Science Olympiad Astronomy Event (2017)

Slide 1:

This presentation is an overview of the content and resources for the National Science Olympiad (NSO) Division C 2017 Astronomy Event. The NSO 2017 national competition will be held at Wright State University in Dayton, OH on May 19th -20th.

Slide 2:

My name is Donna Young, and I work with NASA’s Universe of Learning Astrophysics STEM Learning & Literacy Network. The NASA Astrophysics Universe of Learning Network is supporting both the Division B Reach for the Stars and the Division C Astronomy events.

Slide 3:

The recommended resources for this event will be discussed at the end of the presentation. The 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 2017 is stellar evolution and Type Ia 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. Additional resources for this event will also be discussed at the end of the presentation.

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The event description for the 2017 competition includes the most important properties and characteristics related to the evolution of stars that result in white dwarf stellar cores. The motions of binary systems are important as a Type Ia event requires a binary system. Hubble’s law is included as Type Ia supernovas are used to calculate distances in the universe. The16 deep sky objects listed are all related to important stages of evolution resulting in Type Ia supernovas.

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This slide arranges the deep sky objects into categories: 4 planetary nebulas, 3 binary systems with white dwarfs, 3 AM CVn systems, 4 Type Ia supernovas, and 2 globular clusters.

Slide 7:

Planetary nebulas with white dwarf stellar cores are the end result of the evolution of mid-sized stars that have ~.8 – 8 solar masses. Information related to this sequence is located on the Chandra education website. An introduction to stellar evolution is located at <http://chandra.harvard.edu/edu/formal/stellar_ev/story/> and pages 7&8 specifically relate to the formation of planetary nebulas and white dwarfs.

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There are only ~10,000 planetary nebulas as they are transient. The material spreads out into the interstellar medium (ISM) becoming more and more transient until it is no longer visible – and after no more than ~50,000 years only the white dwarf stellar core remains.

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NGC 2392 shows here as a Hubble optical image, a Chandra X-ray image, and a composite optical/X-ray image. It is about 3,000 LY distant and only ~10,000 years old. The cloud structure is quite complex and not well understood – such as the unusual LY long orange filaments in the outer disk. The unusually high X-ray emissions lead scientists to believe there is an undetected companion to the white dwarf forming in the center. The stellar core is 50,000 degrees Celsius and ejecting the outer layers and creating a wind traveling at 6x106 km/hr.

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NGC 2440 (Hubble images) is a fairly young planetary nebula and it contains one of the hottest white dwarf stars known with a surface temperature of ~200,000 Celsius.

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Henize 2-428 (Hen 2-428) is a planetary nebula that contains a pair of white dwarfs with a combined mass of 1.76 solar masses. Since this exceeds Chandrasekhar’s limit that a white dwarf can support itself against gravity, it is expected that in about 700 million years they will merge and ignite a Type Ia supernova event. This observation was obtained using the Very Large Telescope (VLT) at the Paranal Observatory in Chile. The second image is an artist illustration.

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This Hubble image shows Henize 3-1357 (Hen 3-1357), which is also known as the Stingray Nebula. The Stingray is the youngest known planetary nebula. The bright central stellar core will evolve into a final white dwarf stage – a companion star can be seen at the 10 o’clock position. It is a massive planetary nebula as large as 130 solar systems; however it is 18,000 LY away so appears much smaller. It is thought that the complex shapes of many planetary nebula are the result of companion stars.

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Most stars are in binary or multiple star systems and as a result there are many binary systems that include a white dwarf orbiting with a companion star. White dwarfs can be orbiting with main sequence stars or even highly evolved stars – including another white dwarf. The consequences of the instability of these systems resulting from mass transfer and the formation of accretion disks can lead to different scenarios such as a Type Ia supernova event.

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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 it 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. Sun-sized stars occupy a region called the Mira Instability Strip as they evolve vertically from the main sequence to the giant branch. During this time the stars pulsate and are in the Mira variable stage of evolution. The end products of these stars are located on the white dwarf in the lower left quadrant of the diagram as they are hot but also extremely dim as they are very compact.

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Omicron Ceti is also known as Mira. Mira is the prototype of all Mira variable stars. As stars between ~.8 and 8 solar masses deplete their core hydrogen the radiation pressure countering the force of gravity stops they begin to collapse. This causes the core to become hotter than it was initially and heavier atomic nuclei are produced. Now radiation pressure can once again counter the gravitational forces trying to collapse the star and it expands once more. This process of the star expanding and contracting as heavier and heavier atomic nuclei are fused occurs as the star evolves from the main sequence to the red giant branch of the H-R diagram. The star is now in the red giant stage as it evolves through the Mira instability strip on the H-R diagram. Plotting the pulsations of Mira variable stars – which are basically changes in brightness – over time results in a plot called a light curve which shows the unique behavior of Mira variables. The light curve shows fairly periodic behavior with a pulsation period of ~300 days to a year. The red giant star Omicron ceti also is in a binary system with a white dwarf companion, as shown with the Chandra X-ray image and illustration. This is a GALEX ultraviolet image of Mira moving through space. It has its own proper motions and as it has expanded and collapsed as it fuses heavier and heavier nuclei, Omicron ceti has ejected materials from its outer atmosphere into the surrounding spacetime. A bow shock has developed in front of the star and the material is spreading out behind Mira as it moves through space.

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SS Cygni (SS Cyg) is an extremely bright dwarf nova system composed of a low mass red dwarf main sequence star and a white dwarf that are orbiting in close proximity to each other. Material from the main sequence star is being drawn towards the more massive white dwarf and forming an accretion disk around it. At recurring intervals some critical mass point is reached and material is dumped onto the surface of the white dwarf causing an outburst or flare called a nova. The outbursts causes a sharp increase in magnitude and a plot of the change in brightness over time is called a light curve. SS Cygni was also observed by Chandra in X-ray following an outburst in the optical spectrum.

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Sirius A is the brightest star in the constellation of Canis Major and the entire night sky. It also has a companion white dwarf – Sirius B. Sirius A is a two solar mass main sequence star only a little more than 8 light years away with an apparent visual magnitude of -1.46. In the optical image Sirius A is the bright star and Sirius B is very dim. In the Chandra X-ray image it is the opposite as white dwarfs produce strong emissions in the X-ray part of the spectrum – so the bright star is Sirius B and the dim star if Sirius A!

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AM CVn stars are a rare type of cataclysmic variable stars. Two white dwarf binary systems are AM CVn variables though other configurations are possible. With two white dwarfs one is accreting materials from a hydrogen poor and helium rich white dwarf companion. The orbital periods are extremely short – less than one hour – and should be producing gravitational waves.

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J075141 & J174140 are rare double white dwarf binary systems as they progress to AM CVn systems. The systems were observed by Chandra and XMM-Newton in X-ray, and by the McDonald Observatory in Ft Davis TX and the Mt. John Observatory in New Zealand. Gravitational waves from the two extremely compact white dwarfs cause the orbit to become tighter. The smaller and more massive white dwarf will eventually accrete material from the larger less massive white dwarf and at this point become an AM CVn system. In ~100 million years this will result in an explosive event. The event may well be a Type Ia supernova; it is also possible that the thermonuclear explosion will only damage the white dwarf but leave it intact. The resulting outburst – only one tenth as bright as a Type Ia event is referred to as a .Ia supernova.

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HM Cancri (RX J0806.3+1527) has the shortest orbital period detected of 5 minutes! This pair of white dwarfs is orbiting each other at only 50,000 miles (1/5th the distance to the moon) every 5 minutes at an orbital speed of one million miles per hour. The orbit period is decreasing by 1.2 milliseconds/year which means they are moving closer to each other by 2 feet every day. This system should be producing gravitational waves to compensate for the orbital decay. For this type of binary there are 3 possible outcomes. If the combined mass of the two white dwarfs is less than ~1.4 solar masses a more compact but more massive white dwarf will result. If the combined mass is between ~1.4 and 2.4 solar masses a neutron star will be the result. If the mass is greater than ~2.4 solar masses a Type Ia supernova would be the result.

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Type Ia supernova events are the result of the thermonuclear destruction of a white dwarf stellar core in a binary system. If the white dwarf has a companion star that evolves to the red giant stage and they are close enough to be a contact binary system, the strong gravitational field of the white dwarf can pull materials from the outer loosely held atmospheric layers of the red giant. The material forms an accretion disk around the white dwarf. If a clump of material spirals down to the surface of the white dwarf that approaches the mass limit of the white dwarf it initiates a runaway fusion process that destroys the white dwarf in a thermonuclear event – leaving behind a remnant with no stellar core. (The Roche lobe of both stars make contact.)

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White dwarfs have a thin atmosphere which is mostly either hydrogen or helium that slowly radiates into space and a dense core. If the progenitor star was low mass (less than .8 solar masses) the core will predominately be helium, a mid-sized star like the Sun (~.8-8) will have a carbon and oxygen core, and a star with a mass of ~8-11 solar masses will leave behind a core predominately of oxygen, neon and magnesium. White dwarfs have a designated classification of D followed by letters representing emission lines, magnetic field and/or variability.

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SNR 0509-67.5 is located in the Large Magellanic Cloud galaxy – a galaxy located ~160,000 LY away and visible from the southern hemisphere. This is a composite image with Chandra X-ray data and Hubble optical data. This is a Type Ia supernova that exploded ~400 years ago. The material is ~23 LY in diameter and expanding at a rate in excess of 11 x106 MPH.

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SN 2011fe is located in the Pinwheel Galaxy in the direction of Ursa Major. It was caught by the Palomar Transient Factory less than 12 hours after it exploded. It was observed from two weeks before the event reached its maximum brightness and continued for more than three months afterwards. It is the earliest observation of a Type Ia supernova. It appears to be a “textbook” event. Most likely a carbon-oxygen white dwarf and main sequence star.

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Type Ia supernova remnant SNR G1.9+0.3 is the most recent supernova event in the Milky Way Galaxy (MWG), occurring ~110 years ago. The Chandra data (2007) is in blue and the radio data (1985) from the VLA is orange. The difference in size between the two data sets is evidence of the expansion rate – making it the youngest in the MWG. Further observations with the VLA and Chandra show the increase in both X-ray and radio brightness expected from a Type Ia event. It is important to identify the trigger mechanism for these events because if there is more than one cause the impact on the event from each cause can change over time – affecting the usefulness of Type Ia supernova events as “standard candles” to determine the rate of expansion of the universe.

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Tycho’s SNR is a historic event that was seen by Tycho Brahe in 1572. It has been extensively observed by the Chandra mission. Due to the distribution of material and the “arc” which has been determined to be the material ejected from a companion star, this event was due to the accretion of material from the companion star and not the coalescing of two white dwarfs. The reconstruction of the orbital mechanics shows the probably trajectory of the companion star after the explosion and this information was used to locate the companion star.

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Globular clusters are dense compact spherical groups of stars which reside in the halos of galaxies, above and below the plane of the galaxy. They are very old Population II stars. Populations III is the first generation of stars and have not yet been detected. Population II stars have a little more metallicity because they formed after the first generation Population III stars. As supernovas created elements (metals) that got incorporated in the next generation of stars, each generation had more metals. Population I, II and III have increasing amount of metallicity. The first stars (Population III) – only contained the elements that came into existence with the Big Bang. As these stars went through supernova events heavier elements were created that became incorporated into clouds of gas and dust from which protostars formed. So the next generation (Population II) of stars has a higher metallicity – which is still less than one percent. All stars are ~75% hydrogen, ~ 24% helium, and ~1% metals. There are more than 150 globulars in the MWG. There is less gas, and the older stars are towards the center with younger stars gravitating towards the ended. The orbits of globular clusters can take them through the plane of the galaxy which strips away their gas and dust. Some massive galaxies have more than 13,000 globular clusters.

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The close-up image of the globular cluster M15 from Hubble shows the density of stellar concentration in the core of the cluster. It is located 35,000 LY away in the direction of the constellation Pegasus and can be seen with binoculars. It is ~120 LY in diameter and contains more than 100,000 stars. The cluster contains a surprising stellar population. It is the location of the first planetary nebula discovered in a globular cluster – Pease 1 (K 648) – as well as 112 variable stars, 9 known pulsars discovered to date.

Slide 29:

Globular cluster NGC 1846 is located in the Large Magellanic Cloud galaxy 160,000 LY away in the southern constellation Doradus. The population of stars within clusters is more complex than years ago when they were considered to all be about the same age of older population II stars. However, the discovery of a planetary nebula in NGC 1846 pushes the envelope of age disparity for a globular cluster. Extensive observations and research shows a double main sequence turnoff and this cluster contains two populations of stars with equivalent metallicity but differing in age by ~300 million years. It is thought that the planetary nebula does belong to the cluster.

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The H-R diagram is a plot of stellar temperature (spectral class) versus absolute magnitude (luminosity). The location of a star on the H-R diagram shows its evolutionary stage. The main branches are the main sequence, the giant branch, the supergiant branch, and the white dwarf branch. Stars on the giant branch most probably will result in planetary nebulas and white dwarfs. So the H-R diagram is a plot of stellar evolution and therefore the position of a star is related to its age. Plotting globular cluster stars on the H-R diagram will determine the age of the cluster. The UBV photometric system is a wide band [photometric system](https://en.wikipedia.org/wiki/Photometric_system) for [classifying stars](https://en.wikipedia.org/wiki/Stellar_classification) according to their colors. It is the first known standardized photoelectric [photometric system](https://en.wikipedia.org/wiki/Photometric_system). The letters U, B, and V stand for [ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet), blue, and visual magnitudes, which are measured for a star in order to classify it in the UBV system. Many H-R diagrams use the resulting Color Index B-V with hotter stars increasingly negative and cooler stars increasingly positive.

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Plotting the stars within any cluster – open clusters as well as globular clusters – on the H-R diagram will determine the age of the cluster. The age of clusters is determined from the turnoff point, which is the position where stars exhaust their fuel and leave the main sequence. As you can see with the cluster H-R diagrams on the slide, the further down the main sequence the turn-off point is the older the cluster and the greater the population of stars on the giant and horizontal branches. NGC 2264 is a young cluster only a few million years old, the Pleiades is older however most of its stars are on the main sequence, and M67 is ~5 billion years old. In the extreme lower right corner is the globular cluster M13 which is 12-13 billion years old.

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White dwarfs have unique spectral signatures. The spectrum shown only has absorption lines from hydrogen – and the absorption lines are broadened due to the intense pressure from the surface of the white dwarf caused by the kinetic energy of degenerate matter.

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The spectrum in the upper left 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 image in the lower left shows the condensed spectrum for the Sun and the spectral plot – 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. The image on the upper right shows the typical spectrum for DB, DA and DZ white dwarfs, and in the lower right quadrant a typical DA spectral image and plot. In many ways the interior of a white dwarf acts like a single giant atom. Depending on the layers left around the core when the star expelled its atmosphere into the planetary nebula, there may be a thin layer of ordinary materials compressed into a thin dense atmosphere compressed into tens of meters in diameter. The atmosphere controls the spectrum as just like the Sun, the radiation emitted from the interior is absorbed. So the spectra are especially sensitive to small amounts of heavier elements. White dwarfs with hydrogen-rich atmospheres have absorption in the hydrogen Balmer lines and resemble spectral A stars – and they are classified as DA white dwarfs. (Refer to slide 22 on white dwarf types and classification)

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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. Shown are a few examples of Tycho’s SNR and Omicron Ceti.

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The basic mathematical relationships and equations listed are fundamental to the stellar motions, properties and distances. Explanations for these relationships can be found in any introductory physics textbook.

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The distance modulus is an equation that expresses the relationship among apparent magnitude (m), absolute magnitude (M) and distance (d). It is used with different types of variable stars as well as with Type Ia supernova events to determine cosmological distances. Since Type Ia events are the result of the thermonuclear destruction of a white dwarf and white dwarfs have a similar mass the absolute magnitude (M) for this type of supernova is -19.5.

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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.

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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.

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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.

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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.

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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.