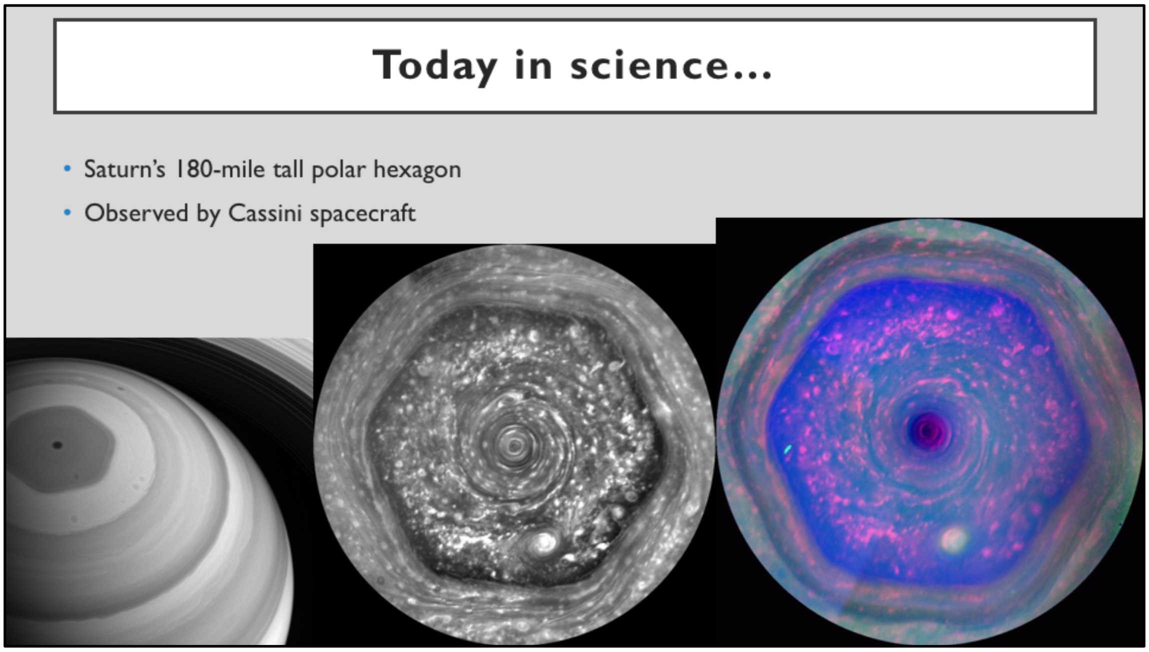
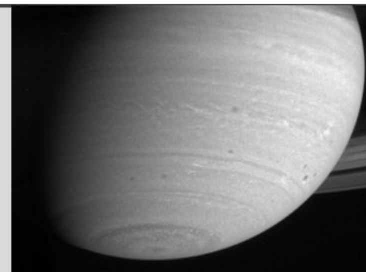
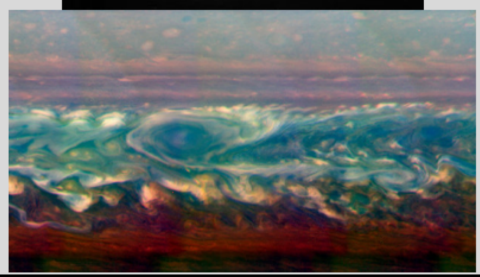


Note: last week, I mentioned dropping fridge-sized bodies onto comets- the Huygens probe (we'll hear about him later) was dropped into Titan's (moon of Saturn) atmosphere to see how far it would get before the atmospheric pressure crushed it
https://www.livescience.com/63497-saturn-high-altitude-hexagon-vortex.html
https://www.space.com/41713-bizarre-saturn-hexagon-180-miles-tall.html

Today in science…

- Saturn is tilted 26 degrees
- Rotating counterclockwise (anyone know why?)
- Atmosphere is stratified: gases of different composition, temperature, density, separate
- Stunningly beautiful and dynamic! Also, deadly
  - Mostly H, but also He, methane, ammonia, etc
  - Ammonia
  - Ammonium hydrosulfide
  - Water clouds
  - Intermingled hydrogen: gas up top, liquid phase down low (increasing pressure)
  - Liquid helium below that

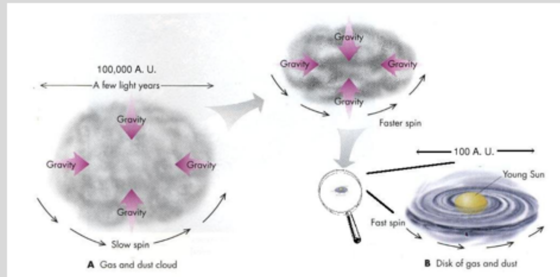




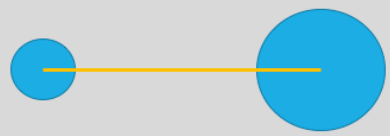
https://www.nature.com/articles/s41467-018-06017-3
https://www.esa.int/Our_Activities/Space_Science/Cassini-Huygens/Saturn_s_atmosphere

Recap from last time…

- Conservation laws
  - Momentum
  - Angular momentum
  - Energy

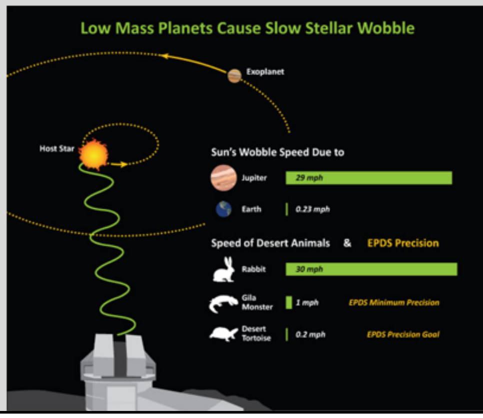


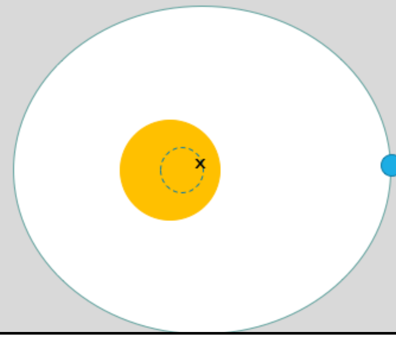
- Newton's universal law of gravitation
  - Depends on product of the masses of two bodies
  - Decreases as $1/d^2$ – *inverse square law*



Something I forgot last time!

- Two bodies orbiting common center of mass
- We can detect the more massive body's tiny orbit, it's how exoplanets were discovered!



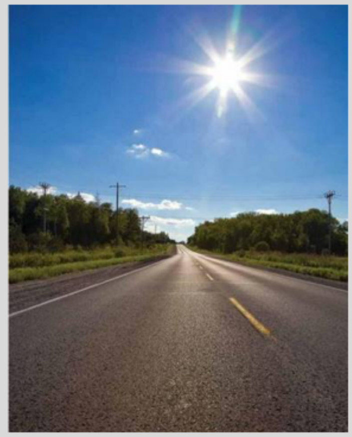



Properties of light
The Cosmic Perspective, Chapter 5, 5.1-5.2

Why are we learning this in an astronomy class? Because it's light!!!

How do we experience light?

- It's bright: reflections and scattering are how we see anything
- It's warm: we can tell light is a form of energy
  - Sunlight warms our skin
  - Sunlight heats up asphalt, which radiates that heat back at us
- It's colorful: we've all seen prisms or materials that behave like them (rainbows on CDs)



We're now 25% through the course!
Last time we talked about forms of energy: kinetic, potential, and I mentioned radiative was next- here we go

Light as a form of energy

- Consider walking outside or sitting by a window in the sun
  - Your skin gets warmer
  - Light is transferring energy to your skin
  - Your thermal energy is increasing, as light speeds up molecules and atoms in your skin

- The energy light has is called radiative energy
- Units of energy are Joules (aka $g*m^2/s^2$)
- For radiative energy, we think more in terms of the rate of energy: we can't store a beam of sunlight itself, but if it hits a surface long enough to deliver enough energy, something like solar panels can charge
  - Power: measured in Watts
    - 1 Watt = 1 Joule/second

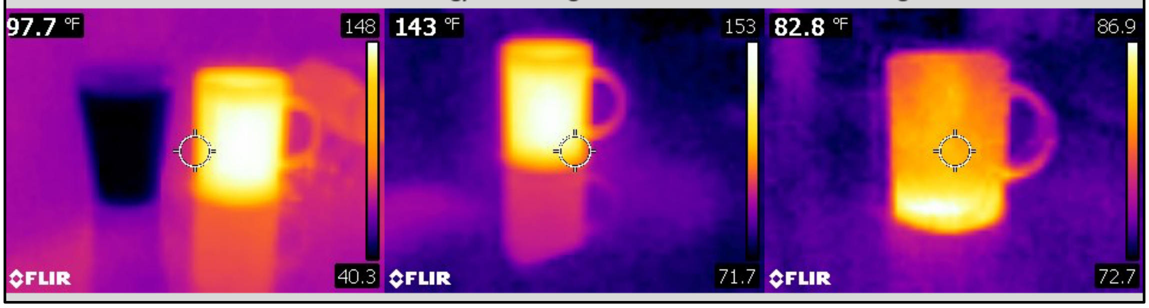
https://www.nbc15.com/content/news/UW-Students-gift-Project-Home-with-25000-solar-array-482130901.html

Behavior of light

- A source of light *emits* it
  - Example: you turn on a lamp. Electricity flows through a filament, which heats up, and the hot filament glows
    - Objects with thermal energy emit light in some wavelength: this is called thermal emission, or thermal radiation
    - Emission of thermal radiation takes energy away from its source, causing it to cool
    - Why doesn't the light bulb cool?
      - Continued supply of electricity

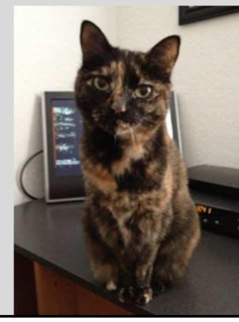
Behavior of light

- What else emits thermally?
  - We do! We have temperature, we emit! We're relatively cool though, so we emit in the infrared (less energetic than visible light)
  - Why do we cool?
    - We're in thermal contact, energy is flowing from us to cooler surroundings



Behavior of light

- Light can be *absorbed*
  - Example: you're trying to enjoy a fire (camping, fireplace), and someone sits in front of you. They're absorbing the light, and they're getting warm from the energy they're absorbing
  - Another: you're watching the game and someone walks in front of the TV. They absorb the light (in this case, they don't get warm because the *power* output of the TV is much lower than a fire)
  - So you tell the person, "you make a better door than a window…"



This is Taffy, a tortoise kitty https://www.pinterest.com/emesero/tortie/

Behavior of light

- Light can be *transmitted*
  - If the person between you and the TV is holding a clear piece of glass, light goes through and they're a little bit less annoying (but weird for bringing a piece of clear glass over to make a physics point)
  - Light is transmitted through glass, but not all light
    - Can you get a sunburn in a car with the windows up?

  - Transparent: some light (and energy) can go through
  - Opaque: no light (or energy) can go through

    - Transparency and opacity often depend on energy of the light

This is what you get when you google, "glass in front of TV" … either my imagination is lacking, or weird

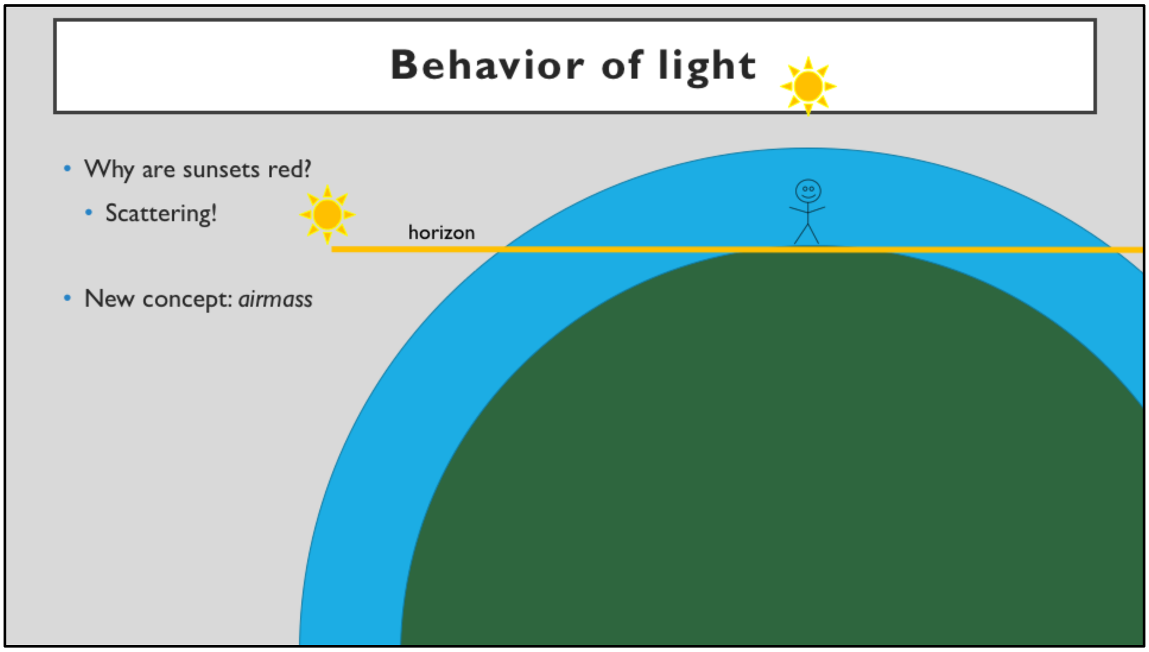
Behavior of light

- Transparency vs opacity

Behavior of light

- Light can also *reflect* and *scatter*
  - Reflections are orderly, like in a mirror
  - Scattering is random in direction, like light in Earth's atmosphere, or light off particles in the solar wind
    - Scattering depends on energy of the light being scattered and the size of the scattering body

Remember the absorption example? To you, the person blocking the fire seems to be absorbing all the light. They're also reflecting it to people who can see them from the other side
http://blog.girlscouts.org/2014/05/



Imagine you’re an enormous stick figure standing on an entirely green globe
You look up through a thinner chunk of atmosphere than if you looked directly out over your horizon. The atmosphere is really good at scattering blue light and bad at scattering red.. The more atmosphere is on your line of sight, the more blue light gets scattered and the less red does, so you see more red when looking through more atmosphere

Behavior of light

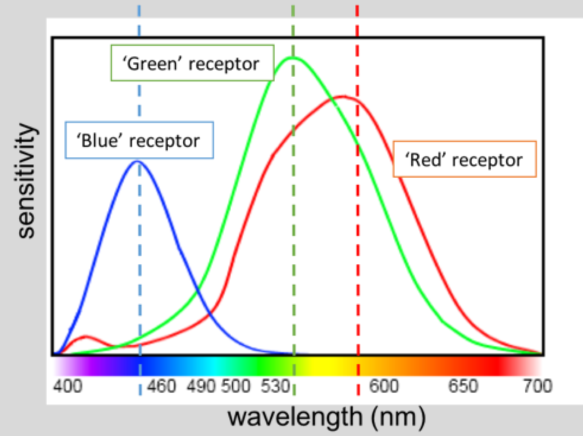
It took me a long time to find this photo. It shows scattering, reflection, and absorption
https://www.pexels.com/photo/sea-sky-sunset-water-8101/
The atmosphere is really good at scattering blue light, and red light is scattered the least. At sunset,

Behavior of light

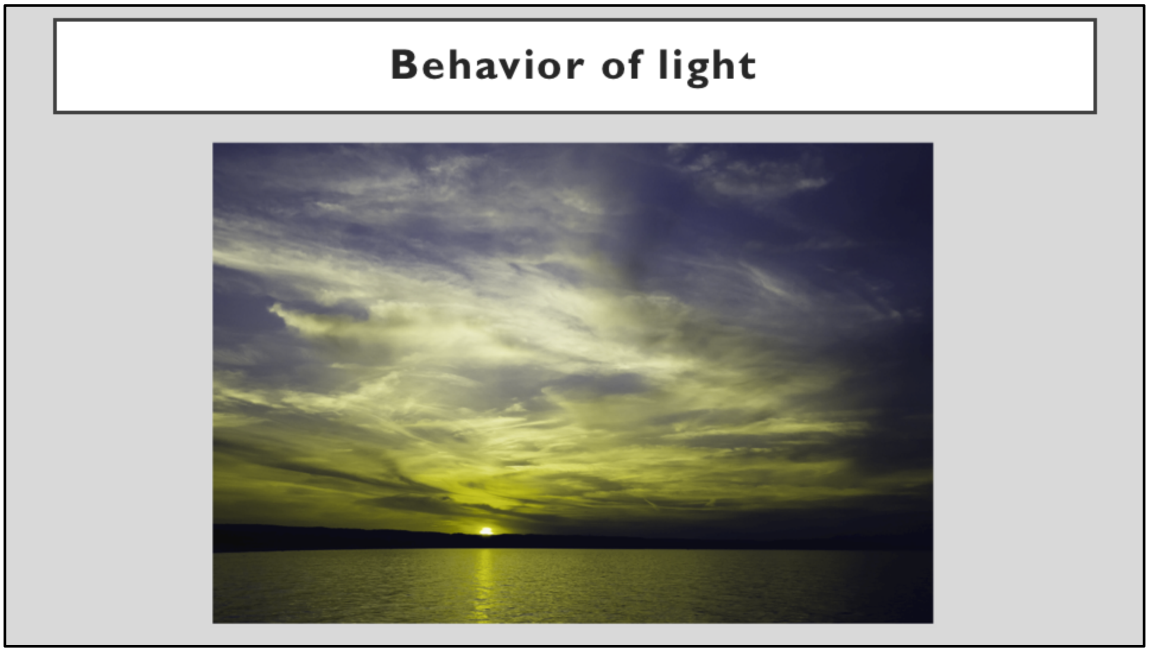
- Why else might the sky be blue and the sunset red? What have I not mentioned yet?

Behavior of light

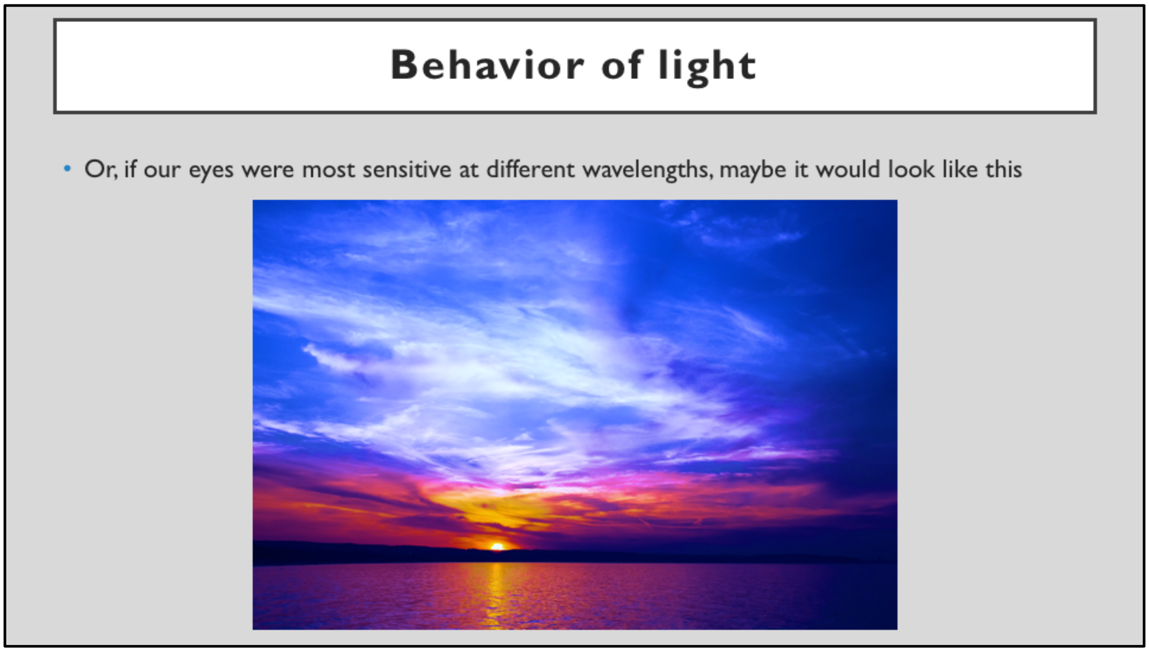
- Why else might the sky be blue and the sunset red? What have I not mentioned yet?
  - Our eyes' sensitivity to light!



http://people.eecs.berkeley.edu/~cecilia77/graphics/a6/
Humans have red, green, and blue receptors in our eyes. Different balances of sensitivity to each color can lead to differing color vision from person to person! If we aren't sensitive to red, sunsets could look a bit different



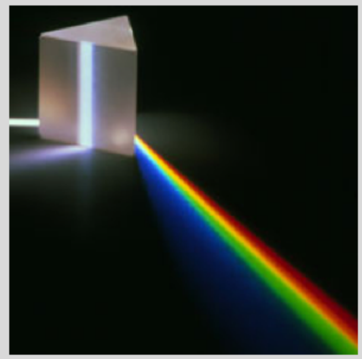
Deuteranopia –called “red-green colorblindness,” it’s either the green or red cones that detect at lower levels, but the end effect is the same; red and green are indistinguishable



If we were more sensitive to blues/purples, perhaps

Light and color

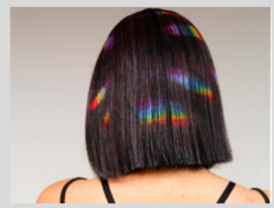
- Remember Neil deGrasse Tyson talking about Roy G Biv? And Newton, his fixation with the number 7, and his work on optics/light?
- White light (all colors) → prism → spectrum (rainbow)



Light and color

- How do rainbows work?
  - Water droplets act like prisms

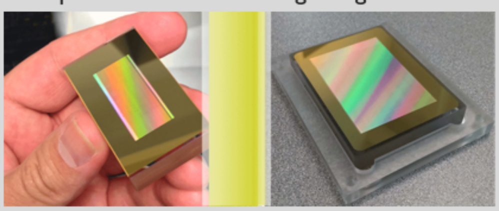
…hair goals.

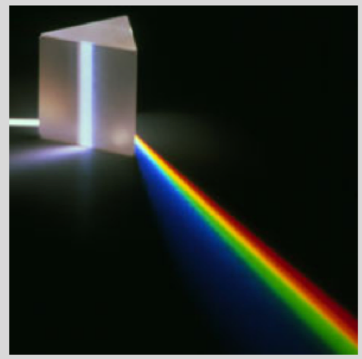


http://skywaterland.com/Ireland.html
And the hair, yes https://www.businessinsider.com/baby-rainbow-hair-perfect-for-festivals-2018-3?r=UK&IR=T

Light and color

- Remember Neil deGrasse Tyson talking about Roy G Biv? And Newton, his fixation with the number 7, and his work on optics/light?
- White light (all colors) → prism → spectrum (rainbow)
- Do astronomers use prisms?
  - Kinda. We call them *diffraction gratings*
- How do prisms and diffraction gratings work?

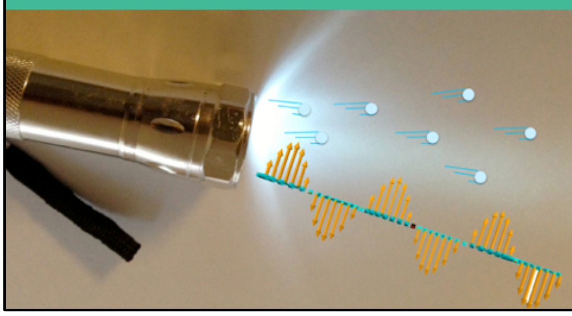




http://www.inprentus.com/diffraction-gratings/ (not an advertisement; got result from GIS)

Properties of light

What is light?



- In the 1660s, Newton had some ideas…
  - It's obviously a stream of particles, delivering energy!
- In the 1670s, Dutch physicist Christiaan Huygens had ideas, too
  - It's a wave! It behaves like waves would

This is one of those infuriating questions- obviously we know what light is, we interact with it all the time! But … what is it?
https://www.wired.com/2013/07/is-light-a-wave-or-a-particle/

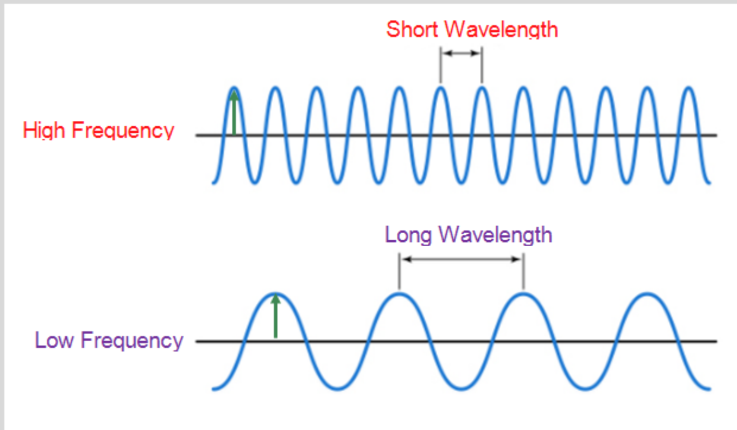
Particles and waves

- Individual molecules, atoms, and the things that make up atoms, are examples of particles
  - Examples of things that behave like particles: a marble, a ball
  - Can have positions, momenta; can exert forces
  - Particles are the *things*
- Waves are motions that move through a medium and have distinct properties
  - Example: waves in water
  - Waves *move* the things
  - Waves have slightly different properties…

https://abcnews.go.com/Lifestyle/photos/surfing-dogs-hang-10-charity-25838539/image-25839087

Properties of waves

- Wavelength
- Amplitude
- Frequency
  - High= more energy
  - Low= less energy



Properties of waves

- Wavelength: the distance between two peaks. Units: distance. So meters, cm, mm, nm (10^{-9}m). Astronomers who study visible light often use Angstroms, 10^{-10}m. X-ray astronomers use units of energy; radio astronomers often use units of frequency instead of wavelength! (think: car radio frequencies)
- Frequency: how frequently do the peaks pass by? Units of 1/s (think, 'peaks passing by per second,' or 'cycles per second'). 1/s also called Hertz, abbreviated Hz
- Amplitude: units vary, but it relates directly to the brightness of the source emitting the wave
  - Examples: waves on earth. Tidal variations ~1m (recall lunar tides from last class). Tsunamis: ~tens of meters in amplitude (30m ~ 100ft!)
- Speed: how fast the peaks travel
  - *What is the speed for light waves?*
  - c, the speed of light! 2.9979×10^8 m/s, or 670 million mph

Properties of waves

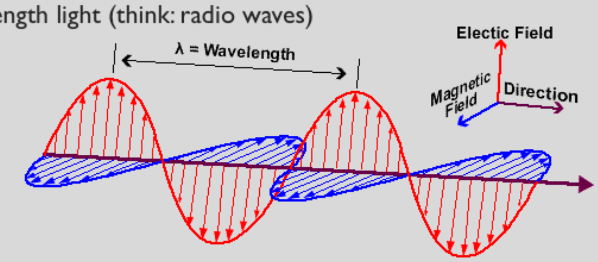
- Waves *diffract* and *interfere*
  - Diffraction is how waves 'bend' around an obstacle encountered

Properties of waves

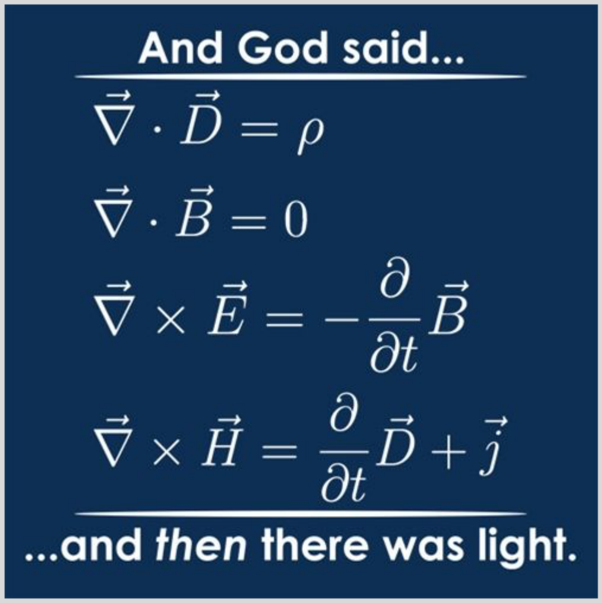
- Waves *diffract* and *interfere*
  - Diffraction is how waves 'bend' around an obstacle encountered
  - Interference is how two waves can interact with each other
    - Constructively: increases total amplitude
    - Destructively: decreases or entirely cancels amplitude

Ok, so… what is light?

- It behaves like both a **wave** and a **particle**!
- In quantum mechanics, this is called *wave-particle duality*
- Discrete "packets" of light are called photons
- Photons carry energy
  - Higher energy photons – shorter wavelength light (think: X-rays, UV light)
  - Lower energy photons – longer wavelength light (think: radio waves)



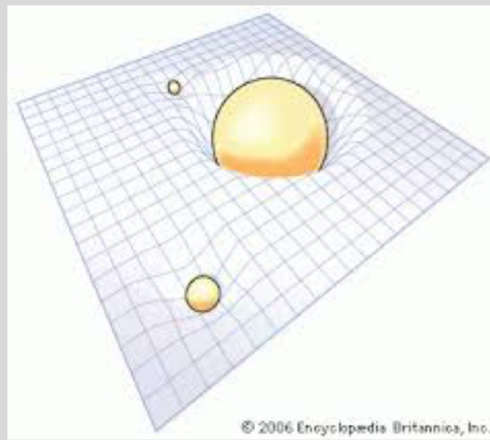
https://physics.stackexchange.com/questions/171144/do-electromagnetic-waves-occupy-varying-amounts-of-space-or-do-they-simply-vary



Maxwell and Faraday

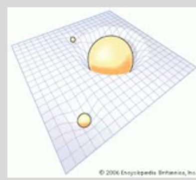
Electromagnetic waves

- Certain fundamental quantities in physics are described as *fields* based on how they interact with each other and with particles
  - Example: gravitational fields



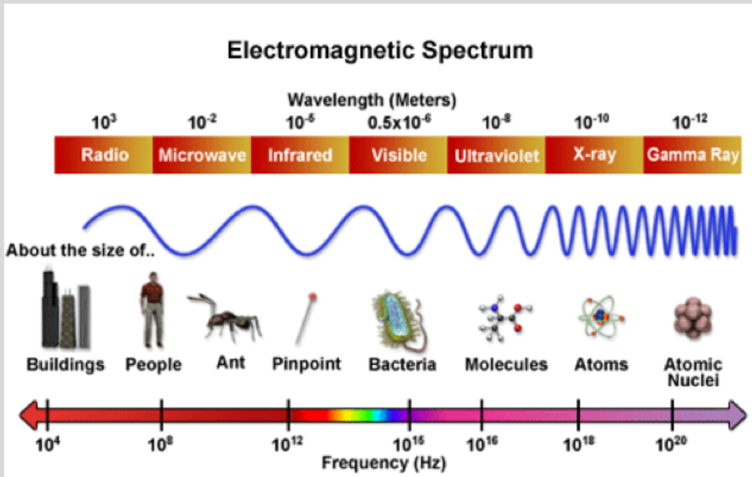
Electromagnetic waves

- The interaction of charges and charged particles are governed by electric fields
- Magnetic fields occur when charged particles move; they interact with each other and with charged particles
- Light is thought to be a wave that travels through both electric and magnetic fields at the same time
- Light interacts with gravitational fields



In-class discussion of bonus background material: Michael Faraday’s experiments that found the polarization of light

The electromagnetic spectrum



Temperatures: 310K 6000K 10^6K

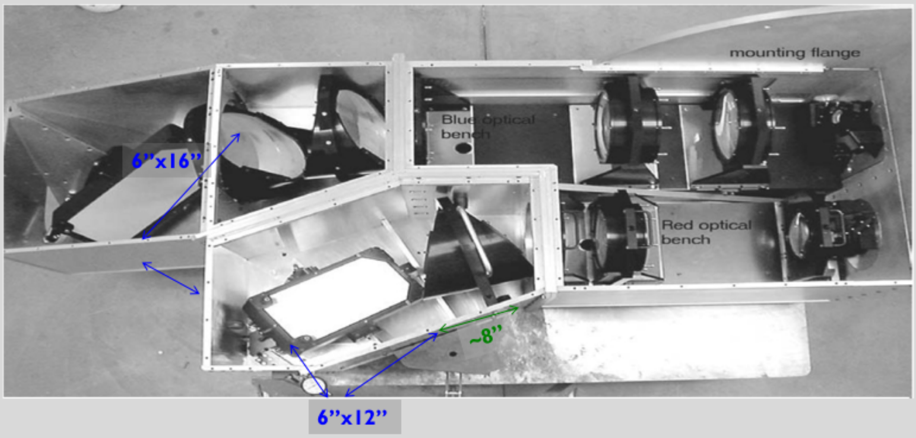
These are temperatures corresponding to the wavelength scale above, not the sizes of things listed…

How do prisms and gratings work?

- Light of different wavelengths *diffracts* off of their surfaces at different angles depending on
  - The wavelength of the light,
  - The angle of the light hitting the prism or grating, and
  - The spacing of the crystal structure or the grooves in the grating

(drawing picture on the board, I'll take a picture of it and upload it later)

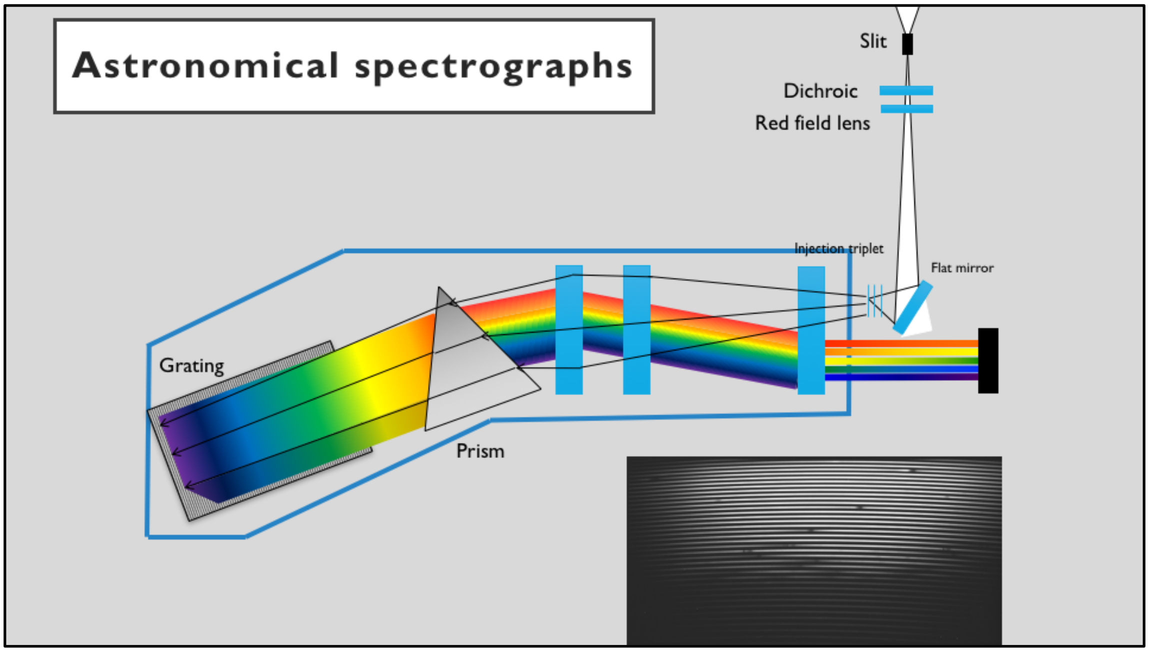
Astronomical spectrographs: MIKE (Magellan Inamori Kyocera Echelle)



Red side: 52.6gr/mm, 63.5deg blaze angle
Reddest order, centered at 10977A, is 66mm long, too wide for the chip. Coverage is complete blueward of 10470A.
Position of the grating can be adjusted to get 4931-10977 or 4661-8725.
Cross dispersion is provided by a single glass prism with an apex angle of 47deg.
500mm focal length camera

Blue side: 52.7gr/mm, 69.0deg blaze angle
Reddest order from blue chip is 39mm long. The CCD itself is ~31mm wide, and the orders 74-107 take up 29mm of that.
Two fused silica prisms with 38deg apex angles provide the equivalent of a single 62deg apex angle prism.
550mm focal length camera

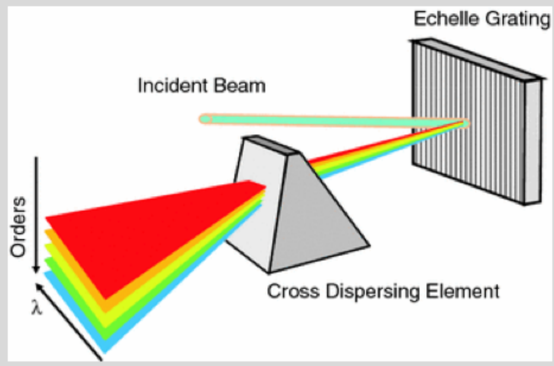
The low number of grooves per mm and the high angle of incidence give high dispersion (recall: Littrow condition)



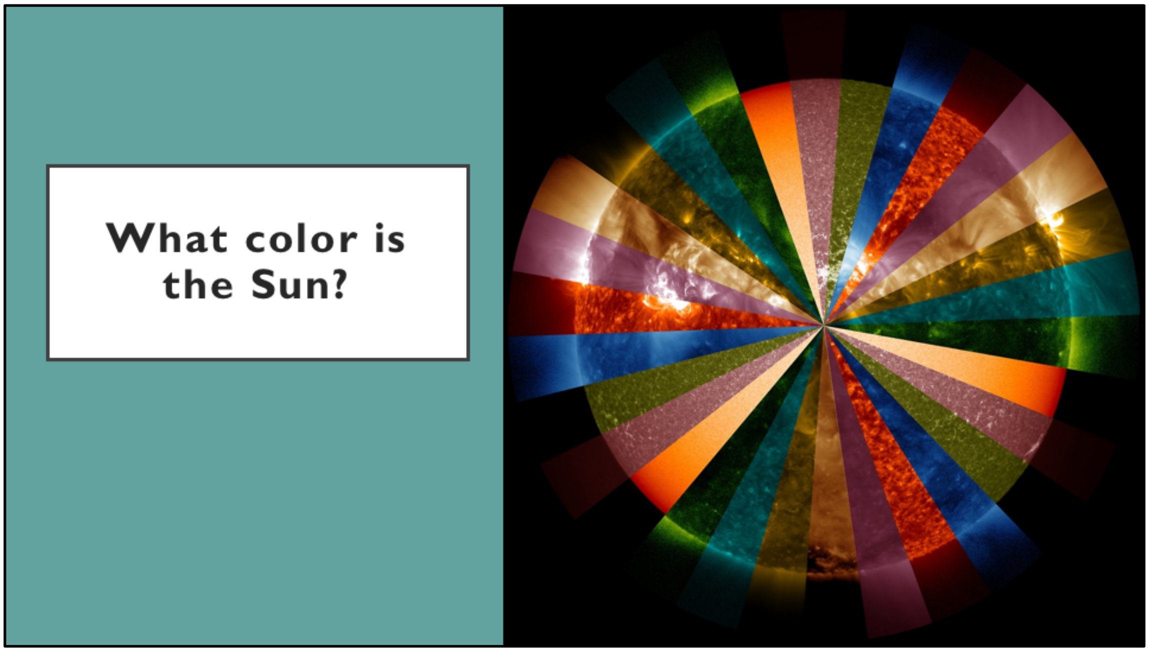
Prism/grating disperse light orthogonally
In MIKE, the cross-disperser is a prism because it's in Littrow- it could be a grating!
The way to tell the difference: a prism disperses non-linearly, so the lowest orders have the smallest separations. Gratings disperse fairly linearly.

Astronomical spectrographs

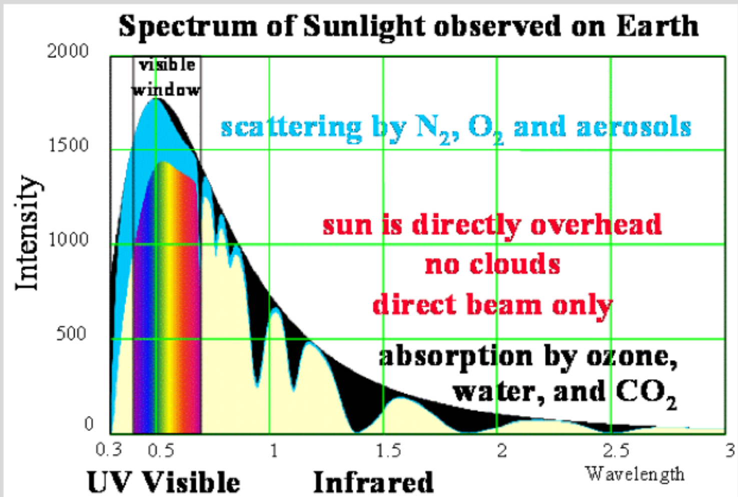
- *Echelle* is the french word for ladder
- Light gets spread out twice; you get a higher resolution (more wavelength separation) spectrum



https://link.springer.com/chapter/10.1007/978-3-642-45085-3_3



Think/pair/share?
https://www.nasa.gov/content/goddard/sdo/wheel-of-colorful-sun-sdo5/



https://web.calpoly.edu/~rfield/Thermalstructure.htm

Ok, so why are plants green?

- It's complicated…
- Color is what we see when some wavelength(s) of light is(are) reflected back at us and others are absorbed
- Common misconception: plants are green because the Sun peaks in green wavelengths so it must absorb the most green light!
  - But if we see green, it means that light was reflected back at us!
  - It's too much green—plants would potentially overheat if they absorbed all that green
- Question for the weekend: What color would plants be around other stars that emit different amounts of light in different colors than the Sun does?

https://everwideningcircles.com/2018/03/14/why-are-plants-green/