Yunnan model: EPS models with binary interactions

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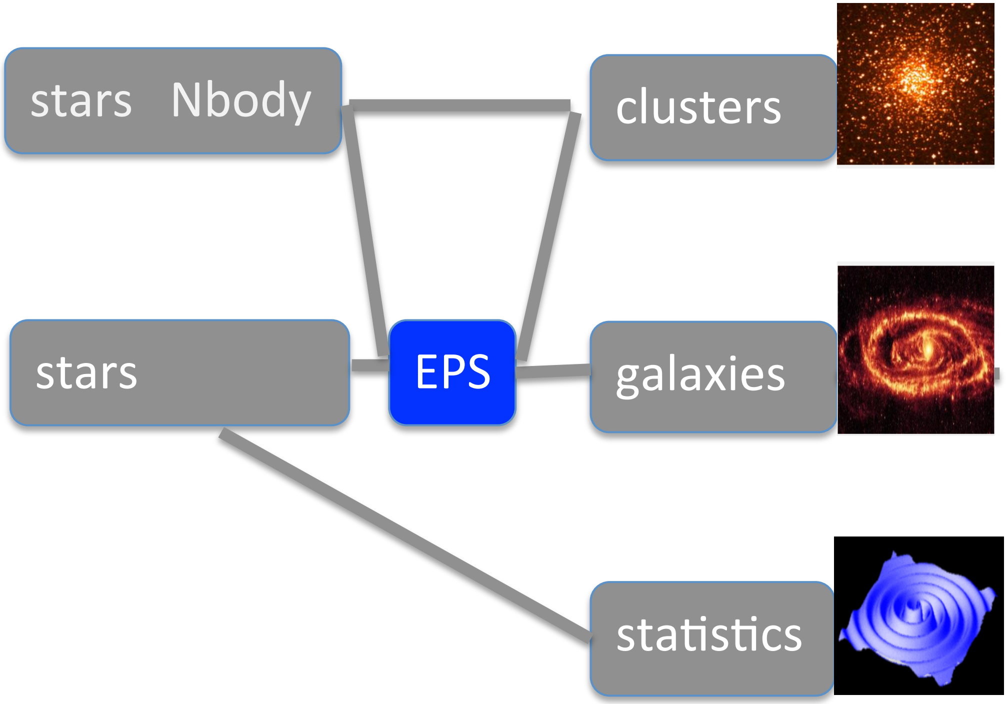
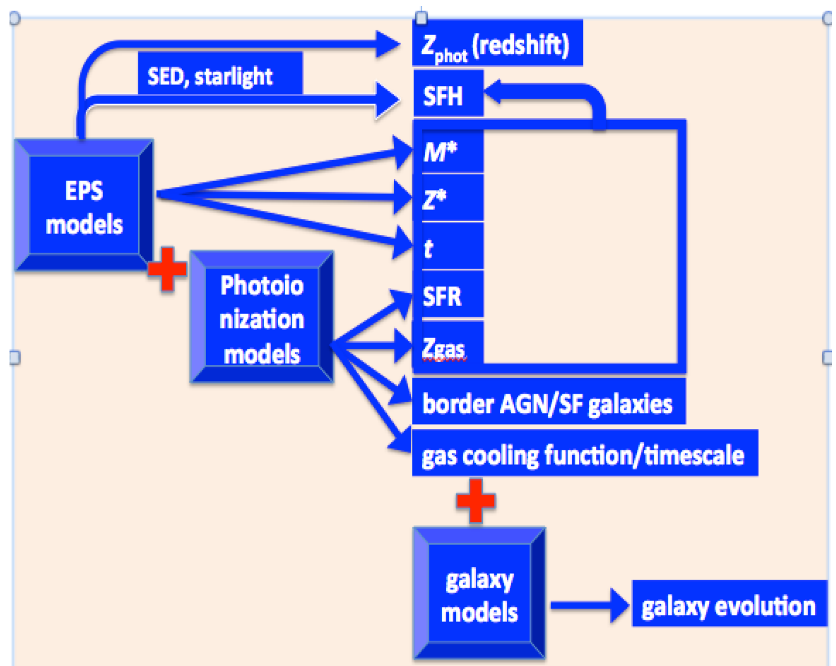

stars Nbody
clusters
stars
EPS
galaxies
statistics


Zphot (redshift)
SED, starlight
SFH
EPS models
M*
Z*
t
Photoionization models
SFR
Zgas
border AGN/SF galaxies
gas cooling function/timescale
galaxy models
galaxy evolution

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I. Stars/EPS: building blocks;
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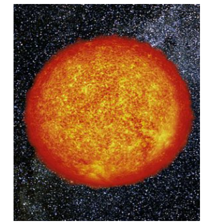
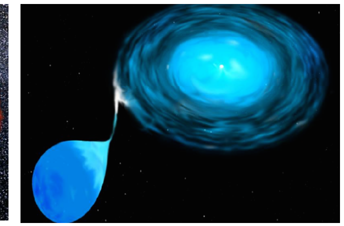
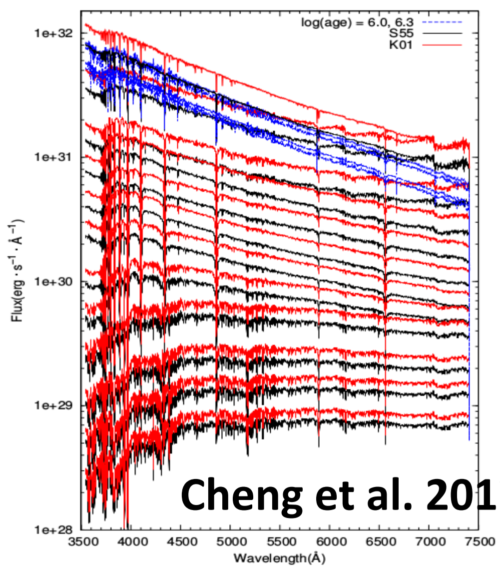
EPS // Yunnan-II models

- **Stellar evolution library**
- **+**
- **stellar spectra library**
- **+**
- **IMFs, …**



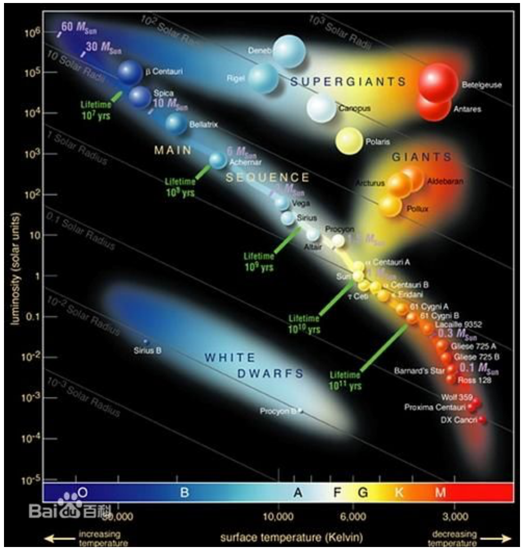




Cheng et al. 2017 MNRAS, submitted

Yunnan models: http://www1.ynao.ac.cn/~zhangfh.

Motivations

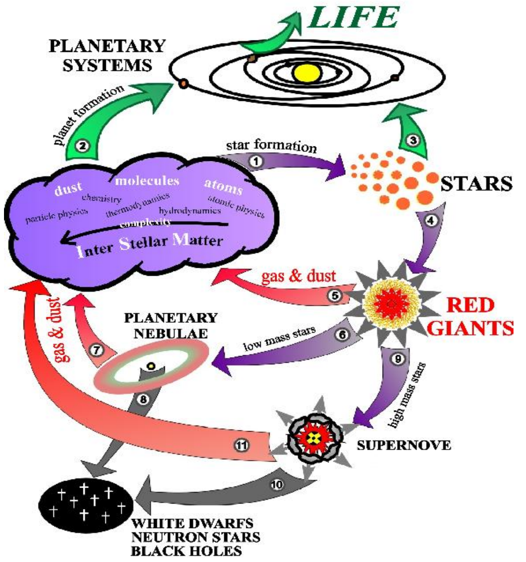


Common in the Universe. Binary fraction f_b:

- 50%, the Galactic field stars;
- 70%, massive O stars, 6 open clusters (Sana et al. 2012);
- 100%, young massive SPs (Kouwenhoven et al. 2007).

Binary interactions (mass transfer, merge, …), different evolution path. means:

- Different distribution in the CMD (*M*/*L*, colours,…, derived properties of galaxies);
- Different amount/kind of elements, ejected wind power (feedback, gas cooling, …, of galaxies).



From Corney's ppt

Motivation: EPS models in history

models	main characteristic
BC series: GISSEL98, BC03, CB07, CB11	
Maraston series: Maraston (1998; 2005); Maraston & Stromback (2011)	TP-AGB ('fuel consumption' technique')
Thomas, Maraston, Bender (2003)	variable element abundance ratios
Vazdekis series: Vazdekis et al. (1996, 2010)	high-resolution empirical spectra, MILES
STARBURST99 (Leitherer et al. 1999, 2010; Vazquez & Leitherer 2005)	
PEGASE (Fioc & Rocca-Volmerange 1997, 1999)	
POPSTAR (Molla, Garcıa-Vargas & Bressan 2009)	
FSPS (Conroy, Gunn & White 2009; Conroy & Gunn 2010; Conroy, White & Gunn 2010)	flexible (github.com/cconroy20/fsps)
Yunnan-II (Zhang et al. 2004, 2005, …)	binary interactions

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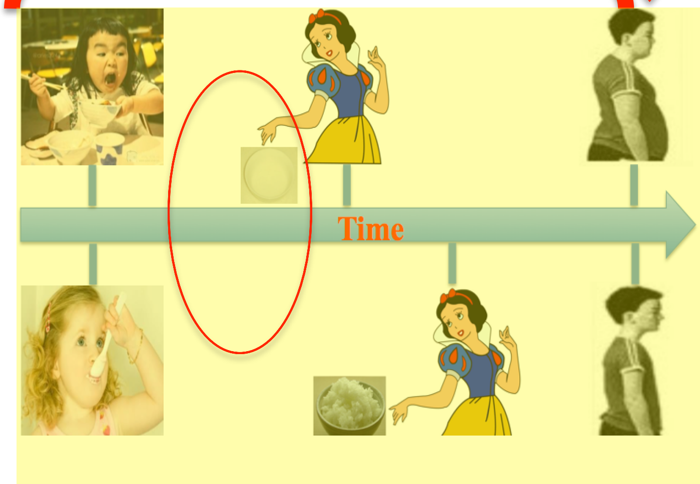
Conclusions: the inclusion of binary interactions can accelerate the galaxy evolution. SF is rapider at early ages; slower at late ages.

M Z* t* ↑ accumulated SF

SFR *Zgas*↓, instantaneous SF (<10^8yr), emission lines, HII, ionize, massive stars

M Z* t* ↑

SFR *Zgas*↓



EPS models → SED, starlight → Z_{phot} (redshift), SFH

EPS models → *M** ↑, *Z** ↑, *t* ↑

\+ photoionization models → SFR ↓, *Zgas* ↓, border: AGN/star-forming galaxies ↗, gas cooling function/timescale

\+ galaxy models → galaxy evolution

Zhang et al. 2004, 2005a,b; 2006, 2009, 2010, 2012, 2013, 2015, 2017

Conclusions: the inclusion of binary interactions can accelerate the galaxy evolution. SF is rapider at early ages; slower at late ages.

M* Z* t ↑

SFR *Zgas* ↓

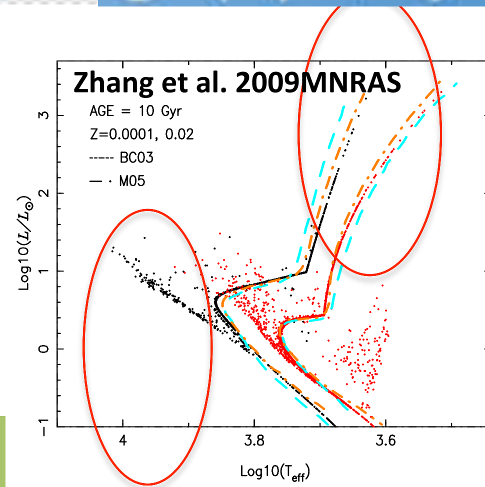
Binary interactions:
--- luminous hot stars↑;
--- the number of giant stars↓(K-band, large radius, RLOF↑) .

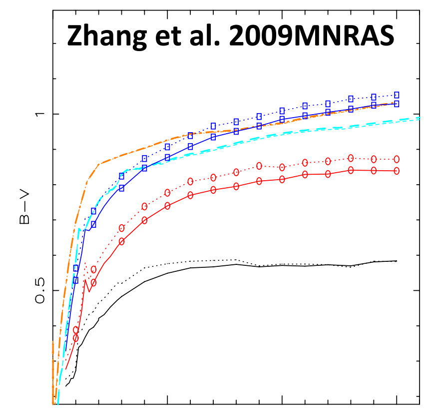
↓

--- bluer colours,
--- larger $(M/L)_K$.

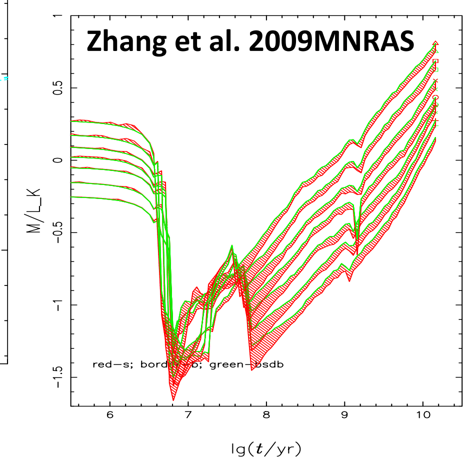
↓

--- t, Z^*↑ (colours redder when Z^*, t ↑)
--- M^*↑ (larger $(M/L)_K$)





Z = 0.02, 0.04 and 0.0001. Also shown are the results of BC03-S (dashed, thick), BC03-C (dashed, thin), M05-S (dot–dashed, thick) and M05-K (dot–dashed, thin)



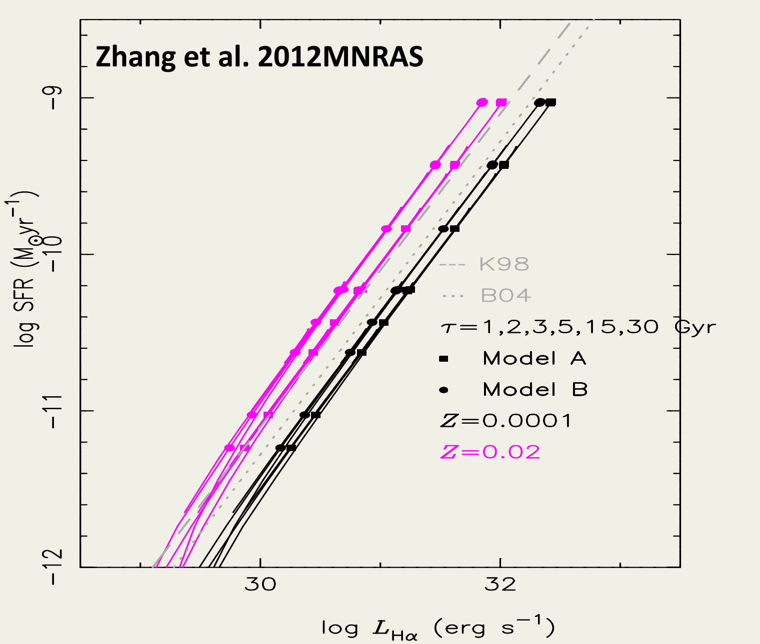
Comparison in the $(M/L)_K$ for SPs with (green) and without (red) binaries at Z = 0.0001- 0.03 (from bottom to top, shifted by a different amount).

Conclusions: **the inclusion of binary interactions can accelerate the galaxy evolution. SF is rapider at early ages; slower at late ages.**

M* Z* t ↑

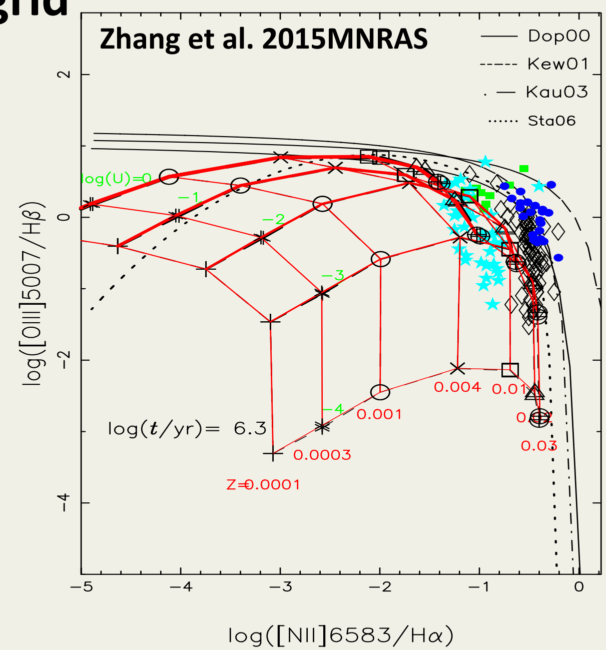
SFR ***Zgas*** ↓

a. SFR method: SFR= c L_{ha};



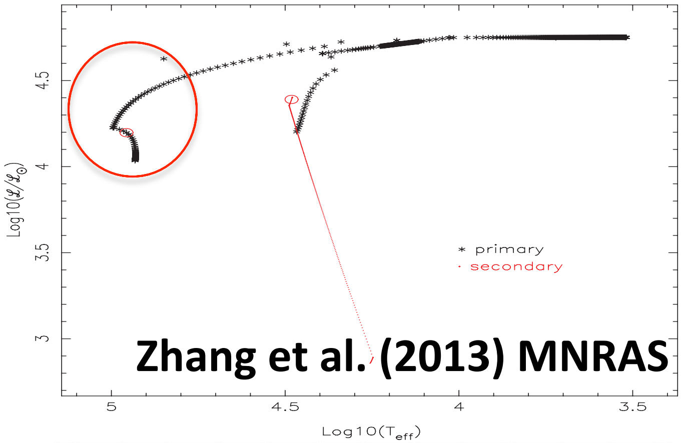
Relation between SFR and $L_{H\alpha}$ (the luminosity of Ha recombination line) **of E, S0, Sa-Sd galaxies when using EPS models with and without binaries.**

b. *Zgas* method: Z- and U- sensitive grid



Y: U sensitive (dimensionless ionization parameter)

X: Z sensitive

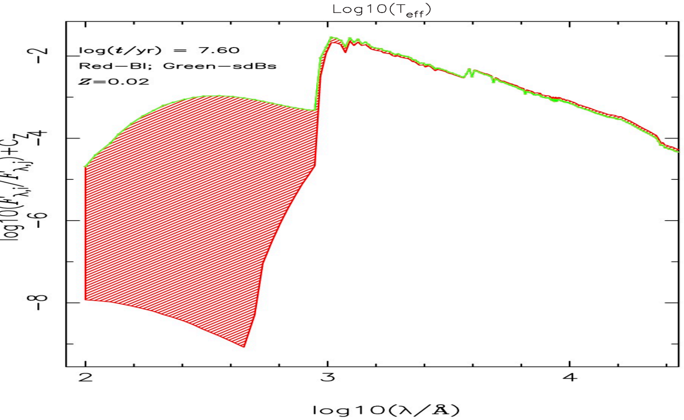


Binary interactions: Naked Helium stars, 10^5K, at intermediate ages (t~10^7-10^8yr).

Our results, for the UV spectra shortwards of Lyman limit:

--- the UV flux is raised by 10^5 ;

--- the spectrum hardness is raised.



Photons blow 912Å,

---ionize surrounding gas, be absorbed by dust, producing emission lines, move the UV luminosity to the IR passband.

Yunnan-II + MAPPING photoionization code

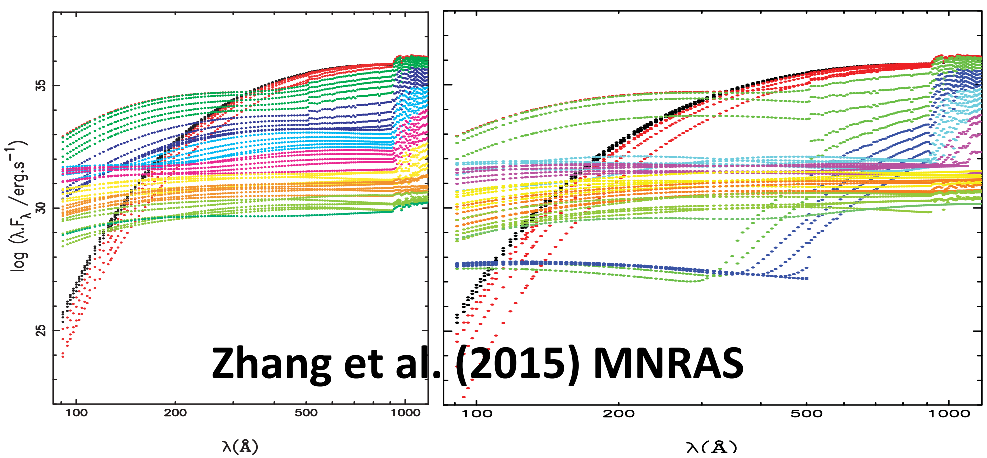
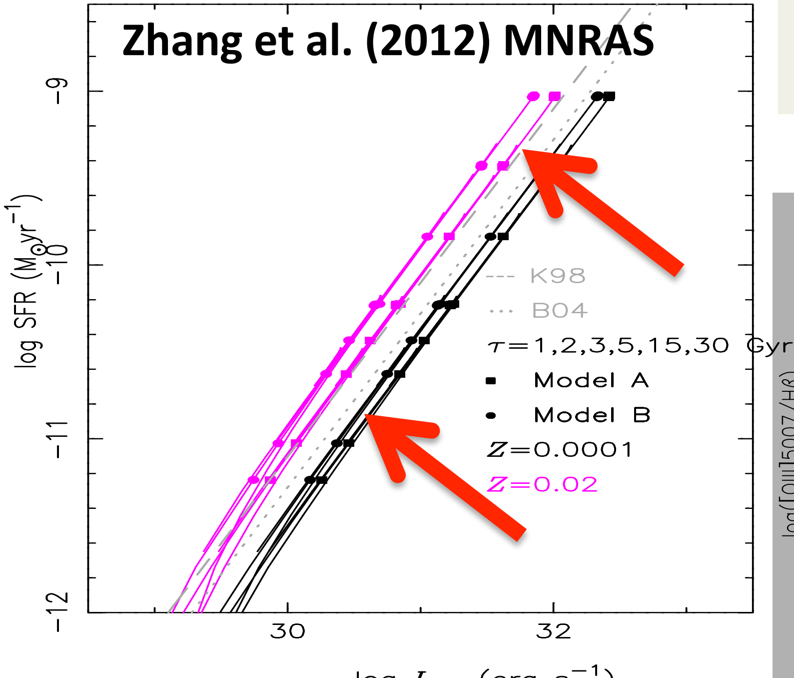


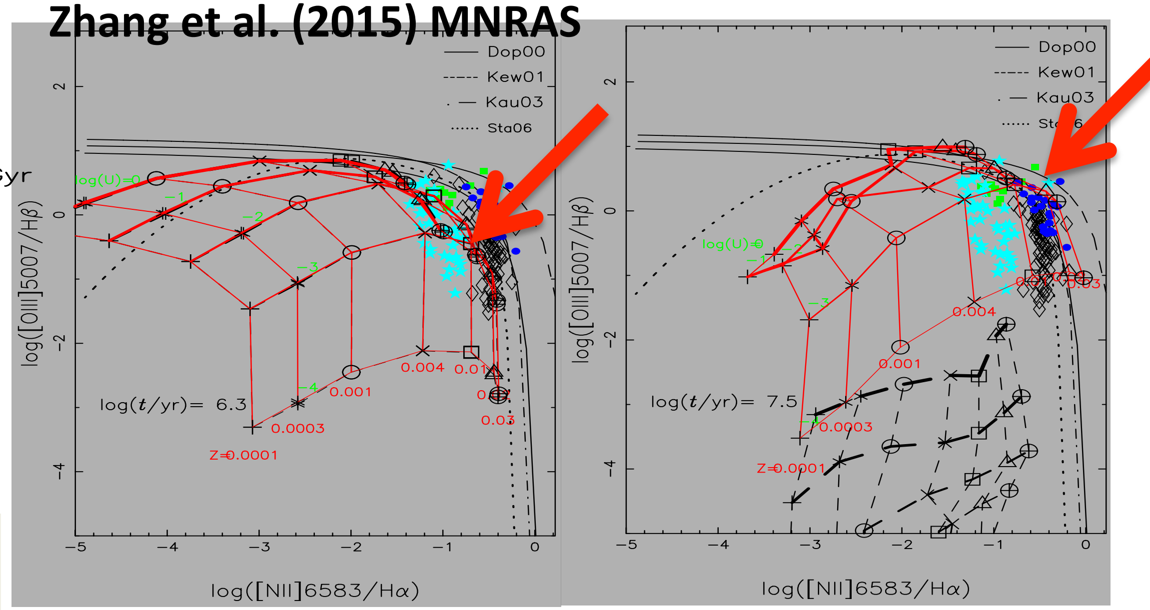
Figure 1. Spectrum evolution ($91 \le \lambda/\text{Å} \lesssim 1100$) for SPs with (left panel) and without (right panel) BIs at $Z = 0.02$. In each panel, 45 values of age are included. Each colour comprises five age values, and the age steps are 0.2 and 0.1/0.08 when $\log(t/\text{yr}) \le 6.5$ and >6.5. By order of SP age, the lines are black [$\log(t/\text{yr}) = 5.1$–5.9], red (6.1–6.7), green (6.8–7.2), blue (7.3–7.7), cyan (7.8–8.2), magenta (8.3–8.7), yellow (8.8–9.2), orange (9.3–9.7) and light-green (9.8–10.18).

a. SFR↓: L_{ha}↑, c ↓ [SFR= c L_{ha}]



Relation between SFR and $L_{H\alpha}$ (the luminosity of Ha recombination line) **of E, S0, Sa-Sd galaxies when using EPS models with and without binaries.**

b. *Zgas*↓: moves towards the upper-right corner; criterion: AGN/star-forming galaxies; central ionizing source of HII regions: IA + young SPs



BPT diagram when using log (*t*/yr) = 6.3 (left) and 7.5 SPs (right) with (red, solid line) and without (black, dashed line) BIs for n_H = 100 cm^{-3}.

Conclusions: accelerate the galaxy evolution. SF is rapider at early ages/more active; slower at late ages/quieter.

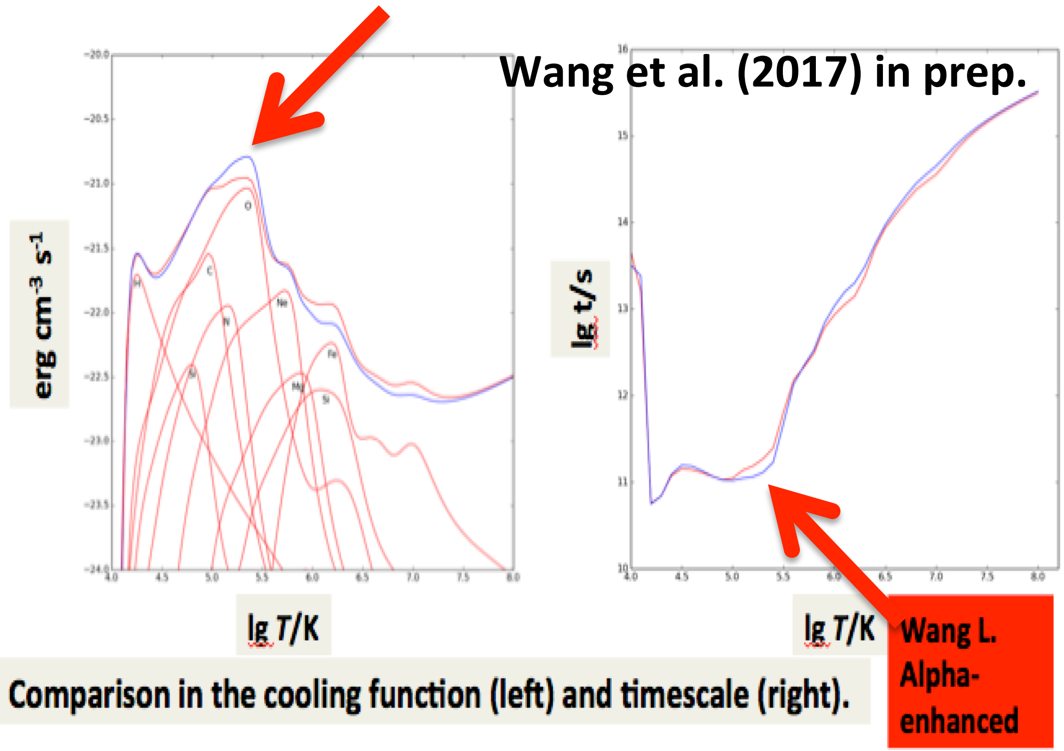
M Z* t* ↑
SFR *Zgas* ↓

Physically?

During galaxy formation process, gas is gradually cooled and turned into stars.
The cooling rate of halo gas is critical for determining how much fuel is available to form stars in galaxies.

- **Gas-cooling function/ timescale.**
- **Except H, C O are the most efficient gas-cooling species.**
- **Binary interactions can eject more C & O into ISM (Zhang et al. in prep.), so accelerate gas-cooling process and galaxy evolution.**

Wang et al. (2017) in prep.



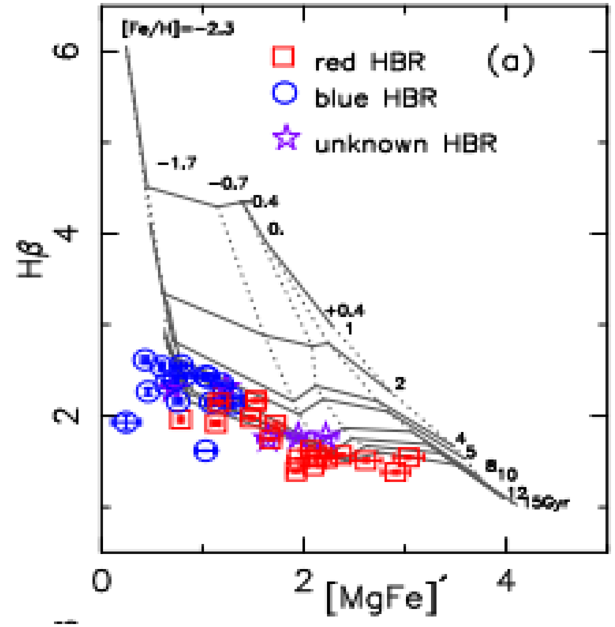
Comparison in the cooling function (left) and timescale (right).

Contents

Two problems:

- **Why GCs lie beyond the model coverage on the Lick-Lick/IDS index diagram? Walcher (2011 Ap&SS review) listed three reasons:**
  - **Dynamical evolution of the clusters;**
  - **Exotic stars;**
  - **Finite number of stars (fitting the current MF).**

  In the dynamical EPS models, finite number of stars is the main reason.



Zhang et al. 2012 MNRAS 421 1678

- **What leads to the difference in the GCs' dynamical evolution among different metallicities? Downing (2012) thought it is caused by the energy provided by black hole.**

  We remove stars M_i>10M_{sun} (BH). The results show that there is no significant difference.

See the paper of Zhuang et al. 2015 MNRAS 446 4260, for full details.

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Take home messages

Galaxies:

The inclusion of binaries can accelerate gas-cooling process (in progress) and the evolution of galaxies.

GCs:

1) The main reason that GCs lie beyond the model coverage on the lick-lick index diagram: finite number of stars;
2) BHs existence can not explain the difference in the GCs' dynamical evolution among different metallicities.