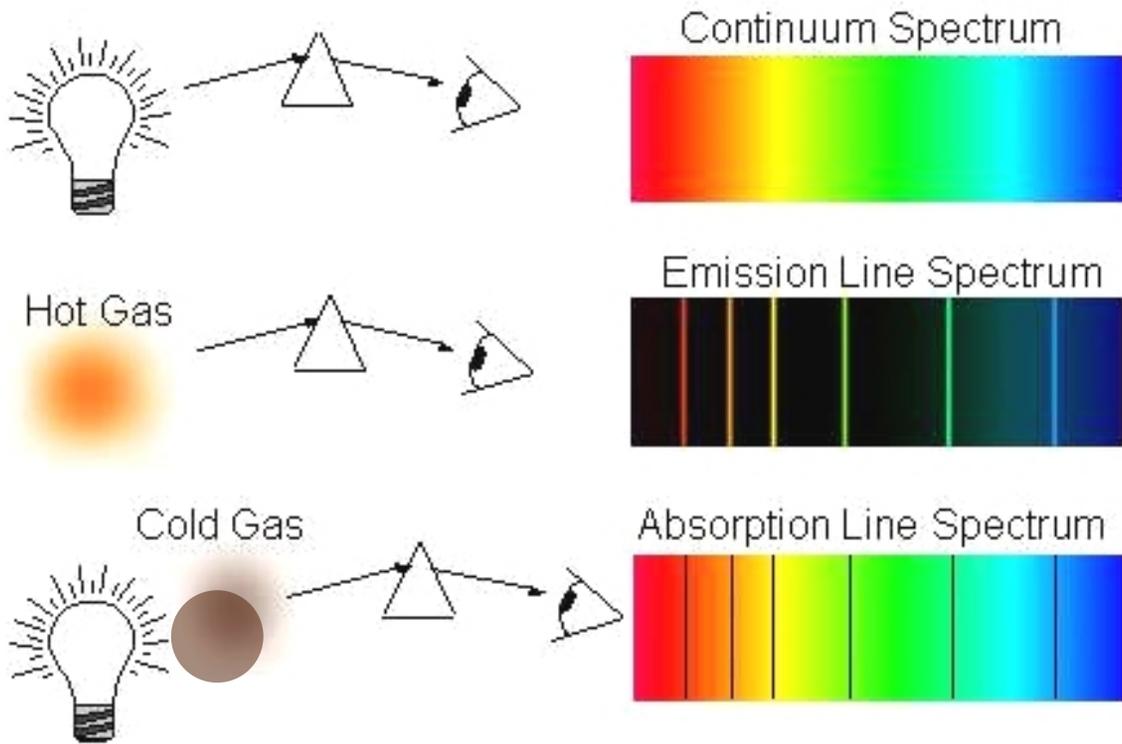


# Spectroscopy

## Spectral lines – Kirchhoff's three empirical laws of spectroscopy



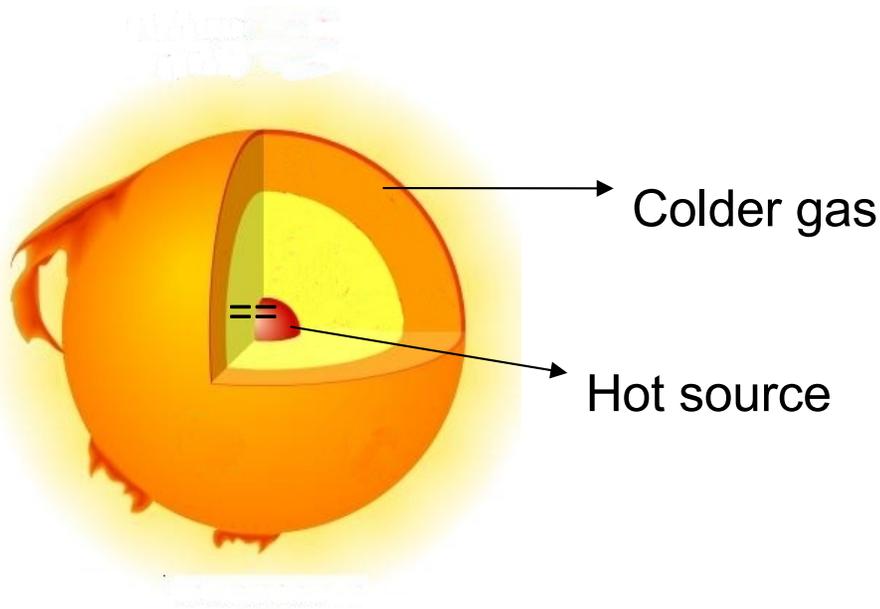
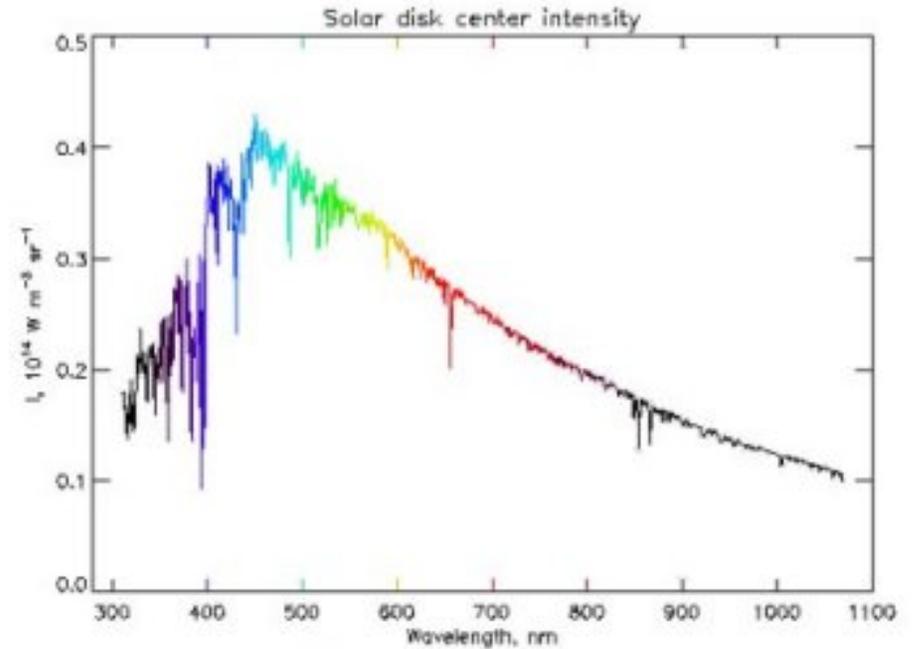
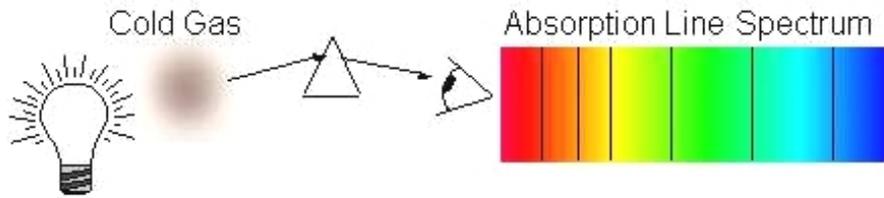
A hot solid or a hot dense gas produces a continuum spectrum.

A hot low-density gas produces an emission-line spectrum.

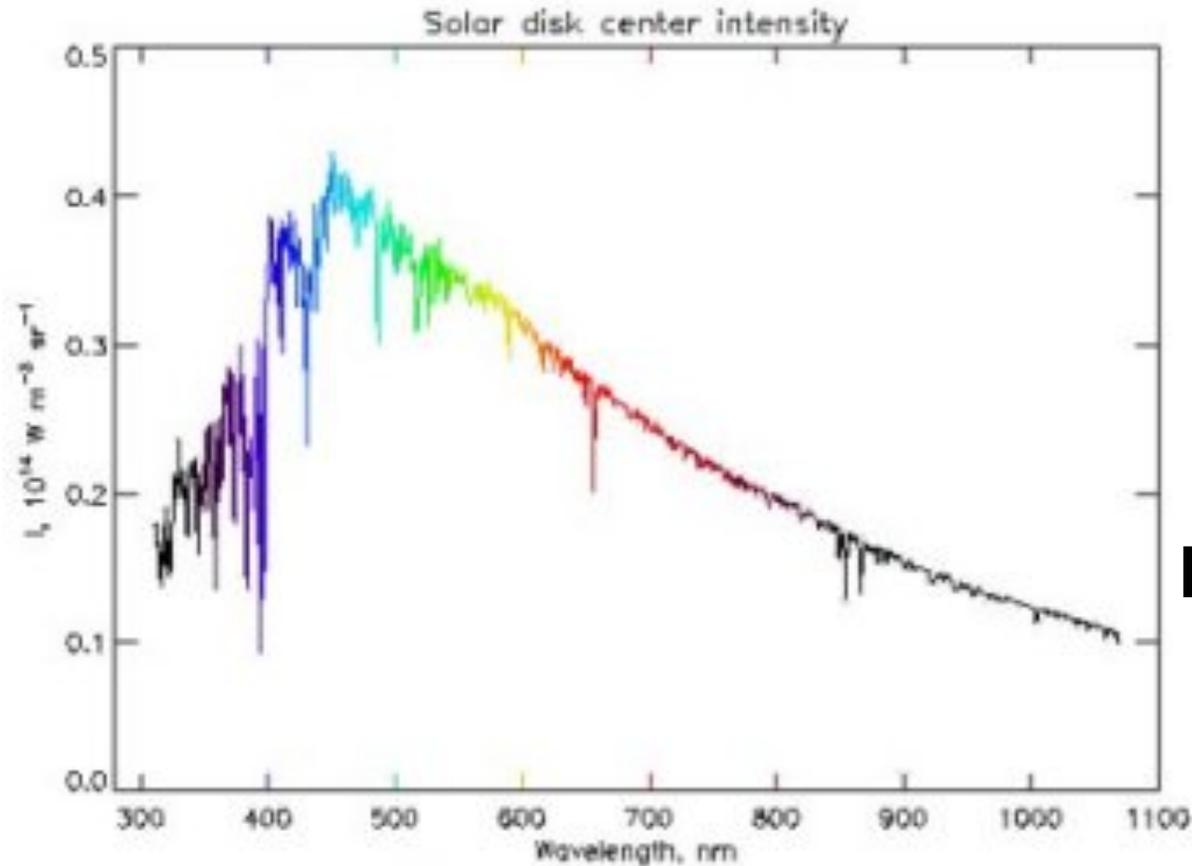
A continuous source viewed through a cold gas produces an absorption-line spectrum.

# Spectroscopy

The third law is what applies to stars. We light we see comes from the hot interior, passing through a colder atmosphere. Thus, we see spectral lines.



# The Solar Spectrum

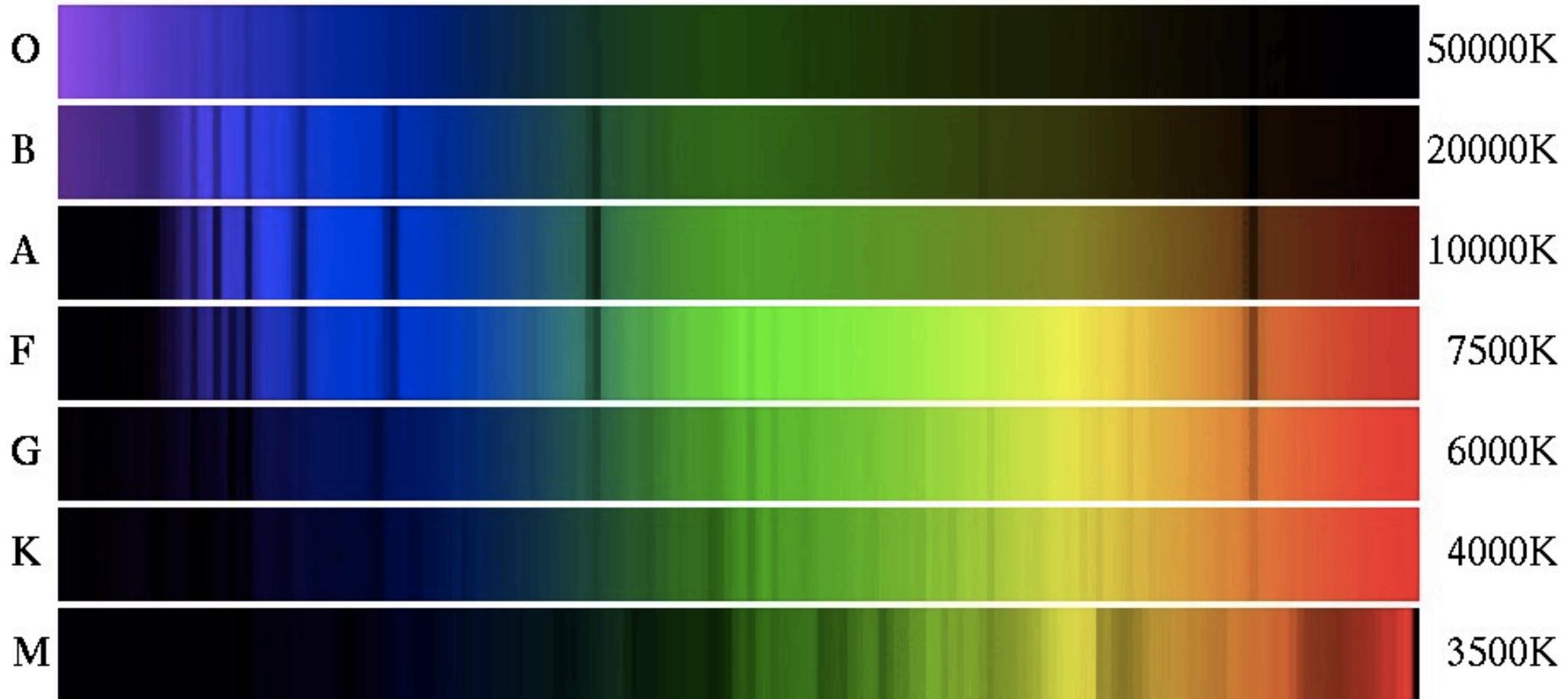


**Main features:**

Continuum  
Absorption lines

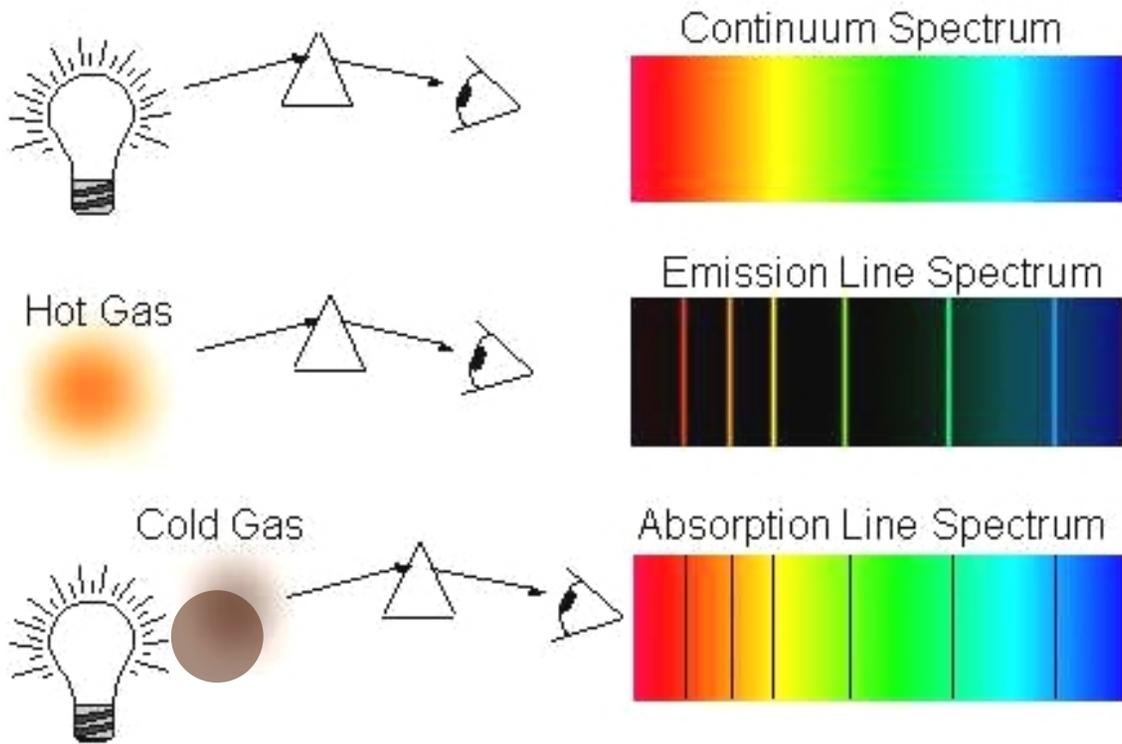
**Most prominent lines:**  
Ca II lines in the blue

# Spectra of other stars have different features



# Spectroscopy

## Spectral lines – Kirchhoff's three empirical laws of spectroscopy

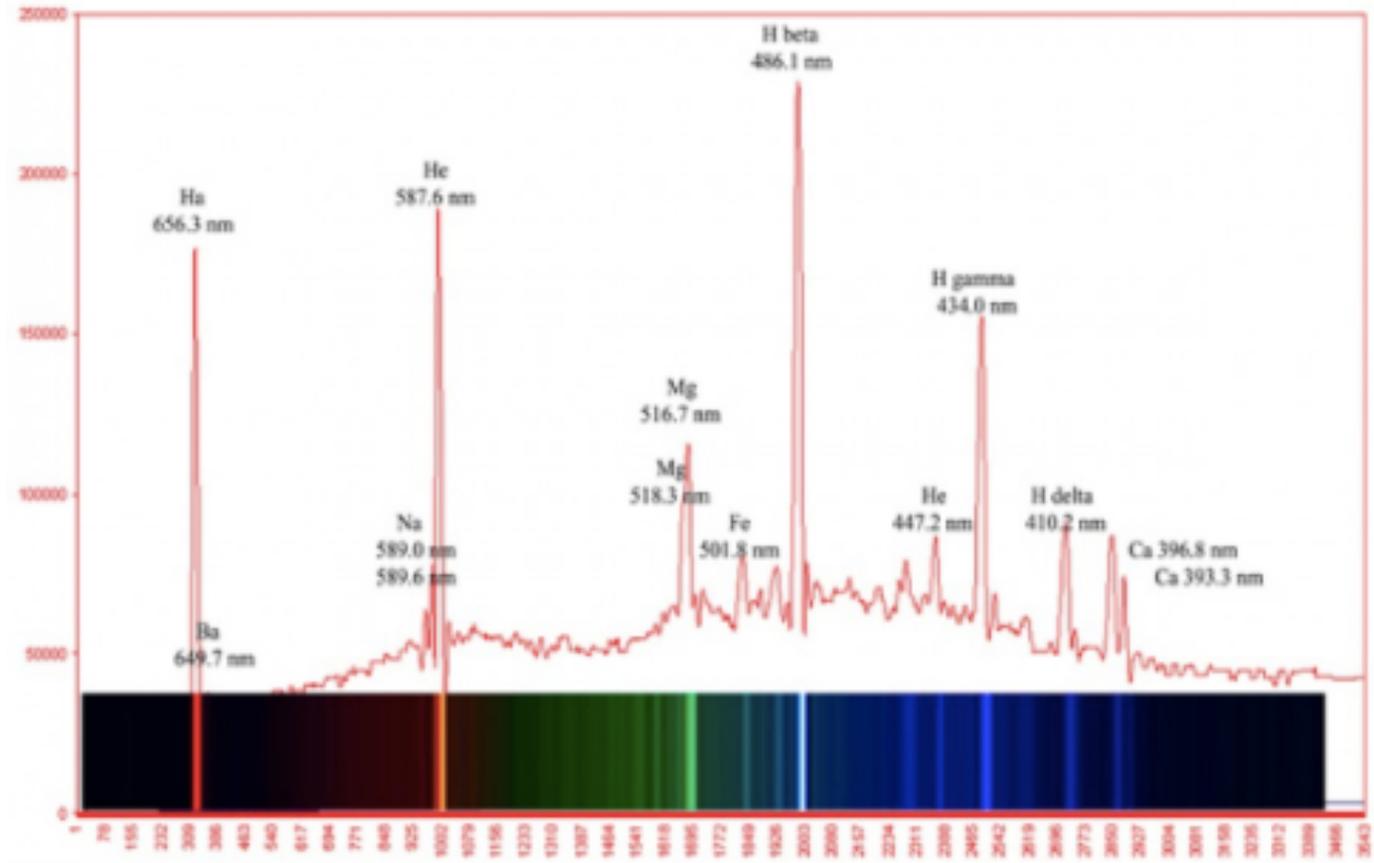


A hot solid or a hot dense gas produces a continuum spectrum.

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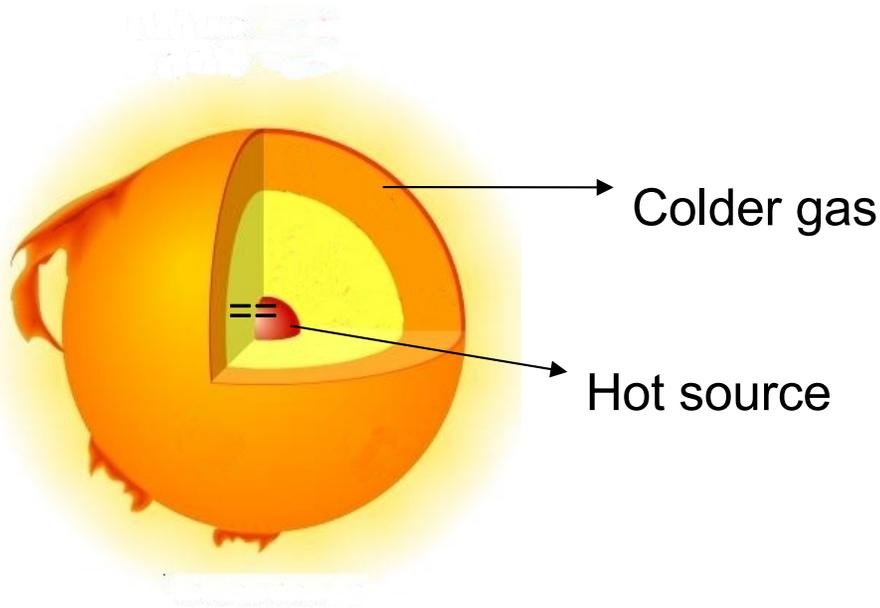
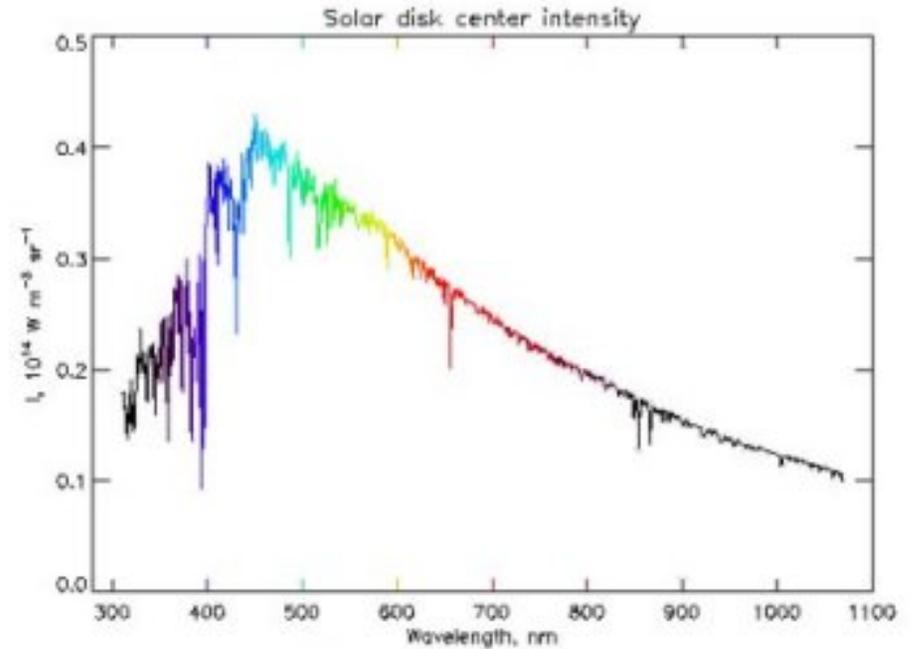
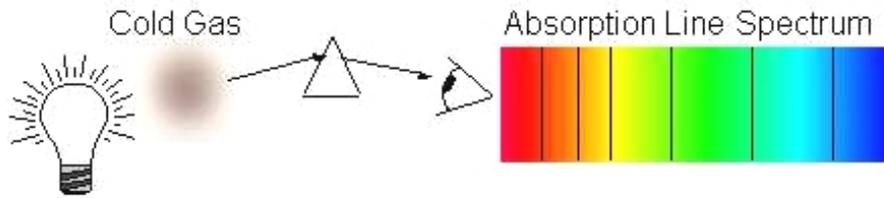
A continuous source viewed through a cold gas produces an absorption-line spectrum.

# The Solar Chromosphere Spectrum (Flash Spectrum)

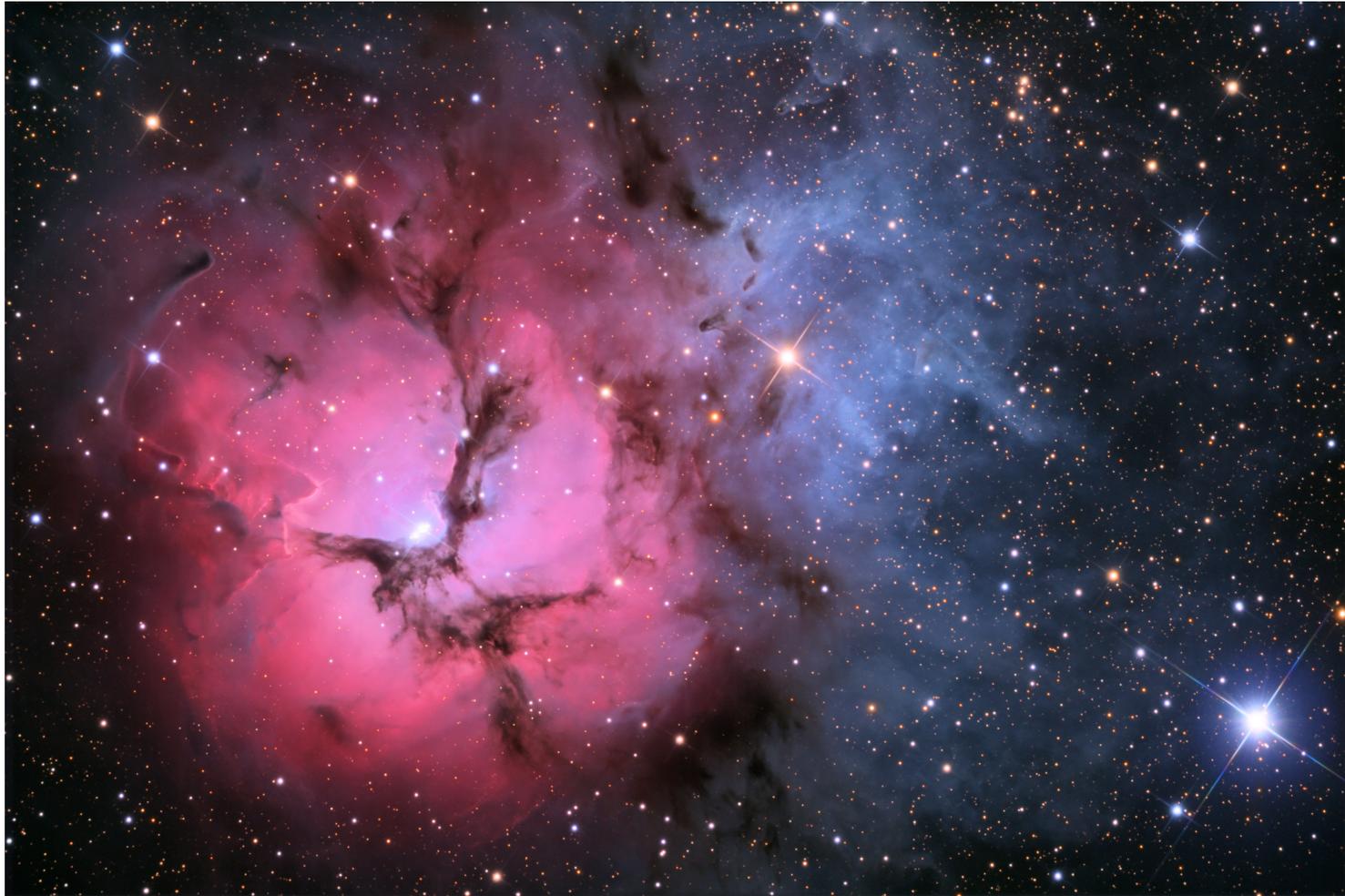


# Spectroscopy

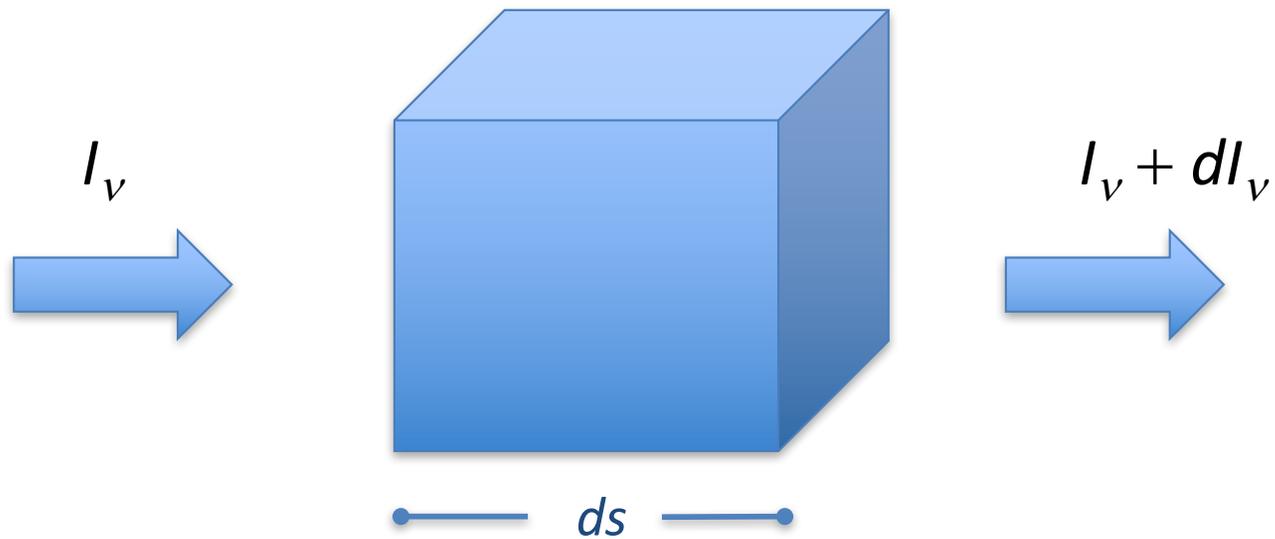
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# Emission and Absorption



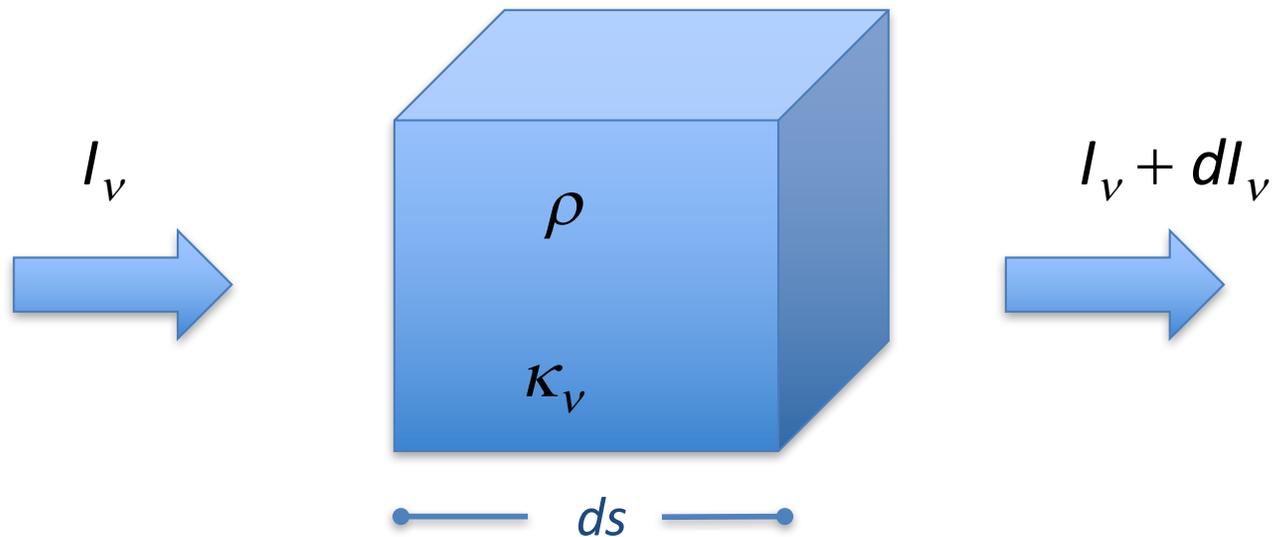
# Emission and Absorption



Radiation of intensity  $I_\nu$  shines through a cube of side  $ds$ .  
What is the intensity that emerges from it?

What is the amount of intensity  $dI_\nu$  that is added or subtracted from the beam?

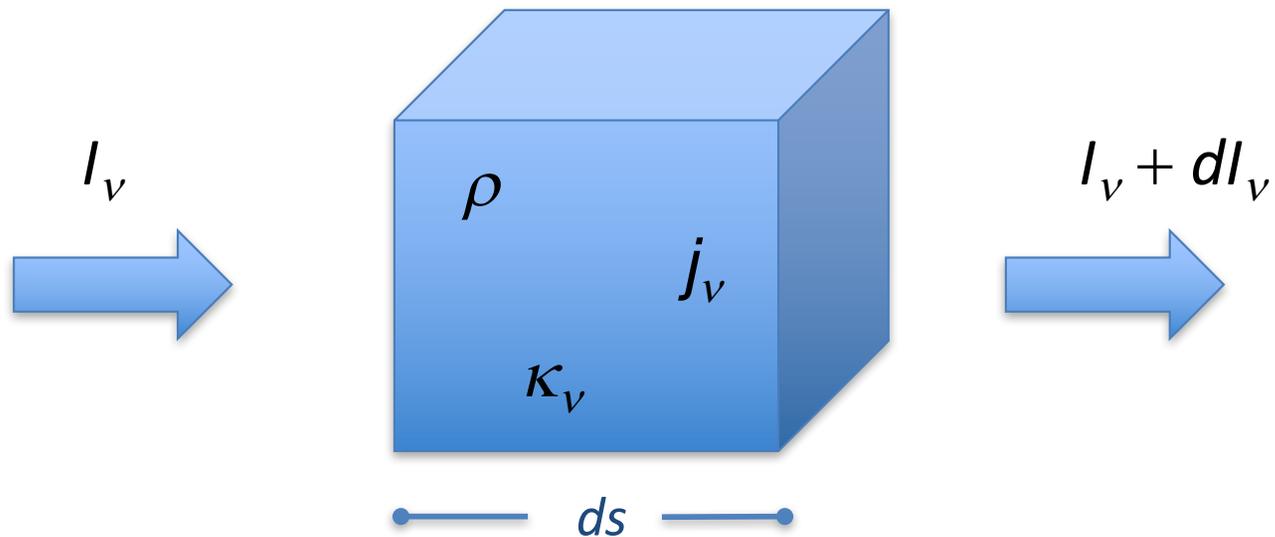
# Emission and Absorption



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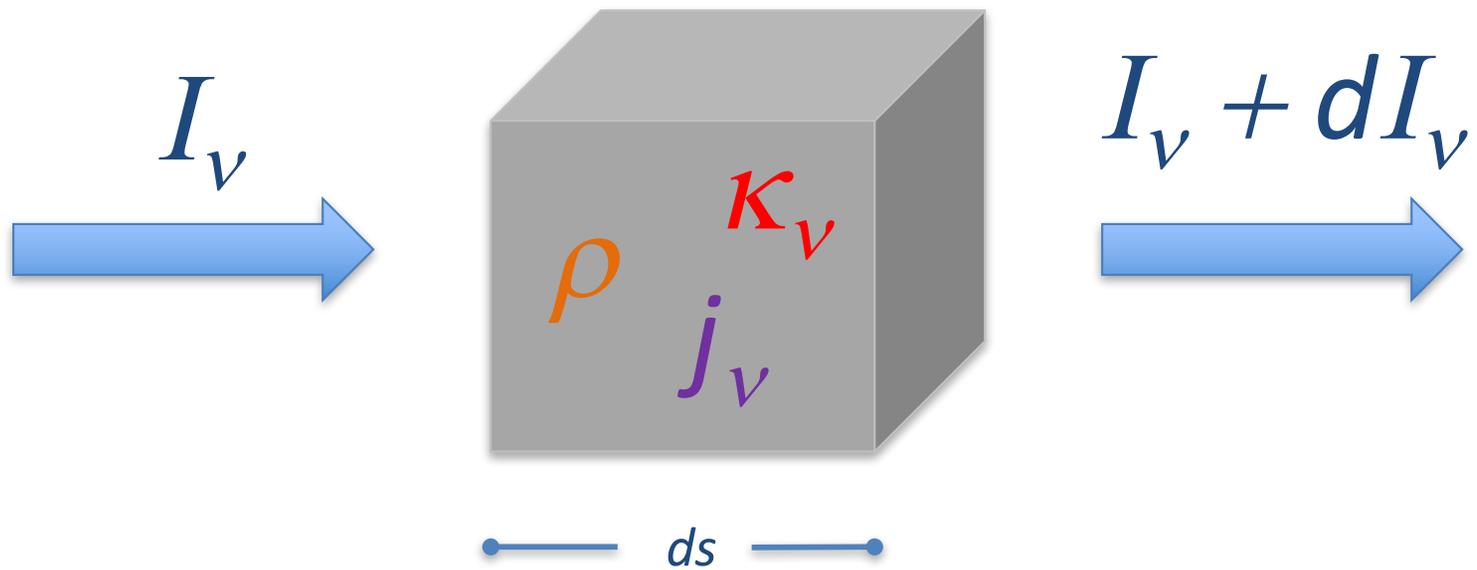
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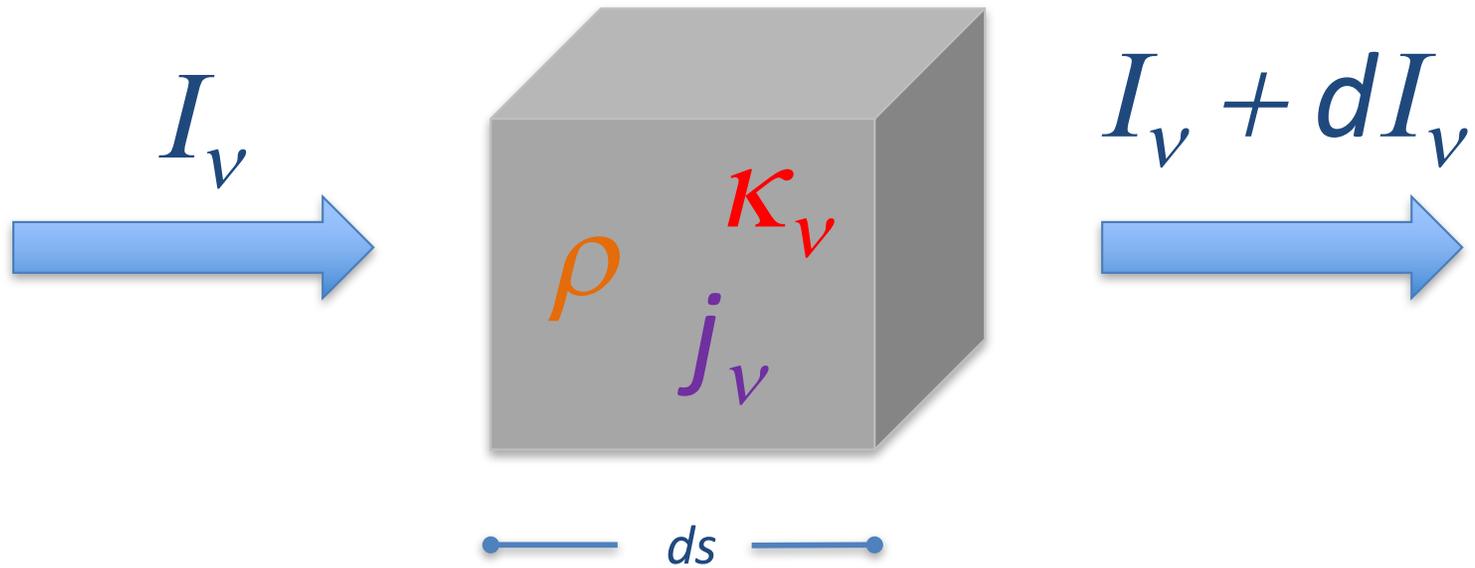
# Emission and Absorption



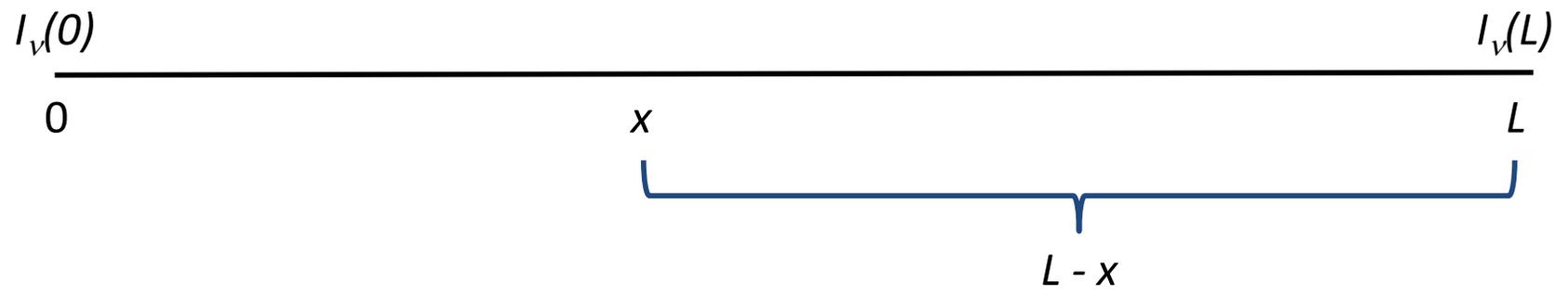
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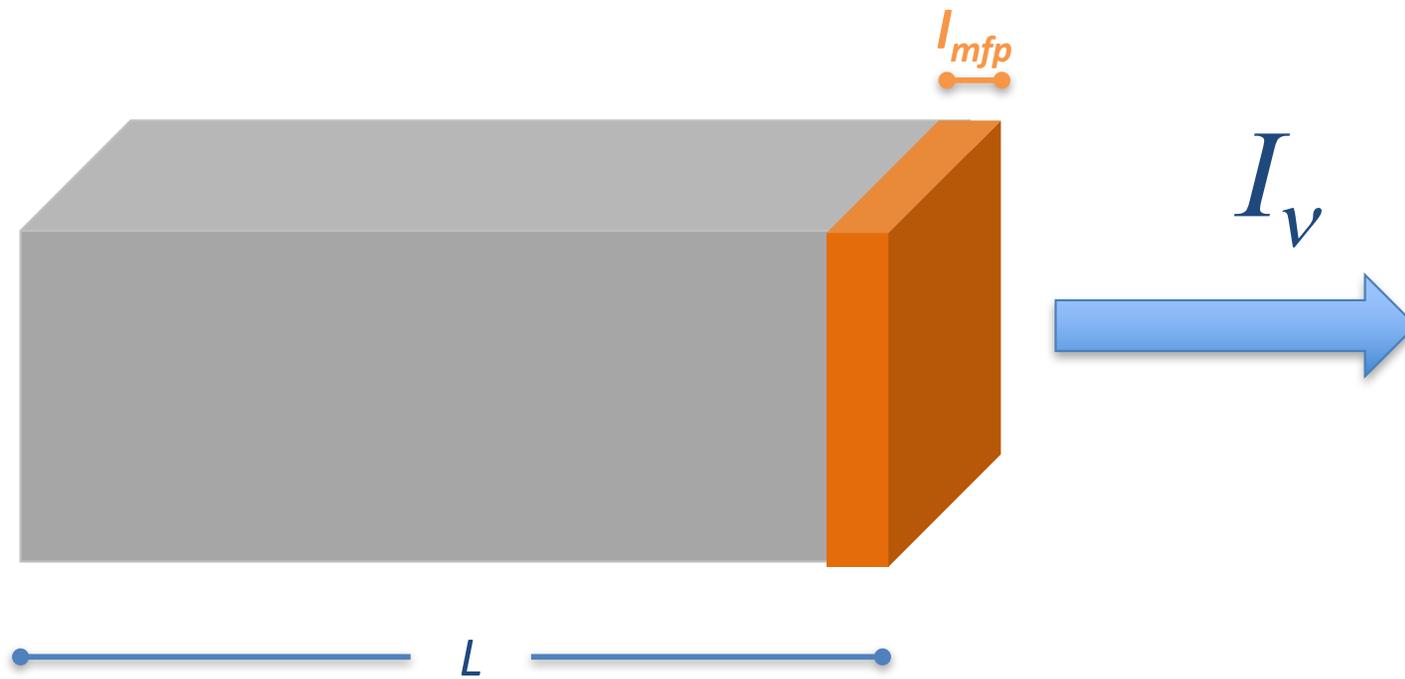
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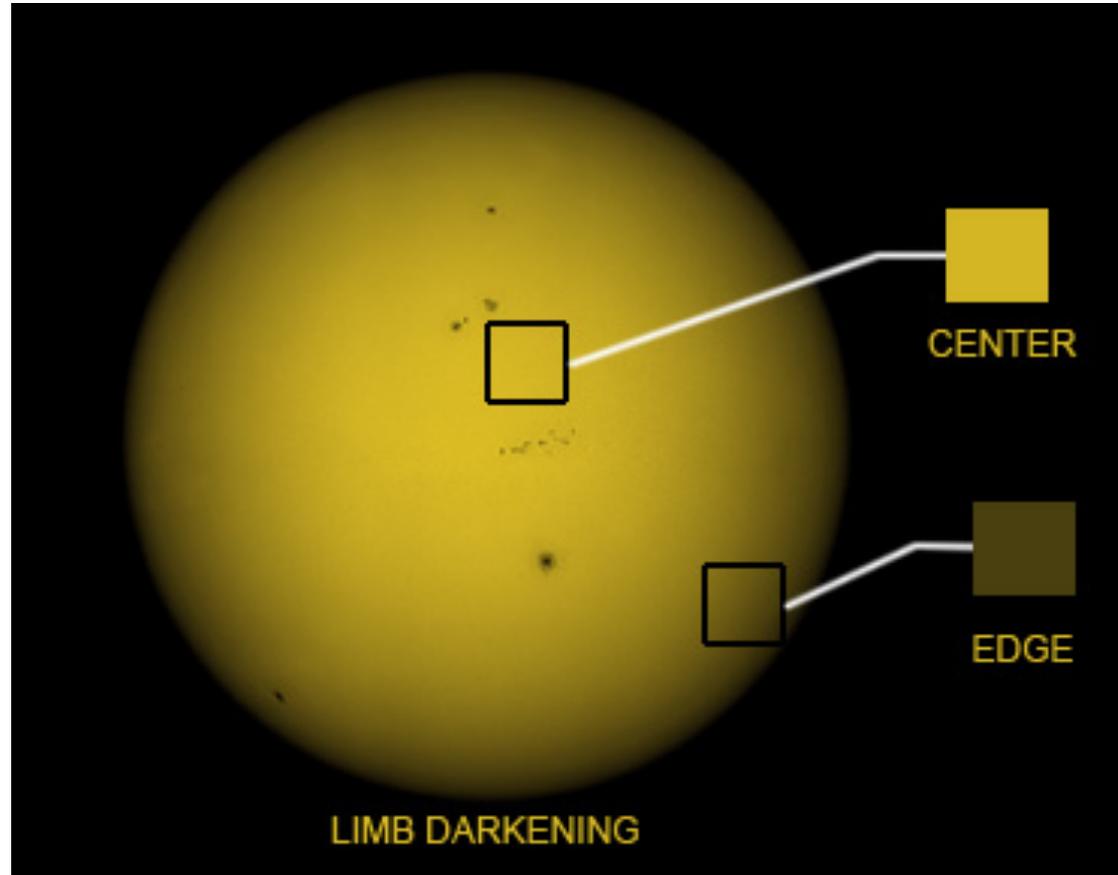
$$dI_v = -\kappa_v \rho I_v ds + j_v \rho ds$$



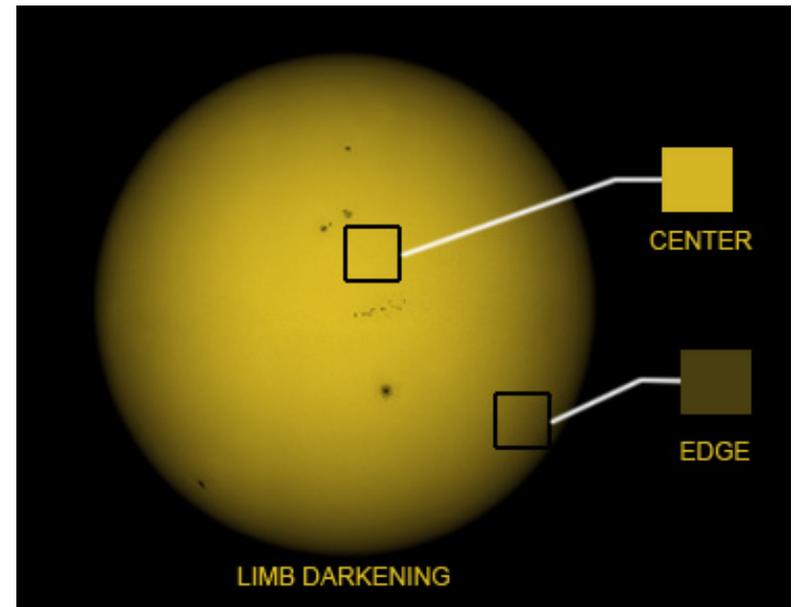
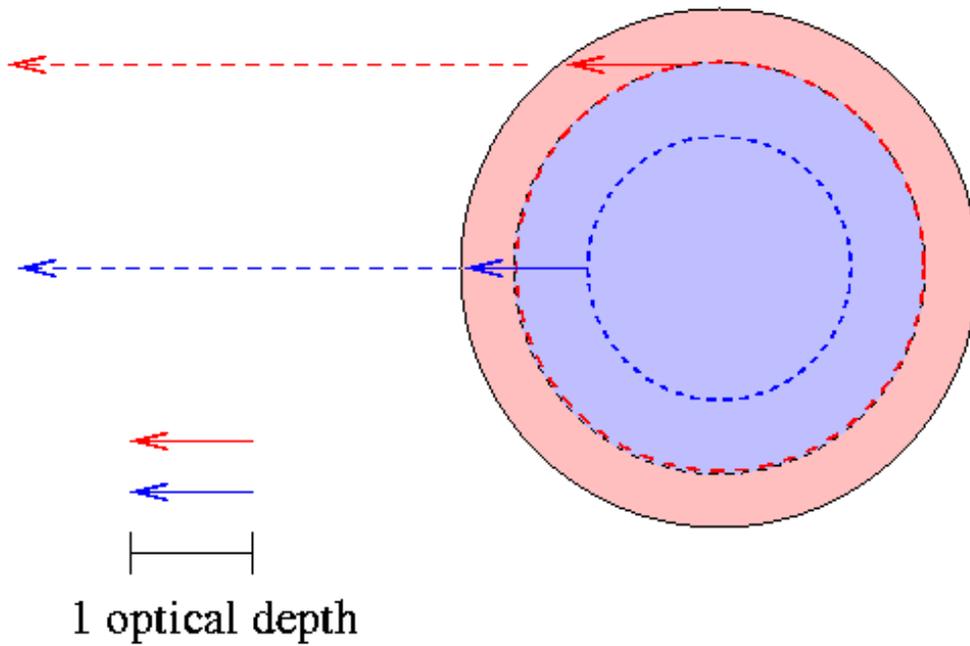


$$I_v = S_v = j_v \rho l_{mfp}$$

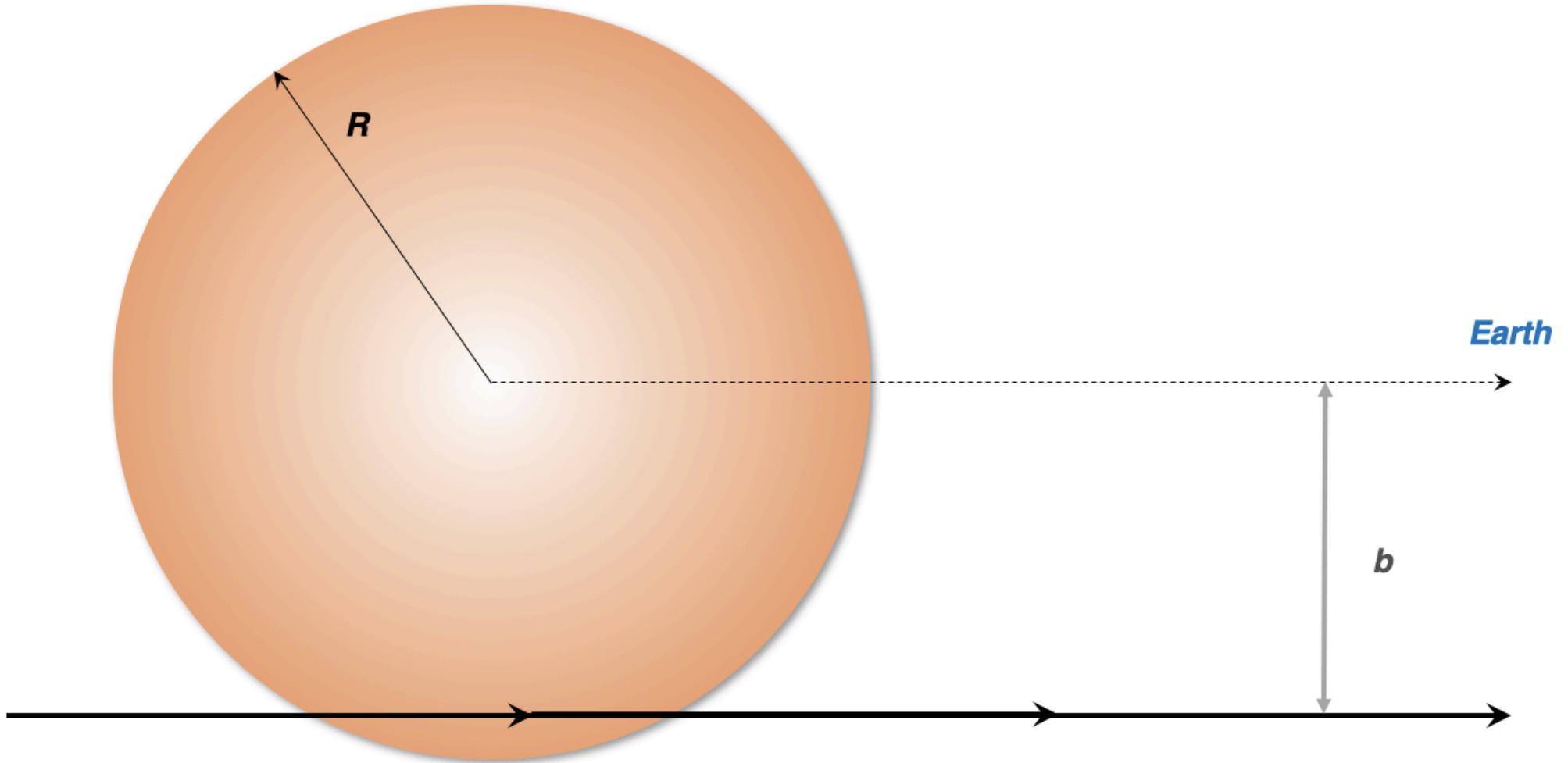
# Limb darkening



# Limb darkening

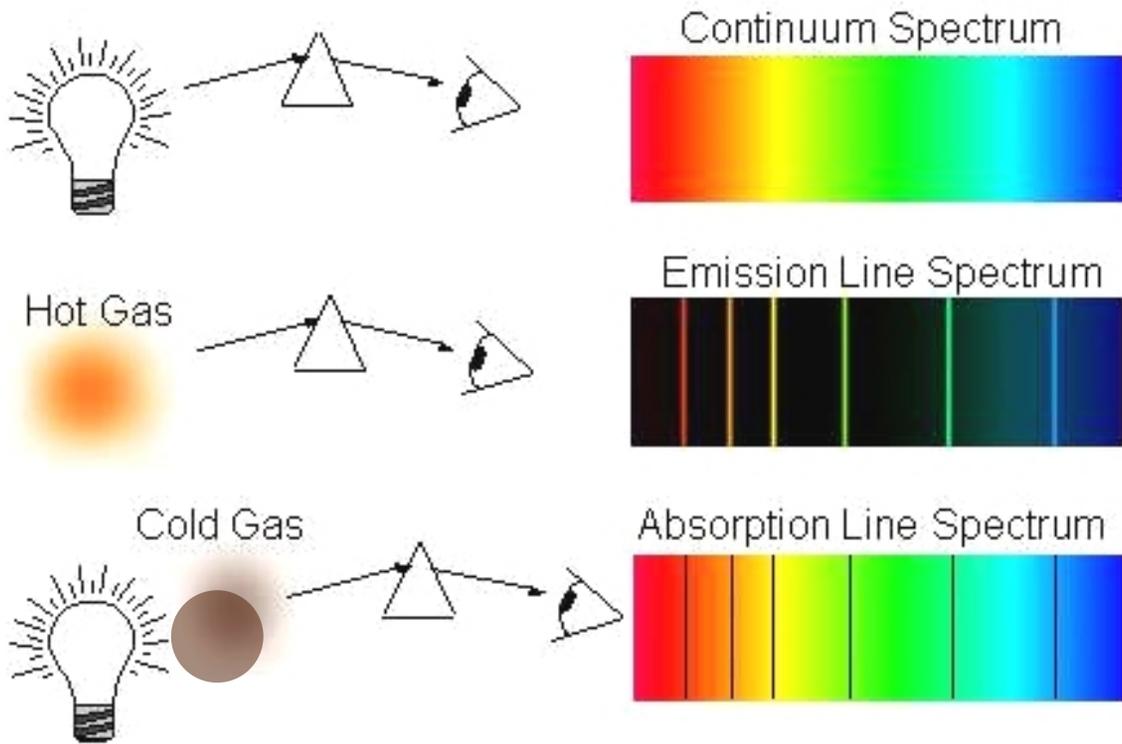


# Limb darkening



# Spectroscopy

## Spectral lines – Kirchhoff's three empirical laws of spectroscopy



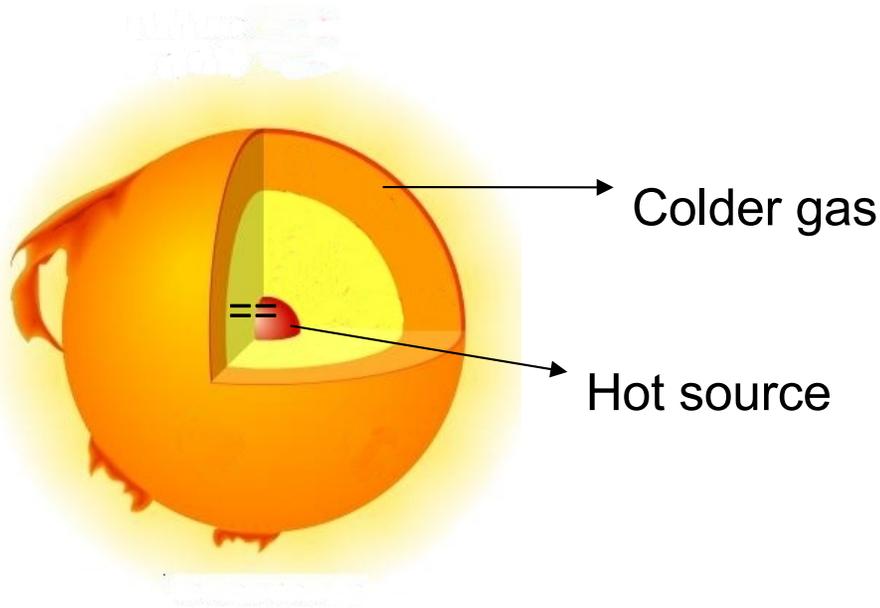
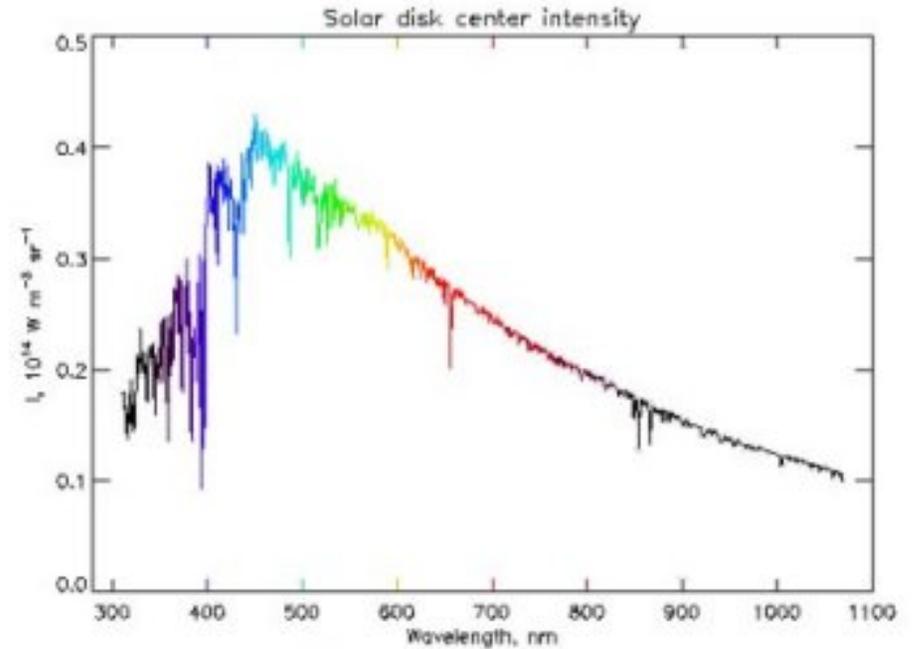
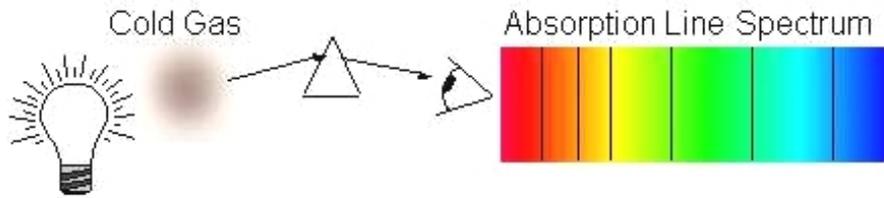
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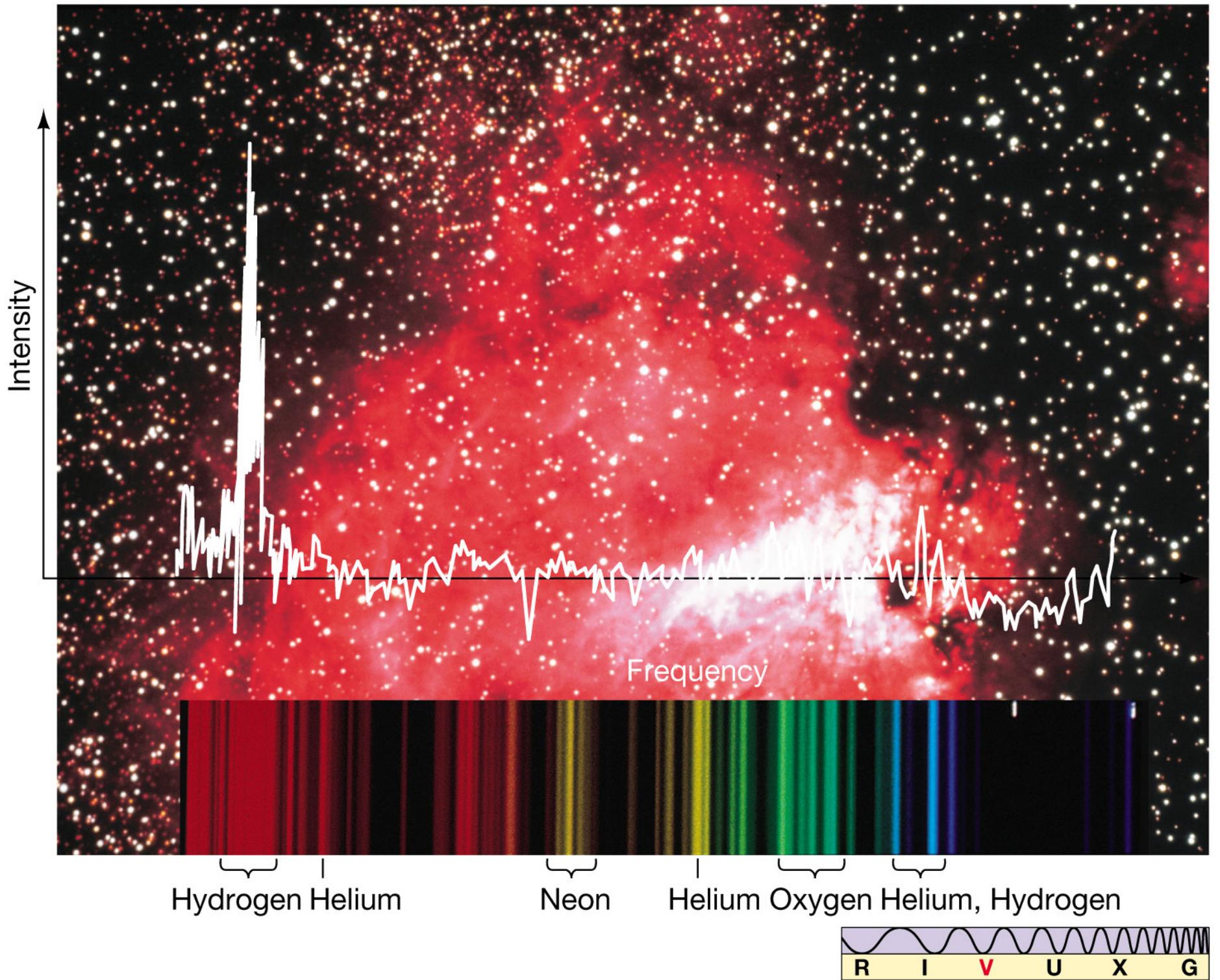
# Spectroscopy

The third law is what applies to stars. We light we see comes from the hot interior, passing through a colder atmosphere. Thus, we see spectral lines.



# Emission and Absorption





# Interstellar Nebulae

Interstellar clouds can be referred to as absorption (dark), reflection or emission nebulae



Absorption Nebula



Reflection Nebula



Emission Nebula

# Interstellar Nebulae

Interstellar clouds can be referred to as absorption (dark), reflection or emission nebulae



Absorption Nebula

## **Absorption Nebulae**

A lot of gas and dust  
simply blocking light

# Interstellar Nebulae

## Reflection Nebulae



Physically the same as dark nebulae,  
but ***illuminated*** by nearby stars.  
**The dust shines by reflected light**

**Usually blue (why?)**



# Interstellar Nebulae

## Reflection Nebulae



Physically the same as dark nebulae,  
but ***illuminated*** by nearby stars.  
**The dust shines by reflected light**

**Usually blue (why?)**

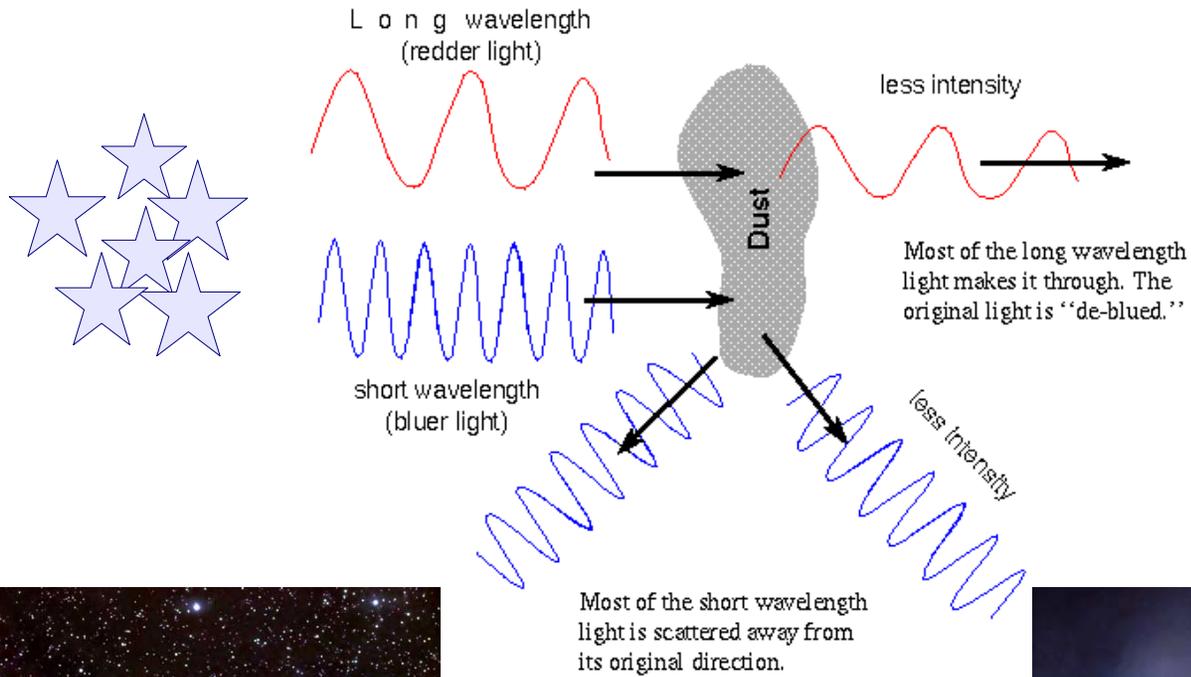
- 1. Illuminated by blue/white stars**
2. Same reason why the sky is blue  
**Blue is better scattered than red**



# Interstellar Nebulae

Absorption and reflection nebulae are the same object

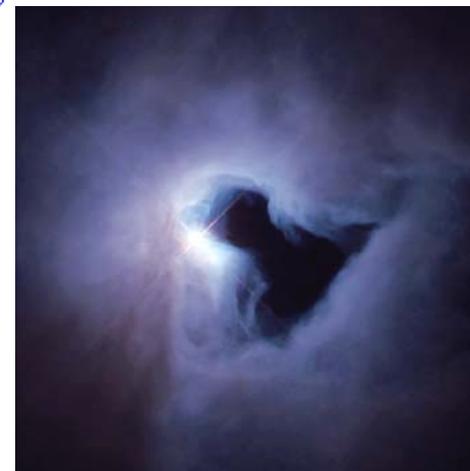
## Reddening and Extinction



## Absorption



Reflection



Reflection + Absorption

# Interstellar Nebulae

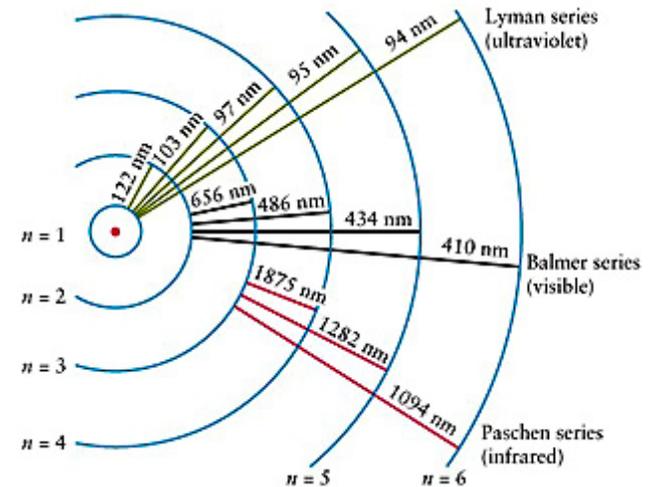
## Emission Nebulae



Glow by their own light

Illuminated by nearby OB stars,  
very hot stars that emit ionizing radiation

When the electrons recombine, they cascade  
emitting light in all the atom's discrete set of  
wavelengths



# Interstellar Nebulae

## Emission Nebulae

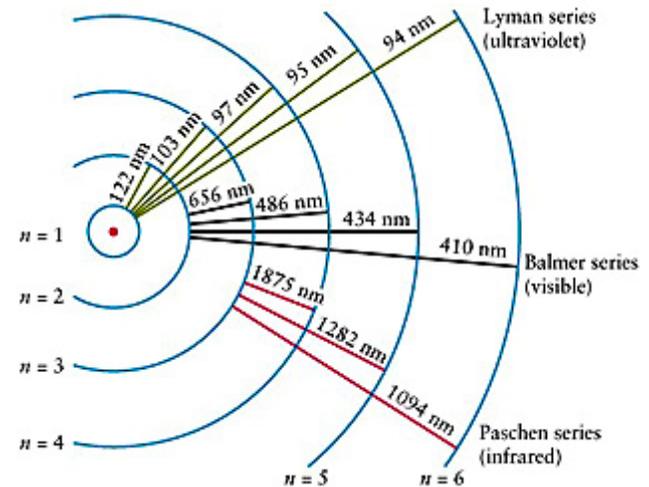


Glow by their own light

**Usually red (why?)**

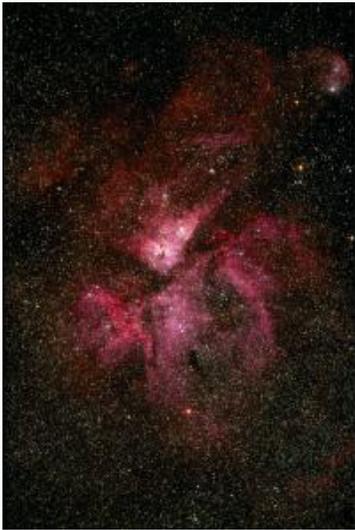
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# Interstellar Nebulae

## Emission Nebulae

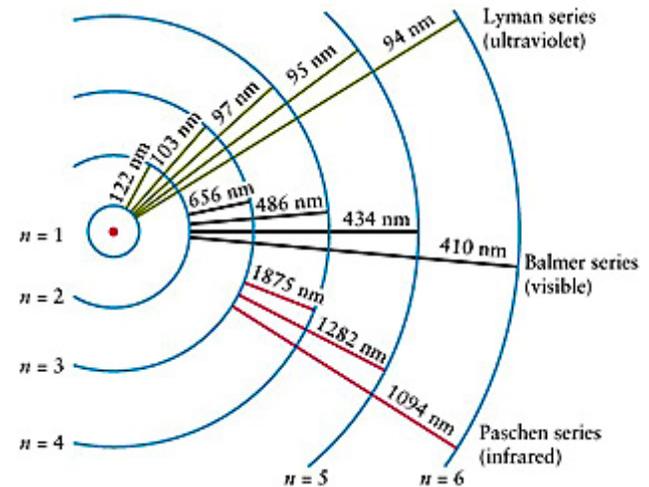


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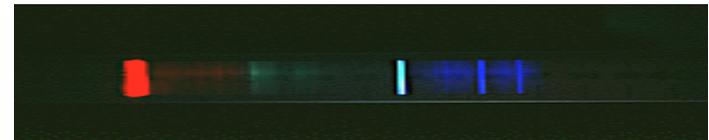
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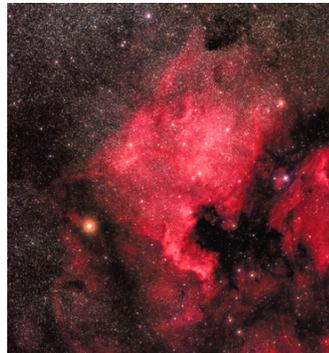


Hydrogen emission in the **6563 Å** line (H $\alpha$ )

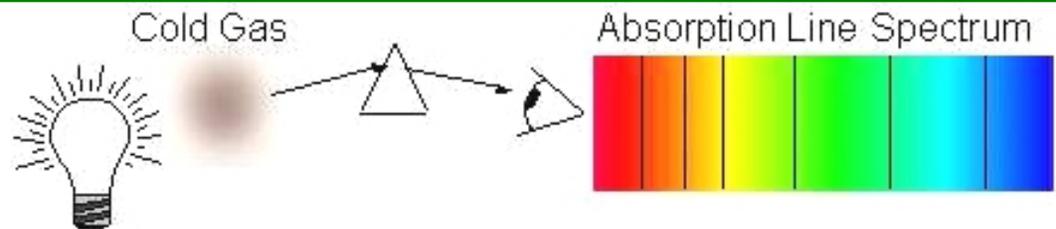
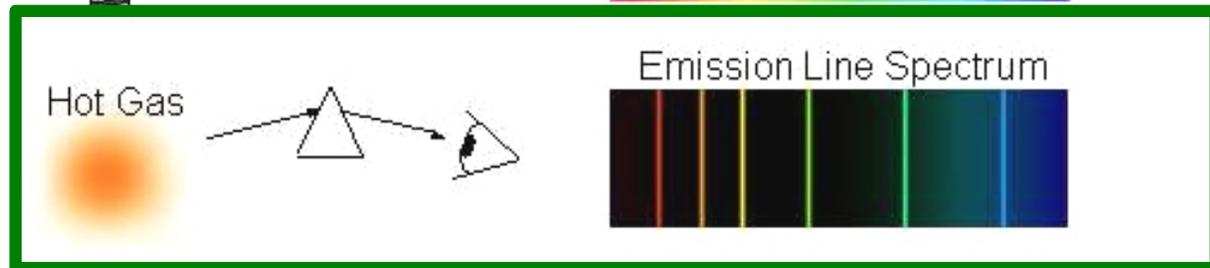
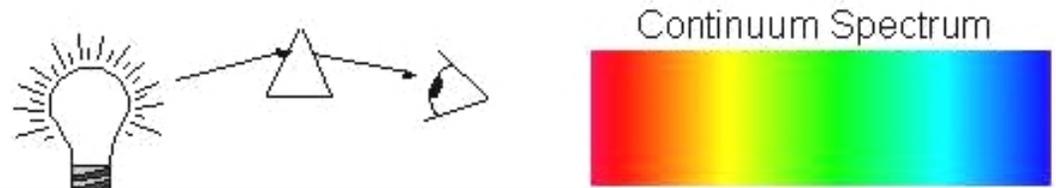


# Interstellar Nebulae

## Emission Nebulae



## Kirchhoff's laws



Hydrogen emission in the **6563 Å** line (H $\alpha$ )



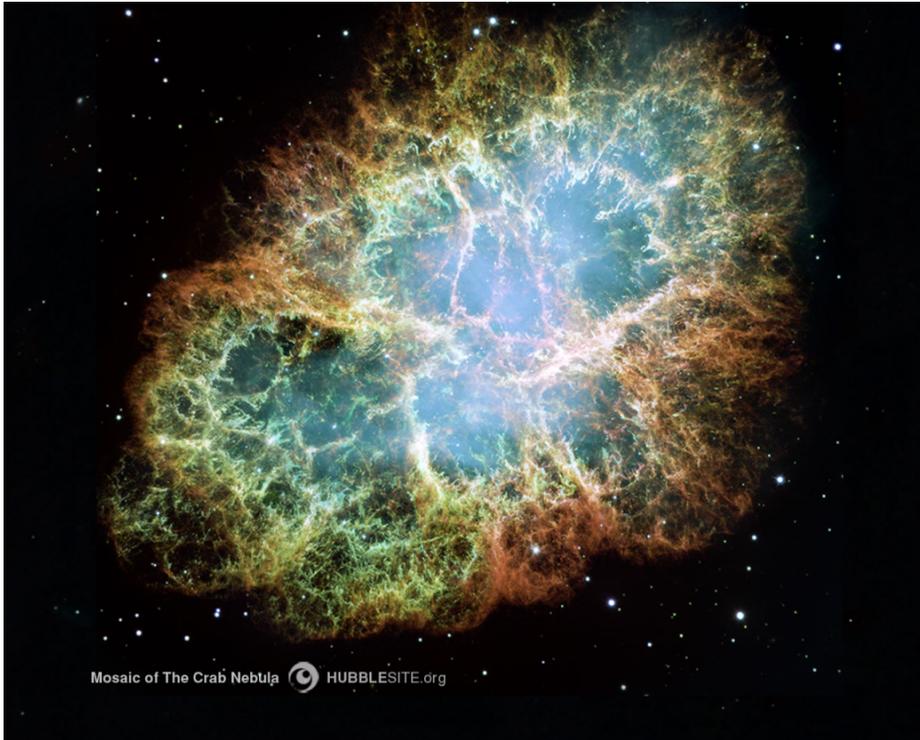
# HII Regions

Emission Nebulae are also called HII Regions  
HII for Ionized Hydrogen  
(Neutral Hydrogen is HI)

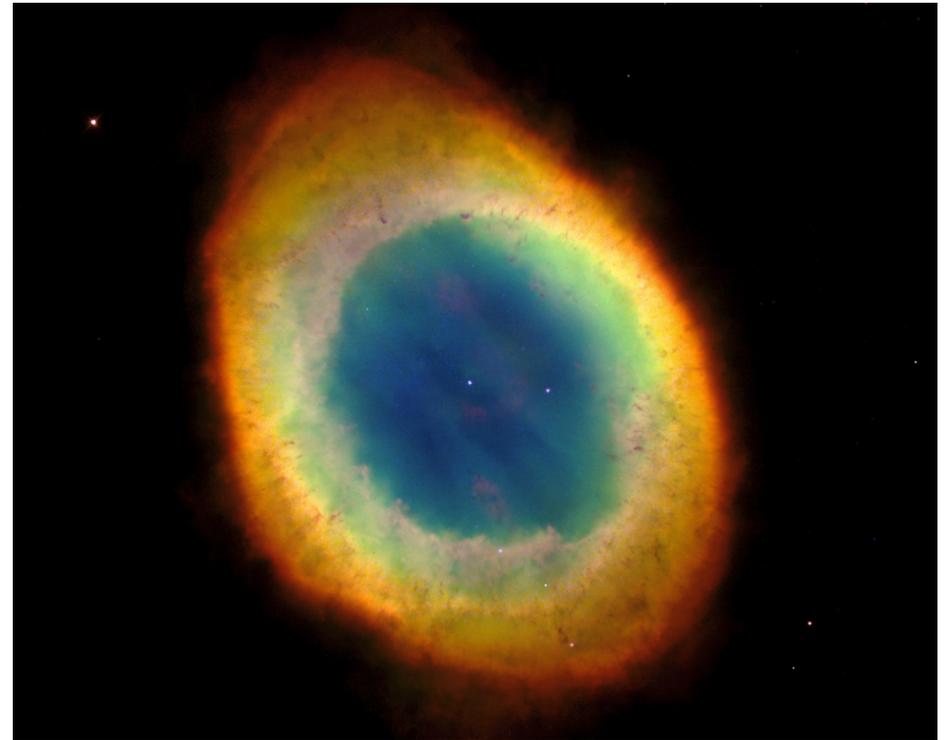


# Emission nebulae

Emission Nebulae are red because of hydrogen emission in H-alpha  
Can you tell then why are Supernovae Remnants and Planetary Nebulae so colorful?



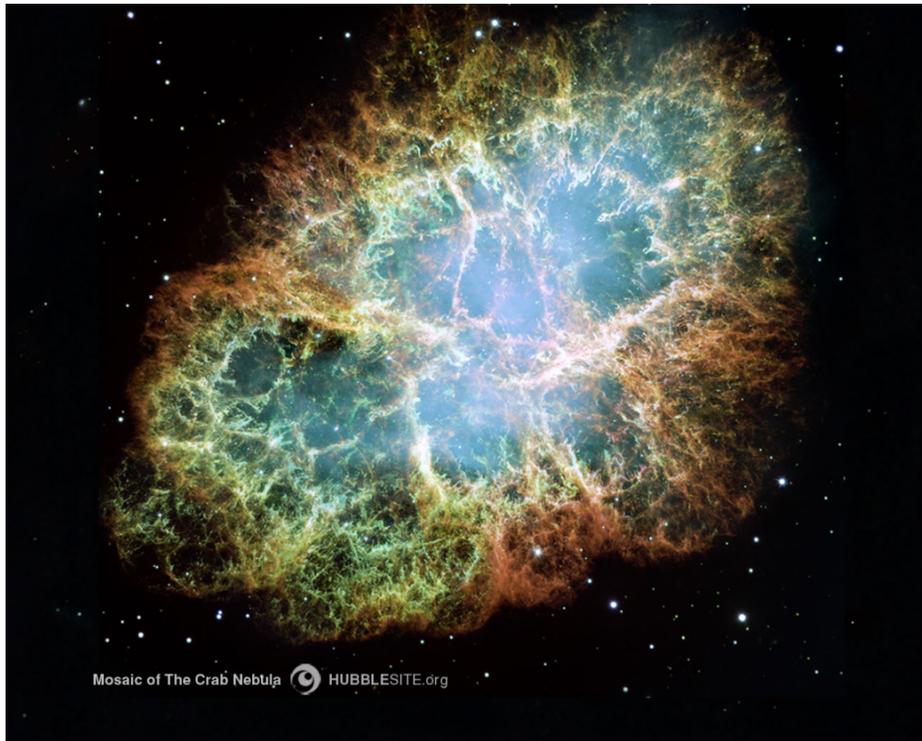
Crab Nebula  
Supernova Remnant



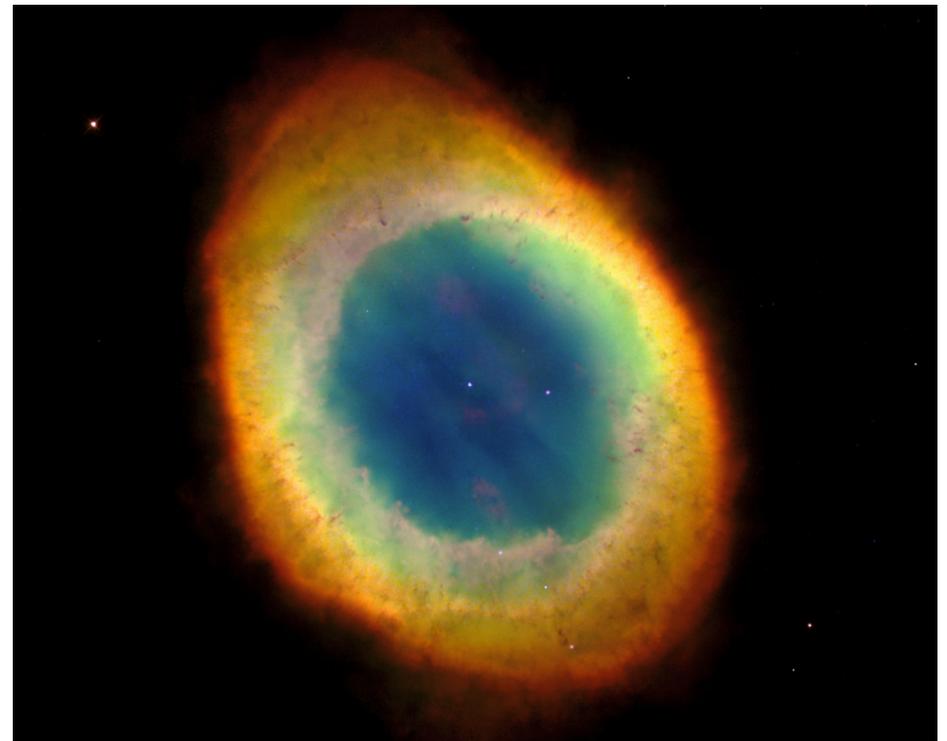
Ring Nebula  
Planetary Nebula

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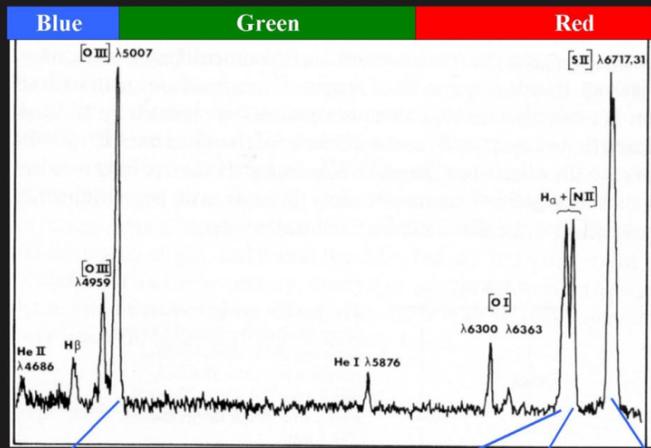


Crab Nebula  
Supernova Remnant

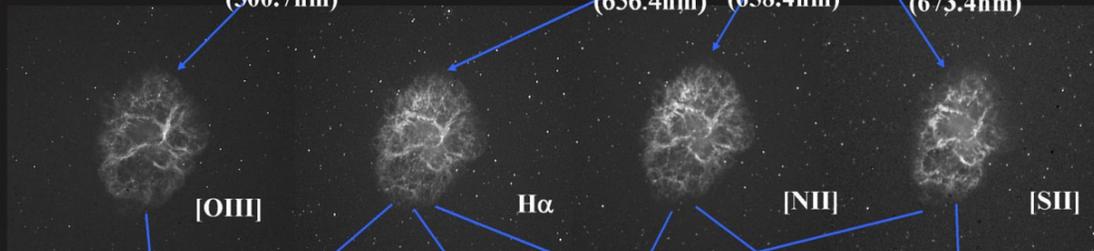


Ring Nebula  
Planetary Nebula

**Chemically enriched !!  
Not just hydrogen...**



[OIII] (500.7nm)      H $\alpha$  (656.4nm)      [NII] (658.4nm)      [SII] (673.4nm)



[OIII]

H $\alpha$

[NII]

[SII]



RGB =  
[SII], H $\alpha$ , [OIII]

RGB =  
H $\alpha$ , [NII], [NII]

RGB =  
[SII], [NII], H $\alpha$

Spectrum of the  
Crab Nebula

Prominent  
**Silicon line**  
(redder than **H-alpha**)  
and **Oxygen line**  
(green)

**Emission**, **Reflection**, and **Absorption**  
in the same nebula



**Trifid Nebula**

# An entanglement of nebulae...

## The Antares-Rho Ophiuchi Region



Can you sort what you see?

# An entanglement of nebulae...

## The Antares-Rho Ophiuchi Region

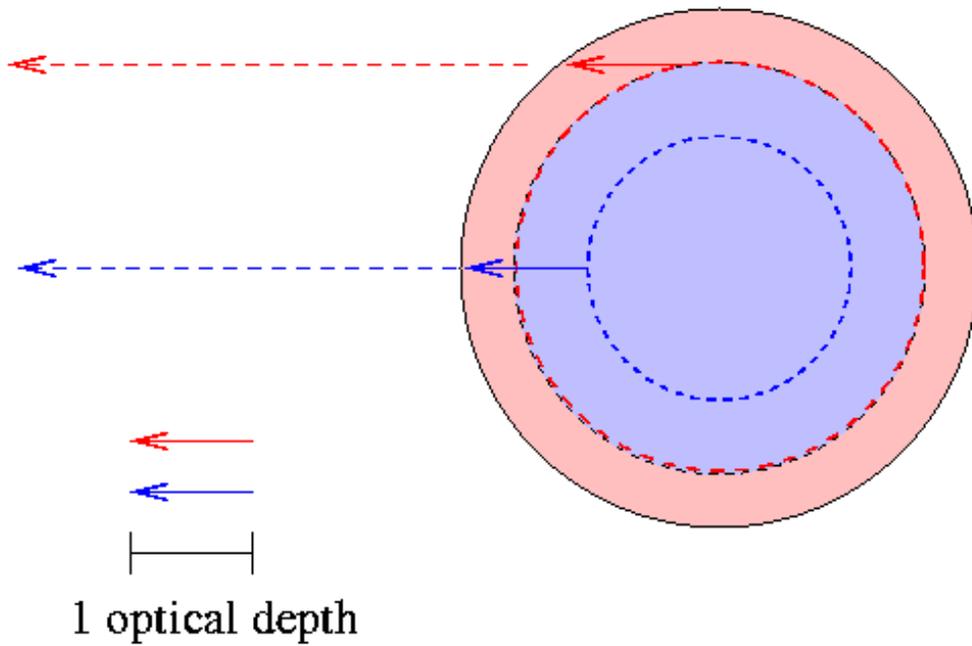


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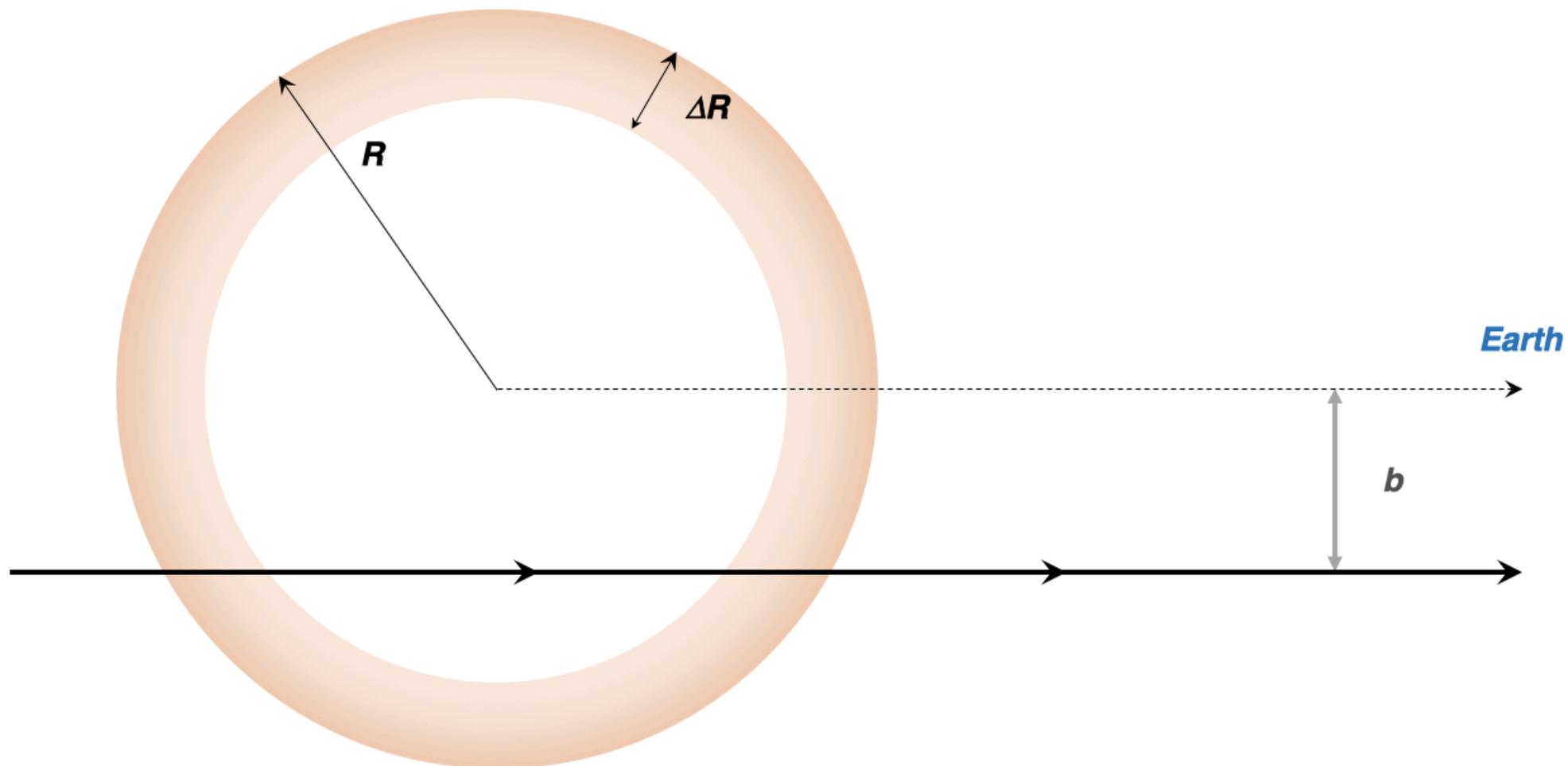
# Limb brightening



# Limb brightening



# Limb brightening



# Limb brightening

