Precision cosmology with HII galaxies, i.e. young SSC.

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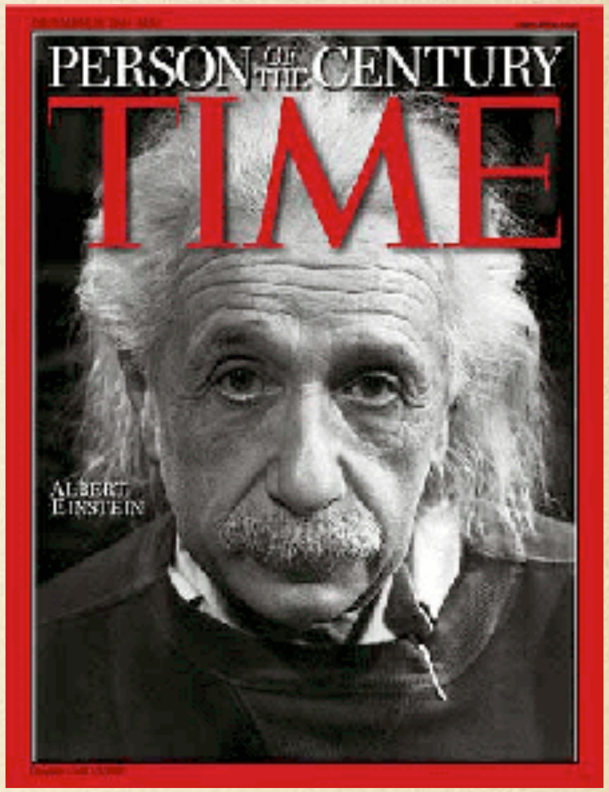
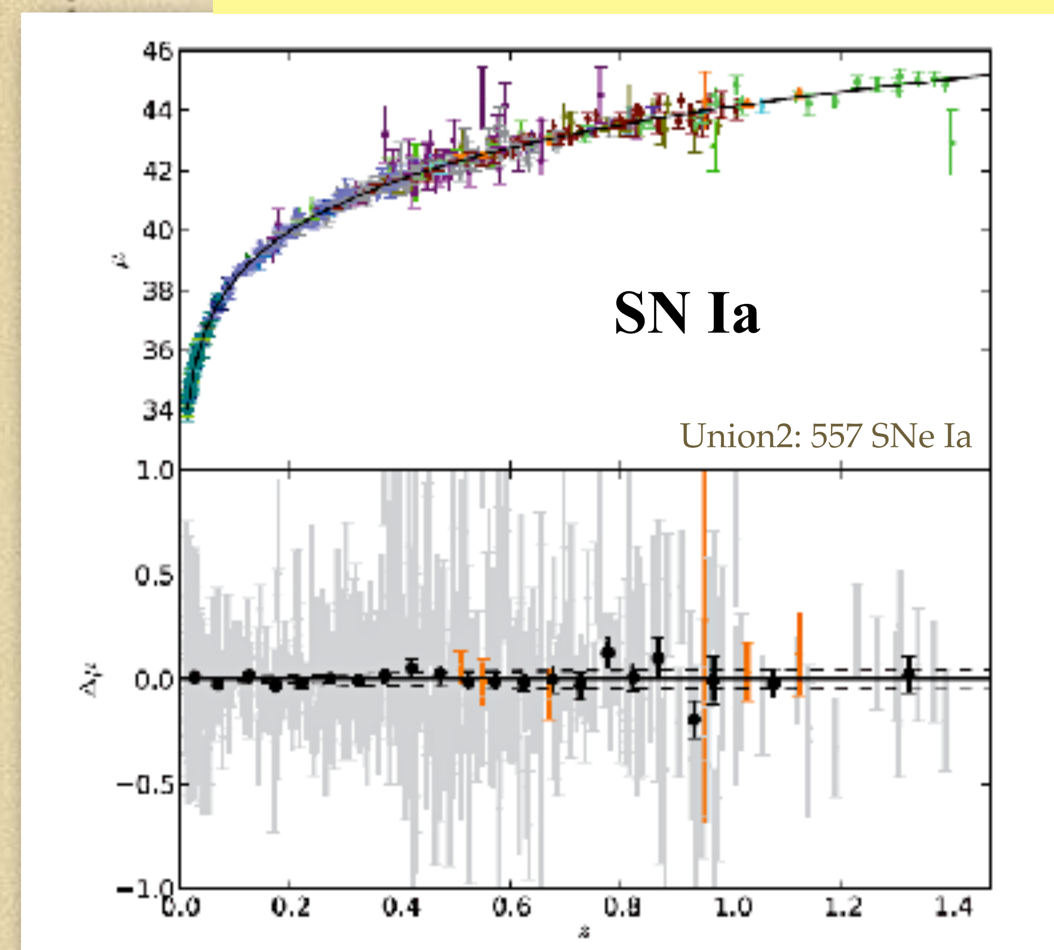
Cosmology Breakthroughs in Recent Past



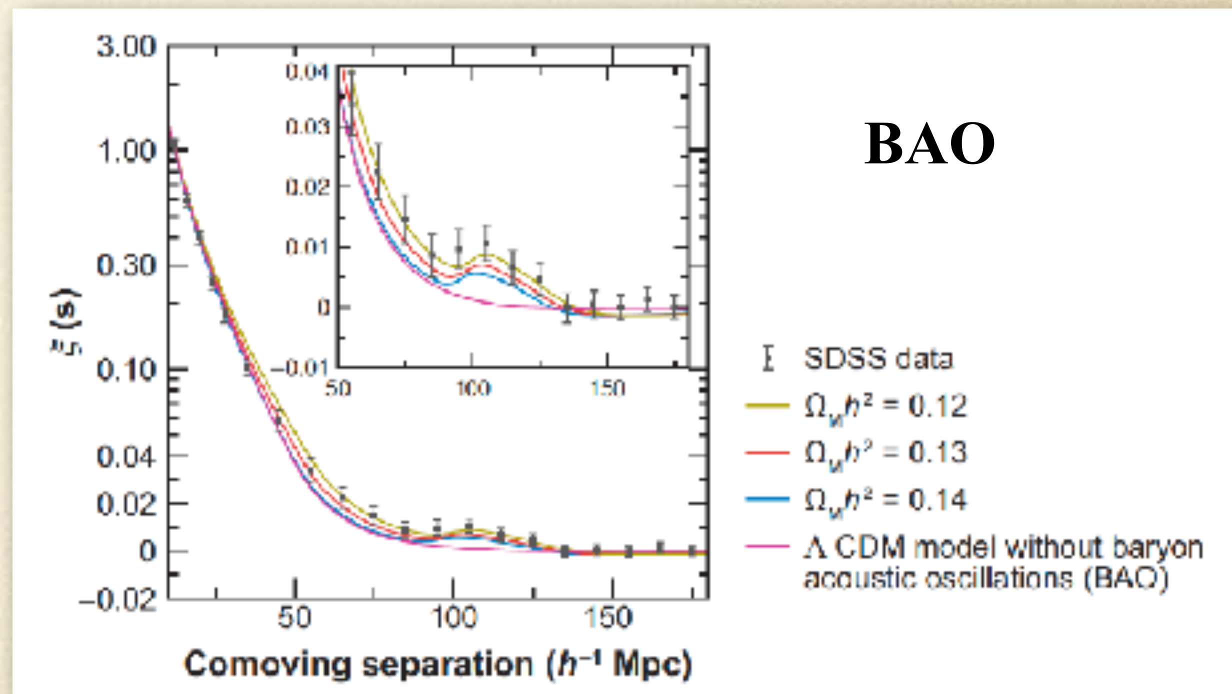
Our theories of the Universe are based upon General Relativity which, like Newton's theory, predicts that gravity is an attractive force which would act to slow any existing expansion.

The discovery that the expansion of the Universe is currently accelerating was heralded as the "Breakthrough of the year" by Science in 1998.

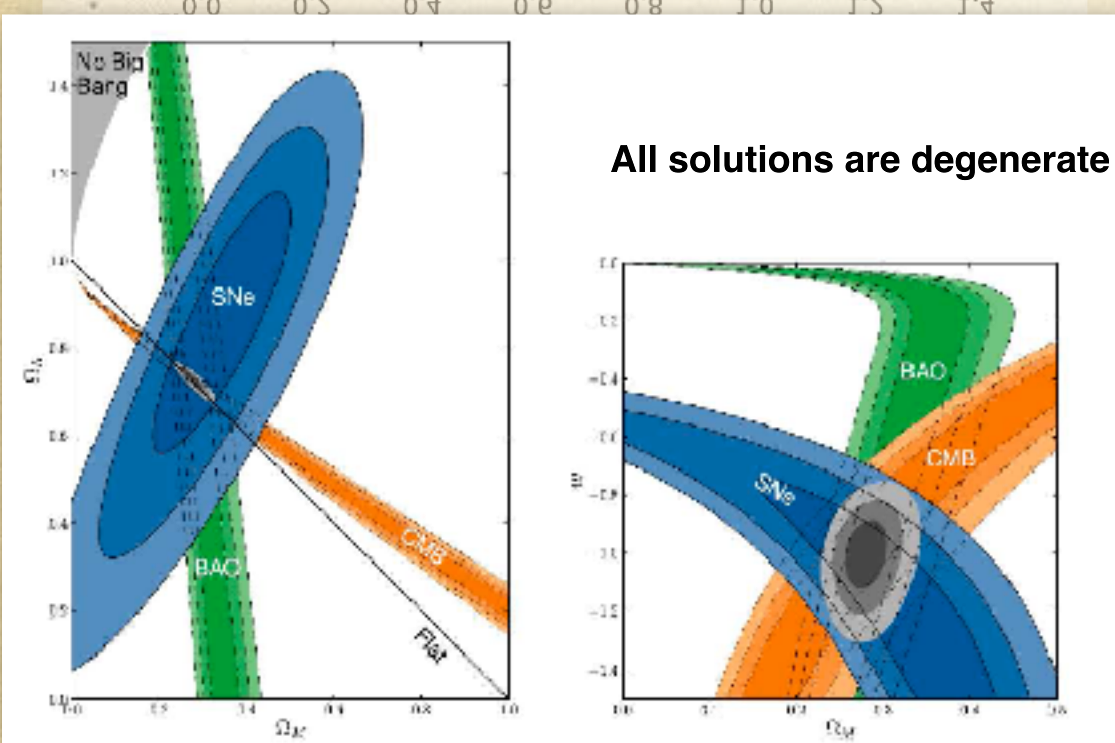
The Observational Landscape

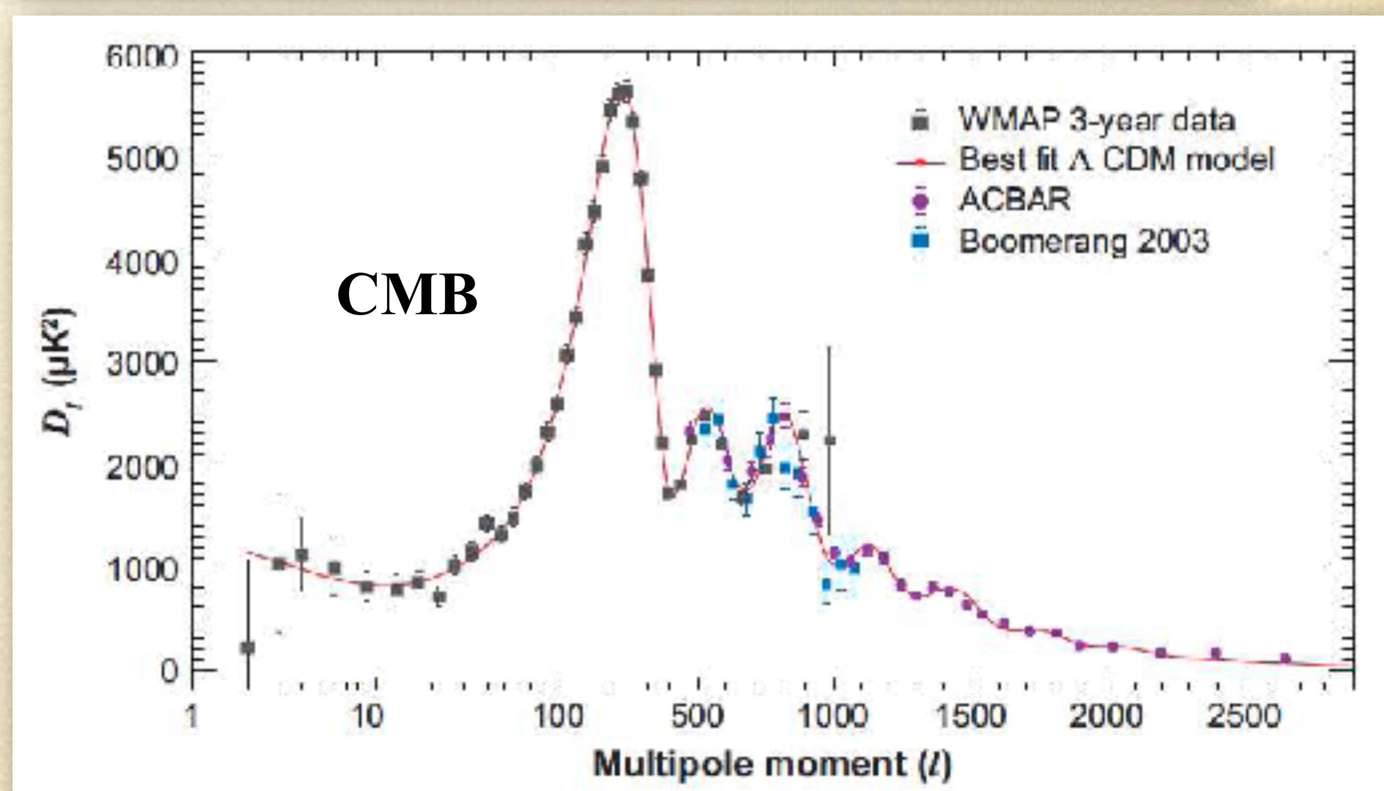


Union2: 557 SNe Ia



From Amanullah et al. 2010





From Frieman et al. 2008

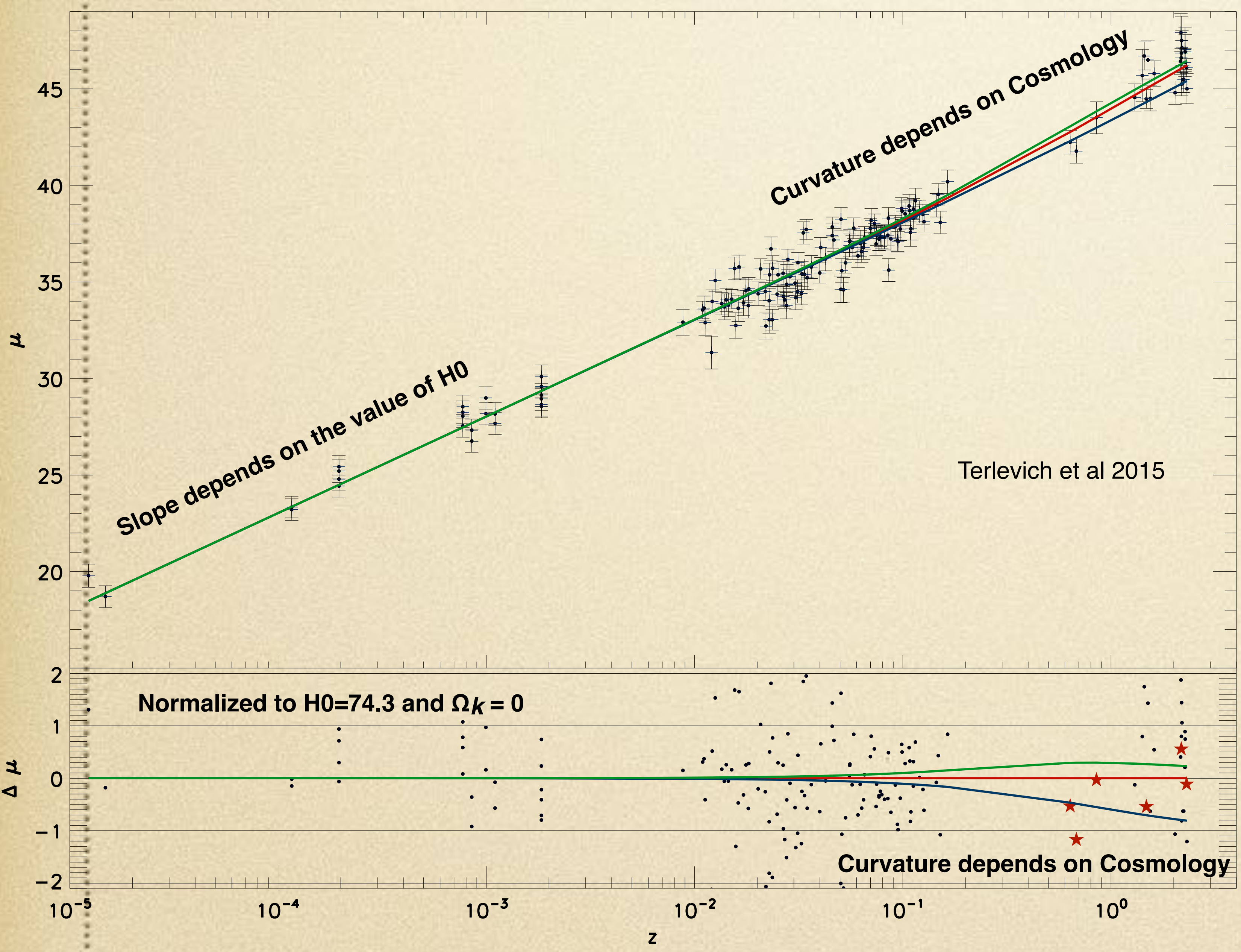
Aims

Our aim is to use the youngest SSC to help discriminating among the various theoretical alternatives to explain the accelerated expansion of the Universe by using a HIIG distance indicator to accurately measure H_0, Ωm , w0 and w1.

I will first discuss the determination of the Hubble constant Ho, then the determination of Ωm and the equation of state of the dark energy. Finally I will touch on the implications for a universal IMF.

The GHIIR and HIIG Hubble diagram

This Hubble diagram includes 25 high z, and 109 nearby HIIG plus 23 GHIIR.
All lines are for H_0 = 74.3 and Ω_k = 0.



Hubble diagram for three different cosmologies.

The red line indicates the concordance CDM cosmology: Ω_m = 0.3 ; w_0 = −1.0.

The green line shows a cosmology with Ω_m = 0.3 ; w_0 = −2.0.

The blue line shows a cosmology with Ω_m = 1.0 ; w_0 = −1.0.

Residuals are plotted in the bottom panel.

Note the huge dynamical range in distance modulus of almost 30 mag covered with the L–sigma distance indicator.

H II Galaxies = Naked starbursts = Extremely young SSC

HII galaxies are compact massive burst of star formation in dwarf galaxies.

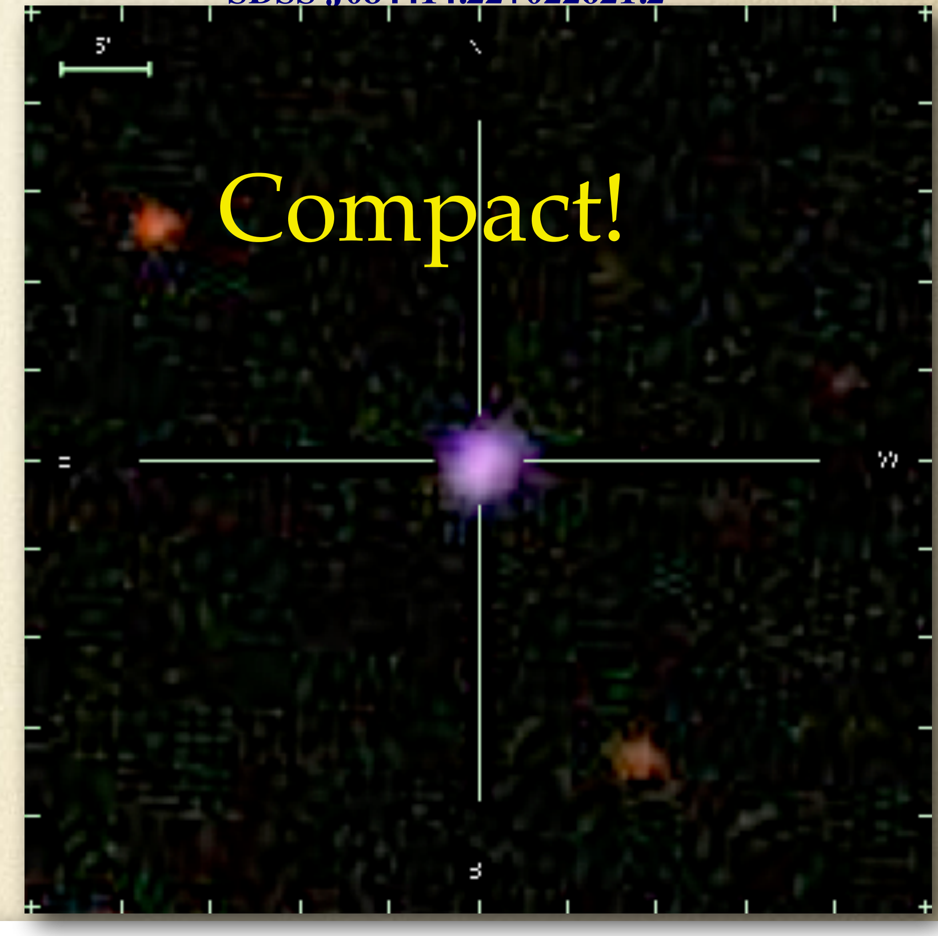
By selection the luminosity of HII galaxies is completely overwhelmed by that of the burst. As a consequence they show the spectrum of an HII region (that's what they are!) and they are very compact.

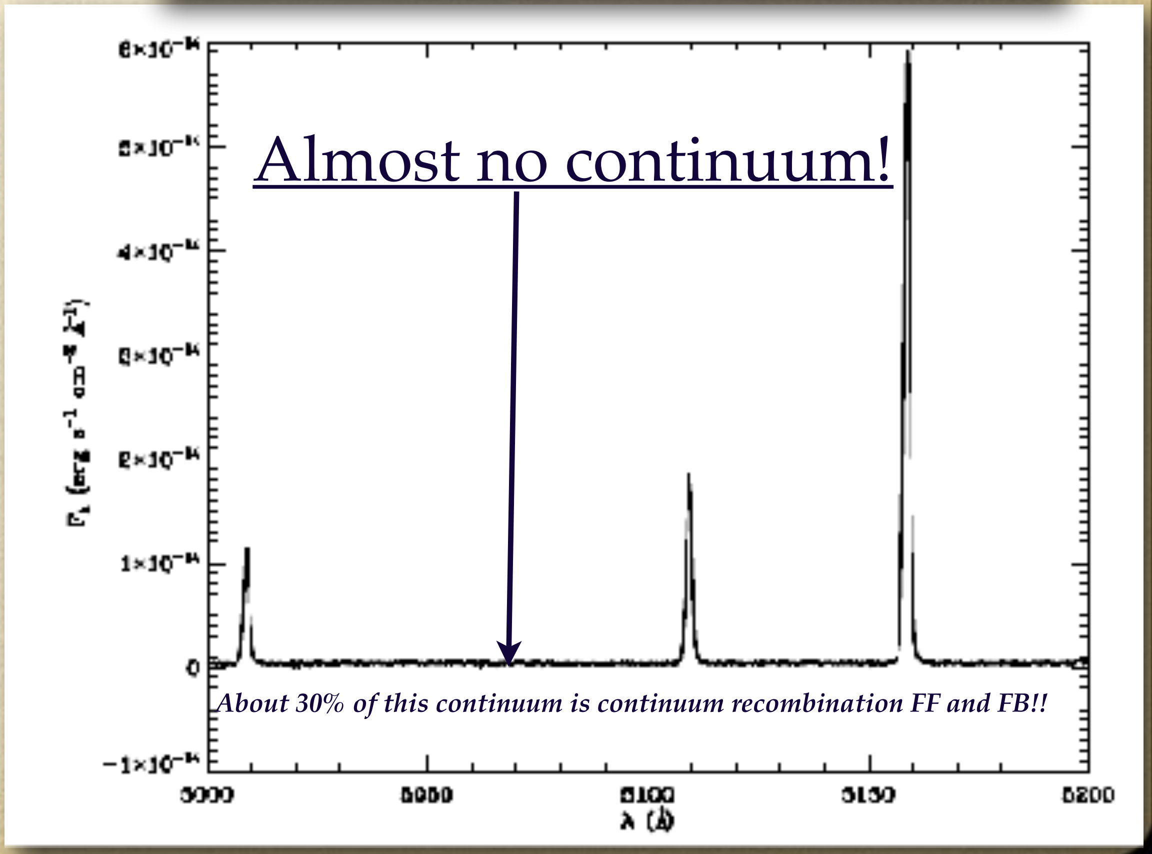
They are discovered mainly in spectroscopic surveys due to their strong narrow emission lines, i.e. very large equivalent width, EW(Hβ) >50Å or EW(Hα) >200Å.

Because the luminosity of HII galaxies is dominated by the starburst component they can be observed at very large redshifts, and this fact makes them cosmologically interesting objects.

The observed properties are those of the youngest SSC with almost no information (contamination) from the parent galaxy. This is a consequence of selecting candidates with EW(Hα)>200Å.

SDSS J084414.22+022621.2





Evolution of the Eq. width of Hβ in a burst (SB99)

Selecting compact narrow emission line systems with EW of Hβ > 50Å or Hα > 200Å provides a sample with:

-An upper limit to its age (~ 5Myr),

-Limited escape of ionising radiation,

-Limited contamination by an older population

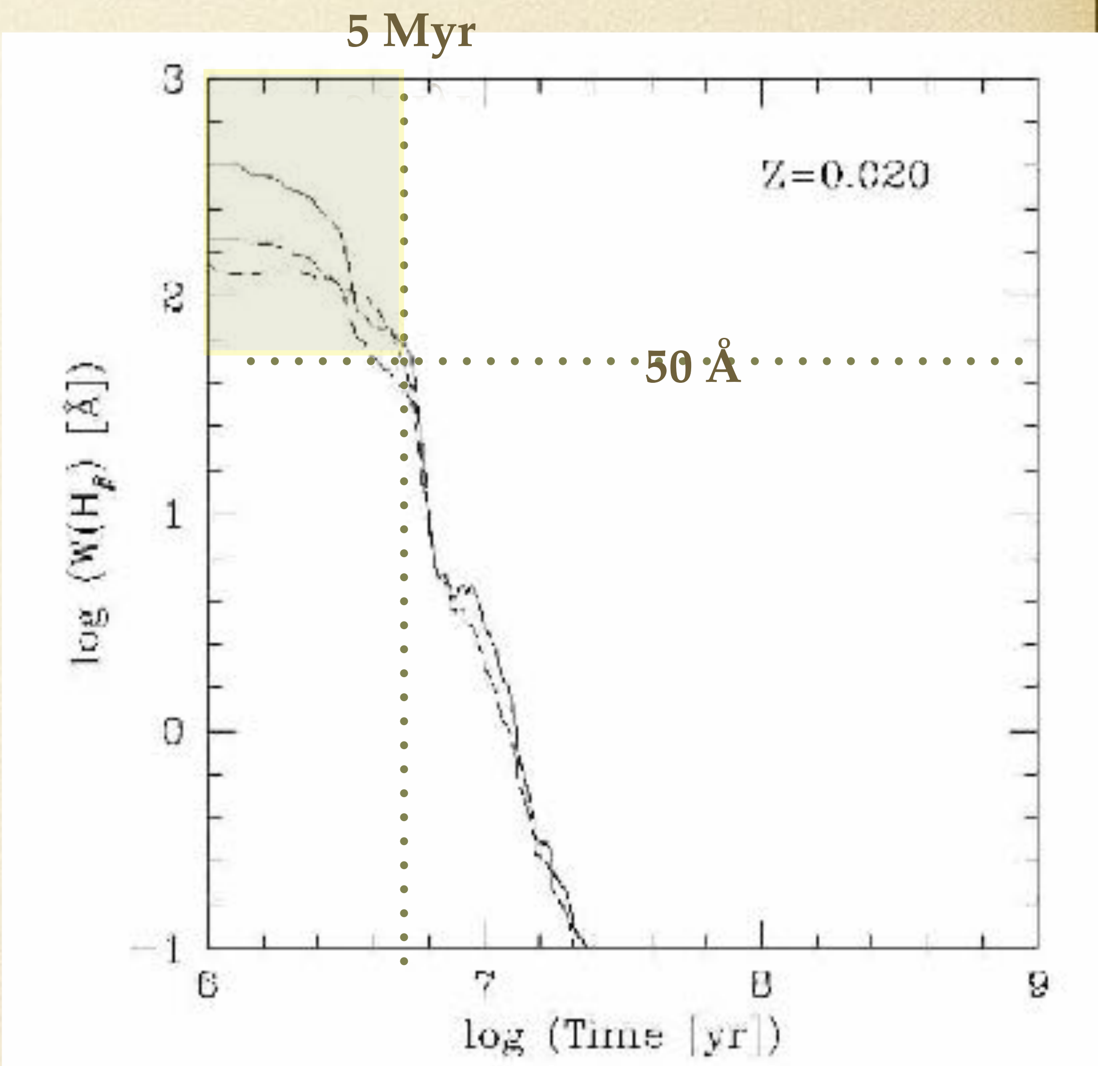
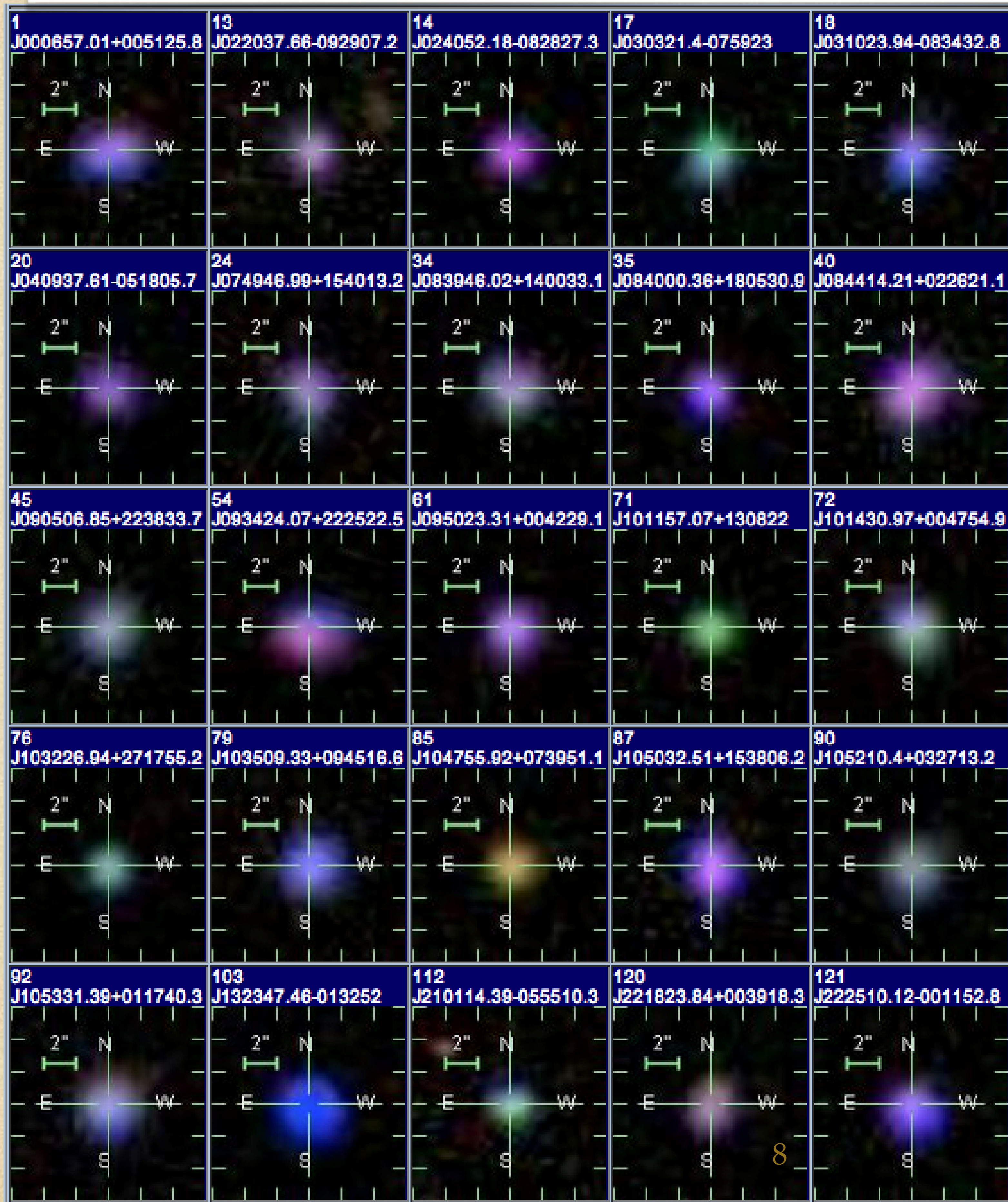


FIG. 85b

FIG. 85.—Hβ equivalent width vs. time. Star formation law: instantaneous; *solid line*, $\alpha = 2.35$, $M_{up} = 100\ M_\odot$; *long-dashed line*, $\alpha = 3.30$, $M_{up} = 100\ M_\odot$; *short-dashed line*, $\alpha = 2.35$, $M_{up} = 30\ M_\odot$; (*a*) $Z = 0.040$; (*b*) $Z = 0.020$; (*c*) $Z = 0.008$; (*d*) $Z = 0.004$; (*e*) $Z = 0.001$.

SDSS Images of H II Galaxies - COMPACT!!



The colour in these SDSS stamp images depends on redshift.

Some are green most are not.

Are BCD HII Galaxies?

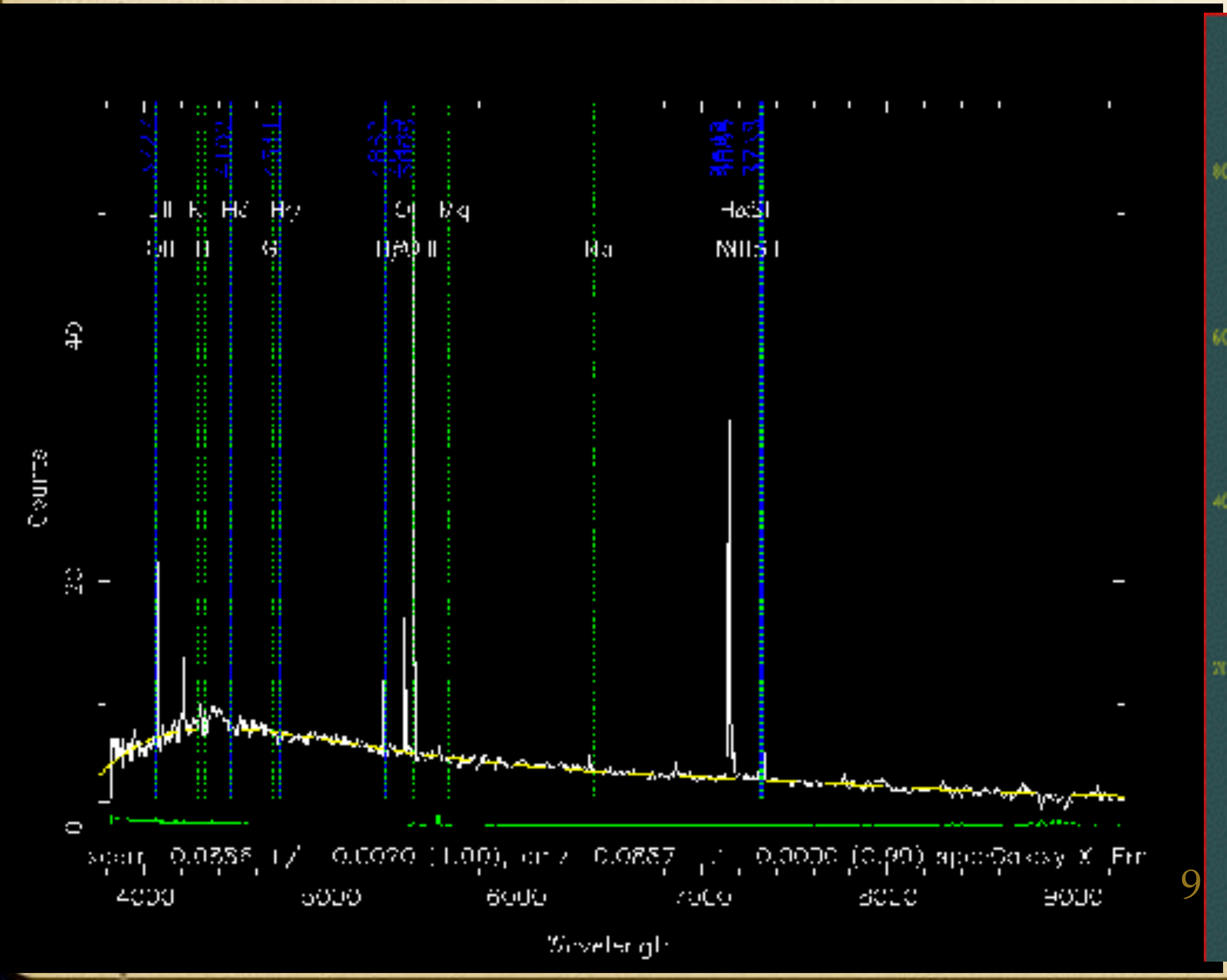
The answer is: generally no.

Blue Compact Dwarf (BCD) were selected by Fred Zwicky by colour and compactness. This selection provides samples of galaxies with a young population but in contrast with HII galaxies, the underlying galaxy is clearly visible in the images and the spectrum.

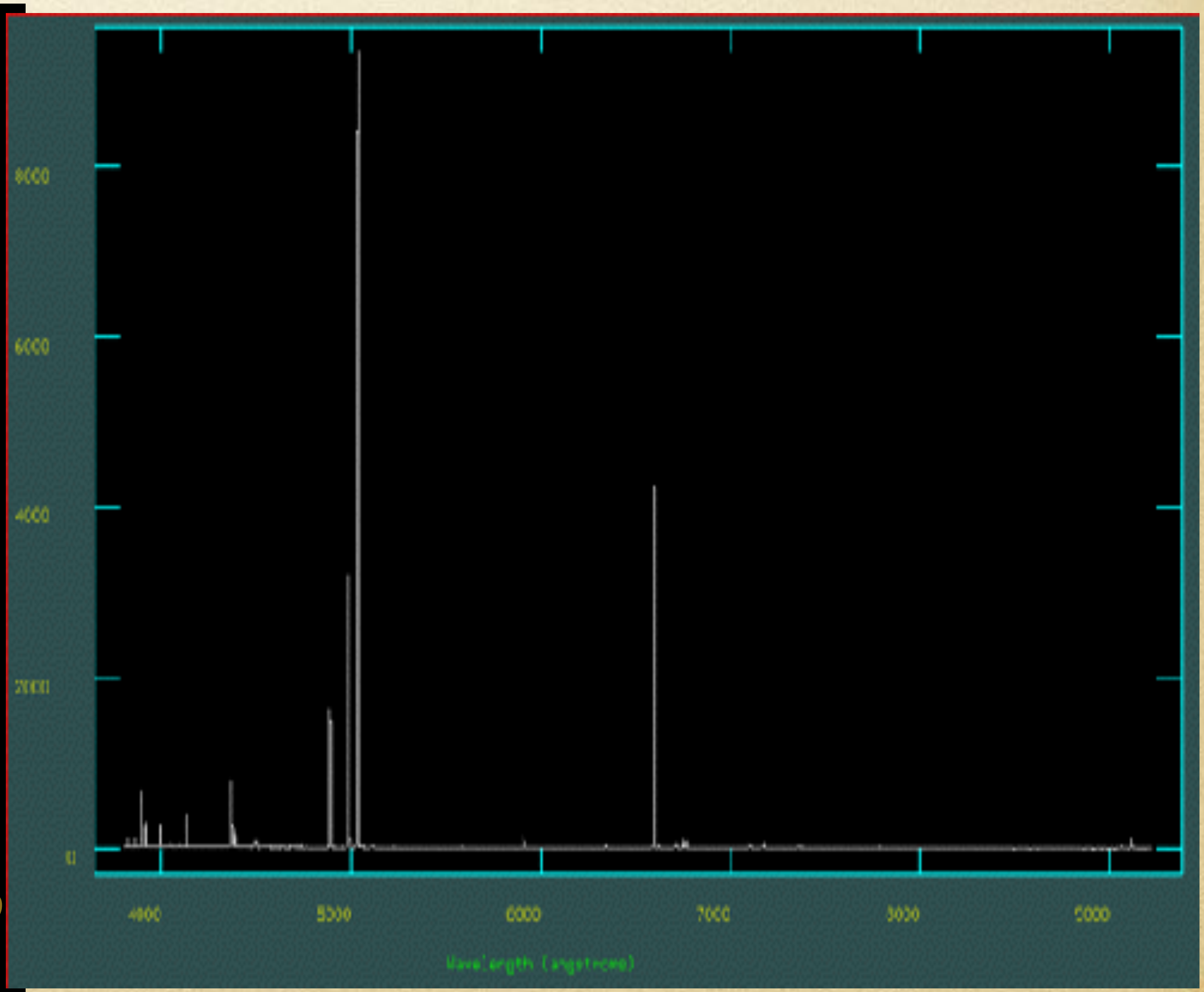
Only those BCD that satisfy the criteria EW(Hα)>200Å are HII galaxies.

HII galaxies are the youngest BCDs.

BCD



HIIGx



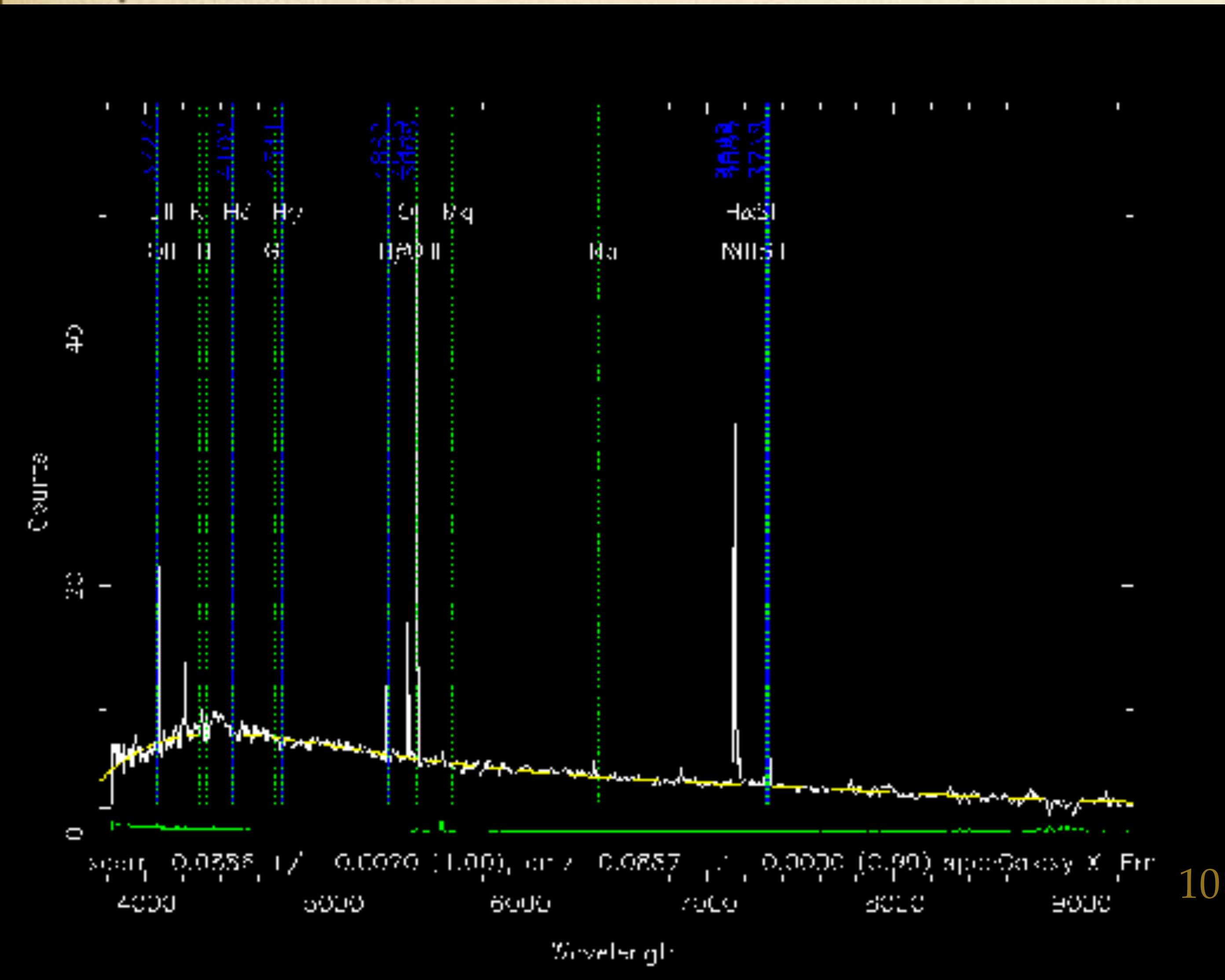
Are BCD HII Galaxies?

Can HII galaxies evolve into BCD?

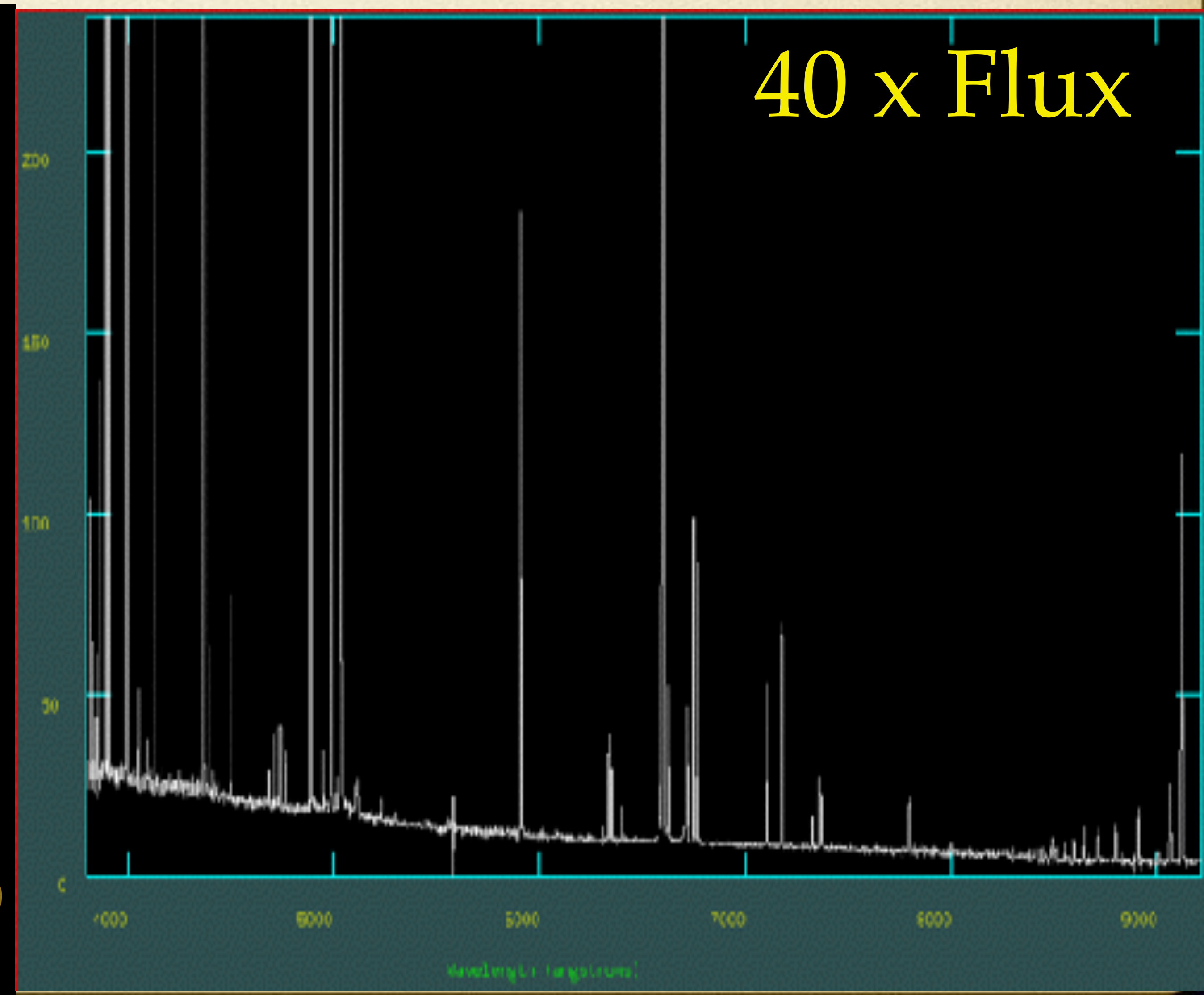
Possibly. As the burst evolves, its luminosity rapidly diminishes and after few million years i becomes less luminous than the parent galaxy.

A problem though is that in general BCDs have higher [O/H] than HIIGx.

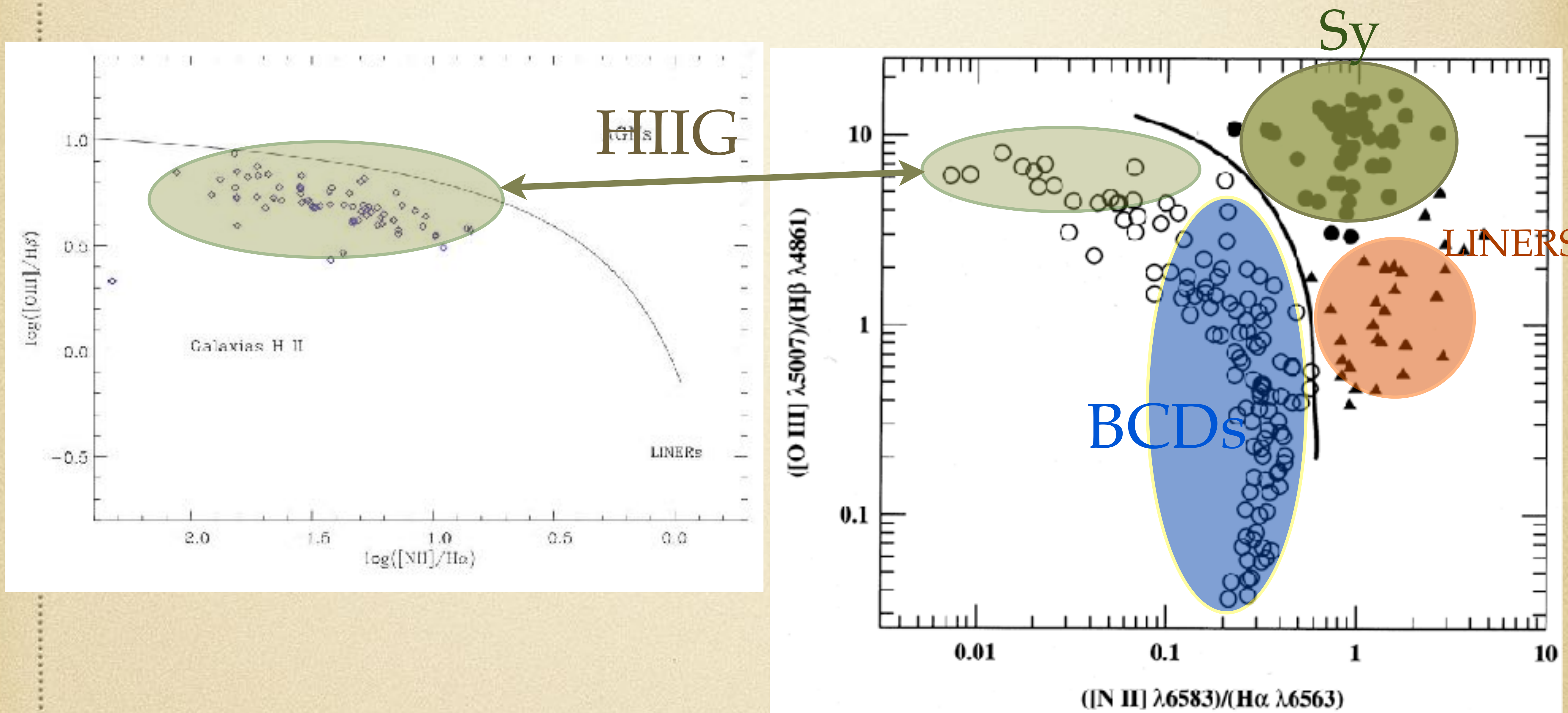
BCD



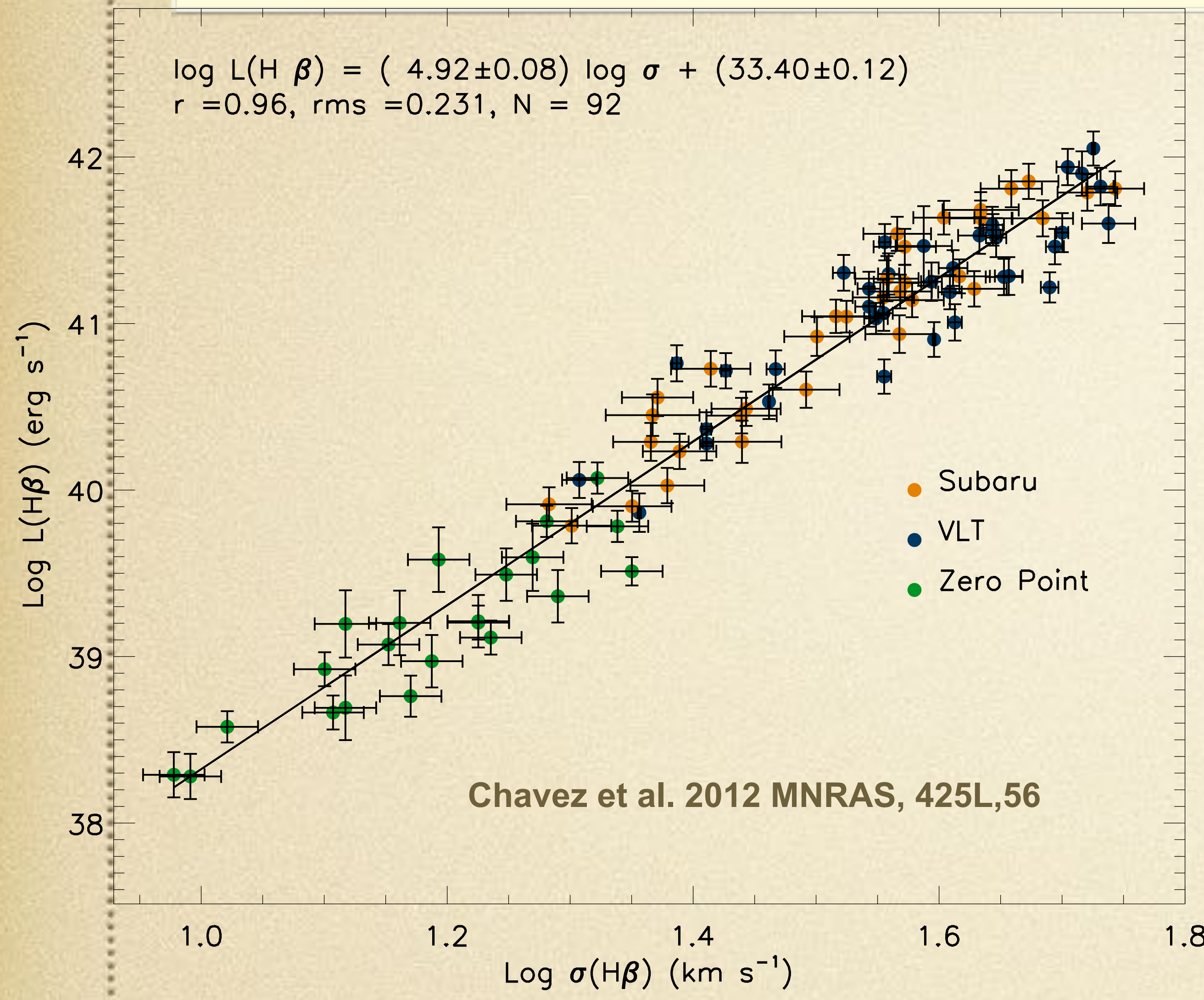
HIIGx

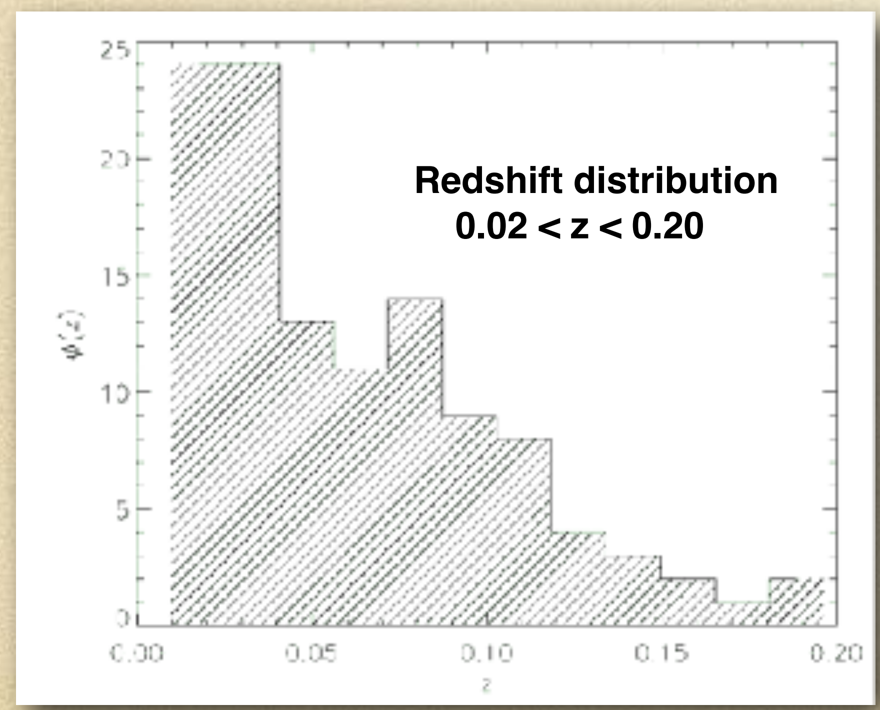


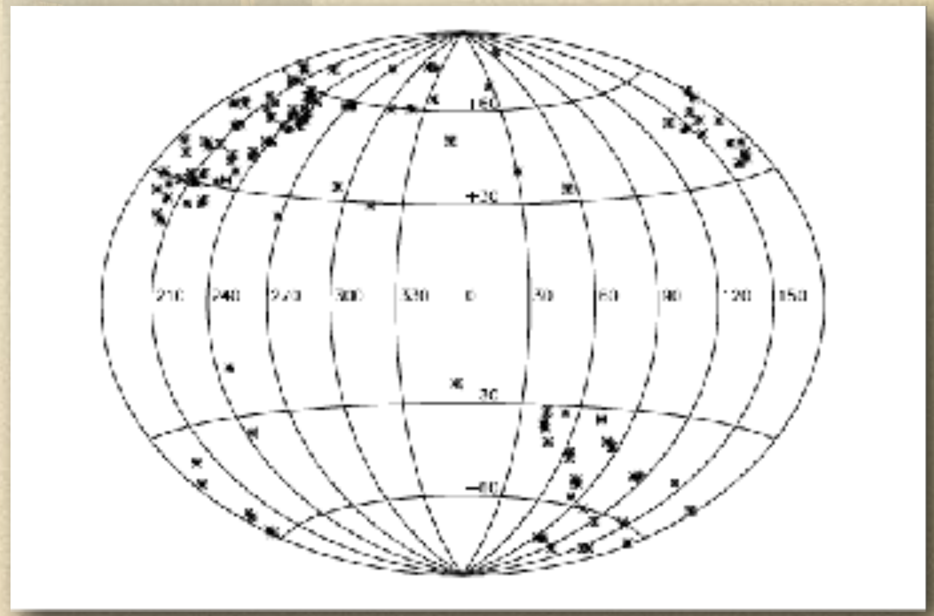
HIIG and BCD Diagnostic Diagrams



Measuring H_0 -The L-sigma relation for HIIG and GHIIR







Four of the 36 GHIIR

Fernandez Arenas et al 2017

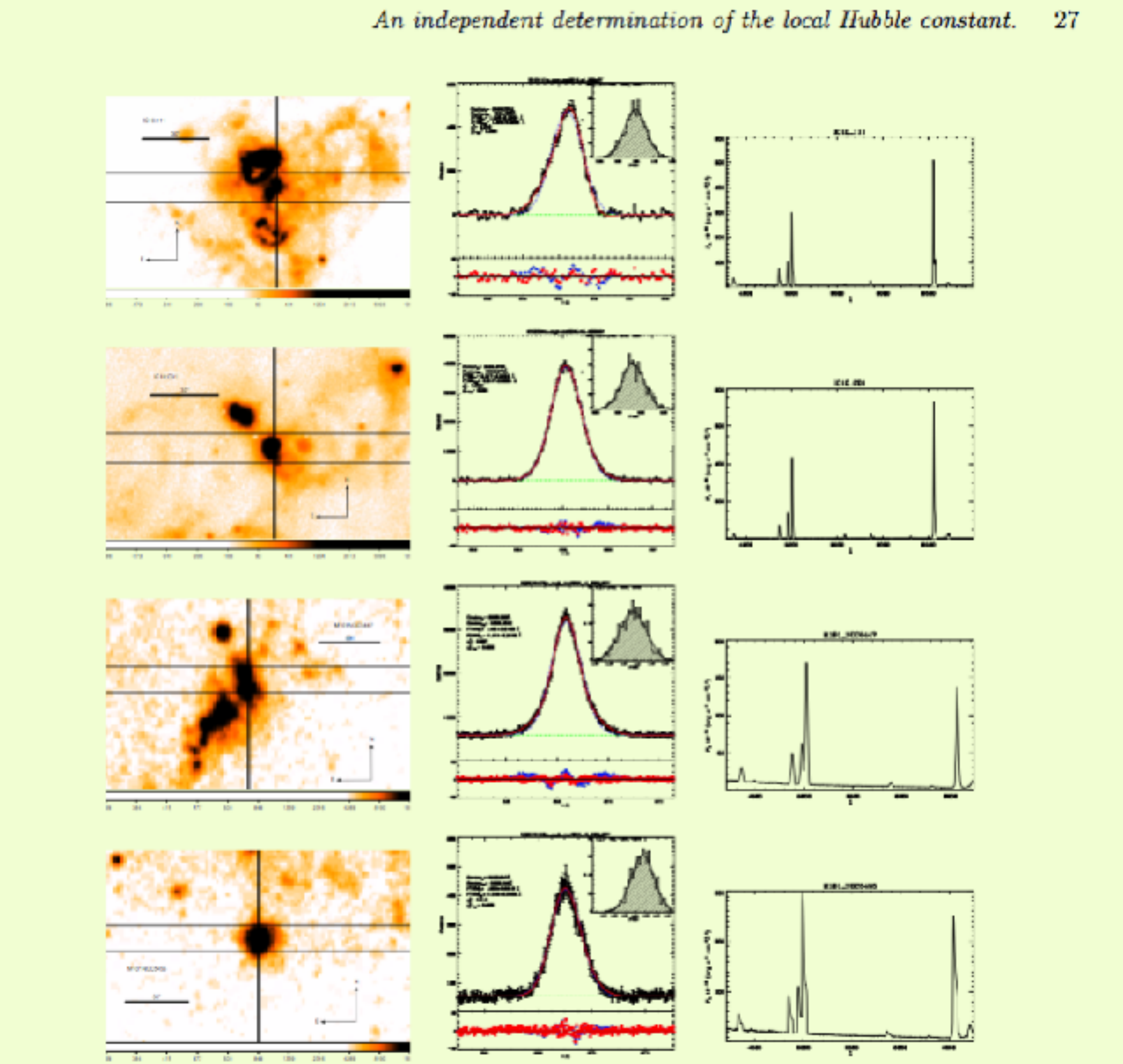
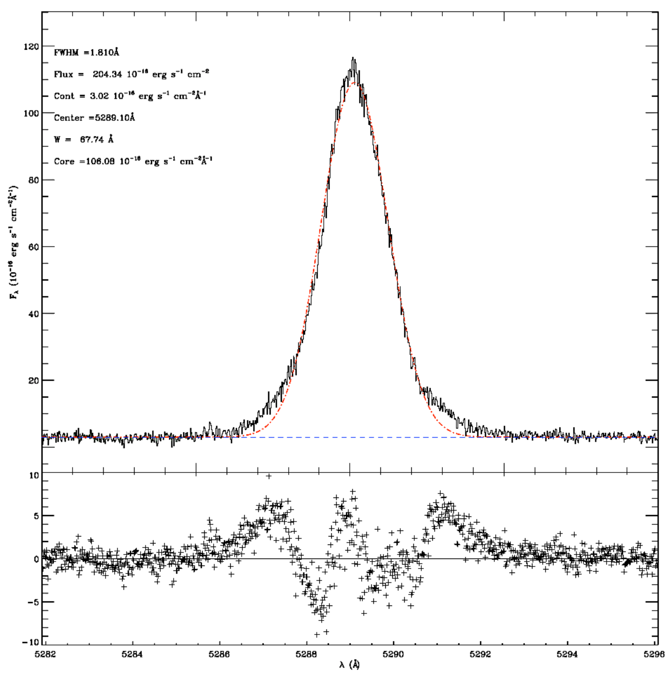


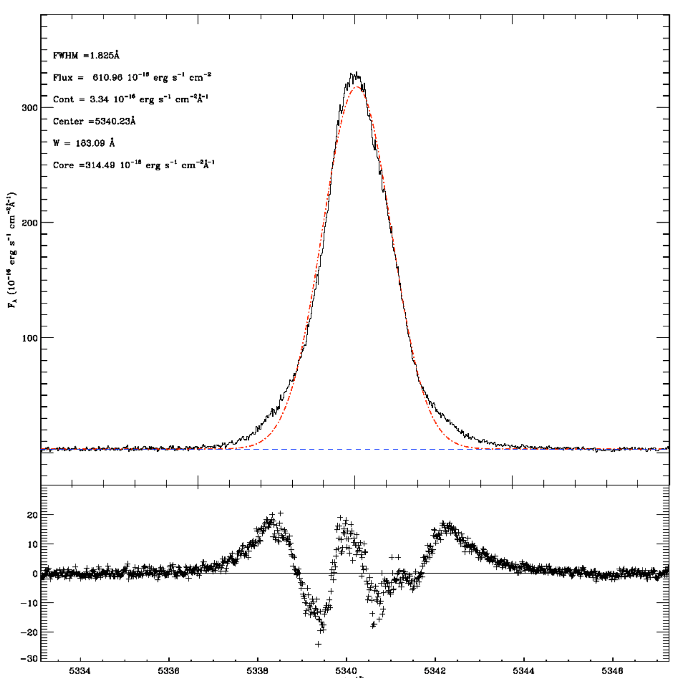
Figure B1. Hα image obtained from NASA/IPAC Extragalactic Database (NED), high-resolution profile for the GHIIRs and low-resolution spectrum.

Velocity dispersions: UVES Data

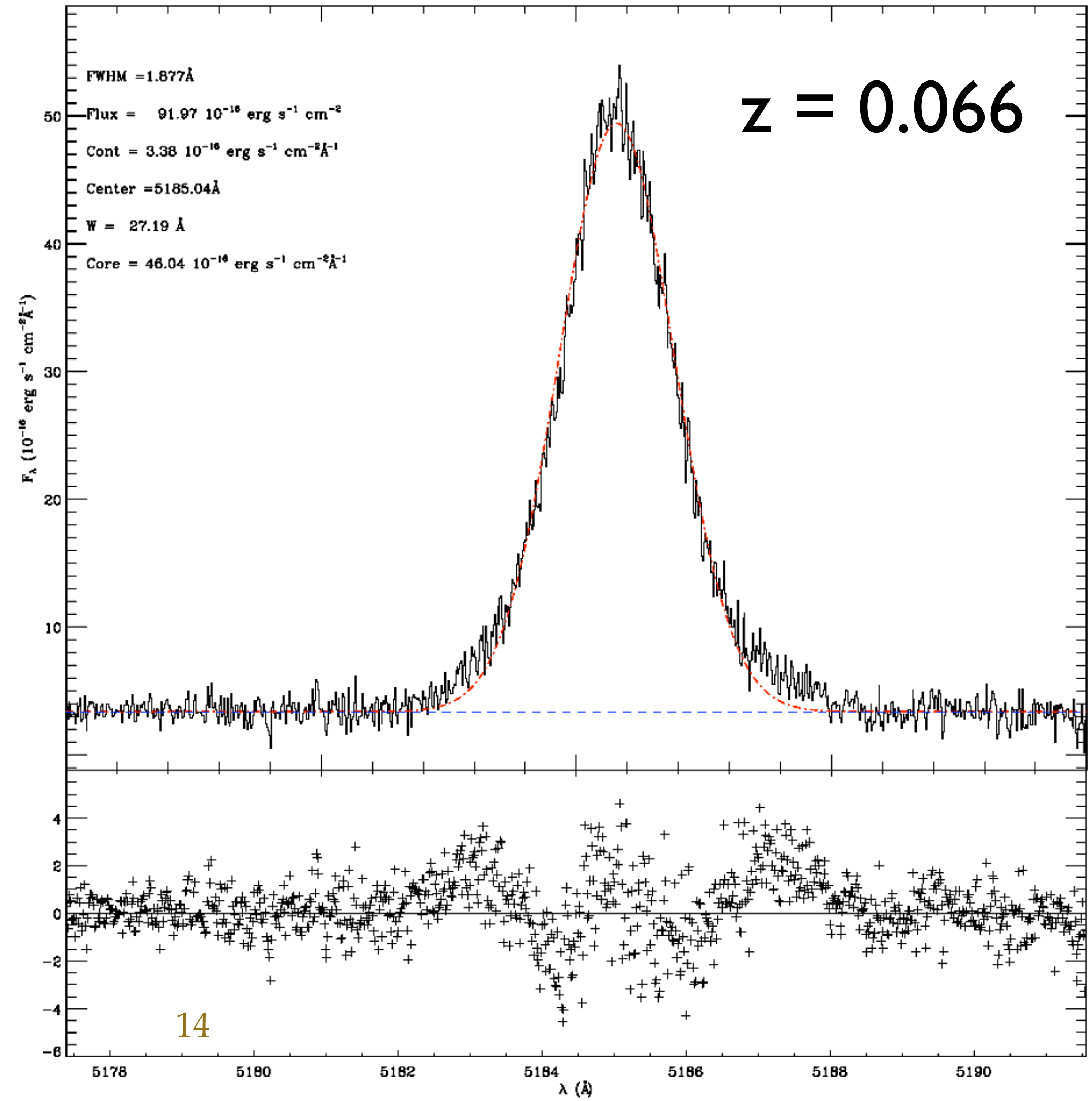
[O III] λ 4959



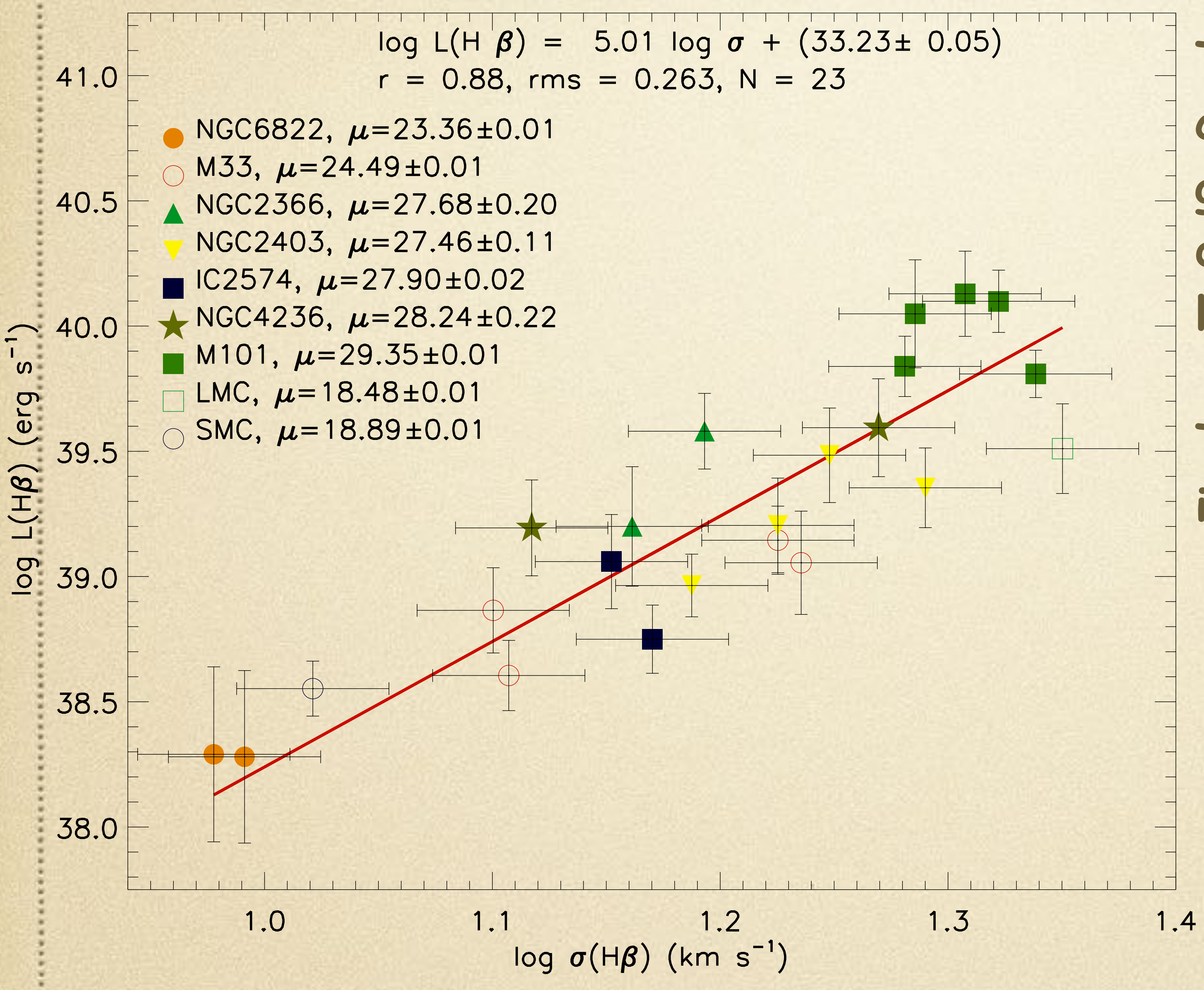
[O III] λ 5007



J222510-001152 Hβ



Measuring H_0 - The L-σ relation of the anchor sample



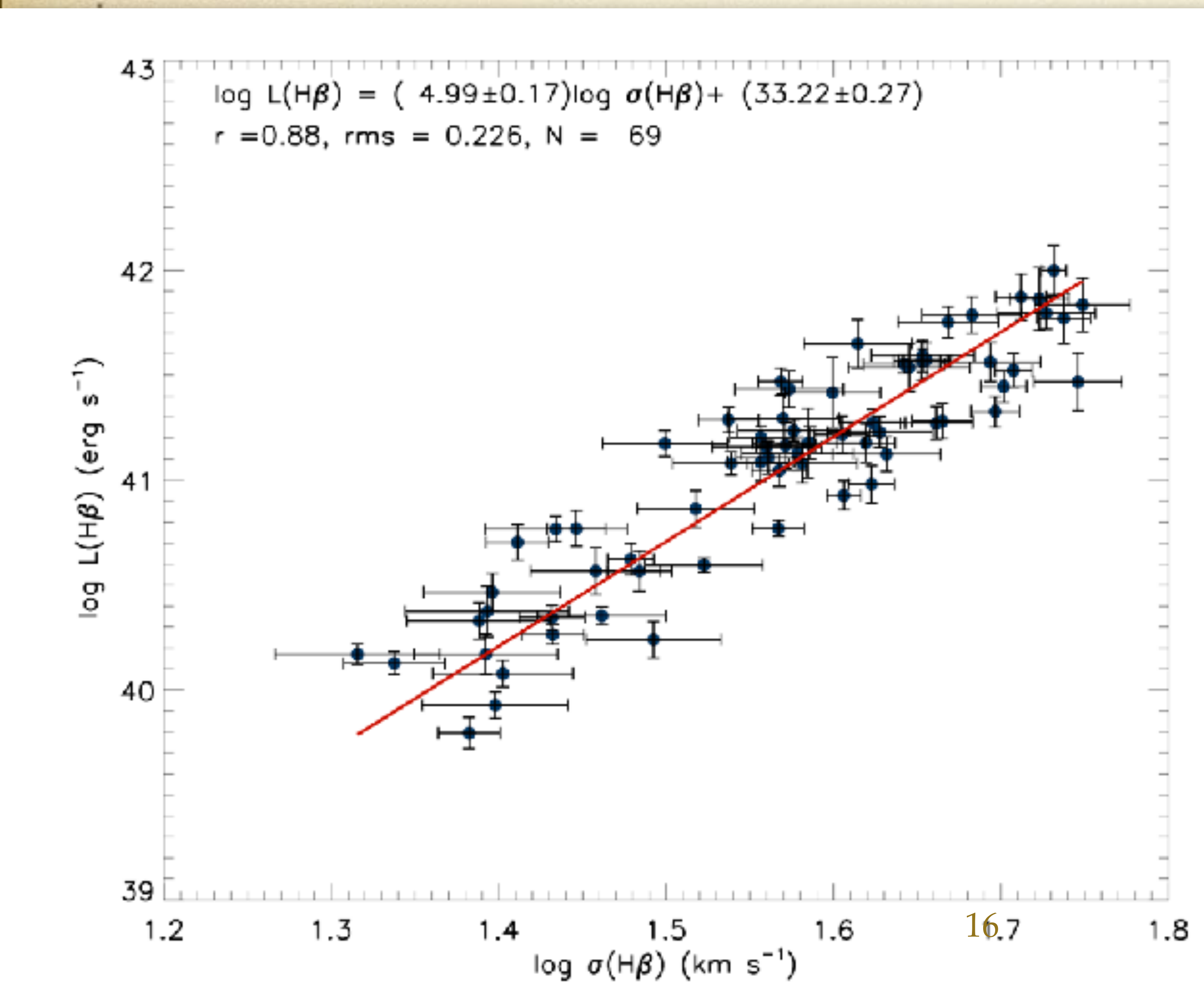
The anchor sample is composed by GHIIR in galaxies with distances determined using Cepheid light curves.

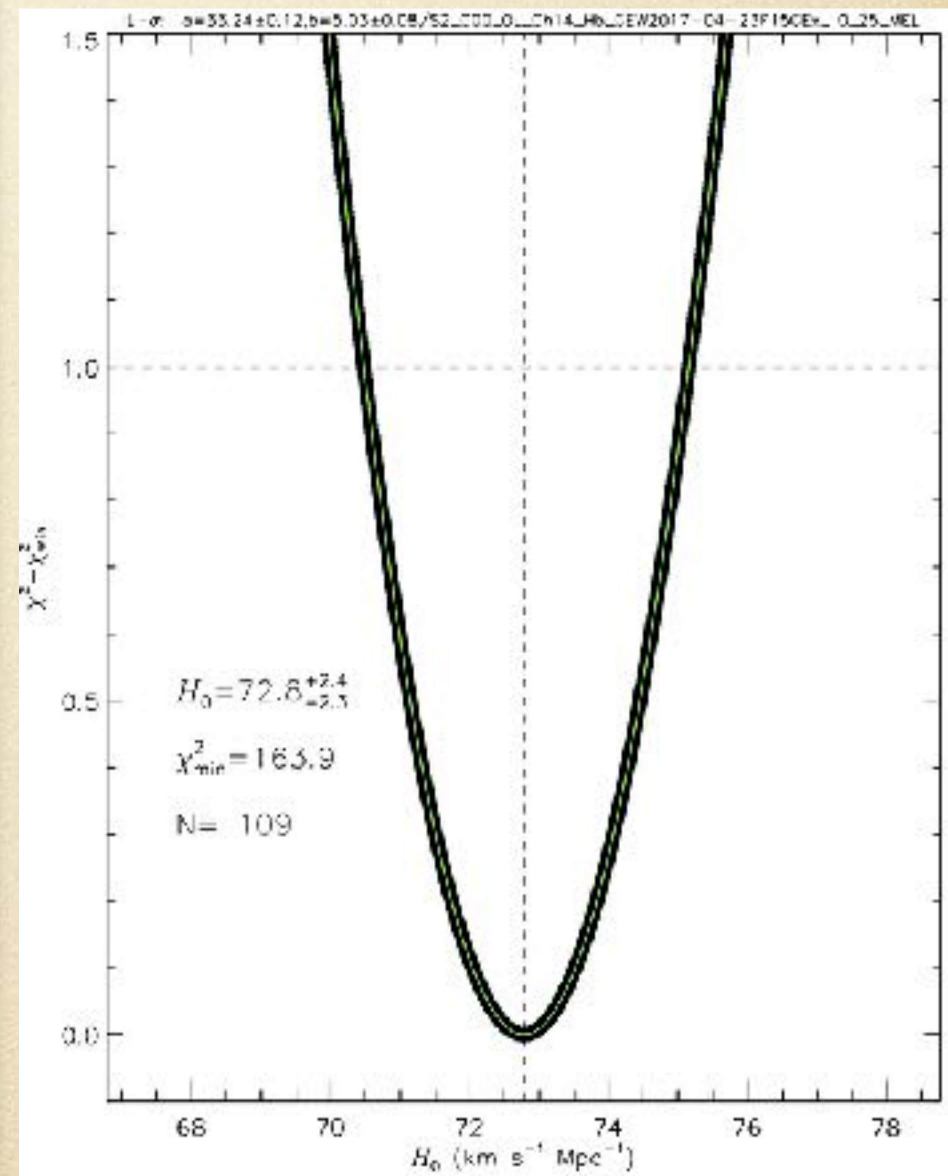
Their luminosity is therefore independent of H_0 .

Measuring H_0 -The L-σ relation of the H II Galaxies

The luminosity depends of H_0 .

χ^2 solution





Measuring H_0

We obtained:

Chavez etal 2012 $H_0 = 74.3 \pm 4.2$ (random+systematic)

That should be compared with:

Freedman etal 2001: $H_0 = 72 \pm 8$ (random+systematic)

Sandage etal 2006: $H_0 = 62.3 \pm 5.0$ (random+systematic)

Riess etal 2009: $H_0 = 74.2 \pm 3.6$ (random+systematic)

Riess etal 2012: $H_0 = 73.8 \pm 2.4$ (random+systematic)

and since Chavez etal 2012:

Freedman etal 2012: $H_0 = 74.3 \pm 2.6$ (random+systematic)

Riess etal 2016: $H_0 = 73.2 \pm 1.7$ (random+systematic)

Our results is in excellent agreement with the latest more precise determinations.

Measuring H_0 - Final comments

While the error in distance for a Giant HII region or HII galaxy is about 0.16 dex, i.e. about 3 times larger than that of the SNIa, the fact that there are more than one HII region per galaxy (typically 2-3) and furthermore there are many more nearby galaxies with Cepheid determination and HII regions than with SNIa, makes our method a strong competitor capable of reaching random errors of ~ 1 km/s in the determination of H_0 .

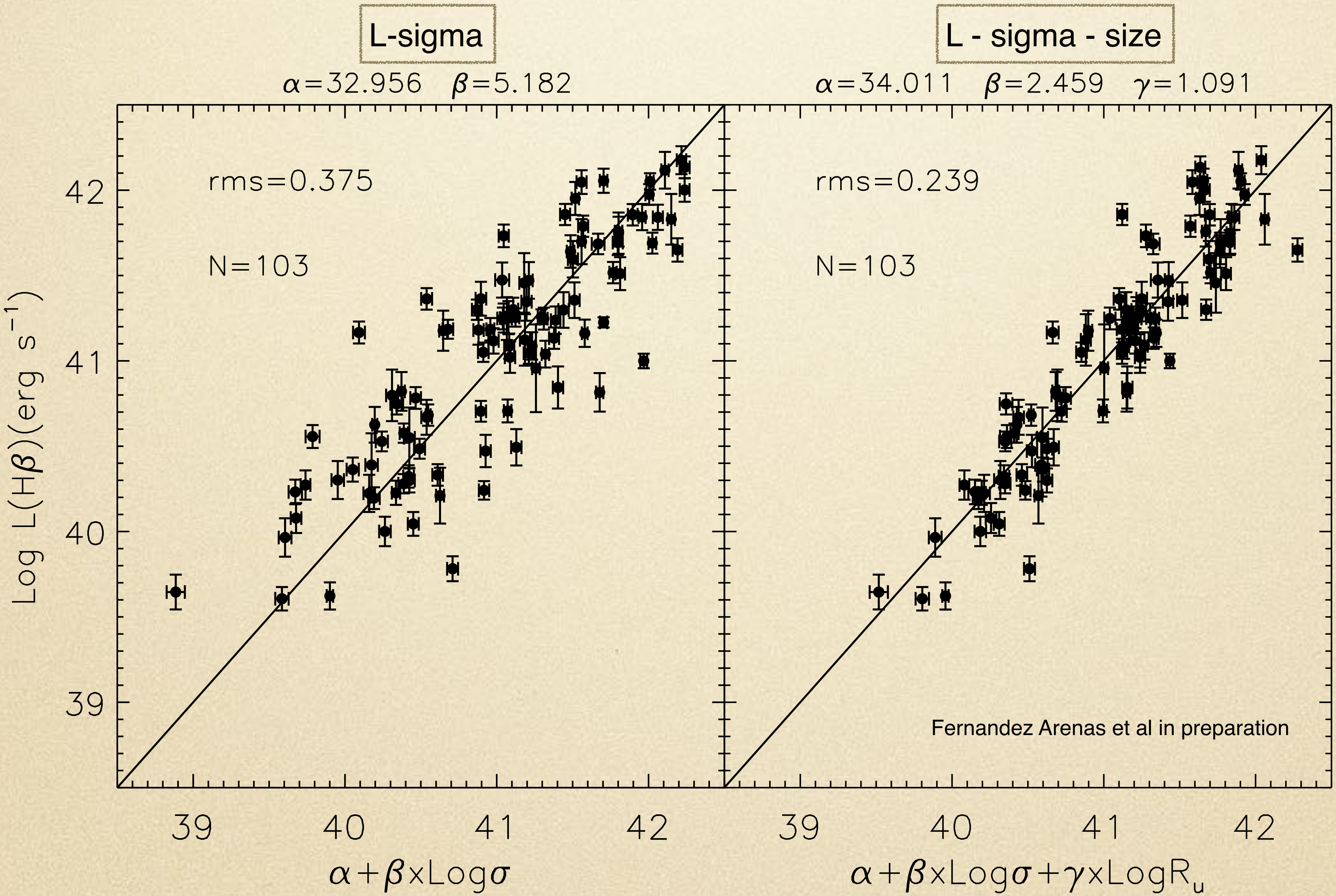
An important point mentioned by Riess et al 2016, is that the SNIa results will not improve substantially in the future because the rate of discovery of SNIa in nearby galaxies is on average only one a year and after its discovery a lengthy process has to be started to determine the redshift independent distance to the parent galaxy that without HST will be more difficult.

On the other hand, GHIIR in nearby galaxies with redshift independent distances are at present more than 200 and the number of HIIG run into several thousands.

L - sigma Fundamental Plane and the viral theorem

Introducing the size as a second parameter reduces the scatter to the observational errors level.
This indicates that the L-sigma is a 2-D projection of the 3-D fundamental plane, L-sigma-size.

The virial relation predicts exponents 2.0 and 1.0 for the velocity dispersion and size respectively.
The values from the fit to HIIG, 2.46 and 1.1 are not far from the predicted values.



$M_{dynamical}$ vs $M_{stars} + M_{ionized\ gas}$

Comparing the dynamical and photometric masses of HIIG

$M_{ion} = 5.0 \times 10^{-34}\, L(H\beta)\, m_p / \alpha_{eff}(H\beta)\, h\, \nu_{H\beta}\, N_e \quad M_\odot$

$M_{stellar} = 7.1 \times 10^{-34}\, L(H\beta) \quad M_\odot$

$M_{dyn} = k\, G^{-1}\, r_{eff}\, \sigma^2 \quad M_\odot$

There is not much difference in the mass estimates.

This result is very interesting considering the uncertainties involved in these estimates.

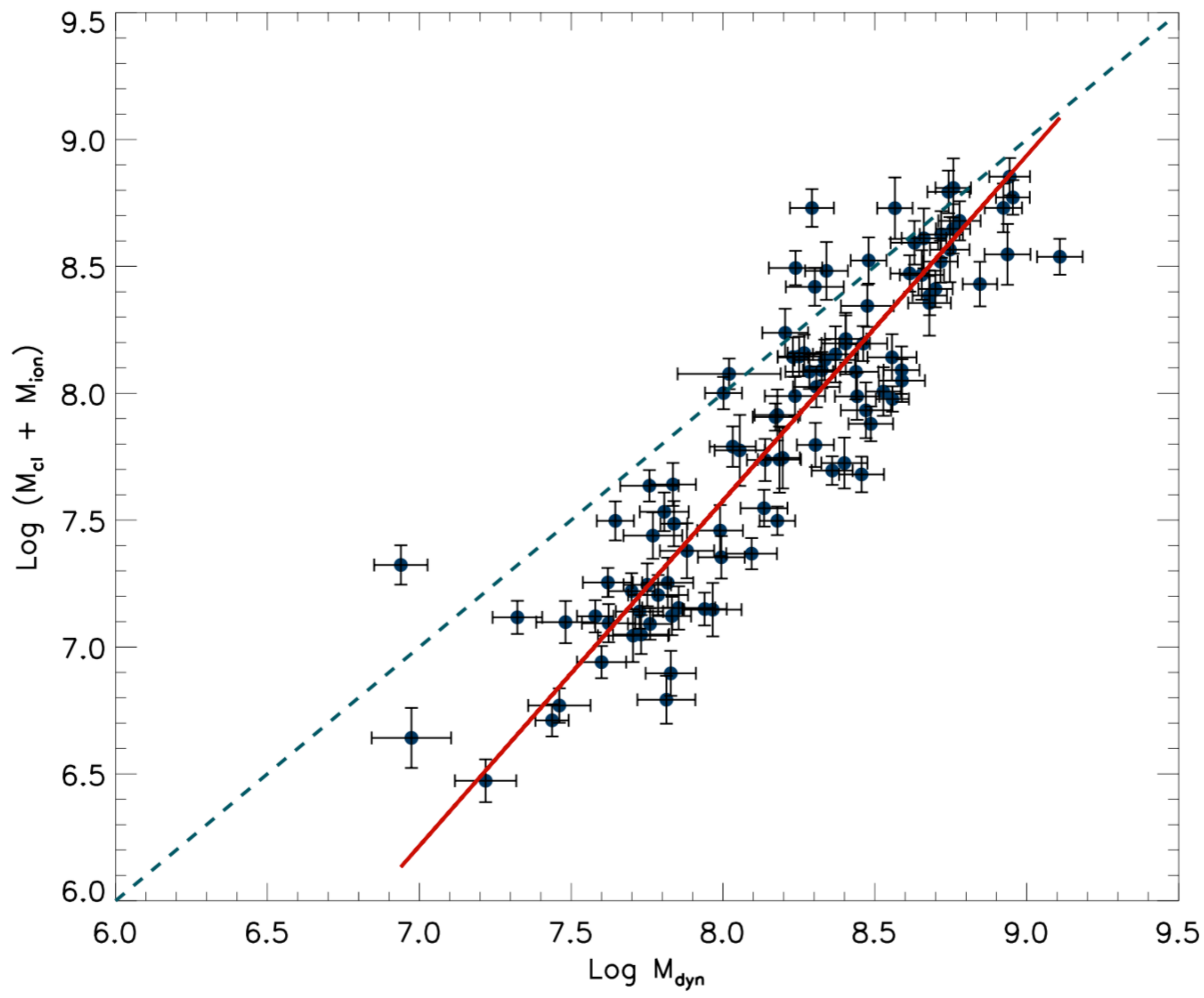


Figure 15. Comparison between $M_{cl} + M_{ion}$ and M_{dyn}. The continuos thick line represents the best fit to the data. The dashed line shows the one-to-one relation.

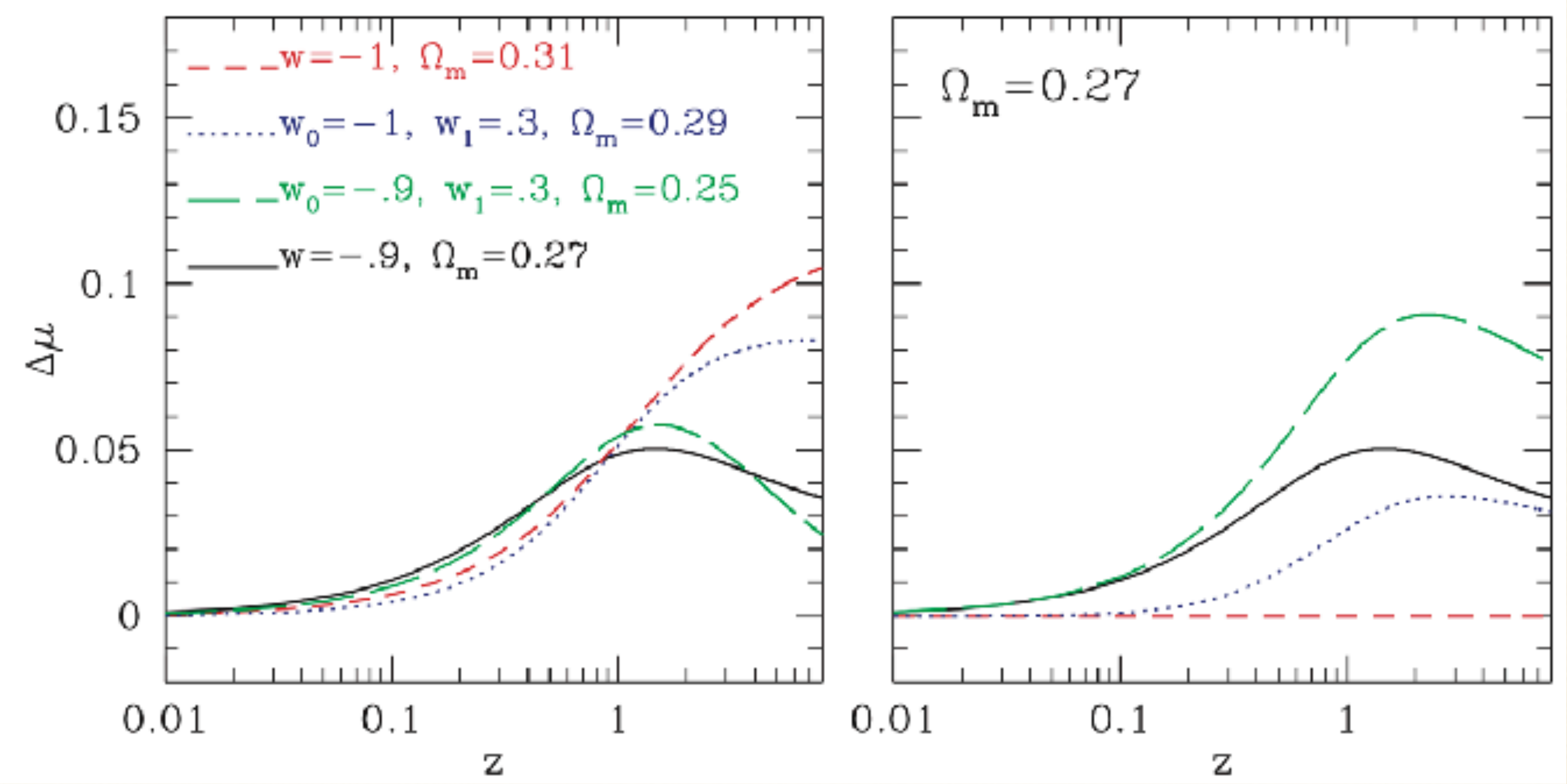
We therefore postulate that the young SSC that ionise the HIIG and GHIIR are gravitationally bound systems and that the velocity dispersion of the ionised gas is a good measure of the depth of the gravitational potential.

Manifestations of different Dark Energy models

The plot shows the relative distance modulus, $\Delta\mu=\Delta(m-M)$, between different models.

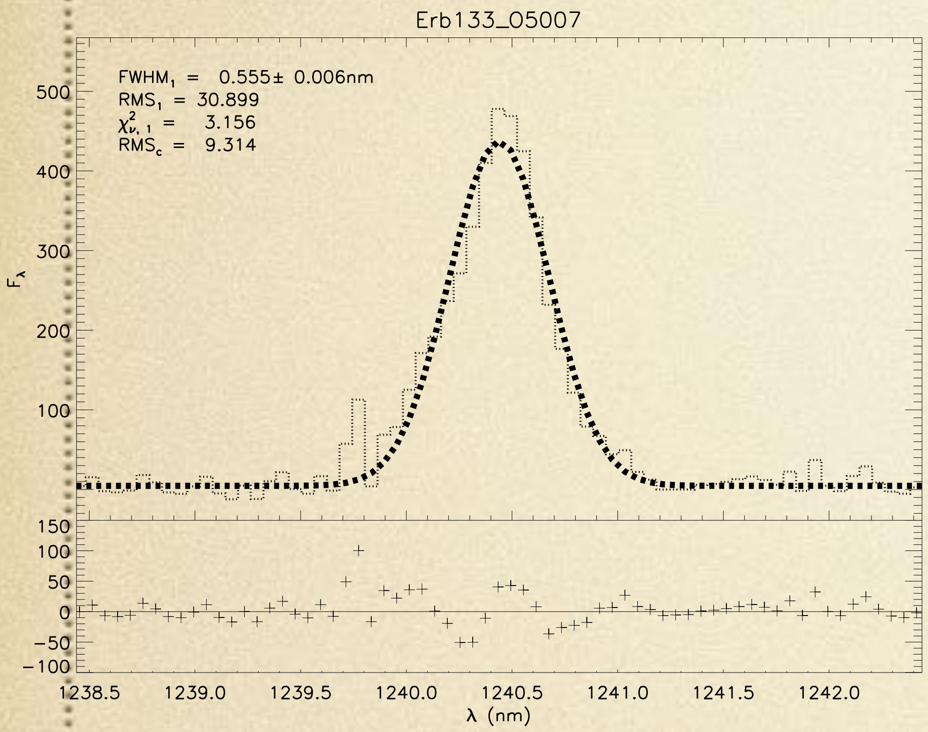
Even with fixed Ω_m there are important $\Delta\mu$ differences with respect to a reference model ($w=-1$, $\Omega_m=0.27$) due to w variation and/or w evolution.

Maximum $\Delta\mu$ variation occurs at z>2, i.e. out of reach of current SN Ia surveys.



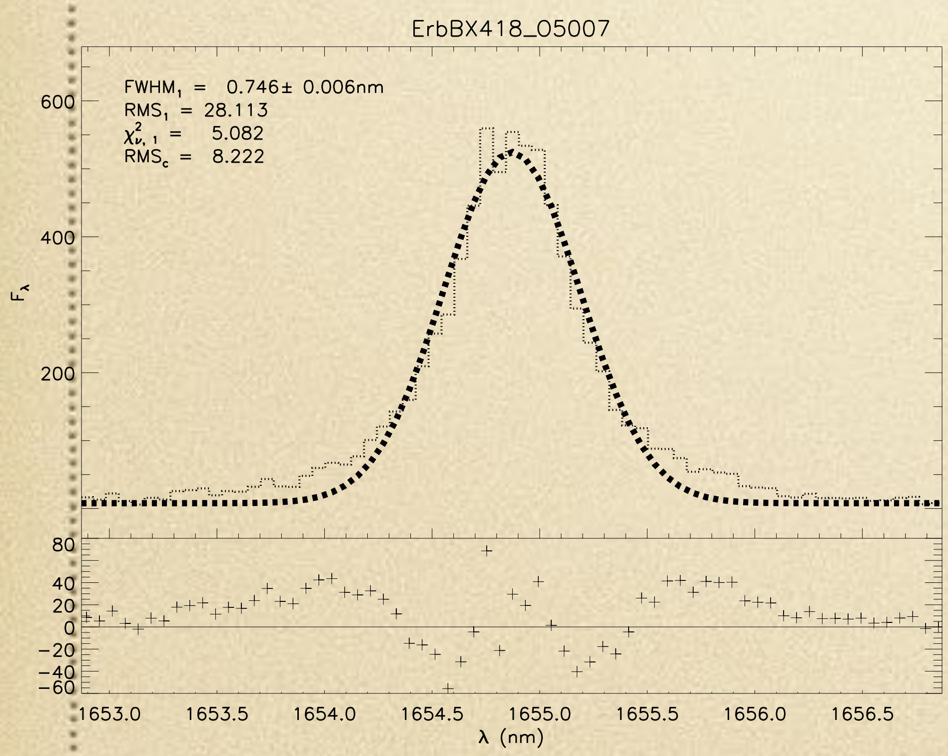
Plionis etal 2011, MNRAS.416.2981

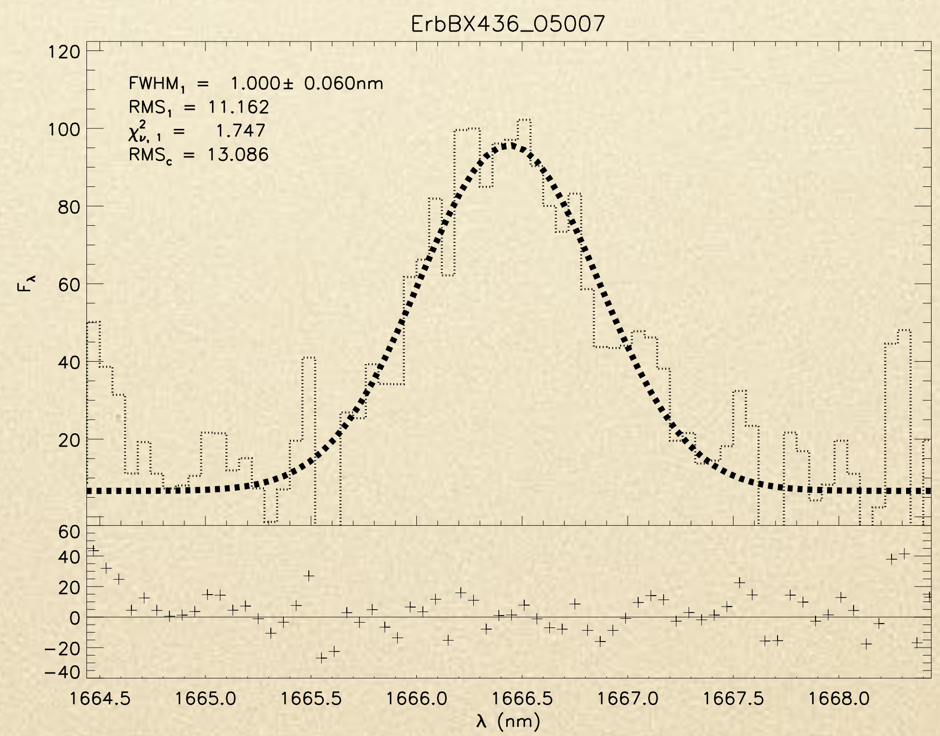
Left Panel: The expected distance modulus difference between the DE models shown and the reference Λ-model ($w=-1$) with Ωm = 0.27. Right Panel: The expected distance modulus differences once the Ωm-w(z) degeneracy is broken (imposing the same Ωm value as in the comparison model).



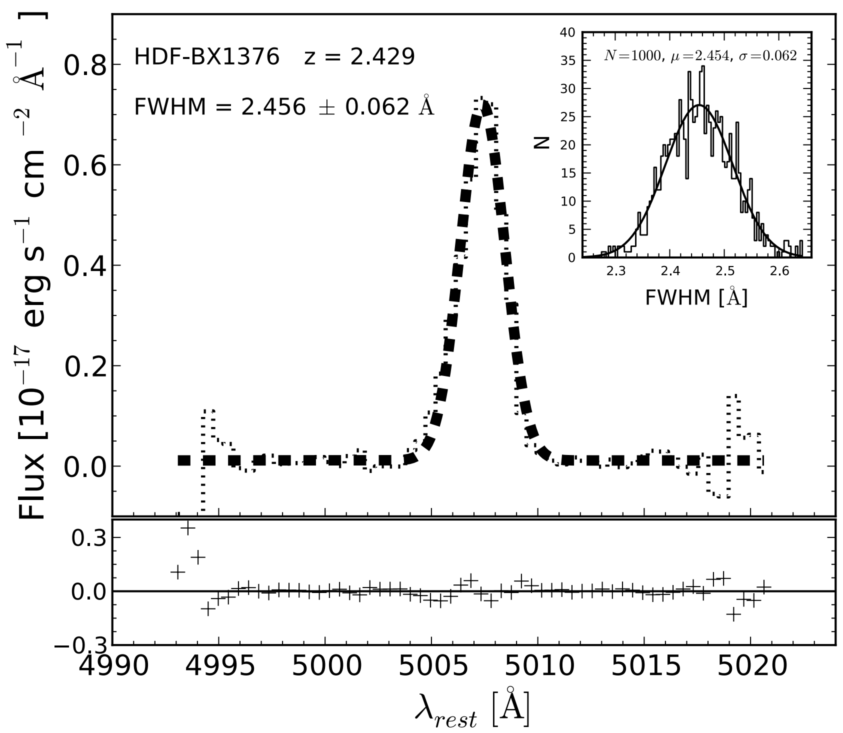
New data
[OIII]5007 profiles observed with XShooter in HIIG at z~2.5

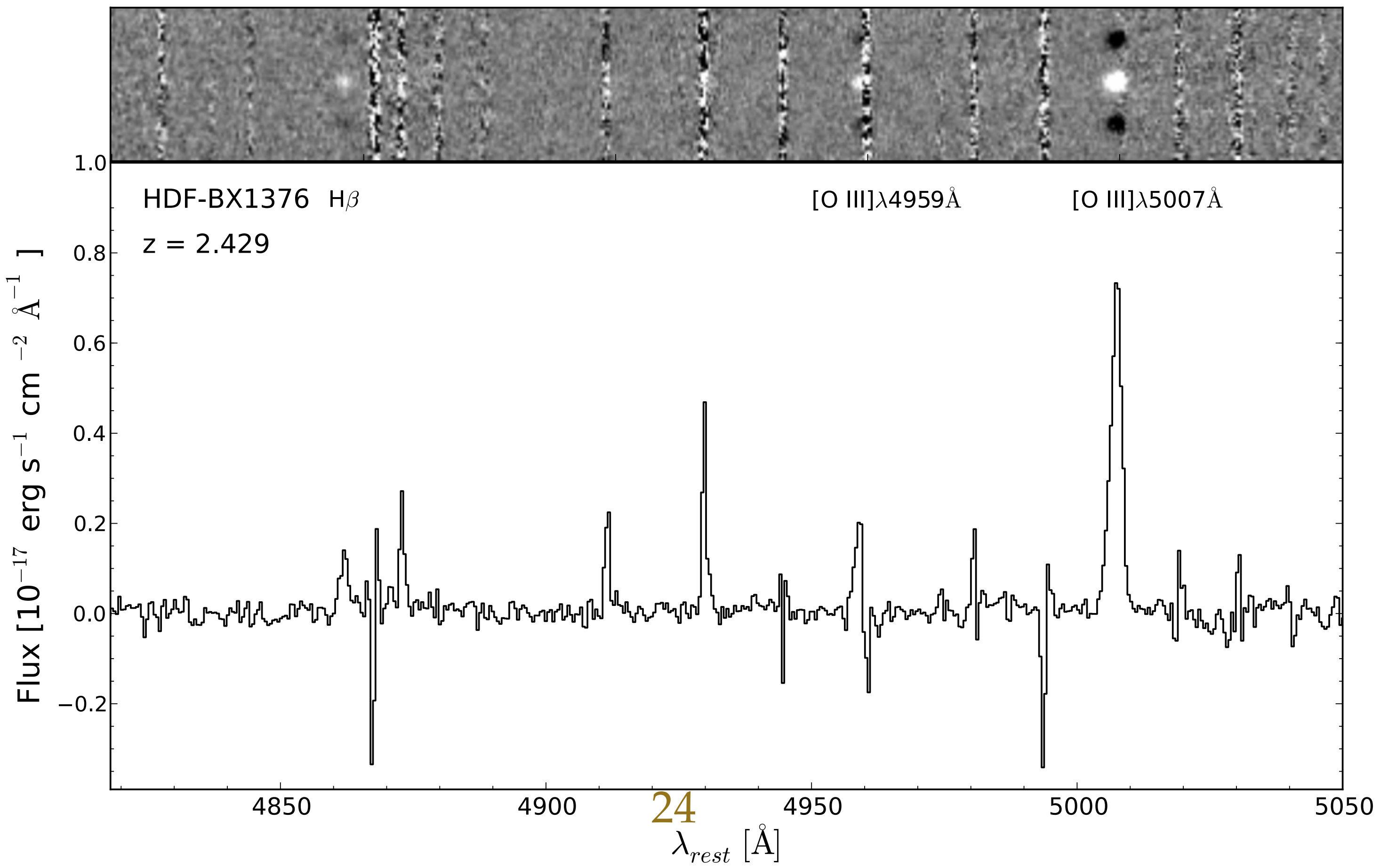
The six HIIG with best XShooter data and 19 HIIG from the literature were included in Terlevich et al. 2015.



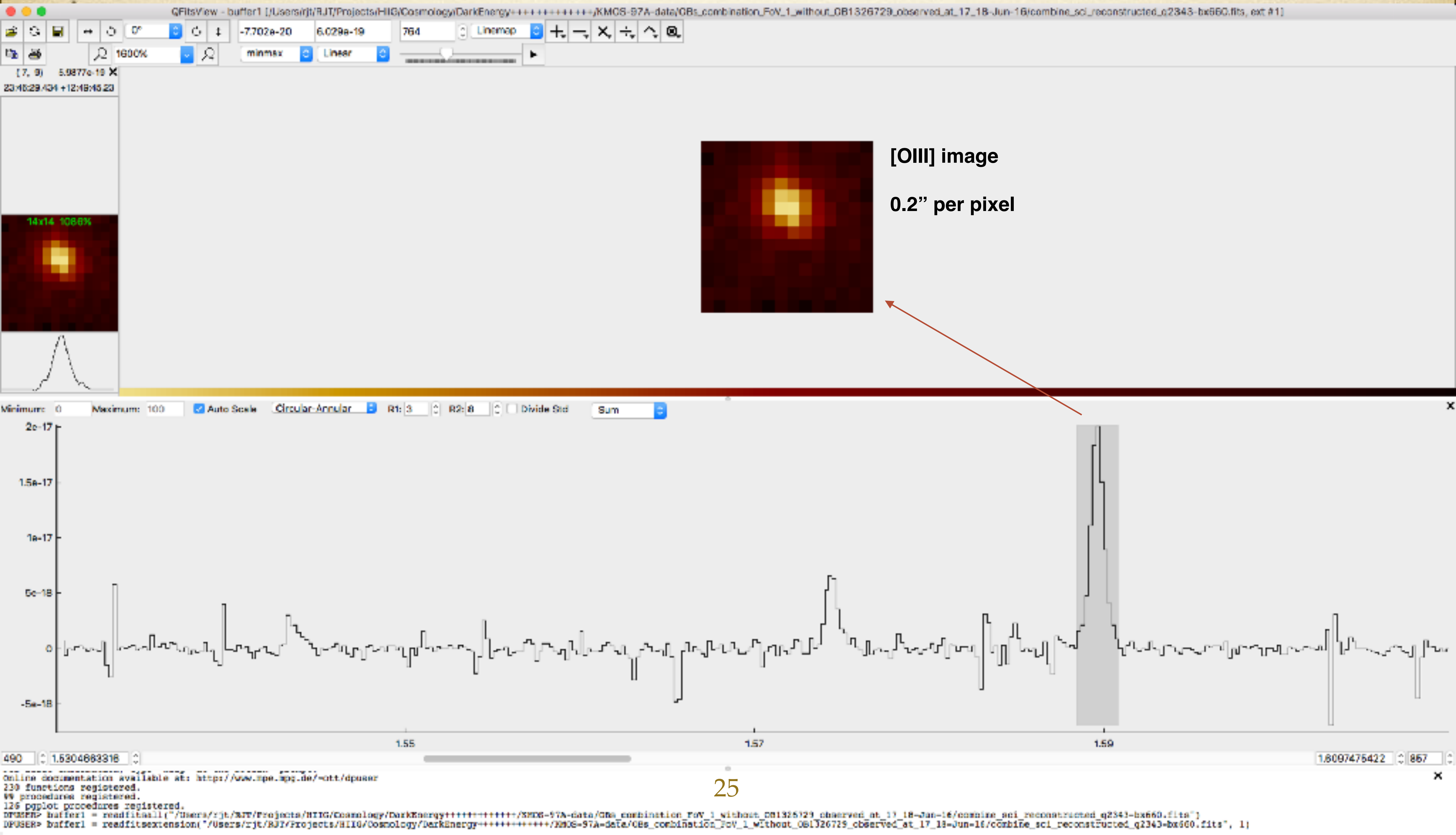


HIIG at z=2.43 observed with MOSFIRE at KECK

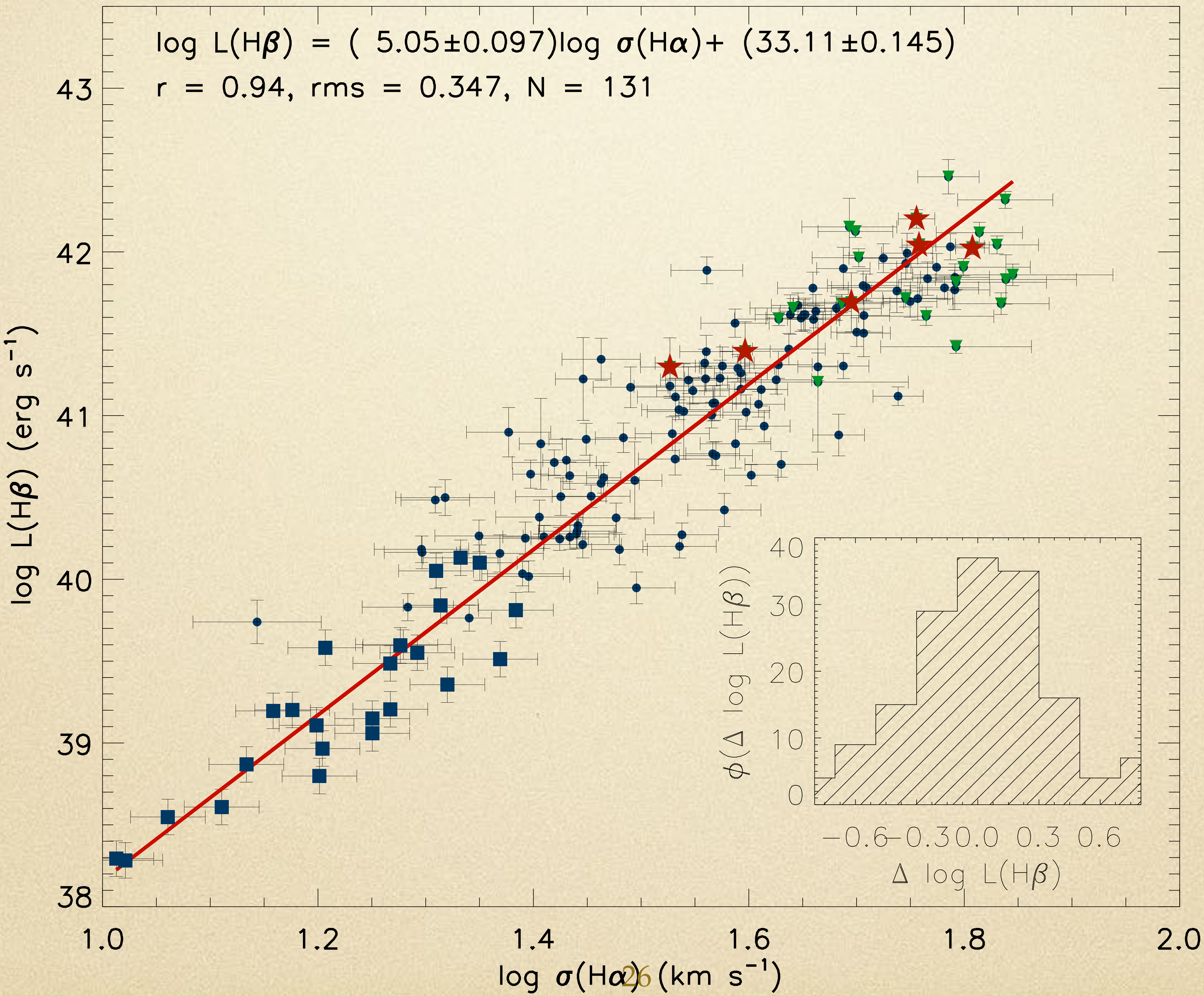




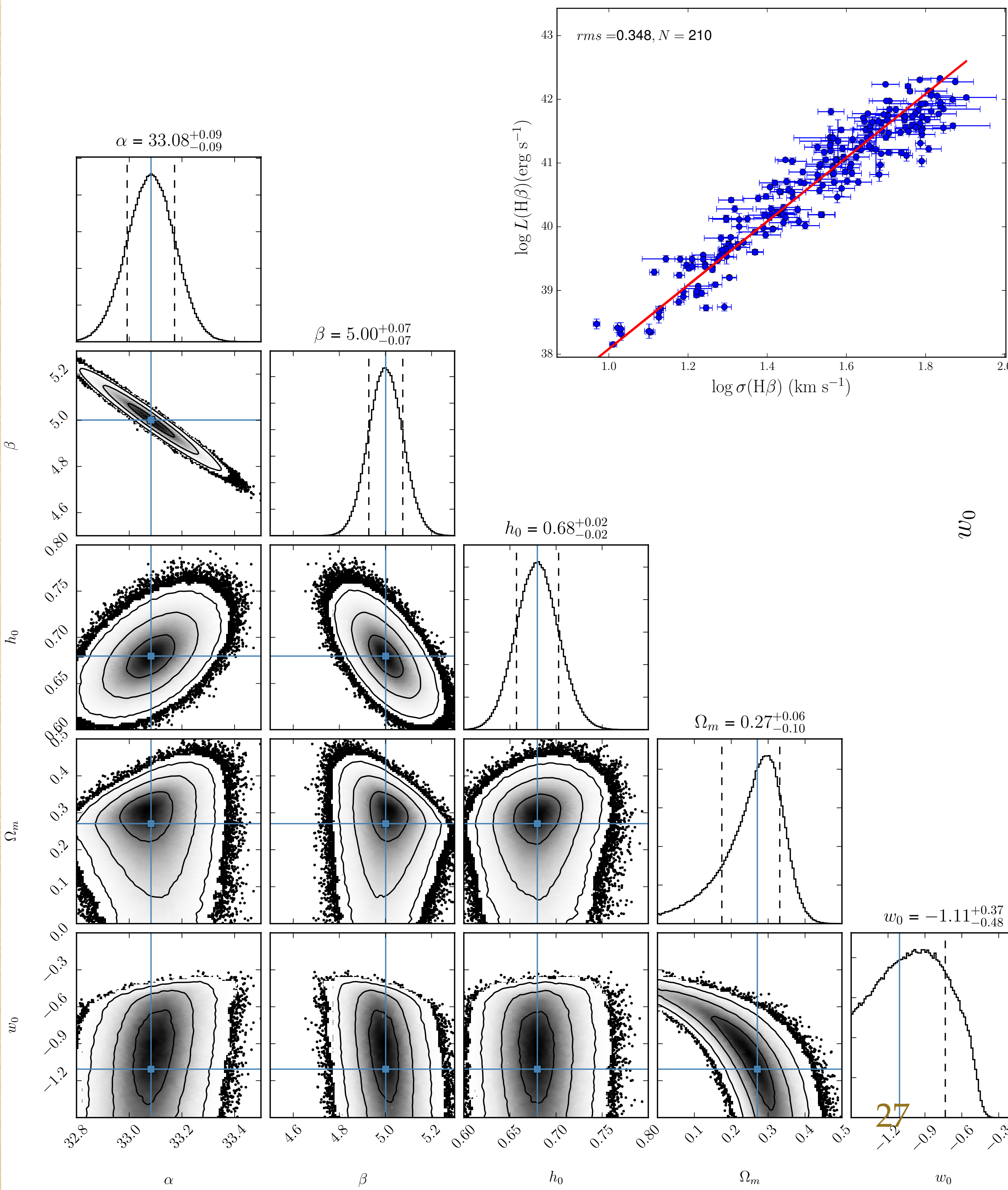
HIIG at z=2.17 observed with KMOS at VLT

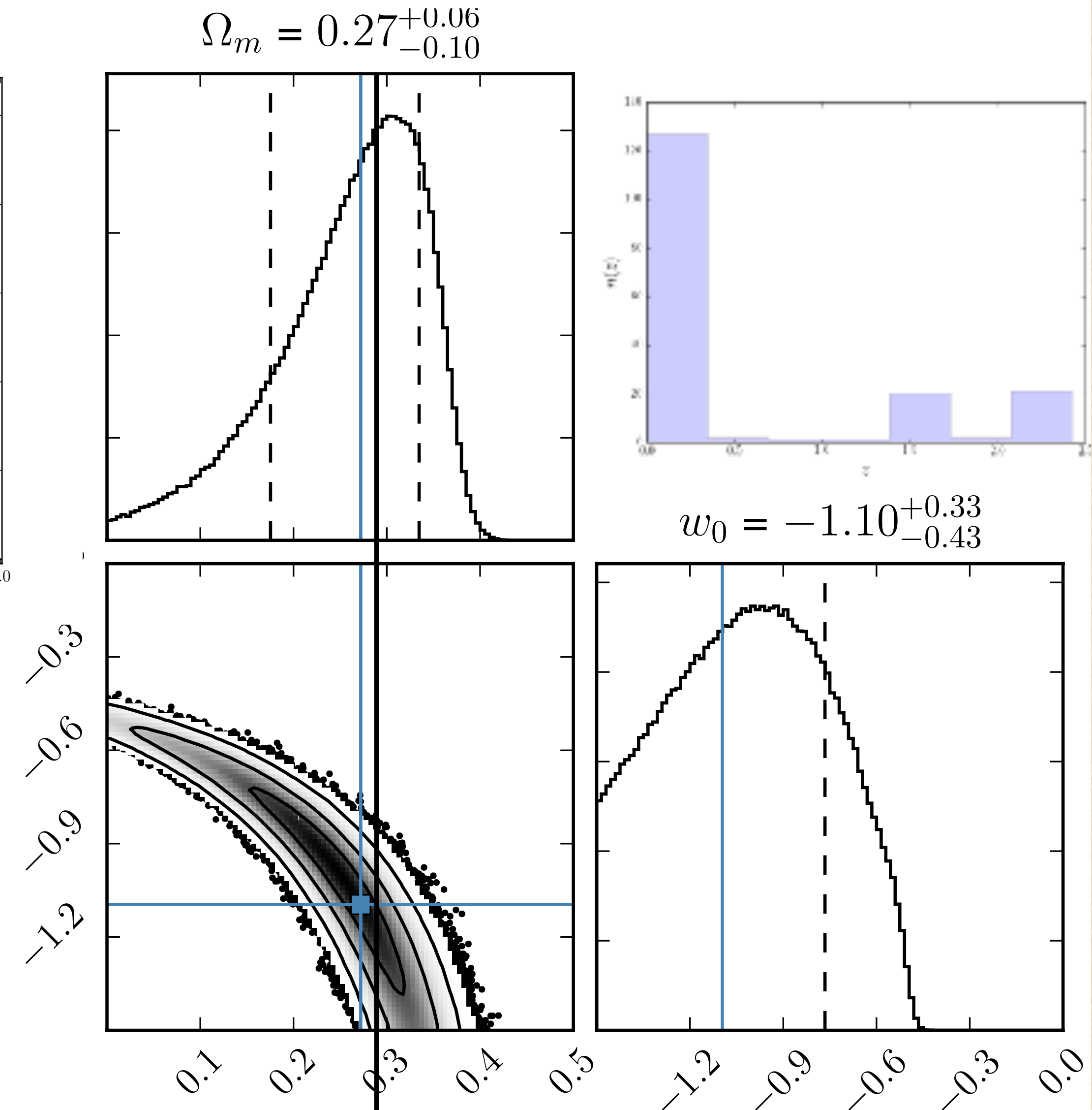


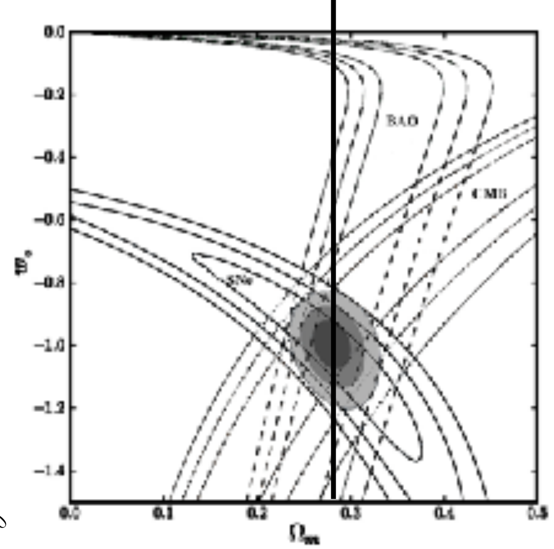
The L-sigma relation including high z HIIG



Preliminary results including our MOSFIRE high z HIIG







From Suzuki et al 2012

Preliminary results including our MOSFIRE high z HIIG data

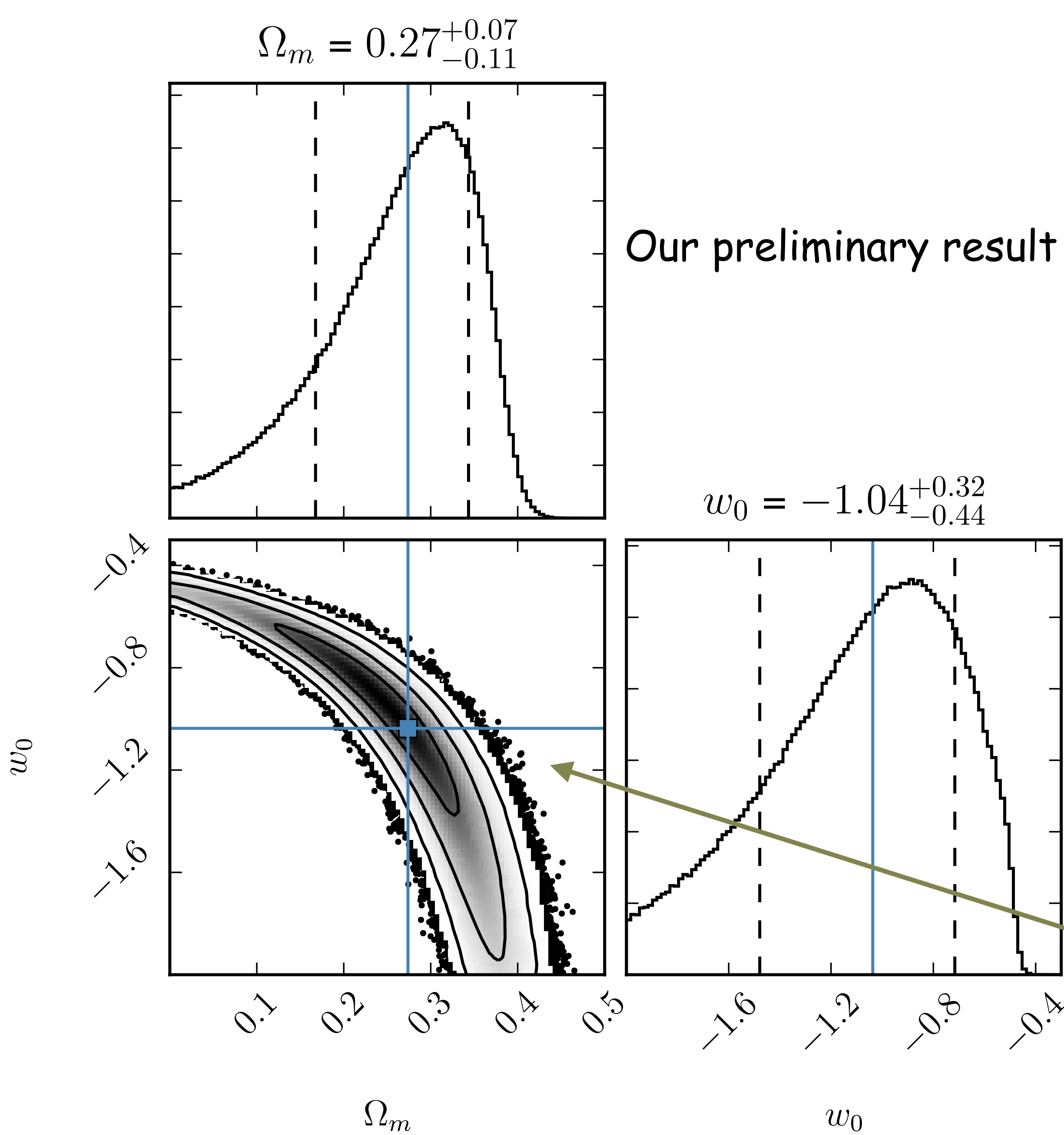
Our MCMC result for a flat universe ($\Omega_k = 0$) with H_0=74.3.

$\Omega_m = 0.27^{+0.07}_{-0.11}$ and $w = -1.04^{+0.32}_{-0.44}$ (only statistical uncertainties)

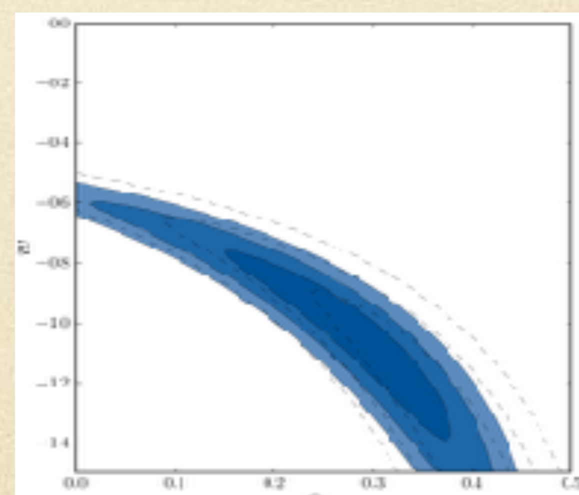
The sample has 109 local HIIG and 22 high z HIIG with high quality data from VLT-XShooter and KECK-MOSFIRE.

The Suzuki et al 2012 580 SNIa solution with statistical uncertainties only gives

$\Omega_m = 0.28^{+0.07}_{-0.09}$ and $w = -1.01^{+0.21}_{-0.23}$



Our preliminary result



Amanullah et al 2010 (dashed)
Suzuki et al 2012 (shadow)

(same scale)

CONCLUSIONS

- HIIG explore a range of high z ($1.5 < z < 3.5$) that is not available to other methods (SNIa and BAO). This range is crucial to study the evolution of the DE equation of state.
- Results are very promising. Cosmology with HIIG and GHIIR is becoming highly competitive. Needs more data and more work.
- The fact that our results are in line with those from SN, BAO and CMB implies that our basic assumptions are correct.
- We will learn more about massive star formation that in turn will allow a better distance estimator.
- Expansion to higher z ($z \sim 7$) depends on availability of instrumentation.