ESO Phase 3 Data Release Description

Data Collection	\<LEGA-C\>
Release Number	\<batch880\>
Data Provider	\<Arjen van der Wel, Kai Noeske\>
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Abstract

This is the first data release (DR1) from the LEGA-C (Large Early Galaxy Census) survey. LEGA-C is an ESO Public Spectroscopic Survey of ∼ 3200 K-band selected galaxies at redshifts z = 0.6–1.0 with stellar masses $M_* > 10^{10}$ $M_\odot$, conducted with VIMOS on ESO's Very Large Telescope. This survey covers the 1.6 square degrees of the UltraVISTA survey within the in the COSMOS field (R.A. = 10h00; Dec. = +2 deg), and performs 20-hour long integrations to produce high-S/N (>10/Å) continuum spectra. The VIMOS high-resolution red grating is used in combination with the GG475 order separation filter, which results in a typical wavelength range of ∼ 6300Å – 8800Å at a resolution of R = 2500 and a dispersion of 0.6Å pix^{-1}.

These LEGA-C spectra reveal ages, metallicities and velocity dispersions of the stellar populations. LEGA-C's unique combination of sample size and depth enables for the first time to map the stellar content at large look-back time, across galaxies of different types and star-formation activity. Core science questions are, among others, galaxies' star formation histories, quenching of star formation, evolution of galaxy kinematics and scaling relations. Observations started in December 2014 and are planned to be completed by mid 2018, with early data releases of the spectra and value-added products.

In this release, we provide the data resulting from our first year of observations, totaling 892 galaxy spectra for 865 unique galaxies as well as a catalog that provides survey IDs, coordinates, and redshifts for this first subsample.

Full details about the survey design, sample selection, observing strategy, data reduction, and science goals can be found in the initial LEGA-C survey paper:

"THE VLT LEGA-C SPECTROSCOPIC SURVEY: THE PHYSICS OF GALAXIES AT A LOOKBACK TIME OF 7 GYR": A. van der Wel , K. Noeske, R. Bezanson, C. Pacifici, A. Gallazzi, et al. 2016, ApJS, 223, 29

Overview of Observations

Out of the 32 total masks in LEGA-C, we completed masks 1 through 7 during our year 1 observations; these are the data provided in the present release.

The data presented here were taken during the ESO observing periods 94 and 95, during the runs 194.A-2005(A) to 194.A-2005(F), with the respective date windows: 22 Dec 2014 – 27 Dec 2014, 15 Jan 2015 – 25 Jan 2015, 14 Feb 2015 – 24 Feb 2014, 15 Mar 2015 – 26 Mar 2015, 13 Apr 2015 – 23 Apr 2015, 12 May 2015 – 22 May 2015. Due to visibility constraints, most of these nights were fractional allocations to LEGA-C. Observations were conducted in visitor mode, during dark time periods.

Every mask was observed over 15-20 Observing Blocks (OBs) of 4 individual 900 second to 4 individual 1200 sec exposures each, chosen such that each mask was observed for a total of 20 hours. Occasionally, an OB was repeated due to bad weather conditions. No dithering was applied to avoid severe efficiency costs (factor of several), justifiable by the sufficiently low amplitude of

fringing found in the spectra. Calibrations were obtained in a non-standard manner: again to avoid a severe penalty in survey efficiency, arcs and screen flats were not taken directly after each OB, but at the end of the (partial) night, at the average rotator angles each OB of that night was observed at. Subsequent analysis of the full calibration dataset showed that proximity in time to the science exposures is more relevant to minimize the effects of flexure and hysteresis than the rotator angle, and our strategy was changed to taking calibration exposures ever 2 to 2.5 hours between science OBs.

Constant monitoring of atmospheric conditions and each incoming exposure allowed us to set tight quality constraints on our data. We observed as long as the criterion was met:

Seeing FWHM [arcsec] x atmospheric transmission [fractions of 1, 1 meaning 100%] < 1.3

During sufficiently long time windows where these conditions were not achieved, LEGA-C observations were halted and the telescope handed back to ESO staff to be used for Service Mode programs.

Release Content

- The position and extent on the sky for the first subsample released here as well as each of the VIMOS slitmasks that contributed to this release can easily be inferred from the target coordinates and mask numbers given in the catalog ("legac_DR1.fits"). The masks 1-7 we release cover a rectangular area with RA and DEC ranging from 149.72620 to 150.44659 and 2.0115111 to 2.5393419 degrees, respectively, with one mask missing to complete the full-coverage interlaced pattern (see the survey paper, van der Wel et al. 2016). After consideration of the two 2' N-S direction gaps in the interlaced pattern, this yields a total area of 0.29 square degrees.

- Targets were selected from the UltraVISTA K_s-band catalog (Muzzin et al. 2013, ApJS, 206, 8). Its 3σ source detection limit is 24.35 mag, with a >90% completeness at <23.4 mag. Our primary sample is hence selected from sources >4 mag (factor of 40) brighter than the 3σ limit, and even the faintest objects from the filler samples II & III (see the survey paper) will typically be selected from UltraVISTA sources with a significance well above 20σ. Practically all our targets are also from the brightness range where the K_s-band catalog is >95% complete.

- This release provides 892 individual 1-d spectrum files for 865 LEGA-C target galaxies (some galaxies were observed on more than one mask), as well as a survey catalog with entries for each spectrum (see below under "Data Format"). The total data volume is 91 Mbytes.

Release Notes

Data Reduction and Calibration

Basic Data Reduction, VIMOS pipeline: The raw frames as obtained from the ESO archive were processed through the recommended ESO tools at the time of observation, Reflex 2.7 with the VIMOS pipeline package 2.9.15. The calibration steps this pipeline was employed for were: bias and flatfield correction, slit definition and rectification, wavelength and spectrophometric calibration as well as rejection of cosmic rays. The output data product, for further processing in the next step, were thus-processed 2-dimensional spectra, each for one OB, a co-addition of the 4 subexposures taken within the respective OB.

Custom pipeline: As detailed in the survey paper (van der Wel et al. 2016), the 2-d, OB-wise co-added spectra delivered by the Reflex data reduction process were further corrected and processed using own custom routines. Reasons were 1) the bleeding of bright skylines between slits due to the unavoidably small gaps between slits, 2) flexure leading to small misalignments between science and calibration (screen flat, arc) exposures, 3) the need for accurate sky subtraction for extended objects, 4) the need for optimal S/N-weighed extraction.

Our customized pipeline performs the following steps:
- Error spectra are calculated from the (background+object) flux in the science frames and the read noise level.
- Slit definitions are automatically verified and adjusted.
- The location and spatial extent of the galaxies are measured by fitting a Gaussian in the spatial direction after summing along a 1000 pixel range in wavelength direction. This location is then traced along the entire wavelength range in bins of 100 pixels. For ~10% of the targets in each mask there is insufficient flux to do this, and the location is assumed to be the expected location and independent of wavelength.
- The default model for sky+galaxy is a flat background with a Gaussian profile of a fixed width and location (as measured above). The two free parameters are the amplitude of the Gaussian (the galaxy flux) and the sky background level. This model is fit to each individual wavelength bin, across the spatial direction, weighed by the error spectrum. For areas with high sky levels or large sky level gradients in the wavelength direction (edges of sky lines) a first-order term is added to the background model. This process produces individual extracted galaxy spectra and associated error spectra for each of the individual OBs and each of the individual galaxies.
- Telluric absorption features are corrected for through dividing by normalized blue star spectra.
- Spectra from the individual OBs are then co-added, weighing by the S/N as measured in the observed wavelength range 8030Å – 8270Å, which is relatively devoid of bright sky lines.
- Flux calibration is achieved by comparing with the photometric spectral energy distribution from the UltraVISTA catalog. The best-fitting spectral template (also used to derived stellar mass and rest-frame colors) is fit with a polynomial across the wavelength range covered by the LEGA-C spectra and divided by the polynomial fit to the spectra themselves. This calibration polynomial is divided into the LEGA-C spectra, delivering accurate flux calibrations across the entire wavelength range. See "Known issues" below for notes on the accuracy.

Data Quality

Reduction Quality Control: The output of the custom-made pipeline was visually verified on an OB-by-OB and object-by-object basis. Any problems with the slit definition, tracing, and sky subtraction were identified and, if appropriate, the pipeline rerun. The combined 1D and 2D spectra were verified on an object-by-object basis as well.

Signal to noise: The figure below shows the S/N distribution (as measured at 8000Å in the observed frame) of the 892 targets included in this release (yellow), compared with the expected S/N distribution for the full survey. The S/N ratios satisfy the specifications stated in the survey design and original proposal.

Quality of spectra
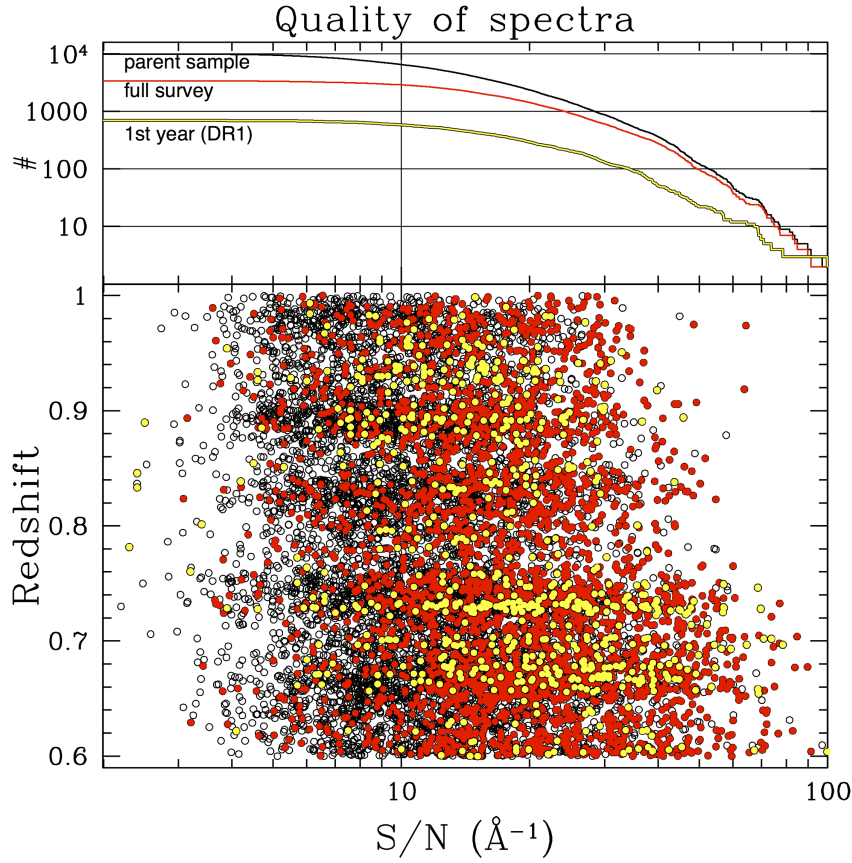
Redshifts: Only 100% secure redshifts based on multiple emission and/or absorption lines, or unique features such as the [OII] 3727Å doublet are included in our catalog. The redshift uncertainties are typically 0.0002, dominated by misalignments between objects and slits (the wavelength calibration is typically accurate and precise to 0.02 Å or better).

Known issues

Object alignment within the slits: During the observations, some acquisition images (through-slit images) taken for the mask alignment showed slight offsets where the galaxies were not perfectly centered within the slits, but offset in dispersion direction (detector y coordinate). Despite careful repeated efforts, a perfect alignment was not always possible for all 4 mask quadrants that have to be simultaneously aligned. A post-hoc extensive analysis of alignment images from three masks revealed a pattern where the alignment of the objects varies relatively smoothly across VIMOS' field of view. This systematic suggests that the source of this issue is not the accuracy of coordinates in our target catalog, but in the accuracy of the optical model in the VIMOS mask design software. The effect amounts to *average* object offsets in dispersion direction of : -0.14 pixels in quadrant 1, +0.23 pixels in quadrant 2, +0.08 pixels in quadrant 3 and -0.35 pixels in quadrant 4, with offsets measured with respect to the positive detector y coordinate (dispersion direction). The standard deviation of object misalignments in detector y coordinate was 0.8 pixels for all quadrants.

This result means that for some galaxies, their PSF is not fully contained within the slit, possibly leading to fractional flux losses that will depend strongly on the galaxy's morphology and light concentration. The resulting slit losses range from 10% to 40% . Since absolute flux calibrations are obtained from broad-band photometry (see "Data Reduction and Calibration"), such losses are mostly compensated for in the calibrated spectra. However, the accuracy of the flux calibration, typically 5% for individual galaxies, may be affected for some sample targets. Because galax-

ies have radial gradients in their spectral energy distribution, both the limited slit width capturing only a part of the galaxy, as well as slight slit misalignments, inevitably introduce wavelength-dependent calibration imperfections in a spectroscopic study.

Previous Releases

N/A

Data Format

File Types

This release contains

- One catalog file (*legac_DR1.fits*), a one-extension FITS bintable, with columns described in the next subsection.
- 892 1-dimensional spectra, containing one galaxy spectrum each, named:

  legac_M[mask number]_[legac target ID]_v1.0.fits

Spectra

The 1-d spectra files hold the spectrum in their sole bintable extension, in four columns:

1. Wavelength, label "WAVE", unit Å, format 4-byte FLOAT
2. Flux, label "FLUX", unit 10^{-19} erg s^{-1} cm^{-2} Å^{-1}, format 4-byte FLOAT
3. Flux error, label "ERR", unit 10^{-19} erg s^{-1} cm^{-2} Å^{-1}, format 4-byte FLOAT – *see note!*
4. Quality flag, label "QUAL" (no unit), format 2-byte INTEGER – *see note!*

   *Note on **flux error and quality flag**:* Some elements in the "error" column are set to zero. This does NOT indicate a very small error, but means that this element should be excluded from further analysis. Such elements show a large 2nd derivative in the 1d spectrum, too large to be explained by spectral features or random noise, which typically indicates the presence of a systematic imperfection in the sky subtraction at that location.
   For such elements, the "quality flag" is set to 1.

   Note on the **FITS keyword "SNR"** in the primary header: Signal-to-Noise values are calculated as the weighted mean for all pixels with non-zero weight. Six objects have been assigned SNR = 0, as the total Signal-to-Noise was measured to be consistent with 0.

Catalogue Columns

The catalog "*legac_DR1.fits*" contains for each spectrum in this first release the target galaxy's LEGA-C object ID, the number of the mask containing the object, RA and DEC as well as the redshifts measured from the LEGA-C spectra. These values are given in the file's sole bintable extension, with columns as follows:

1. LEGA-C target ID, label "OBJECT", no unit, format: 4-byte LONG INTEGER
2. LEGA-C Mask number + target ID as unique spectrum identifier (since some objects were observed on more than one mask), label "SPECT_ID", no unit, format: ASCII string
3. Right ascension (J2000.0), label "RAJ2000", unit degrees, format 8-byte double precision FLOAT
4. Declination (J2000.0), label "DECJ2000", unit degrees, format 8-byte double precision FLOAT
5. Redshift, label "z", no unit, format 4-byte FLOAT

6. Filename of the 1-dimensional spectrum file belonging to the target listed in the current row.

Acknowledgements