Astro 350

Lecture 10

Sept. 14, 2011

Announcements:

- Discussion Question 3 due today
- HW3 available, due Friday

  Office hours: instructor today, after class

  TA: tomorrow 2-3pm

Last time: cosmic barcode

Q: if look at thin gas of excited atoms, what is spectrum?

Q: why useful?

Q: what causes the patterns?

Kirchoff's Laws

relates light, heat, and matter: what do you see?

`www: Kirchoff's laws`

1. if look at hot *solid, or dense gas*
atoms move rapidly, collide often
dense → when photons emitted in collisions, "bottled up" unless at surface
⇒ surface emits **continuous** spectrum: see blackbody radiation

2. if look at hot *thin, low-density, rarefied gas*
rarefied → when photons emitted in collisions, can escape
⇒ atmos emit characteristic lines → see **emission line** spectrum

3. if look at *"backlit" cool gas*
that is, continuous spectrum passes thru gas
atoms absorb light → see **absorption line** spectrum

Measuring the Composition of the Cosmos

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!

Example: Foreground of Quasars

Quasar: really–monstrous supermassive black hole
devouring gas and ejecting luminous jet
for our purposes today: a lightbulb/cosmic beacon
→ light from hot material across universe passes thru
intervening gas (if any) to get to us

Q: is there much intervening gas? (guess!)
Q: if so, what elements might be prominent?
Q: should it give emission or absorption features?

`www: Quasar spectrum`

Quasar spectra show *many* absorption lines
$\rightarrow$ of all atoms, but mostly hydrogen

Implications:
$\star$ the cosmos filled with lotsa hydrogen $\rightarrow$ Sun not special
$\star$ absorption: today (and "recently") H in form of cold gas

Job for cosmology theory: explain it all!
- where did the H come from?
- how did it get to be cold and gaseous today?
- and what about those quasars? what are they? where/when did they come from?

Stars and Cosmology

The Facts of Life for Stars

Fact: stars constantly radiates energy
and at a huge rate!
the Sun: a lightbulb with wattage $L_\odot = 4 \times 10^{26}$ Watts!

Fact: stars have a finite ($\neq \infty$) mass
and thus a finite fuel supply (whatever that fuel may be)

Fact: Energy is conserved
no free lunch!

Q: therefore?

Star Lives and the Consequences of Energy Conservation

the Sun and all stars:

- are constantly releasing energy to the rest of the universe, and
- require fuel, and are unable to "refuel" out of nothing, and
- thus must eventually run of out fuel

Thus:

- all stars – including the Sun – must eventually "burn out"
  = run out of fuel: *all stars are doomed to die*
  Q: important followup question?
- stars do not live forever

And thus:

- stars alive today were not alive forever
- *all stars must be born* as well as die

stars have life cycles

Star Birth

stars born in cold clumps of interstellar matter
called *molecular clouds*

`www: interstellar gas clouds`

- most (about 98%) cloud mass is *gas*, mostly H and He
- but about 2% of mass *dust* = small microscopic solid bodies made of heavier elements ("metals" = not H, He)

  `www: interplanetary dust under microscope`

Total mass of a giant molecular cloud huge, about $100,000 M_{\text{sun}}$!
a huge stellar nursery!
but clouds very clumpy
$\rightarrow$ new stars born in coldest, densest regions

consider different points in the cold, low-density cloud
∞ *Q: what force(s) act on each point?*
Q: how will the cloud respond to these forces?

Forces in Gas Clouds

in cold, low-density cloud, forces are

- gravity (cloud has mass!)
- and gas pressure

but if cloud is *cold*, gas pressure low

$\rightarrow$ only important force is gravity

each point in cloud feel gravity of rest of cloud

force pulls toward center

net force exists $\rightarrow$ cloud accelerates!

- every point moves toward center $\rightarrow$ cloud *compressed*!

iClicker Poll: Gravity and Cloud Compression

consider a cold cloud begins at rest
but then compressed by its own gravity
without losing or gaining mass

for each point in the cloud
How does the gravity force change after compression?

A gravity force weaker

B gravity force same

C gravity force stronger

Q: and so what eventually happens?

Gravitational Collapse

- then: in cloud, same mass, smaller distances
  $F \propto m_2 m_2 / R^2$: *gravity stronger!*
  compression *amplifies* gravity!
- still contract, but faster!

Result: gravitational collapse! all matter to center!

Q: so why doesn't everything collapse to a point (black hole!)?

Preventing Death By Black Hole

if gravity were the only force in the cloud
entire cloud in *free fall*!
collapse becomes ever more violent
$\rightarrow$ all matter pulled to center
$\rightarrow$ black hole!

but this obviously is false! stars do exist!
and are stable – Sun doesn't shrink daily!

but because Sun keeps same size
$\rightarrow$ surface at rest
$\rightarrow$ not accelerating
$\rightarrow$ no *net* force
yet Sun definitely has gravity acting inward
$\Rightarrow$ must be another force acting outward: **gas pressure**

Atoms, Gasses, Pressure, and Temperature

Take microscopic view of gas: what's going on with atoms?
in any gas (stars, Universe, this room):

- atoms widely spread $\rightarrow$ empty space between
- *constantly in motion* as free bodies until collision with other gas particles
- collisions "scramble"/randomize motion direction and tend to "equalize" particle energy

Now zoom back to our macroscopic view:

- enclosed gas exerts force–pressure–on walls
  Q: how does atom picture explain this?
- *Q: how does gas change if turn up T? what are atoms doing?*

Gas Pressure

atom bombardment exerts force (transfers linear momentum)
e.g., atoms collide with piston, push it outward
this leads to outward pressure force
$\rightarrow$ have to overcome this to compress gas

Gas Temperature

temperature T is a measure of average atom speed
more precisely: $T \propto$ average atom energy
for experts: ideal nonrelativistic gas has $kT = \frac{2}{3}\langle E \rangle = \frac{1}{3} m \langle v^2 \rangle$
$\rightarrow$ hotter gas $\rightarrow$ faster particles
$\rightarrow$ faster particles $\rightarrow$ higher pressure: $P \propto T$!

Q: so how does gas pressure affect star birth?

Star Birth: The Quest for Stability

cold gas clouds have small T $\rightarrow$ small pressure
$\rightarrow$ initially, pressure forces small
$\rightarrow$ gravitational collapse is (nearly) free fall

but *compression* $\rightarrow$ *heating*
as cloud collapses, pressure rises
until pressure forces as strong as gravity

eventually, star stabilized by becoming hot
inward gravity balanced by outward pressure
"hydrostatic equilibrium"

newborn stars remain stable as long as equilibrium maintained
$\rightarrow$ have to keep *hot* to maintain pressure