Impact of (neglecting) sub-solar metallicities and evolutionary corrections on photometric redshifts

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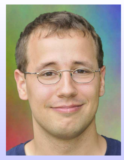

Faint galaxies in deep photometric surveys are very different from local galaxies:

- wide range of luminosities out to high redshifts
- many intrinsically faint galaxies
- significantly sub-solar metallicities and
- in significantly younger evolutionary states.

Our aim is to determine the impact of different template sets used to derive photometric redshifts for those galaxies in the distant universe.

We use our chemically consistent galaxy evolutionary synthesis code GALEV to generate

- three large grids of Spectral Energy Distributions (**SEDs**)
- galaxies of spectral types E and Sa through Sd
  1. one accounting in a chemically consistent way for the increasing initial metallicities of successive stellar generations (matching local observations)
  2. one using exclusively solar metallicities
  3. one appropriate for local galaxies, hence including no evolution at all.

We use our new photometric redshift code GAZELLE to compare observed and model SEDs for two cases.

- Analysing sub-solar metallicity galaxies with solar metallicity templates
- Analysing high-redshift galaxies with local templates without evolution

In both cases we found significant biases arising from this mismatch between observations and comparison templates, that have to be taken into account if one wants to derive *accurate* and *unbiased* photometric redshifts.

Introduction

With the advent of deep photometric surveys the use of photometric redshifts, obtained with a variety of techniques, has become more and more widespread. We studied on how far one can trust the underlying assumptions inherent in those redshifts, in particular the influence of the template set on the resulting photometric redshifts.

We therefore ran simulated observations generated from our GALEV models through our new and innovative photometric redshift code GAZELLE, using solar-metallicity-only templates or local observed galaxies as templates.

Simulated observations and the comparison model grid

For the study presented here we use three separate grids, each for 5 different spectral types E and Sa to Sd.

- Chemically consistent models for E through Sd types, containing both spectral and chemical evolution
- The solar-metallicity sample consisting of 5 galaxy models with only spectral evolution, and no chemical enrichment.
- The "local template" sample made from model spectra of local, 13 Gyr old models, that then are redshifted. This set does not contain any evolution.

To generate our catalog of input SEDs we performed Monte-Carlo simulations and added 0.1 mag of photometric noise, simulated by gaussian noise, to each of the filters (UBVIJHK). For each input SED 1000 representations were generated, yielding an input catalog of $> 10^6$ simulated galaxies per galaxy type.

GALEV evolutionary synthesis models now available at www.galev.org

Our chemically consistent GALEV evolutionary synthesis models allow to model

- spectral evolution, including
- gaseous emission and stellar absorption features (e.g. Lick indices)
- including the chemical evolution for
- galaxies with star formation histories appropriate for different spectral types, e.g. E, Sa-Sd,
- including both starburst and post-starburst phases,
- in any cosmological model (or as function of time) and
- to compute magnitudes for any given set of filter definitions

in a chemically consistent way, using input physics for the increasing initial abundances of successive stellar generations.

GALEV models are now interactively available at www.galev.org.

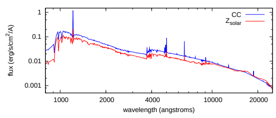

Fig. 1: Comparison of a Sd-type spectrum with fixed to solar metallicity (red) and the chemically consistent stellar populations (blue) for a galaxy age of 4 Gyr. Bicker & Fritze (2005, A&A Letter 443, 19) found, that applying solar-metallicity diagnostics to low-metallicity galaxies would lead to severe overestimations of star-formation rates ($\lesssim \times 2$) and galaxy masses ($\lesssim 50\%$) and underestimated ages ($\lesssim \times 2$)

For more details see our upcoming paper (submitted to MNRAS):
Kotulla, Fritze, Weilbacher & Anders 2008: GALEV models on the web

Our photometric redshift code GAZELLE

Our new photometric redshift code GAZELLE is specifically optimized to work with our GALEV models. It utilizes a dropout-detection scheme with a χ^2 algorithm to compute probabilities for each combination (observed SED, model-SED), and by keeping the full probability density distribution it allows to derive:

- best-match redshift incl. 1σ-uncertainty
- stellar mass incl. 1σ-uncertainty
- galaxy type

Since we have the full information from the modeling process at hand, we can furthermore estimate:

- Total baryonic (stars + gas) masses incl. 1σ-uncertainties
- Star formation rate, incl. 1σ-uncertainties
- Gaseous metallicity, incl. 1σ-uncertainties
- Stellar metallicity, incl. 1σ-uncertainties

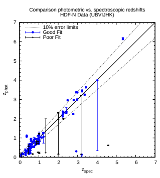

Fig. 2: Comparison of spectroscopic and derived photometric redshifts for $\gtrsim 100$ galaxies from the Hubble Deep Field (data from Fernandez-Soto et al. (1999, ApJ 513, 34)). The used template set consists of undisturbed types E...Sd and a grid of starburst templates.

For more results see our upcoming paper (in prep):
Kotulla & Fritze 2008: Galaxies to the redshift desert and beyond: I. The template set and II. The photometric redshift code GAZELLE

Results: Impact of sub-solar metallicities

We compared our catalog of simulated observations to our grid of fixed-to-solar metallicity galaxies and find:

- Very large best-match χ^2 values (Fig. 3) indicating poor fits
- Significantly biased photometric redshifts towards an underestimation of up to $\Delta z \sim 0.2$ (Fig. 4).

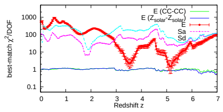

Fig. 3: Very large χ^2 values resulting from mismatched metallicities for different galaxy types E (red), Sa (pink) and Sd (light blue).

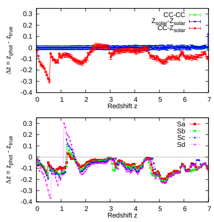

Fig. 4: Redshift offset $\Delta z = z_{\rm phot} - z_{\rm true}$ for the elliptical (top panel) and spirals Sa, Sb, Sc, and Sd (lower panel). In the top panel, blue and green lines are for matching combinations, red symbols show the errors resulting from the use of solar metallicity templates for the analysis of lower metallicity galaxies. Each point represents the median value in a bin of width $\Delta z = 0.05$.

For more results see our upcoming paper (submitted to MNRAS Letters):
Kotulla & Fritze 2008: Impact of sub-solar metallicities on photometric redshifts

Results: Impact of evolutionary corrections

We compared our catalog of simulated observations to our grid of local templates without evolutionary corrections, and find:

- Systematically underestimated photometric redshifts
- Misidentification of galaxy types

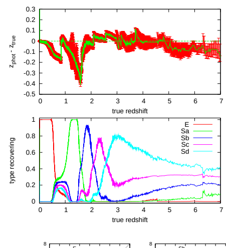

Fig. 5: Difference between true and retrieved photometric redshift (top panel) and integrated probability for each of the templates (lower panel) as function of true redshift. As long as dropouts are not important ($z<2$) redshifts are underestimated. From $z\sim0.5$ on retrieved types are biased towards the latest, most actively star-forming galaxies.

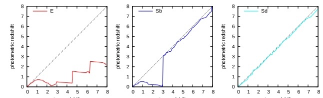

Fig. 6: If one only compares galaxies with evolution to templates without evolution no correct redshift solution can be found without dropouts, except for the Sd model, that only shows very little evolution.

For more results see our upcoming paper (in prep):
Kotulla & Fritze 2008: Impact of evolutionary corrections on photometric redshifts

Summary and Outlook

We use our chemically consistent GALEV evolutionary synthesis code to create a large and realistic catalog of simulated observations of galaxies in the high-redshift universe. Using our new photometric redshift code GAZELLE we compare these "observations" to templates derived from fixed-to-solar metallicity templates or local galaxy templates. In both cases we point out significant biases:

- Ignoring the sub-solar abundances of high-redshift galaxies leads to an underestimation of photometric redshifts as long as dropouts are not important.
- Without evolutionary correction:
  - galaxy types are systematically misidentified towards later, more actively star-forming galaxy types, and
  - photometric redshifts are systematically underestimated
- Both effects can NOT be compensated for by additional parameters, such as e.g. dust.

Our results not only apply to template-based photometric redshift codes, but also to neural networks or training-set based codes, since spectroscopic redshifts are only available for the brightest and therefore most metal-rich galaxies at each redshift.

We particularly stress the importance of accurate evolutionary corrections in combination with a realistic treatment of the chemical enrichment history for current studies of large galaxy samples compiled from deep photometric surveys. Those samples reach far below today's spectroscopic magnitude limits, where low-mass and hence increasingly metal-poor galaxies dominate the galaxy population.

⇒ These effects are of paramount importance for the analysis of deep fields.

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