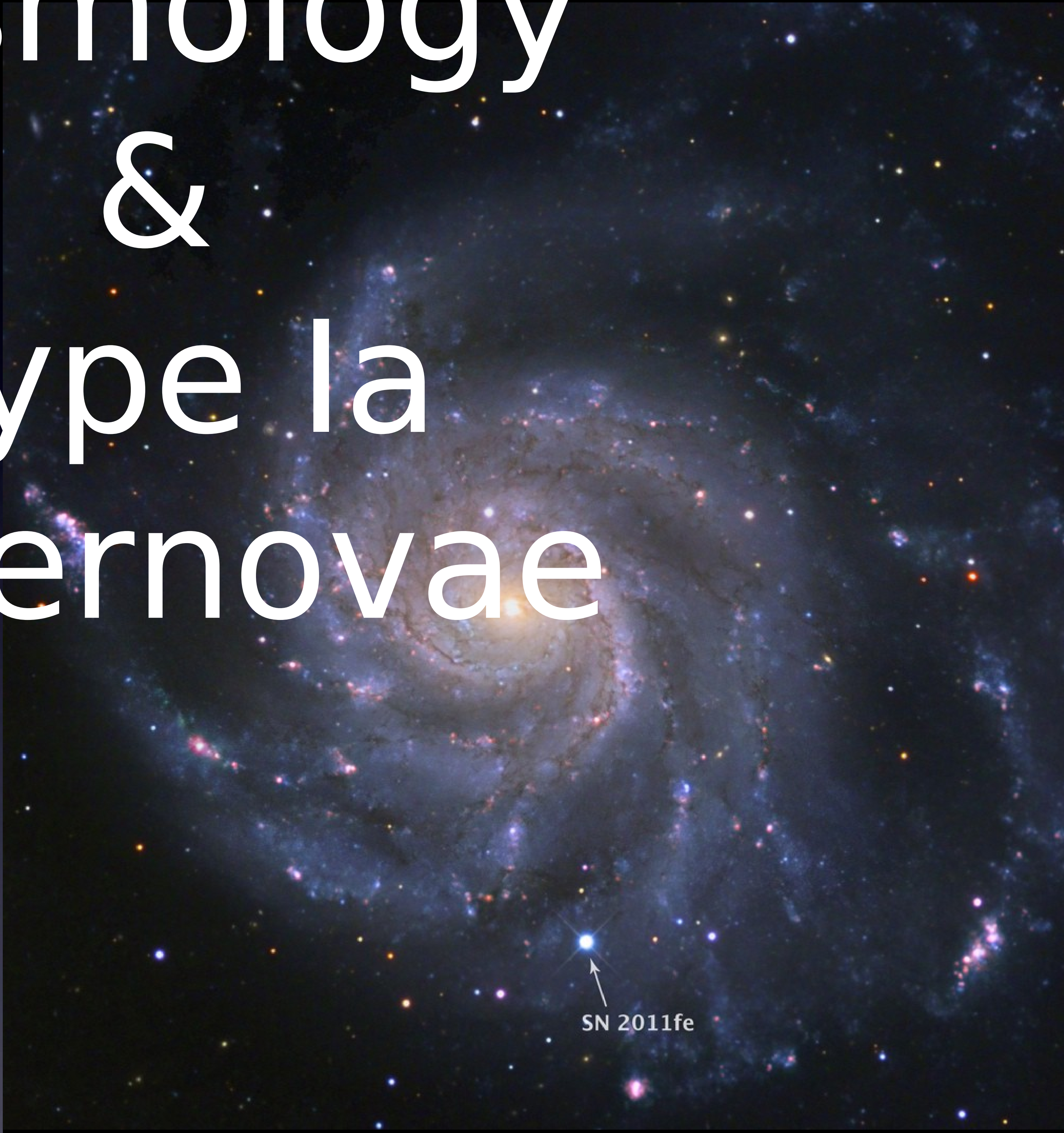
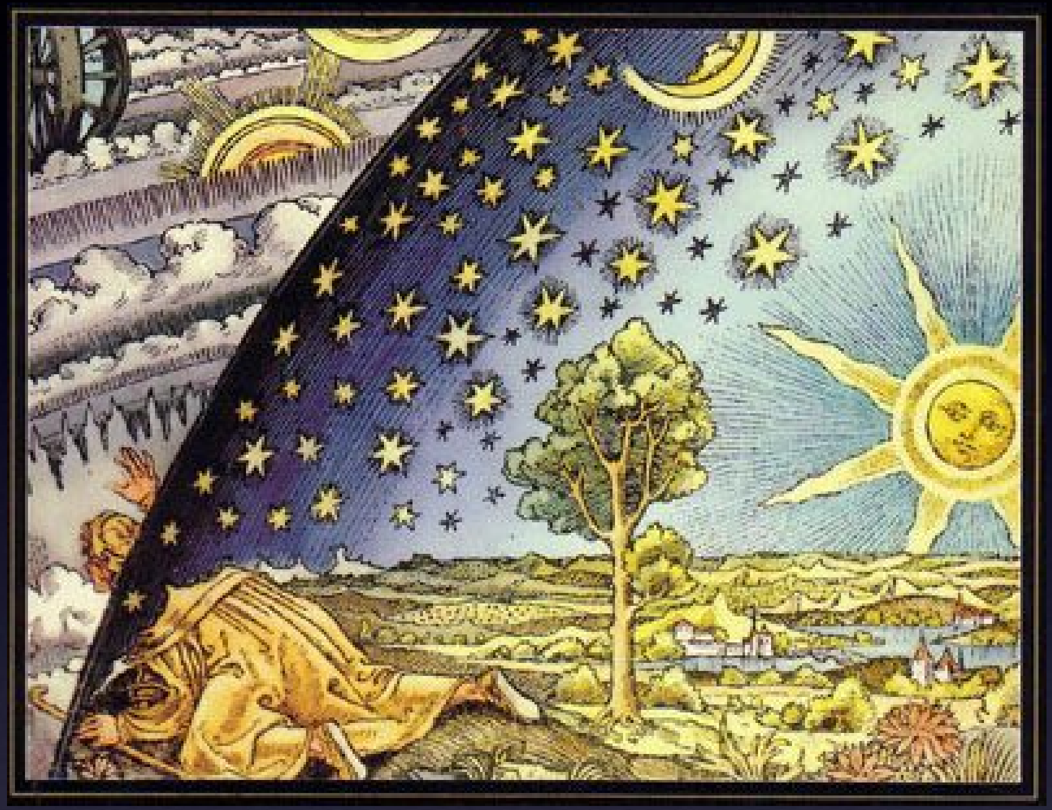
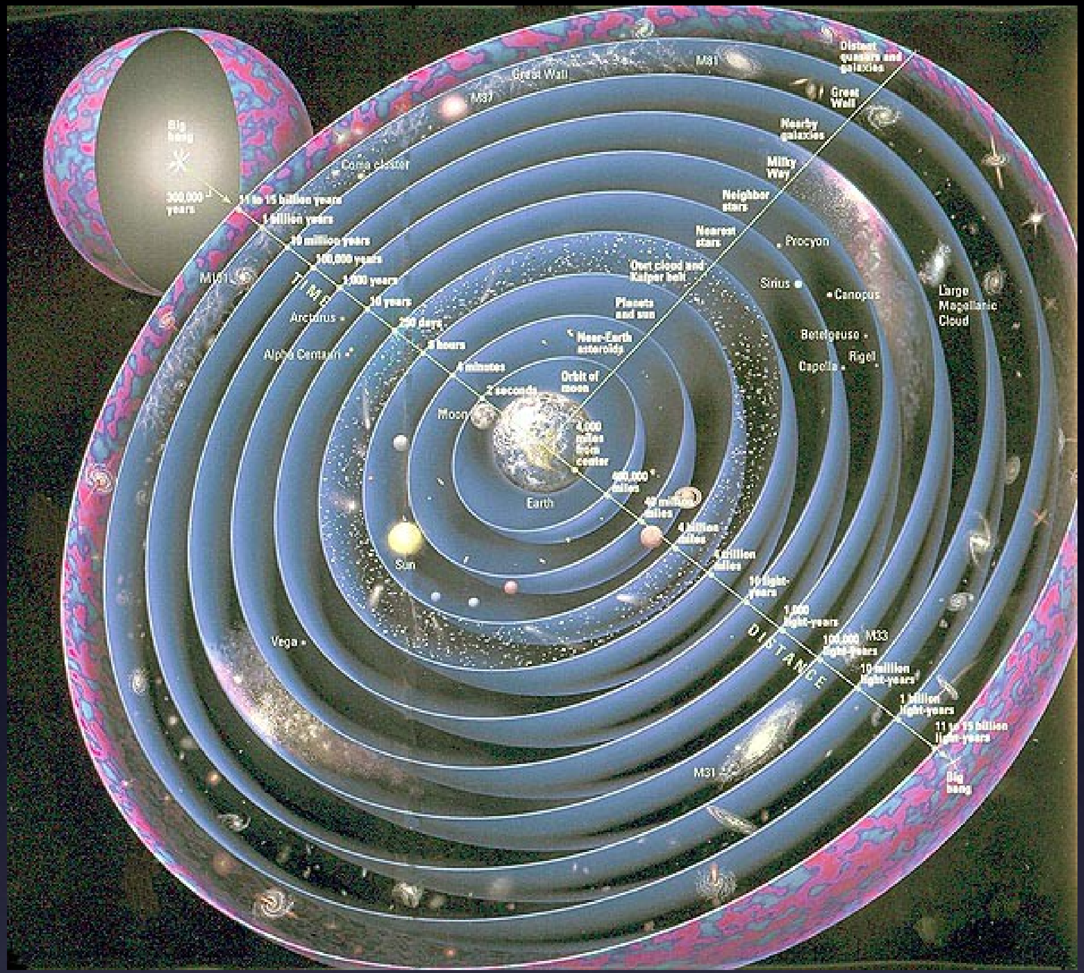
Cosmology
&
Type Ia supernovae



Sébastien “Ze Frog” Bongard

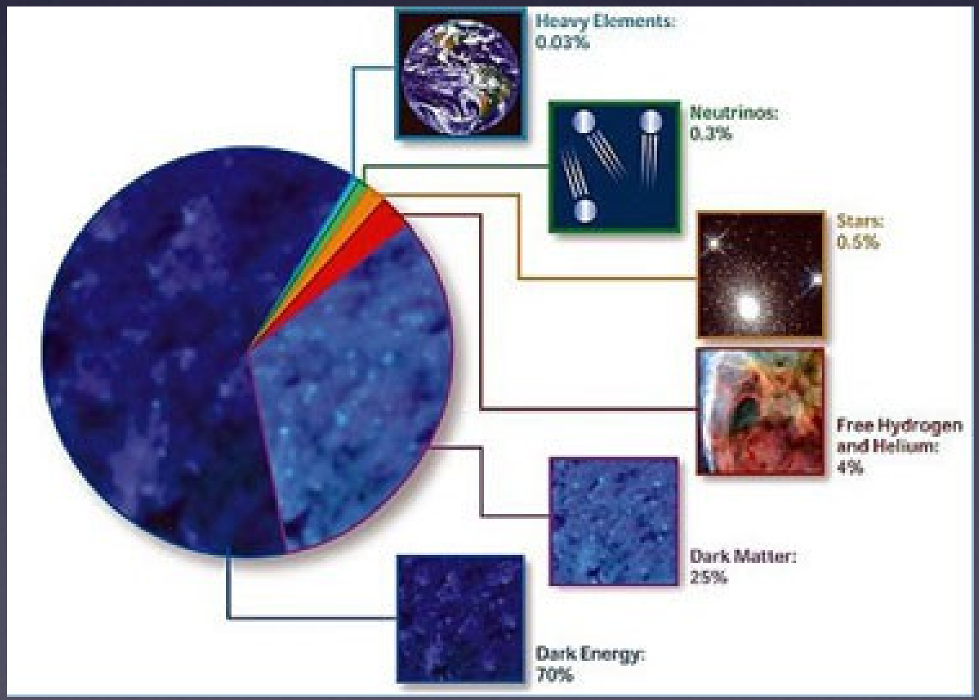
Observational cosmology





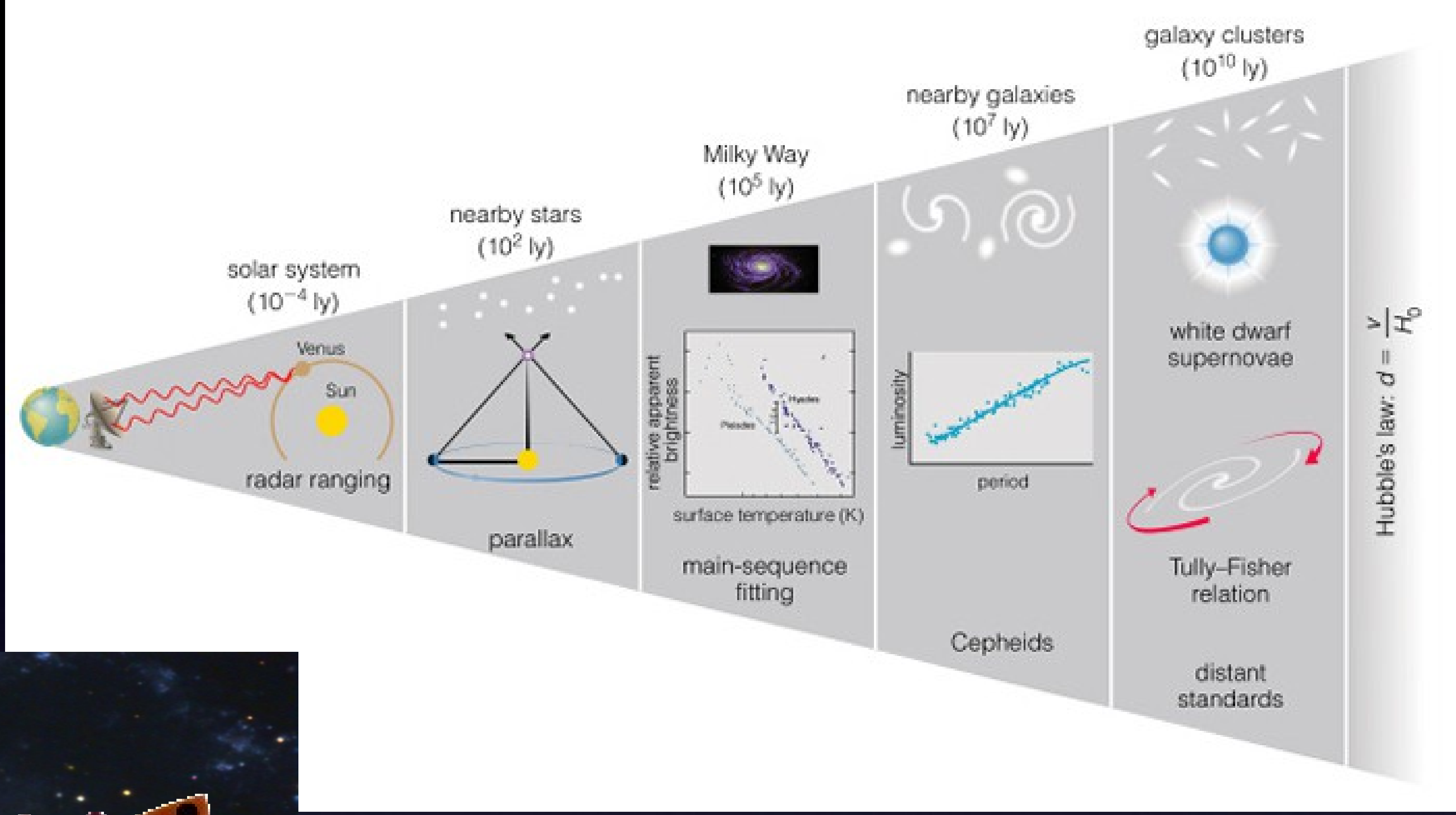
Observing around us

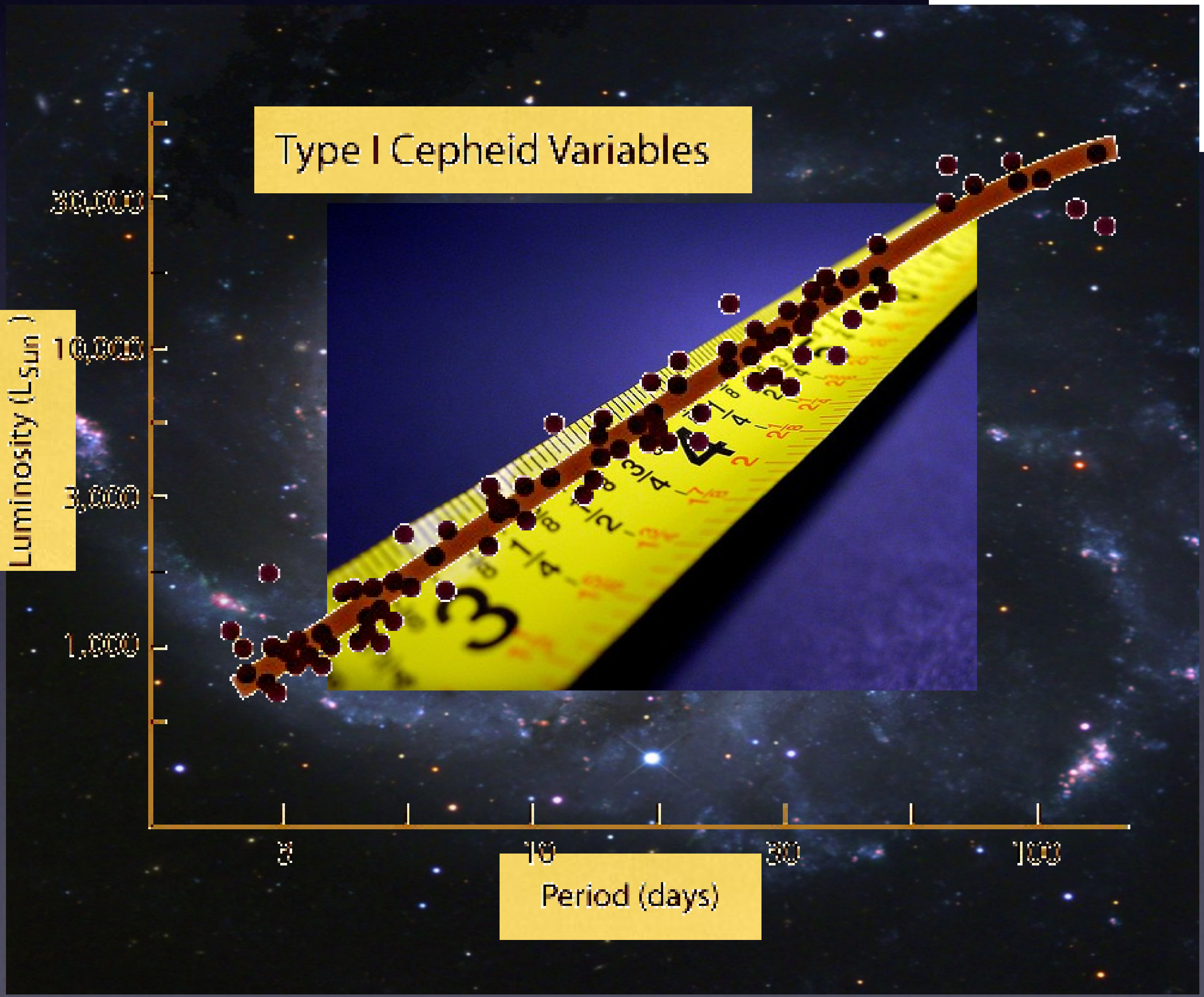
and build models to explain what we perceive

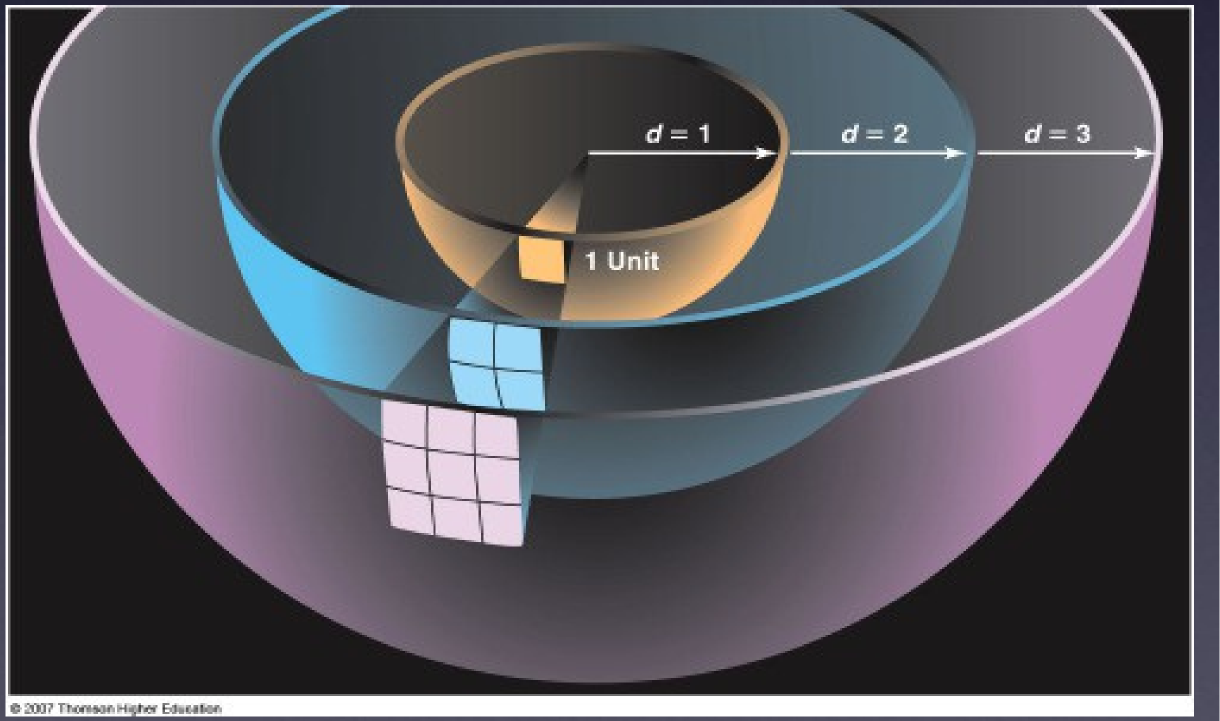


The universe is the object of study

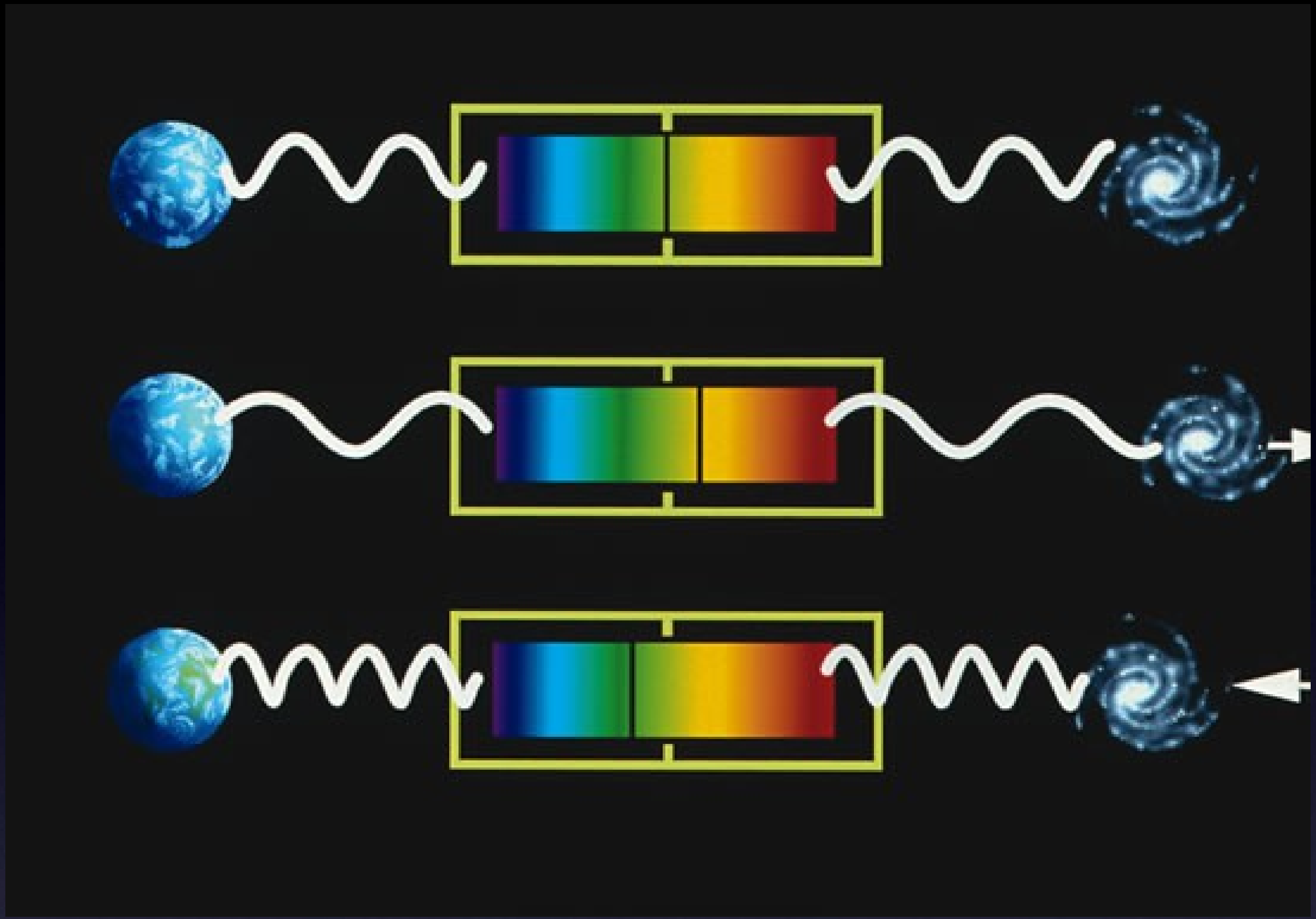
Measuring distances







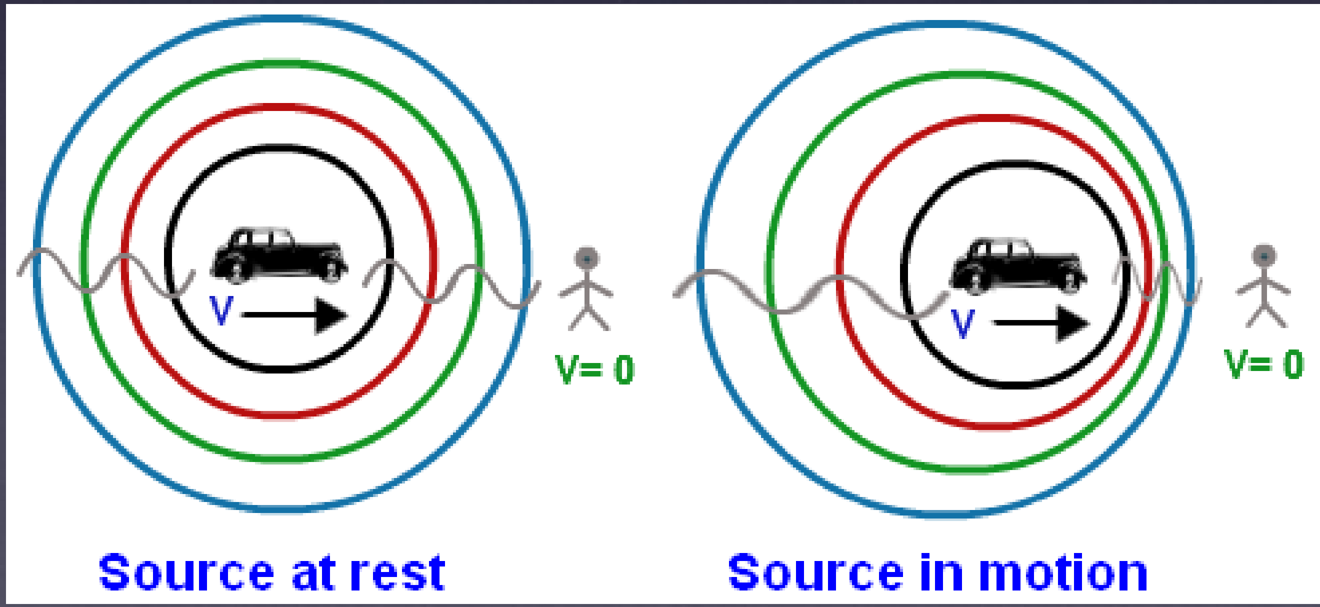
Measuring velocities



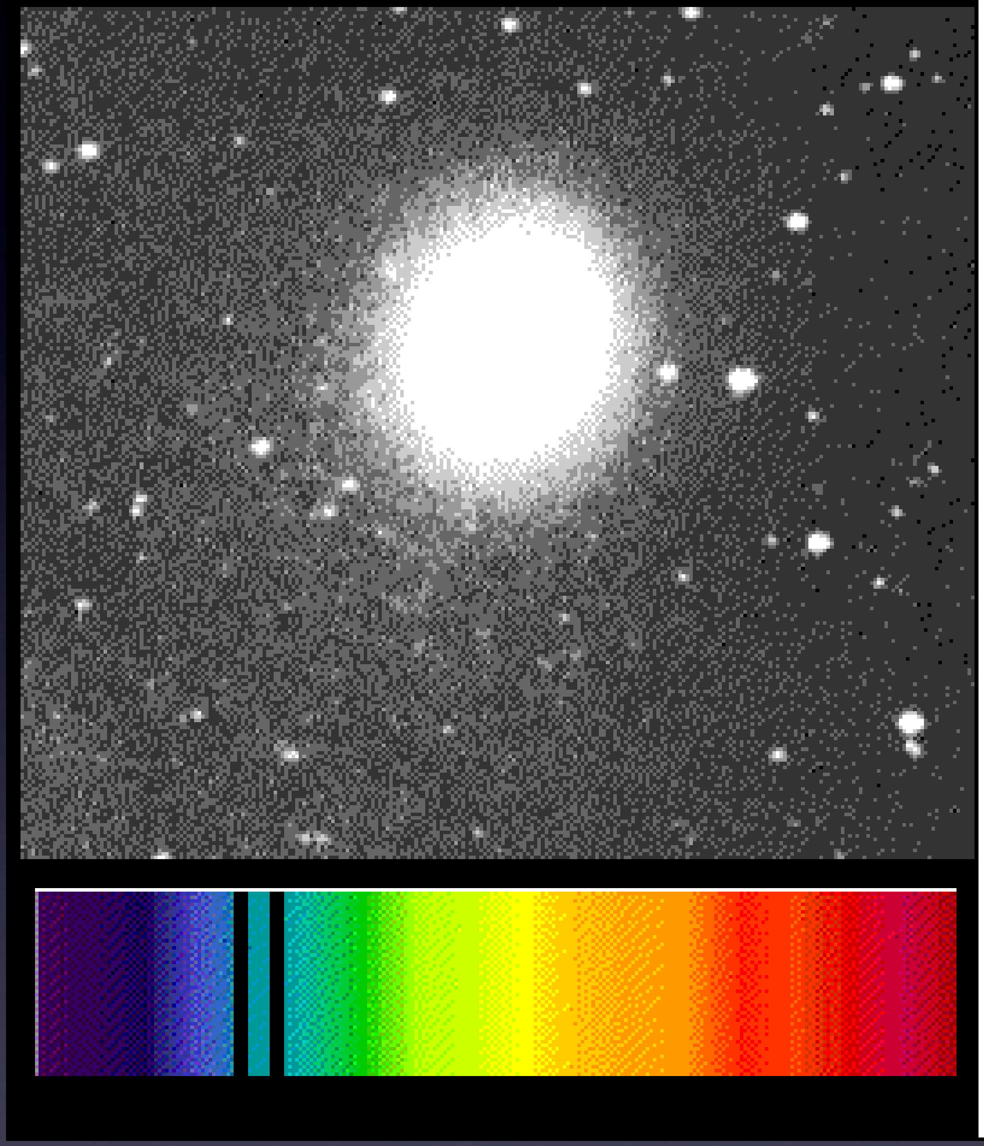
Redshift

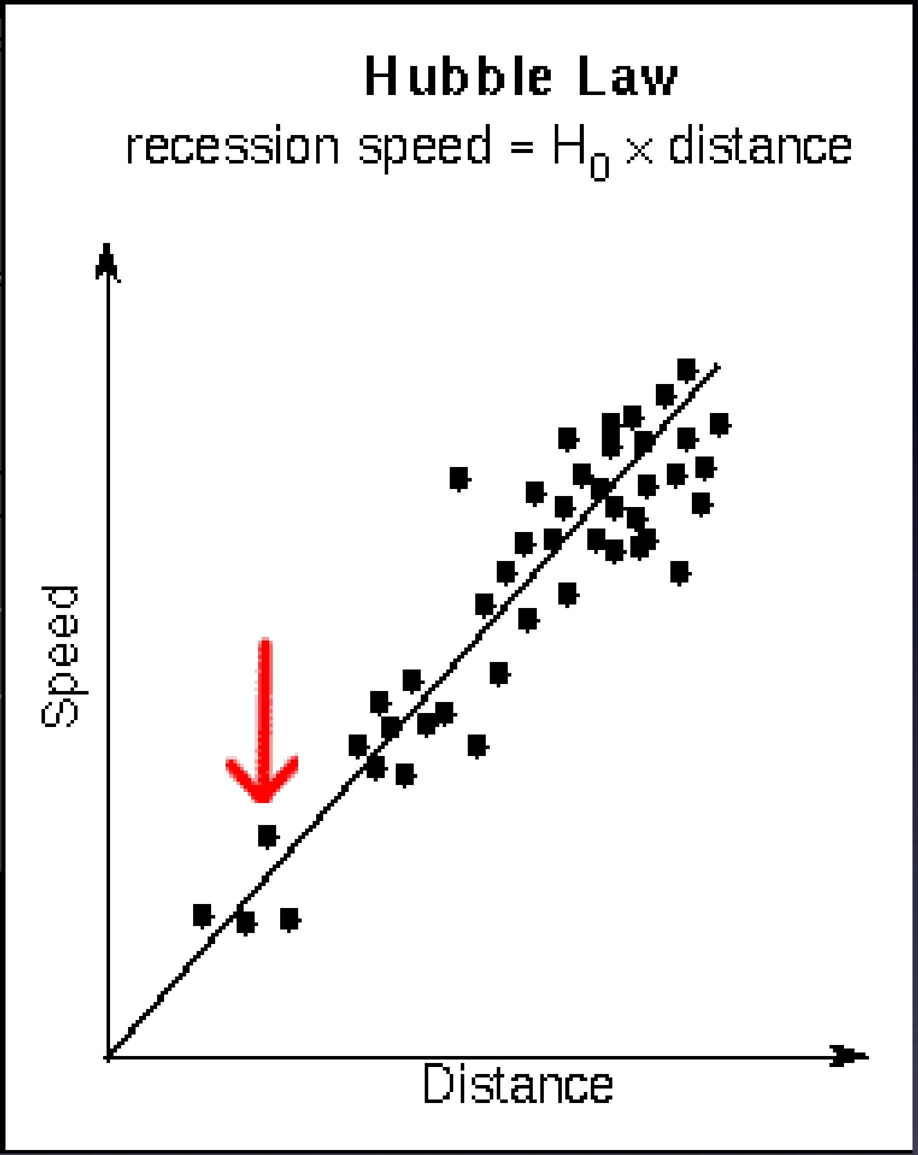
$$\frac{\Delta\lambda}{\lambda_0} \sim \frac{\Delta v}{c}$$

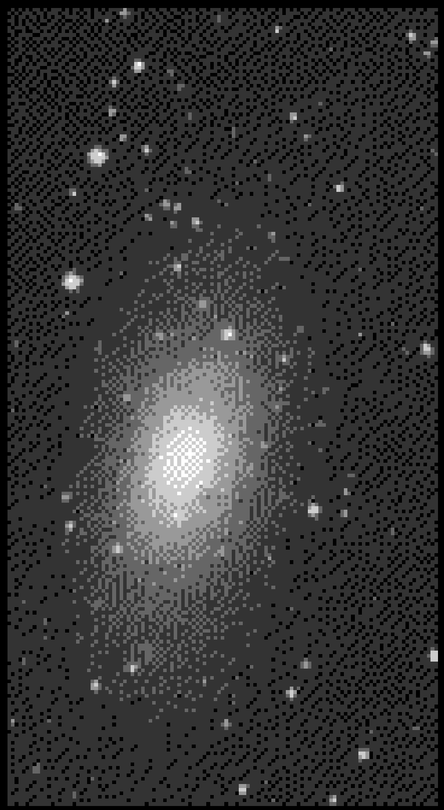
"run away" velocity

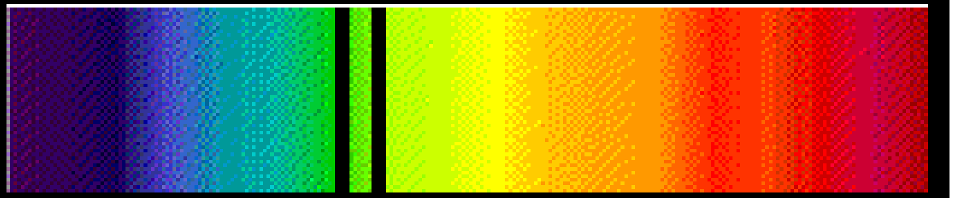


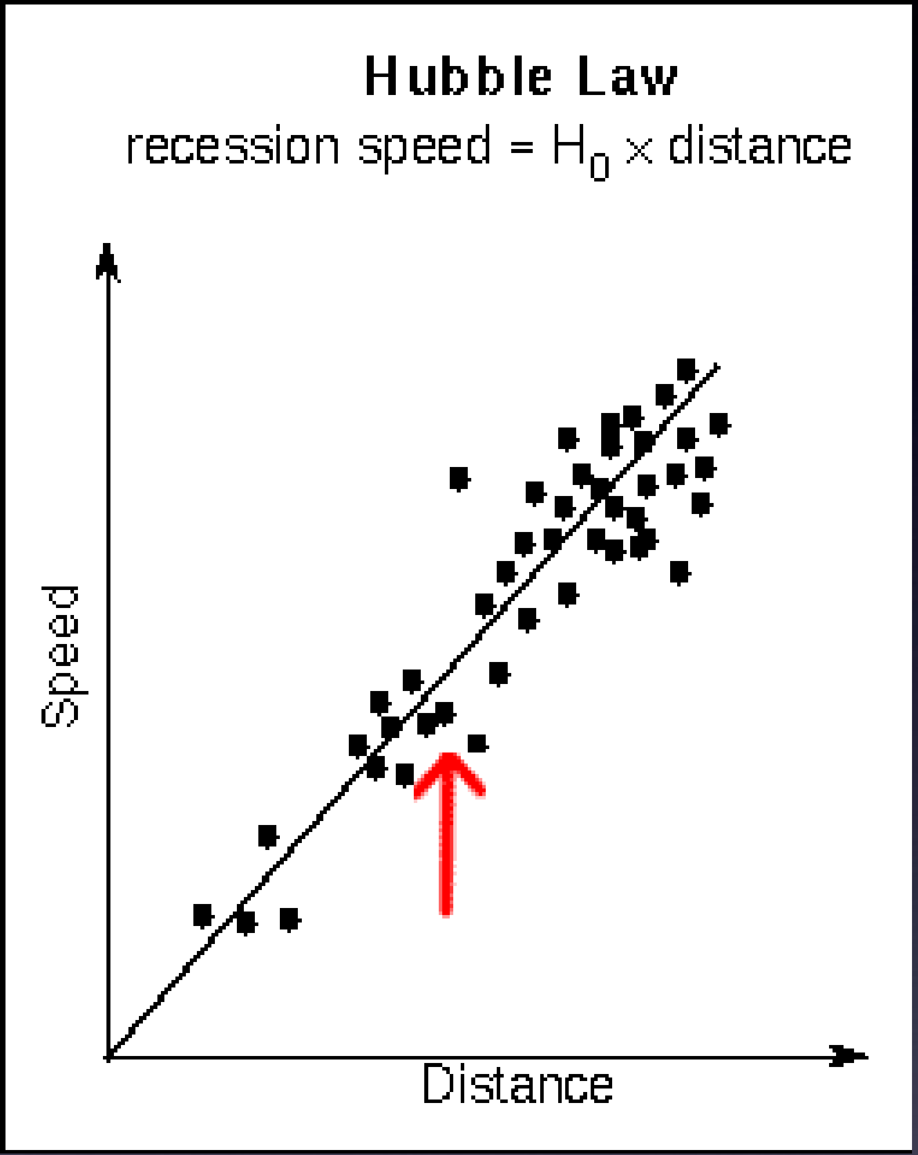
The further the galaxies are

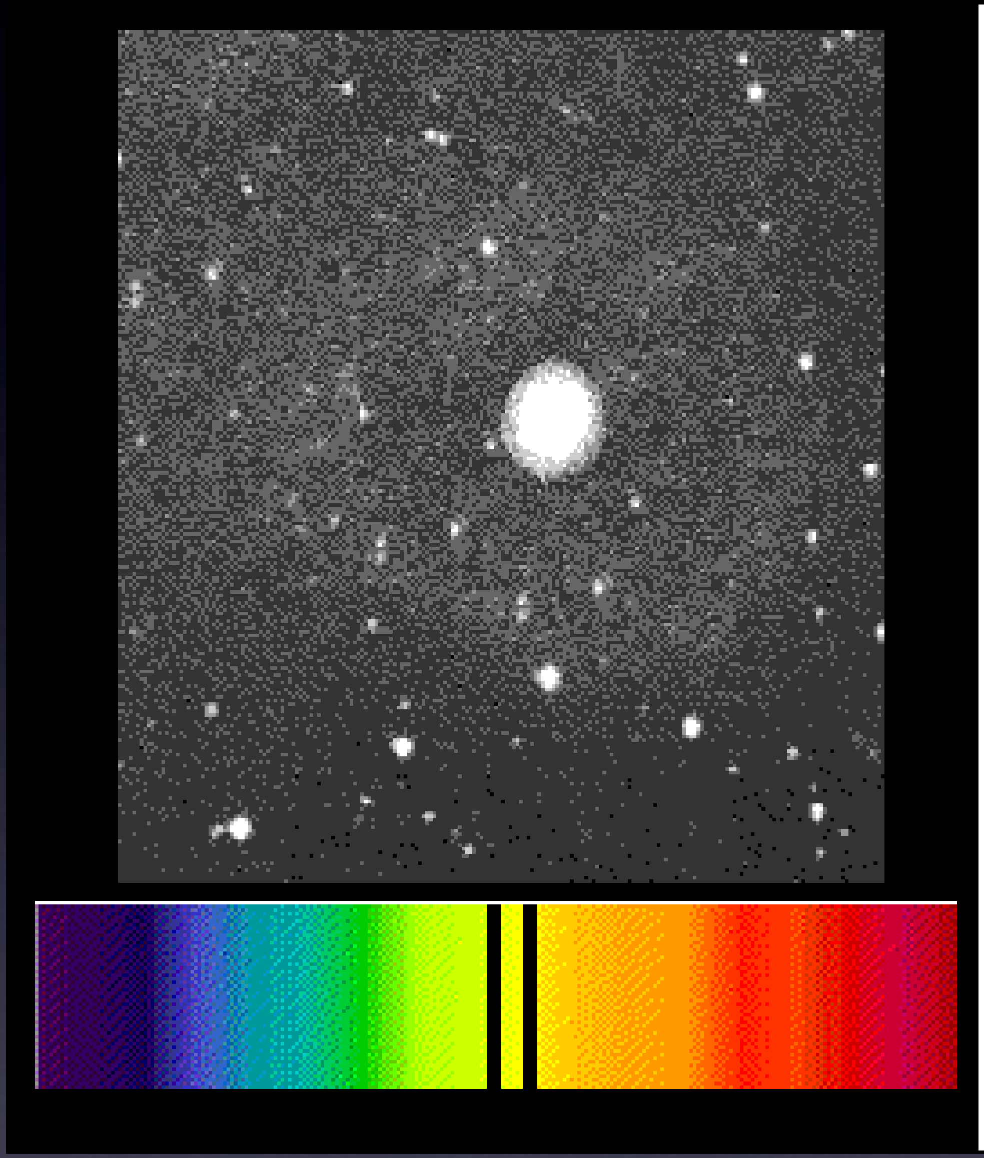


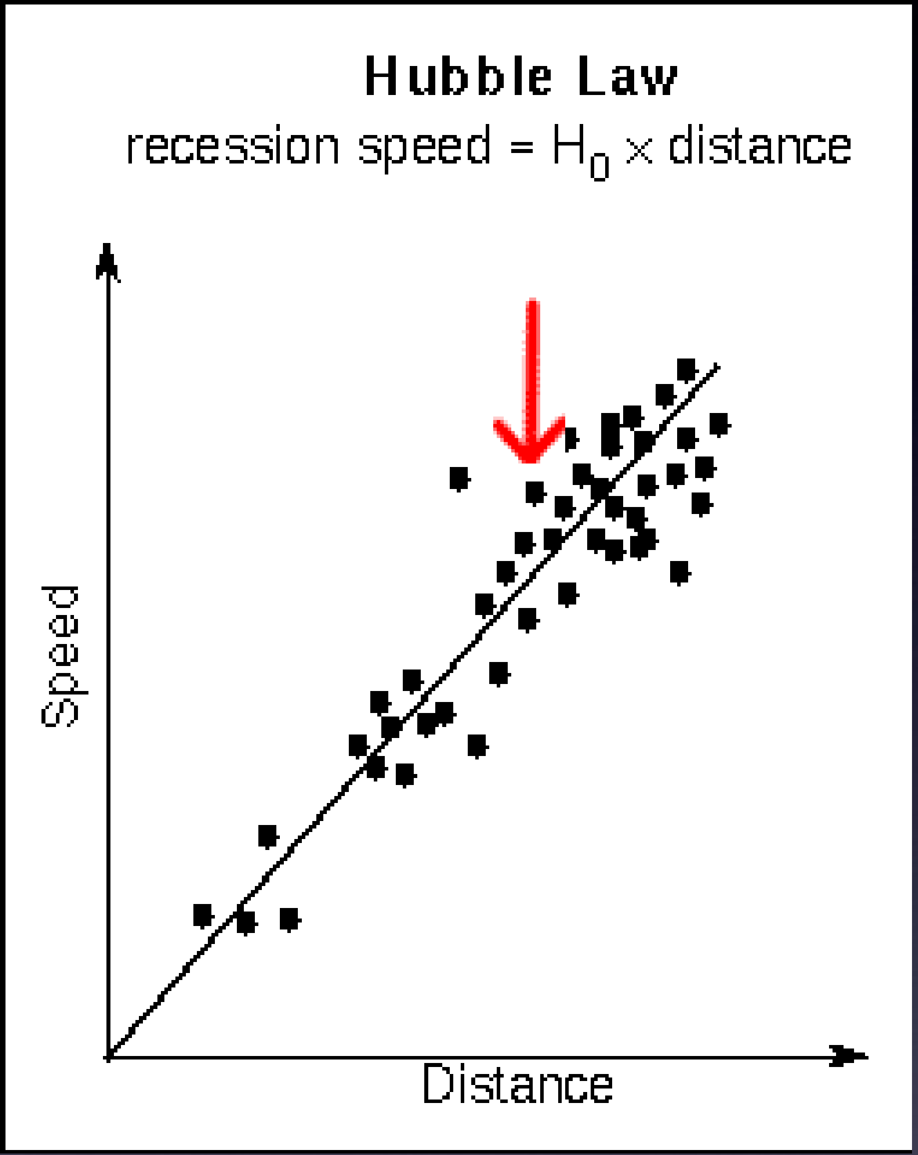







Hubble Law
recession speed = $H_0 \times$ distance
Speed
Distance

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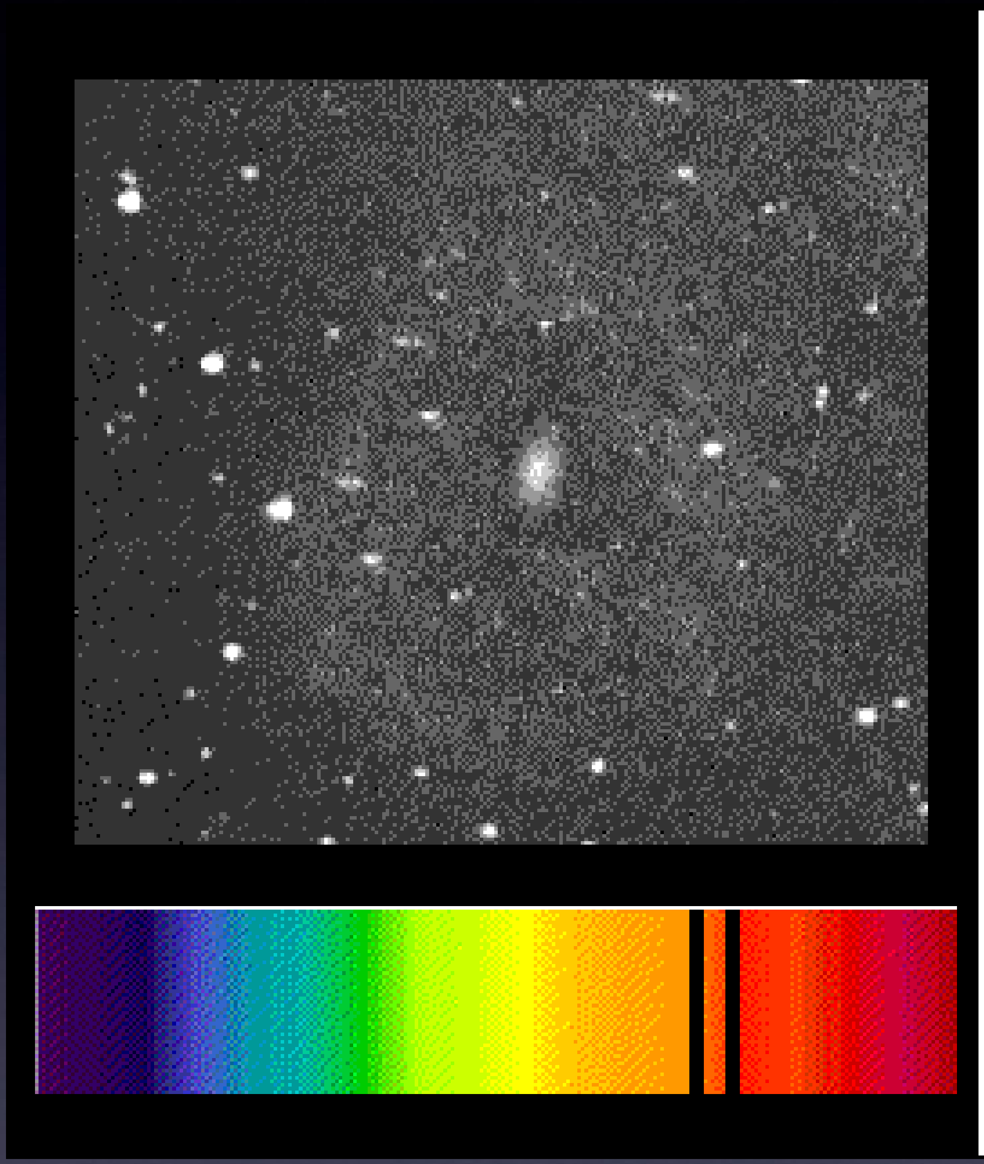
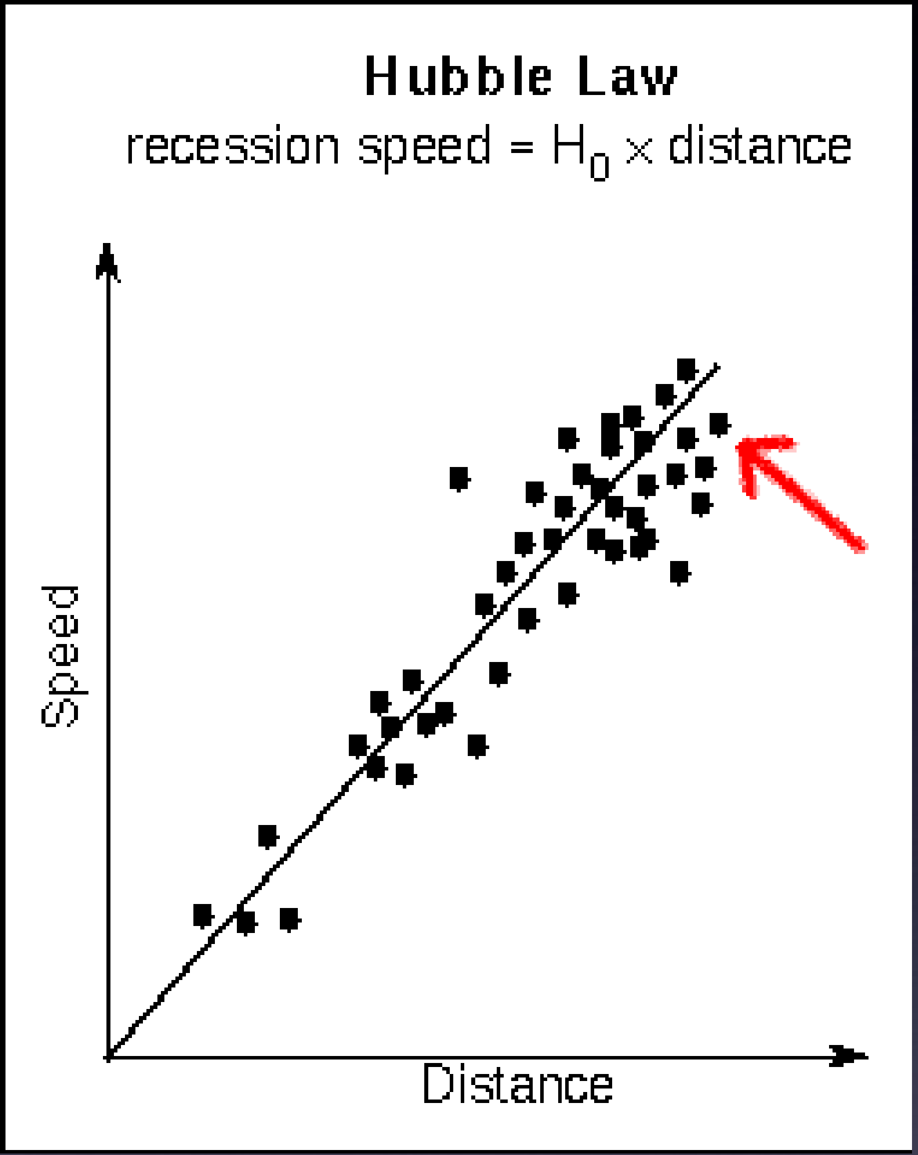
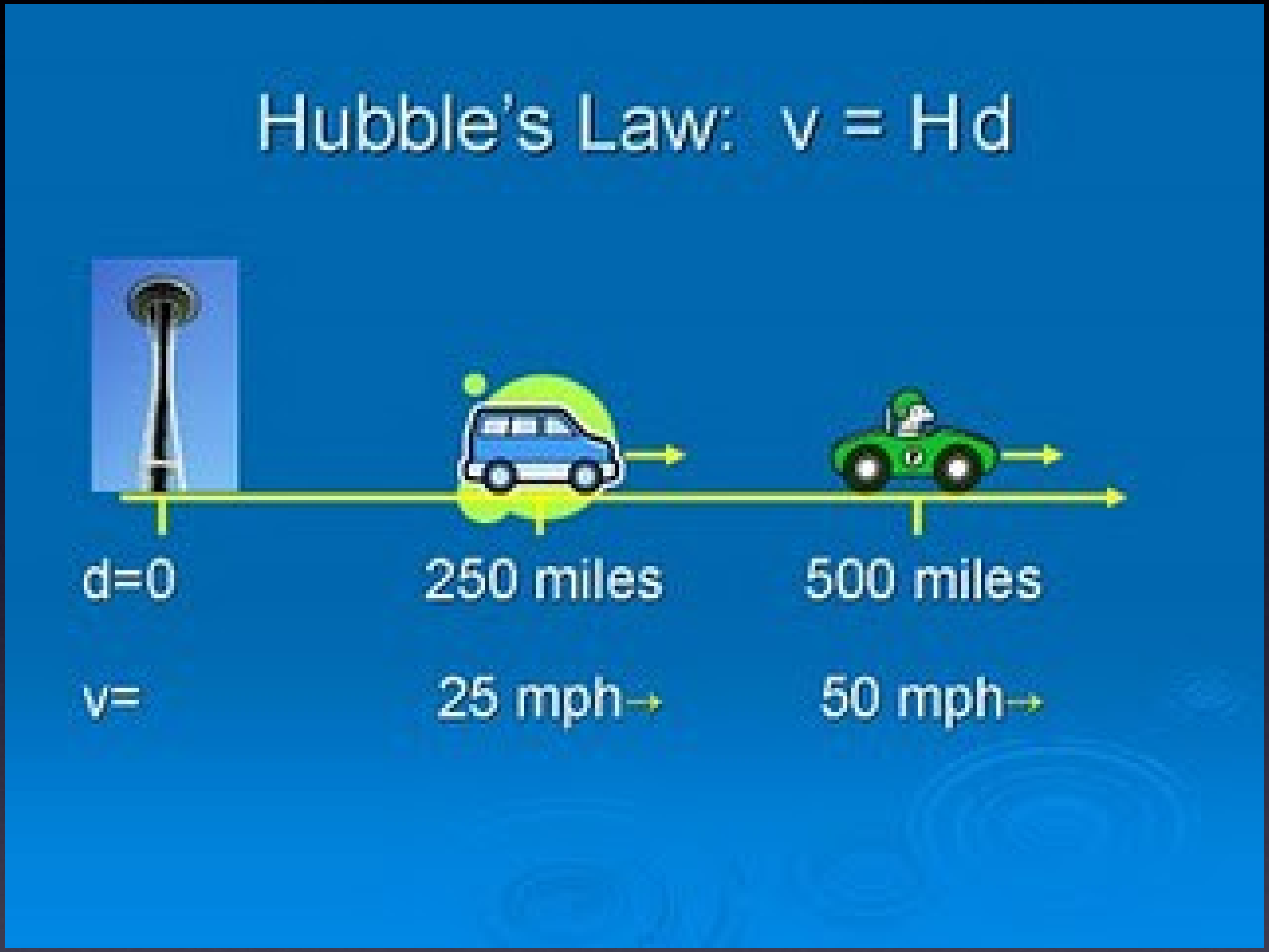
The further the galaxies are



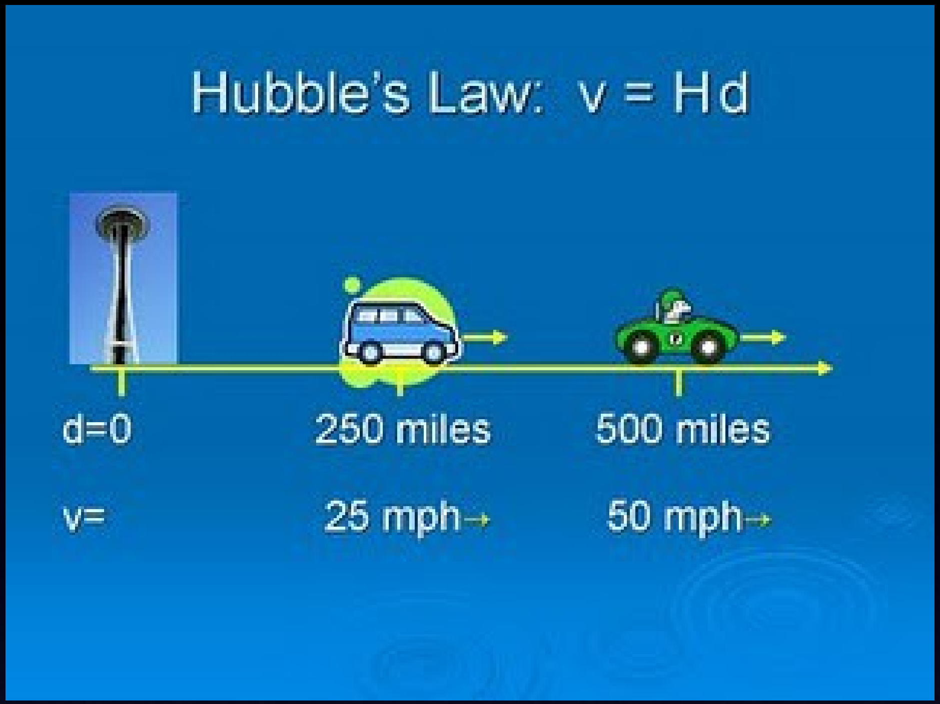


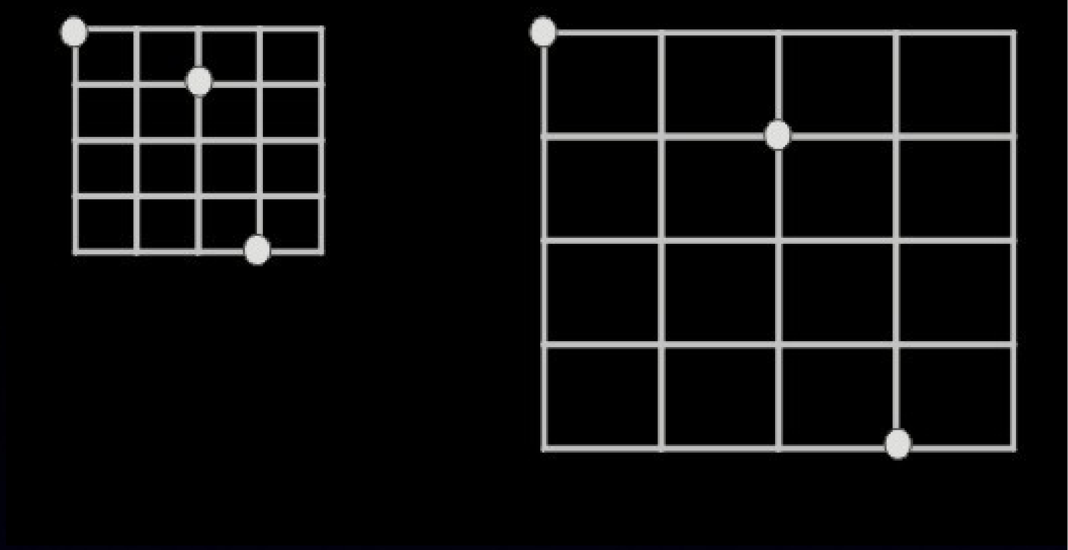
The faster they run away from us

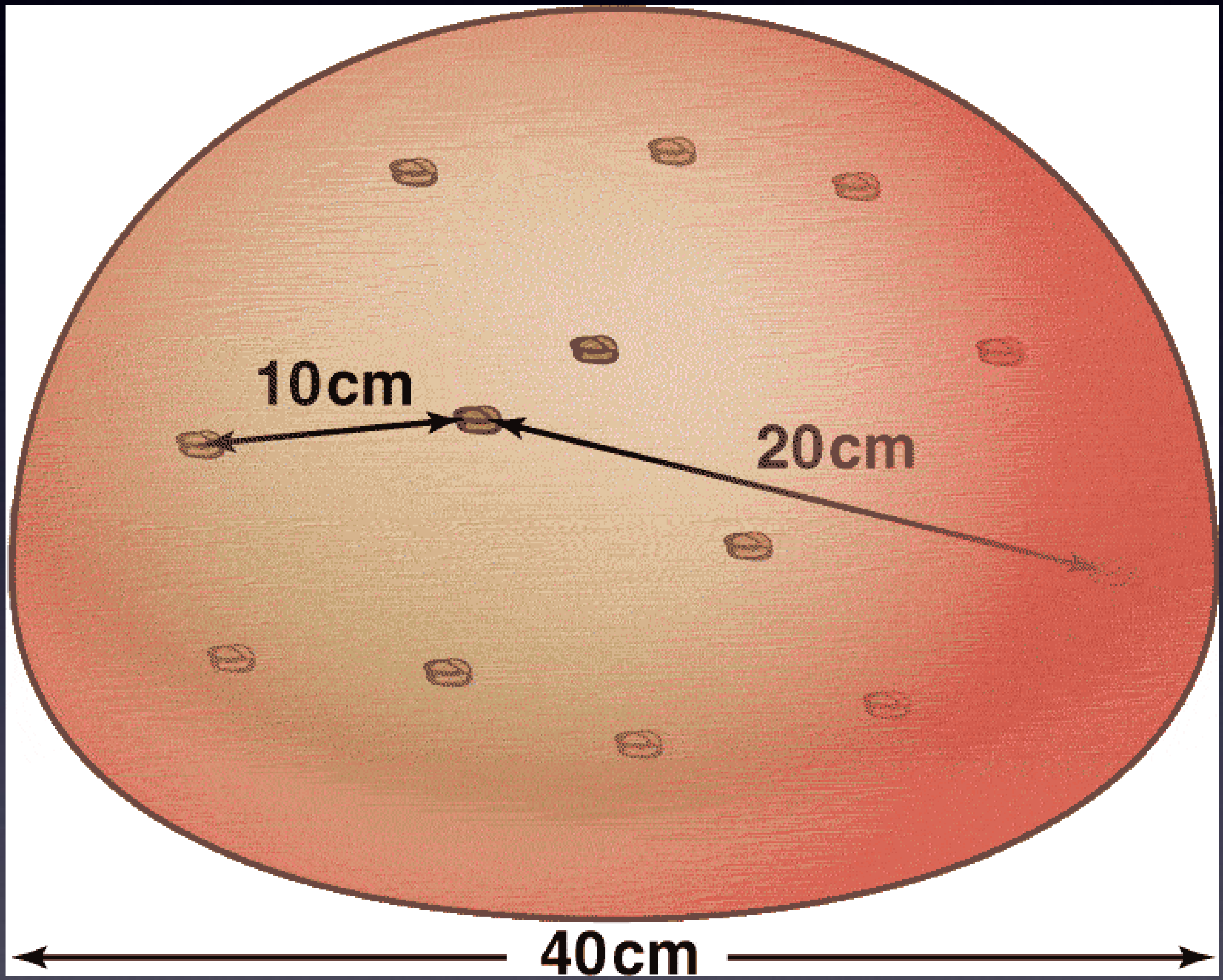
So, we are at the Center...

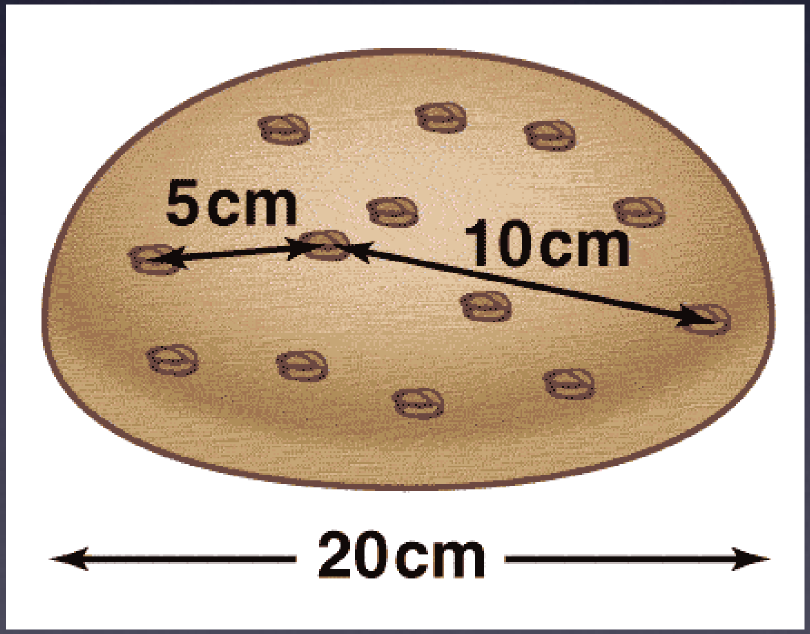


... and yet, maybe not



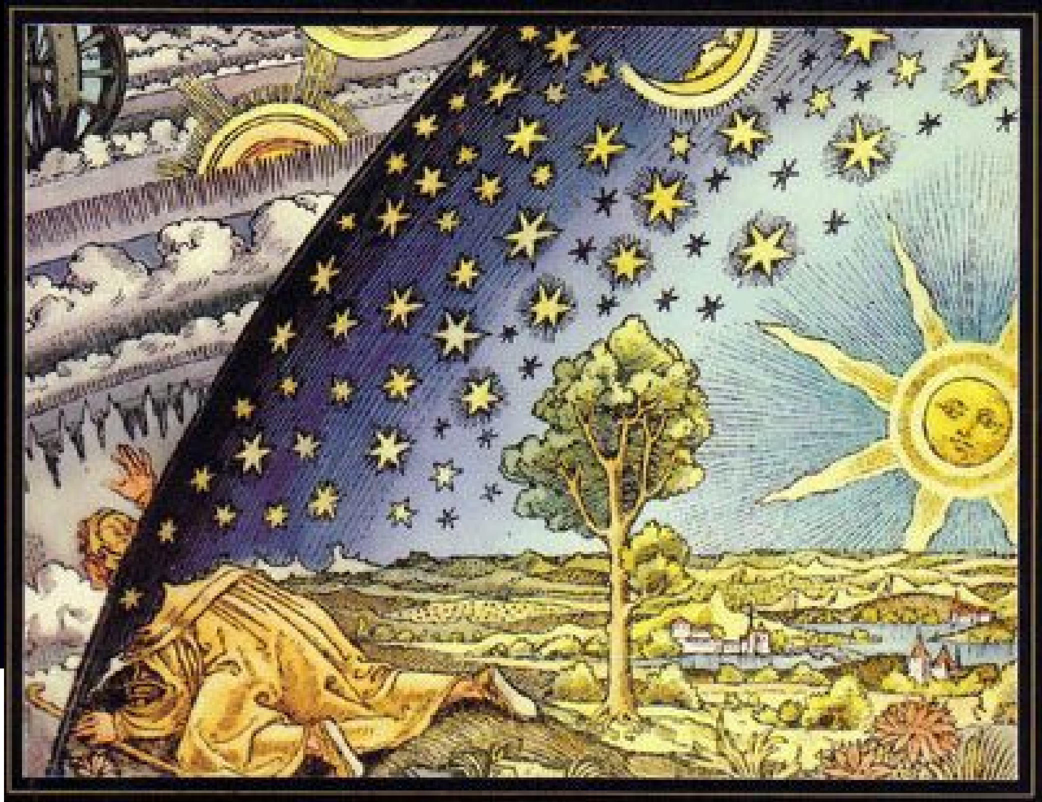






Maybe the Universe is expanding

The Model we chose:



Assuming the Cosmological Principle :

$$\begin{aligned} ds^2 &= g_{\mu\nu} dx^\mu dx^\nu \\ &= -c^2 dt^2 + a^2(t) \left[\frac{dr^2}{1-kr^2} + r^2 \left(d\theta^2 + sin^2\theta d\phi^2 \right) \right] \\ &= -c^2 dt^2 + a^2(t)\, dl^2_{(3)} \end{aligned}$$

Now throw in some physics (GR) :

energy density

curvature

$$H^2 \equiv \left(\frac{\dot{a}}{a} \right)^2 = \frac{8\pi G}{3} \left(\rho - \frac{k\, c^2}{a^2} \right)$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} (\rho + 3\, p\, /c^2)$$

critical density

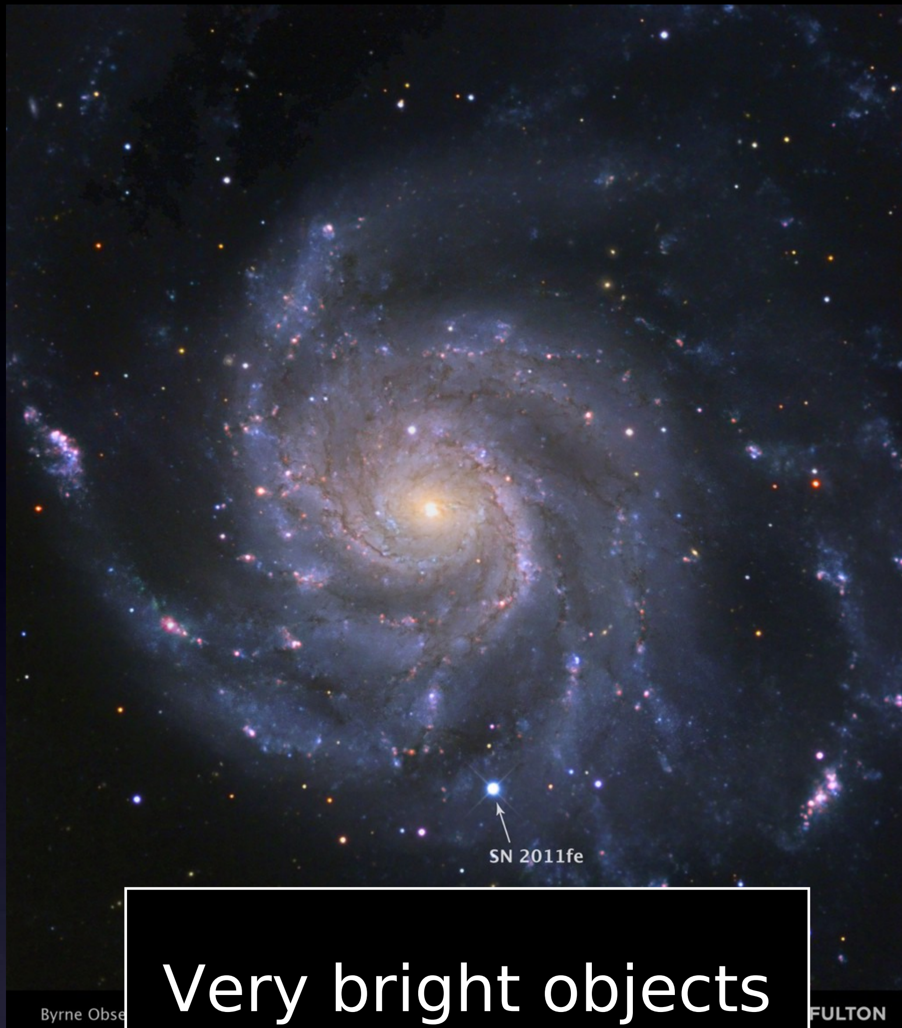
pressure

E.O.S. parameter

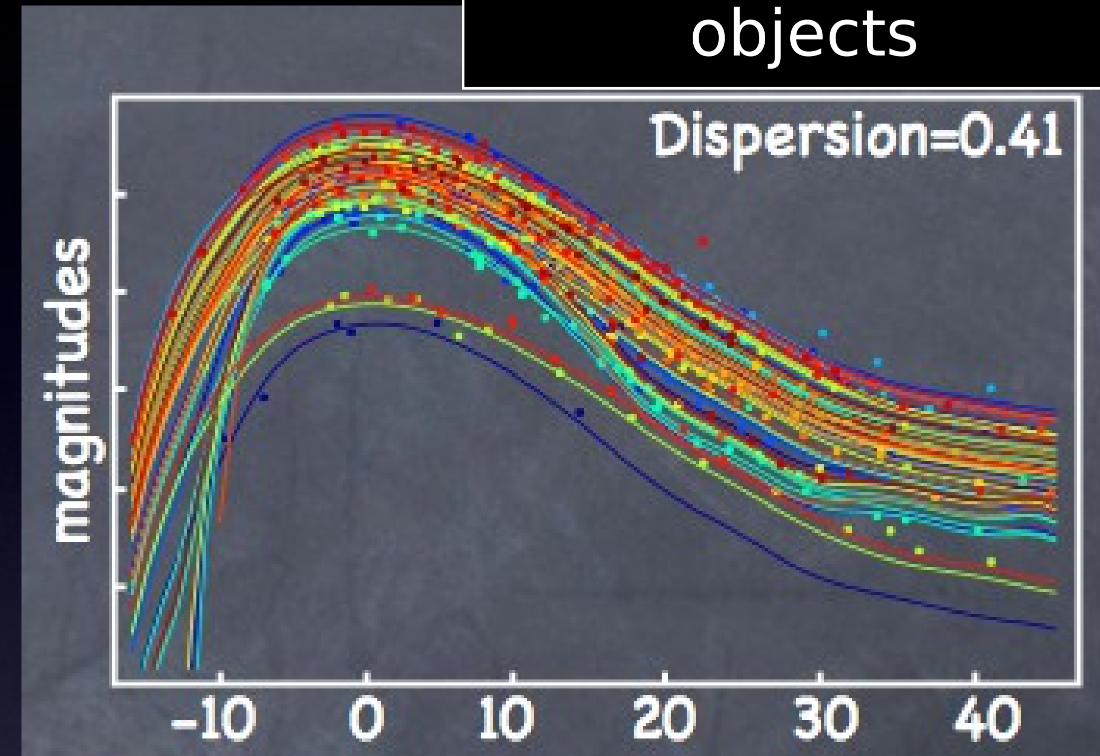
Define $\rho_C = 3H_0^2/8\pi G$, treat everything as an ideal fluid $p = w \times \rho$:

$$\frac{H^2}{H^2} = \sum \Omega_i a^{-3(1+w_i)} + \Omega_k a^{-2}$$

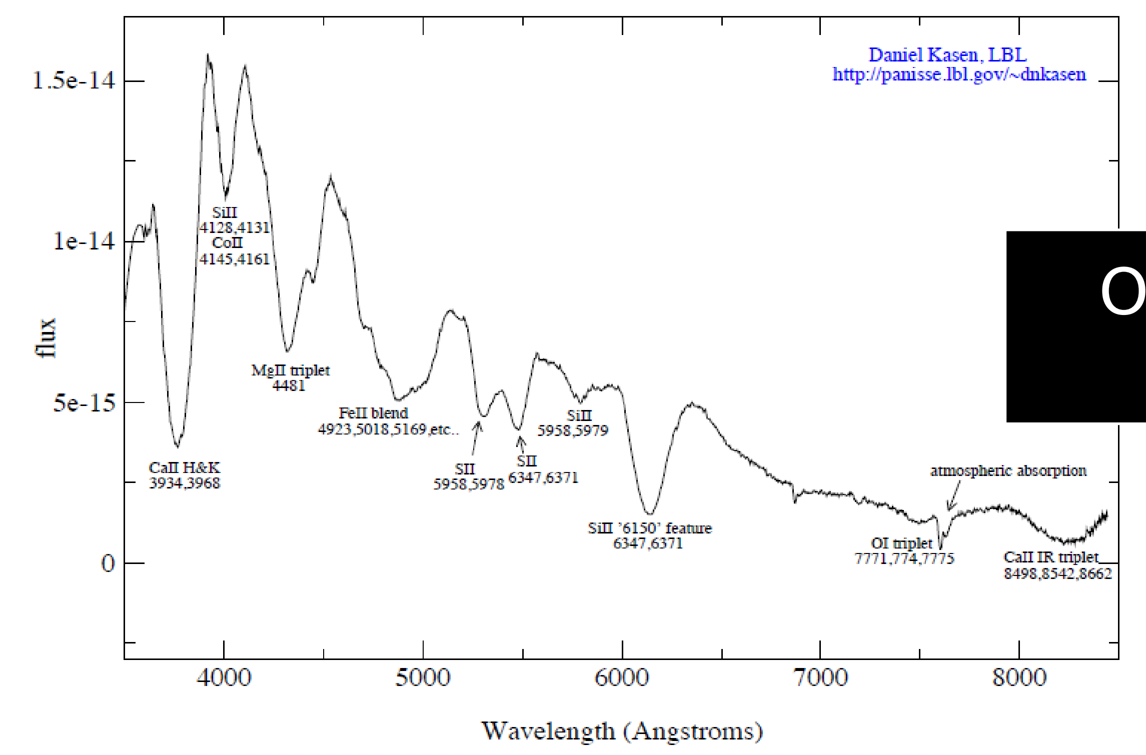
Going further with SNe Ia



Very bright objects

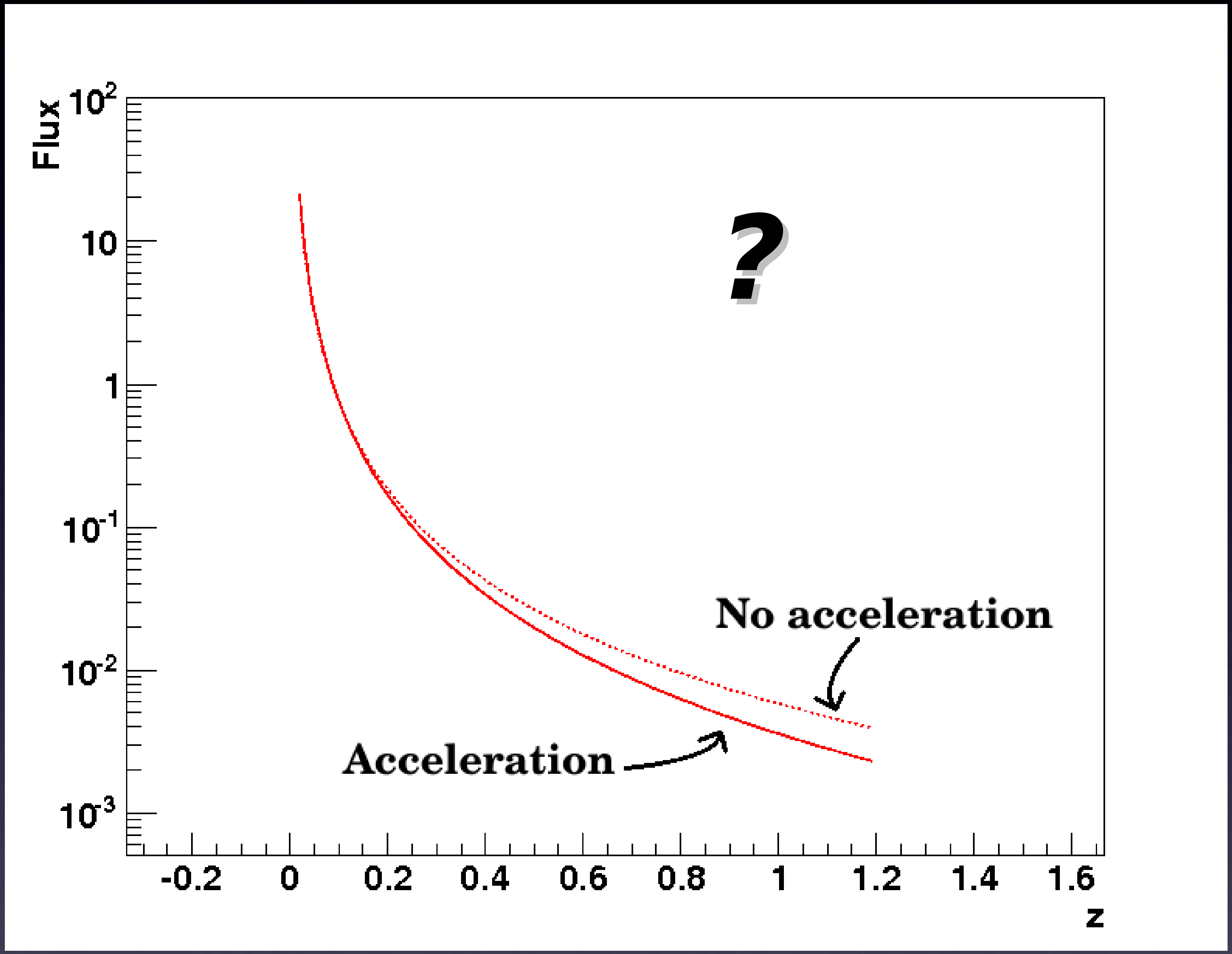


Very standard objects



Objects easy to recognize

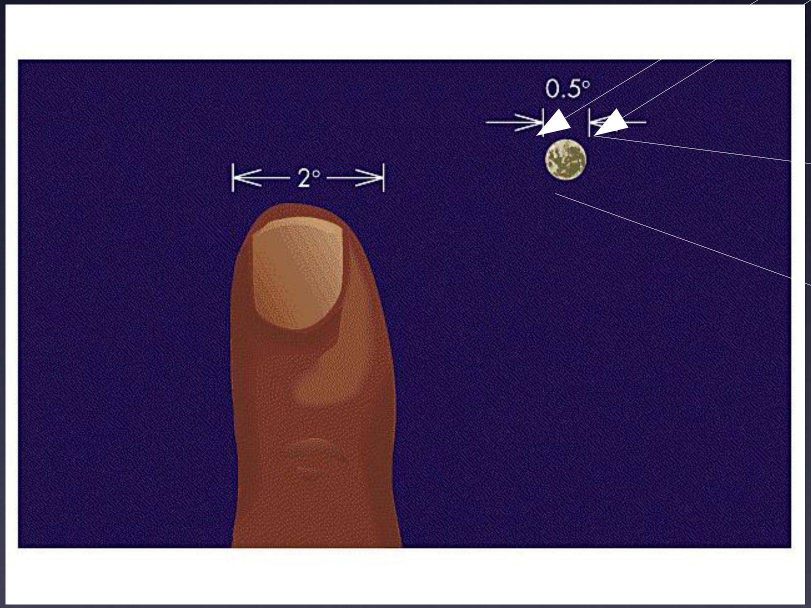
So, why is that hard ?

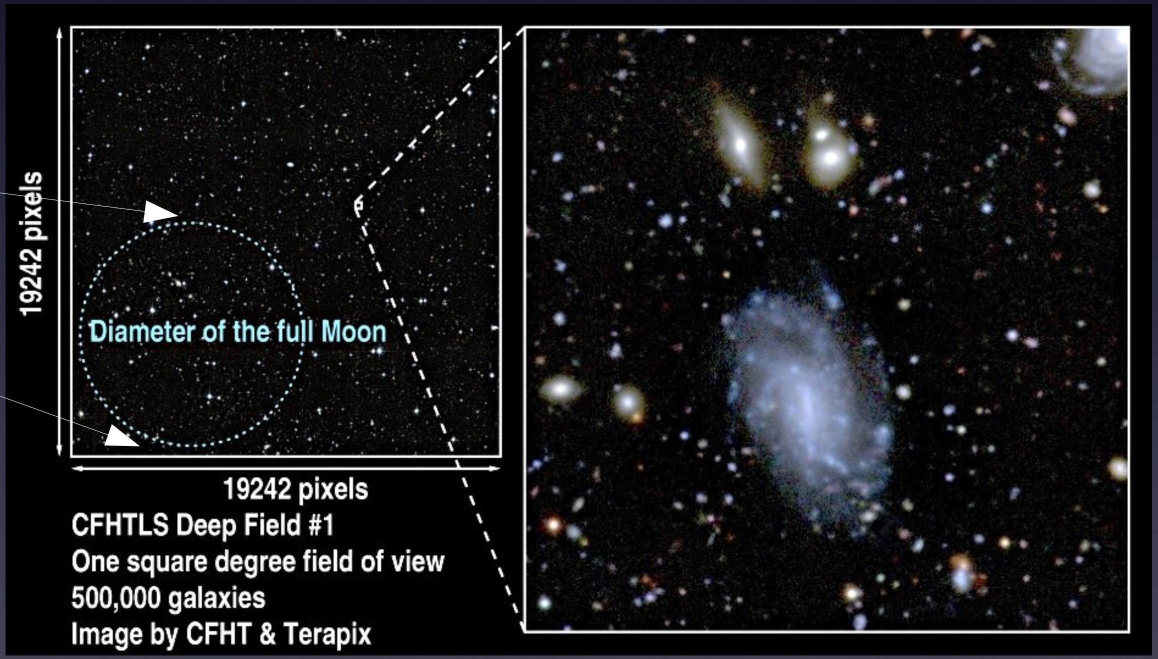


Finding SNe Ia

Sky ain't no small

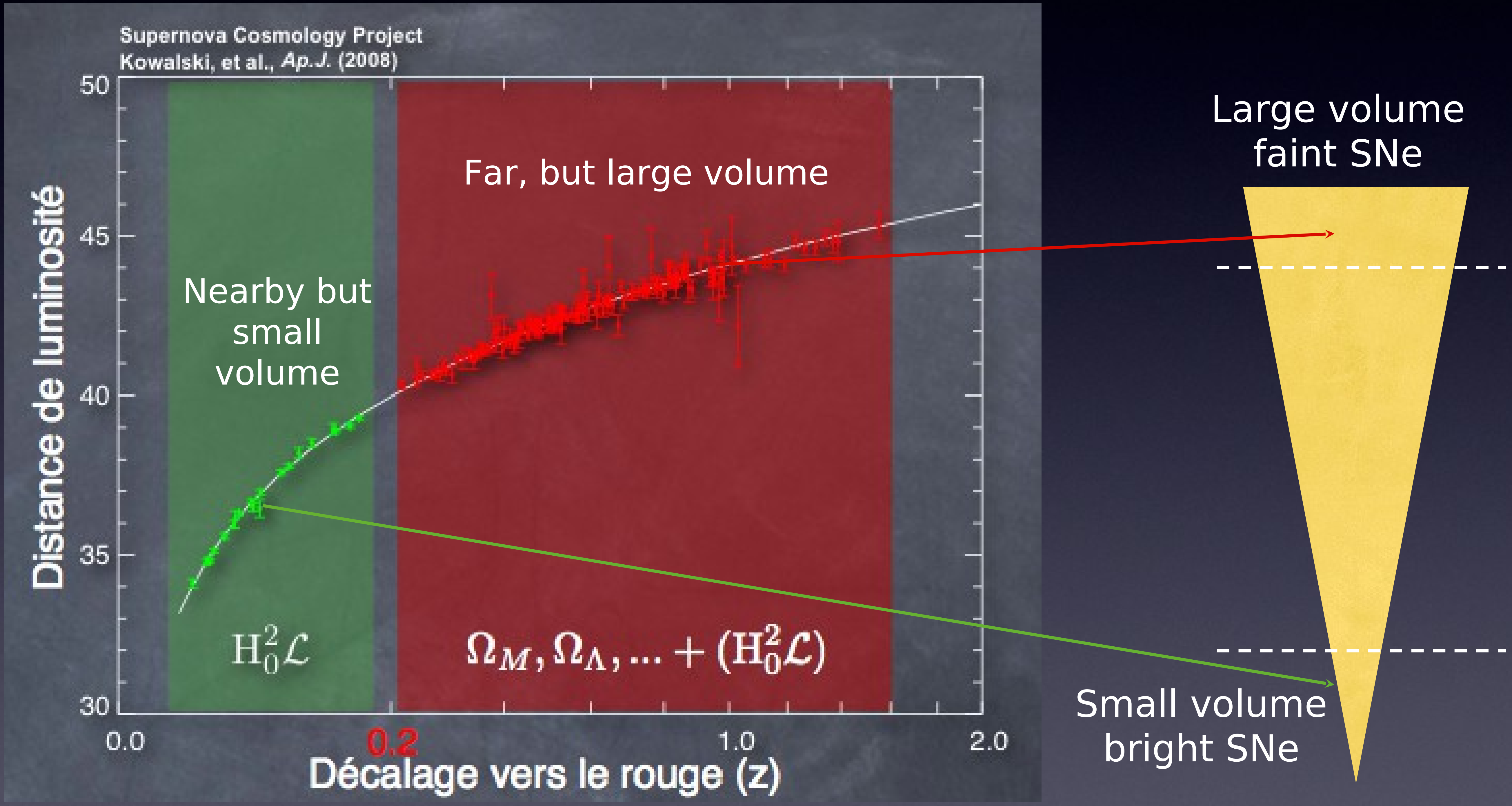
1 SN Ia per galaxy per millenium



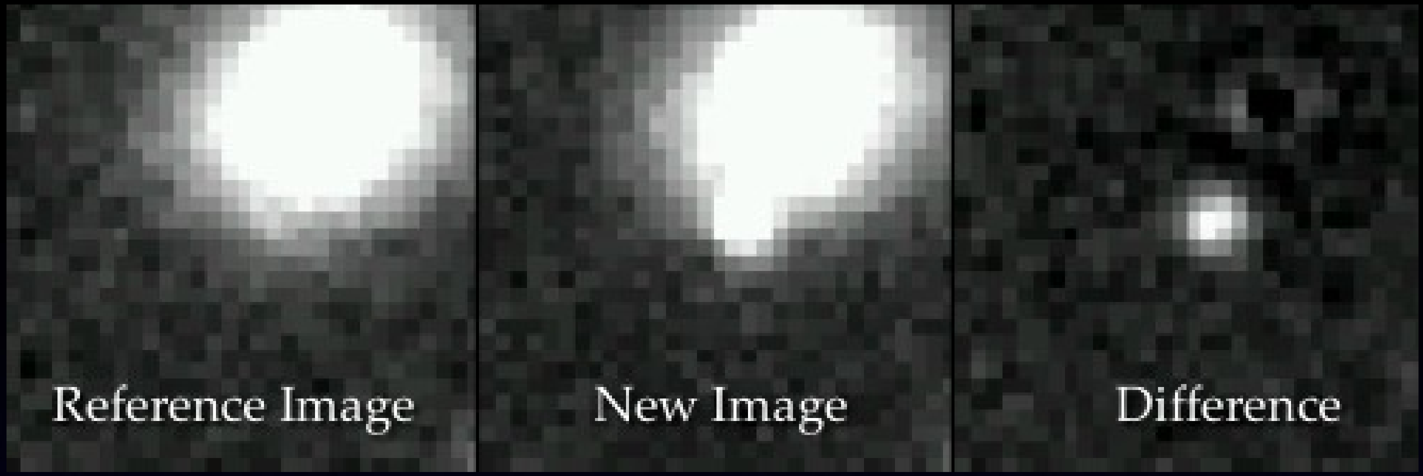


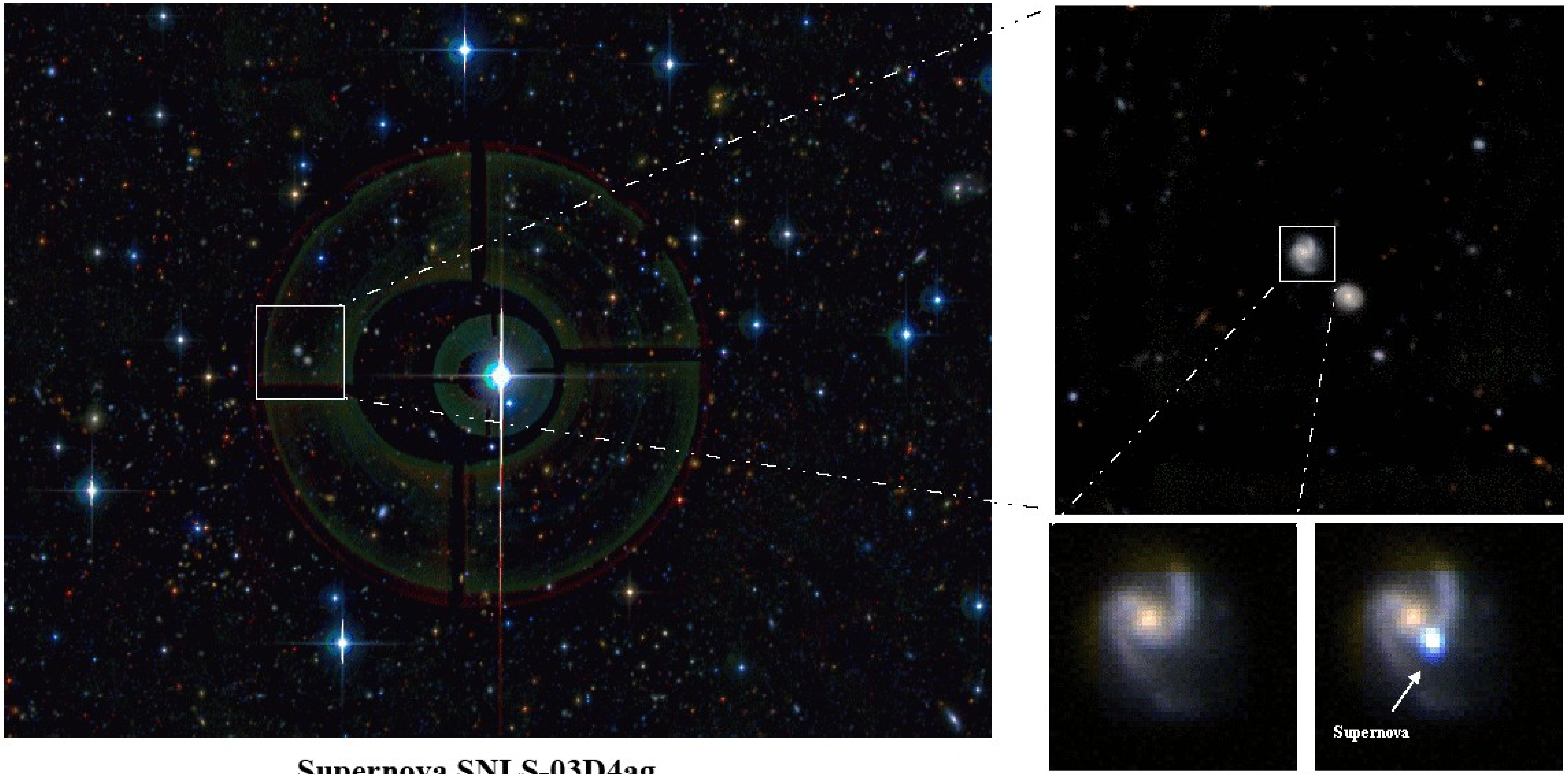
Telescope size matters...

... as well as the observed volume



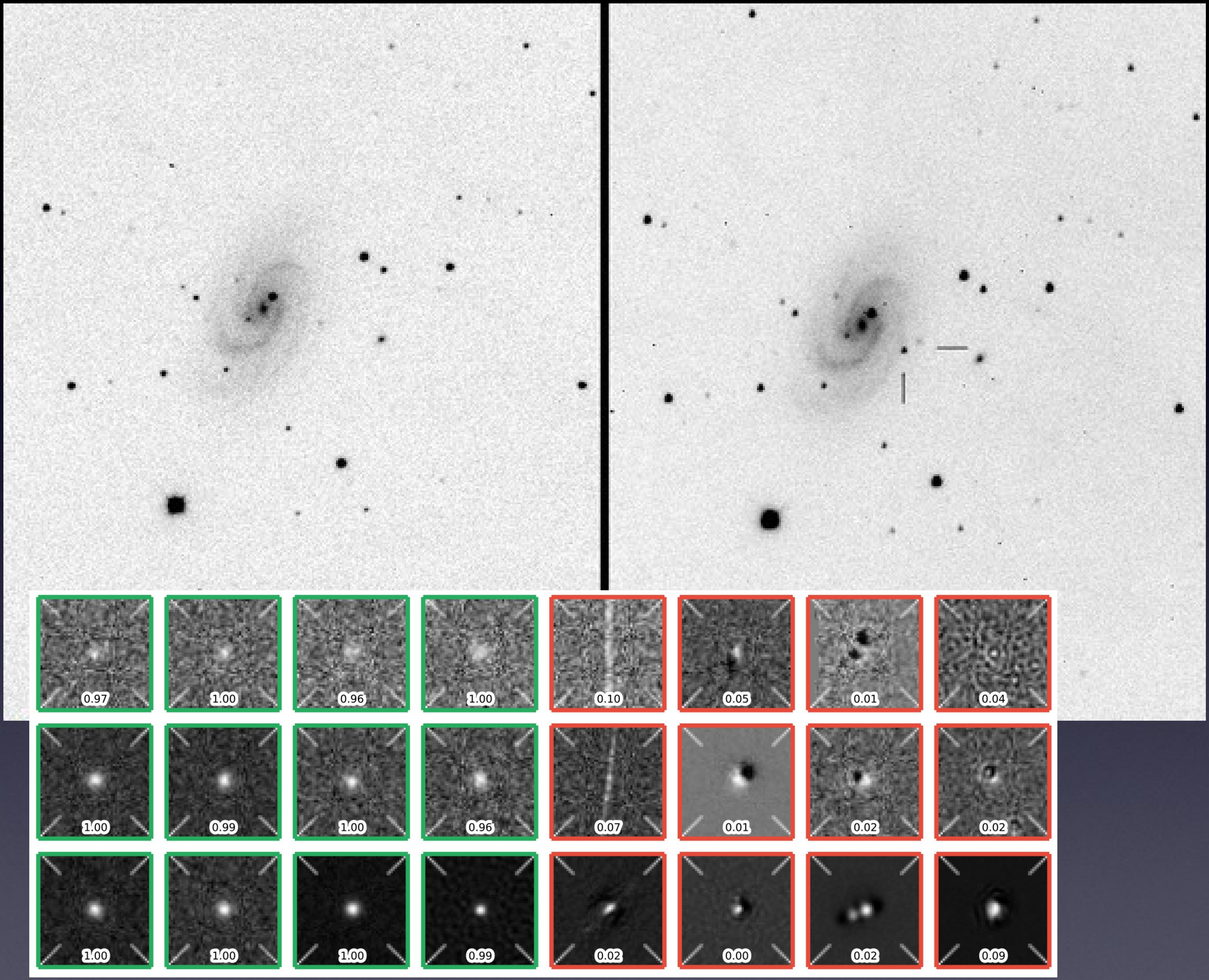
Comparing images





Supernova SNLS-03D4ag

Many candidates, few interesting targets

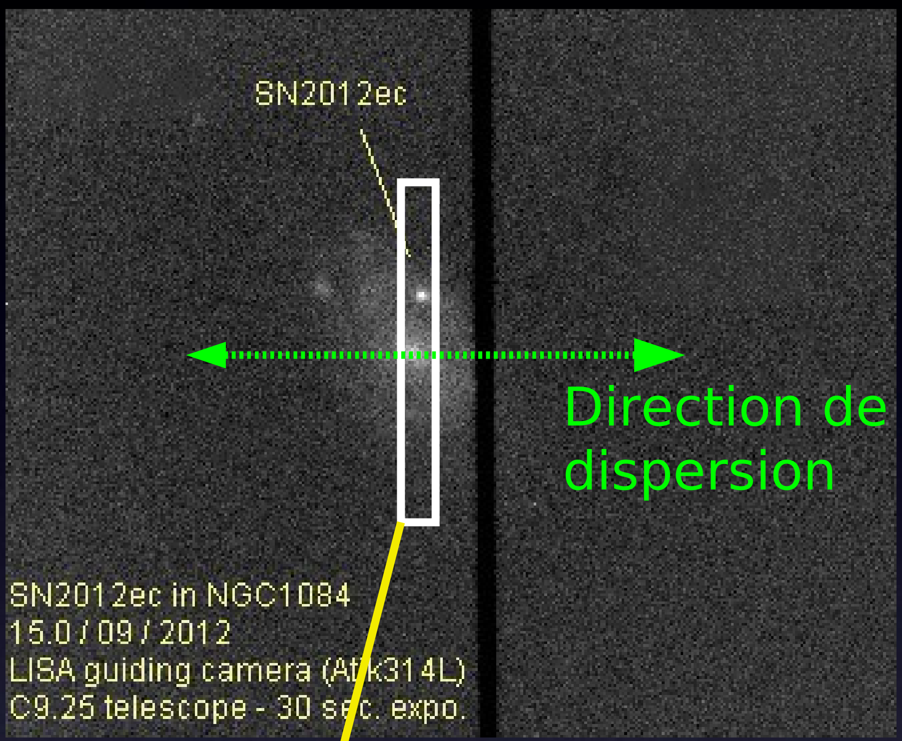


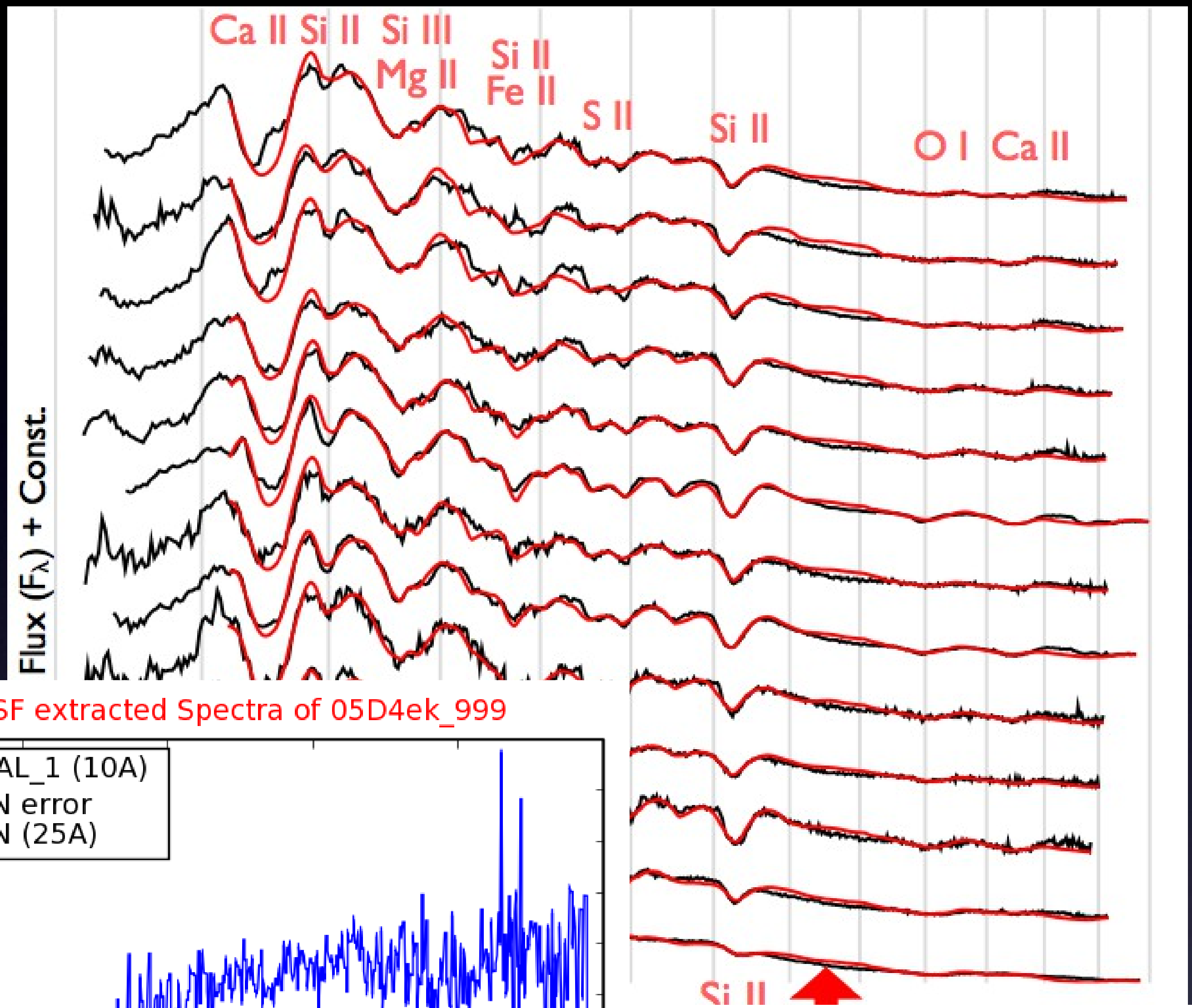
So, what's so hard ?

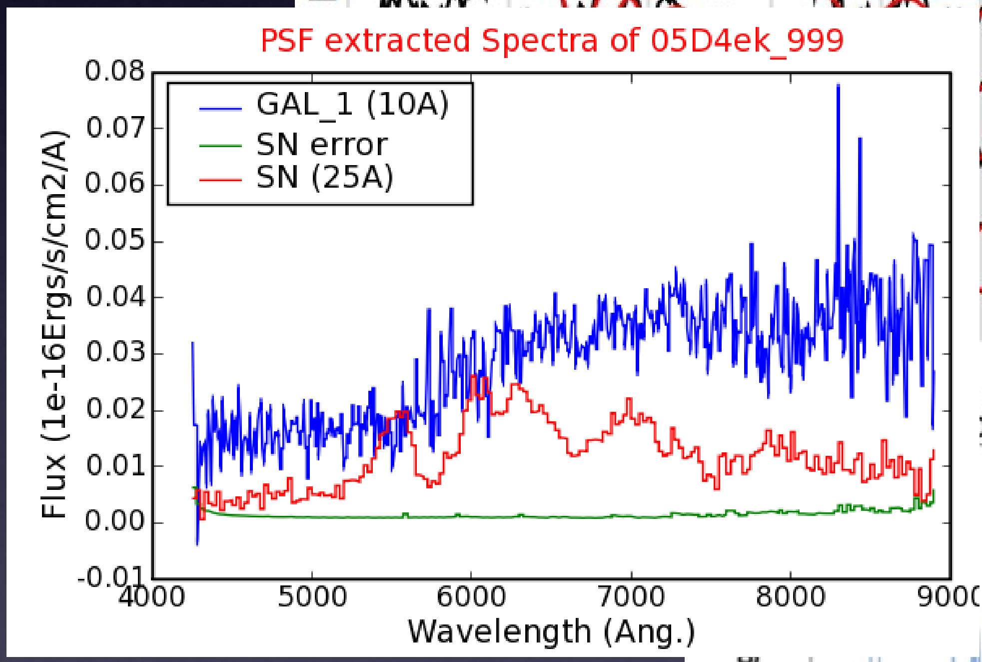
1) Finding the SNe Ia

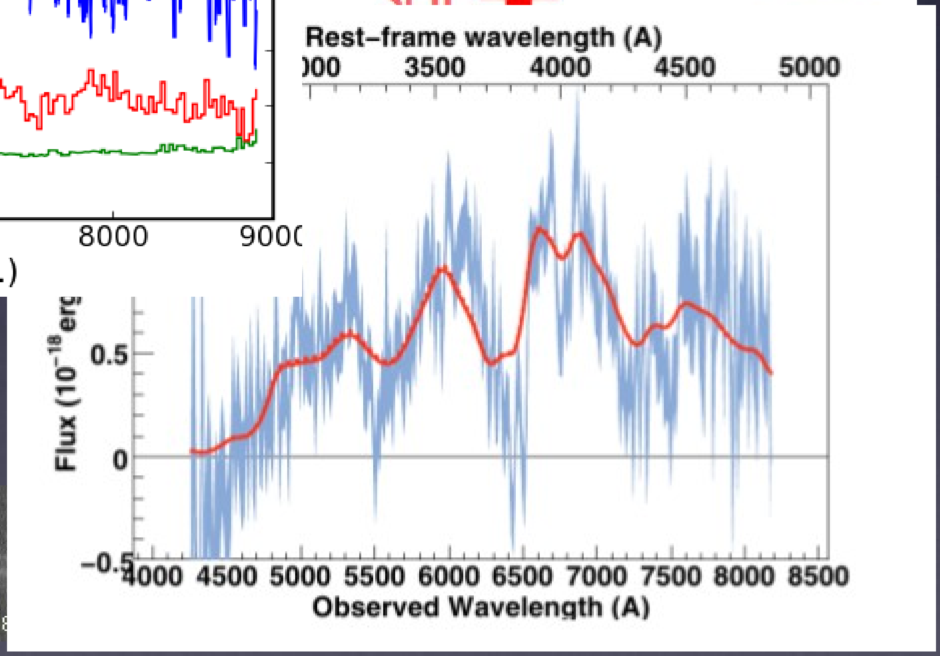
Identifying SNe Ia

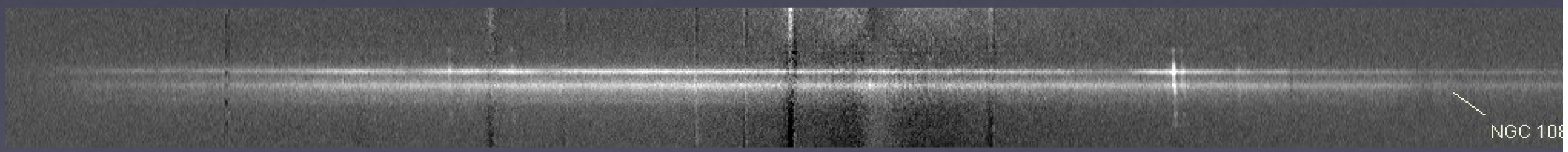
And redshift measurement











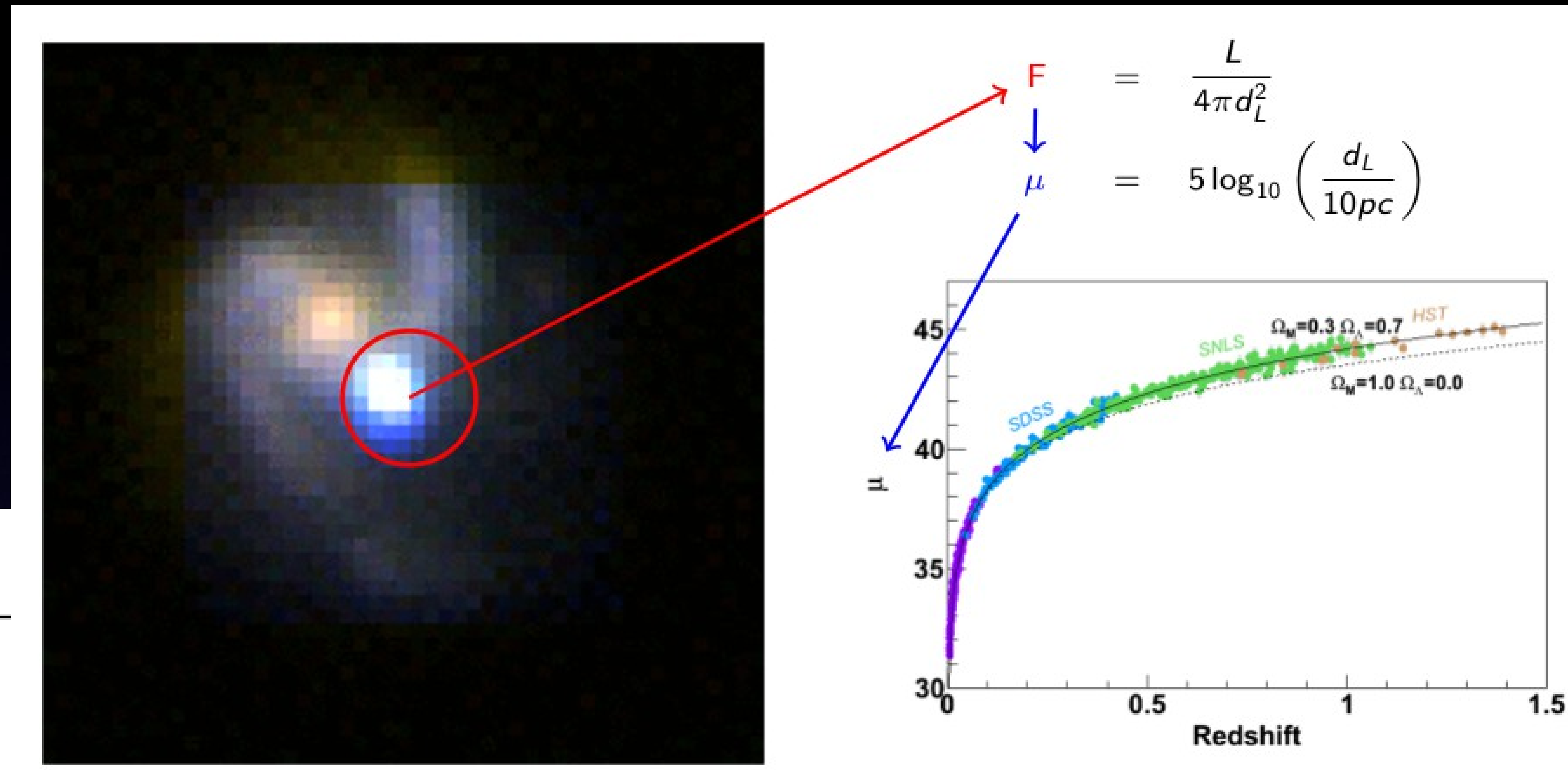
So, what's so hard ?

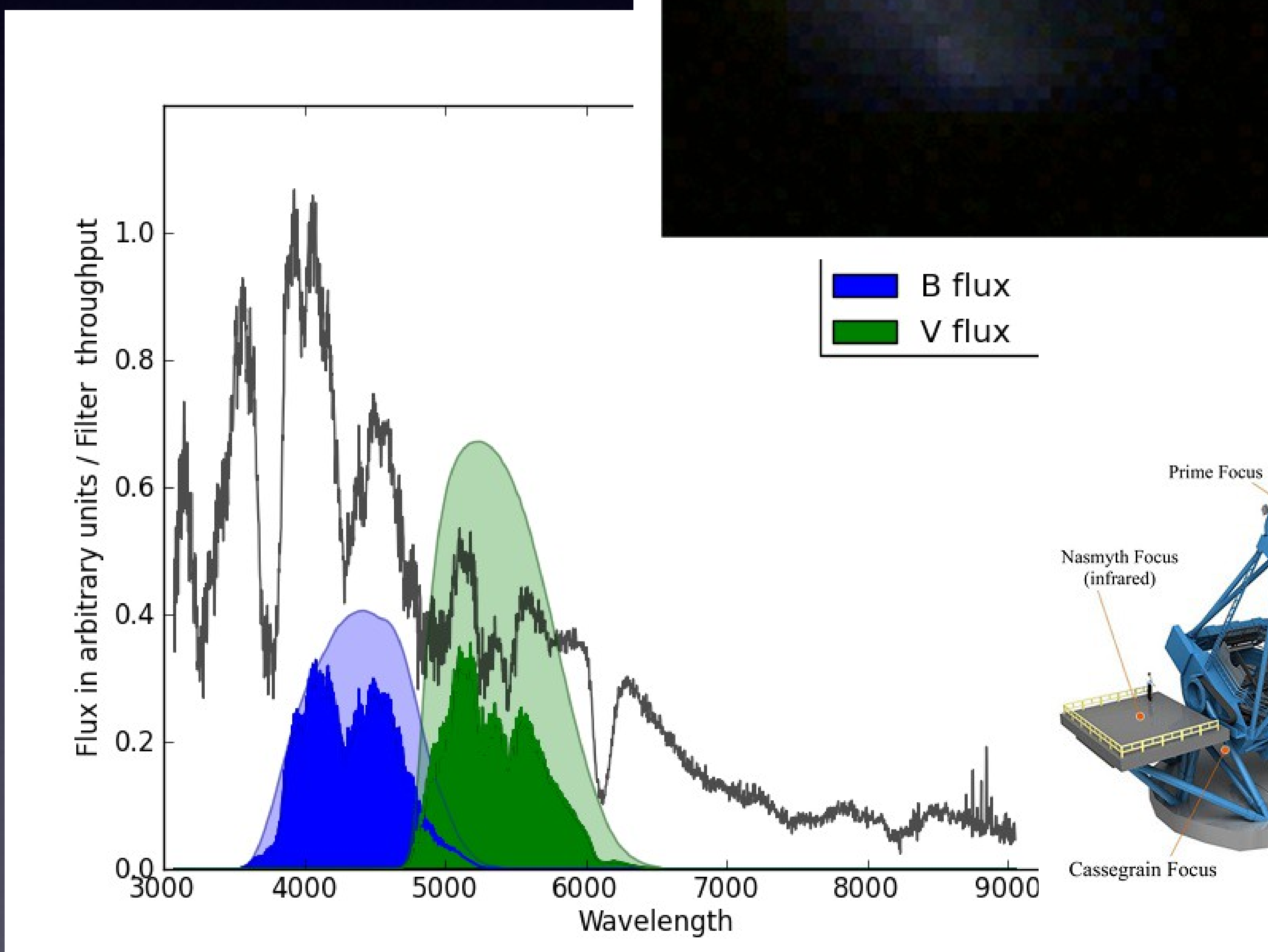
1) Finding the SNe Ia

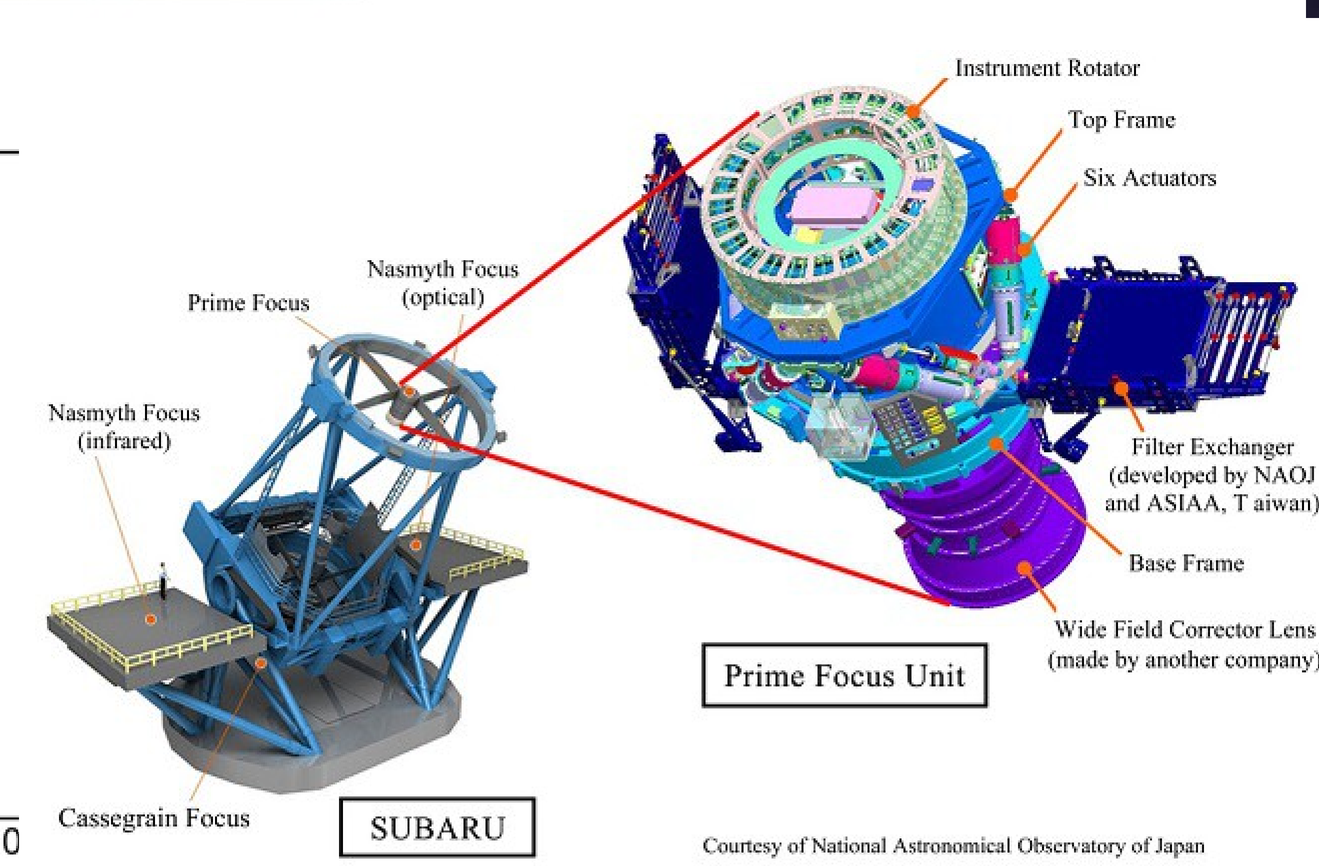
2) Identifying the SNe Ia

Observing SNe Ia

Optical filters to integrate the light

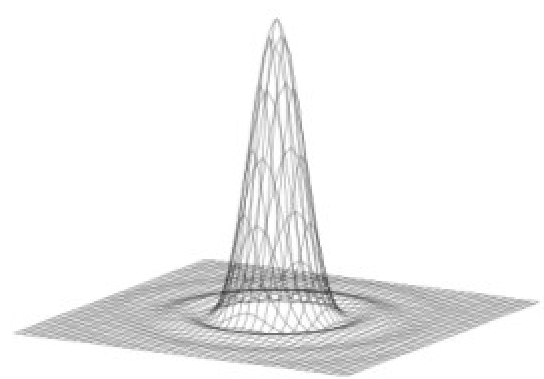


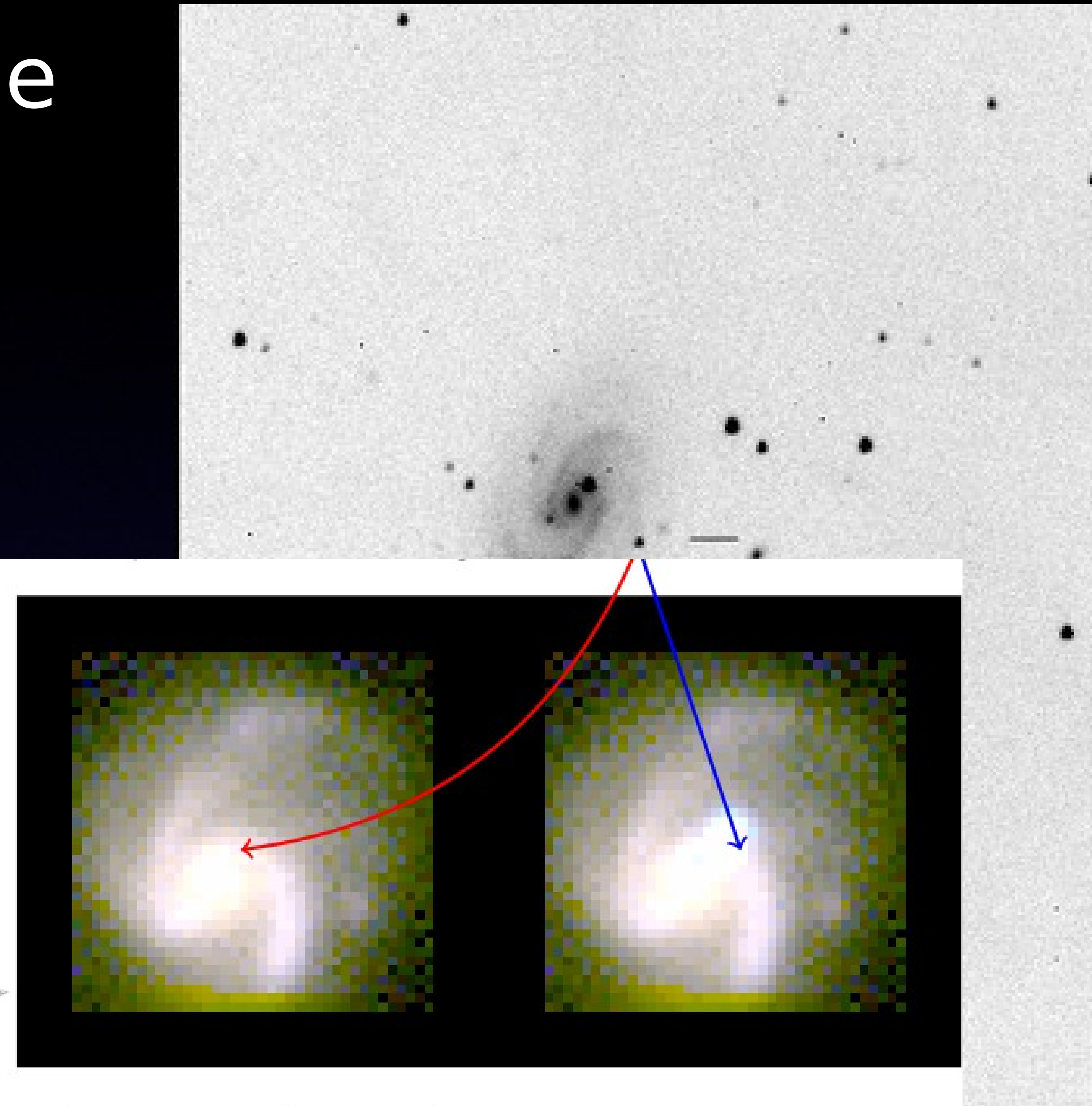




Accounting for CCD “features”

Extracting the flux of the SN Ia





The fitted model M for image i at position p is given by :

$$M_{i,p} = \left\{ \left[f_i \times PSF(\vec{x}_p - \vec{x}_{SN}) + gal_{ref} \right] \otimes K_i \right\}_p + s_i$$

0 Flux before explosion

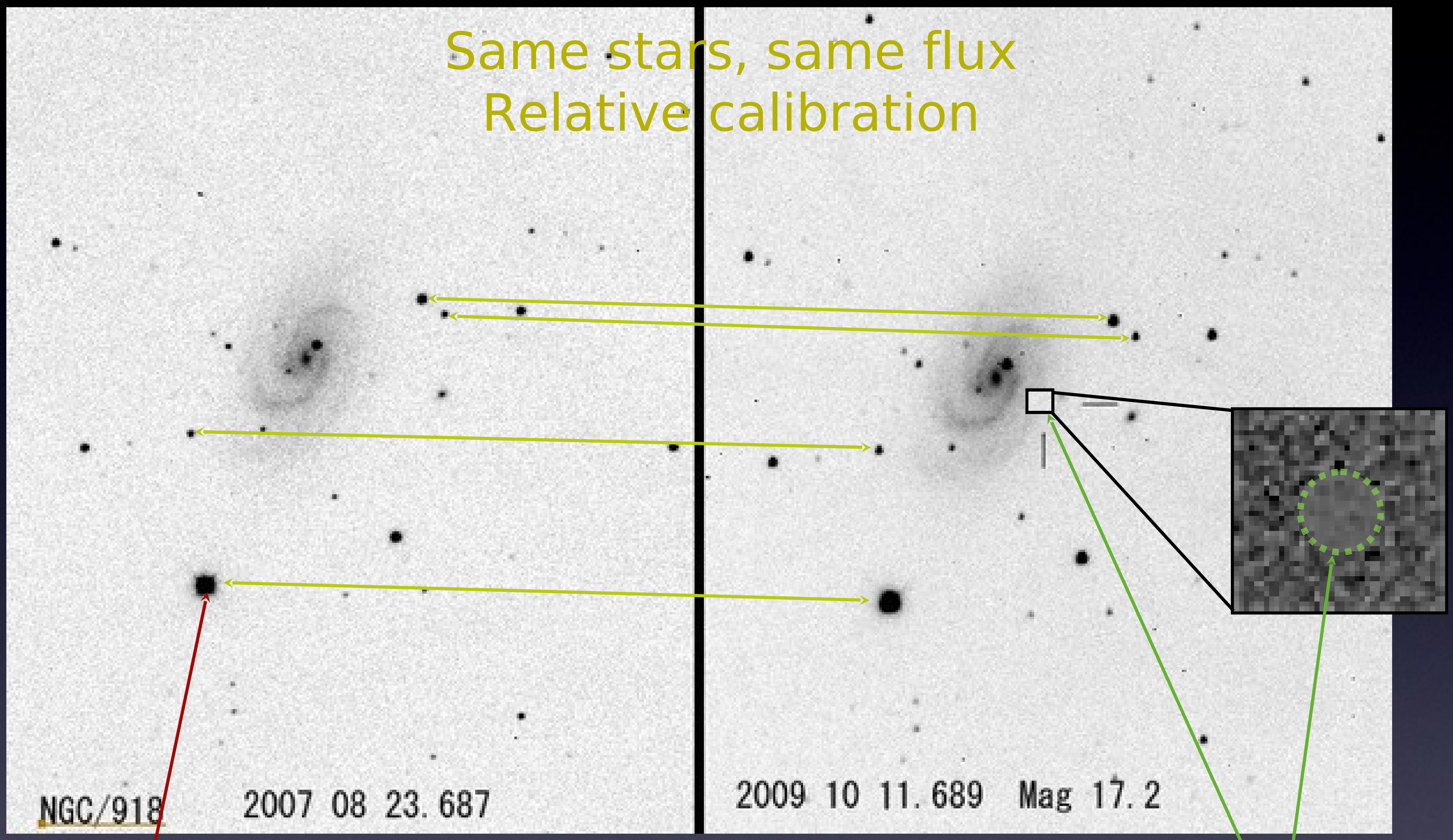
Point Spread Function

Host galaxy flux

Sky variation

PSF variation

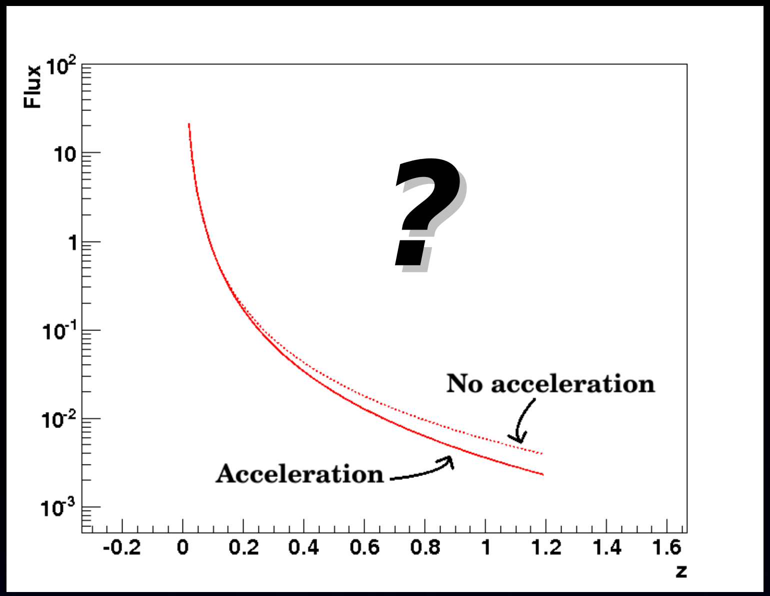
Calibrating the flux



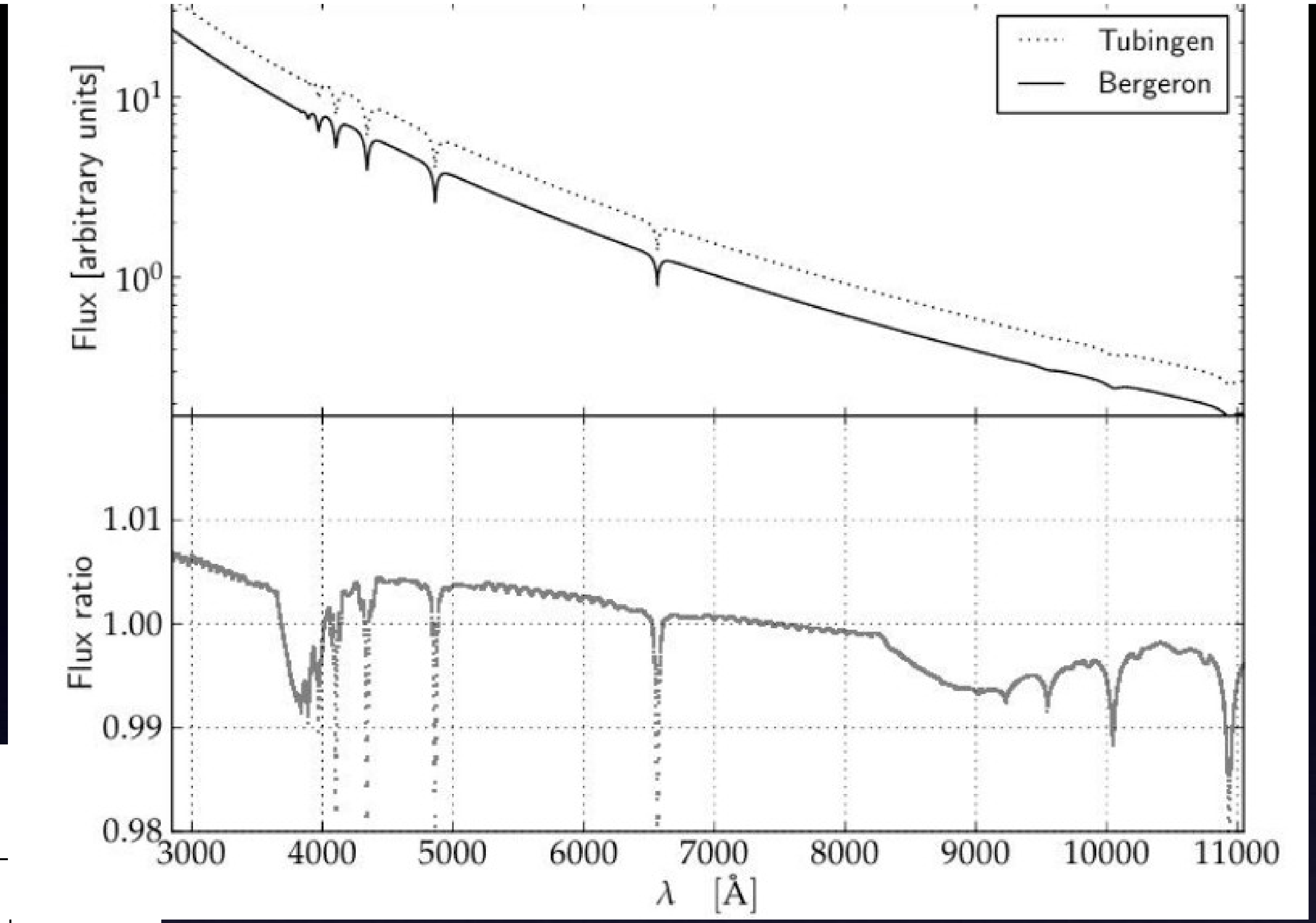
Flux reference
ergs / ADUs

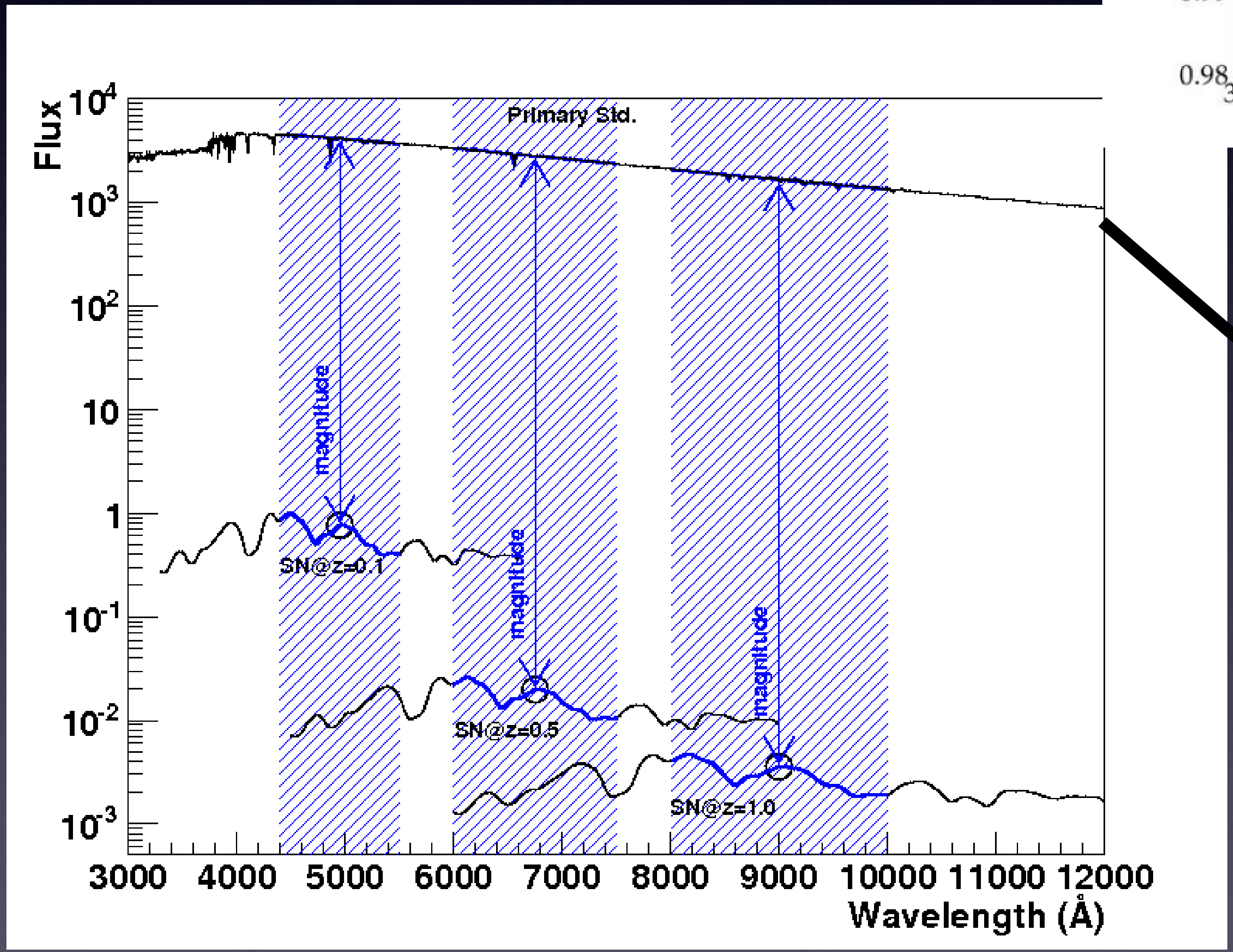
Supernova

Flux calibration

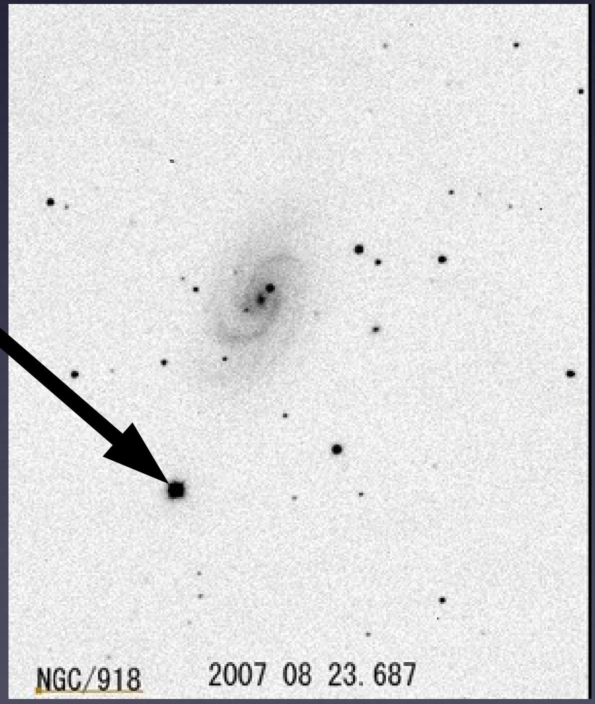


HST observations and DA White Dwarf models

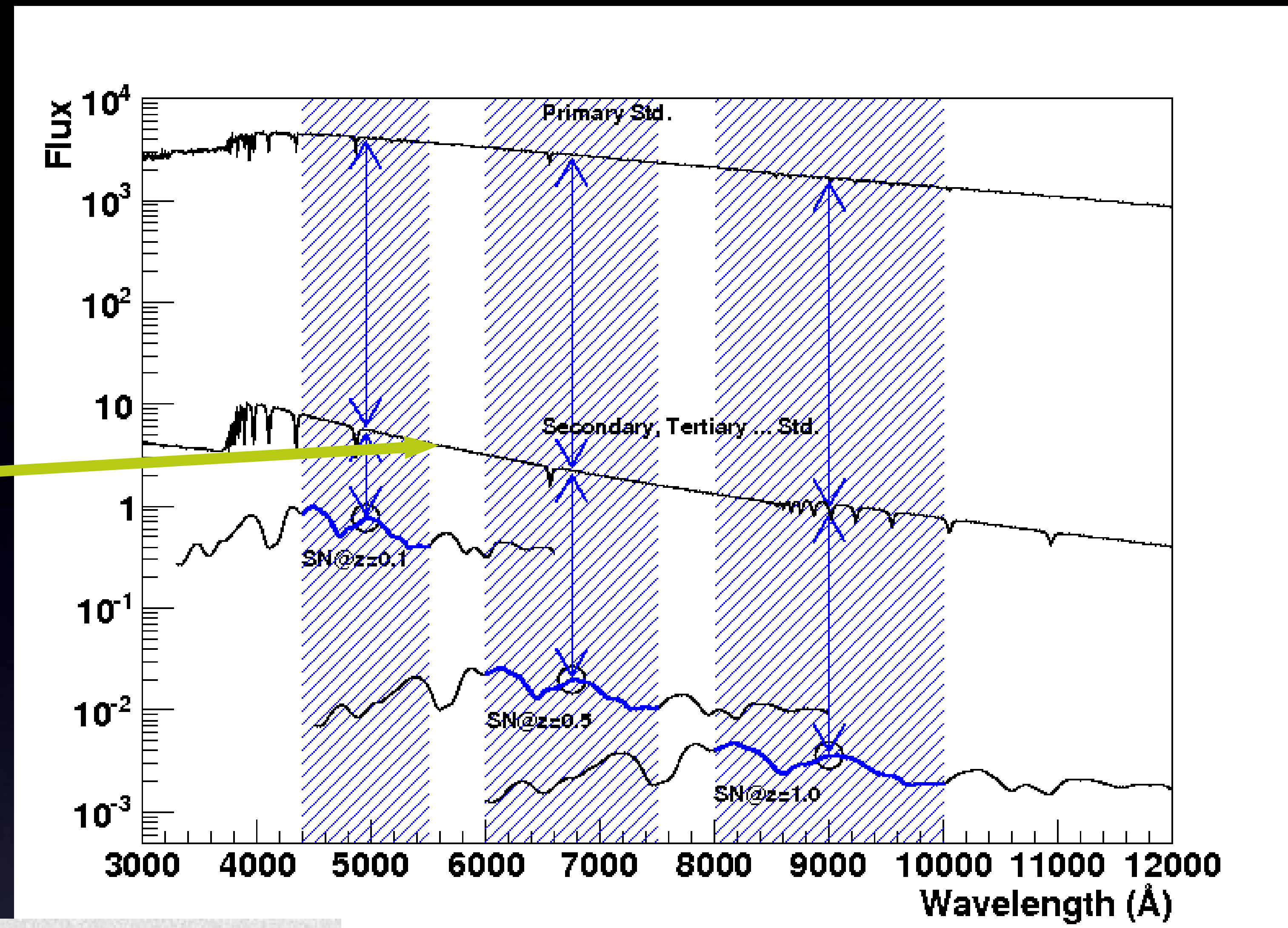


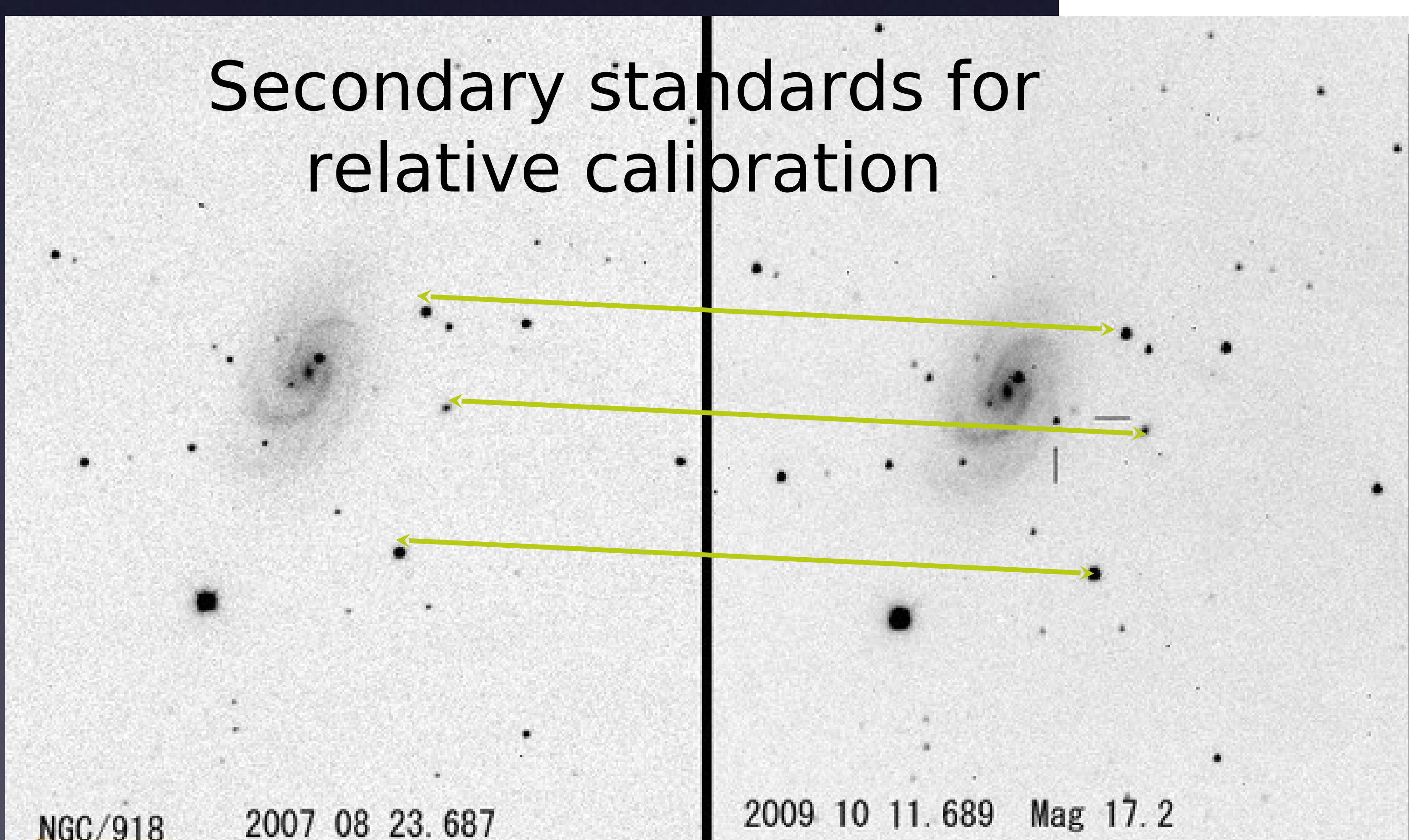


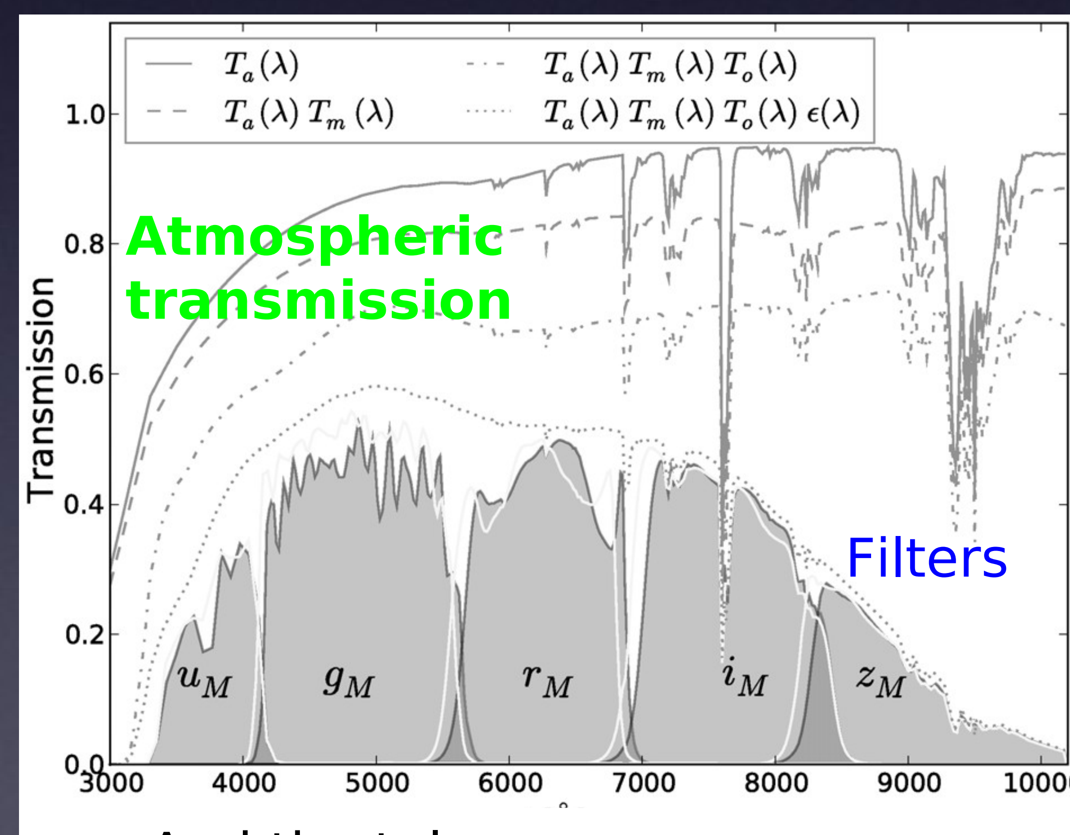
absolute flux reference



Most of the time no absolute standard in the field



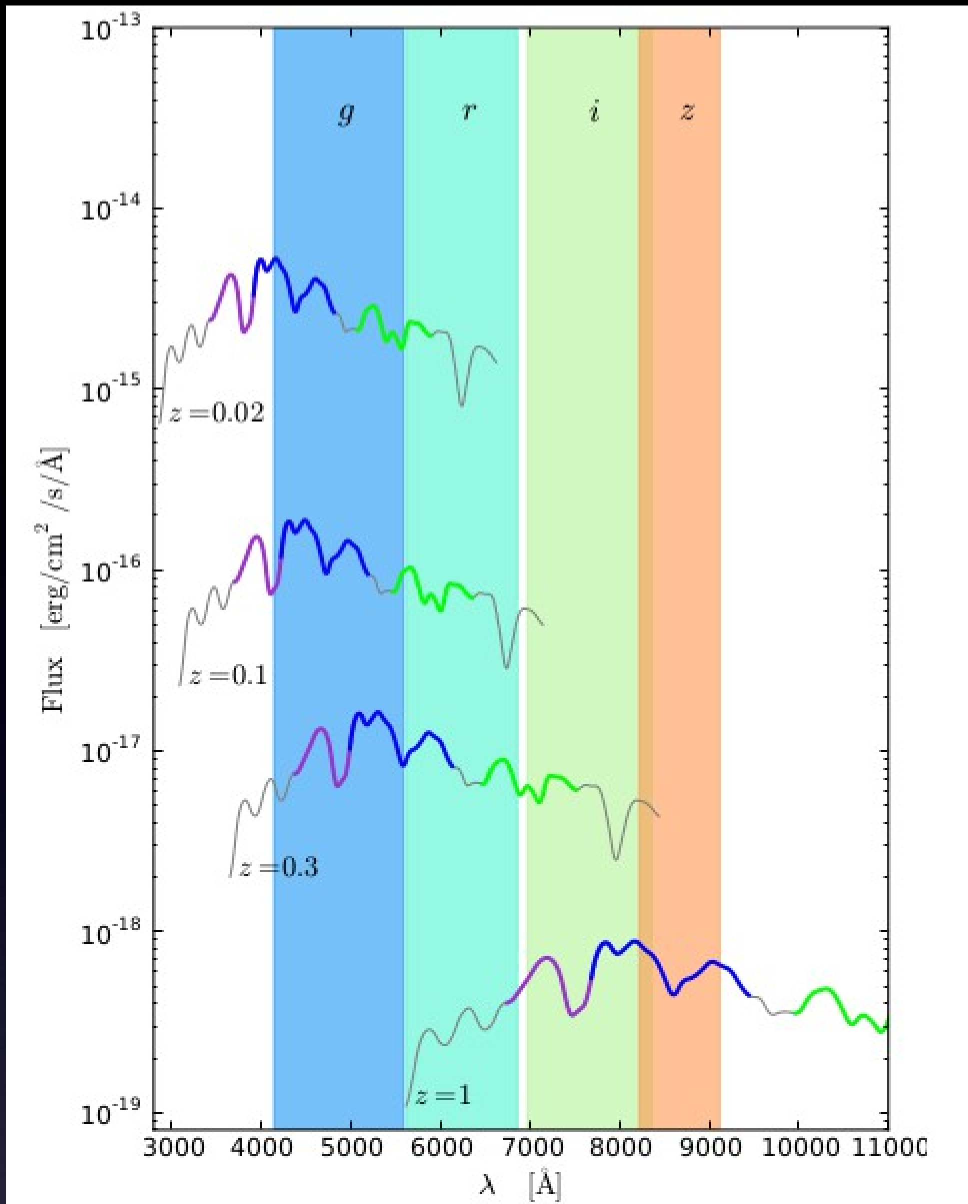


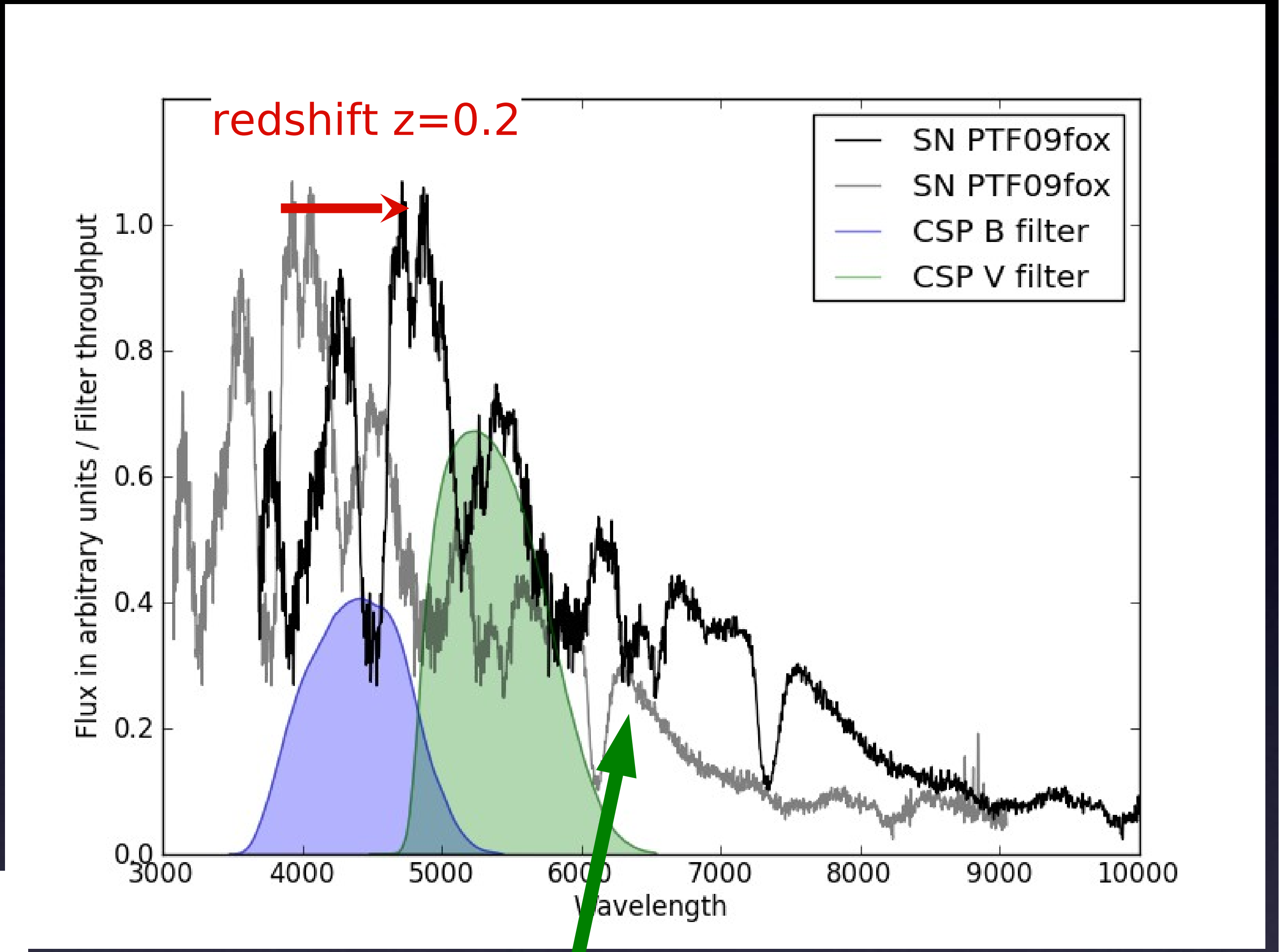


And the telescope...

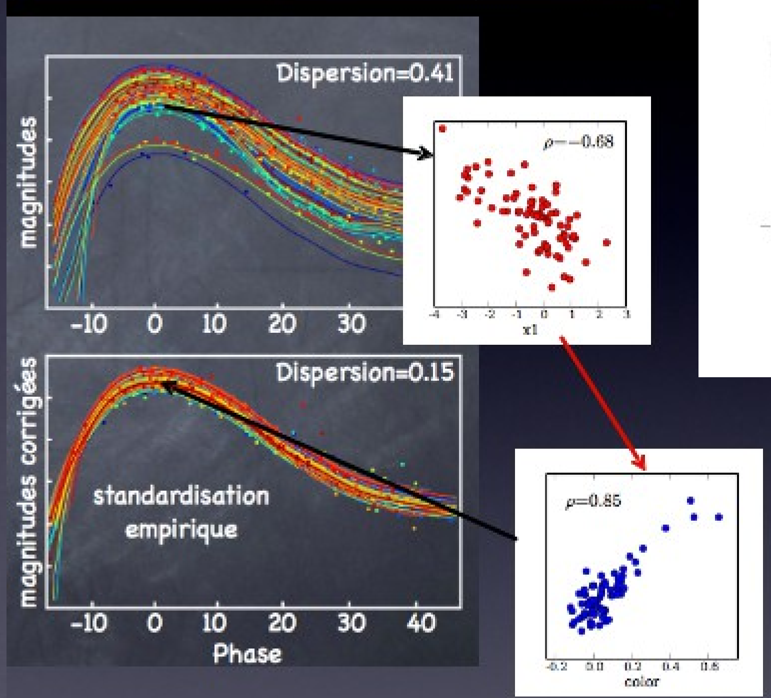
The SN Ia is **redshifted**

But we need it **restframe**

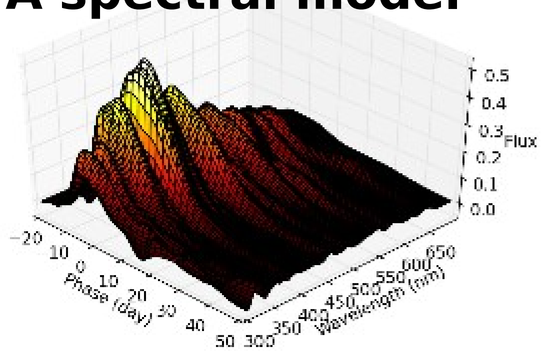




$m_{obs} = M_0 + \mu_0 + \alpha\ x + \beta\ c + \mu$



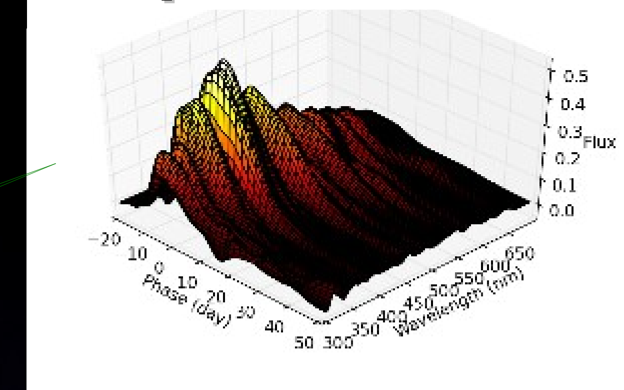
A spectral model

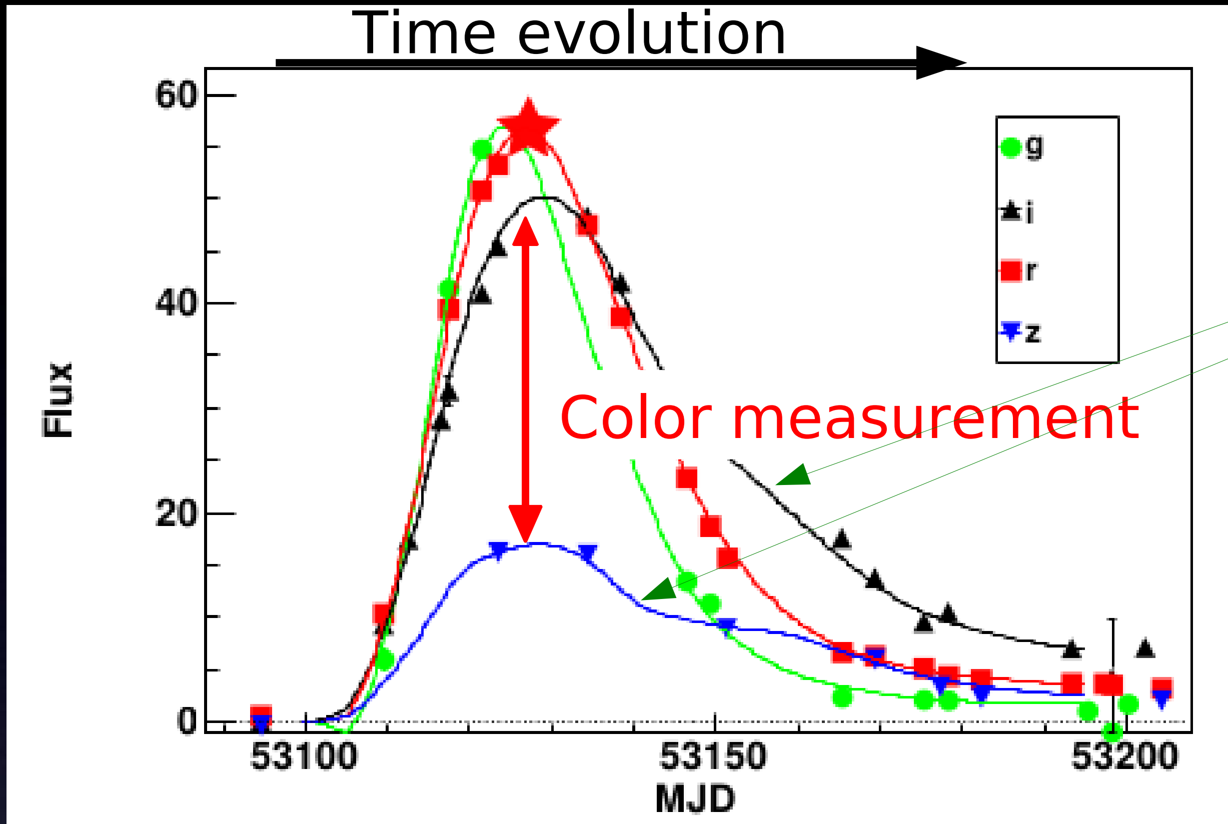


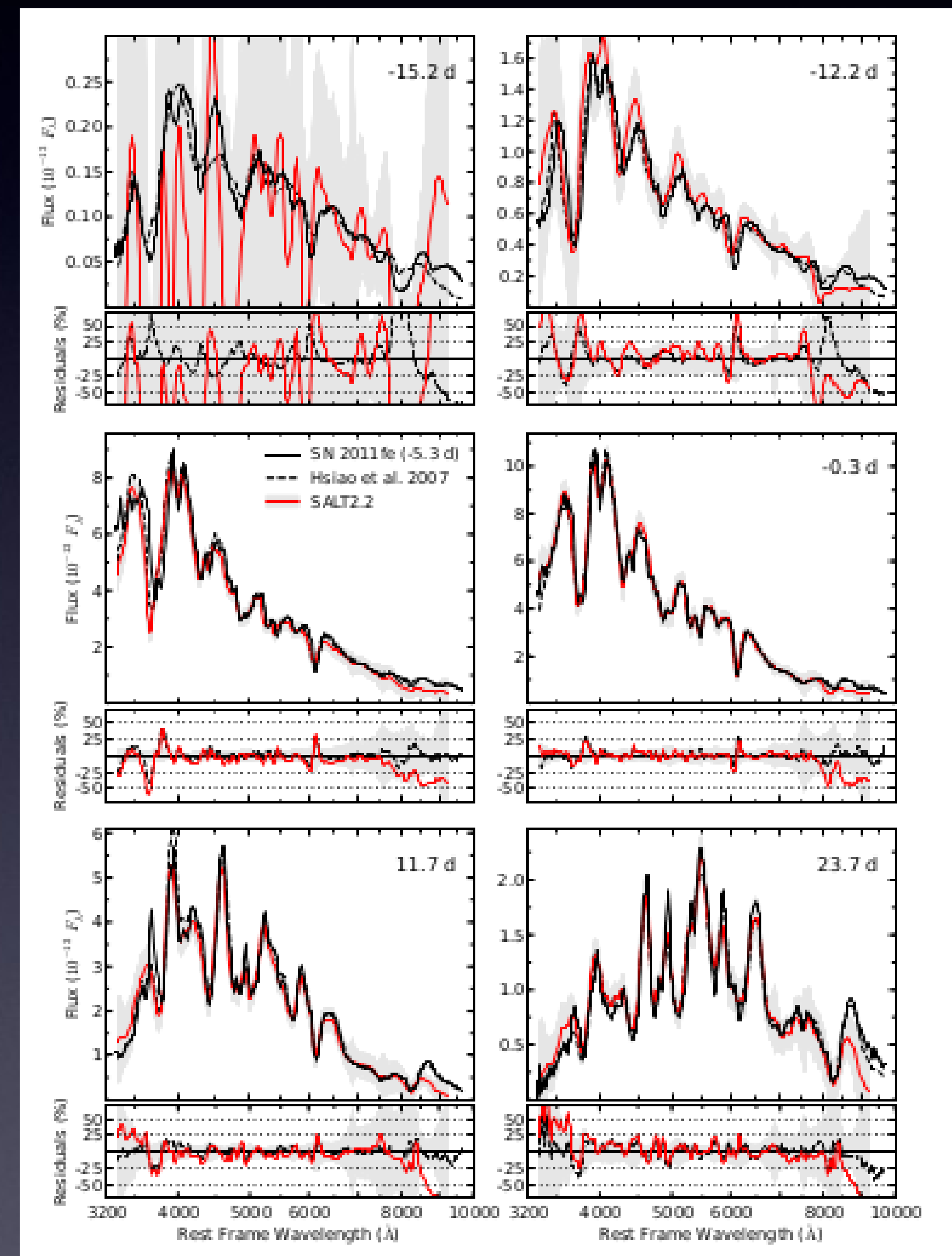
We need to know how much light would have ended in the RESTFRAME FILTERS

$$S(\lambda, \phi) = x_0\, S_0(\lambda,\phi)\ [1 + x_1 S_1(\lambda,\phi)]\ \exp[-c\ CL(\lambda)]$$

A spectral model







Plain lines = Light curve fit

Forward fitting approach of a deconvolution problem

Yields x1 and c

So, what's so hard?

1) Finding the SNe Ia

2) Identifying the SNe Ia

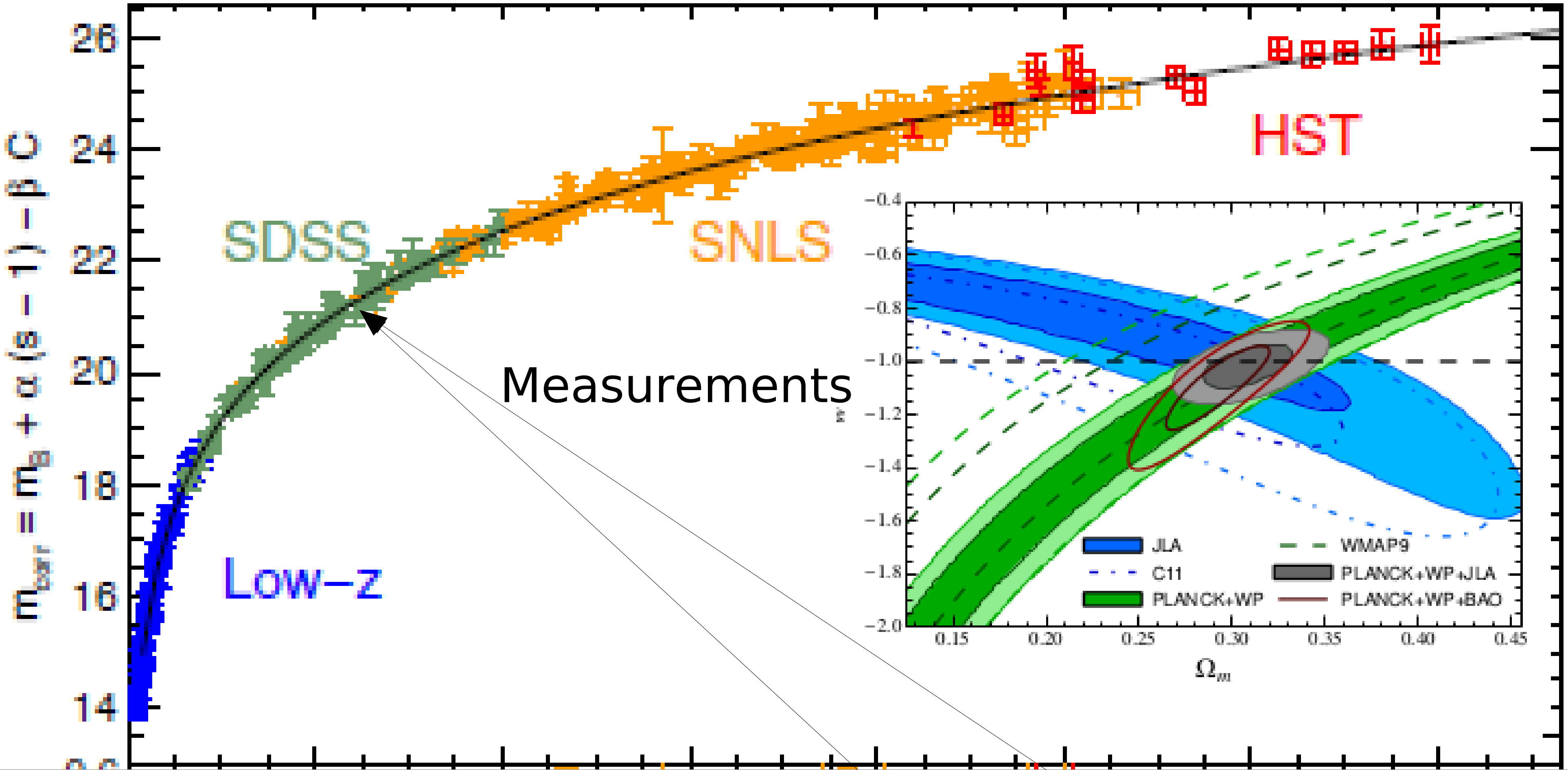
3) Measuring and calibrating SNe Ia fluxes

At least, we are done !

Best measurement of w

- Planck + SN: $w = -1.018 \pm 0.057$
- Planck + BAO: $w = -1.01 \pm 0.08$

$$\frac{\ell(z)}{\mathcal{L}_0} \approx \frac{1}{d_L(z)}$$



$$m_{obs} = M_0 + \mu_0 + \alpha\, x + \beta\, c + \mu$$

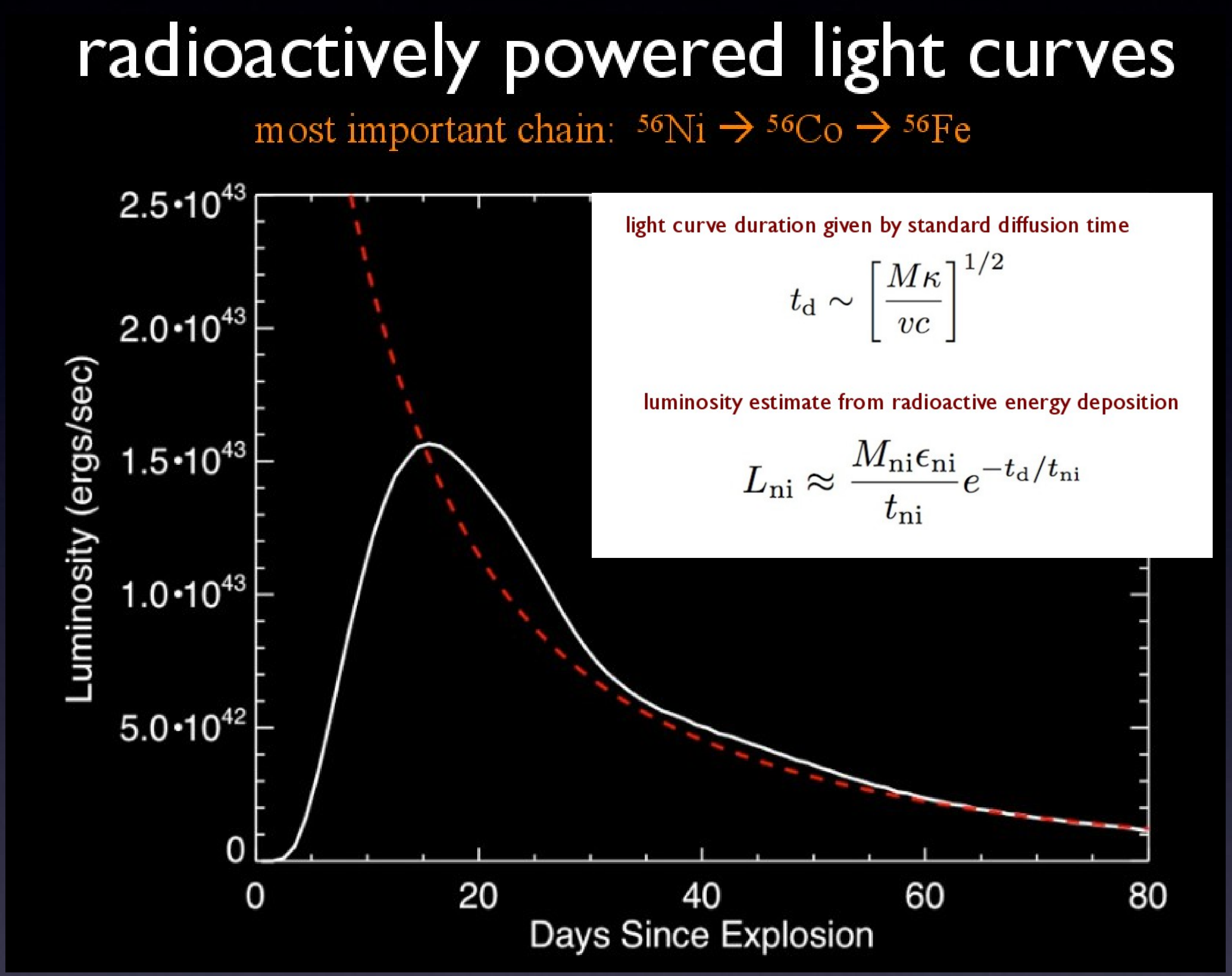
$$d_L(z) = (1+z)\frac{c}{H_0}\int dz \left(\Omega_m(1+z)^3 + \Omega_x(1+z)^{3(1+w)}\right)^{-1/2}$$

Fitted together with the cosmology

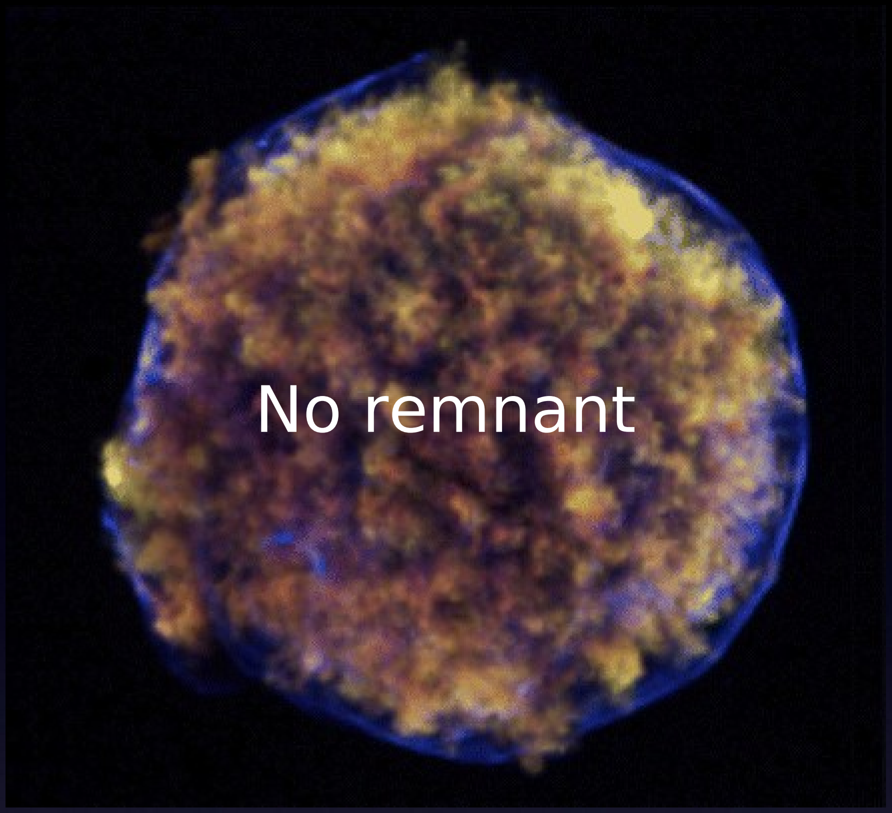
$\mathcal{L}_0 H_0^2$ is a nuisance parameter for SN cosmology

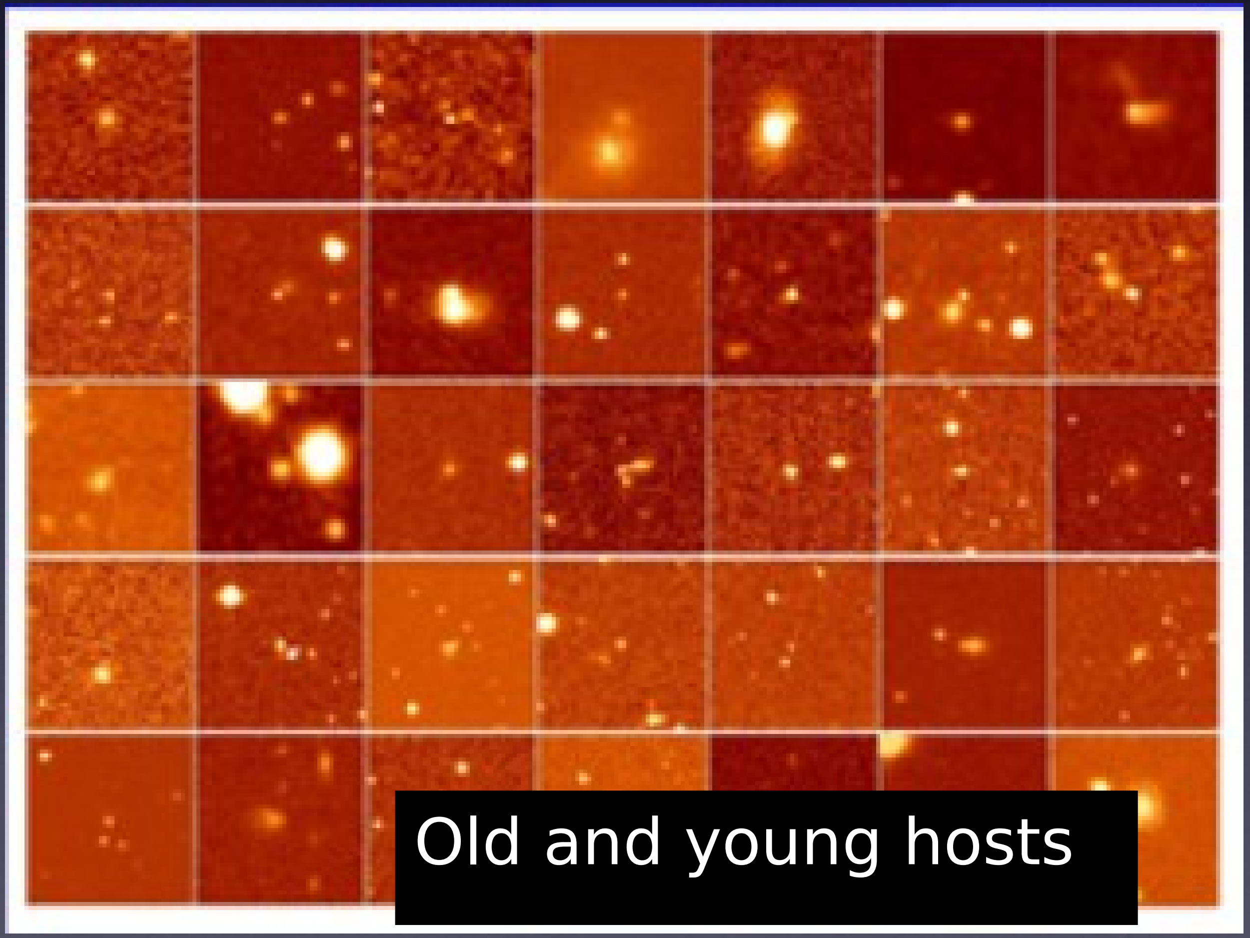
... But for one question: what is a type Ia supernova?

What can we learn from imaging ?

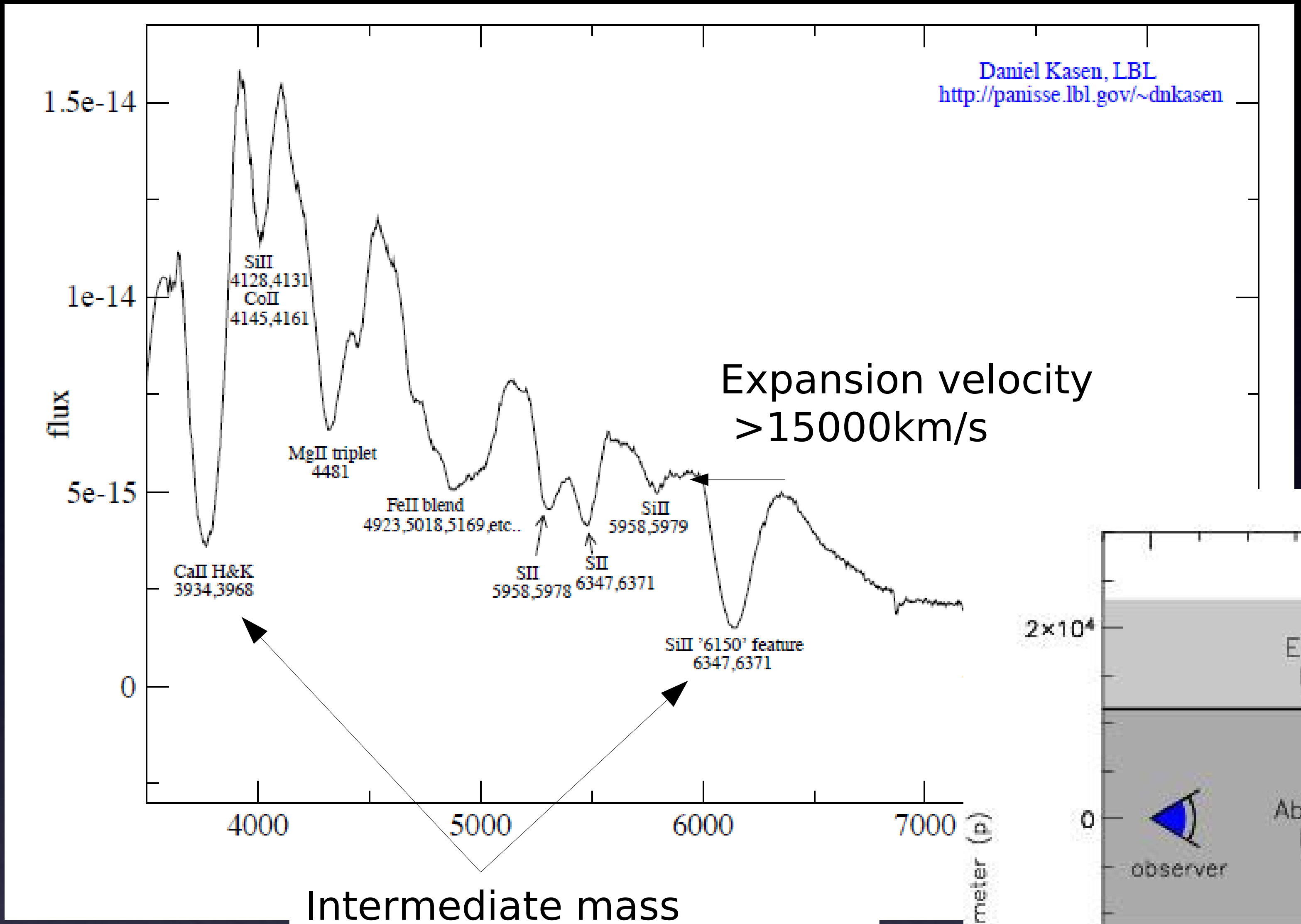


$$^{56}Ni \xrightarrow{\text{7 day half life}} {}^{56}Co \xrightarrow{\text{77 day half life}} {}^{56}Fe$$





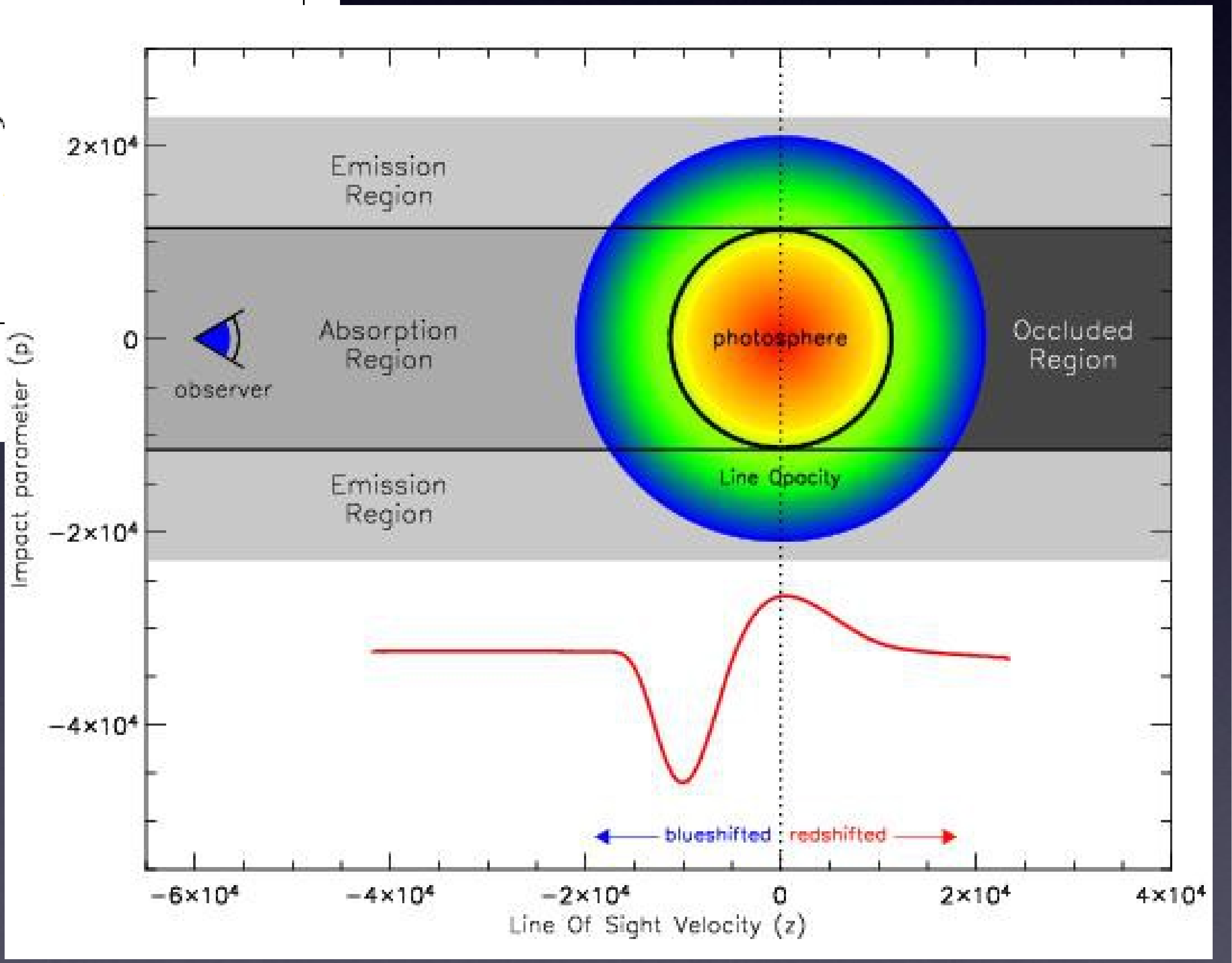
What can we learn from the spectra ?



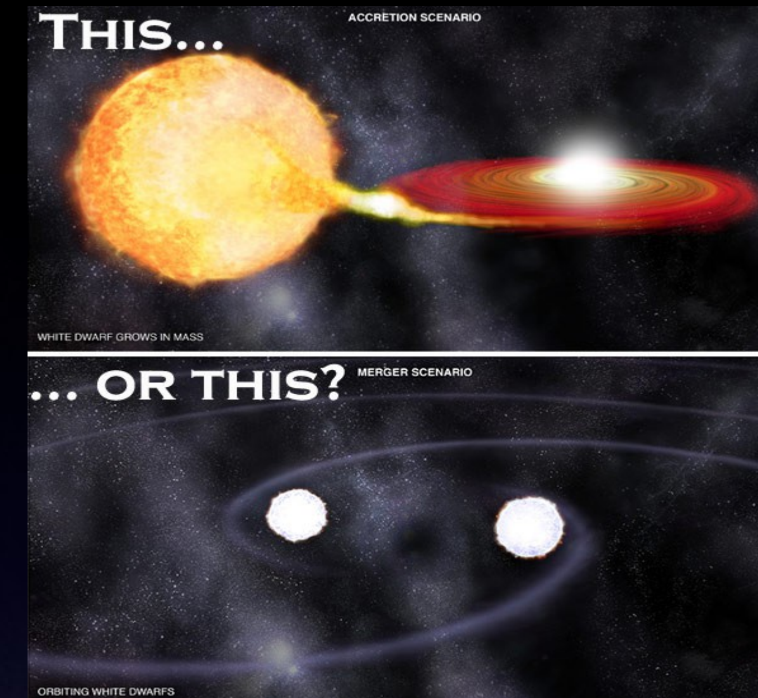
Expansion velocity
>15000km/s

Intermediate mass elements (Si, S, Mg, Ca ...)

$^{56}\text{Ni} \xrightarrow{\text{7 day half life}} {}^{56}\text{Co} \xrightarrow{\text{77 day half life}} {}^{56}\text{Fe}$



Thermonuclear explosion of one... or two White Dwarves



Very difficult to model

stellar evolution (>10^6 years)

↓ ρ(r), T(r), A_i(r) at ignition/collapse

explosion (seconds/hours)

hydrodynamics, equation of state
nuclear burning, neutrino transport

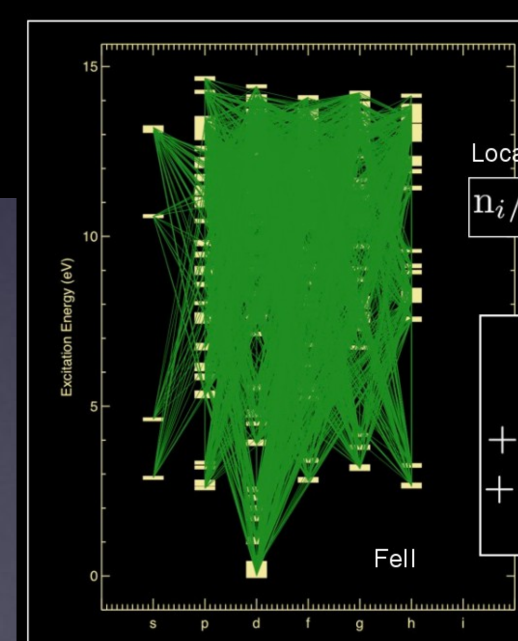
→ neutrinos
grav. waves
x-rays, γ-rays

↓ ρ(x,y,z), v(x,y,z), T(x,y,z), A_i(x,y,z)
in free expansion

expanding ejecta (months)

photon transport
matter opacity
thermodynamics
radioactive decay

→ optical spectra
light curves



line interactions

~1/2 GB atomic data

Local Thermodynamic Equilibrium (LTE)

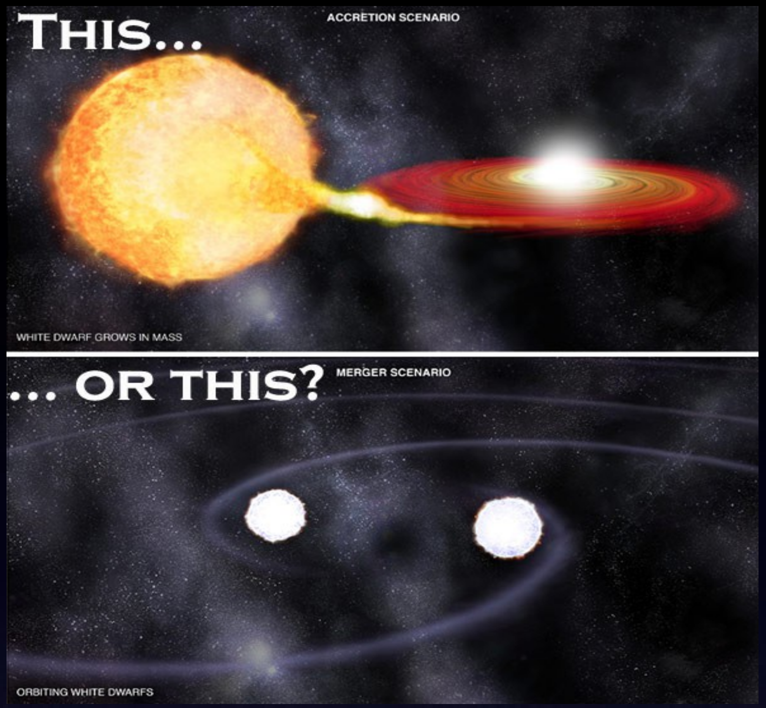
$$n_i/n_j = \frac{g_i}{g_j}\exp(-\Delta E/kT)$$

non-equilibrium (NLTE)

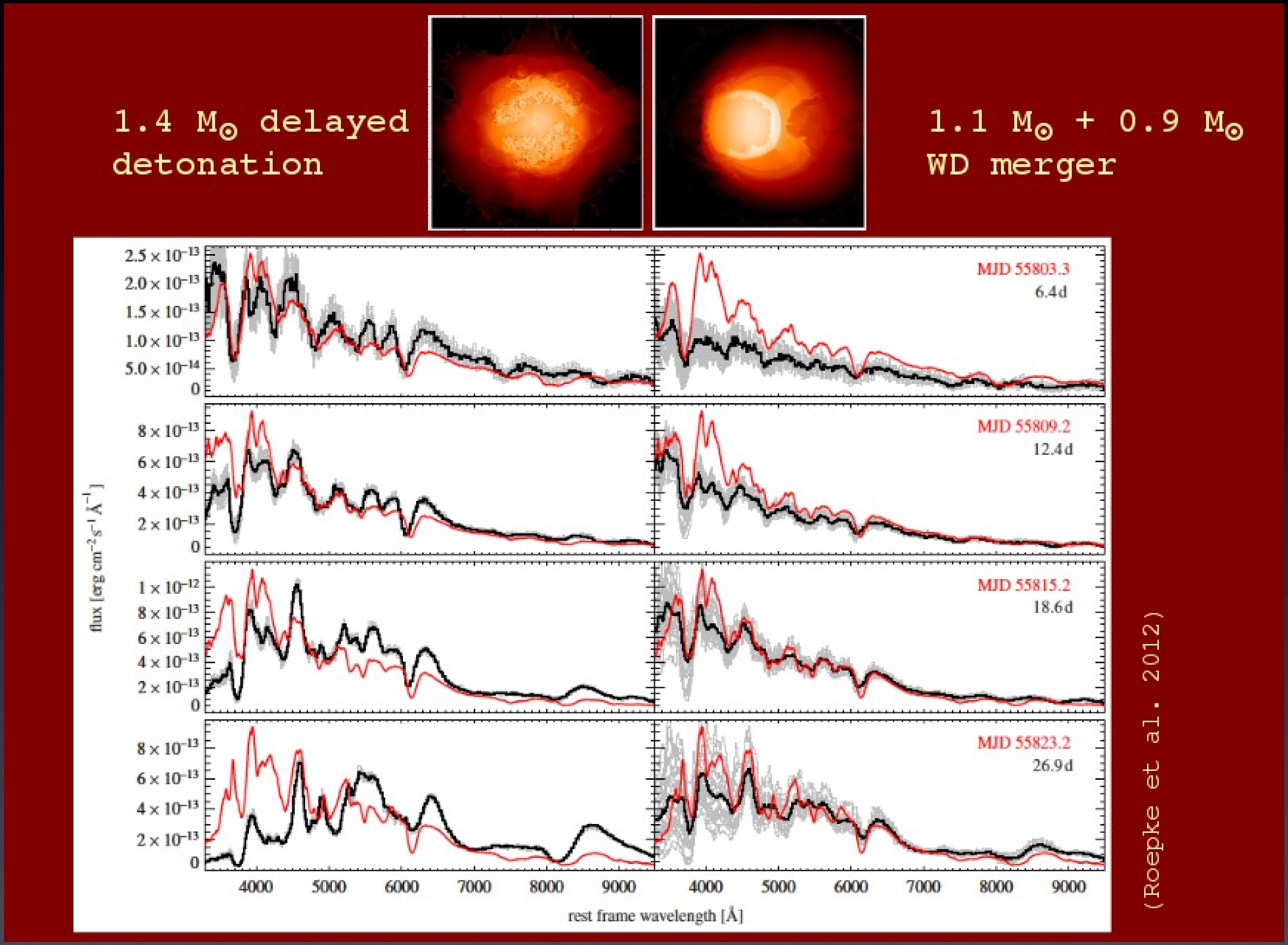
$$\partial n_i/\partial t = \sum_{j\neq i}(n_j R_{ji} - n_i R_{ij}) + \sum_{j\neq i}(n_j C_{ji} - n_i C_{ij}) + \sum_{j\neq i}(n_j G_{ji} - n_i G_{ij}) = 0$$

nxn matrix, where n = number of atomic levels (sparsity depends on number of transitions included)

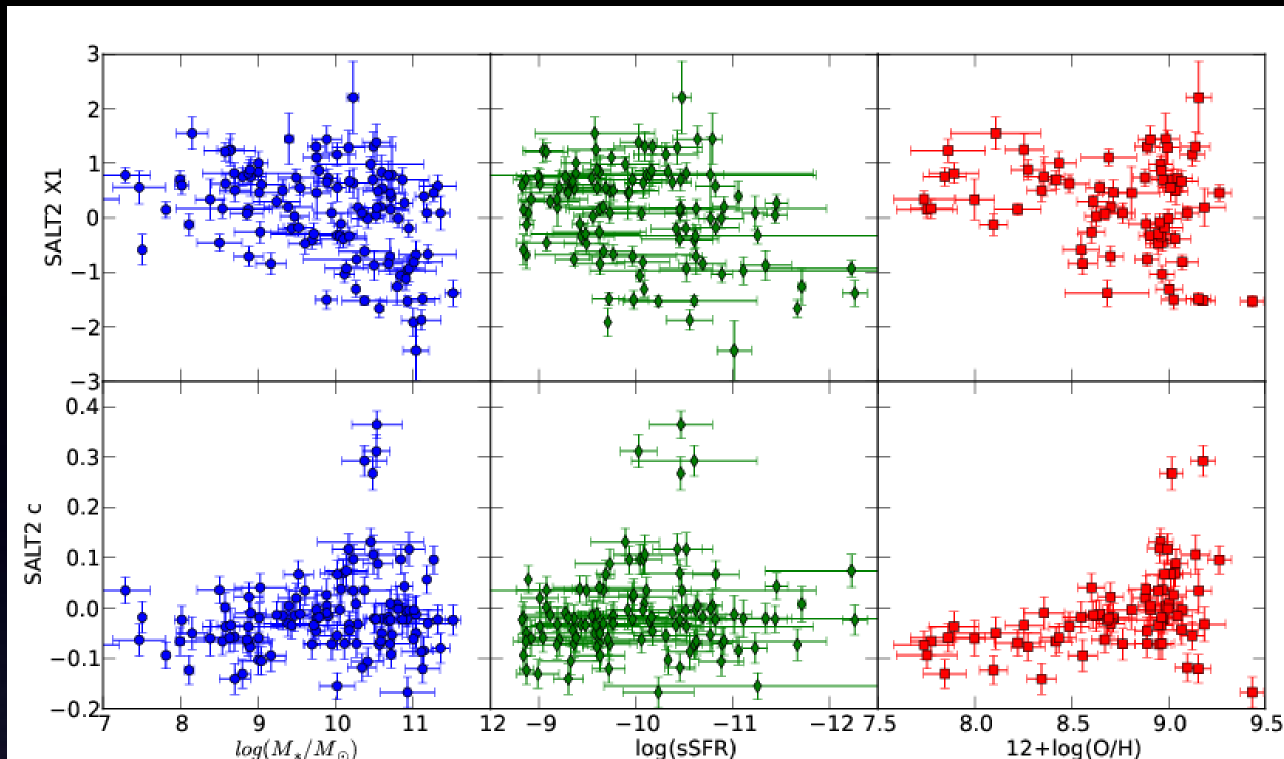
Thermonuclear explosion of one... or two White Dwarves



Only qualitative agreement between models and data

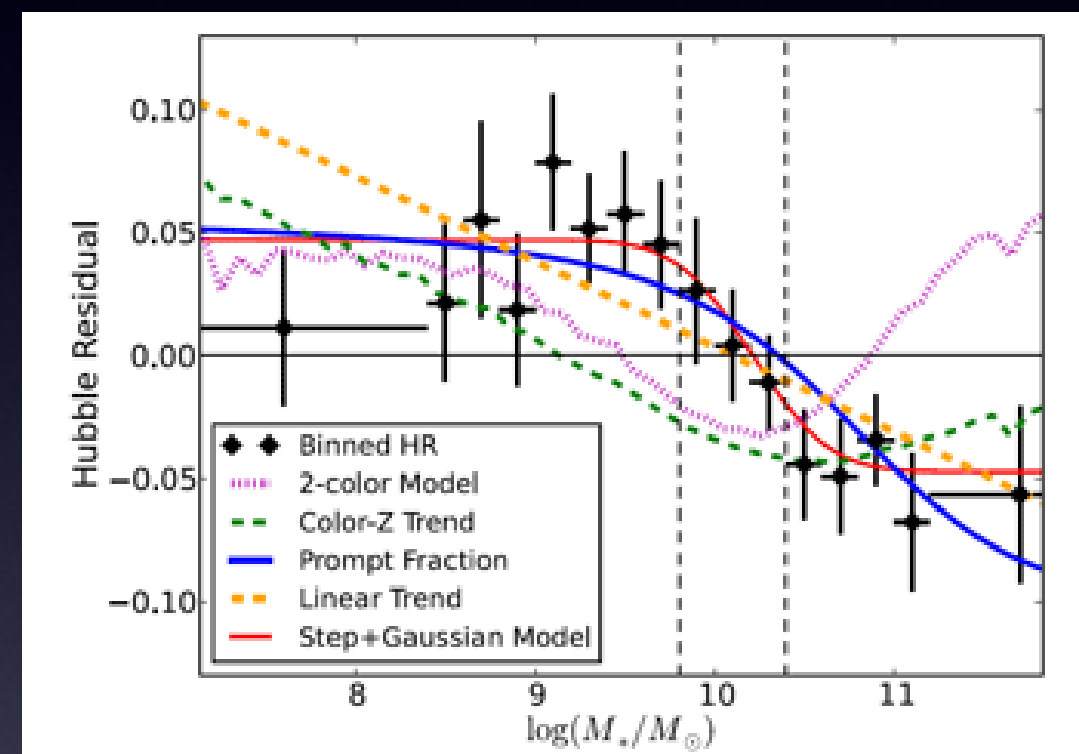


Some “hints” that the environment matters:



Host metallicity correlated with SALT2 c

Distance residual correlated with host mass



Could those depend on z ?

$$m_{obs} = M_0 + \mu_0 + \alpha\ x + \beta\ c + \mu$$

This will matter for next generation surveys

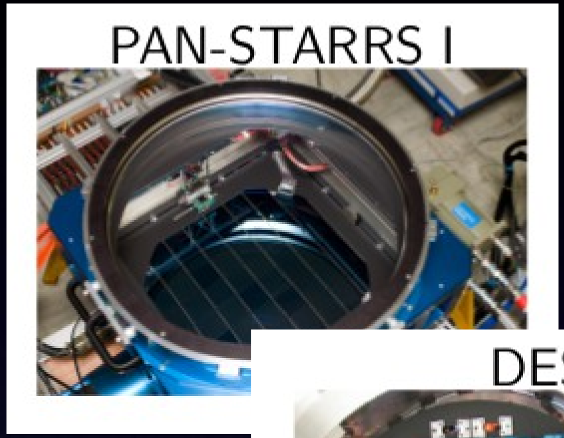
Besides, SNe Ia don't explode in a Void

Dust average properties can depend on z

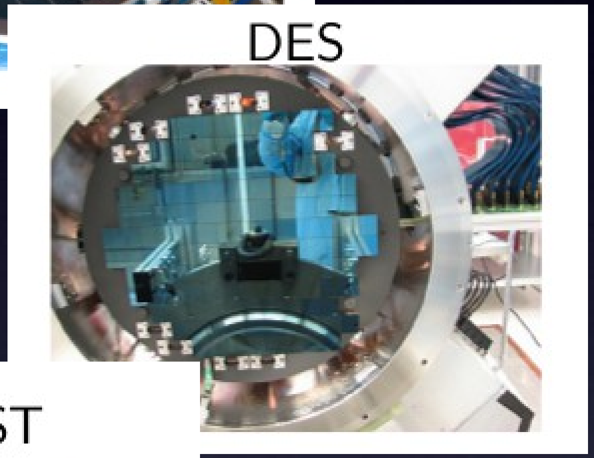
$$m_{obs} = M_0 + \mu_0 + \alpha\ x + \beta\ c + \mu$$

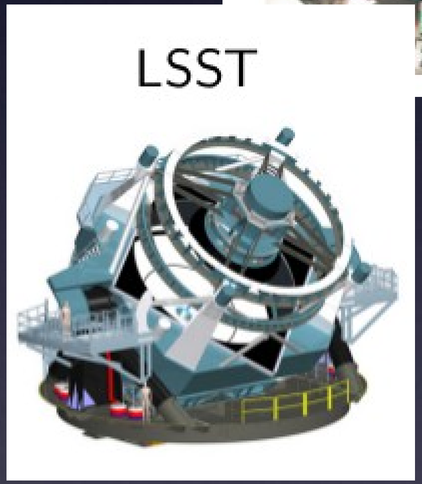
Next generation of SNe Ia cosmological surveys

More

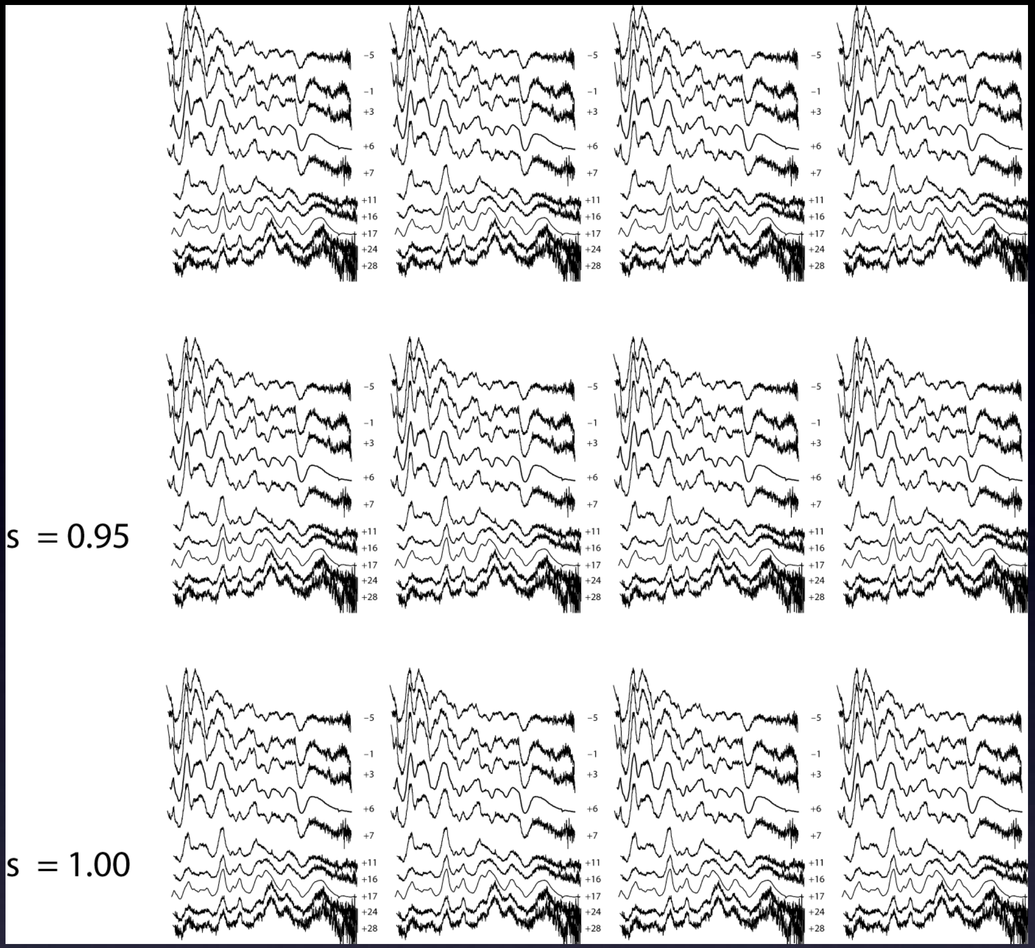


More





More !



Spectroscopic surveys to understand the object

SNLS 5: 500 high redshift SNe Ia vs 200 Nearby SNe Ia

Nearby SNe Ia might become the bottleneck