##### Slide 1

Hello everyone. My name is Robert and welcome to the 2023 National Science Olympiad Astronomy webinar.

##### Slide 2

Before I start, I would like to thank NASA's Universe of Learning as well as the Chandra X-ray center, both of whom support and allow us to bring this event to you.

You can find the UoL website here, along with the official Science Olympiad website for the Astronomy event. This site is particularly useful as it includes many links to educational resources and past exams. I really recommend going through the exams, as they will give you a good sense of what to study up on and what to expect at a competition.

##### Slide 3

The Chandra website can be found here, which contains this year’s webinar, past years’ webinars, and talks given by subject matter experts on topics like gravitational waves and galaxy evolution. The website will soon also contain a link for Astronomy tests, so you will be able to access them that way as well. Throughout the competition season, we will be uploading tests and answer keys from various invitationals around the nation, so stay tuned!

##### Slide 4

Now let's dive into the 2023 rules.

As always, stellar evolution will be one of the main topics this year. Last year, the topic was low and mid-mass variable stars. So this year, we will be broadening our horizons and covering variability as a whole.

Teams will still be able to bring in binders or laptops, keeping in mind that all resources used during the event must be accessible without internet access.

##### Slide 5 [SKIPPED]

##### Slide 6

As you can see, many of the fundamental topics from last year have been retained for this year, such as Mira variables and RR Lyrae variables. But a whole host of high-mass variable stars have been introduced, like pulsars and luminous blue variables.

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The math is much the same, except with the introduction of radiation laws. Students are expected to be familiar with the general properties of the Planck spectrum. And of course, we have a whole suite of 16 new and familiar deep-sky objects.

##### Slide 8

I have divided the DSOs into various categories. The vast majority of them are variable stars, which are stars that exhibit changes in their brightness, as seen from Earth. This is further broken down into two categories: intrinsic variables, whose luminosity changes; and extrinsic variables, whose apparent brightness changes. Under intrinsic variables, there are pulsating, eruptive, and cataclysmic variables. Under the miscellaneous category are the non-variable star objects this year, but that doesn’t make them any less interesting!

Under each of the DSO slides, I have included links to some introductory and advanced resources. The former are for you to get a basic introduction to the DSO and the latter are for further reading. I have tried to include resources that touch on the significance of the object and what makes it special. Note that these resources are not exhaustive, so do more research on your own if need be.

In addition to the articles and papers that are typically included, this year I have also added review papers discussing the different types of variable stars. Review papers are different from typical papers as they do not contain original research, but rather summarize existing literature to best explain the current state of research in a particular field.

Finally, before we start going over the DSOs, I wanted to say that if you don’t understand all the terminology right now, that’s okay! You can look these things up and learn them as you go. It definitely took me a lot of time to get used to all of the technical terms in Astronomy, even now I come across things I’ve never seen before. It’s all a learning process!

##### Slide 9

Our first DSO is RS Puppis. RS Puppis is a supergiant star and classical Cepheid variable, which means it is a population I, metal-rich star. As a Cepheid variable, it follows a strong period-luminosity relationship allowing it to be used as an accurate standard candle.

Light echos have been observed off the surrounding reflection nebula, which can be used to further refine the distance measurement to the star with greater accuracy.

##### Slide 10

Our next DSO is W Virginis, the prototype of the W Virginis variable, which is a subclass of type II Cepheids with a period of 10 to 20 days and a spectral class from F6 to K2. It has a mass less than that of the sun, but expands and contracts from 20 to 50 times the sun’s radius as it pulsates. It also follows the period-luminosity relationship, albeit at a lower luminosity, as can be seen in the bottom right graph. The dashed line on top is for classical Cepheids and the solid line below is for W Vir stars. The light curve of W Vir is much different from a classical Cepheid, as can be seen by the “hump” on the descending branch.

##### Slide 11

R Hydrae is a Mira variable red giant, another type of pulsating variable star. These stars are luminous and cool, having periods of several hundred days. They are typically 0.5 to 8 solar masses and reside on the asymptotic red giant branch past the “second main sequence”, which is when stars burn helium in their core. As they evolve, they pass through the Mira instability strip and pulsate as heavier atomic nuclei are formed in the core. Their high luminosity is a product of their outermost hydrogen-burning shell, causing their outer layers to puff up and creating powerful stellar winds.

A unique feature of R Hydrae is the discovery of a bow shock by Spitzer. It is formed from the collision of stellar ejecta and interstellar medium, which is invisible in visible wavelengths, but can be seen in infrared.

##### Slide 12

R Aquarii is a binary system containing a Mira variable red giant and a white dwarf with an orbital period of 44 years. This system is classified as a symbiotic binary with the white dwarf accreting matter from the red giant. For R Aquarii, and all other symbiotic binary systems, emissions can be seen from three parts of the system: the red giant, the white dwarf, and the nebulosity surrounding them. However, the overall light curve is still dominated by the pulsations of the Mira variable. This system has been constantly evolving over the last few decades and has been observed by Chandra (bottom), Hubble (upper middle), and the Very Large Telescope (VLT) (upper right).

R Aquarii is the last of the pulsating variables, now we move on to eruptive variables.

##### Slide 13

AG Carinae is a luminous blue variable, which is thought to be a transitional stage between an O-type main sequence star and a Wolf-Rayet star. Luminous blue variables are identified only by observing S Dor variability or a giant eruption, meaning it (S Dor) pulsates erratically over a period of decades with large outbursts, which is the source of the surrounding nebula. Without this observation, it is hard to distinguish an LBV from supergiants.

##### Slide 14

NaSt1 is a Wolf-Rayet star, and an extremely peculiar one at that. Wolf-Rayet stars are stars showing strong, broad emission lines of ionized helium and nitrogen or carbon. These stars have unusual spectra due to stellar interior turbulence, strong stellar winds, and steady ejection of large amounts of material, and, with only a few hundred cataloged, are rare as well. This is because they are high-mass stars and that the Wolf-Rayet stage is short, relative to astronomical terms, only lasting 100,000 years. As opposed to the typical twin lobes of gas flowing out from the poles of the star, Hubble discovered a pancake-shaped disk of gas, nearly 2 trillion miles in diameter, enshrouding the star. This is evidence that NaSt1 may be a double star system, with the nebula being formed by spilled matter from the mass exchange between the two stars.

Recent observations have discovered a 310-day photometric period, which may be the orbital period of the inner system.

##### Slide 15

HD 184738, or better known as Campbell’s Hydrogen Star, is a WC Wolf-Rayet star. This subdivision of Wolf-Rayet stars into WN, WC, and WO classifications is dependent on which elements exhibit broad emission lines. A large amount of ejecta has surrounded Campbell’s Hydrogen Star in the form of a small planetary nebula, with high carbon and oxygen content.

Campbell’s Hydrogen Star is the last of the eruptive variables, next are the cataclysmic variables.

##### Slide 16

G344.7-0.1 is a 3000 to 6000-year-old type Ia supernova, which means it is a supernova caused by a white dwarf exceeding the Chandrasekhar limit. Its age means that a reverse shock wave has been able to develop through the entire debris field. This shock wave was formed as expanding debris hit the interstellar medium. This heated the debris to millions of degrees, resulting in the emission of X-rays.

Recent observations from Chandra, Spitzer, and VLT allowed astronomers to discern the composition and distribution of “heavy” elements, which are all elements heavier than helium. Regions of high density iron and arc-like structures of silicon have been discovered, and the overall results agree with the current type Ia supernova models.

##### Slide 17

SN 2008D is another supernova, specifically a type Ibc supernova. Its designation as 2008D means it was the 4th supernova observed in 2008. This is the first time a supernova has been observed from its beginning and was first detected by the Swift telescope. It was found to occur in the spiral galaxy NGC 2770. The properties of the X-ray outburst were found to be consistent with a shock wave bursting through the surface of a massive star as it collapses.

##### Slide 18

E0102-72.3 is an oxygen rich supernova remnant in the Small Magellanic Cloud formed from a type IIb supernova. The composite image on the bottom right includes X-rays from Chandra in blue and purple, and visible light from the VLT MUSE instrument in bright red, as well as additional data from Hubble in dark red and green.

The remnant is dominated by a large X-ray ring from the shock wave of the core collapse. A smaller ring of gas, in red, can be seen moving more slowly than the outer shock wave. At the center of this ring is an X-ray source. Observations suggest that this is an unusual, isolated neutron star with a low magnetic field, offset from the center of the supernova event. Ten of these objects have been discovered in the Milky Way galaxy; however, this is the first one found outside the galaxy.

##### Slide 19

SS Cygni is a close binary system with a white dwarf and a red dwarf. This system has been well observed over the last 126 years due to being the brightest star in its dwarf nova class. The primary white dwarf accretes material from the red dwarf, which results in an accretion disk surrounding the white dwarf. Instability in the disk causes variations in the mass transfer dynamics causing regular outbursts. However, they come in ever-changing intervals of wide and narrow outbursts, of about 18 and 8-day durations, as can be seen in the bottom right light curve. Occasional anomalous outbursts also occur.

##### Slide 20

PSR J2030+4415 is a gamma-ray pulsar, formed from the core collapse of a massive star. Chandra observations discovered an extremely long filament, which actually extended beyond the edge of the telescope’s detector, and required an additional observation. This filament is the longest ever detected from Earth. This pulsar also travels at a great speed through the interstellar medium, forming a bow shock ahead of it, which appeared to have stalled 20 to 30 years ago.

A large number of positrons are detected here on Earth and some astronomers theorize that pulsars like PSR J2030 may be producing this antimatter. The fast rotation and high magnetic field of pulsars form electron and positron pairs, which may have leaked out due to the magnetic field of the pulsar wind linking up with the interstellar magnetic field as a result of the bow shock stall.

##### Slide 21

47 Tucanae is a dense globular cluster, consisting of primarily old, low mass stars in a tight concentration, along with many RR Lyrae, which are a class of pulsating variable stars. They are horizontal branch stars with initial masses around one solar mass. Just like Cepheids, they can be used as standard candles to measure galactic distances.

47 Tuc also contains hundreds of X-ray sources. One of these sources is called X9, a low-mass X-ray binary with a primary compact object, likely a black hole or a neutron star, and a secondary donor object, likely a white dwarf. This system has an extremely short orbit of 28 minutes and X-rays are emitted as material is pulled off the white dwarf.

##### Slide 22

NGC 7027, also known as the Jewel Bug Nebula due to its resemblance to the jewel bug, is a young planetary nebula located 3,000 light years away, with an age of only 600 years. Its concentric shells of ejected debris resulted in a rectangular-shaped photodissociation region, where high-energy photons ionize atoms and break apart molecules. Currently, the central object of NGC 7027 is unknown.

A recent observation by SOFIA, the Stratospheric Observatory for Infrared Astronomy, discovered helium hydride within the planetary nebula, which, before this observation, had never been found in interstellar space. Helium hydride, first synthesized in 1925, is one of the first types of molecules to form in the early universe. So, its observation has finally put a decades-long dilemma to rest.

##### Slide 23

GW 170817 was a gravitational wave event detected in 2017 by LIGO, the Laser Interferometer Gravitational-Wave Observatory, that was produced from the merger of two neutron stars. This was the first ever multi-messenger event, with the detection of a short gamma-ray burst by the Fermi telescope, 1.7 seconds after the GW signal. Additional observations following the fading glow of the merger were made by ESA’s INTEGRAL satellite, NASA’s Swift, Hubble, Chandra, and Spitzer missions, and additional ground-based observatories.

Chandra has continued to observe the emitted X-rays, which have remained at a constant level at the end of 2020, three and a half years after the initial event. Astronomers predict this may be the result of a “kilonova afterglow” or matter falling onto a black hole that formed from the merger. Further observations in X-ray and radio waves are required to rule out one or the other.

##### Slide 24

Now that we’ve gone through all of the DSOs, I wanted to go over some fundamental concepts in astronomy. I hope to give some direction to those just starting to learn about astronomy and give a refresher to those returning for another season.

The cornerstone of astronomy is light. Since the objects we observe are so far away, the only way for us to gather information about them is through what they emit. Light, seemingly ordinary, is packed full of information. Its brightness, intensity, wavelength, and polarization are all properties that give us a hint at what’s happening.

As you can see, this galaxy looks very different depending on the wavelength it’s observed in. Infrared images cut through the gas and dust in the galaxy to reveal stars that would otherwise be obscured if viewed through optical wavelengths. X-ray observations pinpoint the highly energetic objects at the centers of the galaxy and the dwarf galaxy above. And even more narrow wavelength bands, like the hydrogen line, or also known as the 21 centimeter line, can show us the distribution of neutral hydrogen along the galaxy’s spiral arms. This is why it is important to observe the DSOs in many different wavelengths.

##### Slide 25

Observed light can also be expanded into a spectrum to show its intensity as a function of wavelength. This gives us insight into the chemical composition of what is emitting the light or what the light is passing through. Take a look at the spectra on the left, there are sharp peaks and troughs at certain wavelengths, which vary depending on the elements in the object’s chemical composition.

Historically, stars were classified depending on the intensity of a specific trough: the hydrogen absorption line. Spectra with strong hydrogen absorption lines would be class A or B, whereas those with virtually no lines would be class O.

##### Slide 26

This classification system would eventually be replaced by the Morgan–Keenan system, which ranked stars by their temperature. However, some of the O through A letters were integrated into the new system, resulting in classes O-B-A-F-G-K-M from hottest to coldest. Or as I like to say: “OBAFGKM”.

The reason why this is important is that this system is often used as the x-axis to one of the most important plots in astronomy: the H-R diagram. The H-R diagram is a scatter plot of stars between their absolute magnitude or luminosity versus their spectral class or temperature. This diagram put stars into visible categories and acted as a tool for astronomers to better understand stellar evolution.

##### Slide 27

Another important aspect of astronomy is measuring distances to objects. There are many different methods to do so, each with its own set of pros and cons. This creates what we call the “cosmic distance ladder”, where each new method represents a rung of the ladder. No single method can cover all distances, so each rung can support the next higher rung. For instance, parallax is a common method used for determining distances using geometry. However, it works well only up to about ten thousand light-years from Earth. Using the aforementioned period-luminosity relationships with Cepheids and RR Lyrae, we can improve our distance out to a hundred million light-years. Finally, the extremely bright and standardized type Ia supernova can push us out even further.

##### Slide 28

As I mentioned before, type Ia supernovae are caused by white dwarfs with masses greater than around 1.4 solar masses. These are used as standard candles due to the fact that they should have a fairly consistent brightness. Astronomers expected these white dwarfs to exceed their mass limit and explode by slowly gaining mass through mass transfer from a binary companion. This way we would know the approximate mass of the progenitor star. However, a fair number of supernovae occur through a merger with another white dwarf, which breaks this assumption.

##### Slide 29

Now, we move on to the calculation portion of the event. I have listed out some of the common equations that show up.

Distance modulus is used to calculate an object’s distance based on the difference between its apparent magnitude (lowercase m) and its absolute magnitude (uppercase M). You may find it helpful to know that the absolute magnitude of a type Ia supernova is fairly constant at -19.6.

Other relationships like parallax, angular diameter, and the inverse square law are also important to look into. Astronomy also uses a lot of unique units, some of which you may have heard of, such as parsecs, light-years, and astronomical units.

##### Slide 30

Radiation laws govern the spectra and luminosity of stars, which often behave like blackbodies. Blackbody radiation is described by Planck’s law, and gives us a general picture of the distributions of stellar spectra. The most notable of which is Wien’s law, an inversely proportional relationship between the surface temperature of a star and its peak wavelength.

The Stefan-Boltzmann law relates the temperature and surface area of a star with its luminosity. This relationship can be further extended to relate the luminosity, radius, and temperature of any star. So, if you know any two of those three quantities, you can calculate the third.

##### Slide 31

Kepler’s third law governs the relationship between two orbiting bodies, relating their total mass to their separation and orbital period. Make sure to take care when using this equation and use the right units!

Circular motion often appears in orbits and can be described by the listed equations.

##### Slide 32

Last but not least, there is JS9, a JavaScript version of DS9, which is a piece of software used for looking at and analyzing astronomical images and data. JS9 can be accessed at this first link and tutorials, guides, and investigations can be found at the second link. Additionally, we hope to increase the amount of educational tools available for students to learn how to use JS9 by creating a series of short webinars walking through the tools and solving JS9 problems that could show up on a test. As always, JS9 will be used at Nationals, and may be used at the regional and state levels.

##### Slide 33

Here is a collection of some of the resources that you may find helpful. As I said before, the NSO website is a wonderful resource to use. You may have noticed that many of these NASA missions were mentioned throughout the DSO introduction, so their websites are a good place to look for more information. Finally, the National Radio Astronomy Observatory and APOD are great resources as well.

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The National event supervisors are Donna Young and Tad Komacek and rules clarifications can be found at soinc.org under “Events”.

##### Slide 35

Here are some best practices for how to prepare for the event.

* Read the Event Description for content and allowable resources. It’s always good to know the rules well, no matter the event. For Astronomy, this will let you know what you need to emphasize in your studying and what you don’t.
* Use this webinar and its attached PowerPoint for an overview of the content topics and deep sky objects. I’ve included many useful resources under each of the slides. I would highly encourage you to look at them.
* Use the Astronomy Coaches Manual from NSO as a guide for background information.
* Use the resources listed in the event description for images and content.
* If your team has the capability to go to invitationals, I would highly recommend it. You get to practice in a real timed setting and who doesn’t love more Science Olympiad.
* And, as I said before, tests from invitationals will be posted on the NSO and Chandra website for teams to use for practice.

##### Slide 36

Finally, before I go, here are some of my personal tips and tricks I used when I competed.

* Read the Wikipedia article on each of the topics listed in the rules. It’s a good way to quickly familiarize yourself with everything in this year’s rules.
* Use introductory astronomy college courses or textbooks. Emphasis on introductory. It’s very easy to get lost in the weeds, so if you find yourself Googling every other word, it’s most likely past the introductory level.
* Get started early on DSO research. I know it’s easy to procrastinate, but you’ll definitely thank yourself the night before the competition if you do so.
* Keep your DSO notes (and all notes in general) organized. During the test, you don’t have lots of time to sift through all of the information you collected when you were studying, so staying organized will keep you from getting stuck on a question.
* About reading scientific papers. The most useful parts are the abstract, introduction, and figures. Don’t worry if you don’t understand everything! Most of the time the minutia is really not that important.
* Spend time to really get to know how to use the formulas and what they mean. The vast majority of calculation questions come from the same set of fundamental formulas. Knowing them well will take you a long way.
* Finally, take lots of practice tests! I found that this was the key to doing well in Science Olympiad.

Thank you for watching and good luck in the season!