Astro 210

Lecture 14

Feb 21, 2011

Announcements

- HW4 due at start of class Friday
- last Planetarium show tonight
  registration, report forms, info online
- Night Observing this week – *Dress warmly!*
  report forms, info online

Before exam: light & matter

*blackbody radiation* = *thermal radiation*

*Q: what is it? What objects emit it? How does it depend on* $T$*?*

*Q: how is it useful to astronomers?*

Blackbody radiation:

- glow of hot objects
- emitted by solids, liquids, dense gasses
  with any temperature $T$ (= in thermal equilibrium)
- spectrum: $F(\lambda)$ increases sharply to peak at $\lambda_{\rm max}$
  then falls off at long $\lambda$
  `www: blackbody spectra`
- a $T$ increases: flux higher, peak shifts $\rightarrow$ shorter $\lambda$

**Wien's law**

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

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



Example: the Sun

`www: solar spectrum` *Q: comments?*

solar spectrum:
not perfectly a blackbody (e.g., absorption lines)
but very close

solar spectrum peaks in middle of visible range:
$\lambda_{\mathrm{max},\odot} \simeq 500$ nm
Surface temperature is:

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

# 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*

# Blackbodies: Total Flux

Total flux over all $\lambda$ = 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: "Wattage"

= 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 $\lambda$: "blue shift"

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

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

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

where $v_r > 0$ means moving away

# Observer's Scorecard

Doppler effect: speed $\leftrightarrow$ $\lambda$ shift

**redshifts/blueshifts $\rightarrow$ speedometer**

namely: measure $\lambda_{\text{obs}}$, know $\lambda_{\text{em}}$ $\rightarrow$ find $v_r = \dfrac{\Delta\lambda}{\lambda}\, c$

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

# TELESCOPES

# Telescopes

so far: how light encodes information
today: how to collect & decipher it

Telescopes:
1. collect/concentrate photons
2. detect photons

*Q: collection methods–naked eye? scopes?*

**Light Collection**: bring to focus, form image

1. lens "*refractor*"
Snell's law: light bent due to change in index of refraction
i.e., change of speed–slower in glass.
With curved surface, can concentrate rays

problems:
- spherical aberration
- chromatic aberration
- lens "sag" increases with size $\rightarrow$ limits lens size

2. mirror "reflector"

mirrors: angle of incidence = angle of reflection.

With curved surface, can bring to focus.

merits:

- no chromatic abberation
- no sag *Q: because?*

problems:

- spherical abberation

| all modern research telescopes are reflectors |
|---|

# iClicker Poll: Telescope Properties

What is the most important aspect of a telescope?

A Ability to magnify small angular regions

B Ability to detect faint objects (small flux)

C Ability to see fine detail (features on small angular scales)

# Telescope Power

telescope priorities and dependence on
lens/mirror diameter $D$ ("aperture")

⋆ **Light Gathering Power**
astronomical objects are **dim** $\rightarrow$ need as much light as possible
$\rightarrow$ need "photon bucket"
light gathering power $\propto$ area of lens/mirror $\propto D^2$
**bigger is better!**
Hubble: $D = 2.4$ m (`www: HST primary`)
Keck (Hawaii): $D = 10$ m (`www: Keck primary`) $\rightarrow$ 17× the LGP!

- so for a fixed exposure time,
  Keck can see objects 17× fainter flux
- or to see the same level of brightness
  Keck needs to expose 17× less time

## ⋆ Angular Resolution

ang res = smallest angular separation distinguishable

$\rightarrow$ sets *angular size* of *finest detail* in image

best resolution allowed by wave nature of light:

**diffraction** limit: smallest angular size

$$\theta_{\rm obs} \geq \theta_{\rm min,obs} = \theta_{\rm diff} = 1.22\frac{\lambda}{D} \tag{8}$$

objects separated by $\theta < \theta_{\rm obs}$ smeared together as one blob

Keck: $\theta_{\rm diff} = 0.01$ arc sec at 500 nm

but: Earth atm $\rightarrow$ turbulence ("twinkling")

`www: twinkle animation`

$\rightarrow \theta_{\rm obs,Keck} = \theta_{\rm atm} \geq 1$ arc sec $\gg \theta_{\rm diff}$: Aaargh!

*Q: so obviously, the solution is?*

go to space! $\rightarrow$ HST $\theta_{\rm diff} = 0.05$ arc sec at 500 nm
this is the main motivation for Hubble Telescope!
$\rightarrow$ unprecedented angular resolution

## ⋆ Magnification

only worthwhile if enough light gathering power & resolution
$\rightarrow$ need to have a sharp image to magnify!
magnification set by focal lengths of objective (i.e., main mirror) and eyepiece: magnification $= f_{\rm obj}/f_{\rm eye}$