BEAGLE

EURECA, 02/16
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BayEsian Analysis of GaLaxy sEds (BEAGLE)

Developed by Jacopo Chevallard, Stéphane Charlot, Emma Curtis-Lake etc.
https://www.iap.fr/beagle/

Originally described in Chevallard & Stéphane 2016
Nebular emission in Gutkin, Charlot & Bruzual 2016

> BEAGLE incorporates the **consistent modelling of stellar radiation** and **its transfer through the interstellar and intergalactic media**, allowing one to **build mock galaxy catalogues as well as to interpret**, in a **Bayesian** framework, **any combination of photometric and spectroscopic galaxy observations**.

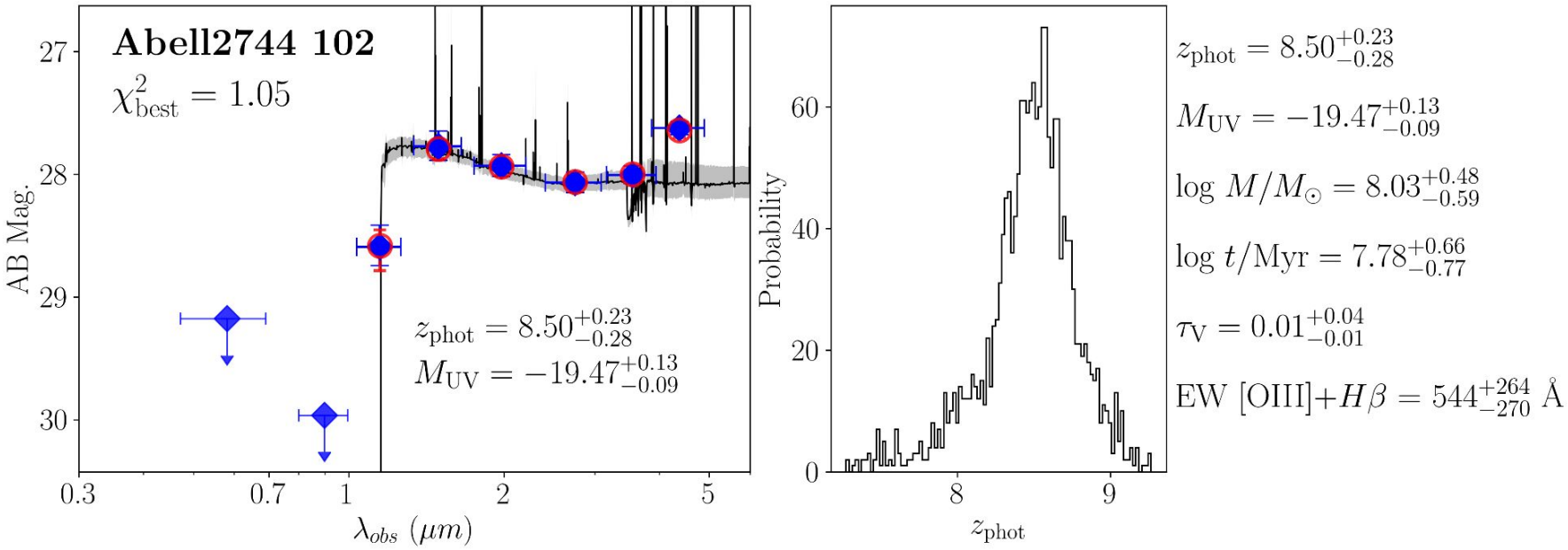
Well suited to model extremely emission line galaxies that are becoming common at highz in this JWST era

The models underlying BEAGLE

- The **latest version of the Bruzual & Charlot (2003) stellar population synthesis code**: updated stellar evolutionary tracks + the optical/ultraviolet spectral libraries (*Chevallard & Stéphane 2016*), IMF up to 300 Msun.
- **BC03+CLOUDY**: Physically self-consistent modeling of stellar continuum and the nebular emission processed by the interstellar medium (*Gutkin, Charlot & Bruzual 2016*)
- **Nebular emission from the narrow-line regions surrounding active galactic nuclei** (*Vidal-García et al. 2024*)
- Binary stellar population models?? (*Lecroq et al. 2024*)

“Efficient” exploration of a wide grid of physical parameters affecting the light emitted by a galaxy (redshift, stellar age, metallicity, ionization parameter, chemical abundance, star formation history, dust, etc)

Example usage: fitting to NIRCam photometry

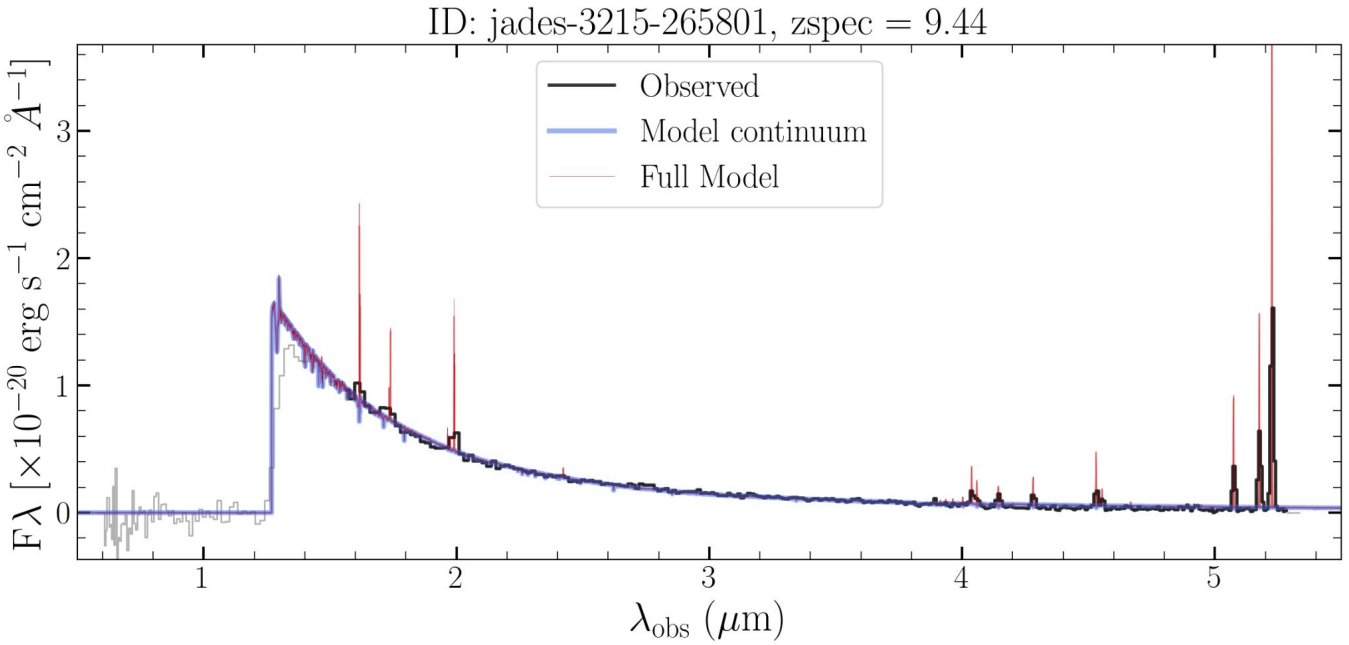


Simultaneously explore the possible range of redshift, stellar mass and age, dust attenuation.

Example parameters files (after obtaining BEAGLE access)

https://github.com/jacopo-chevallard/BEAGLE-general/tree/master/params

Example usage: fitting to NIRSpec prism spectrum

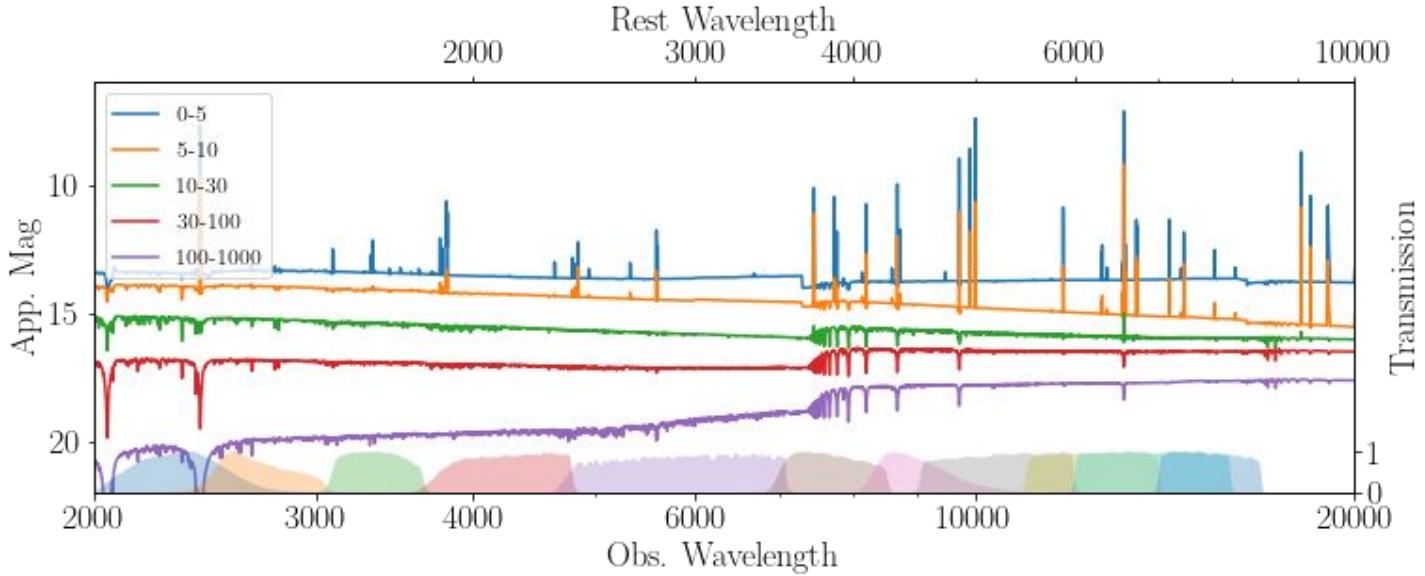


Example parameter file, accounting for wavelength-dependent resolution
https://github.com/jacopo-chevallard/BEAGLE-configurations/tree/main/JWST_NIRSPEC_PRISM

Photometry + Spectroscopy fit

- ❏ Photometry + Line fluxes (e.g., NIRCam photometry + Grism line fluxes)
- ❏ Photometry + Line equivalent widths (e.g., SDSS photometry + line equivalent widths from ground-based spectroscopy, in order to avoid aperture issue)
- ❏ Pure line fluxes for photoionization modeling (e.g., use BEAGLE to explore properties of ionized gas with pure measured line fluxes as input, including attenuation, metallicity, ionization parameter)

Mock SED

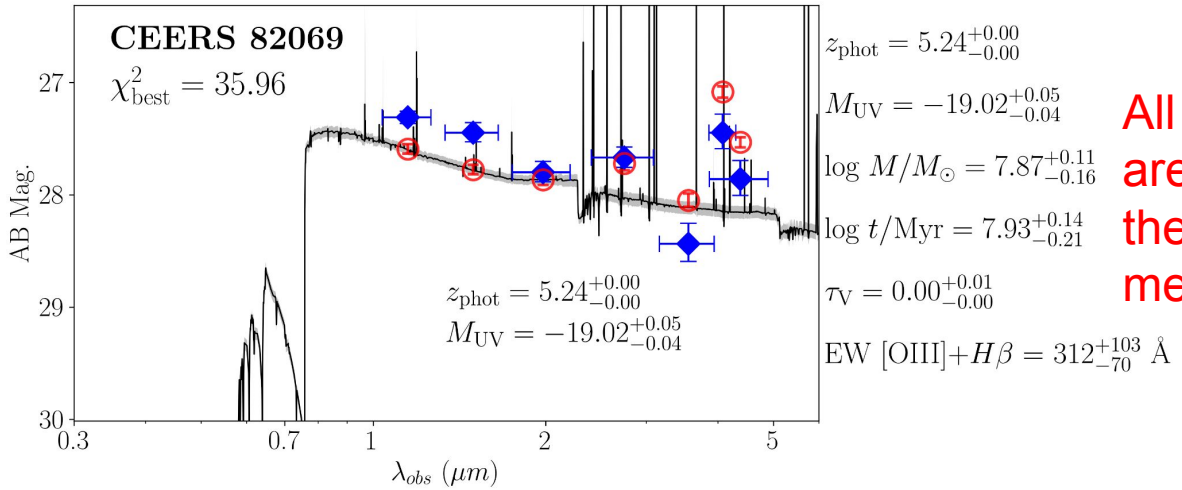


- Synthesize spectrum and photometry with a given set of galaxy parameters, allowing us to explore how galaxy properties may affect the observables.
- Example parameters files (after obtaining BEAGLE access)

https://github.com/jacopo-chevallard/BEAGLE-general/tree/master/params

Miscellaneous - modeling

- Obviously BEAGLE may not model Lya well, and you can remove it in your modeling (e.g., by commenting it out in the line wavelength file: cb2016_Jan16_line_wavelengths_may2017.dat)
- Try with the ionizing photon escape fraction as an additional parameter in fitting weird sources



All ionizing photons are reproccessed by the interstellar medium

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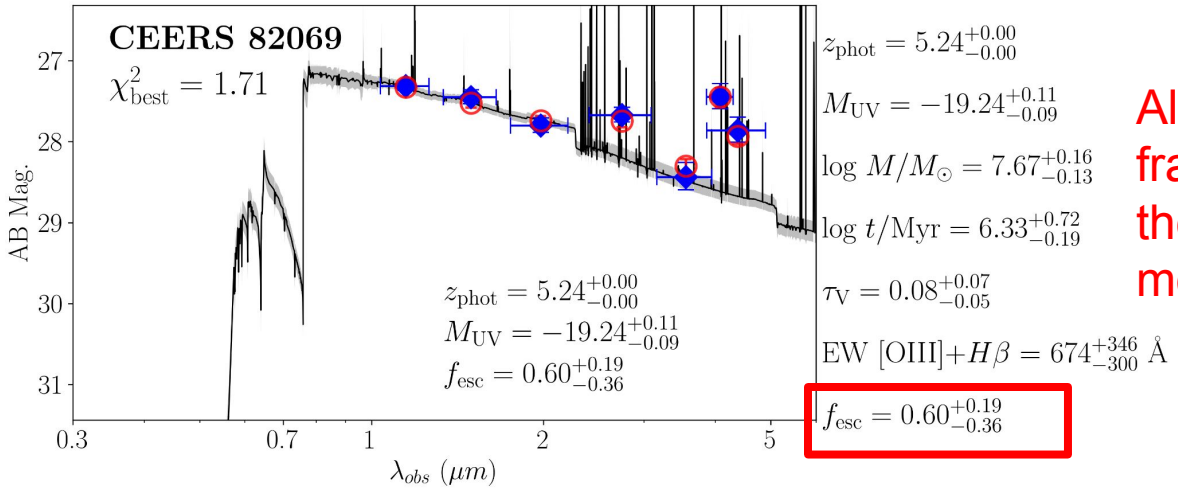

Allowing a escape fraction escape from the interstellar medium

Miscellaneous - modeling

- Obviously BEAGLE may not model Lya well, and you can remove it in your modeling (e.g., by commenting it out in the line wavelength file: cb2016_Jan16_line_wavelengths_may2017.dat)
- Try with the ionizing photon escape fraction as an additional parameter in fitting weird sources
- Are we extracting reliable galaxy physical properties?
  (e.g., Be aware of what the inferred properties actually mean – The stellar mass assuming a constant star formation history would correspond to mass associated with the recent star formation epoch)
  Or are we exploring what physical properties are required to reproduce the observables?

Miscellaneous - technical

- Running on UA HPC without sudo privileges:
  Run with singularity container
  https://github.com/jacopo-chevallard/BEAGLE-general/issues/21
- Run in parallel with large catalogs: launch BEAGLE with docker/singularity using the same command (and parameter file) multiple times, and BEAGLE will figure it out not duplicate the fitting for each source.
- The uncertainty floor: How high SNR do you actually believe you can achieve with your photometry? (one may set the minimum relative uncertainty in the filter configuration file, e.g. min_rel_err:0.05)

BEAGLE Access

- BEAGLE is not yet publicly released (most updated version v0.29.2), but Stéphane, Jacopo, and Emma generally welcome people to ask for access.
- Email them! (Let them know your needs). They will provide the instruction to access BEAGLE and download the necessary files.
- There will be a BEAGLE policy document to sign. The document also asks for associating the BEAGLE people in the resulting scientific publication.
- The BEAGLE github wiki provides instructions for using BEAGLE and the user manual. The github issue is also a good place to discuss any bugs you may encounter.
- PyP-BEAGLE for post-processing the results. (You can also sample from the output posterior based on their probabilities).

BEAGLE fitting: the parameter file

```
#*****************************************************************
# ****************** TEMPLATES  ****************************
#*****************************************************************

#TEMPLATES = $BEAGLE_TEMPLATES/bc03/bc03_miles_chab_spectra
TEMPLATES NEBULAR =
$BEAGLE_TEMPLATES/ineb_Jan16_C100/cb2013_n2_mup100_N015_O01_deplO70_C100_Jan16
EMISSION LINES CONFIGURATION =
$BEAGLE_TEMPLATES/ineb_Jan16_C100/cb2013_n2_mup100_N015_O01_deplO70_C100_Jan16_l
ine_wavelengths_PHOTOMETRY.dat

#SHRINK TEMPLATES WL RANGE = 900 60000
REBIN TEMPLATES = 10
```

BEAGLE fitting: the parameter file

```
#*************************************************************
# ****************** PHOTOMETRY ****************************
#*************************************************************
#
FILTERS THROUGHPUTS = /groups/dpstark/zychen/beagle/specz_nrc/nrs/jades.fits

FILTERS CONFIGURATION = /groups/dpstark/zychen/beagle/specz_nrc/nrs/jades.dat

PHOTOMETRIC CATALOGUE = /groups/dpstark/zychen/beagle/specz_nrc/nrs/phot_nircam_spec.fits
# e.g. $BEAGLE_DATA/jades_v0p4/ID.fits

# If you want to fix redshift to a given value (see sec 3.7.1 of the Beagle
# manual, version 0.17.1)
PRIORS CATALOGUE = /groups/dpstark/zychen/beagle/specz_nrc/nrs/phot_nircam_spec.fits
```

BEAGLE fitting: the parameter file

```
#*************************************************************
#******************** IGM ABSORPTION *******
#*************************************************************

IGM ABSORPTION = Inoue
```

BEAGLE fitting: the parameter file

```
# ************************************************
# ************** SF BIN #1 ************************
# ************************************************
SF_PARAMETER  = name:sfh_type                type:fixed  char_value:constant
#options for analytic SFHs are 'ssp' (for a burst), 'constant', 'exponential', 'delayed', 'rising'

# ln log(yr)
#SF_PARAMETER  = name:tau                    type:fitted  order_priority:1  prior:distribution:uniform
prior:range:[7.,10.5]

# in log(Z/Z_sun)
SF_PARAMETER  = name:metallicity             type:fitted  order_priority:1  prior:distribution:uniform
prior:range:[-2.2,0.24]

# ln log M/M_sun
SF_PARAMETER  = name:mass                   type:fitted  order_priority:0  prior:distribution:uniform
prior:range:[5.,12.]
```

BEAGLE fitting: the parameter file

```
# ************************************************
# *************  OTHER SF PARAMETERS *************************
# ************************************************

# ln log(yr)
#SF_PARAMETER  = name:current_sfr_timescale       type:fitted  order_priority:1  prior:distribution:uniform
prior:range:[6.0,7.0]
SF_PARAMETER  = name:current_sfr_timescale       type:fixed  value:0.0

# ln log(yr^-1)
#SF_PARAMETER  = name:specific_sfr              type:fitted  order_priority:1  prior:distribution:uniform
prior:range:[-10.,-6.]

# ln log(yr)
SF_PARAMETER  = name:max_stellar_age   type:fitted   order_priority:1  prior:distribution:uniform
prior:range:[6.,10.2]

# ln log(M_sun/yr)
#SF_PARAMETER  = name:sfr              type:fitted  order_priority:1  prior:distribution:uniform
prior:range:[-4.,4.]       mock:type:random
```

BEAGLE fitting: the parameter file

```
#************************************************************
# ****************** PRINTED OUTPUT  ***************************
#************************************************************

RESULTS DIRECTORY = /xdisk/dpstark/zychen/beagle/specz_nrc/nrs/
# e.g. $BEAGLE_RESULTS/jades_v0p4/ID

PRINT PHOTOMETRY = T
PRINT SPECTRUM = T
PRINT SPECTRAL INDICES = F
PRINT SF AND ChE HISTORIES = F
```

BEAGLE fitting: the parameter file

```
#************************************************************
# ****************** PARAMETERS HANDLING  ***************************
#************************************************************

PDF SAMPLER FILE = $BEAGLE_PARAM_DIR/MCMC_new.param

# PARAMETER  = name:redshift     type:fitted  order_priority:0  prior:distribution:uniform  prior:range:[0.,20.]
# Uncomment the line below, and comment out the line above, to use the redshift
# in the photometric catalogue instead of letting Beagle determine a photo-z
# together with the other parameters (see sec 3.7.1 of the Beagle manual,
# version 0.17.1)
PARAMETER = name:redshift      type:fitted  prior:distribution:dirac  prior:colName:zspec

PARAMETER  = name:nebular_logU type:fitted  order_priority:0  prior:distribution:uniform  prior:range:[-4.,-1.]

PARAMETER  = name:nebular_xi   type:fixed   value:0.3

PARAMETER  = name:nebular_Z    type:dependent

PARAMETER  = name:attenuation_type  type:fixed  char_value:SMC
# values can be: CF00, Calzetti, CCWW13_universal, CCWW13_full

PARAMETER  = name:tauV_eff     type:fitted  order_priority:0      prior:distribution:log-uniform   prior:range:[0.001,5.]
```