Time Allocation Committee for
MPG time at the ESO 2.2m-telescope
c/o MPI für Astronomie
Königstuhl 17
D-69117 Heidelberg / Germany

Application No.
Observing period January 2023
Received

APPLICATION FOR OBSERVING TIME

from [X] MPIA [ ] MPG institute [ ] other

1. Telescope: 2.2-m [X]

2.1 Applicant

József **Varga**	Leiden Observatory
Name	Institute
Niels Bohrweg 2	2333CA Leiden
street	ZIP code - city
jvarga	varga@strw.leidenuniv.nl
ESO User Portal username	e-mail

2.2 Collaborators

R. van Boekel, T. Trifonov, M. Kürster	MPIA
name(s)	institute(s)
P. Ábrahám, T. Juhász, A. Moór	Konkoly Observatory, Budapest
name(s)	institute(s)

2.3 Observers

name	name

By specifying the names under item 2.3 it is obligatory to also send out these observers to La Silla, if required. Correspondence on the rating of this application will be sent to the applicant (P.I.) as quoted under 2.1 above.

3. Observing programme: Category: C

Title : **The dynamical inner disk of the Herbig Ae binary DX Cha**

Abstract : Young multiple stellar systems are ideal testbeds for studying disk evolution in an asymmetric and time-variable gravitational potential. One such spectroscopic binary, DX Cha, will be monitored with VLTI/MATISSE in order to track the changes in the circumbinary disk during the orbital motion of the central stars. The complexity of the system makes the interpretation of the MATISSE data difficult. Any knowledge on the positions of the stars at the MATISSE epochs would be extremely important in resolving the ambiguities in the modeling. Thus, we request to monitor DX Cha with FEROS, to measure the radial velocity variations of the components, and derive a new orbital solution. The proposed FEROS data will provide essential auxiliary data on the central binary.

4. Instrument: [ ] WFI [X] FEROS [ ] GROND

5. Brightness range of objects to be observed: from 6.6 to 6.6 V-mag

6. Number of hours:

applied for			already awarded	still needed
17.6			0	0
no restriction	grey	dark		

7. Optimum date range for the observations: .... 24.12.22 – 20.06.23
Usable range in local sideral time LST: .... 6:30h – 17:30h

Astrophysical context

Planet-forming disks exhibit a lot of dynamical phenomena, as seen by their photometric and spectral variability. Young multiple stellar systems are ideal testbeds for studying disk evolution in an asymmetric and time-variable gravitational potential. **DX Cha (aka. HD 104237)** is a nearby (d = 107 pc; [1]) young SB2 spectroscopic binary with a circumbinary disk, consisting of a Herbig Ae (A4V) primary and a K3-type companion [2]. The binary orbit is eccentric, with a semi-major axis of 0.22 au (2.1 mas) and a period of 20 days [2, 5]. Dunhill et. al (2015) performed a smoothed particle hydrodynamics (SPH) simulation of the system [4], and showed that the binary carves out a large inner cavity (∼3 au in diameter), and it causes the disk to become strongly eccentric on the inner edge (Fig. 1). The short orbital time scale of the binary allows us to see in real-time what kind of variations such a binary system imposes on the disk.

Immediate aim

In the ESO p110 semester we will **monitor DX Cha with VLTI/MATISSE with the aim to track the changes in the disk geometry during the orbit of the binary** (the program is in service mode). MATISSE resolves the disk at sub-au spatial scales in the thermal infrared (IR). We will fit parametric disk models to the data to derive the morphology of the circumbinary disk. The eccentric binary provides a great opportunity for detecting strong interaction signatures. However, the emission of the binary components is also present in the MATISSE data, thus the model has to include both stars as well. This leads to many parameters in the model, and given the sparse spatial coverage of the VLTI, the fit may become degenerate. Any additional **knowledge on the positions of the stars would be extremely important in resolving the ambiguities in the modeling.** Spectroscopic observations with **radial velocity (RV)** measurements offer a way to obtain the separation of the binary over the period (provided that the stellar masses are known). Böhm et al. (2004) performed a spectroscopic monitoring of DX Cha [2], and presented an orbital solution. Later, Järvinen et al. (2019) updated the solution with new data obtained in 2010 and 2015 ([6], Fig. 2). Because the last RV measurement was more than 5 years ago, the uncertainty in the orbital solution prevents us to have any meaningful constraints on the orbital phases for our upcoming MATISSE observations. Thus, **we need new RV data to update the orbital solution of the binary**. Here we request to **monitor DX Cha with FEROS**, which is well suited for RV measurements. The FEROS data will severely **constrain the allowed solutions for the binary contribution to the MATISSE data**, making the fit to the disk contribution much more robust. To our knowledge, this will be the first case where RV and IR interferometric data are combined in order to uncover the architecture of a binary YSO.

Previous work

There are existing MATISSE observations on DX Cha, obtained in the frame of our GTO survey. The L-band interferometric visibilities measured at two epochs are presented in Fig. 3. The differences between the datasets indicate changes in the morphology of the system within ∼ 0.5 au radius. We fitted these data with a simple model containing two point sources (binary), and an extended Gaussian component (disk). The best-fit model (Fig. 4) reproduces well the visibilities. The off-center point source is located towards the East at 0.15 au separation in the first epoch, and towards SSW at 0.3 au separation at the second epoch. The modeling thus confirms the significant change in the direction of the asymmetry between the two epochs. The point sources in the model may be consistent with the binary, although the actual **morphology of the system is very likely to be more complex** than our simple model.

Layout of observations

We want to sample a complete orbit of the binary with a frequency to capture the rapid change in RV during the periastron passage (Fig. 2). This can be accomplished by a **1-day cadence. To cover the full period we thus require 20 observations**, 1 per night. Some deviations from the strict 1-day cadence can be still tolerated. The data processing will yield the RV curves of both components. We will compute a new orbital solution from the FEROS data. Once we have the MATISSE monitoring data, we will compute the separation of the stars for the MATISSE epochs and use that to constrain the interferometric modeling. Total time requested is 17.6 h.

Strategic importance for MPIA

The structure and dynamics (variability) of inner disks are key research areas in the PSF department. In order to achieve progress in this field, MPIA has invested in the VLTI instrument MATISSE, which is now producing high-quality data. Unexpectedly large dynamical perturbations on sub-au scales have been detected in HD 163296 [9], and now the variable disk of DX Cha will be monitored with MATISSE. **The proposed FEROS data provide essential auxiliary data on the central binary.** Half of the proposing team belongs to the MPIA. This is a collaborative project between the MPIA, the MATISSE consortium, and Konkoly Observatory Budapest.

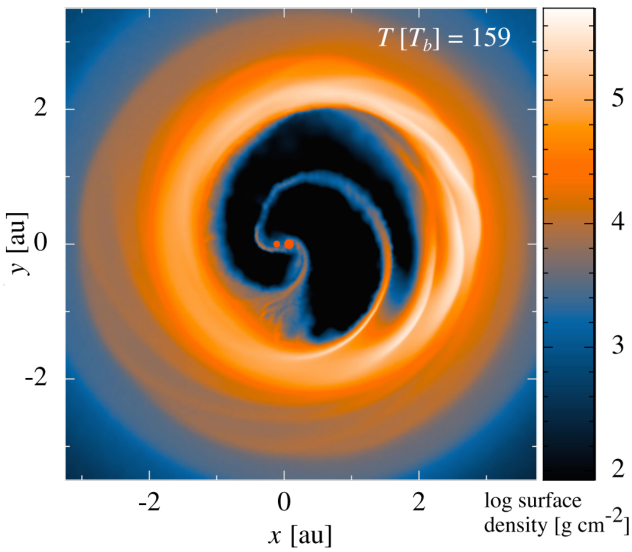

Figure 1: Surface density map from an SPH simulation of the DX Cha system [4]. The stars are shown as red dots inside the disk cavity.

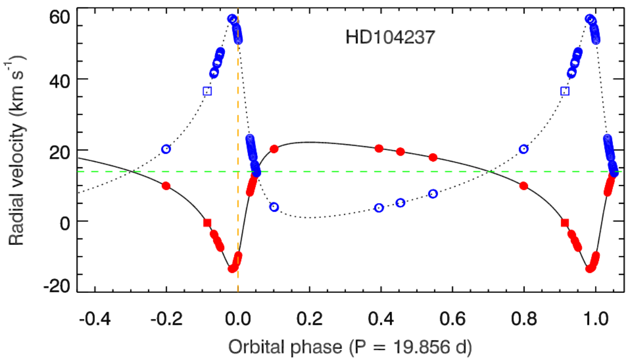

Figure 2: The orbital phase curve of DX Cha, plotted on RV measurements of the primary (red symbols) and secondary (blue symbols). The vertical dashed line indicates the periastron. From Järvinen et al. (2019) [6].

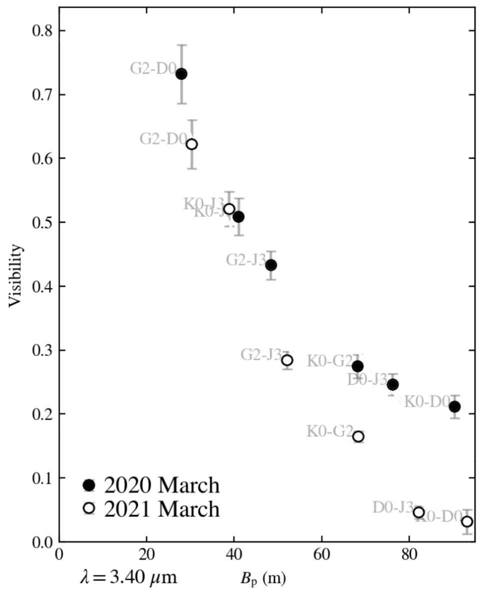

Figure 3: VLTI/MATISSE L-band visibilites as function of the baseline length in 2020 (filled black circles), and in 2021 (empty black circles). On the longer baselines there is a significant change in visibilities between the two epochs.

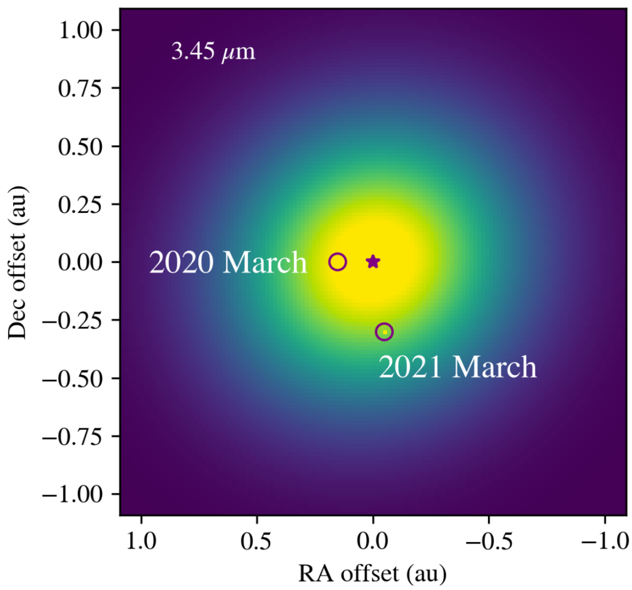

Figure 4: Model image of our fit to the L-band MATISSE data (N is up, E is left). One of the point sources is shown in the middle (star symbol), the other point source is indicated with a circle (positions for both epochs are shown). The circumstellar emission is modeled as an extended Gaussian.

9. Objects to be observed

(Objects to be observed with high priority should be marked in last column)

Designation	α (2000)	δ (2000)	magnitude in spectral range to be observed	priority
DX Cha	$12^{\mathrm{h}}\,00^{\mathrm{m}}\,05\overset{\mathrm{s}}{.}087$	$-78^\circ\,11'\,34.57''$	6.6	1

10. `Justification of the amount of observing time requested:`

As we require accurate radial velocity measurements for a spectroscopic binary in the visible, FEROS ($R = 48000$) is highly suited for our purposes.

Exposure time. DX Cha is a double-lined spectroscopic binary. The primary is of A4V spectral type ($T_{\rm eff} = 8250$ K, $\log g = 4.2$, $v \sin i = 8$ km s^{-1}), and the secondary is of K3 ($T_{\rm eff} = 4800$ K, $\log g = 3.7$, $v \sin i = 12$ km s^{-1}) [3]. Total brightness is $V = 6.6$ mag, and the brightness ratio in V between the primary and secondary is $\sim$10 : 1. Based on this, we estimate the V magnitude of the secondary to be $\sim$9 mag. We require an SNR of $50 - 100$ for the fainter, secondary component, in order to be detect both components reliably. Because of the large contrast, we assume that the main noise component in our data will be the shot noise from the primary. We used the FEROS ETC to estimate the signal of the secondary component, and the noise on the primary, and we find that 15 min exposure time yields an SNR of $50 - 100$ for the secondary in most of the FEROS wavelength range. This is assuming the limiting airmass of 2, mediocre atmospheric conditions (70% turbulence category, moon phase 0.5, PWV = 30 mm), and using the CCD mode 1x1 (fast readout, low gain). For the primary the typical SNR under those conditions and integration time is $300 - 600$. The user manual recommends to multiply the exposure time by a factor in order to maximize the probability of achieving the required SNR in less-than-optimal atmospheric conditions. We request a factor of 2, which results in a 30 min exposure time on the object per epoch.

We checked with the ETC that saturation occurs if the exposure is longer than 8 min; in case of extremely good conditions (10% turbulence category), and at the highest elevation of the target (airmass of 1.5). Thus, we plan to divide the exposure into five 6 min-long integrations, in order to avoid saturation and to mitigate the issue of cosmic rays.

Overheads. We request to use the OBJSKY observing mode. There is a 5 min overhead for pointing, target acquisition, and centering on the fiber. Then, there is 1 min for the adapter and calibrator unit setup. After an exposure, the readout takes 41 s. We ask a calibration exposure with the ThArNe or ThAr+Ne lamp after each science exposure, to have an accurate wavelength calibration (using 10 s exposure time). We calculate 212 s of overhead per science exposure (2x60 s FCU+adapter setup + 2x41s readout + 10s lamp exposure). With 5 science exposures the overheads will be 300 s (pointing) + 5x212s = 1360 s = 22.7 min. Adding 30 min for the science exposures, the total time with overheads for a single observation is 52.7 min. As we ask for 20 monitoring epochs, **the total time requested is 17.6 hours**.

11. `Constraints for scheduling observations for this application:`

This is a monitoring program. The ideal case is to sample a whole orbit ($P \approx 20$ d) of the binary with a cadence of 1 day. Thus we need 20 points. However, we can tolerate if a few points in the sequence are lost to weather or because it does not fit in the schedule for those nights. Such dropouts will cause the average sampling frequency to become longer than 1 day, and the overall time span of the monitoring to be extended.

Best months to observe the object are January-March 2023. Most likely the MATISSE monitoring will also take place at that time. It is not important to coordinate the FEROS observations with the MATISSE run, we just require that the two programs should be executed in the same semester.

12. `Observational experience of observer(s) named under 2.3:`
`(at least one observer must have sufficient experience)`

We are assuming that observations will still be done in service mode for this period.

13. `Observing runs at the ESO 2.2m-telscope (preferably during the last 3 years)`
`and publications resulting from these`

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	Dec 2012, Dec 2016	0.8		[7]
2.2m	FEROS	Dec 2017, Mar 2019	2		[8]

14. References for items 8 and 13:

[1] Bailer-Jones et al. (2021): *Estimating Distances from Parallaxes. V. Geometric and Photogeometric Distances to 1.47 Billion Stars in Gaia Early Data Release 3*, AJ, **161**, 147

[2] Böhm et al. (2004): *Spectroscopic monitoring of the Herbig Ae star HD 104237. I. Multiperiodic stellar oscillations*, A&A, **427**, 907

[3] Cowley et al. (2013): *The Herbig Ae SB2 system HD 104237*, MNRAS, **431**, 3485

[4] Dunhill et al. (2015): *Precession and accretion in circumbinary discs: the case of HD 104237*, MNRAS, **448**, 3545

[5] Garcia et al. (2013): *Pre-main-sequence binaries with tidally disrupted discs: the Brγ in HD 104237*, MNRAS, **430**, 1839

[6] Järvinen et al. (2019): *The two magnetic components in the Herbig Ae SB2 system HD 104237*, MNRAS, **486**, 5499

[7] Moór et al. (2021): *A New Sample of Warm Extreme Debris Disks from the ALLWISE Catalog*, ApJ, **910**, 27

[8] Nagy et al. (2021): *Dipper-like variability of the Gaia alerted young star V555 Ori*, MNRAS, **504**, 185

[9] Varga et al. (2021): *The asymmetric inner disk of the Herbig Ae star HD 163296 in the eyes of VLTI/MATISSE: evidence for a vortex?*, A&A, **647**, A56

Tolerance limits for planned observations:

maximum seeing: 1.5″	**minimum transparency:** 50%	**maximum airmass:** 2.0
photometric conditions: no	**moon: max. phase / ∠ :** 0.8/30°	**min. / max. lag:** 1/3 nights