Slide 1:
This slide set is an overview of the content and resources for the National Science Olympiad (NSO) Division C 2024 Astronomy Event. The NSO 2024 national competition will be held at Michigan State University (MSU) in East Lansing, MI on May 24th -25th. Forty years ago, MSU was the host site for the first national tournament.

This transcript includes links with most of the slides that provide information and/or a starting point for information about the content and the DSOs.

LINKS:
https://www.universe-of-learning.org/resources/projects
https://msutoday.msu.edu/news/2023/MSU-to-host-40th-Science-Olympiad-National-Tournament
https://www.soinc.org/rules-2024

Slide 2:
The Astronomy Event content focus for 2024 is early-stage star formation and exoplanets. As always, the Event Parameters state that each team is permitted to bring two computers, two 3-ring binders, or one computer and one 3-ring binder, and a calculator. Internet access is not allowed, except for the NASA JS9 website. If the event takes place in a room with computers, the JS9 program and software tools will be pre-loaded. If the room does not have computers, teams can use their own laptops to access the JS9 website. If any teams do not have a computer, one will be provided.

Slide 3:
The competition gives a brief description of the main concepts and mathematical relationships necessary to understanding the past, current, and future dynamics, and evolutionary sequences of this year's Deep Sky Objects (DSOs). The information that has changed since last year is red.

Slide 4:
This slide arranges the DSOs into categories: 2 star formation regions, 4 pre-main sequence objects, 2 systems that have one or

more brown dwarfs, 6 gas giants exoplanets, and one terrestrial object. I like this grouping; however, note that it is my design. Someone else may prefer a different arrangement. 2M1207 contains a brown dwarf, and a gas giant. I like grouping the brown dwarfs together instead of grouping 2M1207 with the gas giants. There is no right or wrong way. The red/pink object in the image is the Carina Nebula as seen from the southern hemisphere. (Not to scale)

Slides 5:
The Carina Nebula (NGC 3382) is a massive and energetic star formation complex visible in the night sky in the southern hemisphere. The Carina Nebula contains two types of ionized hydrogen regions, red emission nebulas where the material has been heated enough to emit radiation, and blue reflection nebulas when the surrounding material is reflecting UV radiation from massive stars forming nearby. Carina also has dark, or absorption nebulas which make up the giant molecular clouds.

LINK:
https://hubblesite.org/contents/media/images/2007/16/2099-Image.html

Slide 6:
Molecular clouds are cold, extremely dense, and opaque clouds of gas and dust that contain molecular hydrogen.   The form of molecular clouds, also called dark clouds, is very irregular: they have no clearly defined outer boundaries and sometimes take on convoluted serpentine shapes because of turbulence. Cold molecular clouds are associated with star formation. The massive stars forged in these regions emit copious amounts of UV light that ionize the surrounding gas. These HII regions are emission nebulas when the material has been heated enough to emit radiation (red) and reflection nebulas when the material is reflecting UV radiation from the massive stars forming nearby.

LINK:
https://esahubble.org/images/opo1029a/

Slide 7:
Bok globules are not listed in the event description; however, you will come across the term as you study how protostars form. They are small, dark, dense nodules of gas and dust that form from dark molecular clouds that have not been eroded away by photoionization. If they accrete enough mass, they form protostars. The Bok globule in this Hubble image is nicknamed the "caterpillar". These objects could collapse into protostars.

LINK:
https://esahubble.org/images/heic0707c/

Slide 8:
This close up Hubble image shows the violent and turbulent process of intense star formation. This massive structure is 3 light years across and shows both massive and smaller protostars forming, ejecting jets of material, and being eroded away by intense photoionization.

LINKS:
https://hubblesite.org/contents/media/images/2010/13/2707-Image.html
https://www.jameswebbdiscovery.com/astronomy-news/james-webb-telescopes-expedition-to-the-mystic-mountain-in-carina-nebula

Slide 9:
Even though the Eagle Nebula in this image is NOT in the Carina nebula, it beautifully displays the different wavelengths of radiation produced by star formation processes. This is one of the interactives on the Universe of Learning and Universe Unplugged Viewspace

website (follow the link below.) As you manipulate the sliders, you can explore objects and materials from different wavelengths.

LINK:
https://viewspace.org/interactives/unveiling_invisible_universe/star_formation/eagle_nebula

Slide 10:
NGC 1333 is seen in visible light as a reflection nebula, dominated by bluish hues characteristic of starlight reflected by interstellar dust. Only 1,000 light-years away, it lies at the edge of a large, star-forming molecular cloud. This striking close-up spans about two full moons on the sky or just over 15 light-years at the estimated distance of NGC 1333. It shows details of the dusty region along with telltale hints of red emission from Herbig-Haro objects, jets, and shocked glowing gas emanating from recently formed stars. In fact, NGC 1333 contains hundreds of stars less than a million years old, most still hidden from optical telescopes by the pervasive stardust.

LINK:
https://spaceref.com/science-and-exploration/ngc-1333-the-star-forming-perseus-molecular-cloud-as-seen-by-hubble/

Slide 11A:
The H-R diagram is a plot of the temperature (stellar classification) and absolute magnitude (luminosity) of a star. The location of a star on the H-R diagram is basically a plot of its current stage of evolution – giving you the age, mass, composition, and complete 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.

LINKS:
https://chandra.harvard.edu/edu/formal/stellar_ev/story/index3.html
https://chandra.harvard.edu/edu/formal/stellar_ev/story/index4.html

Slide 11B:

Herbig Ae/Be stars are 2-8 solar mass pre-main sequence objects. T Tauri stars are less massive. Pre-main sequence objects. These two protostars are still in the gravitational contraction stage of star formation and approaching the main sequence. Hydrogen fusion has not yet started. On the Hertzsprung–Russell diagram these stars are located to the right of the main sequence. Objects more than 8 solar masses in the pre-main sequence stage are not observed, because they evolve too rapidly: when they become visible (i.e. disperses surrounding circumstellar gas and dust cloud), the hydrogen in the center is already fusing and they are main-sequence objects.

LINKS:
https://chandra.harvard.edu/edu/formal/stellar_ev/story/index3.html
https://chandra.harvard.edu/edu/formal/stellar_ev/story/index4.html

Slide 12:

This is a collection of 30 Hubble images of embryonic planetary protoplanetary disks in the Orion nebula.

LINK:
https://science.nasa.gov/mission/hubble/science/science-highlights/finding-planetary-construction-zones/

Slide 13:

A protoplanetary disk is a rotating circumstellar disk of dense gas surrounding a young newly formed star, such as a T Tauri star, or

Herbig Ae/Be star. The protoplanetary disk is an accretion disc as gaseous material may be falling from the inner edge of the disk onto the surface of the star. This accretion process can add mass to the newly forming star.

LINK:
https://en.wikipedia.org/wiki/Protoplanetary_disk

Slide 14:
This animation (follow the link in the notes section) shows a protostar forming from its cloud of gas and dust. These protostars can produce enormous amounts of radiation – including-X-rays. The shock wave produced by these high energy emissions travels through the material surrounding the protostar. This pushes the disk further away from the protostar, which is then unable to gain any more mass. This sets up an environment conducive to planet formation as the material accretes into planetesimals.

LINK:
https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System

Slide 15:
A debris disk is a circumstellar disk of dust and debris in orbit around a star. Sometimes these disks contain prominent rings, and debris disks have been found around both mature and young stars. Debris disks constitute a stage in the formation of a planetary system following the protoplanetary disk phase, where accreting planetesimals can form exoplanets.

LINKS:
http://planetimager.org/debris-disks-searching-for-dust-to-find-planets/

https://www.llnl.gov/article/48286/lost-space-rocky-planets-formed-missing-solar-system-material

Slide 16:
The Solar System has remnants left behind from its collapse, so it is surrounded by a disk of debris – both the Kuiper Belt and the Asteroid belts contain disk shaped material left behind after the Sun and planets formed, as well as the more distant and sphere of cometary material.

LINK:
https://www.sciencenews.org/article/kuiper-belt-discovery-solar-system-planets-space

Slide 17:
TW Hya is a classical T Tauri star. It is the most studied member of the TW Hydra association of approximately 20 low mass stars with similar ages and motions. TW Hya has a hot inner disk, a larger cold dust disk, and a hot optically thick disk that suggests that the optically thin disk could be due to gas clearing by a planet. TW Hya is apparently still accreting from a face-on protoplanetary disk of gas and dust as observed by ALMA. The image on the slide is an ALMA observation and the typical T Tauri type of light curve.

LINK:
https://www.sci.news/astronomy/hubble-herbig-haro-objects-ngc-1333-06773.html

Slide 18:
HH 7-11 is a pre-main sequence Herbig Haro object. The Herbig–Haro objects numbered 7 to 11 (HH 7–11) are visible in blue in the top center of this Hubble image (The image on the left). These objects are located within the NGC 1333 star formation region already discussed in Slide 10 lie within NGC 1333, a reflection nebula full of gas and dust. Bright patches of nebulosity near newborn stars, Herbig-Haro objects like HH 7–11 are transient phenomena. They disappear within a few tens of thousands of years. The young star that is the source of HH 7–11 is called SVS 13. The

current distance between HH 7 and SVS 13 is about 20,000 times the distance between Earth and the Sun. Herbig–Haro objects are formed when jets of ionized gas ejected by a young star collide with nearby clouds of gas and dust at high speeds. The Herbig-Haro objects visible in this image are no exception to this and were formed when the jets from the newborn star SVS 13 collided with the surrounding clouds. These collisions created the five brilliant clumps of light within the reflection nebula.

LINK:
https://www.sci.news/astronomy/hubble-herbig-haro-objects-ngc-1333-06773.html

Slide 19:
AB Aurigae is a Herbig AE star. Knots of materials in the disk surrounding AB Aurigae are thought to be the initial stage of planet formation. AB Aurigae is ~2-4 million years old. Younger protostars do not show such a clumpy structure, and older protostars (~8-10 million years) show gaps in their protoplanetary disks. This protoplanet is forming through an intense and violent process, called disk instability. Disk instability is very different from the dominant core accretion model. In this scenario, a massive disk around a star cools, and gravity causes the disk to rapidly break up into one or more planet-mass fragments.

LINK:
https://www.sci.news/astronomy/ongoing-planet-formation-ab-aurigae-system-08452.html

Slide 20:
HD 169142 is a pre-main sequence Herbig Ae/Be star. It has a large dust and gas rich circumstellar disk view nearly face-on. Studying this star has confirmed that chemical signatures can be used to determine what types of planets might be forming in the disks around young protostars. Besides carbon monoxide and sulfur monoxide,

silicon monosulfide was detected. This means that the protoplanet is producing powerful shockwaves. The image on the slide shows the movement of protoplanet candidate b around HD 169142.

LINK:
https://en.wikipedia.org/wiki/HD_169142

Slide 21:
Luhman 16A and 16B is a binary brown dwarf system, and the closest brown dwarf system to Earth. Brown dwarfs never accrete enough mass for core hydrogen fusion to begin, and never reach the main sequence. The technique of polarimetry was used for the first time to determine the properties of clouds outside the solar system. These two objects have very different weather. LUHMAN 16B does not have stationary cloud bands. It shows evidence of more irregular, patchy clouds, unlike Luhman 16A. The large image on slide 21 is from the WISE mission. Luhman A belongs to spectral class L. It is possible it shines because thermonuclear reactions are still going on inside it, and not because it shines with residual light.

LINK:
https://www.nasa.gov/mission_pages/WISE/news/wise20130311.html

Slide 22:
The 2M1207 system consists of a brown dwarf and a planetary companion. The exoplanet 2M1207 b is the first exoplanet (red object) directly imaged and the first one orbiting a brown dwarf (blue object). It is 5 times more massive than Jupiter.

LINK:
https://exoplanets.nasa.gov/resources/300/2m1207-b-first-image-of-an-exoplanet/

Slide 23:

V1298 Tau b is a gas giant exoplanet and one of four exoplanets orbiting a K-type star. V1298 Tau is only ~28 X 10^6 years old and therefore very active and the flares it produces bombard the planets with high energy radiation. The planets are all observed to be large, and could still be contracting and cooling from their original formation. The young age of V1298 Tau, together with the expected extended atmospheres of the planets, makes the system exciting for studying evaporating atmospheres.

LINK:
https://exoplanets.nasa.gov/exoplanet-catalog/7426/v1298-tauri-b/

Slide 24:
WASP-18b is also a gas giant exoplanet. The name of this exoplanet is derived because it is the 18th planet discovered by the Wide Angle Search for Planets (WASP) Project. This hot Jupiter gas giant is more than 10 times as massive as Jupiter; however, it completes an orbit in less than one day. The extreme tidal forces are changing the internal structure of the companion star, causing the star to act much older than its estimated age.

LINK:
https://astronomynow.com/news/n0908/27wasp18/

Slide 25:
The gas giant WASP 39-b is also a hot Jupiter exoplanet. It orbits a G-type star, similar to the Sun. It is 0.28 Jupiters in mass, and orbits its star in a little more than 4 days. This was the first exoplanet to be observed by JWST, and provided the first clear evidence of carbon dioxide in the atmosphere of a planet outside the solar system. Further studies provided the first observation of sulfer dioxide and chemical changes influenced by starlight in an exoplanet atmosphere.

LINKS:

https://exoplanets.nasa.gov/exoplanet-catalog/5673/wasp-39-b/

https://www.youtube.com/watch?v=7YbJWu8FBK8

Slide 26:

The hot Jupiter WASP-43b gas giant is the size of Jupiter with double the mass of Jupiter and orbits its parent star in only 19 hours. The planet is tidally locked with its parent star and has winds traveling at the speed of sound from the day side (hot enough to melt iron at 1500 degrees C) to the pitch black night side (temperatures of 500 degrees C). Astronomers working on two companion studies have produced a detailed temperature map at different layers within the atmosphere and traced the amount and distribution of water vapor in the atmosphere. The teams combined transmission and emission spectroscopy by observing the planet through its orbital phase to produce the detailed weather map.

LINK:https://exoplanets.nasa.gov/exoplanet-catalog/5673/wasp-39-b/

Slide 27:

HR 8799 is a young main-sequence star located 129 light years away from Earth in the constellation of Pegasus, with roughly 1.5 times the Sun's mass and 4.9 times its luminosity. It is part of a system that also contains a debris disk and at least four massive planets. Those planets, along with Fomalhaut b, were the first extrasolar planets whose orbital motions was confirmed via direct imaging. The spectral type is complicated with the spectrum and temperature showing the typical properties of an F0 V star. However, the strength of the calcium II K absorption line and the other metallic lines are more like those of an A5 V star. The image on the left shows the location and motions of the 4 large planets. The illustration on the lower right is a 3D representation of the HR 8799 system compared to the Solar System.

LINK:
https://hubblesite.org/contents/media/images/2011/29/2896-Image.html

Slide 28:

The Beta Pictoris system is very young – 20-26 million years – even though the A-type star Beta Pictoris is already on the main sequence stage of the H-R diagram. Detailed observations have revealed a large disk of dust and gas orbiting the star, which was the first debris disk to be imaged around another star. The system has two planets, and recently 30 exocomets have been found orbiting Beta Pictoris. The exoplanet Beta Pictoris b is a gas giant.

LINK:
https://www.cnn.com/2022/04/29/world/exocomet-discovery-beta-pictoris-scn/index.html

Slide 29:
TRAPPIST-1 is a cool red dwarf star with 7 known exoplanets. It is the most studied planetary system outside of the Solar System. All 7 of the roughly Earth-sized exoplanets transit TRAPPIST-1. Three of the exoplanets are within the habitable zone. It has been imaged by JWST.

LINK:

https://exoplanets.nasa.gov/trappist1/
http://www.trappist.one/#about

Slide 30:
This animation (click on link below) shows the number of exoplanets discovered from the first one confirmed in 1992, until 2022 when more than 5000 had been discovered. It also shows the total numbers for the different methods of detection. As of August 2023, there are 5,502 confirmed exoplanets.

LINK:
https://drive.google.com/file/d/1fB0mKTg1ZYCcFZ7vr-imrLFLHt30KDzn/view

Slide 31:

The vast majority of exoplanets have been discovered by the transit method, followed by radial velocity.

LINK:
https://www.nasa.gov/kepler/overview/planetdetectionmethods

Slide 32:
The 2024 event will focus on 3 methods of detecting exoplanets, including radial velocity, two types of transit photometry, and direct imaging. Each method has both advantages and disadvantages and differs in the physical characteristics of the detected planets, i.e., mass, radius and/or atmospheres.

LINK:
https://exoplanets.nasa.gov/alien-worlds/ways-to-find-a-planet/#

Slide 33:
This slide shows all the DSOs for 2024, along with the method used to detect them.

Slide 34:
The radial velocity method uses the fact that if a star has a planet (or planets) around it, it is not strictly correct to say that the planet orbits the star. The planet and the star orbit their common center of mass. Because stars are so much more massive than planets, the center of mass is within the star and the star appears to wobble slightly as the planet travels around it. This wobble is measured by using Doppler spectroscopy. If a star is traveling towards Earth, its light will appear blueshifted, and if it is traveling away from Earth the light will be redshifted. Spectroscopy shows this change in color from a star as it moves towards or away from Earth as it orbits the center of mass of the star-planet system. This method enables calculation of the mass and orbital period of an exoplanet.

LINK:
https://www.planetary.org/articles/color-shifting-stars-the-radial-velocity-method

Slide 35:

With the transit photometry method, If the orientation of the planet-star system is oriented to Earth so that the planet passes in front of the star, the change in magnitude can be detected. The duration of the partial eclipse is an indication of the size of the planet, and the depth of the partial eclipse is an indication of the size of the star.

LINK:

https://exoplanets.nasa.gov/faq/31/whats-a-transit/

Slide 36:

This animation demonstrates the transit timing method of detecting exoplanets.

LINK:

https://www.planetary.org/articles/timing-variations

Slide 37:

Photometry and spectroscopy of extrasolar planets provides information about their atmospheres and surfaces. From extrasolar planet spectra and photometry, the composition and temperature of the atmospheres as well as the presence of molecular species and gases can be inferred. As the light from the parent star filters through the atmosphere of a transiting exoplanet, a small fraction of the light is absorbed by the upper atmosphere of the planet making the exoplanet appear larger. The degree of atmospheric absorption is dependent on which atomic and molecular species are present, as well as the wavelength of the observations.

LINK:

https://www.planetary.org/articles/down-in-front-the-transit-photometry-method

Slide 38:

Young debris disks can constitute a phase in the formation of a planetary system following the protoplanetary disk phase, when

terrestrial planets may finish forming. These disks can also be produced and maintained by collisions between objects such as asteroids and comets. Exoplanets in debris disks can be detected through direct imaging. Interactions of giant planets with the disk produce characteristic signatures, and primary signatures of planets embedded in disks are gaps in young disks and asymmetric density patterns. So, features in dust disks suggest the presence of full-sized planets. Some debris disks have a central cavity, meaning that they are really ring-shaped. The central cavity may be caused by a planet "clearing out" the dust inside its orbit. Other disks contain clumps that may be caused by the gravitational influence of a planet.

LINK:
https://lco.global/spacebook/exoplanets/direct-imaging/

Slide 39:
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 goes in comes out. Stellar atmospheres are very good 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.

LINK:
https://asd.gsfc.nasa.gov/archive/mwmw/mmw_bbody.html

Slide 40:
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 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.

LINK:
https://www.eso.org/public/teles-instr/technology/spectroscopy/

Slide 41:
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. All of these equations and relationships have been a part of every NSO Astronomy Event. The only difference is the addition of the Equilibrium Temperature equation highlighted in white. The planetary equilibrium temperature is a theoretical temperature that the planet would be at when considered as if it were a black body being heated only by its parent star. The theoretical black body temperature is treated as if it came from an idealized surface of the planet. This calculation can help determine the habitability of the planet.

Slide 42:
The JS9 image analysis tools are used by scientists to study astronomical images. There is always a JS9 question on the national

test, and several invitationals are now also including JS9 questions. The Chandra website link in the notes section will connect you to the NSO dedicated JS9 website. There are tutorials and investigations that will demonstrate how scientists learn about astronomical objects.

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

Slide 43-44:
Slide 43 shows the Universe of Learning Universe Unplugged websites will provide a wealth of information about stellar evolution and exoplanets. The second link in the notes section of Slide 43 will bring up the Astrophysics Variety Hour. Scroll down to the Exoplanet Explorations section and you will find a wide variety of multi-media resources. There are also presentations by experts that were recorded for NSO. There will be more talks, so check back occasionally for new talks dedicated to exoplanets and early formation of stars and planets. After the Exoplanet Explorations section is a Learning Resources section with exoplanet activities.

LINKS:

https://www.universe-of-learning.org/
https://www.universeunplugged.org/series/avh
https://www.jpl.nasa.gov/topics/exoplanets

Slide 44 includes other resources. 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 The JWST, Hubble, Chandra, NRAO and Spitzer websites are also valuable resources.

LINKS:

https://www.universe-of-learning.org/
https://www.universeunplugged.org/series/avh
https://www.jpl.nasa.gov/topics/exoplanets

Slide 45:

Follow these basic 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

Enjoy the journey!

And if you would like to continue your Science Olympiad Astronomy journey after high school, please contact one of the event supervisors. Their names and email are listed on this slide. We would love to have some of you help write Astronomy, Reach for the Stars or Solar System test questions for invitationals, regionals, states, or the national tournament.

May The Stars Be With You!