PUCHEROS: a cost-effective solution for high-resolution spectroscopy with small telescopes

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ABSTRACT
We present PUCHEROS, the high-resolution echelle spectrograph, developed at the Center of Astro-Engineering of Pontificia Universidad Catolica de Chile to provide an effective tool for research and teaching of astronomy. The instrument is fed by a single-channel optical fibre and it covers the visible range from 390 to 730 nm in one shot, reaching a spectral resolution of about 20 000. In the era of extremely large telescopes our instrument aims to exploit the capabilities offered by small telescopes in a cost-effective way, covering the observing needs of a community of astronomers, in Chile and elsewhere, which do not necessarily need large collecting areas for their research. In particular the instrument is well suited for long-term spectroscopic monitoring of bright variable and transient targets down to a $V$ magnitude of about 10. We describe the instrument and present a number of text case examples of observations obtained during commissioning and early science.

Key words: instrumentation: spectrographs – binaries: spectroscopic – stars: individual: o Pupis – stars: individual: T Pyxidis – stars: individual: V1200 Cen – novae, cataclysmic variables.

1 INTRODUCTION
Chile possesses in its territory the Atacama desert, one of the best regions on the planet for ground-based astronomical observations. Numerous international observatories have been installed in the area in the past decades and more are planned for the future. This circumstance has produced a fast growth of observational astronomy in Chile. If, on one side, the concentration of international large observatories is high in Chile, on the other side, national facilities have been virtually absent so far and the development of local technology and instrumentation for astronomy has been limited. Maintaining a high level of technical capability and productivity is, without any doubt, of vital importance for a lively and developed country, for this reason increasing the activity in the field of astronomical instrumentation is one of the major challenges undertaken lately by the scientific Chilean community. This can only be achieved in small steps and following a well-conceived path.

The next-generation astronomical telescopes (extremely large telescopes or ELTs) and their instruments are beyond the reach of any single country in terms of budget and complexity both in technology and management. The effort of building these facilities, able to reach front line science cases or to open completely new fields of research, is currently absorbing most of the resources of the international astronomical community. While the focus on these new and highly challenging projects is certainly a necessity which deserves the highest priority, it leaves uncertain the fate of smaller facilities as well as the destiny of areas of research that do not need large collecting areas to be carried out. Observations of bright or relatively bright targets will keep being a need of the astronomical community but will be difficult to carry out with an ELT and would certainly be a waste if executed with these large and expensive instruments. This opens an interesting window where even a small group with limited resources can develop interesting ideas and, at the same time, gain experience to join more challenging projects in the future. In addition, qualified manpower for the largest telescopes can only be generated if smaller and less expensive instruments keep being accessible to Universities.

In this picture we aimed at building a low-cost high-performing instrument with the potential of being an effective tool for science when attached to a small telescope, to be offered to the national and international observers. The path that we followed is that of

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echelle spectroscopy and fibre coupling to the telescope. Small-size telescopes, with diameter smaller than about 1 m, proved to be an ideal platform for installing high-resolution echelle spectrographs operating in the visible. These instruments can be an efficient tool in the study and characterization of variable bright targets such as eruptive variables, novae, binary or multiple systems and massive stars (Kaufer 1998; Porter 2000; Hearnshaw et al. 2002; Fuhrmann et al. 2011). In this frame we believe that our project reaches an unprecedented high ratio benefit–cost.

The layout of this paper is as follows. In Section 2 we present the instrument and telescope in detail. In Section 3 we present the results of the commissioning of the instrument. In Section 4 a few examples of observations obtained during an early science phase are described. Finally, in Section 5 the conclusions of this work are summarized.

2 PUCHEROS

PUCHEROS is the Pontificia Universidad Catolica High Resolution Optical Spectrograph developed at the Center of Astrophysics Engineering of Pontificia Universidad Catolica de Chile (AIUC) (Infante et al. 2010). The spectrograph is based on a classic echelle design and it was built mostly employing off-the-shelf components, in this way it was possible to obtain a very cost-effective result (Vanzì et al. 2010). The instrument is interfaced with the telescope via a single-channel fibre link. The main characteristics of the instrument are summarized in Table 1. The total budget of the instrument in hardware was about 25 000 USD. The instrument is operational since mid-2011 and it is offered since to the national and international observers.

In the following sections we provide technical details of the instrument.

2.1 Telescope interface, calibration unit and fibre link

The instrument is installed at the 50-cm telescope of the Observatory UC Santa Martina, located at long. = 70:32:04, lat. = −33:16:09 and 1450 m o.s.l, at about 22 km from the centre of Santiago, Chile. The telescope is the European Southern Observatory (ESO) 50 formerly at La Silla, moved to the new location in 2005 and refurbished in its control system (Baffico et al. 2008; Shen et al. 2012). Despite its location near a very large metropolis the site is well suited for its control system (Baffico et al. 2008; Shen et al. 2012). Despite the layout of this paper is as follows. In Section 2 we present the instrument and telescope in detail. In Section 3 we present the results of the commissioning of the instrument. In Section 4 a few examples of observations obtained during an early science phase are described. Finally, in Section 5 the conclusions of this work are summarized.

2.2 Spectrograph

The spectrograph is based on a classic echelle design. The collimator is a parabola with focal length of 647.7 mm and enhanced aluminium coating used with an off-axis angle of 3°. This angle is small enough not to introduce significant aberrations in the collimated beam, whose diameter is 33 mm. The main disperser is an echelle grating with 44.41 grooves mm$^{-1}$ and blaze angle of 70°, mounted in Littrow configuration with $\gamma = 3^\circ$; the size of the grating is 50 $\times$ 100 mm. The cross-dispersion is provided by two identical prisms of SF2 with 48° angle working in minimum deviation, all surfaces have anti-reflecting coating optimized for the angle of incidence of the beam. The two cross-dispersers are the only optical elements that were custom made. For the objective we adopted the simplest possible solution: an achromatic doublet plus a field corrector, the achromat has 355 mm focal length and the field corrector is a single meniscus lens. The objective effective focal length is 221 mm and it has an aperture I/3.5. All surfaces are antireflection coated. The optical layout of the spectrograph is shown in Fig. 1.

All components are mounted on an aluminium breadboard of 600 $\times$ 900 mm. The instrument is protected against dust and spurious light by a plastic enclosure.

Simple paraxial calculations indicate that a reduction of 17 800 would be reached at 550 nm wavelength. The closest order separation at the red end of the spectrum (order 60 to 61) is about 300 nm.

The entire system was simulated and optimized using ZEMAX SE, version 2010 February 4. The spot diagrams at nine positions of the focal plane are shown in Fig. 2. The optics provides a reduction factor of 2.9 so that the 200 μm image of the fibre is projected on to 68 μm; however, the reduction factor is not uniform across the field because of distortion. The distortion is anamorphic. Some elongation of the image of the fibre and a tilt of about 24°–28° are produced as the result of the $\gamma$ angle of the echelle. Most of the chromatic aberration present is compensated by a tilt of about 1° of the detector. To optimize its positioning the detector was

<table>
<thead>
<tr>
<th>Table 1. Main characteristics of PUCHEROS.</th>
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<tr>
<td>Spectral resolution $\lambda/\Delta\lambda$ (average)</td>
</tr>
<tr>
<td>Spectral coverage (single shot)</td>
</tr>
<tr>
<td>Orders</td>
</tr>
<tr>
<td>Aperture on sky (diameter)</td>
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<tr>
<td>Limiting mag. (1 h, S/N = 20)</td>
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<tr>
<td>Detector</td>
</tr>
<tr>
<td>Spectral sampling</td>
</tr>
<tr>
<td>Total efficiency</td>
</tr>
<tr>
<td>Volume</td>
</tr>
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mounted on a mechanical support that allows us to adjust the tilt angle around two axes perpendicular to the optical axis. These effects produce lower spectral resolution of the instrument at the edges of the field. The full width at half-maximum (FWHM) of the fibre image measured across the field ranges from 68 to 81 µm.

We carried out an optical element tolerance analysis of the system in ZEMAX and found that the most critical parameter is the collimator tilt, where a deviation of ±0.08 would produce a loss of 2 per cent in spectral resolution; similar to the CCD, the collimator was mounted on a support with micro-metric tilt adjustment. A Monte Carlo simulation of the system gave a mean spectral resolution loss of 4 per cent and a worst case of 11 per cent.

Most mechanical components of the telescope interface and spectrograph were manufactured at the Department of Mechanics and Metallurgy UC. The kinematic mounts of the fibre feeding system, collimator and detector, all with fine adjustment and the optical breadboard are commercial components.

2.3 Detector

The detector is a Finger Lake Instrumentation FLI ProLine PL1001E, based on a Kodak KAF-1001E sensor with 1024 × 1024 pixel of 24 µm. The image of the fibre, ranging from 68 to 81 µm, is sampled by 2.4 to 3.4 pixel. The minimum order separation being 300 µm corresponds to 12.5 pixel. The CCD is cooled at −35 C by a Peltier cell and operated in 1-MHz high-gain readout mode, 16 bits. In this configuration we measured a readout noise of 10 electrons in good agreement with the specifications provided by the manufacturer and a dark current of 0.02 electrons s⁻¹. The linearity of the CCD is better than 2 per cent up to about 60 000 counts, or more than 90 per cent of the well, also in agreement with the manufacturer specifications. The conversion factor is 1.7e⁻ ADU⁻¹.

The main limitation of the detector is a strong remanence effect produced by the trapping of photoelectrons at the substrate surface; this effect is known as residual bulk image (RBI) (Crisp 2008). The RBI depends on the level of illumination, on the operating temperature and has a long-term constant; it is virtually unaffected by the readout of the detector so that acquiring a sequence of biases or darks does not help getting rid of it. For saturated pixels we measure a signal of about 1 electron s⁻¹ in a dark frame acquired immediately after the saturation; this is similar to the values present in the literature. The RBI can be controlled filling the substrate traps by flooding the CCD; in our detector this can be done with a built-in near-infrared (NIR) led. The drawback of this technique is an overhead time of about 15 s per acquired frame, an increase in the background signal and consequently in the shot noise.

In Fig. 3 we show the dark signal in ADU measured without and with RBI NIR flooding; the data refer to four areas in the CCD. The measurements without RBI were obtained immediately after the CCD reached the operation temperature without any previous exposure being taken.
2.4 Observations and data reduction

The spectra are recorded in Flexible Image Transport System (FITS) format. A typical observation consists of dark, bias and flat frames taken before the beginning of the night, science targets and spectrophotometric standard stars acquired during the night. Spectra of Th–Ar are acquired as needed, typically before and after each scientific exposure. Flat-fields are acquired pointing the telescope towards a luminous panel installed on the roof of the observatory.\(^1\)

The flats are used to track the orders, determine the instrument response (blaze function) and correct for pixel-to-pixel variations in the response of the CCD. The data reduction follows the standard steps of bias and dark subtraction, order extraction and wavelength calibration. The frames show some degree of contamination by scattered light; this can be subtracted fitting a 2D function on the interorder illumination pattern. We performed the data reduction with the echelle environment in IRAF.

3 Performances

As part of the commissioning we measured the spectral resolution across the focal plane, the instrument efficiency curve and the limiting magnitude. Particular attention was paid to the evaluation of the instrument stability. The full spectral range of the instrument in the present configuration is 3881–7313 Å on 50 orders. Due to low efficiency in the blue we mostly use 40 orders towards the red, spanning from 4237 to 7313 Å. In principle, we can record Ca II H and K lines at 3968.5 and 3933.7 Å, but typically this would require saturation of the red orders.

We found that the resolution is consistent with the theoretical prediction; the image quality is worst at the edges of the field, as expected because of the image of the fibre is elongated by anamorphic distortion and tilted as product of the \(\gamma\) angle. This effect is shown in Fig. 4 where we plot the spectral resolution versus wavelength.

The observation of spectrophotometric standard stars from the list of Hamuy et al. (1992, 1994) indicated an overall efficiency of the system of about 4 per cent in the best case, which is in reasonable agreement with the value expected if we consider the aperture of 3.5 arcsec and a typical seeing of about 3 arcsec. In Table 2 we resume an approximate evaluation of the efficiency budget of the instrument. The measurements of efficiency however can provide values as low as 1 per cent; we attribute the occurrence of these poor values mainly to bad seeing, an important limitation at our site.

The average level of scattered light scales with the brightness of the source; we measured about 0.01 ADU s\(^{-1}\) for a \(V = 8.5\) star and about 0.5 ADU s\(^{-1}\) for a \(V = 4.5\) star. The tight relation between the level of scattered light and the brightness of the source observed clearly indicates that scattered light is produced by the target star, not by other sources of contamination.

Based on the previous measurements, we can estimate the instrument performances in terms of signal-to-noise ratio (S/N) versus integration time for different target magnitudes; the results are shown in Fig. 5 both with and without RBI control. Sources brighter than about \(V = 6\) are dominated by the target photon noise; in those cases agreement with the value expected if we consider the aperture of 3.5 arcsec and a typical seeing of about 3 arcsec. In Table 2 we resume an approximate evaluation of the efficiency budget of the instrument. The measurements of efficiency however can provide values as low as 1 per cent; we attribute the occurrence of these poor values mainly to bad seeing, an important limitation at our site.

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\(^1\) Panel Aurora by Gerd Neumann Jr.

\[\text{Table 2. PUCHEROS efficiency budget at blaze wavelength and CCD efficiency maximum. (\(^*\)) FRD = fibre focal ratio degradation.}\]

<table>
<thead>
<tr>
<th>Component</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>0.90</td>
</tr>
<tr>
<td>Telescope</td>
<td>0.90(^3)</td>
</tr>
<tr>
<td>FRD((^*))</td>
<td>0.75</td>
</tr>
<tr>
<td>Fibre (20 m)</td>
<td>0.95</td>
</tr>
<tr>
<td>Fibre optics</td>
<td>0.98(^4)</td>
</tr>
<tr>
<td>Fibre surf.</td>
<td>0.96(^5)</td>
</tr>
<tr>
<td>Collimator</td>
<td>0.98</td>
</tr>
<tr>
<td>Echelle</td>
<td>0.50</td>
</tr>
<tr>
<td>X disp. prisms</td>
<td>0.98(^6)</td>
</tr>
<tr>
<td>Objective</td>
<td>0.98(^4)</td>
</tr>
<tr>
<td>CCD</td>
<td>0.50</td>
</tr>
<tr>
<td>Total</td>
<td>0.08</td>
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Figure 4. Resolution versus wavelength. The resolution decreases at the edges of the field as a result of worst image quality.

Figure 5. log S/N versus log of the integration time in seconds for stellar sources with \(V\) magnitude 0, 2, 4, 6, 8 and 10. The results refer to \(\lambda = 0.55\) μm. The blue line refers to the CCD operation without RBI control, and the red line refers to CCD operation with RBI control.
the effect of the increased dark current produced by the RBI control is negligible and does not introduce any limitation, only for fainter targets does the RBI control decrease the performances of the instrument. On the other hand, the need for the RBI control depends on the application; for instance, the measurement of radial velocity it is hardly affected by the remanence from previous exposures.

We estimate a conservative limiting magnitude of $V = 9$ (1 h, S/N = 20) for the worst case of poor seeing and efficiency 1 per cent.

We monitored the wavelength stability of the instrument versus time and found a stabilization time of about 2 h after the CCD power is turned on; the radial velocity (RV) shift during this time can be of the order of few km s$^{-1}$ as shown in Fig. 6. We monitored carefully the temperature of spectrograph and found that the effect is directly related to it; in particular we observed that the heat transferred from the CCD to the instrument increases its temperature by about 1°C. In Fig. 7 we show the behaviour of the temperature measured in three points of the instrument optical bench and on the external surface of the enclosure, the plot can be easily compared with the wavelength shift shown in Fig. 6. The time when the CCD is turned on is marked by the sudden increase of the temperature measured by sensor 2. The external temperature is decreasing due to the lower night time temperature of the environment. By monitoring the wavelength through Th–Ar lamp exposures on time-scale of about 2 h, we typically reach accuracy below 50 m s$^{-1}$ and in the best cases of about 25 m s$^{-1}$. On the stellar spectra we reached a precision of 200 m s$^{-1}$ for RV standard stars LHS 249, HD 71479 and LTT 3283, and about 120 m s$^{-1}$ for a double-lined binary HD 60803 (rms of the orbital fit).

The instrument was designed having in mind the perspective of future improvements, in particular three aspects were considered.

(1) We can increase the spectral resolution by a factor of about 2 using a 2 times image slicer at the entrance of the spectrograph. The closest order separation of 12.5 pixel allows it. The spectral sampling would change from 2.8 to 1.4 pixel. The solution that we considered is one of a modified Bowen–Walraven device proposed by Avila & Guirao (http://spectroscopy.wordpress.com). This slicer is based on two reflective surfaces positioned face-to-face at a defined distance and rotated with respect to each other by a given angle around an axis perpendicular to the reflecting surface. The slicer plane is tilted by 45° with respect to the optical axis. To slice our 0.2 mm fibre image the separation between the surfaces must be $200/\sqrt{2} \mu m = 141 \mu m$ and to obtain two slices the angle must be 67.8°. The instrument efficiency is decreased slightly with the slicer, in particular as one-half of the beam is directly transmitted while the other half is subject to two reflections, the final efficiency depends on the coating used and can be calculated as $0.5 + 0.5 \times r^2$, where $r$ being the reflectivity of the coating. A regular aluminium coating would give a factor 0.86 at 500 nm, while protected silver would give 0.95. We built a prototype slicer which is working well as shown in Fig. 8 and that eventually can be implemented in the instrument. With the slicer the spectra would be undersampled by the current detector.

(2) As the instrument is not used on a daily basis the CCD is normally switched on only before the beginning of the

Figure 6. Shift in wavelength measured during the thermal stabilization time.

Figure 7. Temperature measured in four points of PUCHEROS versus time. Sensors 1, 2 and 3 are located on the optical bench, respectively, at the position of the collimator mirror, CCD camera and fibre optics. Sensor 4 is on the external surface of the enclosure. The effect of turning on the CCD is clearly observable in the temperature measured by sensor 2.

Figure 8. Image of the fibre produced by the optics feeding the spectrograph, without and with image slicer. The diameter of the image of the fibre is 200 μm.
observations. The heat transmitted by the CCD to the instrument produces a shift in wavelength with a stabilization time of about 2 h. If the wavelength is properly monitored taking exposures of the Th–Ar lamp before and after the scientific observation, this transient does not decrease significantly the accuracy of the measurements. However, an active control of temperature of the instrument can also be implemented. To this purpose we can use a air-conditioning split device in the instrument room and a simple control on the optical bench.

(3) The RBI effect would disappear completely and the detector efficiency would improve by a factor of almost 2 at the peak using a back-illuminated CCD. The manufacturer quotes for our detector a quantum efficiency above 50 per cent in the spectral range between about 500 and 800 nm. At 400 nm the detector efficiency drops already below 40 per cent.

4 EARLY SCIENCE RESULTS

The instrument was installed at the telescope in 2011 January. Early science started in 2011 March. Since mid-2011 the instrument is offered to the national and international communities. The early observations mainly focused on the monitoring of a sample of bright Be stars and eclipsing binaries. In this section we present some of the preliminary results obtained.

4.1 The monitoring of bright Be stars

About 15 per cent of all early B-type stars exhibit Balmer (and often other) emission lines and so are Be stars, which are comprehensively characterized in Portier & Rivinius (2003). The emission lines arise from a circumstellar Keplerian disc, the evolution of which is governed by so-called viscous decretion. The star-to-disc mass-transfer mechanism is not known. However, Be stars rotate close (75–95 per cent) to the critical velocity so that rapid rotation most probably is a central factor. The physics of rapid rotation, mass loss, non-radial pulsation and circumstellar discs combined with pronounced variability on all scales makes Be stars high-yield targets for observational monitoring campaigns. Because most variations are not strictly periodic and the physical conditions vary substantially from hot poles through cooler equators to colder discs, a large wavelength coverage such as offered by PUCHEROS is needed. The abundance of bright Be stars brings them within convenient reach even of small telescopes such as the 50-cm telescope of the Santa Martina Observatory.

The circumstellar discs of Be stars share important properties with accretion discs in protoplanetary systems and active galactic nuclei. Since many Be stars are much closer and brighter and, therefore, can be resolved by long-baseline interferometers, they are sometimes used as proxies for such and other gaseous discs. Because it is not practical and/or economical to monitor the complete variability by means of interferometry, dense sequences of echelle spectra have to be relied on as a substitute. This is one of the science drivers adopted for PUCHEROS. Regular observations also provide alarms when special events (particularly in the mass loss) occur, calling for more specialized data.

o Pup (HD 63462 = HR 3034; B1IVnne, $V = 4.50$) was selected as one of the commissioning targets after detailed inspection of two archival spectra obtained with the Fiber-fed Extended Range Optical Spectrograph (FEROS) (Kaufer et al. 2000) at the 2.2-m Max Planck Gesellschaft (MPG)/ESO Telescope of ESO’s La Silla Observatory. They indicated an asymmetry of the He I line emission, which is typical of the still small group of $\phi$ Per-type binaries.

In $\phi$ Per, the profiles of He I emission lines are variable due to a hotspot at the outer edge of the Be disc, roughly where the line connecting the Be primary and the companion intersects the disc. The secondary is a bare helium core stripped of its outer layers by Roche lobe overflow to the primary. The radiation from this very hot secondary star, which originally was the more massive component but now is fainter by several magnitudes in the visual region yet dominates in the extreme ultraviolet through X-ray region, heats and ionizes the part of the disc most strongly exposed to this radiation (Hummel & Stefl 2001). The orbital motion makes the additional line emission from the hotspot periodically appear at either positive or negative velocities, i.e. superimposed on either the red or the blue part of the general line emission from the disc. Phenomenologically, this takes on the appearance of a periodic variation of the violet-to-red emission peak ratio, $V/R$.

In general, Be stars are thought to be formed as rapid rotators. But in the case of $\phi$ Per mass transfer must have significantly spun up the present Be primary. Note that the presently observed disc is not the remnant of the mass-transfer process but is, similar to single Be stars, decreted from the Be primary.

Although $\phi$ Per-type binaries represent an important phase of an important branch of the evolution of massive binaries, $\phi$ Per was until 2005 the sole confirmed member of this class of stars (e.g. Thaller et al. 1995). Only more recently were 59 Cyg and FY CMa added (Rivinius et al. 2004; Maintz et al. 2005; Peters et al. 2008). HR 2142 is a suspected additional member (Waters, Cote & Pols 1991).

A first crude period analysis was performed of the $V/R$ ratio in the He I 6678 line measured in 12 PUCHEROS spectra complemented by the two archival FEROS spectra and one spectrum downloaded from the BES data base (observed by C. Buil; Neiner et al. 2011). The observations obtained with PUCHEROS had an integration time of 900 s per each spectrum, the $S/N$ was typically of about 100 on the continuum at 6600 Å. The analysis suggested a candidate periods of 15.183 ± .013 and 7.882 ± .002 d. Phased with the longer of these periods, the line-profile variations exhibit the behaviour typical of the prototype star $\phi$ Per, see Fig. 9. 15.2 d would, however, be the orbital period. The 7.882-d value may be an alias of the first harmonic of this period. While the true periodic nature of the variability still requires confirmation, the relatively rapid variability firmly rules out a one-armed density wave, which is common in Be discs and has superficially similar-looking effects on the emission lines but takes place on time-scales of several years (Okazaki 1997). Accordingly, persistent short-period $V/R$ variations are a good indicator of Be stars orbited by a hot subdwarf.

Similarly, the observations available from the commissioning of PUCHEROS are not sufficient to confirm o Pup beyond reasonable doubt as the fourth known Be+subdwarf binary. But they do nominate it as a very promising candidate. Apart from a denser and longer series of spectra needed for the checking of the periodicity, lines in the blue spectral region will permit the orbital parameters to be determined. Detection of He II 4686 in absorption would strengthen the hotspot and helium-core hypothesis.

4.2 A case for eclipsing binaries

During the commissioning phase we also used PUCHEROS to acquire a number of spectra of detached eclipsing binaries selected from the catalogue of the All Sky Automated Survey (ASAS; Pojmanski, 2002). The goal is to determine the absolute parameters of stars from a sample of bright ($V_{\text{max}} < 9$) systems, by combining their ASAS light curves and PUCHEROS radial velocities.
Three systems were observed during the commissioning phase, and another 17 were selected for further monitoring. Large fraction of the systems is not listed in any other variable star catalogue, and only few of them have any RV measurements published. For every target of this project we combine four expositions of 900 s each, and the wavelength solution is based on the Th–Ar lamp expositions before and after the sequence. We typically get the S/N at 5000 Å of the order of 20–40, depending on the observing conditions. The RVs are then calculated with the two-dimensional cross-correlation technique TDOCOR (Zucker & Mazeh 1994).

In Fig. 10 we present the first initial RV curves of the project, obtained from five observations of the star V1200 Cen observed during the commissioning phase. The period was calculated from the ASAS light curve in $V$ and held fixed, $P = 2.482 874$ d. Due to the large luminosity ratio, the spectral features of the secondary were not recognized on every spectrum we got. The rms of the presented solution is 2.94 km s$^{-1}$ for the primary and 8.66 km s$^{-1}$ for the secondary. The resulting $M_{\sin i}^3$ are 1.09(6) and 0.73(3) M$_{\odot}$. This makes the system a potentially important target for testing the evolutionary models of late-type stars due to its low-mass ratio (Hełminiak et al. 2011) and the secondary component having mass $<0.8$ M$_{\odot}$. In this mass regime there are not many well-characterized objects known (Torres, Andersen & Gimenez 2010) and our models of stellar evolution do not reproduce the observed stellar properties, especially radii and temperatures. The monitoring is ongoing and the results of the project will be presented in a dedicated paper.

### 4.3 T Pyxidis campaign

T Pyxidis is a member of a rare subgroup of cataclysmic variables (CVs) called the Recurrent Novae (RNe), which are stars known to undergo multiple ‘nova-like’ outbursts (Webbink et al. 1987). Eruptions of T Pyx took place in 1890, 1902 (actual discovery year), 1920, 1944 and 1966. The event predicted to happen in mid-1980s did not occur, and the star kept quiet for over 40 years. It was finally discovered in outburst by M. Linnolt (Hawaii, USA) on 2011 April 14.2931 (JD 245 5665.7931).

By lucky coincidence PUCHEROS had recently been installed at the telescope and was undergoing commissioning and early science. It was precisely the kind of event the instrument had been designed for! Having a large amount of observing time available and being the target within the reach of the instrument, we started a monitoring campaign with the first spectrum taken on JD $= 245 5667.475$ (2011 April 15, 23:24:19 UT) still during the magnitude ingress, which we believe is one of the first high-resolution spectra of the 2011 event.

Observing T Pyx regularly from 2011 April to July we have collected an unprecedented set of spectroscopic data of the nova during a burst episode. In Fig. 11 we present parts of the spectra centred around H$\alpha$, obtained at three different epochs. The spectra were normalized to the maximum intensity of the H$\alpha$ emission profile and shifted for the clarity. The data and analysis will be presented extensively in a dedicated paper.

### 5 CONCLUSIONS

(i) We presented PUCHEROS, the high-resolution echelle spectrograph of Pontificia Universidad Catolica de Chile, giving details of its design and performances.

(ii) To show the scientific capabilities of the instrument we presented the results from the observations of three science cases obtained during the early science phase: the study of Be stars, the study of eclipsing binaries and the spectroscopic monitoring campaign of the 2011 burst of the RN T Pyxidis.

(iii) We proved that a simple, very inexpensive instrument installed at a small-size telescope can provide valuable data for the study and medium- to long-term monitoring of bright sources and transient events.
Figure 11. Exemplary PUCHEROS spectra of T Pyx during the 2011 outburst, centred around the H\textalpha emission line. All spectra were normalized to the maximum intensity of the emission profile and shifted for the clarity.

(iv) For the first time the Chilean community has access to a national instrument to carry out astronomical observations; the instrument is operated by the Center of Astro Engineering UC and offered to the broad community.

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