A Distance Limited Sample of Massive Molecular Outflows

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Outline

- Do massive stars form via discs in the same way as low-mass stars?
- Can we observe a common formation phenomena easily?
- Can we compare the results directly with low-mass stars?

Outline

- Do massive stars form via discs in the same way as low-mass stars?
  - ➡Some observations suggest this...
- Can we observe a common formation phenomena easily?
  - ➡Molecular outflows...
- Can we compare the results directly with low-mass stars?
  - ➡Yes...

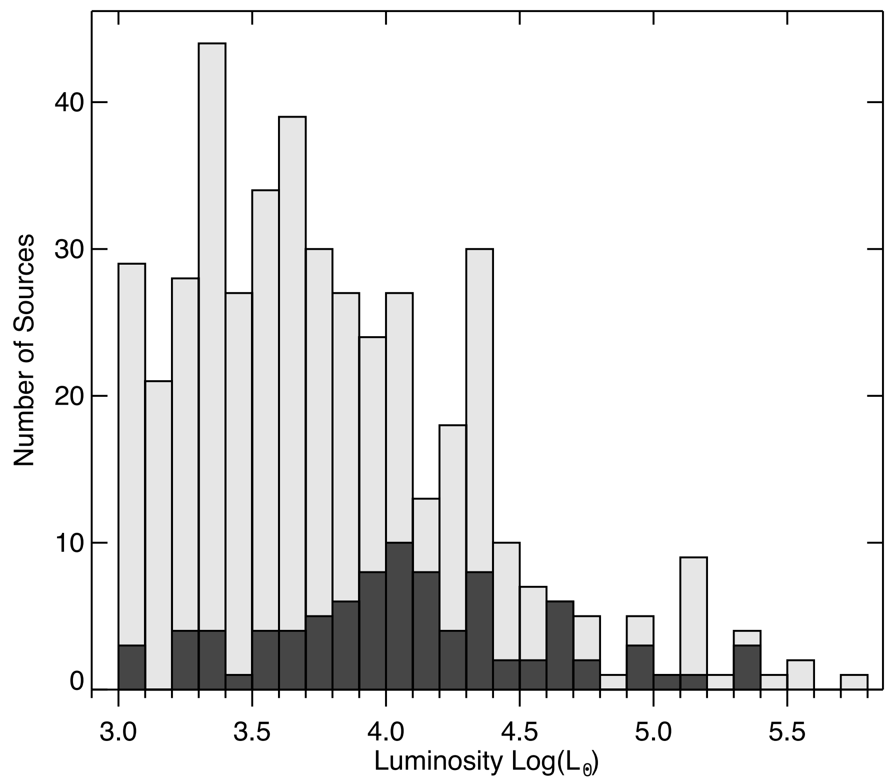
Sample and Observations

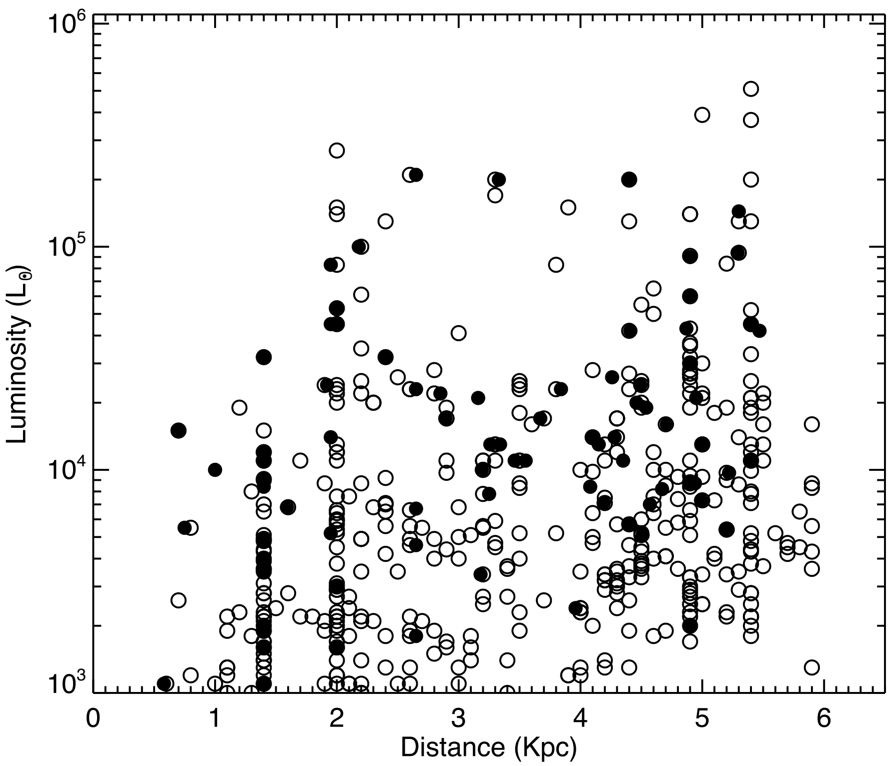
- 99 mid-IR bright massive young stellar objects and compact HII regions from RMS survey Lumsden et al. 2013

- J = 3-2 transition of ^{12}CO, ^{13}CO and $C^{18}O$ with the JCMT

- **89** sources in the distance limited sample (D < 6 kpc)

- Representative ($L > 10^4\ L_\odot$) of the 450 in the RMS database that meet the criteria





Method

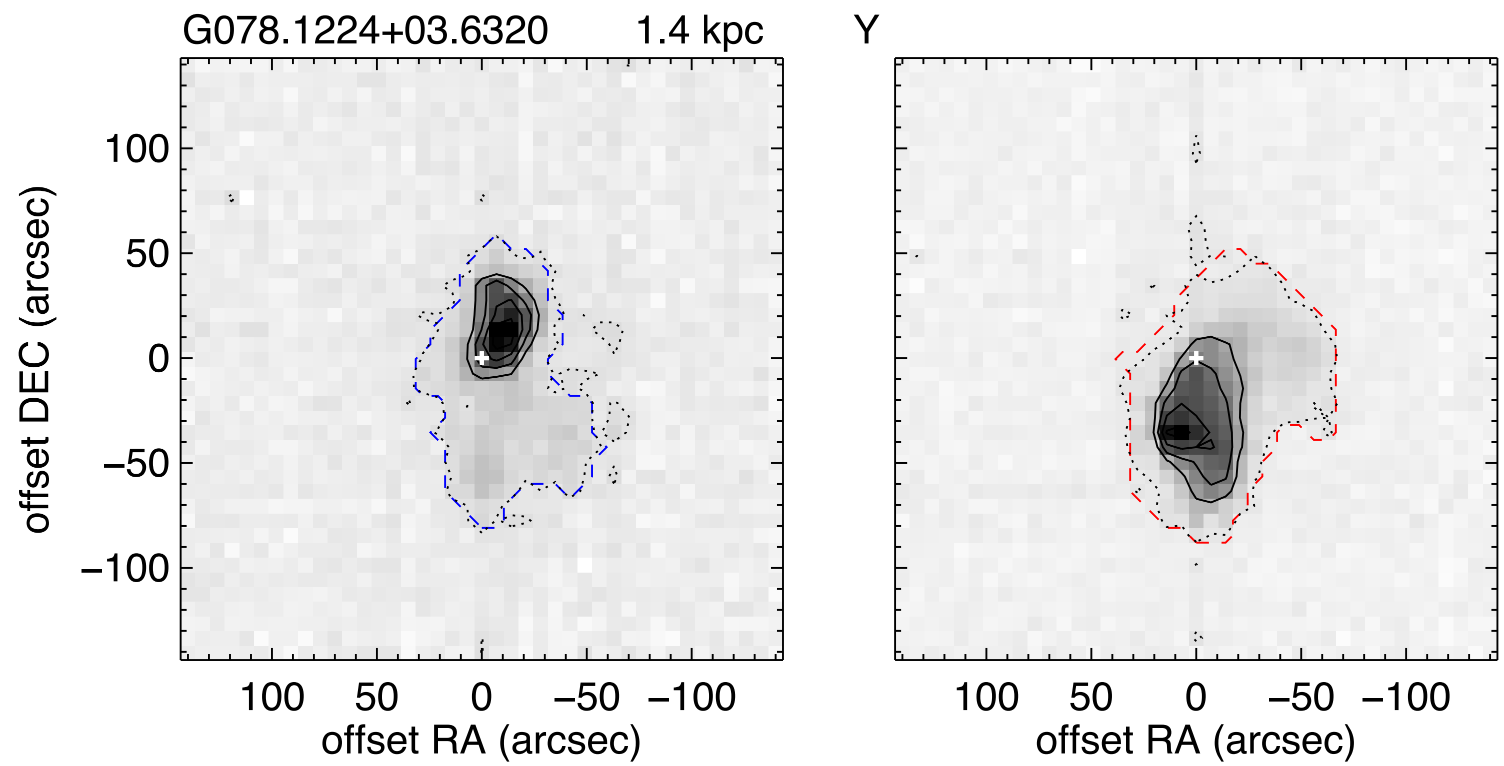
- Calculated temperature
- Corrected for optical depth (x,y,v)
- $C^{18}O$ used to remove the core
- Aperture for summation after velocity integration

- Full **Cube** analysis

Cabrit & Bertout 1990

$$P = \sum_{x,y,i} M_i v_i$$

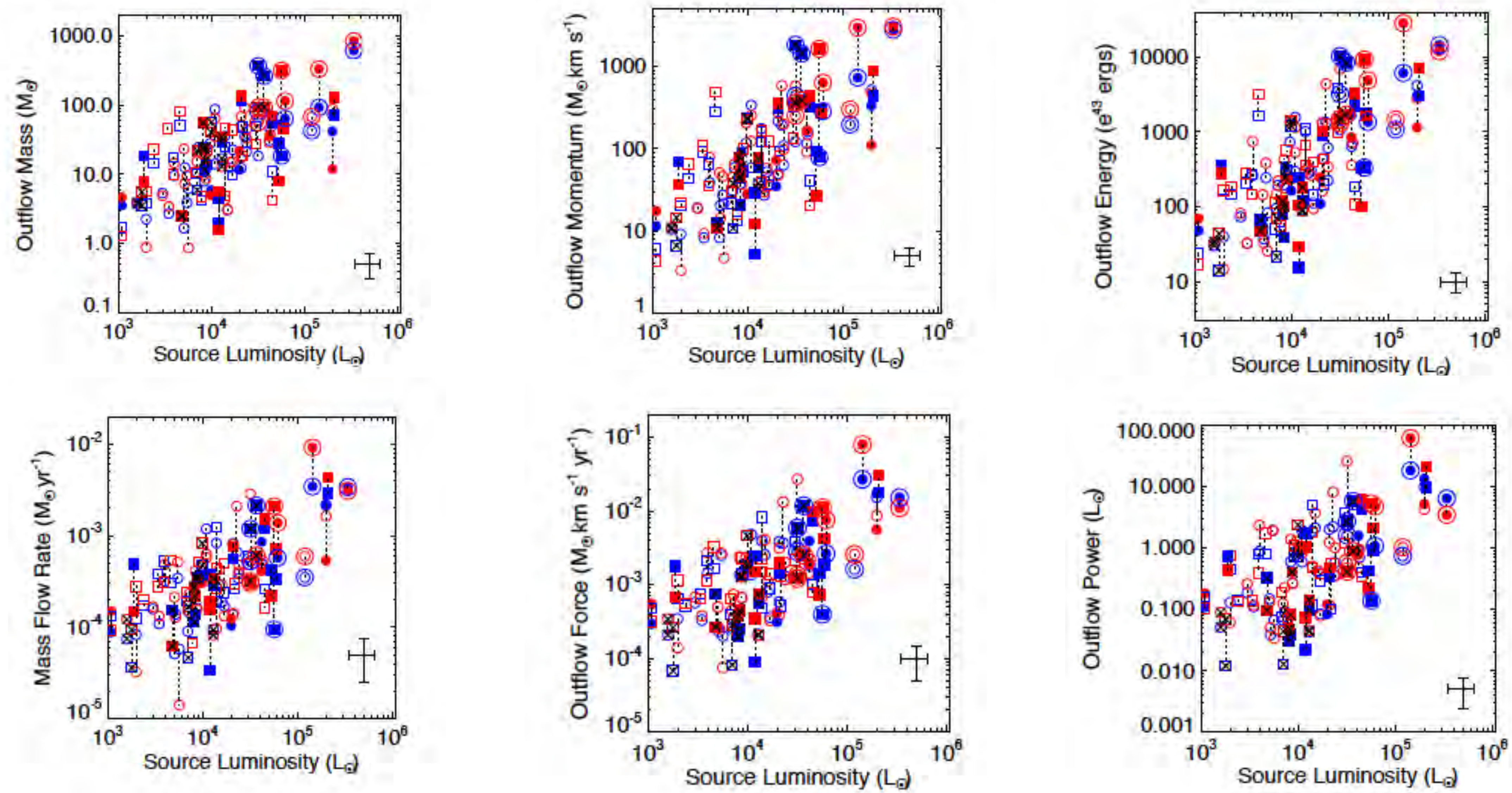
$$E = \frac{1}{2} \sum_{x,y,i} M_i v_i^2$$



Results

- 59(65) with outflows
- 17(20) maybe outflows
- 13(14) no outflows

- Clear scaling of outflow parameters with luminosity
- Many bipolar flows



Results

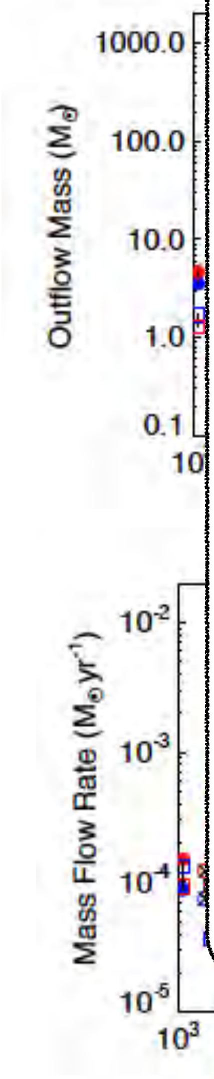
- 59(65) with outflows
- 17(2
- 13(1

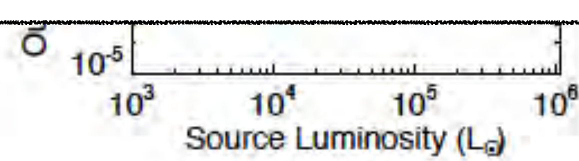
- Clear scaling of outflow parameters

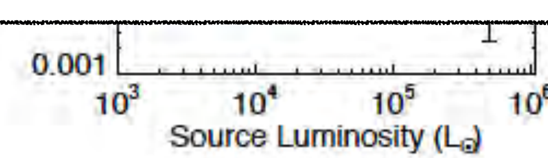
➡At face value…

- Scaling over 3 orders of magnitude
- MYSOs and compact HII regions equivalent
- Interpret as a cluster of protostars

➡More luminous sources, more massive protostars, more massive outflows, more massive core, scaled accretion mechanism per protostar…







Dynamical Timescale - Accretion Rates....

- We use position dependent to calculate outflow flow, force and luminosity

$T_{dyn(x,y)} = R_{(x,y)} / \langle V_{(x,y)} \rangle$

Lada & Fitch 1996

- Classically $T_{dyn} = R_{max} / V_{max}$

e.g. Beuther et al. 2002

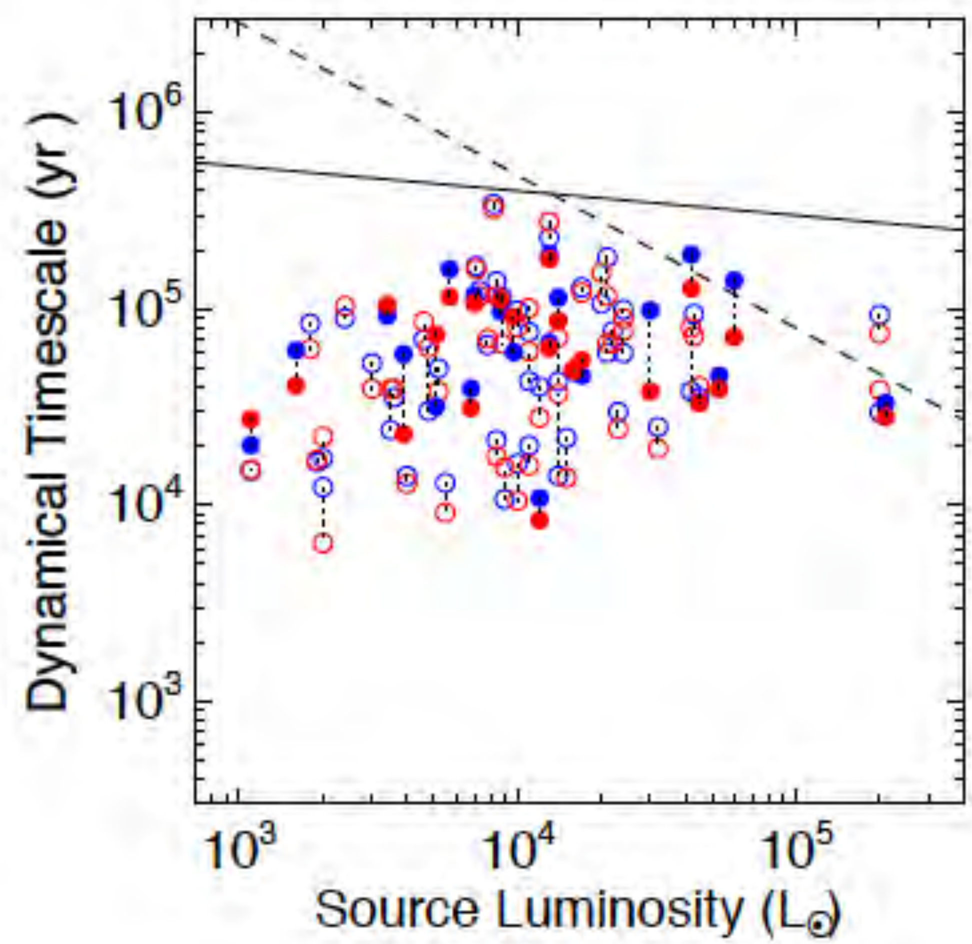
- Better to use $1/3\ R_{lobe}/\langle V \rangle$

Downes & Cabrit 2007

- Do NOT over-interpret as source age

- Timescales are below the phase lifetimes

Mottram et al. 2011

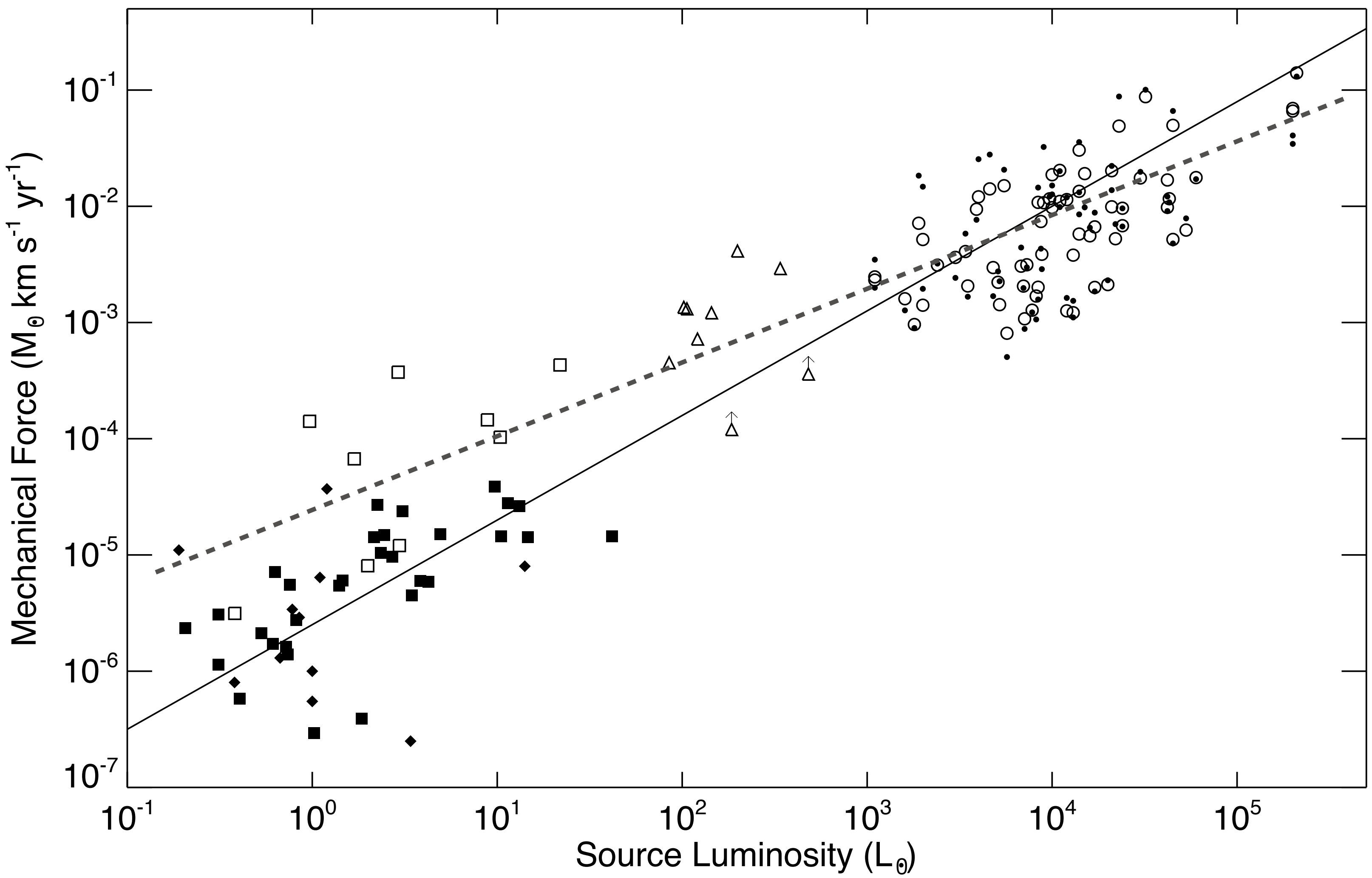


- T_{dyn} as CRUDE cluster age accretion rates 1.3×10^{-4} to $8.7\times10^{-3}\ M_{\odot}\ yr^{-1}$

SFE at 40% - Maud et al. 2015 MNRAS Submitted

Low-mass Analogues

- Compare with:
  - Low-mass Class 0/I - Bontemps et al. 1996 (filled/open square)
  - Young low-mass - van der Marel et al. 2013 (diamonds)
  - Class-0 High-mass analogues - Duarte-Cabral et al. 2013 (triangles)
- Circles use position dependent $T_{dyn(x,y)}$, dots use classical T_{dyn}



Low-mass Analogues

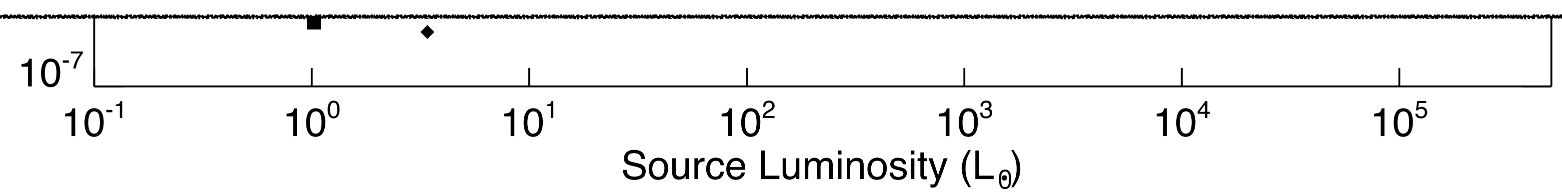
- Compare with: Low-mass Class 0/I – Bontemps et al. 1996 (filled/open square)

es)

- Circl

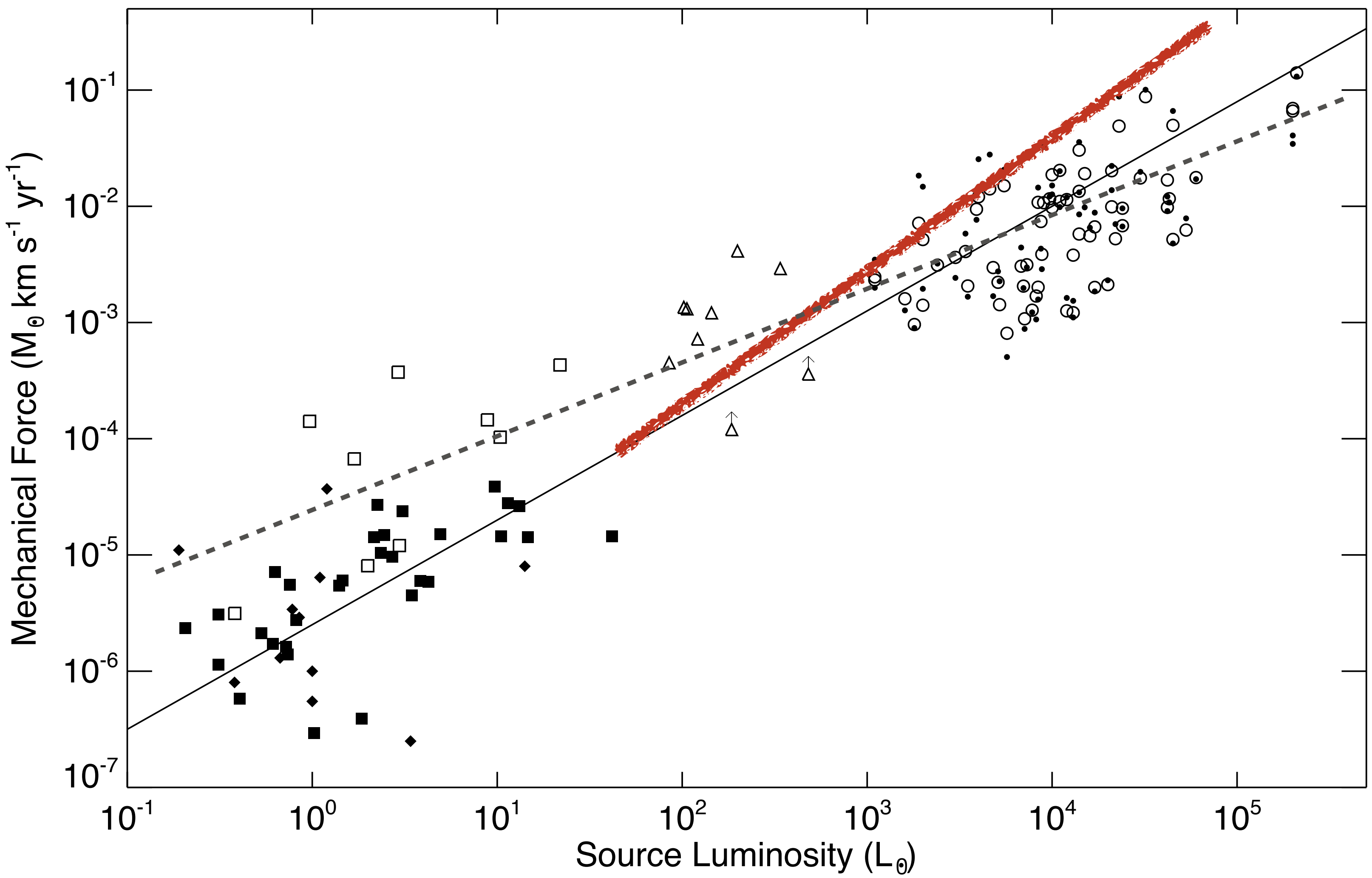
➡ At face value...

- Scaling over 6 orders of magnitude
- Accretion mechanism scale right up from low-mass to massive $M=30M_\odot$
- Do the most massive stars contribute in a protostellar cluster ??
- Can low and intermediate mass actually be responsible??



Low-mass Analogues

- Model as coeval protostellar cluster with an IMF distribution of ZAMS stars and where each protostar generates an outflow following the relation from Bontemps et al. 1996
  - Luminosity is that of most massive star only - all protostars provide the outflow



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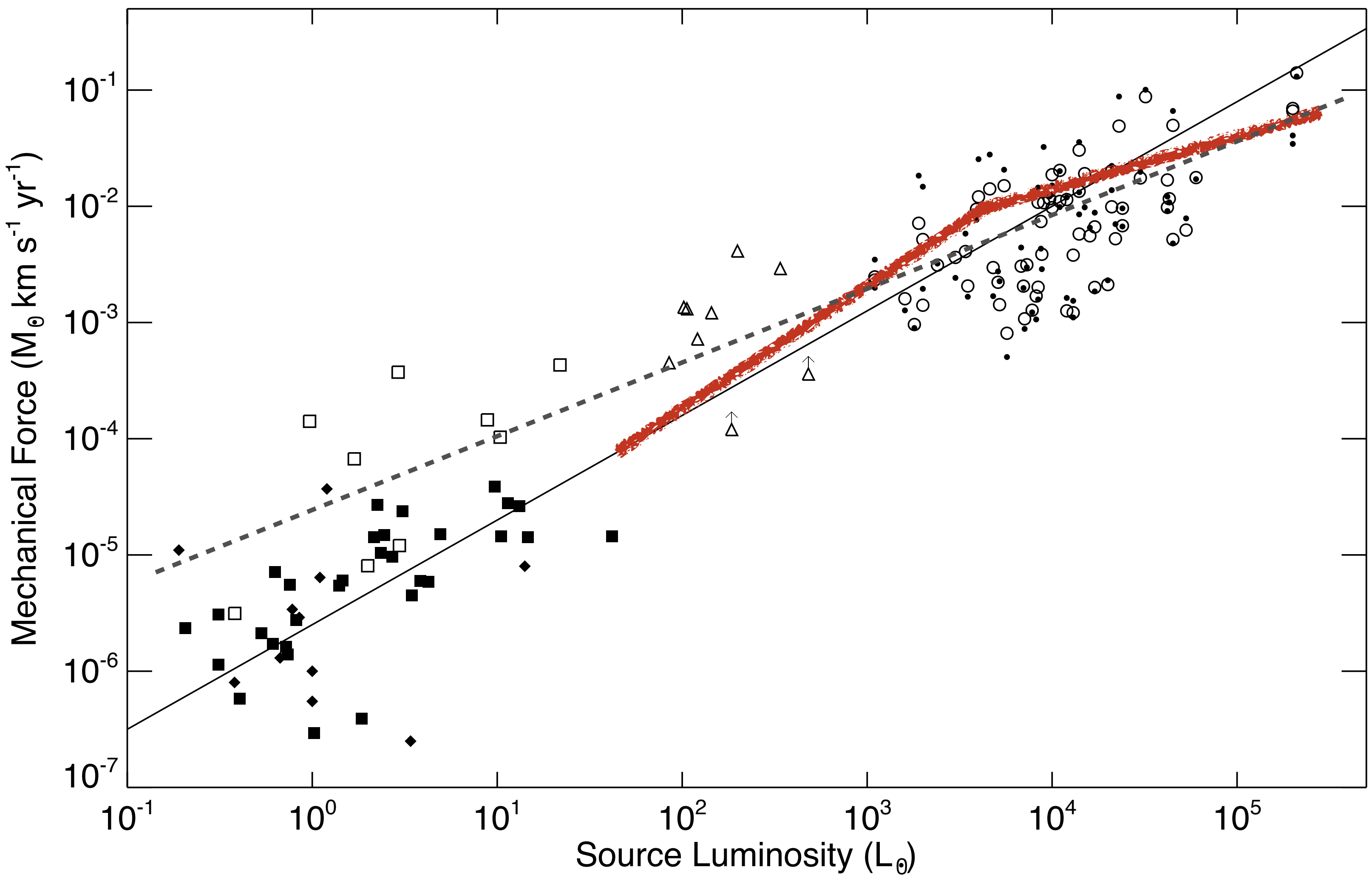

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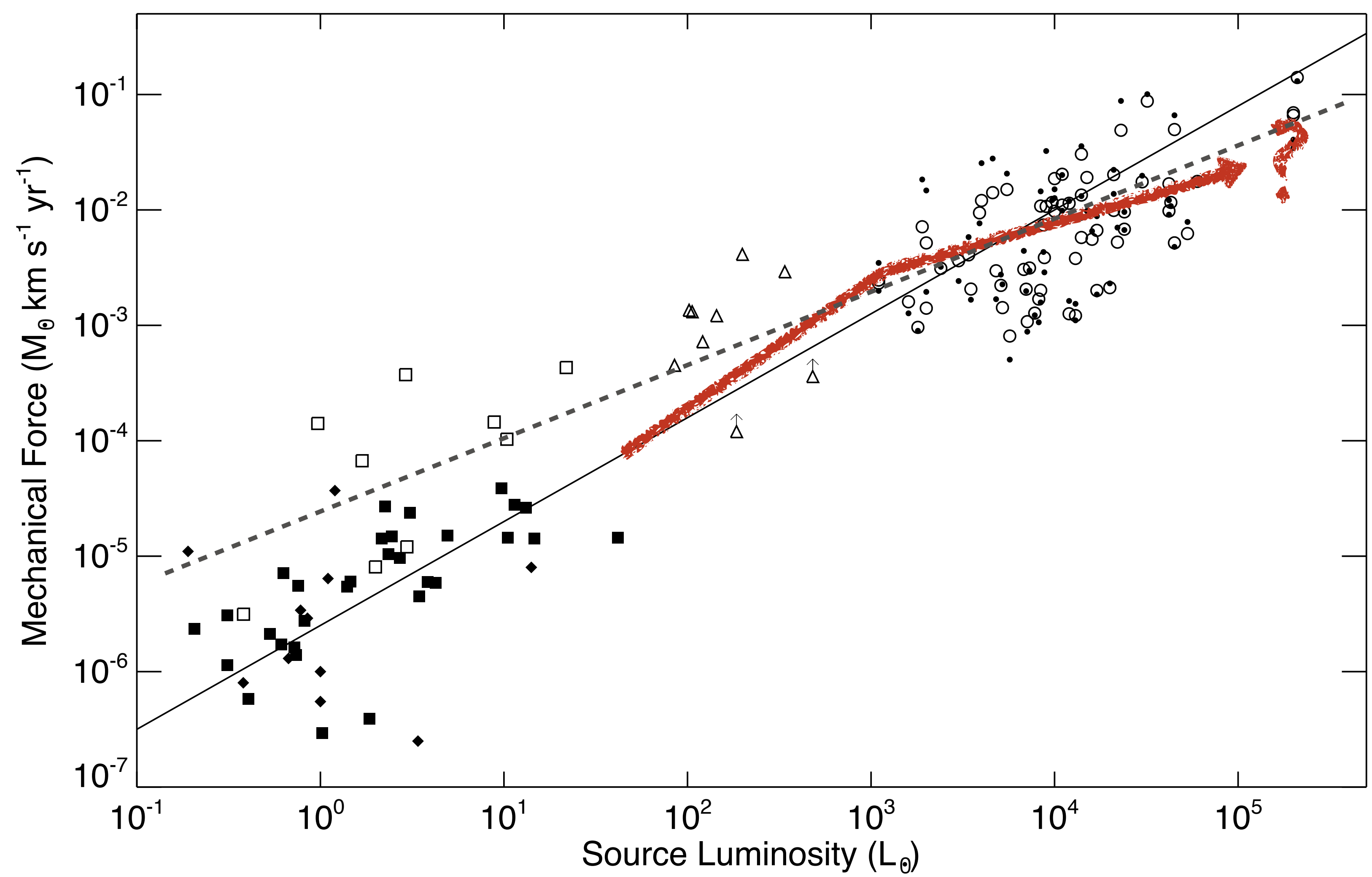
    - ~~Luminosity is that of most massive star only - M<8M⊙ protostars provide the outflow~~
    - Luminosity is that of most massive star only - M<6M⊙ protostars provide the outflow



Low-mass Analogues

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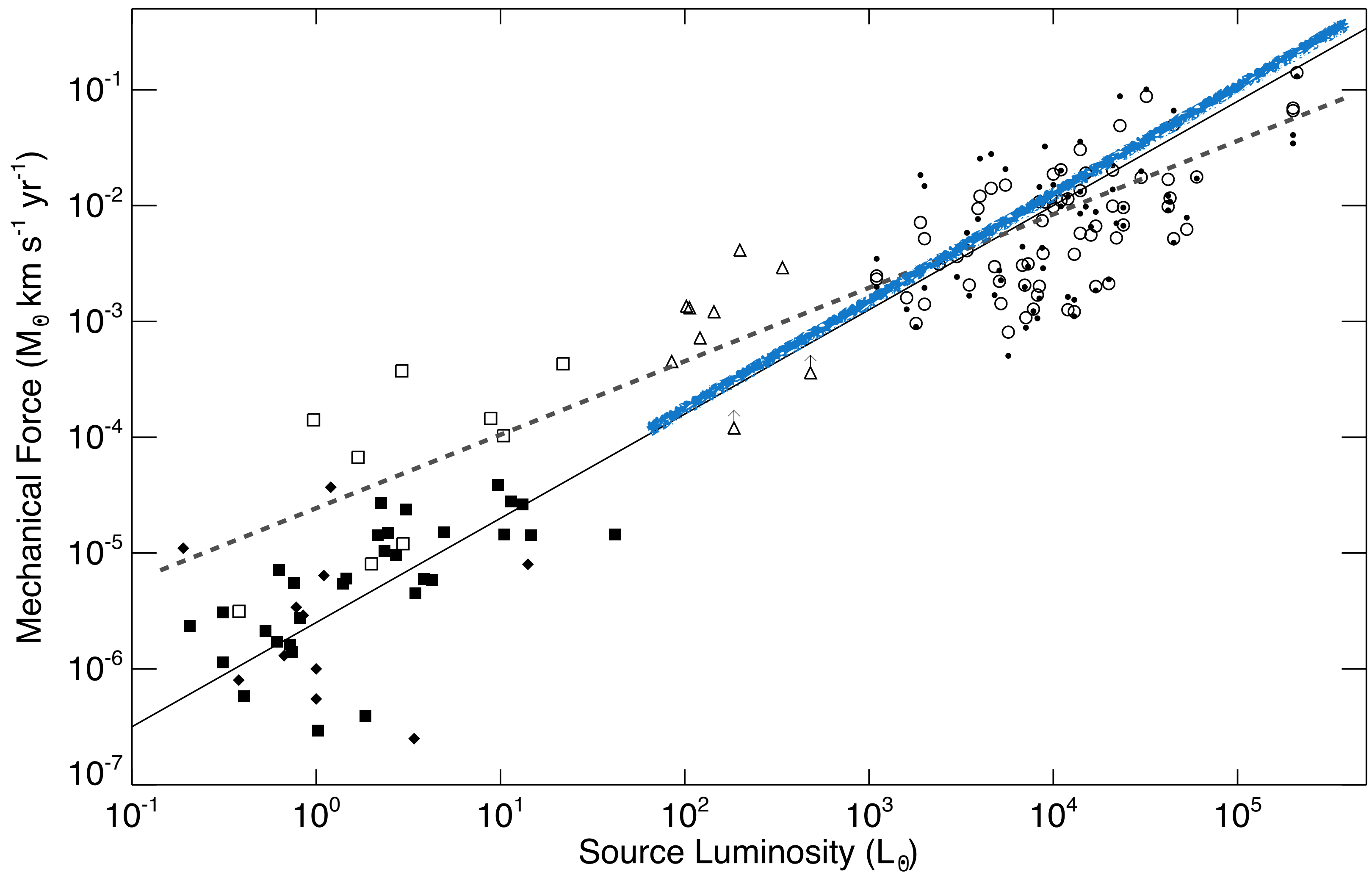
2 • Luminosity is that of the cluster - all protostars provide the outflow



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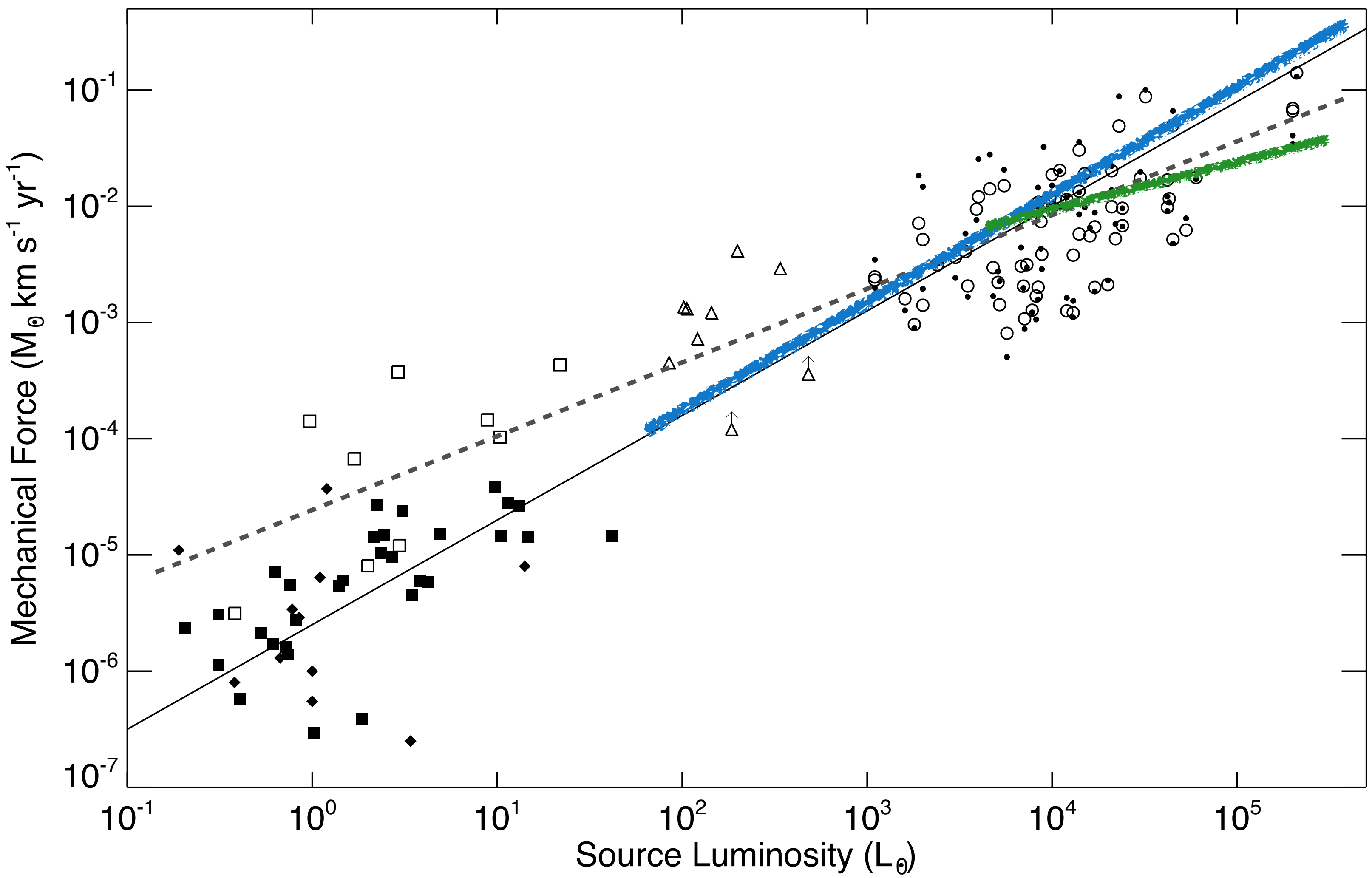


An Alternative Scenario...

- Mass is the sole driver

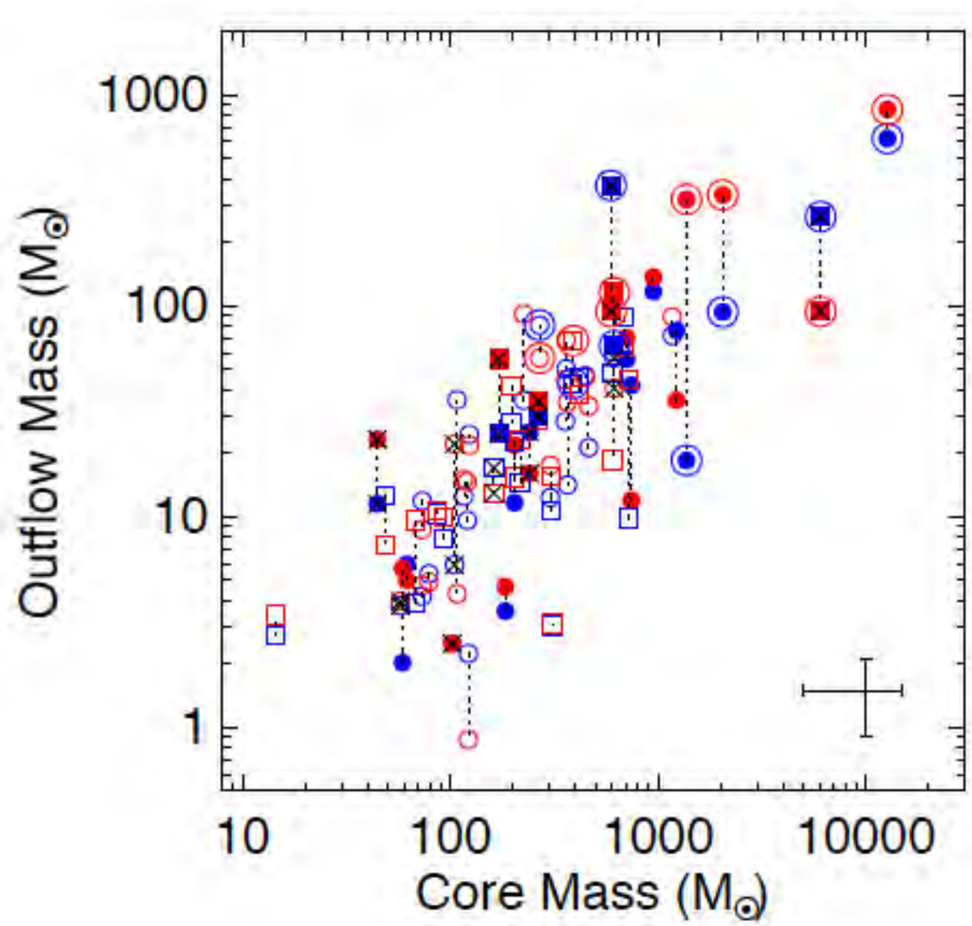
Ridge & Moore 2000

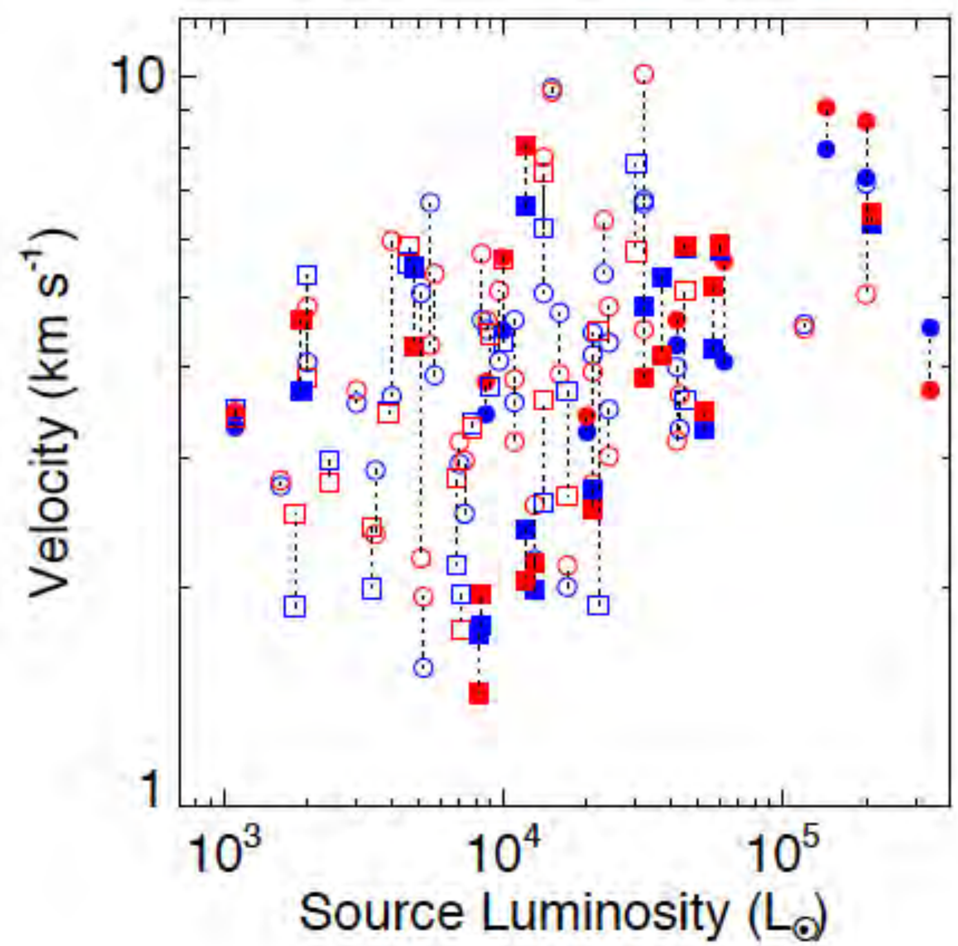
- Core-outflow mass slope 0.80

e.g. Beuther et al. 2002, de Villiers et al. 2014

- Slope of <V> vs. L only 0.12

➡entrained mass is the fundamental property - only depends on core mass





An Alternative Scenario...

- Mass is the sole driver
- Cor
- Slo

➡ent ... e mass

- Dyson 1984 - cannot conserve both momentum and energy
- Jets, if driving outflows may burst out of the cloud - unknown transfer of momentum/energy
- Similar parameters from other mass driving events

➡Outflow unrelated to driving mechanism, and therefore accretion mechanism

Outflow Mass ($M_\odot$)

10 100 1000 10000

Core Mass ($M_\odot$)

10^3 10^4 10^5

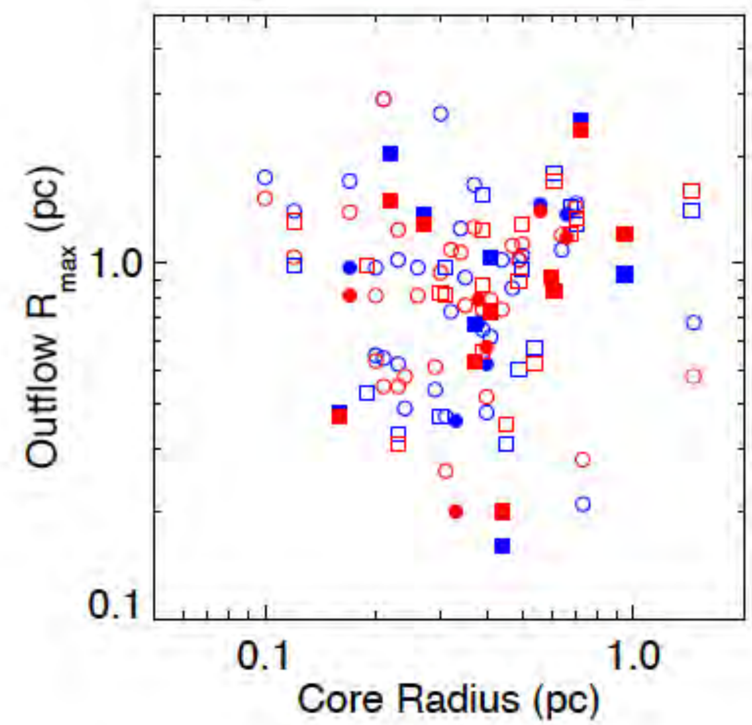
Source Luminosity ($L_\odot$)

An Alternative Scenario...

- Mass is the sole driver
- Cor
- Slo
- ➡ent ... e mass

➡HOWEVER

- Clear bipolar structure
- Core size and outflow size not related



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Summary

- Do massive stars form via discs in the same way as low-mass stars? ➡Maybe...
  - Outflow parameters scale from low to high-mass
  - Unclear if these are driven by only low and intermediate-mass protostars in the clusters
  - Mass could be the main driver of the relationships

Summary

- Do massive stars form via discs in the same way as low-mass stars? ➡Maybe...
  - Outflow parameters scale from low to high-mass
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Thank you - Questions?

Dynamical Timescale

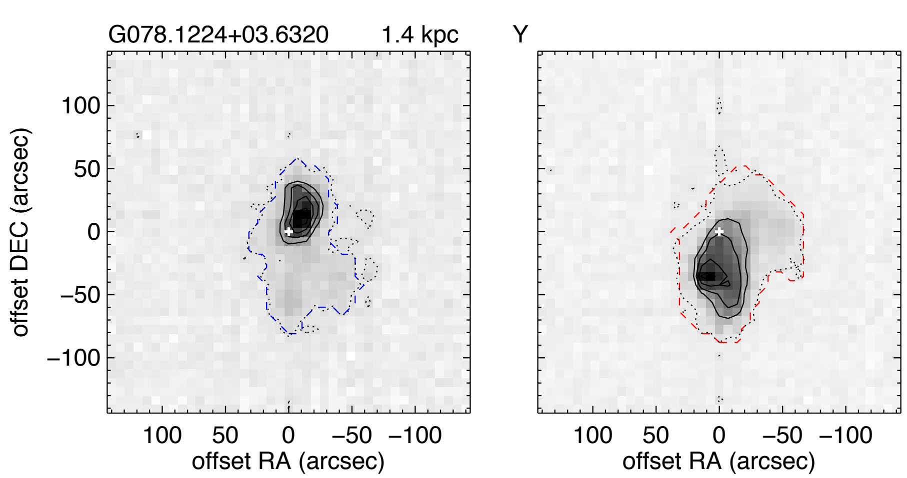
- We use position dependent to calculate outflow flow, force and luminosity

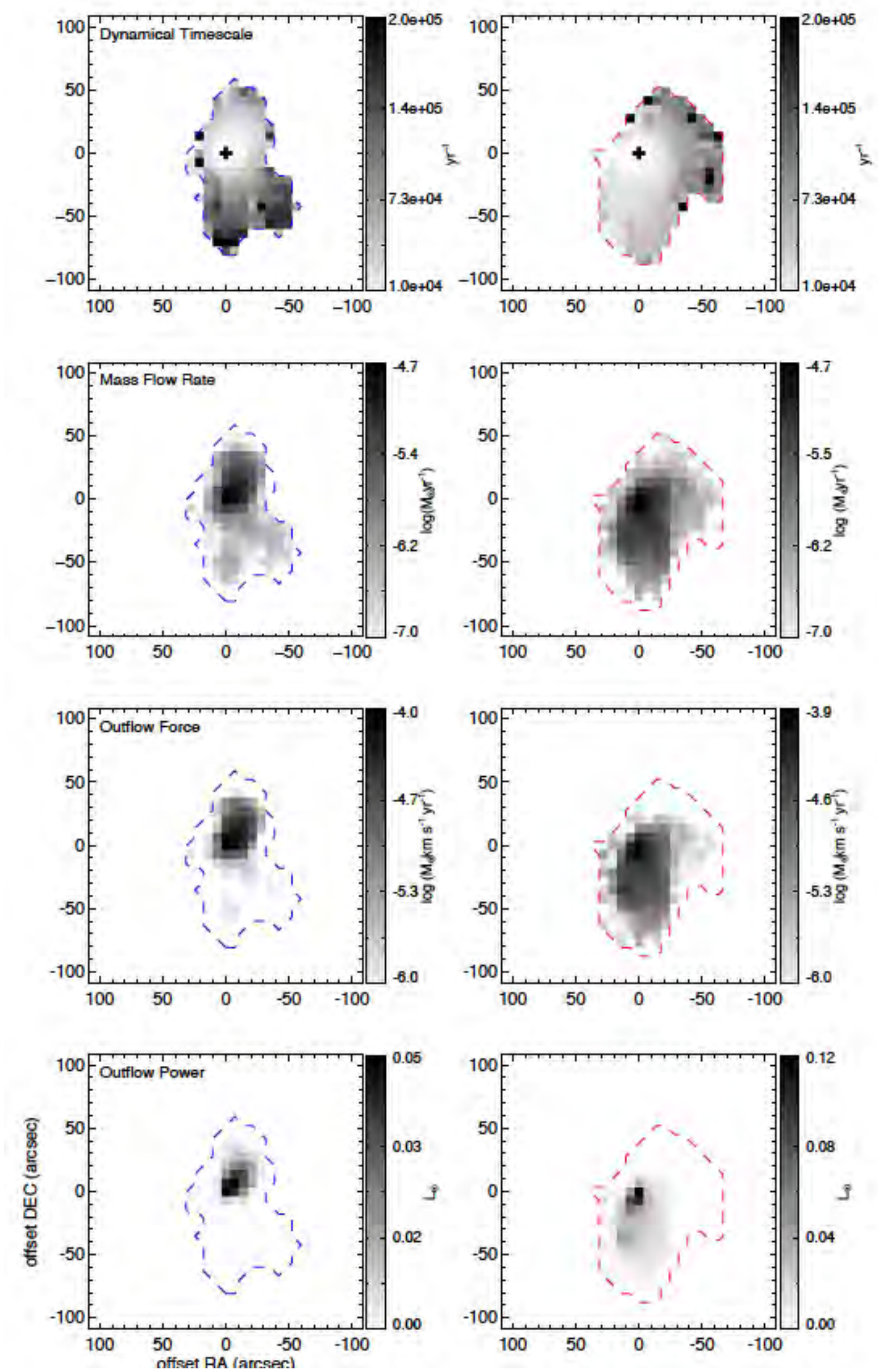
$$T_{dyn(x,y)} = R_{(x,y)} / \langle V_{(x,y)} \rangle$$

Lada & Fitch 1996

- $\langle V \rangle$ is better description of bulk velocity of the outflow

- Only low T_{dyn} contribute the most, i.e. larger velocity



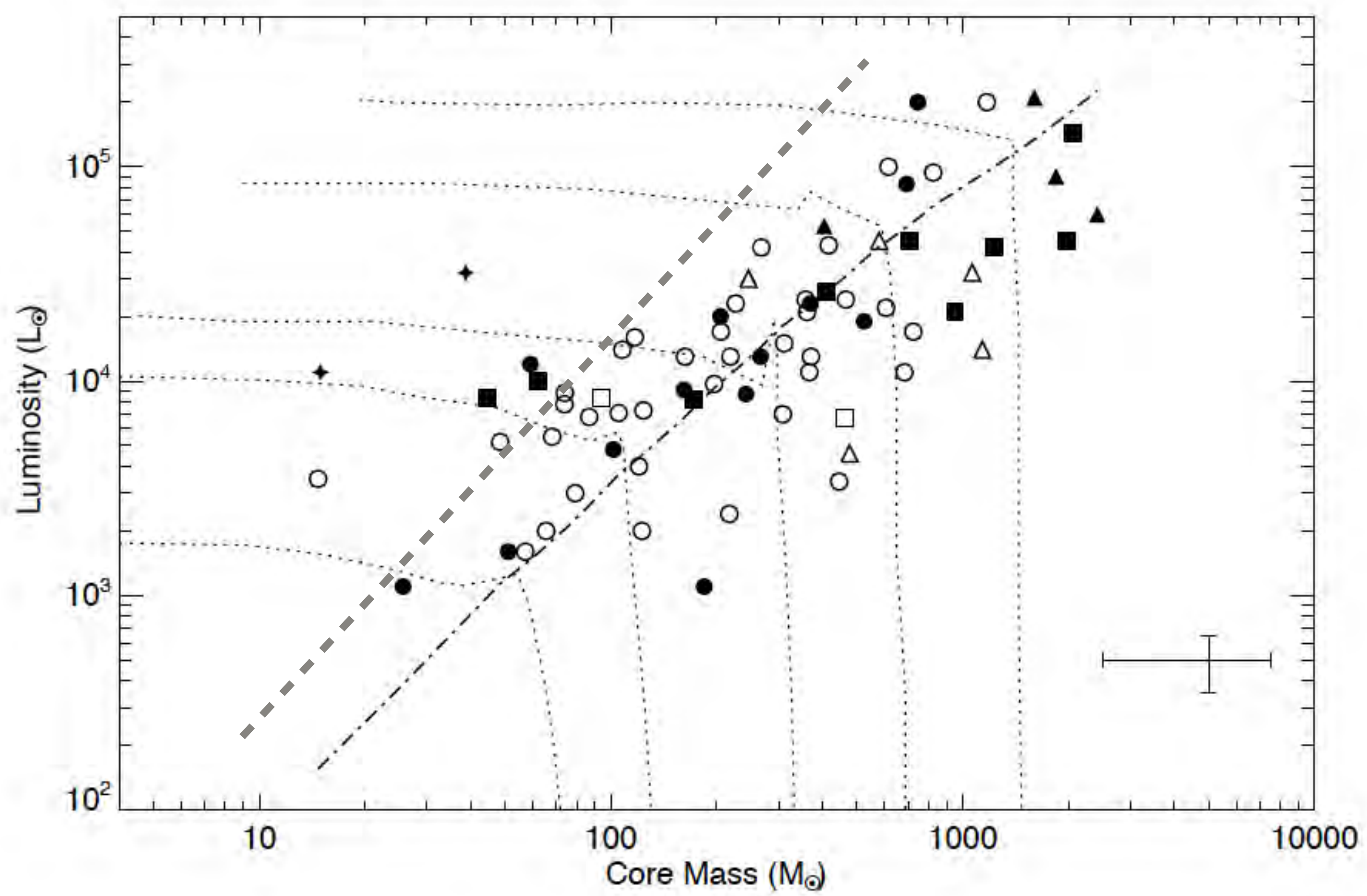


Accretion Rates

- Core mass vs. Luminosity
- ZAMS stars with 50% SFE
- Cluster luminosity - SFE 40%
- SFE = $M_{stars}/(M_{stars} + M_{core})$

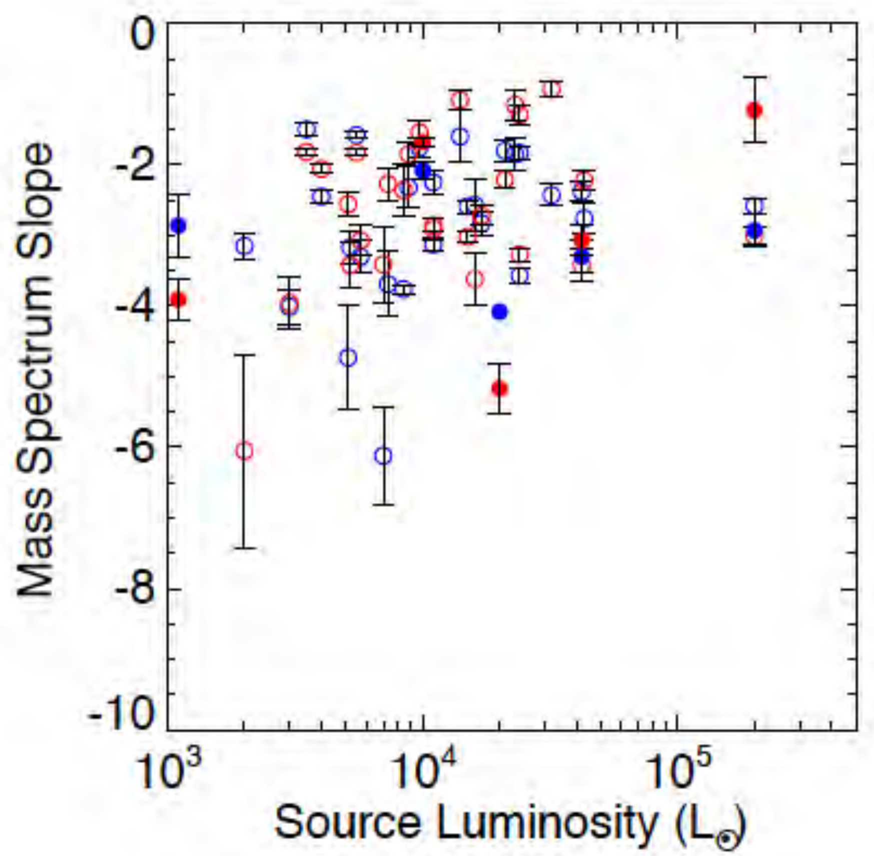
Lada & Lada 2003

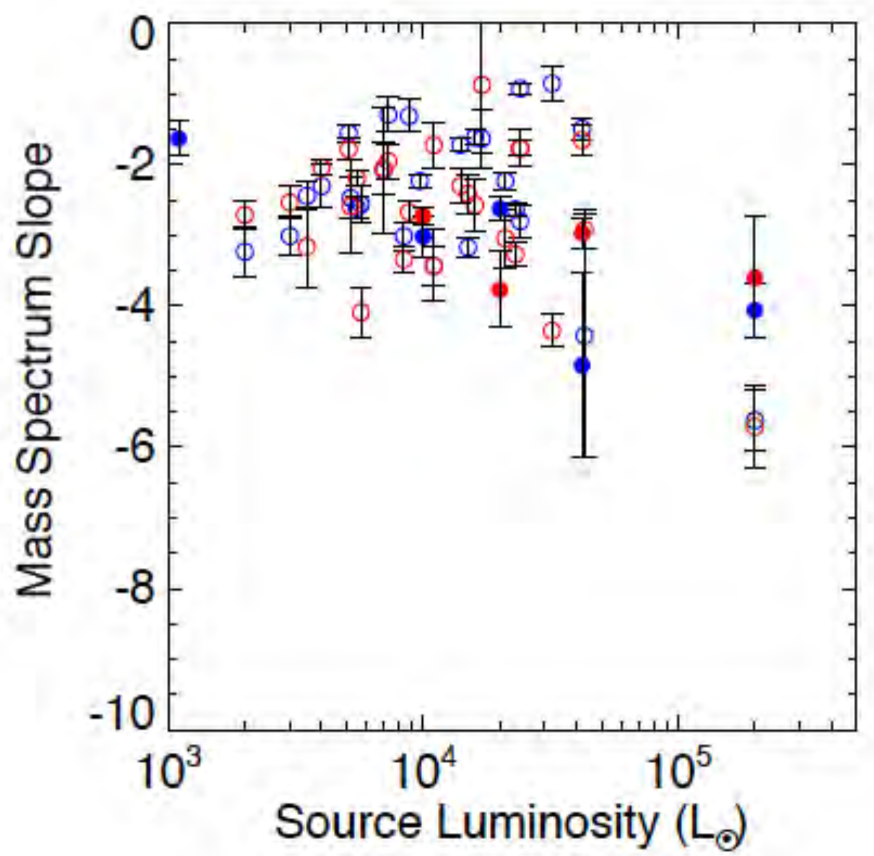
- Ideally all stars under ZAMS line (inc SFE)



Mass - Velocity Relation

- Mass spectrum due to jets ?
- Requires MHD collimation
- Optically thick and thin material have comparable slopes





Impact on the Core

- Turbulent and outflow energy are related
- Turbulent energy also scales with luminosity
- Cores with no outflows have comparable turbulent energy