MARK HARTMAN: Remember that every detector is not sensitive to every kind of light. In particular, when I shine this remote control at you, you don't see the light because your eyes aren't sensitive to the photons that this emitter is putting out. This emitter is putting out photons that are a little bit less than two electron volts-- well, I think a little bit less than 1.8 electron volts, and your eyes don't pick up that energy. When those photons hit the back of your eyes, it doesn't send a little signal to your brain, but if I shine this at our projector, if you look on the screen, you can see that we can tell that there is a little light flashing. In that case, that detector is sensitive to photons that have that low of an energy.

However, if I were to look at something with a telescope, I'm not always going to get the same number of photons that my source puts out. I'm putting out photons here, but when I look at it, I'm not collecting that. It's not that there's no flux there or that there's no flux to collect. I'm just not sensitive to it. So we are going to put together a little model that's going to help us answer this question-- how is-- and again, I want you to write a couple of these notes down. So today is the 11th, and it is about 10:10. How is the light we record different from what the source emits?

And we're going to draw a little diagram. Again, we're going to have-- and here's our source. It could be a cloud like we said with the Orion nebula. It could be some stars. It's putting out light in all directions. Some of that light happens to be moving towards us, and over here-- I want you to leave some space in the middle because we're going to come back to this in a second. Over here, we've got our detector. It's this grid of pixels.

We said that the detectors are at the back of our telescopes. So our telescope is going to collect some of this light. It's going to keep going this way. Some of it is going to get here to our detector. Now, if we were to grab all the light from right here-- if we were to take this light-- if we were to take all the light that we could just grab from right there, and if we could somehow grab that and look at it and we wanted to look at its spectrum, we look at the intensity. We look at a bar chart of intensity versus energy. And in particular, we could say we'd look at red, yellow, green, and blue.

This histogram tells us what kind of light is the source giving out, but the only thing that we can measure is what our detector tells us. So from the detector, we actually would get a different intensity versus energy graph-- red, yellow, green, and blue. What we're going to do-- we are going to represent-- we're going to model. We're going to make a model, and each group is one part of the source or detector.

So half of us are going to be the source. We're going to be one part of the source, and we're going to give out light. And then one part of us is going to be one pixel of the detector. We're going to look at a thing called detector response, and what detector response means is we record only part of the light, and that depends on what the energy of the photons are.

So here we have-- I've reversed them. So here we have the source from our flat spectrum. This is what the spectrum looks like when the source produced it. It's flat. It's just bars that go straight across, but our detector-- what is different about our detector, what it shows to us?

AUDIENCE: Took out some.

MARK HARTMAN: Say that again.

AUDIENCE: Took out some of the photons.

MARK HARTMAN: It took out some of the photons?

AUDIENCE: It didn't collect all the photons.

MARK HARTMAN: It didn't detect, or it didn't collect all of the photons. They were there, but the detector wasn't-- it's not as sensitive to blue light as it is to red light. So even though the source gave out a spectrum that looked like this, the detector gives us in our measurement a spectrum that looks like that.

So let me ask you this. What if I had-- in the same way, this is the response of our eyes. Our eyes are less sensitive to blue light. So if we had a spectrum where the same amount of blue was put out, it would look like a lower intensity to us. I want you to just give a prediction, and I just want you to sketch in your notebook what would a flat spectrum look like if, instead of having this detector response, maybe we had a different detector that was made out of a different material? And instead, we kept two out of five red, three out of five yellow, four out of five green, and five out of five blue? Say our detector was sensitive to blue, and it detected everything, but it wasn't very sensitive to red.

So in this case, let's look at what we came out with. What is different between these two graphs?

AUDIENCE: [INAUDIBLE].

MARK HARTMAN: You may have to squeeze over a little bit.

AUDIENCE: [INAUDIBLE].

MARK HARTMAN: So how would you describe the difference between these two energy histograms or spectrums-- spectra?

AUDIENCE: Spectra.

MARK HARTMAN: It's giving us the number of counts in one second that were emitted, and then this is the number of counts in one second that we collected at our detector. We didn't collect all of them. So how would you describe the difference between these using the words intensity and energy?

AUDIENCE: The intensity of the first one is higher.

MARK HARTMAN: The intensity of this one is higher because the bars are higher. The y-axis measures in density. So what we detect-- we detect less intensity. What else?

AUDIENCE: And there was more energy in the first one, and there's less energy in the second. We collected less energy.

MARK HARTMAN: Which axis here has to do with energy?

AUDIENCE: The one with the photons.

MARK HARTMAN: The x-axis, right? So I think you're saying here at high energies, or blue photons, there was a lot that were put out, but we didn't actually collect a whole lot. Is that what you're trying to say? What else? Azeith?

AUDIENCE: The intensity is low for yellow and green. When it started off, was high, and when it got to the detector, it equaled out.

MARK HARTMAN: So even though our source put out more yellow-- or, I'm sorry-- put out more green-- or put out more blue than green and yellow, what we detect is that it actually collects or records a little bit more green and yellow than it does blue. Well, that's great. Doesn't that screw us?

If we're interested in what's physically going on at the object, but we record this, how is that useful at all? How can we get around this problem? David, what do you think?

AUDIENCE: The ratio is from what you have to receive to get the source's actual emissions.

MARK HARTMAN: If I know how my detector responds, if I know that it only collects two out of five or five out of five, I can take my measurements, and I can kind of turn it back into this. So I have to know exactly what my detector is doing to be able to then reconstruct or figure out what's really going on over here. So I want you guys to take a break, and I want you to--

For each group, you guys are the source, you guys are the cloud, you guys are the detector. So I want you to figure out who's going to be responsible for red light, red photons, who's going to be responsible for yellow photons, who's going to be responsible for green, and who's going to be responsible for blue. Same thing over there. And then I want you to add this to your notes.

[SIDE CONVERSATION]

So I want you guys to add this onto your notes. We're going to put on interstellar material. Interstellar just means in between the stars. So if we're looking at another star, we're looking at interstellar material. If you're looking at another galaxy, you may be looking at intergalactic material, but we've still got our source. It's still sending out photons in all directions.

The photons move this way, some of them, and we're looking first at the-- if we were to grab these photons and look at the intensity right there. Then we've got some photons that go through here, some photons that get stopped here. So some photons get stopped there. So now we're going to actually put in another graph, and we're going to say, let's look what do these photons-- so first we're going to look at the source. Then we're going to look at what the photons after they've passed through the cloud-- what do those look like in intensity as a function of energy? And then those-- the cloud-- that light gets to the detector, and then the detector is going to say, all right, what do I detect? So in each of these cases, we're going to look at what is the spectrum of the light just after the source, just after the interstellar material, and then by the time it gets to the detector.

So I know you guys are in the middle of predicting, but let's take a look at what we actually had. So if everybody needs to scoot in a little bit, here we had our source from our flat spectrum. We had 20 photons of each color. What happened after it went through the cloud? Oh, I wanted us to keep the same scale, but we'll see. So what happened when it went through the cloud?

AUDIENCE: Which one's the cloud?

AUDIENCE: The middle.

MARK HARTMAN: So this is just-- so this represents this light that just came out of the source. The middle represents the light after it came out of the cloud, and then the right hand one represents the light that we actually record from the detector. So in this case-- good. Nice. Good work. So what happened to the light that came from the source? After it went through the cloud, how was it different?

AUDIENCE: The could collects some photons from the source.

MARK HARTMAN: Use the word energy in that sentence.

AUDIENCE: The cloud collects some energy from the source.

MARK HARTMAN: Does it collect energy as red photons? Does it stop photons with energies that we see as red?

AUDIENCE: No. It only collects green and blue.

MARK HARTMAN: So the cloud collects or stops some green and some blue. This is what was let through. So we started off with all the same, but when we let through, we see that blue is let through less. So we went from 20 photons per second down to-- what is this, 12? 12 photons per second.

So then, of course, we can't go out in space and grab that light. We still have to grab what we see from the detector. Now, what is the difference from the detector? It's hard to tell because they expanded their scale and put 0 to 20 all the way up here, but let's compare.

We've got 20 counts of red that we got through the cloud, but we detect 20 counts of red. Then we only detect 12 counts of yellow, but there were 20 counts of yellow before. So what happened to some of the yellow light?

AUDIENCE: It got stopped. It didn't get collected by the detector.

MARK HARTMAN: It didn't get detected. The photons hit there, but it didn't get detected. What about green light? What happened to the green light? Here we had 16, and here we have 10.

AUDIENCE: It reduced even more.

MARK HARTMAN: It did what?

AUDIENCE: It reduced even more.

MARK HARTMAN: It reduced even more because the detector response is even lower at blue-- or, I'm sorry-- at green light. What about blue? We started with 20 in blue. After the cloud, we only had 12 left, and down here the detector only picks up four. So what happened?

AUDIENCE: It's the least sensitive to blue.

MARK It's least sensitive to blue, and the cloud knocked out a lot of our blue light, just like we saw over there in the bin.

HARTMAN: So what I want you guys to do now. I want--