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**CN2022B-8**
Galactic panel
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# Spectroscopic follow-up of visual and spectroscopic binaries

## Abstract

We propose an Echelle spectroscopic follow-up of strategically selected Hipparcos southern visual doubles, and Geneva-Copenhagen spectroscopic binaries (GCSB2), for which high-precision orbital parameters are being determined by an on-going Speckle campaign at SOAR and Gemini South, and for which precise parallaxes are provided by Gaia. The combination of high-resolution spectroscopy (yielding radial velocities, stellar parameters and metallicities), with orbital parameters and distances will allow for high quality estimates of idividual masses and luminosities of these stars. Our targets span the entire Hertzsprung-Russell diagram, which will allow us to place tight constrains on the basic properties of a wide variety of spectral types. This program will provide a fundamental data set for stellar astrophysics. Southern binaries are currently being monitored systematically only by our team, which makes our survey unique, and in a way a low cost legacy survey.

## Observing Blocks

| Instrument/Telescope | Req. time | Min. time | $1^{st}$ Option | $2^{nd}$ Option |
|---|---|---|---|---|
| FEROS/MPG 2.2-m | 4 nights | 2 nights | June Any | July Any |
| FEROS/MPG 2.2-m | 4 nights | 2 nights | December Any | January Any |

## CoIs

| Name | Institution | e-mail | Observer? |
|---|---|---|---|
| Rene Mendez | UCH | rmendez@uchile.cl | True |
| Marcelo Mora | PUC | mmora@astro.puc.cl | False |
| Jennifer Anguita | UCH | janguita@das.uchile.cl | False |
| Maximiliano Dirk | UCH | dirkmaximiliano@das.uchile.cl | False |
| Camila Caballero | UCH | camila.caballero@ing.uchile.cl | False |

## Status of the project

- Past nights: 16
- Future nights: 8
- Long term: False
- Large program: False
- Thesis: False

## List of Targets

| ID | RA | DEC | Mag |
|---|---|---|---|
| HIP-14524 | 03:07:33.9 | -03:58:14 | V=11.60 |
| HIP-45139 | 9:11:48.9 | -42:17:44 | V=11.07 |
| HIP-77725 | 15:52:8.4 | 10:52:30 | V=9.59 |
| HIP-90198 | 18:24:17.4 | -04:05:18 | V=7.53 |
| HIP-33973 | 07:02:55.1 | -13:13:40 | V=7.72 |
| HIP-112816 | 22:50:47.1 | -65:42:52 | V=8.64 |
| HIP-20802 | 04:27:26.6 | -29:11:49 | V=7.75 |
| HIP-7601 | 01:37:55.0 | -82:58:31 | V=5.88 |

## SCIENTIFIC AIM AND RATIONALE

Double-line spectroscopic binaries with known radial velocity (RV) curves and astrometric orbits are powerful laboratories to determine precise astrophysical parameters (e.g. mass; Kiefer et al. 2018), as well as parallax-free distances (thus allowing, e.g., an independent assessment of *Gaia's* trigonometric parallaxes; Pourbaix 2000, Mason 2015). Unfortunately, the number of these systems for which the required data - an RV curve and a precise astrometric orbit - is available is rather small.

This proposal, seeks to alleviate this situation, by determining RV curves and stellar parameters for a subset of southern binary systems from the *Hipparcos* visual doubles and Geneva-Copenhagen Spectroscopic Binaries (GCSB2) calalogs, which are being monitored by our HRCam@SOAR + Zorro@GS Speckle survey (see e.g. Tokovinin et al. 2021; Mendez et al. 2021). Our survey, along with parallaxes from *Gaia*, is providing high precision orbital parameters and mass sums for systems within 250 pc of the Sun. Our program complements the northern Speckle survey carried out with the WIYN and DCT telescopes by Horch et al. (2017); together they will provide the first all-sky, volume-limited, determination of orbital parameters and distances for the above samples. Extension of this work to the south will also significantly improve the science in terms of the metallicity range that can be studied (given the Galactic distribution of the sources), and will open the door to many tests of stellar evolution theory.

We will add a large number of new points to the mass-luminosity relation (MLR), and thus we will be able to investigate effects such as metallicity and age on the MLR for the first time. Currently, the best MLR for main sequence stars are those of Torres et al. (2010) and Benedict et al. (2016), but neither of them include low metallicity stars. In cases where one component has evolved off of the main sequence, age determinations will also be possible. In addition to having confirmed and resolved many systems, notable results from our observations include the discovery of many inner or outer subsystems in previously known binaries (i.e., trinary systems), as well as two quadruple system. Several publications have already resulted from this effort.

Securing high-resolution spectroscopy for these systems -yielding RVs, stellar parameters and metalicities- will further enable high quality estimates of their *individual* masses, (parallax-free) distances and luminosities, allowing us to place tight constraints on the mass to luminosity relationship and, in general, on current stellar models. Our Speckle + Echelle survey will provide a fundamental data set for stellar astrophysics and other astrophysical areas, such as star formation and comprehensive studies of the solar neighborhood.

In Fig. 1 we show an example of a double-line binary being targeted by our astrometric/spectroscopic survey: HIP 6626, a K7V dwarf within 25 pc from the Sun. Monitoring at SOAR during four years, together with the first Hipparcos resolution, define the orbit quite well. The light-blue insert shows a pilot Echelle observation made on 2018.916, by A. Tokovinin (co-I of our SOAR survey). Further astrometric/spectroscopic monitoring, plus a future precise parallax from *Gaia* (DR3 or later) will lead to very well determined individual masses of the components.

Our targets span a broad range in spectral types and luminosity class. As shown by their HR diagram given in Fig. 2 (based on published data; courtesy of H. Horch), they define an heterogeneous sample, composed principally of dwarfs, but also includes giants, supergiants, pre-main sequence stars and sub-dwarfs. Thin and thick stars are expected to be included, and both low and high metallicity stars. Our combined survey (astrometric orbits + RV curves) will thus allow us to place tight constraints on the fundamental properties of a wide variety of stars.

**Southern binaries are currently being monitored systematically only by our team, which makes our survey unique, and in a way a low cost legacy survey**.

## Specific goals & procedures

In the earliest version of this program we proposed to target all GCSB2 systems that we had already resolved with SOAR (and for which we could thus compute a combined astrometric + RV solution in a relatively short timescale), *plus* all "fast" (estimated periods less than 1,000 days) *Hipparcos* binaries. Of the GCSB2 systems scrutinized at SOAR at the time this program was started, 96 had been resolved, but an RV curve was not available for them. On the other hand, out of 1896 *Hipparcos* confirmed/suspected binaries included in our SOAR program, 168 turned out to be fast pairs which also lack an RV curve. This added up to a total of 264 targets, covering the whole RA range (we note that these numbers do not match those in our latest SOAR/CNTAC proposal because the target list of the present program has been frozen). In order to comply with a request made by the TAC, we decided to concentrate on the GSCB2 systems and leave the fast moving binaries for a future proposal. In the HR diagram presented in Fig. 2, our restricted sample is similarly scattered.

For RV curve determinations, we need to secure high-resolution spectra for each system on **multiple-epochs**. Envisioning a program with a time-scale of three years, we will require at least two visits per system per semester to obtain well-sampled RV curves for all our targets. Given the brightness range ($V\sim$ 6–12) of our targets, two Echelle setups are ideal for our needs: the Echelle@duPont@LCO and FEROS@MPI 2.2m@La Silla. Both cover the required wavelength range (roughly $\lambda$: 3700-7000Å) and provide enough resolution ($R$ ~45,000/48,000) for precise RV determinations ($\sigma_{RV} < 1$ kms$^{-1}$). This wavelength coverage includes the spectral lines needed to determine spectral types and luminosity classes: H-Balmer lines, He lines for hot stars and enough metal lines for the cooler targets. Through model atmosphere fitting, the spectroscopy will also allow us to determine effective temperature $T_{\rm eff}$, surface gravity ($\log g$), and elemental abundances for these stars. Spectroscopic parameters will also yield a precise placement of these stars on the HR diagram.

This program was started using both setups, but since the duPont Echelle will probably no longer be available, we will complete it using only FEROS.

### References


- Benedict, G. et al. 2016, AJ, 152, 141
- Horch, E., et al. 2017, AJ, 153, 212
- Kiefer, F., et al. 2018, MNRAS, 474, 731
- Mason, B. 2015, IAU General Assembly, 23, 2300709
- Mendez, R.A., Clavería, R. & Costa, E. 2021, AJ, 161, 155
- Pourbaix, D. 2000, A&AS, 145, 215
- Tokovinin, A., et al. 2021, AJ, 162, 41
- Torres, G., Andersen, J. & Giménez, A. 2010, A&ARv, 18, 67


### Comment on target list

We could not upload the complete file. For this reason, in List of Targets we have included only 8 examples, which illustrate well the sky distribution of our objects and their magnitude range.

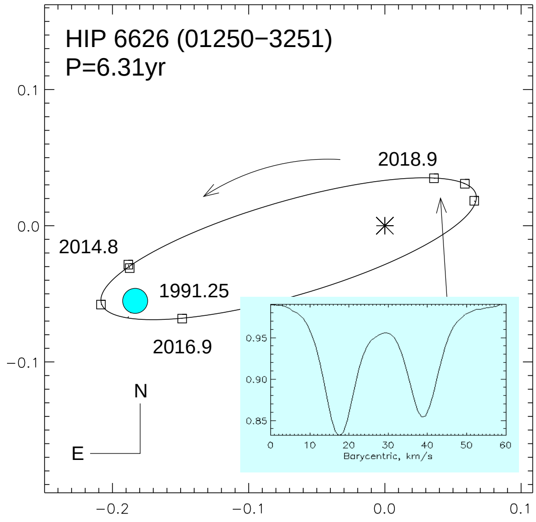


**Figure 1:** Example of a double-line binary from our Hipparcos sample, HIP 6626. The primary component is located at the coordinate origin and the ellipse marks the trajectory. Scale is in arcseconds. Monitoring at SOAR during four years, together with the first Hipparcos resolution, define the orbit quite well. The original Hipparcos discovery (at epoch 1991.25) is marked by the light-blue circle and the SOAR measurements from 2014.8 to 2018.9 by squares. The light-blue insert shows a pilot Echelle observation made on 2018.916 shortly after periastron by A. Tokovinin (co-I of our SOAR survey), showing the double lines.

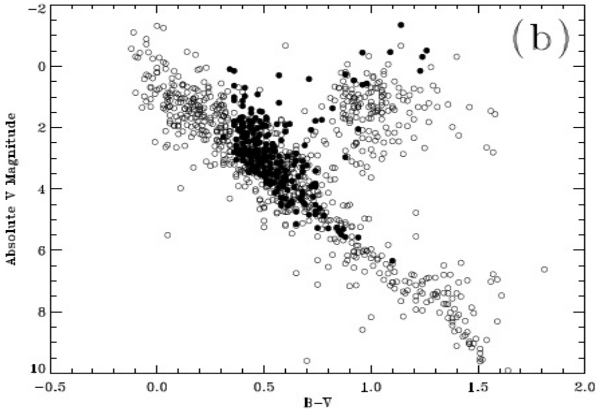


**Figure 2:** H-R diagram for *all* our survey stars. They define an heterogeneous sample, composed principally of dwarfs, but also includes giants, supergiants, pre-main sequence stars and sub-dwarfs. Thin and thick stars are expected to be included, and both low and high metallicity stars. Solid dots indicate objects with published metallicity. Our restricted sample is similarly scattered.

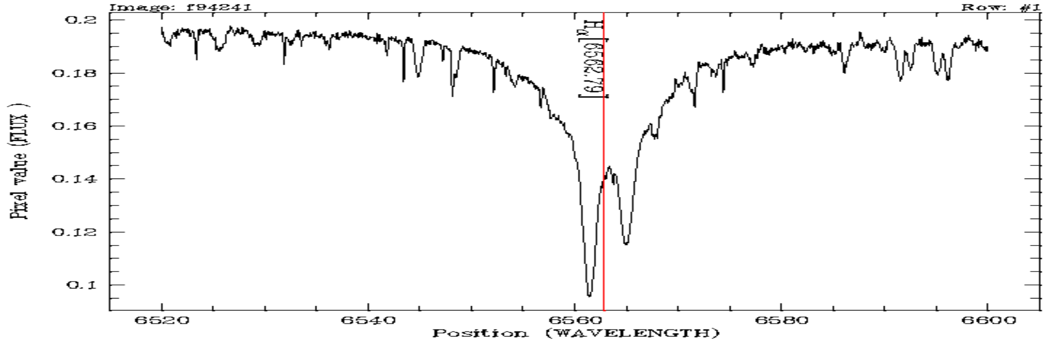


**Figure 3:** Section in the region of H$\alpha$, of a FEROS Echelle spectrum taken on **April 2022** of the SB2 spectroscopic binary HIP 48273. This system has been resolved on multiple epochs during our SOAR Speckle survey

## CURRENT STATUS OF THE PROJECT

In 2019A we were awarded 4 nights (2 epochs) with the du Pont Echelle; runs that had a poor outcome due to weather conditions. In 2019B we were awarded 4 nights (one epoch) with FEROS; run that was partially successful. In 2020A we were awarded 5 nights (2 epochs) with the duPont Echelle, but these observations were never carried out due to the Pandemic. Finally, in 2022A we were awarded 8 nights (2 epochs) with FEROS: April /September.
Data is being reduced. An example is shown in **Fig.3**. We have recently incorporated new students to this program (Camila Caballero and Maximiliano Vega - who are being trained) to speed-up data reduction.

Publications of the proposers in the last three years, relevant to the proposal (resulting from the SOAR Speckle program) are:

- Anguita-Aguero, J., **Méndez, R. A**, Clavería, R., **Costa, E.**, 2022, AJ, 163, 118: "Orbital Elements and Individual Component Masses from Joint Spectroscopic and Astrometric Data of Double-line Spectroscopic Binaries" *****
- Docobo, J., Gomez, J., Campo, P., Andrade, M., Horch, E., **Costa, E., Mendez, R.A.** 2019, MNRAS 482, 4096: "Orbits of 14 binaries based on 2018 SOAR Speckle observations"
- Gómez, J., Docobo, J., Campo, P., Andrade, M., **Mendez, R.A., Costa, E.** 2021, MNRAS.tmp.2373G: "20 Orbits of binaries based on soar speckle observations"
- **Mendez, R.A.**, Clavería, R., **Costa, E.** 2021, AJ 161, 155: "Orbits and Masses of Binaries from Speckle Interferometry at SOAR"
- Tokovinin, A., Mason, B., **Mendez, R. A., Costa, E.**, Horch, E., 2020, AJ 160, 7: â€œSpeckle Interferometry at SOAR in 2019"
- Tokovinin, A., Mason, B., **Mendez, R.A., Costa, E.**, et al. 2021, AJ 162, 41: "Speckle Interferometry at SOAR in 2020"
- Tokovinin, A., Mason, B., **Mendez, R. A., Costa, E.**, 2022, Submitted to AJ: "Speckle Interferometry at SOAR in 2021"

***** Mrs. Jennifer Anguita, a **graduate student** who is co-I of this proposal, will use data from this program to obtain combined orbits for GCSB2 systems resolved by SOAR. This will happen in the context of her thesis. She has shown that using a Markov Chain Monte Carlo approach, and combining an astrometric orbit from SOAR with a RV orbit, it is possible to obtain individual component masses for double-line spectroscopic binaries with a formal uncertainty as small as $0.01 M_\odot$ (Anguita et al. 2022).

## STUDENT THESIS

TECHNICAL DESCRIPTION

To be able to use multiple lines (which vary in intensity depending on Spectral Type) to measure RV, we need a high SNR (∼100). For the original 2019B/22A versions of this proposal we used the FEROS ITC, with airmass=1.5 and IQ=1.3, to carry out tests for various magnitude/spectral type combinations and thus estimate the exposure times required to reach our SNR goal (at the central wavwlength). The ITC predictions were certainly "in the ballpark", but here we have determined the integration times from examination of the data obtained in average conditions with this instrument in early April 2022.

Our **real life** experience with FEROS showed that in the case of our brightest objects a SNR of ∼100 could be achieved, in average conditions, with an exposure time of ∼100 sec, while in the case of the faintest targets exposure times as long as ∼3000 sec were required in good conditions. Adding telescope pointing, readout, quick look. etc. overheads -which in the case of the brighter targets are significant- this resulted in that we could do about 25 pointings per night; including RV standards (2 per night) and a Telluric standard. Given the size of our current sample (96 systems), we thus need 4 good nights per semester to reach the goal of two visits per target, per semester. From our poor weather runs with Dupont@LCO, we also learned that a fairly good sky condition is mandatory, and that only the brightest targets can be observed successfully in bad weather.

Because of the high resolution, efficiency and stability of FEROS, our RV precision goal can be easily achived. It's resolution/precision is sufficient to separate multiple RV components for most spectroscopic binaries, and, in combination with the high SNR, it is adequate to determine accurate spectroscopic parameters. We must note however, that the RV precison attainable depends strongly on the profile of the spectral lines of each particular object; as much as on the instrument's capabilities.

In Fig.3 we present a section centered on H$\alpha$, of a FEROS Echelle spectrum taken on **April 2022** of the SB2 spectroscopic binary HIP 48273. This system has been resolved on multiple epochs during our SOAR Speckle survey