Adaptive Optics for the VLT high-resolution infrared spectrograph CRIRES

G. Wiedemann
European Southern Observatory

This paper presents the rationale and concept for an adaptive optics system for the high-resolution infrared echelle spectrograph, CRIRES, at the VLT.

Introduction

The high-resolution infrared echelle spectrograph CRIRES has been selected to complete the initial instrument ensemble for ESO's Very Large Telescope. CRIRES operates in the 1 - 5 μm range with a nominal resolving power $\lambda / \delta\lambda$ of 100,000, resp. an equivalent velocity resolution of 3 km/sec. Greatly superior sensitivity has been the main reason for choosing an echelle over a Fourier instrument for high-resolution spectroscopy at a ground-based telescope. The large theoretical sensitivity gain of an echelle spectrograph over the multiplexing Fourier transform spectrometer or Fabry-Perot can be achieved in practice after the advent of large, low-noise infrared detector arrays. Combined with the light collecting power and image quality of an actively controlled VLT, a high-resolution IR echelle spectrograph will open a new regime in observational astronomy.

One obstacle on this route is the well known requirement to scale the size of the grating with that of the telescope for a given spectral resolution. A grating larger than the longest presently commercially available 40 cm echelle will be developed for CRIRES, yet within the stringent size limits imposed by the cryogenic instrument. In order to recover the full light gathering advantage of the 8 m telescope, CRIRES will instead employ an adaptive optics front end to match the telescope images to the narrow entrance slit. In principle, image slicers can be used to re-distribute the light along the spectrograph's entrance slit, however, at the expense of unnecessary use of detector real estate, and increasing readout noise, and with a background noise penalty in the thermal infrared.

Current adaptive optics developments will likely give a stronger boost to infrared spectroscopy than to any imaging application.

The rationale for AO in IR spectroscopy

Light concentration

To achieve a spectral resolving power of 100,000 at an 8 m telescope with a 40 cm grating, a projected slit width of 0.2 arcsec must be used. This is less than the best short-period seeing ever recorded at the VLT site Paranal, and much less than the average seeing expected during the operation of the infrared spectrograph as opposed to the high-resolution imagers. Observing with the nominal 0.2 arcsec slit in 1 arcsec seeing would be equivalent to using the instrument at a 1.5 m class telescope. In the mid- infrared, where only the brightest stars outshine the background, light concentration improves detection limits by eliminating thermal background noise.

Spatial resolution

As in high-resolution images, much of the information content from extended sources is on the smallest spatial scales. Long-slit spectroscopy with a pixel resolution of 0.08 arcsec along the slit is the primary observing mode of CRIRES.

Spatial stability of a narrow spectral profile is an additional relevant aspect of adaptive optics in spectroscopy. The wavelength vs. pixel dispersion varies along the slit in most spectrograph designs. A very stable position is particularly important for observations requiring very high precision, such as radial velocity measurements for planet detection.

CRIRES has a coronographic mode with a small aperture mask inside the 0.2 arcsec entrance slit. This mode is used to improve the contrast between a bright central star and its spectroscopically studied environment.

Bad pixel elimination

Current infrared detector arrays, in particular InSb arrays used in the 1-5 μm range, frequently suffer from 'bad' pixels with anomalous response to the incident light. Some of the bad pixels are spontaneous, i.e. their behavior is not stable in time. Consequently, their response cannot be well calibrated. In order to minimise bad pixel effects for observations requiring very high S/N, it can advantageous to distribute the photon flux over a greater number of spatial detector elements - keeping the flux levels well above the read noise - and to eliminate the few bad ones. The broadening of the spatial profile only can be achieved by the deformable mirror in the AO system. This technique should work well for high S/N observations of bright stars, where a small image is not required, but stability and bad pixel elimination are critical.

Nonlinearities

Spreading the spatial profile along the entrance slit naturally reduces the brightness contrast between the center and the wings. This can help to keep flux levels on all detector elements in the linear response range when very bright compact objects are observed.

Technical concept

The AO system foreseen for CRIRES is of the curvature sensing type with a 36 actuator bimorph mirror. The opto-mechanical system will be built around the AO core, which is developed at ESO under the Multiple Application Curvature Adaptive Optics, MACAO, program. The CRIRES spectrograph is mounted stationary on the Nasmyth platform. In order to minimise opto-mechanical complexity, a decision has been made for a stationary AO front end. Compensation for the apparent sky rotation at the Nasmyth focus of the alt-az. telescope will be achieved through an optical de-rotator in front of the AO system. Although most of the gain from an AO system is in the light concentration at the entrance slit, there is an increase in thermal background from the considerable number of additional mirrors. Cooling of the de-rotator and AO is therefore an option retained for a future upgrade.