Science Olympiad Astronomy Event (2018)

Slide 1:

This presentation is an overview of the content and resources for the National Science Olympiad (NSO) Division C 2018 Astronomy Event. The NSO 2018 national competition will be held at Colorado State University in Fort Collins, CO on May 18th -19th. One of the deep sky objects is SN 1987A – 2017 was the 30th anniversary of this supernova event.

Slide 2:

My name is Donna Young, and I work with NASA’s Universe of Learning network. The NASA Astrophysics Universe of Learning network supports the National Science Olympiad space science events. The Chandra X-Ray Observatory website has several educational products designed for Science Olympiad team members to learn about stellar evolution, including this webinar.

Slide 3:

The recommended resources for this event will be discussed at the end of the presentation. This Webinar and transcript will be posted on the Chandra X-Ray Observatory website at <http://chandra.harvard.edu/edu/olympiad.html> and the accompanying PowerPoint slides will be posted and available for download from the National Science Olympiad website. The PowerPoint slide set also has a notes section with links to websites with information pertaining to the content for each slide.

Slide 4:

The Astronomy event content focus for 2018 is stellar evolution and Type II supernovas. Each team is permitted to bring two computers (tablets and iPads acceptable), two 3-ring binders or one computer and one 3-ring binder. Internet access is not allowed.

Slide 5:

The event description for the 2018 competition includes the most important properties and characteristics related to the evolution of massive stars. The motions of binary systems are important as Type II events occur in binary systems. Hubble’s law is included as the Cepheid stage through which some massive stars transition is used to calculate distances in the universe. The16 deep sky objects (DSOs) listed are all related to important stages of evolution involving Type II supernovas.

Slide 6:

This slide arranges the 16 deep sky objects into categories: 2 star formation regions, 4 massive stars, 5 Type II supernovas, 3 pulsars, and 2 binary systems.

Slide 7:

This stellar evolution graphic shows the basic transitions from protostar to final objects based on stellar masses. A 13-page introduction to stellar evolution is posted on the Chandra X-Ray Observatory website at <http://chandra.harvard.edu/edu/formal/stellar_ev/story/> and page 9 is the beginning of the description of the transitional sequences associated with massive stars. The sequences within the white box result in Type II supernovas with stellar cores that range from neutron stars, magnetars and pulsars to black holes. The yellow arrow indicates the SN 1987A supernova event.

Slide 8:

The H-R diagram is a plot of the temperature and luminosity of a star and it is similar to the periodic table of the elements. In chemistry, if you understand the periodic table, you know everything there is to know about any element. Somebody can discover an unknown element, place it on the periodic table and you know everything about it: mass, radius, number of energy levels, how many electrons in the outer energy level, if it easily gives up electrons or accepts electrons, if it forms covalent or ionic bonds, if it is a metal or a nonmetal. The H-R diagram is the same thing. Once the temperature (stellar classification) and absolute magnitude (luminosity) of a star is plotted, you know the age, mass, composition, and evolutionary history of the star. Absolute magnitude is the intrinsic brightness of the star and luminosity is how much power the star is emitting relative to the Sun. The sun is arbitrarily assigned the value of one solar luminosity and other stellar luminosities are relative to the luminosity of the Sun. The sun’s position on the H-R diagram it is plotted at one solar luminosity and ~6000K, which corresponds to a G2 stellar classification. This diagram is a cartoon, a simplified version of the H-R diagram. Stars are more diverse and complicated than this diagram would lead you to believe. For instance, there are many more stellar classes than OBAFGKM; however for simplicity’s sake, only the classes that contain a large majority are shown. Absolute magnitude – the intrinsic brightness of stars – is similar to the pH scale, as it is a logarithmic scale. If all the stars in the sky were placed in a row at the same distance of 10 parsecs, then our Sun would be a +5 in absolute magnitude. The faintest stars you can see in the night sky are +6 in absolute magnitude, so the Sun is not a very bright star overall. Most H-R diagrams have magnitude labels that range from the brightest (-10) at the top of the scale to the dimmest (+15) at the bottom of the scale. The lower left quadrant of the diagram contains hot and dim stars; the upper left quadrant shows hot and bright stars, the upper right quadrant cool and bright, and the lower right quadrant cool and dim. The major branches (locations) of stars are: main sequence, white dwarfs, supergiants, and giants. There are other regions where stars reside on the H-R diagram when they are transitioning from one branch to another as they evolve. Some of those regions will be discussed later on.

Slide 9:

NGC 6357 is a star formation region 6500 light years away near the tail of the constellation Scorpius. The first image is a close up of the region from a ground-based observation. The second image (NASA, ESA & IAA) is a close up of the star cluster Pismis 24 which contains some of the most massive stars known in the galaxy – many nearly 100 times more massive than the Sun – with the brightest star above the gas 200 times more massive than the Sun! The third image is an optical image from the ESO VLT telescope. This image has a zoomable version that contains ~ two billion pixels – one of the largest ever released.

Slide 10:

This slides shows NGC 6357 in optical (SuperCosmos Sky Survey from the UK), Infrared (Spitzer) and X-ray (Chandra and ROSAT) and a composite image merging all three wavelength observational data.

Slide 11:

This image of NGC 7822 is an observation from a ground based telescope. This star formation region is 3000 light years away in the constellation of Cepheus. The HII region, bordered by cold molecular clouds of gas and dust, contains hot new stars that are producing powerful radiation and winds that form the columns and pillars. Many potential protostars within the pillars of gas and dust will be destroyed by the intense radiation. The second image is a close up from another ground based telescope observation. The third image is an IR observation from NASA’s WISE satellite.

Slide 12:

The ESO’s VLT Digitized Sky Survey 2 discovered HR 7151A – the largest yellow hypergiant detected to date. Hypergiants are among the largest stars in the universe with enormous mass and luminosity and unstable with an extremely high rate of mass loss. They have extended atmospheres and initially had a mass of 20-60 solar masses before losing as much as half of that mass and have an incredibly short lifespan. Only 8 have been detected in the Milky Way Galaxy. HR 7151A has a companion so close it is a contact binary system – the companion is 2.8 AU away and eclipses the primary star every 1300 days. The distance from center to center of the two stars is 10 AU. (AKA HD 119796, HIP 67261, V766 Centauri). Future – LBV? Wolf-Rayet? – followed by supernova event.

Slide 13:

AG Carinae (AKA AG Car, HIP53461, and HD94910) is a luminous blue variable (LBV) star which is losing mass at a phenomenal rate – the 7 x 106 km/hr winds have cleared the region surrounding the star. The bright glare in the center is not the star and the white cross is an artifact of Hubble’s Wide Field and Planetary Camera 2. The second radio image shows the nebula of material ejected from the star about 10,000 years ago – approximately 15% of its mass. AG Car is in a transitional state between LBV and Wolf-Rayet star. The third image is a Hubble observation showing the sculpting of the ejecta from the extensive stellar winds from the star. The light curve shows the instability of AG Car from January 1940 to November 2010.

Slide 14:

S Doradus (S Dor) is the prototype for the S Doradus class of variable stars – also known as LBVs. It is one of the brightest stars known and the brightest star in the Large Magellanic Cloud

(LMC). Like all other LBVs, S Doradus is extremely massive and luminous and has an intense stellar wind blowing away significant portions of its mass. Current observations of S Dor show its optical spectrum currently resembles an F-type supergiant – as cool as an LBV can get. The second image is the S Doradus instability strip region of the H-R diagram which shows the maximum and minimum outbursts of S Doradus and AG Car.

Slide 15:

The light curve at the top of this slide shows the behavior of S Doradus from 1988 to 2016, and the light curve below is a zoom in of the years from 2012 to 2016.

Slide 16:

This Hubble image of the Orion Constellation Shows the reddish colored red supergiant star Alpha Orionis (AKA Betelgeuse). The second image is a mid-infrared image taken by the ESO VLT. This image shows an enormous nebula of gas and dust 400 AU in diameter that Alpha Ori has been shedding. The star itself is only 4.5 AU in diameter. The third image in the near-infrared (ESO VLT) shows a huge plume of material being ejected from the surface. The plume is ~30 AU in length. The next image is a UV image (Hubble/NASA/ESA) showing the pulsations of Alpha Orionis which is a semiregular pulsating variable. The next image is a reconstruction of several IR interferometry observations and shows two large and hot convection cells. The final image is a light curve that shows the semiregular behavior of Alpha Ori.

Slide 17:

RCW 103 is a Type II supernova remnant. The first images show the remnant in X-ray, optical and an X-ray/optical composite. This unusual object has been observed by multiple telescopes – including Hubble, SWIFT, Chandra, Einstein and XMM-Newton. The compact central object exhibits very bizarre behavior as observed by XMM-Newton, SWIFT and Chandra. The stellar core is the slowest spinning neutron star ever detected – rotating once every 6.5 hours compared to several times a minute for other neutron stars. The observational data leads to the conclusion that the object is a magnetar – a neutron star with an extremely strong magnetic field.

Slide 18:

SN W49B may have the Milky Way Galaxy’s youngest black hole in the center. The images show W 49B in X-ray (Chandra), Radio (VLA), IR (Palomar) and as a composite of the three wavelengths. The next earlier image is a composite of Chandra X-ray and Palomar IR observational data. The flattened ends of the X-ray jets rich in iron and nickel produced during the collapse are produced by the jets ramming into a dense cloud of gas and dust. It is an ejecta dominated remnant with evidence of a stratified distribution of elements. (Iron in the central regions and silicon & sulfur in the outer regions) The detection of a jet and the non-detection of a neutron star make W49B a candidate for a gamma-ray burst remnant with a black hole.

Slide 19:

The Jellyfish Nebula – IC 443 – is a supernova remnant in the direction of the constellation Gemini. The first image is from an astrophotographer, Paul C. Swift, who uses “basic equipment and a modest home observatory”. The wide-field optical astrophotograph provided by B. Franke at the Focal Pointe Observatory is used in the next image to show the location of the stellar core from Chandra data. Chandra X-ray data & optical data from the Digitized Sky Survey show an image of IC 443 in the box on the upper right. Earlier observations combining X-ray and radio

data show the neutron star stellar core, however it is not aligned with the direction towards the apparent center of the remnant. Recent Chandra observations again show the misalignment of the pulsar – called JO617 – from the center of the remnant so maybe the pulsar is not associated with IC 443, or maybe there is movement towards the left of the materials in the remnant pushing JO617’s cometary tail to one side.

Slide 20:

SN 1987A, discovered on February 23, 1987 in the Large Magellanic Cloud, provided the opportunity to study the entire sequence of phases before, during and after the collapse of a massive star. A dense ring of gas surrounding the supernova around 20,000 years before the collapse is the diameter of one LY and glows in optical light. The central structure is half a LY in diameter and two clumps of debris in the center are moving away from each other at 20 x 106 MPH. An expanding ring of X-ray emission became steadily brighter as the shock wave from the collapse moved through the ring of gas surrounding the supernova until 2013 and since then has remained constant. This is evidence that the shock wave has moved through and beyond the ring of gas into a less dense gas region. The collapse of the progenitor star has created vast amounts of dust. When the supernova occurred, a flash of neutrinos was detected so it is thought that a compact object formed at the center – either a neutron star or a black hole. So far there is no evidence of this object.

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ASASSn-15lh is 3 x 109 LY distant and produced twice the power of any previously known supernova event. The mystery of ASASSn-15hl is that three months after the light started dimming, even though optical radiation continued to fade, the UV radiation increased fivefold where it remained for two months before once again starting to fade. This supernova and a few others are not thought to have enough radioactive nickel to explain the amount of energy coming from the event. If the shock wave from collapse ran into nearby gas it would produce a specific set of emission lines that are absent from ASASS-15lh. Strong emission lines would also be present if the shock wave was interacting with its own ejecta. The most reasonable explanation is that the core is a magnetar – a neutron star with a magnetic field 100 x109 stronger than the Sun. This explanation barely holds together as it does not really explain the resurgence of the UV emissions. The nature of the stellar core remains a puzzle.

Slide 22:

Geminga was the first unidentified gamma-ray source. Geminga & PSR BO355+54 are pulsars with very different shapes and structures. Some pulsars generate pulsar wind nebulas of high energy particles. The shapes of these pulsar wind nebulas (PWNs) may explain the presence or absence of radio and gamma-ray pulses. The observational data is a combination of Chandra X-ray data (blue and purple) and Spitzer infrared data. Both pulsars rotate 5 times/second and are 500,000 years old. Geminga has gamma-ray pulses with no bright radio emissions and BO355+54 is one of the brightest radio pulsar known but is not observable in gamma rays. The illustrations show the torus structures and jets as they are crushed and swept back as the pulsar move through space. A study of the orientation of the donut-shaped disk and jets demonstrates why the radio emissions from Geminga and the gamma-ray emissions from B0355+54 are orientated away from our line of sight and therefore not visible.

Slide 23:

M82 X-2 is an ultraluminous X-ray source (ULX) located in the galaxy M82 12 x 106 LY away. It is a pulsar that rotates every 1.37 seconds and revolves around a ~5.2 solar mass companion star in a binary system. It was thought to be a black hole but is the brightest pulsar ever recorded. The composite image includes X-rays from NuSTAR (purple) and Chandra (blue) and optical from NOAO (gold). NuSTAR detected pulsations which are associated with pulsar and the Chandra data helped determine the exact source of the pulsations and therefore the location of the pulsar.

Slide 24:

Circinus X-1 is an X-ray binary system consisting of a neutron star and a massive companion. Clouds of gas and dust form four rings around Circinus. Bursts of X-rays from the neutron star bounce off the rings of gas and dust producing light echoes. The composite image includes X-ray energies with optical from the Digitized Sky Survey. The Chandra X-ray light echo data combined with radio data from Australia were used to measure the distance to Circinus X-1. The resulting measurement of 30,700 LY settled previous measurements that placed it twice as far away as thought. The difficulty now arises that if it is twice as far away its energy output is twice as much as thought which leads to the implication that the system has exceeded the Eddington Limit – the balance between gravity in and radiation pressure out. It is thought that this limit can only be exceeded by black holes – not neutron stars. The extreme velocity of the high-energy particles produced by the system are at least 99.9% the speed of light – again usually associated with black holes. The graphic shows how the geometry of the light echoes are used to measure the distance to the system.

Slide 25:

DEM L241 is an HII region located in the Large Magellanic Cloud. The Chandra X-Ray data in purple shows the location of the supernova remnant. The yellow and Cyan from the MCLS telescope in Chili traces the HII emission from DEM L241. The white is additional optical data from the Digitized Sky Survey. The observational data shows an X-ray point likely to be a neutron star or black hole and a massive star which survived the catastrophic collapse of its companion. The composition of the remnant and presence of the massive star imply that the progenitor star was between 25 and 40 solar masses. If these results hold up, this is only the third system containing both a massive star and a neutron star or black hole found in the aftermath of a supernova.

Slide 26:

Massive star transitions on the H-R diagram include Cepheid variables, blue luminous variables (BLVs) and semiregular variables. These regions of instability are where stars reside when they are transitioning from one branch to another as they evolve through their evolutionary stages. The Cepheid Instability Strip contains massive Cepheid variable stars that are evolving horizontally from the main sequence to the supergiant branch. The Semiregular Instability Strip is the region where the most massive stars are transitioning from the main sequence to the supergiant branch – all these stars will eventually undergo supernova events. A plot the change in the brightness of a star over time is called a light curve, and light curves are unique for each specific type of variability. Observing and plotting light curves of variable stars produce distinctive shapes. When the resulting shape resembles one of these classes of variable you have a lot of information about the evolution and behavior of the star. Most of the light curves have JD (Julian Day) on as the unit of time on the X-axis. This is starting to change and sometimes light curves use days, weeks or years as the unit of time instead of Julian Day. Julian Day is the number of days that has passed since January 1, 4713 BC. Noontime (today) is Julian Day 2,456,542. JD begins at noon time – universal time – and .041667 is the fraction of time that has

passed since noon time. Cepheid light curves show a very periodic pulsation and the semiregular light curve shows the behavior of red supergiants. The light curve in the upper left shows the behavior of luminous blue variable (LBV) stars, which includes the S Doradus variables. S Doradus variables differ from the more general luminous blue variable classification. S Doradus variables do not just vary up and down erratically – every now and then they have a major event and eject huge amounts of material and then settle back down to their usual erratic variability.

Slide 27:

There are several methods used to determine distances in the universe. For example, cosmological distances can be calculated using the distance modulus, an equation that expresses the relationship among apparent magnitude (m), absolute magnitude (M) and distance (d). Distances to nearby galaxies can also be calculated using Cepheid variable stars. The most distance objects are measured using Hubble’s law.

Slide 28:

This image shows V1 – the first Cepheid variable used by Hubble to calculate the distance to M31 and showed that those little spiral nebulas were outside the MWG and the universe became a very large place! The period of a Cepheid variable can be calculated using its light curve – the plot of the change in brightness over time. The period can then be used to apply the period-luminosity relationship which gives the luminosity. Since there is a relationship between luminosity and absolute magnitude, the absolute magnitude can be determined and used with the distance modulus to calculate the distance to the Cepheid variable star.

Slide 29:

Hubble’s law shows a direct correlation between the distance to a galaxy and its recessional velocity. The Hubble constant is thought to be 70km/s/Mpc though it has changed several times over the years. The relationship is determined by measuring the red shift of galaxies and the further away a galaxy the faster it is receding from us. No matter where in the universe you are located, you would see the same effect – all galaxies are receding from your location.

Slide 30:

The spectrum in the lower right corner is the optical portion only of the total radiation produced by the Sun. There are several absorption lines – which show the elemental composition of the Sun. The typical spectral images shown in textbooks are gross cartoons of a stars total emission. The two spectra at the top – the image to the left and the corresponding plot to the right is a WN – Wolf-Rayet emission spectra showing the broad nitrogen emission line. The other images show spectral plots – wavy lines with dips to show where absorption is happening. Stars are classified by their spectra – and their spectral classification depends on their temperature. Spectral plots are more useful than images for scientific measurements. Hydrogen Balmer lines and the Fraunhoffer lines from other elements are used for classification and each stellar temperature has a unique set of absorption spectra.

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The stellar radiation laws and blackbody radiation have been a part of every past Astronomy event as they explain basic physical properties fundamental to all stars. A blackbody is an artificial construct that absorbs all radiation it receives and then emits it all away – everything that comes in goes out. Stellar atmospheres are very good approximations of blackbody radiators, absorbing radiation produced by the core and emitting it out into the interstellar medium. The hotter the star the more energy it emits at every single wavelength than a cooler star. The graphic shows a 12,000K star, a 6,000K star and a 3,000K star and nowhere does the 3,000K star emit more radiation at any wavelength than the two hotter stars. That principle is called Planck’s Law. Wien’s Law states the maximum radiation that comes from any star or blackbody has a peak with a specific temperature and corresponding wavelength. The mathematical relationship is used to determine the temperature and/or wavelength of stellar objects. The Stefan-Boltzmann Law shows that the area beneath the curve is equal to the total power of the star and is related to the temperature and area of the star.

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It is important to be able to recognize the deep sky objects as they have been observed across the electromagnetic spectrum. Each band of the spectrum – Radio, IR, Optical, UV, X-ray, and Gamma – is produced by a different process. Some DSOs emit mostly X-ray radiation and can barely be detected in other wavelengths. Stars and other objects look very different when imaged in different parts of the spectrum and teams should be familiar with images of the DSOs in all wavelengths. W49B and NGC 6357 are shown as two examples.

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The radiation laws and the basic mathematical relationships and equations shown on this slide are the most important for answering the problem sets in this event.

Slide 34:

The National Science Olympiad (NSO) is an excellent resource for materials and resources for the 2017 Astronomy competition. The Astronomy Coach’s Manual is available from the NSO store, as well as links to this webinar and accompanying transcript for teams, coaches and event supervisors. The PowerPoint slide set used for the webinar will also be posted on the NSO website; the slides have notes attached with links to sites that describe the content of each slide. State directors and organizers of invitational competitions can request sample events for invitational, regional and state competitions. Some invitational tests will be posted on the NSO website after the competitions are over so all teams can use them to prepare for competition. Former astronomy competitors are invited to write questions for the astronomy test bank.

Slide 35:

The Chandra educational classroom ready materials website at <http://chandra.harvard.edu/edu/formal/index.html> includes a complete introduction to stellar evolution as well as several activities and investigations such as card sets, self-guided tutorials, web quests and flash versions of the content.

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A new card set has been developed to use as a sequencing activity for teams to learn the stages of stellar evolution. An introduction to the set is located at <http://chandra.harvard.edu/edu/formal/stellar_ev/imageset_introduction.html> and coaches can request a set of the cards on heavy card stock to use with their teams. A set of flash cards will also be made available in a PPT format that coaches can download and use that will contain the specific DSO’s that are part of this year’s NSO Astronomy competition. (A set will also be available for the Reach for the Stars event. These will be located on the NSO website.

Slide 37:

The Ds9 has image analysis software that is listed as a resource is being transitioned to a new format called Js9 – it is browser based with embedded web pages and will work on any mobile device such as iPads, tablets and smart phones. This will make this software more user friendly than having to download a toolbox onto a computer. There is a small chance that a question that utilizes Js9 may appear on the 2017 competition using screen shots; however, it is still in a beta version and will not be used in a serious sense until it has been further developed. I would suggest just looking at <http://js9.si.edu/> and playing around with what has been made public so far. Any questions on test would not need prior knowledge of js9.

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The resources listed with the event description are sufficient to prepare for competition. Always check out the resources on the NSO website. The Astronomy Picture of the Day (APOD) website is a good place to search and collect images. Search the APOD archive for the DSO’s, and the first page of images will show images in all wavelengths. The Chandra website has a variety of excellent stellar evolution materials and resources to help learn about stellar evolution, and the webinars are posted under the Education Menu. The Chandra, Hubble, NRAO and Spitzer websites are also valuable resources. The PowerPoint presentations for the webinars are posted on the NSO website with links to the webinars (Astronomy and Reach for the Stars) on the Chandra website along with transcripts for the webinars.

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Follow these suggestions to prepare for competition. Teams that have questions about the event description should access the rules clarification link on the NSO website. This is the place to post questions about clarification issues – the event description and/or resources. Before you post your question check to see if someone has already asked that question and it has been answered. If no one has posted that question yet, then post it and you will be sent an answer. This way if more than one team has the same question, then the answer is already posted when they access the website. Event supervisors are not allowed to answer individual questions. Use the Astronomy Coaches Manuel, the webinar and PowerPoint for content, and the resources listed in the event description for information. The PowerPoint slides have links to sites with useful information. The 2013 Test Packet for Division C events includes the 2012 Astronomy event which also focused on stellar evolution and Type Ia supernovas. That event could be useful as a practice event or just to get an idea of the format for the Astronomy event.

Slide 40:

Flash card sets of the deep sky objects will also be available on the NSO website. The missions have several animations and podcasts that discuss specific DSOs and processes pertinent to the 2017 competition and many of these are posted on YouTube so check the website out. Also many invitationals are being offered around the country and teams are taking advantage of a “practice competition” so coaches might want to see what is available in their state. Many of these are posted on the NSO website. Astronomy tests from a couple of these invitationals will be posted on the NSO website probably in March for teams to use for further preparation. I am also a resource so please contact me if you have difficulty finding any of the resources listed here or if there are additional materials that would enhance preparation for competition.

The Scioly test exchange website has several postings of regional and state events which are also wonderful resources to use for preparation.