Methodological challenges in the *spectroscopic* estimates of *stellar population* parameters from low to high redshift

Stefano Zibetti & Anna Gallazzi
INAF-OAArcetri

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From reduced spectra to stellar population parameters
How?

- Basic idea: **compare** some *measurements* made on **observed spectra** with the same measurements made on **models** and build a probability distribution function for the "latent" *parameters* (e.g. mean stellar age, mean stellar metallicity… SFH?), which we only know in the models

    - What to measure on spectra?

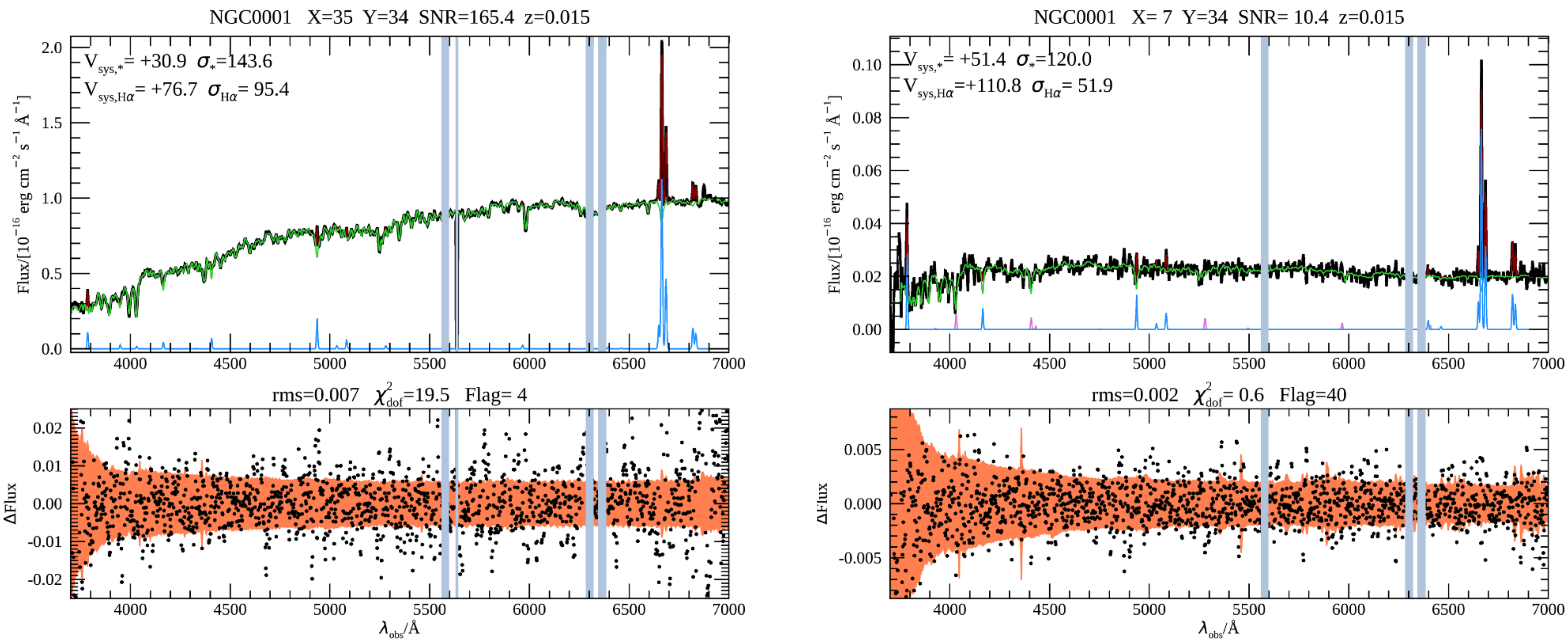
    - How to build the models?

What to measure on spectra?

- Galaxy spectra are a combination of (dust attenuated) starlight and (dust attenuated) nebular emission
  - Decouple starlight from nebular emission lines?
  - Or just forget those “contaminated” regions?
    - just missing all Balmer lines…

Example of decoupling in our CALIFA pipeline

(based on pPXF+GANDALF)



- Computationally intensive: combine kinematics+stelpops+lines
- Requires some wisdom to work safely

Use the full spectrum or just pieces?

- Ideally, to maximise information and enhance SNR
- BUT
  - Models do not encompass all physical complexity of real stellar populations (alpha enhancement, IMF…)
  - Not all features are reliable
- Spectral indices are still a reasonable choice

Bayesian Inference

from Gallazzi+05

- Create a library of model spectra with some prescription
  - Measure observable parameters
  - Extract “latent” physical parameters (prior distribution defined)
- For a given “observation”, the likelihood of it given each model is computed
- Compute the posterior probability distribution function for physical parameters, by marginalizing the likelihood function

"Library" concept in a shell

evolution of Gallazzi+05 to Zibetti+17,19

Ingredients

- 500,000 models, based on BC03 "evo"+MILES
- variable SFHs á la Sandage (1986, declining and rising) + stochastic bursts
- variable Chemical Enrichment Histories ("generalized" leaking box, Erb 2006)
- dust treatment á la Charlot & Fall (2000): differential attenuation from ISM and birthcloud — stochastic distribution
- Full coverage of age-metallicity plane, equalisation in observables plane

→

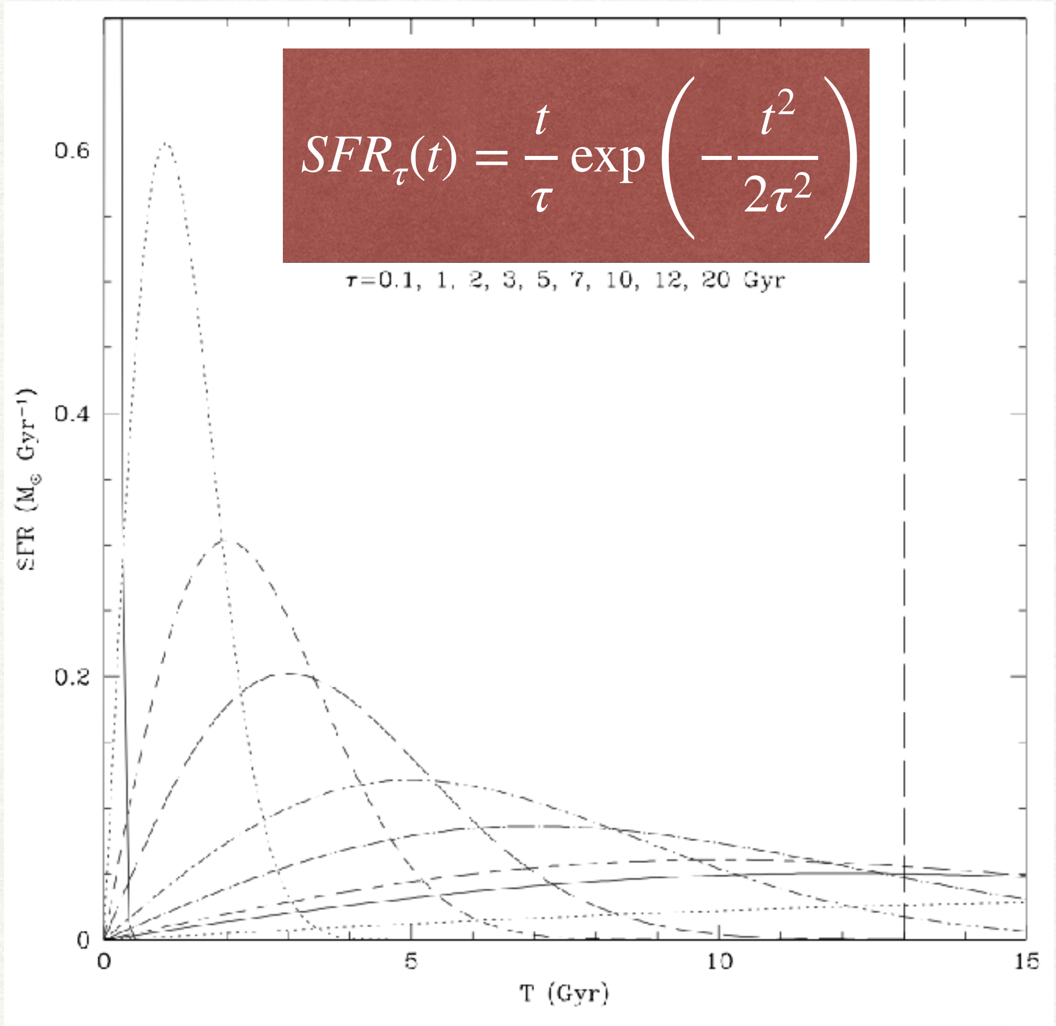
- ### *Synthetic observables*
  - spectra
  - spectral absorption indices
  - broad-band photometry
- ### *Physical parameters*
  - stellar mass
  - light-weighted and mass weighted age, metallicity
  - effective dust attenuation
  - …

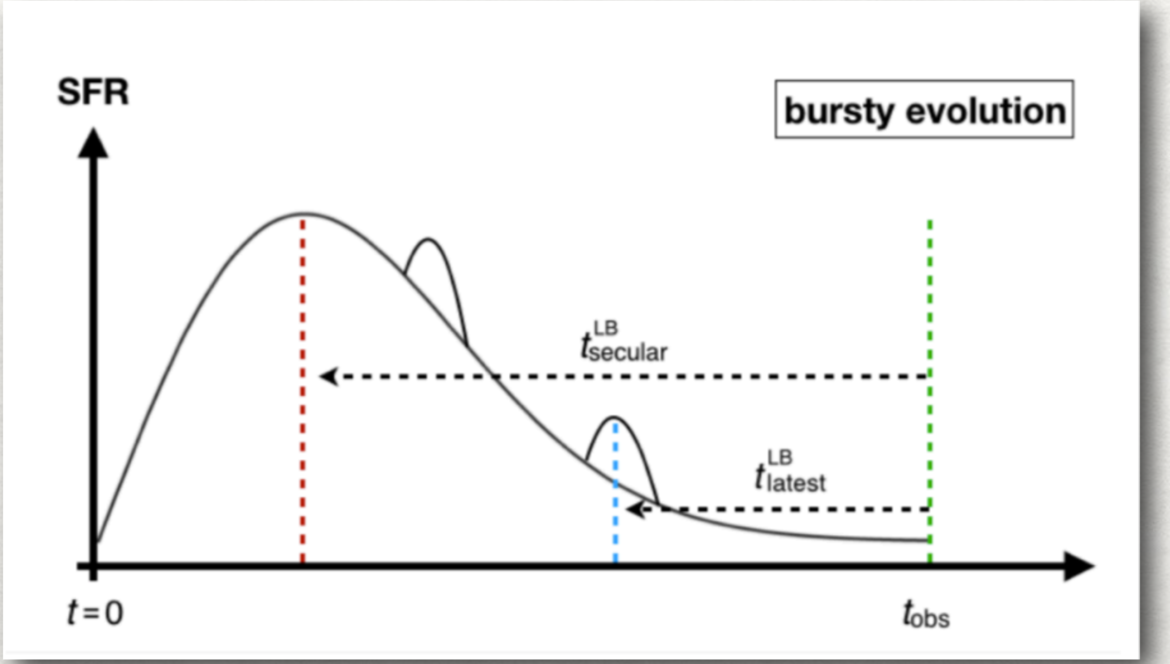
Why a “comprehensive” library?

- Cover the full parameter space of observables
- Cover the full range of “degeneracy”, i.e. account for all possible combination of ingredients that produce a given set of observables
    - The posterior PDF reflects the degeneracy-driven uncertainties
    - A good PDF should be stable against allowing more freedom in the ingredients
- We have done extensive testing… but always use the priors with lots of caution!

STAR FORMATION HISTORIES

- "Secular" component á la Sandage (1986)
  - delayed/declining/rising
  - t_0, τ randomly generated
  - ~uniform log distribution in age
- "Bursty" component in 2/3 of the models
  - up to 6 random bursts
  - 1/1000 to 2 times the total mass in secular SFH
    - "frosting" mode

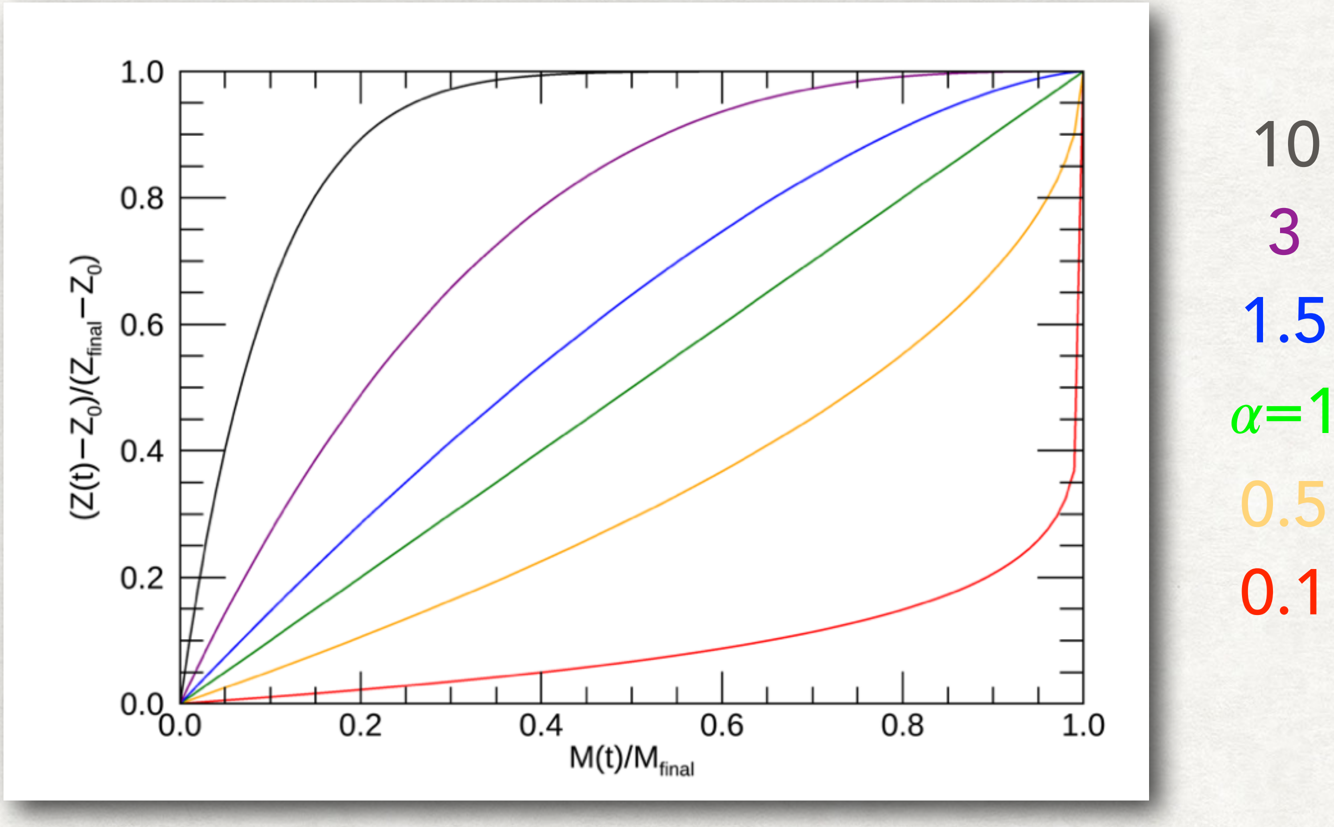




CHEMICAL ENRICHMENT HISTORIES

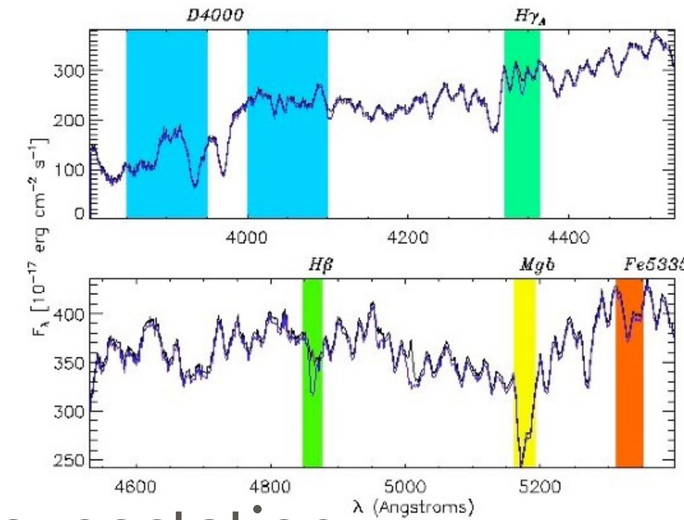
- Generalisation of the equation for a "leaking box" model (Erb 2006) for the "secular" component of stars

$$Z_*(t) = Z_*\left(M(t)\right) = Z_{*\,\mathrm{final}} - \left(Z_{*\,\mathrm{final}} - Z_{*\,0}\right)\left(1 - \frac{M(t)}{M_{\mathrm{final}}}\right)^{\alpha}, \alpha > 0$$

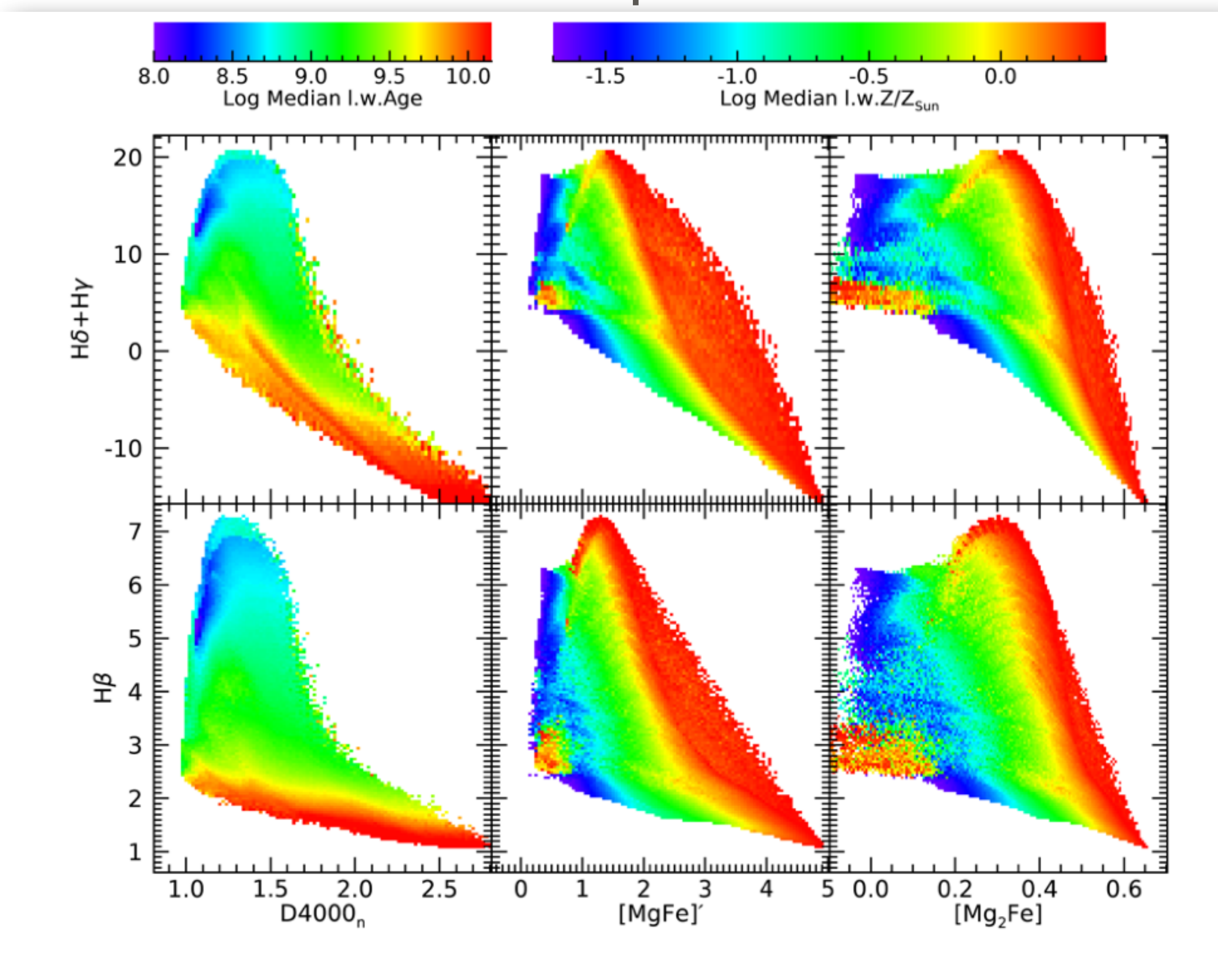


- Bursts are assigned a random Z, distributed around the expected metallicity of the stars in the "secular" component, at that time

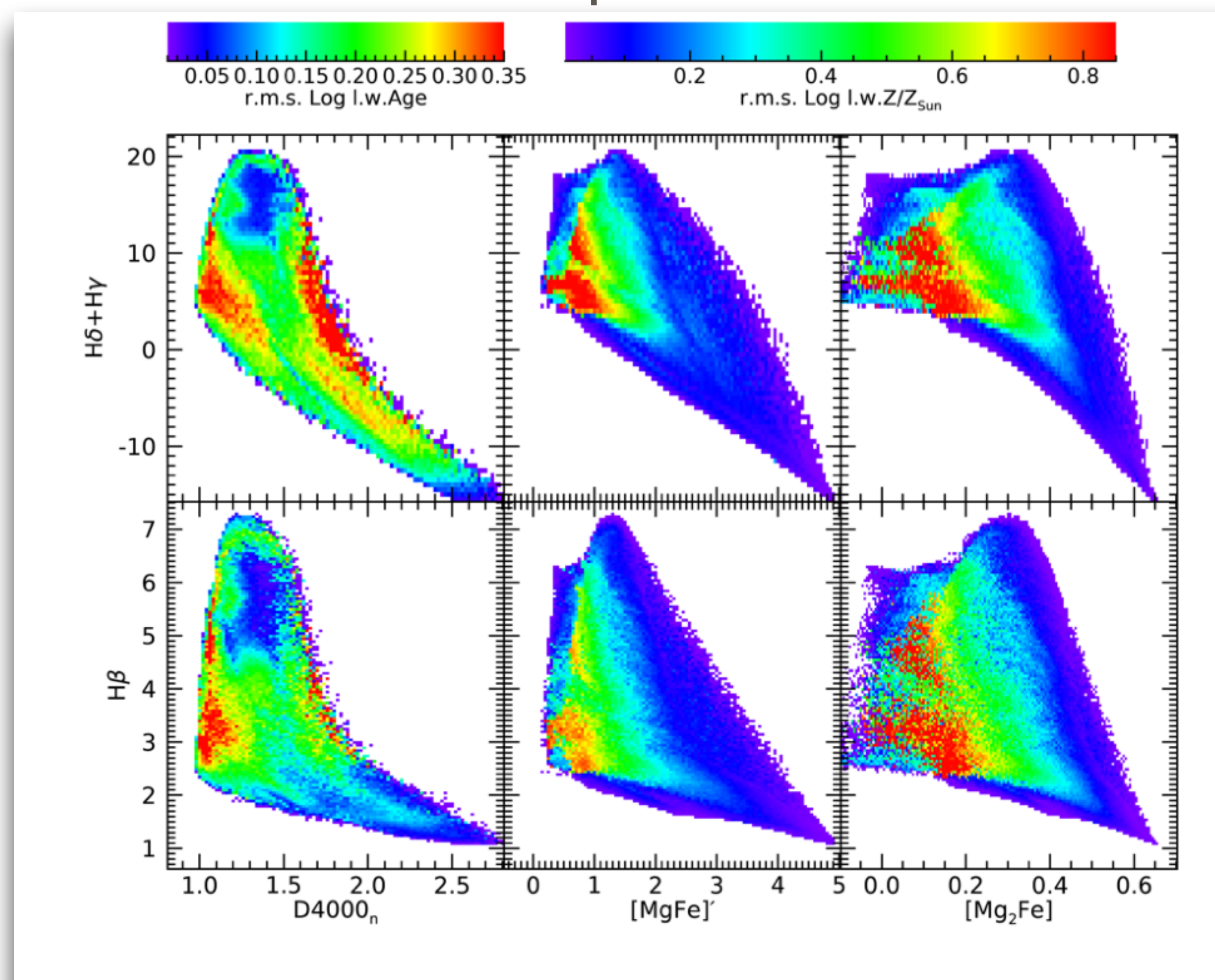
The library in the index space



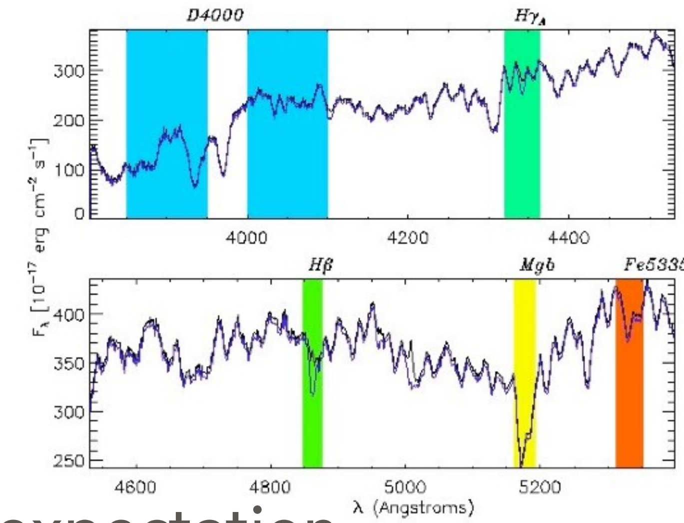
Median expectation



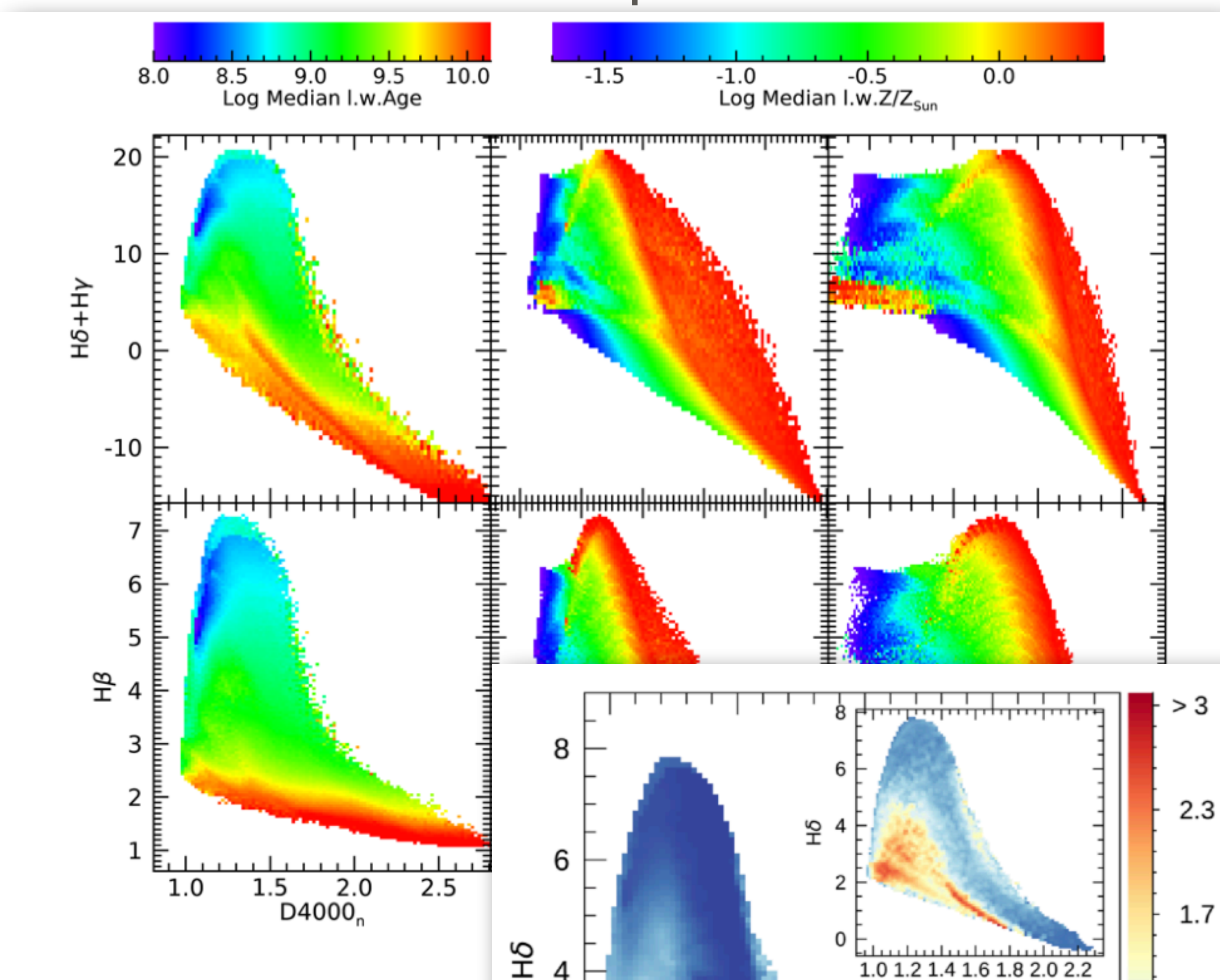
rms expectation



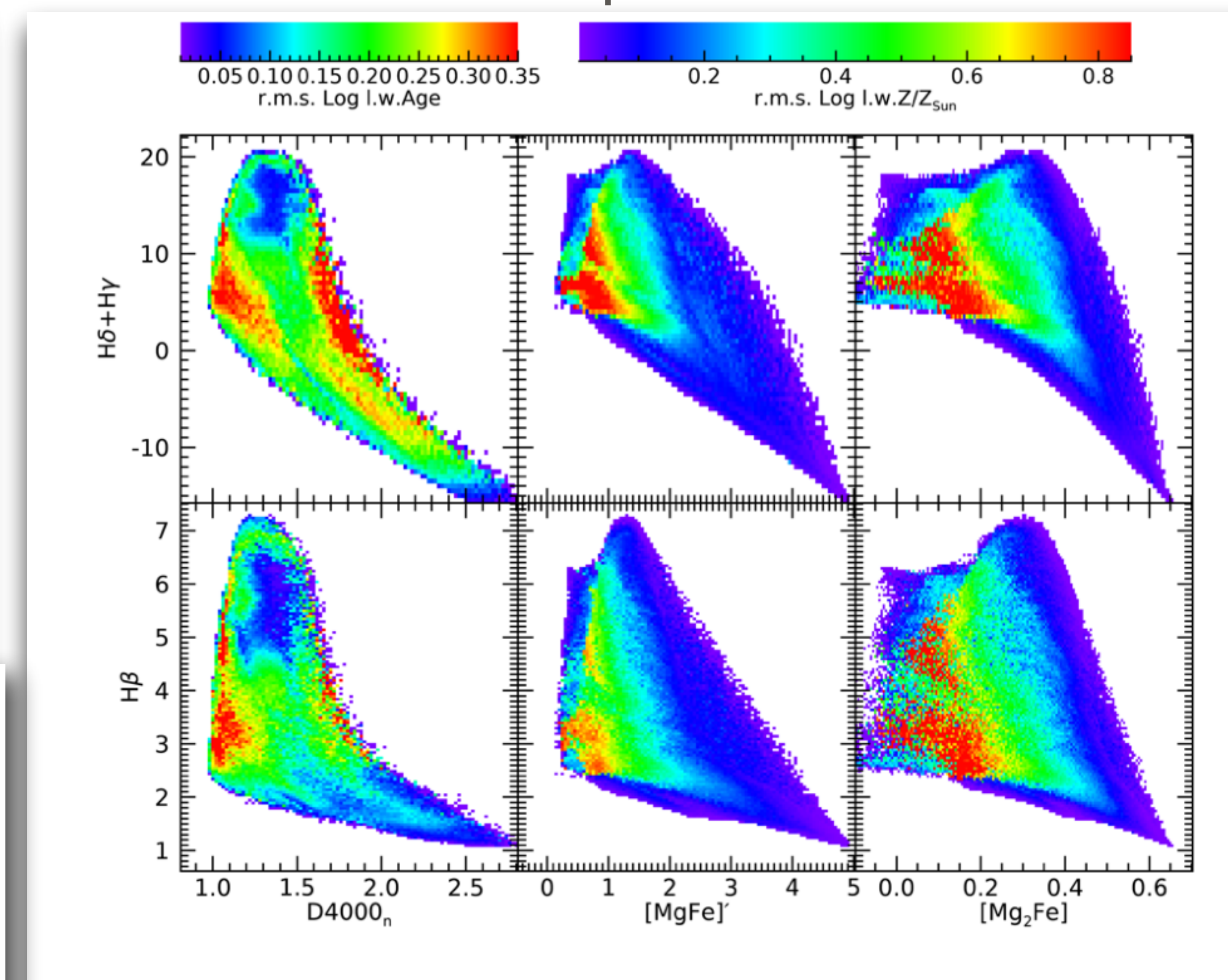
The library in the index space



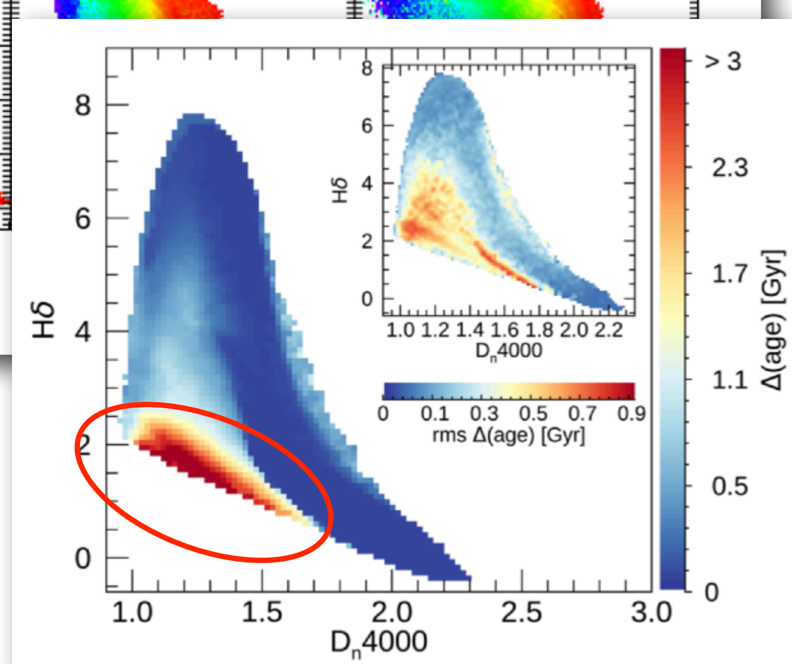
Median expectation



rms expectation



"Frosting"

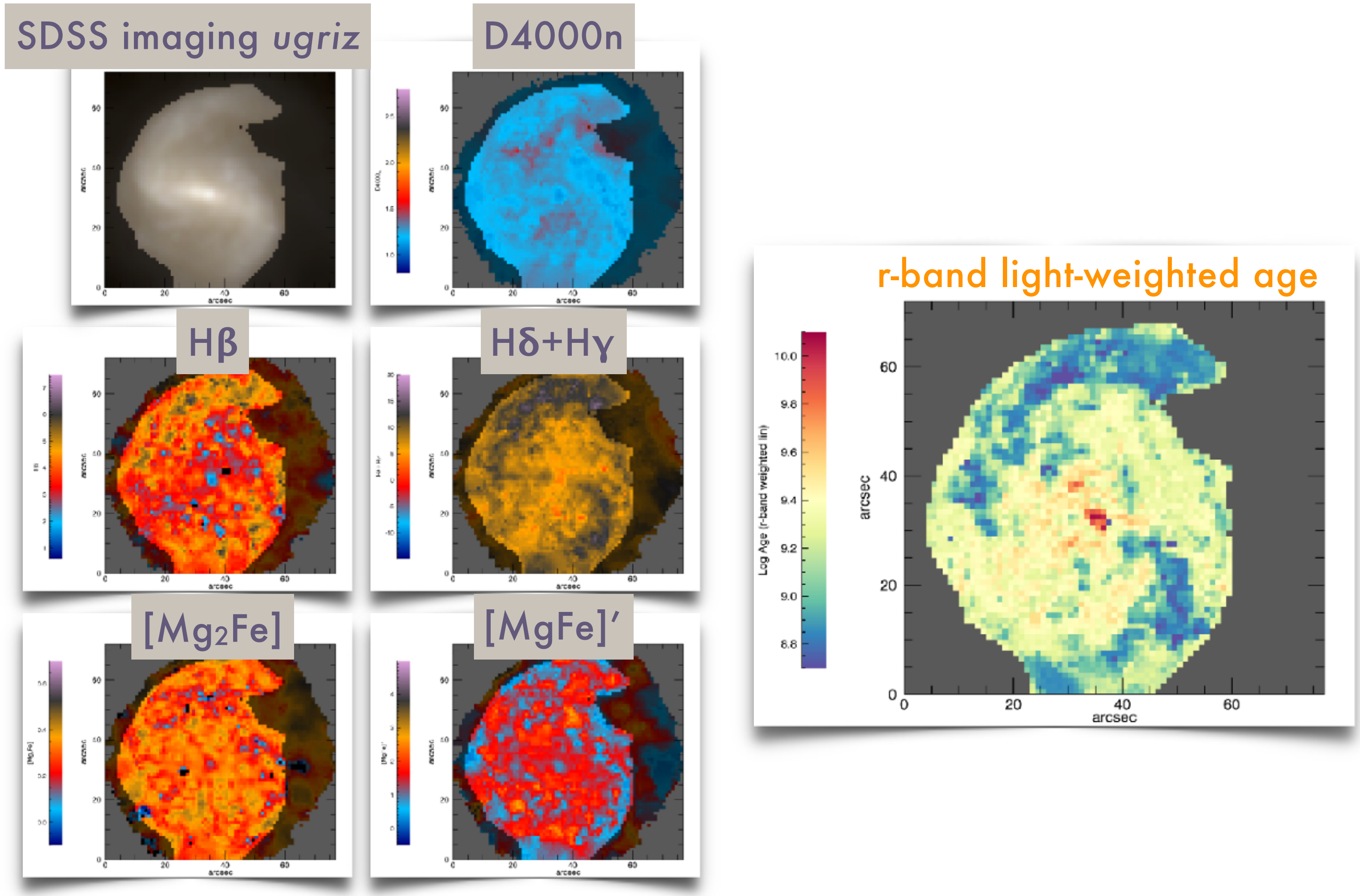


Costantin et al. (in prep.)

Beyond spectroscopy

- Synergy between multi-walvelength datasets
- Our approach (library) naturally integrates spectroscopic quantities and photometric quantities

CALIFA



Fighting against redshift: the variable w.l. coverage

- Are stellar population parameters consistently derived for samples at different z?

- Not all the same indices (or wavelength ranges) accessible in a give survey at z=0 are accessible to other surveys at different z, as features move in and out of the observable range

- Testing should be done for possible biases, based on the synthetic library

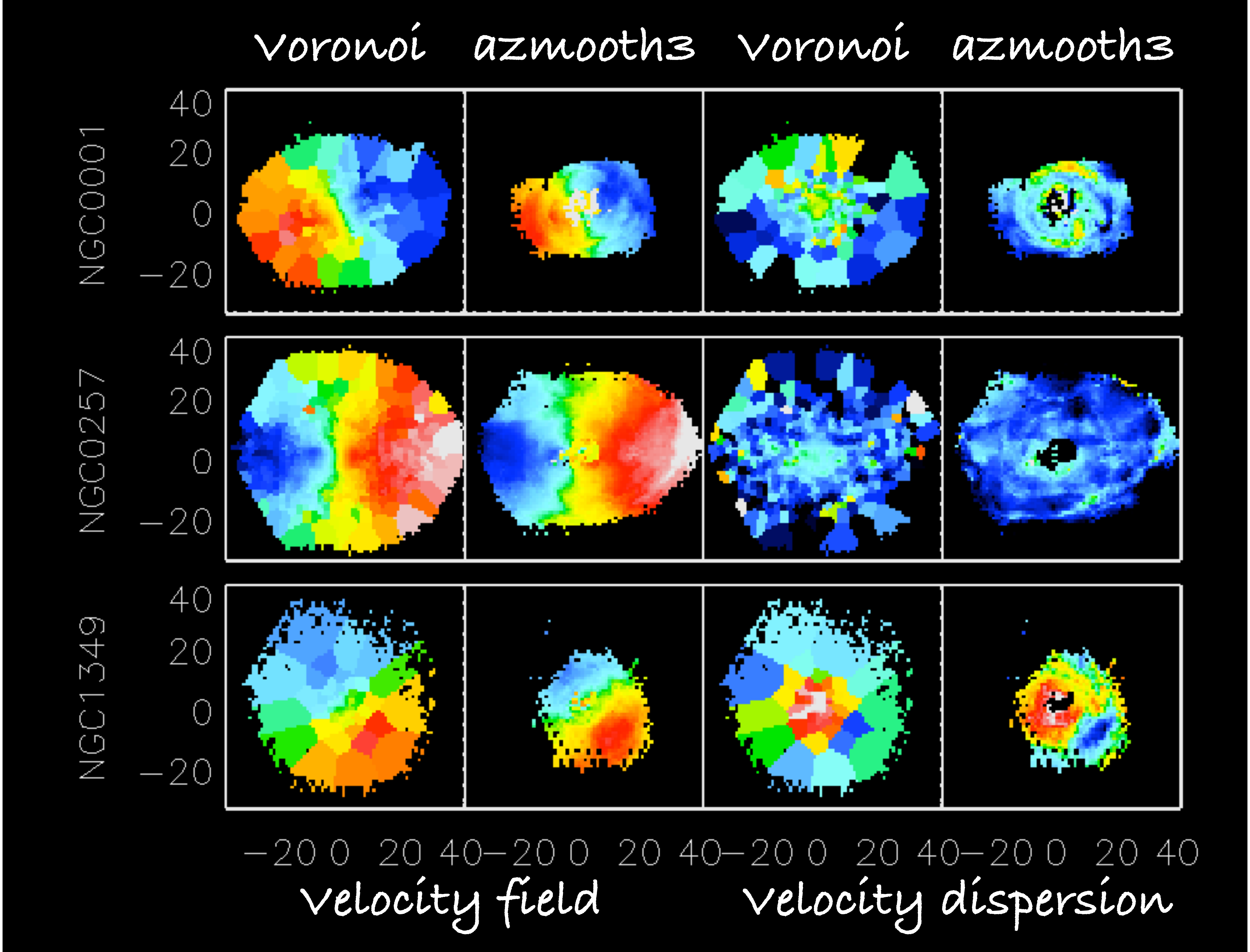
- Check for new discovery space (see Angela's talk, Costantin et al. in prep.)

Future challenges

- Not terrible in terms of computation
- ~1M spectra are ok to manage in these tasks (kinematics, nebular-stellar decoupling, basic parameter estimations)
    - but this is just one MUSE datacube!
- Challenges may come if we aim at constraining “higher order” parameters or expand the physical parameter space… the “library” explodes!

Beyond 1+1D: IFU

- Much more than a collection of spectra:
  - the different parts of a galaxies are not “independent”
- Imaging techniques applied to N lambda
  - the adaptive smoothing code azmooth[3]
    - spatial adaptive smoothing to preserve continuity (vs. tessellation)



Voronoi
azmooth3
Voronoi
azmooth3
NGC0001
NGC0257
NGC1349
40
20
0
−20
−20 0 20 40
Velocity field
Velocity dispersion

Challenges in multi-D

- Every piece of a galaxy is tied to other pieces, by structure and dynamics
- Is it conceivable to constrain stellar populations to obey these ties and simultaneously solve for orbital decomposition of stars?
- In principle, yes!
- In practice it's a massive computational effort

Final remarks from this experience

- Many “wheels” invented or re-invented
    - Some are “plug&play” (eg azmooth3, and they were thought to be)
    - Some are probably “sharable”, with a big grain of salt (synthetic libraries)
    - Most are mainly a concept, yet are a wealth of know-how and in-depth understanding of the data
- What about the “lab”?
    - Sell ready-to-use wheels for all purposes?
    - Provide support to build the best wheels for each track?