EGOs: Massive YSOs in IRDCs

Ed Churchwell & Claudia Cyganowski
with co-workers:
Crystal Brogan, Todd Hunter, Barb Whitney
Qizhou Zhang

Dense Cores in Dark Clouds LXV
Oct. 21-22, 2009
The Evolution of IR-selected MYSOs
(which occur in Dense and Massive Cores)

IRAS
MSX
Spitzer (IRAC)

Cyganowski et al. 2008

RGB: 100, 25, 12 µm
Resolution ~ 0.5’-2’

RGB: 21.4, 12.1, 8.3 µm
Resolution ~ 18”

RGB: 8.0, 4.5, 3.6 µm
Resolution ~ 2”
A New Diagnostic: Spitzer’s 4.5µm band

Reach et al (2006)
A New MYSO Outflow Sample: Extended Green Objects (EGOS) from GLIMPSE

Red: 8.0um, Green: 4.5um, Blue: 3.6um

Cyganowski et al. (2008)
G28.83-0.25 (N49)
8(R), 4.5(G), 3.6(B) \( \mu \text{m} \)

D=5.7\pm0.6 \text{ kpc}

N_{\text{UV}} \geq 7.8 \times 10^{48} \text{ s}^{-1}

=> O6V or hotter

Diam\sim 5 \text{ pc}
N49 (4.5, 8.0, 24µm)
SEDs of two typical EGOs

Integrated flux density (mJy)

Wavelength (microns)

G11.92−0.61

G28.83−0.25
EGOs: Infrared Properties

- Average separation between an EGO and nearest IRAS point source ≤2’
- MIR colors of EGOs are consistent with young protostars still embedded in infalling envelopes

> 300 EGOs in GLIMPSEI survey area

Cyganowski et al. (2008)
EGOs: Found in Molecular Cloud Cores CO

EGO positions overplotted on integrated CO emission (contours) from Dame et al. (2001).

Cyganowski et al. (2008)
EGOs also located toward IRDCs
note images
EGOs: Correlation with 6.7 GHz Class II CH$_3$OH masers from the literature

6.7 GHz Class II CH$_3$OH masers are associated exclusively with massive YSOs (e.g. Minier et al. 2003)

- Correlation analysis based on published surveys requires: (1) maser positions known to <1” and (2) maser surveys with well-defined coverage
- Of EGOs in areas of published surveys, 47% associated with 6.7 GHz masers
- But, coverage limited and sensitivity uneven: dedicated maser searches towards EGOs required
Are EGOs *Massive YSOs with Outflows*?

Observational Tests:

• High-resolution (E)VLA survey for 6.7 GHz CH$_3$OH masers (associated exclusively with massive YSOs, Minier et al. 2003)

• High-resolution VLA survey for 44 GHz CH$_3$OH masers (associated with molecular outflows, Kurtz et al. 2004)

• Single-dish (JCMT) surveys for SiO, HCO$^+$, H$^{13}$CO$^+$, thermal CH$_3$OH emission

• Sample of ~28 EGOs, selected to:
  • Cover range of MIR properties (8/24um counterparts, morphology, angular extent of 4.5um emission)
  • Be visible from northern hemisphere
EGO Survey Results: Spatial Distribution of CH$_3$OH Masers

Images:
Red: 8um,
Green: 4.5um,
Blue: 3.6um
(GLIMPSE).

Yellow contours:
MIPS 24 um

Magenta Crosses:
44 GHz Class I CH$_3$OH masers.

Black Diamonds:
6.7 GHz Class II CH$_3$OH masers

Cyganowski et al. 2009
EGO Survey Results: Kinematics of CH$_3$OH Maser and Thermal Molecular Line Emission

Profiles:
- Dotted: HCO$^+$ (3-2)
- Solid: H$^{13}$CO$^+$ (3-2)
- Dashed: 6.7 GHz CH$_3$OH maser (scaled)

Diamonds show velocity range spanned by 44 GHz CH$_3$OH maser emission
EGO Survey Results: CH$_3$OH Maser Kinematics

Left: Grayscale: 4.5 $\mu$m (GLIMPSE). X: 44 GHz CH$_3$OH masers, color-coded by velocity. The black rectangle is the field of view shown at right. Right: Fitted positions, with errors, of 6.7 GHz CH$_3$OH masers, color-coded by velocity. Fitted positions with errors $>0.15^\prime\prime$ (S/N<10) are not shown, those with errors between 0.05$^\prime\prime$ and 0.15$^\prime\prime$ (10$<$S/N$<$30) are shown as light lines. The bin color-coded green is approximately centered on the gas v(LSR) of ~60 km/s. To increase the range of distinguishable colors, purple is used to represent the most blueshifted masers.
EGO Survey Results: Methanol Masers and Thermal Line Emission

Image: Red: 8um, Green: 4.5um, Blue: 3.6um (GLIMPSE). Yellow contours: MIPS 24 um
Magenta Crosses: 44 GHz Class I CH$_3$OH masers.
Black Diamonds: 6.7 GHz Class II CH$_3$OH masers

Cyganowski et al. 2009
Images: Red: 8um, Green: 4.5um, Blue: 3.6um (GLIMPSE). Contours: 1.3 mm continuum emission (black) and high velocity $^{12}$CO(2-1) emission from the SMA. (a) The EGO G11.92-0.61. $^{12}$CO (2-1) integrated over v~ -24 to 25 km/s (blue) and v~ 41-71 km/s (red). Though multiple compact cores are present, there is one dominant outflow. (b) The EGO G19.01-0.03. $^{12}$CO (2-1) emission integrated over v~ -46 to 40 km/s (blue) and v~ 79-92 km/s (red); emission nearer the systemic velocity is dominated by an extended envelope, indicating that the source is very young. The SMA synthesized beam is shown at lower left in each panel (~3”~12000 AU at ~4 kpc).
EGO Survey Results: Summary

- 6.7 GHz CH$_3$OH maser detection rate towards EGOs >64%
  - Nearly double the detection rate of surveys using other MYSO selection criteria
  - Centrally concentrated, coincident with 24μm emission
- 44 GHz CH$_3$OH maser detection rate ~ 89% towards EGOs with 6.7 GHz masers
  - Spatially distributed, coincident with 4.5μm emission
- HCO$^+$ (3-2) line profiles->broad vel widths (mostly infall)
- SiO (5-4) detection rate 90% -> recently shocked gas (outflows and/or infall)
- 95% non-detection rate for bright 44 GHz continuum emission->most surveyed EGOs are not UC HII regions

Bottom line: Surveyed EGOs are young MYSOs with active outflows, and hence presumably ongoing accretion
SMA Results (Preliminary)

In 2 EGOs, both selected to have bipolar 4.5 \( \mu \text{m} \) morphology, an associated 24 \( \mu \text{m} \) source, and 6.7 and 44 GHz CH\(_3\)OH masers:
- there is a single dominant bipolar molecular outflow, traced by \(^{12}\text{CO}(2-1)\) and coincident with the 4.5 \( \mu \text{m} \) lobes
- the driving source of the 4.5 \( \mu \text{m} \) outflow is a compact mm core

Diversity:
- One EGO is associated with a cluster of at least 3 compact cores, while the other appears to be a single MYSO (at the \( \sim 3'' \) resolution of the SMA data)
- In G11.92, the driving source of the outflow is a hot core (upper left); other 2 mm cores are devoid of line emission
- G19.01 has weaker hot core signatures, CO emission near \( v(\text{LSR}) \) indicative of extended envelope (younger?)

---

CH\(_3CN(J=12-11)\)

G11.92-0.61 (SE source)

\( Jy/\text{beam} \)

G19.01-0.03

\( \text{mJy/beam} \)

\( \text{km/s} \)

Cyganowski et al., in prep.
Understanding EGOs: Next Steps

• Preliminary analysis of a small subsample of EGOs shows range of properties (SMA 1.3 mm observations)

• Need high resolution (sub)mm data for larger samples of EGOs (SMA, upcoming ALMA Early Science):
  • Outflow kinematics
  • Multiplicity, physical conditions, and masses of dense cores (possible driving sources)

• High resolution cm continuum observations to constrain presence and physical properties of ionized gas