A New Hubble Expansion Probe and Cosmological Constraints

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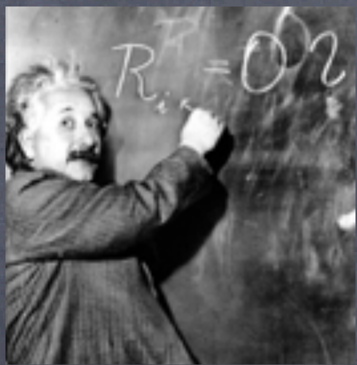
Contents of my talk

- Some basics of dynamical cosmology and definition of cosmological parameters
- The Hubble expansion Cosmological Probe, recent results and future prospects.
- A new Hubble expansion tracer, alternative to SNIa, and results (some definite and some preliminary).



A Mathematical description of our Universe

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

Energy Conservation

A useful representation of the source terms is that of virtual fluids with (ρ,P)

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\left[\rho_m + \rho_k + \ldots\right]$$

parametrization of ρ_i as fractional contribution to the global energy density

$$\Omega_i(a) = \frac{\rho_i}{\rho_{\text{total}}} = \frac{8\pi G\rho_i}{3H^2}$$

+

$$\rho(a) = \rho(0)\left(\frac{a}{a_0}\right)^{-3(1+w)}$$

$$P = w\rho c^2$$

$$\Omega_m + \Omega_k + .. = 1 \quad \forall z$$

Important relation between Ωs which just reflects mass conservation

The 1st Friedmann eq. can now be written in the form (known as Hubble relation):

$$H^2(z) = H_0^2\left[\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_w \exp\left(3\int_0^z \frac{1+w(x)}{1+x}dx\right)\right]$$

$$w(z) = w_0 + w_1 f(z)$$

$$f(z) = z/(1+z)$$

The main Cosmological parameters that we seek to determine in order to define the Cosmic Dynamics are: H_0, Ω_m, Ω_k, Ω_w, $w(z)$

Hubble expansion Probe (SN Ia)

Type-Ia Supernovae (SNe Ia) result from explosion of White Dwarf having accreted mass from a companion star, beyond the critical Chandrasekhar limit (~ 1.4 $M_\odot$).

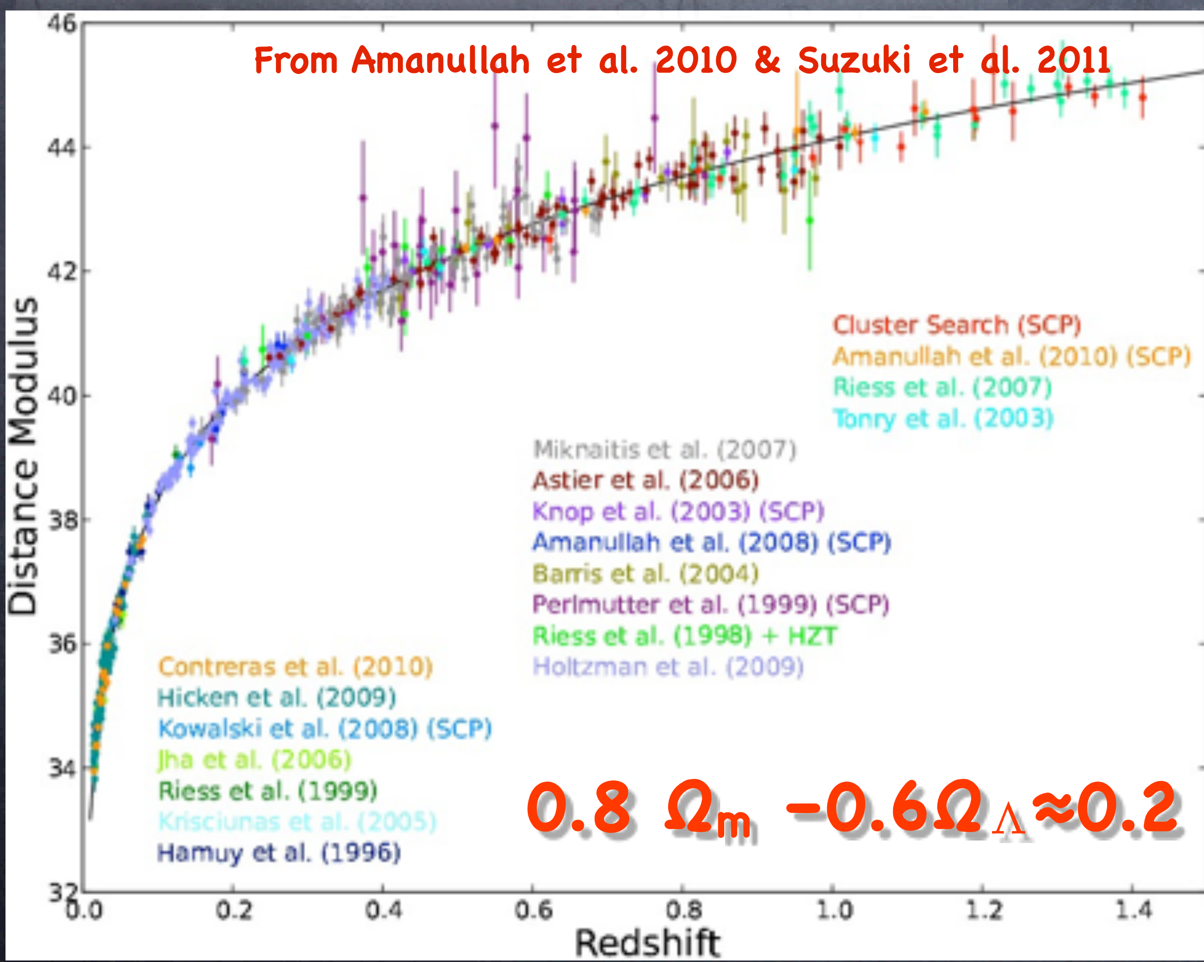
In 1998 two teams (Perlmutter, Riess) found that distant SNIa are dimmer than expected, a fact interpreted as being due to an accelerated expansion of the Universe. Ever since the new accumulation of data and better understanding of systematics confirm constantly this interpretation.

$$\mu = m - M = 5\log_{10} D_L + 25$$

+

$$D_L = (1+z)\int_0^z \frac{c}{H(z)}\mathrm{d}z \rightarrow H(z)$$

$$H^2(z) = H_0^2\left[\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_w \exp\left(3\int_0^z \frac{1+w(x)}{1+x}dx\right)\right]$$

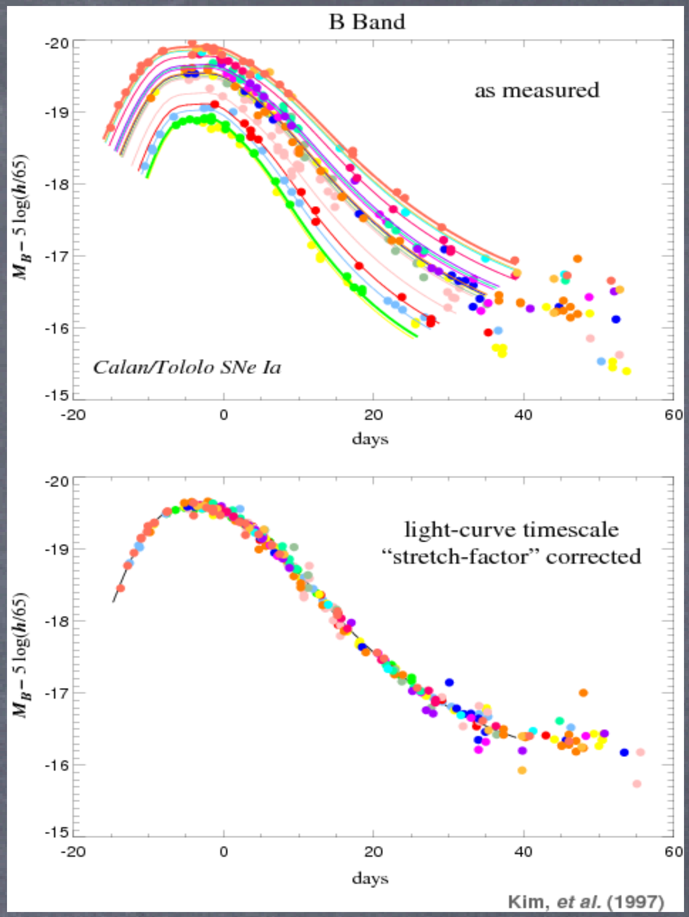


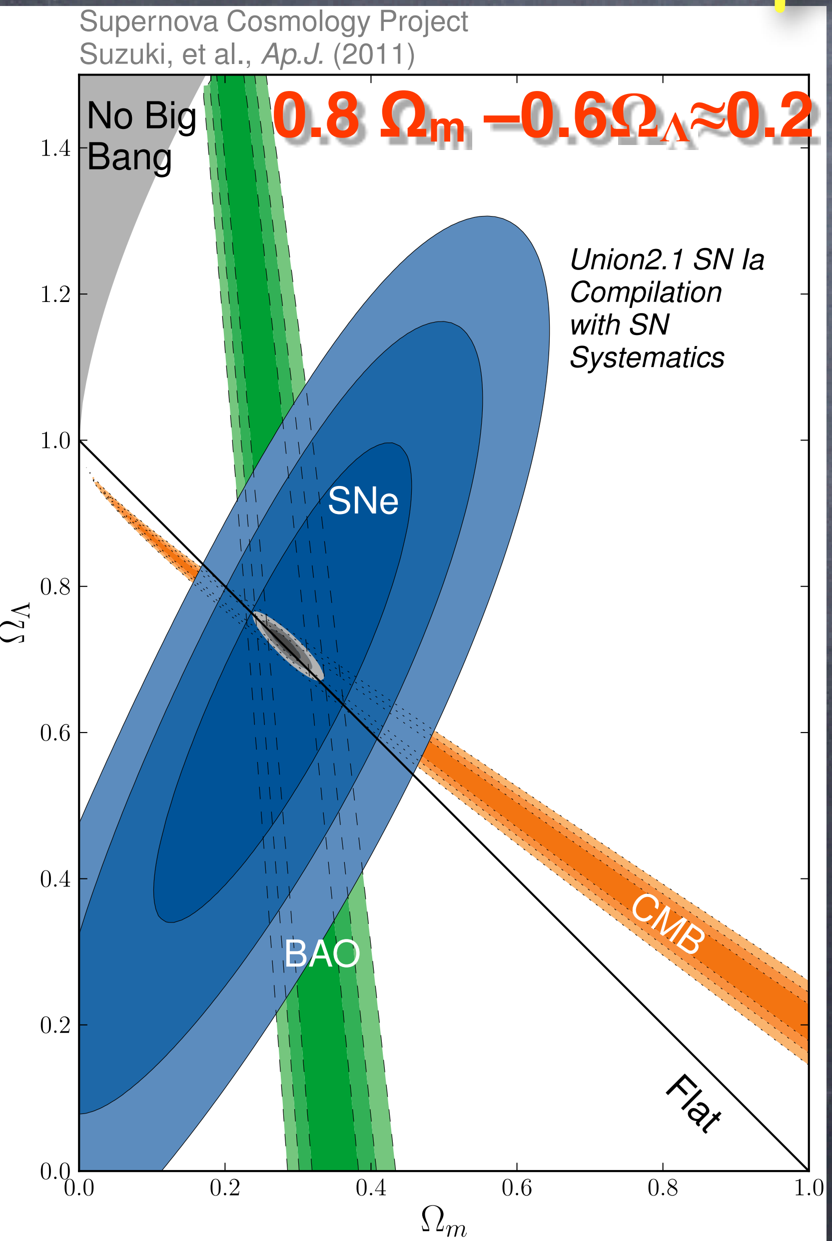
$$\chi^2(\mathbf{p}) = \sum_{i=1}^{n} \frac{[\mu_{\rm th}(z_i,\mathbf{p}) - \mu_{\rm obs}(z_i)]^2}{\sigma_i^2}$$

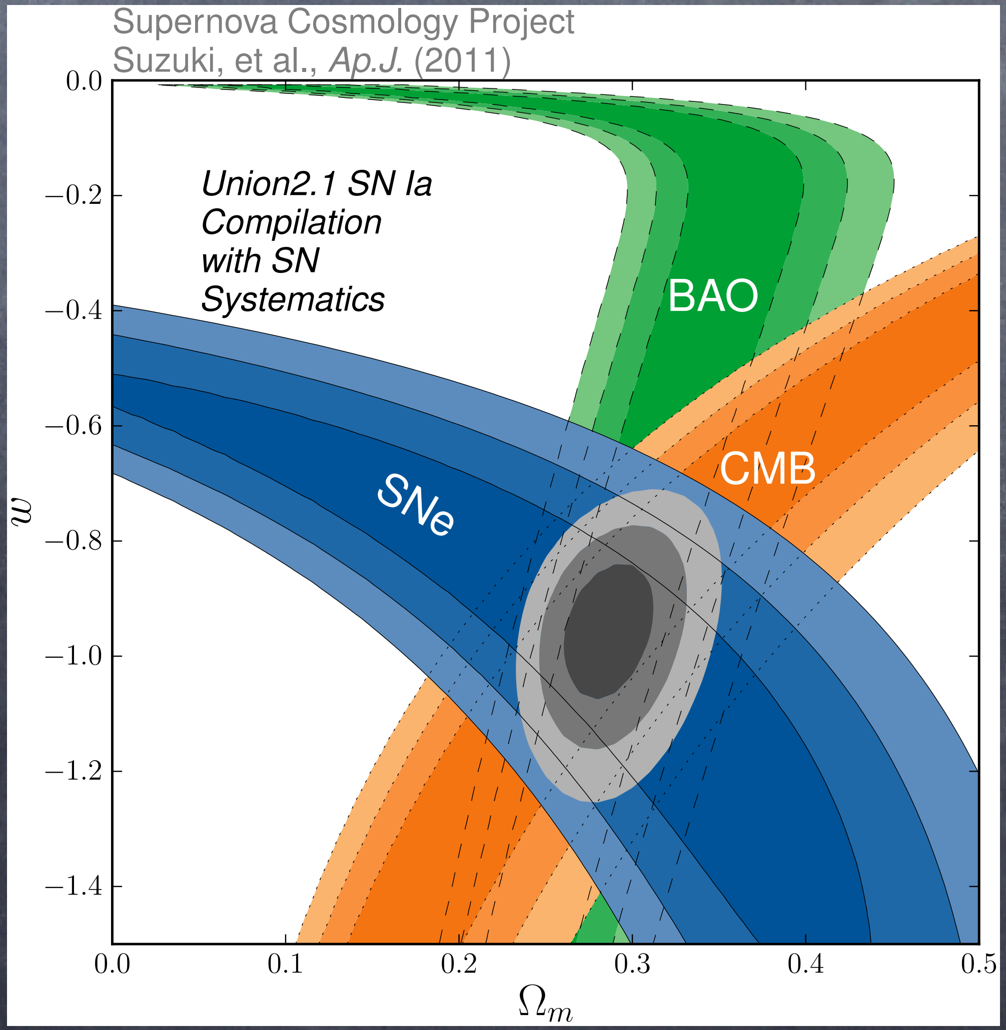
χ2 minimization provides Cosmological parameter space

Hubble expansion Probe (SN Ia)

Systematics? Dependence on galaxy Hubble type indicates effects of absorption is important, while the change of Hubble type progenitor with z could introduce significant uncertainties in Cosmological parameters.







Only SNIa

ΛCDM: $\Omega_m=0.295\pm0.041$

wCDM: $\Omega_m=0.296\pm0.140$,

$w=-1.001\pm0.370$

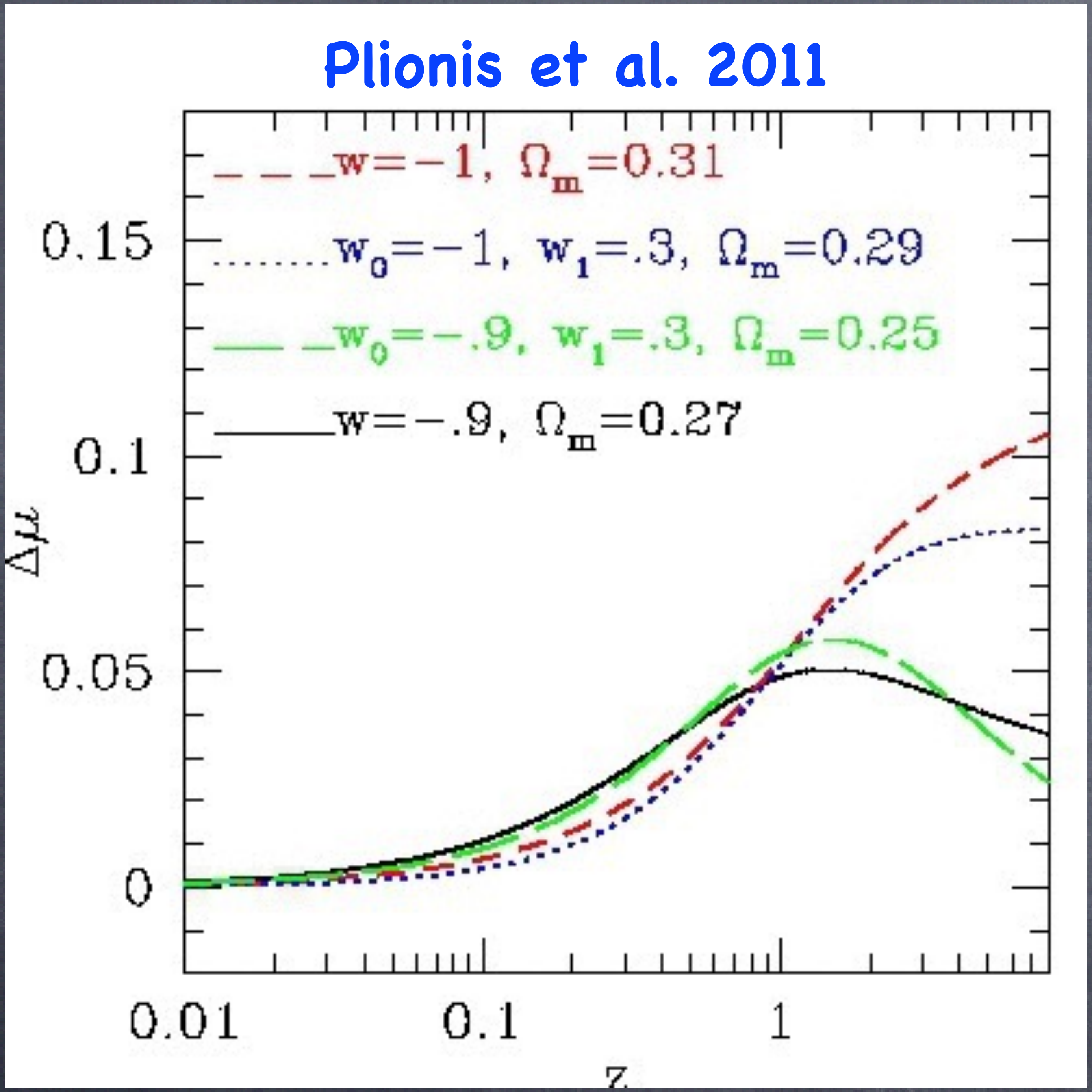
SNIa+BAO+H_0

wCDM: $\Omega_m=0.320\pm0.035$,

$w=-1.097\pm0.100$

Suzuki et al. 2011

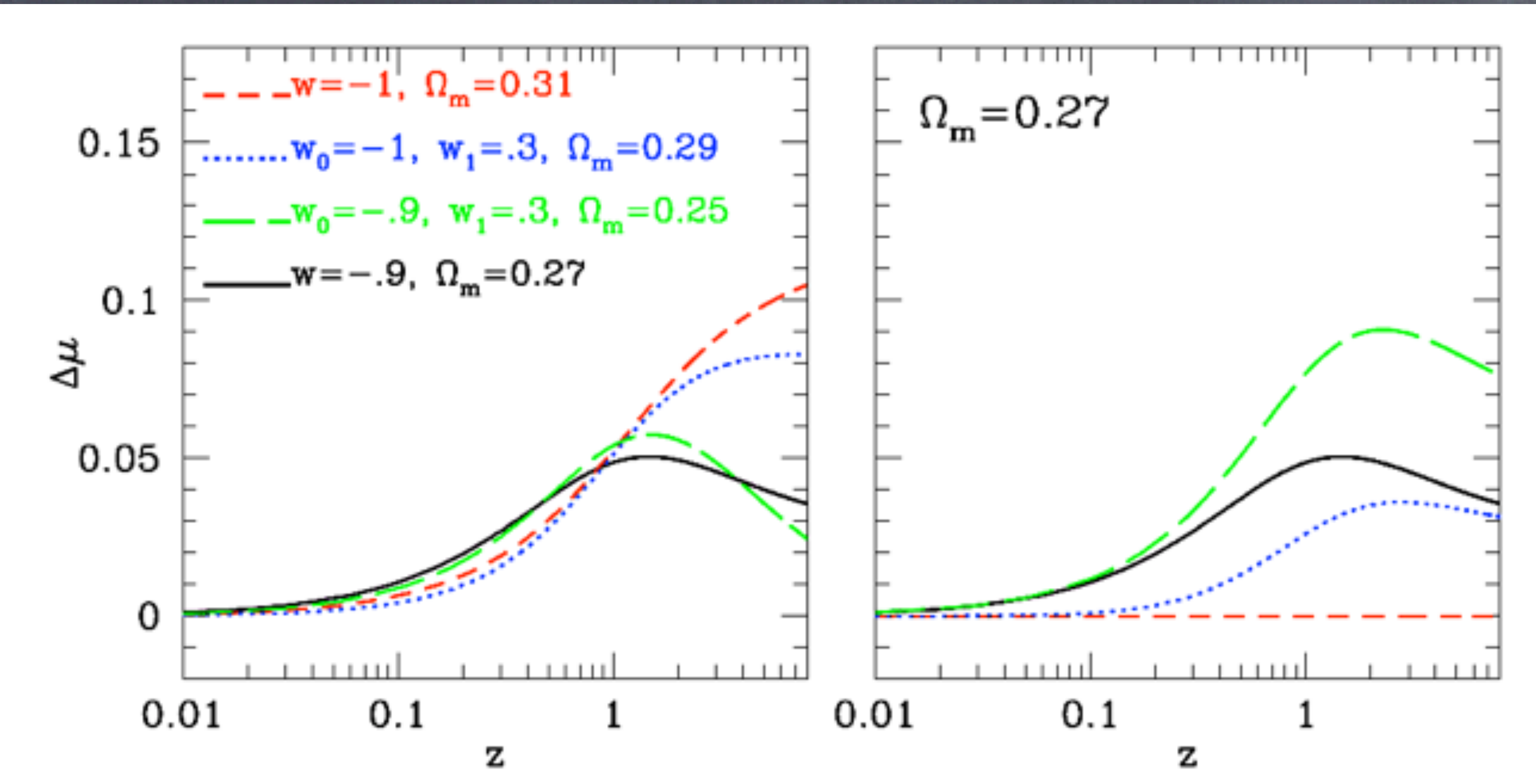
Which are the optimum depths in order to differentiate between different DE models?



Important observation: the largest differences between models occur at $z>2$

Conclusion: We need tracers of Hubble expansion that go deeper than what currently do the SNIa

Severe Problem: Degeneracies of Cosmological parameters



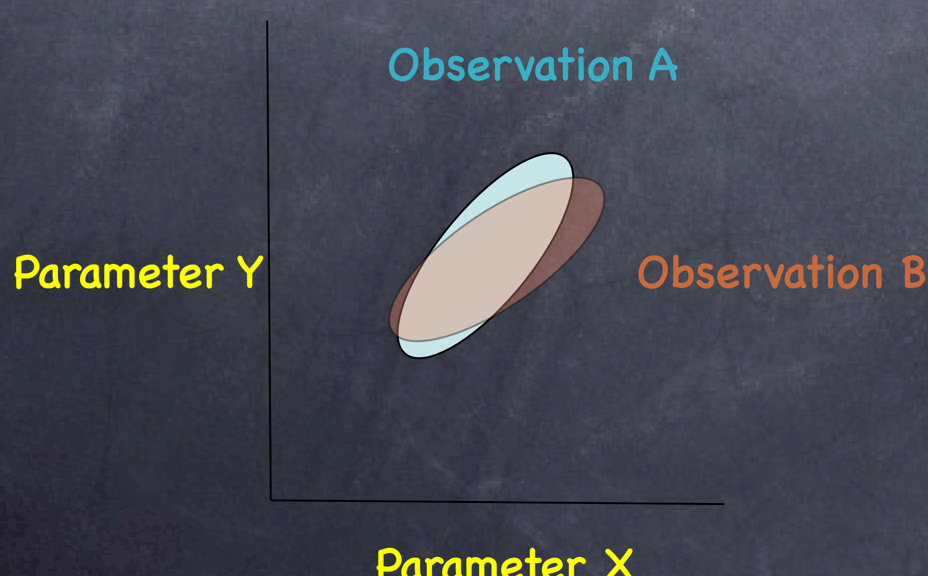
Important observations:

(1) the largest differences between models occur at $z>1.5-2$, and

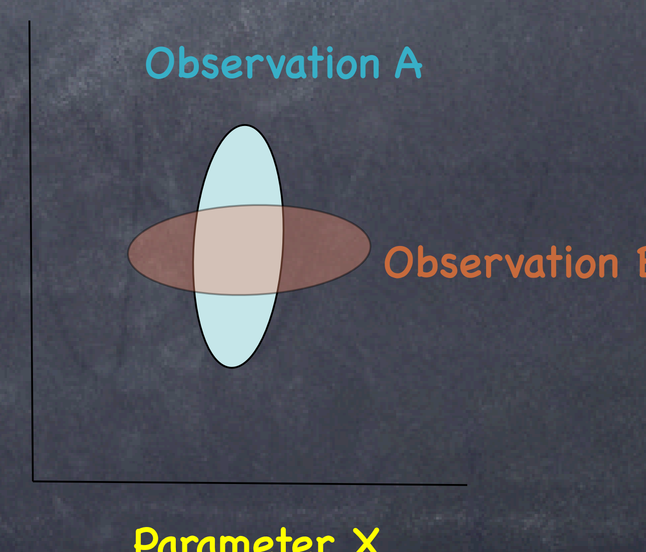
(2) Necessary to break degeneracies (eg., estimating independently Ω_m)

To break degeneracies it is necessary to join different Cosmological Probes in order to get useful constraints on parameters:

Degenerate Solutions to Observations



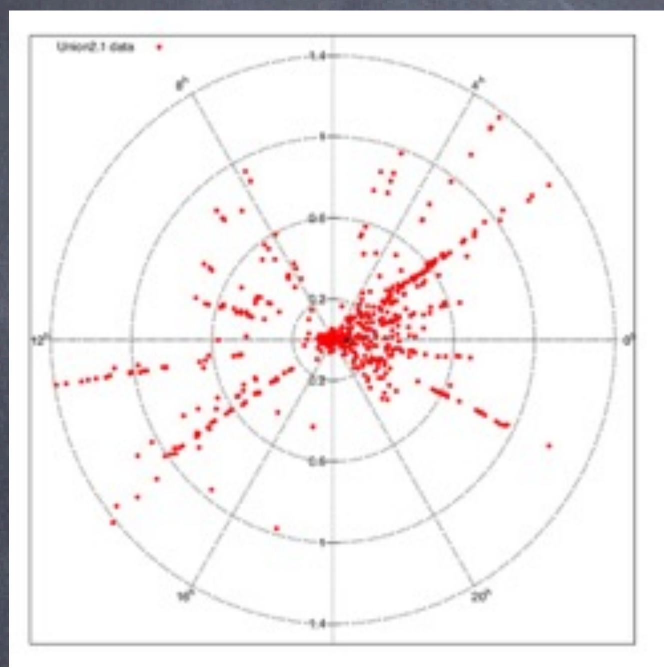
Non-Degenerate Solutions to Observations

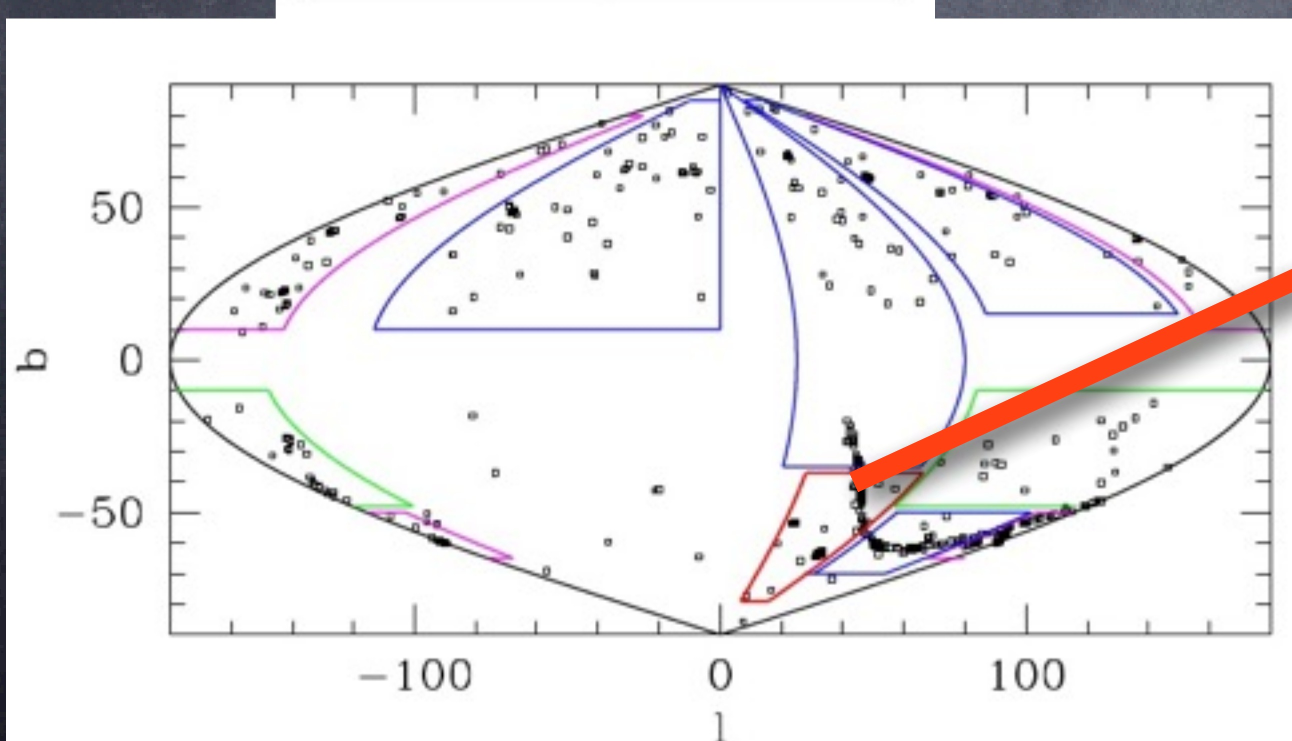


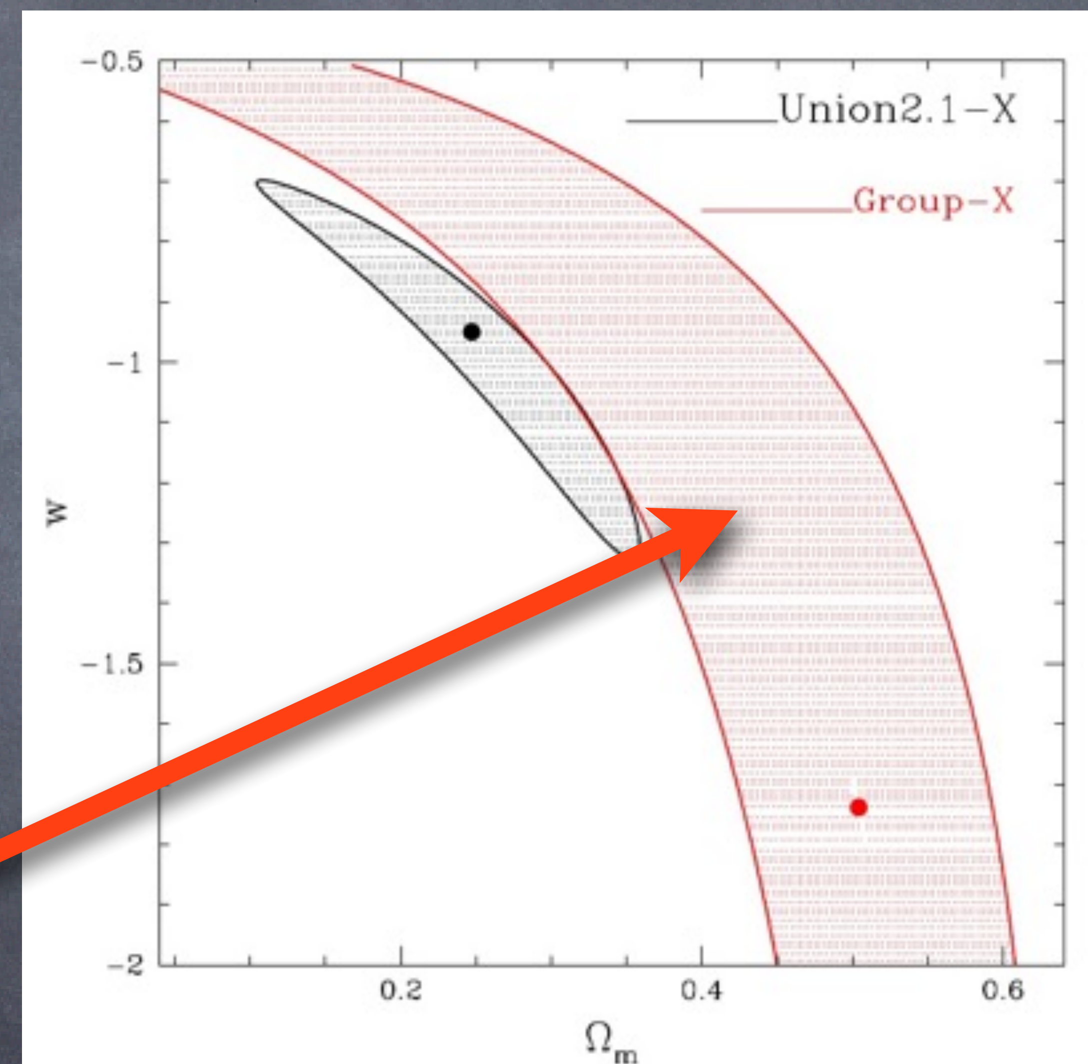
Is the Hubble expansion Isotropic?

Basic assumption in which the FRW models are based is that the expansion is isotrpopic

We have tested this using the Union2.1 SNIa (**Migkas & Plionis 2016, Tanidis & Plionis 2017**)







Finally, we found that the difference is due to only 3 erratic out of the 82 SNIa of Region-X.

A NEW H(z) TRACER

GRECO-LATIN Collaboration

INAOE, Aristotle Univ., Academy of Athens, Obs. of Hawai, ESO
(collaborators: Terlevich, R., Terlevich, E., Plionis, M., Basilakos, S., Bressolin, F., Melnick J., Chavez, R.)

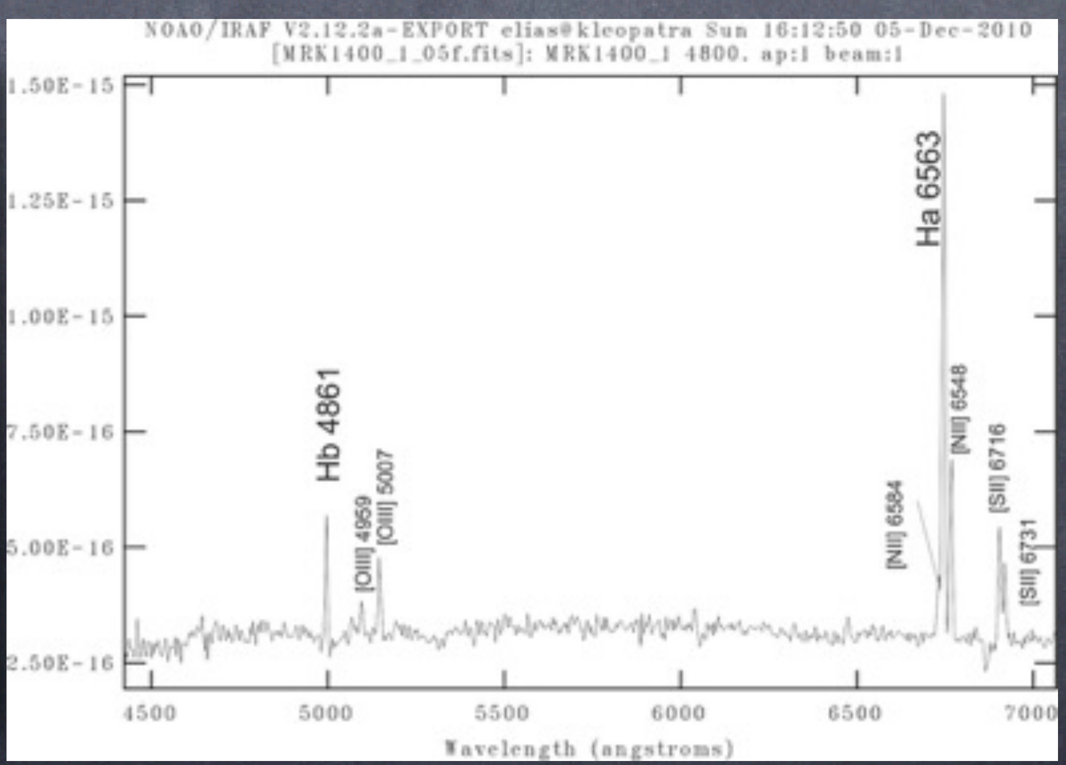
Two basic necessities make the use of a new H(z) tracer an important task:

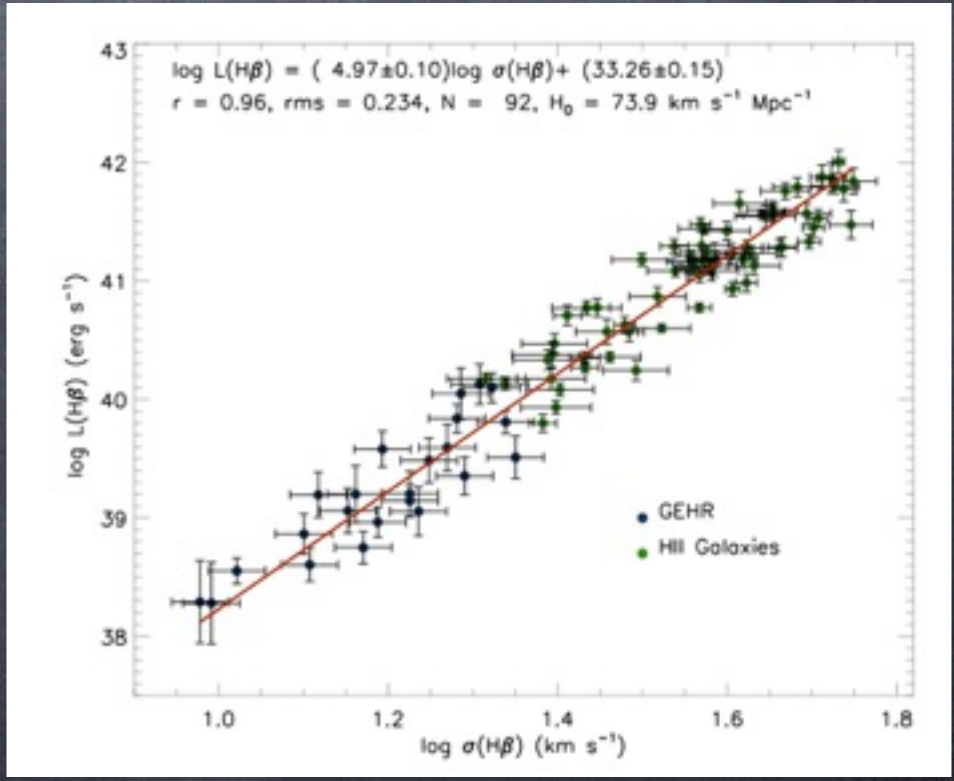
(a) The need to verify the Cosmological results based only on one single type of tracer (SNIa).

(b) The need to go much deeper in redshift in order to break degeneracies between different DE models.

A NEW H(z) TRACE

Our proposal is to use HII galaxies (**compact galaxies with massive burst of SF dominating total L**) and their local counterparts Giant HII regions. Optical spectra dominated by strong Balmer lines, produced by gas ionized by massive star cluster. The Higher the Star cluster mass, larger the No of ionizing γ, larger the motions of the gas) ---> Tight correlation between $L(H_\beta)$ and stellar velocity dispersion, σ (Melnick & Terlevich 1981; Melnick et al. 1988; 2000).

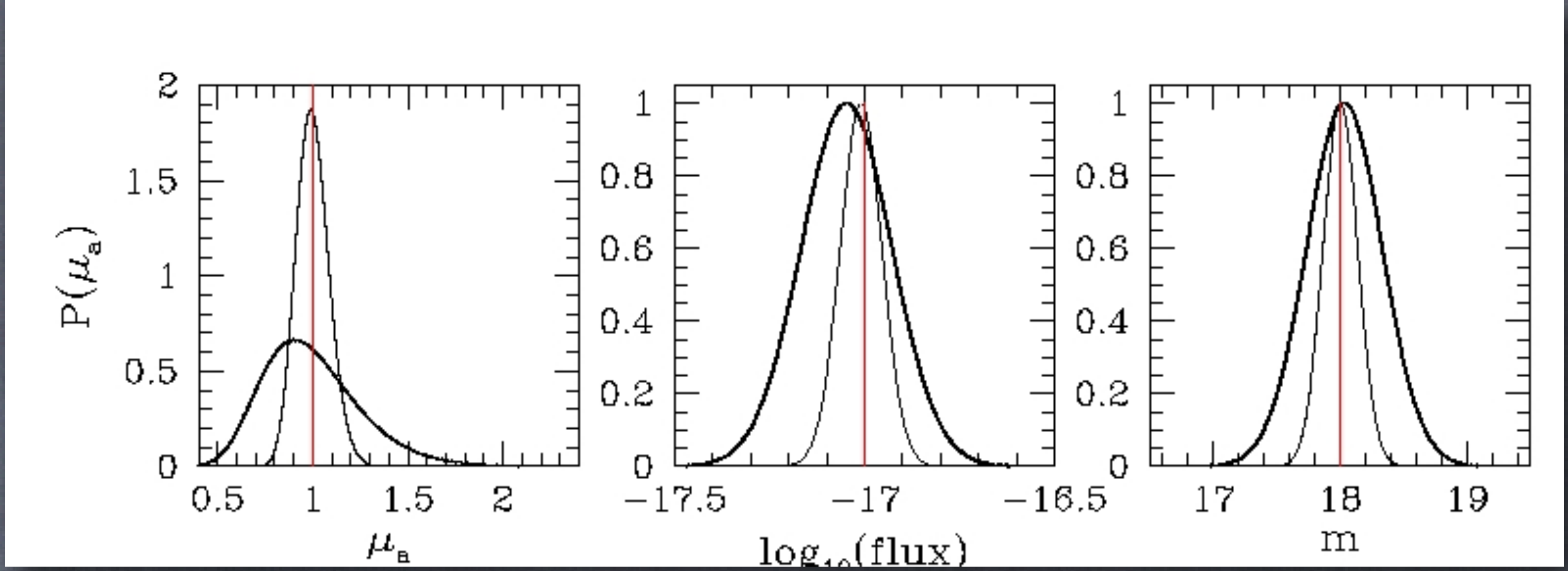




H II Galaxies are high-z probes (more than SNIa)

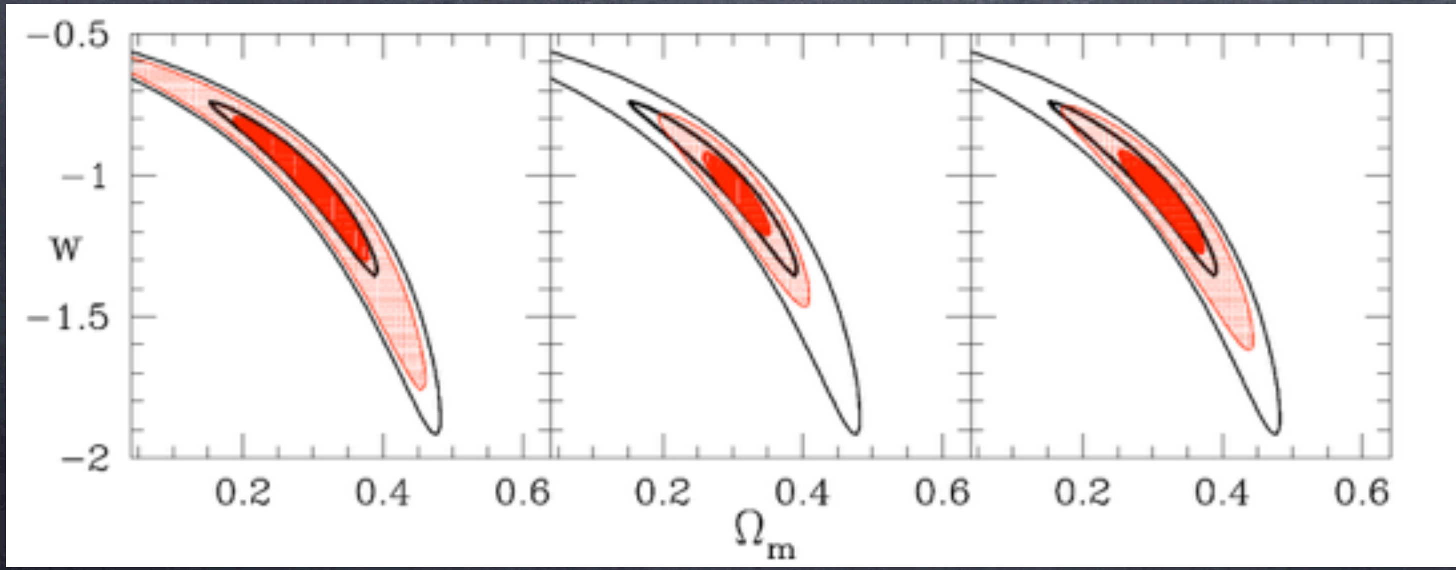
verified in detail in **Plionis et al. 2011**

Extensive Monte-Carlo Simulations to test methodology



Problems due to gravitational lensing

(eg., Holz & Wald 1998; Holz & Linder 2005; Brouzakis & Tetradis 2008). Assuming a Robertson-Walker background superimposing a locally inhomogeneous universe and taking into account both strong and weak lensing effects, results in a magnification distribution of a single source over different paths which is non-Gaussian. The magnification probability density function P(μ_α) resembles a log-normal distribution with μ=0 (mean flux over all possible different paths is conserved since photon numbers are unaffected by lensing), with the mode shifted towards the de-magnified regime with a long tail to high magnification.



Thus most sources will be de-magnified, inducing an apparently enhanced accelerated expansion, while a few will be highly magnified.

HII Galaxies: Low-z sample

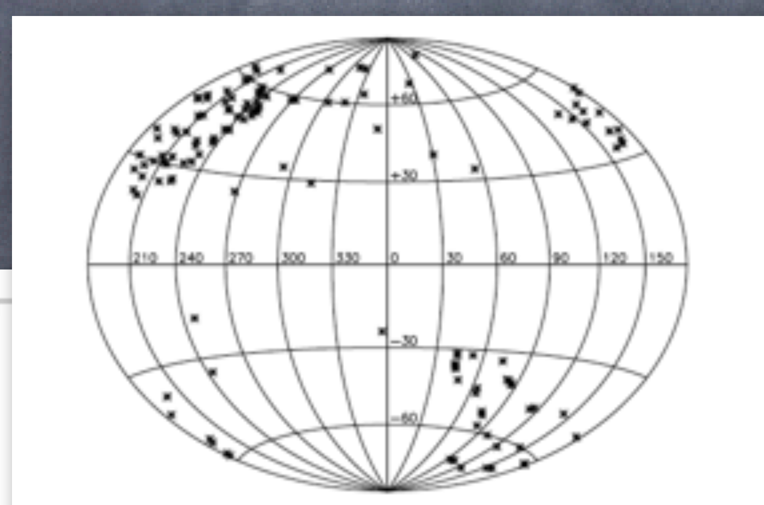
We select 128 HII galaxies from the spectroscopic DR7 SDSS catalogue within $0.01<z<0.16$ Their characteristics are: compact, with large Hβ fluxes and equivalent widths (W). The clean sample after excluding peculiar line profiles, double lines, or rotationally broaden lines is 92 HII galaxies.

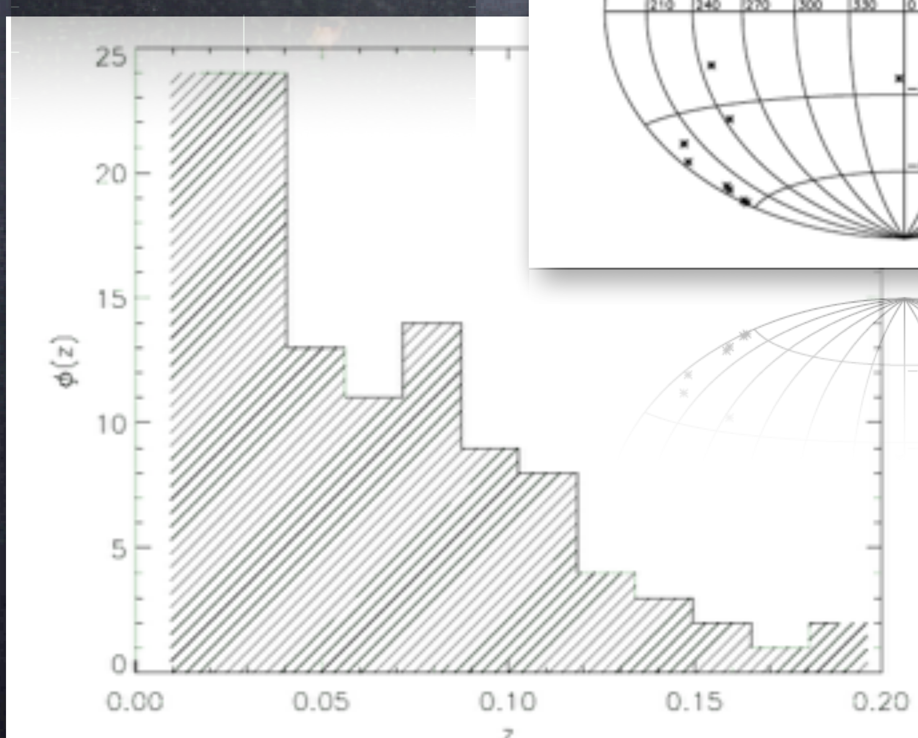
Telescopes used:

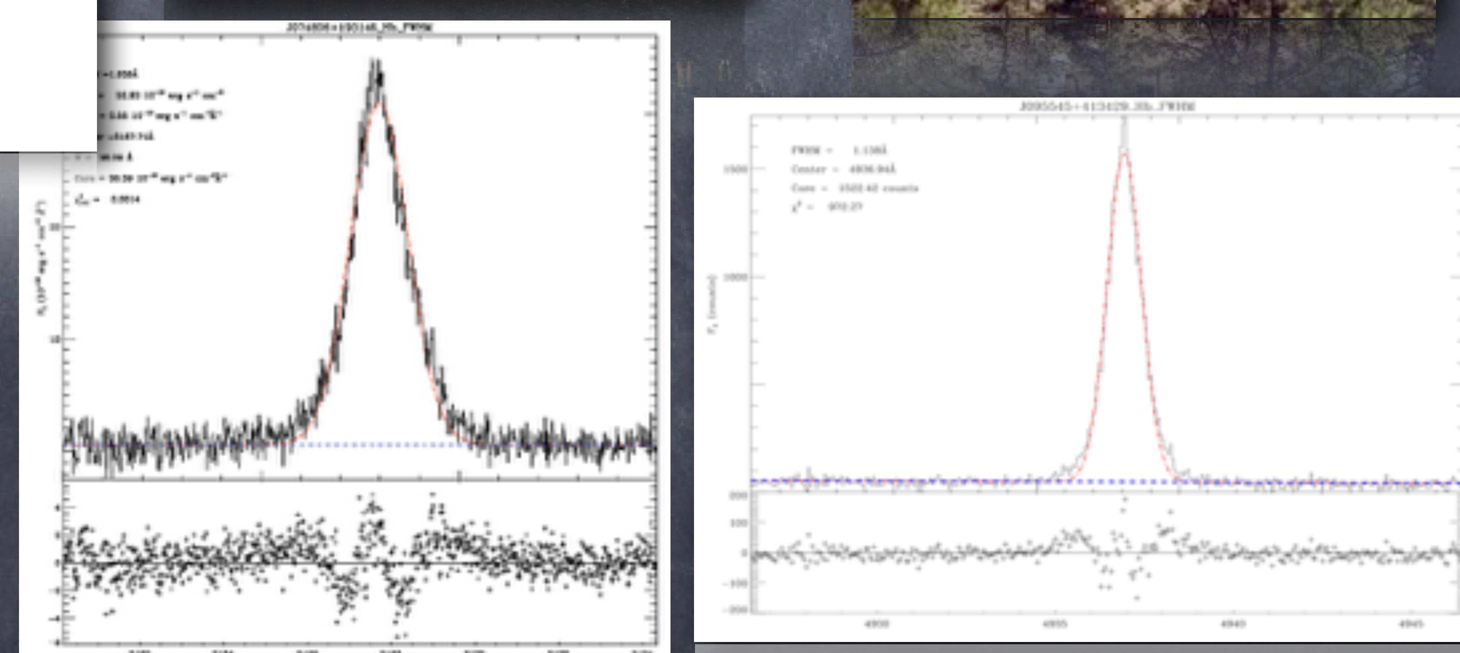
Subaru 8m (HDS),

VLT 8m (UVES) to measure velocity dispersions,

SPM & Cananea 2.1m (integrated fluxes)







Measuring H_0

The Hubble Constant: Current and Future Challenges
Kavli Institute for Particle Astrophysics and Cosmology, February 2012
Sherry H. Suyu, Tommaso Treu, Roger D. Blandford, Wendy L. Freedman, ed.

The Hubble constant and new discoveries in cosmology

S. H. Suyu[1,2], T. Treu[1], R. D. Blandford[2], W. L. Freedman[3], S. Hilbert[2], C. Blake[4], J. Braatz[5], F. Courbin[6], J. Dunkley[7], L. Greenhill[8], E. Humphreys[9], S. Jha[10], R. Kirshner L. Macri[11], B. F. Madore[3], P. J. Marshall[7], G. Meyla B. Reid[12], M. Reid[8], A. Riess[13,14], D. Schlegel[12], V. L. Verde[15]

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Abstract.
We report the outcome of a 3-day workshop on the Hubble constant during February 6-8 2012 at the Kavli Institute for Particle Astrophysic the campus of Stanford University†. The participants met to address the Are there compelling scientific reasons to obtain more precise and more ac of H_0 than currently available? If there are, how can we achieve this goa emerged from the workshop are (1) better measurements of H_0 provide constraints on dark energy, spatial curvature of the Universe, neutrino ph general relativity, (2) a measurement of H_0 to 1% in both precision and ac rigorous error budgets, is within reach for several methods, and (3) multiple determinations of H_0 are needed in order to access and control systematic

1% accuracy essential for Precision Cosmology

First Application: Determine H_0 within $z<0.1$ (HII the only alternative to SNIa)

Monthly Notices of the Royal Astronomical Society LETTERS

Mon. Not. R. Astron. Soc. (2012) doi:10.1111/j.1745-3933.2012.01299.x

Determining the Hubble constant using giant extragalactic H II regions and H II galaxies

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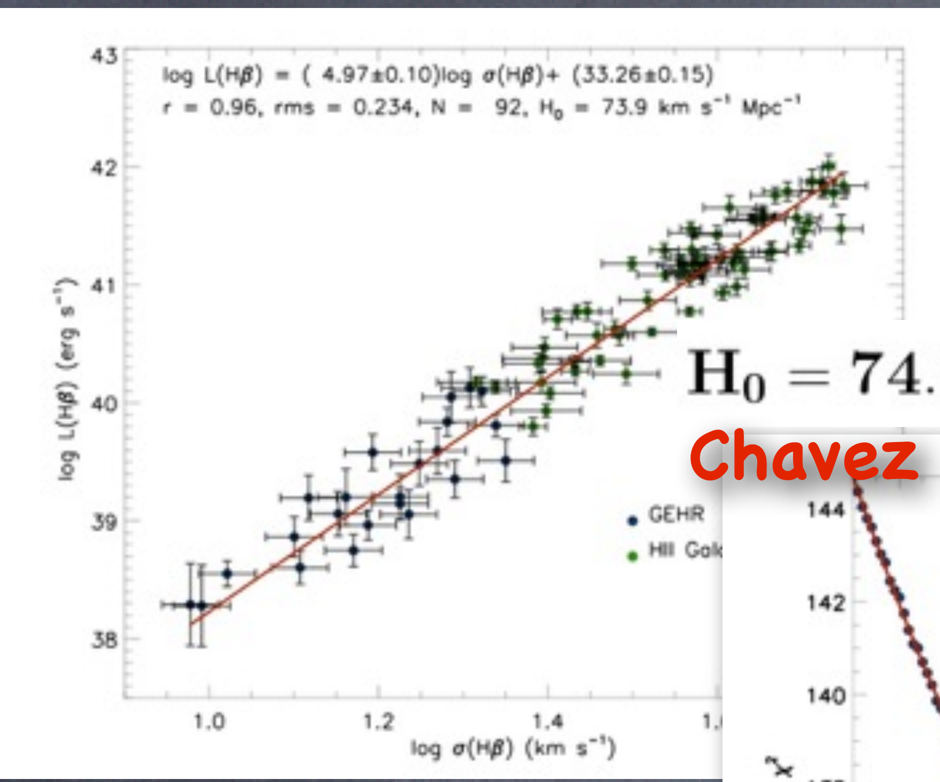
ABSTRACT
We report the first results of a long-term programme aiming to provide accurate independent estimates of the Hubble constant (H_0) using the $L(H\beta)-\sigma$ distance estimator for giant extragalactic H II regions (GEHR) and H II galaxies.

We have used Very Large Telescope and Subaru high-dispersion spectroscopic observations of a local sample of H II galaxies, identified in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7) catalogue in order to redefine and improve the $L(H\beta)-\sigma$ distance indicator and to determine the Hubble constant. To this end, we utilized as local calibration or 'anchor' of this correlation GEHR in nearby galaxies which have accurate distance measurements determined via primary indicators. Using our best sample of 69 nearby H II galaxies and 23 GEHR in nine galaxies, we obtain $H_0 = 74.3 \pm 3.1$ (statistical) ± 2.9 (systematic) km s^{-1} Mpc^{-1}, in excellent agreement with, and independently confirming, the most recent Type Ia supernova based results.

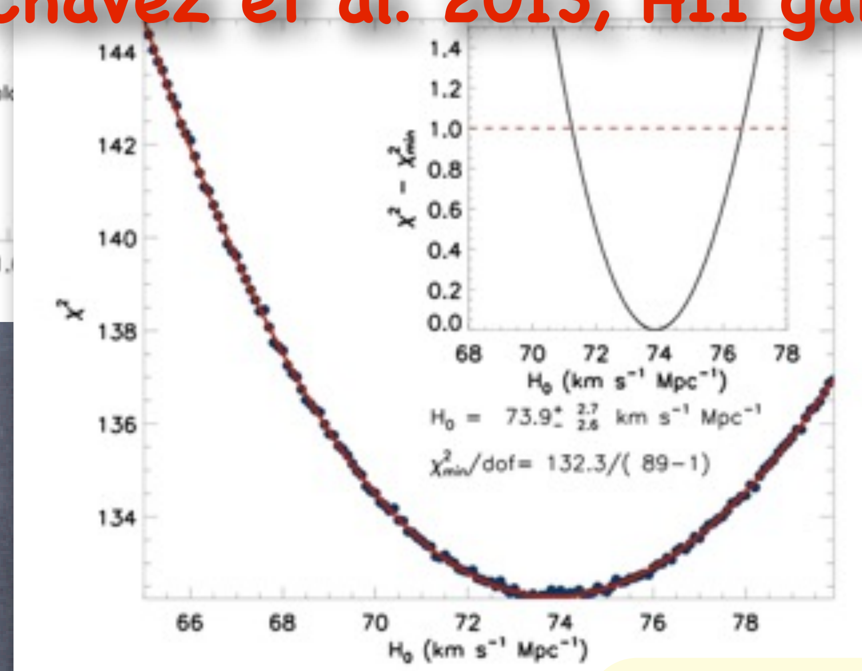
Key words: H II regions – cosmological parameters – distance scale.

Using 92 HII galaxies with z<0.1 and 23 local zeropoint calibrators (Giant HII regions with primary indicator distances) we derived the (H_β)-σ relation and H_0



$$H_0 = 74.3 \pm 4.2 \text{ km sec}^{-1} \text{ Mpc}^{-1}$$

Chavez et al. 2013, HII gals



Riess et al. 2011, 600 Cepheid in 8 calibration local SNeIa:

H_0=73.8±2.4 km/sec/Mpc

Freedman et al. 2012: HST key project new Spitzer 3.6μm calibration of Cepheid distance scale:

H_0=74.3±2.2 km/sec/Mpc

Planck 2013:

H_0=67.4±1.4 km/sec/Mpc

WMAP-9yr: Hinshaw et al. 2013

H_0=69.7±2.5 km/sec/Mpc

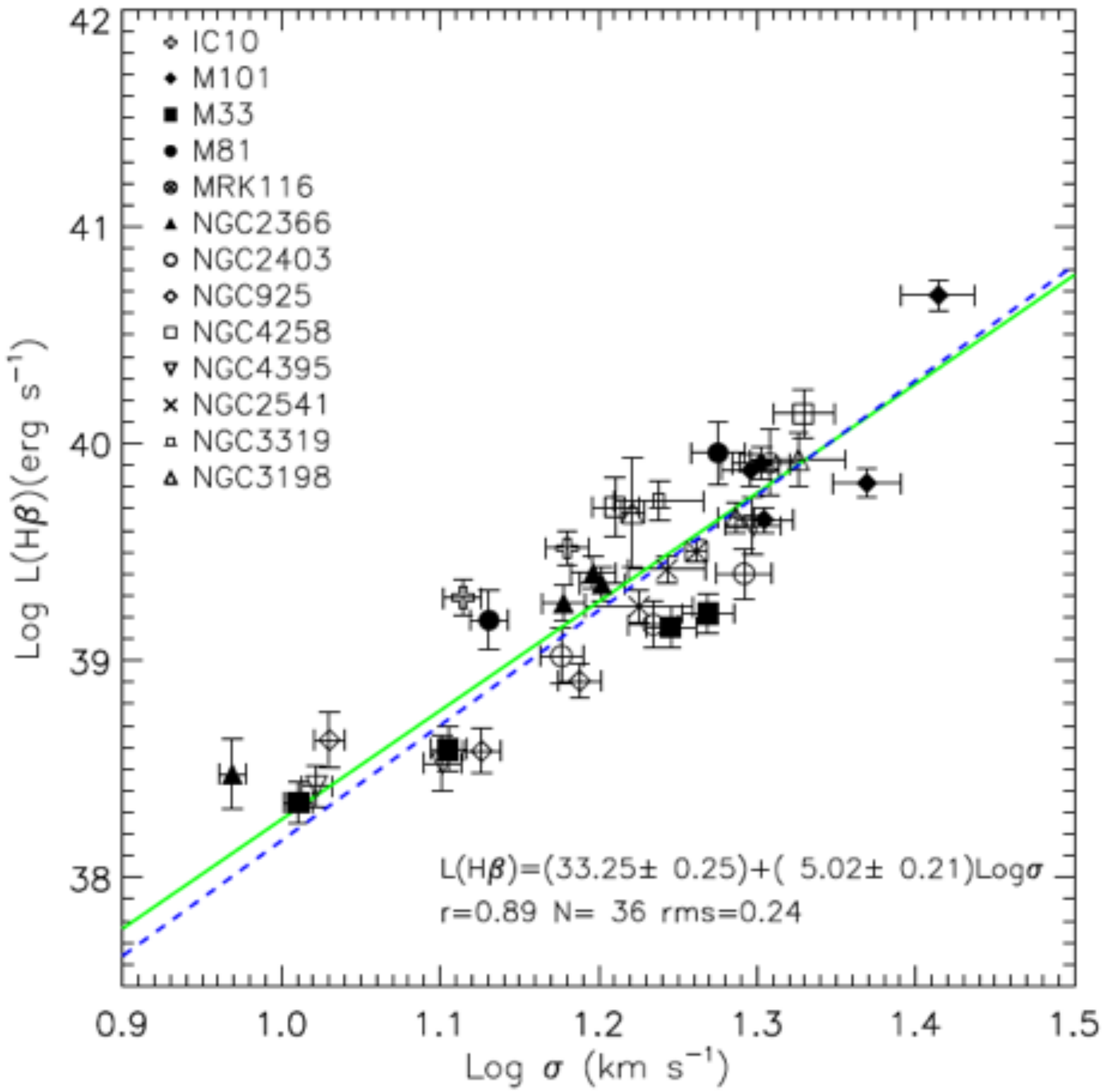
H_0 CONFLICT between direct methods and CMB fits!! Could it be that we live in a local underdensity ?

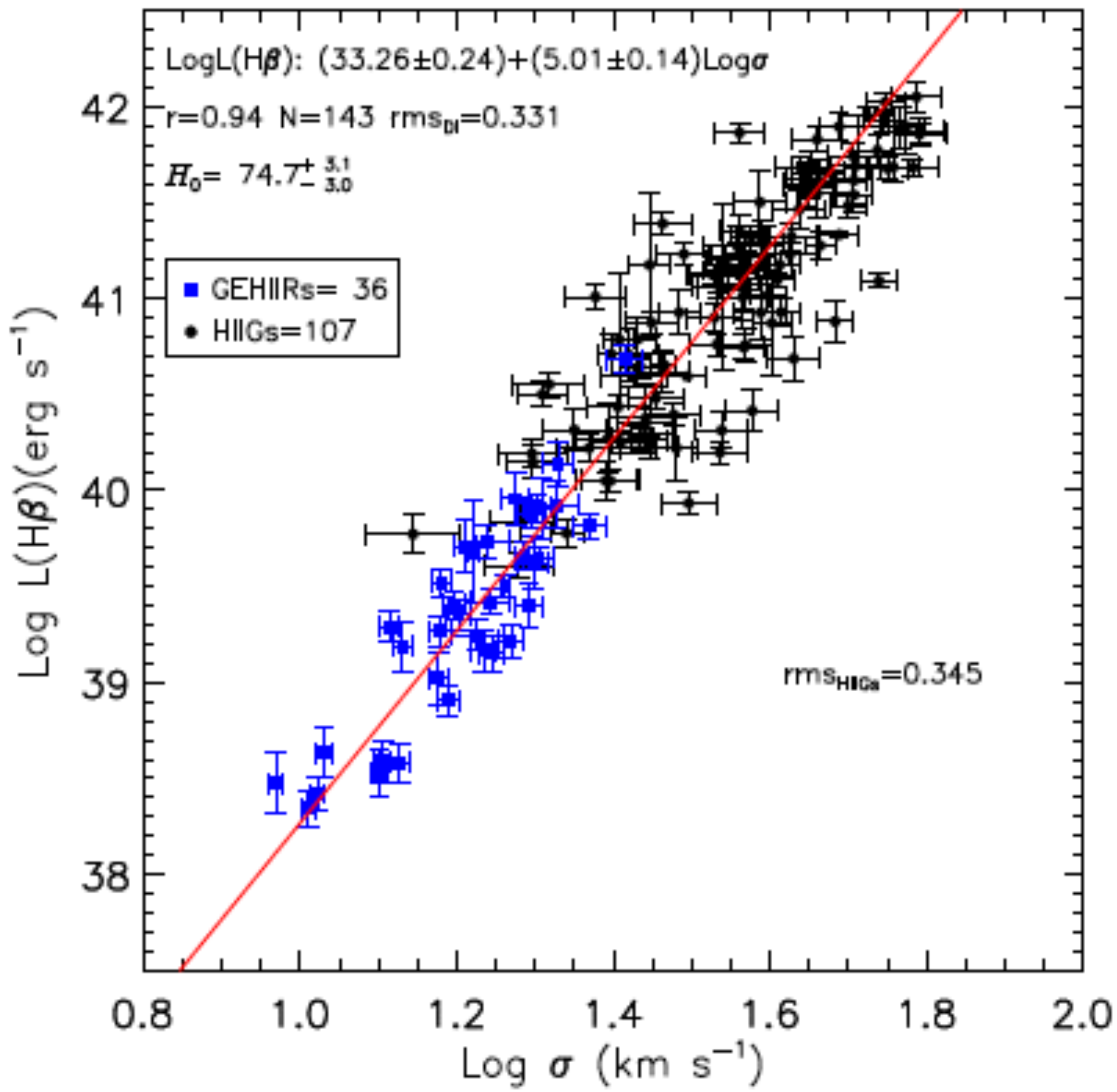
NEW GHIIR LOCAL CALIBRATION DATA

23 (in 9 galaxies) -> 36 (in 13 galaxies)

Arenas et al. 2017

same Ho=74.7 unless one uses evolutionary corrections in which case Ho=70.8 (+-2.8+-2.2)

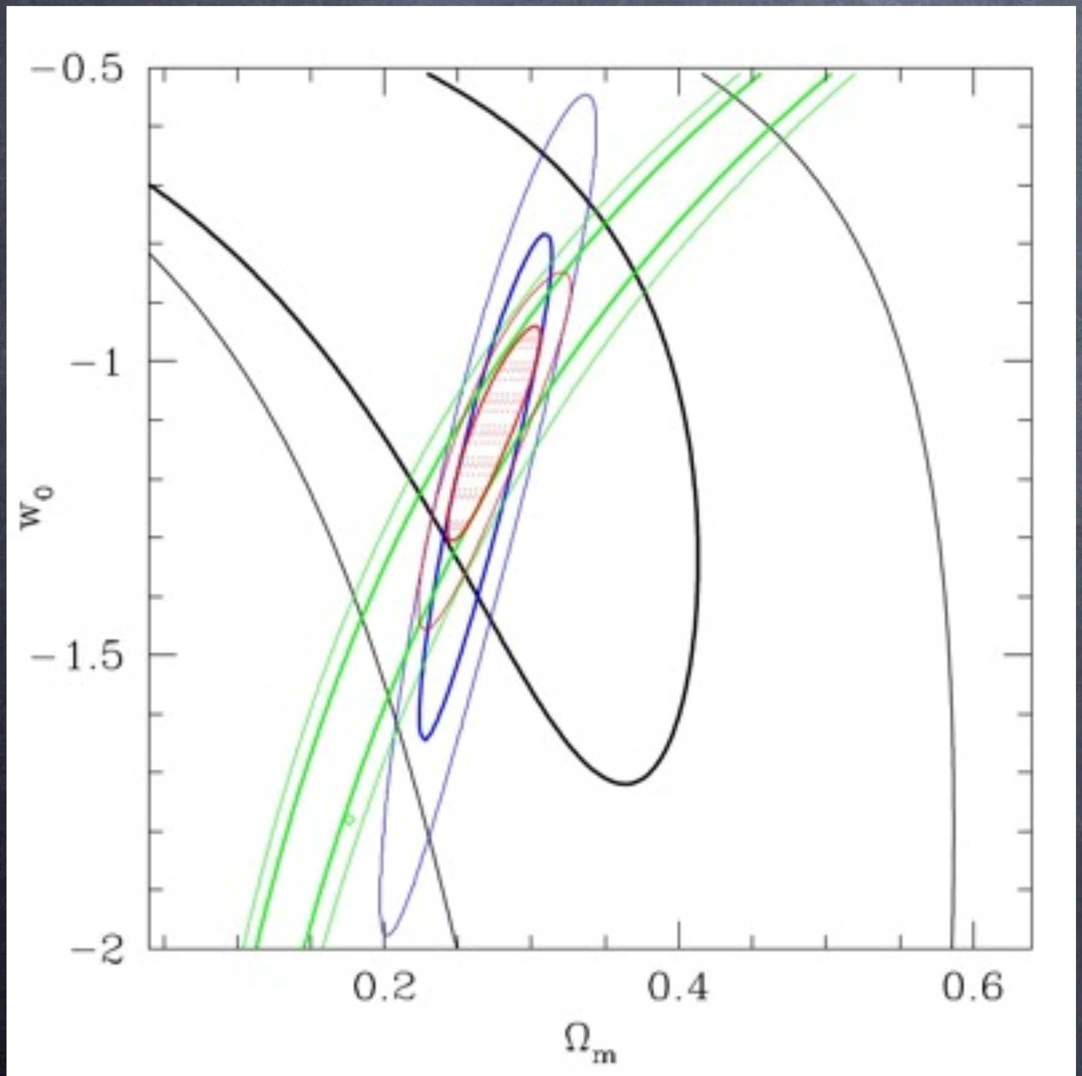




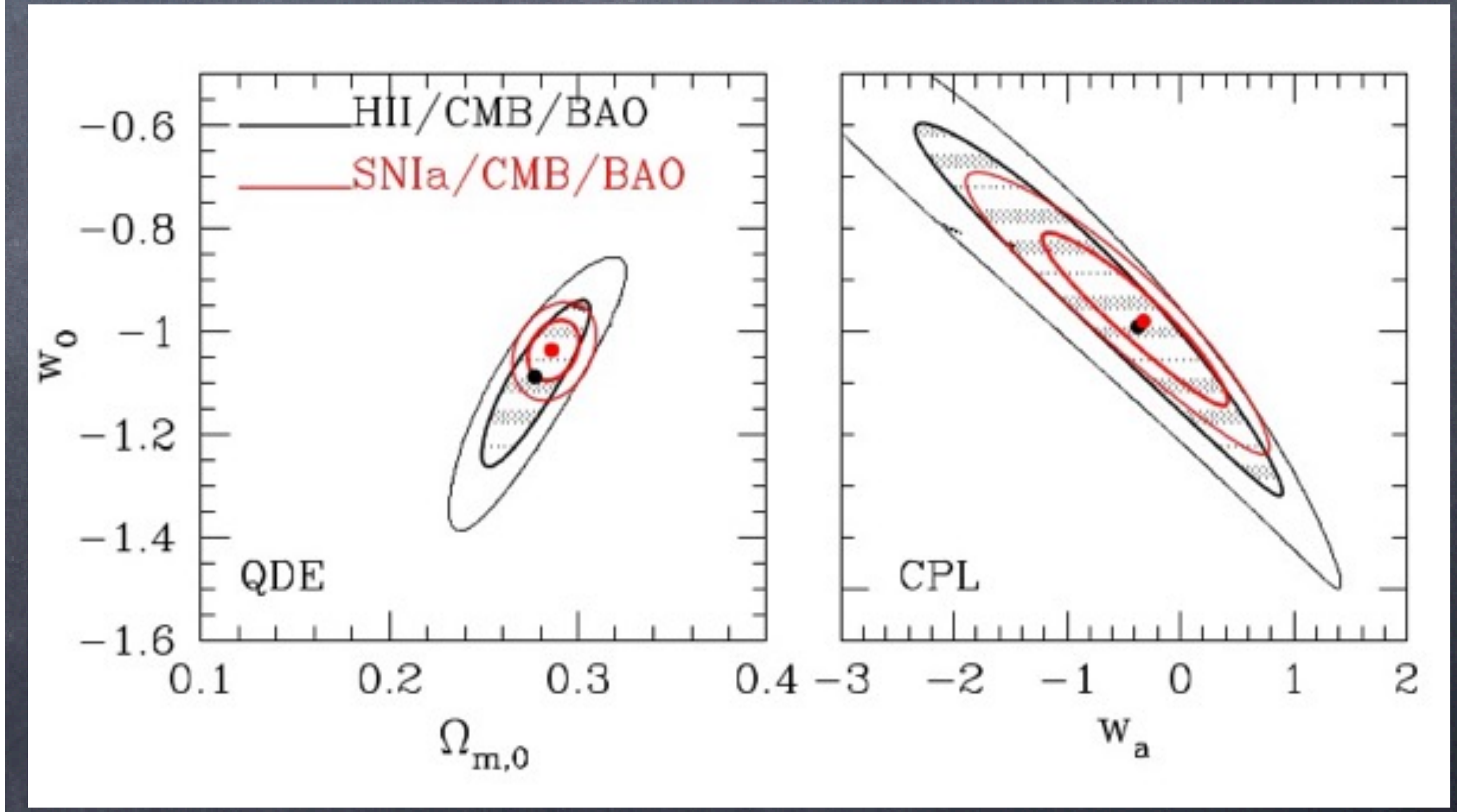
2nd Application: High-z HII Cosmological Constraints

Chavez, Plionis, Basilakos et al. 2016

Our current sample of high-z HII galaxies consists of 25 sources (VLT data) and using a Joint analysis with BAO & CMB we find (QDE EoS):



Comparing with current Joint SNIa we find extremely consistent although weaker constraints. Need for more high-z HII galaxies.

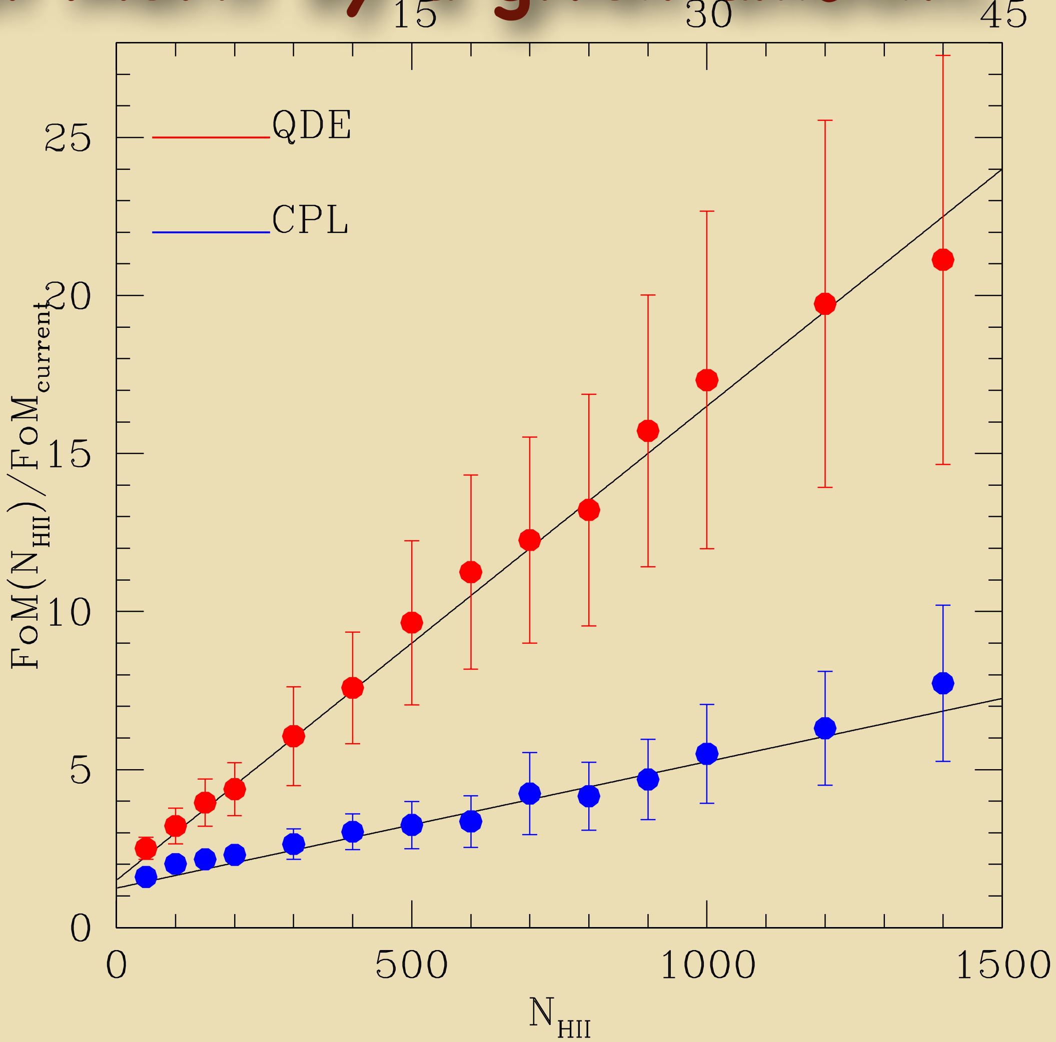


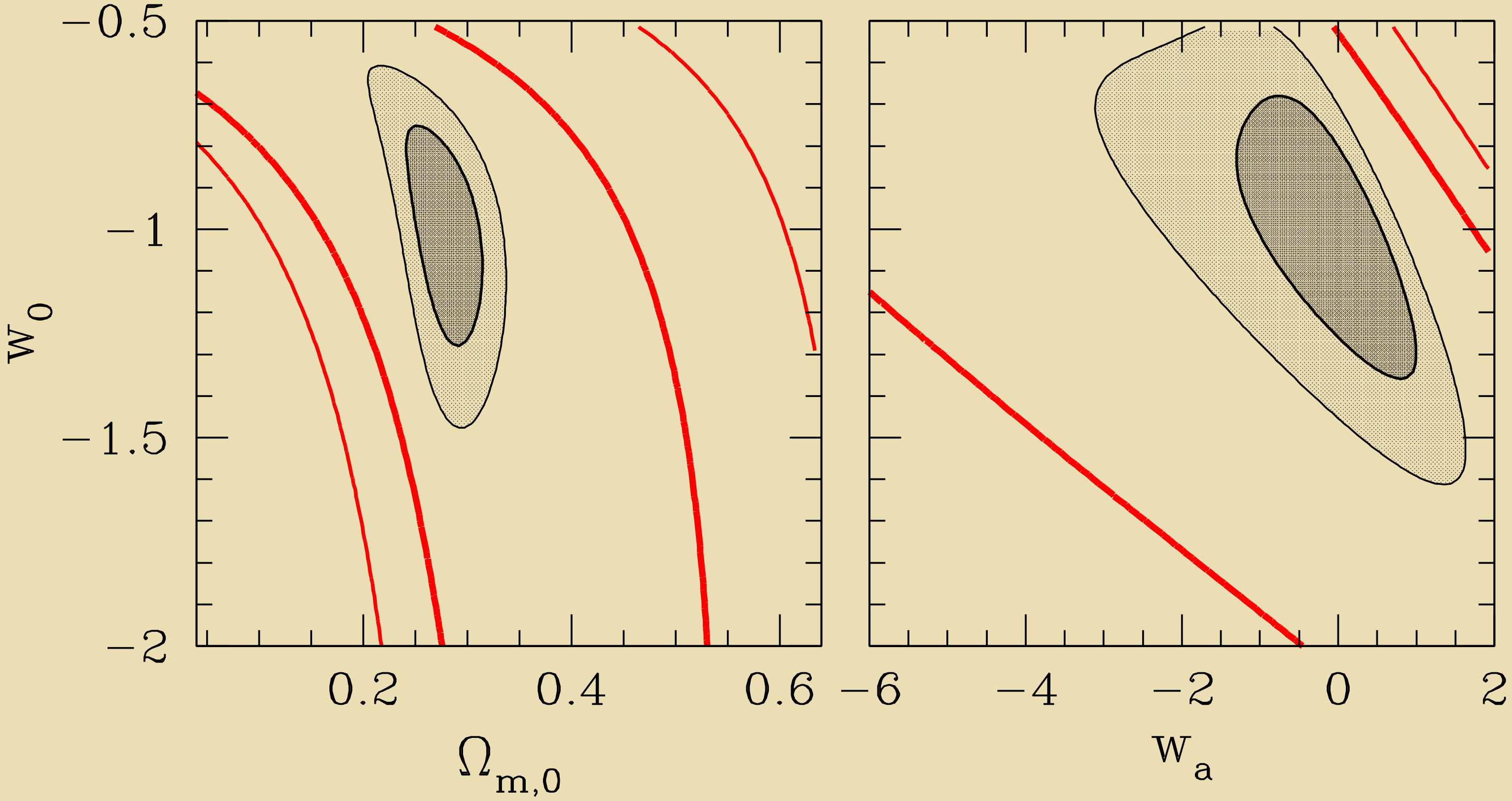
2nd Application: High-z HII Cosmological Constraints

Chavez, Plionis, Basilakos et al. 2016

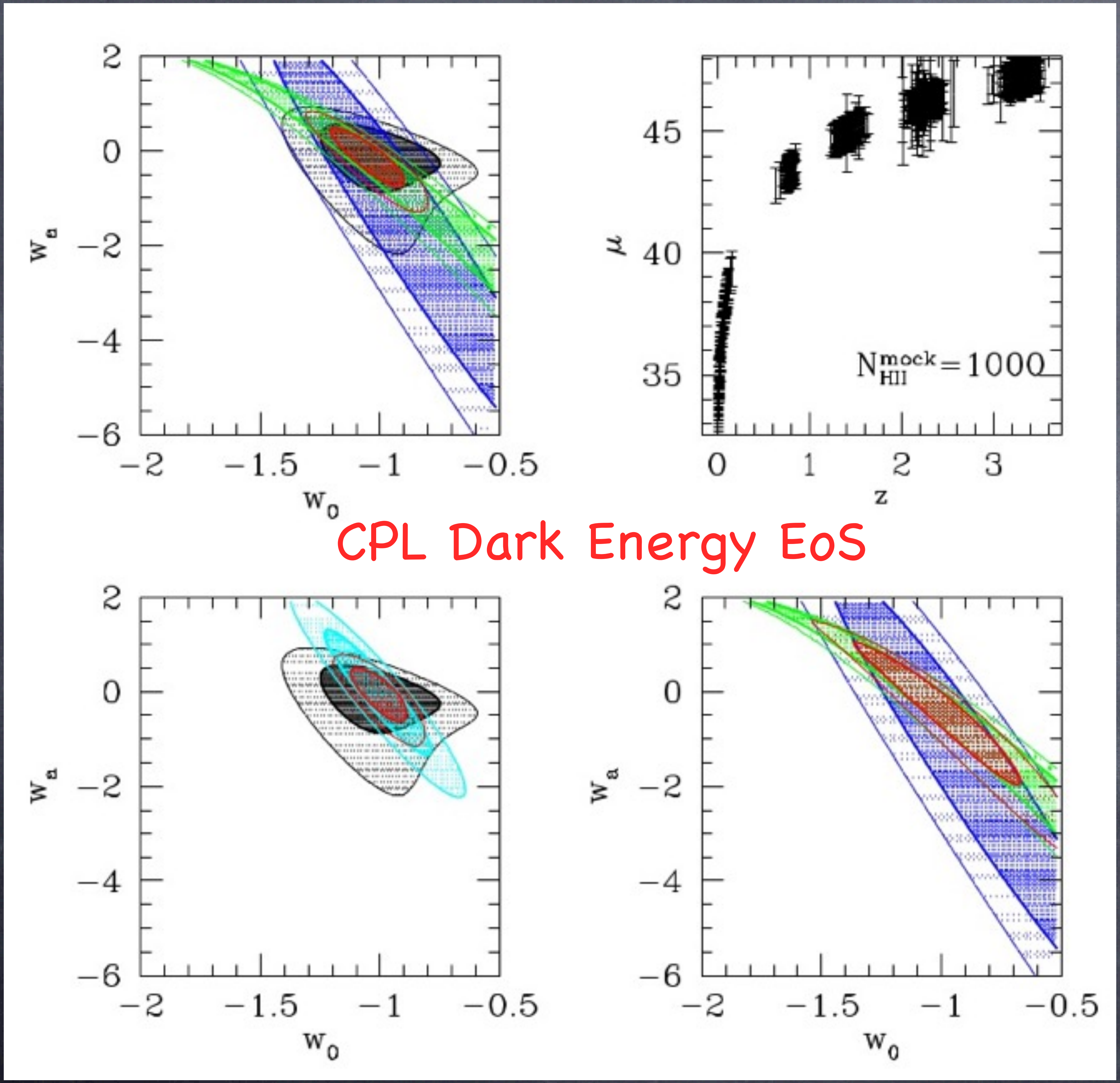
We have performed extensive simulations to determine necessary numbers of high-z HII galaxies to be observed in order to increase the Figure of Merit by a given amount.

Comparing the current constraints (red contours) with the expected for 500 high-z HII galaxies, for the QDE and CPL DE EoS.





New Simulations tailored to the L-σ relation



Our final aim is to provide DE equation of state using the joint liklehood of the Hubble expansion probe (using the alternative HII galaxies) and other cosmological probes, like the clustering of X-ray AGN (or LRGs) & Clusters of galaxies

Concluding Remarks

- **High redshift (2<z<3.5) tracers are necessary for the Hubble expansion Cosmological Probes** in order to obtain better constraints to the Cosmological Parameters space and distinguish among Dark Energy models.

- **We have shown the consistency of H II galaxies as an alternative H(z) tracer to SNIa: (a)** A 1st application provided **H_0=74.3 ± 4.2 km/s/Mpc** in excellent agreement with SNIa. A further target is to reduce uncertainty to 1% level, which is necessary for DE studies. **(b) Our current high-z HII galaxy sample (25 galaxies only)** gives consistent Ω_m–w and w_0–w_a with those of SNIa. Not competing with SNIa yet...

- **Monte-Carlo simulations show that future observations will provide stringent DE EoS parameter constraints.**

SNIa Hubble expansion: Where do we go from here and now?

TO DATE

Today there are ~750 SNIa in the largest homogenised sample

FUTURE

Ongoing Surveys:

CfA $z<0.1$

PTF (Law et al. 2009) $z<0.1$

SN factory (Aldering et al. 2002) $z<0.1$

Pan-STARRS (Kaiser 2004) $z<0.7$

DES (Bernstein 2011) $z<1.2$

Future Surveys:

Large Synoptic Survey Telescope - LSST ($0.1<z<1.5$)

Euclid (IR follow-up of high-z SNe-Ia)

How we construct a cosmological model? The main steps are:

1. Define the modified Einstein-Hilbert action (S) in which we include all the ingredients (gravity including modified scenarios, scalar fields, matter, radiation etc).

2. Varying the action ($\delta S=0$) in order to obtain the modified Einstein's field equations as well as the Klein Gordon equation (if a scalar field is present).

3. Using the FRW metric we derive the so called Friedmann equations (equations of motion) which describe the cosmic dynamics of the Universe.