ELLIPTICAL GALAXIES: THE AGE - METALLICITY DILEMMA

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Abstract. In this paper, we briefly report on the study by Bressan et al. (1995, BCT) who examine the properties of elliptical galaxies in the space of the parameters H_β, [MgFe], (1550-V), and velocity dispersion Σ, try to infer the age of these systems, and cast light on the age-metallicity dilemma.

1. Introduction

The merge of the recent work on population synthesis for the line strength indices H_β and [MgFe] by Worthey et al. (1994) and the spectro-photometric models for elliptical galaxies by Bressan et al. (1994, BCF) and Tantalo et al. (1995, TCBF) allows us to tackle the question whether or not these systems span a large range of ages. The indices H_β and [MgFe] are particularly suited to this purpose because H_β is a measure of the turn-off colour and luminosity, and age in turn, whereas [MgFe] is more sensitive to the RGB colour and hence metallicity. Gonzales (1993) analyzing the distribution of a sample of galaxies in the H_β - [MgFe] plane of single stellar populations with different metallicity and age concluded that a large spread in age seems to exist. BCT re-analyzed the same galaxies adding two more dimensions to the problem, i.e. the intensity of the UV excess as measured by the (1550–V) colour (Burstein et al. 1988) and the velocity dispersion Σ. No details are given here for the sake of brevity. Suffice it to recall that the source of the UV flux in the models is an admixture of old stars in various evolutionary stages, i.e. the classical P-AGB stars and the so-called hot HB and AGB-manqué stars of high metallicity, whose proportions and characteristics vary with the mean and maximum metallicity of the stellar mix (see BCF and TCBF). They also made use of the constraint imposed

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by the colour-magnitude relation (CMR) for elliptical galaxies of Bower et al. (1992) for the Virgo and Coma clusters. The small scatter of the CMR in the (U–V) colour (0.04 mag) is understood as the signature of a small scatter in the age of elliptical galaxies (13.5 $\div$ 15 Gyr). Since Bower's et al. (1992) and Gonzales' (1993) samples refer to different groups of galaxies, one may wonder whether they can simultaneously be used. The two samples have five objects in common, namely NGC 4374, 4472, 4478, 4552, and 4697, whose positions in the H_β - [MgFe] plane is not particularly distinct from that of all remaining galaxies, perhaps suggesting that the analysis below will not depend on the particular CMR in usage.

2. Galaxies in the four dimensional space

The model galaxies of BCT in the H_β - [MgFe] plane are shown in Fig. 1 (left panel) together with the Re/8 data of Gonzales (1993). The solid lines are loci of constant mass (in units of $10^{12} M_\odot$) and nearly constant mean and maximum metallicities, the dotted lines are loci of constant age (in Gyr). The locus named CMR-strip is the expected trend for galaxies obeying the CMR of Bower et al. (1992) on the notion that this is a mass-metallicity sequence of old (13 $\div$ 15 Gyr), nearly coeval objects. There are two important hints emerging from the H_β - [MgFe] data:

(1) In spite of their different luminosity and mass, most galaxies seem to possess nearly identical chemical structures.

(2) Galaxies do not distribute along the locus expected for coeval old objects following the mass-metallicity sequence of the CMR. In contrast, they seem to follow a sequence of about constant metallicity and varying age, which is the conclusion reached by Gonzales (1993).

In order to reconcile things, one may argue that the large spread along the H_β direction could be the result of a recent episode of star formation shifting the galaxies from their natural location (the CMR-strip) to the one we actually see. Deciphering the true age is not possible (see BCT for details). The major drawback with this idea is that a mechanism synchronizing the bursts in different galaxies is required. Using the simultaneous inspection of the data in the H_β - [MgFe] - (1550–V) - Σ space we get the following results: 1) There is a group of galaxies (NGC 4649 as a prototype) with ages confined in the range 13 $\div$ 15 Gyr whose $(1550 - V)$ colour is normal, i.e. fully compatible with the theoretical expectation for old objects containing a certain fraction of high metallicity stars. Differences from object to object can be accounted for by differences in mass and hence mean metallicity and perhaps in age by as much as 3 Gyr. 2) There is another group of galaxies (M32 and NGC 584 as prototypes) whose H_β is too blue for their [MgFe] and $(1550 - V)$. While these latter parameters suggest an

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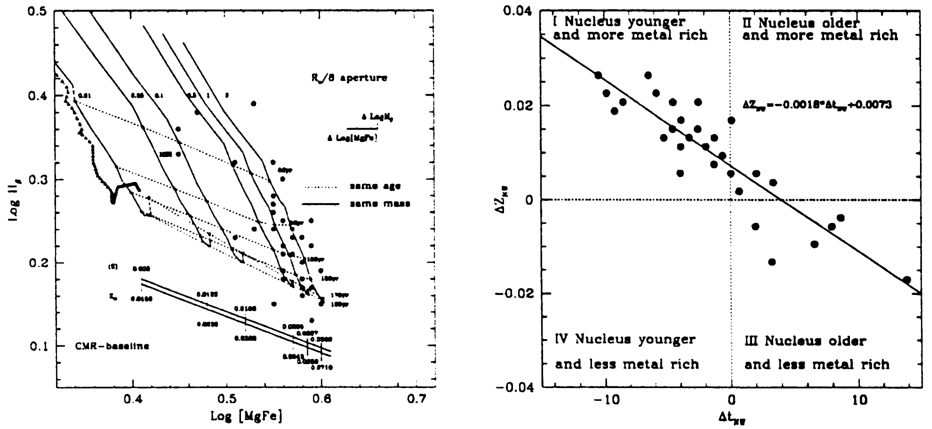

Figure 1. **Left Panel: The H_β - [MgFe] plane of theoretical models and observational data. Right panel: the relation between Δt_{WN} and ΔZ_{WN}, i.e. the age and metallicity difference between the whole galaxy and its central regions**

old age, H_β indicates a young age. It looks as if old objects suffered from a recent episode of of star formation that changed H_β leaving [MgFe] and (1550 − V) unaltered.

Although the bursting hypothesis seems to be inevitable, before accepting this conclusion we examine the information provided by the gradients in H_β and [MgFe] observed across the galaxies under examination.

3. Gradients in age and metallicity

The quantities $\Delta H_{\beta NW} = \Delta \log H_{\beta N} - \Delta \log H_{\beta W}$ and $\Delta[\mathrm{MgFe}]_{NW} = \Delta \log [\mathrm{MgFe}]_N - \Delta \log [\mathrm{MgFe}]_W$ where N and W stand for the Re/8- and R/2–data set of Gonzales (1993), i.e. for the central regions and the whole galaxy, measure the gradients within each individual galaxy. Translating $\Delta H_{\beta NW}$ and $\Delta[\mathrm{MgFe}]_{NW}$ into Δt_{NW} and ΔZ_{NW}, i.e. in the age and metallicity difference between the nucleus and the whole galaxy, respectively, (see BCT for all details), one gets the correlation between Δt_{NW} and ΔZ_{NW} shown in the right panel of Fig. 1. Of the four quadrant's, the one characterized by $\Delta t_{NW} < 0$ and $\Delta Z_{NW} > 0$ is particularly rich of galaxies. In this region the nucleus is younger and more metal-rich than the external regions of the galaxy. This corresponds to a sort of out-inward process of

galaxy and star formation that in some cases continued for significantly long periods of time. Whether the star formation process took place continuously or in a series of episodes we cannot say. BCT find the correlation $\Delta t_{NW} = 3.327 \times \log \Sigma - 10.65$, where Δt_{NW} is in Gyr, Σ is in km sec^1, and the correlation coefficient is 0.43. Δt_{NW} gets shorter at increasing velocity dispersion Σ (and perhaps galactic mass).

4. Conclusions

(1) The distribution of galaxies in the H_β - [MgFe] plane is neither a sequence of sole metallicity with bluer galaxies significantly more metal-poor than the red ones, nor a sequence of sole age with bluer galaxies significantly younger than the red ones. Furthermore, the observed distribution seems to be in conflict with the expectation from the CMR if this latter is interpreted as a mass-metallicity sequence of nearly coeval, old objects. The hypothesis of a random burst of star formation in order to reconcile the interpretation of the H_β, [MgFe], $(1550 - V)$ and Σ data and the CMR requires a sort of *ad hoc* mechanism of synchronization. We rather favour the idea that the overall duration of the star forming activity is somehow related to Σ and perhaps galactic mass.

(2) The scenario emerging from the analysis of the gradients in H_β and [MgFe] is consistent with current data on abundance ratios in elliptical galaxies (Carollo et al. 1993, Carollo & Danziger 1994, Matteucci 1994) and the expected trend for the ratio [Mg/Fe] inferred from the narrow band indices (Faber et al. 1992, Davies et al. 1993). [Mg/Fe] seems to increase with the galactic mass up to a value exceeding that of the most metal-rich stars in the solar vicinity by $0.2 \div 0.3$ dex. According to Matteucci (1994) this trend hints that the efficiency of star formation increases with the galactic mass and that massive ellipticals should have formed the bulk of their stars on shorter time scales than smaller ellipticals.

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Dickinson: We are now at the point where we can observe clusters of galaxies directly out to z=1 and beyond, select ellipticals morphologically from HST images, and study the evolution of the CMR. So far, these data show that both the slope and the very small scatter in the CMR are preserved out to z=1, i.e. to lookback times of $\simeq 10 \times H_{50}^{-1}$ Gyr. Can any of the models invoking wide age variations among elliptical galaxies account for these observations ?

Chiosi: By age of a galaxy we mean the age of the constituent stellar populations. In this context we tried to show that indeed the bulk stars are old objects (as indicated by their [MgFe] and (1550-V) data). Superposed to the old component, in some cases there might be a younger one (as suggested by the H_β and gradients in H_β and [MgFe]), which can mimic an age sequence. We do not expect the CMR to be much affected by the presence of this younger popualtion, considering the very short time scale on which a galaxy after a minor period of stellar activity recovers the previous situation. This can be inferred from comparing isochrones with the observational CMR (and blue luminosity to mass ratio).

Lee: If there is an age spread among elliptical galaxies, we do not need super metal-rich hot HB stars (see Lee & Park, this volume) to produce systematic variation of UV upturn. Then, why do we have to add completely ad-hoc assumptions required to produce hot super metal-rich HB stars in population models in addition to age spread ?

Chiosi: First excluding ongoing star formation as source of UV radiation, past the period of star formation the color (1550-V) gets very red (cf. BCF and TCB). Second, let us suppose that the the source of UV flux are the normal P-AGB and HB stars. In such a case, it would be difficult to match the observational dependence of the UV upturn with the galaxy mass, Mg2 index (metallicity ?) and luminosity (cf. BCF fo details). The hot HB and AGB-manqué channels are the natural consequence of the chemical evolution ($\Delta Y/\Delta Z$) inside a galaxy. This is suggested by the detailed shape of the spectrum in the UV, the above relation, and the mean metallicities (cf. for instance the data in H_β - [MgFe] plane), only to mention a few. The kind of age spread we are talking about has little relationship with the UV properties.

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