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CRIRES-POP: A library of high resolution spectra in the near-infrared

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Abstract: We describe an ongoing project to obtain a library of high signal-to-noise, high spectral resolution stellar spectra from ~1-5μm using CRIRES on the ESO Very Large Telescope (VLT). New instrumental capabilities make the near-infrared an increasingly important wavelength range for high resolution spectroscopy, yet our knowledge of the spectral features in this regions is far from complete. The motivations of our group in conducting this survey are broad, from providing fundamental line data for laboratory spectroscopists, improving wavelength calibration and the removal of telluric lines for CRIRES to applications in astrophysical topics from observations of circumstellar matter to modelling stellar atmospheres. Substantial effort is being invested in producing a library of spectra reduced using a common procedure to ensure homogeneity of the results. So far, we have obtained spectra of 9 sources and hope to complete a sample size of ~25 to give good coverage of the HR diagram. Most of our targets were selected from the UVES-POP spectral library source list, so that complete coverage of the spectra from the UV to the NIR will be available. An important goal for the project is that the library is public. The data are available at http://www.univie.ac.at/crirespop/.

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1 Introduction and Motivation

The importance of infrared observations has grown rapidly in recent years thanks to the improvements in instrumentation that is driven partly by the availability of detectors in large formats. Coupled with the increase in telescope aperture from 4-m to 8-m this means that previously photon-starved high spectral resolution observations are now being made routinely at near-infrared wavelengths. This presents us with the opportunity to expand further our understanding of the diagnostics and content of the infrared spectrum and to confront existing models with very high quality infrared spectra. Early high resolution infrared atlases of stellar spectra are from work on the Sun. Examples include the 3–10μm spectrum by Delbouille, Roland & Neven (1973), with extensions to longer wavelengths in later works by this group (e.g. Farmer et al. 1995), and from 0.7–22μm by Wallace et al. 1996. For stars other than the Sun, there are libraries at medium resolving power of around a few thousand (see Rayner, Cushing, & Vacca 2009 for a compilation) but few at higher resolving power. Published examples include the spectrum of the K2 giant Arcturus from 0.9–5.3μm with R$\sim$ 100000 (Hinkle, Wallace & Livingston 1995) and K band spectra of 12 cool stars by Wallace & Hinkle (1996). The CRIRES-POP project (Lebzelter et al. 2010) will greatly advance our knowledge of the high resolution NIR spectra of stars by observing the $\sim$1-5μm spectrum of 25-30 stars over the whole Hertzsprung-Russell diagram at the R$\sim$ 100000 resolving power achievable with the CRIRES spectrometer on the ESO VLT. Stellar spectra are observed at all wavelengths that are not heavily absorbed by the Earth's atmosphere. The library will be made publicly available.

1.1 Science goals of CRIRES-POP

Here we highlight some of the particular science interests and goals of the team working on the project. The identification of molecules in cool stellar atmospheres via their NIR transitions is a major aim of CRIRES-POP. Transitions of either oxygen-bearing molecules (H_2O, SiO) or carbon-bearing molecules (CN-, CH-, C_2-compounds and of course CO, CO_2) will be seen depending on the chemistry of the target. Objects enriched in s-process elements offer a unique opportunity to identify lines of these interesting elements and also of iron-peak elements whose line lists are far from complete in the NIR. We anticipate the identification of new diagnostic features of stellar atmospheres, which will be developed using the CRIRES-POP spectral library through collaboration between the observational astronomers and laboratory spectroscopists in our team.

The spectra of cool stars obtained will also be used to help optimise future exo-planet studies. Nearby M dwarfs are one target sample for searching for planets; the first successful results were recently published (Bean et al. 2010). These low mass stars are potentially good candidates for planet searches using the radial velocity method, as the reflex motion of the star due to a planet is comparatively large, and the NIR wavelength range is potentially optimal as these cool stars are brightest at these wavelengths. However, fully understanding the effectiveness of this approach compared with ongoing searches at optical wavelengths is limited, in part, by a lack of information on the detailed NIR spectrum. A detailed analysis of this and other factors affecting these studies is given in Reiners et al. (2010).

Studies of circumstellar matter in general are expected to benefit from a better understanding of stellar spectra. Systematic errors due to the signature of the stellar atmosphere can effect the accuracy of the results obtained, for example when observing gas emission lines in circumstellar disks. Ramsay Howat & Greaves (2007) published a velocity-resolved emission line spectrum of H_2 from the M3 giant ECHAJ0843.3-7905 from which the stellar continuum was removed. This increased the measured H_2 line flux by 10% with a corresponding effect on the estimated gas mass in the disk. By providing a set of template spectra over different spectral types, such techniques may be

Table 1: Targets observed and pending.

name	Classification	vsini (kms^{-1})	J	H	K	L	M
τ Sco	B0.2V	$\sim$4	+3.30	+3.50	+3.60	+3.6	+3.7
3 Cen A	B5IIIp	2	+4.9	+4.95	+4.97		
e Vel	A6II	6±1	+3.80	+3.66	+3.60	$\sim$3.5	$\sim$3.4
γ Gem	A0IV	10	+1.73	+1.84	+1.92	+2.06	+1.88
HD 118022	A1 P	10±1	+5.19	+4.98	+4.88	+4.89	+4.93
LHS 1515	F8IV	5±1	+2.80	+2.32	+2.40	+2.3	+2.4
τ Leo	G8Iab	4	+3.49	+2.95	+2.83		
HD109379	G5II	6±1	+1.20	+0.80	+0.70	+0.70	+0.80
HD225212	K3Iab	8	+2.27	+1.61	+1.40		
HD83240	K1III	1±2	+3.36	+2.80	+2.66	+2.5	+2.6
HD49331	M1I	$\sim$9	+1.70	+0.80	+0.60	+0.40	+0.30
YY Psc	M3III	4±1	+0.70	-0.25	-0.50	-0.7	-0.5
Barnard's star	M4V	<3	+5.24	+4.83	+4.52	+4.2	
X TrA	C5	0±?	+1.0	-0.0	-0.6	-1.2	-0.8
NZ Gem	S	?	+1.59	+0.64	+0.56		+0.80

more widely used to improve the accuracy of high resolution spectroscopic analyses.

Testing and improving model atmospheres across the complete HRD is one of the goals of CRIRES-POP team members. For hotter stars in particular, the extrapolation of models from the optical to NIR is non-trivial due to the increasing importance of non-local-thermodynamic-equilibirium effects. Only recently has significant progress been made in obtaining a consistent model of the simplest atom, hydrogen, from the optical to the NIR (Przybilla & Butler 2004).

2 Target selection and strategy

At optical wavelengths, the UVES-POP spectral library has been an invaluable resource (Bagnulo et al. 2003). The target list from this programme was therefore used as the starting point when selecting CRIRES-POP sources, so that ultimately the spectrum from $\sim$0.3-5μm will be available for certain stars. CRIRES is a single-order spectrometer (Käufl et al. 2004), therefore we require $\sim$200 grating settings and 10–20 hours per target for our observations. The scope of the programme was set to around 25-30 targets, which provides reasonable coverage of the HR diagram. Table 1 gives details of the targets selected for which observations have been obtained or are scheduled. Stars are selected only if they are slow rotators so that the intrinsic spectrum without rotational broadening is obtained. The CRIRES-POP observations do not require any strong constraints on atmospheric conditions, making it very suitable for execution in service mode and in below average weather conditions.

3 Data reduction and analysis

A strength of the proposed library will be a common data reduction for all spectra. The data are being reduced using the CRIRES data-reduction pipeline. This produces individual spectra for each grating setting. Example spectra of the M3 giant YY Psc in the K and M bands are shown in Figures 1 and 2 respectively. The K band spectrum is centred around the CO Δv = 2–0 overtone bandhead which is seen in great detail and which dominates the spectrum at these wavelengths. In the M band, CO is

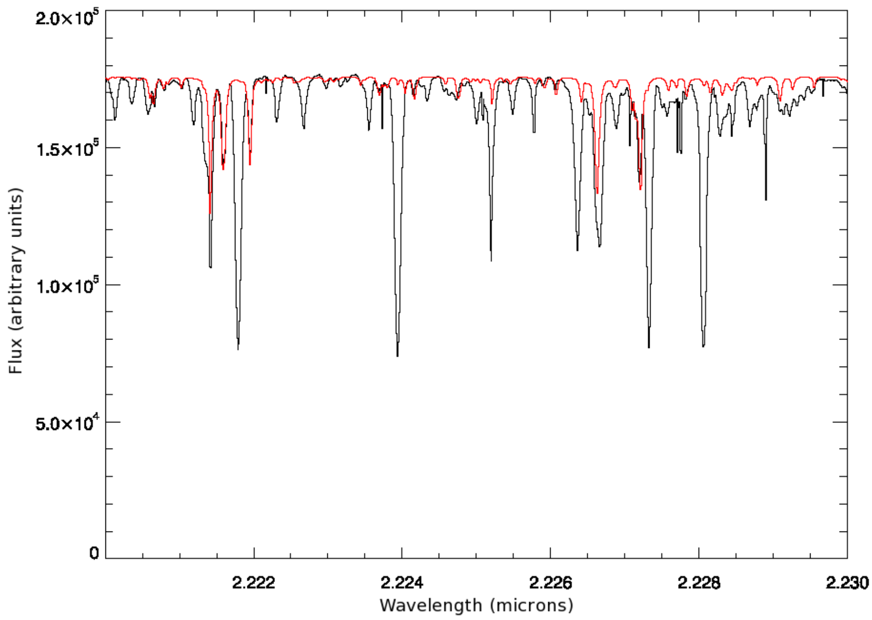

Figure 1: The M3 giant YY Psc in the K band. The star spectrum is in black; the telluric model in red.

also one of the main constituents; isotopic lines of $^{13}C^{16}O$ and $^{12}C^{18}O$ are also detected with a high signal-to-noise ratio. Subsequent to this, the individual spectra will be combined into the complete 0.97–5.26μm spectrum using IDL routines developed by the CRIRES-POP team. This approach was previously successfully used to reduce CRIRES data from single setting observations (Seifahrt & Käufl 2008) and for a more automated approach to the homogeneous reduction of wide wavelength scans (Nieva et al. 2009; Przybilla et al. 2009). An important step is the removal of the telluric absorption lines which are prevalent in the stellar spectra. Standard practice for NIR spectroscopy is to obtain a very high quality spectrum of a spectrally featureless standard star at similiar airmass and close in time to the target. Then the target spectrum is ratioed by the standard star spectrum with the aim of cancelling the telluric absorption lines. This is imperfect - changes in the depth of the telluric lines and the presence of features in the standard star spectrum introduce systematic errors in the target spectrum. At high spectral resolution, obtaining a spectrum of sufficient signal-to-noise that does not degrade the target spectrum can add a substantial overhead. An alternative is to fit and remove the telluric emission features using a model of the Earth's atmosphere. The CRIRES-POP spectra will be used to calibrate these models and then the technique will be used to correct for telluric features in the remainder of the library. Further details can be found in Seifahrt et al. (2010). Also shown with the YY Psc spectra in Figures 1 and 2 is a first attempt to fit a model to the telluric lines.

4 Status

In the first two periods of observations on the VLT, starting in October 2009, 1-5μm data have been obtained of YY Psc, LHS1515, e Vel and HD 83240. At time of writing, partial spectra of τ Sco, X Tra, HD 118022, Barndard's Star and HD 109379 are also available. The raw data are available from the ESO archive immediately (Programme ID 084.D-0912(A)). After a quality check of the pipeline reduced data, they are made available on the CRIRES-POP website: http://www.univie.ac.at/crirespop/. Please reference Lebzelter et al. (2010) when using the data.

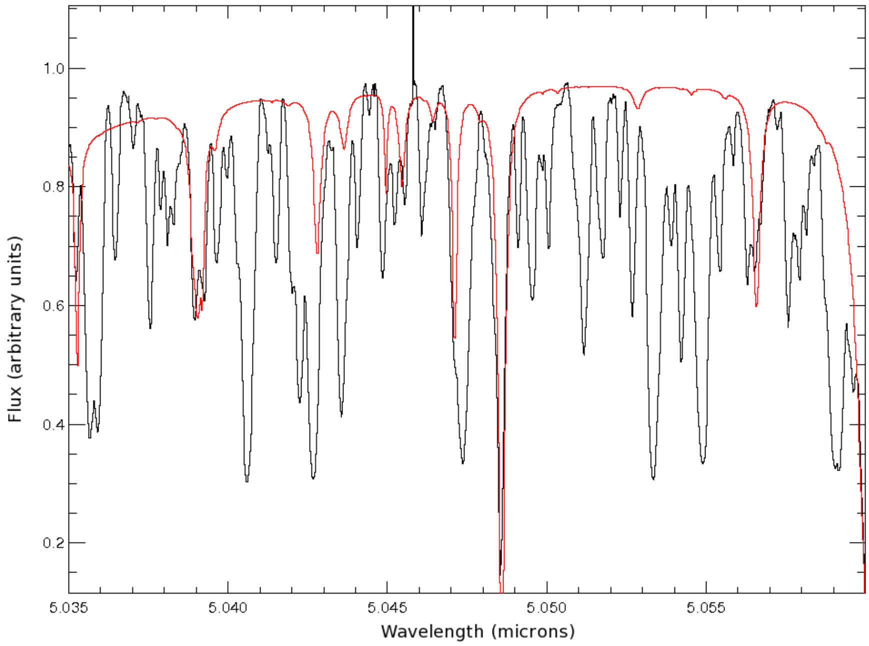

Figure 2: The M3 giant YY Psc in the M band. The star spectrum is in black; the telluric model in red.

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