Astro 210

Lecture 10

Feb 7, 2018

Announcements

Announcements

- **HW3 due online in PDF, Friday 5:00 pm**
- **Office Hours:** Instructor–2:00-3:00 today, or by appointment
  TA–3:30-4:30 tomorrow
- HW1 grades posted today!
- first Planetarium shows **Today** and **Wednesday**
  online: **reservations**, schedules, directions, **report form**

Changing Gears

Ready to begin scientific exploration of the cosmos

`www: Big Picture`

Need to assemble & understand available tools

What can we **directly** measure, from Earth,
about planets/stars/galaxies?
With partner: write list

Astrophysicist's Wishlist

Note that much of what we would *like* to know about celestial objects, such as

- properties: distance, size, mass, temperature, speed, spin rate, composition, ...
- physics: orbits, origin, evolution, ...

are **not** directly observable
i.e., these data aren't output of a telescope

what is?

Observer's Toolbox

hard-nosed list of direct observables which **do** come out of a scope:

- position on sky
- color/spectrum
- brightness
- polarization
- time changes in any/all of these above

lesson: can only measure light (and other messenger from afar)!
can look but not touch!
$\Rightarrow$ need to understand light
and its interactions with matter
to decode maximum available cosmic information

amazingly lucky circumstance: can get there from here!

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You can't always get what you want
No you can't always get what you want
You can't always get what you want
But if you try sometimes
You might find
You get what you need
  -- Astrophysicist Mick Jagger
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Electromagnetic Radiation: Wave-Particle Duality

Heads-up: in physics/astrophysics "radiation" $\equiv$ EM radiation
i.e., transport of EM energy across space by particles or waves
$\neq$ radioactivity = "ionizing radiation"
Q: examples of radiation in ASTR210 sense?

Wave Properties

Maxwell's eqs: electric & magnetic fields* can support waves
$\rightarrow$ light is **electromagnetic radiation**

simplest wave: sinusoidal; more complex patterns
can be decomposed into sums of sinusoids (Fourier)
Q: basic anatomy of any propagating sinusoidal wave?
Q: corresponding properties of light waves?
i.e., how interpreted by your personal photodetectors?

* no relation to instructor

Electromagnetic Waves

- EM wave speed: $c = 3.0 \times 10^8$ m/s
- spatial oscillation period: **wavelength** λ
- time oscillation period: P [sec/cycle]
  related to **frequency**: $f = \nu = 1/P$ [cycles/sec = Hertz]
- wave travels: in time $\Delta t = P = 1/f$, pattern moves distance $\Delta x = \lambda$, and since speed is $c = \Delta x / \Delta t \rightarrow \boxed{c = \lambda f}$

Electromagnetic Spectrum

note: EM radiation can have any wavelength
from subatomic through to macroscopic!

your eyes detect narrowλ range: “optical band”
experience λ as **color**

	radio	infrared	visible	ultraviolet	X-ray	γ-ray
ν [Hz]	$< 10^{11}$	$\sim 10^{13}$	$\sim 5 \times 10^{14}$	$\sim 10^{16}$	$\sim 10^{18}$	$\sim 10^{20}$
λ [m]	$> 10^{-3}$	$\sim 10^{-5}$	$\sim 5 \times 10^{-7}$ m	$\sim 10^{-9}$	$\sim 10^{-11}$	$\sim 10^{-12}$

Example: what is freq. of green light at 500 nm?

$$f = \frac{c}{\lambda} = \frac{3 \times 10^{8}\ \text{m/s}}{5 \times 10^{-7}\ \text{m}} = 6 \times 10^{14}\ \text{Hz} \tag{1}$$

Radiation Particle Properties: Photons

leap forward: 20th century revolution of quantum mechanics
Max Planck (1858–1947):
light comes in "chunks" or "packets" of energy
$\rightarrow$ **quantized** $\Rightarrow$ photon (symbol γ)

A photon's energy set by color: $E_\gamma = hf = hc/\lambda$
where Planck's constant $h = 6.63 \times 10^{-34}$ J s
often also use $\hbar = h/2\pi$

∞

Ex: what is energy of 1 photon of green light?

$$
\begin{aligned}
E_\gamma &= \frac{hc}{\lambda} &(2)\\
&= \frac{6.6 \times 10^{-34}\ \text{Js}\ 3.0 \times 10^{8}\ \text{m/s}}{5.0 \times 10^{-7}\ \text{m}} = 4.0 \times 10^{-19}\ \text{J} &(3)\\
&= 2.5\ \text{eV} &(4)
\end{aligned}
$$

very small!

new energy unit: electron Volt

$1\ \text{eV} = 1.602 \times 10^{-19}$ Joule

energy gained by 1 e^- going thru

potential difference of 1 Volt

iClicker Poll: Laser Pointer

Demo: laser pointer – emits photons all with one *same* wavelength

if I double the power output of green laser pointer beam:
e.g., crank from 1 mWatt $\rightarrow$ 2 mWatt
What changes, what stays the same?

A more photons emitted, but each photon has same energy

B same number of photons emitted, but photon each has more energy

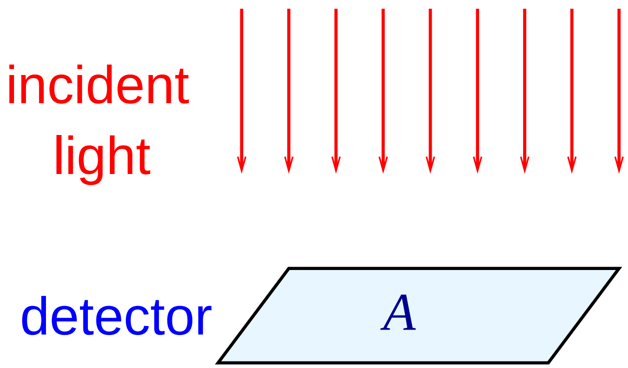
C more photons emitted *and* each photon has more energy

- each photon's E depends on f only
- **total** energy in light beam depends on # photons

crank emitted power $\rightarrow$ add more photons
so total energy output (power) $\propto$ # photons emitted per sec

Energy Flow

idealized detector of area A
receives incident radiation
over exposure time dt



energy received in exposure dE depends on detector
because $dE \propto dA\, dt$ *Q: why?*

thus energy received is detector-dependent via dA
Q: how to remove detector dependence?

Energy Flux

energy flux (or just "flux")

$$F = \frac{dE}{dA\,dt} = \frac{d\text{Power}}{d\text{Area}} \tag{5}$$

independent of detector, and
intrinsic to source and distance

cgs units: $[F] = [\text{erg cm}^{-2}\ \text{s}^{-1}]$

physically: corresponds to *apparent brightness*

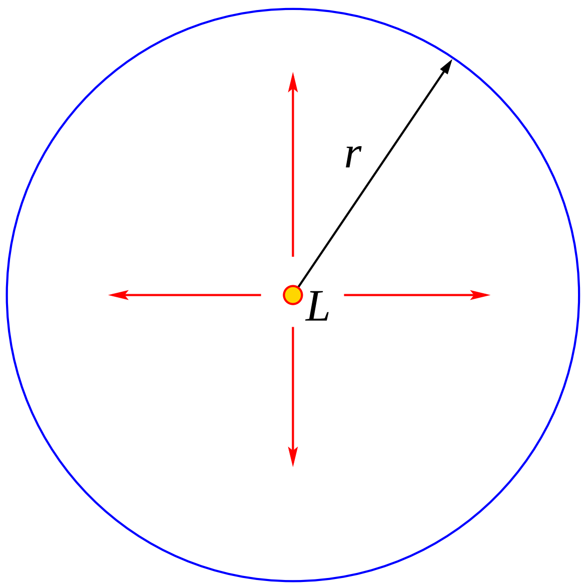
- in wave picture: $F \leftrightarrow$ wave amplitude
- in particle picture: $F \leftrightarrow$ density of photon flow

Inverse Square Law

consider spherical source of size R
emitting isotropically
with constant power L ("luminosity")

at radius $r > R$ (outside of source)
area $A = 4\pi r^2$, and flux is

$$F = \frac{L}{4\pi r^2} \tag{6}$$



inverse square law

Q: what principle at work here?
Q what implicitly assumed?

Inverse Square Law

Ultimately relies on *energy conservation*

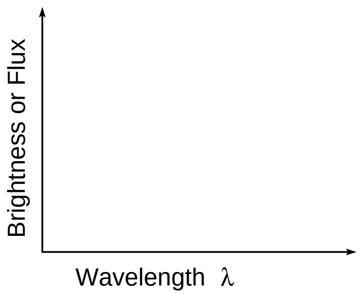
$\longrightarrow$ energy emitted $dE_{\mathrm{emit}} = L\ dt_{\mathrm{emit}}$ from source
is same as energy observed $dE_{\mathrm{obs}} = F\ A\ dt_{\mathrm{obs}}$

Thus: inverse square derivation assumes

- no emission, absorption, or scattering outside of source
  we will soon consider these

Spectroscopy

spectrum: flux distribution vs λ



Demo: use gratings

Q: what does white light spectrum look like?

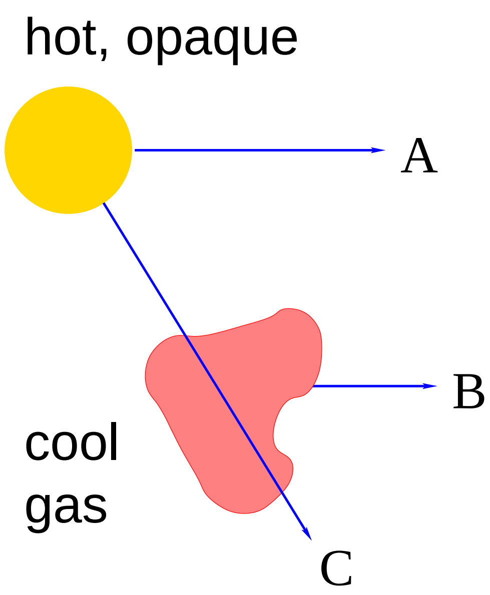
Q: what does laser pointer spectrum look like?

Q: what's the spectrum of a neon light?

Q: what's the spectrum of a mercury, hydrogen, helium light?

Q: what's the spectrum of a heated solid filament?

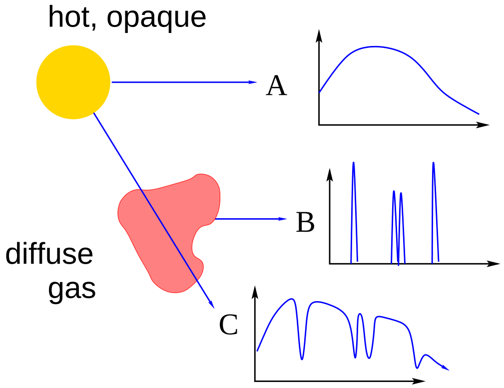
can classify three basic kinds of spectra: **Kirchoff's Rules**



Q: what does A see? hint–space heater demo

Q: what does B see? hint–neon light

Q: what about C?



A. a hot and opaque solid, liquid or dense gas emits
a *continuous spectrum* (A)

B. a hot low-density (transparent) gas produces
an *emission line spectrum*
note: *pattern of lines specific to element*

C. Continuous radiation viewed though cooler gas produces
an em absorption line spectrum, note: the lines absorbed have same color/wavelength as the emission lines in B

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

Observer's Scorecard

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You can see an awful lot, just by looking.
  -- Asrophysicist Yogi Berra
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can use emission/absorption lines to inventory kinds of elements in an astronomical source

light spectrum gives atom "fingerprint" or "barcode"

spectrum $\rightarrow$ composition

Example: The Sun

Sun, stars hotter, denser in center cooler, less dense at surface

so: sunlight/starlight shows *Q: what kind of spectrum?*

`www: Sun spectrum`

amount absorbed in each line → amount of atoms

→ **composition** of Sun; works for other stars too!

Note: as yet, don't know where lines comes from

who assigns cosmic barcodes?

for this, need to understand how light interacts with matter