Independent Cosmological Constraints from high-z HII Galaxies

Ana Luisa González-Morán[1]; Ricardo Chávez[2]; Roberto Terlevich[1,3]; Elena Terlevich[1]; Fabio Bresolin[4]; David Fernández-Arenas[1]; Manolis Plionis[5,6]; Spyros Basilakos[5,7]; Jorge Melnick[8,9] and Eduardo Telles[9]

1.- Instituto Nacional de Astrofísica, Óptica y Electrónica, México 2.- CONACyT-Instituto de Radioastronomía y Astrofísica, México 3.- Institute of Astronomy, University of Cambridge 4.- Institute for Astronomy, University of Hawaii 5.- National Observatory of Athens, Greece 6.-Academy of Athens Research Center for Astronomy & Applied Mathematics, Greece 7.- Academy of Athens Research Center for Astronomy & Applied Mathematics, Greece 8.- European Southern Observatory, Chile 9.- Observatorio Nacional, Brazil.

Introduction

Due to the finite speed of light, a look at distant objects is automatically a look into the past. In astronomy, we observe the properties which the object had a long time ago, when the light was emitted. Therefore, high redshift objects are interesting not only for their distance in the space, but also for their distance in the time. In this sense, high redshift observations contain important information of physical process in the early Universe, beside of providing constraints on the components of our Universe.

The best technique we have for understanding what the Universe is made out of is not to directly count up everything that is out there. If that were so, we would literally miss 95% of the energy-mass in the Universe!

Instead, what we can do is use the General Relativity: specifically the fact that all the different forms of matter and energy affect the spacetime itself, as well as how it changes with time.

Describes the curvature of spacetime

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Describes the distribution of energy-matter in the spacetime

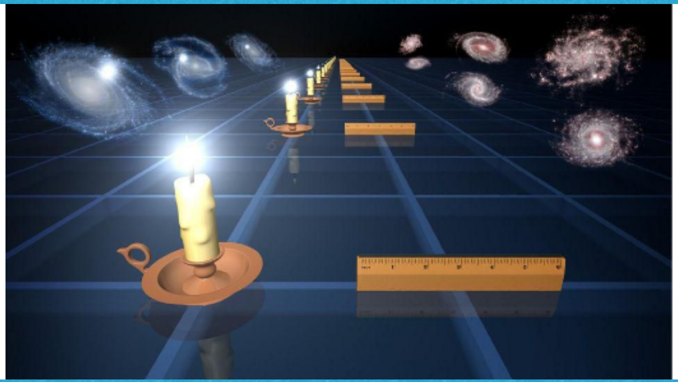
"Matter tells spacetime how to curve, but is the curvature of spacetime that tells the matter how to move."

Derivations for an accelerated cosmic expansion, obtained two decades ago, show that the observed expansion of the Universe can be explained only if a significant non-zero, cosmological constant, Λ term is assumed (Riess et al. 1998; Perlmutter et al. 1999). This large vacuum energy density, which is required to explain the observed cosmic expansion law, is usually referred to as the dark energy (DE).

The most of the mass-energy in the Universe is due to the least well-understood components, like DE and dark matter (DM). The contribution of the stars, planets and interstellar matter, the most understood components, is almost negligible (see e.g. Fukugita & Peebles 2004, for a discussion and description of the methods for deriving these components to the total cosmic mass density).

Techniques to measure the expansion of the Universe

Standard candles: where the intrinsic behavior of a light source is known, and we can measure the observed brightness, thereby inferring its distance. By measuring both distance and redshift for a large number of sources, we can reconstruct how the Universe has expanded.



Standard rulers: where an intrinsic size scale of an object is known, and we can measure the apparent angular size of that very object or phenomenon. By converting from angular size to physical size and measuring redshift, we can similarly reconstruct how the Universe has expanded.

Extensive observing programs at high redshift need to be carried out to determine a more exact value of DE Equation of State (EoS) and to decide whether the w parameter (relation between the pressure p and the mass-energy density ρc^2 in the DE EoS) evolved with look-back time (Peebles & Ratra 1988; Wetterich 1988).

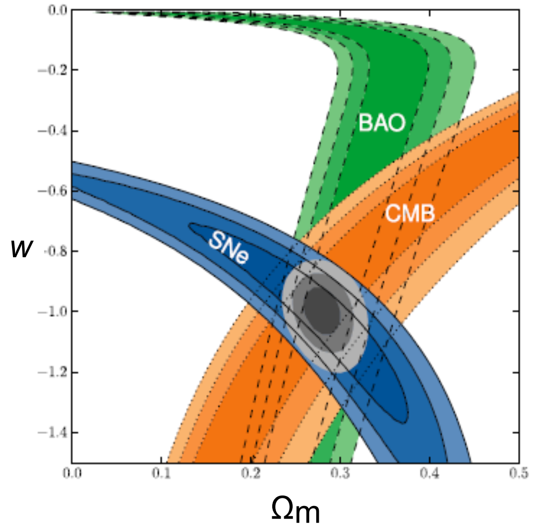


Figure 1.The cosmological parameters Ω_m and w obtained combining the low redshift results (z<1.5) for Baryon Acoustic Oscillations, BAO and Type Ia Supernovae, SNIa with high redshift results (z~1000 Planck the Cosmic Microwave Background, CMB, fluctuations). Taken from Suzuki et al. (2012).

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It is important to remark that there are no determinations of cosmological parameters using a large sample at intermediate redshift (1<z<3), where the maximum difference in cosmological models that include an evolving DE EoS occurs (cf. Plionis et al. 2011), see Fig. 2.

In fact, to have a precise cosmological model it is necessary to constrain cosmological parameters and confirm the results through different and independent methods.

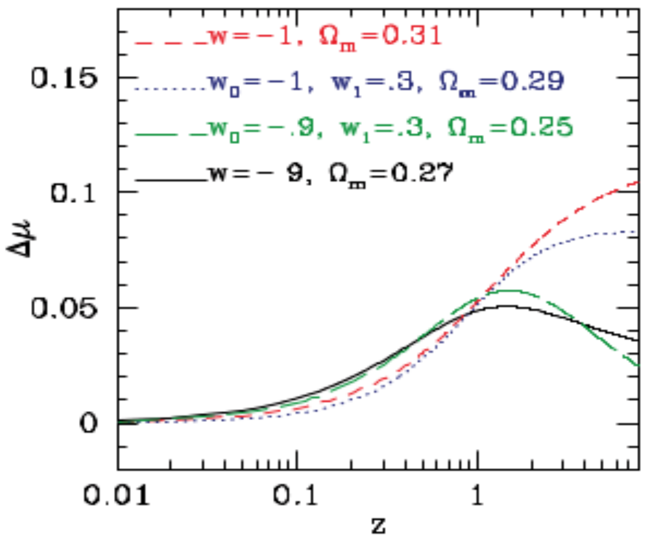


Figure 2. The expected distance modulus difference between distinct DE models. Taken from Plionis et al. 2011.

Objective Use H II Galaxies (HIIG) to constrain in an independent manner cosmological parameters on the important range of redshift 1 < z < 3.

What are the HIIG? They are extremely young and massive super stellar clusters (SSC) dominating the emitted luminosity (up to L(Hβ) ≈ 10^43 erg/s) of their host galaxies. Therefore, the observed properties are those of a young massive SSC, not those of an entire galaxy!

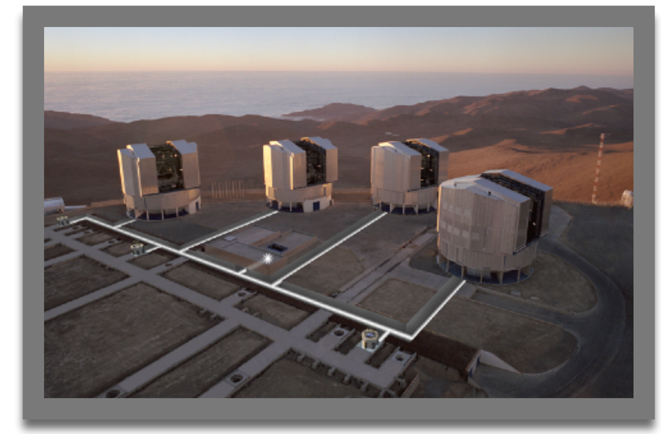
What we do? We use the L−σ relation between the emission lines velocity dispersion (σ) and Balmer-line luminosity (L[Hx], usually Hβ) of HIIG (Terlevich & Melnick 1981; Melnick et al. 1988) and a Markov Chain Monte Carlo (MCMC) method to find the probability distribution of the solutions of the DE EoS and Ωm. We also combine the HIIG results with those obtained using different probes (SNIa, BAOs, CMB).

To reach the objective, we need to observe a large sample of HIIG at high redshift using **high resolution spectrographs at 8-10 m class telescopes**, in order to measure with great accuracy the flux and the FWHM in the emission lines.

Observations

The Near-IR spectra used in this work were obtained using MOSFIRE spectrograph at KECK 1 telescope and KMOS spectrograph at VLT telescope with a resolution of R=5,340 and R=4000, respectively, in the H band and seeing conditions between 0.5 and 0.8 arcseconds.

MOSFIRE at KECK



KMOS at VLT

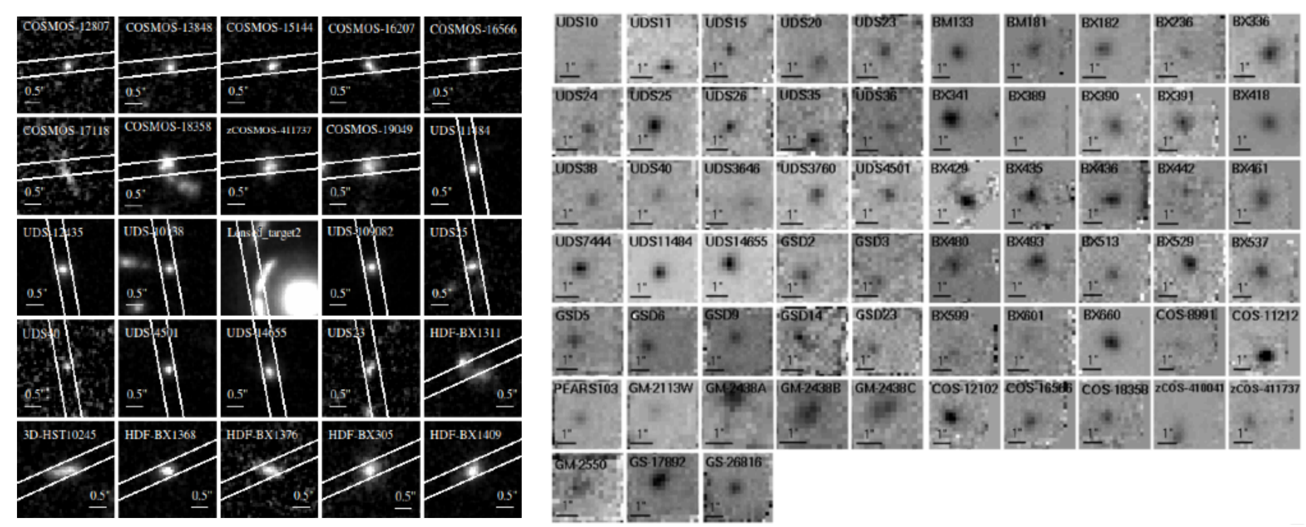


Figure 3. Left panel: Targets image in the filter f160w (H band) from CANDELS HST Program. Superposed are the slits with the orientation and width as observed with MOSFIRE Spectrograph at KECK (González-Morán et al. 2019). Right panel: Target images built from data cubes in the H band taken with KMOS Spectrograph at VLT (González-Morán et al. in prep).

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Analysis

We have analysed a new set of 100 high spectral resolution star-forming galaxies obtained with KMOS at VLT on the range of redshift 1.3< z <2.6 of which 40 were selected for this work. These were combined with another 21 high-z galaxies observed by us of which 15 belong to KECK-MOSFIRE (González-Morán et al. 2019) and 6 belong to VLT-XShooter (Terlevich et al. 2015) plus a compilation of 24 more objects from the literature.

Combining the repeated targets between MOSFIRE and KMOS which helped us to correct for slit loss flux the MOSFIRE observations and to have a better spectral resolution for 9 targets from KMOS, we have in total 76 high redshift and 107 local HIIG (Chávez et al. 2014), **making a grand total of 183 HIIG covering the redshift range 0.01< z <2.6**.

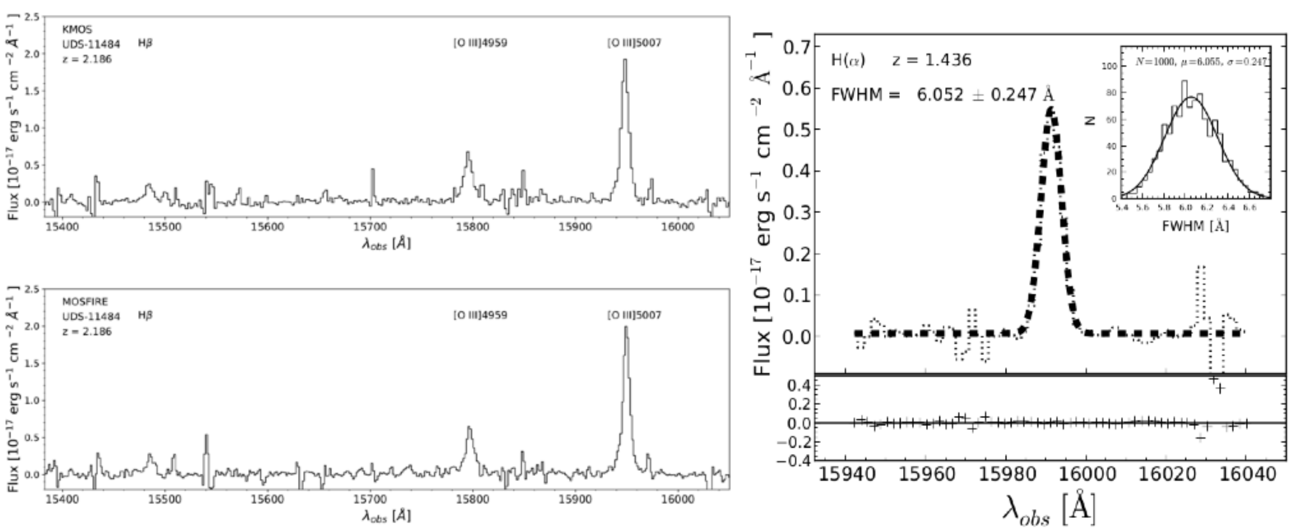

Figure 4. Left panels: The 1D spectra from the target UDS-11484 for: top) KMOS observations and bottom) the MOSFIRE observations. Right panel: The fit to the H(α) emission line, the distribution of FWHM obtained from the Montecarlo simulations in the inset at the upper right corner and the residuals in the box below.

Results

L-sigma Relation

While more massive is the star forming region

↓

Higher the intrinsic ionizing flux

↓

Higher gas turbulence

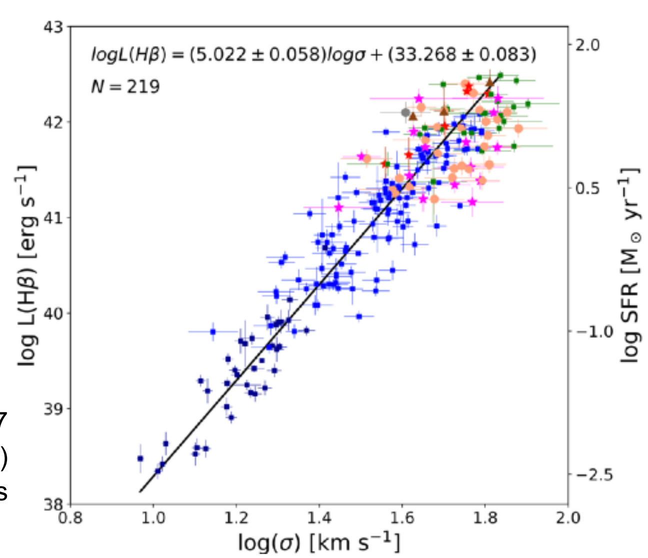

Figure 5: L − σ relation for the combined local (107 HIIG and 36 Giant Extragalactic HII Regions, GHIIR) and high redshift (76 HIIG) samples. The parameters of the fit are indicated at the top.

The Hubble Diagram

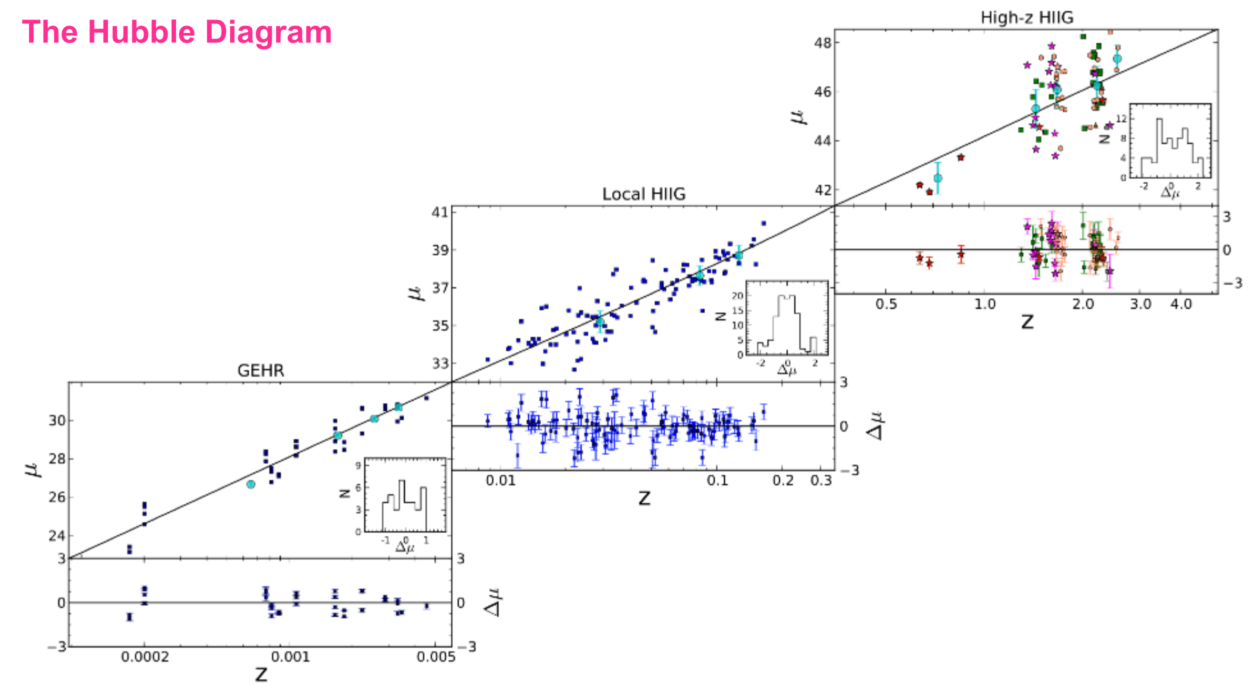

Figure 6: Hubble Diagram connecting our local and high redshift samples up to z~2.6. Dark blue squares: GHIIR; blue squares: local HIIG; orange circles: our high-z KMOS observations; pink stars: our high-z MOSFIRE observations; red stars: our high-z XShooter observations and green squares: data from the literature. Continuum line represent our best cosmological model. Residuals are plotted in the bottom panel.

HII Galaxies Constraints

We define the following likelihood function:

$$\mathcal{L}_{HIIG} \propto \exp\left(-\frac{1}{2}\chi^2_{HIIG}\right)$$

where:

$$\chi^2_{HIIG} = \sum_n \frac{(\mu_o(\log f, \log \sigma|\alpha,\beta) - \mu_m(z|\theta))^2}{\epsilon^2}$$

Constraining Ω_m from HIIG

Applying an H_0 independent method and the L − σ relation's intercept and slope showed on the top of the Fig. 5 to the joint local and high-z sample of 183 HIIG, we find:

$\Omega_m = 0.256 +0.042 -0.52$ (stat).

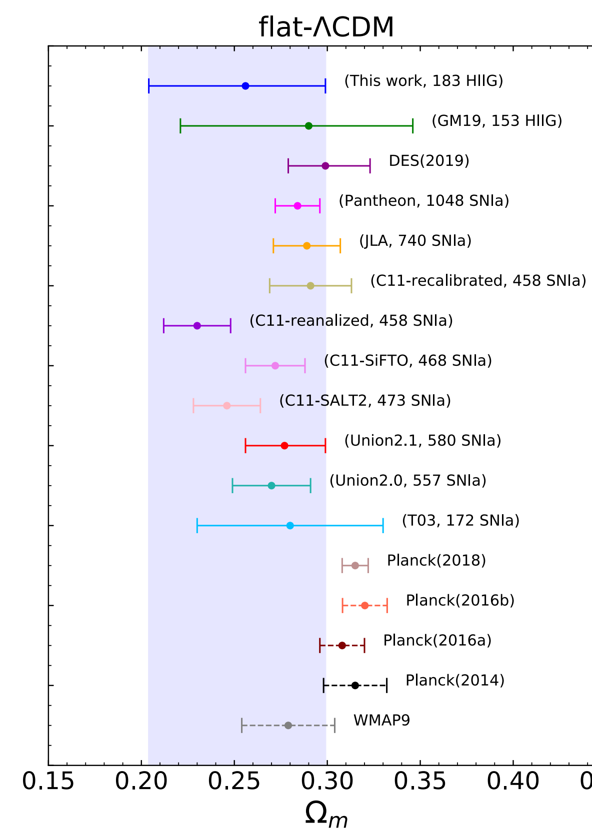

Figure 7. Comparison of our Ω_m estimation with other literature results.

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Constraining the {Ω_m,w_0} plane from HIIG

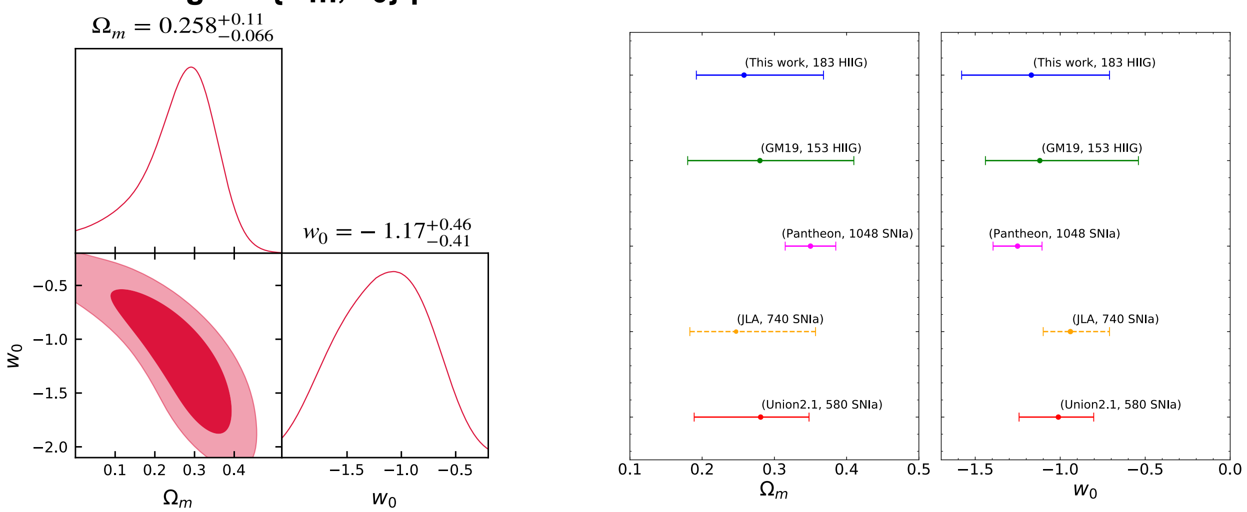
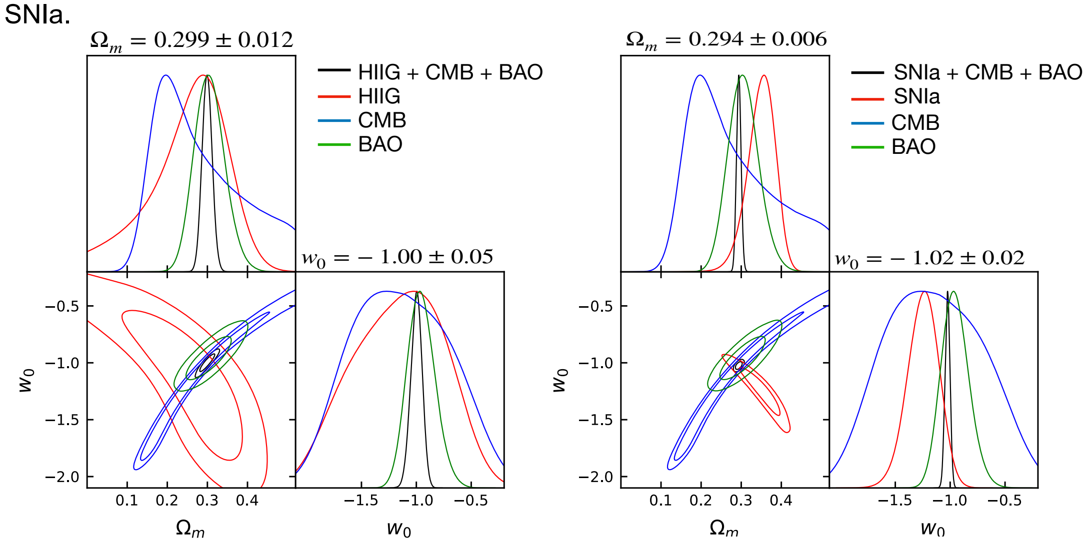
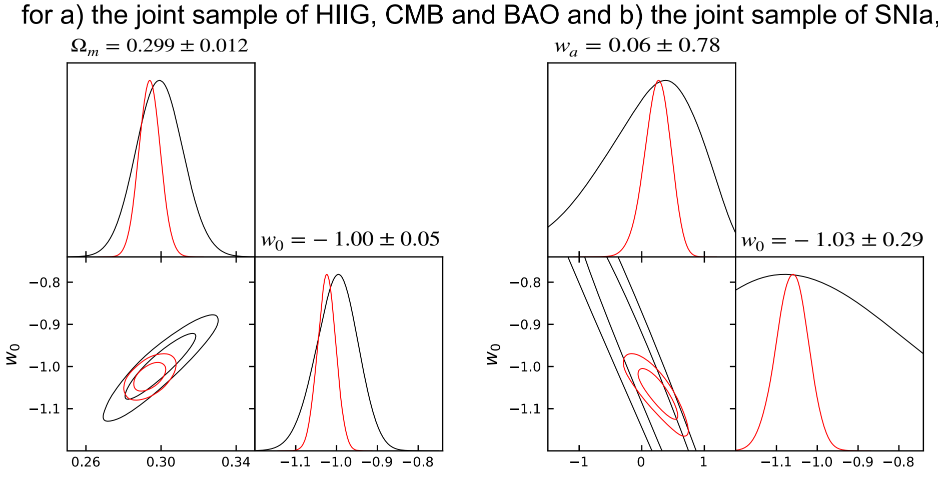


Figure 8. Left panel: Likelihood contours corresponding to the 1σ and 2σ confidence levels in the {Ω_m,w_0} space for our HIIG sample. Right panel: Comparison of our estimation for {Ω_m,w_0} plane with other literature results of SNIa.



(a) HIIG + CMB + BAO **(b) SNIa + CMB + BAO**

Figure 9. Likelihood contours corresponding to the 1σ and 2σ confidence levels in the {Ω_m,w_0} space for a) the joint sample of HIIG, CMB and BAO and b) the joint sample of SNIa, CMB and BAO.



(a) wCDM **(b) CPL**

Figure 10: Comparison of the joint likelihood contours of the HIIG/CMB/BAO (black contours) and of the SNIa/CMB/BAO (red contours) probes.

Conclusions

We present independent determinations of cosmological parameters using a distance estimator based on the established correlation between the Balmer emission line velocity dispersion and luminosity for HIIG. These were obtained using new high spectral resolution observations of 40 high-z (1.3 < z < 2.6) HIIG with KMOS at the ESO-Very Large Telescope combined with already published data for another 46 high-z and 107 z < 0.15 HIIG.

- Using only HIIG to constrain the dark matter, we find Ω_m = 0.256 +0.042 -0.52 (stat).
- Constraining the {Ω_m, w_0} plane, the marginalized best-fit parameter values are Ωm = 0.258 +0.11 -0.066 and w0 = −1.17 +0.46 -0.41 (stat).
- Combining HIIG, CMB and BAO yields our best estimate: Ω_m = 0.299± 0.012 and w_0 = −1.00±0.05 which, although less constrained, are certainly compatible with the solution space of SNIa/CMB/BAO.
- After adding constraints from the CMB and BAO measurements, we provide limits on the evolution of dark energy with time, w_0 = −1.03 ± 0.29, w_a = 0.06 ± 0.78 for the CPL DE EoS parameterizations which are in agreement with a ΛCDM cosmology.

Future Work

We plan to considerably increase the current sample of intermediate redshift (0.1 < z < 1) HIIG with guaranteed observations from MEGARA spectrograph at GTC. Besides with incoming instruments, like NIRSpec on the JWST, we will be able of exploring the Hubble Diagram up to z≈9 using a unique distance estimator (L-σ relation), which is not available with other methods.

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About Me

I am a PhD at Instituto Nacional de Astrofísica, Óptica y Electrónica in México.

My research interest includes Observational and Theoretical Cosmology, Star Formation and Data Analysis with Large Telescopes.

E-mails:

analuisagm@inaoep.mx

analuisagonzalezmoran@gmail.com