ALMA reveals a candidate to hot accretion disk around the O-type protostar IRAS 16547-4247

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Two modes for the massive star formation.

-> Throughout disks and outflows as low mass stars.

-> Mergers of low- and intermediate- mass young stars in dense clusters.

-> or both... (e.g. Orion KL )
MHD simulations
Disks around high-mass stars

Krumholz et al. (2009)
Kuiper et al. (2010)
Peters et al. (2010)

Note the sizes of the massive disks
Some observational cases of disks around massive stars

Zapata et al. (2009)
Zapata, Tang and Leurini (2011)
Goddi et al. (2015)

Fernández-López et al. (2011)
Carrasco-González et al. (2014)
Girart et al.
Qiu, Zhang et al.
Mergers of low- and intermediate- mass young stars in dense clusters.

MHD Simulations
Ian Bonnell, Matthew Bate, et al.
Zapata et al. (2009)

Merge of massive protostars?

Zapata et al. (2009)
Mergers...

Bally and Zinnecker (2005); Reipurth (2000)
What we are looking for?
Our dreams about disks around massive stars...
Pineda et al. (2014)
Fig. 4.— PV diagram of CO (3–2) along the major axis shown in Fig. 3. Contours are shown at [3, 6, 12, 24, 48, 96] × rms, where rms is 27 mJy beam$^{-1}$ per channel. Negative contours are shown by dashed lines. Orange and red curves show the expected keplerian velocity for a central star of 2.4 M$_\odot$ and inclination angle of 30° and 40°, respectively. See Section 4.4 for discussion.
IRAS 16547-4247: A young O-type Star.

At a distance of 2.9 kpc, it has a bolometric luminosity of $6.2 \times 10^4 \, L_{\text{sun}}$, equivalent to that of a single O8 zero-age main-sequence star.

VLA – 3.6 cm

SMA – 1.3 mm

Rodríguez et al. (2005)
Franco-Hernandez et al. (2009)
ALMA – Atacama Larger Millimeter Array Telescope → Chile
66 Antenna Array
Detected spectral lines in IRAS 16547
Table 1. Transitions detected toward IRAS 16547

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Transition</th>
<th>Rest Freq. (GHz)</th>
<th>$S_{ij}\mu^2$ (D$^2$)</th>
<th>$E_u$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$ v=0</td>
<td>18$<em>{4,14}$–18$</em>{3,15}$</td>
<td>338.30599</td>
<td>26.81</td>
<td>197</td>
</tr>
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<td></td>
<td>20$<em>{1,19}$–19$</em>{2,18}$</td>
<td>338.61181</td>
<td>26.02</td>
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<td>28$<em>{2,26}$–28$</em>{1,27}$</td>
<td>340.31641</td>
<td>32.05</td>
<td>392</td>
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<td></td>
<td>5$<em>{3,3}$–4$</em>{2,2}$</td>
<td>351.25722</td>
<td>7.32</td>
<td>36</td>
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<tr>
<td>SO$_2$ v$_2$=1</td>
<td>4$<em>{3,1}$–3$</em>{2,2}$</td>
<td>338.34874</td>
<td>7.07</td>
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<td>8$<em>{2,6}$–7$</em>{1,7}$</td>
<td>338.37638</td>
<td>5.09</td>
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<td>$^{34}$SO$_2$ v=0</td>
<td>1$<em>{3,12}$–1$</em>{2,11}$</td>
<td>338.32036</td>
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<td>$^{33}$SO$_2$ v=0</td>
<td>8$<em>{4,4}$–8$</em>{3,5}$, F=19/2–19/2</td>
<td>351.17796</td>
<td>11.16</td>
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<td>9$<em>{4,6}$–9$</em>{3,7}$, F=21/2–21/2</td>
<td>351.28137</td>
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<td>19$<em>{4,16}$–19$</em>{3,17}$, F=41/2–41/2</td>
<td>353.74156</td>
<td>25.37</td>
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<tr>
<td>SO$^{18}$O</td>
<td>20$<em>{0,20}$–19$</em>{1,19}$</td>
<td>338.63882</td>
<td>43.41</td>
<td>184</td>
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<td>OCS</td>
<td>28–27</td>
<td>340.44927</td>
<td>14.32</td>
<td>237</td>
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<tr>
<td>HNCS a-type</td>
<td>30$<em>{1,30}$–29$</em>{1,29}$</td>
<td>351.22743</td>
<td>80.60</td>
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<tr>
<td>SO$^{17}$O</td>
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<td>263.56</td>
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<tr>
<td>CH$_3$SH</td>
<td>14$<em>{13}$–13$</em>{13}$ $–/+A$</td>
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<td>14$<em>{13}$–13$</em>{13}$ E</td>
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<td>14$<em>{9}$–13$</em>{9}$ $–/+A$</td>
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<td>14$<em>{8}$–13$</em>{8}$ $–/+A$</td>
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<td>353.78050</td>
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</table>
Three classes of the line emission depending on the excitation temperature in the upper levels.
CH$_3$OH -- ALMA

Low temperatures in the upper levels (about 100 K)

Higuchi et al. (2014)
Franco-Hernandez et al. (2009)

Temperatures in the upper levels (about 200 K)
Candidate to Rotating Disk around an O-type (proto)star

IRAS 16547

Size of the disk about 1000 AU

Temperatures in the upper levels (about > 400 K)
Candidate to Rotating Disk around an O-type (proto)star

Pros:

1. Very compact rotating molecular structure (about 1000 AU)
2. Elongated perpendicular to the radio jet and molecular outflow
3. Traced by highly excited complex molecules

Cons:

1. No Keplerian motions at all in the innermost parts