Big Eyes on stellar population models
SDSS-based stellar population models

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The Big Eyes' requests to models

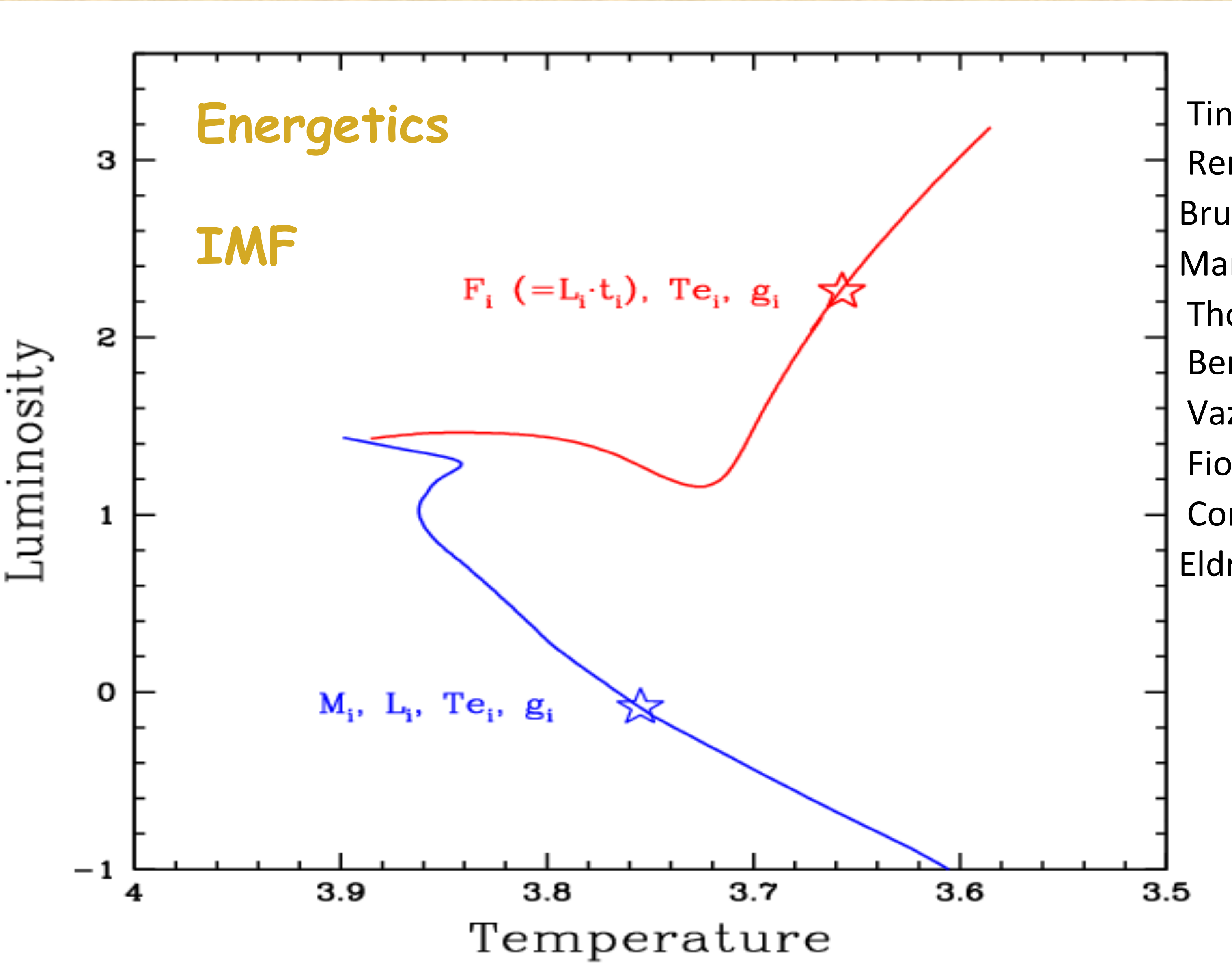
- Sound Input Physics (overshooting, stellar rotation, mass-loss) and Parameters (binarity, IMF)

- Spectral resolution – R=10,000-20,000

- Wavelength extension – UV to near-IR rest-frame

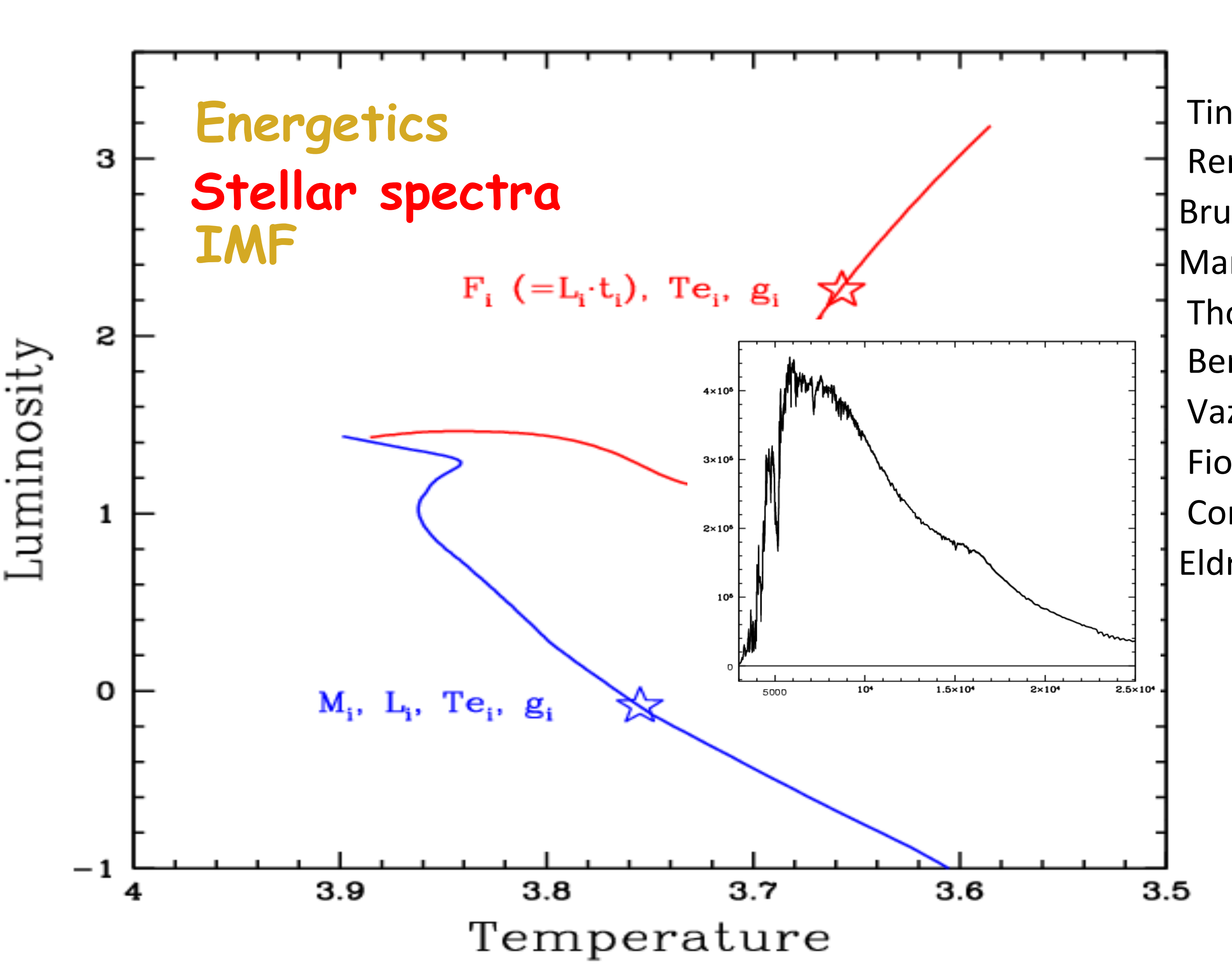
- What S/N to achieve what? Stellar age, chemical composition, stellar mass, SFH, SFR

The spectral ingredient in Evolutionary Population Synthesis



Tinsley 1972;
Renzini 1981;
Bruzual & Charlot 03
Maraston 98; 05; 11;
Thomas, Maraston Bender 2003;
Vazdekis et al. 96;16
Fioc & Rocca 97;
Conroy et al. 2010;
Eldridge et 2012

The spectral ingredient in Evolutionary Population Synthesis



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Theoretical vs Empirical

Theoretical

- Wide coverage of stellar parameters, wavelength (far UV) and resolution
- Free from observational degrade

- Line and opacity missing (e.g. Hβ, Carbon molecules, TiO in giants)
- non-LTE effects

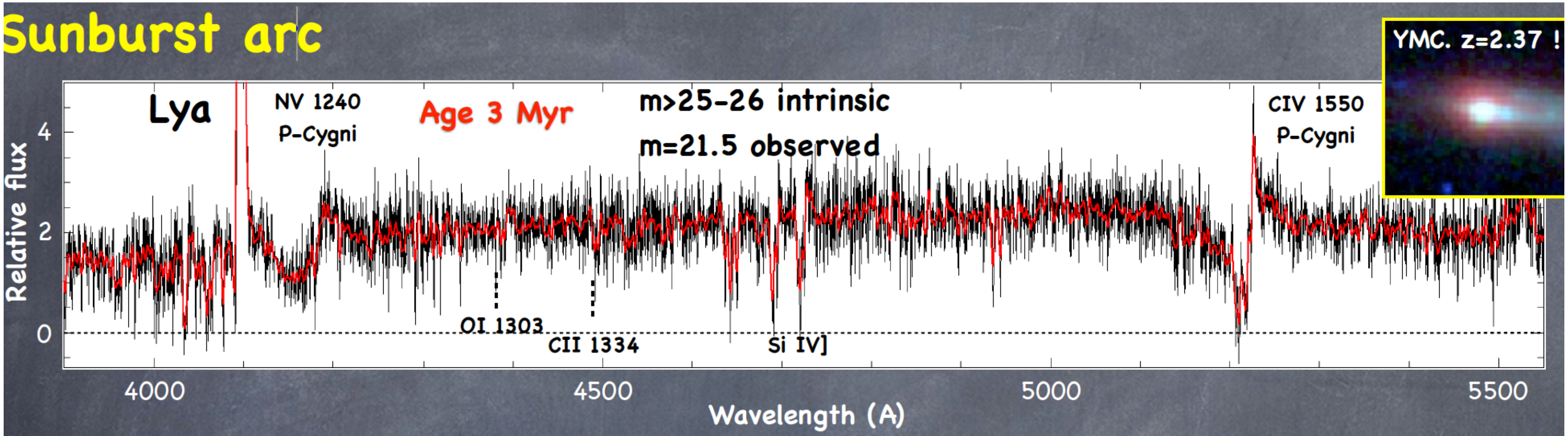
Empirical

- Real lines of real stars
- **Same observational setup of galaxies to be studied**

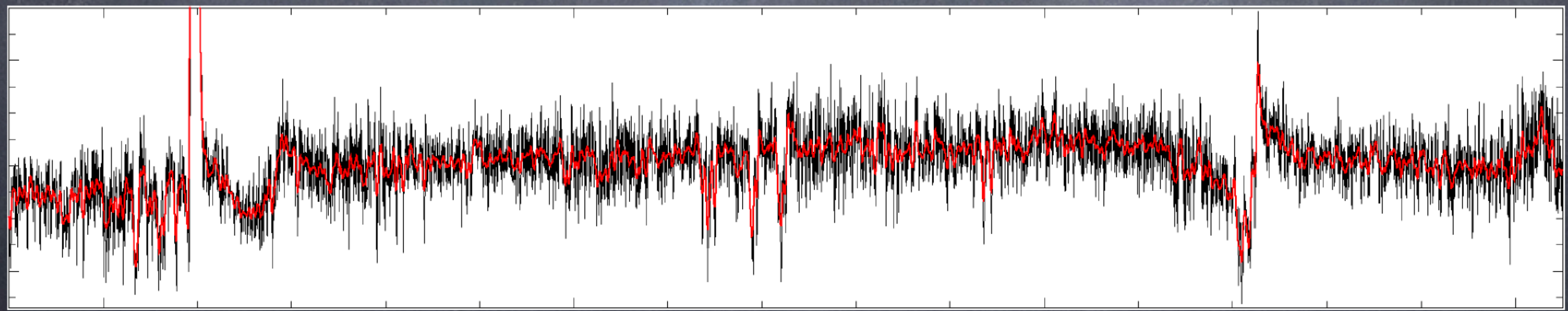
*Limited parameter range - Te,logg, [Z/H], [el/Fe] – defined by the Milky Way star formation history and present stage
*Limited wavelength range

Stellar Parameters need to be determined

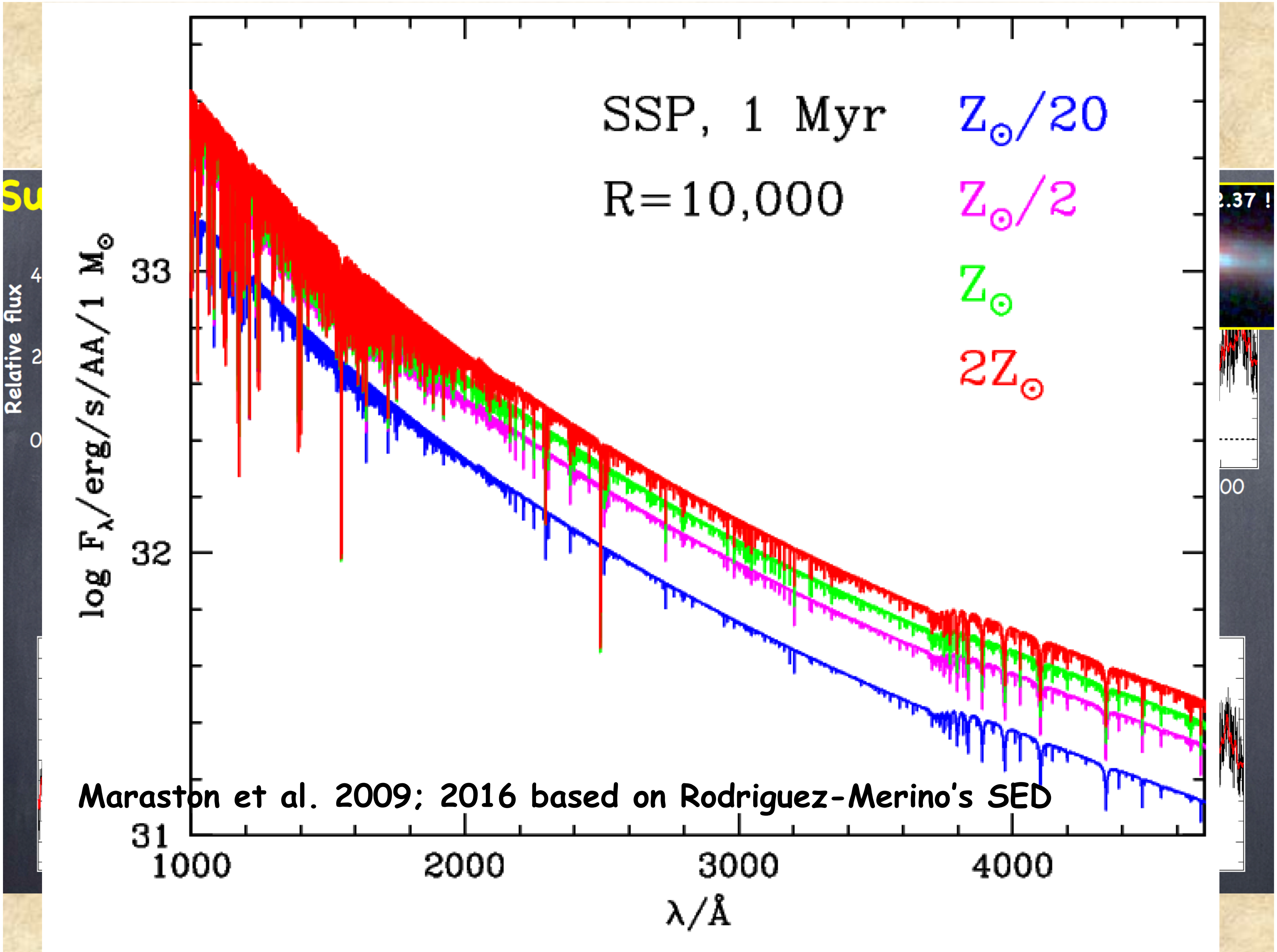
Rest-frame UV with the E-ELT



Mimicking a ELT spec R=11400,
887s (X-Shooter, PI Vanzella)

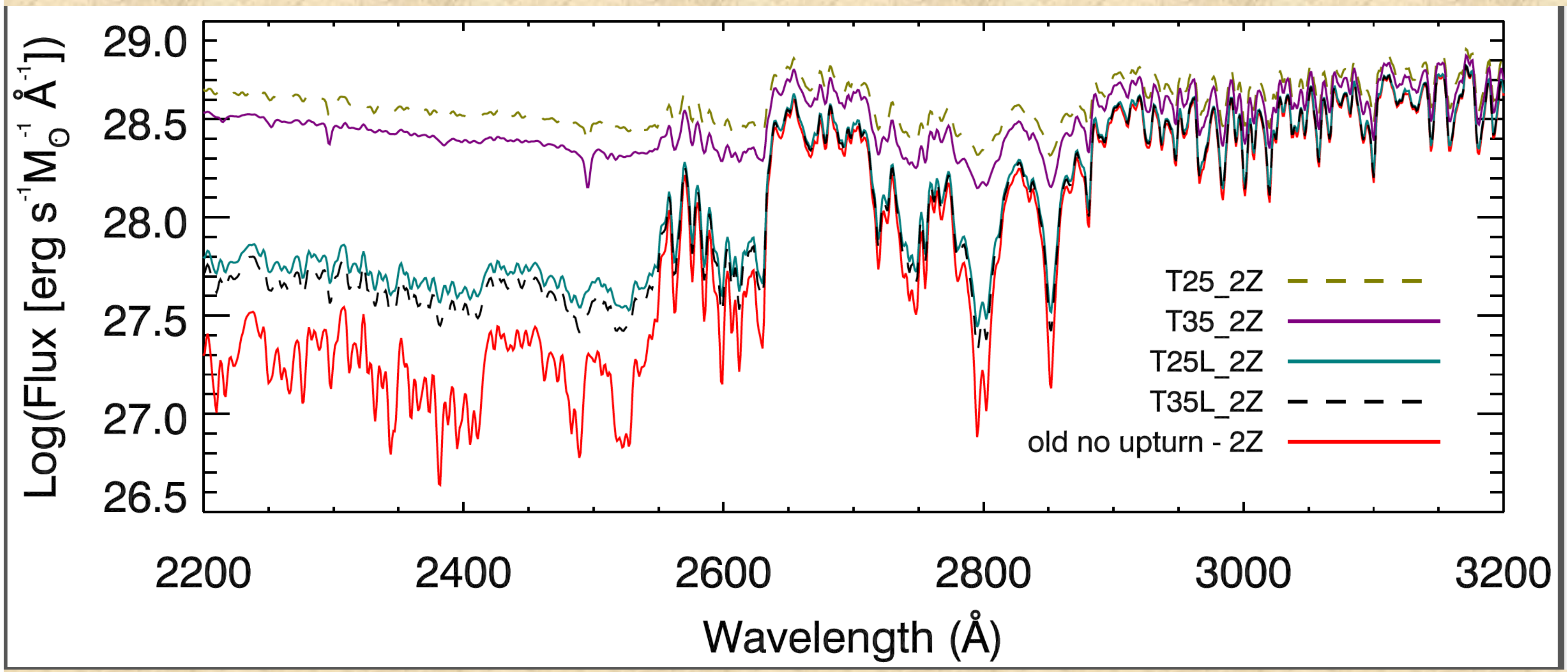


Credit: Eros Vanzella



Maraston et al. 2009; 2016 based on Rodriguez-Merino's SED

The UV upturn in mature galaxies



UV upturn models as a function of Temperature and fuel consumption,

Detected up to z~0.9, Le Cras et al. 2016 and higher Lonoce et al. 2019, subm.

Rest-frame Optical/near-IR

Crucial for

- Metallicity and alpha-element abundance determinations

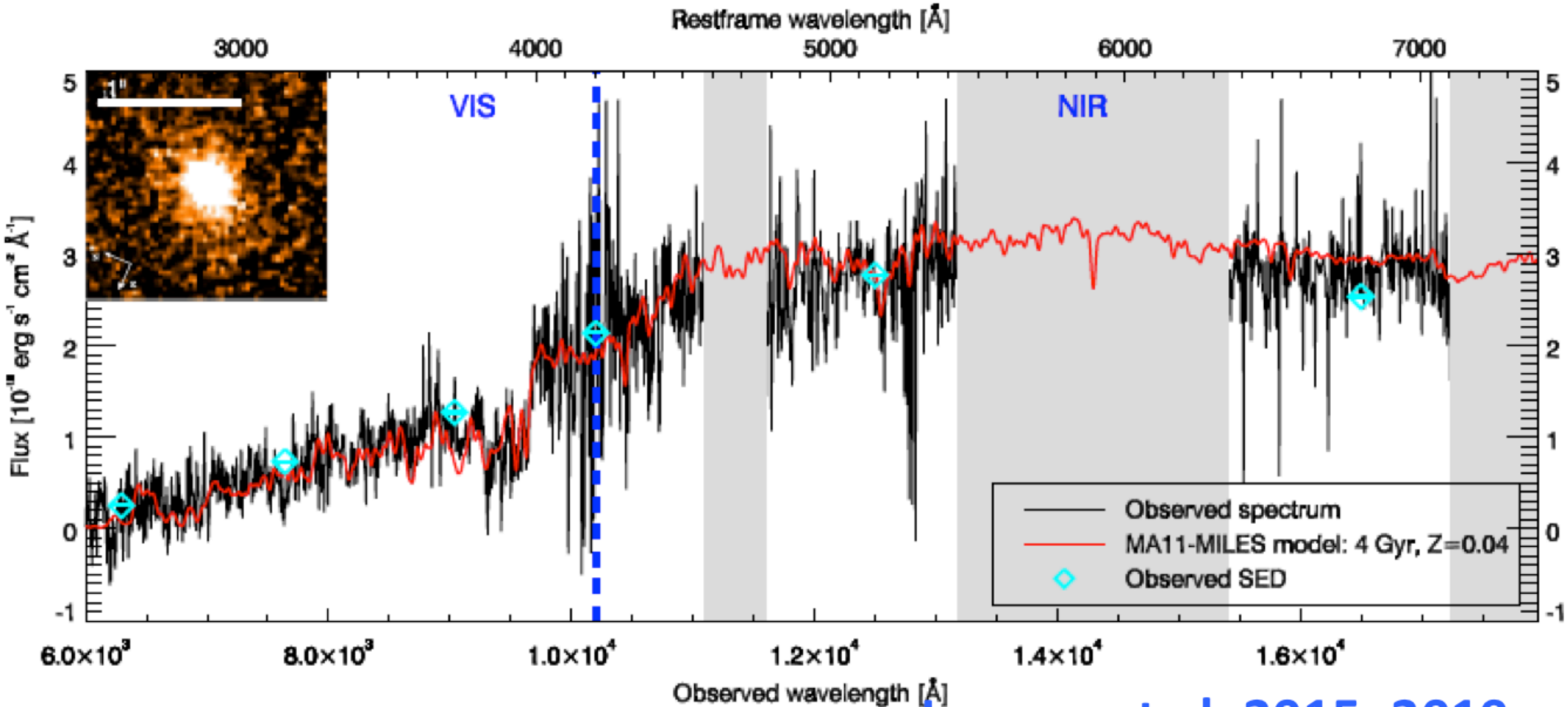
- Age of the bulk stellar population → M*, M/L

- IMF

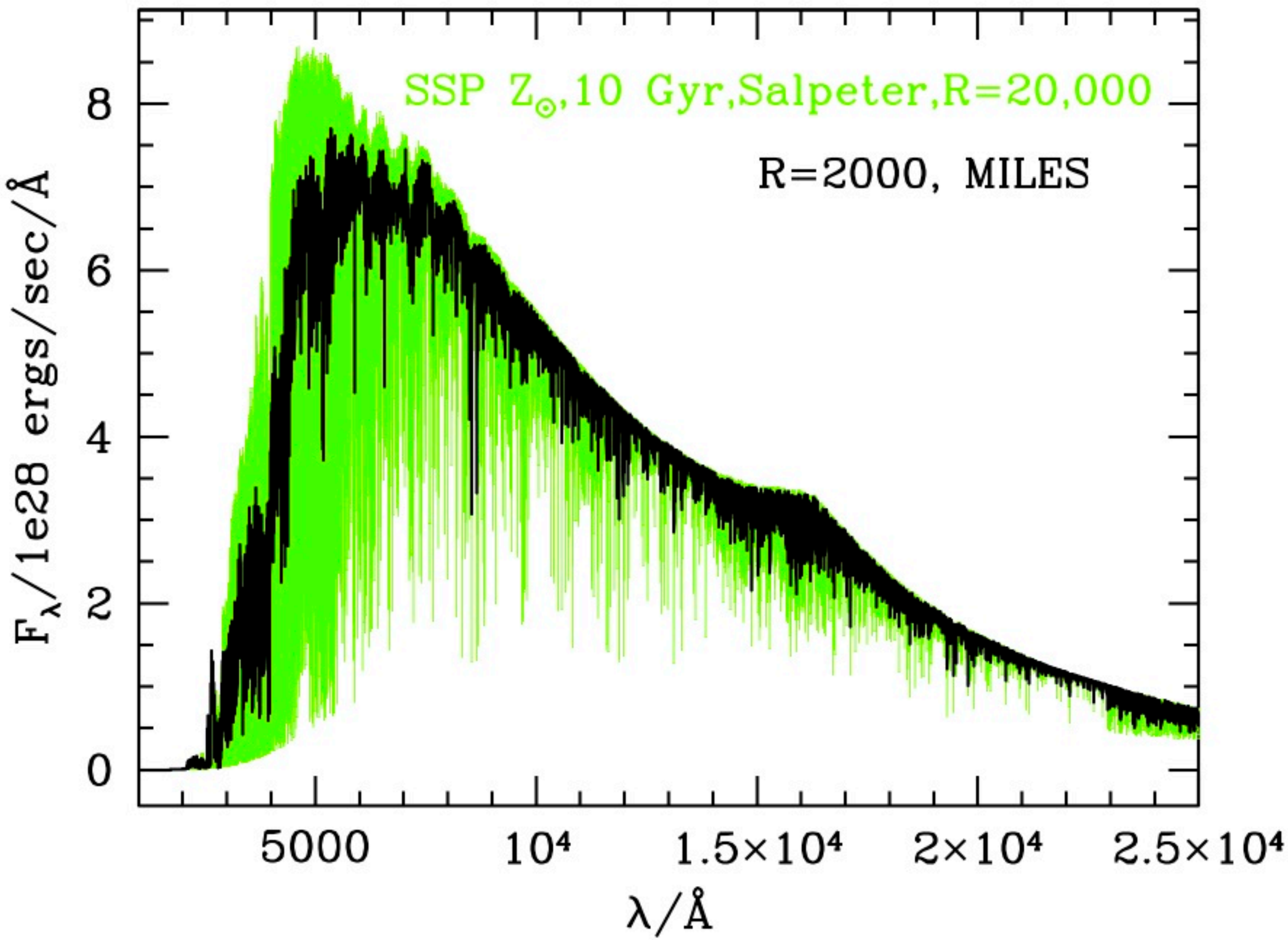
Rest-frame Optical/near-IR

Individual stellar metallicity measure of a z ∼ 1.4 early-type galaxy

[Mg/Fe]~0.4



Lonoce et al. 2015; 2019 sub



Maraston & Stromback 2011 EXTREMELY high resolution based on MARCS model atmospheres

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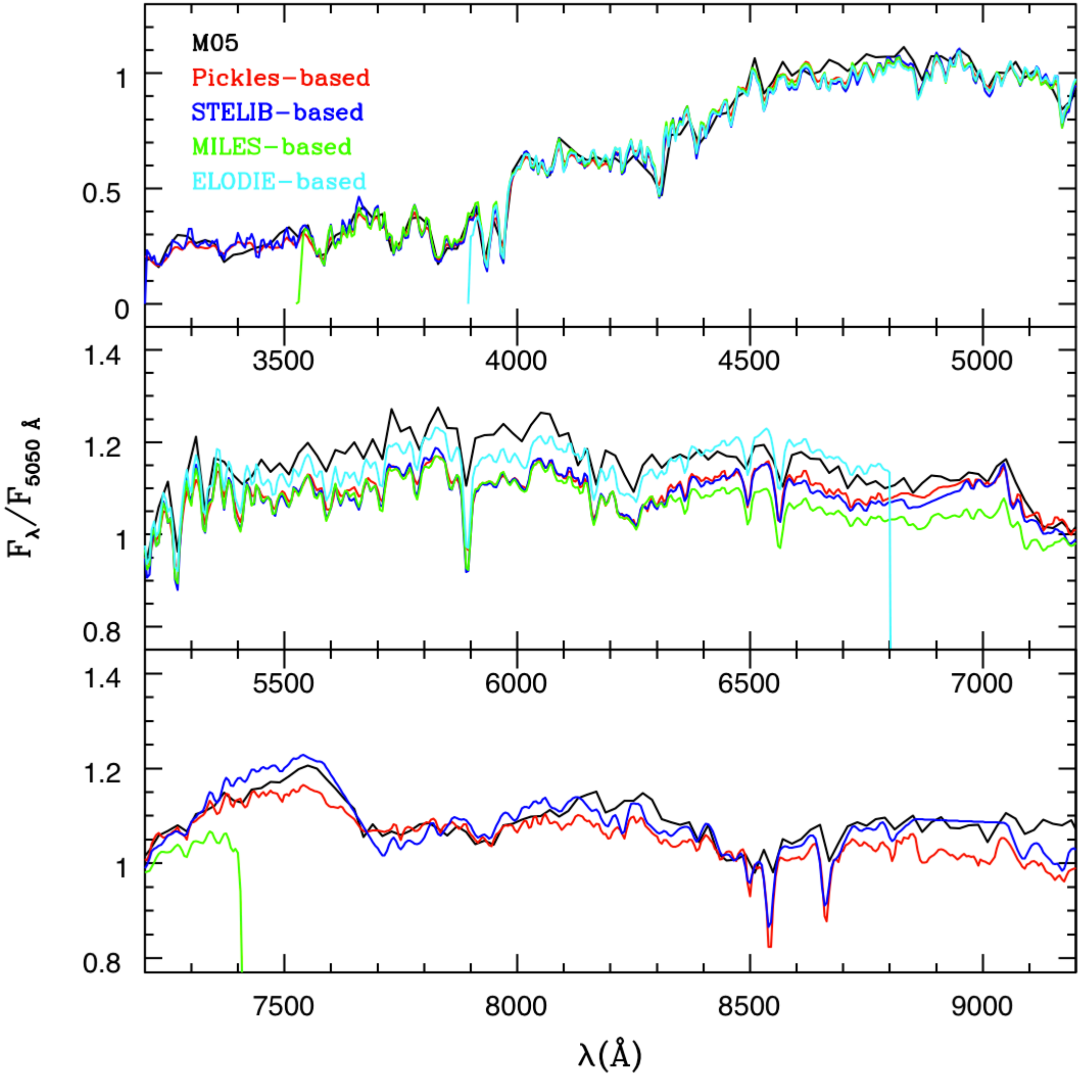
SP model spectra based on empirical libraries



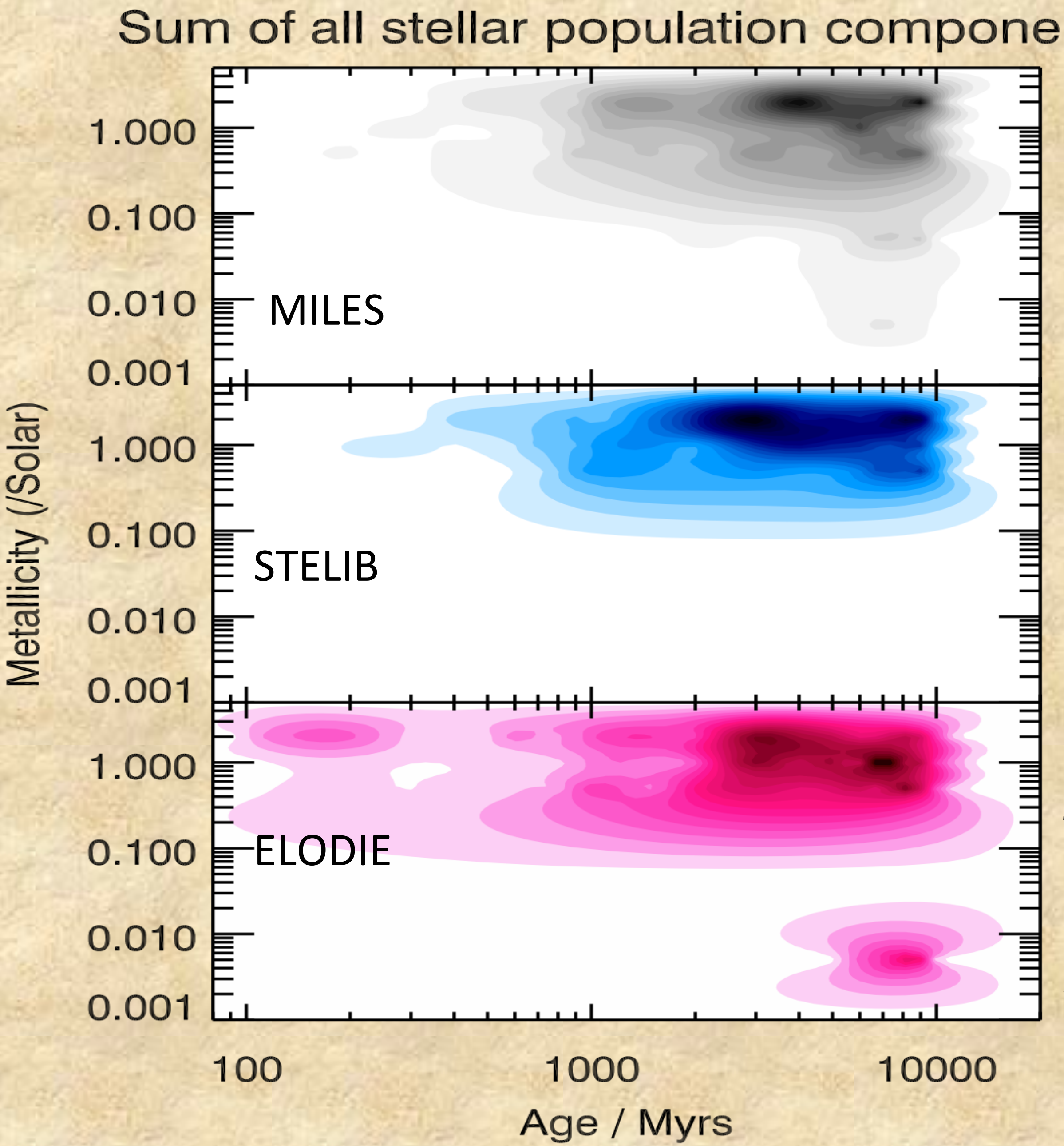
Discrepancies between MW-based empirical stellar Libraries

12 Gyr solar metallicity population

Maraston & Stromback 11, www.maraston.eu/M11

high spectral resolution from the UV to the near-IR

Inferred galaxy properties depends on stellar library



MILES-based models:
Old ages, spread in metallicity

STELIB: spread in age

ELODIE-based models find young ages in galaxies

SDSS/BOSS spectral fits
Wilkinson et al. 2017
Comparat et al. 2018

Aiming to a new empirical stellar library

- Cover the widest possible wavelength range with the same instrument - MILES up to 7000 AA – leave out CN bands, TiO, CaT, FeH

- Better coverage of under-represented stellar species, e.g.

•- M-dwarf: crucial for studies aimed at the IMF (e.g. Conroy & van Dokkum)

•- TP-AGB C, O stars star-forming and high-z galaxies

•- metal-poor stars – local dwarf and high-z galaxies

•- metal-rich and alpha-enhanced stars: crucial for **massive Es**

- Collect a large number of spectra

The SDSS-based MaStar EXTREMELY LARGE stellar library

Yan et al. 2018

- 8700 spectra for 3200 MW stars (MILES~900 stars)

30,000 spectra at completion

- R=1800, S/N>50

* **wide wavelength range - 0.36-1 micron** with the same instrument
* wide coverage of stellar parameters

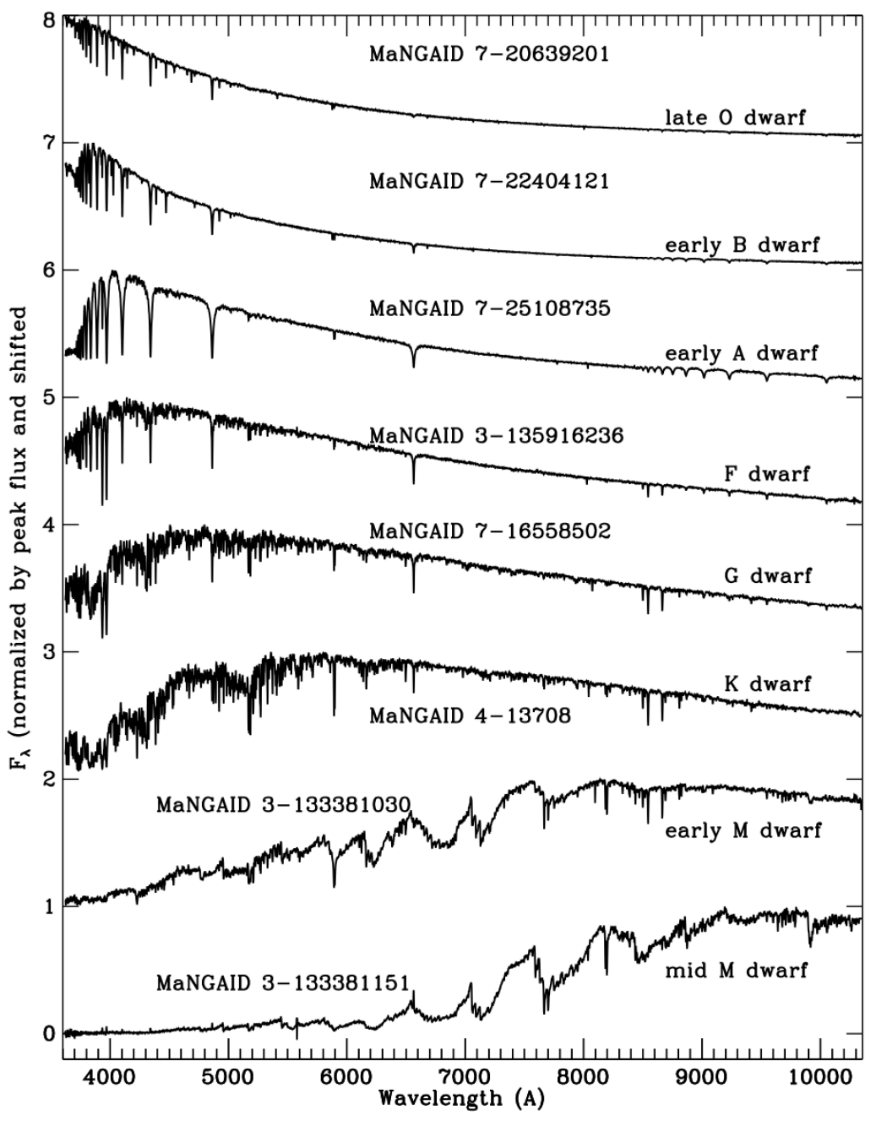


Figure 3. Example per-visit spectra for some main sequence stars in the MaStar Library.

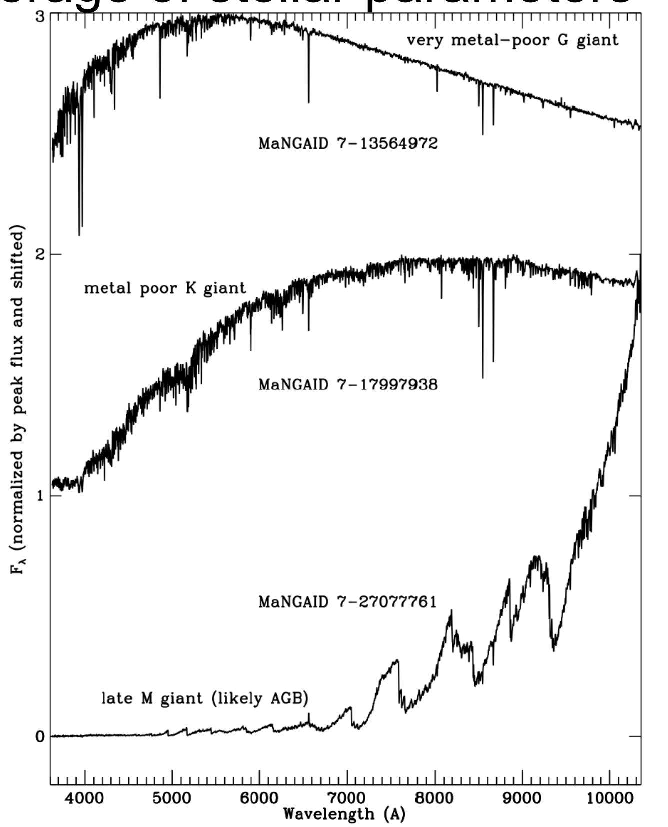


Figure 4. Example per-visit spectra for some giant stars in the MaStar Library.

The SDSS-based MaStar EXTREMELY LARGE stellar library

Yan et al. 2018

* 8700 spectra for 3200 MW stars
* R=1800, S/N>50
* wide wavelength range - 0.36-1 micron with the same instrument
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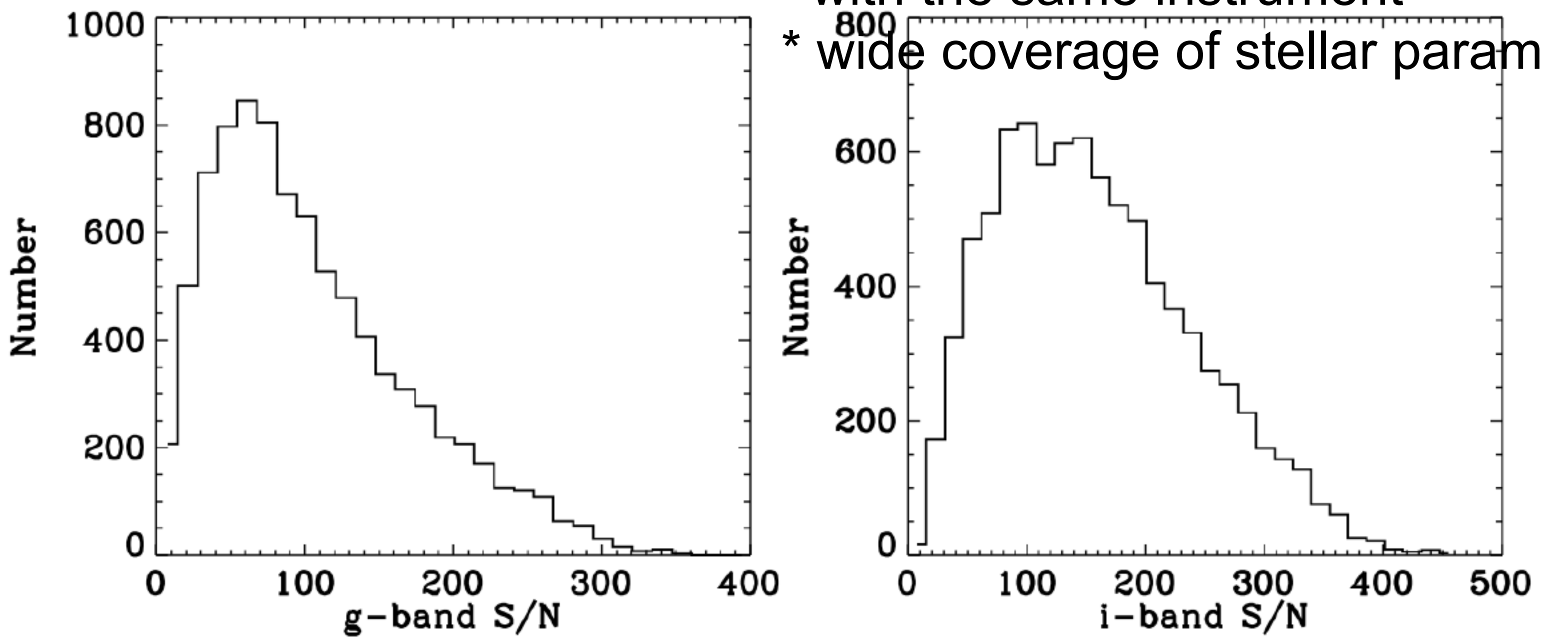
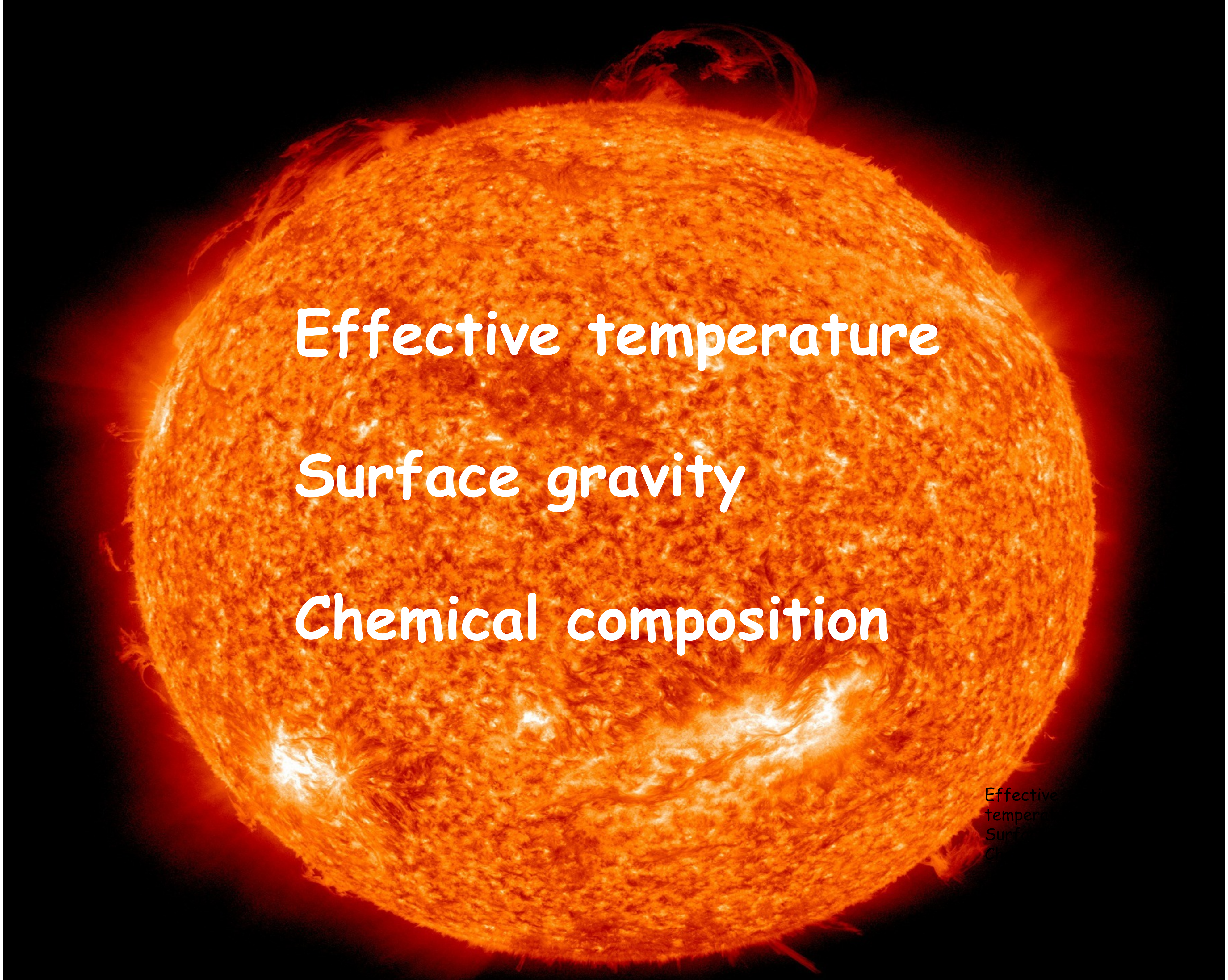


Figure 5. Distributions of median S/N per pixel for all the good per-visit spectra in the *g*-band (left) and the *i*-band (right).



Effective temperature

Surface gravity

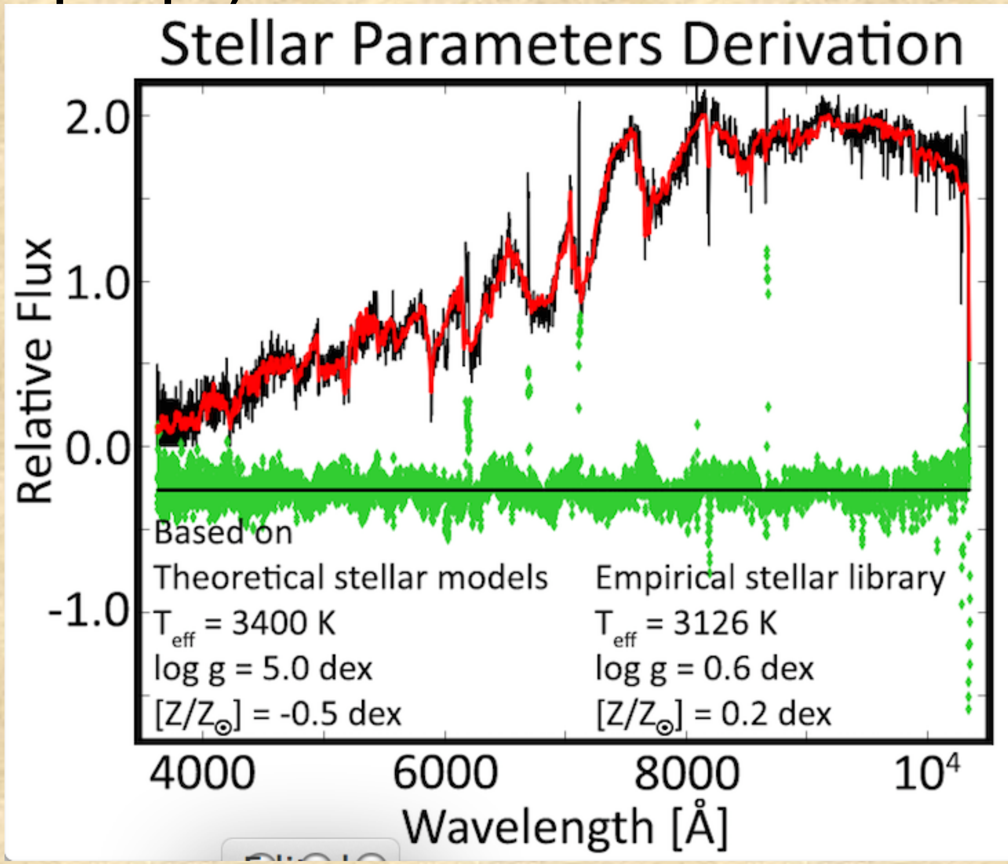
Chemical composition

Calculation of Stellar parameters

Individual full spectral fits with extensive grids of *theoretical spectra* (from MARCS, Kurucz) + GAIA constraints to break degeneracies

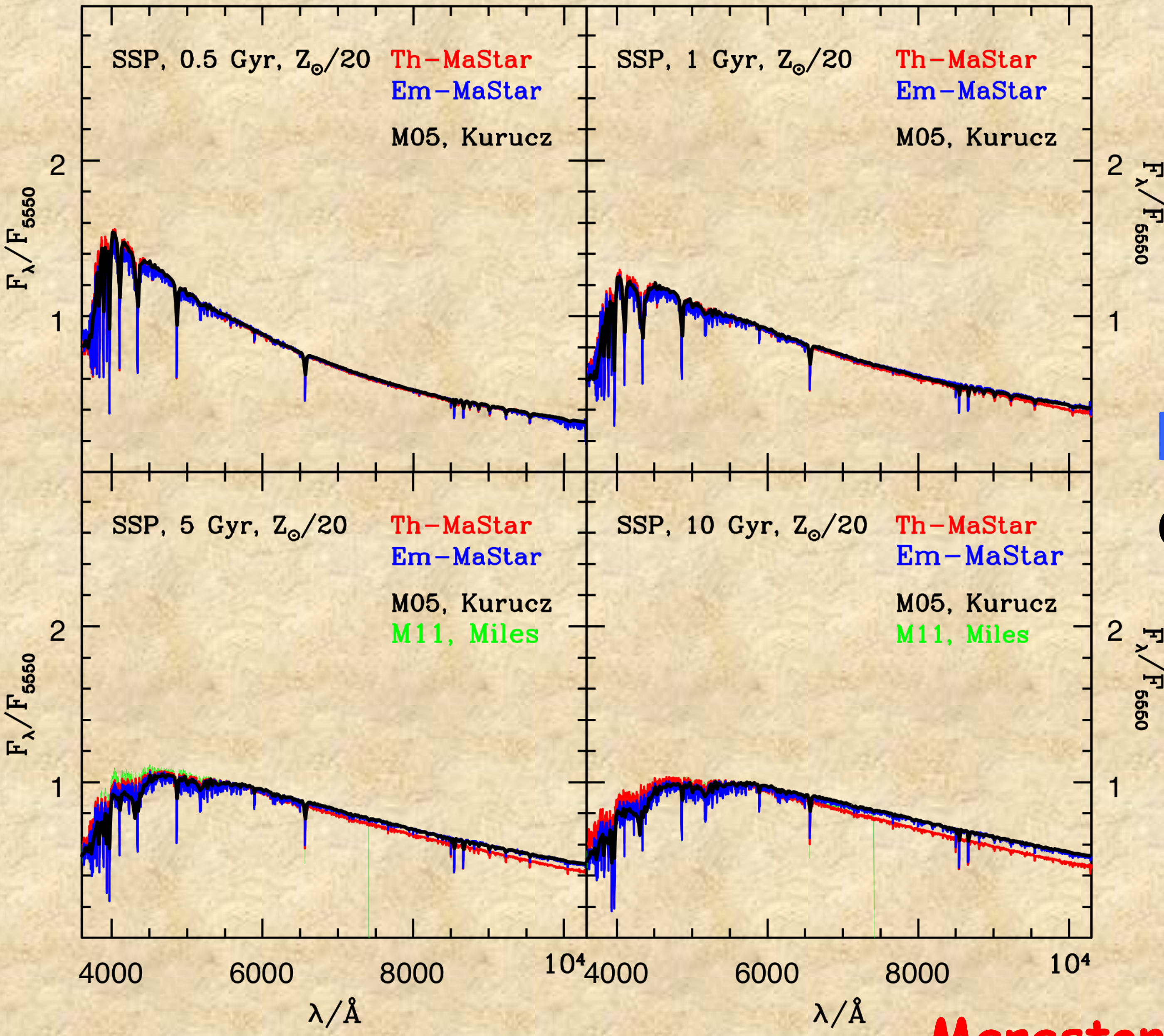
Hill et al. in prep.)

Lewis Hill, PhD student, University of Portsmouth



Need a supercomputer to run due to the large number of entry spectra and templates

MaStar Population Models



At [Z/H]=-1.3 models as young as 300 Myr

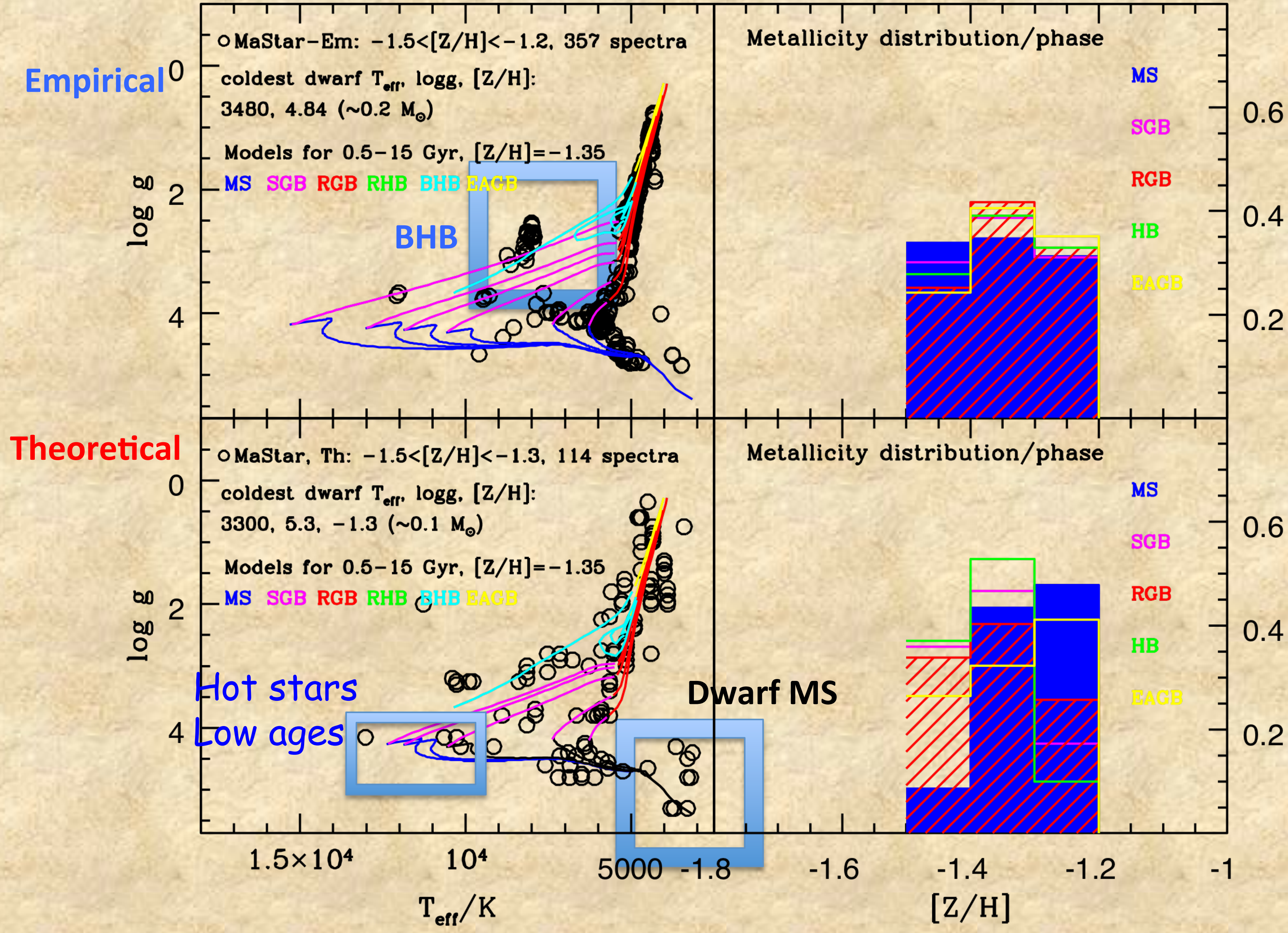
high-z galaxies

dwarf galaxies

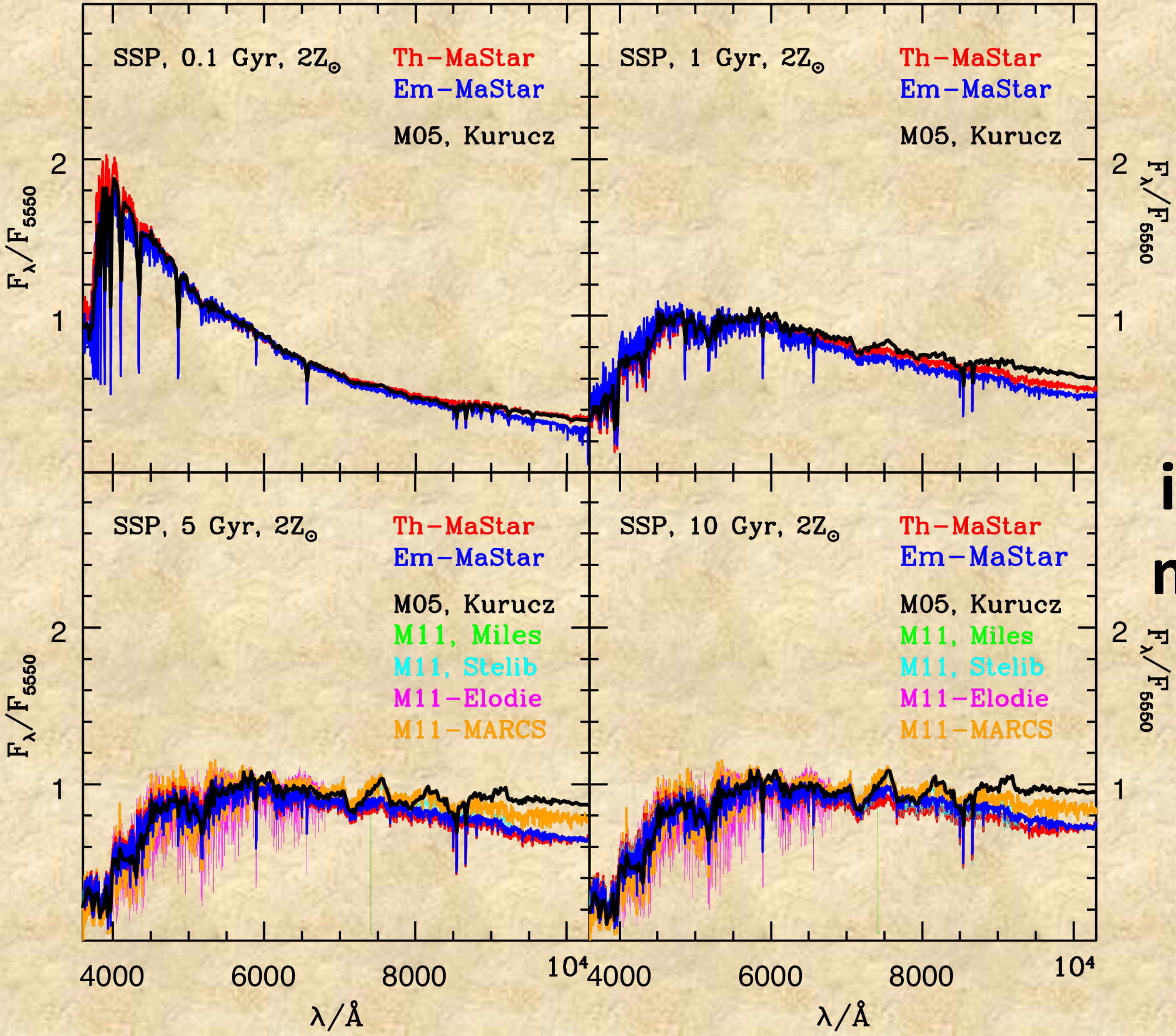
MILES-based: 3 Gyr

Maraston et al. 2019

Population Parameter Coverage – Metal Poor

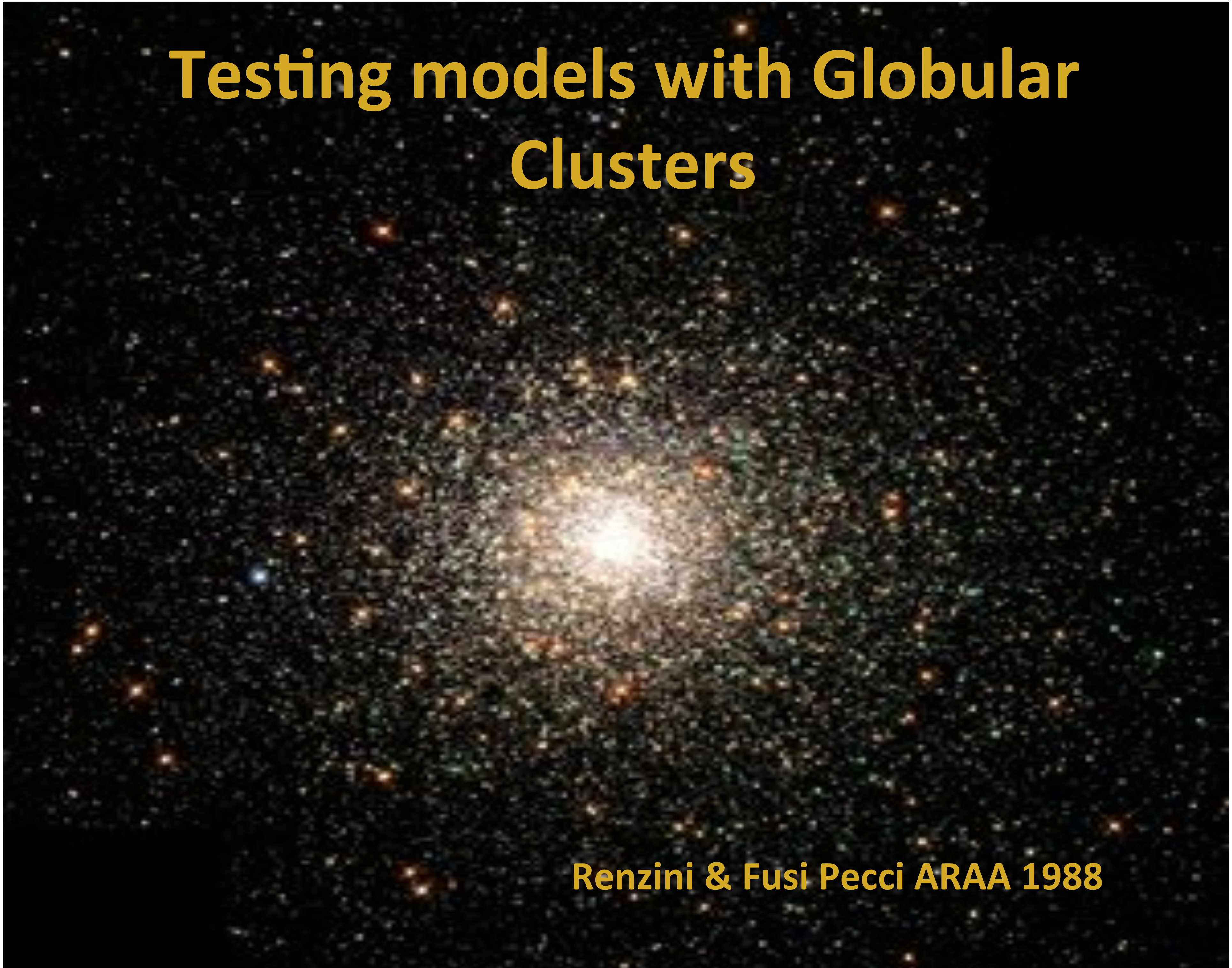


MaStar Population Models – Metal Rich



Slope and bands longwards 7000 A interesting for metallicity and IMF

Testing models with Globular Clusters

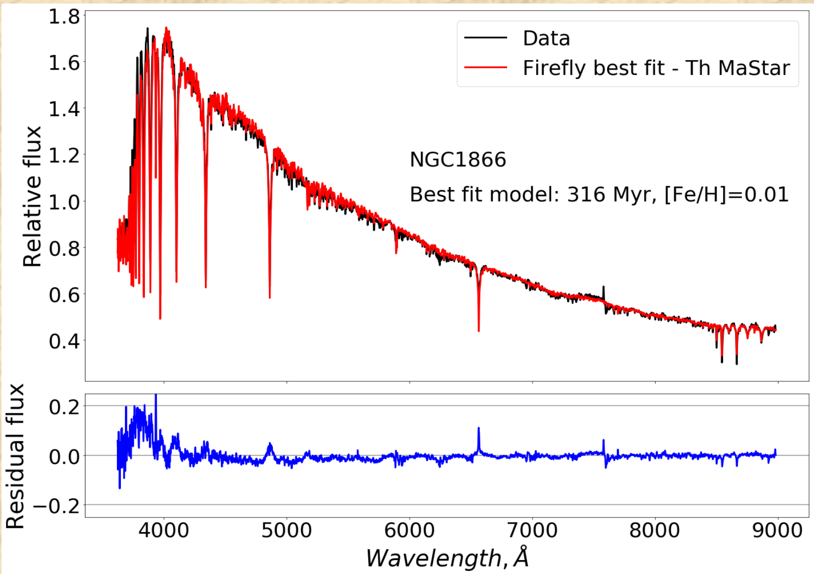


Renzini & Fusi Pecci ARAA 1988

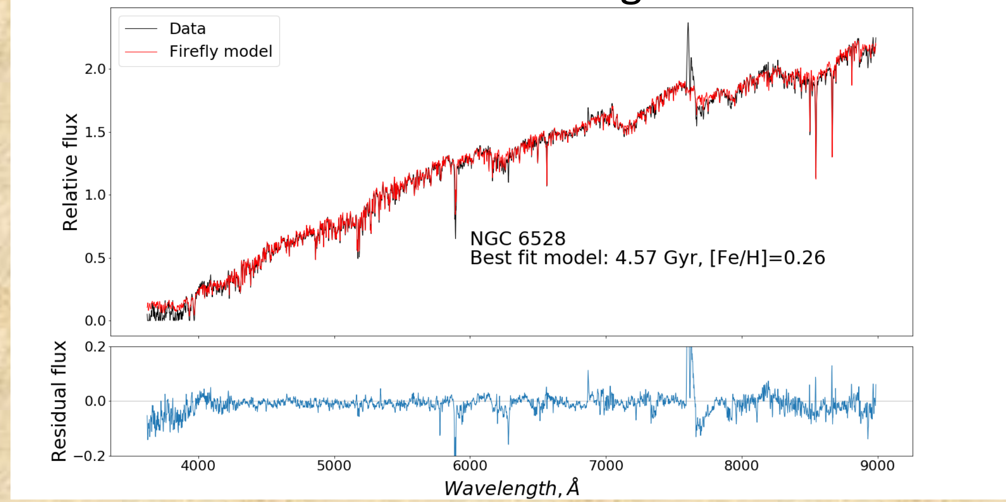
Full spectral fitting of GC spectra

Fitting code: **Firefly**, Wilkinson, CM etal. 17
GC Data: Usher et al. 2017

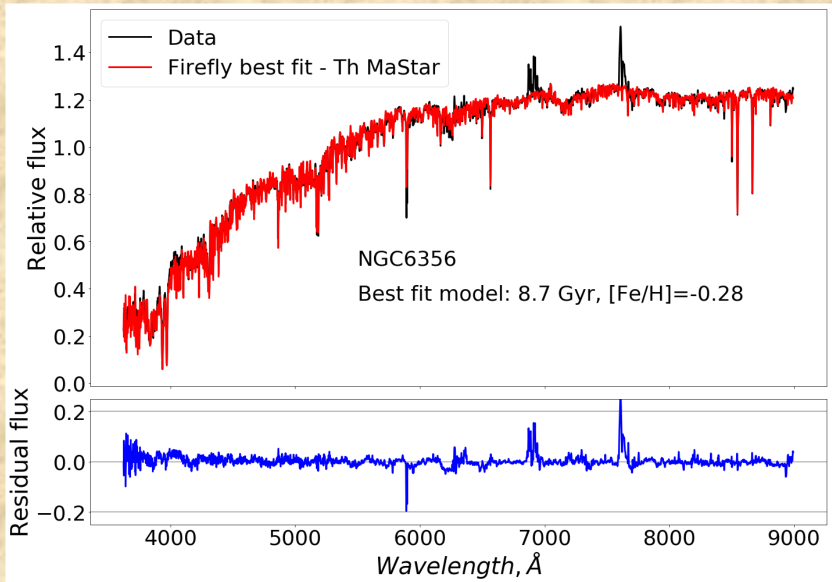
Young intermediate Z MW GC



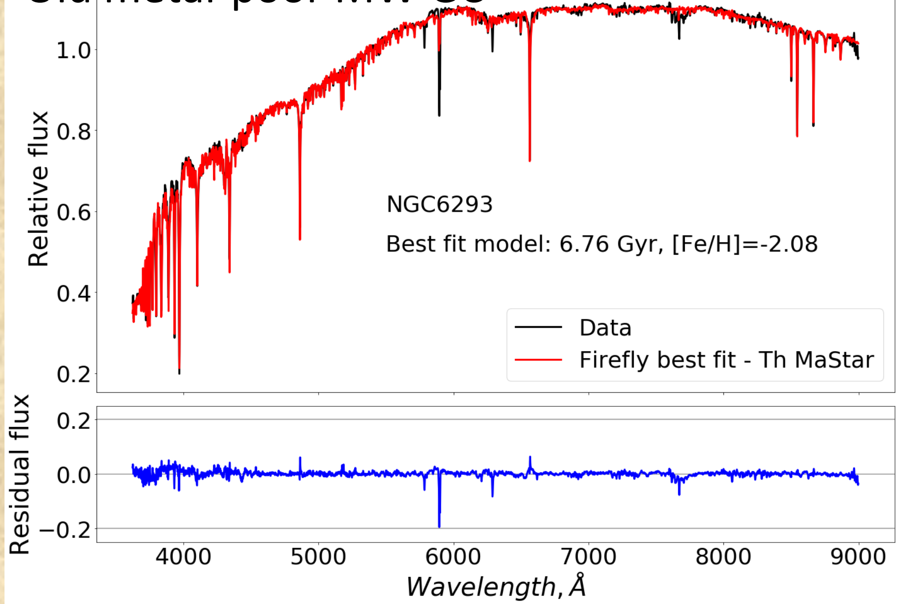
Old metal-rich Bulge GC



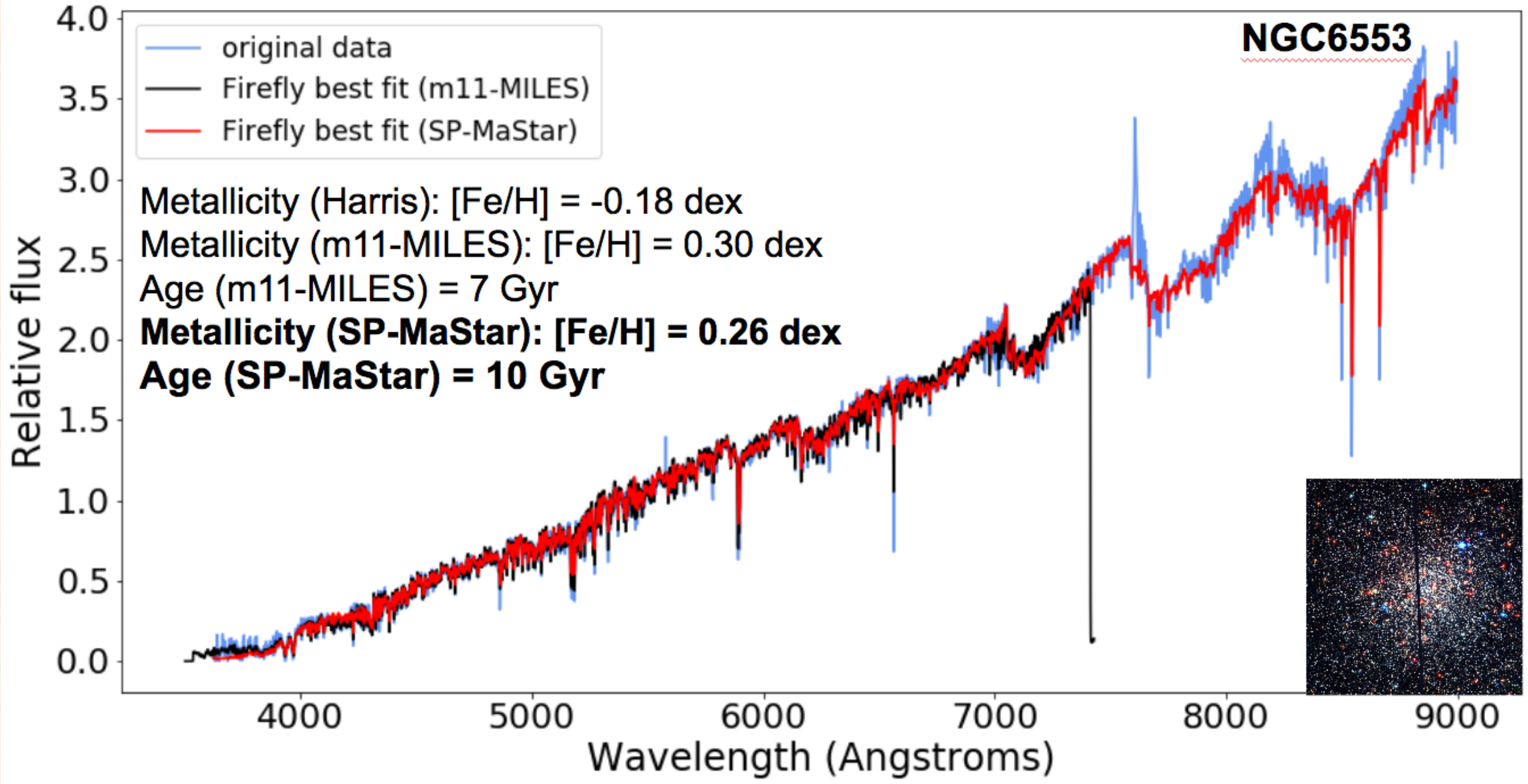
Old intermediate Z MW GC



Old metal-poor MW GC



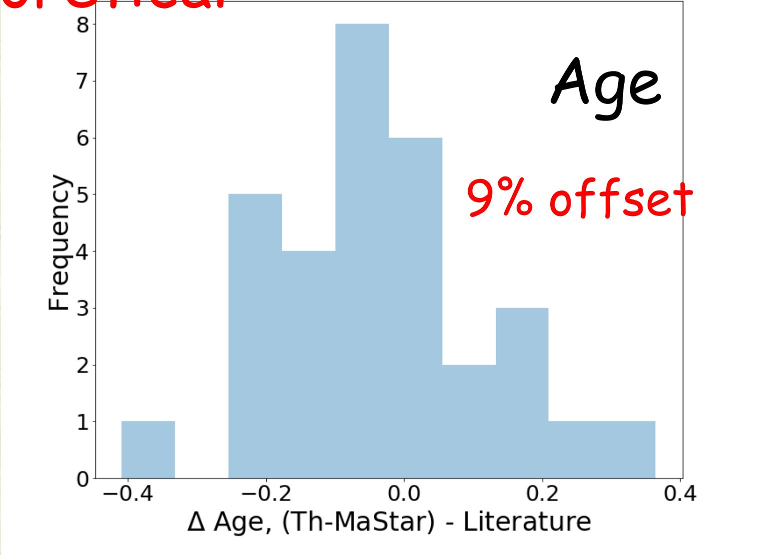
Old and metal-rich GCs alike galaxies

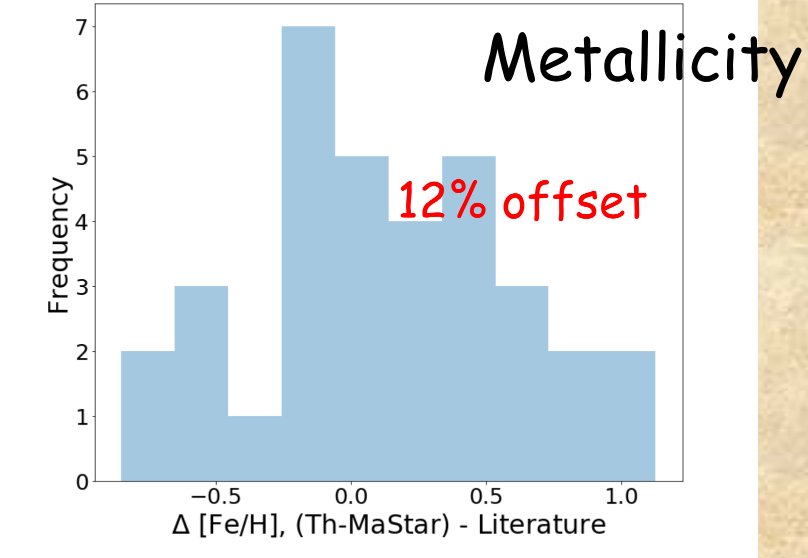


Credit: Lewis Hill, PhD student, Portsmouth

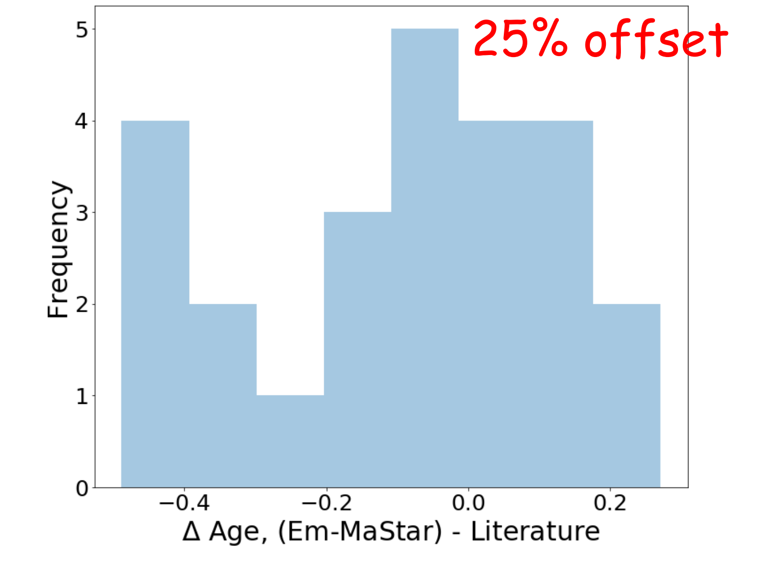
Quantitative Testing

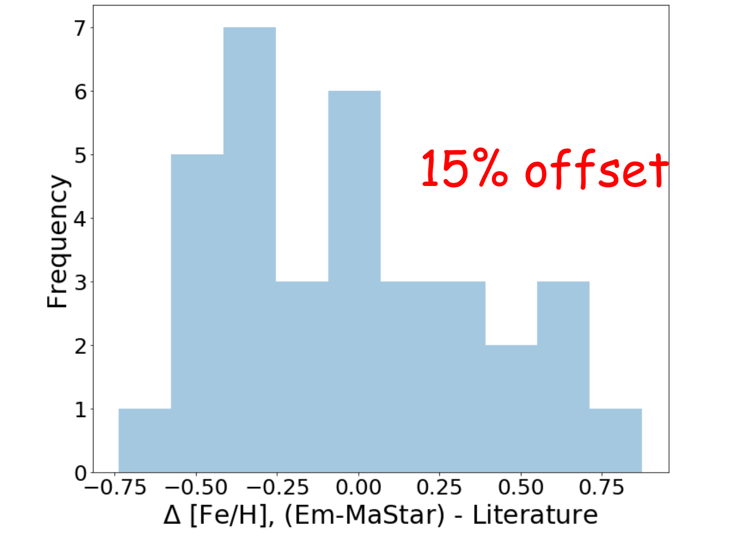
Theoretical



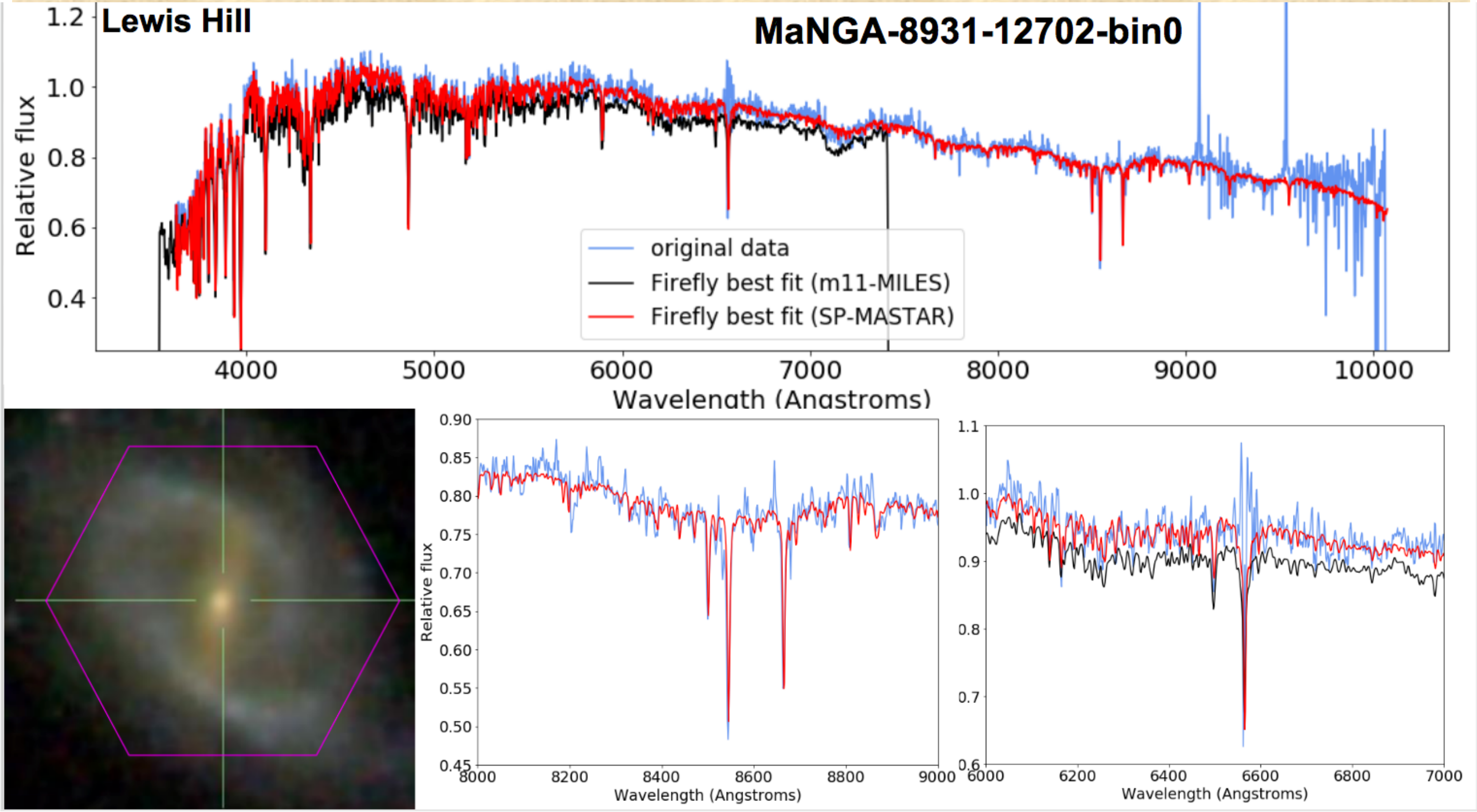


Empirical



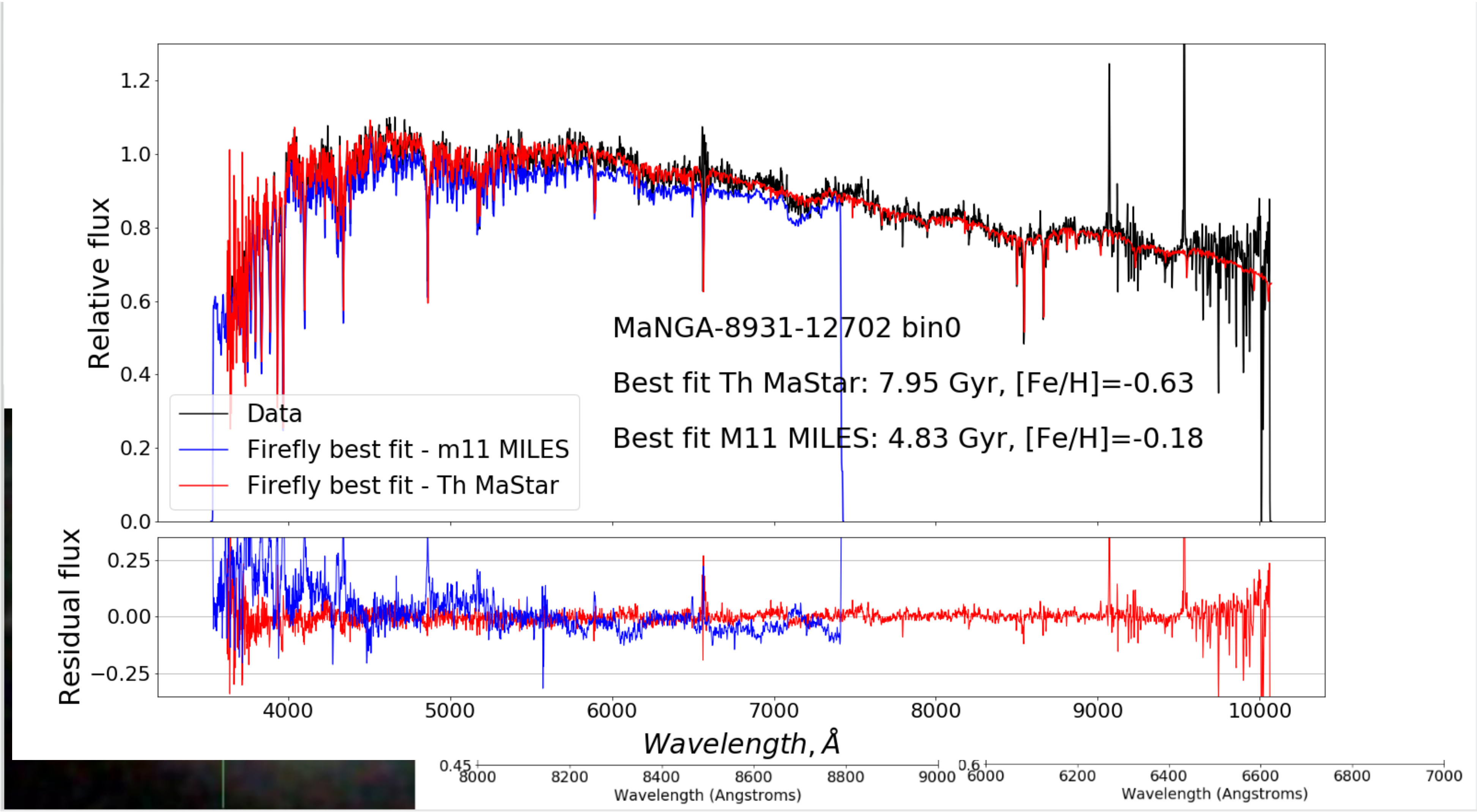


Fitting galaxies



IFU data from SDSS-IV/MaNGA, Bundy et al. 2016

Fitting galaxies



IFU data from SDSS-IV/MaNGA, Bundy et al. 2016

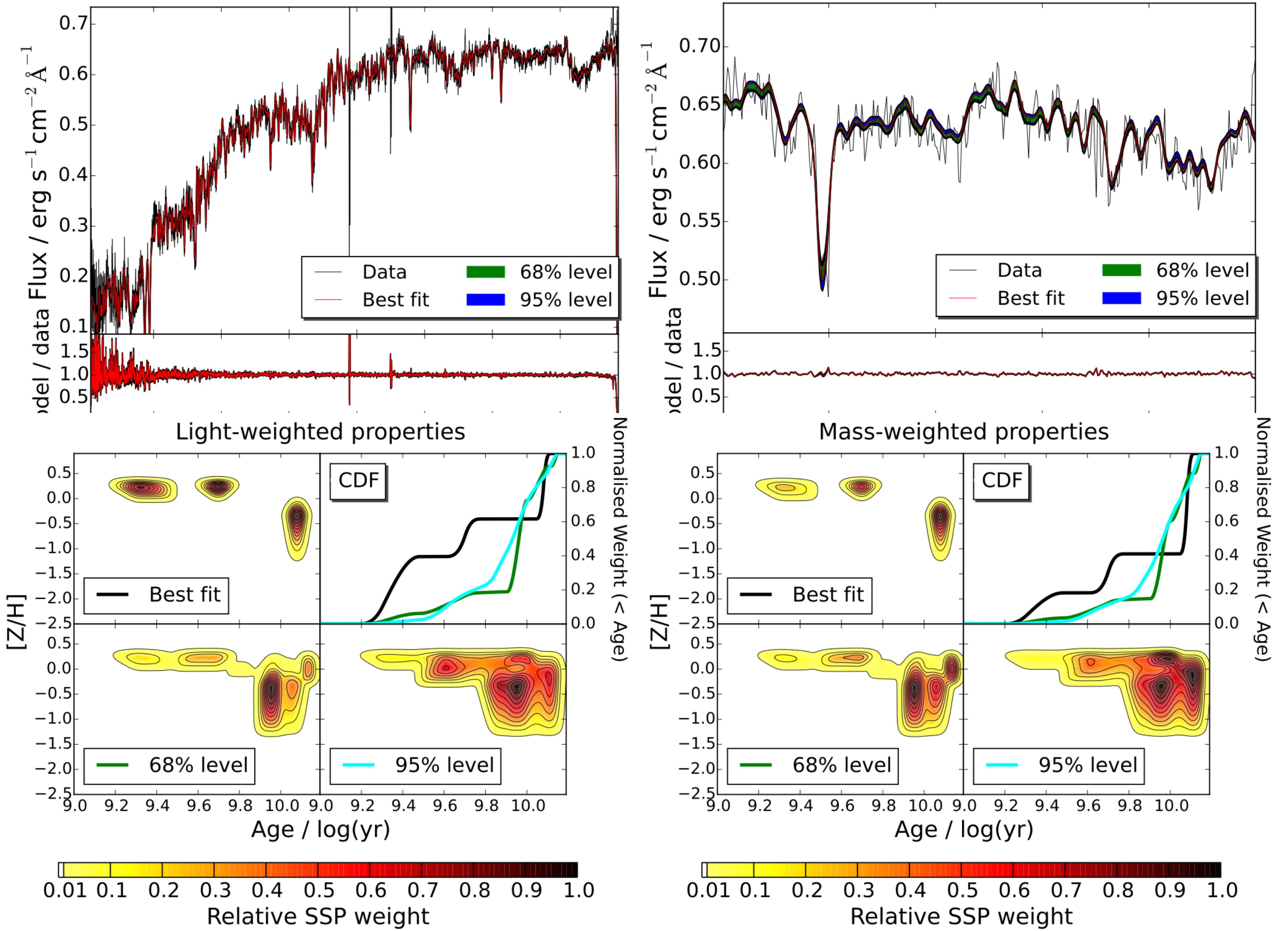
Which S/N? Experiments with mock spectra

- Wilkinson, Maraston et al. 2017: full spectral fitting of model galaxies with known properties and various S/N

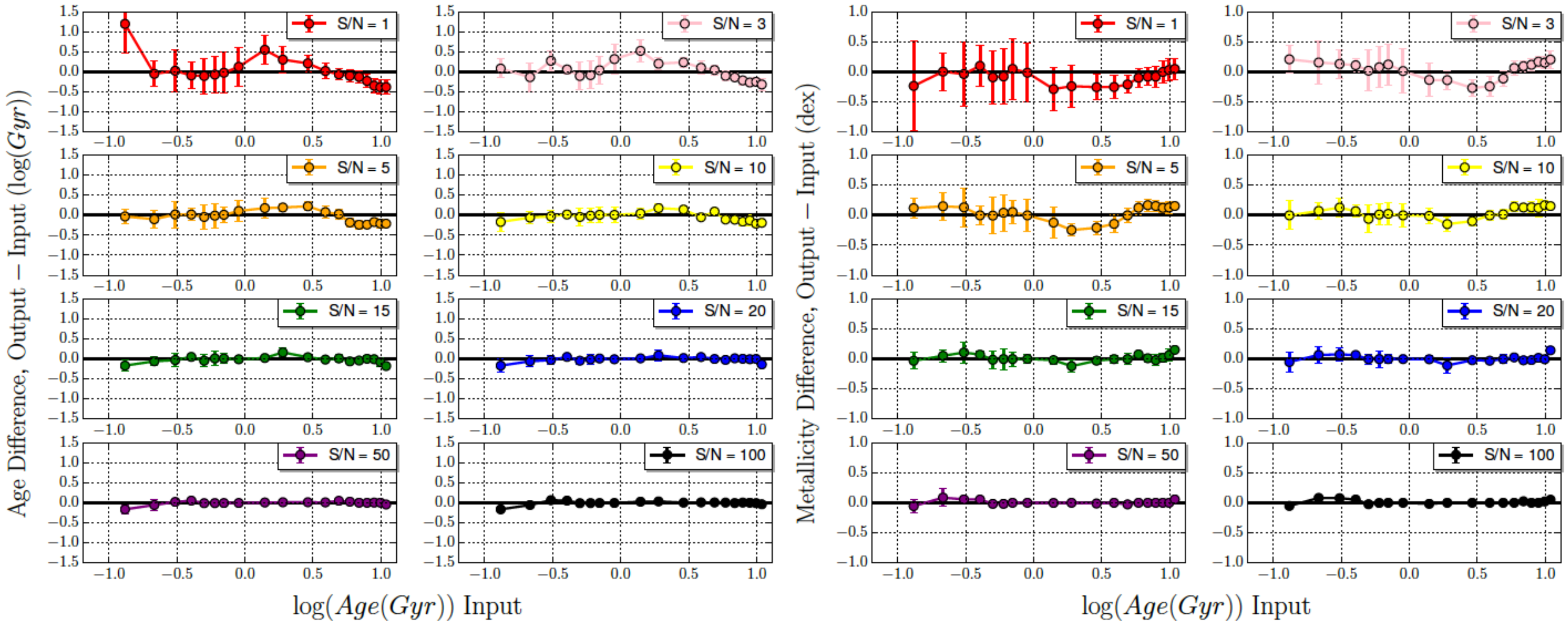
- Firefly (Fitting IteRativEly For Likelihood analYsis)

https://www.icg.port.ac.uk/firefly/

Violeta Gonzalez-Perez


Flux / erg s^{-1} cm^{-2} Å^{-1}
Data
Best fit
68% level
95% level
odel / data
Light-weighted properties
Mass-weighted properties
CDF
Best fit
68% level
95% level
[Z/H]
Normalised Weight (< Age)
Age / log(yr)
0.01 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Relative SSP weight

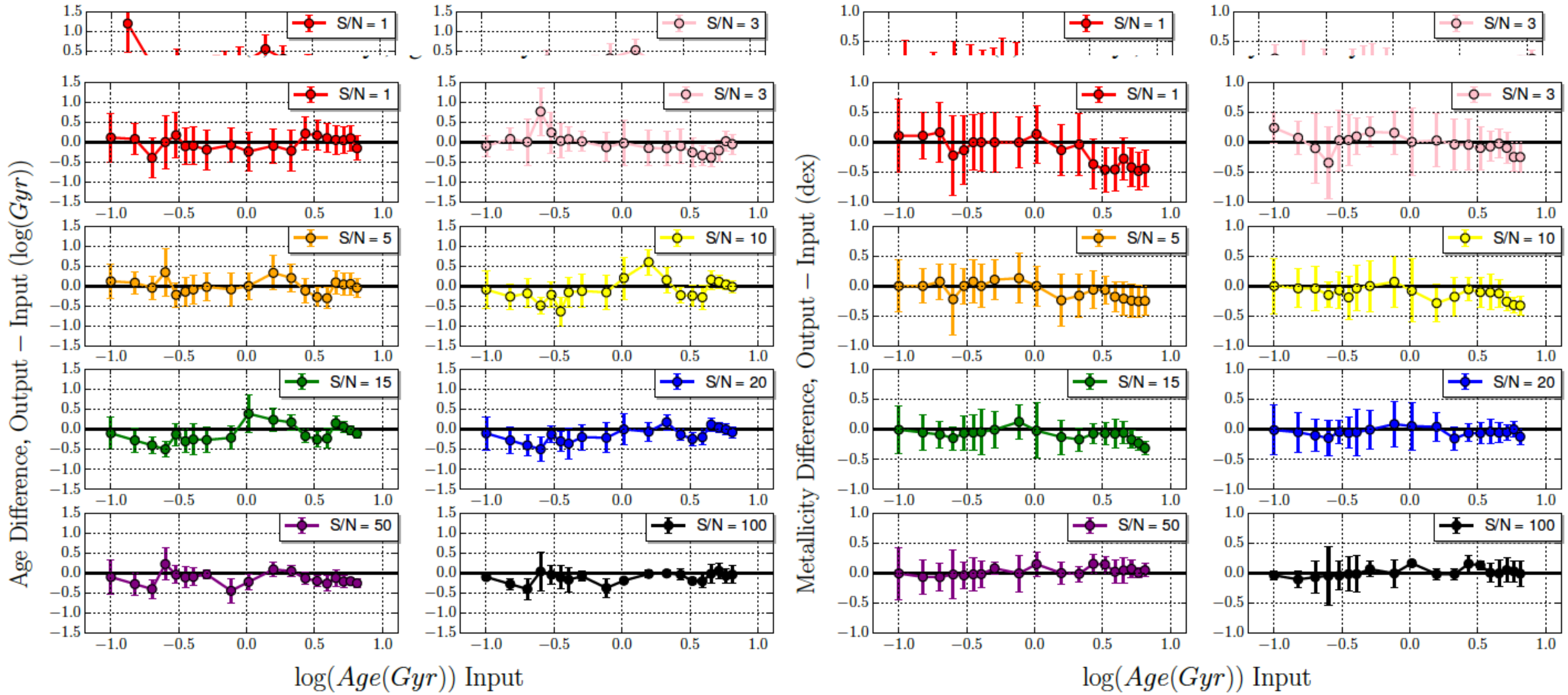
Age, Metallicity, M* as a function of S/N



(a) τ = 0.1 Gyr, age recovery. (b) τ = 0.1 Gyr, metallicity recovery.

Age, Metallicity, M* as a function of S/N

18 *David M. Wilkinson et al.*



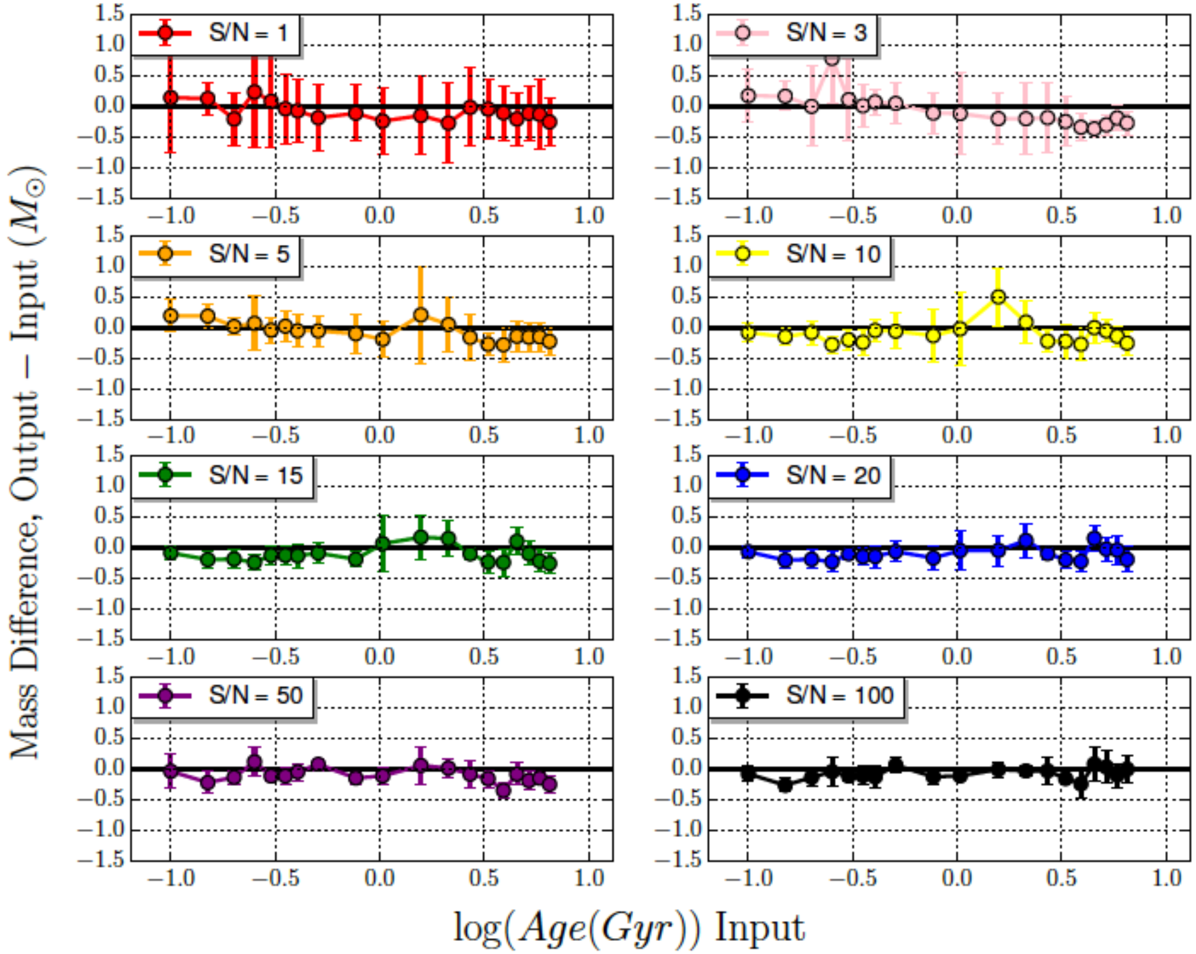
(e) τ = 10 Gyr, age recovery.

(f) τ = 10 Gyr, metallicity recovery.

S/N at least 5-10 for short formation histories

S/N 20 for extended ones

Age, Metallicity, M* as a function of S/N



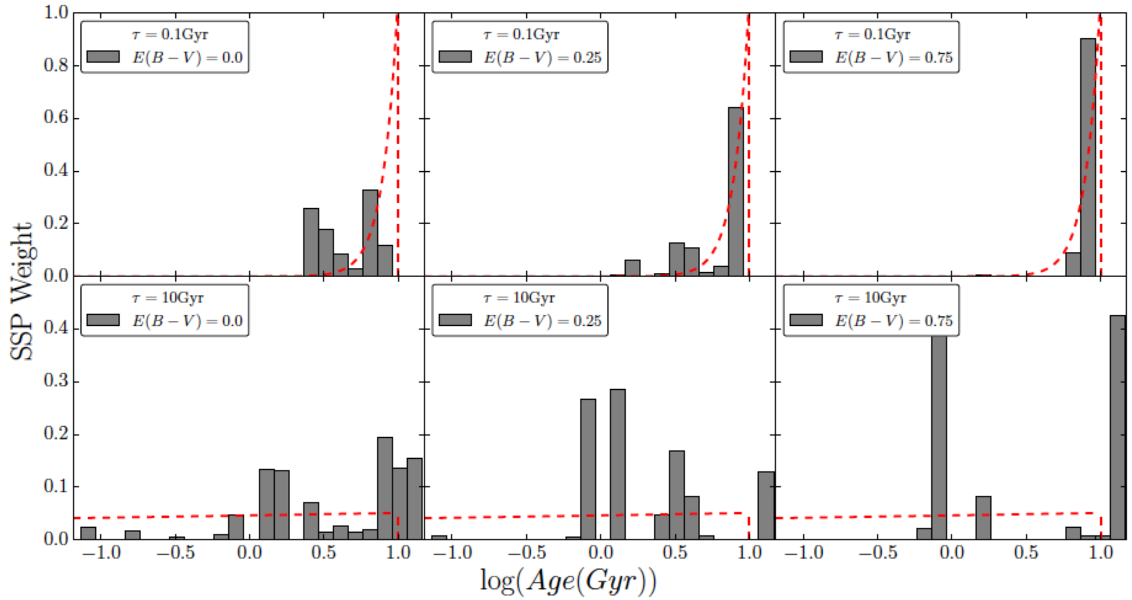
(c) τ = 10 Gyr.

Figure 12. As in Fig. 11 for the recovered stellar mass.

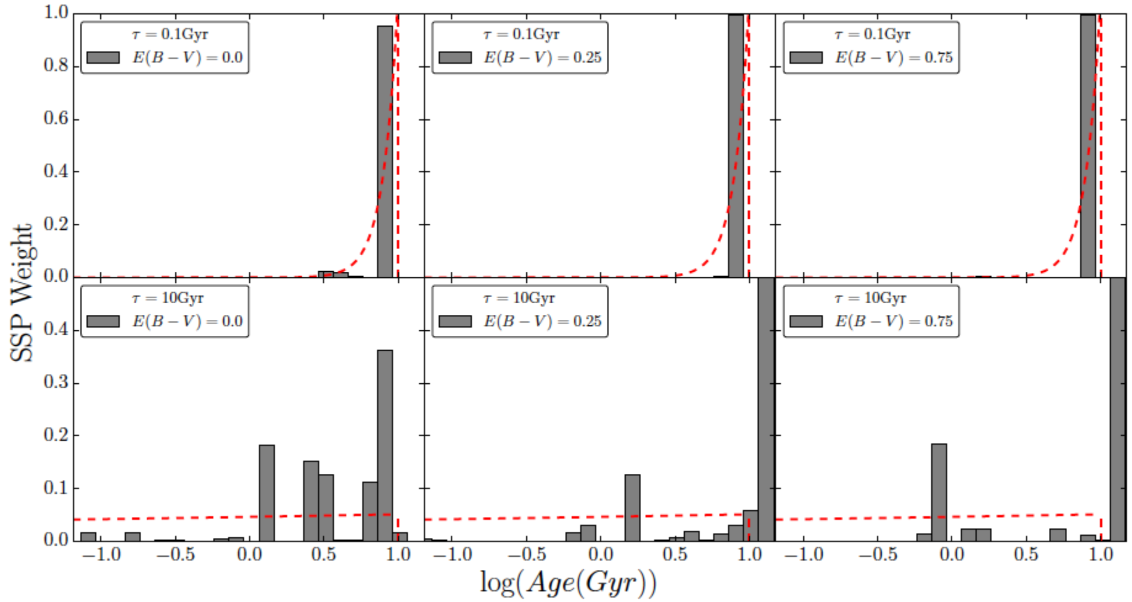
Recovering the SFH

S/N=5

S/N=20



(a) Simulations at $S/N = 5$.



(b) Simulations at $S/N = 20$.

Summary

- Models are already pretty fit for the Big Eyes era
- Theoretical models: very high resolution
- Semi-empirical models: R=1800, but with an extremely large number of observed spectra (SDSS-IV/MaStar) Maraston et al. 2019, sub
- Strategy planning: experiments with models to guide S/N per individual physical property as a function of galaxy parameters Wilkinson et al. 17