Переход к формализму ОТО

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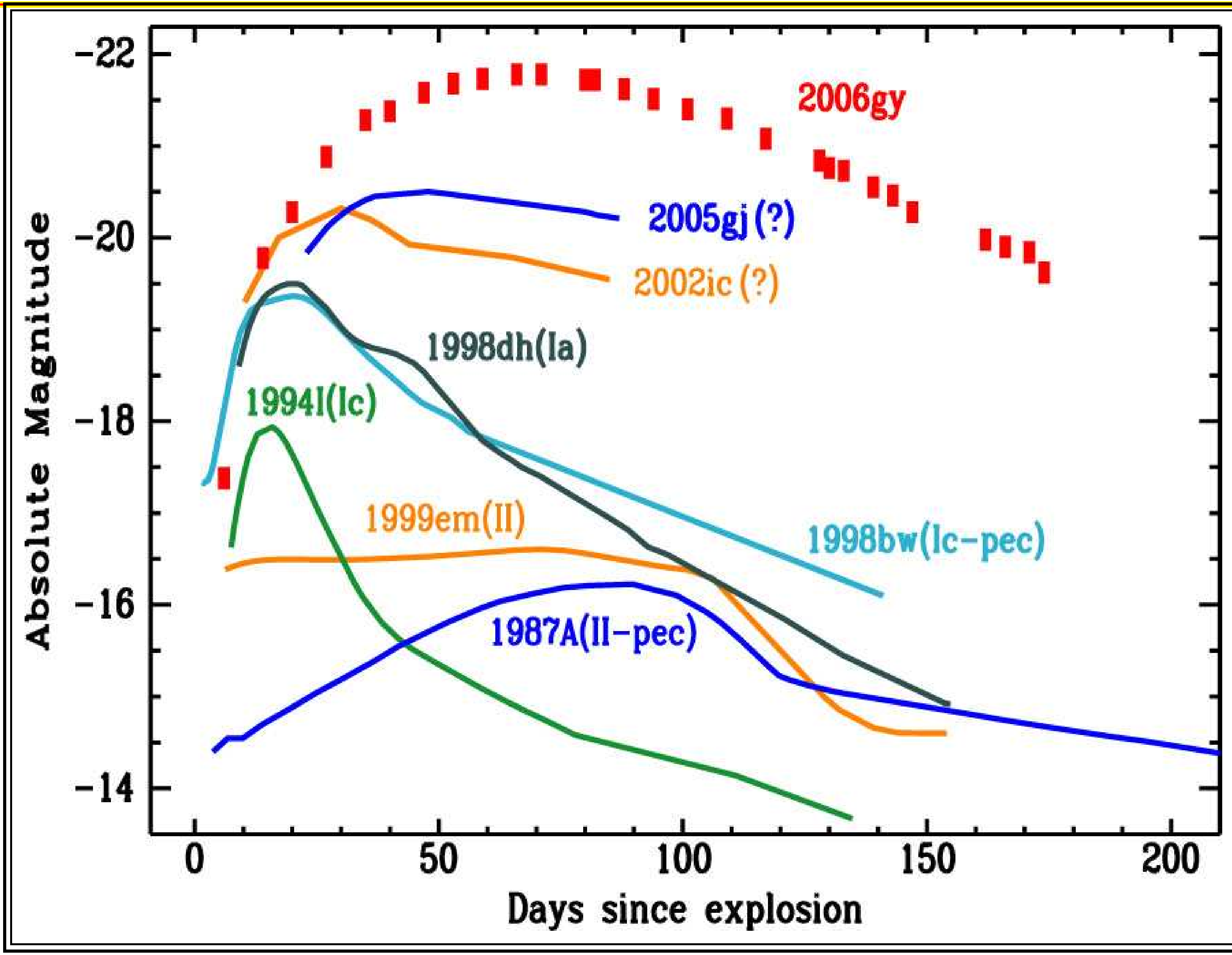
НГУ 29 сентября 2012

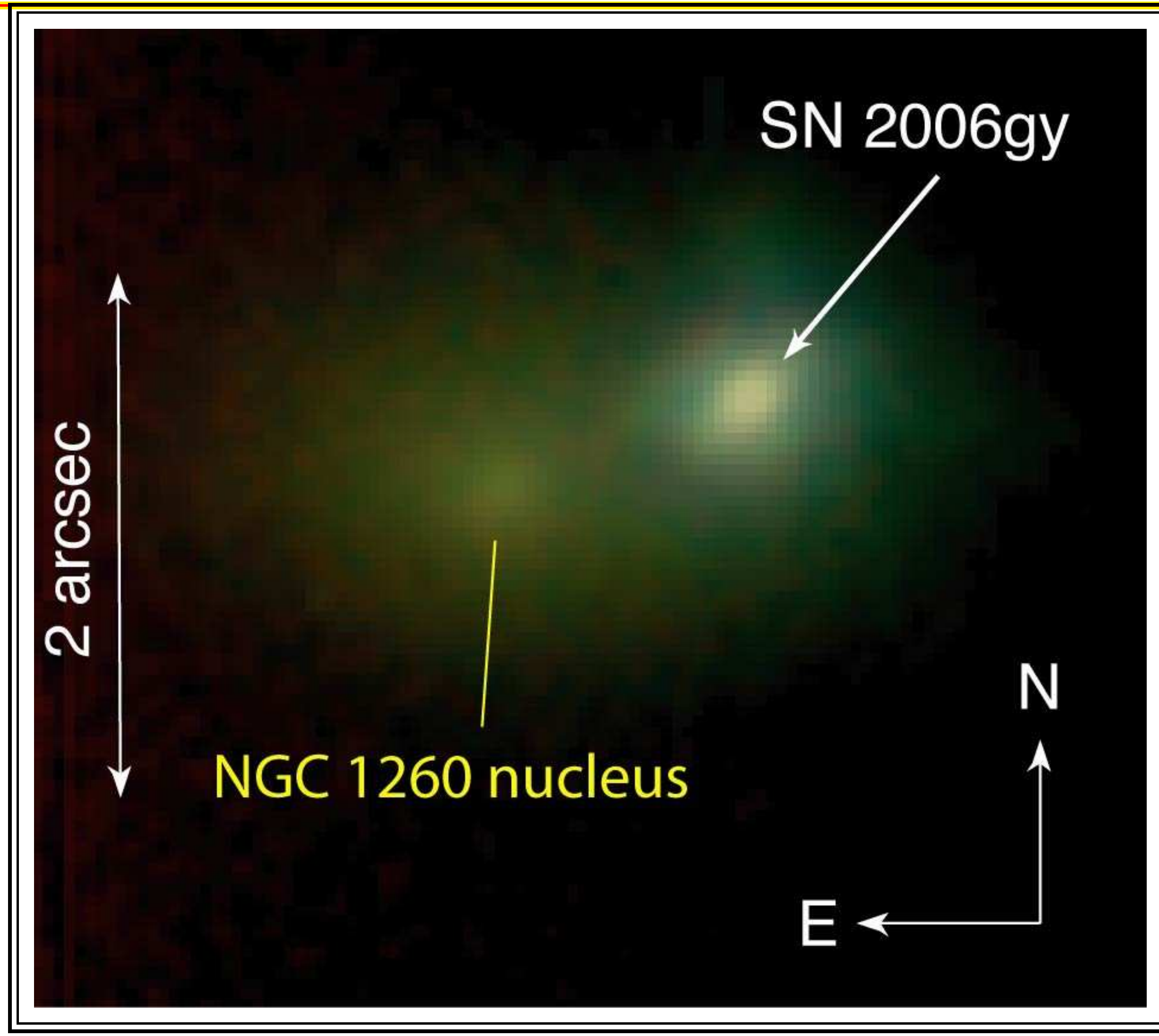
Most Luminous SNe



SN 2006gy – сверхмощная сверхновая

Ofek et al. 2007, ApJL, astro-ph/0612408)

Smith et al. 2007, Sep. 10 ApJ, astro-ph/0612617)



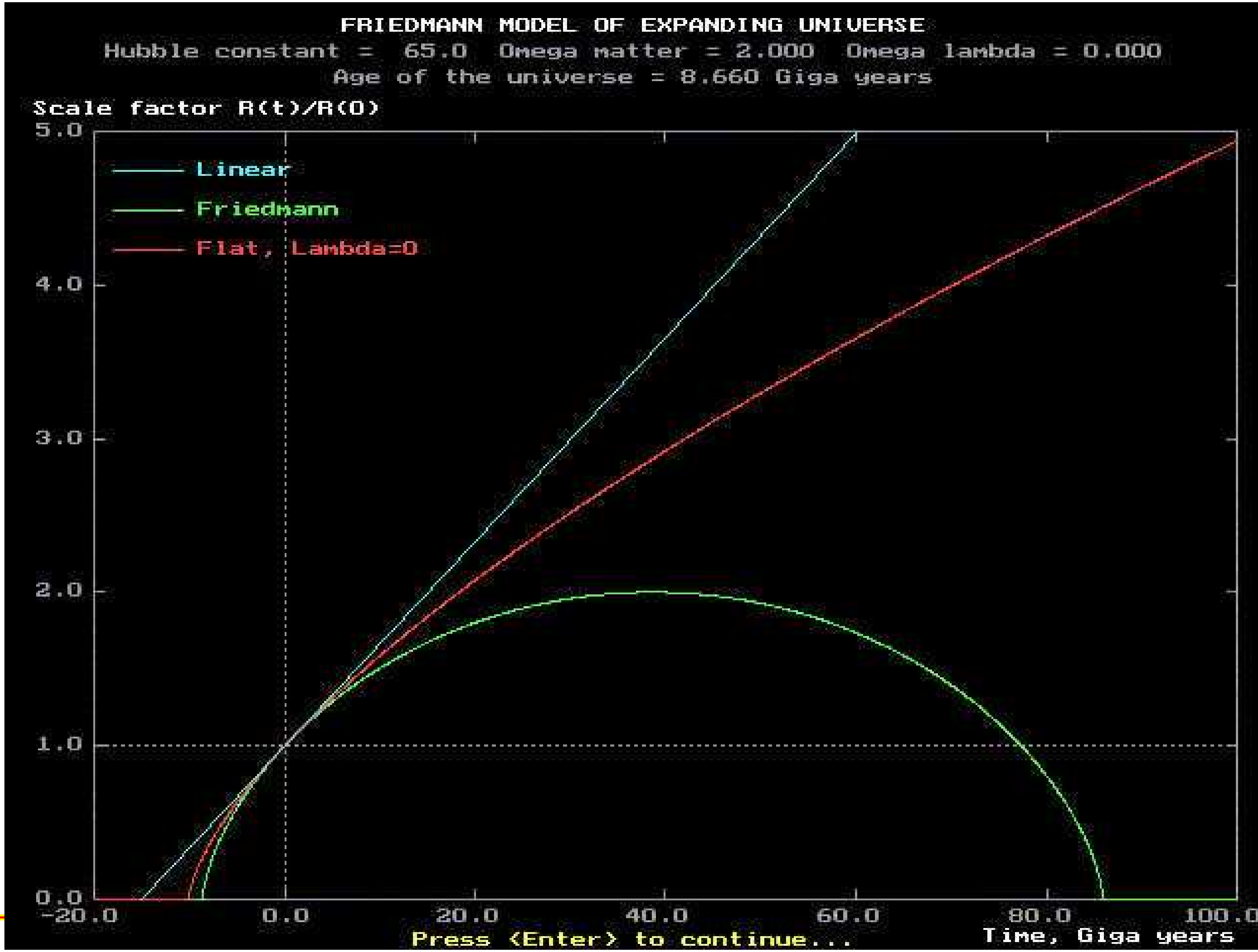
Тёмная энергия Dark Energy (DE)

Что такое Тёмная энергия?

Ответ до сих пор не известен!

Как её нашли?

Scale factor $\Omega = 1, \Omega = 2$



Scale factor $\Omega_\Lambda = 0.9,\ \Omega_m = 0.1$

Deceleration or Acceleration

We see that in case of the accelerating growth of the scale factor the objects in the past are more distant for the same time difference $t_0 - t$. I.e. they would appear fainter than in standard decelerating scenario with attractive gravity and no antigravity which may be due to the Λ-term or, say, to $P = w\rho$ with $w < 0$.

However, the plots like above are not good to extract Omegas, since $a(t)$ and t are not directly observable.

Observables are redshifts and distances (the latter depend on a definition)

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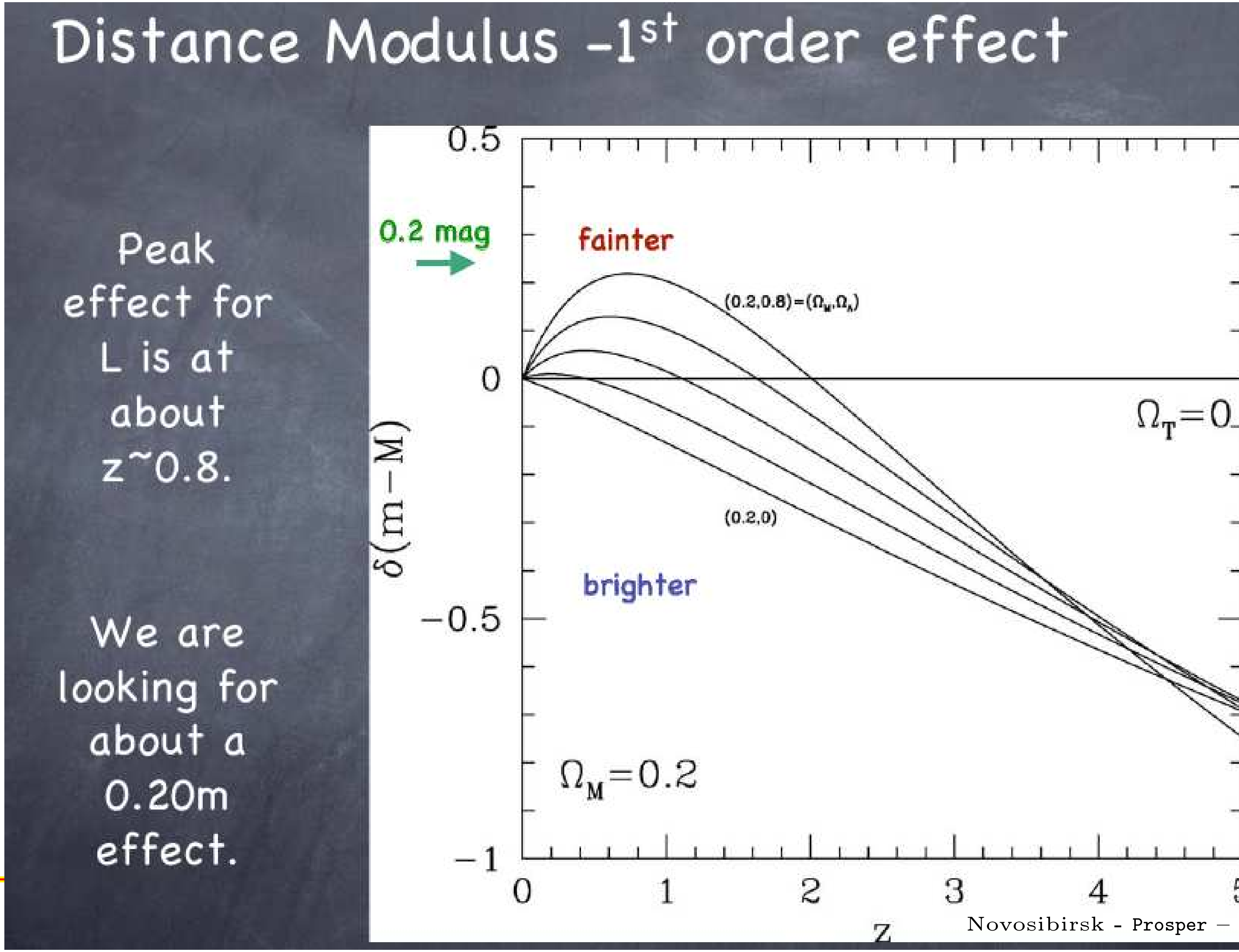


Driving force for Acceleration?

В слабых полях и при малых скоростях уравнения ОТО сводятся к Ньютону.

$M = 4\pi\rho R^3/3$, and Newton's laws give us the energy conservation:

$$\frac{u^2}{2} = \frac{G_\mathrm{N} M}{R} - \text{const}\,,$$

If $\rho \propto 1/a^3 \propto M/R^3$, i.e. $M = \mathrm{const}$, then $\dot{a} = u$ goes down (e.g. ordinary matter or CDM), – decelerating.

If ρ has a slowly changing or a constant component (M grows!), then $\dot{a}$ grows, – accelerating. E.g. for $\rho = \rho_\Lambda = \mathrm{const}$:

$$\dot{a}/a \to \mathrm{const}.$$

Vacuum energy

Introducing energy into the vacuum is equivalent to introducing a cosmological constant Λ into Einstein's equations. The vacuum energy has the form of a perfect fluid with

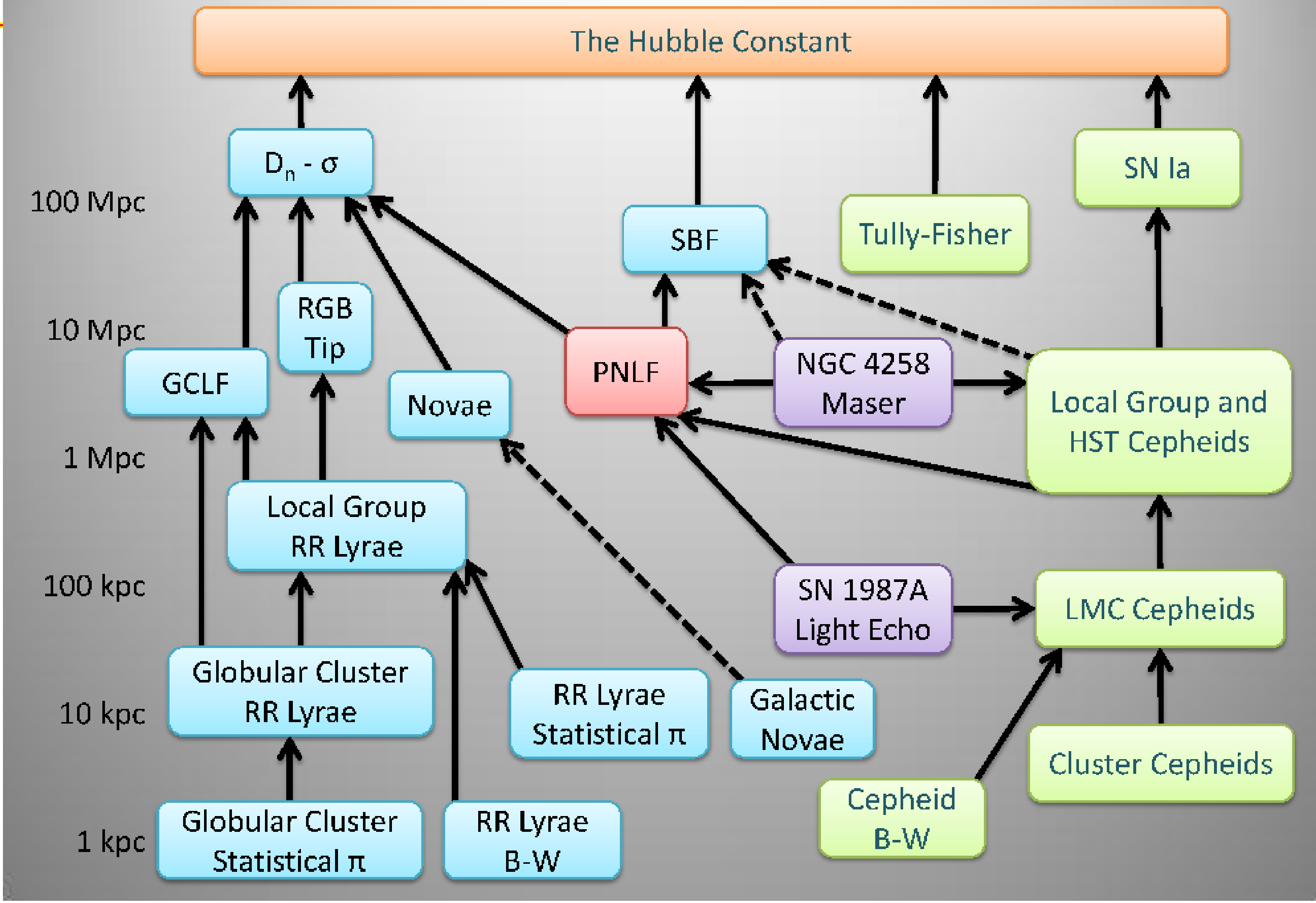
$$\mathcal{E} = \frac{c^4 \Lambda}{8\pi G} \ .$$

Ho

$$dE + PdV = d(\mathcal{E}V) + PdV = 0, \quad \Rightarrow PdV = -\mathcal{E}dV.$$

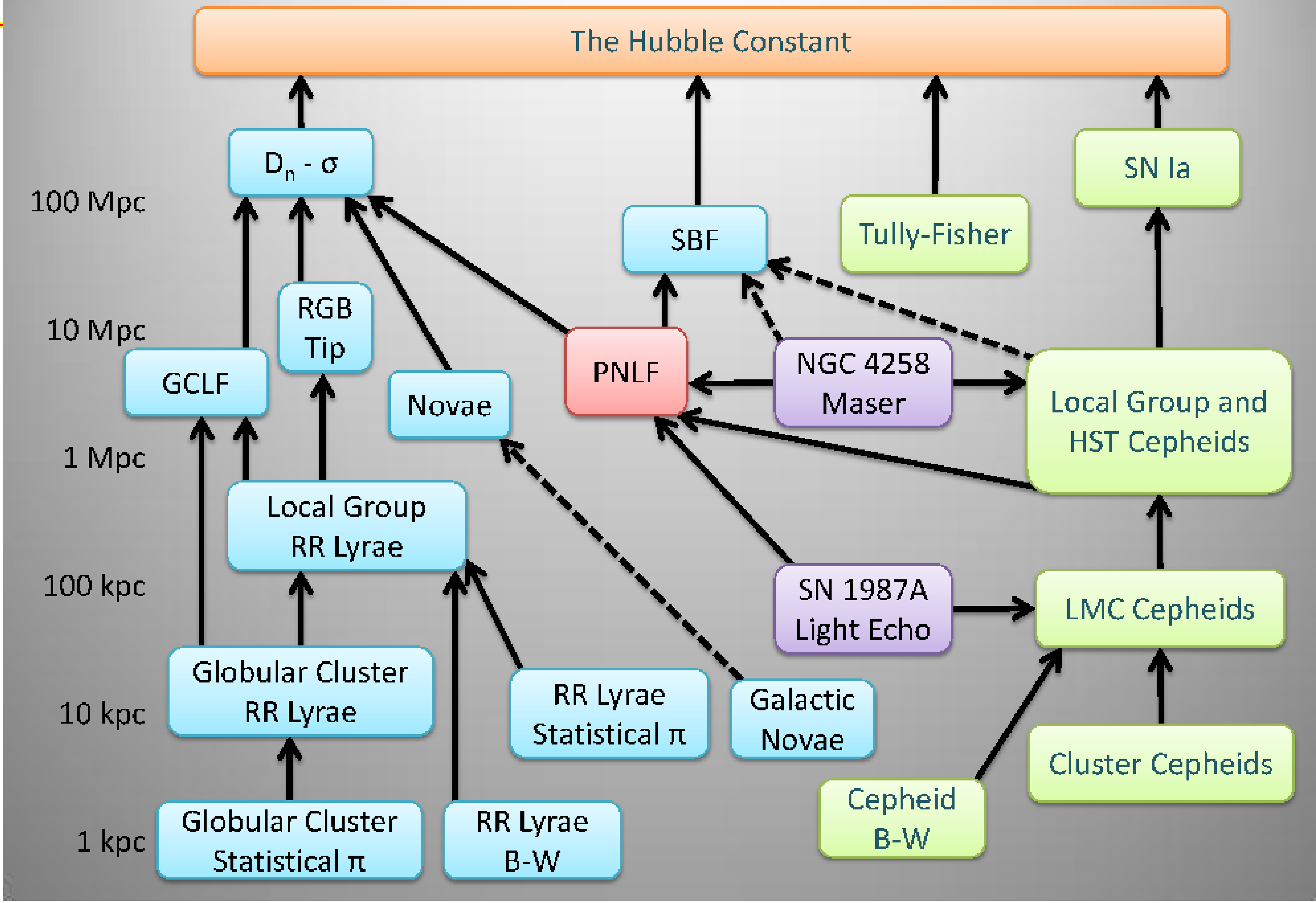
We immediately get $P = -\mathcal{E}$, and the energy density is independent of a, which is what we would expect for the energy density of the vacuum.

Extragalactic Distance Ladder

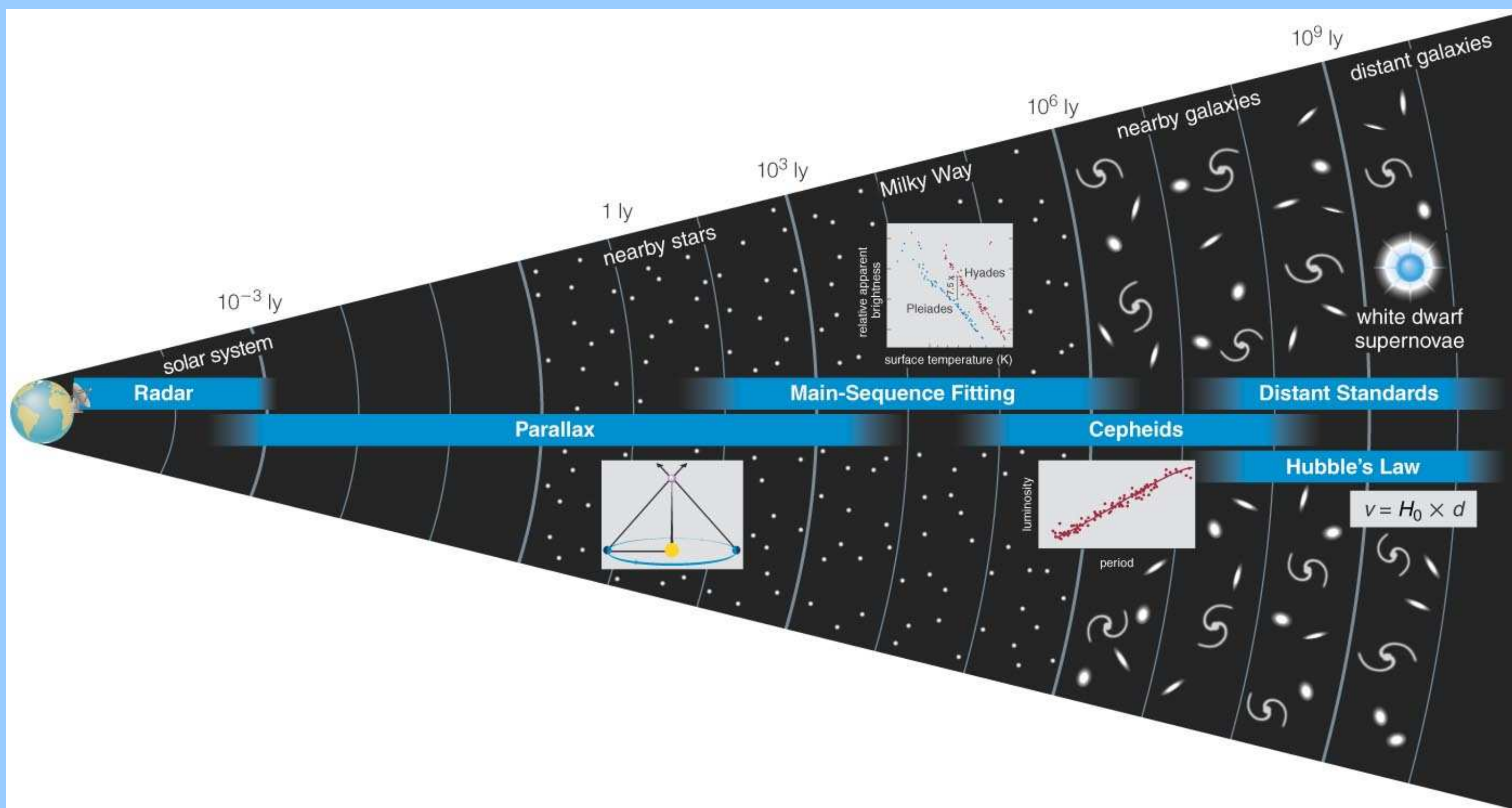


SN 2006X in M100 in Virgo Cluster

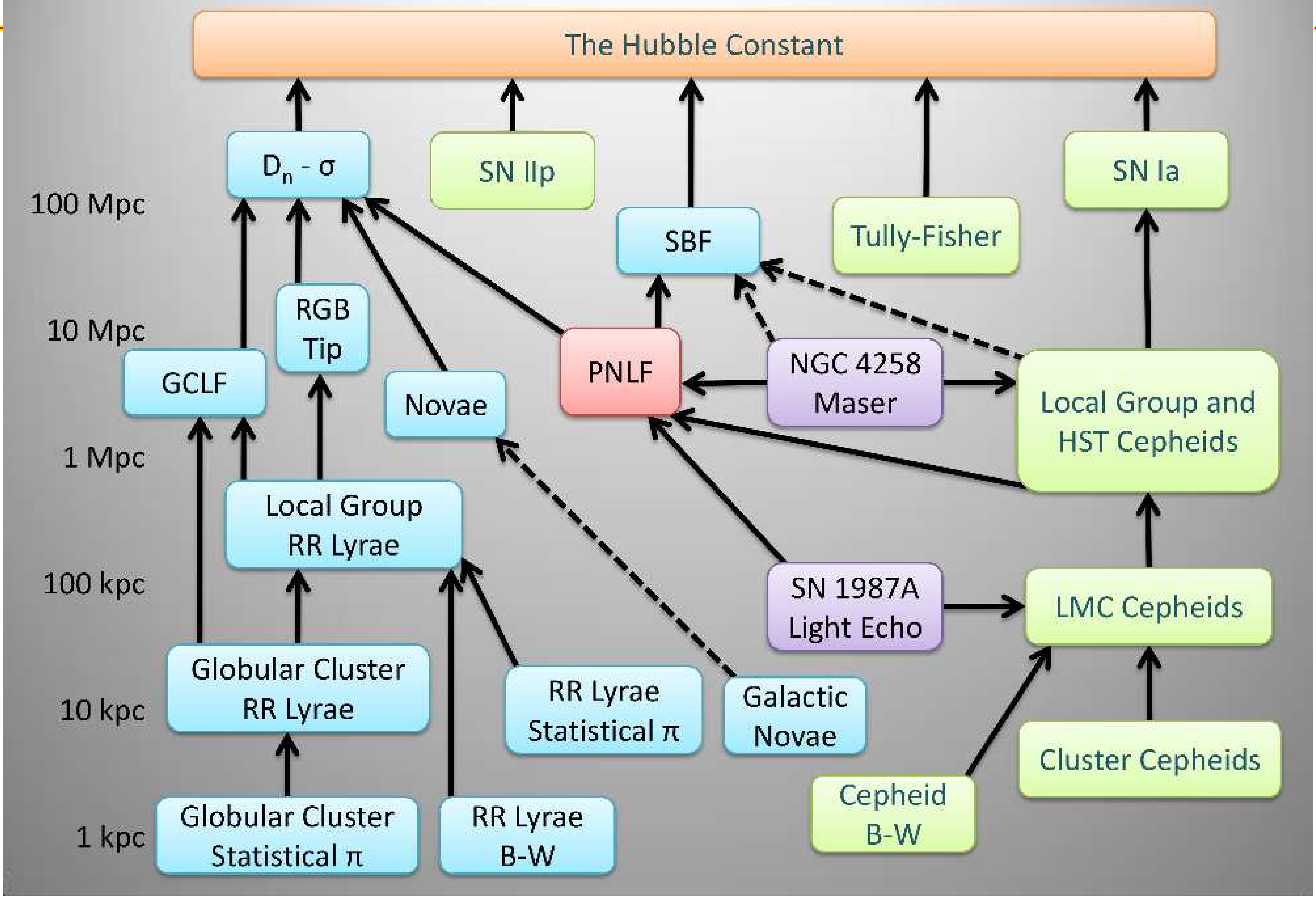
Extragalactic Distance Ladder

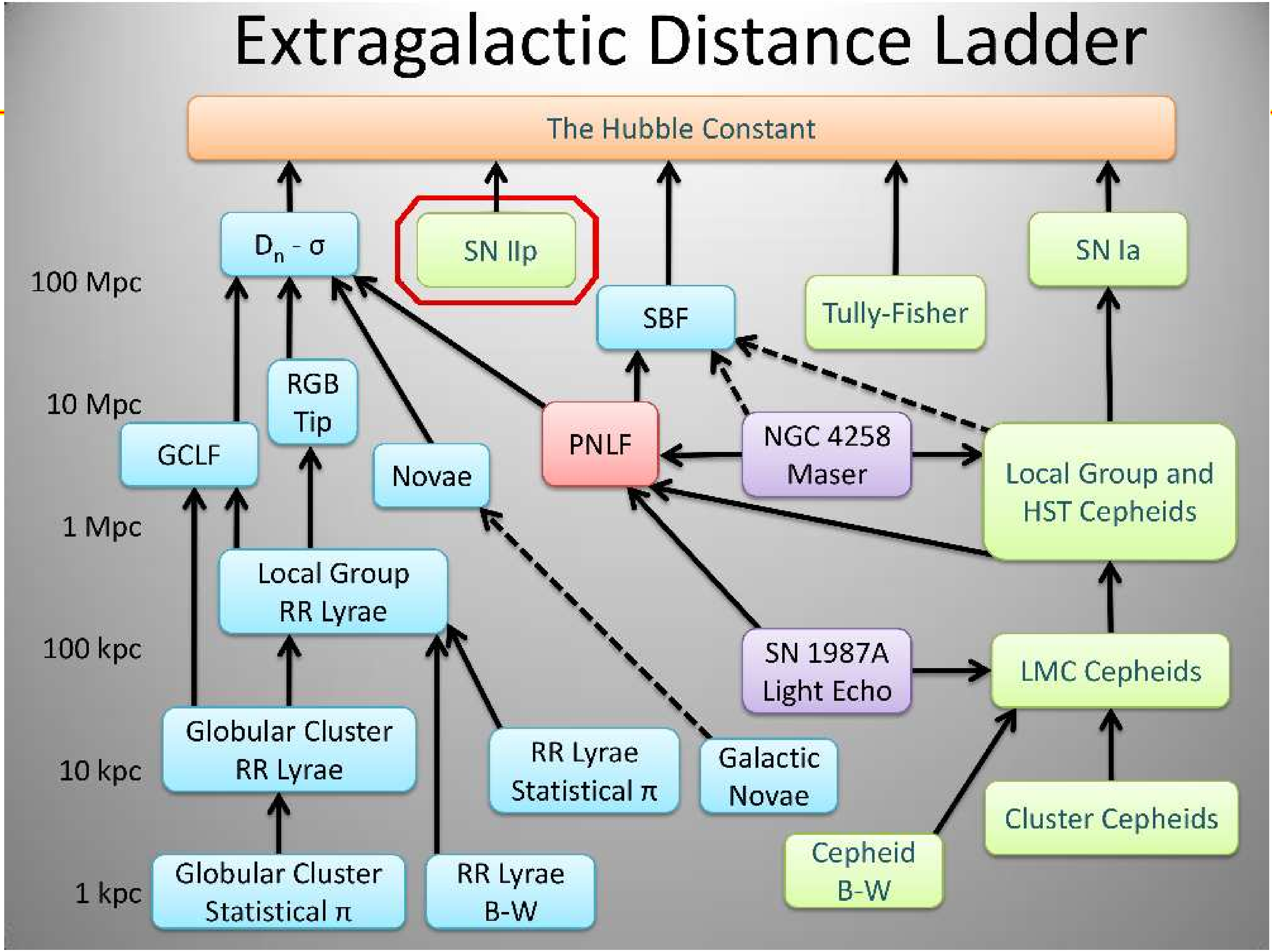


Distance Ladder Cone



Extragalactic Distance Ladder

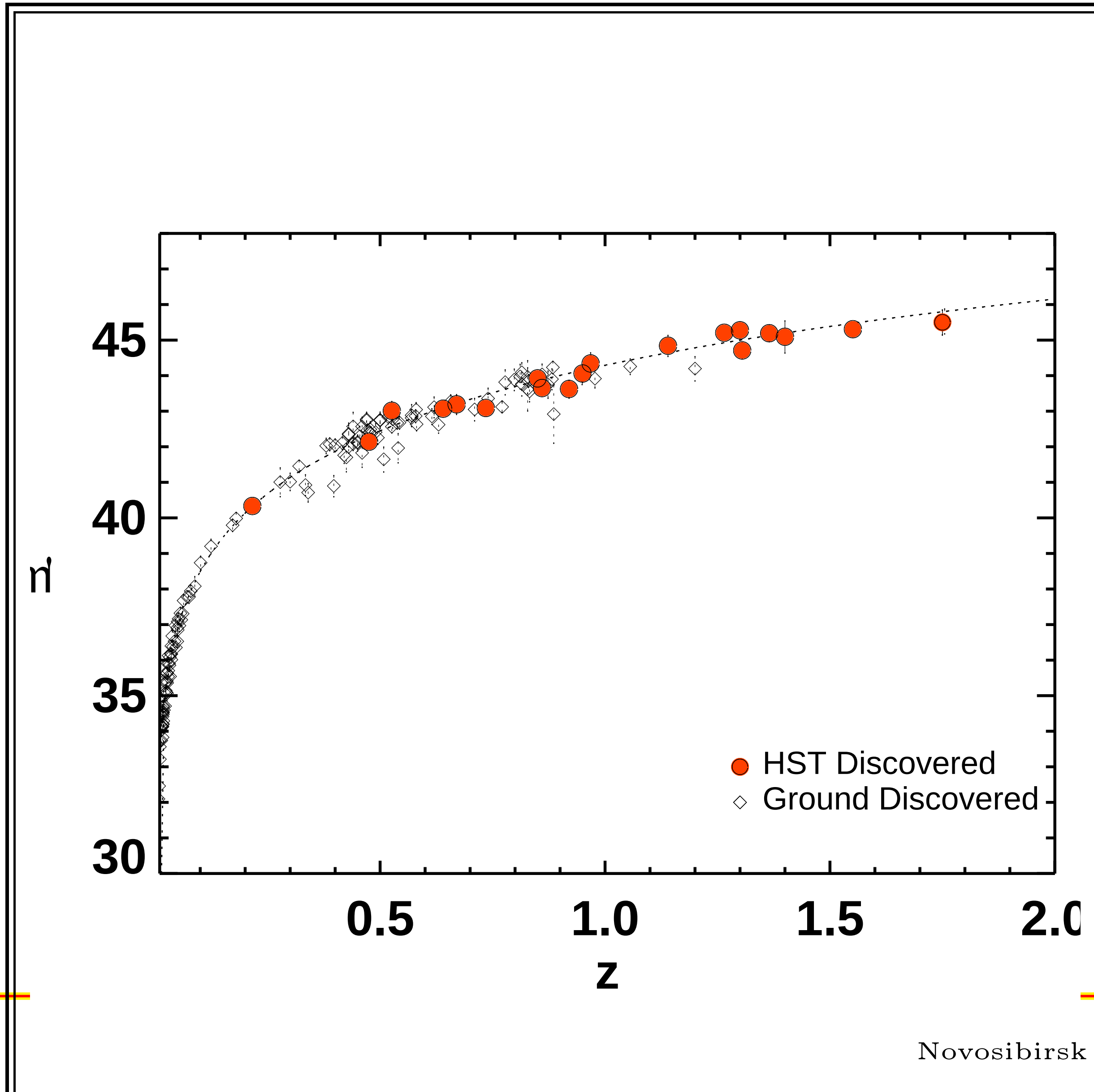




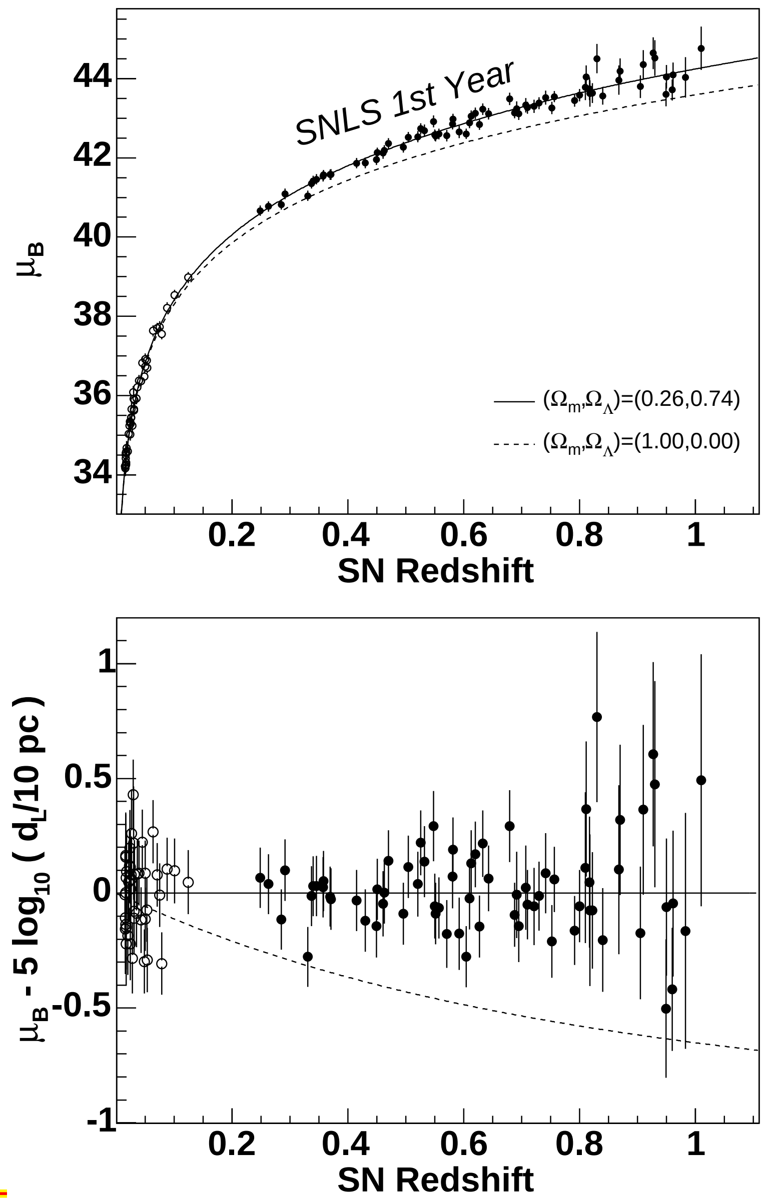
Extragalactic Distance Ladder
The Hubble Constant
D_n - σ
SN IIp
SBF
Tully-Fisher
SN Ia
100 Mpc
10 Mpc
1 Mpc
100 kpc
10 kpc
1 kpc
RGB Tip
GCLF
Novae
PNLF
NGC 4258 Maser
Local Group and HST Cepheids
Local Group RR Lyrae
SN 1987A Light Echo
LMC Cepheids
Globular Cluster RR Lyrae
RR Lyrae Statistical π
Galactic Novae
Cluster Cepheids
Cepheid B-W
Globular Cluster Statistical π
RR Lyrae B-W

Hubble diagram, Feb 2004

for SN Ia (A.Riess et al.)

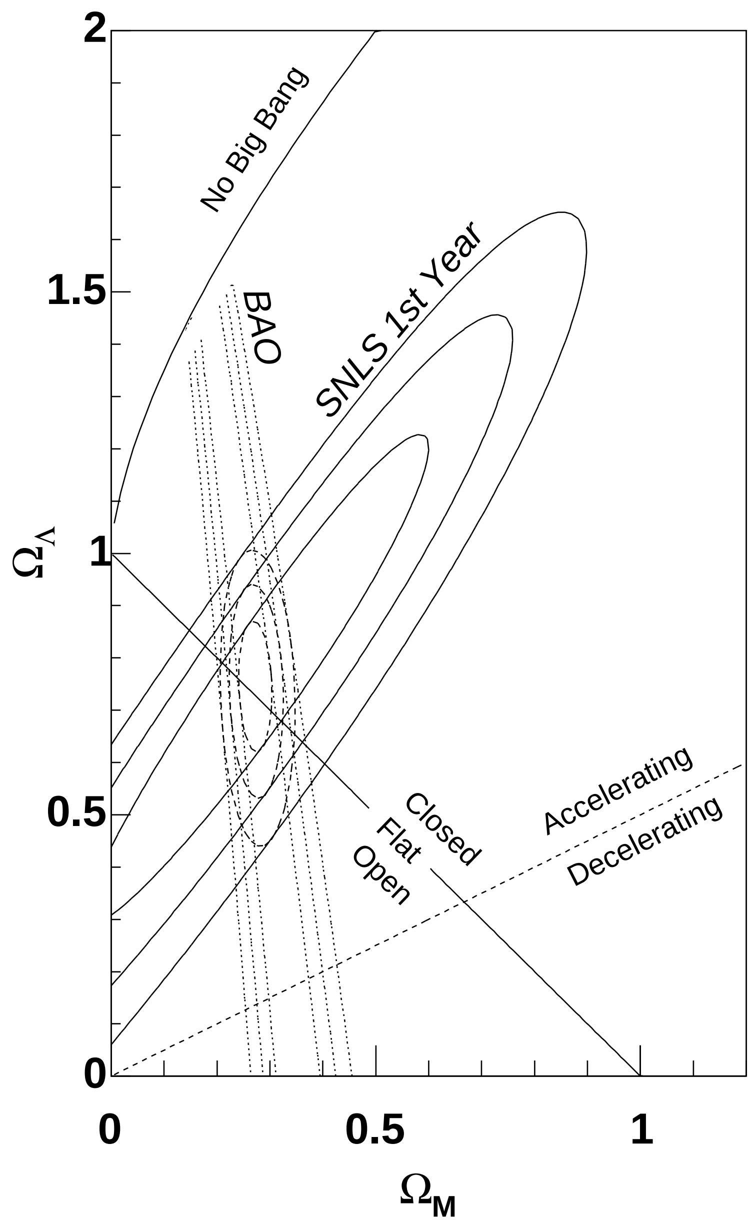


Hubble diagram SNLS



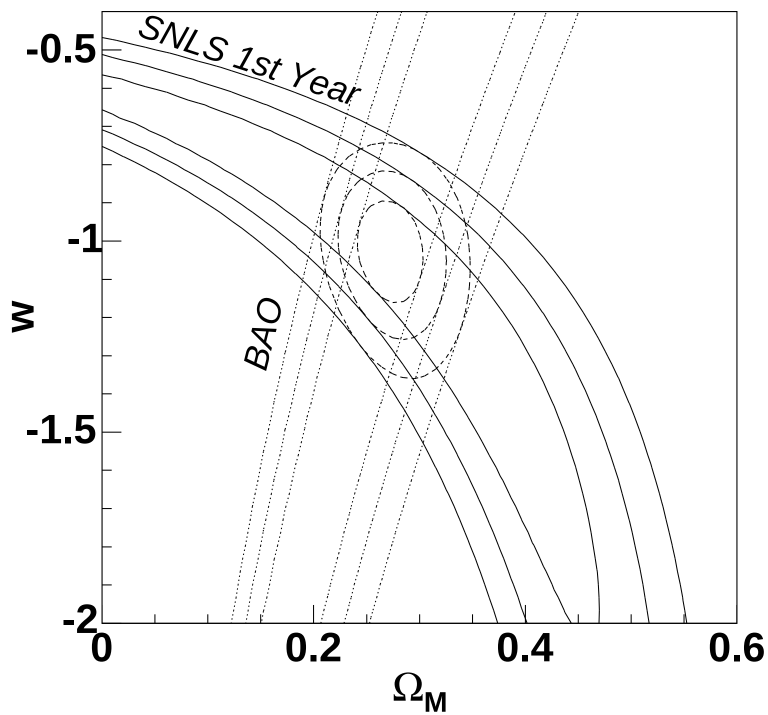
The bottom plot shows the residuals for μ_B when $d_{\text{ph}}(z)$ is for the best fit flat Λ-cosmology ($\Omega_M = 0.26,\ \Omega_\Lambda = 0.74$). Dashed line is for the flat zero Λ model. Adopted with corrections from (Astier et al., 2006).

$(\Omega_m, \Omega_\Lambda)$ cosmology, SNLS



68.3%, 95.5% and 99.7% confidence levels for the SNLS Hubble diagram (solid contours), the SDSS baryon acoustic oscillations (Eisenstein et al. 2005, dotted lines), and the joint confidence contours (dashed lines). (Astier et al., 2006).

(Ω_m, w) cosmology



Contours at 68.3%, 95.5% and 99.7% confidence levels for the fit to cosmology with equation of state $P = w\mathcal{E}$ for flat 3D space, from the SNLS Hubble diagram alone, from the SDSS baryon acoustic oscillations alone (Eisenstein et al. 2005), and the joint confidence contours. From (Astier et al., 2006).

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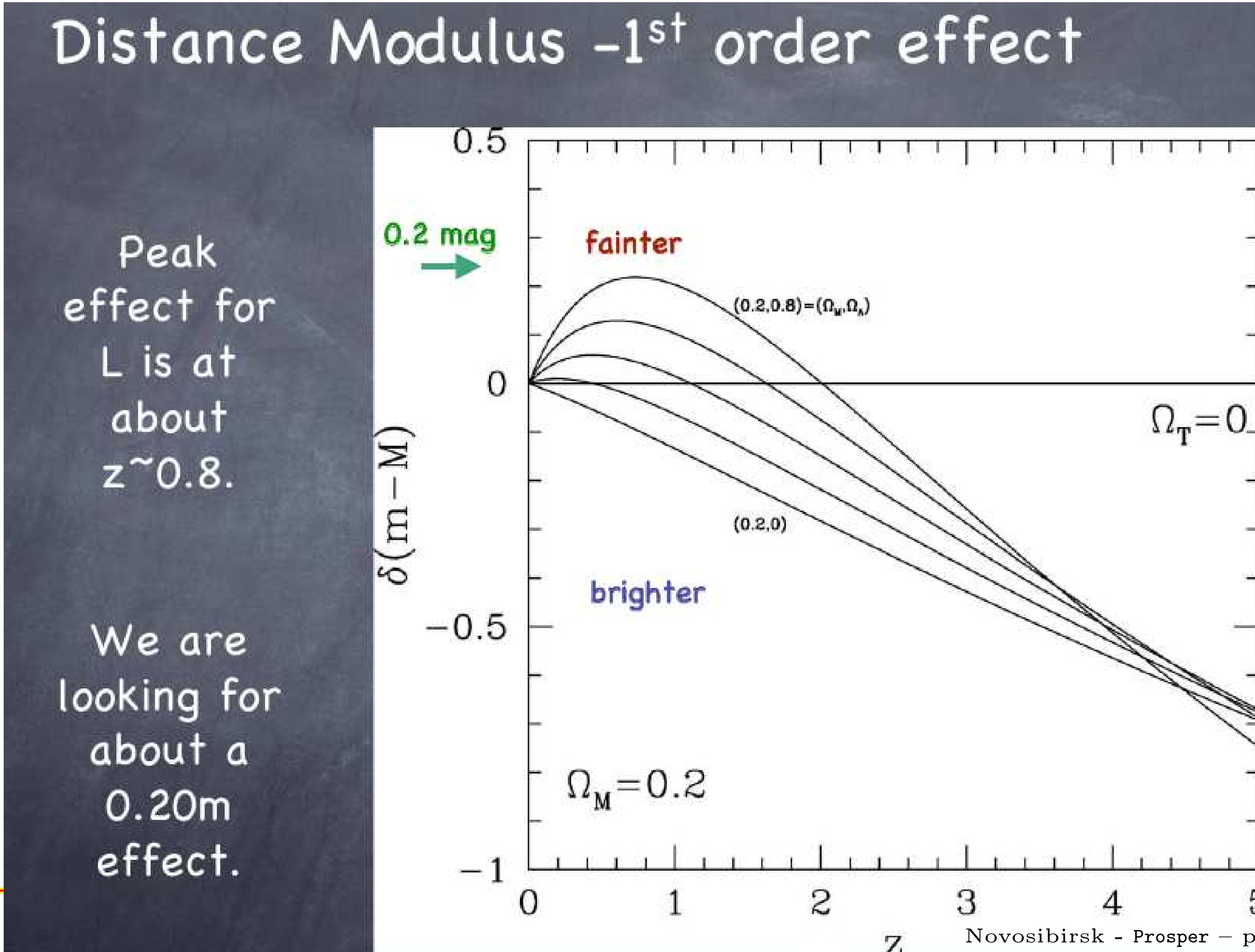
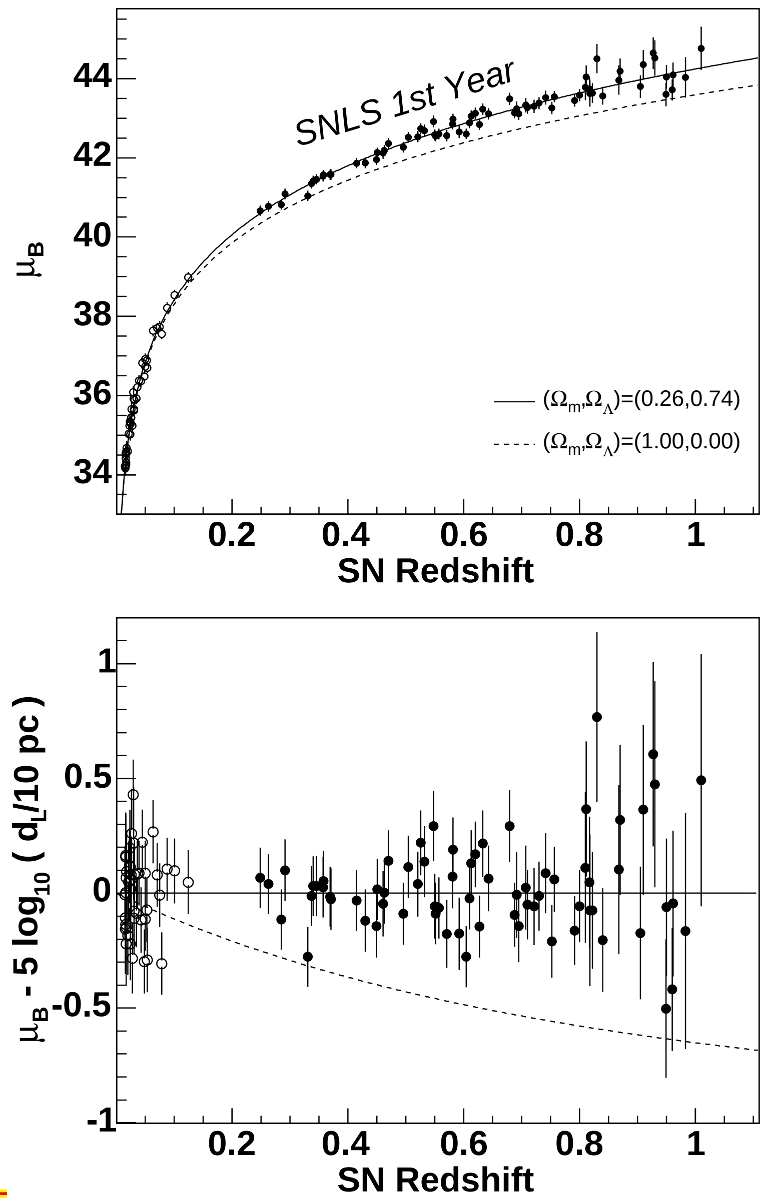
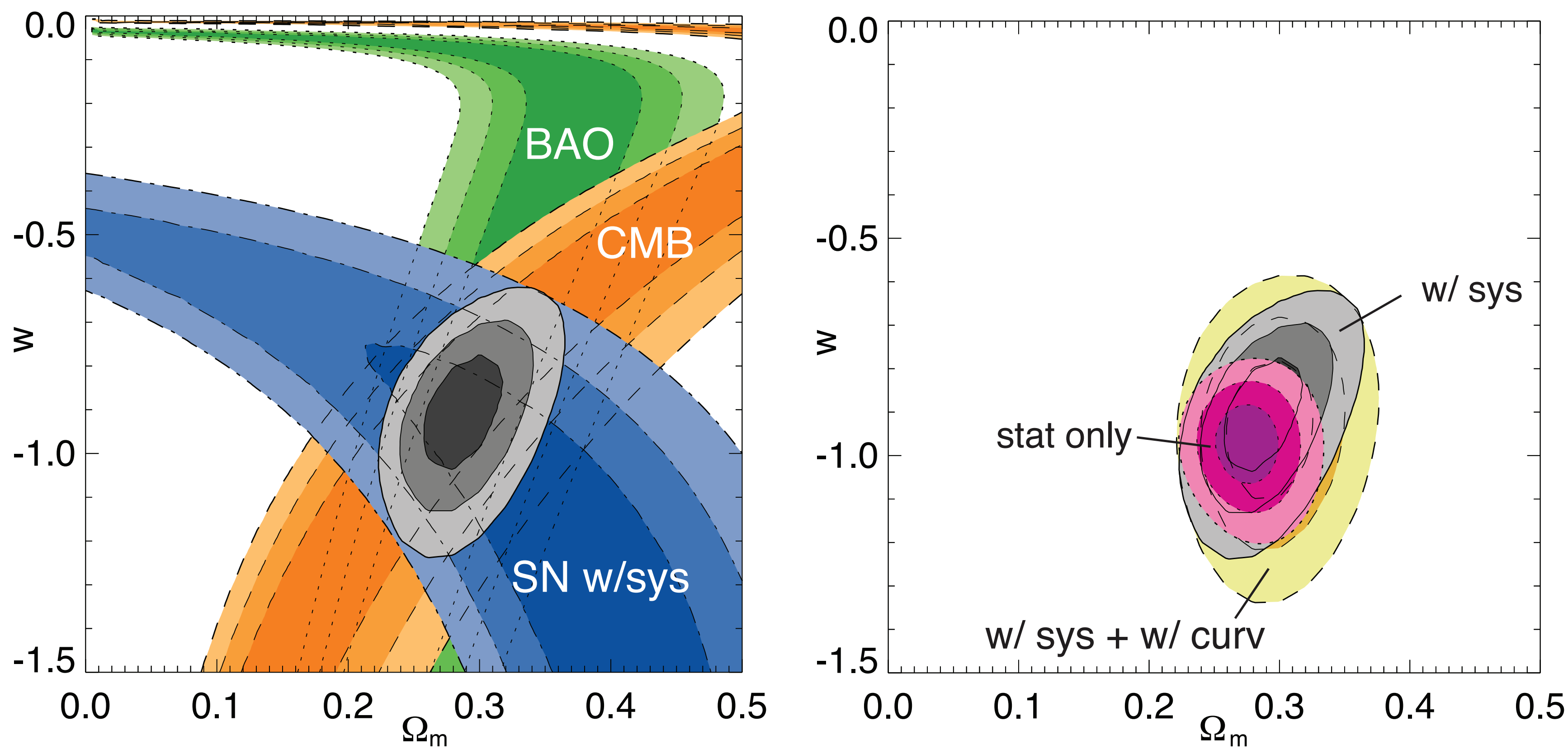


Hubble diagram SNLS



The bottom plot shows the residuals for μ_B when $d_{\rm ph}(z)$ is for the best fit flat Λ-cosmology ($\Omega_M = 0.26,\ \Omega_\Lambda = 0.74$). Dashed line is for the flat zero Λ model. Adopted with corrections from (Astier et al., 2006).

D.Rubin, E.V.Linder, M.Kowalski et al. ApJ 2009



68.3%, 95.4%, and 99.7% conf. levels on a constant EOS w and Ω_m for the individual and combined data sets. The left panel shows individual and combined probes in the flat universe case; the right panel repeats the combined systematics contour, and also compares to the statistical only contour, and to the systematics contour when simultaneously fitting for spatial curvature.

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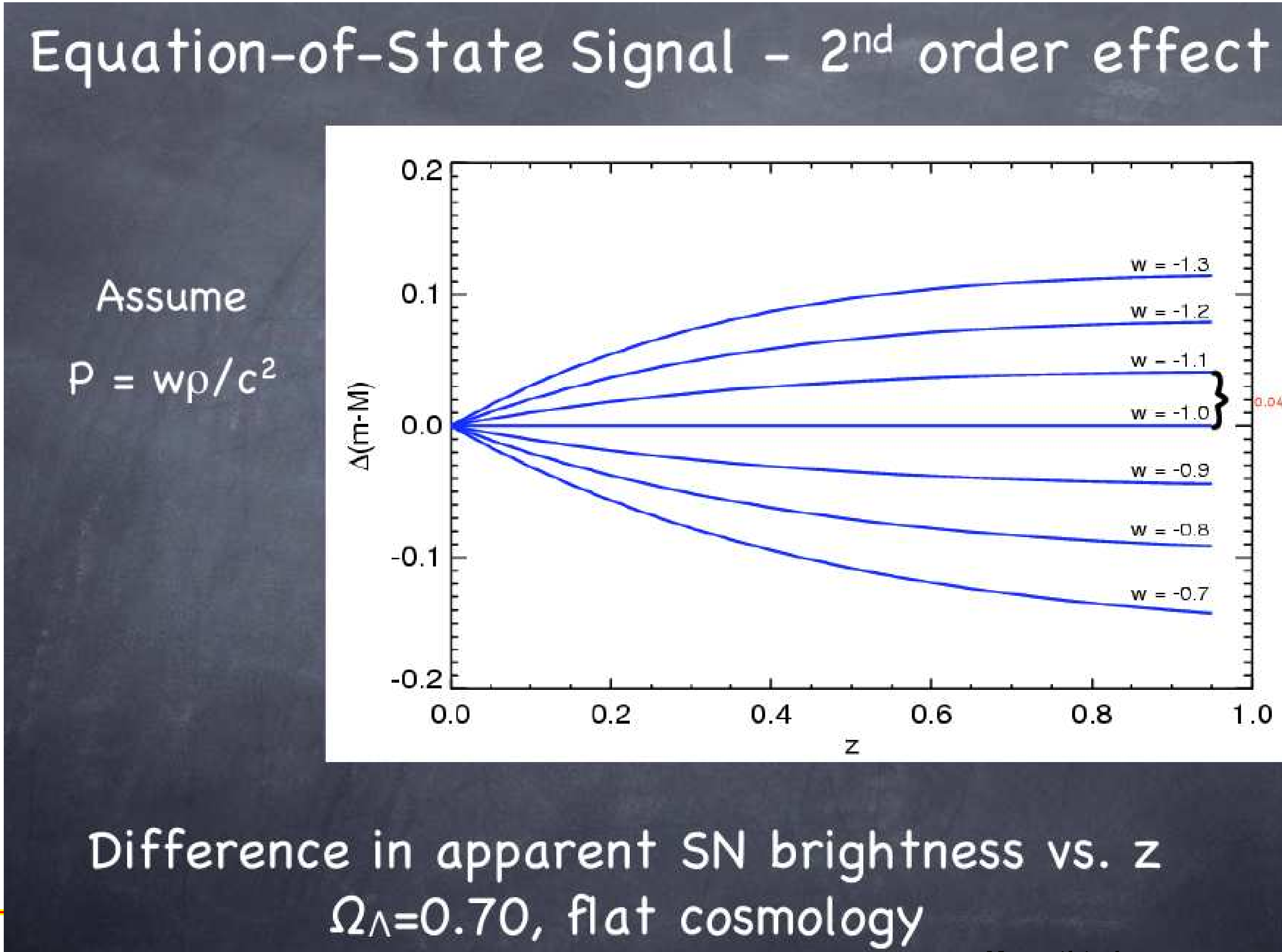

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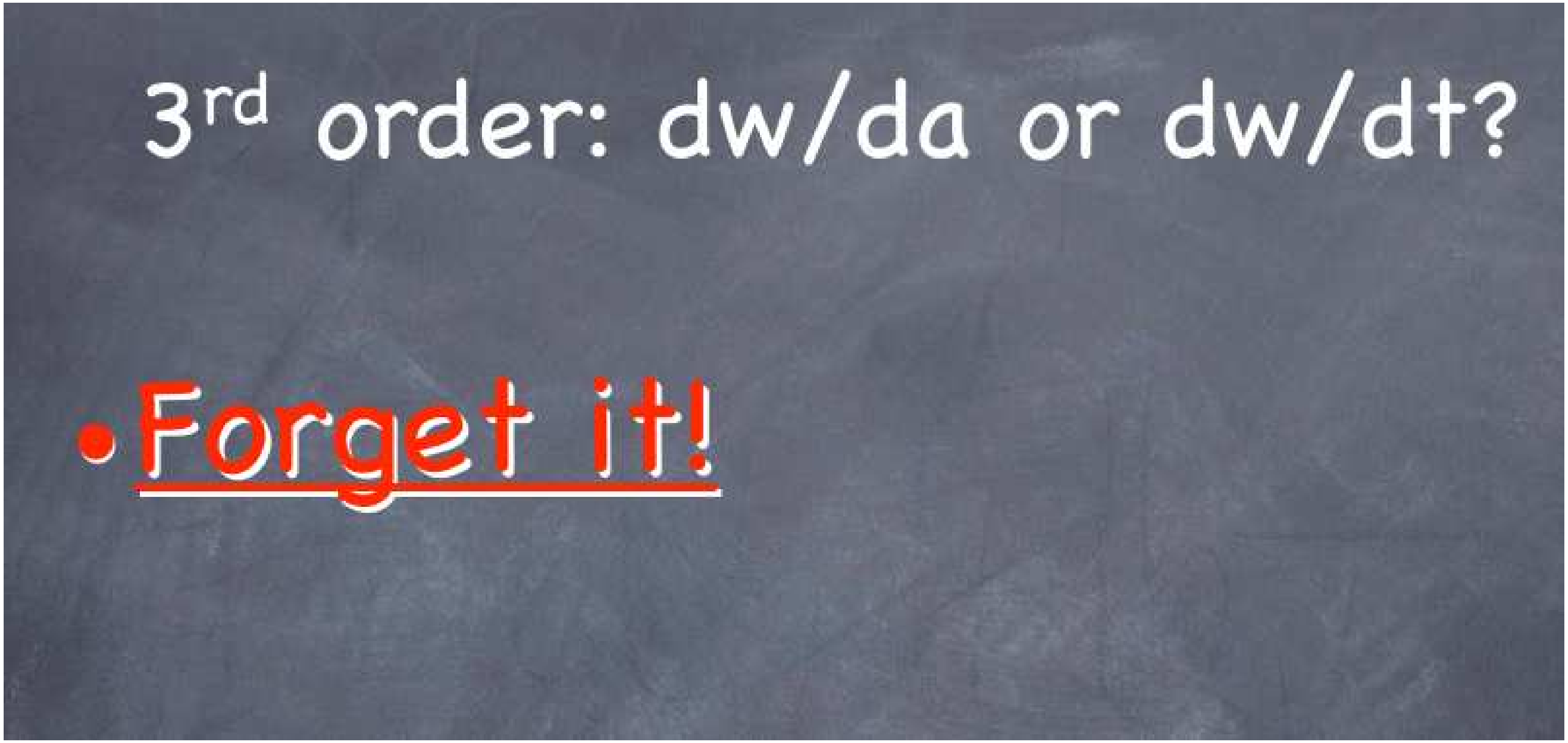
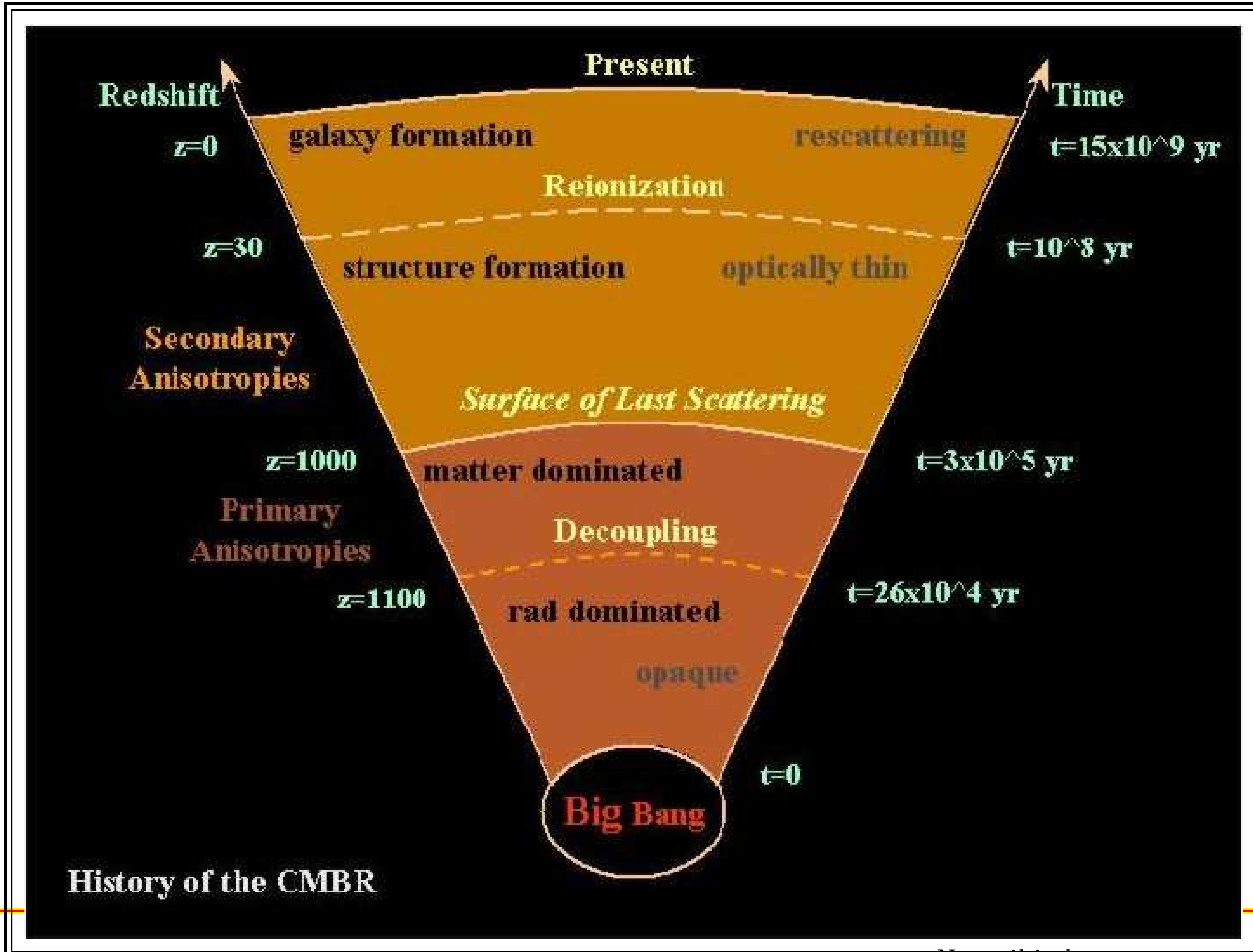


Surface of Last Scattering



Dark Matter and Dark Energy pie