Characterizing the PBRS: A Herschel-detected Sample of The Youngest Protostars in Orion

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We have detected a sample of the reddest, and likely youngest, protostars in the Orion molecular clouds using PACS observations from the Herschel Space Observatory as part of the Herschel Orion Protostar Survey (HOPS). We find 19 sources (12 of which are Herschel-only sources) that have extremely red 24 μm to 70 μm colors (Figure 1). We refer to these sources as the "PACS Bright Red sources" or PBRS. Stutz et al. (2013) concluded that the red colors of the PBRS (Figure 1) are best explained by high envelope densities, the highest Class 0 envelope densities of all the observed protostars in Orion. To further characterize these the PBRS, we have now obtained follow-up CARMA 2.9 mm continuum and CO (J=1-0) maps toward 14/19 PBRS, in addition to Herschel/PACS spectroscopy toward 8/19 PBRS.

Key Results

- CARMA observations show that the PBRS have the highest ratio of 2.9 mm luminosity to Lbol when compared to protostars in nearby star forming regions (Figure 2). This is further evidence that they have very dense envelopes and are in a very early stage of protostellar evolution.
- Both flat and declining 2.9 mm visibility profiles are found. The flat profiles require either an unresolved component and/or a very steep density law (p < 1), see Figures 3 and 4.
- The PBRS with flat visibility profiles are systematically less luminous than those with declining profiles. The flat visibility profiles may evolve from flat to rapidly declining. The flat visibility profile sources could be undergoing a period of brief, rapid infall.
- The CO (J=1-0) outflows are detected toward 10/14 of the PBRS, including both compact and extended outflows. The emission morphologies show that most of the outflows are inclined, and that the PBRS are at intermediate inclinations. This implies that the very red colors and cold Tstars are associated with the extended outflows. The emission morphologies show that most of the outflows are inclined, and that the PBRS are at intermediate inclinations. This implies that the very red colors and cold Tstars are associated with the extended outflows.
- The PBRS with flat visibilities are most consistent with p = -2.5. This is suggestive of the youthful nature of these sources. Both HOPS 373/093003 and 135003 have more well-developed extended outflows and declining visibility amplitudes.
- The right panel shows that PBRS appear to be extreme Class 0 objects, with similar luminosities but systematically colder Tbol. The rarity of the PBRS suggest they have lifetimes of only ~20,000 years, 1/4 of the typical lifetimes (Ghez et al. 2011).

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Table 1: List of sources and characteristics observed with CARMA and the PACS Spectrometer.

<table>
<thead>
<tr>
<th>Source</th>
<th>Characteristics</th>
<th>PACS Lines</th>
<th>CO Transitions</th>
<th>Outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOPS 373/093003</td>
<td></td>
<td></td>
<td>Strong CO</td>
<td>Yes</td>
</tr>
<tr>
<td>135003</td>
<td></td>
<td></td>
<td>Weak CO</td>
<td>No</td>
</tr>
</tbody>
</table>

References