Probing Galaxies through Quasar Absorption Lines
Proceedings IAU Colloquium No. 199, 2005
P. R. Williams, C. Shu, and B. Ménard, eds.

doi:10.1017/S1743921305003029

The metallicities of Luminous Infrared Galaxies at $z \sim 0.7$, hints to the evolution of galaxies

Y. C. Liang[1,2], F. Hammer[2], H. Flores[2], D. Elbaz[3], X. Z. Zheng[4], L. C. Deng[1], D. Marcillac[3], and C. J. Cesarsky[4]

[1]National Astronomical Observatories, Chinese Academy of Sciences,
20A Datun Road, Chaoyang District, Beijing 100012, P.R. China, email: ycliang@bao.ac.cn
[2]GEPI, Observatoire de Paris-Meudon, 92195 Meudon, France
[3]CEA, Saclay-Service d'Astrophysique, Orme des Merisiers, F91191, Gif-sûr-Yvette, France
[4]Max-Planck Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany
[5]ESO,Karl-Schwarzschild Strase 2, D85748 Garching bei München, Germany

Abstract. A sample of distant ($z > 0.4$) luminous infrared galaxies (LIRGs) selected from ISOCAM deep survey fields (CFRS, UDSR, UDSF) have been studied on the basis of their high-quality optical spectra from VLT/FORS2 (R=5Å). Robust estimates of dust extinction can be considered via the energy balance between the infrared and Hβ luminosities, after correcting the underlying Balmer absorption properly. Oxygen abundances [12+log(O/H)] in the interstellar medium of the sample galaxies estimated from the "strong-line" method show a range from 8.36 to 8.93, with a median value of 8.67, which is 0.5 lower than that of local bright disks (i.e. L^*) at the given magnitude. The timescale to double the stellar masses of such LIRGs can be very short, 0.1-1 Gyr. A significant fraction of distant large disks are indeed LIRGs. Such massive disks could have formed $\sim 50\%$ of their metals and stellar masses since $z \sim 1$.

1. Introduction

Understanding how and when galaxies and the stars and metals in them were formed is still a considerable challenge for astrophysicists. The "**downsizing**" model suggests that massive galaxies were in place at the $z \sim 1$ epoch, and the following star formation mainly occurred in dwarf galaxies with low mass and low luminosity (Fontana *et al.* 2004; Glazebrook et al. 2004; Lilly *et al.* 1998; Brinchmann & Ellis 2000, BE00). This picture contradicts the "**hierarchical**" model (Kauffmann *et al.* 1999). Recent studies have provided some observational evidence for the "hierarchical" scenario (Heavens *et al.* 2004; Drory *et al.* 2004; Hammer *et al.* 2005, H05). The Luminosity-Metallicity (L-Z) relation of galaxies will be an important tracer/probe to understand the assembly history of the stellar mass and metals.

In the local Universe, metallicity correlates well with the absolute luminosity (stellar mass) of galaxies over a wide magnitude range (e.g. $7-9$ mag, Liang *et al.* 2004 and references therein; Tremonti *et al.* 2004). The L-Z relations of some galaxies in the intermediate-z Universe have also been obtained (Liang *et al.* 2004; Kobulnicky *et al.* 2003; Maier *et al.* 2004; Kobulnicky & Kewley 2004). The common results show that, at a given magnitude, galaxies at intermediate-z were more metal-poor than the local star-forming galaxies, such as the sample of Kennicutt (1992, K92) and Jansen *et al.* (2000, J20). In this study, we show the L-Z relation of a sample of LIRGs at $z > 0.4$ detected by ISO.

The cosmic infrared background resolved by ISOCAM shows that the co-moving density of infrared light due to LIRGs ($L_{\rm IR} \geqslant 10^{11} L_{\odot}$) was more than 40 times greater at $z \sim 1$ than today (Elbaz *et al.* 2002). The main driver for this evolution is the emergence of luminous infrared starburst galaxies with high star formation rates (SFR) seen by ISO at $z > 0.4$ (Flores *et al.* 1999; Franceschini *et al.* 2003). Here, we present the derived L-Z relations of distant LIRGs, and discuss the hints to the formation and evolution of galaxies therein. Throughout this paper, a cosmological model with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_{\rm M} = 0.3$, and $\Omega_{\Lambda} = 0.7$ has been adopted. M_B is given in the AB magnitude system.

2. The sample and extinction estimates

The sample galaxies were selected from three ISO deep survey fields: the CFRS 3h field, the Ultra Deep Survey Rosat (UDSR) and the Ultra Deep Survey FIRBACK (UDSF) fields. In total, 105 objects were selected, and observed using VLT/FORS2 with R600 and I600, at a resolution of 5Å and covering 5000 − 9200Å. The IR luminosities (and deduced SFRs) were calculated using the procedure given in Elbaz *et al.* (2002). To study the SFRs of distant LIRGs (in the later part of this study), the objects detected in the CFRS 14h field have also been collected.

For the $z > 0.4$ galaxies, the dust extinction can be estimated from the Hγ/Hβ ratio. Because of the large uncertainties related to measurements of the Hγ line, we assumed that the infrared data provides a robust SFR estimate for IR-luminous galaxies (Elbaz *et al.* 2002; Flores *et al.* 2004). Then, the dust extinction of LIRGs can be estimated by considering the energy balance between the IR and Hβ luminosities. The derived median value of A_V(IR) is 2.36. The stellar absorption under the Balmer lines was estimated from synthesised stellar spectra obtained using the stellar spectral library of Jacoby *et al.* (1984). We adopt the interstellar extinction law of Fitzpatrick (1999) with $R = 3.1$.

3. Abundances in the interstellar medium and SFRs

The derived 12+log(O/H) of the galaxies via R_{23} (and O_{32}) following the calibration of Kolbinicky *et al.* (1999) show a range of 8.36 to 8.93, with a median value of 8.67.

The left panel of Fig. 1 compares the L-Z relation for the LIRGs to that of local disks (K92, J20), which are restricted to moderately star-forming [EW(Hβ) $<$ 20 Å] galaxies. These distant LIRGs exhibit $\sim$ 0.3 dex ($\sim$50%) lower oxygen abundances than local ones at the given magnitude (the median value). PÉGASE2 models (Fioc & Rocca-Volmerange 1999) predict a total mass ranging from 10^{11} M$_{\odot}$ to $\leqslant 10^{12}$ M$_{\odot}$ for the LIRGs, which can be twice the stellar mass of distant LIRGs ($1.4 \times 10^{10} - 2.9 \times 10^{11}$ M$_{\odot}$) derived by Zheng *et al.* (2004) on the basis of K-band luminosities. The right panel of Fig. 1 shows that the timescale to double the stellar mass of such LIRGs can be very short, 0.1-1 Gyr. Comparison with the corresponding estimates from [OII]3727 lines following the adopted calibration in BE00 shows that an important part of the star formation can be hidden using UV estimates of the SFR.

There is a growing consensus that z<1 LIRGs are associated with star formation in spirals (H05). About 36% of LIRGs are large disks (Zheng *et al.* 2004), and a similar fraction (about 32%) was estimated from the sample of large disks of Lilly *et al.* (1998). These massive LIRGs have high SFRs. The time-scale to double their stellar mass can be very short. Such massive disks could have formed $\sim$50% of their metals and stellar masses since $z$$\sim$1. This could be consistent with the hierarchical model. However, further work is required to identify the major mechanisms occurring in the formation of a significant part of present-day spiral stars, including a large fraction of them in disks.

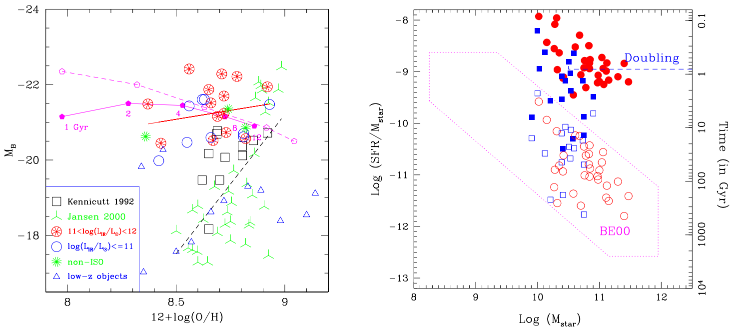

Figure 1. *The left panel:* the M_B-metallicity relation of distant LIRGs (with a typical uncertainty of 0.08 dex on metallicity), compared with the local galaxies from K92 and J20; PÉGASE2 infall models are superimposed, assuming a total mass of 10^{11} $M_\odot$ and infall times of 5 Gyr and 1 Gyr (solid and dashed lines with pentagons, respectively). *The right panel:* typical timescales for forming stellar mass in the z>0.4 LIRGs (full dot, the filled squares are for luminous compact galaxies presented in H05); The dotted line box indicates the position occupied by the galaxies when their SFR is derived from [OII]3727 line, following the calibration adopted in BE00. Similar estimates have been done for this sample for LIRGs (empty dots) and for compact galaxies (empty squares). This gives evidence that an important part of the star formation can be hidden using UV estimates of the SFR.

Acknowledgements

Y. C. Liang wishes to thank the Natural Science Foundation of China (NSFC) support under No. 10403006.

References

Brinchmann, J., Ellis, R., 2000, ApJ, 536, L77 (BE00)
Drory, N., Bender, R., Feulner, G., *et al.*, 2004, ApJ, 608, 742
Elbaz, D., Cesarsky, C. J., Chanial, P., *et al.*, 2002, A&A, 384, 848
Fioc, M., Rocca-Volmerange, B., 1999, astro-ph/9912179 (PÉGASE2)
Fitzpatrick, E. L., 1999, PASP, 111, 63
Flores, H., Hammer, F., Elbaz, D., *et al.*, 2004, A&A, 415, 885
Flores, H., Hammer, F., Thuan, T. X., *et al.*, 1999, ApJ, 517, 148
Fontana, A., Pozzetti, L., Donnarumma, I., *et al.*, 2004, A&A, 424, 23
Franceschini, A., *et al.*, 2003, A&A, 403, 501
Glazebrook, K., Abraham, R. G., McCarthy, P. J., *et al.*, 2004, Nature, 430, 181
Hammer, F., Flores, H., Elbaz, D., Zheng, X. Z., Liang, Y. C., *et al.*, 2005, A&A, 430, 115 (H05)
Heavens, A., Panter, B., Jimenez, R., Dunlop, J., 2004, Nature, 428, 625
Jacoby, G. H., Hunter, D. A., Christian, C. A., 1984, ApJS, 56, 257
Jansen, R. A., Franx, M., Fabricant, D., Caldwell, N., 2000, ApJS, 126, 331 (J20)
Kauffmann, G., *et al.*, 1999, MNRAS, 307, 529
Kennicutt, R. C. Jr., 1992, ApJ, 388, 310 (K92)
Kobulnicky, H. A., *et al.*, 2003, ApJ, 599, 1006
Kobulnicky, H. A., Kennicutt, R. C. Jr., Pizagno, J. L., 1999, ApJ, 514, 544
Kobulnicky, H. A., Kewley, L. J., 2004, ApJ, 617, 240
Liang, Y. C., Hammer, F., Flores, H., Gruel, N., Assémat, F., 2004, A&A, 417, 905
Lilly, S. J., *et al.*, 1998, ApJ, 500, 75
Maier, C., Meisenheimer, K., Hippelein, H., 2004, A&A, 418, 475
Tremonti, C. A., *et al.*, 2004, ApJ, 613, 898
Zheng, X. Z., Hammer F., Flores, H., Assémat, F., Pelat, D., 2004, A&A, 421, 847

https://doi.org/10.1017/S1743921305003029 Published online by Cambridge University Press