What are the youngest galaxies telling us about Cosmology?

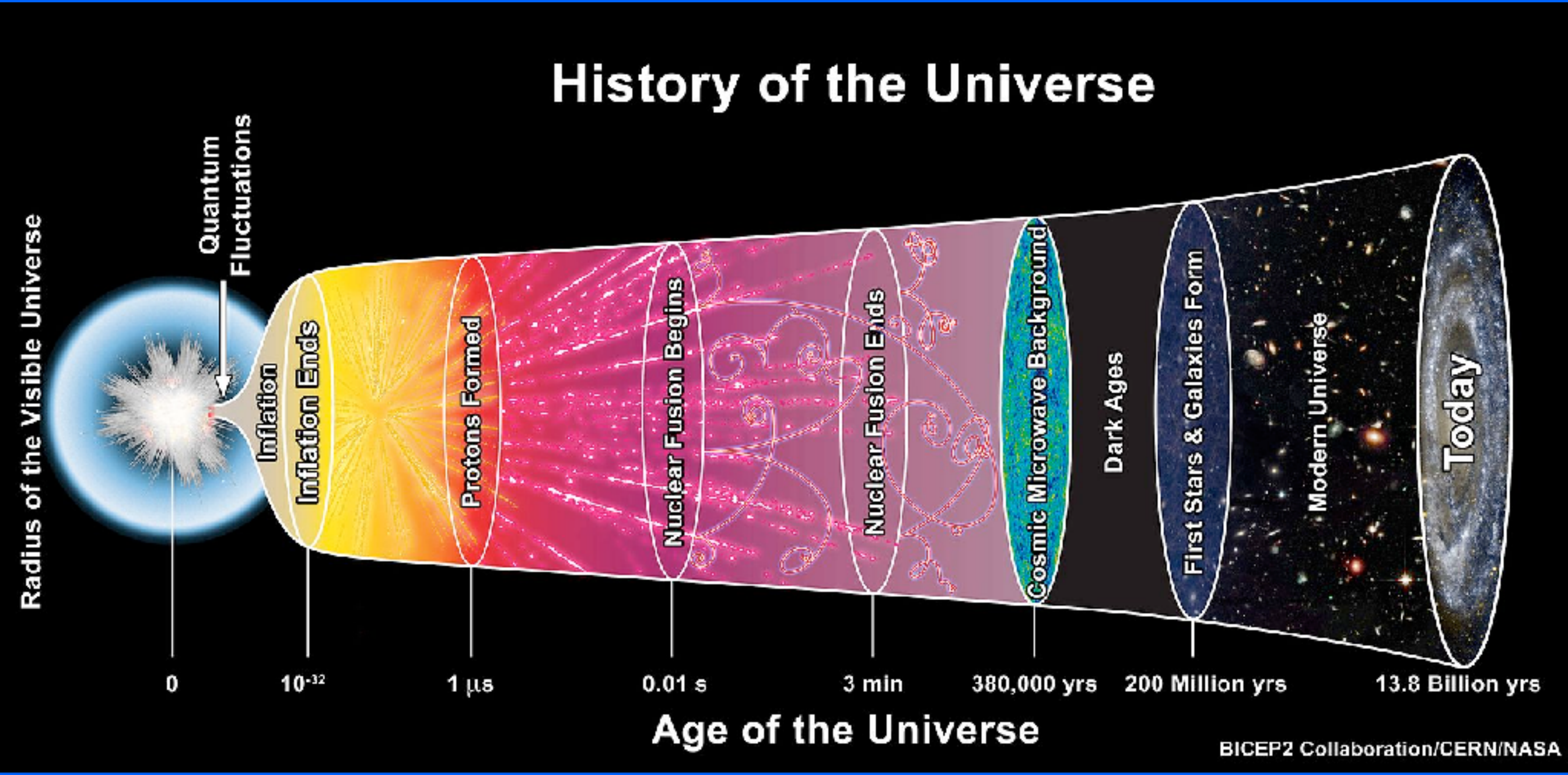
Roberto Terlevich , INAOE(Mexico), IoA(UK)

<u>David Fernandez Arenas, INAOE</u>*
<u>Ana Luisa Gonzalez, INAOE</u>*
Elena Terlevich,INAOE
Ricardo Chavez, Cavendish Lab. Univ. of Cambridge
Fabio Bresolin, IfA-Hawaii
Jorge Melnick, ESO
Manolis Plionis, NAO & AU Greece
Spyros Basilakos, Science Academy-Athens
Eduardo Telles, Observatorio Nacional, Rio de Janeiro

** PhD Students*

The evolution of the Universe can be compared to a display of fireworks that has just ended: some few wisps, ashes and smoke. Standing on a cooled cinder, we see the slow fading of the suns, and we try to recall the vanished brilliance of the origin of the worlds.

George-Henri Lemaítre



History of the Universe

BICEP2 Collaboration/CERN/NASA

The pillars of the Big Bang theory

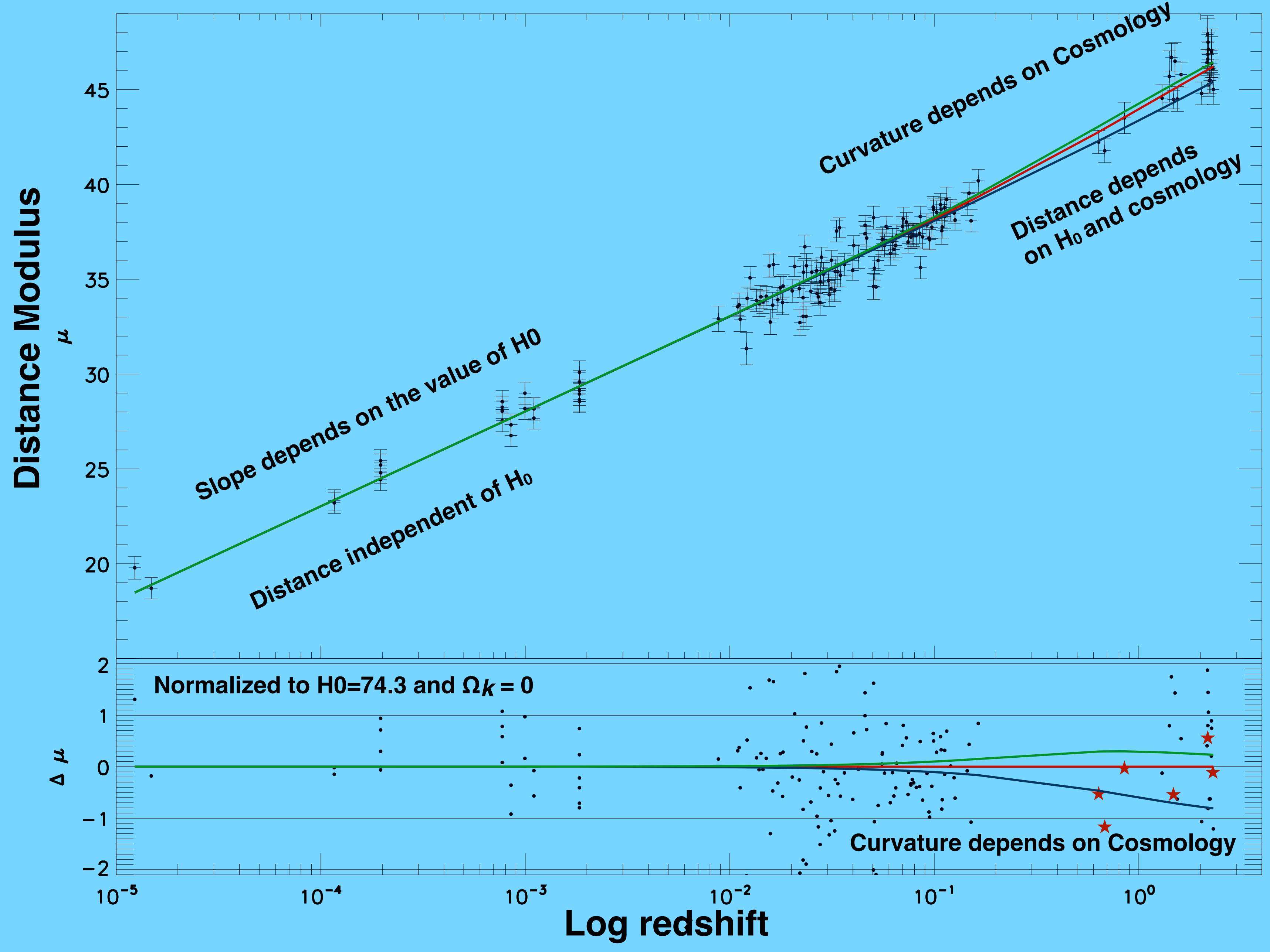
1. The expansion or Hubble's Law
2. The Cosmic Backgroud Radiation
3. The abundance of Helium and Deuterium

EVOLUTION

- How are cosmic time scales estimated?
- Two independent methods have historically been used.
- One is the age of the oldest stars.
- The other is the time scale of the expansion of the Universe.
- One expects the Universe to be older than the stars. This was not always achieved in the past.

The Hubble diagram

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

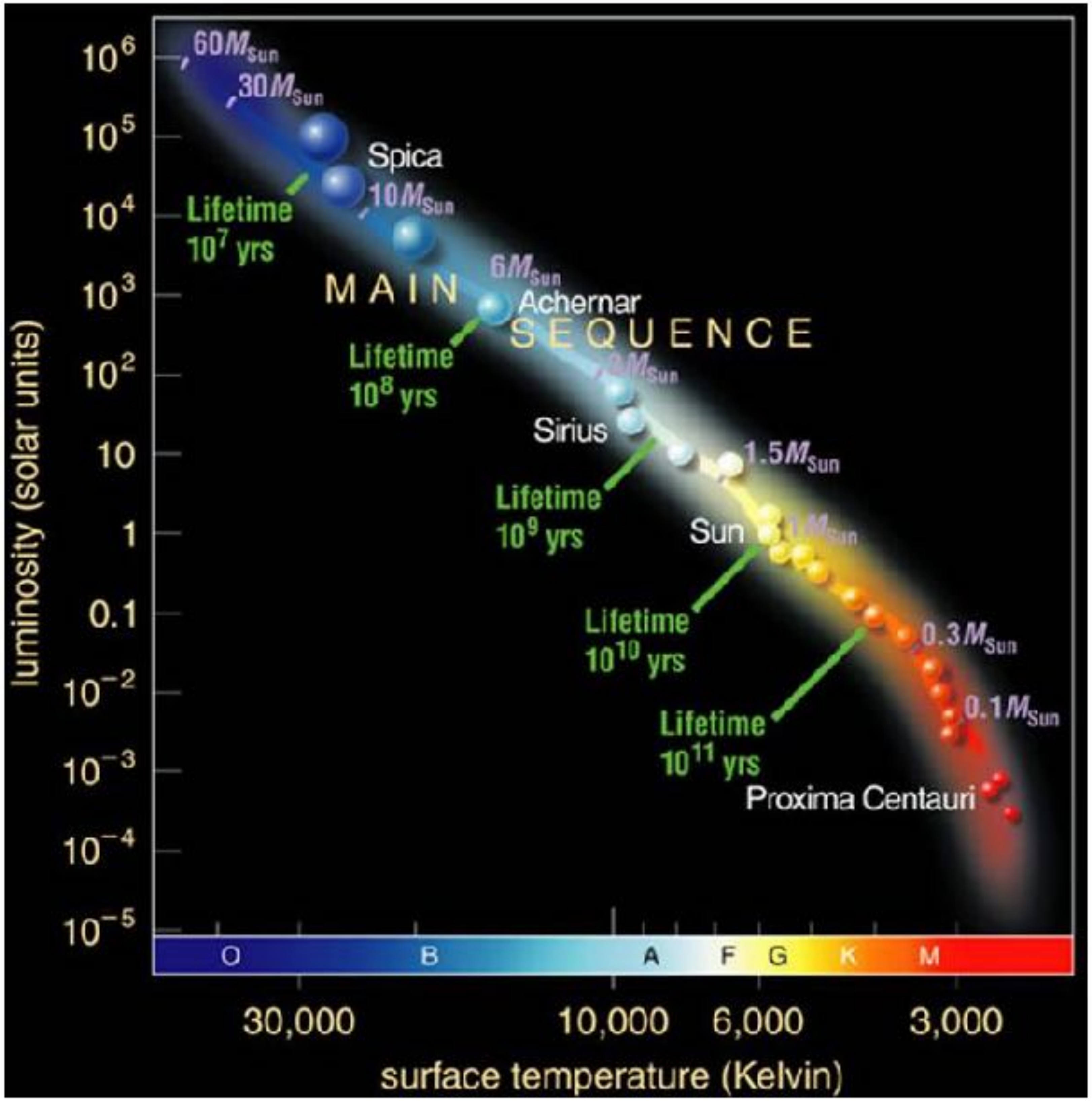


The universe is expanding, knowing the expansion rate of the Universe — the Hubble constant — is the key to determine the universe's age.

If the Universe had the same current properties and expansion rate as today but were made of 100% normal matter and no dark matter or dark energy, and the Hubble constant were 50 km/s/Mpc instead of 70 km/s/Mpc, our Universe would be 16 Gyr old.

With the combination of ingredients we have today, however, the age of the Universe is 13.8 Gyr with a small uncertainty.

The life time of stars



Most stars fall somewhere on the ***main sequence*** of the H-R diagram

This narrow correlation between the temperature (colour) and the luminosity of stars represents the basis of our understanding of the structure and evolution of stars.
Is also an illustration of the difficulties encountered by astrophysicists

Calculating the life-time of the Sun: its time-to-empty.

We know the mass of the Sun, its luminosity and chemical composition.

The luminosity of the Sun is generated in its core by a nuclear reaction where four hydrogen atoms transform into a helium atom. Every time this happens a fix amount of energy is released.

The core of the Sun contains about 12 x 10^{55} hydrogen atoms (the amount of fuel)

The Sun Luminosity requires 8.8 x 10^{37} reactions/sec (rate of consumption) and each reaction requires 4 hydrogen atoms.

Sun's lifetime = (3 x 10^{55} reactions)/(8.8 x 10^{37} reactions/sec) = 3.4 x 10^{17} sec = 10.9 Gyr.

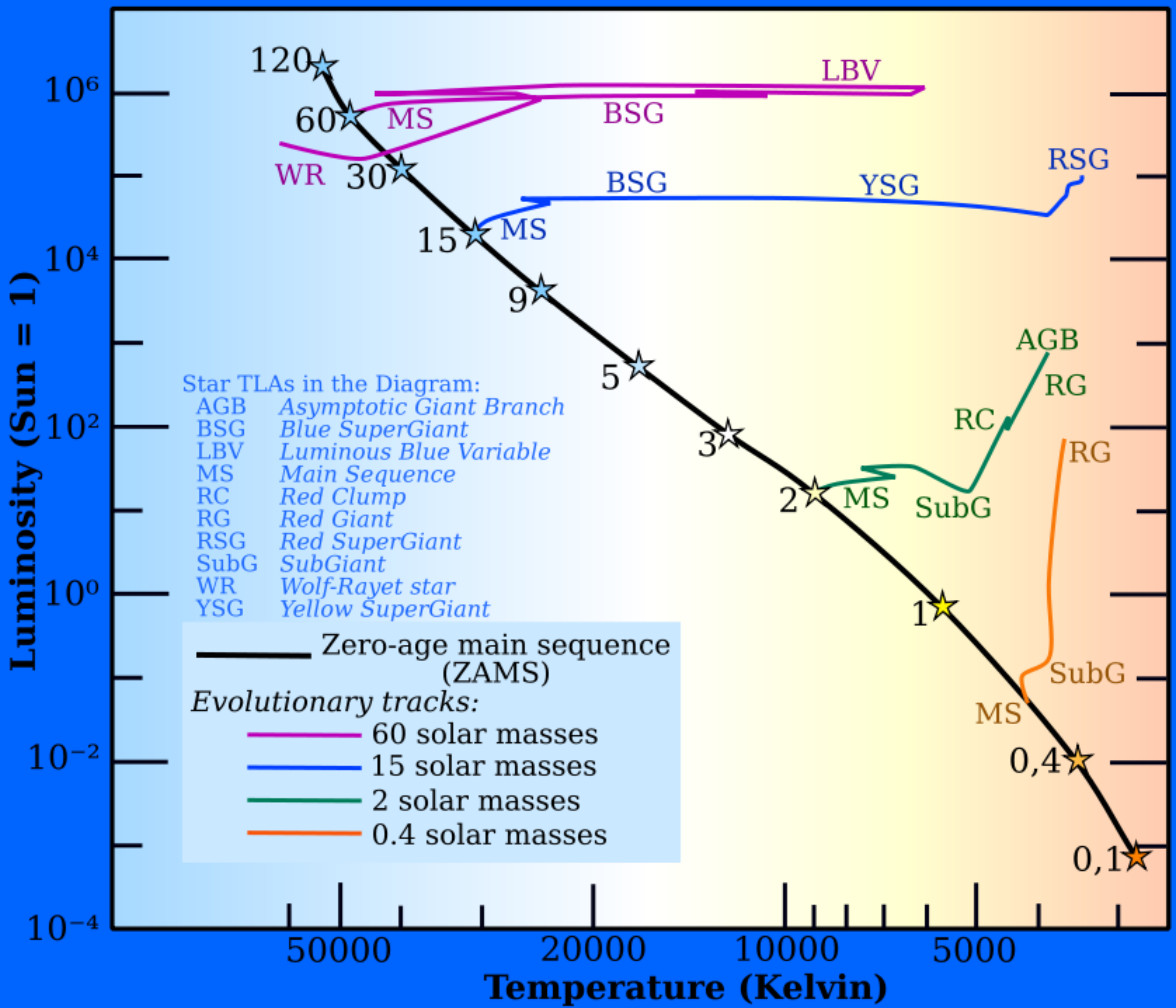
The oldest stellar systems known are the Globular clusters.

The stars in these clusters are slightly less massive than the Sun and a bit less luminous resulting in a life time of about 10.5 to 12 Gyr. These values are smaller than the age of the Universe.

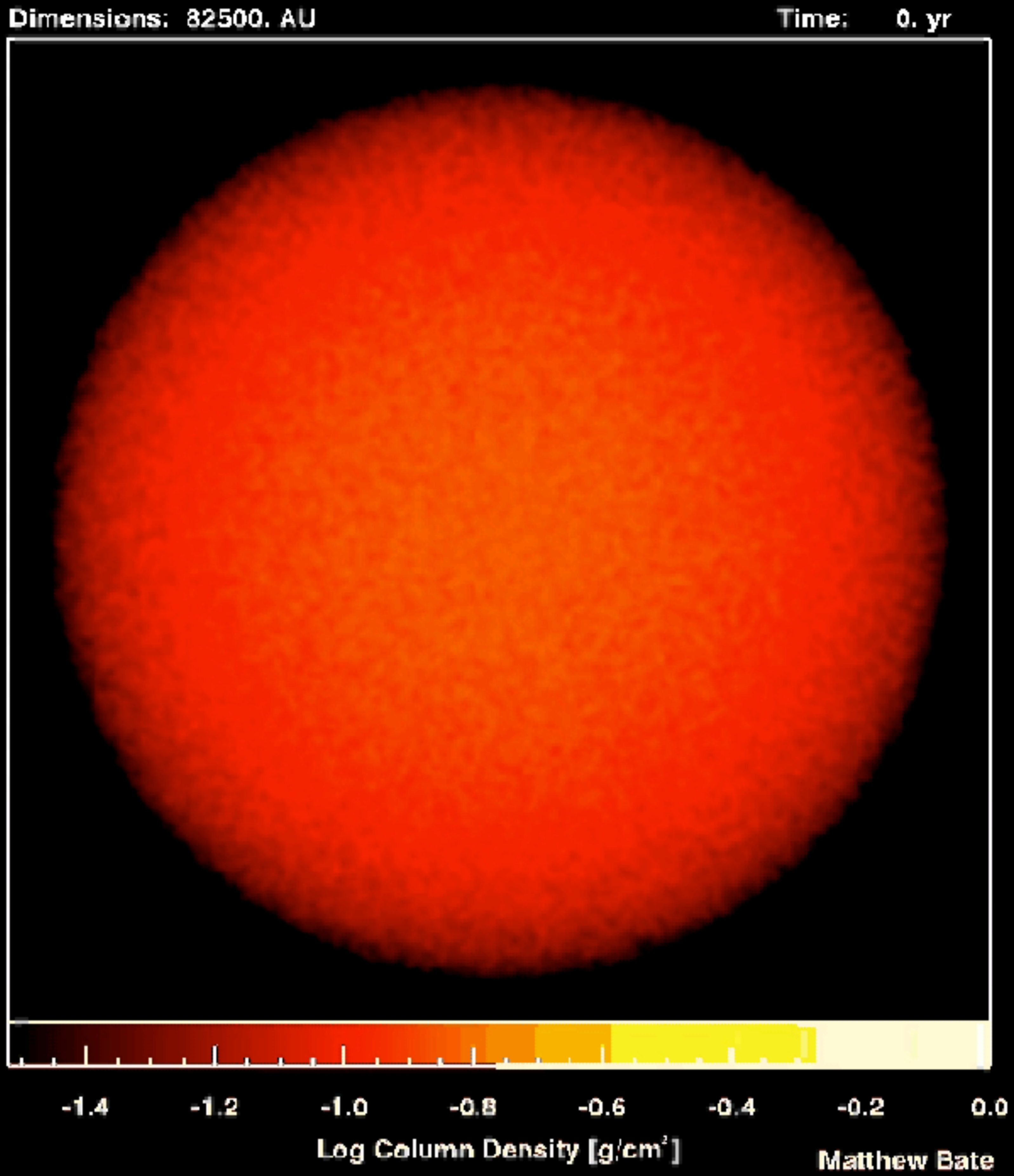
What about the youngest stars?

The most massive stars known have about 100 Solar masses and more than 10^6 Solar Luminosities, thus their lifetime will be at least 10^4 times shorter than that of the Sun i.e. less than 10^7 years. These stars are also very hot.

Thus to find young galaxies or young stellar clusters we look for luminous hot stars.


Luminosity (Sun = 1)
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
Temperature (Kelvin)
50000
20000
10000
5000
120
60
30
15
9
5
3
2
1
0,4
0,1
LBV
BSG
MS
WR
RSG
BSG
YSG
MS
AGB
RG
RC
MS
SubG
RG
SubG
MS
Star TLAs in the Diagram:
AGB Asymptotic Giant Branch
BSG Blue SuperGiant
LBV Luminous Blue Variable
MS Main Sequence
RC Red Clump
RG Red Giant
RSG Red SuperGiant
SubG SubGiant
WR Wolf-Rayet star
YSG Yellow SuperGiant
Zero-age main sequence (ZAMS)
Evolutionary tracks:
60 solar masses
15 solar masses
2 solar masses
0.4 solar masses

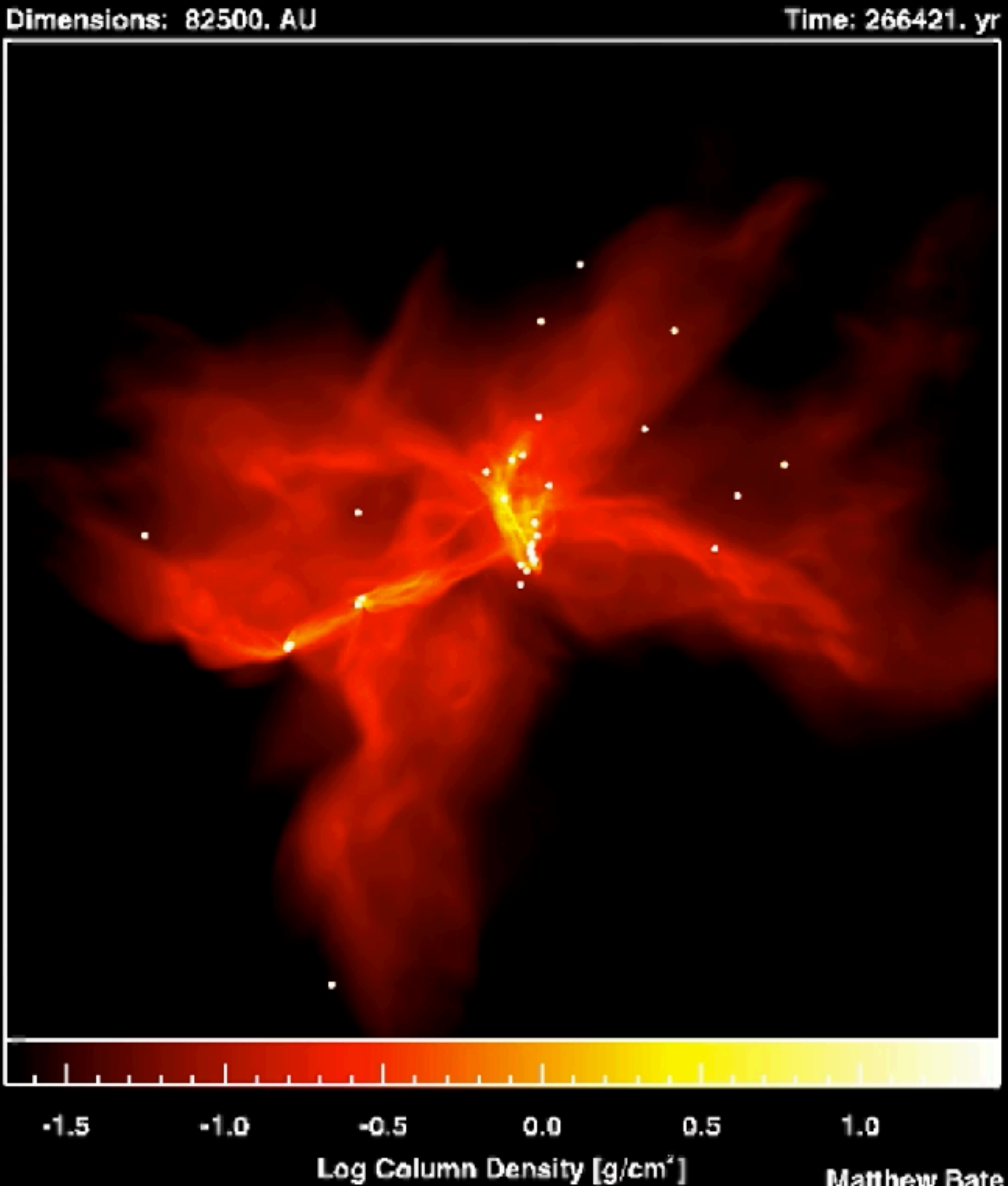
Lets look at a realistic simulation of cluster formation



Simulated star cluster formation (M. Bate)

The massive stars formed from the initial cold and dense molecular cloud are hot and emit most of their luminosity as UV photons of more than 13.6ev thus capable of ionising the remainder hydrogen that did not end up in stars.

We call these ultra young systems,
HII regions, HII being the spectroscopic notation for ionised hydrogen (H^+ in atomic physics notation). They are very bright in the optical region of the spectrum.

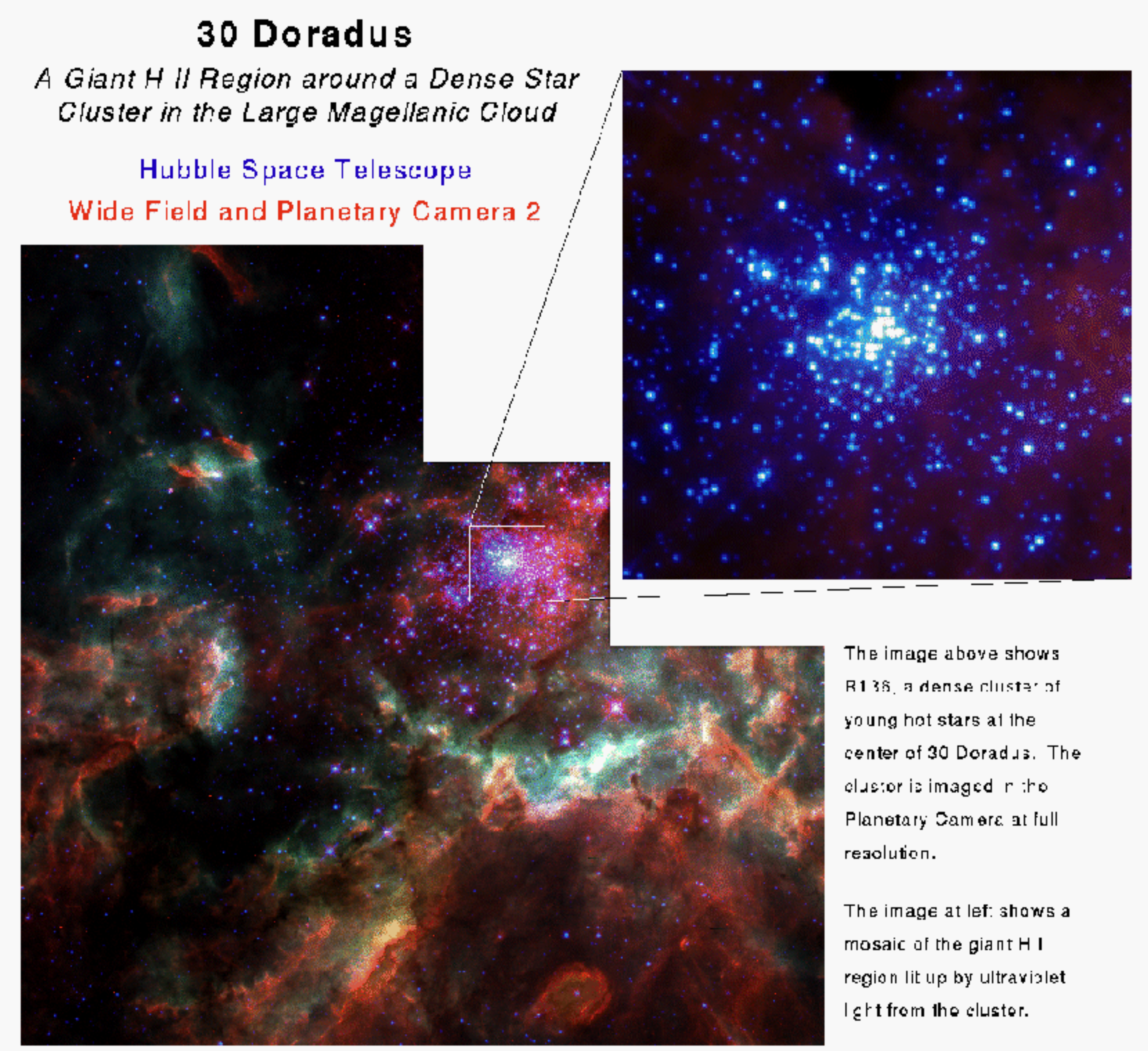

Dimensions: 82500. AU
Time: 266421. yr
-1.5
-1.0
-0.5
0.0
0.5
1.0
Log Column Density [g/cm^2]
Matthew Bate

The prototypical giant star forming region - 30 Doradus in the LMC

The Tarantula Nebula (VLT KUEYEN + FORS2)

ESO PR Photo 05a/00 (8 February 2000)

© European Southern Observatory



30 Doradus

A Giant H II Region around a Dense Star Cluster in the Large Magellanic Cloud

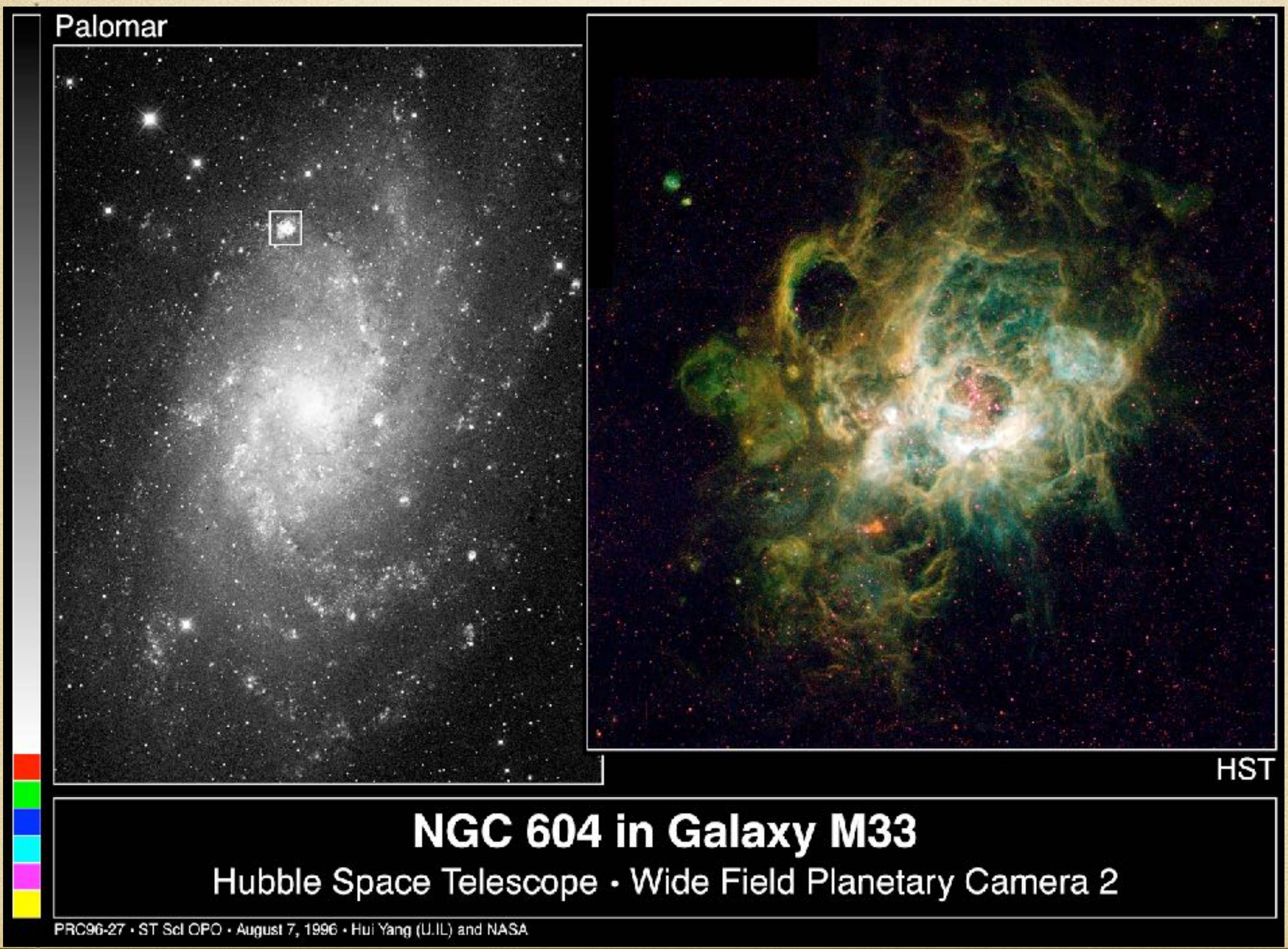
Hubble Space Telescope

Wide Field and Planetary Camera 2

The image above shows R136, a dense cluster of young hot stars at the center of 30 Doradus. The cluster is imaged in the Planetary Camera at full resolution.

The image at left shows a mosaic of the giant H II region lit up by ultraviolet light from the cluster.

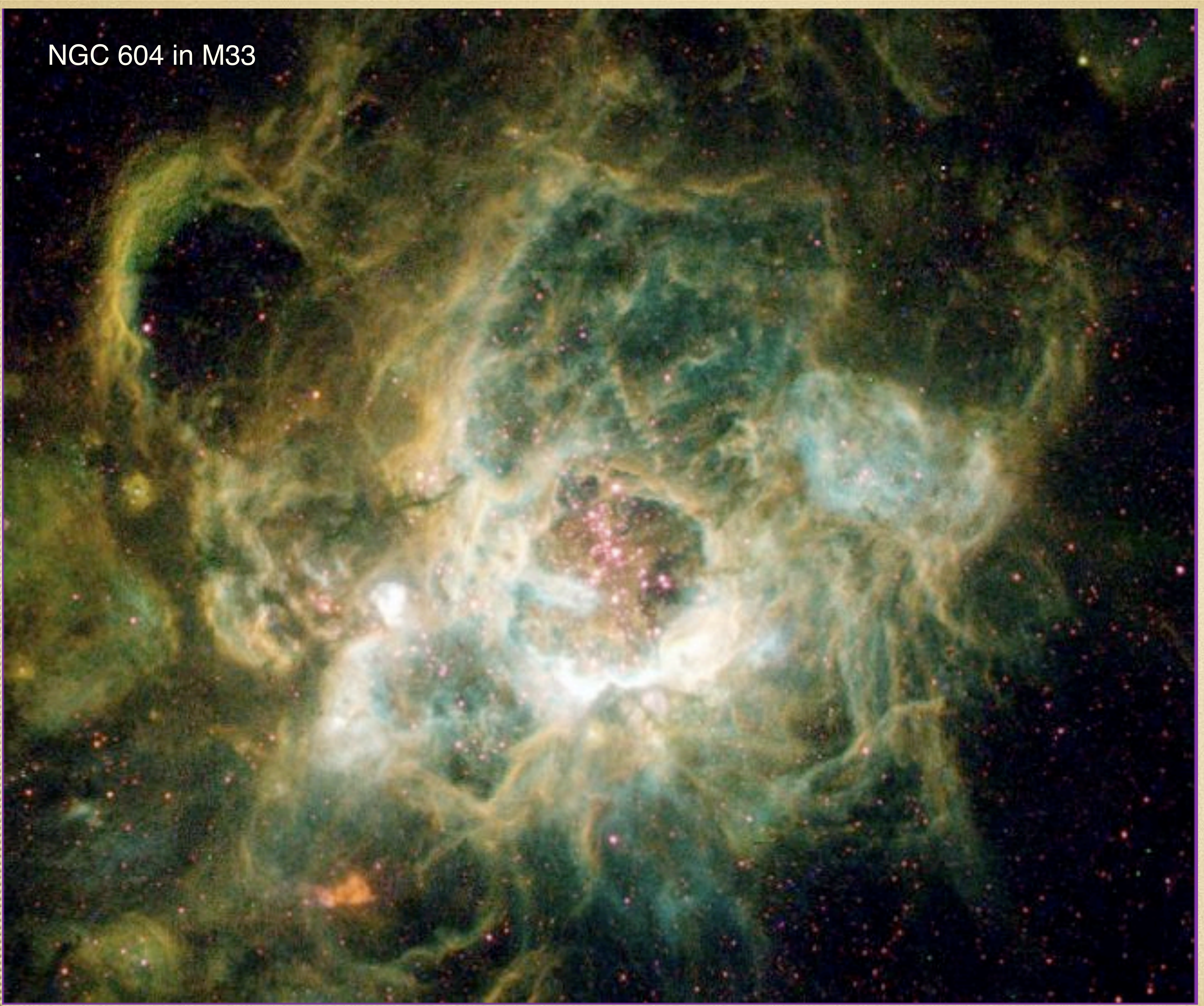
Another prototypical massive region of star formation



NGC 604 in Galaxy M33

Hubble Space Telescope • Wide Field Planetary Camera 2

PRC96-27 • ST ScI OPO • August 7, 1996 • Hui Yang (U.IL) and NASA



NGC 604 in M33

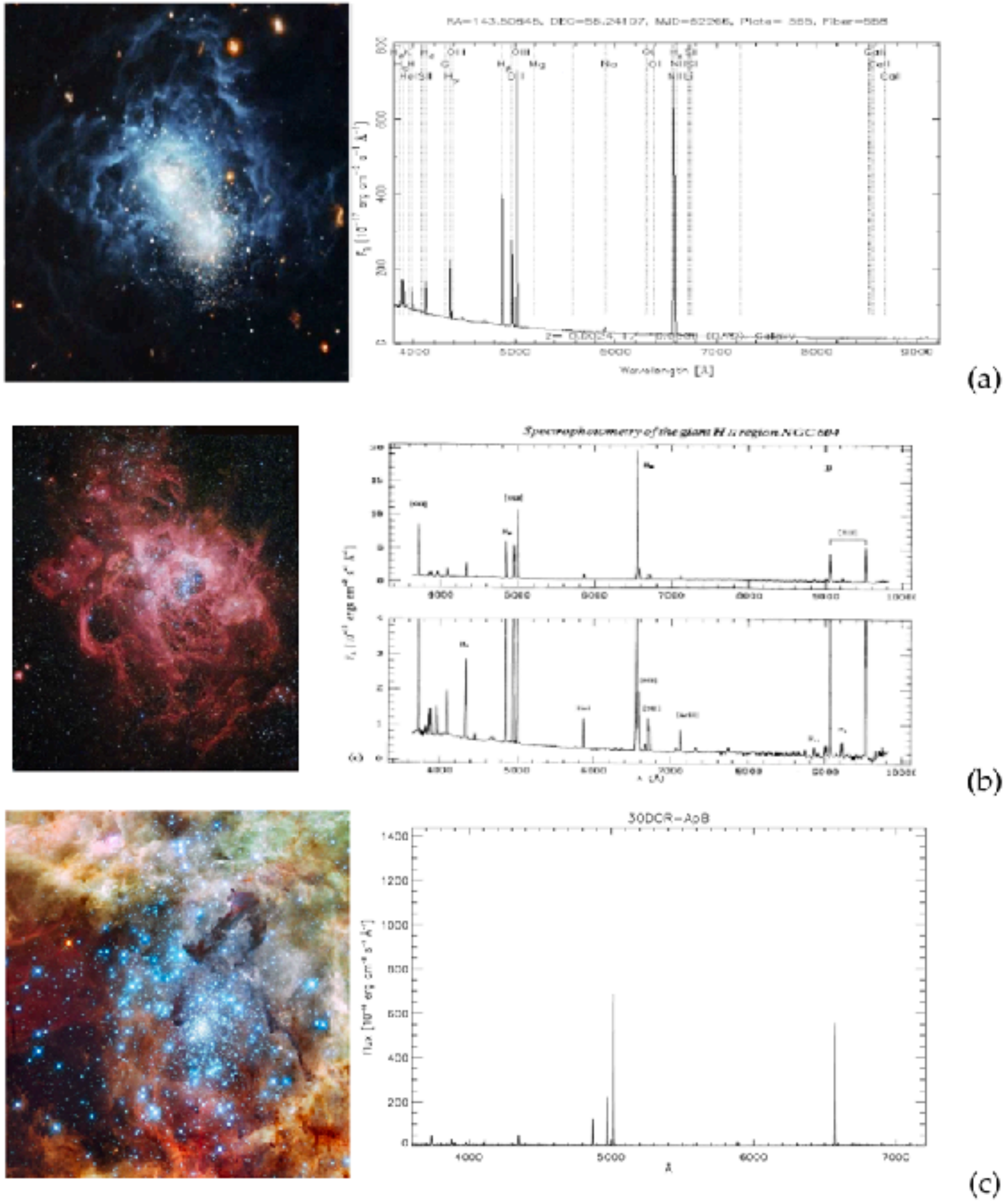


Figure 2.3: (a) Spectra and images of one HII galaxy (IZw18); (b) H II region in M33 (NGC 604) and (c) 30 Dorado, the spectra were taken from Sloan Digital Sky Survey (SDSS), (Díaz et al., 1987) and Terlevich et al. (1991b), credit for the images Hubble Space Telescope (HST).

Their optical spectrum is rich in narrow emission lines of H,He,O,N,S,Ne,Ar,C,....

Modern instrumentation and theory allows to make precise abundance determination of the above elements.

Particularly important is the helium abundance.

H II Galaxies = The youngest and more massive SSC

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

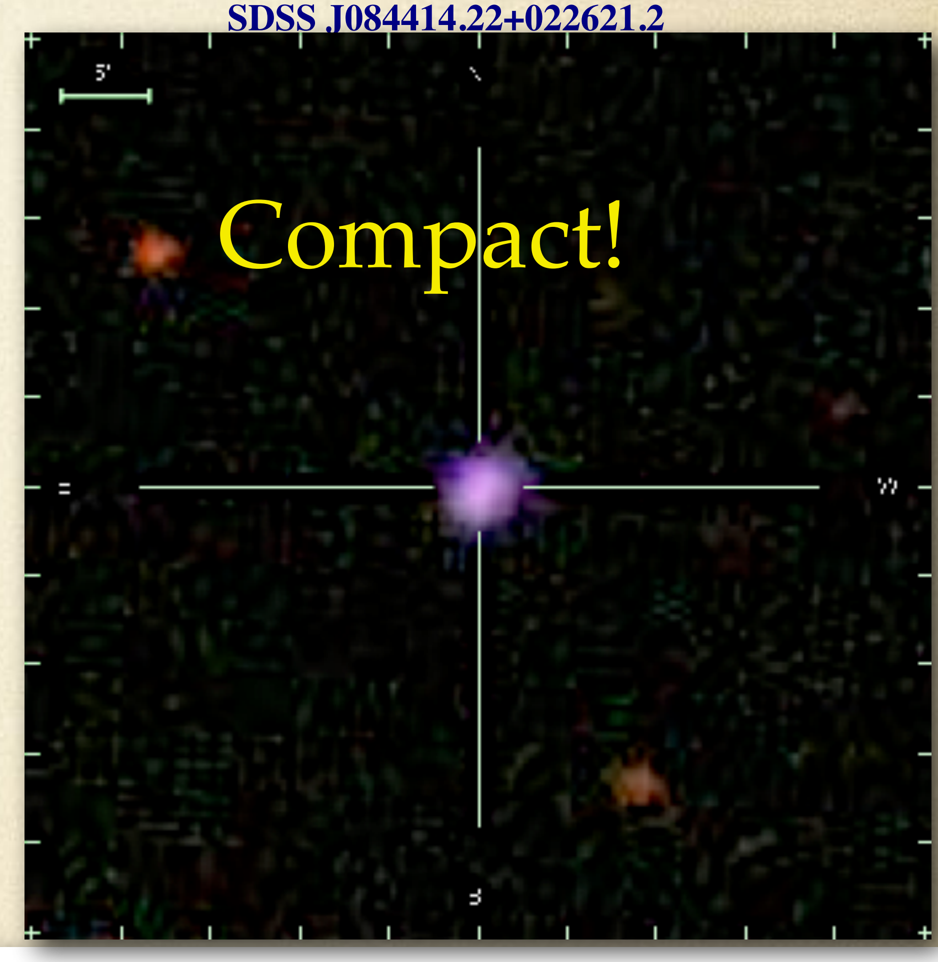
By selection the luminosity of HII galaxies is completely overwhelmed by that of the burst. As a consequence they show the spectrum of an HII region (that's what they are!) and they are very compact.

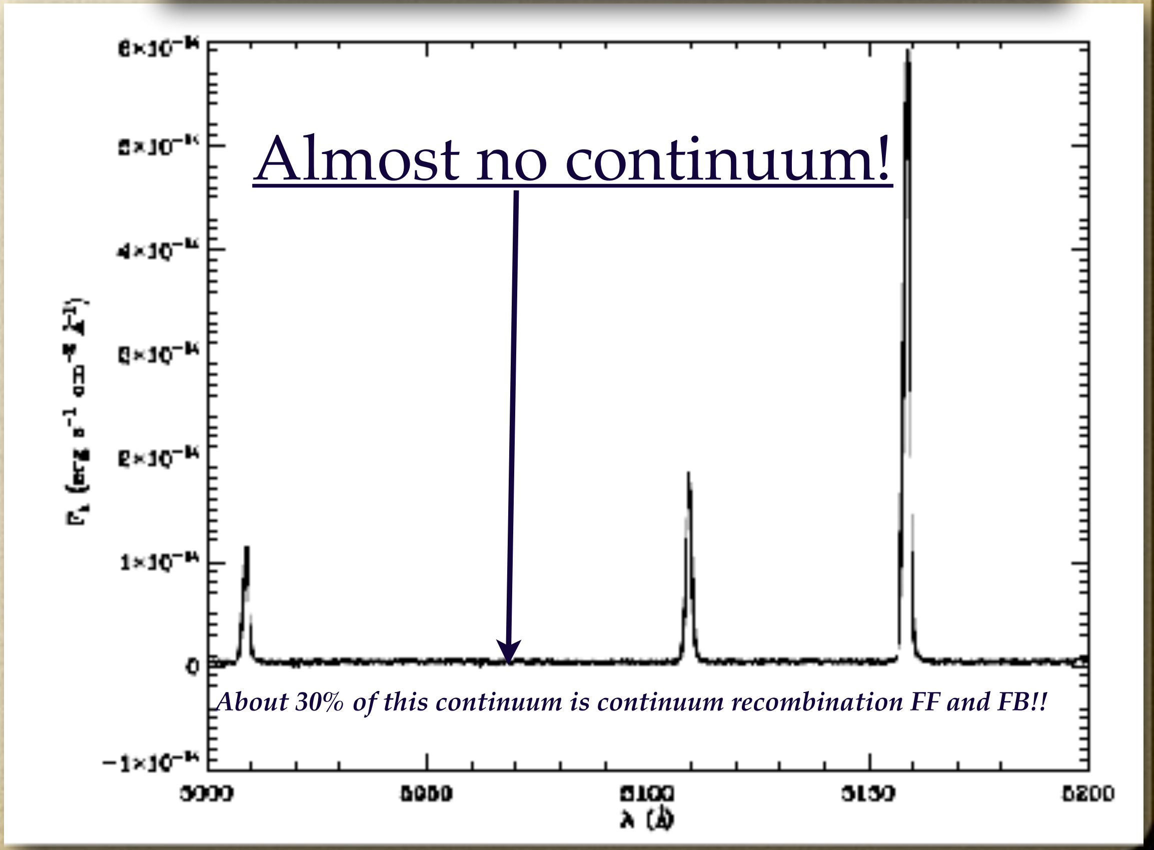
They are discovered mainly in spectroscopic surveys due to their strong narrow emission lines, i.e. very large equivalent width, EW(Hβ) >50Å or EW(Hα) >200Å.

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.

<u>**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.**</u>

SDSS J084414.22+022621.2





Evolution of the Equivalent width of Hβ in a burst (SB99)

EW = Line flux / Continuum flux (Hot stars number / Cold stars number)

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

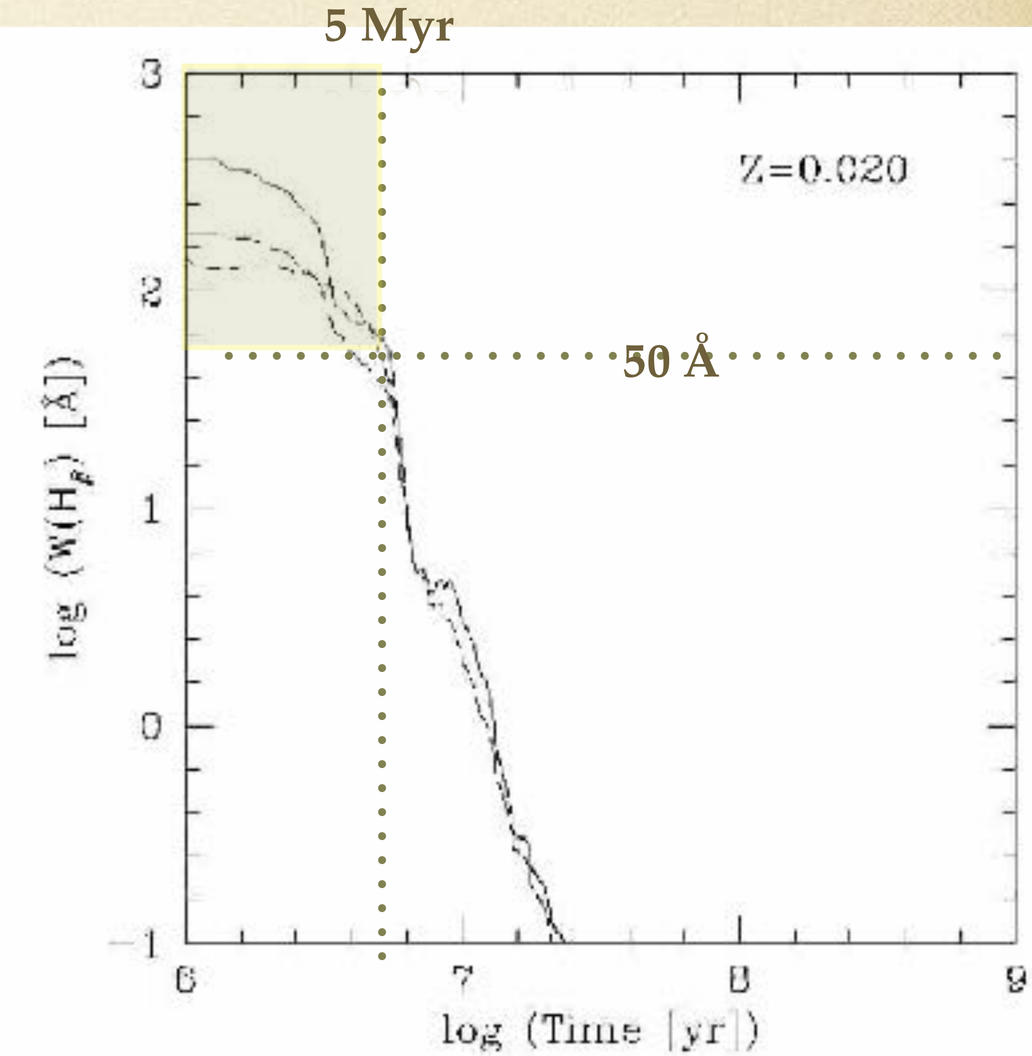


FIG. 85b

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

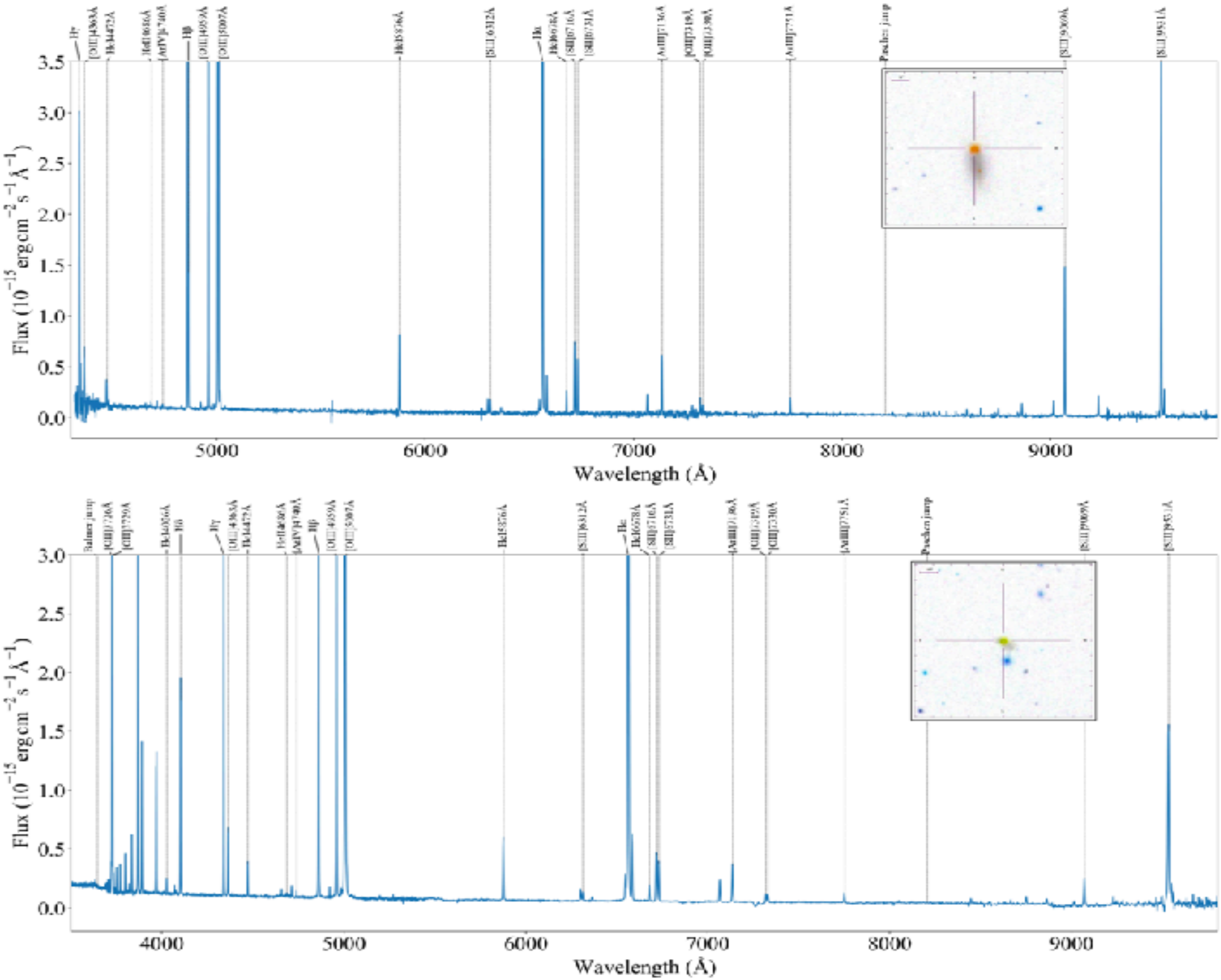


Figure 2. Sample of reduced spectra for objects FTDR6 (top, configuration I) and SHOC579 (bottom, Configuration II). Relevant lines are labelled. The object images belong to the SDSS database.

Hot Big-bang nucleosynthesis

- Gamow, Alpher, Herman (1945-1953)
- => created all the elements

ref.: Pagel, B. Nucleosynthesis and Chemical evolution of galaxies C.U.P. 2nd. edition (2009)

Hot Big-bang nucleosynthesis

- Hayashi (1950) into sound physics
- High ρ and T => thermal equilibrium => n,p freezing, + no stable nuclei with A=5,8 (triple collision of α-nuclei in stars... time consuming)
- => no nucleosynthesis after ^{4}He.
- + Successes in stellar evolution and nucleosynthesis theories (Burbidge,Burbidge,Hoyle & Fowler)...
- **BBNS was abandoned.**

Hot Bing-bang nucleosynthesis revived

…till Penzias and Wilson (1964) **CMB**

(predicted by Gamow et al.)

⇒SBBN … Peebles, Wagoner, Fowler, Hoyle, Schramm, Steigman, etc…

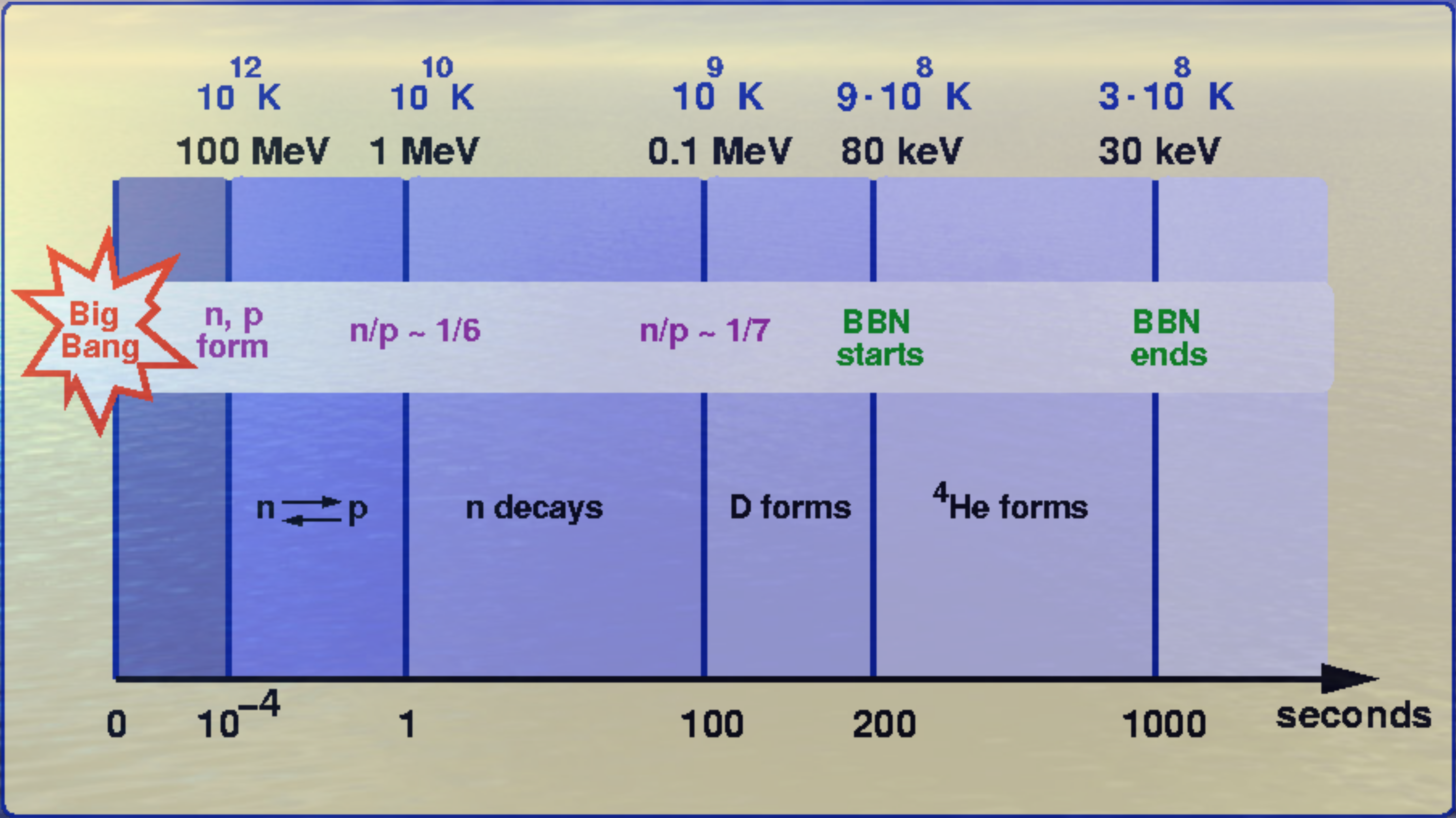
⇒**Successful:**

- ➢ Predicts primordial abundances of

  D, ^{4}He, ^{3}He, ^{7}Li

  covering 9 orders of magnitude.
- ➢ Predicts number of neutrino species.
- ➢ Predicts neutron half life.

The first light nuclides were synthesized in a short time interval following the Big Bang



10^{12} K
100 MeV

10^{10} K
1 MeV

10^{9} K
0.1 MeV

$9 \cdot 10^{8}$ K
80 keV

$3 \cdot 10^{8}$ K
30 keV

Big Bang

n, p form

n/p ~ 1/6

n/p ~ 1/7

BBN starts

BBN ends

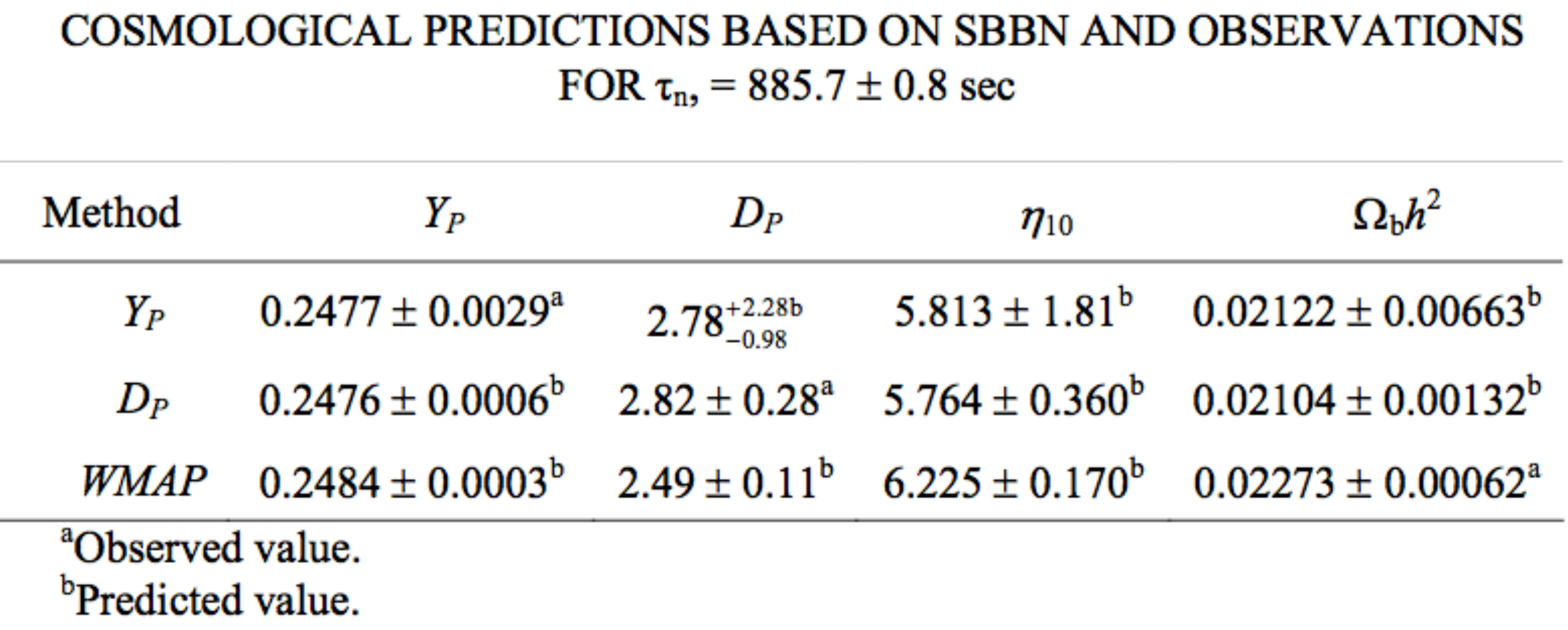
$n \rightleftarrows p$

n decays

D forms

^{4}He forms

0
10^{-4}
1
100
200
1000
seconds



COSMOLOGICAL PREDICTIONS BASED ON SBBN AND OBSERVATIONS FOR τ_{n}, = 885.7 ± 0.8 sec

Method	Y_P	D_P	η_{10}	$\Omega_b h^2$
Y_P	0.2477 ± 0.0029[a]	$2.78^{+2.28}_{-0.98}$[b]	5.813 ± 1.81[b]	0.02122 ± 0.00663[b]
D_P	0.2476 ± 0.0006[b]	2.82 ± 0.28[a]	5.764 ± 0.360[b]	0.02104 ± 0.00132[b]
WMAP	0.2484 ± 0.0003[b]	2.49 ± 0.11[b]	6.225 ± 0.170[b]	0.02273 ± 0.00062[a]

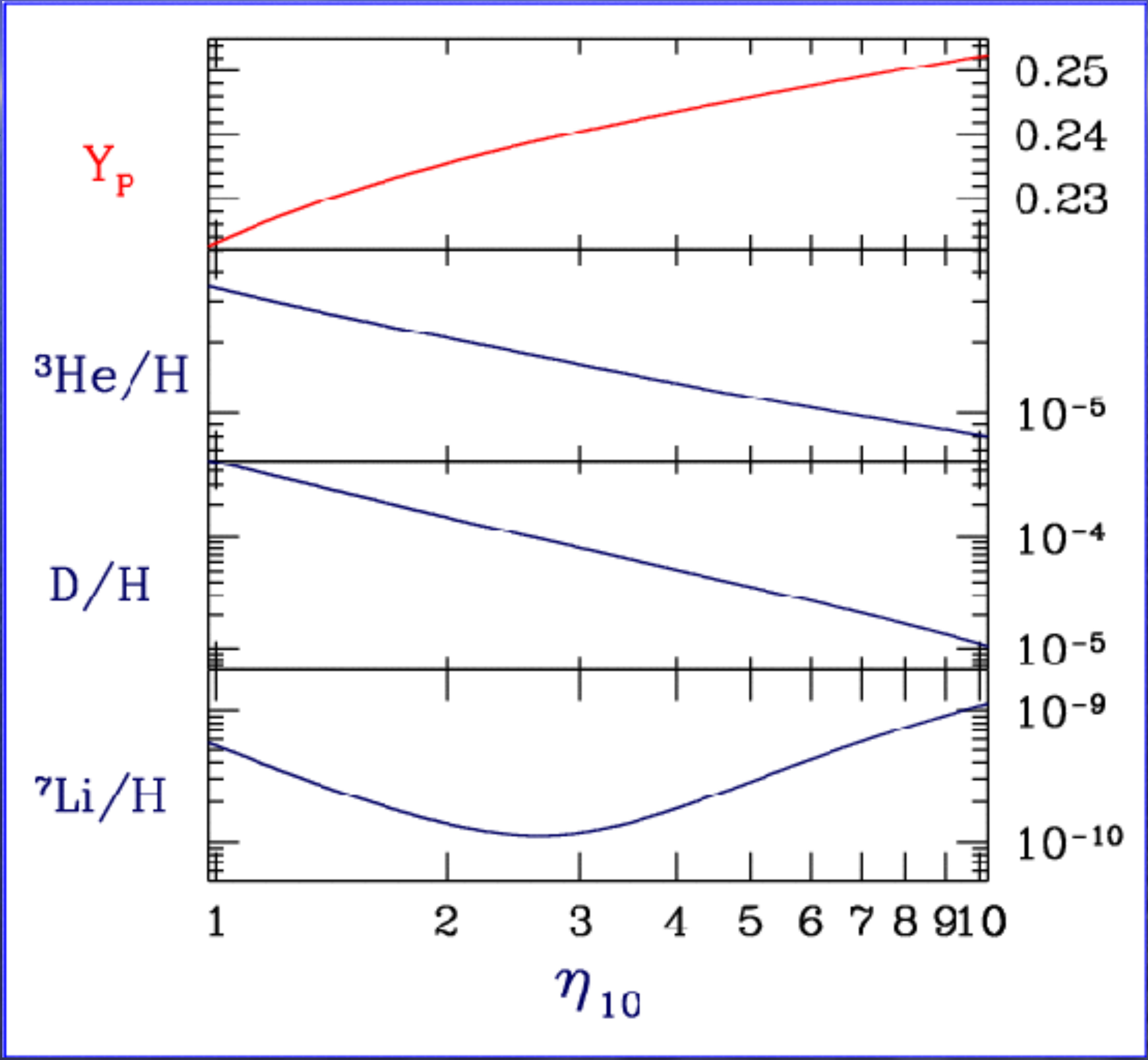
[a] Observed value.

[b] Predicted value.

From M. Peimbert (2008) review

The primordial abundances can be used to estimate the baryon-to-photon density η

the abundances of the first elements depend on the interplay between the reaction rates and the expansion of the Universe



(Fiorentini et al. 1998, PhRD 58, 63506)

^{4}He is the easiest to measure

but is the one least sensitive to η

How we know an element is primordial?

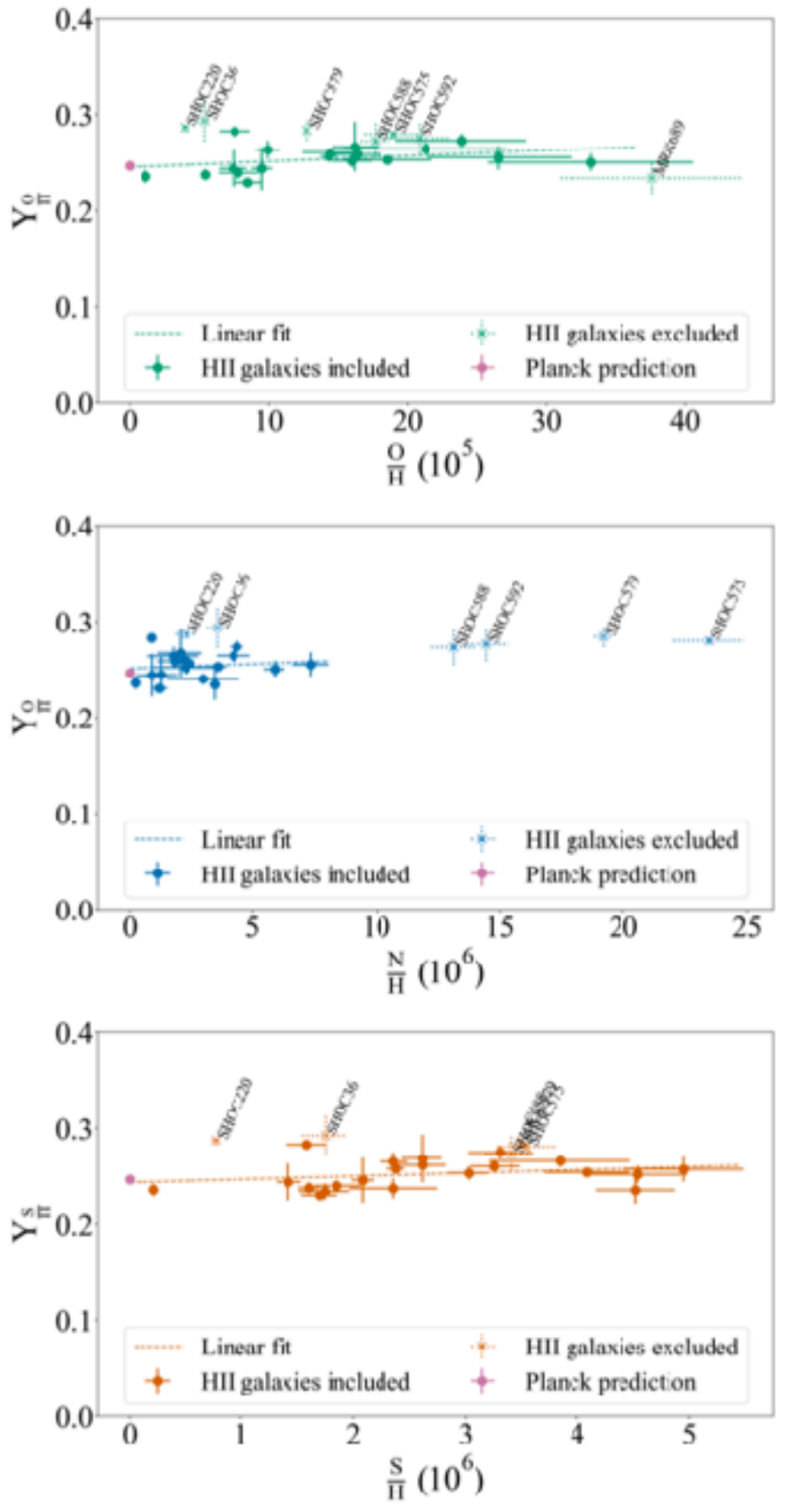


Figure 9. Primordial helium linear regressions using oxygen, nitrogen and sulphur as metalicity tracer.

Primordial elements have a non zero initial value while heavier elements should be absent in the first star generation or primeval clusters

Thus a plot of He vs a heavy element should show a "plateau". First noticed by Searle & Sargent (1970).

The primordial Helium value (Yp) is found by extrapolation of the He vs Z relation to O/H, N/H or S/H = 0.0

(Vital Fernández PhD thesis)

Cosmological implications

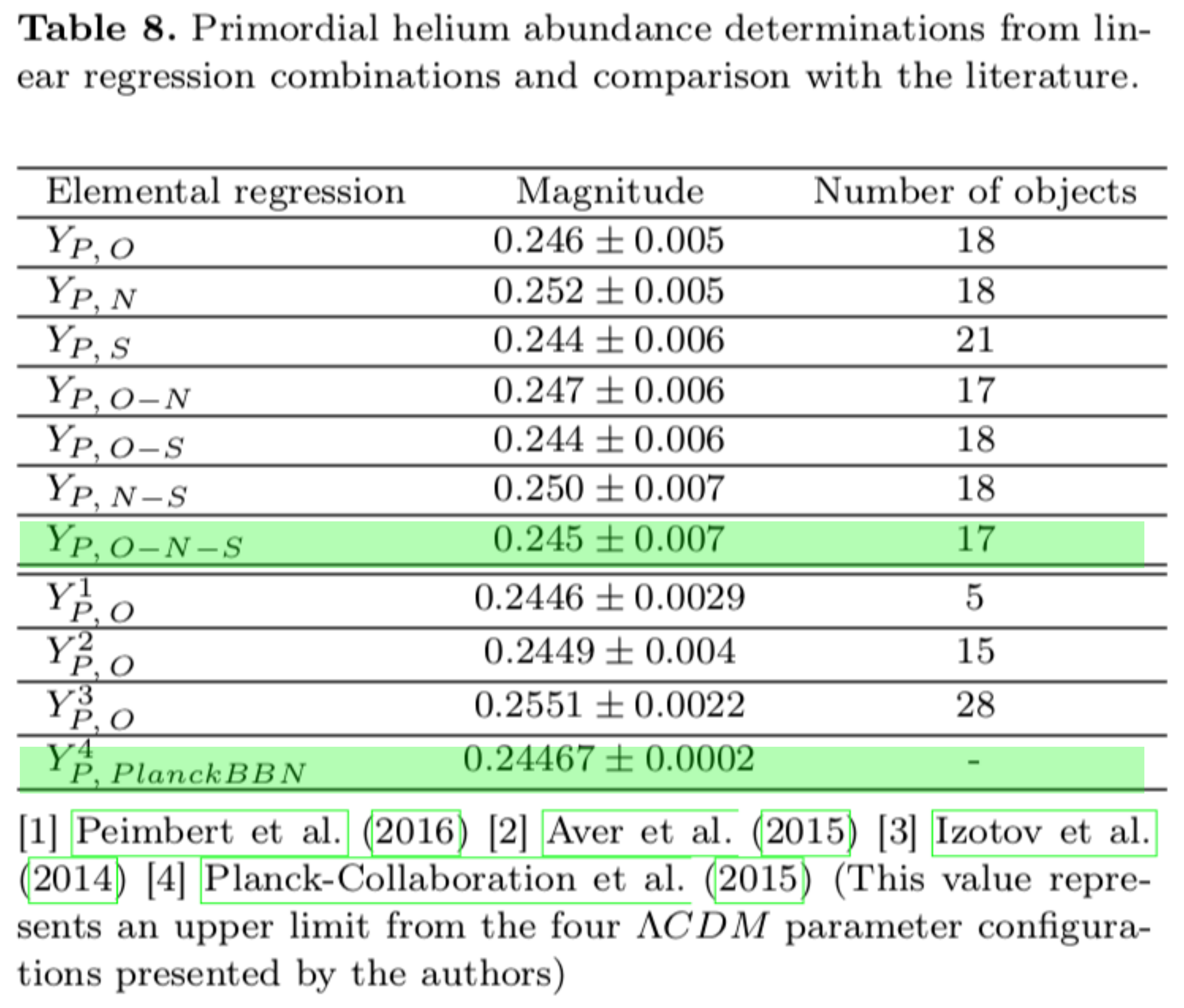


Table 8. Primordial helium abundance determinations from linear regression combinations and comparison with the literature.

Elemental regression	Magnitude	Number of objects
$Y_{P,\,O}$	0.246 ± 0.005	18
$Y_{P,\,N}$	0.252 ± 0.005	18
$Y_{P,\,S}$	0.244 ± 0.006	21
$Y_{P,\,O-N}$	0.247 ± 0.006	17
$Y_{P,\,O-S}$	0.244 ± 0.006	18
$Y_{P,\,N-S}$	0.250 ± 0.007	18
$Y_{P,\,O-N-S}$	0.245 ± 0.007	17
$Y^1_{P,\,O}$	0.2446 ± 0.0029	5
$Y^2_{P,\,O}$	0.2449 ± 0.004	15
$Y^3_{P,\,O}$	0.2551 ± 0.0022	28
$Y^4_{P,\,PlanckBBN}$	0.24467 ± 0.0002	-

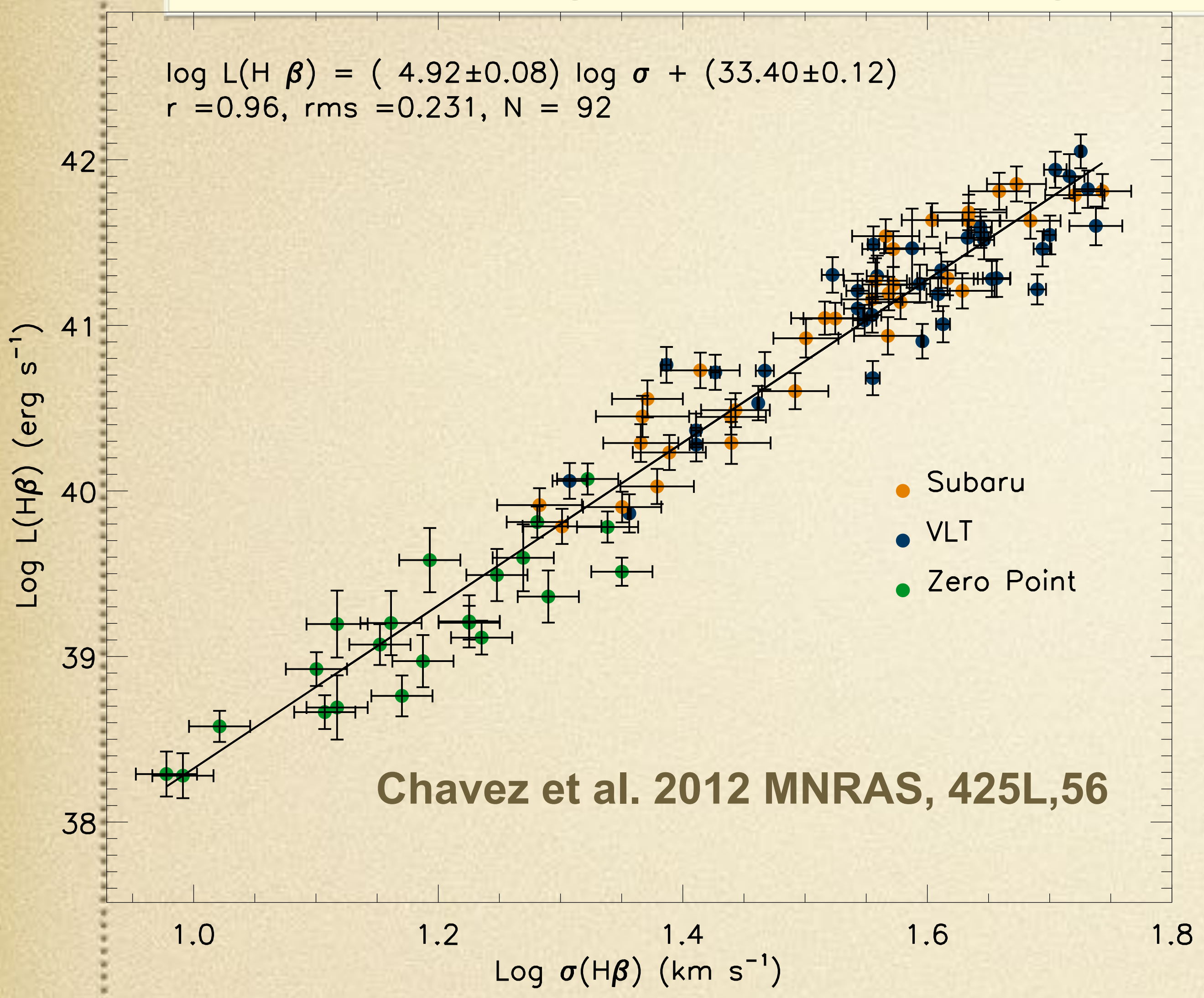
[1] Peimbert et al. (2016) [2] Aver et al. (2015) [3] Izotov et al. (2014) [4] Planck-Collaboration et al. (2015) (This value represents an upper limit from the four ΛCDM parameter configurations presented by the authors)

- The primordial He value obtained from HII galaxies (cosmology independent method) shows a good agreement with the estimate from the analysis of the fluctuations of the CBM (cosmology dependent).

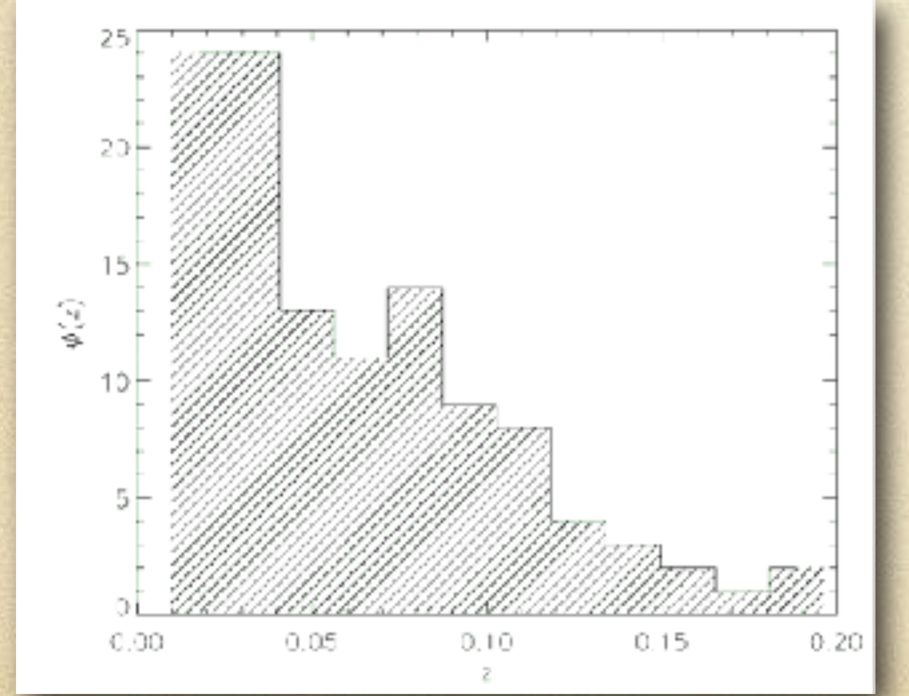
The Hubble constant

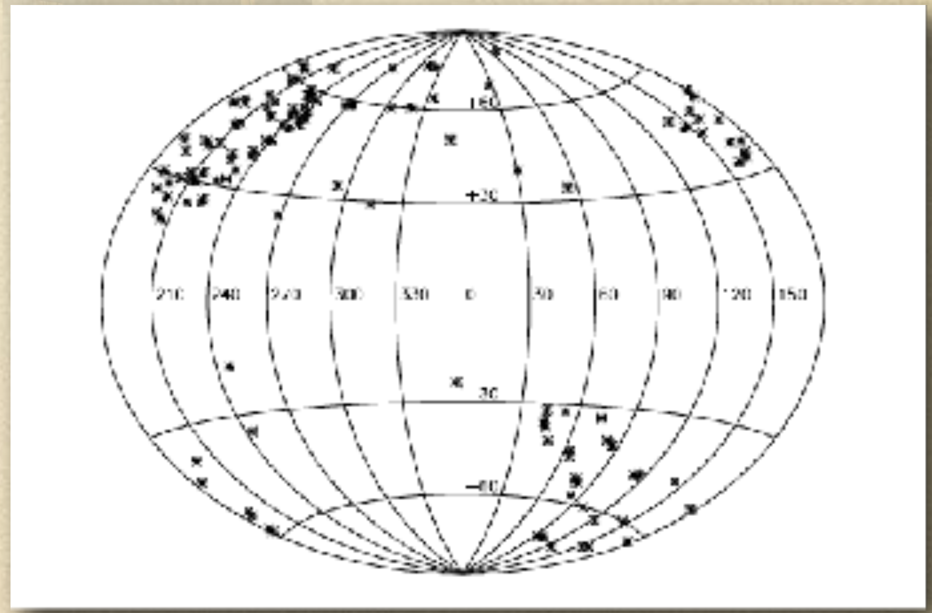
- H_0 determines the scale for all cosmological times and distances and allows to get to grips with the cosmological parameters breaking degeneracies among them (e.g. the equation of state for dark energy and the mass of the neutrinos).
- The expansion rate of the universe can either be <u>directly</u> measured or <u>estimated</u> for a particular cosmological model through analysis of the fluctuations of the cosmic microwave background (CMB).
- While direct methods measure the <u>local</u> H_0, the CMB estimate gives its value at $z \sim 1000$.

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

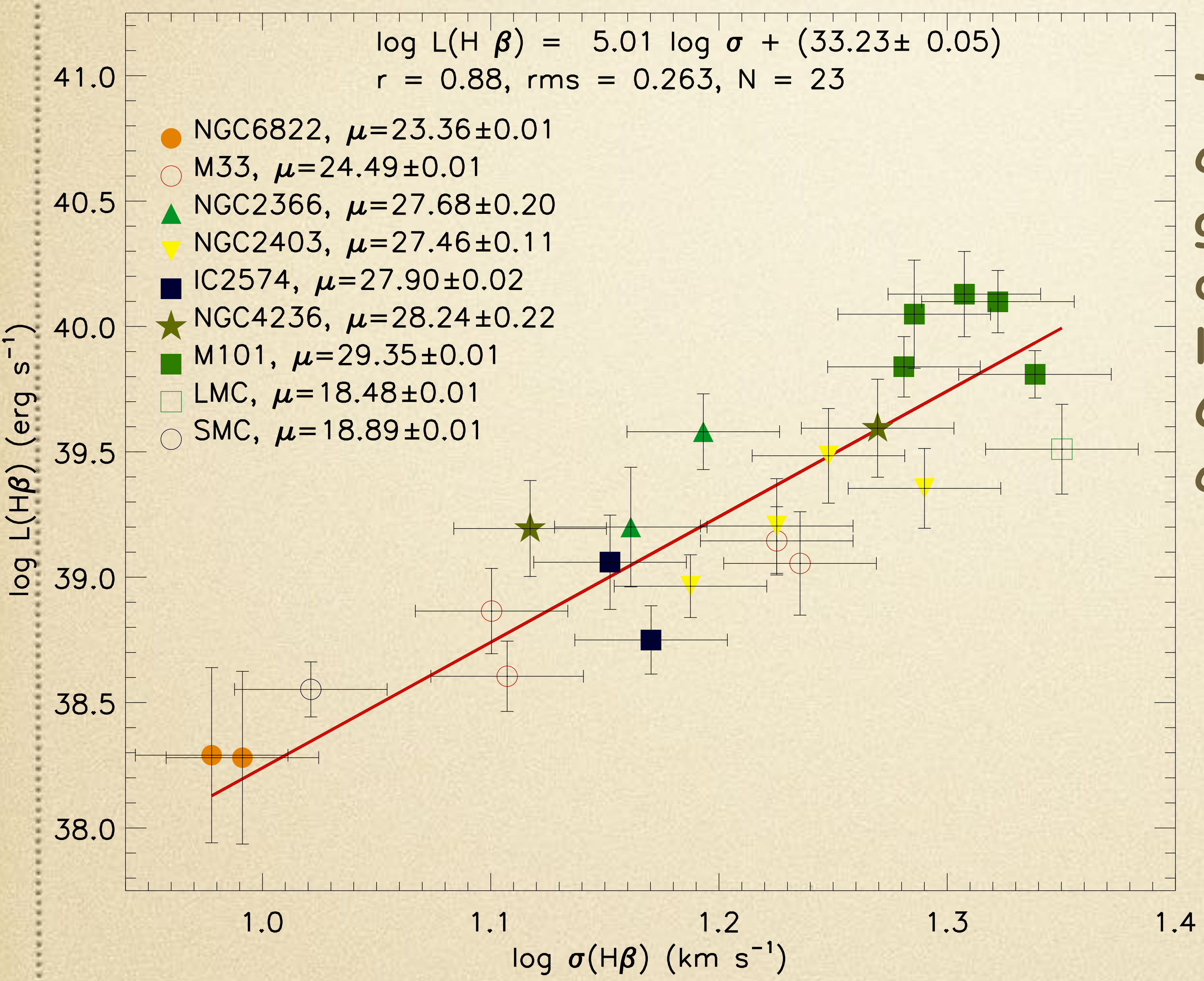


Chavez et al. 2012 MNRAS, 425L,56



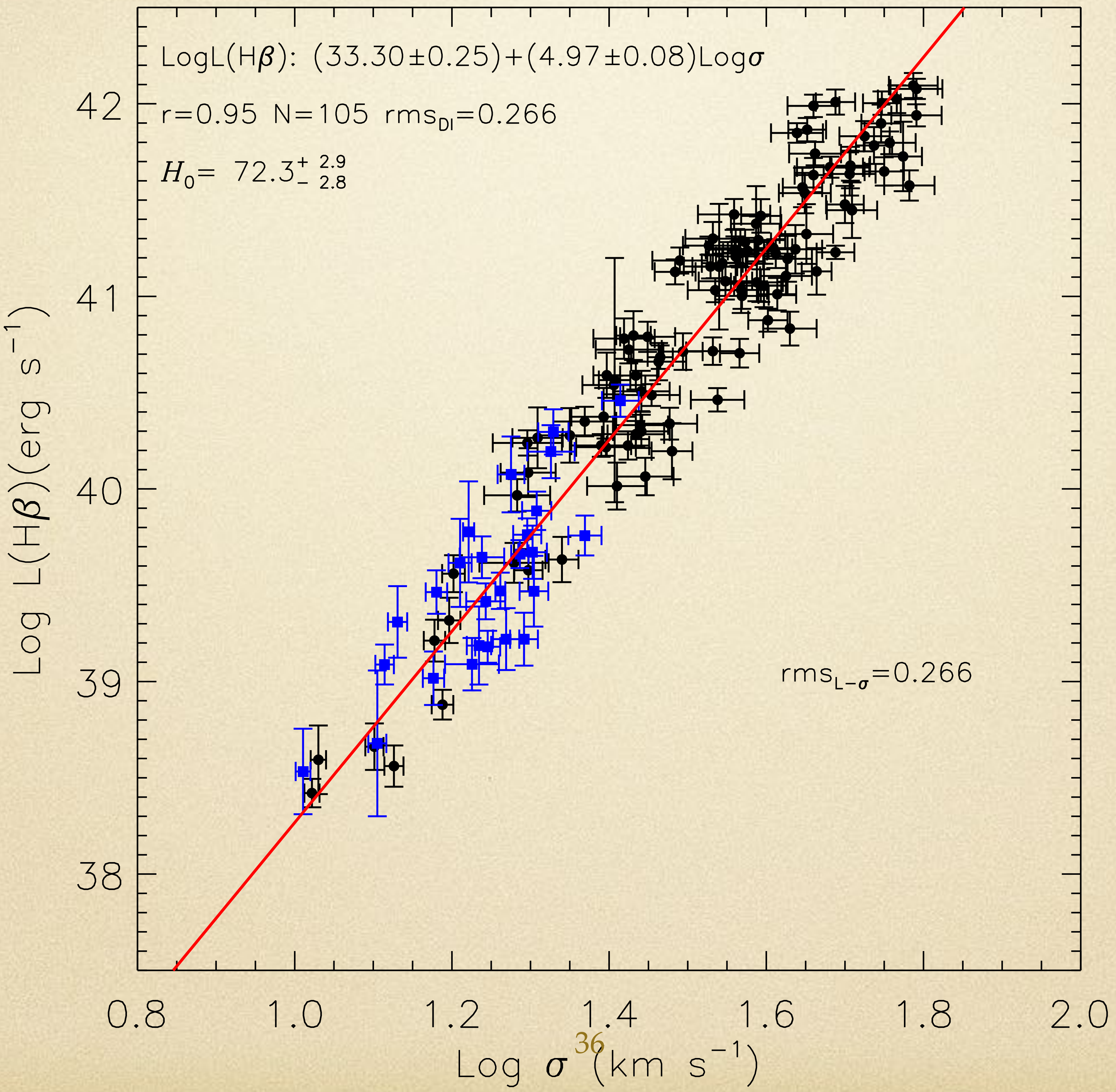


Measuring Measuring H_0 - The L-σ relation of the anchor sample



The anchor sample is composed by GHIIR in galaxies with distances determined using the period-luminosity relation of Cepheids independently of cosmology

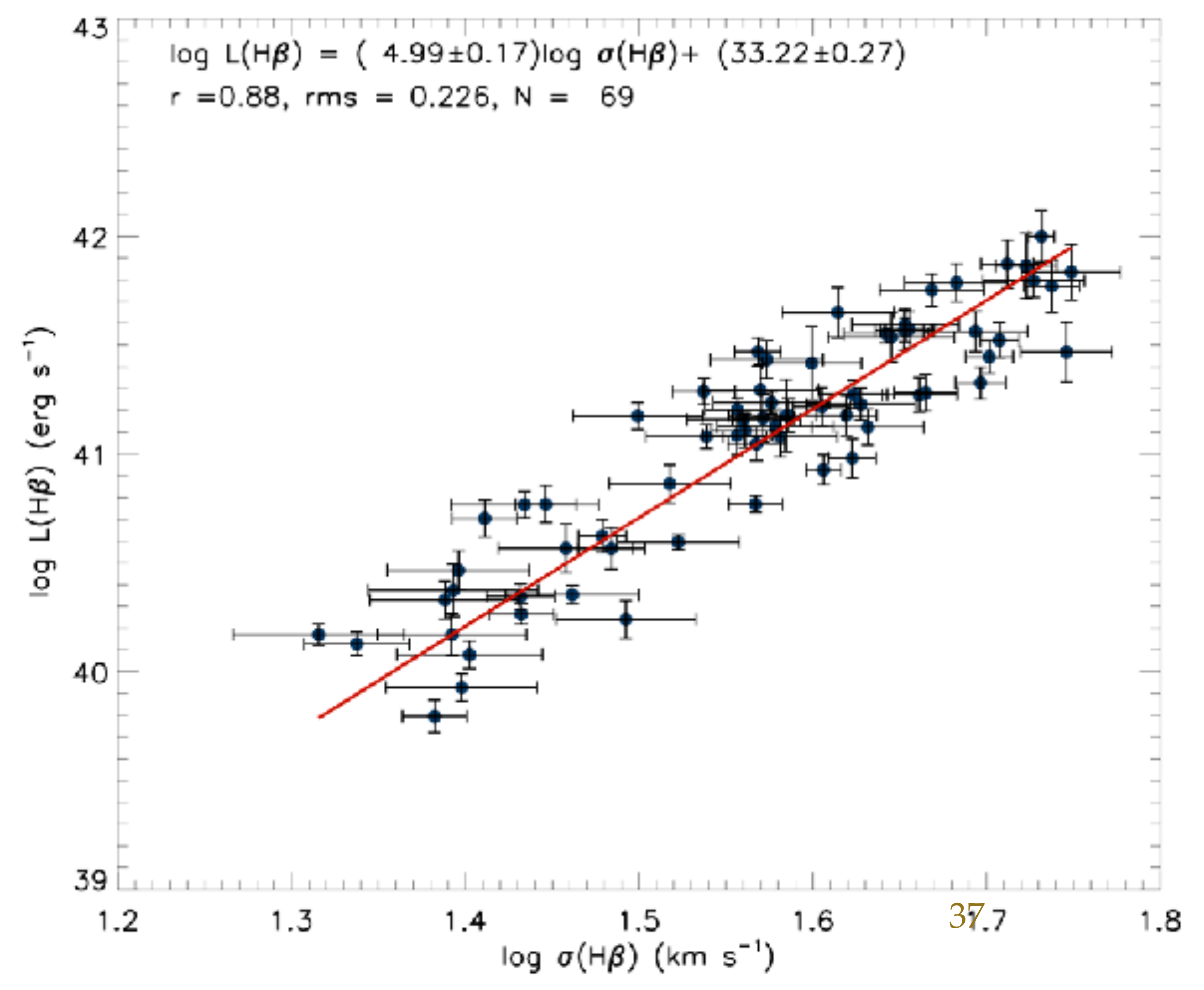
The distance indicator

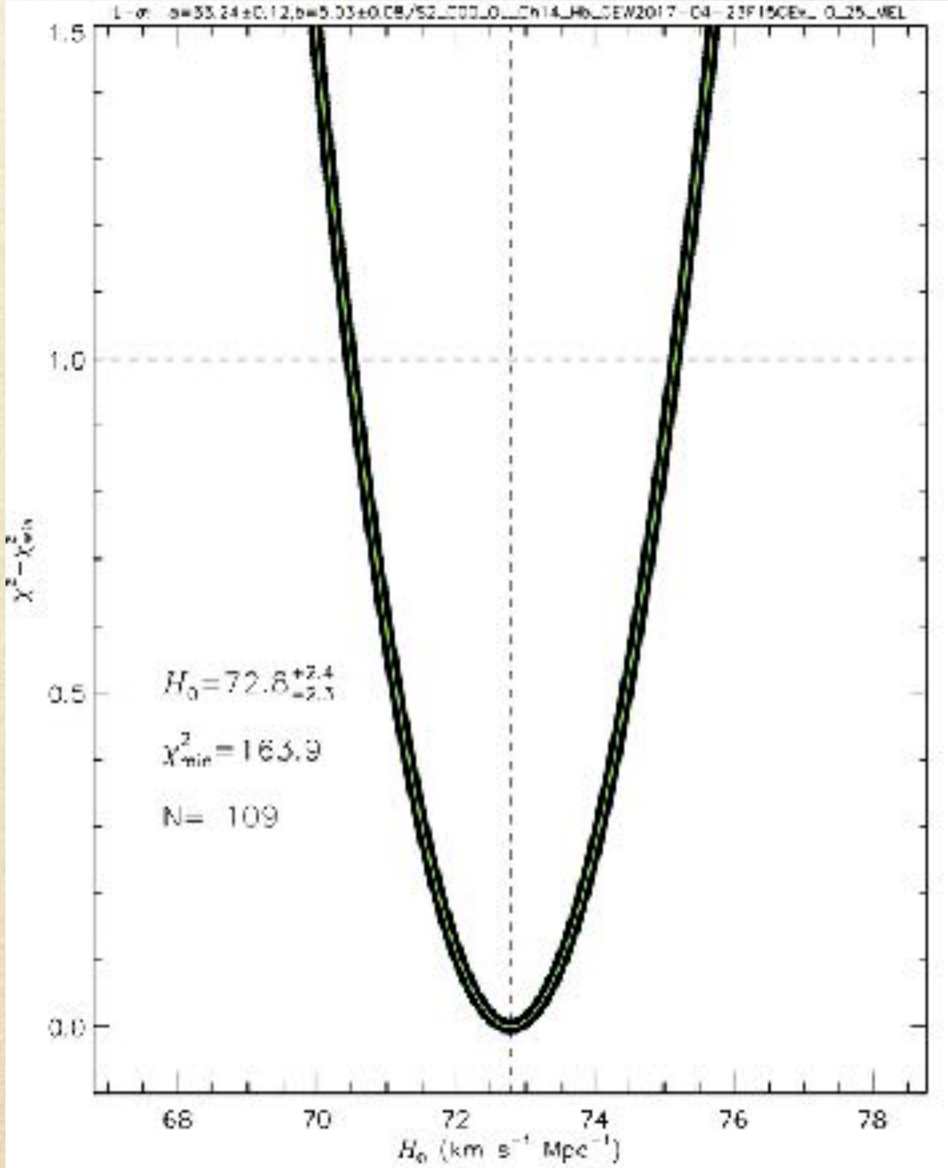


Measuring H_0 -The L-σ relation of the H II Galaxies

The luminosity depends of H_0 .

χ^2 solution





Measuring H_0: Results

We obtained:

Chavez etal 2012 H_0=74.3 ± 4.2 (random+systematic)
Fernandez-Arenas etal 2017 H_0=71.0 ± 3.5 (random+systematic)

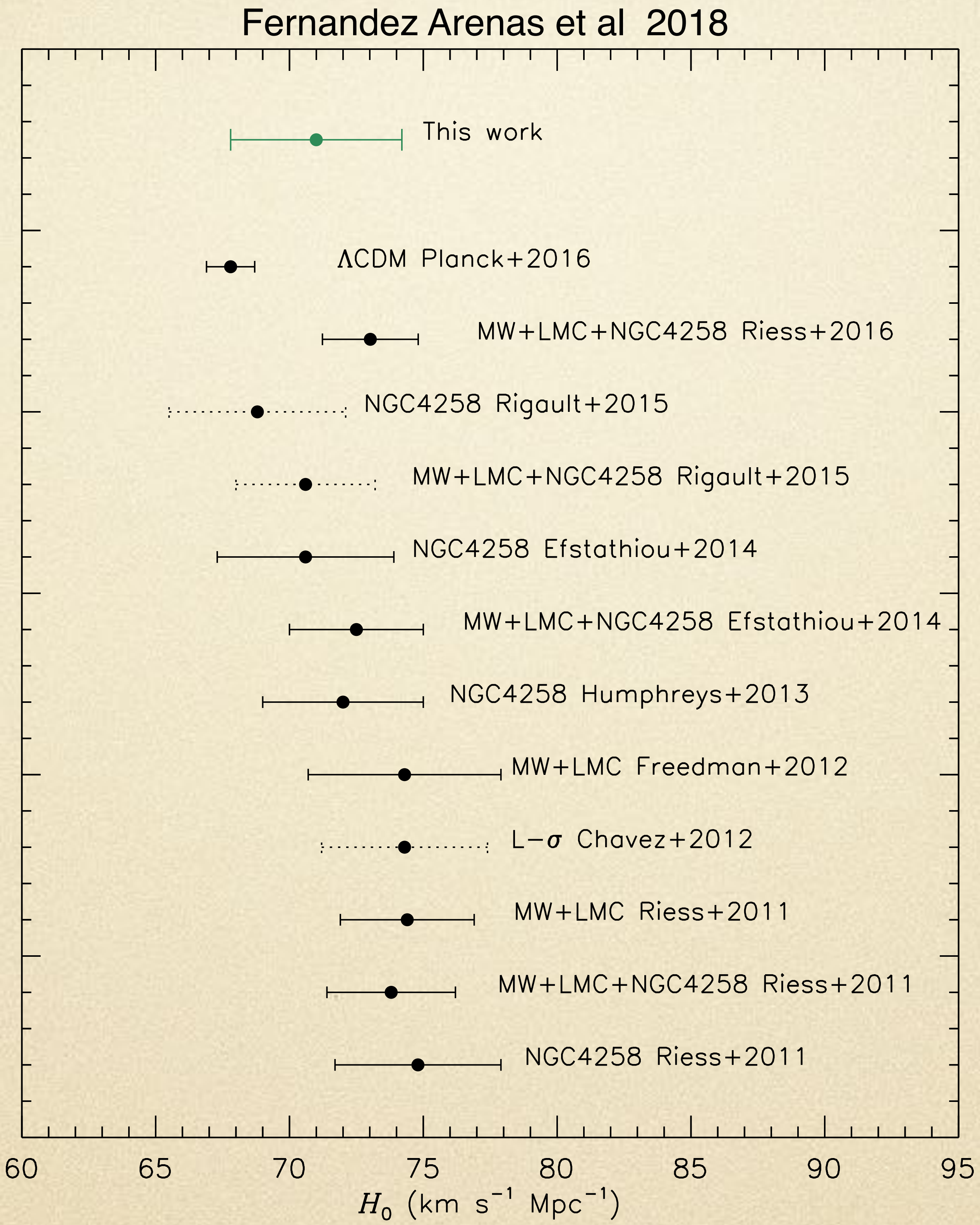
That should be compared with:

Freedman etal 2001: H_0 = 72 ± 8 (random+systematic)
Sandage etal 2006: H_0 = 62.3 ± 5.0 (random+systematic)
Riess etal 2009: H_0 = 74.2 ± 3.6 (random+systematic)
Riess etal 2012: H_0 = 73.8 ± 2.4 (random+systematic)
Freedman etal 2012: H_0 = 74.3 ± 2.6 (random+systematic)

Riess etal 2016: H_0 = 73.2 ± 1.7 (random+systematic)

showing excellent agreement.

H_0 results


Fernandez Arenas et al 2018
This work
ΛCDM Planck+2016
MW+LMC+NGC4258 Riess+2016
NGC4258 Rigault+2015
MW+LMC+NGC4258 Rigault+2015
NGC4258 Efstathiou+2014
MW+LMC+NGC4258 Efstathiou+2014
NGC4258 Humphreys+2013
MW+LMC Freedman+2012
L−σ Chavez+2012
MW+LMC Riess+2011
MW+LMC+NGC4258 Riess+2011
NGC4258 Riess+2011
60
65
70
75
80
85
90
95
H0 (km s−1 Mpc−1)

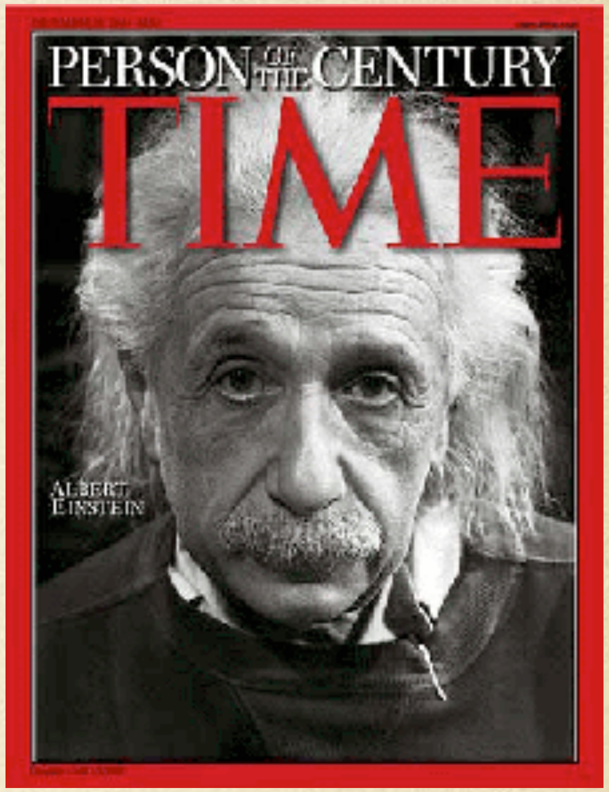
Measuring H_0 - Final comments

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.

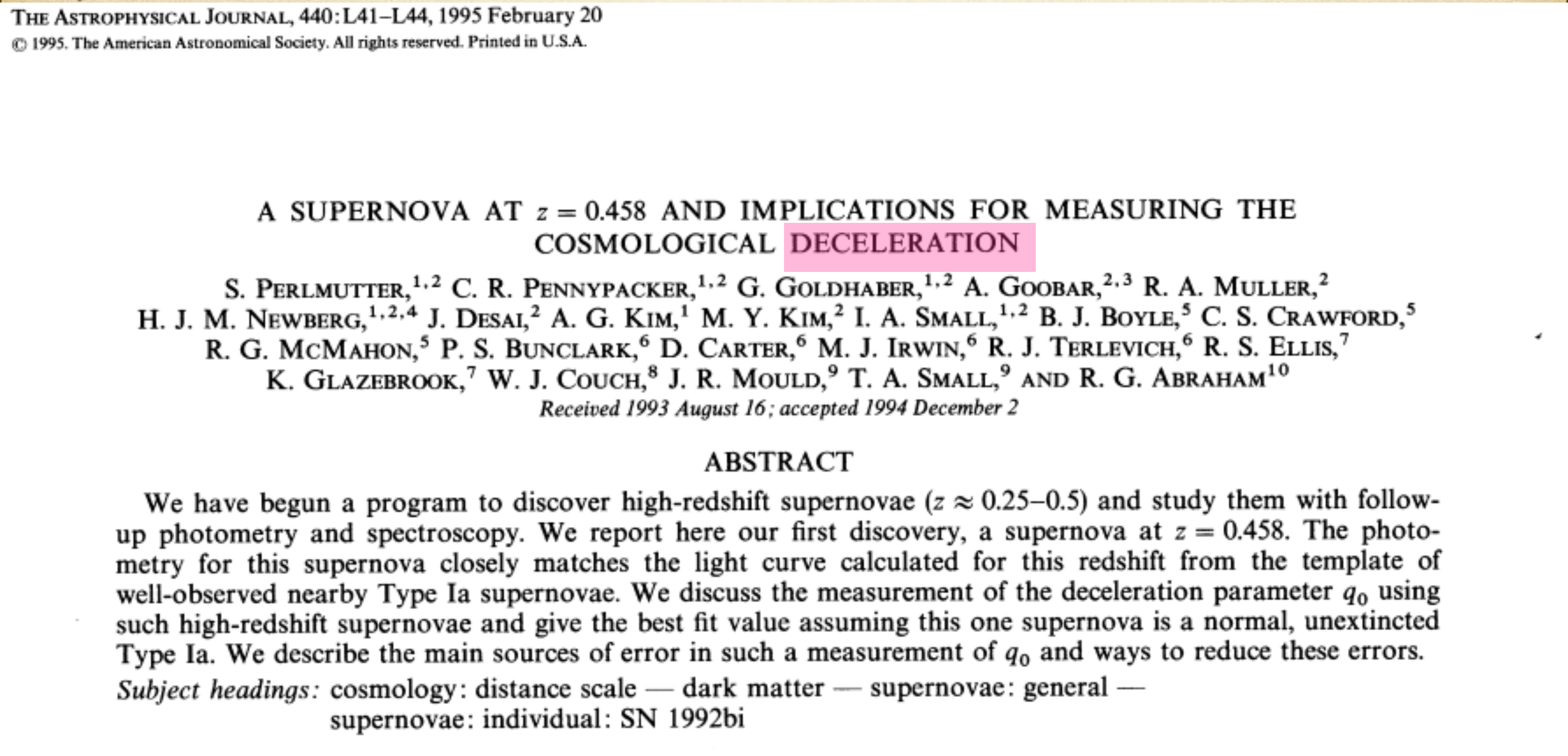
Cosmology Breakthroughs in Recent Past



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 start of the road to the accelerated expansion



THE ASTROPHYSICAL JOURNAL, 440:L41–L44, 1995 February 20

A SUPERNOVA AT $z = 0.458$ AND IMPLICATIONS FOR MEASURING THE COSMOLOGICAL DECELERATION

S. PERLMUTTER,[1,2] C. R. PENNYPACKER,[1,2] G. GOLDHABER,[1,2] A. GOOBAR,[2,3] R. A. MULLER,[2]
H. J. M. NEWBERG,[1,2,4] J. DESAI,[2] A. G. KIM,[1] M. Y. KIM,[2] I. A. SMALL,[1,2] B. J. BOYLE,[5] C. S. CRAWFORD,[5]
R. G. MCMAHON,[5] P. S. BUNCLARK,[6] D. CARTER,[6] M. J. IRWIN,[6] R. J. TERLEVICH,[6] R. S. ELLIS,[7]
K. GLAZEBROOK,[7] W. J. COUCH,[8] J. R. MOULD,[9] T. A. SMALL,[9] AND R. G. ABRAHAM[10]

Received 1993 August 16; accepted 1994 December 2

ABSTRACT

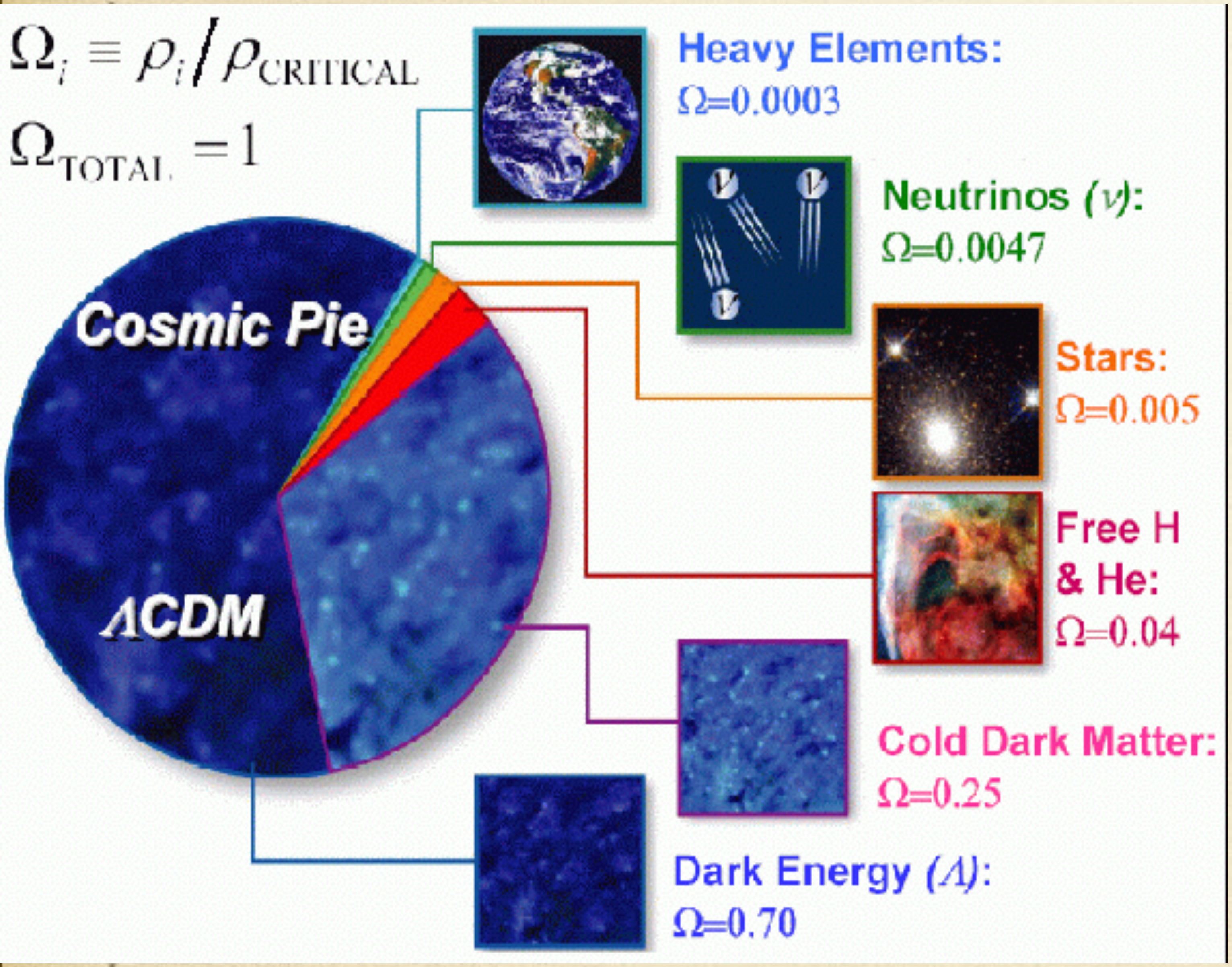
We have begun a program to discover high-redshift supernovae ($z \approx 0.25$–0.5) and study them with follow-up photometry and spectroscopy. We report here our first discovery, a supernova at $z = 0.458$. The photometry for this supernova closely matches the light curve calculated for this redshift from the template of well-observed nearby Type Ia supernovae. We discuss the measurement of the deceleration parameter q_0 using such high-redshift supernovae and give the best fit value assuming this one supernova is a normal, unextincted Type Ia. We describe the main sources of error in such a measurement of q_0 and ways to reduce these errors.

Subject headings: cosmology: distance scale — dark matter — supernovae: general —
supernovae: individual: SN 1992bi

This project lead to the discovery in 1999 of the accelerated expansion, but its support was almost cancelled in 1994 by the authorities because it was perceived as useless.

Saul Perlmutter shared both the 2006 Shaw Prize in Astronomy and the 2011 Nobel Prize in Physics with Adam Riess and Brian P. Schmidt for the discovery of the accelerated expansion.

Cosmology Breakthroughs in Recent Past



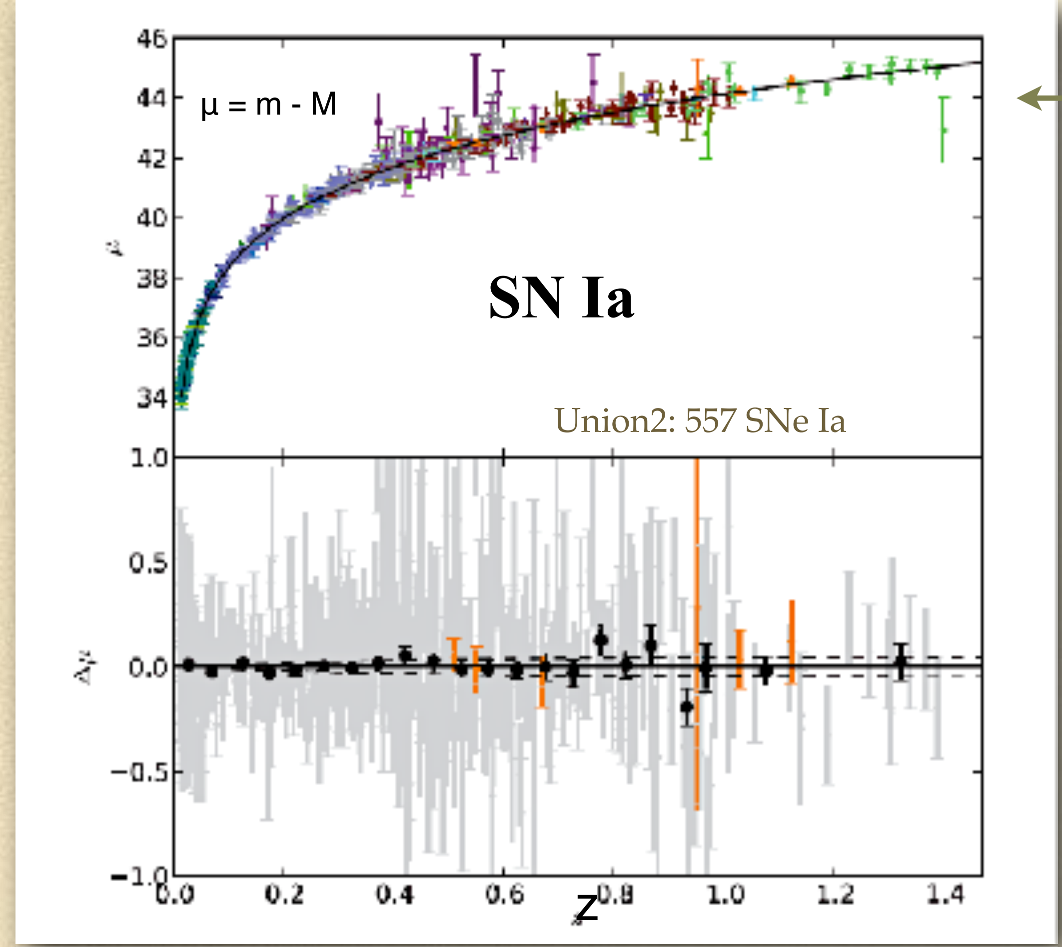
"Dark Energy" and **Dark Matter** are the dominant constituent of the Universe => 95% of the Universe is in forms unknown to us!

2003 Science breakthrough of year

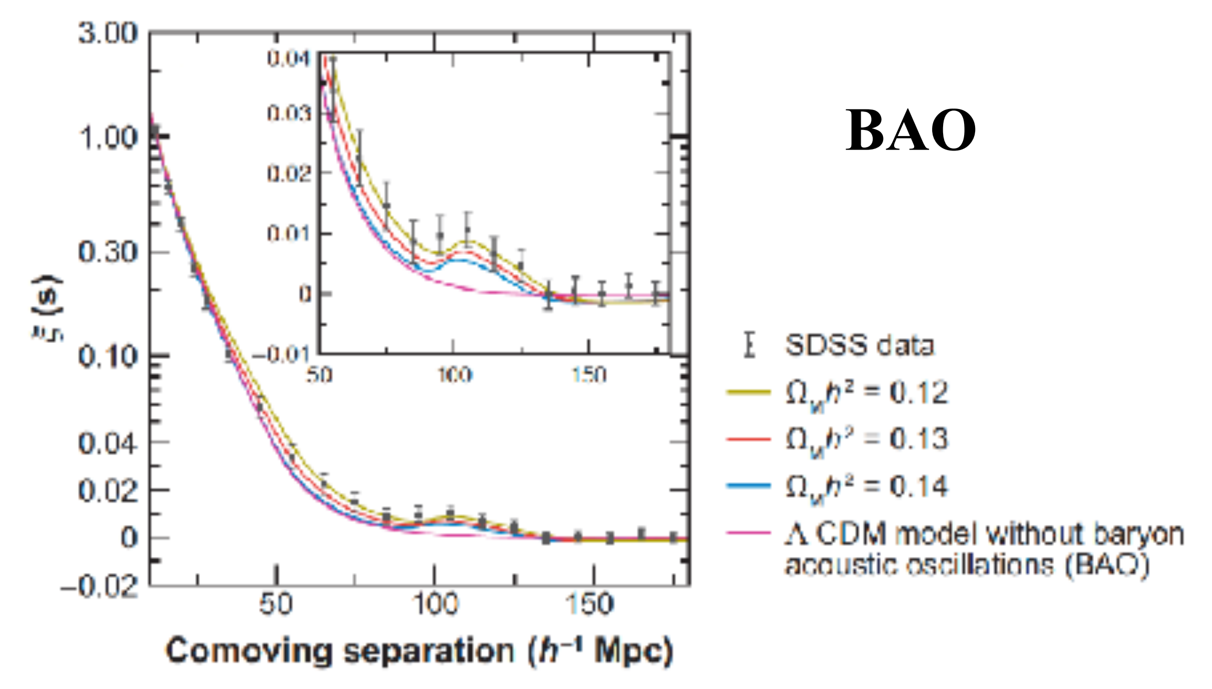
- **"Dark Energy"** is **TOP PRIORITY** for future research: Outcome of 2 very extensive, recently released reports, "Report of the Dark Energy Task Force (advising DOE, NASA and NSF), Albrecht et al. (2006), and "Report of the ESA/ESO Working Group on Fundamental Cosmology", Peacock et al. (2006).

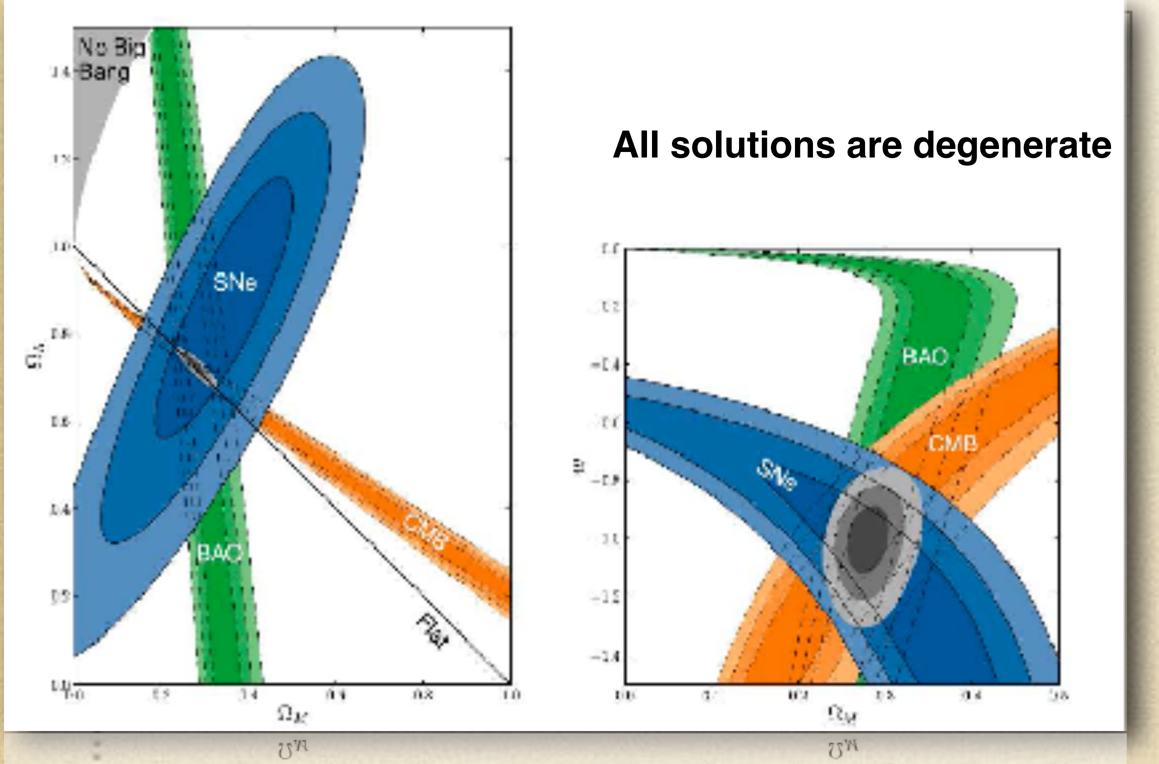
The Observational Landscape (2010)

Union2: 557 SNe Ia

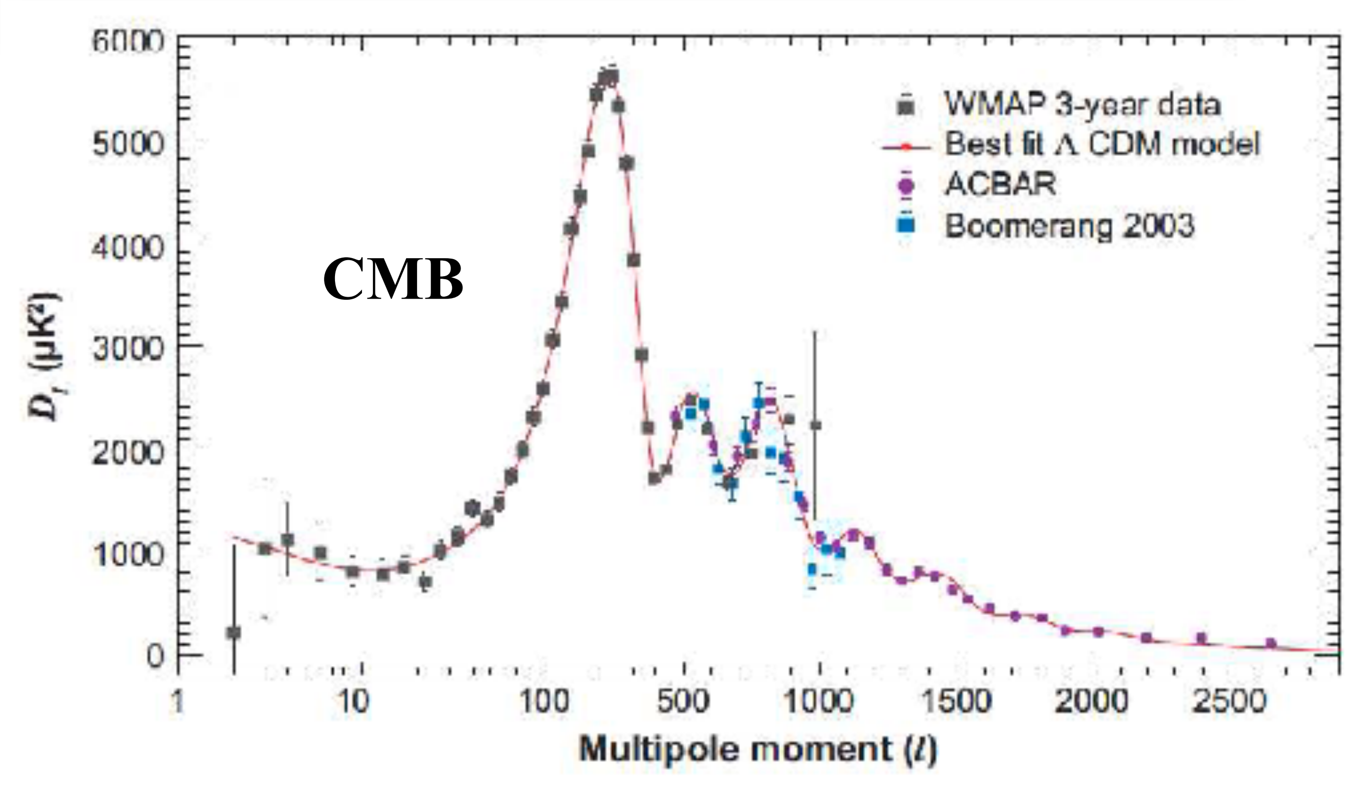


From Amanullah et al. 2010





All solutions are degenerate



From Frieman et al. 2008

Probing Dark Energy

We "see" dark energy through its acceleration of the expansion of the universe

We have three (3) main approaches:

1 - Standard candles: measure D_l (integral of H) (SNIa)
2 - Standard rulers: measure D_a (integral of H) and H(z) (BAO)
3 - Growth of fluctuations (CMB).

This acceleration indicates that:

a) Either our theory of gravity (General Relativity) is wrong.

b) Or the universe is dominated by a material that it cannot be any fluid we are familiar with, but some weird "stuff" which dominates the energy density of the Universe (today). We refer to it as dark energy.

c) The most prosaic explanation is Einstein's cosmological constant, which can be interpreted as the energy of empty space.

- What distinguishes models is the time-evolution of the DE. This is usually described by the equation of state: $w=p/\rho$.
– A cosmological constant, vacuum energy, has $w=-1$.
– Many (most) dark energy models have $w>-1$, and time evolving.

So the "holy grail" of DE research is to demonstrate that $w \neq -1$ at any epoch.

Dark Energy

Dark Energy is manifested in the expansion rate of the Universe, via:

$$H^2(z) = H^2_0[\Omega_m(1+z)^3 + \Omega_R\,(1+z)^4 + \Omega_{DE}\,(1+z)^{3(1+w)}\,]$$

matter radiation dark energy

Equation of state parameter w measures the evolution of the density of dark energy with redshift.

For Λ cosmology: $w = -1$ ($p_{VAC} = - w\rho_{VAC} = -\Lambda/8\pi G$).

w is currently constrained to ~20% by WMAP, SDSS, and SN Ia.

But: Does dark energy vary with epoch?

Variable, time-dependent equation of state:

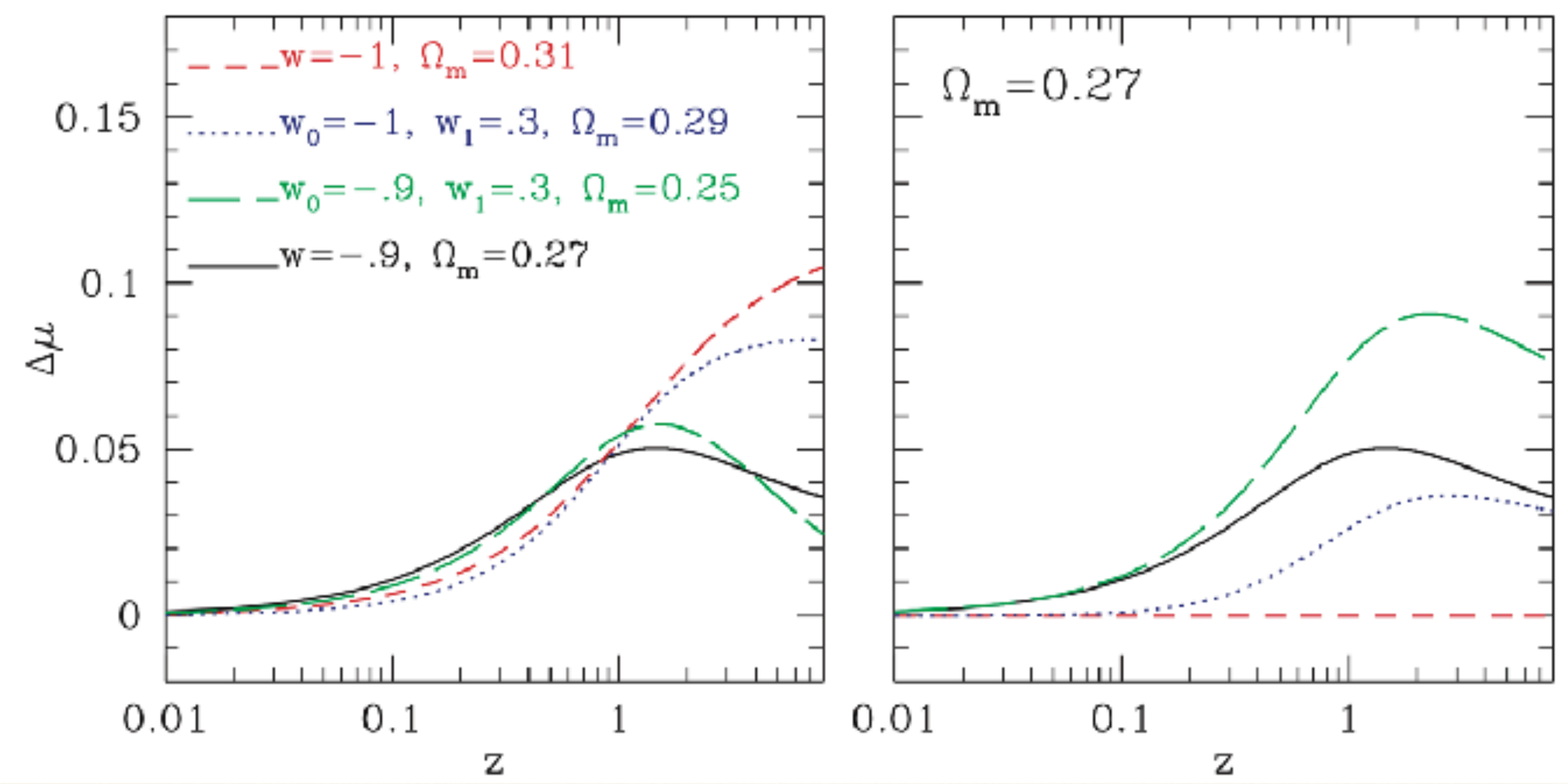
$$w(z) = w_0 + w_1\,[z/(1+z)]\ \text{(CPL model)}$$

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 $\Omega m = 0.27$. 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).

Aims

It is important to use alternative geometrical probes at higher redshifts than those explored by SNIa and BAO and where the differences between models is maximised and the time-evolution of the DE is optimally tested.

It is also important to obtain more stringent constraints to the cosmological parameters solution space, independently of cosmological priors like those used by CMB and BAO.

Our aim is to help discriminating among the various theoretical alternatives that attempt to explain the accelerated expansion of the Universe using the HIIG distance estimator to accurately measure H_0, Ω_m , w_0 and w_1 .

The reason that we have not started this project until very recently is obvious.

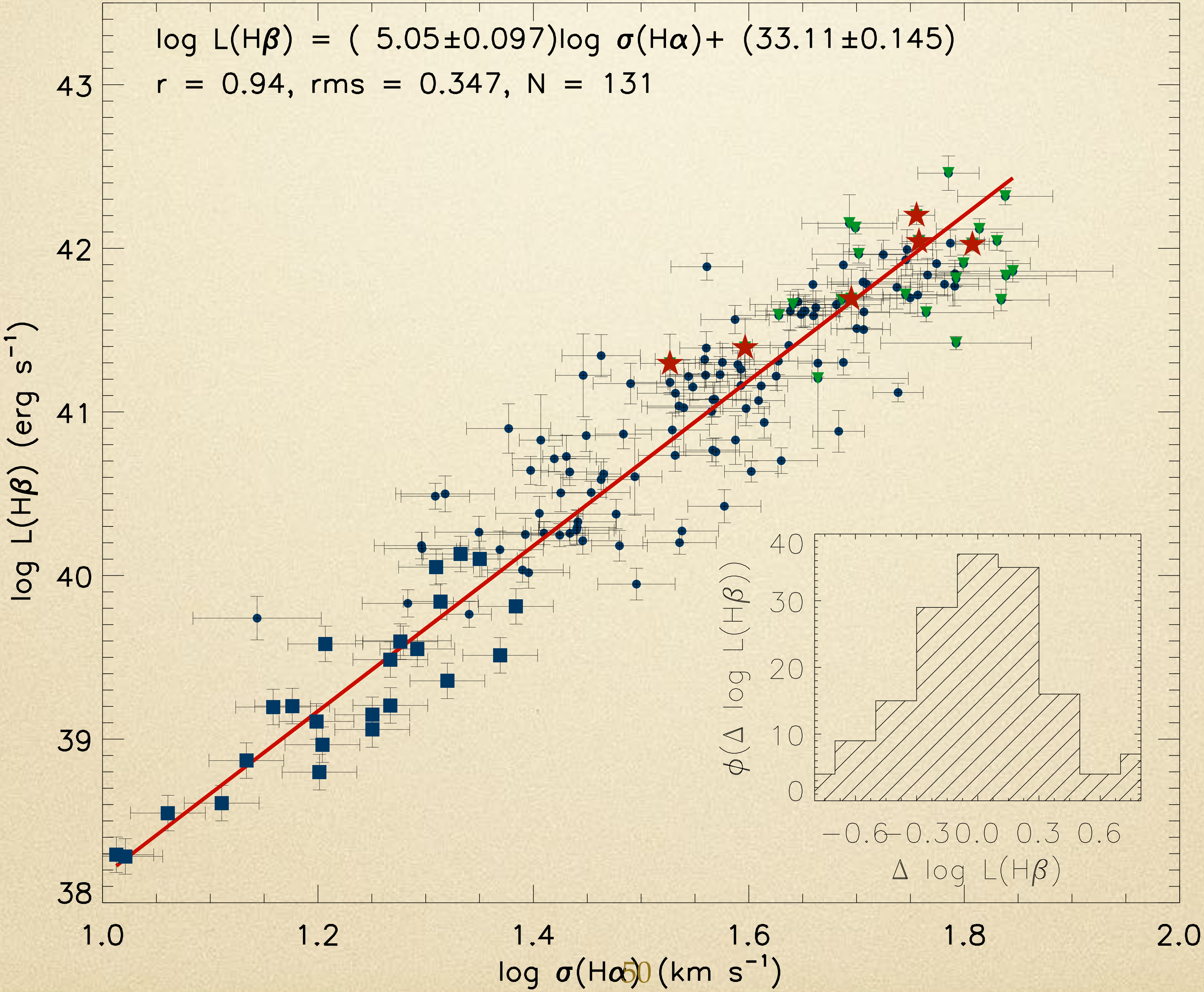
There was no instrument in a 10m class telescope capable of obtaining multiple spectra of moderate dispersion (R>4000) in the near IR ~ 2 microns.

At present there are two, MOSFIRE at KECK and KMOS at VLT.

During 2018 they will be joined by EMIR at GTC.

In MTT2000 we concluded that "Using the high-efficiency IR spectrographs that are becoming available in the new generation of 8-10 m telescopes, it will be possible to determine the Hβ line widths, luminosities, and equivalent widths of these objects over a wide range of luminosities with high accuracy. This will allow, for the first time, the use of the distance estimator to probe the cosmological parameters out to unprecedented distances."

The L-sigma relation including high z HIIG



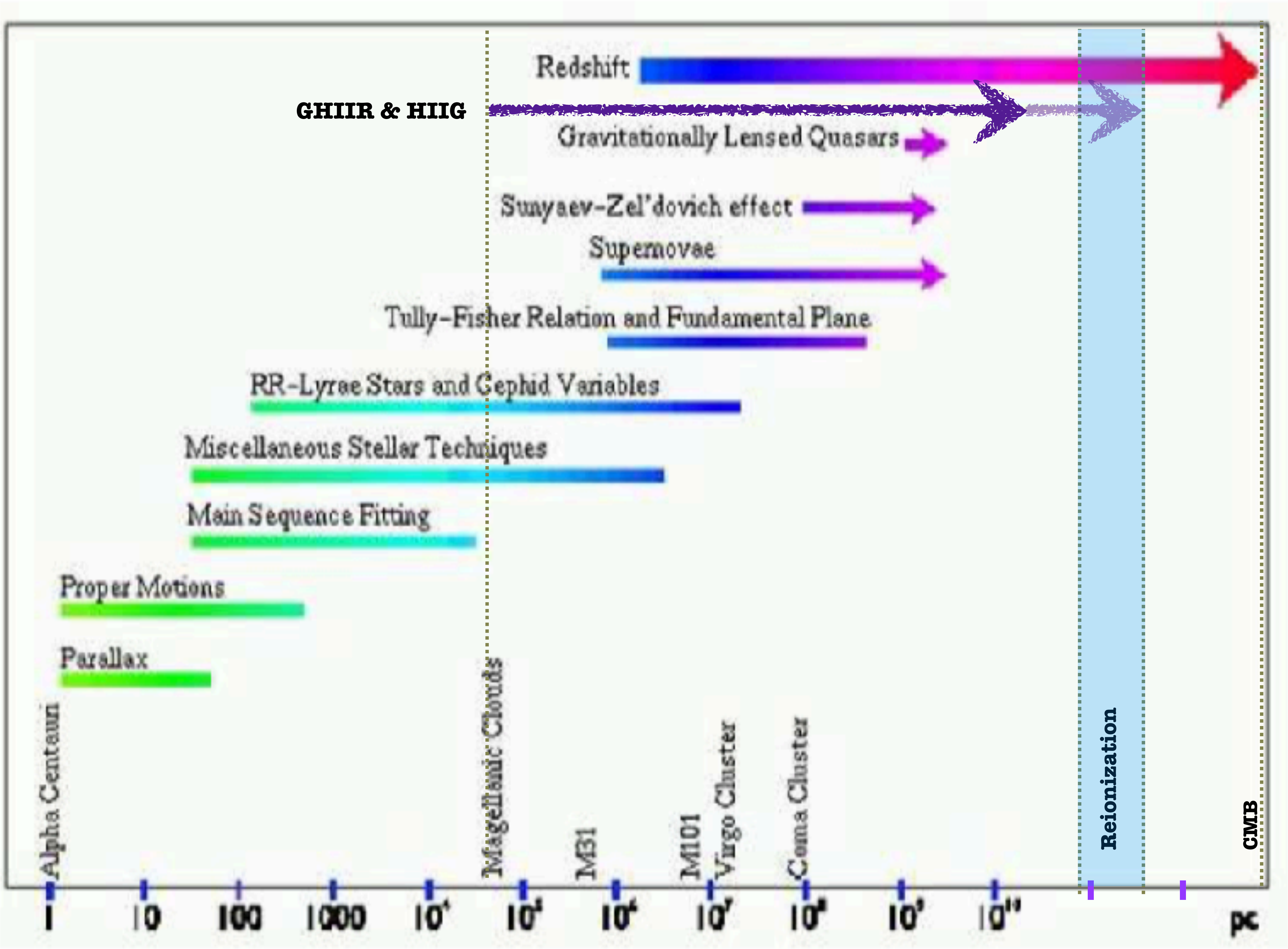
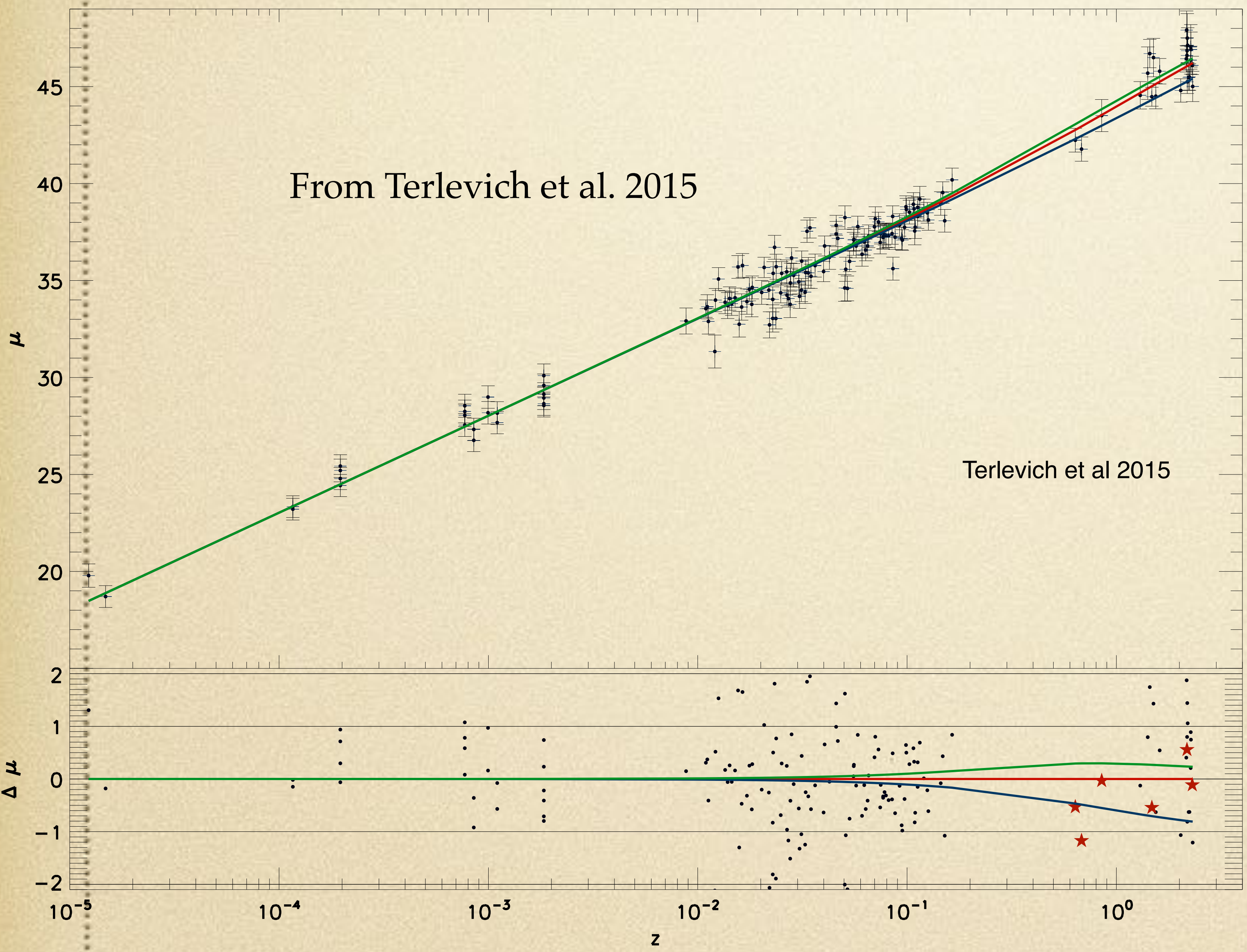


Figure A.2: The different distance estimators. Adapted from (Roth & Primack, 1996).

The GHIIR and HIIG Hubble diagram

The Hubble diagram includes 25 high z, 109 nearby HIIG and 23 GHIIR.
All lines are for $H_0 = 74.3$ and $\Omega_k = 0$.



Hubble diagram for three different cosmologies.

The solid red line indicates the concordance CDM cosmology with $\Omega_m = 0.3$; $w_0 = -1.0$.

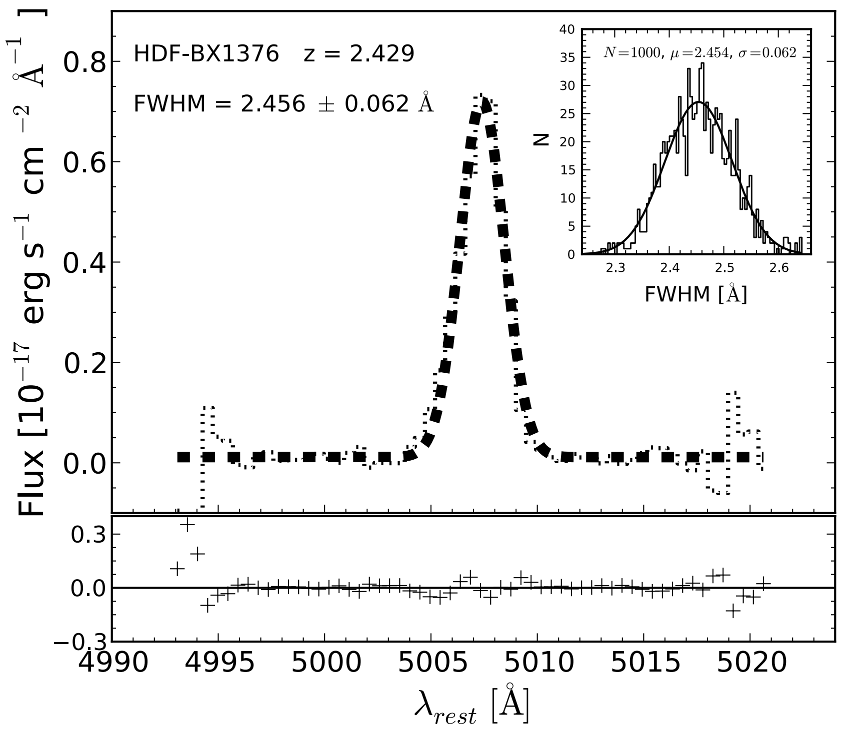
The solid green line shows a cosmology with $\Omega_m = 0.3$ and $w_0 = -2.0$.

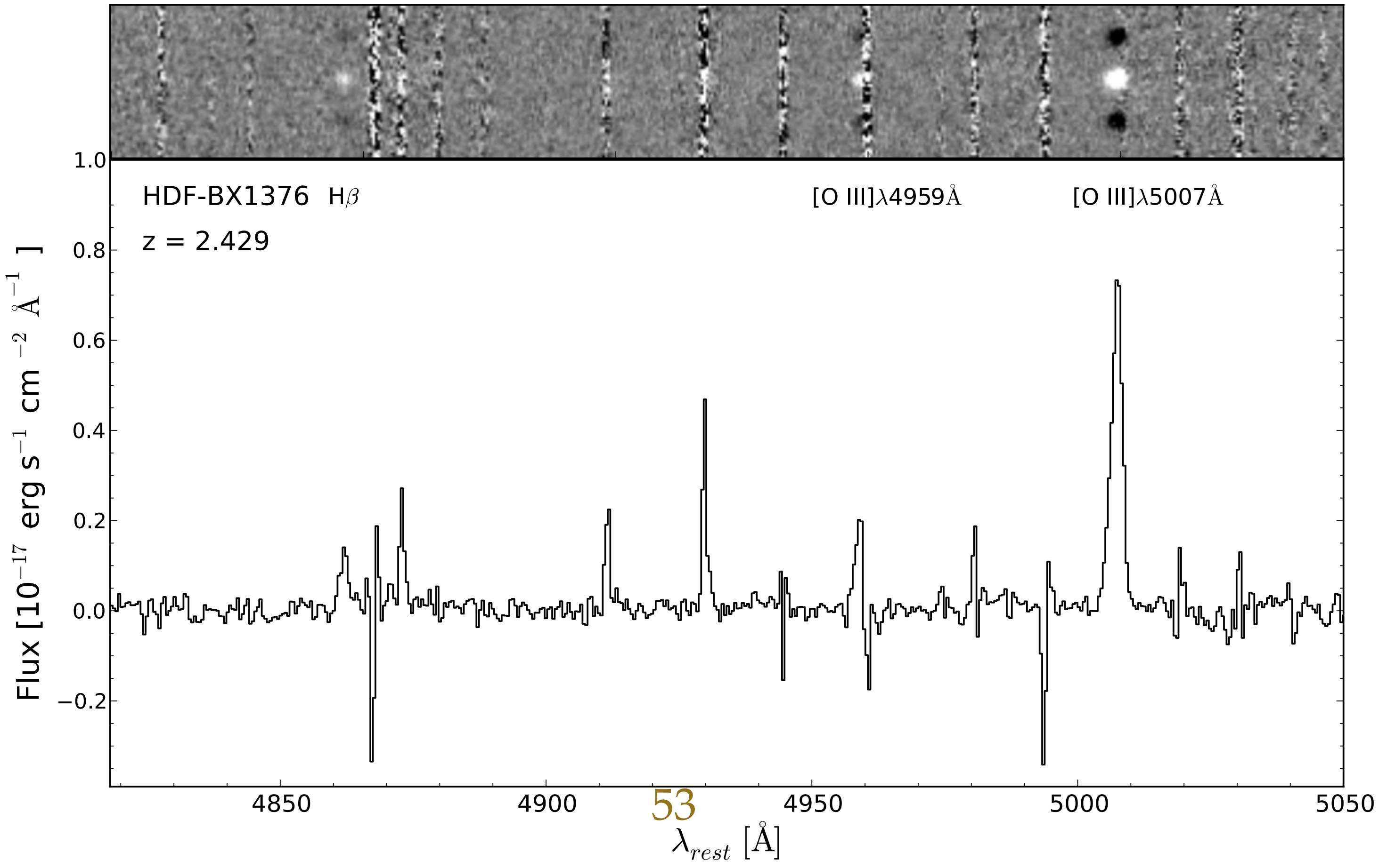
The solid blue line corresponds to $\Omega_m = 1.0$.

Residuals are plotted in the bottom panel.

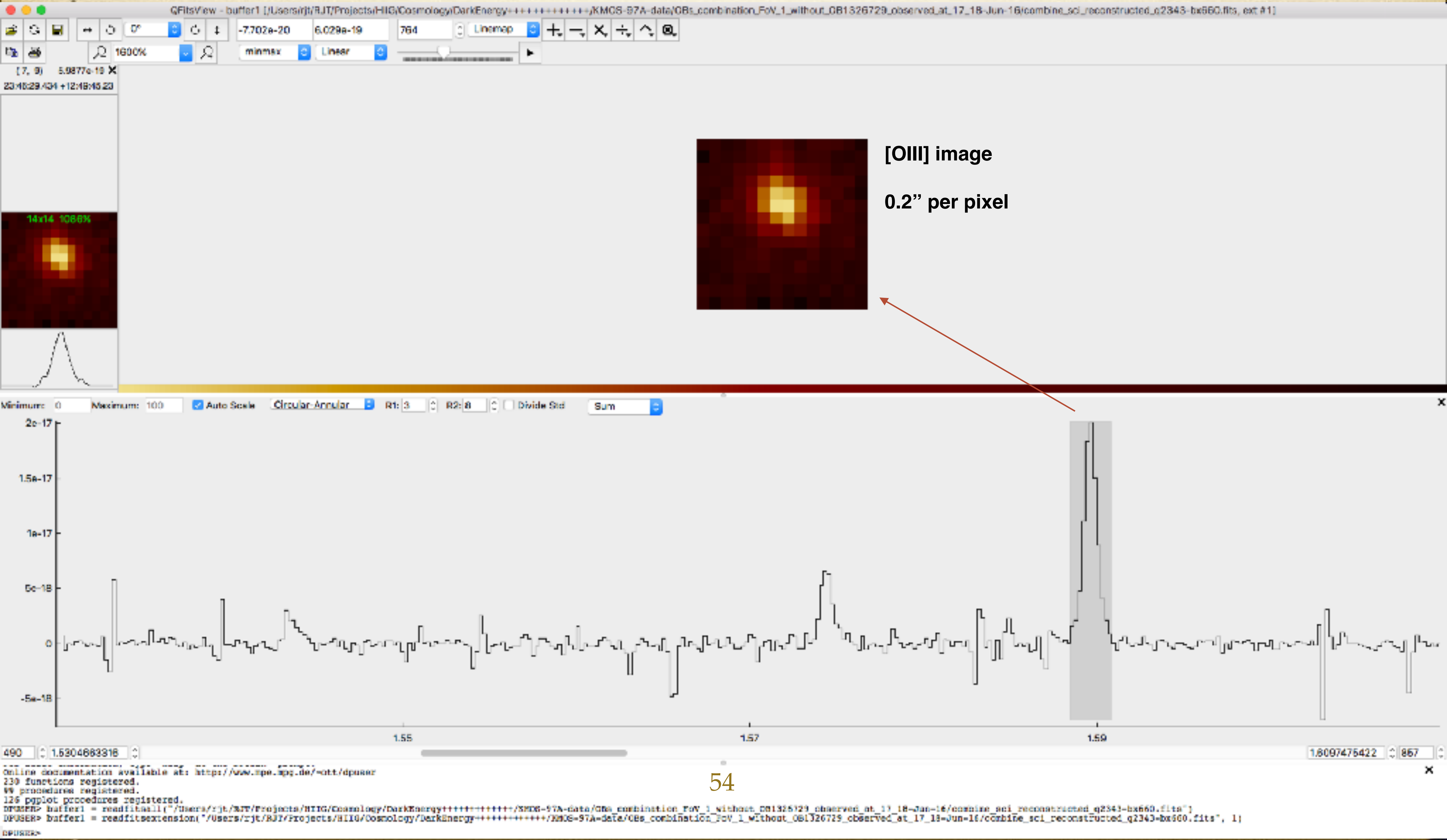
Note the huge dynamical range in distance modulus of almost 30 mag covered with the L–sigma distance indicator.

HIIG at z=2.43 observed with MOSFIRE at KECK





HIIG at z=2.17 observed with KMOS at VLT



[OIII] image

0.2” per pixel

Minimum: 0 Maximum: 100 ☑ Auto Scale Circular-Annular R1: 3 R2: 8 ☐ Divide Std Sum

```
Online documentation available at: https://www.mpe.mpg.de/~ott/dpuser
230 functions registered.
99 procedures registered.
126 pgplot procedures registered.
DPUSER> buffer1 = readfitsall("/Users/rjt/RJT/Projects/HIIG/Cosmology/DarkEnergy++++++++++++/KMOS-97A-data/OBs_combination_FoV_1_without_OB1326729_observed_at_17_18-Jun-16/combine_sci_reconstructed_q2343-bx660.fits")
DPUSER> buffer1 = readfitsextension("/Users/rjt/RJT/Projects/HIIG/Cosmology/DarkEnergy++++++++++++/KMOS-97A-data/OBs_combination_FoV_1_without_OB1326729_observed_at_17_18-Jun-16/combine_sci_reconstructed_q2343-bx660.fits", 1)
DPUSER>
```

Preliminary results including our MOSFIRE high z HIIG

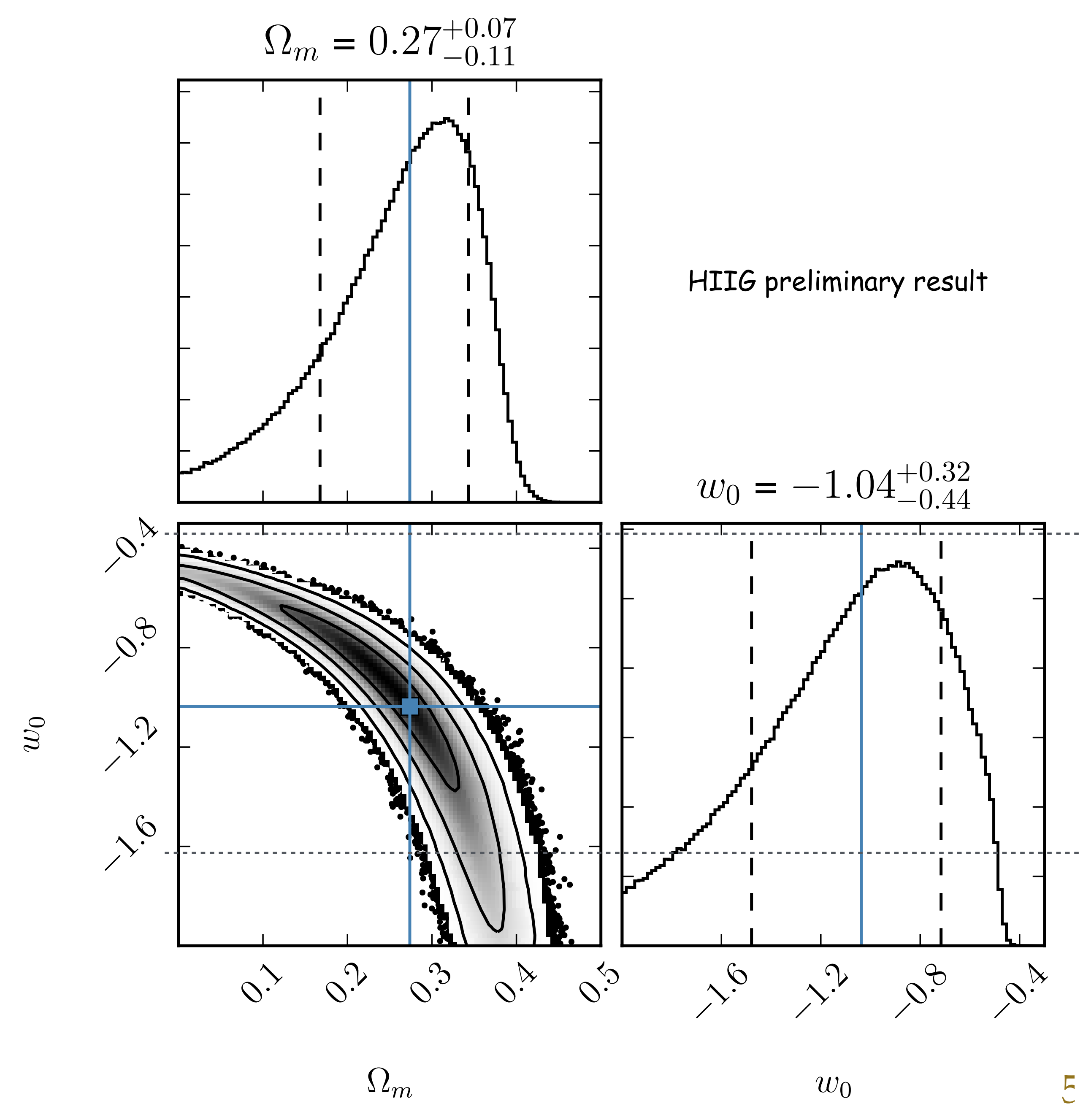
MCMC result for a flat universe ($\Omega_k = 0$) with $H_0=74.3$.

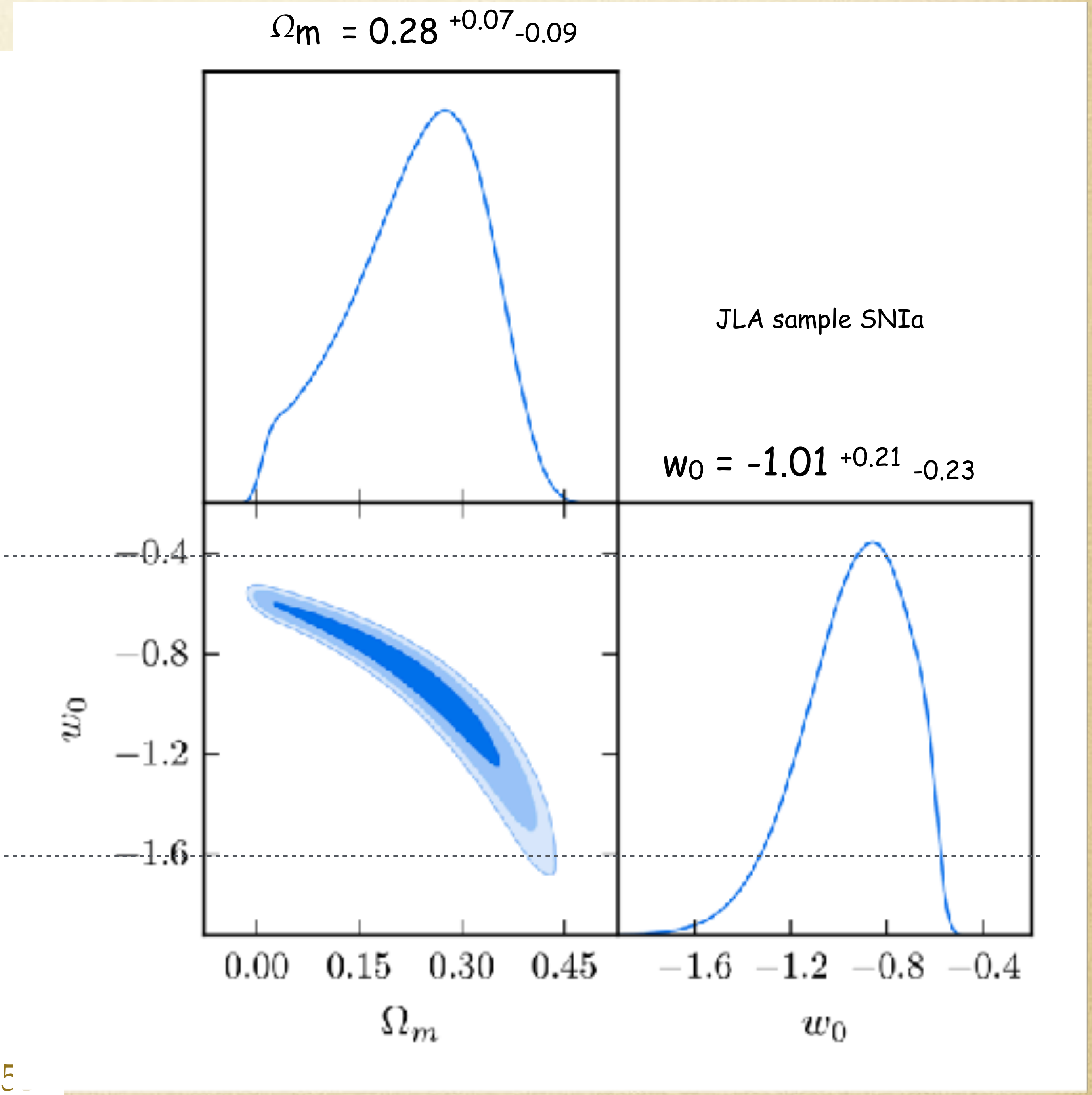
$\Omega_m = 0.27^{+0.07}_{-0.11}$ and $w = -1.04^{+0.32}_{-0.44}$ (statistical uncertainties only)

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

The solution for JLA sample of 740 SNIa (Betoule et al 2014) gives

$\Omega_m = 0.28^{+0.07}_{-0.09}$ and $w_0 = -1.01^{+0.21}_{-0.23}$





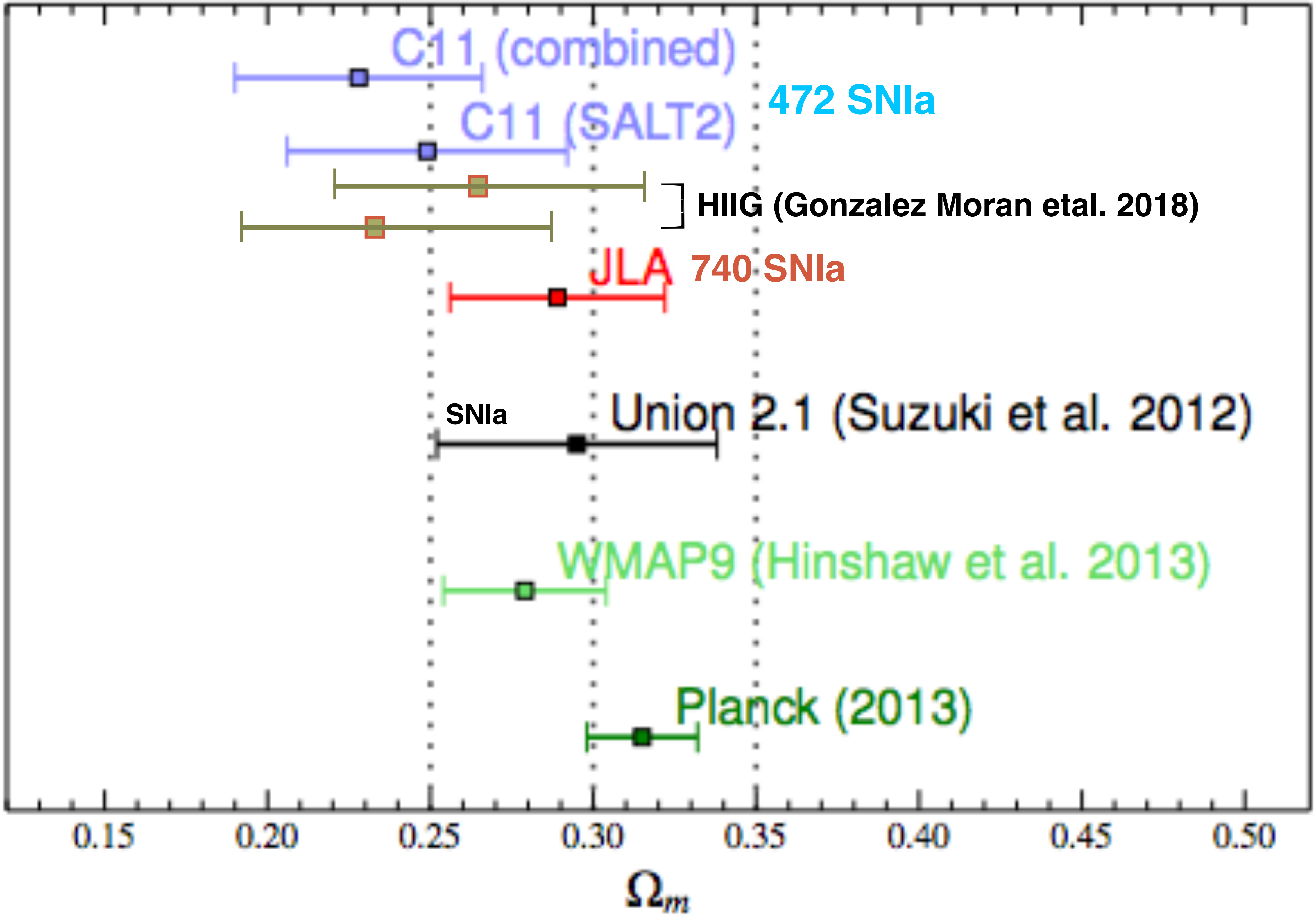


Fig. 14. Comparison of various measurements of Ω_m for a ΛCDM cosmology.

Joint HIIG-SNIa results compared with Joint BAO-CMB

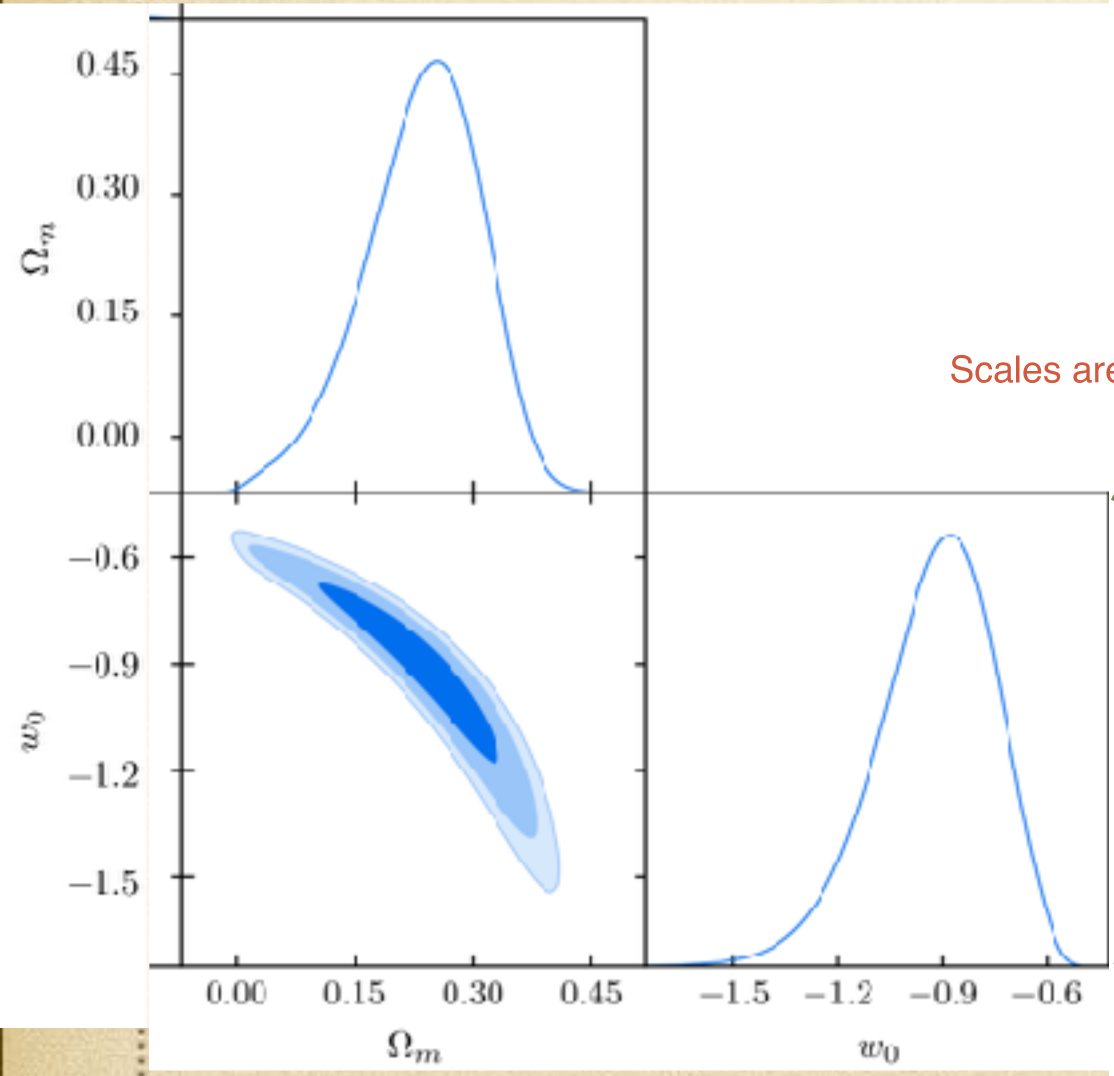
It is important to compare the results from empirical approach of HIIG and SNIa , that it is independentnt (almost) of cosmology, with the results from CMB and BAO that are dependent on the adopted cosmology.

Joint BAO-CMB

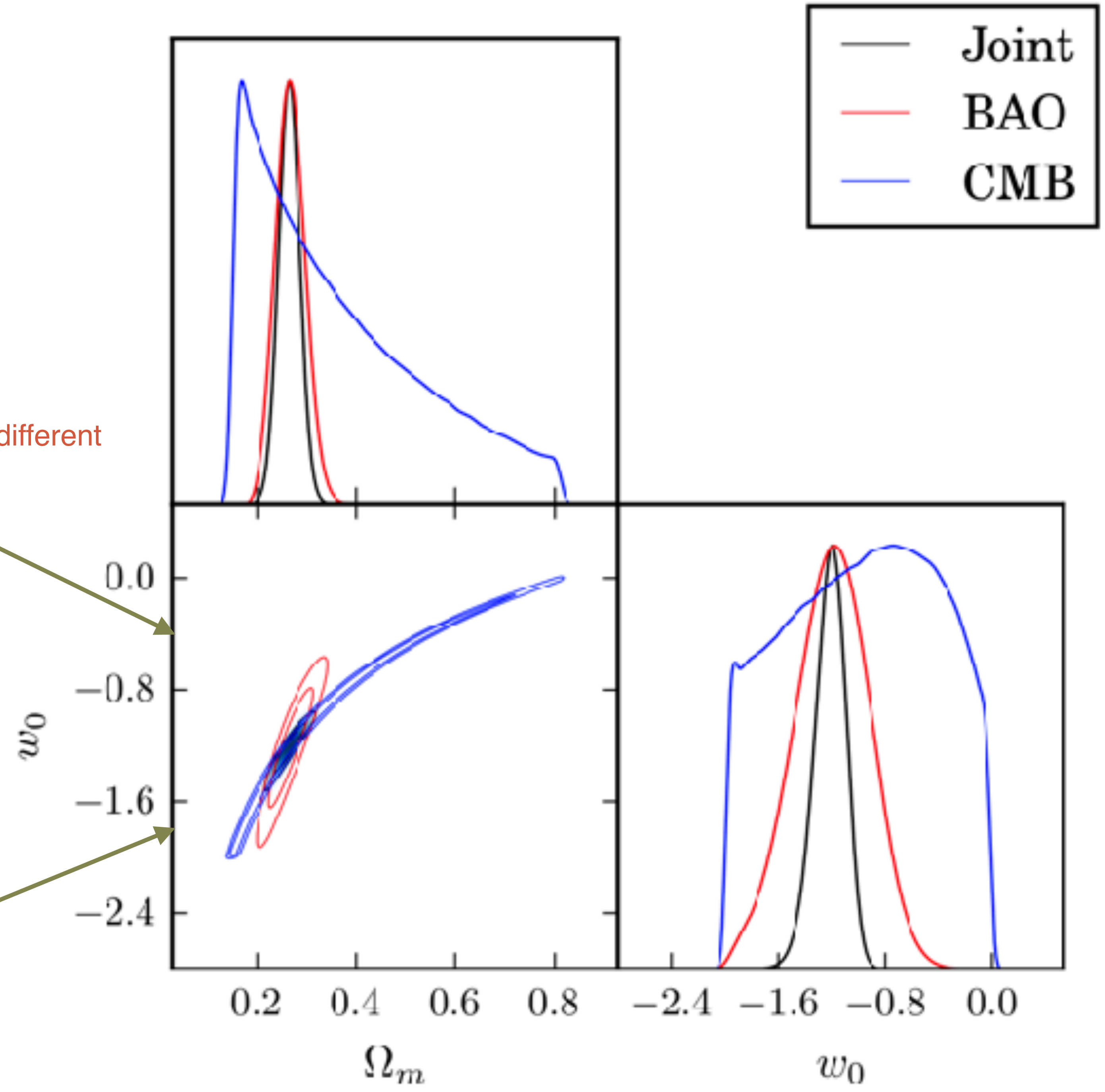
$\Omega m = 0.265 \pm 0.021$ $w_0 = 1.22 \pm 0.12$

Joint SNIa-HIIG

$\Omega m = 0.235 \pm 0.072$ $w_0 = 0.92 \pm 0.17$



Scales are different



CONCLUSIONS

- The study of these young systems provides an alternative and sometimes unique method to determine and constrain cosmological parameters.
- The primordial He abundance.
- HIIG explore a range of high z that is not available to other methods ($1.5 < z < 9$). This range is crucial to study the evolution of the DE equation of state.
- The fact that our results are in line with SN, BAO and CMB implies that there is no evolution with redshift in the properties of HIIG and therefore their ionizing young SSC.
- We are learning more about the intrinsic properties of these massive star formation systems that in turn will allow a better distance indicator.

Muchas Gracias