Outflows and clustered star formation on scales of cores to clouds

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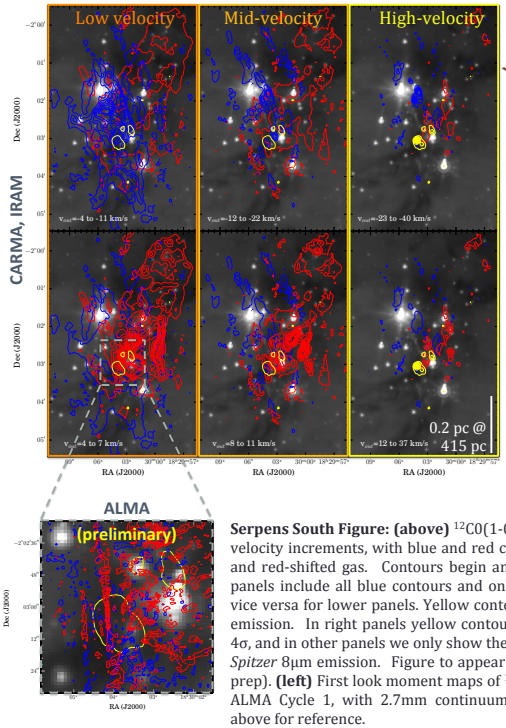
Overview

Protostellar clusters are the complex environments that host the majority of star formation. During the star formation process, molecular outflows are generally understood to be necessary and ubiquitous, but quantifying their impact on the nearby protostars and the surrounding cloud remains a challenge. Outflows inject momentum and energy into the cluster, feed turbulent motions, and may disperse surrounding gas. Distinguishing between these outcomes may constrain the timescales relevant to the clustered star formation process, and observations will provide constraints for outflow parameters in current models. Observations of clusters over a range of evolutionary stages provide evidence of the impact of outflows as protostellar sources evolve.

Molecular line observations

Here we present maps of ^{12}CO (J=1-0) to show outflow morphology. For mass, momentum, and energy calculations, ^{13}CO is critical to correct for optical depth of the ^{12}CO line, and the (J=3-2) transition is utilized to estimate excitation temperature. For details, please see Plunkett et al. (2013, 2014 in prep).

Serpens South



Distance (More nearby)

415 pc [2] — 235 pc [4]

Age (Youngest)

10^5 – 10^6 years [3,7] — 1-2 x 10^6 years [6]

Membership (Early SF)

Protostellar fraction:

80-90% — 30-50%

Continuum sources:

Six, several are likely binaries/multiples — Nine, of which six have associated outflows [a]

Outflows (Disruptive)

Complex web of outflows — 22 outflow lobes, from 12 driving sources [a]

Mass:

5 M_{sun} in 0.27 pc^2 region — 6 M_{sun} in 0.23 pc^2 region [a]

Energy:

E_{out}=9x10^{44} erg — E_{out}=7 x 10^{44} erg [a]

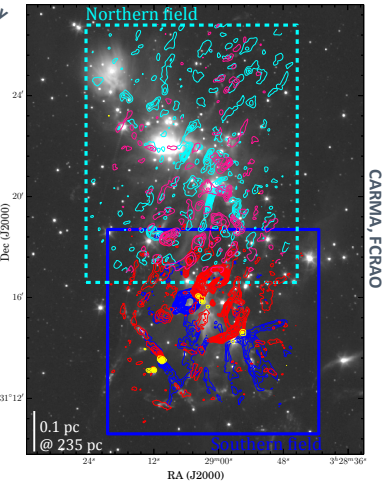
$R_L = L_{out} / L_{turb} \approx$ 1-4 — $R_L \approx$ 5-20

$\eta \equiv -2E_{out}/W$ = 0.1-0.3 — $\eta \equiv$0.2-0.7 (inclination ξ=0-57.3°)

[a] Totals for NGC 1333 southern field (blue outlined region)

Serpens South Figure: (above) ^{12}C0(1-0) moment maps of distinct velocity increments, with blue and red contours representing blue- and red-shifted gas. Contours begin and increment by 4σ. Upper panels include all blue contours and only the 4σ red contour, and vice versa for lower panels. Yellow contours are 2.7mm continuum emission. In right panels yellow contours begin and increment by 4σ, and in other panels we only show the 4σ contour. Background is *Spitzer* 8μm emission. Figure to appear in Plunkett et al. (2014, in prep). **(left)** First look moment maps of ^{12}CO(2-1) as observed with ALMA Cycle 1, with 2.7mm continuum in yellow 4σ contour as above for reference.

NGC 1333



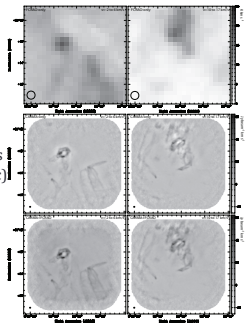
NGC 1333 Figure: ^{12}CO(1-0) moment maps, with blue/aqua and red/magenta contours representing blue- and red-shifted gas. Contours begin at 3σ and increment by 6σ. Yellow contours show 2.7mm continuum sources, beginning with 4σ and incrementing by 12σ. Background is *Spitzer* 4μm emission. Blue/red contours in lower (blue) box correspond to southern region presented by Plunkett et al. (2013), while aqua/magenta contours in upper (aqua, dashed) box correspond to northern region also observed with CARMA and currently in prep.

Observational techniques

Single dish (e.g. FCRAO, IRAM 30m)
+ On-the-fly mapping technique
+ Scales up to map sizes of ~1 pc → cloud scales
– Lower resolution (~few x 10", or ~10,000 AU)

Interferometry (e.g. CARMA,)
+ Mosaic mapping technique
+ High resolution (~5", or ~1000 AU) pc → core scales
– Filter out cloud-scale emission (beyond ~90", ~.1 pc)

Combined map
+ Probe scales ~1000 AU to 1 pc in nearby regions
+ Necessary to accurately measure dynamics of outflows with small- and large-scale structure
+ To be done efficiently with ALMA



Takeaway points

- ✧ We probe scales over two orders of magnitude, corresponding to sizes ranging from cores to clouds in nearby star-forming regions.
- ✧ It is necessary to combine interferometer mosaic (i.e. CARMA) and single dish OTF maps (e.g. FCRAO, IRAM 30m).
- ✧ In NGC 1333 we associate 22 outflow lobes with their driving sources.
- ✧ In Serpens South, higher resolution observations (i.e. ALMA Cycle 1, Plunkett et al. in prep) required to untangle a complex web of outflows.
- ✧ Outflows drive energy sufficient to sustain turbulence.
- ✧ In these regions, outflows *do not yet* contribute enough energy to cause total disruption.
- ✧ Outflows in Serpens South likely have less impact on the cloud so far, compared with NGC 1333, because Serpens South is less evolved.

References

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