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Understanding the Spectral Energy Distribution of galaxies:

from Lyman Alpha Emitters to the future challenges of SED fitting

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Abstract

A galaxy's Spectral Energy Distribution (SED) contains information about its physical properties, such as redshift, stellar population age, mass, star formation rate, dust content, and metallicity. These properties can be inferred via SED fitting, the procedure of comparing theoretical templates to observations to find the properties of the models that best resemble the data. This idea is simple and powerful; however, it is essential that it is implemented while avoiding biasing assumptions on the shape of the probability distribution function, and while maximizing the accuracy in the reported uncertainties. For this purpose, we have built GalMC, a publicly available MCMC code for SED fitting, and SpeedyMC, a less flexible but much faster version suitable for SED fitting of catalogs with large numbers of objects. I show some of the results obtained using GalMC for Lyman Alpha Emitting galaxies at z ~ 3 and z ~ 2 from the MUSYC survey, and describe how the assumptions made in modeling the stellar populations influence our estimates of galaxy properties. Many open problems still limit our understanding of the physical nature of galaxies, and I plan to help solve some of them, hopefully with suggestions from other participants to this conference.

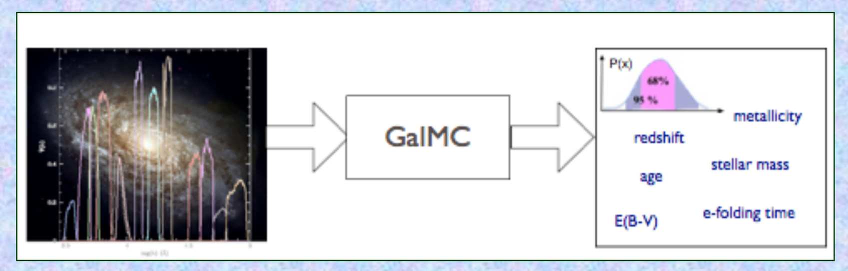
Methodology and Tools

Why Markov Chain Monte Carlo for SED fitting?

- Faster and more efficient than grid- based methods
- Exploration of the full probability distribution rather than best-fit values
- Powerful in discovering and handling degeneracies
- Easy, accurate, assumption-free evaluation of uncertainties in a Bayesian formalism

GalMC: a publicly available code for SED fitting
(Acquaviva, Gawiser, Guaita 2011)

http://www.physics.rutgers.edu/~vacquaviva/web/GalMC.html

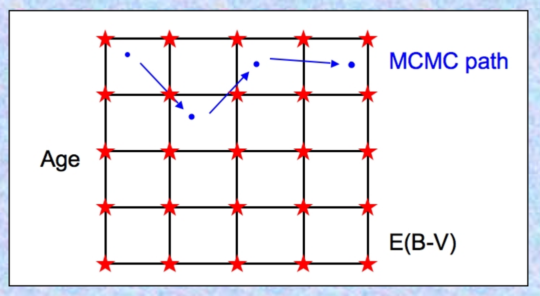


Input: Photometric fluxes from rest-frame UV to IR

Output: Probability distributions and marginalized constraints for age, timescale of star formation, metallicity, dust content, stellar mass, and redshift

Based on Bruzual and Charlot stellar pop models, includes modeling of nebular emission, dust absorption, multiple stellar populations and flexible Star Formation Histories (SFHs)

SpeedyMC: applying GalMC to large galaxy surveys
(Acquaviva, Gawiser, Guaita 2011)

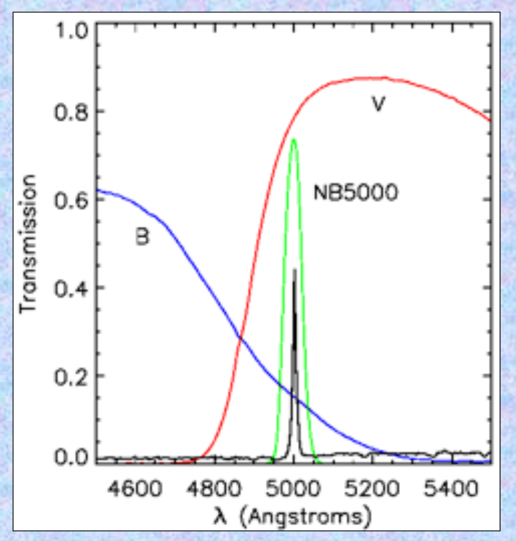


After computing the SED for a reference grid of models and saving the relevant photometric points, SpeedyMC explores the parameter space in the usual MCMC way and computes the model SED using multi-linear interpolation (here shown in 2D):

20,000 times faster!
(8 chains of 100,000 steps = 1 galaxy/second)

Suitable for large surveys (CANDELS, LSST)

Results



Motivation: Lyman Alpha Emitting (LAE) galaxies have been shown to be building blocks of galaxies like our own Milky Way, and are powerful probes of galaxy formation and evolution. Thanks to the strength of the Ly-α line at 1216 Angstrom in rest-frame, they can be detected easily even at high redshifts.

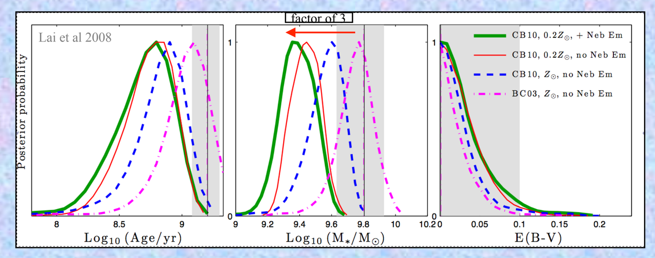
Technique: LAEs can be found by estimating the excess flux in a narrow band filter at the wavelength of the redshifted Ly-α line with respect to the continuum, evaluated via broad-band photometry as shown above for $z = 3.1$ LAEs.

Data: The MUSYC survey (Gawiser et al 2006) imaged the Extended Chandra Deep Field South, and built a sample of several hundred LAEs at $z = 3.1$ and $z = 2.1$ in 13 wavebands ranging from U Band (370 nm) to Spitzer's IRAC Channel 4 (8 μm).

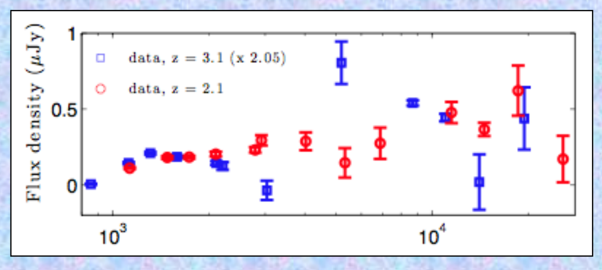
Stacked SEDs: Because LAEs are faint in the continuum, it is difficult to obtain meaningful constraints from SED fitting of individual objects. Instead, the images of LAEs at the same redshift are stacked to increase the S/N ratio in the SEDs. We use median stacking in order to minimize our sensitivity to outliers.

The evolution of LAEs between $z = 3$ and $z = 2$: Guaita et al (2010) showed that LAEs at $z = 2$ are hosted by dark matter halos that can be the descendant of those that host LAEs at $z = 3$ found by Gawiser et al (2007). **Could the LAEs also be in a progenitor-descendant relation?**

The state of the art: LAEs at $z = 3$ and $z = 2$ have been widely studied in the literature, but different groups make different and/or simplified assumptions in modeling the stellar populations. This makes it difficult to discriminate between evolutionary effect and analysis biases, as shown here:

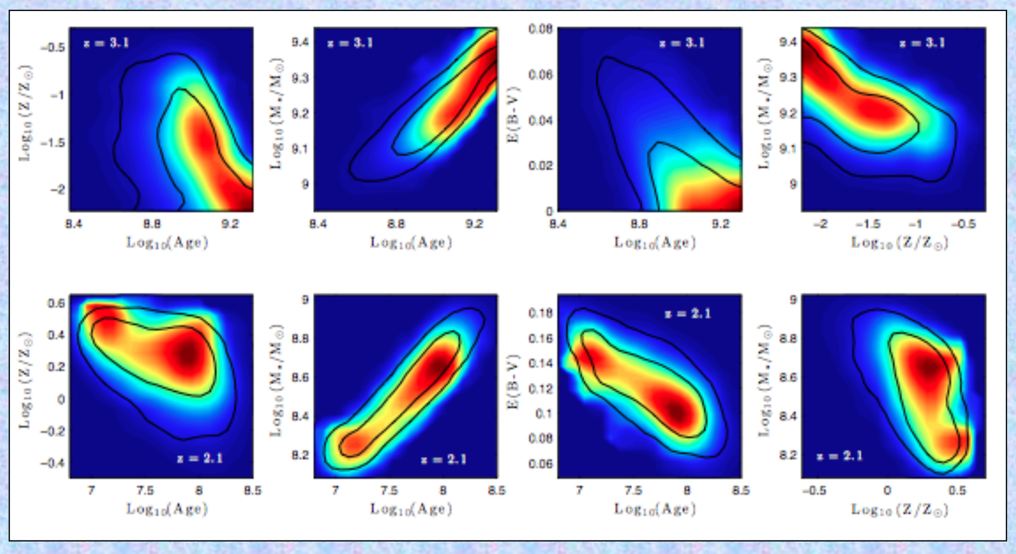


Our solution: We eliminated the systematic inconsistencies by building the stacks at $z = 3$ and $z = 2$ in the same way and using the same, state-of-the-art algorithm (GalMC) and stellar population models to analyze the SEDs.



The stacked SEDs of LAEs at $z = 3$ and $z = 2$, shown above, appear to be fundamentally different (Acquaviva et al 2012).

Results from SED fitting: 2-D marginalized constraints for the parameters of our MCMC fit, for LAEs at $z = 3$ and $z = 2$. Blue-to-red colors denote increasing probability density, and the black curves enclose the 68 and 95% confidence regions on the joint parameters, computed with Bayesian statistics.



LAEs at $z = 3$ are found to be MUCH OLDER than LAEs at $z = 2$, ruling out the progenitor-descendant scenario.

Checks on the analysis. We considered several systematic effects as the possble cause of the discrepancy: **wrong data points** in the $z = 3.1$ SED, **wrong metallicity estimate** due to the paucity of models available at low Z, and repeated the analysis with **multiple stellar populations**, and **different SFHs.**

The devil could still be in the stacking: improved photometry is needed to obtain constraints on individual objects (Vargas et al 2012, in prep.)

Work in progress (feedback welcome!)

- Study of individual SEDs of LAEs from the CANDELS survey
- The contribution of TP-AGB stars to the SEDs is an important cause of systematic uncertainty: can we constrain it using CANDELS data?
- SpeedyMC: how best to interpolate in n > 3 dimensions
- Comprehensive tests of GalMC/SpeedyMC as SED fitting + photo-z codes
- Machine learning techniques (decision trees? Neural Nets?) applied to finding outliers in spectroscopic surveys

References: Acquaviva, Gawiser and Guaita, ApJ 737, 747, 2011; Acquaviva, Gawiser, and Guaita, Proceedings of IAU meeting "The SED of galaxies", ArXiv: 1111.4243; Acquaviva, Vargas, Gawiser, and Guaita, ApJL in press, 2012; Gawiser et al, ApJS 62, 2006; Gawiser et al, ApJ 671, 2007; Guaita et al, ApJ 714, 2010; Vargas et al, 2012 in prep.

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