Sensitive indices in SPS

主要参考文献：

La Barbera F., et al. 2013, MNRAS, 433, 3017

Conroy C., 2013, ARA&A, 51, 393

Kauffmann G, et al. 2003. MNRAS 341:33–53

Worthey, G., & Ottaviani, D. L. 1997, ApJS, 111, 377

Worthey G. 1994. Ap. J. Suppl. 95:107–149

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outline

- Stellar population synthesis (SPS)
- Lick/IDS system
- Sensitive indices

- **Stellar population synthesis (SPS)**
  - Lick/IDS system
  - Sensitive indices

Stellar population synthesis (SPS)

1. Information in SEDs

   star formation history (SFH)

   stellar metallicity

   abundance pattern

   stellar initial mass function (IMF)

   total mass in stars

   the physical state and quantity of dust and gas

Stellar population synthesis (SPS)

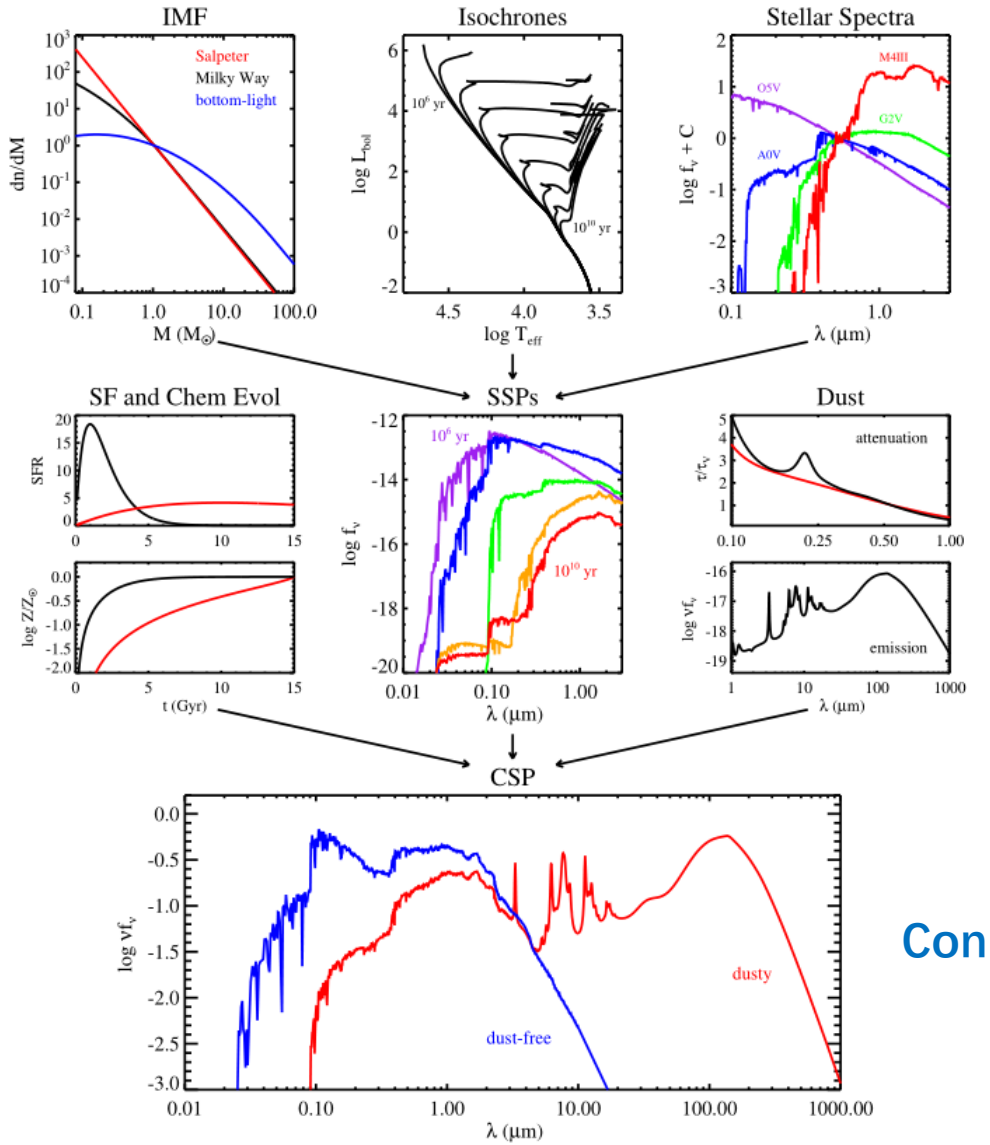
2. methods of extracting information from the SEDs of galaxies

combining mixtures of stars in ad hoc ways until a match was achieved with observations (e.g., Spinrad & Taylor 1971)

→ incorporated physical constraints and automated fitting techniques (Faber 1972)

→ stellar evolution theory in the 1980s and 1990s paved the way for the latter approach to become the de facto standard in modeling the SEDs of galaxies

Stellar population synthesis (SPS)



3. Data：

SEDs+Spectral indices: can be used to low resolution spectra

Full spectrum: require high resolution spectra

Conroy C., 2013, ARA&A, 51, 393

- Stellar population synthesis (SPS)
- **Lick/IDS system**
- Sensitive indices

Lick/IDS system

- The Lick/IDS system is the most popular index system, defining 21 indices in the wavelength range 4000 − 6500 ° A (Burstein et al. 1984, Worthey et al. 1994)
- The LickX library has 63 spectral indices including the 25 from Worthey et al. (1994), Worthey & Ottaviani (1997), the modified $H\beta_0$ index of Cervantes & Vazdekis (2009)

Lick/IDS system

1. Index Definitions

Worthey G. 1994. Ap. J. Suppl. 94:687–722

j (1)	Name (2)	Index Bandpass (3)	Pseudocontinua (4)	Units (5)	Measures[a] (6)	Error[b] (7)	Notes (8)
1	CN_1	4142.125–4177.125	4080.125–4117.625 4244.125–4284.125	mag	C, N, (O)	0.018	1, 2
2	CN_2	4142.125–4177.125	4083.875–4096.375 4244.125–4284.125	mag	C, N, (O)	0.019	1, 2
3	Ca4227	4222.250–4234.750	4211.000–4219.750 4241.000–4251.000	Å	Ca, (C)	0.25	1

NOTES.—(1) Wavelength definition has been refined. See text. (2) C, N are dominant as CN. (3) C is dominant as C_2. (4) TiO appears at M0 and cooler.

[a] Dominant species; species in parentheses control index in a negative sense (index weakens as abundance grows). See Tripicco & Bell 1995 and Worthey 1996.

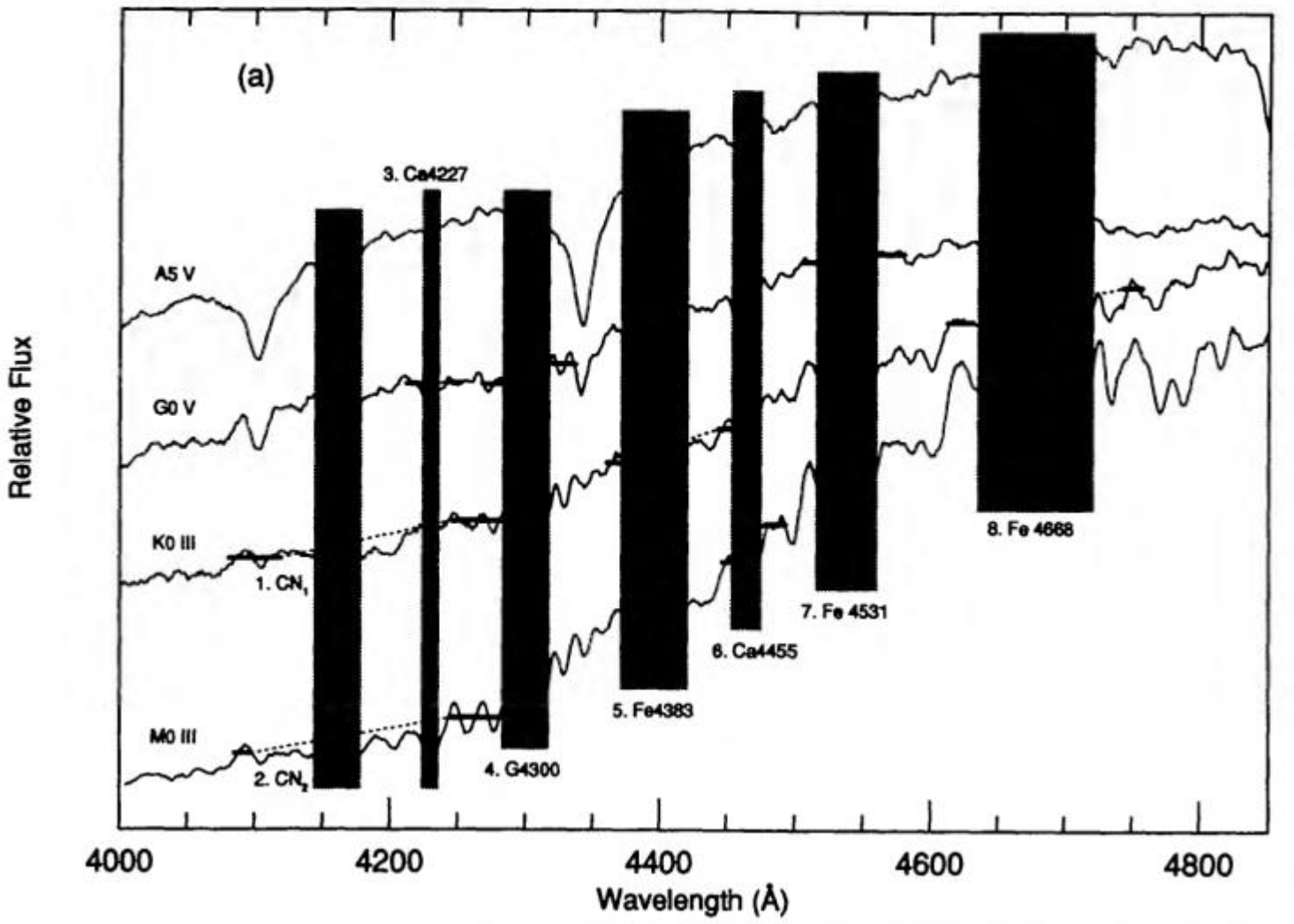
[b] Standard star error. See text.

Lick/IDS system

1. Index Definitions

Index passbands are shown as shaded boxes. An indication of placement of pseudocontinua is shown as heavy lines connected by dotted lines on one of the four spectra for each index

Worthey G. 1994. Ap. J. Suppl. 94:687–722



Lick/IDS system

2. Absorption-Line Measurements

Molecular bands are expressed in magnitudes, while atomic features are expressed in angstroms of equivalent width.

$$\mathrm{EW} = \int_{\lambda_1}^{\lambda_2} \left(1 - \frac{F_{I\lambda}}{F_{C\lambda}}\right) d\lambda$$

$$\mathrm{Mag} = -2.5 \log \left[\left(\frac{1}{\lambda_2 - \lambda_1} \right) \int_{\lambda_1}^{\lambda_2} \frac{F_{I\lambda}}{F_{C\lambda}} \, d\lambda \right]$$

where $F_{I\lambda}$ and $F_{C\lambda}$ are the fluxes per unit wavelength in the index passband and the straight-line continuum flux in the index passband, respectively.[6]

- Stellar population synthesis (SPS)
- Lick/IDS system
- **Sensitive indices**

Sensitive indices

- Problem in SPS

  age-metallicity degeneracy

  burst age-burst strength degeneracy

  IMF-abundance degeneracy

Sensitive indices —age/metallicity

1. The most promising indices are Hß and higher Balmer lines for age sensitivity, and Fe4668 (renamed C24668 later)and other promising metal sensitive indices

Index	$\left(\frac{\Delta age/age}{\Delta Z/Z}\right)_1$
$U-V$	1.5
$B-V$	1.4
$V-R_C$	1.3
$V-I_C$	1.4
$V-J$	1.9
$V-K$	1.9
$J-H$	1.7
$J-K$	1.9
$J-L$	1.8
$J-L'$	1.8
$J-M$	1.7
01 CN_1	1.9
02 CN_2	2.1
03 Ca4227	1.5
04 G4300	1.0
05 Fe4383	1.9
06 Ca4455	2.0
07 Fe4531	1.9
08 Fe4668	4.9
09 Hβ	0.6
10 Fe5015	4.0
11 Mg_1	1.8
12 Mg_2	1.8
13 Mg b	1.7
14 Fe5270	2.3
15 Fe5335	2.8
16 Fe5406	2.5
17 Fe5709	6.5
18 Fe5782	5.1
19 Na D	2.1
20 TiO_1	1.5
21 TiO_2	2.5
D(4000)	1.3

larger numbers indicating greater metallicity sensitivity

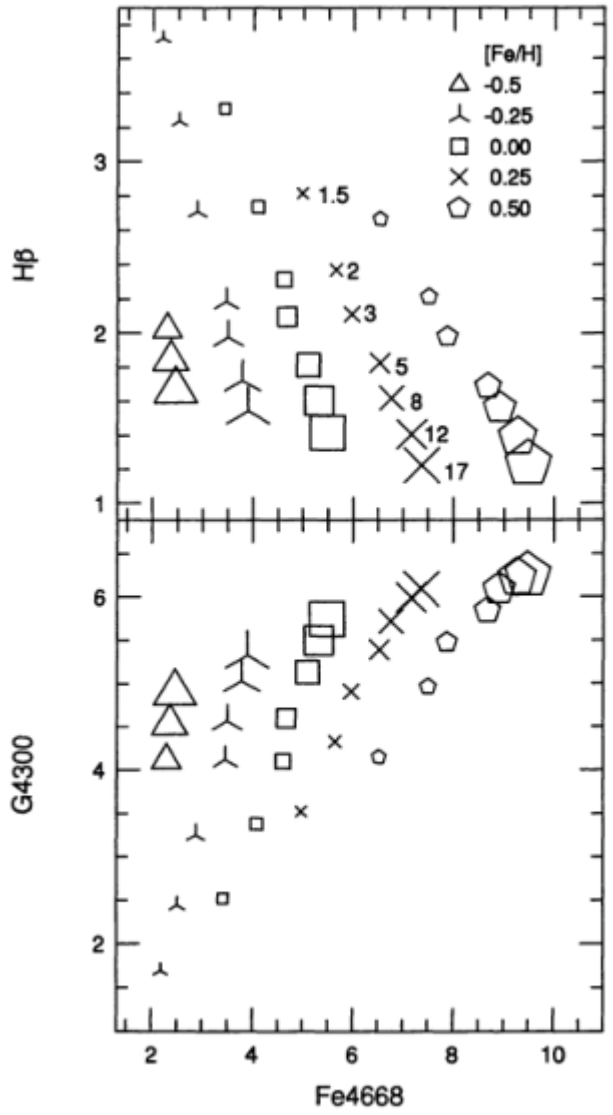
Worthey G. 1994. Ap. J. Suppl. 95:107–149

Sensitive indices —age/metallicity

Worthey G. 1994. Ap. J. Suppl. 95:107–149

G4300 as a function of Fe4668. Ages 1.5,3,5,8,12, and 17 Gyr are shown, except for [Fe/H] = —0.5, for which only the oldest models are shown.

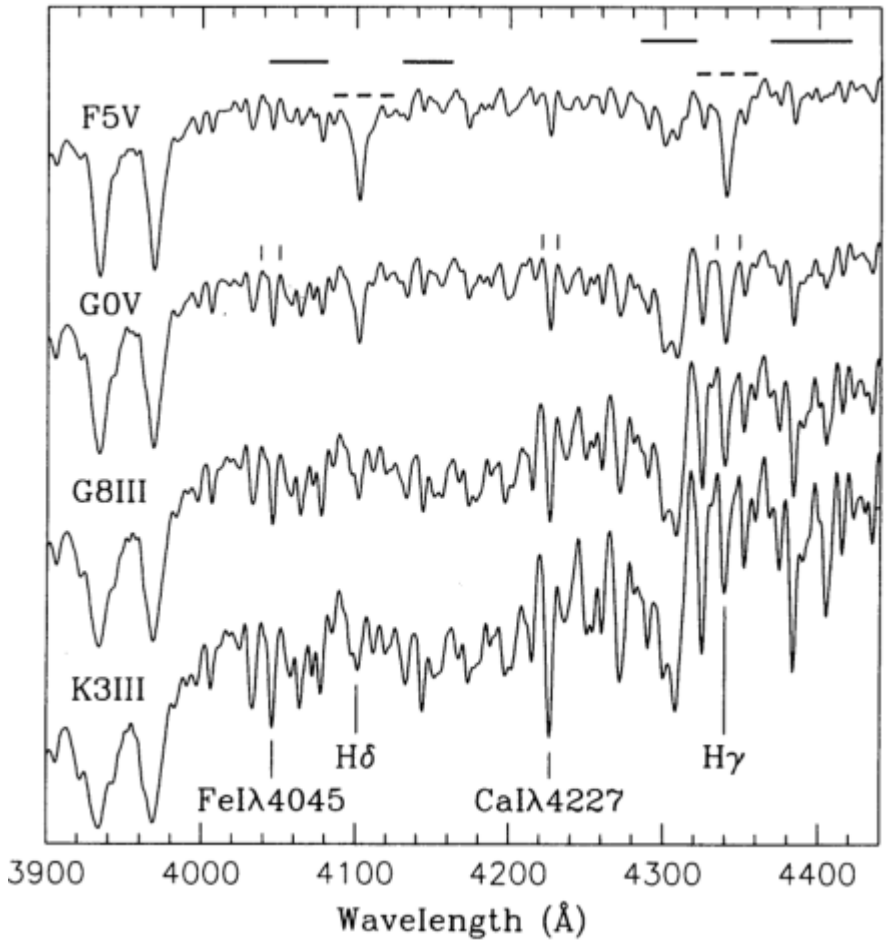
If the symbols are separated from each other in grid fashion, an age indicator has been discovered. If all points lie in a line, the situation is degenerate



Sensitive indices
—age/metallicity

2. Extraction of information depends critically on the precise index definition adopted

Jones, L. A., & Worthey, G. 1995, ApJ, 446, L31



Sensitive indices
—age/metallicity

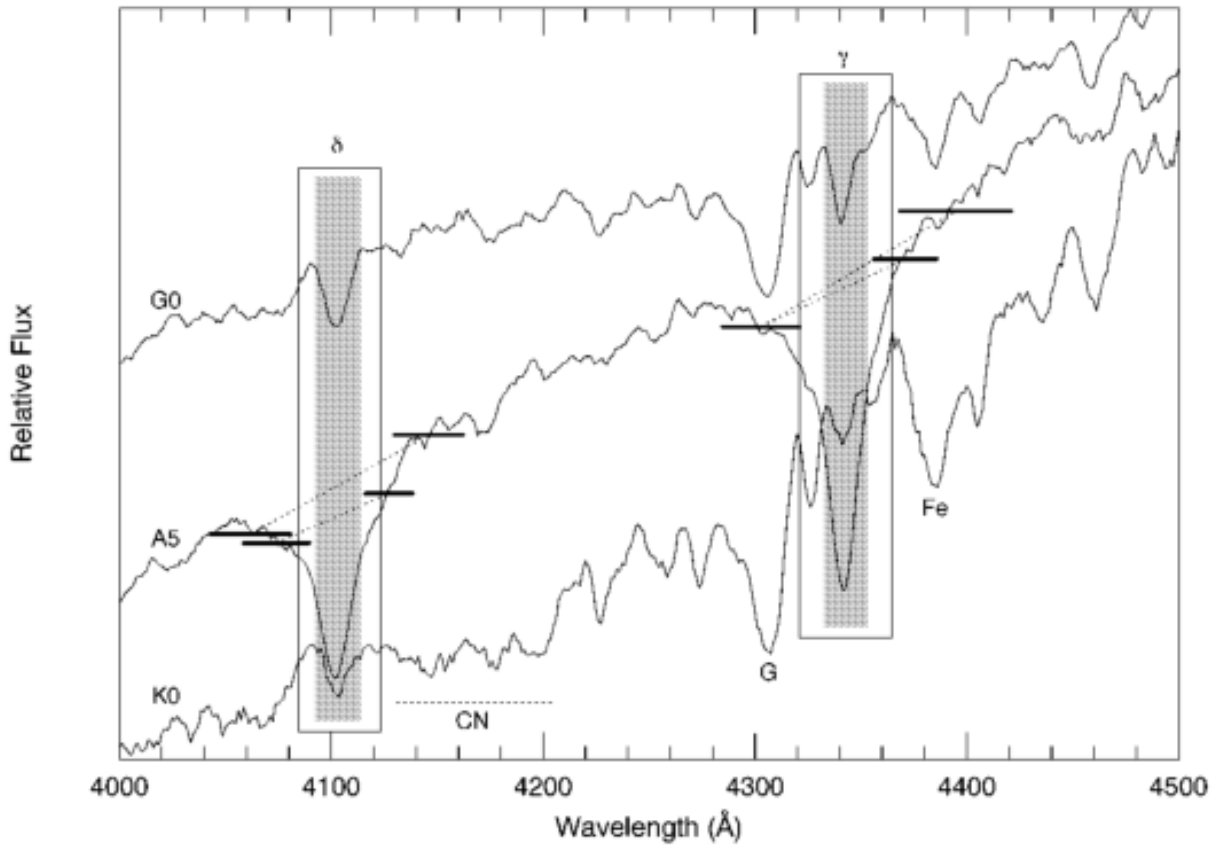
Jones, L. A., & Worthey, G. 1995, ApJ, 446, L31

Index	d(log age)/d(log Z)	Index	d (log age)/d(log Z)
Hδ/λ4045	1.0	FeI_{HR}	1.4
Hδ/λ4063	1.0	CaI_{HR}	1.6
SrII/λ4045	1.2	Hγ_{HR}	0.0
SrII/λ4063	1.3	Hδ_A	1.1
Hγ/λ4325	1.2	Hγ_A	1.0
λ4289/λ4271...	1.4	Fe4668...	4.9
λ4384/λ4352...	1.5	Mg_2	1.8
p[Fe/H]	1.5	$B-V$	1.4
λ3888/λ3859...	1.2	Hβ	0.6

Sensitive indices

—age/metallicity

Worthey, G., & Ottaviani, D. L. 1997, ApJS, 111, 377

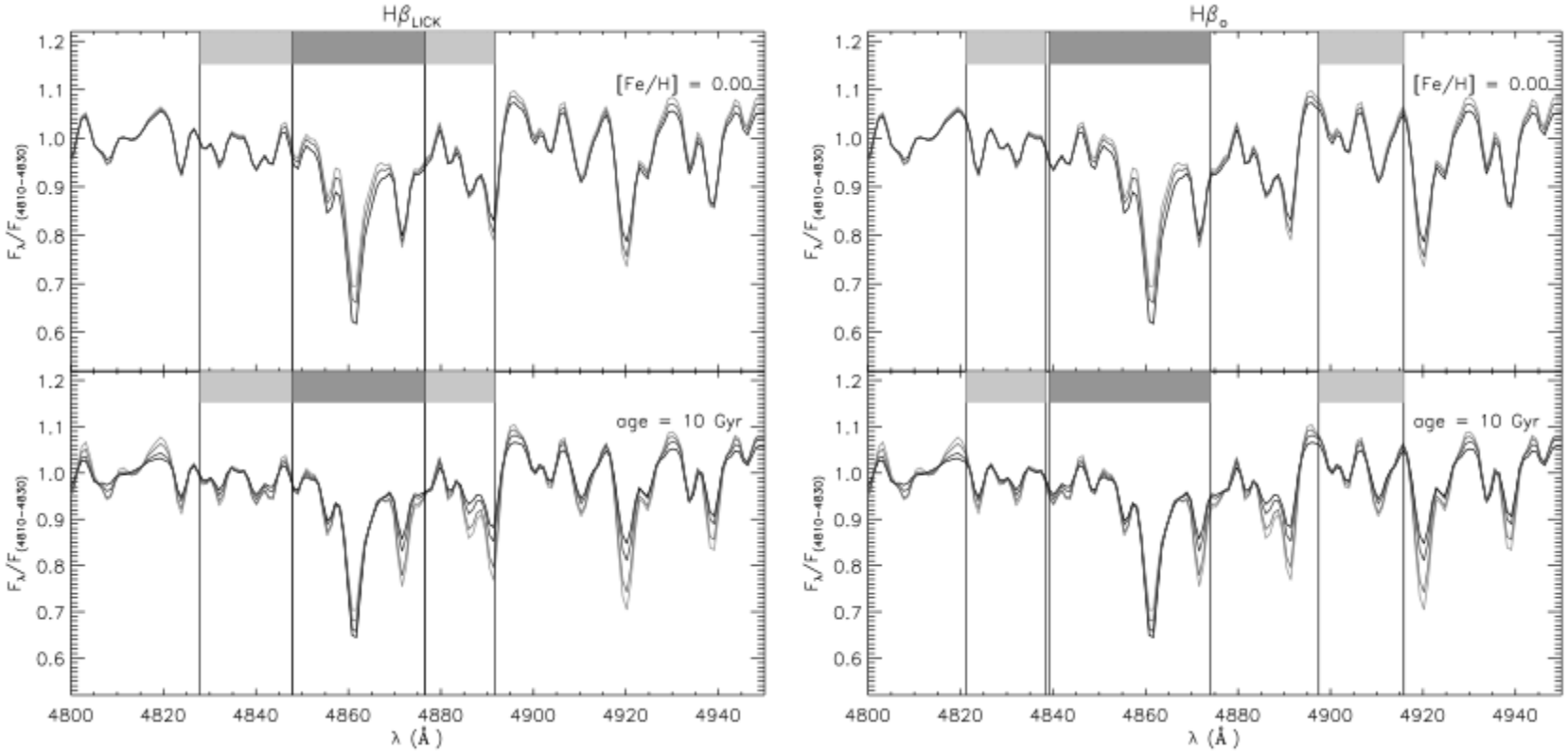


Index	$[d \log (\text{age})/d \log Z]_I$
Colors	1.6
Mg_2	1.8
Fe4668	4.9
$H\beta$	0.6
$H\delta_A$	1.1
$H\gamma_A$	1.0
$H\delta_F$	0.9
$H\gamma_F$	0.8

Sensitive indices

—age/metallicity

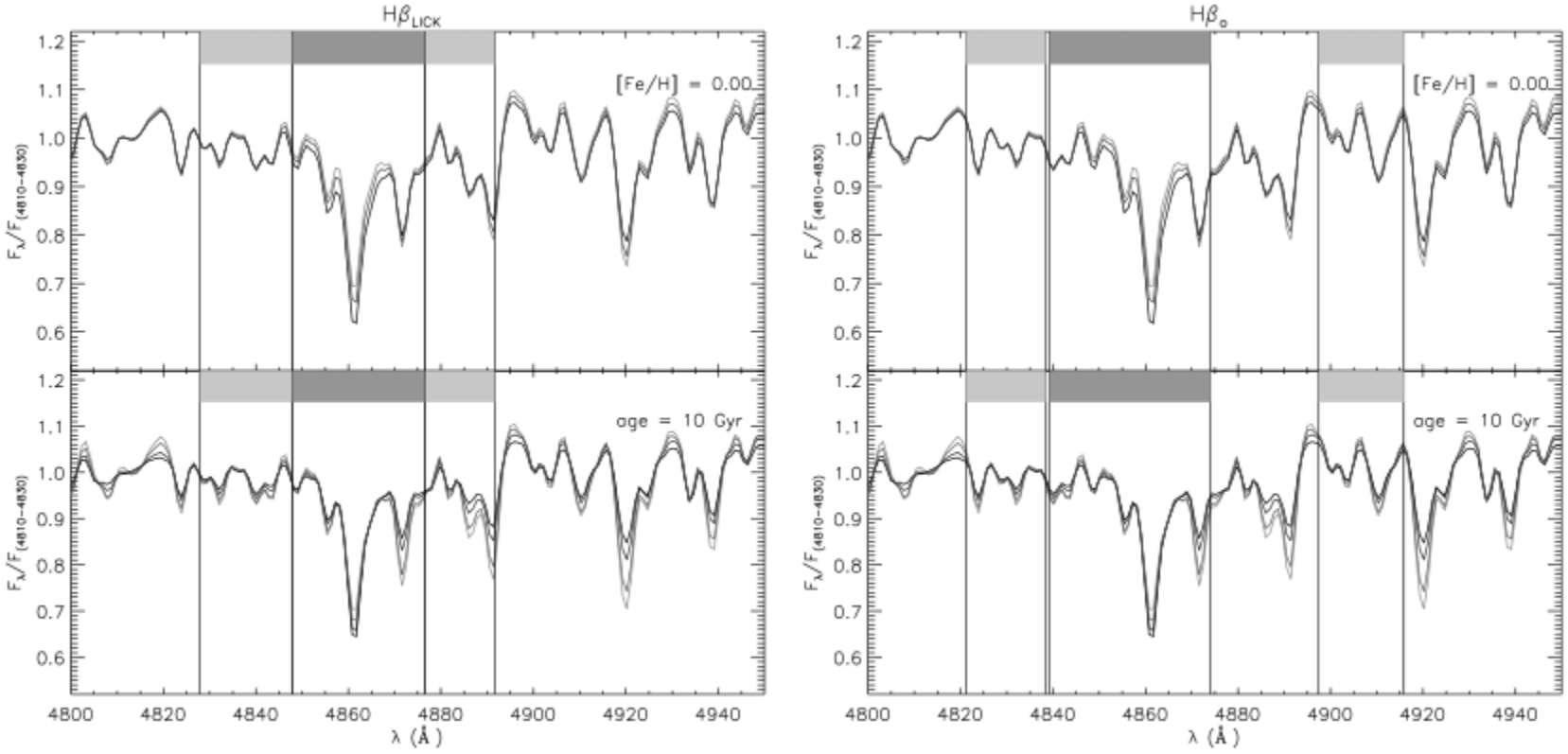
3. Extraction of information depends critically on the locus of index definition adopted Cervantes, J. L., & Vazdekis, A. 2009, MNRAS, 392, 691



Sensitive indices —age/metallicity

Cervantes, J. L., & Vazdekis, A. 2009, MNRAS, 392, 691

The stronger age disentangling power of $H\beta_o$ is achieved by avoiding the metallic lines of the red pseudo-continuum of $H\beta_{LICK}$.

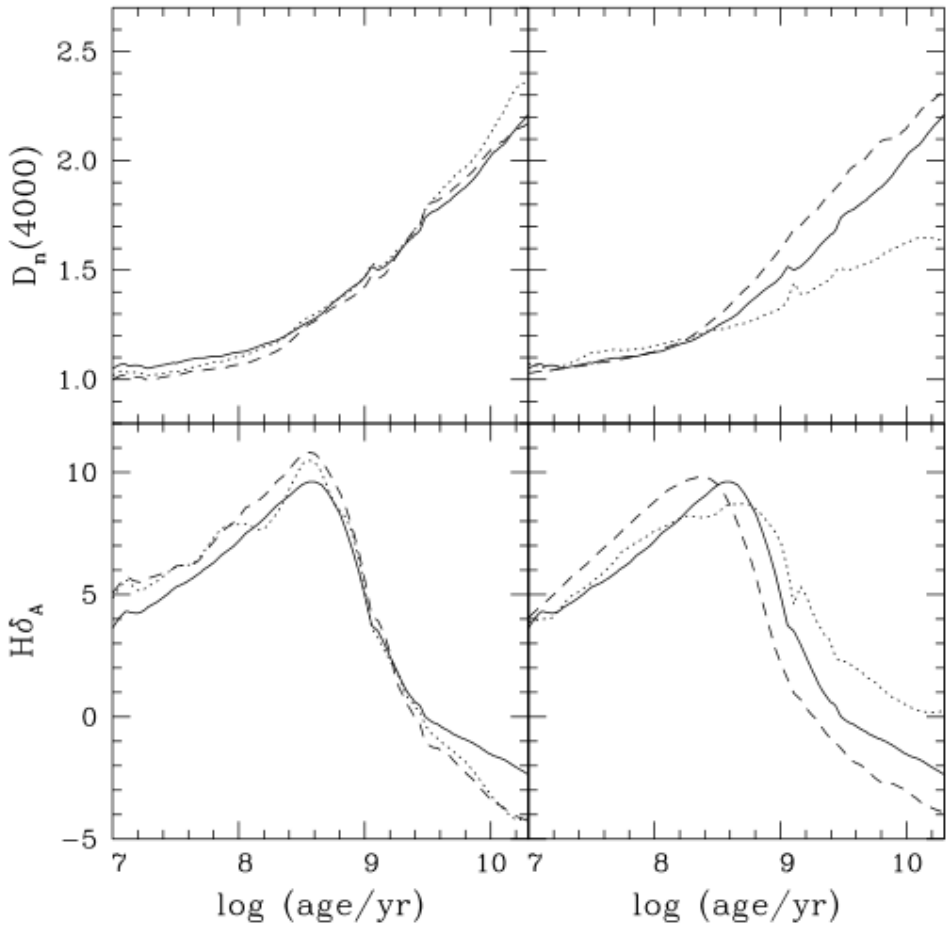


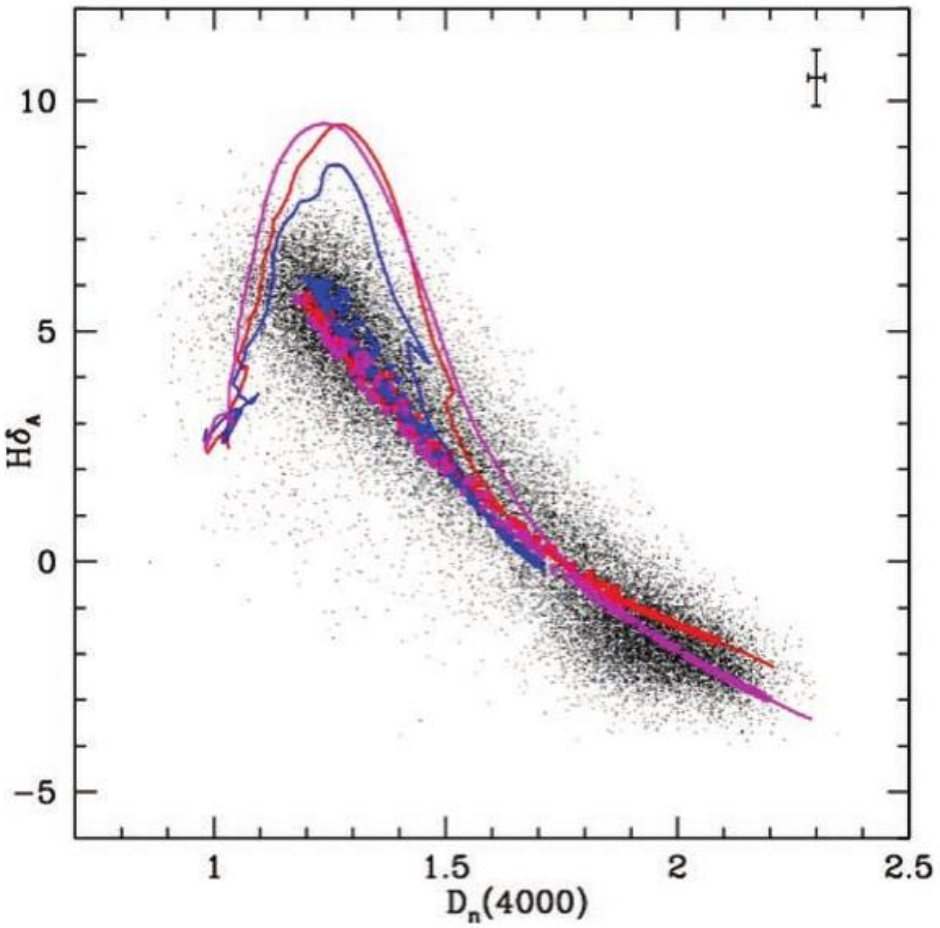
Parameter	$H\beta_{LICK}$	$H\beta_o$
β/α	~0.45	<0.1

Sensitive indices
—age/metallicity

4. D4000

Kauffmann G, et al. 2003. MNRAS 341:33–53





Sensitive indices

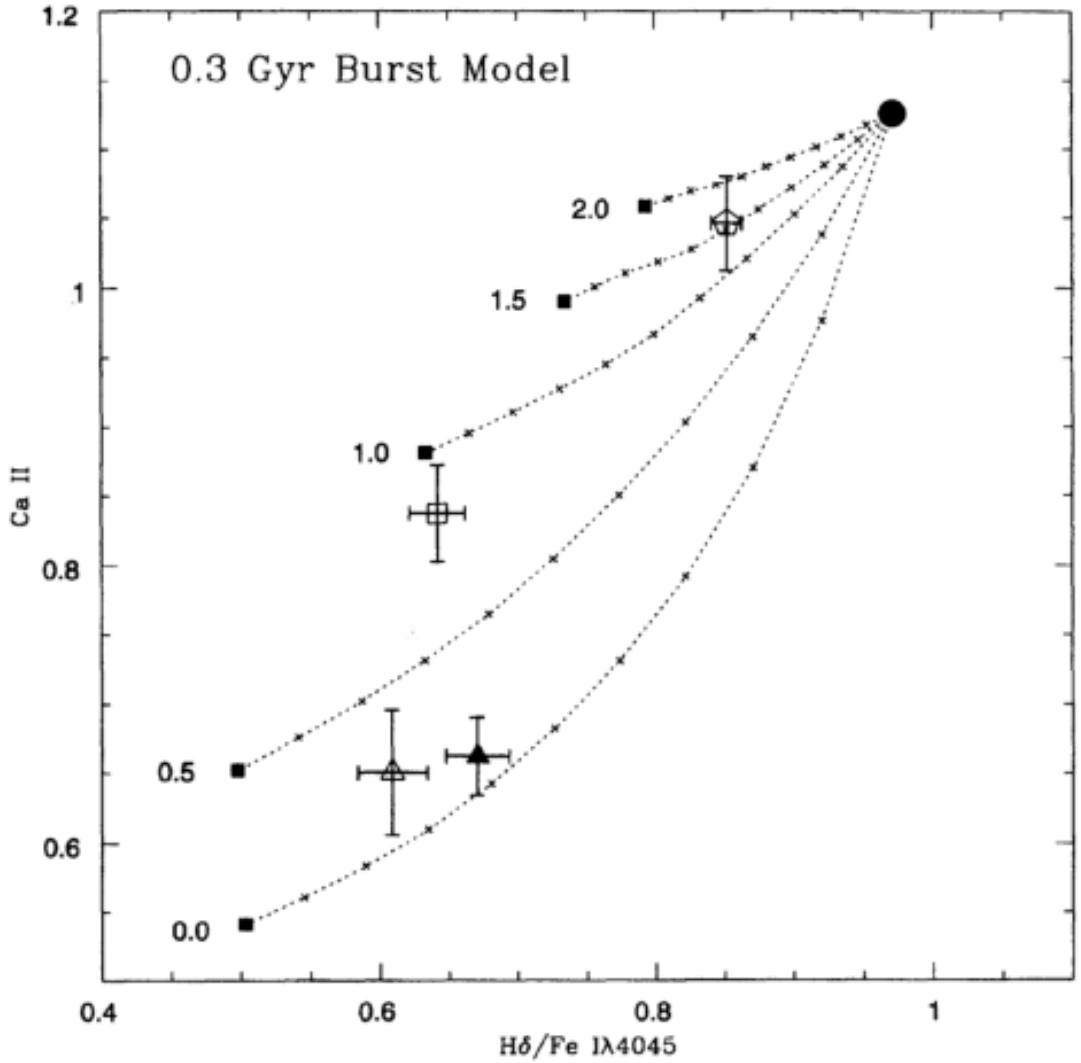
—age/strength

- The $H_\delta/\lambda4045$ index decreases smoothly from spectral type K through A_0, where it reaches a minimum value. For spectral types earlier than A_0, $H_\delta/\lambda4045$ increases again, due to the fact that the Baimer lines weaken in B and O stars.
- the CaII H+He/CaII K index (Ca II) is constant in stars later than about F2, but then decreases dramatically for earlier type stars as the Ca n lines weaken and He strengthens. The index also reaches a minimum at spectral type AO and then increases towards earlier spectral types as He fades at hotter temperatures.

Sensitive indices

—age/strength

Leonardi, A. J., & Rose, J. A. 1996, AJ, 111, 182



Sensitive indices

—IMF/abundance La Barbera F., et al. 2013, MNRAS, 433, 3017

- Imf-sensitive indice

Mg4780, TiO1, TiO2 SDSS , Na8190 SDSS ,CaT

Combined with abundance indices can break the degeneracy