EGOs: Massive YSOs in IRDCs

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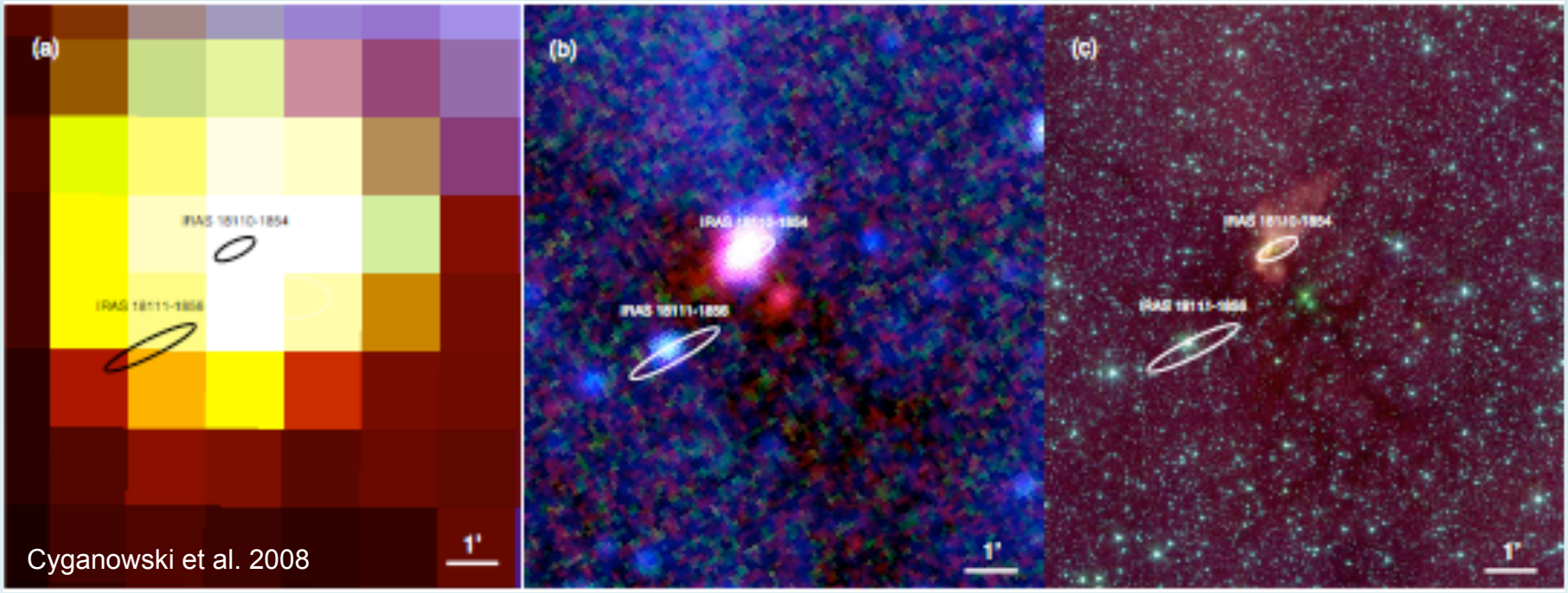
The Evolution of IR-selected MYSOs

(which occur in Dense and Massive Cores)

IRAS *MSX* *Spitzer (IRAC)*

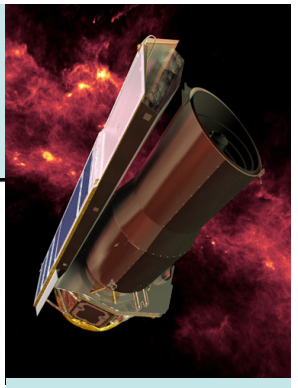


RGB: 100, 25, 12 μm
Resolution ~ 0.5'-2'

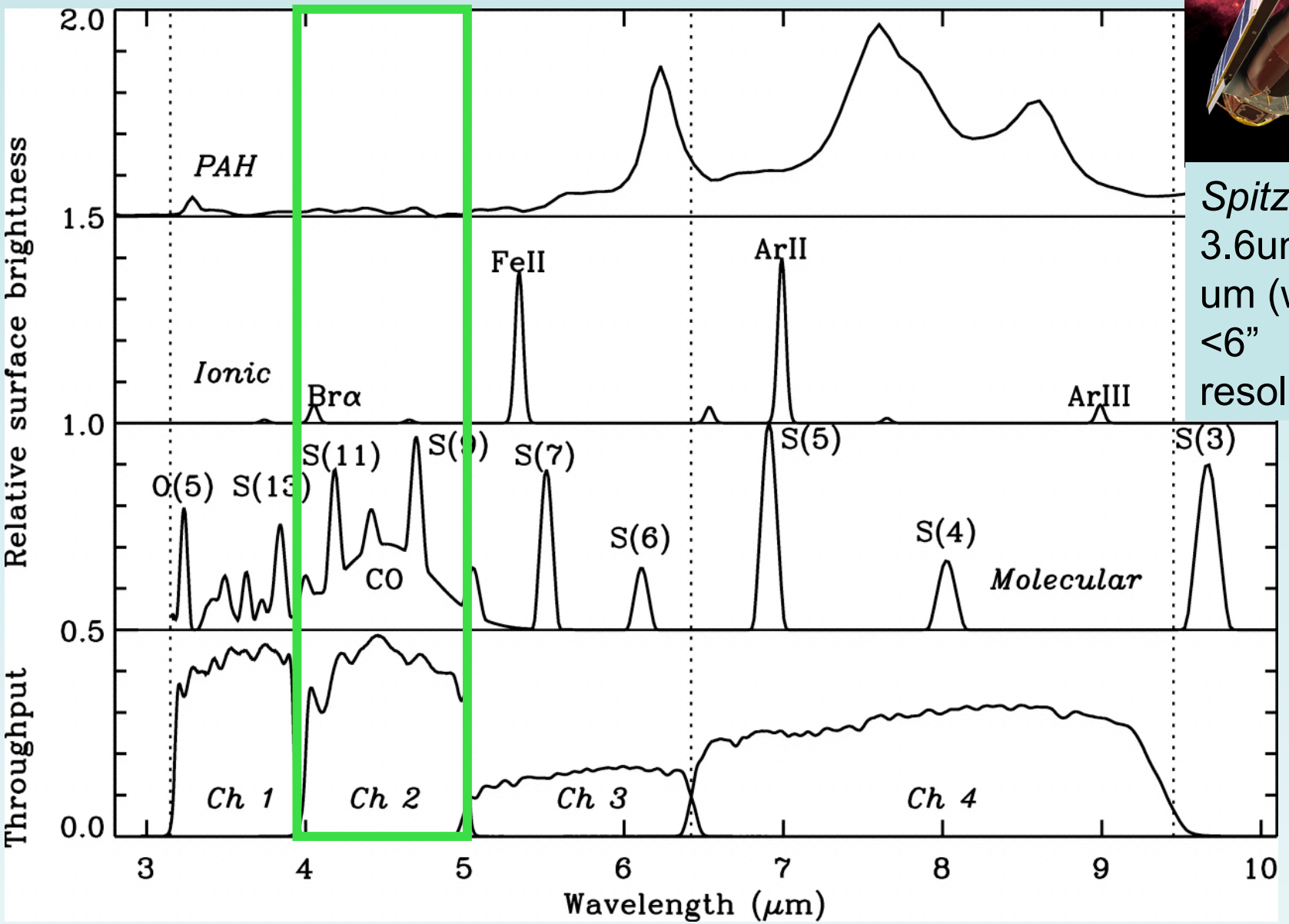
RGB: 21.4, 12.1, 8.3 μm
Resolution ~ 18"

RGB: 8.0, 4.5, 3.6 μm
Resolution ~ 2"

A New Diagnostic: *Spitzer*'s 4.5μm band

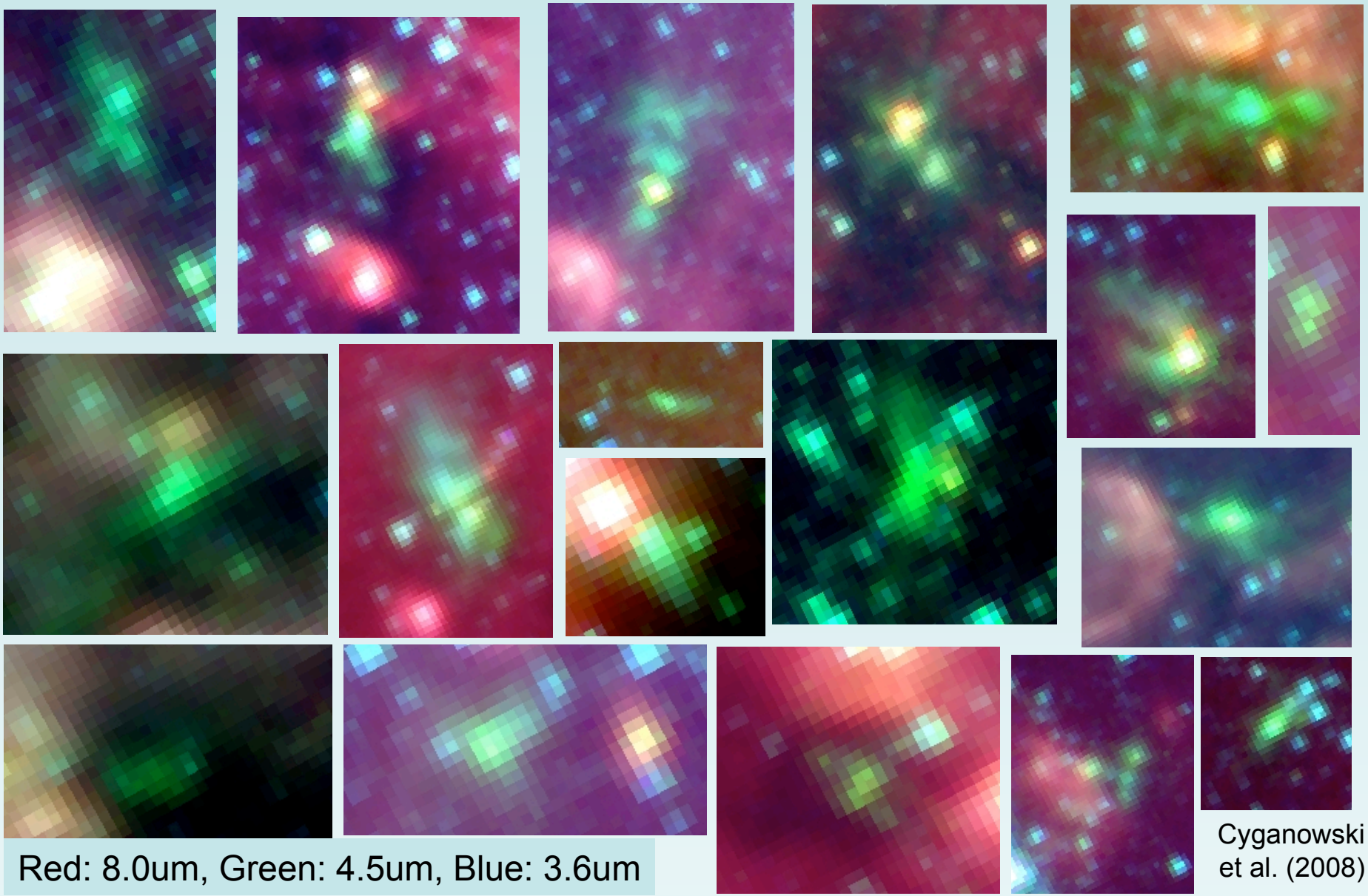


Spitzer, 3.6um-24 um (with <6" resolution)



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) μm

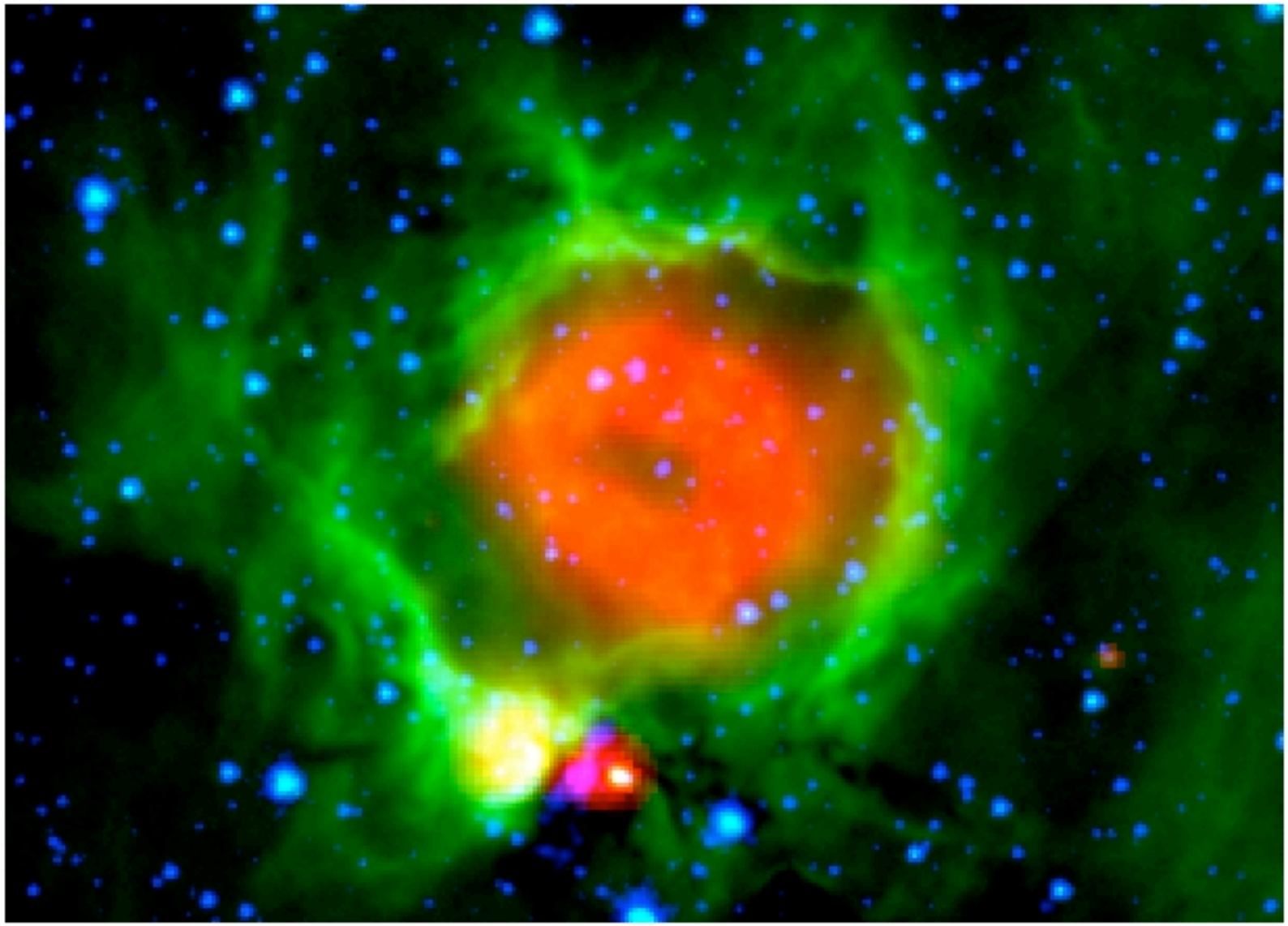
D=5.7±0.6 kpc

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

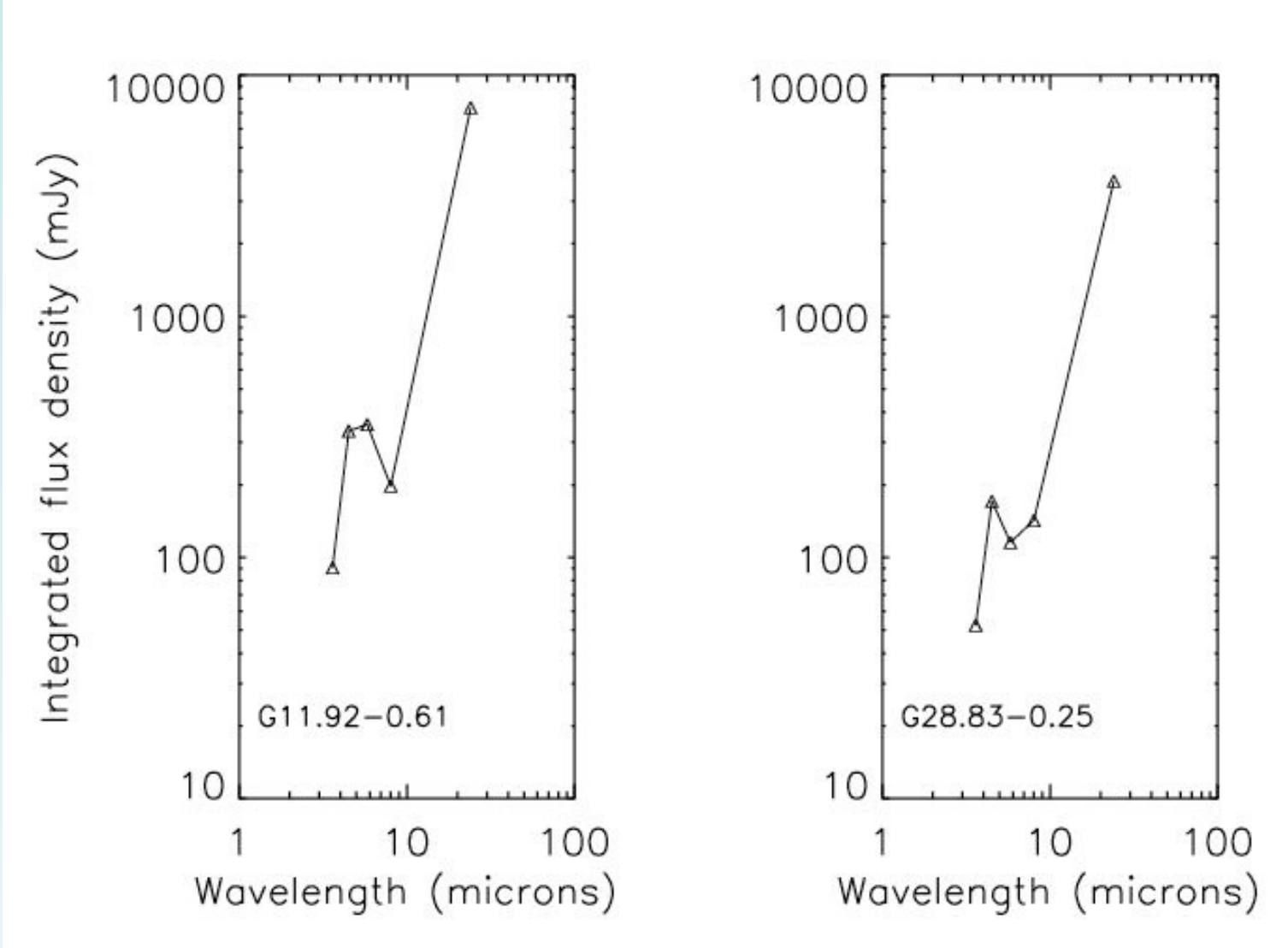
=>O6V or hotter

Diam~5 pc

N49 (4.5, 8.0, 24μm)

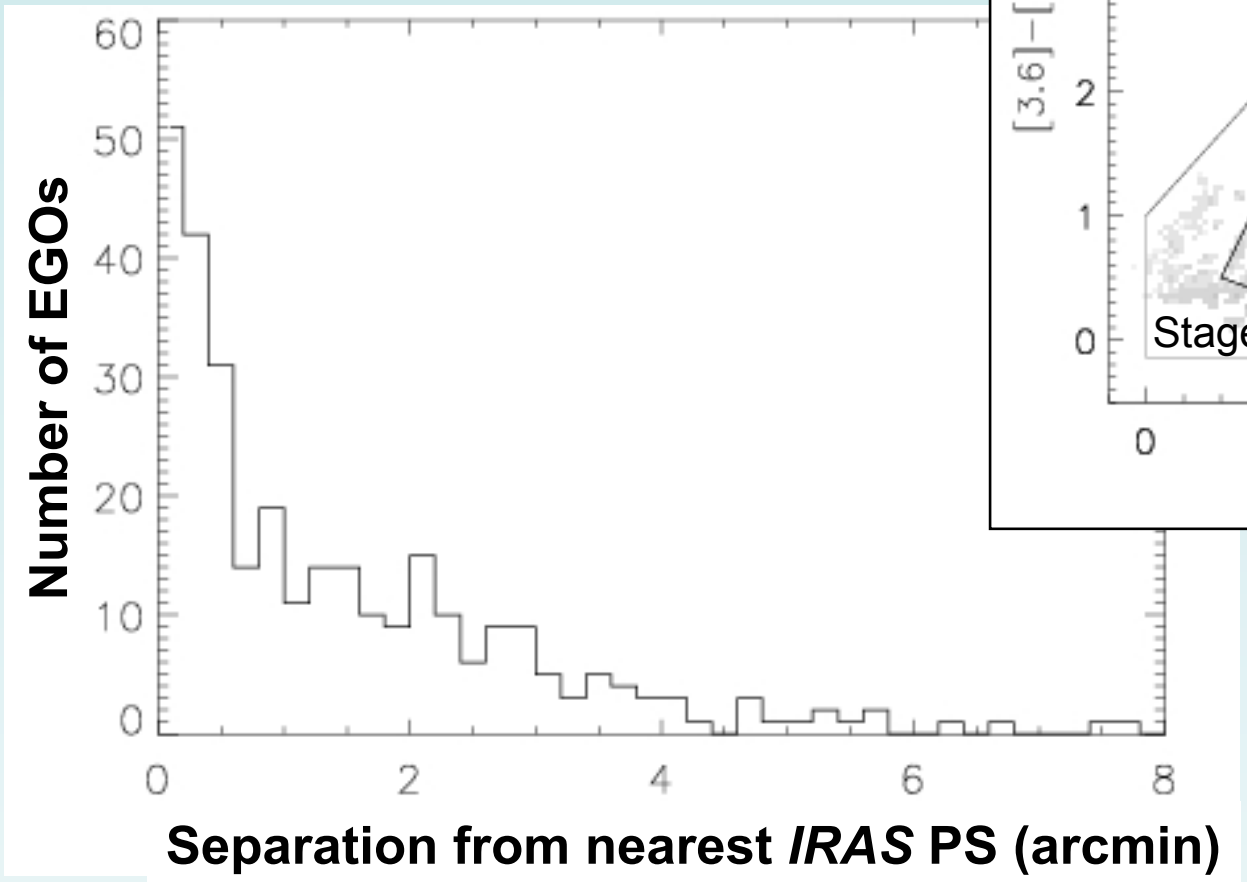


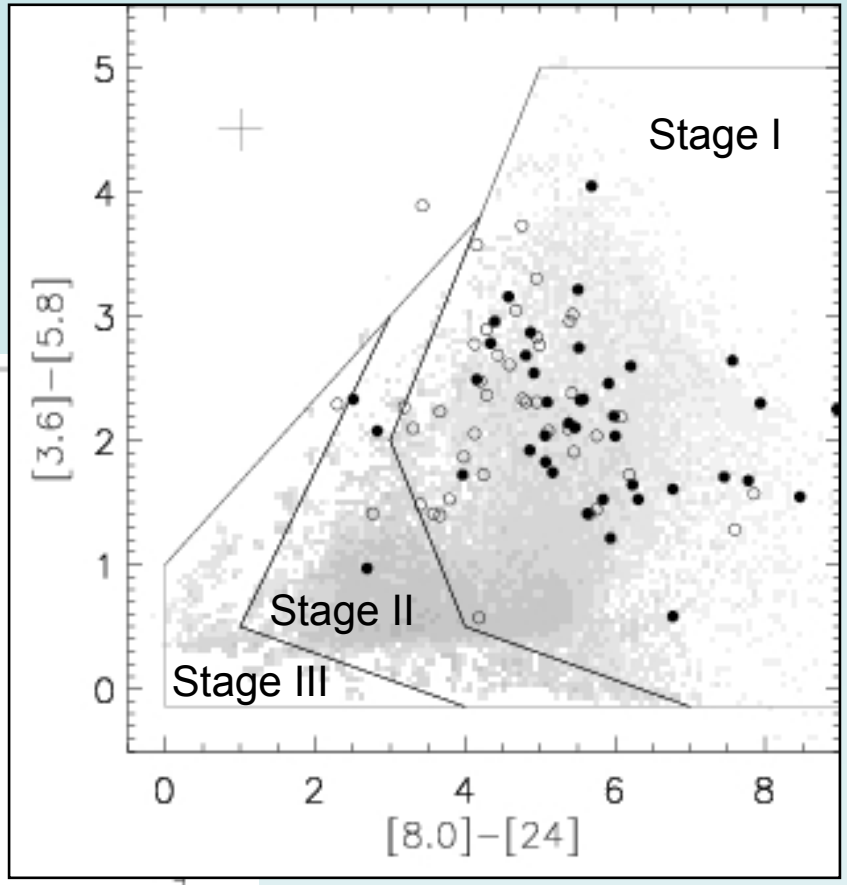
SEDs of two typical EGOs



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

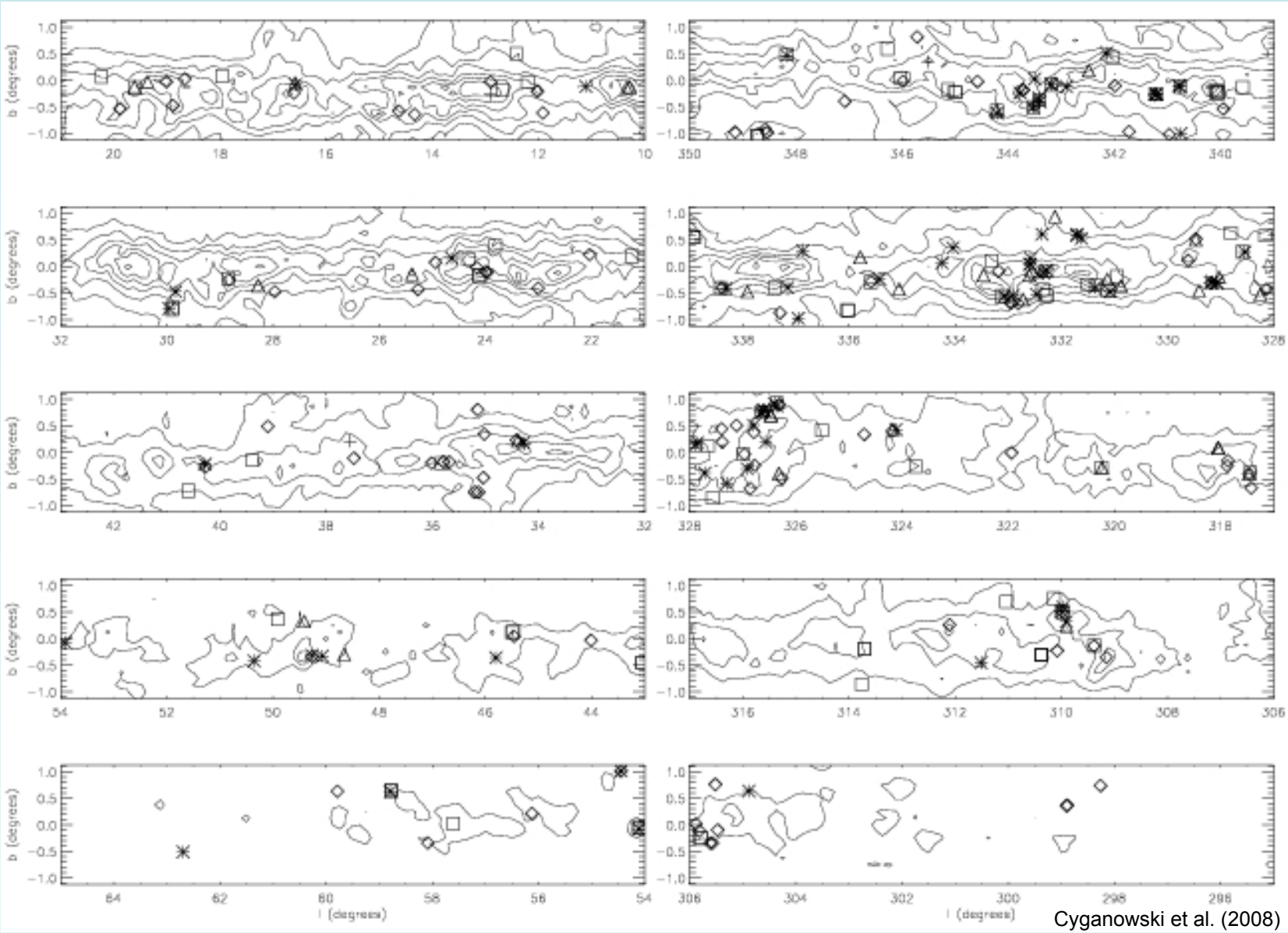




> 300 EGOs in GLIMPSEI survey area

Cyganowski et al. (2008)

EGOs: Found in Molecular Cloud Cores CO

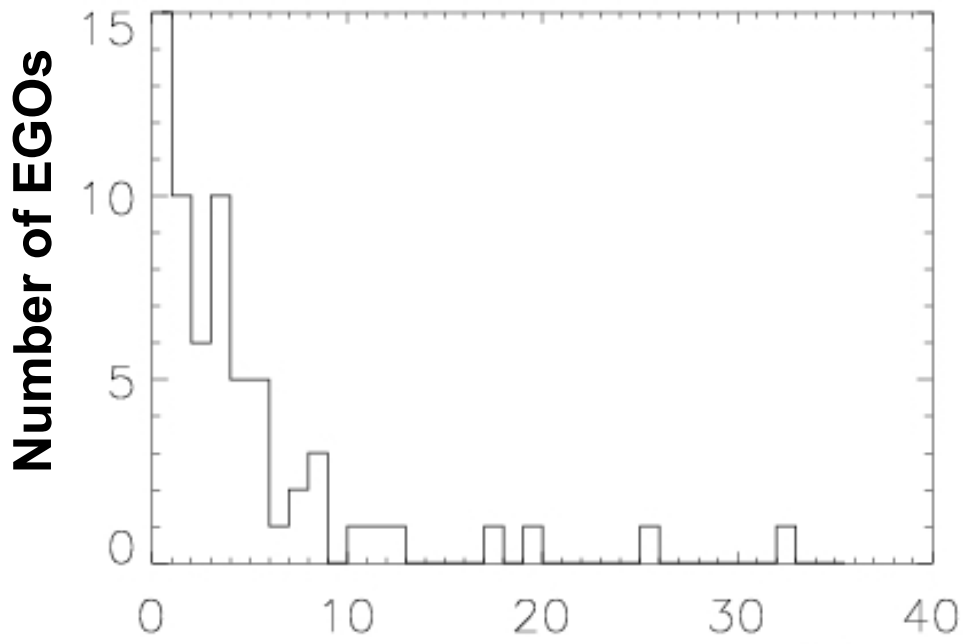


EGO positions overplotted on integrated CO emission (contours) from Dame et al. (2001).

EGOs also located toward IRDCs
note images

EGOs: Correlation with 6.7 GHz Class II CH_3OH masers from the literature

6.7 GHz Class II CH_3OH masers are associated exclusively with *massive* YSOs (e.g. Minier et al. 2003)



Cyganowski et al. (2008)

- 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

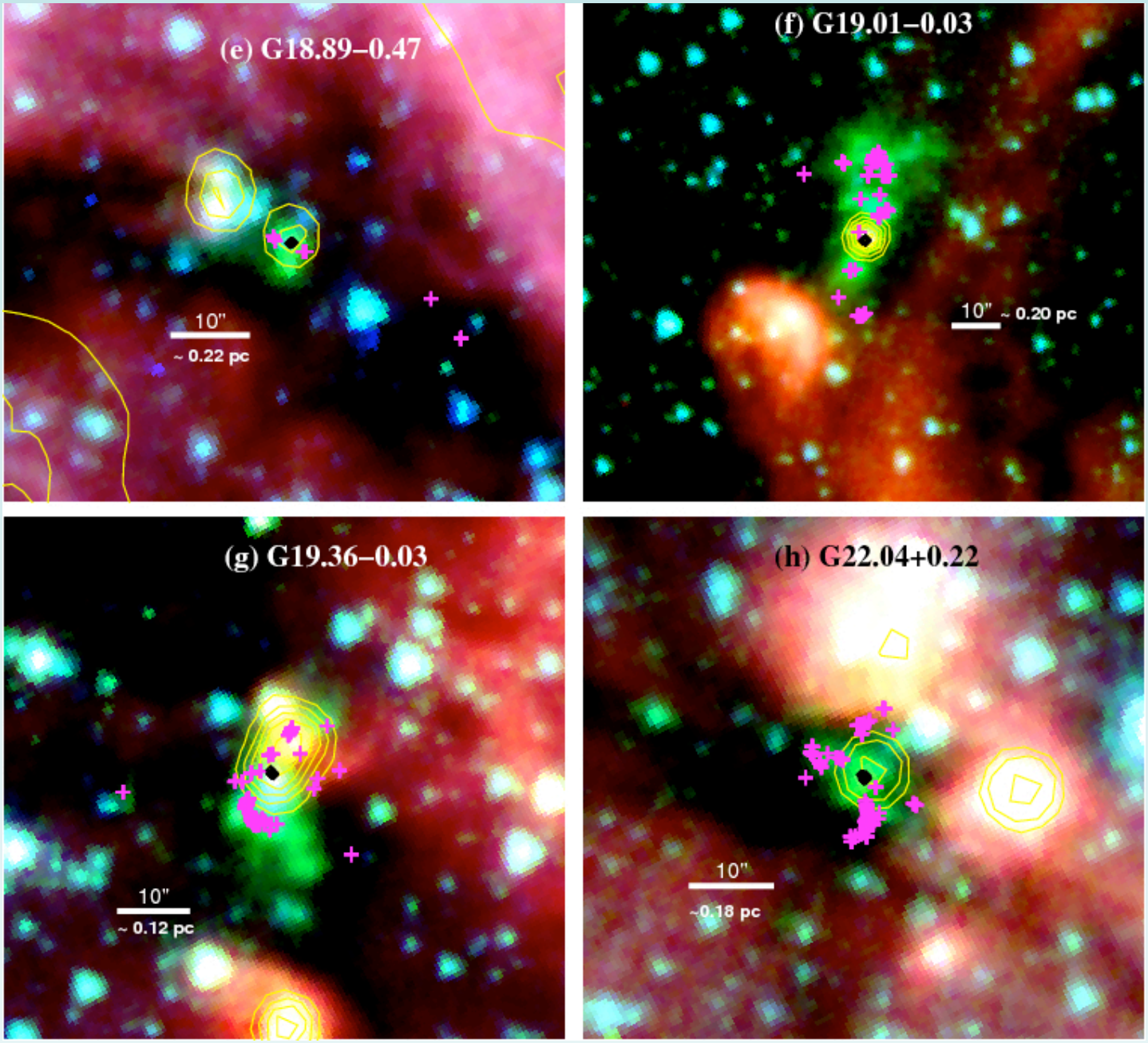
Are EGOs *Massive* YSOs with Outflows?

Observational Tests:

- High-resolution (E)VLA survey for 6.7 GHz CH_3OH masers (associated exclusively with *massive* YSOs, Minier et al. 2003)
- High-resolution VLA survey for 44 GHz CH_3OH masers (associated with molecular outflows, Kurtz et al 2004)
- Single-dish (JCMT) surveys for SiO, HCO^+, $H^{13}CO^+$, thermal CH_3OH 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_3OH Masers



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

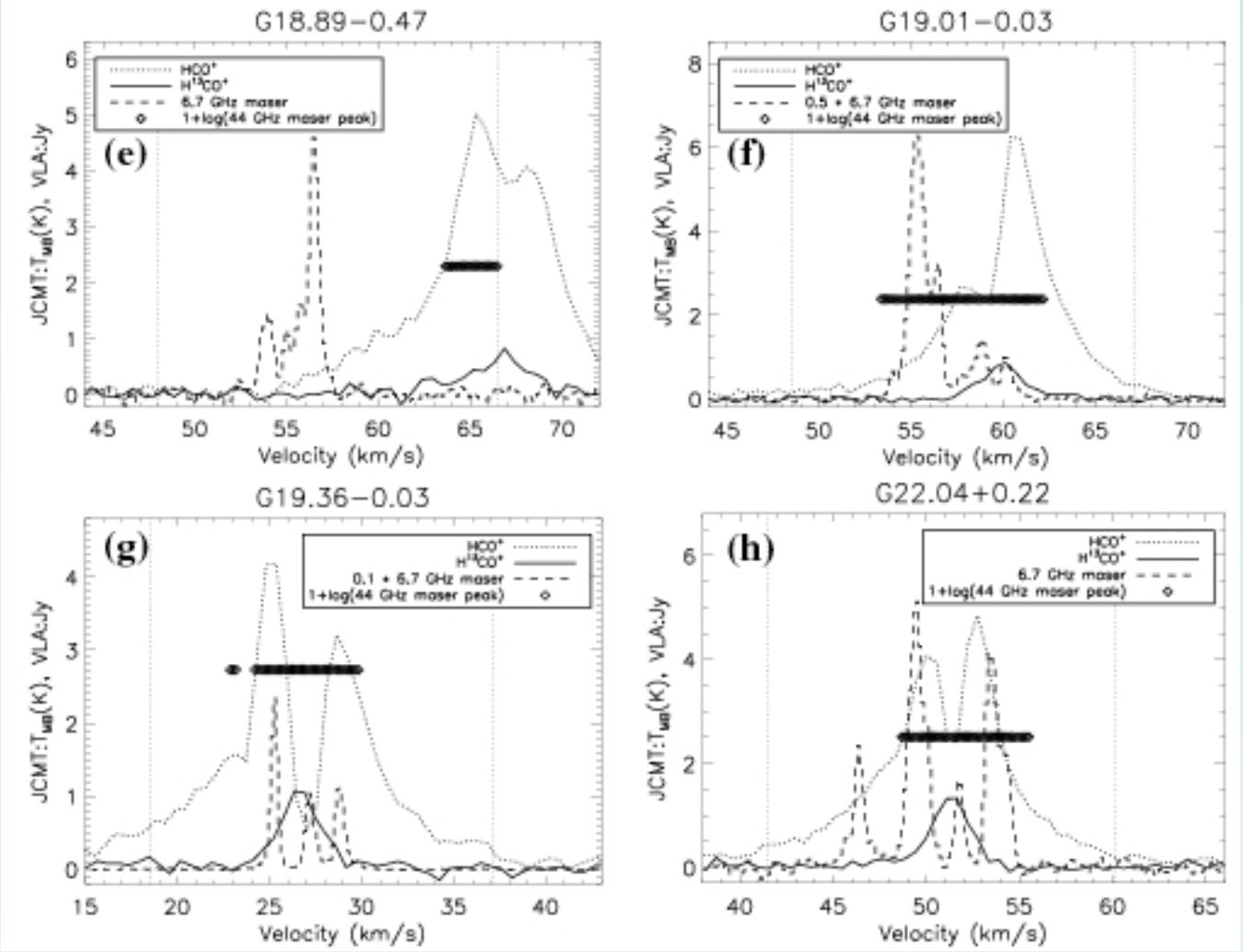
Yellow contours:
MIPS 24 um

Magenta Crosses:
44 GHz Class I
CH_3OH masers.

Black Diamonds:
6.7 GHz Class II
CH_3OH masers

Cyganowski et al. 2009

EGO Survey Results: Kinematics of CH_3OH Maser and Thermal Molecular Line Emission

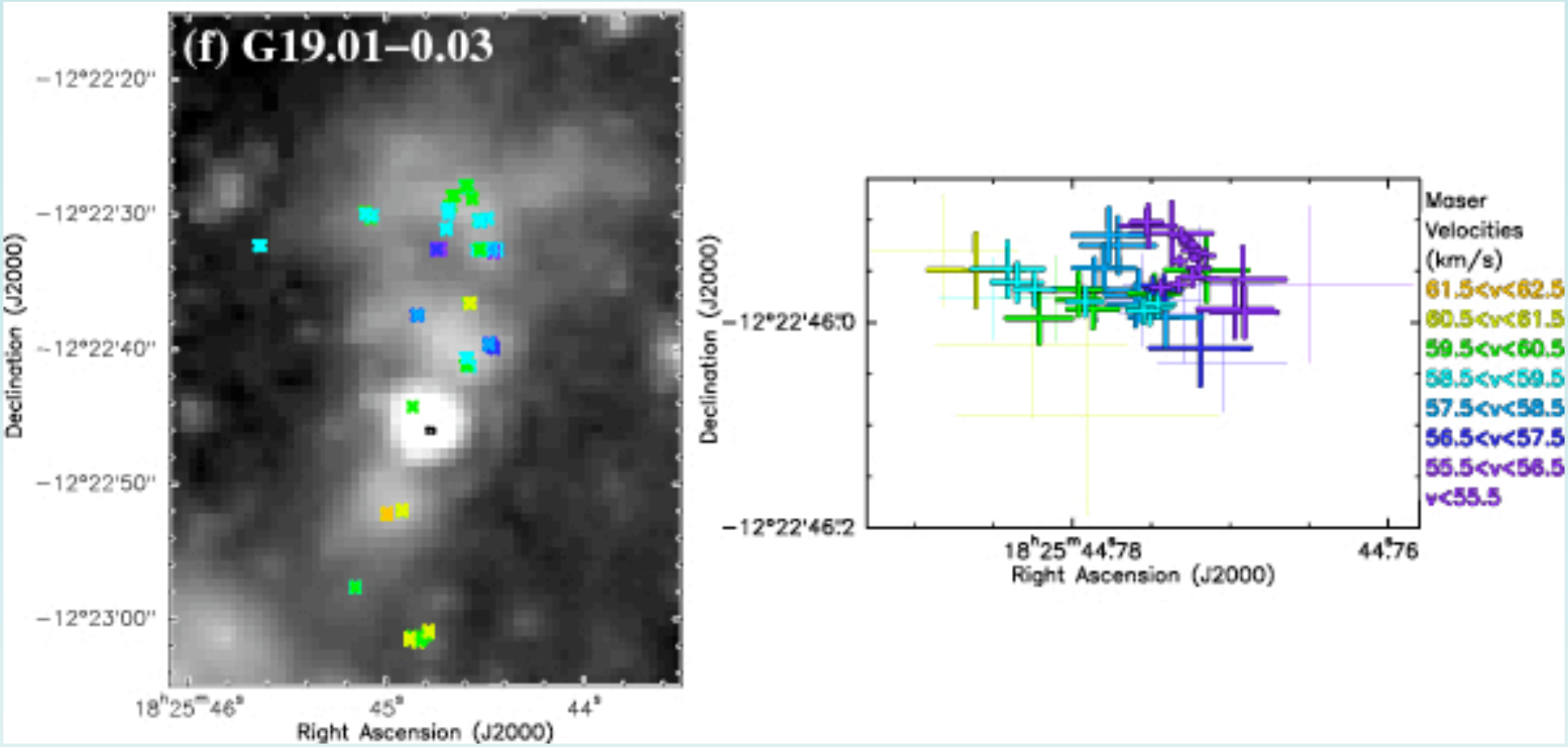


Profiles:
Dotted: HCO^+ (3-2)
Solid: $H^{13}CO^+$ (3-2)
Dashed: 6.7 GHz CH_3OH maser (scaled)

Diamonds show velocity range spanned by 44 GHz CH_3OH maser emission

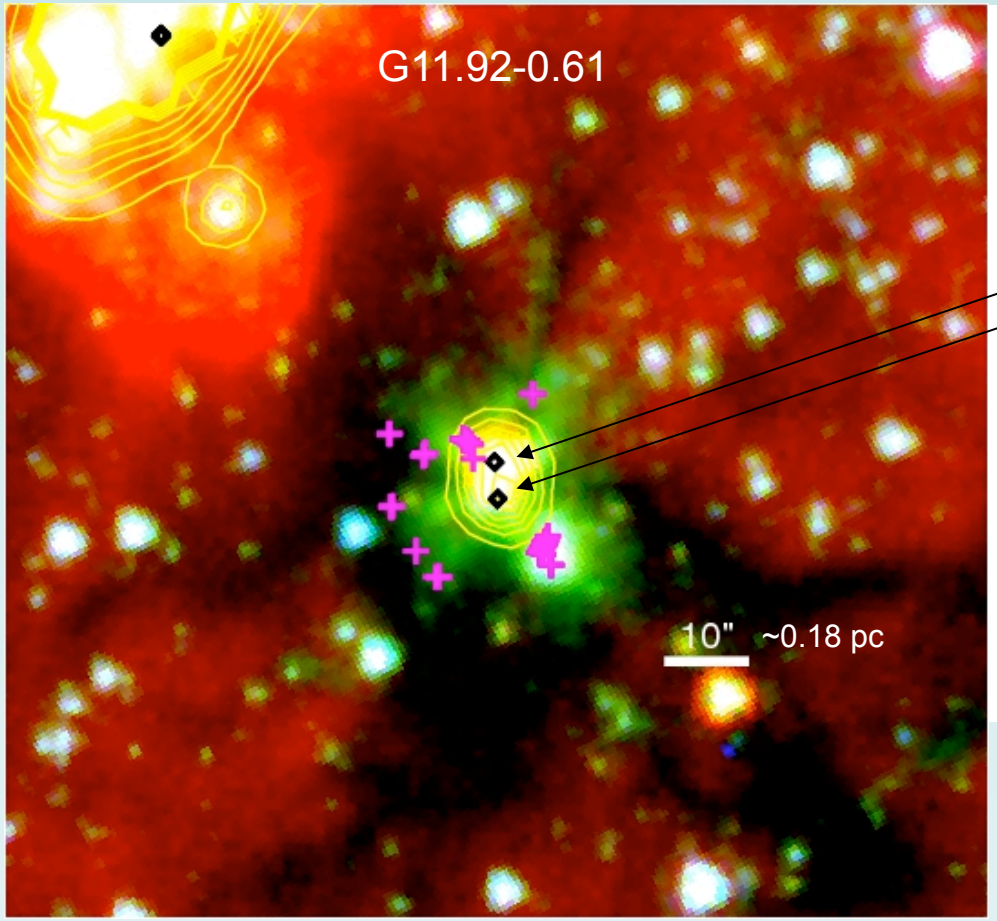
Cyganowski et al. 2009

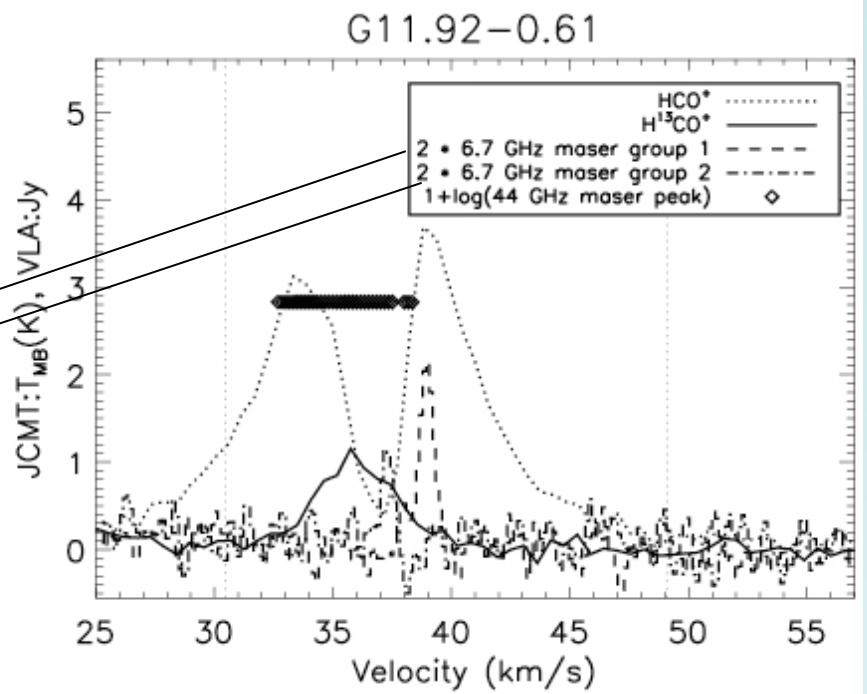
EGO Survey Results: CH_3OH Maser Kinematics



Left: Grayscale: 4.5 μm (GLIMPSE). X: 44 GHz CH_3OH 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_3OH masers, color-coded by velocity. Fitted positions with errors >0.15" (S/N<10) are not shown, those with errors between 0.05" and 0.15" (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





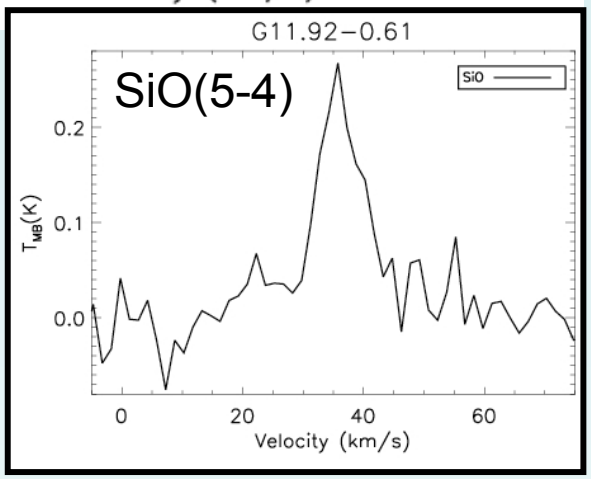
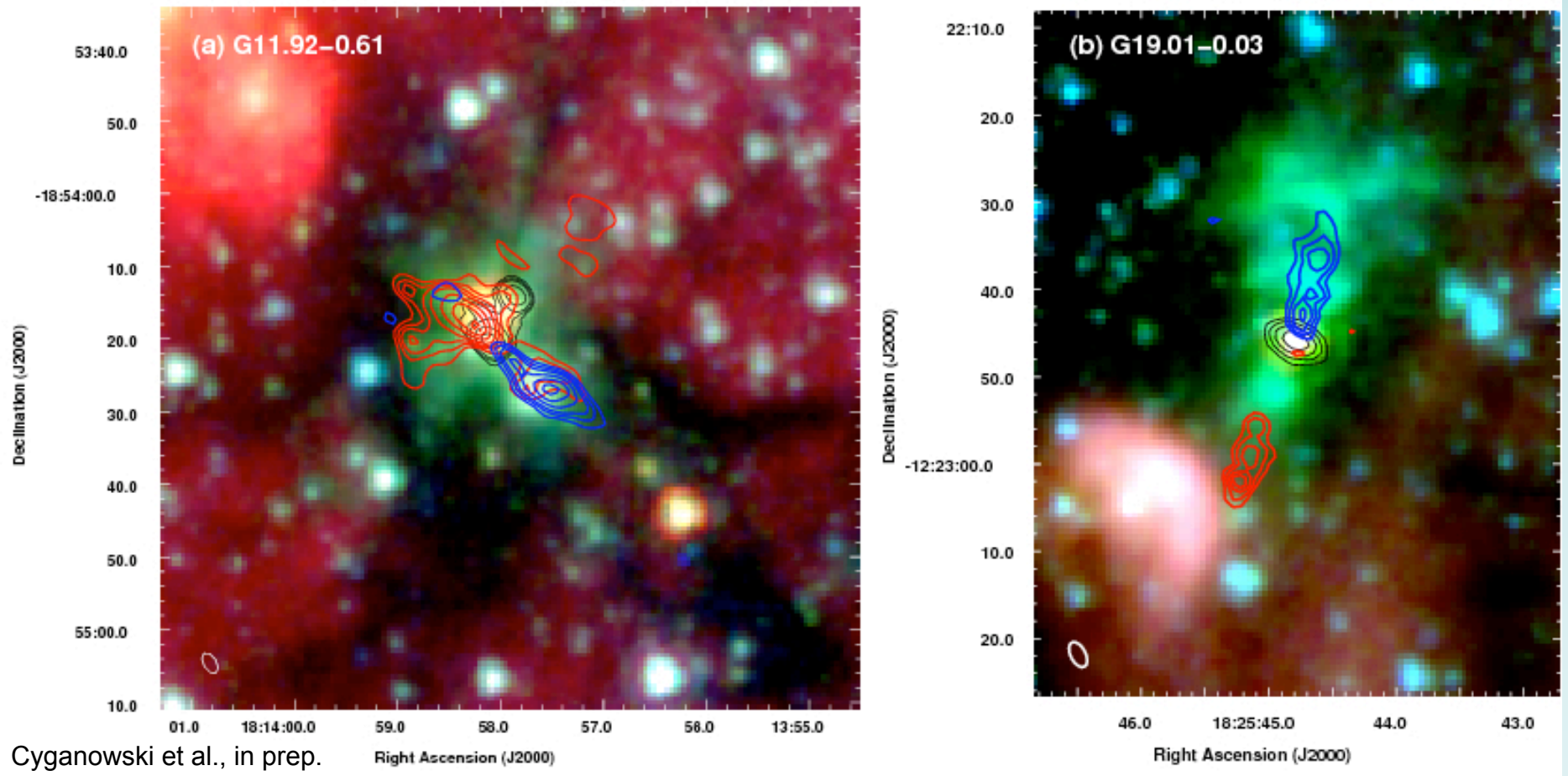


Image: Red: 8um, Green: 4.5um, Blue: 3.6um (GLIMPSE).
Yellow contours: MIPS 24 um
Magenta Crosses: 44 GHz Class I CH_3OH masers.
Black Diamonds: 6.7 GHz Class II CH_3OH masers

Cyganowski et al. 2009

Next Steps: (Sub)mm Line and Continuum Observations



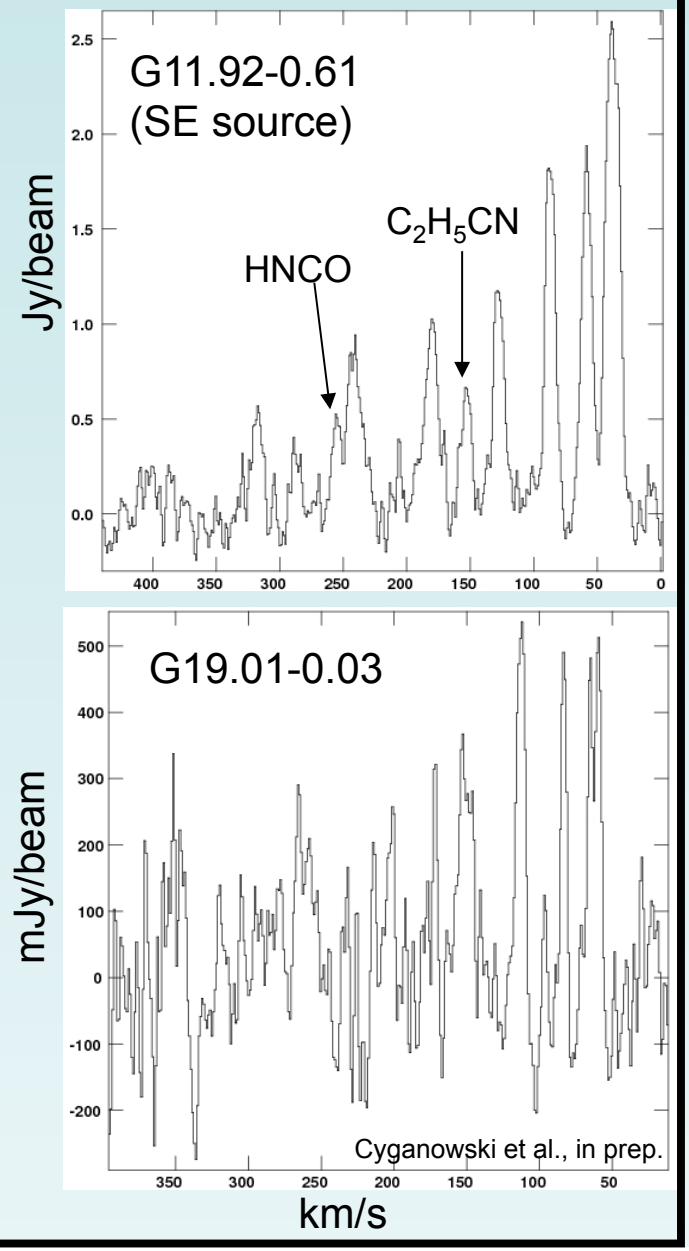
Cyganowski et al., in prep.

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_3OH 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_3OH 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 μm morphology, an associated 24 μm source, and 6.7 and 44 GHz CH_3OH masers:

- there is a single dominant bipolar molecular outflow, traced by ^{12}CO(2-1) and coincident with the 4.5 μm lobes
- the driving source of the 4.5 μm 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 ~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(LSR) indicative of extended envelope (younger?)

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