# *ESSENCE/FORS1 High-z Type Ia Supernovae*

## Abstract

The ESSENCE Survey was initiated to determine the nature of the "dark energy" that causes the accelerated expansion of the universe by determining its equation-of-state parameter, *w*. We aim to answer a simple, but very important, question: is the dark energy of the universe consistent with a cosmological constant ($w = -1$)? If not, this means the dark energy must be a more general energy field such as "quintessence".

Over the six-year period of the survey (2002-2007) we have discovered and followed-up ~200 Type Ia supernovae (SNe Ia) over a large redshift range (out to $z \sim 0.8$). To properly identify these SNe Ia and determine their redshift, we have carried out optical long-slit spectroscopy using the FORS1 instrument of the VLT at ESO's Cerro Paranal Observatory, Chile. These spectra were obtained under programme IDs 170.A-0519 and 176.A-0319 (PI: Bruno Leibundgut). The spectra were obtained with a 1" slit and the 300V grism (+GG435 filter), yielding a wavelength coverage of ~4350-8950 Å sampled at roughly 2.6 Å/pixel (and resolving power $R \sim 440$). For one SN Ia we obtained two spectra with the 300I grism (+OG590 filter), yielding a wavelength coverage of ~6350-10350 Å sampled at roughly 2.5 Å/pixel (and resolving power $R \sim 660$).

More information on the ESSENCE survey can be found in the following refereed publications:

"Spectroscopy of High-Redshift Supernovae from the ESSENCE Project: The First 2 Years", Matheson et al. 2005 (2005AJ....129.2352M)

"Hubble Space Telescope Observations of Nine High-Redshift ESSENCE Supernovae", Krisciunas et al. 2005 (2005AJ....130.2453K)

"The ESSENCE Supernova Survey: Survey Optimization, Observations, and Supernova Photometry", Miknaitis et al. 2007 (2007ApJ...666..674M)

"Observational Constraints on the Nature of Dark Energy: First Cosmological Results from the ESSENCE Supernova Survey", Wood-Vasey et al. 2007 (2007ApJ...666..694W)

"Scrutinizing Exotic Cosmological Models Using ESSENCE Supernova Data Combined with Other Cosmological Probes", Davis et al. 2007 (2007ApJ...666..716D)

"Exploring the Outer Solar System with the ESSENCE Supernova Survey", Becker et al. 2008 (2008ApJ...682L..53B)

"Spectroscopy of High-Redshift Supernovae from the ESSENCE Project: The First Four Years", Foley et al. 2009 (2009AJ....137.3731F)

"Light Curves of 213 Type Ia Supernovae from the ESSENCE Survey", Narayan et al. 2016 (2016ApJS..224....3N)

## Overview of Observations

Description of the ESSENCE search fields and supernova candidates can be found in Miknaitis et al. 2007 (2007ApJ...666..674M) and Narayan et al. 2016 (2016ApJS..224....3N).

# Release Content

The spectra were obtained with a 1" slit and the 300V grism (+GG435 filter), yielding a wavelength coverage of ~4350-8950 Å sampled at roughly 2.6 Å/pixel (and resolving power *R* ~ 440). For one SN Ia we obtained two spectra with the 300I grism (+OG590 filter), yielding a wavelength coverage of ~6350-10350 Å sampled at roughly 2.5 Å/pixel (and resolving power *R* ~ 660). Total exposure times (summed across multiple exposures when applicable) are in the range 900-5400s, with a median signal-to-noise ratio in the range ~1-67 per pixel.

We include both the final, wavelength and flux-calibrated 1D spectra as well as the processed 2D spectra (overscan- and bias-corrected, trimmed, flat-fielded, and wavelength calibrated). When more than one spectra of a given object were obtained on a same UT date, we combined them into a single 1D spectrum, weighted by the exposure time.

This release contains a total of 435 FITS files, of which 184 1D spectra and 251 2D spectra. The 184 1D spectra consist of: 143 spectra of 133 individual objects that were identified as possible SN candidates (79 SNe Ia, 23 galaxies, 10 SNe II, 8 AGN, 8 unknown events, 4 SNe Ib/c, and 1 star), 37 spectra of 35 host galaxies (26 SN host galaxies + 8 galaxies not associated with a SN + 1 galaxy associated with an unknown event, E143), and 4 spectra of combined SN+host galaxy signal (in the case of supernovae spectra heavily contaminated by their host galaxy).

# Release Notes

## Data Reduction and Calibration

The 2D spectra were processed using standard IRAF routines. For supernova spectra that were heavily contaminated by the spectrum of the host galaxy, we extracted the 1D spectra using a two-channel iterative technique employing the Richardson-Lucy restoration method outlined in Blondin et al. 2005 (2005A&A...431..757B), and implemented in the IRAF code specinholucy (see Lucy & Walsh 2003; 2003AJ....125.2266L). For all other cases we used the standard "apall" routine in IRAF.

Wavelength units for both the 1D and 2D spectra are Angstroms. However, the 1D spectra have a barycentric correction applied, while the 2D spectrum do not. The flux unit for the 1D spectra is 1e-15 erg/s/cm^2/Å (cf. TUNIT2 and TUNIT3 keywords in the FITS header).

The (relative) flux calibration was performed using our own set of routines written in IDL; these are described by Matheson et al. 2008 (2008AJ....135.1598M). These routines also adjust the wavelength solution using sky emission lines and perform a barycentric correction. We used spectra of standard stars taken during the same night as the science spectrum for the flux calibration.

Finally, we manually remove residual signal from sky lines as well as cosmic rays to generate the final 1D spectrum.

The data reduction methods are described more thoroughly by Matheson et al. 2005 (2005AJ....129.2352M). The final redshifts and spectroscopic classifications for the objects included in this release are available in Table 6 of Narayan et al. 2016 (2016ApJS..224....3N).

## Known issues

As noted in Matheson et al. 2005 (2005AJ....129.2352M), two objects in this release were inadvertently assigned two different internal identifications:

D106 is the same as D009

E142 is the same as D093

Also, the declinations of the following objects were incorrectly reported in Table 6 of Narayan et al. 2016 (2016ApJS..224....3N), due to a simple sign error:

| ID | INCORRECT | CORRECT |
|---|---|---|
| e022 | +00:23:58.180 | -00:23:58.180 |
| e103 | +00:36:43.930 | -00:36:43.930 |
| f247 | +00:31:12.730 | -00:31:12.730 |

The corrected declinations are reported in the FITS header under the keyword DEC.

### Previous Releases

The previous data release (DR2, from 2014) contained 54 1D spectra of 50 individual objects, obtained from 95 2D spectra (149 files in total). All the data from DR2 are included in the present DR3, which includes an additional 130 1D spectra and an additional 156 2D spectra that were inadvertently excluded from DR2 (i.e. an additional 286 files).

## Data Format

### Files Types

For each object spectrum taken on a specific UT date we include both the 1D spectrum as well as the 2D spectrum (or spectra). When more than one spectra of a given object were obtained on a same UT date, we combined them into a single 1D spectrum, weighted by the exposure time. The FITS header contains all the relevant parameters for a given spectrum.

The following file naming convention has been adopted for all the 1D spectra:

ESSENCE_FORS1_<ESSENCE ID>(_SNGAL,GAL,HOST)_<UT DATE>(_300I)_v3.0.fits

where <ESSENCE ID> is the internal ESSENCE object identification (e.g., D033), <UT DATE> is in YYYYMMDD format and "_300I" indicates the spectrum obtained with the 300I grism. "_SNGAL" indicates the spectrum corresponds to the total SN+host galaxy signal, "_GAL" indicates the spectrum is an extraction of the host-galaxy signal only from the 2D spectrum that also includes the SN, and "_HOST" indicates a spectrum of the host galaxy taken after the SN had faded below the detection limit.

For the 2D spectra, files are named according to:

ESSENCE_FORS1_<ESSENCE ID>(_SNGAL,GAL,HOST)_<UT DATE>(_300I)(_A,B,C)_v3.0_2D.fits

where "_A,B,C" indicates multiple spectra of a given object taken on the same UT date.

NOTE: the objects E132(=D093; see note above about "Known issues") and E133 are located on the same 2D frame, at Y-pixel coordinate 59 and 224, respectively; hence the ESSENCE_ID in the associated 2D spectrum is given as E132_E133, and the target coordinates in this 2D spectrum file is set to that of object E132.

## Acknowledgements

When using data products provided in this release, we request acknowledgement of the ESSENCE

Survey and a reference to the relevant publication indicated by the REFERENC keyword in the FITS header. Please also use the following statement in your articles when using these data:

*Based on data products from observations made with ESO Telescopes at the La Silla or Paranal Observatories under ESO programme ID 170.A-0519 and 176.A-0319.*

According to the Data Access Policy for ESO data held in the ESO Science Archive Facility, all users are required to acknowledge the source of the data with appropriate citation in their publications.

Since processed data downloaded from the ESO Archive are assigned Digital Object Identifiers (DOIs), the following statement must be included in all publications making use of them:

- *Based on data obtained from the ESO Science Archive Facility with DOI: https://doi.org/10.18727/archive/22*

Publications making use of data which have been assigned an archive request number (of the form XXXXXX) must include the following statement in a footnote or in the acknowledgement:

- *Based on data obtained from the ESO Science Archive Facility under request number <request_number>.*