Age-Metallicity-Dust degeneracy in Stellar Population fitting

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Galaxies: Structure, Dynamics, and Evolution
Paper Presentations 30/4/2026

Stellar Population Synthesis (SPS)

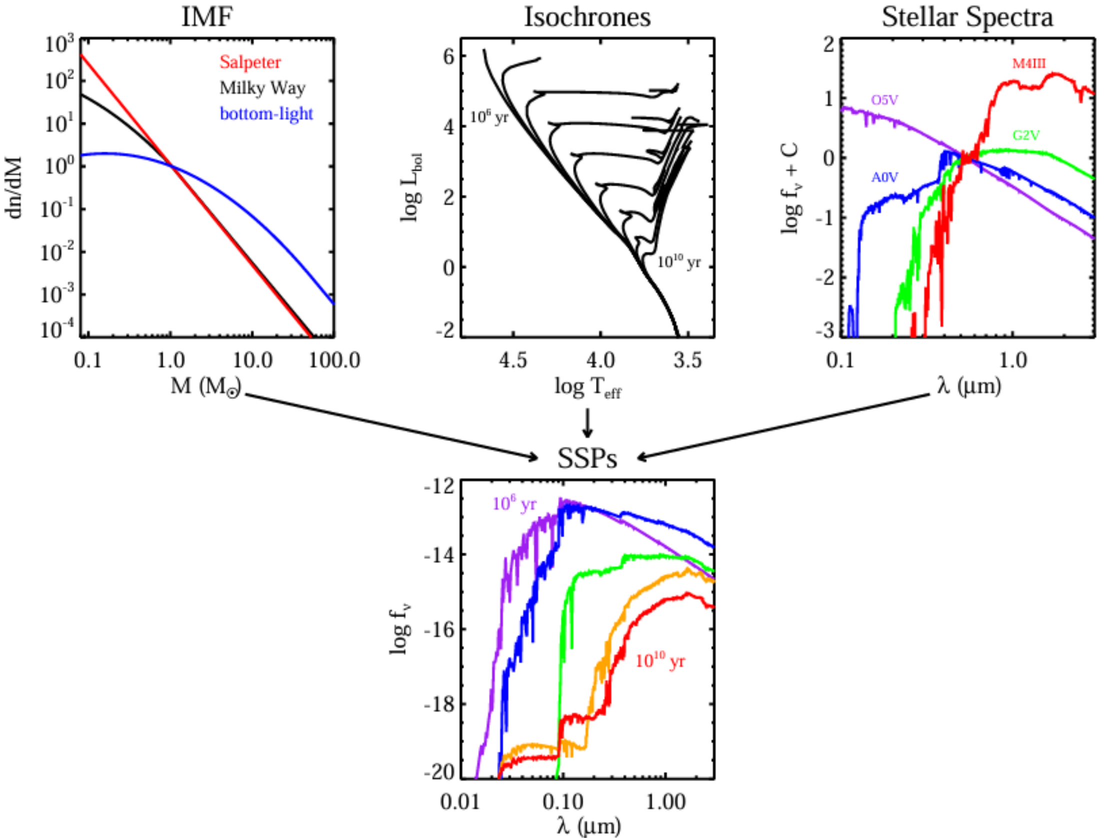
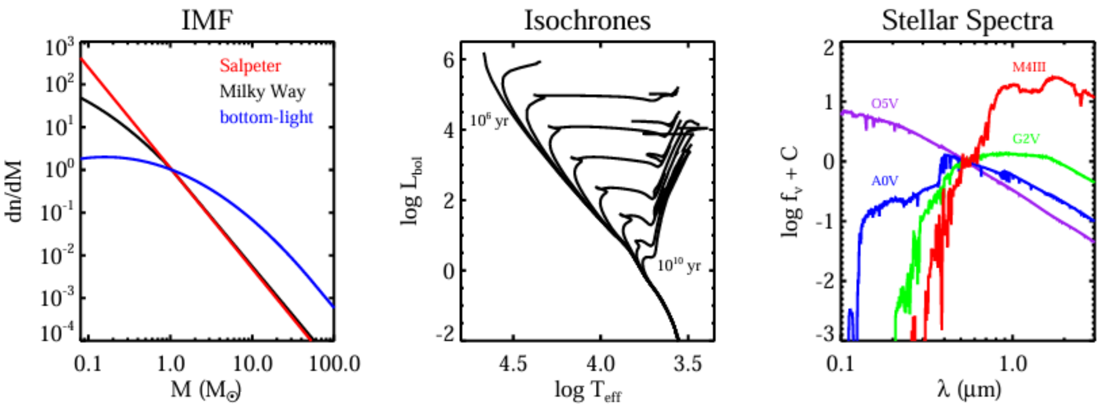


Figure 1. Conroy, C. (2013)

Stellar Population Synthesis (SPS)



From Lecture 10

IMF: Probability distribution of stellar masses at each point of the isochrone.

Isochrones: Location in HR diagram where stars have same age and Z, but different mass.

Stellar Spectra: Libraries that convert stellar evolution calculations into SEDs.

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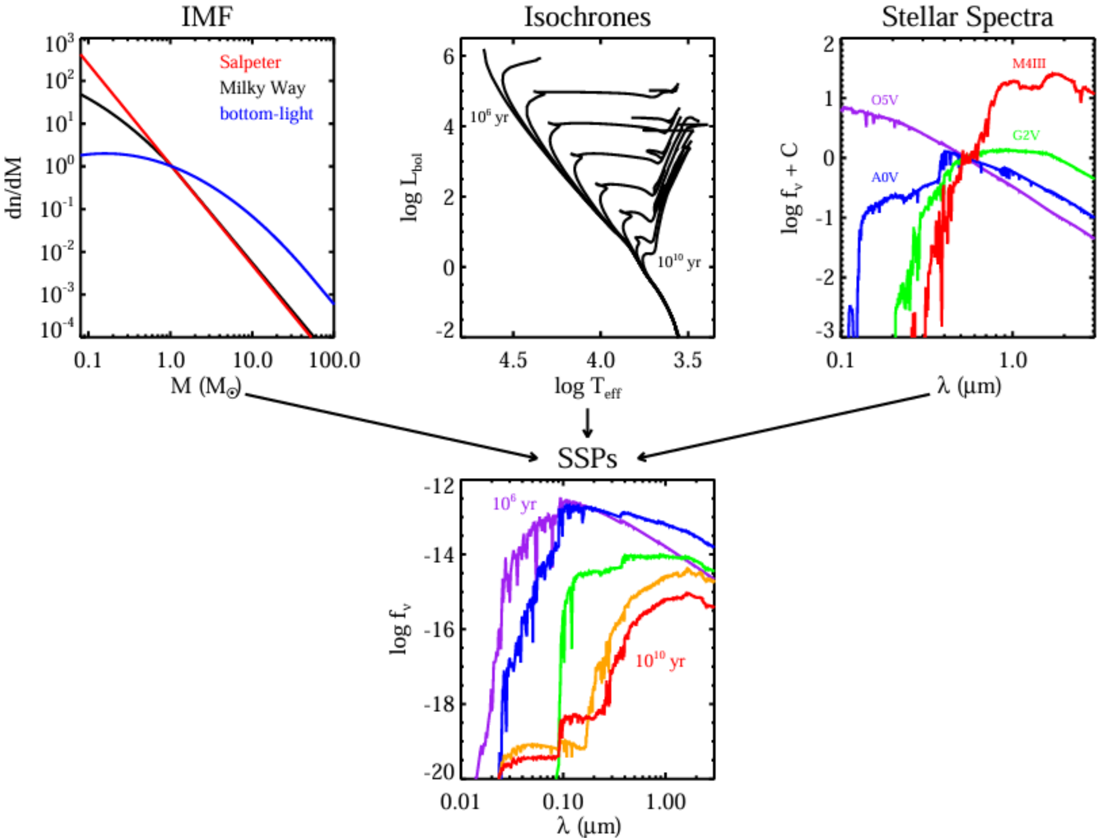
Stellar Population Synthesis (SPS)



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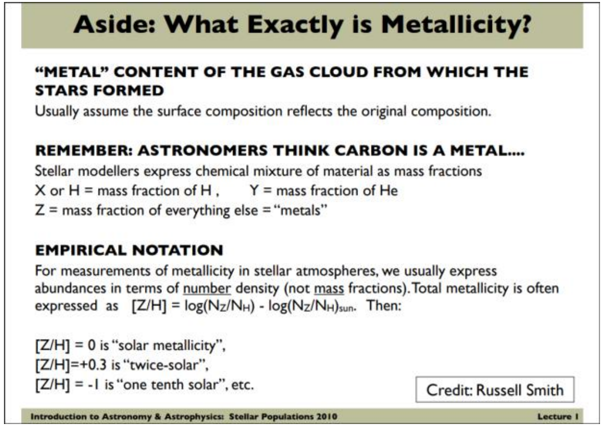

Aside: What Exactly is Metallicity?

"METAL" CONTENT OF THE GAS CLOUD FROM WHICH THE STARS FORMED

Usually assume the surface composition reflects the original composition.

REMEMBER: ASTRONOMERS THINK CARBON IS A METAL....

Stellar modellers express chemical mixture of material as mass fractions

X or H = mass fraction of H , Y = mass fraction of He

Z = mass fraction of everything else = "metals"

EMPIRICAL NOTATION

For measurements of metallicity in stellar atmospheres, we usually express abundances in terms of number density (not mass fractions). Total metallicity is often expressed as $[Z/H] = \log(N_Z/N_H) - \log(N_Z/N_H)_{sun}$. Then:

[Z/H] = 0 is "solar metallicity",

[Z/H]=+0.3 is "twice-solar",

[Z/H] = -1 is "one tenth solar", etc.

Credit: Russell Smith

Introduction to Astronomy & Astrophysics: Stellar Populations 2010 Lecture 1

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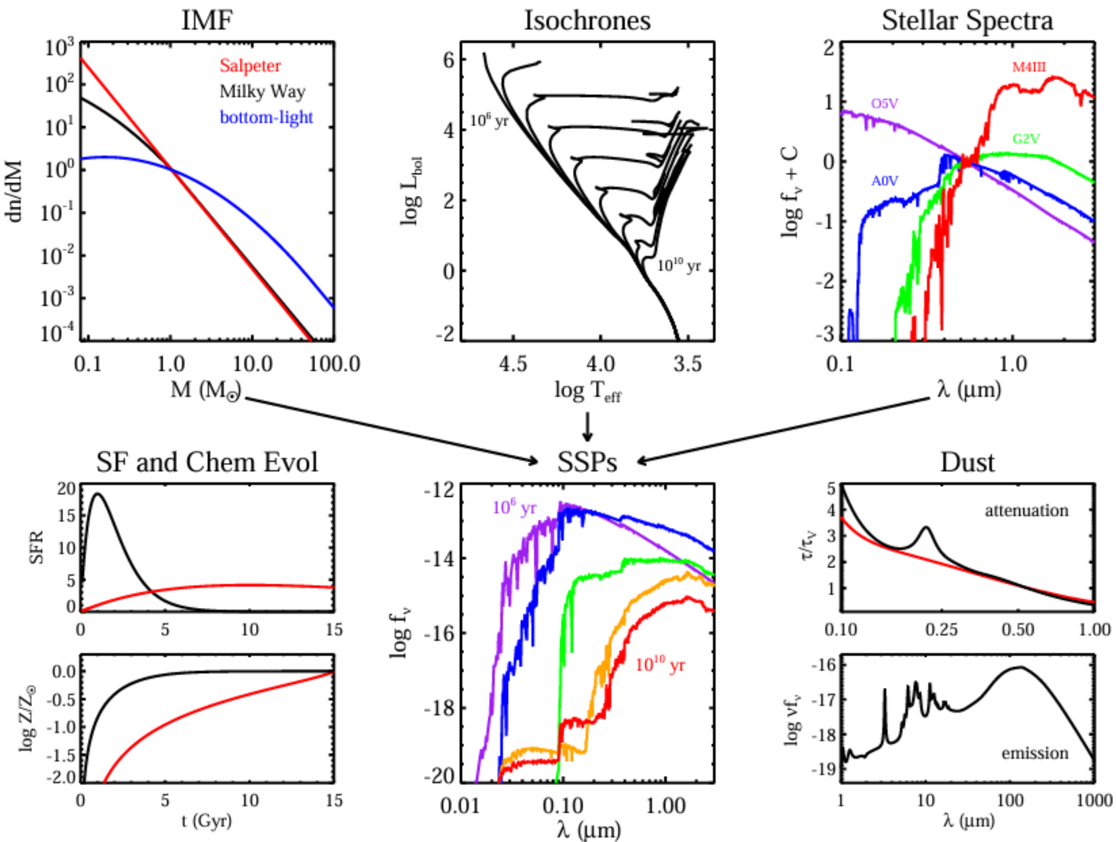
Stellar Population Synthesis (SPS)



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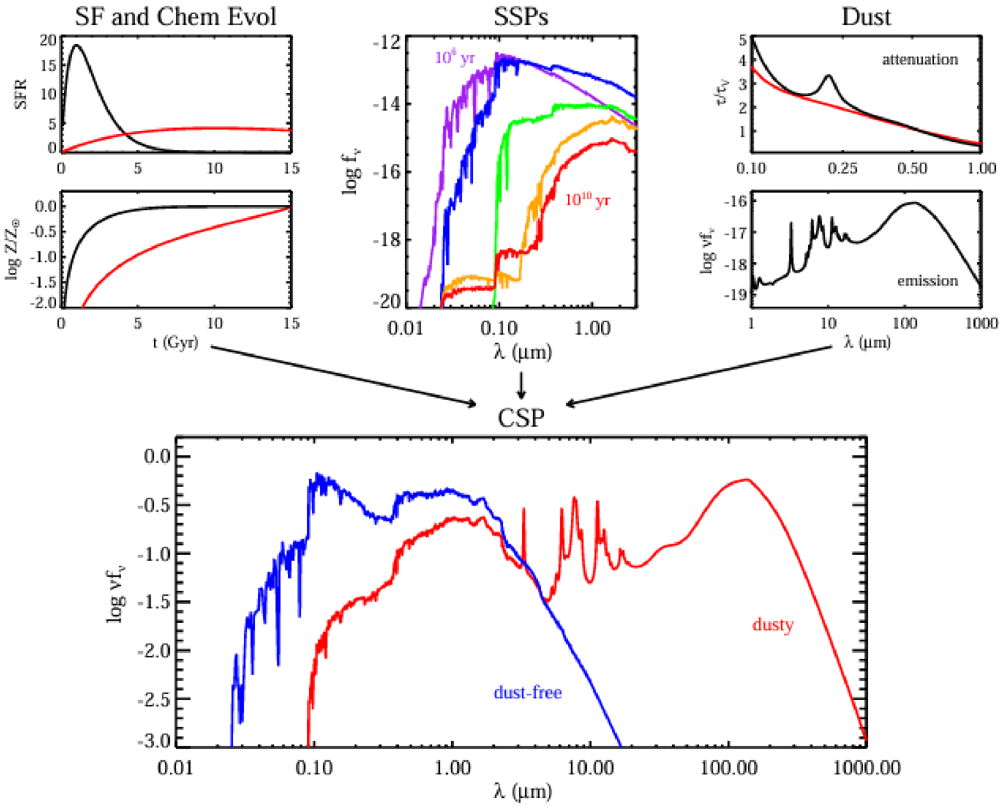
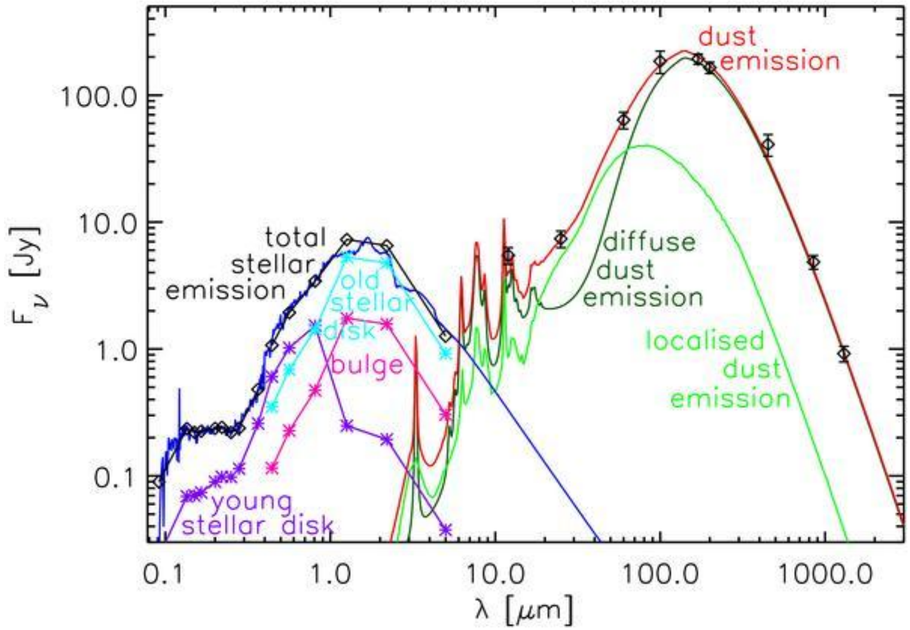


Figure 1. Conroy, C. (2013)

We end up with:



Best fit model SED of NGC 891

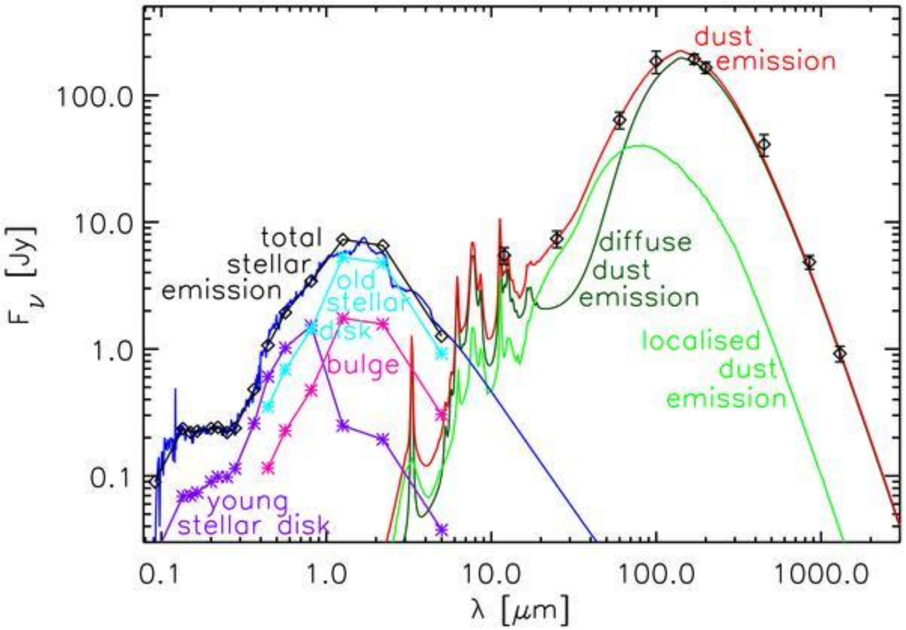
Figure 2. Popescu, C. et al. (2010)

Age-Z-dust degeneracy: all of them redden the SED!

Dust can be constrained more easily:

- **Spectroscopy: Dn4000 and Balmer lines to constrain age**
- **Energy conservation**

We end up with:



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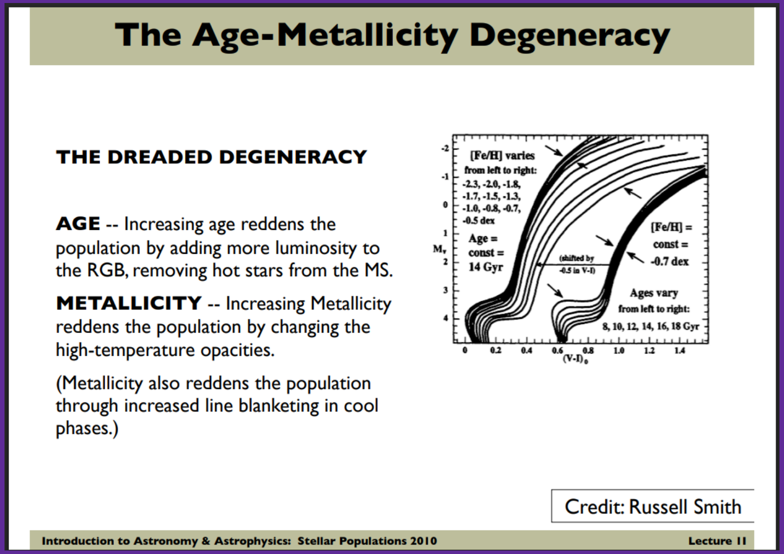

From Lecture 10

3/2 rule: a change in age by 3 is a change in Z by 2 (Worthey, 1994).

How can age - Z degeneracy be solved?

- **Balmer Lines**

  Highly dependent in temperature.

  Stronger in Type A stars (7400 K - 10000 K).

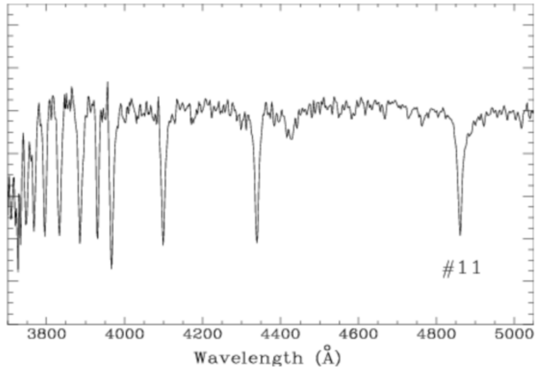

Figure 3. Comeron, F. & Pasquali, A. (2005)

- **Metallicity Lines**

  Sensitive to presence of metals.

  Also depend on elemental abundance patterns.

  [MgFe] stays robust against abundance pattern variations

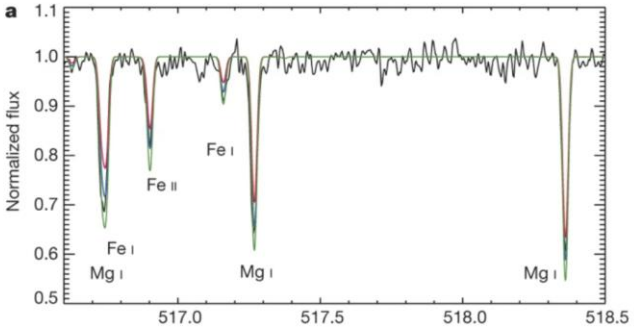

Figure 4. Howes, L.M., et al.. (2015)

How can age - Z degeneracy be solved?

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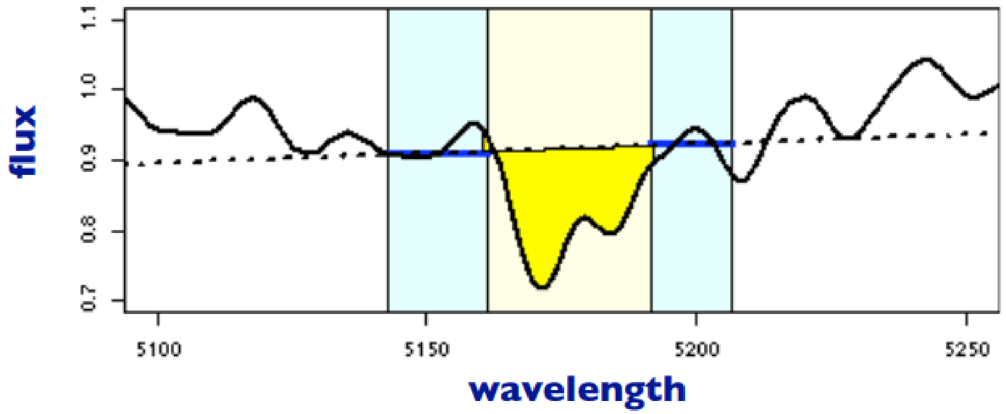


System of indices developed at Lick Observatory

Feature of interest is bracketed with passbands.

A pseudo continuum is created.

The difference in flux between pseudo continuum and absorption feature is integrated.

How can age - Z degeneracy be solved?

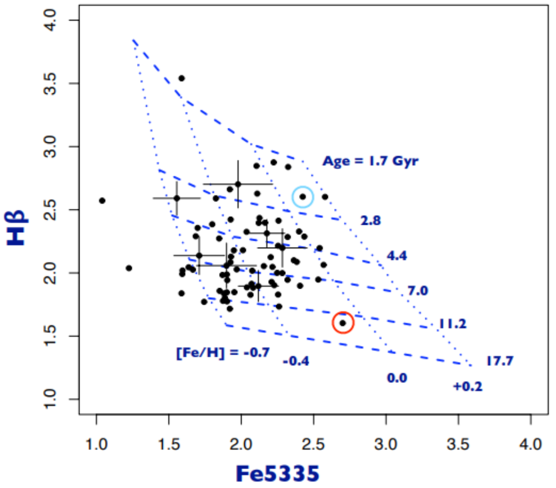
From Lecture 10

Predicting Indices

Either: Sum library spectra along isochrone and measure indices on the synthetic spectra(e.g. Vazdekis, Coelho, Percival).

Or: Measure indices on the library stars and compute luminosity-weighted average index along the isochrone (e.g. Worthey, Schiavon)

Result: Balmer-vs-metallic grids widely separate the constant-age and constant-metallicity tracks. So we can "read off" the results for an observed galaxy.



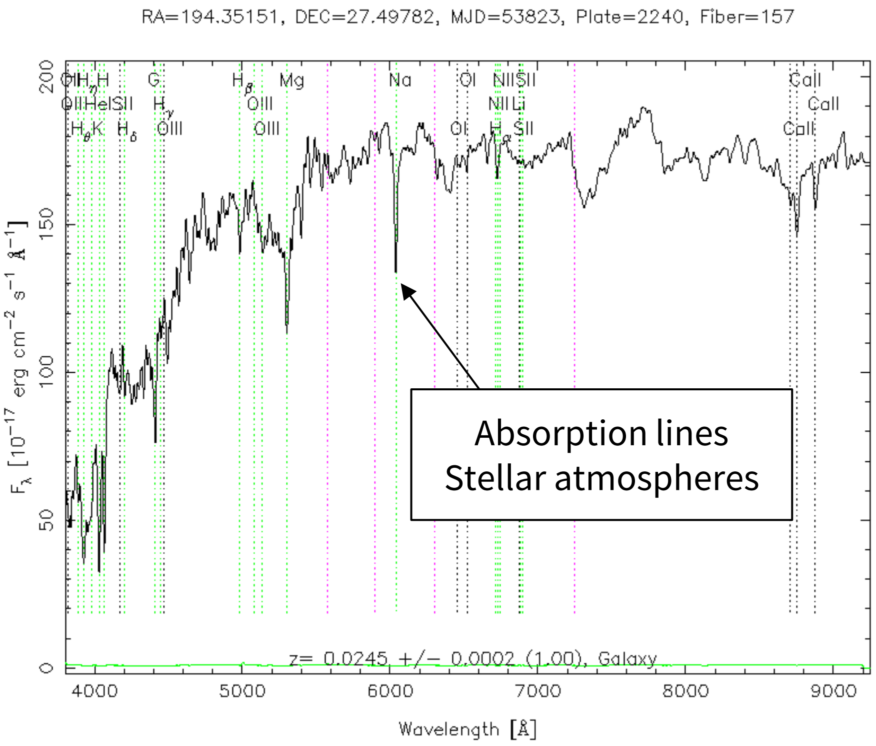
Grids: Schiavon et al. (2007).
Data for Coma cluster dEs from RJS et al. (2008)

Many pairs of indices could be chosen: do they all give the same results for a given galaxy?

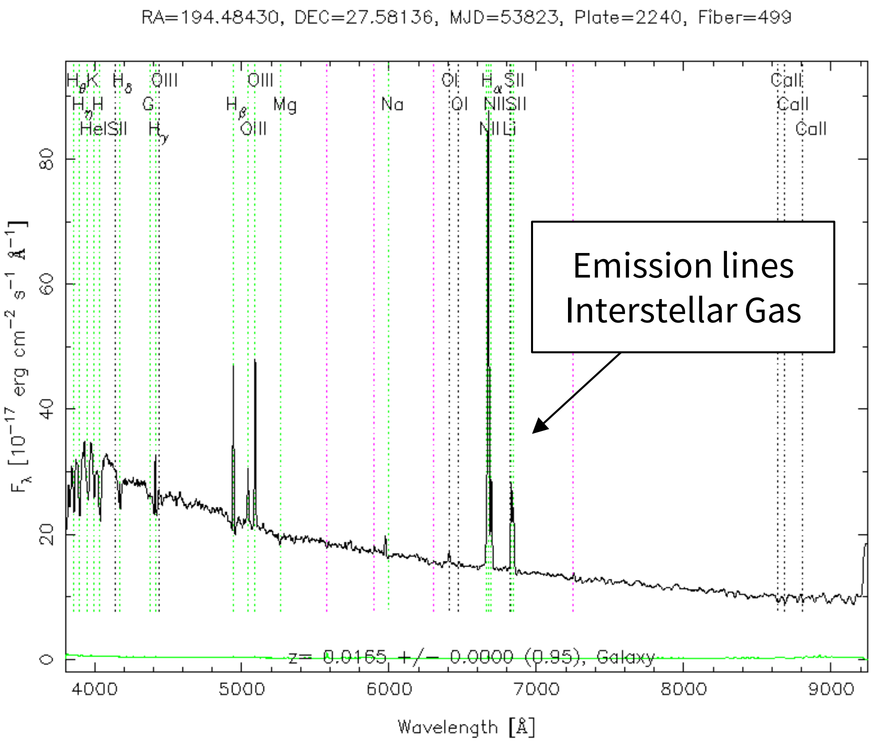
Credit: Russell Smith

For a lower S/N, full spectral fitting is more effective to solve the degeneracy

Stellar population Metallicity



Gas-phase Metallicity



Gas-phase metallicity estimation:

→ Electron temperature (Te) from auroral/nebular line ratios

Direct probe of the **processes** that regulate the physics of **ionized nebulae**	Observationally challenging: **weak lines for low Te, metal-rich objects**

→ Ratio between O and H recombination lines (RLs)

Direct abundance measurement (weakly affected by temperature)	Observationally challenging: **very faint for objects at d~ few kpc**

→ Srong lines - CELs to Balmer line ratios

Stronger and **easier to observe** in various environments and distances	Indirect proxy → **sensitive to calibration** and **assumptions** about T, d, ionization

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Indirect proxy → **sensitive to calibration** and **assumptions** about T, d, ionization

Large discrepancies among methods !!

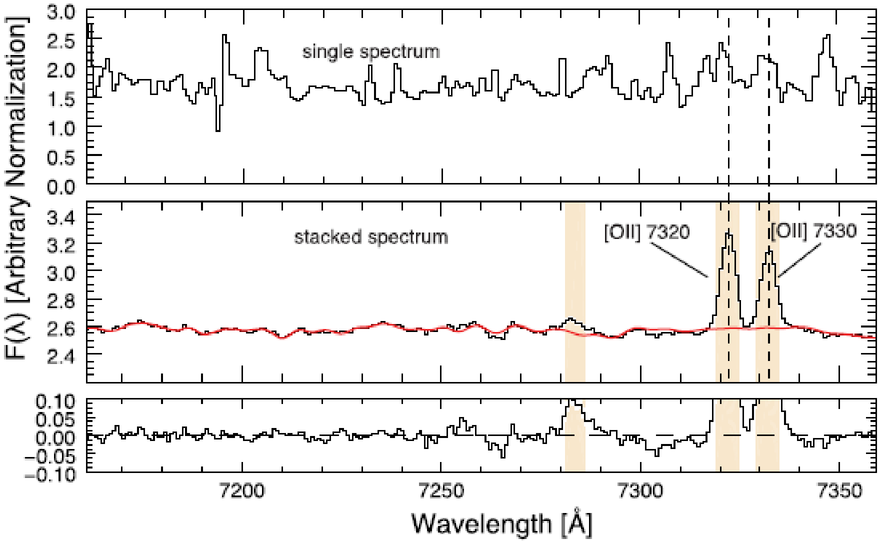
Methodology A.

1. Measured key **strong emission lines** in individual galaxy spectra

2. Calculated reddening corrected **line ratios** **[OIII]/Hβ, [OII]/Hβ**

3. Stacked galaxies with the same line ratio values

4. Fit and **subtracted** the **stellar continuum**



Increased SNR
Auroral lines visible

Paper 2: Cutri M. et al (2017). New fully empirical calibrations of strong-line metallicity indicators in star-forming galaxies

Methodology B.

5. Measured **Te** from **nebular to auroral** flux ratios

6. Derived **O/H abundance** directly from Te

7. Empirically fit an **ff relation,** connecting strong lines and metallicity

8. Extended the range with **individual** low-metallicity spectra

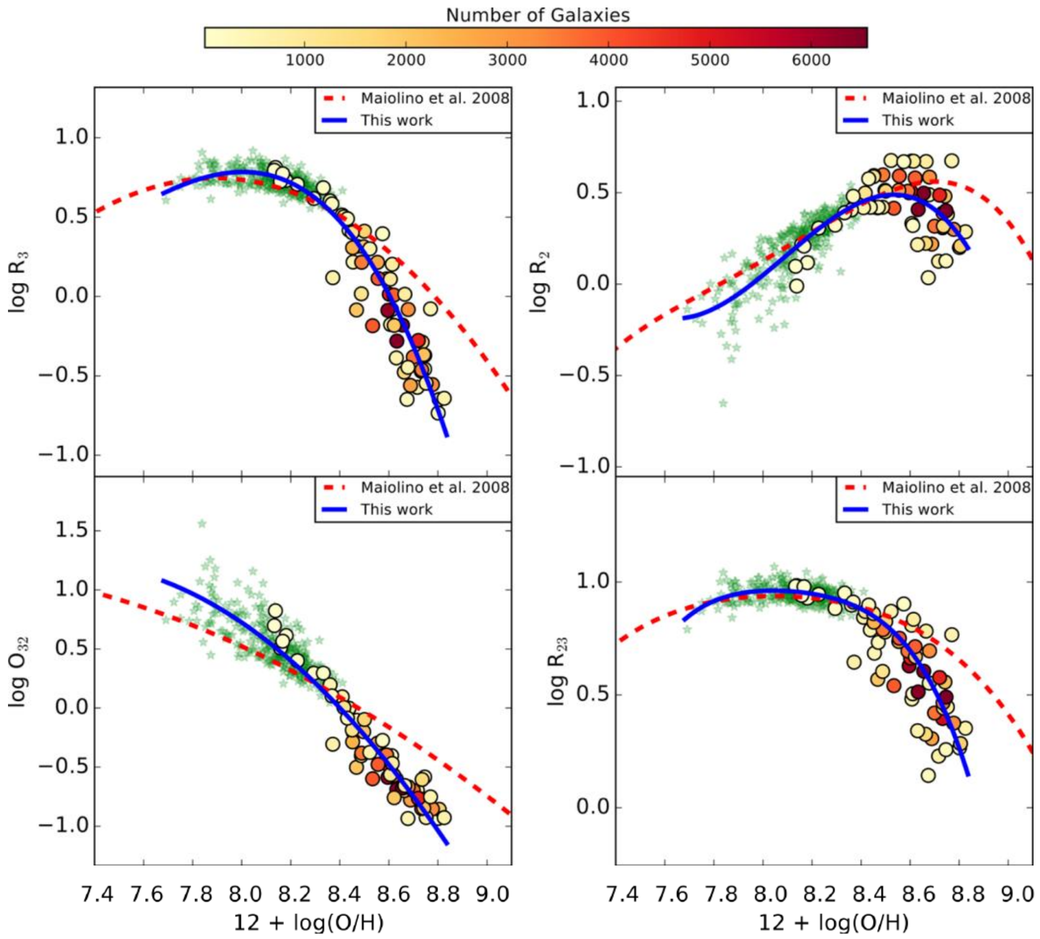
ff relation:

Empirically connecting strong line widths with

Paper 2: Cutri M. et al (2017). New fully empirical calibrations of strong-line metallicity indicators in star-forming galaxies

Results

- self-consisten results
- significant deviation from past empirical and theoretical models (lower O than expected)



Conclusions

- Cutri M. et al (2017) offers an empirical relation to infer metallicity from strong line emission
- The gas-phase metallicity of a galaxy sets a lower bound for the stellar population metallicity
- It can help resolve the age-metallicity discrepancy explained in Conroy (2013) by constraining the age-metallicity parameter space

Thank you!

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