The Detection of C_{60} in the Well-Characterized Planetary Nebula M1-11

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We performed multiwavelength observations of the planetary nebula (PN) M1-11 and we obtained its elemental abundances, dust mass, and the evolutionary status of the central star.

Using Subaru/HDS, OAO/ISLE, and *Spitzer*/IRS spectra, we detected over 220 emission lines and we detemined the eleven elemental abundances. Our determined elemental abundances are in excellent agreement with a nucleosynthesis model for initially 1.5 $M_{\odot}$ stars with the metallicity $Z = 0.004$.

The *AKARI*/IRC, VLT/VISIR, and *Spitzer*/IRS spectra show features due to carbon-rich dust, such as the 3.3, 8.6, and 11.3 μm features due to polycyclic aromatic hydrocarbons (PAHs), a smooth continuum attributable to amorphous carbon, and the broad 11.5 and 30 μm features often ascribed to SiC and MgS, respectively. We also reported the presence of an unidentified broad feature at 16–22 μm, similar to the feature found in Magellanic Cloud PNe with either C-rich or O-rich gas-phase compositions. We identified for the first time in M1-11 spectral lines at 8.5 (blended with PAH), 17.3, and 18.9 μm that we attribute to the C_{60} fullerene (Fig. 1). Using the detected C_{60} lines, we determined the C_{60} mass ($2.75 \times 10^{-8}\ M_{\odot}$) and temperature (399 K) in M1-11.

Using the radiative transfer code CLOUDY, combined with a modified blackbody, we have fitted the ~0.1–90 μm spectral energy distribution (SED) and determined physical properties of the central star and the ionized gas and dust masses (Fig. 2). Our chemical abundance analysis and SED model suggest that M1-11 is perhaps a very young C-rich PN (~1000 yrs), and that it evolved from a ~1.5 $M_{\odot}$ star.

The obtained values in M1-11, namely, the C_{60} mass and temperature, the elemental composition of the gas in the nebula, the mass of the progenitor star, and the evolutionary status, are very similar to those seen in other C_{60} containing PNe.

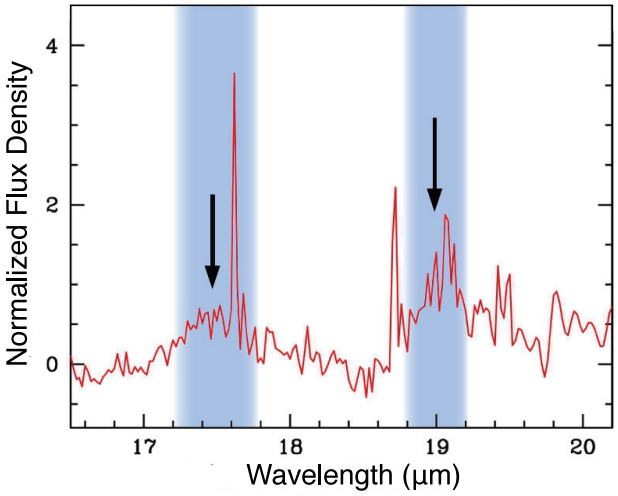

Figure 1: Detection of C_{60} bands in M1-11. Arrows indicate the positions of the 17.3 μm and 18.9 μm C_{60} bands.

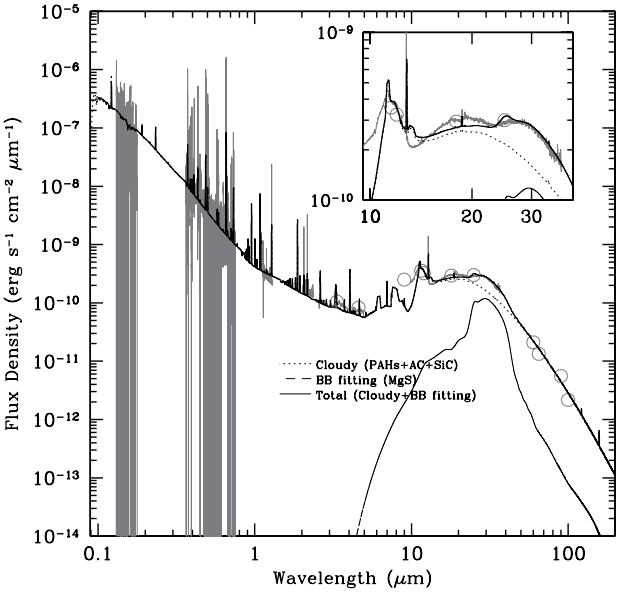

Figure 2: The fitted SED from the Cloudy modeling (dots) and the modified blackbody fitting (long dash) and the resultant SED (thick black line). The gray circles and lines are the observed data. In the CLOUDY model, we considered PAHs, amorphous carbon (AC), and SiC. The modified blackbody fitting is performed for MgS only. The close-up feature of the observed and fitted SEDs around 10–40 μm are presented in the inner box.

Reference

[1] Otsuka, M., et al.: 2013, *ApJ*, **764**, 78.