Slide 1:

This presentation is an overview of the content and resources for the National Science Olympiad (NSO) Division B 2018 Solar System Event. The NSO 2018 national competition will be held at Colorado State University in Fort Collins, Colorado from May 18th-19th, 2018. My name is Claire Burch, and I am a former competitor in both B and C Division Science Olympiad and a physics major at Harvard College. I am now working to develop the astronomy event materials for middle and high school competitors. The recommended resources for this event will be discussed at the end of the presentation. The Webinar and transcript are posted online and the accompanying PowerPoint presentation will be posted and available for download on the NSO website.

Slide 2:

This is the first year for Solar System in the B Division astronomy event rotation; in 2017 the B Division astronomy event was Reach for the Stars. The focus of this year’s Solar System event is Earth’s moon and other rocky bodies of the solar system. Each team may bring two 8.5” x 11” two-sided pieces of paper containing information in any form from any source for use during competition. The notes may be used during all parts of the event. Each student is also permitted to bring one non-programmable calculator to perform calculations during the event. The focus for Part I of this event is identification and knowledge of the geologic surface features and internal structure of the objects listed in the first section of the rules. The focus for Part II of this event is demonstrating understanding and ability to apply knowledge of physical and geologic processes associated with the solar system’s geologic bodies as well as the missions and measurements made by scientists to understand these objects.

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The objects in the Solar System included in this year’s event and listed in Part I of the rules are the planets Mercury, Venus, and Mars, the Moons of Earth and Mars as well as Jupiter’s moon Io, and the Asteroid Belt and Near Earth Asteroids. Students are expected to be able to identify surface features by name and classification, and to be familiar with the surface feature nomenclature systems for each object. Students should also be familiar with the history of both entire objects and hypotheses regarding their formation as well as the geologic history of the objects and the formation of different geologic surface features. Students should understand what internal and external factors contribute to the evolution of the surfaces of these objects and be prepared to compare and contrast these characteristics.

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The geologic planets included in the 2018 Solar System event are Mercury, Venus, and Mars. Students should be familiar with the internal, surface, and atmospheric composition and evolution of these objects, with a focus on their geologic properties. It is important for students to develop an understanding of the concepts of years, days, and seasons on each of these planets as well as understanding of the history of the inner solar system and the events that may have contributed to the evolution of each. Questions about the Earth will be limited to Earth’s relationship with the moon, as will be discussed later on in this presentation.

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Mercury is the smallest planet in the solar system, and the innermost. Mercury orbits the sun in a 3:2 resonance, meaning it rotates 3 times for every 2 times it orbits the Sun. Mercury is a “differentiated” body, meaning it is massive enough and was hot enough for a long enough period of time for materials of different densities to layer themselves from the inside out under the influence of Mercury’s gravitational field. Mercury’s density is second only to Earth’s, and is attributed to the abundance of heavy elements like silicon in the mantle and iron in the massive core, which makes up 55% of Mercury’s volume. It is possible that Mercury once had a much greater volume but lost its less dense outer layers to a violent collision with another body or by intense interactions with the proto-Sun early in its evolution.

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Mercury’s surface is heavily cratered and exhibits ridges called dorsa as well as highlands, mountains, and plains. Its surface geology is characterized by pyroclastic deposits, vents, and hollows indicative of a volcanic history. Mercury’s caloris basin is its most notable surface feature. Mercury had been studied primarily by the Mariner missions 40 years ago, meaning the recent Messenger mission has provided new insights on Mercury’s surface geology for the first time in decades.

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Venus is the second largest terrestrial planet and has the longest day in the solar system, equal to over 240 Earth days. Additionally, Venus rotates in the opposite direction that it orbits the Sun, unlike most solar system objects. The reason for this angular-momentum-defying behavior is unknown, but many scientists believe it can be attributed to a collision with a large body early in Venus’s evolution. Most scientists believe Venus and Earth have similar core-mantle-crust structures, but that the lack of a strong magnetic field on Venus may contribute to an absence of core solidification. Very little is known about the interior of Venus, in part because its exterior conditions make it so difficult to study.

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Venus’s thick atmosphere is primarily composed of carbon dioxide and results in a surface atmospheric pressure nearly 100 times that of Earth’s surface. Thermal inertia and heat transfer via wind control the atmospheric dynamics on the surface of Venus, while higher clouds of sulfuric compounds reflect most incoming light and break down small meteors before they can impact the surface. Venus’s surface geology has been shaped primarily by volcanoes and craters, with craters formed in relatively recent history in nearly pristine condition indicating global crust recycling and decline of volcanism within the last 300 million years.

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Mars, the red planet, is geologically similar to Earth but has only about one-ninth the mass. The core of Mars is dense and metallic, similar to Earth’s, but is composed of iron and nickel with significant amounts of sulfur and other lighter elements in comparison with Earth. This core is surrounded by a mantle that contributes to surface volcanism and tectonics, which are relatively suppressed by Mars’ thick crust.

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The surface of Mars has been studied in detail by flyby, orbital, and lander missions, and has been mapped in more detail than Earth’s ocean floor! The surface of Mars is characterized by a reddish color due to the abundance of ferrous or iron-containing minerals, but also exhibits darker regions and polar ice caps. Craters, scarps, and glacial plains are among the most notable features of Mars’s surface, the most famous being the large Hellas impact basin. Mars has a thin carbon dioxide atmosphere about 1/100th as thick as Earth’s.

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The major satellites that are included in the 2018 version of Solar System are those large rocky satellites that have dynamic and very different surface geologies, as well as fascinating histories of formation and evolution. The satellites included in this year’s version of the rules are Earth’s Moon, Mars’s moons Phobos and Deimos, and Jupiter’s moon Io.

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The Moon has a differentiated internal structure, a fact that was surprising to many scientists given its size, composition, and distance from the Sun. Many scientists believe that a large impact early in the Moon’s history provided the necessary heat for the differentiation and the emergence of a plagioclase-rich or “lighter” crust atop a mafic mantle. “Moonquakes”, the equivalent of Earthquakes on the moon, are caused not by tectonics but rather from thermal expansions and contractions as the moon rotates and continues to cool internally, as well as from tidal stresses caused by Earth.

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You may have heard people reference “The dark side of the moon” or the side of the moon we never see from Earth. The moon is tidally locked with Earth, meaning the same side always faces Earth and has a synchronous orbit, meaning its rotation period and orbital period are the same. The geology of the Moon, the study of which is called selenology, is characterized primarily by cratering and volcanism. Features known as Highlands, dark plains called Maria, and rilles, domes, and grabens are also found on the moon. There are many more craters on the far side of the Moon than the near side, as it is exposed to bombardment coming towards the Earth-Moon system.

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The formation of the moon has long presented questions to scientists, as the Moon is the largest satellite relative to its host planet in the solar system. One of the most favored explanations of the formation of the moon is called the “giant-impact hypothesis” and poses that the moon was created when a large body collided with Earth, breaking off a significant amount of material that then coalesced in orbit around Earth.

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Phobos and Deimos are large rocky moons of Mars that exhibit surface geology characteristic of C- or D- type asteroids, supporting the popular hypothesis that both moons did not condense in orbit around Mars and were in fact captured from the asteroid belt later in the solar system’s history. Both moons are tidally locked to Mars. The most famous surface feature of Phobos is the large Stickney crater while Deimos has only two named surface craters, Swift and Voltaire.

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Io is the innermost of Jupiter’s 4 large Galilean moons. Io is slightly larger than Earth’s moon and has over 400 active volcanoes and is the most geologically active body in the solar system. Io is tidally locked and also has a synchronous orbit around Jupiter. Io’s dynamically changing surface shows no impact craters and exhibits regions of many different colors due to the presence of different chemical compounds in its atmosphere, surface, and interior. Io has been imaged primarily by the Pioneer, Voyager, and Galileo missions.

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The final important geologic bodies in the solar system are the main asteroid belt and near earth asteroids. The asteroid belt lies between Mars and Jupiter, while near earth asteroids orbit the sun in less circular paths, typically inside the bounds of the asteroid belt, and which all have perihelion - or closest approach – distances of at least 1.3 Astronomical Units from the sun.

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The asteroid belt contains hundreds of thousands of small rocky bodies that were unable to condense into a planet under the gravitational influence of Mars and Jupiter. The Asteroid Belt’s “Kirkwood Gaps” occur at distances between Mars and Jupiter where no gravitationally stable orbits exist.

Slide 19: There are 3 main types of asteroids, characterized by composition and appearance. C-type or carbonaceous asteroids are rich in carbon and have low albedo, meaning they are very non-reflective. C-type asteroids more prevalent in the outer regions of the asteroid belt. S-type or silicate asteroids are composed primarily of silicates, indicating the presence heating and reformation after their initial formation, which contributed to their relatively high albedo. These asteroids are more common towards the inside of the asteroid belt. M-type or metallic asteroids make up only 10% of all asteroids in the belt, and are composed primarily of iron and nickel. It is unknown how M-type asteroids were formed, and many believe that they may be the cores of differentiated progenitor bodies that were later broken up.

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Over 15,000 Near Earth Asteroids are currently known to be orbiting the sun. Near Earth Asteroids are commonly classified into “Families” based on the shapes and sizes of their orbits. Few Near Earth asteroids survive in their orbits for more than a few million years, as many collide with planets or the sun or are gravitationally ejected from the solar system. Ability to detect and predict the orbital paths of Near Earth Asteroid has accelerated within the past few decades, raising the question of how likely a potential collision with one of these asteroids may be, and what it might be possible for us to do to avoid or lessen the damage due to such a collision.

Slide 21:

The asteroid belt was formed early in the solar system’s evolution between Mars and Jupiter, where some scientists believe a small planet originally orbited that was then gravitationally destructed by the pull of Mars and Jupiter. Over time, many asteroids were consumed by Jupiter or gravitationally ejected from the solar system, leaving the total mass of the asteroid belt at less than 5% that of the moon. Most Near Earth Asteroids are asteroids that were ejected from the main asteroid belt due to gravitational interactions with Jupiter, while some are extinct comets caught in smaller orbits around the sun.

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The formation of the Solar System as is pertinent to its geologic bodies may also be tested in this event, primarily focusing on the distribution of different substances around the Sun during the condensation of the protoplanetary disk, the large cloud of dust that condensed around the Sun early in its formation. This describes the most popular of Solar System formation theories, and is known as the “Nebular Hypothesis”

Slide 23: Part II of the 2018 Solar System event tests students’ knowledge of the history and observation of physical and geological processes through both qualitative and quantitative understandings. This part of the exam may include calculations, questions involving real data, as well as diagrams and maps. Questions that fall under this section of the rules may be paired with questions from Part I.

Slide 24: Students may be asked questions about remote sensing and imagery as related to measuring and observing the objects in Part I especially their geologic features. Exams may test students’ understanding of why specific wavelengths or specific types of measurements are used for different objects, as well as the roles that object mass, surface, atmosphere, or location play in determining our ability and strategy in studying these objects. Tests may include questions about different kinds of telescopes and instrumentation, including Earth-based or Earth-orbiting observatories as well as missions to the objects themselves. Example types of remote sensing that could be asked about are radar altimetry, spectroscopy, imaging in different regions of the electromagnetic spectrum, and gravity sensing.

Slide 25:

Exams may include questions on specific past, present, or future missions to study the objects included in Part I. Students should be familiar with how and when important discoveries about these objects were made, and understand the origin of the measurements and imagery of these objects. The focus on future missions to study these objects should include an understanding of what kinds of questions future missions will be able to answer and how they will answer them.

Slide 26:

Students are expected to have both a quantitative and qualitative understanding of Kepler’s Laws of Planetary motion, and should be able to recognize these laws in words, equations, or pictoral form as well as perform calculations using real data. Kepler’s 1st law: The orbit of a planet is an ellipse with the Sun at one of the two foci. Students are not required to be familiar with the complete geometry of an ellipse, but should understand the basic principles of its construction and the relationship between perihelion (the distance of closest approach to an object), apehelion (the distance of further approach), semimajor axis (the average of perihelion and apehelion distance), and eccentricity (the variance of an orbit from circular).

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Kepler’s 2nd law, or “the law of equal areas”: A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.

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Kepler’s 3rd law: The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit. This may be expressed as “P squared = A cubed”. Students should be comfortable using this relation with units of Astronomical Units for distance and Years for period for objects orbiting the Sun, but need not be familiar with the role that mass plays for using Kepler’s third law in systems outside our own solar system.

Slide 29:

Exams may include questions about tides, specifically regarding the Earth-Moon system. Tides are caused by changes in the relative positions of the Moon and Earth and the gravitational bulges created by the Moon’s gravitational tug on Earth. Students should understand why different parts of the world experience different tidal patterns at different times of day. Students should be familiar with Neap Tides and Spring Tides, which occur when the gravitational forces due to the Sun and the Moon are perpendicular and parallel, respectively.

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Students should understand and be able to identify eclipses both from diagrams of the Sun, Moon, and Earth and as observed from Earth. Solar eclipses occur when the Moon passes in front of the Sun as viewed from Earth, blocking all but the outermost regions. Total solar eclipses occur when the entire face, or photosphere, of the sun is blocked, whereas annular solar eclipses occur when the moon is further from Earth and its projection does not fully eclipse the sun.

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Lunar eclipses occur when the Earth completely blocks the Sun from illuminating the moon, allowing only the outermost light from the sun to shine red on the face of the moon when it is refracted around Earth.

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Students should be familiar with lunar libration or the slight variations in the hemisphere of the moon that is visible to Earth. Questions may cover longitudinal libration, latitudinal librartion, as well as diurnal libration, and what causes each of them. Longitudinal libratiuon is caused by lagging of the Moon’s position relative to Earth due to the Moon’s eccentric orbit. Latitudinal libration is caused by the slight tilt of the moon’s orbital axis relative to Earth’s, and the variation of the relative tilt angle between the two bodies. Diurnal libration is caused by the motion of observers along the surface of the Earth as the Earth rotates, meaning observers experience a different view of the moon as they move relative to Earth’s center.

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The phases of the moon and what causes them are also included in Part II. The lunar cycle and the relationship between the phase of the moon and what time the moon rises and sets each day may also be tested. For example, this diagram shows a full moon among other phases. Students can infer based on the position of the Sun, Moon, and Earth that a full moon rises in the evening, reaches its highest point in the night sky at midnight, and sets in the morning.

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Regolith is a general name for the fine material that makes up the surfaces of geologic bodies in the solar system. Students should be familiar with processes like weathering and cratering that generate regolith on the surface of these bodies as well as the composition of regolith, including whether or not it varies across the surface of the object and how scientists determine its composition.

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Cratering is one of the most significant processes in the solar system with regards to shaping the surfaces of rocky bodies. The size and age of different craters can inform scientists about when and where significant cratering events, such as the Late Heavy Bombardment, occurred in the history of the solar system. Lack of craters, such as the surface of Io exhibits, can inform scientists as to how fast new surface material is being generated.

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Volcanism and weathering are two important geologic processes that shape and recycle the surfaces of geologic bodies in the solar system. Volcanism on Venus, Mars, and Io may be compared and contrasted. Weathering from atmospheric dynamics or fluid flows on the surfaces of the objects specified in Part I may also be included. The atmospheres of the objects included in Part I of this event are important both in contributing to the surface characteristics of the objects and in determining how scientists can study them. Different atmospheric compositions, temperatures, and dynamics determine which wavelengths of light and what methods of remote sensing can be used to study the surfaces of different objects.

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Dating the surface of geologic bodies of the solar system is essential to understanding the history of these bodies and determining the frequency, intensity, and nature of the internal and external features that have contributed to the geologic evolution of the surfaces of these bodies. Radioactive dating allows scientists to determine how much of specific isotopes remain in the surface features of these bodies, which may have been present in the atmospheres or surfaces of these objects in different quantities in the past compared to the present. Radioactive dating uses the formula shown, where A represents the current concentration of an isotope, A naught represents the concentration of the isotope present a number of years ago, t represents the age of the feature, and h is a constant or the “half-life” of that isotope that indicates how long it takes for one half of the total atoms of an isotope present to decay. Students do not need to understand the origin of this formula, but should be familiar with the idea of isotopes – versions of atoms with different numbers of neutrons – and radioactivity – the decay of these atoms into other atoms over time.

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The example exam, along with an annotated version, will be posted on the Solar System Division B Page on the National Science Olympiad event website. The annotated version of the exam can be used by coaches and event supervisors to understand the kinds of questions and test formats that are most appropriate for this exam, as well as the appropriate length and difficulty for a typical solar system exam. Students can take the unannotated version of the exam in preparation for competition this season. A number of helpful resource websites for Solar System 2018 are included at the bottom of the rules sheet for this event. These include the NASA Jet Propulsion Laboratory Plantary Geophysics website, the NASA Planets website, the NASA moon website, the NASA Asteroids website, as well as the NASA Space Place eclipse website.

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The national event supervisor for Solar System is Dr. Dustin Schroeder, an assistant professor of geophysics at Stanford University in California. Follow the suggestions provided here to prepare for competition. If you have any questions, please submit them online on the rules clarification website if they involve the event description. Event supervisors are not allowed to answer any individual questions about the event as this would be unfair to others.

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