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ESPRESSO Science Verification

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ESPRESSO Science Verification took place at the end of August and the beginning of September 2019. It was spread over two visitor-mode nights, requiring seven hours of observations taken in service mode. The weather conditions (strong winds and poor seeing conditions) and some telescope problems (failure of guide cameras) hampered the first two nights and additional time was granted to finish the top-ranked programmes. In response to the call for ESPRESSO science verification, 16 proposals were submitted, 10 of which were scheduled for a total of 25 hours of observations. A slight oversubscription of the available time was planned to allow for the prevailing atmospheric conditions. The seven top-ranked programmes were fully completed.

Proposal solicitation and submission

ESPRESSO is offered with one VLT Unit Telescope (1-UT mode) or with all 4 Unit Telescopes (4-UT mode) combined. ESPRESSO has already been offered in 1-UT mode since Period 102 (October 2018) and a call for ESPRESSO science verification proposals with the 4 UTs combined was issued on 14 June 2019[1,2] offering 2 observing nights. Alongside the call, the ESPRESSO science verification webpage[3] was launched and 16 proposals were received by the deadline on 5 July 2019, requesting a total of 32.3 hours.

The science verification team ranked the proposals according to scientific merit. Ten projects were selected for a total of 25 hours of execution time, which resulted in an oversubscription of the available time by about 25%. Proposers were informed of the outcome of the selection on 22 July 2019 in time to meet the Phase 2 deadline on 31 July.

The proposed science cases covered a wide range of topics, including the observation of the most massive star in a distant dwarf galaxy, the detection of water in an outgassing comet from the main asteroid belt, the characterisation of an exoplanet atmosphere during a transit, measuring the chemical composition of a turnoff star in a globular cluster, an attempt to measure the fine-structure constant at high redshift, observations of potential stimulated (laser) emission in a distant galaxy, the first measurement of the ^{12}C:^{13}C ratio in a low-metallicity damped Lyman-α system, and the detection of ^{6}Li in a star in the SMC.

Observations

The ESPRESSO science verification nights were scheduled on 26 and 27 August 2019. The first night was severely affected by inclement weather (high winds), which resulted initially in pointing restrictions and subsequently closure of the domes. The second night started with pointing restrictions and a seeing of 1.5 to 2 arcseconds. The acquisitions proved to be more time consuming than expected owing to the faintness of the science targets. Owing to a technical problem, one UT could not be used, and so the observations continued with three telescopes, the exposure times being adjusted accordingly for some programmes. Despite these problems four programmes could be completed. Owing to the significant loss of observing time the observatory granted another 7 hours of observing time in early September. Data for three additional programmes could be acquired under excellent conditions over the following nights so that 7 out of 10 scheduled programmes could be completed. The ESPRESSO science verification page provides information on the completed programmes and links to the archived data.

Archive and data processing

All raw data are publicly available through the ESO science archive. The ESPRESSO science verification webpage has been updated with direct links to the raw data in the archive. Pipeline-reduced data (version 1.4.2) were also provided, and are linked from the ESPRESSO science verification webpage. The current ESPRESSO pipeline release is version 2.2.1[4]. Some of the data presented below were reduced with the ESO Data Reduction Software (DRS) (Sosnowska et al., 2015) and analysed with the Data Analysis Software (DAS) specifically developed for ESPRESSO (Cupani et al., 2019).

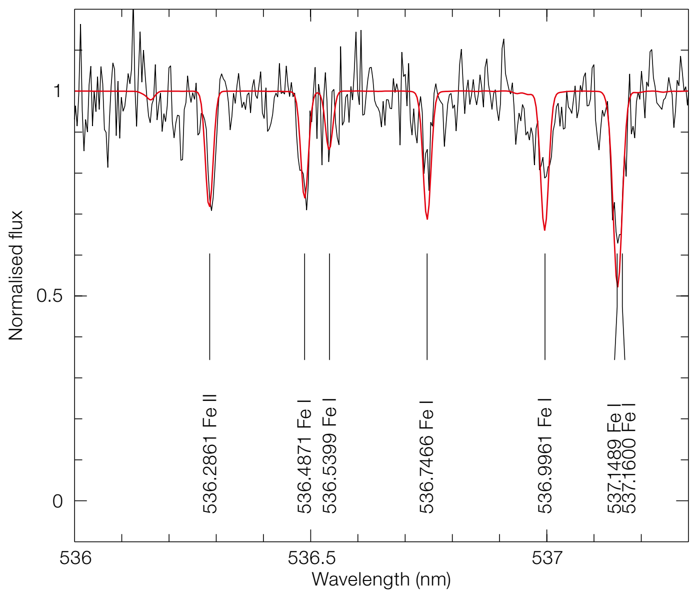

Figure 1. Details of the ESPRESSO spectrum of a blue straggler in the globular cluster Pal12 compared to the MyGIsFoS (Sbordone et al., 2014) analysis. The best fitting synthetic spectrum is shown in red.

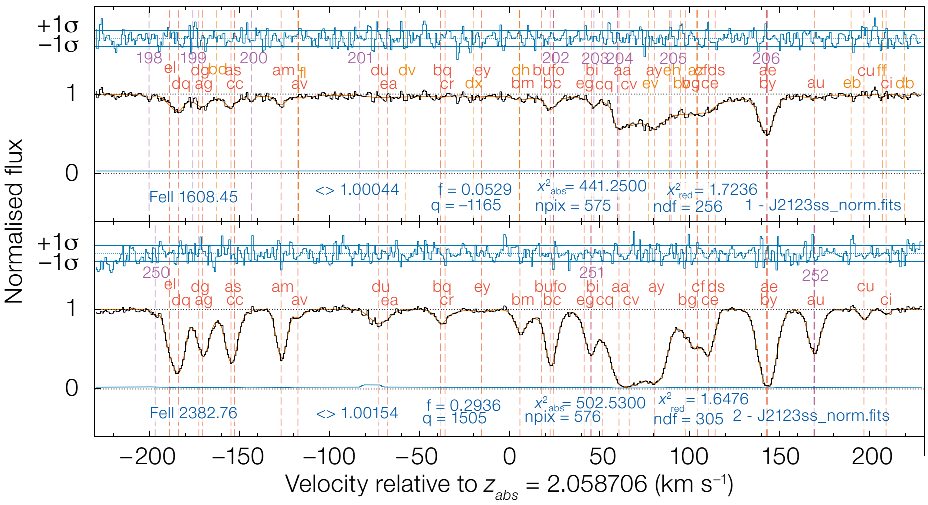

Figure 2. Details of the ESPRESSO spectrum of a sub-damped Lyman-α system. Many suitable transitions are detected in an absorption complex spanning about 400 km s^{-1}. The Fe II transitions falling within the spectral range covered by the 4-UT ESPRESSO data include lines at 1608, 2344, 2374, 2383 and 2600 Å. The figure shows two of these, 1608 Å and 2383 Å. Illustrated along with the 1608-Å profiles are the interesting broad CIV 1550-Å features modelled by Hamann et al. (2011) as outflows from the quasar. Since wavelength calibration makes use of the laser frequency comb, one of the major sources of systematic errors in this sort of study is eliminated. Preliminary results, solving for α, indicate an overall error budget at around the 10^{-6} level, making this one of the most precise measurements of α to date.

Science results

Chemical composition of an extragalactic turnoff star

A blue straggler in the globular cluster Pal 12 was observed. This solar-mass star is close to the main-sequence turnoff of this globular cluster in the Sagittarius dwarf galaxy. It represents the best chance to observe a bona fide extragalactic low-mass star with known age and metallicity. A debate is ongoing as to whether blue stragglers are formed by collision or by fusion of two stars and it should be possible to distinguish between these possibilities by measuring the Li abundance, which is expected to be around A(Li) = 1.0 for collisions and fully depleted in the case of a merger.

This programme aimed to obtain abundances for a star of $V \approx 19.1$ to demonstrate the potential of the 4-UT mode for faint star spectroscopy. Sky subtraction is essential to derive precise abundances at these magnitudes. However, the sky spectra collected on fibre B were found to be contaminated by another source. This is a problem in crowded fields: during one exposure, the field rotates and the sky fibres draw an arc in the sky so they may get contaminated by nearby sources. The geometry of each telescope is different, so it may happen that only one telescope contributes to the contamination. Thanks to this observation, a tool has been now added in the finding charts generator that shows the partial circle "observed" by the ESPRESSO sky fibre, so the user can check that no objects overlap with it.

The signal-to-noise ratio per integrated pixel in the fully reduced data is ~ 23 in the Li 6708-Å region, which is adequate to derive abundances for several elements (see Figure 1). Unfortunately, the upper limit on the Li abundance is not low enough to decide on the blue straggler mechanism formation, but other element abundances and their comparison with the abundances obtained in giants of the same cluster will nevertheless provide interesting results.

Disappearance of a luminous blue variable

Massive stars in low-metallicity environments are very interesting and may be linked to different types of supernovae. The metal-poor dwarf galaxy PHL 293B hosted a luminous blue variable star, for which ESPRESSO was supposed to provide a detailed spectral analysis. The proposers hoped to determine luminosity, effective temperature, surface abundances and wind parameters for this object in a low-metallicity environment. As it turned out the signature of the luminous blue variable — broad hydrogen lines from the wind — had disappeared at the time of the observations in August

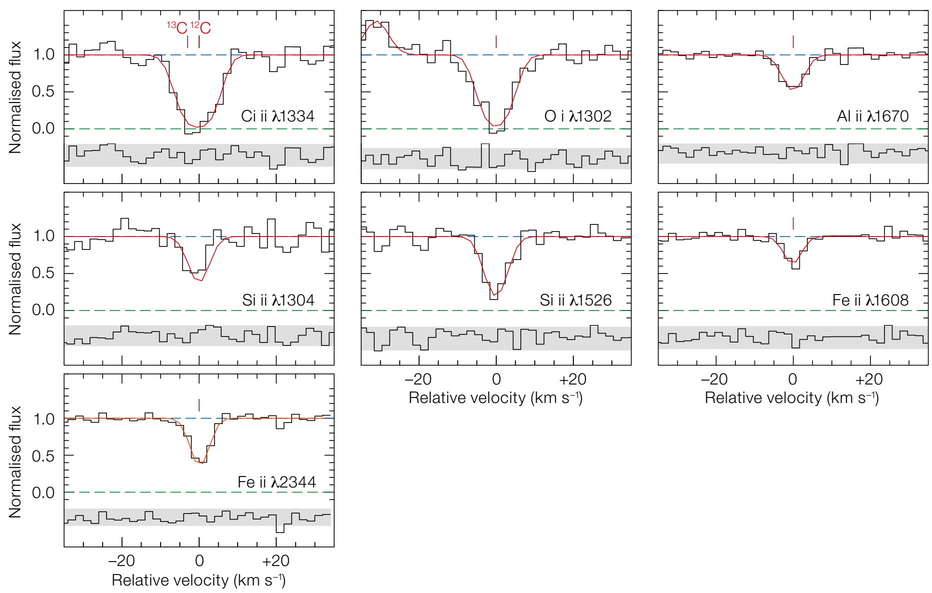

Figure 3. Line fits to various absorption lines in the DLA (z = 2.34) towards J0035-0918. The rest-frame wavelengths are indicated by red tick marks. From Welsh et al. (2020).

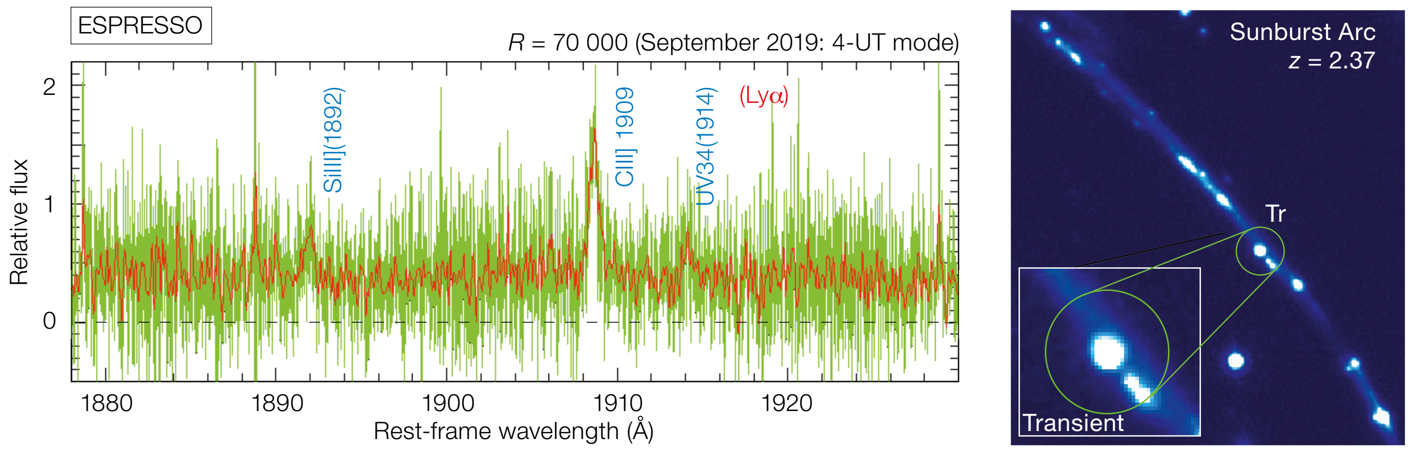

Figure 4. The left panel shows the one-dimensional spectrum obtained with ESPRESSO (green, R = 70 000) and the smoothed version (red, R = 7000). Three lines are indicated, SiIII]1892, CIII]1909 and the faint fluorescent iron line at 1914 Å as part of a group of lines known as UV34. The 1914-Å line is generated by Lyman-α pumping radiation. The right panel displays the HST ACS/F814W image of the lensed arc, with the inset zooming in on the region of the transient Tr observed with ESPRESSO (the green circle corresponds to 1 arcsecond in diameter), while the boxes are 9 arcseconds across. From Vanzella et al. (2020b).

2019 (Allan et al., 2020). A quick double-check with X-shooter was requested and confirmed the disappearance of the luminous blue variable features. This led to the conclusion that the star was in a luminous blue variable outburst in the first decade of this century but that the outburst must have ended after 2011, as deduced from archival data. This was the first time such an event had been found in a low-metallicity galaxy. Possible interpretations include that, after the eruption, the star shifted to a higher temperature, that it suffers dust obscuration or that the star collapsed directly to a black hole without a supernova display. High-resolution imaging to determine the current brightness of the star should provide information that will make it possible to decide between these possibilities.

Fundamental constants

One of ESPRESSO's key scientific goals is to measure the variation of fundamental constants, and if they change in time or spatially. A sub-damped-Lyman-α (DLA) system at z = 2.059 shows well-separated absorption components. The individual components appear strong yet unsaturated and are ideal for a measurement of $\Delta\alpha/\alpha$ promising to provide a strong new constraint on any change. Figure 2 shows part of the high-signal-to-noise spectrum around two Fe absorption lines.

$^{12}C/^{13}C$ molecular ratio at high redshift

The formation of elements proceeds via stellar enrichments. Depending on the enrichment source, different values of the ratio of the two carbon isotopes ^{12}C and ^{13}C are expected. For example, supernovae from massive stars of the first generation of stars (Population III) will mostly produce ^{12}C, while evolved stars on the asymptotic giant branch (a later Population II) will have a higher fraction of ^{13}C. The isotopic wavelength shift for two carbon transitions at 1334 Å is only 0.013 Å, corresponding to a relative velocity shift of 2.99 km s^{-1}. To measure such a tiny wavelength offset, very high spectral resolution and a high signal-to-noise ratio are required — an ideal case for ESPRESSO combining the light of all four UTs. Figure 3 (from Welsh et al., 2020) shows absorption lines from a damped-Lyman-α system at a redshift z = 2.34. This system was chosen because it appears to be one of the most pristine gas clouds known at high redshift. The individual lines are well fitted by models of a single line. The ratio $^{12}C/^{13}C$ is best fitted with $\log(^{12}C/^{13}C) = 1.15 \pm 0.65$ and a 2σ upper limit for this ratio was found to be $\log(^{12}C/^{13}C) > 0.37$. This ratio is not quite tight enough to distinguish between the possible enrichment models. Interestingly, the star formation can be determined to have started only about 1 Gyr after reionisation of the Universe and star formation was quenched by heating of the interstellar medium. The data were of sufficiently high signal-to-noise to provide an upper limit on the variation of the fine-structure constant, one of the main scientific goals of ESPRESSO.

Space foam

Space is generally assumed to be a continuum, but some models of quantum gravity predict that it may have a "frothy" structure. Such models involve a change in the characteristics of an emitted photon — for example, its energy — as it travels through space. A monochromatic light source would gradually disperse as a result of space-time fluctuations. Since these effects are predicted to be tiny, long distances must be probed. ESPRESSO observations were used to investigate the narrow Fe II 1608-Å line in a DLA at z = 2.34, corresponding to a comoving distance of 5.8 Gpc (Cooke et al., 2020). The critical measurement is the broadening of the line caused by space foam effects. For the line broadening, the thermal energy dominates and hence a line from an element with a high atomic number is favoured. At the same time, the effect depends on the ratio between distance and wavelength, and the shortest available wavelength of a heavy element is best suited to this measurement — hence the choice of the Fe II ultraviolet line. The limits derived from the high signal-to-noise ESPRESSO spectrum are promising but not yet competitive with imaging point sources at the highest observed energies.

Lensed transient at $z = 2.37$

ESPRESSO was used to observe a strongly lensed peculiar stellar transient at cosmological distance $z = 2.37$ hosted in the highly magnified Sunburst arc (Vanzella et al., 2020a; Rivera-Thorsen et al., 2019).

The target, indicated by the letters "Tr" in Figure 4, is very faint (around 21 magnitudes) for a high-resolution spectrograph and was observed at an airmass of 1.7. The wavelength-calibrated, sky-subtracted, optimally extracted spectra of the orders produced by the DRS were combined by the DAS into a spectrum of remarkable quality, in which the continuum is detected at a signal-to-noise around 3 (per resolution element) together with several emission lines at signal-to-noise around 3–10 (see Figure 4). The exact nature of the transient is still under investigation to determine where it may fit among the possible categories of supernovae (Vanzella et al., 2020b). Fluorescence emission from iron is detected as the result of possible interaction among the circumstellar material and the explosion event.

Summary

The capabilities of the ESPRESSO 4-UT mode have been amply demonstrated by the presented projects. Four refereed papers have already been published showcasing new results, and they demonstrate the scientific interest this new VLT facility fosters.

Acknowledgements

We received excellent support at the telescope from the Telescope and Instrument Operators. They accommodated additional science verification observations flexibly to conclude as many programmes as possible after the first night was lost to inclement weather. We would like to thank the following Principal Investigators who kindly provided the preliminary science verification results presented in this article: Luca Pasquini and Piercarlo Bonifacio, José Groh, Ryan Cooke and Louise Welsh, Eros Vanzella, and John Webb, Dinko Milakovic and Vincent Dumond.

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Links

[1] Science announcement of the ESPRESSO Science Verification: http://www.eso.org/sci/publications/announcements/sciann17215.html
[2] Announcement of the ESPRESSO Science Verification in the Science Newsletter: https://www.eso.org/sci/publications/newsletter/jun2019.html
[3] ESPRESSO Science Verification website: http://www.eso.org/sci/activities/vltsv/espressosv.html
[4] Latest ESPRESSO pipeline release: http://www.eso.org/sci/software/pipelines/espresso/espresso-pipe-recipes.html

Y. Beletsky (LCO)/ESO

A panorama of the VLT platform with distinctive red airglow visible overhead.