Physics 2D Lecture Slides
Lecture 5: Jan 10 2005

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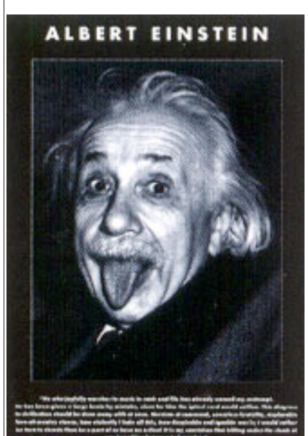
Announcements

- 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/*

First Quiz This Friday !

- Bring a Blue Book, calculator; check battery
  - Make sure you remember the code number for this couse given to you (record it some place safe!)
- No “cheat Sheet” please, I will give you equations and constants that I think you need
- When you come for the quiz, pl. occupy seats in the front first.
- Pl. observe one seat distance in the back rows (there is plenty of space)
- Academic Honesty is for you to observe and for me to enforce:
  - Be a good citizen, in this course and forever !

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

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 !

Contrived Paradoxes of Relativity

A paradox is an apparently self-contradictory statement, the underlying meaning of which is revealed only by careful scrutiny. The purpose of a paradox is to arrest attention and provoke fresh thought

``A paradox is not a conflict within reality. It is a conflict between reality and your feeling of what reality should be like.''

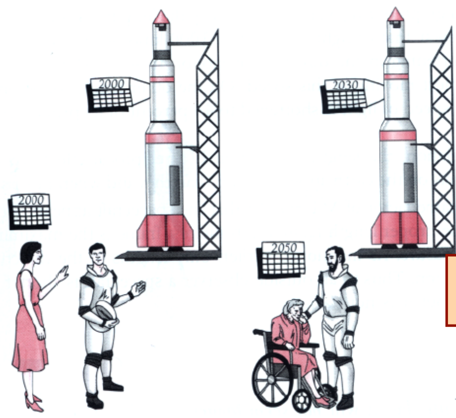
– Richard Feynman

Now We Construct a few paradoxes in Relativity & analyze them

Jack and Jill's Excellent Adventure: Twin Paradox

Jack & Jill are 20 yr old twins, with same heartbeat
Jack takes off with V = 0.8c = (4/5)c to a star
20 light years away.

Jill stays behind, watches Jack by telescope. They
Eventually compare notes



Jill sees Jack's heart slow down compared to her by the factor :

$$\sqrt{1-(v/c)^2}$$
$$= \sqrt{1-(0.8c/c)^2} = 0.6$$

For every 5 beats of her heart
She sees Jack's beat only 3 !

Jack has only 3 thoughts for 5 that Jill has ! .....Every things slows!

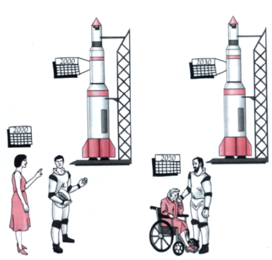
Finally Jack returns after 50 yrs gone by according to Jill's calendar

Only 30 years have gone by Jack's calendar
SO Jack is 50 years old but Jane is 70 !

Where is the paradox ??

Twin Paradox ?

- Paradox : Turn argument around, motion is relative. Look at Jack's point of view !
- Jack claims he at rest, Jill is moving v=0.8c
- Should not Jill be 50 years old when 70 year old Jack returns from space Odyssey?



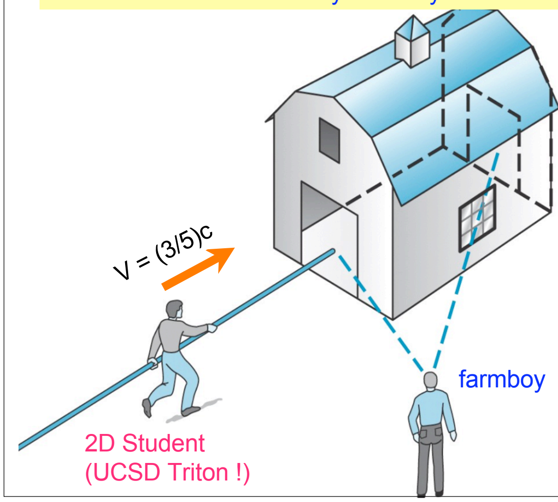
No ! ...because Jack is not always traveling in a inertial frame of reference
TO GET BACK TO EARTH HE HAS TO TURN AROUND => decelerate/accelerate
But Jill always remained in Inertial frame
Time dilation formula valid for Jill's observation of Jack but not to Jack's observation of Jill !!....remember this always

Non-symmetric aging verified with atomic clocks taken on airplane trip around world and compared with identical clock left behind. Observer who departs from an inertial system will always find its clock slow compared with clocks that stayed in the system

Fitting a 5m pole in a 4m Barnhouse ?

Student attends 2D lecture (but does no HW) …so is banished to a farm in Iowa !
Meets a farmboy who is watching 2D lectures online. He does not do HW either!

There is a Barn with 2 doors 4m apart ; There is a pole with proper length = 5m
Farm boy goads the student to run fast and fit the 5m pole within 4m barn
The Triton tells the farmboy: "Dude you are nuts!" …who is right and why ?



Sequence of Events

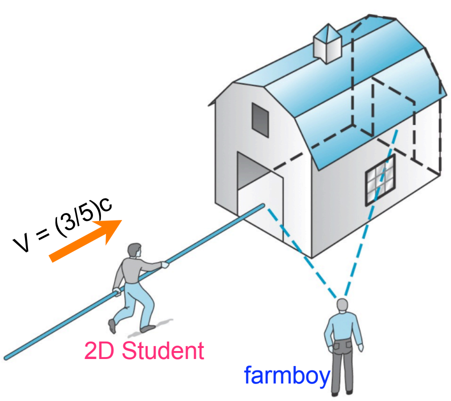
A: Arrival of right end of pole at left end of barn

B: Arrival of left end of pole at left end of barn

C: Arrival of right end of pole at right end of barn

Think Simultaneity !

Fitting a 5m pole in a 4m Barnhouse ?!!



Student with pole runs with v=(3/5)c
farmboy sees pole contraction factor
$\sqrt{1-(3c/5c)^2} = 4/5$
says pole just fits in the barn fully!

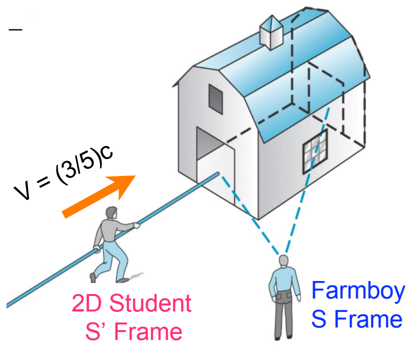
Student with pole runs with v=(3/5)c
Student sees barn contraction factor
$\sqrt{1-(3c/5c)^2} = 4/5$
says barn is only 3.2m long, too short to contain entire 5m pole !

Farmboy says "You can do it"
Student says "Dude, you are nuts"

Is there a contradiction ? Is Relativity wrong?

Homework: You figure out who is right, if any and why.
Hint: Think in terms of observing three events

Fitting a 5m pole in a 4m Barnhouse?



Let S = Barn frame, S' = student frame

Event A : arrival of right end of pole at left end of barn: (t =0, t'=0) is reference

L'_0 = proper length of pole in S'

l_0 = length of barn in S frame $< L'_0$

In S: length of pole $L = L'_0\sqrt{1-(v/c)^2}$

The times in two frames are related:

$$t'_B = \frac{l'}{v} = \frac{l_0}{v}\sqrt{1-(v/c)^2} = t_{BC}\sqrt{1-(v/c)^2}$$

$$t'_C = \frac{L'_0}{v} = \frac{l'}{v}\frac{1}{1-(v/c)^2} = \frac{t_{BC}}{\sqrt{1-(v/c)^2}}$$

$\Rightarrow$ Time gap in S' by which events B and C fail to be simultaneous

Simultaneity Required !

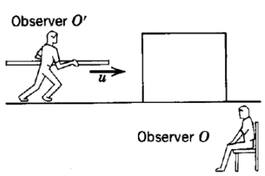
Events

B: Arrival of left end of pole at left end of barn

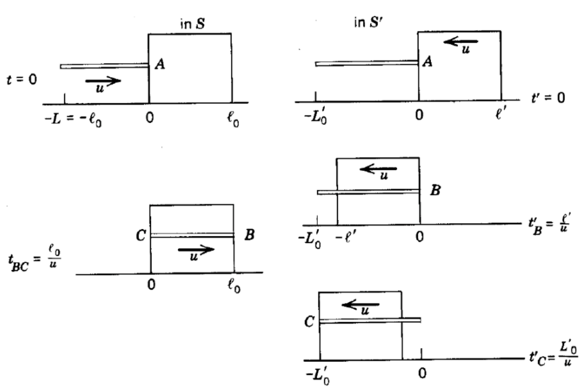
C: Arrival of right end of pole at right end of barn

Farmboy sees two events as simultaneous
2D student can not agree
Fitting of the pole in barn is relative !

Farmboy Vs 2D Student

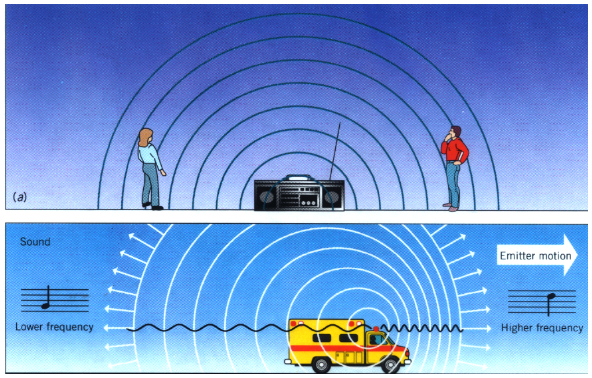


Pole and barn are in relative motion u such that lorentz contracted length of pole = Proper length of barn



In rest frame of pole, Event B precedes C

Doppler Effect In Sound : Reminder from 2A

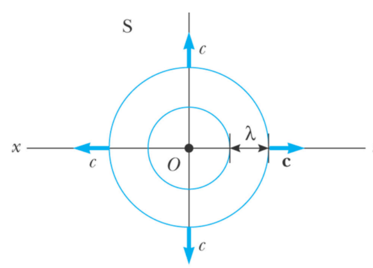


Observed Frequency of sound INCREASES if emitter moves towards the Observer
Observed Wavelength of sound DECREASES if emitter moves towards the Observer

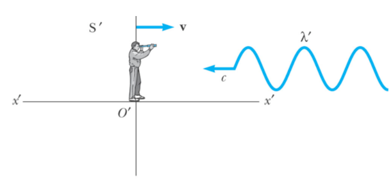
$$v = f\,\lambda$$

Time Dilation Example: Relativistic Doppler Shift

- Light : velocity $c = f\,\lambda, f=1/T$
- A source of light S at rest
- Observer S'approches S with velocity v
- S' measures f' or λ', $c = f'\lambda'$
- 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

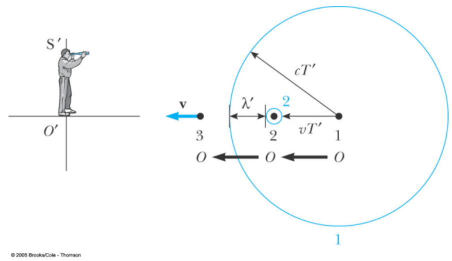


(a)



(b)

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
$\lambda' = cT' - vT'$

$\lambda' = cT' - vT'$, now use $f = c/\lambda$

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

Substituting for T', use f = 1/T

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

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

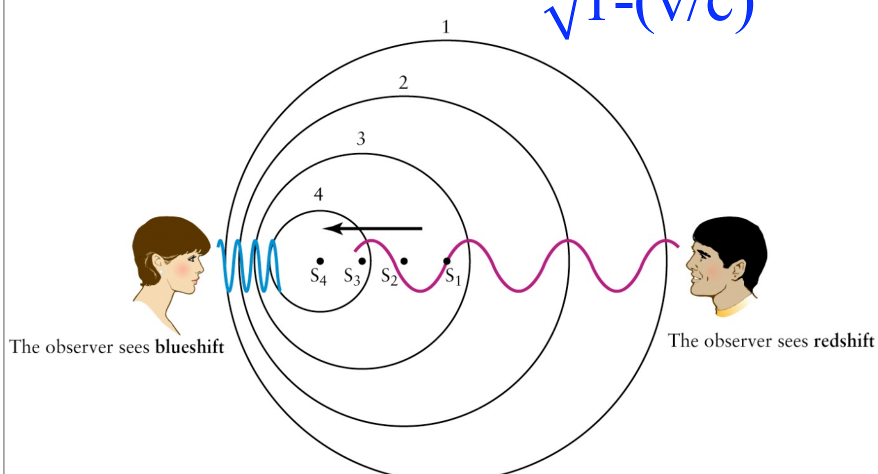
better remembered as:

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

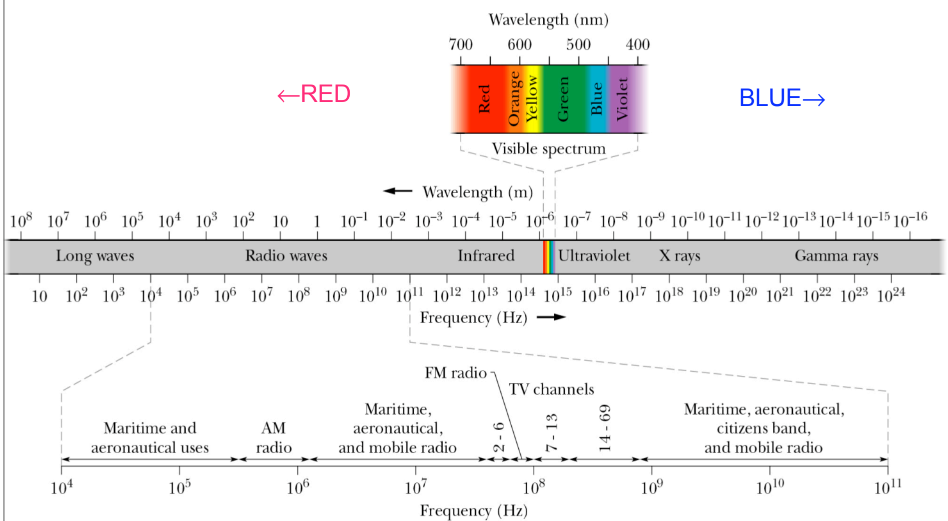
f_{obs} = Freq measured by observer approching light source

Relativistic Doppler Shift

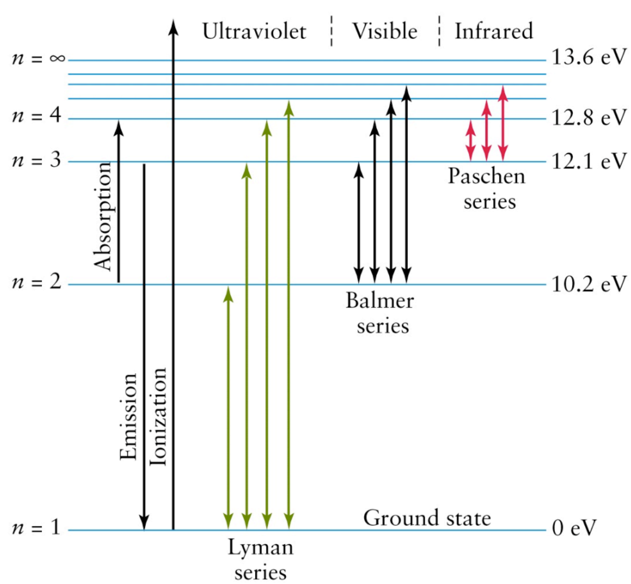
$$f_{obs} = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}} f_{source}$$



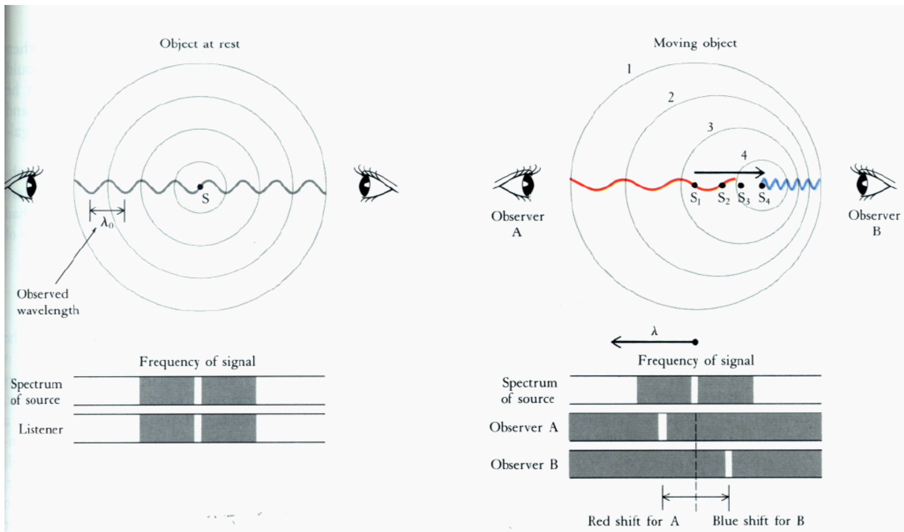
Doppler Shift & Electromagnetic Spectrum



Fingerprint of Elements: Emission & Absorption Spectra



Spectral Lines and Perception of Moving Objects



Doppler Shift in Spectral Lines and Motion of Stellar Objects

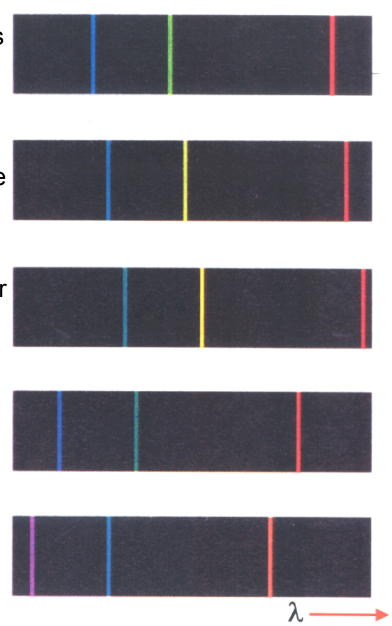
Laboratory Spectrum, lines at rest wavelengths

Lines Redshifted, Object moving away from me

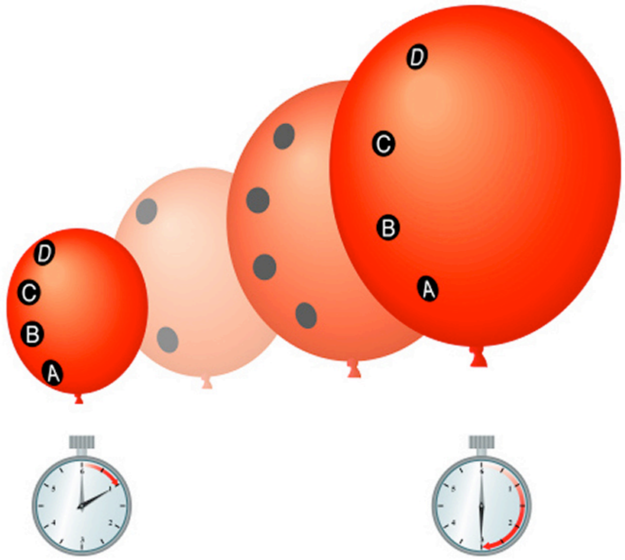
Larger Redshift, object moving away even faster

Lines blueshifted, Object moving towards me

Larger blueshift, object approaching me faster

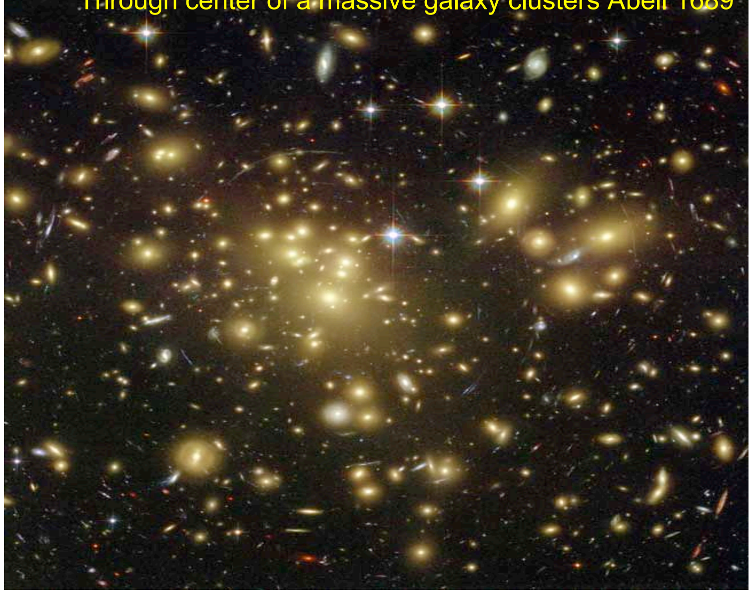


Cosmological Redshift & Discovery of the Expanding Universe:
[Space itself is Expanding]

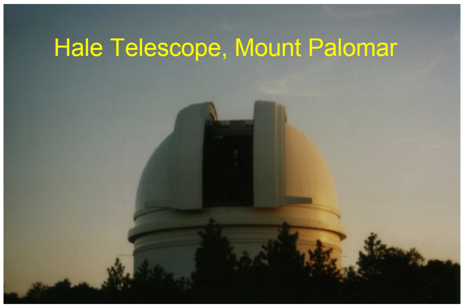


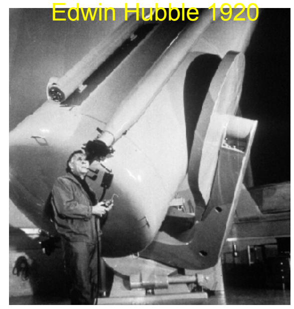
Seeing Distant Galaxies Thru Hubble Telescope

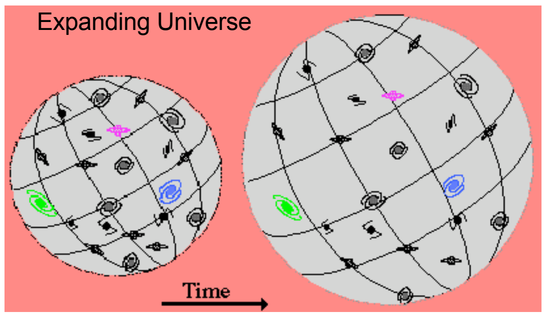
Through center of a massive galaxy clusters Abell 1689



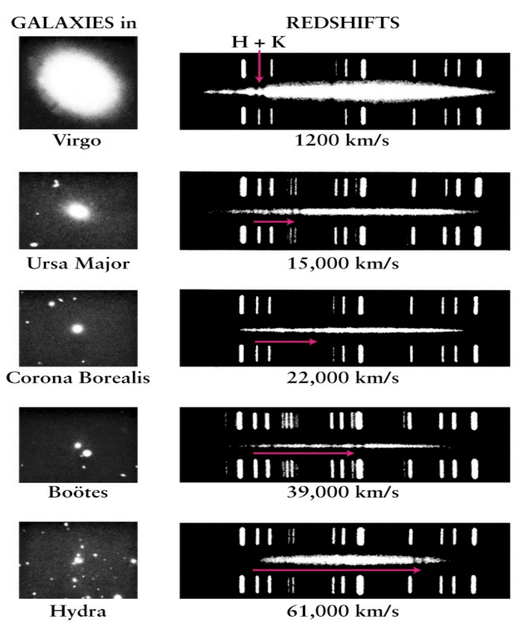
Expanding Universe, Edwin Hubble & Mount Palomar







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