GraF/ADONIS spectro-imaging of η Carinae $0.9'' \times 9''$central region.*

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Abstract – We present long slit spectroscopic and 3D-spectroscopic data of η Car at λ=1.67μm taken with the GraF instrument used with the ESO 3.6 m /ADONIS/SHARPII+. The successfully deconvolved data show the angular resolution of $0.1''$ and spectral resolution of 10 000, illustrating the power of this new instrument. The spots B and D (cf. Weigelt & Ebersberg 1986) are well detected at $0.14''$ and $0.21''$ to the NW from the central star, as well as the SE feature at about $0.7''$ described previously by Rigaut & Gehring (1995). Their spectrum in the lines of hydrogen Br11, [FeII] 1.6769 μm, and FeII 1.6783 μm, 1.6873 μm show different broadening and relative line strength. The central star emission is characterized by a large broadening ($\simeq$800 km/s), with Br11 stronger than FeII lines. The NW spots emit essentially in narrow ($\leq$150 km/s) FeII lines, while the SE feature spectrum is close in appearance to that of the central star. This suggests more reflexion and/or scattering for the SE feature, having therefore a higher dust/gas ratio than the NW spots.

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1 Introduction:

1.1 Spectro-imaging with GraF:

The GraF instrument was built specifically for spectroscopy and spectro-imaging with the ESO adaptive optics system ADONIS at the La Silla 3.6m telescope. We use a Grating spectrograph cross-dispersed with a Fabry-Perot interferometer; this is why the acronym GraF. The set-up has an integral field spectroscopic capacity, alias 3D-spectroscopy, where the image of the field is acquired simultaneously in several quasi-monochromatic wavebands. Removing the FP out of the beam, converts the instrument in a classic long slit spectrograph. The operating wavelength domain is from 1.2 to 2.4 μm. For further details see Chalabaev et al. (this proceedings).

The main feature of the 3Ds-mode is the possibility to use the images in the continuum wavebands as the calibrators both for photometry during channel to channel FP scanning, and as the PSF during deconvolution, provided the source image in the continuum is point-like, which happens frequently in studies of circumstellar gaseous environment. The data come in the form of a 3D cube of 256x256 frames, each frame being a combination of monochromatic "sub-images". At λ 1.7 μm the width of a "sub-images" is about $0.9''$ (with the 300 mm^{-1} grating), the height is about $9''$, the spectral passband as defined by the FP is 1.5Å, and the spacing between the central wavelengths of adjacent windows is about 27Å(one FP inter-order) (see Section 2.2).

During the test observations we were particularly concerned with the evaluation of the accuracy of the GraF data deconvolution. Two effects were thought to make the deconvolution troublesome. First, the use of the grating elongates the image in the direction of the spectral dispersion. Second, the window width of about 15 spatial elements may give rise to edge effects. Observing η Carinae central region, besides the immediate astrophysical interest, provided an excellent opportunity to evaluate the quality and the limits of the deconvolution. Indeed, this

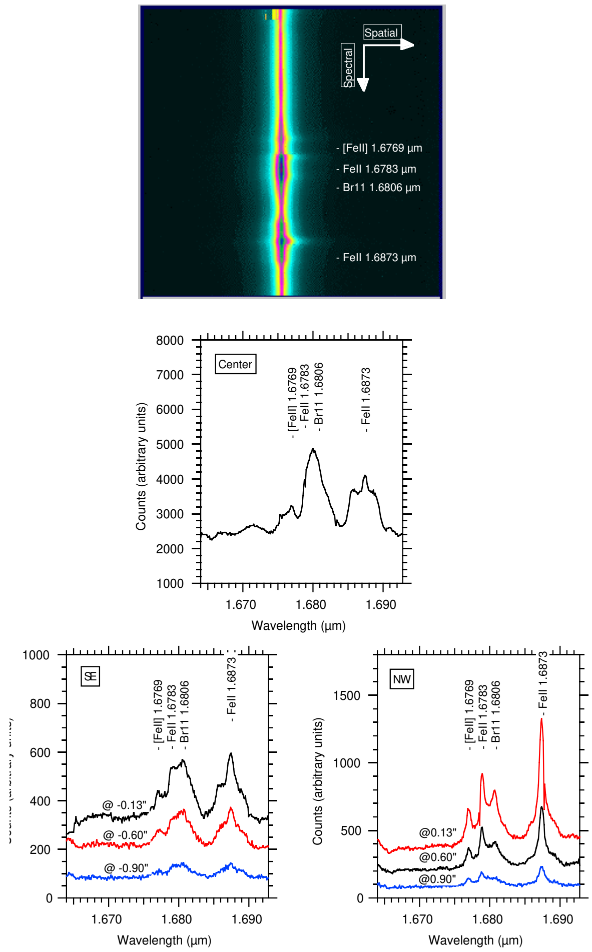

Figure 1: *Upper frame :* The long slit spectrum of the η Carinae central region in the spectral range 1.663-1.691μm. The covered angular extend is 9". West is to the right. *Middle and lower plots :* Spectra at different positions along the slit (core, SE, NW).

region was *a priori* known to be composed of a point-like central source and of secondary spots of line emission at the distances of only 0.1 - 0.2$''$ with however well studied geometry and spectrum (see below). Further challenge was choosing the spectral range of observations at 1.7 μm where the adaptive optics correction is only partial. We present here the results of the deconvolution study in this case at the limits, as well as a preliminary analysis of the spectroscopic data of the detected objects in the lines of hydrogen Br11, [FeII] 1.6769 μm, and FeII 1.6783 μm, 1.6873 μm. The raw data are available on request.

1.2 η Carinae:

η Carinae is a massive luminous star loosing mass in giant eruptions. It is certainly one of the most observed and studied peculiar star (cf. Davidson and Humphreys 1997). The inner 1$''\times$ 1$''$central part of η Carinae has been since long time a challenging target for high angular resolution technics. Chelli et al. (1983) and Perrier et al. (1987), using the near IR speckle-interferometry, found strong indications of secondary condensations at about 0.2$''$ from the central source (see also Bensammar at al. 1985). Weigelt & Ebersberger (1986) and Hofmann & Weigelt (1988), using 2D visible speckle-interferometry, clearly resolved the central region on 3 secondary components B, C and D, to the NW of the stellar core within 0.4$''$ of distance. The HST/GHRS UV-spectroscopy of the BCD spots (Davidson et al. 1995, 1997) showed them to be dense, compact slow-moving ejecta near the equatorial plane with the UV spectrum composed of narrow forbidden lines, while the stellar core spectrum shows broad permitted emission lines formed in the dense fast stellar wind. Finally, Rigaut & Gehring (1995) studied the η Carinae inner core in the 1-5 μm range using COME-ON and COME-ON+ adaptive optics system at ESO. The study revealed a complex picture of the inner part of η Carinae and in particular condensations of material to the NW and SE from the central star.

2 Observations and Data Analysis:

The central region of η Carinae was observed on November 14, 1997, in the long slit and 3D-modes with the parameters given in Table 1.

Table 1: Observing conditions and parameters

	Long Slit mode	3D-mode
Time	09:17 UT	09:01 UT
Central wavelength	1.67	1.67
Pixel scale	35 mas/pix	35 mas/pix
Integration time	15 sec	5 sec
Slit width	0.4″	0.86″
Fabry-Pérot 10 000	OUT	IN
Grating mm^{-1}	300	300
Dispersion	0.113 nm/pix	0.113 nm/pix
Slit Orientation (PA in °)	-41	-41
Spectral Resolving Power	2 500	10 000
Spectral Range	1.663-1.691	1.663-1.691
Others		48 channels

2.1 Long Slit mode:

The long slit spectrum frame and plots of the η Carinae central region are given in Fig. 1. The presence of extended emission regions is well seen in the lines of [FeII], FeII and Br11. The evolution of the spectrum with the distance from the core shows remarkable changes in the line widths and their relative strengths worthwhile to be commented.

In the core spectrum the lines are so broad ($\simeq$800 km/s) that they overlap (cf FeII 1.6783 and Br11), although a narrow component ($\leq$180 km/s) is present as well. The Br11 appears stronger than the two permitted FeII lines. At the NW, lines are narrow, although with a faint broad component, which may be due to contamination by the central core light (PSF wings). The Br11 is fainter then the FeII lines. The SE spectrum differs from that of the NW. The lines are dominated by the broad emission, the narrow line component is much fainter. As in the core, the Br11 is nearly of the same strength as the FeII lines. This suggests that the nature of the SE and NW emissions may be different with more pure scattering at the SE. Further data processing shall quantify the mentioned spectral evolution with the distance to the core.

2.2 3D-mode:

For our first deconvolution trails, we selected 1 out of 48 frames formed by the FP spectral scanning. The selected frame (Fig. 2) was that where the FeII 1.6873 μm line had its maximum to allow the best contrast of the extended features. The left panel displays the frame before deconvolution. It is composed of the 9 simultaneous images of η Carinae at different wavelengths. The data were deconvolved using Lucy algorithm stopped after 200 iterations. The image in the window 1.6704 μm, corresponding to the stellar continuum, was used extracted and used as the PSF. The panel in the middle shows the deconvolution result in a linear scale with the faintest (blue) signal at 100

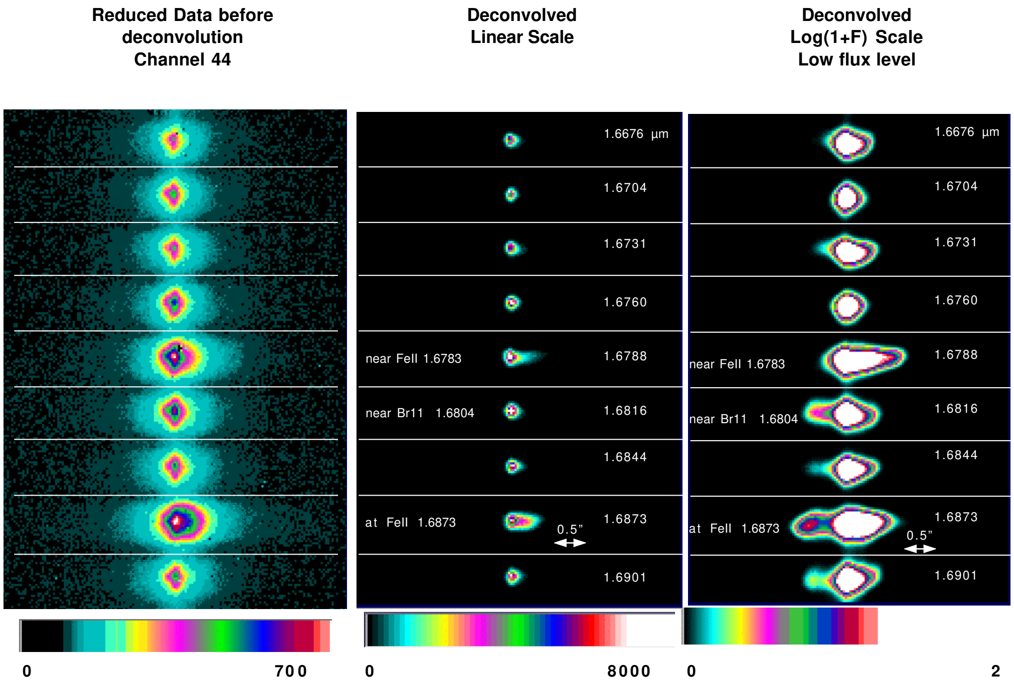

Figure 2: The image of η Carinae corresponding to 1 out of 48 channels in the GraF 3D-mode. Integration time 5 sec. A "sub-image" has a $0.9''$width. The left panel corresponds to the reduced data before deconvolution, the middle panel to the deconvolution result displayed in a linear scale, and the right panel shows the deconvolution result in a logarithmic scale enhancing the low level features.

arbitrary flux units and the strongest a (white) at 8000 units. In the windows corresponding to the continuum emission (cf. Fig. 1) between 1.667 and 1.670 μm, the image appears as a point-like source in the 1.6760 μm window, but in the 1.6676 μm and 1.6731 μm windows shows some extension at levels less than 50 units. It must be investigated further whether we deal with real extended features emitting in faint lines, or with the deconvolution artifacts at low level. The NW spots, although glued together at this angular resolution, are clearly present to the right of the central star in the windows corresponding to the strong FeII emission lines, and noticeably absent in the Br11 window.

Finally, the deconvolved frame is displayed in a logarithmic scale (right panel), enhancing the low intensity levels. Here, the red corresponds to 50 units, and the blue to 10^{-3} units. A SE feature appears in the Br11 and FeII 1.6873 μm windows to the left of the central star at the level of 30-50 units, but is absent in the window 1.6788 μm close to the FeII1.6783 μm line. The reality of the SE feature is corroborated by the results of COME-ON+ broad band observations by Rigaut & Gehring (1995), implying that the level where deconvolution artifacts may appear is lower. At present, awaiting further study it can be said that this level is less than 10 units.

The difference in the window-to-window changes of NW and SE features thus confirms what was already suggested by the long slit spectrum. While the NW features were studied by the HST/UV spectroscopy HST studies (Davidson et al. 1995, 1997), nothing was known on the line spectrum of the SE feature. The present data are the first spectroscopy of it. It turns out the SE feature spectrum suggests more dust in its composition than in the NW spots, to explain the apparent increase of reflexion and/or scattering, implied by the similarity of the SE spectrum to that of the central sore.

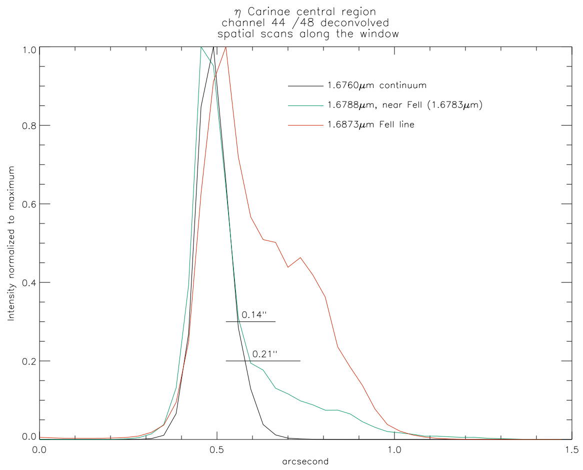

Figure 3: η Carinae central region spectrum obtained with GraF in long slit mode (see text)

Scans in the spatial direction for deconvolved images at 3 different wavelengths are given in Fig. 4. The final angular resolution, achieved after deconvolution (fwhm of the stellar core at 1.6760μm), is 3 pixels or $0.1''$. Assuming the image in the FeII ($\lambda\lambda$ 1.6873) window as composed of the stellar component and two unresolved NW spots, as it is known from Weigelt group results, and measuring the separations we get respectively $0.14''$and $0.21''$in good agreement with the values of $0.114''$ and $0.211''$ given for components B and D by Hofmann & Weigelt (1988), and with the value of $0.22''$ given by Rigaut & Gehring (1995) for the secondary intensity peak in their K band image. It must be mentioned that the faint spot C is not seen in the present data, an issue which must be investigated further.

3 Conclusions

The presented results show that the spectro-imaging in several spectral windows as it is conceived in the GraF instrument allows to deconvolve the data using the PSF given in the continuum windows of the object, despite of the PSF elongation and the limited width of windows. No deconvolution artifacts are present in the dynamic flux range of 800:1; the features appearing in this flux range corresponds to what was expected based on previous high angular resolution observations. The achieved angular resolution is of $0.1''$ (FWHM), close to the telescope diffraction limit of $0.09''$. However, so far, the construction of the PSF was a straightforward extraction of a continuum image. The deconvolution was performed with a simple max likelihood algorithm, the only constraint being on the number of iterations. The investigation was carried out on 1 out of 48 frames of the GraF spectral cube. The further steps under progress are investigation of more elaborated ways of the PSF extraction (smoothing, interpolation), investigation of the deconvolution under regularisation constraints, and the deconvolution of the entire 3Ds cube which will provide the profiles of the emission lines with the spectral resolution of 10 000, giving thus precious information on the kinematics of the features.

Some interesting indications on the properties of the NW and SE spots can be drawn on the basis of the long lit spectrum confirmed and refined by the presented 3Ds deconvolved frame. While the central star line spectrum is characterized by a large broadening ($\simeq$800 km/s) and relatively strong Br11 emission, the NW spots emit in narrow ($\leq$180 km/s) lines of FeII. The emission in Br11 if any is very weak. As to the SE feature, the line broadening reminds that of the central star, and the Br11 is nearly of the same strength as the FeII lines. This suggests more reflexion and/or scattering for the SE feature, having therefore a higher dust/gas ratio than the NW spots.

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