The Shape of the Universe:
the Ellipsoidal Cosmological Model

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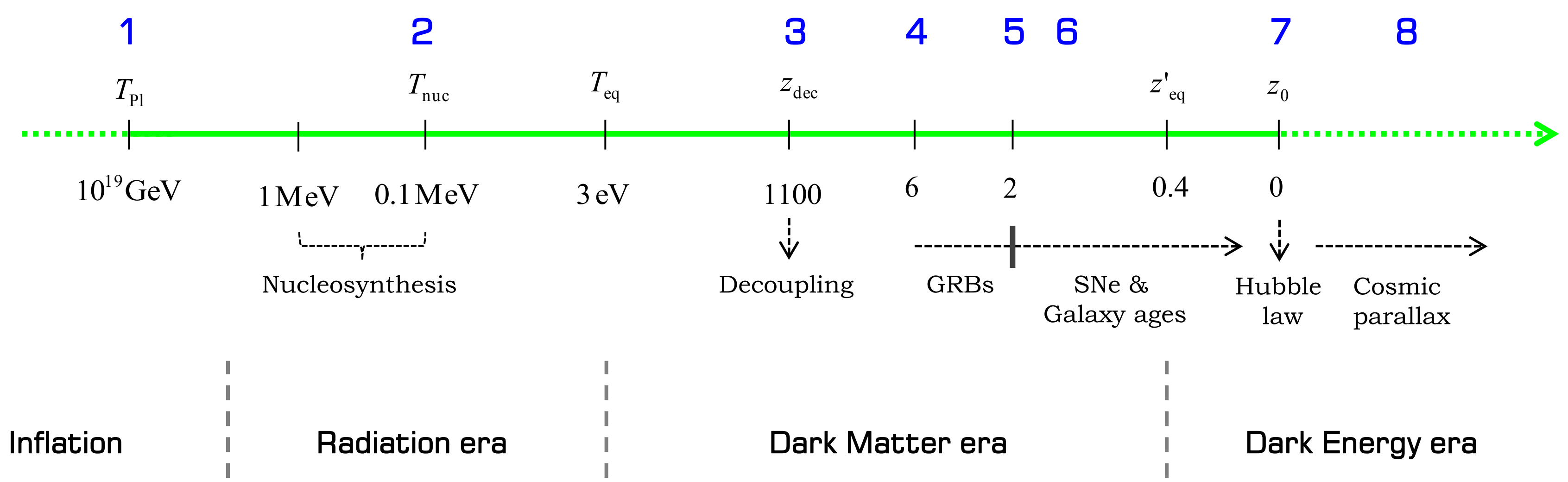
INIFA 2010
Frascati 06/22/10

SUMMARY

Ellipsoidal Universe:

1 Inflation
2 Nucleosynthesis
3 Cosmic Microwave Backround (CMB)
4 Gamma Ray Bursts (GRBs)
5 Supernovae (SNe)
6 Galaxy Ages
7 Hubble Law
8 Cosmic Parallax



ELLIPSOIDAL UNIVERSE

- metric

$$ds^2 = dt^2 - a^2(t)(dx^2 + dy^2) - b^2(t)\,dz^2$$

- Hubble parameter
- cosmic shear

$$H_a = \dot{a}/a \qquad H_b = \dot{b}/b \quad \longrightarrow \quad H = (2H_a + H_b)/3 \qquad \Sigma = (H_a - H_b)/3H \in [-1, 1]$$

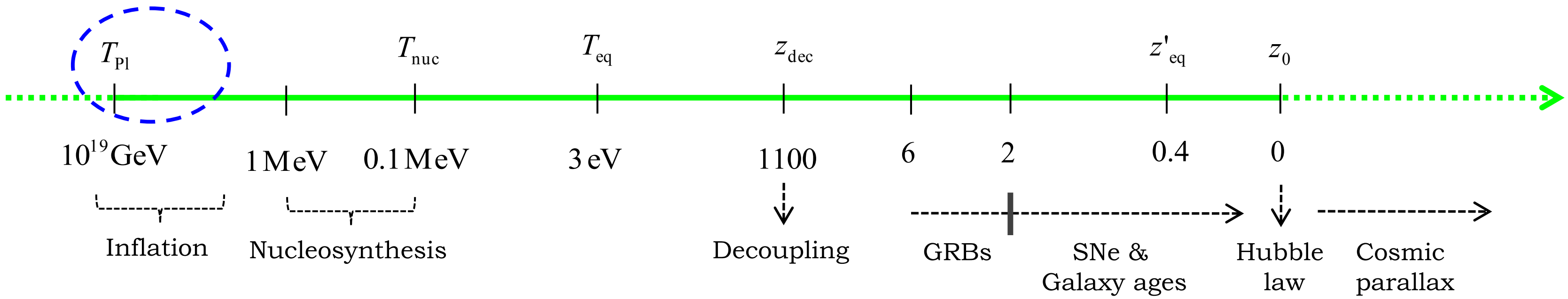
- equation of state
- skewness

$$w_\parallel = p_\parallel/\rho_A \qquad w_\perp = p_\perp/\rho_A \quad \longrightarrow \quad w = (2w_\parallel + w_\perp)/3 \qquad \delta = w_\parallel - w_\perp$$

Anisotropic fluids

- Uniform magnetic field $(w, \delta) = (1/3, 2)$ M. S. Turner and L. M. Widrow, PRD 37, 2743 (1988)
- Planar magnetic field $(w, \delta) = (1/3, -1)$ L. C., PRD 80, 063006 (2009)
- Anisotropic dark energy $(w, \delta) \simeq (-1, \text{small})$ T. Koivisto and D. F. Mota, ApJ 679, 1 (2008)

INFLATION

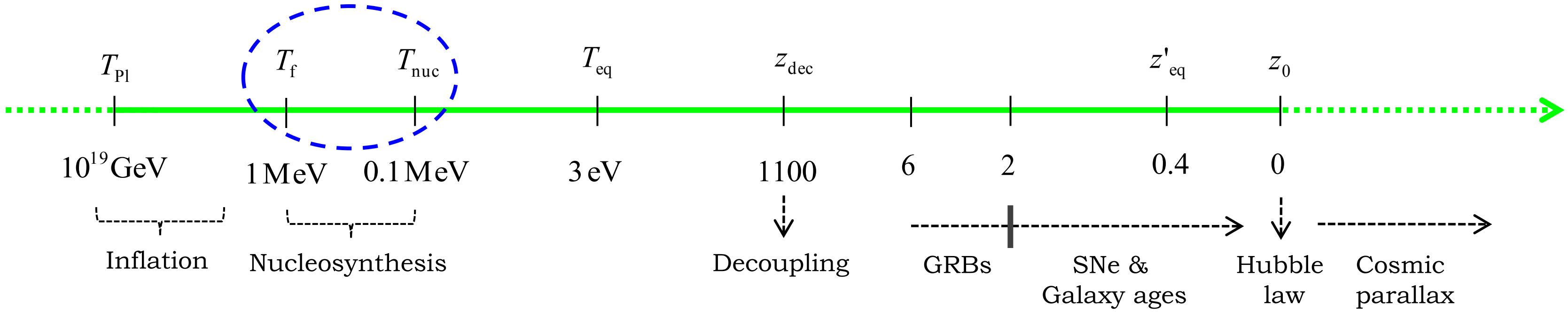


$$\Sigma_{\rm end} \simeq \begin{cases} \Sigma_i \, e^{-3N} & 0 \leq w \\ \Omega_A \, \delta \, e^{-3(1+w)N} & -1 \leq w < 0 \end{cases}$$

- Σ_i = shear at the beginning of inflation
- $N \gtrsim 60$ number of e-folds of de Sitter inflation
- $\Omega_A = (\rho_A/\rho_{\rm cr})_{\rm today}$

J.D. Barrow, PRD 55, 7451 (1997)
L.C., P. Cea, and G.L. Fogli, to appear in arXiv

NUCLEOSYNTHESIS



- n-p number density ratio: $(n/p)^{(0)}_{\rm nuc} \simeq e^{-(m_n - m_p)/T_{\rm f}^{(0)}}\, e^{-t^{(0)}_{\rm nuc}/\tau_n}$

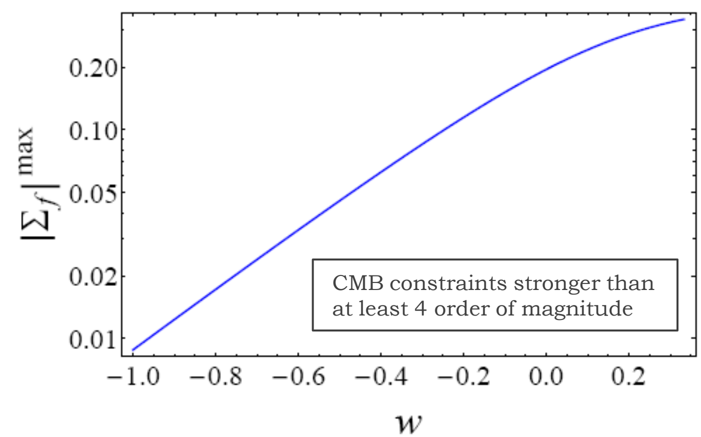
- mass fraction of Helium-4: $Y^{(0)} \simeq 0.25 \qquad Y_{\rm observed} \simeq 0.25 \pm 0.1$

- freeze-out temperature: $T_{\rm f} \geq T_{\rm f}^{(0)}$

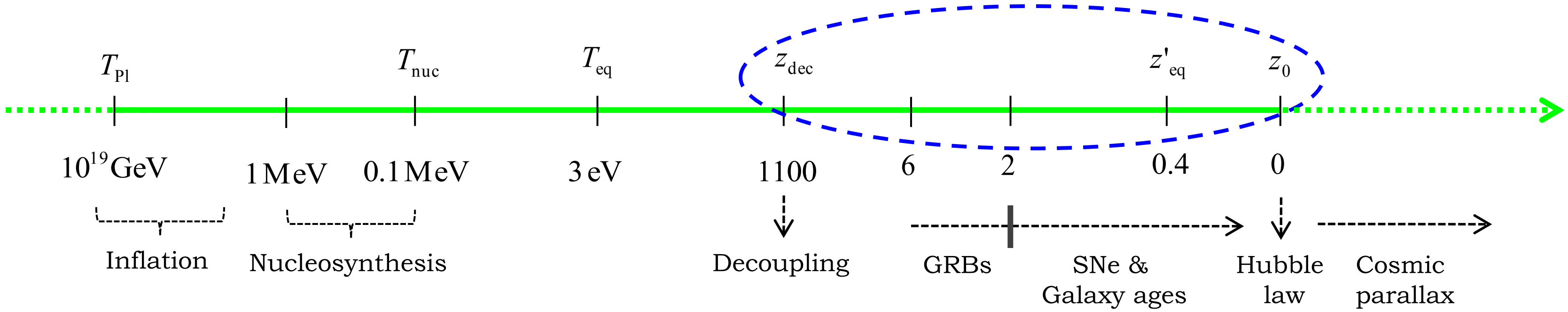
- time of nucleosynthesis: $t_{\rm nuc} \leq t^{(0)}_{\rm nuc}$

$$Y \geq Y^{(0)}$$

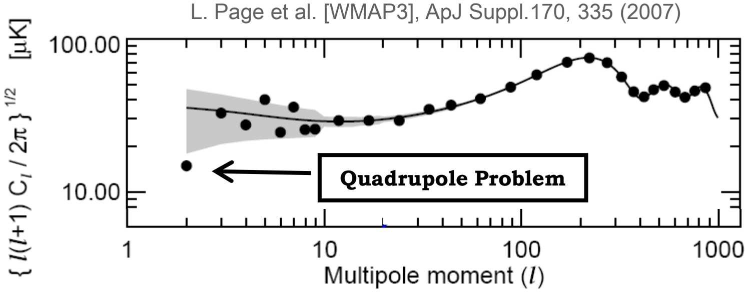
L.C., P. Cea, and G.L. Fogli, to appear in arXiv



CMB



L. Page et al. [WMAP3], ApJ Suppl.170, 335 (2007)



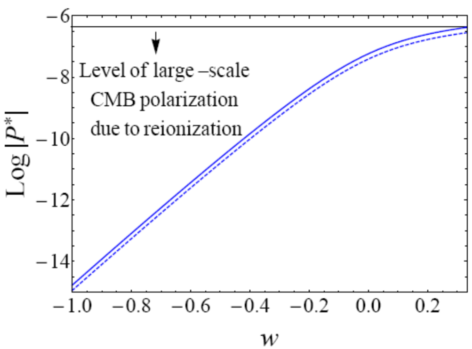
L.C., P. Cea, L. Tedesco, PRL 97, 131302 (2006); PRD 76, 063007 (2007)

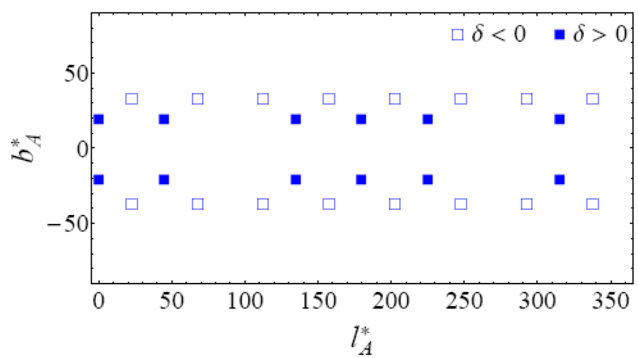
$$Q^2_{\mathrm{tot}} = Q^2_{\mathrm{infl}} + Q^2_{\mathrm{ellips}} - Q_{\mathrm{infl}}\, Q_{\mathrm{ellips}}\, f(l_A, b_A)$$

$$Q_{\mathrm{tot}} = Q_{\mathrm{obs}} \quad \Rightarrow \quad (\Sigma_0, l_A, b_A, P) = (\Sigma^*_0, l^*_A, b^*_A, P^*)$$

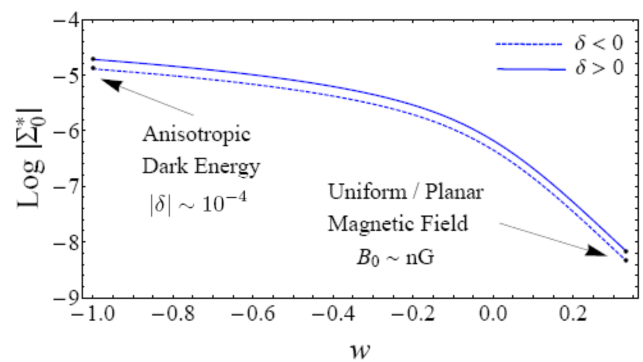
P. Cea, arXiv:astro-ph/0702293

L.C., P. Cea, G.L. Fogli, in progress

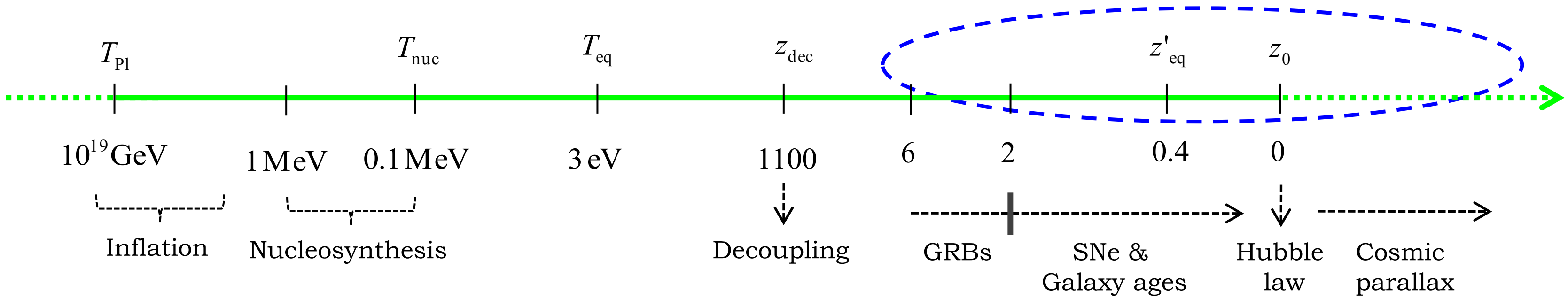




L.C., P. Cea, G.L. Fogli, L. Tedesco, to appear in arXiv



GRB, SN, GALAXY AGES, HUBBLE LAW, COSMIC PARALLAX



- GRBs (standard candles) $d_L = d_L(z, \theta, \Sigma_0, \delta)$ L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress
- Sne (standard candles) $d_L = d_L(z, \theta, \Sigma_0, \delta)$ L.C., P. Cea, G.L. Fogli, and A. Marrone, to appear in arXiv
- Galaxy Ages (cosmic clocks) $t = t(z, \theta, \Sigma_0, \delta)$ L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress
- Hubble Law $v_H = v_H(z, \theta, \Sigma_0)$ L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress
- Cosmic Parallax $\gamma = \gamma(\theta, \Sigma_0)$ L.C., P. Cea, G.L. Fogli, and A. Marrone, to appear in arXiv

$$|\Sigma_0| \lesssim 10^{-2}$$

CONCLUSIONS

Ellipsoidal Universe

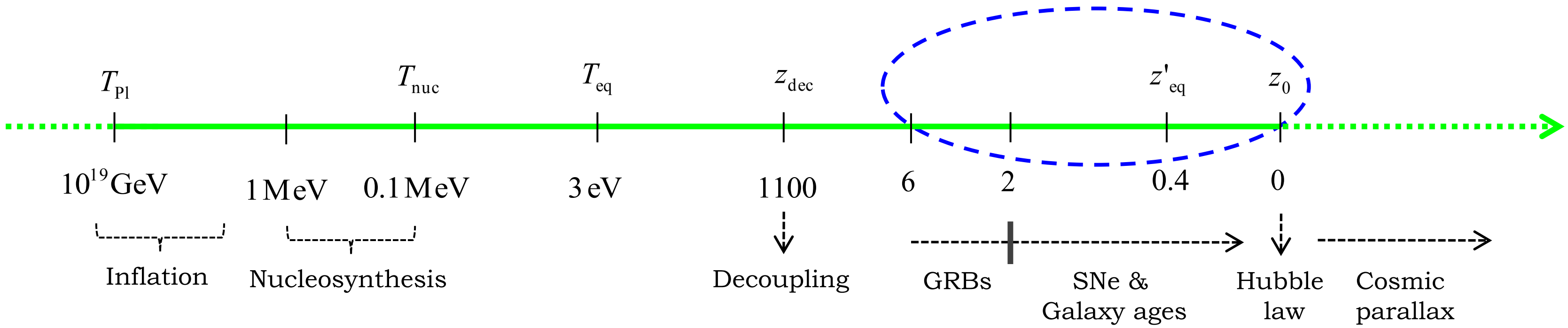
viable anisotropic cosmological model which better matches observations

- Inflation ⟶ sets initial condition
- Nucleosynthesis ⟶ weakest constraint
- CMB ⟶
  - strongest constraint
  - solution to quadrupole problem
  - polarization
- Gamma Ray Bursts
- Supernovae
- Galaxy Ages
- Hubble Law
- Cosmic Parallax

(Gamma Ray Bursts, Supernovae, Galaxy Ages, Hubble Law, Cosmic Parallax) } weak constraints wrt CMB

Future work: Large Scale Structures

GAMMA RAY BURSTS



$$\mu = m - M = 5 \log\left(\frac{d_L}{1\text{Mpc}}\right) + 25$$

$$\boxed{d_L = d_L(z, \theta, \Sigma_0, \delta)}$$

Cepheids: $M = a + b \log P$

SNe: $M = \text{constant}$

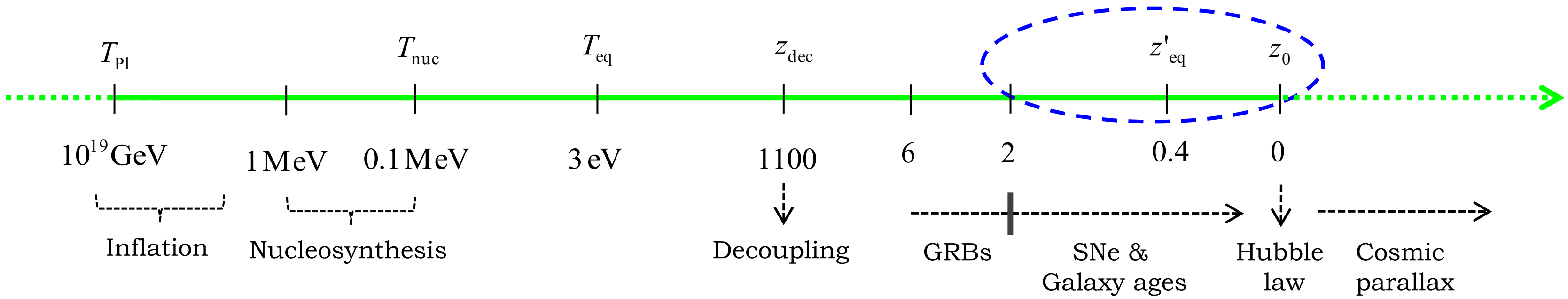
GRBs: $M = a + b \log X$ B.E. Schaefer, ApJ 660, 16 (2007)

- High redshits of GRBs implies a better determination of cosmological parameters
- Uncertainties on GRBs are double those of Sne

GRBs and Sne put similar constraints on the level of cosmic anisotropy

L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress

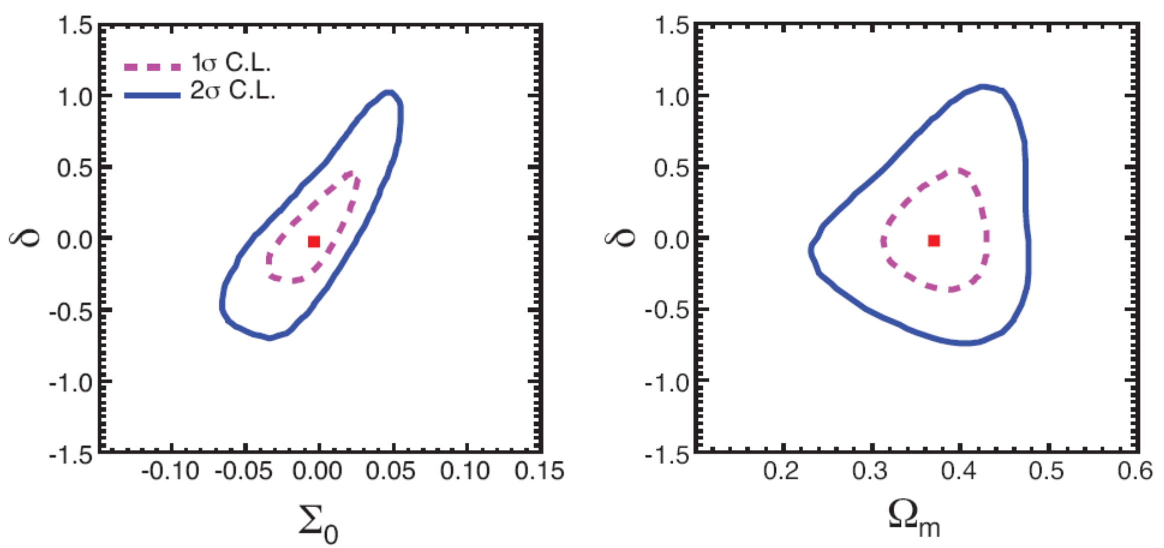
SUPERNOVAE



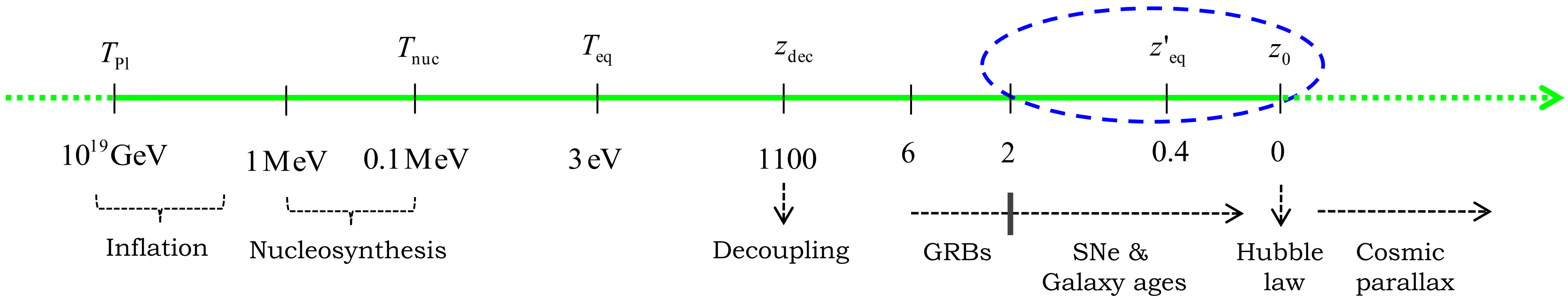
- Model: Anisotropic dark energy
- Data: Union Set (315 Sne)

$$-0.06 \lesssim \Sigma_0 \lesssim 0.05 \quad 2\sigma \text{ C.L.}$$
$$-0.7 \lesssim \delta \lesssim 1.0 \quad 2\sigma \text{ C.L.}$$

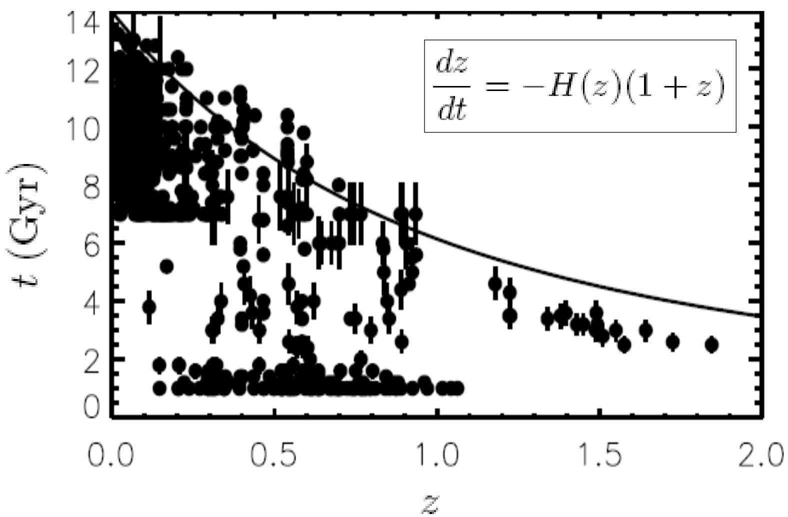
L.C., P. Cea, G.L. Fogli, and A. Marrone, to appear in arXiv

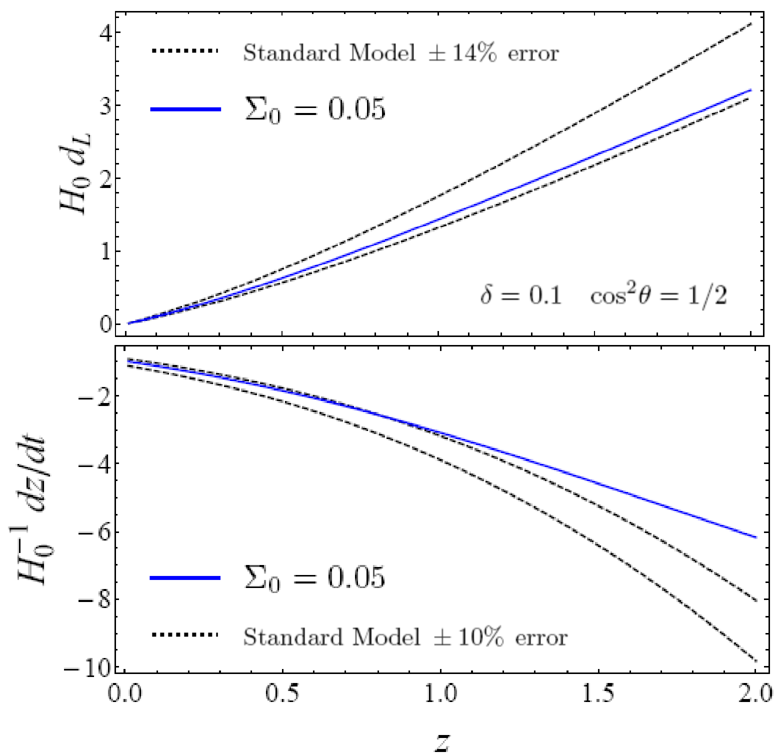


GALAXY AGES



D. Stern, et al., JCAP 1002, 008 (2010)

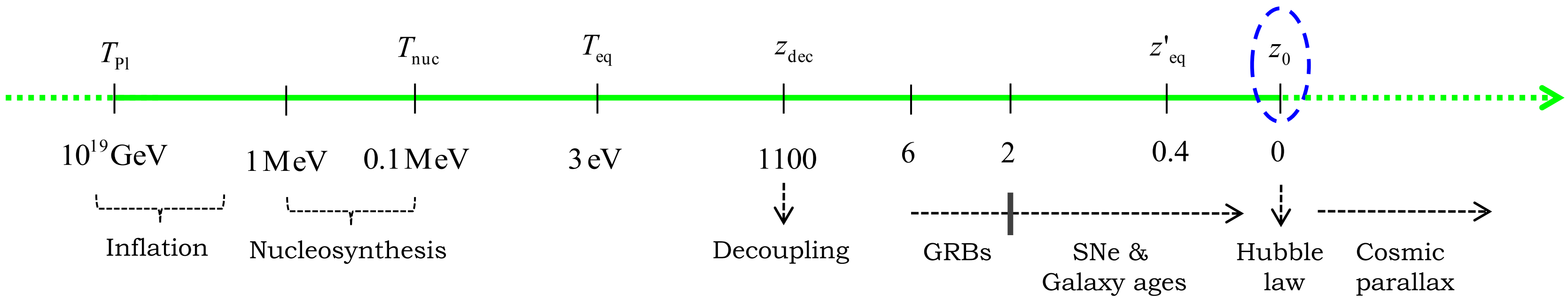




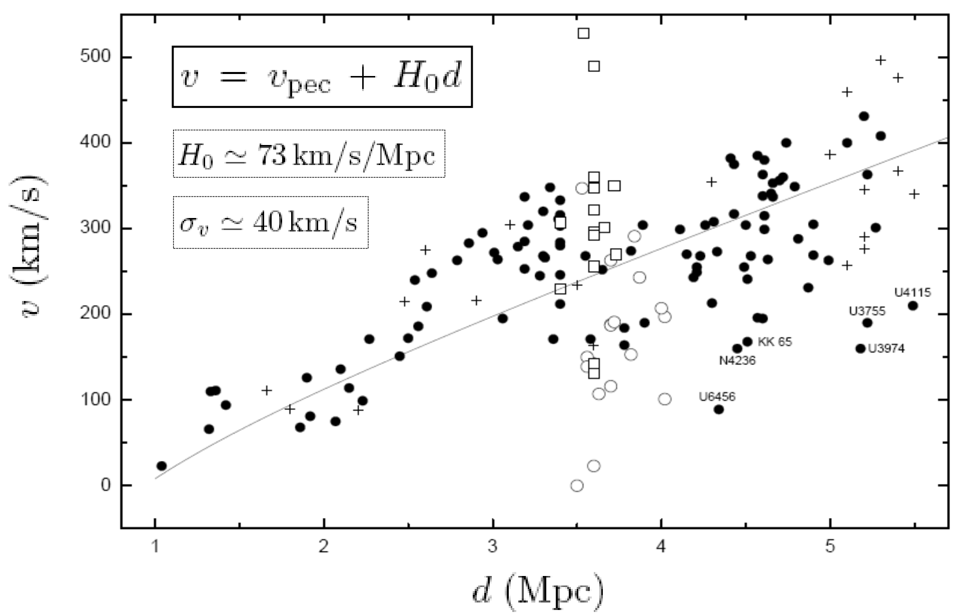
$$\frac{dz}{dt} = -H(z)(1+z)\, f(\theta, \Sigma_0, \delta)$$

L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress

HUBBLE LAW



I..D. Karachentsev, et al., A&A 398, 479 (2003)

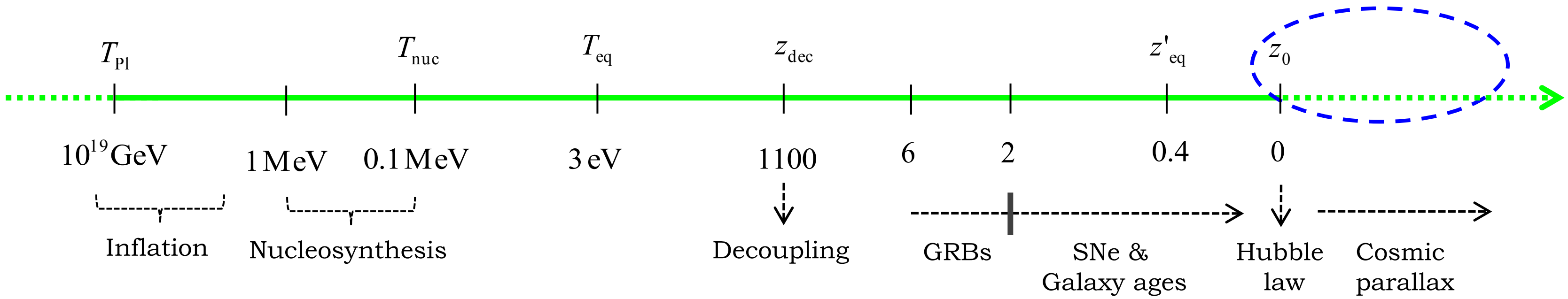


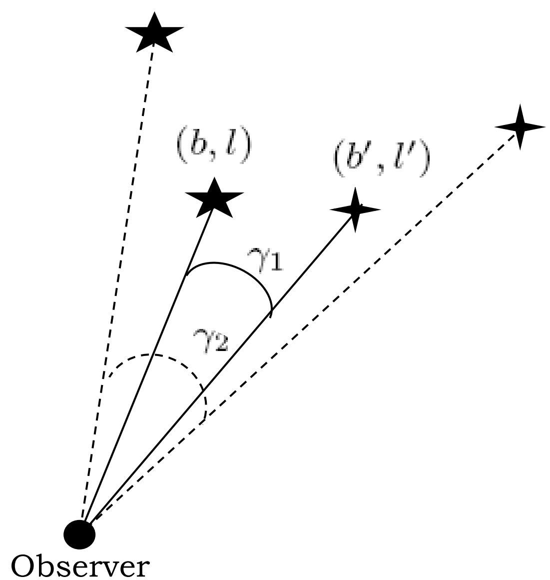
$$v = v_{\rm pec} + f(\theta, \Sigma_0)\, H_0 d$$

$$\Sigma_0 \simeq 0.04\, \frac{\Delta v}{40\,{\rm km/s}}\, \frac{5\,{\rm Mpc}}{d}$$

L.C., P. Cea, G.L. Fogli, and A. Marrone, work in progress

COSMIC PARALLAX





- cosmic parallax : $\Delta\gamma = \gamma_2 - \gamma_1$
- Gaia max resolution : $\Delta\gamma \simeq 6\,\mu\text{as}$

$$\Delta\gamma \simeq 4.5\,\Upsilon\,\frac{\Sigma_0}{10^{-2}}\,\frac{\Delta t}{10\text{yr}}\,\mu\text{as}$$

$$\Upsilon = \Upsilon(b_A, l_A; b, l; b', l') \in [-1, 1]$$

C. Quercellini, et al., PRL 102, 151302 (2009)

L.C., P. Cea, G.L. Fogli, and L. Tedesco, to appear in arXiv