Astro 350

Lecture 11

February 11, 2022

Announcements:

- **Homework 3** due today
- **Discussion 3** due Wednesday

Last time: what is dark matter?

Q: why dark? why matter?

Edwin Hubble and the realm of the nebulae

Q: what are nebulae?

Q: what do the tell us about the scale of the universe?

"Nebulae" – "clouds:" fuzzy pinwheels or blobs on sky
e.g., with spiral swirls

Hubble measured distance to nearest nebulae
found they lie far outside Milky Way

the nebulae are galaxies
"island universes" similar to the Milky Way

Galaxies

galaxies fill universe
galaxies are the "building blocks" of the present-day Universe
$\rightarrow$ stars & other matter concentrated in them
much less matter in spaces in between

typical neighbor separation $\sim 10^6$ pc $=$ 1 Mpc (megaparsec)
most distant 1000's of Mpc

Galaxies sizes span a wide range
from large – like the Milky WAy
to small "dwarf"

Galaxy Types

spiral: disk+bulge
disk material rotates around center
gas, dust evident $\rightarrow$ star formation ongoing

elliptical: elongated sphere, no disk
little to no net rotation
"a ball of stars" very little gas, dust $\rightarrow$ star formation ceased
Q: but the stars are not nailed down, so?

irregular: no simple geometry
gas, dust present $\rightarrow$ can form stars
some show evidence of ongoing or recent merging

Q: Lessons?

Galaxies: Lessons

- *our Milky Way is a typical spiral galaxy*
  on the larger side of average

- merger events show *galaxies can change over time*
  and that their interactions can be important

- galaxy diversity cries out for explanation
  spoiler: merging plays a key role–but not the only role

Revolution Re-Revisited

Copernican Revolution I (17th Century):

Earth is one typical planet among many

not center of solar system

Copernican Revolution II (earth 20th Century):

Sun is one typical star among many

not center of Milky Way Galaxy

Copernican Revolution III (1920's):

Milky Way is one typical galaxy among many

Universe much larger than previously thought

... stay tuned for more...

Poll: Rotation Curves of Other Galaxies

Would like to compare Milky Way rotation curve
to those of other galaxies

Compared to the Milky Way,
measuring the rotation curve of a nearby galaxy is

A easier, but only if the galaxy's disk is seen edge-on

B easier, but only if the galaxy's disk is seen face-on

C always harder

D sorry, can't measure rotation curve of other galaxies

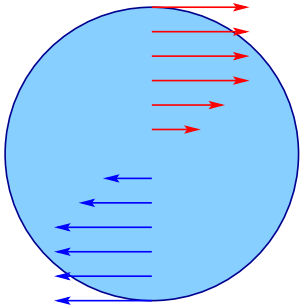
Galaxy Rotation Curves

Rotation curves: orbit speed v vs R

- *easier* to measure for other galaxies:
  we see the whole system at once
  and do not live inside it
- can measure if edge-on or tilted
  part of galaxy receding (redshifted)
  part approahing (blueshifted)
- `www: rotation curve data`

observer

top view



galaxy

Results:

- *all* galaxies show flat rotation curves
  similar to MW – we are not a weirdo!
- flat portion very clearly extends well beyond
  visible matter (stars/gas/dust)

∞

Q: which means?

Galaxies Are Made of Dark Matter

Interpretation:
- *all* galaxies contain large amounts of dark matter!
- in fact, *most* have a *larger* proportion than in MW!

Dark matter fills the Universe!
all galaxies are made mostly of dark matter!
the gravity of dark matter is what holds them together!

Any successful cosmology theory must
- include dark matter as a key ingredient
- explain what the DM is
- explain why we have so much of it

Starting now and in the next classes:
- test dark matter candidates
- will end up excluding most of list

Matter

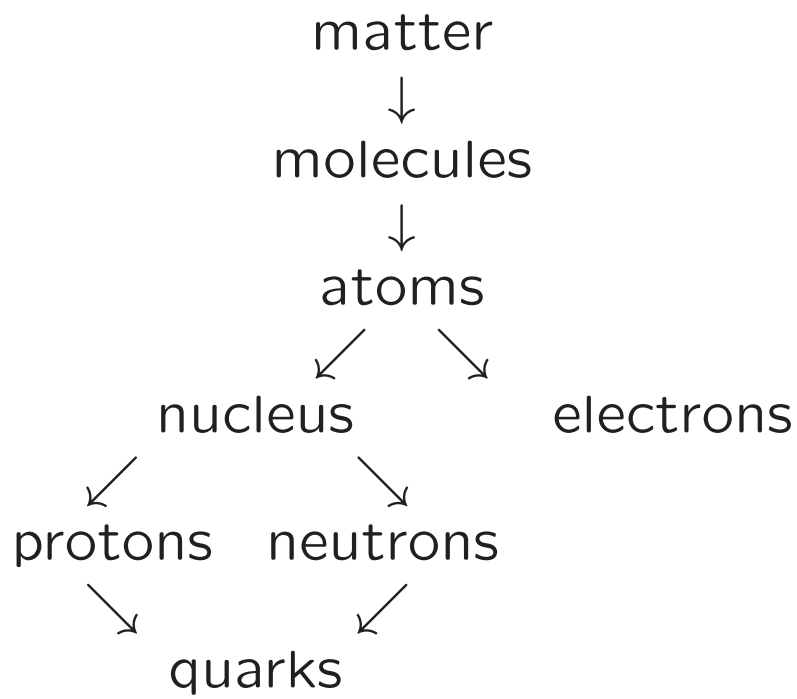
in hunting unknown dark matter, need to sharpen our tools
make full use of hard-won science to date:

- what has been learned about known *matter*
- *and how light can be used to probe it*

Q: As we "zoom in" to everyday matter, what do we find?

"Ordinary" Matter*

All known substances ever found *in any lab*
which we will call **"ordinary" matter**
have the following structure

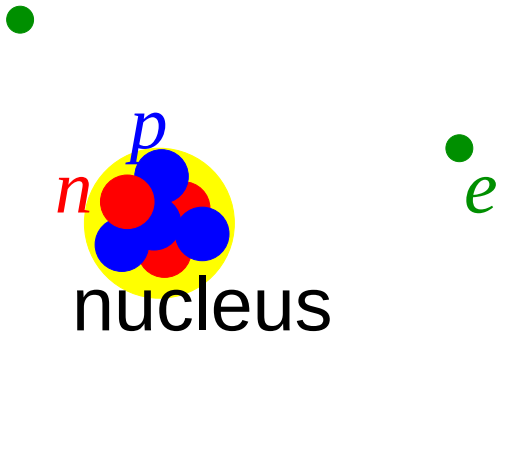


*Dark matter not included!

"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you want to call it) that **all things are made of atoms**–little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied."

–Cosmologist Richard Feynman

Atom Structure



one or more **electrons** orbit a single **nucleus**

electron (e): electric charge -1

nucleus: made of protons (charge +1) & neutrons (charge 0)

mass: $m_p \approx m_n \approx 2000 m_e$

$\Rightarrow$ most of atom mass is in dense nucleus

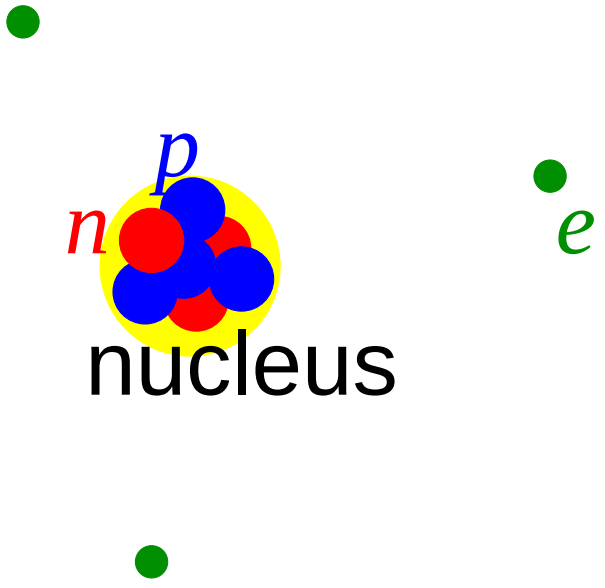
$\Rightarrow$ most of atom volume occupied by electron orbits

Q: what determines atom total charge?

total charge of atom: set by # electrons

e = # p $\rightarrow$ neutral

e = # $p - 1$ $\rightarrow$ charge = +1: singly ionized etc.



e moves around nucleus

Q: what does this tell us about forces in atoms?

electron orbits: curved paths – motion must be *accelerated*
$\rightarrow$ needs to be a net force–and there is!
nucleus & e attracted by **electric** force
  rule: opposite charges attract, like charges repel

atom structure similar to Solar System:
  attractive force $\rightarrow$ orbits
  big object in center, orbiting smaller objects

charge of nucleus $\Rightarrow$ # p
sets force on $e \rightarrow$ orbit properties
determines chemical properties
92 atom varieties = **elements**
from hydrogen = $1p$ to uranium = $92p$
`www: periodic table`