The Age of Things:

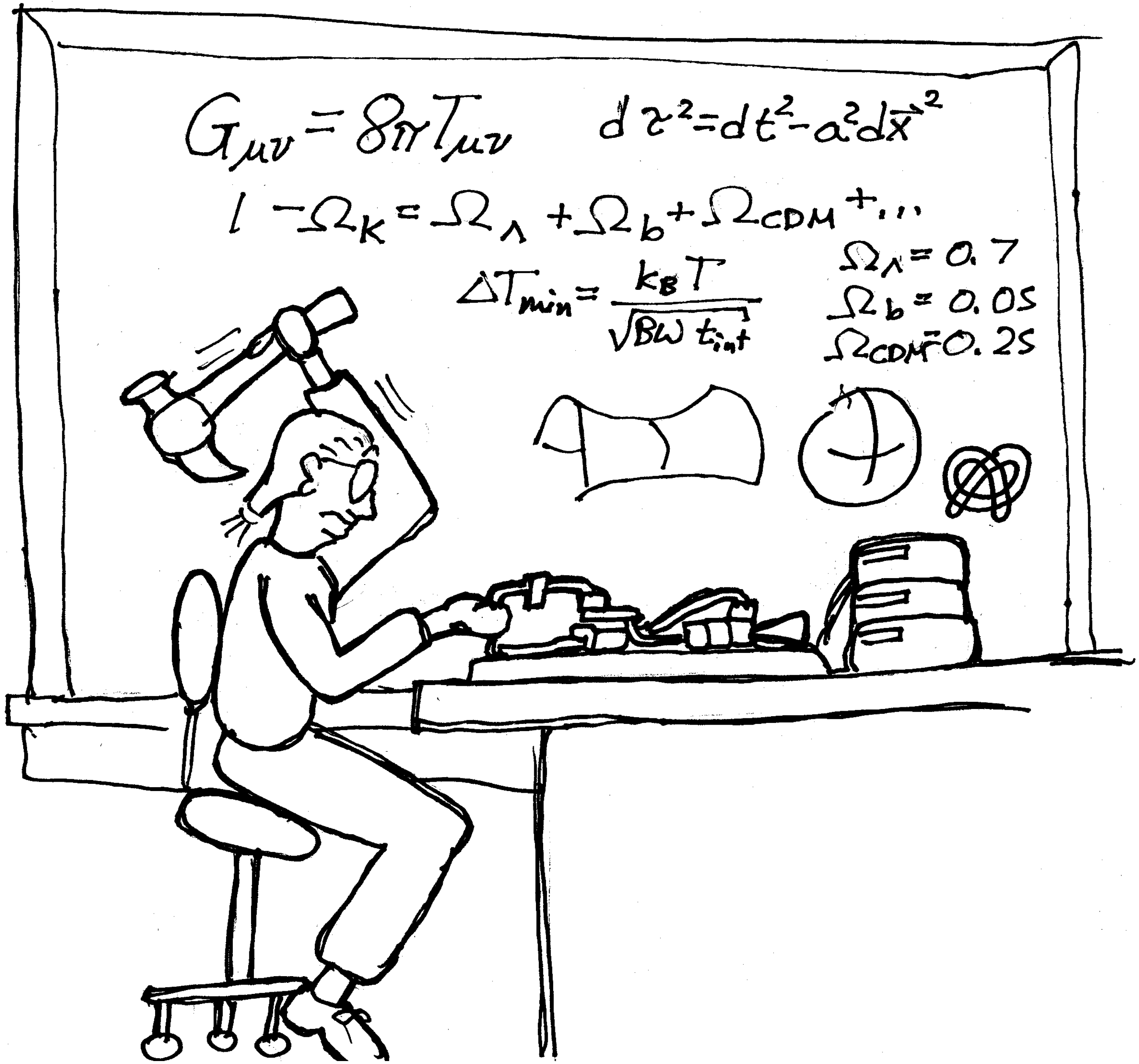
Sticks, Stones and the Universe

Distances, Redshifts and the Age of the Universe

http://cfcp.uchicago.edu/~mmhedman/compton1.html

WARNING!

Cosmologist talking about Cosmology!

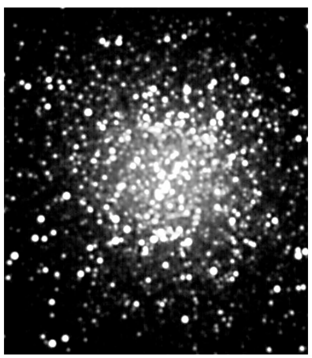


Last Time: Globular Clusters

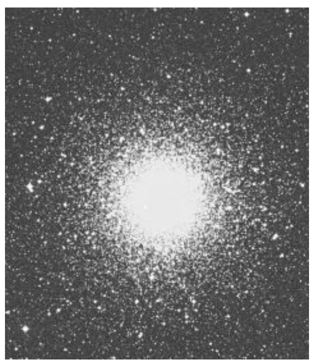
M92

M68

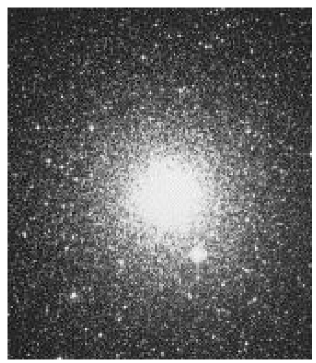
M30



M13



NGC362

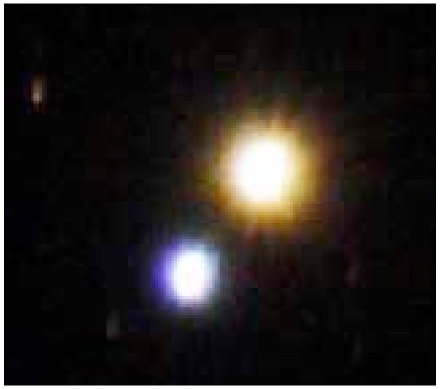


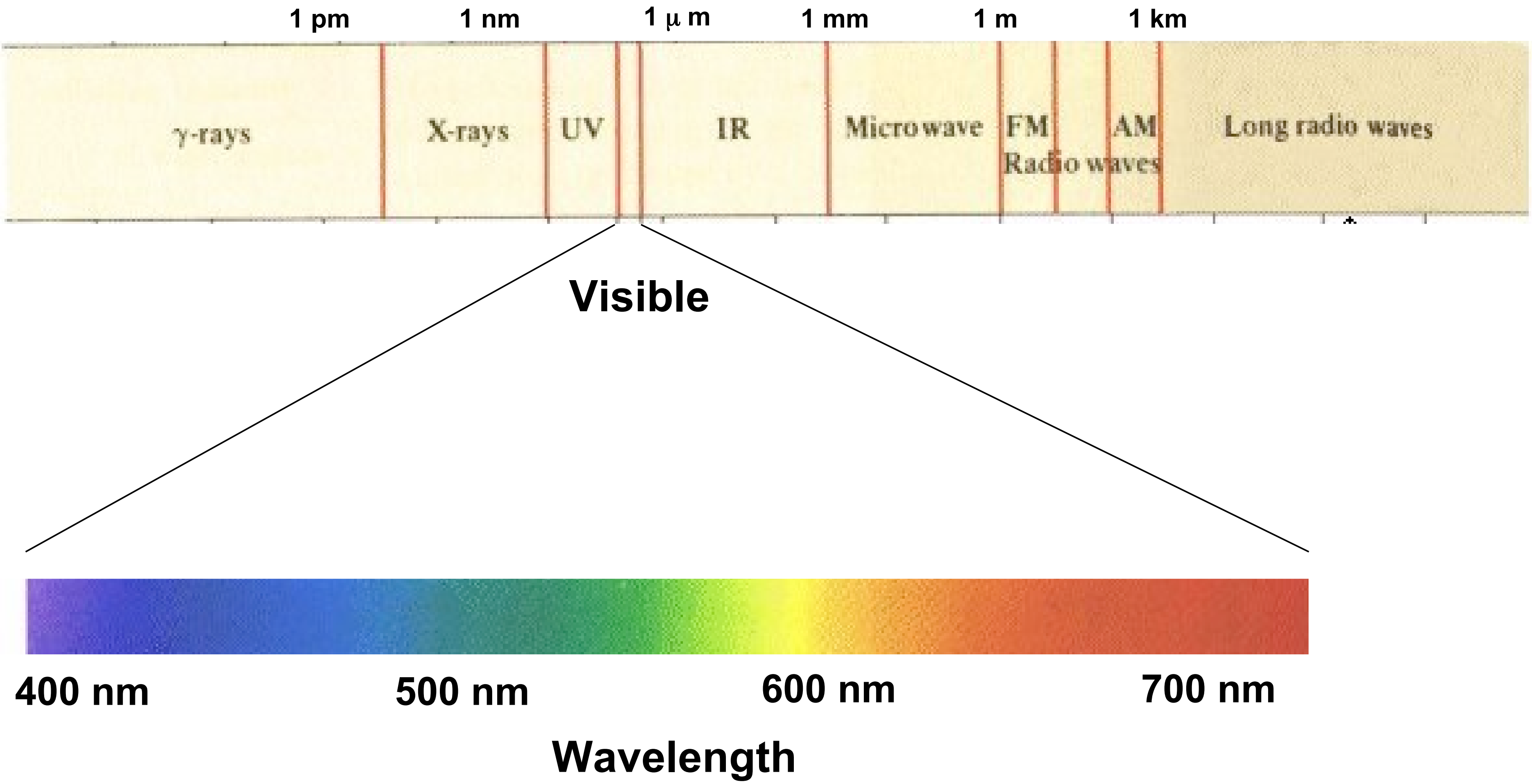
NGC6752

Multiple analyses yield ages of 12-13 billion years, and an uncertainty of about 1 or 2 billion years

Colors and Spectra

Alberio





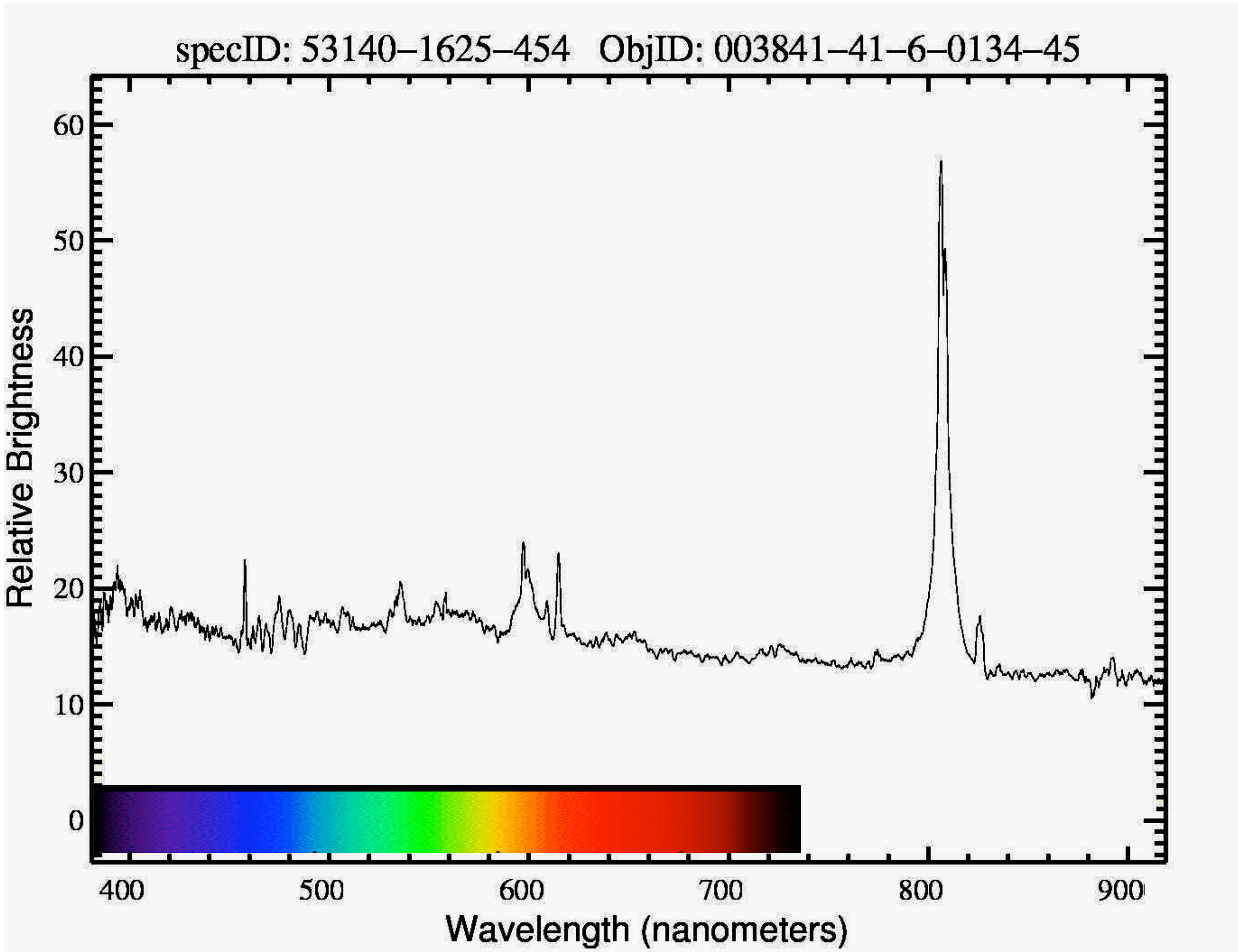
Galaxies


M87
M87 © Anglo-Australian Observatory
Photo by David Malin


Andromeda

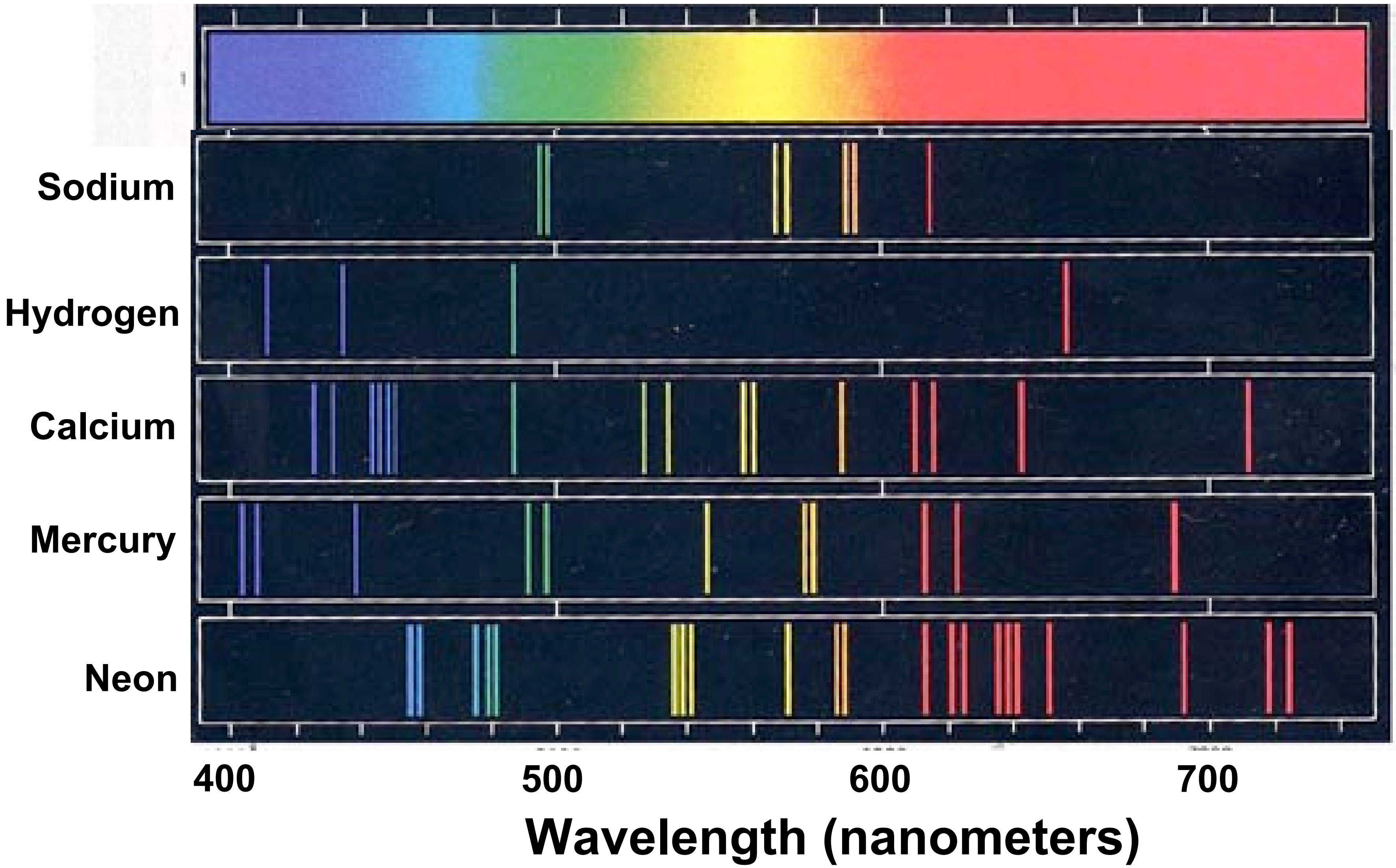

Whirlpool

Galaxy Redshifts

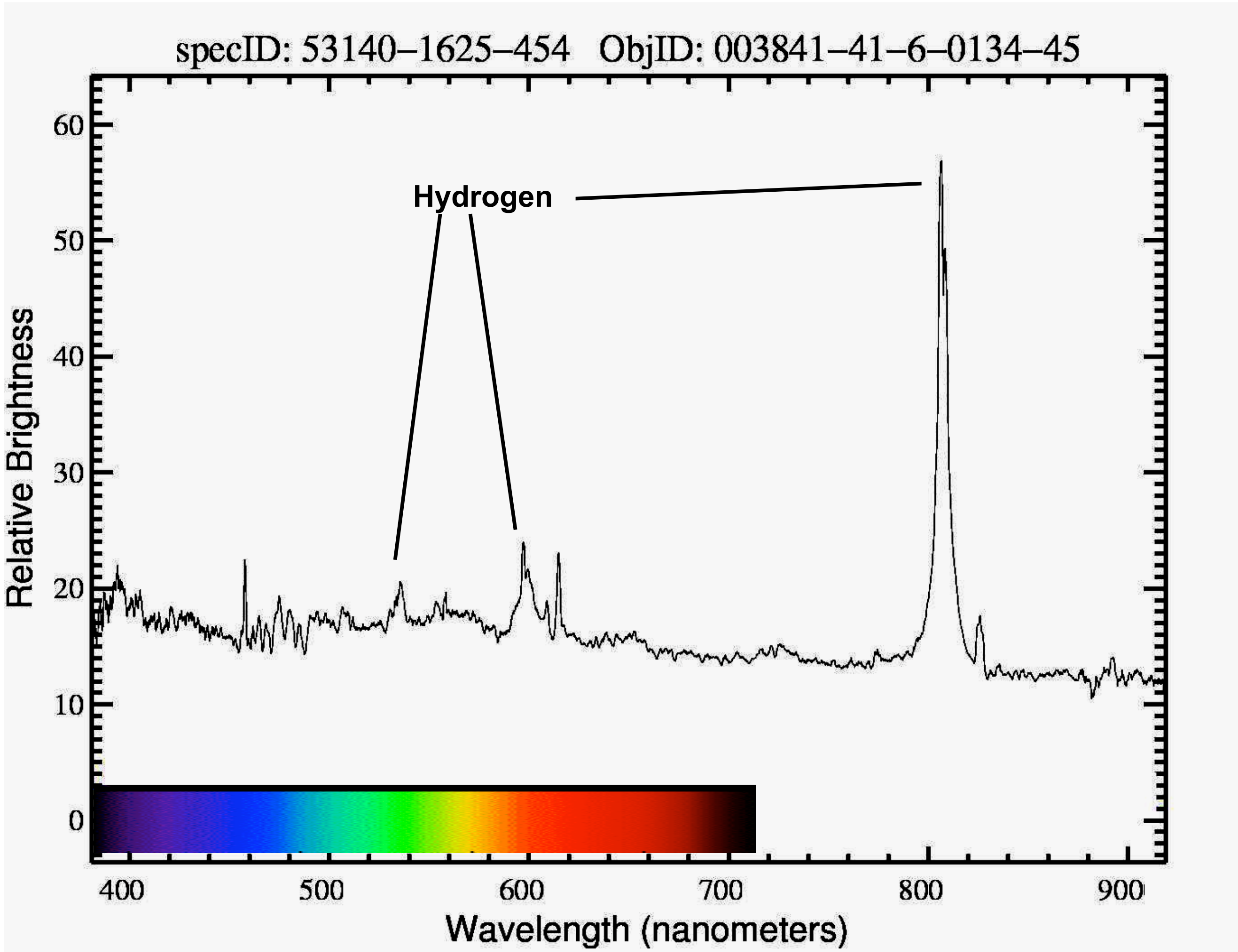


(Coutesy of E. Sheldon)

The Spectra of different atoms

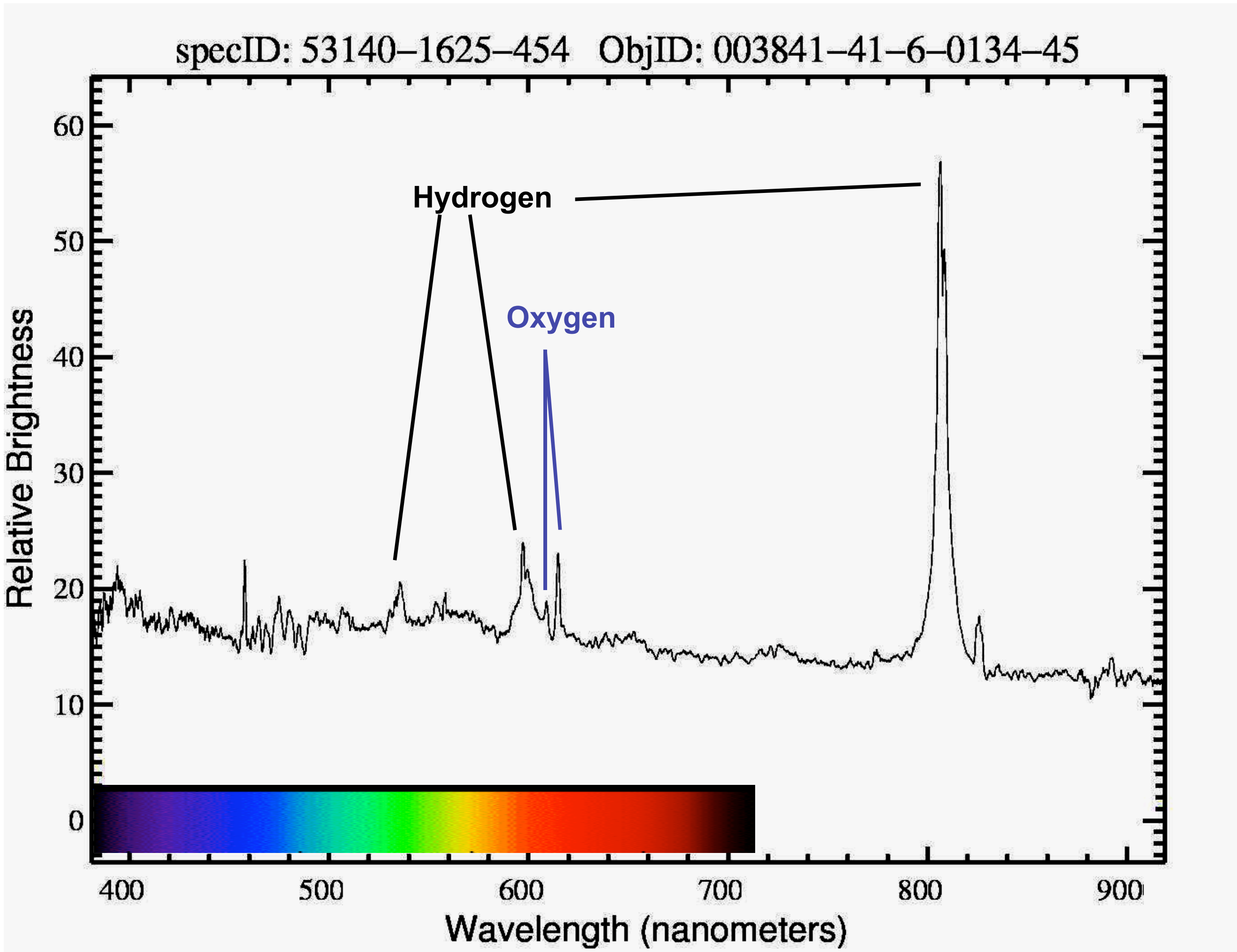


Galaxy Redshifts



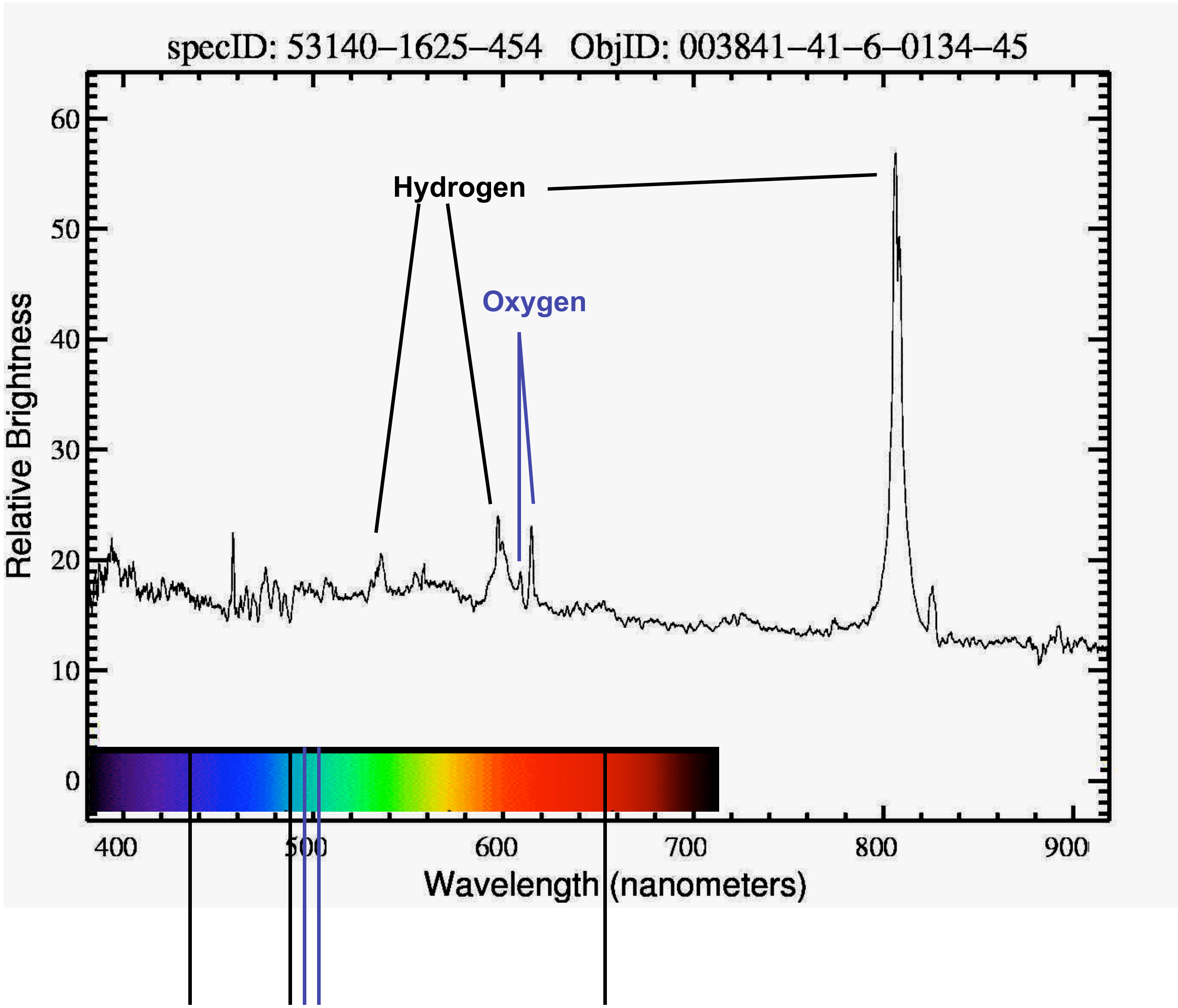
(Coutesy of E. Sheldon)

Galaxy Redshifts



(Coutesy of E. Sheldon)

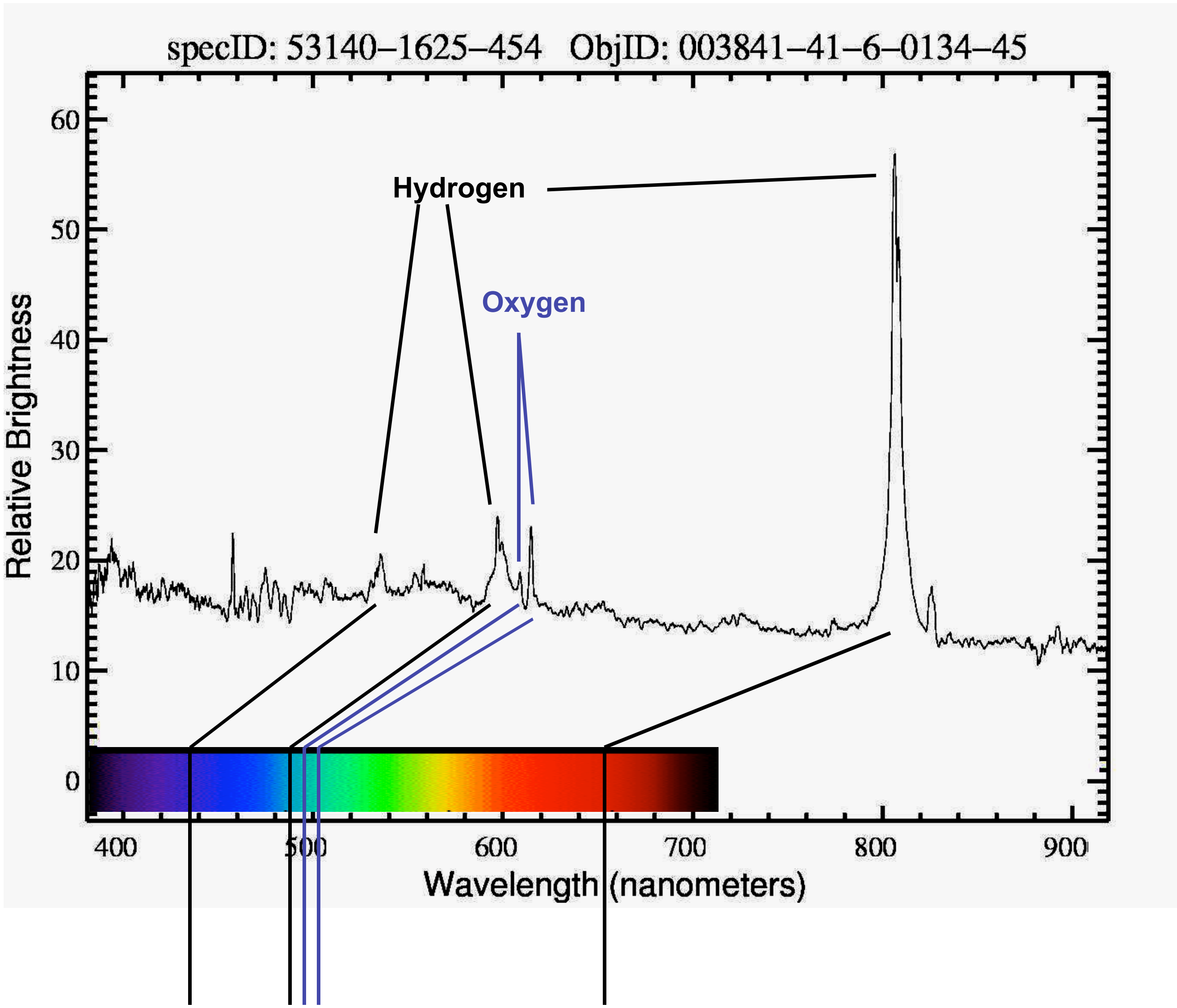
Galaxy Redshifts



Wavelengths measured in Laboratory

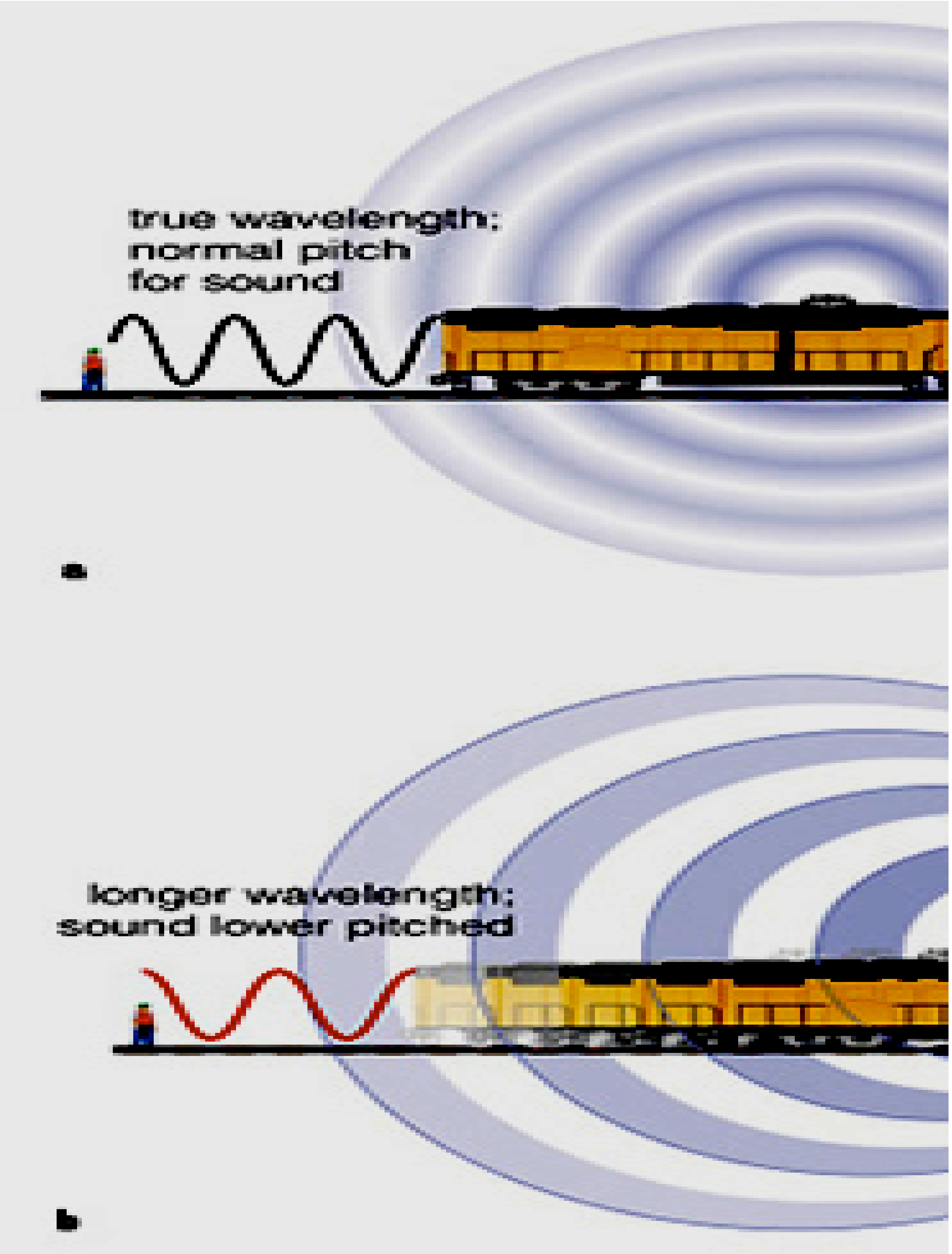
(Coutesy of E. Sheldon)

Galaxy Redshifts

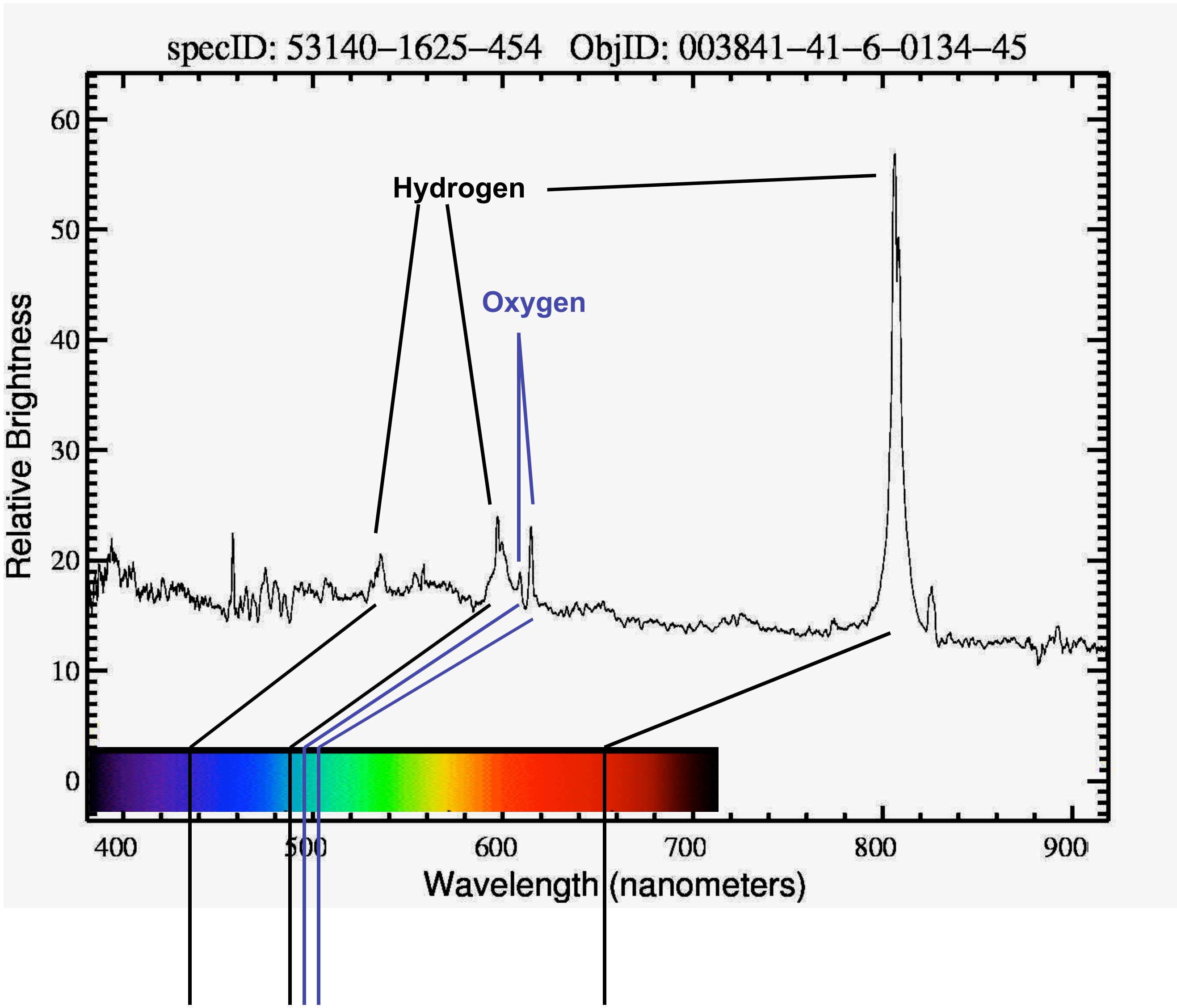


(Coutesy of E. Sheldon)

The Doppler Effect



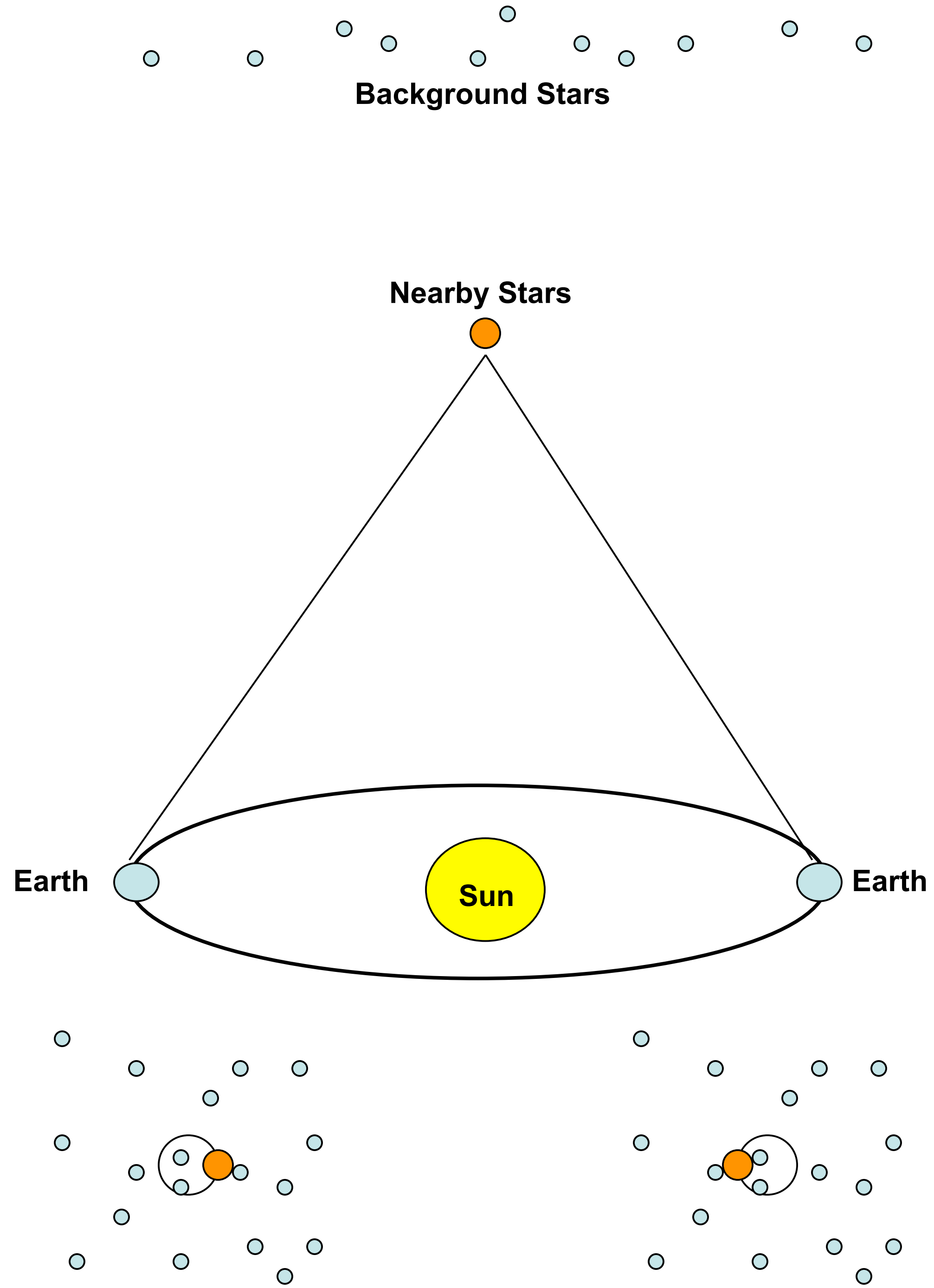
Galaxy Redshifts



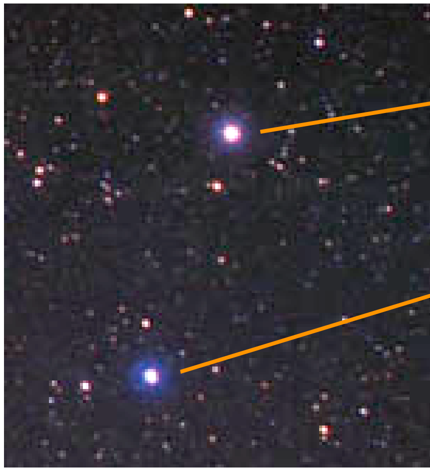
Wavelengths measured in Laboratory

(Coutesy of E. Sheldon)

Measuring the distance to the stars using Parallax

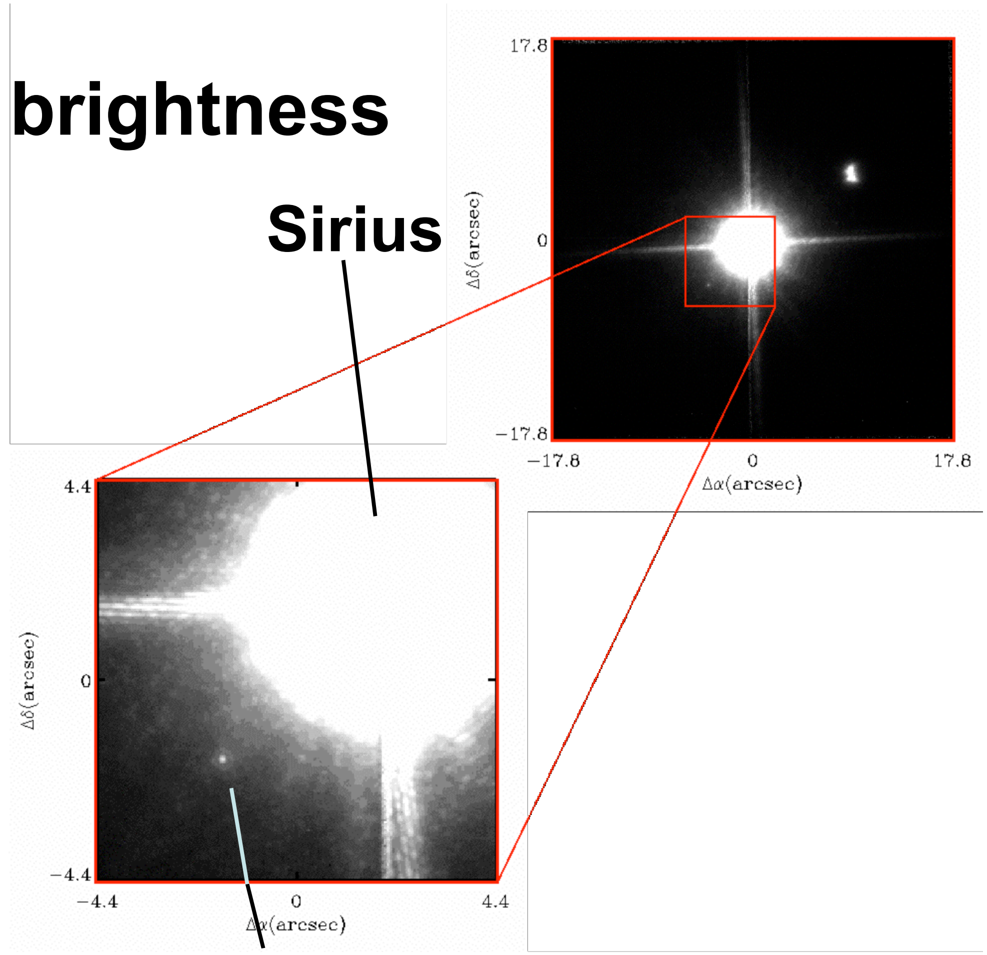


Estimating distance with brightness



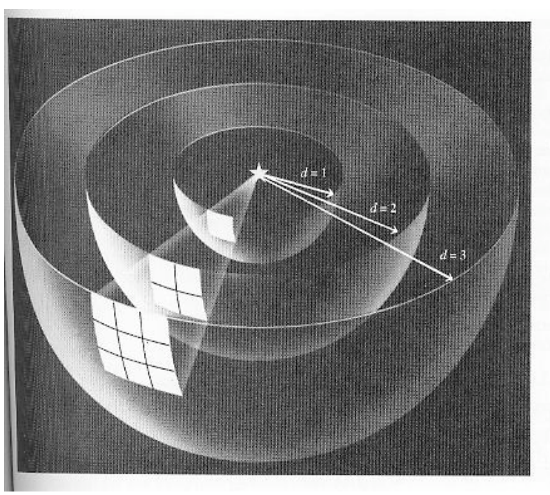
Pollux

Castor



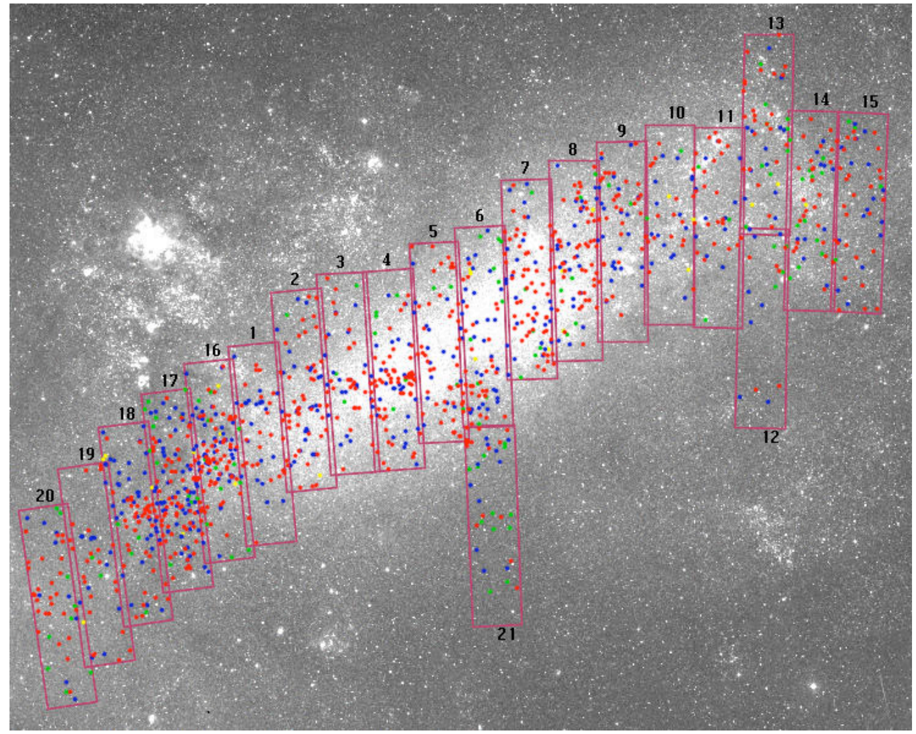
Sirius

Sirius B

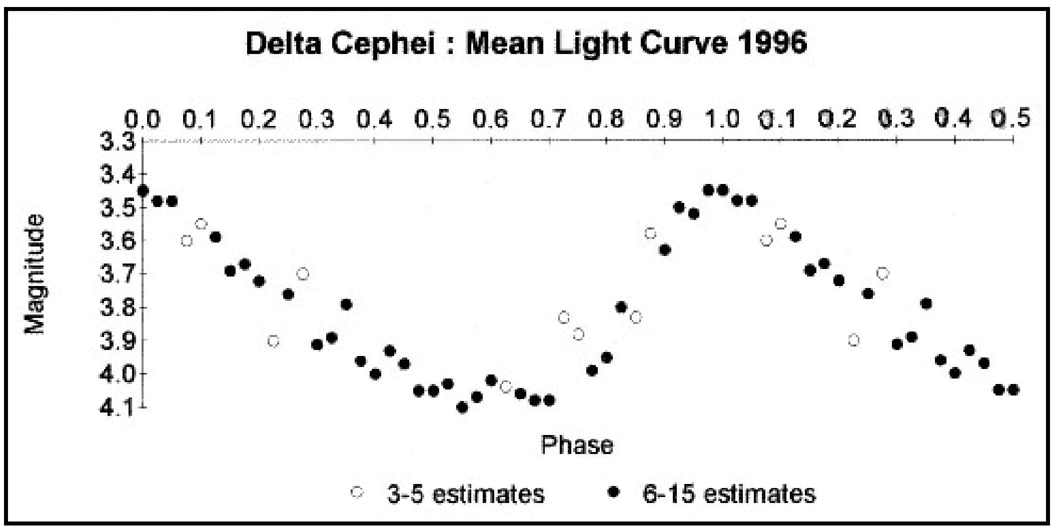


Luminosity = Total power emitted by star in the form of light.

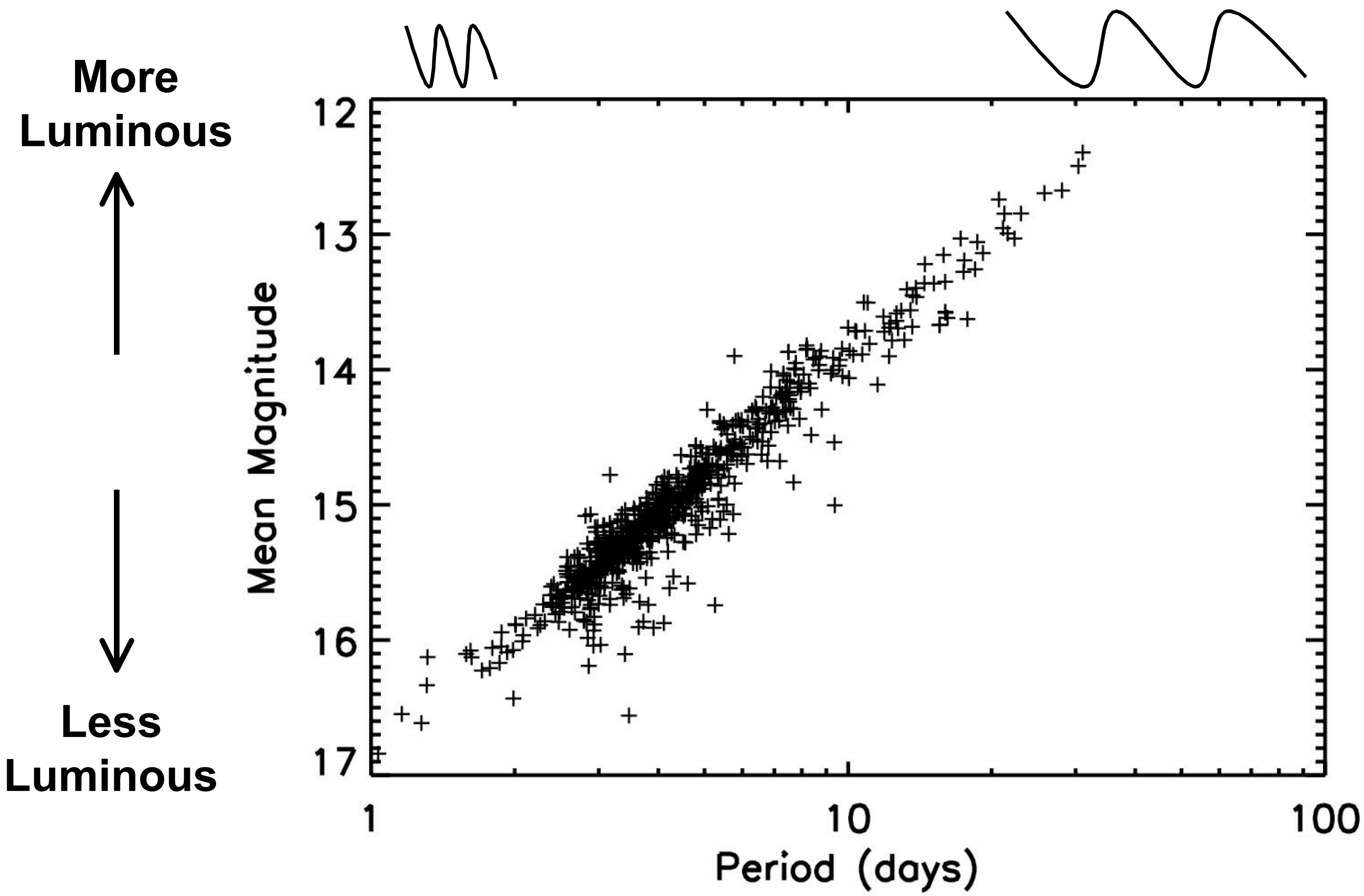
Galaxy Distances: Cepheids



Large Magellanic Cloud



The Period-Luminosity Relation of Cepheids

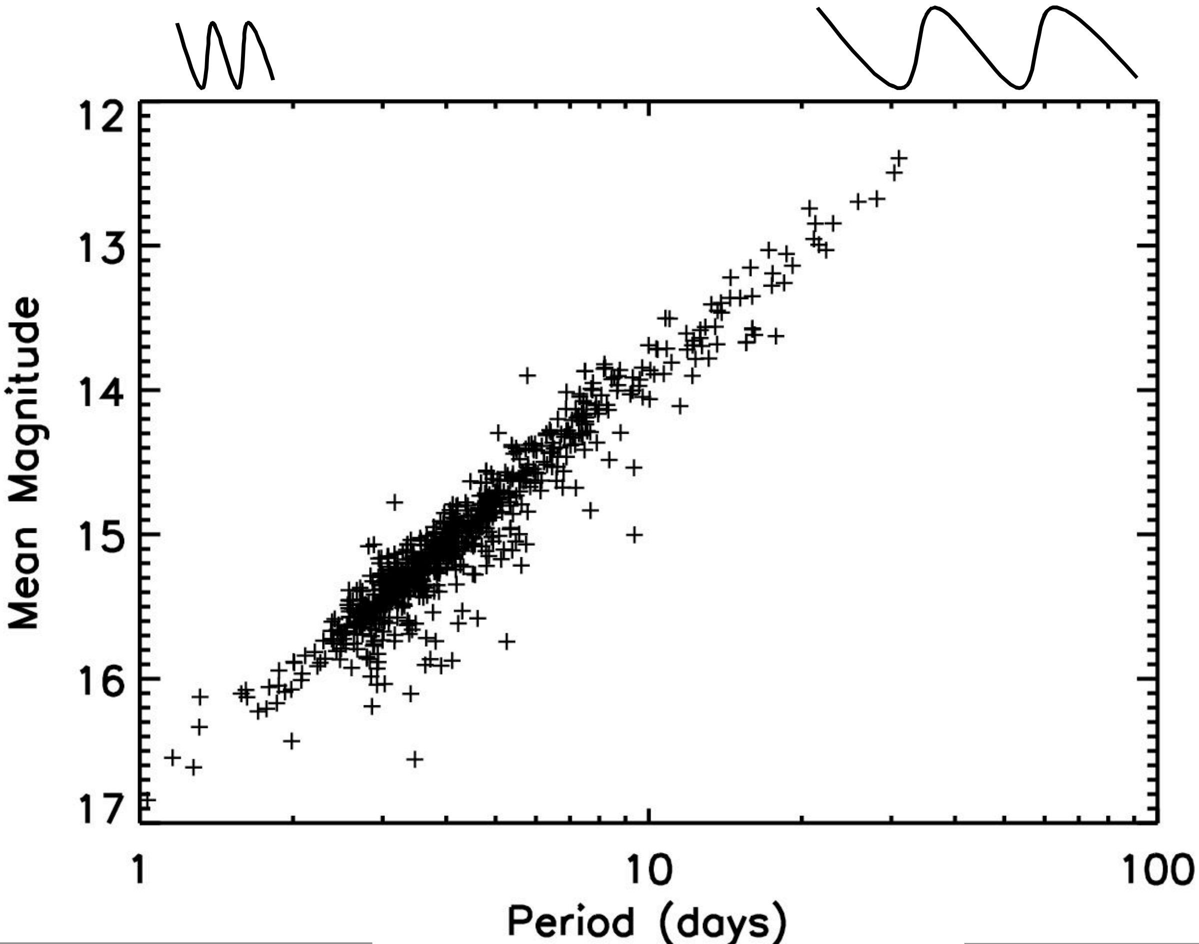


Based on Data from Udalski et. al. In *Acta Astronomica* Vol 49 (1999) pg 223

The Period-Luminosity Relation of Cepheids

More Luminous

Less Luminous



Cepheid in Galaxy:

Period = 10 days

Magnitude = 24

Cepheid in LMC:

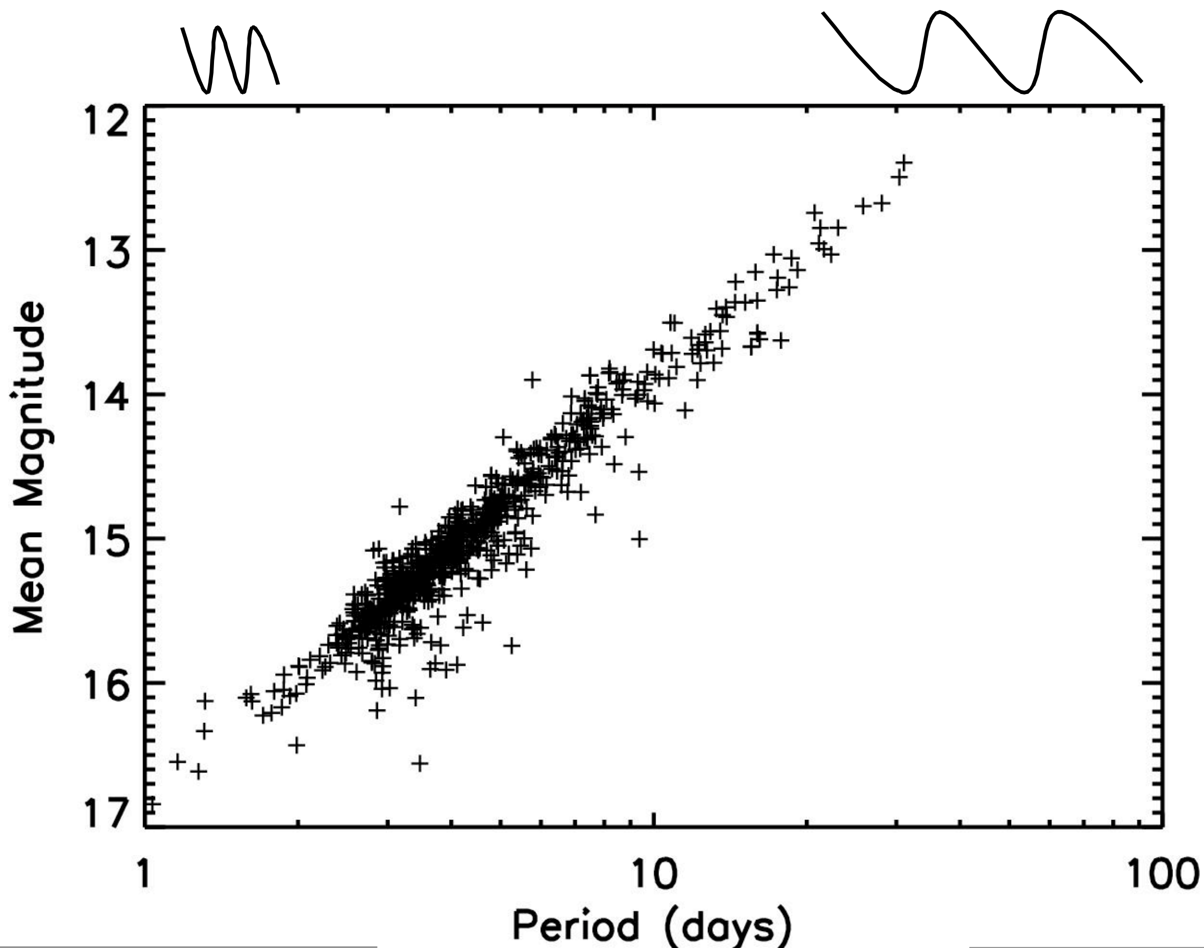
Period = 10 days

Magnitude = 14

The Period-Luminosity Relation of Cepheids

More Luminous

Less Luminous



Cepheid in Galaxy:

Period = 10 days

Magnitude = 24

Same Luminosity

10,000 times fainter

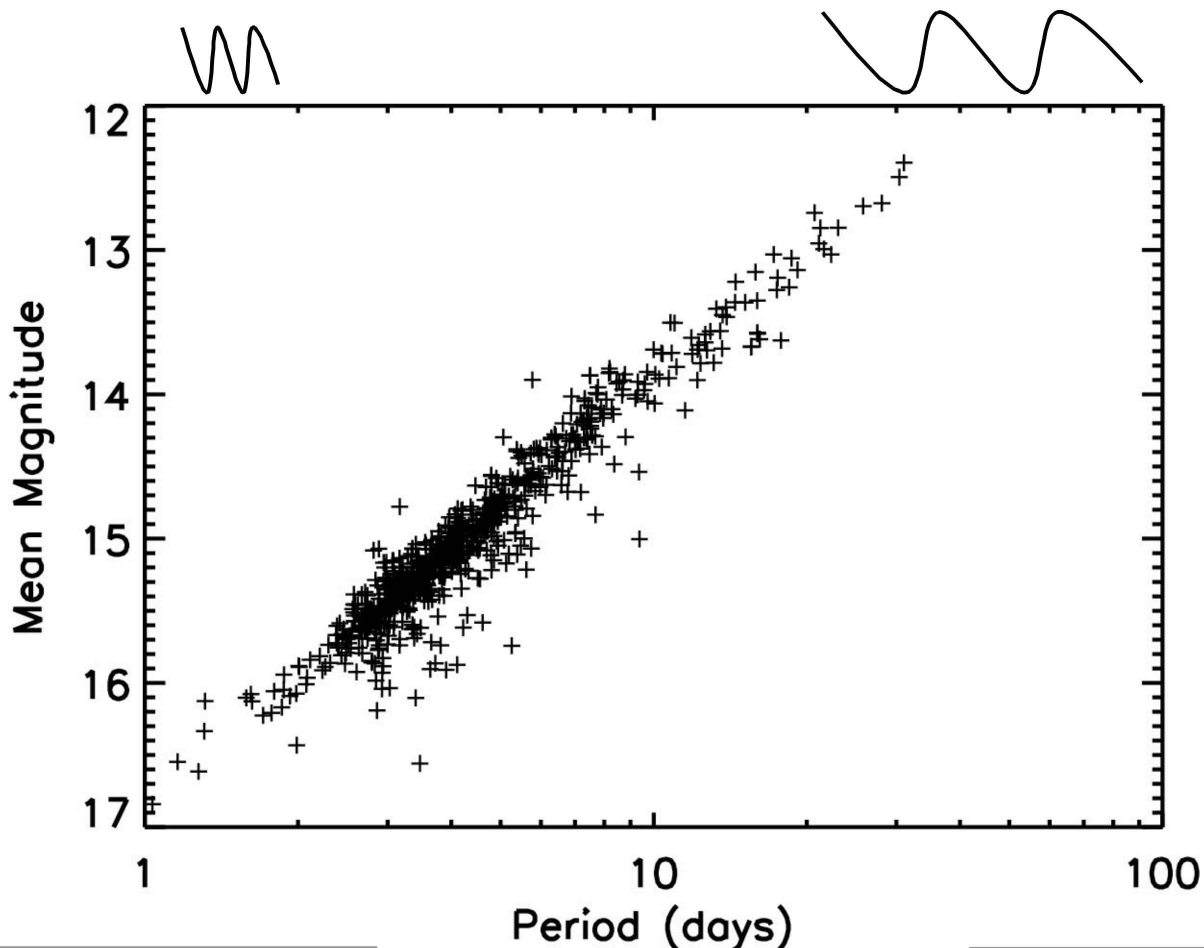
Cepheid in LMC:

Period = 10 days

Magnitude = 14

The Period-Luminosity Relation of Cepheids

More Luminous



Less Luminous

Cepheid in Galaxy:
Period = 10 days
Magnitude = 24

Same Luminosity

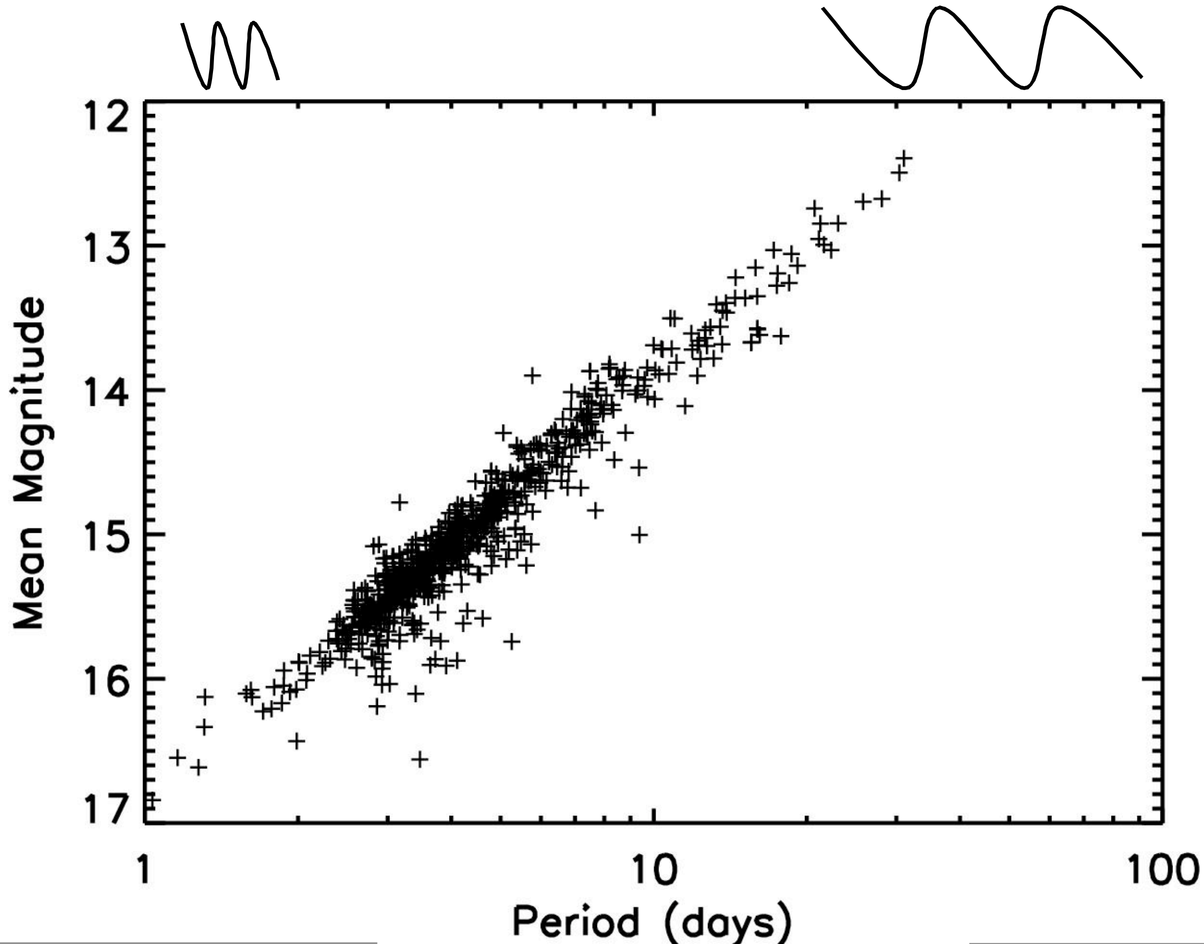
10,000 times fainter

100 times farther away

Cepheid in LMC:
Period = 10 days
Magnitude = 14

The Period-Luminosity Relation of Cepheids

More Luminous



Less Luminous

Cepheid in Galaxy:

Period = 10 days

Magnitude = 24

15 million light years away

Same Luminosity

10,000 times fainter

100 times farther away

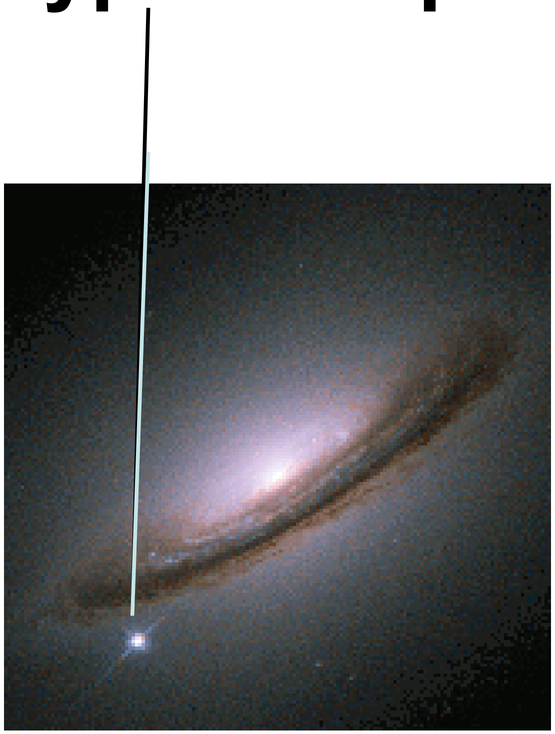
Cepheid in LMC:

Period = 10 days

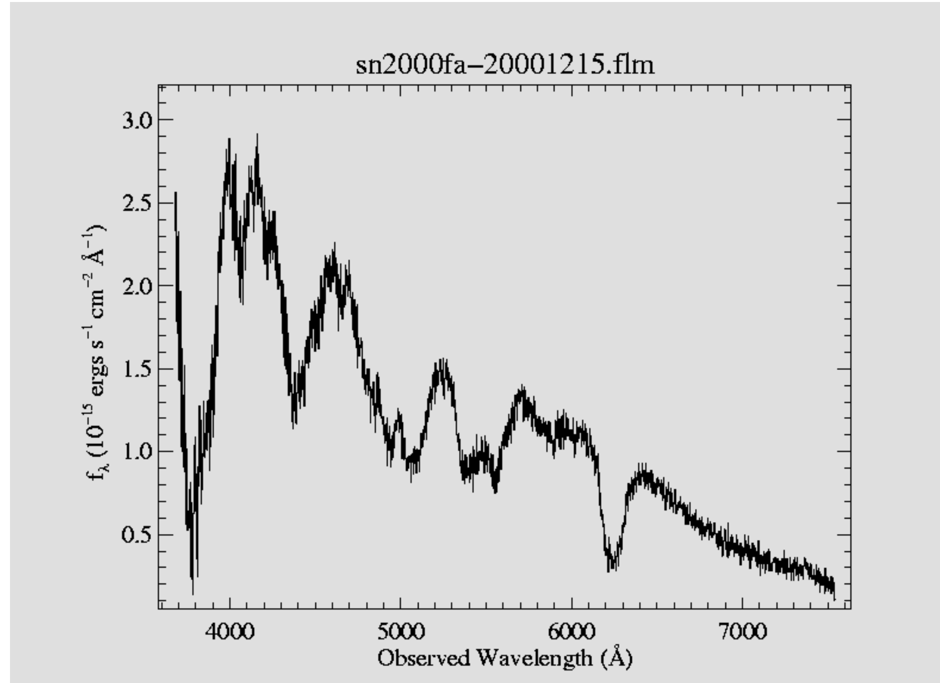
Magnitude = 14

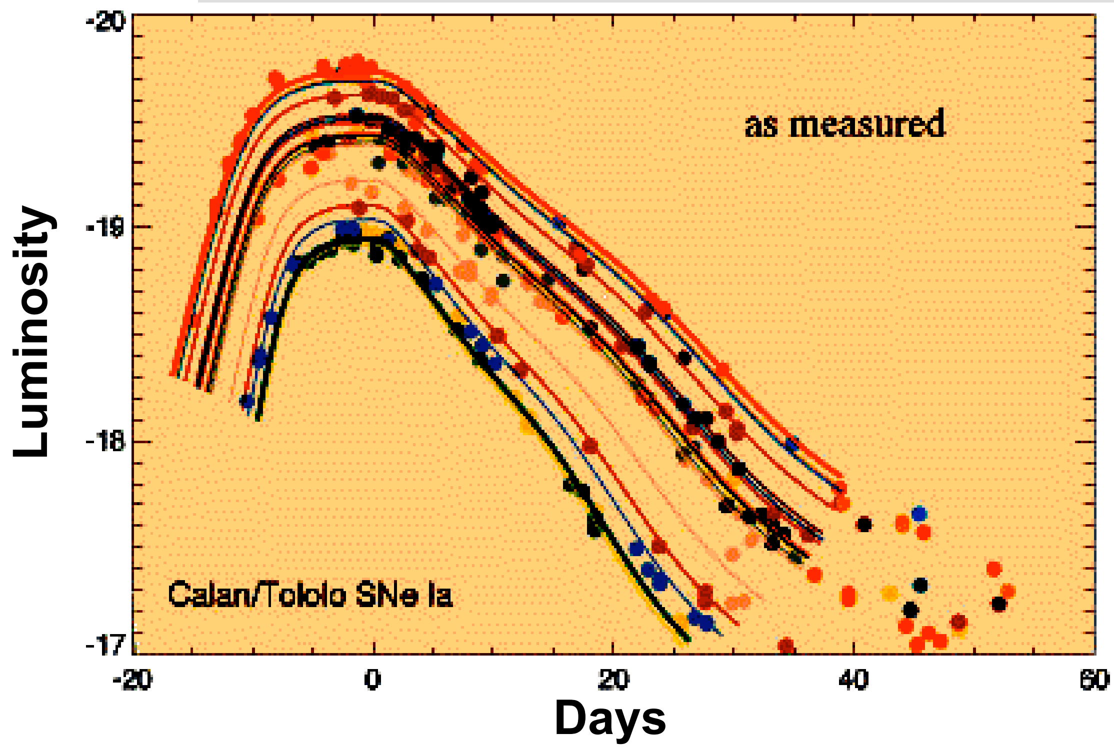
150,000 light years away

Galaxy Distances: Type Ia Supernova

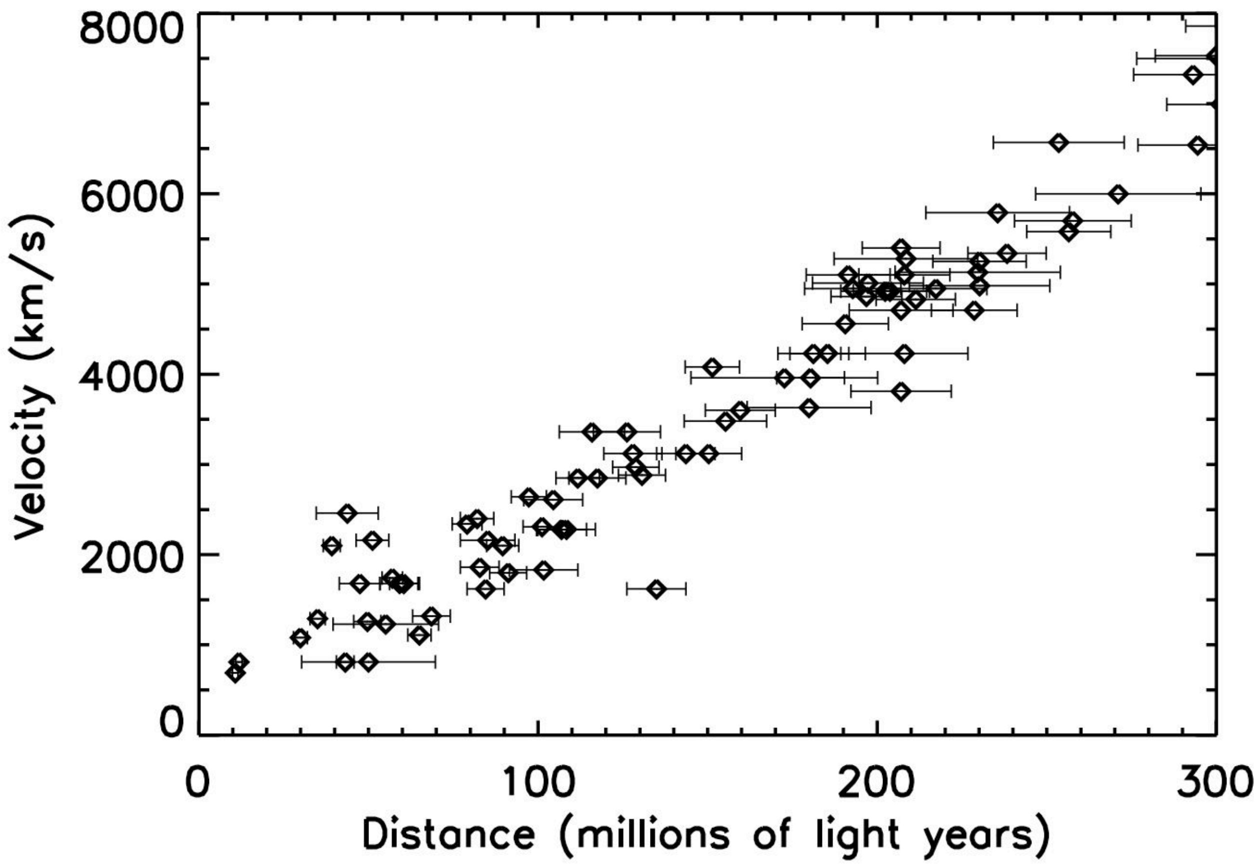


Supernova 1994D

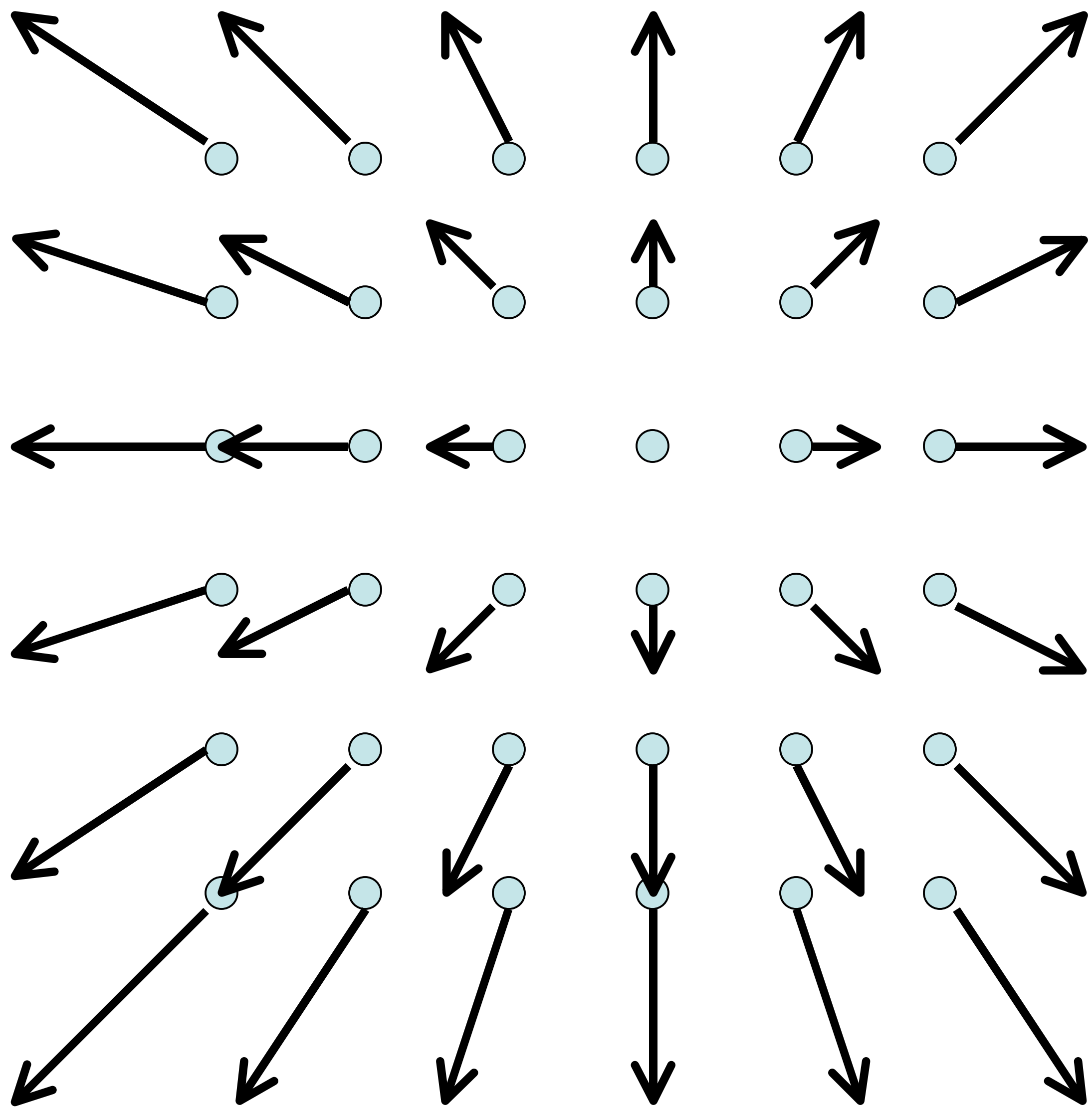




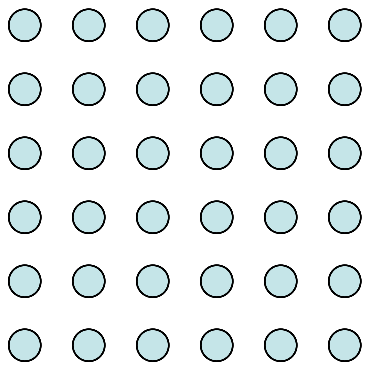
The Hubble Diagram



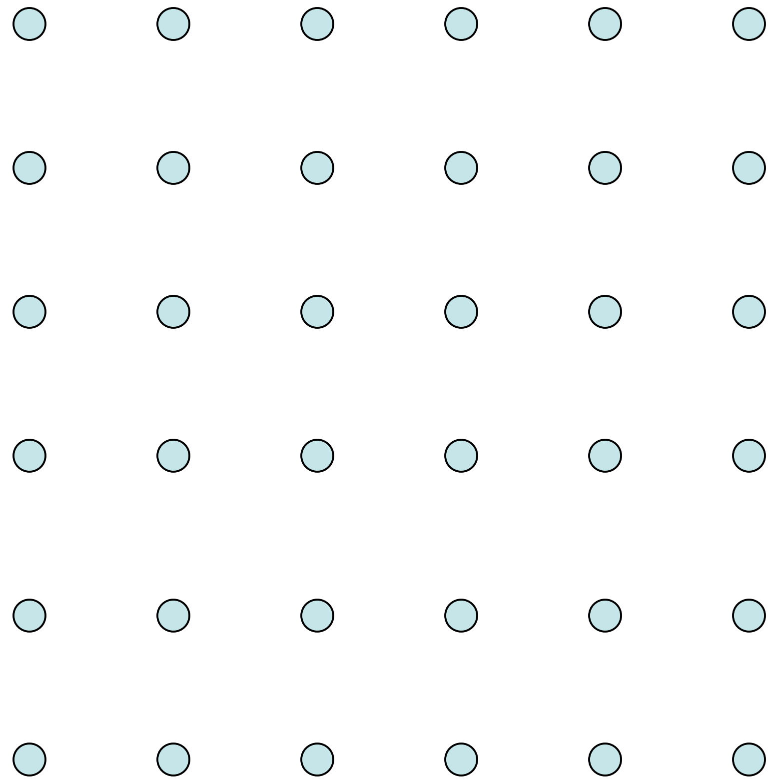
Based on Data from Tonry et. al. astro-ph/0305008

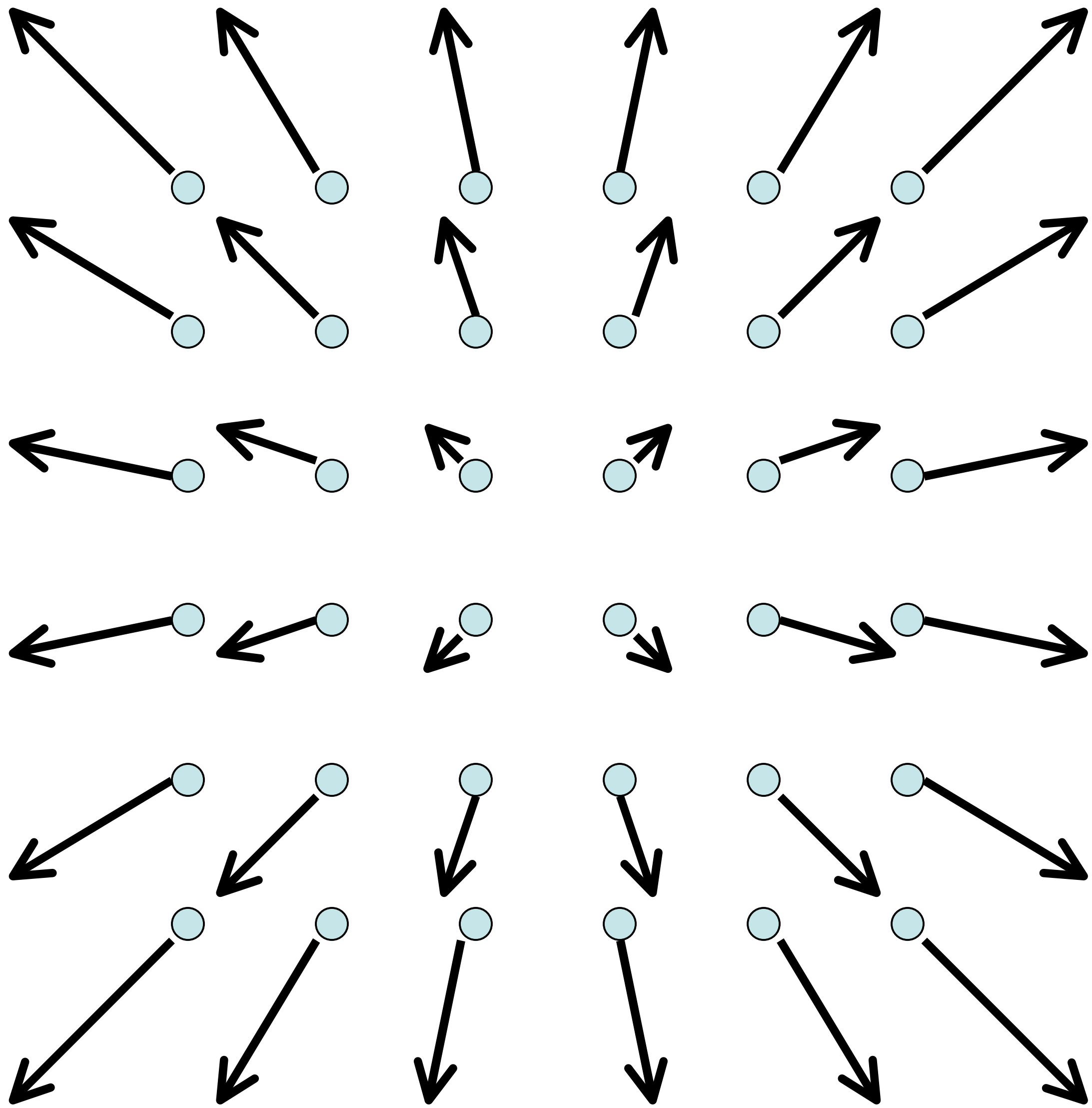


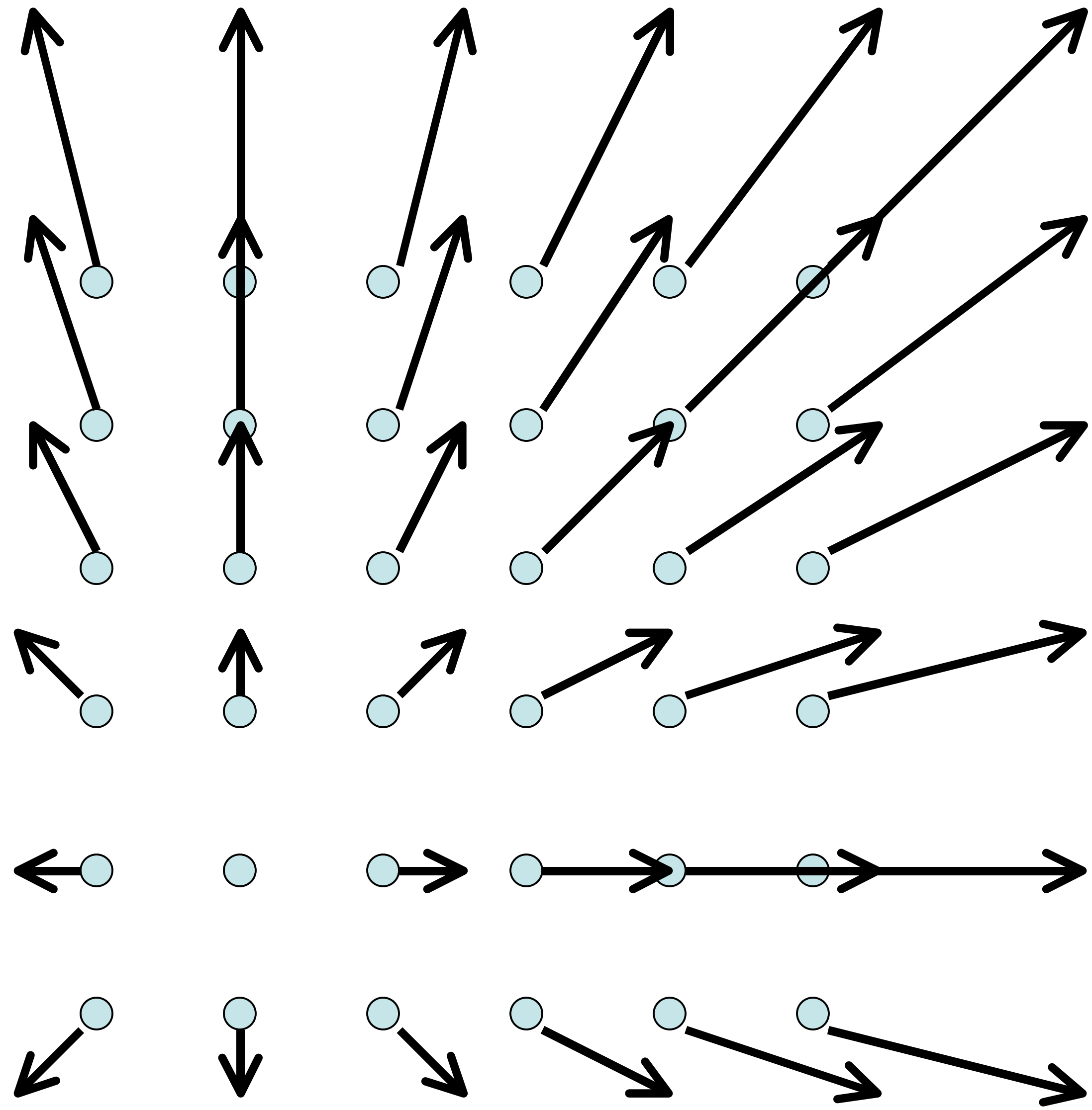
Then



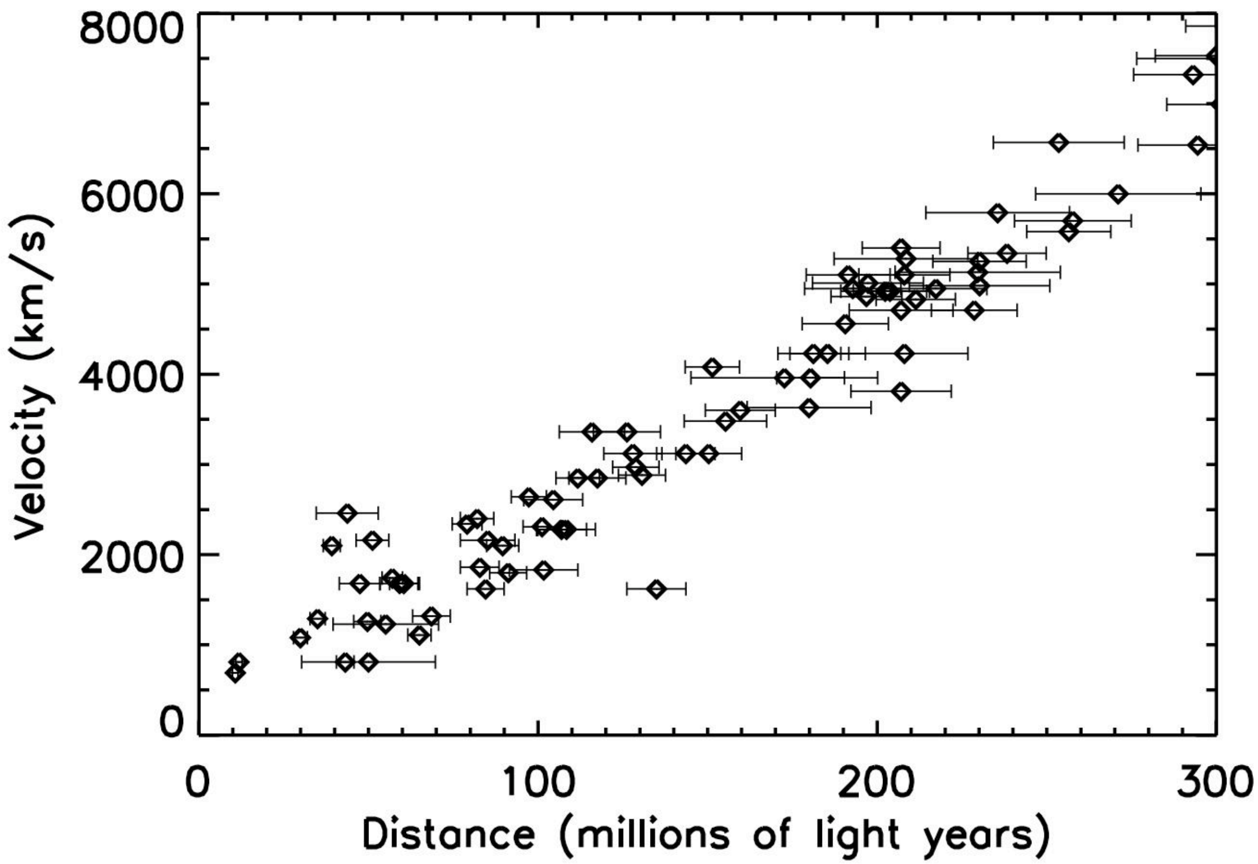
Now



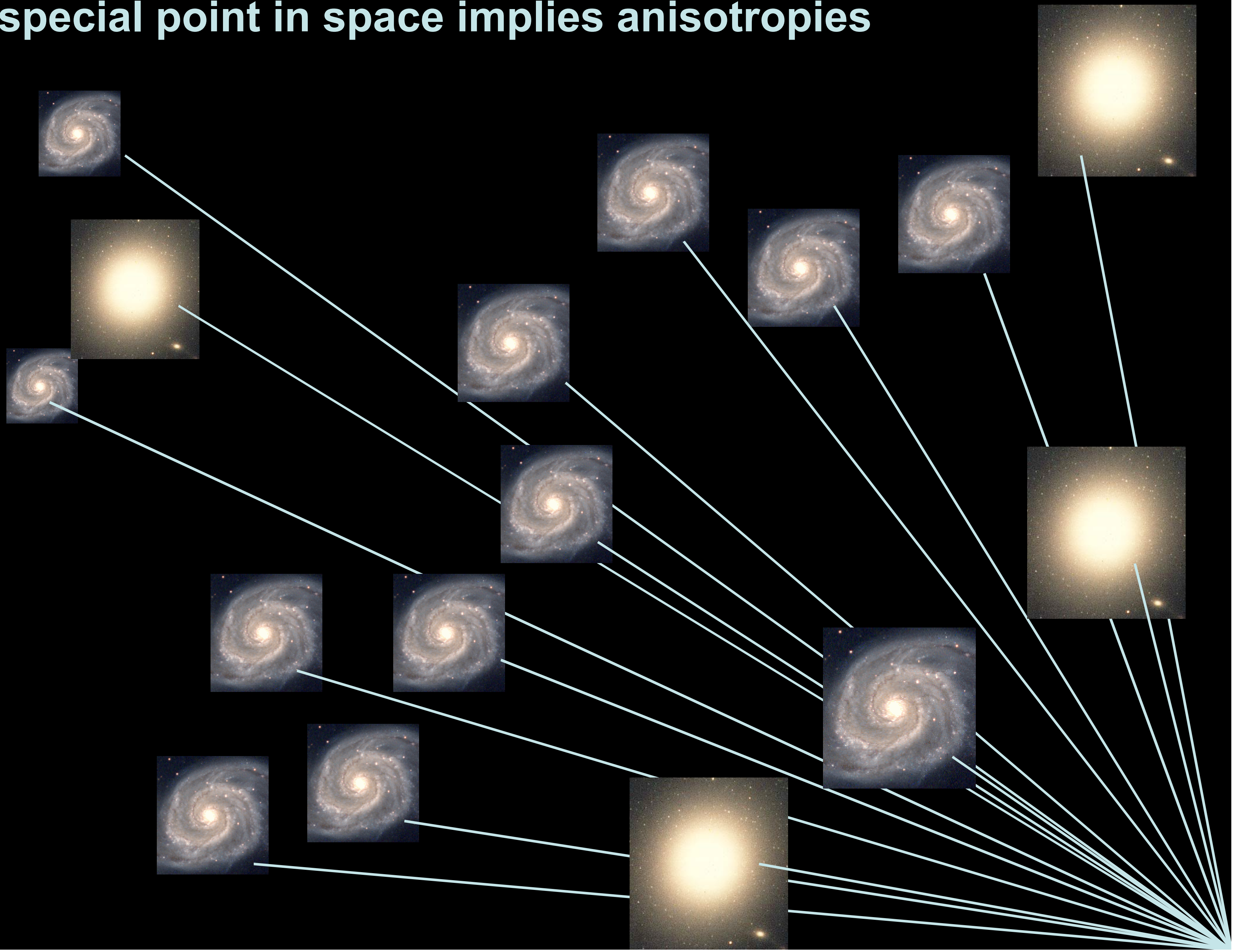




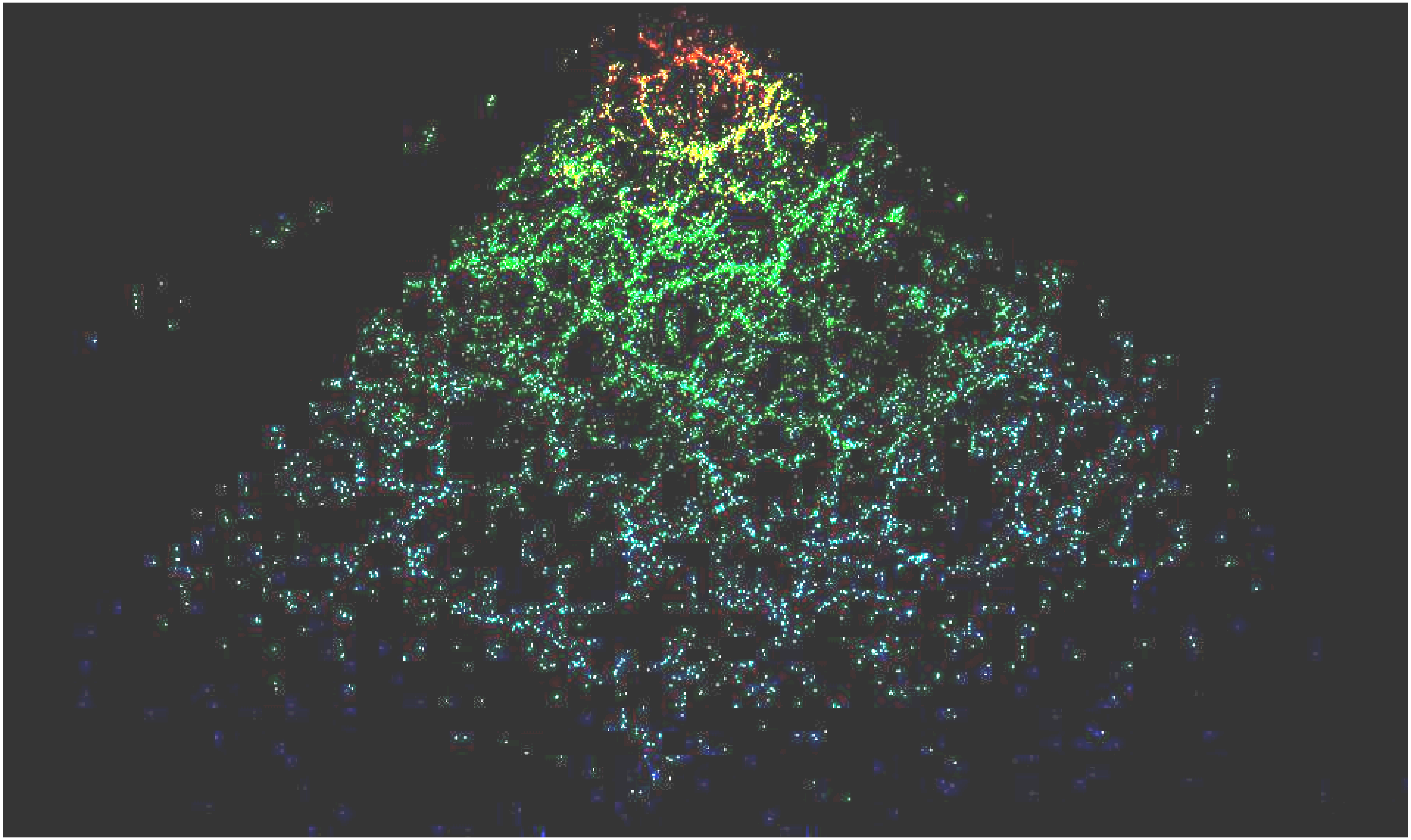
Hubble Diagram



A special point in space implies anisotropies

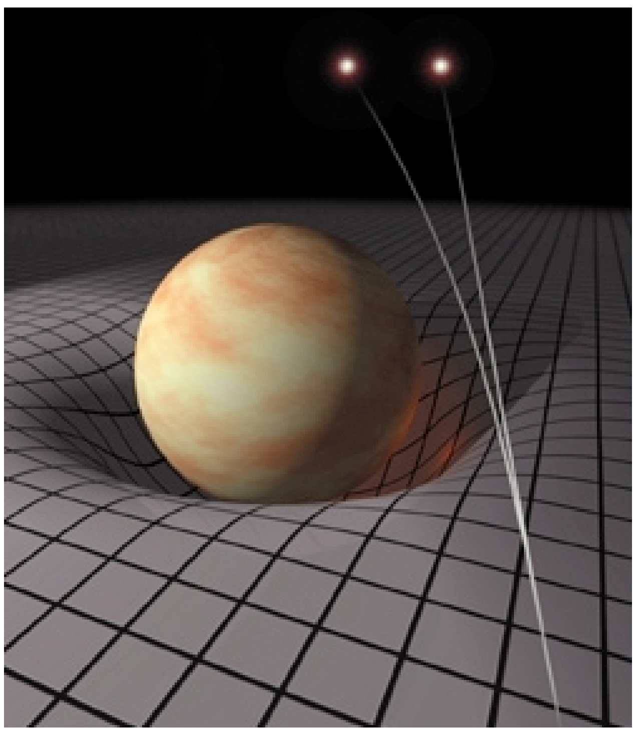


Large scale anisotropies are not observed



Distribution of galaxies from the Sloan Digital Sky Survey

General Relativity



$$\delta R^0{}_{00j} = -(a'/a)' B \mathrm{Y}_j\,,$$

$$\delta R^0{}_{0ij} = 0\,,$$

$$\delta R^0{}_{i0j} = \Big[-2\Big(\frac{a'}{a}\Big)' A - \frac{a'}{a}A' + \frac{k^2}{n}A + \frac{k}{n}\Big(B' + \frac{a'}{a}B\Big)$$
$$+ H_L'' + \frac{a'}{a}H_L' + 2\Big(\frac{a'}{a}\Big)' H_L\Big]\gamma_{ij}\mathrm{Y}$$
$$+\Big[-k^2 A - k\Big(B' + \frac{a'}{a}B\Big) + H_T'' + \frac{a'}{a}H_T' + 2\Big(\frac{a'}{a}\Big)' H_T\Big]\mathrm{Y}_{ij}\,,$$

$$\delta R^0{}_{ijm} = k\Big[-\frac{a'}{a}A + \frac{k}{n}B + H_L' + \frac{1}{n}\Big(1 - \frac{nK}{k^2}\Big)(H_T' - kB)\Big](\gamma_{ij}\mathrm{Y}_m - \gamma_{im}\mathrm{Y}_j),$$

$$\delta R^i{}_{00j} = \Big[\frac{k^2}{n}A - \frac{a'}{a}A' + \frac{k}{n}\Big(B' + \frac{a'}{a}B\Big) + H_L'' + \frac{a'}{a}H_L'\Big]\delta^i{}_j\mathrm{Y}$$
$$+\Big[-k\Big(B' + \frac{a'}{a}B\Big) - k^2 A + H_T'' + \frac{a'}{a}H_T'\Big]\mathrm{Y}^i{}_j\,,$$

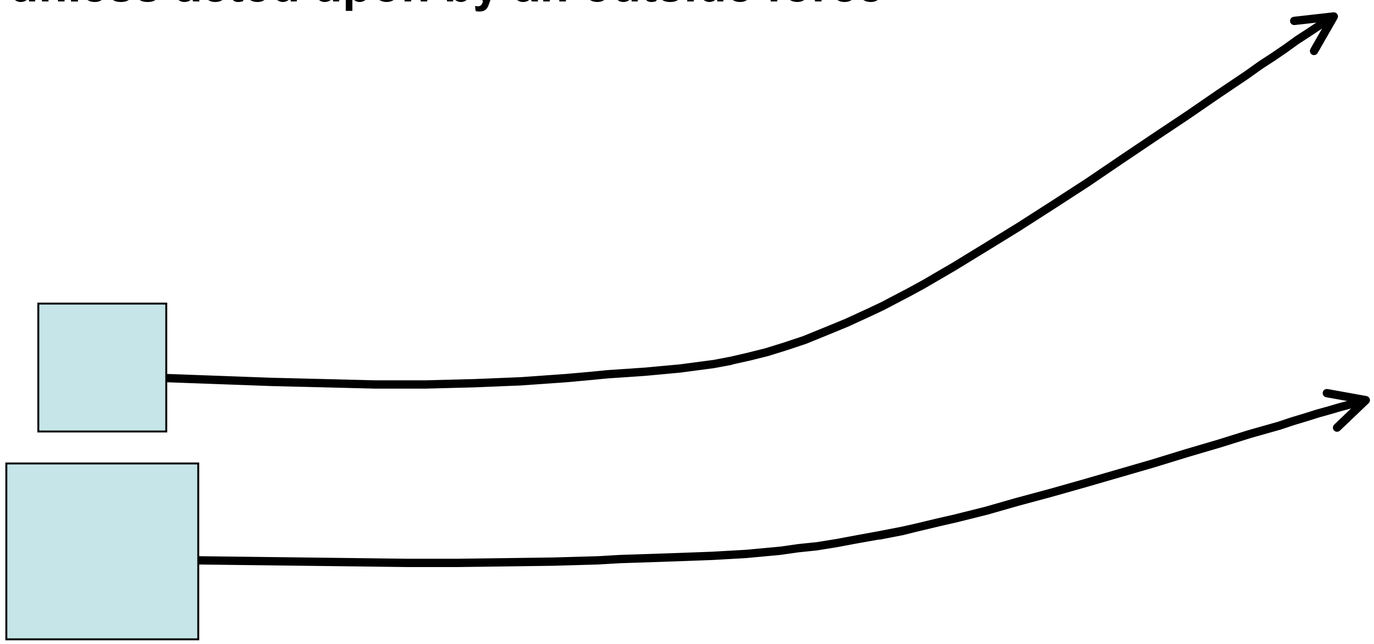
$$\delta R^i{}_{0jm} = \Big[kH_L' - \frac{a'}{a}\Big(kA + \frac{a'}{a}B\Big) + \frac{k}{n}\Big(1 - \frac{nK}{k^2}\Big)H_T'\Big](\delta^i{}_j\mathrm{Y}_m - \delta^i{}_m\mathrm{Y}_j),$$

$$\delta R^i{}_{j0m} = \Big[\frac{a'}{a}\Big(kA + \frac{a'}{a}B\Big) - kH_L' - \frac{k}{n}\Big(1 - \frac{nK}{k^2}\Big)H_L'\Big](\delta^i{}_m\mathrm{Y}_j - \gamma_{jm}\mathrm{Y}^i)$$
$$+\Big(\frac{a'}{a}\Big)' B\gamma_{jm}\mathrm{Y}^i\,,$$

$$\delta R^i{}_{jmp} = \Big[-2\Big(\frac{a'}{a}\Big)^2 A + \frac{2k}{n}\frac{a'}{a}B + 2\frac{a'}{a}H_L' + 2\Big(\frac{a'}{a}\Big)^2 H_L + \frac{2}{n}k^2 H_L\Big](\delta^i{}_m\gamma_{jp} - \delta^i{}_p\gamma$$
$$+\Big[k^2 H_L - \frac{a'}{a}(H_T' - kB)\Big](\delta^i{}_p\mathrm{Y}_{jm} - \delta^i{}_m\mathrm{Y}_{jp} + \mathrm{Y}^i{}_p\gamma_{jm} - \mathrm{Y}^i{}_m\gamma_{jp})$$
$$+2\Big(\frac{a'}{a}\Big)^2 H_T(\delta^i{}_m\mathrm{Y}_{jp} - \delta^i{}_p\mathrm{Y}_{jm})$$
$$+H_T(\mathrm{Y}^i{}_{j|pm} - \mathrm{Y}^i{}_{j|mp} + \mathrm{Y}^i{}_{p|jm} - \mathrm{Y}^i{}_{m|jp} + \mathrm{Y}_{jm}{}^{|i}{}_{|p} - \mathrm{Y}_{jp}{}^{|i}{}_{|m}).$$

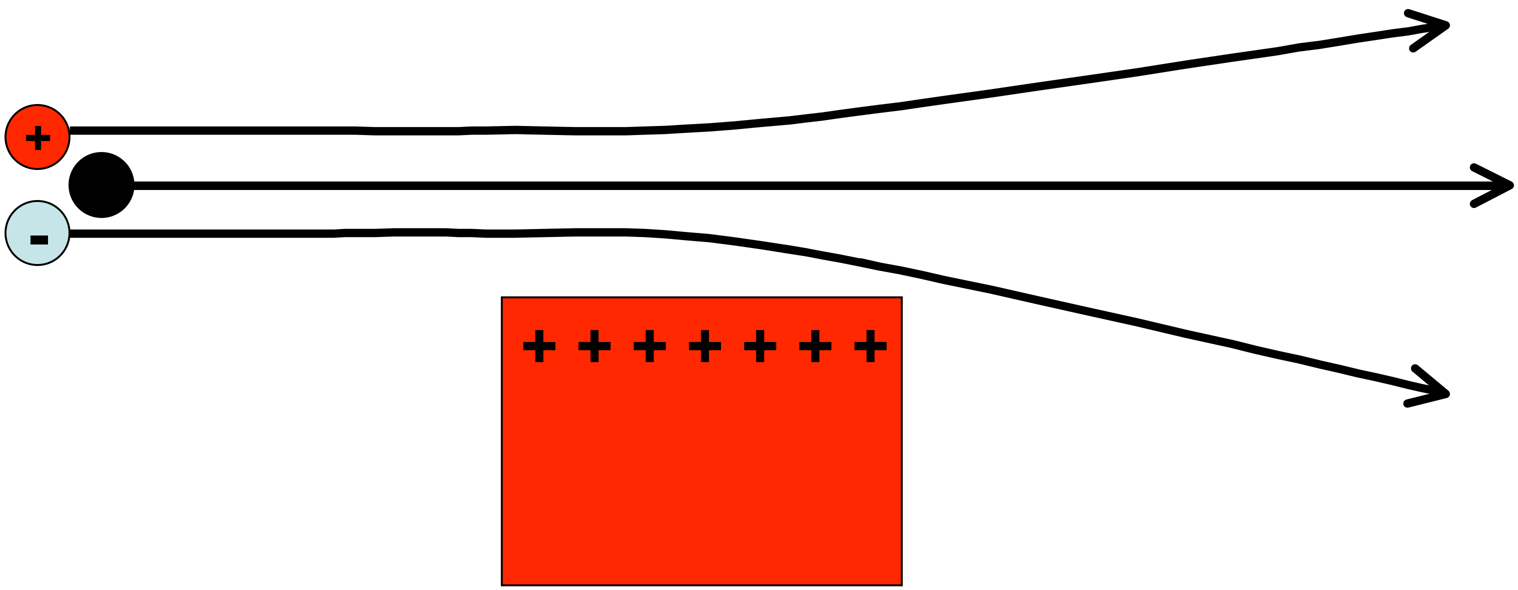
Classical Mechanics

An object travels in a straight line at a constant speed unless acted upon by an outside force

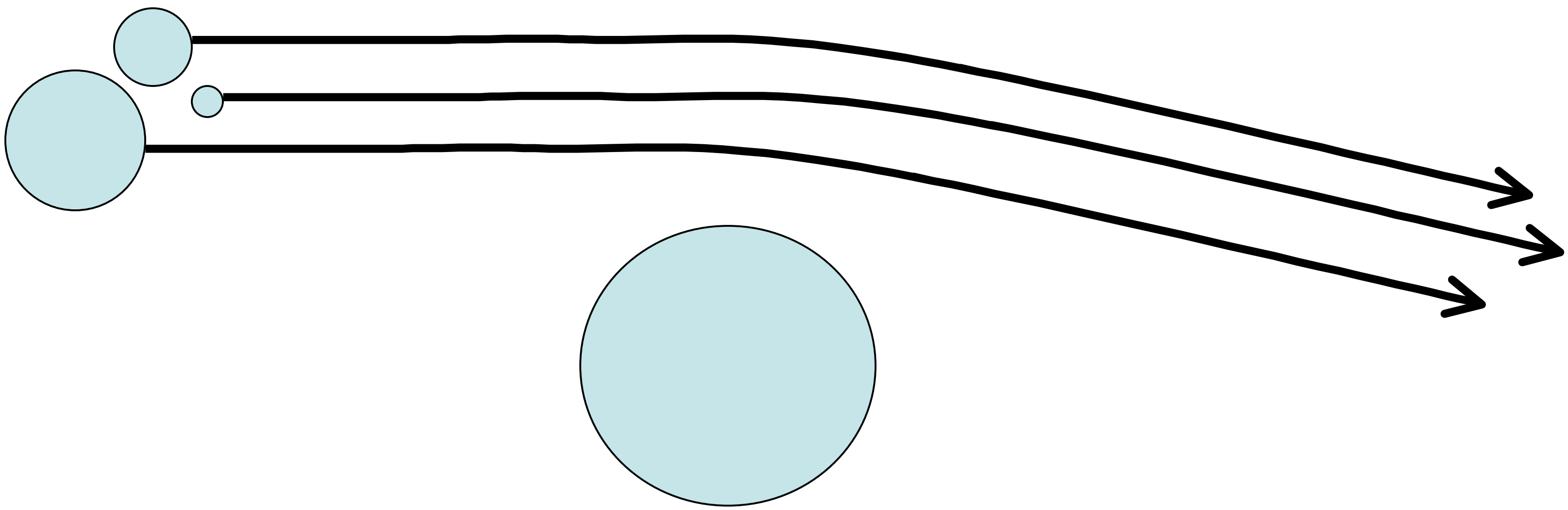


A force changes the motion of an object by an amount that depends on its mass

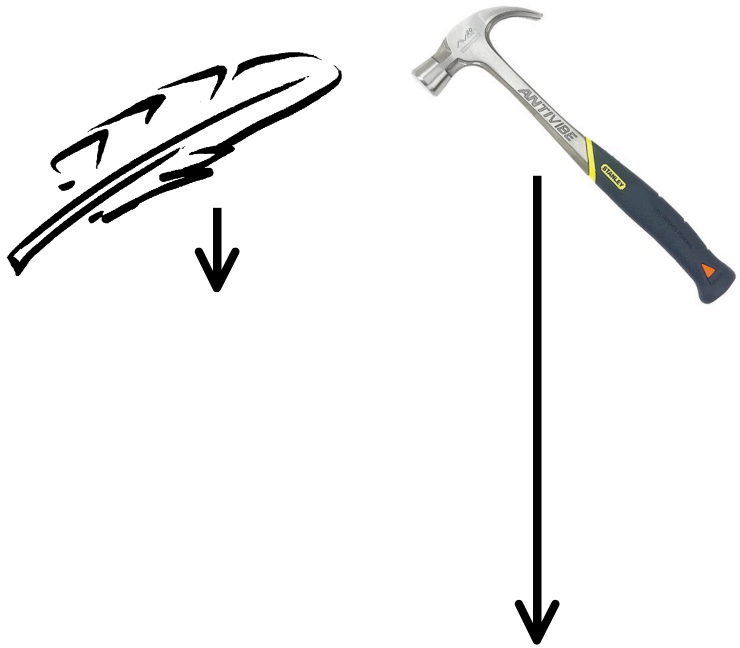
Objects move differently due to their composition



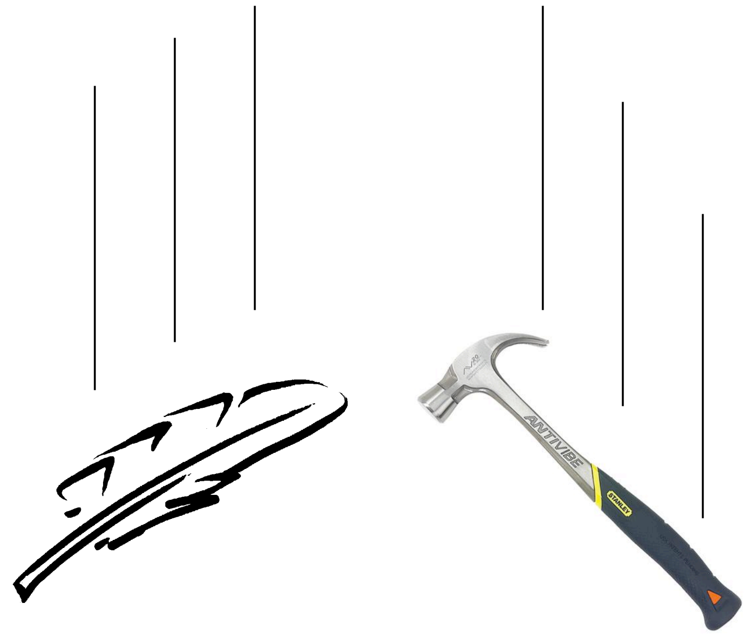
Unless the force is gravity



Gravity in Classical Mechanics

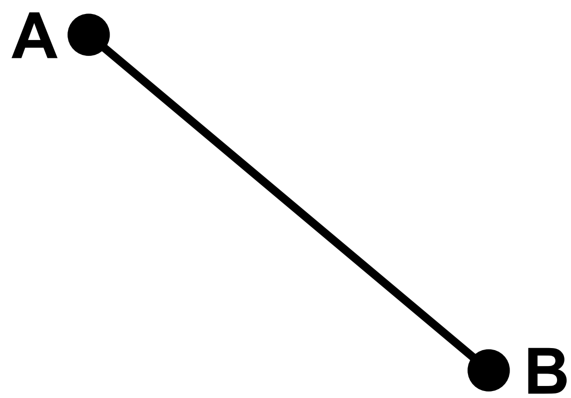


The more massive object feels a sronger force

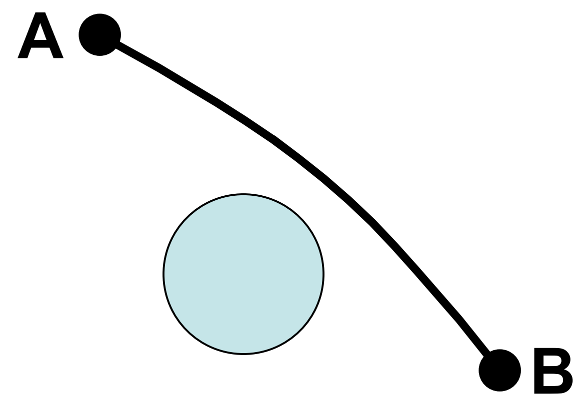


The more massive object requires more force to accelerate it by the same amount

Gravity in Classical Mechanics

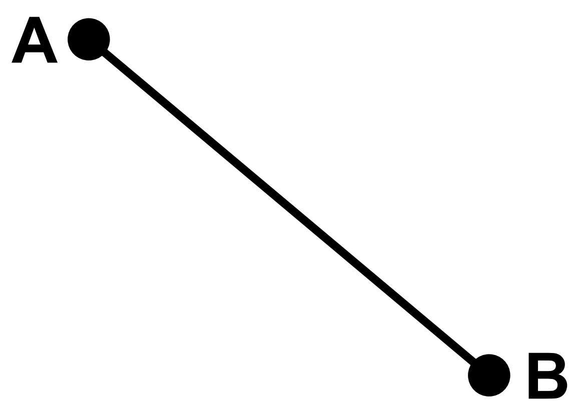


With no outside forces, all particles take the path with the shortest distance between two points

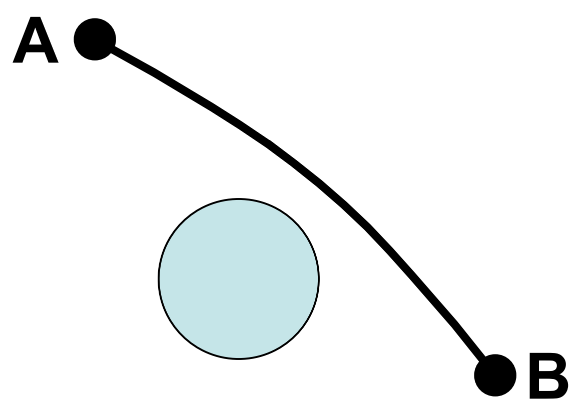


The presence of a massive object exerts a force that causes all objects to deviate from this path by the same amount

Gravity in General Relativity

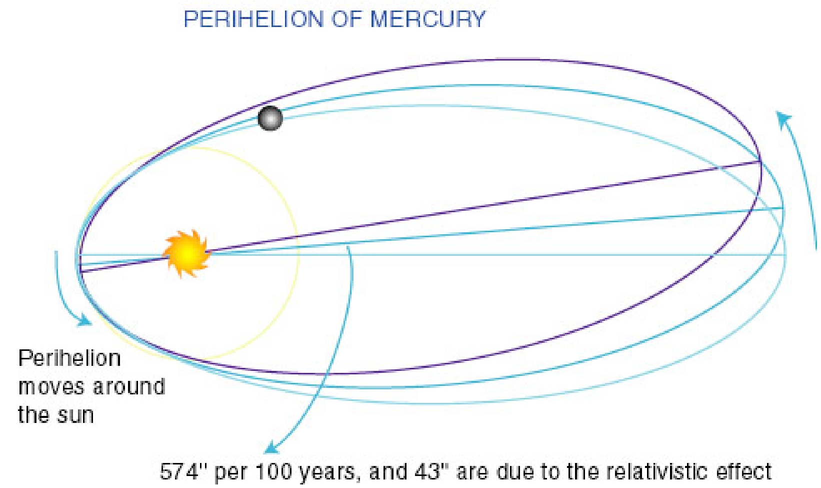


With no outside forces, all particles take the path with the shortest distance between two points

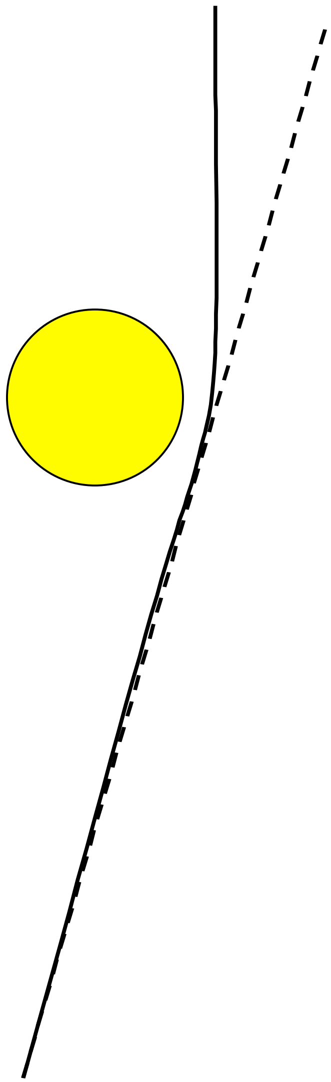


The presence of a massive object **changes which path is the “shortest” distance between the two points**

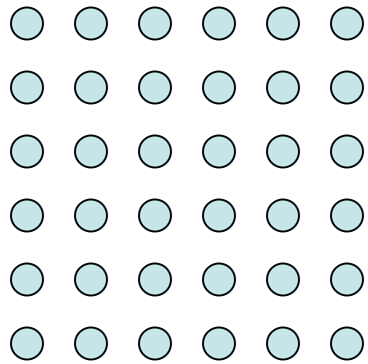
General Relativity Works



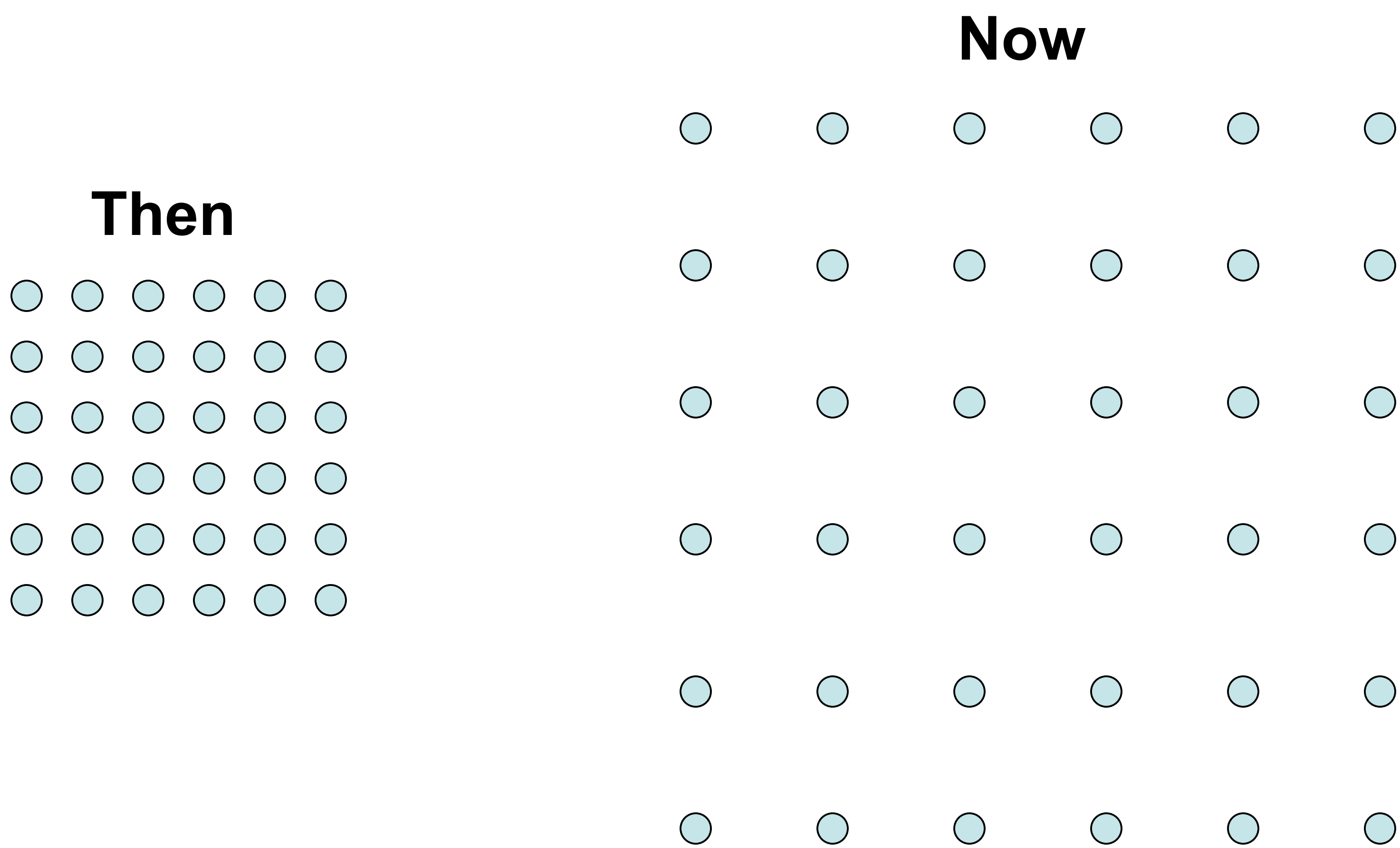
It explains irregularites in Mercury's orbit



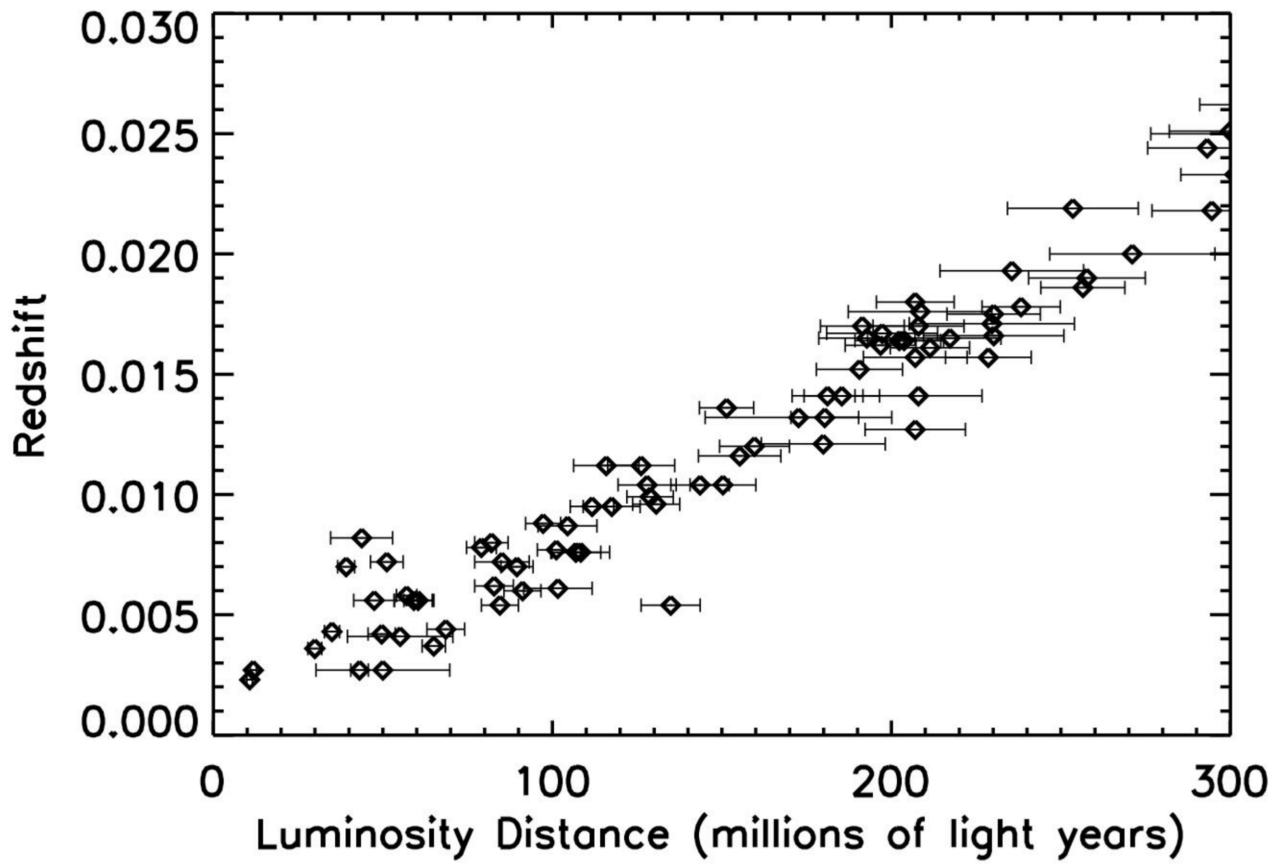
It predicted the gravitational lensing of starlight



The Expanding Universe

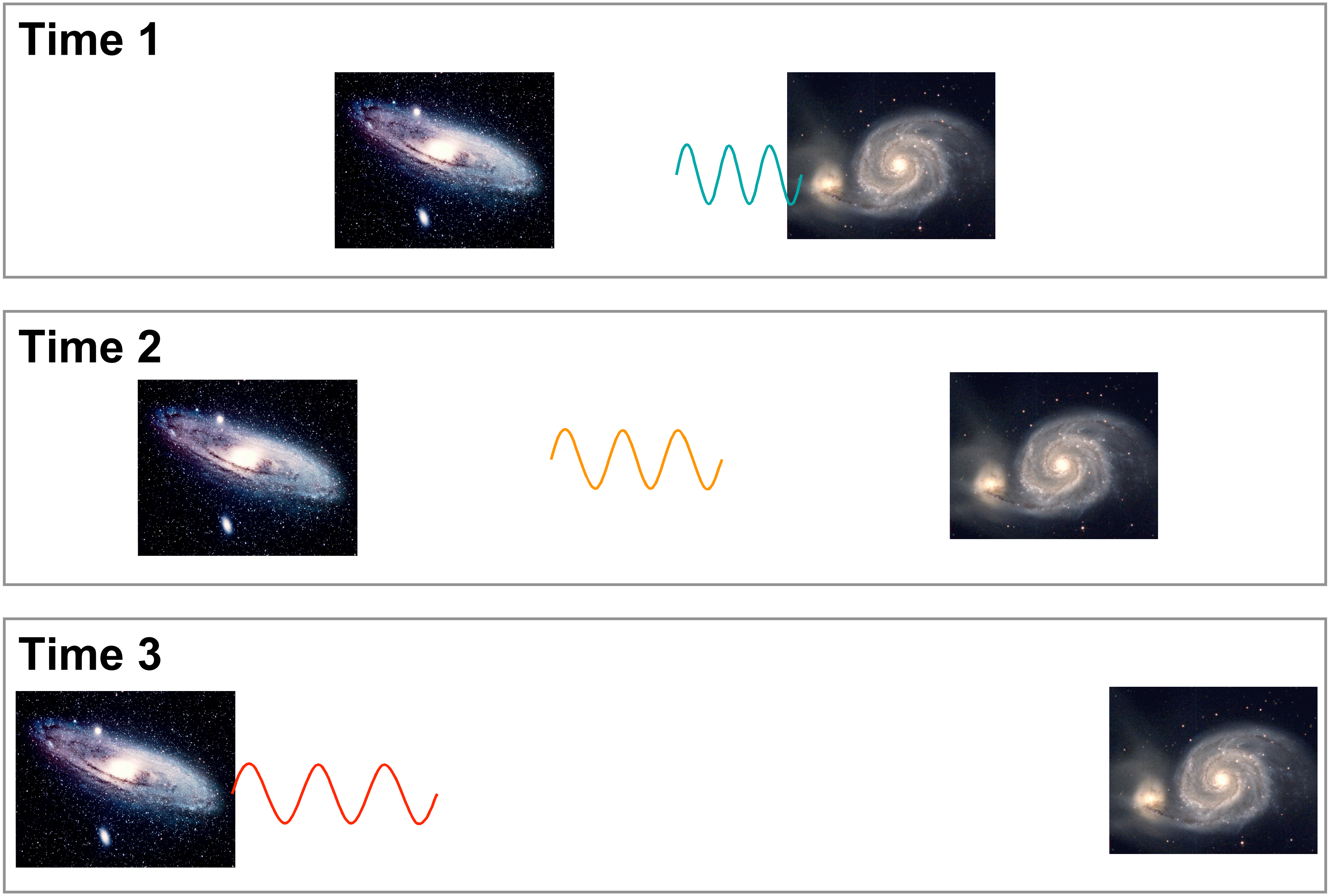


Re-interpreting the Hubble Diagram



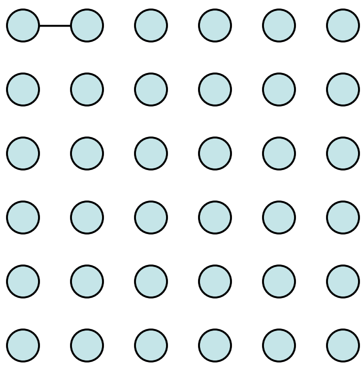
Based on Data from Tonry et. al. astro-ph/0305008

Redshifts in an Expanding Universe

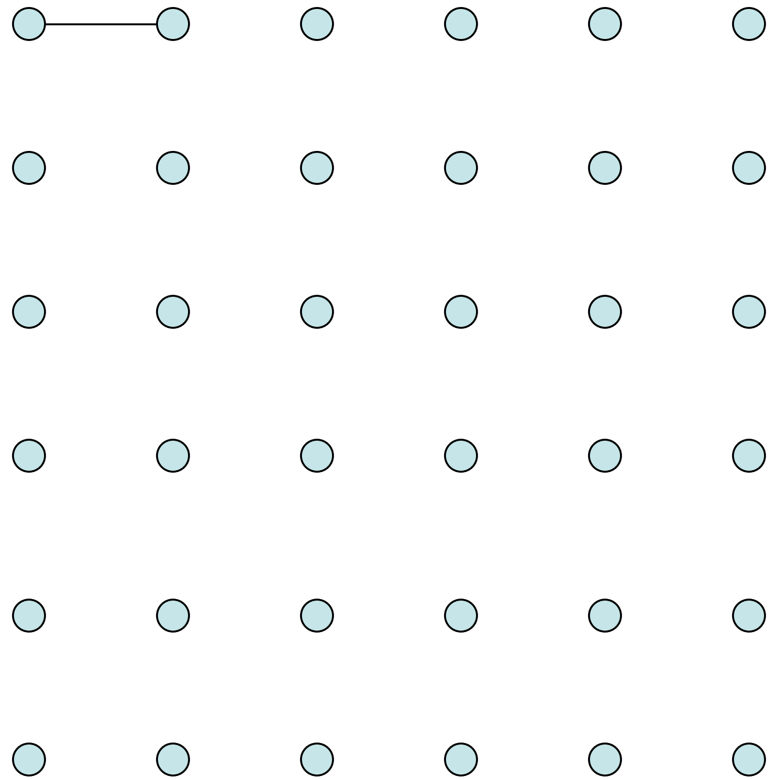


Scale Factor

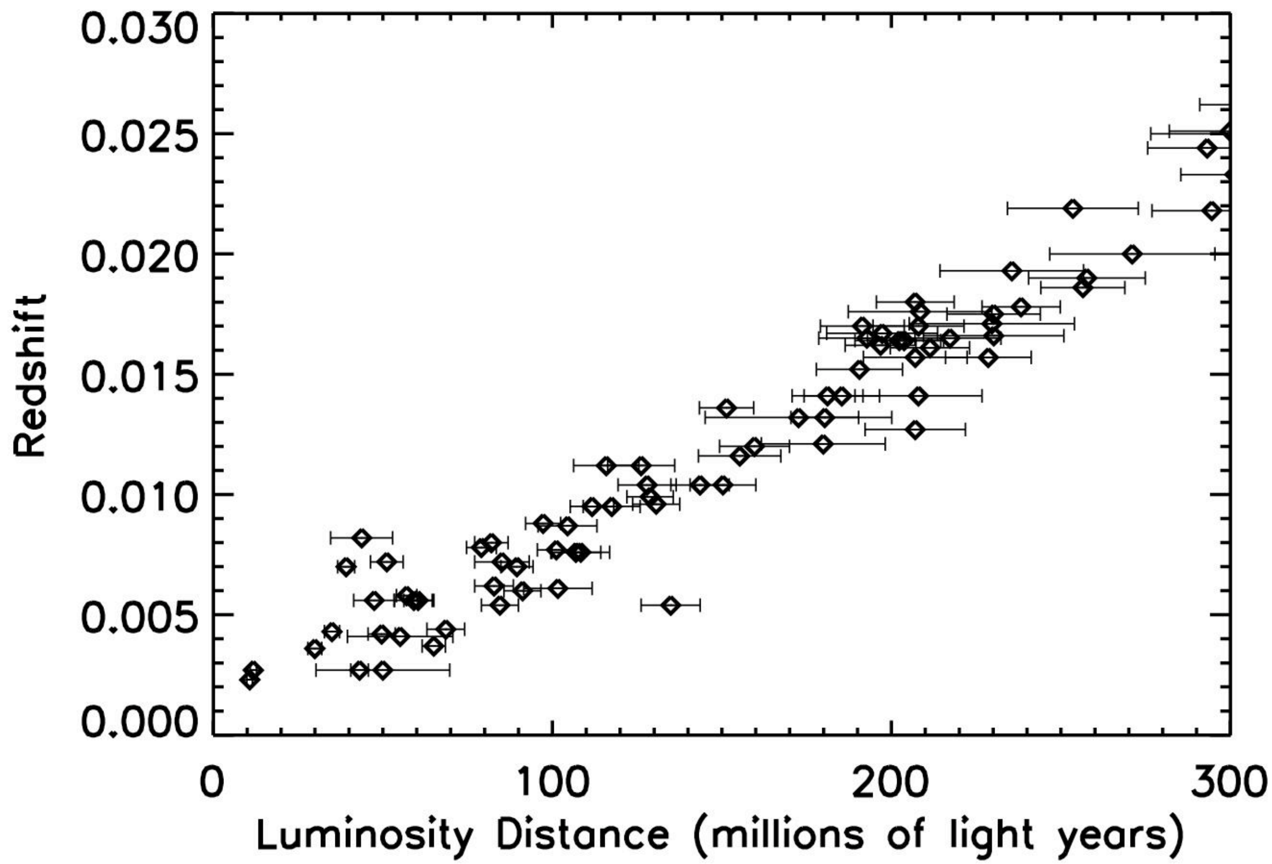
$a = 0.5$



$a = 1$

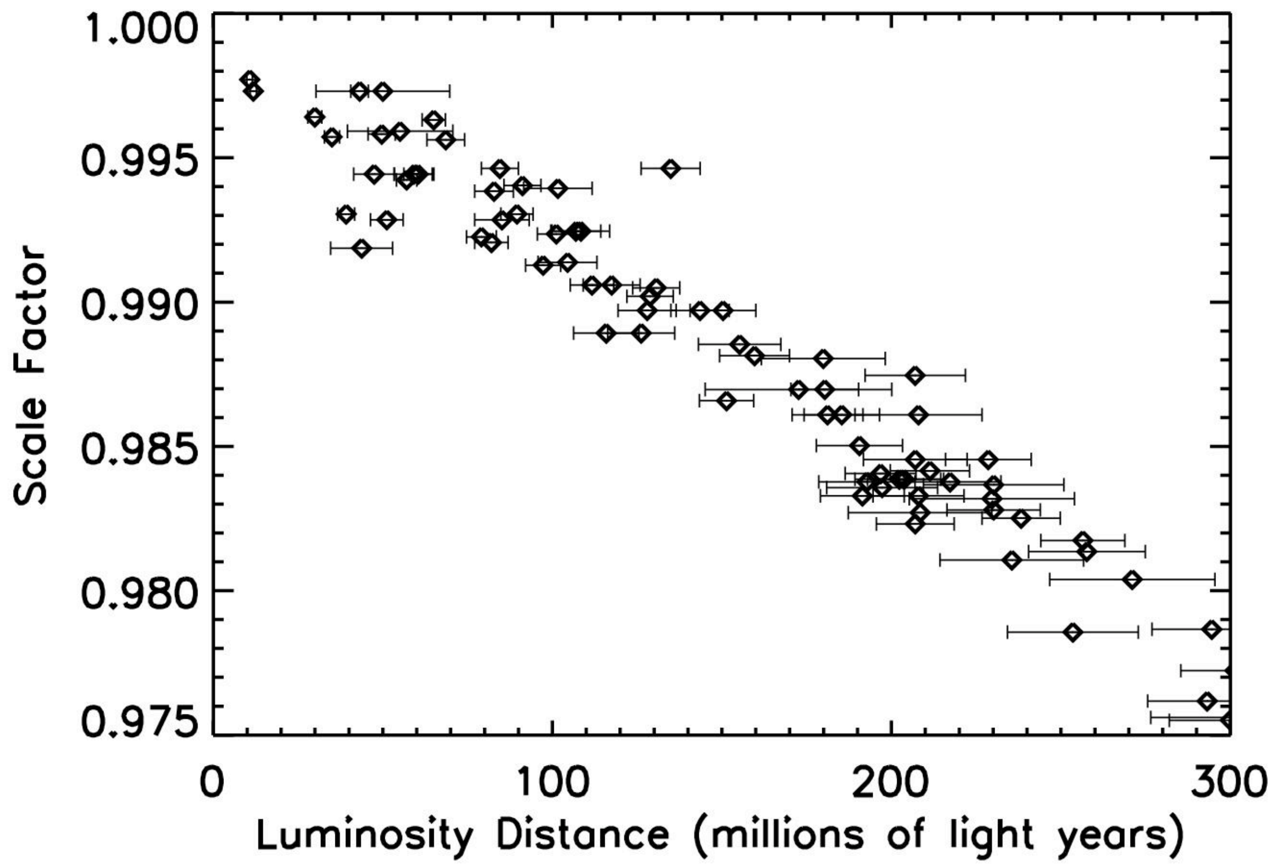


Re-interpreting the Hubble Diagram



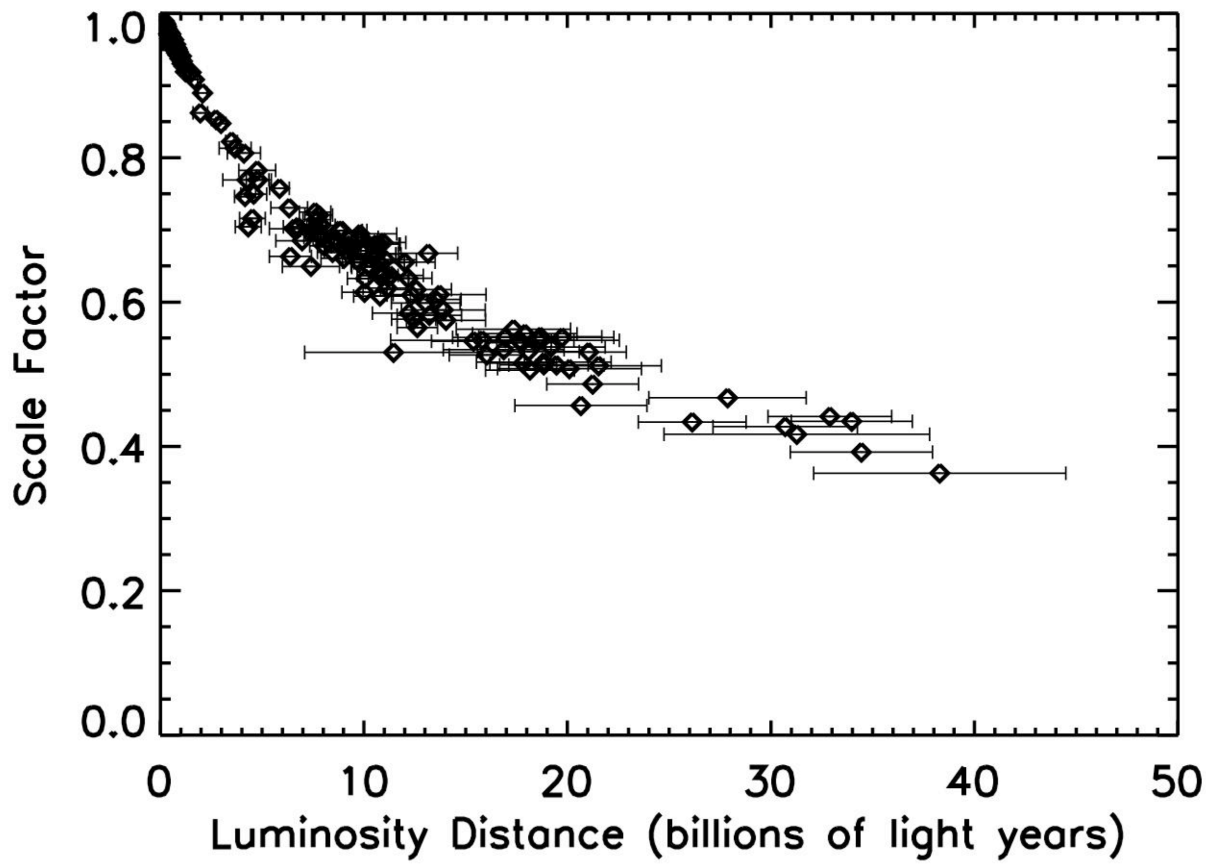
Based on Data from Tonry et. al. astro-ph/0305008

Re-interpreting the Hubble Diagram

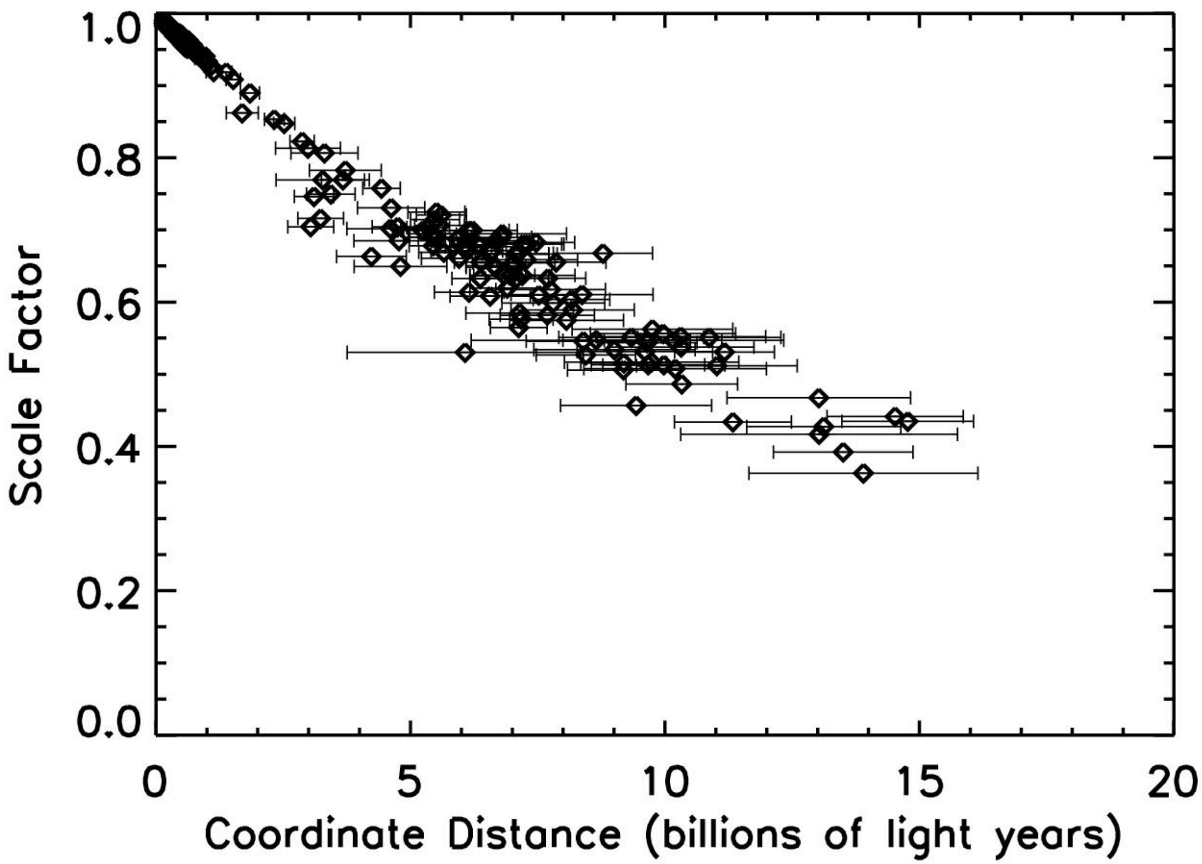


Based on Data from Tonry et. al. astro-ph/0305008

Re-interpreting the Hubble Diagram

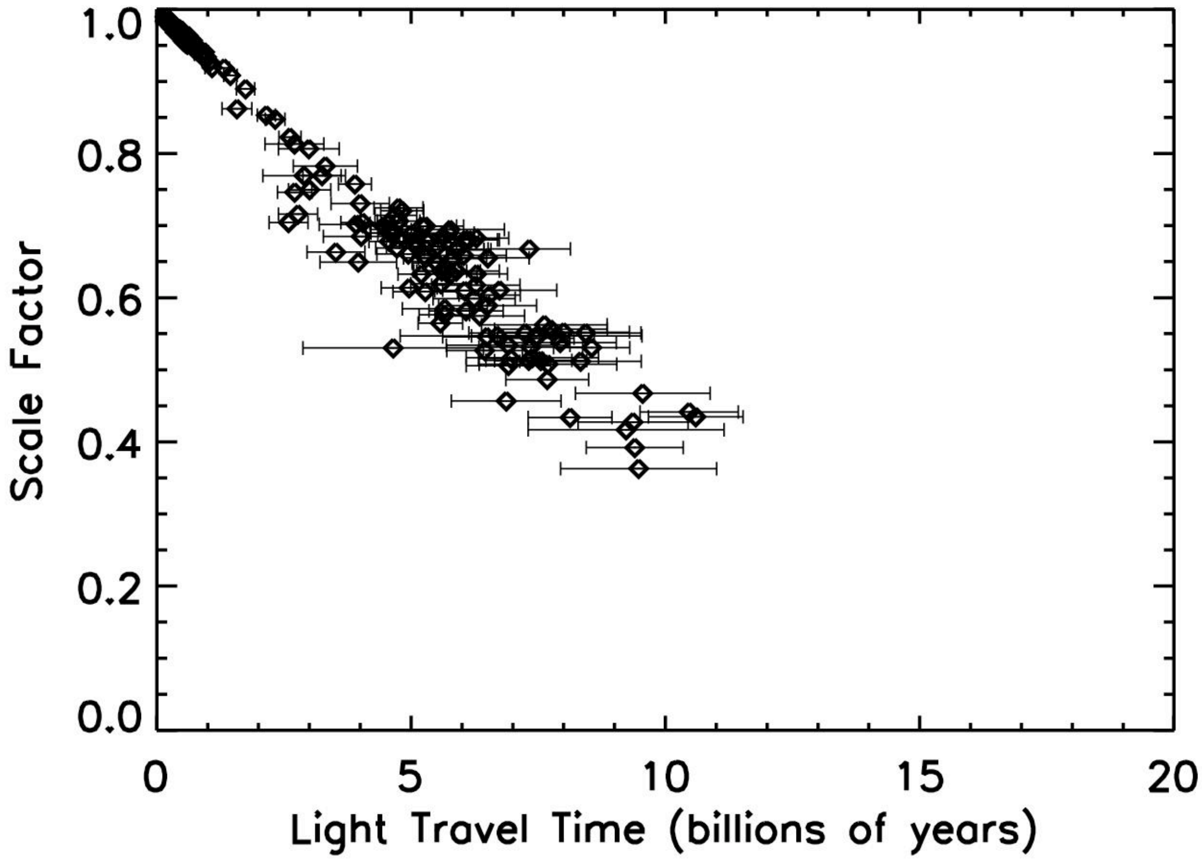


Based on Data from Riess et. al. astro-ph/0402512



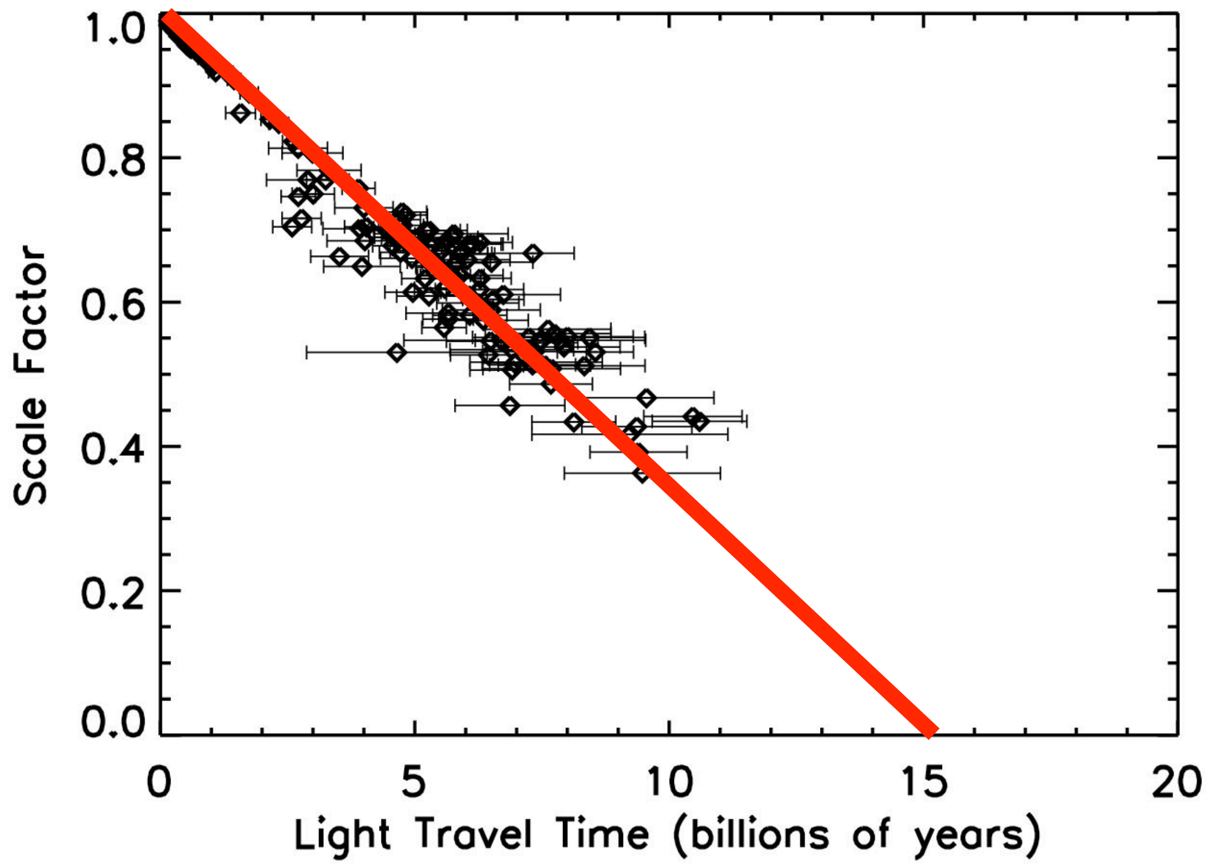
Based on Data from Riess et. al. astro-ph/0402512

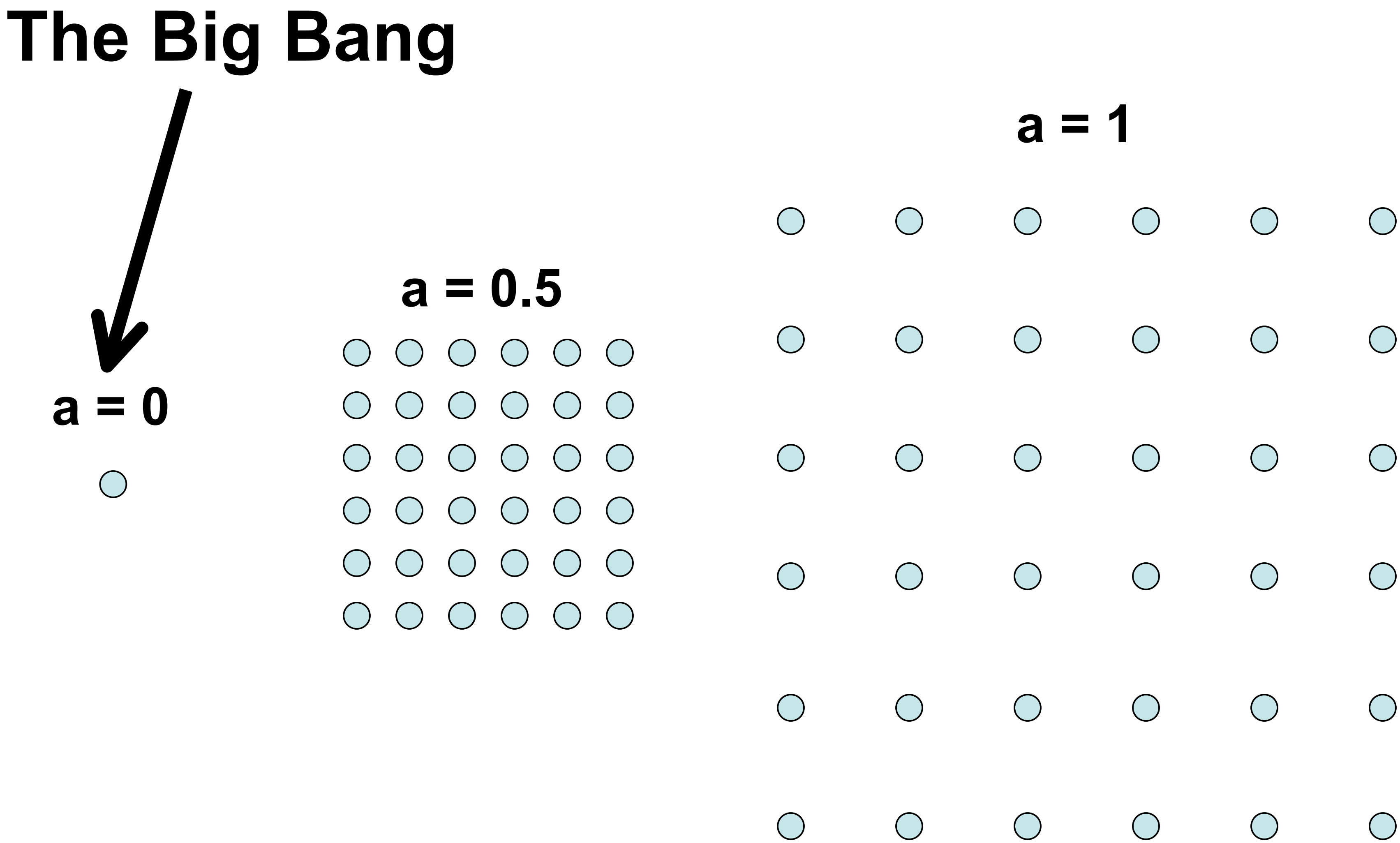
Re-interpreting the Hubble Diagram



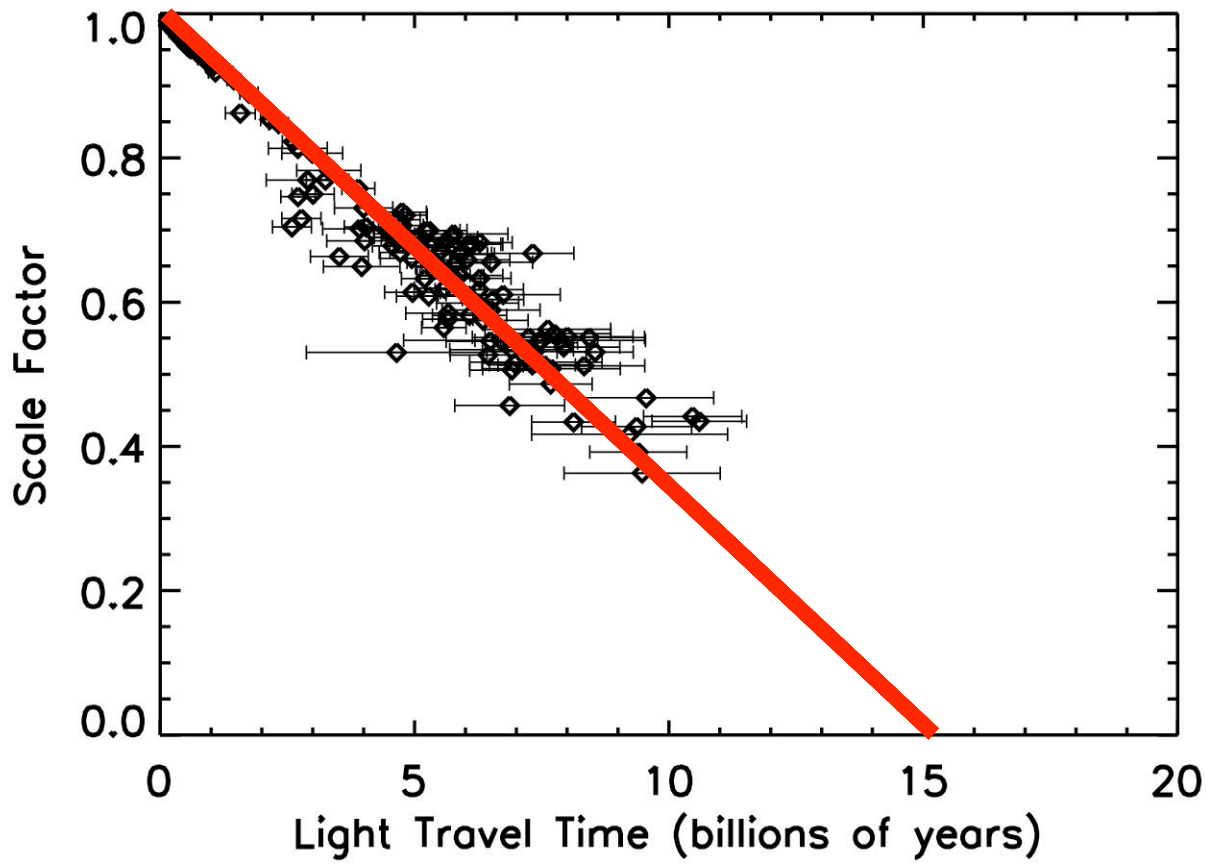
Based on Data from Riess et. al. astro-ph/0402512

Extraopolating back to the Big Bang

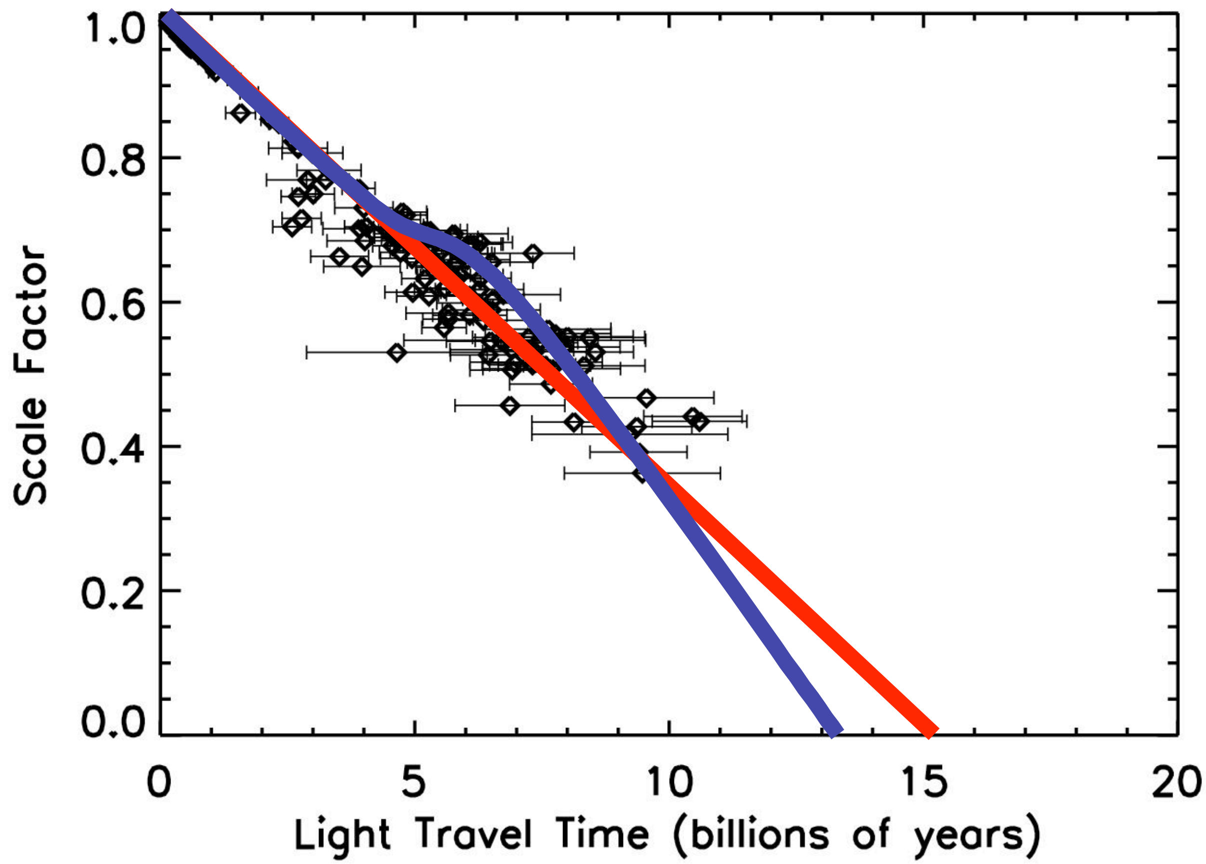



The Big Bang
a = 0
a = 0.5
a = 1

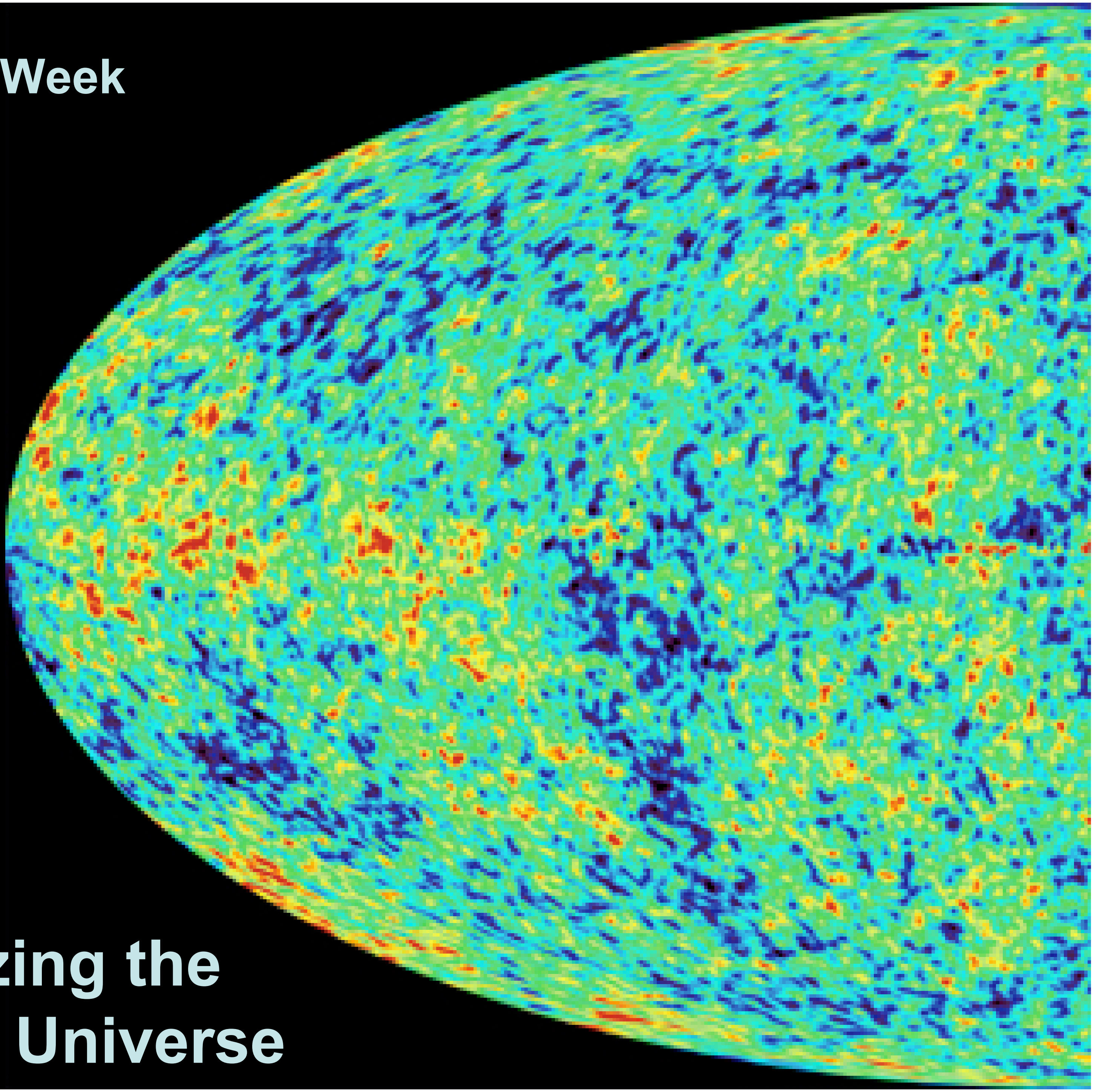
Extraopolating back to the Big Bang



We need more information to do an accurate extrapolation



No Talk Next Week



June 5:

Parametrizing the Age of the Universe