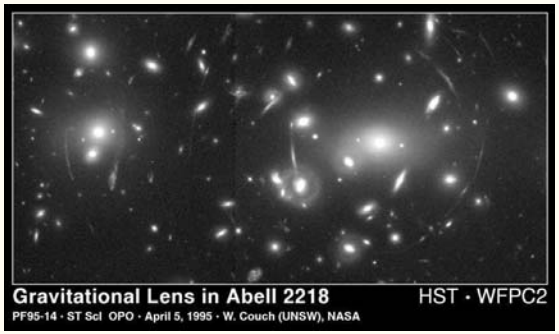



## Out Into the Universe

An overview of the cosmos:

What's out there?

How big is it? Is it getting bigger?



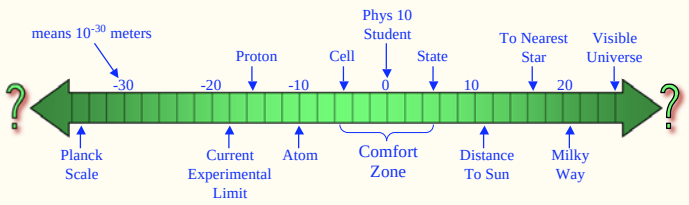
## Beyond Our Comfort Zone

- Direct Experience: $10^{-5}$ to $10^{5}$ meters
  - Dust grain may have 0.01 mm = 10 micron diameter
  - View from mountaintop may extend 100 km
- "Experts" may claim comfort with $10^{-7}$ to $10^{7}$ m
  - Optical surfaces are smoother than wavelength of light
  - Earth diameter about 12,750 km
- Scientists today deal with much larger ranges
  - Particle physics probes $10^{-18}$ m scales
  - Visible Universe spans $10^{26}$ m
  - Theorists stop at "Planck scale"; $10^{-35}$ m





## Graphical Logarithmic Representation of the Physical Scales in our Universe




Does it even *mean* anything to look beyond the scales represented here?
This may be all that matters!





## Outward Journey

- The logarithmic scale is deceptively compact
  - We think linearly, because that's how we perceive *time*
  - Now let's imagine the universe in linear terms…
- We use the speed of light to express large distances
  - $c$ =300,000,000 m/s: 1 light second = $3\times10^{8}$ meters
  - 1 light year is about $10^{16}$ meters
    - 1 yr is about $\pi\times10^{7}$ seconds (actually $3.15576\times10^{7}$ s)
- Imagine how far you could walk in a given amount of light travel-time
  - Puts things into a familiar context
  - Gadzooks, the Universe is big!

## Outward Journey; Solar System

- The moon is 385,000 km away
  - 1.25 light seconds
  - Walk about 2 meters in this time: Across a small room

Note: Deceiving perspective. The moon is about 30 earth-diameters away from earth. Photo from Galileo spacecraft (NASA).





## Outward Journey; Solar System, cont.

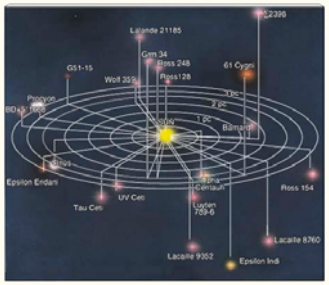
- The sun is $1.5 \times 10^{11}$ m away (1 A.U.)
  - 8 light minutes
  - Walk across campus in this amount of time
- Pluto is 40 A.U. away: $6 \times 10^{12}$ m
  - 5 hours light time
  - Walk to Downtown from here in this time






## Outward Journey; Solar Neighborhood

- Nearest Star to Sun: Proxima Centauri
  - 4.5 light years
  - Walk 5 times around earth at normal walking speed!




Rings are at 0.5 parsec (=1.63 l.y.) intervals.

Proxima Centauri is part of the multiple star group labeled Alpha Centauri, to the lower right of Sun.

Other, familiar naked-eye stars are Sirius and Procyon, each on the left edge of the disk.





## Outward Journey; Milky Way Galaxy

- Milky Way Galaxy
  - 20,000 light years to center from here
  - Forget about walking—try even *living* that long!
  - 100,000 light years in diameter
  - disk is a few hundred light years thick where we live

Not actually our Galaxy, but this is what it would look like.

## Outward Journey, Extragalactic

- Andromeda Galaxy (nearest large spiral)
  - 2,200,000 (2.2 million) light years away
  - Light we receive today is older than *Homo sapiens*

Can actually *see* this galaxy with the naked eye from a dark sky!





## Outward Journey; Extragalactic, cont.

- Virgo Cluster of galaxies (several 1000 members)
  - 50 million light years
  - We're talking dinosaurs now…


Central Part of Virgo Cluster





## Outward Journey; Extragalactic, cont.

- Most distant galaxies yet imaged ($z \approx 4$)
  - 12.5 billion light years
  - Older than Earth/Sun; 90% of Universe age
  - infer 100 billion galaxies in visible Universe

The Hubble Deep Field, taken by the Hubble Space Telescope in 1995.

Almost all objects are galaxies, save one foreground star just to upper left of center.

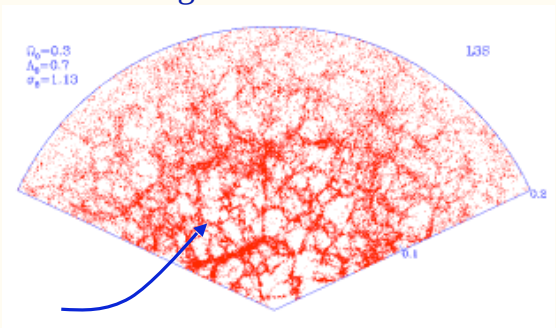
Most galaxies are lower redshift ($z < 1$), but some of the smaller, more distant galaxies are $z > 3$.

www.pbs.org/wgbh/nova/universe/tour_ggsn05.html
oposite.stsci.edu/pubinfo/PR/96/01.html





## The Distribution of Galaxies: Large Scale Structure




10,000 Milky Ways would fit across a typical void

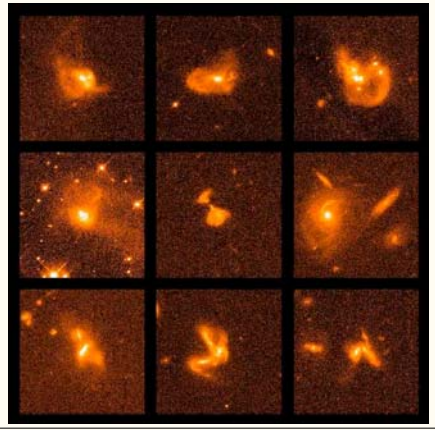
## Telescopes as Time Machines

- More distant galaxies are *old* galaxies
  - Takes time for light to reach us
  - 12 billion light years away means we see it as it was 12 billion years ago
- Bigger telescopes, better technology → see farther back in time
  - and guess what—galaxies don't look like they used to
    - we can see galaxies in the process of forming
    - bottom-up construction, built up by collisions/mergers





## Early Galaxies



Messy Train Wrecks!

All are distorted due to collisions and mergers





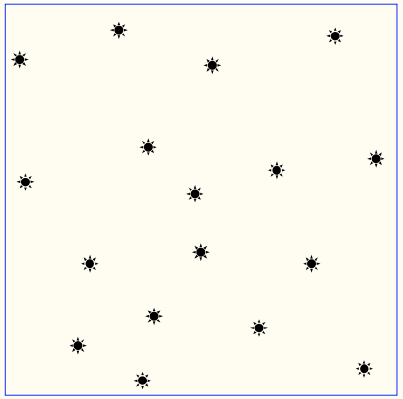
## The Big Bang

- The Universe is expanding like a sponge
  - The farther the galaxy, the faster it *appears* to recede
  - Not expanding *into* anything, *space itself* is expanding
  - There is no center "where the explosion took place"
  - Everything is simply getting farther from everything else as the space between swells
    - This is true for light waves as well, leading to redshifted light
    - Not true for bound objects
      - galaxy, solar system, earth, meter stick, human brain
- If we run the movie in reverse, must've started out very small: thus the Big Bang idea





## Expansion Example



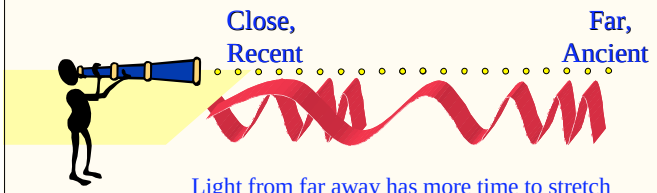
## Useful Analogies (and their limits)

- Balloon being inflated
  - good points:
    - if confined to surface, there is no center of expansion: each galaxy sees all others receding
    - "space" itself is what's expanding
    - can represent "closed" geometry
  - flaws:
    - little pictures of galaxies expand too, which is inaccurate
- Raisin Bread baking
  - good points:
    - raisins all move farther from each other as bread expands
    - 3-dimensional expansion of "space" (bread dough)
    - "galaxies" (raisins) themselves do not expand
  - flaws:
    - bounded; has edge; expands *into* environment





## Cosmic Expansion Redshifts Light




Light from far away has more time to stretch

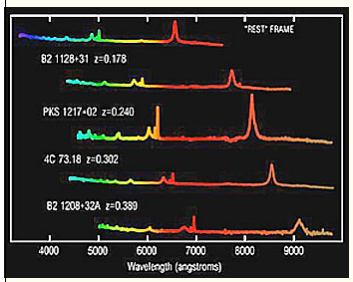
Light from nearby sources gets stretched less

Longer wavelength → redder light → far away light more *redshifted*





## Redshifts Illustrated




- Galaxies have identifiable (usually) unambiguous spectral features (from specific atoms) that serve as wavelength references
- These features get pushed out toward the red the farther away they are
- To the left are spectra of quasars (galaxies with active black holes) at a variety of redshifts
  - spectral features here are primarily from hydrogen and oxygen





## Hubble's Expansion Law

- The farther away the galaxy, the bigger the redshift
  - Redshift is often treated like a Doppler velocity
    - Apparent speed at which galaxy is "receding"
    - Receding truck on freeway sounds lower-pitched—same thing
  - Farther → "faster"
    - Hubble constant: 72±5 km/s per Megaparsec (Mpc)
      - a parsec is 3.26 light years: nearest star is 1.4 pc away
      - Andromeda Galaxy is almost a Mpc (million parsecs) away
  - Alternate form of redshift is $z = v/c$
    - Example: $v$ = 30,000 km/s recession is $z = 0.1$
    - Velocity breaks down for "high-z" ($z > 1$ implies faster than light)
      - $z = \Delta\lambda/\lambda$, where $\lambda$ is the wavelength of light, and $\Delta\lambda$ is the shift
      - Example: observe spectral feature at $\lambda$ = 484 nm, identified as an atomic line intrinsically at 121 nm, so $\Delta\lambda$ = 363 nm, and $z$ = 3.0

## References and Assignment

- **References**
  - http://rst.gsfc.nasa.gov/Sect20/A9.html
- **Assignments:**
  - Read supplement on Universe (access via Assignments page on course website)
  - Homework Exercises for *next* Friday (4/11):
    - Hewitt 1.R.15, 1.R.18, 1.E.7
    - Additional cosmology questions on course website
  - Question/Observation due 4/11 via WebCT