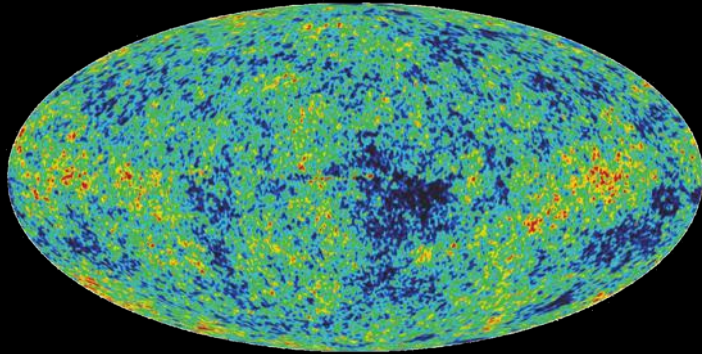


The Universe



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

- Albert Einstein

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

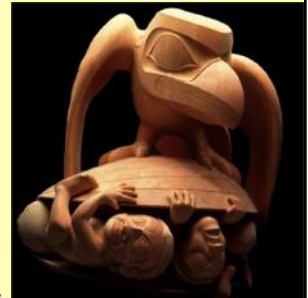
“In the beginning...”

*“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... ?

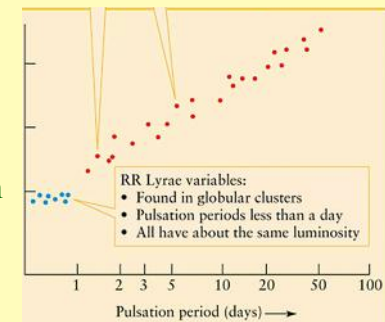
- (a) **required the universe to be too young**
- (b) **required infinitely many stars**
- (c) **disagreed with The Law of Gravitation**
- (d) **conflicted with observations of the night sky**

A Changing Universe?

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

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

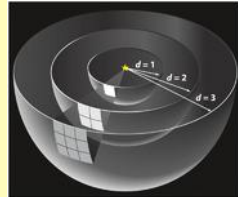
- **Cepheids** have known relationship between **true brightness** & **rate of pulsation**



- 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

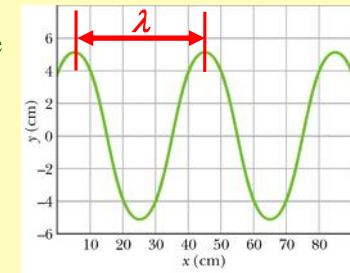
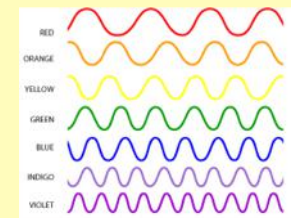


- using *true brightness* \Rightarrow *distance to the star*
- distance to star is **also** distance to host galaxy
- *Hubble* showed *galaxies* are *far away*
- *first step* to show that the universe isn't *static*...

Light

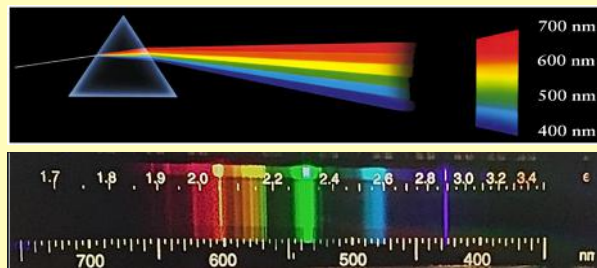
- *light* is an *electromagnetic (EM) wave*

- *wavelength (λ)*: distance from one peak to the next



EM Spectrum

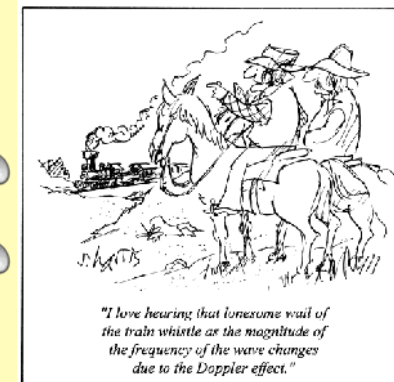
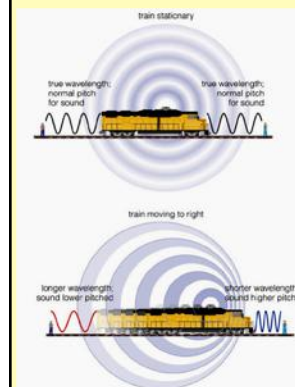
- *spectrum*: split light into *constituent wavelengths* (eg) a prism & ROYGBIV



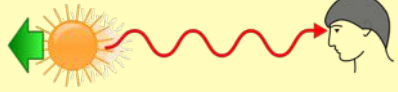
DEMO: spectra of sunlight, class lights

- *substances emit & absorb light in unique patterns*

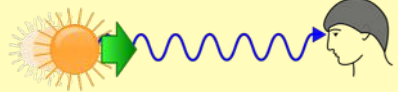
- *spectra of moving objects* are *Doppler shifted*



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?

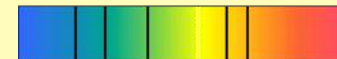
LAB:



(a)



(b)



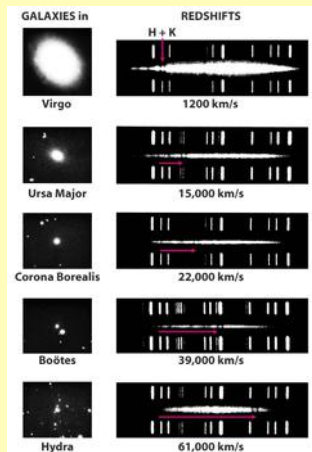
(c)



Hubble's Law

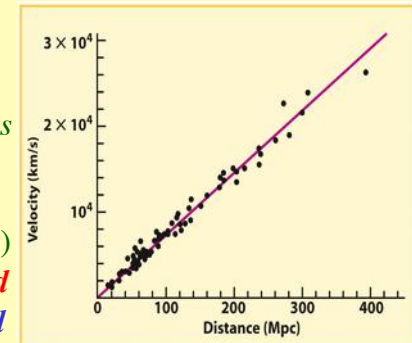
- **Hubble** also recorded galaxies' **spectra**
 - (almost) **all redshifted**
- Q:** What does this **tell** us?
- **spectra** yielded **speed**
 - **Cepheids** yielded **distance**
 - graphed **speed vs. distance**

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**!

• $H_0 \sim 74 \text{ km/s/Mpc} \pm 3\%$ (**HST, 2012**)

- 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?



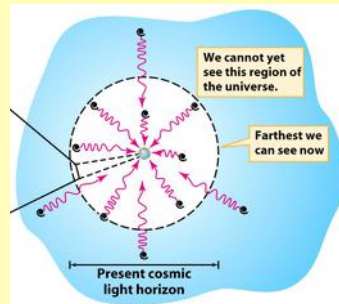
- an expansion *has a beginning: The Big Bang*
- if expansion uniform throughout space, $H_0=74$ km/s/Mpc implies *Big Bang ~ 14 billion years ago*

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* & also *spreads the light over an increasing volume*

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!*