Webinar 1

Hey everybody, I hope everyone is staying home and staying safe. This is the 2021 webinar for the Division C Astronomy event. The theme for this year is the same as the theme from last year, which is star and galaxy formation and evolution. Before I start I want to give a special thanks to NASA's Universe of Learning as well as the Chandra X-ray center, both of whom support us [and allow us] to bring this event to you. You can find their websites here as well as this year's webinar and all previous years' webinars at this link right here. I want to point out this last link right here, which is the official Science Olympiad website for the Astronomy event. It has a bunch of really cool resources for you to check out, including previous exams, the national exam for the 2020 year since it ended up getting cancelled, as well as a bunch of educational links. I really recommend thumbing through this and seeing if you find anything in here useful. The rules for this year are pretty much the same as last year, and I kinda split them up into three parts. Let's take a look. These are the rules from last year. I split them up -- or, the rules are split up into these three categories. The first one is a long list of conceptual ideas. These are ideas in astronomy and astrophysics that are deeply related to the theme for this year. The second part is basically a list of calculations that you're gonna be expected to know how to do on an exam. And the third one is a list of Deep Space Objects, or DSOs. These DSOs, each one of them kinda illustrates a central idea, or concept, or theme, that's related to the overarching theme for a given year (this year it's Star and Galaxy Formation and Evolution). So the rules for the 2021 competition year are gonna be pretty much identical to this set of rules (which is for 2020), with the exception that these three DSOs here are going to be replaced by 3 different DSOs. You'll see what those DSOs are when the rules come out in probably August or September.

Historically, these webinars have been very focused on the Deep Space Objects and the facts that you need to know about them. This year, I want to take a little bit of a different approach, and focus more on the conceptual ideas that you need to be really familiar with to be successful in the Astronomy event, and use a handful of DSOs as case studies or specific examples of these overarching themes and ideas. But nonetheless, I do have a couple of tips and some advice for how to study for the DSO portions of the exam. So I'll walk you through how I would do that. So let's pick one of these DSOs, say, this one: MACS J0717.5, okay. Cool, I've already looked this up before. So, when we Google the DSO, we're immediately hit with a lot of different links. Wikipedia's a classic, let's open that one. Hubblesite, this is the official site for the Hubble Space Telescope, this is probably gonna be a good resource. The Chandra website is killer, it's really awesome, you'll find a lot of really useful information about your DSOs on this website. Anything else super useful? You could go through all of these, but I'll focus on these three for now. So Wikipedia is a pretty good starting point, I think. I think it's really useful for these -- it usually has a table of facts, that you can kinda look up here. It's a good source of images. So what you wanna do is compile all these images that you find of these DSOs, because oftentimes you'll see exams that want you to identify the DSO, or they'll give you a list of images and you have to pick which one corresponds to a certain DSO. So you want to have a database of all the different images for each DSO. So Wikipedia is a good place to find images. It's also a good place to find other links for where to look for more information about this object.

Ok let's take a look at the Hubble. So there's an image, some information, color info -- that could be cool. But not a whole bunch of stuff. Maybe this is a good place to find images, but maybe not much else. Ok let's take a look at this. So the Chandra website often has some really awesome information regarding DSOs. So this is really the first place I would look. So they usually have a picture, or a couple of pictures, and then an article describing what is cool about this DSO, what are its interesting properties, what did we learn by studying this DSO. You can usually find more images, by maybe clicking this right here, and you can find more images. And what you can see here is that these images have been taken at different wavelengths of light. So this image here is the optical image, optical meaning "visible wavelength" -- this is what our eye can see. So this is actually the exact same image we saw earlier on the Hubble Space Telescope site. And that's because the Hubble Space Telescope specializes in taking images in the same wavelengths that our eyes can see. So this is a Hubble image. And then another telescope, on the ground, took a radio image of the same object, and it looks like this. And they've colored it in red -- obviously it's not actually red, this is just the radio wavelengths that they've put into an image and colored it red. And the Chandra telescope specializes in taking X-ray images, so it looks like this, they've colored it blue, and then they've taken all three of these images and stacked them on top of each other, and that's what this composite image is. So this is not actually what it looks when you go and visit, if you were an astronaut and you went and visited this DSO, this is not what it would look like, because the blue is not actually blue, and the red is not actually red. These are coming from different wavelengths of light that our eyes actually can't see. So a lot of astronomy images look more colorful than they actually are, and it's because we have all these telescopes that take images of objects in wavelengths that our eyes can't see, and then we make pretty pictures, all in the rainbow colors that our eyes can see.

So this is an idea called multi-wavelength astronomy, where we basically learn a lot more about objects by looking at them in different wavelengths, not just the visible light wavelengths. And in this table that you can always find at the bottom of these Chandra articles, you'll see a color code, and this color code will tell you exactly what we just explained. And I won't go into a whole bunch of detail right now, but this is actually really really useful information, because hte type of light that an object emits, tells us actually a lot about what physical process is going on in that object. And it can tell us a lot about what's going on in that object. And then the last thing that I want to point out is, if you are really feeling like, "this is really interesting" or "I want to learn a lot more" there's always this reference which is an arxiv link (this is pronounced "archive", a-r-x-i-v). And this is basically a website that

<u>Webinar 5</u>

Hi, welcome to the last webinar segment. This webinar is about cosmology, which is the study of the history of the entire universe, starting from the Big Bang about 13.8 billion years ago. Cosmology is a pretty tricky business conceptually -- at least for me, I remember struggling a lot trying to wrap my mind around some of the things we deal with. And now, with the benefit of hindsight, I think I can distill my personal sources of confusion to two main phenomena. And those are: an effect that I'm going to call the "snail mail delay" and the expansion of the universe.

The snail mail delay is basically the following idea. If you send a letter via mail to someone across the country, it's gonna take some time to get there. Maybe a couple of days? A week? So what that means is, whatever information you wrote in the mail, when the receiver actually reads it, it'll be old news. Whatever the receiver is actually learning is something that *was* true a week ago, but may not still be relevant. Of course, if the receiver is in the same state, then the delay is less, maybe one or two days, but there's still a delay. Astronomy works the same way. Light is fast -- the fastest thing in the universe -- but it's not instant. It takes time, and because the universe is so unfathomably huge, it takes millions or billions of years for light to get from one galaxy to another. So when we're studying other galaxies, we're getting the same snail mail delay; what we're seeing is actually a view of the past, and the further away it is, the further back in the past we're seeing.

The expansion of the universe is another distinct effect that only compounds the confusingness of the snail mail delay. If space itself is getting bigger, what does the notion of distance even mean? Or, when a galaxy is moving away from us, is it because it's actually moving away from us, or just because the expanding space between us is increasing the separation? Is there even a difference between those two things? The answer is: sort of, depending on how you think about it. I don't have time to go into detail about this, but if you want to read more, the keywords you google look for are proper distance, comoving distance, peculiar velocity, and hubble flow.

There's one really important case where the snail mail delay and the expansion of the universe sort of interact and produce an effect, and that's redshift. Redshift is a suggestive name -- it refers to any time youve got some light that appears redder to us than it originally used to be. We measure it using a number, labelled z, which is related to the original wavelength and the observed wavelength.

Redshift usually happens because of the doppler effect -- the same reason a fire truck siren is at a lower pitch when the truck is driving away from you. In this case, the velocity of the object is what causes the wave to be stretched into a longer wavelength. Many times, this is the source of redshift in astronomy. But cosmological redshift actually comes about in a different way. What happens is that a galaxy very far away emits some light, and as that light is travelling towards us, the space is expanding. If the light takes a long time to get to us (which is the snail mail delay) then the space will have expanded a nontrivial amount, and the wavelength will have stretched with the space. So the more space has expanded, the more the redshift; and also, the longer the travel time, the more expansion there is; and also, the further away it is, the longer the travel time (that's the snail mail delay). So all four of these things: expansion of space, observed redshift, distance, and lookback time, are all related to each other.

Earlier I said that the highest redshift we've ever observed is around z=10. This corresponds to a very distant galaxy, whose light was actually emitted a very long time ago, when the universe was much smaller than it currently is. For context, the redshift of the nearest galaxy cluster, the virgo cluster, which is 59 million lightyears away, is 0.0038.

The expansion of space is measured using something called the scale factor, denoted by small a. It's a measure of relative length, calibrated so that a=1 today. In the past when the universe was smaller, a was also smaller. To help visualize it you can sorta think of it as the diameter of the universe, in terms of today's diameter, although technically this isn't a fully accurate statement. The expansion of the universe is basically measured by how fast the scale factor changes over time. As I mentioned earlier, it's intimately related to redshift. If we know how much cosmological redshift has occurred for some very distant object, we can calculate the scale factor of the universe at the time the light was first emitted. That's this equation here. As expected, when the redshift increases, since it's in the denominator, the scale factor becomes small. That just tells us that high redshift objects correspond to light emitted when the universe was small.

Observationally, it's easy to report the redshift because it's very easy to measure. But converting a redshift into a specific time in the past, like 10 billions years ago, is extremely tricky. The reason is because the expansion of space is not a constant thing -- it slowed down and sped up in different eras of the universe. The exact formula to calculate the expansion of space as a function of time is called the Friedmann equation, spelled F-R-I-E-D-M-A-N-N. You can read about that on your own time, it's a little too involved to talk about here.

Ok those are the fundamentals. Let's do a crash course in the history of the universe. We know expansion has been happening since the beginning, the big bang 13.8 billion years ago. As I mentioned, it hasn't been expanding at the same rate the whole time, which is why this picture has got this sideways bell shape. There are a lot of significant eras and events in the history of the universe, but I'll only touch on a few.

Let's talk about the first 400,000 years. That might seem like a long time, but it's very short in terms of the universe's age. If the universe was a 17 year old highschooler, this would be the first 4 hours of its life. In this first era, the universe was filled with bright, hot soup of protons, neutrons, and electrons -- no atoms yet. This gas of particles was opaque, which means that all the photons that were produced by this hot gas were bouncing around between them, kind of like the inside of a star, except it's the whole universe. Just like a star, the radiation was a blackbody spectrum. As the universe expanded, the temperature of the gas cooled, and the radiation reflected that. At the end of this period, 400,000 years after the big bang, the ions had gotten just cool enough to start to combine into atoms, and when that happened, the gas became much more transparent. And so from here on out, all the blackbody photons that were bouncing around could just go, fly freely through the universe. At this time, this radiation peaked pretty close to the visible light range, with an effective temperature of around 3000K. Since then, the universe has expanded a LOT, and the light has correspondingly been redshifted. Incredibly, the math works out so that what used to be a blackbody spectrum produced by hot gas is STILL a blackbody spectrum, just now at a much colder temperature. What that means is, that radiation is still flying around the universe, and it still looks like a blackbody spectrum, but now it’s peaked in the microwave band, with an effective temperature just 3 degrees above absolute zero.

This is what we now call the cosmic microwave background -- it’s just the leftover light from when everything was a much hotter soup of particles. Before falling on our telescopes, the last time that light interacted with matter was when the universe was 400,000 years old -- so if we study this “relic radiation” then we can learn more about what the universe was like back then.

So that’s the first 400,000 years -- or 4 hours, if the universe is a high school student. In this analogy, another 6 months pass before the first stars begin to form. After that, galaxies form and things begin to look a little more similar to what it looks like today.

But let’s talk about that bell shape. Why does it look like that? What actually controls the expansion of the universe? As I mentioned earlier, it’s the Friedmann equation that tells you how the universe expands, and the equation basically says that the expansion rate is a sort of tug-of-war between matter, radiation, the curvature of space, dark matter, and dark energy. This tug-of-war is a really complicated situation -- when I took a cosmology class in college, we spent most of the semester talking about just this. But for Science Olympiad, it’s helpful to know a thing or two about the two main players in the game -- dark matter and dark energy.

Ok let’s compare and contrast them. They really don’t have much in common, despite sounding a little similar. The “dark” just means that we don’t understand them well. It’s basically a PR stunt to make it sound cool and ominous. The main thing to understand about them is that dark matter pulls things together via gravity, whereas dark energy pushes things apart. Dark matter accounts for mysterious gravitational forces that are otherwise unexplained. The flatness of many galaxy rotation curves are one prototypical example of this mysterious gravity. The leading hypothesis is that there literally is a new type of matter that we can’t see, and we can only detect via its gravitational pull. If this is the case, then dark matter is thought to account for 85% of all the matter in the universe, with the other 15% being all the other stuff that we can actually see with telescopes. Another possibility is that we just don’t understand gravity as well as we think we do, and maybe it works differently at galactic scales.

Dark energy is basically a mysterious force that causes the universe to expand faster. We call it “energy” because when you do the calculations, it has the same units as energy. And it’s thought to be a property of vacuum itself. In technical parlance, it’s sometimes called the zero-point vacuum energy, or also cosmological constant (although the term “cosmological constant” also has a rich historical connotation that dates back to Einstein). Anyways, in the current era of the universe, dark energy is the most powerful factor, out of all the ones I mentioned before. That explains why the universe is expanding faster and faster -- in other words, why the picture from before has that flared bell shape near the present day.

Finally, let’s end with a case study. This is the bullet cluster, which is actually two galaxy clusters which have collided head-on with each other. The name bullet comes from this image which on the right side here sorta looks like a pink bullet flying through space. This pink is a color code -- so it’s not actually pink -- it’s a color code that represents x-ray light. X-rays are some of the most energetic light that we see, so when we see this big blob of x-rays, we can make an educated guess that this represents a cloud of gas which is very very hot. This makes sense -- when two huge clouds of gas collide with each other at high speeds, then both clouds heat up a lot, due to friction. That’s what these two pink blobs represent -- two clouds of gas that have passed through each other and heated each other up.

But we can also use gravitational lensing to learn more about this DSO. Remember that gravitational lensing is when a massive object bends the light coming from behind it, therefore distorting the image of whatever’s behind it. In this case, by observing the light and carefully figuring out how much it bent, astrophysicists can figure out where the mass is, and that’s shown in blue. And what’s surprising is that it doesn’t line up with the pink, where all the hot gas is.

The explanation is that most of the matter is particle dark matter, which passes through itself uneventfully, and because there’s no friction, it ends up further where the blue is. The remaining regular matter interacts and there’s a bunch of friction, which slows it down, which is why the pink blobs are lagging behind. So many astronomers believe that this is very strong evidence that dark matter is in fact a form of non-interacting matter, as opposed to other hypotheses which say “oh we just have to modify our theory of gravity.” That being said, there are subtle arguments that suggest that the bullet cluster is not quite the smoking gun for particle dark matter that people say it is, no pun intended. But those arguments are probably beyond the scope of science olympiad astronomy.

This was a really long webinar segment, because cosmology is a very rich and conceptually challenging topic. But I think it’s worth learning about, especially since it sorta ties together a lot of topics this year. I hope you guys have learned something from this series and can apply it to your competition season. Good luck this season!