Age and Metallicity Estimation of Disc Galaxies Using Optical and Near-Infrared Photometry and Spectroscopy

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(University of Texas-Pan American)

MacArthur et al. (2004), *ApJS, 152, 175*

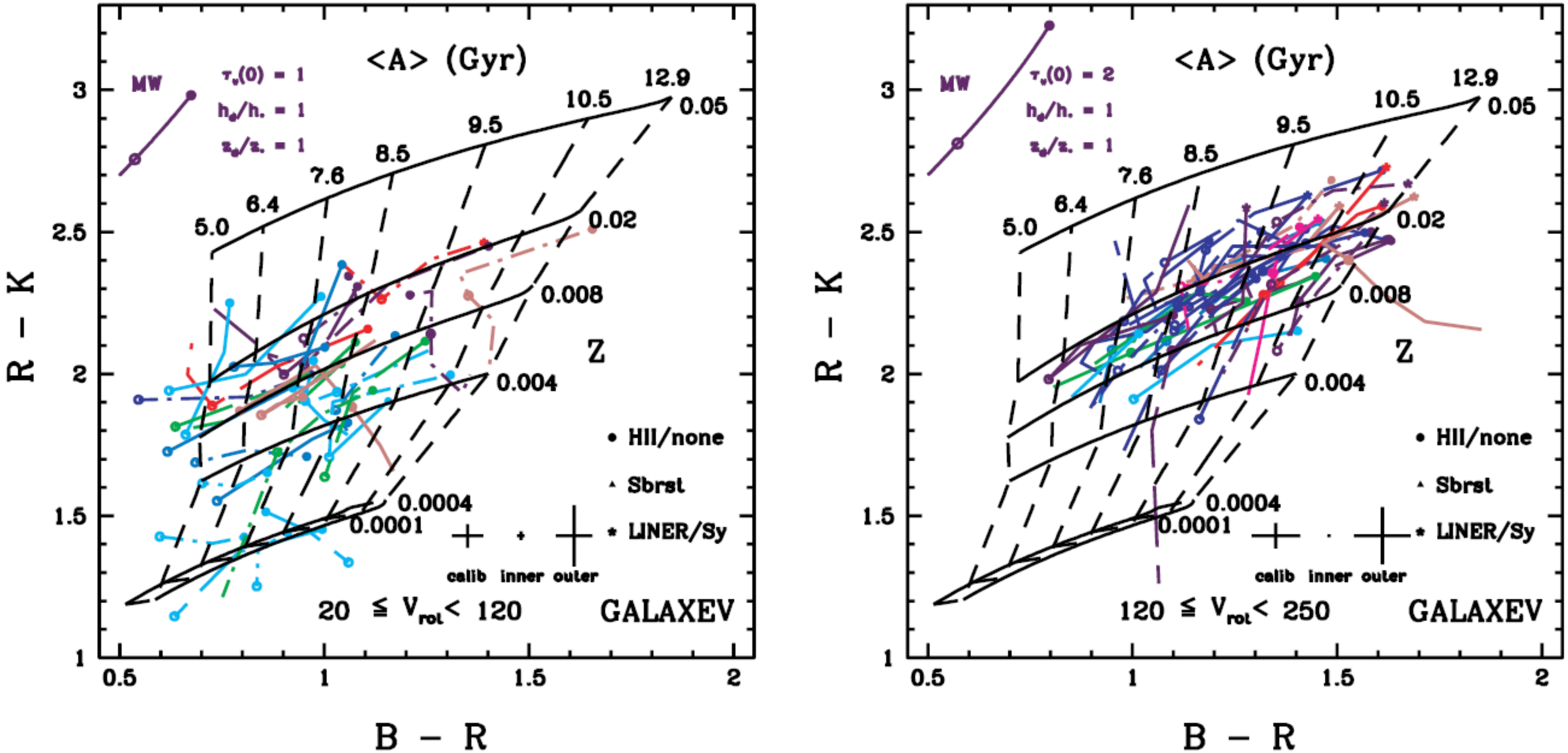

FIG. 11.—Near-IR–optical color-color plots separated by rotational velocity, V_{rot} (km s^{-1}), for the BdJ00 sample. Galaxy center point types correspond to the level of nuclear activity in the galaxies (trends with colors and their gradients with nuclear activity were looked for but none were found, possibly because of small statistics).

The Astrophysical Journal Supplement Series, 152:175–199, 2004 June

STRUCTURE OF DISK-DOMINATED GALAXIES. II. COLOR GRADIENTS AND STELLAR POPULATION MODELS

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ABSTRACT

We investigate optical and near-IR color gradients in a sample of 172 low-inclination galaxies spanning Hubble types S0–Irr. The colors are compared with stellar population synthesis models from which luminosity-weighted average ages and metallicities are determined. We explore the effects of different underlying star formation histories and additional bursts of star formation. Our results are robust in a relative sense under the assumption that our galaxies shared a similar underlying star formation history and that no bursts involving more than ~10% of the galaxy mass have occurred in the past 1–2 Gyr. Because the observed gradients show radial structure, we measure "inner" and "outer" disk age and metallicity gradients. Trends in age and metallicity and their gradients are explored as a function of Hubble type, rotational velocity, total near-IR galaxy magnitude,

Mon. Not. R. Astron. Soc. **312**, 497–520 (2000)

The stellar populations of spiral galaxies

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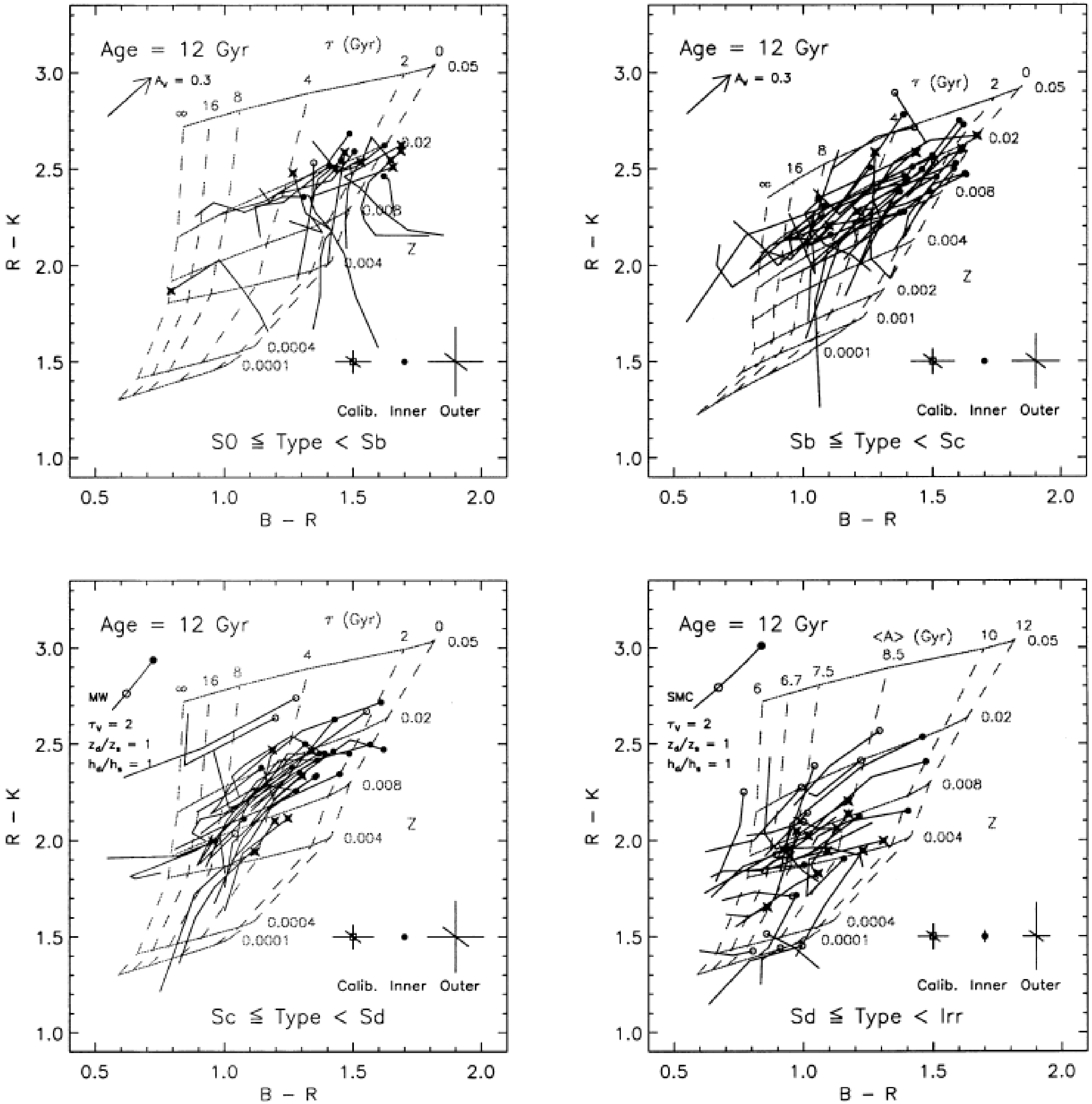
ABSTRACT

We have used a large sample of low-inclination spiral galaxies with radially resolved optical and near-infrared photometry to investigate trends in star formation history with radius as a function of galaxy structural parameters. A maximum-likelihood method was used to match all the available photometry of our sample to the colours predicted by stellar population synthesis models. The use of simplistic star formation histories, uncertainties in the stellar population models and considering the importance of dust all compromise the absolute ages and metallicities derived in this work; however, our conclusions are robust in a relative sense. We find that most spiral galaxies have stellar population gradients, in the sense that their inner regions are older and more metal rich than their outer regions. Our main conclusion is that the surface density of a galaxy drives its star formation history, perhaps through a local density dependence in the star formation law. The mass of a galaxy is a less important parameter; the age of a galaxy is relatively unaffected by its mass; however, the metallicity of galaxies depends on both surface density and mass. This suggests that galaxy-mass-dependent feedback is an important process in the chemical evolution of galaxies. In addition, there is significant cosmic scatter suggesting that mass and density may not be the only parameters affecting the star formation history of a galaxy.



Bell & de Jong (2000), *MNRAS, 312, 497*

H.-c. Lee et al. (2007), *ApJ, 664, 215*

ON THE AGE AND METALLICITY ESTIMATION OF SPIRAL GALAXIES USING OPTICAL AND NEAR-INFRARED PHOTOMETRY

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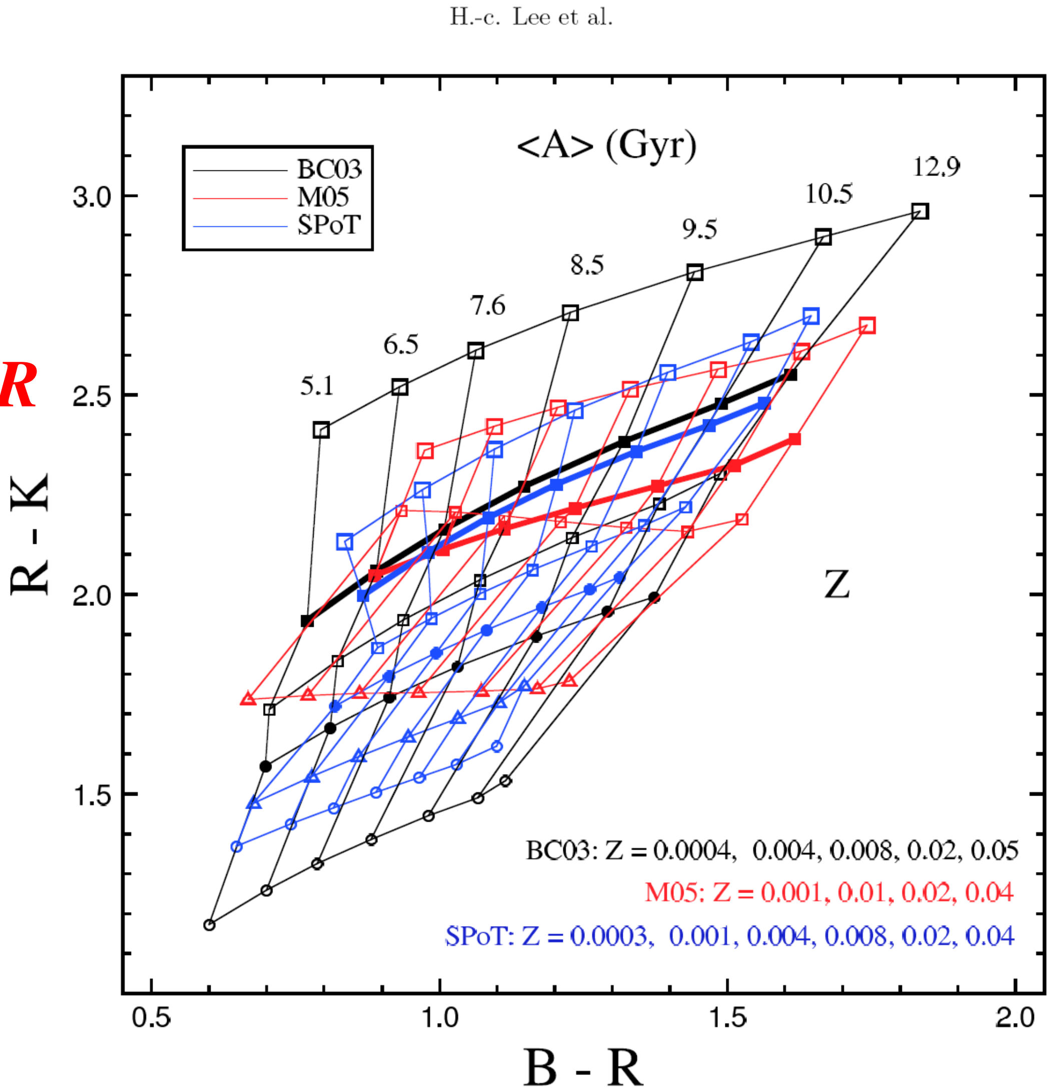
H.-c. Lee et al. (2007), *ApJ, 664, 215*

Near-IR



Optical

Composite Stellar Population Models

=

Simple Stellar Population Models

*

SFH

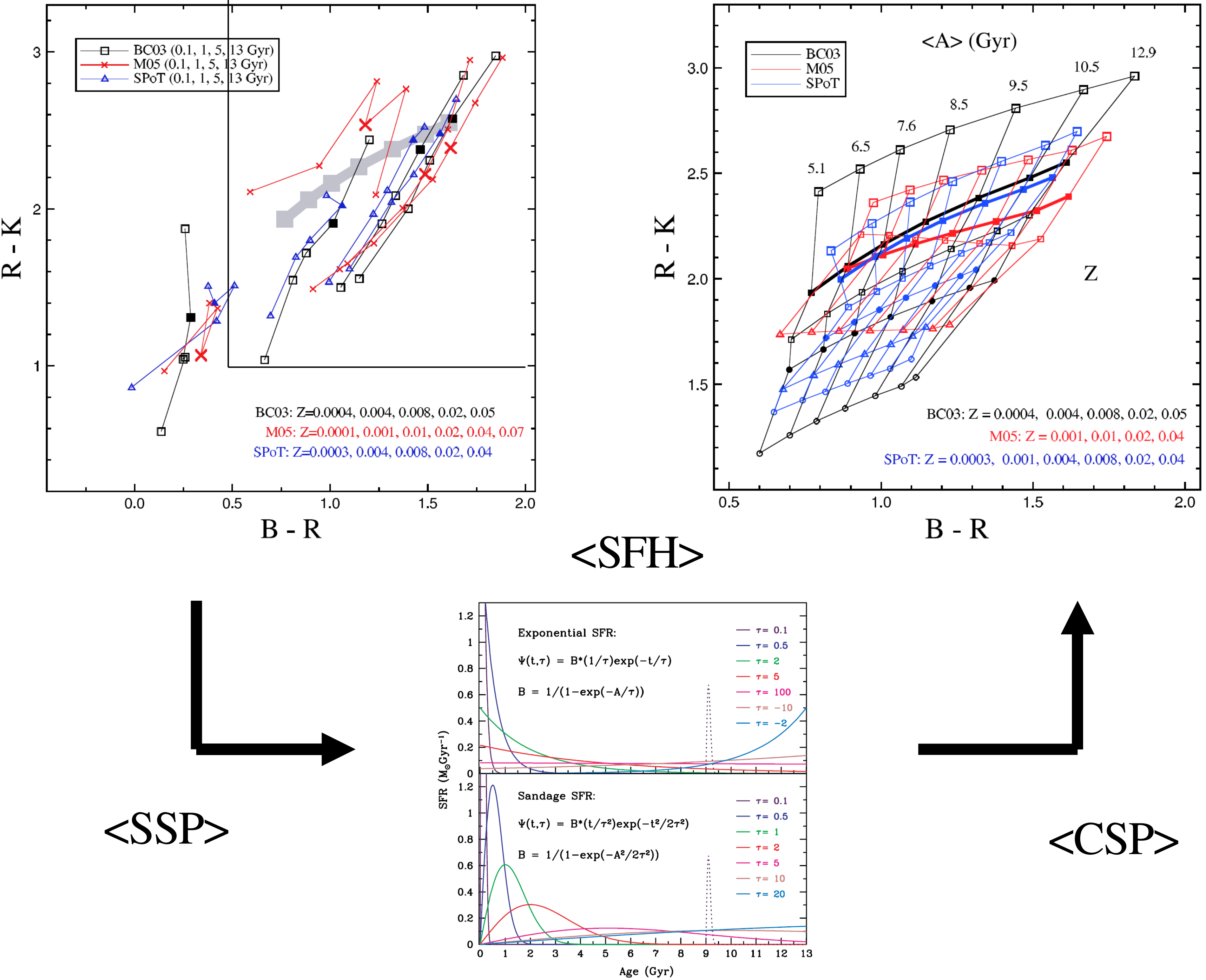
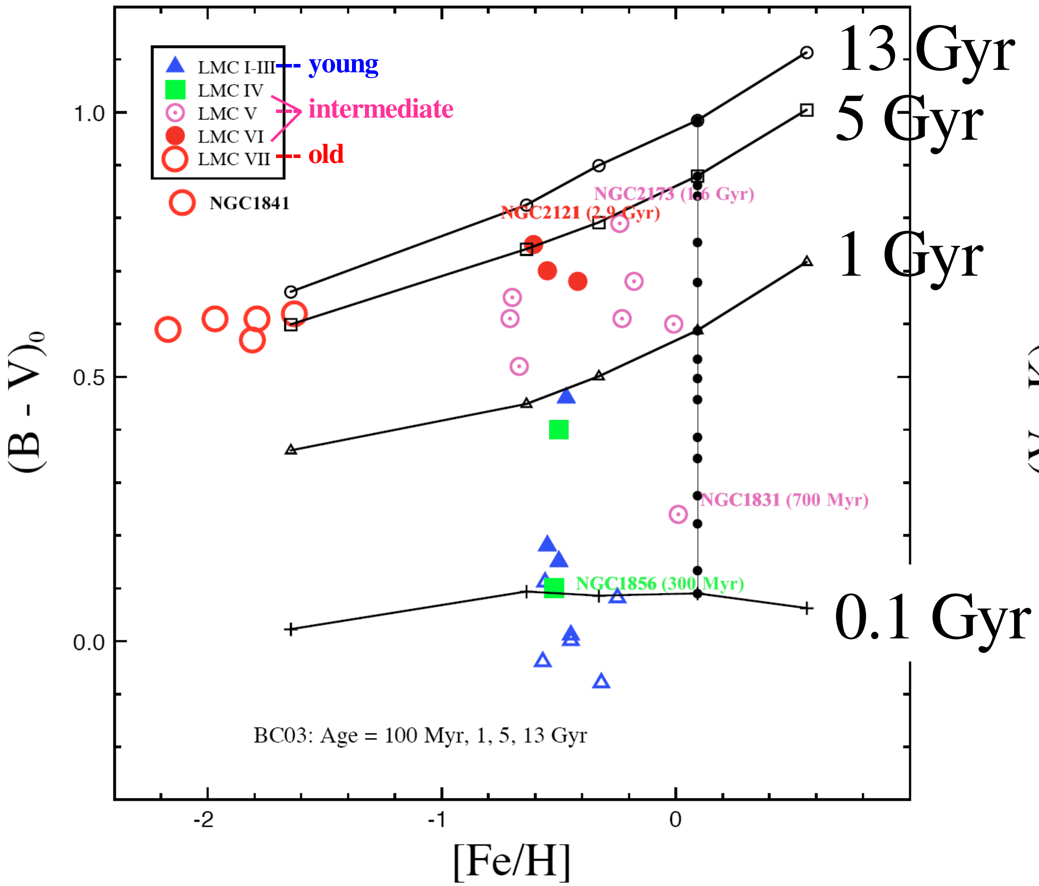
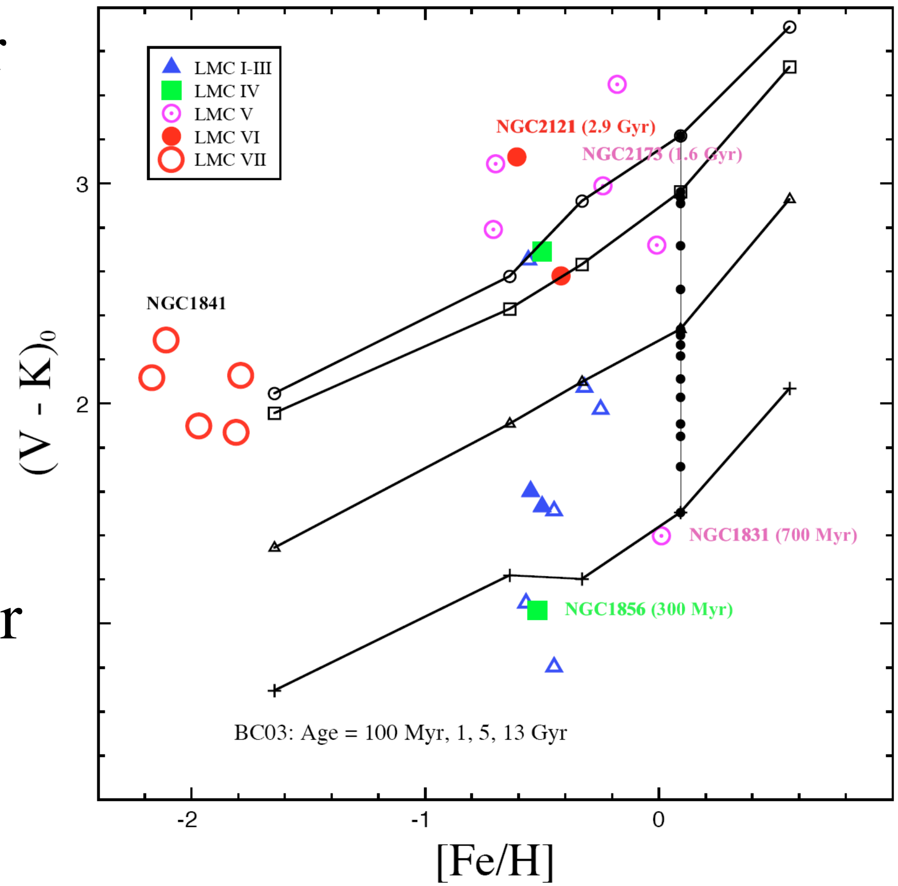


FIG. 4.—Time evolution for the exponential (eq. [6]) (*upper panel*) and Sandage (eq. [8]) (*lower panel*) star formation histories (*solid curves*). The dotted curve is a Sandage-style burst of star formation in which 10% of the total mass of stars are formed. See Fig. 7 for the effect of such a burst on the population model grids.





Optical

Near-IR

BC03: Bruzual & Charlot (2003)

clusters lie at the opposite end of the sequence. The presence or absence of horizontal branch stars has only a minor influence on a cluster's location in this diagram, and the low values of $Q(ugr)$ and $Q(vgr)$ that are characteristic of metal-poor globular clusters evidently result from the weakness of absorption lines in their u and v passbands.

c) The Clusters of the Magellanic Clouds in the Q-Q Diagram

Figure 3 is a plot of the Magellanic Cloud clusters in the $Q(ugr)$, $Q(vgr)$ plane, based on the data in Table 2. The main result illustrated is that the clusters define a sequence in this plane. The sequence has been arbitrarily segmented, and zones have been drawn to *define* a seven-type classification scheme for these clusters. The corresponding assigned types are listed in Table 2. This classification is merely a crude representation of the cluster sequence, and it is the sequence itself that is the physically significant thing.

There is no evidence in Figure 3 that the sequences defined by LMC and SMC clusters differ. The sequence of Magellanic Cloud clusters is, however, very different from that defined by the globular clusters of the Galaxy and from that expected for an age sequence of solar-composition clusters. In Figure 4 a schematic

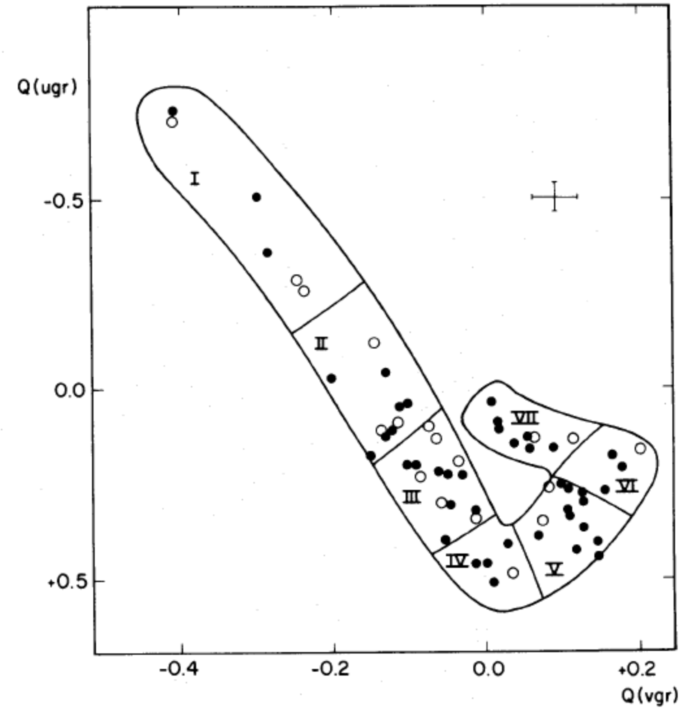
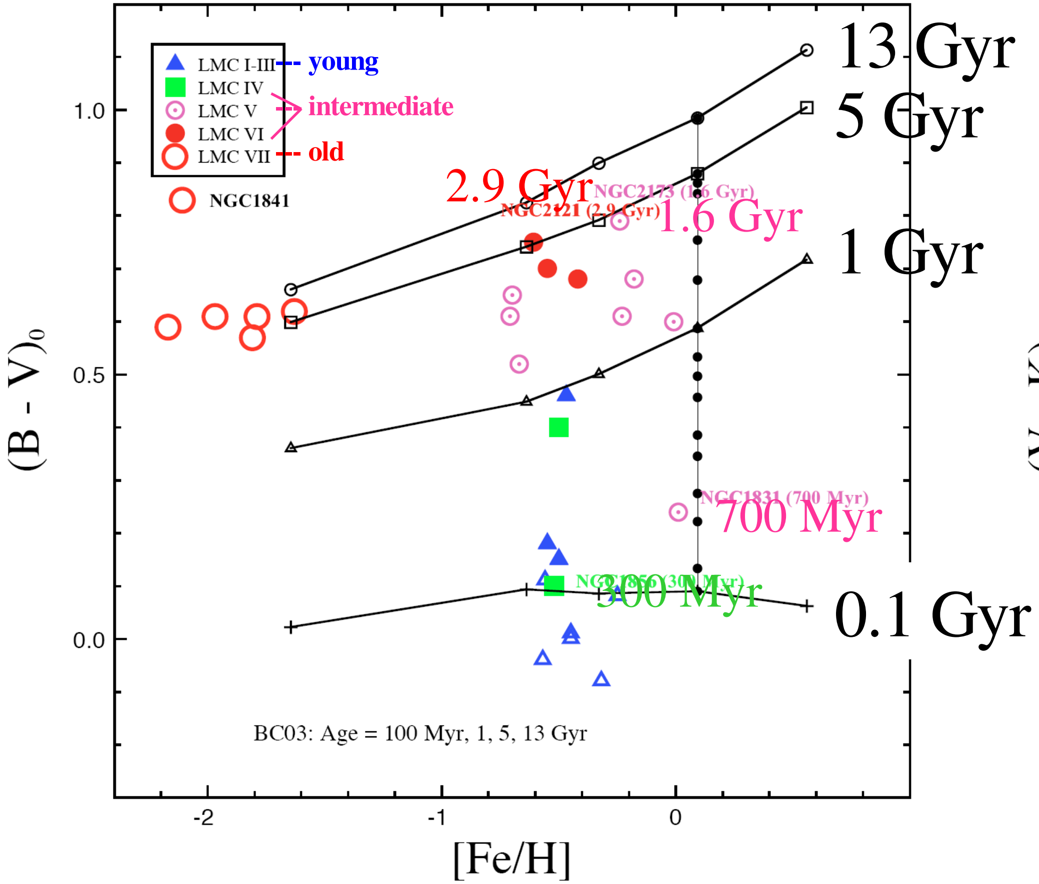
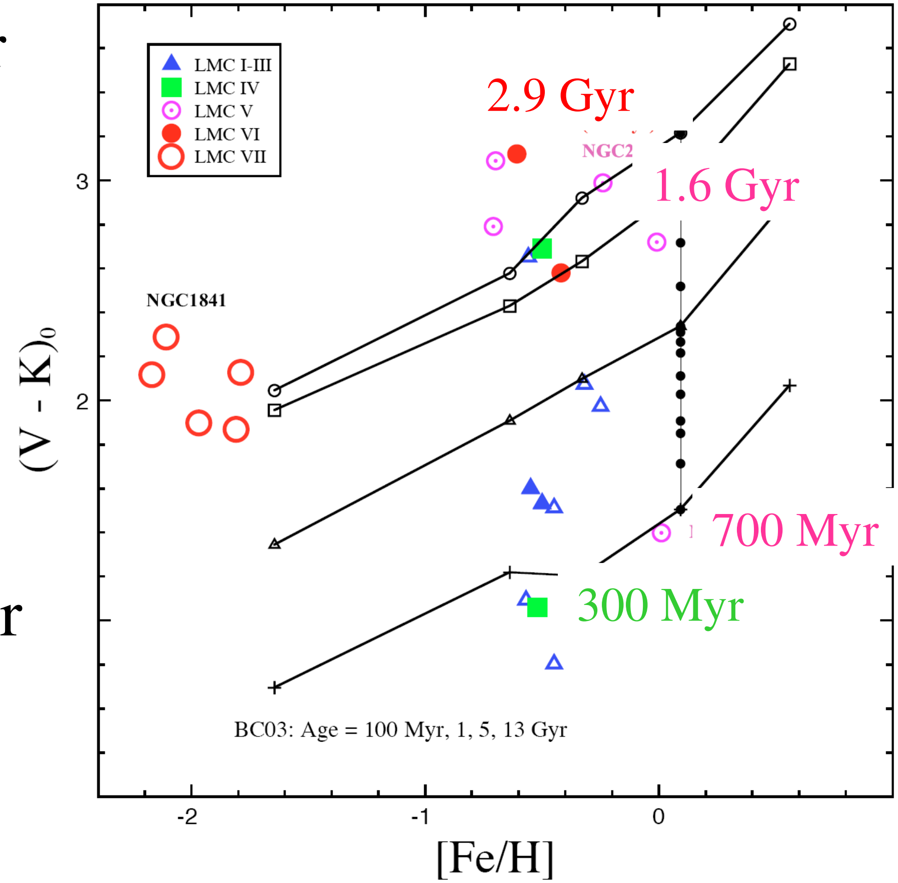


FIG. 3.—Populous clusters of the Magellanic Clouds in the Q-Q plane. Open and closed circles represent clusters of the SMC and LMC, respectively. The Cloud clusters form a sequence in this diagram. The sequence has been arbitrarily segmented, and the zones drawn in this figure define a classification scheme.

Location on these sequences will be an age indicator

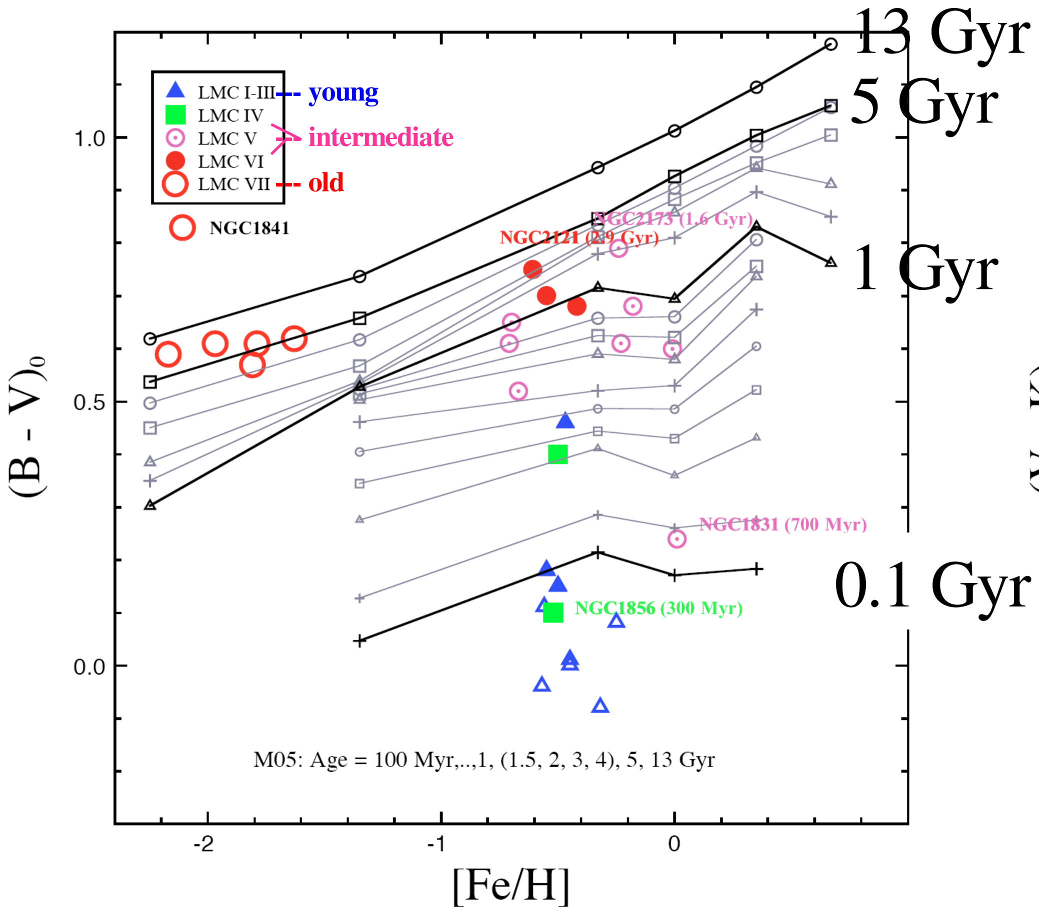


Optical

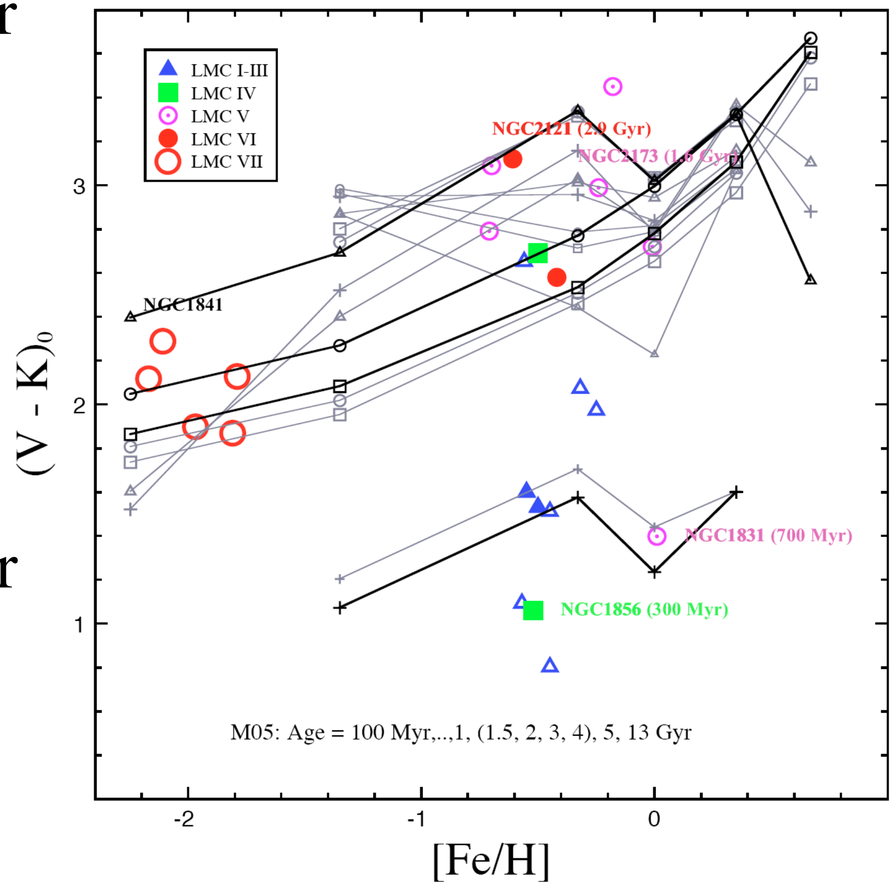


Near-IR

BC03: Bruzual & Charlot (2003)



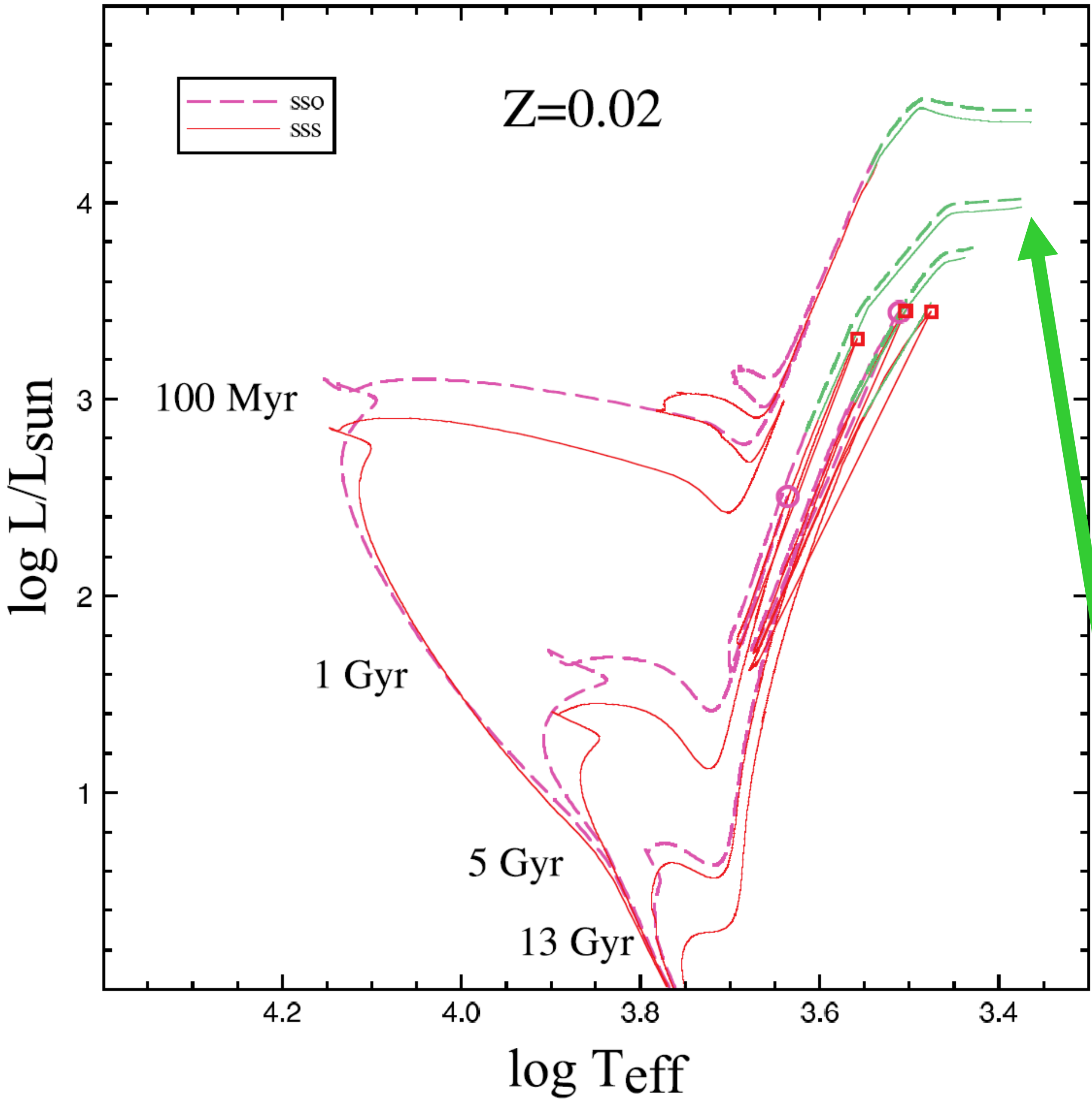
Optical



Near-IR

M05: Maraston (2005) – Fuel Consumption Theorem

H.-c. Lee et al. (2007), *ApJ*, *664*, *215*

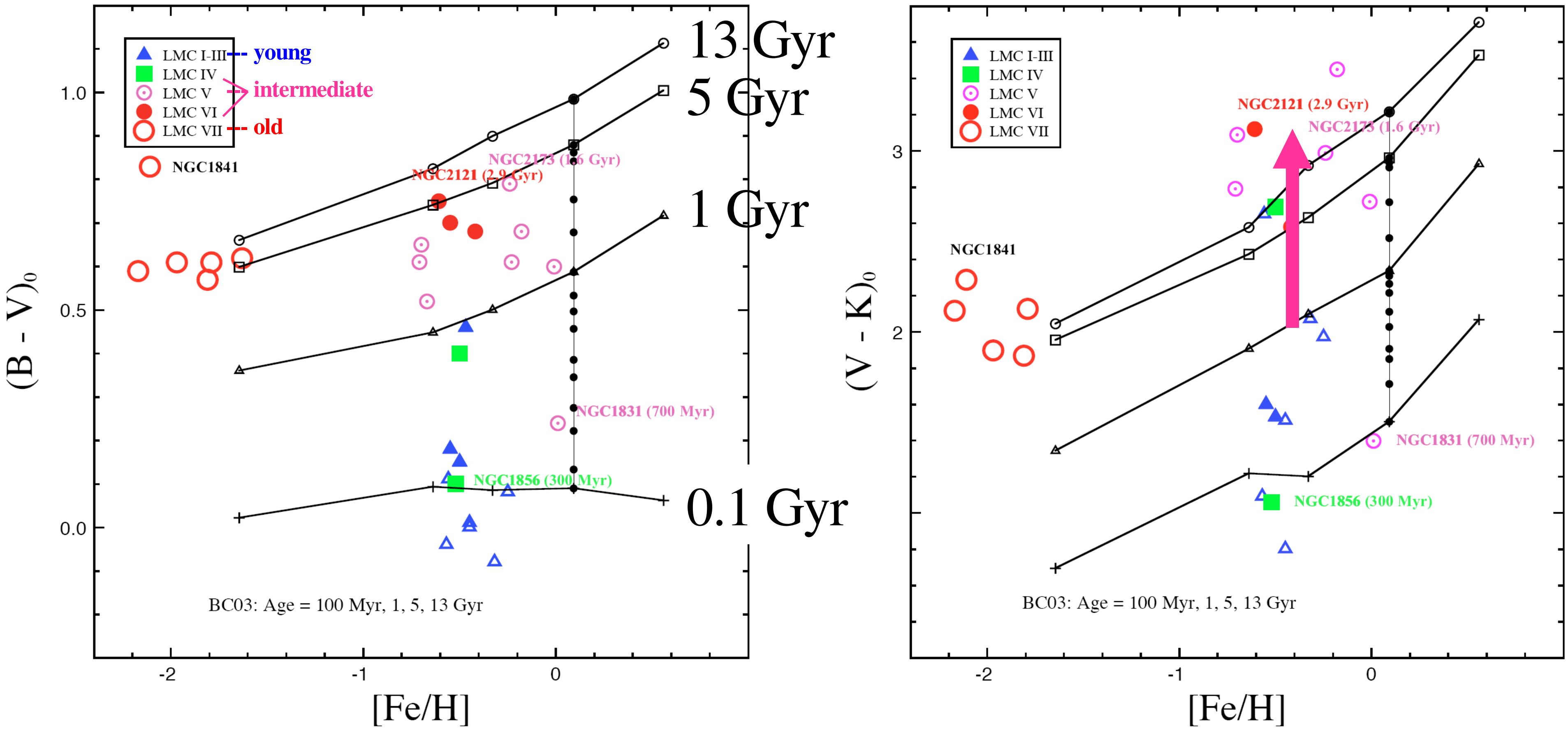


TP-AGB

Teramo Isochrones (BaSTI)

Pietrinferni et al. (2004, 2006)

Cordier et al. (2007)



Optical ***Near-IR***

Bruzual & Charlot's **proposal**: BC03 → CB10

using Padova stellar models (Marigo et al. 2007)

→ High-z galaxies: younger ages, lower stellar masses!

H.-c. Lee et al. (2007), *ApJ, 664, 215*

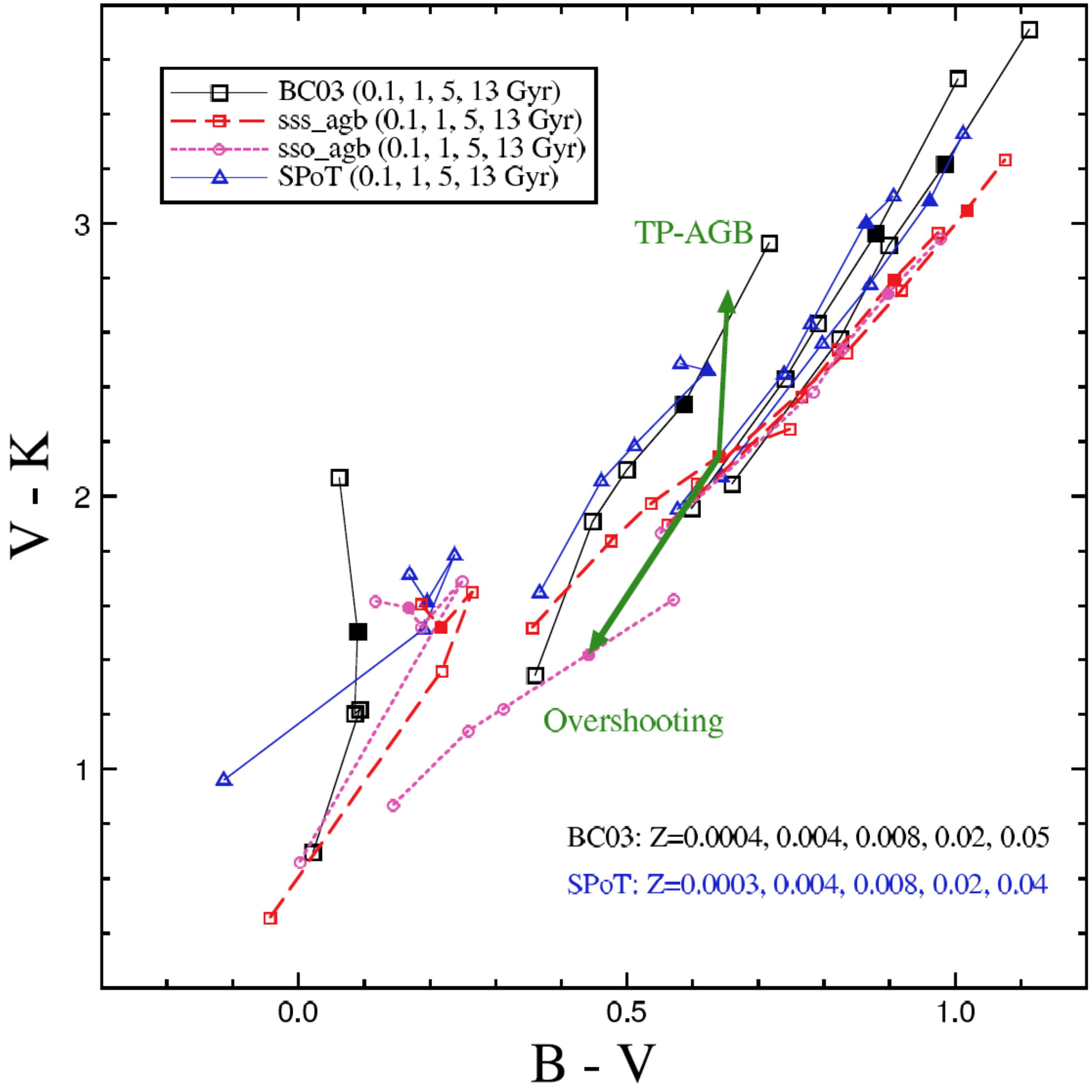
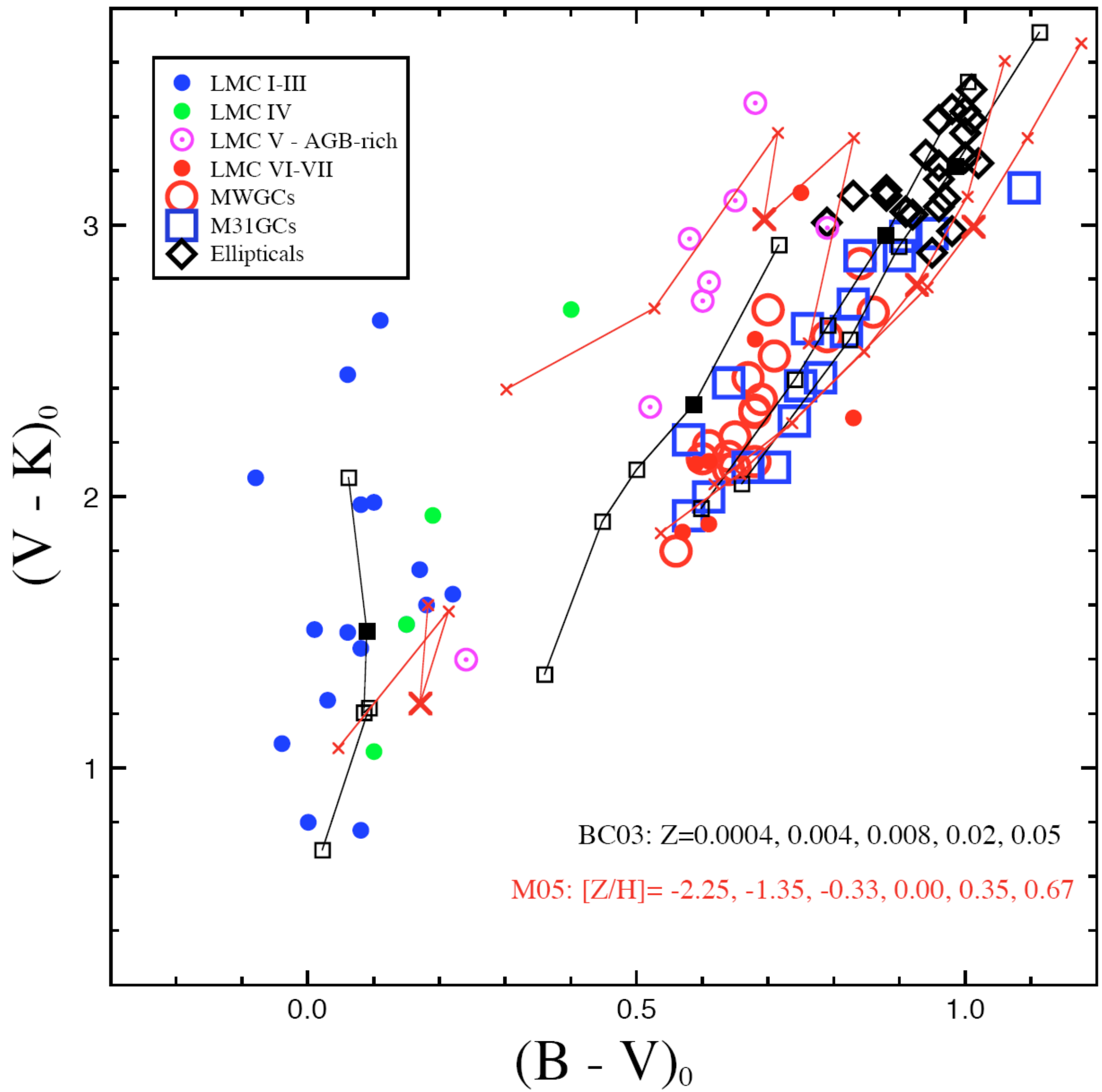
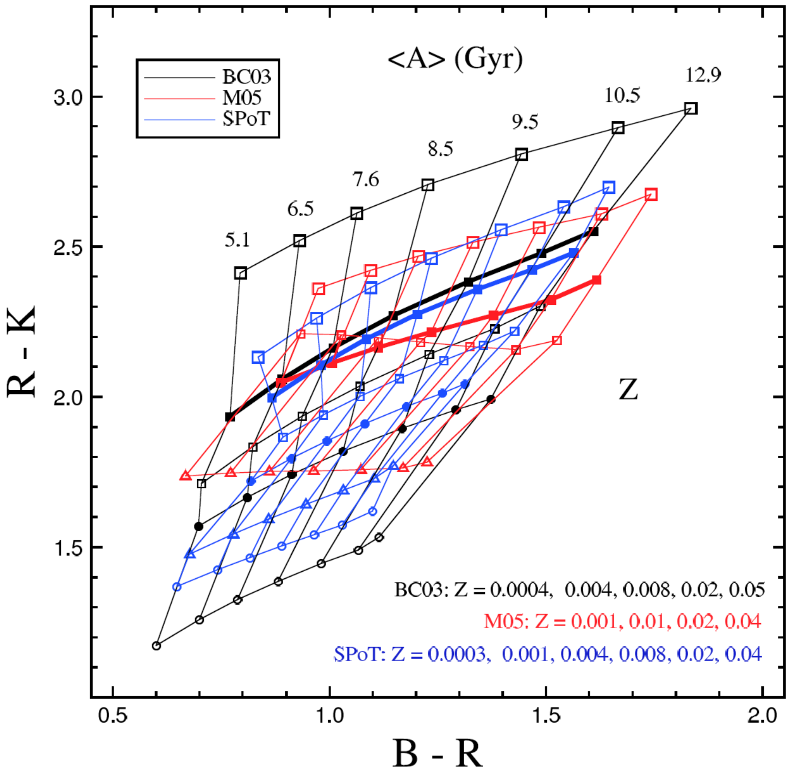


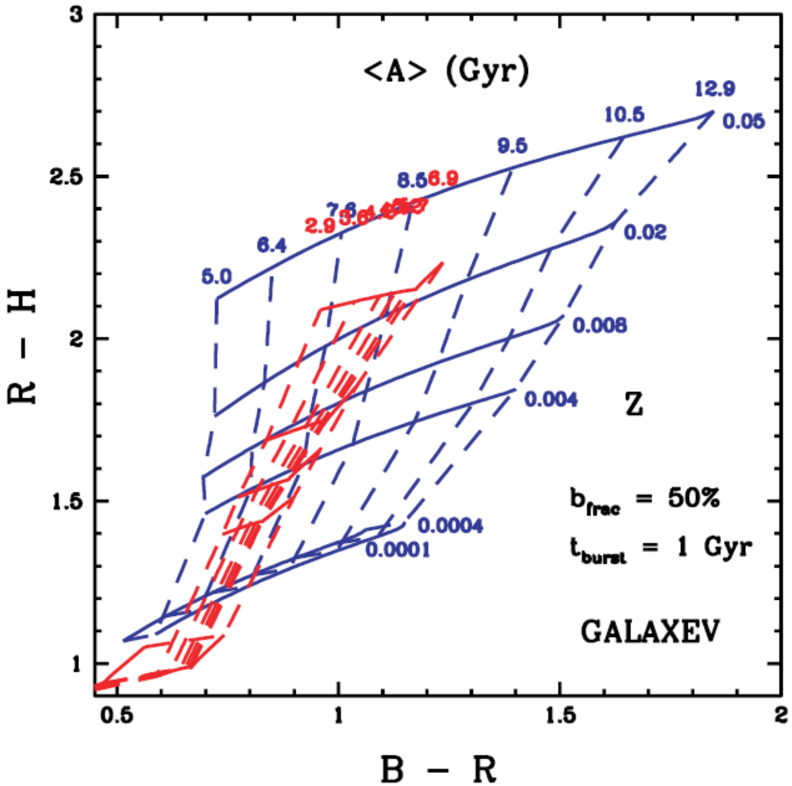
Fig. 5.— Same as Figure 4, but our computations using the Teramo-sss and Teramo-sso isochrones *without* TP-AGB phases are shown as dashed and dotted lines, respectively. At 1 Gyr and solar metallicity, for the Teramo-sss isochrones, the TP-AGB and the overshooting effects are depicted with vectors.


LMC I-III
LMC IV
LMC V - AGB-rich
LMC VI-VII
MWGCs
M31GCs
Ellipticals
BC03: Z=0.0004, 0.004, 0.008, 0.02, 0.05
M05: [Z/H]= -2.25, -1.35, -0.33, 0.00, 0.35, 0.67
(V - K)$_0$
(B - V)$_0$
1
2
3
0.0
0.5
1.0

Summary I. - Photometry

- Optical & near-IR model behaviors are understood.
- Future stellar models with more realistic and sophisticated overshooting and TP-AGB should match red integrated near-IR colors. (CB10)





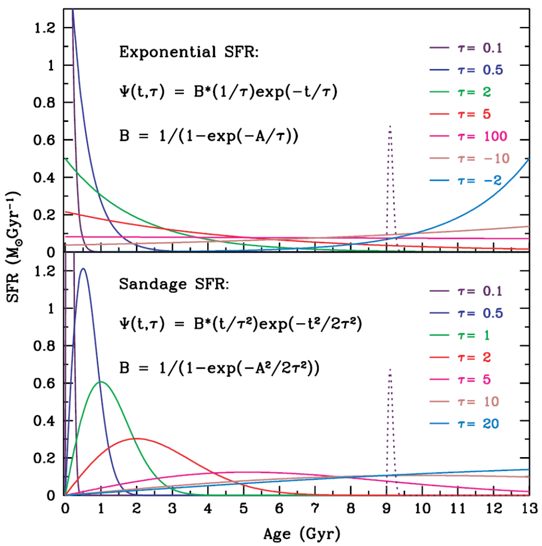
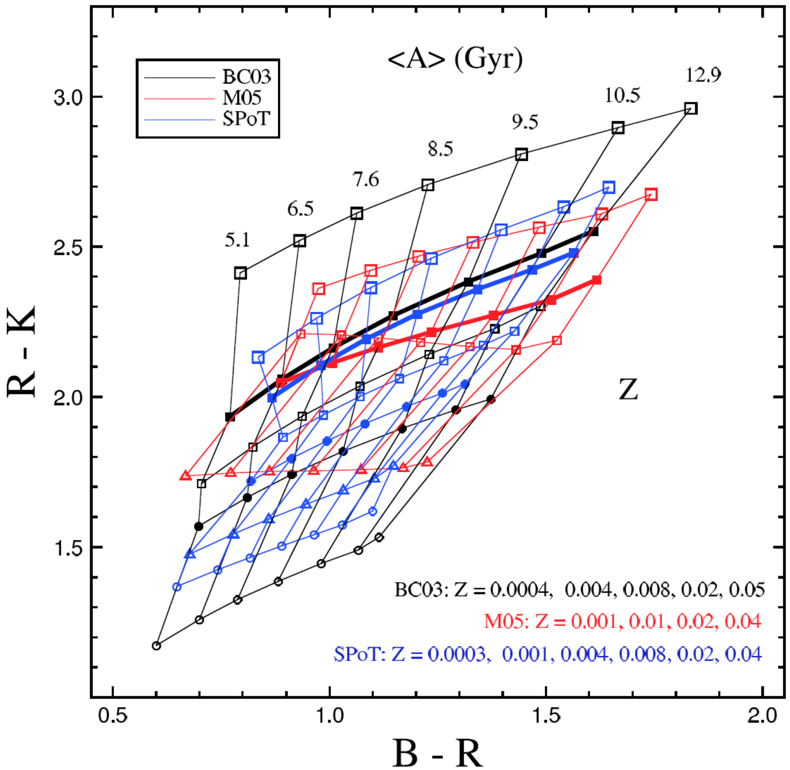


Fig. 4.—Time evolution for the exponential (eq. [6]) (*upper panel*) and Sandage (eq. [8]) (*lower panel*) star formation histories (*solid curves*). The dotted curve is a Sandage-style burst of star formation in which 10% of the total mass of stars are formed. See Fig. 7 for the effect of such a burst on the population model grids.

Star burst??



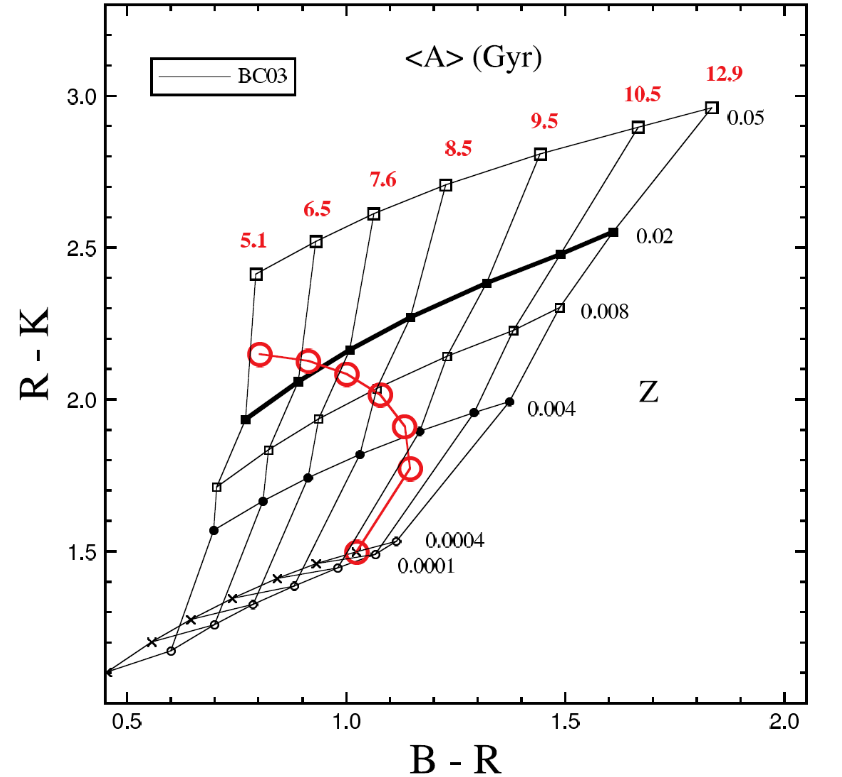
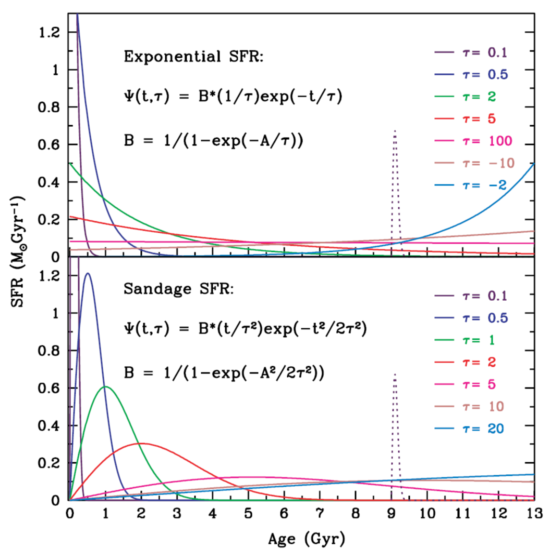


FIG. 10.— Similar to Figure 9, but *a chemical enrichment scheme with a monotonic age-metallicity relation* is incorporated in the B
composite stellar population models at given average ages (see text).



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Chemical Enrichment History??

Summary I. - Photometry

- Optical & near-IR model behaviors are understood.
- Future stellar models with more realistic and sophisticated overshooting and TP-AGB should match red integrated near-IR colors. (CB10)
- And… SFHs + CEHs !!

for a *realistic* composite stellar populations models!!

Summary I. - Photometry

- Optical & near-IR model behaviors are understood.
- Future stellar models with more realistic and sophisticated overshooting and TP-AGB should match red integrated near-IR colors. (CB10)
- And… SFHs + CEHs for a realistic composite stellar populations models!!

- BC03(CB10) & M05: solar-scaled models **(fixed)**

→ Dotter et al. (2007), Lee et al. (2009) introduce stellar population models with *different chemical mixture* **(flexible).**

Collaborative Research:
New Standard Stellar Population Models

Intellectual Merit: The proposed set of stellar population models (isochrones plus stellar colors and spectra) will set a new standard of completeness and excellence. The most novel feature of the models is that they will incorporate flexible chemistry so that almost any interesting chemical mixture can be interpolated. Abundance will be described by parameters for He/H, C, N, O, three choices for "alpha" element mixture, and an overall scaling factor for heavy element abundance. The proposed models will be generated from `PHOENIX` model atmospheres for stellar fluxes and low-temperature opacities, `OPAL` interior opacities, and a state-of-the-art stellar evolution code, `DSEP`, which incorporates accurate equations of state, helium diffusion, heavy element diffusion, and convective overshooting. Known flaws and omissions (temperature issues, mass-loss, late-stage evolution, binarism) of current models will be eliminated or minimized.

Our goals are to demonstrate 10% absolute mean ages derived from a single integrated light spectrum, to derive ages for a sample of local galaxies, to discover the origin of the scatter in 1500-V among elliptical galaxies, to measure He, O, Cr, and Ni abundances from integrated light (high risk), and to measure C, N, Ca, Si, Sc, V, Ti, Fe, and Mg abundances from integrated light (low risk). This new level of detail will open a whole new set of constraints for nucleosynthetic enrichment in clusters and galaxies. As a byproduct, homogeneous data for a series of star clusters of widely varying age and abundance will be collected and made available.

Dotter et al. (2007), *ApJ, 666, 403*

THE ASTROPHYSICAL JOURNAL, 666:403–412, 2007 September 1

STELLAR POPULATION MODELS AND INDIVIDUAL ELEMENT ABUNDANCES. I. SENSITIVITY OF STELLAR EVOLUTION MODELS

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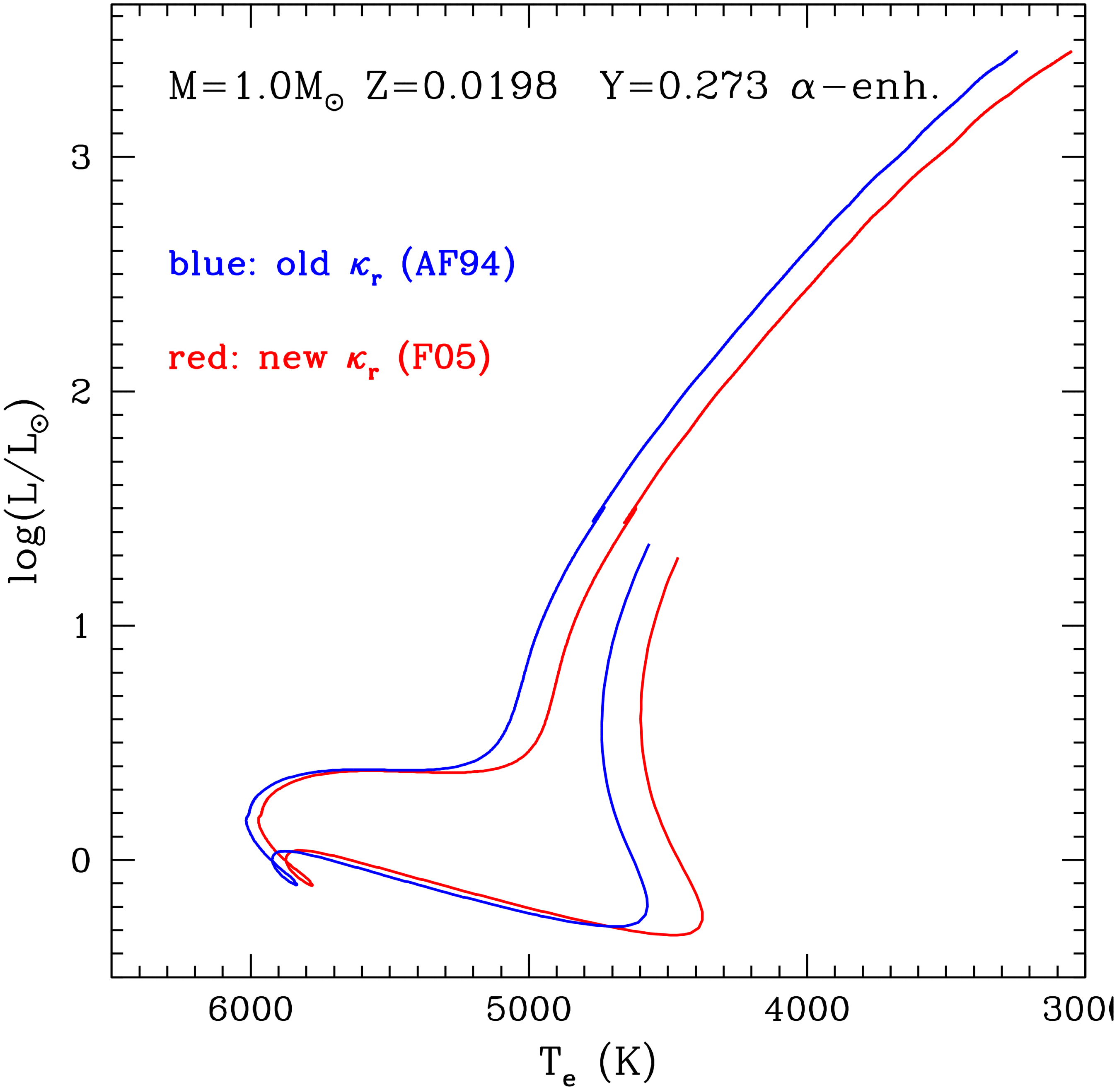
ABSTRACT

Integrated light from distant galaxies is often compared to stellar population models via the equivalent widths of spectral features—spectral indices—whose strengths rely on the abundances of one or more elements. Such comparisons hinge not only on the overall metal abundance, but also on relative abundances. Studies have examined the influence of individual elements on synthetic spectra but little has been done to address similar issues in the stellar evolution models that underlie most stellar population models. Stellar evolution models will primarily be influenced by changes in opacities. In order to explore this issue in detail, 12 sets of stellar evolution tracks and isochrones have been created at constant heavy element mass fraction Z that self-consistently account for varying heavy element mixtures. These sets include scaled-solar, α-enhanced, and individual cases where the elements C, N, O, Ne, Mg, Si, S, Ca, Ti, and Fe have been enhanced above their scaled-solar values. The variations that arise between scaled-solar and the other cases are examined with respect to the H-R diagram and main-sequence lifetimes.

Subject headings: stars: abundances — stars: evolution



Opacity changes!!

H.-c. Lee et al. (2009), *ApJ, 694, 902*

The Astrophysical Journal, 694:902–923, 2009 April 1 doi:10.1088/0004-637X/694/2/902

STELLAR POPULATION MODELS AND INDIVIDUAL ELEMENT ABUNDANCES. II. STELLAR SPECTRA AND INTEGRATED LIGHT MODELS

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ABSTRACT

The first paper in this series explored the effects of altering the chemical mixture of the stellar population on an element-by-element basis on stellar evolutionary tracks and isochrones to the end of the red giant branch. This paper extends the discussion by incorporating the fully consistent synthetic stellar spectra with those isochrone models in predicting integrated colors, Lick indices, and synthetic spectra. Older populations display element ratio effects in their spectra at higher amplitude than younger populations. In addition, spectral effects in the photospheres of stars tend to dominate over effects from isochrone temperatures and lifetimes, but, further, the isochrone-based effects that are present tend to fall along the age–metallicity degeneracy vector, while the direct stellar spectral effects usually show considerable orthogonality.

Key words: stars: abundances – stars: evolution

H.-c. Lee et al. (2009), *ApJ, 694, 902*

THE ASTROPHYSICAL JOURNAL, 694:902–923, 2009 April 1
doi:10.1088/0004-637X/694/2/902

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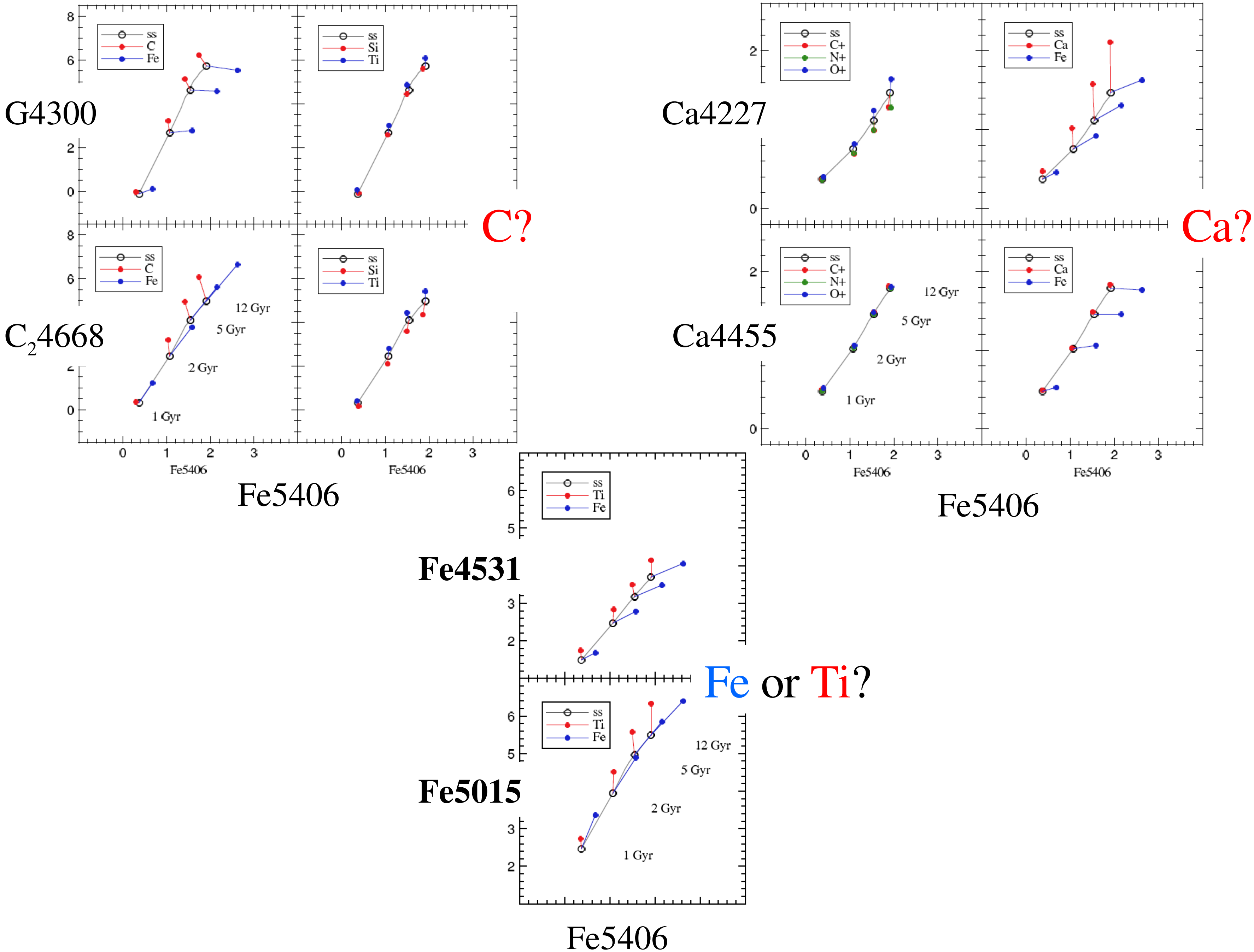
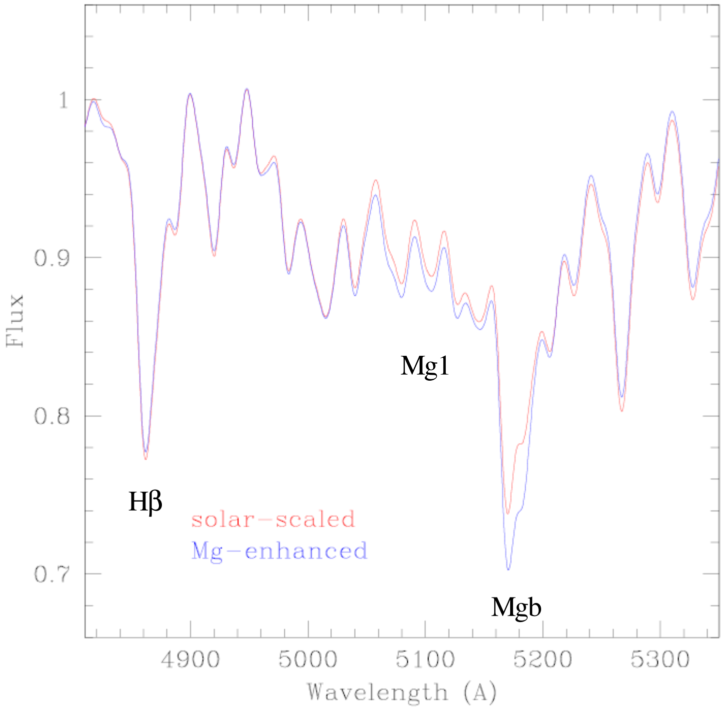
New stellar population models with *flexible chemistry*:

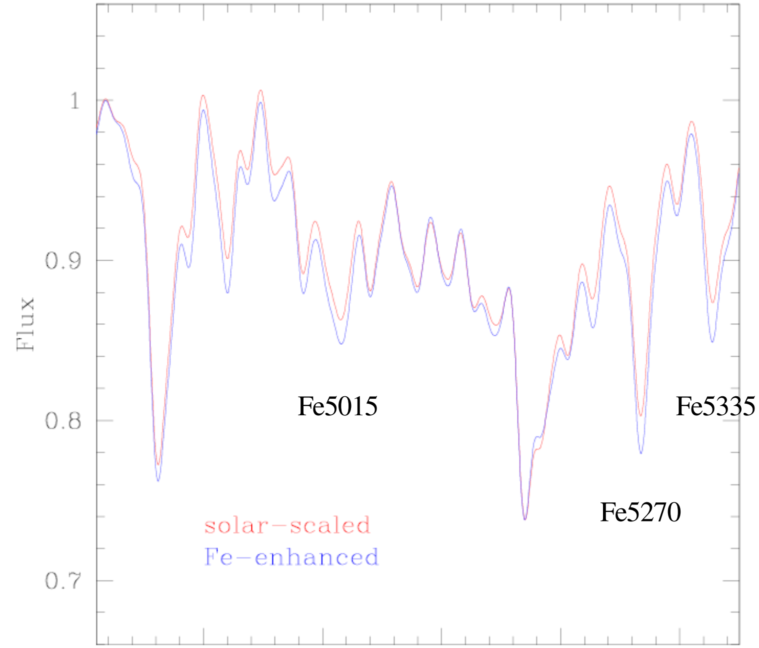
Isochrone effects + **spectral effects** with full internal consistency on Lick spectral and broadband color indices

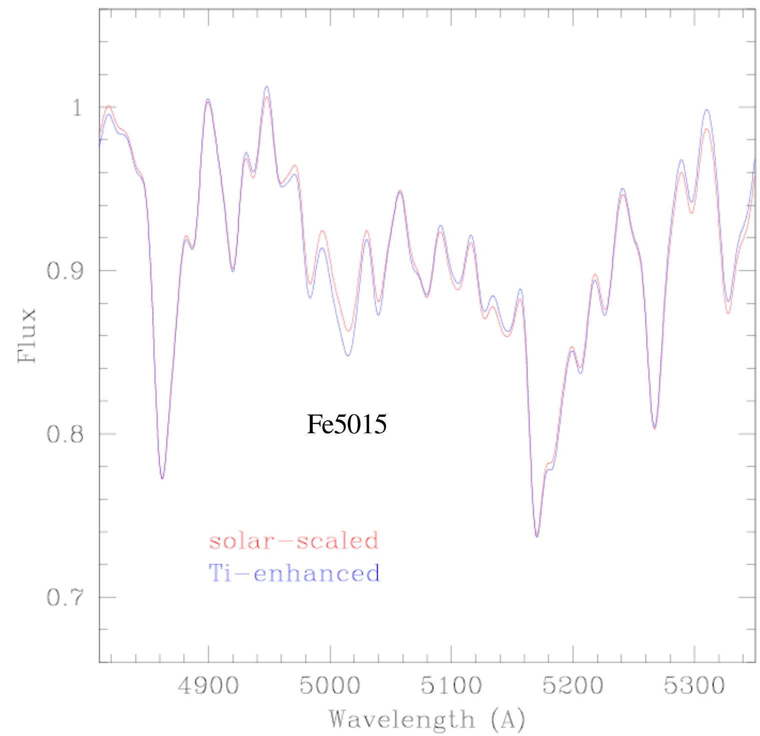
Caveat: Only at solar metallicity & No evolved stars



G4300
C₂4668
C?
Fe5406
Ca4227
Ca4455
Ca?
Fe5406
Fe4531
Fe5015
Fe or Ti?
Fe5406
ss
C
Fe
Si
Ti
C+
N+
O+
Ca
1 Gyr
2 Gyr
5 Gyr
12 Gyr

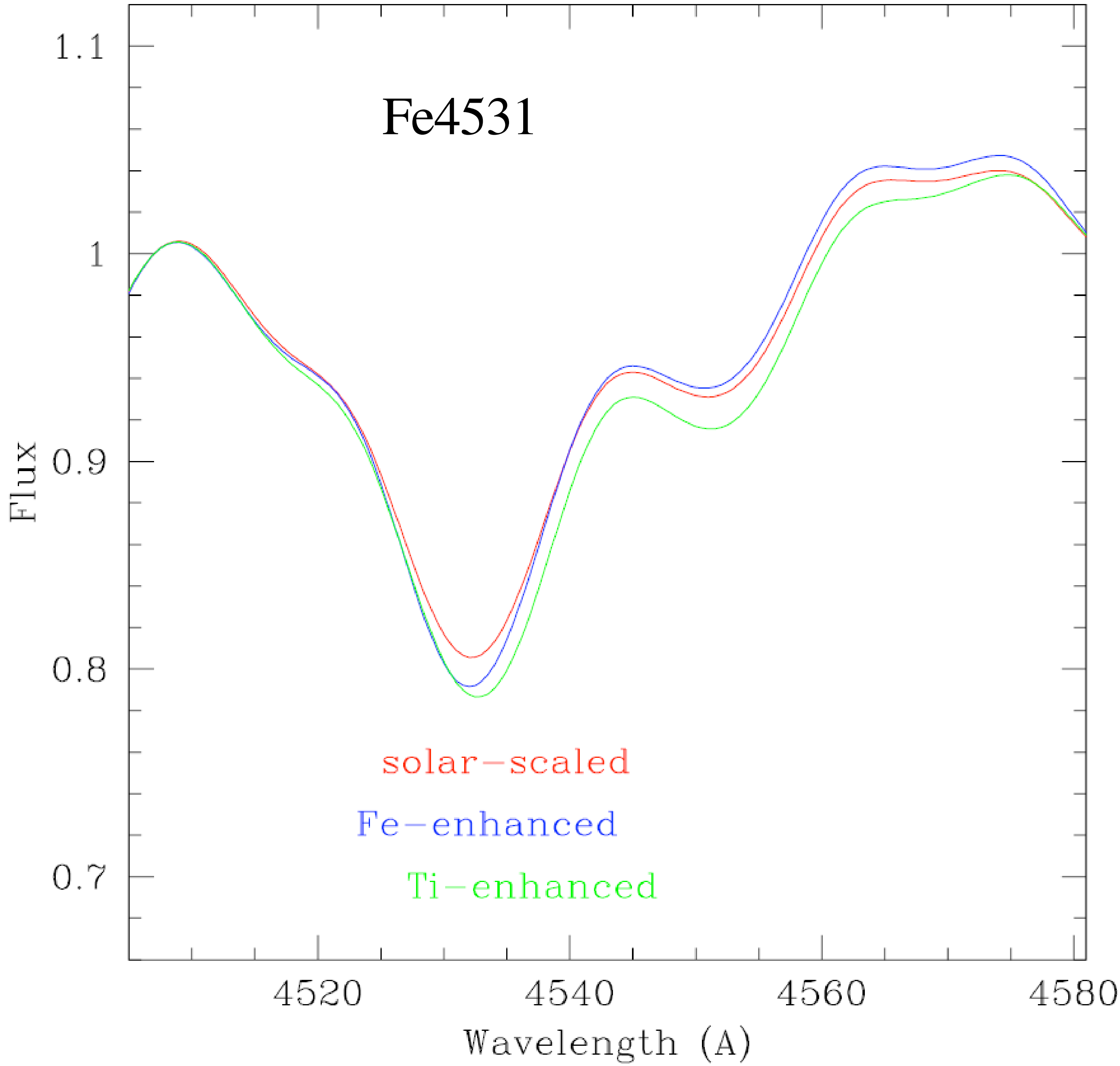




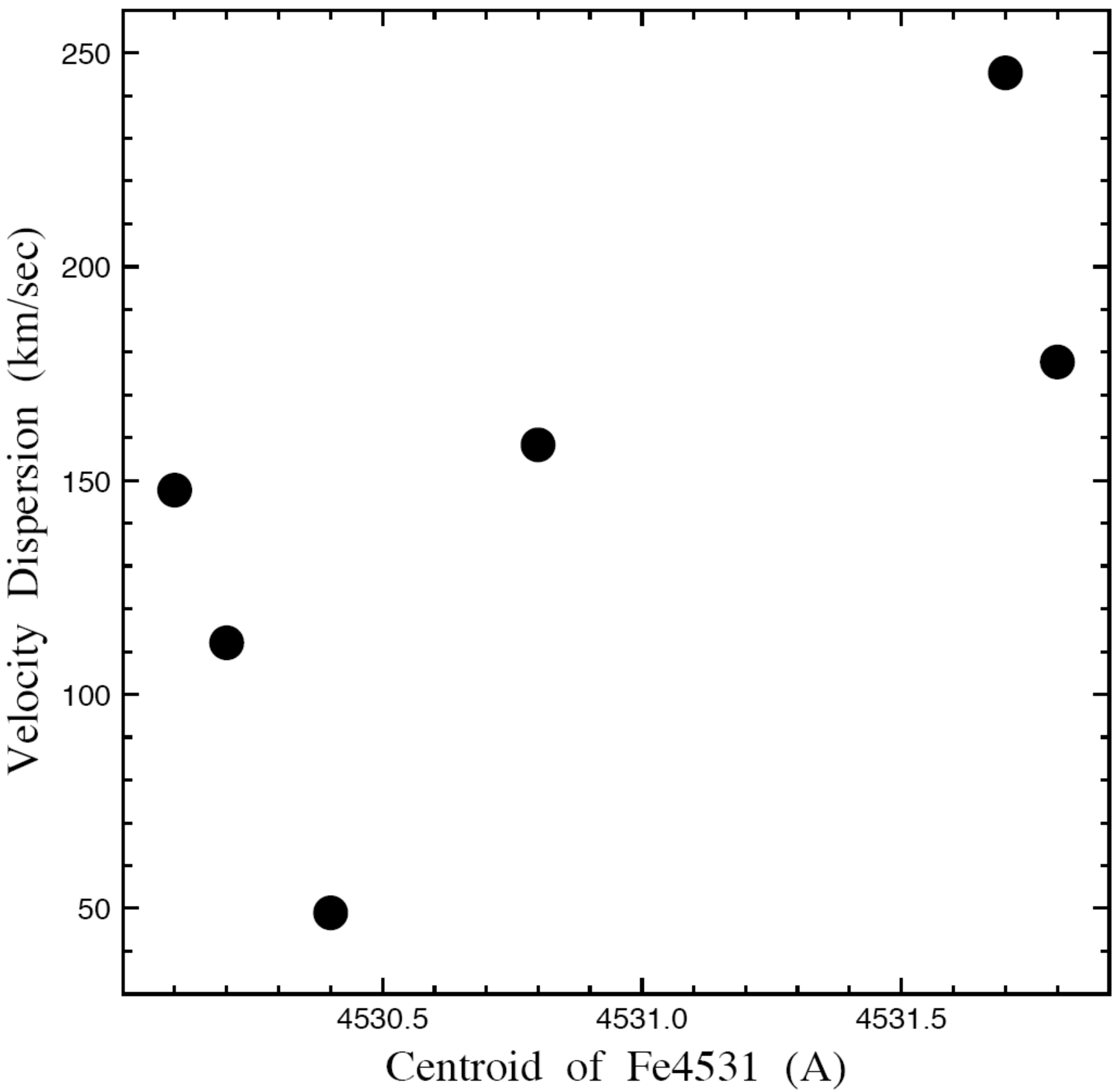


SAURON

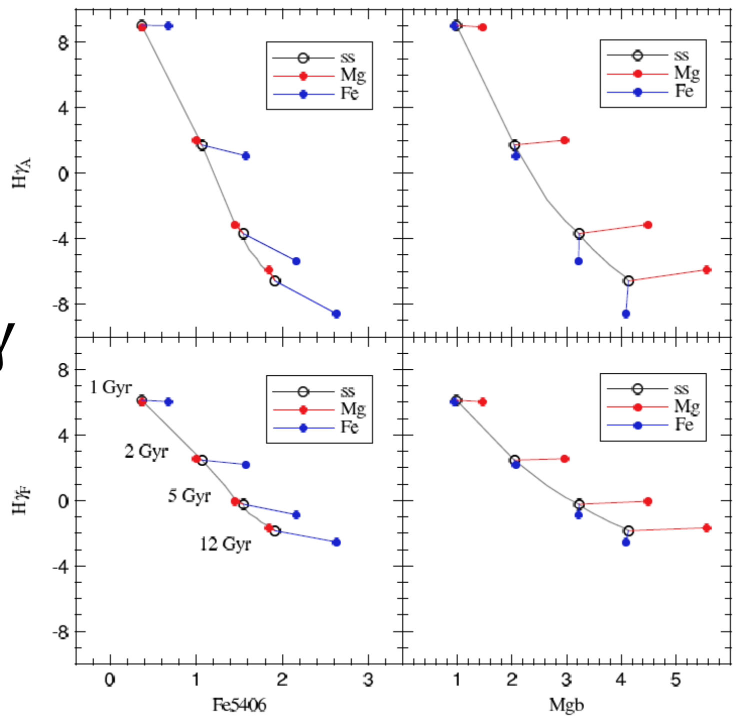
spectral range



Fe4531
solar-scaled
Fe-enhanced
Ti-enhanced
Flux
1.1
1
0.9
0.8
0.7
4520
4540
4560
4580
Wavelength (A)

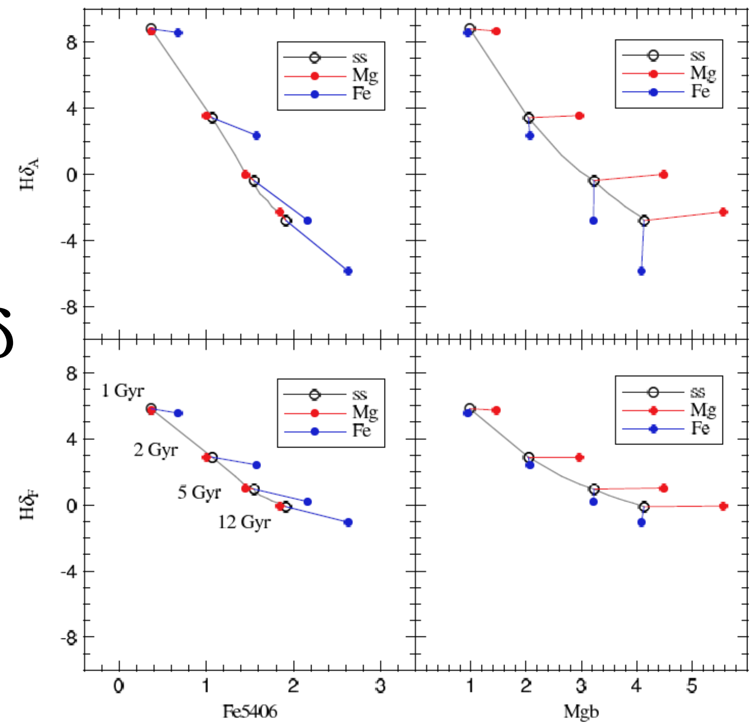

250
200
150
100
50
Velocity Dispersion (km/sec)
4530.5
4531.0
4531.5
Centroid of Fe4531 (A)

Hγ



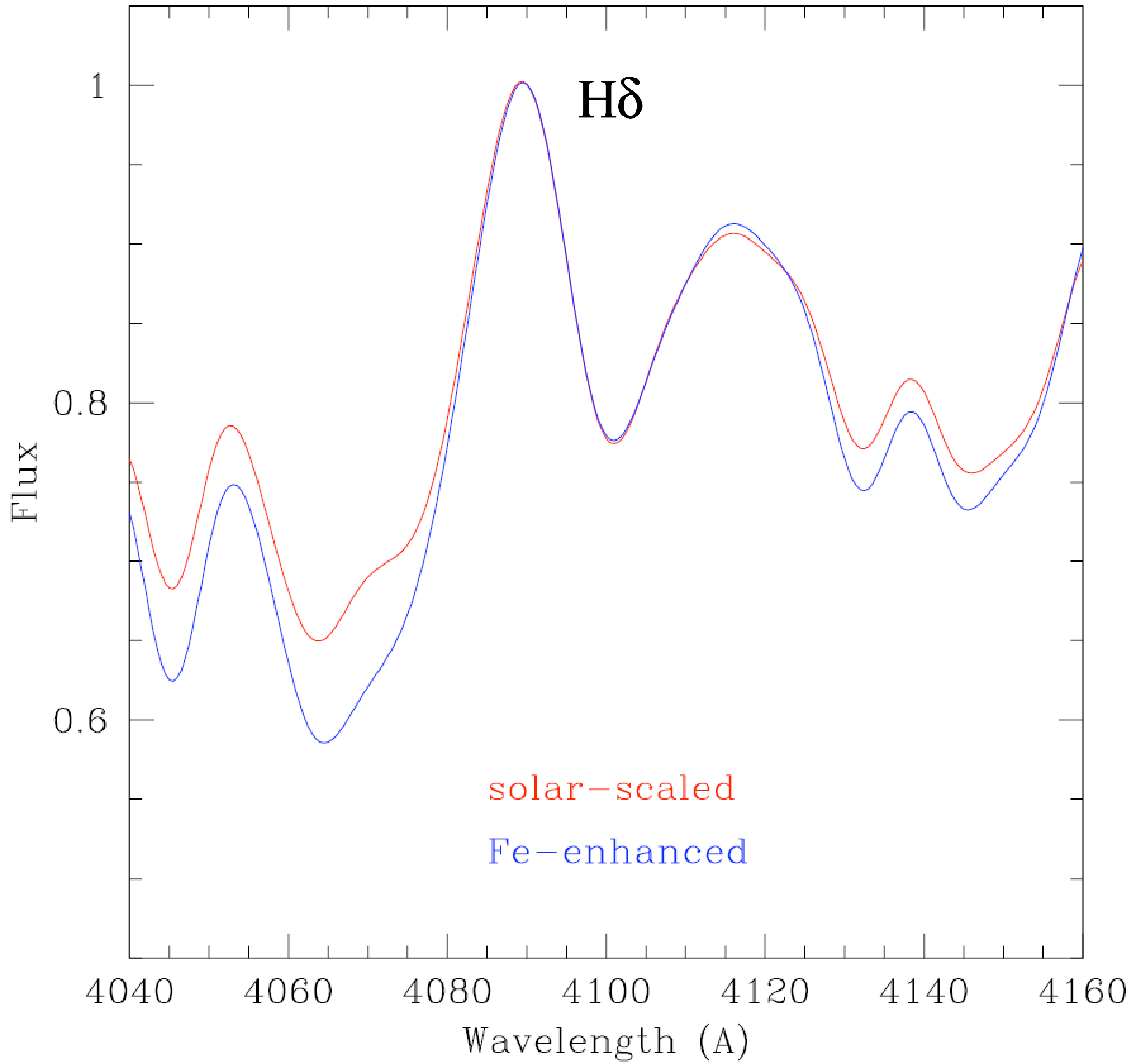
Fe5406 Mg b

Hδ



Fe5406 Mg b

Our *age-sensitive indices (*Hγ, Hδ*):* Fe effects look large



Hδ
1
0.8
0.6
Flux
4040
4060
4080
4100
4120
4140
4160
Wavelength (A)
solar−scaled
Fe−enhanced

Summary II. – flexible chemistry

- Paper I: Isochrones (Dotter et al. 2007)
- Paper II: Integrated sp+ph indices
  (H.–c. Lee et al. 2009)
- Paper III: Full range of metallicity
- Paper IV: Effects of HB, AGB stars…

- Comparison with observational data
  (~20 Virgo cluster galaxies from Kitt Peak 4m)

Lee, Worthey, Dotter (2009), *AJ, 138, 1442*

The Astronomical Journal, 138:1442–1454, 2009 November
doi:10.1088/0004-6256/138/5/1442

COMPARISON OF ALPHA-ELEMENT-ENHANCED SIMPLE STELLAR POPULATION MODELS WITH MILKY WAY GLOBULAR CLUSTERS

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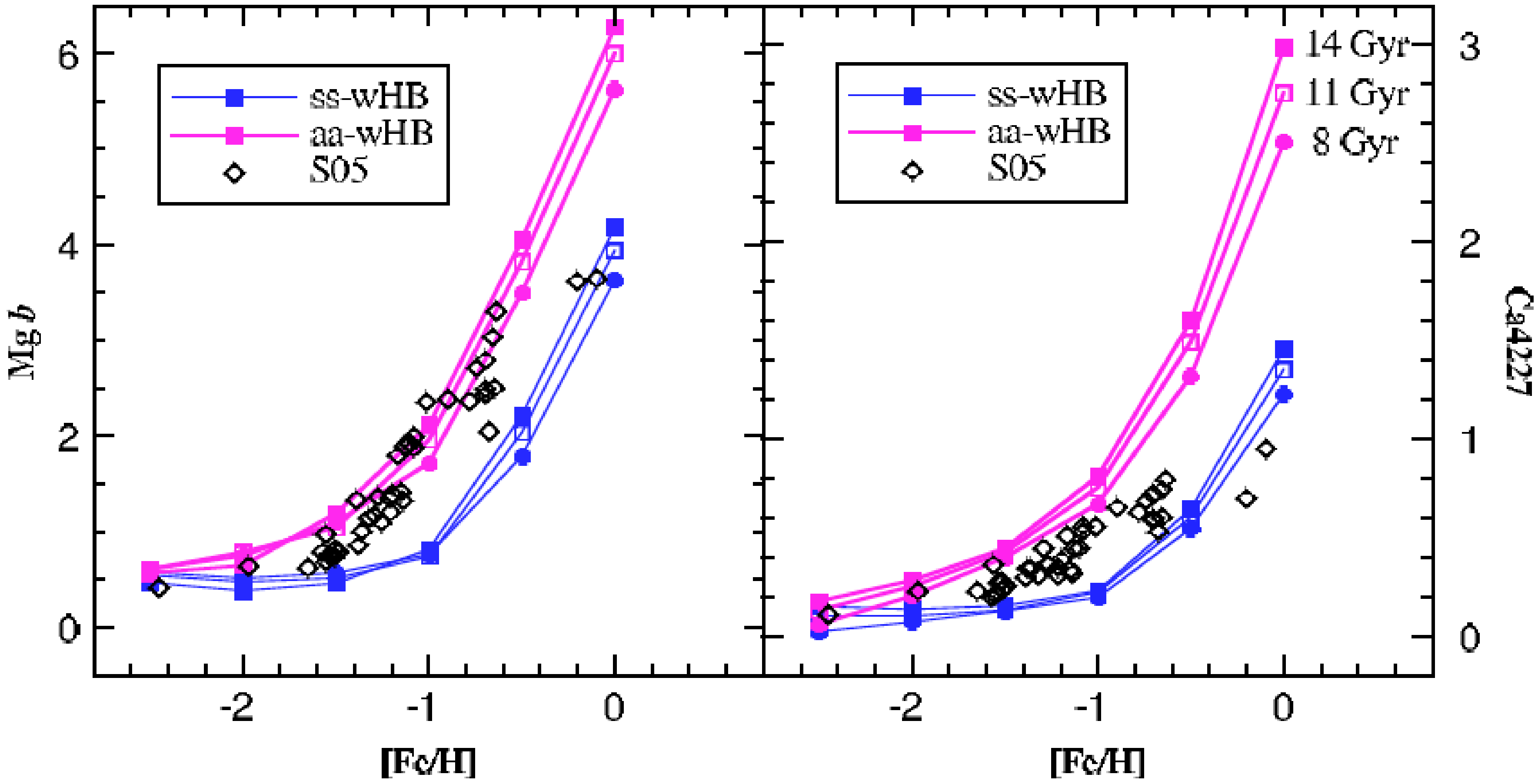
ABSTRACT

We present simple stellar population (SSP) models with scaled-solar and α-element-enhanced abundances. The SSP models are based on the Dartmouth Stellar Evolution Database, our library of synthetic stellar spectra, and a detailed systematic variation of horizontal-branch (HB) morphology with age and metallicity. In order to test the relative importance of a variety of SSP model ingredients, we compare our SSP models with integrated spectra of 41 Milky Way globular clusters (MWGCs) from Schiavon et al. Using the Mg *b* and Ca4227 indices, we confirm that Mg and Ca are enhanced by about +0.4 and +0.2 dex, respectively, in agreement with results from high-resolution spectra of individual stars in MWGCs. Balmer lines, particularly Hγ and Hδ, of MWGCs are reproduced by our α-enhanced SSP models not only because of the combination of isochrone and spectral effects but also because of our reasonable HB treatment. Moreover, it is shown that the Mg abundance significantly influences Balmer and iron line indices. Finally, the investigation of power-law initial mass function (IMF) variations suggests that an IMF much shallower than Salpeter is unrealistic because the Balmer lines are too strong on the metal-poor side to be compatible with observations.

Key words: globular clusters: general – stars: abundances – stars: evolution – stars: horizontal-branch

Lee, Worthey, Dotter (2009), *AJ, 138, 1442*



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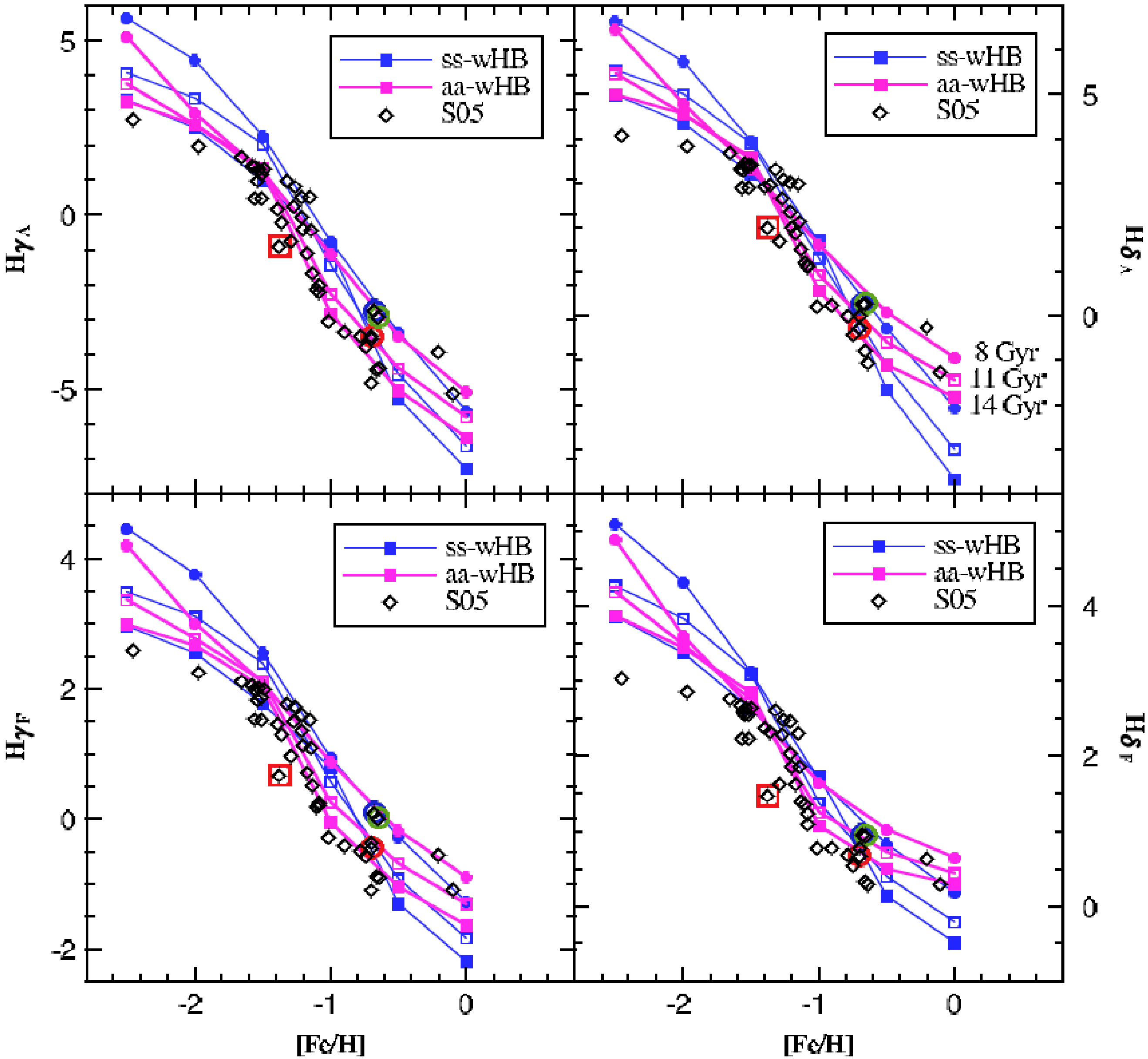

Lee, Worthey, Blakeslee (2010), *ApJ, 710, 421*

THE ASTROPHYSICAL JOURNAL, 710:421–431, 2010 February 10 doi:10.1088/0004-637X/710/1/421

EFFECTS OF α-ELEMENT ENHANCEMENT AND THE THERMALLY PULSING-ASYMPTOTIC GIANT BRANCH ON SURFACE BRIGHTNESS FLUCTUATION MAGNITUDES AND BROADBAND COLORS

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ABSTRACT

We investigate the effects of α-element enhancement and the thermally pulsing-asymptotic giant branch (TP-AGB) stars on the surface brightness fluctuation (SBF) magnitudes and broadband colors of simple stellar populations and compare to the empirical calibrations. We consider a broad range of ages and metallicities using the recently updated Teramo BaSTI isochrones. We find that the α-element-enhanced I-band SBF magnitudes are about 0.35 mag brighter and their integrated $V - I$ colors are about 0.02 mag redder, mostly because of oxygen-enhancement effects on the upper red giant branch and AGB. We also demonstrate, using both the Teramo BaSTI and Padova isochrones, the acute sensitivity of SBF magnitudes to the presence of TP-AGB stars, particularly in the near-IR, but in the I band as well. Empirical SBF trends therefore hold great promise for constraining this important but still highly uncertain stage of stellar evolution. In a similar vein, non-negligible disparities are found among several different models available in the literature due to intrinsic model uncertainties.

Key words: galaxies: stellar content – stars: abundances – stars: evolution

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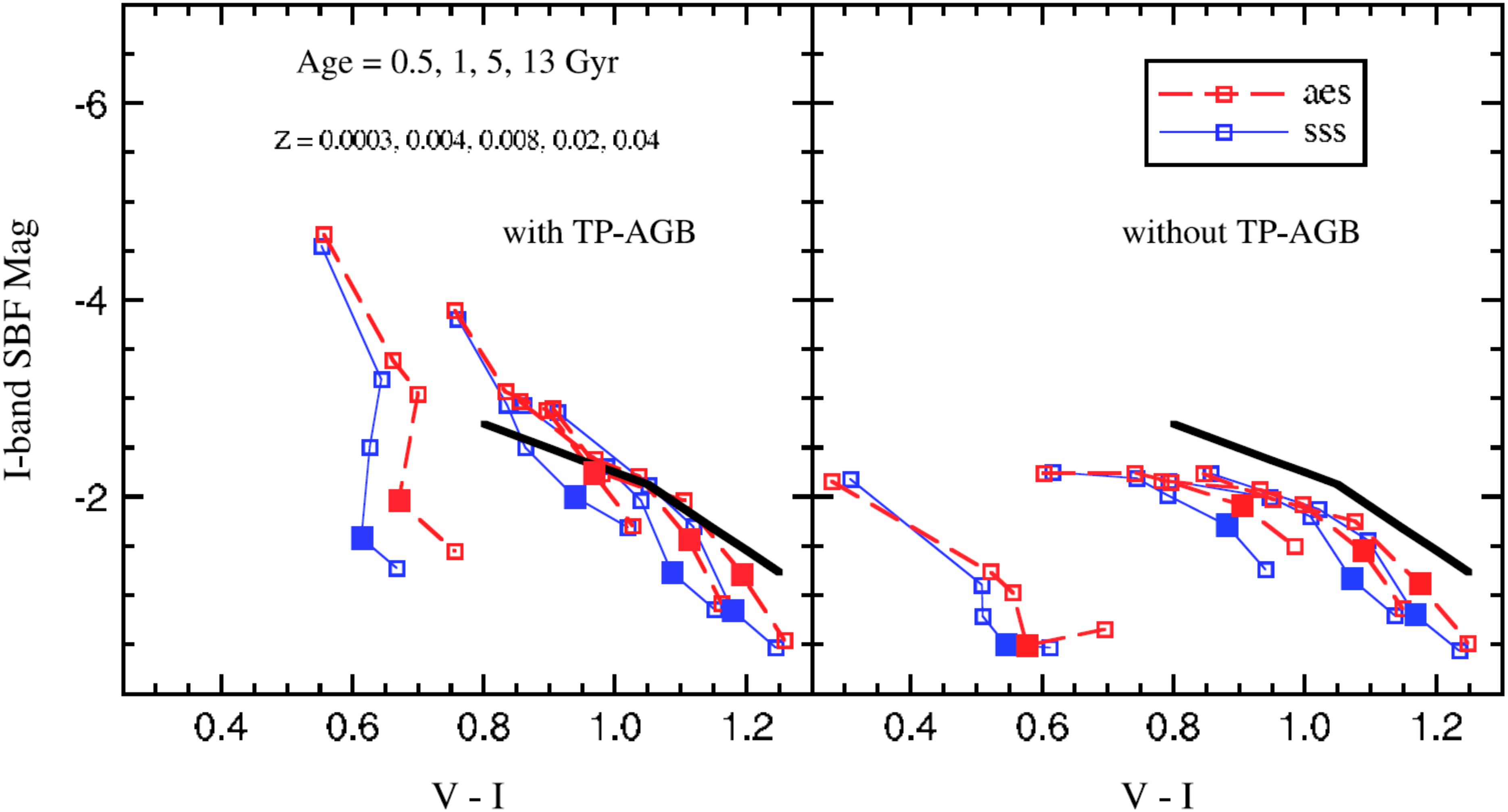

Conclusions

- Optical & near-IR model behaviors are understood.
- Future stellar models with more realistic and sophisticated overshooting and TP-AGB should match red integrated near-IR colors. (CB10)
- And… SFHs + CEHs !!

  for a *realistic composite stellar populations models*!!

- BC03(CB10) & M05: solar-scaled models **(fixed)**

  → Dotter et al. (2007), Lee et al. (2009) introduce

  stellar population models

  with *different chemical mixture* **(flexible).**

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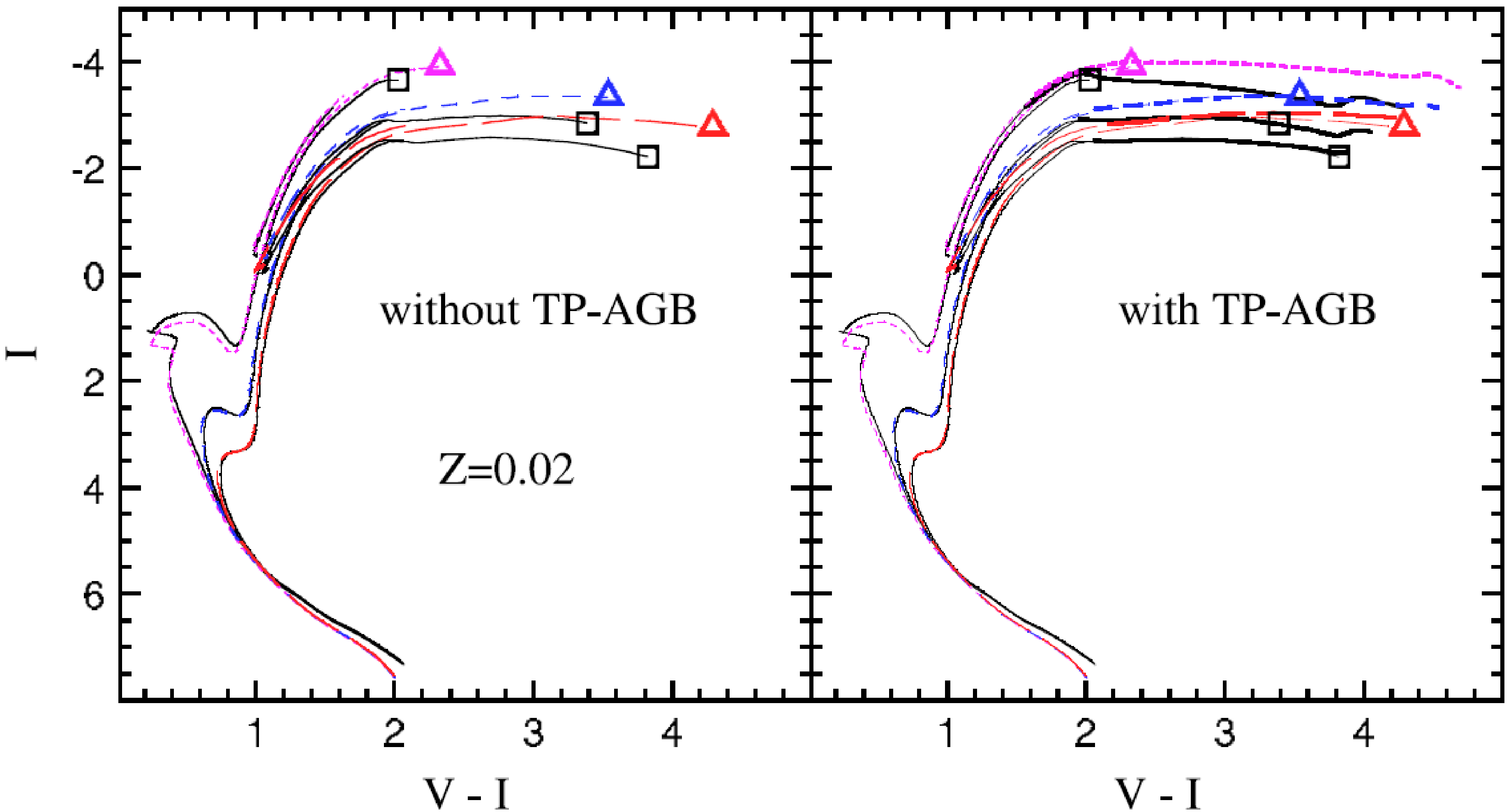

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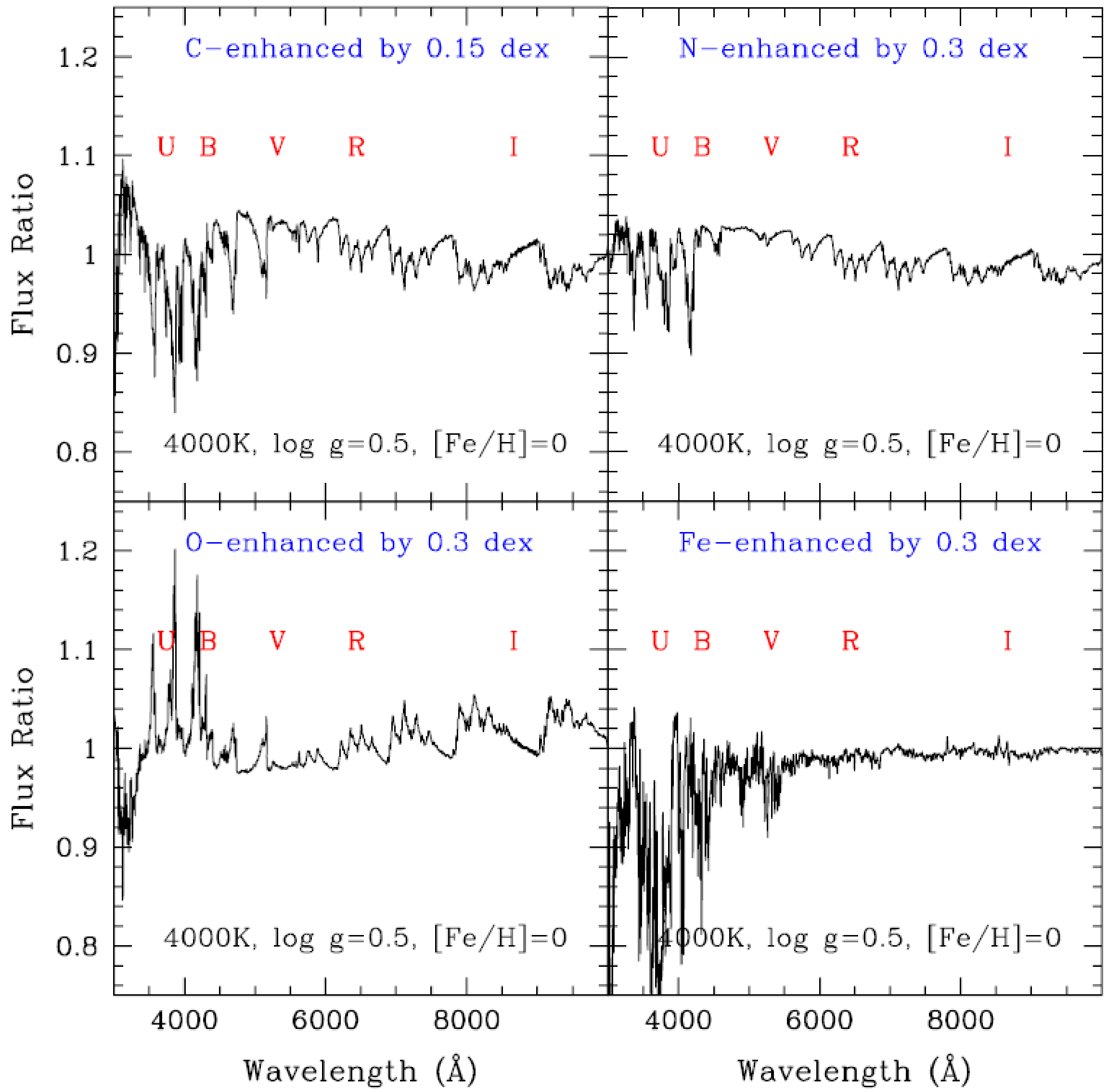

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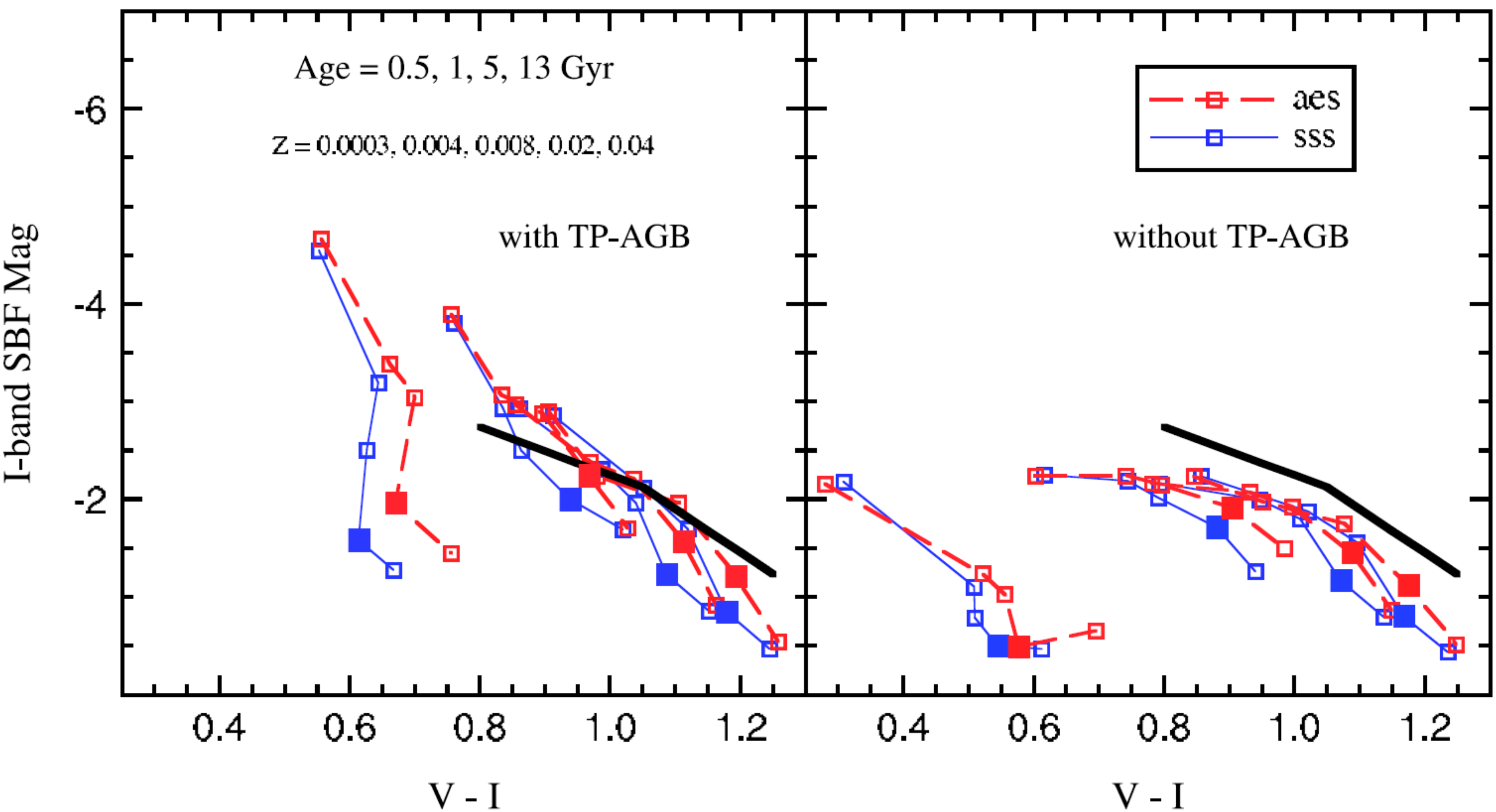

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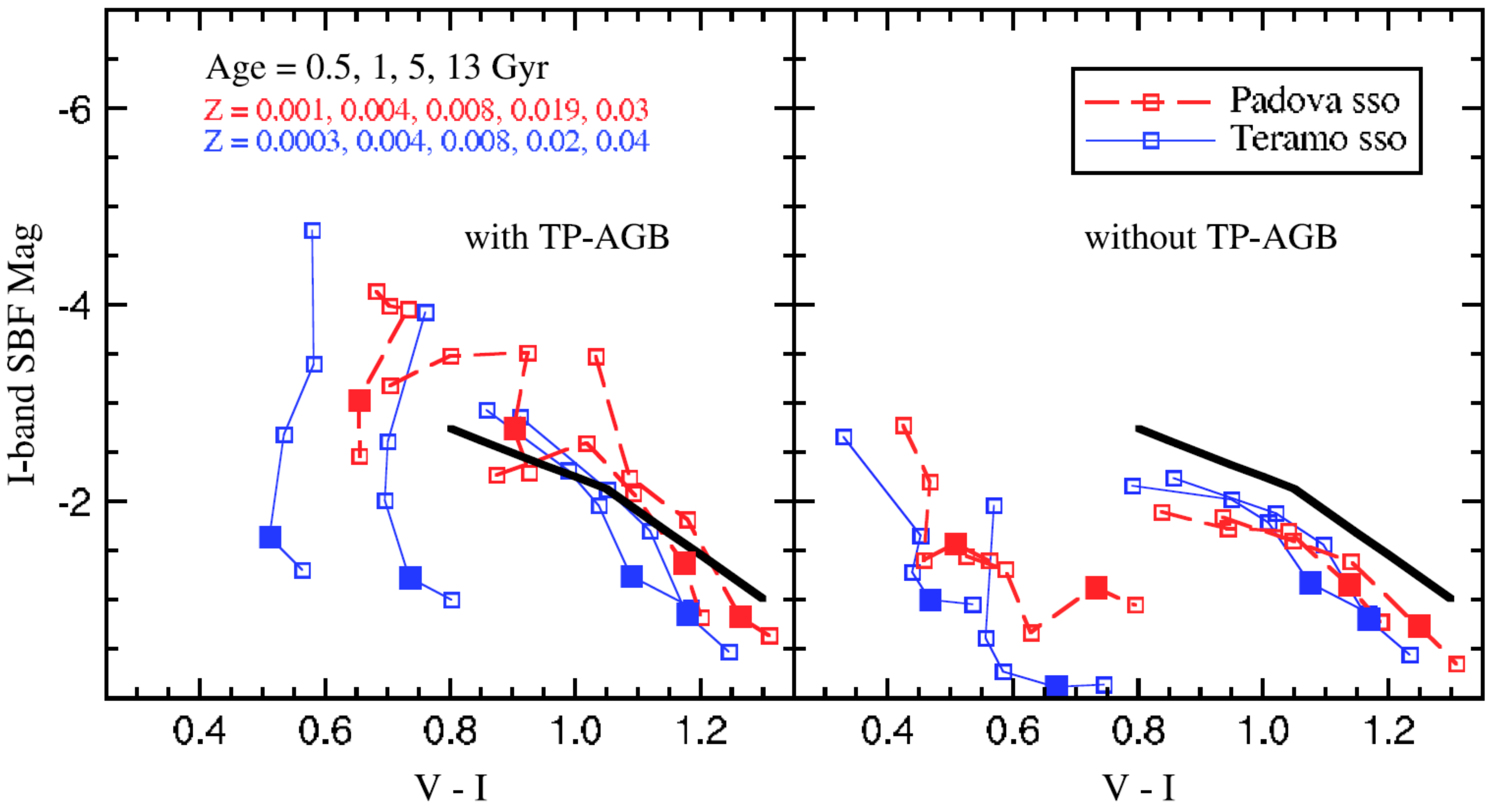

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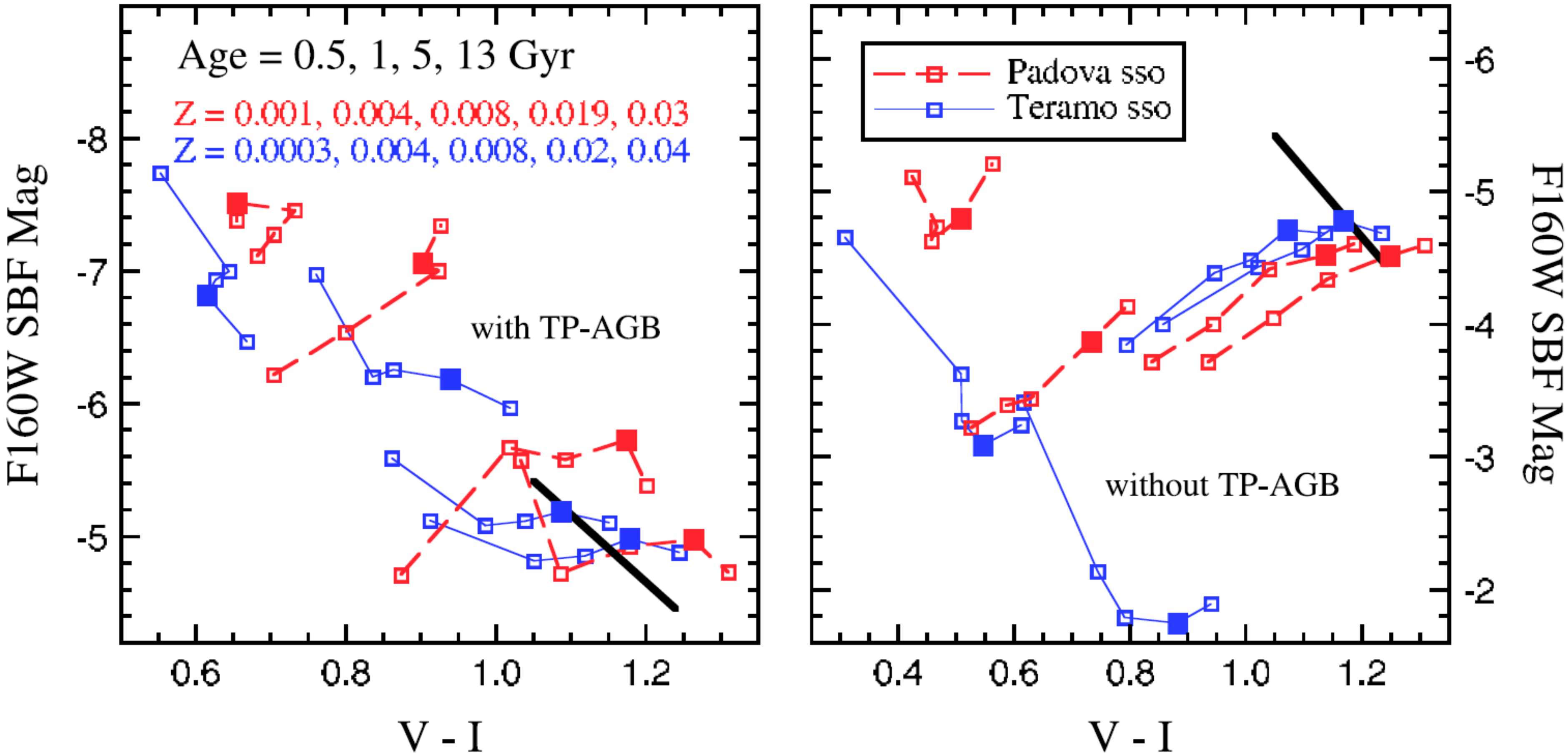
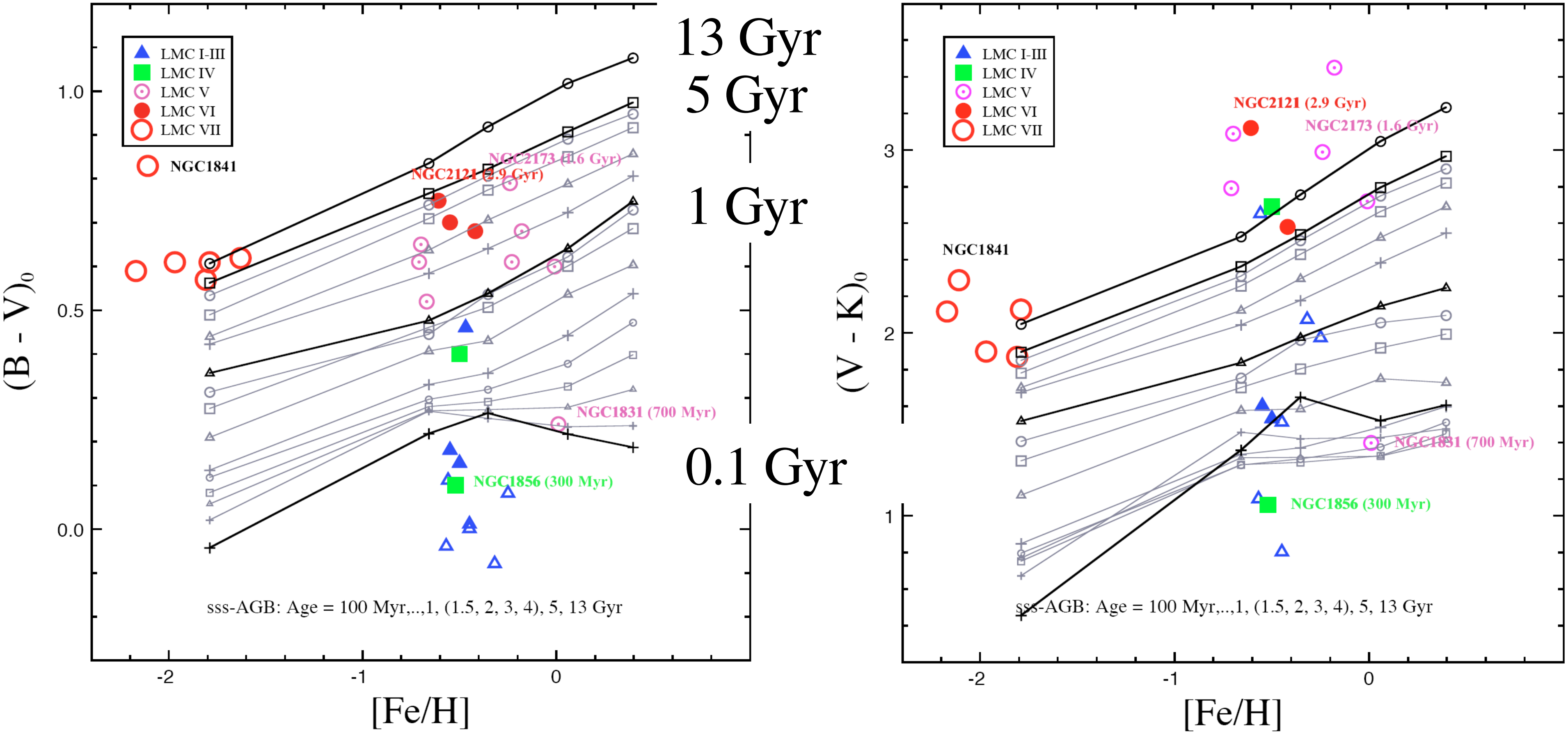
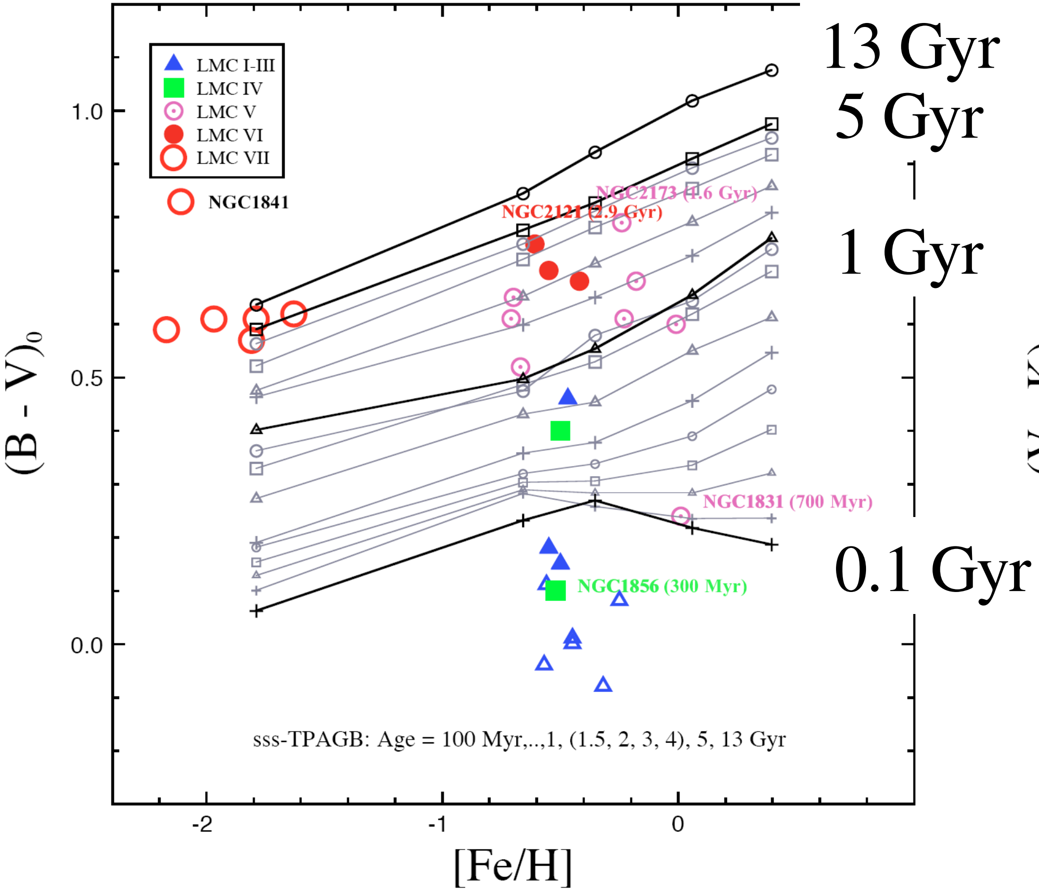




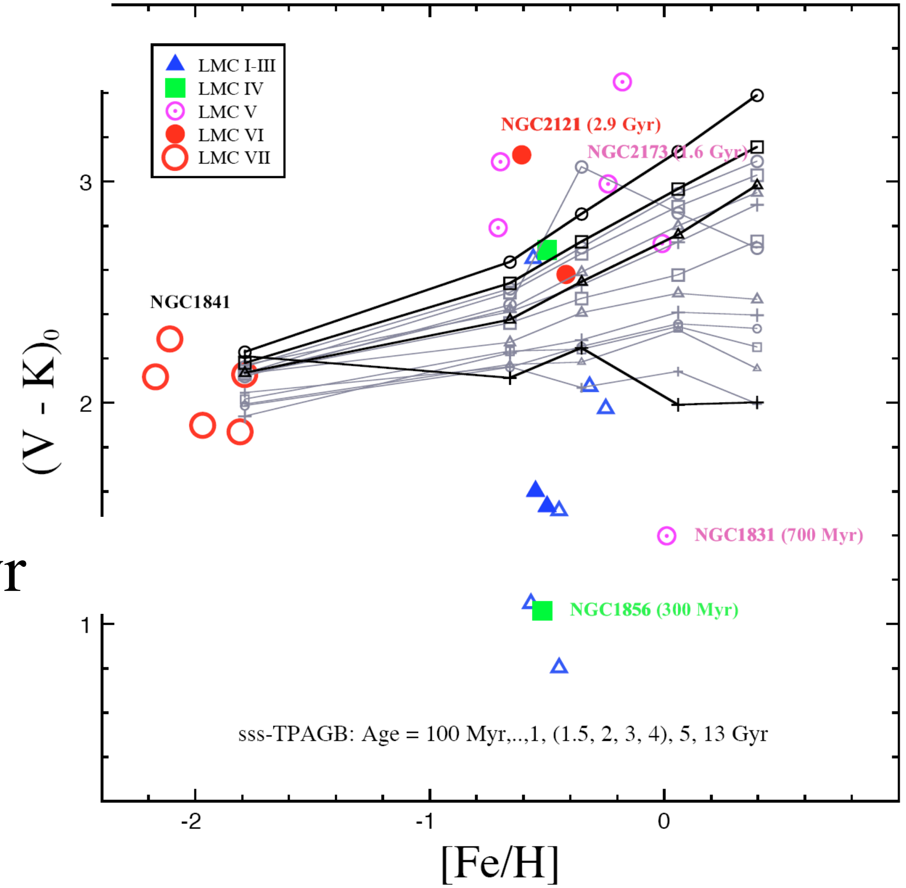
Optical

Near-IR

Lee, Worthey, Trager, & Faber (2007): **without TP-AGB**



Optical



Near-IR

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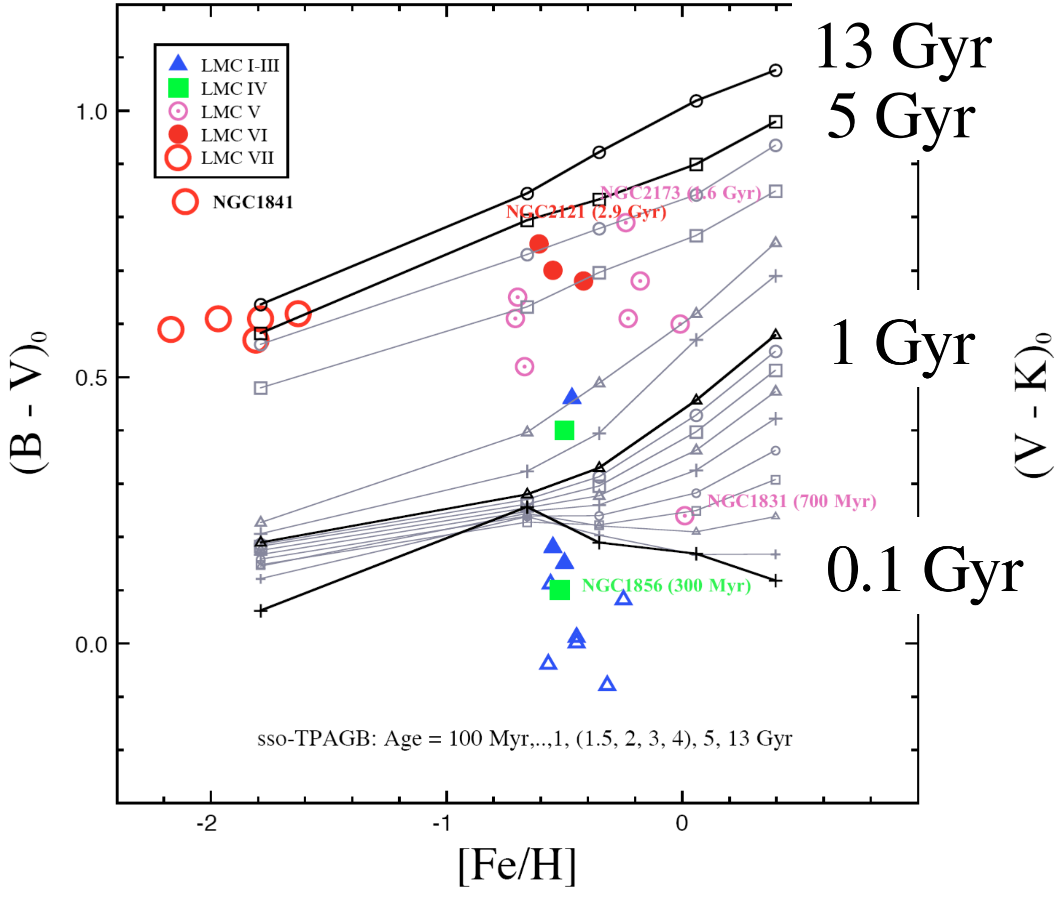
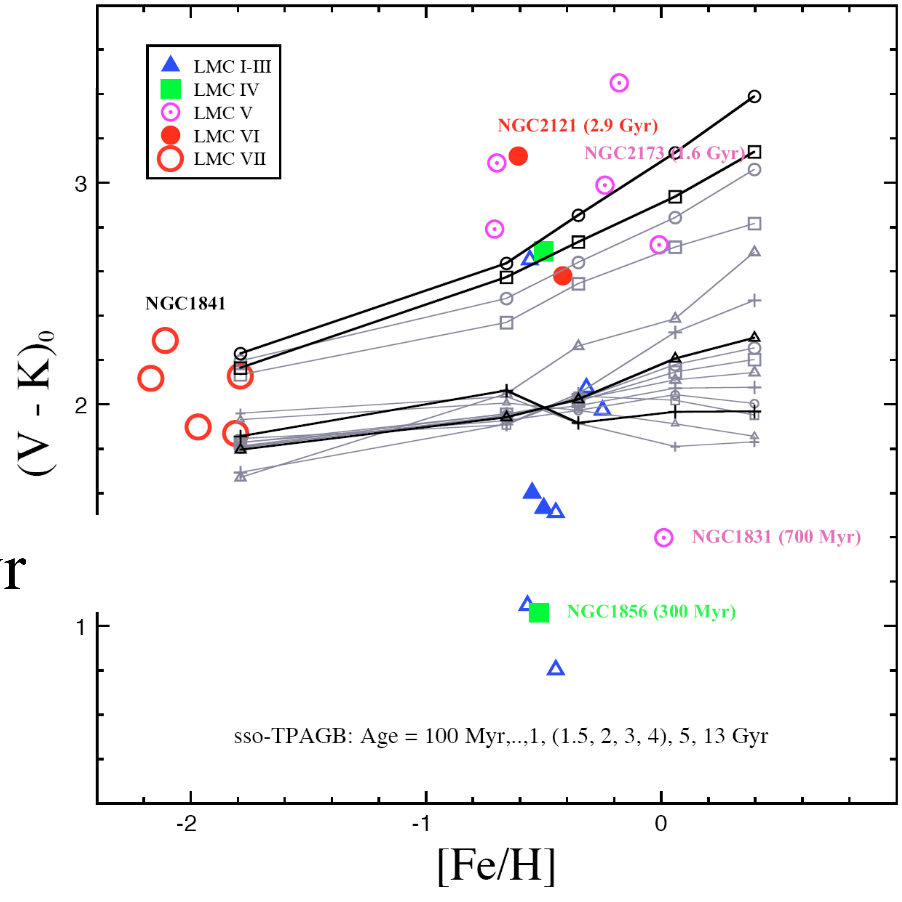


Optical

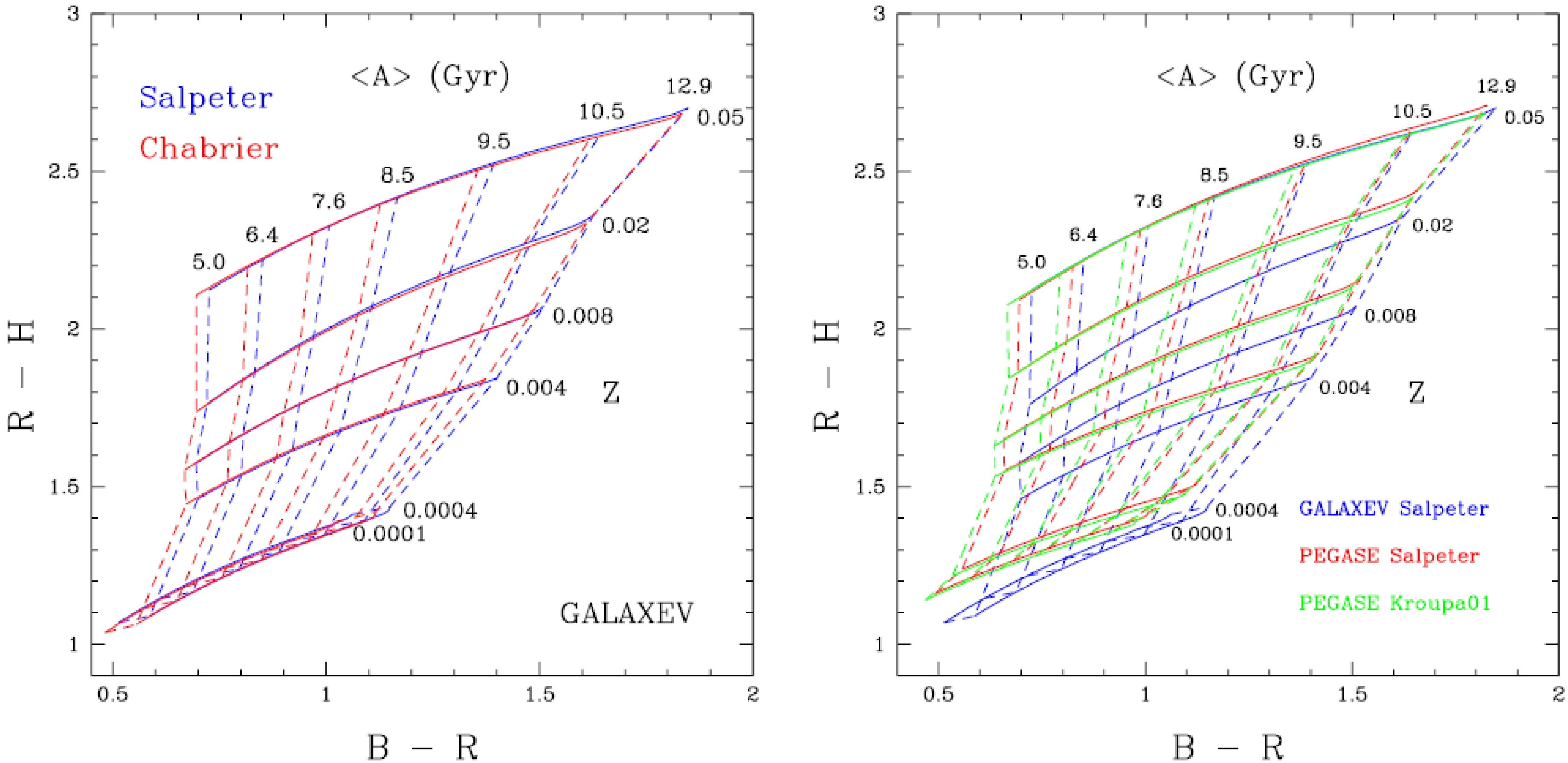


Near-IR

Lee, Worthey, Trager, & Faber (2007): **with TP-AGB &**

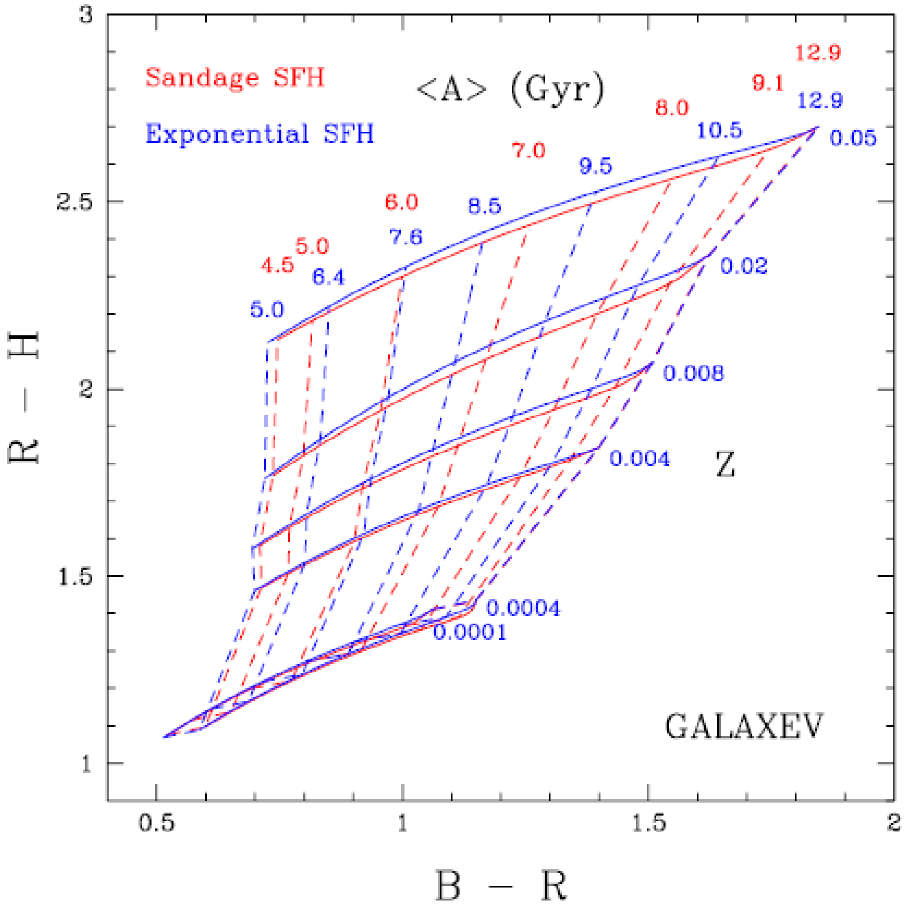
convective core overshooting

IMF effects



MacArthur (2005), *PhD, UBC*

SFH effects



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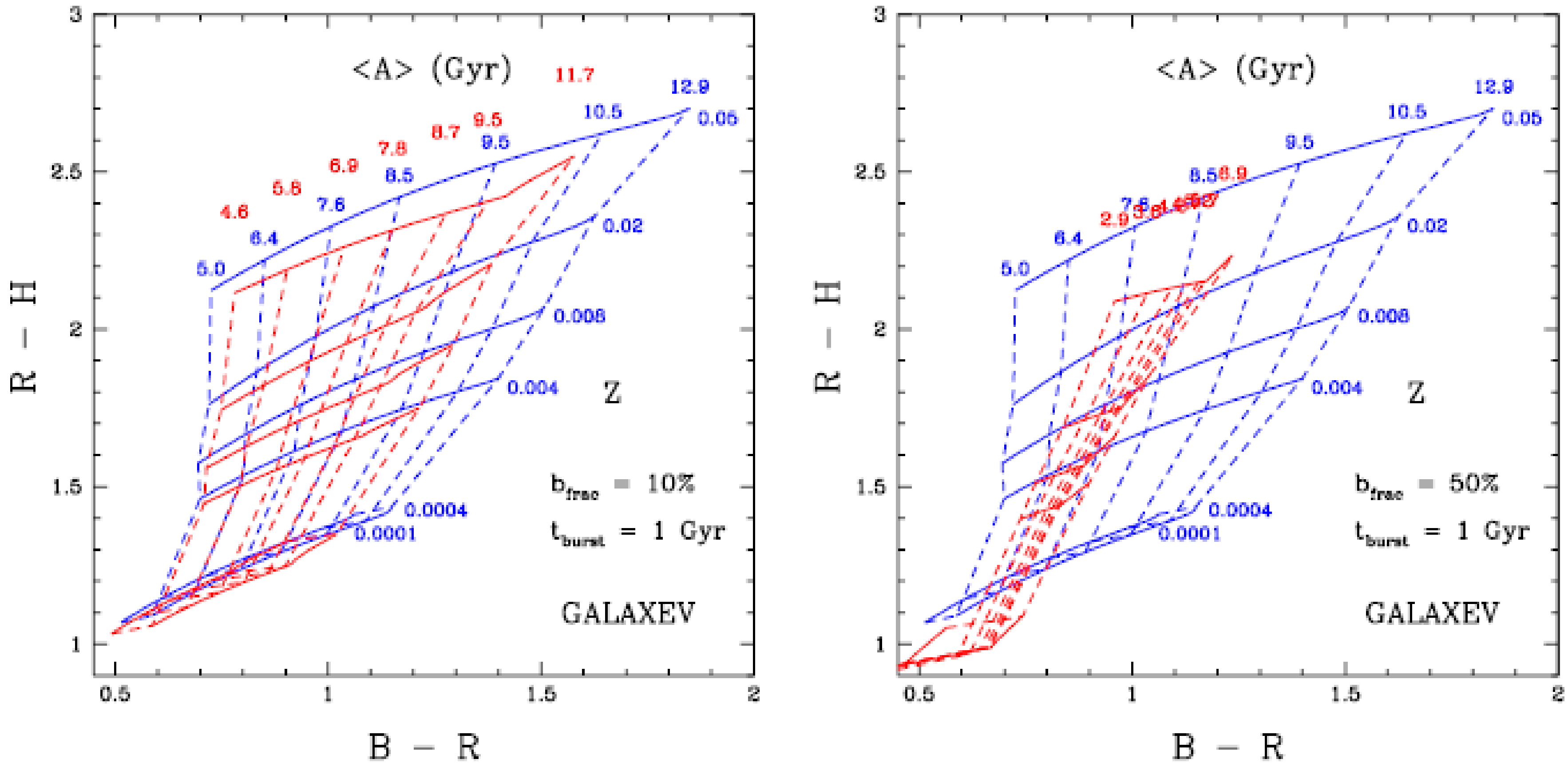
Star burst effects



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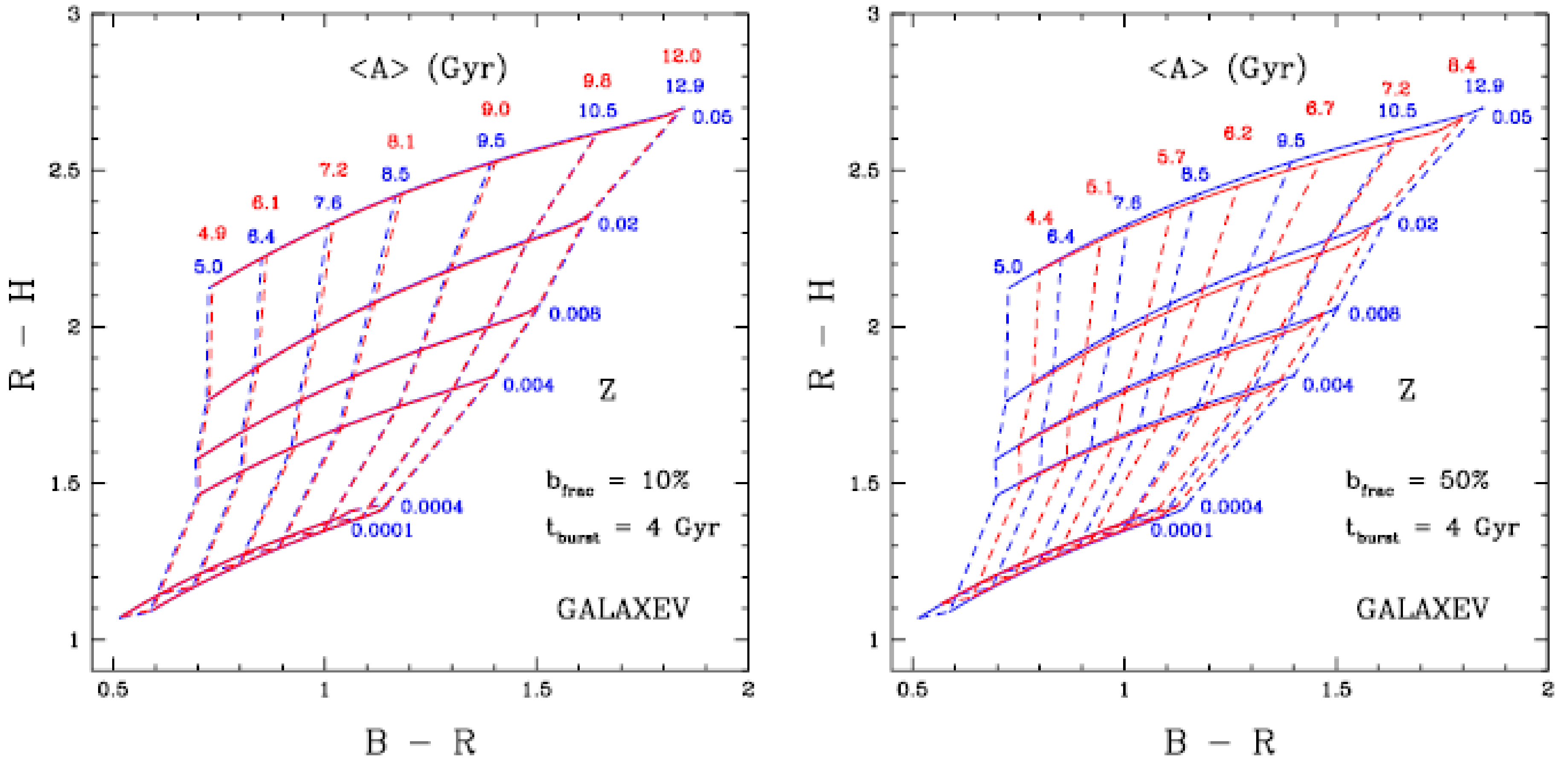

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