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Near-Infrared Spectroscopy of Planetary Nebulae

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Nowadays, almost all astronomers believe that Planetary Nebulae (PNs) are the resultant objects at the final evolutional stage of intermediate-mass ($\sim$ 1 - 8 $M_{\odot}$) stars beyond asymptotic giant branch (AGB) phase. In this thesis, the results of a near-IR spectroscopic survey of 47 PNs in northern hemisphere with 1.88m telescope at the Okayama Astrophysical Observatory are presented, focusing on H_2 molecular emissions. Among 47 PNs, 12 PNs are detected in H_2 molecular emissions, including 6 newly detections. The excitation mechanism of H_2 molecular emissions in these PNs are examined by the intensity ratio of $H_2 v = 1-0$ S(1) and $H_2 v = 2-1$ S(1). There are two objects which are suggested to be excited by vibrational cascade following excitation of atomic states through absorption of UV photons (UV fluorescence). One is Hb12, which has already been reported that its H_2 molecular emissions are purely excited by UV fluorescence. The other is one of the newly detected objects in H_2, M1-11, which is assumed to be in a very similar condition to Hb12. The collisional excitation of H_2 transitions might occur in CRL618, M1-7, NGC2346 and the outer region of NGC6881. As one of new detection in this survey, M1-7 has very similar line ratio to that of CRL618, known as a famous PPN. Nevertheless the central region of NGC6881 seems to be excited rather by UV fluorescence, too.

Further, in this part, by adding our observational results to other results about the most prominent H_2 $\lambda 2.122\mu$m detection, a comparative study of the detection of H_2 molecular emission with other characteristics in PNs is made. This type of comparative study about H_2 detection in PNs with such large sample could be the first attempt in the nebular sciences. In this section, especially, the author paid attention to the physical connection between the detection of H_2 and dust contents in PNs. Because the hydrogen molecular species in PNs are also assumed to be produced on the surface of dust grains which are produced in the cool enhanced atmosphere of AGB envelopes as well, they are expected to be closely related with each other.

The nature of such dust in PNs are becoming clear since the launch of *Infrared Astronomical Satellite* (*IRAS*) in 1983. At first, to understand the changes of detection of H_2 molecular emissions in the evolution from PPNs to PNs, all PNs searched for H_2 are plotted in the *IRAS* two-color diagrams. In the two-color ([12-25]/[25-60]) diagram, it is found that some PNs detected in H_2 molecular emissions fairly deviate from theoretical blackbody lines, indicating the excess in 12 (and/or) 60μm bands. This deviation is not found in another two-color ([25-60]/[60-100]) diagram. The one of association of such peculiar PNs in [12-25]/[25-60] diagram distributed along the blackbody lines with lower temperature (< 100K) in another [25-60]/[60-100] diagram. Therefore, it is assumed that this type of PNs have cold dust envelope (<100K).

and that the dust heating , which followed with shock-excited H_2 line and strengthen 12μm flux, occurs in the central region of its cold envelope. There is also another association of H_2 detected PNs in the higher temperature ($\sim$ 200K) region along with theoretical blackbody line in both of the two-color diagrams. These PNs seems to have a dust cloud with relatively uniform and hot temperature. In this type of PNs with uniform hot dust cloud, some UV excited PNs, Hb12 and M1-11, and CRL618 are included. In such PNs, dense UV photons from its central star should destruct dust and molecules. The difference between these two types of PNs on the two-color diagrams is assumed to originate in the size of their dust and molecular envelope. The PNs with cold dust envelope, which is too large to reach to the thermal equilibrium, could be produced by massive progenitors. Conversely, the PNs with uniform hot dust could be produced by low mass progenitors in the same discussion. Molecular species and dust grains in these PNs can be destructed faster than in the PNs with extended cold dust envelope. Such differences in the size of their envelope could be caused by differences in mass of their progenitors. Therefore, it could be concluded that these PNs take different evolutional tracks due to their progenitor mass in the *IRAS* two-color diagram. According to the predicted evolutional scenario from AGB to PNs on the *IRAS* two-color diagram, stars are assumed to evolve simply from the higher temperature region (where e.g. Miras located at $\sim$ 500K) to the lower region (PNs typically shows that their dust temperature are about 150K) along the theoretical blackbody line. But, the investigation on two-color diagrams in this work lead to the new evolutional scenario of the dust property from PPNs to PNs.

Further, it is also found that both of these types of PNs detected in H_2 molecular emissions have slower expansion velocities observed by optical nebular lines. The expansion velocity of ionized gas in PNs is considered as one of the indicators of PNs' evolutionary state. The slower expansion velocity indicates that they could be younger PNs. Therefore, these all PNs with H_2 molecular emissions, which deviated in the *IRAS* two-color diagrams, are assumed as younger PNs, and this fact supports the assumption that PNs can take various evolutional tracks on these diagrams. But, the expansion velocity seems to be sensitive for nebular density or morphological geometry of nebulae as well as tha age of PNs. So, especially for these types of PNs, including numbers of bipolar PNs, the discussion about expansion velocity and nebular age should be taken more carefully.

Further, it can be said that the correlation between nebular bipolarity and the H_2 detection in PNs is clear to exist, as other works have already mentioned. In our all sample, actually, 80% of the H_2 detected PNs show signs of bipolarity. On the other hands, the nitrogen-to-oxygen abundance ratio, N/O, which is expected to be sensitive to the dredge up effect in the red giant branch and its mass, seems not to have any strong correlation with the H_2 detection. Therefore, it should be better to ignore the connection between progenitor mass and the H_2 detection. According to such arguments, the nebular bipolar morphology itself should be related to the production of H_2 molecular emissions in PNs. In these bipolar nebulae, molecular species and dust grains seem to distribute on their equatorial plane. As the results of the shock occurred at the inside of their equatorial plane, H_2 molecular emissions are practically detected in such place. And this H_2 emission in equatorial plane of bipolar nebulae are expected to remain longer time, according to the conservation of H_2 molecular species.