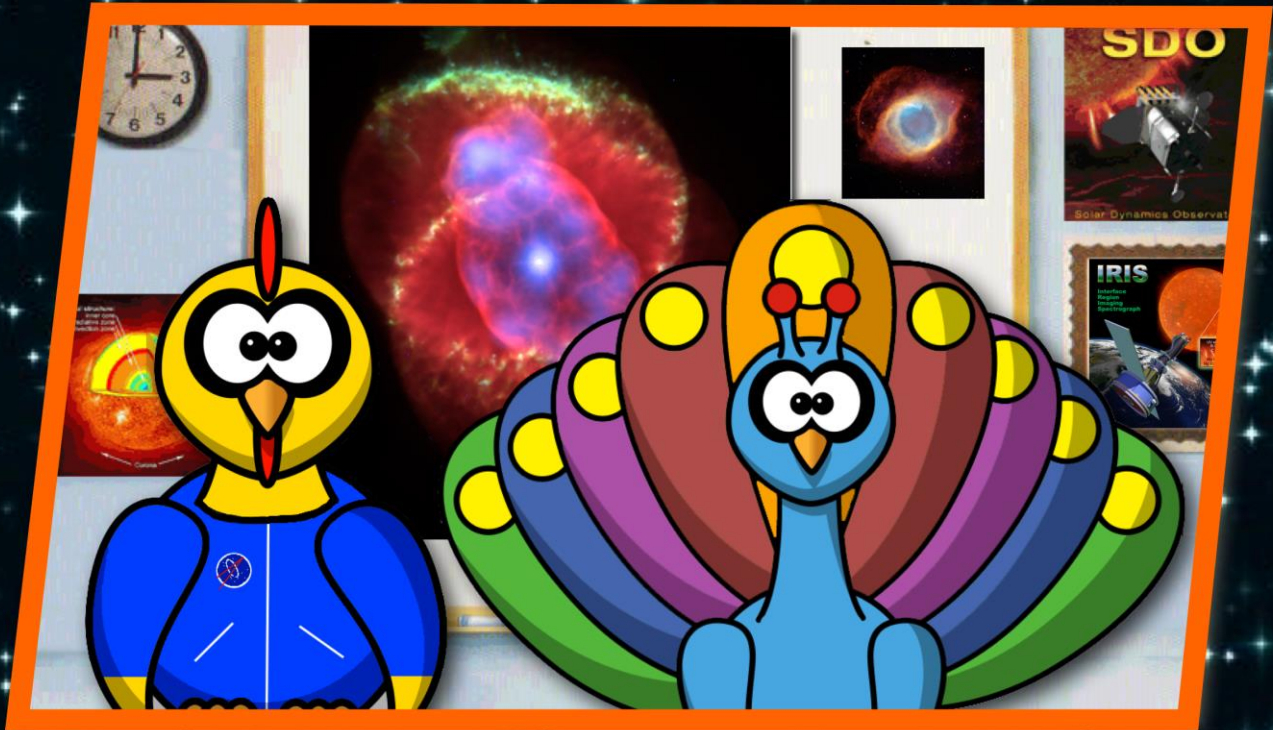




STANFORD SOLAR CENTER



SECRETS IN SUNLIGHT

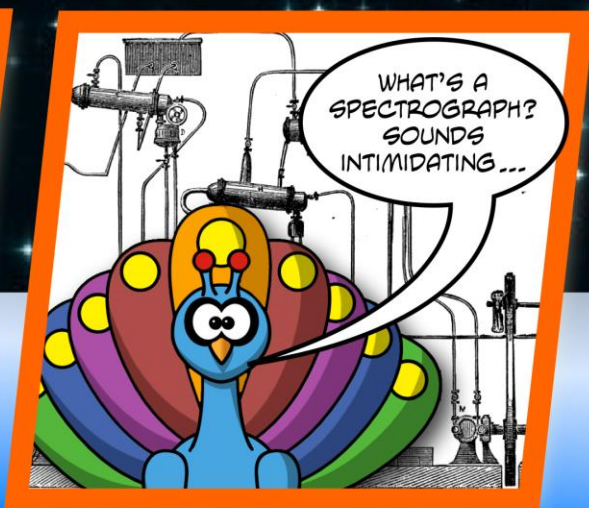
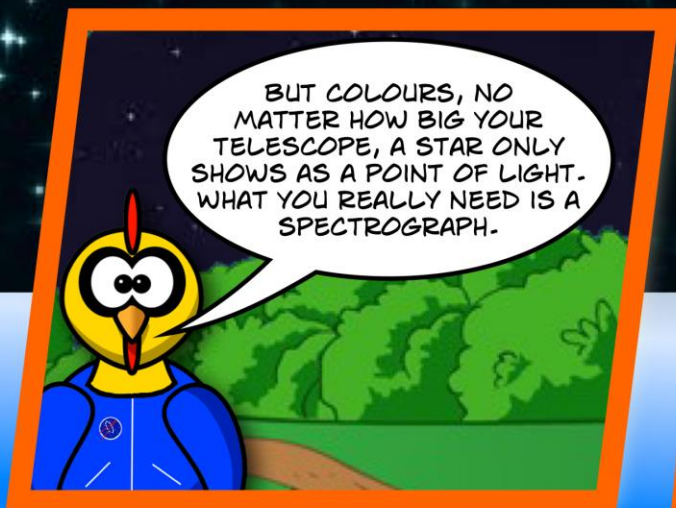
UNDERSTANDING SPECTROSCOPY

STARRING CAMILLA CORONA AND COLOURS O'IRIS



STORY & DESIGN:
DEBORAH SCHERRER AND EMILY KELLAGHER

SECRETS IN SUNLIGHT



THE ELECTROMAGNETIC SPECTRUM

Wavelength (in meters): 10^1 10^2 10^3 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}

Size of a wavelength: larger → smaller

Common name of wave: RADIO WAVES, INFRARED, VISIBLE, ULTRAVIOLET, "HARD" X RAYS, GAMMA RAYS

Sources: AM Radio, FM Radio, Microwave Oven, Radar, People, Light Bulb, The Sun, X-ray Machine, Gamma-ray Emitters

Energy (in joules): 10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

Frequency (in hertz): 10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

Frequency (in cycles per second): 10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

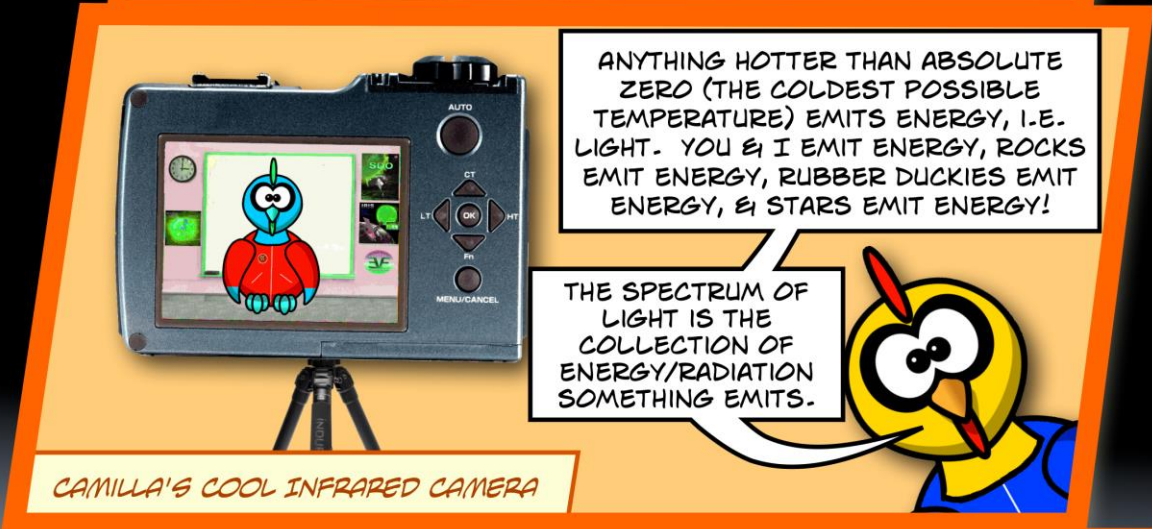
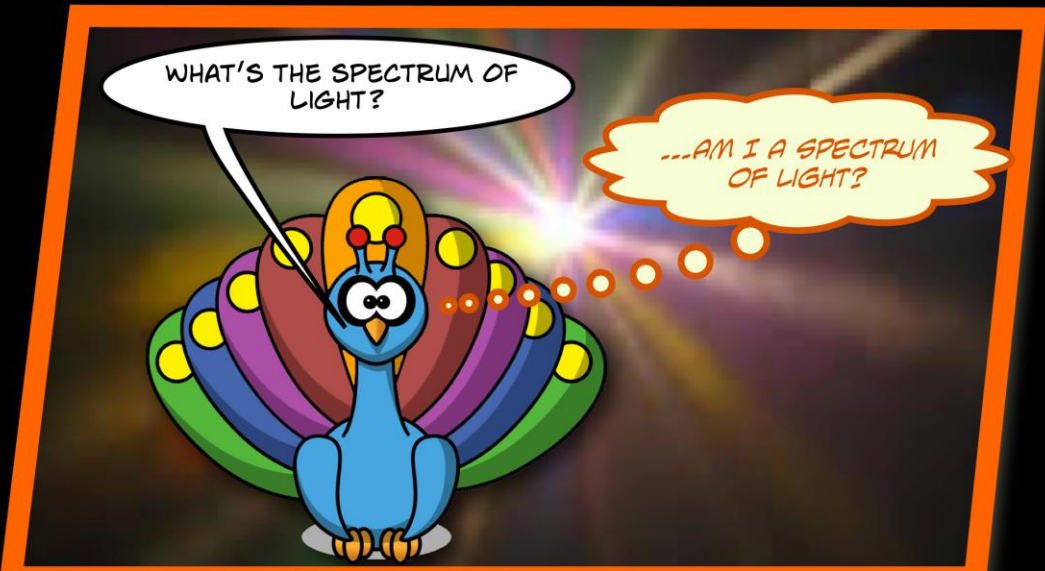
Frequency (in cycles per second): 10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

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.

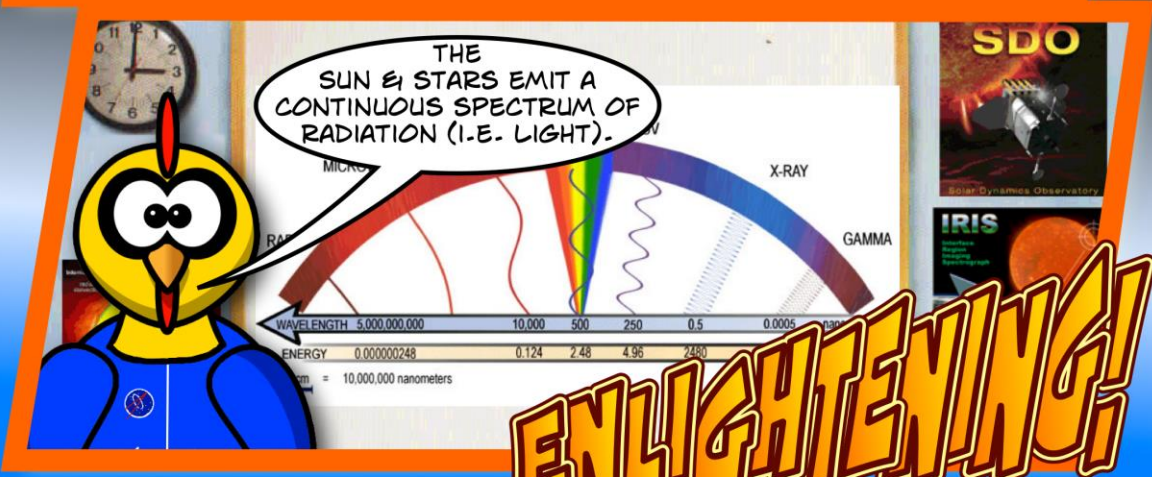
LIGHT HAS SECRETS INSIDE, WHICH PROVIDE INFORMATION ABOUT THE SOURCE. IT'S LIKE SOLVING A MYSTERY!

MYSTERIES ARE FUN! HOW COULD LIGHT HAVE SECRETS? HOW CAN WE UNCOVER THEM? WHAT DO THEY TELL US ABOUT THE STARS?

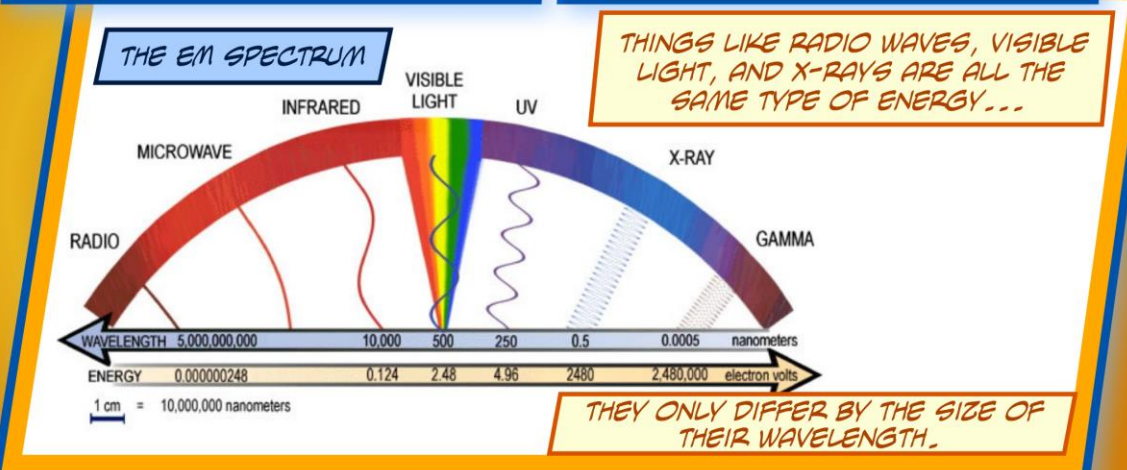
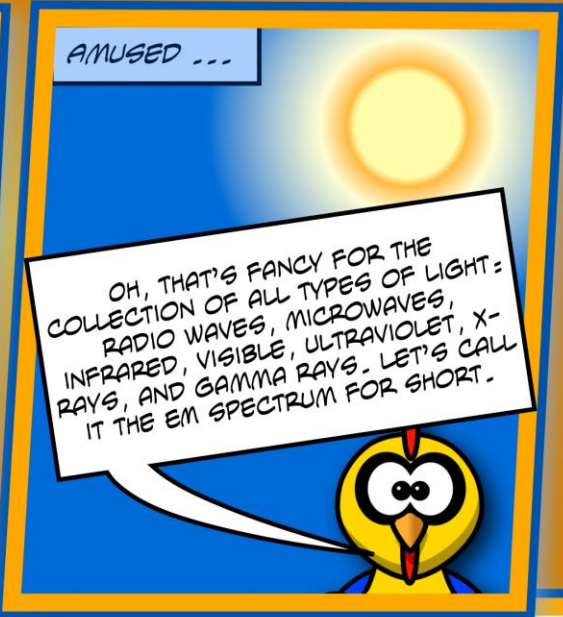
GOOD QUESTIONS! THIS IS WHERE THE SPECTROGRAPH COMES IN. IT'S ACTUALLY A SIMPLE TOOL TO STUDY THE "INSIDE" OF LIGHT. THINK OF IT AS A WAY TO LOOK AT THE SPECTRUM OF LIGHT.

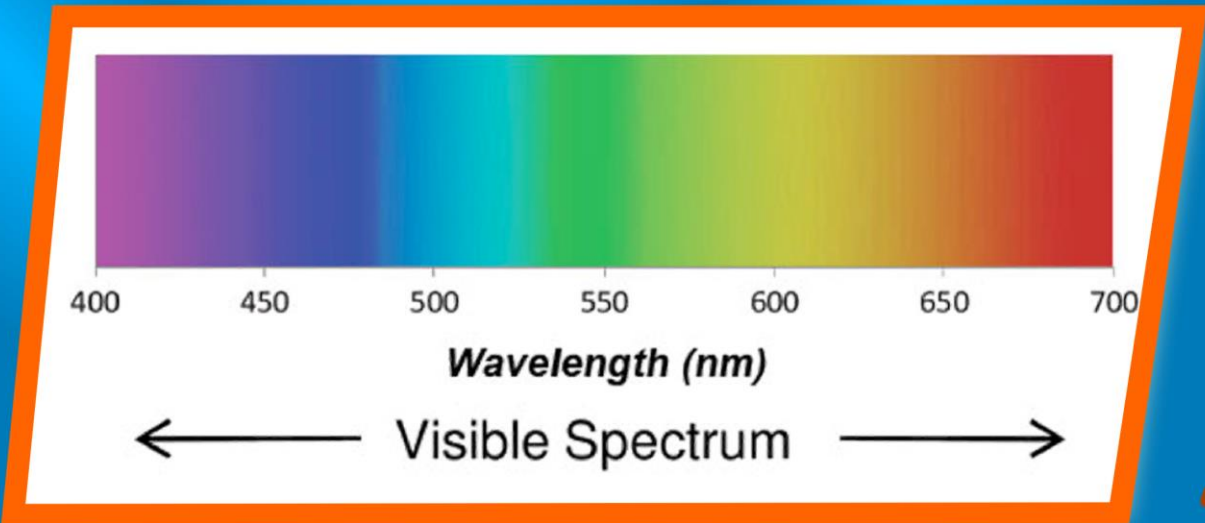
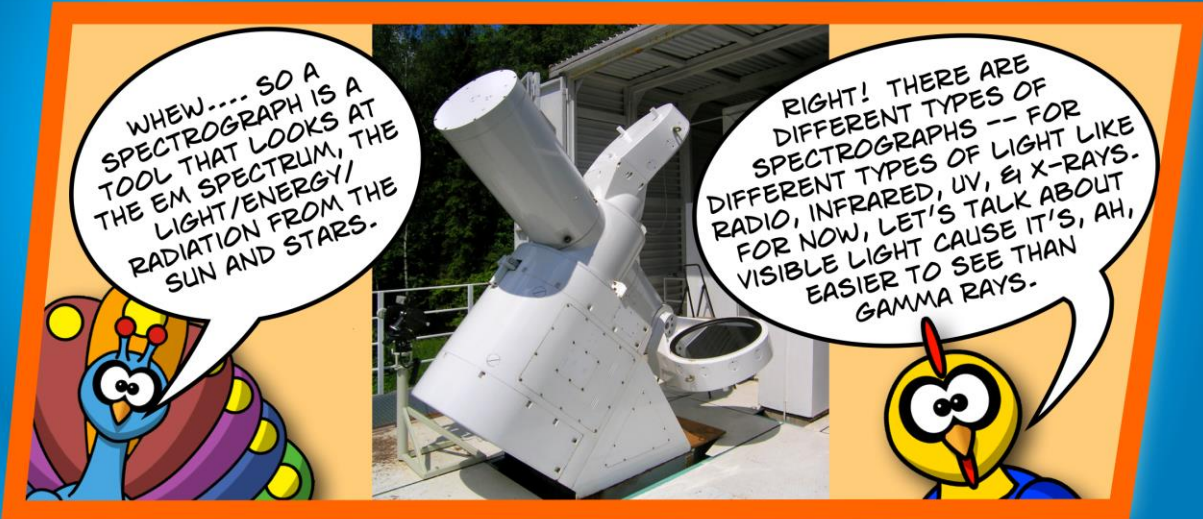
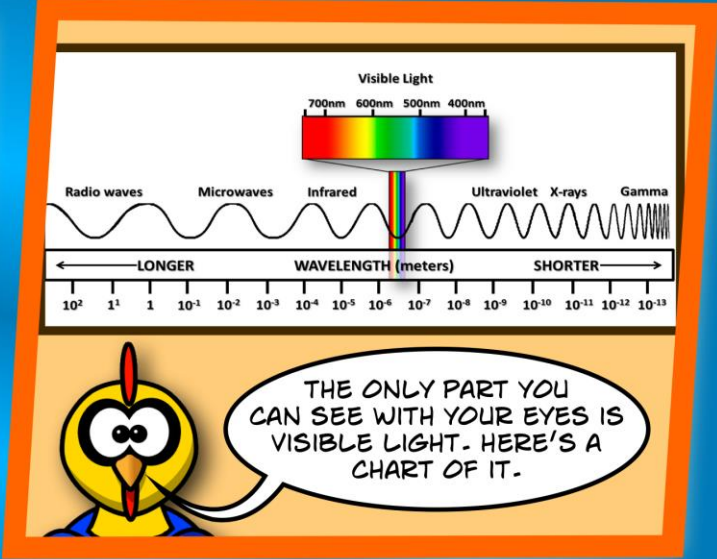


CAMILLA'S COOL INFRARED CAMERA

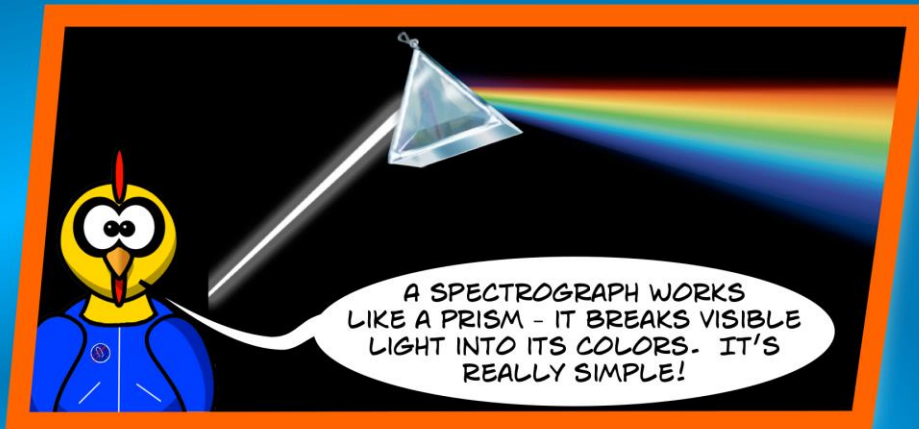


ENLIGHTENING!





6

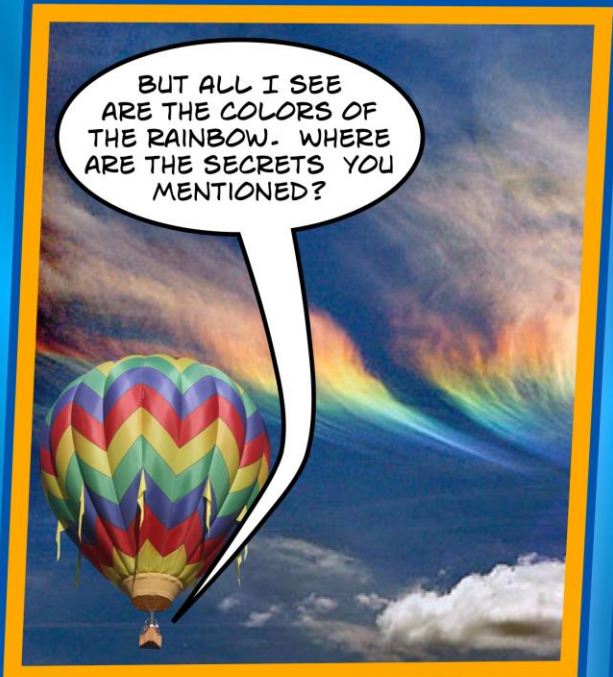


A SPECTROGRAPH WORKS LIKE A PRISM - IT BREAKS VISIBLE LIGHT INTO ITS COLORS. IT'S REALLY SIMPLE!

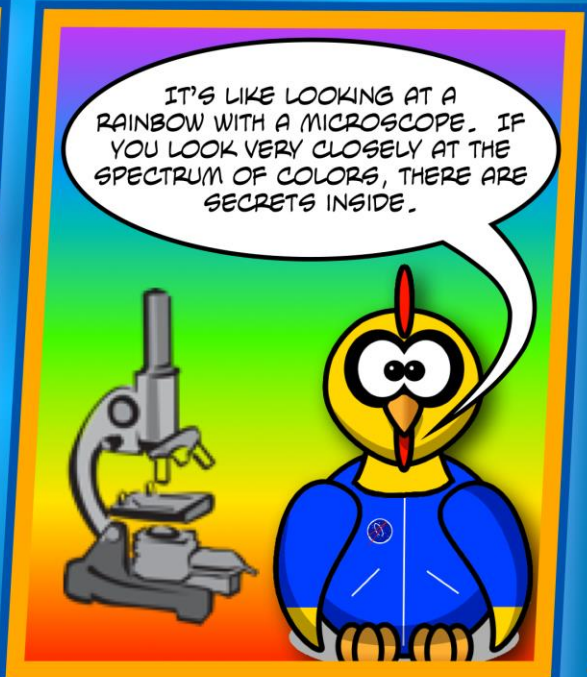


OUTPUT OF A SPECTROGRAPH

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:



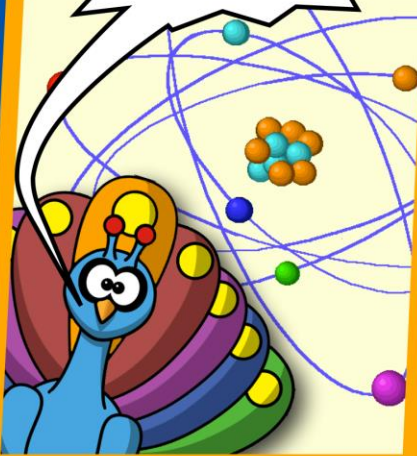

AND SOMETIMES YOU SEE MISSING COLORS:



THE EXTRA-BRIGHT OR MISSING COLORS INDICATE CERTAIN CHEMICAL ELEMENTS HAVE AFFECTED THE LIGHT.



WHAT'S A CHEMICAL ELEMENT?


Periodic Table of the Elements

1	2											10	11				
H	He											Ne	Ar				
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Li	Be	B	C	N	O	F	Ne									Ar	
11	12	13	14	15	16	17	18									Ar	
Na	Mg	Al	Si	P	S	Cl	Ar									Ar	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
Fr	Ra	Ac	Rf	Ha	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs	Hs

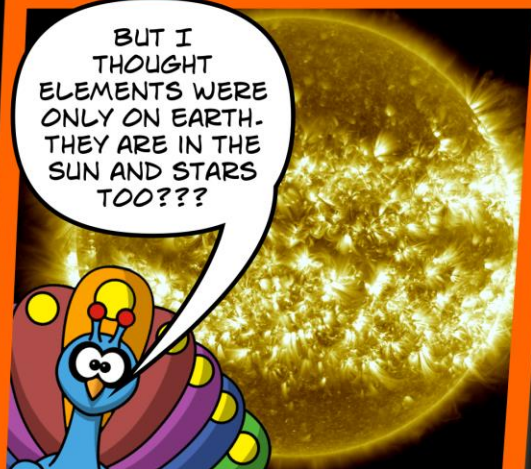
* Lanthanide Series
 * Actinide Series

ARG...

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.



B



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

ALL THE ELEMENTS **CAME** FROM THE STARS!



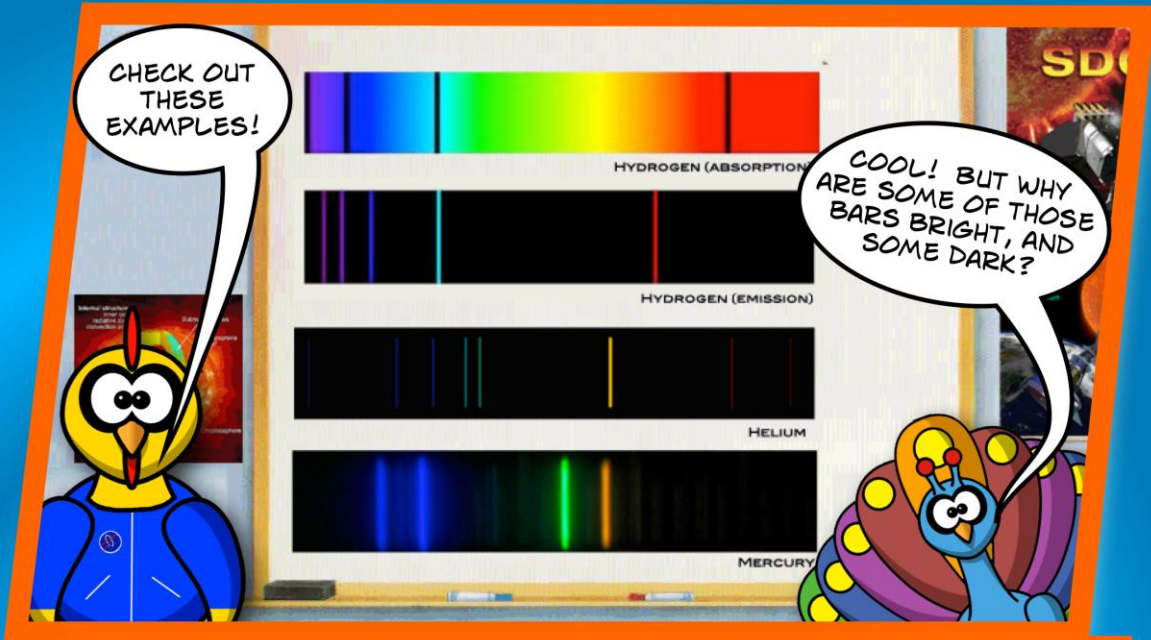
EACH CHEMICAL ELEMENT CHANGES THE SPECTRUM EITHER BY MAKING CERTAIN COLORS BRIGHTER OR REMOVING CERTAIN COLORS. EACH ELEMENT HAS A DIFFERENT AND UNIQUE PATTERN OF COLORS.

Periodic Table of Elements

1	H																	18	Ar
2	He																	18	Ar
3	Li	4	Be															10	Ne
11	Na	12	Mg													18	Ar		
19	K	20	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	30	Zn				
37	Rb	38	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	48	Cd				
55	Cs	56	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	80	Hg				
87	Fr	88	Ra	+Ac	Rf	Hf	Ta	W	Re	Os	Ir	Pt	Au	110	Hg				

* Lanthanide Series
+ Actinide Series





IN THIS IMAGE, THE DARK LINES ARE BECAUSE HYDROGEN HAS ABSORBED THOSE PARTICULAR COLORS. HENCE WE CALL THE DARK LINES "ABSORPTION LINES".

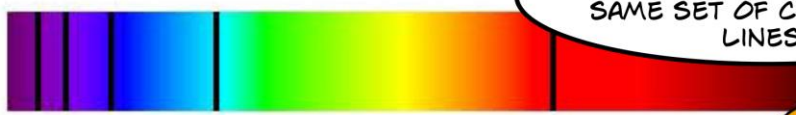
THOSE BARS, THE LITTLE STRIPES OF COLOR, ARE CALLED LINES CAUSE THEY, AH, LOOK LIKE LINES IN THE SPECTRUM.



THE BRIGHT LINES IN THE LOWER IMAGE SHOW THAT HYDROGEN HAS EMITTED EXTRA COLORS. SO WE CALL THOSE LINES "EMISSION LINES".



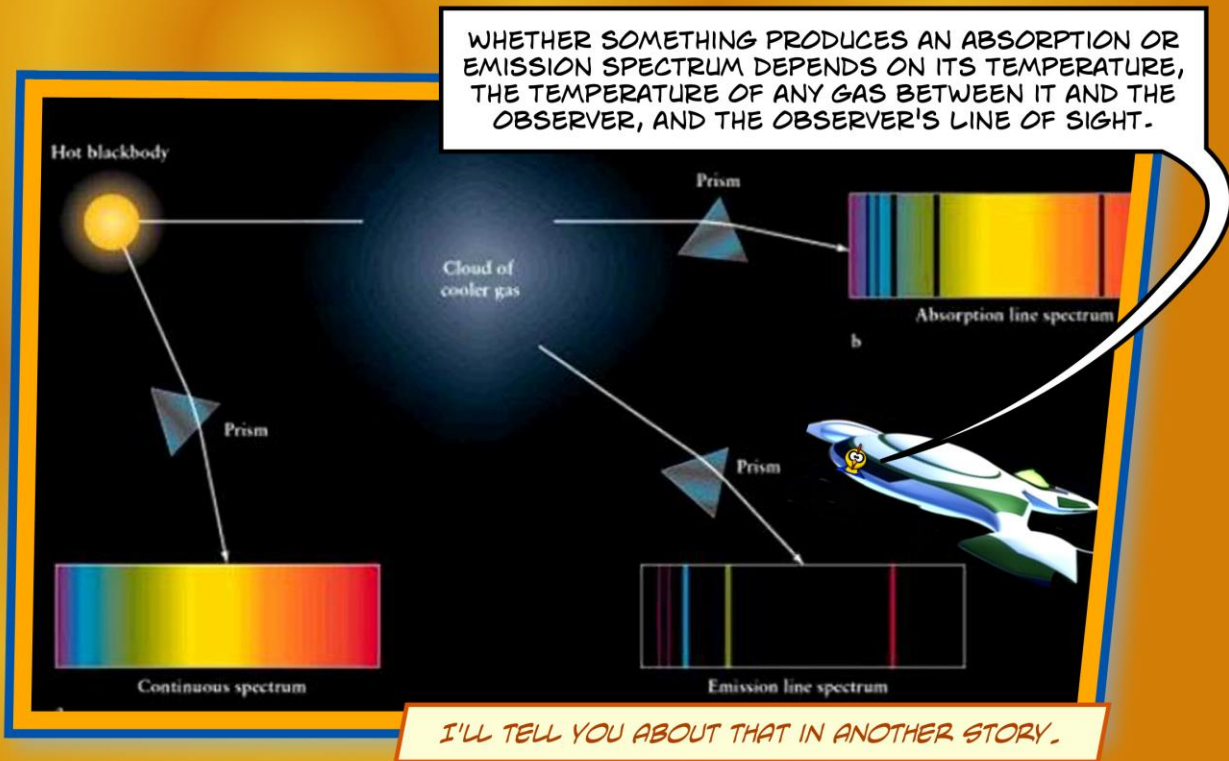
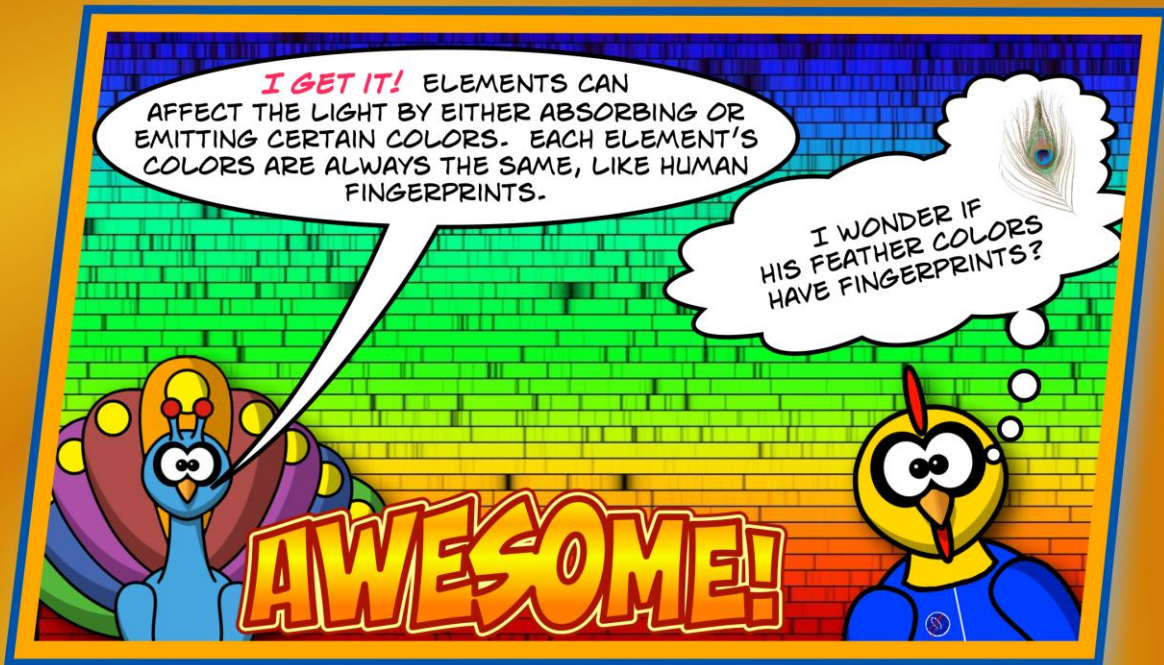
Hydrogen Absorption Spectrum



SO AN ELEMENT EITHER ADDS OR SUBTRACTS THE SAME SET OF COLORS, OF LINES.

Hydrogen Emission Spectrum



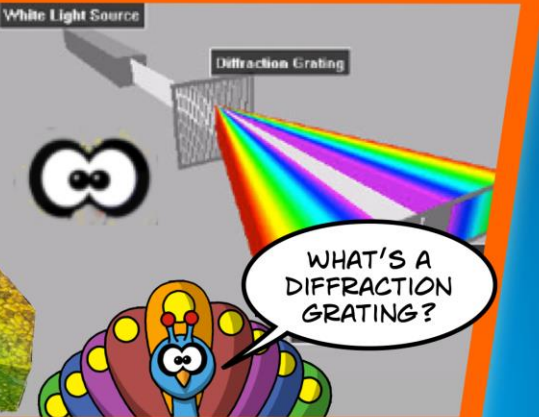
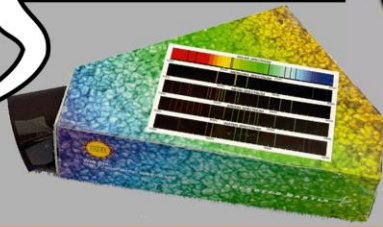




CAN YOU SHOW ME HOW THIS WORKS?

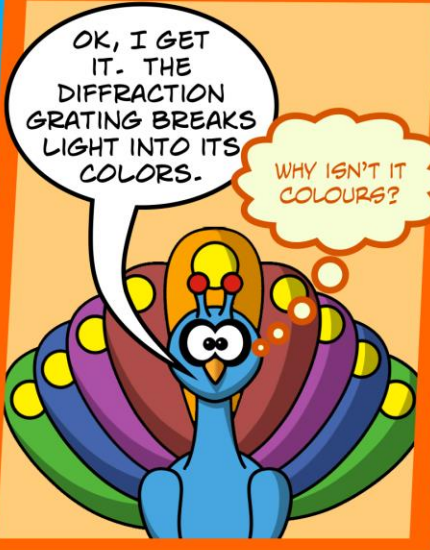
SURE. I HAVE A LITTLE SPECTROGRAPH I GOT FROM THE STANFORD SOLAR CENTER. IT'S REALLY CUTE, AND I MADE IT MYSELF.

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?

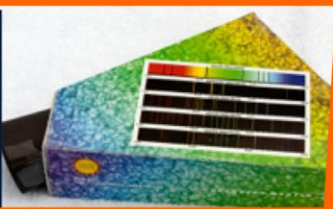
A GRATING WORKS A BIT LIKE A PRISM - IT SEPARATES OUT THE COLORS OF LIGHT. RAIN DROPLETS DO THE SAME WHEN THEY CREATE A RAINBOW. OR YOU CAN SHINE LIGHT ON A CD. OR YOU CAN LOOK AT AN OIL SLICK, OR



OK, I GET IT. THE DIFFRACTION GRATING BREAKS LIGHT INTO ITS COLORS.

WHY ISN'T IT COLOURS?

WANNA TRY IT WITH CAMILLA AND COLOURS? BUILD YOUR OWN SPECTROGRAPH NOW! THEN FINISH READING "SECRETS IN SUNLIGHT"!
[HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES/COTS.HTML](http://solar-center.stanford.edu/activities/cots.html)



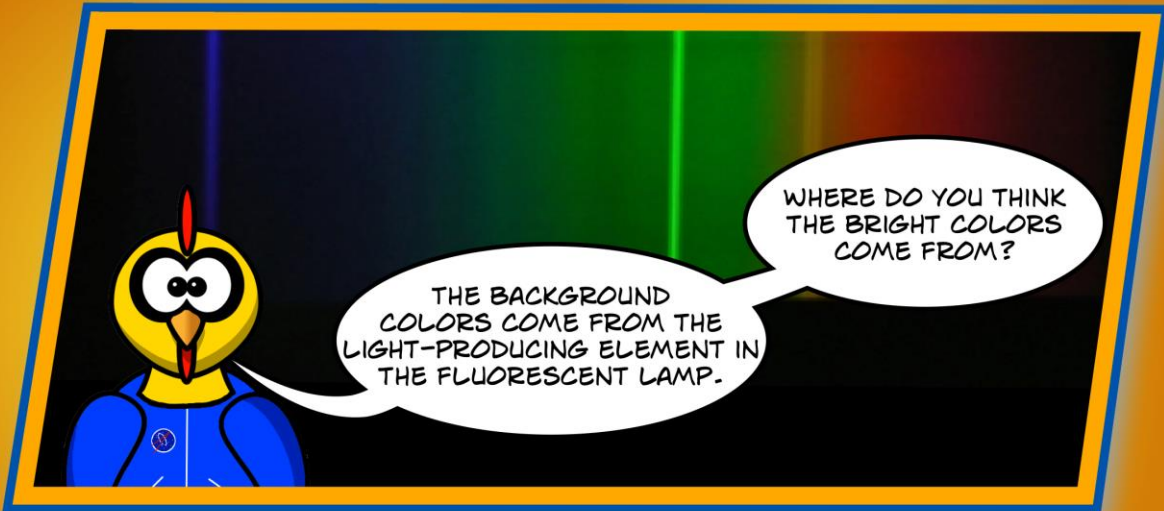
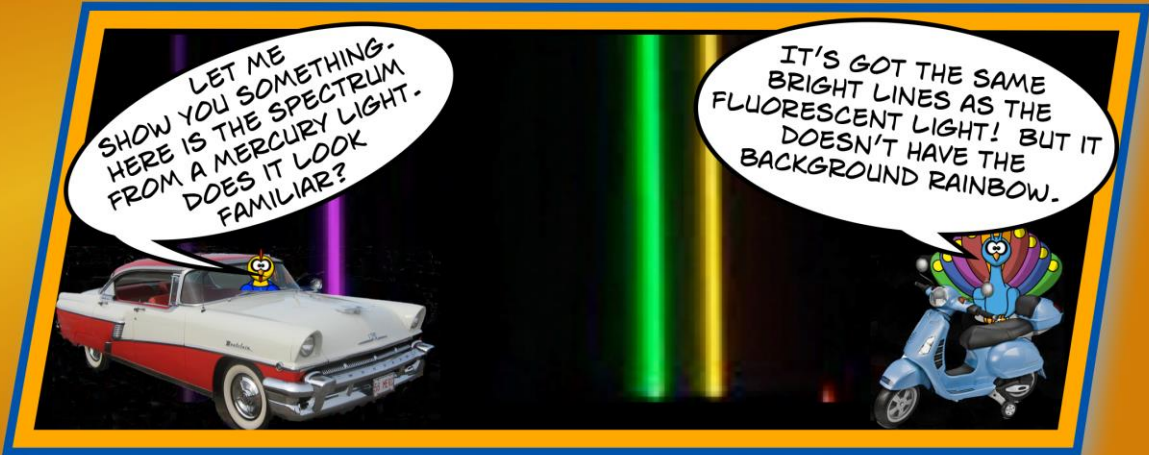
HERE - POINT THE SLIT (OPENING IN THE BOX WHERE THE LIGHT CAN GET IN) AT THAT INCANDESCENT LIGHT BULB. THEN LOOK THROUGH THE EYEPIECE! WHAT DO YOU SEE?

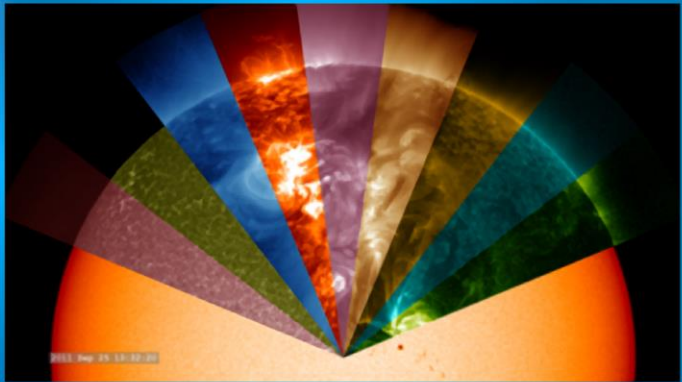
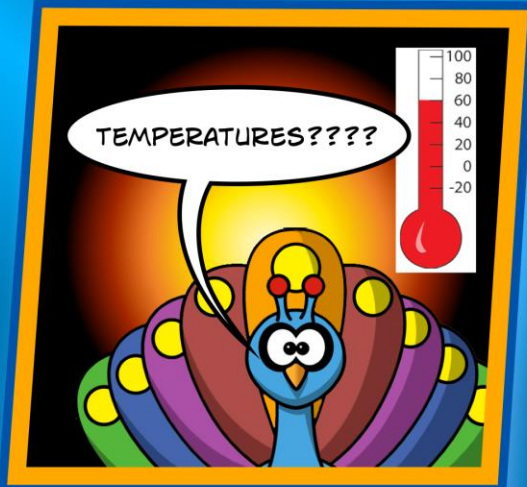
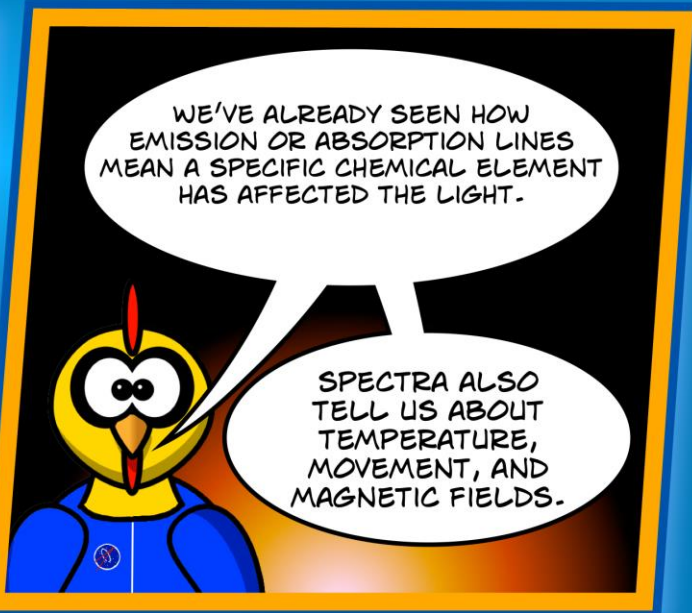
WOW - I SEE WHAT LOOKS LIKE A RECTANGULAR RAINBOW! JUST LIKE THE PIECE OF RAINBOW YOU SHOWED ME EARLIER.

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

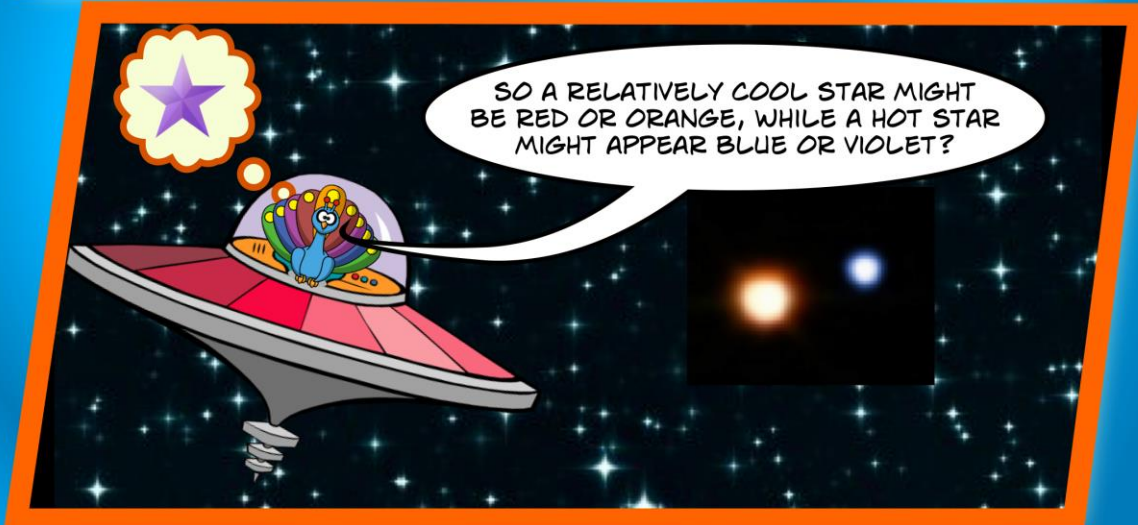
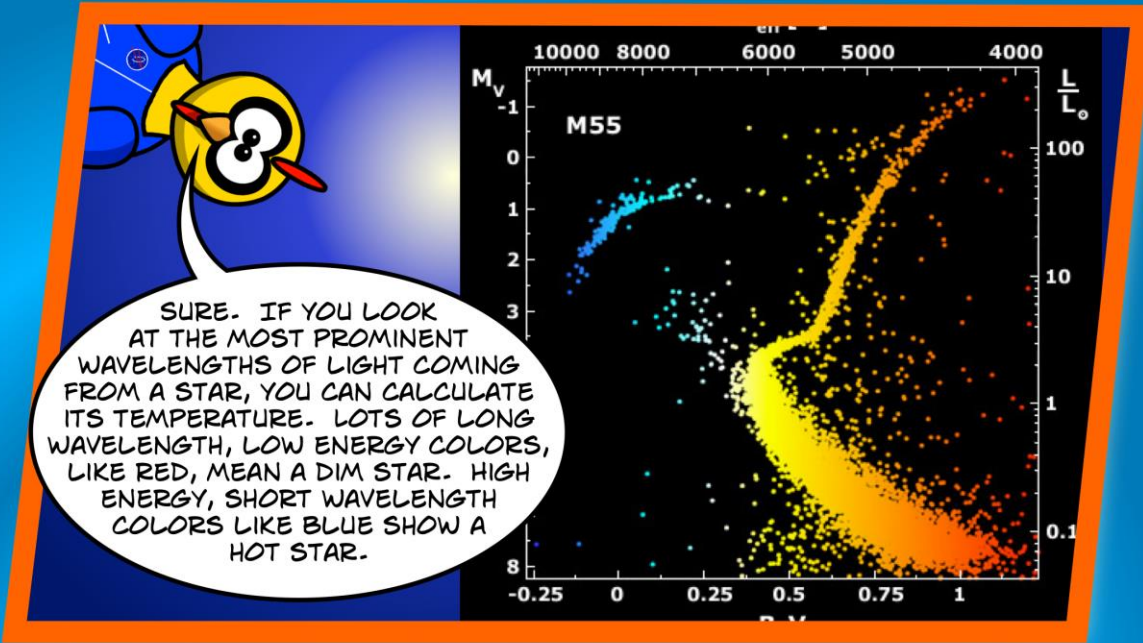
NOW, TRY LOOKING AT THIS FLUORESCENT BULB. WHAT DO YOU SEE?

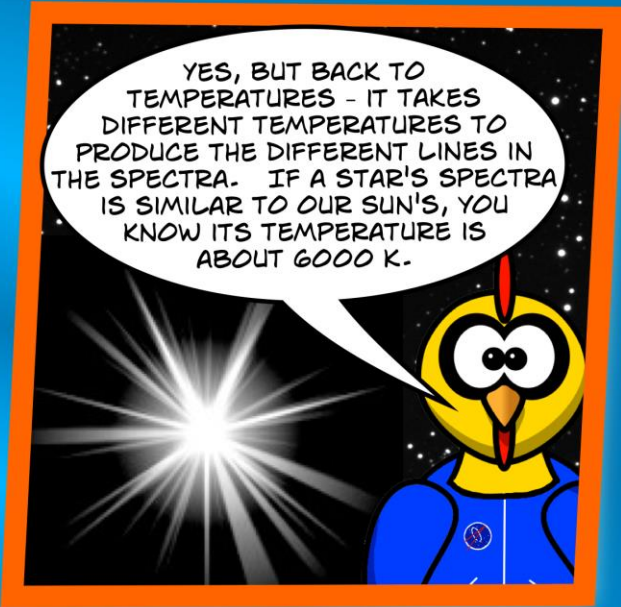
IT'S KINDA THE SAME RAINBOW, I MEAN CONTINUOUS SPECTRUM, EXCEPT THERE ARE SOME EXTRA BRIGHT LINES. I SEE A YELLOW ONE, A BRIGHT GREEN ONE, AND A PURPLE ONE. WHAT DO THEY MEAN?

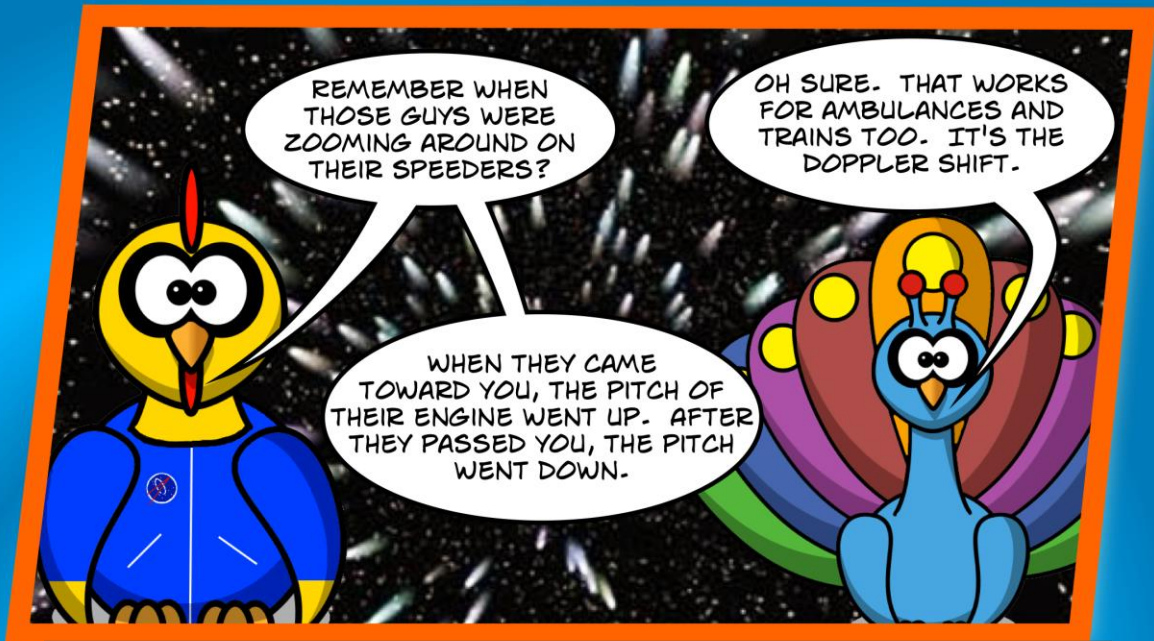




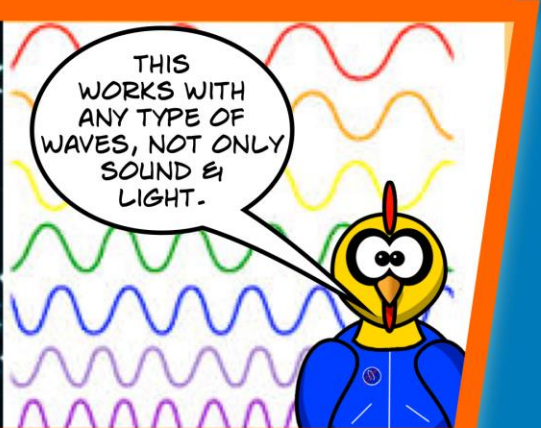
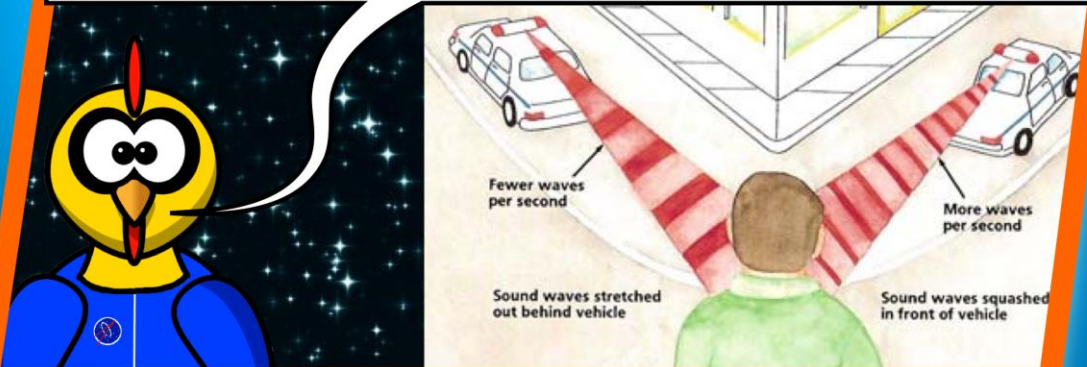
THE SUN IN VARIOUS WAVELENGTHS OF
HIGH TEMPERATURE ULTRAVIOLET LIGHT



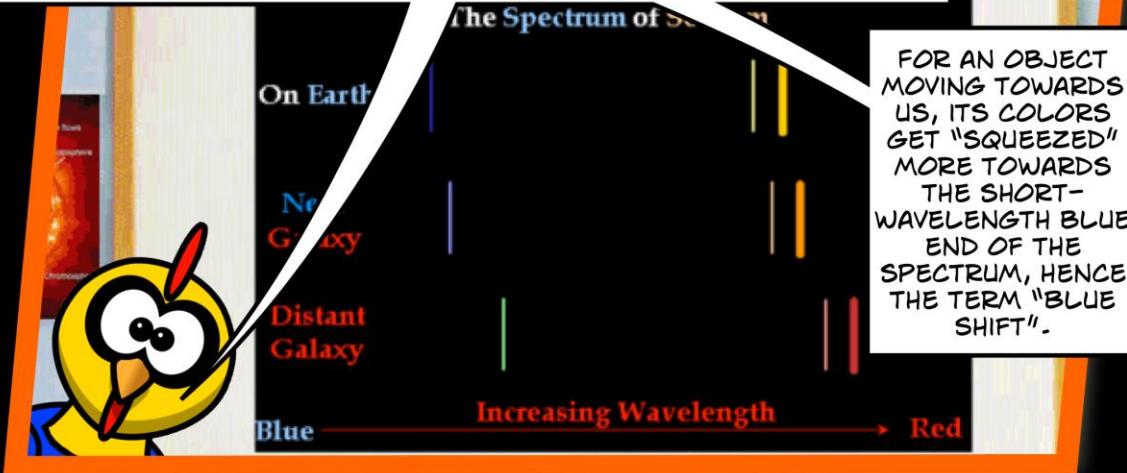




YES - THE DOPPLER SHIFT. IT HAPPENS WHEN A SOUND IS MOVING TOWARDS OR AWAY FROM US. AS IT MOVES TOWARDS US, THE SOUND WAVES GET BUNCHED UP AND THE WAVELENGTHS BECOME SHORTER. AS IT MOVES AWAY FROM US, THE SOUND WAVES GET STRETCHED OUT AND BECOME LONGER.



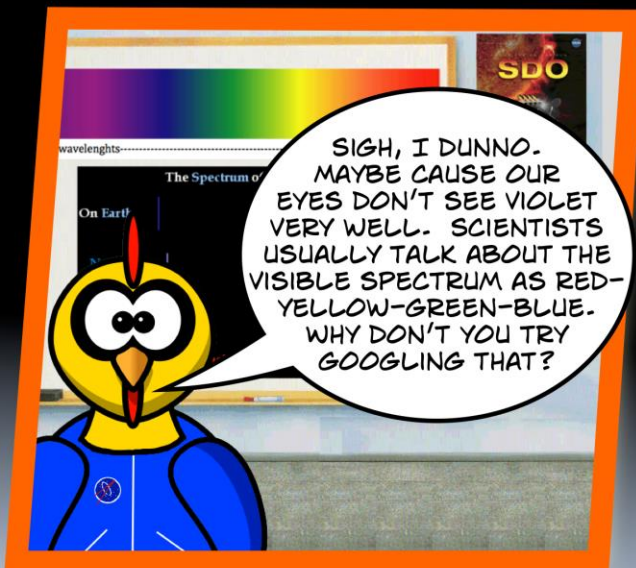
WHEN AN OBJECT LIKE A STAR OR GALAXY IS MOVING AWAY FROM US, ITS SPECTRUM GETS STRETCHED OUT, MEANING ITS WAVELENGTHS GET LENGTHENED AND THE COLORS GO DOWN IN "PITCH" - THEY SHIFT TO LONGER WAVELENGTHS. SO VIOLET BECOMES MORE BLUE, GREEN BECOMES MORE YELLOW, AND ORANGE BECOMES MORE RED. WE CALL THIS A "RED SHIFT"



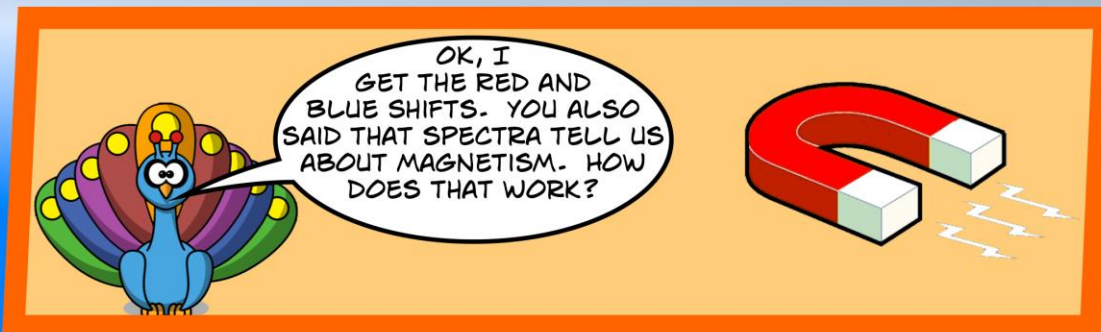
FOR AN OBJECT MOVING TOWARDS US, ITS COLORS GET "SQUEEZED" MORE TOWARDS THE SHORT-WAVELENGTH BLUE END OF THE SPECTRUM, HENCE THE TERM "BLUE SHIFT".



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:



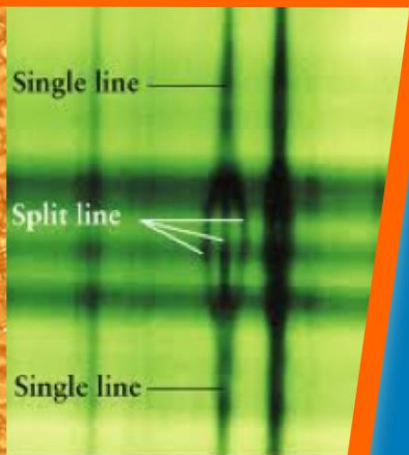
THERE ARE MAGNETS ON THE SUN???



NOT MAGNETS, **MAGNETIC FIELDS!!!**



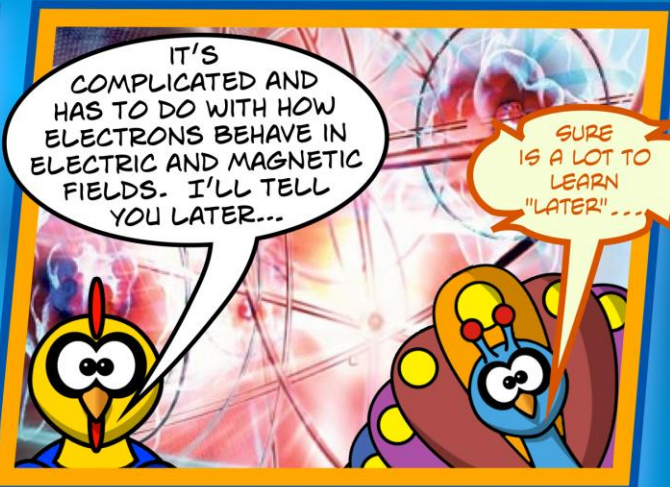
WHEN YOU LOOK AT A SPECTRUM OF LIGHT THAT'S COME FROM A MAGNETIC FIELD, LIKE AROUND A SUNSPOT, THE LINES END UP SPLITTING!



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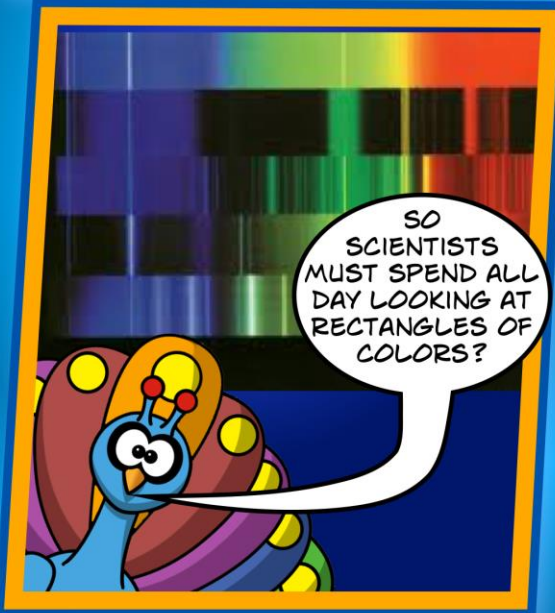


WHOA - THAT'S AWESOME! WHY DOES THAT HAPPEN?



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.

A cartoon chicken character with a yellow body and a red comb, wearing a blue jacket. It has two speech bubbles. The first says "INSTEAD, THE SCIENTISTS GRAPH THEIR SPECTRA DATA." and the second says "THIS WAY THEY CONVERT COLOR PICTURES INTO NUMERICAL DATA THAT COMPUTERS CAN HELP THEM ANALYZE.".

INSTEAD, THE SCIENTISTS GRAPH THEIR SPECTRA DATA.

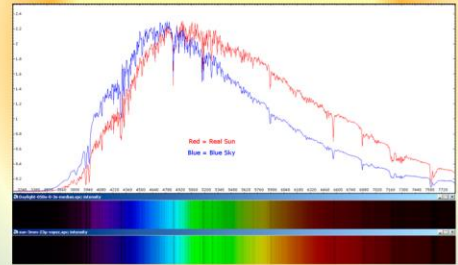
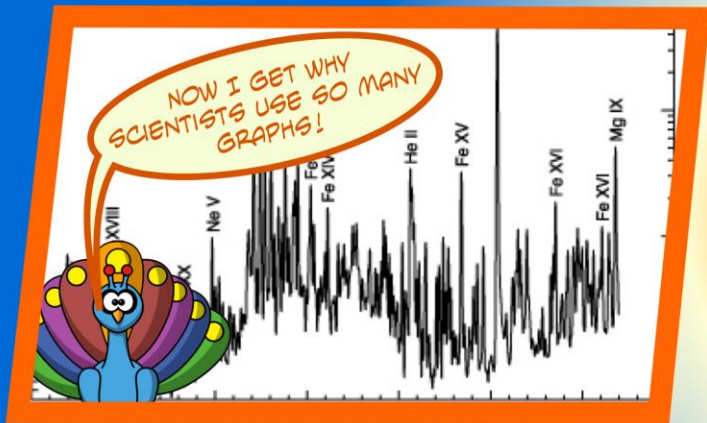
THIS WAY THEY CONVERT COLOR PICTURES INTO NUMERICAL DATA THAT COMPUTERS CAN HELP THEM ANALYZE.

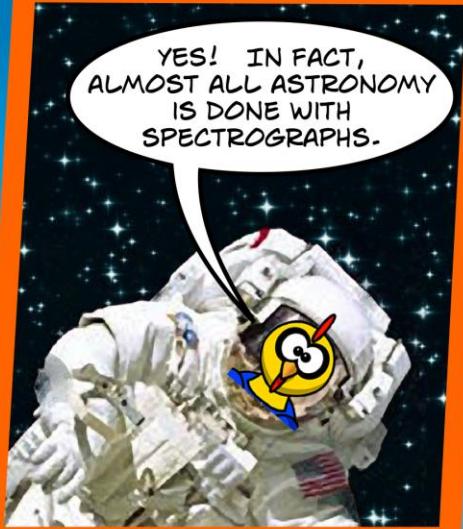
A spectrum graph showing wavelength vs. intensity. The x-axis is labeled with values 6160, 6172, 6175, and 6178. The y-axis represents intensity. The graph shows a series of vertical lines of varying heights, representing different wavelengths. A green line and a yellow line are highlighted, showing their positions on the spectrum.

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

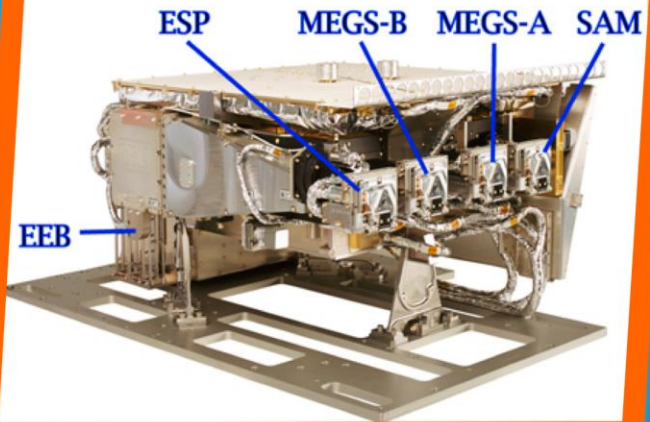
A graph showing a peak and a valley. The x-axis is labeled "Measure Here". The y-axis represents intensity. The graph shows a single peak and a single valley, representing the location and shape changes of the line.

Location and shape changes of the line give us a lot of additional information.





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



NASA'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](http://solar-center.stanford.edu/posters/posters_spec_bulk.html)

ABOUT NASA SOLAR MISSIONS:

SDO - [HTTP://SDO.GSFC.NASA.GOV/](http://sdo.gsfc.nasa.gov/)

IRIS - [HTTP://IRIS.GSFC.NASA.GOV/](http://iris.gsfc.nasa.gov/)

STEREO - [HTTP://WWW.NASA.GOV/MISSION_PAGES/STEREO/MAIN/](http://www.nasa.gov/mission_pages/STEREO/main/)

SOHO - [HTTP://SOHOWWW.NASCOM.NASA.GOV/](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](http://solar-center.stanford.edu/colors)

FOR LOTS OF EXPERIMENTS AND ACTIVITIES ON SPECTRA, GO TO
[HTTP://NASAWAVELENGTH.ORG](http://nasawavelength.org) AND SEARCH ON "SPECTRA"

THE STANFORD SOLAR CENTER HAS ACTIVITIES ABOUT THE SUN TO EXPLORE:
[HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES](http://solar-center.stanford.edu/activities)

FOR TEACHERS:

FOR RESOURCES RELATED TO SPECTROSCOPY SEE:
[HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES/COTS.HTML](http://solar-center.stanford.edu/activities/cots.html)

FOR A POWERPOINT PRESENTATION ON THIS TOPIC, SEE:
[HTTP://SOLAR-CENTER.STANFORD.EDU/ACTIVITIES/FINGERPRINTSINSUNLIGHT/](http://solar-center.stanford.edu/activities/fingerprintsinsunlight/)

THE STANFORD SOLAR CENTER HAS TEACHING RESOURCES RELATING TO THE SUN:
[HTTP://SOLAR-CENTER.STANFORD.EDU/TEACHERS](http://solar-center.stanford.edu/teachers)

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STORY & DESIGN:
DEBORAH SCHERRER AND EMILY KELLAGHER

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