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The "+" for CRIRES: enabling better science at infrared wavelength and high spectral resolution at the ESO VLT

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ABSTRACT

The adaptive optics (AO) assisted CRIRES instrument was a IR (0.92 - 5.2 μm) high-resolution spectrograph in operation from 2006 to 2014 at the Very Large Telescope (VLT) observatory. CRIRES was a unique instrument, accessing a parameter space (wavelength range and spectral resolution) up to now largely uncharted. It consisted of a single-order spectrograph providing long-slit (40 arcsecond) spectroscopy with a resolving power up to $R=100\,000$. However the setup was limited to a narrow, single-shot, spectral range of about 1/70 of the central wavelength, resulting in low observing efficiency for many scientific programmes requiring a broad spectral coverage. The CRIRES upgrade project, CRIRES⁺, transforms this VLT instrument into a cross-dispersed spectrograph to increase the simultaneously covered wavelength range by a factor of ten. A new and larger detector focal plane array of three Hawaii 2RG detectors with 5.3 μm cut-off wavelength will replace the existing detectors. For advanced wavelength calibration, custom-made absorption gas cells and an etalon system will be added. A spectro-polarimetric unit will allow the recording of circular and linear polarized spectra. This upgrade will be supported by dedicated data reduction software allowing the community to take full advantage of the new capabilities. CRIRES⁺ has now entered its assembly and integration phase and will return with all new capabilities by the beginning of 2018 to the Very Large Telescope in Chile. This article will provide the reader with an update of the current status of the instrument as well as the remaining steps until final installation at the Paranal Observatory.

Keywords: astronomical instrumentation, infrared spectrographs, high spectral resolution, upgrade of existing VLT instruments, infrared spectrometers, wavelength calibration, radial-velocities, extra-solar planets

1. INTRODUCTION

High-resolution infrared (IR) spectroscopy plays an important role in astrophysics from the search for exoplanets to cosmology. The majority of currently existing IR spectrographs are limited by their small simultaneous wavelength coverage. The scientific community has recognized the need for large wavelength range, high-resolution IR

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spectrographs, and several are currently either in the design, integration phase or at the telescope. Examples are ISHELL (Rayner et al., 2013) at the NASA Infrared Telescope Facility, SPIROU (Delfosse et al., 2013) for the Canada France Hawaii Telescope (CFHT) and CARMENES for the Calar Alto Observatory (Quirrenbach et al., 2012).

The adaptive optics (AO) assisted CRIRES instrument, previously installed at the Very Large Telescope (VLT), was an IR (0.92 - 5.2 μm) high-resolution spectrograph which was in operation since 2006. CRIRES was a unique instrument, accessing a parameter space (wavelength range and spectral resolution), which up to now was largely uncharted, as described in Käufel et al. (2004) and for the AO system by Paufique et al. (2004). In its setup, it consisted of a single-order spectrograph providing long-slit (40 arcsecond) spectroscopy with a resolving power up to $R=100\,000$. However the setup was limited to a narrow, single-shot, spectral range of about 1/70 of the central wavelength, resulting in low observing efficiency for many modern scientific programmes requiring a broad spectral coverage. By introducing cross-dispersing elements and larger detectors, the simultaneous wavelength range can be increased by a factor of ten with respect to the old configuration, while the total operational wavelength range can be preserved (see Figure 1).

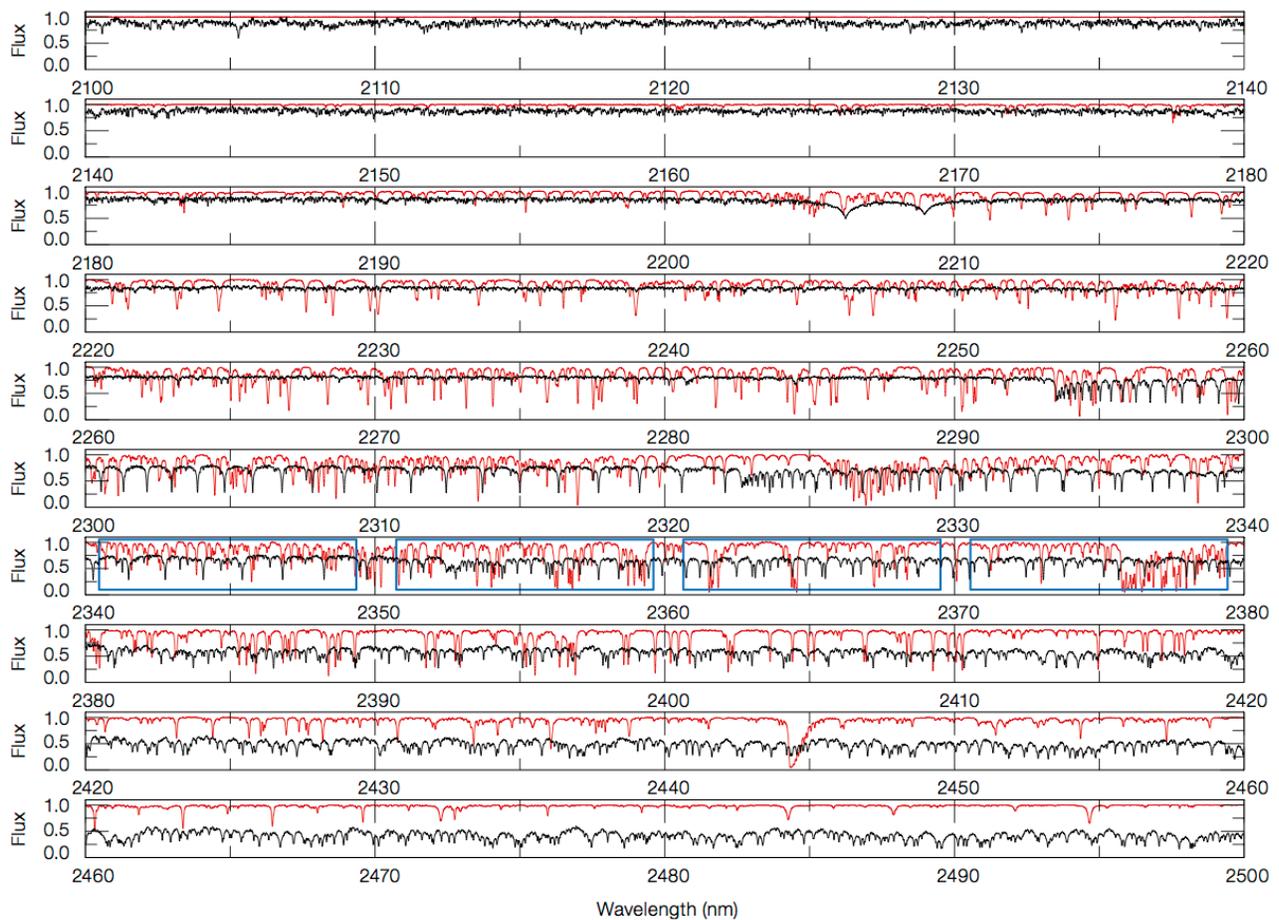


Figure 1 The wavelength coverage of the old CRIRES (blue boxes correspond to the four Aladdin detectors) in the K -band compared to the expected coverage of a single exposure from CRIRES^{*}. The black line shows the spectrum of an M4 dwarf star ($\sim 0.15 M_{\text{sun}}$) and the red line is a laboratory spectrum of the first gas cell prototype being developed at the University of Göttingen.

2. SCIENCE DRIVERS

2.1 A search for super-Earths in the habitable zone of low-mass stars

A large fraction of all exoplanets has been discovered primarily through radial velocity (RV) measurements. However, only 5% of the planets detected so far orbit stars with stellar masses less than about $0.5 M_{\text{sun}}$. Thus, we lack key knowledge about the process of planet formation around the most numerous stars in our galaxy – M dwarfs. Low mass stars are especially interesting because these objects are cool and the habitable zones are quite close to the star. The reflex motion of an M star ($0.15 M_{\text{sun}}$) with a $1 M_{\text{Earth}}$ planet in its habitable zone is about 1 m s^{-1} . Since M dwarfs and brown dwarfs have low effective temperatures, radiating most of their energy in the IR (1.0 - 2.5 μm), a high-resolution IR spectrograph is therefore ideal for searching for low mass planets around these objects. A new gas absorption cell to provide a stable wavelength reference as well as the increase in wavelength coverage by about a factor of ten should result in an attainable RV precision for CRIRES⁺ of 2-3 m s^{-1} . This would enable the detection of super Earth-mass planets in the habitable zone of an M-dwarf star in the Solar Neighbourhood.

2.2 Atmospheric characterization of transiting planets

In-transit spectroscopy of exoplanets currently provides us with the only means of studying exoplanetary atmospheres. Transiting planets are almost always close-in planets that are hot and radiate most of their light in the IR. Furthermore the IR is a spectral region where lines of molecular gases like CO, NH₃, CH₄, etc. are expected from the exoplanetary atmosphere. This important wavelength region is covered by CRIRES⁺, which will additionally allow tracking multiple absorption lines simultaneously.

2.3 Origin and evolution of stellar magnetic fields

Magnetic fields play a fundamental role in the life of all stars: they govern the emergence of stars from proto-stellar clouds, control the in-fall of gas onto the surfaces of young stars and aid the formation of planetary systems. Measurements of magnetic fields have mostly been confined to A- and B-type stars, so our knowledge of magnetic fields in Sun-like stars, and the low end of the main sequence, is still poor. CRIRES⁺ will make it possible to measure with greater accuracy magnetic fields in M-dwarfs and brown dwarfs for several reasons:

1) The Zeeman splitting of a spectral line is proportional to λ^2 , so there is a huge leverage in going to the IR; 2) For cool objects most of the flux is in the IR so there is also a gain due to the increased signal-to-noise ratio. 3) In order to disentangle Zeeman broadening from other broadening effects one must compare the broadening of Zeeman sensitive lines to magnetically insensitive lines. The large wavelength coverage of CRIRES+ will include many more lines of different magnetic sensitivities needed for an accurate determination of the field strength. 4) The capability of CRIRES⁺ to take circular and linear polarized spectra will support these measurements.

3. THE “+” FOR CRIRES

Many astrophysical applications will benefit significantly from the increase in wavelength coverage introduced by turning CRIRES into a cross-dispersed echelle spectrograph. The CRIRES upgrade project improves the instrument by either refurbishing or replacing subsystems. Furthermore, it is planned to add subsystems providing additional observing modes. The project identified the following upgrades as significantly impacting the scientific capabilities of CRIRES. The main drivers for this upgrade and the initial designs are described in articles by Dorn et al. and Follert et al. (2014).

3.1 Transform CRIRES into an cross dispersed echelle spectrograph

To cover the additional orders the spatial extent of the main slit was reduced from 40 to 10 arcseconds, providing a balanced compromise between cross-dispersion implementation and catering for the current CRIRES long slit usage. The cross-dispersion of the spectrum will be performed by the use of reflection gratings. The optical layout of the new design is shown in Figure 2. Six gratings are foreseen, mounted on a cryogenic wheel. Each of them is optimized for operation in a single wavelength band (*Y*, *J*, *H*, *K*, *L* and *M*). Another wheel will carry order-sorting filters to eliminate contamination by second- and higher- order spectra of the gratings. The re-imaging of the slit is then performed by a fixed-lens camera, designed for the full wavelength coverage and used for all observing modes. In this configuration, the observing modes will require only one exposure to cover the full *Y*-band, two exposures, with different echelle angles, for the *J*- and *H*-bands, three exposures for the *K*-band, four for the *L*- and five exposures are needed to cover the *M*-band. A new optical design for the slit viewer will complement the new pre-optics unit. Overall the new design will maintain the current

throughput of CRIRES (with the goal of increasing it) and the spectral resolution of 50,000 and 100,000, as before. The slit length (10 arcseconds) will not limit observations of moderately extended sources and will allow nodding for precise background subtraction.

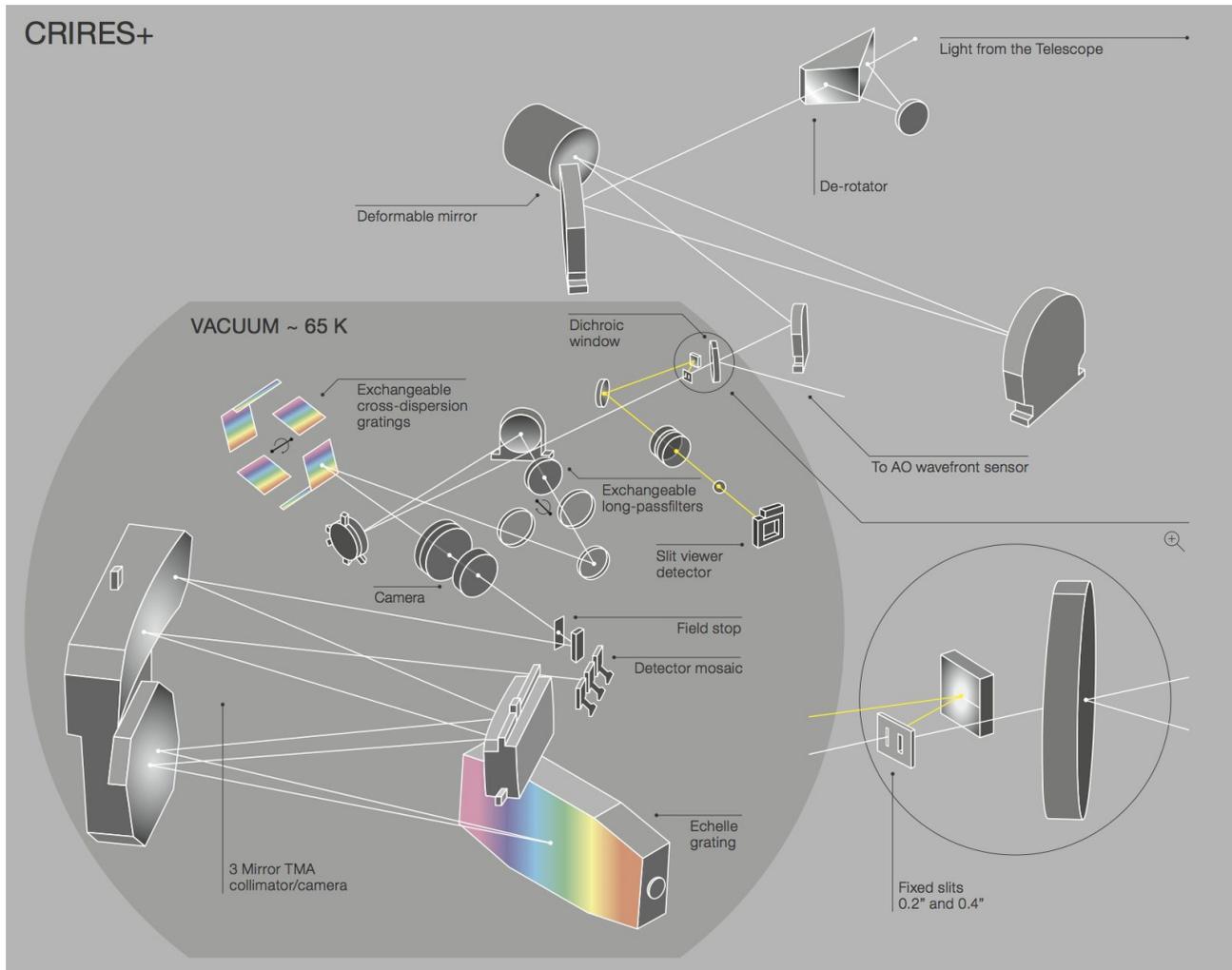


Figure 2 The optical design of the new cross-dispersion pre-optics is shown.

A basic summary of the new and main instrument parameters is given below:

spectral resolution	50,000 and 100,000
wavelength coverage	0.95 - 5.3 μm YJHKLM bands
RV precision	2-3 m/s
slit length	10 arcseconds
slit width	0.2 and 0.4 arcseconds
polarimetry	linear + circular (YJHK bands)
adaptive optics	60 actuator curvature sensing (MACAO)
cross-disperser	6 gratings

3.2 Optomechanical design of the new pre optics unit

The fore-optics of the original CRIRES will be completely renewed as shown in Figure 3. It is replaced by an off-axis parabola, which creates a collimated beam with a diameter of 50 mm, followed by two flat mirrors with distances and angle adjusted to match the new fore-optics with the already existing three-mirror anastigmat (TMA) relay optics and the echelle grating which will remain from the original CRIRES. A new entrance slit (A) will be implemented at a location just before the entrance window. The entrance window is a dichroic reflecting visible light for the adaptive optics system. Light not passing the entrance slit is reflected to the upgraded slit viewer system (B). The slit unit comprises a movable mask with two slits: 0.2" (resolving power $\sim 100,000$) 0.4" slit (resolving power $\sim 50,000$). The mask can also be positioned so that neither slit is in the optical path and the spectrograph is closed to light from the telescope. The reproducibility and stability are significantly enhanced compared to the old slit mechanism. In addition, the CRIRES⁺ entrance slit mechanism includes a decker for polarimetric observations allowing for the left and right-hand polarised beams at two nodding positions.

As for the original CRIRES, the aim of the slit viewer is to perform the acquisition of the observed target and to measure the offset with respect to the tracking position on the slit. However, the slit viewer subsystem is substantially modified. The CRIRES⁺ slit viewer subsystem is composed of two folding mirrors, a camera to image the entrance slit on a detector and a filter wheel to select the filter for guiding. Relative to the original CRIRES, the Aladdin detector is replaced with an engineering grade H2RG which significantly will enhance the SV camera performance.

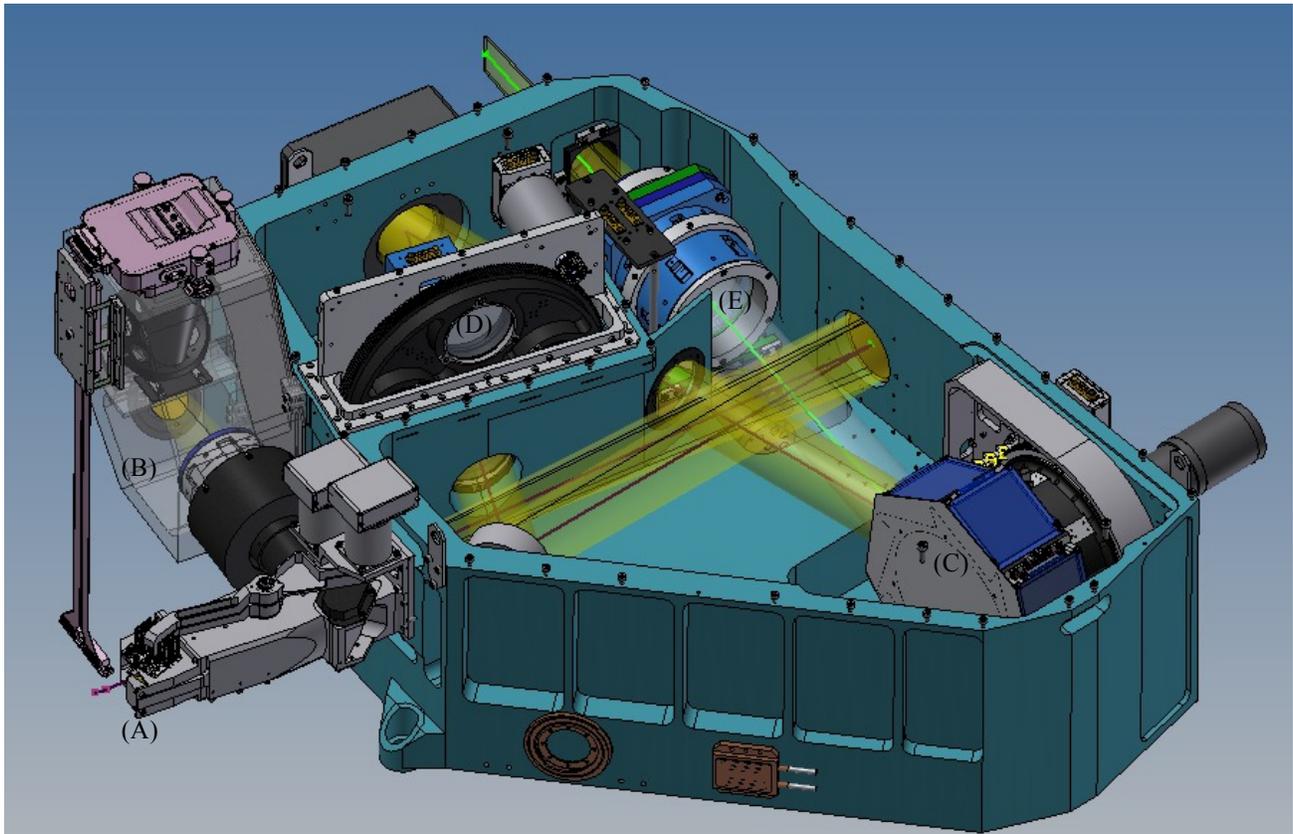


Figure 3 Top view of the new CRIRES⁺ fore-optics assembly with heat exchangers, jitter mirror unit, SV camera subsystem, slit/decker subsystem, CDU subsystem, camera unit and one of the fixation points.

The old pre-disperser prism is replaced by a cross-disperser subsystem. As can be seen in Figure 3, the beam from the f/15 focus at the new entrance slit is collimated by a parabolic mirror and arrives at the cross-disperser wheel (C) via two flat mirrors and a long pass filter to block the 2nd and higher orders of the cross-disperser gratings. The jitter mirror has two piezo actuators that allow the echellogram to be translated at sub-pixel accuracy on the detectors. The order-sorting filter (D) can be selected from one of three filters (or an open position) on a wheel to be appropriate to the chosen cross-

disperser grating (in pairs YJ, KH, LM). The cross-disperser wheel contains six reflection gratings, one for each of the bands Y, J, K, H, L and M. To measure the grating efficiency and quality, the Physikalisch Technische Bundesanstalt (PTB) Berlin has been contracted to characterize all foreseen gratings for CRIRES⁺. The results on characterizing the cross dispersion reflection gratings of CRIRES⁺ are described in detail in Follert et al. (2016, these proceedings). A locking mechanism will ensure accurate repeatability of the cross-disperser wheel.

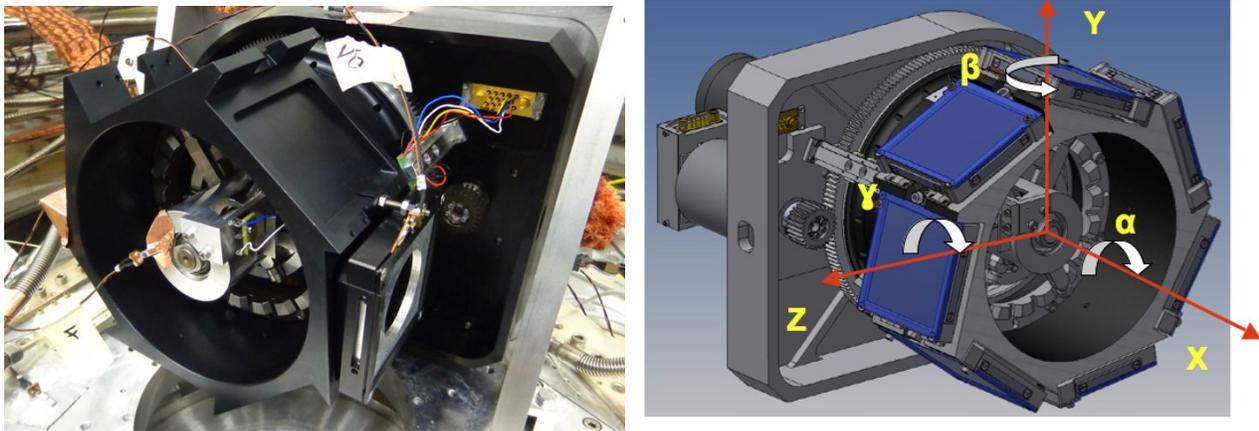


Figure 4 Grating wheel design with locking mechanism and build prototype to verify repeatability and stability.

During the design phase the grating wheel unit as shown in Figure 4 has been identified as one critical function of the instrument. Its operation and more specifically its positioning accuracy is demanding. Therefore, it has been decided to build a prototype of this function in order to assess its real feasibility and demonstrate early enough the ability to meet the positioning repeatability. Table 1 summarizes the required technical specifications and the measured values.

	Repeatability		Stability (4hrs)	
	Specification:	Measured:	Specification:	Measured:
Wheel rotation (α) (cross dispersion direction)	< 4.5 arc sec	2.5 arc sec p/p	< 0.5 arc sec	0.55 arc sec p/p
Parallel to rotation axis (β) (main dispersion)	< 2 arc sec	0.4 arc sec p/p	< 0.23 arc sec	0.25 arc sec p/p
Normal to the grating surface (γ)	< 9 arc sec	0.4 arc sec p/p	< 1 arc sec	Not measured

Table 1 shows the performance of the wheel compared to the requirements. It shows that the prototype already fulfills most of the requirements.

Following the cross-disperser grating, an achromatic camera (E) working at a fixed focal length brings the collimated beam to an f/8 focus at the field stop. In order to avoid time consuming thermal cycling during the AIT phase the camera is mounted on a small and simple focusing stage. This focusing functionality is only intended for AIV and maintenance, not for regular operations. Finally a piezo-driven flat mirror allows fine positioning of the spectral format on the detector array. The echelle grating subsystem is unchanged relative to the original CRIRES. More details on the optical and opto-mechanical designs can be found in Lizon et al. (2014) and Oliva et al. (2014) respectively.

3.3 Gas cells for a new level of wavelength calibration

The CRIRES⁺ science cases also demand specialized, highly accurate wavelength calibration techniques. Therefore, another part of the upgrade is concerned with the installation of novel IR absorption gas cells with multi-species gas fillings (NH₃, ¹³CH₄, C₂H₂). These gases will provide a set of densely distributed absorption lines imprinted on the stellar spectra in the H- and K-bands (see Figure 5). In addition the existing Thorium Argon hollow cathode lamp is replaced with similar Uranium-Neon lamp that produce a richer wavelength calibration spectrum.

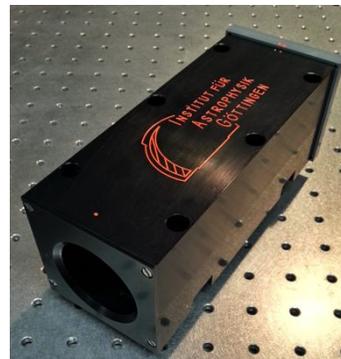
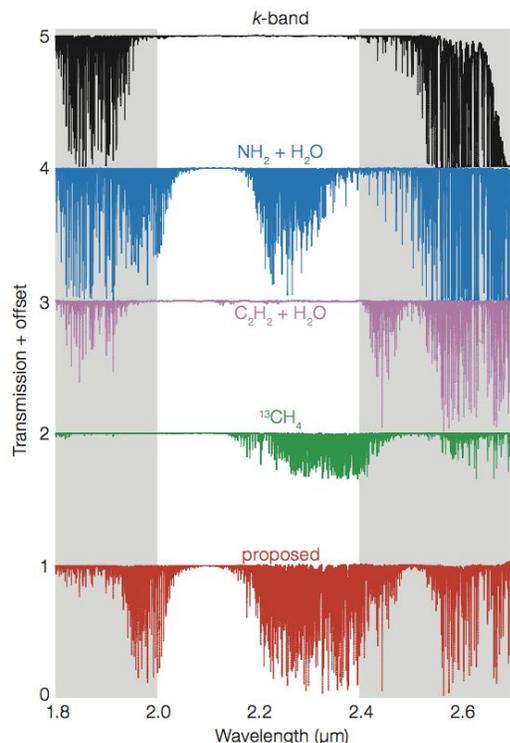


Figure 5 Transmission spectra of the gases for the CRIRES⁺ gas cell in the K-band are shown. The top panel plots the telluric (water) contribution, while the second to fourth panels show measurements of the individual species. The bottom panel spectrum presents the spectrum of the measured compound gas cell, which is a mixture of the above.

3.4 Fabry-Perot interferometer

An etalon for CRIRES⁺ is an addition that was recommended during the design reviews. Such an additional wavelength calibration device mitigates shortcomings of other devices such as the hollow cathode lamp. A Fabry-Perot etalon (or Fabry-Perot interferometer, FPI) can be used to create a periodic signal in frequency space by means of interference. Each of these fringes serves as a reference marker to tackle the wavelength calibration. For this purpose, a continuum light source with a feature free, flat broadband spectrum is coupled to a Fabry-Perot cavity, where interference is produced. The choice of cavity length and the properties of the cavity's windows/mirrors (finesse, F) determine the peak separation (free spectral range, FSR) and the line strength (sharpness, contrast). The FSR and contrast can thus be tuned and optimized to match the spectrograph's resolving power, sampling, and wavelength range. The major advantages are comb-like, equidistant reference lines over the design range with high homogeneity, equally strong spectral features, thus homogeneous line contrast, broadband coverage with no gaps and a high line density. The FPI subsystem comprises a sealed vacuum vessel, standard ESO vacuum pump and a halogen light source. The vessel shall be pressure tight. Sub-atmospheric pressure will be achieved by daily pumping (duration ~ 30 mins) to $\leq 10^{-3}$ mbar, this pumping process is independent of the main spectrograph cryo-vacuum subsystem. An interlock valve will close the FPI chamber in case of pump failure. All three components will be secured on a bench in the base of the warm structure as illustrated in Figure 10. As can be seen, the base is attached to the warm structure, not directly to the Nasmyth platform. The FPI feeds a fibre which delivers the FPI spectrum to the integrating sphere. The calibration system is described in more detail in articles by Seemann et al. (2014 and 2016).

3.5 New state-of-the-art detectors

Another major part of the upgrade project is to increase the coverage of the focal plane by introducing a set of new detectors. The original CRIRES scientific detector system used four Raytheon 1024 x 1024 pixels InSb Aladdin arrays as described in Dorn et al. (2006). Another Aladdin detector was used for the slit-viewer camera. Owing to the planned cross dispersion, a larger field is required to cover the ten orders per band with a slit length of 10 arcseconds. Therefore a new and current state-of-the-art detector mosaic is foreseen. Figure 6 presents a comparison between the original

CRIRES focal plane array area and the future array of CRIRES+. The future detector array, composed of three Hawaii 2RG detectors (the CRIRES+ H2RG detectors are shown in Figure 7 on the right together with the detector mount on the left), will span 6144 x 2048 pixels (111mm x 37mm) at a pixel size of 18 μ m. For comparison, the old Aladdin mosaic spanned only 4096 x 512 pixels (111mm x 14mm) with a pixel size of 27 μ m.

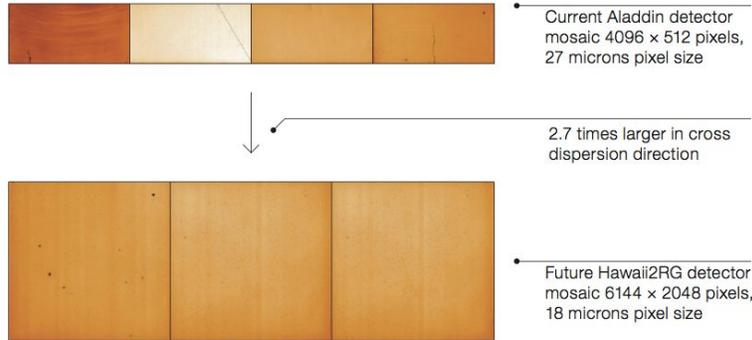


Figure 6 The original CRIRES detector mosaic focal plane array area compared to the new detectors with an increase of a factor of 2.7 in the cross dispersion direction.

The new detector mosaic will not only provide a larger area but also lower noise, higher quantum efficiency, better cosmetic quality and much lower dark current. Also the gaps between the detectors in the mosaic will be smaller. The detectors will be operated at 40K with cryogenic preamplifiers located next to the focal plane.

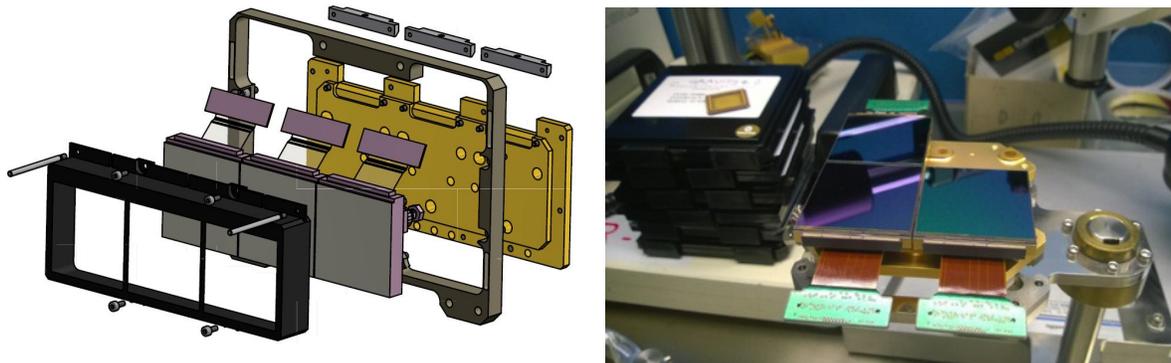


Figure 7 The 3 CRIRES⁺ H2RG detectors are shown (right) together with the detector mount (left)

All detector systems, including the slit viewer camera, will be upgraded to the current ESO standard New General Detector Controller (NGC). This detector upgrade will not only significantly increase the coverage of the focal plane, but the increased spatial homogeneity of the pixel response, lower readout noise and dark current as well as higher QE will result in improved data quality. All detectors have been received and tested at the ESO detector labs and the full detector system is ready to be integrated in the CRIRES⁺ instrument.

3.6 Spectropolarimetry with CRIRES+

The new polarimetry module planned for CRIRES⁺ uses polarizing gratings (PGs) to split the incoming converging beam into left- and right-circularly-polarized beams that continue along parallel optical axes. The choice of PGs as polarizing elements is motivated by their different behaviour at short and long wavelengths, their small thickness, the possibility of producing large and homogeneous samples, and their modest price. The geometry of the periodic pattern that makes up the PGs is chosen such that infrared light (with wavelength longer than 1 μ m) is deviated, while optical light is transmitted essentially unaltered. Thus the PG will act as a polarizing beam splitter for circular polarization without disturbing the operation of the AO system as described by Lockhart et al. (2014). The polarimetric unit is very compact and will be installed on the current CRIRES calibration slide. The gratings are mounted on a rotating stage capable of

carrying two circular and two linear beam-splitters each pair covering YJ and HK bands. Each beam-splitter unit includes two optical elements (polarising gratings) and a rotating stage needed for beam switching. The rotation axis is parallel to the axis of the incoming beam. It allows the positions of the two output beams to be switched enabling calibration of the difference in throughput for the two beams.

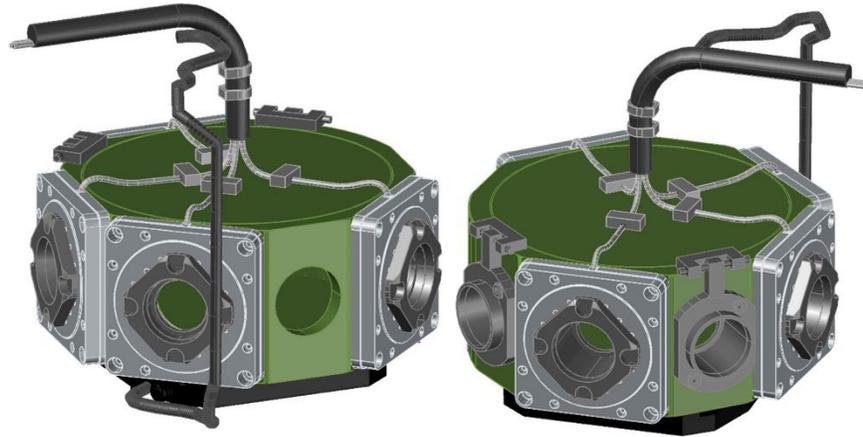


Figure 8 Polarimeter unit view from the derotator side (left) and from the telescope side (right). Polarisation optics are mounted on the sides of a rotating turret. Left panel shows (from left to right) the YJ circular polarisation beam-splitter, the YJ quarter wave plates, openings to feed the light to the HK beam-splitter and the HK quarter wave plates. Right panel shows the YJ linear polarisation, the HK circular polarisation beam-splitter, the HK linear polarisation beam-splitter and YJ circular polarisation beam-splitter. Linear polarisation beam-splitters are fixed to the turret but have the slit alignment mechanisms.

3.7 The CRIRES+ metrology concept

In order to obtain deep enough data sets to explore exoplanetary atmospheres, CRIRES⁺ will need to be able to perform stable exposures with high repeatability. The original CRIRES was limited by a spectral format reproducibility of about one pixel due to imperfect positioning of the pre-disperser and echelle grating mechanisms. However, a system of metrology was developed that facilitated the fine-tuning of the positioning of these mechanisms such that a 0.1 pixel reproducibility was achieved. Since CRIRES⁺ retains the original echelle grating mechanism, an adapted version of the metrology system is required. This will comprise a fibre feed with an arc lamp spectrum that illuminates the echelle grating, automated detection and identification of reference lines, computation of correctional adjustment, and feedback to the grating mechanism and to a piezo actuator for fine tuning. The metrology system's source on the original CRIRES was the Thorium / Argon lamp, jointly used for wavelength calibration exposures and for metrology light feeding optical fibers. This functionality will be retained, but with a new fiber bundle and without the former variable neutral density filter. The Hollow Cathode lamp will be reimaged directly into a 7 fiber bundle, which terminates in the cold part at the field mask (see Figure 9). This is to directly illuminate the echelle grating without being cross-dispersed. The metrology fiber source lines will be used to correct the echelle grating mechanism by placing Argon lines in the inter-order space of the echellogramme in each setting, always on the same pixels. The light from the hollow cathode lamp will be filtered so that only a narrow wavelength range is transmitted, 745nm - 755nm. Within this range there are a few of the brightest Ar lines (eg. wavelengths 750.59 and 751.67 nm). The lines were already used in the original CRIRES, and the procedures will be reused. These features will appear in orders 71 – 78 on the science detectors regardless of the cross dispersion setting, thus appearing in all bands. At least one Ar line from any of the seven metrology fibers will end up in the inter-order space in any setting, and can be exploited. The metrology will then ensure that these features are indeed at their pre-determined positions before any science exposure follows.

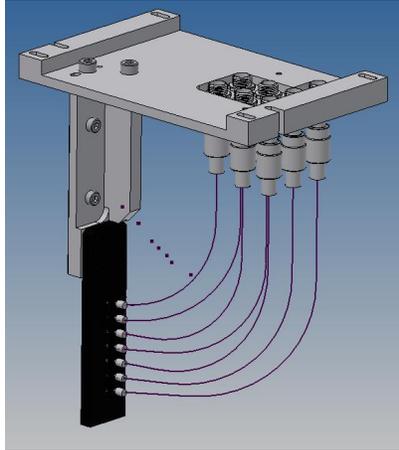


Figure 9: Termination mask of the metrology fibers in the cold part.

3.8 New data reduction software

The CRIRES⁺ project will also provide the community with a new data reduction software (DRS) package. The CRIRES⁺ DRS will support all of the offered observing modes. The improved repeatability of the instrument settings and the newly defined set of standard echelle angle settings will allow re-use of calibration data between nights, thereby minimizing overheads. The new calibration sources will provide better coverage for wavelength calibration up to the *K*-band with the cross-dispersed spectral format also increasing the amount of wavelength calibration information per exposure. Beyond 2.5 μm a table of atmospheric lines will be used to constrain wavelength calibration as for the old CRIRES. The pipeline will determine the tilt of the slit from wavelength-calibration exposures that use the deckers to block parts of the light along the slit. After combining nodded spectra, they will be extracted optimally to render the best signal-to-noise ratio. For the new polarization mode, a set of frames, obtained by rotating the beam splitter and nodding between the decker positions, will be used to determine the Stokes parameters on the pixel-level, before extraction. In addition a dedicated simulation code, CRIFORS, has been developed to provide synthetic test data to support the development of the DRS pipeline and generally help understand the data format of CRIRES⁺ and what drives the S/N achieved in various scenarios. CRIFORS makes an empirical optical ray trace output for a range of echelle grating angles across all bands. Given a suitable input spectrum (stellar source, sky background, calibration lamps etc.) and slit illumination, CRIFORS will produce a simulated echellogramme that is convolved with the blaze function on the science FPA. It is possible to include telluric absorption and various noise sources.

3.9 Warm Part / MACAO refurbishment and recovery

The foreseen lifetime for the upgraded CRIRES⁺ is at least ten years. CRIRES is operated in conjunction with a 60-element curvature adaptive optics system, Multi-Application Curvature Adaptive Optics (MACAO), described by Paufigue (2004), and will require interventions to prevent its obsolescence. This is already planned for the MACAO Very Large Telescope Interferometer (VLTI) systems installed in the Coudé laboratory of the VLT Unit Telescopes (UTs). Accordingly, the CRIRES MACAO system will be refurbished in a similar manner to the VLTI systems by replacing and upgrading obsolete electronic boards. In addition it is planned to exchange the membrane mirror, re-coat additional mirrors, realign the optics and re-commission the full AO system. In July 2014 the MACAO-CRIRES warm bench was damaged during its transport. The recovery from this damage is now part of the CRIRES⁺ project. The Warm Optics bench was replaced and re-designed to allow better handling and secure installation at the telescope with a crane-lifting device (violet parts of the drawing). A loss in throughput of the CRIRES instrument has been measured under operation in Paranal and the CRIRES⁺ project wants to make sure that the optical quality of the warm mirrors has not been degraded over the years of operation. To measure the mirror quality, the Physikalisch Technische Bundesanstalt (PTB) Berlin has been contracted to characterize all mirrors on the warm part including the DM. PTB will measure the mirror in the wavelength range of 950nm to 5300 nm and at optical wavelength from 400 to 1000 nm. If the mirrors show a significant degradation in reflectivity of the desired wavelength range the project will replace those mirrors with new ones.

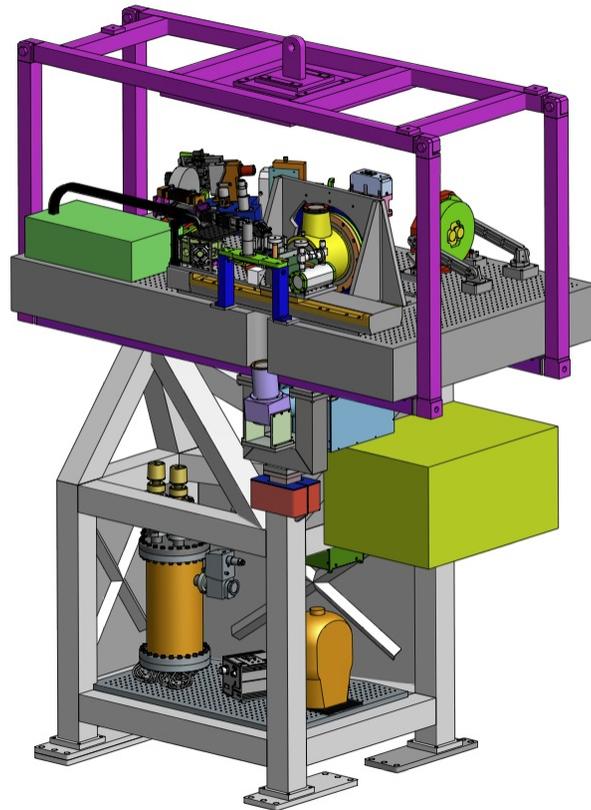


Figure 10 The new CRIRES+ warm part assembly with etalon system, calibration slide, AO system and de-rotator mechanism.

4. PROJECT ORGANIZATION AND SCHEDULE

The project is developed by ESO in collaboration with a consortium led by the Principal Investigator (PI) Artie Hatzes from the Thüringer Landessternwarte. Co-PIs are Ansgar Reiners (Göttingen) and Nikolai Piskunov (Uppsala). The partner institutes are the Thüringer Landessternwarte, Tautenburg (Germany), the Georg-August-Universität Göttingen, Institut für Astrophysik (Germany), the Istituto Nazionale di Astrofisica, Osservatorio di Arcetri and di Bologna (Italy) and Uppsala University, Department of Physics & Astronomy (Sweden).

A CRIRES⁺ Phase A study was concluded in June 2013. The reinstallation of the VLT instrument NAOS-CONICA at the CRIRES focus of UT1 required the removal of CRIRES in mid 2014, one year earlier than foreseen in the original CRIRES⁺ schedule. For the upgrade the instrument was shipped back to ESO in Garching. The preliminary design phase including an optical FDR was concluded at the end of April 2015 allowing the project to procure long lead item optical components in advance and the CRIRES⁺ final design review was held on the 3rd and 4th of May 2016 in Garching according to schedule. The project has now entered its integration phase lasting to the end of 2017 to be concluded with Provisional Acceptance Europe (PAE). Re-installation at the Paranal Observatory and commissioning is planned in 2018. CRIRES⁺ will replace the VIMOS instrument currently installed on platform B of VLT Unit telescope UT3. Figure 11 shows a picture of the happy faces of some of the CRIRES⁺ instrument team members as well as the part of the review board members during the FDR meeting on the 4th of May in Garching.



Figure 12 Picture of the CRIRES⁺ team and the final design review board member during the FDR review meeting on the 4th of May 2016 in Garching/Germany. In the background the open vessel of the CRIRES⁺ instrument can be seen as well as the new optical table for the warm part of the instrument on the left side of the picture.

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