Constraining Ω_m from High-z HII Galaxies

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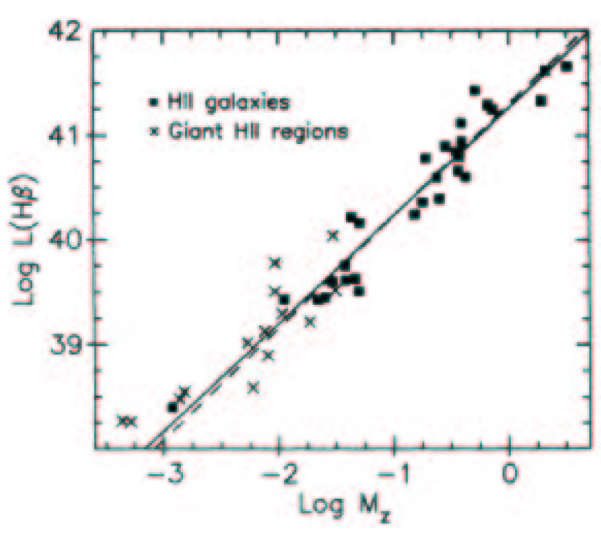
Abstract

We investigate the use of a well-known empirical correlation between the velocity dispersion (σ), metallicity (O/H), and luminosity in Hβ of nearby HII galaxies to measure the distances to HII-like galaxies at high redshifts. This method was first suggested by Melnick, Terlevich, and Terlevich (2000), who showed that the resulting distance measurements may place an independent constraint on the cosmological parameter Ω_m. We apply their method to a sample of 16 HII-type galaxies with redshifts between z=2.15 and z=3.38, using data available from the literature. A detailed analysis of systematic errors, their causes, and their effects on the values derived for the distances and Ω_m was carried out. With the available data, we obtain a best-fit value of $\Omega_m = 0.37^{+0.24}_{-0.16}$ in a Λ-dominated universe and of $\Omega_m = 0.32^{+0.28}_{-0.21}$ in an open universe. We discuss how future work will dramatically improve the constraints on Ω_m by reducing both systematic and random errors.

The Distance Indicator

Melnick, Terlevich, and Moles (MTM) [1] proposed the following empirical correlation for HII galaxies:

$$\log L(H\beta) = \log M_z + const \qquad M_z \equiv \frac{\sigma^5}{[O/H]} \qquad (1)$$



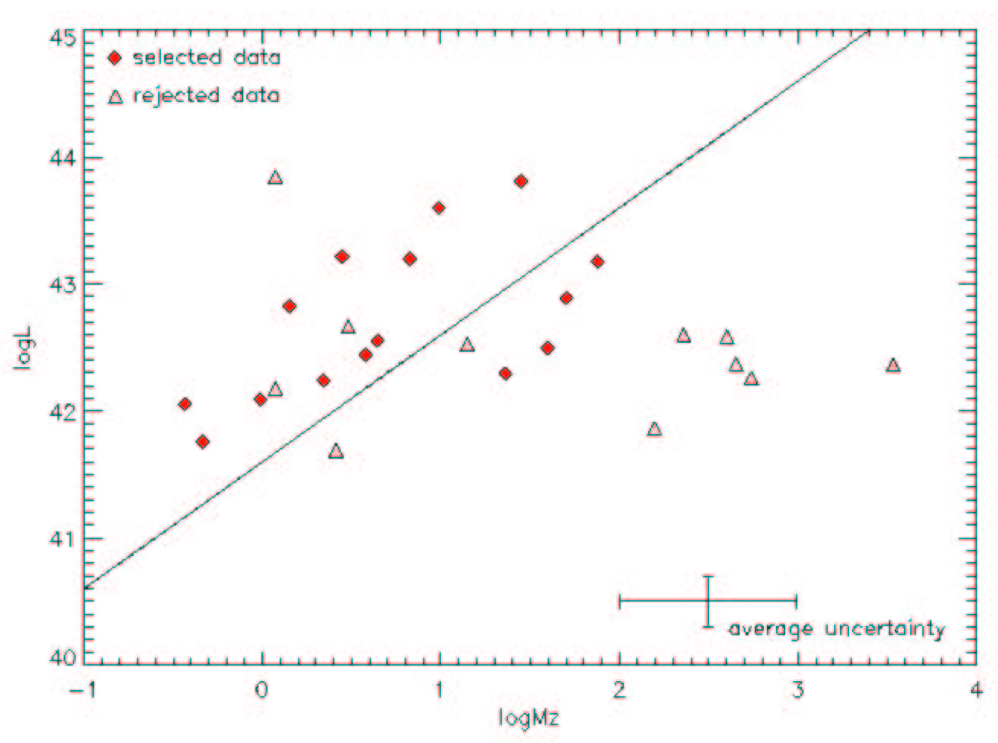
We apply this correlation to HII galaxies at high redshift (z≥2) to obtain their distance moduli, following Melnick, Terlevich, and Terlevich (MTT) [2]. From the data set of distance moduli and redshifts, we extract the cosmological parameter Ω_m.

Application to High-z

Following MTT, we have derived an equation for the distance modulus as a function of velocity dispersion (σ), flux in $H\beta$ ($F(H\beta)$), metallicity (O/H), extinction in $H\beta$ ($A_{H\beta}$), and equivalent width in $H\beta$ (EW). Our equation is:

$$DM = 2.5\log\left(\frac{\sigma^5}{F(H\beta)}\right) - 2.5\log O/H - A_{H\beta} - 26.17 \qquad (2)$$

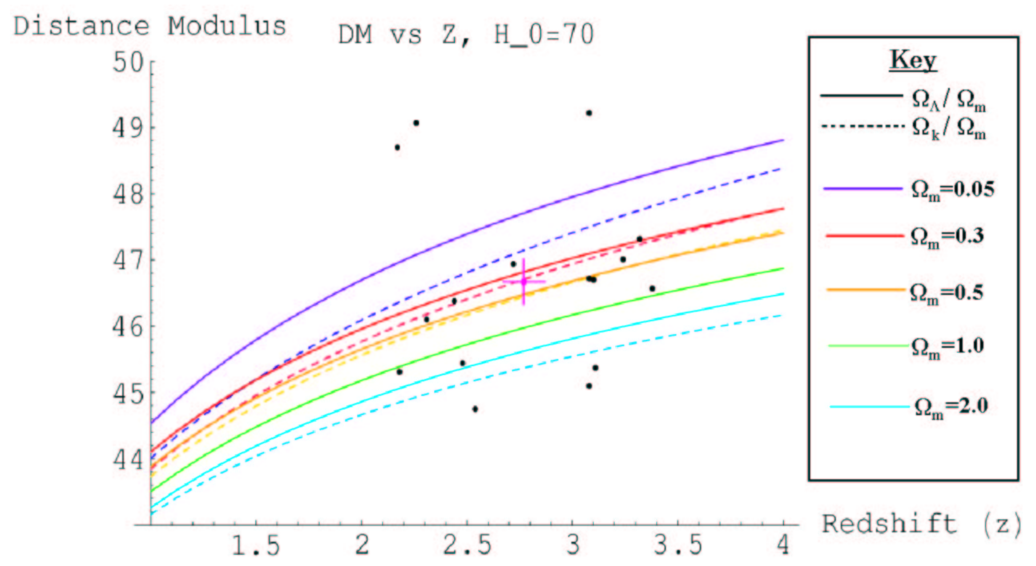
with H_0=70 km s^{-1} Mpc^{-1}. From our measurements (from [3] and [4]), we check the validity of our empirical correlation for our new sample, obtaining the figure below.



There is a noticeable discontinuity in the data points at $M_z = 2$, thus we cut all data for which $M_z > 2$. This corresponds to cutting data for which $\sigma > 125$ km s^{-1}. We also cut out galaxies with $EW < 25$Å to reduce evolutionary effects. Similar cutoffs were applied by MTM. Our applicable high-z data set is shown in the data table.

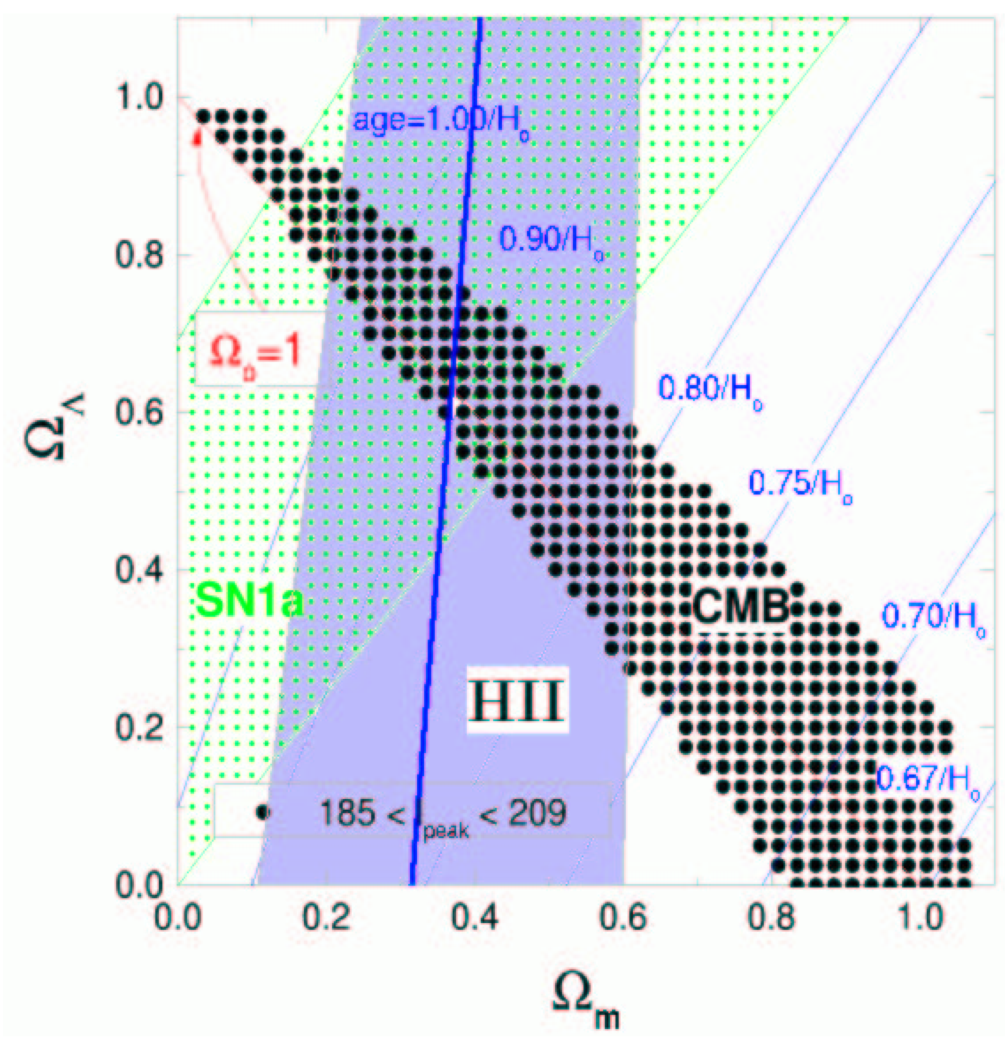
Results

For our data points, we plot the distance moduli against redshift on a graph with different cosmological models corresponding to different values of Ω_m. (Note the slight sensitivity of DM to an $\Omega_\Lambda + \Omega_m$ universe vs. an $\Omega_k + \Omega_m$ universe.)



By averaging the values of DM and z, and taking 1-σ error bars from the distribution of points alone, we obtain a best fit of z=2.77±0.12, DM=46.68±0.34. This corresponds to Ω_m=$0.37^{+0.24}_{-0.16}$ for a Λ-dominated universe and to Ω_m=$0.32^{+0.28}_{-0.21}$ for an open universe. Combined with SNIa and CMB data [5], we can see all three constraints on the Ω_m+Ω_Λ parameter space (below).

Constraints on Ω_m



The blue region above illustrates our 1-σ constraints on Ω_m from HII galaxies.

Data Table

Galaxy	z^a	σ^b	F(Hβ)^c	12+Log[(O/H)]^d	A(Hβ)^e	W^f	DM^g
CDFb-BN88	2.26	96 ± 46	0.9 ± 0.3	8.55	0.72 ± 0.15	yes	49.07 ± 2.17
Q1623-BX432	2.18	51 ± 22	2.0 ± 0.6	8.55	0.24 ± 0.15	yes	45.31 ± 1.98
Q1623-BX522	2.48	< 44	1.0 ± 0.3	8.55	0.06 ± 0.15	yes	45.44 ± 1.25
Q1623-MD107	2.54	< 42	1.3 ± 0.4	8.55	0.21 ± 0.15	yes	44.75 ± 1.28
Q1700-BX717	2.44	< 60	1.4 ± 0.4	8.55	0.43 ± 0.15	yes	46.38 ± 1.25
Q1700-MD103	2.31	75 ± 21	3.0 ± 1.0	8.55	1.10 ± 0.15	yes	46.10 ± 1.38
SSA22a-MD41	2.17	107 ± 15	2.9 ± 0.9	8.55	0.48 ± 0.15	yes	48.70 ± 0.79
CDFa C1	3.11	≤63	3.4 ± 1.0	8.55	0.75 ± 0.15	28	45.37 ± 1.24
Q0347-383 C5	3.24	69 ± 4	1.7 ± 0.5	8.55	0.35 ± 0.15	≤27	47.01 ± 0.46
B2 0902+343 C12	3.38	87 ± 12	2.7 ± 0.3	8.71	1.15 ± 0.15	37	46.57 ± 0.72
Q1422+231 D81	3.10	116 ± 8	4.1 ± 0.4	8.62	0.35 ± 0.15	43	46.70 ± 0.40
SSA22a MD46	3.08	67 ± 6	2.3 ± 0.7	8.55	0.16 ± 0.15	≤31	46.72 ± 0.58
SSA22a D3	3.08	113 ± 7	1.3 ± 0.3	8.39	1.15 ± 0.15	25	49.22 ± 0.43
DSF 2237+116a C2	3.32	100 ± 4	3.5 ± 0.4	8.55	1.27 ± 0.15	25	47.32 ± 0.28
B2 0902+343 C6	3.08	55 ± 15	3.0 ± 1.0	8.55	0.42 ± 0.15	40	45.10 ± 1.35
MS 1512-cB58	2.72	81 ± 20	1.4 ± 0.2	8.49	1.70 ± 0.15	26	46.94 ± 1.22

^{a}Vacuum heliocentric redshift of nebular emission lines
^{b}Velocity dispersion in km s^{-1}
^{c}Line Flux in units of 10^{-17} ergs s^{-1} cm^{-2}
^{d}Oxygen abundance
^{e}Extinction in Hβ in magnitudes
^{f}Rest frame line equivalent width in Å
^{g}Distance modulus in magnitudes

Sources of error

Our sources of error fall into the following three categories: random errors, systematic errors inherent to our method, and systematic errors specific to our data set.

- Random Errors: These include errors from the distribution of points and from measurements of σ, $A_{H\beta}$, $F(H\beta)$, and O/H. For our 16 galaxies, all sources of random errors combined lead to an uncertainty in the distance modulus of ±0.38 [6]. These are the errors that will diminish as more galaxies are sampled. As data improves, this number will decrease as $N^{1/2}$, where N is the number of HII galaxies.
- Inherent Systematic Errors: These errors are inherent to our method, and will bias the distance modulus to either higher or lower values. The assumed relation of M_z may not be exact, and introducing the 1-σ errors from MTM, we derive a systematic uncertainty in DM of ±0.30. Our assumption of universality of HII galaxies, if incorrect, could bias the DM in any direction by any amount. We cut on σ and on EW to minimize these effects and restrict our range to galaxies we believe follow this empirical correlation. Finally, the values of $A_{H\beta}$ were derived assuming the extinction law for the Milky Way to be valid for HII galaxies. This may not be the case. If the extinction law for the LMC is used, the DM is systematically raised by 0.28 mag. If the true extinction law for HII galaxies can be adequately parametrized to ±10%, systematics due to extinction corrections may be reduced to a net uncertainty in DM of only ±0.09 mag.
- Sample-Specific Systematic Errors: These are errors specific to our data sample, which can be 100% eliminated in the future by improved measurements. Our two data sets, [3] and [4], have consistent color measurements at only the 2-σ level, inducing an uncertainty in DM of ±0.18. The unavailability of EW for all data makes our estimates for that cut unreliable, and induces a systematic of ±0.08 magnitudes. Hα to Hβ conversions are known [7] and induce no uncertainty. We do not have accurate measures of the metal abundance O/H because the values were derived from the metallicity indicator R_{23} for only 5 galaxies in our 16 galaxy sample. Assuming the upper branch in the R_{23} vs. O/H calibration [8], and considering the average O/H value for the 5 objects to be representative of the HII galaxy population at high redshift, we estimate a systematic in DM of ±0.32 mag.

Conclusions

- Preliminary results show this to be a viable, new method of measuring Ω_m.
- Current technology is capable of surveying hundreds of HII galaxies at $z \geq 2$, while obtaining measurements to reduce systematics. This provides a promising avenue for determining Ω_m in the immediate future.
- A sample of 600 HII-like galaxies at $2 < z < 4$ with accurate measurements for σ, $F(H\beta)$, $E(B-V)$ color, O/H, z, and EW will allow for a precise measurement of Ω_m with uncertainties of ±0.04 due to systematics and ±0.03 due to random errors.

References

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