Two New Diagnostics of Dark Energy

Based on arXiv:0807.3548
Varun Sahni, Arman Shafieloo, Alexei A. Starobinsky

Arman Shafieloo
University of Oxford

25th September 2008, 2nd UniverseNet Meeting
Oxford University

I.U.C.A.A

Oxford Physics

Introduction:

- Current cosmological observations indicate that the universe expands today with acceleration.
- The driving agent of this acceleration is what is called “dark energy”, a uniformly distributed component constituting about 70% of total energy density and having negative pressure.
- The nature of the “dark-energy” phenomenon remains to be unknown and is one of the biggest puzzles in modern cosmology.

Dark Energy Models

- Cosmological constant
- Quintessence and k-essence (scalar fields)
- Exotic matter (Chaplygin gas, phantom, etc.)
- Braneworlds (higher-dimensional theories)
- …..

But which one is really responsible for the acceleration of the expanding universe?!

The most direct indication for the current accelerating expansion of the universe comes from the accumulating type Ia supernovae data:

$$F = \frac{L}{4\pi d_L^2}$$

Supernovae Ia as Standard Candles

$$d_L(z) = (1+z)\int_0^z \frac{dz'}{H(z')}$$

$$H(z) = \left[\frac{d}{dz}\left(\frac{d_L(z)}{1+z}\right)\right]^{-1}$$

$$\frac{H^2(z)}{H^2_0} = \left[\Omega_{0M}(1+z)^3 + \Omega_X X(z)\right]$$

Dark Energy

Most general form

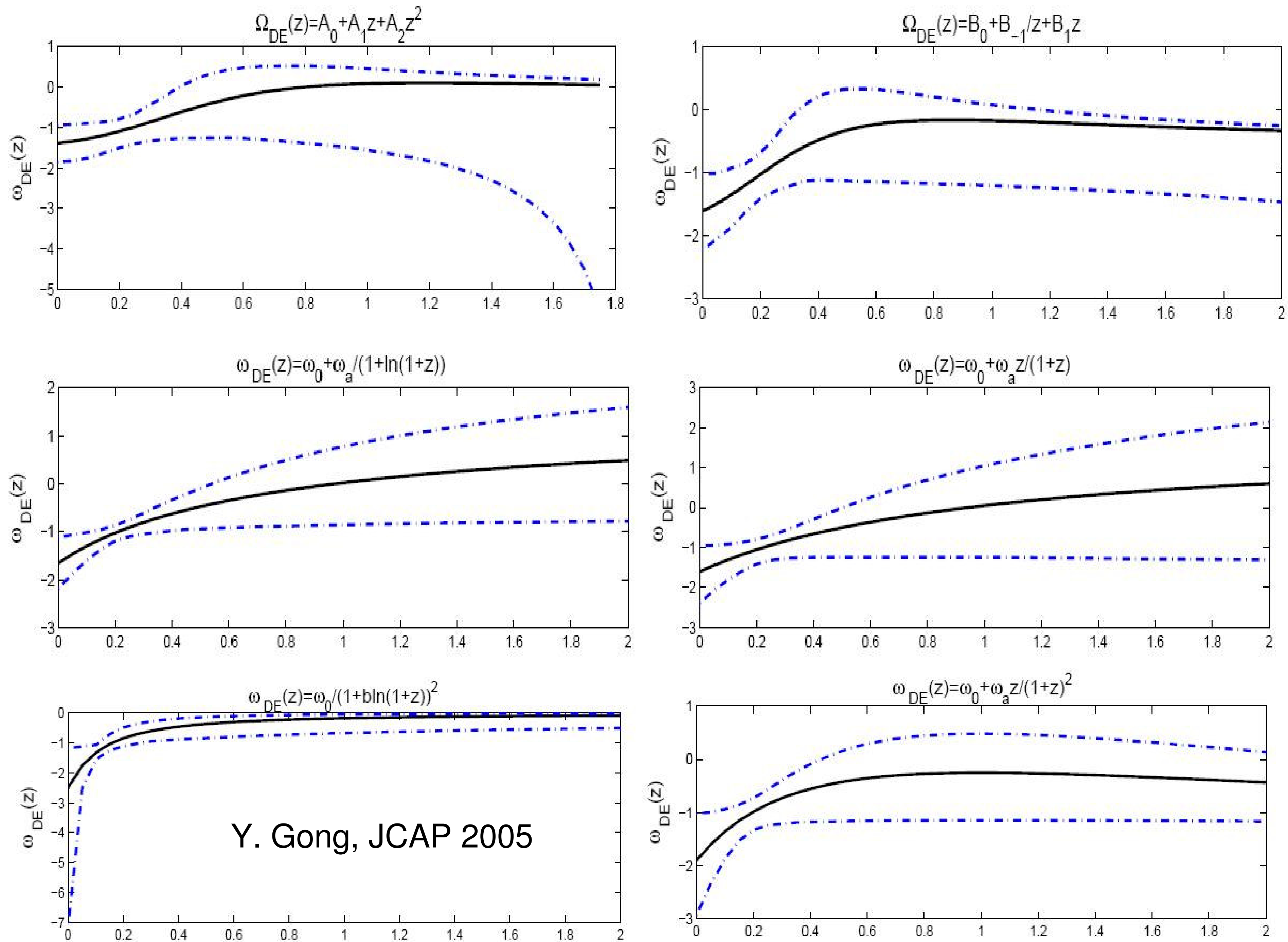
$$\frac{H^2(z)}{H^2_0} = \left[\Omega_{0M}(1+z)^3 + \Omega_{DE}\exp[\int 3(1+w(z))\frac{dz}{1+z}]\right]$$

BUT!

➔The observed luminosity distances of supernovae are not so accurate.

➔To calculate the Hubble parameter and the equation of state of dark energy, we should use the first and second derivatives of this data, which enlarges the errors by huge factors.

➔Even future supernovae data (like SNAP) will not be that accurate to be used directly to calculate these cosmological parameters.



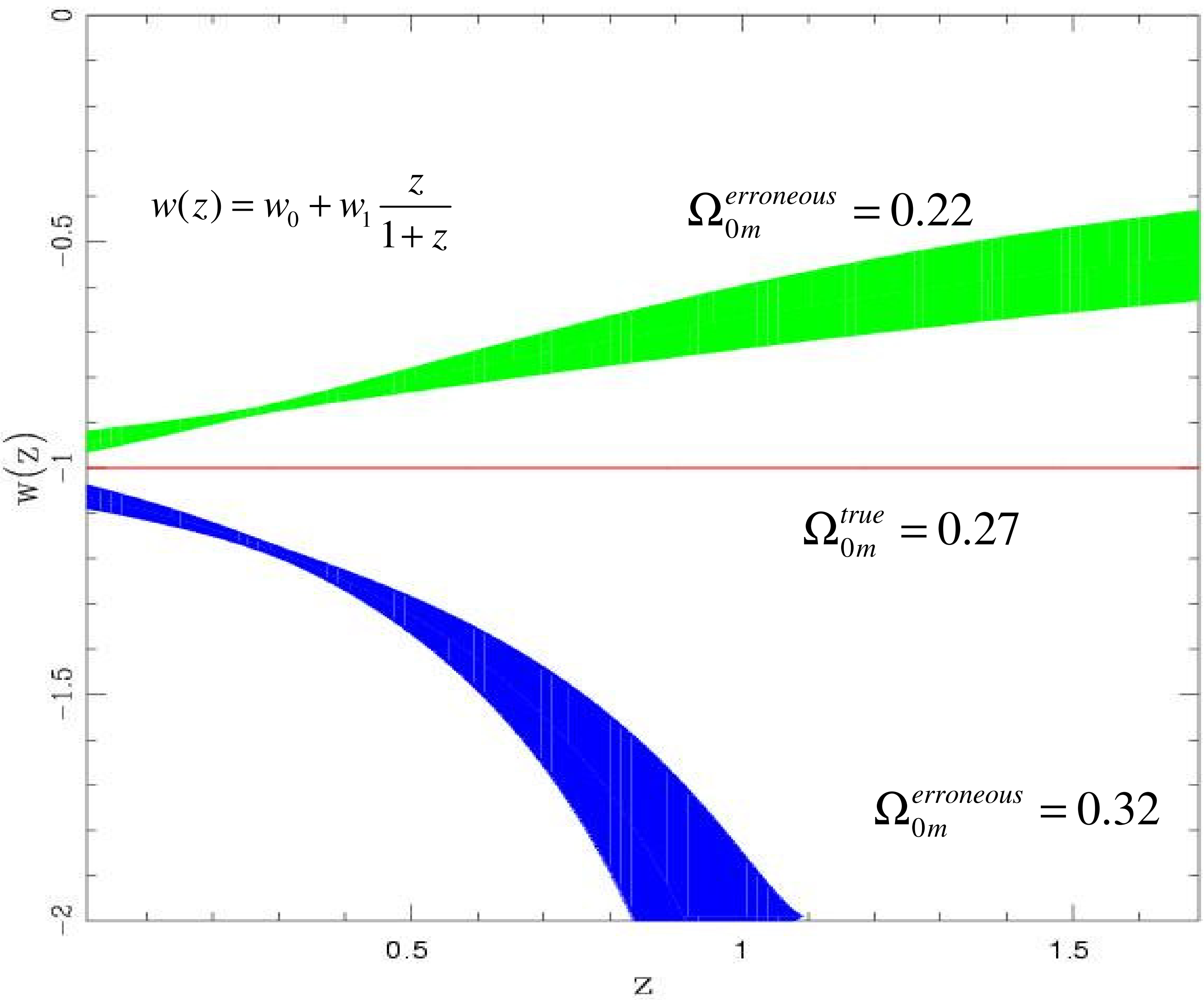
Ω_DE(z)=A_0+A_1z+A_2z^2
Ω_DE(z)=B_0+B_-1/z+B_1z
ω_DE(z)=ω_0+ω_a/(1+ln(1+z))
ω_DE(z)=ω_0+ω_az/(1+z)
ω_DE(z)=ω_0/(1+bln(1+z))^2
ω_DE(z)=ω_0+ω_az/(1+z)^2
ω_DE(z)
Y. Gong, JCAP 2005

Dealing with observational uncertainties in matter density

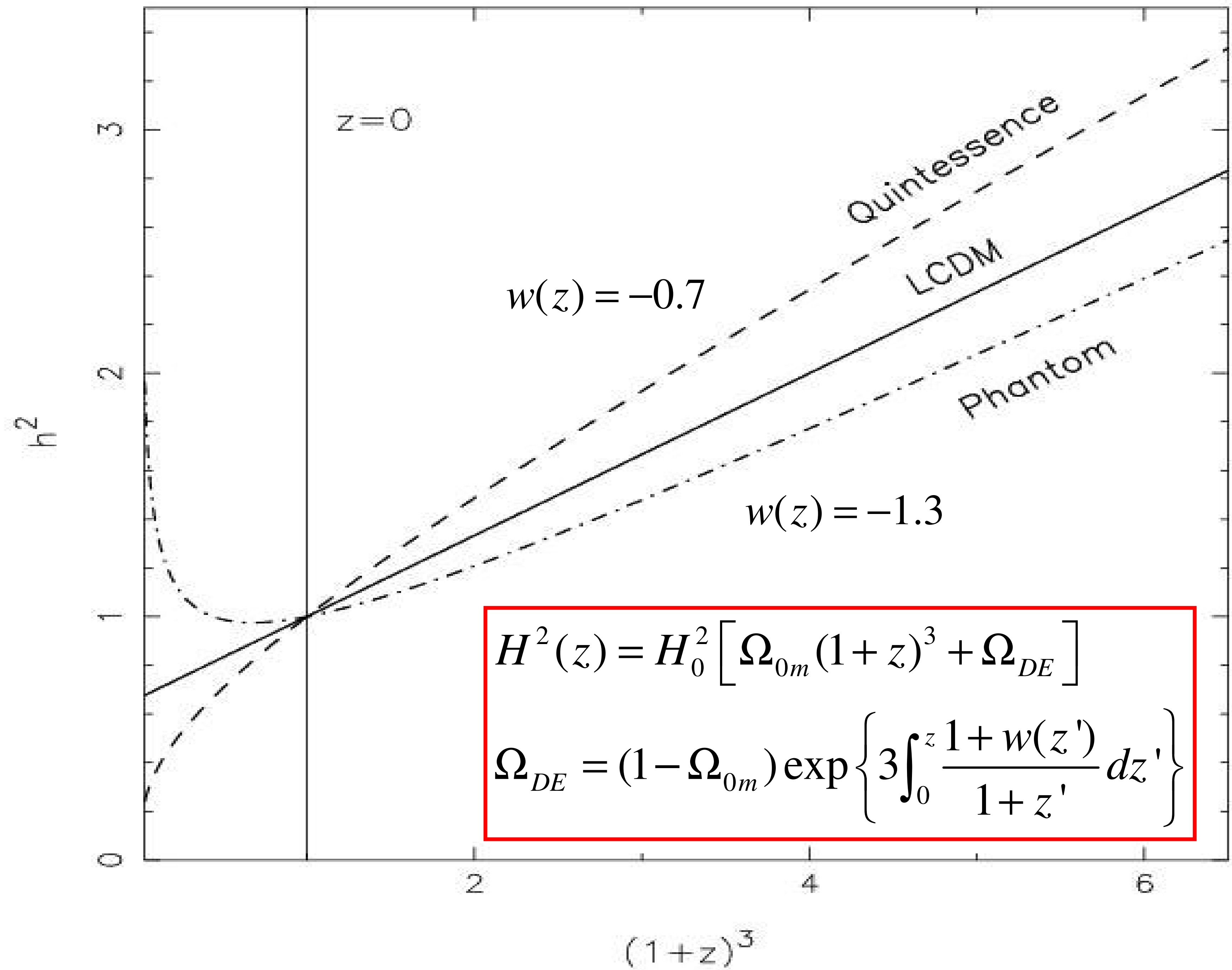
- Small uncertainties in the value of matter density may affect the reconstruction exercise quiet dramatically.
- Hubble parameter is not affected to a very high degree by the value of matter density.
- Any uncertainties in matter density is bound to affect the reconstructed w(z).

$$\boxed{H(z) = \left[\frac{d}{dz}\left(\frac{d_L(z)}{1+z}\right)\right]^{-1}}$$

$$\boxed{\omega_{DE} = \frac{\left(\frac{2(1+z)}{3}\frac{H'}{H}\right) - 1}{1 - \left(\frac{H_0}{H}\right)^2 \Omega_{0M}(1+z)^3}}$$



$w(z) = w_0 + w_1 \frac{z}{1+z}$
$\Omega_{0m}^{erroneous} = 0.22$
$\Omega_{0m}^{true} = 0.27$
$\Omega_{0m}^{erroneous} = 0.32$
w(z)
z
0
−0.5
−1
−1.5
−2
0.5
1
1.5


z=0
Quintessence
LCDM
Phantom
$w(z)=-0.7$
$w(z)=-1.3$
$H^2(z)=H_0^2\left[\Omega_{0m}(1+z)^3+\Omega_{DE}\right]$
$\Omega_{DE}=(1-\Omega_{0m})\exp\left\{3\int_0^z\frac{1+w(z')}{1+z'}dz'\right\}$
h^2
$(1+z)^3$
0
1
2
3
2
4
6

Om diagnostics

$$Om(z) = \frac{h^2(z) - 1}{(1+z)^3 - 1}$$

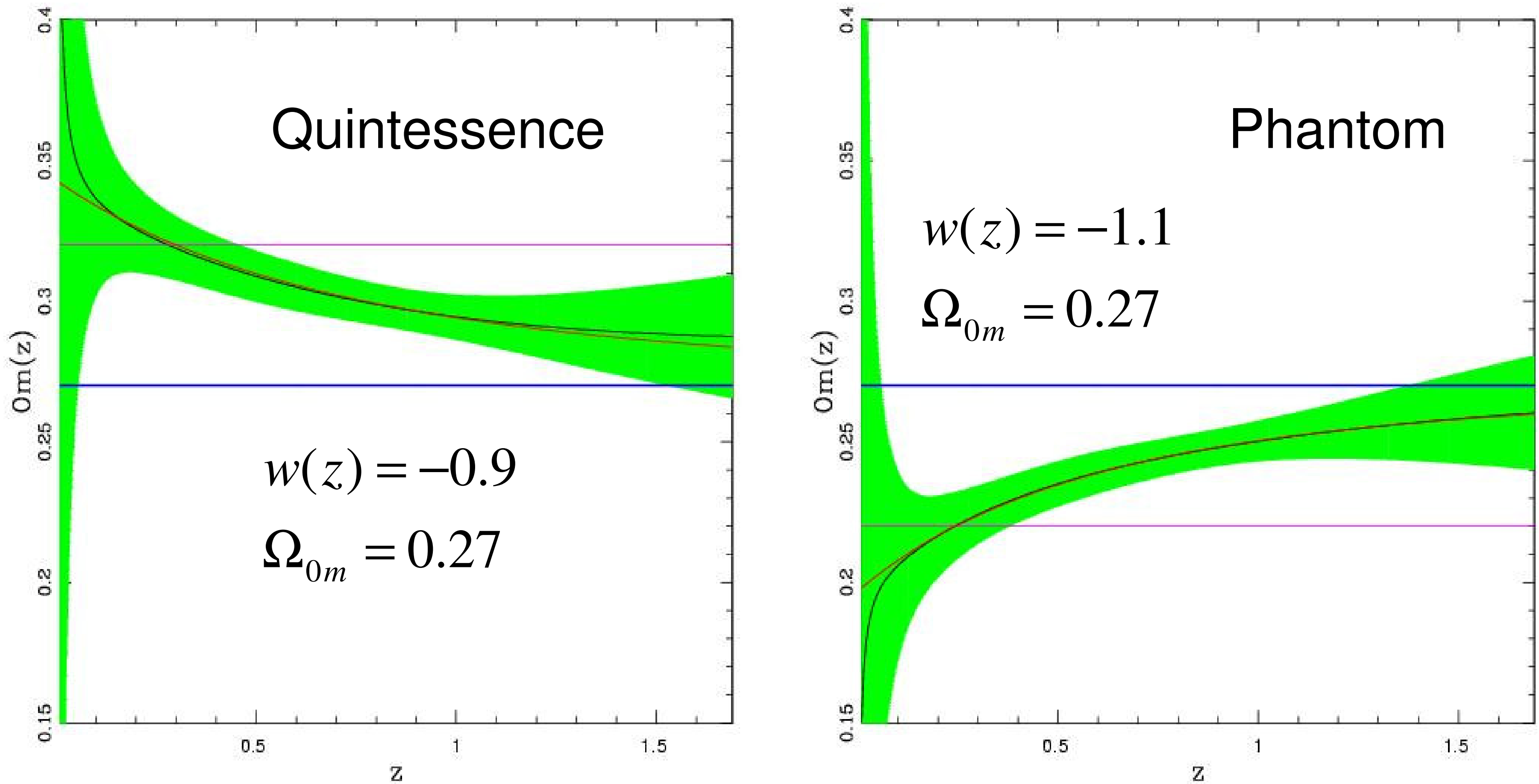
$$Om(z) = \Omega_{0m} + (1 - \Omega_{0m})\frac{(1+z)^{3(1+w)} - 1}{(1+z)^3 - 1}$$

$w = -1 \rightarrow Om(z) = \Omega_{0m}$ ***LCDM***

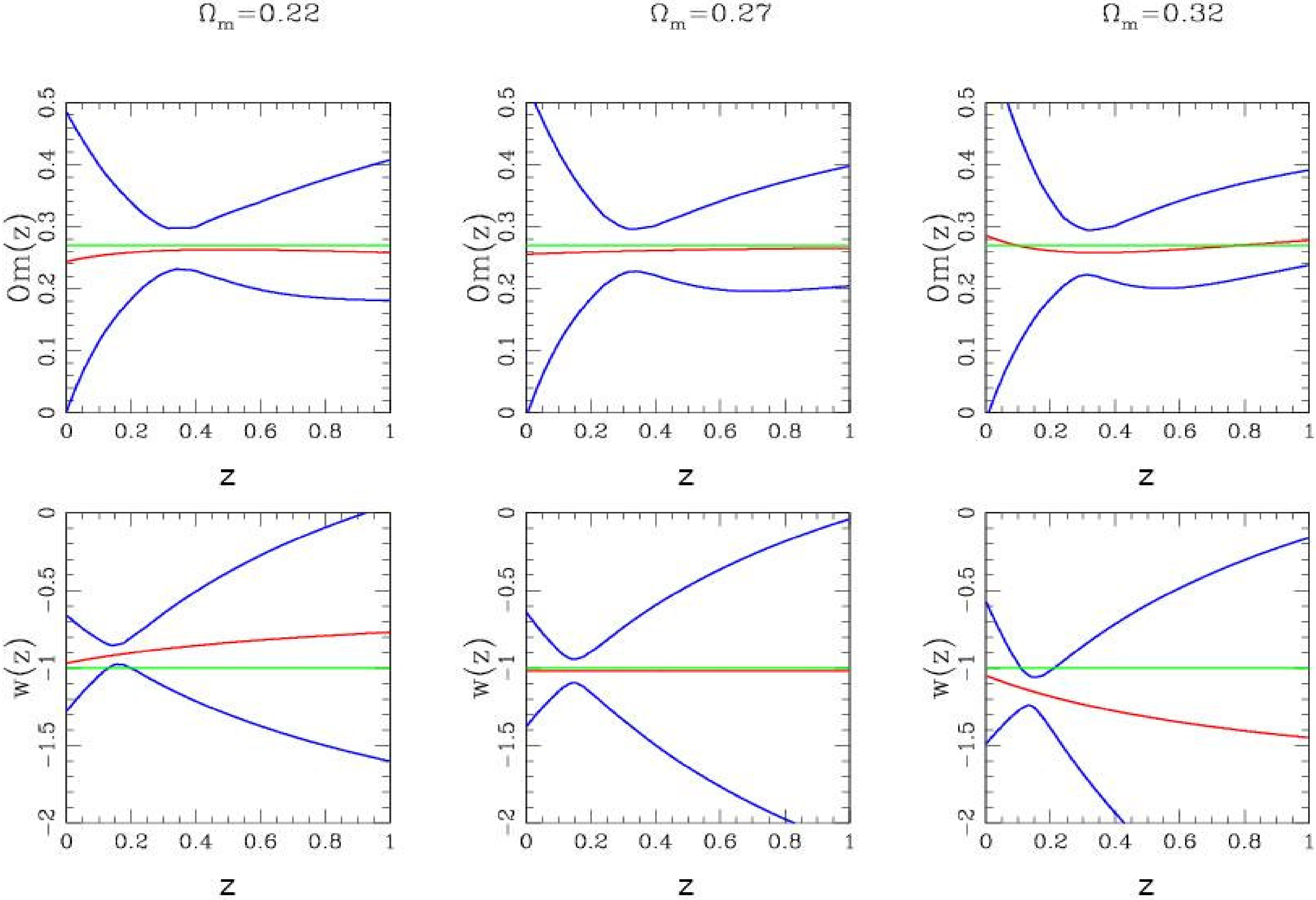
$w < -1 \rightarrow Om(z) < \Omega_{0m}$ ***Phantom***

$w > -1 \rightarrow Om(z) > \Omega_{om}$ ***Quintessence***

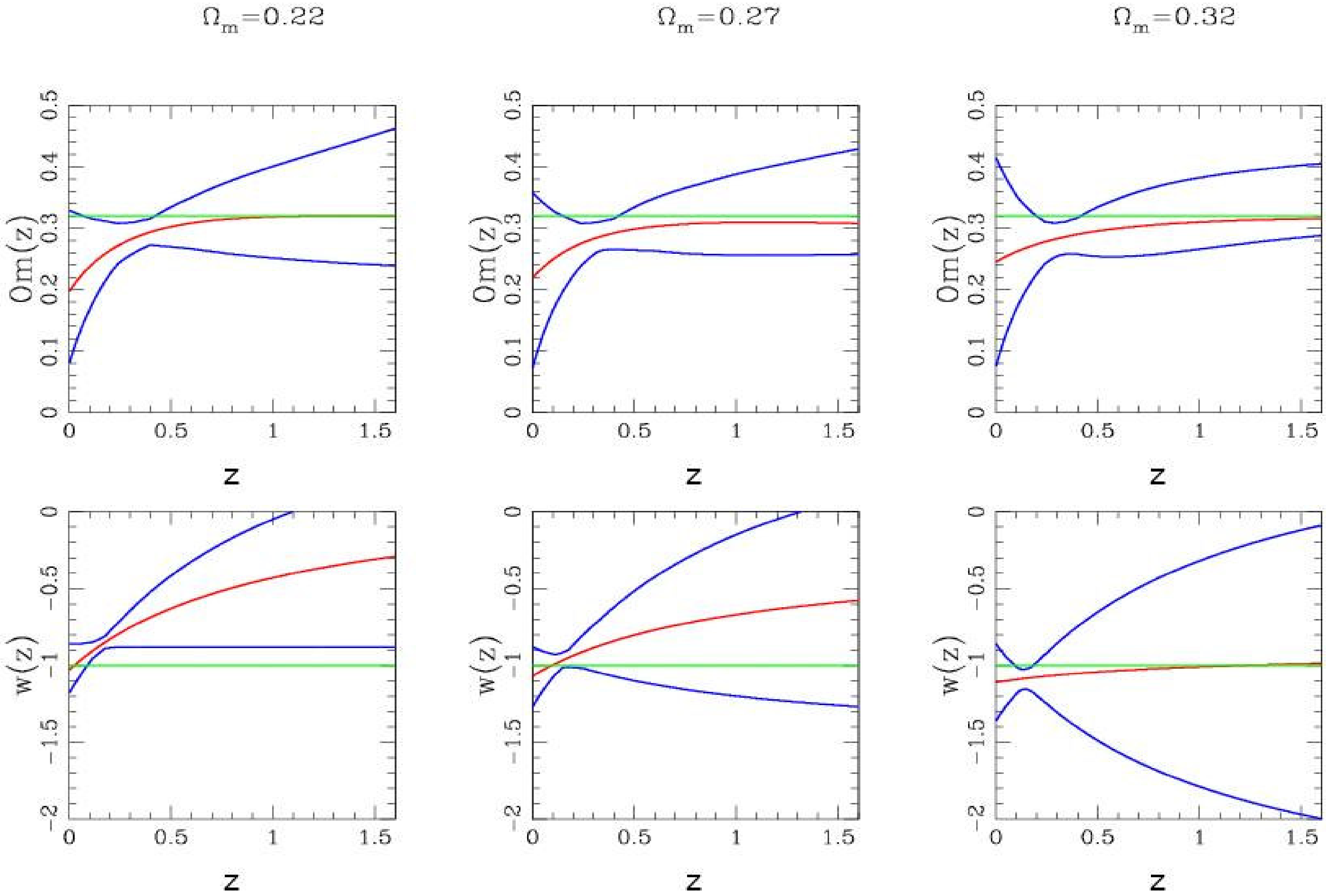
Simulated results for 1000 realization of SNAP data, using smoothing method (Shafieloo et al, MNRAS 2006).



SNLS data, CPL parameterization, $w(z) = w_0 + w_1 \frac{z}{1+z}$



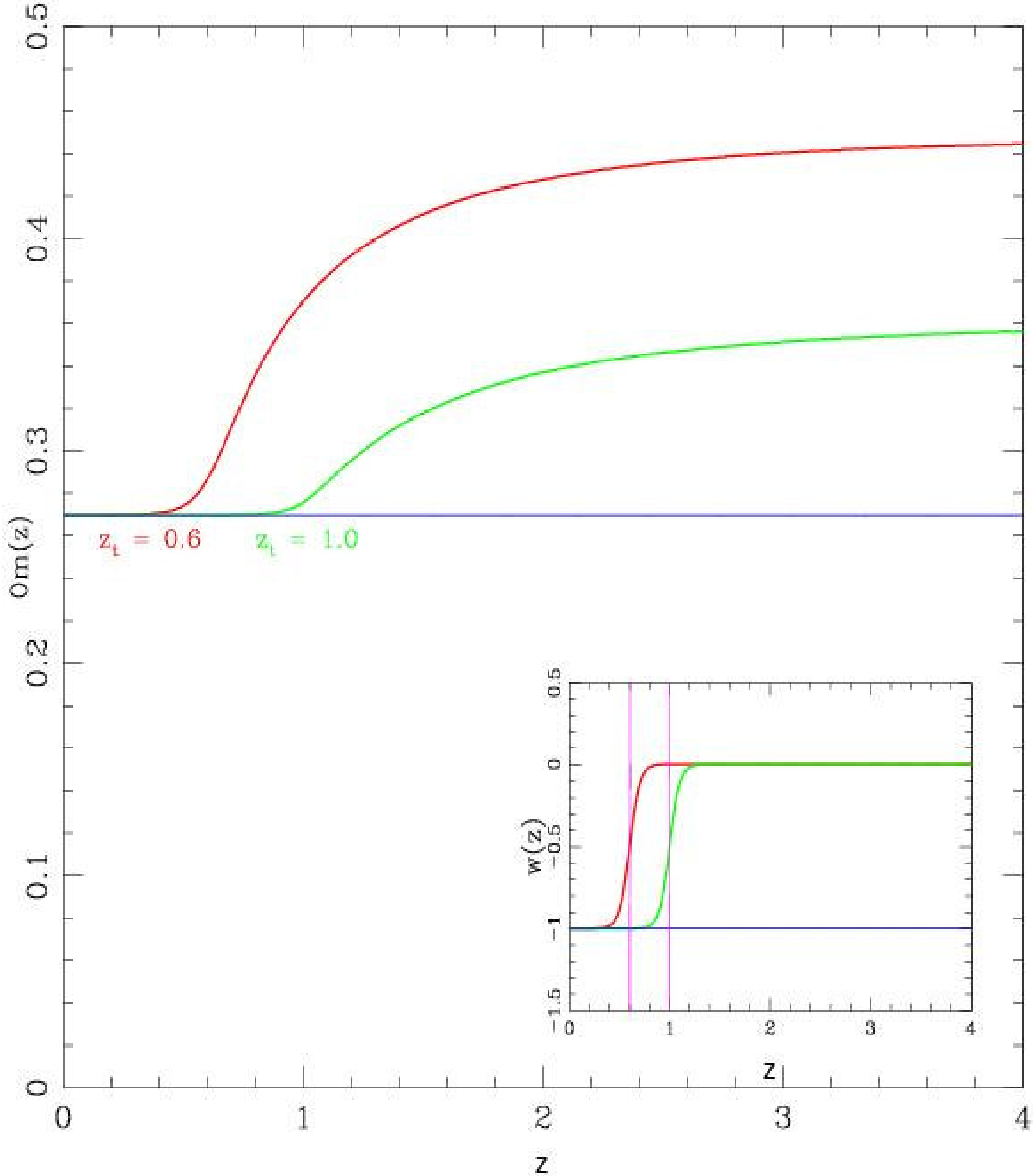
Union data, CPL parameterization



Tracker Models

$$z \gg z_t$$

$$Om(z) \simeq \Omega_{0m} + \frac{1-\Omega_{0m}}{(1+z_t)^3}$$



Acceleration Probe

- Acceleration probe is the mean value of the deceleration parameter:

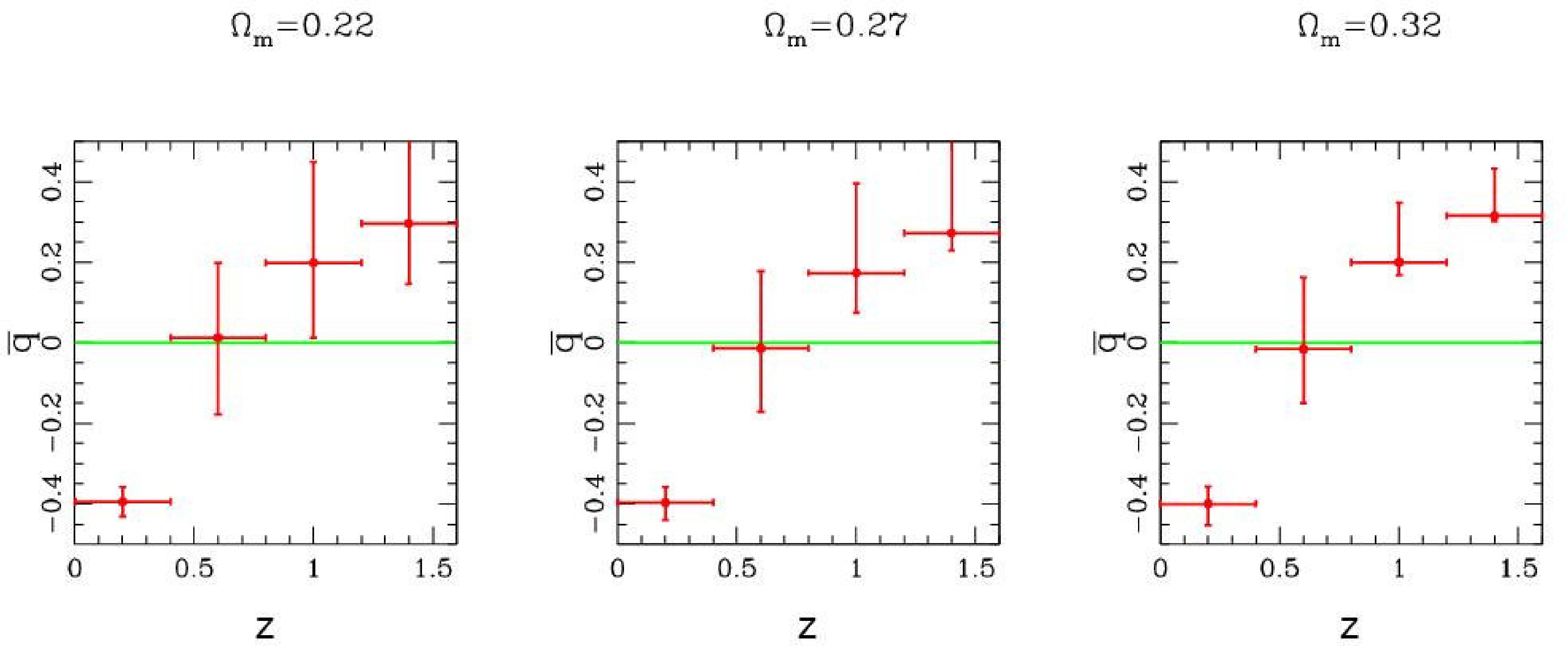
$$\bar{q} = \frac{1}{t_1 - t_2} \int_{t_2}^{t_1} q(t)dt$$

$$q(t) = \frac{d}{dt}\left(\frac{1}{H}\right) - 1$$

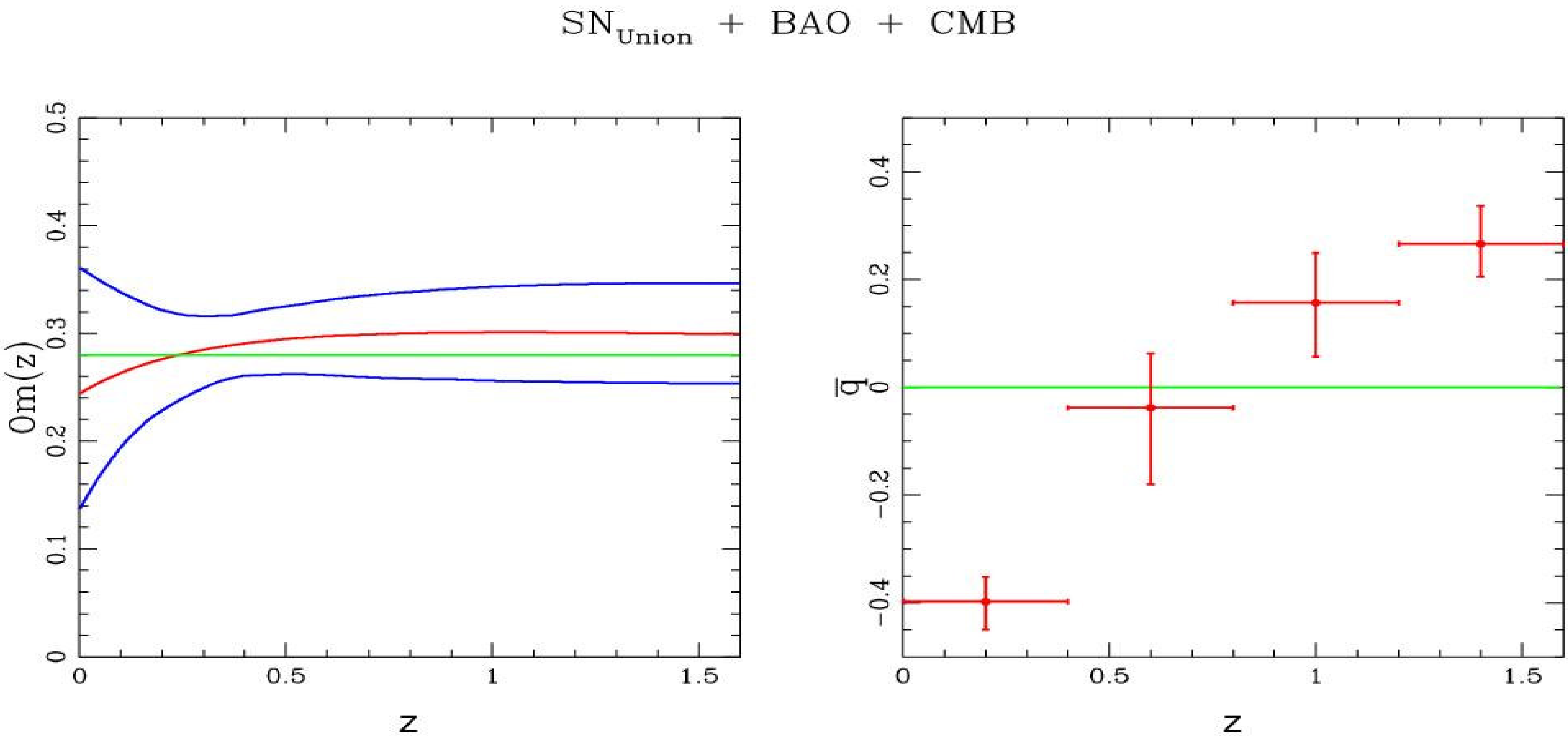
$$\boxed{1 + \bar{q} = \frac{1}{\Delta t}\left(\frac{1}{H_1} - \frac{1}{H_2}\right)}$$

$$H(z) = -\frac{1}{1+z}\frac{dz}{dt}$$

Union SN data, CPL parameterization

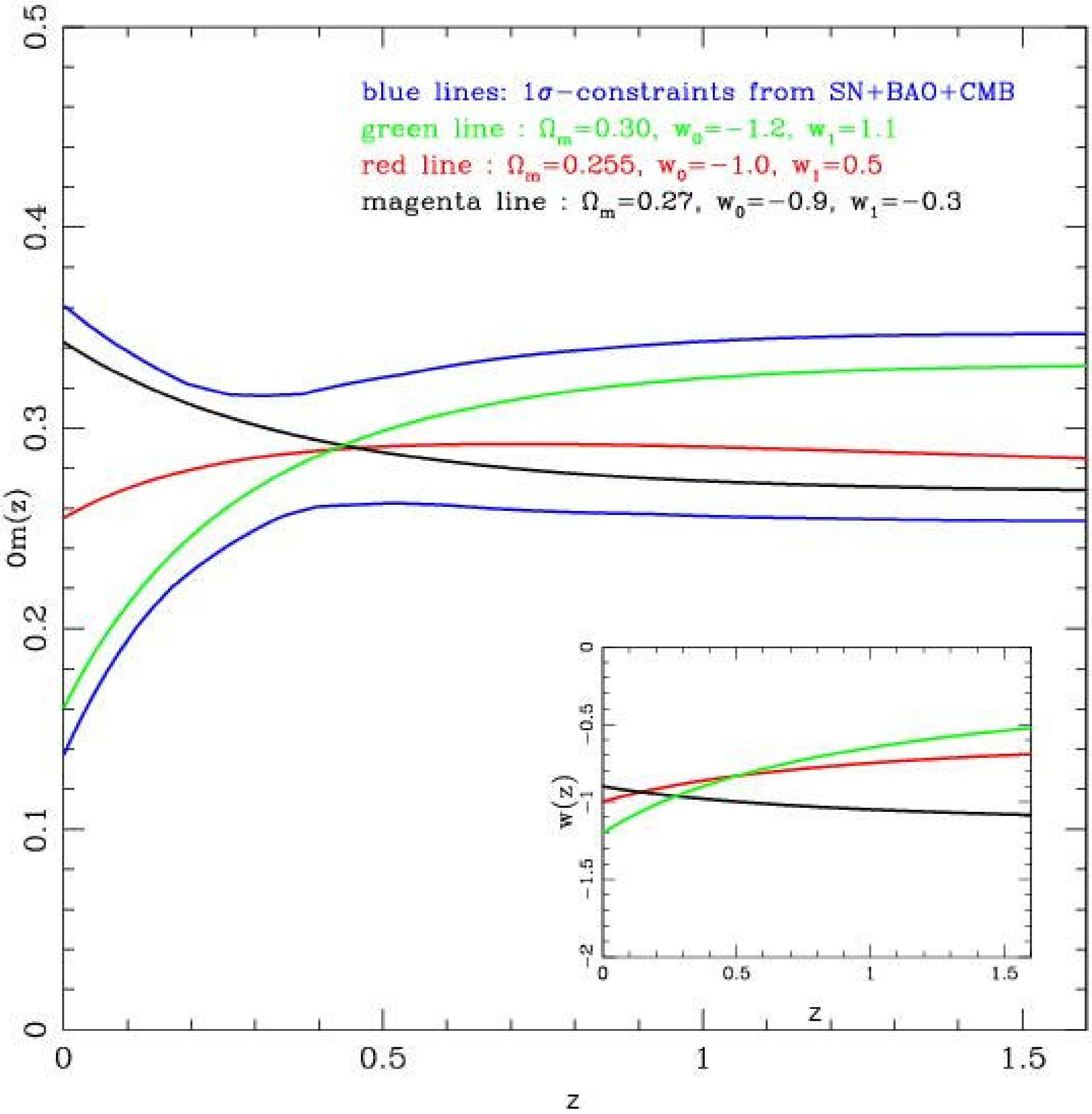


Union SN data + BAO + CMB, CPL parameterization



$$A = \frac{\sqrt{\Omega_m}}{h(z_1)^{1/3}} \left[\frac{1}{z_1} \int_0^{z_1} \frac{dz}{h(z)} \right]^{2/3} \qquad R = \sqrt{\Omega_{0m}} \int_0^{z_{1s}} \frac{dz}{h(z)}$$

$$A = 0.469 \pm 0.017 \ldots z_1 = 0.35 \qquad R = 1.715 \pm 0.021 \ldots z_{1s} \simeq 1088$$



Some dark energy models consistent with the data.

Summary:

- Om provides a ***null test*** of dark energy being a cosmological constant.
- Om can be derived directly from the Hubble parameter and not its derivatives.
- Errors in the reconstruction of Om are smaller than those appearing in the EOS.
- Om is not sensitive to the value of matter density.
- Om can be determined using parametric as well as non-parametric reconstruction methods.
- Acceleration probe depend upon the value of Hubble parameter and the look-back time.
- Om and acceleration probe can be applied on non-uniform data.