New results on the Galactic Center Helium stars

Thibaut Paumard[1]**, Jean-Pierre Maillard**[1]**,** and **Susan Stolovy**[2]

[1] Institut d'astrophysique de Paris (CNRS), 98b Bd. Arago, 75014 Paris, France
[2] SIRTF Science Center, CalTech, MS 220-6, Pasadena, CA 91125, USA

The cluster of helium stars around Sgr A* has been re-observed with the BEAR spectro-imager on CFHT, in the 2.06 μm helium line, at a spectral resolution of 52 km s^{-1} and on a field of $\simeq 40''$. This new analysis confirms and completes a previous study at a spectral resolution of 74 km s^{-1} and on a smaller field of $24''$, corresponding to the central parsec (Paumard *et al.* 2001). Nineteen stars are confirmed as helium stars. These observations led to a clear differentiation between two groups of hot stars based on their emission linewidth, their magnitude and their positions relative to Sgr A*. The first class of 6 members is characterized by narrow-line profiles (FWHM $\simeq 200$ km s^{-1}) and by their brightness. The other, fainter in K by an average of 2 mag, has a much broader emission component of width $\simeq 1,000$ km s^{-1}. Several of the emission lines show a P Cygni profile. From these results, we propose that the narrow-line group is formed of stars in the LBV phase, while the broad-line group is formed of stars in or near the WR phase. The division into two groups is also shown by their spatial distribution, with the narrow-line stars in a compact central cluster (IRS 16) and the other group distributed at the periphery of the central cluster of hot stars. HST-NICMOS data in Paα (1.87 μm) of the same field reveal a similar association. The identification of the Paα counterpart to the He I stars provides an additional element to characterize the two groups. Bright Paα emitters are found generally associated with the narrow-line class stars while the weak Paα emitters are generally associated with the broad-line stars. A few particular cases are discussed. This confirms the different status of evolution of the two groups of massive, hot stars in the central cluster. As a by-product, about 20 additional candidate emission stars are detected in the central, high-resolution $19''$ field from the NICMOS data.

1   Findings from BEAR 97 He I 2.06 μm observation

With the BEAR spectro-imager, an imaging FTS (Maillard 2000) the central pc of the Galaxy was observed in 1997 at a spatial resolution of $0.5''$ and spectral resolution of 74 km s^{-1} in the He I 2.058 μm domain, covering a field of $24''$. The observation provided a homogeneous set of fully resolved line profiles. The spectro-imaging data were associated with Adaptive Optics data from CFHT in the K band (Lai *et al.* 1997) to check the possible confusion of sources. That particular study of the helium emission-line stars in the central parsec of the Galactic Center was published in Paumard *et al.* (2001). The main results can be summarized as follows:

1. 16 fully resolved P Cygni emission line profiles, cleaned of ISM emission, of purely stellar origin, were extracted.
2. they were found to divide into two distinct classes, with narrow (FWHM $\simeq 200$ km s^{-1}) and broad-line profiles (FWHM $\simeq 1,000$ km s^{-1}).
3. a difference in K of ~ 2 mag between the two classes was measured.
4. the spatial distribution of the two groups is different, with the narrow-line objects arranged in a central cluster, and the other class dispersed in a ring beyond a radius of $\simeq 0.3$ pc from SgrA*.

From these findings it was concluded that the group of narrow-line stars can be considered as formed of stars in the LBV phase, and the other one of stars at the WR stage.

2 Observations

New BEAR data in He I 2.06 μm were obtained in June 2000 at higher spectral resolution (52 km s^{-1}). The field, composed of three overlapping circular sub-fields, was wider, and the signal-to-noise ratio higher by a factor of $\simeq 1.6$. km s^{-1}.

Paα HST/NICMOS observations were taken in 1998 of the central parsec with Camera 1 (Stolovy *et al.*1999) and of the central 4 pc with Cameras 2 and 3 (Scoville *et al.* 2003). Dithered Images were taken in filters F187N centered on the 1.87 μm Paα line and in F190N for the nearby continuum. By subtracting a suitably scaled F190N mosaic image from the F187N mosaic, a map of the stellar and interstellar Paα emission can be obtained. Figure 3 shows the central region of the composite Camera 2 and Camera 3 Paα image, for which the central $19'' \times 19''$ has a spatial resolution of $0.''18$.

3 He I stars and Paα emission

With the new BEAR data, almost all the stars mentioned in Paumard *et al.* (2001) are confirmed, except the star numbered "N6". The Paα data show a bright, very small ISM feature and no stellar counterpart to this point-like He I emission. Four new broad-line stars are added. Two were out of the previously studied field, and the better signal-to-noise ratio is responsible for the other two new detections. The star "B5" was associated with IRS 13E. Maillard *et al.* (2003) have shown that there was indeed two emission line stars in the IRS 13E complex, namely IRS 13E2 and IRS 13E4. The broad line clearly detected in He I belongs to E2 only from Fabry-Perot imaging associated with adaptive optics by Clénet *et al.* (2003). The line profiles and locations of the 19 stars are shown in Fig. 1 and Fig. 2a. Fig. 2b clearly confirms that the narrow-line stars are generally much brighter in K than the broad-line stars. For B11, the signal-to-noise ratio is just sufficient to claim a detection, but not to derive reliable line parameters.

Table 1 Physical properties of the helium stars: K magnitude, full width at zero intensity (FWZI) of the 2.06μm He I line (km s^{-1}), Paα line flux in units of 10^{-20} W cm^{-2}, calibrated from Paα emission in AF (Najarro *et al.* 1994). ID 180 is from the photometric list of Ott *et al.* (1999), HeI N3 is from Paumard *et al.* (2001).

ID	Name	m$_K$	FWZI$_{HeI}$	ϕ_{Pa_α}
N1	IRS 16NE	8.8	210	3.46
N2	IRS 16C	9.6	490	2.14
N3	IRS 16SW	9.4	520	2.09
N4	IRS 16NW	9.9	470	1.15
N5	IRS 33SE	9.9	460	1.12
N7	IRS 34W	11.8	500	0.14

ID	Name	m$_K$	FWZI$_{HeI}$	ϕ_{Pa_α}
B1	ID 180	12.4	1,400	0.40
B2	IRS 7E2	12.2	1,500	0.28
B3	IRS 9W	11.8	1,900	0.83
B4	IRS 15SW	11.5	1,400	0.76
B5	IRS 13E2	11.0	1,300	2.27
B6	IRS 7W	12.0	1,600	0.44
B7	AF	10.6	1,200	4.40
B8	AFNW	11.5	1,800	1.05
B9	HeIN3	12.7	1,600	0.14
B10	BSD WC9	10.6	2,000	0.37
B11	IRS 29N	9.9	1,100	0.07
B12	IRS 15NE	11.2	1,500	0.37
B13	IRS 16SE2	11.8	940	1.15

Fig. 3a shows that the He I stars are associated with the Paα emission stars. The narrow-line stars (circles) are coincident with bright Paα emitters (mean intensity $\simeq 2\,10^{-20}$ W cm^{-2} without taking into account IRS 34W, Table 1), whereas the broad-line stars correspond to fainter Paα emitters (mean intensity $\simeq 0.97\,10^{-20}$ W cm^{-2}). Other Paα emitters are present, which may be also associated with He I emission, but too faint to have been detected with BEAR. A source extraction with the StarFinder procedure (Diolaiti *et al.* 2000) gives 52 point-like emission features in the high-resolution $19''$ central field, of which 43 are emission line stars with a high degree of certainty. The 9 other need further observation to rule out the possibility that these point sources are compact ISM features or incomplete continuum subtraction of stars. However, this result (Fig. 3b) is generally consistent with an independent analysis made by Scoville *et al.* (2003).

4 Discussion

The central cluster of helium stars is confirmed with a total of 19 members currently identified. The various conclusions on the characteristics of these stars from the first paper, reviewed in the Introduction are confirmed: division into two groups from their linewidths (Fig. 1 and Fig. 2b), from their brightness and from their location (Fig. 2a). The difference of brightness (Fig. 2b) presents few exceptions which were already noticed in the first paper. One of the narrow-line stars (N7, IRS 34W) is weak and one of the broad-line stars (B11, IRS 29N) is brighter than the average of the other stars of the same group. From a long-term photometric study (Ott *et al.* 1999) IRS 34W is indicated as a variable star. It was weak at the time of our observations (Ott *et al.*, private communication).

It was proposed in Paumard *et al.* (2001) that the group of bright, helium stars was made of LBV-type stars. The high intensity of Paα (Table 1), the variability of IRS 34W confirm that these stars are hot, mass-losing stars, still rich in hydrogen. On the contrary, the weakness of the Paα emission combined with the very broad helium line are consistent with the other group being more evolved stars. A few sources are exceptions – IRS 13E2, AF, IRS 16SE2 – showing a broad-line He I profile, but strong Paα emission. This apparent anomaly could certainly be due to the fact that the Paα filter is not perfectly adapted to distinguish between rich and poor hydrogen emitters. Since the Paα line is blended with another significative helium line, He I (4-3) at 1.869 μm, the intensity detected by the F187N can remain strong even if the hydrogen emission is intrinsically weak. Already mentioned, the weakness of the K magnitude of IRS 34W (Table 1) is due to the star being in a phase of enhanced intrinsic extinction. Naturally, the measured Paα intensity is extremely weak, a factor 14 lower than the mean intensity. However, all these elements confirm the different status of evolution of the two groups of massive, hot stars in the central cluster. Assuming that all these stars were formed in the same star formation event, the differences in evolutionary state would come from the differences in their initial mass.

The Paα data can help to address the question of whether the identification of emission line stars in the central region is complete or not. Possibly, about twenty new stars, associated with weak Paα emission are detected in the central parsec (Fig. 3b). With only this indication, it cannot be concluded that they are more WR candidates. A deep, spectroscopic analysis using adaptive optics in the K band is needed. Besides more WRs, some of them could be Be stars, or could belong to the old star population as symbiotic or Mira-type stars in a phase of emission. At any rate, these data represent a new element in the census of spectral type in the central parsecs to better constrain the peculiar star formation conditions in this region of the Milky Way.

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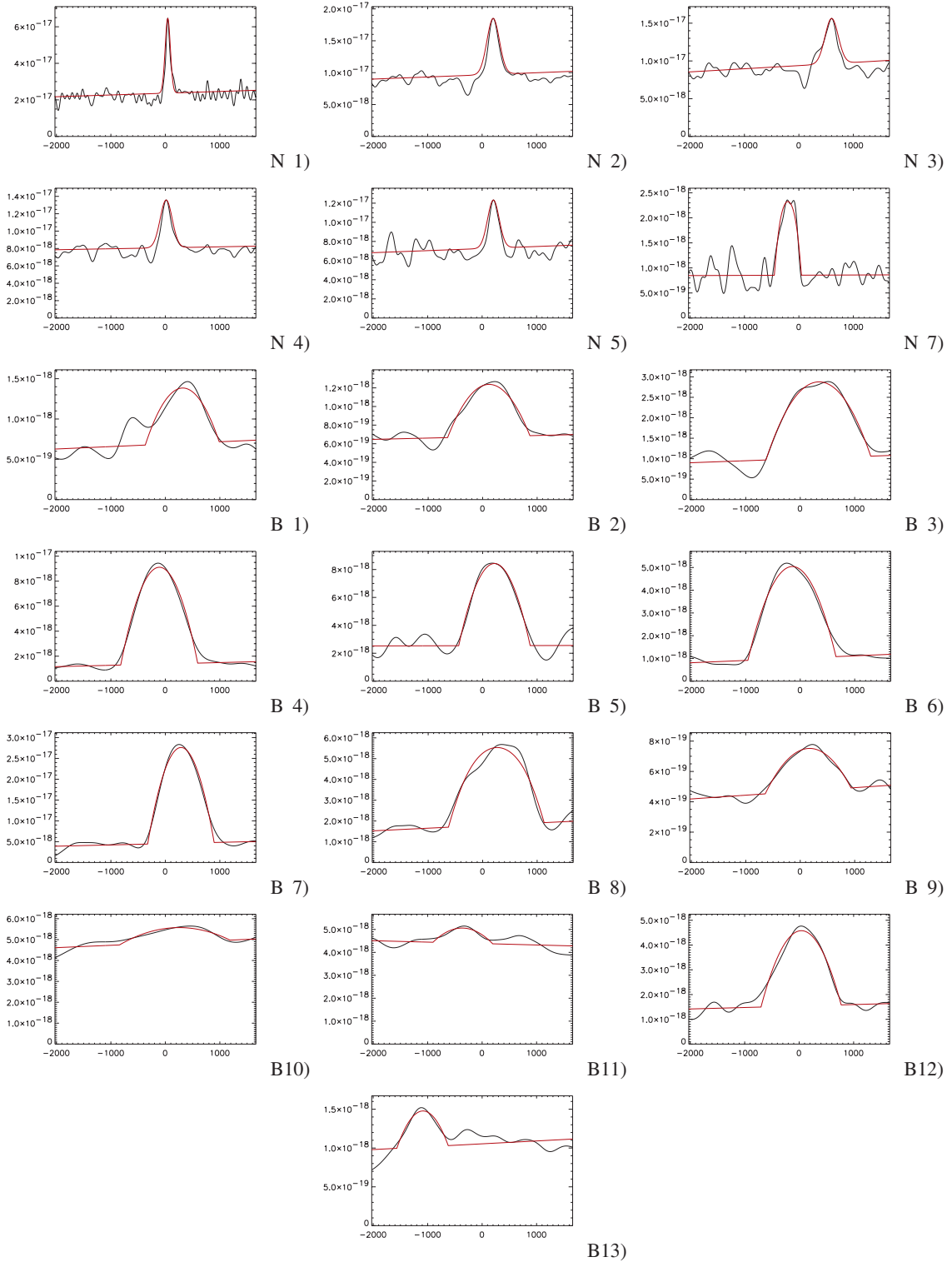
Fig. 1 Two upper rows: the 2.06 μm He I narrow-line profiles; five lower rows, the broad-line profiles, all on the same velocity range of -2,000 to +2,000 km s^{-1}. The intensities are in W m^{-2} cm^{-1} (Continuum: a few 10^{-17} for N1–N5, a few 10^{-19} or 10^{-18} for the other stars). Simple line models are overplotted allowing to determine the full width at zero intensity.
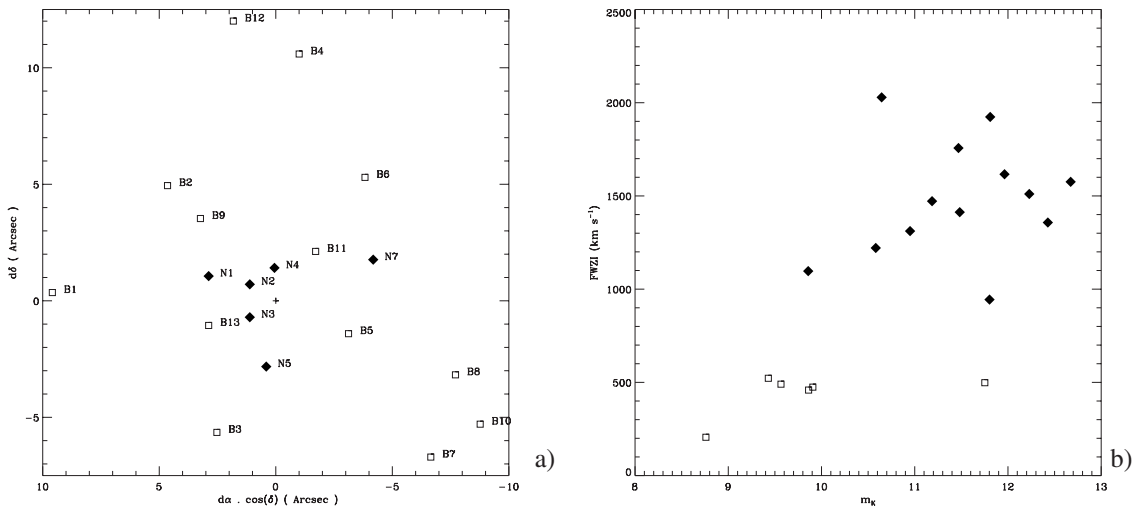
Fig. 2 a) Positioning of the helium stars, b) full width at zero intensity (FWZI) against K magnitude plot. The empty squares represent the broad-line stars, while the filled diamonds represent the narrow-line stars. On plot b), two regions can be seen: all the narrow-line stars, except IRS 34W – that is variable (see text) –, are grouped with a K magnitude brighter than 10, and all the broad-line stars, except one, have a K magnitude fainter thant 10.5 (mean value $\simeq$ 12).
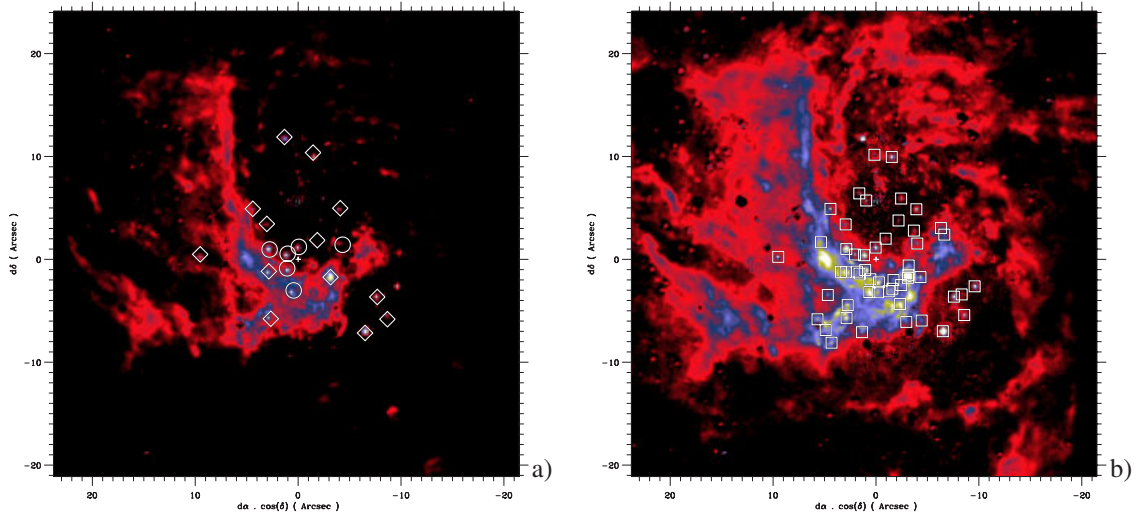

Fig. 3 a) Paα map of the central 2 pc, with the inner $19''$ comprised of the high resolution Camera 2 data. Diamonds indicate the locations of the broad-line stars while the narrow-line stars are indicated by circles. All of these stars show emission in this Paα filter. b) All emission line star candidates, in the central region, marked by square boxes. The intensity scale is stretched to show fainter emission.