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# Instrumentation Division

# CRIRES
# User Manual

Doc. No. VLT-MAN-ESO-14500-3486

Issue 1, Date 06/01/2006

## Prepared for Review - INTERNAL USE ONLY

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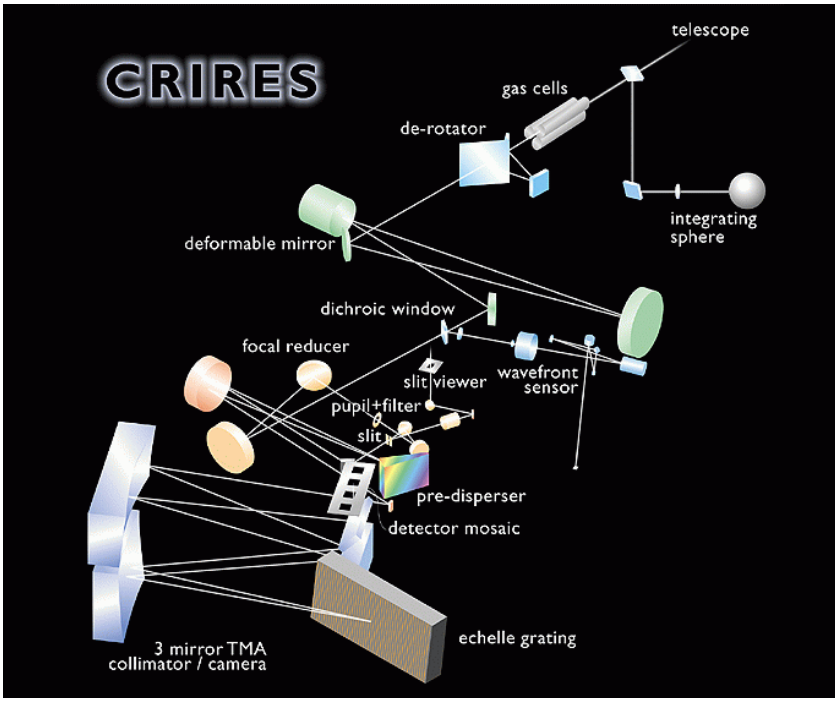
Prepared . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Date Signature

## Change Record

| Issue/Rev. | Date | Section/Parag. affected | Reason/Initiation/Documents/Remarks |
|---|---|---|---|
| Issue 0.5 | 06/12/04 | RSI | First draft |

## Abbreviations and Acronyms

| | |
|---|---|
| AO | Adaptive optics |
| APD | Avalanche photo-diode |
| CRIRES | High-resolution infrared echelle spectrometer of the VLT |
| DM | Deformable mirror |
| DMD | Data management division |
| ESO | European Southern Observatory |
| ETC | Exposure time calculator |
| FC | Finding chart |
| FoV | Field of view |
| FWHM | Full width at half maximum |
| NIR | Near infrared |
| OB | Observing block |
| P2PP | Phase II proposal preparation |
| PSF | Point spread function |
| QC | Quality control |
| RTC | Real time computer |
| SM | Service mode |
| SR | Strehl ratio |
| TIO | Telescope and instrument operator |
| USG | User support group |
| VLT | Very large telescope |
| VM | Visitor mode |
| WF | Wave front |
| WFS | Wave front sensor |



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|---|---|
| Wavelength range | $1 - 5\mu$m |
| Resolving power (2 pixels) | $10^5$ |
| Slit width | $0.2'' - 1''$ |
| Slit length | $50''$ |
| Pixel scale | $0.1''$ |
| Adaptive optics | 60 actuator curvature sensing NACAO system |
| Calibration system | 2 balckbodies, 2 spectral lamps, gas cells |
| Slit viewer | 1k Aladdin III array, filters, $0.05''$/pixel scale |
| Pre-disperser | ZnSe prism |
| Echele grating | $40 \times 20$cm, 31.6 lines/mm, $63.5^o$ blaze |
| Polarimetry | circular using Fresnel rhomb and Wollaston prism |
| Detector science array | $4096 \times 512$ pixels using 4 Aladdin III detectors |

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# Contents

# 1 Introduction

The high-resolution infrared echelle spectrometer of the VLT (CRIRES) is built by ESO. CRIRES provides in the $1-5\mu$m spectral range a resolving power of $10^5$ with a $0.2'' \times 50''$ slit. Signal to noise and spatial resolution is optimized with an adaptive optics (AO) system.

## 1.1 CRIRES

The cryogenic high resolution IR Echelle Spectrometer – CRIRES has been conceived for the VLT in order to exploit the enormously enhanced sensitivity provided by a dispersive instrument with a large detector array at an 8m telescope. The gain entails a quantitative and qualitative improvement of the observational capabilities. It can boost all scientific applications aiming at fainter objects, higher spatial (extended sources), spectral and temporal resolution. The cryogenic echelle will provide:

- High-resolution spectroscopy in the 1-5 $\mu$m range at the VLT. This instrument employs the largest available grating for a spectral resolving power of $10^5$ (for 2 pixel Nyquist sampling) with a 0.2″ slit.
- Spectral coverage maximized through four 1024 x 1024 pixel InSb detector arrays in the focal plane.
- Spectral imaging using a 50″ long slit
- Adaptive Optics to maximize SNR and spatial resolution.

Functionally, the instrument can be divided into four units.

1. The fore-optics section provides for field de-rotation, cold pupil and field stops, curvature sensing adaptive optics, and slit viewing.
2. The prism pre-disperser isolates one echelle order and minimizes the total amount of light entering into the high-resolution section.
3. The high-resolution section comprises the collimator, the echelle which is tilt-tuned for wavelength selection, the camera providing the 0.1″/pixel scale, and the detectors.
4. The calibration unit outside the cryogenic environment contains light sources for flux/wavelength calibration and detector flat-fielding.

## 1.2 Science drivers

The IR spectrograph will make previously inaccessible phenomena and objects available for spectroscopic studies. Some high lights are:

- *Extra-solar planets*:
  - radial velocities
  - spectroscopy of CO, $CH_4$

- *Solar system*:
    - Giant planets/Titan: $H_3^+$, $CH_4$, $CH_3$, $NH_3$, HCN, ...
    - Terrestrial planets: CO,HCL, HDO, $H_2O$, ...
    - Mars: imaging spectroscopy of CO depletion at 40km resolution
    - Io: volcanic activity ($SO_2$)
    - Pluto, Charon, Triton: CO, $CH_4$ search
    - Comets: $H_2O$ abundance, temperatures, velocities
- *Stars*:
    - stellar evolution and nucleosynthesis: CNO abundance
    - stellar mass
    - stellar radii
    - stellar winds and mass loss
    - atmospheric structure and oscillations
    - magnetic field structure
- *Star formation and ISM*:
    - accretion and outflows
    - ISM chemistry and cloud structures: $H_3^+$, $H_2O$, $CH_4$, ...
- *Extragalactic astronomy*:
    - AGN: velocity structure of the broad and narrow line region, [FeII], $H_2$ lines in low extinction regions, H recombination
    - fine structure lines

## 1.3 Structure and scope of the User Manual

The CRIRES user manual is structured as follows:

- A technical description of CRIRES and its adaptive optics system (AO) is summarized in Sect.2 and Sect.3.
- Observing modes offered for this period and performance of the instrument are given in Part. II.
- A guide through phase I and phase II observation preparation is given in Sect. 6. An overview on how to observe with CRIRES at the VLT can be found in Sect. 7.
- Acquisition, observing and calibration templates are explained in Sect. 10.

This is the first issue of the CRIRES User Manual. It provides information required for the proposal preparation phase I. The manual will be up–dated for the proposal phase II when more comprehensive information is available on performance and observing templates. The manual reflects knowledge gathered during laboratory tests and is in this respect to be considered in some aspects to be preliminary. Therefore we strongly recommend to consult:
`http://www.eso.org/instruments/crires/` for additional information and updates. Further support during proposal preparation and OB submission please contact ESO's User Support Group (usg-help@eso.org).

## 1.4 Glossary

*Active optics* is the active control of the primary and secondary mirror of the *telescope*. It is performed using a telescope guide star.

*Adaptive optics* is the correction of wavefront errors induced by atmospheric turbulence. The wavefront is measured from the AO guide star, and the corrections are sent to the deformable mirror within the *instrument*. Although, the instrument can run in closed loop without the active optics system, controlling the primary and secondary mirror. However, one gets better adaptive optics performance if the active optics system of the telescope is running.

# Part I

# CRIRES hard ware

## 2 Instrument design

The CRIRES instrument design is presented by Moorwood et al. 2003, SPIE 4841, 1592; a summary is presented in the following subsections.

### 2.1 Optics

The optical layout of CRIRES is shown in Fig.1. Light enters from the direction of the telescope Nasmyth focus, either via the telescope or from a calibration unit consisting of an integrating sphere illuminated by continuum or line lamps for flat-fielding and wavelength calibration. There are four lamps: 3200 K (Halogen) and 1000 K blackbody and spectral lamps with Neon and Krypton. The integrating sphere provides uniform illumination of the entrance slit of the spectrometer and its flux can be adjusted by a moving baffle.

Higher accuracy wavelength calibration is achieved using sky lines or narrow absorption lines in the gas cells which can be inserted in the beam as shown. The gas cell turret also contains a Fresnel rhombus or quarter wave plate whose insertion can be combined with that of a Wollaston prism for measuring circular polarisation. The Fresnel rhombus is a two mirrors and a prism device which can be rotated to transform circular into linear polarisation, however, at the expense of a reduced filed of view: from nominal $50''$ to $5''$.

Following the calibration unit there is a 3 mirror de-rotator which is used to counteract the telescope field rotation when making long slit observations. In this way offsets of the source position due to different atmospheric diffraction in the optical and IR can be compensated and small mechanical instabilities can be corrected. The de-rotator allows to perform the nodding in the slit observing strategy.

Then comes the adaptive optics system used to concentrate the light at the $0.2''$ wide spectrograph slit. The AO system comprises a 60 element deformable mirror, mounted on a tip-tilt stage, on which is formed a pupil image by the two mirror relay optics; the dichroic window which transmits infrared light to the cryogenically cooled spectrograph while reflecting visible light to the wavefront sensor (WFS) which uses an avalanche photodiode (APD) detector and can be translated in x,y at $\sim 0.5$Hz to maintain object centering as determined by the slit viewer. As far as possible, the design of the AO system and its individual components have been copied from the MACAO system developed by ESO for VLTI and the SINFONI instrument. Further details of the AO system can be found in Sect. 3 of this manual.

The spectrograph itself is housed in a vacuum vessel. Following the input window, a pupil image is formed at the position of a cold stop which limits parasitic background and where the Wollaston prism can be inserted. Light then either passes through the slit or is reflected to the slit viewing camera. Light passing through the slit enters the prism spectrometer where it is dispersed and then exits through an output slit sized to limit the wavelength range passing into the high resolution section to a single order. The high resolution spectrograph consists of a $40 \times 20$ cm, 31.6 lines/mm, $63.5^o$. blaze echelle grating plus a TMA (three mirror anastigmat) which acts first as a collimator and then as a camera to image the spectrum on the four Aladdin detectors which are used to make a $4096 \times 512$ pixel image of the spectrum.

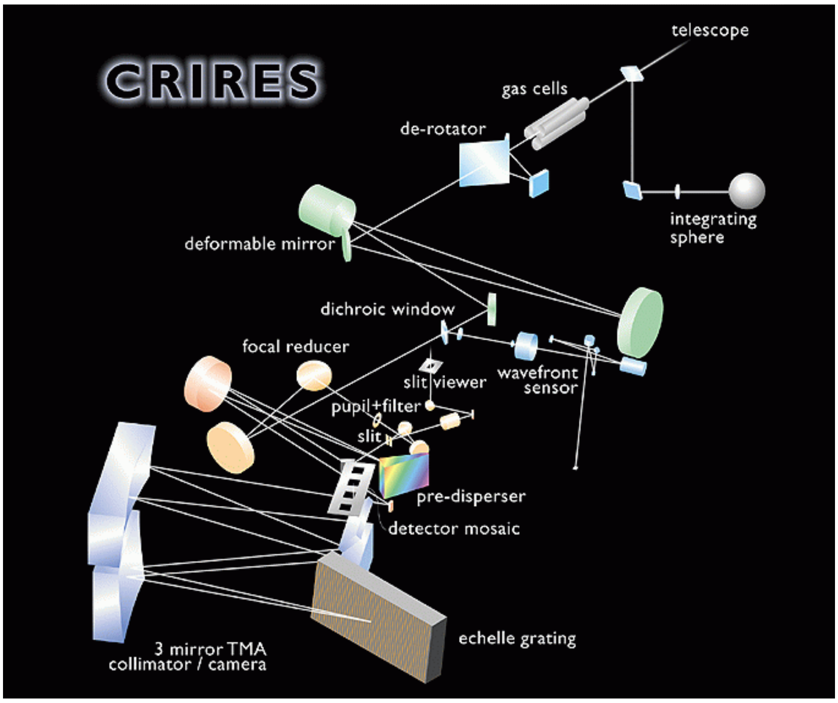

Figure 1: Layout of the CRIRES optical design.

## 2.2 Mechanics

CRIRES is stationary at Nasmyth A focus of VLT Antu (UT1). The instrument is mounted in a vessel of 3m diameter and 1m height. Including support structure the total weight of the instrument is 6.2t. The warm part of the instrument is 2t and the cold parts 4.2t, respectively. The optics inside the cryo-vessel is cooled to $\sim 65$K and the detectors to $\sim 25$K.

A main design feature of CRIRES are its cryogenic mechanisms which are required for scanning the prism ($\sim 1^{\rm o}$) and echelle grating ($\pm 6^o$), the two slits plus the slit viewer filter and Wollaston wheels. The scanning functions are driven by cryogenic stepper motors (baseline Phytron) and high precision screws and encoders. The main elements are the cryogenically cooled spectrograph in its vacuum vessel, the table mounted un-cooled pre-optics (calibration unit, field de-rotator, adaptive optics system) between it and the telescope Nasmyth adapter/rotator and the electronics racks. The instrument is mounted stationary on the platform primarily to ensure achievement of the high wavelength stability requirements by minimizing flexure and temperature variations. The vacuum vessel is made of austenitic stainless steel with a high internal reflectivity achieved by manual polishing followed by electro-polishing. Attached to it are two Leybold closed cycle coolers, the instrument mounted turbomolecular pump, connector flanges, pressure gauges, overpressure safety valve and the small temperature controlled cabinets housing the two sets of front end electronics for the detectors. Underneath is the support, the pre-vacuum pump and alignment structure which also provides access to a port in the lower lid of the vacuum vessel through which the grating unit can be accessed and removed. Inside, the mirror optics and most of the mechanical structure is made of Aluminum alloy. The TMA mirrors have a thin ($\sim 30\mu$m) nickel coating on the reflective surface which is diamond turned then conventionally polished and finally ion beam polished before gold coating. Although nickel coating is usually applied on both sides we have found by modeling that, although reducing bending, this increases the total wavefront aberration compared with plating a single surface. The remaining mirrors are being nickel plated, diamond turned and hand post polished. The only non-reflecting optics in the system apart from the window is the ZnSe prism using for order sorting.

The thermal stability is stable within 0.1K and limit any variations of temperature gradients to $\leq 50\,\mathrm{mK/m/hr}$. To counter drifts due e.g to the external diurnal temperature variations, however, active temperature control is also foreseen using heaters mounted on a ring whose temperature will be controlled to 0.1K and is connected to various points in the instrument by conducting braids. The pre-disperser collimator mirror is also equipped with piezos to allow fine active control of the spectrum position using atmospheric spectral lines for programs requiring the highest spectral resolution. In order to meet the stringent thermal and stray-light requirements the entire optical system is enclosed within a light shield plus two AlMg radiation shields with mirror finish quality. Care is also being taken (e.g by using an intermediate connector) to avoid light leaks at the penetrations of cables. Essentially the only light path into the high resolution section of the instrument is through the narrow order isolation slit at the exit of the prism pre-disperser.

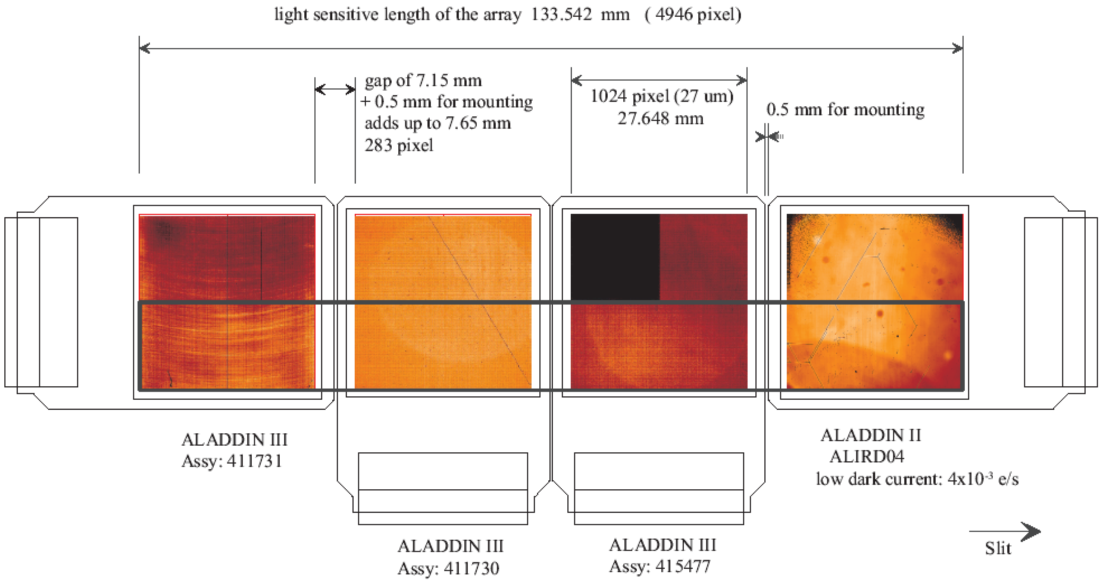

Figure 2: Layout of the 4 Aladdin detector mosaic of the spectrometer array. The fifth Aladdin detector of the slit viewer camera is not shown.

## 2.3 Detectors

CRIRES uses 5 Raytheon 1024x1024 pixel InSb Aladdin arrays, one for the slit viewer and 4 in the spectrograph focal plane which provides a useful optical field of $135 \times 21\,\mathrm{mm}$. The four science arrays are packed in a 4x1 format with a spacing between arrays of only 264 pixels. To do this, each array was removed from its original LCC package by Raytheon and glued on the ESO mount consisting of a multilayer, Aluminum–nitride, ceramic carrier. On the mount are a copper block for the cooling braid connections, a 3–point kinematic mount, a temperature sensor and a heating resistor.

Also there is a connector to the two layer Manganin boards which interface each detector to a preamplifier board equipped with 64 cryogenic operational amplifiers. As the slit is only 512 pixels long there is no need to require 4 usable quadrants per array. The actual arrays selected will be optimally oriented as shown in Fig. 2. The array on the right is one remaining from the first, ESO funded, foundry run in the 90th and exhibits the lowest dark current measured so far in any array at ESO (14 electrons/hour with drift correction using dead pixels with open indium bumps) despite or maybe due to the presence of several pronounced cracks. This array has been included specifically to ensure the best possible noise performance at the shortest wavelengths. The arrays will be read-out using standard ESO IRACE controllers 4 having 64 channels $(4 \times 16)$ for the science arrays and 32 channels for the slit viewing camera.

# 3 Adaptive optics system

The adaptive optics system of CRIRES is discussed by Paufique et al. 2004, SPIE (5490–15). The multi-applications curvature adaptive optics system (MACAO) for CRIRES corrects a turbulent wavefront and provides diffraction limited images at the focal plane. The overall sensitivity thereby is improved by about a factor two for point-sources. To highlight the advantage of combining MACAO and CRIRES a PSF is shown in Fig.3 in AO open loop (uncorrected) and closed loop, where the PSF is reconstructed from wavefront measurements. The non–circular PSF in open loop is due to the very short integration time used.

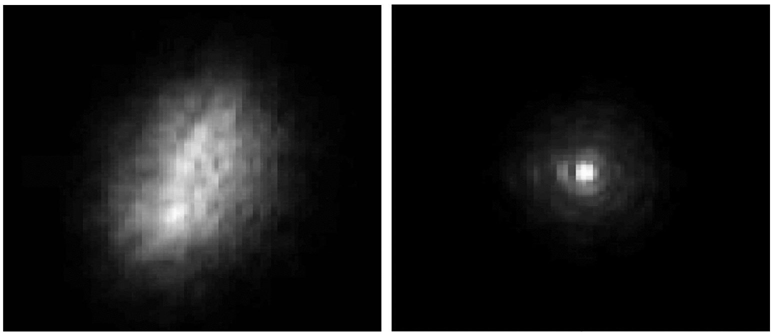

Figure 3: PSF without (left) and with (right) AO correction for a short integration time.

## 3.1 Introduction

The following section provides only a introduction in the field of adaptive optics and atmospheric turbulences, and essentially taken from the NACO user manual. For further reading see for example: "Adaptive optics in astronomy", Rodier 1999, Cambridge University Press, or "Introduction to adaptive optics", Tyson 2000, Bellingham/SPIE.

### 3.1.1 Atmospheric turbulence

The VLT has a diffraction–limited resolution of $1.22 \cdot \lambda/\mathrm{D} = 0.07$ arcsec at $\lambda = 2.2\mu$m. But the resolution is severely limited by atmospheric turbulence to $\lambda/r_0 \approx 1$ arcsec, where $r_0$ is the Fried parameter. It is directly linked to the strength of the turbulence and depends on the wavelength as $\lambda^{5/6}$. For average observing conditions, $r_0$ is typically 60cm at 2.2 $\mu$m.

Temperature inhomogeneities in the atmosphere induce temporal and spatial fluctuations in the air refractive index and therefore cause fluctuations in the optical path. This leads to random phase delays that corrugate the wavefront (WF). The path differences are, to a good approximation, achromatic. Only the phase of the WF is chromatic. The correlation time of WF distortions is related to the average wind speed V in the atmosphere and is typically of the order of $r_0/\mathrm{V} =$ 60ms at 2.2 $\mu$m for V = 10m/s.

### 3.1.2 Adaptive Optics

A technique to overcome the degrading effects of atmospheric turbulence is real-time compensation of the deformation of the WF by adaptive optics (AO, Figure 4).

The wavefront sensor (WFS) measures WF distortions which are processed by a real-time computer (RTC). The RTC controls a deformable mirror (DM) to compensate the WF distortions. The DM is a continuous thin plate mirror mounted on a set of piezoelectric actuators that push and pull on the back of the mirror.

Because of the significant reduction in the WF distortions by continuous AO correction, it is possible to record near diffraction-limited images with exposure times that are significantly longer than the turbulence correlation time. The residual error from the WF compensation (WF error) directly determines the quality of the formed image. One of the main parameters characterizing this image quality is the Strehl ratio (SR), which corresponds to the amount of light contained in the diffraction-limited core relative to the total flux.

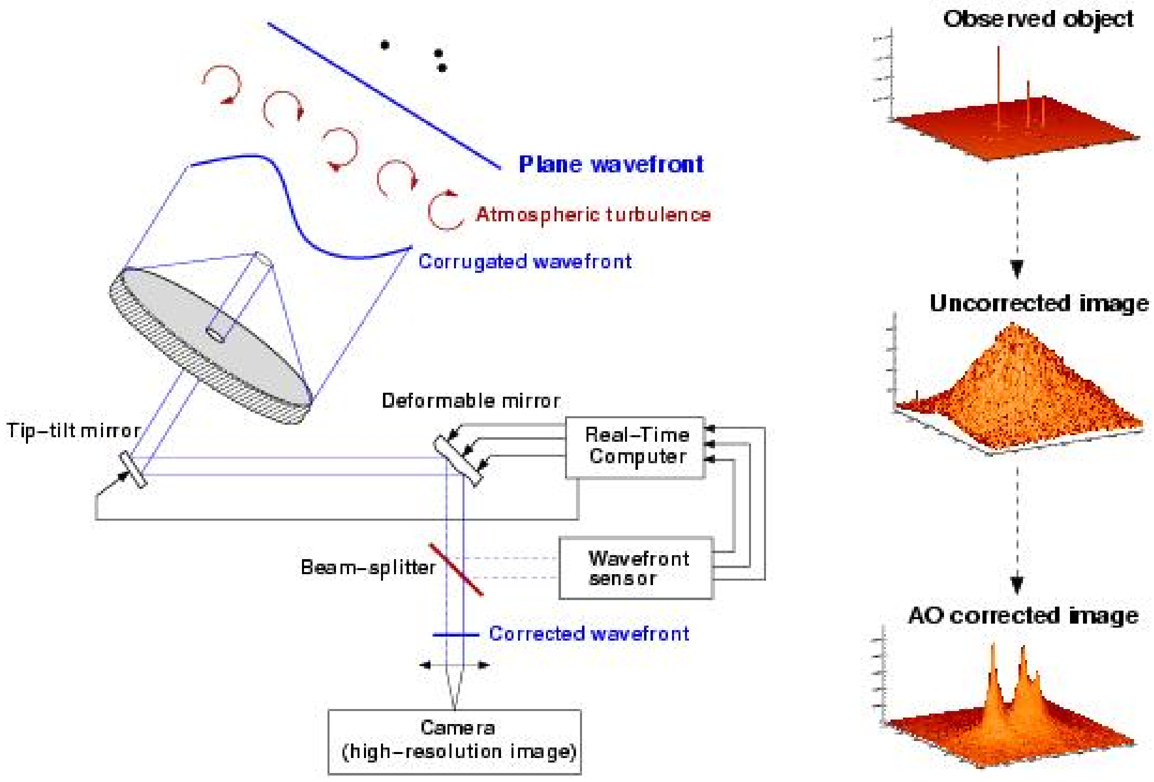

Figure 4: Principle of Adaptive Optics. Note that in practice, and contrary to this schematic design, CRIRES has no dedicated Tip-Tilt mirror, but performs low- and high-order corrections with a single deformable mirror (mounted on a tip-tilt stage).

An AO system is a servo-loop system working in closed loop. The DM flattens the incoming WF and the WFS measures the residual WF error.

A commonly used WFS is the Shack-Hartmann WFS (cf. NACO). However, CRIRES (as well as the other ESO MACAO systems) relies on a Curvature WFS. The curvature sensor is designed to measure the WF curvature (as opposed to the WF slope). This is achieved by comparing the plane irradiance distributions of two planes placed behind and before the focal plane. In practice, a variable curvature mirror (membrane) is placed in the telescope focus. By vibrating, inside and outside focus blurred pupil images can be imaged on a detector array (for CRIRES a lenslet array feeding avalanche photo-diodes, APDs. The modulation frequency of the membrane corresponds to the temporal sampling frequency of the WFS. The difference between the inside and outside pupil image measures the local WF curvature.

The performance of an AO system is related to the number of lenslet in the lenslet array, the number of actuators behind the DM, and the rate at which WF errors can be measured, processed and corrected (the server-loop bandwidth).

The performance of an AO system is also linked to the observing conditions. The most important parameters are the seeing, the brightness of the reference source used for WFS and the distance between the reference source and the object of interest.

In case of good conditions and a bright, nearby reference source, the correction is good and the resulting point spread function (PSF) is very close to the diffraction limit. A good correction in the K-band typically corresponds to a SR larger than 30%.

At shorter wavelengths (particularly in the J-band) or in the case of poor conditions or a faint, distant reference source, the correction is only partial - the Strehl ratio may only be a few percent.

## 3.2 Hardware description

The MACAO system for CRIRES is based on a 60 actuator deformable mirror, inserted in a so-called relay optics. These optics and the wavefront sensor optics are mounted on a breadboard, which is located between the Nasmyth focus and the spectrometer. It is about 1.5m wide and a top view of the warm optics overlayed by the optical path is shown in Fig. 5, the assembly of the deformable mirror is displayed in Fig. 6.

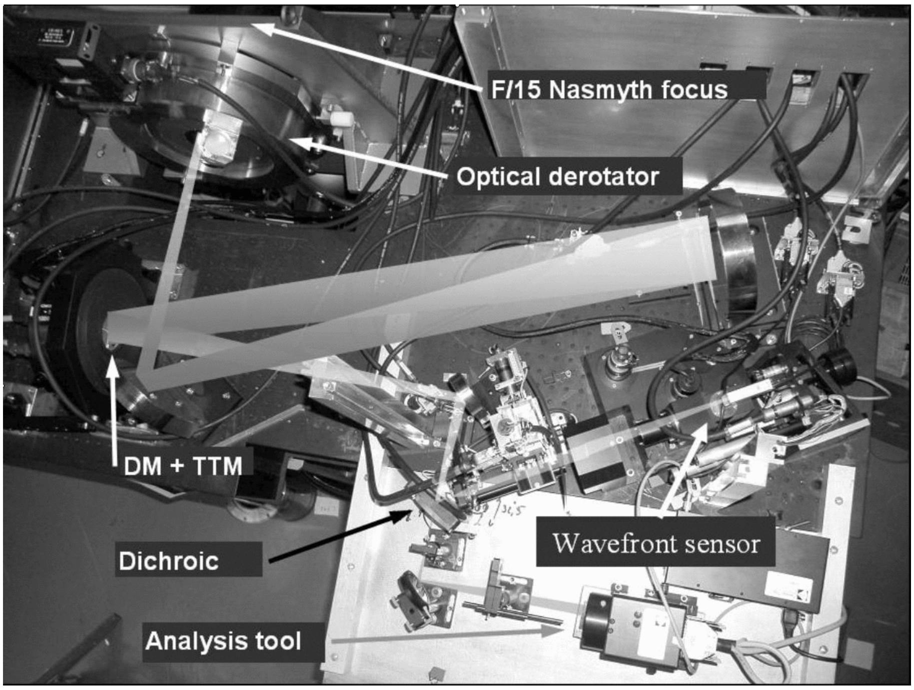

Figure 5: Top view of the warm optics of the MACAO – CRIRES system. From f/15 Nasmyth focus and after the optical derotator, one notice the deformable mirror and tip–tilt mount assembly. Light enters from the dichroic to the cold and warm part of the instrument. For the latter the wavefront sensor and some analysis tools are visible.

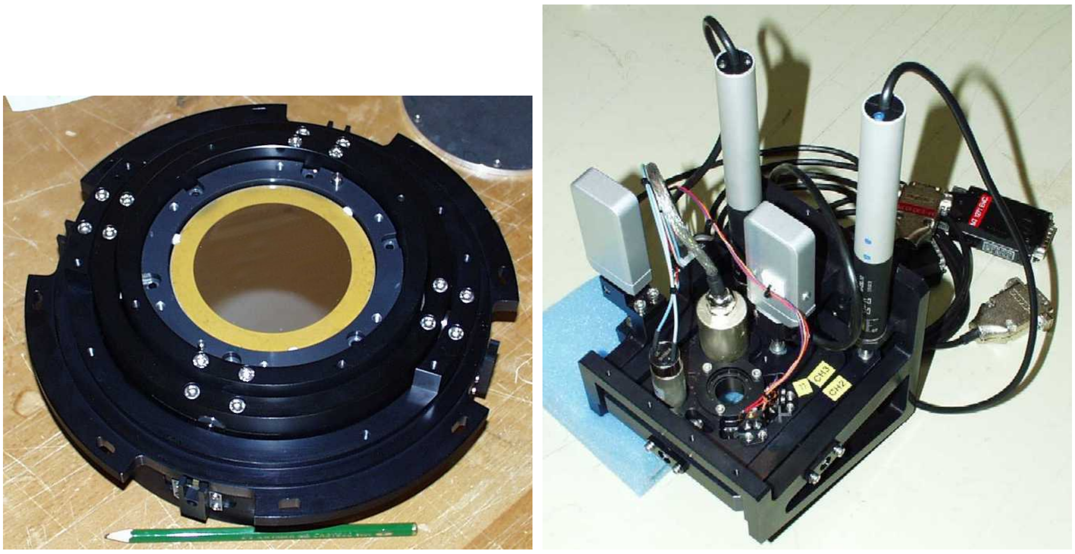

Figure 6: Assembly of the deformable mirror and tip–tilt mount (left) and of the gimbal mount (right).

### 3.2.1 The corrective optics

The wavefront correction is performed by a 60 electrodes bi-morph mirror developed by CILAS, with a pupil diameter of 60mm. The 60 electrodes sandwiched between two thin piezoelectric PZT layers with opposite polarization. The outside surface of the PZT layers are grounded and covered with 0.1mm glass layers, the mirror side being silver coated. Applying a voltage to one electrode produces a constant curvature over its surface. The geometry of the electrodes in the 4 central rings (40 electrodes) matches that of the lenslet array sub-apertures, while the 20 remaining electrodes are located outside the pupil and constrain the edge of the pupil to correct 0-curvature aberrations: tip–tilt, astigmatism, etc. The deformable mirror (DM) provides a stroke to compensate atmospheric aberrations up to a optical seeing of $1''$. In order to relax the use of the outer electrodes of the mirror, the tip–tilt error is slowly offloaded to a tip–tilt mount designed and built by LESIA, which provides a $\pm 240''$ mechanical stroke, i.e. $\pm 3.6''$ on the sky, with a 100Hz -3dB internal closed-loop bandwidth. The assembly of the DM and tip–tilt mount is shown in Fig.6.

### 3.2.2 The Wavefront Sensor

The following functions are sequentially implemented in the wavefront analyzer:

- Extraction of the reference star beam (field selector).
- Projection of the reference star image on the membrane mirror (imaging lens).
- Scan of the intra– and extra–pupil regions by modulation of the membrane mirror curvature.
- Creation of a pupil image centered on the lenslet array.
- Reduction of the flux (for bright reference stars) within the linear range of the APDs by means of neutral density filters.

- Re-imaging of the 60 sub-pupils on the 60 fiber cores by the lenslet array unit.
- Injection of the collected beams in the 60 APDs.

The scanning lens of the field selector is mounted on an XYZ table: the XY axes enable the guiding star to be selected in the $50'' \times 50''$ field-of-view, while the Z stage compensates for the VLT field curvature. The position of the field selector defines the reference for the pointing. The imaging lens is creating an image of the guiding star on the membrane mirror, which is mounted to an acoustic cavity. A voice coil is mounted to the other end of the cavity, and driven at 2.1kHz by the APD counter module to force an oscillation of the focus mode of the membrane mirror. The incidence angle of the beam on the membrane mirror depends on the position of the guiding star in the field. In order to keep the pupil image (obtained when the membrane mirror is flat) centered on the lenslet array, the membrane mirror is mounted on a 2 axis gimbal, which is co-ordinated with the field selector. For each $(x, y)$ positions of the field selector the gimbal mount is moved so that the light is reflected to the same focus. A diaphragm in front of the membrane enables the field to be adjusted to the observing conditions (seeing and guiding reference size). The assembly of the gimbal mount is shown in Fig. 6.

The wavefront sensor box consists of 4 mirrors, which provide parallel beam to image the pupil on the lenslet array. First, the beam is collimated by a spherical mirror. It is then folded by a flat mirror and injected in the beam expander, which adapts its diameter to the lenslet array (14mm). The optical path of the wavefront sensor box is shown in Fig. 7.

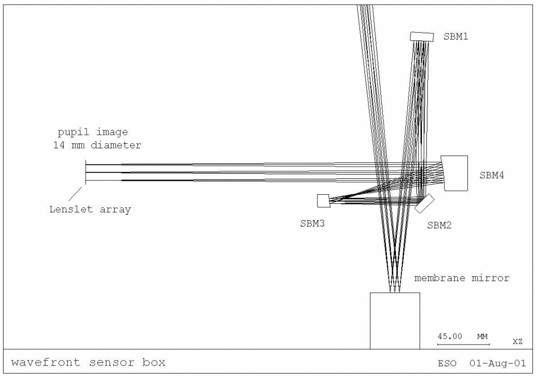

Figure 7: The optical path of the wavefront sensor box.

The lenslet array intercepts the beam and divides the flux in 60 sub-aperture. Each sub-pupil is imaged on a fiber, with a 100 $\mu$m core diameter. When the membrane mirror vibrates, the pupil image is projected on both sides of the lenslet array plane. The normalized difference between the intra– and extra–pupil flux collected by each sub–aperture is proportional to the local curvature of the wavefront, which provides the wavefront error. The fibers drive the signal from the fiber feed module to the APD cabinet, mounted to the instrument. The APD counts are recorded by the APD counter module, synchronously with the membrane signal. The front–end assembly of the fibre bundle is shown in Fig. 8.

### 3.2.3 Control loop

The oscillating membrane produces a signal modulated proportional to the local wavefront curvature. This signal, collected by avalanche photo-diodes (APD), is sent to the real time computer.

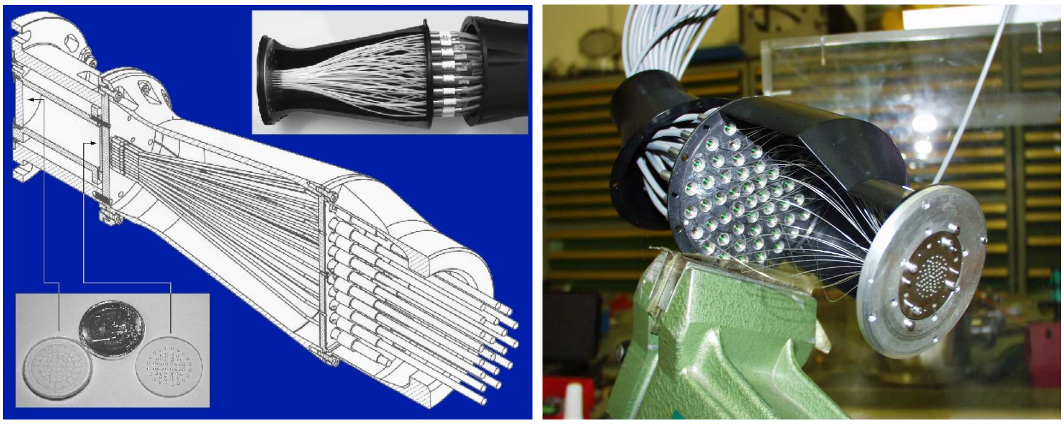

Figure 8: Front–end assembly of the 60 fibre bundle which guide the light to the sensors.

The RTC computes this modulation, and retrieves the voltages to be applied to the mirror and tip-tilt mount to optimally compensate for the local curvature measured. For this, an precise calibration of the system is required (membrane mirror synchronisation, membrane curvature, pupil alignment, interaction matrices being the main ones).

### 3.2.4 Limitations

The membrane mirror curvature represents an optical gain for the aberrations measurements. A way to increase the performance of the system is therefore to increase the curvature of this mirror. But increasing this requires increasing as well the field of view of the wavefront sensor optics and some other non-linear effects can degrade the estimate of the curvature. For the same reason, extended sources will affect the quality of curvature measurement, and lead to a different optimal gain. In some extreme cases, the system can be unable to close the loop (extended $6''$planetary nebula with a faint blue white dwarf in the middle, or a faint star close to the Moon, for example). There is a trade-off to do, and an optimal optical gain to apply. This optimal gain will depend mainly on the seeing size, and marginally on the star magnitude and other factors. This optimal gain is tabulated in the configuration of the software and is transparent for the user.

## 3.3 AO performance

The performance achieved by the MACAO system of CRIRES has been evaluated by laboratory simulations. Two cases are distinguished: i) in closed loop with guide stars of various magnitudes and ii) in open loop, so without AO corrections. The optimization was done over the encircled energy on a $0.2''$ slit, representative of the available energy for the spectrograph. The lab results demonstrate a weak gain in J and a strong (factor $\sim 2$) increase of the fraction of the energy available for the spectrometer in the K and M band, respectively (Fig. 9).

## 3.4 Summary

The high-resolution infrared echelle spectrometer of the VLT (CRIRES) provides in the $1-5\mu$m spectral range a resolving power of $10^5$ (for 2 pixel Nyquist sampling) with a $0.2'' \times 50''$ slit. Signal to noise and spatial resolution is optimized with an adaptive optics (AO) system.

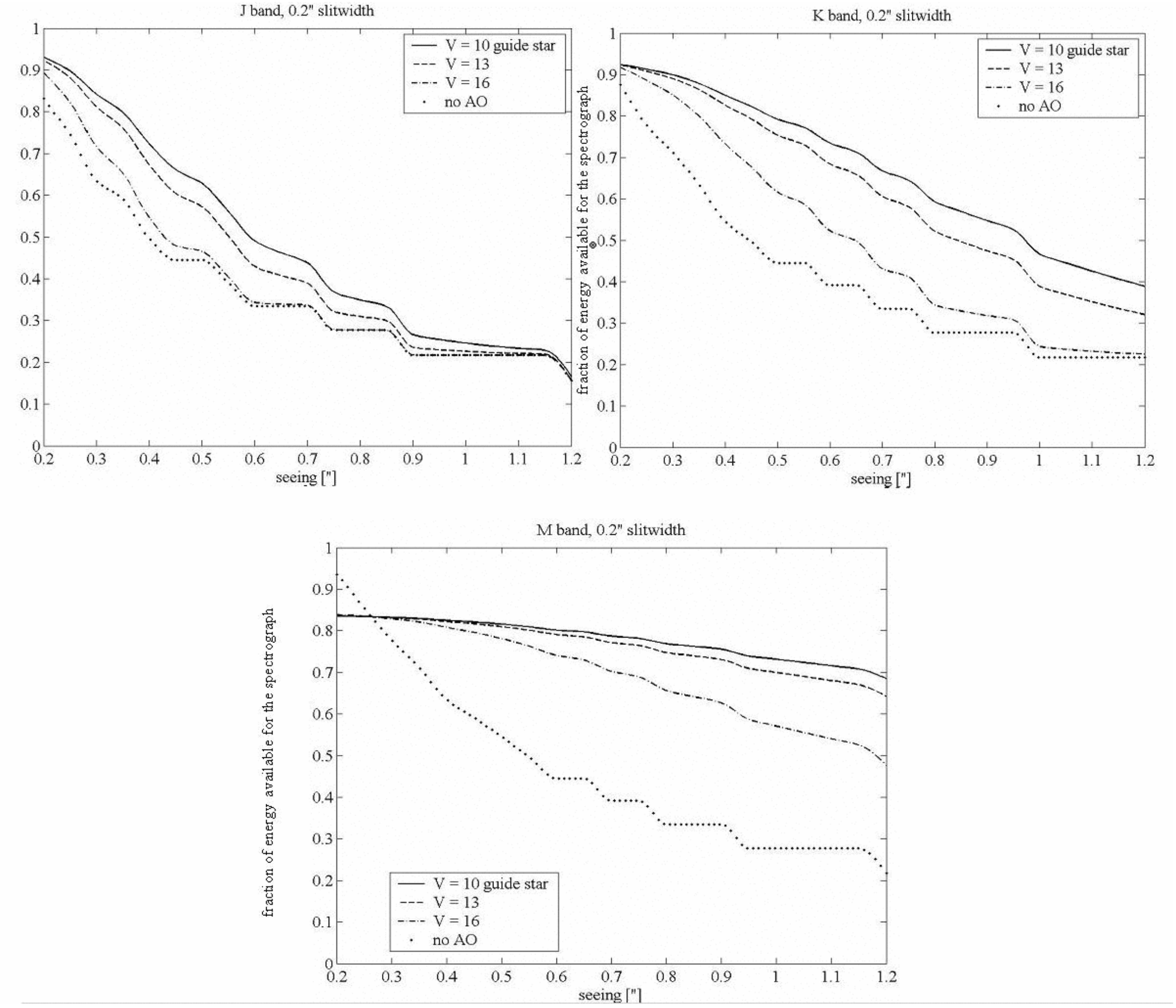

Figure 9: The fraction of energy available for the spectrograph in the 0.2″ slit, as a function of seeing is shown for the J (top left) , K (top right) and M (bottom) band for guide star magnitudes V=10, 12, 16 and without AO correction.

CRIRES can be used without adaptive optics guide star, in which case the AO module just acts as relay optics and the spatial resolution is given by the natural seeing.

The full power of the instrument is achieved when an adaptive optics guide star is available. For best correction, the star should be brighter than $R \sim 11$ mag. However, the AO can work (and will provide a moderate image quality improvement) with stars as faint as $R \sim 16 - 17$ mag in the best seeing conditions. Ideally, the AO guide star should be as close as possible to the scientific target (if not the science target itself), and usually closer than 10″ . Depending on the atmospheric conditions (atmospheric coherence length) the AO guide star could be chosen as far as 30″ for the AO system to still provide a mild improvement of the encircled energy.

# Part II

# Observing with CRIRES

## 4 Introduction

### 4.1 Atmospheric Transmission

The transmission of the Earth's atmosphere in the J, H, K, L and M bands is shown in Fig. 10. The amount of telluric absorption varies with zenith distance and precipitable water vapor.

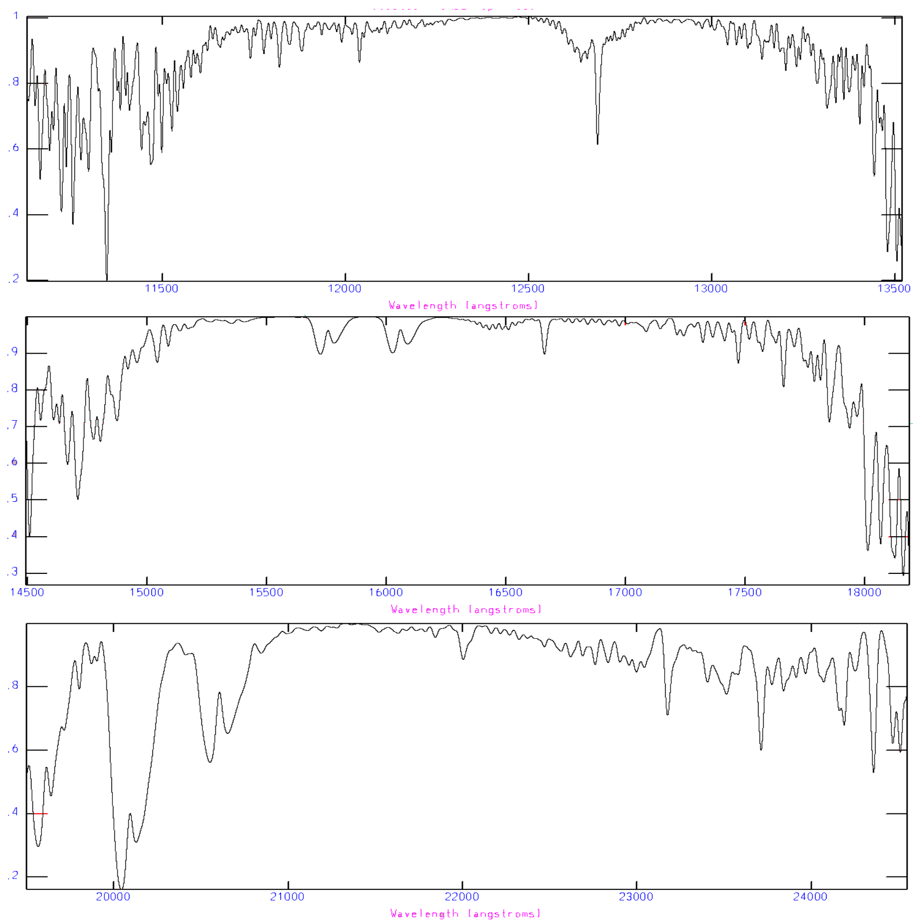

Figure 10: Atmospheric transmission in the J, H, K,L and M bands. These graphs are based on FTS data at the McMath/Pierce Solar Telescope on Kitt Peak, produced by NSF/NOAO.

### 4.2 Background Emission

There are two regimes in the sky background emission. Below 2.2 $\mu$m, the sky emission is dominated by OH emission, taking place at an altitude of 80 km. Detailed sky spectra with OH line identifications are available on the ISAAC web page. Beyond 2.2 $\mu$m, the thermal background dominates. The thermal background consists of atmospheric and telescope emission.

## 4.3 Spectrophotometric Calibration

Calibration of spectroscopic data in the IR is a complicated procedure that requires care. It is generally done in three steps. The first step removes telluric features, with what is commonly called a telluric standard; the second step removes the spectral features of the telluric standard that are imprinted onto the science spectrum because of the first step; and the third step sets the absolute scale with what one may call a spectroscopic (flux) standard. In general the spectroscopic standard and the telluric standard are the same star, but this does not need to be the case.

The most prominent features in IR spectra are the telluric lines of the Earth's Atmosphere. Unfortunately, many of the telluric lines do not scale linearly with airmass, so it is necessary to observe a standard at the same airmass and with the same instrument setup as that used for of the science target. Furthermore, the strength of the telluric lines varies with time, so it is also necessary to observe the standard soon after or soon before the science target.

The spectrum of the telluric standard is divided directly into that of the science target. Ideally, the spectrum of the telluric standard should be known, so that features belonging to it can be removed. However, this is not normally the case, so one has to use standards in which the spectrum is approximately known.

In general, we use either hot stars or solar analogs as telluric standards and, generally, these stars are selected from the Hipparchus Catalog. The spectra of hot stars, those hotter than B4, are relatively featureless and are well fit by blackbody curves. So, by knowing the spectral type of the star, one uses a blackbody curve with the appropriate temperature to fit the continuum of the standard. The spectra of stars that are cooler than A0 start to have many more features and cannot be fit with a blackbody curve for wavelengths below 1.6 microns.

Unfortunately, hot stars do contain some features, usually lines of hydrogen and helium, that can be difficult to remove. If the region around the hydrogen and helium lines are of interest, then one can also observe a late type star, which should have weak hydrogen and helium lines. This star is then used to correct for the helium and hydrogen absorption in the spectrum of the hot star. Some hot stars also have emission lines or are in dusty regions. These stars should be avoided. The V-I color of the star can be used as an indicator of dust. For stars hotter than A0, it should be negative. And lastly, hot stars tend to lie near the galactic plane, so there may be situations where there are no nearby hot stars.

Solar analogs, (for the purpose of removing telluric features) are stars with spectral type G0V to G4V. These standards have many absorption lines in the IR, particularly in the J band. The features can be removed by dividing by the solar spectrum that has been degraded to the resolution of the observations. In addition to hot stars and solar analogs, IR astronomers have used other stellar types as telluric standards. For example, F dwarfs are commonly used.

Given the expected sensitivity for CRIRES (see below) we have scanned the Hipparchus Main Catalog to select potential spectroscopic standards using the following selection criteria: $\delta \leq 30^{\mathrm{o}}$, stars B8 or earlier with $V \leq 4.0^{mag}$ and stars with spectral types B8-G0 with $V \leq 4.8^{mag}$. This left us with a list of 466 stars bright enough to be used up to $\lambda \approx 5\mu$m (for wavelengths up to the L-band there are about 900 stars earlier then A1 which can be used). In some critical areas it will be necessary to measure stellar spectral templates and this is another good reason to restrict the number of grating settings supported by the observatory.

Please decide carefully about which star is best suited for your program. Although the observatory will automatically observe a telluric standard for service programs, we cannot guarantee that we will make the best choice, as this depends on the science users wish to do. If you think that a specific spectral type suits your program better than others, we recommend that you submit calibration

OBs.

The observatory selects telluric standards from four catalogs: the IRIS Photometric Standards, the MSSSO photometric standards, a composite list of bright spectroscopic standards and the Hipparchus Catalog. The majority of the standards come from the Hipparchus Catalog. Although, the Hipparchus Catalog is an excellent source of telluric standards for ISAAC, most of the stars in the catalog do not have IR magnitudes, which means that IR magnitudes have to be taken from 2MASS/DENIS or even inferred from the spectral type. Such an extrapolation leads to an uncertainty of 5-20% in the absolute flux calibration. If users wish to have a more certain absolute flux calibration, they should provide their own standards (and should have included these observations in their requested time in Phase 1). Alternatively, if the broad-band magnitudes of the object are known, the absolute flux calibration can be derived by convolving the measured spectrum with the broad-band filter curves. In this case, the IR magnitude of the standard is irrelevant, only the spectral type is important.

# 5 Performance

Compared with most infrared astronomy programs so far at the VLT, a larger fraction of the CRIRES science is likely to depend less on detection limit and more on the achievement of high signal to noise ratios on relatively bright objects (stars) and/or accurate radial velocities (e.g for detecting exo-planets).

Sensitivity expectations (before first light) for CRIRES are given in figure 11. Note that K-band performance (and off course L and M) are more or less limited by the thermal background whereas in J and H the detector performance is setting the limits. This means, that J and H band could profit from technical development in the field of detectors, whereas for $\lambda \geq 2\mu m$ the performance is no longer strongly affected by the detector characteristics. On the other hand in this field the point-source sensitivity approaches that of the lower resolution spectrograph ISAAC. In this wavelength regime some projects, which do not necessarily need the spectral resolution of CRIRES may still profit from the high spectral resolution, as this allows for a better discrimination against telluric interferences. In order to be able to realize these high sensitivity values in practice, however, possible sources of fringing (e.g interference filters) have had to be avoided and the requirement on the grating reproducibility is set to $\sim 0.05$ pixel in order to avoid limitations by flat field artifacts. If the wavelength reproducibility cannot be achieved "blind" it will be obtained by active spectrum control using sky lines as the reference. This means that the nominal velocity accuracy corresponds to this or $\sim 70$m/s. Even higher accuracy is possible using the absorption gas cells although the actual gain depends strongly on the actual line density of the selected gas in the wavelength region of interest.

First light image of the sky is shown in Fig 13. The OH doubled at 1708.6nm is resolved at the resolution of CRIRES. This doubled still appears as a single line in the high resolution mode of ISAAC demonstrating the resolving power of CRIRES. In dispersion direction the FWHM is 2.8pixels.

## 5.1 AO Guide Stars

In CRIRES, the wavefront sensing occurs with the optical light ($<1\mu$m).

**The distance of the AO guide star:**

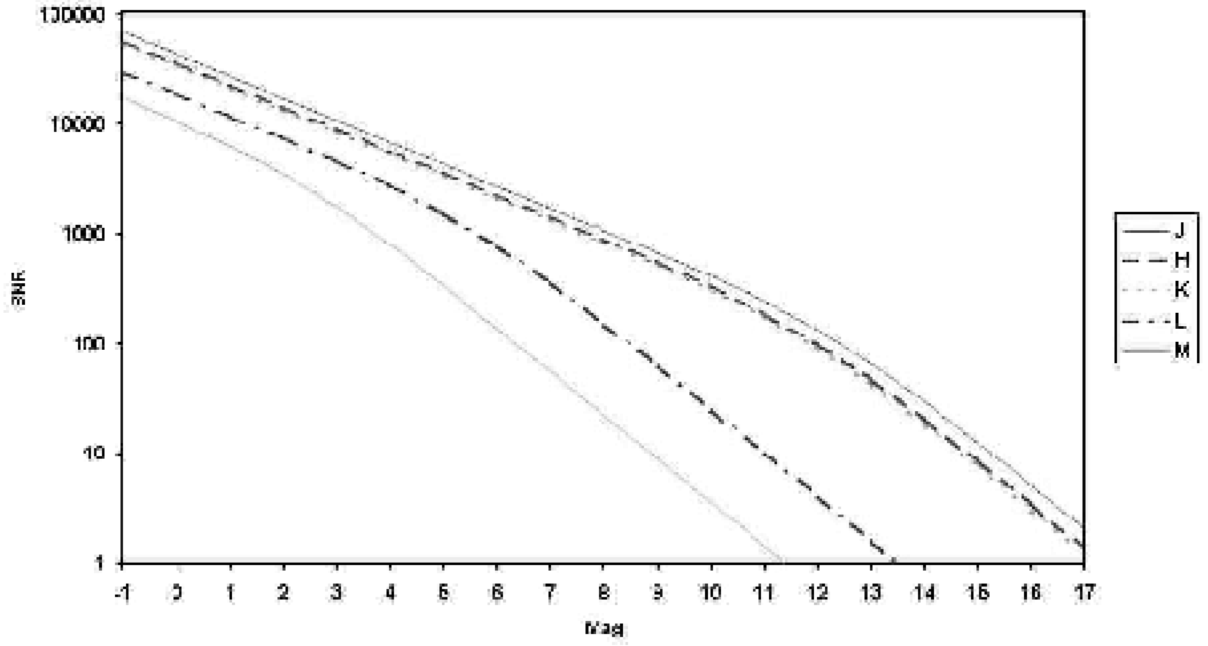

Figure 11: Expected CRIRES sensitivity: S/N versus magnitude have been calculated for 1 hour integration time on a point source conservatively, based on the acceptance measurements of components and the expected detector performances. The graphs for H and K nearly overlap. During comissioningl we reached for $m_K = 13$ a S/N of 25.

Figure 12: First light

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Begin | End | Begin | End | Begin | End | Begin | End |
| NAME wave-length ID | Reference Wavelength nanometer [nm] | File name spectral reference | Detector # 1 | Detector # 1 | Detector # 2 | Detector # 2 | Detector # 3 | Detector # 3 | Detector # 4 | Detector # 4 |
| | | | | | | | | | | |
| 59/0/n | 958.003 | OH_Lines | 943.523 | 948.517 | 949.899 | 954.698 | 955.962 | 960.560 | 961.754 | 966.145 |
| 59/0/i | 958.003 | OH_Lines | 946.432 | 951.375 | 952.743 | 957.491 | 958.740 | 963.287 | 964.466 | 968.805 |
| 58/0/n | 974.520 | OH_Lines | 959.796 | 964.875 | 966.280 | 971.160 | 972.445 | 977.121 | 978.334 | 982.799 |
| 58/0/i | 974.520 | OH_Lines | 962.754 | 967.781 | 969.171 | 974.000 | 975.270 | 979.893 | 981.093 | 985.504 |
| 57/0/n | 991.617 | OH_Lines | 976.641 | 981.806 | 983.235 | 988.199 | 989.506 | 994.262 | 995.496 | 1000.038 |
| 57/0/i | 991.617 | OH_Lines | 979.649 | 984.762 | 986.177 | 991.088 | 992.380 | 997.082 | 998.302 | 1002.789 |
| 56/0/n | 1009.324 | OH_Lines | 994.087 | 999.342 | 1000.796 | 1005.847 | 1007.176 | 1012.016 | 1013.272 | 1017.893 |
| 56/0/i | 1009.324 | OH_Lines | 997.148 | 1002.350 | 1003.789 | 1008.786 | 1010.100 | 1014.885 | 1016.126 | 1020.692 |
| 55/0/n | 1027.676 | OH_Lines | 1012.167 | 1017.516 | 1018.996 | 1024.137 | 1025.490 | 1030.415 | 1031.693 | 1036.397 |
| 55/0/i | 1027.676 | OH_Lines | 1015.282 | 1020.577 | 1022.042 | 1027.127 | 1028.466 | 1033.336 | 1034.599 | 1039.246 |
| 54/0/n | 1046.707 | OH_Lines | 1030.917 | 1036.363 | 1037.869 | 1043.103 | 1044.481 | 1049.496 | 1050.797 | 1055.586 |
| 54/0/i | 1046.707 | OH_Lines | 1034.088 | 1039.479 | 1040.970 | 1046.149 | 1047.511 | 1052.470 | 1053.756 | 1058.488 |
| 53/0/n | 1066.456 | OH_Lines | 1050.373 | 1055.920 | 1057.455 | 1062.786 | 1064.189 | 1069.297 | 1070.622 | 1075.500 |
| 53/0/i | 1066.456 | OH_Lines | 1053.604 | 1059.095 | 1060.613 | 1065.887 | 1067.275 | 1072.325 | 1073.636 | 1078.455 |
| 52/0/n | 1086.965 | OH_Lines | 1070.579 | 1076.230 | 1077.794 | 1083.225 | 1084.655 | 1089.859 | 1091.210 | 1096.179 |
| 52/0/i | 1086.965 | OH_Lines | 1073.870 | 1079.464 | 1081.012 | 1086.385 | 1087.799 | 1092.945 | 1094.280 | 1099.191 |
| 51/0/n | 1108.278 | OH_Lines | 1091.576 | 1097.336 | 1098.930 | 1104.466 | 1105.923 | 1111.228 | 1112.605 | 1117.670 |
| 51/0/i | 1108.278 | OH_Lines | 1094.931 | 1100.633 | 1102.210 | 1107.687 | 1109.128 | 1114.374 | 1115.734 | 1120.739 |
| 50/0/n | 1130.443 | OH_Lines | 1113.413 | 1119.286 | 1120.912 | 1126.557 | 1128.042 | 1133.452 | 1134.855 | 1140.021 |
| 50/0/i | 1130.443 | OH_Lines | 1116.833 | 1122.648 | 1124.256 | 1129.841 | 1131.311 | 1136.659 | 1138.047 | 1143.150 |
| 49/0/n | 1153.513 | OH_Lines | 1136.141 | 1142.133 | 1143.790 | 1149.549 | 1151.064 | 1156.582 | 1158.014 | 1163.283 |
| 49/0/i | 1153.513 | OH_Lines | 1139.630 | 1145.561 | 1147.202 | 1152.899 | 1154.398 | 1159.854 | 1161.270 | 1166.476 |
| 48/0/n | 1177.545 | OH_Lines | 1159.816 | 1165.930 | 1167.622 | 1173.499 | 1175.046 | 1180.677 | 1182.138 | 1187.516 |
| 48/0/i | 1177.545 | OH_Lines | 1163.377 | 1169.430 | 1171.104 | 1176.918 | 1178.448 | 1184.016 | 1185.461 | 1190.774 |
| 47/0/n | 1202.599 | OH_Lines | 1184.498 | 1190.741 | 1192.468 | 1198.468 | 1200.047 | 1205.797 | 1207.289 | 1212.779 |
| 47/0/i | 1202.599 | OH_Lines | 1188.134 | 1194.314 | 1196.023 | 1201.959 | 1203.521 | 1209.206 | 1210.681 | 1216.106 |
| 46/0/n | 1228.743 | OH_Lines | 1210.253 | 1216.630 | 1218.394 | 1224.523 | 1226.136 | 1232.009 | 1233.533 | 1239.141 |
| 46/0/i | 1228.743 | OH_Lines | 1213.967 | 1220.279 | 1222.025 | 1228.089 | 1229.684 | 1235.491 | 1236.998 | 1242.539 |
| 45/0/n | 1256.048 | OH_Lines | 1237.153 | 1243.670 | 1245.473 | 1251.736 | 1253.384 | 1259.386 | 1260.943 | 1266.675 |
| 45/0/i | 1256.048 | OH_Lines | 1240.948 | 1247.399 | 1249.183 | 1255.380 | 1257.011 | 1262.945 | 1264.484 | 1270.148 |
| 44/0/n | 1284.595 | OH_Lines | 1265.275 | 1271.938 | 1273.782 | 1280.186 | 1281.871 | 1288.007 | 1289.600 | 1295.460 |
| 44/0/i | 1284.595 | OH_Lines | 1269.155 | 1275.751 | 1277.576 | 1283.912 | 1285.579 | 1291.646 | 1293.221 | 1299.011 |
| 43/-1/n | 1299.404 | OH_Lines | 1278.837 | 1285.919 | 1287.881 | 1294.701 | 1296.498 | 1303.049 | 1304.751 | 1311.021 |
| 43/-1/i | 1299.404 | OH_Lines | 1282.980 | 1289.994 | 1291.936 | 1298.688 | 1300.466 | 1306.947 | 1308.631 | 1314.831 |
| 43/1/n | 1329.534 | OH_Lines | 1310.622 | 1317.156 | 1318.962 | 1325.227 | 1326.874 | 1332.863 | 1334.415 | 1340.117 |
| 43/1/i | 1329.534 | OH_Lines | 1314.407 | 1320.872 | 1322.658 | 1328.854 | 1330.482 | 1336.399 | 1337.932 | 1343.563 |
| 42/-1/n | 1330.350 | OH_Lines | 1309.300 | 1316.548 | 1318.556 | 1325.537 | 1327.376 | 1334.081 | 1335.823 | 1342.241 |
| 42/-1/i | 1330.350 | OH_Lines | 1313.540 | 1320.719 | 1322.706 | 1329.617 | 1331.438 | 1338.071 | 1339.794 | 1346.140 |
| 42/1/n | 1361.181 | OH_Lines | 1341.823 | 1348.511 | 1350.360 | 1356.773 | 1358.459 | 1364.589 | 1366.177 | 1372.015 |
| 42/1/i | 1361.181 | OH_Lines | 1345.698 | 1352.315 | 1354.144 | 1360.485 | 1362.152 | 1368.209 | 1369.778 | 1375.542 |
| 41/-1/n | 1362.806 | OH_Lines | 1341.249 | 1348.672 | 1350.728 | 1357.877 | 1359.761 | 1366.627 | 1368.411 | 1374.983 |
| 41/-1/i | 1362.806 | OH_Lines | 1345.590 | 1352.942 | 1354.978 | 1362.056 | 1363.920 | 1370.713 | 1372.478 | 1378.977 |
| 41/1/n | 1394.372 | OH_Lines | 1374.546 | 1381.396 | 1383.289 | 1389.857 | 1391.584 | 1397.862 | 1399.489 | 1405.468 |
| 41/1/i | 1394.372 | OH_Lines | 1378.514 | 1385.292 | 1387.164 | 1393.659 | 1395.366 | 1401.570 | 1403.177 | 1409.081 |

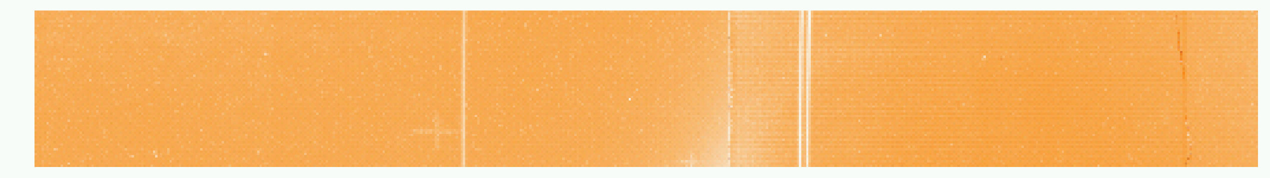

Figure 13: First light image of the sky. The OH doubled at 1708.6nm is resolved at the resolution of CRIRES.

Two field selectors allow to pick the AO guide star within a $2' \times 1'$ field centered on the spectrograph field. However, only under good atmospheric conditions, a star at a distance $>10''$ will provide a significant image quality improvement. Under Excellent conditions, bright stars as far as $20'' - 30''$ can still be used to provide a mild improvement of the image quality.

**The brightness of the AO guide star:**

The intra- and extra-focal pupil of the AO guide star is imaged on a lens-let array, and each lens-let fed to an Avalanche Photo Diode (APD) that ultimately forward its signal to the Real Time Computer (RTC).

The Flux on the APD is limited to 1 million counts (in order not to damage the devices) and thus, stars brighter than R$\sim$11 mag are dimmed by a set of neutral density filters (for up to $\sim$ 9 mag). Hence, stars brighter than R$\sim$2 mag cannot be used as AO guide star. Stars brighter than R$\sim$17 mag will not improve further the performance of the AO system.

Good correction under average seeing are still obtained with stars as faint as R$\sim$14 mag. Any star fainter than this will require good to excellent atmospheric conditions to provide an image quality improvement.

**Service mode:** we do not recommend to prepare observations with an AO guide star fainter than R$\sim$14 mag, unless you provide a very restricted constraint set that forces the observatory staff to observe your target under the very best atmospheric conditions (which in turn reduces dramatically your chances of seeing this observation ever performed).

**Visitor mode:** the above recommendation is also valid, but for cases in which you have selected a very faint AO guide star, you could, in parallel, prepare OBs with no AO acquisition, i.e. if the atmospheric conditions are not sufficient to close the AO loop on your guide star, you would fall back on the same observation without AO.

**The color of the AO guide star:**

The color of the guide star is important for two reasons:

1. The APD response curve extends from 450nm to 900nm and peaks around 650nm. Thus, the R band magnitude provides only a crude estimate of the number of photons that the wave front sensor (WFS) will collect. The B$-$R color provides a color term with which we can correct the R band magnitude to get a better estimate of this number. Very crudely, the magnitude computed by the RTC scales as:
   $\mathrm{RTC_{mag}} = \mathrm{R_{mag}} - 2.8 + 1.65*(\mathrm{B-R})$
   I.e. Blue stars will provide more photons to the WFS. The RTC estimates magnitudes for

stars with (B-R)$\sim$1.7 (e.g. K2V star).

2. The color is also essential for atmospheric refraction compensation. The WFS corrects the telescope guiding for the atmospheric refraction difference between its (optical) guiding wavelength and the (near-infrared) central wavelength of the spectrograph set-up.
   Once the response curve of the WFS is taken into account, the optical guiding wavelength can be derived from the (B-R) color as follows:
   Guiding wavelength(nm)$= 590 + 40*$(B-R)

## 5.2 Spectrograph modes

At the nominal spectral resolution[1] of CRIRES typically 50 grating settings will be sufficient to cover the entire infrared spectrum accessible from the ground in the range of $0.95 \leq \lambda \leq 5.2 \mu m$.

Offered instrument wavelengths settings.

| wavelength | wavelengths ID |
|---|---|
| | |

However, for this period only a subset of discrete settings will be supported by the observatory for science observations.

- allowed instrument wavelengths settings which could be commissioned for this period are given in Tab. **??**.
- Set-ups will be done, by using the instrument model, to position the spectrum with the precision of typically a few pixels.
- In case that sky lines can be detected in starring frames they will be used to improve the absolute wavelength calibration by the pipeline. However, not for each setting one can expect to have sufficient sky lines. Therefore (in general) the absolute wavelength calibration is not better than given by the present instrument model (see item before). It is a goal of future commissioning runs to improve the absolute wavelength calibration.
- The *field-of-view* of the spectrograph is: slit width $\times 50''$ . The nominal slit width is 0.4arcsec giving a resolving power of about 50,000. Using the smallest slit width of 0.2″ (and hence higher spectral resolving power) is not recommended for the moment because of large slit losses of as much as a factor 3 compared to the nominal slit width.
- Caused by some bad detector characteristics we recommend to apply as observing strategy nodding of one or more (AB) cycles. Starring observation on one nodding position (A) is possible but shall be avoided because of detector glow effects which is strong for bright targets.

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[1] At the price of vignetting the resolving power can be ramped up to more than $10^5$. Such an operation is not excluded but not part of the baseline considerations for instrument calibration and operation.

## 5.3 Detector characteristics

CRIRES is equipped with four 1024 x 1024 pixel InSb detector arrays in the focal plane of the spectrograph. Observers shall use the ETC to optimize DIT, NDIT values. All other detector settings, voltages, best read out scheme, etc. are calculated for each setting automatically by the system. Some detector characteristics are summarized in the following Table and Figures.

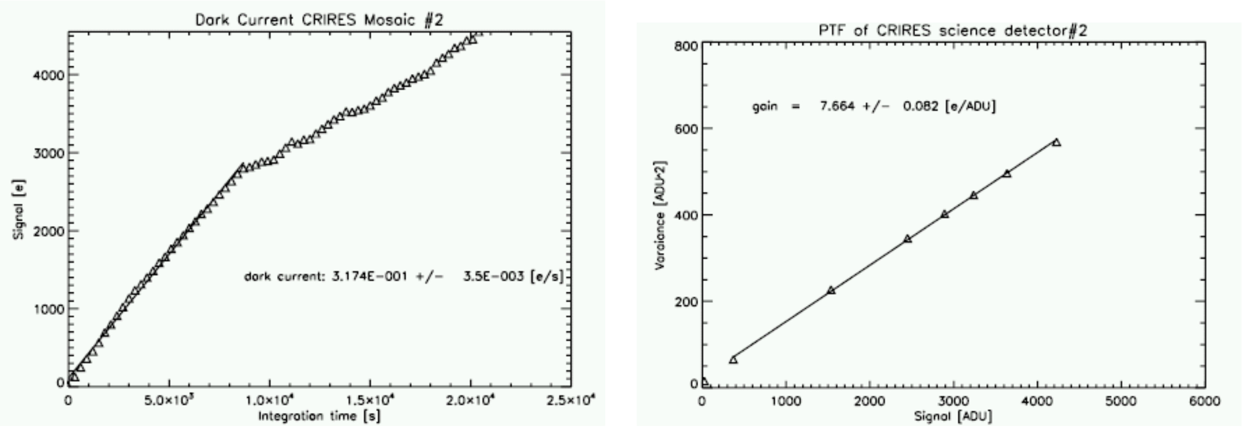


Figure 14: Dark current (left) and conversion gain (right) of one of the four science detectors .

In Fig. 14 dark current and conversion gain of detector 2 is shown. The dark current is estimated from the slope of the signal in ADU or $e^-$ as a function of integration time (s) for the linear region. Dark current of the four detectors 1, 2, 3, and 4 is 0.0527, 0.0317, 0.0369 and 0.0344 [$e^-$/s], respectively. The conversion gain is measured by taking flat fields at different flux levels. One estimates the noise in a good, cosmetically clean, part of the individual detector arrays and plots the variance versus mean signal. The inverse slope is the conversion gain [$e^-$/ADU]. The conversion gain of the four detectors 1, 2, 3, and 4 is 7.737, 7.664, 7.689 and 8.077 [$e^-$/ADU], respectively. Saturation levels for the science detector 1 and 2 is 16000ADU corresponding to a storage capacity of 120000$e^-$. The cosmetic performance of the detectors is improving by lowering the detector temperatures. On the other hand as readout noise is lower for higher detector operating temperatures one needs to search for the optimal setting. In Fig. 15 the noise histogram and map of detector 2 is shown as a function of operating temperature. Best compromise is found operating detectors at at 27.5K.

Summary of mean detector parameters.

| | |
|---|---|
| Dark current | 0.04 $e^-$/s |
| Gain | 8 $e^-$/ADU |
| Read-out-noise | 10 $e^-$ rms |
| Saturation level | 120000$e^-$ |
| Operating Temperature | 27.5K |

### Read out settings

There are only two detector read-out parameters to be adjusted by the observer, DIT and NDIT. As the dark depend on DIT setting we recommend to use:

- In general if there are no starvation or saturation risk on medium bright stars use DIT = 30s.

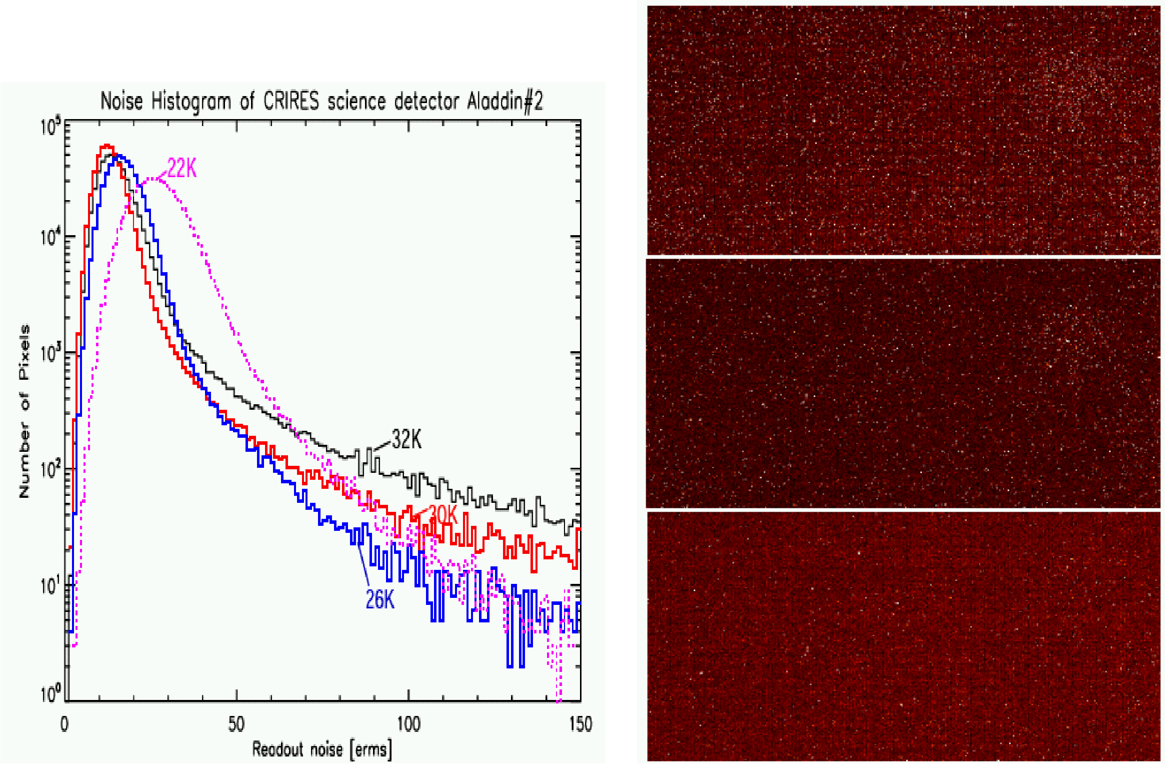


Figure 15: For science detector 2 we show: on the left, the noise histogram for different operating temperatures (left) and on the right, the noise map at detector temperature of 32 (top), 30 (middle) and 26K (bottom). Note that the cosmetic quality improves by lowering the temperature while the read out noise increases. Best compromise is found operating the detectors at 27.5K.

- For short exposures on standard stars brighter than J,H,K $\sim$ 8–10 mag, DITs of 1s and NDIT between 2 and many ($\geq 10$).
- for long exposures on faint targets in which no saturation risk is given, DIT depending on the frequency on which the sky is obtained, so for faint targets DIT of 120, 300, 600, and 900s may be used.

## 5.4 System efficiency and throughput

The overall efficiency of CRIRES is measured on spectrophotometric calibration standard stars. The photometric flux of such a star in Jy, $F_\nu$, is converted to the flux in photons/s/pixel, $F_\lambda$. It holds, usnig SI units, that:

$$F_\lambda = \frac{c}{\lambda^2} F_\nu \cdot \frac{10^{-26}}{E_\gamma} \cdot A_{\rm Tel} \Delta\lambda$$

where $E_\gamma$ is the photon energy, $A_{\rm Tel}$ is the telescope are and $\Delta\lambda = \lambda/R$ is the dispersion in units of $\mu$m/pixel.

The conversion gain after multiplication by the interpixel capacitance of 0.9 yields 7.73 e$^-$/ADU. The overall efficiencyis defined as the ratio of e$^-$/s/pixel as measured on the detector divided by the theoretical expected photon flux (photons/s/pixel) arrivnig above the Earth's atmosphere.

In Fig. 16 the overall efficiency as a function of slit width for order 26 at 2150nm is shown together with the peak efficiency versus slit width. Below a slit width of 0.3″ the efficiency in this measurement is below 3%. One of the main reason is that for short coherence times (2ms) the AO does not work effectively and most of the energy of the star is in the seeing disk not entering the spectrograph. Opening the slit to 0.7″ increases the throughput to 12% and for widely opened slit it reaches 17%. Repeatnig this measurement with better seeing conditions was not possible during the first comissionnig run. For this period we therefroe strongly encourage observers to use a slit width of 0.4″ at the expense of a reduced resolving power of 50000. In case the highest possible resolution of nominally 100000 is important to reach for a particular observing proposal a slit width of 0.2″ can be used only at the expense of drastically reduced efficiency and therefore much longer exposure times. This issue is subject to further instrument characterisations in future comissioning runs but can also not propserly considered in the ETC for the time being.

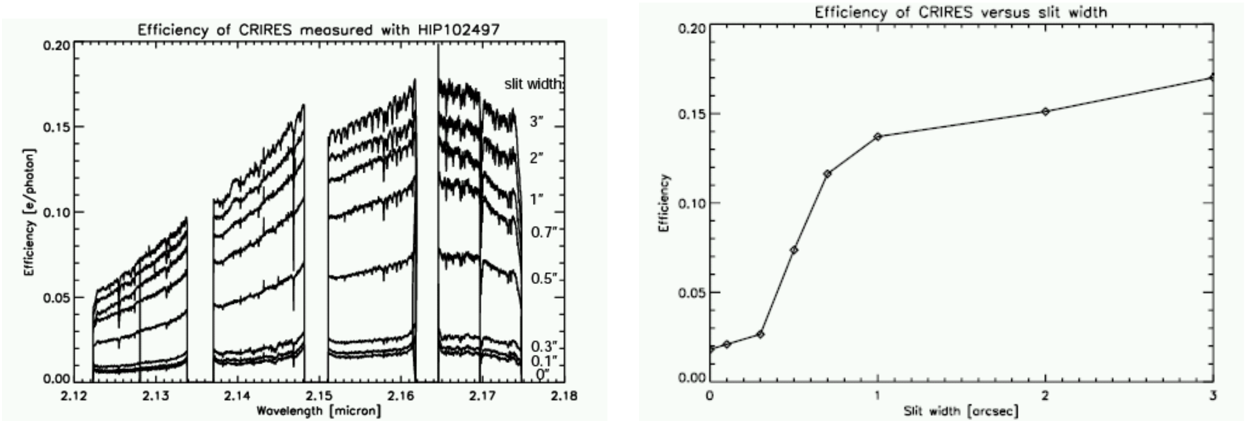


Figure 16: Overall system efficiency. The wavelength dependence of the efficiency for a particular wavelength setting is shown left for different slit widths. The peak efficiency as a function of slit widths is given on the right.

## 5.5 Stabillity

For wavelength calibration the stabillity and reproducibillity of the different mechanical functions of CRIRES are important. The positioning reproducibillity of the prism as a function of read out of the encoder shows a peak to peak variation of $\pm1.5$pixels. This reproducibility can be reduced to an rms of 0.44 pixels by introducing the stabilisation times of 10s. In Fig.17 the positioning reproducibility of the prism is shown as a function of mean values of the encoder reads which are averaged over a period of 10s. Similar figures are found for the positioning reproducibility of the grating which shows a peak to peak variation of $\pm2.5$pixels and by introducing stabilisation times a rms reproducibility of 1.1pixels. A FFT analysis classifies thsoe oscillations to have white noise characteristics also we will analyse this performance in more detail in the future. The rms reproducibility of the positioning of the slit is 0.07 pixels and that of the piezo is 0.035pixels. Demonstarting the superb stability of the piezo.

The good point is also that the oscillations noted by inspecting encoder values of the prism and grating are not directly coupled to the wavelength stabillity. For example if one analysis the stabillity of lines one find a rms fluctuation of 0.33 pixels.

In general the calibration strategy is that the absolut wavelength calibration is performed by cross correlation of the observered sky lines with information provided by catalogs such as HITRAN or OH line lists. So wavelength calibration is aimed to be done from the data of a particular observations. In the moment we cannot granty that this strategy is working for all offered wavelengths settings.

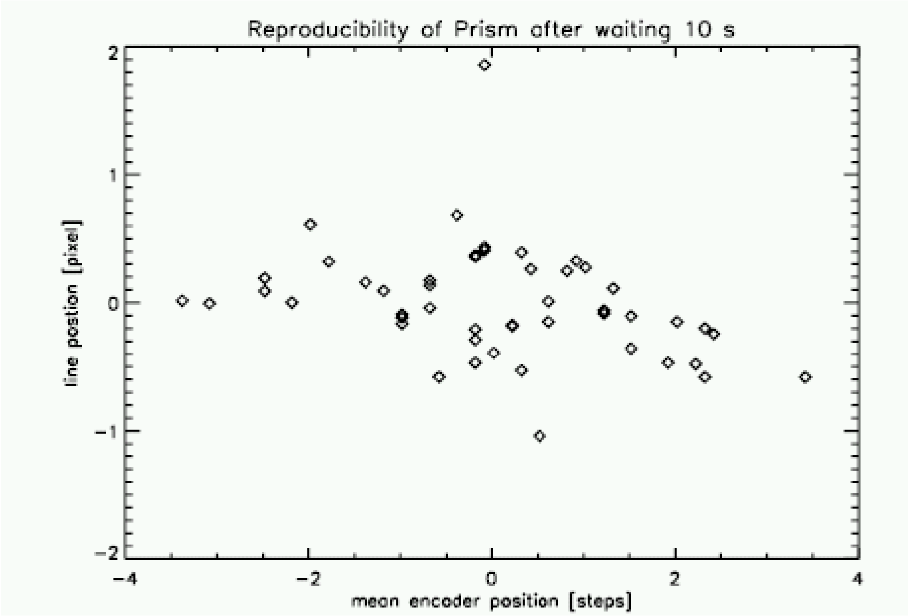


Figure 17: Positioning reproducibility of a line centered on a specific detector pixel is shown as a function of mean values of the encoder reads. Mean values are computed by averaging over a period of 10s. The computed rms is 0.44pixels.

## 5.6 Limiting magnitudes

Limiting magnitudes (S/N=10 per spectral pixel, for a point source in 1h on source integration are:

| Band | Limiting Magnitudes (continuum) |
|---|---|

For more detailed exposure time calculation, we encourage to use the exposure time calculator.

## 5.7 The Exposure Time Calculator

The CRIRES exposure time calculator can be found at:

`http://www.eso.org/observing/etc`

it returns a good estimation of the on source integration time necessary to achieve a given S/N, as a function of atmospheric conditions.

A few notes on *input parameters* :

- the parameters to be provided for the input target are standard. The input magnitude can be specified for a point source, for an extended source (in which case we compute an integration over the surface defined by the input diameter), or as surface brightness (in which case we compute values per square arcseconds.

- if an AO guide star is used, do not forget to *tick the box AO* under instrument set-up, and provide the values for AO guide star distance, its R mag and (B-R) color. The two latter can be obtained from many of the online star catalogs (e.g. GSC II, USNO, UCAC, ...), and are used to compute how much photons will be available to the wavefront sensor (whose response curve ranges from 450nm to 900nm and peaks around 650nm).
- Results can be given as exposure time to achieve a given S/N or as S/N achieved in a given exposure time. In both cases, you are requested to input a typical DIT, which for long exposures will probably be anything between 300 and 900s, typically.

The *output from the ETC* summarize your input values and provides some output for which you should remember the following:

- The integration time is given on source: depending on your technique to obtain sky measurements, and accounting for overheads, the total observing time will be much larger.
- The S/N is given per spectral pixel, not per resolution element! i.e. to compute your S/N for a resolution element, make sure that you sum the right number of pixels (typically 2).

For more detailed information on ETC see online help provides as links from the ETC page.

## 5.8 Proposal form

For CRIRES proposals, no specific input to the ESO proposal form is needed.

In particular, as CRIRES can be used with and without AO guide star, your target list will not be checked for valid AO guide stars (as it is done e.g. for NACO). However, you are requested to state whether you will or will not use AO. Choices of set-ups are given below.

```
%\INSconfig{}{CRIRES}{no-AO}{provide HERE list of setting(s) (J,H,K,H+K, ?????)}
%\INSconfig{}{CRIRES}{NGS}{provide HERE list of setting(s) (J,H,K,H+K, ????)}
%
```

# 6 Preparation of observing blocks

This sections guides through some details in preparing CRIRES observing blocks during ESO proposal submission phase 2. Observations may either be submitted for service or visitor mode. Familiarize yourself with some general information about phase 2 and submission of OBs by consulting the following web pages:

`http://www.eso.org/observing/observing.html`
and
`http://www.eso.org/observing/p2pp`
and
`http://www.eso.org/paranal/sciops`

These web pages set the phase 2 policy and its information overrules this manual. Unlike other VLT instruments OB preparation for CRIRES does not require specific software preparation tools.

## 6.1 Information required

The following information is required for a successful creation of CRIRES observing blocks:

- Target coordinates: Also CRIRES has a slit viewer target coordinates should be as precise as possible.
- Observations with AO guide star: target coordinates are offset from the AO guide star coordinates, i.e. it is *strongly recommended* to obtain the AO guide star and target coordinates from the same catalog/reference system. Further, the AO guide star coordinate should be accurate enough such that it is visible during the acquisition performed. VLT absolute pointing accuracy is $1'' - 2''$ .
- Observations without AO guide star: there are two possibilities.: i) to specify the *telescope* guide star in the acquisition template, and provide target coordinates in the same reference system – this will guarantee a pointing accuracy of typically $0.1''$ –$0.2''$ . Or ii) to point to a bright, nearby star and perform an offset from this star at the end of your acquisition. In this case, coordinates of science target and bright star shall be from the same reference system.
- Sky measurements: Using the long slit of CRIRES and by nodding with an amplitude smaller than the slit length ($50''$ ) the object is still in the slit while the sky is measured. Otherwise sky measurements have to be obtained from offset fields, and the acquisition templates allow for several option (see Sec. 10). The frequency of sky measurements depend on the band (more frequent in J, H, less in K) and on the accuracy on which one wants to subtract them. Sky variations are of order a few minutes. Thus sky measurements could vary from 120s to 600s. It is recommended to choose the same DIT, and vary NDIT only if noise characteristics are not important for your subtraction.

## 6.2 OBs and P2PP

CRIRES follows very closely the template design set by other VLT instruments such as ISAAC, SINFONI and NACO (see also Sect. 10).

### 6.2.1 Templates

Here we give an overview of the CRIRES templates. A more detailed description can be found in Sec. 10.

**Acquisition**

Two acquisition templates allow to distinguish between the cases of observing without AO (`..._acq_noAO`) and with a Natural Guide Star (NGS) for AO corrections (`..._acq_NGS`).

The former resembles other VLT acquisition templates, except for two particularities:

- It allows to flag whether the Deformable Mirror (DM) should be flatten after the telescope preset, before the observations – this is highly recommended in order to obtain the best image quality.
- It allows an end-offset to be made, i.e. to acquire a bright star and perform a known offset to the real target.

The acquisition for AO using a natural guide star has also a few particularities, concerning information on the AO guide star:

- It requires the absolute coordinates of the AO guide star. Unless you tick the box 'Target = AO Guide Star' in which case it will use the target coordinates as the one for the AO guide star.
- It also asks for the B-R color of the AO guide star. This is used to compute the guiding wavelength for the field selector holding the AO guide star. Which in turn is used to correct for atmospheric refraction effects. [Roughly speaking: the field selector takes over the function of the telescope guiding in AO mode by locking on the AO star; for longer observations at high airmass, or during acquisition, the offset due to atmospheric refraction at the different wavelength (visible on the AO system vs. NIR on the spectrograph) needs to be taken into account].
- Finally, it requires the FWHM of the AO Guide star in order to optimize a diaphragm in the AO system. This diaphragm is set as a function of the seeing such as to optimize the amount of light received from the object with respect to the amount of background light from the sky. If your object is a point source, leave this to zero (only the seeing will be taken into account). Only if your AO guide 'star' is significantly extended with respect to the seeing (i.e. comparable to the seeing value), this optimization parameter will have a noticeable effect.

Finally, both acquisition templates will usually acquire during the acquisition sequence a sky image to be subtracted from the object image (to enhance the contrast). If your object is bright in the NIR (e.g. K<10 mag), this is not needed and you can save a bit of time by setting the "Alpha and Delta offset to sky" to 0 – this will force the template to skip the sky measurement.

**Observing**

The observing templates are standard if you have observed with other NIR instruments at the VLT or NTT. They allow variations in the strategy of obtaining sky measurements.

**Calibration**

Darks, arc (wavelength calibration), and lamp (flat-field) exposures are taken during daytime as part of the calibration plan (see sect. 9).

If, for a particular reason, you wish to obtain arcs or lamps immediately after your exposure, you can attach the template `..._cal_Nightcalib` at the end of your OB. However, any kind of instrument flexure in the spectral direction are very small.

If you wish to estimate exactly the image quality obtained on your AO guide star, you can insert in your OB the template `..._cal_NGS` immediately after your acquisition. This will set back the AO guide star into the spectrograph field of view and obtain an image of the NGS which can later be used for performance/PSF analysis.
Note that such an image is *not* taken by default during the acquisition (unlike for NACO for example).

Telluric standard stars are part of the calibration plan for all your observations. PSF standard stars are *not*. If you wish to observe a PSF standard star, prepare a corresponding OB with the template `..._cal_PSF`.

### 6.2.2 Observing Blocks – OBs

Any CRIRES science OB should contain one and only one acquisition template, followed by a number of science templates.

CRIRES foresees two cases in which calibration templates can be attached to such science OBs.
The special nighttime calibrations (`..._cal_Nightcalib`), that can be attached after every set-up in the OB, or preferably the OB should contain only one instrument set-up and the Nightcalib template be attached to the end of the OB.
And `..._acq_NGS`, to be attached typically right after the acquisition template in order to record an image of the AO Natural Guide Star.

### 6.2.3 P2PP

Using P2PP to prepare CRIRES observations does not require any special functions:. Also no file has to be attached except for the finding chart, all other entries are standard.

## 6.3 Finding Charts

In addition to the general instructions on finding charts and README files that are available at:

http://www.eso.org/observing/p2pp

the following is recommended:

- Ideally, the finding chart should show the filed in the NIR, or at least in the red, and the wavelength of the image should be specified in the FC or the README file.
- The AO guide star (if used) should be clearly marked.
- The bright star from which to offset (if used) should be clearly marked.
- The 0.2″ ×50″ field-of-view of the slit should be marked.
- The OB names for PSF calibration stars should be prefixed with the string *PSF_*.

- The magnitude of the brightest object in all fields, including standard stars, should be explicitly given in the README file (or otherwise indicated on the Finding Charts).

# 7 Observing with CRIRES at the VLT

## 7.1 Overview

As for all ESO/VLT instruments, users prepare their observations with the P2PP software. Acquisitions, observations and calibrations are coded via templates (Sec. 10) and two or more templates make up an Observing Block (OB). OBs contain all the information necessary for the execution of an observing sequence. CRIRES and the telescope are setup according to the contents of the OB. They are executed by the instrument operator.

The CRIRES Real–Time Display (RTD) is used to view the raw frame as well as the reconstructed images. During acquisition sequences, it is mostly used in slit viewer mode, for proper centering of the targets in the slit. Scientific exposures are typically checked in the raw frame display mode, in order to view spectral features. Beside an overview of the instrument set-up, the wavefront pupil as well as other information on the AO system can be displayed on a separate screen.

Daytime calibrations are executed the following morning by observatory staff.

## 7.2 Visitor Mode Operations

Information/policy on the Visitor Mode operations at the VLT are described at:

http://www.eso.org/paranal/sciops

The procedure for CRIRES does not deviate from the standard operations.

Visitors should be aware that about 30 minutes of their time will be taken for calibrations: for each scientific target for which the users do not observe a telluric standard, the observatory staff will do so.

## 7.3 The influence of the Moon

Moonlight does not noticeably increase the background in any of the CRIRES modes, so there is no need to request dark or gray time for this reason. However, it is recommended not to observe targets closer than 30$^{\rm O}$ to the moon to avoid problems linked to the telescope guiding/active optics system. The effect is difficult to predict and to quantify as it depends on too many parameters. Just changing the guide star often solves the problem. Visitors are encouraged to carefully check their target positions with respect to the Moon at the time of their scheduled observations. Backup targets are recommended whenever possible, and users are encouraged to contact ESO in case of severe conflict (i.e. when the distance to the Moon is smaller than 30$^{\rm o}$). Visitors can use the tools that are available at http://www.eso.org/observing/support.html (select the link "airmass" which is under "User Support Tools") to help determine the distance between targets and the moon for given dates.

However, the moon may affect the quality of the adaptive optics correction, if the source used for wavefront sensing is fainter than R=15 mag. In these cases, reducing the lunar illumination (FLI) constraint to approximately 0.7 and increasing the distance to the Moon to approximately 50 degrees is generally adequate. Even here, it is important not to over-specify the constraints, as this reduces the chances of the Observing Block to be executed.

## 7.4 Target Acquisition

Schematic description of the sequence of events occurring during the target acquisition.

The acquisition sequence for observation with AO is the following:
- Preset the telescope to the target coordinates
- offset the telescope to the AO guide star
- Interactively allow to re-center the AO guide star
- Close the loop, and offset the telescope back to the target
- Interactively allow to re-center the target in the slit

The acquisition sequence for observation without AO is the following:
- Preset the telescope to the target coordinates
- Flatten the Deformable Mirror using the calibration fiber
- Interactively allow to re-center the target in the slit
- If requested, offset from the centered object (e.g. to point to a faint target)

## 7.5 Offset conventions and definitions

CRIRES follows the standard astronomical offset conventions and definitions.

All offsets are given in arc seconds, but the reference system can be chosen to be the sky (Alpha, Delta) or the Detector (X,Y).

For a position angle of 0, the reconstructed image on the RTD will show North up and East left. The positive position angle is defined from North to East.

Note that the templates use cumulative offsets!
That is, your position at a given time is derived from the *sum* of all offsets specified so far in the template.
For example, the series of offsets: 0, -10, 0, 10 brings you back to the original position for the last exposure. This could have been the definition of a series in which we define an exposure on object, followed by two sky exposures at -10″ of the original position, before pointing back on the object for the fourth exposure.

## 7.6 Overheads

The telescope and instrument overheads are summarized below.

| Hardware Item | Action | Time (minutes) |
|---|---|---|
| Paranal telescopes | Preset | 6 |
| Paranal telescopes | Offset | 0.25 |
| CRIRES | Acquisition without AO | 3 |
| CRIRES | Acquisition with AO | $2 + 4 * (\mathrm{DIT} * \mathrm{NDIT})$ |
| CRIRES | Acquisition target (with/without AO) | $4 + 4 * (\mathrm{DIT} * \mathrm{NDIT})$ |
| CRIRES | Instrument setup (grating change) | 2.5 |
| CRIRES | Science exposure read-out (per DIT$>$ 1min) | 1 |

Note: table needs to be updated! ???

For acquisition with AO, DIT and NDIT refer to the ones requested for the AO natural guide star (NGS). Instrument set-up is usually absorbed in the telescope preset. Changing grating within an OB is *very slow* (2.5 min on average).

Acquisition without AO takes 3 minutes, mostly used to drive in the calibration fiber, close the AO loop once in order to flatten the deformable mirror, and drive out the fiber. In this way, the optimal image quality at the telescope preset is obtained.

# Part III

# CRIRES data format

## 8 The CRIRES data reduction cookbook

The CRIRES pipeline has been/will be developed by ESO/DMD and uses the ESO/CPL library. The main observation templates are supported by the pipeline reductions. Raw images are recombined, spectra extracted and calibrated in wavelength. Sensitivity estimates based on standard star observations are provided.

More information will be found at:
`http://www.eso.org/observing/dfo/qc`
once the pipeline will be ready for distribution.

# Part IV

# Reference Material

## 9 CRIRES scientific calibration

The calibration plan defines the default calibrations obtained and archived for you by the Paranal Science Operations. This is what you can rely on without asking for any special calibrations. CRIRES science calibrations plan includes the following measurements. AO calibration tasks are not mentioned.

| Calibration | Purpose |
|---|---|
| CRIRES_spc_cal_Darks | Darks and bad pixel map, instrumental background |
| CRIRES_spc_cal_DetecTrans | RON, gain, bad pixel |
| CRIRES_spc_cal_Flats | Pixel to pixel gain variation, flats |
| CRIRES_spc_cal_Emis | Pixel to wavelength relation using emission lines |
| CRIRES_spc_cal_Abs | Pixel to wavelength relation using absorption lines |
| CRIRES_spc_cal_Dist | Fit parameters for distortion map |
| CRIRES_spc_cal_StandardStar | Photometric conversion, sensitivities |
| CRIRES_spc_cal_scale | Measure plate scale on binary stars |
| CRIRES_spec_cal_prism | Measure transmission profile of the prism |

# 10 CRIRES template reference

All scientific and calibration observations with ESO instruments are prepared as observing blocks (OBs) with the phase 2 proposal preparation tool (P2PP). The scheduling of these OBs is then done on the site with the broker of observing block (BOB) and p2pp in visitor mode and with bob and the observation tool (OT) during service mode observation runs.

Observing blocks consist of the target information, a small number of user selected templates, the constraints sets and the scheduling informations. The observing templates which are described below are lists of keywords (parameters of the respective templates) to define the configuration and setup to be used for the respective observations.

Parameters are user defined or hidden to the user to simplify the appearance of the parameter lists. Hidden parameters cannot be changed by the users but by the instrument operators. Since the hidden parameters will be rarely changed during science observation runs we do not provide an explanation here in the template reference section.

Unlike for other instruments there are only a few templates available for CRIRES. There exists only one acquisition template which however is a rather complex tool box operated by the instrument operator. The user has only to specify input parameters. A summary of supported templates together with the short description is given in the following table:

| acquisition templates | functionality | comment |
|---|---|---|
| CRIRES_ifs_acq_NGS | Interactive Natural Guide Star Acquisition | recommended |
| science templates | | |
| CRIRES_ifs_obs_GenericOffset | IFS with user defined offsets | |
| night calibration templates | | |
| CRIRES_ifs_cal_StandardStar | Standard star calibration observation | calibration plan |
| day time calibration templates | | |
| CRIRES_ifs_cal_Darks | Darks calibration | calibration plan |

Most users can prepare the complete observation runs with templates marked as "recommended". The calibration templates marked as "calibration plan" are executed by the observatory staff without being specifically requested during the phase 2 observation preparation. The observatory will guarantee that these basic calibration observations are taken within the framework of the calibration plan.

A typical observation block with natural guide star adaptive optics in a normal field would consist of the following templates:

| | |
|---|---|
| CRIRES_ifs_acq_NGS | natural guide star acquisition |
| CRIRES_ifs_obs_xxxx | staring/nodding along/perpendicular to the slit |

Calibration templates could be of interest in the case that special night time standards or calibrations are requested. Night time arcs and flats are typically not needed even though they are offered for the time being.

The usual rules for OBs apply: you can include only 1 acquisition template, it can be followed by several science templates, changes to set-up are possible between the science templates, offsets of more than typically 1 arcmin will imply the re-acquisition of the telescope guide star, i.e. produce a large overhead (unless you specify smartly your telescope guide star in the template).

## 10.1 Acquisition Templates

The purpose of an acquisition template is to point the telescope (preset) to a given celestial position. Four different CRIRES acquisition tasks are distinguished:

1. science target used for AO and SV. This should be the default option.
2. AO and SV adjusted on bright – compact object outside the slit and where science target (e.g. nebulosity) position is given as offsets from bright – compact object
3. no AO, calibration star is used and the slit is wide open $(> 0.5 - 1")$
4. no AO, on extended science object without bright – compact object in the field.

The slit is, at the moment, mechanically frozen to a fixed slit width of 0.2″ so that it cannot be moved as foreseen in task 3 above and is therefore omitted. All acquisition tasks required for CRIRES are implemented using a single interface which is driven by pop up windows. Starting from the usual BOB interface which is shown in Fig.18 there are four additional interactive windows as for the four main steps during the acquisition tasks. For each step the pop-up window gives a short description followed by a parameter section with default parameters. They can be overwritten by the IOP. After parameters are reviewed the IOP can execute them by clicking on SETUP. The window include a short message of the action describing the next acquisition step. The interface is coded so that the IOP is able to go to the next step but it also able to return back to the previous step without aborting the sequence. The four main acquisition steps are:

- Center NGS in open AO loop (Fig.19)
- Fine center NGS and close AO loop (Fig.19)
- Center target in closed loop (Fig.20)
- Adjust slit viewer guiding (Fig.20)

The main function of the acquisition template is to preset the telescope, to setup the instrument and to move the target to the center of the field of view. Furthermore the acquisition sequence will start, in case it is requested, the adaptive optics in closed loop mode or flatten the deformable mirror which is required to achieve good image quality in open loop (no AO). Optionally a sky subtraction frame can be taken in an offset field for faint targets. Finally some adjustment to the SV camera can be performed.

In the following the acquisition template keywords are described:

## 10.2 Parameter description:

| **CRIRES−0.01/CRIRES_acq.tsf** | | |
|---|---|---|
| *To be specified:* | | |
| Parameter | Range *(Default)* | Label |
| **SEQ.TIME** | 60..3600 *(NODEFAULT)* | Total integration time (sec) |
| **TEL.TARG.ALPHA** | ra *()* | |
| **TEL.TARG.DELTA** | dec *()* | |
| **TEL.TARG.EQUINOX** | *(2000.0)* | |
| **TEL.TARG.ADDVELALPHA** | *(0.0)* | RA additional tracking velocity |
| **TEL.TARG.ADDVELDELTA** | *(0.0)* | DEC additional tracking velocity |
| **TEL.TARG.WCONJY** | 0..300000 *(1)* | Source/Line flux in Jy or Jy/arcsec$^2$ at observing wavelength |
| **TEL.TARG.HMAG** | -2..10 *(0.)* | Source magnitude in H |
| **TEL.TARG.KMAG** | -2..10 *(0.)* | Source magnitude in K |
| **TEL.TARG.VMAG** | -2..15 *(0.)* | Source magnitude in V |
| **TEL.ROT.OFFANGLE** | -235..235 *(0.)* | PA on sky (deg) |
| **TEL.AG.GUIDESTAR** | CATALOGUE SETUPFILE NONE *(CATALOGUE)* | Get Guide Star from |
| **TEL.GS1.ALPHA** | ra *()* | Guide star RA |
| **TEL.GS1.DELTA** | dec *()* | Guide star DEC |
| **TEL.SKY.OFFALPHA** | -120..120 *(0.)* | Tel offset RA to sky (deg) |
| **TEL.SKY.OFFDELTA** | -120..120 *(30.)* | Tel offset Dec to sky (deg) |
| | | |
| **SEQ.NGS.ISTARGET** | T..F *T*) | Target is AO GS |
| **SEQ.NGS.ALPHA** | ra *()* | RA of AO GS |
| **SEQ.NGS.DELTA** | dec *()* | Dec of AO GS |
| **SEQ.NGS.MAG** | -2..25 *(12)* | AO GS magnitude in R |
| **SEQ.NGS.COLOR** | -1..5 *()* | AO GS B-R |
| **SEQ.NGS.FWHM** | -0..10 *(0)* | AO GS FWHM (arcsec) |
| | | |
| **DET.DIT** | *isf*) | Detector integration time (s) |
| **DET.NDIT** | *isf*) | Number of integrations |
| **INS.WLEN** | CATALOGUE SETUPFILE NONE *(CATALOGUE)* | Order/Sub-order/Nominal-Interlaced (e.g. interlaced: "19/2/I") |
| **INS.DROT.MODE** | ELEV, SKY, STAT *(ELEV)* | Mode of de-rotation |
| **INS.DROT.POSANG** | 0..359 *(0.0)*[1] | Position Angle on sky |
| *Hidden parameters* | | |
| **SEQ.PRESET** | T..F *(T)* | Telescope preset flag |
| **DPR.CATG** | ACQUISITION | Data product category |
| **DPR.TYPE** | OBJECT | Data product type |

---

[1] North = 0$^o$ ; East = 90$^o$

Parameter ranges for H,K magnitudes needs to be determined according to slit viewer detector starvation or saturation limits, respectively.

Parameter ranges for V magnitude needs to be determined according to AO requirements

**INS.WLEN.ID:** defines the optical configuration of the instrument and set up DIT and the detector read out mode. INS.WLEN.ID is given by three parameters: *order number, scanning number and mode*. Higher order numbers are at short wavelengths where it is not necessary to scan the order to get its full wavelength range. However, at larger wavelengths, respectively small order numbers, the detector cannot cover the full wavelength range of the order. In this case and to be able to measure the complete order one needs to apply a scanning strategy. For the highest wavelengths up to 5 scans are necessary. They are labeled by an interger number which is $\leq \pm 2$. Finally, INS.WLEN.ID includes the mode, which can be 'I' for interlaced or 'n' for normal. In normal mode there are gaps in spectral regions which coincide with physical gaps between the four individual detectors. To fill those gaps the inerlaced mode is applied. One example of INS.WLEN.ID is '59/0/n'. The observer is restricted to enter values of INS.WLEN.ID as described in Appendix X.

**DIT and NDIT** are Detector Integration Time and the number of DITs to be integrated before writing the data to the disk. NDIT is a user defined parameter and controls the total nitegration time but DIT is not. DIT is specified by the optical configuration which is given by INS.WLEN.ID.

**RA, DEC, Equinox and Position angle on the sky** define the respective celestial target coordinates. The position angle on the sky is given in the standard astronomical convention (N = 0, NE = 45, E = 90, …in degrees). Note that for PA=0 (North up, East left), the slitlets are oriented East-West, i.e. you will coarsely sample the field in the North-South direction (250,100,25 mas per spaxel) and obtain a finer sampling of the field in East-West direction (125,50,12.5 mas per spaxel). Also, for PA=0 the slitlet number 1 will lie at the top of the detector (high y).

**Differential tracking** is only available for the telescope. There is no differential tracking between the natural guide star and the target. Accordingly the adaptive optics loop can be only closed on the moving target and not on background stars. The value is to be given in units of arcseconds/s. For service mode observations, an ephemerides file needs to be provided. Please consult the P2PP manual concerning the format and submission procedure.

**Telescope guide stars** are either selected from the "CATALOG"s available at the telescope, or selected by the users if the option "SETUPFILE" was selected.

**Telescope offset RA, DEC to sky:** These keywords define the position where the sky field is to be observed if set to values "$! = 0$". The sky exposure is taken before starting the interactive target identification. If the value is set to $= 0$, the step is skipped and the overhead time is shortened. It may not be the best choice to skip the sky for faint targets of $J, H, K, H + K >> 15$.

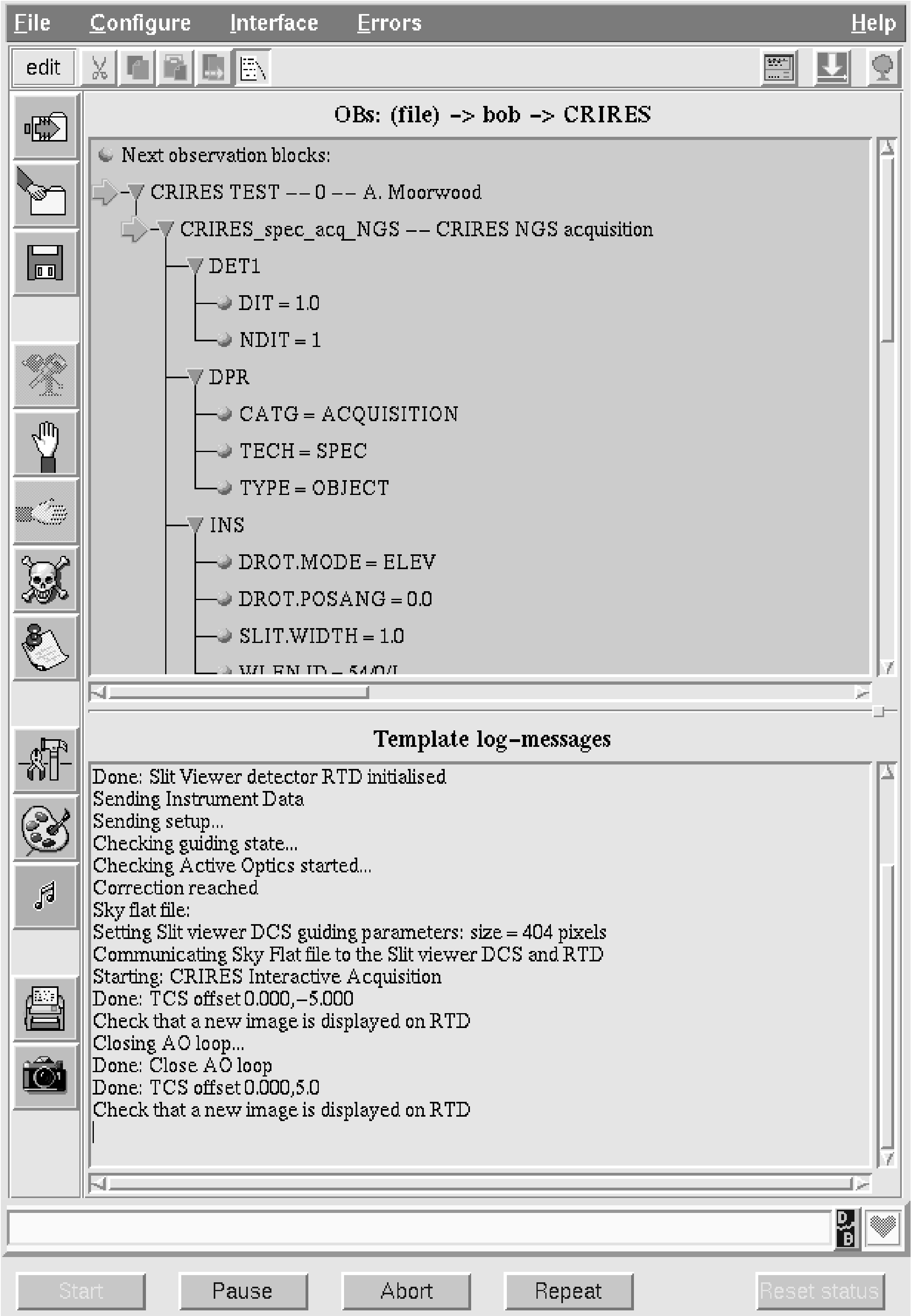
**Please note:** The coordinates of the telescope guide star, the target and the natural guide star of the AO system should be measured in the same consistent coordinate system with an accuracy of a small fraction of the CRIRES field of view. For bright natural guide stars (NGS) the AO system will detect in closed loop the small offsets of the NGS and correct it with a tip tilt movement of the deformable mirror.

**NGS parameters:** The parameters for the AO guide star are a logical flag (Science Target = AO Guide Star) and the coordinates of the AO guide star in RA and DEC (for the equinox we presume the value given for the target coordinates). Furthermore the approximate size of the AO guide star (0 for point sources, only specify the size if you expect it to contributed significantly with respect to the seeing) and the approximate color of the AO guide star are to be selected.These parameters are required to properly setup the AO system with respect to aperture size of the WFS and differential atmospheric refraction between the visual light WFS and the IR spectrograph.

For any NGS fainter than 11 or 12 magnitudes it is mandatory that the telescope guide star coordinates are given by the user and aligned defined in the same reference system as the AO guide star (Telescope Guide Star Selection == SETUPFILE). The reason for this is that slight inaccuracies ($\sim 2''$ ) in the telescope and/or AO guide star coordinates could not be corrected for by the field selector - for brighter magnitudes the field selector 'drags' back and centers the AO guide star .

For normal field (not for globular clusters, not for the galactic center,. . . ) the coordinates of the UCAC2 catalog should be accurate enough. The coordinates of the science target and NGS should be also known in the absolute celestial coordinate system in case of a UCAC2 telescope guide star.

**Blind Offsets:** In case of blind offset acquisitions the coordinates of the reference star must be entered into the target package of p2pp. The offsets are defined from the reference star to the target (positive offsets for targets North/East of the reference stars). The relative offset between reference star and target should be accurately known to about a small fraction of the field of view.

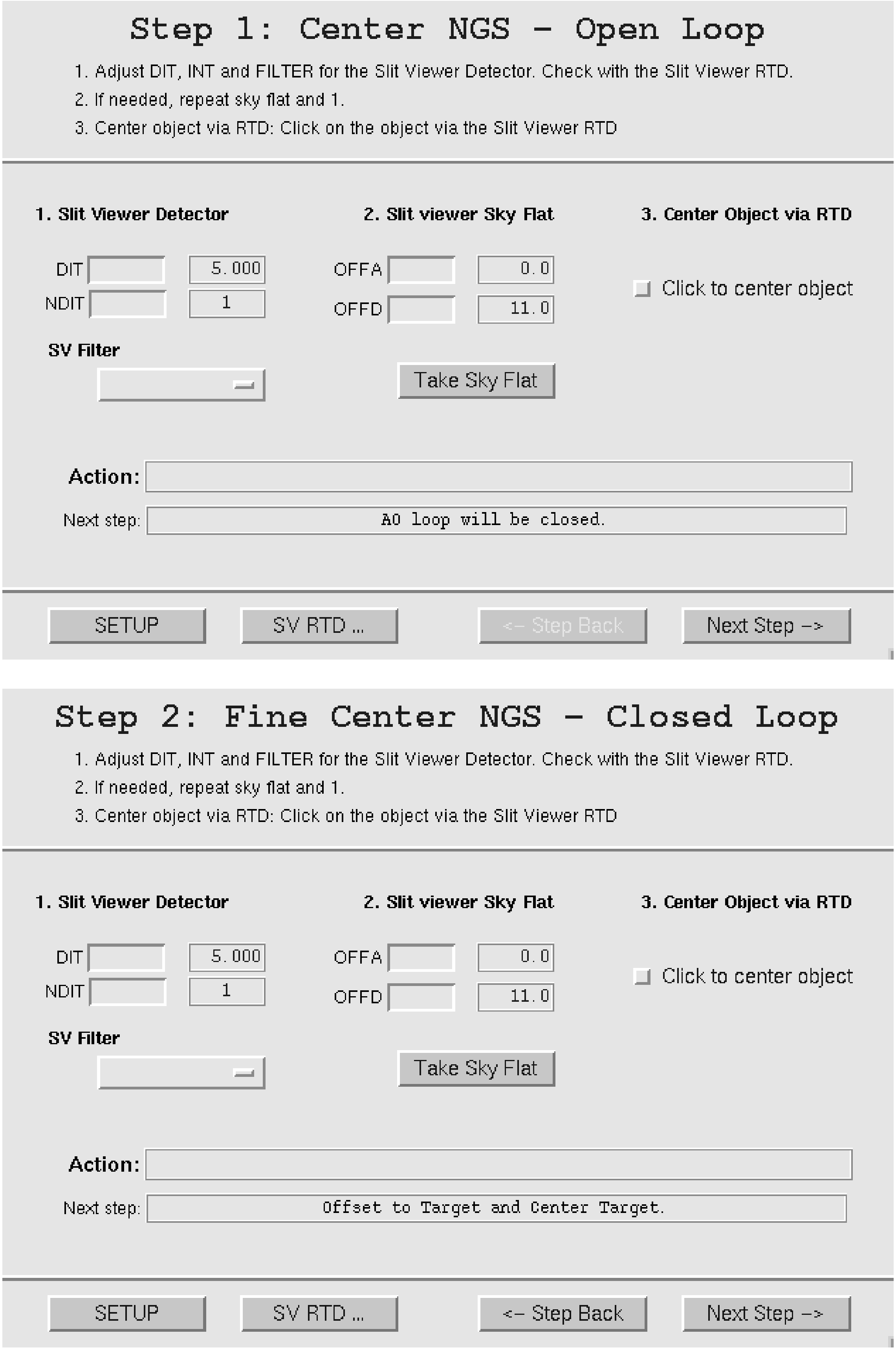


Next observation blocks:

- CRIRES TEST -- 0 -- A. Moorwood
  - CRIRES_spec_acq_NGS -- CRIRES NGS acquisition
    - DET1
      - DIT = 1.0
      - NDIT = 1
    - DPR
      - CATG = ACQUISITION
      - TECH = SPEC
      - TYPE = OBJECT
    - INS
      - DROT.MODE = ELEV
      - DROT.POSANG = 0.0
      - SLIT.WIDTH = 1.0

```
Done: Slit Viewer detector RTD initialised
Sending Instrument Data
Sending setup...
Checking guiding state...
Checking Active Optics started...
Correction reached
Sky flat file:
Setting Slit viewer DCS guiding parameters: size = 404 pixels
Communicating Sky Flat file to the Slit viewer DCS and RTD
Starting: CRIRES Interactive Acquisition
Done: TCS offset 0.000,-5.000
Check that a new image is displayed on RTD
Closing AO loop...
Done: Close AO loop
Done: TCS offset 0.000,5.0
Check that a new image is displayed on RTD
```

Figure 18: BOB window interface of acquisition template .



Step 1: Center NGS - Open Loop

1. Adjust DIT, INT and FILTER for the Slit Viewer Detector. Check with the Slit Viewer RTD.
2. If needed, repeat sky flat and 1.
3. Center object via RTD: Click on the object via the Slit Viewer RTD

**1. Slit Viewer Detector**

DIT 5.000

NDIT 1

**SV Filter**

**2. Slit viewer Sky Flat**

OFFA 0.0

OFFD 11.0

**3. Center Object via RTD**

☐ Click to center object

**Action:**

Next step: AO loop will be closed.

Step 2: Fine Center NGS - Closed Loop

1. Adjust DIT, INT and FILTER for the Slit Viewer Detector. Check with the Slit Viewer RTD.
2. If needed, repeat sky flat and 1.
3. Center object via RTD: Click on the object via the Slit Viewer RTD

**1. Slit Viewer Detector**

DIT 5.000

NDIT 1

**SV Filter**

**2. Slit viewer Sky Flat**

OFFA 0.0

OFFD 11.0

**3. Center Object via RTD**

☐ Click to center object

**Action:**

Next step: Offset to Target and Center Target.

Figure 19: Pop of window of step 1 and 2 during execution of acquisition template .

Step 3: Center Target - Closed Loop

1. Adjust DIT, INT and FILTER for the Slit Viewer Detector. Check with the Slit Viewer RTD.
2. If needed, repeat sky flat and 1.
3. Center object via RTD: Click on the object via the Slit Viewer RTD

1. Slit Viewer Detector

DIT 5.000

NDIT 1

SV Filter

2. Slit viewer Sky Flat

OFFA 0.0

OFFD 11.0

3. Center Object via RTD

☐ Click to center object

Action:

Next step: Adjust guiding window size on RTD.

Step 4: Slit viewer guiding

1. Adjust DIT, INT and FILTER for the Slit Viewer Detector. Check with the Slit Viewer RTD.
2. If needed, repeat sky flat and 1.
3. Center object via RTD: Click on the object via the Slit Viewer RTD

1. Slit Viewer Detector

DIT 5.000

NDIT 1

SV Filter

2. Slit viewer Sky Flat

OFFA 0.0

OFFD 11.0

3. Center Object via RTD

☐ Click to center object

Action: Adjust guiding window size on RTD when needed.

Next step: Continue with template.

Figure 20: Pop of window of step 3 and 4 during execution of acquisition template .

## 10.3 Science Templates

Science observing templates provide various strategies for nodding between object and sky positions, for jitter offsets between images taken at the selected object and sky positions or offer the possibillity to perform staring observations. The template will automatically take exposures in an ABBA sequence with the respective A (object) and B (sky) positions randomly jittered with respect to each other. The common parameters of science templates are:

**DIT and NDIT** are the user defined integration time (for the exposures of the target) and the number of DITs to be integrated before writing the data to disk.

**Number of AB or BA cycles:** defines how often the AB cycle is repeated. Set to zero the template will just take exposures on source (position A), set to one will perform take a sequence AB, and set to two will do ABBA (object,sky, sky, object). For best sky subtraction the parameter should be set to values of one or larger.

### 10.3.1 CRIRES_obs_jitter

The science template `CRIRES_obs_jitter` follows the one of SINFONI called: `SINFONI_ifs_obs_FixedSkyOffset`. It moves the telescope alternatively between 'object' and 'sky' positions (nodding) but in one dimension which is along the slit. The 'object' positions are randomly distributed (jittered) around the object (initial telescope position) and within a box whose dimensions are set by the parameter "Jitter box width" (in arcsec). The jitter is only performed along the slit. The size of the jitter box should be typically a few arcsec. If set to zero no jitter will be performed. The default parameters are those for staring observations.

The offsets are along the slit positions and are randomly distributed around a fixed offset position and defined by the parameter "INS.NODTHROW" from the original (target) telescope position. The dimension of the random positions are along the slit and set by the parameter "Jitter box width" around the initial 'sky' position, and therefore identical to those of the target jitter box.

The following two items are already defined by the acquisition task: i) Derotation can be done in sky or elevation mode and is given by INS.DROT.MODE. ii) The positon angle of the slit is given by TEL.ROT.OFFANGLE and is defined as the negative of the astronomical position angle (P.A.) on the sky: TEL.ROT.OFFANGLE = −P.A. and is measured counter clockwise from North to East.

| **CRIRES_obs_jitter** | | **IFS with jitter and nodding** | |
|---|---|---|---|
| *Parameters to be specified:* | | | |
| **Parameter** | **Range** | **Default** | **P2PP Label** |
| INS.WLEN.ID | isf | NODEFAULT | Wavelength ID: '58/1/n' |
| SEQ.NDIT | 1..10000 | NODEFAULT | NDIT read-outs |
| SEQ.JITTER.WIDTH | 0..8 | 0 | Jitter box width in arcsec |
| SEQ.NABCYCLES | 0..100 | 0 | Number of AB cycles, 0 for staring on source |
| INS.NODTHROW | 0..60 | 0 | Nodding offset along the slit (″) |
| *Hidden parameters:* | | | |
| SEQ.POISSON | 1..100 | 10 | |
| SEQ.RETURN | T F | T | Return to Origin ? (T/F) |
| DPR.CATG | SCIENCE | SCIENCE | Data product category |
| DPR.TECH | IFU,NODDING | IFU,NODDING | Data product technique |
| DPR.TYPE | OBJECT | OBJECT | Data product type |

## 10.4 Nighttime Calibration Templates TBW

There are xxxx templates available to calibrate during the night. The StandardStar template is used to observe telluric standards of known JHK magnitudes to allow the removal of telluric features and to derive an estimate of the instrument response function for the flux calibration of the science data. This template would be typically used by the observatory staff spart of the calibration plan, unless there is a special request for a user selected standard. In that case, the user has to supply his/her own standard using this template. The PSF template is available to obtain an estimate of the instrument PSF by observing a user selected (typically bright) PSF reference star. The StandardStar and PSF templates are identical to the GenericOffset template in keyword content and function. There is furthermore an NGS template offered which will center the natural guide star (NGS) to the center of the image slicer to estimate the PSF by on-axis observations of the NGS. There are no parameters to be set in the template except the DIT, NDIT and a fixed sky offset. The template is only useful if target and NGS are not identical.

Attached lamp calibrations are also provided. These templates will read the exposure times and lamp setups from a local data base. Accordingly, there is only one parameter left over – the spectral dither flag – which defines whether spectrally dithered calibration should be taken or not.

## 10.5 Daytime Calibration Templates TBW

The day time calibration observations are typically prepared by the staff astronomers with an automatic tool (calobBuild) which will scan the headers of the frames taken during the nights. Based on this data it will then define and sort the required sequence of calibration exposures according to the CRIRES calibration plan. It is not foreseen that users will use any of the day time calibration templates below. We only present these templates to provide a reference between the data files and the respective templates.

# 11 CRIRES wavelength configuration

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Begin | End | Begin | End | Begin | End | Begin | End |
| NAME wave-length ID | Reference Wavelength nanometer [nm] | File name spectral reference | Detector # 1 | Detector # 1 | Detector # 2 | Detector # 2 | Detector # 3 | Detector # 3 | Detector # 4 | Detector # 4 |
| | | | | | | | | | | |
| 59/0/n | 958.003 | OH_Lines | 943.523 | 948.517 | 949.899 | 954.698 | 955.962 | 960.560 | 961.754 | 966.145 |
| 59/0/i | 958.003 | OH_Lines | 946.432 | 951.375 | 952.743 | 957.491 | 958.740 | 963.287 | 964.466 | 968.805 |
| 58/0/n | 974.520 | OH_Lines | 959.796 | 964.875 | 966.280 | 971.160 | 972.445 | 977.121 | 978.334 | 982.799 |
| 58/0/i | 974.520 | OH_Lines | 962.754 | 967.781 | 969.171 | 974.000 | 975.270 | 979.893 | 981.093 | 985.504 |
| 57/0/n | 991.617 | OH_Lines | 976.641 | 981.806 | 983.235 | 988.199 | 989.506 | 994.262 | 995.496 | 1000.038 |
| 57/0/i | 991.617 | OH_Lines | 979.649 | 984.762 | 986.177 | 991.088 | 992.380 | 997.082 | 998.302 | 1002.789 |
| 56/0/n | 1009.324 | OH_Lines | 994.087 | 999.342 | 1000.796 | 1005.847 | 1007.176 | 1012.016 | 1013.272 | 1017.893 |
| 56/0/i | 1009.324 | OH_Lines | 997.148 | 1002.350 | 1003.789 | 1008.786 | 1010.100 | 1014.885 | 1016.126 | 1020.692 |
| 55/0/n | 1027.676 | OH_Lines | 1012.167 | 1017.516 | 1018.996 | 1024.137 | 1025.490 | 1030.415 | 1031.693 | 1036.397 |
| 55/0/i | 1027.676 | OH_Lines | 1015.282 | 1020.577 | 1022.042 | 1027.127 | 1028.466 | 1033.336 | 1034.599 | 1039.246 |
| 54/0/n | 1046.707 | OH_Lines | 1030.917 | 1036.363 | 1037.869 | 1043.103 | 1044.481 | 1049.496 | 1050.797 | 1055.586 |
| 54/0/i | 1046.707 | OH_Lines | 1034.088 | 1039.479 | 1040.970 | 1046.149 | 1047.511 | 1052.470 | 1053.756 | 1058.488 |
| 53/0/n | 1066.456 | OH_Lines | 1050.373 | 1055.920 | 1057.455 | 1062.786 | 1064.189 | 1069.297 | 1070.622 | 1075.500 |
| 53/0/i | 1066.456 | OH_Lines | 1053.604 | 1059.095 | 1060.613 | 1065.887 | 1067.275 | 1072.325 | 1073.636 | 1078.455 |
| 52/0/n | 1086.965 | OH_Lines | 1070.579 | 1076.230 | 1077.794 | 1083.225 | 1084.655 | 1089.859 | 1091.210 | 1096.179 |
| 52/0/i | 1086.965 | OH_Lines | 1073.870 | 1079.464 | 1081.012 | 1086.385 | 1087.799 | 1092.945 | 1094.280 | 1099.191 |
| 51/0/n | 1108.278 | OH_Lines | 1091.576 | 1097.336 | 1098.930 | 1104.466 | 1105.923 | 1111.228 | 1112.605 | 1117.670 |
| 51/0/i | 1108.278 | OH_Lines | 1094.931 | 1100.633 | 1102.210 | 1107.687 | 1109.128 | 1114.374 | 1115.734 | 1120.739 |
| 50/0/n | 1130.443 | OH_Lines | 1113.413 | 1119.286 | 1120.912 | 1126.557 | 1128.042 | 1133.452 | 1134.855 | 1140.021 |
| 50/0/i | 1130.443 | OH_Lines | 1116.833 | 1122.648 | 1124.256 | 1129.841 | 1131.311 | 1136.659 | 1138.047 | 1143.150 |
| 49/0/n | 1153.513 | OH_Lines | 1136.141 | 1142.133 | 1143.790 | 1149.549 | 1151.064 | 1156.582 | 1158.014 | 1163.283 |
| 49/0/i | 1153.513 | OH_Lines | 1139.630 | 1145.561 | 1147.202 | 1152.899 | 1154.398 | 1159.854 | 1161.270 | 1166.476 |
| 48/0/n | 1177.545 | OH_Lines | 1159.816 | 1165.930 | 1167.622 | 1173.499 | 1175.046 | 1180.677 | 1182.138 | 1187.516 |
| 48/0/i | 1177.545 | OH_Lines | 1163.377 | 1169.430 | 1171.104 | 1176.918 | 1178.448 | 1184.016 | 1185.461 | 1190.774 |
| 47/0/n | 1202.599 | OH_Lines | 1184.498 | 1190.741 | 1192.468 | 1198.468 | 1200.047 | 1205.797 | 1207.289 | 1212.779 |
| 47/0/i | 1202.599 | OH_Lines | 1188.134 | 1194.314 | 1196.023 | 1201.959 | 1203.521 | 1209.206 | 1210.681 | 1216.106 |
| 46/0/n | 1228.743 | OH_Lines | 1210.253 | 1216.630 | 1218.394 | 1224.523 | 1226.136 | 1232.009 | 1233.533 | 1239.141 |
| 46/0/i | 1228.743 | OH_Lines | 1213.967 | 1220.279 | 1222.025 | 1228.089 | 1229.684 | 1235.491 | 1236.998 | 1242.539 |
| 45/0/n | 1256.048 | OH_Lines | 1237.153 | 1243.670 | 1245.473 | 1251.736 | 1253.384 | 1259.386 | 1260.943 | 1266.675 |
| 45/0/i | 1256.048 | OH_Lines | 1240.948 | 1247.399 | 1249.183 | 1255.380 | 1257.011 | 1262.945 | 1264.484 | 1270.148 |
| 44/0/n | 1284.595 | OH_Lines | 1265.275 | 1271.938 | 1273.782 | 1280.186 | 1281.871 | 1288.007 | 1289.600 | 1295.460 |
| 44/0/i | 1284.595 | OH_Lines | 1269.155 | 1275.751 | 1277.576 | 1283.912 | 1285.579 | 1291.646 | 1293.221 | 1299.011 |
| 43/-1/n | 1299.404 | OH_Lines | 1278.837 | 1285.919 | 1287.881 | 1294.701 | 1296.498 | 1303.049 | 1304.751 | 1311.021 |
| 43/-1/i | 1299.404 | OH_Lines | 1282.980 | 1289.994 | 1291.936 | 1298.688 | 1300.466 | 1306.947 | 1308.631 | 1314.831 |
| 43/1/n | 1329.534 | OH_Lines | 1310.622 | 1317.156 | 1318.962 | 1325.227 | 1326.874 | 1332.863 | 1334.415 | 1340.117 |
| 43/1/i | 1329.534 | OH_Lines | 1314.407 | 1320.872 | 1322.658 | 1328.854 | 1330.482 | 1336.399 | 1337.932 | 1343.563 |
| 42/-1/n | 1330.350 | OH_Lines | 1309.300 | 1316.548 | 1318.556 | 1325.537 | 1327.376 | 1334.081 | 1335.823 | 1342.241 |
| 42/-1/i | 1330.350 | OH_Lines | 1313.540 | 1320.719 | 1322.706 | 1329.617 | 1331.438 | 1338.071 | 1339.794 | 1346.140 |
| 42/1/n | 1361.181 | OH_Lines | 1341.823 | 1348.511 | 1350.360 | 1356.773 | 1358.459 | 1364.589 | 1366.177 | 1372.015 |
| 42/1/i | 1361.181 | OH_Lines | 1345.698 | 1352.315 | 1354.144 | 1360.485 | 1362.152 | 1368.209 | 1369.778 | 1375.542 |
| 41/-1/n | 1362.806 | OH_Lines | 1341.249 | 1348.672 | 1350.728 | 1357.877 | 1359.761 | 1366.627 | 1368.411 | 1374.983 |
| 41/-1/i | 1362.806 | OH_Lines | 1345.590 | 1352.942 | 1354.978 | 1362.056 | 1363.920 | 1370.713 | 1372.478 | 1378.977 |
| 41/1/n | 1394.372 | OH_Lines | 1374.546 | 1381.396 | 1383.289 | 1389.857 | 1391.584 | 1397.862 | 1399.489 | 1405.468 |
| 41/1/i | 1394.372 | OH_Lines | 1378.514 | 1385.292 | 1387.164 | 1393.659 | 1395.366 | 1401.570 | 1403.177 | 1409.081 |
| 40/-1/n | 1396.885 | OH_Lines | 1374.795 | 1382.401 | 1384.508 | 1391.834 | 1393.764 | 1400.800 | 1402.628 | 1409.363 |
| 40/-1/i | 1396.885 | OH_Lines | 1379.244 | 1386.777 | 1388.864 | 1396.116 | 1398.026 | 1404.988 | 1406.796 | 1413.456 |
| 40/1/n | 1429.223 | OH_Lines | 1408.904 | 1415.924 | 1417.864 | 1424.596 | 1426.365 | 1432.799 | 1434.467 | 1440.594 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 40/1/i | 1429.223 | OH_Lines | 1412.971 | 1419.917 | 1421.836 | 1428.492 | 1430.241 | 1436.599 | 1438.246 | 1444.297 |
| 39/-1/n | 1432.712 | OH_Lines | 1410.061 | 1417.861 | 1420.021 | 1427.533 | 1429.512 | 1436.726 | 1438.601 | 1445.507 |
| 39/-1/i | 1432.712 | OH_Lines | 1414.623 | 1422.348 | 1424.487 | 1431.923 | 1433.882 | 1441.020 | 1442.874 | 1449.703 |
| 39/1/n | 1465.860 | OH_Lines | 1445.024 | 1452.223 | 1454.213 | 1461.115 | 1462.930 | 1469.528 | 1471.238 | 1477.521 |
| 39/1/i | 1465.860 | OH_Lines | 1449.195 | 1456.317 | 1458.285 | 1465.111 | 1466.905 | 1473.425 | 1475.114 | 1481.318 |
| 38/-1/n | 1470.425 | OH_Lines | 1447.184 | 1455.187 | 1457.403 | 1465.111 | 1467.142 | 1474.544 | 1476.467 | 1483.553 |
| 38/-1/i | 1470.425 | OH_Lines | 1451.865 | 1459.791 | 1461.986 | 1469.616 | 1471.626 | 1478.950 | 1480.852 | 1487.859 |
| 38/1/n | 1504.425 | OH_Lines | 1483.045 | 1490.432 | 1492.473 | 1499.557 | 1501.419 | 1508.189 | 1509.944 | 1516.391 |
| 38/1/i | 1504.425 | OH_Lines | 1487.324 | 1494.633 | 1496.653 | 1503.657 | 1505.497 | 1512.188 | 1513.921 | 1520.288 |
| 37/-1/n | 1510.177 | OH_Lines | 1486.314 | 1494.531 | 1496.806 | 1504.720 | 1506.806 | 1514.406 | 1516.381 | 1523.657 |
| 37/-1/i | 1510.177 | OH_Lines | 1491.120 | 1499.258 | 1501.512 | 1509.346 | 1511.410 | 1518.930 | 1520.883 | 1528.078 |
| 37/1/n | 1545.075 | OH_Lines | 1523.120 | 1530.705 | 1532.802 | 1540.075 | 1541.987 | 1548.940 | 1550.742 | 1557.362 |
| 37/1/i | 1545.075 | OH_Lines | 1527.514 | 1535.020 | 1537.093 | 1544.286 | 1546.176 | 1553.046 | 1554.826 | 1561.363 |
| 36/-1/n | 1552.138 | OH_Lines | 1527.618 | 1536.061 | 1538.399 | 1546.531 | 1548.674 | 1556.483 | 1558.513 | 1565.989 |
| 36/-1/i | 1552.138 | OH_Lines | 1532.556 | 1540.918 | 1543.234 | 1551.284 | 1553.405 | 1561.132 | 1563.139 | 1570.532 |
| 36/1/n | 1587.982 | OH_Lines | 1565.421 | 1573.216 | 1575.370 | 1582.844 | 1584.809 | 1591.954 | 1593.805 | 1600.609 |
| 36/1/i | 1587.982 | OH_Lines | 1569.937 | 1577.649 | 1579.780 | 1587.171 | 1589.113 | 1596.173 | 1598.002 | 1604.721 |
| 35/-1/n | 1596.497 | OH_Lines | 1571.283 | 1579.964 | 1582.369 | 1590.731 | 1592.935 | 1600.966 | 1603.052 | 1610.740 |
| 35/-1/i | 1596.497 | OH_Lines | 1576.360 | 1584.959 | 1587.341 | 1595.619 | 1597.800 | 1605.746 | 1607.810 | 1615.412 |
| 35/1/n | 1633.341 | OH_Lines | 1610.138 | 1618.155 | 1620.370 | 1628.057 | 1630.078 | 1637.425 | 1639.329 | 1646.327 |
| 35/1/i | 1633.341 | OH_Lines | 1614.782 | 1622.714 | 1624.905 | 1632.506 | 1634.504 | 1641.765 | 1643.646 | 1650.555 |
| 34/-1/n | 1643.466 | OH_Lines | 1617.516 | 1626.451 | 1628.926 | 1637.532 | 1639.800 | 1648.065 | 1650.213 | 1658.125 |
| 34/-1/i | 1643.466 | OH_Lines | 1622.742 | 1631.592 | 1634.043 | 1642.562 | 1644.807 | 1652.985 | 1655.109 | 1662.933 |
| 34/1/n | 1681.367 | OH_Lines | 1657.485 | 1665.736 | 1668.016 | 1675.928 | 1678.008 | 1685.571 | 1687.531 | 1694.733 |
| 34/1/i | 1681.367 | OH_Lines | 1662.265 | 1670.429 | 1672.684 | 1680.508 | 1682.564 | 1690.037 | 1691.974 | 1699.086 |
| 33/-1/n | 1693.283 | tbd | 1666.552 | 1675.756 | 1678.305 | 1687.170 | 1689.506 | 1698.020 | 1700.232 | 1708.383 |
| 33/-1/i | 1693.283 | tbd | 1671.935 | 1681.051 | 1683.576 | 1692.352 | 1694.664 | 1703.088 | 1705.276 | 1713.336 |
| 33/1/n | 1732.302 | tbd | 1707.700 | 1716.200 | 1718.549 | 1726.700 | 1728.843 | 1736.634 | 1738.653 | 1746.072 |
| 33/1/i | 1732.302 | tbd | 1712.624 | 1721.035 | 1723.358 | 1731.418 | 1733.536 | 1741.235 | 1743.230 | 1750.556 |
| 32/-1/n | 1746.214 | tbd | 1718.654 | 1728.144 | 1730.772 | 1739.912 | 1742.320 | 1751.098 | 1753.379 | 1761.783 |
| 32/-1/i | 1746.214 | tbd | 1724.204 | 1733.603 | 1736.206 | 1745.254 | 1747.638 | 1756.323 | 1758.579 | 1766.889 |
| 32/1/n | 1786.421 | tbd | 1761.053 | 1769.817 | 1772.240 | 1780.644 | 1782.853 | 1790.887 | 1792.969 | 1800.619 |
| 32/1/i | 1786.421 | tbd | 1766.130 | 1774.802 | 1777.198 | 1785.509 | 1787.693 | 1795.631 | 1797.688 | 1805.243 |
| 31/-1/n | 1802.562 | tbd | 1774.118 | 1783.912 | 1786.624 | 1796.057 | 1798.543 | 1807.602 | 1809.956 | 1818.629 |
| 31/-1/i | 1802.562 | tbd | 1779.846 | 1789.546 | 1792.232 | 1801.571 | 1804.031 | 1812.995 | 1815.323 | 1823.899 |
| 31/1/n | 1844.029 | tbd | 1817.846 | 1826.892 | 1829.392 | 1838.067 | 1840.347 | 1848.639 | 1850.788 | 1858.685 |
| 31/1/i | 1844.029 | tbd | 1823.086 | 1832.037 | 1834.510 | 1843.088 | 1845.342 | 1853.536 | 1855.659 | 1863.457 |
| 30/-1/n | 1862.667 | tbd | 1833.282 | 1843.399 | 1846.202 | 1855.947 | 1858.515 | 1867.874 | 1870.306 | 1879.266 |
| 30/-1/i | 1862.667 | tbd | 1839.199 | 1849.220 | 1851.995 | 1861.643 | 1864.185 | 1873.445 | 1875.851 | 1884.711 |
| 30/1/n | 1905.477 | tbd | 1878.424 | 1887.770 | 1890.354 | 1899.317 | 1901.673 | 1910.240 | 1912.460 | 1920.619 |
| 30/1/i | 1905.477 | tbd | 1883.838 | 1893.086 | 1895.642 | 1904.505 | 1906.834 | 1915.300 | 1917.494 | 1925.551 |
| 29/-1/n | 1926.919 | tbd | 1896.527 | 1906.991 | 1909.890 | 1919.969 | 1922.625 | 1932.305 | 1934.820 | 1944.087 |
| 29/-1/i | 1926.919 | tbd | 1902.646 | 1913.011 | 1915.882 | 1925.860 | 1928.489 | 1938.067 | 1940.555 | 1949.719 |
| 29/1/n | 1971.161 | tbd | 1943.177 | 1952.845 | 1955.517 | 1964.788 | 1967.226 | 1976.088 | 1978.384 | 1986.824 |
| 29/1/i | 1971.161 | tbd | 1948.778 | 1958.344 | 1960.987 | 1970.155 | 1972.564 | 1981.322 | 1983.591 | 1991.925 |
| 28/-1/n | 1995.763 | tbd | 1964.291 | 1975.127 | 1978.128 | 1988.566 | 1991.316 | 2001.340 | 2003.945 | 2013.541 |
| 28/-1/i | 1995.763 | tbd | 1970.628 | 1981.361 | 1984.333 | 1994.666 | 1997.388 | 2007.307 | 2009.883 | 2019.372 |
| 28/1/n | 2041.535 | tbd | 2012.554 | 2022.566 | 2025.333 | 2034.935 | 2037.459 | 2046.637 | 2049.015 | 2057.756 |
| 28/1/i | 2041.535 | tbd | 2018.354 | 2028.261 | 2030.998 | 2040.493 | 2042.988 | 2052.058 | 2054.407 | 2063.039 |
| 27/-1/n | 2069.708 | tbd | 2037.077 | 2048.312 | 2051.424 | 2062.246 | 2065.098 | 2075.491 | 2078.192 | 2088.141 |
| 27/-1/i | 2069.708 | tbd | 2043.647 | 2054.776 | 2057.858 | 2068.571 | 2071.394 | 2081.678 | 2084.349 | 2094.188 |
| 27/1/n | 2117.119 | tbd | 2087.066 | 2097.449 | 2100.318 | 2110.275 | 2112.892 | 2122.409 | 2124.876 | 2133.940 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 27/1/i | 2117.119 | tbd | 2093.081 | 2103.354 | 2106.193 | 2116.038 | 2118.626 | 2128.031 | 2130.467 | 2139.418 |
| 26/-1/n | 2149.345 | tbd | 2115.465 | 2127.131 | 2130.362 | 2141.597 | 2144.558 | 2155.349 | 2158.153 | 2168.484 |
| 26/-1/i | 2149.345 | tbd | 2122.287 | 2133.842 | 2137.041 | 2148.165 | 2151.095 | 2161.772 | 2164.546 | 2174.761 |
| 26/1/n | 2198.514 | tbd | 2167.307 | 2178.088 | 2181.068 | 2191.407 | 2194.125 | 2204.008 | 2206.569 | 2215.981 |
| 26/1/i | 2198.514 | tbd | 2173.553 | 2184.220 | 2187.168 | 2197.392 | 2200.079 | 2209.845 | 2212.375 | 2221.670 |
| 25/-1/n | 2235.357 | tbd | 2200.128 | 2212.258 | 2215.617 | 2227.301 | 2230.379 | 2241.600 | 2244.515 | 2255.257 |
| 25/-1/i | 2235.357 | tbd | 2207.221 | 2219.236 | 2222.563 | 2234.129 | 2237.176 | 2248.279 | 2251.162 | 2261.785 |
| 25/1/n | 2286.416 | tbd | 2253.963 | 2265.175 | 2268.274 | 2279.026 | 2281.852 | 2292.130 | 2294.794 | 2304.582 |
| 25/1/i | 2286.416 | tbd | 2260.458 | 2271.552 | 2274.617 | 2285.250 | 2288.044 | 2298.201 | 2300.832 | 2310.498 |
| 24/-1/n | 2328.540 | tbd | 2291.851 | 2304.484 | 2307.983 | 2320.150 | 2323.356 | 2335.043 | 2338.079 | 2349.266 |
| 24/-1/i | 2328.540 | tbd | 2299.238 | 2311.751 | 2315.216 | 2327.262 | 2330.435 | 2341.998 | 2345.002 | 2356.065 |
| 24/1/n | 2381.640 | tbd | 2347.835 | 2359.514 | 2362.742 | 2373.941 | 2376.886 | 2387.591 | 2390.366 | 2400.562 |
| 24/1/i | 2381.640 | tbd | 2354.601 | 2366.157 | 2369.349 | 2380.425 | 2383.335 | 2393.915 | 2396.656 | 2406.725 |
| 23/-1/n | 2429.833 | tbd | 2391.555 | 2404.735 | 2408.385 | 2421.080 | 2424.424 | 2436.617 | 2439.784 | 2451.456 |
| 23/-1/i | 2429.833 | tbd | 2399.262 | 2412.317 | 2415.932 | 2428.499 | 2431.810 | 2443.873 | 2447.007 | 2458.549 |
| 23/1/n | 2485.138 | tbd | 2449.863 | 2462.050 | 2465.418 | 2477.104 | 2480.177 | 2491.348 | 2494.243 | 2504.883 |
| 23/1/i | 2485.138 | tbd | 2456.923 | 2468.981 | 2472.313 | 2483.870 | 2486.907 | 2497.947 | 2500.807 | 2511.314 |
| 22/-1/n | 2511.493 | tbd | 2470.043 | 2484.295 | 2488.246 | 2501.998 | 2505.625 | 2518.859 | 2522.301 | 2534.997 |
| 22/-1/i | 2511.493 | tbd | 2478.409 | 2492.532 | 2496.447 | 2510.068 | 2513.660 | 2526.761 | 2530.168 | 2542.729 |
| 22/0/n | 2569.189 | tbd | 2530.699 | 2543.973 | 2547.645 | 2560.404 | 2563.763 | 2575.990 | 2579.163 | 2590.840 |
| 22/0/i | 2569.189 | tbd | 2538.427 | 2551.568 | 2555.204 | 2567.828 | 2571.150 | 2583.241 | 2586.378 | 2597.918 |
| 22/1/n | 2626.885 | tbd | 2591.726 | 2603.897 | 2607.257 | 2618.898 | 2621.954 | 2633.050 | 2635.922 | 2646.456 |
| 22/1/i | 2626.885 | tbd | 2598.736 | 2610.772 | 2614.094 | 2625.597 | 2628.616 | 2639.573 | 2642.408 | 2652.802 |
| 21/-1/n | 2631.236 | tbd | 2587.823 | 2602.750 | 2606.888 | 2621.291 | 2625.090 | 2638.950 | 2642.555 | 2655.852 |
| 21/-1/i | 2631.236 | tbd | 2596.585 | 2611.377 | 2615.477 | 2629.743 | 2633.505 | 2647.226 | 2650.794 | 2663.949 |
| 21/0/n | 2691.531 | tbd | 2651.212 | 2665.116 | 2668.964 | 2682.329 | 2685.847 | 2698.655 | 2701.979 | 2714.211 |
| 21/0/i | 2691.531 | tbd | 2659.307 | 2673.073 | 2676.881 | 2690.106 | 2693.586 | 2706.252 | 2709.538 | 2721.626 |
| 21/1/n | 2751.827 | tbd | 2714.987 | 2727.741 | 2731.261 | 2743.459 | 2746.661 | 2758.287 | 2761.296 | 2772.335 |
| 21/1/i | 2751.827 | tbd | 2722.333 | 2734.945 | 2738.425 | 2750.478 | 2753.642 | 2765.123 | 2768.093 | 2778.984 |
| 20/-1/n | 2762.976 | tbd | 2717.406 | 2733.075 | 2737.418 | 2752.538 | 2756.525 | 2771.074 | 2774.858 | 2788.815 |
| 20/-1/i | 2762.976 | tbd | 2726.604 | 2742.131 | 2746.434 | 2761.409 | 2765.358 | 2779.761 | 2783.506 | 2797.315 |
| 20/0/n | 2826.108 | tbd | 2783.776 | 2798.374 | 2802.414 | 2816.446 | 2820.140 | 2833.587 | 2837.077 | 2849.920 |
| 20/0/i | 2826.108 | tbd | 2792.275 | 2806.728 | 2810.726 | 2824.611 | 2828.265 | 2841.563 | 2845.013 | 2857.705 |
| 20/1/n | 2889.240 | tbd | 2850.549 | 2863.943 | 2867.640 | 2880.451 | 2883.814 | 2896.025 | 2899.185 | 2910.778 |
| 20/1/i | 2889.240 | tbd | 2858.264 | 2871.509 | 2875.164 | 2887.823 | 2891.146 | 2903.204 | 2906.323 | 2917.762 |
| 19/-1/n | 2908.616 | tbd | 2860.662 | 2877.151 | 2881.722 | 2897.631 | 2901.828 | 2917.138 | 2921.120 | 2935.806 |
| 19/-1/i | 2908.616 | tbd | 2870.341 | 2886.680 | 2891.209 | 2906.967 | 2911.122 | 2926.279 | 2930.220 | 2944.751 |
| 19/0/n | 2974.851 | tbd | 2930.293 | 2945.659 | 2949.911 | 2964.681 | 2968.569 | 2982.723 | 2986.396 | 2999.914 |
| 19/0/i | 2974.851 | tbd | 2939.239 | 2954.452 | 2958.660 | 2973.275 | 2977.121 | 2991.118 | 2994.750 | 3008.109 |
| 19/1/n | 3041.085 | tbd | 3000.346 | 3014.449 | 3018.342 | 3031.830 | 3035.372 | 3048.229 | 3051.556 | 3063.764 |
| 19/1/i | 3041.085 | tbd | 3008.470 | 3022.416 | 3026.264 | 3039.594 | 3043.092 | 3055.789 | 3059.073 | 3071.119 |
| 18/-1/n | 3070.481 | tbd | 3019.879 | 3037.278 | 3042.101 | 3058.890 | 3063.317 | 3079.472 | 3083.674 | 3099.171 |
| 18/-1/i | 3070.481 | tbd | 3030.092 | 3047.333 | 3052.112 | 3068.740 | 3073.125 | 3089.118 | 3093.276 | 3108.609 |
| 18/0/n | 3140.120 | tbd | 3093.090 | 3109.308 | 3113.796 | 3129.386 | 3133.489 | 3148.429 | 3152.307 | 3166.575 |
| 18/0/i | 3140.120 | tbd | 3102.532 | 3118.589 | 3123.031 | 3138.457 | 3142.516 | 3157.291 | 3161.124 | 3175.224 |
| 18/1/n | 3209.760 | tbd | 3166.742 | 3181.633 | 3185.744 | 3199.987 | 3203.726 | 3217.303 | 3220.817 | 3233.708 |
| 18/1/i | 3209.760 | tbd | 3175.321 | 3190.046 | 3194.110 | 3208.185 | 3211.879 | 3225.286 | 3228.755 | 3241.475 |
| 17/-1/n | 3251.445 | tbd | 3197.887 | 3216.303 | 3221.408 | 3239.177 | 3243.864 | 3260.962 | 3265.409 | 3281.812 |
| 17/-1/i | 3251.445 | tbd | 3208.696 | 3226.945 | 3232.003 | 3249.603 | 3254.244 | 3271.171 | 3275.572 | 3291.801 |
| 17/0/n | 3324.833 | tbd | 3275.038 | 3292.210 | 3296.962 | 3313.468 | 3317.812 | 3333.631 | 3337.736 | 3352.843 |
| 17/0/i | 3324.833 | tbd | 3285.035 | 3302.037 | 3306.740 | 3323.072 | 3327.370 | 3343.013 | 3347.071 | 3362.001 |
| 17/1/n | 3398.221 | tbd | 3352.653 | 3368.427 | 3372.781 | 3387.869 | 3391.830 | 3406.212 | 3409.934 | 3423.591 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17/1/i | 3398.221 | tbd | 3361.740 | 3377.339 | 3381.643 | 3396.553 | 3400.466 | 3414.669 | 3418.343 | 3431.819 |
| 16/-1/n | 3455.110 | tbd | 3398.229 | 3417.787 | 3423.209 | 3442.081 | 3447.058 | 3465.218 | 3469.941 | 3487.360 |
| 16/-1/i | 3455.110 | tbd | 3409.708 | 3429.090 | 3434.461 | 3453.153 | 3458.082 | 3476.059 | 3480.733 | 3497.968 |
| 16/0/n | 3532.635 | tbd | 3479.729 | 3497.974 | 3503.022 | 3520.560 | 3525.176 | 3541.983 | 3546.344 | 3562.395 |
| 16/0/i | 3532.635 | tbd | 3490.351 | 3508.414 | 3513.411 | 3530.764 | 3535.331 | 3551.951 | 3556.263 | 3572.125 |
| 16/1/n | 3610.160 | tbd | 3561.717 | 3578.486 | 3583.114 | 3599.154 | 3603.365 | 3618.656 | 3622.613 | 3637.132 |
| 16/1/i | 3610.160 | tbd | 3571.378 | 3587.960 | 3592.536 | 3608.387 | 3612.548 | 3627.647 | 3631.554 | 3645.881 |
| 15/-2/n | 3644.994 | tbd | 3582.400 | 3603.897 | 3609.861 | 3630.635 | 3636.119 | 3656.143 | 3661.356 | 3680.599 |
| 15/-2/i | 3644.994 | tbd | 3595.059 | 3616.370 | 3622.281 | 3642.866 | 3648.298 | 3668.130 | 3673.291 | 3692.340 |
| 15/-1/n | 3727.094 | tbd | 3668.500 | 3688.676 | 3694.264 | 3713.695 | 3718.816 | 3737.478 | 3742.326 | 3760.191 |
| 15/-1/i | 3727.094 | tbd | 3680.296 | 3700.280 | 3705.814 | 3725.052 | 3730.119 | 3748.585 | 3753.381 | 3771.046 |
| 15/1/n | 3809.194 | tbd | 3755.050 | 3773.754 | 3778.924 | 3796.862 | 3801.579 | 3818.728 | 3823.173 | 3839.507 |
| 15/1/i | 3809.194 | tbd | 3765.887 | 3784.395 | 3789.509 | 3807.249 | 3811.911 | 3828.859 | 3833.250 | 3849.382 |
| 15/2/n | 3891.294 | tbd | 3842.193 | 3859.228 | 3863.923 | 3880.170 | 3884.429 | 3899.867 | 3903.855 | 3918.464 |
| 15/2/i | 3891.294 | tbd | 3851.945 | 3868.779 | 3873.417 | 3889.461 | 3893.664 | 3908.897 | 3912.831 | 3927.235 |
| 14/-2/n | 3906.556 | tbd | 3839.546 | 3862.560 | 3868.944 | 3891.184 | 3897.055 | 3918.490 | 3924.070 | 3944.669 |
| 14/-2/i | 3906.556 | tbd | 3853.098 | 3875.912 | 3882.239 | 3904.276 | 3910.092 | 3931.321 | 3936.846 | 3957.236 |
| 14/-1/n | 3993.717 | tbd | 3930.957 | 3952.567 | 3958.553 | 3979.366 | 3984.850 | 4004.838 | 4010.031 | 4029.165 |
| 14/-1/i | 3993.717 | tbd | 3943.591 | 3964.996 | 3970.924 | 3991.529 | 3996.957 | 4016.734 | 4021.871 | 4040.792 |
| 14/1/n | 4080.878 | tbd | 4022.843 | 4042.890 | 4048.432 | 4067.660 | 4072.715 | 4091.097 | 4095.862 | 4113.371 |
| 14/1/i | 4080.878 | tbd | 4034.459 | 4054.297 | 4059.778 | 4078.793 | 4083.791 | 4101.957 | 4106.664 | 4123.956 |
| 14/2/n | 4168.039 | tbd | 4115.350 | 4133.628 | 4138.667 | 4156.101 | 4160.671 | 4177.239 | 4181.520 | 4197.200 |
| 14/2/i | 4168.039 | tbd | 4125.816 | 4143.879 | 4148.857 | 4166.073 | 4170.584 | 4186.932 | 4191.154 | 4206.614 |
| 13/-2/n | 4208.742 | tbd | 4136.654 | 4161.413 | 4168.282 | 4192.207 | 4198.522 | 4221.580 | 4227.583 | 4249.740 |
| 13/-2/i | 4208.742 | tbd | 4151.231 | 4175.775 | 4182.583 | 4206.289 | 4212.545 | 4235.382 | 4241.325 | 4263.257 |
| 13/-1/n | 4301.487 | tbd | 4233.926 | 4257.189 | 4263.632 | 4286.038 | 4291.941 | 4313.458 | 4319.049 | 4339.645 |
| 13/-1/i | 4301.487 | tbd | 4247.526 | 4270.569 | 4276.949 | 4299.131 | 4304.974 | 4326.264 | 4331.794 | 4352.160 |
| 13/1/n | 4394.231 | tbd | 4331.696 | 4353.298 | 4359.269 | 4379.987 | 4385.435 | 4405.243 | 4410.377 | 4429.245 |
| 13/1/i | 4394.231 | tbd | 4344.213 | 4365.589 | 4371.496 | 4391.985 | 4397.370 | 4416.946 | 4422.018 | 4440.652 |
| 13/2/n | 4486.975 | tbd | 4430.120 | 4449.842 | 4455.279 | 4474.092 | 4479.024 | 4496.905 | 4501.525 | 4518.449 |
| 13/2/i | 4486.975 | tbd | 4441.415 | 4460.905 | 4466.276 | 4484.855 | 4489.723 | 4507.367 | 4511.924 | 4528.612 |
| 12/-2/n | 4561.918 | tbd | 4483.930 | 4510.717 | 4518.148 | 4544.030 | 4550.861 | 4575.805 | 4582.297 | 4606.263 |
| 12/-2/i | 4561.918 | tbd | 4499.699 | 4526.252 | 4533.617 | 4559.262 | 4566.030 | 4590.732 | 4597.160 | 4620.883 |
| 12/-1/n | 4660.759 | tbd | 4587.605 | 4612.795 | 4619.772 | 4644.032 | 4650.424 | 4673.722 | 4679.775 | 4702.075 |
| 12/-1/i | 4660.759 | tbd | 4602.330 | 4627.282 | 4634.190 | 4658.208 | 4664.535 | 4687.586 | 4693.574 | 4715.625 |
| 12/1/n | 4759.601 | tbd | 4691.804 | 4715.223 | 4721.696 | 4744.158 | 4750.064 | 4771.541 | 4777.107 | 4797.566 |
| 12/1/i | 4759.601 | tbd | 4705.375 | 4728.549 | 4734.953 | 4757.167 | 4763.005 | 4784.230 | 4789.730 | 4809.934 |
| 12/2/n | 4858.442 | tbd | 4796.685 | 4818.105 | 4824.011 | 4844.447 | 4849.805 | 4869.231 | 4874.251 | 4892.642 |
| 12/2/i | 4858.442 | tbd | 4808.957 | 4830.126 | 4835.960 | 4856.142 | 4861.431 | 4880.601 | 4885.553 | 4903.687 |
| 11/-2/n | 4927.739 | tbd | 4840.417 | 4870.379 | 4878.696 | 4907.686 | 4915.342 | 4943.318 | 4950.605 | 4977.525 |
| 11/-2/i | 4927.739 | tbd | 4858.104 | 4887.815 | 4896.061 | 4924.794 | 4932.381 | 4960.097 | 4967.315 | 4993.972 |
| 11/-1/n | 5033.059 | tbd | 4950.666 | 4979.001 | 4986.856 | 5014.190 | 5021.398 | 5047.694 | 5054.532 | 5079.751 |
| 11/-1/i | 5033.059 | tbd | 4967.289 | 4995.366 | 5003.147 | 5030.219 | 5037.357 | 5063.387 | 5070.155 | 5095.104 |
| 11/0/n | 5138.378 | tbd | 5061.406 | 5087.950 | 5095.295 | 5120.810 | 5127.526 | 5151.978 | 5158.324 | 5181.677 |
| 11/0/i | 5138.378 | tbd | 5076.859 | 5103.139 | 5110.409 | 5135.657 | 5142.300 | 5166.481 | 5172.755 | 5195.833 |
| 11/1/n | 5243.698 | tbd | 5172.764 | 5197.310 | 5204.088 | 5227.577 | 5233.745 | 5256.146 | 5261.945 | 5283.225 |
| 11/1/i | 5243.698 | tbd | 5186.917 | 5211.194 | 5217.894 | 5241.109 | 5247.203 | 5269.327 | 5275.052 | 5296.053 |
| 11/2/n | 5349.018 | tbd | 5284.944 | 5307.219 | 5313.351 | 5334.539 | 5340.085 | 5360.160 | 5365.340 | 5384.200 |
| 11/2/i | 5349.018 | tbd | 5297.623 | 5319.621 | 5325.675 | 5346.582 | 5352.053 | 5371.847 | 5376.952 | 5395.628 |