

# A long trail behind the planetary nebula HFG1 (PK 136+05) and its pre-cataclysmic binary central star V664 Cas

P. Boumis,<sup>1</sup>\* J. Meaburn,<sup>2</sup> M. Lloyd<sup>2</sup> and S. Akras<sup>1,3</sup>

<sup>1</sup>*Institute of Astronomy and Astrophysics, National Observatory of Athens, I. Metaxa & V. Pavlou, GR-152 36 P. Penteli, Athens, Greece*

<sup>2</sup>*Jodrell Bank Centre for Astrophysics, University of Manchester, Manchester M13 9PL*

<sup>3</sup>*Astronomical Laboratory, Department of Physics, University of Patras, 26500 Rio-Patras, Greece*

Accepted 2009 March 16. Received 2009 March 16; in original form 2009 February 11

## ABSTRACT

A deep wide-field image in the light of the H $\alpha$  and [N II] 6548 & 6584 Å emission lines, of the planetary nebula HFG1 which surrounds the pre-cataclysmic binary system V664 Cas, has revealed a tail of emission at least 20 arcmin long, at a position angle of 316°. Evidence is presented which suggests that this is an  $\approx 10^5$  yr old trail of shocked material, left behind V664 Cas as it ejects matter whilst ploughing through its local interstellar media at anywhere between 29 and 59 km s<sup>-1</sup> depending on its distance from the Sun.

**Key words:** stars: AGB and post-AGB – binaries: general – stars: individual: V664 Cas – novae, cataclysmic variables – planetary nebulae: individual: HFG1.

## 1 INTRODUCTION

Heckathorn, Fesen & Gull (1982) discovered a 10 arcmin diameter planetary nebula (PN) HFG1 around what later was recognized to be a 13.7 mag pre-cataclysmic binary star named V664 Cas (Bond et al. 1989; Acker & Stenholm 1990; Exter et al. 2005). This stellar close binary system was found to have a period of 13.96 h and brightness amplitude of 1 mag. Exter et al. (2005) give its distance  $D = 310\text{--}950$  pc, but there is as yet no parallax measurement to determine this with more certainty. Shimanskii et al. (2004) show that V664 Cas is a pre-cataclysmic variable with an orbital period of  $\approx 0.58$  d and with the inclination of the rotation axis along a position angle  $PA = 177^\circ \pm 5^\circ$ .

The first deep wide-field image of HFG1 in the light of the H $\alpha$  and [N II] 6548 & 6584 Å nebular emission lines has now been obtained which reveals what appears to be a long trail of emission. This discovery will be reported here. Such trails have been postulated for stellar systems ejecting material such as the Galactic luminous blue variable (LBV) P Cygni (Meaburn, López & O'Connor 1999; Boumis et al. 2006 and references cited therein), Mira AB (Martin et al. 2007; Wareing et al. 2007) and the Large Magellanic Cloud LBV, R 143 (Meaburn et al. 2004). It is suggested that they form as the stars plough through their local interstellar media (ISM) during periods of mass ejection. Several planetary nebulae (PNe) with central binary systems, one star of which has evolved beyond its Mira A asymptotic giant branch phase, exhibit bow-shocks emitting optical emission lines as they plough through the local ISM (Bond & Livio 1990 and references therein), but only the PN Sh2-188, even without a binary system (Wareing et al. 2006), has been shown

to have a similar, though somewhat less spectacular, tail to the one revealed here for this pre-cataclysmic variable star.

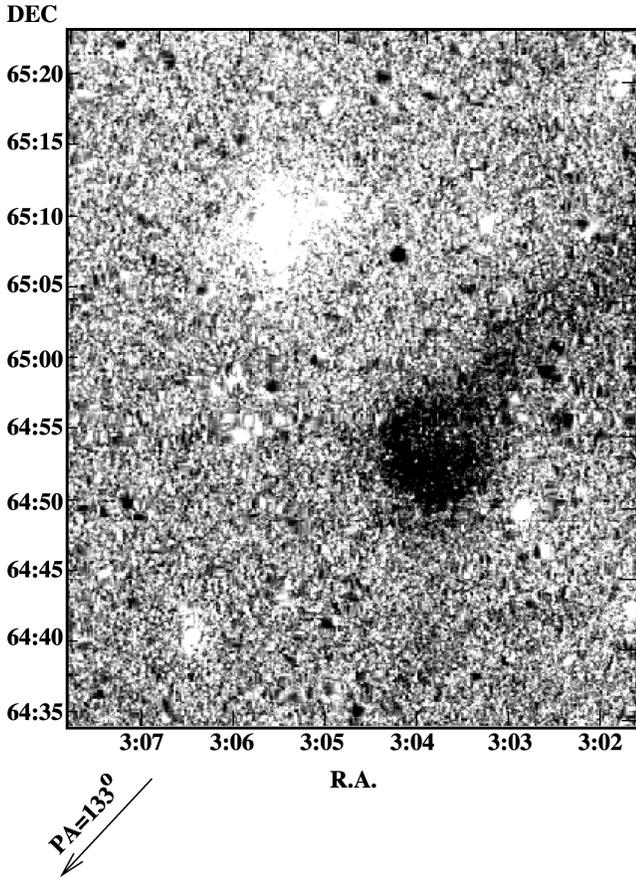
## 2 OBSERVATIONS

The wide-field image of the HFG1 nebula shown in Fig. 1 was obtained with the 0.3-m Schmidt–Cassegrain telescope at Skinakas Observatory, Crete, Greece on 2008 August 2. The observations were performed with a 1024 × 1024 Thomson CCD which provides a 70 × 70 arcmin<sup>2</sup> field of view and an image scale of 4 arcsec pixel<sup>-1</sup>. The HFG1 nebula was observed for 900 s through the H $\alpha$  plus [N II] 6548 & 6584 Å filter and for 180 s with the corresponding continuum filter. Standard IRAF and Starlink routines were employed for the data reduction. All frames were bias subtracted and flat-field corrected using a series of well-exposed twilight flat fields. The continuum image was scaled to the same intensity as the emission line image by comparing the total star signal (above sky) for a number of unsaturated stars in both images and multiplying the continuum image by the appropriate factor. The two images were then aligned by deriving an astrometric solution using the *Hubble Space Telescope* (HST) Guide Star Catalog (Lasker, Russel & Jenkner 1999). Finally the scaled and aligned continuum image was subtracted from the emission line image to eliminate the confusing star field and reveal the extent of the nebulosity. Note that the equatorial coordinates quoted in this work refer to epoch 2000.

## 3 DISCUSSION

The image shown in Fig. 1 reveals extended emission from around the star (diameter  $\sim 10$  arcmin), with the brightest, arc-like, sharpest

\*E-mail: ptb@astro.noa.gr



**Figure 1.** A deep, negative grey-scale, representation of the continuum subtracted H $\alpha$  plus [N II] 6548 & 6584 Å image. This is an enlargement from the wider 70 × 70 arcmin<sup>2</sup> field. Only residual star images are apparent after the subtraction process. The PM of V664 Cas is arrowed. This is known to  $\pm 6^\circ$  accuracy.

edge to the south-east and with a faint tail extending to the north-west, about 5 arcmin wide and extending at least 20 arcmin. The sharp SE rim is likely to be a bow shock and the long tail that is aligned with this feature is likely to be the remnant trail behind the PN/star as it moves through the ISM.

The first test of the suggestion that the extended emission feature shown in Fig. 1 and directed along PA = 316° (north through east) from HFG1 is caused by the passage of the PN through its local ISM is to determine the proper motion (PM) direction of the progenitor star V664 Cas, corrected for any relative motion due to differential Galactic rotation. Hanson, Klemola & Jones (2004) measure the PMs as  $d(\alpha, \delta)/dt = (7.6, -7.8)$  mas yr<sup>-1</sup> where  $\alpha$  and  $\delta$  are the right ascension and declination directions, respectively. These values are accurate to  $\pm 0.6$  mas yr<sup>-1</sup>. Using Oort's constants  $A = 14$  and  $B = -12$  km s<sup>-1</sup> kpc<sup>-1</sup>, the correction for differential Galactic rotation is  $-2.3$  mas yr<sup>-1</sup> along Galactic longitude, at constant latitude. The PM values then become  $9.6 \pm 0.6, -8.9 \pm 0.6$  mas yr<sup>-1</sup>. This correction is independent of distance to V664 Cas. Galactic longitude at constant latitude increases along PA = 120° for V664 Cas. A PM =  $13 \pm 1.5$  mas yr<sup>-1</sup> along PA = 133° ± 6° due to the motion of V664 Cas through its local ISM is indicated. This apparent motion, within the uncertainties, is directly opposite to the direction of the proposed trail seen in Fig. 1.

For the range of possible distances to V664 Cas of  $D = 310$ –950 pc as given by Exter et al. (2005), the tangential veloc-

ity (in the plane of the sky) is then between  $19 \pm 2$  and  $58 \pm 6$  km s<sup>-1</sup> for this corrected PM =  $13 \pm 1.5$  mas yr<sup>-1</sup>. The correction for differential Galactic rotation for V664 Cas to its radial velocity for the same distance range then amounts to  $-4$  to  $-13$  km s<sup>-1</sup>. As the measured<sup>1</sup> local standard of rest radial velocity of V664 Cas is  $-26 \pm 2$  km s<sup>-1</sup> then the radial velocity of HFG1 with respect to its local ISM is between  $-22 \pm 2$  and  $-13 \pm 1.3$  km s<sup>-1</sup> for this same range of possible distances. Similarly, the range of space velocities again with respect to its local ISM is therefore  $V_o = 29 \pm 4$  to  $59 \pm 9$  km s<sup>-1</sup> tilted towards the observer by between  $\theta = 49^\circ \pm 5^\circ$  and  $13^\circ \pm 3^\circ$ , respectively. The higher  $V_o$ , and hence the further distance, would be favoured if the trail found here has been caused by shock ionization as the mass-ejecting stellar system V664 Cas ploughs through its local ISM. If this is the case, the measured PMs and the trail angular length of >20 arcmin in Fig. 1 indicate that this process has occurred over a kinematic age of  $\geq 10^5$  yr, i.e. simply the angular length of the trail divided by the stellar PM. This is far too long for the trail to be ionized by the leakage of Lyman photons during the PN phase of the primary 0.57 solar mass (Shimanskii et al. 2004) star of the binary system. In any case, there is tentative evidence in Fig. 1 that a bow shock in the PA = 133° direction precedes the motion which then favours the shock ionization explanation (seen also in the [O III] 5007 Å image of Heckathorn et al. 1982, in figs 1 and 2).

An alternative possibility is that the trail is material ejected in one direction, along the orbital axis of the central binary system which is oriented along PA =  $177^\circ \pm 5^\circ$  (Shimanskii et al. 2004). However, the trail reported here in Fig. 1 is substantially tilted (a PA difference of 41°) with respect to this direction which precludes any monopolar ejection mechanism for its creation. Detailed kinematical observations of both the tail and the PN itself are now required to investigate the relationships between the tail, the main part of the PN and the central binary system.

## ACKNOWLEDGMENTS

We would like to thank the referee for constructive comments that have improved the paper considerably. Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology-Hellas and the Max-Planck-Institut für extraterrestrische Physik. This research has made use of the SIMBAD data base, operated at CDS, Strasbourg, France.

## REFERENCES

- Acker A., Stenholm B., 1990, A&A, 233, L21
- Bond H. E., Livio M., 1990, ApJ, 355, 568
- Bond H. E., Ciardullo R., Fleming T. A., Grauer A. D., 1989, in Torres- Peimbert S., ed., Proc. IAU Symp. Vol. 131, Planetary Nebulae. Reidel, Dordrecht, p. 310
- Boumis P., Meaburn J., Redman M. P., Mavromatakis F., 2006, A&A, 457, L13
- Exter K. M., Pollacco D. L., Maxted P. F. L., Napiwotzki R., Bell S. A., 2005, MNRAS, 359, 315
- Hanson R. B., Klemola A. R., Jones B. F., Monet D. G., 2004, AJ, 128, 1430
- Heckathorn J. N., Fesen R. A., Gull T. R., 1982, A&A, 114, 414

<sup>1</sup> <http://simbad.u-strasbg.fr/simbad/>

Lasker B. M., Russel J. N., Jenkner H., 1999, in the HST Guide Star Catalog, version 1.1-ACT. The Association of Universities for Research in Astronomy, Inc.

Martin D. C. et al., 2007, *Nat*, 448, 780

Meaburn J., López J. A., O'Connor J., 1999, *ApJ*, 516, L29

Meaburn J., Boumis P., Redman M. P., López J. A., Mavromatakis F., 2004, *A&A*, 422, 603

Shimanskii V. V., Borisov N. V., Sakhbullin N. A., Surkov A. E., 2004, *Astron. Rep.*, 48, 563

Wareing C. J., O'Brien T. J., Zijlstra A. A., Kwitter K. B., Irwin J., Wright N., Greimel R., Drew J. E., 2006, *MNRAS*, 366, 387

Wareing C. J., Zijlstra A. A., O'Brien T. J., Seibert M., 2007, *ApJ*, 670, L125

This paper has been typeset from a  $\text{\TeX}/\text{\LaTeX}$  file prepared by the author.