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PROBING COSMOLOGICAL PARAMETERS WITH H II GALAXIES AND THE NEW GENERATION TELESCOPES

Elena Terlevich,[1] Roberto Terlevich,[2] and Jorge Melnick[3]

RESUMEN

Re-investigando el uso del diagrama de Hubble para medir la constante cosmológica (Λ) y la densidad de masa del Universo (Ω_M), hemos vuelto a encontrar un importante efecto de "enfoque" en Λ para $z \sim 3$, que implica que la magnitud aparente de una candela estandard a $z = 2$–3, prácticamente no depende de Λ para $\Omega_M > 0.2$ y que, eligiendo el rango de corrimientos al rojo de acuerdo con una estimación del valor de Ω_M, éste puede ser medido independientemente de Ω_Λ. Exploramos la evidencia que sugiere que galaxias con brotes extremos de formación estelar, (galaxias H II), pueden ser usadas como estimadores de distancia sobre un amplio rango de z. Hemos recopilado datos de la literatura de galaxias H II hasta $z \sim 3$, y encontramos una buena correlación (a pesar de efectos sistemáticos: edad, metalicidad, extinción, cinemática), entre sus luminosidades y dispersión de velocidades confirmando así la correlación conocida para galaxias H II en el Universo cercano. Aquí presentamos la existente necesidad de nuevas observaciones de galaxias H II a z medianos y grandes con la nueva generación de telescopios de 10 m, y con espectrógrafos capaces de obtener medianamente alta resolución espectral.

ABSTRACT

Investigating the use of the Hubble diagram to measure the cosmological constant (Λ) and the mass density of the Universe (Ω_M) we found an important focusing effect in Λ for $z \sim 3$. This effect implies that the apparent magnitude of a standard candle at $z = 2$–3 has almost no dependence on Λ for $\Omega_M > 0.2$, and that Ω_M can be measured independently of Ω_Λ by targeting the z range according to an estimate of the value of Ω_M. We explore the evidence in support of the suggestion that extreme starburst galaxies (H II G) can be used as distance estimators up to high redshifts. We have compiled literature data of H II G up to $z \sim 3$ and found a good correlation (in spite of systematic effects such as age, extinction, kinematics, and metallicity) between their luminosity and velocity dispersion measured from their strong emission lines, thus confirming the correlation already known to exist for H II G in the nearby Universe. We discuss the need for new observations of intermediate–high redshift H II G with the new generation 10 m class telescopes and using mid to high spectral resolution.

Key Words: **COSMOLOGY: DISTANCE SCALE — ISM: H II REGIONS — GALAXIES: H II**

1. INTRODUCTION

Inconsistencies in recent results from distant supernova surveys (in fact, unphysically low values for Ω_M in disagreement with CMB results) have led to a renewed exploration of cosmological models with cosmological constant Λ different from zero (Lineweaver 1998; White 1998). The use of supernovae to measure simultaneously Ω_M and Ω_Λ (the energy density of vacuum) was pioneered by Goobar & Perlmutter (1995). Perlmutter et al. (1998) and Riess et al. (1998) showed that type Ia SNe at redshifts $0.1 < z < 1$ could strongly constrain the allowed range in these cosmological parameters. These supernovae cannot be used as standard candles much beyond the redshift of 1 because of the time needed for the progenitors to become supernovae.

We have shown (Melnick et al. 2000) that the strong *focusing* effect of Hubble diagrams with Λ (already mentioned by Refsdal et al. 1967) allows us to separate the effects of mass and vacuum density in the expansion, provided one can measure distances in the range $1 < z < 3$. This is shown in Figure 1, which plots the predicted luminosity distance (normalized to $\Omega_M = 0.5$ and $\Omega_\Lambda = 0$) as a function of z for different combinations of cosmological parameters. For a given Ω_M the world models of different Ω_Λ converge in a narrow redshift range and the degree of convergence increases with increasing mass density.

Distance estimators such as the Tully–Fisher relation for spiral galaxies, or the $D_n - \sigma$ relation for ellipticals, cannot be applied much beyond redshifts

[1]INAOE, Tonantzintla, Puebla, Mexico. Visiting Fellow, IoA, Cambridge.
[2]IoA, , Cambridge, UK. Visiting Professor, INAOE.
[3]ESO, Santiago, Chile.

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of 0.5 because of significant systematic evolutionary effects of the stellar population with look-back time. SNe of type Ia can be used up to $z \sim 1$ but there are discrepancies due to extinction correction uncertainties, and perhaps also to yet unknown effects (e.g., metallicity effects). It is therefore desirable to explore distance estimators such as the $L(\mathrm{H}\beta)$–σ relation in H II galaxies (Melnick et al. 1988, hereafter MTM) that can be potentially used from the Local Group of galaxies up to redshifts of cosmological interest with today's technology. We have used published data to show that the $L(\mathrm{H}\beta)$–σ relation for local galaxies is also satisfied by emission line objects of redshifts up to $z \simeq 3$. We argued that strong emission line galaxies are very promising objects to be used for a global determination of the cosmological parameters Ω_M and Ω_Λ.

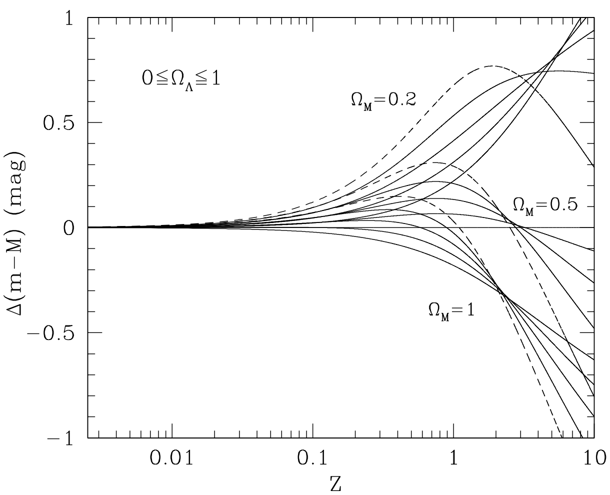

Fig. 1. Normalized distance modulus $\Delta(m-M) = (m-M)_{\Omega_M,\Omega_\Lambda} - (m-M)_{.5,0}$ as a function of redshift. For each value of Ω_M as labeled in the figure we plot a family of vacuum energy density $\Omega_\Lambda = 0, 0.25, 0.5, 0.75, 1.0$. For each family, the dashed line corresponds to $\Omega_\Lambda = 1$.

Figure 2 shows the $L(\mathrm{H}\beta)$–σ relation for the published samples; filled triangles are the local galaxies from MTM; squares represent data from Koo et al. (1995) and Guzman et al. (1997); circles are the high redshift objects from Pettini et al. (1998). No extinction corrections have been applied. The most important systematic effects (age, extinction, kinematics, metallicity, and the very physics of the relation) have been discussed at length by Melnick et al. (2000).

2. CONCLUSIONS

The existing focusing effect in Λ for values of $z \sim 3$ as seen in Figure 1 means that the apparent magnitude of an astrophysical candle at $z = 2 - 3$

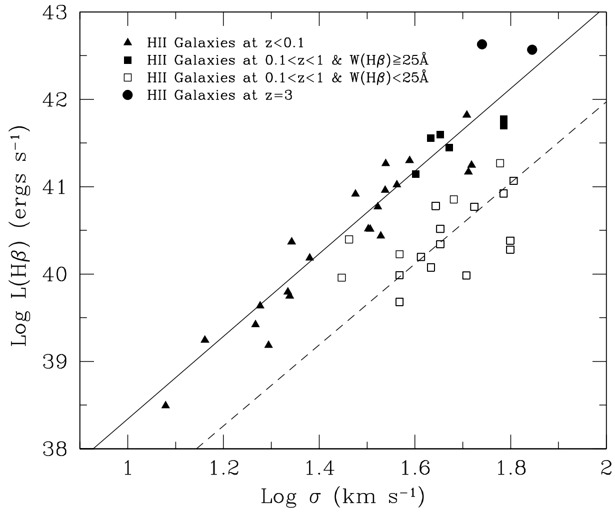

Fig. 2. The luminosity–sigma correlation for H II galaxies at a wide range of redshifts. The solid line shows the maximum likelihood fit to the young H II galaxies in the local Universe. The dashed line shows the predicted $L(\mathrm{H}\beta)$–σ relation for an evolved population of H II galaxies. The cosmology is $\mathrm{H}_0 = 65, \mathrm{q}_0 = 0, \Lambda = 0$.

has almost no dependence on Ω_Λ for values of Ω_M greater than 0.2.

Our strong conclusion is that using the redshift–magnitude diagram method Ω_M can be measured independently of the value of Ω_Λ by targeting the z range according to an estimate of the value of Ω_M. In particular, for small Ω_M, the optimum redshift is $z \sim 3$ where already a significant sample of H II galaxies does exist (e.g. pcitePet98) Ω_Λ is best determined well away from the region where the focusing occurs, i.e., either $z < 1$ or $z > 5$.

H II galaxies can potentially be used up to redshifts of 4 or 5. Given the quality of the existing data, it is remarkable how well they follow the L–σ relation of the Balmer emission lines for the range of redshifts between 0 and about 3. It will be necessary in the future, to change the search techniques from broad to narrow band surveys in order to maximize the possibility of detection of the youngest emission line galaxies at high redshifts. Observing the youngest of the samples will minimize dispersion effects due to evolution of the stellar population (see Figure 2). This is already within reach by using the high efficiency IR spectrographs in the new generation 8–10 m telescopes.

Systematic changes of 0.2 dex in metallicity and 0.2 magnitudes (from extinction), which roughly correspond to 1σ deviation in the local sample, produce a dispersion of 0.7 mag in $(m - M)$. New observations should aim at reducing this dispersion as this will be crucial in order to discriminate between different values of Ω_M at $z \sim 3$.

In order to significantly reduce the scatter, we need to determine line intensities—e.g., $F(\mathrm{H}\beta)$—to better than 10 percent to reduce the systematic errors in the photometry, and to measure σ better than 5 percent. These galaxies show typically emission line widths corresponding to $\sigma < 80$ km s^{-1}, so for this program one needs spectrographs with a resolving power of at least $R > 10000$.

Under these conditions it will be possible to determine the Hβ line widths, luminosities, and equivalent widths of high z H II galaxies over a wide range of luminosities with high accuracy. We are looking forward to the chance, for the first time, of using the distance estimator to probe the cosmological parameters out to unprecedented distances.

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Elena Terlevich: INAOE, Tonantzintla, 51 y 216, 71200 Puebla, Mexico (eterlevi@inaoep.mx)
Roberto Terlevich: Institute of Astronomy, Madingley Rd., Cambridge, CB3 0HA, UK (rjt@ast.cam.ac.uk)
Jorge Melnick: ESO, Alonso de Cordova 3107, Santiago de Chile, Chile (jmelnick@eso.org)