CLASSIFICATION OF ISO SWS 01 SPECTRA OF PROTO-PLANETARY NEBULAE: A SEARCH FOR PRECURSORS OF PLANETARY NEBULAE WITH [WR] CENTRAL STARS.

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ABSTRACT

We have analyzed ISO SWS 01 observations for 61 proto-planetary nebulae candidates and classified their spectra according to their dominant chemistry. On the basis of our classification and the more general classification of SWS 01 spectra by Kraemer et al. (2002) we discuss the connection between proto-planetary nebulae candidates and planetary nebulae, with emphasis on possible precursors of planetary nebulae with [WR] central stars.

Key words: ISO SWS 01, proto–planetary nebulae, precursors of planetary nebulae with [WR] central stars.

1. INTRODUCTION

The proto-planetary nebula (PPN) phase, in the context of the late stages of low- and intermediate-mass star evolution, is a short lasting period (of the order of at most a few thousands of years) when stars evolve from Asymptotic Giant Branch (AGB) to planetary nebula (PN). The PPN phase is characterized by a rather small mass loss rate (∼10−7 M⊙yr−1), a decrease of the circumstellar shell optical depth due to expansion, and a decrease of the star radius and consequent increase of the effective temperature (typically from about 4000 K until the onset of ionization at about 25000 K) due to gradual consumption of stellar envelope, both by nuclear processing and by stellar wind.

PPNe, being immediate precursors of PNe deserve special attention because they offer the possibility to identify the main physical and chemical processes which lead to diversity of shapes and chemical compositions in PNe and their central stars. One of the most intriguing class of PNe is the class of planetary nebulae with Wolf-Rayet type central stars (hereafter [WR]PNe – see e.g. Tylenda et al. 1993, Górny & Stasińska 1995, Tylenda 1996, Leuenhagen & Hamann 1998). Among about 1500 galactic PNe ∼50 are [WR]PNe (Górny & Tylenda 2000). Observations with the Infrared Space Observatory (ISO, Kessler et al. 1996) have shown that in [WR]PNe both forms of dust (C-rich: PAHs and O-rich: crystalline silicates) are present (Waters et al. 1998a, Cohen et al. 1999). For a discussion of scenarios put forward to explain this unexpected discov-

2. SAMPLE AND ISO DATA REDUCTION

Recently, Szczeska et al. (2001b) compiled from the literature a list of 220 PPNe candidates. We have searched the IDA for SWS 01 data within 1 arc-min around the IRAS position (or other position if the source has no IRAS name) for all PPNe candidates from the Szczeska’s list. We have found 83 SWS 01 spectra for 61 objects.

The ISO SWS 01 data (offline processing - OLP version 10.1) analyzed in this work were all processed using ISAP (ISO Spectroscopic Analysis Package) version 2.1. The data analysis consisted of extensive bad data removal primarily to minimize the effect of cosmic rays. First, all detectors were compared to identify possible features. Then, the best detector was chosen to compare one by one with others. Finally, the spectra were averaged, using median clipping to discard points that lay more than 2.5σ from the median flux. Whenever memory effects or irregularities were present in the two scans of SWS 01 data, we averaged the two scans separately. Then the resulting two sub-spectra were used to check the reality of possible features. The spectra were averaged typically to a resolution of 300, 500, 800 and 1500 for SWS 01 data taken with speed 1, 2, 3 and 4, respectively. For the purpose of this paper the spectra were truncated at 27.5 μm since bands 3E and 4 have usually poor signal-to-noise ratio. In addition, the memory effects can influence our ability to recognize crystalline silicates, while cosmic rays could produce spurious features. Both these effects are difficult to take into account using the ISAP software only. This then almost precludes the recognition of the presence of crystalline silicates from the spectra we considered (see discussion below).
3. RESULTS

The main criterion applied during the classification of the SWS 01 spectra for the 61 PPNe candidates was based on the widely accepted CO paradigm (the chemistry depends on the C/O ratio in the ejected material). Some unexpected discoveries of mixed chemistry among late type stars are still rather more exceptional than typical. The two main groups (C- and O-rich) are easily recognized from the analysis of dust and/or molecular features. Among sources dominated by C-based chemistry we have distinguished PPNe with the 21 μm feature (C 21 class), sources with C$_2$H$_2$ and HCN absorption features around 13.8-14 μm (C mol class), R CrB type sources with their characteristic maximum of emission around 6 μm (C RCrB class). Finally, all the sources only characterized by PAH features were grouped in a so-called C PAH class. A representative SWS 01 spectrum for each of these groups is shown in Figs. 1-4. Concerning O-rich sources, we simply distinguished between PPNe with the 9.7 μm feature in absorption (Si A class) or in emission (Si E class), and added a class of RV Tauri type sources where the emission feature around 10 μm has a peculiar shape (Si RVTau class). Representative SWS 01 spectra of O-rich PPNe are shown in Figs. 5-7. We were able to classify in such a way 47 sources out of 61 (the spectra of the remaining ones are too peculiar to determine what is their dominant chemistry). Table 1 shows the classes we assigned for these 47 sources, together with the KSPW class (Kraemer et al. 2002). Inside each of our classes, the sources are ordered by decreasing IRAS 25 and 12 μm flux ratio ($c21=F_{25}/F_{12}$). It can be seen that both classifications agree rather well.

Since Kraemer et al. (2002) used automatically reduced data from the IDA, their classification is not always ac-
curate. On the other hand, as mentioned in Sect. 2, our classification does not take into consideration the possible presence of crystalline silicate features.

4. DISCUSSION

From Table 1, the proportion of C-rich sources is 25/47 (53%). However, because of source selection, the ISO sample is biased towards sources with the 21 µm feature, which amount to 9 objects in our sample. Therefore, the unbiased proportion of C-rich PPNe candidates is somewhere between 16/38 (42%) and 53%. Interestingly, the proportion of C-rich PNe is 35–40% (Rola & Stasinska 1994, Kingsburgh & Barlow 1994). This suggests that most PPNe candidates from our sample will indeed become PNe (from now on we will drop the word “candidate” for simplicity).

We can now roughly estimate what number of PPNe from our classified ISO sample are expected to become [WR]PNe. Górny & Stasinska (1995) argued that the proportion of [WR]PNe relative to the total number of PNe is about 8%. Then one expects the same proportion of [WR]PNe precursors among the sample of PPNe. This implies that 8% of 47 PPNe, i.e. ~4 will become [WR]PNe.

As discussed recently by De Marco & Soker (2002) the most important characteristic of [WR]PNe seems to be dual dust chemistry. About 80% of late [WR]PNe show the presence of silicates – mostly crystalline – while at the same time all of them show PAH emission, see Szczerba et al. (2001a). Very likely the dual dust chemistry is a result of O-rich dust being formed when the star was O-rich and stored in some stable reservoir in the stellar vicinity, while the carbon chemistry occurs later when the [WR]PN progenitor is already C-rich. As concerns early [WR]PNe, crystalline silicates are seen in only one object (NGC 5315 – K. Volk, private communication) out of 6 with available ISO spectra. The reason for such a small proportion is not clear. Górny & Tylenda (2000) argued that there is an evolutionary link between late and early [WR]PNe, so a stable reservoir of crystalline silicates should be seen in later phases as well, unless a fast wind is able to destroy or remove the crystalline material from the star surroundings. Non-detection of crystalline silicates can also be due to a worse quality of ISO SWS data for early [WR]PNe. From the above considerations, it is natural to think that PPNe showing dual dust chemistry should evolve into [WR]PNe. In our sample, the famous Red Rectangle (IRAS 06176−1006) and IRAS 16279−4757 contain both C-rich dust and crystalline silicates (from the KSPW classification, see also Waters et al. 1998b and Mester et al. 1999) which makes them good candidates to be precursors of late [WR]PNe. Note that not all [WR]PNe are C-rich (Górny & Stasinska 1995, De Marco 2002), in
Table 1. Source classification

| IRAS name | KSPW\(^1\) class | C21 | IRAS name | KSPW\(^1\) class | C21 |
|----------|------------------|-----|----------|------------------|-----|
| C21      |                  |     |          |                  |     |
| 16594−4656 | 4.CT           | 7.72 | 20000+3239 | 4.CT           | 3.68 |
| 23304+6147 | 4.CT           | 7.13 | Z02229+6208 | 4.CT           | 2.96 |
| 19500−1709 | 4.CT           | 5.18 | 22272+5435 | 4.CT           | 2.94 |
| 07134+1005 | 4.CT           | 5.14 | 05341+0852 | 4.PN           | 1.79 |
| 22574+6609 | 4.PUp          | 4.09 |          |                  |     |
|            |                 |     |          | Cmol            |     |
| RAFLG 2688\(^2\) | 4.CN     | 7.15 | 01144+6658 | 4.CR           | 1.79 |
| 23321+6545 | 4.CN:          | 4.69 | 19548+3035 | 4.CR           | 1.57 |
| 19480+2504 | 4.F            | 3.17 |          |                 |     |
|            |                 |     |          | CPaH            |     |
| 13428−6232 | 4.Fu           | 15.1| 13416−6243 | 4.CN\(\alpha\) | 3.34 |
| 01005+7910 | 4.PUp:         | 4.66 | 06176−1036 | 4.U/SC         | 1.24 |
| 17347−3139 | 4.U:           | 6.42 | 16235−4832 | 3.CR::         | 0.74 |
| 16279−4757 | 4.U/SC:        | 3.82 | 1018+2844  | 2.U            | 0.21 |
|            |                 |     |          | SiA             |     |
| 15553−5230 | 4.SA:          | 7.01| 15452−5459 | 4.SA\(\alpha\) | 3.55 |
| 18276−1431 | 4.SA:          | 6.45| 17195−2710 | 4.SA           | 2.97 |
| 17150−3224 | 4.SA:          | 6.43| 19386+0155 | 4.SB           | 2.57 |
| 22036+5306 | 5.SA:          | 5.49| 19343+2926 | 5.SA           | 2.44 |
| 18506+0315 | 5.SA:          | 3.84| 17516−2525 | 4.SAp          | 1.89 |
|            |                 |     |          | SiE             |     |
| 12175−5338 | 4.SE:          | 7.98| 11385−5517 | 5.SE:          | 1.49 |
| 18095+2704 | 4.SE:          | 2.79| 20004+2955 | 2.SEc          | 3.55 |
| 18062+2410 | 4.SE:          | 2.59| 17534+2603 | 3.SEp          | 0.46 |
| 19244+1115 | 4.SE:          | 1.71|          |                 |     |
|            |                 |     |          | SiRV/Tau        |     |
| 18281+2149 | 4.SE:          | 1.49| 18448−0545 | 2.SEa:         | 0.45 |
| 22327−1731 | 4.SE::         | 1.30| 12185−4856 | 7 R            | 0.35 |
| 20117+1634 | 4.SE::         | 0.56|          |                 |     |

\(^1\)Kraemer et al. (2002);  
\(^2\)RAFLG 2688 has not been observed by IRAS.

If non-detection of dual dust chemistry in some [WR] PNe is due to observational effects but is a sign of real absence of crystalline silicates, then it is possible that the precursors of these [WR]PNe may also not show crystalline silicate features. Recently, Hony et al. (2001) reported that some [WR]PNe show the 21 \(\mu\)m feature suggesting a possible link between them and PNe with the 21 \(\mu\)m feature (our class C21 or KSPW class CT). To our knowledge none of the C21 source shows evidence of dual dust chemistry so they could be candidates for precursors of [WR]PNe without crystalline silicates. Demographic arguments show that this could be the case for only a small fraction of them. Indeed, there are at least 12 PPNe with the 21 \(\mu\)m feature (see e.g. Kwok et al. 2002) among 220 known PPNe, i.e. 5.5%. On the other hand only 20% of late type [WR]PNe with analyzed ISO spectra do not have crystalline silicates. According to Görny & Tylenda (2000), 30% of all [WR]PNe are of late type and, as mentioned above, [WR]PNe represent 8% of the total number of PNe. Thus, the proportion of late [WR]PNe without crystalline silicates is at most 20% \(\times\) 30% \(\times\) 8% = 0.5% of the total population of PNe. Therefore, most of 21 \(\mu\)m sources will not go through the late [WR]PN phase. One could still argue that they could evolve into PNe in which the [WR] phenomenon will appear only later. However, Görny & Tylenda (2000) have shown that most [WR]PNe do evolve from late to early type. Besides, among PNe, the 21 \(\mu\)m feature has been seen only in [WR]PNe, meaning that PPNe with the 21 \(\mu\)m feature cannot evolve to early [WR]PNe that have not gone through a late [WR] stage. Therefore, PPNe with the 21 \(\mu\)m feature cannot be considered, as a class, as precursors of [WR]PNe.

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