Massive Molecular Outflows: A High-Resolution Observational View

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Background

**Low Mass Outflows**

The mass-loss process starts at the very beginning of the growth of a star, carrying away excess angular momentum; clearing out surrounding dense gas; altering surroundings …

Leading theories for low-mass molecular outflows (e.g., MHD wind v.s. X-win)

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**HH 211** (Hirano et al. 2006)

**HH 212** (Lee et al. 2006)
**Background**

*Massive Molecular Outflows?*

They commonly occur in massive star formation sites.

Significant results come from systemic single-dish studies.

![Collimation Factor vs Luminosity](image)

*Fig. 3: Collimation factor vs luminosity for high and low mass objects. Wu et al. (2004)*
Background

Massive Molecular Outflows

\[ \frac{M_{\text{out}}}{t_d} \sim L_{\text{bol}}^{0.6} \]

Churchwell (2002, ARA&A)
A systemic study of massive molecular outflows based on the Submillimeter Array observations

A moderate sample of luminous (10⁴ to 10⁶ Lsun) star-forming regions

CO, ¹³CO outflows at 2” to 3” resolutions (1000s AU to 10000 AU)

Complemented by single-dish observations to recover extended structures and missing flux
SMA Survey – Jetlike Outflows

HH 80–81
8μm (green)/6cm (red)

SMA CO (2-1)

HH 80-81 \( \left( 10^{4.3} \, L_\odot \right) \)
Qiu et al. (2008)
SMA Survey – Jetlike Outflows

High Collimation
Extremely High Velocity
Bullets
SMA Survey – Wide-angle Outflows

G240.31 \( \left( 10^{4.7} \, \text{L}_\odot \right) \)
Qiu et al. (2009)
SMA Survey – Wide-angle Outflows

Lee et al. (2001)
SMA Survey – Large-angle Outflow Shells

G45.47; G45.07 ($\geq 10^6$ $L_\odot$)
A very tentative proposal for morphological evolution of massive molecular outflows

Beuther & Shepherd (2005)
Luminosity

- $10^6 \, L_\odot$
- $10^5 \, L_\odot$
- $10^4 \, L_\odot$

Time

- "Class 0" MYSO
- HMC / HC H$_\text{II}$
- UC H$_\text{II}$
SMA Survey – Outflow Energetics

Qiu et al. (2009)

Combine SMA and single-dish Data

Simultaneous imaging of $^{12}$CO and $^{13}$CO
SMA Survey – Outflow Energetics

\[ \frac{M_{\text{out}}}{t_d} \sim L_{\text{bol}}^{0.6} \]
Ubiquity, mass, energetics:
playing a major role in the formation of massive stars;
probing the accretion at the center.

Models, theories of outflows, massive star formation …