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Fossil group origins

IX. Probing the formation of fossil galaxy groups with stellar population gradients of their central galaxies⋆,⋆⋆

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ABSTRACT

Context. Fossil groups (FGs) are galaxy aggregates with an extended and luminous X-ray halo, which are dominated by a very massive early-type galaxy and lack of L^* objects. FGs are indeed characterized by a large magnitude gap between their central and surrounding galaxies. This is explained by either speculating that FGs are failed groups that formed without bright satellite galaxies and did not suffer any major merger, or by suggesting that FGs are very old systems that had enough time to exhaust their bright satellite galaxies through multiple major mergers.

Aims. Since major mergers leave signatures in the stellar populations of the resulting galaxy, we study the stellar population parameters of the brightest central galaxies (BCGs) of FGs as a benchmark against which the formation and evolution scenarios of FGs can be compared.

Methods. We present long-slit spectroscopic observations along the major, minor, and diagonal axes of NGC 6482 and NGC 7556, which are the BCGs of two nearby FGs. The measurements include spatially resolved stellar kinematics and radial profiles of line-strength indices, which we converted into stellar population parameters using single stellar-population models.

Results. NGC 6482 and NGC 7556 are very massive ($M_* \simeq 10^{11.5}$ $M_\odot$) and large ($D_{25} \simeq 50$ kpc) galaxies. They host a centrally concentrated stellar population, which is significantly younger and more metal rich than the rest of the galaxy. The age gradients of both galaxies are somewhat larger than those of the other FG BCGs studied so far, whereas their metallicity gradients are similarly negative and shallow. Moreover, they have negligible gradients of α-element abundance ratio.

Conclusions. The measured metallicity gradients are less steep than those predicted for massive galaxies that formed monolithically and evolved without experiencing any major merger. We conclude that the observed FGs formed through major mergers rather than being failed groups that lacked bright satellite galaxies from the beginning.

1. Introduction

Fossil groups (FGs) were first proposed by Ponman et al. (1994), when they found that the apparently isolated galaxy RX J1340.6+4018 was surrounded by an X-ray halo typical of a

Several samples of FGs selected using the Δm_{12} or Δm_{14} criteria have been presented in the last decade thanks to the availability of new surveys (Khosroshahi et al. 2007; Santos et al. 2007; Voevodkin et al. 2010; Proctor et al. 2011; Harrison et al. 2012). As the number of FGs increased, their observational properties became clearer. In particular, many studies focused on the properties of the hot intra-cluster component (Khosroshahi et al. 2007, 2014; Proctor et al. 2011; Harrison et al. 2012; Girardi et al. 2014; Kundert et al. 2015) or on the properties of the satellite galaxy population (Khosroshahi et al. 2006, 2014; Mendes de Oliveira et al. 2006; Aguerri et al. 2011, 2017; Adami et al. 2012; Lieder et al. 2013; Zarattini et al. 2014, 2015, 2016).

The formation and evolution of the brightest cluster galaxies (BCGs) has also been a main topic in the study of FGs. Indeed, BCGs are a fundamental component of a galaxy group or cluster. They are often located close to the X-ray center of the cluster (Jones & Forman 1984; Lin & Mohr 2004; Lauer et al. 2014), and they can be as luminous as $10L^*$, where L^* is the characteristic luminosity of the cluster LF (e.g., Schombert 1986). Their

galaxy group. They suggested that this was a fossil relic of an old galaxy group that had enough time to merge all its bright satellite galaxies into the central one. In this scenario, FGs formed at high redshift ($z > 1$), with few subsequent accretions (D'Onghia et al. 2005). If these systems really exist today, they can offer a unique

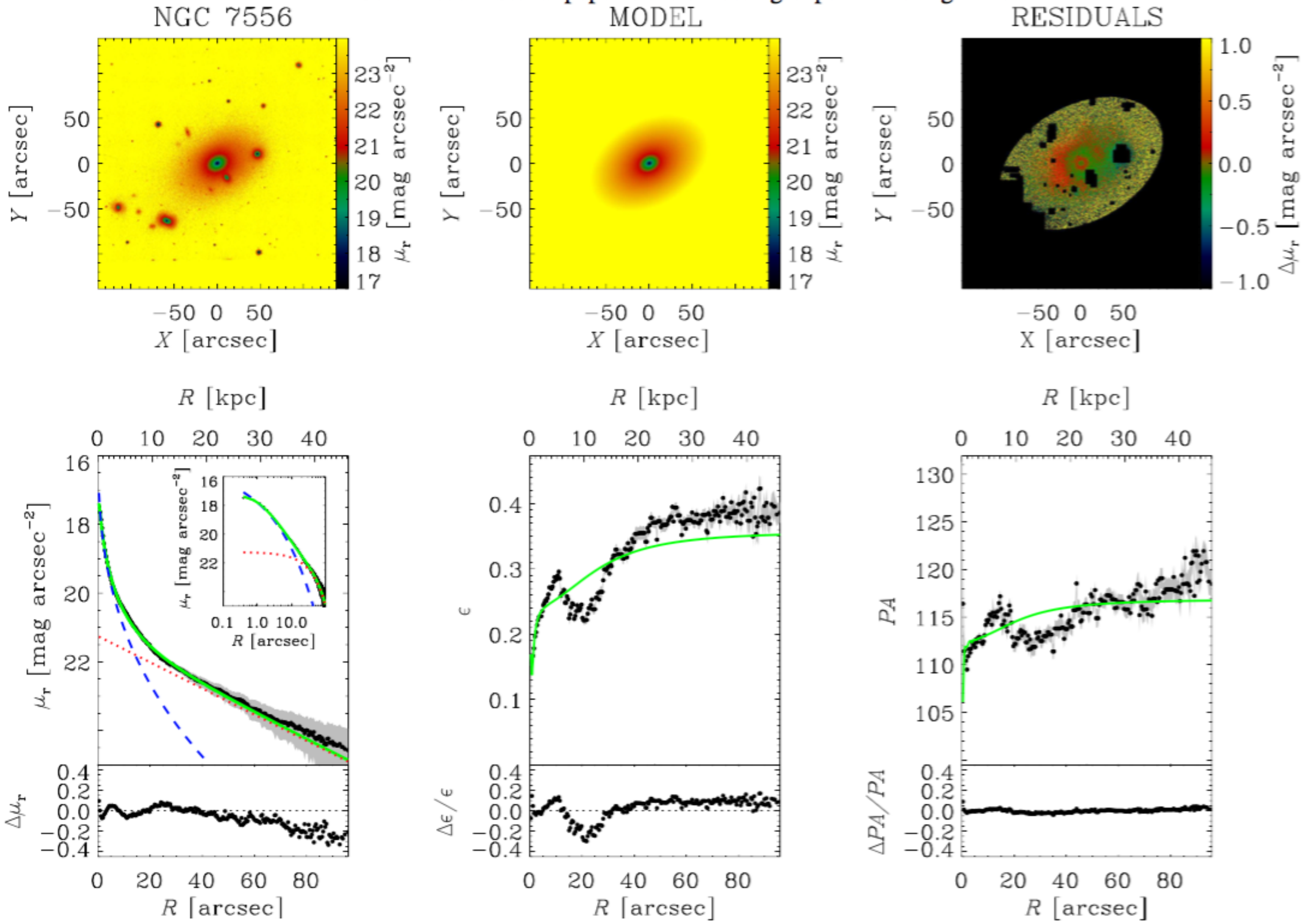
At the same time, numerical simulations show that the magnitude gap alone is not a good indicator of the dynamical stage of a group or cluster (D'Onghia & Lake 2004; D'Onghia et al. 2005). Von Benda-Beckmann et al. (2008) suggested that the fossil status is just a stage in the evolution of a system. This result has been recently confirmed by Kundert et al. (2017), who showed how the fossil status changes every 2 – 3 Gyr. Moreover, there are hints that FGs suffered the last major mergers more recently than non-FGs (Díaz-Giménez et al. 2008; Kundert et al. 2017). On the other hand, Gozaliasl et al. (2014) pointed out that there is a difference in the evolution of the faint end of the luminosity function (LF) in FGs and non-FGs. In particular, the faint end of the LF of FGs suffered no evolution after $z \sim 1$, whereas non-FGs went through an intense evolution, as also confirmed by Kundert et al. (2017). They found that the main difference between FGs and non-FGs is the halo accretion history in the last few gigayears.

quite controversial. However, the BCGs in FGs are amongst the most massive and luminous galaxies observed in the universe (Méndez-Abreu et al. 2012; Kundert et al. 2017) and this means that the merging process in FGs had to be particularly efficient.

The stellar populations of the BCGs could help in shedding light on the possible differences in the formation processes of FGs and non-FGs. La Barbera et al. (2009) found a striking similarity between the stellar population properties of FG BCGs and bright field galaxies indicating that they had similar star formation histories. This observational result is in agreement with subsequent findings obtained by Cui et al. (2011) from cosmological simulations and galaxy formation models. They showed that FG BCGs have similar properties to those in non-FGs in terms of age, metallicity, color, concentration, and total mass-to-light ratio. Results along these lines were also reported for compact (Proctor et al. 2004; Mendes de Oliveira et al. 2005) and large-gap groups (Trevisan et al. 2017), which are somehow related to FGs. According to Proctor et al. (2004) and Mendes de Oliveira et al. (2005), the majority of galaxies in compact groups, which are possible progenitors of FGs, are

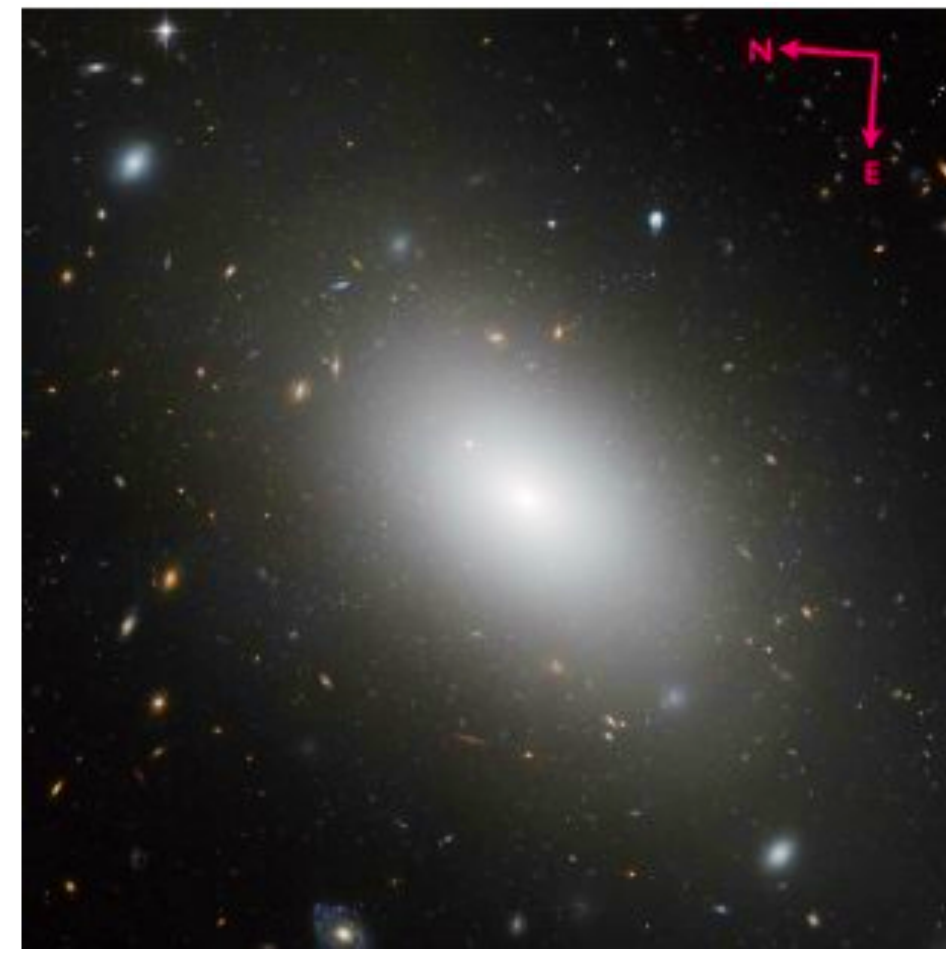
All the previous studies investigated the integrated stellar population properties of BCGs in FGs, except for Eigenthaler & Zeilinger (2013) and Proctor et al. (2014). Eigenthaler & Zeilinger (2013) analyzed spatially resolved stellar populations in a sample of six BCGs in FGs: they concluded that FGs formed via the merging of the L^* galaxies with the central one, excluding the monolithic collapse in which the magnitude gap would not be produced by evolutionary effect but would have been in place *a priori*. Proctor et al. (2014) performed a similar analysis on a sample of two FGs finding that, despite remarkable similarities in their morphology, photometric properties, and kinematics, the stellar populations of the two galaxies were clearly different. One shows a strong gradient all the way to the center, with signs of a burst of stellar formation located in the center of the galaxy and superimposed onto an old and extended population. On the contrary, the second galaxy of their sample showed a flat core-like structure in the metallicity gradient, but no age gradient.

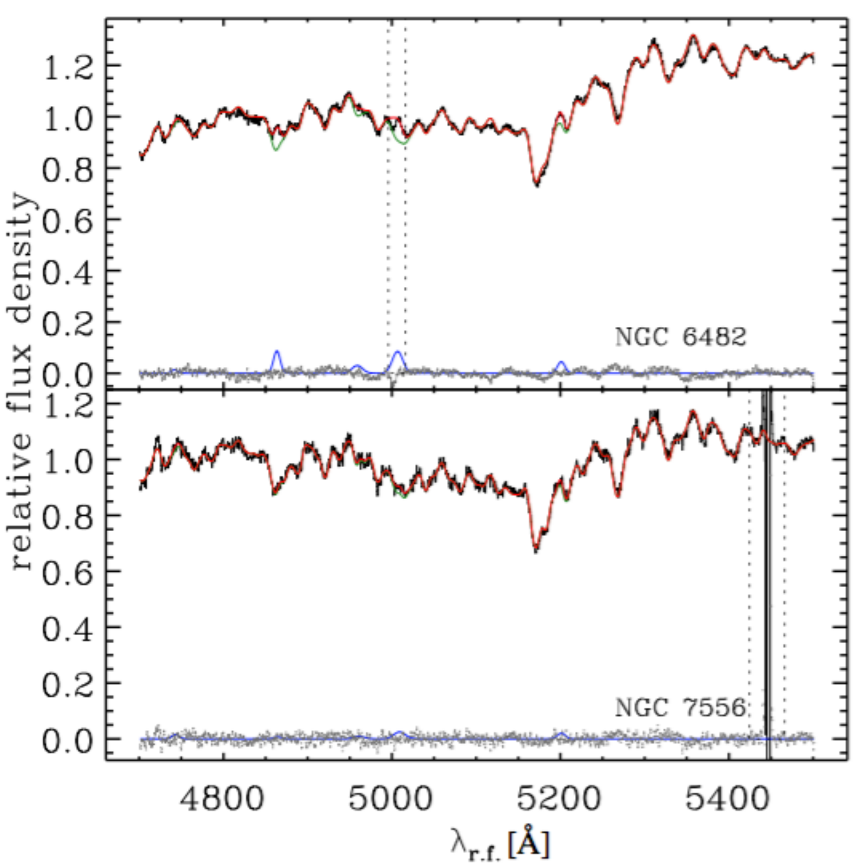
This paper is part of the Fossil Group Origins (FOGO) project (Aguerri et al. 2011), whose aim was to study a large sample of FG candidates, spanning wide ranges in mass and redshift by using multi-wavelength observations. To date, the collaboration has published results on the properties of the BCGs (Méndez-Abreu et al. 2012; Zarattini et al. 2014), on their dark matter halos (Girardi et al. 2014; Kundert et al. 2015), on the galaxy population (Zarattini et al. 2015, 2016; Aguerri et al. 2017), and on the comparison between observations and current cosmological simulations (Kundert et al. 2017). Here, we focus our attention on the stellar populations of two BCGs in FGs, namely NGC 6482 and NGC 7556. They are interesting because there are only a few nearby FG BCGs that are sufficiently bright at radii larger than the effective radius to obtain in a reasonable amount of time the high signal-to-noise ratio spectra needed for measuring their stellar population gradients. We aim at in-



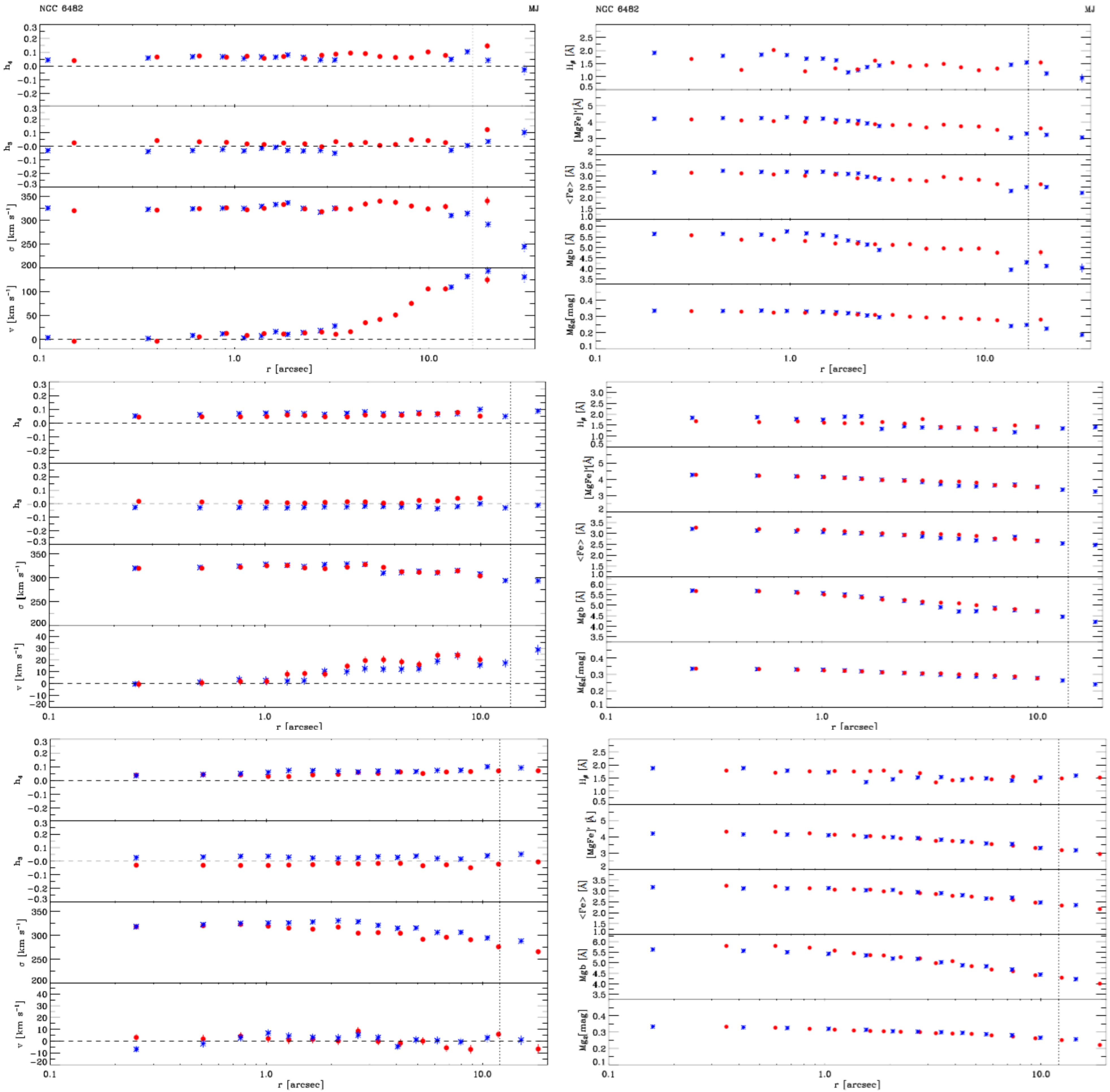
Parameter (1)	NGC 6482 (2)	NGC 7556 (3)
I_e [mag arcsec^{-2}]	19.88 ± 0.02	20.92 ± 0.03
r_e [arcsec]	16.7 ± 0.1	9.6 ± 0.2
n	2.82 ± 0.03	2.74 ± 0.03
PA_{sph} [°]	…	112.5 ± 0.5
q_{sph}	…	0.756 ± 0.003
I_0 [mag arcsec^{-2}]	…	21.25 ± 0.01
h [arcsec]	…	28.5 ± 0.3
PA_{env} [°]	…	117.0 ± 0.2
q_{env}	…	0.639 ± 0.002

Notes. (2) From Lieder et al. (2013). We calculated the effective ra along the galaxy major axis from the circularized effective radius (14.20 ± 0.09 arcsec) and effective ellipticity ($\epsilon(r_e^c)$ = 0.28). (3) F this paper.





$$L(v_{los}) = \frac{e^{-\frac{1}{2}w^2}}{\sqrt{2\pi}}\left[1 + \frac{h_3}{\sqrt{3}}\left(2w^3 - 3w\right) + \frac{h_4}{\sqrt{6}}\left(2w^4 - 6w^2 + \frac{3}{2}\right)\right], (3)$$


NGC 6482
MJ
NGC 6482
MJ
h4
h3
σ [km s⁻¹]
v [km s⁻¹]
r [arcsec]
Hβ [Å]
[MgFe]' [Å]
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Mg2 [mag]

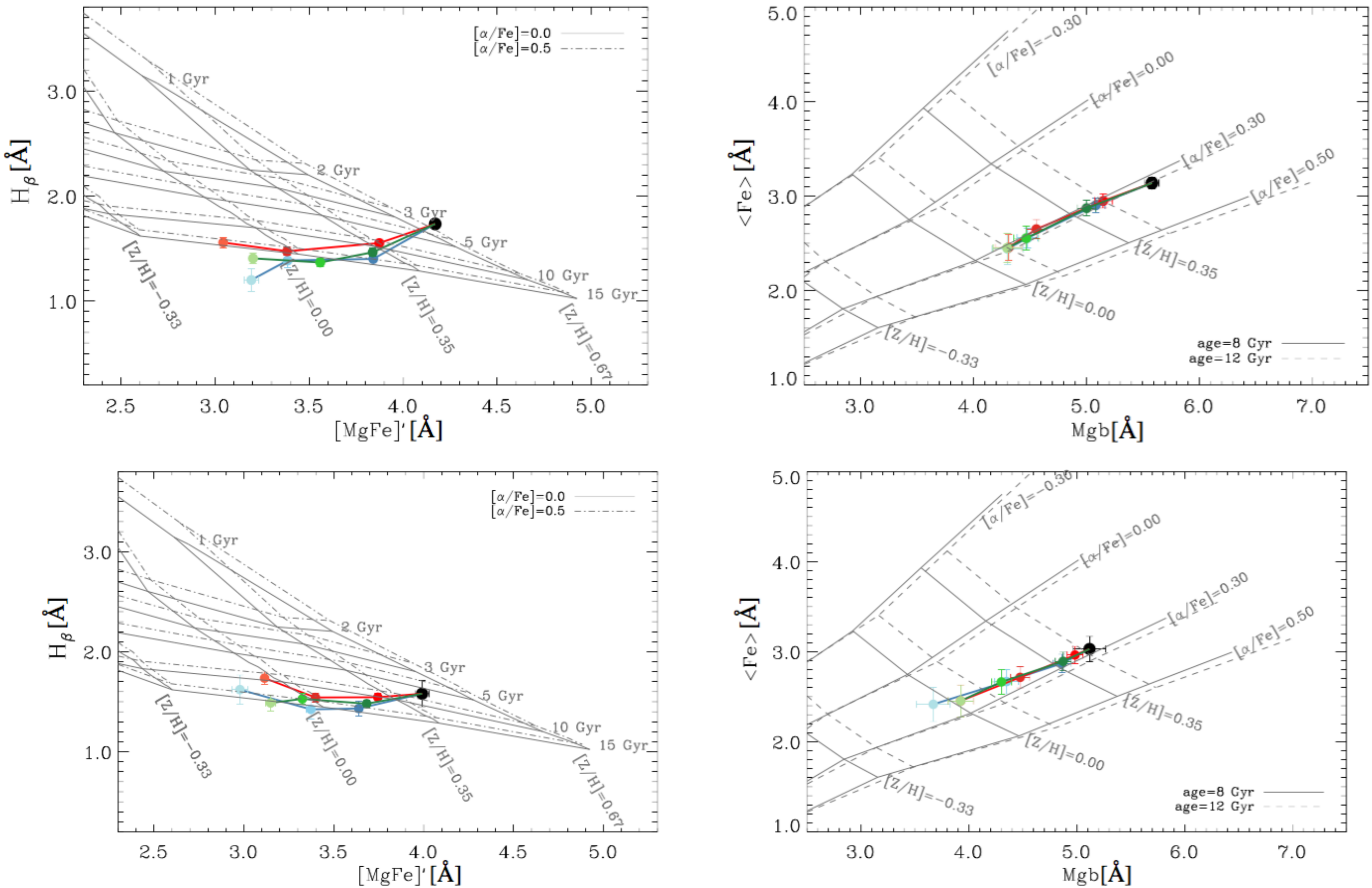


Fig. 6. Same as in Fig. 5 but for NGC 7556.

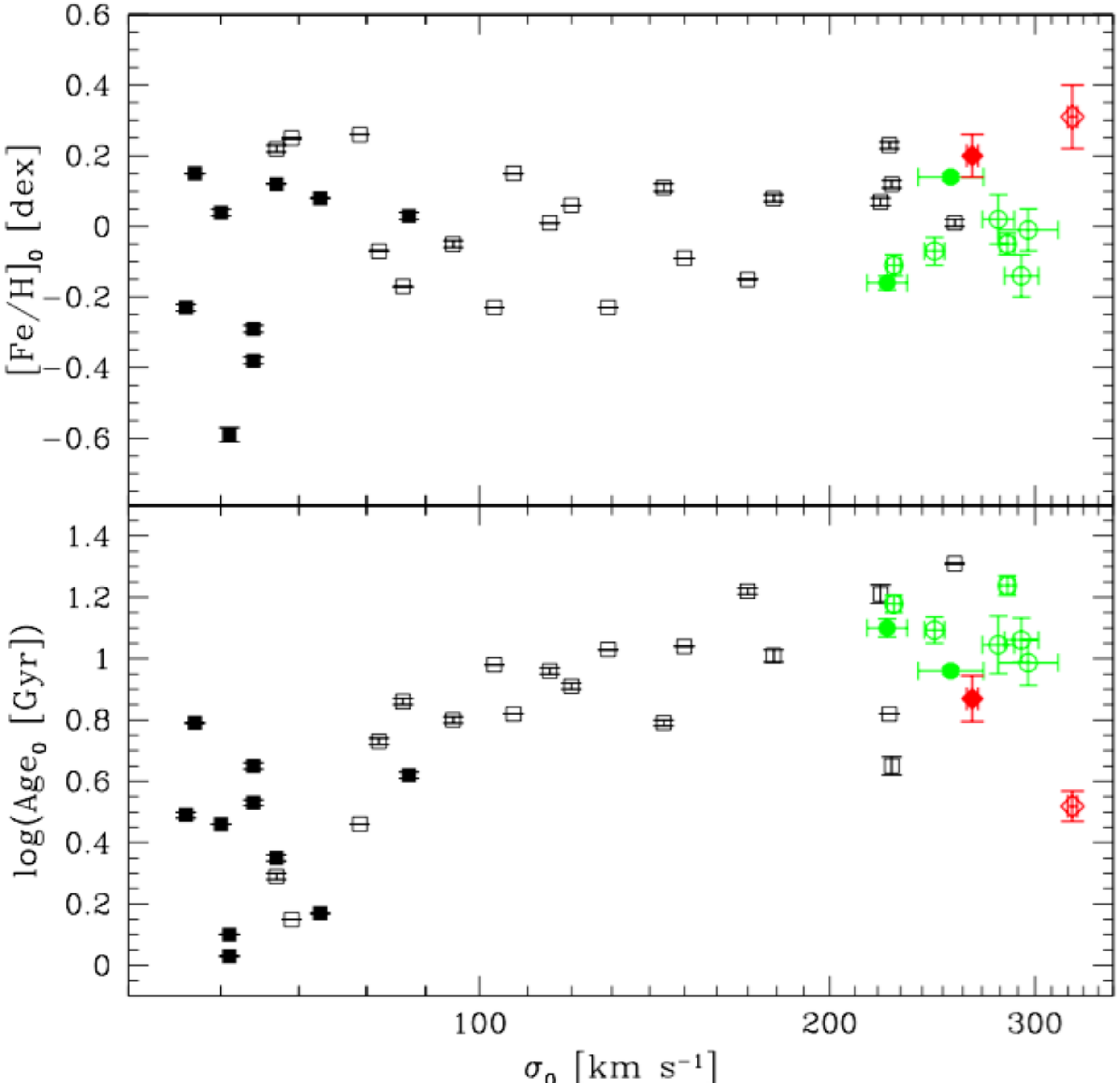
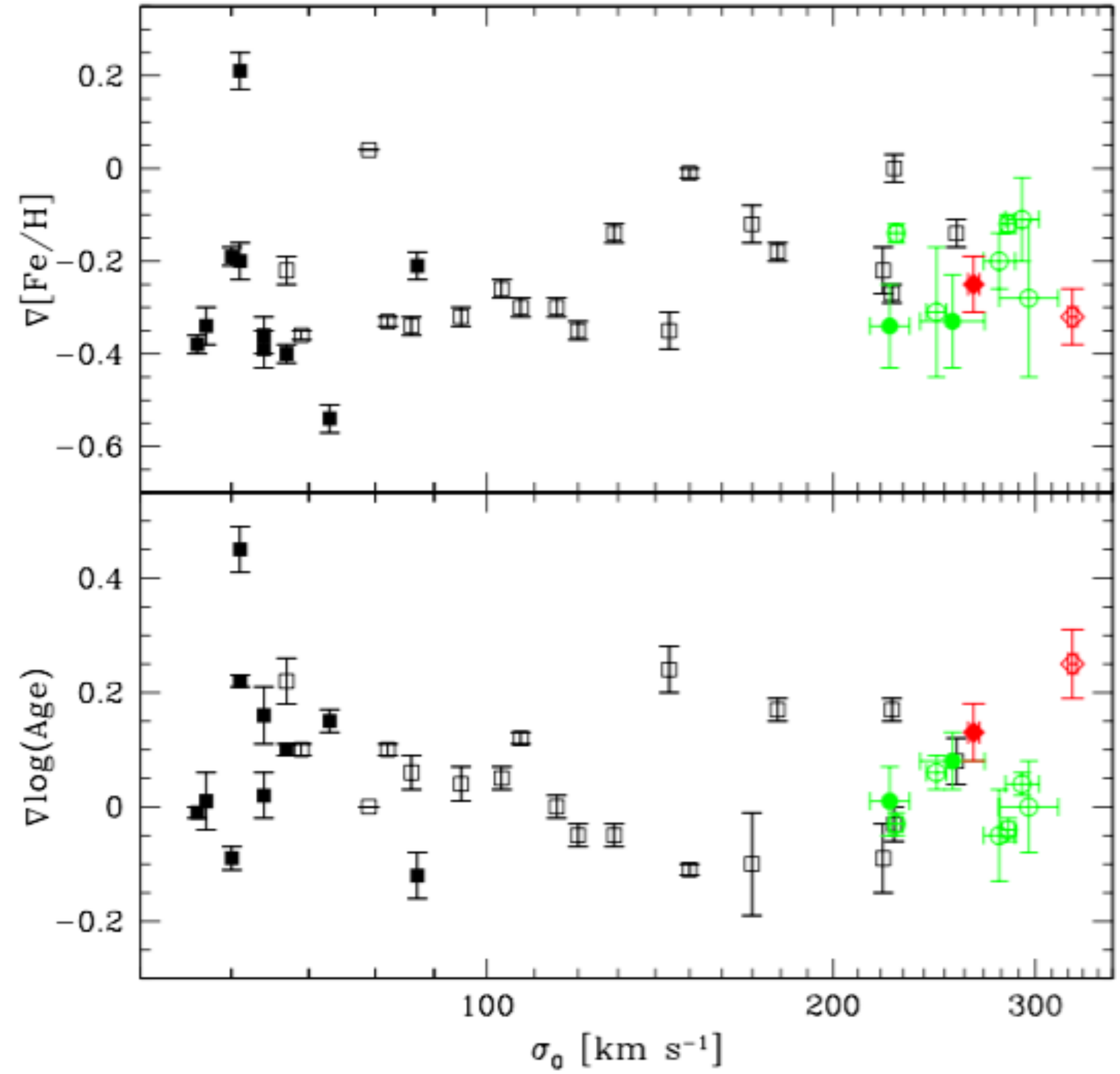


Fig. 8. Central metallicity (top panel) and central age (bottom panel) as a function of the central velocity dispersion for NGC 6482 (red open diamond) and NGC 7556 (red filled diamond), the FG BCGs from Eigenthaler & Zeilinger (2013, green open circles) and Proctor et al. (2014, green filled circles), and the early-type normal (open squares) and dwarf (filled squares) galaxies with $\sigma > 50$ km s^{-1} from Koleva et al. (2011).



merging events. The age gradients of both galaxies are somewhat larger than those of the other FG BCGs with stellar population parameters measured at different radii (Eigenthaler & Zeilinger 2013; Proctor et al. 2014), whereas their metallicity gradients are similarly negative and shallow. Moreover, both galaxies have negligible gradients of α-element abundance ratio at supersolar value.

The metallicity gradients of all the FG BCGs studied so far are less steep than those predicted for massive galaxies that formed monolithically and evolved without experiencing any major merger. This result holds for different models of galaxy formation based on the dissipative collapse of pristine gas clouds (Carlberg 1984; Kobayashi 2004; Pipino et al. 2010). In addition, we do not observe a correlation between metallicity gradient and mass and an increase of the scatter of the metallicity gradients with mass, when FG BCGs are compared to giant and dwarf ETGs from Koleva et al. (2011). FG BCGs have the same metallicity and age gradients of the bulk of ETGs confirming early results by La Barbera et al. (2009). They found no difference between the integrated stellar population properties of FG BCGs and bright field ellipticals and concluded that the FGs might not be a distinct family of true fossil systems, but rather the final stage of mass assembly. All these findings favor a formation scenario of FG BCGs from wet major mergers following an early hierarchical assembly, as investigated by Kobayashi (2004) with numerical simulations of galaxy merging. They reported a typical value of the metallicity gradient for major merger galaxies, which is close to what we measure for FG BCGs. Therefore, we conclude that the observed BCGs assembled through major mergers and their FGs are not failed galaxy groups that lacked bright satellite galaxies from the beginning. This is in agreement with the recent findings by Kundert et al. (2017) based on cosmological hydrodynamic simulations. They showed that the origin of the magnitude gap and BCGs of FGs depends on the recent accretion history of the groups and that selecting galaxy groups by their magnitude gap does not guarantee obtaining either early-formed galaxy systems