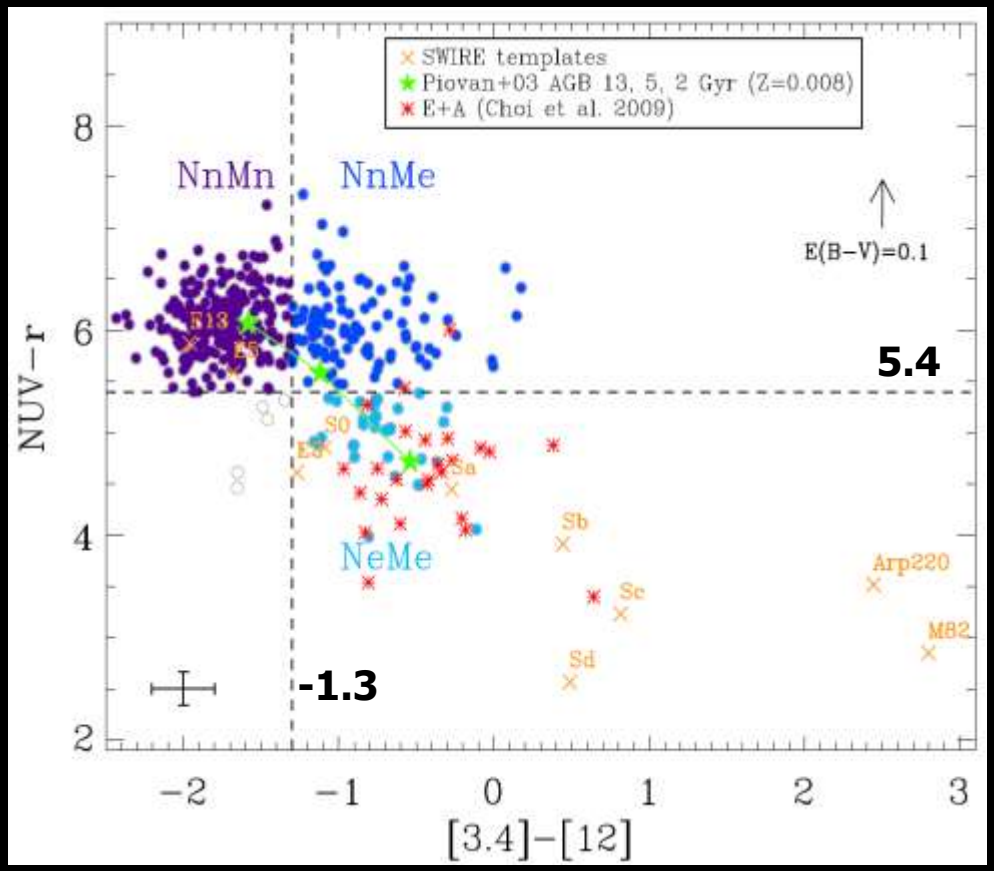
Stellar Populations of Early-type Galaxies with Mid-infrared Excess Emission

Haeun Chung, **Jongwan Ko**, **Ho Seong Hwang** and **Jong Chul Lee**

Based on Ko, J., Chung, H., Hwang, H. S., and Lee, J. C. 2016, ApJ, 820, 132

- We presented stellar populations of early-type galaxies with recent star formation
- We focus on the ETGs with mid-IR excess and **quantify the amount of intermediate-age stars** through a stellar population analysis of the SDSS stacked spectra.

1. Data and Sample



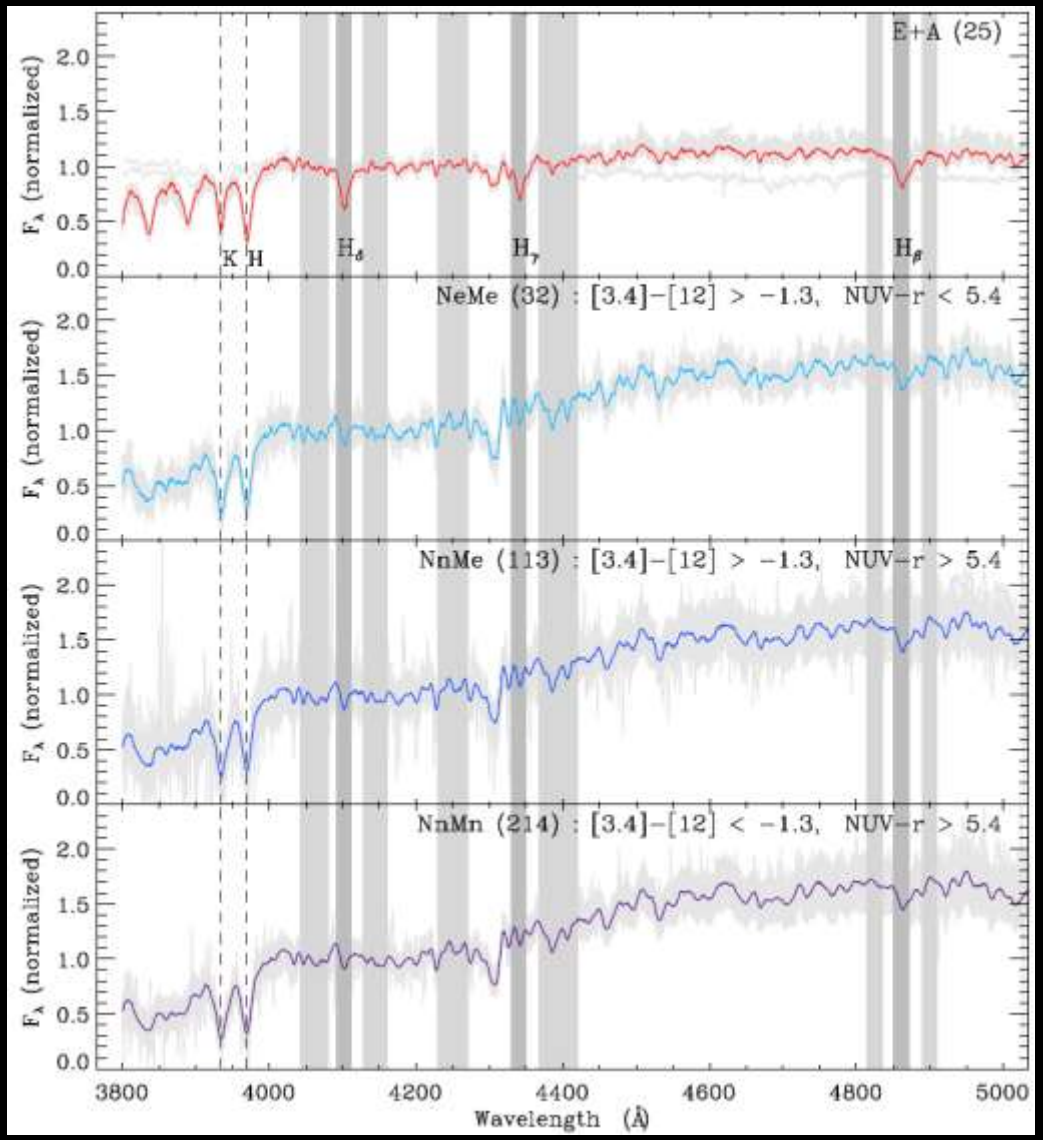
- Bright ETGs (Mr < -21.5) from **WISE mid-IR** and **GALEX near-UV** data with **spectroscopic sample of SDSS** galaxies at 0.04 < z <0.11.

- **397** bright (Mr < -21.5), quiescent, red ETGs without AGNs.

- Classifying ETGs based on near-UV and mid-IR excess emissions.

2. SDSS Stacked Spectra of ETGs

- We **stacked** the SDSS spectra of bright ETGs with different amounts of mid-IR and near-UV excess emissions!

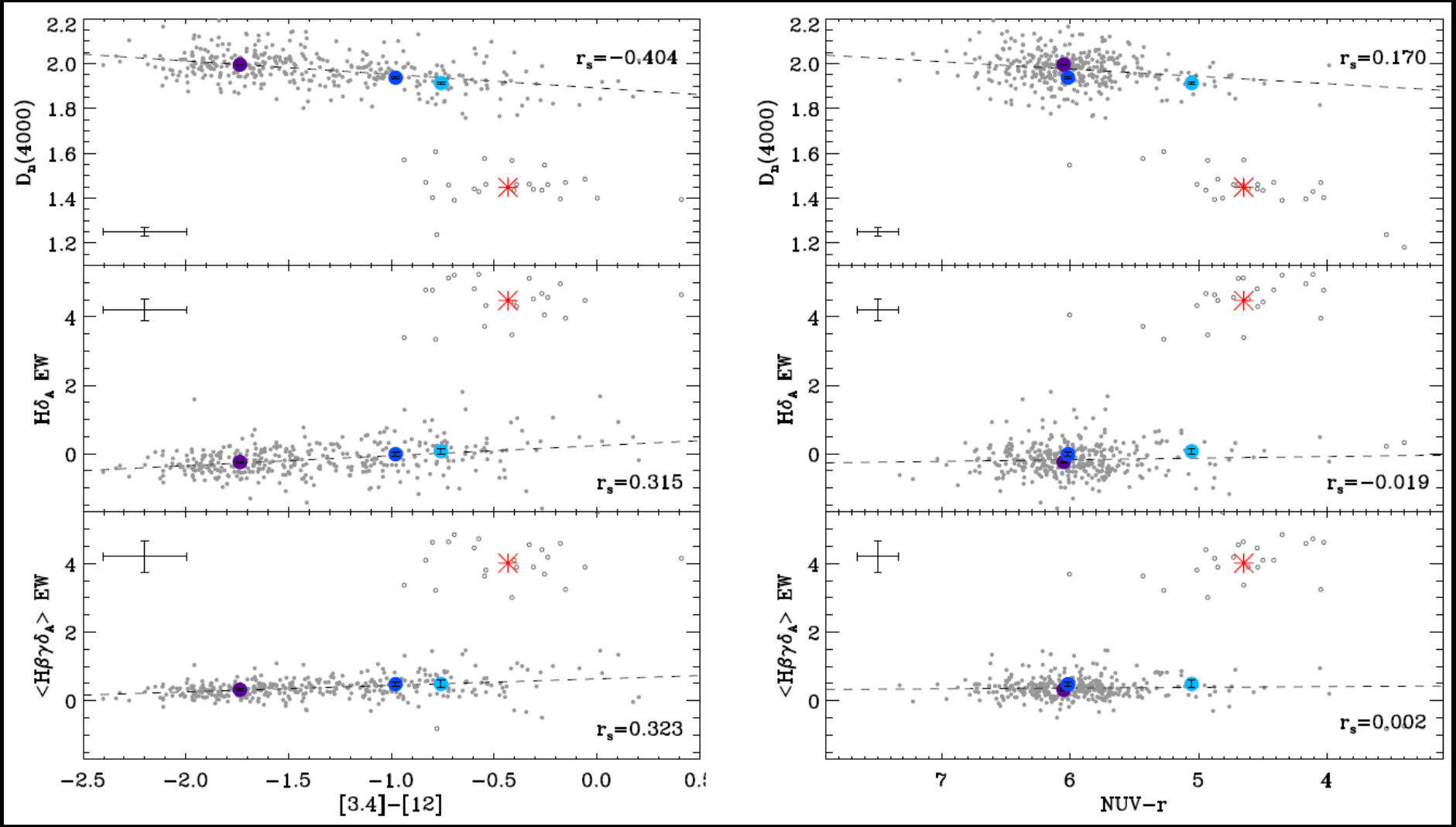


- **Median stacking** with normalized (by Median of 4150-4250 Å range) spectra.

- **S/N increased by an order of magnitude** (~71-281) compared to individual spectrum (~11)

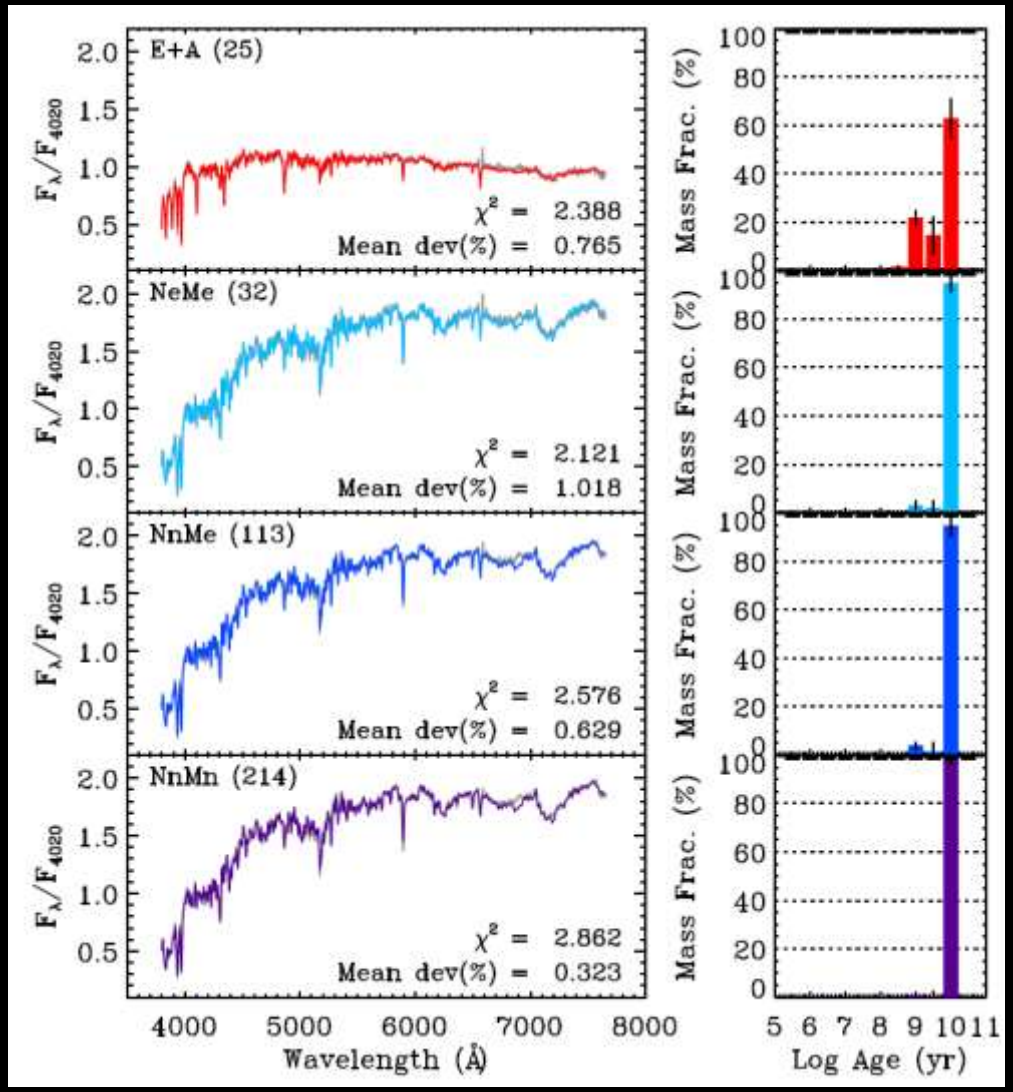
- Measurement of 4000 Å break and Lick indices of Balmer absorption lines.

3. Tracing Recent Star Formation History of ETGs

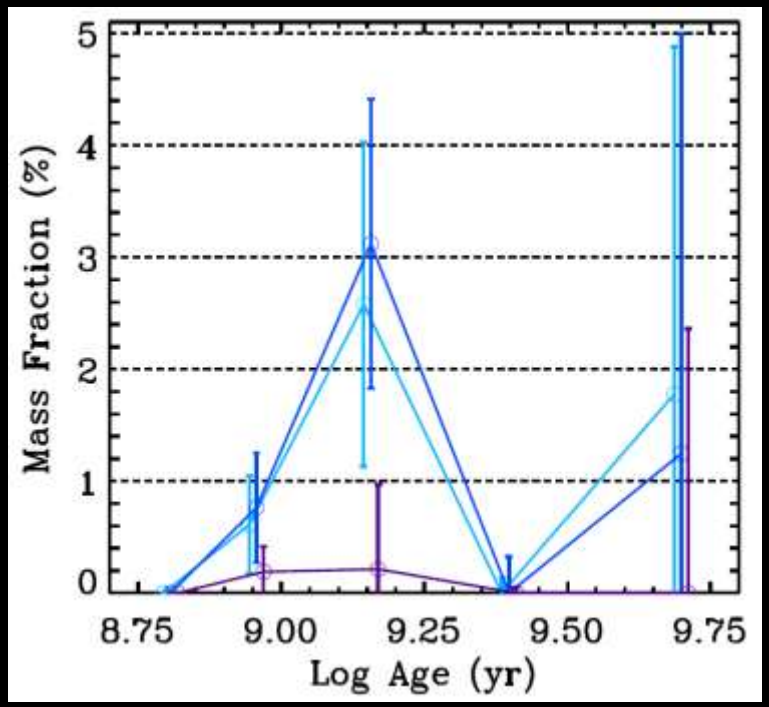


- [3.4]-[12] color is likely to be more correlated with the D_n4000 and Hδ EW than NUV-r color.
- Mid-IR can be a useful diagnostic tool of the existence of young (<1 Gyr) and intermediate (1-5 Gyr) age stars.

4. Stellar Populations of ETGs with mid-IR Excess



- **STARLIGHT** at 3800-7650 Å
- 45 templates of Bruzual & Charlot (2003) model generated from STELIB library
  - 15 ages (between 1 Myr and 13 Gyr)
  - 3 metallicities (Z=0.004, 0.02, 0.05)



- The mass fraction of young (~1Gyr) and intermediate-age (1–5 Gyr) populations for the **ETGs with mid-IR excess** is small, but is **not negligible** compared to the **ETGs without mid-IR excess.**
- **ETGs with mid-IR excess emission have experienced star formation in the previous 1-5 Gyr.**

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Stellar Populations of Early-type Galaxies with Mid-infrared Excess Emission

Haeun Chung[a,b], Jongwan Ko[b], Ho Seong Hwang[b] and Jong Chul Lee[b]
[a]Seoul National University (SNU), Seoul, Korea; [b]Korea Institute for Advanced Study (KIAS), Seoul, Korea
[b]Korea Astronomy and Space Science Institute (KASI), Daejeon, Korea

Abstract

We present a stellar population analysis of bright ($M_r < -21.5$) early-type galaxies (ETGs) with recent star formation. We select ETGs based on WISE mid-infrared (3.4) and GALEX near-ultraviolet (NUV) data among a spectroscopic sample of SDSS galaxies at $0.04 < z < 0.11$. We stack the optical spectra of ETGs with different amounts of mid-IR and near-UV excess emissions to measure the strength of 4000 Å break (D_n4000) and Balmer absorption line width (HδA) that are indicative of recent (~1 Gyr) star formation activity. The stellar populations derived from the fit of the stacked spectra with STARLIGHT show that the contribution of young and intermediate-age (~1–5 Gyr) stars rises to ~5%, in the total stellar mass fraction of ETGs with mid-IR excess. Furthermore, the WISE [3.4]-[12] colors have stronger correlations than NUV−r colors in age-sensitive spectral features, indicating the mid-IR can be a useful diagnostic tool of the existence of young and intermediate-age stars. Our results suggest that the ETGs with mid-IR excess have experienced star formation in the previous 1–5 Gyr. This work has been published on Ko et al. 2016, ApJ, 820, 132

1. Data and Sample

(1) Galaxy catalog

- Bright ETGs ($M_r < -21.5$) from WISE mid-IR and GALEX near-UV data with spectroscopic samples of SDSS galaxies at $0.04 < z < 0.11$

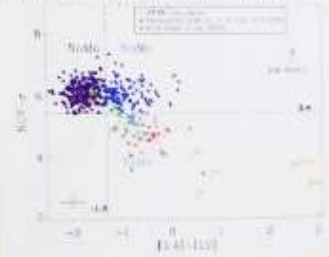
(2) Sample: quiescent ETGs on the optical red-sequence

- Optical color-magnitude cut
- Hδ equivalent width > 1.5 Å: quiescent
- Axis ratio (b/a > 0.6: reject star-forming galaxies with large dust obscuration
- AGN removal

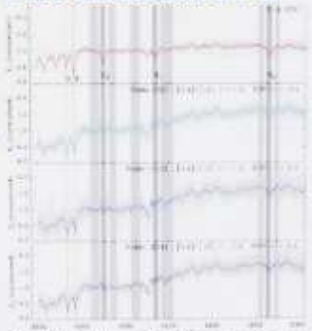
> 397 bright ($M_r < -21.5$), quiescent, red ETGs without AGNs

(3) Subsamples: classifying ETGs based on near-UV and mid-IR excess emissions

- near-UV excess and mid-IR excess and (NUVMIR)
- mid-IR excess but without near-UV excess (NoNUV)
- without both near-UV excess and mid-IR excess (NoNoR)



2. SDSS Stacked Spectra of ETGs



- Median stacking with normalized (by Median of 4150-4250 Å range) spectra
- S/N increases by a factor of magnitude (~71-281) compared to individual spectrum (~11)
- Measurement of 4000 Å break and Lick indices of Balmer absorption lines

Figure 2 (Above): SDSS stacked spectra of three subclasses of ETGs based on NUV-r and [3.4]-[12] colors, and E+A galaxies. The light and dark gray-shaded region show the pseudo continuum for the Balmer absorption line index and the Balmer absorption line bandpass, respectively.

Figure 1 (Left): [3.4]-[12] vs. NUV-r colors for bright ($M_r < -21.5$) quiescent (without star-forming) ETGs. Model colors are color-coded by their [3.4]-[12] and NUV-r colors. Asterisks represent bright ($M_r < -21.5$) E+A galaxies showing early-type morphology from Choi et al. (2009). The cross in the lower left corner indicates median color errors.

Figure 3. D_n4000 versus Hδ absorption line width for SDSS stacked spectra of three subclasses and E+A galaxies (same symbols). Colors are the same as those in Figure 1. Gray filled and open symbols represent individual spectra for three subclasses and E+A galaxies, respectively. The cross indicates median errors of individual spectra. The solid line represents a model of continuous star formation histories with a solar metallicity, a fixed $\tau = 0.5$ Gyr, and different formation time (10 Gyr to 0.1 Gyr). The formation ages 5 and 10 Gyr are printed.

3. Tracing Recent Star Formation History of ETGs

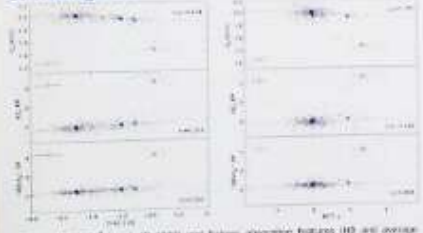
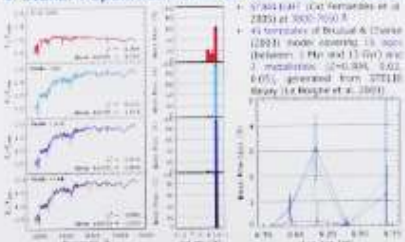


Figure 4: 4000 Å break (D_n4000) and Balmer absorption features (Hδ and average equivalent width <Hδ,0>) as a function of WISE [3.4]-[12] (Left) and NUV-r (Right) colors for SDSS individual spectra of three subclasses (Gray circles) and E+A galaxies (open circles). The Spearman rank correlation coefficient r_s between colors and spectral features for three ETG subclasses are printed in the right of each panel. The indicators that [3.4]-[12] color is likely to be more correlated with the D_n4000 and Hδ than that NUV-r color. Large symbols represent the data from the stacked spectra and their median colors of three subclasses and E+As.

4. Stellar Populations of ETGs with mid-IR Excess



- STARLIGHT (Cid Fernandes et al. 2005) at 3900-7000 Å
- 45 templates of Bruzual & Charlot (2003): model assuming 15 ages (between ~1 Myr and 13 Gyr) and 3 metallicities (Z=0.004, 0.02, 0.05), generated from STELIB library (Le Borgne et al., 2003)

Figure 5: **(Left)** STARLIGHT fit to the stacked spectra of the three subclasses of ETGs and E+A galaxies. The gray and black-solid lines represent the stacked spectra and the best-fit models, respectively. **(Middle)** The contributions of stellar populations in different ages to the total stellar mass fraction. Each error bar (1σ) represents the distribution of the fitting from 100 different seeds. The mass fraction of young (~10yr) and intermediate-age (1–5 Gyr) populations for the ETGs with mid-IR excess (i.e., NoNUV and NuMIR) is small (~ 5%–5%), but is not negligible compared to the ETGs without mid-IR excess (NoMIR). **(Right)** The distribution of young and intermediate-age (1–5 Gyr) populations for the three subclasses of ETGs.

Conclusions

- We **stack the SDSS spectra of bright ETGs with different amounts of mid-IR and near-UV excess emissions** to measure **4000 Å break (D_n4000) and Balmer absorption line width (HδA FW)** that are indicative of recent star formation activity.
- The WISE [3.4]-[12] colors have stronger correlations than NUV-r colors in all features, indicating the **mid-IR can be a useful diagnostic tool of the existence of young (<1 Gyr) and intermediate (1–5 Gyr) age stars**.
- The contribution of **young (~1 Gyr) stars rises to ~5%, with ~1% of ~5 Gyr,** in the mass fraction of ETGs with mid-IR excess.
- **ETGs with mid-IR excess emission have experienced star formation in the previous 1–5 Gyr.**

Poster #1 !

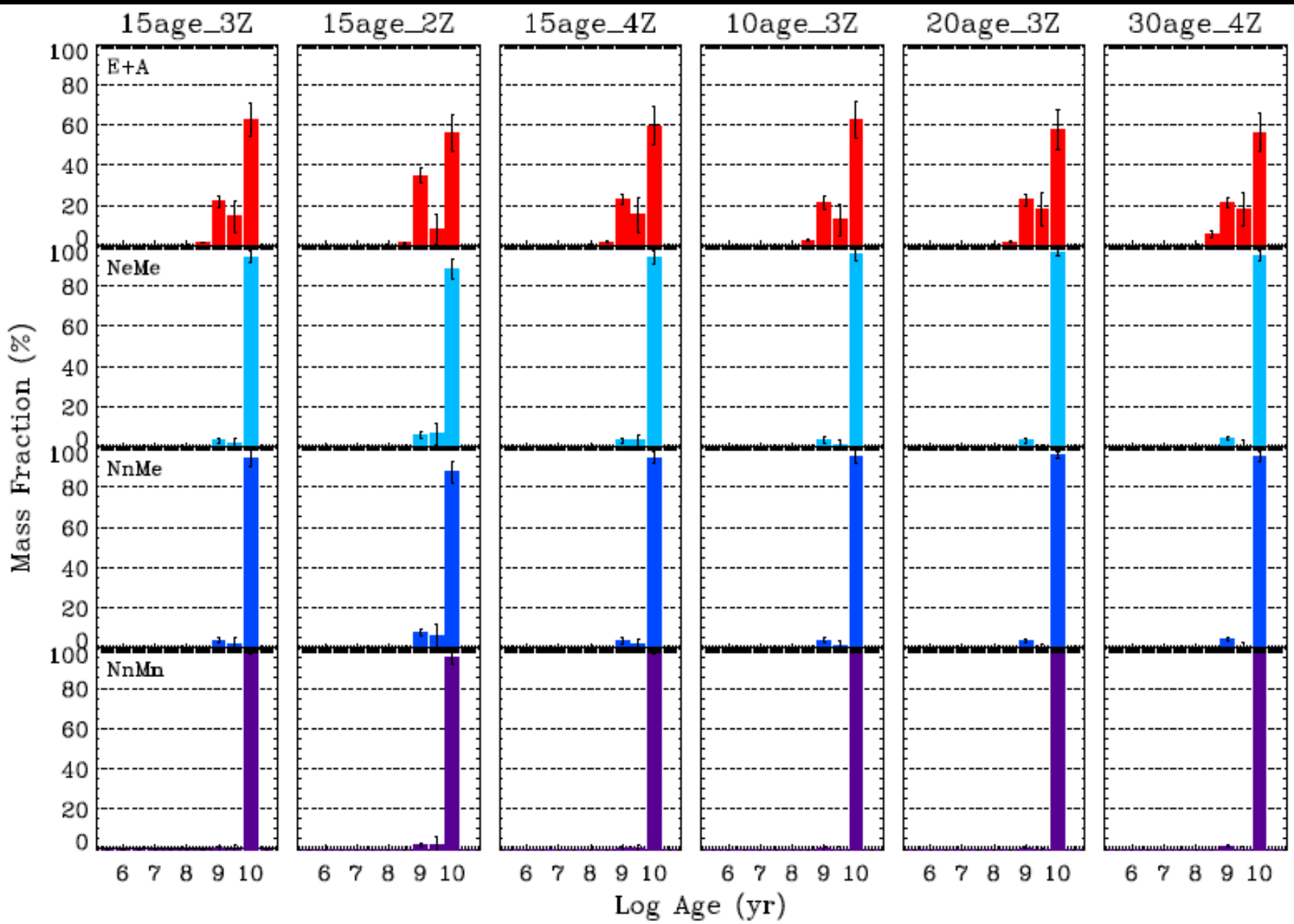


Figure 6. The fractions of stellar populations with different ages in the total stellar mass for E+As (top panel) and three subclasses (bottom panels). Each column indicates the result from the fit with templates of different age and metallicity distributions. The title in each column indicates which template we use for the fit; the number in age means the numbe metallicity means the number of metallicity bins: 2 ($Z = 0.02$, 0.

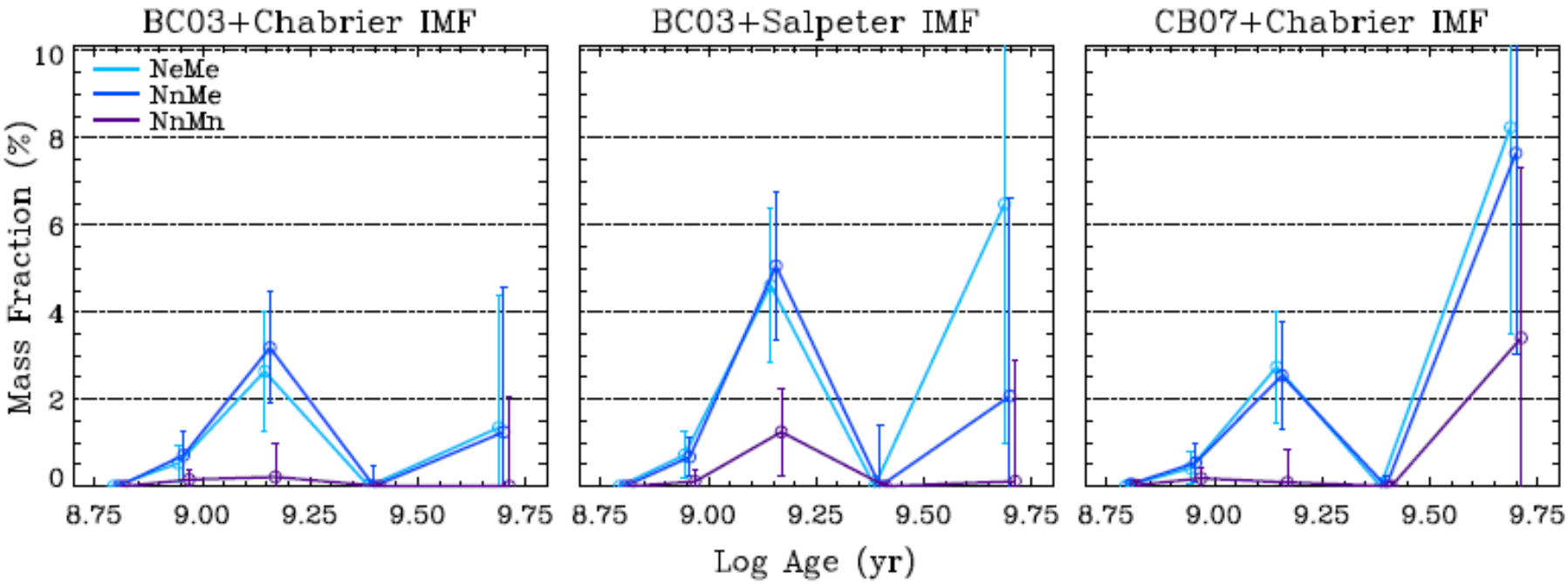


Figure 7. Same as middle panels of Figure 5, but for young and intermediate-age populations of the three subclasses of ETGs in three different combinations of models and IMFs at the same age and metallicity distributions as in Figure 5.

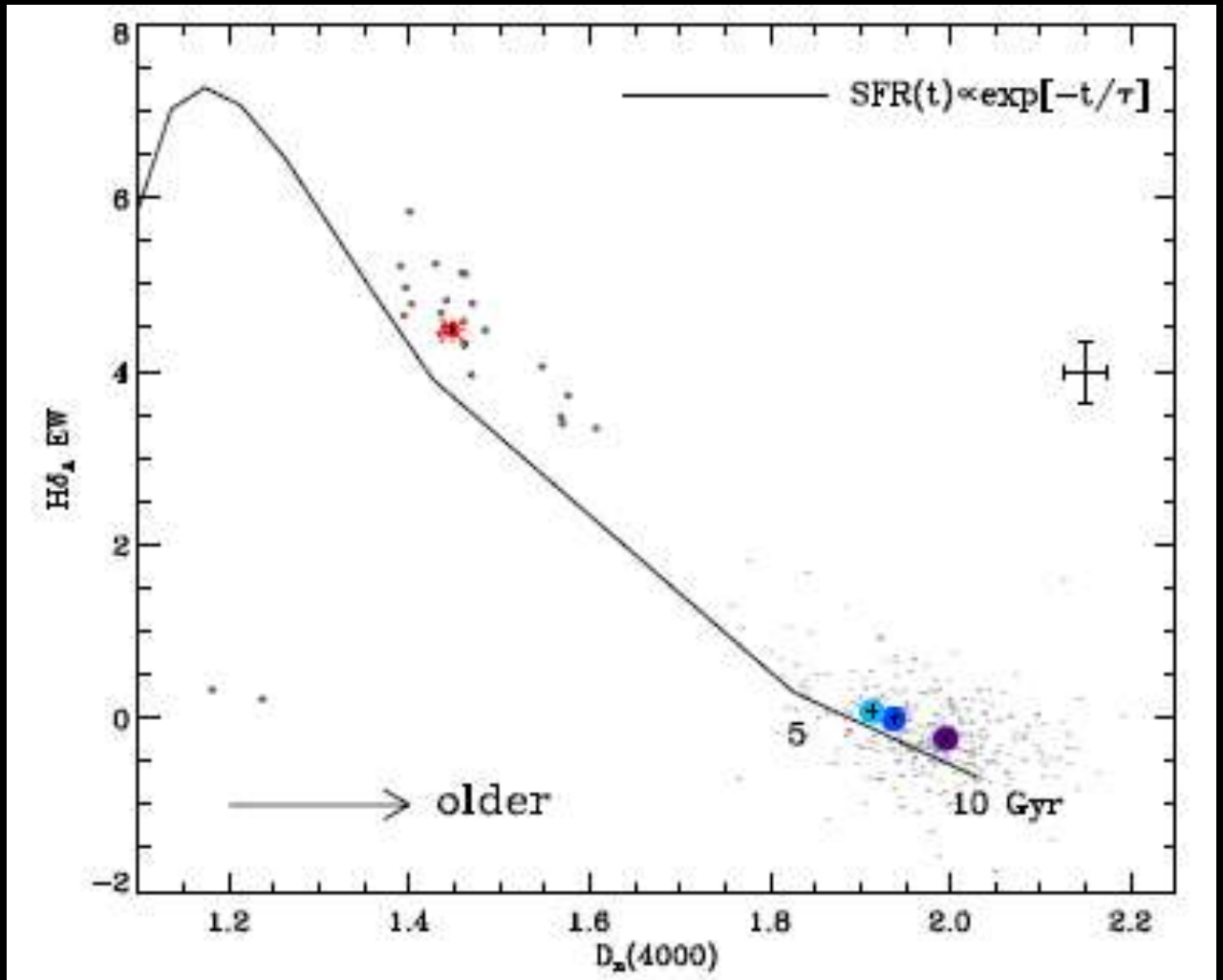
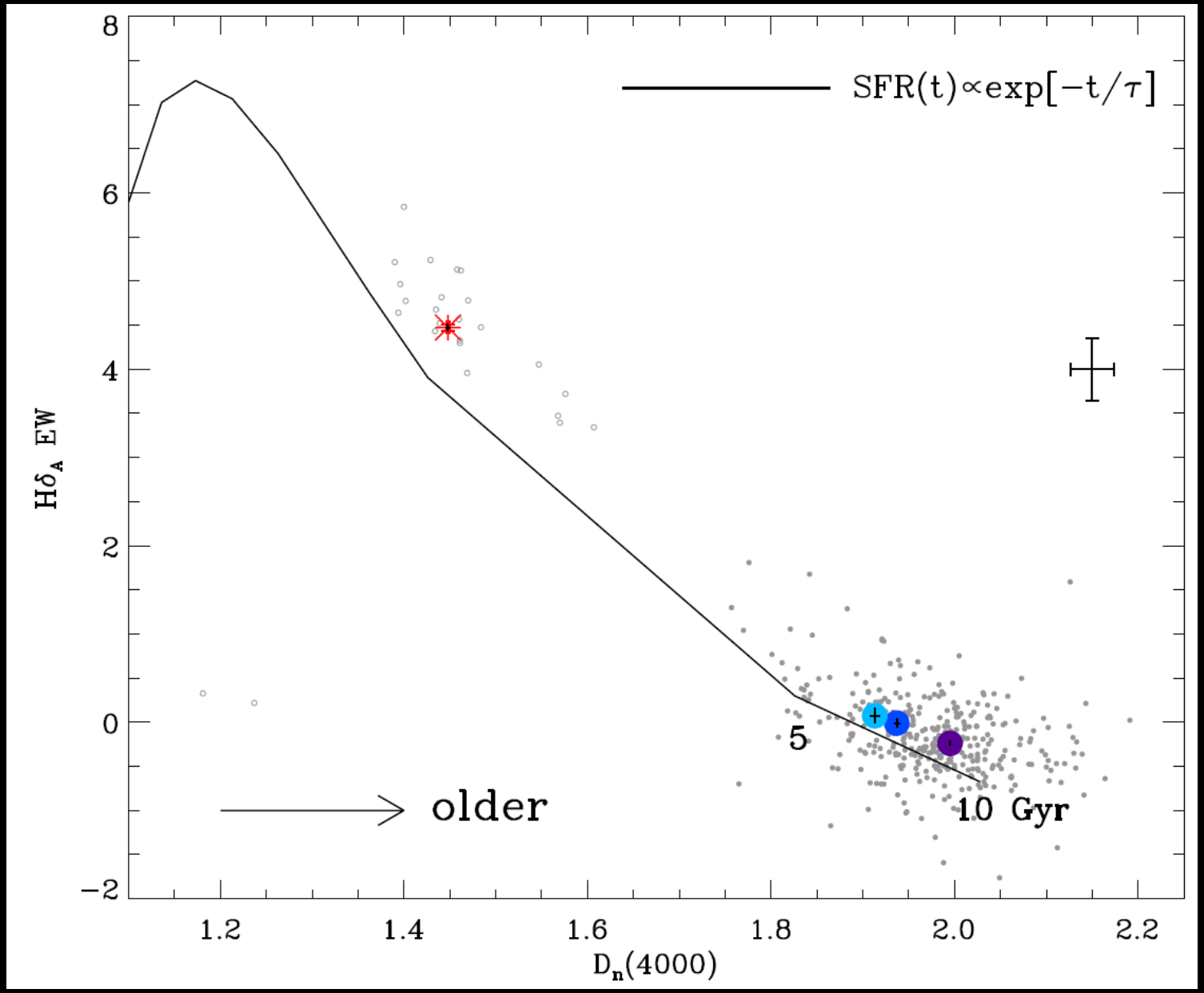


Figure 3. $H\delta_A$ vs. D_n4000 for the SDSS stacked spectra of three subclasses of ETGs and E+As (large symbols). Colors are the same as in Figure 1. Gray filled and open symbols represent individual spectra for three subclasses and E+As, respectively. The large cross indicates median errors of individual spectrum. The solid line represents a model of continuous star formation histories with a solar metallicity, a fixed $\tau = 0.5$ Gyr, and different formation time (10–0.1 Gyr). We indicate two formation ages of 5 and 10 Gyr.


SFR(t)∝exp[−t/τ]
older
5
10 Gyr
Hδ_A EW
D_n(4000)
8
6
4
2
0
−2
1.2
1.4
1.6
1.8
2.0
2.2