

# Topic D

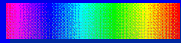
## "Part 5. Radiation Laws"

(Web Version: 08-15-01)

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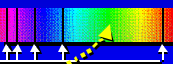

## Continuous Spectra

### Importance & Uses



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## Continuous Spectra

- **Appearance** 
  - What *cannot* do — chemical identification (*Why?*) 
  - What *can* do — obtain temperatures of objects
- **Real Stellar Spectra**
  - Usually show *dark lines* 
  - Also show a *continuum* 
  - A temperature indicator!

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## Radiation Laws

See Fig. 7

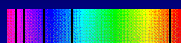
Three laws characterize continuous spectra  
(Listed in *Study Guide*, Fig. 7)

- Planck
- Wien
- Stefan-Boltzmann


Why important? — Can determine temperature

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## A Note: Black and White

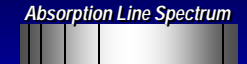

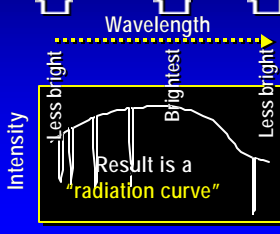
Stars show this 

*But spectrograms usually not in color*  
(B/W easy to produce)

Get used to this 

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## Radiation Curves

- Stellar spectra look like 
- Measure intensity (brightness) from end to end (with "light meter")
- Graph results  

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### Dips Show Lines

- Stellar spectra look like
- Measure intensity (brightness) from end to end (with "light meter")
- Graph result

Absorption Line Spectrum

Intensity

Wavelength

Dark Lines

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### Erase Lines

If erase lines from graph . . .

Looks like a continuous spectrum

Now analyze as if spectrum has no lines!

Continuous Spectrum

Intensity

Wavelength

radiation curve without lines

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### Perfect Radiators

- Invent "idealized radiator"
- Often called a black body (BB)
- Simplifies understanding of radiation
- Stellar radiation curves (lines erased) often resemble BB's

Continuous Spectrum

Intensity

Wavelength

Use BB radiation curves to simulate stars

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### Cool Black Bodies

At room temperature

- Absorb *all* incoming radiation
- Radiate back *all* radiation received
- Then — why look black?

Answer . . .

Most radiation emitted in ?

So, In = Out

Mostly?

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### Hot Black Bodies

Heat Black Body

- Absorbs *all* incoming radiation
- Radiates back *all* radiation received
- Now looks bright — why?

Answer . . .

Significant radiation emitted in ?

So, In = Out

Substantial Visible

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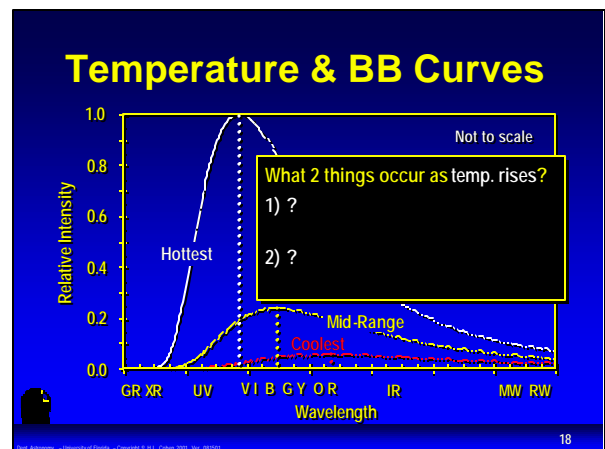
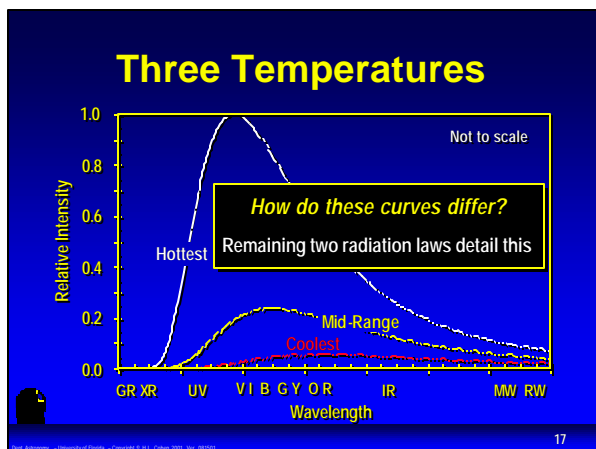
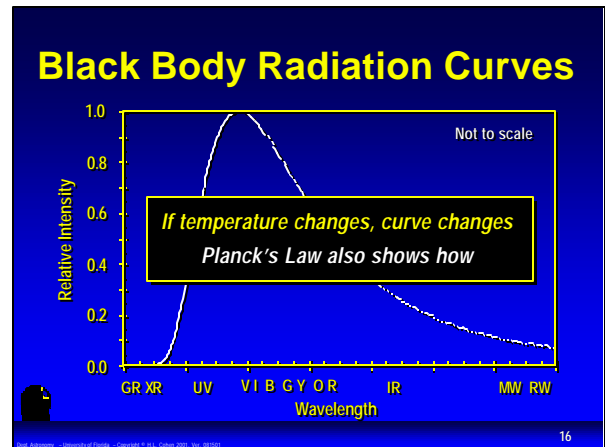
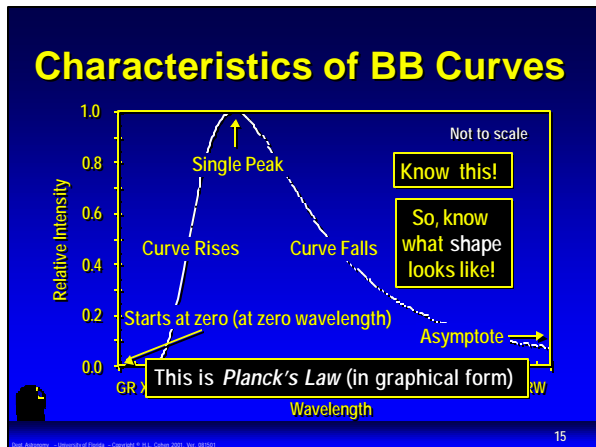
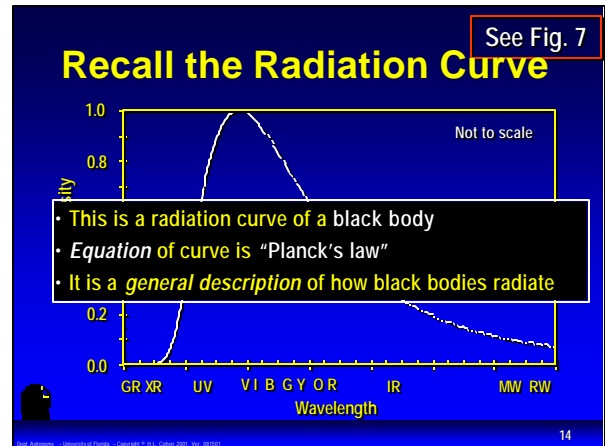
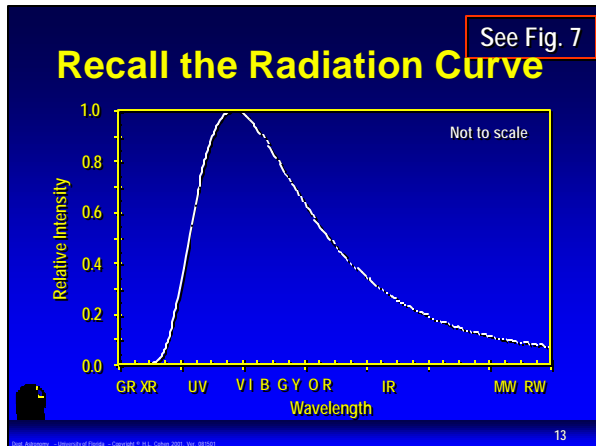
### The Radiation Laws

Three laws characterize continuous spectra

- Planck
- Wien
- Stefan-Boltzmann

(Listed in Study Guide, Fig. 7)

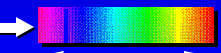
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## Second Radiation Law

Three laws characterize continuous spectra

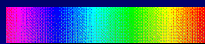
- Planck: General description of radiation
- Wien: Peak shifts toward shorter wavelengths if  $T$  increased

(Brightness unequal) 

Brighter here if *hotter*      Brighter here if *cooler*

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## Wein's Law

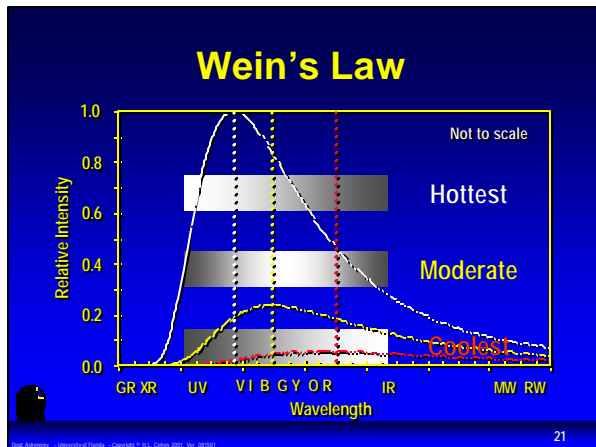
In Color 

In B/W

- Hottest: Brightest (at short wavelength)
- Moderate: Brightest (at intermediate wavelength)
- Cooler: Brightest (at long wavelength)

Increasing Wavelength  $\rightarrow$

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## Color of a Black Body

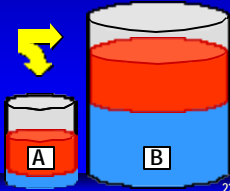
What is the color of a (hot) black body?

- Ans. It depends on the *distribution* of colors in its light

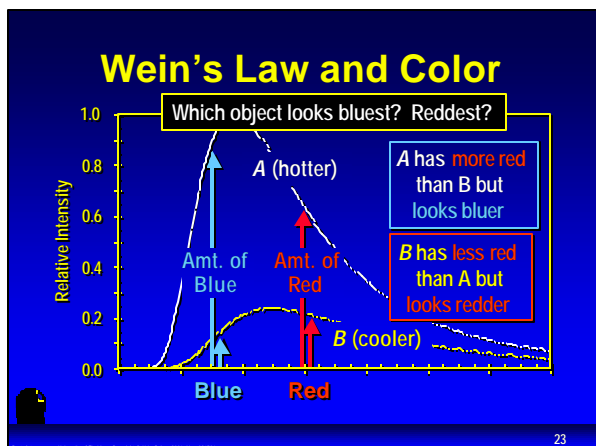
Analogy

Which bucket of paint (after paint in each can mixed)

- Looks reddest?
- Has the most red paint?



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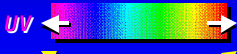


## Second Radiation Law

Three laws characterize continuous spectra

- Planck: General description of radiation
- Wien: Peaks shifts toward shorter wavelengths if  $T$  increased

Peak can even shift into UV or IR



Brighter if *hotter*      Brighter if *cooler*

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## Second Radiation Law

Three laws characterize continuous spectra

- Planck: General description of radiation
- Wien: Peak shifts toward shorter wavelengths if  $T$  increased

**Mathematical Statement**

Wavelength of Radiation Peak  $\propto \frac{1}{\text{Temperature}}$

Inverse proportion

## A Consequence

- Recall — Wavelength of violet (400 nm) about half of red (700 nm)
- Consequence — Suppose temperature of Sun
  - Doubled (6,000 @ 12,000 K), peak moves into UV
  - Halved (6,000 @ 3,000 K), peak moves into IR

UV ← Double or halving  $T$  shifts peak out of visible → IR

## A Consequence

**Conclusion**

Stars with more than about twice or one-half of Sun's temperature have radiation peaks in UV or IR respectively

**Examples**

*Sirius*  
12,000 K

*Betelgeuse*  
3,000 K

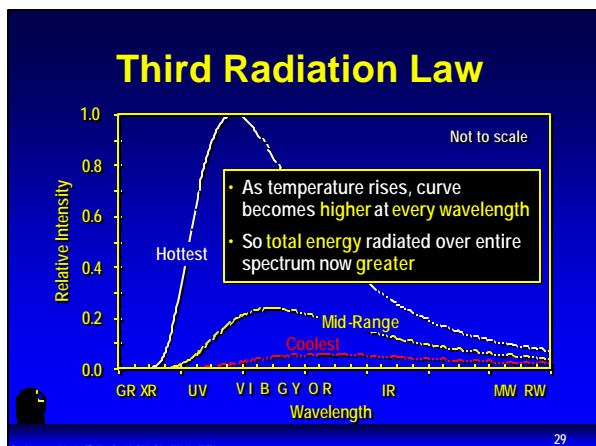
UV ← Double or halving  $T$  shifts peak out of visible → IR

## Second Radiation Law

Example of Wein's Law

See Study Guide

Example Worked Problem #3



## Total Energy Radiated

Let  $E_{\text{Tot}}$  = Total energy radiated

- Over entire spectrum
- Through some area (say a square meter)

*Not from whole star (So star's radius irrelevant)*

then  $E_{\text{Tot}} \propto T^4$  where  $T$  = Temperature

**Note!**

See Fig. 7

## Summary: Radiation Laws

Three laws characterize continuous spectra

- **Planck**                      General description of radiation
- **Wien**                         Peak shifts *toward shorter wave-lengths* if *T* increased [  $WL_{pk} \propto 1/T$  ]
- **Stefan-Boltzmann**        Total energy radiated (over entire spectrum) increases if *T* increased [  $E_{Tot} \propto T^4$  ]

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## Here's How it Works

Star A:  $T_A = 12,000\text{ K}$   
 Star B:  $T_B = 6,000\text{ K}$

*If can measure ratios of total energies emitted, can find how temperatures compare*

then

$$\frac{E_{Tot\ of\ A}}{E_{Tot\ of\ B}} = \frac{(12,000\text{ K})^4}{(6,000\text{ K})^4} = \frac{(2)^4}{(1)^4} = \frac{16}{1}$$

See Study Guide Example #4

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## A Few Examples

Common objects illustrate the radiation laws

- Celestial bodies
- Household items

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## Color of the Sun?

Before you answer, remember

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## The Solar Impression

Impression of Sun's color tailored by viewing Sun near horizon

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## So . . . Color of the Sun?

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## Range of Star Colors

bluish

bluish-white

whitish

yellowish-white

yellowish-orange

orangy

**Typical star colors**

- Range — bluish to orange
- Whitish most common
- Books may call some red**
- Exaggerated!
- Most too hot to appear red

See *Study Guide* Table 11, next-to-last column (**Know**)

## See Star Colors for Yourself

**Orion**

Look at bright stars — eye can't see color if brightness low

## Wien's Law and Color

Changing color of many hot objects a consequence of Wien's Law

- Results from a shifting *distribution* of color
- Everyone has experienced Wien's Law

Watch a stove burner heat and change color (or heating element or light bulb filament)

## Watch a Stove Burner Heat

Burner Heats →

*Visible only because of reflected room light*

Off

Visible light undetectable (most radiation emitted as IR)

Dull Red

Orange-Red

Bright Orange

(Burner does not become hot enough to show further changes)

**Color Change**  
Wien's Law

**Increasing Brightness**  
Stefan-Boltzmann

## Light Bulb on Dimmer Switch

Filament Heats →

Bulb Off

Dull Red

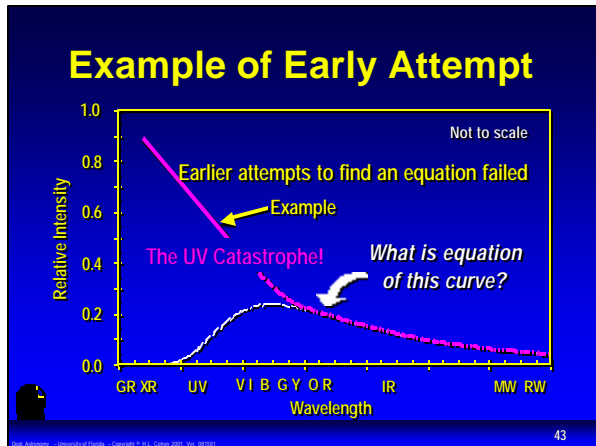
Dim Orange

Bright Yellow

Brilliant Yellow-White

## Side Note: Planck's Law

- Many tried to find equation for BB curve
- That is, a relation between
  - Intensity
  - Wavelength
  - Temperature
- Early attempts failed (example follows)



### Why Planck Succeeded

- Like Kepler — threw away old ideas
- Previously . . .  
Radiation visualized as water flowing continuously from a hose  
*Continuous Flow*
- Success due to new hypothesis about radiation  
(Recall Kepler did same for celestial motions)

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### What Planck Did

Planck postulated . . .

- Radiation bundled into particles of energy
- Energy packets called *photons*
- Radiation spurts like water from a spray bottle or water gun
- Each "spurt" or "packet" like a **photon**

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### What Resulted . . .

Planck derives equation fitting black body curves

$$I = \frac{2\pi^5 k^4 T^4}{15\pi^3 hc^3} \frac{1}{e^{hc/k\lambda T} - 1}$$

(Do not have to know this !!)

Today BBs sometimes called *Planck radiators*

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