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

U. Munari\textsuperscript{1} A. Siviero\textsuperscript{1} M. Graziani\textsuperscript{2} A. Maitan\textsuperscript{2} A. Henden\textsuperscript{3} L. Baldinelli\textsuperscript{2} S. Moretti\textsuperscript{2} S. Tomaselli\textsuperscript{2}

\textsuperscript{1} INAF Osservatorio Astronomico di Padova, via dell’Osservatorio 8, 36012 Asiago (VI), Italy\textsuperscript{2} ANS Collaboration, c/o Osservatorio Astronomico, via dell’Osservatorio 8, 36012 Asiago (VI), Italy\textsuperscript{3} AAVSO, 49 Bay State Road, Cambridge, MA, USA

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Abstract.

We carried out a $V_R C_I C$ photometric monitoring of StHα-55, and in addition we obtained low resolution absolute spectro-photometry and high resolution Echelle spectroscopy. 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 suffers from a low reddening ($E_{B-V}$ = 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 sec$^{-1}$. 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 $^{13}\text{C}/^{12}\text{C}$ isotopic ratio is normal, and lines of BaII and other s-type elements, as well as LiI, 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, as previously hypothesized.

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

1. INTRODUCTION

Very scanty information is available in literature on StHα-55. It was discovered by Stephenson (1986) as a $V$~13.5 mag stellar source displaying Hα in emission. A low-resolution spectrum of StHα-55 was obtained by Downes and Keyes (1988), who classified it as a carbon star and confirmed the presence of Hα and Hβ in 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 and Keyes (1988) was larger than in normal, single carbon stars. A second spectrum of StHα-55 was presented by Munari and Zwitter (2002) as part of their multi-epoch spectro-photometric atlas of symbiotic stars, which surveyed the vast
Table 1: Magnitude and colors of the photometric comparison stars.

|   | V (±)    | B-V (±)   | V-Rc (±) | R-Ic (±) | V-Lc (±) |
|---|----------|-----------|----------|----------|----------|
| α | 13.710   | 0.018     | 1.803    | 0.021    | 1.004    | 0.012    | 1.033    | 0.059    | 2.062    | 0.065    |
| β | 13.890   | 0.030     | 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    | 0.032    |
| δ | 14.992   | 0.018     | 1.576    | 0.024    | 0.925    | 0.009    | 0.978    | 0.055    | 1.908    | 0.051    |
| a | 12.633   | 0.013     | 1.786    | 0.007    | 0.994    | 0.030    | 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    | 0.659    | 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    |

The majority of the sources listed by Belczynski et al. (2000). The Munari and Zwitter (2002) spectrum of StHα55 was virtually identical to that of Downes and 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 StHα55 among the ∼80 symbiotic stars that the ANS (Asiago Novae and Symbiotic star) Collaboration is monitoring spectroscopically and photometrically (UBVRcIC bands). In this paper we report observations and analysis that show StHα55 to be a normal carbon Mira with no hint of a symbiotic binary nature.

2. OBSERVATIONS

2.1. Photometry

As a first step, a BVRCIC photometric sequence was calibrated around StHα55 for use by all of the telescopes participating in the monitoring effort. The sequence is presented in Table 1 and identified in the finding chart of Figure 1. The sequence was calibrated against Landolt (1983, 1992) equatorial standards with observations obtained with the 0.35m robotic telescope of Sonoita Research Observatory (SRO, Arizona, USA). It uses BVRCIC Optec filters and an SBIG STL-1001E CCD camera, 1024×1024 array, 24 µm pixels ≡ 1.25′′/pix, with a field of view of 20′×20′.

All our subsequent observations of StHα55 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 Poissonian noise, color transformations and residuals in the dark/flat/bias corrections) are 0.035 mag in V, 0.027 in V-Ic, and 0.018 in Rc-Ic. The observations of Table 2 were collected with the following ANS Collaboration telescopes. R020: the 0.40-m f/5 Newton
2.2. Spectroscopy

A low resolution, absolutely fluxed spectrum of StHα 55 was obtained on February 25, 2008 with the B&cC spectrograph of the INAF Astronomical Observatory of Padova attached to the 1.22m telescope operated in Asiago by the Department of Astronomy of the University of Padova. The slit, aligned with the parallactic angle, had a 2 arcsec 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/pix and a wavelength
range extending from 3400 to 8100 Å.

A high resolution spectra of StHα 55 was obtained on 20 March 2008 with the Echelle spectrograph mounted on the 1.82m telescope operated in Asiago by INAF Astronomical Observatory of Padova. The detector was an EEV CCD47-10 CCD, 1024×1024 array, 13 μm pixel, covering the interval 3600−7300 Å in 31 orders. A slit width of 200 μm provided a resolving power \( R_P = 22000 \).

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 bluer colors when the star is brighter and redder colors when it is fainter. These are distinctive features of Mira-like pulsations.

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-band data in the ASAS database (All Sky Automated Survey,Pojmanski 1997), covering the time interval from 18 January 2006 to 27 April 2006. We carried out a Deeming-Fourier (Deeming 1975) period search on our V-band set combined with that from ASAS, which resulted in a clear and strong 395 day periodicity. The combined V-band data are phase plotted in Figure 3 according to the ephemeris:

\[
Max(V) = 2453849 + 395 \times E
\]

The lightcurve 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 lightcurve appears quite symmetric, the pulsation period is rather long and
the amplitude is small, all distinctive characteristics of carbon Miras in comparison with their O-rich counterparts (Mennessier et al. 2000).

The lightcurve in Figure 2 shows a short-lasting departure from a smooth trend around day 315. This part of the lightcurve 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 $\Delta (V-I_C) \sim 0.2$ mag, $\Delta (R_C-I_C) \sim 0.15$ mag blueness of the colors. This occurrence briefly interrupted the smooth fading of the lightcurve 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 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 StH$\alpha$ 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$^2_6$, i.e. 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 BaII and other s-type elements, as well as LiI, have the same intensity in StH$\alpha$ 55 as in field carbon stars of the same spectral type (see for ex. Jaschek and Jaschek 1987, Wallerstein and Knapp 1998).
3.4. Reddening

Feast et al. (1990) proposed the following statistical expression for the reddening as function of distance and galactic $b$ latitude: $E_{B-V} = 0.032(\csc|b| - 1)[1 - \exp(-10r\sin|b|)]$, where $r$ is the distance in kpc. For the 5 kpc distance derived in 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 StHα 55.

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

The 2MASS survey measured StHα 55 at $J = 8.114 \pm 0.034$, $H = 6.507 \pm 0.034$ and $K_s = 5.297 \pm 0.023$ 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 days period have amplitudes in the $K$ band of the order of 0.85 mag (Whitelock et al. 1991), and their C-rich counterparts have distinctively lower amplitudes $\Delta K \approx 0.6$ mag (Whitelock et al. 2006). Because the $K$-band lightcurve of carbon Miras are closely 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 $\langle K_s \rangle = 5.297 + 0.3 \times 0.73 \approx 5.52$ mag. Whitelock et al. (2008) have calibrated, on the revised Hipparcos parallaxes by van Leeuwen (2007), 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 $K$ bands (cf. Tokunaga et al. 2002), the distance to StHα 55 would be 5.0 kpc for the $E_{B-V} = 0.15$ above derived. This is remarkably close to the distance obtained above from the reddening-free Weisenheit $W_I$ index.

In this paper we therefore adopt a 5 kpc distance to StHα 55. It agrees with the lack of significant proper motion of StHα 55, as listed by the NOMAD database. At Galactic coordinates $l=199.3$ and $b=-11.1$, the corresponding height above the Galactic plane of StHα 55 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 and 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⊙ mass for StHα 55.

3.5. Radial velocity

The heliocentric radial velocity of StHα 55 on the Echelle spectrum is +23.7 (±0.2) km sec⁻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 minimum brightness, when the 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 ∼8 km sec⁻¹ (Sanford 1950, Barnbaum 1992a), and therefore we could conclude that the optical mean velocity of StHα 55 should be near +28 km sec⁻¹. It is known that the optical mean velocity of Carbon Miras is offset by some km sec⁻¹ from the barycentric velocity (better traced by CO infrared observations, Nowotny et al. 2005). Barnbaum (1992b) and Barnbaum and Hinkle (1995) find that barycentric velocities of Carbon Miras are on average blue shifted by ∼6 km sec⁻¹ from mean optical velocities. This would translate into a heliocentric systemic velocity of +22 km sec⁻¹ for StHα 55.

The heliocentric radial velocity of the Hα emission line is +19.3 (±0.6) km sec⁻¹, i.e. blue-shifted by 4.4 km sec⁻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 in both oxygen- and carbon-rich Miras. The difference for carbon Miras is reported as <RV_Hα em - RV_Hα abs> = −30 km sec⁻¹ according to Menzies et al. (2006) and −20 km sec⁻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, is the difference between the radial velocity of the absorption spectrum and that of the Hα emission as small as it is in StHα 55.

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 "HI 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 Mikulasek and Graf (2005). On the contrary, the Hα emission lines of symbiotic stars are far 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.

The intensity of the Hα emission component of StHα 55 appears normal for a carbon Mira variable. Mikulasek and 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 (i) the Hα emission component can reach an intensity 5× stronger in field carbon Miras than seen in StHα 55, and (ii) 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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