SECRET IN SUNLIGHT
UNDERSTANDING SPECTROSCOPY

STARRING CAMILLA CORONA AND COLOURS O’IRIS

STORY & DESIGN:
DEBORAH SCHERRER AND EMILY KELLAGHER
Hey Camilla, I've always been fascinated by the stars. I think I'll get a telescope to study them.

But colours, no matter how big your telescope, a star only shows as a point of light. What you really need is a spectrograph.

What's a spectrograph? Sounds intimidating...
THE BEST WAY TO LEARN ABOUT DISTANT OBJECTS LIKE THE SUN AND STARS IS THROUGH THEIR LIGHT - THE ENERGY THEY PRODUCE. WE CALL THIS COLLECTION OF ENERGY THE ELECTROMAGNETIC (EM) SPECTRUM.

LIGHT HAS SECRETS INSIDE, WHICH PROVIDE INFORMATION ABOUT THE SOURCE. IT'S LIKE SOLVING A MYSTERY!

Mysteries are fun! How could light have secrets? How can we uncover them? What do they tell us about the stars?

GOOD QUESTIONS! THIS IS WHERE THE SPECTROGRAPH COMES IN. IT'S ACTUALLY A SIMPLE TOOL TO STUDY THE "INSIDE" OF LIGHT. THINK OF IT AS A WAY TO LOOK AT THE SPECTRUM OF LIGHT.
WHAT’S THE SPECTRUM OF LIGHT?

...AM I A SPECTRUM OF LIGHT?

ANYTHING HOTTER THAN ABSOLUTE ZERO (THE COLDEST POSSIBLE TEMPERATURE) EMITS ENERGY, I.E. LIGHT. YOU & I EMIT ENERGY, ROCKS EMIT ENERGY, RUBBER DUCKIES EMIT ENERGY, STARS EMIT ENERGY!

THE SPECTRUM OF LIGHT IS THE COLLECTION OF ENERGY/RADIATION SOMETHING EMITS.

THE SUN & STARS EMIT A CONTINUOUS SPECTRUM OF RADIATION (I.E. LIGHT).
YIKES - WHAT IS A “CONTINUOUS SPECTRUM OF RADIATION”?

OH, THAT’S FANCY FOR THE COLLECTION OF ALL TYPES OF LIGHT: RADIO WAVES, MICROWAVES, INFRARED, VISIBLE, ULTRAVIOLET, X-RAYS, AND GAMMA RAYS. LET'S CALL IT THE EM SPECTRUM FOR SHORT.

THE EM SPECTRUM

THINGS LIKE RADIO WAVES, VISIBLE LIGHT, AND X-RAYS ARE ALL THE SAME TYPE OF ENERGY...

THEY ONLY DIFFER BY THE SIZE OF THEIR WAVELENGTH.

SO ALL THE ENERGY Emitted BY SOMETHING LIKE A STAR - THE EM SPECTRUM. AND, LIKE YOU SHOWN ME WITH WHITE LIGHT, DIFFERENT ENERGIES OF LIGHT HAVE DIFFERENT WAVELENGTHS, OR COLORS.

RIGHT!

WOW, HE GOT IT!
Can you show me the EM spectrum?

The only part you can see with your eyes is visible light. Here's a chart of it.

When... so a spectrograph is a tool that looks at the EM spectrum, the light/energy/radiation from the sun and stars.

Right! There are different types of spectrographs -- for different types of light like radio, infrared, UV, & X-rays. For now, let's talk about visible light cause it's, ah, easier to see than gamma rays.
A spectrograph works like a prism - it breaks visible light into its colors. It's really simple!

Output of a spectrograph

Hey - that looks like you cut a piece out of a rainbow!

But all I see are the colors of the rainbow. Where are the secrets you mentioned?

It's like looking at a rainbow with a microscope. If you look very closely at the spectrum of colors, there are secrets inside.
Sometimes you see extra bright colors:

And sometimes you see missing colors:

The extra-bright or missing colors indicate certain chemical elements have affected the light.

What’s a chemical element?

Chemical elements are those things you see on a periodic table of elements - the building blocks of the universe, like hydrogen, helium, gold, and einsteinium.
BUT I THOUGHT ELEMENTS WERE ONLY ON EARTH. THEY ARE IN THE SUN AND STARS TOO???

THINKING ... WHY DON'T THEY BURN UP?

YIKES, HOW DID THAT HAPPEN???

TELL YOU LATER...

ALL THE ELEMENTS CAME FROM THE STARS!

EACH CHEMICAL ELEMENT CHANGES THE SPECTRUM EITHER BY MAKING CERTAIN COLORS BRIGHTER OR REMOVING CERTAIN COLORS. EACH ELEMENT HAS A DIFFERENT AND UNIQUE PATTERN OF COLORS.

Periodic Table of Elements

LIKE FINGERPRINTS!

YES, LIGHT HAS FINGERPRINTS!!

HERE ARE THE SUN'S FINGERPRINTS
Cool! But why are some of those bars bright, and some dark?

In this image, the dark lines are because hydrogen has absorbed those particular colors. Hence we call the dark lines “absorption lines”.

Those bars, the little stripes of color, are called lines cause they, ah, look like lines in the spectrum.

The bright lines in the lower image show that hydrogen has emitted extra colors. So we call those lines “emission lines”.

So an element either adds or subtracts the same set of colors, of lines.
I get it! Elements can affect the light by either absorbing or emitting certain colors. Each element’s colors are always the same, like human fingerprints.

I wonder if his feather colors have fingerprints?

Whether something produces an absorption or emission spectrum depends on its temperature, the temperature of any gas between it and the observer, and the observer’s line of sight.

I’ll tell you about that in another story.
Sure, I have a little spectrograph I got from the Stanford Solar Center. It’s really cute, and I made it myself.

All it has is a cardboard frame, a diffraction grating, a scale to read the spectrum. It also has an eyepiece and needs an eye to look through it.

What’s a diffraction grating?

A grating works a bit like a prism - it separates out the colors of light. Rain droplets do the same when they create a rainbow. Or you can shine light on a CD, or you can look at an oil slick, or ....

Ok, I get it. The diffraction grating breaks light into its colors.

Wanna try it with Camilla and colours? Build your own spectrograph now! Then finish reading "Secrets in Sunlight"!

HERE - POINT THE SLIT (OPENING IN THE BOX WHERE THE LIGHT CAN GET IN) AT THAT INCANDESCENT LIGHT BULB. THEN LOOK THROUGH THE EYEPIECE! WHAT DO YOU SEE?

WOW - I SEE WHAT LOOKS LIKE A RECTANGULAR RAINBOW! JUST LIKE THE PIECE OF RAINBOW YOU SHOWED ME EARLIER.

YES! THAT'S WHAT WE CALL A CONTINUOUS SPECTRUM -- MEANING ALL THE COLORS OF VISIBLE LIGHT ARE THERE.

NOW, TRY LOOKING AT THIS FLUORESCENT BULB. WHAT DO YOU SEE?

IT'S KINDA THE SAME RAINBOW, I MEAN CONTINUOUS SPECTRUM, EXCEPT THERE ARE SOME EXTRA BRIGHT LINES. I SEE A YELLOW ONE, A BRIGHT GREEN ONE, AND A PURPLE ONE. WHAT DO THEY MEAN?
LET ME SHOW YOU SOMETHING. HERE IS THE SPECTRUM FROM A MERCURY LIGHT. DOES IT LOOK FAMILIAR?

IT'S GOT THE SAME BRIGHT LINES AS THE FLUORESCENT LIGHT! BUT IT DOESN'T HAVE THE BACKGROUND RAINBOW.

WHERE DO YOU THINK THE BRIGHT COLORS COME FROM?

THE BACKGROUND COLORS COME FROM THE LIGHT-PRODUCING ELEMENT IN THE FLUORESCENT LAMP.

OH - I GOT IT - MERCURY! THERE MUST BE MERCURY IN THE FLUORESCENT LIGHT!!!!

YEP. THAT'S WHY WE CAN'T THROW FLUORESCENT LIGHTS AWAY IN LANDFILL. THEY HAVE POISONOUS MERCURY IN THEM.
This really is exciting! What other secrets do spectra tell us?

We've already seen how emission or absorption lines mean a specific chemical element has affected the light.

Spectra also tell us about temperature, movement, and magnetic fields.

All that?

Even more, but let's start with these...

Temperatures????

The Sun in various wavelengths of high temperature ultraviolet light
SURE. IF YOU LOOK AT THE MOST PROMINENT WAVELENGTHS OF LIGHT COMING FROM A STAR, YOU CAN CALCULATE ITS TEMPERATURE. LOTS OF LONG WAVELENGTH, LOW ENERGY COLORS, LIKE RED, MEAN A DIM STAR. HIGH ENERGY, SHORT WAVELENGTH COLORS LIKE BLUE SHOW A HOT STAR.

SO A RELATIVELY COOL STAR MIGHT BE RED OR ORANGE, WHILE A HOT STAR MIGHT APPEAR BLUE OR VIOLET?

ALMOST.... THERE AREN'T ANY VIOLET STARS, BUT THERE ARE LOTS OF RED, ORANGE, AND BLUE ONES.

SOME STARS EVEN PEAK IN THE ULTRAVIOLET OR INFRARED RANGES!

OUR SUN PEAKS IN THE VISIBLE LIGHT RANGE, MEDIUM WAVELENGTHS, SO LOOKS WHITE.
SO BEINGS ON PLANETS AROUND ULTRAVIOLET OR INFRARED STARS MIGHT HAVE DIFFERENT KINDS OF EYES THAN US?

YES, BUT BACK TO TEMPERATURES - IT TAKES DIFFERENT TEMPERATURES TO PRODUCE THE DIFFERENT LINES IN THE SPECTRA. IF A STAR'S SPECTRA IS SIMILAR TO OUR SUN'S, YOU KNOW ITS TEMPERATURE IS ABOUT 6000 K.

COOL...I MEAN HOT!

SPECTRA ALSO TELL US ABOUT MOVEMENT.

HOW COULD COLORS TELL ABOUT MOVEMENT???

YOU LIKE STAR WARS, RIGHT?

OF COURSE I DO - EPISODE IV IS MY FAVORITE!
Remember when those guys were zooming around on their speeders?

Oh sure. That works for ambulances and trains too. It's the Doppler shift.

When they came toward you, the pitch of their engine went up. After they passed you, the pitch went down.

Yes - the Doppler shift. It happens when a sound is moving towards or away from us. As it moves towards us, the sound waves get bunched up and the wavelengths become shorter. As it moves away from us, the sound waves get stretched out and become longer.

I get that. Pitches with longer wavelengths are lower and those with shorter wavelengths are higher. But how does that work with light?

This works with any type of waves, not only sound & light.
When an object like a star or galaxy is moving away from us, its spectrum gets stretched out, meaning its wavelengths get lengthened and the colors go down in “pitch”. They shift to longer wavelengths. So violet becomes more blue, green becomes more yellow, and orange becomes more red. We call this a “red shift”.

For an object moving towards us, its colors get “squeezed” more towards the short-wavelength blue end of the spectrum, hence the term “blue shift”.

Why isn’t it called a violet shift?

Sigh, I dunno. Maybe cause our eyes don’t see violet very well. Scientists usually talk about the visible spectrum as red-yellow-green-blue. Why don’t you try googling that?

OK, I get the red and blue shifts. You also said that spectra tell us about magnetism. How does that work?
Well, sunspots are magnetic disturbances on the Sun. The arching prominences you see are plasma caught in the magnetic fields. You can imagine it like this:

There are magnets on the Sun???

Not magnets, magnetic fields!!!

When you look at a spectrum of light that's come from a magnetic field, like around a sunspot, the lines end up splitting!
WHOA - THAT'S AWESOME! WHY DOES THAT HAPPEN?

IT'S COMPLICATED AND HAS TO DO WITH HOW ELECTRONS BEHAVE IN ELECTRIC AND MAGNETIC FIELDS. I'LL TELL YOU LATER...

SURE IS A LOT TO LEARN "LATER" ...

SO SCIENTISTS MUST SPEND ALL DAY LOOKING AT RECTANGLES OF COLORS?

NOT EXACTLY. SCIENTISTS USE COMPUTERS, AND COMPUTERS DON'T DEAL WITH COLORS VERY WELL.

INSTEAD, THE SCIENTISTS GRAPH THEIR SPECTRA DATA.

THIS WAY THEY CONVERT COLOR PICTURES INTO NUMERICAL DATA THAT COMPUTERS CAN HELP THEM ANALYZE.

A spectrum can be graphed as wavelength vs. intensity. That turns the colors into numbers.

Location and shape changes of the line give us a lot of additional information.
NOW I GET WHY SCIENTISTS USE SO MANY GRAPHS!

THIS IS REALLY EXCITING! IF I WANT TO STUDY THE SUN OR STARS I NEED A SPECTROGRAPH AS WELL AS A TELESCOPE. THAT WAY I CAN LEARN ABOUT WHAT ELEMENTS ARE IN THE STARS, HOW HOT THEY ARE, ABOUT THEIR MOVEMENT, AND EVEN ABOUT THEIR MAGNETIC FIELDS.
YES! IN FACT, ALMOST ALL ASTRONOMY IS DONE WITH SPECTROGRAPHS.

THE EVE INSTRUMENT ON NASA'S SOLAR DYNAMICS OBSERVATORY IS A SPECTROGRAPH.

NAGA'S INTERFACE REGION IMAGING SPECTROGRAPH (IRIS) IS OBVIOUSLY A SPECTROGRAPH.

HUBBLE EVEN HAS SPECTROGRAPHS!

HOW COME NOBODY EVER TOLD ME ABOUT SPECTROGRAPHS BEFORE???

...YOU SHOULD HAVE PAID MORE ATTENTION IN CLASS...
RESOURCES

TO GET SPECTROGRAPHS FOR YOUR CLASSROOMS:
HTTP://SOLAR-CENTER.STANFORD.EDU/POSTERS/POSTERS_SPEC_BULK.HTML

ABOUT NASA SOLAR MISSIONS:
SDO - HTTP://SDO.GSFC.NASA.GOV/
IRIS - HTTP://IRIS.GSFC.NASA.GOV/
STEREO - HTTP://WWW.NASA.GOV/MISSION_PAGES/STEREO/MAN/
SOHO - HTTP://SOHOWWW.NASCOM.NASA.GOV/

FOR STUDENTS:
FOR A COOL VIDEO ON HOW THE STANFORD SOLAR TELESCOPE IS REALLY A SPECTROGRAPH, SEE:
HTTP://SOLAR-CENTER.STANFORD.EDU/COLORS

FOR LOTS OF EXPERIMENTS AND ACTIVITIES ON SPECTRA, GO TO
HTTP://NASAWAVELENGTH.ORG AND SEARCH ON “SPECTRA”

THE STANFORD SOLAR CENTER HAS ACTIVITIES ABOUT THE SUN TO EXPLORE:
HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES

FOR TEACHERS:
FOR RESOURCES RELATED TO SPECTROSCOPY SEE:
HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES/COTES.HTML

FOR A POWERPOINT PRESENTATION ON THIS TOPIC, SEE:
HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES/FINGERPRINTSINSUNLIGHT/

THE STANFORD SOLAR CENTER HAS TEACHING RESOURCES RELATING TO THE SUN:
HTTP://SOLAR-CENTER.STANFORD.EDU/TEACHERS