Main High-Resolution Near-IR Spectrometer for the VLT

N. Piskunov

Uppsala University, Uppsala, Sweden; nikolai.piskunov@physics.uu.se

Abstract. We present the ongoing CRIRES+ project on the development of a cross-dispersed high resolution near-infrared spectrometer for the ESO Very Large Telescope. The presentation highlights the relation between science objectives, technical solutions, and the structure of the project. We also share some of the insights on the implementation and management of the project that are crucial for keeping the tight time-line through efficient interaction between consortium members.

1. The Original CRIRES Instrument

The CRIRES+ project is the upgrade of the ESO workhorse instrument CRIRES that was decommissioned in 2014 after serving nearly 10 years to the European astronomical community. CRIRES stands for CRyogenic InfraRed Echelle Spectrograph. It was part of the VLT suit of instruments covering the near-infrared domain (Y to M bands) at high resolution \( R = 100,000 \). High resolution is achieved with the help of a dedicated adaptive optics system that helps squeezing most of the light through the entrance slit. The original CRIRES was a single-order instrument with a filter system used to select the corresponding wavelength range in pre-dispersion unit. The down-sides were short wavelength coverage, infinite number of setting with poor stability and variable quality wavelength calibration. The detector array consisting of four Aladdin 1K×1k devices was not of good quality with modest quantum efficiency, high dark current and poor cosmetics.

Despite of all shortcomings, CRIRES was extremely successful and produced several ground-breaking results. For example, Snellen et al. (2010) using transiting spectroscopy found the presence of CO in the atmosphere of an exoplanet orbiting HD 209458. Spectroastrometry in the rovibrational band of CO at 4.7 micron allowed Pontoppidan et al. (2014) to study gaps in protoplanetary discs reaching spatial resolution of less than 1 AU at distances of 50–100 pc.

2. The Upgrade Project

In 2012 consortium consisting of Uppsala University, Tautenburg Landessternwarte, Institute for Astrophysics of Göttingen University, and INAF at Florence proposed to upgrade CRIRES optimizing it to a few interesting science cases in return for a fair amount of guaranteed observing time. The detailed description of the upgrade was presented in Follert et al. (2014). The top three in the list of science cases are: (1) char-
acterization of the atmospheres of planetary companions around cool stars, (2) search for exoplanets around cool stars, and (3) origin and evolution of stellar magnetic fields.

2.1. Exoplanetary Atmospheres

Detection and characterization of exoplanetary atmospheres using transit spectroscopy is not a new idea. The problem is that today we do not have an instrument to reach the earth-size planets even those orbiting M-dwarf stars. CRIRES was successfully used to study the atmospheres of gas giants both in transmission and reflection detecting such important molecules as CO, water and methane. CRIRES covers the wavelengths with distinct spectral features of many important atmospheric species. The resolution is sufficiently high to "see between" the telluric lines and an 8m telescope photon collecting power allows achieving sufficient signal-to-noise ratio. To make CRIRES fully suitable for exoatmospheric research we need much larger wavelength coverage in a single exposure, better stability and repeatability, more homogeneous wavelength calibration and higher throughput.

Recently we have come up with a novel method for extracting the transmission spectrum from a sequence of transmission spectra (Aronson et al. 2015), demonstrated its performance using the data collected with the original CRIRES and predicted what can be achieved with the proposed improvements.

2.2. Search for Exoplanets around Cool Stars

There is currently a consensus that the most suitable targets for characterization of the earth-size planets are planetary systems around M dwarfs. The habitable zone corresponds to shorter orbits permitting to observe several transits per year, planet-to-star size ratio is larger etc. Ongoing and planned transit surveys like MEarth (Berta et al. 2013), TESS (Ricker et al. 2015), and Euclid (http://sci.esa.int/euclid) will produce large numbers of candidates even among sufficiently bright (for an 8m telescope) stars in the solar neighborhood. Verification of the radial velocity (RV) measurements with the optical spectrometers remains problematic: most of the specialized RV instruments are installed on 2.5–3.5m telescopes incapable of reaching 15–17 magnitude targets. This is a broader case even for 10m telescopes that are forced to use absorption gas cell to obtain simultaneous wavelength reference. The only instrument marginally capable of reaching these target in the optical is the VLT ESPRESSO (Pepe et al. 2010), but it can reach only a limited number of targets. CRIRES+, on the other hand, will easily perform RV measurements provided that its stability is improved, the wavelength coverage is extended, and there is a possibility for gas cell calibrations. This is due to the collecting area of the UT telescope and the fact that M dwarfs become 2–3 magnitude brighter in the near infrared.

2.3. Magnetic Fields of Cool Stars

Recent measurements of light polarizaion for solar-type stars demonstrated the possibility of reliably detecting global magnetic fields of a fraction of 1 Gauss, similar to ones observed on the Sun. It was even possible to see the rotational modulation of the field and reconstruct its surface distribution using magnetic Doppler Imaging technique (Rosén et al. 2015). Extending such studies to the late M dwarf domain is a very interesting task as it opens possibilities to provide observation constrains on dynamo action in these objects (that is supposed to be qualitatively different from the Sun) and to estimate the level of stellar activity experienced by exoplanets in habitable zones of such
stars. To achieve these goals CRIRES must be equipped with an infrared polarimeter unit with high sensitivity, compatible with the adaptive optics system operating at the visible wavelengths. The polarimeter must work over a large wavelength range to allow using line combining technique, such as LSD (e.g., Kochukhov et al. 2010).

Figure 1. Spectral format of CRIRES+ in comparison with old CRIRES (marked in the fourth order from the bottom).

2.4. The Upgrade Plan

Based on the requirements derived from the science cases the new CRIRES+ needs to have a cross-dispersion, a new calibration system, a polarimeter, new detectors and new data reduction pipeline. Several of the proposed technical solutions deserve a closer look.

The mosaic of three 2k×2k Hawaii 2RG detectors covers in a single exposure each of the Y, J and H bands. The K band needs two exposures with rotation of the echelle. The M band is covered in four exposures. The new mosaic is much tighter leaving gaps of only 5 pixels between the detectors. The new vacuum clamping mechanism was implemented for both echelle and cross-disperser dramatically improving the stability and repeatability in the focal plane (Lizon et al. 2014). Large wavelength coverage allows selecting a fixed number of standard settings while clamping reproduces the setting within 0.2 pixel. Cross-dispersion and detector mosaic increase the wavelength coverage in single exposure by a factor of 10 (Fig. 1), and the throughput by a factor of 2.
The polarimeter unit (Lockhart et al. 2014) is part of the warm calibration system and as such it is located directly in front of the Nasmyth focus of the telescope. This has an advantage of minimum instrumental polarization (the tertiary mirror of the telescope introduces only broad-band linear polarization that is removed by data reduction) but it makes the AO system see the target through the polarimeter compromising its performance. An elegant solution was found by constructing the beam-splitter using polarizing gratings (PG). This transmission device deflects left and right circular polarizations in opposite directions similar to spectral orders of a diffraction grating. This property of a PG is wavelength dependent: deflection occurs only for the wavelength longer than the period of PG pattern. For shorter wavelengths PG is a transparent glass plate. Thus we the conventional operation of the AO is achieved by matching the the PG period to the cut-off wavelength of the dichroic window of CRIRES+.

The new wavelength calibration system (Seemann et al. 2014) includes two gas cells for imprinting the reference into the target spectrum and a Fabry–Pérot etalon. The latter provides homogeneous wavelength calibration making the maximum error of the wavelength scale across the whole image (10 spectral orders) very close to the mean error.

The upgrade work was distributed between the four consortium partners and spread in time: the long-lead items, such as detectors and cross-dispersion gratings, were ordered even before the final design review in May 2016. At the moment of writing all the components of the cross-dispersion have been produced and assembled, the components of the calibration system and the polarimeter were ordered or delivered. They will be assembled and tested before integration of the whole instrument in the ESO headquarters in Garching. The preliminary acceptance is planed for May 2017 followed by the transportation to Paranal in the end of 2017. The commissioning is is scheduled for the first half of 2018 and normal operation will start in the 2nd half of the same year.

Acknowledgments. The author would like to thank the Knut and Alice Wallenberg Foundation for generous support of the CRIRES+ project and my colleagues in the CRIRES+ Consortium for making it happen.

References