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StHα-55: A CARBON MIRA, NOT A SYMBIOTIC BINARY

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Abstract. We carried out a $VR_{\rm C}I_{\rm C}$ photometric monitoring of StHα 55. In addition, we obtained low resolution absolute spectro-photometry and high resolution Echelle spectroscopy of the star. Our data show that StHα 55 is a carbon Mira, pulsating with a 395 day period, with $<V> = 13.1$ mean brightness and $\Delta V = 2.8$ mag amplitude. It has a low reddening of $E_{B-V} = 0.15$, lies at a distance of 5 kpc from the Sun and 1 kpc from the Galactic plane, and its heliocentric systemic velocity is close to +22 km s^{-1}. The difference between the radial velocity of the optical absorption spectrum and that of the Hα emission is unusually small for a carbon Mira. The spectrum of StHα 55 can be classified as C-N5 C$_2$6$^-$. Its ^{13}C/^{12}C isotopic ratio is normal, and the lines of Ba II and other *s*-type elements, as well as Li I, have the same intensity as in field carbon stars of similar spectral type. The Balmer emission lines are very sharp and unlike those seen in symbiotic binaries. Their intensity changes in phase with the pulsation cycles in the same way as seen in field carbon Miras. We therefore conclude that StHα 55 is a bona fide, normal carbon Mira showing no feature supporting a symbiotic binary classification, which has been suggested previously.

Key words: stars: pulsations – stars: variables – stars: AGB

1. INTRODUCTION

Very scanty information is available in the literature on StHα 55. It was discovered by Stephenson (1986) as a $V \approx 13.5$ mag stellar source displaying Hα emission. A low-resolution spectrum of StHα 55 was obtained by Downes & Keyes (1988), who classified it as a carbon star and confirmed the presence of Hα and Hβ emission. The star was then long forgotten until Belczynski et al. (2000) inserted it in their Catalog of Symbiotic Stars. They cataloged it as a suspected symbiotic star, arguing that the intensity of the Hα emission on the spectrum presented by Downes & Keyes (1988) was larger than in normal, single carbon stars. The second spectrum of StHα 55 was presented by Munari & Zwitter (2002) as part of their multi-epoch spectro-photometric atlas of symbiotic stars, which surveyed the vast majority of the sources listed by Belczynski et al. (2000). The Munari &

Table 1: Magnitude and colors of the photometric comparison stars.

	V	(±)	B–V	(±)	V–R_C	(±)	R–I_C	(±)	V–I_C	(±)
α	13.710	0.018	1.803	0.021	1.004	0.012	1.053	0.059	2.062	0.065
β	13.899	0.020	2.070	0.019	1.230	0.012	1.319	0.073	2.558	0.067
γ	14.631	0.012	1.605	0.019	0.953	0.005	1.000	0.050	1.959	0.052
δ	14.992	0.018	1.576	0.024	0.925	0.009	0.978	0.055	1.908	0.051
a	12.653	0.013	1.786	0.007	0.994	0.020	1.022	0.055	2.020	0.041
b	13.713	0.006	0.900	0.009	0.563	0.006	0.604	0.036	1.171	0.030
c	13.937	0.015	1.849	0.019	1.046	0.008	1.090	0.066	2.141	0.065
d	15.038	0.011	1.152	0.029	0.706	0.007	0.760	0.049	1.470	0.046
e	15.237	0.035	1.241	0.038	0.706	0.034	0.761	0.039	1.473	0.059
f	15.370	0.010	0.929	0.021	0.565	0.011	0.618	0.025	1.188	0.028
g	15.651	0.013	1.162	0.044	0.722	0.020	0.742	0.036	1.468	0.044
h	15.699	0.013	1.303	0.024	0.764	0.012	0.811	0.046	1.579	0.045
i	15.769	0.018	0.964	0.030	0.604	0.025	0.639	0.037	1.246	0.037
j	15.811	0.011	0.851	0.039	0.549	0.023	0.616	0.030	1.171	0.039

Zwitter (2002) spectrum of StHα 55 was virtually identical to that of Downes & Keyes (1988), arguing in favor of very modest, if any, spectroscopic variability.

The rarity of Galactic symbiotic stars containing a carbon donor star prompted us to insert StHα 55 among the ~ 80 symbiotic stars that the ANS (Asiago Novae and Symbiotic star) Collaboration is monitoring spectroscopically and photometrically ($UBVR_CI_C$ passbands). In this paper we report observations and analysis that show StHα 55 to be a normal carbon Mira with no hint of a symbiotic binary nature.

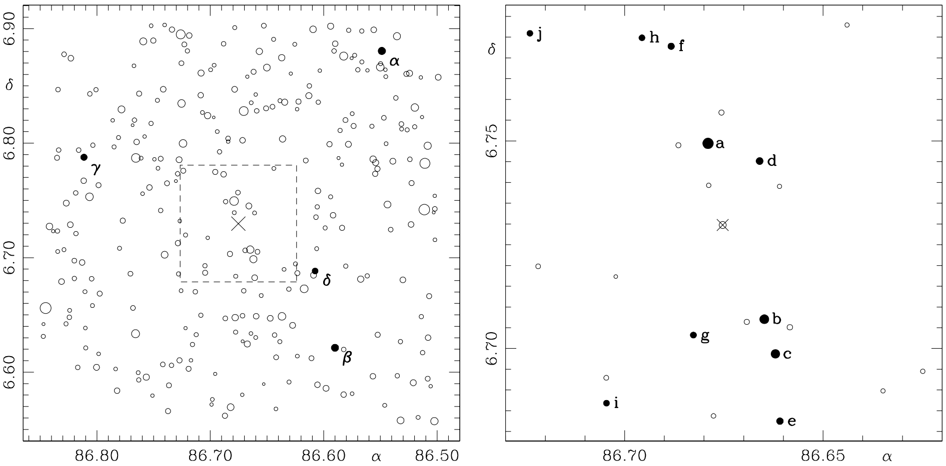

Fig. 1. Identification charts for the photometric comparison stars around StHα 55 listed in Table 1.

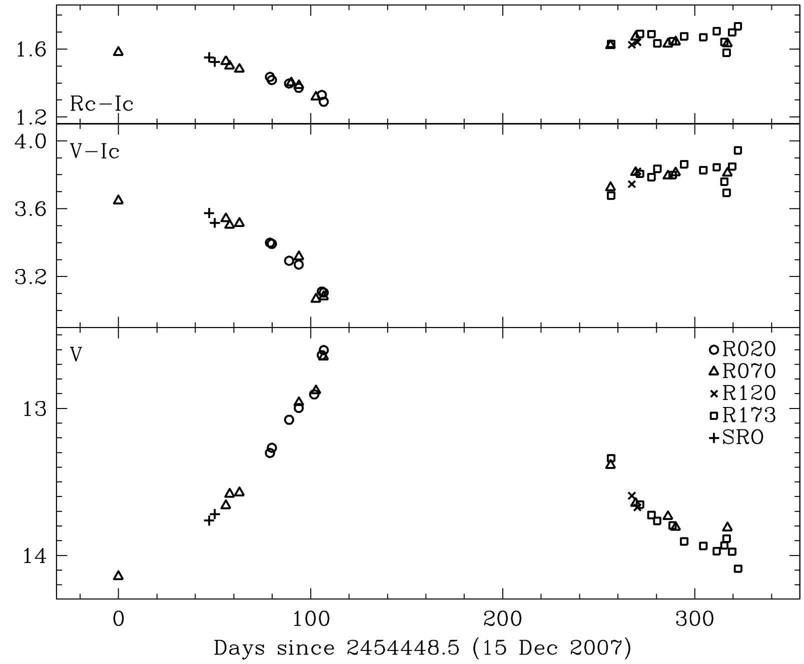

Fig. 2. Light- and color-curves of StHα 55 plotted with the data in Table 1. For instrument identification, see Section 2.1.

2. OBSERVATIONS

2.1. Photometry

As a first step, the BVR_CI_C photometric sequence was calibrated around StHα 55 for use by all of the telescopes participating in the monitoring effort. The sequence is presented in Table 1 and is identified in the finding chart shown in Figure 1. The sequence was calibrated against Landolt (1983, 1992) equatorial standards with observations obtained with the 0.35 m robotic telescope of Sonoita Research Observatory (SRO, Arizona, U.S.A.). It uses BVR_CI_C Optec filters and an SBIG STL-1001E CCD camera having an 1024×1024 array with 24 μm pixels equivalent to $1.25''$, with a field of view of $20' \times 20'$.

All our subsequent observations of StHα 55 were accurately reduced and color-corrected against the sequence in Table 1. The results are listed in Table 2. Typical global errors (including quadratically the contribution of the Poissonian noise, color transformations and residuals in the dark/flat/bias corrections) are 0.035 mag in V, 0.027 in V–I_C and 0.018 in R_C–I_C. The observations of Table 2 were collected with the following ANS Collaboration telescopes.

R020: the 0.40 m f/5 Newtonian reflector of the P. Pizzinato Observatory located in Bologna (Italy). The CCD is a HiSis 23ME, 768×1157 array, 9 μm pixels $\equiv 0.62''$/ pixel, with a field of view of $8' \times 12'$. The BVR_CI_C filters are from Schuler.

R070: a 0.30 m f/10 Meade LX200 telescope privately owned by one of us (M.G.) and operated in Alfonsine (RA, Italy). It is equipped with BVR_CI_C

Table 2: Magnitude and colors of StHα 55 from our observations.

HDJ	V	V-Ic	Rc-Ic	obs	HDJ	V	V-Ic	Rc-Ic	obs
4448.4647	14.143	3.647	1.551	R070	4704.9557	13.339	3.677	1.600	R173
4495.6190	13.763	3.574	1.551	SRO	4715.6420	13.594	3.744	1.595	R120
4498.6000	13.719	3.516	1.524	SRO	4717.6022	13.645	3.814	1.641	R070
4504.3106	13.661	3.541	1.498	R070	4718.6056	13.673	3.820	1.621	R120
4506.3882	13.583	3.502	1.470	R070	4719.9607	13.655	3.790	1.659	R173
4511.4412	13.573	3.514	1.451	R070	4725.9501	13.725	3.785	1.658	R173
4527.3074	13.303	3.400	1.406	R020	4728.9306	13.766	3.835	1.604	R173
4528.2966	13.268	3.393	1.388	R020	4734.5475	13.735	3.793	1.600	R070
4537.2903	13.077	3.293	1.367	R020	4736.8969	13.796	3.798	1.617	R173
4538.4019			1.372	R070	4738.5688	13.809	3.812	1.612	R070
4542.2895	12.997	3.271	1.342	R020	4742.9018	13.905	3.861	1.644	R173
4542.4027	12.960	3.317	1.355	R070	4752.9105	13.936	3.827	1.639	R173
4550.3513	12.904			R020	4759.8598	13.971	3.844	1.675	R173
4551.2941	12.879	3.067	1.288	R070	4763.8349	13.932	3.759	1.612	R173
4554.3119	12.637	3.112	1.300	R020	4764.9699	14.026	3.693	1.548	R173
4555.3041	12.649	3.082		R070	4765.5047	13.886	3.810	1.602	R070
4555.3100	12.603	3.106	1.260	R020	4767.8906	13.975	3.848	1.668	R173
4704.6327	13.386	3.725	1.591	R070	4770.9523	13.951	3.873	1.654	R173

Schuler filters. The CCD is a Finger Lake Instruments ML0261E, 512×512 array, 20 μm pixels $\equiv 1.35''$/ pixel, with a field of view of $11' \times 11'$.

R120: the 0.42 m f/5.4 Newtonian telescope operated in Bastia (Ravenna, Italy) by Associazione Ravennate Astrofili Rheyta. It has an Apogee Alta 260e CCD camera, 512×512 array, 20 μm pixels $\equiv 1.83''$/ pixel, for a field of view of $16' \times 16'$. It is used in combination with Schuler $UBVR_{\rm C}I_{\rm C}$ filters.

R173: a 0.30 m f/11.9 Dall-Kirkham robotic telescope, part of the GRAS network (GRAS1, New Mexico, U.S.A.). It carries a Finger Lake Instruments IMG1024 DM CCD camera, 1024×1024 array, 24 μm pixels $\equiv 1.38''$/ pixel, with a field of view of $24' \times 24$arcmin. The $BVR_{\rm C}I_{\rm C}$ filters are from Optec.

2.2. Spectroscopy

A low resolution, absolutely fluxed spectrum of StHα 55 was obtained on 2008 February 25 with the B&C spectrograph of the INAF Astronomical Observatory of Padova attached to the 1.22 m telescope operated in Asiago by the Department of Astronomy of the University of Padova. The slit, aligned with the parallactic angle, had a $2''$ sky projection, and the total exposure time was 55 minutes. The detector was an ANDOR iDus 440A CCD camera, equipped with a EEV 42-10BU back-illuminated chip, 2048×512 pixels of 13.5 μm size. A 300 ln/mm grating blazed at 5000 Å provided a dispersion of 2.26 Å/pixel and a wavelength range extending from 340 to 810 nm.

A high resolution spectra of StHα 55 were obtained on 2008 March 20 with the Echelle spectrograph mounted on the 1.82 m telescope operated in Asiago by INAF Astronomical Observatory of Padova. The detector was an EEV CCD47-10 CCD, 1024×1024 array, 13 μm pixels, covering the interval 360–730 nm in 31 orders. A slit width of 200 μm provided a resolving power of $R_P = 22\,000$.

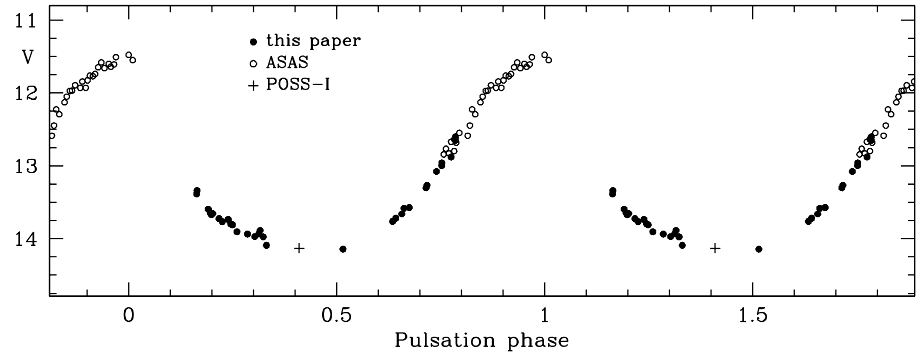

Fig. 3. Light curve in V of StHα 55 plotted from our data (Table 1, solid circles) and from ASAS (open circles). Phases are calculated according to Equation (1).

3. RESULTS

3.1. A carbon Mira

The light curve presented in Figure 2 shows that StHα 55 is indeed variable, with a large amplitude, a long period and the bluer colors when the star gets brighter and the redder colors when it is fainter. These are distinctive features of Mira-like pulsations.

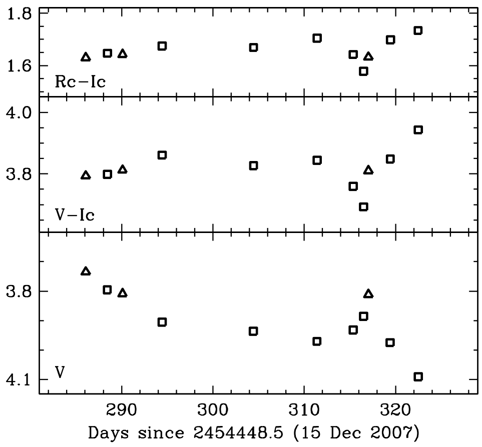

Fig. 4. A portion of the light curve shown in Figure 2 that includes the brightening at the day ~315.

To derive the pulsation period, we have searched external data archives for additional observations that would fill in the gaps of our photometric monitoring. We found additional V data in the ASAS database (All Sky Automated Survey, Pojmanski 1997), covering the time interval from 2006 January 18 to April 27. We carried out a Deeming-Fourier (Deeming 1975) period search on our V set combined with that from ASAS, which resulted in a clear and strong 395 day periodicity. The combined V data are phase plotted in Figure 3 according to the ephemeris:

$$Max(V) = 2453849 + 395 \times E \quad (1)$$

The light curve shown in Figure 3 is that of a Mira variable, with $<V> = 13.1$ mean brightness and $\Delta V = 2.8$ mag amplitude, that varies between $V = 14.28$ and $V = 11.48$ mag. The light curve appears quite symmetrical, the pulsation period is rather long and the amplitude is small, all distinctive characteristics of carbon Miras in comparison with their oxygen-rich counterparts (Mennessier et al. 2000).

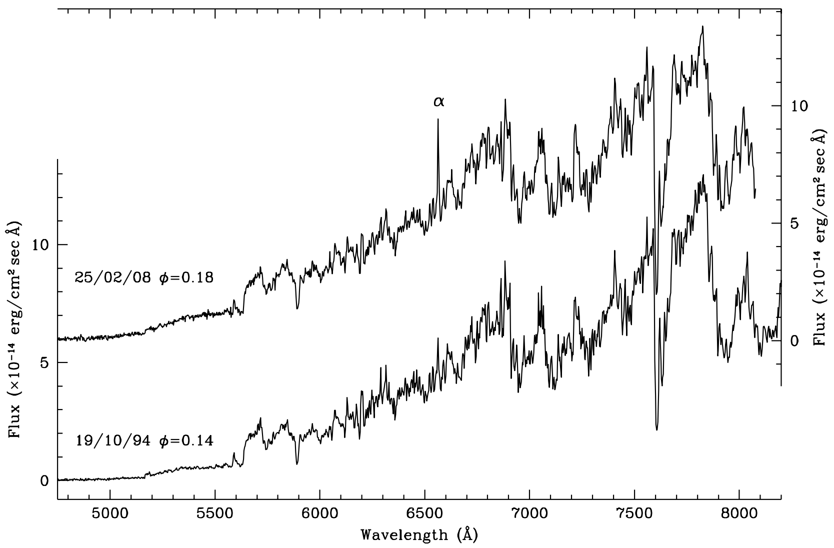

Fig. 5. Comparison of the Asiago 1.22 m and ESO 1.5 m low resolution, absolutely fluxed spectra of StHα 55. ϕ indicates the pulsation phase according to ephemeris (1).

The light curve of Figure 2 shows a short-lasting departure from a smooth trend around the day 315. This part of the light curve is magnified in Figure 4, which shows that the event lasted about a week and was characterized by a $\Delta V = 0.1$ mag brightening accompanied by a simultaneous $\Delta(V - I_{\rm C}) \approx 0.2$ mag and $\Delta(R_{\rm C} - I_{\rm C}) \approx 0.15$ mag blueing of the colors. This occurrence has interrupted briefly the smooth fading of the light curve towards minimum. Its isolated occurrence makes its interpretation rather speculative. For sake of discussion, it could be argued that the event traced either a short-lived halt in the expansion of the atmosphere of the Mira toward the minimum brightness (corresponding to the largest radius), or the emergence of a convection cell hotter than the surrounding stellar surface.

3.3. Carbon star classification

The spectrum of StHα 55 presented in Figure 5 is that of a normal carbon star. A comparison with the Barnbaum et al. (1996) spectral atlas suggests a classification on the revised MK system of Keenan (1993) as C-N5 C_26^-, i.e., the star falls among the coolest and C-richest carbon stars. The $^{13}C/^{12}C$ isotopic ratio is normal, as derived by the comparison of the strength of the 6260 Å band of $^{13}C^{14}N$ with the 6206 Å band of $^{12}C^{14}N$. Lines of Ba II and other s-type elements, as well as Li I, have the same intensity in StHα 55 as in field carbon stars of the same spectral type (see e.g., Jaschek & Jaschek 1987; Wallerstein & Knapp 1998).

3.4. Reddening

Feast et al. (1990) proposed the following statistical expression for the reddening as a function of distance and Galactic latitude b:

$$E_{B-V} = 0.032(\mathrm{cosec}|b| - 1)[1 - exp(-10r \sin|b|)],$$

where r is the distance in kpc. For the 5 kpc distance derived in the next section, this relation provides $E_{B-V} = 0.13$ for StHα 55. The three-dimensional mapping of the Galactic interstellar extinction by Arenou et al. (1992) gives for the direction and distance to StHα 55 the value $A_V = 0.53$, and thus a quite similar reddening $E_{B-V} = 0.17$. Therefore, in this paper we adopt $E_{B-V} = 0.15$ as the interstellar reddening affecting the star.

3.5. Distance

The most recent calibration of the various period-luminosity relations applicable to RGB and AGB variables can be found in Soszynski et al. (2007). Their relation for C-rich Mira variables in LMC is

$$W_I = -6.618 \log^2 P + 25.468 \log P - 12.522,$$

where $W_I = I_{\rm C} - 1.55(V - I_{\rm C})$ is a reddening-free Weisenheit index. The mean values for StHα 55 are $< I_{\rm C} > = 9.7$ and $< V - I_{\rm C} > = 3.4$, that correspond to an observed $W_I^{\rm obs} = +4.43$. The value computed for a 395 day pulsation period is $W_I^{\rm calc} = +8.94$. Adopting a LMC distance modulus of $(m - M)_0 = 18.39$ (van Leeuwen et al. 2007), a LMC reddening of $E_{B-V} = 0.06$ (Mateo 1998), the extinction relation $A_{I_{\rm C}} = 2.1 \times E_{B-V}$ (valid for a cool spectral distribution and the standard extinction law with $R_V = 3.1$ (Fiorucci & Munari 2003), and scaling to the solar metallicity (following Soszynski et al. 2007), the distance to StHα 55 is 5.2 kpc.

The 2MASS survey measured StHα 55 at J= 8.114±0.034, H= 6.507±0.034 and K_s= 5.297±0.023 mag on JD 2451458.8462, which corresponds to a pulsation phase 0.98 according to Eq.(1). This translates into a pulsation phase 0.88 in the infrared, where the maximum occurs about 0.1 phases later than in the optical. O-rich Miras of 395 day period have amplitudes in the K band of the order of 0.85 mag (Whitelock et al. 1991), and their C-rich counterparts have distinctly lower amplitudes $\Delta K \approx 0.6$ mag (Whitelock et al. 2006). Because the K-band light curve of carbon Miras is almost sinusoidal in shape (Kerschbaum et al. 2006), the 2MASS K_s= 5.297 at phase 0.88 would translate into a mean K_s brightness of StHα 55 of $< K_s > = 5.297 + 0.3 \times 0.73 \approx 5.52$ mag. Whitelock et al. (2008), using the revised *Hipparcos* parallaxes by van Leeuwen (2007), obtained the following period-luminosity relation for Galactic carbon Miras:

$$M_K = -3.52(\pm 0.36)[\log P - 2.38] - 7.24(\pm 0.07).$$

Ignoring the difference between the K_s and K passbands (cf. Tokunaga et al. 2002) and taking $E_{B-V} = 0.15$ (derived above), we obtain a distance of 5.0 kpc. This is remarkably close to the distance obtained above from the reddening-free Weisenheit index W_I.

Therefore, in this paper we adopt a distance of 5 kpc to StHα 55. It agrees with the lack of significant proper motion of StHα 55, as listed by the NOMAD database. At Galactic coordinates $\ell = 199.3°$ and $b = -11.1$, the corresponding height of StHα 55 above the Galactic plane is $z = 1$ kpc. It is quite far from the 190 pc scale-height of N-type carbon stars found by Dean (1976) and the 180 pc scale-height of Galactic carbon Miras found by Kerschbaum & Hron (1992). It suggests a possible association of StHα 55 with the thick disk / inner halo of the Galaxy and not with the thin disk with which N-type carbon stars are usually associated (Keenan 1993). Using the results of Feast et al. (2006), the 395 day period would correspond to a 2.7 Gyr age and initial 1.6 $M_\odot$ mass for StHα 55.

3.5. Radial velocity

The heliocentric radial velocity of StHα 55 on the Echelle spectrum is +23.7 ($\pm$ 0.2) km s^{-1}, obtained by cross-correlation with the appropriate spectrum from the synthetic spectral library of carbon stars of Pavlenko et al. (2003). The spectrum was obtained at pulsation phase 0.52, thus at the minimum brightness, when radial velocity, normally associated with the Mira pulsation, reaches its minimum velocity (cf. Joy 1954; Hoffmeister et al. 1985). The typical radial velocity amplitude at optical wavelengths of carbon Miras is $\sim$ 8 km s^{-1} (Sanford 1950; Barnbaum 1992a), and therefore we could conclude that the optical mean velocity of StHα 55 should be near +28 km s^{-1}. It is known that the optical mean velocity of carbon Miras is offset by some km s^{-1} from the barycentric velocity (better traced by CO infrared observations, Nowotny et al. 2005). Barnbaum (1992b) and Barnbaum & Hinkle (1995) find that barycentric velocities of carbon Miras are on average blueshifted by $\sim$ 6 km s^{-1} from mean optical velocities. This would translate into a heliocentric systemic velocity of +22 km s^{-1} for StHα 55.

The heliocentric radial velocity of the Hα emission line is +19.3 ($\pm$ 0.6) km s^{-1}, i.e., it is blue-shifted by 4.4 km s^{-1} with respect to the Mira absorption spectrum. It is known that the velocity of the emission lines differs from that of the absorption spectrum both in oxygen- and carbon-rich Miras. The difference for carbon Miras is reported as $< RV_{\rm em}\,({\rm H}\alpha) - RV_{\rm abs} >$ = -30 km s^{-1} according to Menzies et al. (2006) and -20km s^{-1} following Sanford (1944), with minimal dispersions around the respective means. In none of the 43 stars analyzed by Menzies et al., or in the 34 stars studied by Sanford, the difference between the radial velocity of the absorption spectrum and that of the Hα emission is as small as it is in StHα 55.

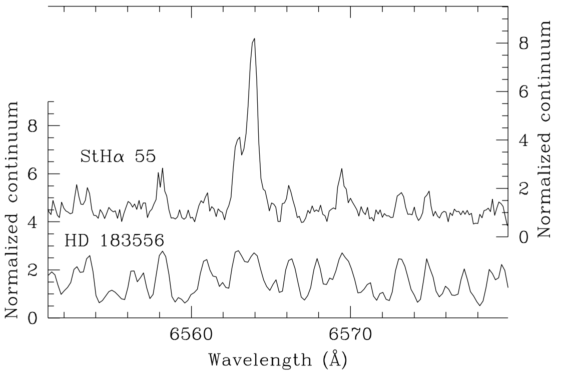

Fig. 6. Comparison of the region around Hα from Asiago 1.82 m Echelle spectra of StHα 55 and of the non-Mira, C 6-4 carbon star HD 183556.

3.6. Profile and variability of Hα emission

The main reason for Belczynski et al. (2000) to include StHα 55 in their list of suspected symbiotic stars was the "H I emission lines too strong for a single carbon star". Figure 6 shows a portion of our Echelle spectrum of StHα 55 centered on Hα and for comparison the equivalent portion of a spectrum of the non-variable carbon star HD 183556 obtained with the Asiago Echelle spectrograph and the same instrumental set-up as adopted for StHα 55.

The Hα emission component of StHα 55 is sharp and very similar to those typically observed in carbon Miras, as nicely seen in comparison with the high resolution Hα spectral atlas of Mikulašek & Graf (2005). Contrary, the Hα emission lines of symbiotic stars are much wider and present multi-components and frequent central reversals (e.g., Ivison et al. 1994; van Winckel et al. 1993). Carbon symbiotic stars are no exception, as illustrated by the Asiago Echelle observations of Munari (1991) about the evolution of the Hα emission line in the carbon symbiotic star Draco C-1.

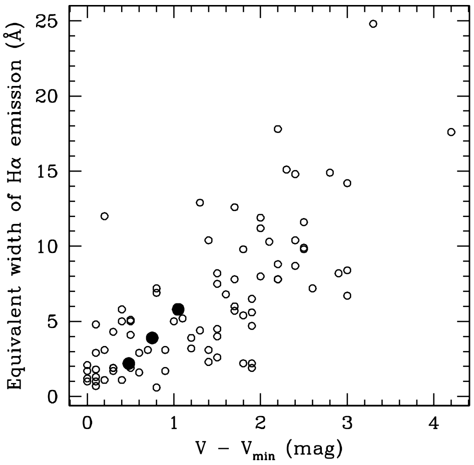

Fig. 7. Relation between the equivalent width of Hα (in Å) and magnitude of carbon Miras (from Mikulašek & Graf 2005, open circles). The solid points represent our measurements of the equivalent width of Hα emission in StHα 55.

The intensity of the Hα emission component of StHα 55 appears normal for a carbon Mira variable. Mikulašek & Graf (2005) have measured the integrated flux of the Hα along the pulsation cycles of many carbon Miras. Their results, expressed as equivalent width of the Hα emission vs. the carbon Mira brightness above the minimum value, are presented in Figure 7. This figure shows that (1) the Hα emission component can reach an intensity 5 times stronger in the field carbon Miras than is seen in StHα 55, and (2) the variability of the Hα emission component in StHα 55 follows the mean relation for carbon Miras.

Therefore, the Balmer emission lines observed in StHα 55 are similar in shape and intensity to those seen in normal carbon Miras, and therefore do not support a binary, interactive nature of StHα 55.

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