Molecular Outflows in the R Coronae Australis Region

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The molecular complex associated with the young Herbig Ae star R CrA is a region of low- to intermediate-mass star formation in the southern hemisphere. It is nearly, the generally accepted distance being 130 pc (although it is possibly 170 pc; Knude & Heg 1998). A cluster or association of newly-formed low-mass stars around the molecular core associated with R CrA is seen in the near-infrared (Wilking et al 1997). A more dispersed population of young stellar objects is revealed through X-ray surveys (Neuhäuser et al 2000). More deeply obscured objects are detected in the mid- and far-infrared and in the millimetre and radio continuum. A recent survey by Wang et al (2004) identifies 50 Herbig-Haro (HH) objects in the region.

The southern location (8 = 37°) has meant that relatively few millimetre-wave surveys of this region have been made to date (this is likely to change dramatically with the advent of ALMA). Only two CO surveys for molecular outflows in the R CrA region have been published. Levreault (1988) mapped 159 square arc minutes in CO(J=1−0) at 78° resolution and with poor pointing accuracy angle of ~ 40°. The driving source for the second outflow, offset from HH 99 in the south-west (blue) to HH 101 in the south-west (blue) at a distance of 12 arc minutes in CO(J=1−0) and CO(J=4−3) with resolutions of 60° and 90° respectively.

Here, we present results from a large-scale moderate-resolution (43′) CO(J=1−0) survey observed with the Swedish-ESO Submillimetre Telescope (SEST) and the initial results of an ongoing high-resolution (14′) CO(J=3−2) survey observed by the James Clerk Maxwell Telescope (JCMT). The goal of these observations is to identify outflows in the region, clarify their association with HH objects and potential driving sources, and to investigate the impact of outflows on the larger-scale cloud structure.

Low Resolution Observations

At least two major CO outflows have been thought to be present in the region (Figure 1). One extends ~ 6′ from east (blue) to west (red) and may be driven by IRS 7, a candidate Class 0 object ~ 30′ south-east of R CrA (Anderson et al 1997), but this conclusion is perhaps not secure (Groppi et al 2004). The second outflow overlaps with the first and extends ~ 12′ from HH 59 in the north-east (red) to HH 101 in the south-west (blue) at a position angle of ~ 40°. The driving source for the second outflow has been suggested to be the embedded object HH 100 IRS.

Figure 1. The CO(J=1−0) map of Levreault (1988). High-velocity emission integrated over the LSR velocity ranges -8 to +2 (blue-shifted, solid contours) and +10 to +20 (red-shifted, dashed contours). Crosses: young stars detected in the optical, infrared, or in X-rays. Circles: centimetre continuum sources. Squares: HH objects. Triangles: millimetre continuum sources. The SEST map (Figure 2) covers 653 square arc minutes, but is undersampled at the periphery. It confirms the gross characteristics of the Levreault (1988) map but reveals new features. The SEST map resolves the rather amorphous red-shifted emission seen in the Levreault (1988) map into at least four structures.

(1) A central compact and bright red-shifted lobe which is elongated north-west to south-east.

(2) A tongue of red-shifted emission extending from the map centre eastwards to the YY Ori-type young stellar object S CA. Some of this emission forms part of a newly-discovered molecular outflow from this object.

(3) A southern red-shifted structure that curves south-west around the HH 100 IRS region to meet HH 101.

(4) One or more very compact red-shifted lobes east of the map centre.

(5) Red-shifted emission north of the map centre.

It is unclear whether the very extended faint red-shifted emission in the south of the map is a real feature. Blue-shifted gas in this part of the map is unresolved.

(6) A faint blue-shifted lobe associated with S CA.

(3) A southern red-shifted lobe near HH 101 with an eastern extension, overlapping with feature 3.

(4) A tongue of weak emission extending east of the map centre, possibly associated with feature 4.

JCMT Observations

The SEST map strongly suggests that more than two molecular outflows are present but are confused. To attempt to remedy this, an ongoing program of mapping at high resolution is underway at the JCMT (see Figure 3). These observations show that numerous molecular outflows emanate from the R CrA core. Possibly as many as seven distinct blue-shifted outflow lobes (B1 to B7 in Figure 3) and twelve red-shifted lobes (R1 to R12) can be discerned. Among these are a compact bipolar outflow from HH 100 IRS, a blue-shifted lobe from IRS 5, and red-shifted emission in the vicinity of IRS 2. In accordance with the SEST observations, it appears that red-shifted emission lobes extend both north and south outside the current JCMT map. A very peculiar structure appears east of the map centre where it appears that a highly collimated red-shifted lobe composed of two parallel filaments is adjacent to and parallels a highly collimated blue-shifted lobe. We plan to continue mapping at the JCMT in order to cover completely the outflows found with SEST, but within the R CrA core itself, the higher angular resolution of millimetre-wave aperture synthesis will be needed in order to resolve outflows and determine driving sources.

Figure 2. SEST CO(J=1−0) outflow map. Blue-shifted contours integrated from ~3 to +2 km/s and red-shifted contours (with greyscale) integrated from +9 to +14 km/s. Contour levels 1, 2, 3, 4, 6, 8, 10, ... K km/s. Squares: HH objects. Triangles: millimetre continuum sources. Circles: centimetre continuum sources. Crosses: young stars detected in the optical, infrared, or in X-rays. Beam 43′.

Figure 3. JCMT CO(J=3−2) outflow map. Upper panel: blue-shifted contours integrated from ~3 to +2 km/s and red-shifted contours (with greyscale) integrated from +9 to +14 km/s. Contour levels 1, 2, 5, 10, 20, 40, 80, ... K km/s. Symbols as in Figure 2. Lower panel: blue-shifted contours integrated from ~8 to ~3 km/s and red-shifted contours (with greyscale) integrated from +14 to +19 km/s. Contour levels 2, 4, 6, 8, 16, ... K km/s. Symbols as in Figure 2. Beam 14′.

References

Wang, Mundt, Henning, & Apai 2004, private communication

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