MITOCW | Investigation 2, Part 6

MARK HARTMAN: Invisible light. And Steve, why do we call it invisible light?

AUDIENCE: Because it cannot be detected by the human eye.

MARK HARTMAN: It's invisible to us, but it's not that it's not there. So normally for photons of light a natural unit of energy-- we don't want to deal with stuff that's as big as a joule. A joule is a large amount of energy. We want to deal with one electron volt-- two separate words-- electron volt. That is actually equal to 1.6 times 10 to the minus 19th joules. So is an electron volt a large amount of energy or a small amount of energy?

AUDIENCE: Small.

MARK HARTMAN: What's that, Juan? I couldn't quite hear you.

AUDIENCE: Small.

MARK HARTMAN: It is a small amount of energy. 1 electron volt is actually the amount of energy that it takes to move an electron around a circuit from one side of a battery to another if you have a 1 volt battery. So it's not a very large amount of energy, but then again, photons are streaming out of light sources all the time. So each photon can carry a small amount of energy.

Let's look at how much energy each one of these different kinds of photons can produce, because we've got on our chart here gamma ray light, x-ray light, ultraviolet light, visible light, infrared light, microwave light, and radio light. Let's start at visible light. I'm going to leave this chart up for a little bit of reference for us.

Visible light is typically each photon is somewhere between 2 electron volts and 3 electron volts. So we're just going to say visible light is about 2 to 3 electron volts, and this is the way that we write electron volts. We write it as a lowercase e and a capital V.

So each photon of energy-- somewhere between 2 and 3 electron volts. What would you predict-- knowing what you know about light, what would be the energy of a photon that we would record-- or that we would experience as red? Would it be closer to 2 electron volts or 3 electron volts?

AUDIENCE: 2.

AUDIENCE: 2.

MARK HARTMAN: 2. Why 2, Chris?

AUDIENCE: Because red is low.

MARK HARTMAN: Low energy photons we experience as red. So red photons are down here at around 2 electron volts. Blue photons around 3 electron volts, and I'm rounding off. I don't know exactly what it is, but it's around there.

So what do you think is going to be true about the energy of ultraviolet photons? Is it going to be larger than 3, or is it going to be less than 2 electron volts?

AUDIENCE: Large.

AUDIENCE: It's going to be larger.

MARK HARTMAN: It's going to be larger. If we look here, we have a listing-- ultraviolet is somewhere between 3 electron volts and 10 to the power of 3 electron volts, so 3 electron volts up to 1,000 electron volts. So there's actually a pretty wide range of photon energies that we can deal with. And you don't have to write that one down. That's just as an example.

What about radio light? Radio light is very, very low energy light. It has photons. Each photon carries less than 10 to the minus sixth electron volts, so 1 millionth of the light that a visible light photon carries.

So a lot of you asked in your reflections yesterday, why can't we just have one mega telescope that can be sensitive to all the different kinds of light? Well, the problem is you have to be sensitive to very, very low energy photons, as well as if we look at x-ray photons-- this is the other one that's important to us. X-ray photons have an energy between 1,000 electron volts and 100,000 electron volts. So we're going to say x-rays go from 1,000 to 100,000 electron volts.

I want you to rewrite these two numbers as scientific notation underneath that in your notes. Just real quick, how would you rewrite those as scientific notation? Just write it in your notes, and then I'm going to ask somebody to share. Just a little bit of extra practice with scientific notation. So how do we write 1,000 as scientific notation, Peter?

AUDIENCE: Either 10 to the third of 1 times 10 to the fourth.

MARK HARTMAN: Let's look at that. So 10 to the third, or 1 times 10 to the fourth. What do you guys think?

AUDIENCE: No.

AUDIENCE: No.

MARK HARTMAN: No. Why not, Nicki?

AUDIENCE: I say 1 times 10 to the third power.

MARK HARTMAN: Remember, by putting a 1 in front of something, you just multiply-- you don't change the number after it. So you can write this as 10 to the power of 3 or 1 times 10 to the power of 3, but it's not equal to 1 times 10 to the power of 4. If you had 10 times 10 to the power of 4, that would be-- or I'm sorry. If you had 10 times 10 to the power of 3, that would be 10 to the power 4.

So let's rewrite this 1,000 as 1 times 10 to the power of 3. What about 100,000? Azeith?

AUDIENCE: 10 to the fifth.

MARK HARTMAN: 1 times 10 to the fifth eV, or electron volts. So we can rewrite our range that way. So what we see here is that we've got a really wide range of photon energies. Now, we also have listed under here wavelength, and we're not going to worry too much about that, but we know that high energy photons can be thought of as having a short wavelength. Low energy light can have a very long wavelength, but you'll see there's a bunch of different telescopes here.

We are going to be interested in-- we've already used data from the Hubble Space Telescope, which is sensitive to visible light. The Chandra X-ray Observatory, which you read about this morning, is sensitive to x-ray light. We've got these other things, too. There was a satellite that was up about a decade ago called The Compton Gamma Ray Observatory. It was in space, and it looked at gamma rays. There's also a thing that got decommissioned shortly a little while ago called the Extreme Ultraviolet Explorer, or EUVE. It looked at ultraviolet light.

There's the most recent of the large telescopes that NASA has put into outer space. All of these are space based telescopes. They're satellites. The Spitzer Space Telescope looks at infrared light, and there's also-- there's an older satellite that is now done-- its useful life is over-- called the CoBE satellite-- and it looked at micro-wave, but then there's a bunch of dishes here on earth-- actually in South America-- called ALMA, and it looks at radio light. So there are different telescopes that look at these different energy ranges. So Shakib, do we have our--

True color images let's say in visible light and x-ray light. Now, the process by which we make a true color image is the same thing that we did yesterday. So what I'm going to do is I'm going to draw a little diagram that kind of takes us through the process for what we did yesterday, and then also-- can we not have that in the way?

AUDIENCE: [INAUDIBLE].

MARK HARTMAN: So if people-- I'm not sure what's going on with the screen over there. We're going to diagram out the process of how you make a true color image in both visible light and x-ray light. So the first thing we're going to look at is visible light.

This is yesterday when we used the filters. We use filters to help us filter out only photons of a certain energy. So I'm going to draw-- you want to leave space across your page to have this whole diagram, so I'm going to draw. Here's our source. We looked at the Orion nebula, and then over here we had our telescope, and then we had our detector on the back. So this is our telescope. This is our detector.

And what we did was we put a filter in front of the telescope in front of the detector. So this was a filter. And what does the filter do? The filter only lets through a certain energy of light, a certain range of energies. So red photons, which are around 2 electron volts-- a red filter will only let those photons through. A green filter will only let through green photons.

So what we have is-- I guess I don't have any colored markers, but we have from each point on the Orion nebula there are photons that are being produced and sent out, again, in all directions. We only collect some of them. We only collect the photons that actually get through the filter. Some of them stop if it's the wrong color, and then some of them go through.

So this is the filter color. So the filter colors get through, and then they hit the detector. And so some of our photons end up in the different pixels of the detector. Now, after that, I'm just going to draw a line from the detector from the telescope. That's where we get our images.

So I'm just going to go on to the next line, and we're going to get three images. We've got a red filtered image, a green filtered image, and a blue filtered image. So this is red filtered image, green, and blue. We have to take three separate pictures because we have to put three different filters in front. So first we take an exposure that has a red filter in front. Then we take an exposure-- or another image that has the green filter in front. Then we take another image that has the blue filter in front.

So we use the filters to help us find out energy information, because from our images, the only information that we have is we have the number of photons. So the info in each of those images-- the number of photons at each position on the detector. So we only get the number of photons. When we looked at the images before we put them into the RGB frame, we were just saying, oh, there were five counts in this pixel, and there were three counts or 100 counts in another pixel. So the only information we have is the number of photons at each position.

The color information, or the energy information, comes from the filter. So we get energy information from the filter. So now that we have these three images, we take those three images, and we put them into the computer. Here's our little computer. There's our little keyboard, and we put it into the DS9 image processing software. Image processing means that we can change how we display the image so that we can then combine the images using this image processing software into one true color image.

And we say it's true color because when we have different colors in the image-- here's our image of the Orion nebula. Can somebody toss me a red marker? Anybody see one? Just throw it. Missed it.

So the Orion nebula we saw. It was mostly red. There was a little bit of green and a little bit of blue there, as well. And when we say true color image, we mean an image where the color represents energy because we got the energy information from the filter.

So when something looks red in a true color image, that's because it actually would look red to your eyes if you were out there in space looking at it, because it has higher energy photons-- or I'm sorry. It has lower energy photons that you've collected.

So now what I want to do is to talk about how we make a true color image in x-ray light. I'm going to go through this kind of quickly because you guys are then going to go through it on your own, and we're going to have you create your own true color image in x-ray light.

So in this case, we still have the Orion nebula, but instead of giving off visible light photons, we're going to have it give off x-ray light photons. And I'm going to represent x-ray light photons with a little x. Except when we looked at the Orion nebula, did it look like a cloud when we looked at it in x-rays? What did it look like?

AUDIENCE: Light.

AUDIENCE: [INAUDIBLE].

MARK HARTMAN: What did it look like?

AUDIENCE: A bunch of stars.

MARK HARTMAN: A bunch of stars.

AUDIENCE: A bunch of stars.

MARK HARTMAN: A bunch of stars. It looked like a bunch of points, round dots. It didn't have all this weird kind of fuzzy stuff. So it's not the cloud. It's not the fuzzy stuff that's giving off the x-rays, but it's the actual stars that are giving off x-rays. And they're giving off x-rays that are moving outward in all directions.

Now, again, now we have the Chandra telescope, and to make it look like Chandra we're going to put-- well, yeah, we'll put the little wings on it. So this is the Chandra telescope. And then we have again same kind of idea. We have a detector, except this detector is sensitive to x-rays. However, from this detector, we only get one image.

We don't need filters in front of the Chandra telescope because this detector works differently. The x-rays still come in. Some of them miss. Some of them go in. The ones that go in are the ones we collect. So that's our flux, but at the detector, it still tells you in different pixels how many x-ray photons you get, but in the picture now, which kind of looks like this because it's a picture of that three dimensional thing up above-- now we get the number of photons, which is the same as in the visible light image. We get the number of photons at each position, but we also get-- and we get the energy of each photon.

So in this case, our energy information is actually collected on the detector. Each time a photon hits the detector, Chandra says, OK, the photon hit right here on the detector, and it hit with an energy of 100 electron volts-- I'm sorry-- of, say, 2,000 electron volts. So the detector sits there. I got another x-ray photon, and it landed at this place on the detector, and it has an energy of 50,000 electron volts. And this process just goes on, and on, and on.

So from this one image, we get the number of photons in each position and the energy of each photon. We take that-- just the one image. We go to our computer, which looks a little bit worse for wear than the first computer because I can't draw it as well. And we don't use DS9. We use the Chandra education tools. That's what we get to when we go to the virtual observatory, and we get those extra tools that we can pull up, that extra pull down.

Using those Chandra education tools, we filter out the different energies in the computer. We don't have a special filter out front, because if we've recorded the energy of each photon, we can actually tell the computer, OK, now, computer, show me only the photons that have low energies-- say, between 1,000 electron volts and 2,000 electron volts. So we do the filtering because the energy information is already there. And what comes out-- we can get high energy image, which means the light-- the photons that we've collected there have high energies.

So we're going to get a high energy image. We're going to get a medium energy image. And that means an image that has medium energy photons. We're actually going to use the range for the high energy photons. We're going to say 4,000 electron volts to 8,000 electron volts. For medium energy image, we're going to say 1,600 electron volts to 4,000 electron volts. And for low energy, that's going to be 300 electron volts up to 1,600 electron volts.

Chandra is actually sensitive to a little bit lower than 1,000 electron volts. So just like that detector was a little bit sensitive to the infrared light, now we are going to separate out all the photons that are in these different ranges. So we've created the images afterwards. Again, we put them back into the computer, and we still use the DS9 image processing software to put the images together. So DS9 image processing-- again, here's the computer. And we put that together to make a true color image.

Well, let me ask you this. What do we mean by x-ray color? Do x-rays have a red color or a blue color?

AUDIENCE: No.

MARK HARTMAN: Who said that?

AUDIENCE: Me.

MARK HARTMAN: So what color are x-rays?

AUDIENCE: Black and white.

MARK HARTMAN: Black and white. Well, that's right, because we can count the intensity of the photons. We can count the number that we've collected, the flux, but how do we represent this, Azeith?

AUDIENCE: X-rays usually [INAUDIBLE].

MARK HARTMAN: Say that again.

AUDIENCE: They say it's red, red, red, red color [INAUDIBLE].

MARK HARTMAN: So we can see it is a red color, but I thought red photons had an energy of 2 electron volts. Here we've got like 300 electron volts. Can we-- go ahead, Steve.

AUDIENCE: Are they invisible?

MARK HARTMAN: Those colors are invisible to us. This range of x-rays-- if we had x-ray eyes, we would experience it in a different way. Our mind would say, oh, this looks like banana, some new thing that we can't interpret. So x-ray colors don't mean anything to us because we can't see x-rays. We have no experience of what these would look like, but what we can do is we can make an analogy. And we can say, well, when we look in images, or when we look at things, we see low energy photons as red. And we see medium energy photons-- low energy meaning 2 electron volts is red. Maybe 2.5 electron volts is green. 3 electron volts is blue.

Well, let's do that same thing, and let's just kind of pretend that low energy x-ray photons will represent in our image as red, will represent medium energy x-ray photons as green, and will represent high energy x-ray photons as blue. It's not that that's the actual color, but if we were to make a true color x-ray image, it would just be blank, because we can't see x-ray colors.

So what we have to do is we have to add on, and we represent these different energy ranges with color. Now, the reason we still call it a true color image-- where did my blue marker go? Is again, it's a true color image because now still color represents energy-- energy of the photons, but we have to tell people. When we make this true color image, well, red actually means any x-ray photon that's between 4,000 electron volts and 8,000 electron volts.