Stellar Population Study of Nearby Elliptical Galaxies

using Spectroscopic Age and Metallicity

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Abstract

We determined luminosity-weighted ages and metallicities of 27 elliptical galaxies (14 in cluster and 13 in field/group) from $H\gamma_\sigma$ and other absorption line indices, and studied their star formation histories.

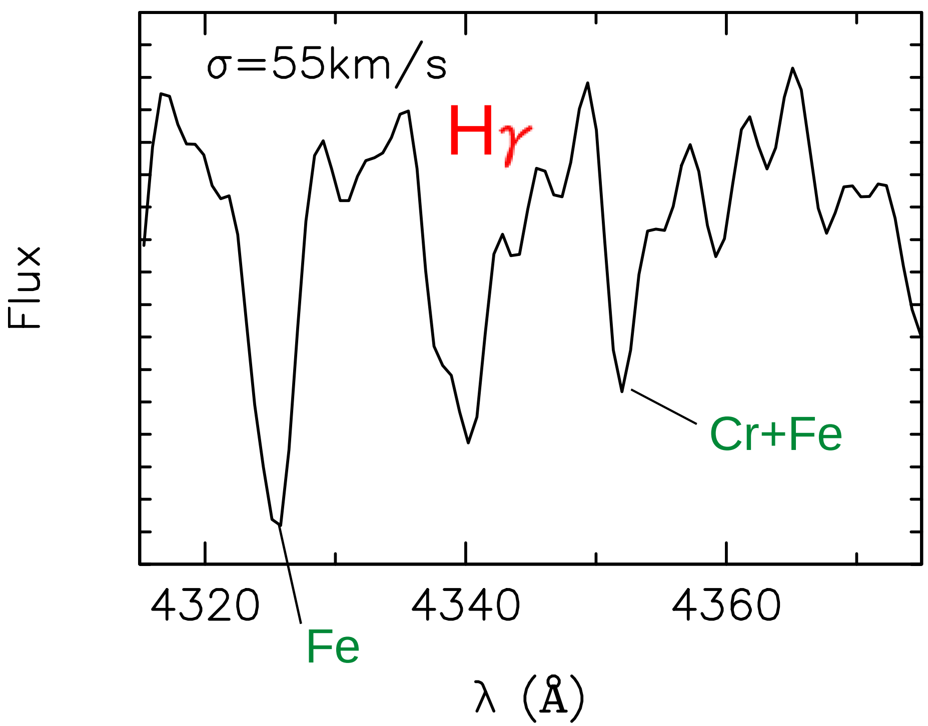
We used the $H\gamma_\sigma$ method (Vazdekis & Arimoto 1999) to distangle the age-metallicity degeneracy. In the cluster, less massive galaxies show a large age dispersion (3->15 Gyrs) while massive galaxies are uniformly old (>10 Gyrs). We found that field massive galaxies show an age spread (6->15 Gyrs), while cluster elliptical galaxies have uniformly old ages (>10 Gyrs). We concluded that the galaxies in the dense cluster region formed earlier than those in the low density region. Also we found that [Z(Mg)/Z(Fe)] increases tightly with the velocity dispersion σ of galaxies both in cluster and field. This suggests that less massive galaxies have longer star formation period than massive ones.

Introduction

Since elliptical galaxies are common objects in the universe, many people studied the their formation and evolution. Elliptical galaxies have been traditionally considered as old stellar populations from several evidence such as tightness of the colour-magnitude relations (Bower, Lucey & Ellis 1992) and the fundamental plane (Dressler et al. 1987). On the other hand, spectroscopic observations showed the presence of young stellar populations in early-type galaxies (Trager et al. 2000). Ages can settle controversy whether elliptical galaxies are old or not, but it has been difficult to measure ages due to age-metallicity degeneracy on spectral features (colour, line indices); i.e., colours and line indices can be reproduced in several ways of a combination of ages and metallcities (Worthey 1994; Arimoto 1996). We use the Hγ_σ method developped by Vazdekis & Arimoto (1999). which can distangle the age-metallicity degeneracy, With this method, we can study abundance ratio of elliptical galaxies.

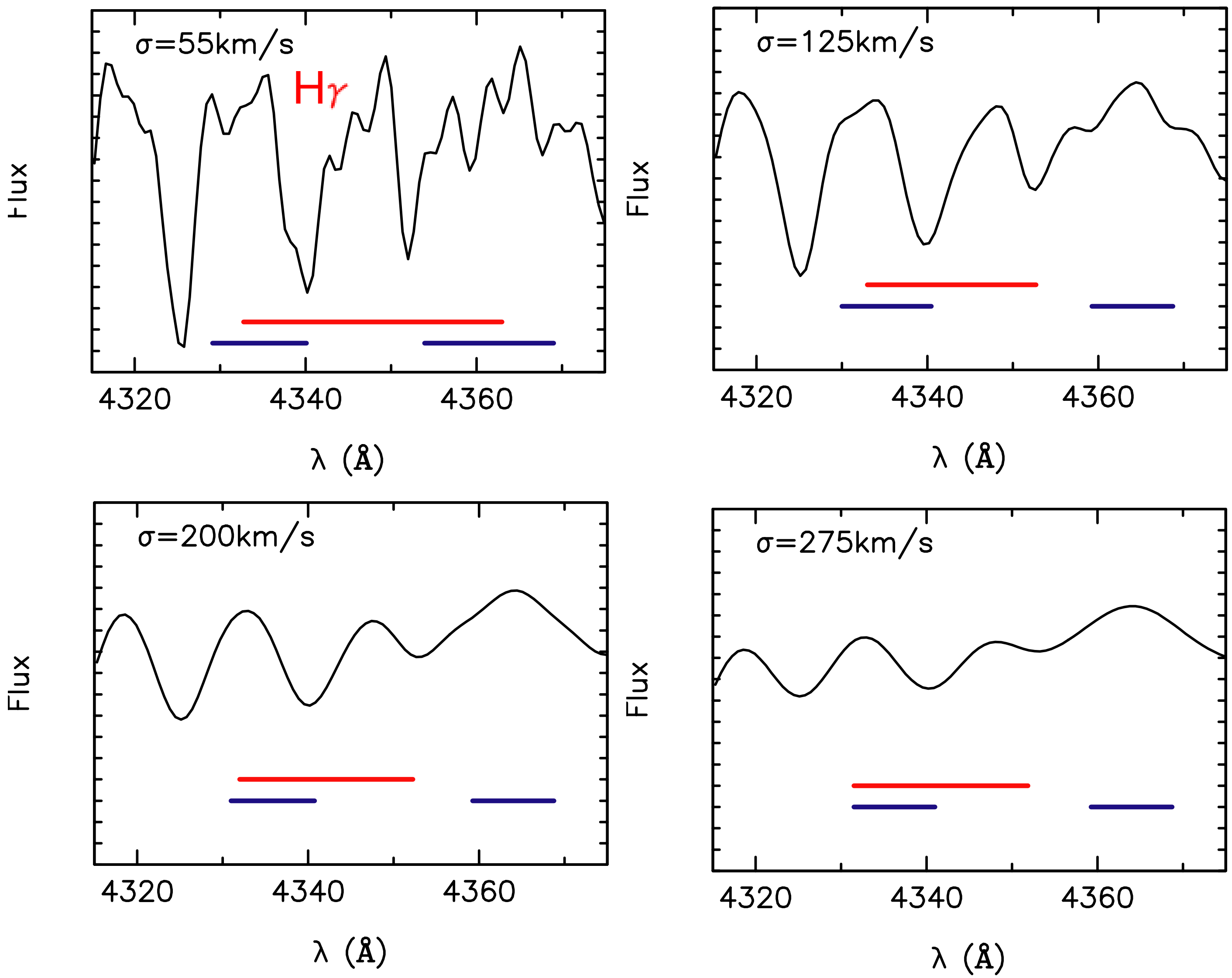
Age Determination with Balmer Lines

Worthey & Ottaviani (1997), Jones & Worthey (1998) found that the Balmar lines (Hβ, Hγ) are sensitive to age of galaxies, and SSP models are developped from Lick library (Worthey 1994). Age-metallicity degeneracy is a difficult problem to estimate galaxy age and metallcity.



Many metallic abosorption lines around Hγ lines affect the age determination of galaxies, therefore unless we know their metallicities beforehand we can not determine their ages.

Age Determination with $H\gamma_\sigma$

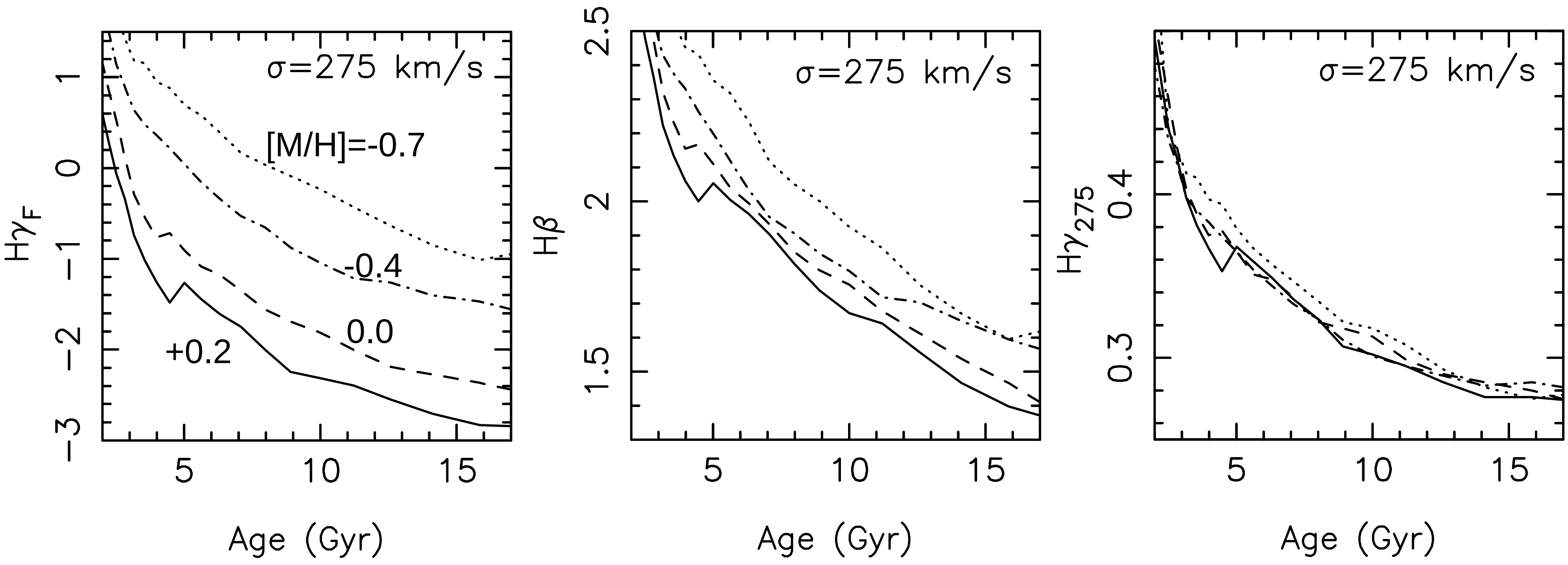


Since spectra of galaxies are smoothed by their velocity dispersions, we should take into account. $H\gamma_\sigma$ has 4 slightly different wavelength definition for each mass of galaxies.

The wavelength definition of $H\gamma_\sigma$ is taken effects of metallic lines into account (Vazdekis & Arimoto 1999)

Age Determination with $H\gamma_\sigma$

This figure shows comparison of 3 Balmer line indices, $H\gamma_F$, $H\gamma_\sigma$, $H\beta$.
$H\gamma_\sigma$ has the most strong power of age determination.
Since line indices are affected by galaxy velocity dispersion, $H\gamma_\sigma$ has 4 difinition of continuum and feature wavelength for each σ range.
($H\gamma_{<130}$, $H\gamma_{125}$, $H\gamma_{200}$ and $H\gamma_{275}$)



Stellar Population Models

We use revised SSP models of Vazdekis (1999), which have made from the empirical stellar spectra library of Jones (1999), and revised for Padova isochrones (Giraldi et al. 2000). The models predict spectral energy distributions (SEDs) in the optical wavelength.

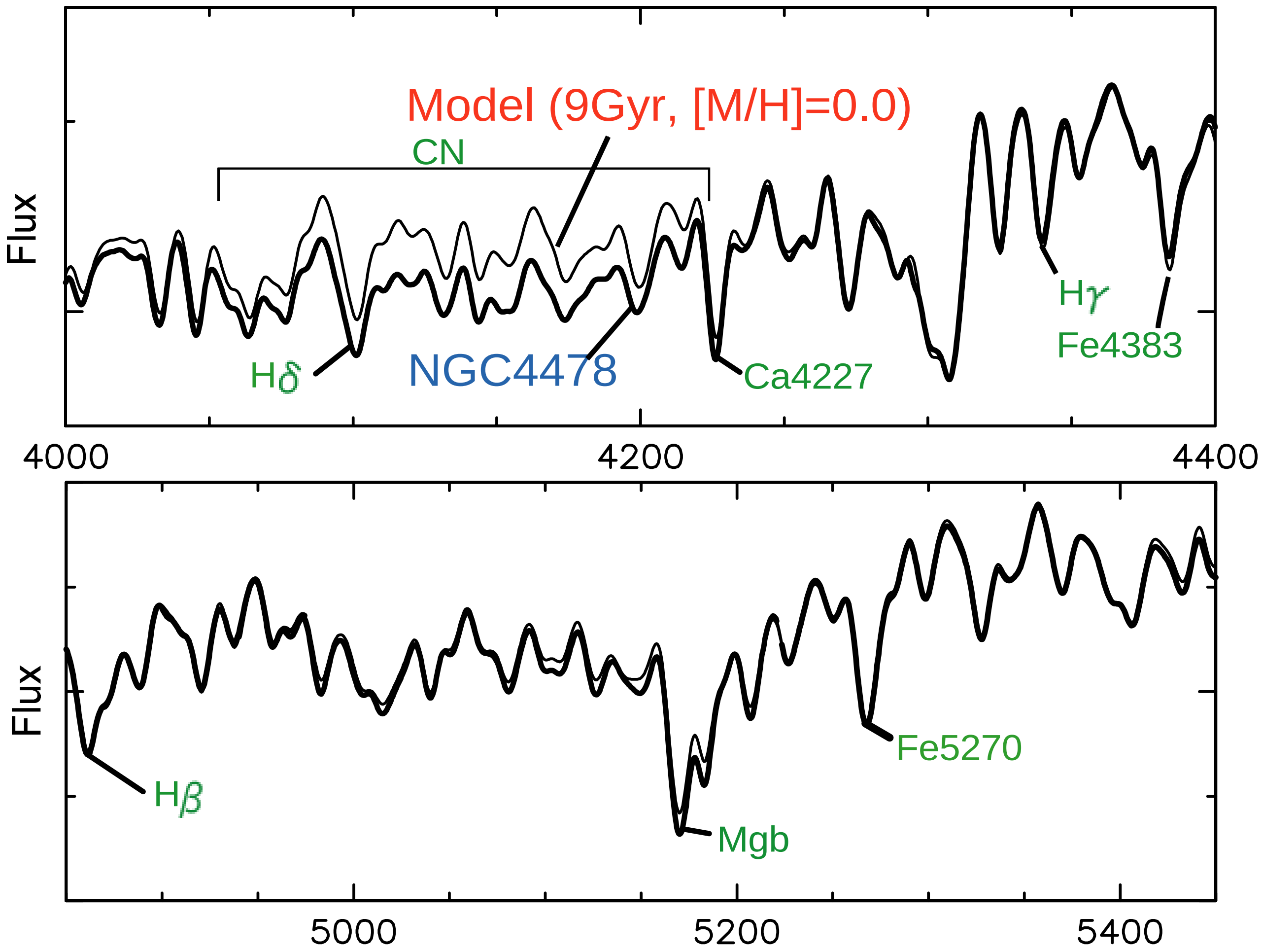


Figure shows the fitting of model spectrum (9 Gyrs, [M / H] = 0.0), with observed galaxy spectrum. We estimate that this galaxy has 8.6 Gyrs and [M/H] = +0.1 from line indices. The fitting is exellent, and show CN and Mg enhancement.

Observations and Samples

Virgo Cluster : 14 elliptical galaxies

(magnitude spans 5.8 mag in V, while 3.3 in Vazdekis et al. 2001)

Field & Group : 13 elliptical galaxies

with **Extremely High S/N Ratio !!**

Subaru Telescope 8.3m (Apr. 2002, Jun. 2003)

3800-5900 Å, 0.67 Å/pixel,

R=2000 or 1300

William Herschel Telescope 4.2m

(Oct. 1997, Apr. 1999)

4000-5500 Å, 0.45 Å/pixel,

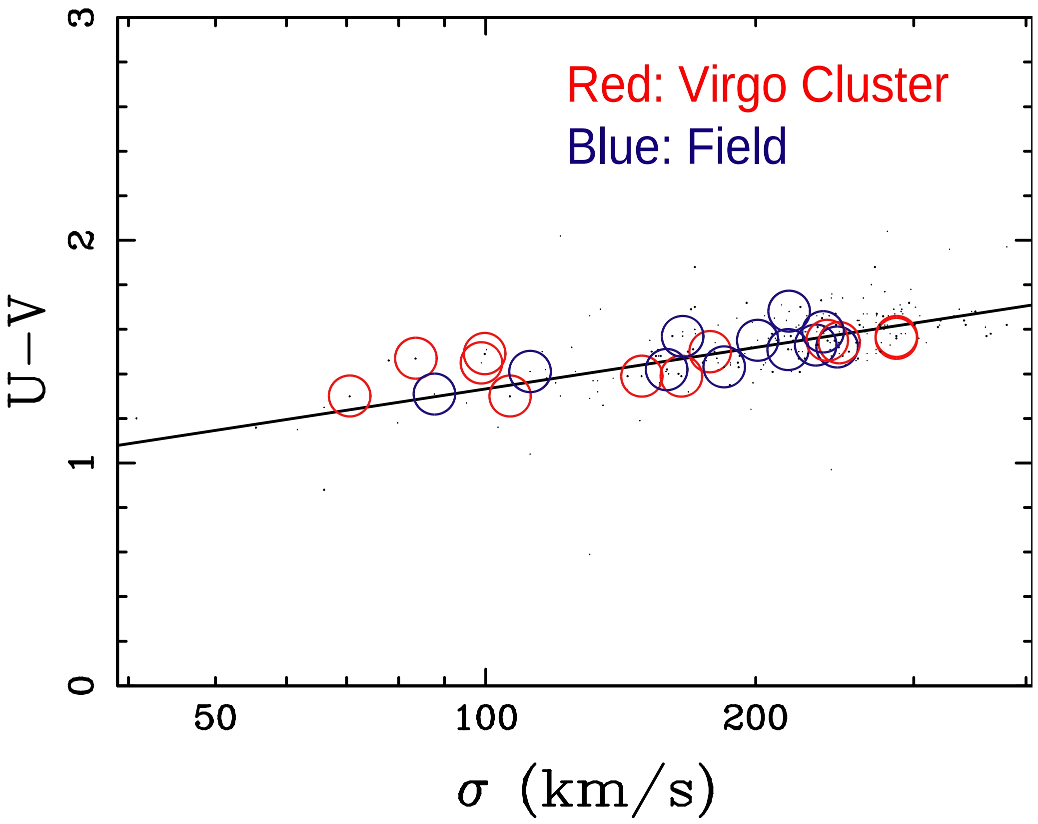
R=1800

ESO NTT Telescope 3.5m

(May 2002)

3600-4800 Å, 0.92 Å/pixel,

R=1200



Samples

Cluster (Virgo)

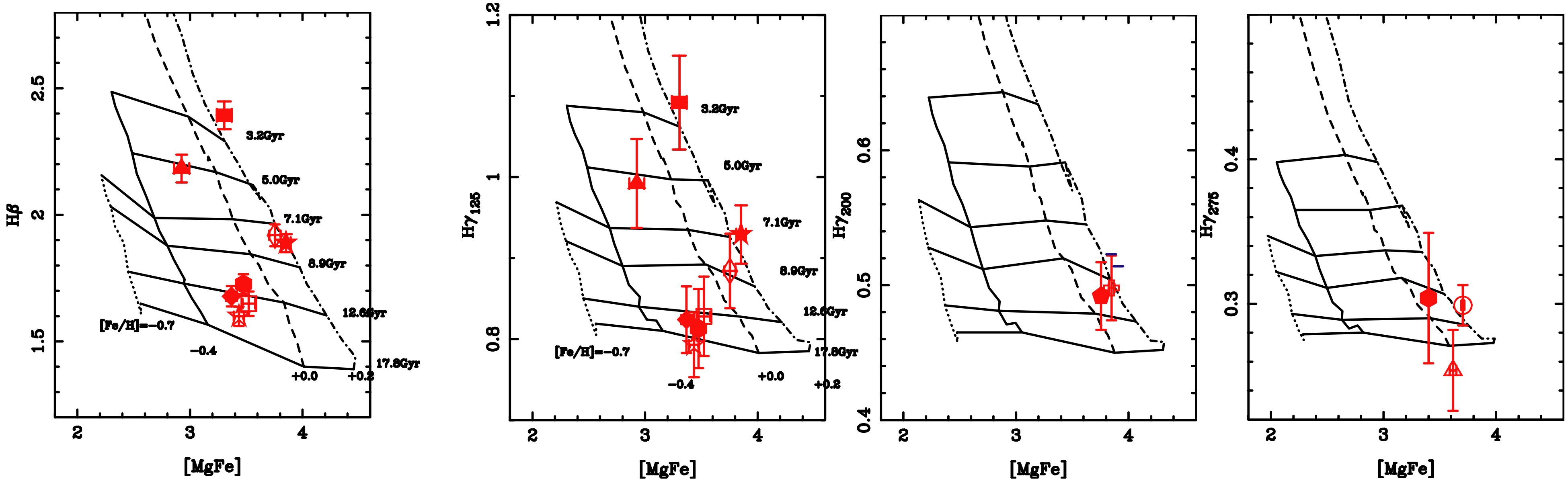
NGC	sigma (km/s)	m(V)	U-V	Expos. (min)	S/N R. /A
Subaru					
4239	92	13.70	-	100	130
4339	99	12.26	1.35	50	175
4458	106	12.93	1.30	70	160
4467	83	14.33	1.46	150	115
4472	287	9.37	1.60	20	195
4489	49	12.84	1.21	40	135
4551	100	12.97	1.45	80	190
4697	165	10.14	1.40	30	305
WHT					
4365	248	10.52	1.52	70	250
4387	84	13.01	1.37	105	105
4464	121	13.46	1.29	105	135
4473	178	11.16	1.48	70	280
4478	149	12.36	1.32	105	135
4621	240	10.57	1.52	140	490

Field & Group

NGC	sigma (km/s)	m(V)	U-V	Expos. (min)	S/N R. /A
NTT					
3617	88	13.69	1.25	180	140
5638	159	12.14	1.37	150	135
5898	218	12.49	1.66	180	135
5903	235	12.20	-	210	165
7144	185	11.70	1.34	120	160
Subaru					
M32	78	7.84	1.28	10	285
5831	166	12.45	1.55	60	190
WHT					
584	217	11.44	1.45	60	235
720	247	11.16	1.45	90	190
821	199	12.20	-	60	190
1700	233	10.24	1.47	60	180
3379	201	12.78	1.49	20	115
5831	166	12.45	1.55	35	90
7454	112	12.78	1.31	105	110

Estimating Age and Metallicity

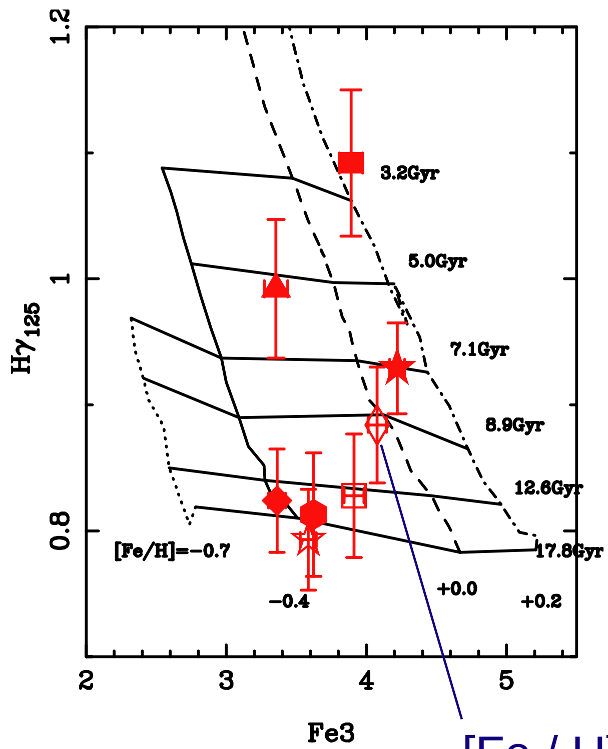
Ages and metallicities are determined by comparing with SSP model grid. In this figure model grid of $H\gamma_\sigma$ index looks more orthogonal than that of $H\beta$ index.



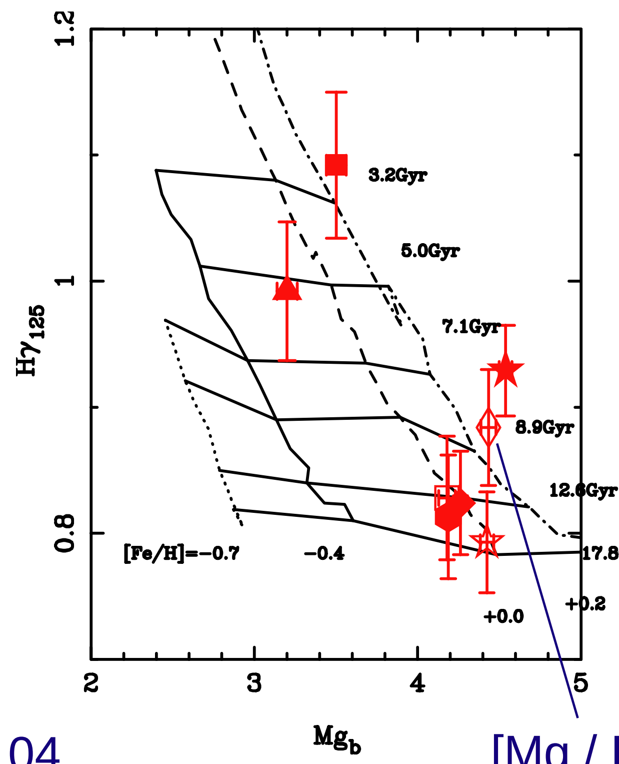
$H\beta$ 150km/s $H\gamma_\sigma$ 150km/s 190km/s 300km/s

Estimating Metallicities for Several Elements

Metallicities of each element or molecule such as Fe, Mg, Ca, CN and CH also can be estimated from indices which sensitive to each element or molecule. Fe, Mg, Ca, CN and CH come from Fe3 (defined in Kuntschner 2000), Mgb, Ca4227, CN_2 and G-band, respectively. We estimate these by comparison with model grids of solar metallicty in the diagrams with different metallic indices. We show an example fo Fe and Mg.



[Fe / H] = -0.04



[Mg / H] = +0.2

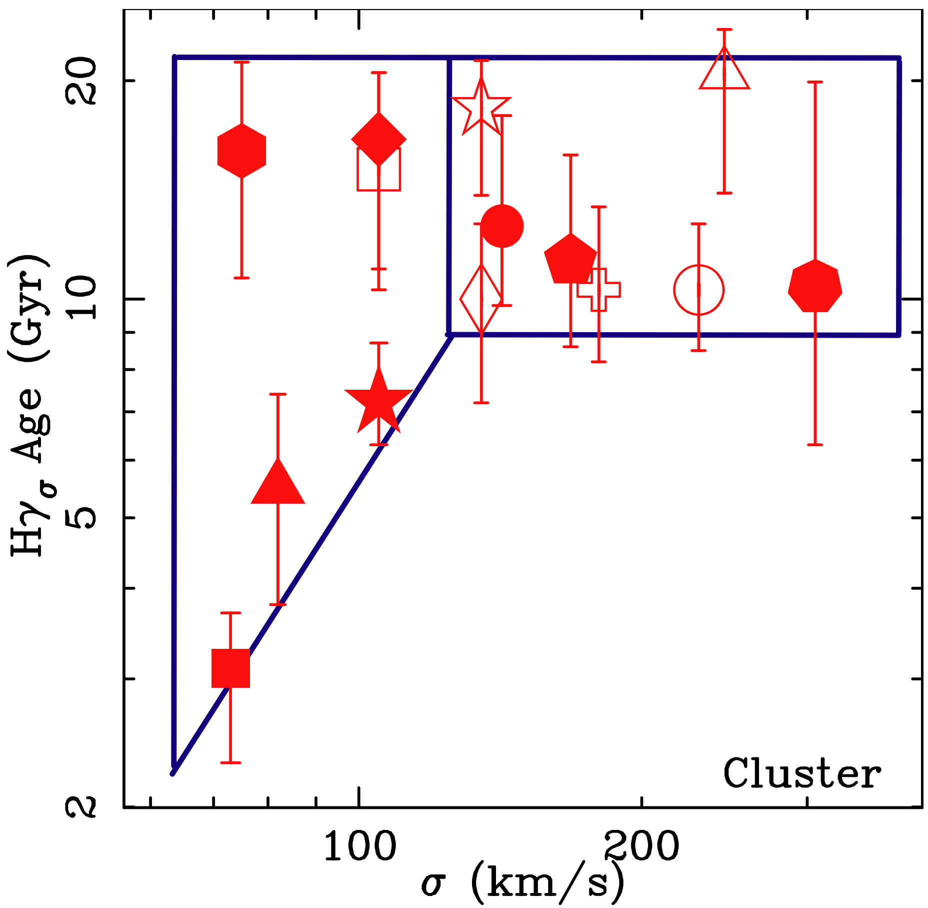
Age for Virgo Ellipticals

Less massive galaxies show a large age dispersion (3 - >15 Gyrs) while massive galaxies are uniformly old (>10 Gyrs).

The past studies (Kuntschner 2000; Terlevich & Forbes 2002; Trager et al. 2000) presented the σ - age diagram for the nearby cluster elliptical galaxies and they concluded that bulk of cluster galaxies have old ages, whereas young galaxies exist in our sample. There are two reasons for this difference of age distribution.

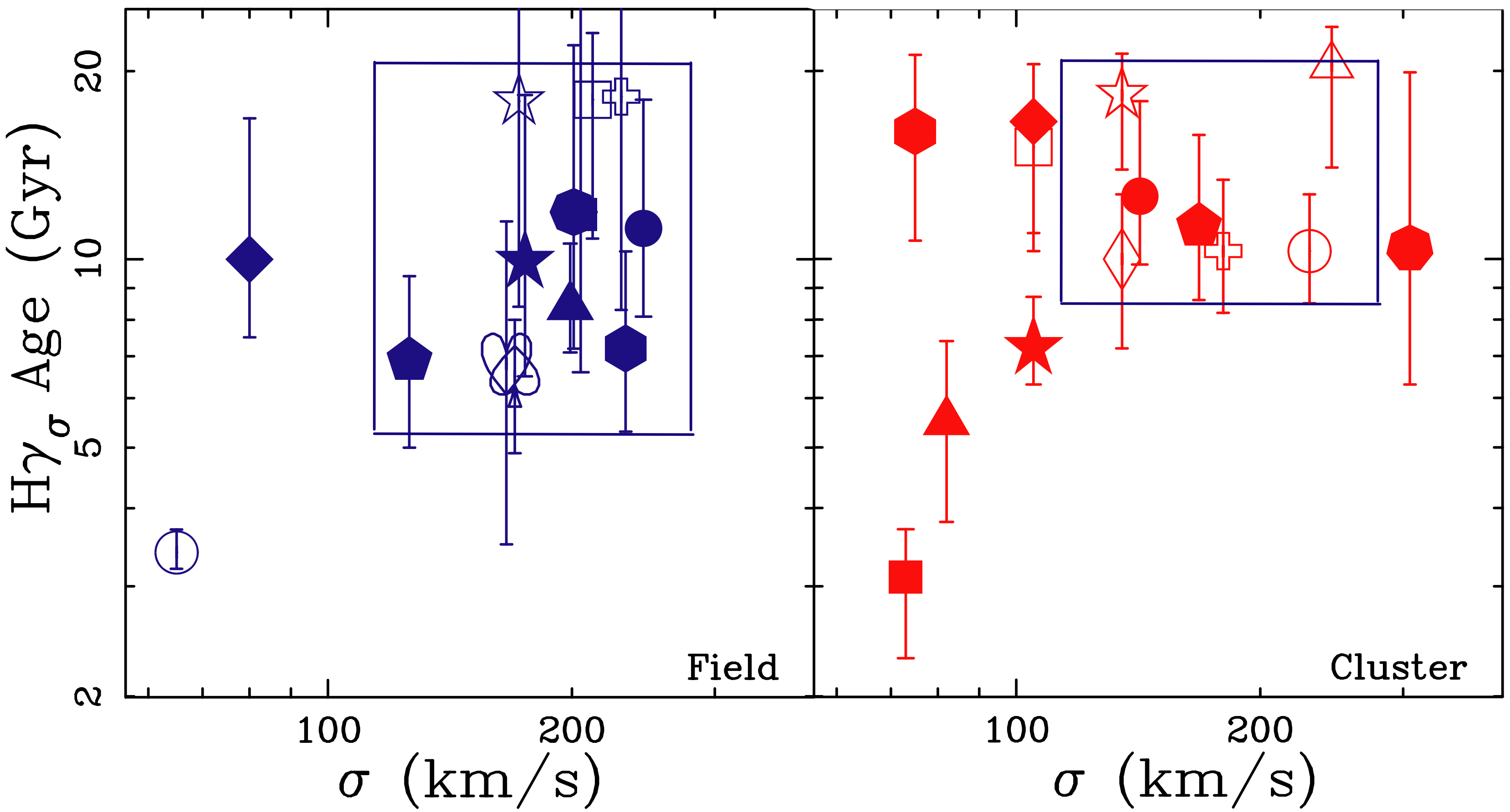
1) Those studies all used the Lick/IDS system and low spectral resolution spectra ($\Delta\lambda$ > 8 Å). Low resolution spectra are not sufficient for breaking age - metallicity degeneracy.

2) They had small sample of less massive galaxies (σ < 120 km/s). Galaxies with σ < 120 km/s show young ages in our sample, so that previous authors could not find clear age dispersion. Since Poggianti et al. (2001) and Caldwell et al. (2003) also used un-othogonal diagram, this trend was not clear.



Ages for Field & Group Ellipticals

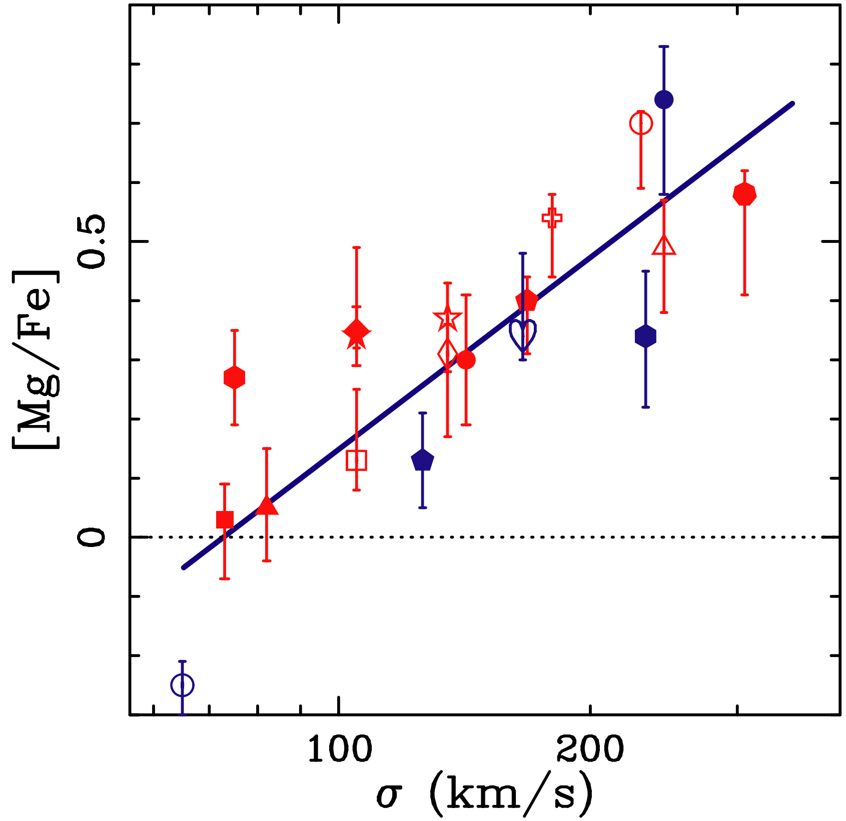
We found that field massive galaxies show an age spread (6->15 Gyrs), while cluster elliptical galaxies have uniformly old ages (>10 Gyrs). We concluded that the galaxies in the dense cluster region have formed earlier than those in the low density region.



[Mg / Fe] for Elliptical Galaxies

We found that [Z(Mg) / Z(Fe)] show very tight correlation with the velocity dispersion σ of galaxies both in cluster and field. This suggests that less massive galaxies have longer star formation time scale than massive ones.

The elemental abundance ratios provide constraints on IMF and the star formation histories, since the origin of each element is different and has different time scale of evolution. The progenitors of SNe II which mainly eject the α - elements (O, Mg etc.) are massive stars (M > 8-10 Mo) and they explode in 10^6-10^8 years. On the other hand, major products of SNe Ia explosion are the Fe - peak elements. Their progenitors are binaries of white dwarf which explode ~1 Gyrs after the outset of star formation. Hence, high [Mg / Fe] means top heavy IMF or shortly lasting star formation. But it is too large variation in IMF to explain the trend which we found. Therefore we concluded that the main reason for [Mg / Fe] trend is time scale of star formation.

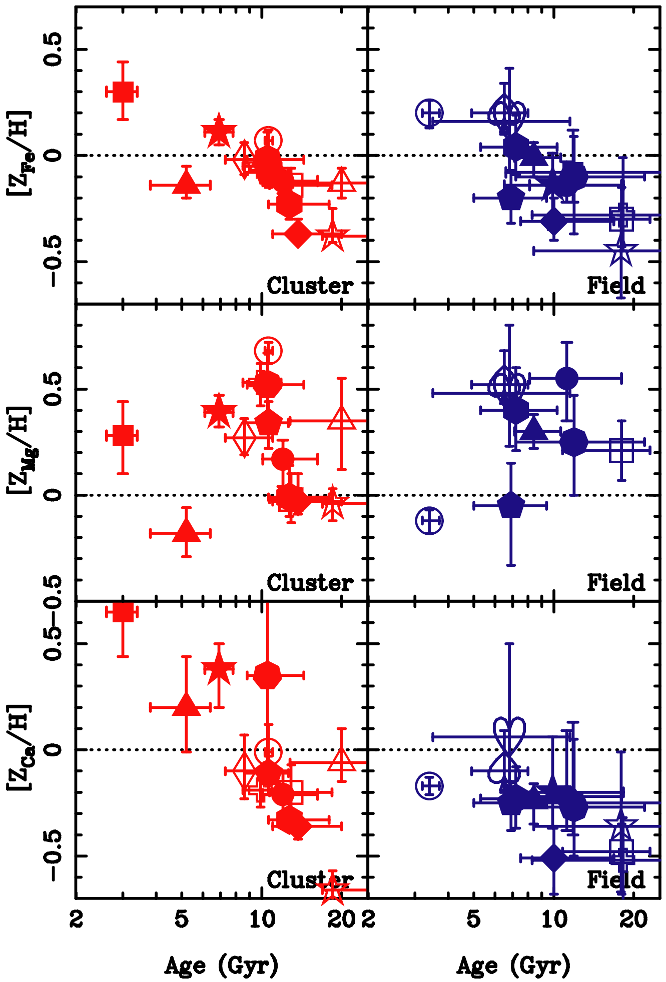


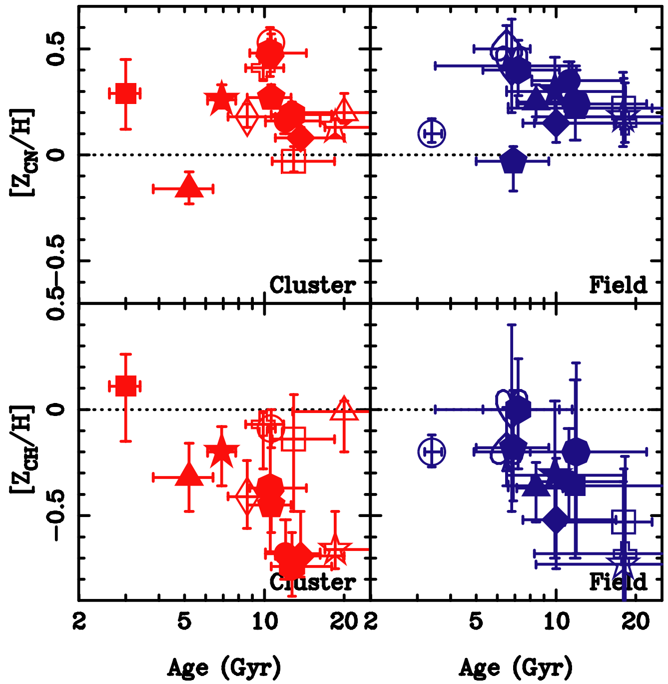
Conclusion

We determined luminosity - weighted ages and metallicities of 27 elliptical galaxies from $H\gamma_\sigma$ and other absorption line indices. Age and metallicity trends which we found were not clear in previous studies due to age - metallicity degeneracy of indices, errors coming from complex conversion into the Lick/IDS system and emission correction. In this study, by using $H\gamma_\sigma$ indices, we clarified those trends such as age spread of small galaxies in the cluster, the age difference between cluster and field, and tight [Mg / Fe] - σ relation. Since ages and metallicities which we derived from $H\gamma_\sigma$ indices are consistent with those from fitting with SSP models, those age and metallicities are reliable measurements. We concluded from those age and metallicity trends, that though galaxies have variety in their star formation, but in principal, massive galaxies tend to finish star formation earlier than less massive ones, and galaxies in denser region tend to finish star formation earlier than galaxies in lower density region.

Age - Metallicity Relations

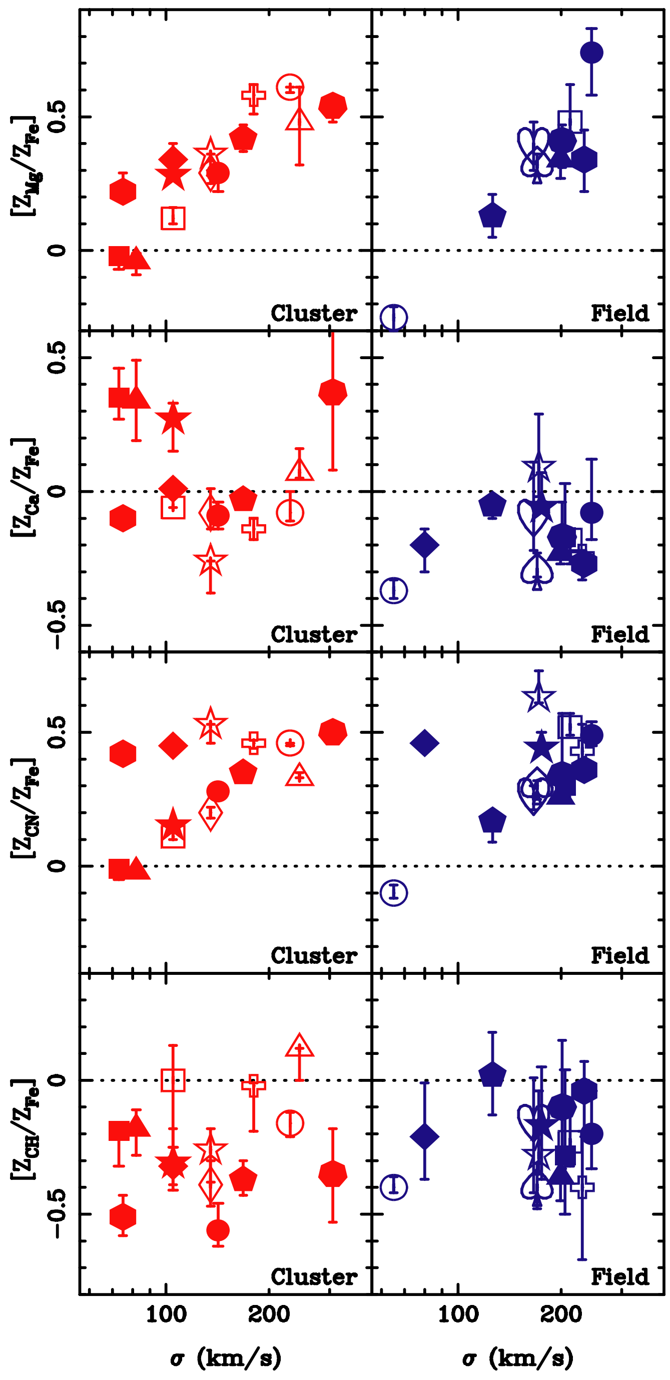
Diagrams for age vs. pseudo-metallicity.
Moderately correlation for [Fe / H] implies that stars in young galaxies contain Fe ejected by SNe Ia. Ca also has correlation, but the reason is to be study.





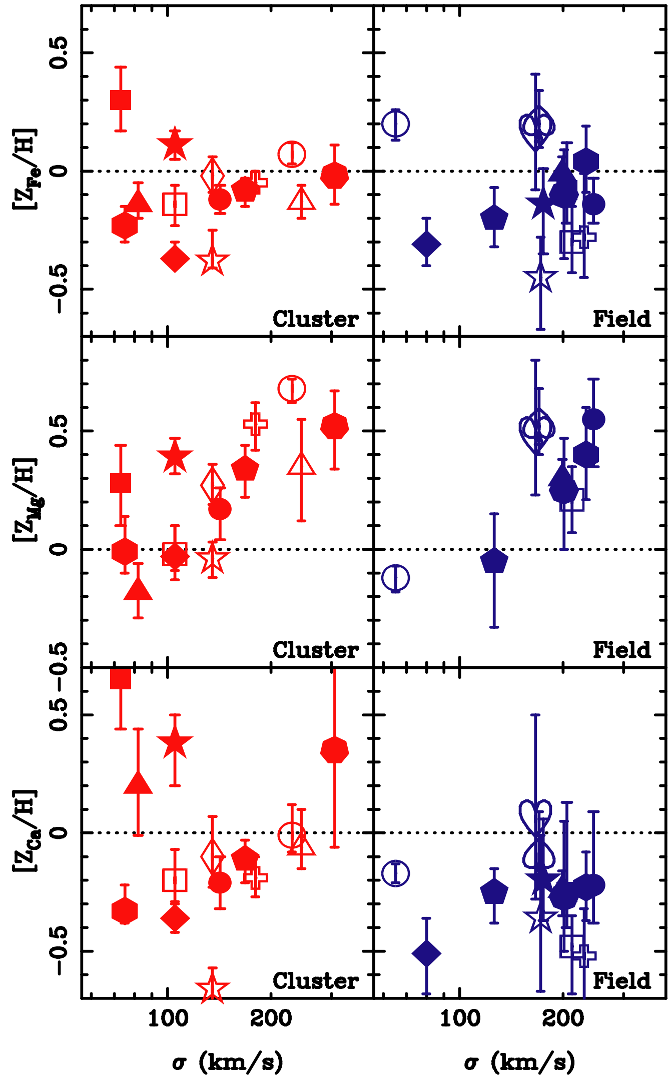
σ - Abundance Ratio Relations

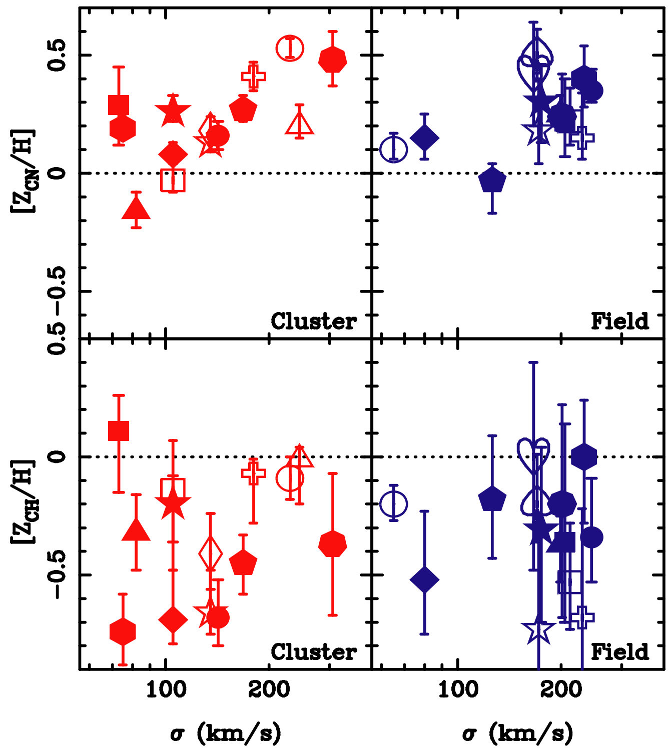
Diagrams for σ vs. abundance ratios. There is strong correlation (Spearman's rank order coefficient = 0.89) for [Mg / Fe], and weak correlation (0.60) for [CN / Fe]. Especially the correlation for [Mg / Fe] seems stronger than considered in the past studies (Kuntschner 2000; Trager et al. 2000). Mg and CN are strongly connected to the star formation time scale, since it is considered that those origins are from different mass stars.



σ - Metallicity Relations

We present velocity dispersion σ vs. pseudo-metallicities for several elements or molecule. Weak correlation is exist for Mg and CN. Though Ca is α - element, Ca does not trace Mg. This trend may be due to IMF variation (Cenarro et al. 2003; Vazdekis et al. 2004).





Age - Abundance Ratio Relations

Diagrams for age vs. abundance ratios.
Weak correlations for [Mg / Fe] and [CN / Fe] may reflect trends of the star formation timescale; i.e. younger galaxies have longer time scale of star formation.