SUBARU & HST High Resolution Near-Infrared Multi-Color Images of Class II Young Stellar Object, RNO91

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ABSTRACT

Understanding a variety of planetary systems is one of the most important subjects of current astronomical research. It is important to investigate whether the variety comes from different initial conditions of primordial disks. Also, the evolution of protoplanetary disks should be observed directly as the change in circumstellar structures along the evolution of central stars, thus allowing us to trace the early evolutionary phases of planet formation as a consequence of disk structure evolution.

In order to better understand the variety and evolution of planet formation in early stages, we made a systematic imaging survey of circumstellar disks and companions stars. We have conducted high-resolution imaging observations in the near-infrared with the infrared camera CIAO mounted on the Subaru 8.2m Telescope since 2002. We present one example of our obtained images in which circumstellar structures around young stellar objects are detected in the scattered light at the sub-arcsecond resolutions, and discuss mainly morphology of such structures.

1. INTRODUCTION

What is RNO91?

① located in the L43 dark cloud in Ophiuchus at a distance of 160 pc (Herbst & Warner 1981)

②class II embedded source in the transient phase between protostar and visible PMS star (Parker 1991).

③a source of complex molecular outflow. The redshifted outflow lobe extends to the north; the blueshifted outflow lobe extends to the south (Levreault 1988; Myers et al. 1988; Mathieu et al. 1988).

④associated with an ammonia envelope (Mathieu et al. 1988), HCO^+ envelope (Lee et al. 2005), a reflection nebula (Hodapp 1994), and shock-excited H_2 emission (Kumar et al. 1999).

⑤mass: 0.5 solar mass (Levreault 1988)

⑥magnitude: J=11.0, H=9.6, K=8.5 (2MASS: 1998 April)

2. OBSERVATION

Telescope+instrument : SUBARU+CIAO
Venue: Mauna Kea (Hawaii)
Wavelength: 1.25, 1.65, 2.2 μm(J, H, K band)
Pixel scale: 0".0213 $pixel^{-1}$
Field of View: 22".0×22".0
Observation Date: 2001 May 15, 2005 June 2
Diameter of Occulting Mask: no mask
Exposure time: 400s(J), 180s(H), 180s(K)
FWHM: 0".55(J), 0".52(H), 0".46(K)

Fig.1. JHK color-composite image of RNO91. The field of view is 4'.8×4'.6. This image was obtained with IRSF1.4m+SIRIUS. (Nagoya Univ. & NAOJ.2004)

3. RESULTS

3-1. Nearby Emission around RNO91

The J, H and K band images of RNO91 obtained in 2001 are presented in Figure 2 together with an HST optical image (HST archive). We categorized the faint nebulosity structures associated with RNO91 to categories based on a wavelength which detects the each structures as follows. Names of each structures can be identified in Figure 3.

(R)---seen at J and optical, unseen at H and K, arc-like shaped.
(S)---seen at K
(V)---seen at all wavelength
(P)---seen at all wavelength, western arm
(T)---seen at all wavelength, eastern arm
(G)---seen at all wavelength, south-western arm
(M1, M2)---seen at J, H and optical, unseen at K
(N1, N2, N3)---seen at J and optical
(Q1, Q2)---seen at all wavelength

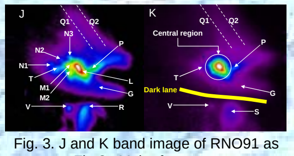

Fig. 3. J and K band image of RNO91 as same as Fig.2. Major features are identified

3-2. Color of RNO91

Fig. 4 shows H-K, J-K color image of RNO91. In these figures, brighter parts indicate redder regions, while darker parts indicate bluer regions. Fig. 5 shows pseudo-true color composites of CIAO(K), CIAO(J), and HST-WFPC2(optical) broadband observations of RNO91. Detailed descriptions for each color image are as follows:

(i)H-K color:
① Central redder region is extending to north-west →optically thick structures.
②a bridge-like structure extending to west from central peak position.
(ii)J-K color
①looks very similar to H-K color.
②Very red color of central region →optically thick structures

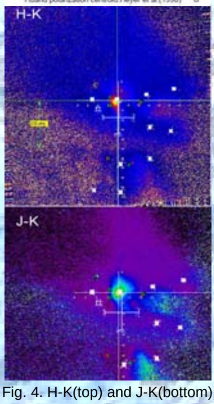

Fig. 4. H-K(top) and J-K(bottom) color images of RNO91.

3-3. Radial Surface Brightness Profile

Fig. 6 shows an azimuthally averaged radial brightness profile of RNO91. The surface brightness decreases as $r^{-1.3\pm0.1}$, $r^{-1.5\pm0.1}$, $r^{-2.0\pm0.1}$ with the radius r from 48 to 192 AU, for J, H, and K band, respectively. The surface brightness decreases as $r^{-1.6\pm0.1}$, $r^{-1.8\pm0.1}$, $r^{-1.8\pm0.1}$ with the radius r from 256 to 688 AU, for J, H, and K band, respectively. The power-law dependence revealed the following point.

At all wavelength, power-law index is shallower than that of r^{-2} for the normal stars, and indicating that RNO91 is still optically thick objects. The profile showed a cut-off at 256AU from the central peak especially at H, suggesting the morphological difference beyond this point.

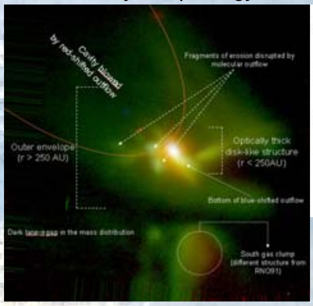

Fig. 5. Pseudo-true color composites of Subaru-CIAO(K), Subaru-CIAO(J), and HST-WFPC2(optical) broadband observations of RNO91. Major features are identified.

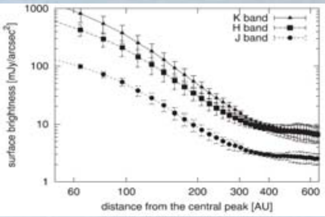

Fig. 6. Azimuthally averaged radial profile of the surface brightness of RNO91.

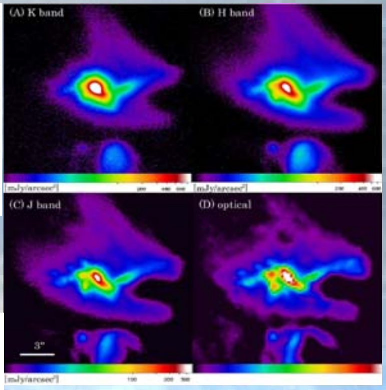

Fig. 2. SUBARU J, H and K band images of RNO91 with an HST optical image (HST archive). Field of View (FOV) is 17''. North is up and east to the left.

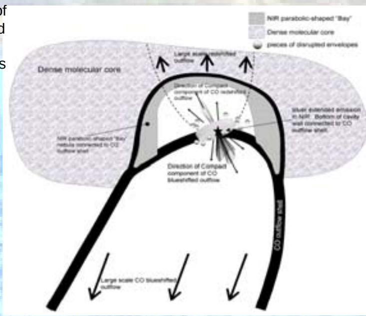

Fig. 7. Illustration of front view of RNO91 and its surrounding. The position of the central source is marked by the star. The hatched regions represent compact component of molecular outflow resolved by Arce & Sargent (2006). The sizes of disk, outflow, and molecular core are not drawn with the same scale. The field of view of our SUBARU images covers immediate circumstellar environment around the central source such as disk and roots of bipolar cavity.

4. DISCUSSIONS

We discuss the each structures based upon the results described above. We suggest the morphology of RNO91 as seen in Fig. 5 and 7.

4-1. Disk-like structure

The NIR images show significant halo emission detected within 2'' around the peak position (see Fig. 3) while less halo emission is seen in the optical image. The nebula appears to become more circular and more diffuse with increasing wavelengths. An azimuthally averaged radial surface brightness profile showed a cut-off at 2'' from the central peak, suggesting the morphological difference beyond this point. The power-law dependence of this profile is shallower than that of normal stars, indicating that RNO91 is still optically thick objects. It is thus natural to suggest that this halo emission within 2'' around the peak position is the near-infrared light scattered by an optically thick disk surrounding the RNO91 and outer region beyond 2'' is the near-infrared light scattered by an envelope structure (See Fig. 5). Based on the assumption that this halo emission is attributed to a disk, calculated inclination and P.A. of the disk would be 45～90° and 145°, respectively.

At J and optical, several bluer clumps (M1, M2, N1, N2 and N3 in Fig. 3) are detected around the central peak position and they are aligned nearly perpendicular to the outflow axis. Schild et al. (1989) conducted spectroscopic observation toward RNO91, and did not detect any emission lines in their spectra of the nebular features except for the bright Hα also seen in RNO91. They concluded that the nebular emission is mostly , and likely entirely, reflection light from RNO91, and not from other emission sources. They also showed optical images and reveal that RNO91 comprises a group of clumps which are aligned nearly perpendicular to the outflow axis and suggested these clumps may be attributed to a disk. Positions of these bluer clumps are measured in our images and compared with those in images obtained by Schild et al. (1989). These positions are almost consistent, but our images showed higher resolved clumps. Thus as suggested by Schild et al. (1989), these bluer clumps seen in our shorter wavelength images, are not other emission sources, but part of reflection nebula. Furthermore, in conjunction with the conclusions of Schild et al. (1989), these optically thin clumps would be interpreted as fragments or part of erosion occurred in a disk and envelope structures which are disrupted by molecular outflows.

4-2. Outflow

In J band and HST optical images, the nebula appears to become more extended (2''.3 long) to the southwest (P.A.～225°)(G in Fig. 3). Previous radio observations revealed that the redshifted outflow lobe extends to the north; the blueshifted outflow lobe extends to the south (Levreault 1988; Myers et al. 1988; Mathieu et al. 1988). Lee et al. (2000) indicated that the blue lobe is not symmetric about the driving source: the centroid of the outflow emission seems to curve eastward with increasing distance from the source. This could indicate that there is an interaction with ambient material that guides the orientation of the outflow. Alternatively, it could be that the intrinsic outflow axis is changing with time as a result of precession in the exciting source (Lee et al.2000). An orientation of extended nebula in our J band and HST optical image is almost consistent with that of blueshifted outflow axis derived from previous radio observations, which suggest that this extended emission might trace a bottom of outflow cavity opening to the southwest direction.

4-3. cavity

Our color composite image of RNO91 shows that the color of arc-shaped emission extending to the north (Q1 and Q2 in Fig.3) and to the east (T in Fig. 3) through RNO91 is redder than the inner region of this arc. And an orientation of this arc-shaped structure is almost parallel to that of extended emission discussed above. Thus, this arc-shaped structure is interpreted as a part of the cavity wall seen relatively edge-on. Redshifted molecular outflow might construct this cavity opening to north-east. The northern ridge is 11" long and eastern ridge is 7" long.

references

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