Scatter-Induced Dust Polarization from an Accretion Disk Around a Massive Protostar

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Half a Decade of ALMA: Cosmic Dawns Transformed, September 21, 2016
Protostellar phase: NGC 1333 IRASA, an "textbook" case?
A disk around a Class I/0 YSO

ALMA observations: spatial resolution of ~50AU with dynamic range of ~5000
Radial profile along major axis
A massive disk around the B-type star powering the 18 pc long HH 80/81/80N radio jet

Hot, optically thick disk

Peak: 72.4 mJy/Beam => 660 K

Red contours:
10, 20, 30, 50 x 1 mJy/Beam
91, 182, 273, 455 K

White contours:
0.6, 1, 2, 4, 7 x 1 mJy/Beam
5, 9, 18, 36, 64 K

Beam: 0.048x0.040, -63°
Wavelength: 1.14mm
Polarization dust emission from a disk around $10^4 \, L_\odot$ YSO
The Outflow: The parsec scale HH 80-81-80N Jet

- **GGD 27/28 objects** (Gyulbudaghian et al. 1978).
- **Herbig Haro objects, HH 80 and HH 81**, at 4’-5’ south of GGD 27 (Reipurth & Graham 1988).
- **VLA at cm**: collimated jet spanning over 10 pc. (Masqué et al. 2012, 2015)
- **HH 80N**: obscured North counterpart of HH 80-81
- **IRAS 18162-2048**: $1.7 \times 10^4 L_\odot$ (Aspin & Geballe 1992)
- HH 80-81 are the brightest HH known
- **D = 1.7 kpc**
Radio jet emission is polarized

- Polarization properties: Reveals a helical magnetic field within the jet

UV radiation in the shocks induces a PDR around the jet
Two massive circumstellar dense cores

1.36 mm SMA continuum maps of the central region in GGD 27

Fernández-López, et al. 2011a
The circumstellar gas: The GGD 27 MM1 accretion disk

1.3 cm → radio jet
7 mm → quadrupolar N-S emission → radio jet
E-W emission → disk

Carrasco-González et al. (2012)

MM1 compact disk, R~200 AU, similar to that found in low-mass protostars
Two massive circumstellar dense cores

CO collimated bipolar outflow associated with MM 2

Qiu & Zhang 2009, Fenández-López et al. 2013
New SMA observations: at 345 GHz & ~0.4 arcsec

Rotating disk resolved:

- $\text{SO}_2$ traces disk
- CH$_3$OH traces cavity created by outflow?
- SO: traces both molecular component
Modelization of MM1, as an accretion disk around a massive star

$$M_{\text{star}} = 3-12 \ M_\odot$$

$$dM/dt \approx 10^{-4} \ M_\odot \ yr^{-1}$$

$$M_{\text{disk}} \geq M_{\text{star}}$$

$$t_{\text{YSO}} \geq 10^4 \ yrs$$
The circumstellar gas: The GGD 27 MM1 accretion disk

**GGD 27 MM1**

### Disc model: Best fit parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beamwidth</td>
<td>$0'40 \times 0'40$</td>
</tr>
<tr>
<td>Linewidth</td>
<td>$2.40 \text{ km s}^{-1}$</td>
</tr>
<tr>
<td>Reference radius $r_0$</td>
<td>$0'40$</td>
</tr>
<tr>
<td>Rotat. power-law index $q_r$</td>
<td>$-0.5$</td>
</tr>
<tr>
<td>Disk center $x_0$</td>
<td>$0'31$</td>
</tr>
<tr>
<td>Disk center $y_0$</td>
<td>$0'065 \pm 0'005$</td>
</tr>
<tr>
<td>Disk central $v_0$</td>
<td>$0.15 \text{ km s}^{-1}$</td>
</tr>
<tr>
<td>Disk inner radius $r_1$</td>
<td>$0'02$</td>
</tr>
<tr>
<td>Disk outer radius $r_2$</td>
<td>$0.61 \pm 0'03$</td>
</tr>
<tr>
<td>Infall velocity $v_i$</td>
<td>$0.00 \text{ km s}^{-1}$</td>
</tr>
<tr>
<td>Rotat. velocity $v_r$</td>
<td>$-4.26 \pm 0.02 \text{ km s}^{-1}$</td>
</tr>
<tr>
<td>Disk inclination $i$</td>
<td>$44.6 \pm 0.2^\circ$</td>
</tr>
<tr>
<td>Best fit rms</td>
<td>$0.076-0.066$</td>
</tr>
<tr>
<td>Dynamical mass</td>
<td>$17.4 \text{ M}_\odot$</td>
</tr>
</tbody>
</table>
The circumstellar gas: The GGD 27 MM1 accretion disk

GGD 27 MM1

Inner accretion dusty disk
R = 200 AU
Bright at sub/mm wavelengths
Molecular dissociation R<100AU?

Ionized Jet
Bright at cm wavelengths
No molecular emission: CO & SiO

Outer accretion oxo-sulfurated disk
R = 1000 AU
Bright at SO, SO₂
No dust emission

“Illuminated” Cavity
Bright at SO & CH₃OH

B0 protostar
Magnetic field around a disk around a $10^4 \, L_\odot$ YSO ???
Figure 4. Polarization degree times the albedo $P\omega$ against the maximum grain size. This figure represents a grain size that contributes most to the polarized intensity. Each line corresponds to the wavelengths of 0.34, 0.87, 3.1, and 7 mm. The band numbers correspond to the ALMA band numbers for each wavelength.
Scattering around a disk around a $10^4 \, L_\odot$ YSO ???

Relative ICRS Declination (arcsec)

Relative ICRS Right Ascension (arcsec)

$263 \, \text{GHz}$

$\nu/\text{beam} \times 10^{-3}$

0.25

0.2

0.15

0.1

0.05

0

-0.05

-0.1

-0.15

-0.2

-0.2

-0.3

-0.3

0.05

0.1

0.15

0.2

0.25

0.3

0.35
Scattering is more likely to be generating the mm polarization

Rao’s Poster

Beam=0.3 arcsec
IRAC 3.6/4.5/8.0 μm (blue/green/red) three-color composite images of all nine regions. Red circles, red triangles, and brown diamonds represent protostars, Class I/II, and Class II objects.
Figure 2 from GGD 27: X-rays from a Massive Protostar with an Outflow
A massive disk around the B-type star powering the 18 pc long HH 80/81/80N radio jet
Most mm sources do NOT have Radio/IR/X-ray counterparts
Summary

Full polarizations observations with ALMA toward a massive disk around a luminous B-type YSO with unprecedented sensitivity and angular resolution.

ALMA reveals disk scales never before explored in mm polarization: Are we entering in the scattering regime??

Detected ~25 continuum compact sources

ALMA reveals a population of low mass YSO at a distance of ~2000 AU around the young, massive stars?