National Science Olympiad

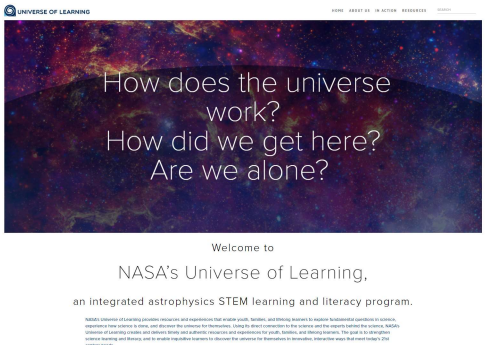
Astronomy 2019 (Division C)

Stellar Evolution in Normal & Starburst Galaxies

NASA Universe of Learning/CXC/NSO

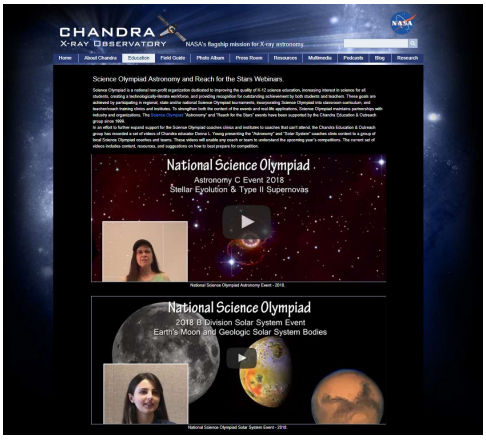
https://www.universe-of-learning.org/

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



Chandra X-Ray Observatory

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



2019 Rules

1. DESCRIPTION: Teams will demonstrate an understanding of stellar evolution in normal & starburst galaxies.

A TEAM OF UP TO: 2

APPROXIMATE TIME: 50 minutes

2. EVENT PARAMETERS: Each team is permitted to bring two computers (of any kind) or two 3-ring binders (any size) containing information in any form from any source, or one binder and one computer. The materials must be inserted into the rings (notebook sleeves are permitted). Each team member is permitted to bring a programmable calculator. No internet access is allowed; however teams may access a dedicated NASA data base.

2019 Rules

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 (X-ray, UV, optical, IR, radio), charts, graphs, and JS9 imaging analysis software, teams will complete activities and answer questions related to:

a. Stellar evolution, including stellar classification, spectral features and chemical composition, luminosity, blackbody radiation, color index and H-R diagram transitions, star formation, Cepheids, RR Lyrae stars, Type Ia & Type II supernovas, neutron stars, pulsars, stellar mass black holes, supermassive black holes, X-ray & gamma-ray binary systems, ultraluminous X-ray sources (ULXs), globular clusters, stellar populations in normal & starburst galaxies, galactic structure and interactions, and gravitational waves.

2019 Rules

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 (X-ray, UV, optical, IR, radio), charts, graphs, and JS9 imaging analysis software, teams will complete activities and answer questions related to:

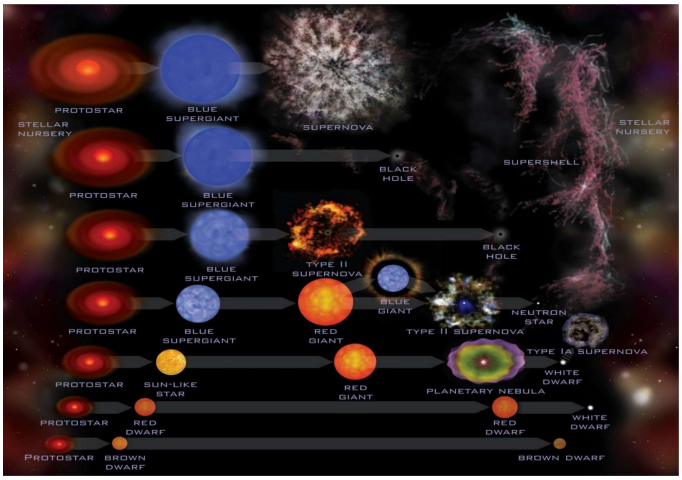
b. Use Kepler's laws, rotation and circular motion to answer questions relating to the orbital motions of binary systems and galaxies; use parallax, spectroscopic parallax, the distance modulus, the period-luminosity relationship, Hubble's law, and the Tully-Fisher relationship to calculate distances.

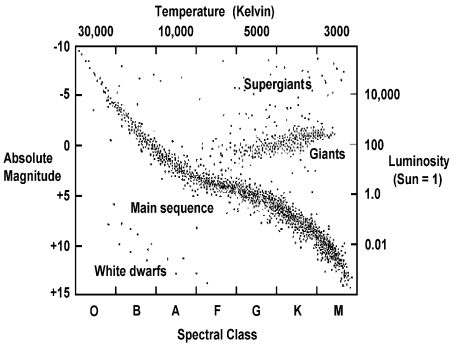
2019 Rules

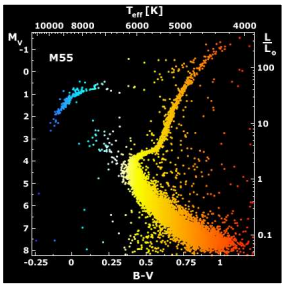
3. <u>THE COMPETITION</u>: Using information which may include Hertzsprung-Russell diagrams, spectra, light curves, motions, cosmological distance equations and relationships, stellar magnitudes and classification, multi-wavelength images (X-ray, UV, optical, IR, radio), charts, graphs, and JS9 imaging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

c. Identify and answer questions relating to the content areas outlined above for the following objects: M51/NGC 5195, IC 10, SPT 0346-52, M81/M82, ESO 137-001, SN2014J, Phoenix Cluster, NGC 4993, 47 Tucanae/X9, Chandra Deep Field South, Cen A, M100, Abell 400, Antennae Galaxies, Sagittarius A*

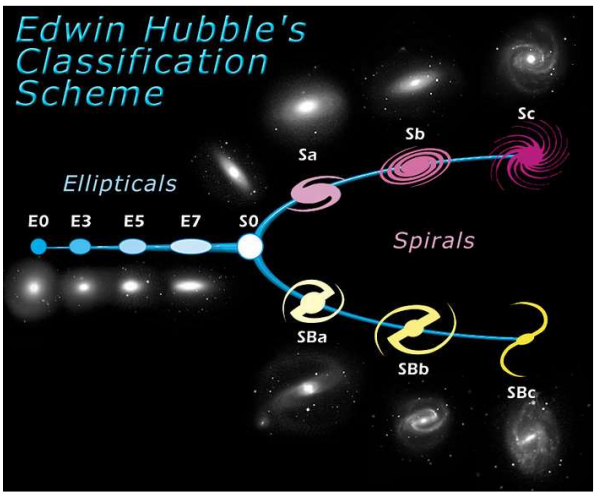
Stellar Evolution…

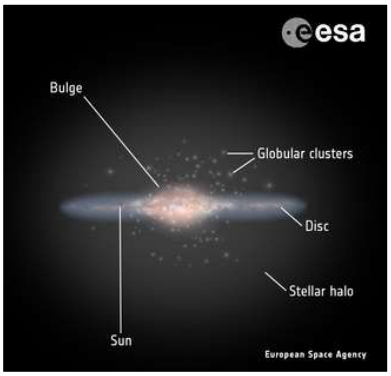






…in Galaxies





Deep Sky Objects

Compact Objects (and their explosions):

- SN2014J
- NGC 4993
- 47 Tucanae/X9

Supermassive Black Holes (SMBHs):

- Sagittarius A*
- Abell 400
- Chandra Deep Field South

Interacting Galaxies:

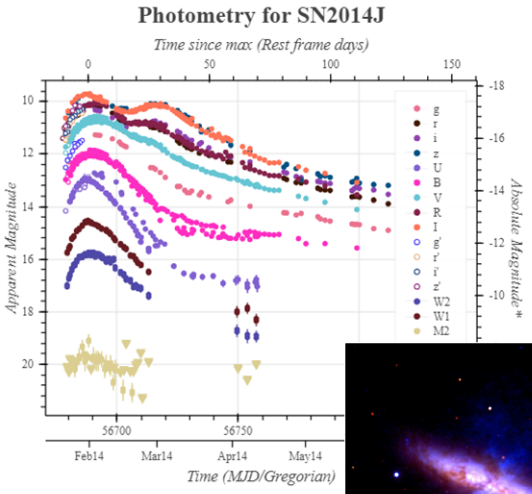
- Antennae Galaxies
- M51/NGC 5195
- M81/M82
- ESO 137-001

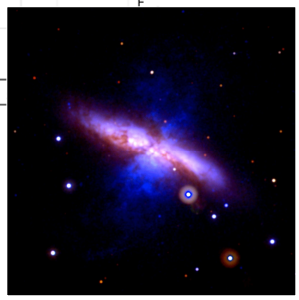
Starburst Galaxies:

- IC 10
- M100
- Cen A
- Phoenix Cluster
- SPT 0346-52

SN2014J

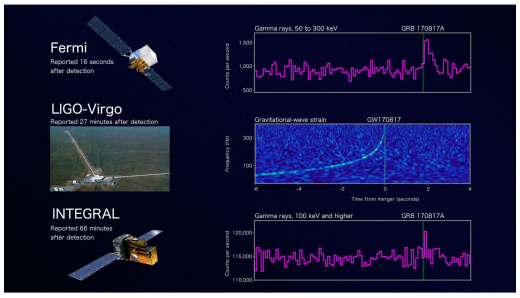
- Type Ia SN in M82
  - Closest in 40+ years
- Unusual variations in the "standard candle"
  - Fast rise to maximum brightness
  - Little nearby material for blast to collide with

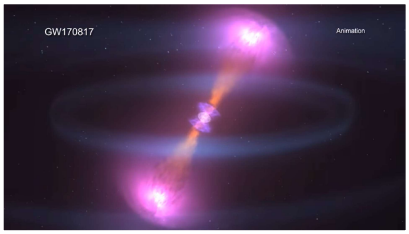


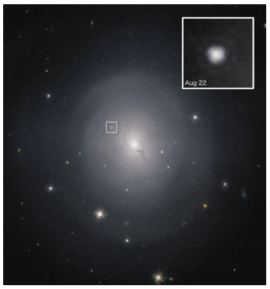


NGC 4993

- Elliptical/lenticular galaxy
- Host galaxy of GW170817
  - Kilonova (merger of binary neutron stars)
  - "Multi-messenger" event observed through both gravitational waves & many EM wavelengths

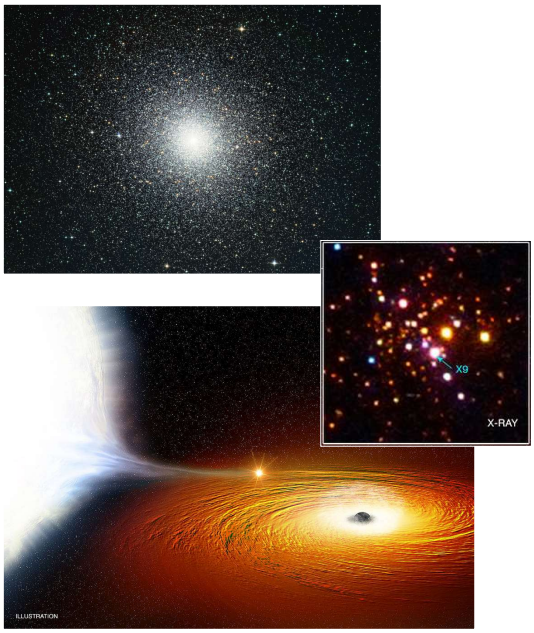






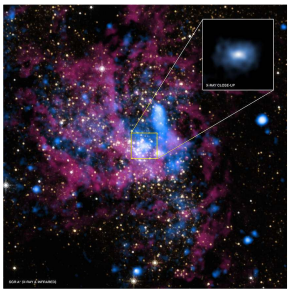
47 Tucanae / X9

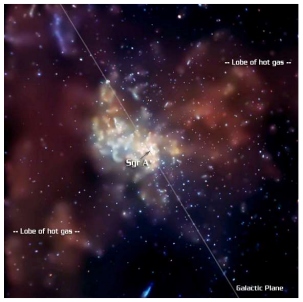
- Massive globular cluster
  - Primarily old, low mass stars
  - Many X-ray sources in core
- X9 is a Low Mass X-ray Binary
  - Stellar mass black hole pulling material from white dwarf
  - Very close orbit – period 28 min (!)

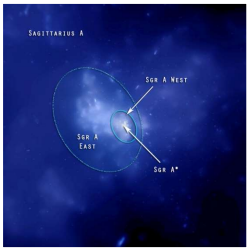


Sagittarius A*

- Radio source corresponding to Milky Way's SMBH
  - Difficult to see in visible light due to extinction
- A typical (?) quiet SMBH
  - Mass determined by orbits of nearby stars
  - Most material ends up ejected, not consumed
  - Flares and past outbursts

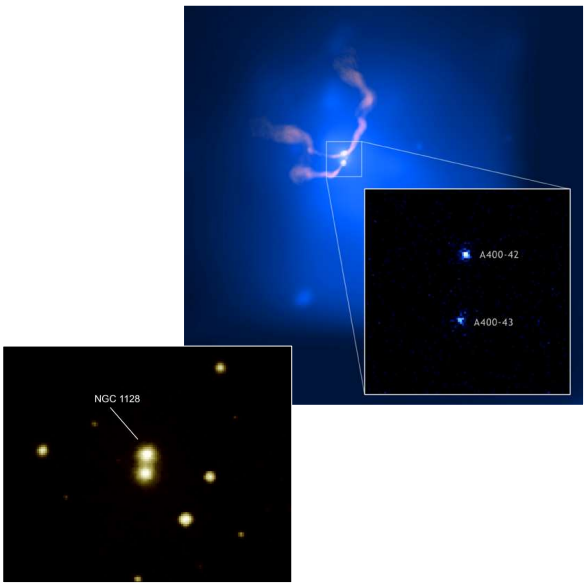






Abell 400

- Galaxy cluster
  - Diffuse, super-hot intergalactic gas throughout
- "Dumbbell" galaxy NGC 1128 (2 merging galaxies)
  - SMBHs will eventually merge too
  - Radio jets (source 3C 75) show common motion

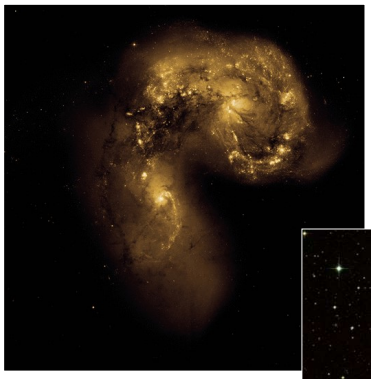


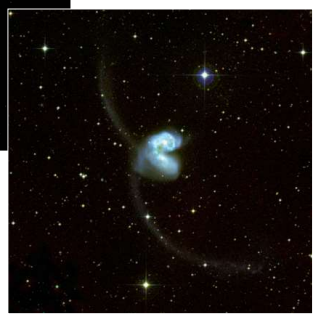
Chandra Deep Field South

- Deep imaging to study early X-ray universe
  - 7,000,000+ seconds of observing time
- Formation and growth of young SMBHs
  - May not grow in sync with their galaxies
- X-ray transient – GRB?

Antennae Galaxies

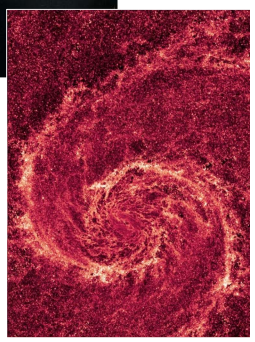
- Galaxies in the middle of colliding
  - Used to be spirals
  - Compression of gas causes star formation
- Long tidal tails
  - Stars flung outwards by gravitational interactions

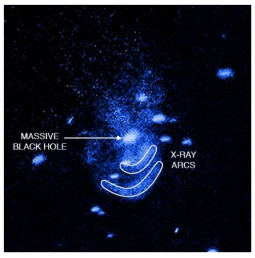




M51 / NGC 5195

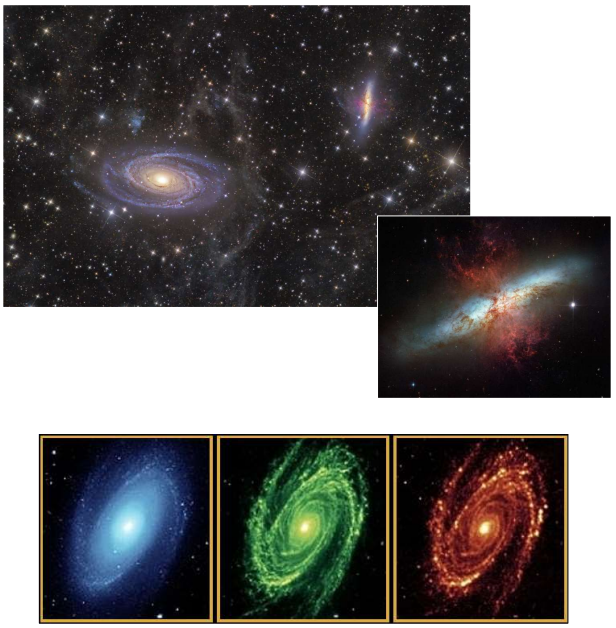
- Grand design spiral + irregular dwarf galaxy
- Not colliding, just passing
  - Gravitational interaction triggers star formation in spiral arms
- "Feedback" in NGC 5195
  - Hot gas from SMBH sweeps up cooler gas





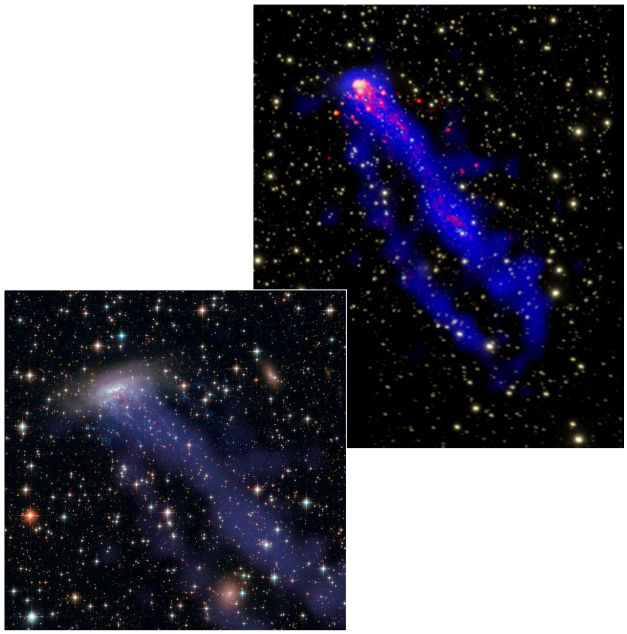
M81 / M82

- 2 spiral galaxies
  - M82 much more distorted
- Starburst in core of M82
  - Galactic "superwind" from combined stellar winds
- Some star formation in spiral arms of M81, but not central bulge



ESO 137-001

- Spiral galaxy in cluster Abell 3627
- Trails of gas and young stars
  - Ram pressure stripping (drag force from intergalactic gas)
  - No gas left for future star formation



IC 10

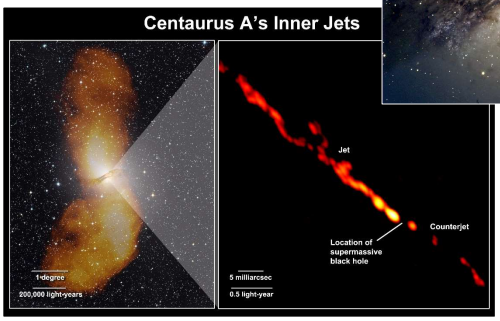
- Irregular dwarf galaxy
- Only starburst galaxy in the Local Group
  - Distance = 2.3 million ly
- Many X-ray binaries
  - Starburst means lots of young, massive stars exist

M100

- Grand design spiral
  - 2 small companion galaxies
- Starburst strongest near core
  - Disk deficient in H because gas is stripped away
- Distance determined by Cepheids and supernovae

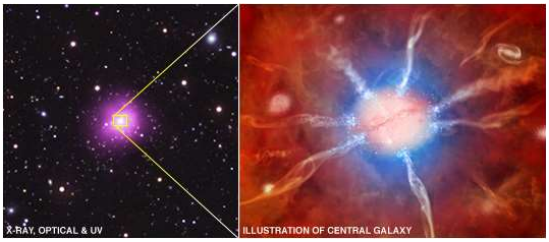
Cen A

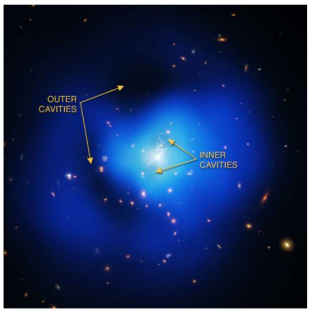
- Starburst elliptical galaxy
  - Ellipticals shouldn't be forming many stars
  - Probably ate a small spiral
- Radio jets (AGN)
  - Huge amounts of energy being ejected
  - Link between starburst and AGN activity?



Phoenix Cluster

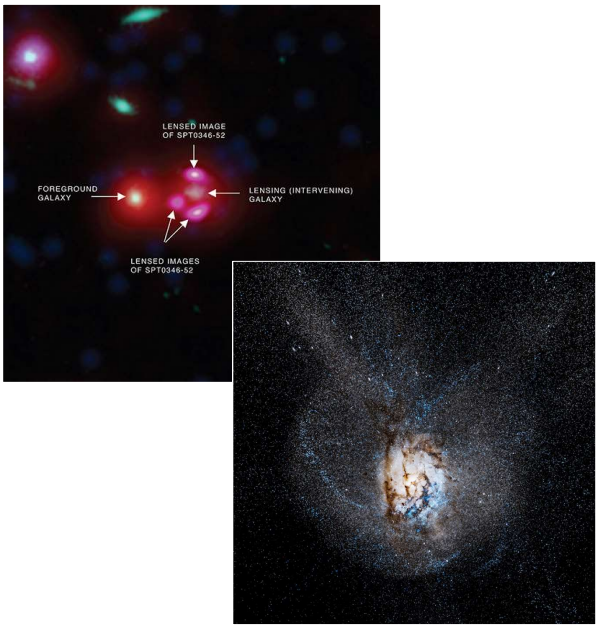
- Massive galaxy cluster with lots of X-ray emission
- Central galaxy has extremely high star formation rates AND a growing SMBH
  - AGN jets usually prevent star formation (gas can't cool)
  - Gas is condensing at the edges of cavities



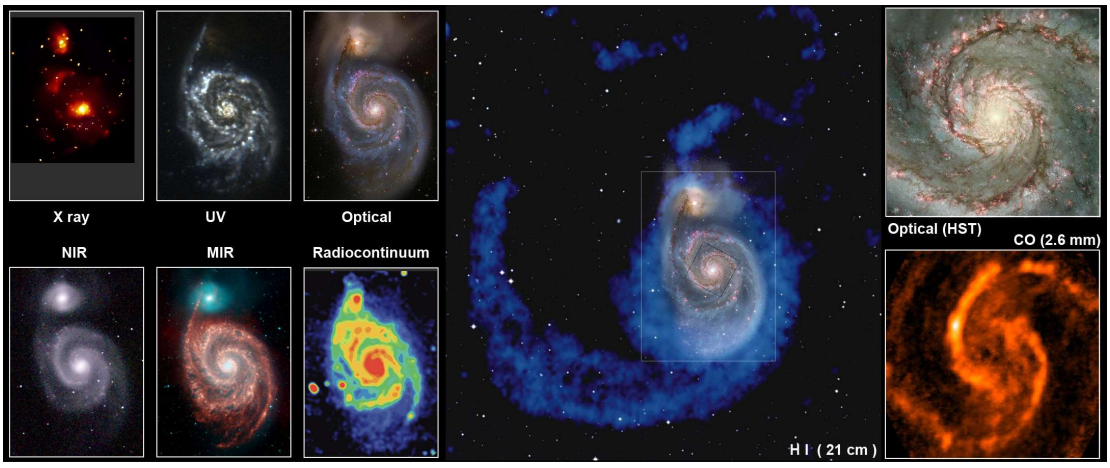


SPT 0346-52

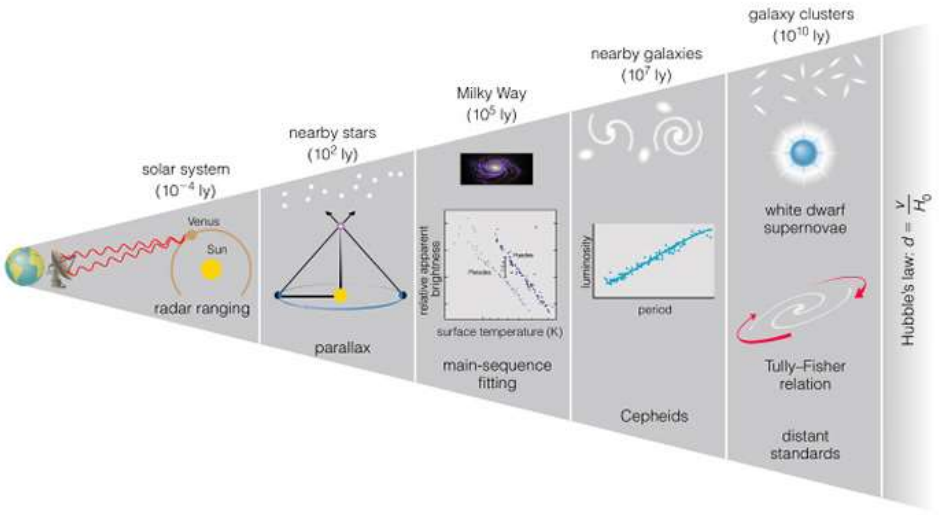
- "Hyper-starburst" galaxy 12.7 billion ly away
  - Era of early galaxy growth
- Infrared excess, but no evidence of growing SMBH
  - Extreme star formation (4500 solar masses/year), possibly due to merger



Multiwavelength Observations

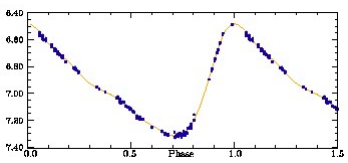


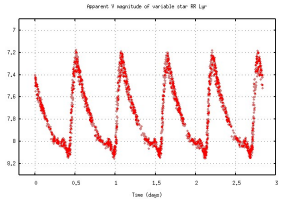
Measuring Distances

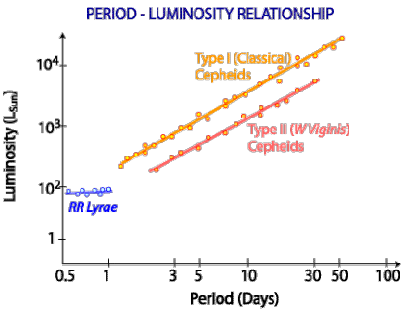


Cepheids & RR Lyrae

- Cepheids follow Leavitt Law (Period-Luminosity Relationship)
- RR Lyrae are also "standard candles"
  - Much shorter periods (~ 1 day)
  - Often found in globular clusters







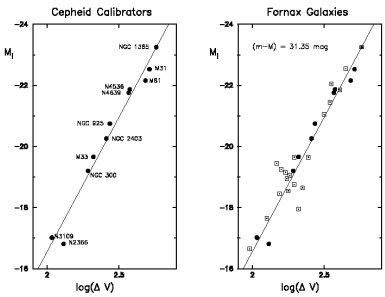
Tully-Fisher Relation & Hubble's Law

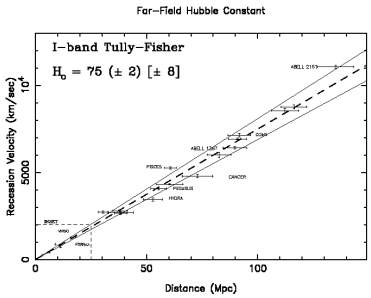
Tully-Fisher Relation:

$\log(L) \propto \log(v_{rot})$

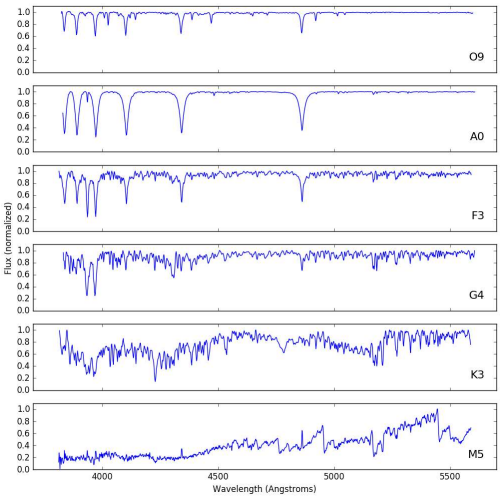
Hubble's Law:

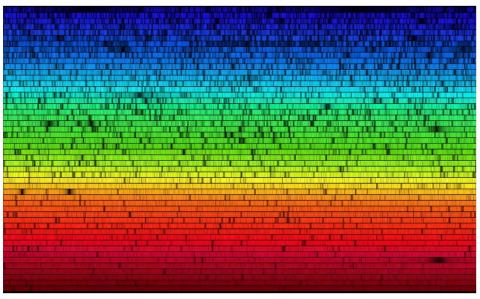
$v_{rec} = H_0 d$

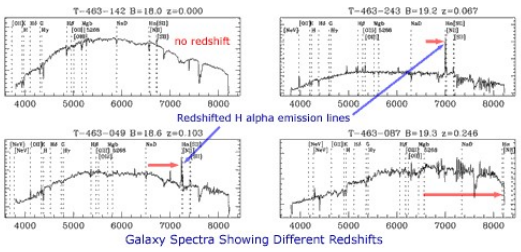




Spectra







Radiation Laws

Wien's Law:

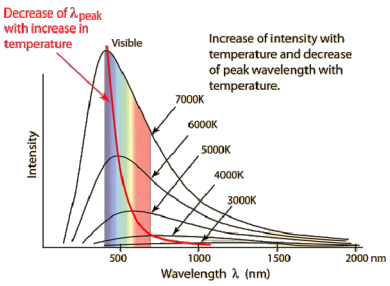
$$\lambda_{max} = \frac{2.9*10^6\ nm\ K}{T}$$

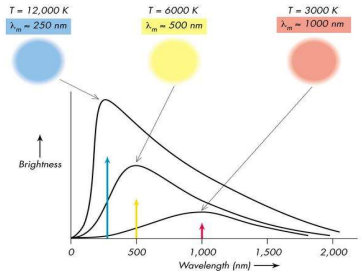
Stefan-Boltzmann Law:

$$L = e * A * \sigma T^4$$

(e = emissivity, A = surface area)

Planck's Law/Blackbody Radiation





Basic Equations & Relationships

Distance Modulus:

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

$$d = 10^{\frac{m-M+5}{5}}$$

Kepler's Third Law:

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

(in solar masses, AU, & years)

Circular Motion:

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

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

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

$$F_c = ma_c$$

$$a_c = \frac{v^2}{r} = r\omega^2$$

Basic Equations & Relationships

Small Angle Formula:

$$d = \frac{\alpha D}{206{,}265}$$

Inverse Square Law:

$$L = \frac{1}{r^2}$$

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

Astronomical Units:

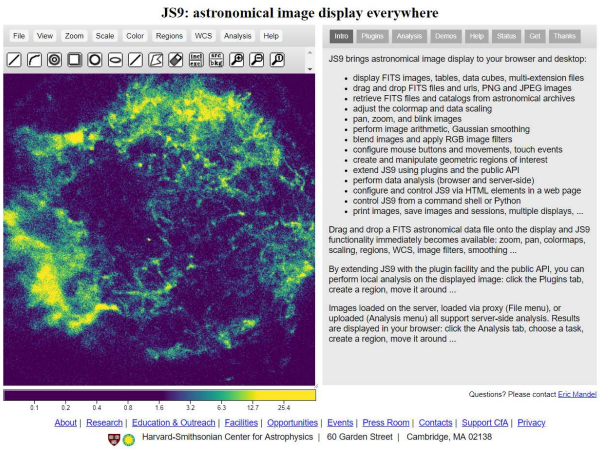
$$1\ pc = 3.26\ ly = 206{,}265\ au = 3.08 * 10^{16}\ m$$

$$1° = 60\ arcmin = 60'$$

$$1' = 60\ arcsec = 60''$$

JS9

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
National Radio Astronomy Observatory	https://public.nrao.edu
Astronomy Picture of the Day	http://apod.nasa.gov

Event Information

National Event Supervisors:

Donna L. Young (dlyoung.nso@gmail.com) and 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.
4. Use the resources listed in the event description for images and content.

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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/2018_Test_Exchange).