SFR history and bayesian ages of MW stars

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Age determination of individual stars from isochrones is a typical inverse problem: the aim is to derive estimates of theoretically computed values of the physical parameters (e.g. age) from "observational" data (effective temperature, absolute magnitude or surface gravity, and metallicity).

A typical approach to tackle this problem is to assign the proper age to the object of interest by selecting (or interpolating) the isochrone or the evolutionary track nearest to the object observed data.

A different and more robust method to obtain unbiased estimates of the physical parameters is based on the Bayesian probability theory; the goal is to use information from the data ($\mathbf{D}$) and from our prior knowledge to infer posterior probability distribution on the parameters of our model ($\mathbf{M}$).

$$\mathbf{P}(\mathbf{M}|\mathbf{D}) \equiv \boldsymbol{P}(\mathbf{D}|\mathbf{M}) \cdot \frac{\boldsymbol{P}(\mathbf{M})}{\boldsymbol{P}(\mathbf{D})}$$

$\boldsymbol{P}(\boldsymbol{M}|\boldsymbol{D})$ is the *posterior* probability function, i.e. the probability of the model parameter given the data
$\boldsymbol{P}(\boldsymbol{D}|\boldsymbol{M})$ is the *likelihood* probability function, i.e. the probability of the data given the model parameter
$\boldsymbol{P}(\boldsymbol{M})$ is the *prior* function, i.e. the probability of the model parameter
$\boldsymbol{P}(\boldsymbol{D})$ is the *evidence*, i.e. a normalization constant which does not depend on the model parameter

If we assume that the errors in our measurements are independent, normally distributed, with known variances:

$$\mathrm{P(D|M)} \propto \frac{-(logT_{obs}-logT)^2}{2\sigma^2_{Tobs}} \cdot \frac{-(\log g_{obs}-\log g)^2}{2\sigma^2_{log\ gobs}} \cdot \frac{-\left(\log[\frac{M}{H}]_{obs}-\log[M/H]\right)^2}{2\sigma^2_{[M/H]obs}}$$

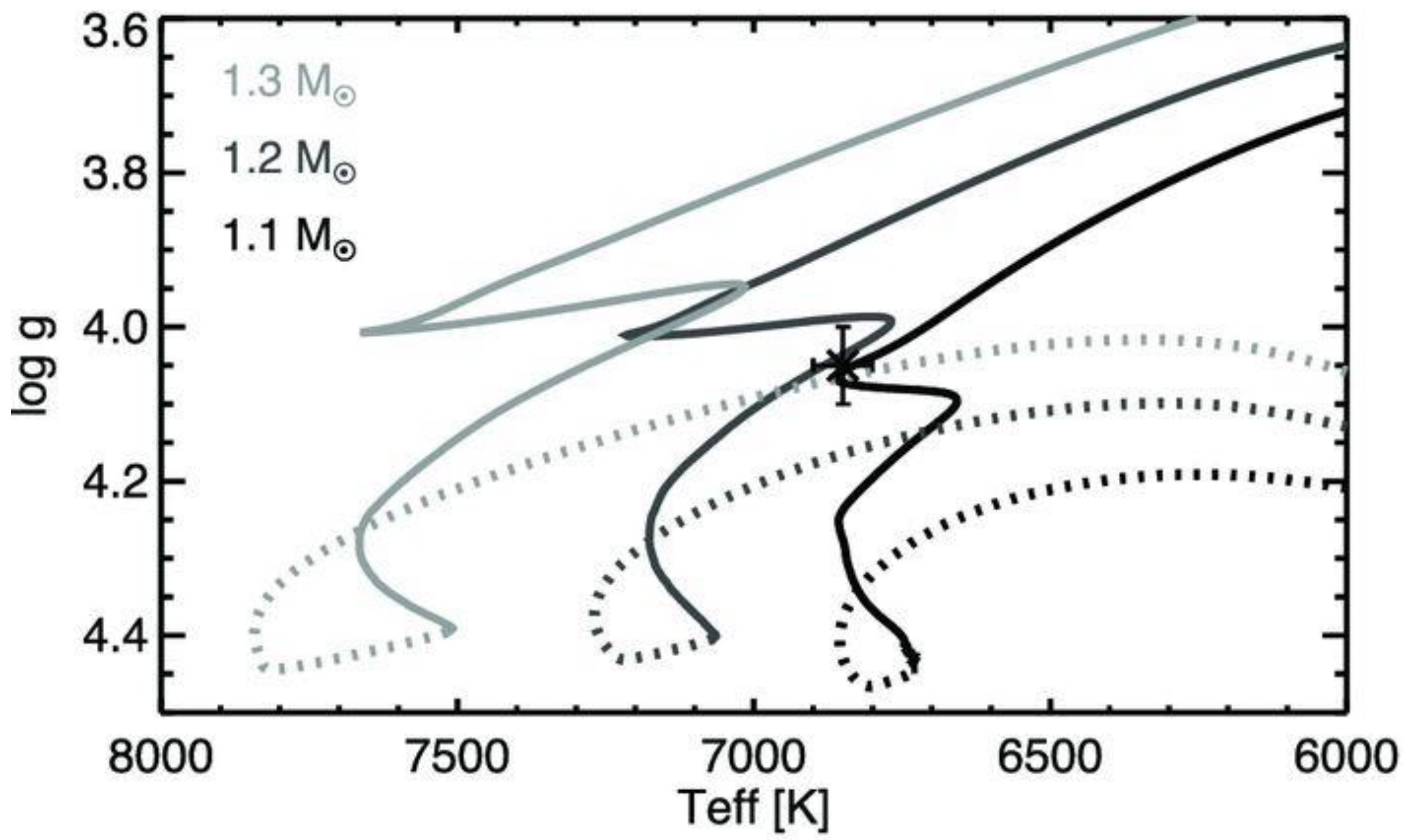
or

$$\frac{-(\mathrm{M}_{v\,obs}-\mathrm{M_V})^2}{2\sigma^2_{\mathrm{Mv\ obs}}}$$

→ but you need **distances**, **reddening** and **Bolometric Correction**

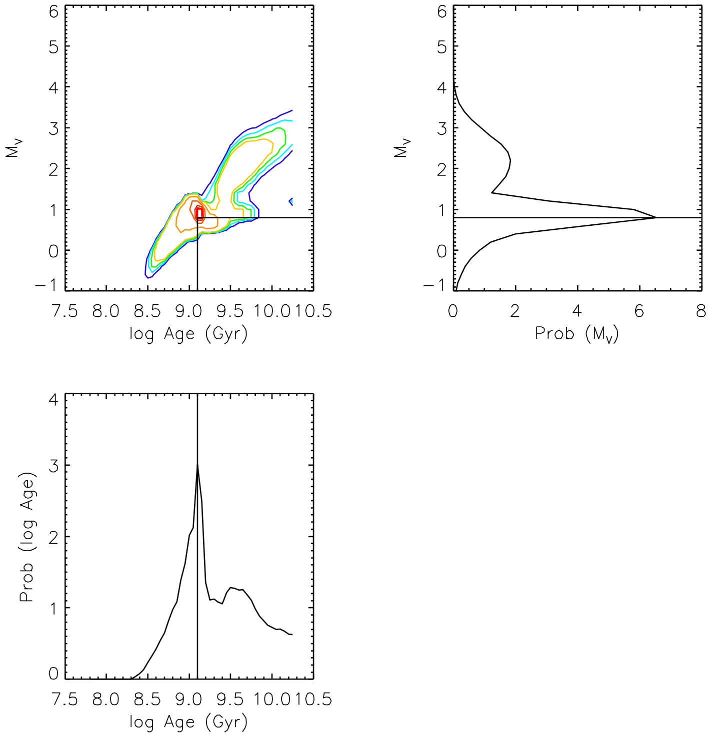
$\mathrm{P(M)} \equiv \mathrm{P}(\mathscr{M})\cdot\mathrm{P}(\tau)\cdot\mathrm{P(Z)}$, $\mathrm{P}(\mathscr{M})$ → IMF; $\mathrm{P}(\tau)$ → SFR; ~~$\mathrm{P(Z)}$ → AMR~~

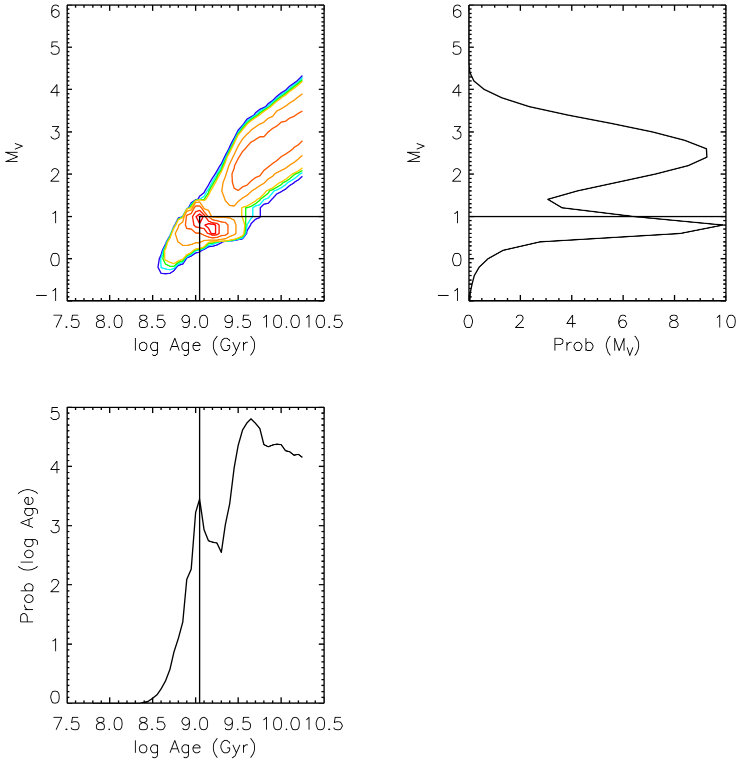
Bayesian technique helps to remove degeneracy



Serenelli A. M. et al. MNRAS 2013;429:3645-3657

Examples of bi-dimensional posterior probability $\mathbf{P(\tau,M_V)}$





The importance of deriving simultaneously **τ** and $\mathbf{M_V}$ from the **2-D** $\mathbf{P(\tau,M_V)}$ instead of using individual $\mathbf{P(\tau)}$ and $\mathbf{P(M_V)}$ is illustrated with two different cases: in the first one the **τ** and $\mathbf{M_V}$ *of* the max of $\mathbf{P(\tau,M_V)}$ coincide with the **τ** of the maximum of the **1-D P(τ)** and with the $\mathbf{M_V}$ of the maximum of the **1-D** $\mathbf{P(M_V)}$; in the second case this is not true.

IAC-STAR - SYNTHETIC COLOR-MAGNITUDE DIAGRAM COMPUTATION ALGORITHM

Aparicio & Gallart (2004), The Astronomical Journal, 128,1465 http://iac-star.iac.es/cmd/index.htm

IAC-STAR

SYNTHETIC COLOR-MAGNITUDE DIAGRAM COMPUTATION ALGORITHM

Main | IAC-STAR | IAC-STAR input/output | Paper | Contact | Acknowledge

A. Your Personal Data ?

Name

Institution

e-mail

B. Libraries ?

Select stellar evolution library: (•) Bertelli 94 ( ) Teramo ( ) Girardi00

Select bolometric correction library: (•) Lejeune et al. 1997 ( ) Castelli & Kurucz 2002 ( ) Girardi et al. 2002 ( ) Origlia & Leitherer 2000 (HST-WFPC2) ( ) Bedin et al. 2005 (HST-ACS)

C. Control Parameters ?

Total number of computed stars (*n*): 10000000

Number of stars saved to output file (*m*): 10000

Limiting magnitude for stars to be written in the ouput file: 0

Filter < 0

C-2. Mass loss at RGB and AGB ?

Mass loss parameter at the RGB: 0.35

Mass loss parameter at the AGB: 0.35

D. Star Formation Rate ?

Two formats are possible
1. Provinding *n* sampling points: n, t[1->n], SFR[1->n], (max n=20; t(n) is the present age (in Gyr) of the system)
2. Exponencial law of the form SFR=exp(t/-β): 1, T, β (T is the present age (in Gyr))

2, 0, 13, 1, 1

E. Metallicity Law ?

E.1) Defined by sampling points

Lower or unique law: n, t[1->n], Z[1->n] (max n=20, 0 to define law by physical parameters: see below)

2, 0, 13, 0.02, 0.02

Upper law (optional): n, t[1->n], Z[1->n] (max n=20, 0 to ignore)

0

E.2) Defined by physical parameters (all parameters 0 to ignore)

Lower or unique law		Upper law (optional)	
Starting Z (Z_i)	0	Starting Z (Z_i)	0
Final Z (Z_f)	0	<Final Z (Z_f)	0
<>Final gas fraction (μ_f)	0	Final gas fraction (μ_f)	0
Infall parameter (α)	0	Infall parameter (α)	0
Outflow parameter (λ)	0	Outflow paramter (λ)	0

F. Initial Mass Function ?

IMF: n, m [1->n], x [1->(n-1)]

3, 0.1, 0.5, 120., -1.3, -2.3

G. Binary Stars ?

Fraction of binary stars (f): 0

Minimum mass ratio (q): 1

H. Random Number Generator ?

Seed: 33659254

Submit | Reset

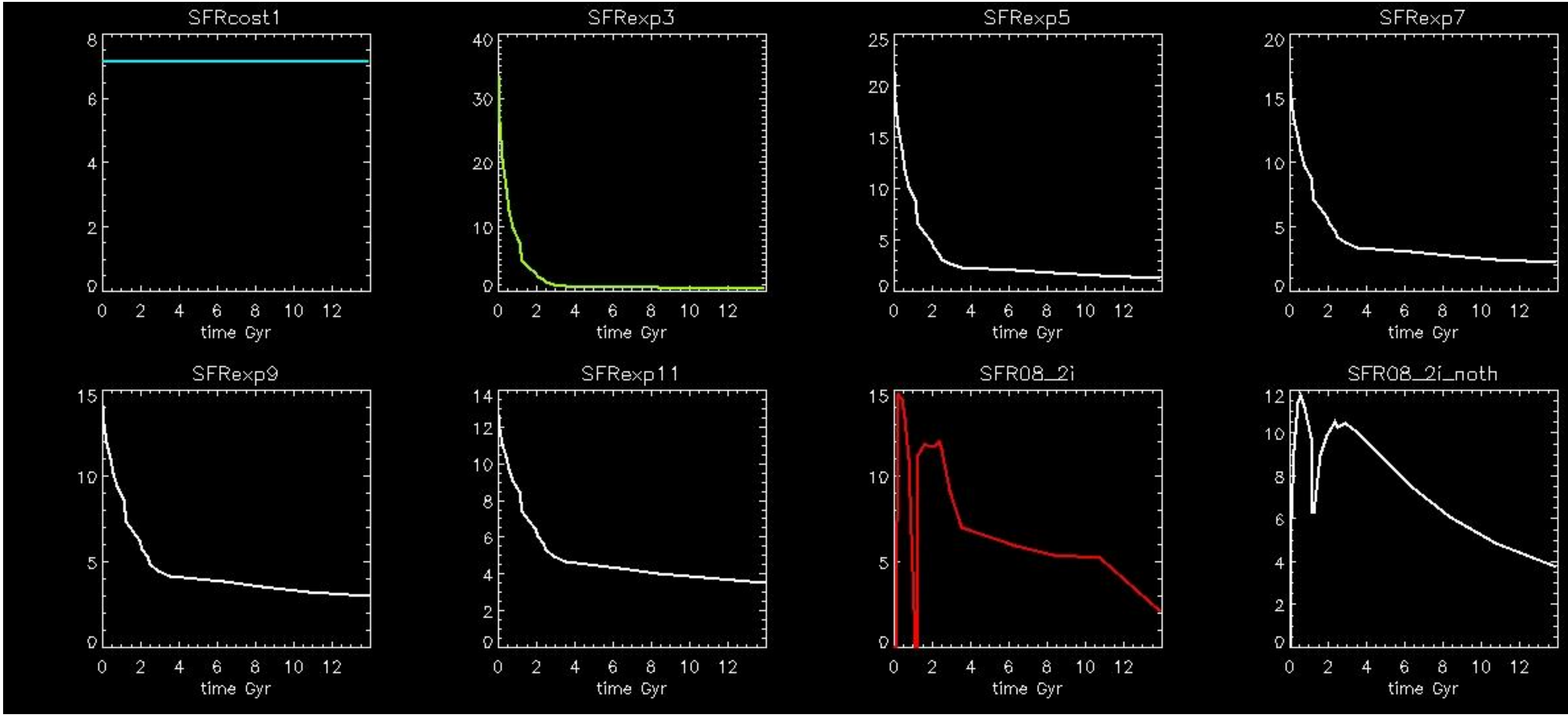
- Stellar evolution libraries: Bertelli et al. Astronomy and Astrophysics Suppl. 106, 275-302 (**Bertelli**),
  Pietrinferni et al. The Astrophysical Journal, Volume 612, Issue 1, pp. 168-190 (**Teramo**),
  Girardi et al. Astronomy and Astrophysics Supplement, v.141, p.371-383 (**Girardi**).

- Bolometric corrections: Lejeune et. al. A & A Supplement series, Vol. 125, 229-246 (**Lejeune**),
  Castelli&Kurucz Proceedings of the 210th Symposium of the IAU, p.A20 (**Castelli&Kurucz**),
  Girardi et al. Astronomy and Astrophysics, v.391, p.195-212 (**Girardi 02**).

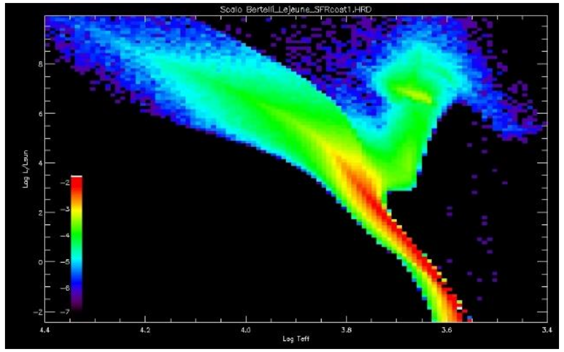
- SFR: cost, exp3, exp5, exp7, exp9, exp11 +
  SFR08_2i, SFR08_2i_noth (Spitoni & Matteucci, 2011 A&A, 531, A72)

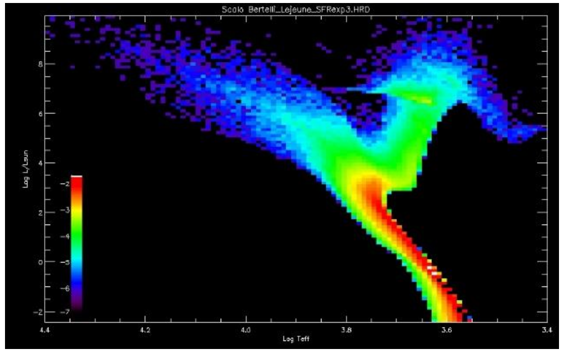
- Metallicity law: flat between Z=0.0001 and Z=0.05 (**Bertelli**),
  Z=0.0001 and Z=0.04 (**Teramo**),
  Z=0.0004 and Z=0.03 (**Girardi**).

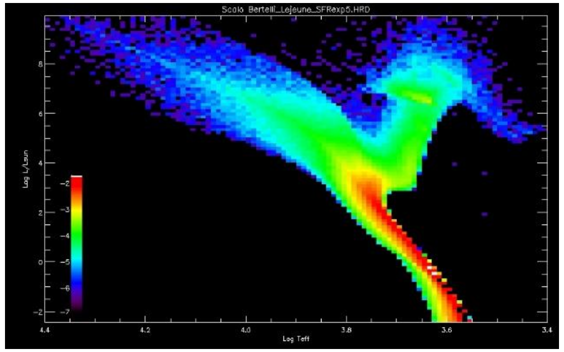
- IMF: Scalo J.M., Fundamentals of Cosmic Physics ,vol. 11, p. 1-278 (**Scalo**),
  Kroupa P., MNRAS, Volume 322, Issue 2, pp. 231-246 (**Kroupa**),
  Chabrier G., PASP, Volume 115, Issue 809, pp. 763-795 (**Chabrier**).

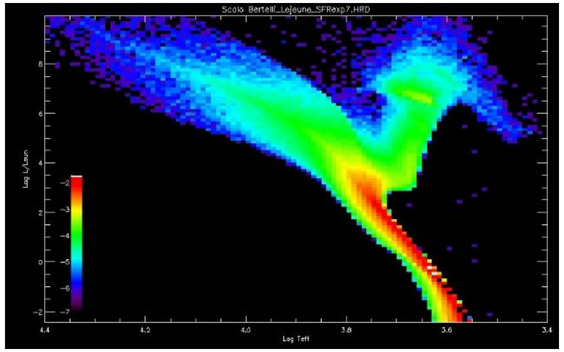

SFRcost1
SFRexp3
SFRexp5
SFRexp7
SFRexp9
SFRexp11
SFR08_2i
SFR08_2i_noth
time Gyr

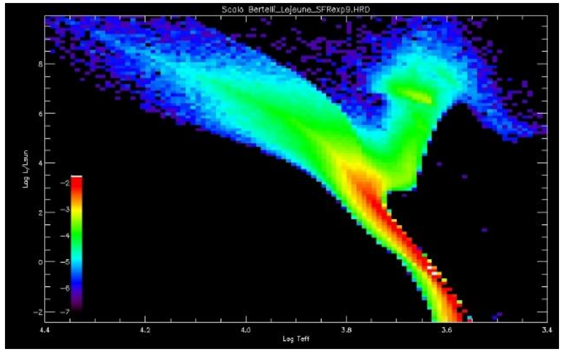
Prior probability in the **(log T – Mv)** diagram for different **SFR**'s

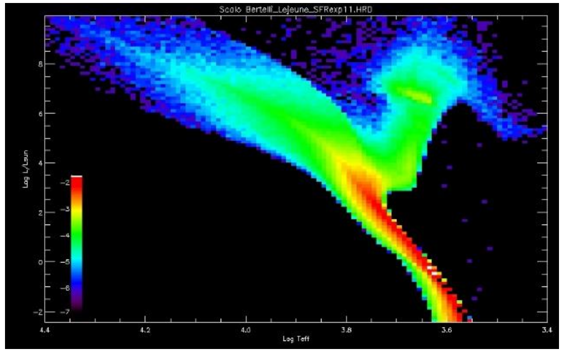


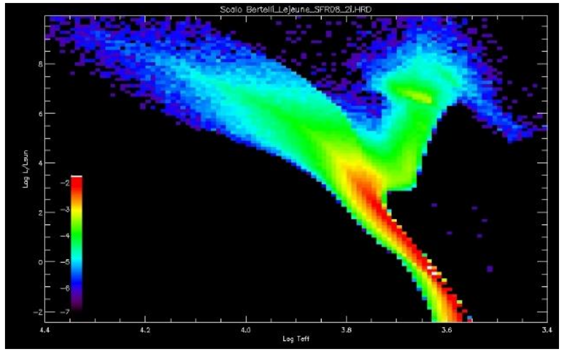


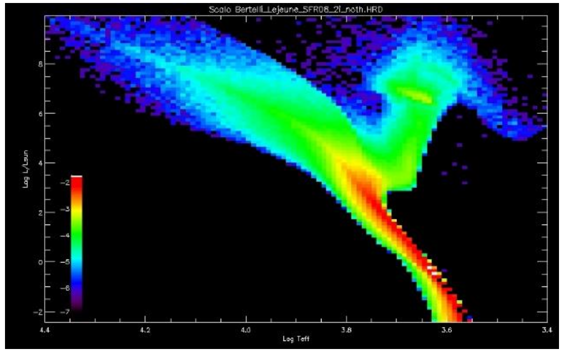




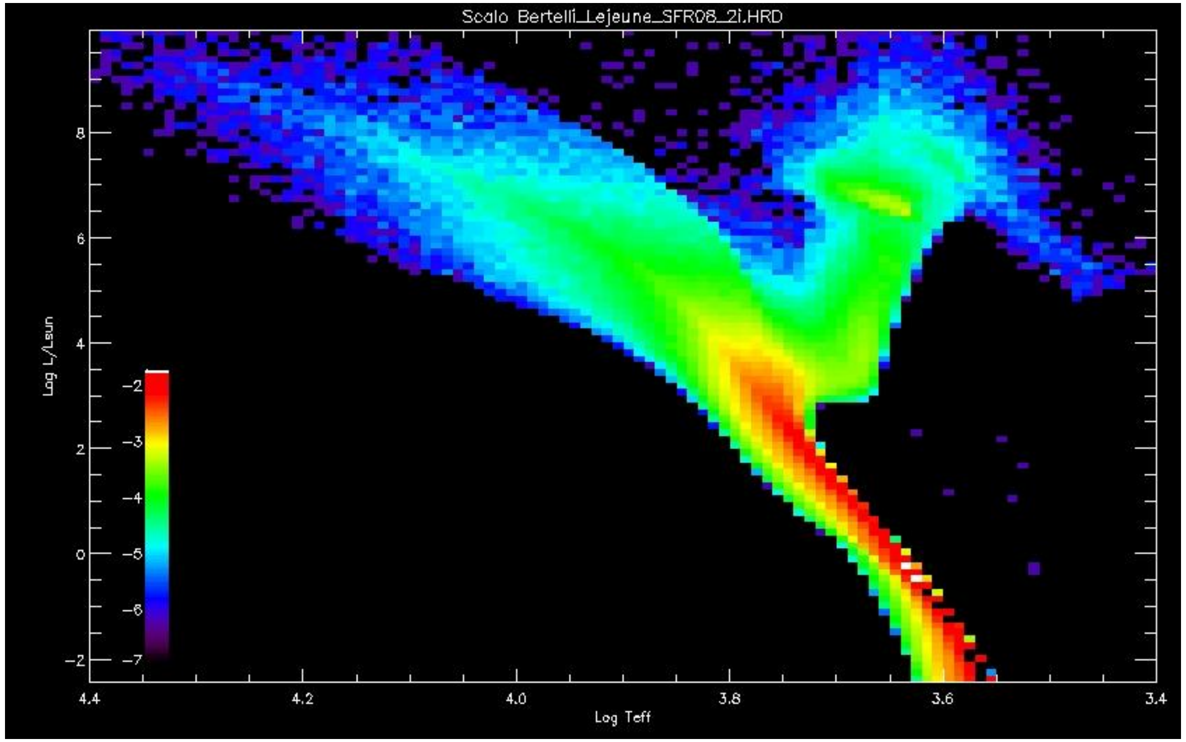


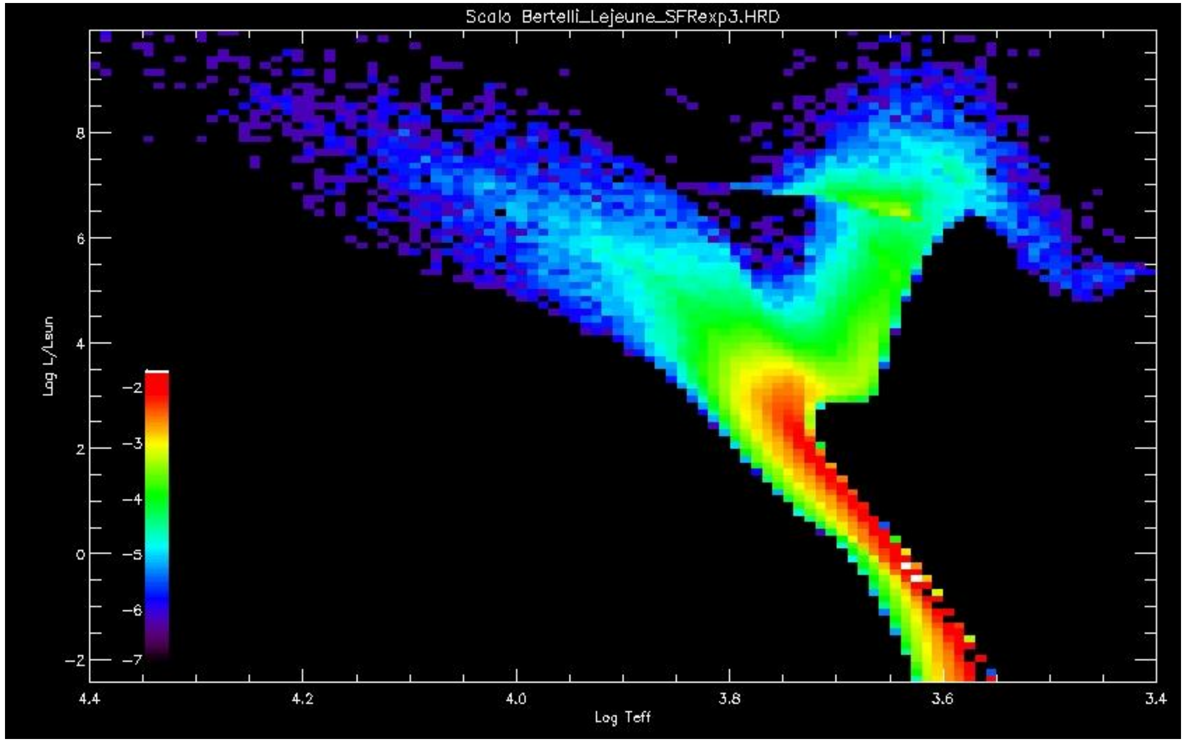




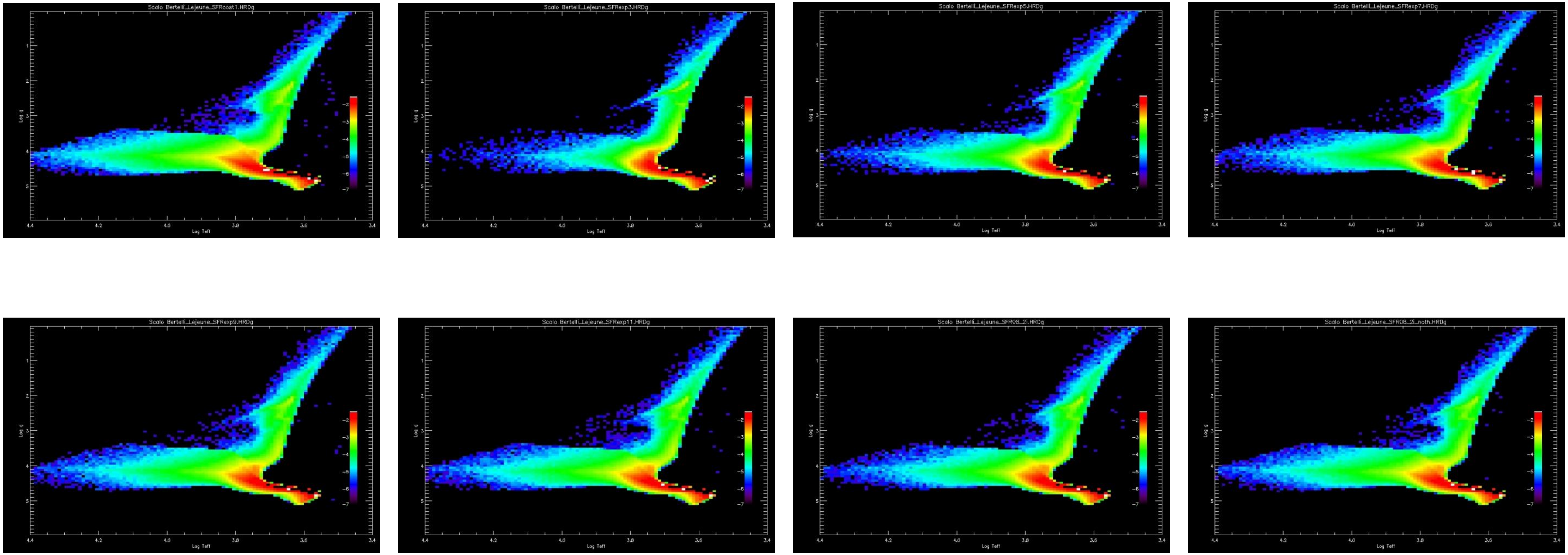


Prior probability in the (log T – Mv) diagram for **SFR_08_2i** and **EXP3**

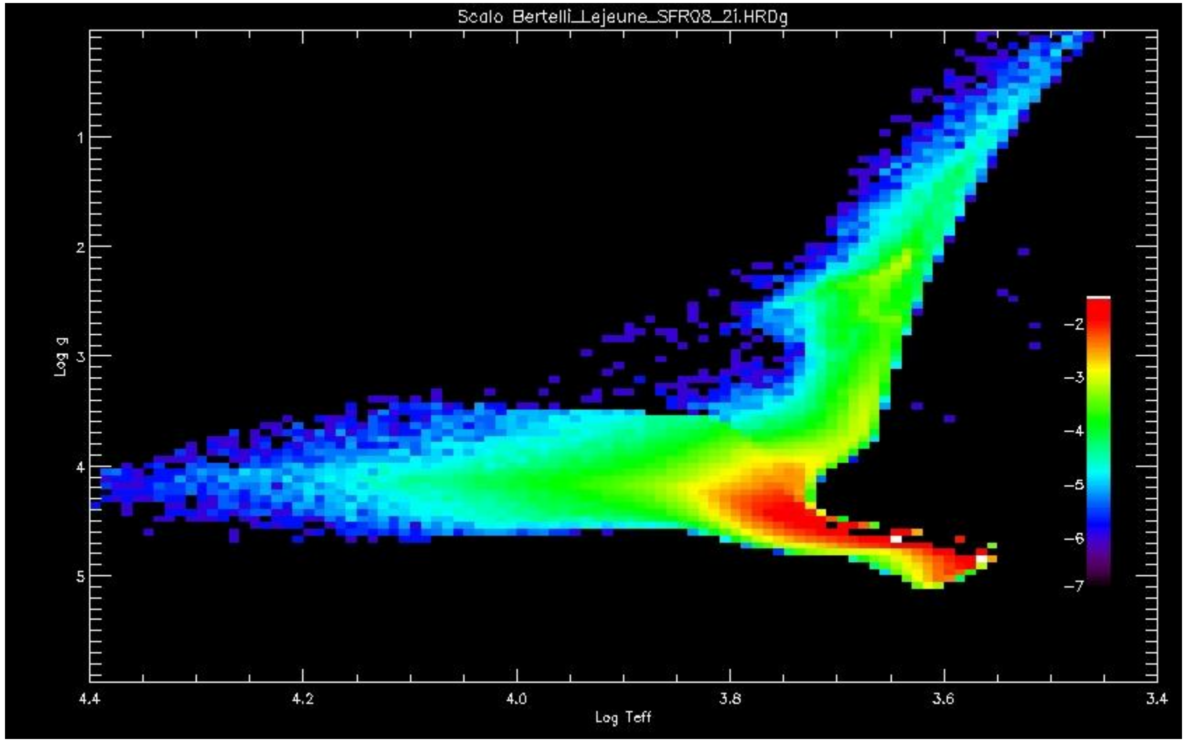


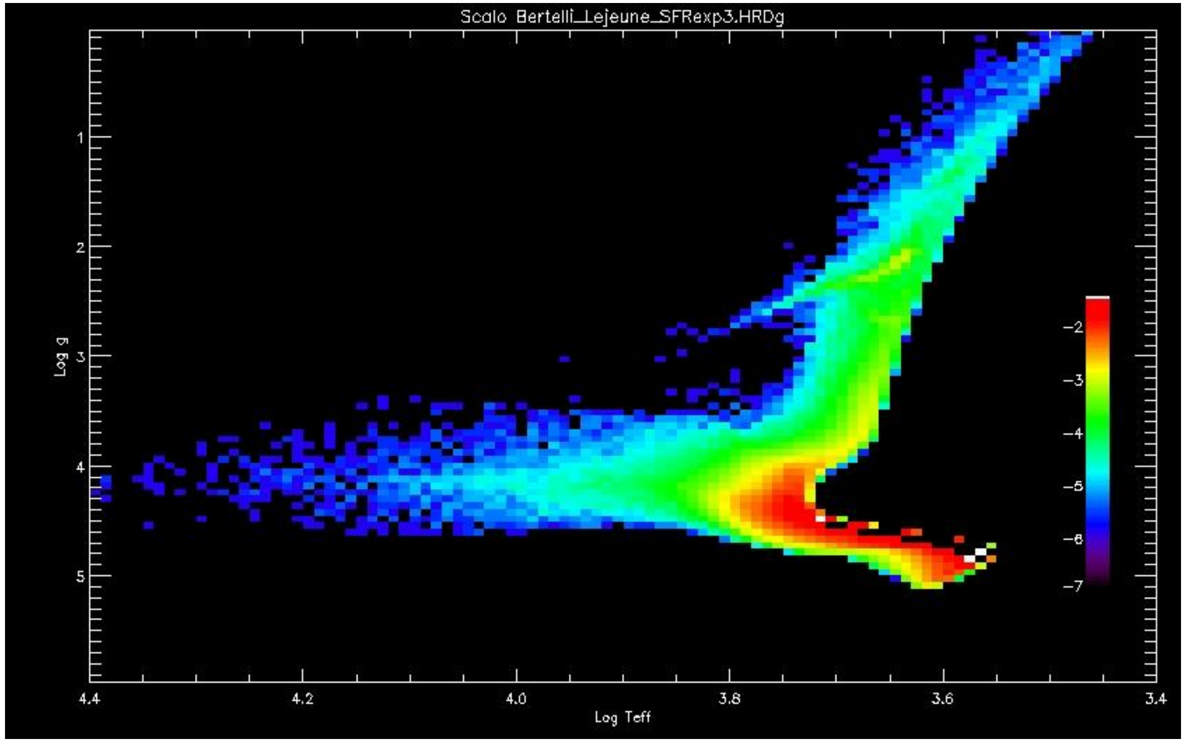


Prior probability in the (log T – log g) diagram for different **SFR**'s



Prior probability in the (log T – log g) diagram for **SFR_08_2i** and **EXP3**





Using stellar clusters with “known” ages to find the “correct” SFR

- **NGC 2420**: age = 2.0 Gyr+/- 0.4, [M/H] = -0.37, dist = 2510 pc, E[B-V] = 0.04
  - Meszaros 2013, AJ 146,133; Jacobson 2011, AJ 142, 59; Cayrel 2001, A&A,373, 159; Cenarro 2007, MNRAS, 374, 664; Pancino 2010, A&A 511, 56; Lee 2008, AJ 136, 2050

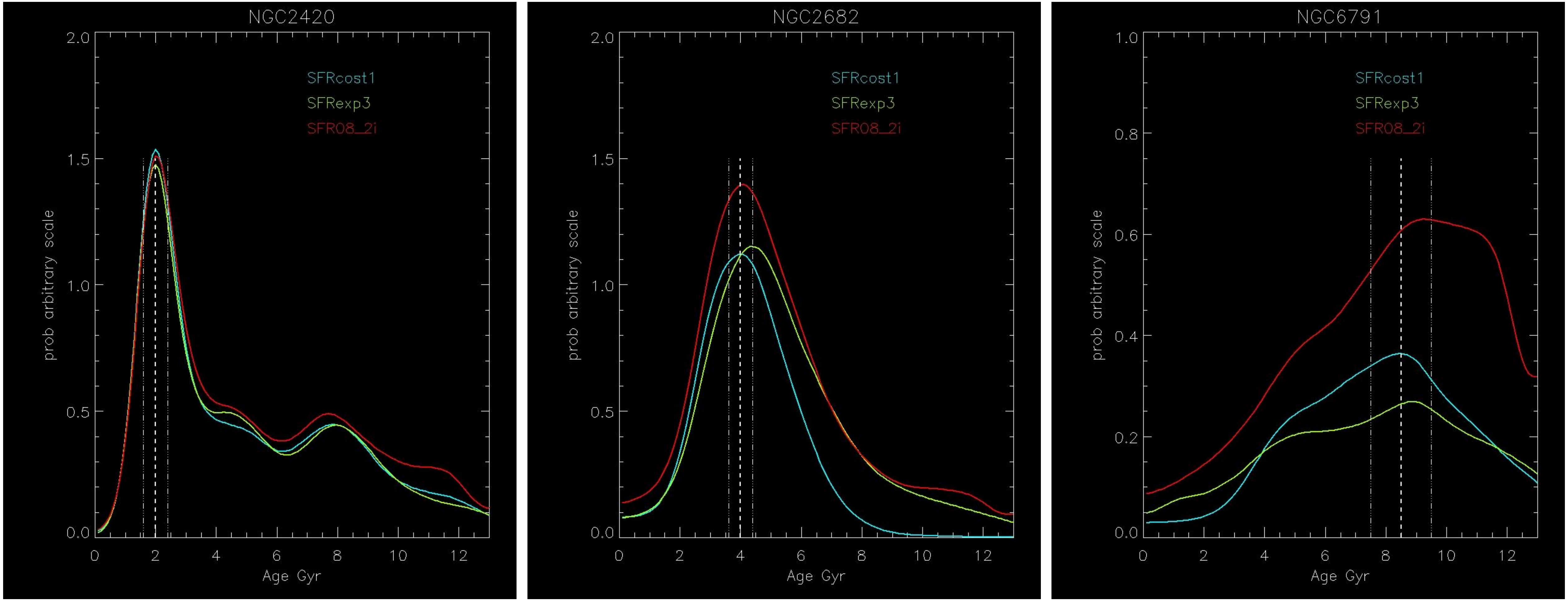
- **NGC 2682**: age=4.0 Gyr +/- 0.4 , [M/H] = 0.02, dist = 908 pc, E[B-V] = 0.032
  - Reddy 2013, MNRAS 431,338; Lee 2008, AJ 136, 2050; Friel 2010, AJ 139, 1942; Jacobson 2013, AJ 145, 107; Yong 2005, AJ 130, 597; Randich 2006, A&A 450, 557; Meszaros 2013, AJ 146,133; Pancino 2010, A&A 511, 56; Pace 2008, A&A 489, 403; Santos 2009, A&A 493, 309; Shetrone 2000, AJ 120, 1913; Hobbs 1991, AJ 102, 1070; Tautvaisiene 2000, A&A 360, 499;

- **NGC 6791**: age=8.5 Gyr +/- 0.5 , [M/H] = 0.30, dist = 3890 pc, E[B-V] = 0.117
  - Bragaglia 2014, ApJ 796, 68; Smolinski 2011, AJ 141, 89;

Percentage of stars with the “correct” age in each cluster by using different SFR’s

	N star	SFR_{cost}	SFR_{exp3}	SFR_{exp5}	SFR_{exp7}	SFR_{exp9}	SFR_{exp11}	SFR_{2i}	SFR_{2i_noth}
NGC 2420	64	47 %	44 %	46 %	47 %	47 %	45 %	44 %	45 %
NGC 2682	81	51 %	51 %	64 %	59 %	60 %	57 %	**78 %**	58 %
NGC 6791	81	30 %	23 %	26 %	26 %	27 %	26 %	**63 %**	37 %
…									

Cluster ages from individual stellar ages using different SFR's (cost, exp3 and SFR08_2i)



Using the "correct" SFR to derive the age of field stars

- Spectroscopic properties of cool stars (**SPOCS sample**):

  Valenti J.A., Fischer D.A. Astrophys. J. Suppl. Ser., 159, 141-166 (2005)

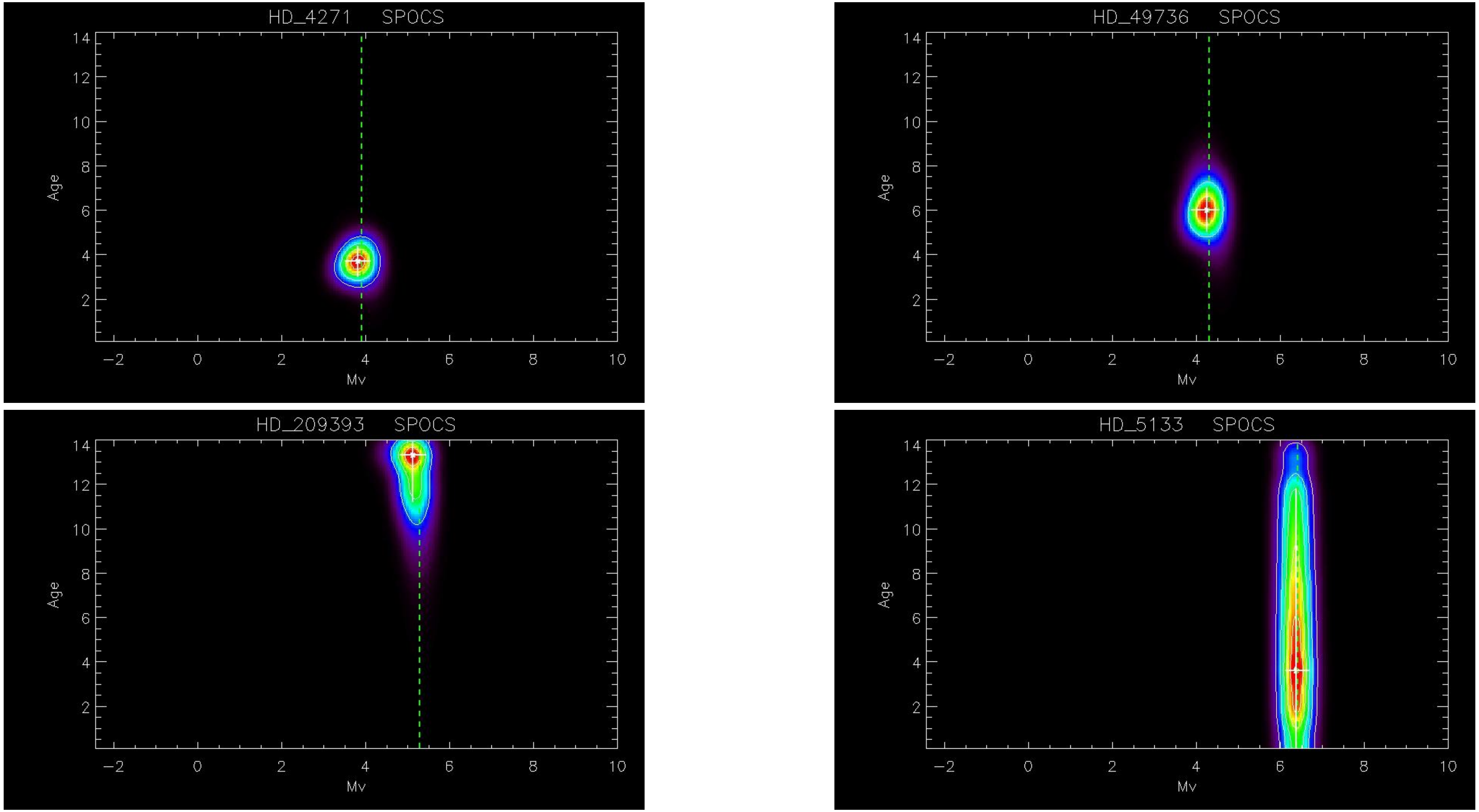
  " … a uniform catalog of stellar properties for 1040 nearby F, G, and K stars that have been observed by the Keck, Lick, and AAT planet search programs. Fitting observed echelle spectra with synthetic spectra yielded effective temperature, surface gravity, metallicity, projected rotational velocity, and abundances of the elements Na, Si, Ti, Fe, and Ni, for every star in the catalog."

- The FEROS-Lick/SDSS observational data base of spectral indices of FGK stars for stellar population studies (**FEROS sample**):

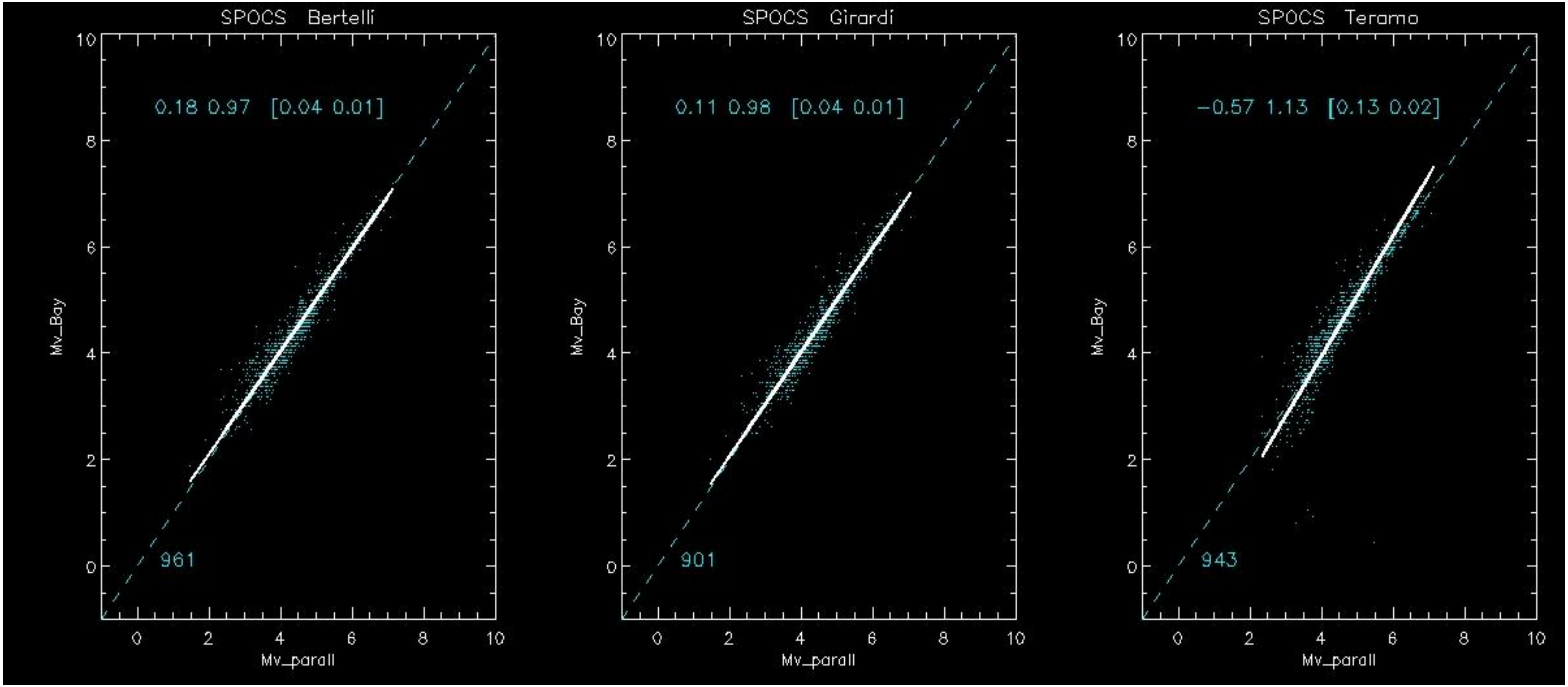
  Franchini, M.; Morossi, C.; Di Marcantonio, P. ; Malagnini, M. L.; Chavez, M. MNRAS, Volume 442, 220-228 (2014)

" … 1085 non-supergiant F, G, and K stars with atmospheric parameter estimates from the AMBRE project."

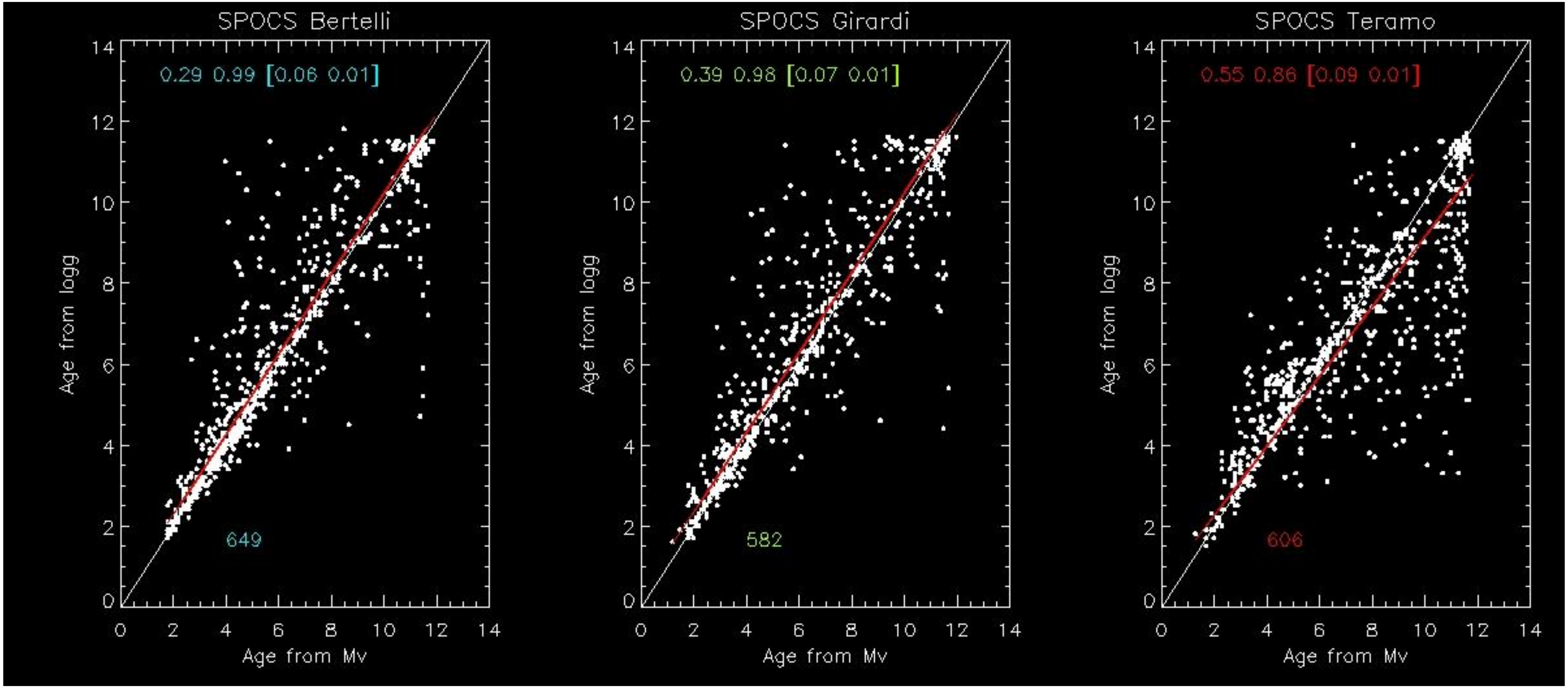
SPOCS sample: examples of 2-D P(τ, MV)



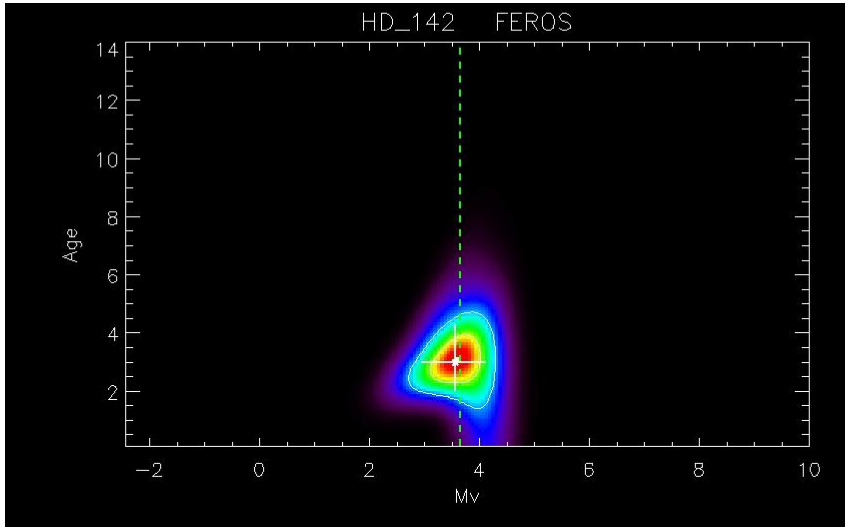
SPOCS sample: M_v from $P(\tau, M_v)$ versus M_v from parallasses using different stellar evolution libraries

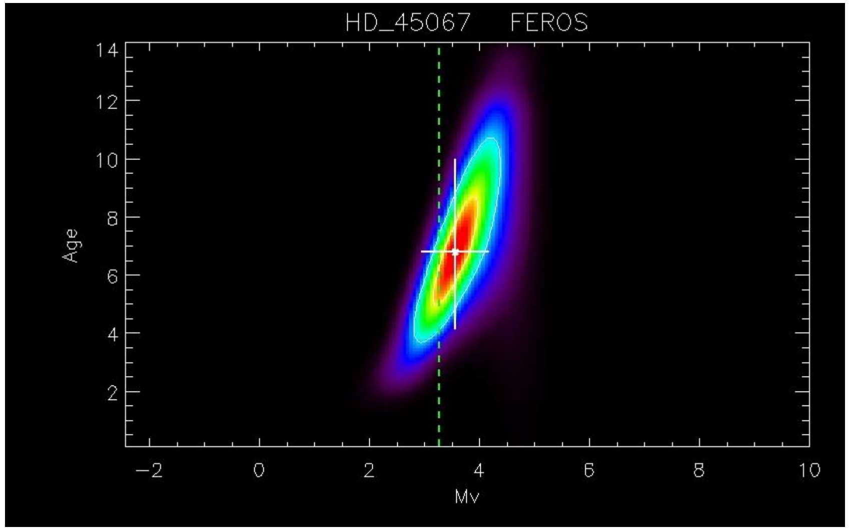


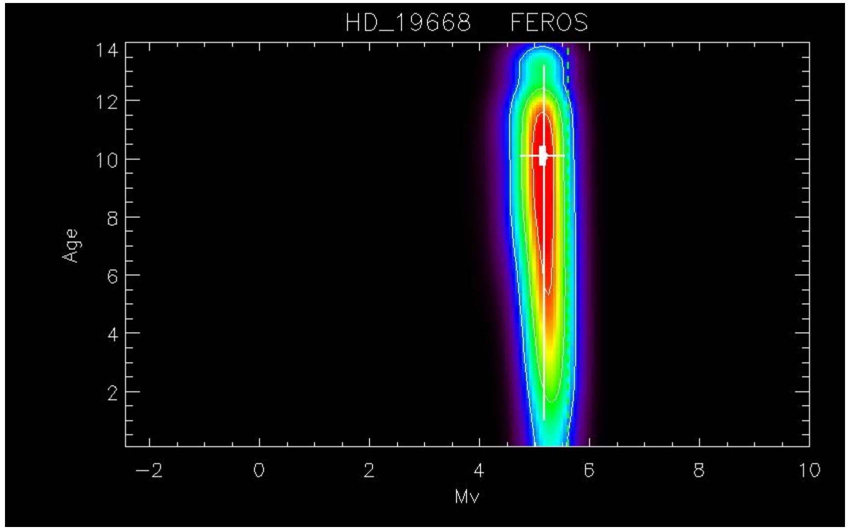
SPOCS sample: comparison of ages derived from (log T, log g, [M/H]) and from (log T, Mv, [M/H])

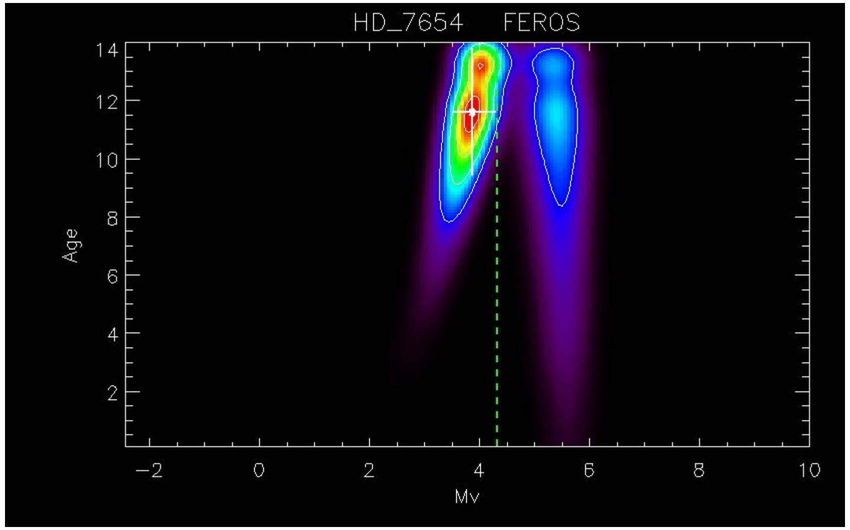


FEROS sample: examples of 2-D P(τ, MV)

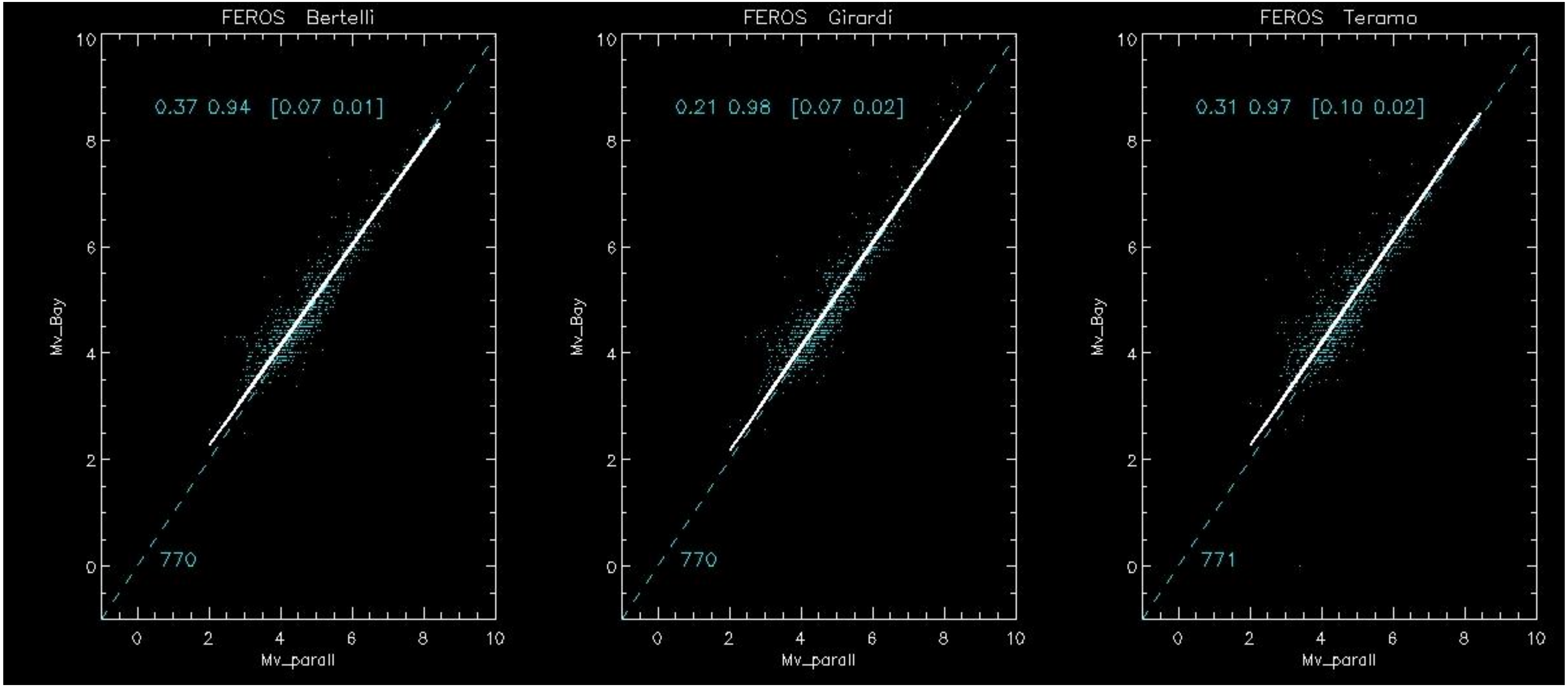




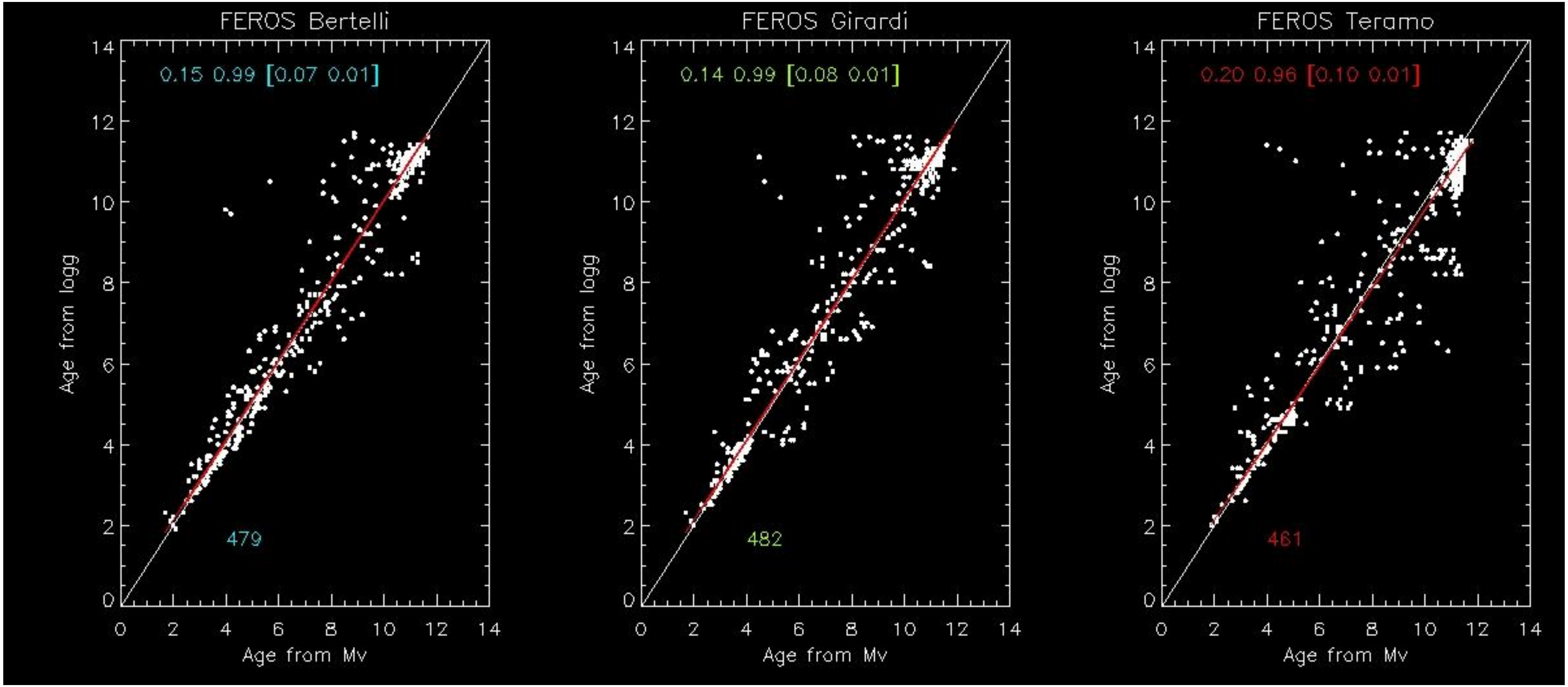




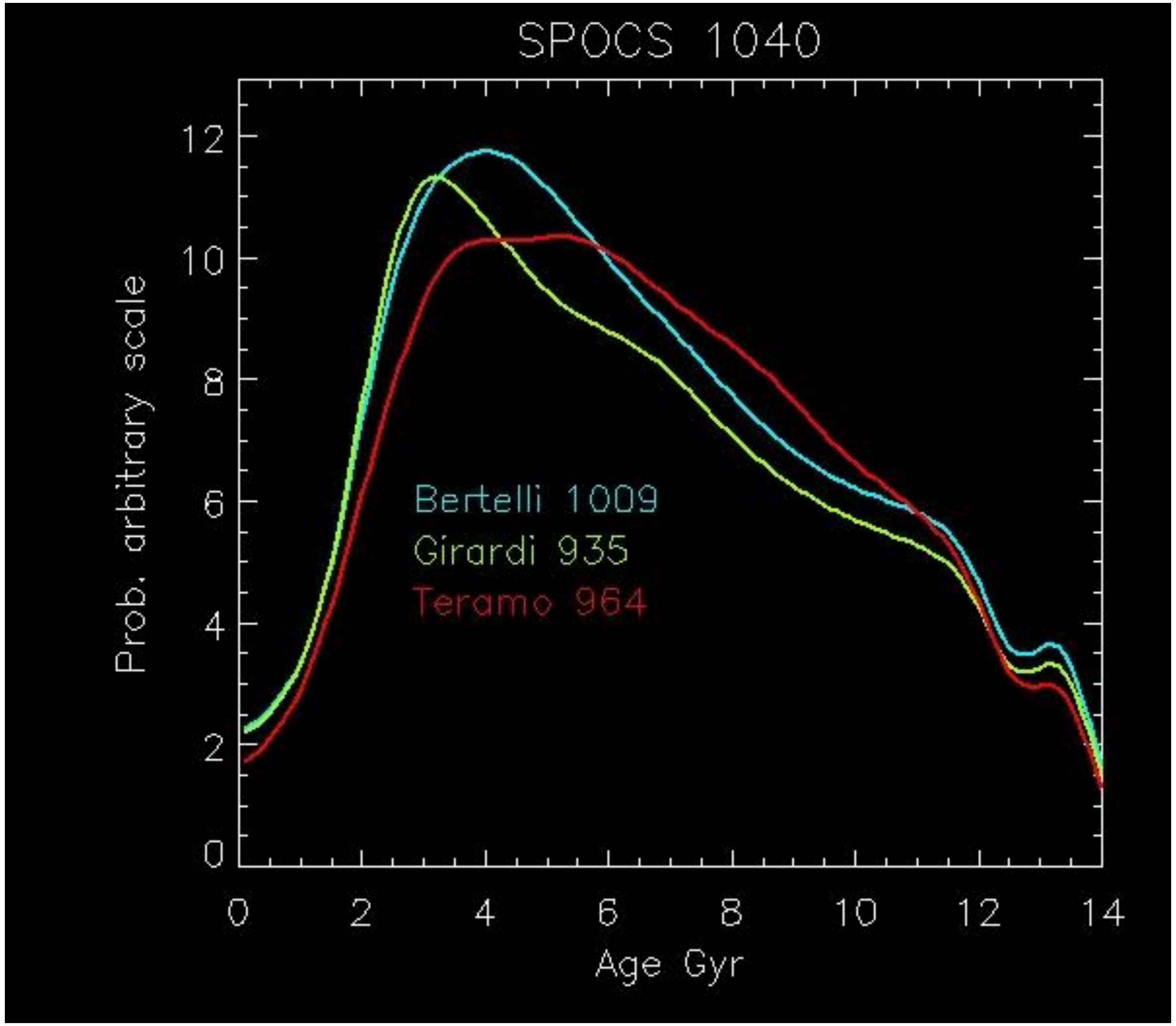
FEROS sample: M_v from $P(\tau, M_v)$ versus M_v from parallasses using different stellar evolution libraries

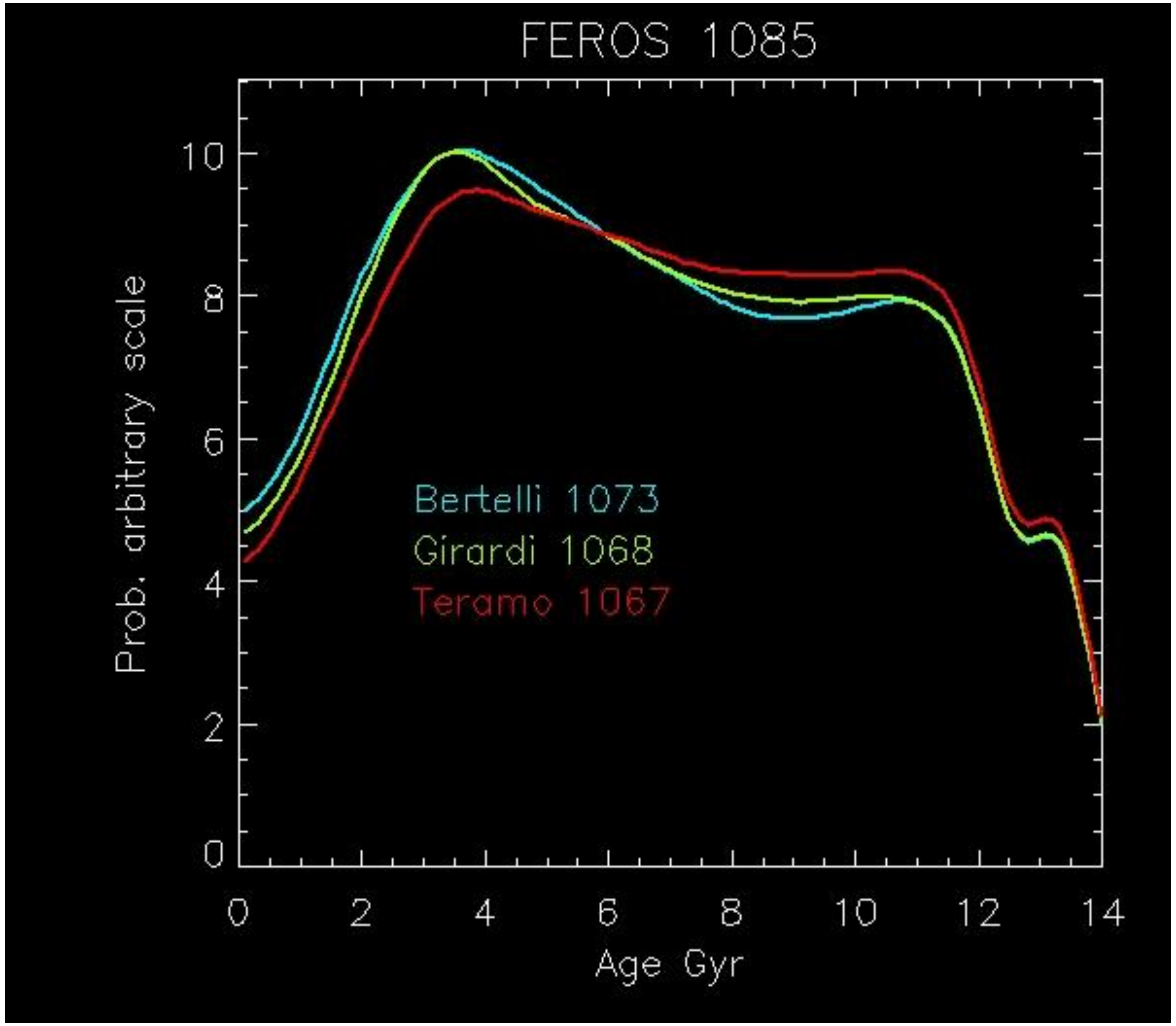


FEROS sample: comparison of ages derived from (log T, log g, [M/H]) and from (log T, Mv, [M/H])



Age distributions for SPOCS and FEROS sample using different stellar evolution libraries





Age – metallicity relation for the stars in SPOCS sample