# ASTR2115
# Angles, Units, Temperature, Light

Chapters 1 and 5

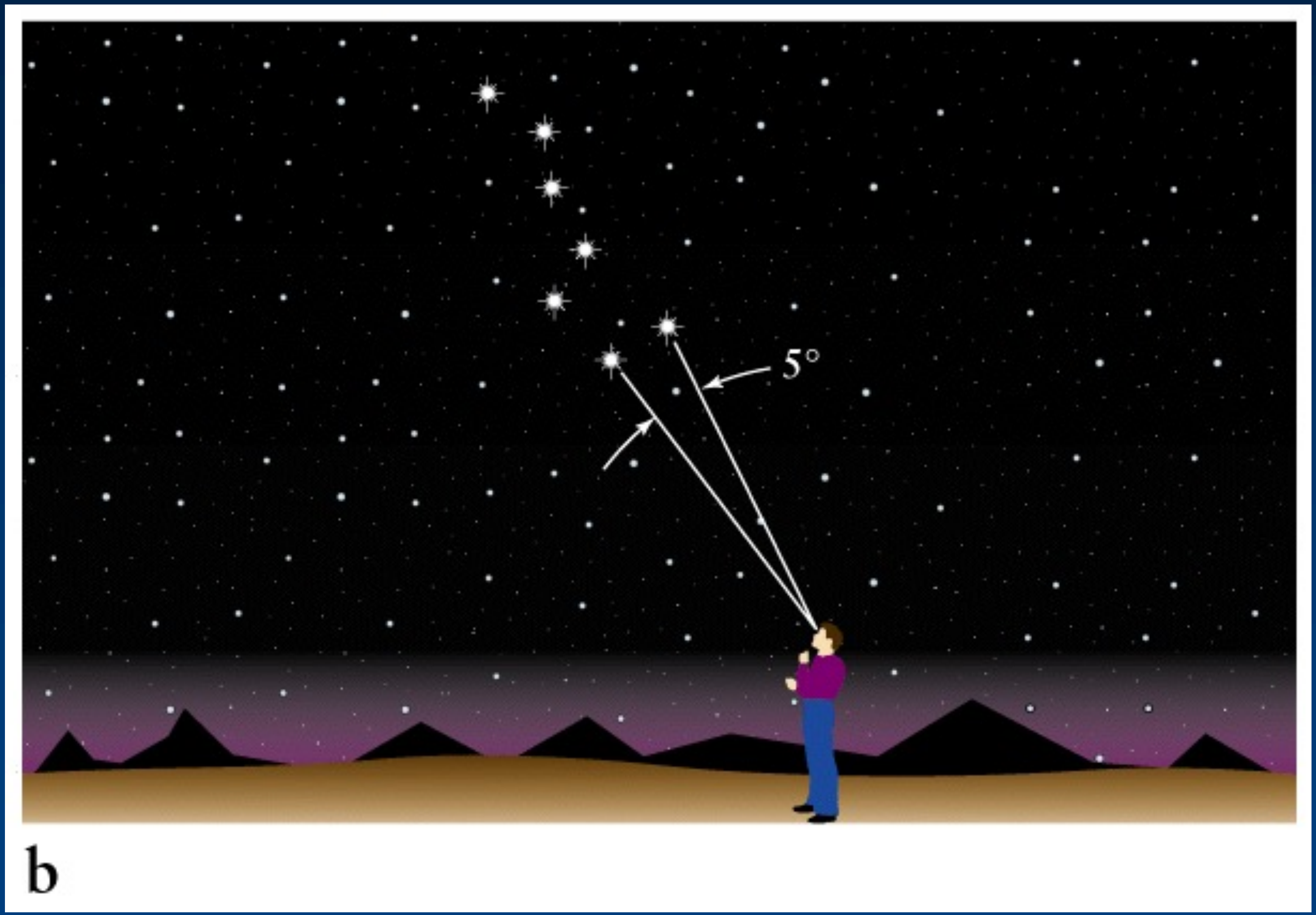
# Announcements

- First Homework is due next week

# The process of astronomy research

- Build a telescope (instrumentation)
- What is it that we see? (observing)
- How does it work? (analysis)
- How was it formed, and how will it evolve? (theory & predictions)

Example of angular distance:  the “pointer stars” in the big dipper




The Moon subtends about one-half a degree

# Angular size - linear size - distance

Use the *small-angle formula*:

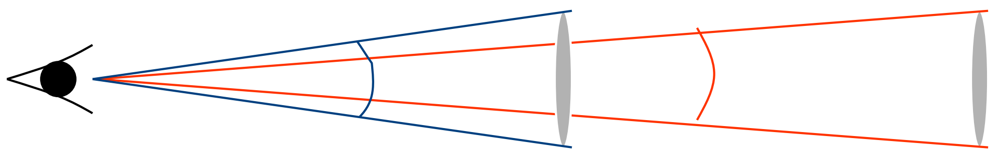
$$D = \frac{\alpha d}{206265}$$

where D = linear size of an object (any unit of length),
d = distance to the object (*same* unit as D)
$\alpha$ = angular size of the object (in arcsec),

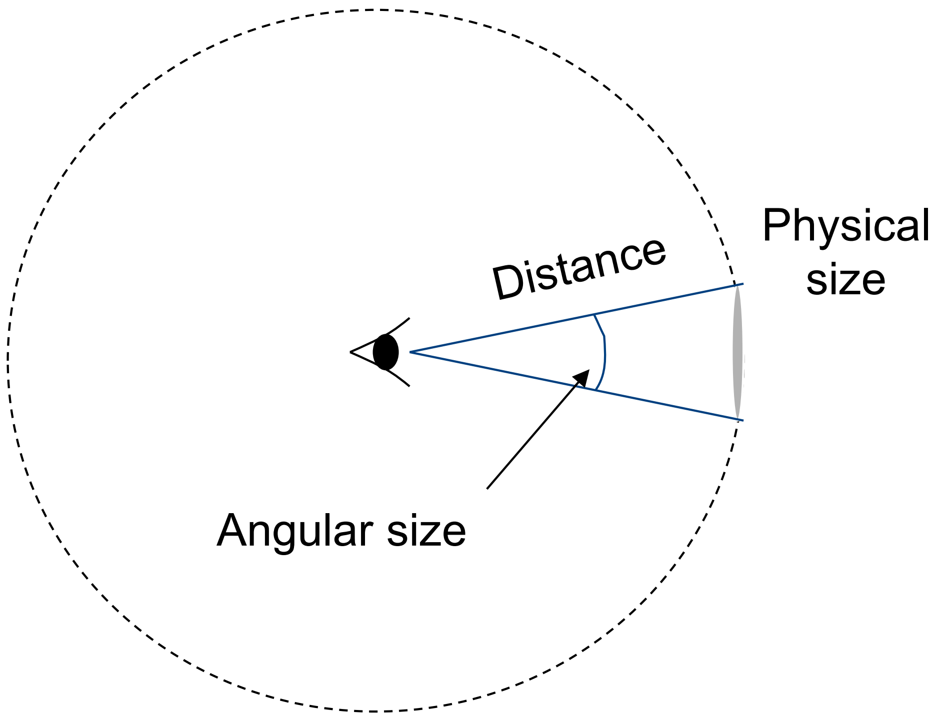
The 206,265 is required in the formula - it's the number of arcseconds in a circle divided by $2\pi$.

*Where does this formula come from?*

**The same idea in pictures: the angular size depends on the linear (true) size AND on the distance to the object. See Box 1-1.**



Moving an object farther away reduces its angular size.




$$C = 2\pi r$$

As long as the angular size is small, we can think of the object's physical size as a small piece of a circle.

# Units in astronomy

Astronomers use the normal metric system and powers-of-ten notation, plus a few “special” units.

Example: Average distance from Earth to Sun is about $1.5 \times 10^{11}$ m = 1 Astronomical Unit = 1 AU

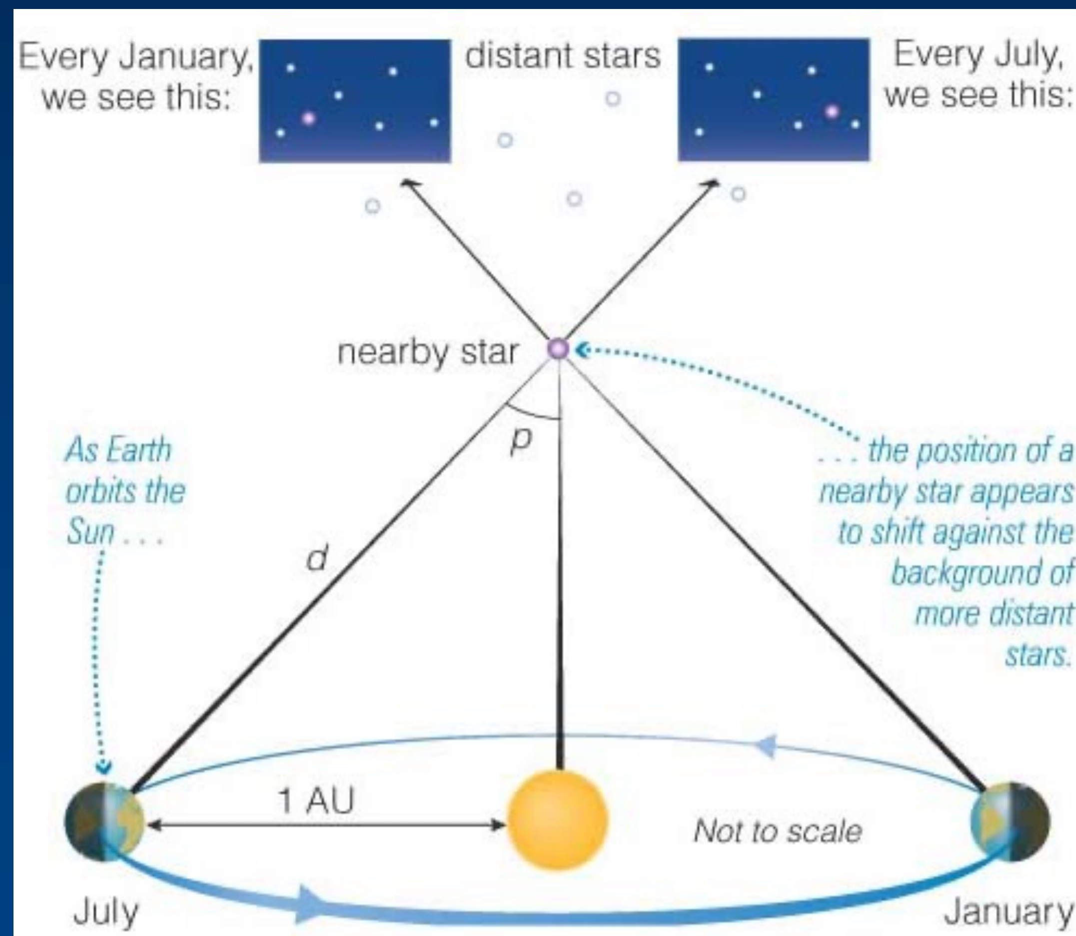
Used for distances in the Solar system.

This fall we are working on much larger scales, in which case we normally use the unit of parsec.

# The parsec unit

- Relation between angular size and linear distance => basic unit of distance in astronomy: the parsec
- Short for "parallax of one second of arc"
- The distance between Earth and a star at which the radius of the Earth's orbit around the Sun (1AU) subtends an angle of 1"

**The nearest star is 1.3 pc away (1 pc = 3.09 x $10^{16}$ m)**



# Positions of celestial objects

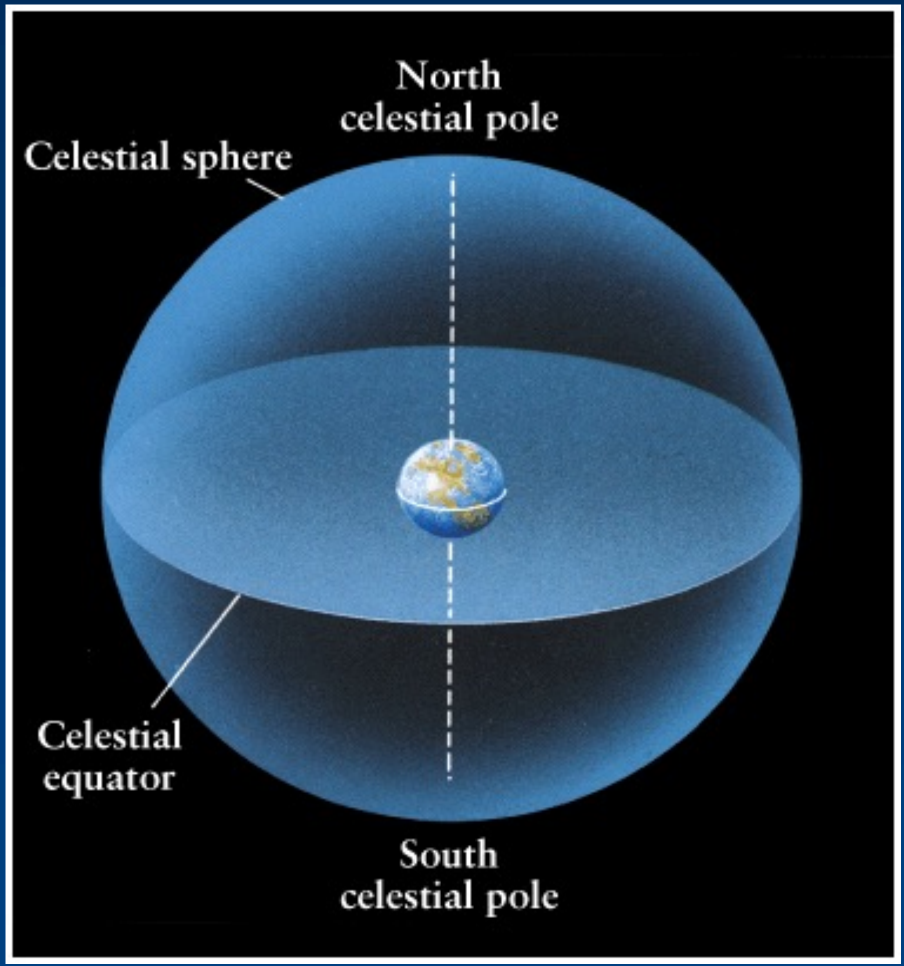
- Same idea when we describe the position of a celestial object
- The Sun, the Moon and the stars are so far away that we cannot perceive their distances by eye - no depth perception.
- Instead, the objects appear to be projected onto a giant, imaginary sphere centered on the Earth.
- All objects seem to be on the surface of this imaginary sphere

# The celestial sphere

- Stars are really distributed in 3-dimensional space, but they *look* like they're on a 2-dimensional sphere centered on Earth.

- To locate an object, two numbers (angular measures), like longitude and latitude are sufficient.

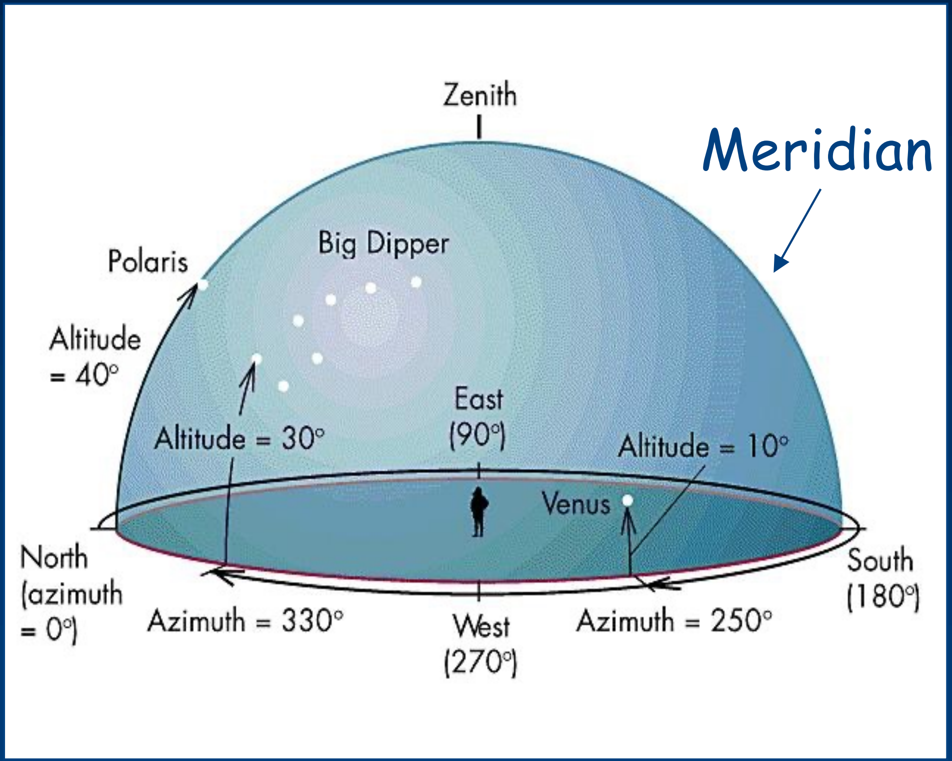
- Useful if we want to decide where to point our telescopes.



# Horizon coordinate system

- The Horizon coordinate system (used for telescopes):

- Altitude
  - Angle above the horizon
  - 0-90º
  - The altitude of the north celestial pole equals the observer's latitude on Earth.

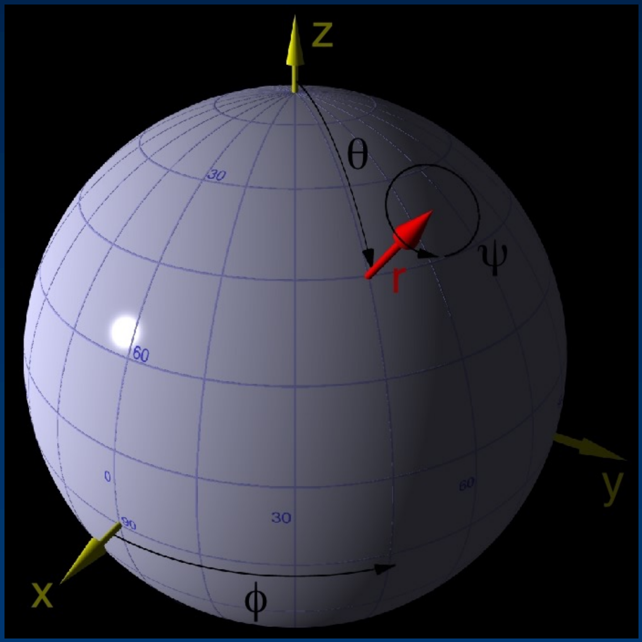



- Azimuth
  - Angle measured eastward along horizon, starting from the north
  - 0-360º

# Pros and cons of the Horizon system

- Pros
  - Easy to tell and understand

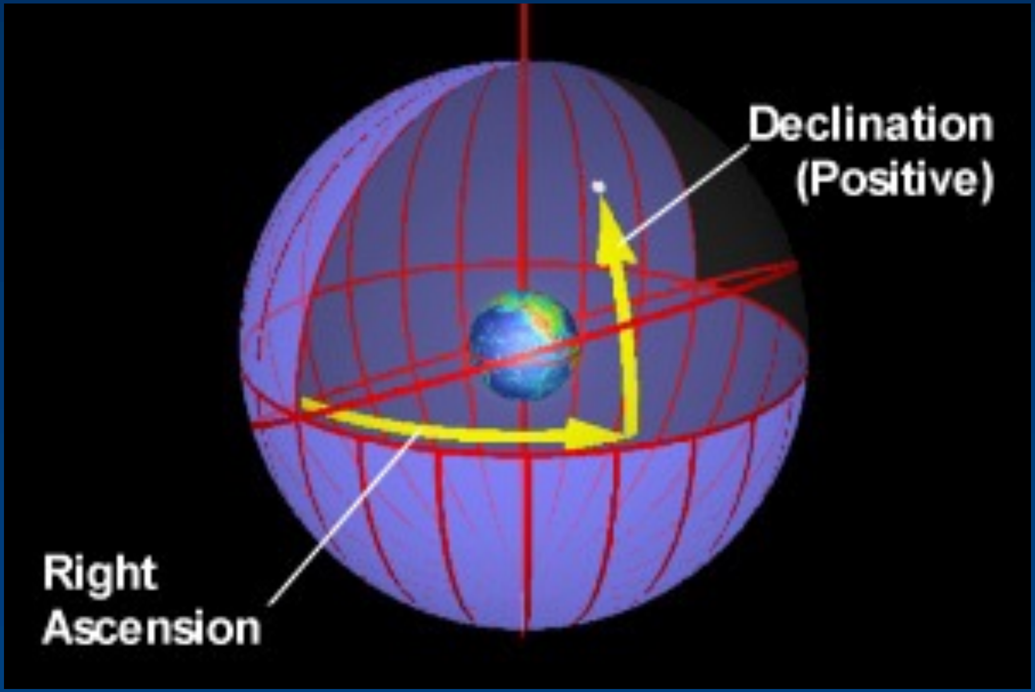
- Cons
  - At different position on the Earth, the same object has different coordinates
  - At different times, the same object has different coordinates




The coordinates of an object change in this system!

# The Equatorial system

- A system in which the coordinates of an object does NOT change.
- The coordinates are called Right Ascension and Declination, and are analogous to longitude and latitude on Earth.




- The equatorial coordinate system rotates with stars and galaxies.

# RA and Dec

- Declination (Dec) is measured in degrees, arcminutes, and arcseconds.

- Right ascension (RA) is measured in units of time: hours, minutes, and seconds.

- Example 1: The star Regulus has coordinates

  $RA = 10^{h}\ 08^{m}\ 22.2^{s}$

  $Dec = 11^{\circ}\ 58'\ 02''$

Stellarium Demo

**Zero point of RA:** ***The vernal equinox,*** **which is the point on the celestial equator the Sun crosses on its march north - the start of spring in the northern hemisphere (cf. Greenwhich 0° longitude).**

# Properties of Light
# Chapter 5

# Light carries information to astronomers

- How hot is the Sun?
- How does it compare to other stars?
- What is its composition?
- Is there anything between the stars? Between galaxies?
- How do we know that the Universe is expanding?

All of this comes from the study of light!

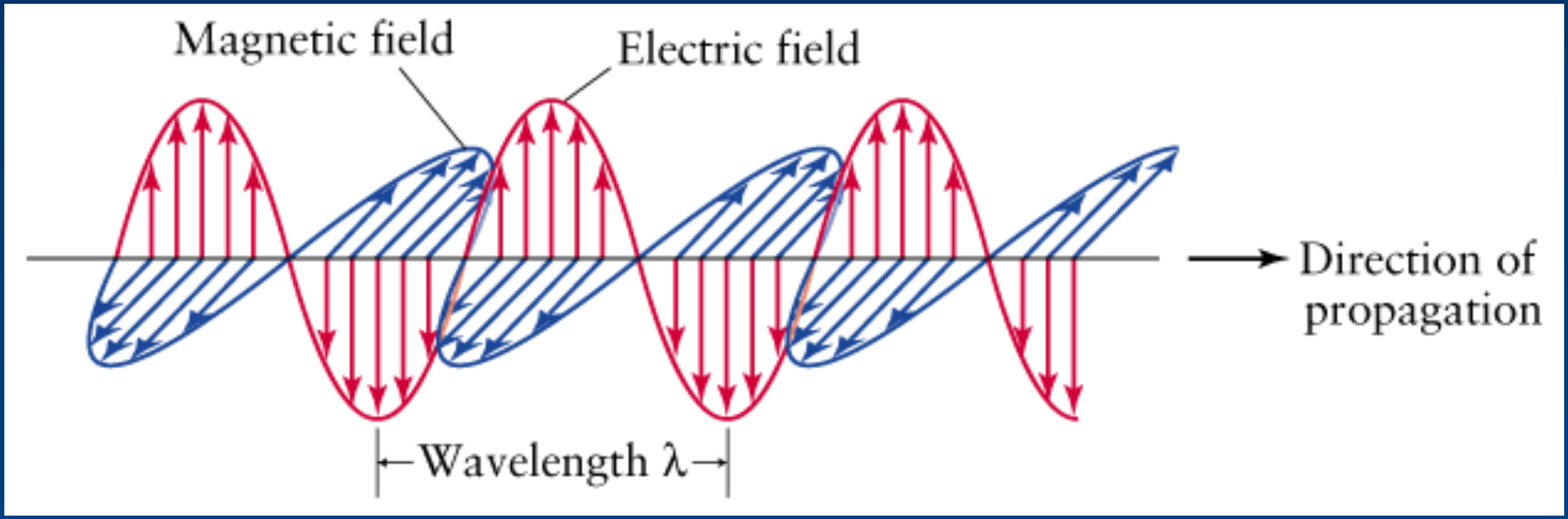
*Astronomers use telescopes to collect light of distant objects, and then extract information from this light.*

# What is light?

- Light is *electromagnetic (EM) radiation*
- Light can be treated either as
  - EM waves
  - Photons (particles of light)
- Both natures have to be considered to describe all essential properties of light

# Light as electromagnetic waves

- EM waves: self propagating electric and magnetic fields (changes in strengths of E- and B-fields).
- Traveling (in vacuum) at the constant speed of light $c = 3 \times 10^8$ m/s.
- $\nu = c/\lambda$, where $\nu$ is the frequency [Hz] and $\lambda$ is the wavelength [m].




**EM waves are different from other waves, since it doesn't need a medium to propagate in!**

# Properties of light

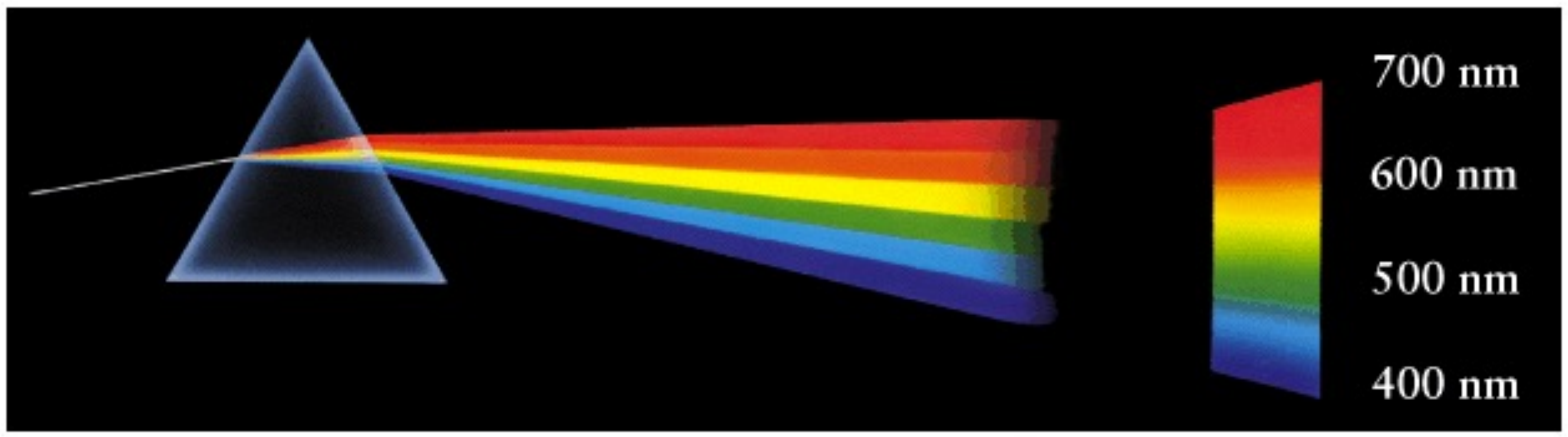
- It heats up material (e.g. your skin), thus it is a carrier of energy.
  - This is radiative energy, one out of three basic categories of energy (kinetic, potential and radiative)

- It has a "color", especially in the visible regime you are used to the colors of the rainbow:

- The human eye is sensitive to light with colors from violet to red, which corresponds to a wavelength range:

  4,000 Å < $\lambda$ < 7,000 Å where an Å is $10^{-10}$ m (Å=Ångström).

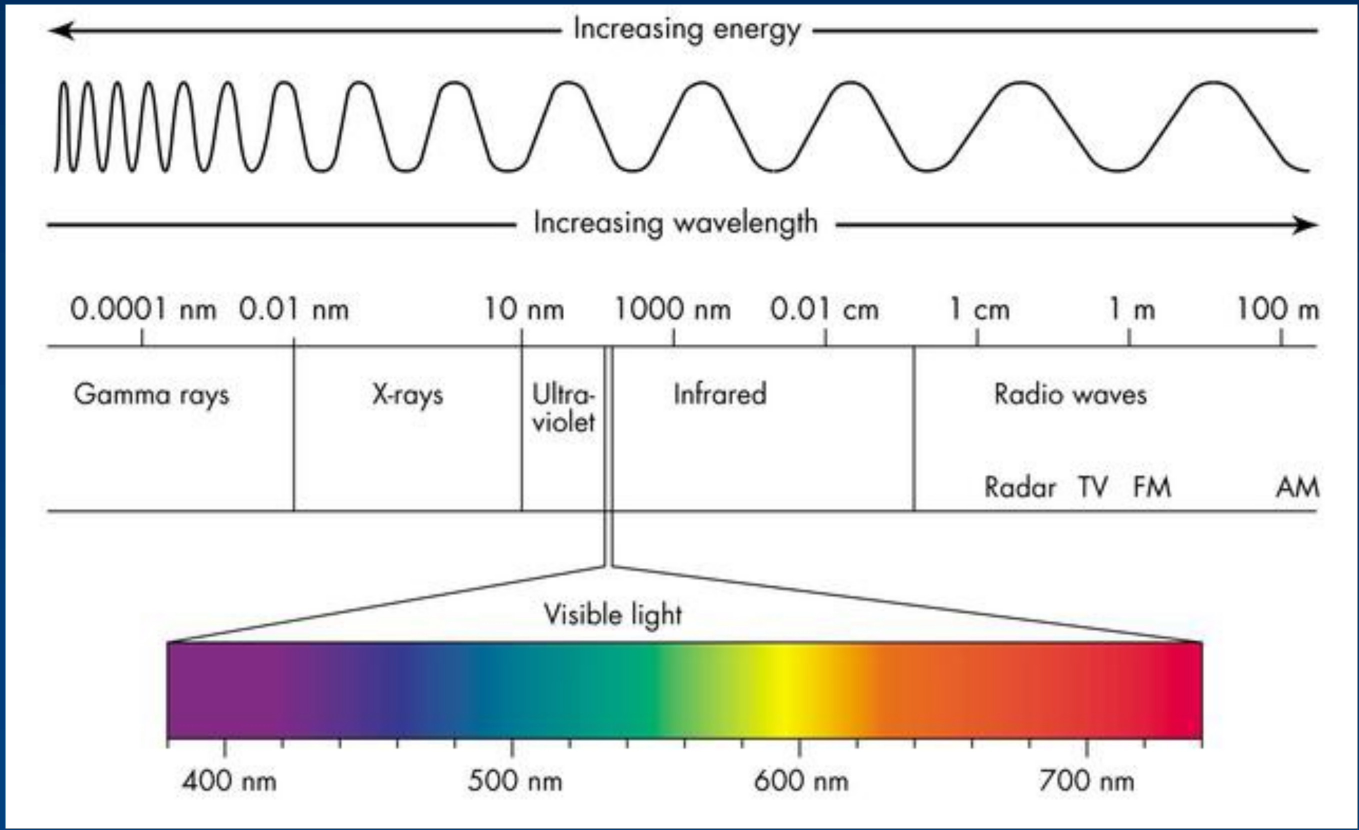
  = 400 nm < $\lambda$ < 700 nm where 1 nm =$10^{-9}$ m.




- White light: all colors of the rainbow
- Black: no light, hence no colors

# The electromagnetic spectrum

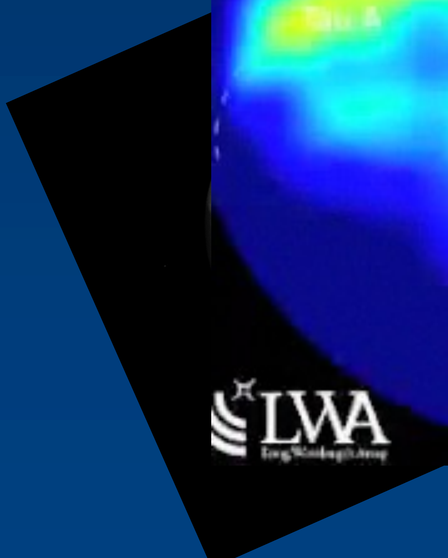
- Light extends beyond the visible regime, and the continuous and infinite distribution of wavelengths is called the electromagnetic spectrum

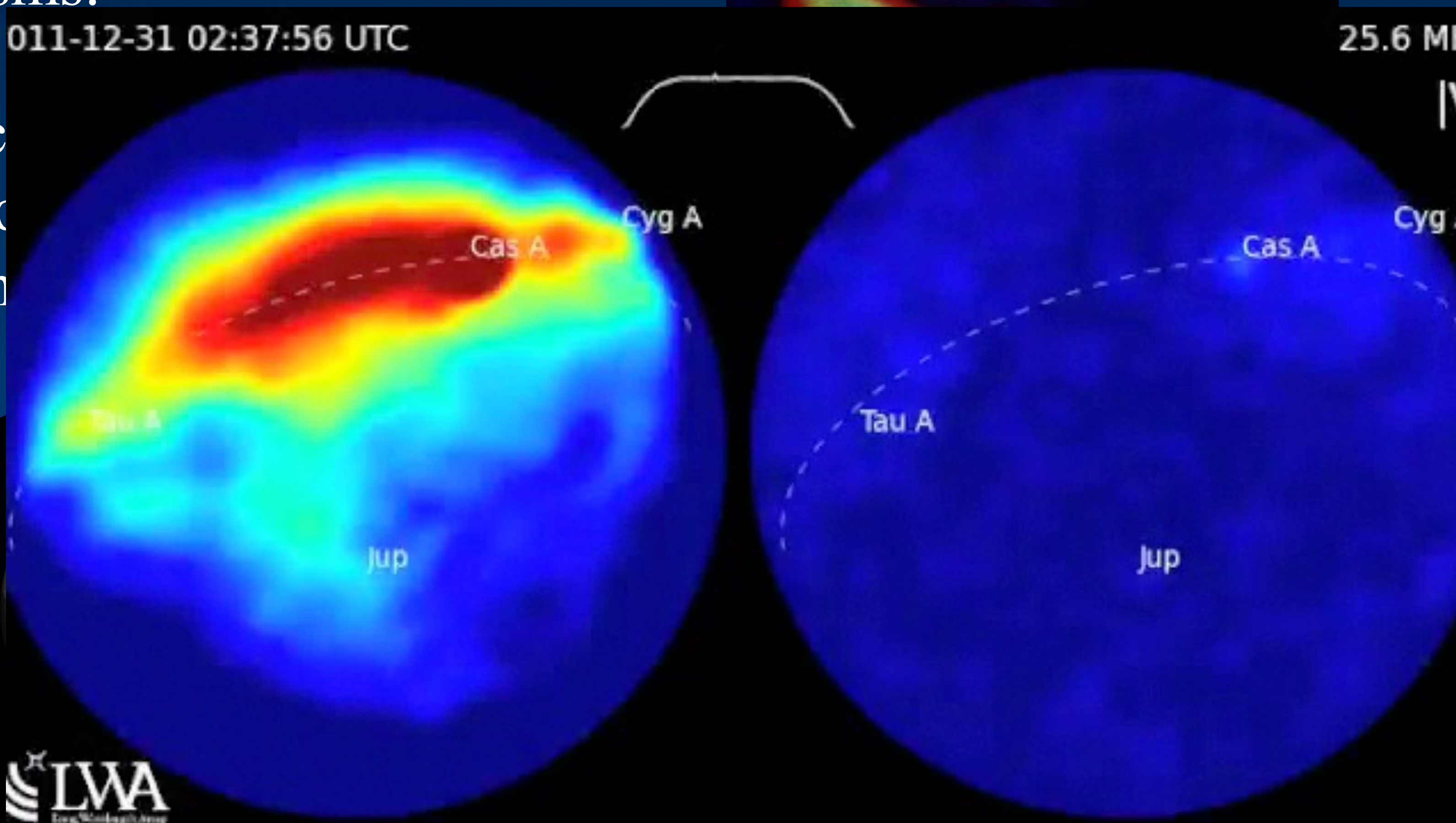



Light of different wavelengths interacts in different ways with matter

# Different types of emission mechanisms:

Optic
due t
or 'lin






us different information
about objects.

# The dual nature of light

Light often acts like a wave but also can act like a particle – in interactions with atoms and molecules.

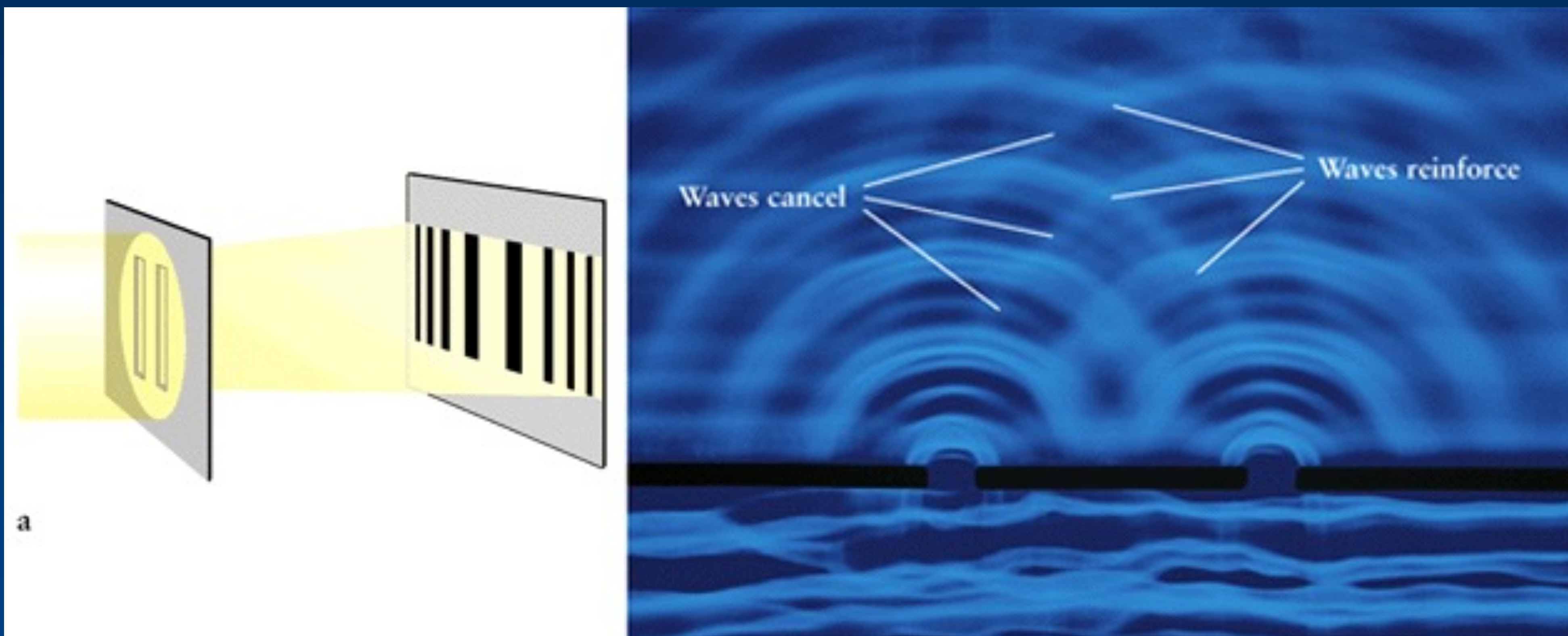
- The particles are called *photons*.
- A photon is a mass-less particle that carries energy E at the speed of light.
- $E = hc/\lambda = h\nu$ where $h = 6.6 \times 10^{-34}$ J s (Planck's constant)

Question: which has more energy, a photon of blue light, or of red light? UV or radio?

# Young's double slit experiment

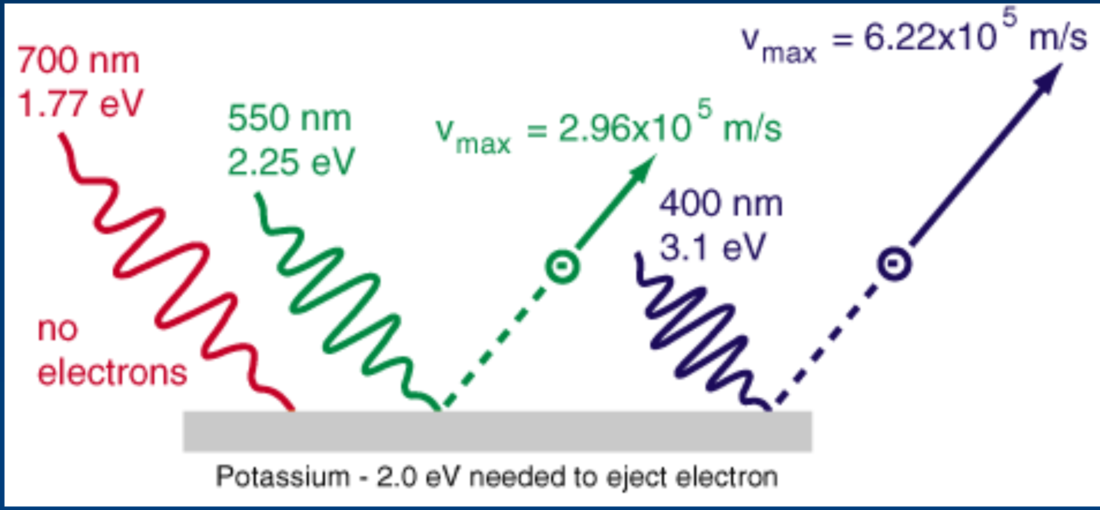
Demonstrates the wave-like nature of light:

Like water waves (right), EM waves can interfere.



# The photoelectric effect

- Illustrates the particle nature of light: Photons hitting a piece of metal will knock out single electrons, but only if they have enough energy.
- Above this energy level the kinetic energy of the photon does NOT depend on the intensity of the incident radiation, but on the frequency.




- IF light had only wave-nature, the kinetic energy of ejected electrons should depend on the amplitude (intensity) of the wave, but instead it depends on the frequency ($E=h\nu$)

# How do light and matter interact?

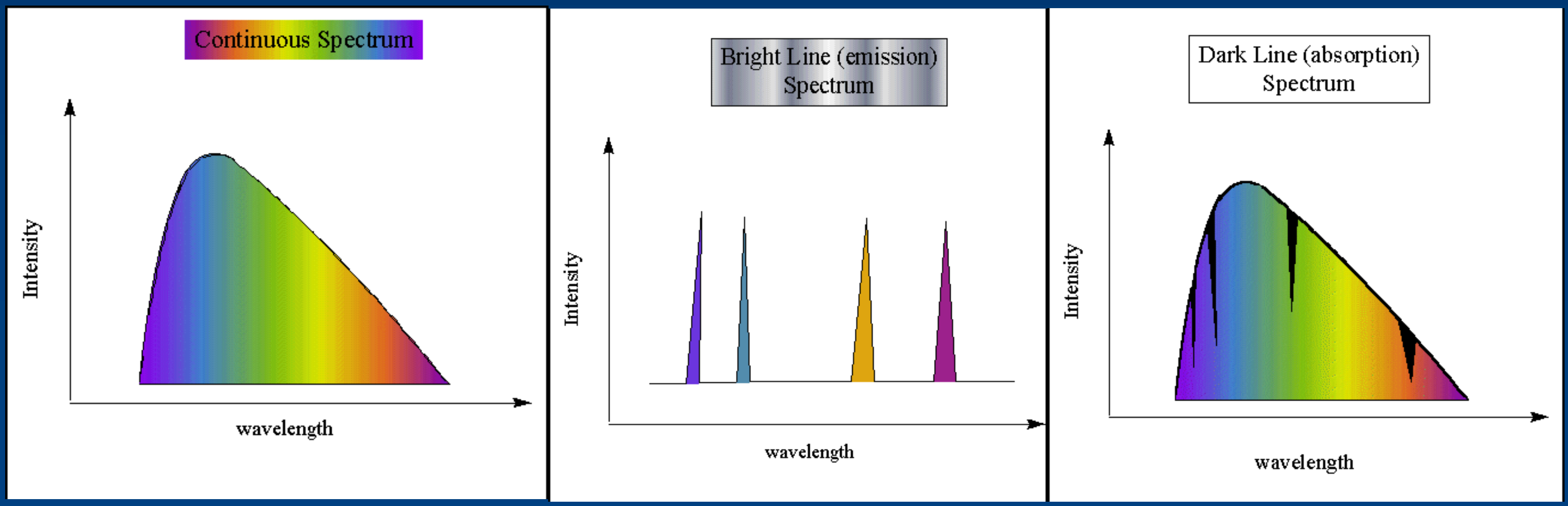
- Emission - light bulb, star
- Absorption - your skin can absorb light, in turn the absorbed energy heats your skin
- Transmission - glass and air lets the light pass through
- Reflection and scattering - light can bounce off matter leading to reflection (same direction of reflected light) or scattering (random direction of reflected light)

**Materials that transmit light are *transparent.***
**Materials that absorb light are *opaque.***

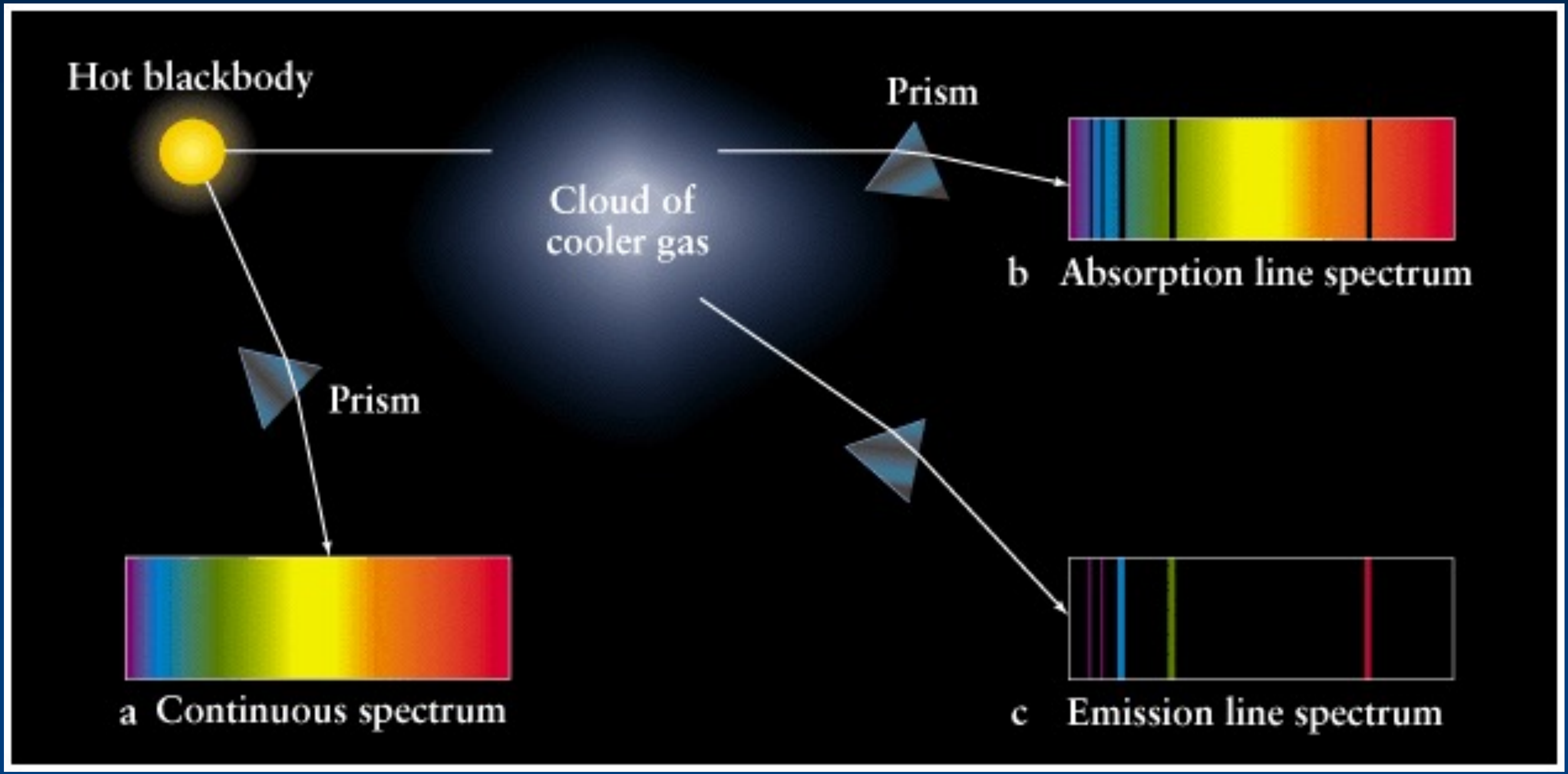
# Three basic types of spectra

- Kirchoff's laws of spectroscopy:

  1. A hot, opaque body, or a hot, dense gas produces a continuous spectrum.
  2. A hot, transparent gas produces an emission line spectrum.
  3. A cool, transparent gas in front of a source of a continuous spectrum produces an absorption line spectrum.



# Illustration Kirchoff's laws



## Astrophysical examples:

- Continuous: asteroids, planets, etc.
- Emission line: hot interstellar gas -- HII regions, planetary nebulae, supernova remnants.
- Absorption line: stars (relatively cool atmospheres overlying hot interiors), cool interstellar gas.

*Important concepts: temperature and blackbody.*

# Kelvin temperature scale

- An absolute temperature system in which the temperature is directly proportional to the internal energy.

  - Uses the Celsius degree, but a different zero point.
  - 0 K: absolute zero
  - 273 K: freezing point of water
  - 373 K: when water boils

# Thermal radiation

- Let's consider the concept of a "blackbody"
  - Tenuous gas: most light can pass through relatively unaffected
  - Denser matter (like a rock) will not allow light to pass as easily
- A dense body will absorb light photons over a wide range of wavelengths
- This also means the absorbed photon cannot easily escape - once reemitted it immediately interacts with another molecule
- The photons bounce around inside the body for a long time, and when they finally escapes it has randomized wavelength

=> results in a smooth, continuous spectrum

*A perfect absorber/emitter is called a blackbody*

# Blackbody (thermal) radiation

- A blackbody is an object that absorbs all light, at all wavelengths: perfect absorber
  - No reflected light
- As it absorbs the light, it will heat up
  - Characterized by its temperature
- A black body will emit light at all wavelengths (continuous spectrum): perfect emitter
  - Energy emitted depends on temperature

The radiation the blackbody emits is entirely due to its temperature.

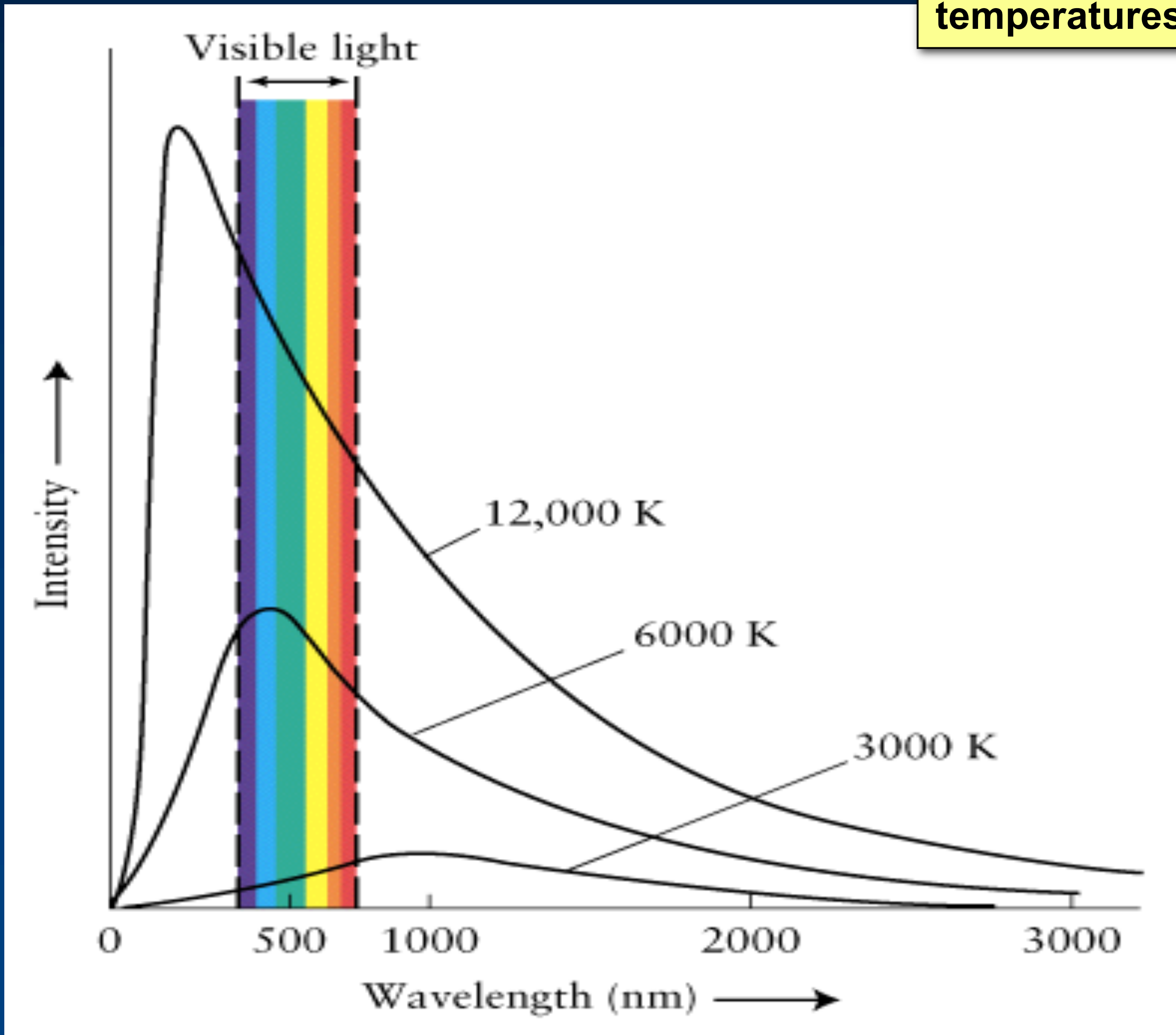
Intensity, or brightness, as a function of frequency (or wavelength) is given by Planck's Law:

$$I_\nu = \frac{2h\nu^3}{c^2}\left[\frac{1}{e^{h\nu/kT} - 1}\right]$$

where k is Boltzmann constant = $1.38 \times 10^{-23}$ J/K

Units: J $s^{-1}$ $m^{-2}$ $ster^{-1}$ $Hz^{-1}$

$$I_\lambda = \frac{2hc^2}{\lambda^5}\left[\frac{1}{e^{hc/\lambda kT} - 1}\right]$$




**Example: 3 blackbody (Planck curves) for 3 different temperatures.**

DEMO
Hot wire

# Wien's law for a blackbody

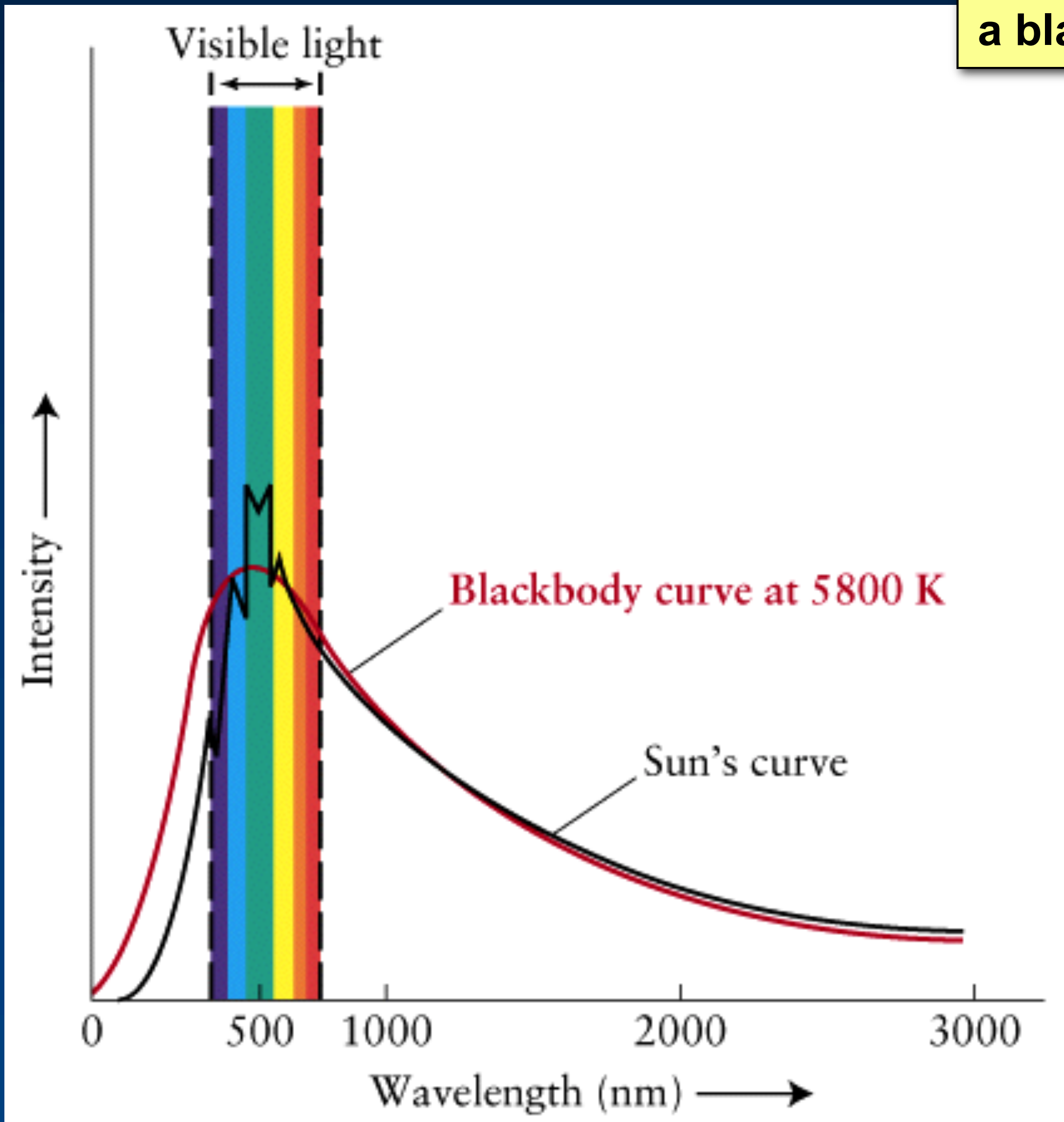
$$\lambda_{max} = 0.0029/T$$

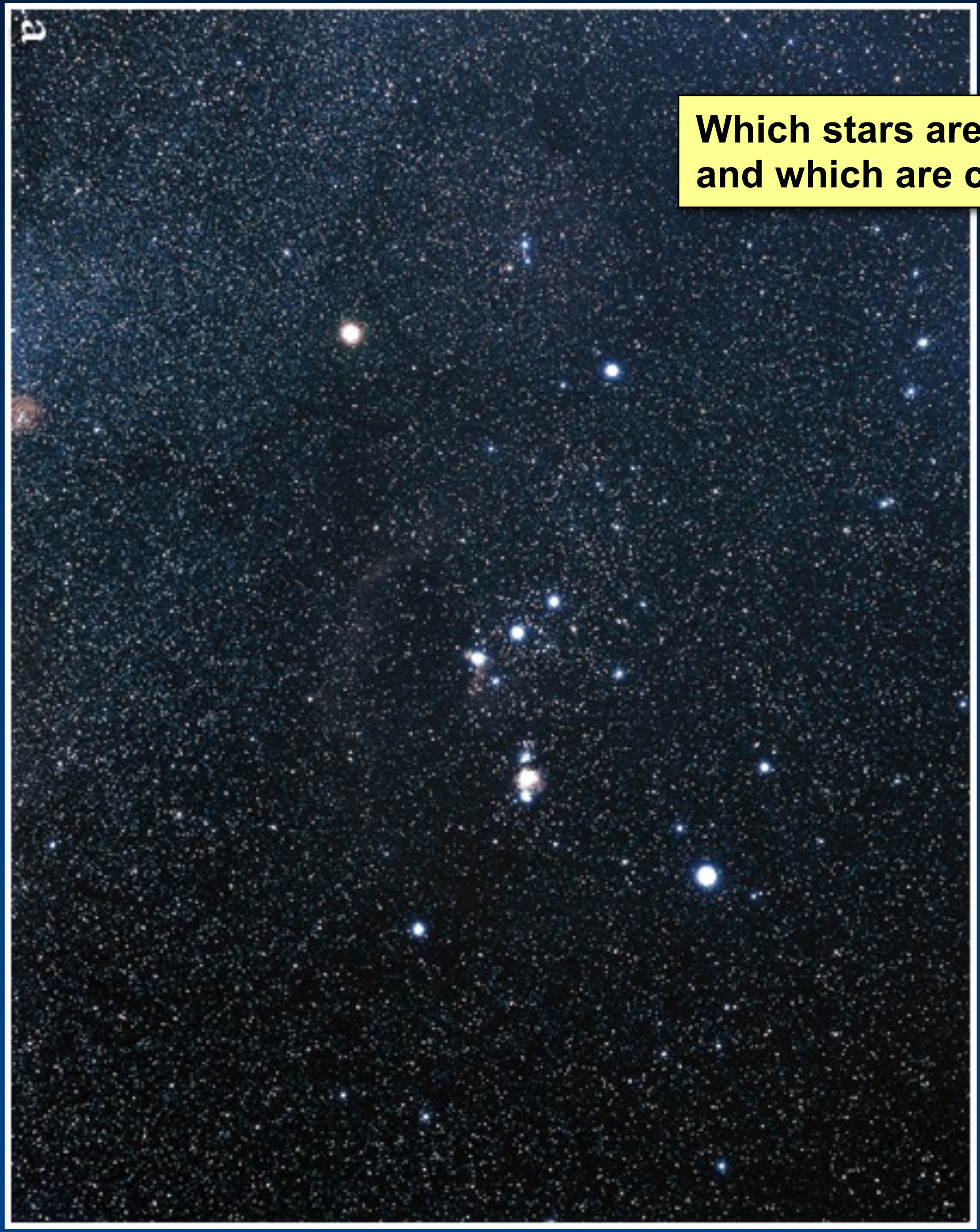
where $\lambda_{max}$ is the wavelength of maximum emission of the object (in m), and T is the temperature of the object (in K).

**=>** The hotter the blackbody, the shorter the wavelength of maximum emission

Hotter objects are bluer, cooler objects are redder.

**The spectrum of the Sun is *almost* a blackbody curve.**






Which stars are hotter, and which are cooler?

# Stefan-Boltzmann law for a blackbody

$$F = \sigma T^4$$

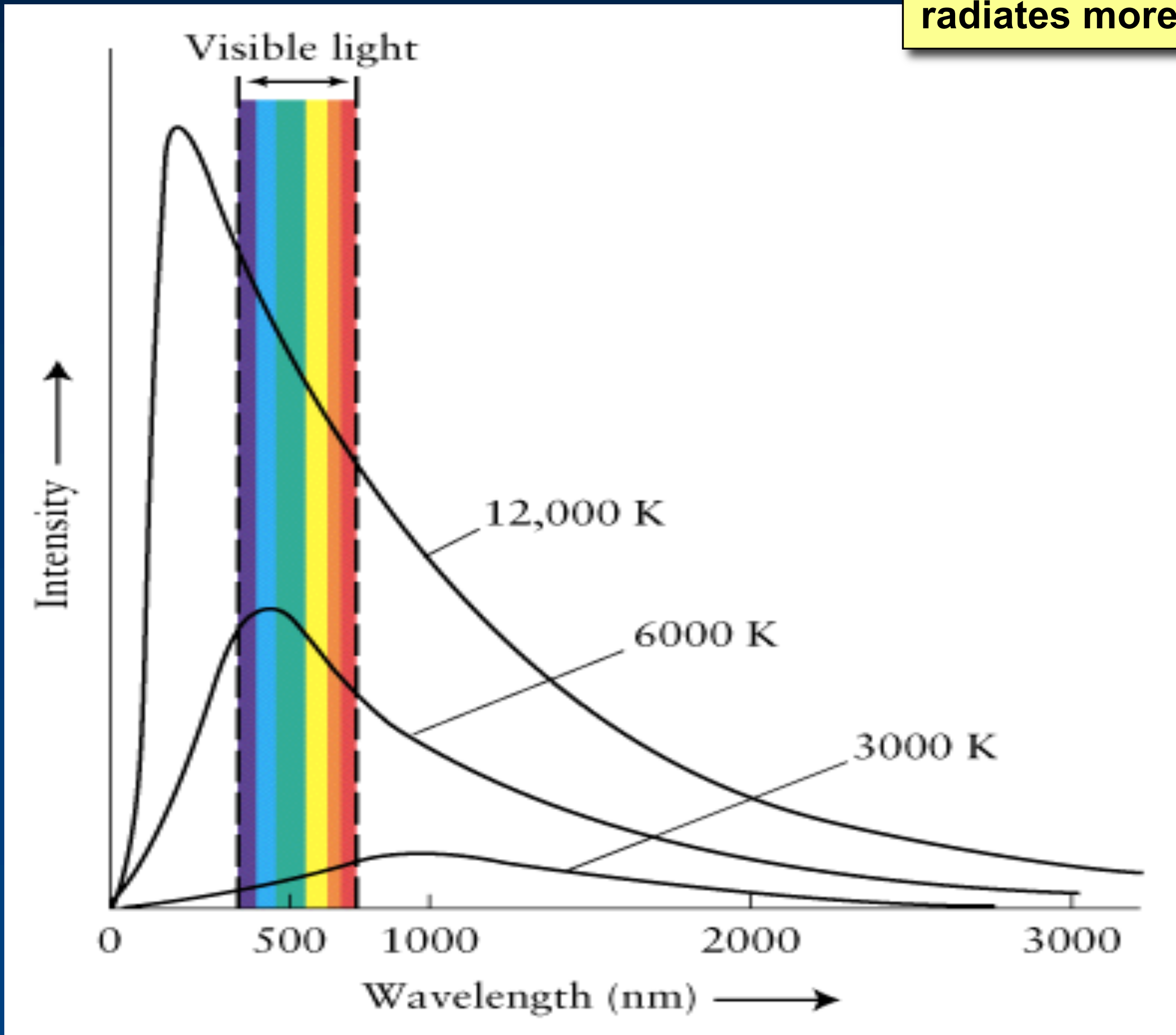
F is the energy flux, in joules per square meter of surface per second,

$\sigma$ is a constant = $5.67 \times 10^{-8}$ W $m^{-2}$ $K^{-4}$,

T is the object's temperature (in K).

The hotter the blackbody, the more radiation it gives off at all wavelengths.

At any wavelength, a hotter body radiates more.



Example: If the temperature of the Sun were twice what it is now, how much more energy would the Sun produce every second?

See box 5-2 for more examples.

WS1: How hot is the photosphere of the Sun?

Example 2: At what wavelength would the spectrum peak for a star which is 5800/2 = 2900 K?

For a star with T= 5800 x 2 = 11,600 K?

What colors would these stars be?

WS1: How hot is the photosphere of the Sun?

Measure $\lambda_{max}$ to be about 500 nm, so

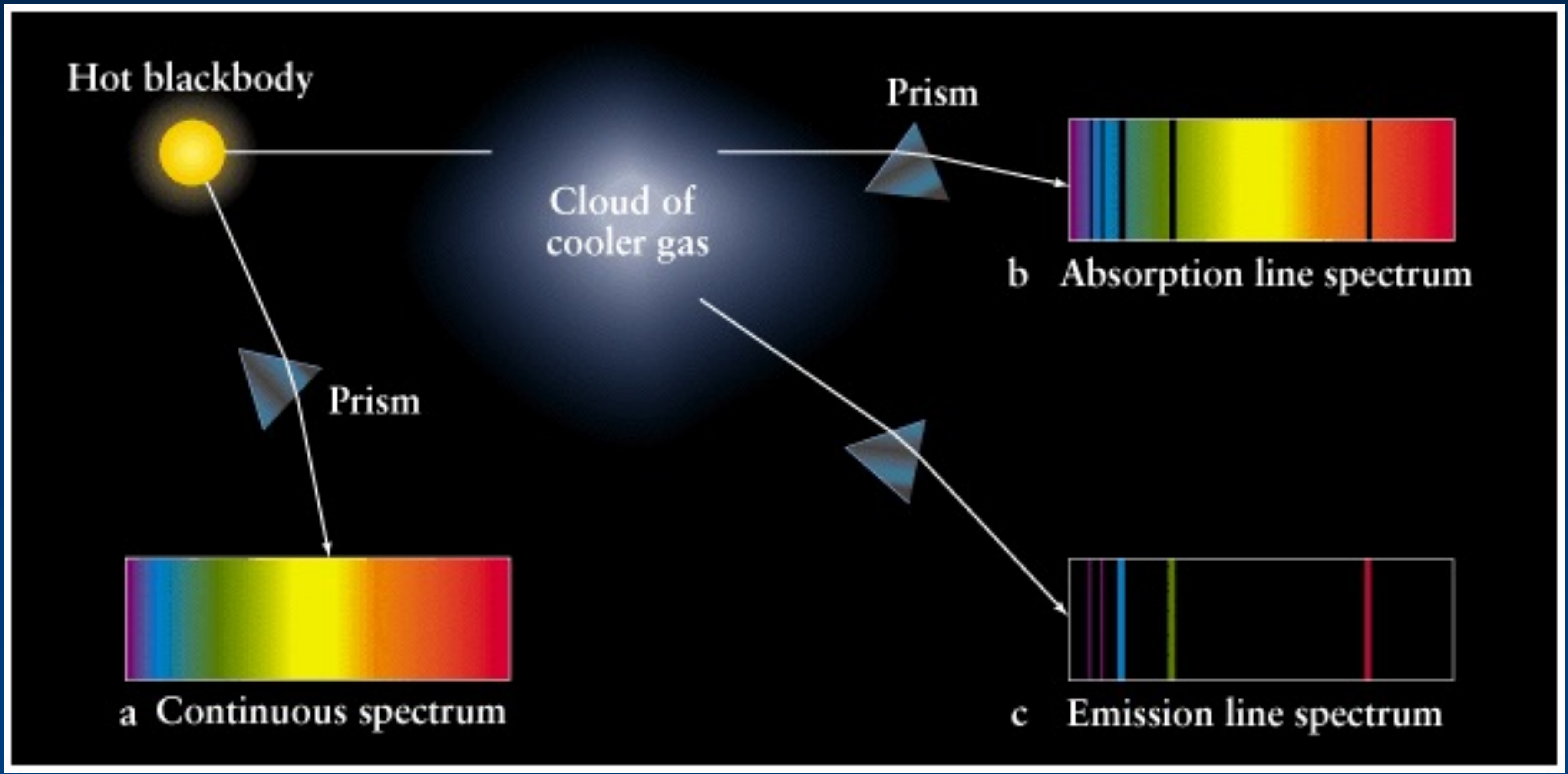
$T_{sun} = 0.0029/\lambda_{max} = 0.0029/5.0x10^{-7} = 5800$ K

At what wavelength would the spectrum peak for star A which is 5800/2 = 2900 K?

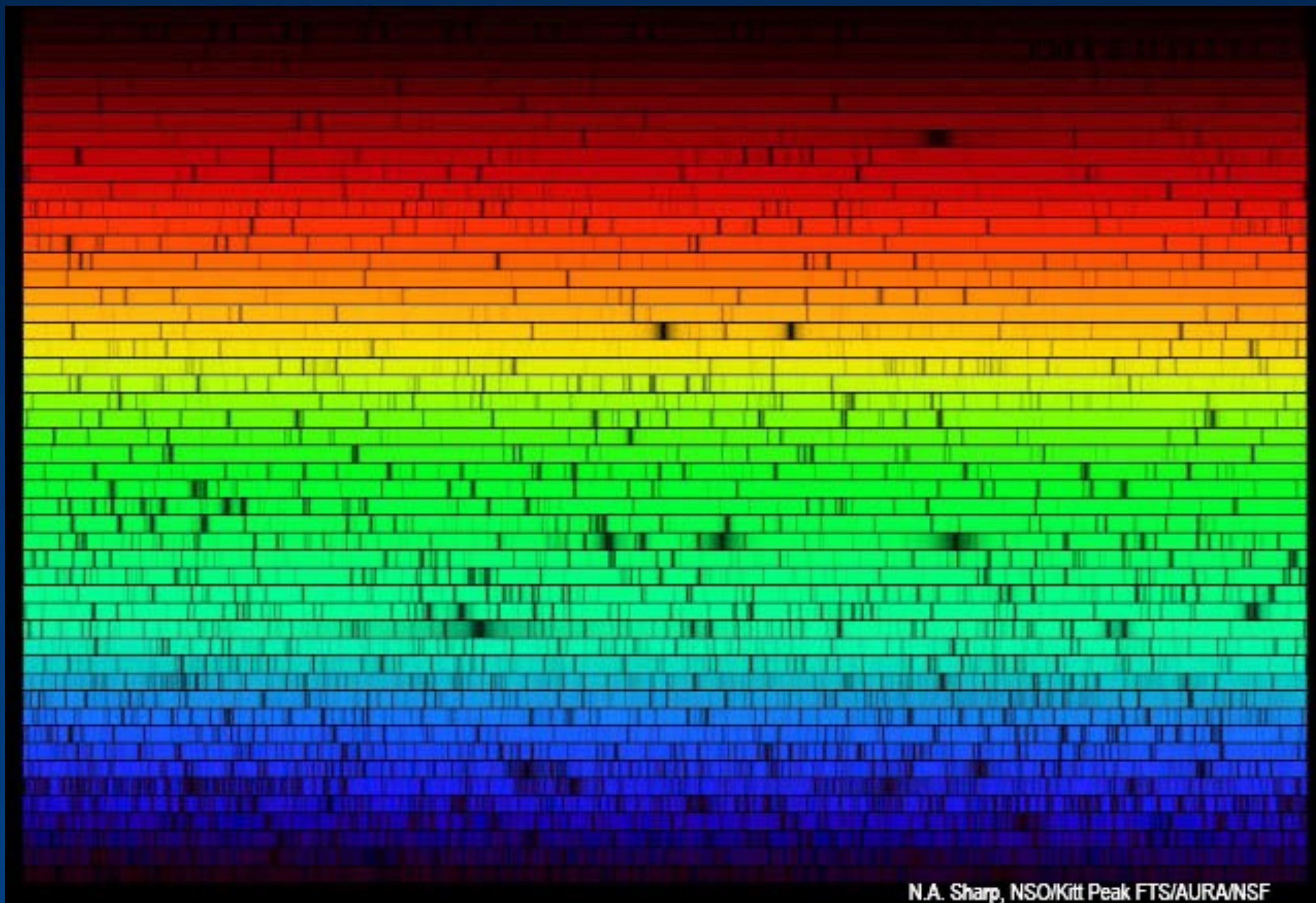
For star B with T= 5800 x 2 = 11,600 K?

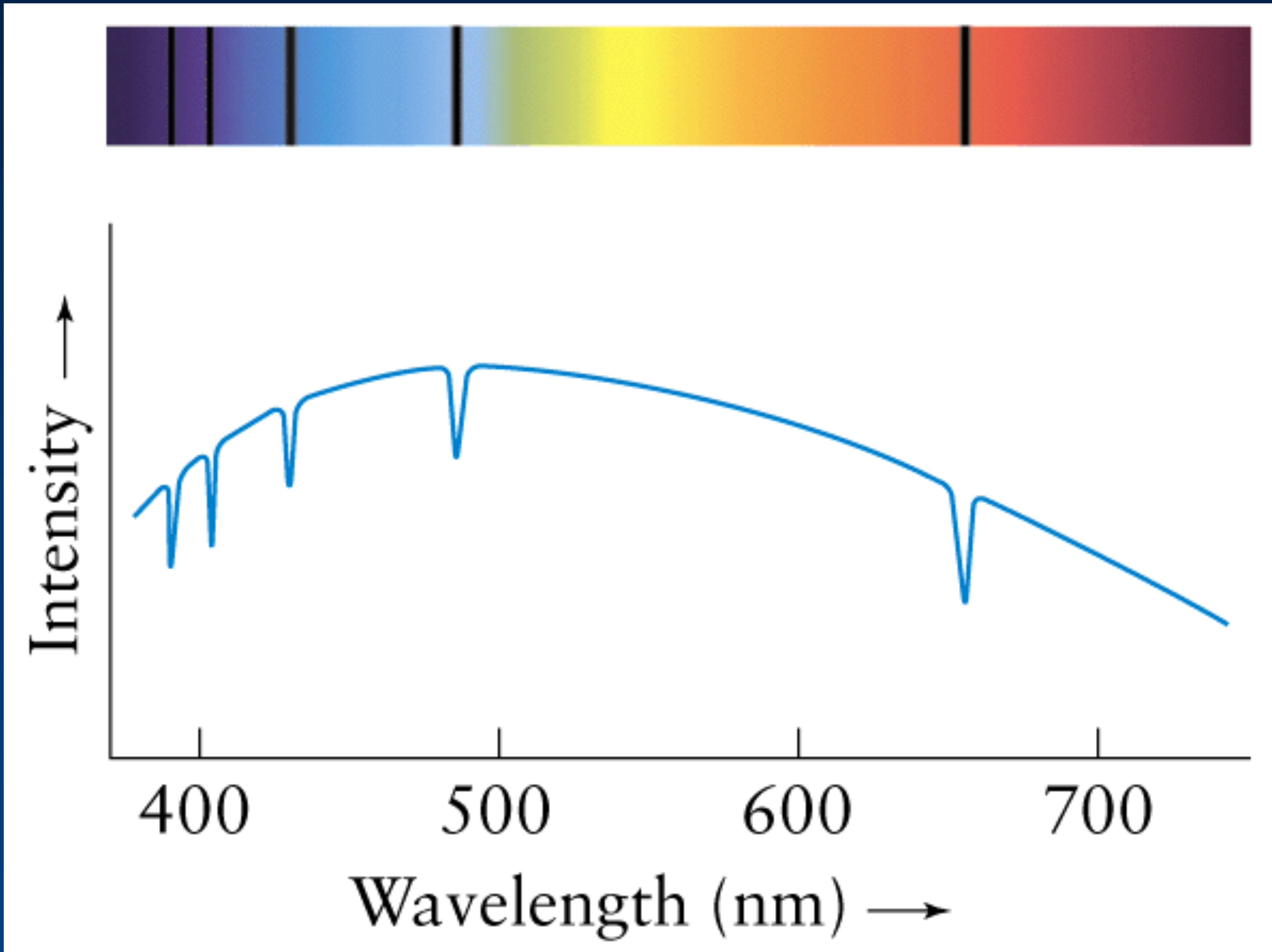
What colors would these stars be?

# Kirchhoff's laws illustrated

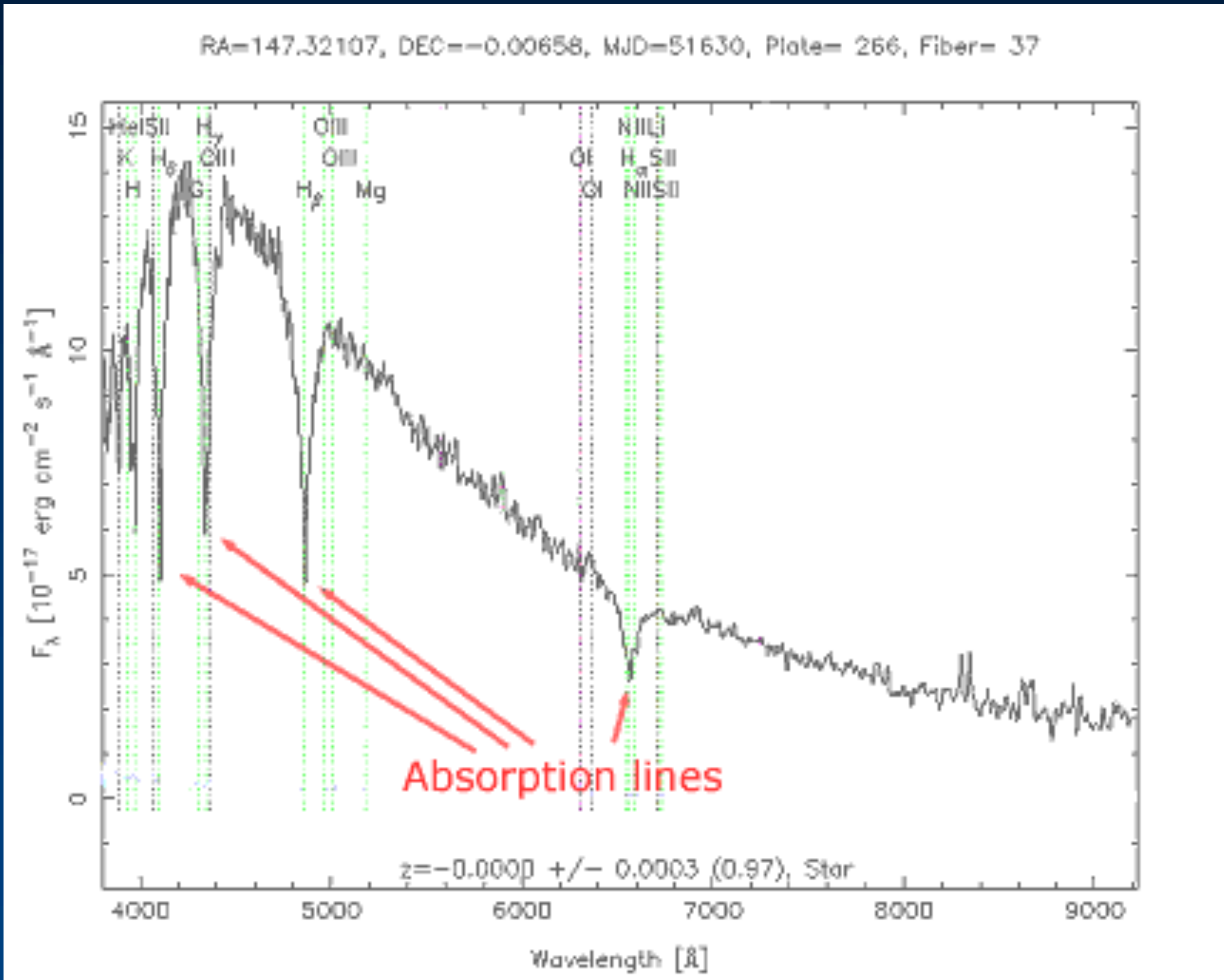


# Spectrum of the Sun – what kind of spectrum is this?





Intensity →
400
500
600
700
Wavelength (nm) →



RA=147.32107, DEC=-0.00658, MJD=51630, Plate= 266, Fiber= 37
Absorption lines
z=-0.0000 +/- 0.0003 (0.97), Star
Wavelength [Å]

Spectrum of a “quasar” – what kind of spectrum is this?