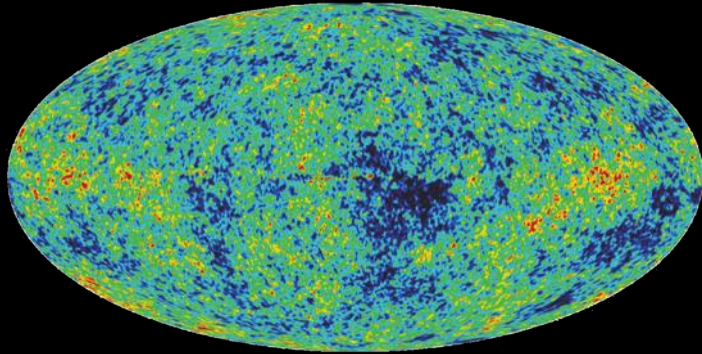


The Universe



The most incomprehensible thing about the universe is that it is comprehensible.

- Albert Einstein

(paraphrased from a 1936 journal article)

The Universe

Q: What is the Universe? How old is it? How big is it? What shape does it have? Where did it come from? Are we alone in it?

- **cosmogony**: study of the *origin* of the universe
- *cosmos* (“world, order”) + *gineo* (“birth”)
- **cosmology**: study of the *nature* of the universe
- *cosmos* (“world, order”) + *logia* (“study”)

How did it all begin?

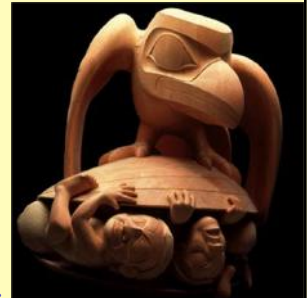
- have long *wondered about origin* of all we see

“In the beginning...”

“Verily, all things have we created in proportion and measure...”

And from the seed Brahma made the heavens and the Earth...

And Raven found man in a clamshell and brought him forth...



- our early attempts to explain "*how*"

Early Cosmology

- **cosmology** studies the *structure & evolution* of the universe using **science**

“Why is the night sky dark?”

- **Newton** believed in *infinite, uniform, unchanging universe*

- **The Steady State** or **Static Universe model**

Q: Why did Newton (& others!) believe this?



- *gravitational forces* between a **finite** number of *static* stars would *collapse* the universe

Q: With static model, how would night sky look?

- **sky** would be bright *everywhere* (eg) *trees in a dense forest*

- **not** what we observe at night!

- called **Olbers' Paradox** (1800's) but discussed by **Kepler** in 1600's



Q: If a model contradicts observation, then... ?

- the universe **must deviate from being infinite, uniform, and unchanging in some way...**

CLICKER: The core objection to Newton's Static Universe Model is that it... ?

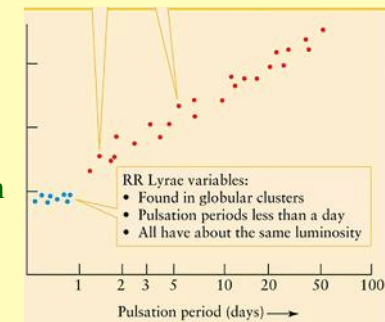
- (a) *required the universe to be too young*
- (b) *required infinitely many stars*
- (c) *disagreed with The Law of Gravitation*
- (d) *conflicted with observations of the night sky*

A Changing Universe?

- 1920's: **Edwin Hubble** used Mount Wilson Observatory to photograph *galaxies*

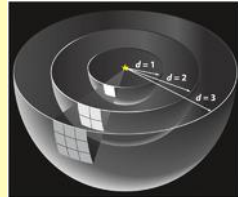
- in *Andromeda*, found special pulsating stars (**Cepheid variable**)

- **Cepheids** have known relationship between *true brightness* & *rate of pulsation*



- able to determine how bright they *really* are, *not just how bright they look to us from Earth*

- calculate *distance* to a *Cepheid* using its *true & apparent brightnesses*

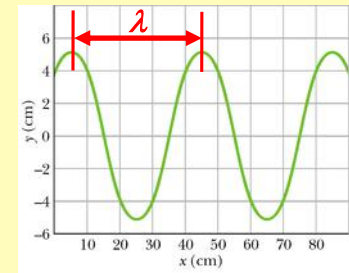
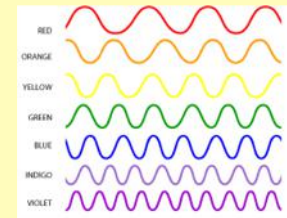


DEMO: flashlight intensity

- using *true brightness* \Rightarrow *distance to the star*
- distance to star is **also** distance to host galaxy
- **Hubble** showed *galaxies* are *far away*
- **first step** to show that the universe isn't *static*...

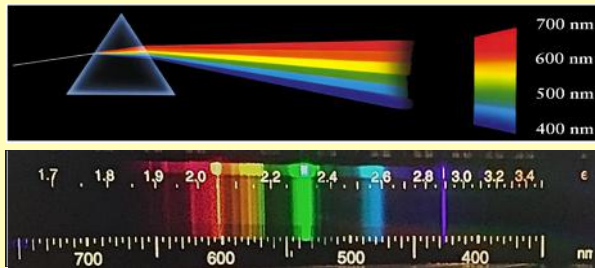
Light

- **light** is an *electromagnetic (EM) wave*
- **wavelength (λ):** distance from one peak to the next



EM Spectrum

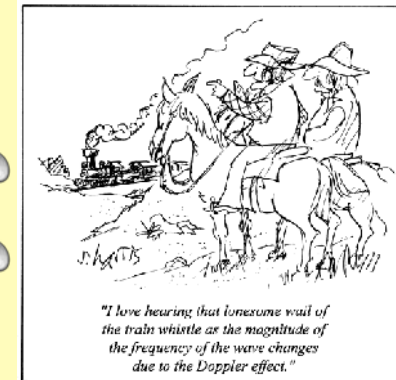
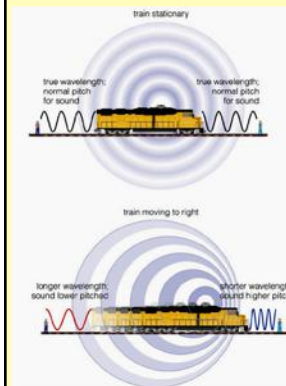
- **spectrum:** split light into *constituent wavelengths* (eg) a prism & ROYGBIV



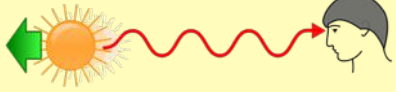
DEMO: spectra of sunlight, class lights

- **substances emit & absorb light in unique patterns**

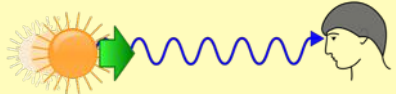
- **spectra of moving objects** are *Doppler shifted*



DEMO: doppler "ball" on a string



- **redshift**: observed wavelength *longer* than emitted; **receding source**



- **blueshift**: observed wavelength *shorter* than emitted; **approaching source**
- **faster motion** results in a **greater 'shift'**

Q: Why don't we notice visual doppler shift daily?

CLICKER: Given the "lab" measured spectra, which of the others represents the same spectra but emitted from a very rapidly **receding** galaxy?

LAB:



(a)



(b)



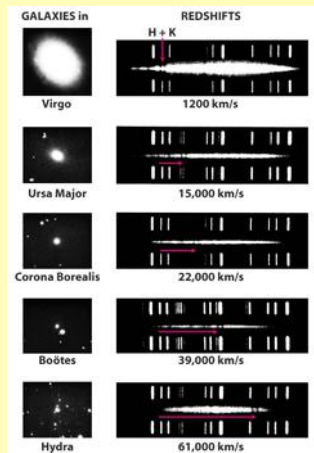
(c)



Hubble's Law

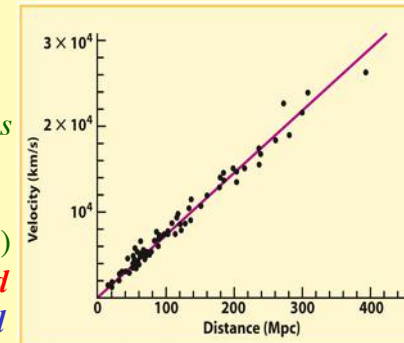
- **Hubble** also recorded galaxies' **spectra**
 - (almost) **all redshifted**
- Q: What does this tell us?*
- **spectra** yielded **speed**
 - **Cepheids** yielded **distance**
 - graphed **speed vs. distance**

Q: What shape might we expect for a graph like this?



- galaxies **recede** in **all** directions
- more **distant** galaxies **recede more quickly**

• **Hubble's Law** (1929) relates **recession speed** to **distance**: $v = H_0 \times d$



- **Hubble Constant** (H_0) is **slope of graph**
- H_0 is related to the **age of universe!**

• $H_0 \sim 70 \text{ km/s/Mpc} \pm 4\%$ (HST, 2019)

- law *does NOT* mean *all* galaxies are receding
- *clusters & close ones* do not obey *Hubble's Law*

- *Hubble's Law* implies *universe is expanding*

Q: Why can't galaxies be moving through a static universe instead?



- every expansion *has a beginning: The Big Bang*

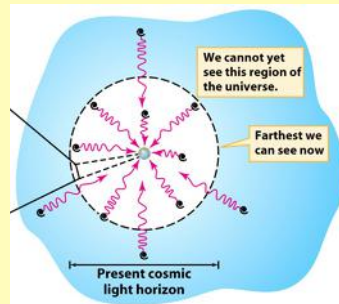
- if expansion uniform throughout space, $H_0=70$ km/s/Mpc implies *Big Bang ~ 14 billion years ago*

Resolving Olbers' Paradox

- if Universe *infinitely old & unchanging* we should see light *everywhere*; *we do not see this*
- Universe *is not* infinitely *old: had a beginning!*
- speed of light is *fast* (**1 billion km/h**) but *finite*
- *light has only had 14 billion years* to travel across space & so *we can only observe objects whose light has been able to reach us, i.e. within some distance*

- this *visible* region is our “*observable universe*”

- there are a *finite number* of galaxies & stars within *observable universe* so *we don't see light everywhere in the sky*



- in addition, *expansion of the universe stretches light* from distant galaxies to *longer wavelengths* & *spreads the light over an increasing volume* (*faint*)

Review: Cosmology

- “big” question: “*How did universe begin/evolve?*”
- *Static Universe* once believed to be most likely
- *Olbers' Paradox*: “*Why is night sky dark?*”
- *Hubble's* observations imply *expanding universe*
- *expansion* implies a *beginning: BB!*