EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **67**

To be submitted only to: proposal@eso.org
Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Panel: **D–4**

High quality spectroscopy of faint Galactic WN stars: searching for hitherto unknown binary systems

2. Abstract

We propose to search for the spectroscopic signature of binary companions in a sample of faint Galactic WN stars. The stars in our sample were selected based on their relatively weak emission lines that could be diluted by the effect of the continuum light of a hitherto unknown companion. We suggest to obtain high resolution spectroscopy of these stars allowing us to search for absorption lines belonging to the companion. The results of this study will be provide a more accurate census of the fraction of binaries among WN stars. The best binary candidates discovered in this study will be selected for a follow-up programme to set up orbital elements and thus to improve our knowledge of the masses of WN stars. These results will eventually be important for a better understanding of the evolutionary link between the different WN-subclasses.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	NTT	EMMI	2n	apr	n	n	THN	v

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		0n
b) still required to complete this project:	NTT	4n

5. Special remarks

This proposal is complementary to a proposal of van der Hucht et al. aiming at the detection of binary systems among a sample of faint Galactic WC stars. Depending on the results of the present study a follow up programme aiming at the determination of orbital elements will be proposed in period 69.

6. Principal Investigator: G. Rauw (Institut d'Astrophysique, Liège, B, rauw@astro.ulg.ac.be)

CoI(s): K.A. van der Hucht (SRON, Utrecht, NL), P.M. Williams (Royal Observatory, Edinburgh, UK), J.-M. Vreux (Liège, B), E. Gosset (Liège, B)

7. Is this proposal linked to the PhD thesis preparation of one of the applicants?

8. Description of the proposed programme

A) Scientific Rationale: As a consequence of the powerful interactions with their surrounding interstellar medium, hot stars of spectral type O and Wolf-Rayet play an important role in the ecology of the galaxies and trigger the star formation processes in starburst regions (e.g. Maeder & Meynet 1995). In spite of considerable progress achieved over the past twenty years, many questions related to Wolf-Rayet (WR) stars are still awaiting a solution. For instance, while it is generally accepted that WR stars are the evolved descendants of massive O-stars, the exact evolutionary sequence between O and WR stars is far from being established. Moreover, the importance of mass transfer in massive O + O binary systems leading to the formation of WR + O binaries is still a matter of debate (e.g. Maeder & Meynet 1994, Vanbeveren et al. 1998).

Nowadays, a total of 226 WR stars are known in our Galaxy (van der Hucht 2000). Among this sample, there are only 52 **known** spectroscopic binaries and only 32 of them have reliable RV solutions. The *VIIth Catalogue of Galactic Wolf-Rayet Stars* (van der Hucht 2000) lists another 30 stars that are potential WR + OB binaries. Most of the newly discovered WR stars are faint objects that have been poorly studied and of which binarity has not yet been investigated.
For most of the WR + OB candidates identified by van der Hucht (2000), binarity has been tentatively inferred from diluted emission lines. In fact, the 'contamination' of the WR spectrum by the continuum light of the companion in a WR + OB binary yields lower than typical emission line intensities for a given WR spectral type (e.g. Royer et al. 1998) and provides a diagnostic to select promising WR + OB candidates. A firmer confirmation of a composite spectrum requires however high quality spectra allowing to detect the absorption lines of the OB companion.
In this application, we propose therefore to obtain high quality, high resolution (for the brighter stars in our sample) spectra of the southern WN + OB candidates listed by van der Hucht (2000). These data will allow us to search for typical OB-type absorption lines and hence to identify those systems that deserve a more intensive study to set up a full orbital solution (such a study would be the goal of a future proposal). A parallel proposal on possible WC + OB systems has been submitted by van der Hucht et al.

There are good reasons to believe that our present day census of WR binaries is not complete. Indeed, Langer & Heger (1999) argued that most SNeIb/c occur in post-mass-transfer close binaries and supernova statistics show that there should be more WR + OB binaries than single WR stars. However, the observed binary frequency among Galactic WR stars is as yet below 50%. Therefore many more WR binaries could be hidden among the poorly studied WR stars. Improving our knowledge of the binary population among WN stars will have important consequences for our understanding of the Wolf-Rayet phenomenon and could help us to quantify the importance of mass exchange during the progenitor O + O binary phase.
Those stars of our sample which will be found to display absorption lines associated with an OB secondary will be selected for a follow-up programme aiming at the determination of orbital elements. So far, only 13 WN + OB double-line spectroscopic binaries have accurate orbital solutions required to derive reliable masses of WN stars in different evolutionary stages. Increasing the sample of WN + OB binary systems will ultimately lead to a better determination of the fundamental properties (such as the masses and radii) of WN stars. These results will be important to address important questions related to massive stars research:

- What is the evolutionary link between the various WR subtypes (e.g. Crowther et al. 1995)? The SB2 systems studied so far display a rough trend of a decreasing mass ratio $q = m_{\rm WR}/m_{\rm O}$ when going from late to early subtypes (van der Hucht 2000). However, the statistics are still very poor and data on more WR binaries are definitely needed to confirm this result.

- Are the very massive WNL + abs stars in WR 22 (Schweickhardt et al. 1999) and WR 29 (Niemela & Gamen 2000) exceptional objects or are all WNL + abs stars massive objects that are in the core hydrogen burning stage (Rauw et al. 1996)? Recent evolutionary tracks for single rotating stars (Meynet & Maeder 2000) suggest that for reasonable values of the rotational velocity, rotational mixing in the most massive stars can be sufficient to produce a surface chemical composition typical of late WN stars, while the stars are still in the H-burning phase. The study of more WNL stars in binary systems should allow us to determine the fraction of these stars that are still probably in the core H-burning phase. This issue is extremely important for a better understanding of the transition between O-stars and 'classical' He-burning WR-stars.

B) Immediate Objective: We suggest to obtain high quality spectroscopic observations of a sample of WN stars that display diluted emission lines in their spectra. As stated above, these stars are good candidates for WN + OB binary systems. Our observations will be used to search for absorption lines belonging to the O-star companion. For the brighter stars ($m_V \leq 13$) in our sample, we will take advantage of the relatively high resolution and wide spectral range provided by the EMMI echelle spectrograph to search for the signature of the O-star over a wide wavelength range. For the fainter stars, we will obtain long slit spectroscopy concentrating on the wavelength range 3800 - 4800Å that is the most useful for a spectral classification of the O-star companion

8. Description of the proposed programme (continued)

(e.g. Walborn & Fitzpatrick 1990).
Our experience in this field (Rauw et al. 1996) shows that high quality data (S/N $\geq$ 100) are requested to detect the signature of the companion. This is especially the case for binaries harboring luminous WNL stars.
Those stars that display absorption lines that can be associated with an OB secondary will be selected for a follow-up programme aiming at the determination of orbital elements needed to constrain the fundamental parameters of the stars.

Crowther P.A., Smith L.J., Hillier D.J., Schmutz W. 1995, A&A 293, 427
Langer N., Heger A. 1999, in *Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies*, Proc. IAU Symp. 193, eds.: K.A. van der Hucht, G. Koenigsberger, P.R.J. Eenens, ASP, 187
Maeder A., Meynet G. 1994, A&A 287, 803
Maeder A., Meynet G. 1995, The Messenger 80, 19
Meynet G., Maeder A. 2000, A&A 361, 101
Niemela V.S., Gamen R.C. 2000, A&A, in press
Rauw G., Vreux J.-M., Gosset E., Hutsemékers D., Magain P., Rochowicz K. 1996, A&A 306, 771
Royer P., Vreux J.-M., Manfroid J. 1998, in *The Magellanic Clouds and Other Dwarf Galaxies*, Proc. of the Bonn/Bochum-Graduiertenkolleg Workshop, eds.: T. Richtler. J.M. Braun, Shaker Verlag, 287
Schweickhardt J., Schmutz W., Stahl O., Szeifert T., Wolf B. 1999, A&A 347, 127
Vanbeveren D., de Donder E., van Bever J., van Rensbergen W., de Loore C. 1998, New Astronomy 3, 443
van der Hucht K.A. 2000, New Astronomy Reviews, in press
Walborn N.R., Fitzpatrick E.L. 1990, PASP 102, 379

C) Telescope Justification: To achieve our scientific goals, we need to gather high quality (S/N $\geq$ 150) spectra of a sample of selected Galactic WN stars. The spectroscopic signature of a companion OB star is best identified if we observe at relatively high resolution (R$\sim$ 5000 − 10000) over a wide wavelength range (in order to cover simultaneously as many lines as possible). We propose therefore to use the EMMI echelle spectrograph for the brighter objects ($m_V \leq 13$) in our sample and the long slit spectroscopic mode for the fainter stars. Given the magnitudes of our targets and the fact that the EMMI instrument allows to meet the above requirements, the NTT provides the optimal choice for our project.

D) Observing Mode Justification (visitor or service): We request the visitor mode for our programme. In fact, since the detection of OB absorption lines in the spectra of WN stars requires high quality data, an 'on-line' inspection of the data will be performed to optimize the observing strategy in order to achieve our scientific goals.

E) Strategy for Data Reduction and Analysis: Given our experience in the detection of OB absorption lines in the spectra of WN stars (Rauw et al. 1996, A&A 306, 771), the analysis of the data from this project is quite straightforward. Data reduction will be carried out with the appropriate contexts of the MIDAS package implemented on our computers in Liège. The analysis of the reduced spectra will include a detailed inspection of the spectra to detect OB absorption lines, the measurement of the radial velocities and equivalent widths of emission and absorption lines, as well as the spectral classification of the OB spectra that we will detect. This analysis will be used to select the sample of stars to be considered for a follow-up programme.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: The lunar phase is not a critical issue for the present programme.

Time Justification: From our experience with the requested echelle mode configuration, we can estimate exposure times of the order of 30 minutes for stars of magnitude 11, 1 hour for $m_V \sim 12$ and about 2 hours for stars with $12 \leq m_V \leq 13$. Therefore, a total of 15 hours exposure time (on the sky) for the stars to be observed in echelle mode is required. For the fainter stars, we will use grating #3 with two different wavelength settings allowing to cover the critical wavelength range 3800 - 4800Å. For each setting we have estimated an exposure time of 30 minutes using the EMMI exposure time calculator (version 2.5.1). This gives us therefore a total of 6 hours observation for the fainter stars. Therefore, a total of two nights observations with the NTT is requested to achieve our scientific goals.

Calibration Request: Standard Calibration

10. Report on the last use of ESO facilities

64.H-0040 / G. Rauw / The binary nature of the unique transition star R 84 in the LMC

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
NTT	EMMI	30 Oct 1999, 16 Fev 2000	67%	33%	weather

Current status of obtained data: paper-submitted

Remarks: The observations were done in service mode.

11. Applicant's publications related to the subject of this application during the past two years

Rauw G., Vreux J.-M., Bohannan B., 1999, ApJ, 517, 416: The interacting early-type binary BD+40° 4220. Modeling the colliding winds region

Rauw G., Stevens I.R., Pittard J.M., Corcoran M.F., 2000, MNRAS, 316, 129: ASCA spectroscopy of the hard X-ray emission from the colliding wind interaction in γ^2 Velorum

Marchenko S.V., Rauw G., Antokhina E.A. et al., 2000, MNRAS, 317, 333: Coordinated Monitoring of the Eccentric O-star Binary Iota Orionis. Optical Spectroscopy and Photometry

Rauw G., Sana H., Gosset E., Vreux J.-M., Jehin E., Parmentier G., 2000, A&A, 360: A new orbital solution for the massive binary system HD 93403

Pittard J.M., Stevens I.R., Corcoran M.F., Gayley K.G., Marchenko S.V., Rauw G., MNRAS, in press: Coordinated Monitoring of the Eccentric O-star Binary Iota Orionis. The X-ray Analysis

Heydari-Malayeri M., Royer P., Rauw G., Walborn N.R., A&A, in press: Compact star clusters of the LMC H II region N 11C

Rauw G., Nazé Y., Carrier F., Burki G., Gosset E., Vreux J.-M., A&A, submitted: The strange case of the massive binary HD 149404

12. List of targets proposed in this programme

Run	Target/Field	α	δ	Equinox	Mag.	Diam.	Additional information
A	WR 8	07 44 58	-31 54 30	J2000	10.5		WN7/WCE
A	WR 20a	10 23 58	-57 45 49	J2000	14.1		WN7:h/WC
A	WR 21a	10 25 56	-57 48 44	J2000	12.8		WN6 + OB?
A	WR 25	10 44 10	-59 43 11	J2000	8.14		WN6h + OB?
A	WR 26	10 44 32	-57 50 24	J2000	14.6		WN7/WCE
A	WR 28	10 48 59	-59 03 38	J2000	13.0		WN6(h) + OB?
A	WR 35	11 00 22	-61 13 51	J2000	13.8		WN6h + OB?
A	WR 36	11 02 33	-59 26 22	J2000	13.6		WN5-6 + OB?
A	WR 44	11 16 58	-59 26 24	J2000	13.0		WN4 + OB?
A	WR 51	13 18 23	-62 28 21	J2000	14.6		WN4 + OB?
A	WR 63	14 50 58	-59 51 27	J2000	12.8		WN7 + OB?
A	WR 67	15 15 33	-59 02 31	J2000	12.1		WN6 + OB?
A	WR 71	16 03 49	-62 41 36	J2000	10.2		WN6 + OB?
A	WR 87	17 18 53	-38 50 05	J2000	12.6		WN7h + OB?
A	WR 89	17 19 01	-38 48 51	J2000	11.5		WN8h + OB?
A	WR 108	18 05 26	-23 00 20	J2000	10.2		WN9h + OB?
A	WR 109	18 07 52	-35 10 20	J2000	14.5		WN5h + ?

13. Scheduling requirements

14. Instrument configuration

Telescope	Instrument	Parameter	Value or list
NTT	EMMI	Grating-spectro-blue-arm	Gratings#3 and #5
NTT	EMMI	Echelle-spectro-red-arm	Echelle-grating#9
NTT	EMMI	Echelle-spectro-red-arm	Cross-disperser-grism#3