# Light: What it is

And God Said

$$\nabla \cdot \vec{D} = \rho_{\text{free}}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$

and *then* there was light.

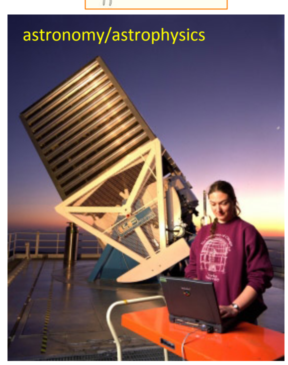
***E*** = electric field
***B*** = magnetic field

## What does an astronomer do?

She collects light.
Astronomers are all about that light!



A physicist in a lab can interact with her experiment, change variables, and record different outcomes to learn about an object or process. She can also investigate objects using different means, such as collisions, response to gravity, heating or cooling, and can change and/or repeat the experiment as needed.




An astronomer can only collect light. Sometime the light has been traveling for millions or billions of years. She can collect the light for only a brief time (a cosmic instant).

To understand the universe, you must understand light.
You must also understand how light interacts with matter.

***E*** = electric field
***D*** = electric field density
***B*** = magnetic field
***H*** = magnetic field density

rate of change in spatial component of electric field

rate of change in time of magnetic field

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$

rate of change in spatial component of magnetic field density

Electric "current" in free space

rate of change in time of electric field density

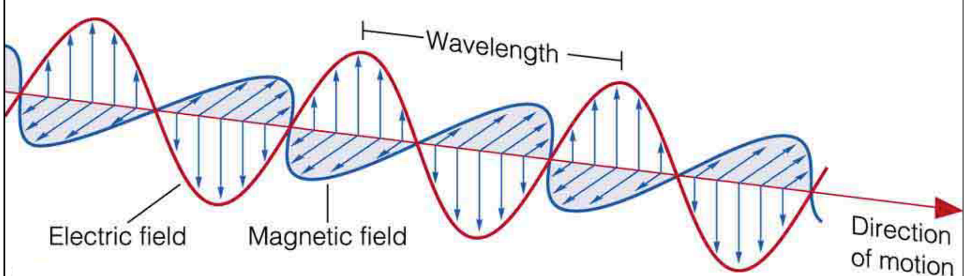
TOP EQUATION: a change in space of an electric field creates a magnetic field that changes in time.

BOTTOM EQUATION: a change in space of a magnetic field causes a electrical current and an electric field that changes in time

As the electric and magnetic field move through space, this **causes a self-propagating wave**!!!

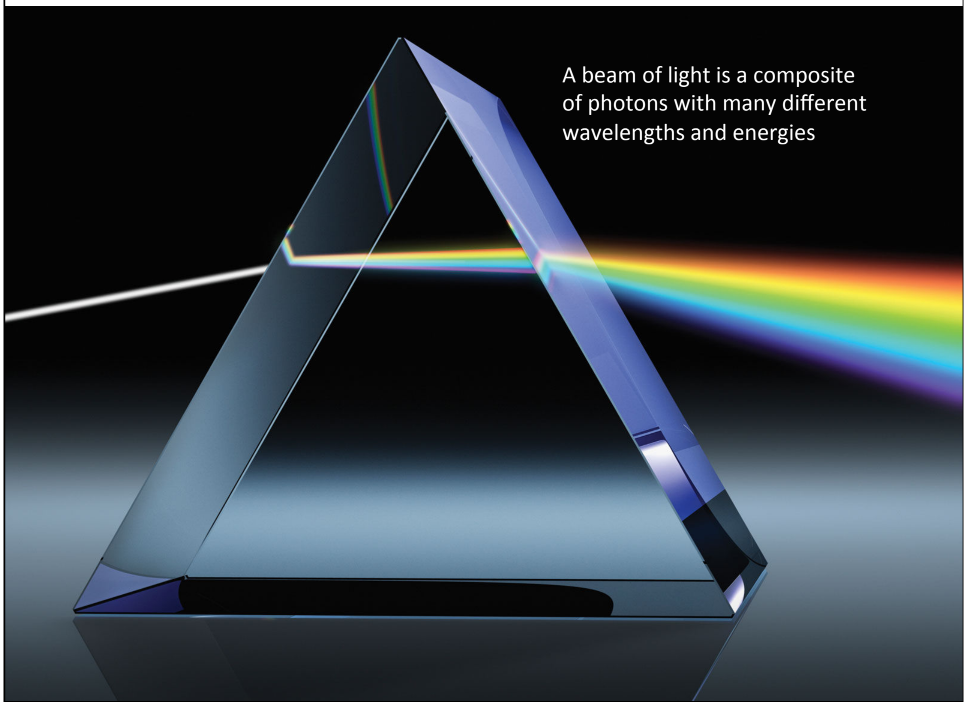
**Light is a self-propagating wave of electric and magnetic energy**

The electric+magnetic energy is distributed in "packets", like cars on a train.
We call the "train" of electric+magnetic energy packets photons.
Photons travel at the speed of light – always.

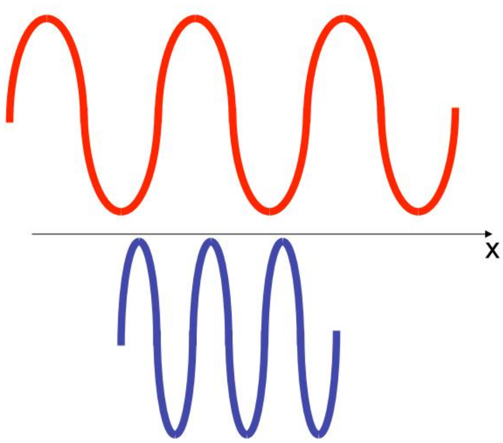



The speed of light is 186,000 mi/s = 300,000 km/s

http://youtu.be/9VpDO2iYpRU Mechanical Universe electric field propagation




## Photons - wave packets of energy

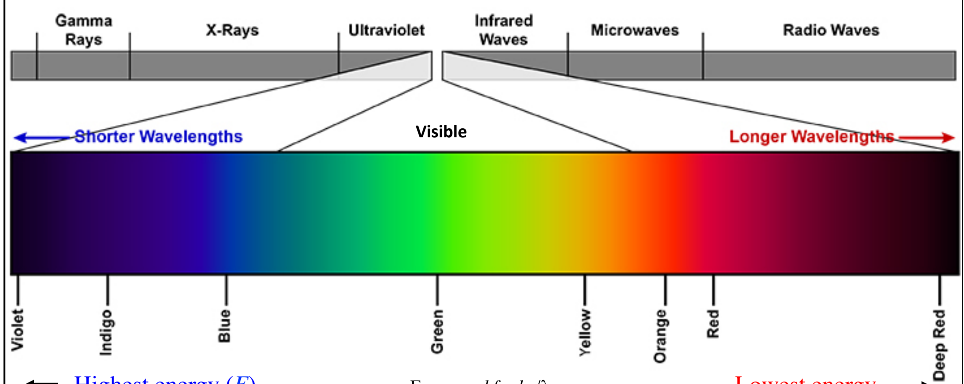



<u>Red Light</u>
$\lambda$ = 650 nm
Long wavelength
Low frequency
Low energy

<u>Blue Light</u>
$\lambda$ = 488 nm
Short wavelength
High frequency
High energy

1 nm = 1 nanometer = $10^{-9}$ meter (1 billionth of a meter!)

## The Electromagnetic Spectrum of Light



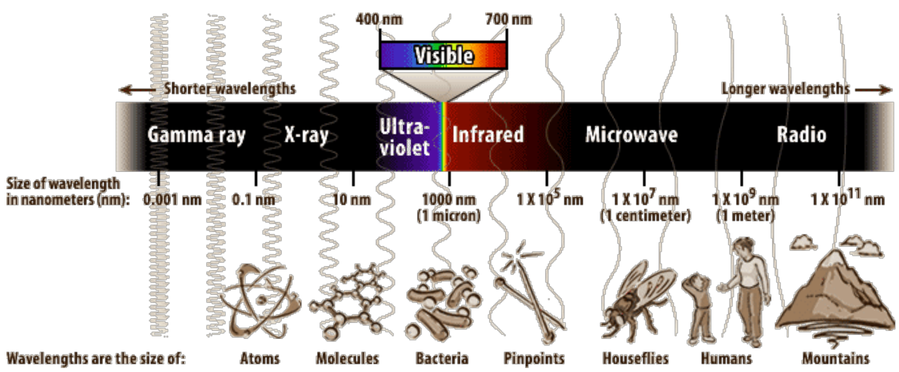

← Highest energy ($E$)
← Highest frequency ($f$)
← Shortest Wavelength ($\lambda$)

Energy $= hf = hc/\lambda$
$f$ = frequency
$h$ = Planck's constant
$\lambda$ = wavelength

Lowest energy →
Lowest frequency →
Longest Wavelength →

The smaller the packets (the shorter the wavelength), the faster they oscillate (the higher the frequency). The higher the oscillations frequency, the higher the energy. The smaller the packets the higher the energy density of the packets.

## The Electromagnetic Spectrum of Light

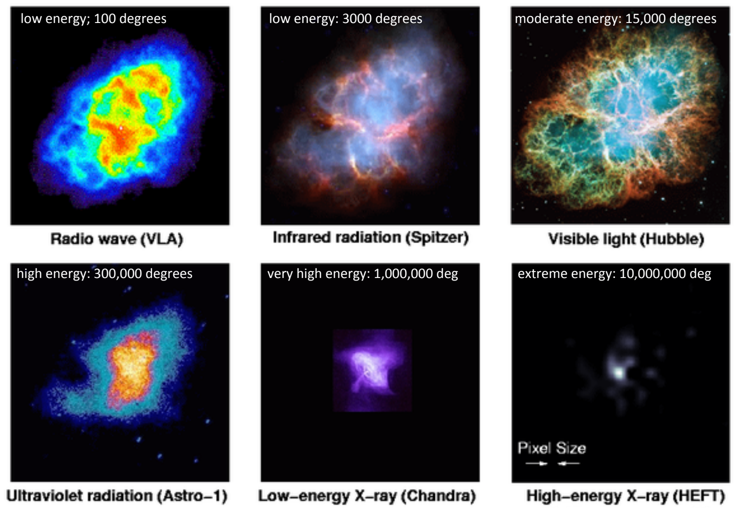



Gamma rays- that you avoid at all costs, the E&M packets are smaller than an atomic nucleus
X rays- that the doctors see your bones with, the E&M packets are the size of molecules
Micro waves- that you heat your food with, the E&M packets are the size of peas
Radio waves- that you tune into in your car, the E&M packets are the size of football fields

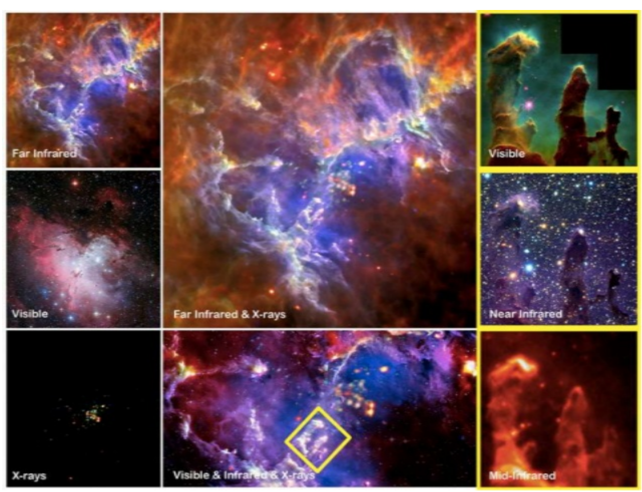
Low energy light is emitted from cool objects
High energy light is emitted from hot objects

**If we want to see energetic processes we collect x-rays and ultraviolet light; for low energy processes, we collect radio and infrared light. Study different physics/parts of a single object!!**

**Crab Nebula: Remnant of an Exploded Star (Supernova)**




**Star Forming Region known as "The Pillars of Creation"**



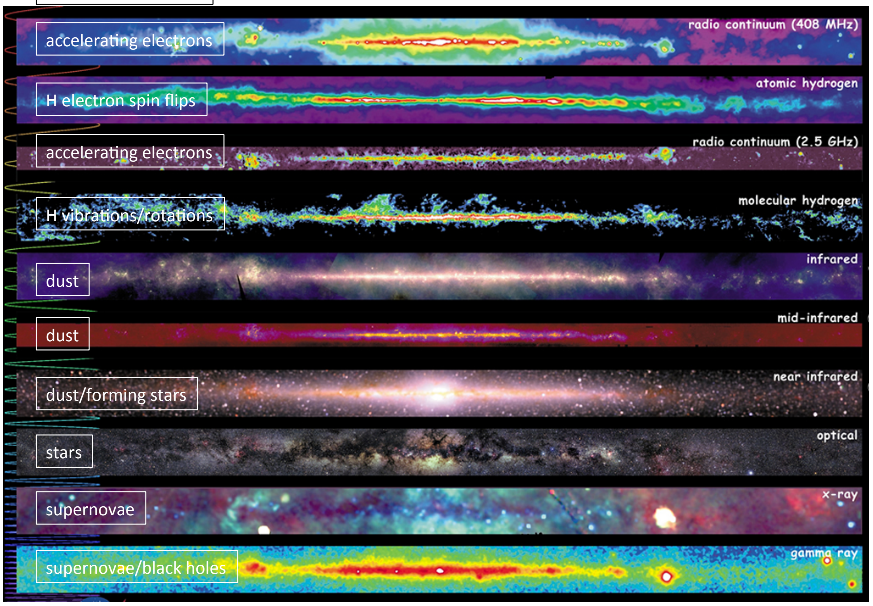

- X-rays show hot cores that are compact; far- and mid-infrared shows emission from dust and gas.
- Visible and near-infrared shows stars and gas (in reflected light and in silhouette, i.e., absorbed light).
- Not that X-ray emitting objects are distributed in the under-dense regions of the gas nebula.

**Using multiple regions of the electromagnetic spectrum teaches about how stars are born from gas clouds.**

## The Strip of Sky along The Milky Way

What you are seeing

spectral region



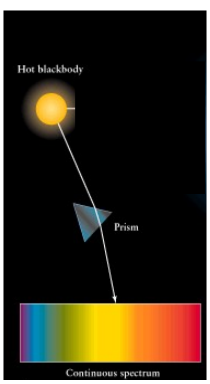

Pictures are nice, but the detailed physical information comes from spectra…

Absolute Temperature is measured in degrees Kelvin (K)

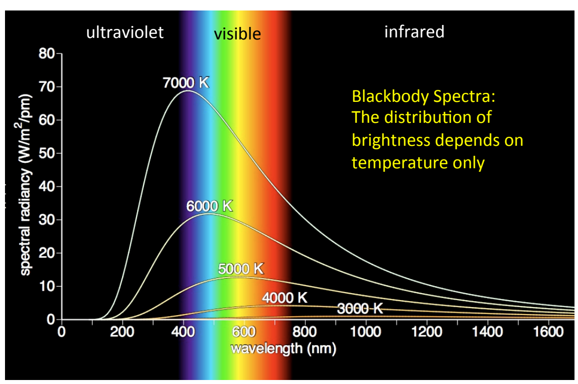
## Spectra

**A dense hot object emits a continuous spectrum of light**

**A "perfect" hot dense object emits a blackbody continuous spectrum**



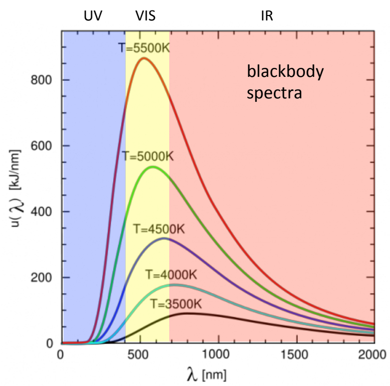

A hot dense object emits a continuous spectrum- all wavelengths of light are present in the light beam.



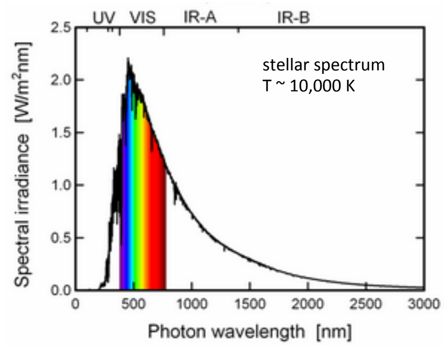

A perfectly radiating hot dense object (called a "blackbody") emits a continuous spectrum with a specific distribution of brightness with wavelength. The distribution depends upon only one quantity- the **absolute temperature** of the object.

At all wavelengths, hotter objects emit brighter light than cooler objects.
The peak brightness is at shorter wavelengths for hotter objects.

Though stars are hot and dense, they are not perfect emitters.
Still, you can learn about the temperature of a star from its spectrum.




Examples of blackbody continuous spectra for typical stellar temperatures.




The spectrum of a star with a temperature of roughly 10,000 K. Note that it is not a "perfect" blackbody spectrum, but its brightness distribution is still very revealing of the star's temperature. Note small features in the spectrum- we will show later that these can exploited to measure the star's chemical composition, density, and even the turbulence of the gas in the star's atmosphere.

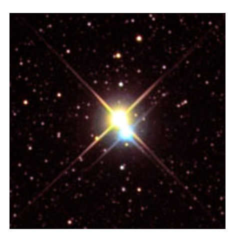
The apparent color of a star in the sky is indicating whether it is hot or cool

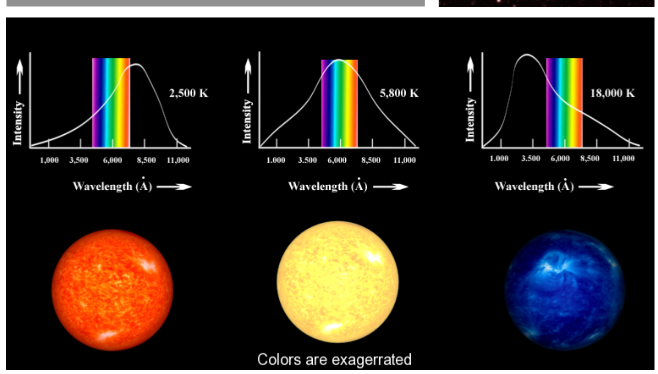
Reddish → cool

Yellowish → moderate

Bluish → hot

Your brain combines the light into a single "color", dominated by the brightest wavelengths of the spectrum



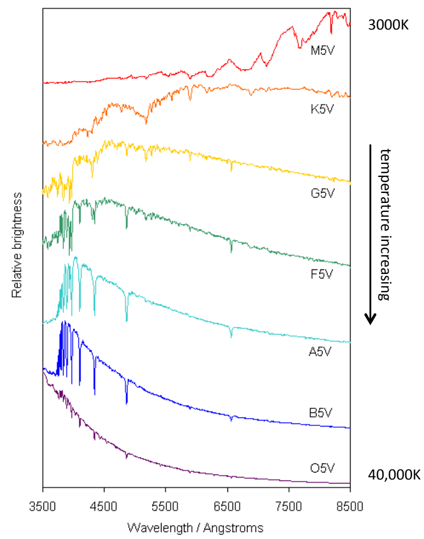


## What real stellar spectra look like

The over all shape of the spectrum and the many small features are the result of how **matter** (composed of different chemical elements in gas of different densities, pressures, temperatures, etc.,) generates **light**, and interacts with light.

To decode a spectrum, and astronomer needs to know the physics of atoms, molecules, gas, fluid flow, and gravity.

Astronomer:
*A physicist who does it with light.*

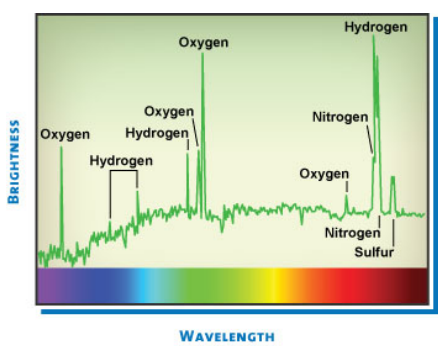



This means, if an astronomer knows the physics of light and matter, she can decode a spectrum to determine the physical properties of the object.

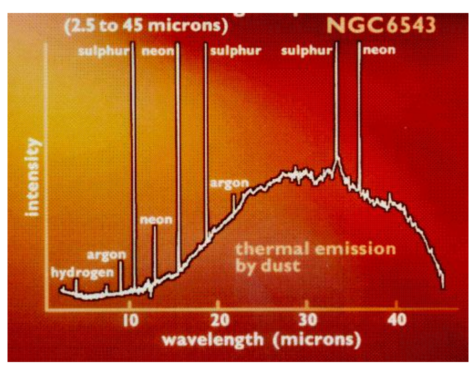
THAT'S WHAT WE DO!

## What real galaxy spectra look like

A galaxy is made up of 100s of billions of stars having a wide range of temperatures, chemical makeup, etc. They also have lots of gas and dust in them, and this dust and gas is at different temperatures and densities, etc., and made up of different chemical elements.




**visible spectrum of a galaxy**- the overall shape reflects the composite spectra of billions of stars; the other features are due to emission from the gas of star forming nebulae and their relative strength can provide the chemical make up and the rate at which stars are forming in the galaxy!!




**infrared spectrum of a galaxy**- the overall shape reflects the composite thermal emission from the dust in the gas between the stars; the other features provide insights on the chemical make up of the gas in which this dust resides. One can even determine the sizes of the dust grains!

So, now you know.

Astronomy is performed by studying light and applying the laws of physics to figure out what is creating or absorbing the light. We apply the whole electromagnetic spectrum because it tells the whole story.

**A main point of this lecture** is to understand the power of light. Even though astronomers are "handicapped" in that they can only collect light, the laws of physics provide us great power to study what is going on out in space- no matter how far away the object is.