Astro 210
Lecture 28
November 1, 2010

Announcements

- HW 8 available, due in class Friday
- **Solar Observing** this week only!
  - ▷ go anytime 10:30am to 3:30pm Mon–Thurs
  - ▷ allow about 30min
  - ▷ schedule online
  - ▷ report form online

Today: Swiching Gears
The Sun–a star in our backyard

Shifting Gears

`www: big picture`

Thus far:
- night sky
- geocentric vs heliocentric theories
- solar system properties, bodies, origin

now–the Sun: nearest star

which leads to
⋆ stars
⋆ our Galaxy
⋆ other galaxies
⋆ the Universe

The Sun

The nearest star
and we will show: a typical star

The Sun: Vital Statistics

- distance: $d = 1$ AU (by def'n)!

- radius: $R_\odot = 7 \times 10^8$ m $\simeq 100 R_{\text{Earth}}$!

- mass: $M_\odot = 2.0 \times 10^{30}$ kg
  Sun has most of SS mass (99.8%)

- $\rho_{\text{avg}} = 1400$ kg/m^3: $< \rho_{\text{rock,metals}}$
  composed of hot gasses (plasma)

The Sun: Stability

Sun size constant
$\Rightarrow$ not expanding, collapsing
$\Rightarrow$ $\boxed{\text{stable}}$
Why?

Note: not a trivial result, could have been otherwise
compare terrestrial, interstellar clouds–irregular shape, morph with time
→ in lab, expect gasses expand to fill available space

consider a small chunk of gas in Sun
at rest: doesn't move inward or outward
Q: How many forces act on the chunk of gas? which ones?

2. gas blob has weight: inward (downward) force

3. But: at rest → no net force

⇒ must be a force acting *upward*

hot gas has **pressure**: $P = nkT = \rho kT/m_{\text{gas particle}}$

upward pressure exactly balances downward gravity

"hydrostatic equilibrium" (Oct 6 notes)

⇒ $dP/dr = -g\rho = -GM(r)\rho(r)/r^2$

Note what this means:

→ Sun's mechanical structure $\rho(r), M(r)$ intimately related to thermal structure $P(r) \propto T(r)$

analogy: balloon, basketball (inward elastic force vs outward P)

But what if equilibrium is disturbed?

⋆ consider a small perturbation (force) which
gives an extra downward push to our gas blob
Q: what might cause such a perturbation?

⋆ *Q: how does gas blob respond to this squeeze?*

extra downward force on gas blob
→ extra compression: ρ increase
but for ideal gas, $P \propto \rho T$
→ compression → heating, pressurization
→ extra upward force
→ restores blob back to original height
(or even overshoots somewhat–oscillations: waves!)
⇒ no harm, no foul! equilibrium is stable!

basketball analogy: dribble
hit floor → extra force → compressed
internal pressure increased → bounces back

`www:  waves on Sun after flare`

What is the Sun's "Surface"?

the Sun made of gas
cannot have a sharp, hard surface, has no edge

but does not look hazy; instead, do *see* sharp boundary:
Sun appears to have surface!
`www:  Sun in white light`

Q: Why? what's going on?

The Solar Photosphere

observed surface → visible light emitted from
thin region/layer: "photosphere"
but why does light only come from this surface?
what defines the location of this surface?

Key idea: **photon scattering**
in Sun, photons *scatter* off electrons, ions
each photon scattered many (millions!) times
outward progress erratic: "random walk" *diagram:* γ *trajectories*
less scattering as move outwards and gas ρ decreases *Q: why?*
until finally γs escape → we see them

Q: so what sets photosphere location?

scattering frequency/probability increases with
higher gas $\rho \to$ more “targets” to hit
can define mean free path $\ell_{\rm mfp}$:
average γ pathlength (“stepsize”) between scatterings

iClicker Poll: Mean Free Path and Density

Does photon mean free path $\ell_{\rm mfp}$ depend on the *density* ρ of the medium?

Which of these is most physically reasonable?

- A $\ell_{\rm mfp} \propto \rho$
- B $\ell_{\rm mfp} \propto 1/\rho$
- C $\ell_{\rm mfp}$ independent of ρ

turns out: $\ell_{\text{mfp}} \propto 1/\rho$

not crazy: if no medium at all, then no scattering:

so stepsize infinite $\ell_{\text{mfp}} \to \infty$

and $\rho \to 0$ gives right answer

but if ultradense medium, many scatterers:

$\rho \to \infty$ means $\ell_{\text{mfp}} \to 0$

Apply to photons in the Sun:

- at center: highest ρ, smallest $\ell_{\text{mfp}} \sim 1$ cm (!) $\ll R_\odot$
  guaranteed scattering before leaving
- but as move outwards, $\rho \downarrow$ and so $\ell \uparrow$
- until ρ so low that $\ell_{\text{mfp}} > R_\odot$
  → scattering finally "turns off"

Fun fact: the sunlight we see from the photosphere took millions of years to come from the Sun's core!

So: photons from Sun come from "last scattering" surface

this is the photosphere: region where $\ell_{\text{mfp}} \rightarrow \infty$

- $\delta r_{\text{photosphere}} \sim few$100's of km thick
- $T_{\text{photosphere}} \sim$ 6400 K at base, $\sim$ 4200 K at "top"

$\Rightarrow$ we see T "mixture" – not perfect single-T blackbody

can see deeper at center than at edge ("limb"):
photons at edge come from higher, cooler region
"limb darkening"

Sun's surface shows activity!
in photosphere, gas motion:
hot rises, cool sinks: convection
Demo: lighter, show on screen
granulation

Sunspots

dark regions on photosphere
`www: today's sun in white light`
`www: sunspot seething`

spots transient, last ∼ 2 weeks
#, location of sunspots varies
periodic: 11-year "sunspot cycle"
`www: sunspot counts` – were' in minimum now (sorry!)

sunspots move: reveal solar spin
`www: real time Sun movie`

sunspots created by magnetism
strong mag. field "locks" plasma in place
keeps hot gas from rising
cooler gas → dark spot