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CN2022B-53

Galactic panel
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UV
faculty

Structure, kinematics, and evolution of the circumstellar material of massive stars in transition phases (resubmission)

Abstract

Evolved massive stars undergo strong, often eruptive, mass-loss phases that shape and enrich their circumstellar environment. This proposal is aimed to determine the structure and kinematics of the circumstellar medium of these stars in short-lived evolutionary phases (B[e]SGs and YHGs). We propose to use FEROS/MPG for observing a sample of these massive stars, because its high-spectral resolution is necessary for modelling strategic lines (hydrogen recombination series and forbidden emission lines) to determine densities, temperatures, and kinematics within the various line forming regions. The data of this project will also allow us to confirm the classification of these stars, and consequently increase the number of known objects in each of these classes. In addition, we intend to better constrain time-scales, variabilities and preferential direction of mass ejections in these massive stars.

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
FEROS/MPG 2.2-m	12 hours	12 hours	March Any	January Any

CoIs

Name	Institution	e-mail	Observer?
Marcelo Borges Fernandes	OnCL	borges@on.br	False
Michaela Kraus	OnCL	michaela.kraus@asu.cas.cz	False
Catalina Arcos	UV	catalina.arcos@uv.cl	True

Status of the project

- Past nights: 2
- Future nights: 2

- Long term: False
- Large program: False
- Thesis: False

List of Targets

ID	RA	DEC	Mag
HD268757	04:54:14.3	-69:12:36.4	10.2
HD271182	05:21:01.7	-65:48:02.4	9.6
HD269723	05:32:25.0	-67:41:53.6	9.9
HD269953	05:40:12.2	-69:40:04.9	10.0
IRAS07080+0605	07:10:43.9	+06:00:07.9	12.8
IRAS07377-2523	07:39:48.0	-25:30:28.2	12.5
V*FXVel	08:32:35.8	-37:59:01.5	9.7
HD85567	09:50:28.54	-60:58:02.95	8.6
Hen2-91	13:10:04.8	-63:11:30.0	14.4
Hen3-938	13:52:42.8	-63:32:49.2	13.5
SS255	14:13:59.0	-63:11:30.0	13.5
CD-4211721	16:59:06.76	-42:42:08.41	11.0
HD326823	17:06:53.91	-42:36:39.71	9.0

Authors: M. Curé[1], C. Arcos[1], M. Borges Fernandes[2], M. Kraus[3]
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Title: Structure, kinematics, and evolution of the circumstellar material of massive stars in transition phases (resubmission)

Abstract:
Evolved massive stars undergo strong, often eruptive, mass-loss phases that shape and enrich their circumstellar environment. This proposal is aimed to determine the structure and kinematics of the circumstellar medium of these stars in short-lived evolutionary phases (B[e]SGs and YHGs). We propose to use FEROS at 2.2 MPG telescope for observing a sample of these massive stars, because its high-spectral resolution is necessary for modeling strategic lines (hydrogen recombination series and forbidden emission lines) to determine densities, temperatures, and kinematics within the various line forming regions. The data of this project will also allow us to confirm the classification of these stars, and consequently increase the number of known objects in each of these classes. In addition, in combination with information obtained from previous FEROS observations, we intend to better constrain time-scales, variabilities and preferential direction of mass ejections, which are important ingredients to describe a reliable mass-loss history scenario for these massive stars. This proposal is part of Marie Curie RISE project POEMS (Physics Of Extreme Massive Stars) and the data we will acquire with it constitute an important contribution.
Note: this proposal is a re-submission of the granted project CNTAC 0109.A 9022(A), because we couldn't observe the first round due to technical problems with the dome motor. Also, we added 4 targets to the original list.

SCIENTIFIC AIM AND RATIONALE

Massive stars (> 8 $M_\odot$), though few in number, play a major role in the evolution of their host galaxies. They are the main responsible, via their stellar winds, by the enrichment of the interstellar medium with chemically processed material in their interiors. Through their strong radiation, they also deposit large amounts of momentum and energy into their surroundings during their entire lifetime, before they end their lifes in supernova explosions.

As they evolve out of the main sequence, massive stars go through several short-lived transition phases, experiencing increased mass-loss. This is the case with yellow hypergiants (YHGs) and B[e] supergiants (B[e]SGs). Thus, a proper knowledge of the processes of mass-loss, their dynamics and rates in these different phases is extremely important to feed stellar and Galactic evolutionary models.

B[e]SGs and YHGs are often surrounded by rings or disk-like structures. These circumstellar environments are so dense and cool that measurable amounts of molecular gas and dust emission are produced, generating strong infrared (IR) excess. The detection of CO and other molecular band emissions, like SiO and CS, in the near-IR spectra of these objects, has been used as a diagnostic tool for circumstellar physical conditions. As a result, it was possible to reveal for B[e]SGs multi-ring structures rotating in (quasi-)Keplerian orbits (e.g., Kraus et al. 2016, Torres et al. 2018, Maravelias et al. 2018).

On the other hand, the structure and kinematics of the atomic (neutral and ionized) circumstellar regions can be retrieved from strategic emission features (e.g., Kraus et al. 2005), especially seen in the optical and IR spectra. Recombination emission lines from the hydrogen Pfund, Humphreys, and Bracket series trace distinct regions within the ionized wind, because they are sensitive to different densities. In this context we want to validate our hydrodynamical theory that we developed for the

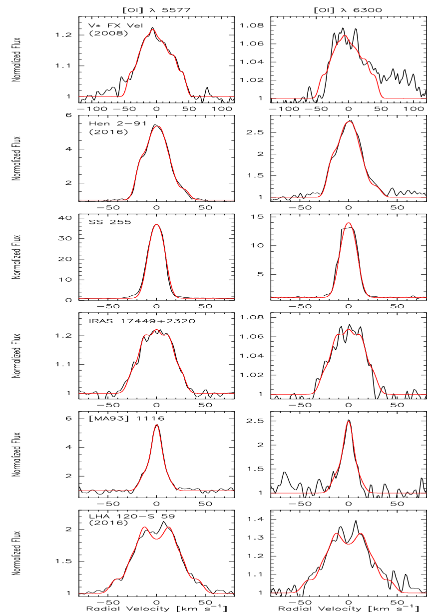

Figure 1: Fit (red) to the observed (black) [OI] forbidden line profiles present in the FEROS spectra of some B[e] stars in our sample (Condori et al. 2019).

outflowing material from the equator of these stars (Curé 2004). Using the density profile obtained by our hydro-code HYDWIND as input in HDUST (3D Monte Carlo NLTE radiative transport code), we can obtain different Hydrogen line profiles at different wavelength ranges. Furthermore, forbidden emission lines are ideal tracers for the gas dynamics at different distances from the star. Their line emission is typically optically thin so that their profiles contain the full kinematic information of the line formation region. Moreover, forbidden lines from various elements mark regions of different conditions, e.g., [CaII] lines that arise at high densities, [OI] lines at medium densities (Kraus et al. 2007, 2010, Aret et al. 2012, Maravelias et al. 2018, Condori et al. 2019), and [FeII], [SII], and [NII] lines, which trace regions of (much) lower wind density. Figure 1 shows how we model optical forbidden emission present in the FEROS spectra of a sample of stars with the B[e] phenomenon.

We propose to use FEROS to obtain high-resolution (R $\sim$ 48000) optical spectra for a large sample of evolved massive stars (B[e]SGs, YHGs) in the Magellanic Clouds and in the Galaxy. High spectral resolution is necessary for modeling strategic lines (hydrogen recombination series and forbidden emission lines) using our numerical codes (Kraus et al. 2000, 2005, 2007, 2010) to determine densities, temperatures, and kinematics within the various line forming regions. This project will also allow us to confirm their classification, and consequently increase the number of known objects of these classes. In combination with information obtained from previous FEROS observations, we intend to constrain time-scales, variabilities and preferential direction of mass ejections, which are important ingredients to describe a reliable mass-loss history scenario for these massive stars. The amount of mass lost during the different evolutionary phases obtained from our project will be an essential ingredient for more reliable future stellar and Galactic evolution calculations. Additionally, it will allow us to characterize for the first time the structure and the kinematics around these sources. These results will supplement previous reconstructions of the observed structures especially around the B[e]SGs that will be used to compare them with predictions from theoretical models and they will drive their advance (Curé 2004; Curé et al. 2005, Curé et al. 2011). Therefore, the results of this proposal can lead to immediate publications.

References:

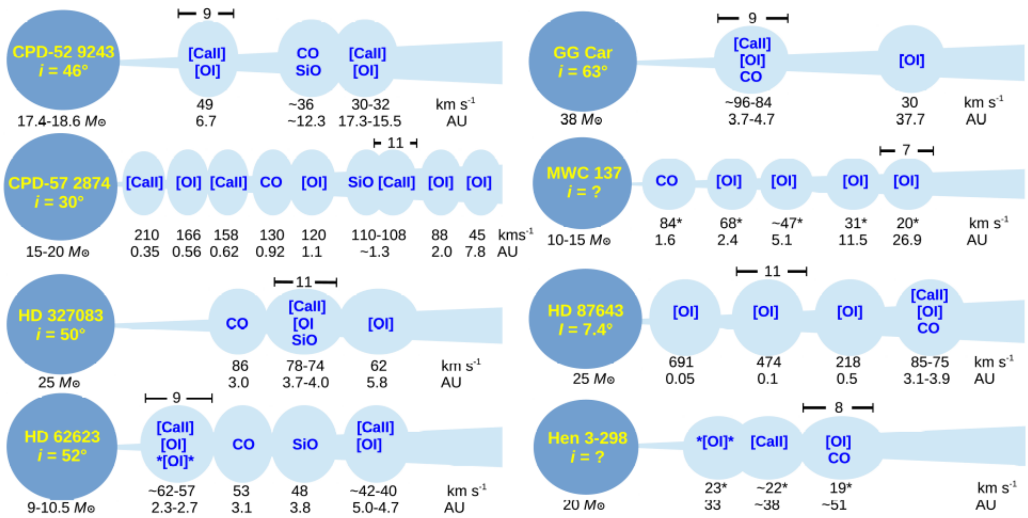

Figure 2: A cartoon illustration of the disc structures derived from the modeling of forbidden lines and molecular band emissions present in the spectra of B[e]SGs The arrows above the rings indicate the typical ring-widths and are given in km s^{-1} (extracted from Maravelias et al. 2018).

Aret A., et al. 2012, MNRAS, 423, 284

Campagnolo, J. C. N., et al. 2018, A&A, 613, A33

Condori C. A. H., et al. 2019, MNRAS, 488, 1090

Curé M., 2004, ApJ, 614, 929

Curé M., et al. 2005, A&A, 437, 929

Curé M., et al. 2011, ApJ, 737, 18

Kraus M., et al. 2000, A&A, 362, 158

Kraus M., et al. 2005, A&A, 441, 289

Kraus M., et al. 2007, A&A, 463, 627

Kraus M., et al. 2010, A&A, 517, A30

Kraus M., et al. 2016, A&A, 593, A112

Maravelias G., et al. 2018, MNRAS, 480, 320

Torres A. F., et al. 2018, A&A, 612, A113

CURRENT STATUS OF THE PROJECT

This proposal was sent last year and was awarded time with a very good grade. We are sending it again because we have lost one observation night due to technical problems with the dome motor. We added 4 targets to the original list.

It is worth to notice that all the members of this proposal participate actively in the Marie Curie RISE project POEMS (Physics Of Extreme Massive Stars) and the data we will acquire with this proposal constitute an important aspect of this project.
This proposal is part of our long-term campaign targeting evolved massive stars. We have used FEROS previously to obtain high-resolution spectra for known B[e]SGs and LBVs that have led already to a number of publications, also we include other recent publications of hypergiants stars:

- Kourniotis, M., **Kraus, M.**, Maryeva, O., **Borges Fernandes M.**, Maravelias, G., Revisiting the evolved hypergiants in the Magellanic Clouds, 2022, MNRAS, 511, 4360
- Maravelias, G., **Kraus, M.**, Cidale, L. S., **Borges Fernandes, M.**, Arias, M. L., **Curé, M.**, Vasilopoulos, G., Resolving the kinematics of the disks around Galactic B[e] supergiants, 2018, MNRAS, 480, 320-344
- Condori C. A. H., **Borges Fernandes M., Kraus M.**, Panoglou D. & Guerrero C. A., The study of unclassified B[e] stars and candidates in the Galaxy and Magellanic Clouds, 2019, MNRAS, 488, 1090
- Campagnolo J. C. N, **Borges Fernandes M.**, Drake N. A., **Kraus, M.**, Guerrero C. A. & Pereira C. B., Detection of new eruptions in the Magellanic Clouds luminous blue variables R 40 and R 110, 2018, A&A, 613, A33
- **Kraus M.**, Liimets T., Cappa C. E., Cidale L. S., Nickeler D. H., Duronea N. U., Arias M. L., Gunawan D. S., Oksala M. E., **Borges Fernandes M.**, Maravelias G., **Curé M.** & Santander-Garcia M., Resolving the circumstellar environment of the Galactic B[e] supergiant star MWC 137 from large to small scales, 2017, AJ, 154, 186.
- **Kraus M.**, Cidale L. S., Arias M. F., Maravelias G., Nickeler D. H., Torres A. F., **Borges Fernandes M.**, Aret A., **Curé M.**, Vallverdu R., & Barba R. H., Inhomogeneous molecular ring around the B[e] supergiant LHA120-S 73, 2016, A & A, 593, A112

Moreover, a physical model to explain the structures around these stars has been developed, and these observations will help us to test this scenario and provide important feedback for future improvements:

- **Curé M.**,The Influence of Rotation in Radiation-driven Wind from Hot Stars: New Solutions and Disk Formation in Be Stars, 2004, ApJ, 614, 929
- **Curé M.**, Rial D. F. & Cidale L. S., Outowing disk formation in B[e] supergiants due to rotation and bi-stability in radiation driven winds, 2005, A&A, 437, 929
- Araya I., **Arcos C.** & **Curé M.**, Disk formation in oblate B[e] stars, in The B[e] Phenomenon: Forty Years of Studies, ASP Conference Series, 508, 87
- Venero R. O. J., **Curé M.**, Cidale L. S. & Araya I., The Wind of Rotating B Supergiants. I. Domains of Slow and Fast Solution Regimes, 2016, ApJ, 822, 28

TECHNICAL DESCRIPTION

This proposal is aimed to determine the structure and kinematics of the circumstellar medium of evolved massive stars in short-lived, eruptive evolutionary phases (B[e]SGs and YHGs) at different metallicities (Magellanic Clouds and our Galaxy). To fully resolve the profiles of the strategic emission lines, a high-spectral resolution, as provided by FEROS, is essential.

We have selected a sample of 13 massive stars, some of them with known variability in the literature. The combination of new observations with previous FEROS data will allow us to study the time evolution of the their circumstellar medium.

Considering the V-band magnitudes of our targets and assuming an airmass of 1.4 and a seeing of 0.8 arcsec, the exposure times were computed using Pickles template spectra appropriate for the spectral types of our objects. Exposure times were computed using the ESO ETC for FEROS such that we will achieve a S/N at 6000 Å of $\sim$ 70-100 for the stars of our sample. This wavelength for the S/N determination is chosen, because many of the lines of our interest (e.g., the [OI] lines) arise in this spectral region.

To achieve the expected S/N, avoid the saturation of the strong H line emission of many objects, and for an easy identification and removal of cosmic rays, the total needed exposure times were split into two or more individual exposures. However, to avoid an excessive number of cosmic rays in the spectra, we limit ourselves to a maximum exposure time of 40 min (2400 sec). As for our purposes standard day-time calibration is sufficient, no extra time for special calibration needs to be added. We find that a total exposure time of 10.83 h is necessary to achieve our S/N and science goals. Based on our experience, an overhead time of 5 min per pointing needs to be considered, adding 1.08 h. Hence we request a total time of 11.91 h. **Most of our objects can be observed during the whole period 2022B and all of them can be observed in March in just one run.**
In table 1, we list our targets and number of exposures and exposure time in seconds. We request for service mode observations.

Table 1: List of our targets.

Name	α (J2000)	δ (J2000)	V (mag)	N_{exp}	exp_time (s)
HD 268757	04 54 14.3	-69 12 36.4	10.2	2	400
HD 271182	05 21 01.7	-65 48 02.4	9.6	2	210
HD 269723	05 32 25.0	-67 41 53.6	9.9	2	300
HD 269953	05 40 12.2	-69 40 04.9	10.0	2	400
HD 326823	17 06 53.9	-42 36 39.7	9.0	2	150
IRAS 07377-2523	07 39 48.0	-25 30 28.2	12.5	2	2400
SS 255	14 13 59.0	-63 11 30.0	13.5	3	2400
V FX Vel	08 32 35.8	-37 59 01.5	9.7	2	210
IRAS 07080+0605	07 10 43.9	+06 00 07.9	12.8	2	2400
Hen 3-938	13 52 42.8	-63 32 49.2	13.5	3	2400
Hen 2-91	13 10 04.8	-63 11 30.0	14.4	4	2400
CD-42 11721	16 59 06.8	-42 42 08.4	11.0	2	900
HD85567	09 50 28.5	-60 58 03.0	8.6	2	120