National Science Olympiad

Astronomy 2023 (Division C)

Stellar Evolution & Variability

Supported by NASA Universe of Learning STEM Literacy Network

NASA Astrophysics Division/CXC/NSO

https://www.universe-of-learning.org
https://www.soinc.org/astronomy-c

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Chandra X-Ray Observatory

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

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

2023 Rules

1. **DESCRIPTION:** Teams will demonstrate an understanding of Stellar Evolution & Variability

A TEAM OF UP TO: 2 **APPROXIMATE TIME:** 50 minutes

2. **EVENT PARAMETERS:**

a. 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; or,

iii. two three-ring binders.

2023 Rules

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). If the participants are using a computer/tablet they may use the calculator app or other program on their device in place of a stand-alone calculator.

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 asked to access a dedicated NASA image analysis website to answer some JS9 questions. If so, supervisors will provide an alternative (e.g., proctor-supplied computer or screen shots) for teams that did not bring a laptop/tablet.

2023 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 (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 evolution including stellar classification, spectral features and chemical composition, luminosity, blackbody radiation, color index and H-R diagram transitions, white dwarfs, planetary nebulas, neutron stars, pulsars, red giants, Mira variables, semiregular variables, RR Lyrae variables, globular clusters, Population I & II stars, Wolf-Rayet stars, Classical & Type II Cepheid variables, luminous blue variables, dwarf novas, symbiotic variables, X-ray binaries, Type II & Type Ia, Ib & Ic supernovas, kilonovas, gravitational waves.

2023 Rules

b. Use orbital mechanics, Kepler's laws, rotation and circular motion to answer questions relating to the orbital motions of binary and multiple star systems; use parallax, spectroscopic parallax, period-luminosity relations, and the distance modulus to calculate distances, use the radiation laws to answer questions relating to stellar structure and evolution.

c. Identify and answer questions relating to the content areas outlined above for the following objects: AG Carinae, GW170817, PSR J2030+4415, R Hydrae, R Aquarii, NGC 7027, RS Puppis, NaSt1, E0102-72.3, HD 184738 (Campbell's Hydrogen Star), W Virginis, G344.7-0.1, SS Cygni, E0102-72.3, 47 Tucanae, X9, and SN 2008D

Deep Sky Objects

Intrinsic variable

Pulsating
- RS Puppis
- W Virginis
- R Hydrae
- R Aquarii

Eruptive
- AG Carine
- NaSt1
- HD 184738 (Campbell's Hydrogen Star)

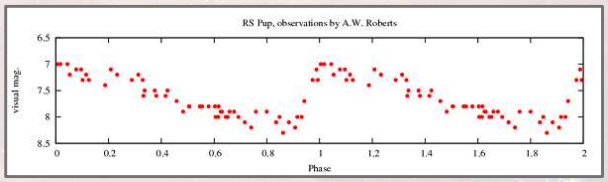
Cataclysmic
- G344.7-0.1
- SN 2008D
- E0102-72.3
- SS Cygni

Extrinsic variable
- PSR J2030+4415
- X9

Miscellaneous
- 47 Tucanae
- NGC 7027
- GW 170817

RS Puppis

- Classical Cepheid variable
  - Population I
  - Follows period-luminosity relation with a period of 41.5 days
  - Standard candle
- Light echos?
  - Reflected light off the surrounding reflection nebula
  - More accurate distance measurement

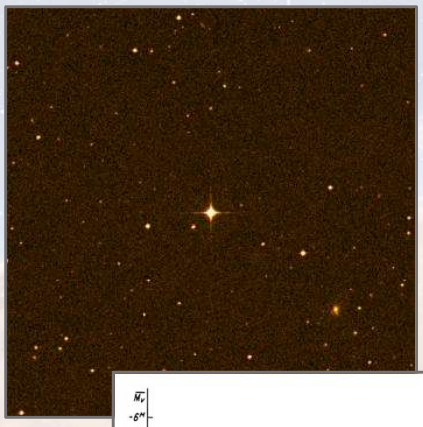


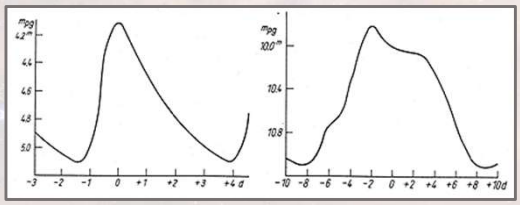
Introductory
https://www.aavso.org/vsots_rspup
https://hubblesite.org/contents/media/images/2013/51/3263-Image.html

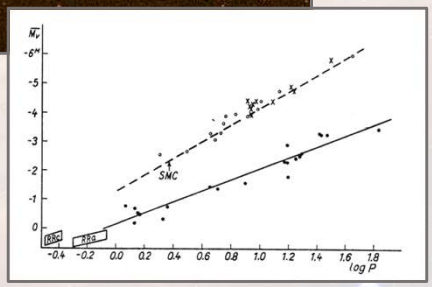
Advanced
https://arxiv.org/abs/0802.1501
https://arxiv.org/abs/0811.2943
https://arxiv.org/abs/1408.1697

W Virginis

- Prototype W Virginis variable
  - Type II Cepheid variable subclass
  - Population II
  - Also follows the period-luminosity relation
- Light curve contains a “hump”





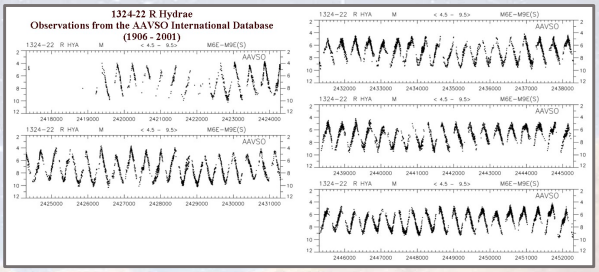


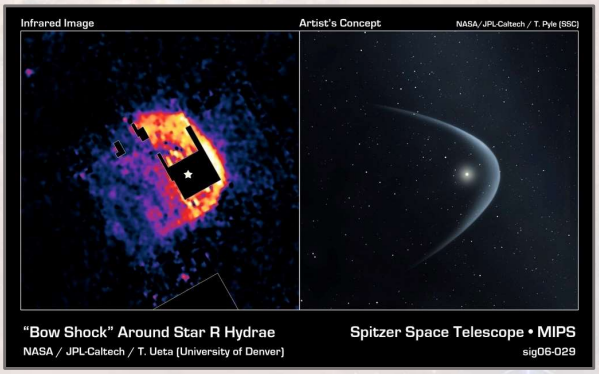
Introductory
https://www.aavso.org/vsots_wvir

Advanced
https://arxiv.org/abs/0709.0401
https://iopscience.iop.org/article/10.1086/341698

R Hydrae

- Mira variable
  - Period of several hundred days
  - Transitory phase between main sequence and asymptotic red giant branch
- Large, extended bow shock
  - Collision of stellar ejecta and interstellar medium
  - Visible in infrared



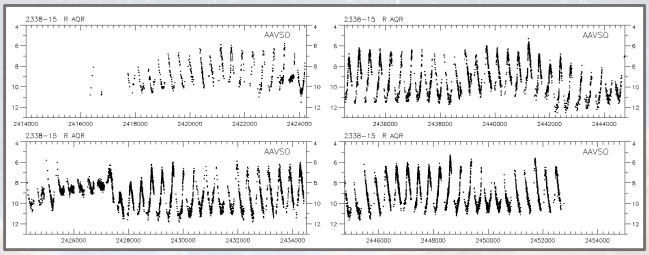


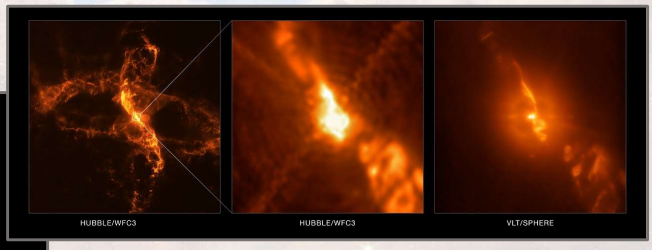
Introductory
https://www.aavso.org/vsots_rhya
https://www.spitzer.caltech.edu/image/sig06-029-red-giant-plunging-through-space

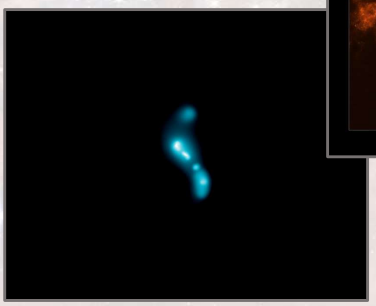
Advanced
https://arxiv.org/abs/astro-ph/0203328
https://arxiv.org/abs/astro-ph/0607303

R Aquarii

- Symbiotic binary system
  - Mira variable red giant + white dwarf
  - 44 year orbit





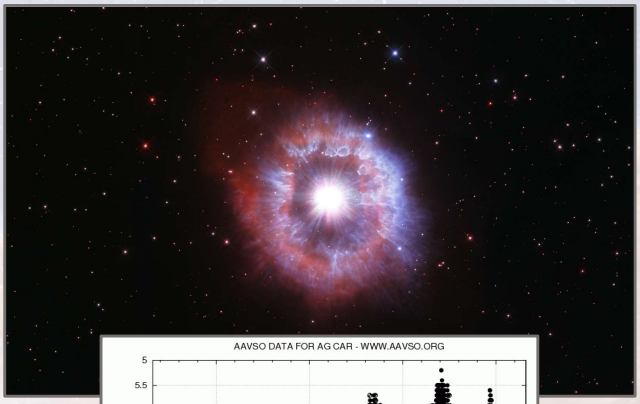


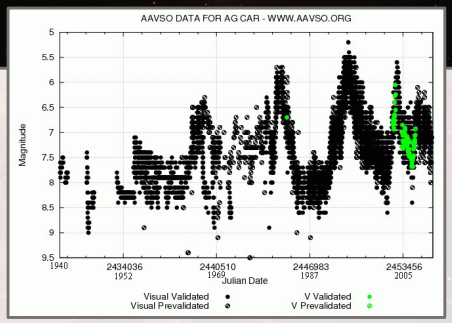
Introductory
https://www.aavso.org/vsots_raqr
https://chandra.harvard.edu/photo/2017/raqr/
https://apod.nasa.gov/apod/ap960104.html
https://www.eso.org/public/news/eso1840/

Advanced
https://arxiv.org/abs/1703.05624

AG Carinae

- Luminous blue variable (LBV)
  - Transitional stage between O type main sequence and Wolf-Rayet star
  - Exhibits S Dor variability
  - Large outbursts eject stellar material to form surrounding nebula



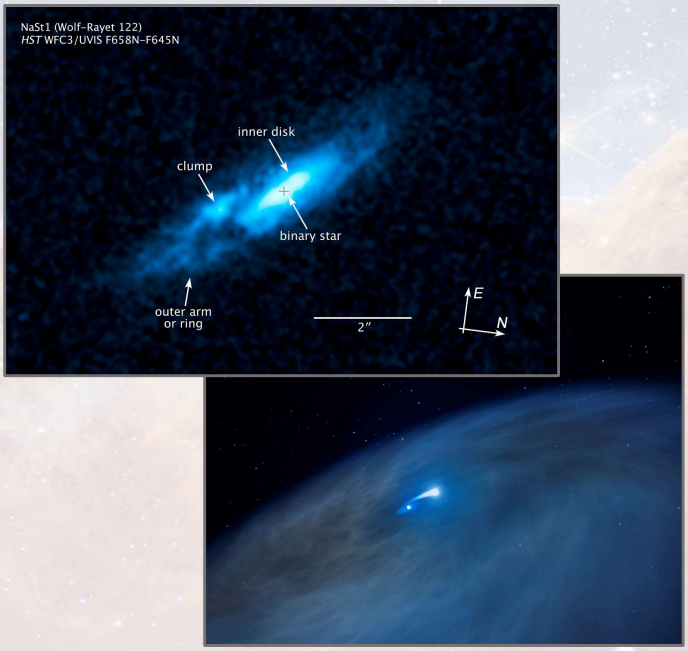


Introductory
https://hubblesite.org/contents/news-releases/2021/news-2021-017
https://esahubble.org/images/potw1439a/

Advanced
https://arxiv.org/abs/0904.2363
https://arxiv.org/abs/2009.03144
https://arxiv.org/abs/astro-ph/0512372

NaSt1

- Wolf-Rayet star
  - Surrounded by a pancake-shaped disk of gas, nearly 2 trillion miles in diameter
  - Evidence of binary system
- Recent observation of 310-day photometric period
  - Potentially be the orbital period of the system



Introductory
https://www.nasa.gov/feature/hubble-observes-one-of-a-kind-star-nicknamed-nasty
https://esahubble.org/images/opo1521c/

Advanced
https://arxiv.org/abs/1502.01794
https://arxiv.org/abs/2103.08771

HD 184738 (Campbell's Hydrogen Star)

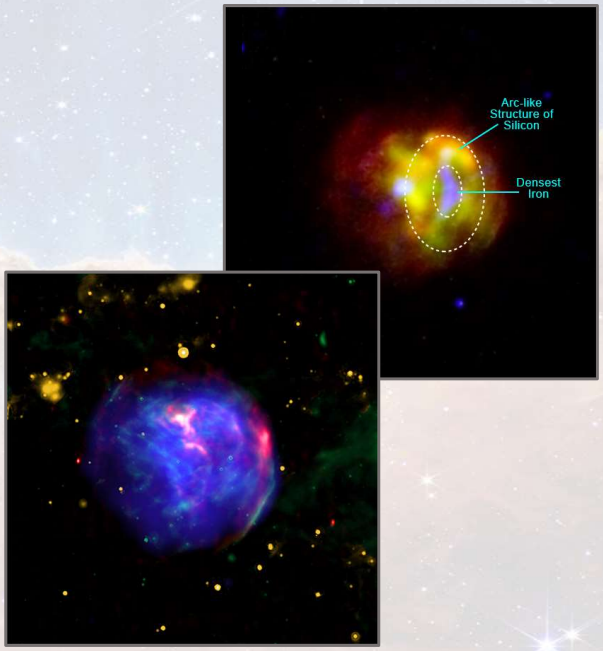
- WC Wolf-Rayet star
  - Wolf-Rayet stars subdivided into WN, WC, and WO stars
  - Classification dependent on strong, broad emission lines of Helium, Nitrogen, Carbon, and Oxygen
- Steady ejection of material
  - Formed a small planetary nebula around the star

Introductory
https://esahubble.org/images/potw1337a/
https://chandra.harvard.edu/photo/2000/pne/
https://observatory.astro.utah.edu/about.html

Advanced
https://iopscience.iop.org/article/10.1086/317335
https://www.annualreviews.org/doi/abs/10.1146/annurev.astro.45.051806.110615

G344.7-0.1

- Type Ia supernova
  - White dwarf progenitor
- Trove of knowledge from x-rays
  - X-rays formed through a reverse shock wave
  - Measured composition and distribution of “heavy” elements

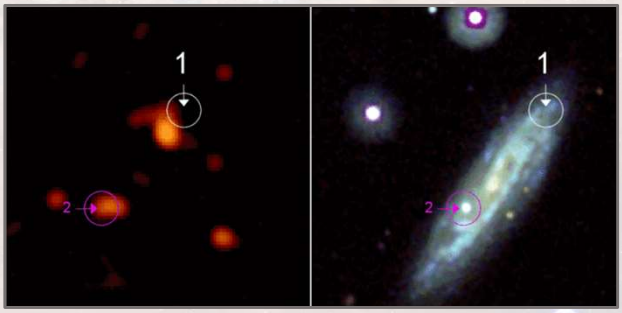


Introductory
https://chandra.harvard.edu/photo/2021/g344/

Advanced
https://arxiv.org/abs/2005.09664
https://www.aanda.org/articles/aa/abs/2011/07/aa16768-11/aa16768-11.html

SN 2008D

- Type Ibc supernova
  - First time a supernova has been observed from its beginning
  - First detected by Swift
- Occurred in the spiral galaxy NGC 2770



Introductory
https://chandra.harvard.edu/photo/2008/sn2008d/index.html
https://www.nasa.gov/centers/goddard/news/topstory/2008/swift_supernova.html

Advanced
https://arxiv.org/abs/0802.1712

E0102-72.3

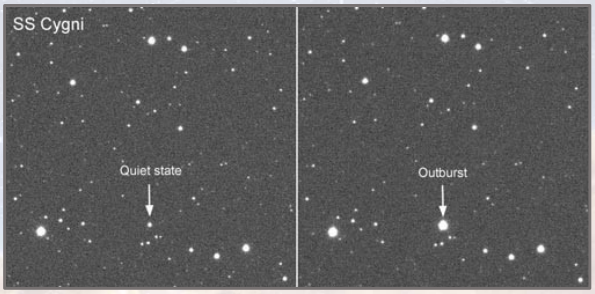
- Type IIb supernova
- SNR structure
  - Outer X-ray shock wave
  - Slower moving inner ring of gas
  - Central X-ray source
- Central object likely an unusual neutron star
  - First found outside the Milky Way

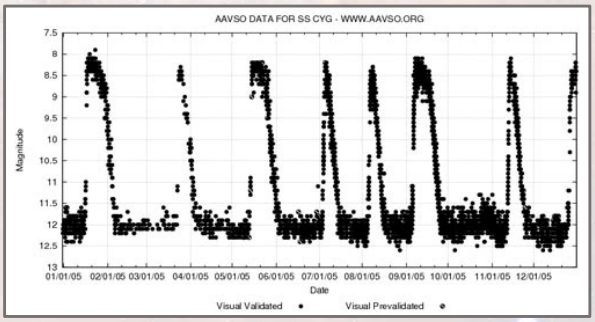
Introductory
https://chandra.harvard.edu/photo/2018/e0102/
https://esahubble.org/news/heic2102/
https://www.spitzer.caltech.edu/image/sig06-016-dusty-death-of-a-massive-star

Advanced
https://arxiv.org/abs/1803.01006
https://arxiv.org/abs/2101.05288

SS Cygni

- Dwarf nova
  - Close binary system with a white dwarf and a red dwarf
- Observed over last 126 years
  - Regular outbursts: wide, narrow, and occasional anomalous ones



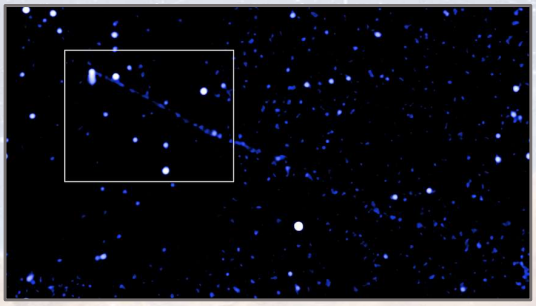


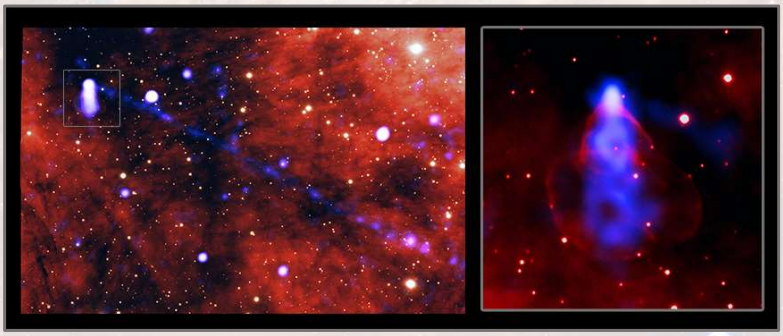
Introductory
https://www.aavso.org/vsots_sscyg
https://skyandtelescope.org/astronomy-news/observing-news/meet-variable-friend-ss-cygni-09102014/

Advanced
https://iopscience.iop.org/article/10.1086/133689

PSR J2030+4415

- Gamma-ray pulsar
- Extremely long filament
  - Made from matter and antimatter
  - Formed due to a stalled bow shock causing a particle leak



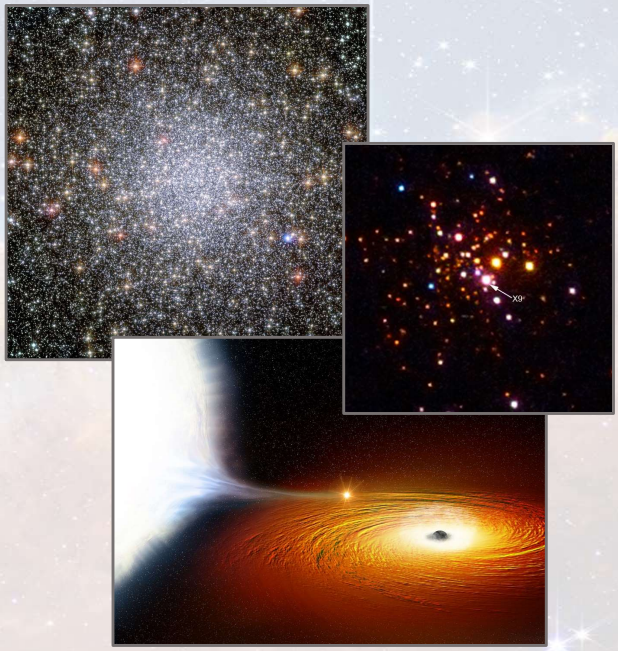


Introductory
https://chandra.harvard.edu/photo/2022/j2030/

Advanced
https://arxiv.org/abs/2202.03506
https://arxiv.org/abs/2005.13572

47 Tucanae & X9

- Globular cluster
  - Old, low mass stars
  - Many RR Lyrae
  - Hundreds of X-ray sources
- X9 is an X-ray source
  - Low mass X-ray binary (LMXB)
    - Black hole or neutron star primary
    - White dwarf secondary
  - Extremely short orbit of 28 minutes!

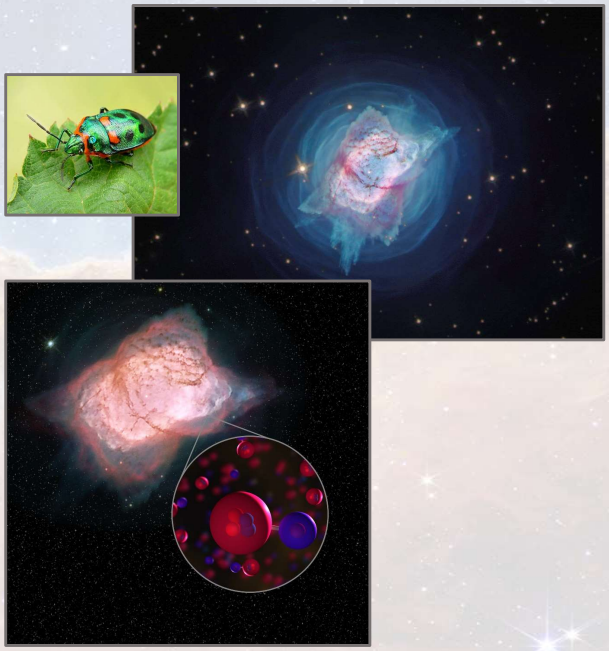


Introductory
https://chandra.harvard.edu/photo/2017/47tuc/
https://www.space.com/3051-mass-migration-stars-move-crowd.html

Advanced
https://arxiv.org/abs/1702.02167
https://arxiv.org/abs/astro-ph/0607597

NGC 7027

- Young planetary nebula
  - 600 years old
  - 4-cornered rectangular shape
- Central object unknown
- First time helium hydride has been observed in space

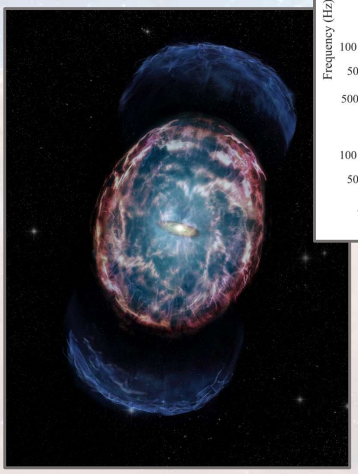


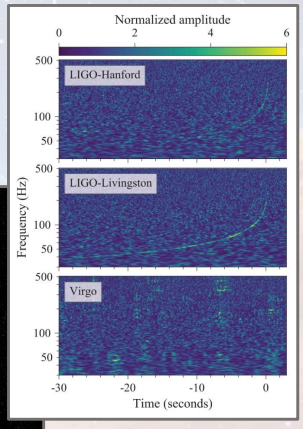
Introductory
https://apod.nasa.gov/apod/ap180109.html
https://www.nasa.gov/feature/the-universe-s-first-type-of-molecule-is-found-at-last
https://hubblesite.org/contents/news-releases/2020/news-2020-31

Advanced
https://arxiv.org/abs/1904.09581
https://www.mdpi.com/2075-4434/8/2/49
https://arxiv.org/abs/astro-ph/0102468

GW 170817

- Gravitational wave event
  - Produced from the merger of two neutron stars
- First multi-messenger event
  - LIGO gravitational wave detection
  - Fermi gamma ray burst detection
  - Also followed by ESA's INTEGRAL satellite, NASA's Swift, Hubble, Chandra, and Spitzer
- 3.5 years later
  - "Kilonova afterglow" or black hole accretion

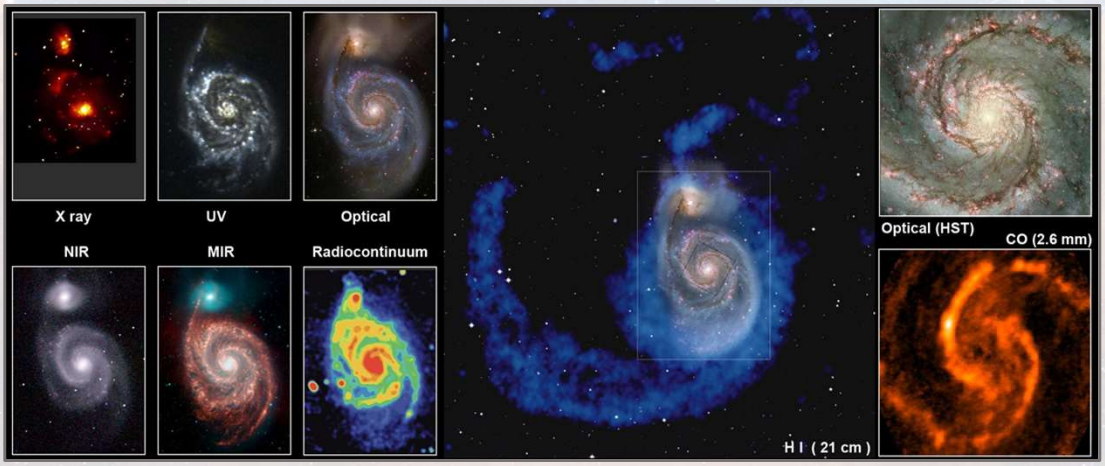




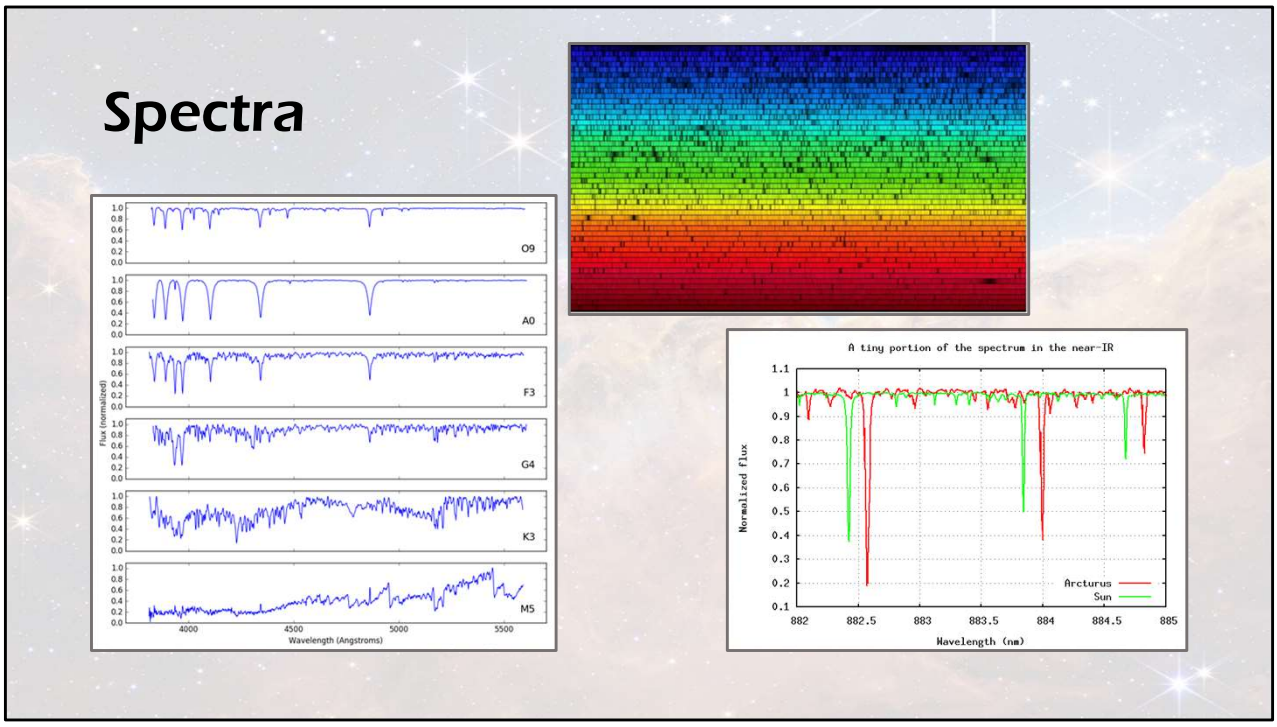
Introductory
https://www.youtube.com/watch?v=txpIT0PW02E
https://chandra.harvard.edu/photo/2022/gw170817/
https://www.ligo.caltech.edu/page/press-release-gw170817
https://www.science.org/content/article/merging-neutron-stars-generate-gravitational-waves-and-celestial-light-show

Advanced
https://arxiv.org/abs/2104.02070
https://iopscience.iop.org/article/10.3847/2041-8213/aa920c

Multi-Wavelength Observations

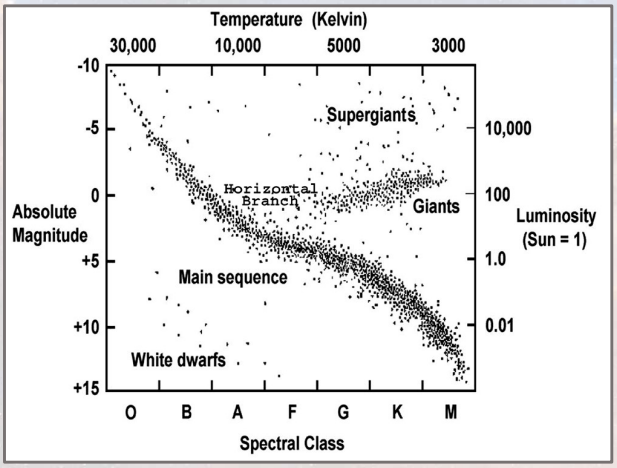


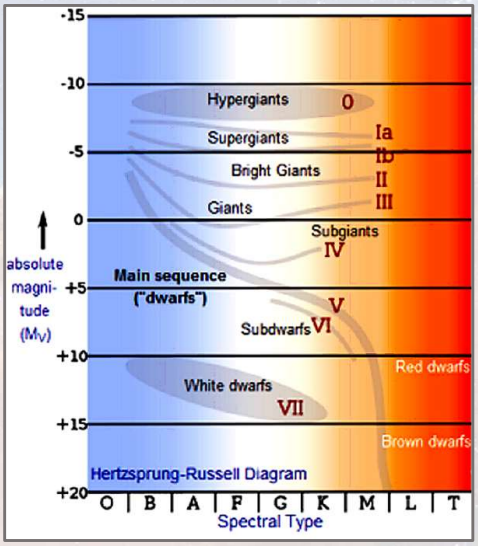
Multi-Wavelength Observations
http://www.atnf.csiro.au/people/lop009/multiwave.html



Spectra
http://spiff.rit.edu/classes/phys230/lectures/spec_interp/spec_interp.html
http://star-www.st-and.ac.uk/~spd3/Teaching/PHYS1002/phys1002_lecture4.pdf
http://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectra_astro_types.html
http://spiff.rit.edu/classes/phys301/lectures/doppler/doppler.html

H-R Diagram

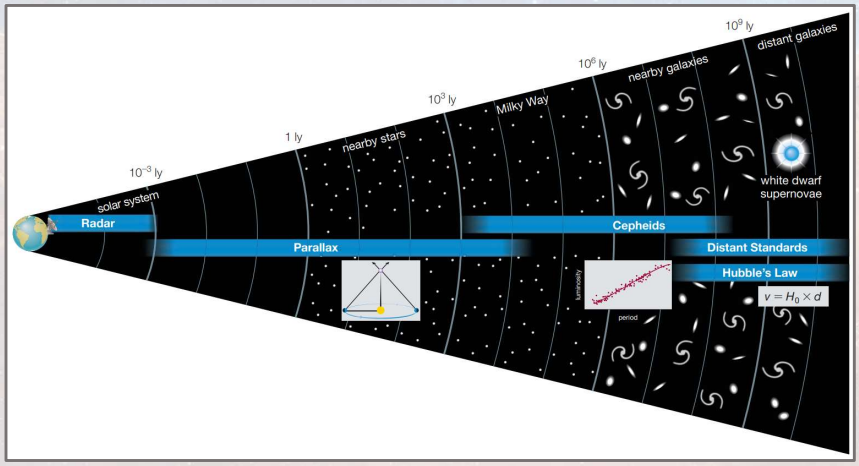




H-R Diagram
https://chandra.harvard.edu/edu/formal/variable_stars/bg_info.html
https://astronomy.swin.edu.au/cosmos/h/hertzsprung-russell+diagram
https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram

Stellar Evolution
https://chandra.harvard.edu/edu/formal/stellar_ev/story/

Cosmic Distance Ladder



Cosmic Distance Ladder

Bennett, J. O., Donahue, M. O., Schneider, N., & Voit, M. (2017). *The essential cosmic perspective* (8th ed.). Pearson.

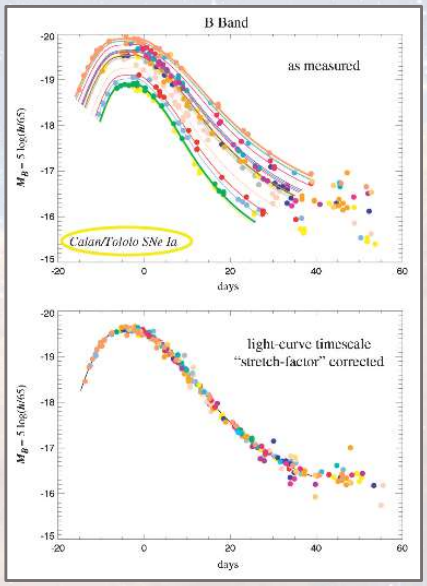
https://www.uwa.edu.au/science/-/media/Faculties/Science/Docs/Explanation-of-the-cosmic-distance-ladder.pdf

http://spiff.rit.edu/classes/phys443/lectures/parallax/parallax.html

http://spiff.rit.edu/classes/phys443/lectures/lmc/lmc.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
  - However…
  - Slow mass transfer from binary companion, known mass
  - Merger with another white dwarf, unknown mass



Type Ia Supernovae
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

Basic Equations & Relationships

Distance Modulus:

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

Type Ia supernova: $M \approx -19.6$

Parallax: $d = \frac{1}{p}$

Angular Diameter: $d = \frac{pD}{206{,}265}$

(in arcsec)

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

Astronomical Units:

1 degree = 60 arcmin = 3600 arcsec

1 pc = 3.26 ly = 206,265 AU = 3.08×10^{16} m

https://astronomy.swin.edu.au/cosmos/d/Distance+Modulus

Radiation Laws

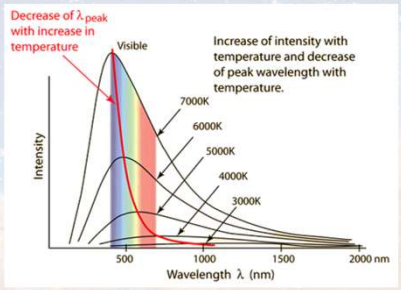
Blackbody radiation follows **Planck's Law**

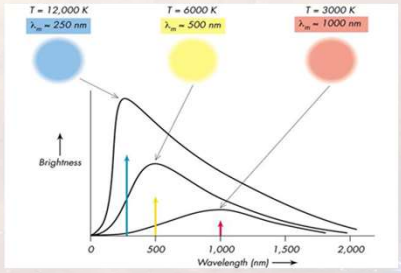
Wien's Law: $\lambda_{\max} = \frac{2.9\times10^{6}\ \mathrm{nm\cdot K}}{T}$

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

$$\sigma = 5.67 \times 10^{-8}\ \frac{\mathrm{W}}{\mathrm{m^2\cdot K^4}}$$

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:

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

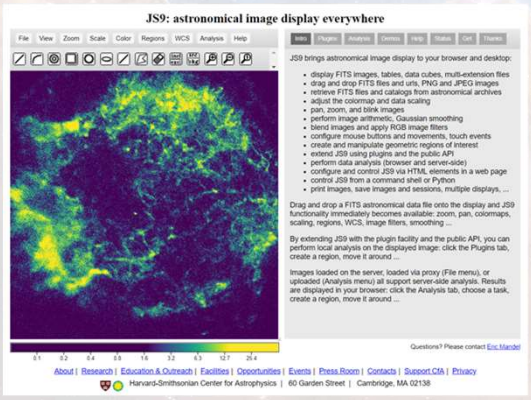
$a = \frac{v}{t}$

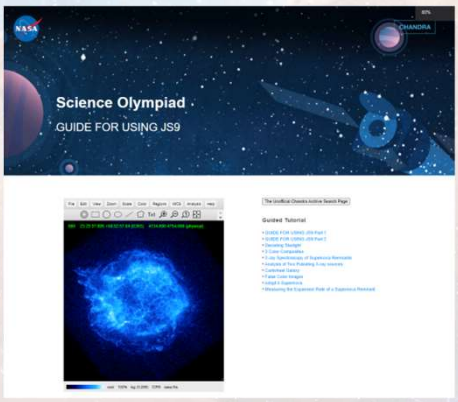
$P = \frac{2\pi r}{v}$

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

JS9

https://js9.si.edu/ https://chandra.harvard.edu/js9/index.html





https://js9.si.edu/
https://chandra.harvard.edu/js9/index.html

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 Events

Preparation Best Practices

1. Read the Event Description for content and allowable resources.
2. Use this webinar and its attached PowerPoint 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.
5. Invitationals.
6. Tests from invitationals will be posted on the NSO and Chandra website for teams to use for practice.

Robert's Tips & Tricks

1. Read the Wikipedia article on each of the topics listed in the rules.
2. Use introductory astronomy college courses or textbooks.
3. Get started early on DSO research.
4. Keep your DSO notes (and all notes in general) organized.
5. About reading scientific papers. Most useful parts: abstract, introduction, figures. Don't worry if you don't understand everything!
6. Spend time to really get to know how to use the formulas and what they mean.
7. Take lots of practice tests!