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ISOPHOT observations of protoplanetary nebulae

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1. Introduction

As intermediate-mass stars (0.8 and 8M$_\odot$) evolve, they follow a path on the H-R diagram up the asymptotic giant branch (AGB) where they begin to lose much of their mass. As they shed their outer envelopes they move to the blue side of the H-R diagram, through the horizontal, post-AGB or protoplanetary nebulae (PPN) branch, evolving toward the planetary nebulae (PN) phase. The AGB mass-loss dominates the evolution of these objects and yet it is not well understood. The most promising theoretical models suggest that mass-loss is due to a combination of stellar pulsation and radiation pressure on dust grains (e.g. Höfner 1999 & Dorfi 1997). PPN should be surrounded by dust shells which contain a fossil record of the mass-loss from the precursor AGB stars. By studying the distribution of matter in these circumstellar shells we can better understand the mass-loss processes involved in the evolution of intermediate mass stars. We present ISOPHOT observations of 3 PPN with extremely large dust shells.

2. Observations

Source	filter (μm)	scan length	image pixel size	θ^*	spectral type	CS† chem.
AFGL 618	120/180	53′	30″×92″	9°	B0	C
AFGL 2688	120/180	53′	30″×92″	8°	F5I	C
HD 161796	90/160	36′/53′	15″×46″/30″×92″	28°	F2-F5	O

* θ is the orientation of the scan, measured east of north. † Chemistry of the circumstellar envelope.

3. Results

HD 161796 is a low metallicity supergiant which is believed to have recently left the AGB on its way to becoming a PN (e.g. Hrivnak, Kwok & Volk 1989). At first glance this object looks like a point source, however, at the ~1-2% flux level there is evidence for weak extended emission out to a radius of ~400″. We have simulated the extended emission using a mapping simulator in the ISOPHOT interactive analysis (PIA) package (see Gabriel & Hur 2000). Unfortunately, our scans have insufficient resolution to distinguish between a continuous extended source and a point source surrounded by a detached ring with up to 50″ between the point source and the inner radius of the ring. Therefore, we cannot determine whether mass-loss has been continuous or episodic for HD 161796.

Like HD 161796, the AFGL 2688 is believed to have left the AGB in the last few hundred years (e.g. Skinner et al. 1997). The linear scans of AFGL 2688 show a bright point source surrounded by less bright (~10%) extended emission out to ~350″. Furthermore, the extended emission shows "bumps" in its distribution, at ~150″ and ~300″.

AFGL 618 is a more evolved PPN/very young PN (e.g. Meixner et al. 1988). This object has progressed further along the path from the tip of the AGB to the PN phase than the previous two objects. The thermal emission from AFGL 618 closely resembles that of AFGL 2688, showing a bright point source surrounded by lower level (~10% flux) "bumpy" extended emission out to ~400″. The simulated emission shows that the enhancements appear at ~160″ and ~275″.

Table 1. Radii and timescales derived from the observations

Source	Distance (kpc)	v_{exp} (km/s)	R_{max} (pc)	t_{AGB} (10^4yrs)	R_1 (pc)	t_1 (10^4yrs)	R_2 (pc)	t_2 (10^4yr)
AFGL 618	1.8	~20	~3.5	~17	~1.3	~6.4	~2.6	12.8
AFGL 2688	1.2	22.4	~2.0	~9	~0.87	~3.7	~1.7	7.4
HD 161796	1.2	12	~2.3	~19	...	...	...	...

v_{exp} = the expansion velocity from CO rotation lines; t_{AGB} = time since oldest part of dust shell was ejected*; R_1 = radius of inner emission enhancement; R_2 = radius of outer emission enhancement; t_1 = time since inner enhancement was ejected*; t_2 = time since outer enhancement was ejected*; * all ages assume constant expansion velocity;

There is evidence for extremely extended dust emission in the three PPN presented here. The approximate ages for the dust shells are in the range 1-2×10^5yrs. For the C-rich objects there also appear to be periodic enhancements every few $\times10^4$ yrs, which may coincide with thermal pulses on the AGB (see e.g. Vassiliadis & Wood 1993; Steffen, Szczerba & Schönberner 1998). For a more detailed discussion of these results and there implications see Speck, Meixner & Knapp (2000)

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