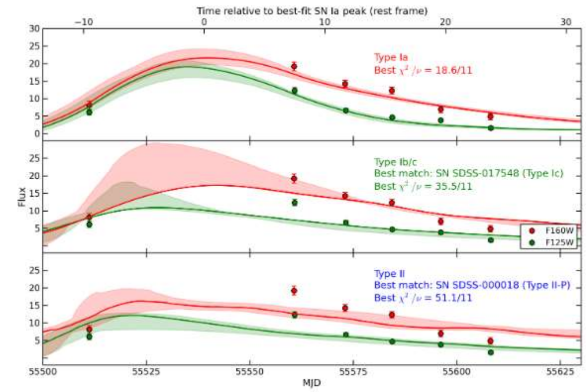


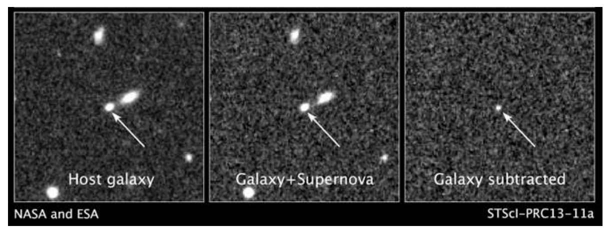
https://apod.nasa.gov/apod/ap091028.html
https://scitechdaily.com/hubble-confirms-distance-galaxy-cluster-jkcs-041/

Advanced:
https://arxiv.org/abs/1310.6754
https://www.aanda.org/articles/aa/pdf/2014/05/aa23077-13.pdf

# 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?



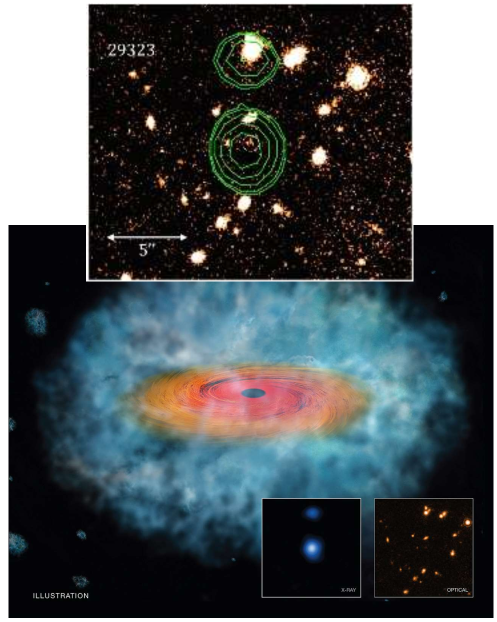




https://www.nasa.gov/mission_pages/hubble/science/sn-wilson.html
https://www.skyandtelescope.com/astronomy-news/the-oldest-loneliest-supernova/

Advanced:
https://ned.ipac.caltech.edu/level5/March18/Czerny/Czerny2.html
https://arxiv.org/abs/1304.0768

# 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

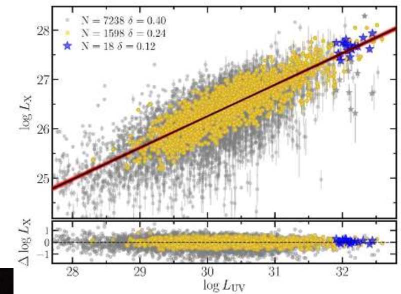


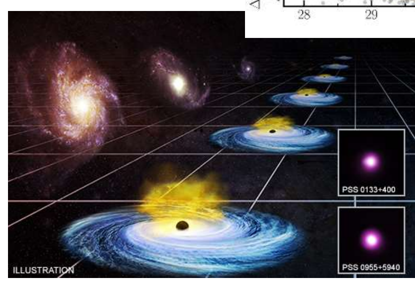

https://www.nasa.gov/mission_pages/chandra/goods-s-29323.html
https://arstechnica.com/science/2016/05/building-a-supermassive-black-hole-skip-the-star/

Advanced:
https://astrobites.org/2016/05/30/monsters-in-the-dark-first-detection-of-a-direct-collapse-black-hole-candidate/
https://arxiv.org/abs/1603.08522

# 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...



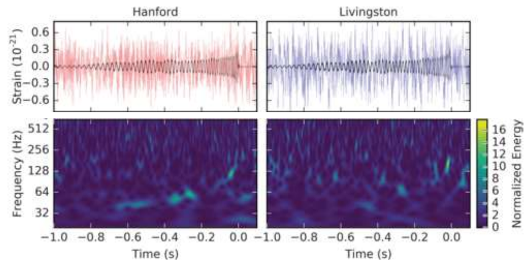



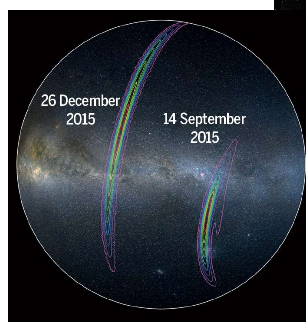

http://chandra.harvard.edu/press/19_releases/press_012919.html
https://www.skyandtelescope.com/astronomy-news/what-quasar-cosmology-can-teach-us-about-dark-energy/

Advanced:
https://arxiv.org/abs/1811.02590

# 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_final = 20.8 Msun, less than combined mass before merger (turned into energy)



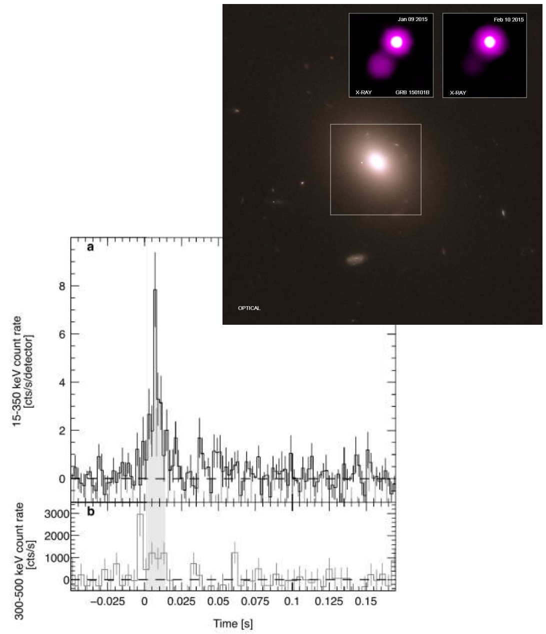




https://www.ligo.org/detections/GW151226.php
https://en.wikipedia.org/wiki/GW151226
https://www.sciencemag.org/news/2016/06/ligo-detects-another-black-hole-crash

Advanced:
https://www.ligo.org/science/Publication-GW151226/index.php
https://arxiv.org/abs/1606.04855

# *GRB 150101B*

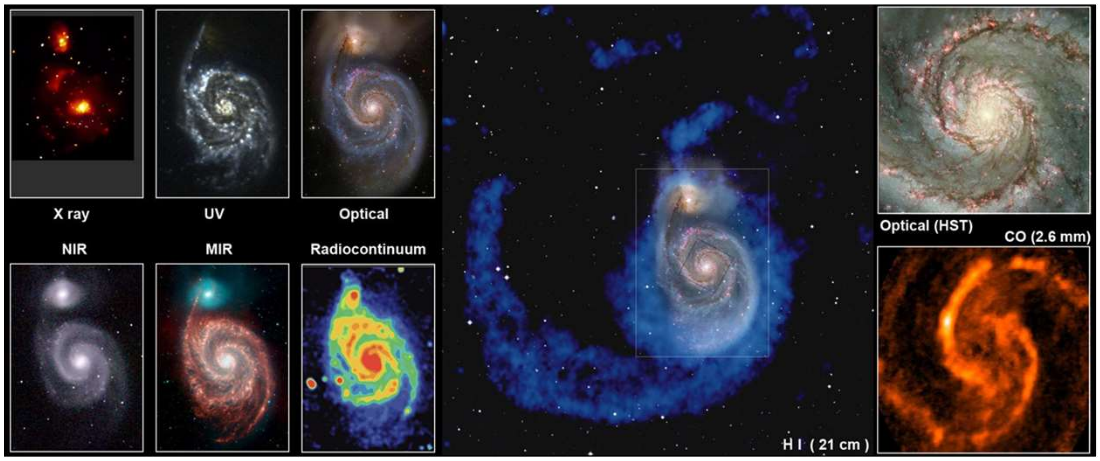
- Short gamma-ray burst (< 0.1 sec!)
  - Detected by Fermi (gamma-ray)
  - Fast follow-up by Swift, Chandra, Hubble, and more!
- Similar to GW 170817
  - Known neutron star + neutron star merger (kilonova)
  - Observed in gravitational waves (LIGO) and multiple wavelengths




http://chandra.harvard.edu/photo/2018/kilonova/
https://www.youtube.com/watch?v=NCVsx6drHrM
https://www.space.com/42158-another-neutron-star-crash-detected.html

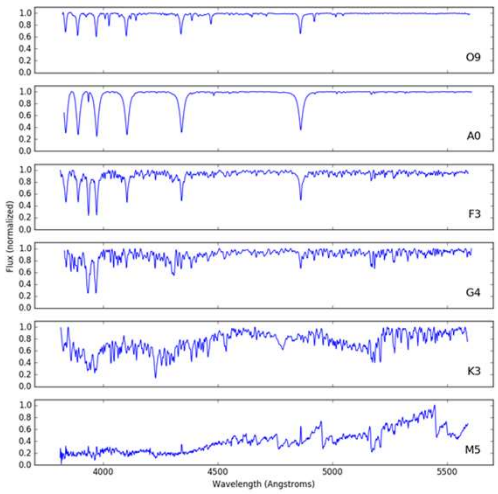
Advanced:
https://arxiv.org/abs/1807.02866
https://arxiv.org/ftp/arxiv/papers/1806/1806.10624.pdf

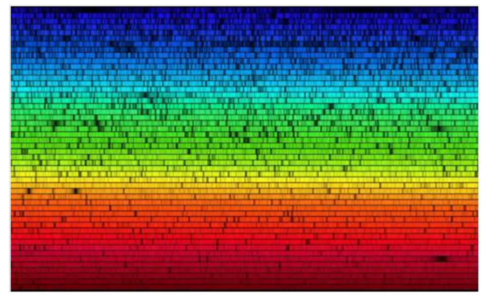
# Multi-Wavelength Observations

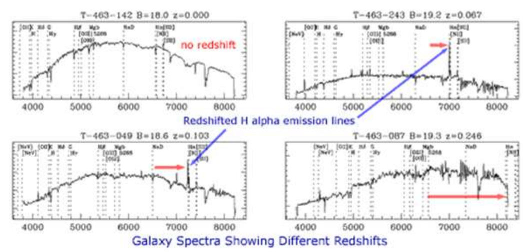



http://www.atnf.csiro.au/people/lop009/multiwave.html

# Spectra



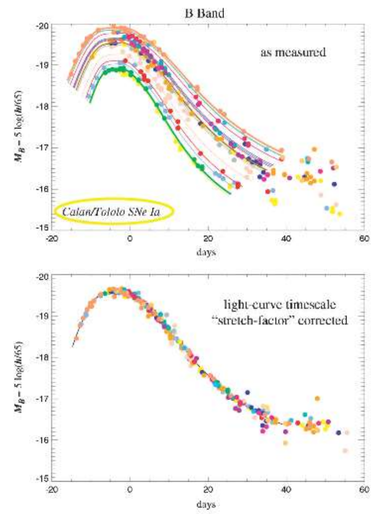






http://spiff.rit.edu/classes/phys230/lectures/spec_interp/spec_interp.html
http://star-www.st-and.ac.uk/~spd3/Teaching/PHYS1002/phys1002_lecture6.pdf
http://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectra_astro_types.html
http://spiff.rit.edu/classes/phys301/lectures/doppler/doppler.html

# Type Ia Supernovae

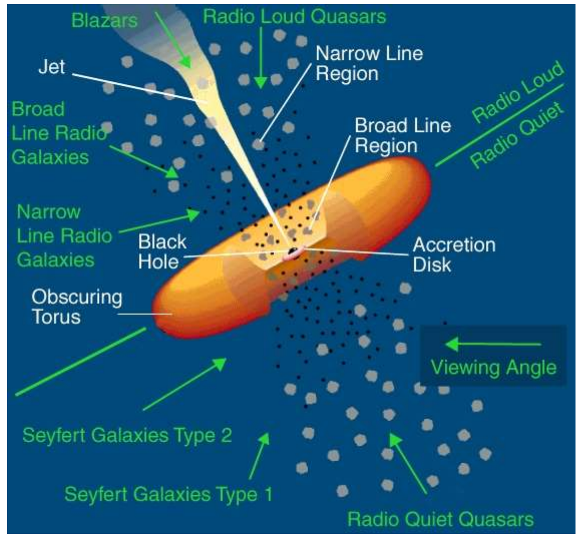
- From white dwarf with mass > 1.4 solar masses (Chandrasekhar Limit)
- “Standard candle” for measuring distance because they are all the same brightness (well... maybe)
  - Slow mass transfer from binary companion, mass = 1.4 solar masses
  - Collision with another white dwarf, mass = ???




https://en.wikipedia.org/wiki/Type_Ia_supernova
https://hubblesite.org/contents/articles/dark-energy
http://astronomy.swin.edu.au/cosmos/T/Type+Ia+Supernova+Progenitors

# AGNs & Quasars

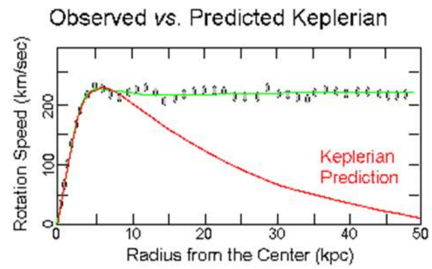
- Bright across many wavelengths, often variable
- Unified Model – all AGNs/quasars are similar, just viewed from different angles
  - Disk of matter accreting onto a supermassive black hole
  - Sometimes (but not always) produces a narrow jet

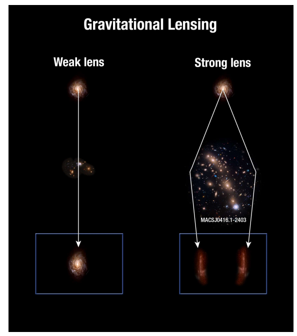



http://astronomy.swin.edu.au/cosmos/A/Active+Galactic+Nuclei
https://imagine.gsfc.nasa.gov/science/objects/active_galaxies1.html
https://www.space.com/17262-quasar-definition.html

# 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)

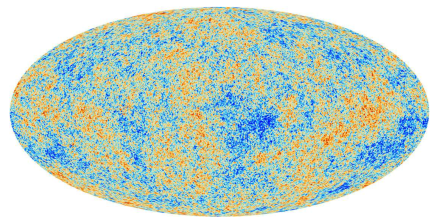


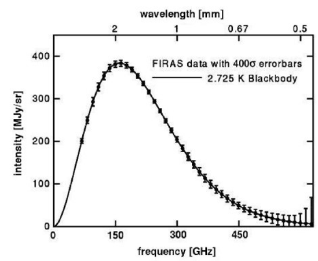




https://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy
https://www.space.com/20930-dark-matter.html
https://frontierfields.org/2014/12/09/mapping-mass-in-a-frontier-fields-cluster/

# 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






https://wmap.gsfc.nasa.gov/universe/bb_tests_cmb.html
http://astronomy.swin.edu.au/cosmos/C/Cosmic+Microwave+Background
https://m.esa.int/Our_Activities/Space_Science/Planck/Planck_and_the_cosmic_microwave_background

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

1 degree = 60 arcmin = 3600 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

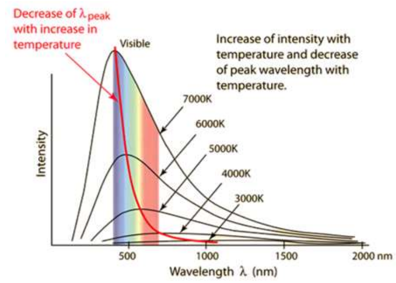
# Radiation Laws

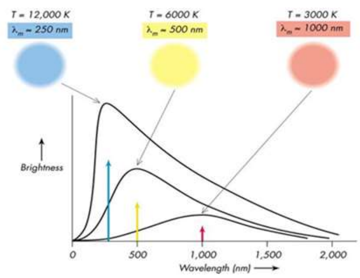
Blackbody – described by Planck's Law

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

**Stefan-Boltzmann Law**: $L = A\sigma T^4$

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




http://hyperphysics.phy-astr.gsu.edu/hbase/wien.html
http://jila.colorado.edu/~ajsh/courses/astr1120_03/text/chapter1/SBLaw.htm

# 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**:

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

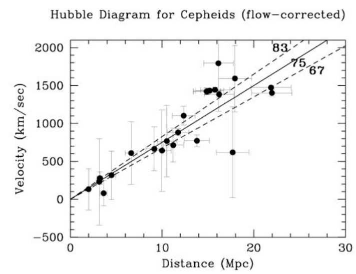
$a = \frac{v}{t}$

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

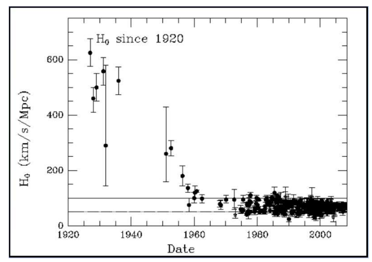
$F_c = ma_c = \frac{mv^2}{r}$

# 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




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

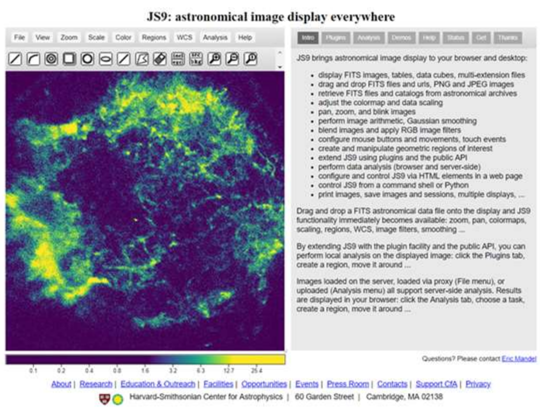



Age of universe $\approx \frac{1}{H_0}$

https://www.e-education.psu.edu/astro801/content/l10_p3.html
http://hosting.astro.cornell.edu/academics/courses/astro201/hubbles_law.htm

# JS9

https://js9.si.edu/




https://js9.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!