R. González Delgado

Stellar Populations models: testing stellar libraries for Starbursts

We revise the relevance of the stellar libraries for fitting the optical stellar continuum of a young and intermediate age components which are the dominance stellar populations in starbursts at optical wavelength. The most up date stellar libraries (Granada library, MILES, STELIB) are using in the evolutionary synthetic models for the spectral synthesis of stellar clusters in the LMC/SMC. These clusters were chosen because due to their ages and metallicities are rich in Balmer absorptions as many local starbursts. The comparison of the results obtained for the stellar clusters derived from this method and previous estimations available in the literature based mainly in CMD method allow us to evaluate the pros and cons of each set of libraries to determine the age, metallicity and extinction for a stellar population. These comparisons allow us to estimate the uncertainties impact of the analysis of optical continuum spectra to estimate the ages and metallicities of starbursts.

Extreme Starbursts in the Local Universe

Stellar Population Models: Testing Stellar libraries for Starbursts

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Instituto de Astrofísica de Andalucía (CSIC) Granada, Spain

&

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Univ. Federal de Santa Catarina Florianopolis, Brasil

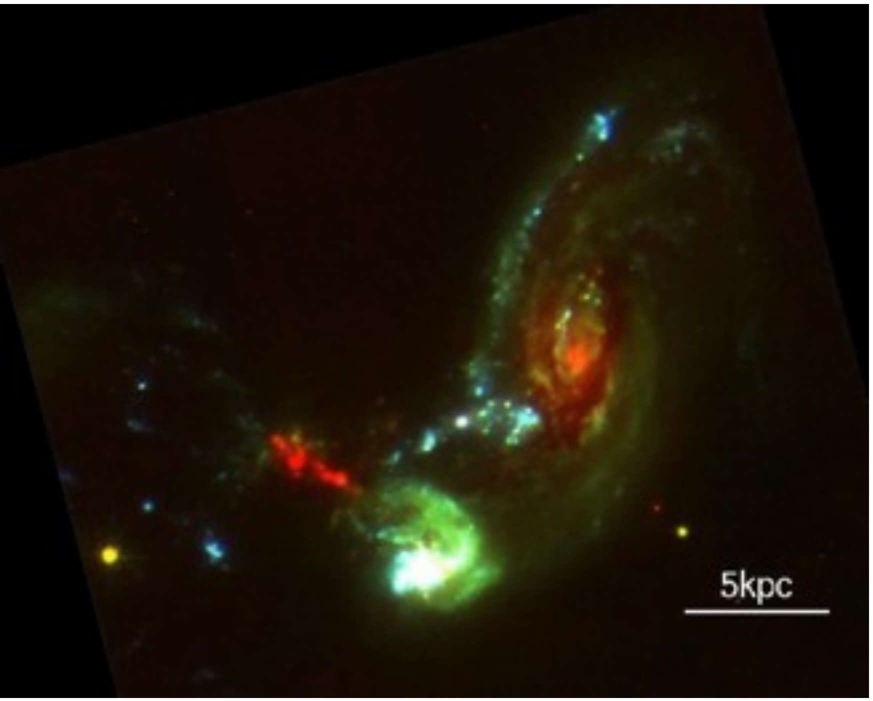
Testing spectral models for stellar populations with star clusters

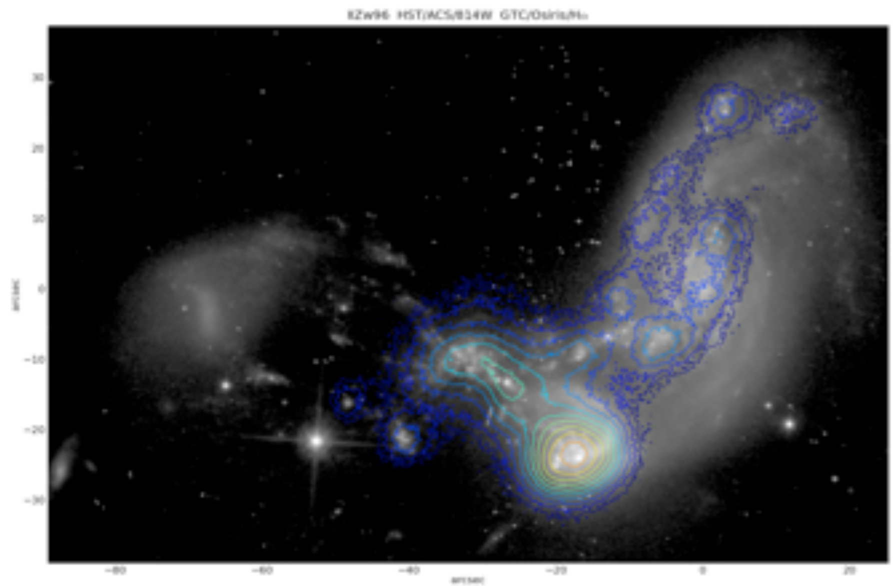
I.Methodology (2010, MNRAS, 403, 780)

II.Results (2010, MNRAS, 403, 797)

UV vs FIR selected Starbursts: LIRGs/ULIRGs vs ULG (LBA)

IIZw96

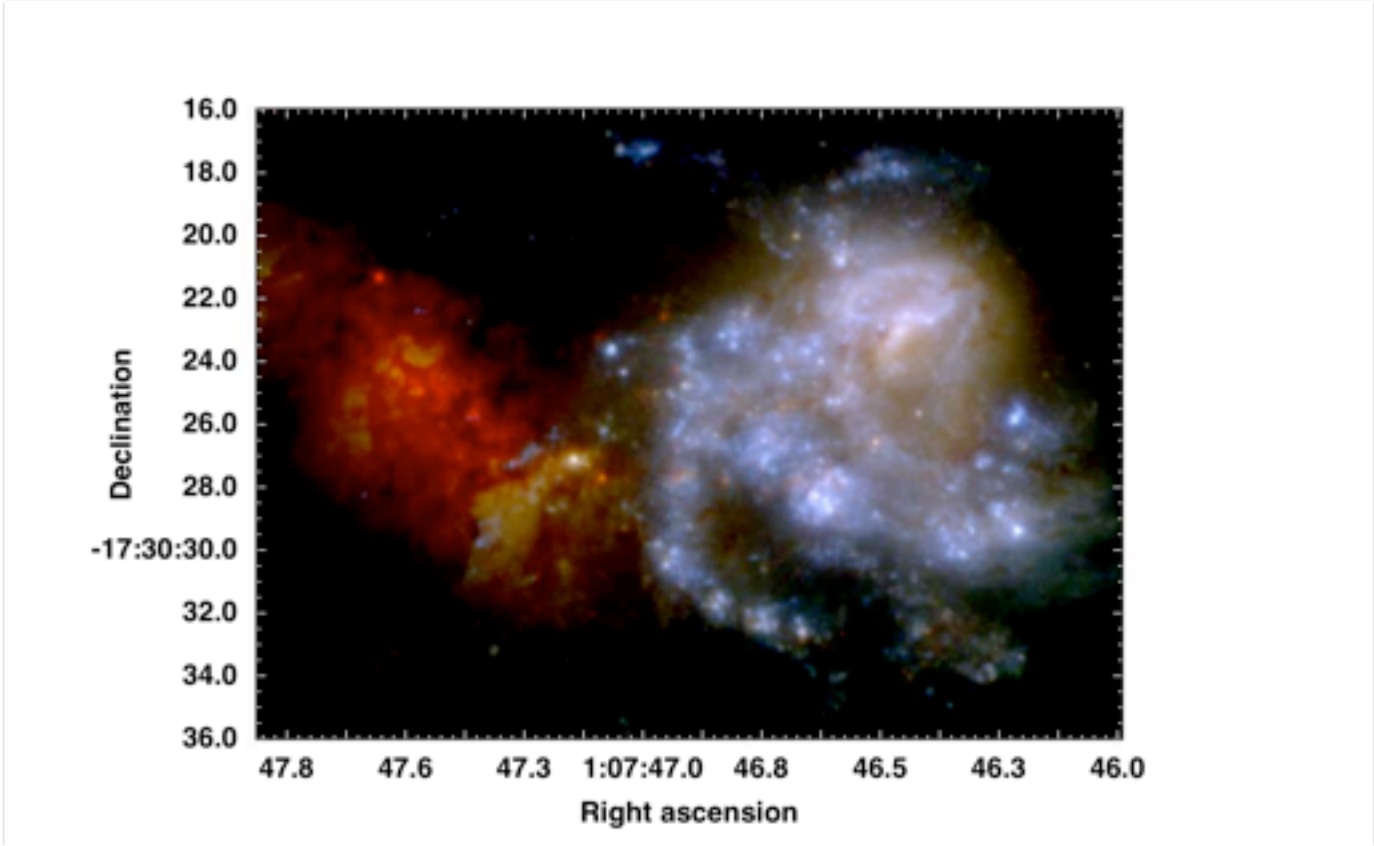




HST : NICMOS, ACS (UV, Optical)
Inami et al. 2010

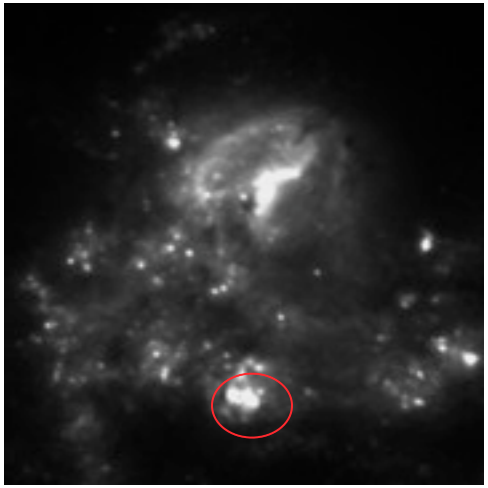
GTC: OSIRIS Tunable Filter Ha

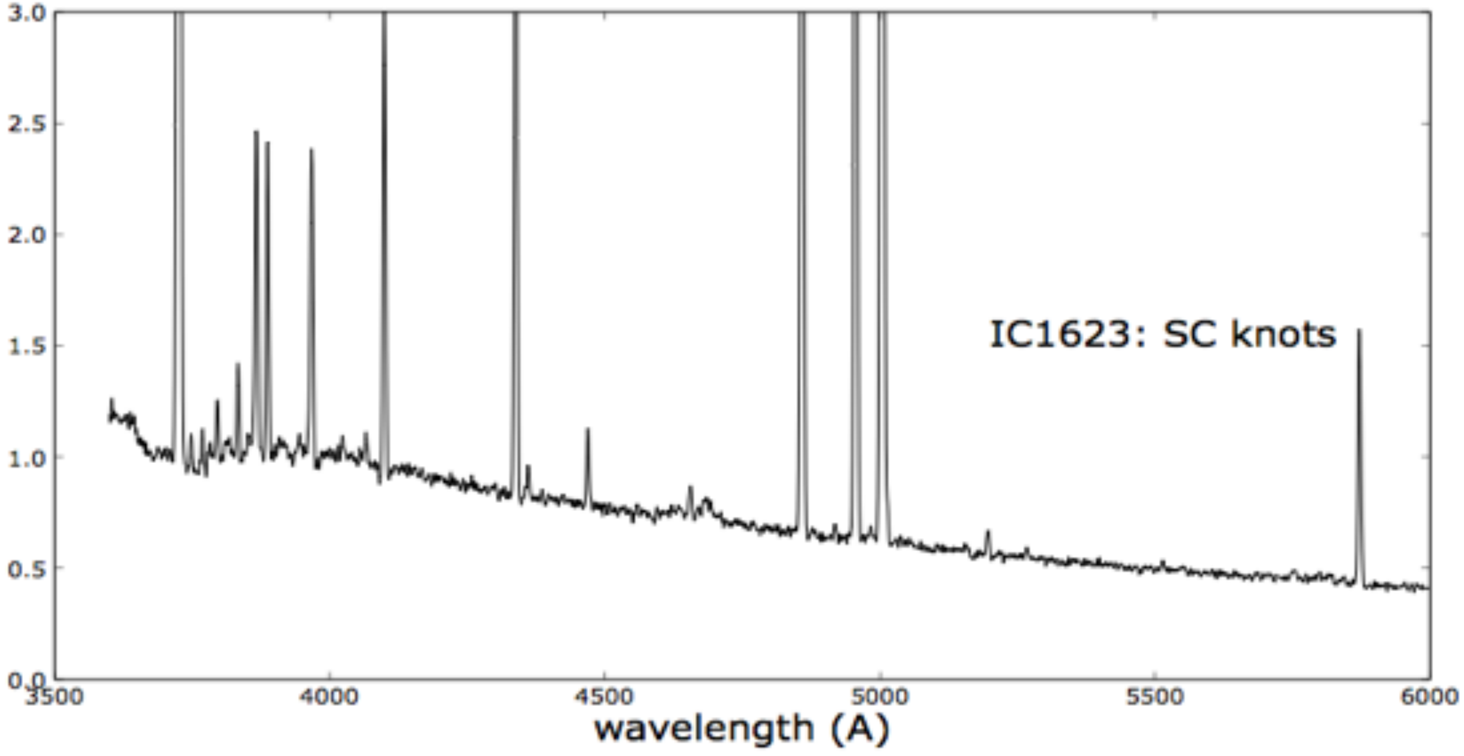
UV vs FIR selected Starbursts: LIRGs/ULIRGs vs ULG (LBA)



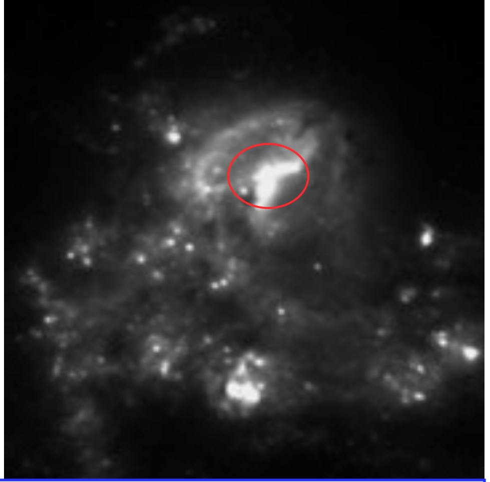
IC1623: Ultraviolet Luminous Galaxy
The most nearby LBA

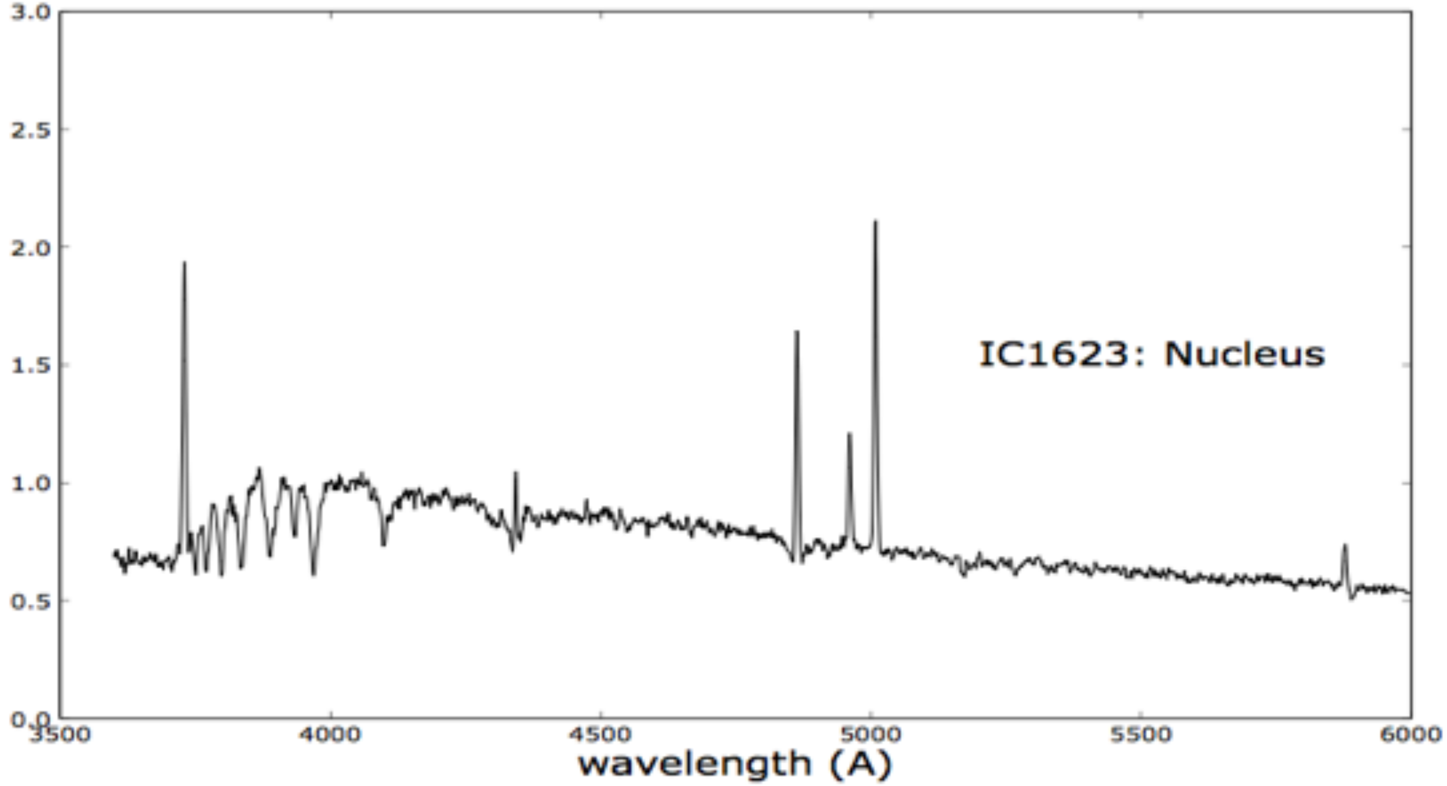
Optical Spectrum





Optical Spectrum





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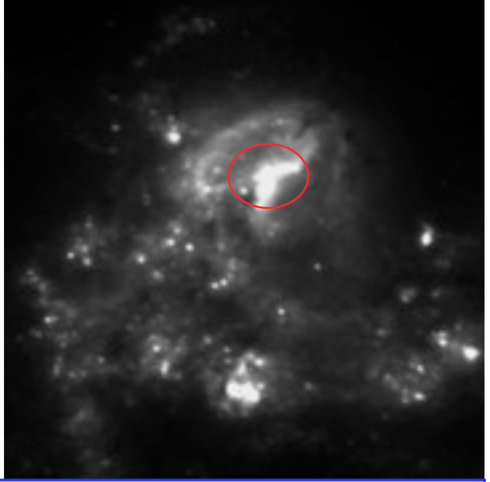
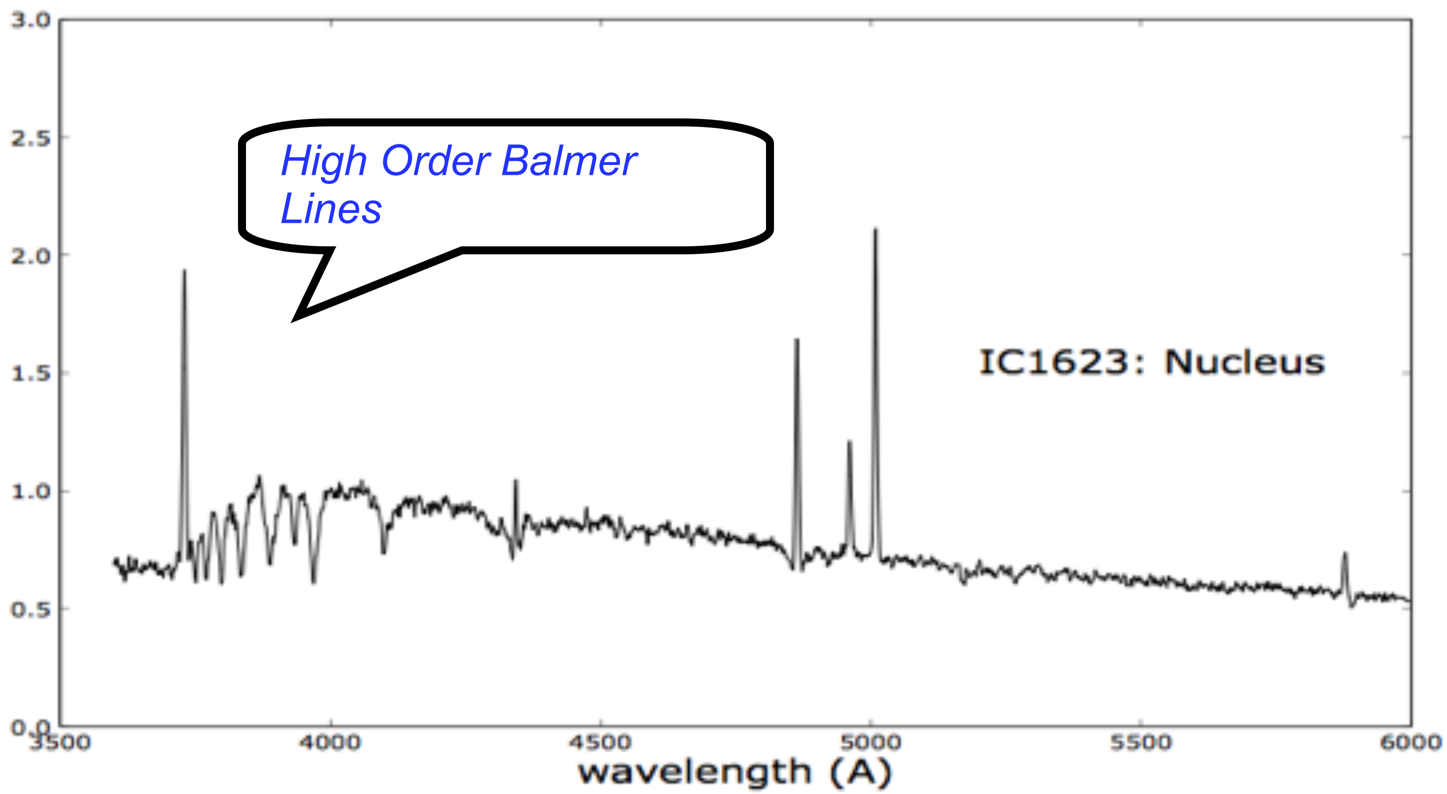
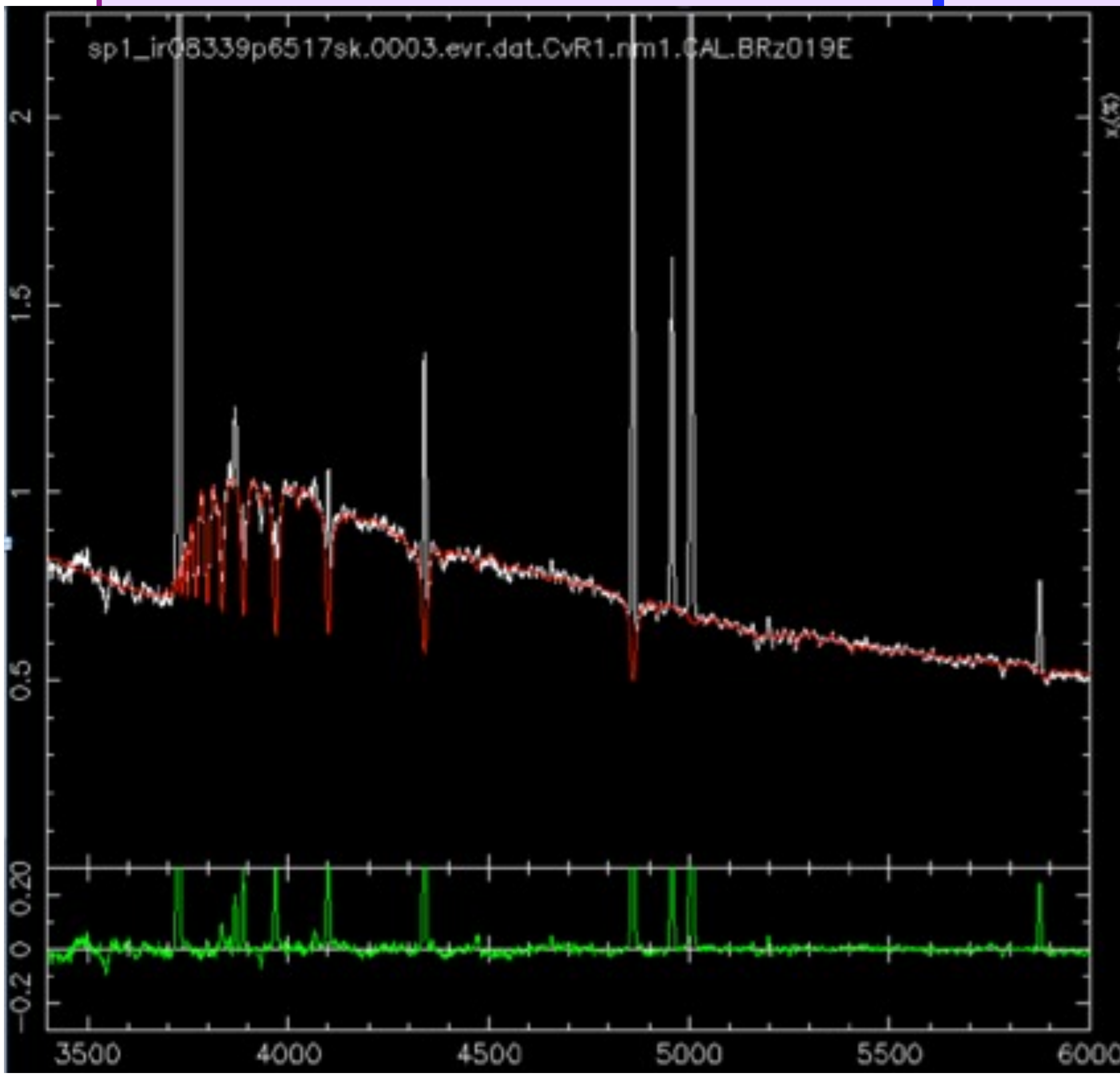
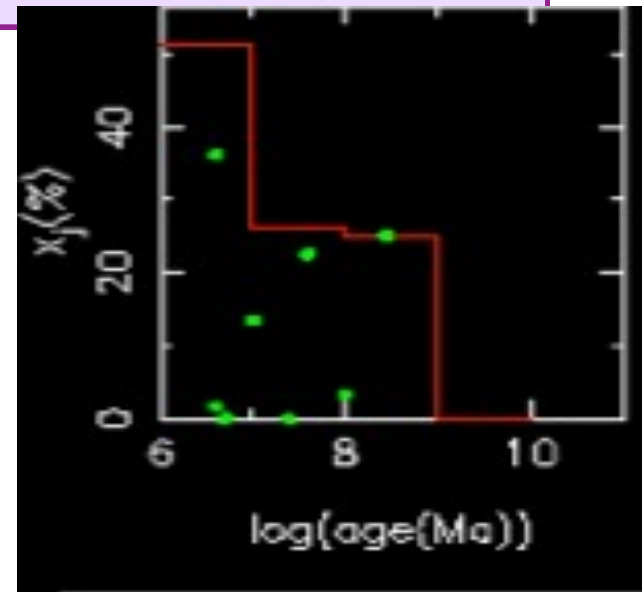




Why to test spectral models for Stellar Populations



λ [Å]

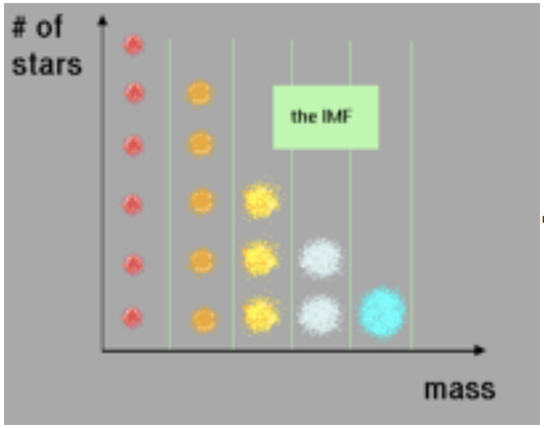


log t [yr]

SFH

- Spectral models for stellar populations are necessary to interpret galaxy data.
  ~ 50% (?) of extragalactic work relies on such models.

Stellar populations are modeled with synthesis models



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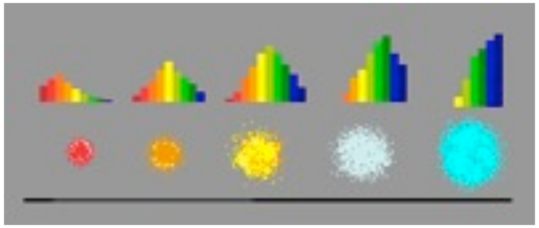
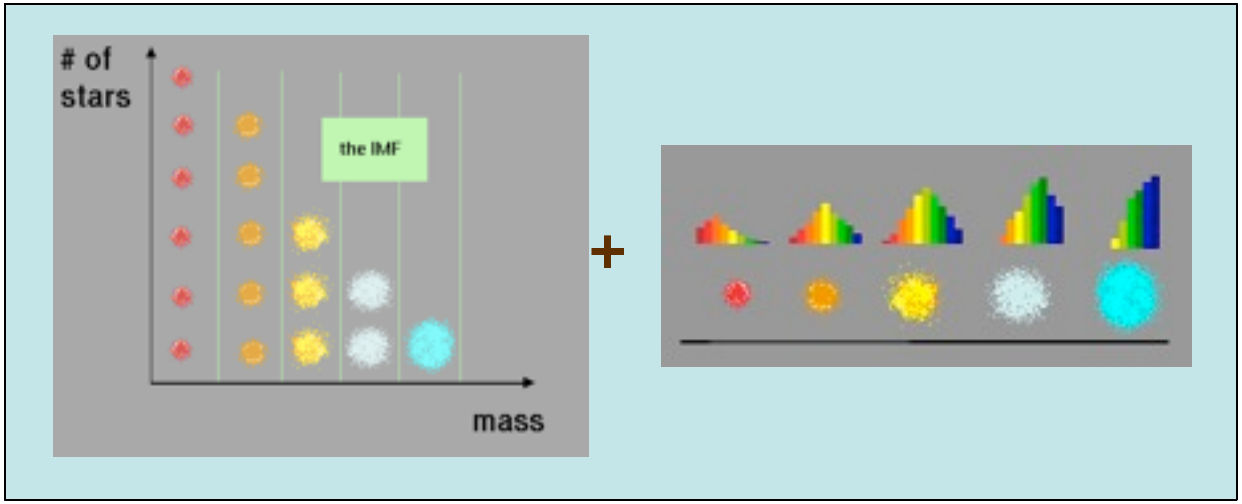
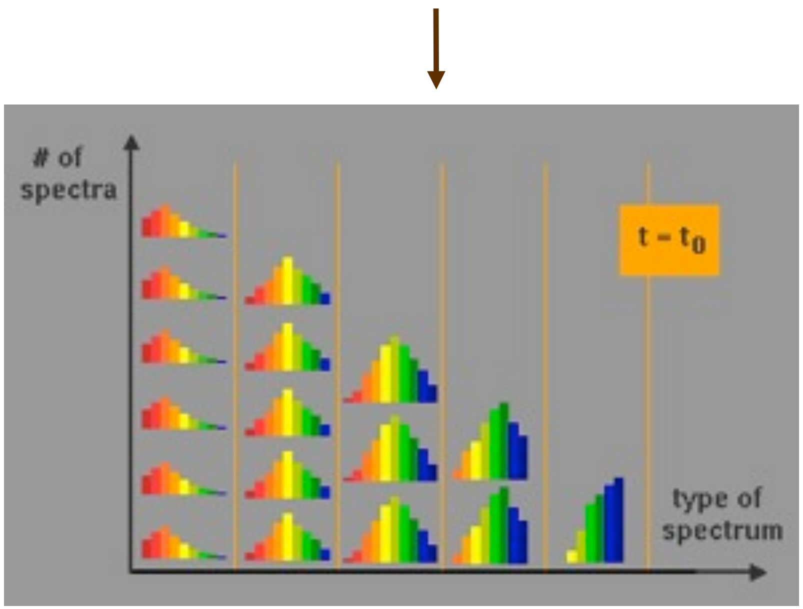


Stellar populations are modeled with synthesis models





@Luridiana & Cerviño

http://ov.inaoep.mx

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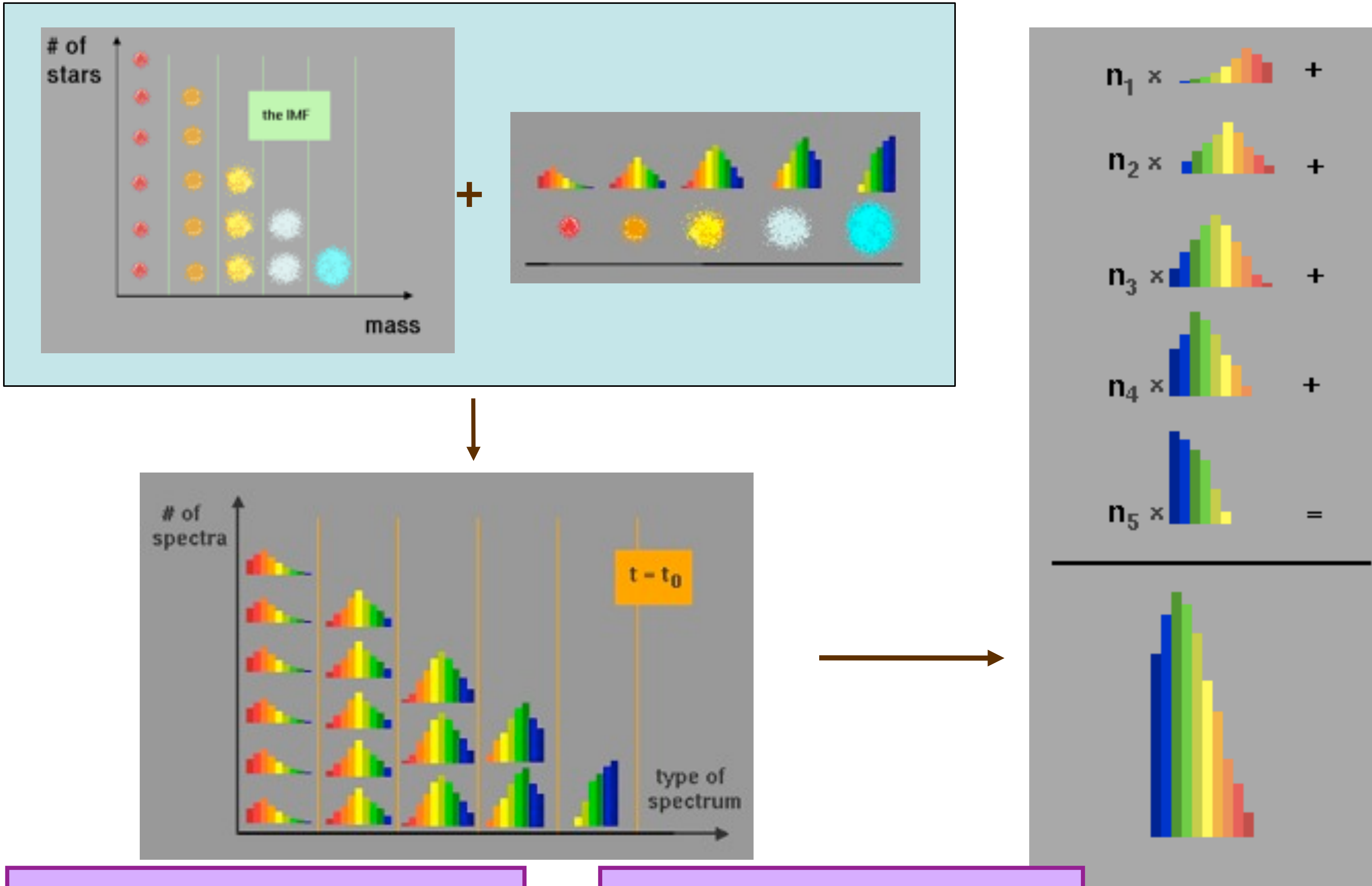

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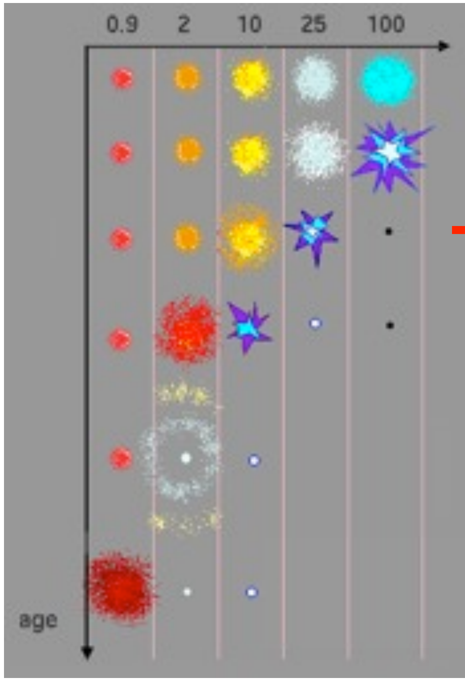

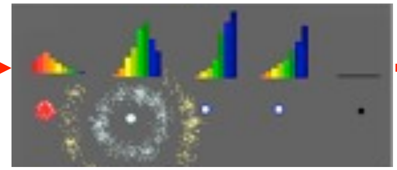

SSP = function (IMF, tracks, stellar libraries...)

- Starburst89 (Cid Fernandes et al)
- Starburst99 (Leitherer et al)
- GALAXEV (Bruzual & Charlot)
- SED (Cerviño et al)
- PEGASE (Rocca-Volmerange et al)
- GALEV (Fritze v. Alvensleben)

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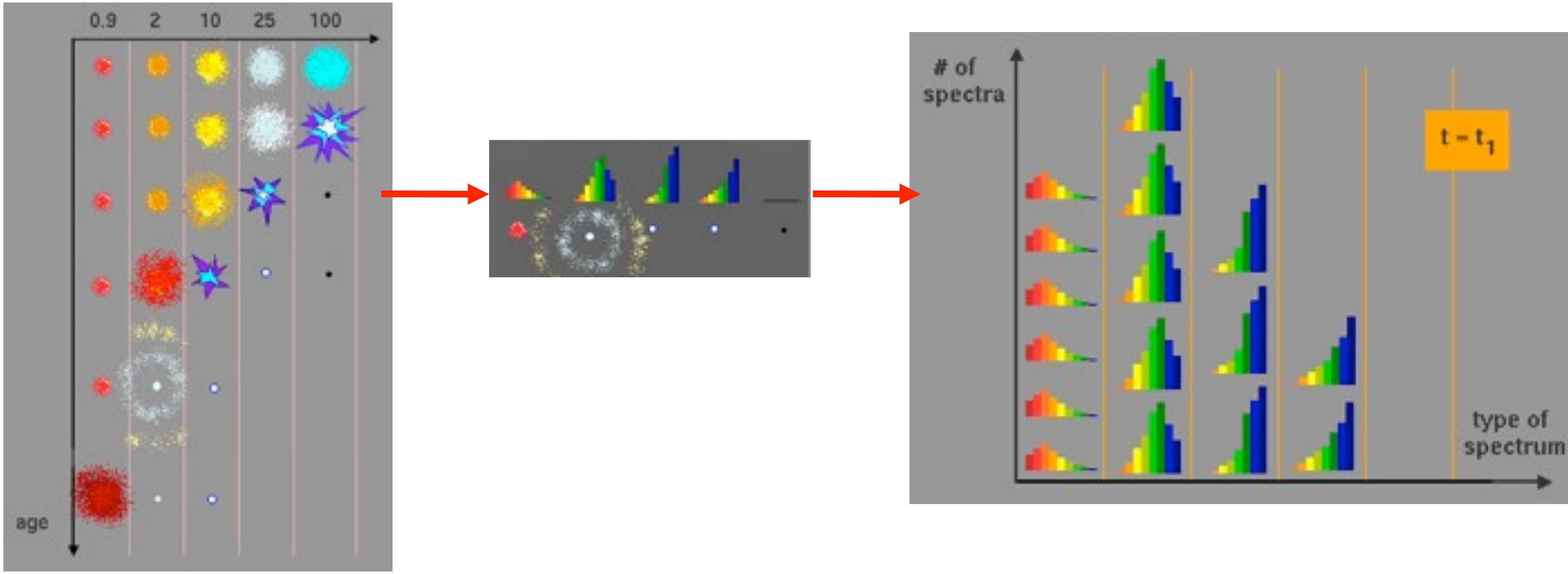
Stellar populations are modeled with synthesis models



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http://ov.inaoep.mx

Stellar Libraries

Empirical Stellar Libraries ……→……… Observations
Synthetic Stellar Libraries ……→……… Stellar Atmosphere Models

Stellar Libraries in the 90's

<u>Synthetic Stellar Libraries</u>

Larger grid in (Teff, g, Z)

BaSeL:
- Kurucz models
- 20 Å resolution

<u>Empirical Stellar Libraries</u>

Abundance ratios following the nature
(alpha elementes: Ca/O, Mg/O, …)

Lick/IDS:
- 425 stars
- 4100-6300 Å
- 9-11 Å resolution
- Spectra are not flux calibrated

<u>Improvements on the empirical and synthetic stellar libraries</u>
- Large coverage in (Teff, g, Z)
- Higher spectral resolution
- Larger spectral range coverage

Stellar Libraries: Improvements on the stellar libraries in 90's

González Delgado & Leitherer (1999)

NLTE (TLUSTY) + LTE (Kurucz)

Hβ, Hγ, Hδ, …, HOBL (Hε, H8, …)

HeI (3819, 4009, 4026, 4121, 4143, 4388,4471, 4922)

0.3 Å resolution and solar metallicity

Synthetic Stellar Libraries

González Delgado et al (1999)

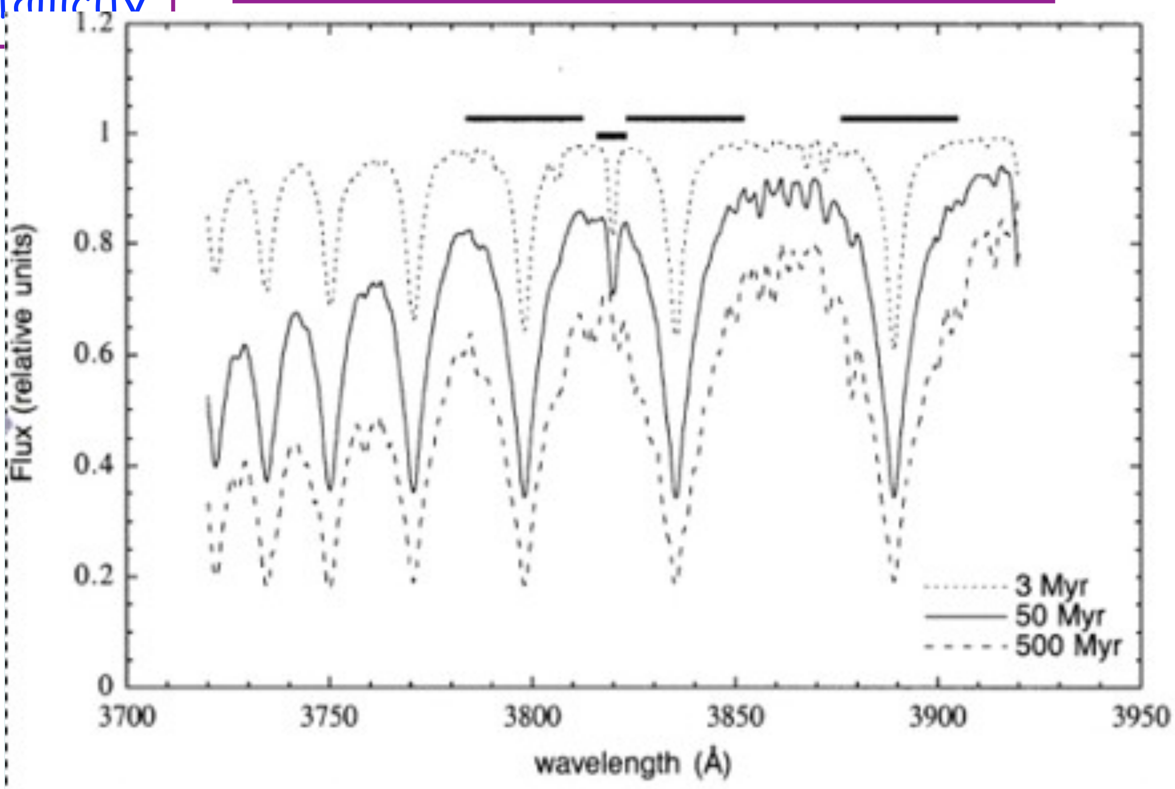
Predict stellar populations for young and intermediate age population

Define HOBL and HeI lines

Stellar Atmospheres Models

Line Profile synthesis code

- SYNTEC (Kurucz)
- SYNSPEC (Hubeny)
- SPECTRUM (Gray)



ALTAS9 (Kurucz): LTE, PP, line blanketing

TLUSTY (Hubeny): NLTE, PP, line blanketing

PHOENIX (Hauschild): LTE, NLTE, PP and Spherical geometry, line blanketing

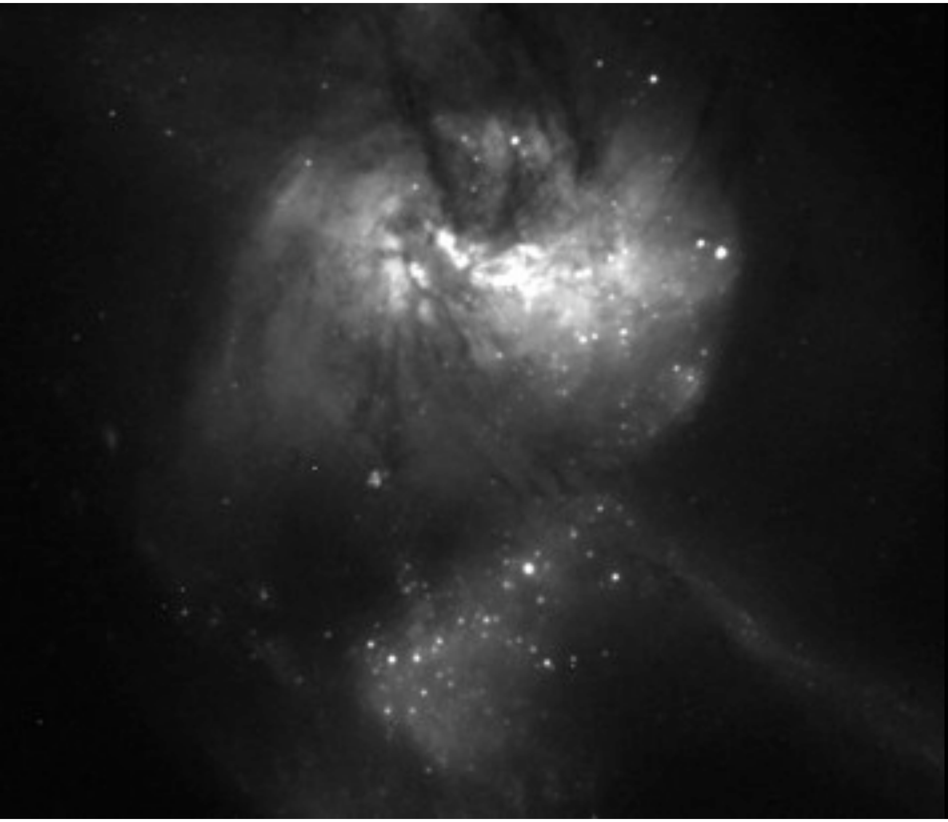
Emprirical Stellar Libraries in the 2000 decade

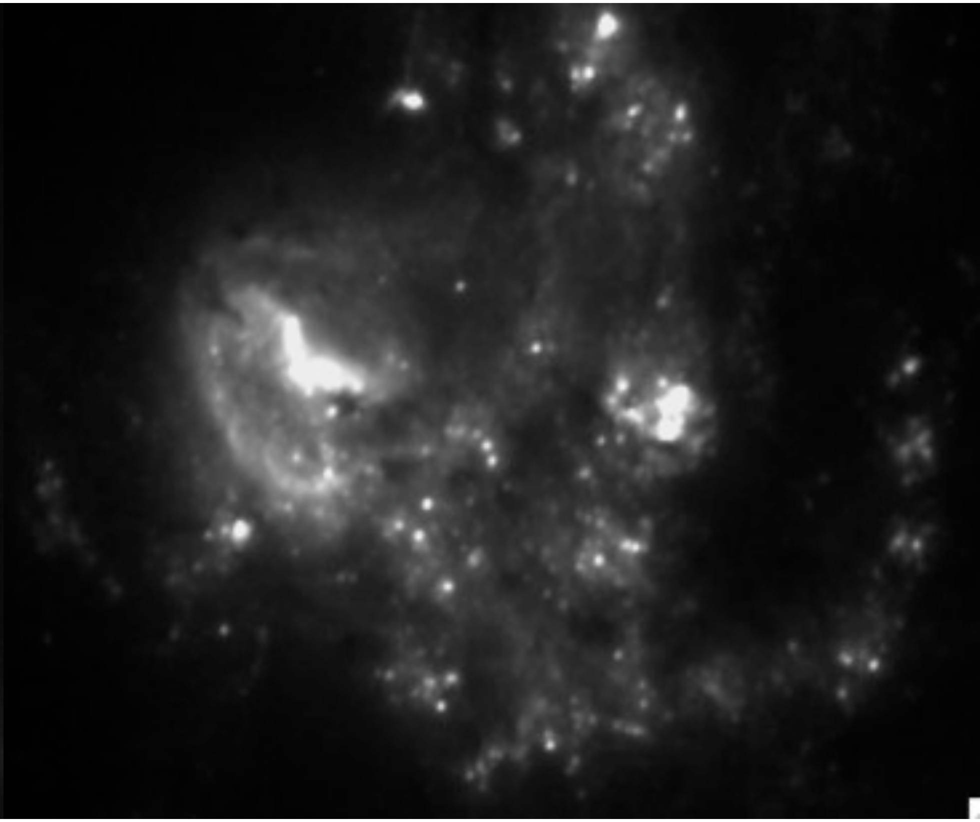
Library	FWHM (Å)	Spectral Range (Å)	No. Stars	Commens	Liders
ELODIE	0.1	4100-6800	1388	Echelle	Prugniel & Soubiran 2004 PEGASE (Le Borgne et al 2005)
STEBLI B	3.0	3200-9500	249	Flux calibrated	Le Borgne et al 2003 GALAXEV (BC03)
INDO-US	1.0	3460-9464	1273	Poor flux calibrated	Valdés et al 2004 GALAXEV (CB07)
MILES	2.3	3500-7500	985	Flux calibrated	Sánchez-Blázquez et al 2006 GALAXEV (CB07) Vazdekis et al.
HNGSL		1700-10200	Few 100	Flux calibrated	Heap & Lanz (2003) GALEXV (CB07)

Synthetic Stellar Libraries in the 2000 decade

Models	Resolution	Spectral Range (Å)	Atmosph	Teff Log g	Metals
Rodríguez-Merino et al 2005	50000	850-4700	Kurucz	3000-50000 Log g= 0--5	[M/H]= -2.0, -1.5, -0.5, 0.0, 0.3, 0.5
Peterson et al 2005	330000	2280-3160	Kurucz	Specific Teff and log g	1/100 to solar
Munari et al 2005	20000 2000	2500-10500	Kurucz	3500-47500 K log g= 0--5	-2.5<[M/H]<0.5 [α/Fe]=0.0, 0.4
Coelho et al 2005	High	3000-18000	Kurucz	3500- 7000 K log g= 0--5	[M/H]= -2.5, -2.0, -1.5, -1.0,-0.5, 0.0, 0.2, 0.5 [α/Fe]=0.0, 0.4
Martins et al 2005 Granada libray	0.3 Å	3000-7000	TLUSTY + Kurucz +PHOENIX	3000-55000 K log g= -0.5--5	Z= 0.04, 0.02, 0.008, 0.004 and 0.001

Stellar Clusters in Starbursts





NGC2623: LIRG

IC1623: Ultraviolet Luminous Galaxy
The most nearby LBA

Goals of the present work

Questions	Answers
Do current models fit SC spectra well?	☺ Yep!
Is **age** well constrained? Is **age** biased? Does **age** depend on model choice?	☺ Yes! ~ 0.1 – 0.2 dex ☺ Nope. ☺ Not too much.
Is **Z** well constrained? Is **Z** biased? Does **Z** depend on model choice?	😐 Hmmm ... ~ 0.3 – 0.4 dex ☹ It can be badly biased! ☹ Yes...
Do newer models do a better job? (Are we going in the right direction?)	☺ Yes!
What's needed to improve things?	Finer/more homogeneous grids More complete stellar libraries

?

Data: Optical Spectra of SC in the Magellanic Clouds

Spectra from Leonardi & Rose (2003, AJ, 126, 1811)

<u>First set of information</u>

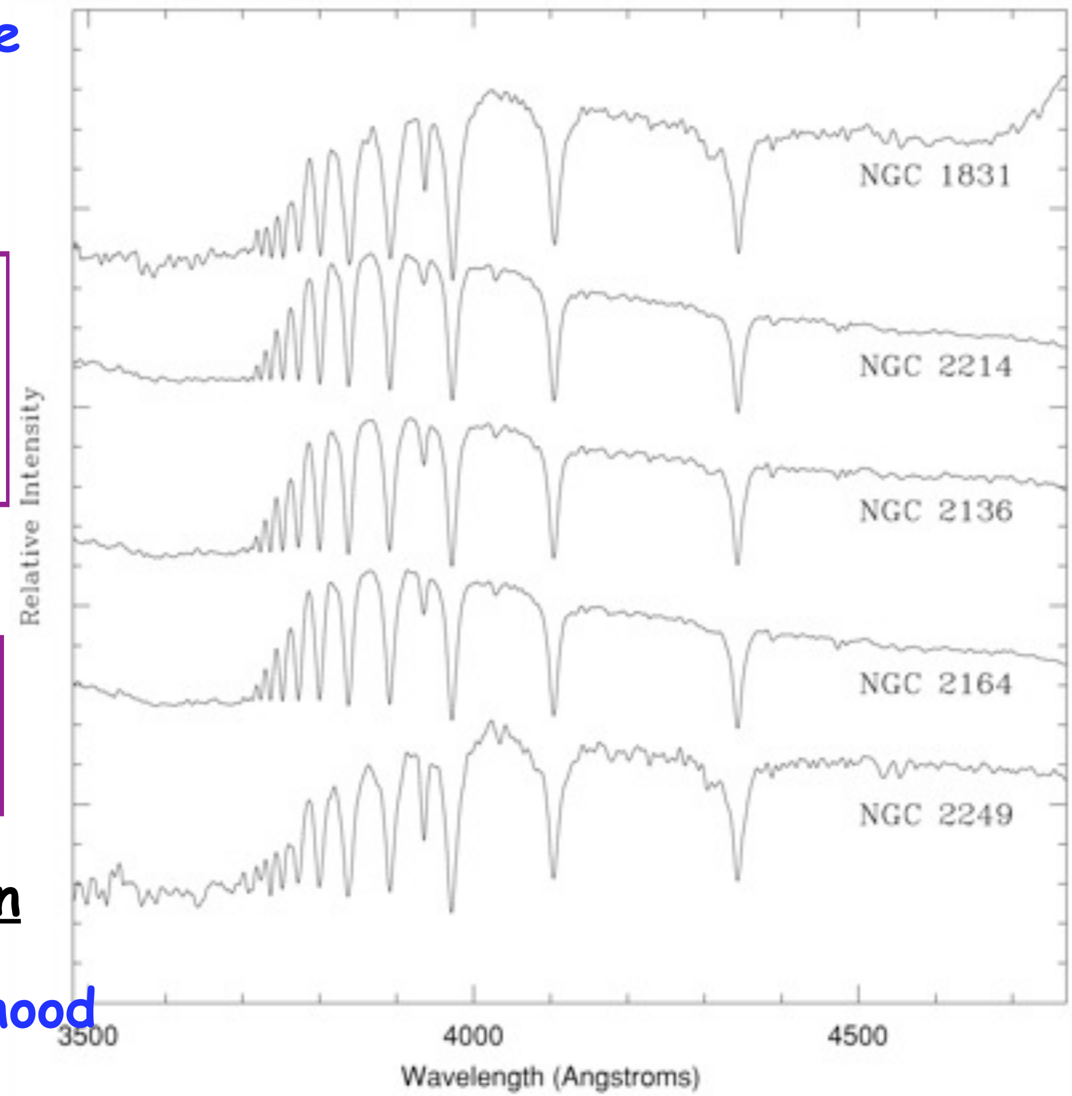
- CMD, broad band optical colors, CaII triplet at 8600 A: <u>Ages, metallicity</u>

<u>Second set of information</u>

- Rose's stellar indices: <u>Ages, metallicity</u>

<u>Additional piece of information</u>

Extinction in the SC neighbourhood



Acknowledgment to Jame Rose
for sending us the spectra

Table of objects

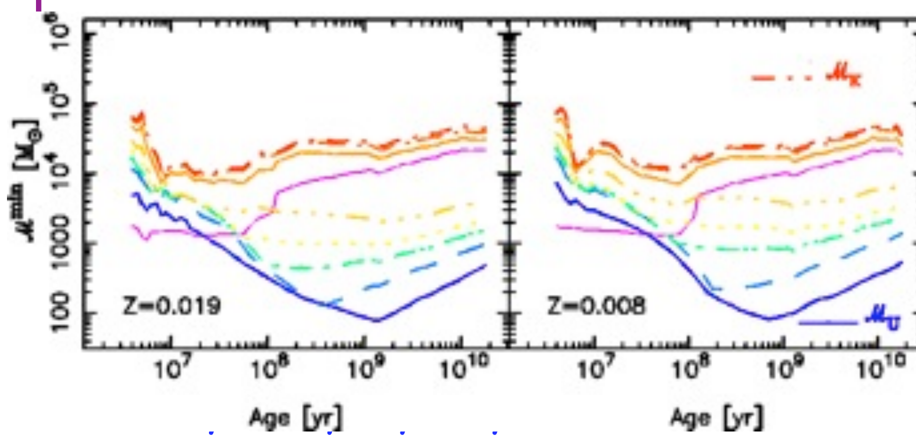
	ClusterName	log age (Rose)	Fe/H (Rose)	log age (CMD)	Fe/H (Lit)
0	NGC411	9.09	-0.430	9.25	-0.840
1	NGC416	9.82	-1.27	9.84	-1.44
2	NGC419	9.22	-0.900	9.08	-0.700
3	NGC1651	9.34	-0.820	9.20	-0.370
4	NGC1754	9.74	-1.44	10.2	-1.42
5	NGC1783	9.19	-0.540	8.94	-0.750
6	NGC1795	9.30	-0.690	9.23	-0.230
7	NGC1806	9.28	-0.640	8.70	-0.230
8	NGC1818	7.30		7.54	-0.900
9	NGC1831	8.70	-0.650	8.57	0.01000
10	NGC1846	9.50	-1.40	9.09	-0.700
11	NGC1866	8.48		8.34	-1.20
12	NGC1978	9.41	-0.720	9.23	-0.420
13	NGC2010	7.92		8.20	0.00
14	NGC2133	8.16		8.11	-1.00
15	NGC2134	8.80		8.28	-1.00
16	NGC2136	7.91		8.04	-0.400
17	NGC2203	9.19	-0.460	9.26	-0.520
18	NGC2210	9.58	-1.16	10.1	-1.97
19	NGC2213	9.32	-0.880	9.01	-0.01000
20	NGC2214	7.72		7.91	-1.20
21	NGC2249	8.44	-0.400	8.72	-0.0500
22	n2121				
23	n2506				
24	47Tuc			10.1	-0.760
25	m0015			10.0	-2.29
26	m0079			10.1	-1.95
27	n1851			9.72	-1.16

From Leonardi & Rose's paper

Caveats: stochastic fluaction effects

V range= 9.8 to 12.4

Mv (mean)= -7.2 or log Lv= 34.5(erg/s/A)



Lowest luminosity limit= 33.4, 32.7,32.4 (erg/s/A)

L10 per cent= 34.2, 33.7, 33.4 (erg/s/A)
for ages 0.2, 2 and 10 Gyr

Weakest SC log Lv= 34.0 but age is 1-2 Gyr when the stochastic fluctuations effect has small impact

Stochastic effect are even smaller at U and B bands than V

Stellar Population Models
High spectral resolution evolutionary synthesis models

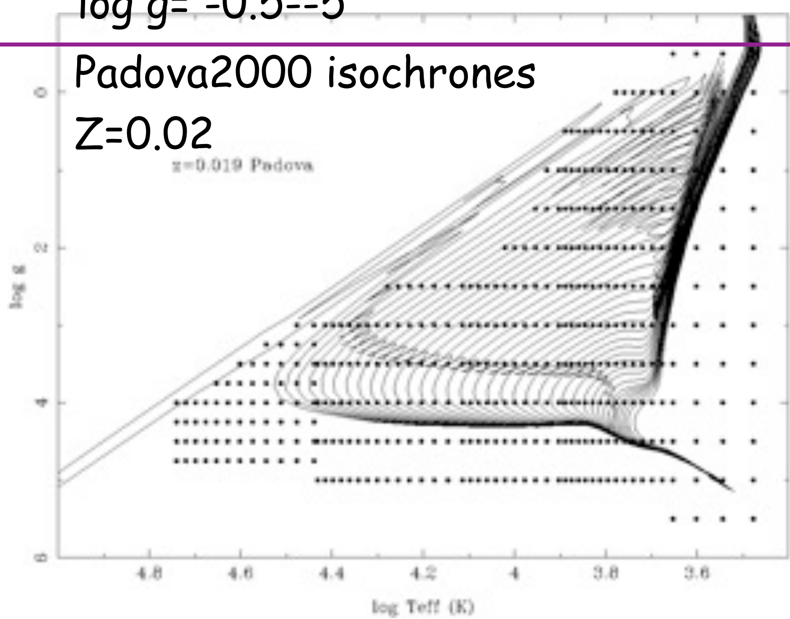
Code	Library	Properties Stellar Library	Code and stellar library web
SED@	Granada	Tlusty+Kurucz +Phoenix 0.3 Å sampling	www.iaa.csic.es/~mcs/sed@ www.iaa.csic.es/~rosa
GALAXEV	a) STELIB b) MILES +Granada	a) 249 stars Fwhm= 3 Å b) 1000 stars	www.cida.ve/~bruzual/bc2003 www.ast.obs-mip.fr
Vazdekis	MILES	985 stars Fwhm= 2.3 Å	www.ucm.es/info/Astrof/miles

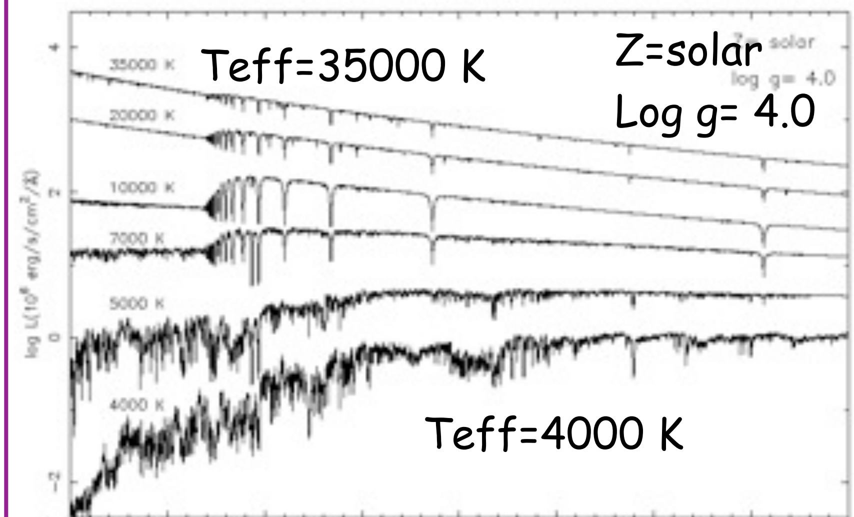
❖**Granada library:** Martins, González Delgado, et al, 2005, MNRAS, 358, 49
❖**SED@ SP Models:** González Delgado, et al, 2005, MNRAS, 357, 945
❖**MILES library:** Sánchez-Blázquez et al, 2006, MNRAS, 371, 703
❖**GALAXEV SP Models:** Bruzual & Charlot, 2003, MNRAS, 344, 1000

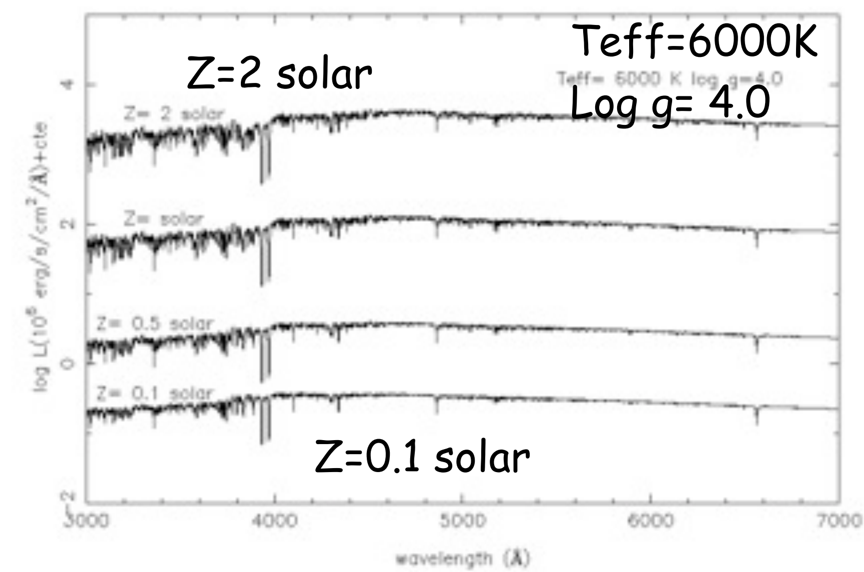
Granada library: http://www.iaa.es/~rosa/

ATLAS9 (Kurucz): LTE, PP, line blanketing
TLUSTY (Hubeny): NLTE, PP, line blanketing
PHOENIX (Hauschild): LTE, NLTE, PP and
Spherical geometry, line blanketing

- Z= 0.04, 0.02, 0.008, 0.004 and 0.001
- Teff= 3000-55000 K
- log g= -0.5--5

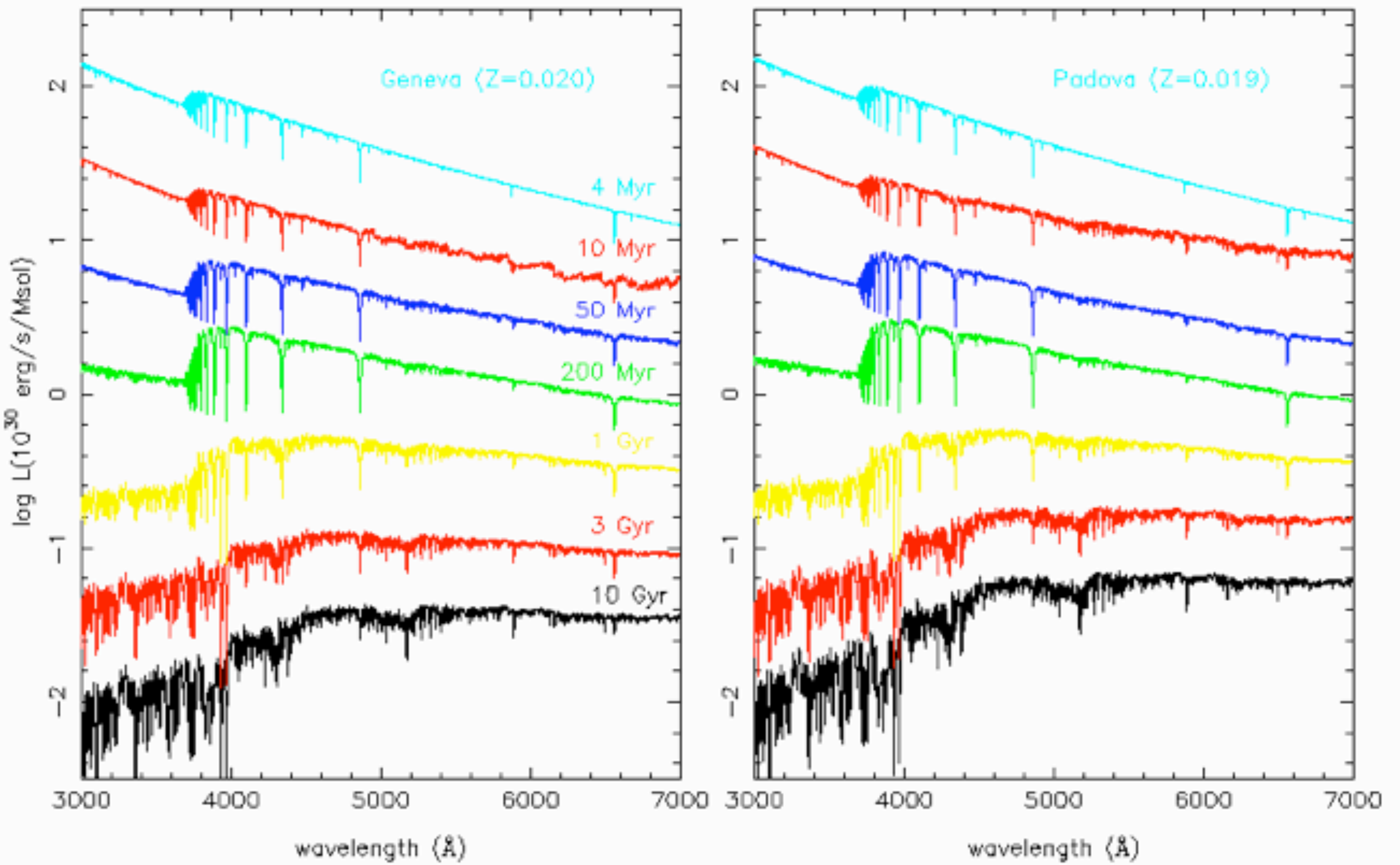




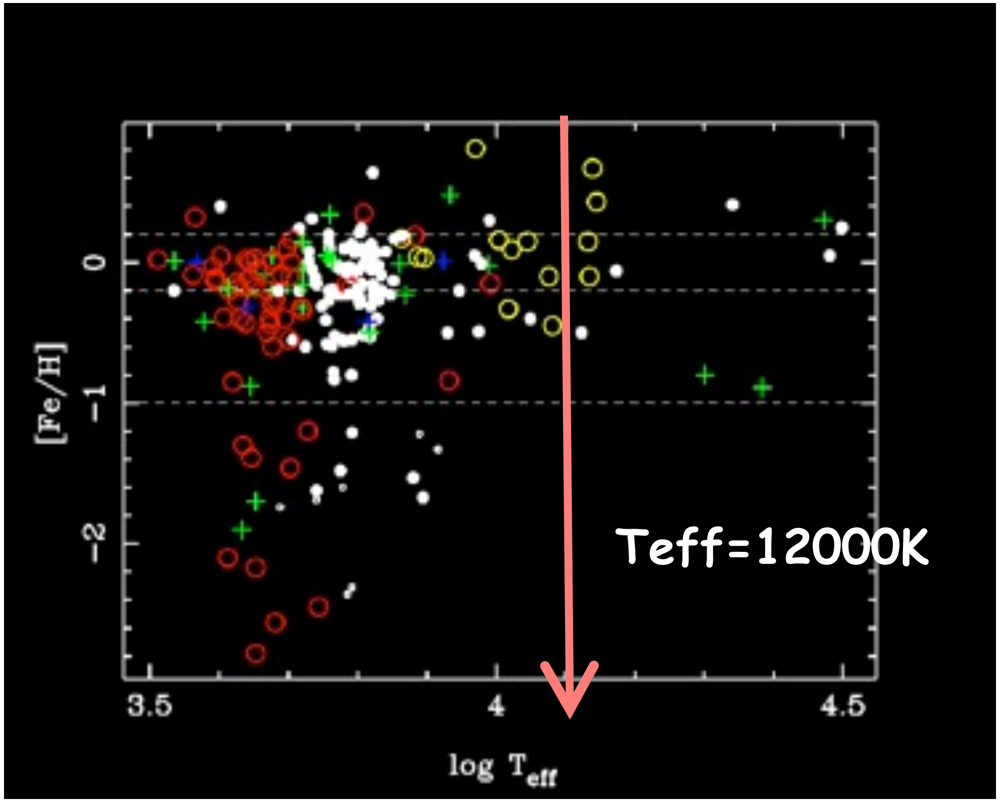


Stellar Population Models
SED@ SP Models + Granada library

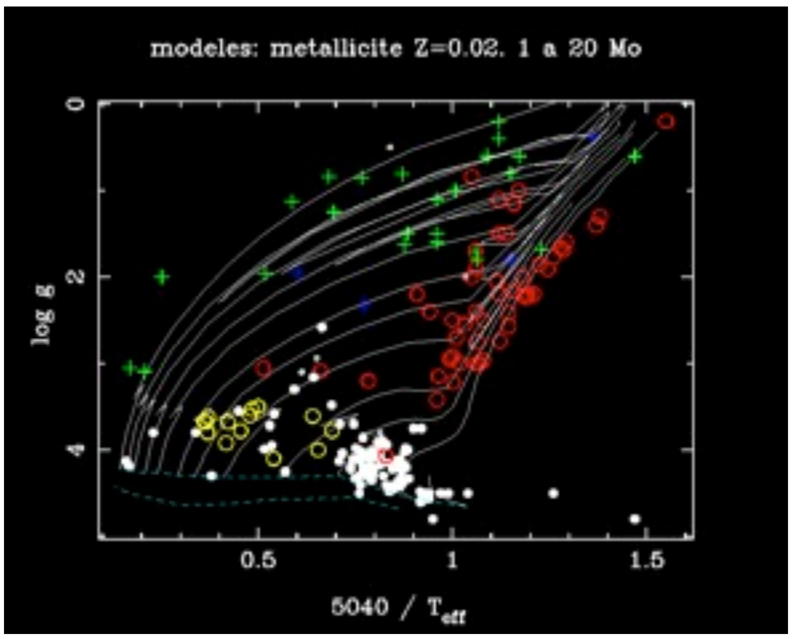
Stellar Population synthesis models (González Delgado et al 2005, MNRAS, 357, 945)



Stelib: http://www.ast.obs-mip.fr/article181.html
Le Borgne et al, 2003, A+A, 402, 433



Stelib:
3200--9500 A
Fwhm= 3A



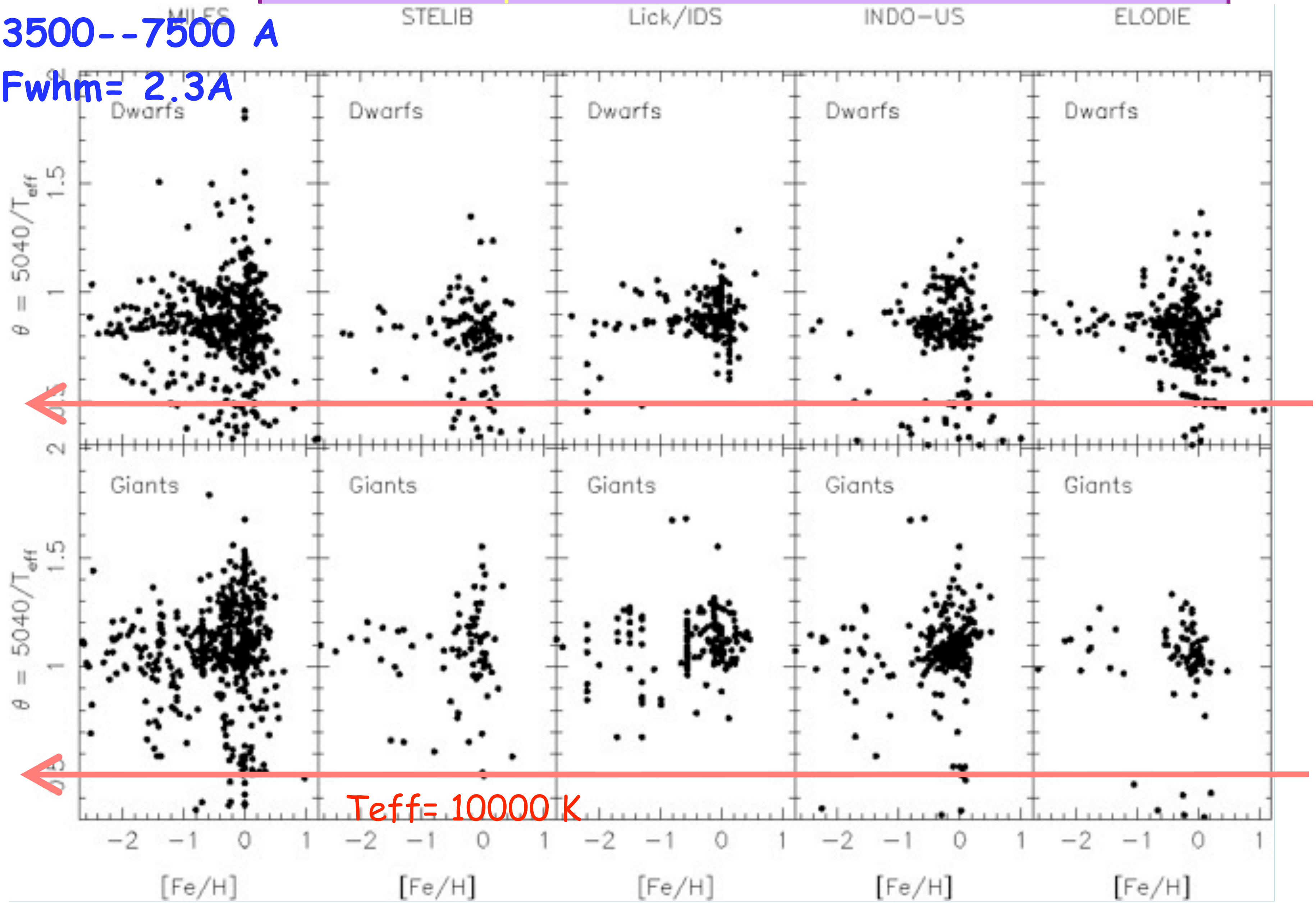
Luminous V
Luminous III
Luminous II
Luminous II with log g>3.2
Luminous I

Miles:

MILES compared with STELIB and other libraries

3500--7500 A

Fwhm= 2.3A



Sánchez-Blázquez et al 2006, MNRAS, 371, 703

The fitting method: STARLIGHT by Cid Fernandes

www.starlight.ufsc.br

- The fit is carried out with a simulated annealing plus Metropolis scheme which searchs for the minimum chi-square between the data and models

- **Inputs:** bases of SSP of high/intermediate spectral resolution evolutionary models

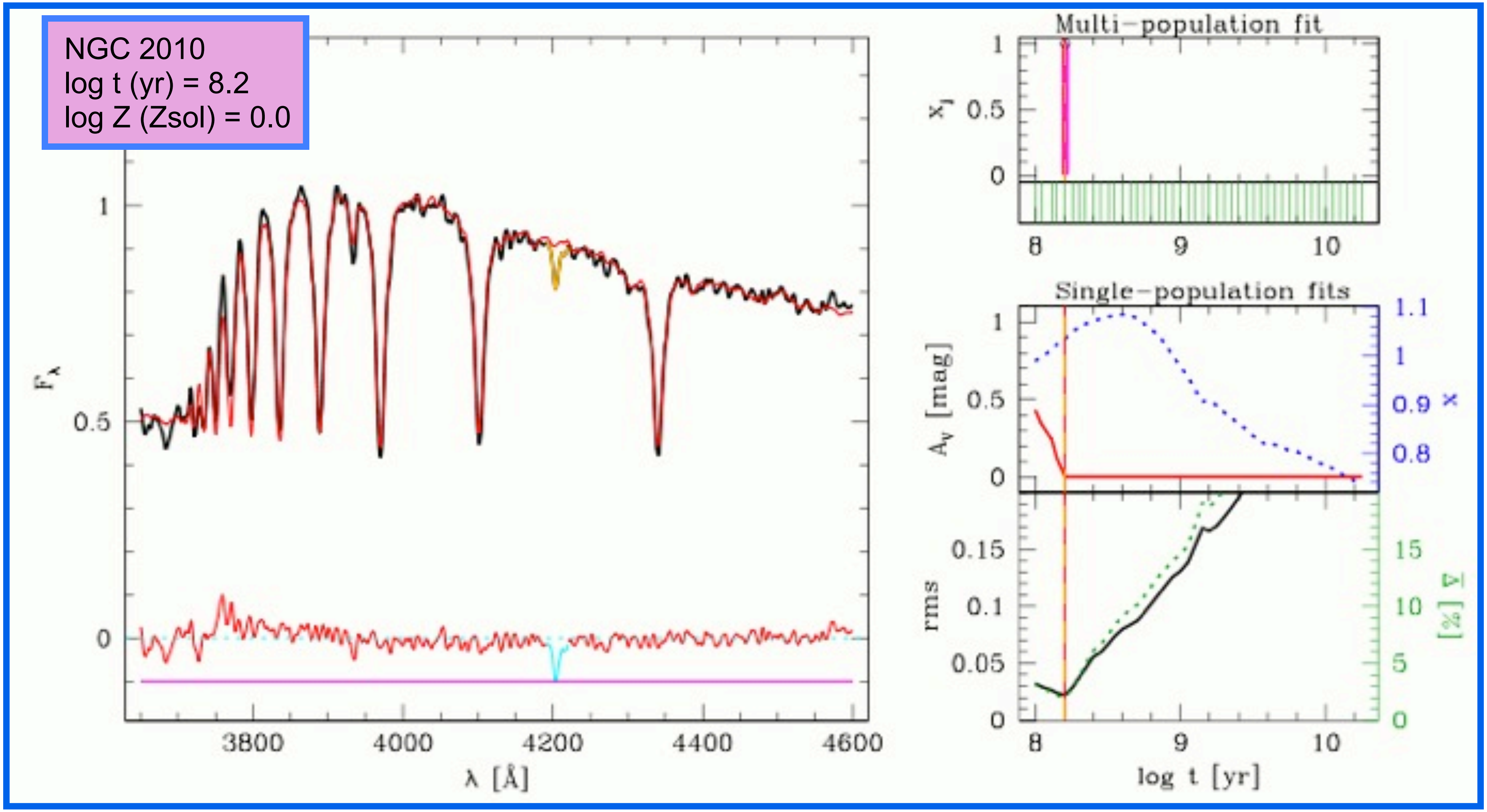
- **Outputs:**
  - The best SSP: age, extinction for a given metallicity
  - Population vector that represents the flux fractional contribution of each SSP of a given age to the model flux at a given wavelength

    Luminosity weighted age
    Extinction
    Metallicity

SSP Bases for Starlight

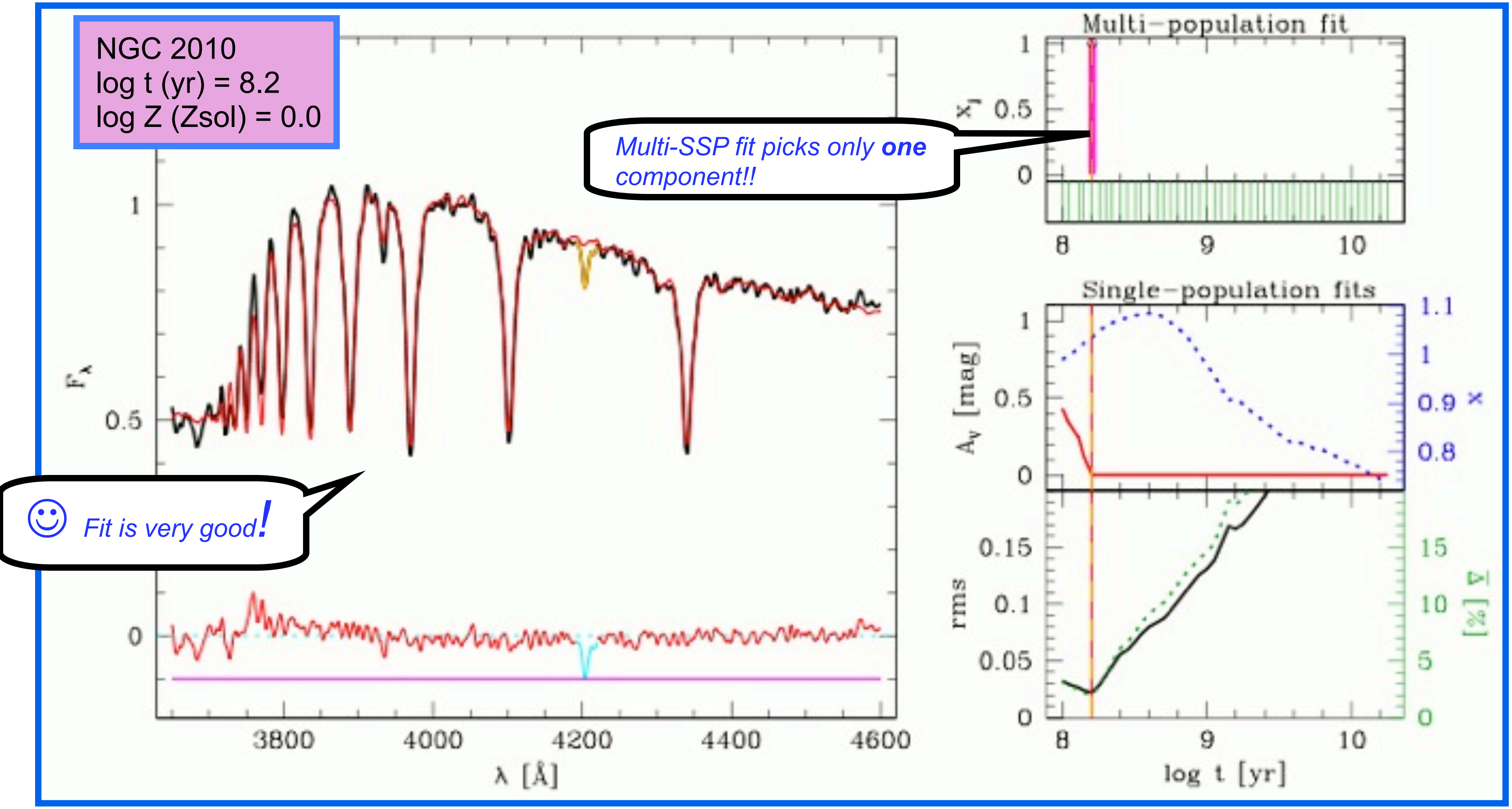
Code	Library	Tracks	IMF	No. SSPs Ages	Metallicities
SED@	Granada	Padova2000	Salpeter (4)	74 4 Myr--17Gyr	0.019, 0.008, 0.004
GALAXEV	MILES	Padova1994	Chabrier (3)	221 0--20Gyr	0.05, 0.02, 0.008, 0.004, 0.0004 0.000
GALAXEV	STELIB	Padova1994	Salpeter (-2) Chabrier (2)	221 0--20Gyr	0.05, 0.02, 0.008, 0.004, 0.0004 0.000
GALAXEV	STELIB	Padova2000	Salpeter (-1) Chabrier (1)	221 0--20Gyr	0.03, 0.019, 0.008, 0.004, 0.001 0.0004
Vazdekis	Miles	Padova2000	Salpeter (-1)	46 100--17Gyr	0.03, 0.019, 0.008, 0.004, 0.001 0.0004

The fitting method: STARLIGHT output



Observed (black) and best-fit (red) spectra of NGC 2010. Residual spectrum is shown at the bottom. Top right: The bar code (green) shows the 46 SSP ages in the V00s (Vazdekis models). Middle right: Best-fit Av and x for single-SSPs a function of age. Bottom right: rms

The fitting method: STARLIGHT output



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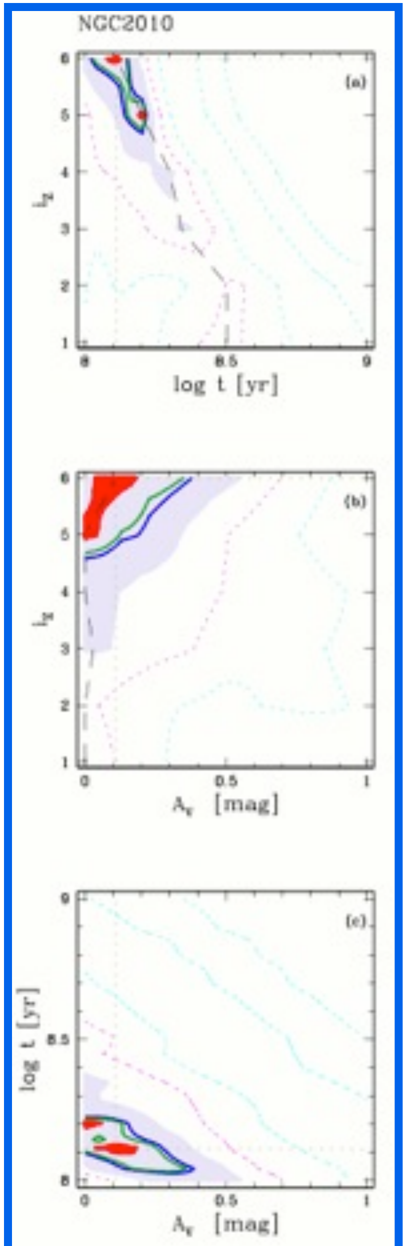
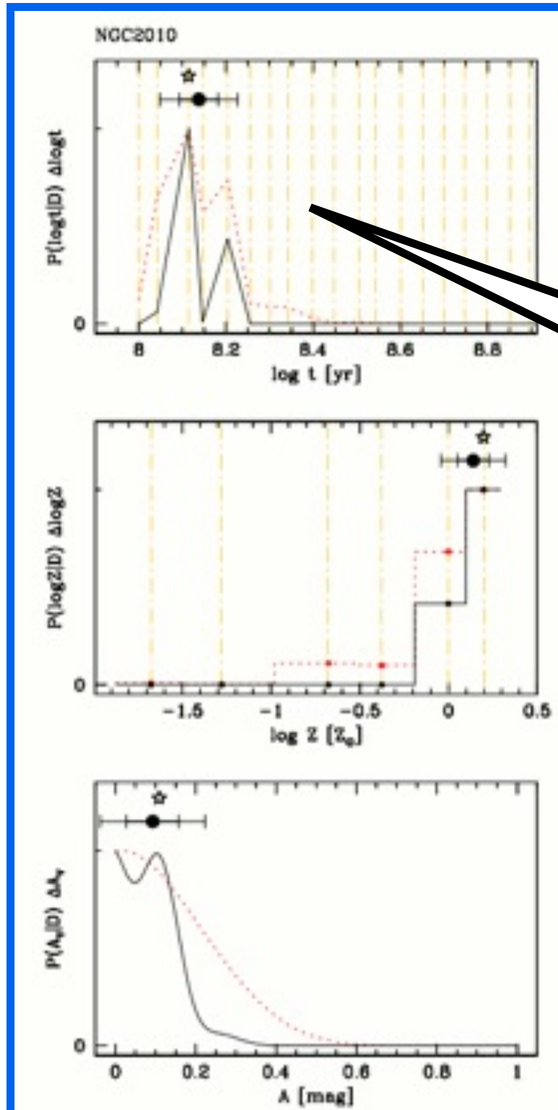
Maping of parameter space: degeneracies/covariances





Bayesianities:PDF of t (age), Z & Av

2 peaks in age correspond to two good Z's

Fig. 1a: χ^2 **contoursin the age-metallicity-extinction space for NGC 2010**
Fig. 1b: **PDF for age (log t), metallicity (Z), and extinction (Av).**

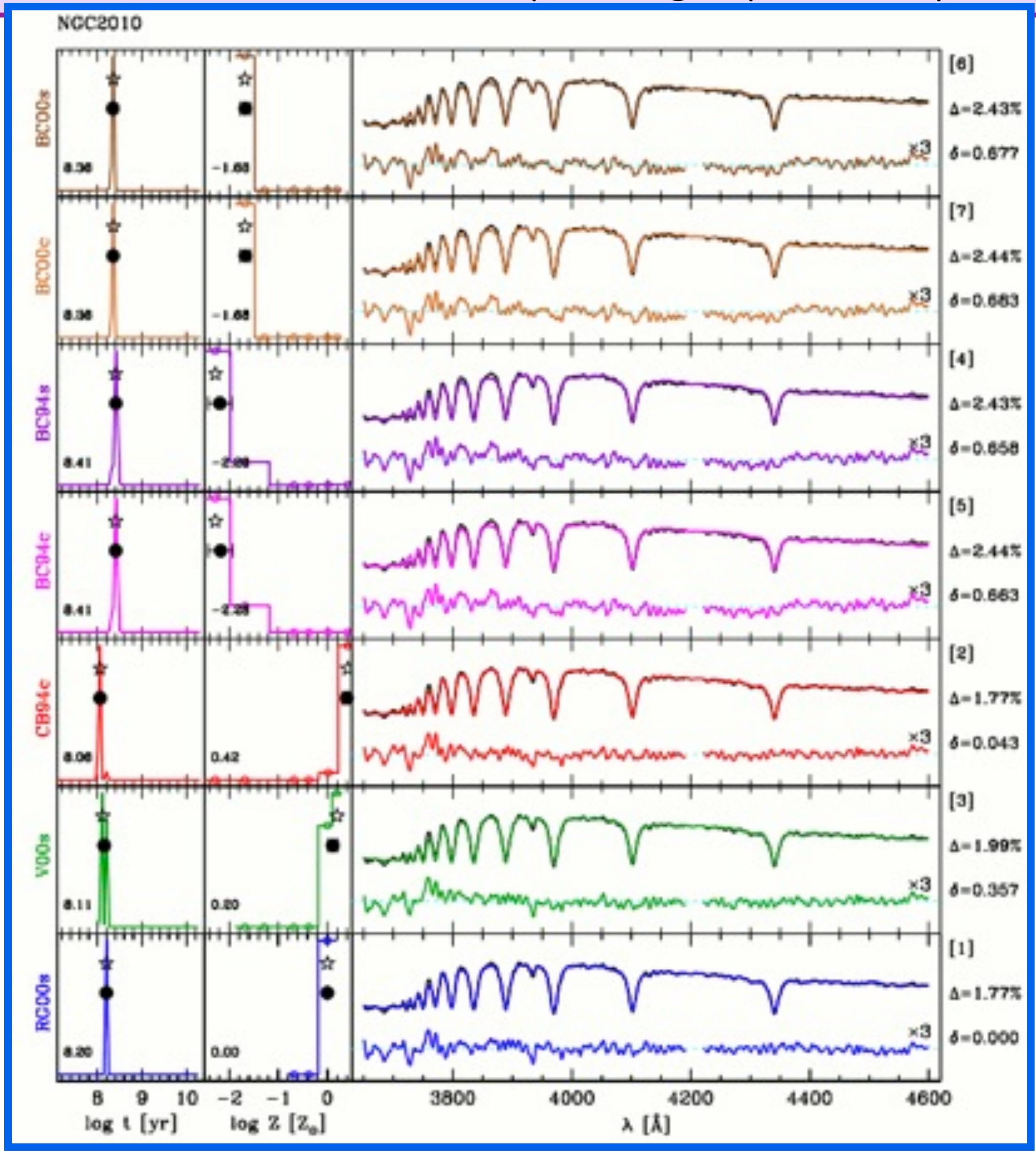
Comparing Models: All the models produce good quality fits. Models based on MILES and Granada libraries yield slightly better spectral fits.

BC03: Stelib

CB2010: Miles+ Granada

Vazdekis2010: Miles

RG00s: Granada



6

7

4

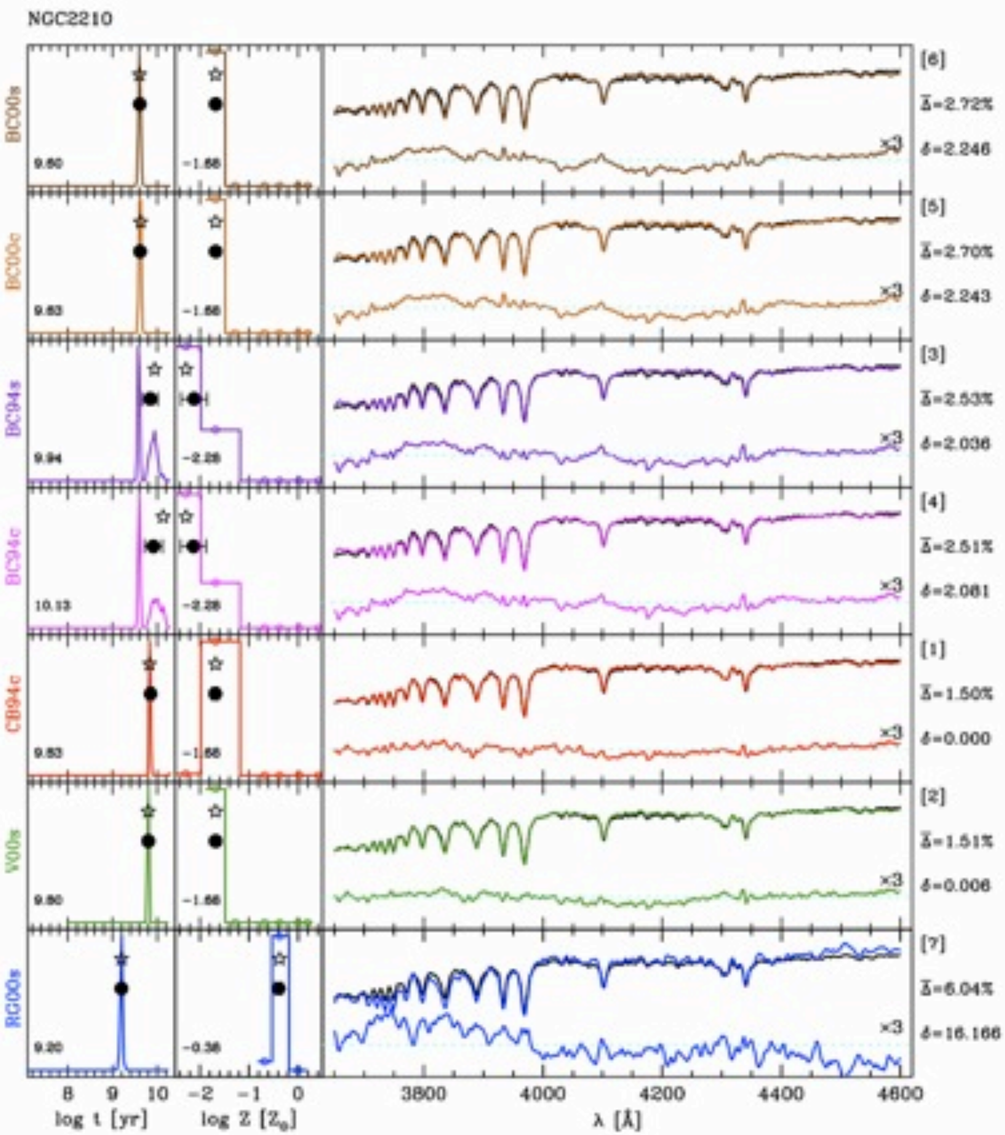
5

2

3

1

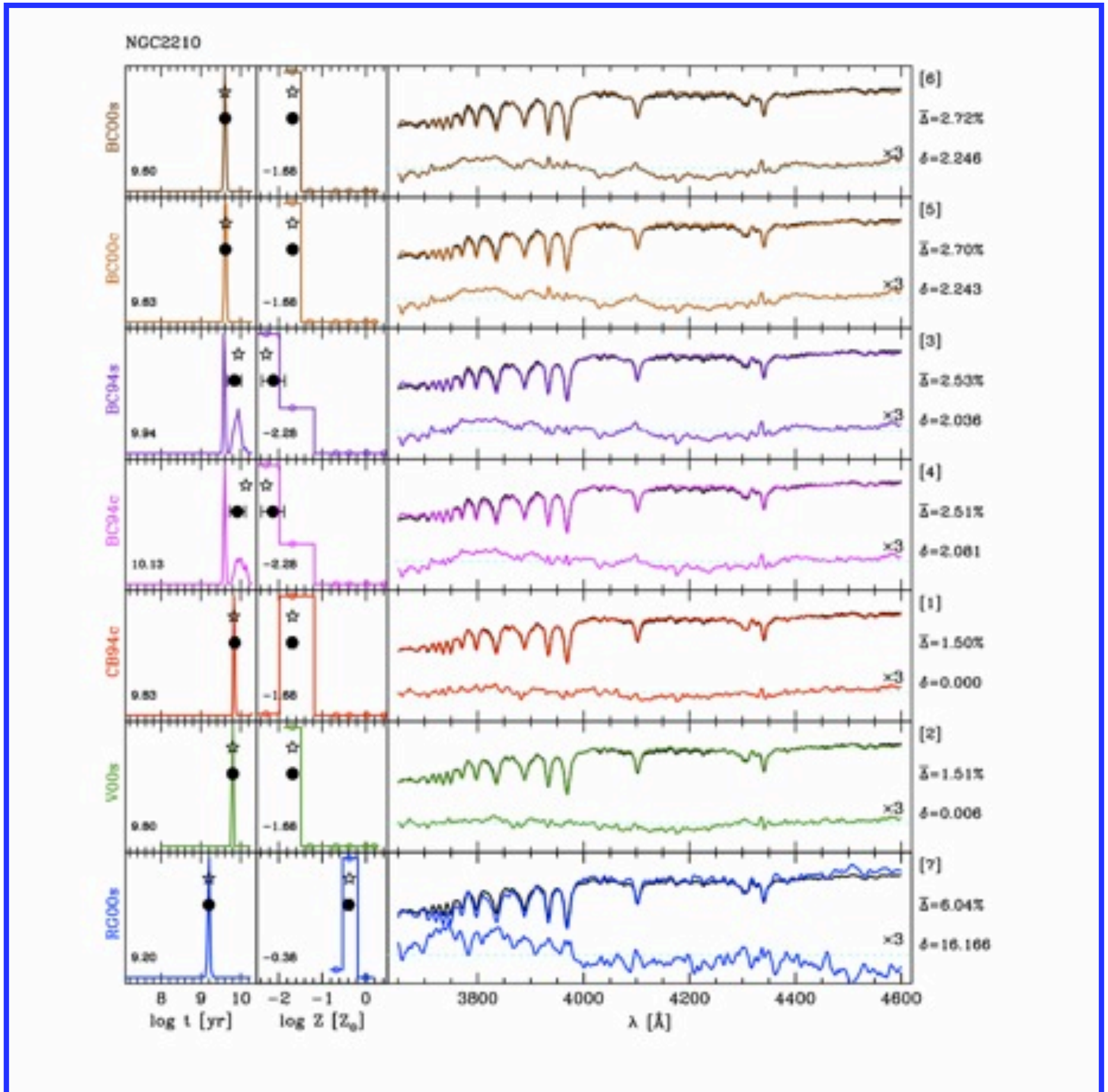
NGC2010:
log t = 8.2
log Z = 0.0



NGC2210:
log t = 10.1
log Z = -2

Comparing Models:

Metal poor clusters are poorly fitted by Granada models as consequence of lack of predictions for Z below 0.2 solar. The error on the age estimated by the other models is also higher than the average precision reflecting also the difficulty of derived ages for metal poor clusters if the Balmer lines are contaminated by the contribution of blue stars in the HB.



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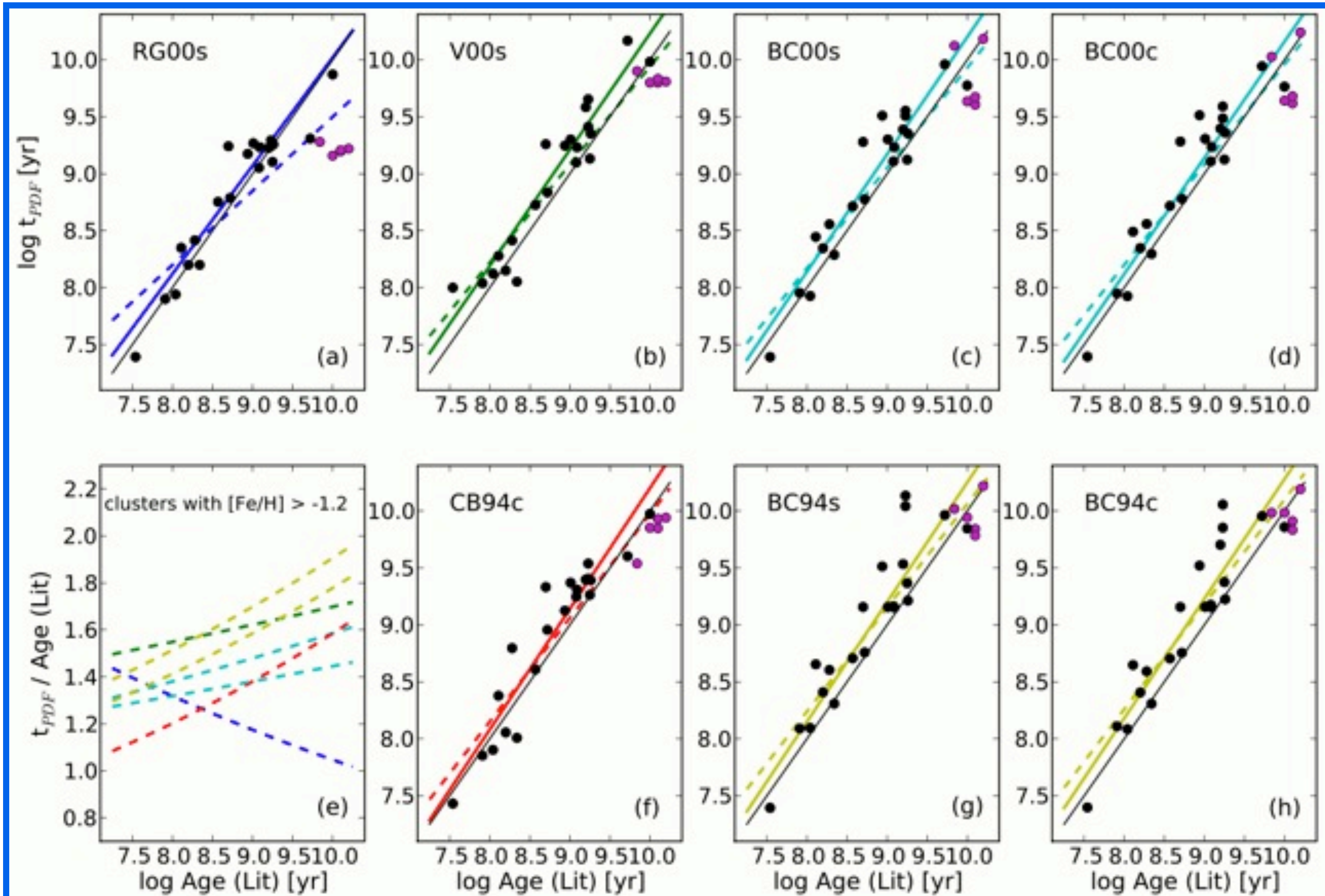
- MILES Ok!

- STELIB lacks low Z stars

- Granada lacks low Z tracks!

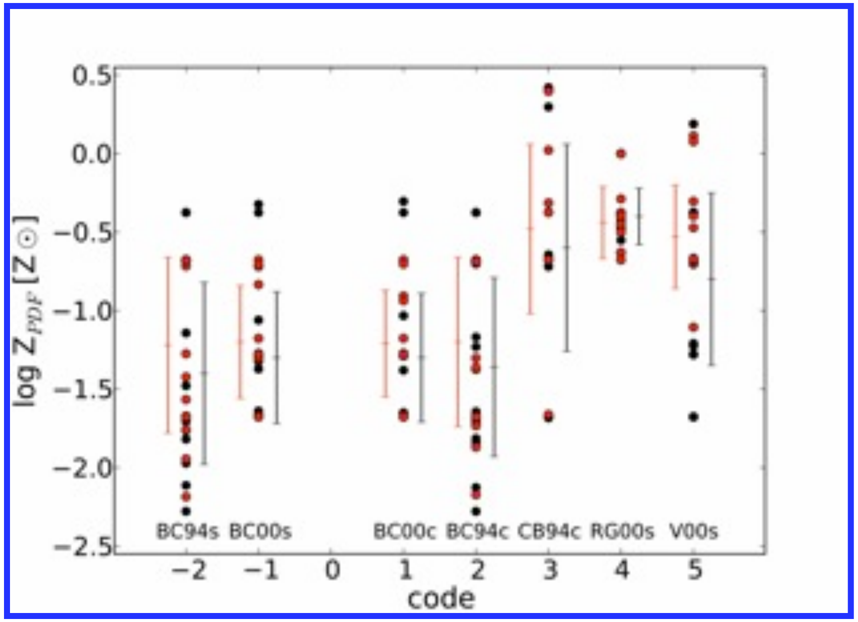
Results: Ages correlate very well with the S-CMD ages, but spectral fit ages are 0.09 dex larger.

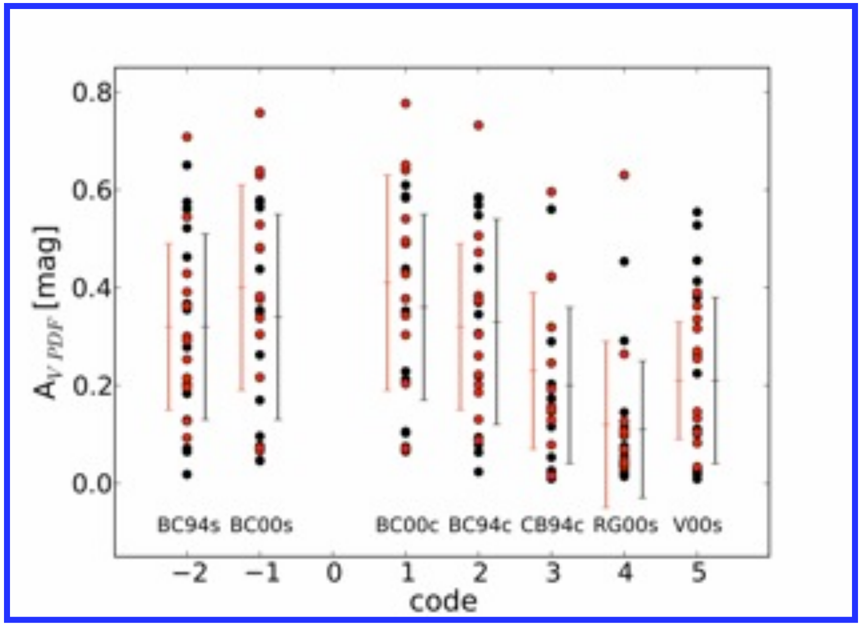


Results:

•Extinction derived are small, as expected for these clusters; but STELIB gives larger values of Av.

•Fits with STELIB models produce metallicities systematically smaller by about 0.6 dex.

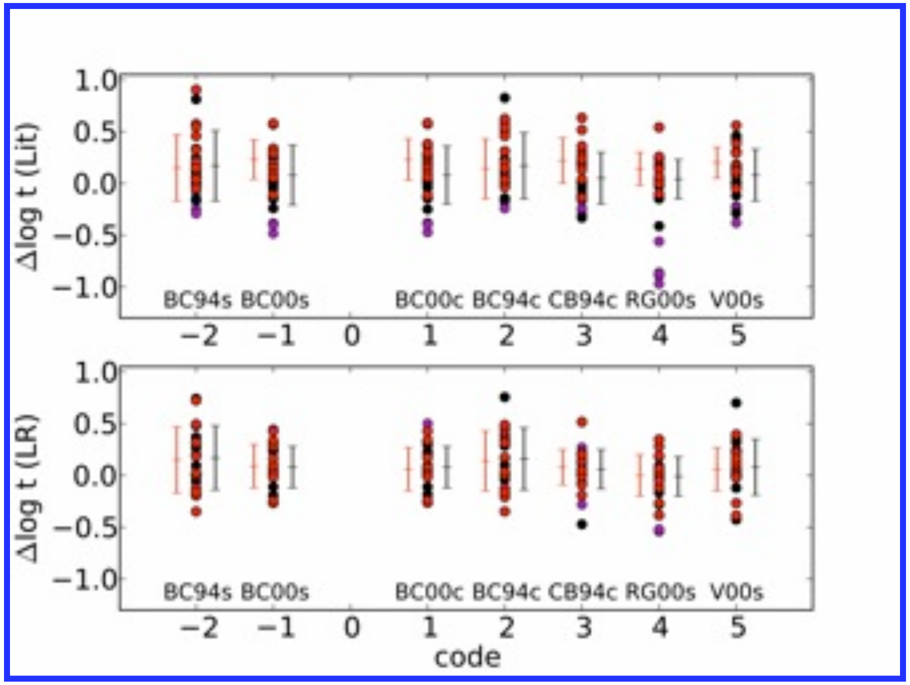


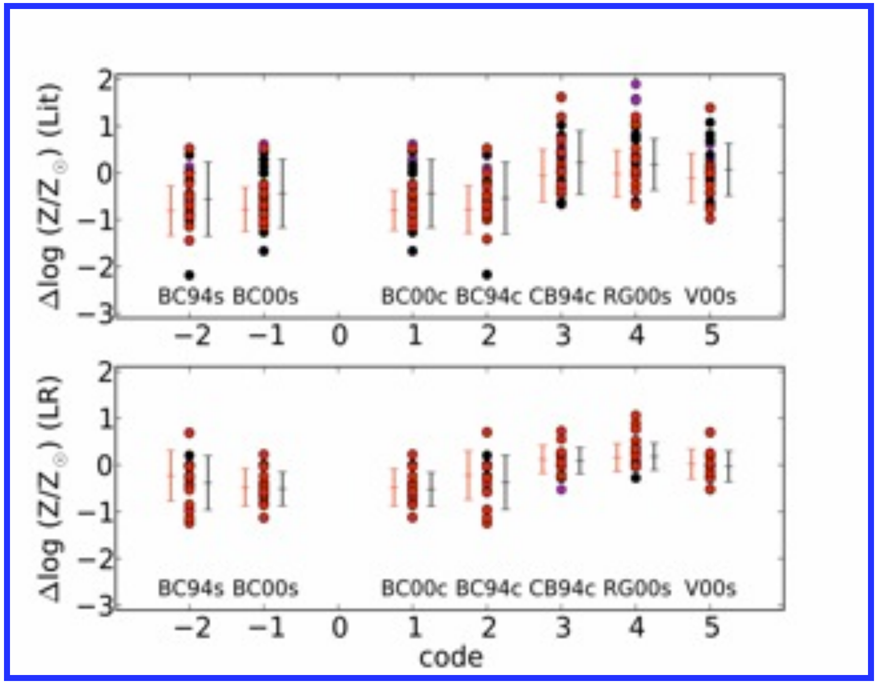


Results:

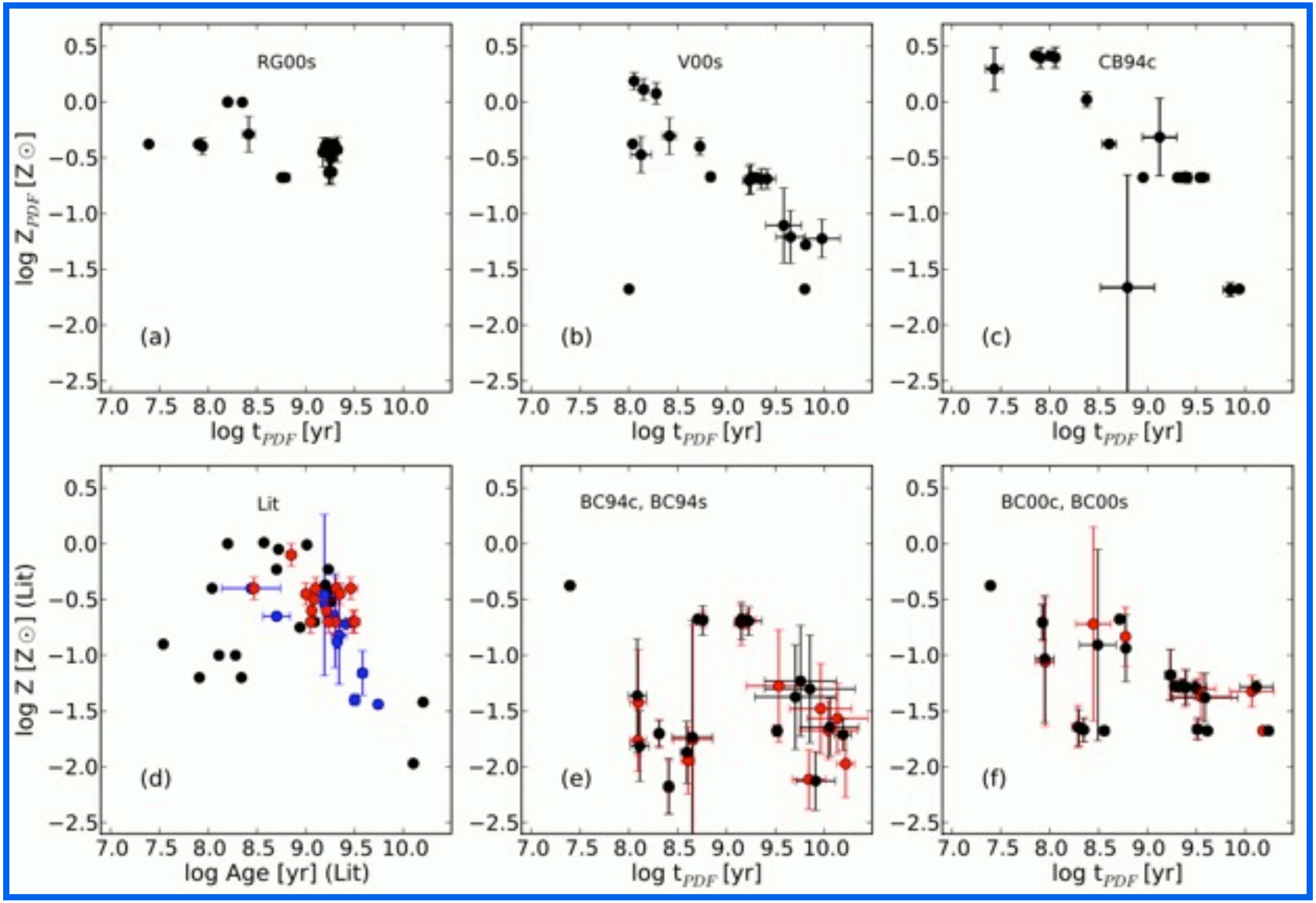
•Metallicities from spectral fits correlate poorly with the literature data. Due to intrinsic difficulty in deriving Z in the limited spectral range, plus inhomogeneity and uncertainties in the literature values.

•Fits with STELIB models produce metallicities systematically smaller by about 0.6 dex.

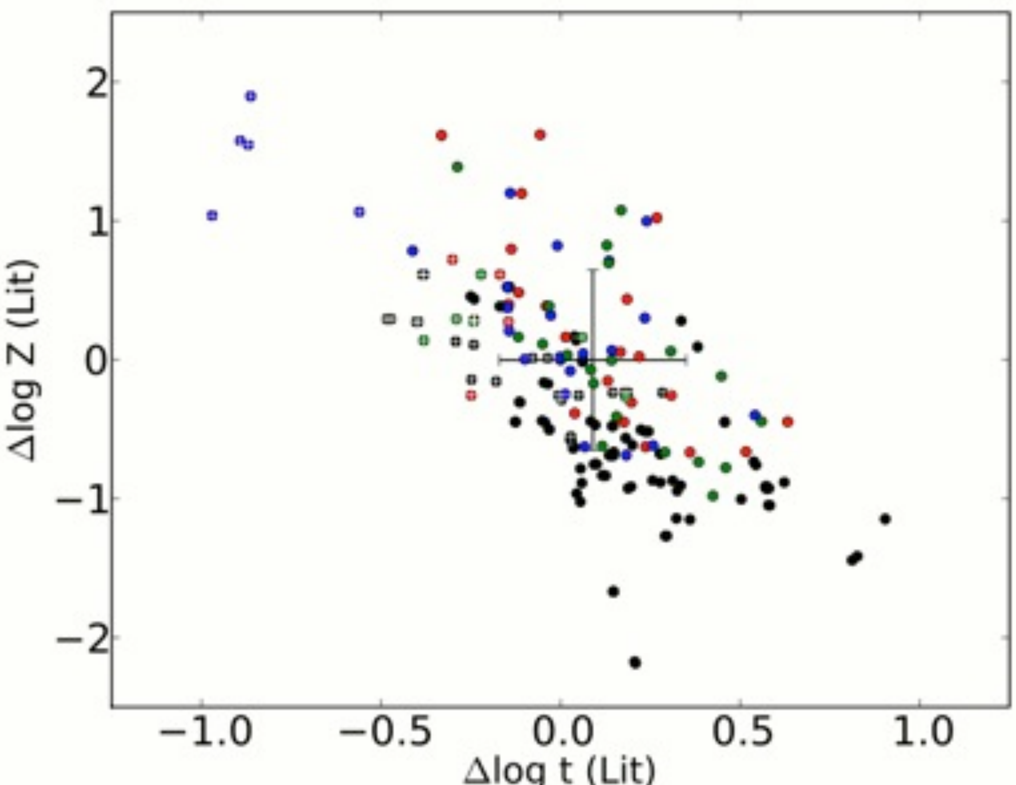




Results: Age-metallicity relation for LMC clusters. Panel (d) shows the data from the Literature; panels a to c and e-f show the results from STARLIGHT



Results



•The precision (or consistency) of the models to determine the age and metallicity is 0.17 dex and 0.5 dex (rms of the models with respect to the mean). If Stelib are excluded, the consistency of the models are better, with an rms of 0.1 dex and 0.3 dex for age and metallicity respectively.

•Model-to-model dispersions in derived age, and Z values are about 0.2 and 0.5 dex, respectively. Removing Stelib results, these values reduce to 0.1 dex in age and 0.3 dex in metallicity. Similar differences are found when comparing the spectral fit results to the literature values for age and Z

Summary and conclusions

Questions

Answers

Do current models fit SC spectra well?	☺ Yep!
Is **t** well constrained? Is **t** biased? Does **t** depend on model choice?	☺ Yes! ~ 0.1 – 0.2 dex ☺ Nope. ☺ Not too much.
Is **Z** well constrained? Is **Z** biased? Does **Z** depend on model choice?	😐 Hmmm ... ~ 0.3 – 0.4 dex ☹ It can be badly biased! ☹ Yes...
Do newer models do a better job? (Are we going in the right direction?)	☺ Yes!
What's needed to improve things?	Finer/more homogeneous grids More complete stellar libraries