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Galactic panel
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UV
faculty

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

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, eruptive evolutionary phases (B[e]SGs, LBVs and YHGs) at different metallicities. We propose to use FEROS for observing a sample of these massive stars, because its high-spectral resolution is necessary for modeling strategic 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, which are important ingredients to describe a reliable mass-loss history scenario for these massive stars.

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
FEROS/MPG 2.2-m	12 hours	1 hours	April Any	Any Any
FEROS/MPG 2.2-m	28 hours	14 hours	September Any	Any Any

CoIs

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

Status of the project

- Past nights: 0
- Future nights: 0
- Long term: False
- Large program: False
- Thesis: False

List of Targets

ID	RA	DEC	Mag
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
IRAS17449+2320	17:47:03.3	+23:19:45.3	10.0
LHA115-S6	00:46:55.03	-73:08:34.14	12.9
LHA115-S18	00:54:09.54	-72:41:43.29	13.8
LHA115-S23	00:55:53.81	-72:08:59.51	13.3 MA93>MA93
1116	00:59:05.9	-72:11:27.0	15.6
LHA115-S38	01:03:42.36	-72:13:42.74	14.0
LHA115-S52	01:07:18.22	-72:28:03.66	10.2
LHA115-N82	01:12:19.70	-73:51:26.02	14.6
2dFS3528	01:21:38.72	-73:58:41.03	12.9
HD268757	04:54:14.26	-69:12:36.44	10.2
ARDB54	04:54:43.4	-70:21:27.5	12.7
LHA120-S149	04:59:22.85	-70:11:45.9	11.6
RMC71	05:02:07.39	-71:20:13.12	10.6
HD271182	05:21:01.71	-65:48:02.42	9.6
HD269723	05:32:24.97	-67:41:53.61	9.9

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Title: Structure, kinematics, and evolution of the circumstellar material of massive stars in transition phases

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, eruptive evolutionary phases (B[e]SGs, LBVs and YHGs) at different metallicities (Magellanic Clouds and our Galaxy). 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.

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 or even intense eruptions. This is the case with yellow hypergiants (YHGs), B[e] supergiants (B[e]SGs), and luminous blue variables (LBVs). 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.

While the ejected material of LBVs usually accumulates in either circumstellar shells or (bipolar) nebulae after eruptions, 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 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. The left panel of Figure 1 shows how we model optical forbidden emission present in the FEROS spectra of a sample of stars with the B[e] phenomenon and the right panel shows how the modeling of these lines and molecular bands can trace the circumstellar medium of these stars.

In addition, some of the objects of our sample show variability seen in previous spectra. The variability is associated to changes in the mass-loss processes, being caused by different reasons, e.g. binarity or new eruptions (see, Campagnolo et al. 2018; Condori et al. 2019). Figure 2 shows the variability of the LBV R40, due to an intense eruption, seen in previous FEROS spectra.

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, LBVs) 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:

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

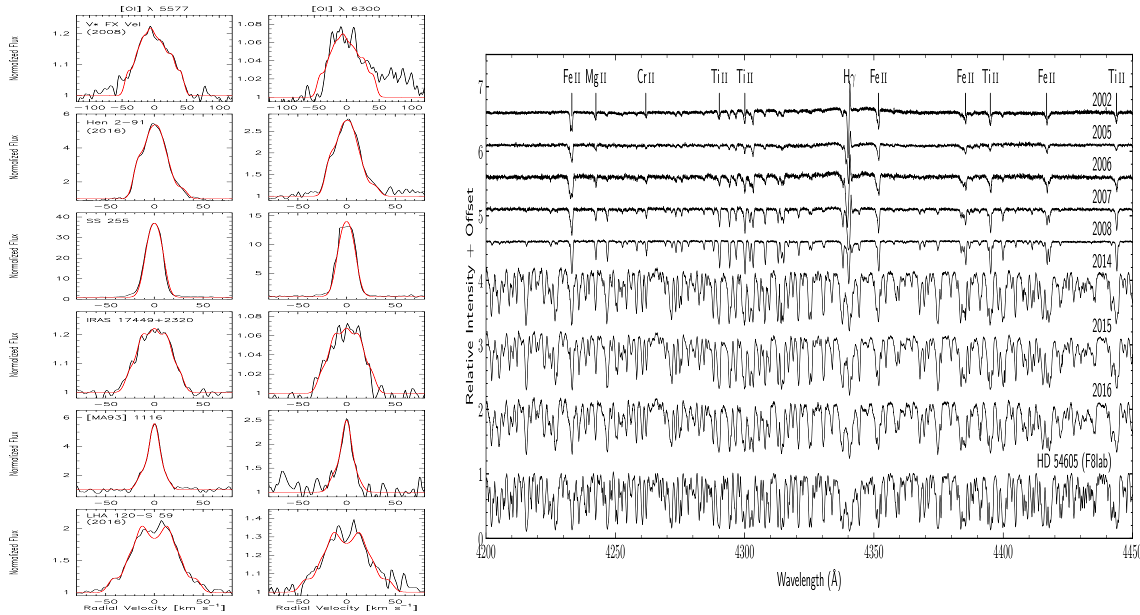

Figure 1: *Left:* Fit (red) to the observed (black) [OI] forbidden line profiles present in the FEROS spectra of some B[e] stars in our sample (Condori et al. 2019). *Right:* Spectral variation of the LBV R 40 seen in FEROS spectra taken from 2002 (top) until 2016 (bottom). We can see the change from a late B/early A-type to a late F-type spectrum, implying a new intense eruption. The spectrum of HD 54605 (F8Ia) is also shown for comparison. Extracted from Campagnolo et al. (2018).

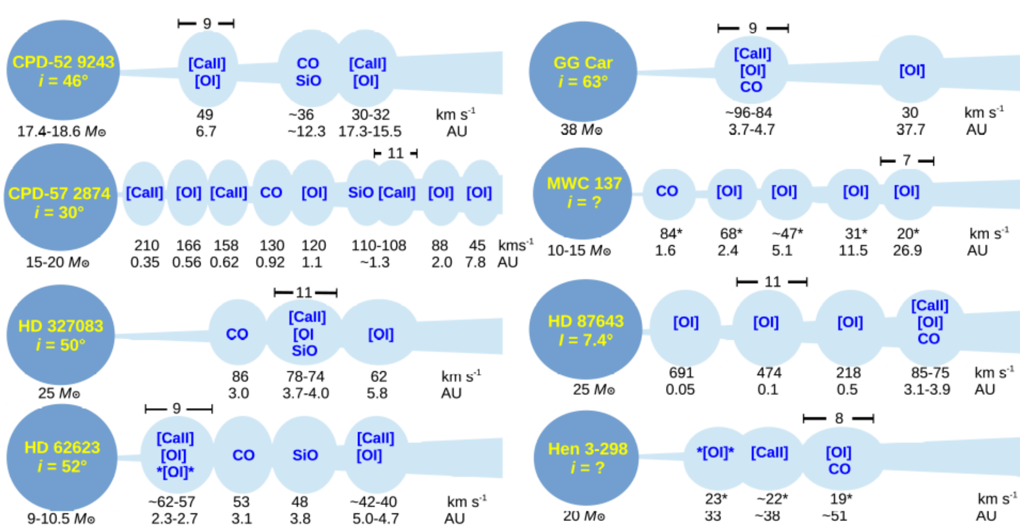

Figure 2: A cartoon illustration of the disc structures derived from the modeling of forbidden lines and molecular band emissions present in the spectra of B[e]SGs The arrows above the rings indicate the typical ring-widths and are given in km s^{-1} (extracted from Maravelias et al. 2018).

CURRENT STATUS OF THE PROJECT

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:

- 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, LBVs 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 32 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 with $m_v < 13.5$ and $\sim$ 40-50 for $m_v > 13.5$. 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 Hα 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 observing time of 35.83 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, in a total of 2.67 h. Hence we request a total time of 38.5 h.

Based on the visibility of our objects in 2022A, we ask for two runs. The first run (run A) is in April for our Galactic objects (11.17 h) and the second run (run B) is in September for our Magellanic Clouds stars or close to it (27.33 h).

In table 1, we list our priority targets (and number of exposures and exposure time in seconds), which are the objects of our sample that we need to observe to confirm the presence of variability and consequently their proper nature. Thus, the minimum time requested for the observation of these priority targets is 14.8 h (0.73 h for run A and 14.07 h for run B). We request for service mode observations.

Table 1: List of our priority targets.

Name	α (J2000)	δ (J2000)	V (mag)	N_{exp}	exp_time (s)	Run
HD85567	09 50 28.54	-60 58 02.95	8.57	2	120	A
CD-42 11721	16 59 06.76	-42 42 08.41	11.00	2	900	A
Hen s23	00 55 53.81	-72 08 59.51	13.25	3	2400	B
[MA93] 1116	00 59 05.9	-72 11 27.0	15.61	6	2400	B
LHA 115-S 52	01 07 18.22	-72 28 03.66	10.2	2	480	B
LHA 115-N82	01 12 19.70	-73 51 26.02	14.63	4	2400	B
ARDB 54	04 54 43.4	-70 21 27.5	12.71	2	2400	B
LHA 120-S 149	04 59 22.85	-70 11 45.9	11.55	2	1500	B
HD38120	05 43 11.89	-04 59 49.88	9.1	2	150	B
LHA 120-S 83	05 27 52.66	-68 59 08.49	11.09	2	900	B
LHA 120-S 116	05 30 51.46	-69 02 58.59	10.28	2	480	B
LHA 120-S 134	05 40 13.32	-69 22 46.49	11.93	2	2100	B
HD50138	06 51 33.40	-06 57 59.45	6.67	2	60	B