Astro 210

Lecture 12

Sept 20, 2010

Announcements

- HW2 Q4 (10 bonus points) available till Oct 1
- Hour Exam 1 this Friday `www: info online`
- Planetarium shows start tonight – optional, 10 bonus points
  online: info and registration
  download & bring question sheet; due Oct 1

Last time: Kirchoff–light, matter, and spectra

- look at hot, opaque source, no intervening material *...and see?*
- look at hot, low-density gas *...and see?*
- look at cool gas in front of hot opaque source *...and see?*

these effects are godsends for astrophysics! *Q: why?*

Continuous Spectra and Blackbody Radiation

hot objects (e.g., stove burner) glow

- radiates! (Kirchoff)
- hotter $\rightarrow$ brigher, color change
- continuous spectrum

useful* to define an ideal substance:
a perfect absorber of light: **"blackbody"**
absorbs all λ, reflects none

*a useful idealization in the same way an "ideal gas" is useful: brings out essential physics, and a good approximation to behavior of many real substances

blackbody absorbs radiation $\rightarrow$ heats $\rightarrow$ re-emits according to T
"blackbody radiation" = thermal radiation
spectrum depends only on T
diagram: Flux F vs λ

Blackbody spectrum:

- $F > 0$ for all λ
- higher $T \to$ higher F at all λ
- **peak** at λ_{max}
- for higher T, peak at smaller λ_{max}

Q: why is this reasonable physically? Hint–photon energy!

Wien's law

$$\lambda_{\text{max}} = \frac{2.9 \times 10^{-3}\ \text{m K}}{T}$$

where T is in Kelvin: $T(\text{K}) = T(^\circ\text{C}) + 273$

Ex: Sun's spectrum peaks in middle of visible range:
$\lambda_{\text{max},\odot} \simeq 500$ nm
Surface temperature is:

$$T_\odot \approx \frac{2.9 \times 10^{-3}\ \text{m K}}{500 \times 10^{-9}\ \text{m}} = 5800\ \text{K} \quad (1)$$

Observer's Scorecard

Blackbody spectrum & Wien's law are powerful tools:
get T from spectrum!

color $\leftrightarrow$ temperature

Q: are stars all the same color? what does this imply?

`www: objective prism spectra`

Q: compare bright stars in Orion: Betelgeuse, Aldebaran

iClicker Poll: Blackbody Radiation and You

What about people & animals?

Do people & animals emit blackbody radiation?

A yes, but flux too faint to see

B yes, but flux is not visible to naked eye

C no, living organisms cannot behave as blackbodies

D no, our skin traps radiation inside our bodies

`www: experiment says...`

Blackbodies: Total Flux

Total flux over all λ = sum of flux at each interval $\Delta\lambda$

$$F = \sigma T^4 \quad \text{Stefan–Boltzmann Law} \tag{2}$$

where

$$\sigma = 5.67 \times 10^{-8} \, \frac{\text{W}}{\text{m}^2 \, \text{K}^4} \quad \text{Stefan–Boltzmann constant} \tag{3}$$

flux units: [energy per per unit area per unit time]

Ex: the Sun

total solar **power** output

= rate per second of energy flow into space

= solar "**luminosity**" $= L_\odot = 3.85 \times 10^{26}$ W

Q: how to calculate this?

given $L_\odot$ and solar radius $R_\odot$

Q:how find Sun's blackbody temperature?

Use Stefan-Boltzmann to relate Sun's surface flux to surface temperature:

$$F_{\odot,\text{surface}} = \frac{L}{\text{surf. area}} = \frac{L}{4\pi R_{\odot}^2} = 6.3 \times 10^7 \frac{\text{W}}{\text{m}^2} \tag{4}$$

$$\Rightarrow T^4 = \frac{F}{\sigma} \tag{5}$$

$$\Rightarrow T = \left(\frac{F}{\sigma}\right)^{1/4} = 5800 \text{ K} \tag{6}$$

check! this luminosity-based value *agrees*
with earlier color-based value using Wein's law
$\rightarrow$ good consistency check, didn't have to agree
Q: what would disagreement mean?

And finally: flag thermodynamics(?)
Wein says: blue $\rightarrow T \sim 8,000$ K
red $\rightarrow T \sim 3,000$ K
Q: why doesn't a US flag burst into flame?
why aren't blue regions twice as hot as red?

Doppler Effect

consider a moving light source

- moves at constant speed v
- emits light of wavelength $\lambda_{\rm em}$
  as measured in emitter's rest frame

Each wave crest propagates spherically from emission point
but emission points move, so...
Q: how does this affect observed wavelength $\lambda_{\rm obs}$?
Q: does the effect depend on viewing angle? how or why not?

in front of emitter: wave crests "bunch up"
$\rightarrow$ approaching objects observed at smaller wavelength
$\rightarrow$ shorter λ: "blue shift"

behind emitter: wave crests "stretched out"
$\rightarrow$ receding objects observed at longer wavelength
$\rightarrow$ longer λ: "red shift"

shift depends only on
relative motion in **radial** direction ("line of sight")

$$\frac{\lambda_{\text{obs}} - \lambda_{\text{em}}}{\lambda_{\text{em}}} = \frac{\Delta\lambda}{\lambda} = \frac{v_r}{c} \tag{7}$$

where $v_r > 0$ means moving away

Observer's Scorecard

Doppler effect: speed $\leftrightarrow$ λ shift

redshifts/blueshifts $\rightarrow$ speedometer

Q: but how does it work in practice?
how do you know a line is shifted?