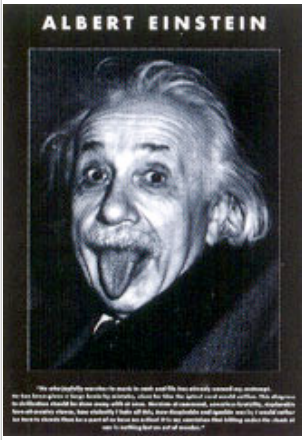
Physics 2D Lecture Slides
Lecture 3: Jan 5 2005

Vivek Sharma
UCSD Physics

Announcements

- Pl. make the following changes in the handout:
  - Final exam is Thursday, March 17 at 11:30am, location TBA
  - Tuesday lectures are in Peterson 110, NOT WLH2005 !
  - TA discussion hours are
    - Wednesday 1:00 pm at WLH 2216
    - Thursday 5:30 pm at WLH 2216
    - Best way to reach TA is to email him: crs@physics.ucsd.edu
- Pl. review material from 2A, 2B, 2C. Read chapters from your past course text ***Physics for Engineers and Scientists (3rd edition)*** by Wolfson and Pasachoff
    - 16 : Waves
    - 34 : Maxwell's Eqn and Electromagnetic Waves
    - 37: Interference and Diffraction
  - Take advantage of Physics Tutorial Center for unlimited drop-in tutoring, see *http://physics.ucsd.edu/students/courses/tutorialcenter/*

Einstein's Special Theory of Relativity



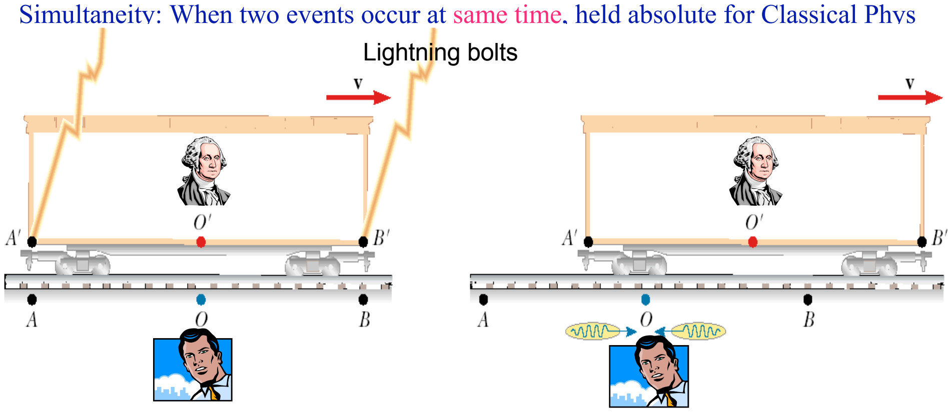
Einstein's Postulates

The laws of physics must be the same in all inertial reference frames

The speed of light in vacuum has the same value *c* = 3.0 x 108 m/s) , in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light

Consequences of Special Relativity: Simultaneity not Absolute

Simultaneity: When two events occur at same time, held absolute for Classical Phys

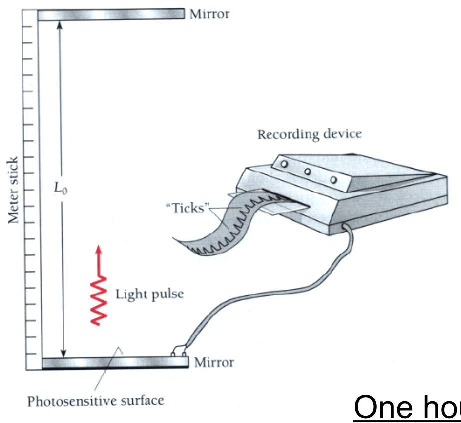


Events that are simultaneous for one Observer are not simultaneous for another Observer in relative motion

Simultaneity is not absolute !!

Time interval depends on the Reference frame it is measured in

A Simple Clock Measuring a Time Interval

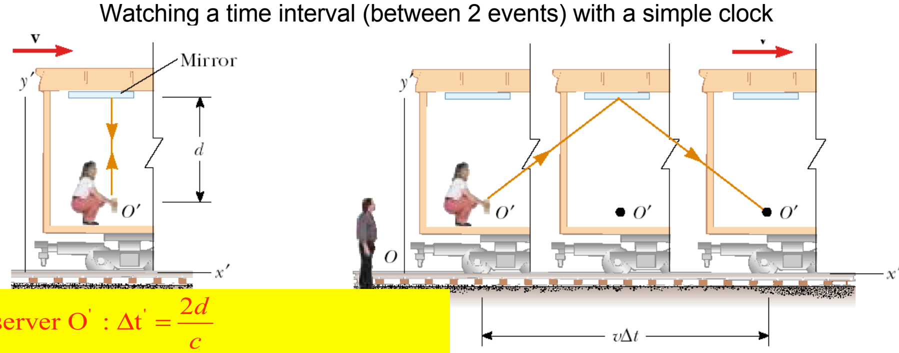


$$t = \int \Delta t$$

One hour = 60 x 1 minute time intervals

Time Dilation and Proper Time

Watching a time interval (between 2 events) with a simple clock



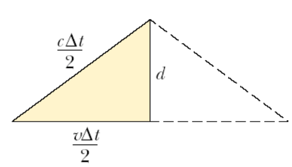
Observer O' : $\Delta t' = \dfrac{2d}{c}$

Observer O : Apply Pythogoras Theorem

$$\left(\frac{c\Delta t}{2}\right)^2 = (d)^2 + \left(\frac{v\Delta t}{2}\right)^2, \text{ but } d = \left(\frac{c\Delta t'}{2}\right)$$

$$\therefore \quad c^2(\Delta t)^2 = c^2(\Delta t')^2 + v^2(\Delta t)^2$$

$$\therefore \quad \Delta t = \frac{\Delta t'}{\sqrt{1-\left(\frac{v}{c}\right)^2}} = \gamma\, \Delta t', \; \Delta t > \Delta t'$$

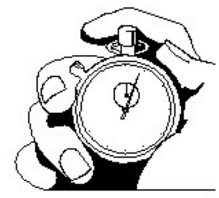


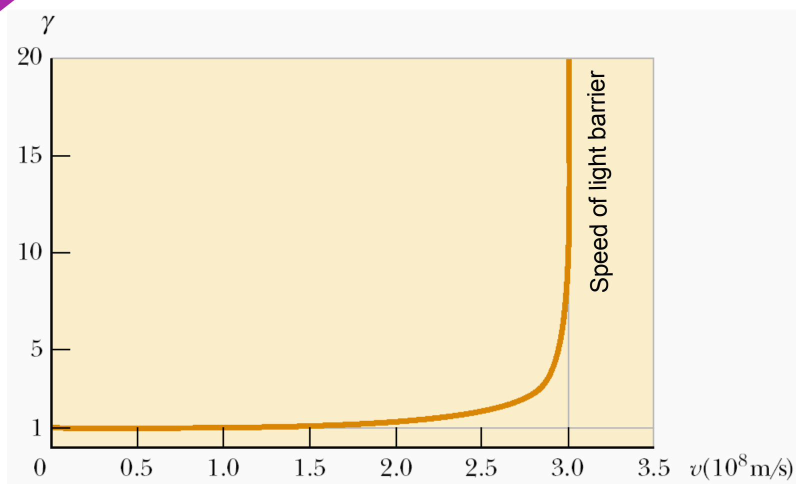
The γ factor

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

as $v \to 0,\ \gamma \to 1$

as $v \to c,\ \gamma \to \infty$





Pop Quiz !

- What happens when I reverse the clocks being watched ?
  - Sally now watches Sam's clock
  - Sally is moving w.r.t. Sam's clock. Sam is at rest w.r.t the clock.
  - What does she make of time intervals as measured by his clock ?

Measuring Time: Period of a Pendulum

- Period of a pendulum is 3.0 s in the rest frame of the pendulum
- What is period of the pendulum as seen by an observer moving at v=0.95c

Answer:

- Proper time T' = 3.0s
- Since motion is relative and time dilation does not distinguish between
  - relative motion →→ (V) from relative motion ← ← (-V)
- lets reformulate the problem like this (??)
  - A pendulum in a rocket is flying with velocity V =0.95c past a stationary observer
  - Moving clocks runs slower [w.r.t clock in observer's hand (rest)] by factor γ
  - → Period T measured by observer = γ T'

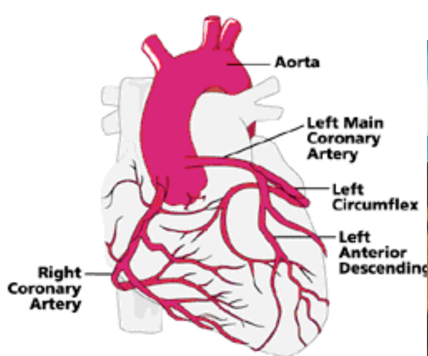
$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(0.95)^2}} = 3.2$$

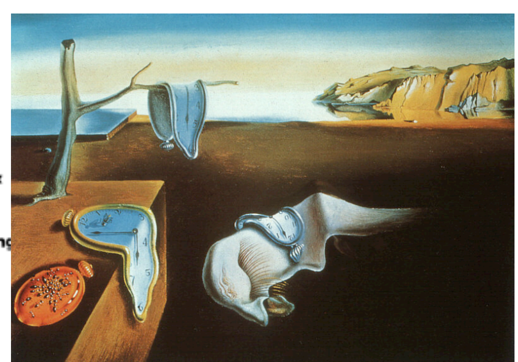
$$\Rightarrow T = \gamma T' = 3.2 \times 3.0s = 9.6s$$

Moving pendulum slows down → takes longer to complete a period

All Measures of Time Slow down from a Moving Observer's Perspective !

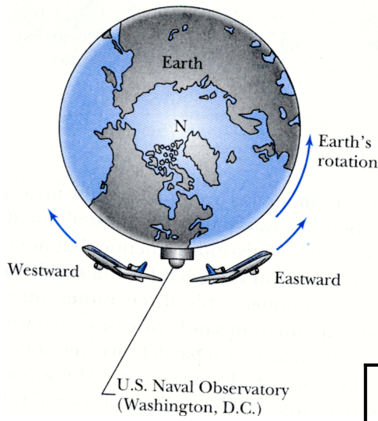
- Your heartbeat or your pulse





- Mitosis and Biological growth
- Growth of an inorganic crystal
- '...Watching the river flow''
- …all measures of time interval

Round The World With An Atomic Clock !

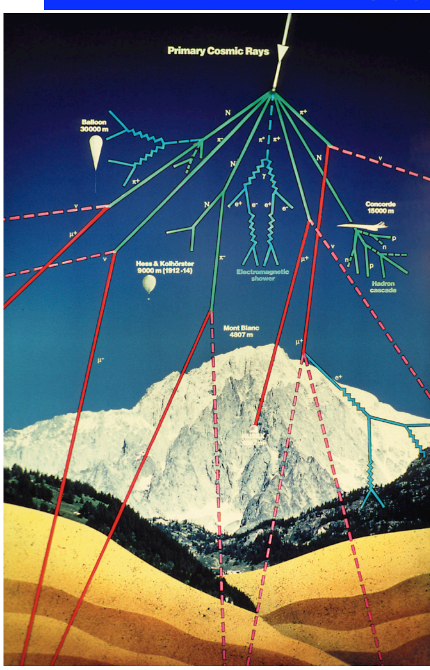


- Atomic Clock : measure time interval for certain atomic level transitions in Cesium atom
- Two planes take off from DC, travel east and west with the atomic clock
  - Eastward trip took 41.2 hrs
  - Westward trip took 48.6
- Atomic clocks compared to similar ones kept in DC
- Need to account for Earth's rotation + GR etc

Travel	Predicted	Measured
Eastward	-40 ± 23 ns	-59 ± 10 ns
Westward	275 ± 21 ns	273 ± 7 ns

Flying clock ticked faster or slower than reference clock. Slow or fast is due to Earth's rotation

Cosmic Rain !



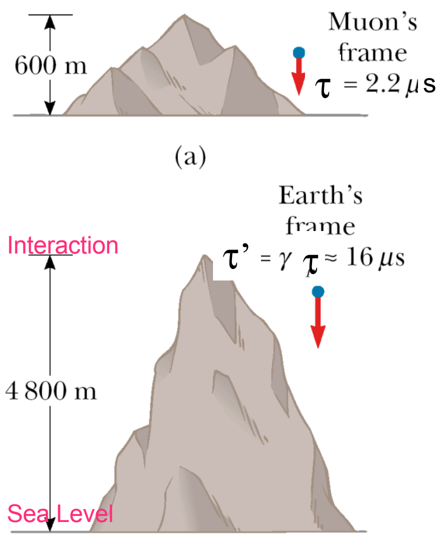
- Cosmic "rays" are messengers from space
- **Produced in violent collisions in the cosmos**
- **Typical Kinetic energy ~ 100 GeV**
- **Smash into Earth's outer atmosphere**
  - **4700 m from sea level**
- **Sometimes produce short lived Muons (μ)**

- **Muon is electron like charged particle**
  - **~ 200 times heavier , same charge**
  - **Lifetime τ= 2.2μs = 2.2 x10^{-6} s**
  - **Produced with speed v ≡ c**
  - **Distance traveled in its lifetime**

$$d = c\tau = 650m$$

  - **Yet they seem to reach the surface!!**
    - **Why => Time Dilation**
    - **Must pay attention to frames of references involved**

Cosmic Rays Are Falling On Earth : Example of Time Dilation



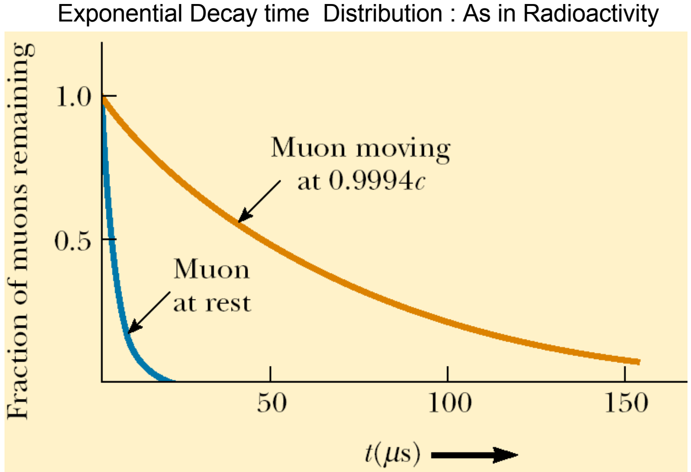
- Consider Two frames of references
  1. You Riding on the Muon Particle
  2. Your twin watching On surface of earth
- Muon Rider has "Proper Time"
  - Time measured by observer moving along with clock
  - $\Delta t' = \tau = 2.2\mu S$
  - $D' = v\,\Delta t' = 650m$
- Earthling watches a moving clock (muon's) run slower
  - $\Delta t' = \gamma\tau$
    - $v = 0.99c, \Rightarrow \gamma = 7.1$
    - $D = v\,\Delta t = 4700m$

Muon Decay Distance Distribution

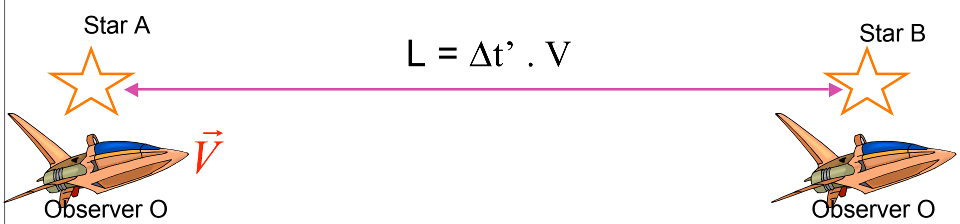
Relative to Observer on Earth Muons have a lifetime

$$t = \gamma\tau = 7.1\ \tau$$

Exponential Decay time Distribution : As in Radioactivity



Offsetting Penalty : Length Contraction



$L = \Delta t' \,.\, V$

$\vec{V}$

$\Delta t'$

$\Delta t = L'/V$

Observer O'
At rest w.r.t stars A & B
Watches rocketship cross from
Star A to Star B in time Δt

Rocketman Vs The Earthling

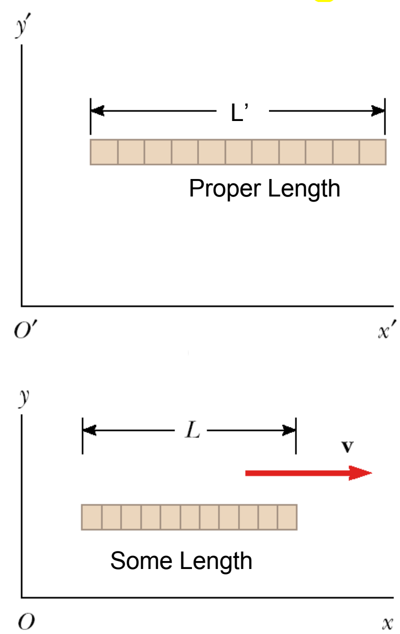
- Earth Observer saw rocketman take time $\Delta t = (L'/V)$
- Rocketman says he is at rest, Star B moving towards him with speed V from right passed him by in time $\Delta t'$, so
  - $L = \Delta t' . V$
  - But $\Delta t' = \Delta t / \gamma$ (time dilation)
  - $\Rightarrow L = V. (\Delta t/ \gamma)$

    $= L'/\gamma$

$$L = L'.\sqrt{1-\frac{V^2}{c^2}}$$

$$L \leq L'$$

Moving Rods Contract in direction
Of relative motion



Immediate Consequences of Einstein's Postulates: Recap

- Events that are simultaneous for one Observer are not simultaneous for another Observer in relative motion
- Time Dilation : Clocks in motion relative to an Observer appear to slow down by factor γ
- Length Contraction : Lengths of Objects in motion appear to be contracted in the direction of motion by factor γ^{-1}
- New Definitions :
  - Proper Time (who measures this ?)
  - Proper Length (who measures this ?)
  - Different clocks for different folks !

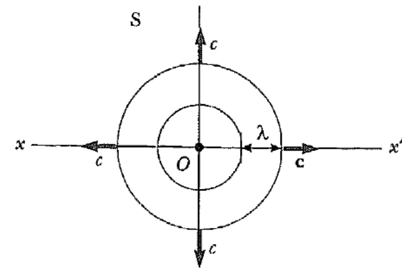
Doppler Effect In Sound : Reminder from 2A

Observed Frequency of sound INCREASES if emitter moves towards the Observer
Observed Wavelength of sound DECREASES if emitter moves towards the Observer

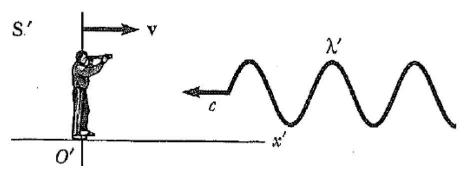
$$v = f\,\lambda$$

Time Dilation Example: Relativistic Doppler Shift

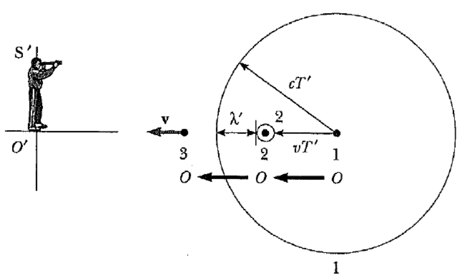
- Light : velocity c = f λ, f=1/T
- A source of light S at rest
- Observer S'approches S with velocity v
- S' measures f' or λ', c = f'λ'
- Expect f' > f since more wave crests are being crossed by Observer S'due to its approach direction than if it were at rest w.r.t source S



(a)



Relativistic Doppler Shift



Examine two successive wavefronts emitted by S at location 1 and 2

In S' frame, T' = time between two wavefronts

In time T', the Source moves by cT' w.r.t 1

Meanwhile Light Source moves a distance vT'

Distance between successive wavefront

λ' = cT' – vT'

λ'=cT'-vT', now use $f = c / \lambda$

$$\Rightarrow f' = \frac{c}{(c-v)T'} \;, \; T' = \frac{T}{\sqrt{1-(v/c)^2}}$$

Substituting for T', use f = 1/T

$$\Rightarrow f' = \frac{\sqrt{1-(v/c)^2}}{1-(v/c)}$$

$$\Rightarrow f' = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}} \; f$$

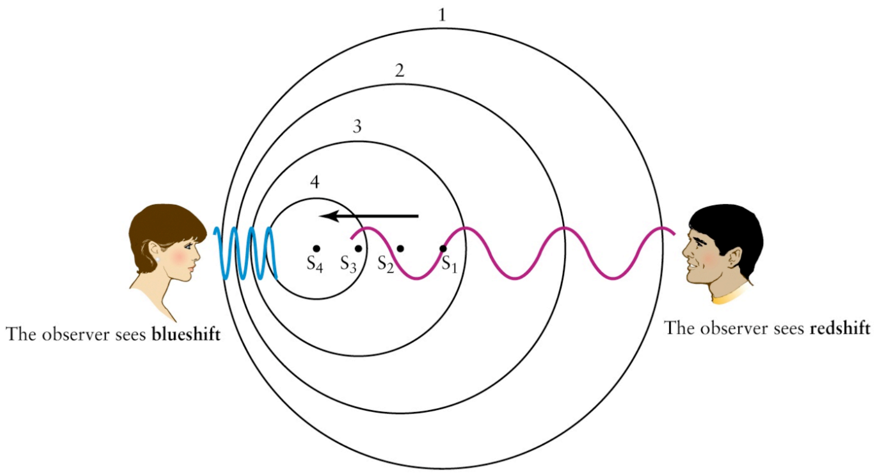
better remembered as:

$$f_{obs} = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}} \; f_{source}$$

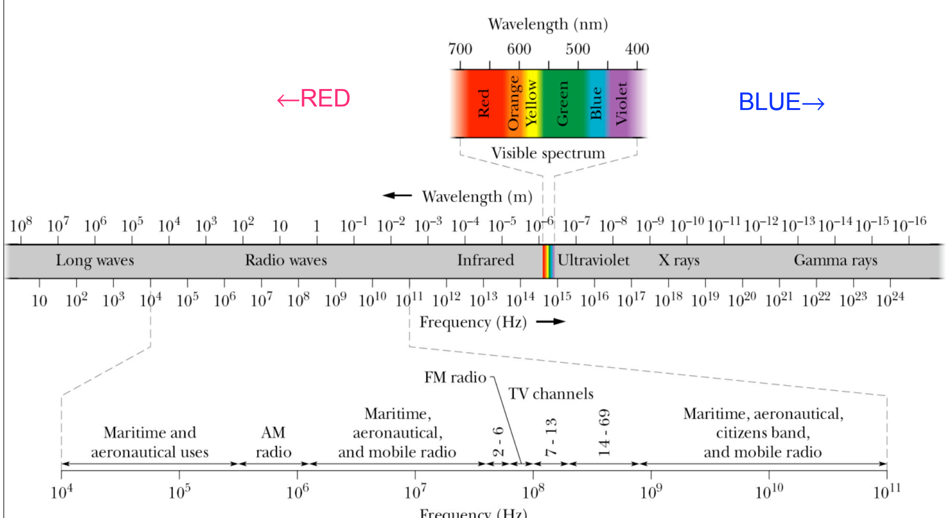
f_{obs} = Freq measured by observer approching light source

Relativistic Doppler Shift

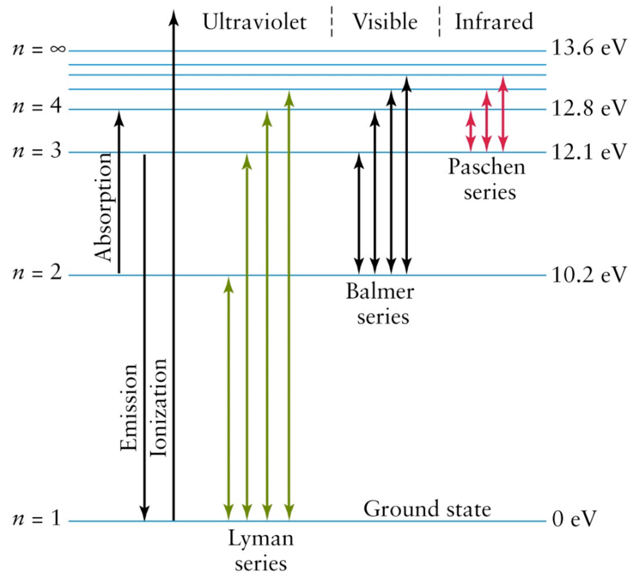
$$f_{obs} = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}}\ f_{source}$$



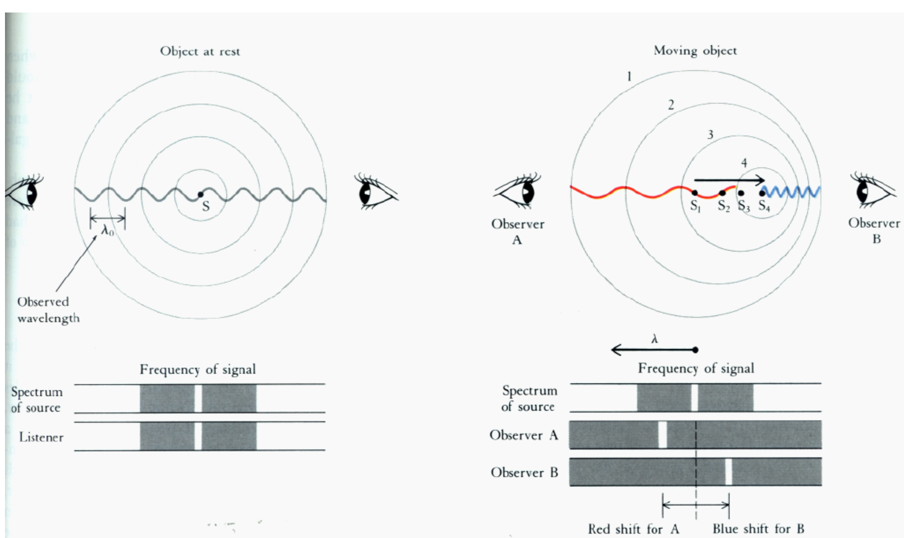
Doppler Shift & Electromagnetic Spectrum



Fingerprint of Elements: Emission & Absorption Spectra



Spectral Lines and Perception of Moving Objects



Doppler Shift in Spectral Lines and Motion of Stellar Objects

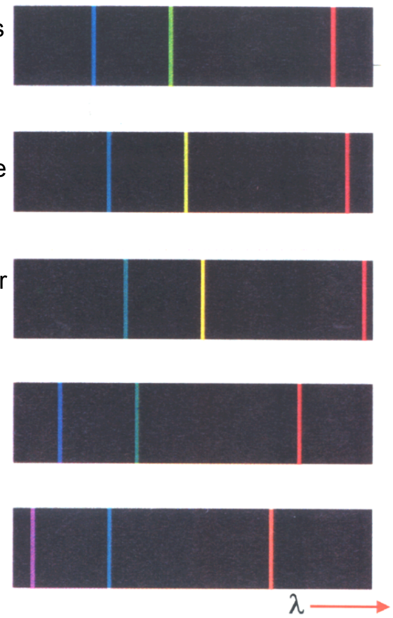
Laboratory Spectrum, lines at rest wavelengths

Lines Redshifted, Object moving away from me

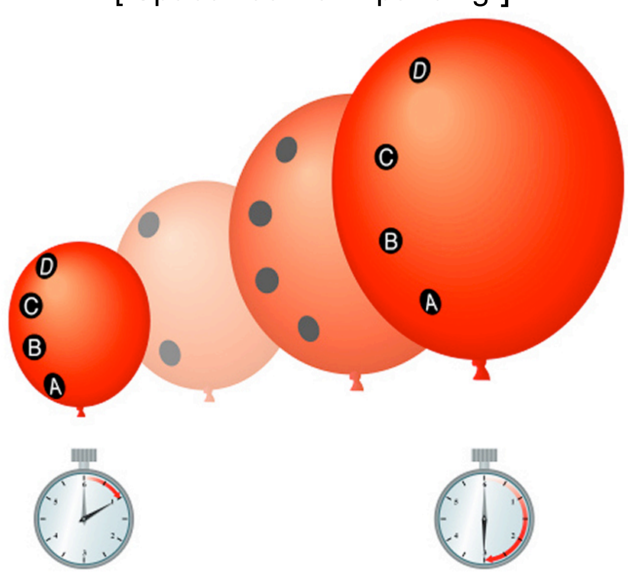
Larger Redshift, object moving away even faster

Lines blueshifted, Object moving towards me

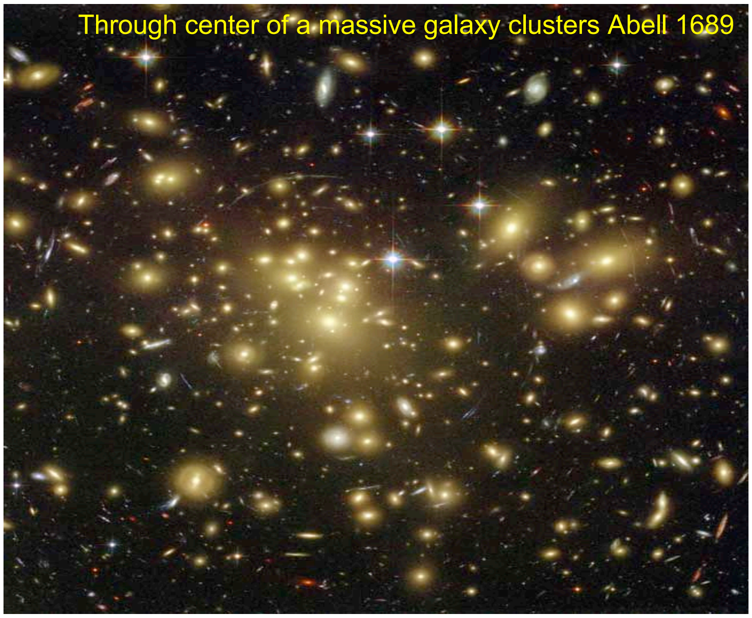
Larger blueshift, object approaching me faster



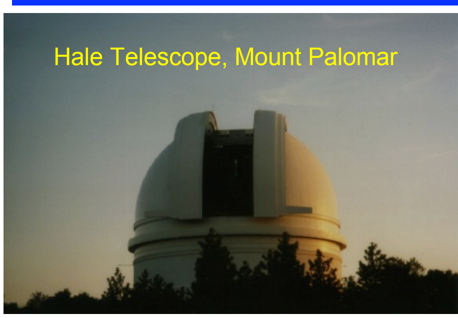
Cosmological Redshift & Discovery of the Expanding Universe:
[Space itself is Expanding]

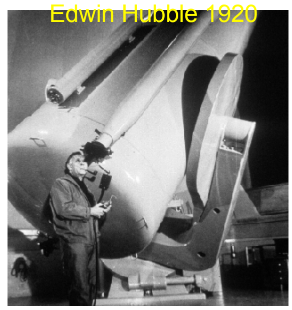


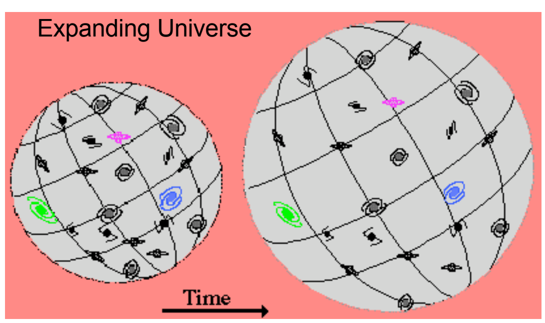
Seeing Distant Galaxies Thru Hubble Telescope



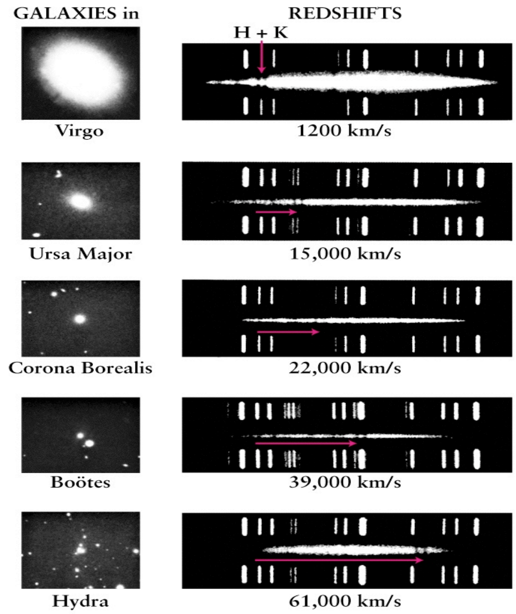
Expanding Universe, Edwin Hubble & Mount Palomar







Galaxies at different locations in our Universe travel at different velocities



Hubble's Measurement of Recessional Velocity of Galaxies

V = H d : Farther things are, faster they go