Astro 210

Lecture 27

March 30, 2011

Announcements

- Good news: no homework due this week
- Bad news: Hour Exam 2 this Friday

  `www: info online`

Last time: exoplanet results as of Jan 2011

*Q: what are main trends?*

*Q: how do these compare with the solar nebula theory predictions?*

# Breaking News: The Kepler Revolution

**www: NASA Kepler** space mission recently launched
precision monitoring of thousands of stars for transits

Feb. 2, 2011: *Kepler* announces discover of

- **1235** planet candidates
- correcting for bias due to edge-on geometry:
  $> 33\%$ of stars have one or more planets!
- planet radii: span earth sized to Jupiter-sized
  **www: size distribution**

*Q: why are these numbers important?*

- **54** candidates are in the habitable zones
  of their host stars
- the first 6-planet system found

## Exoplanets: The Future

*Kepler* will take time to check for “false positives”
which will be about $\sim 20\%$ of the candidates
so $\sim 1000$ confirmed planets will be found!
$\rightarrow$ more major announcements expected soon

much excitement,
will play major role in Astrophysics in upcoming decade

Anyway: planets common.
$\Rightarrow$ good news in search for life elsewhere...

*Stay tuned!*



End of material on Hour Exam 2

# 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 definition)!

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

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

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

# The Sun: Stability

Sun size constant

$\Rightarrow$ not expanding, collapsing

$\Rightarrow$ $\boxed{\text{stable}}$

Why?

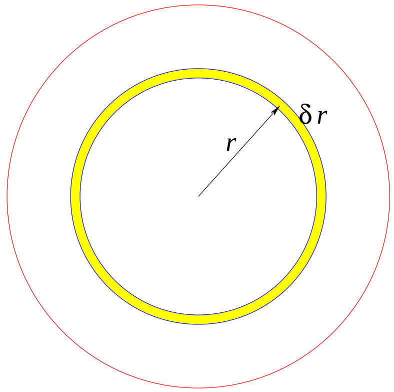
Note: not a trivial result, could have been otherwise

compare terrestrial, interstellar clouds–irregular shape, morph with time

$\rightarrow$ in lab, expect gasses expand to fill available space

# iClicker Poll: Forces on a Shell of Solar Gas

Consider a shell of gas in the Sun, **at rest**
i.e., Sun not expanding, contracting




**How many forces are acting on this shell?**

**A** zero

**B** only one

**C** more than one

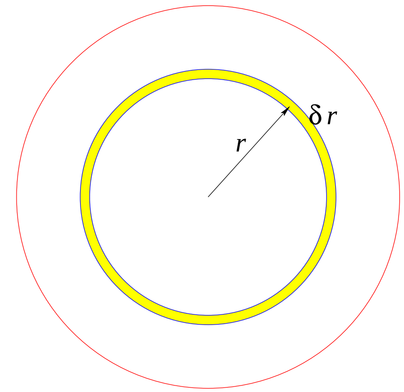
Consider a shell of gas in the Sun, **at rest**

radius $r$, thickness $\delta r \ll r$

shell area $A = 4\pi r^2$

shell volume

$$V = \frac{4\pi}{3}[(r+\delta r)^3 - r^3] \approx 4\pi r^2\,\delta r = A\,\delta r$$




shell mass $m_{\text{shell}} = \rho V = \rho A\ \delta r$

shell weight $F_{\text{w}} = -g m_{\text{shell}} = -g\rho A\ \delta r$:

*downward* force, but doesn't fall!?

*Q: why? gas has weight–why not all at our feet?*

*upward* force

pressure: on bottom $P(r)$, on top $P(r+\delta r)$

net upward force

$$F_{\rm p} \;=\; \Delta P \times A = [P(r+\delta r) - P(r)]A = A\,\frac{dP}{dr}\,\delta r$$

hydrostatic equilibrium: $F_{\rm weight} = F_{\rm pressure}$

upward pressure exactly balances downward gravity

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

Note what this means:

$\rightarrow$ Sun's mechanical structure $\rho(r), M(r)$ intimately related to thermal structure $P(r) = \rho kT/\mu \propto T(r)$



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

$\rightarrow$ extra compression: $\rho$ increase

but for ideal gas, $P \propto \rho T$

$\rightarrow$ compression $\rightarrow$ heating, pressurization

$\rightarrow$ extra upward force

$\rightarrow$ restores blob back to original height

(or even overshoots somewhat–oscillations: waves!)

$\Rightarrow$ no harm, no foul! equilibrium is stable!

basketball analogy: dribble

hit floor $\rightarrow$ extra force $\rightarrow$ compressed

internal pressure increased $\rightarrow$ 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: $\gamma$ trajectories*
less scattering as move outwards and gas $\rho$ decreases *Q: why?*
until finally $\gamma$s 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 $\ell_{\mathrm{mfp}}$:
average $\gamma$ pathlength ("stepsize") between scatterings

## iClicker Poll: Mean Free Path and Density

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

Which of these is most physically reasonable?

A $\ell_{\mathrm{mfp}} \propto \rho$

B $\ell_{\mathrm{mfp}} \propto 1/\rho$

C $\ell_{\mathrm{mfp}}$ independent of $\rho$

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

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

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

and $\rho \to 0$ gives right answer

but if ultradense medium, many scatterers:

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

Apply to photons in the Sun:

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

- $\delta r_{\rm photosphere} \sim few$ 100's of km thick
- $T_{\rm photosphere} \sim 6400$ 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 $\sim$ 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 $\rightarrow$ dark spot