CHEMICAL EVOLUTION OF ELLIPTICAL GALAXIES

Mg_2 Gradients and G-Dwarf Problem

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1. Introduction

Stellar populations of elliptical galaxies were studied extensively in the recent past (eg., Arimoto & Yoshii 1987; Buzzoni et al. 1992; Worthey 1994; Kodama & Arimoto 1997). However, colours and line-strengths analysed by these approaches came mainly from central regions of galaxies and possible variations of stellar population structure within a galaxy were entirely ignored. Kodama & Arimoto (1997) recently show that a colour-magnitude (CM) relation of ellipticals in Coma cluster (Bower, Lucey, & Ellis 1992), and the CM relation of cluster ellipticals in general, should originate from a difference in mean stellar metallicities, as suggested by Arimoto & Yoshii (1987), and cannot be due to an increase of mean stellar age towards luminous galaxies as claimed by Worthey (1994). It is quite often stated that any theory of galaxy formation should explain the origin of CM relation, or in other words, the mass (luminosity) - metallicity relation of elliptical galaxies. However, one should not forget the fact that the CM relation is defined only for stars in the central regions of galaxies; it is possible that the CM relation itself is an observational artifact, since ellipticals show in general radial gradients of metallic-line strengthes, decreasing from a centre towards outer regions (eg., Faber 1977; Davies, Sadler, & Peletier 1993; Gonzalez 1993; Carollo & Danziger 1994). Indeed, Gorgas & Gonzalez (1996) found that ellipticals with larger central Mg_2 indices tend to have steeper Mg_2 gradient, which suggests that global metallicities of ellipticals are perphaps universal and are independent of galaxy luminosities.

In this article we briefly present our latest results derived from a study of Mg_2 gradients of 114 ellipticals available in the literature and address ourselves to a reality of global CM relation of ellipticals. Most galaxies are in the field and details of data, including the references, will be given elsewhere.

2. Global CM Relation

Arimoto et al. (1997) have shown that the mean stellar metallicity of an elliptical galaxy is approximately given by the projected metallicity measured at one effective radius (r_e), if the luminosity profile is given by de Vaucouleurs law and the Mg_2 gradient is well fitted by an exponential law. We have calculated the mean stellar metallicity of each galaxy by actually integrating the observed Mg_2 profile and have confirmed that Mg_2 at $r = r_e$ is indeed a good measure of the mean stellar metallicity. Although Mg_2 index is not usually measured beyond $r = r_e$, we assume that it decreases exponentially outwards. However, we believe that this would not intorduce any significant uncertainty in our results, since it is very unlikely that Mg_2 decreases abruptly beyond $r = r_e$ and even in such a case the resulting metallicity is overestimated no more than twice. Figure 1 shows Mg_2 at the galaxy centre (top) and at an effective radius (bottom). Mg_2 indices are transfered into the metallicity (***but not iron abundance***) [Fe/H] by using the formula given by Buzzoni et al. (1992), where we assume that all galaxies are 15 Gyrs old. In the top panel, a larger sample is taken from Davies et al. (1987), and a small one is ours. There is no systematic difference between

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the two sampled galaxies; we thus believe that our sample represent a fair population of ellipticals in the field. The bottom panel gives the mean stellar metallicities of 114 ellipticals which we analysed. Obviously, the global metallicities are much lower than the central values; for example, the histogram peaks at $Mg_{2,e} \simeq 0.24$ ($[Fe/H]_e \simeq -0.3$) which is about 1/3 of the peak location of the central values at $Mg_{2,c} \simeq 0.31$ ($[Fe/H]_c \simeq +0.2$). We note that the mean metallicity of elipticals is not universal, instead it varies from $[Fe/H] \sim -1.0$ to $\sim +0.2$. This indicates that the metallicity gradients of luminous ellipticals are not steep enough to reduce the global metallicity as low as that of faint dwarf ellipticals.

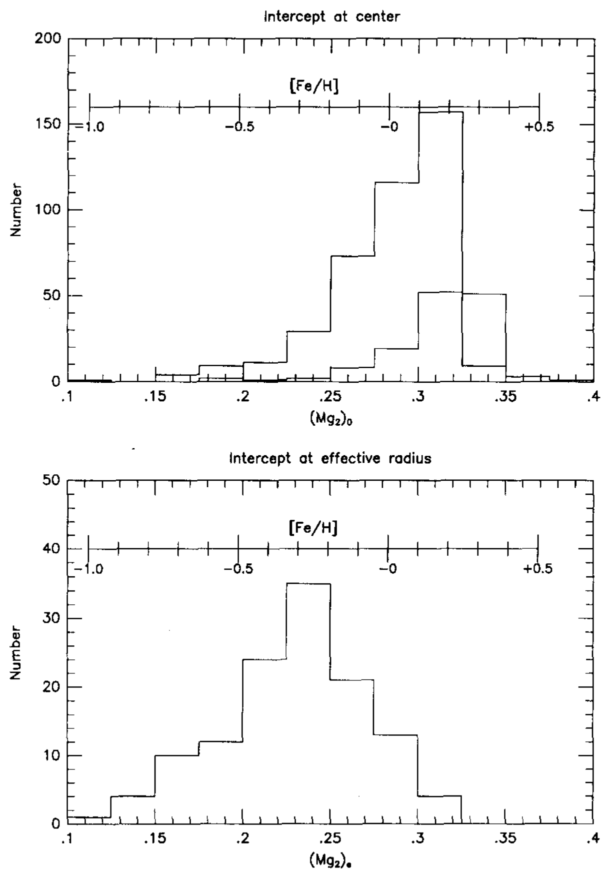

Figure 1. Central Mg_2 indices of 114 ellipticals (top). Larger sample is taken from Davies et al.'s (1987). Mg_2 indices of 114 ellipticals at one effective radius (bottom).

Figure 2 shows a plot of 114 ellipticals in the $Mg_{2,e}$ versus $\log \sigma_0$ (central velocity dispersion) diagram. Although the relationship is not so tight as that of the central Mg_2 index, the global metallicity increases significantly from $[Fe/H]_e \sim -0.6$ at $\log \sigma_0 = 1.9$ to $[Fe/H]_e \sim -0.1$ at $\log \sigma_0 = 2.6$. This could be compared to the equivalent of $Mg_{2,c}$ versus $\log \sigma_0$ relation; $[Fe/H]_c \sim -0.4$ at $\log \sigma_0 = 1.9$ and $[Fe/H]_c \sim +0.3$ at $\log \sigma_0 = 2.6$. Therefore, we conclude that elliptical galaxies do have the global CM relation, but the slope is less steep than the central CM relatioin.

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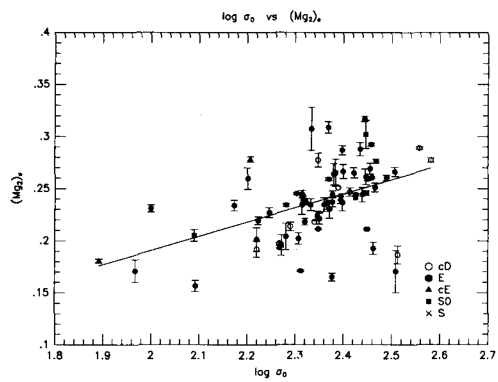

Figure 2. $Mg_{2,e}$ versus $\log \sigma_0$ relation of 114 ellipticals.

In Fig.2 one may immediately notice that the scatter around the $Mg_{2,e} - \log \sigma_0$ relation is unexpectedly large. Possible causes for the dispersion are as follows: 1) variation due to different observation facilities, 2) different correction for velocity dispersion gradient, 3) deviation from de Vaucouleurs luminosity profile, 4) abrupt drop of Mg_2 index beyond $r = r_e$, 5) deviation from an exponential fit for Mg_2 at the central region, 6) errors in effective radius, and 7) gradient of M/L ratio. We have checked each of them in detail and found none of them could cause the dispersion appearing in Fig.2. This leads us to conclude tentatively that the dispersion around the relationship between the mean stellar metallicity and the central velocity dispersion, which should be an indicator of galactic mass, could be real and come directly from the different history of galaxy formation.

3. G-dwarf Problem

The observed luminosity profile and the Mg_2 gradient are the 2D projected ones. By using Abell integral, we have deprojected these 2D distributions and derive the 3D luminosity profile and the 3D metallicity distribution for NGC4472, a giant elliptical galaxy in our sample. If we assume that all stars within a spherical shell $(r, r + dr)$ have an identical metallicity given by the 3D-[Fe/H] distribution thus derived, and if the variation of M/L ratio along the radius is negligible, it is possible to calculate the number fraction of stars with a specfied [Fe/H] value and to derive the stellar metallicity distribution which is found to be quite useful to assign chemical evolution history of the solar neighbourhood disc of the Milky Way Galaxy (eg., Köppen & Arimoto 1990). **A similar kind of chemical evolution analysis is now possible for elliptical galaxies.** We have found that the metallicity distribution of NGC4472 is in the range $-0.5 \leq [Fe/H] \leq +0.9$, but the metallicity of bulk of stars is within $-0.2 \leq [Fe/H] \leq +0.3$ and takes a sharp peak at $[Fe/H] \simeq 0.0$. The metallicity distribution of NGC4472 is somewhat similar to the G-dwarf metallicity distribution in the solar neighbourhood disc, but is shifted systematically by $\Delta[Fe/H] \sim +0.3$. *Unexpectedly, NGC4472 is lacking metal-poor stars of $[Fe/H] \leq -0.2$, a clear sign of the G-dwarf problem.* The G-dwarf problem is usually solved by invoking significant amount of gas infall with a rate similar to that of star formation. The same may apply for elliptical galaxies.

The location of the peak of metallicity distribution gives directly the yield of heavy elements synthesis (Köppen & Arimoto 1990). If a galaxy lost a part of heavy elements to the intragalactic space, the peak metallicity should be read as an effective yield, but it is unlikely that a giant elliptical galaxy NGC4472 had lost a significant amount of gas and metals since its gravitational potential is quite large. Therefore, the peak metallicity should give the true yield, and if so, the yield of NGC4472 is about solar and is almost twice larger than the yield in the solar neighbourhood disc. Since the latter is well reproduced by the Salpeter initial mass function (IMF), our result clearly indicates that the IMF of NGC4472, and perphaps all ellipticals, is less steeper than the Salpeter IMF, thus confirming the claim first made by Arimoto & Yoshii (1987).

4. Conclusions

Elliptical galaxies with larger central Mg_2 index tend to have steeper Mg_2 gradient, but this does not smear out the global CM relation. However, the scatter around the global CM relation is surprisingly large and we tentatively conclude that this dispersion may be associated with the formation mechanism of elliptical galaxies.

The 3D metallicity distribution of NGC4472 shows a symptom of typical G-dwarf problem, ie., a lack of metal-deficient stars. This suggests that elliptical galaxies formed from infalling gas clumps towards the central region of galactic gravitational potential, and that bulk of stars formed intensively with a flat IMF within 1-2 Gyrs, perphaps, within less than 0.5 Gyrs.

References

Arimoto, N., Matsushita, K., Ishimaru, Y., Ohashi, T., & Renzini, A., 1997, *ApJ*, **477**, 128
Arimoto, N. & Yoshii, Y., 1987, *A&A*, **173**, 23
Bower, R.G., Lucey, J.R., & Ellis, R.S., 1992, *MNRAS*, **254**, 601
Buzzoni, A., Gariboldi, G., & Mantegazza, L., 1992, *AJ*, **103**, 1814
Carollo, C.M., & Danziger, I.J., 1994, *MNRAS*, **270**, 523
Davies, R.L., Sadler, E.M., & Peletier, R.F., 1993, *MNRAS*, **262**, 650
Davies, R.L., Burstein, D., Dressler, A., Faber, S.M., Lynden-Bell, D., Terlevich, R.J., & Wegner, G., 1987, *ApJS*, **64**, 581
Faber, S.M., 1977, in The Evolution of Galaxies and Stellar Populations, eds., .T.Tinsley & R.B.Larson (New Heaven: Yale Univ. Press) p.157
Gonzalez, J.J., 1993, PhD thesis, Univ. of Califolnia
Gorgas, J., & Gonzalez, J.J., 1996, *ASP Conference Series*, **86**, 225
Kodama, T., & Arimoto, N., 1997, *A&A*, **320**, 41
Köppen, J., & Arimoto, N., 1990, *A&A*, **240**, 22
Worthey, G., 1994, *ApJS*, **95**, 107

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