Welcome back to PHY 3305

Today's Lecture:

Doppler Shift

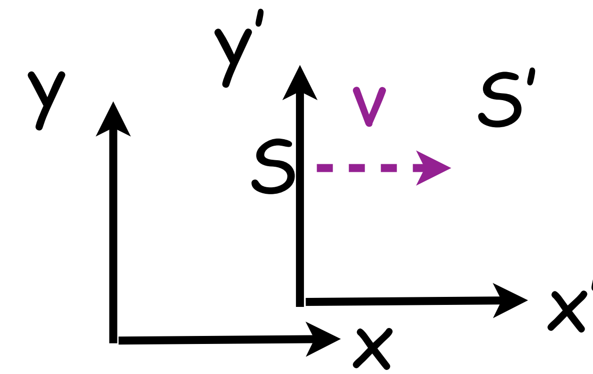
Velocity Tranformations

Christian Doppler
1803-1853

Last Time:

THE LORENTZ TRANSFORMATIONS

We can use γ to write our transformations.



Lorentz Factor:

$$\gamma_\nu \equiv \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

Frame S:

$$x' = \gamma_\nu(x - vt) \quad t' = \gamma_\nu(-\frac{v}{c^2}x + t)$$

Frame S':

$$x = \gamma_\nu(x' + vt') \quad t = \gamma_\nu(\frac{v}{c^2}x' + t')$$

Last Time:

Proper time is the time measured in the frame where all events occur in the same location **in that frame**.

$$\Delta t = \gamma_\nu \Delta t_0$$

t_0 is the time difference in the frame in which the events occur at the same location

Proper length is the length measured in a frame where the object being measured is at rest, so that it doesn't matter WHEN we measure the end points.

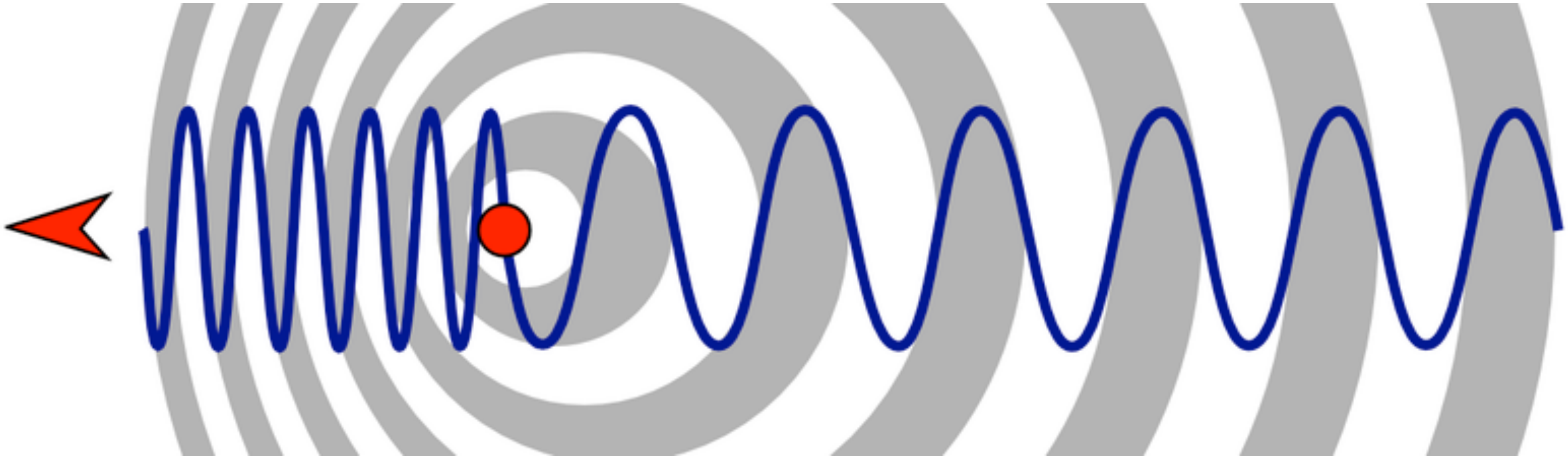
$$L = \frac{L_0}{\gamma_v}$$

L_0 is measured in the frame where the object is at rest.

What is the Doppler Effect?

In classical physics sound experiences a shift in pitch (frequency shift) when the sound source is moving relative to the observer.

Classic example: Police Siren appears to go up in pitch as it approaches you and down in pitch as it goes away.



Doppler Shift in frequency

The source (S') is moving relative to the observer (S).

$$\Delta t = \Delta t' + \frac{v}{c_{sound}} \Delta t' \quad \rightarrow f \equiv \frac{1}{\Delta t}$$

additional time to travel to observer.

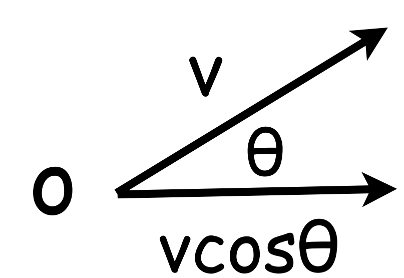
$$f = \frac{f'}{(1 + \frac{v}{c_{sound}})}$$

-v = source moves towards listener

+v = source moves away from listener

What if the source is moving at an angle to the listener?

$$f = \frac{f'}{(1 + \frac{v}{c_{sound}} \cos\theta)}$$



Does the same happen for light?

The source (S') is moving relative to the observer (S).

Yes! But we must apply special relativity.

$$\Delta t' \rightarrow \gamma_\nu \Delta t' \rightarrow \frac{f'}{\gamma_\nu}$$

$$f = f' \frac{\sqrt{1 - \frac{v^2}{c^2}}}{\left(1 + \frac{v}{c}\cos\theta\right)}$$

Assuming that the source is moving away/towards (not at an angle) this can be simplified (exercise for the student).

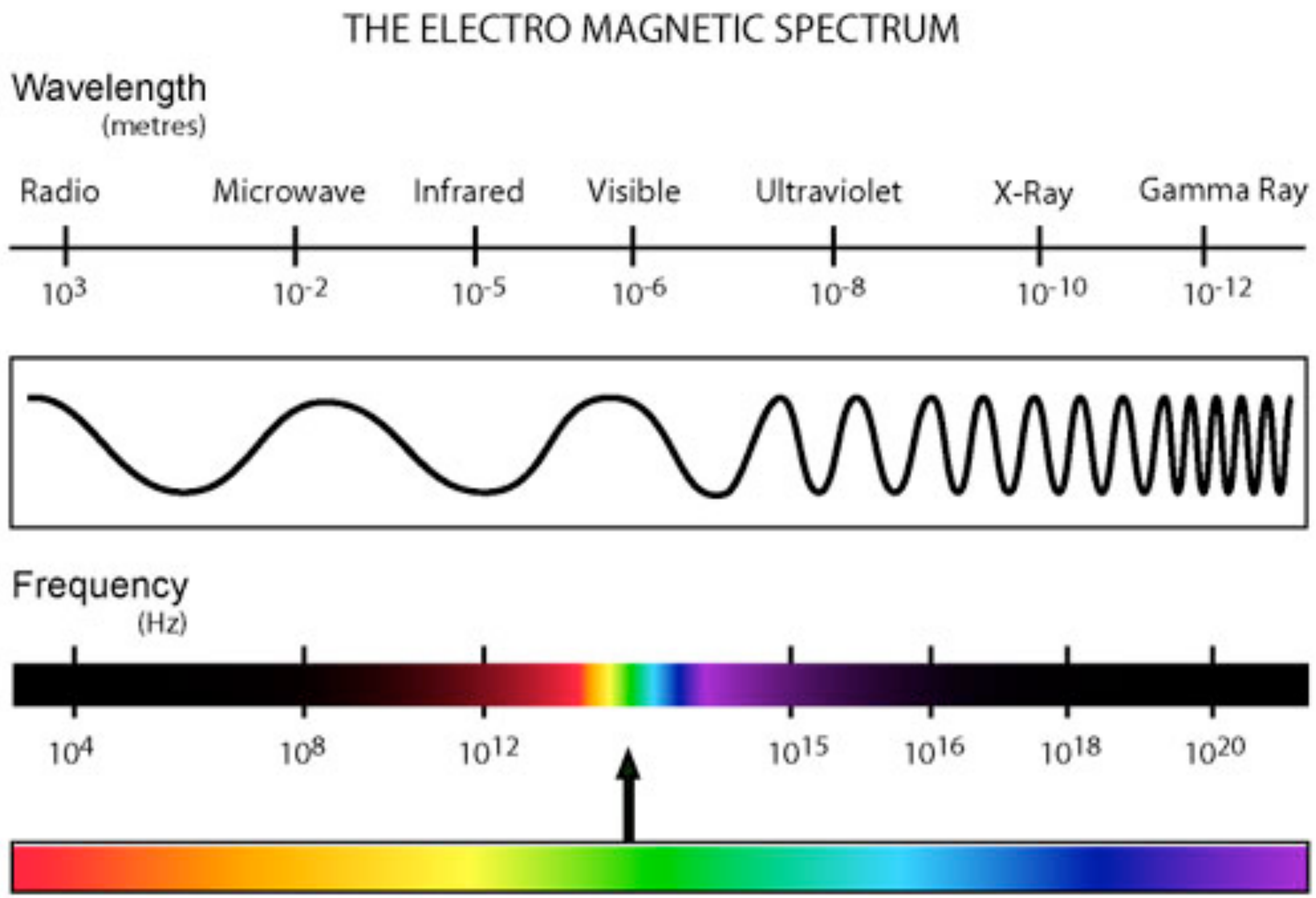
away:

$$f = f' \sqrt{\frac{1 - \frac{v}{c}}{1 + \frac{v}{c}}}$$

towards:

$$f = f' \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$$

Implications:



Classical Physics:

- Light from a source moving away from an observer is redshifted.
- Light from a source moving towards an observer is blueshifted.

Implications:

Modern Physics:

- All objects are redshifted because time moves more slowly (time dilation) for the moving source. The slowed movement lowers the light frequency.
- Small effect which is outweighed by the movement of the source.

REDSHIFT PARAMETER

We know there is a relationship between the velocity at which a celestial object moves away from us and the change in the wavelength of the light it emits.

Astronomers use the **redshift parameter (z)** to describe this change in wavelength.

$$z \equiv \frac{\lambda_{obs} - \lambda'}{\lambda'}$$

If $z > 0$ the object is receding.

2011 Nobel Prize in Physics

From the nobel prize website:
http://www.nobelprize.org/nobel_prizes/physics/laureates/2011/

The Nobel Prize in Physics 2011 was awarded "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae" with one half to Saul Perlmutter and the other half jointly to Brian P. Schmidt and Adam G. Riess.

For more information:
http://www.npr.org/templates/story/story.php?storyId=141031259

SAUL PERLMUTTER: SMU HONORARY DEGREE RECIPIENT (2010)

- Perlmutter was cofounder of the Supernova Cosmology Project which devised methods in 1988 to use distant supernova to measure the expansion of the universe.

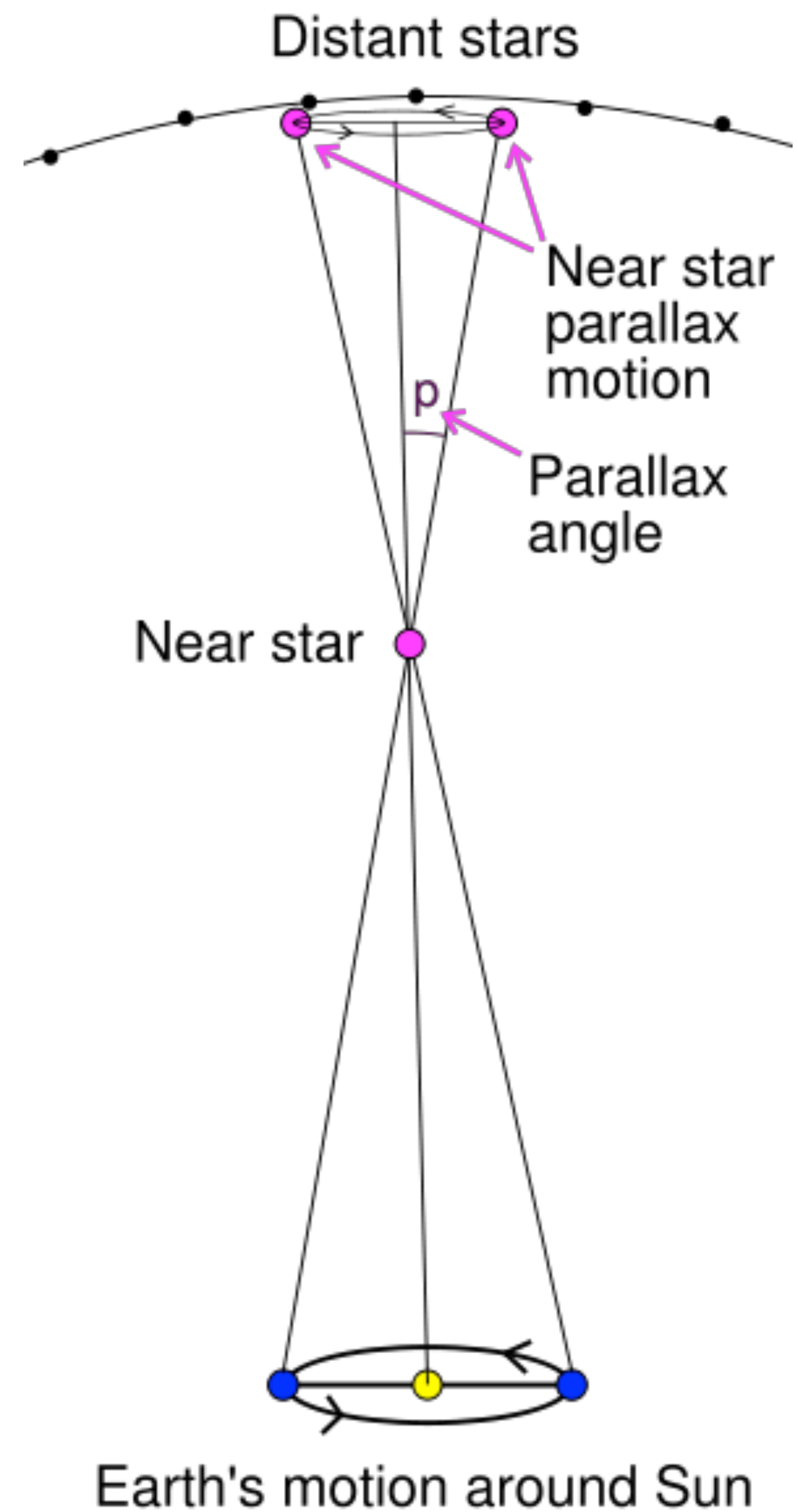
- Schmidt and Reiss where leaders of the High-Z Supernova research team which also used distant supernova to measure the expansion of the universe.

COSMIC DISTANCES

LIDAR: Objects close to us (moon) can be measured using LIDAR. Basic idea - bounce light off an object using a laser. Measure the round trip time of light to travel and then calculate the distance.

COSMIC DISTANCES

Geometry: For objects further away (nearby stars), we use trigonometric Parallax (triangulation).



COSMIC DISTANCES

Standard Candle:

An object of known brightness that can be seen from very far away.

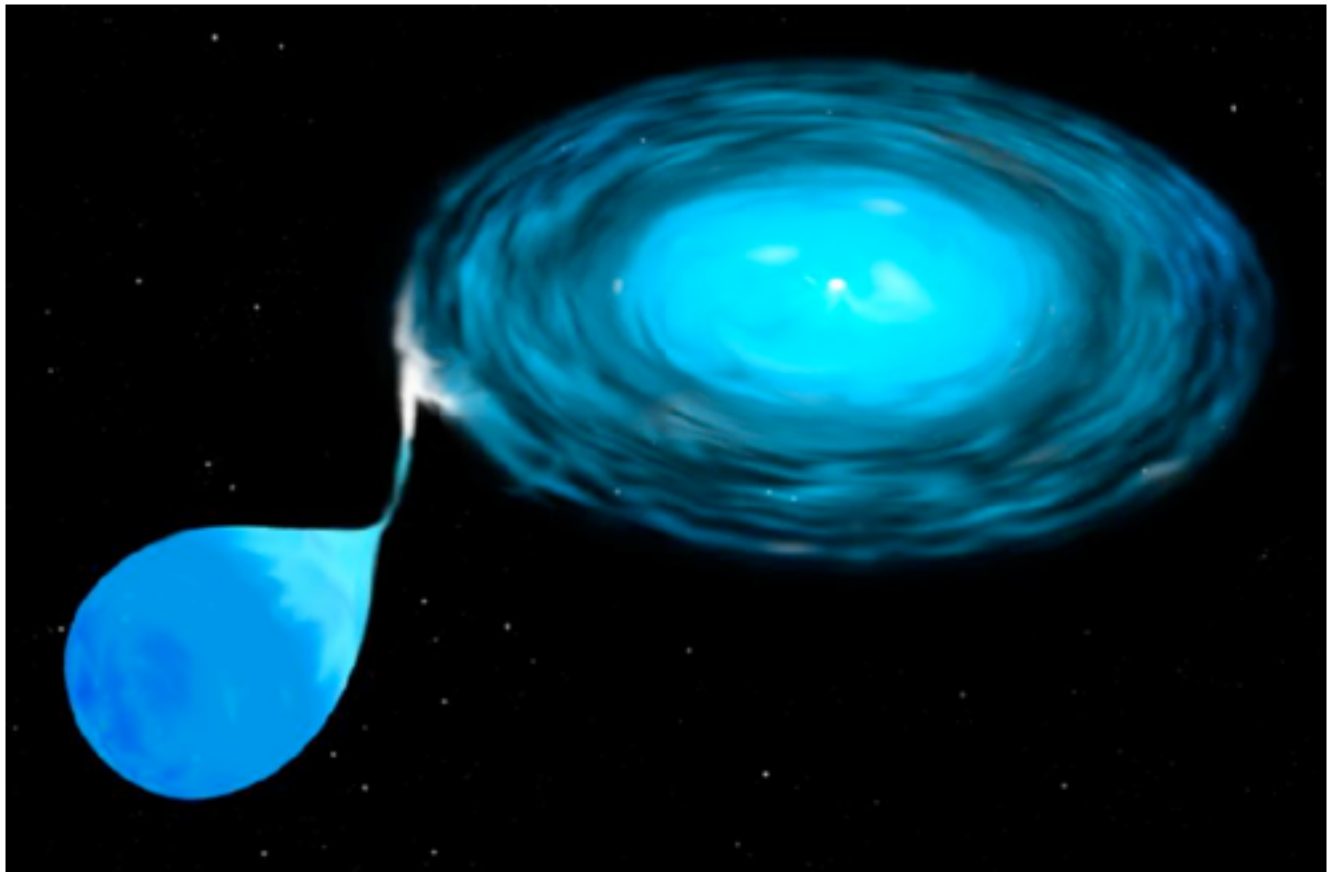
Analogy: Lightbulb

If we have a 40 W lightbulb, we know that there is a relationship between the distance between how bright the lightbulb appears and how far away from the lightbulb we are.

Type 1a Supernova:

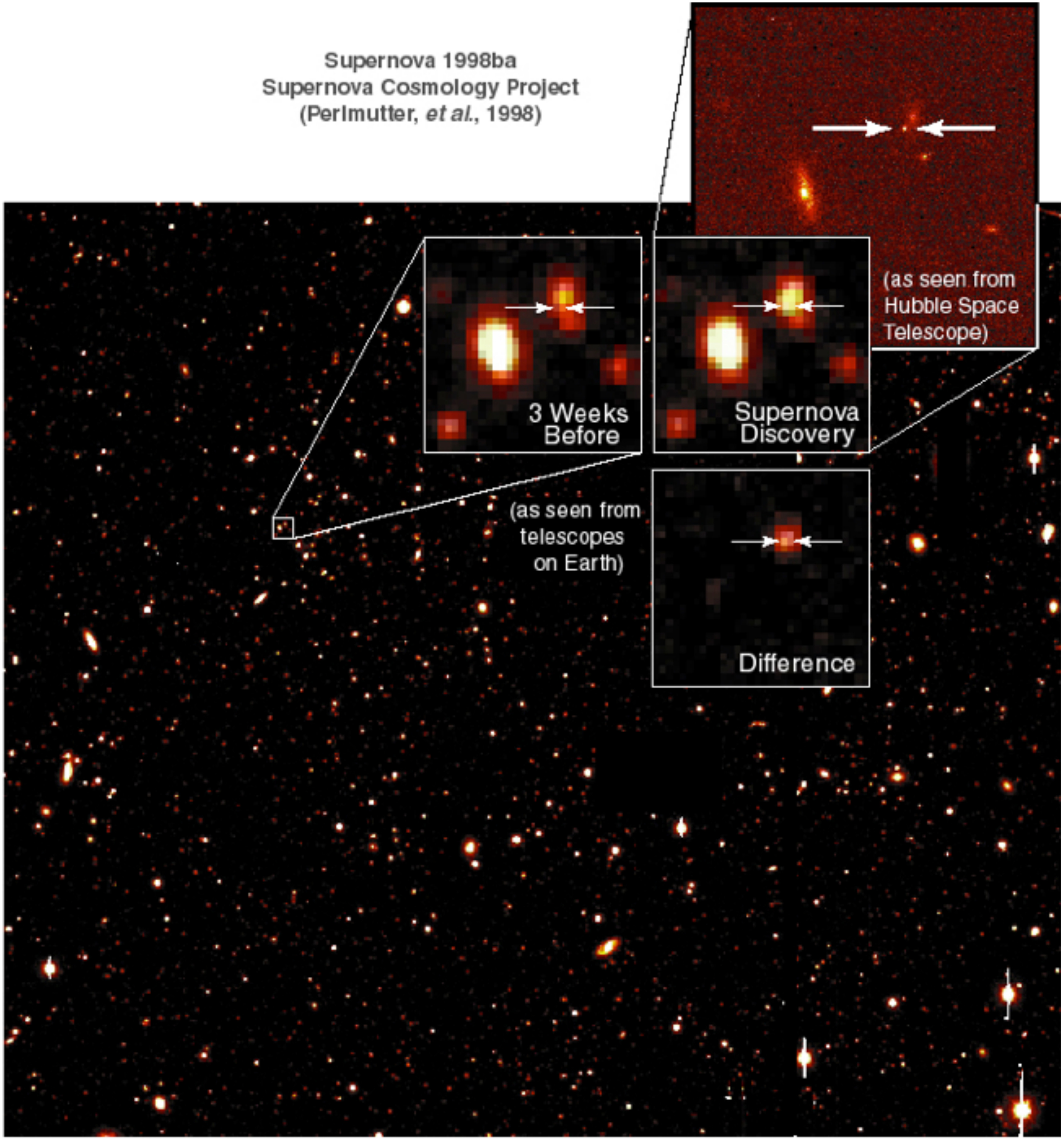
Standard Candles that can be seen from very large distances.

SUPERNOVA (TYPE 1A)



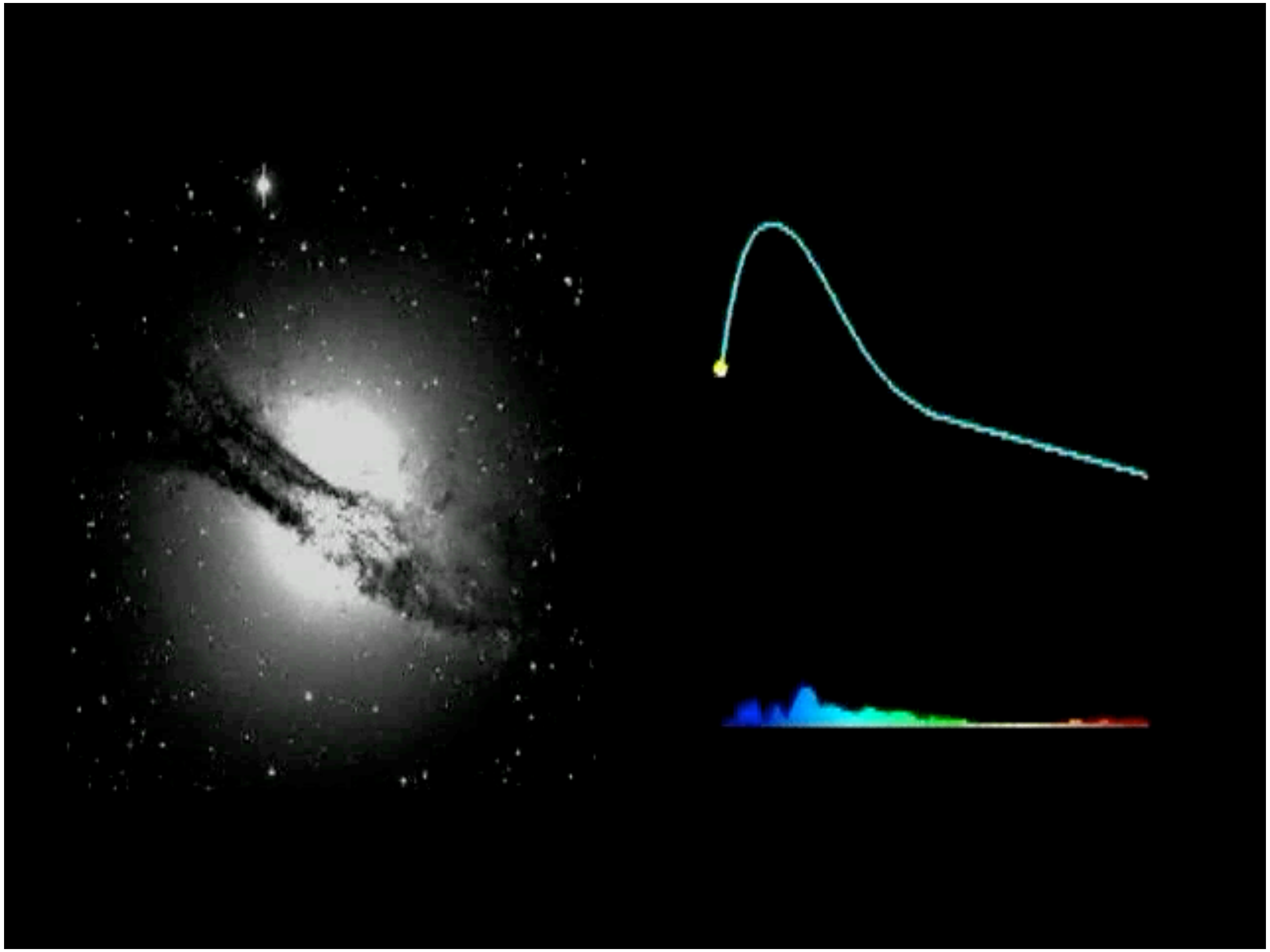
http://en.wikipedia.org/wiki/Type_Ia_supernovae

- Binary systems where 1 of the 2 stars is a white dwarf.
- The companion accretes material onto the white dwarf until the mass of the white dwarf is 1.4 times that of our sun.
- At this mass the white dwarf collapses under its own gravity.



Scan the sky over multiple nights, looking for light to appear that wasn't there before.

Light curve - Intensity Over a Period of Time



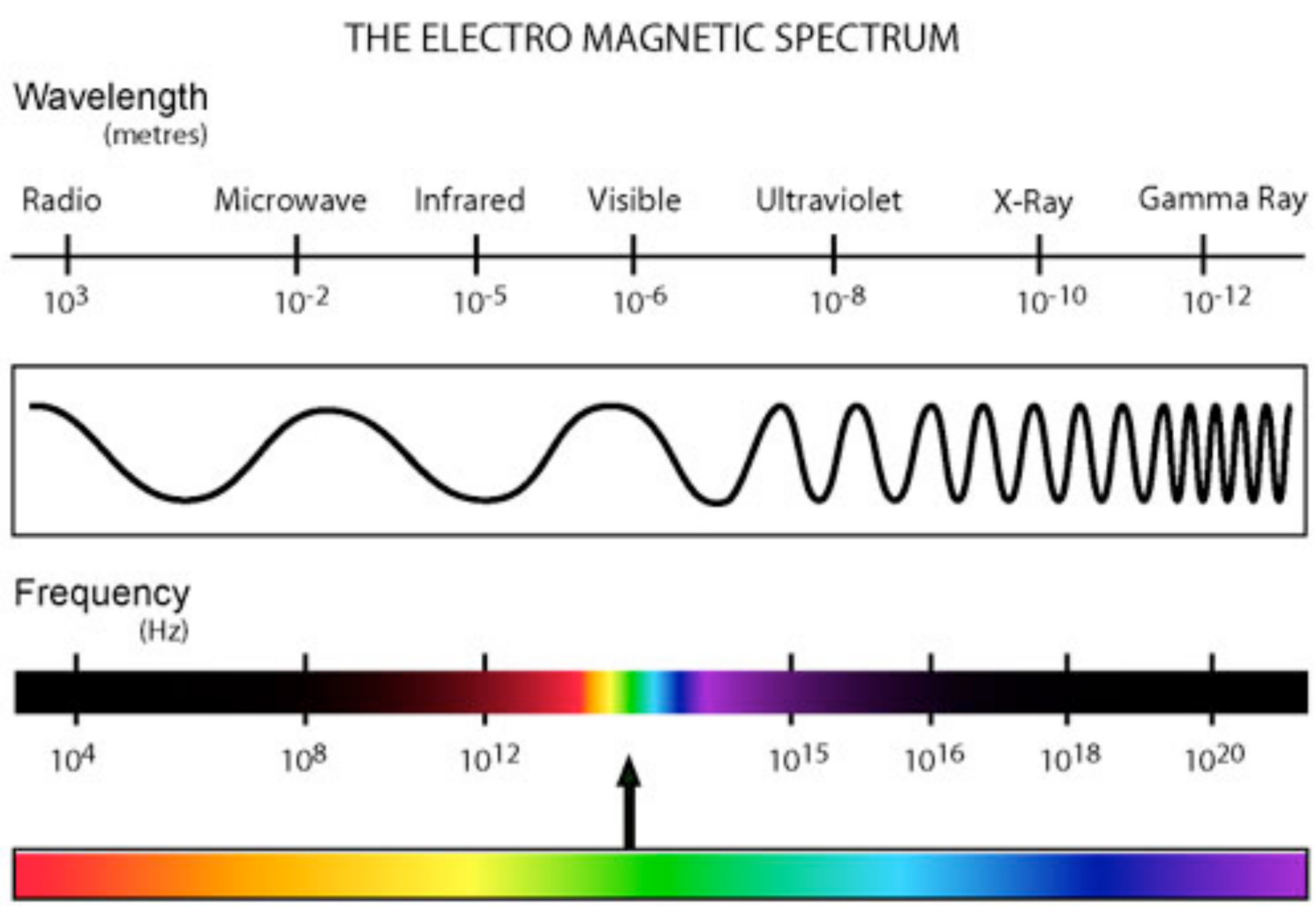
http://www-supernova.lbl.gov/video.html

OPPORTUNITY

The universe is constantly expanding. So, as the light from a supernova explosion travels to us, the space-time underneath it is expanding. As this space-time expands, it changes the wavelength (or color) of the light.

'redshift'

$$z = \frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}}$$



OPPORTUNITY

So, the relationship between measured brightness of the supernova and the redshift of the supernova can tell us about the expansion of the universe.

How to Measure Redshift

1. Supernova are dying stars which are composed of elements. Measure the spectral lines of the elements. Spectral lines are like color signatures of atoms or elements. (http://www.colorado.edu/physics/2000/quantumzone/)

2. Identify which spectral line was created by which element.

3. Measure the wavelength shift of any one of the lines w.r.t. its expected wavelength as measured in a laboratory on Earth.

4. Use a formula to relate the observed shift to the velocity of the object.

$$z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda_0 - \lambda_E}{\lambda_E}$$

SPECTRAL LINES

A) Atoms give off waves of a certain frequency.

B) Each atom in the universe gives off a unique set of colors.

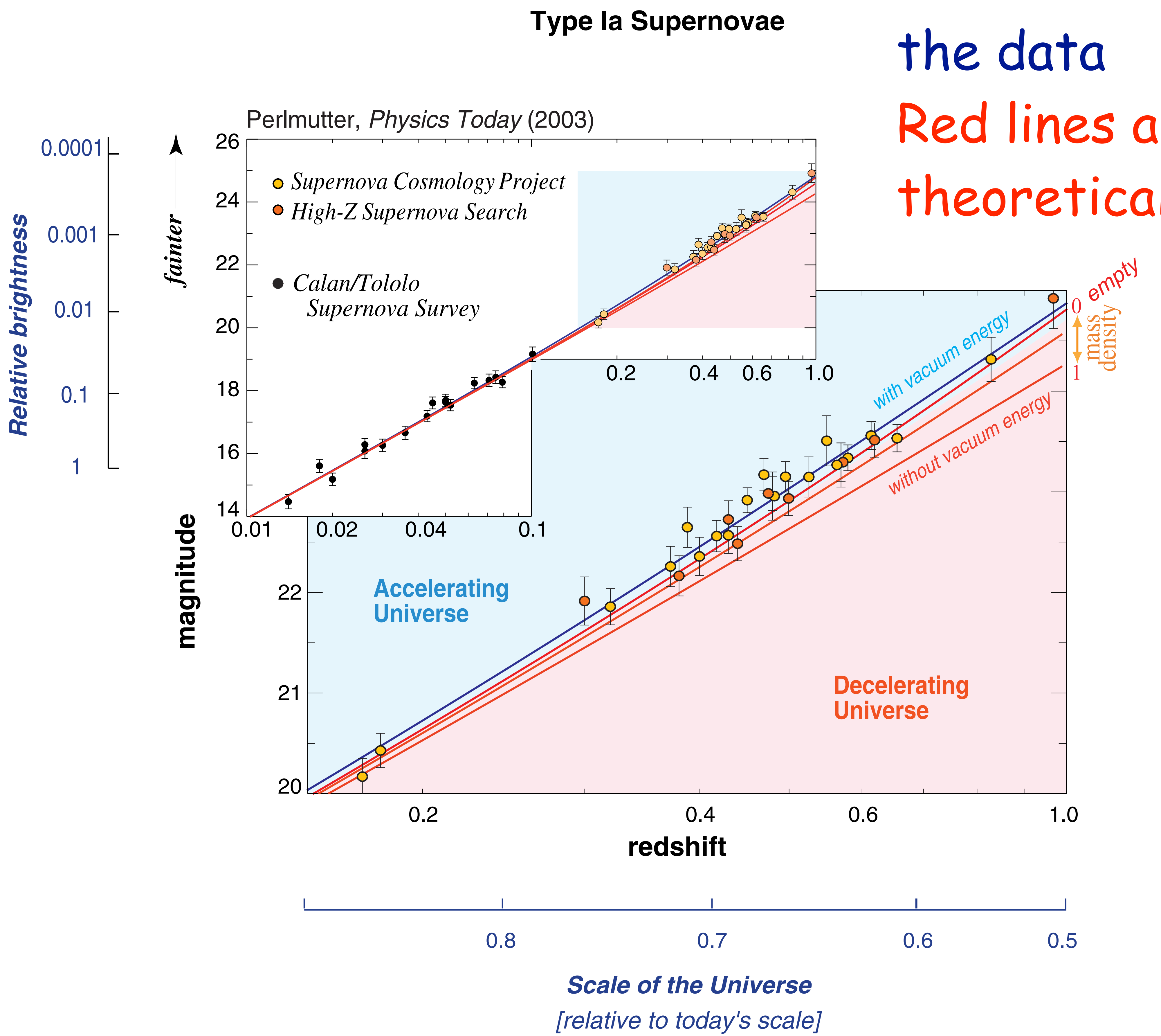
C) This set of colors is known as '**spectral lines**'.

D) **Spectroscopy** is the science of using spectral lines to figure out what atoms an object contains.

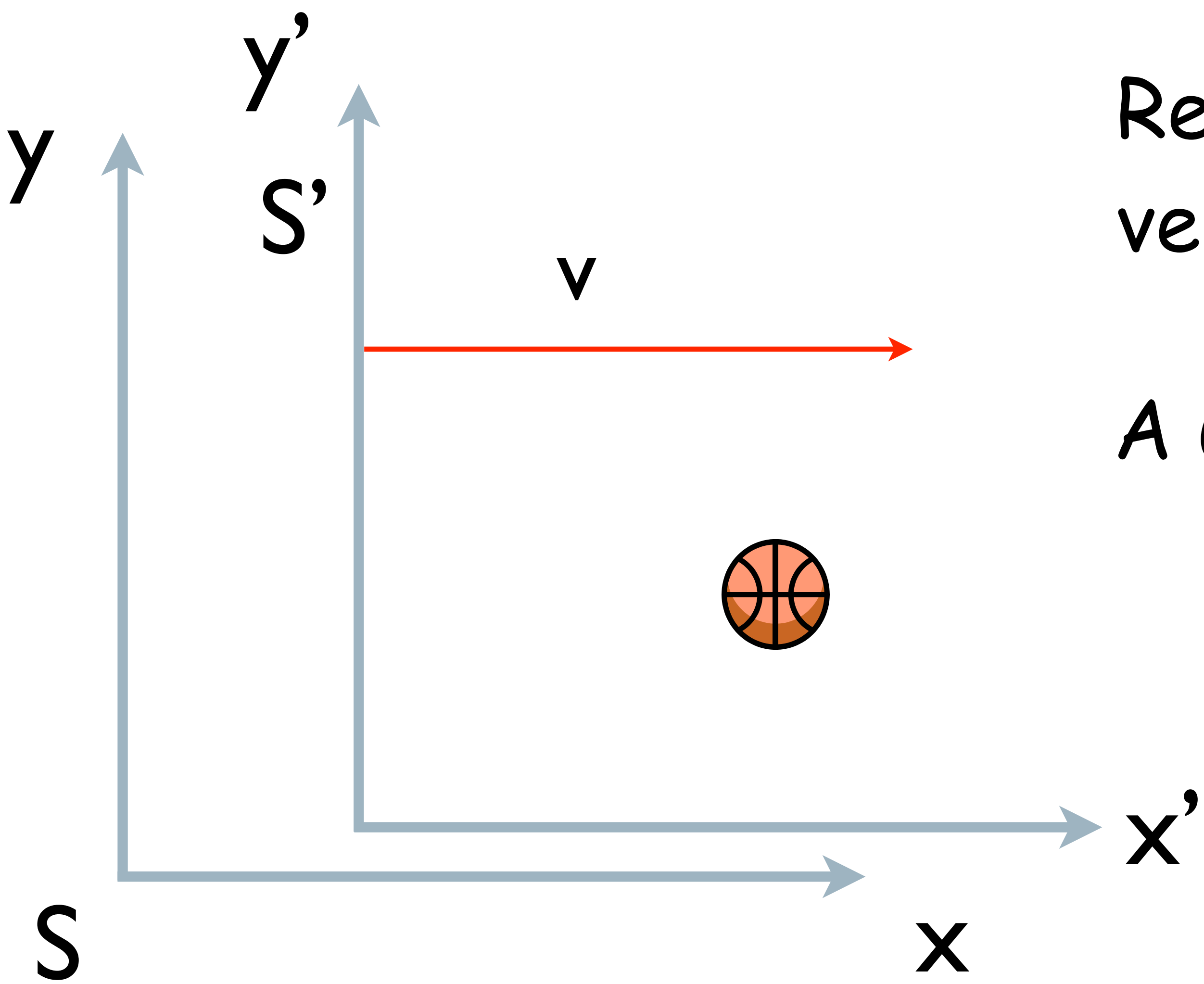
E) This technique is used to determine the composition of distant stars.

Blue line is best fit to the data

Red lines are theoretical models



TRANSFORMING VELOCITY



Recall, that frame S′ moves with a velocity v with respect to frame S.

A Galilean Transformation gives us

Frame S: $u = u' + v$

Frame S′: $u' = u - v$

TRANSFORMING VELOCITY

Remember:

$$u = \frac{dx}{dt} \qquad x = \gamma_\nu(x' + vt') \qquad t = \gamma_\nu(\frac{v}{c^2}x' + t')$$

From this we can derive the following relations. (Exercise for the student).

$$u = \frac{u' + v}{1 + \frac{vu'}{c^2}}$$

and

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}}$$

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}}$$

Quick Check of 2nd Postulate:

Speed of light is the same in all reference frames.

Light is traveling at the speed of light (c) in the u reference frame. Calculate the speed of light in the u' reference frame.

$$u' = \frac{u - v}{1 - \frac{vu}{c^2}} = \frac{c - v}{1 - \frac{vc}{c^2}} = \frac{c(c - v)}{c - v}$$

$$u' = c$$

Einstein's second postulate holds!

THE END
(FOR TODAY)