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A Binary-Induced Pinwheel Outflow from the Extreme Carbon Star, AFGL 3068

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Abstract. The extreme carbon star, AFGL 3068, is losing mass at a rate in excess of 10^{-4} $M_\odot$ yr^{-1}, and has so far been detected only in the infrared because it is hidden by a thick dust photosphere having a color temperature of ∼300K. Using the ACS camera on HST, we have imaged AFGL 3068 with broad-band filters at 0.6 and 0.8 μm and find a thin, apparently continuous spiral arc winding 4 or 5 times around the location of the star, from angular radii of 2 to 10 arcsec. We interpret this as the projection of nested spiral shells such as were predicted to occur when the mass-losing star is a member of a binary system. In this case, the illumination is presumably provided by ambient galactic starlight. Subsequent near-IR observations with the NIRC2 camera on the Keck II telescope using adaptive optics reveal that AFGL 3068 has two components separated by 0.11 arcsec, or 109 AU at a distance of 1 kpc. One very red component is presumably the mass-losing carbon star, while the other component is apparently a much bluer companion. Assuming each component has mass $M(M_\odot)$, and ignoring the projection of the separation vector, we find the binary period to be 810 $M^{-0.5}$ yrs, strikingly comparable to the 710-yr separation of the shells obtained from the known outflow velocity of 14.7 km s^{-1}.

Keywords. stars: AGB and post-AGB, stars: carbon, binaries: general, stars: winds, outflows

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A progression of quasi-concentric shells has been observed around a number of preplanetary nebulae (e.g., Sahai *et al.* 1998; Su 2004), with a characteristic spacing corresponding to time intervals of hundreds of years. No intrinsic mechanism to produce mass loss variations on such a time scale has been identified, but Harpaz *et al.* (1997) raise the possibility that a binary companion in an eccentric orbit might be responsible. Our HST observations (figure 1) show that AFGL 3068 has a more continuous set of such shells than in any other system, and that these shells are arranged in a spiral pattern. Such a pattern would result naturally from a binary system (Mastrodemos & Morris 1999), and indeed, our observations with Keck II reveal that this extreme, mass-losing carbon star (e.g., Winters *et al.* 1997) has a closely-spaced binary companion (figure 2). The binary separation in this system matches that needed to account for the shell spacings, with allowance for projection and assuming stellar masses of 1 - 2 $M_\odot$. The Archimedean spiral form of the shell is well modeled with a circular orbit.

The structure of the AFGL 3068 envelope raises the possibility that binary companions are responsible for quasi-concentric shells in most or all of the systems in which they have been observed. The lack of azimuthal continuity in the shells elsewhere can perhaps

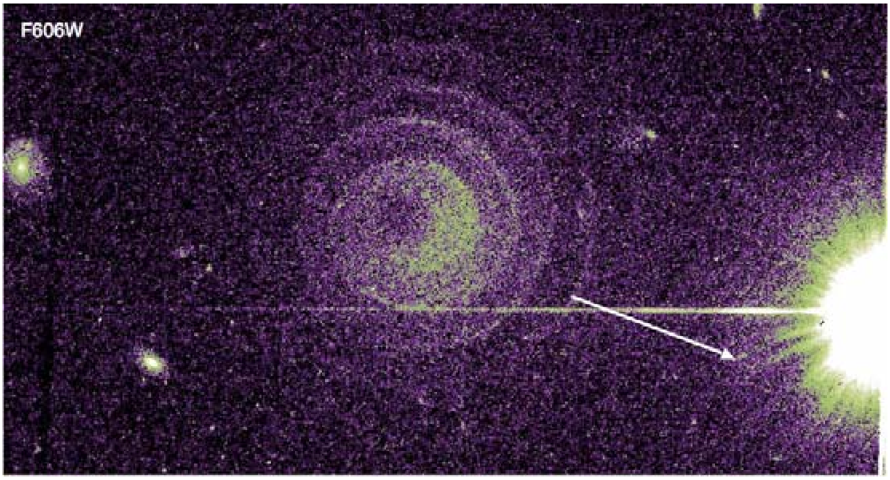

Figure 1. HST/ACS image of AFGL 3068 with the F606W filter (central wavelength 5907 Å). The dimensions are 50"x27". A similar result was obtained with the F814W filter. The bright star at the right was used as the natural guide star for the Keck AO images shown in figure 2. The arrow shows the direction of the Galactic plane, 650 pc away for a source distance of 1 kpc. We propose that the illumination of the shells is by Galactic starlight. [These data have been separately discussed by N. Mauron & P.J. Huggins in a recent preprint, astro-ph/0602623.]

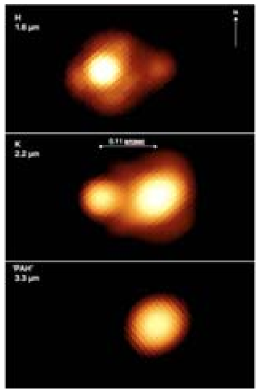

Figure 2. Keck adaptive optics images of AFGL 3068 in 3 near-IR filters. Two sources are apparent, the slightly diffuse one to the west probably being the highly obscured, mass-losing star, and the one to the east being a much less obscured companion at a projected distance of 109 AU at 1 kpc. The first Airy ring in the point spread function for these images has a trefoil pattern which is most evident in the H image of the eastern source. (The "PAH" filter was used to provide a narrow-band sampling of the 3.3 m continuum, since the usual wideband filters saturated on this strong source.)

be ascribed to orbital eccentricity, to different projections of the orbital planes, and to unfavorable illumination geometries.

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