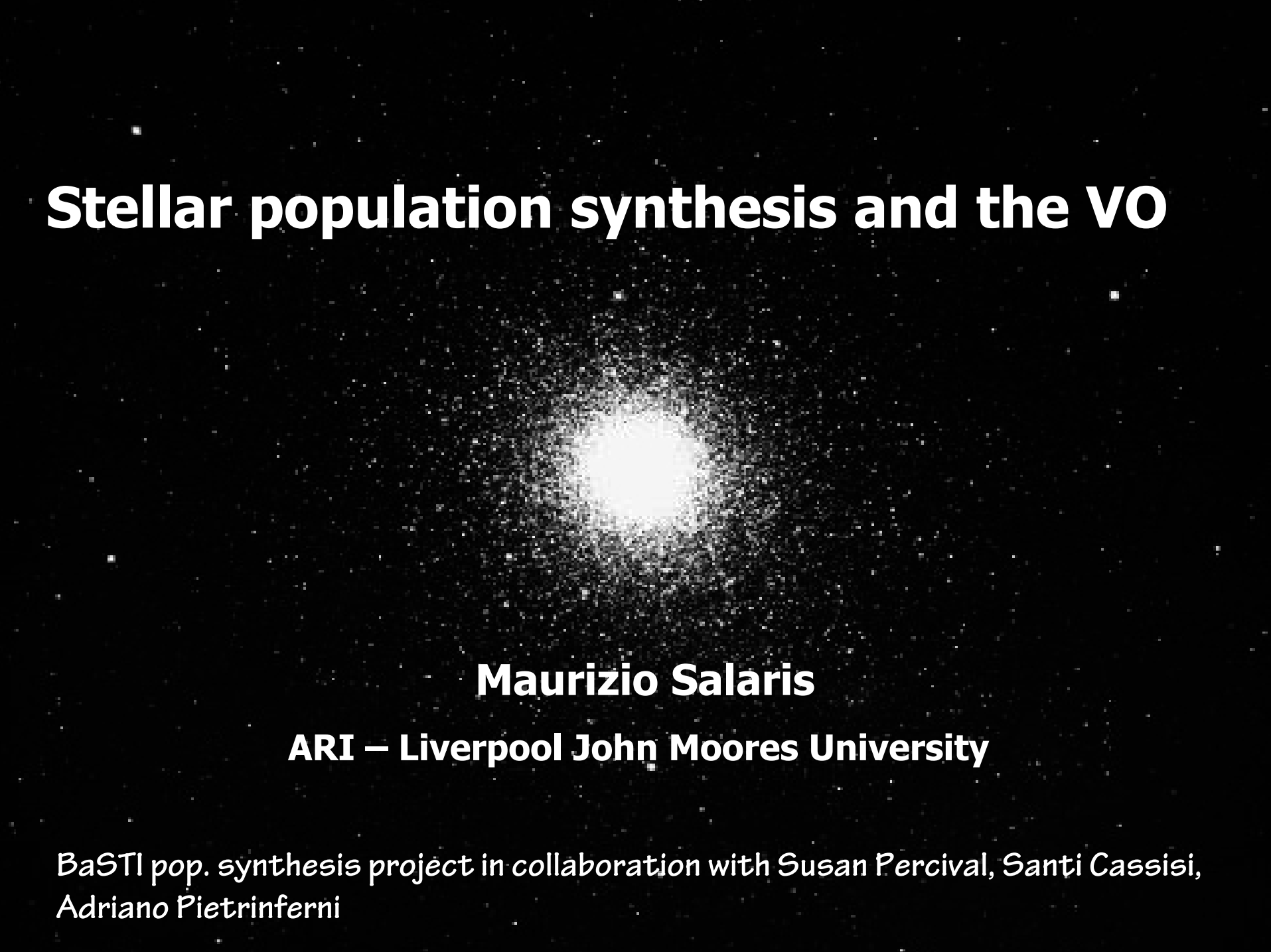
Stellar population synthesis and the VO



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BaSTI pop. synthesis project in collaboration with Susan Percival, Santi Cassisi, Adriano Pietrinferni

OUTLINE

- What/why/How ?
- Model ingredients
- Choices, choices, choices (and what about variable abundance ratios?)….
- Testing the choices (?)
- BaSTI for population synthesis
- Population synthesis and the VO

WHAT

Stellar population synthesis models are tools for interpreting the integrated light that we observe from unresolved stellar populations (galaxies, star clusters).

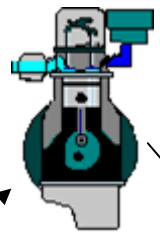
A so-called 'population synthesis model' provides the integrated spectrum and magnitudes/colours (plus mass to light-ratios in various wavelength bands) of a stellar population with a specific star formation history and an assumed IMF

GALAXEV, Pegase, Galadriel, Starburst99, Buzzoni, BaSTI (very soon) ,SED@+ others

WHY
Inverse approach

Photometric/spectroscopic observations unresolved stellar populations

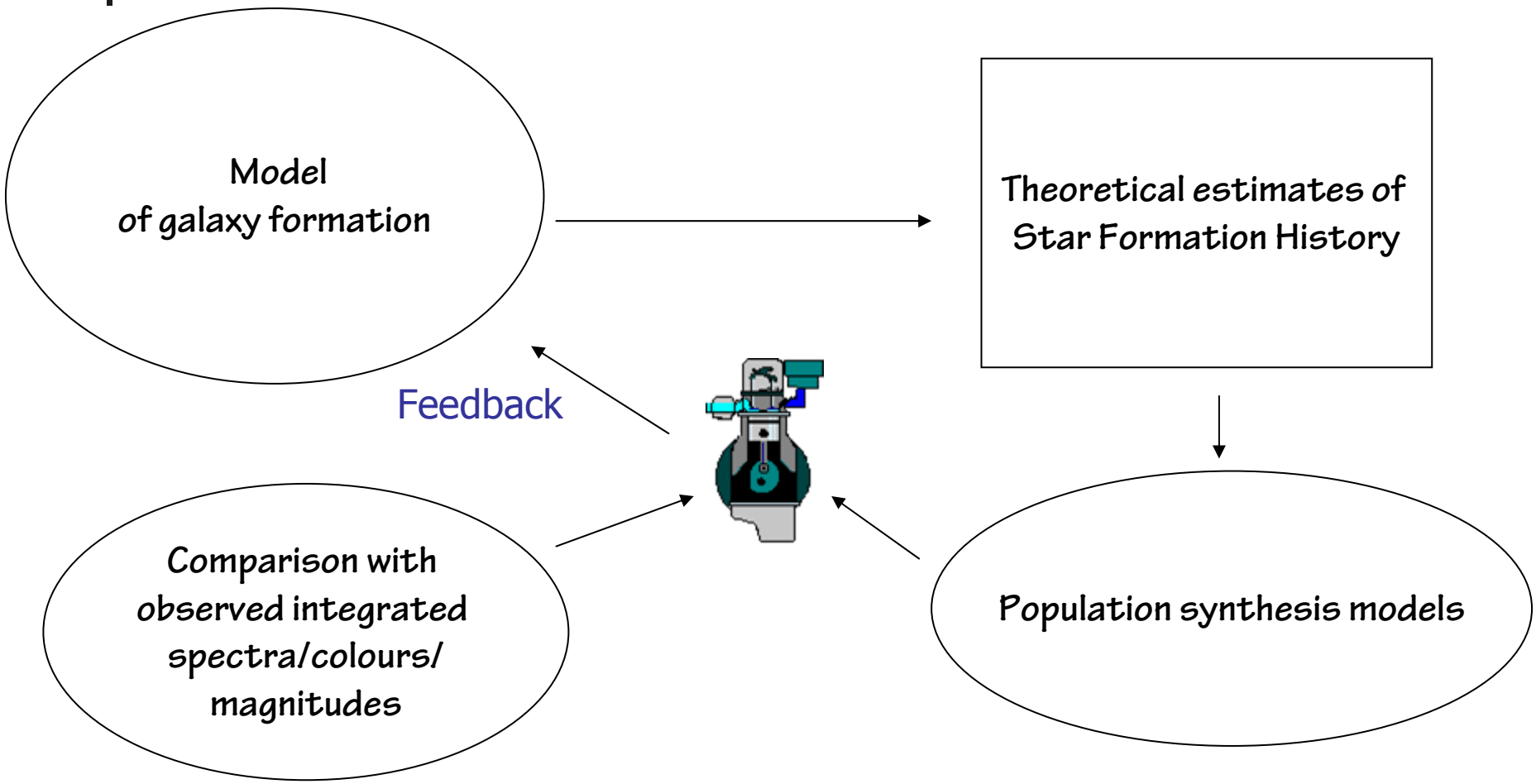
Observed integrated spectrum/colours/ magnitudes



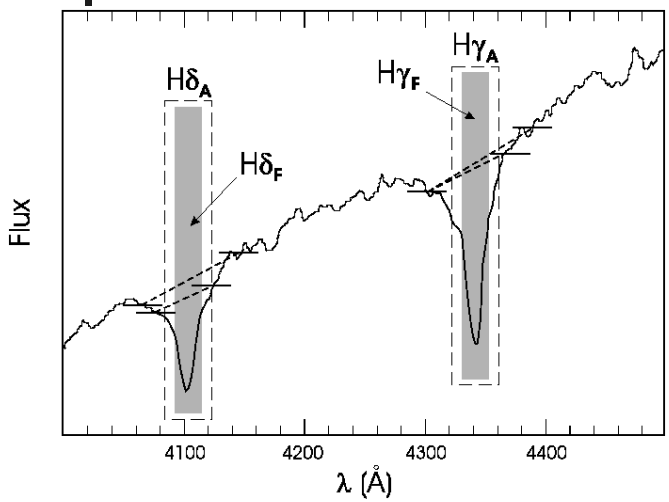
Population synthesis models

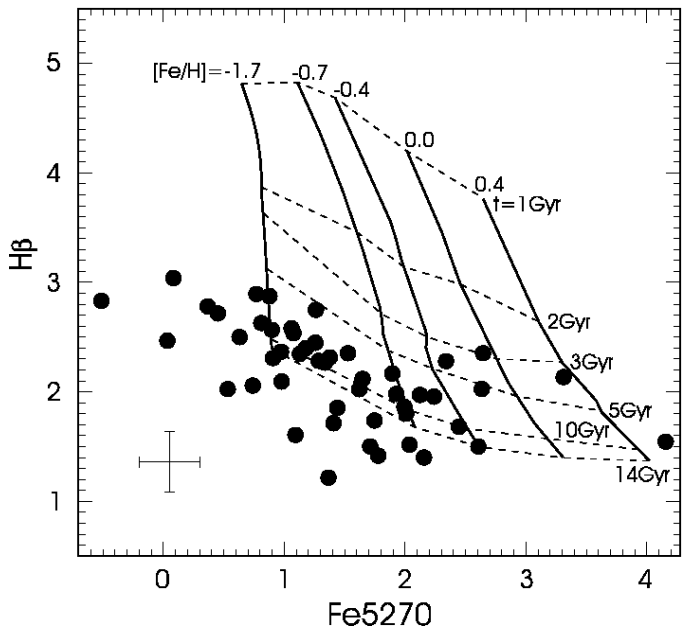
Estimate of population
Star Formation History

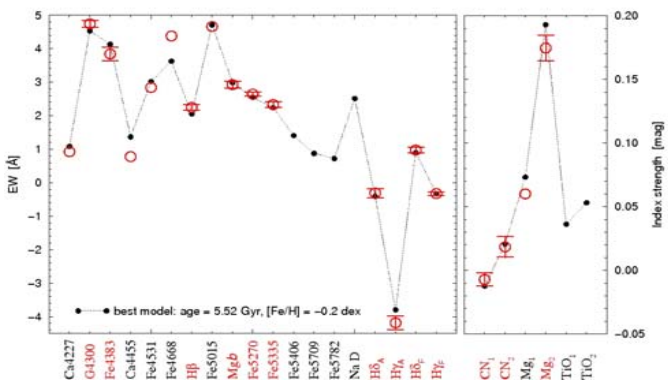
WHY
Direct approach



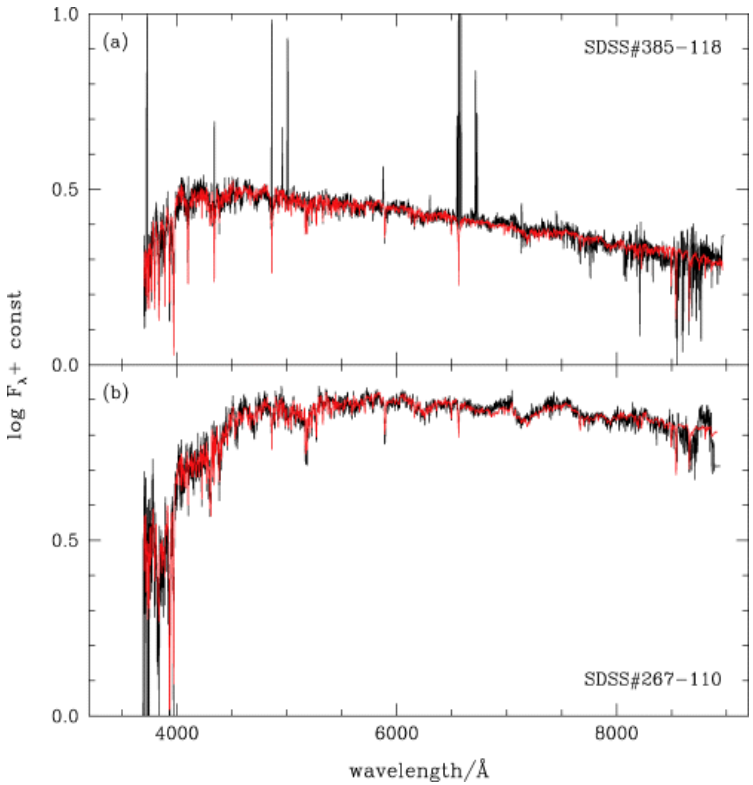
HOW (I)


Hδ_A
Hγ_F
Hγ_A
Hδ_F
Flux
4100
4200
4300
4400
λ (Å)

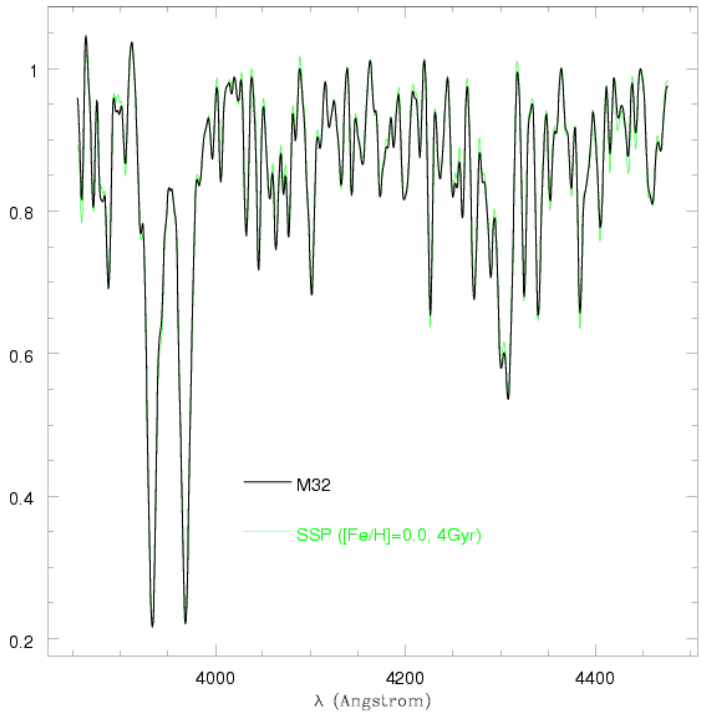

[Fe/H]=-1.7
-0.7
-0.4
0.0
0.4
t=1Gyr
2Gyr
3Gyr
5Gyr
10Gyr
14Gyr
Hβ
Fe5270


EW [Å]
index strength [mag]
best model: age = 5.52 Gyr, [Fe/H] = −0.2 dex
Ca4227
G4300
Fe4383
Ca4455
Fe4531
Fe4668
Hβ
Fe5015
MgB
Fe5270
Fe5335
Fe5406
Fe5709
Fe5782
Na D
HδA
HγA
HδF
HγF
CN1
CN2
Mg1
Mg2
TiO1
TiO2

HOW (II)

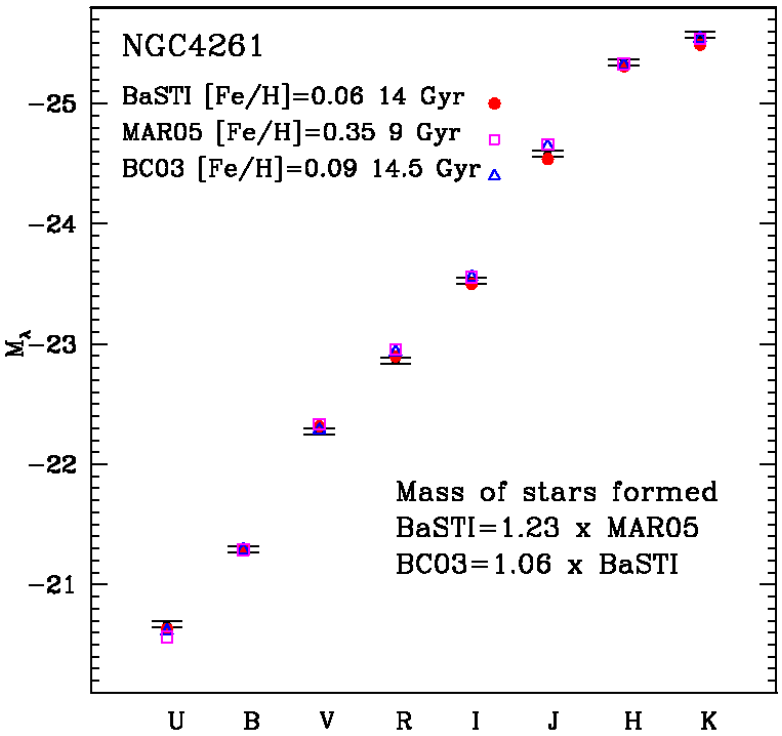


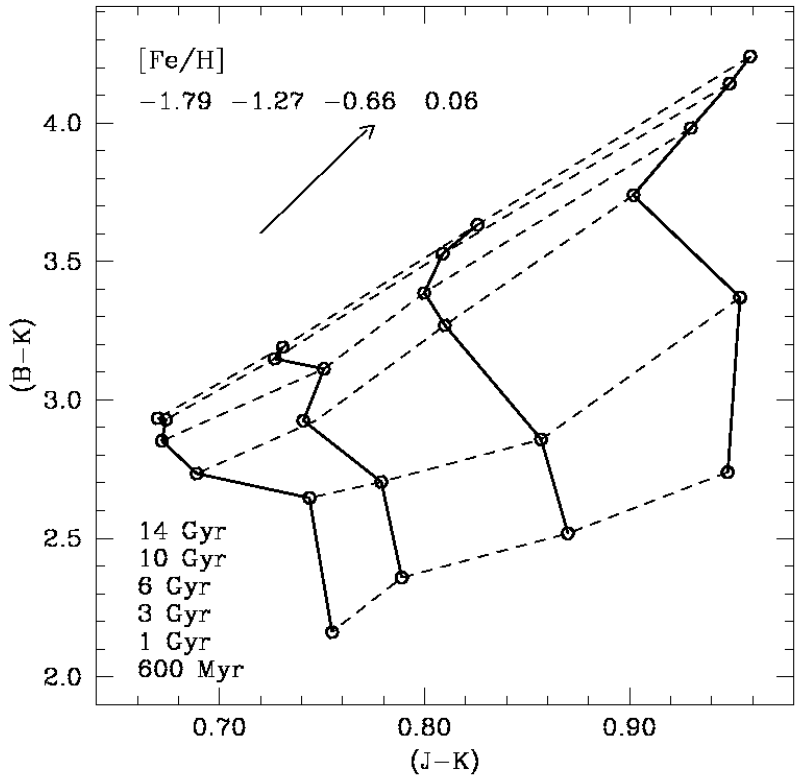
GALAXEV



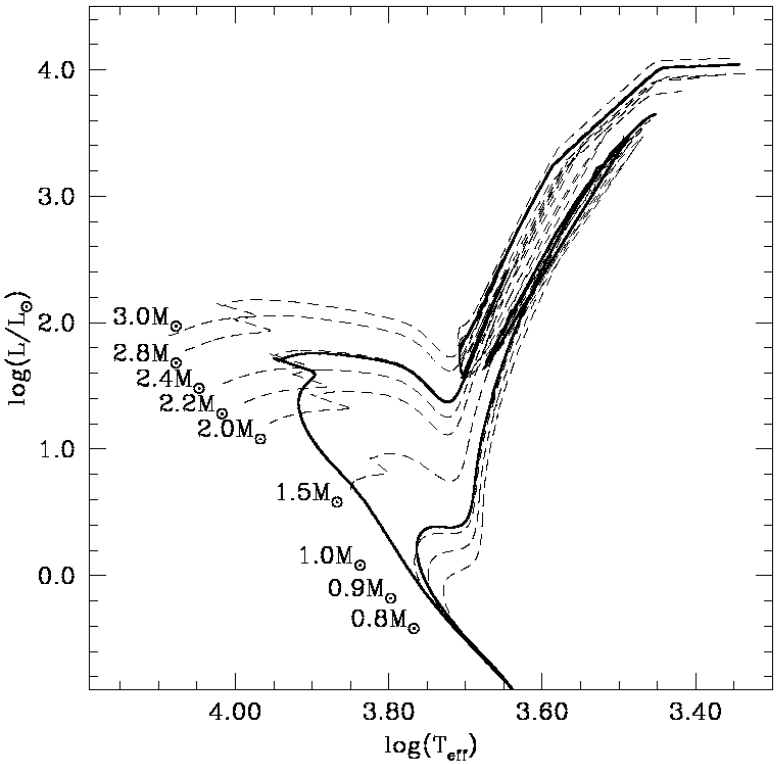
Vazdekis

HOW (III)

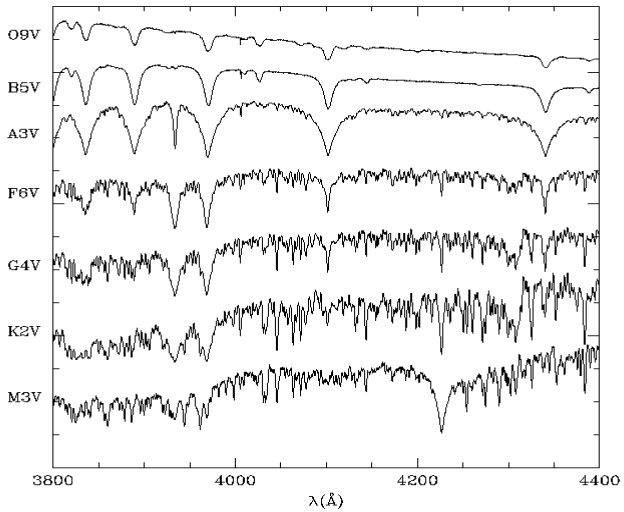

NGC4261
BaSTI [Fe/H]=0.06 14 Gyr
MAR05 [Fe/H]=0.35 9 Gyr
BC03 [Fe/H]=0.09 14.5 Gyr
Mass of stars formed
BaSTI=1.23 x MAR05
BC03=1.06 x BaSTI
M_λ
−25
−24
−23
−22
−21
U
B
V
R
I
J
H
K


[Fe/H]
−1.79 −1.27 −0.66 0.06
14 Gyr
10 Gyr
6 Gyr
3 Gyr
1 Gyr
600 Myr
(B−K)
4.0
3.5
3.0
2.5
2.0
0.70
0.80
0.90
(J−K)

Population synthesis: Ingredients



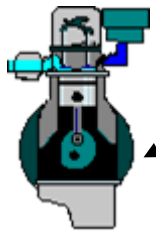
Stellar model/isochrone library



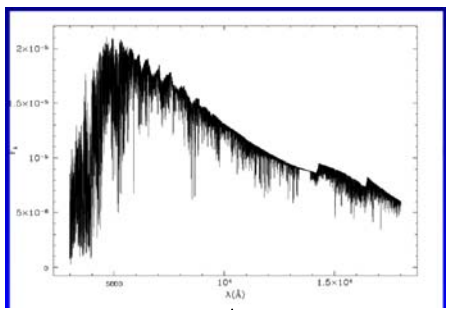
Library of stellar spectra

Each point along an isochrone is specified by (L, Teff, M, [Fe/H]) or also (Teff, g, [Fe/H])

Libraries of stellar spectra. Each spectrum is specified by (Teff, g [Fe/H])



Integrated spectrum



IMF to give number of stars along isochrone for a fixed total mass of the population

Effect of dust

Nebular emission

K-correction

Line strengths,
integrated colours,
magnitudes
mass-to-light ratios

INPUT CHOICES

IMF → Functional form; universal ?

Model/isochrone library → ([Fe/H], [E/H], t) and evolutionary phase coverage; mass loss history (massive stars, HB morphology, AGB)

Spectral library → Resolution; λ range; (g,[Fe/H],[E/H],T_{eff}) coverage; S/N, flux calibration; parameter determination for the library stars; line lists; atmosphere modelling

Model/isochrone library shopping basket

(not exhaustive)

BaSTI (include AGB)

Padua (include AGB)

DSEP (partial post-MS coverage)

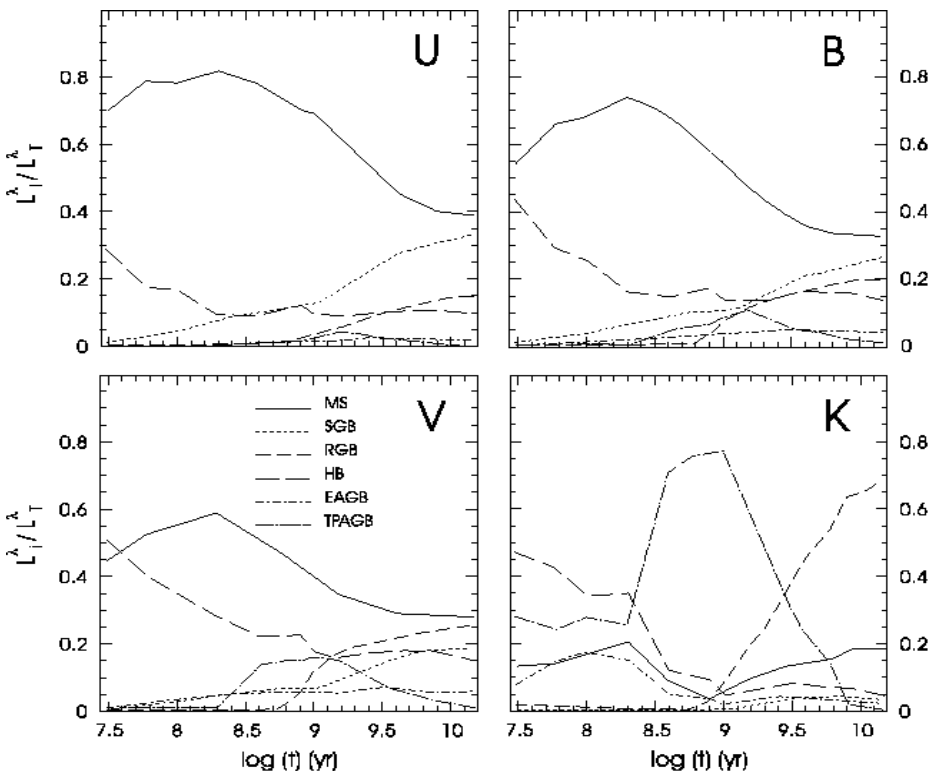
Y2 (partial post-MS coverage)

Victoria (partial post-MS coverage)

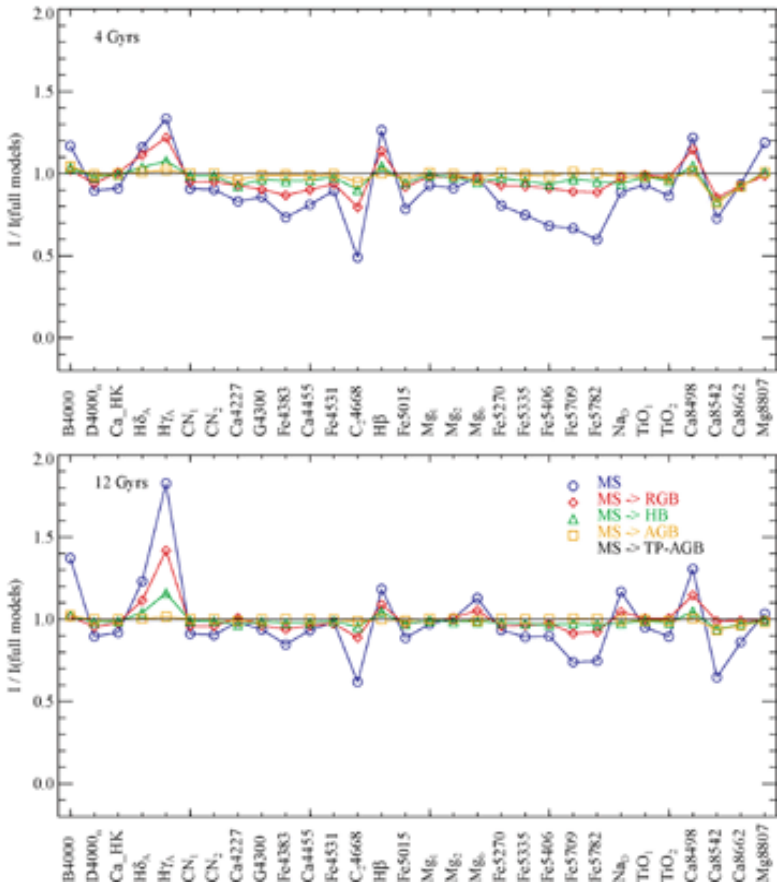
Geneva (partial post-MS coverage)

Evolutionary phase coverage is IMPORTANT

[Fe/H]=0.0



From Coelho et al. (2007)

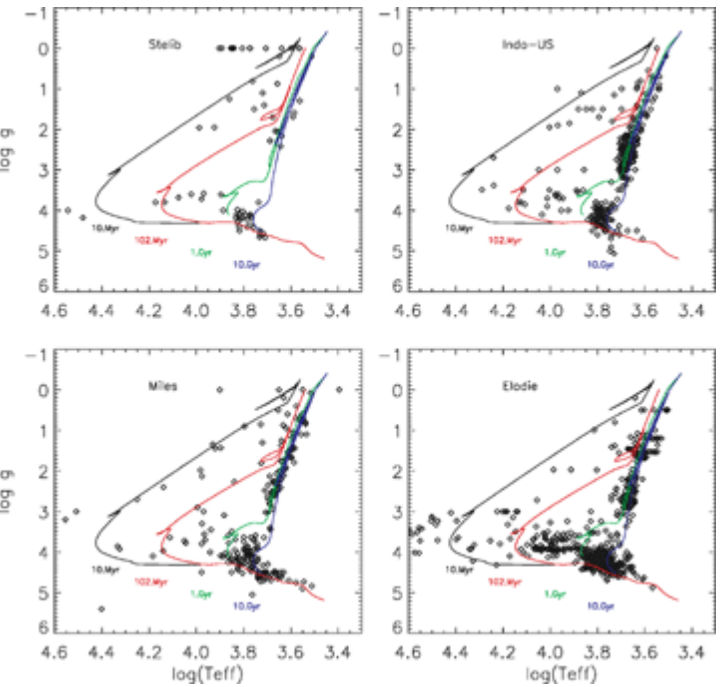


Spectral library shopping basket
(not exhaustive)

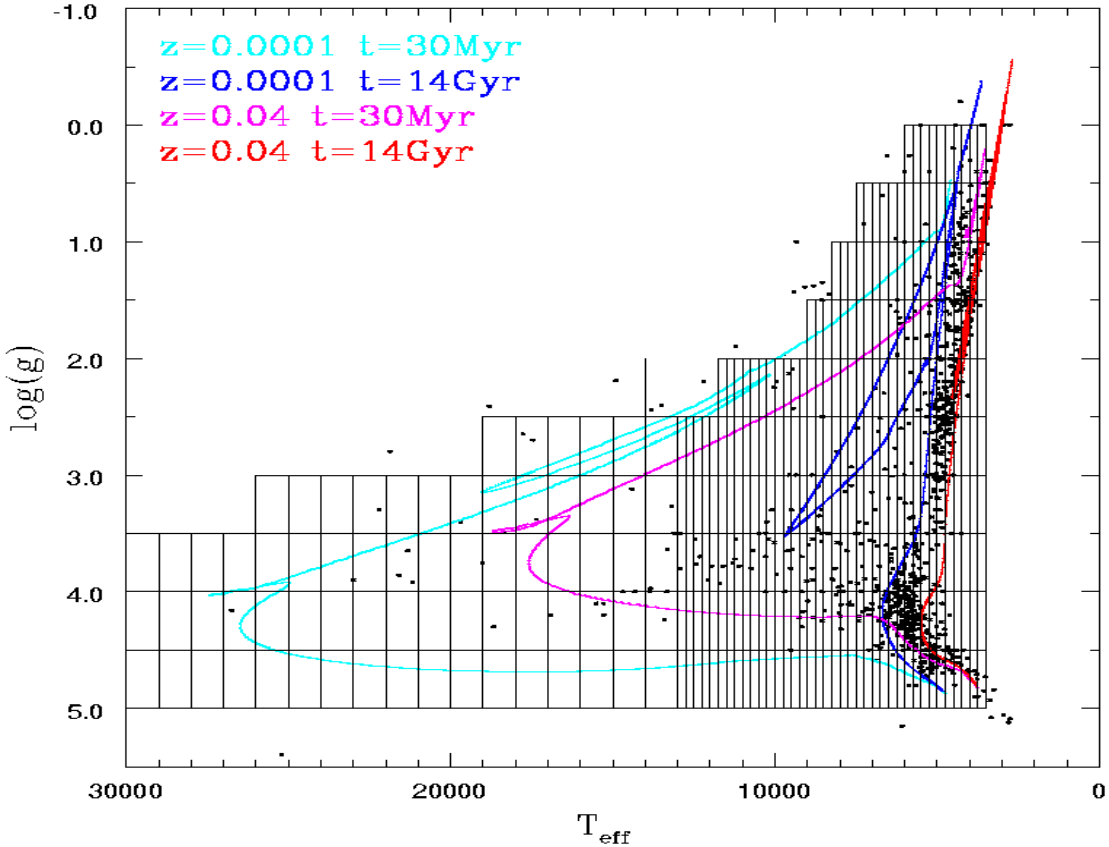
Empirical	Theoretical
STELIB	Munari (ATLAS 9)
ELODIE	Coelho - IAG (ATLAS 9)
INDO-US	Martins
MILES	MARCS
UVES-POP	PHOENIX
HNGSL	Basel (semiempirical)
Pickles	Kurucz (ATLAS 9)

PARAMETER COVERAGE

Solar composition

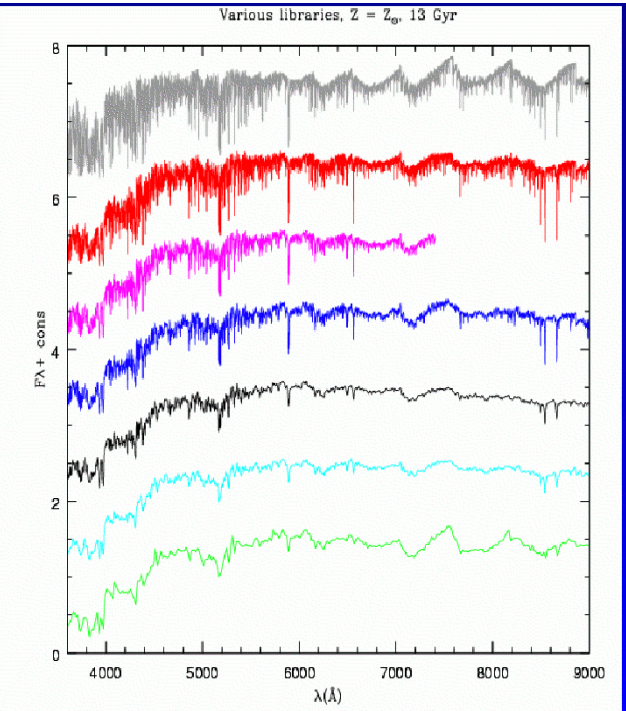


From Martins & Coelho (2007)



Munari – MILES spectral libraries

Different spectral/model libraries → Different integrated spectra

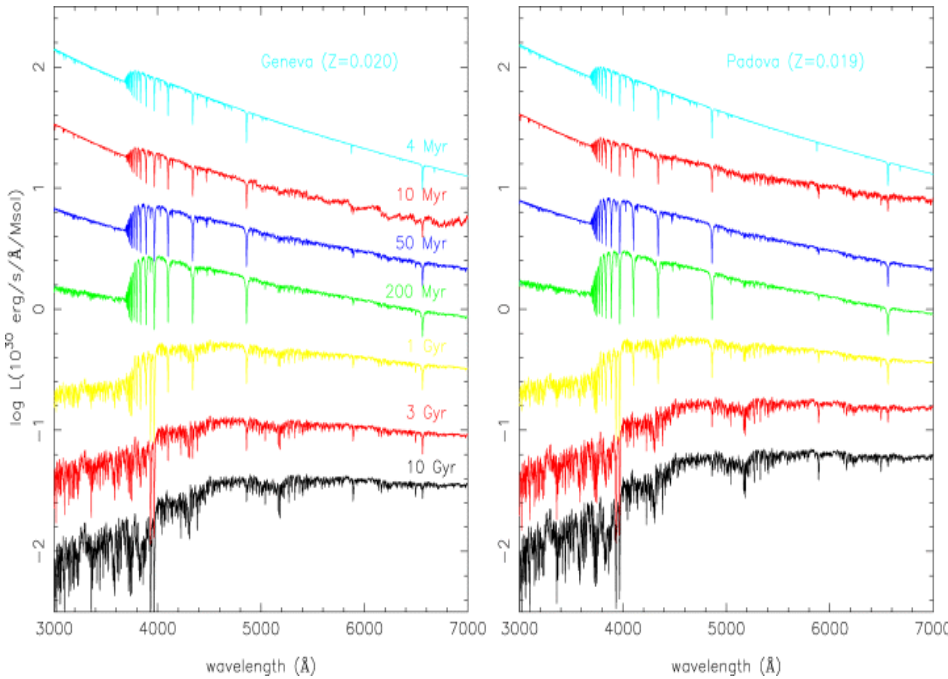


- IAG (< 1Å)
- IndoUS (~ 1Å)
- Miles (2.4 Å)

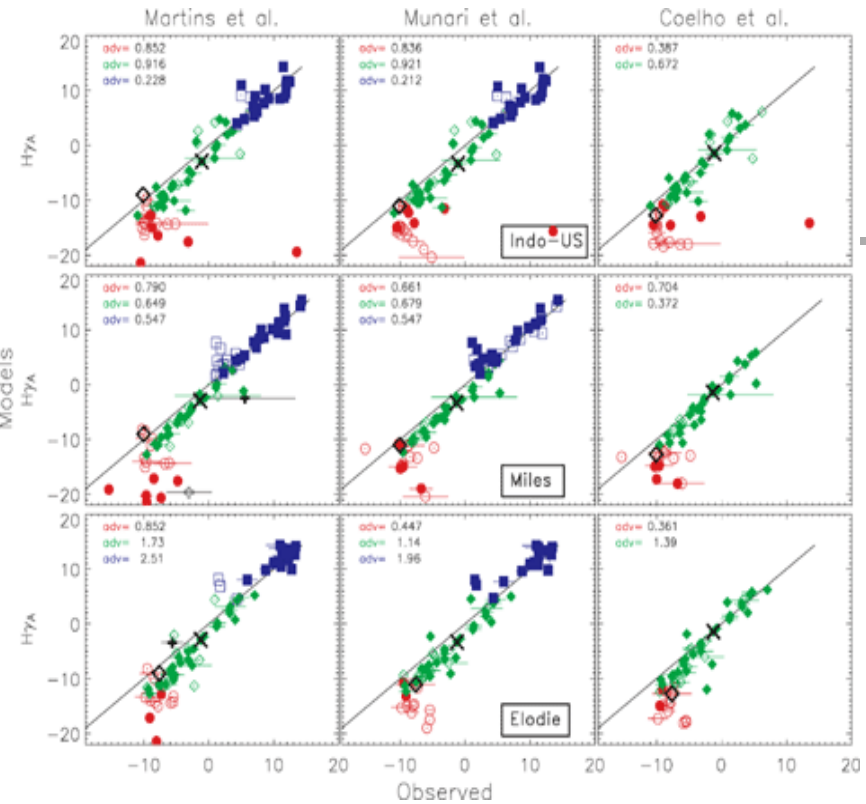
- Stelib (3 Å)
- HNGSL (~ 5Å)
- Pickles (5 Å)
- Kurucz (20 Å)

Padova 94 tracks

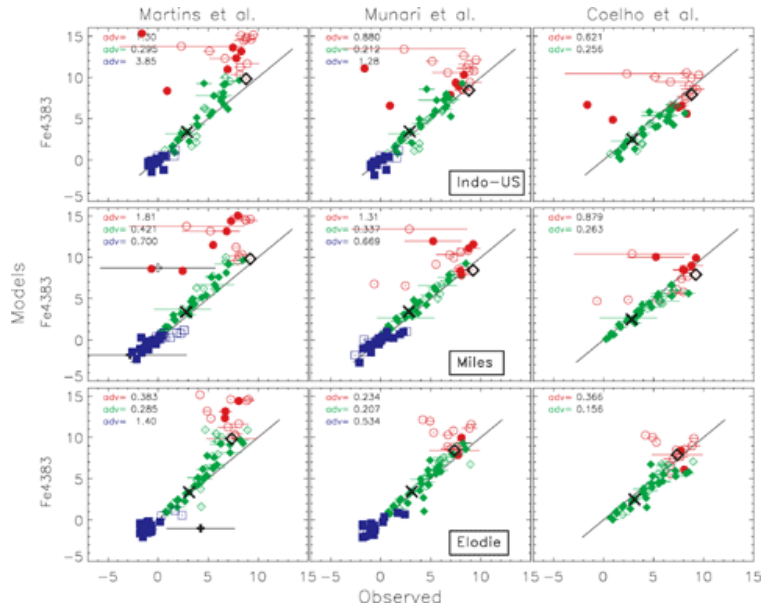
From Bruzual (2007)



From Gonzalez Delgado et al. 2005

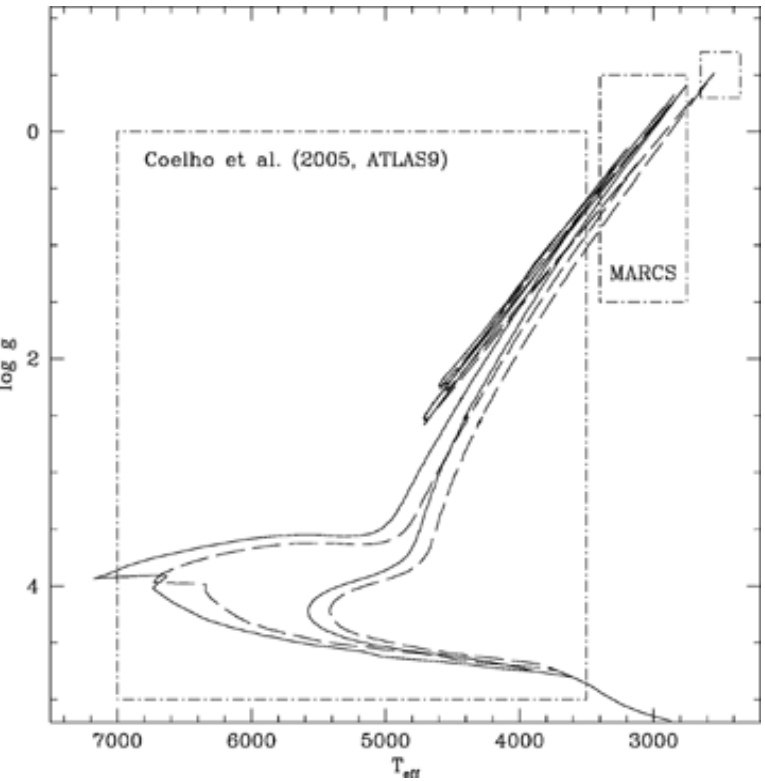


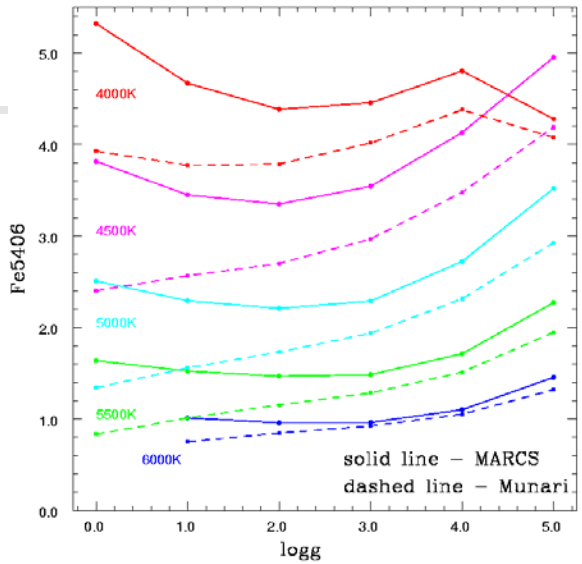
Comparison between line indices of individual stars. Theoretical vs empirical spectral libraries

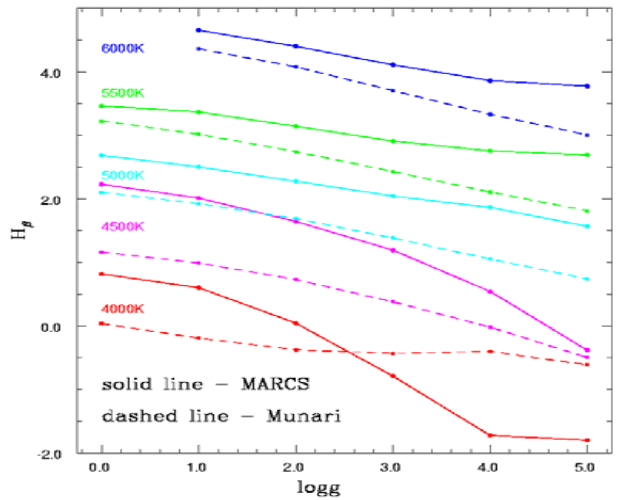


From Martins & Coelho (2007)

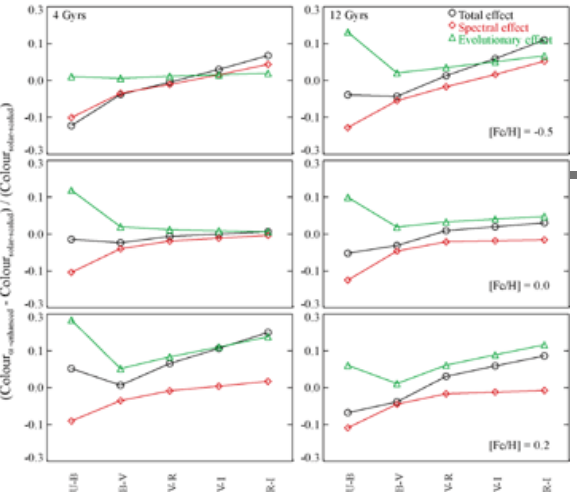
Mix'n match coverage: Different libraries may not match







Non scaled-solar metal mixture

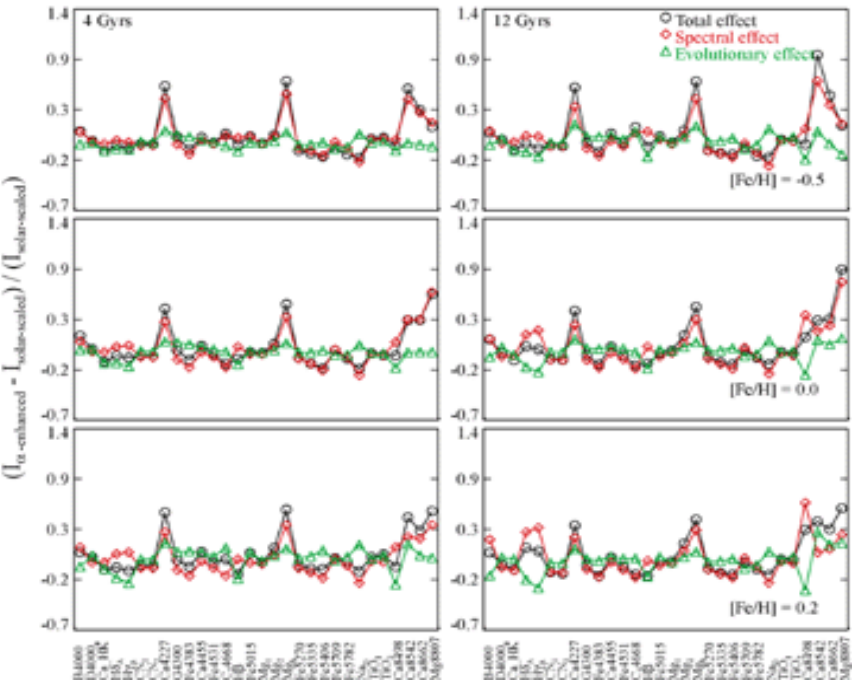


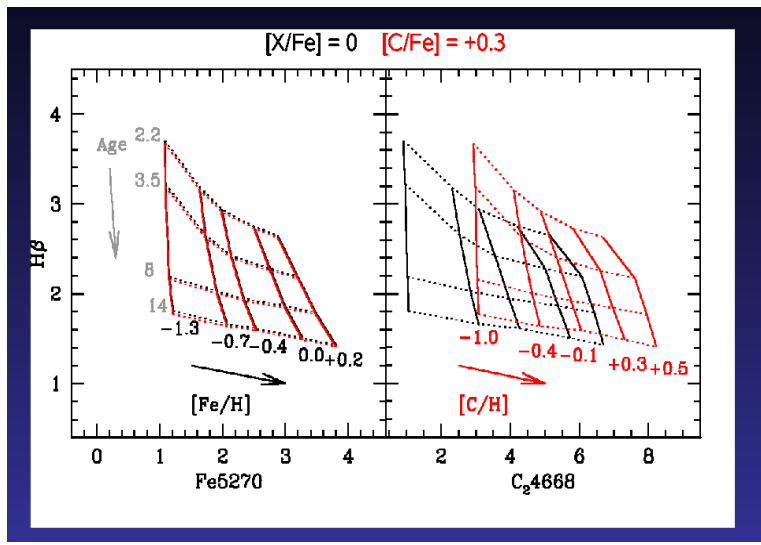
Schiavon (2007)

Consistent treatment

Coelho et al. (2007)

Only effect on stellar spectra, not evolutionary tracks. C affects heavily the TO region of an isochrone





Non scaled-solar metal mixture

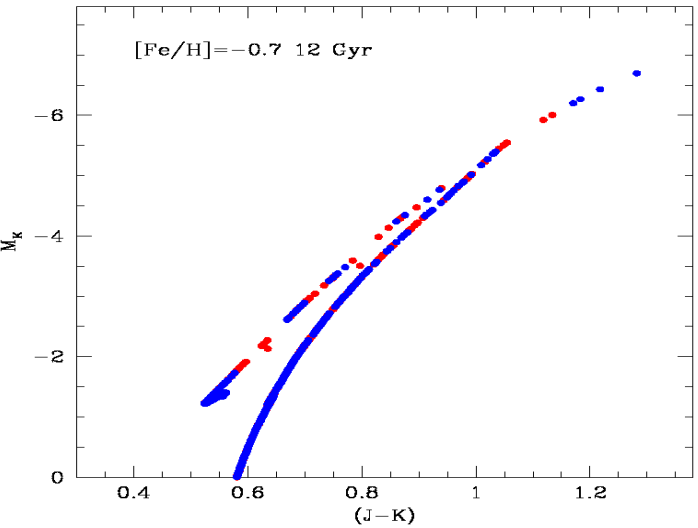
- BaSTI, Victoria, Padua (not exactly homogeneous), DSEP, Y2
- Theoretical spectral libraries (Munari, Coelho, MARCS)
- Fully consistent (non scaled solar) pop. Synthesis models:

  Coelho et al. – BaSTI (α-enhanced)

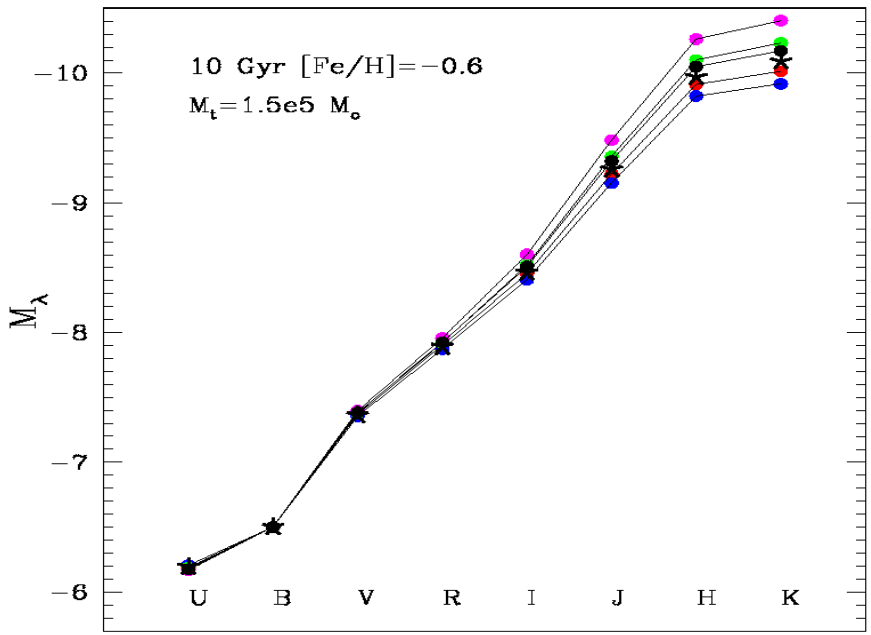
  (much larger parameter space)

Tests on Galactic star clusters
INTEGRATED MAGNITUDES

Statistical fluctuations integrated magnitudes



See also analytical work by Cervino & Luridiana



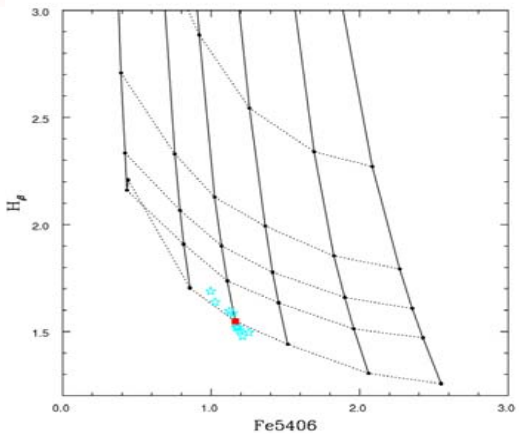
CNONa anticorrelations in Galactic globular clusters,
HB morphology,
Blue stragglers,
[Fe/H] scale of Galactic star clusters (+ detailed metal abundance pattern)

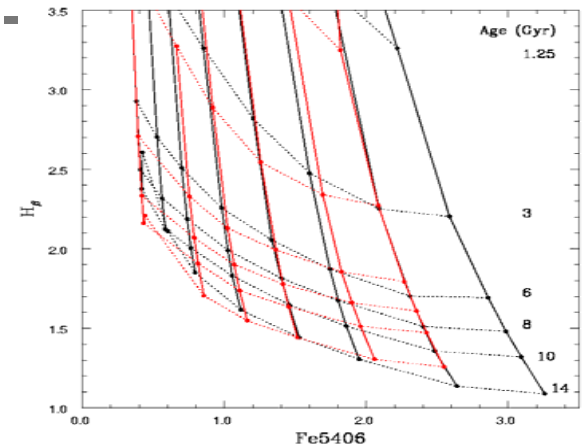
More PROBLEMS

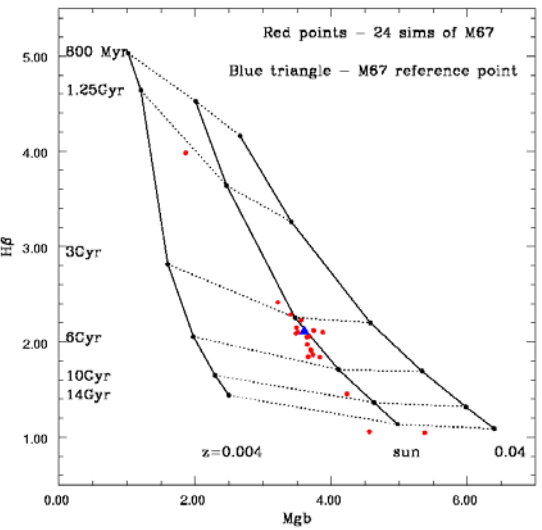
Index fluctuations in star clusters

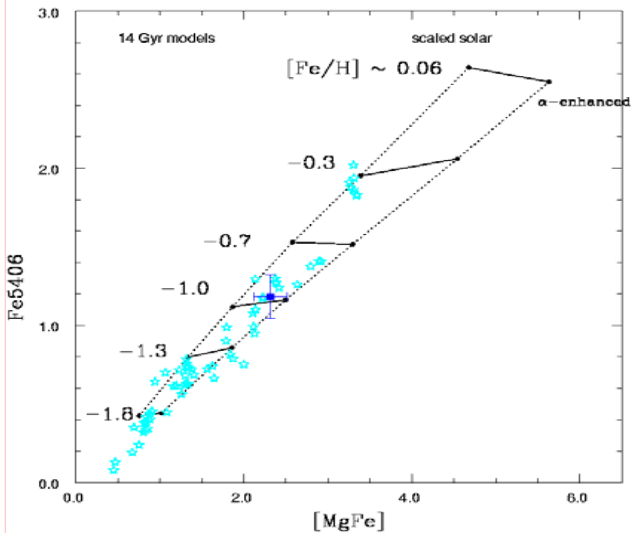
Tests on resolved star clusters

INTEGRATED SPECTRA









PROBLEMS

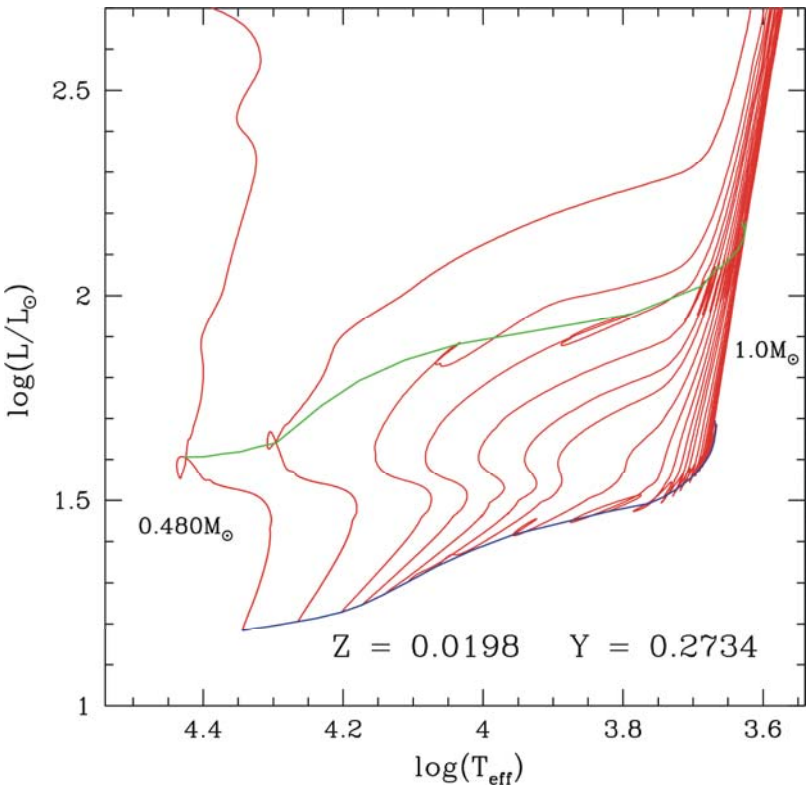
CNONa anticorrelations in Galactic globular clusters

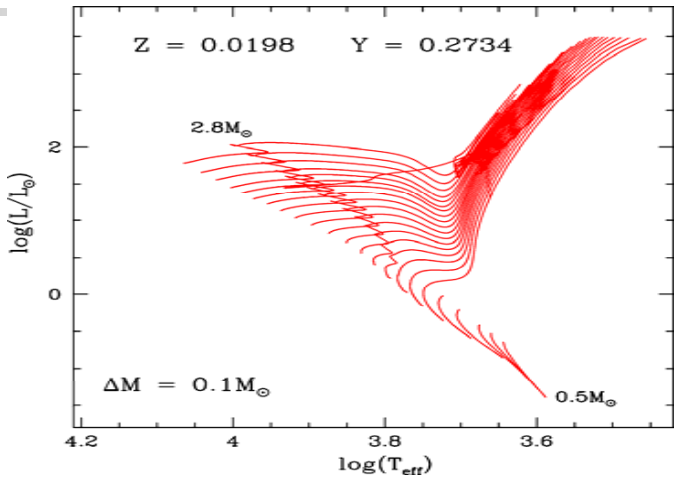
HB morphology

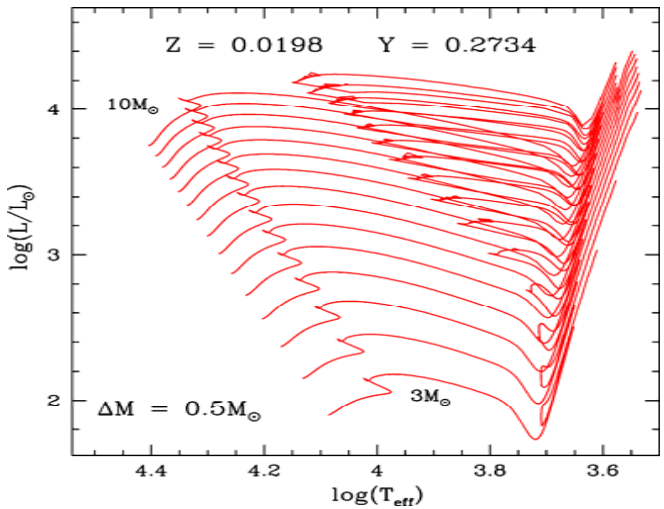
Blue stragglers

[Fe/H] scale of Galactic star clusters (+ detailed metal abundance pattern)

BaSTI models







-2.27 ≤[M/H]≤+0.40 [α/Fe]=0.0, 0.4

Spectral libraries used in BaSTI

Low-resolution spectra ($\lambda/\Delta\lambda$=200 – 500)
$90 \leq \lambda \leq 1.6e6$ Å

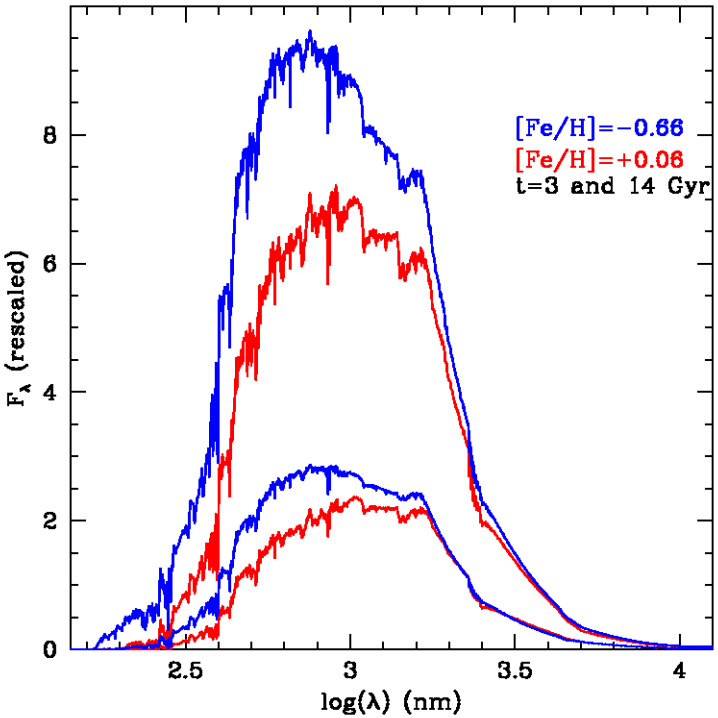
[α/Fe]=0.0, 0.4 **ATLAS9 (Castelli & Kurucz 2004) for T_{eff} between 50000 K and 3500 K**
BASEL 3.1 for T_{eff} < 3500
Lancon & Mouhcine (2002) for C-stars (5Å resolution degraded)

High-resolution spectra (1Å resolution)
$2500 \leq \lambda \leq 10500$ Å

[α/Fe]=0.0, 0.4 **Munari (2005) for T_{eff} > 3500**

Use of high-resolution spectra limited to λ< 6000 Å

BaSTI population synthesis products



λ	F_λ/λ
15.10	0.0000e+00
16.00	0.0000e+00
17.00	0.0000e+00
18.00	2.7122e-26
19.00	1.2707e-25
50.00	5.6080e-25
50.60	1.7638e-24
51.20	4.5013e-24
52.00	1.2984e-23
53.00	4.6885e-23
54.00	1.5861e-22
55.00	5.1802e-22
56.00	1.6084e-21
57.00	4.7892e-21
58.00	1.3546e-20
59.00	3.7719e-20
60.00	1.0019e-19
61.00	2.5730e-19
62.00	6.3944e-19
63.00	1.5407e-18
64.00	3.6084e-18
65.00	8.2107e-18
65.80	1.5556e-17
66.50	2.6819e-17
67.50	5.7240e-17
68.50	1.1937e-16
69.50	2.4326e-16
70.50	4.8328e-16
71.60	1.0104e-15
72.60	1.9295e-15
73.50	3.3986e-15
74.50	6.2664e-15
75.50	1.1352e-14
76.50	2.0249e-14
77.50	3.5463e-14
78.50	6.1244e-14
79.50	1.0337e-13

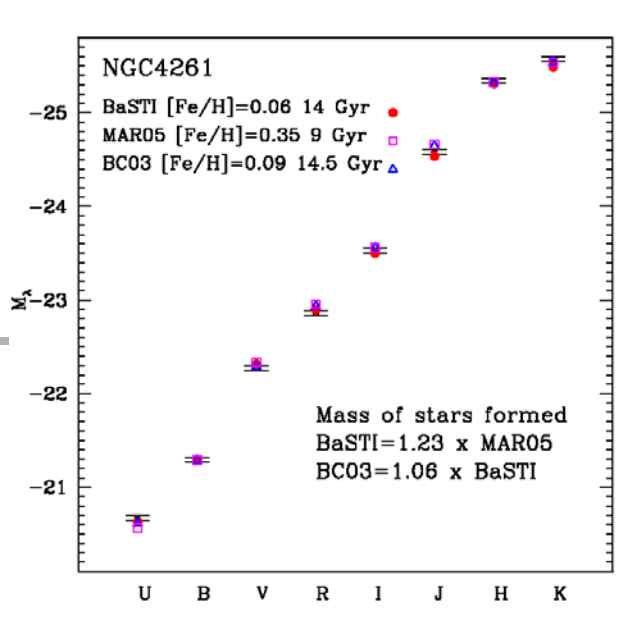
[Fe/H]=0.06 overshooting, Reimers eta=0.2 + TP-AGB superwinds
Initial M_i=1.0$M_\odot$ (M/L) in solar units

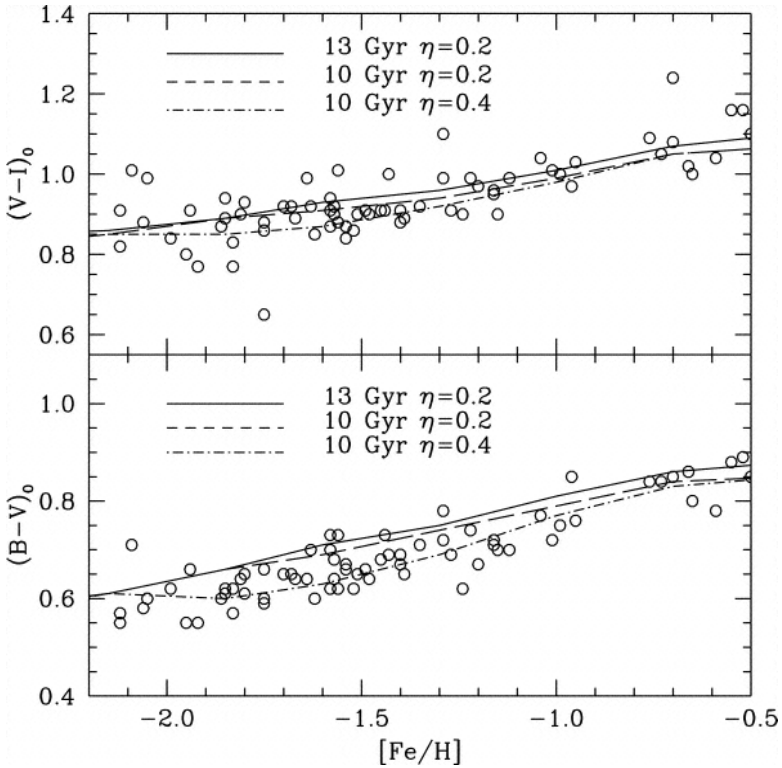
Age (Myr)	U	B	V	R	I	J	H	K	L	u	g	r	i	z	Mev $M_\odot$	Mwd $M_\odot$	Mns $M_\odot$	Mbh $M_\odot$
30.0	0.018	0.031	0.054	0.068	0.075	0.070	0.058	0.054	0.050	0.012	0.032	0.062	0.076	0.079	0.799	0.002	0.008	0.030
40.0	0.024	0.039	0.067	0.081	0.090	0.086	0.074	0.069	0.065	0.016	0.040	0.075	0.092	0.095	0.782	0.005	0.008	0.030
50.0	0.030	0.049	0.080	0.097	0.107	0.102	0.089	0.084	0.079	0.021	0.049	0.090	0.109	0.113	0.769	0.007	0.008	0.030
60.0	0.036	0.056	0.090	0.107	0.116	0.104	0.088	0.081	0.075	0.024	0.057	0.099	0.118	0.121	0.759	0.009	0.008	0.030
70.0	0.041	0.064	0.102	0.120	0.130	0.108	0.087	0.073	0.064	0.028	0.064	0.112	0.133	0.136	0.751	0.010	0.008	0.030
80.0	0.046	0.070	0.112	0.131	0.142	0.117	0.093	0.078	0.069	0.031	0.070	0.123	0.145	0.148	0.743	0.012	0.008	0.030
90.0	0.051	0.076	0.121	0.142	0.153	0.124	0.098	0.083	0.073	0.034	0.076	0.133	0.157	0.159	0.737	0.013	0.008	0.030
100.0	0.056	0.082	0.131	0.154	0.166	0.134	0.106	0.089	0.079	0.037	0.082	0.144	0.170	0.173	0.731	0.014	0.008	0.030
150.0	0.079	0.106	0.169	0.201	0.220	0.181	0.145	0.122	0.108	0.052	0.106	0.188	0.225	0.231	0.710	0.018	0.008	0.030
200.0	0.102	0.128	0.204	0.247	0.271	0.231	0.188	0.160	0.142	0.066	0.128	0.229	0.278	0.288	0.694	0.022	0.008	0.030
250.0	0.124	0.148	0.231	0.278	0.306	0.254	0.206	0.173	0.153	0.081	0.146	0.258	0.311	0.322	0.683	0.024	0.008	0.030
300.0	0.147	0.168	0.258	0.308	0.337	0.275	0.222	0.184	0.162	0.096	0.165	0.287	0.343	0.354	0.674	0.026	0.008	0.030
350.0	0.172	0.190	0.285	0.338	0.368	0.294	0.235	0.193	0.170	0.112	0.185	0.315	0.375	0.386	0.666	0.028	0.008	0.030
400.0	0.197	0.212	0.314	0.369	0.400	0.314	0.249	0.203	0.178	0.129	0.205	0.345	0.409	0.419	0.659	0.030	0.008	0.030
450.0	0.220	0.233	0.340	0.398	0.430	0.330	0.260	0.211	0.184	0.144	0.224	0.372	0.439	0.449	0.652	0.031	0.008	0.030
500.0	0.241	0.255	0.365	0.425	0.457	0.356	0.282	0.231	0.203	0.161	0.243	0.398	0.468	0.478	0.647	0.032	0.008	0.030
600.0	0.294	0.300	0.413	0.471	0.500	0.388	0.308	0.254	0.224	0.195	0.281	0.444	0.513	0.520	0.638	0.035	0.008	0.030
700.0	0.343	0.347	0.461	0.518	0.541	0.419	0.333	0.274	0.242	0.231	0.321	0.489	0.557	0.561	0.630	0.037	0.008	0.030
800.0	0.391	0.394	0.508	0.561	0.580	0.446	0.354	0.292	0.259	0.267	0.361	0.532	0.598	0.599	0.623	0.039	0.008	0.030
900.0	0.439	0.442	0.554	0.602	0.615	0.471	0.373	0.309	0.274	0.303	0.400	0.573	0.636	0.634	0.617	0.040	0.008	0.030
1000.0	0.485	0.489	0.597	0.641	0.648	0.494	0.391	0.325	0.288	0.338	0.438	0.612	0.672	0.665	0.611	0.042	0.008	0.030
1250.0	0.597	0.603	0.700	0.731	0.724	0.550	0.434	0.363	0.325	0.425	0.530	0.702	0.754	0.739	0.599	0.045	0.008	0.030
1500.0	0.697	0.693	0.760	0.769	0.740	0.554	0.434	0.369	0.331	0.504	0.597	0.744	0.776	0.750	0.589	0.048	0.008	0.030
1750.0	0.809	0.800	0.845	0.833	0.778	0.549	0.416	0.350	0.312	0.591	0.680	0.811	0.822	0.780	0.579	0.051	0.008	0.030
2000.0	0.931	0.930	0.975	0.959	0.897	0.665	0.517	0.446	0.403	0.686	0.788	0.934	0.947	0.901	0.570	0.053	0.008	0.030
2250.0	1.041	1.031	1.055	1.024	0.948	0.693	0.534	0.462	0.418	0.773	0.866	1.001	1.003	0.948	0.564	0.055	0.008	0.030
2500.0	1.157	1.136	1.137	1.092	1.000	0.722	0.554	0.480	0.434	0.866	0.946	1.070	1.062	0.997	0.558	0.057	0.008	0.030
2750.0	1.284	1.250	1.189	1.123	1.014	0.723	0.552	0.481	0.437	0.967	1.011	1.104	1.080	1.007	0.553	0.059	0.008	0.030
3000.0	1.421	1.300	1.191	1.093	0.955	0.636	0.469	0.404	0.365	1.076	1.048	1.083	1.026	0.937	0.547	0.060	0.008	0.030
3250.0	1.590	1.424	1.274	1.156	1.000	0.654	0.478	0.413	0.372	1.209	1.138	1.149	1.077	0.977	0.541	0.062	0.008	0.030
3500.0	1.768	1.551	1.359	1.221	1.045	0.673	0.489	0.422	0.381	1.349	1.230	1.216	1.129	1.018	0.535	0.064	0.008	0.030
3750.0	1.949	1.677	1.444	1.287	1.092	0.692	0.500	0.432	0.390	1.490	1.321	1.284	1.182	1.060	0.530	0.066	0.008	0.030
4000.0	2.143	1.822	1.554	1.380	1.168	0.741	0.536	0.465	0.420	1.643	1.430	1.378	1.265	1.133	0.525	0.068	0.008	0.030
4500.0	2.514	2.057	1.704	1.494	1.251	0.778	0.558	0.484	0.436	1.933	1.596	1.496	1.358	1.208	0.516	0.071	0.008	0.030
5000.0	2.894	2.291	1.853	1.609	1.335	0.817	0.582	0.504	0.453	2.230	1.761	1.615	1.453	1.286	0.508	0.074	0.008	0.030
5500.0	3.238	2.500	1.991	1.716	1.415	0.857	0.607	0.525	0.472	2.499	1.909	1.725	1.543	1.360	0.501	0.077	0.008	0.030
6000.0	3.518	2.624	2.042	1.741	1.419	0.840	0.589	0.508	0.456	2.716	1.987	1.755	1.552	1.358	0.495	0.080	0.008	0.030
6500.0	3.872	2.832	2.176	1.841	1.496	0.877	0.614	0.530	0.476	2.991	2.134	1.861	1.638	1.429	0.488	0.083	0.008	0.030
7000.0	4.293	3.076	2.335	1.967	1.585	0.921	0.642	0.555	0.498	3.318	2.307	1.988	1.739	1.511	0.482	0.086	0.008	0.030
7500.0	4.776	3.361	2.526	2.119	1.703	0.988	0.688	0.596	0.535	3.694	2.510	2.143	1.869	1.622	0.476	0.088	0.008	0.030
8000.0	5.272	3.623	2.686	2.239	1.789	1.028	0.713	0.618	0.555	4.079	2.692	2.268	1.966	1.700	0.471	0.091	0.008	0.030

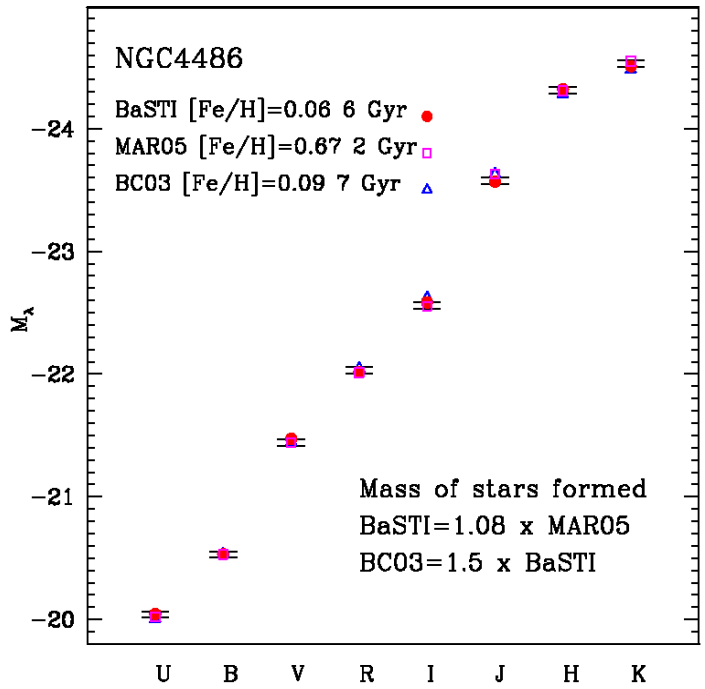
Spectra (low and high resolution), integrated colours, M/L ratios for SSP

In the near future we will provide a web-tool to compute integrated spectra for an arbitrary SFH, and also include spectra in our MC SYNHETIC MAN code. This will enable to study fluctuations of integrated spectra for low-mass stellar populations

BaSTI integrated colours

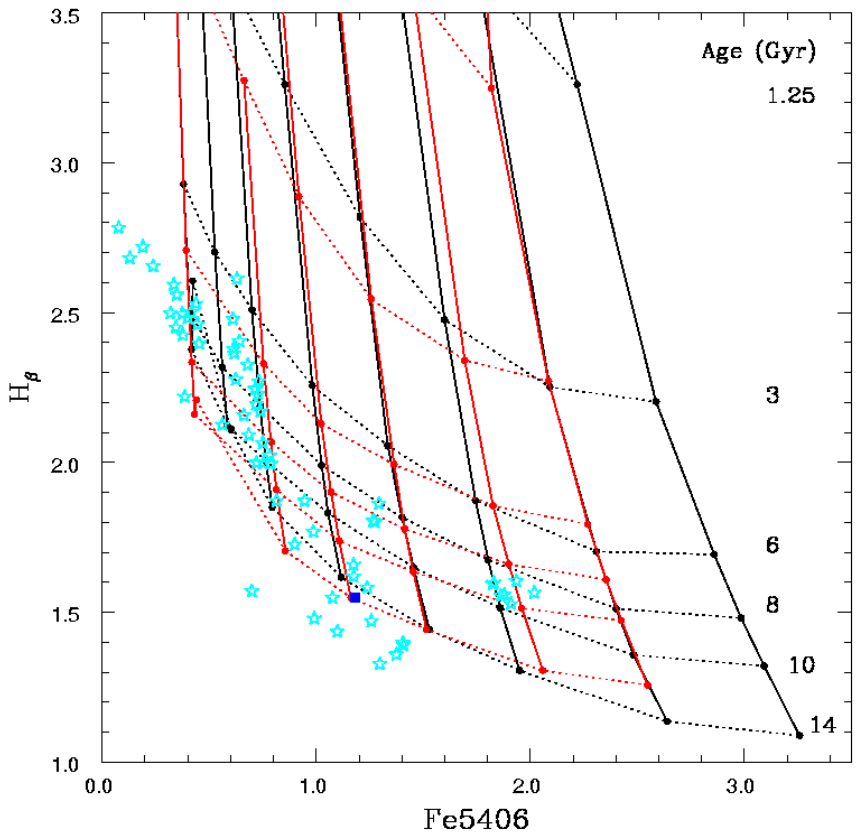


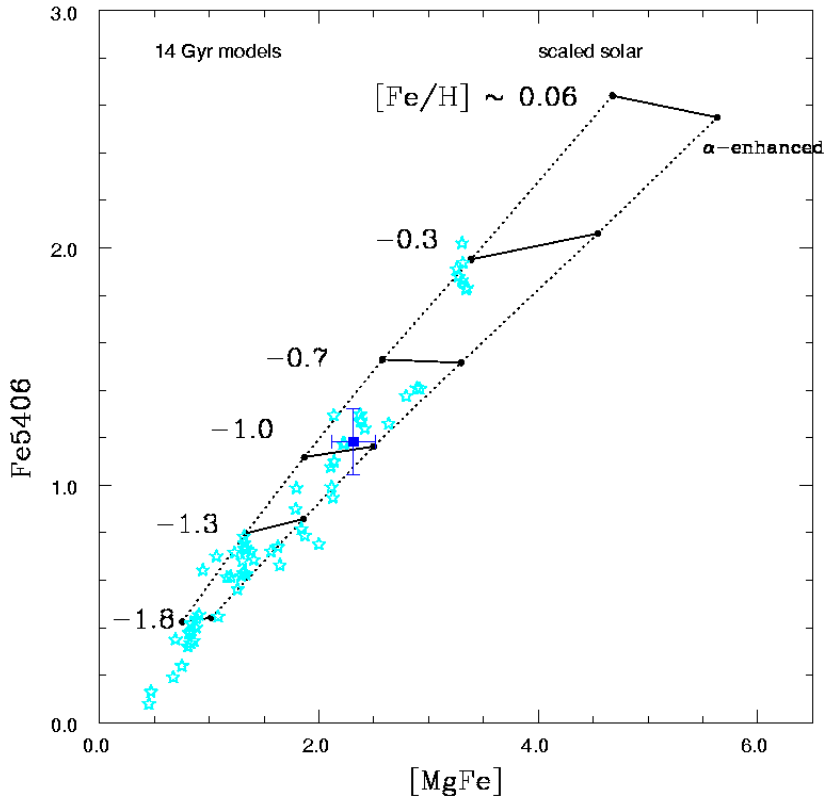




BaSTI

INTEGRATED SPECTRA





Population synthesis models and the VO

i) Minimum requirement

Implementation within the VO of current population synthesis models/packages

i) Standardization of the outputs and data description
ii) Interface with tools for analysis of retrieved data
iii) Identification of models/search of parameter space
iv) Ownership
v) Updating

(see efforts with the BaSTI stellar model database and TSAP developed at LAEFF – Madrid)

ii) One step further

Implementation of several available model and spectral libraries + flexibility to choose among the possible combinations to best tackle the problem at hand.

a) Standardization of formats and data description of pop. Synth. building blocks

b) Keep track of characteristics of each library. Search within the whole parameter space for the combination(s) most suited to interpret the data (resolution, λ (or broadband filters) range……..)

c) Option to test the final model on template objects (?)

d) Updates