When and how is protostellar feedback important to (massive) star formation?

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Five reasons to consider protostellar outflow feedback in massive star formation

1. If outflows are significant, they affect the efficiency, rate, and character of star formation

2. Outflow feedback is immediate, and only becomes stronger if stars form more rapidly

3. Protostellar outflows input more momentum than photons or (on small scales) ionized gas

4. All stars emit protostellar winds and outflows as they form

5. Each high-mass star is accompanied by hundreds or thousands of low-mass stars

In this talk:
- What qualifies as significant feedback?
- When *should* outflow driving be significant?
- How can we tell if it is?
- Implications for ALMA
Physical scenario:

Carroll et al 2008

NASA, ESA, Hubble Heritage Team, (STScI / AURA) and P. McCullough (STScI)

Jay Lavine and Ali Huang/Adam Block/NOAO/AURA/NSF

Allan Cook/Adam Block/NOAO/AURA/NSF
When *should* outflow driving be significant?

Heyer & Brunt 04

$\sigma \approx 0.72 \ R_{\text{pc}}^{1/2}$ km/s

Galactic HI disk

Isolated star-forming cores

Solomon et al 87
When *should* outflow driving be significant?

Molecular gas has a roughly constant acceleration $\sigma^2/R$ (Equivalent to standard turbulent power spectrum slope)

GMCs are self-gravitating: $\sigma^2/R \approx 0.7 \ G \Sigma$

Solomon et al 87
$\sigma \approx 0.72 \ R_{pc}^{1/2} \ km/s$

\[ \text{[Acceleration]} = \text{[momentum injection rate per mass]} \]
(cloud property) $\leftrightarrow$ (feedback mechanism property)

\[ R \ (pc) \]
When *should* outflow driving be significant?
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Rate per volume
\[ S = \text{SFR}_{ff} \rho / \langle m_* \rangle t_{ff} \]

Impulse
\[ I = \langle m_* \rangle v_c \]

Mean density
\[ \rho \approx 1 / 30 \text{ to } 1 / 2 \text{ M}_\odot \]
\[ \approx 40 \text{ km/s} \]

– dimensional analysis –

Acceleration scale
\[ \frac{S I}{\rho} = 10^{-8} \text{ (stuff) } n_{H_4}^{1/2} \text{ cm s}^{-2} \]

Driving length
\[ [I / (S \rho)]^{1/7} = 0.4 \text{ pc (stuff)}^{1/7} n_{H_4}^{-5/14} \]

Characteristic turb. velocity
\[ [I^4 S^3 / \rho^4]^{1/7} = 1.0 \text{ km s}^{-1} (\text{stuff})^{4/7} n_{H_4}^{1/14} \]

*(collimation alters somewhat)*

see Matzner 2007
When *should* outflow driving be significant?

- Protostellar acceleration stronger than gravity
- Protostellar outflows unimportant
What does outflow driving look like?

1. Increased turbulent motions*
2. Flatter line width-size relation
3. Higher column density*

* Significant increases
What does outflow driving look like?

1. Increased turbulent motions*

2. Flatter line width-size relation

3. Higher column density*

4. Partial equipartition between outflow and turbulent energies

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Michael Gorelick & CDM in prep

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$E_{\text{kin}}(>\mid v_z\mid)$

$|v_z/\sigma_{\text{turb}}|$
What does outflow driving look like?

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2. Flatter line width-size relation 
3. Higher column density* 
4. Partial equipartition between outflow and turbulent energies 
5. Tortured, porous molecular gas; mass loss

[Images: NGC 1333, Circinus, Simulation]
What does outflow driving look like?

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4. Partial equipartition between outflow and turbulent energies
5. Tortured, porous molecular gas; mass loss
6. Slowdown of overall collapse

Matzner 2007
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Implications for ALMA?

High sensitivity: apply tests using optically thin tracers

High resolution: map dynamics of distant, massive proto-cluster environments

- The End -