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

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

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

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

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

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

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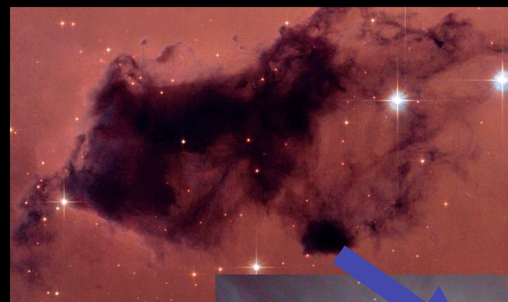
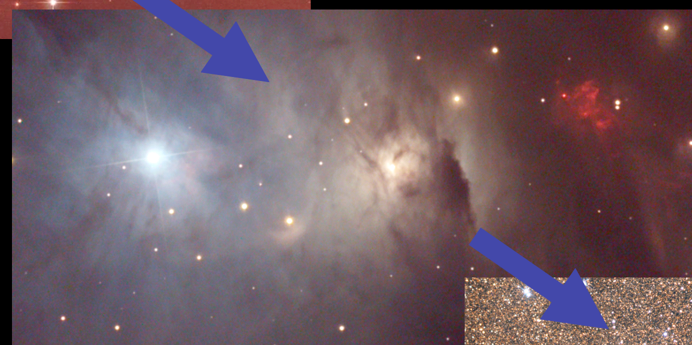
In this talk:

- What qualifies as significant feedback?
- When *should* outflow driving be significant?
- How can we tell if it is?
- Implications for ALMA

Physical scenario:

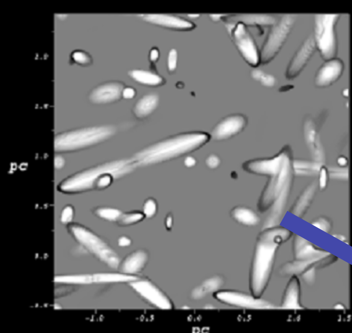


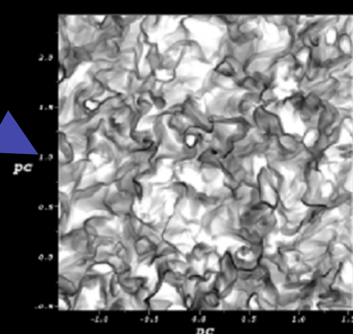
NASA, ESA, Hubble Heritage Team,
(STScI / AURA) and P. McCullough (STScI)



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

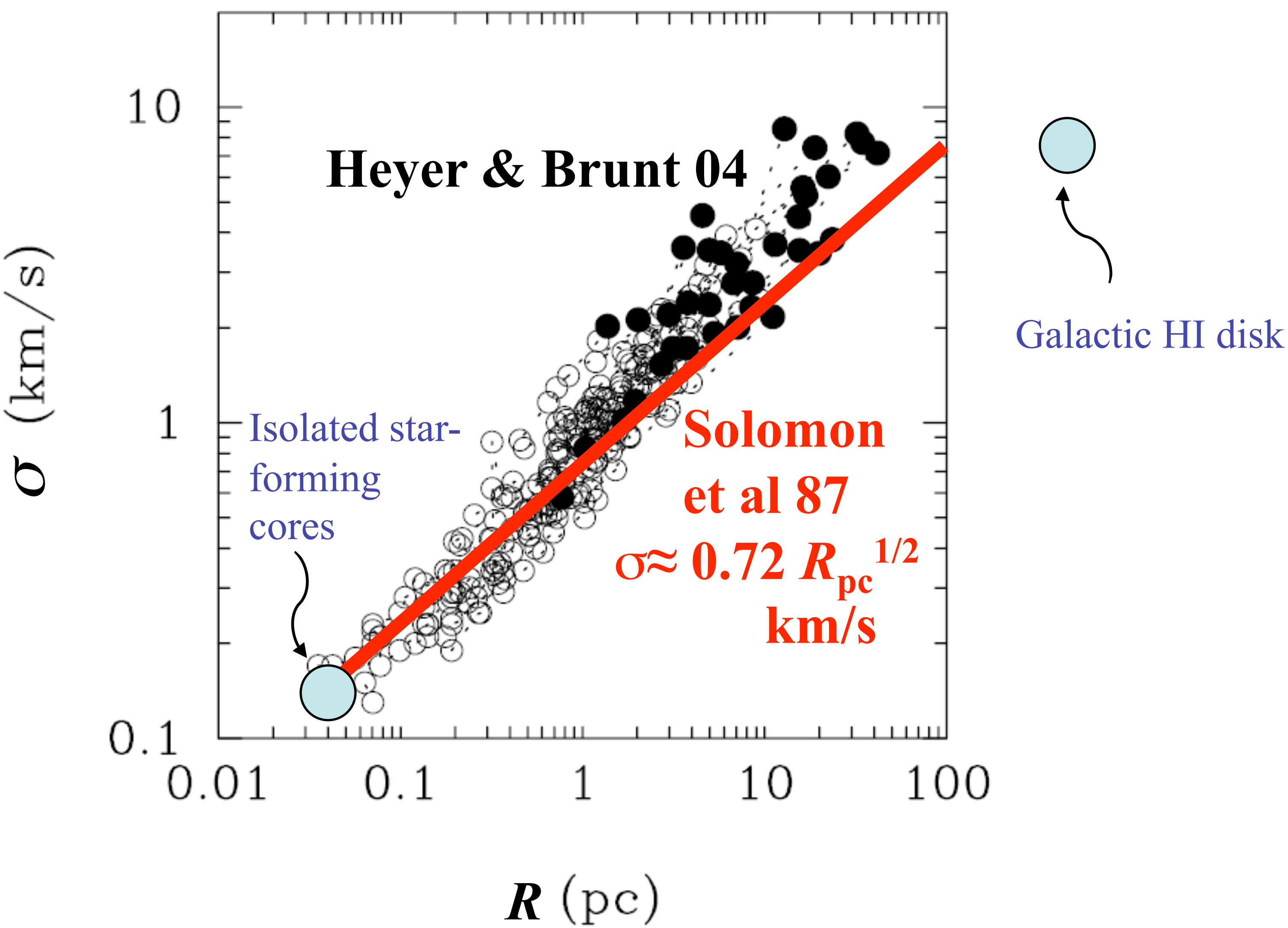
Allan Cook/Adam Block/NOAO/AURA/NSF





Carroll et al 2008

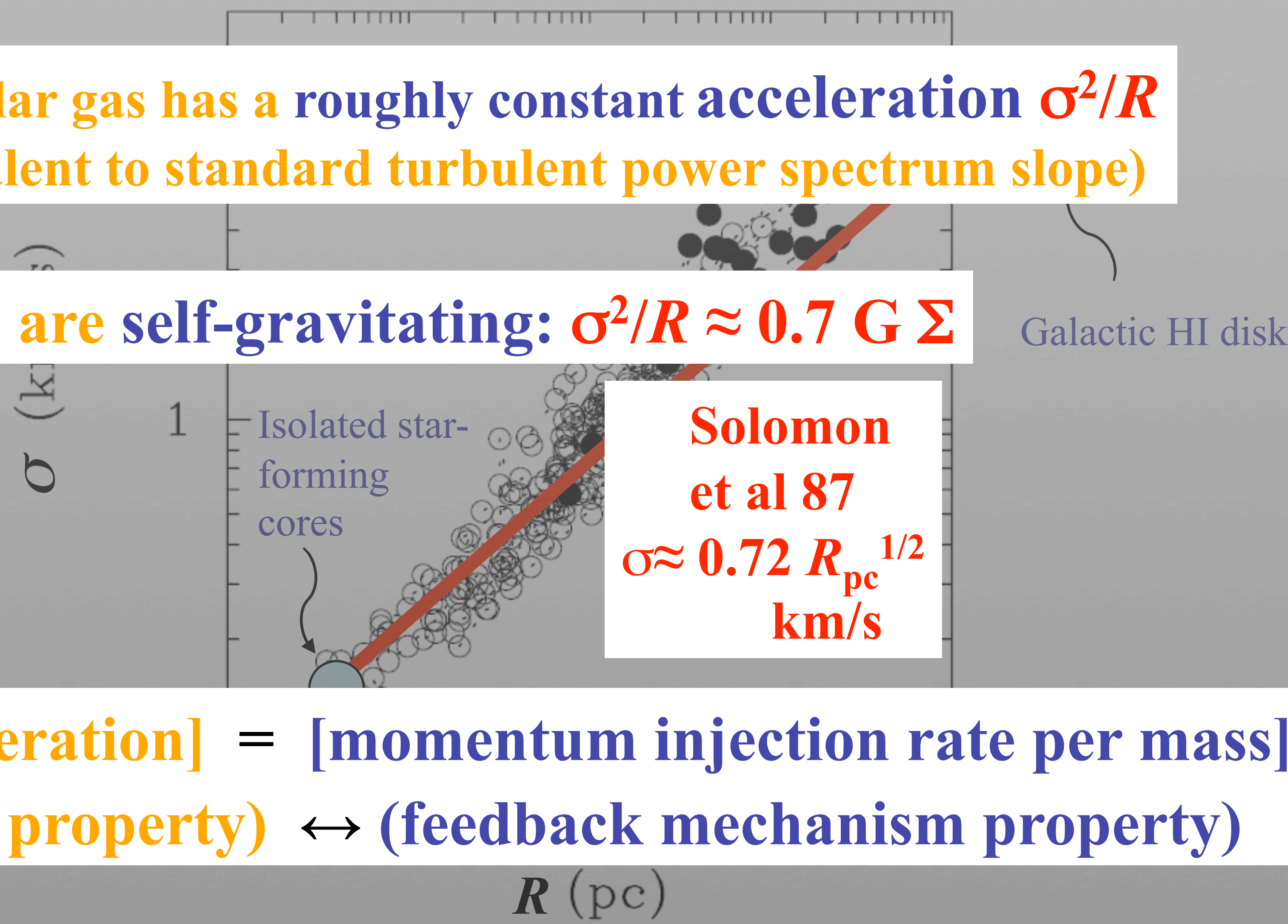
When *should* outflow driving be significant?



When *should* outflow driving be significant?

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

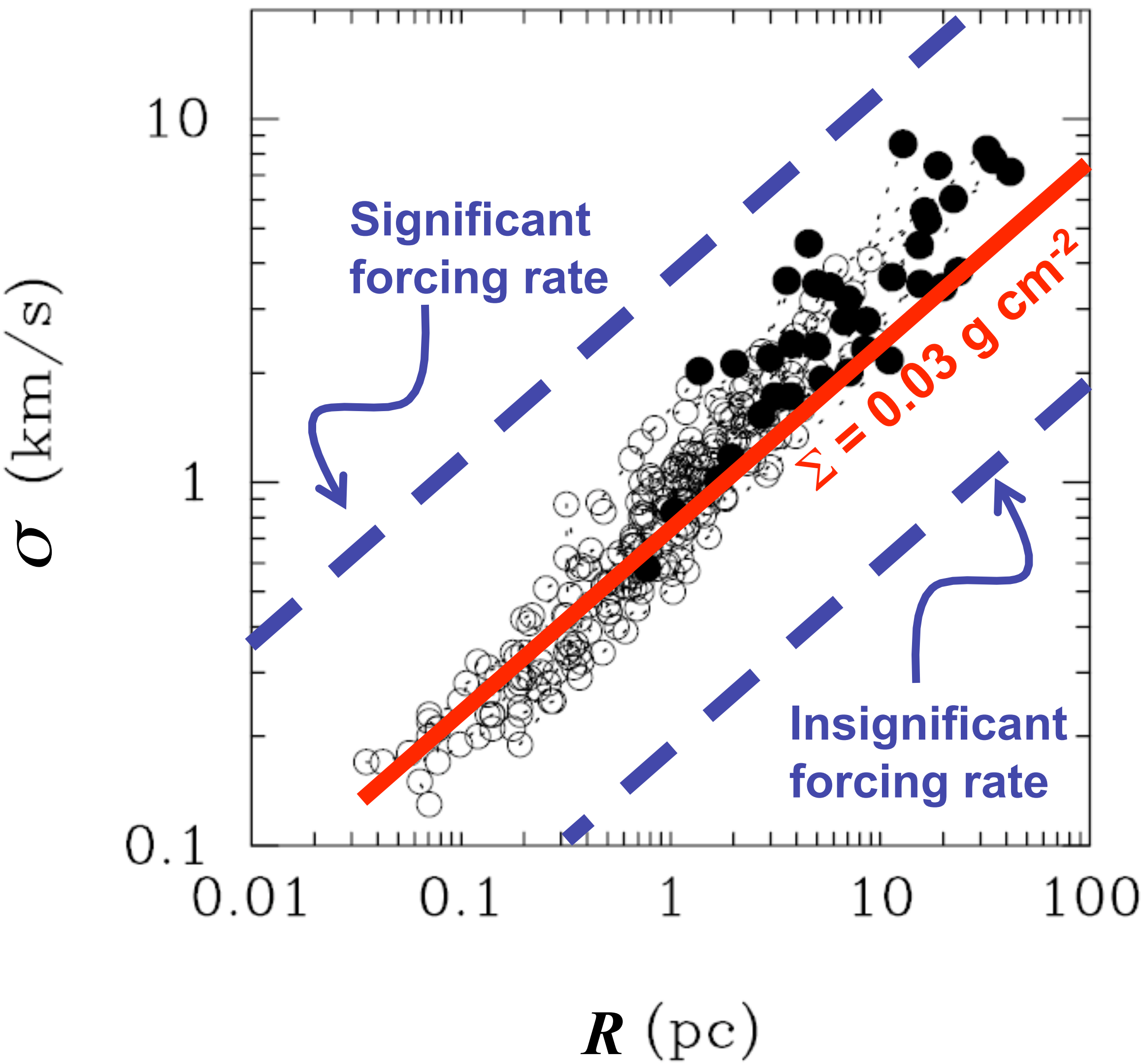
GMCs are self-gravitating: $\sigma^2/R \approx 0.7\ G\ \Sigma$



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

[Acceleration] = [momentum injection rate per mass]
(cloud property) ↔ (feedback mechanism property)

When *should* outflow driving be significant?



When *should* outflow driving be significant?

Rate per volume $S = \mathrm{SFR}_{\mathrm{ff}}\, \rho \,/\, (\langle m_* \rangle t_{\mathrm{ff}})$

Impulse $I = \langle m_* \rangle\, v_c$

Mean density ρ

~1/30 ($\mathrm{SFR}_{\mathrm{ff}}$)

~1/2 M_{sun} ($\langle m_* \rangle$)

~40 km/s (v_c)

– dimensional analysis –

Acceleration scale $\dfrac{S\,I}{\rho} = 10^{-8}\,(\mathit{stuff})\, n_{H4}^{1/2}\ \mathrm{cm\ s^{-2}}$

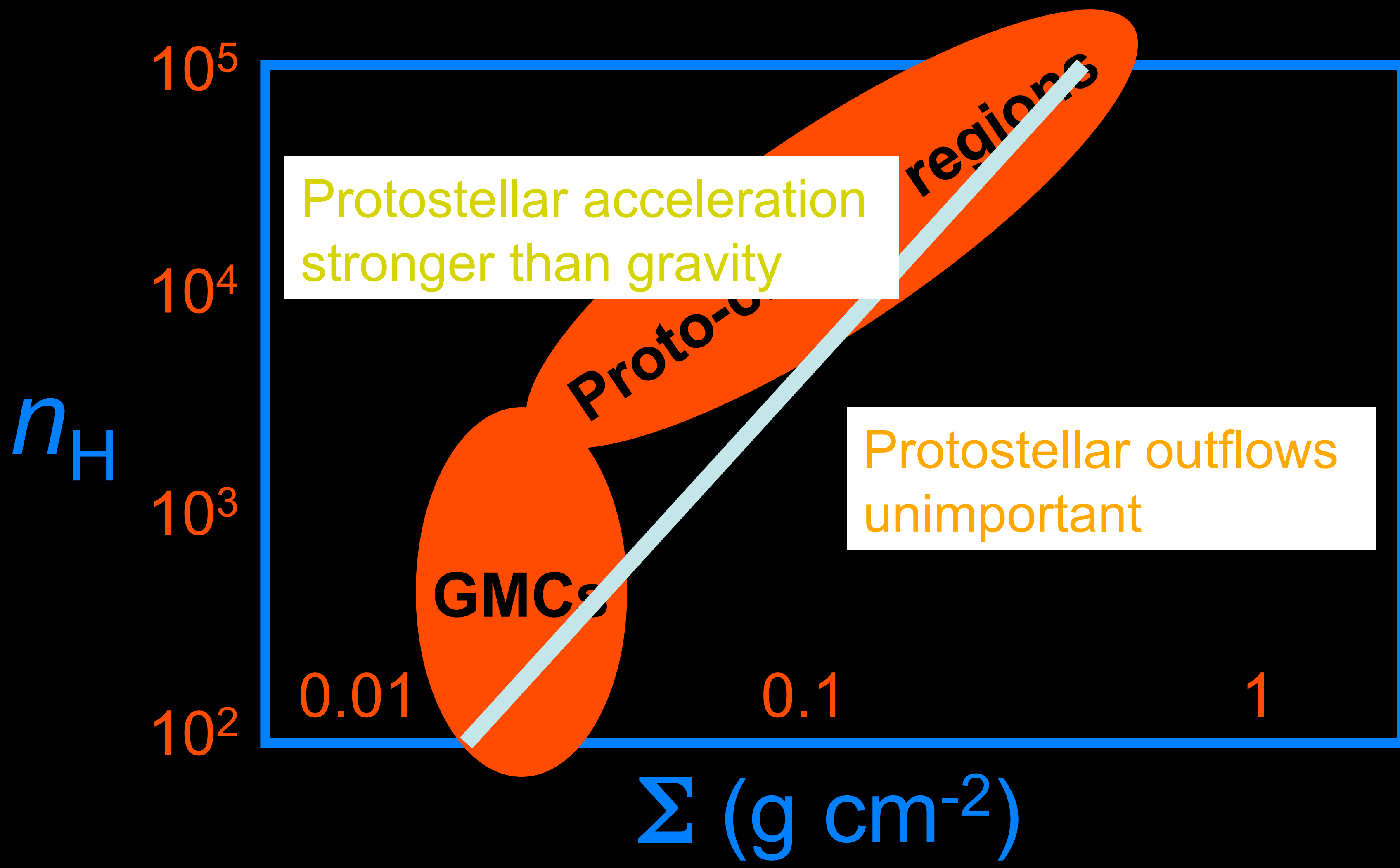
Driving length* $[\, I \,/\, (S\,\rho)\,]^{1/7} = 0.4\ \mathrm{pc}\ (\mathit{stuff})^{1/7}\, n_{H4}^{-5/14}$

Characteristic turb. velocity* $[\, I^4\, S^3 \,/\, \rho^4\,]^{1/7} = 1.0\ \mathrm{km\ s^{-1}}\ (\mathit{stuff})^{4/7}\, n_{H4}^{1/14}$

*(collimation alters somewhat)

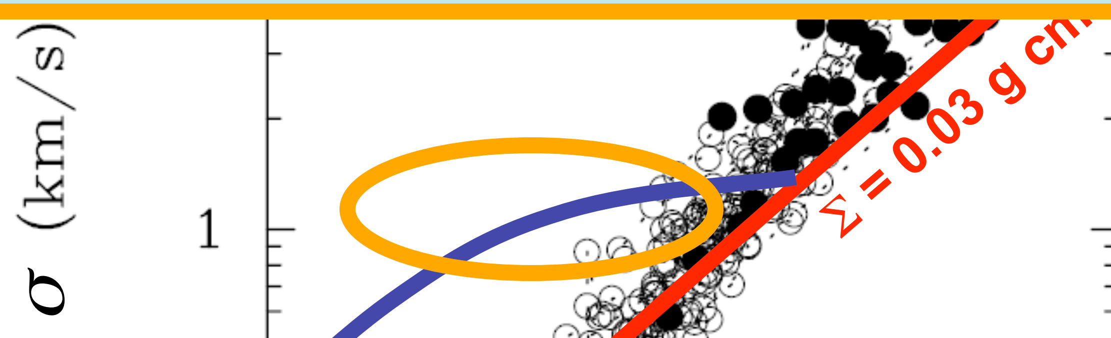
see Matzner 2007

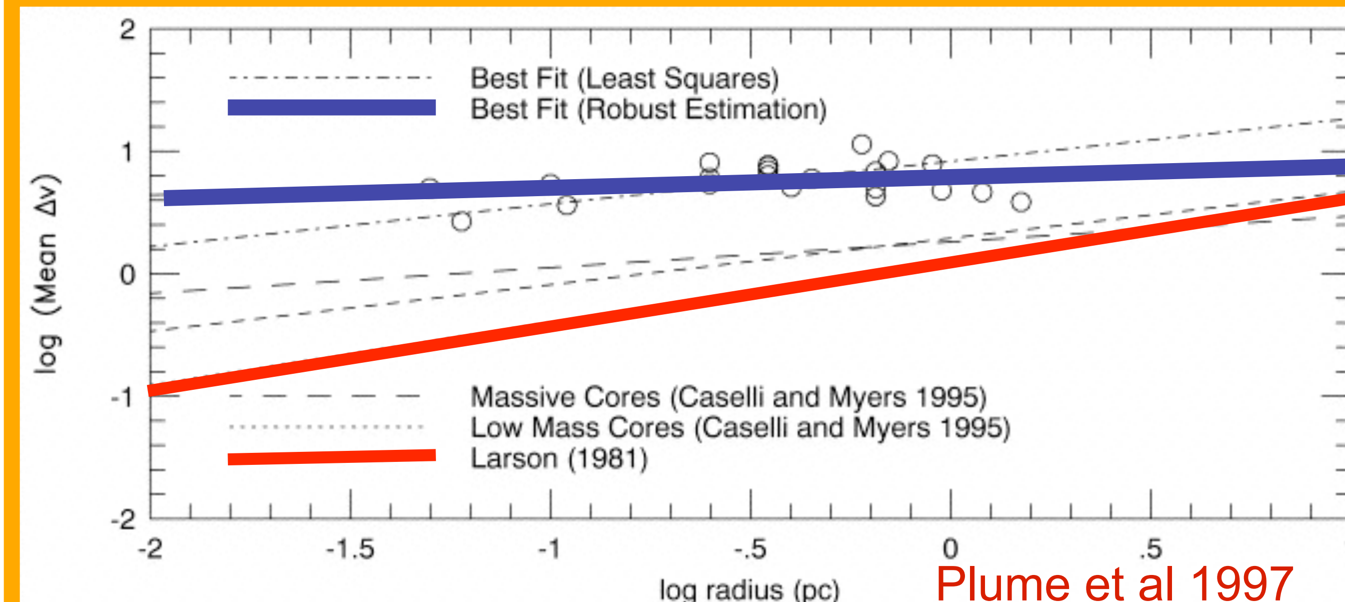
When *should* outflow driving be significant?



What does outflow driving look like?

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

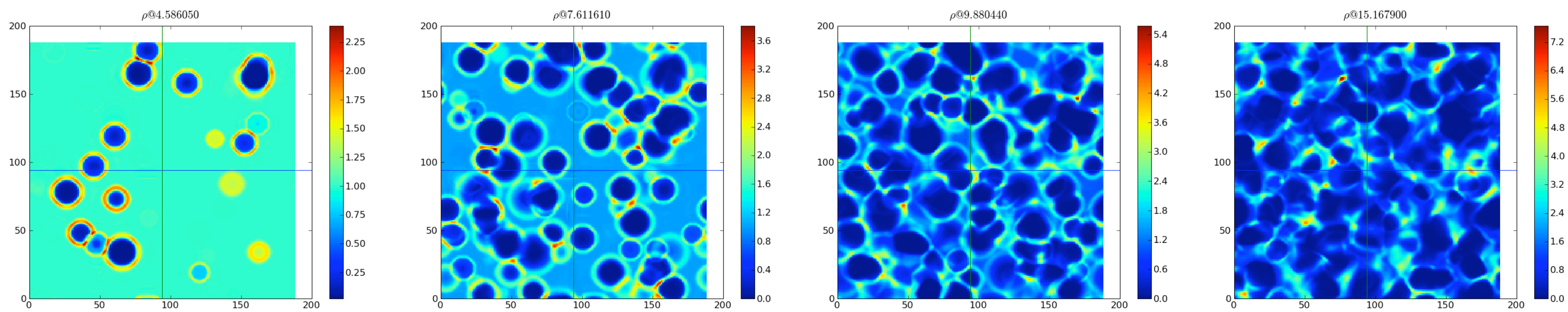


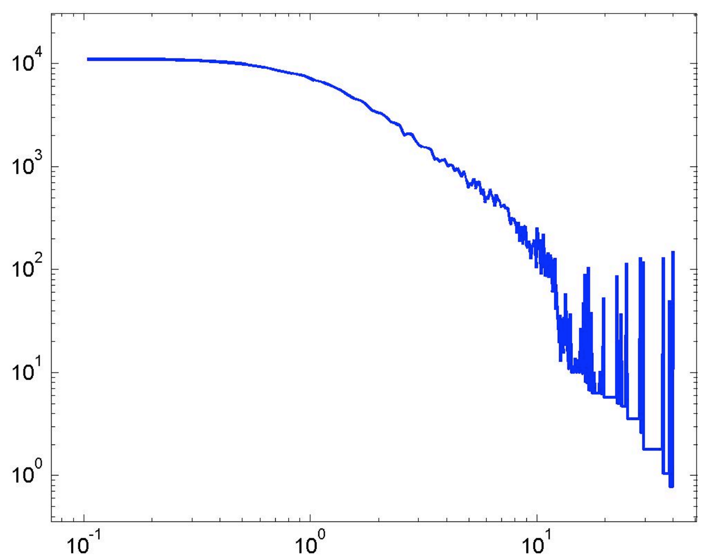


Plume et al 1997

What does outflow driving look like?

1. Increased turbulent motions*





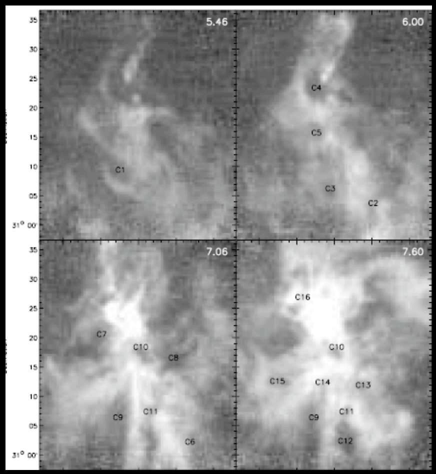
simple model:
- spherical outflows
- unmagnetized gas
- no gravity

Michael Gorelick & CDM in prep

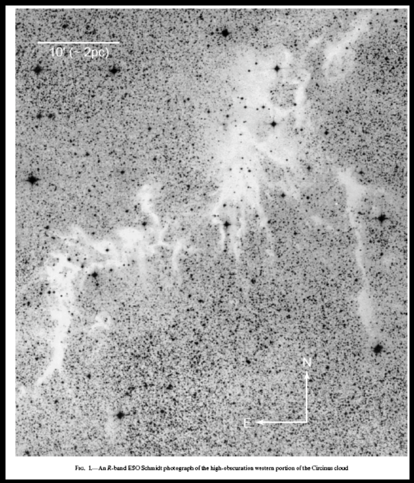
$|v_z/\sigma_{turb}|$

What does outflow driving look like?

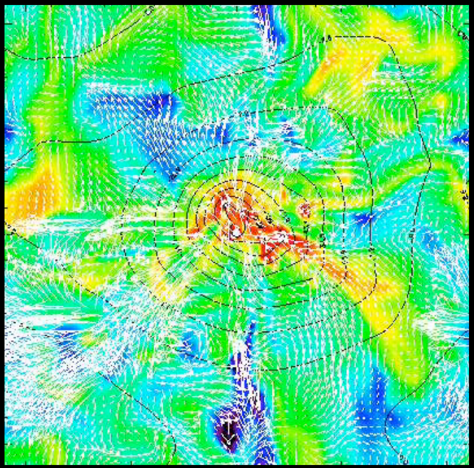
1. Increased turbulent motions*
2. Flatter line width-size relation
3. Higher column density*
4. Partial equipartition between outflow and turbulent energies
5. **Tortured, porous molecular gas; mass loss**



NGC 1333
Quillen et al 05



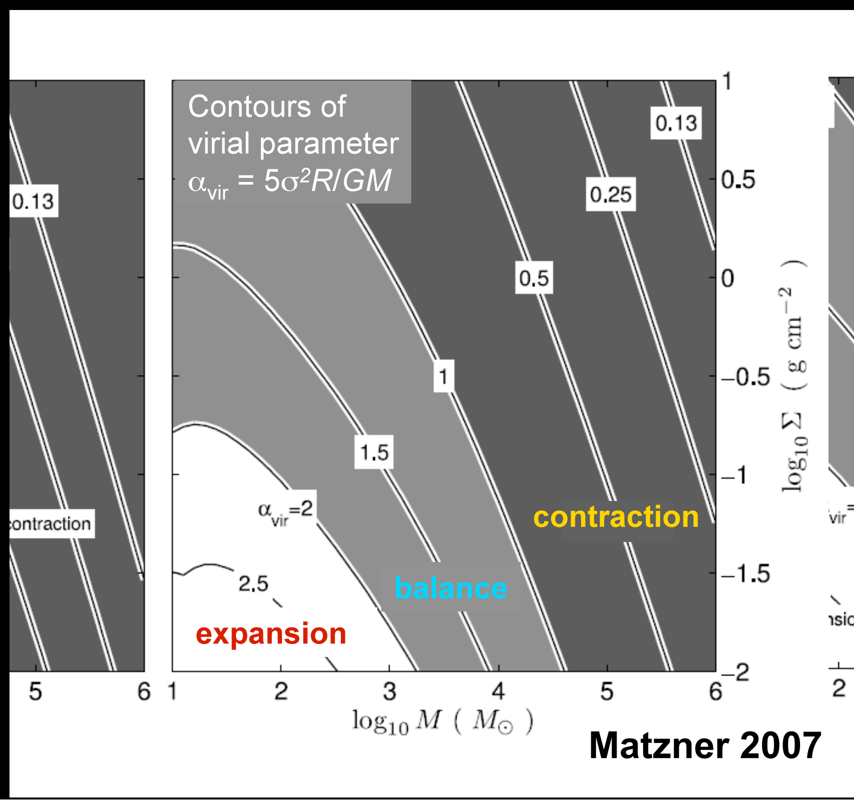
Circinus
Bally et al 99



Simulation
Li, Nakamura

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
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 -