MASSES: An SMA Large-Scale Program Surveying Protostars to Reveal How Stars Gain their Mass

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SMA science in the Next Decade
Friday, October 28, 2016

Image credit: Lynn Hilborn

Physical Processes Regulating Accretion

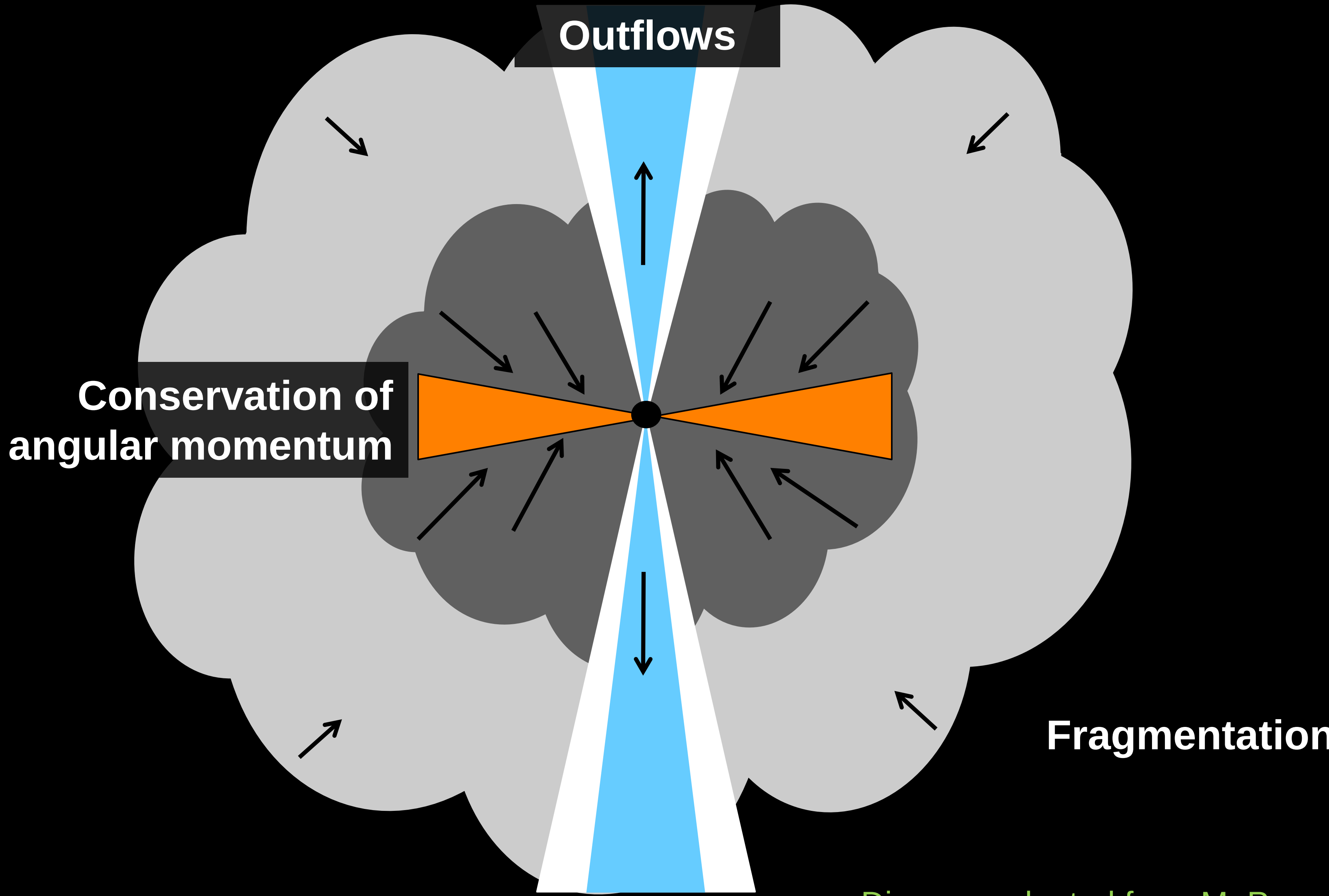
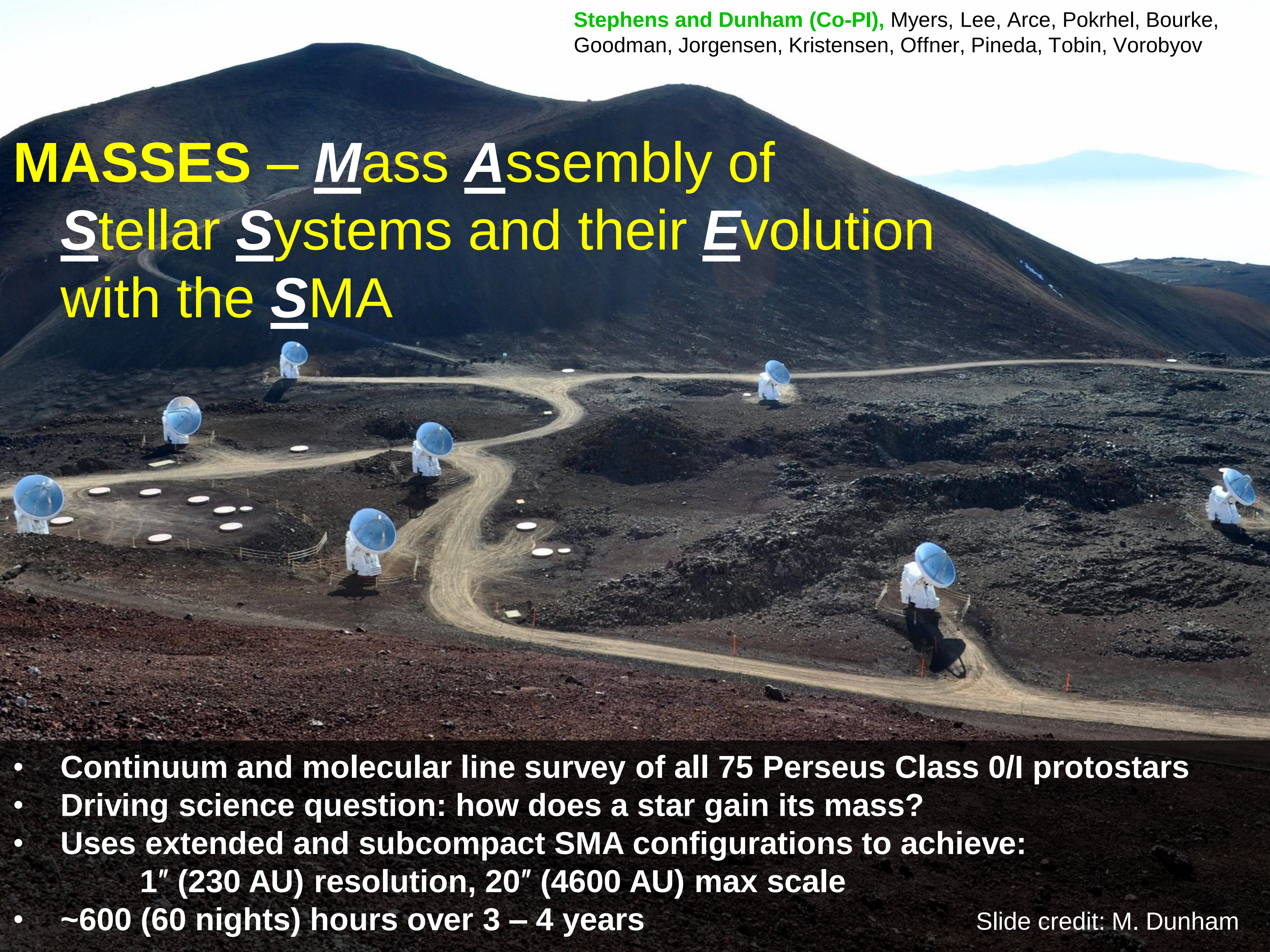


Diagram adapted from M. Persson

Stephens and Dunham (Co-PI), Myers, Lee, Arce, Pokrhel, Bourke, Goodman, Jorgensen, Kristensen, Offner, Pineda, Tobin, Vorobyov



MASSES – ***M***ass ***A***ssembly of ***S***tellar ***S***ystems and their ***E***volution with the ***S***MA

- **Continuum and molecular line survey of all 75 Perseus Class 0/I protostars**
- **Driving science question: how does a star gain its mass?**
- **Uses extended and subcompact SMA configurations to achieve:**
  1″ (230 AU) resolution, 20″ (4600 AU) max scale
- **~600 (60 nights) hours over 3 – 4 years**

Slide credit: M. Dunham

Observing Parameters

Subcompact

ASIC and SWARM+ASIC
230 GHz @ 4″ resolution
345 GHz @ 2.5″ resolution
Max angular scale: 20″

Extended

SWARM+ASIC and SWARM only
230 GHz @ 1″ resolution

230 GHz

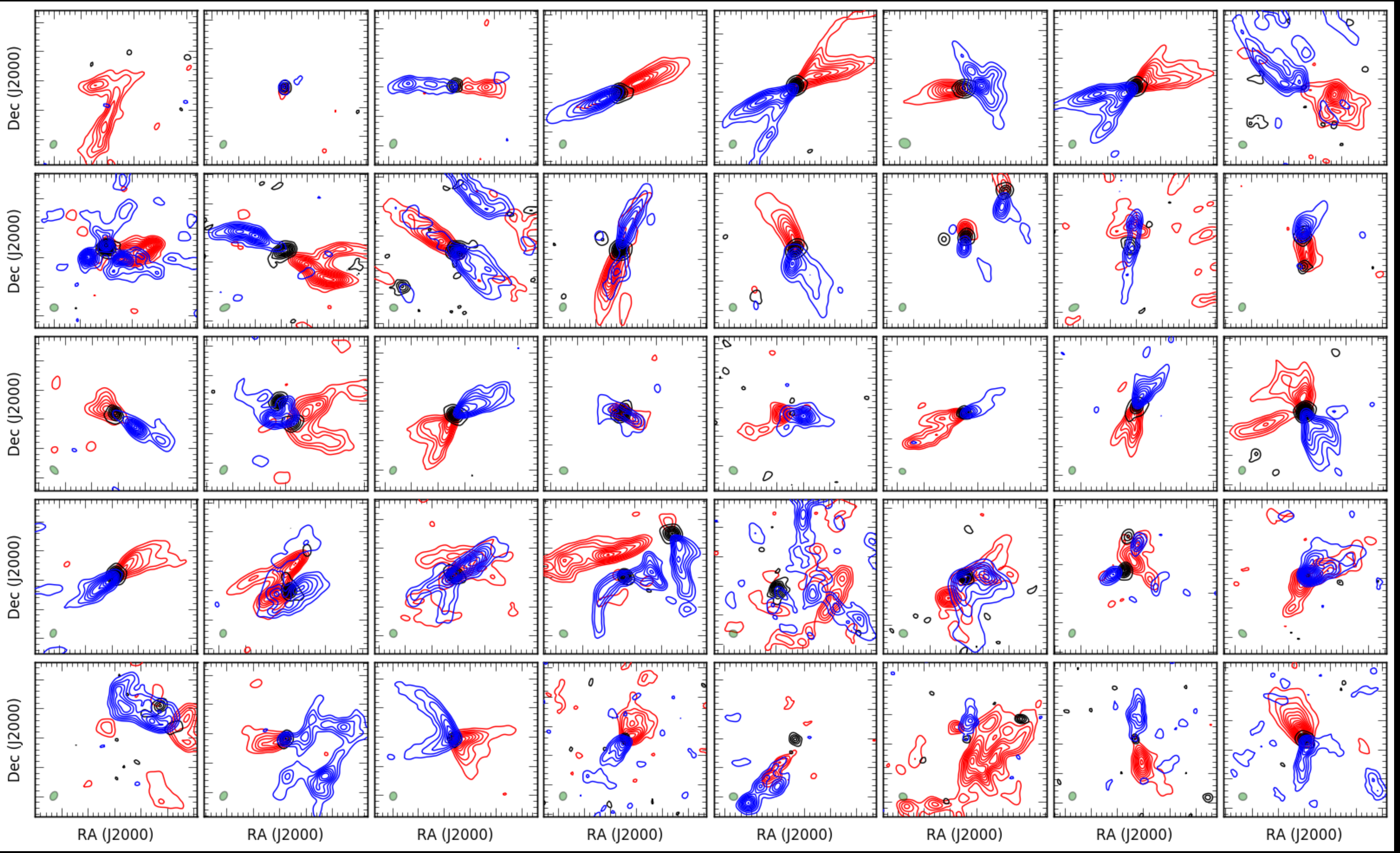
Continuum	Spectral Resolution
CO (2-1)	0.26 km/s
^{13}CO (2-1)	0.26 km/s
$C^{18}O$ (2-1)	0.13 km/s
N_2D^+ (3-2)	0.13 km/s

345 GHz

Continuum	Spectral Resolution
CO (3-2)	0.085 km/s
HCO^+ (4-3)	0.085 km/s
$H^{13}CO^+$ (4-3)	0.085 km/s

For all 75 Perseus Class 0/I Protostars!

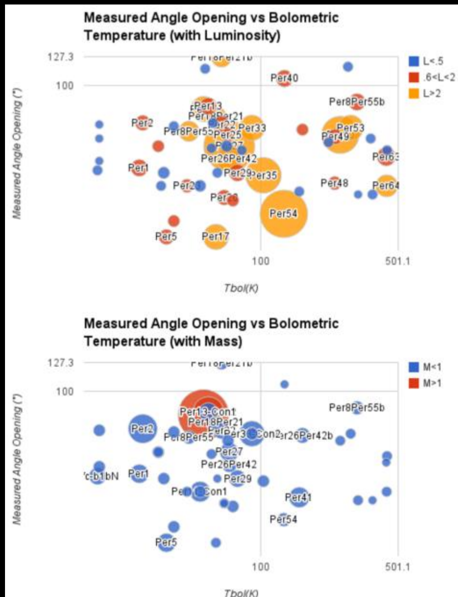
CO(2-1) Outflows



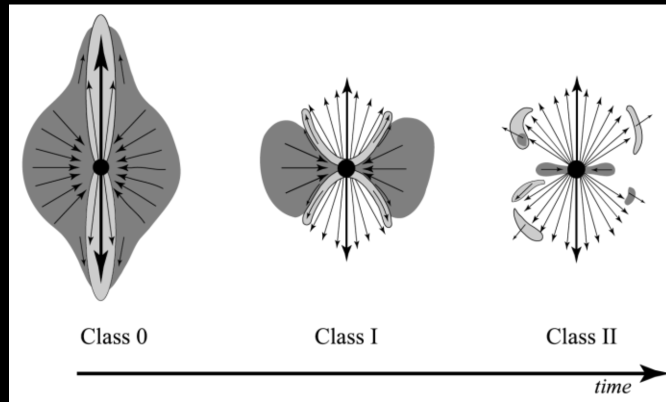
Stephens et al. (in preparation)

First MASSES Results

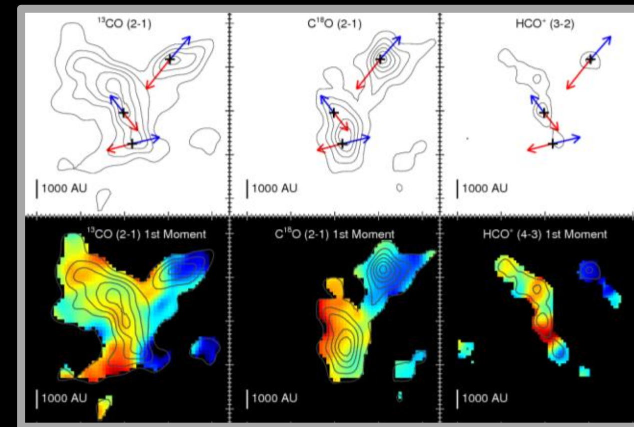
Oscar de la Rosa
CfA/UMass Lowell
Undergraduate



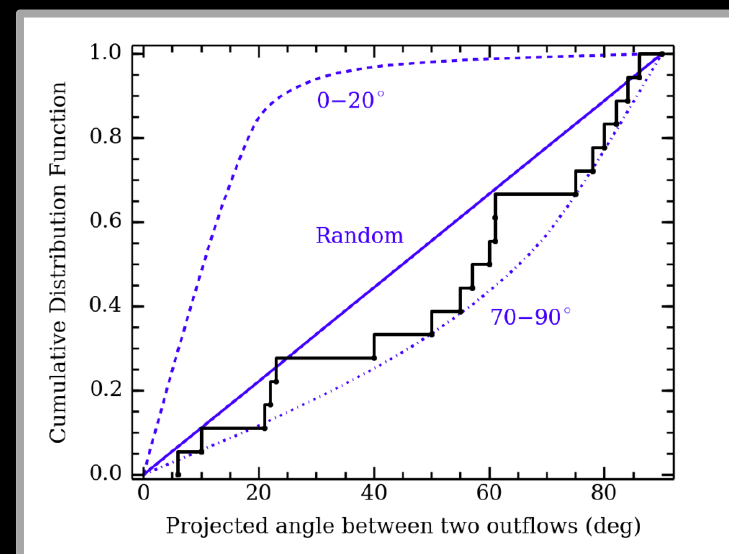
Sean Dillett
Harvard
Undergraduate



Katherine Lee
CfA Postdoctoral Fellow

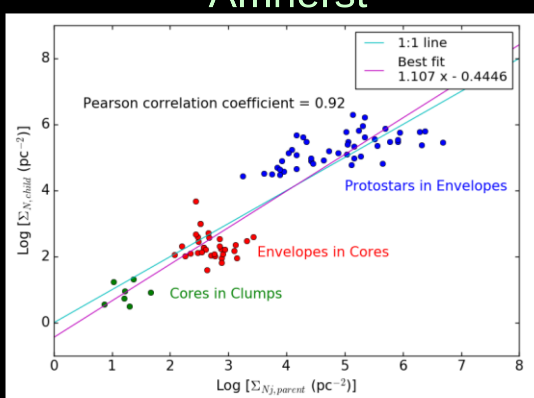


Kinematic origins of multiplicity
Lee et al. (2015)



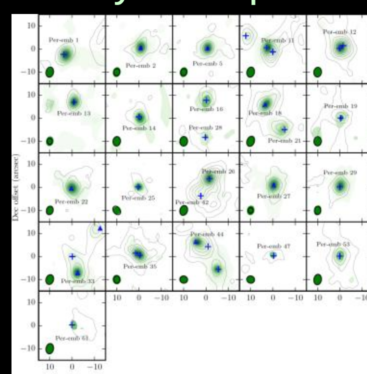
Multiple systems are preferentially randomly or anti-aligned
Lee et al. (2016), Offner (2016)

Riwaj Pokrehl
CfA Predoc/UMass Amherst



Hierarchical Fragmentation

Soren Frimann
University of Copenhagen



Episodic Accretion
Soren et al. (submitted)

Accretion

Multiplicity/Fragmentation

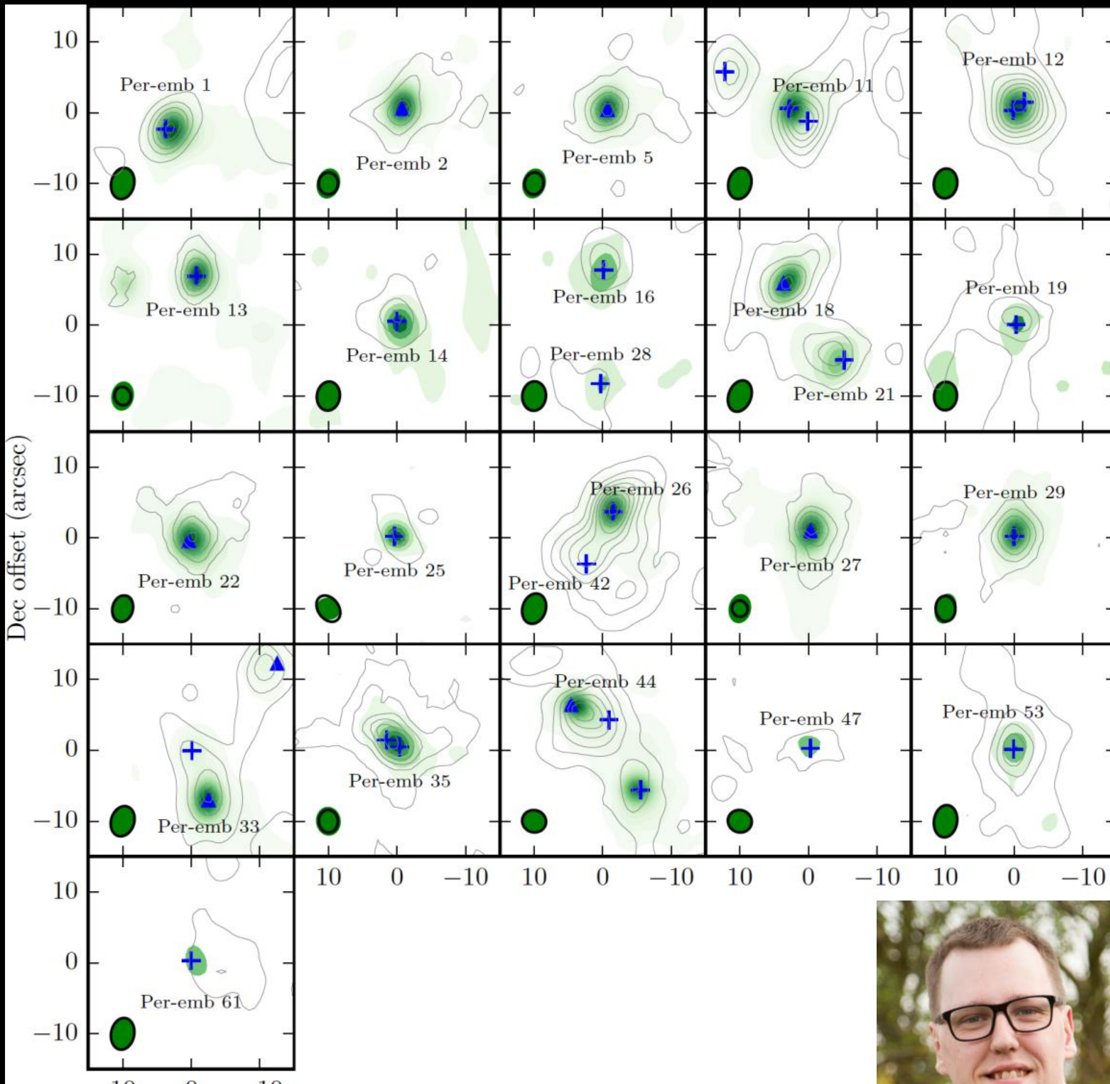
Angular Momentum/Outflows

Accretion

Protostellar accretion traced with chemistry

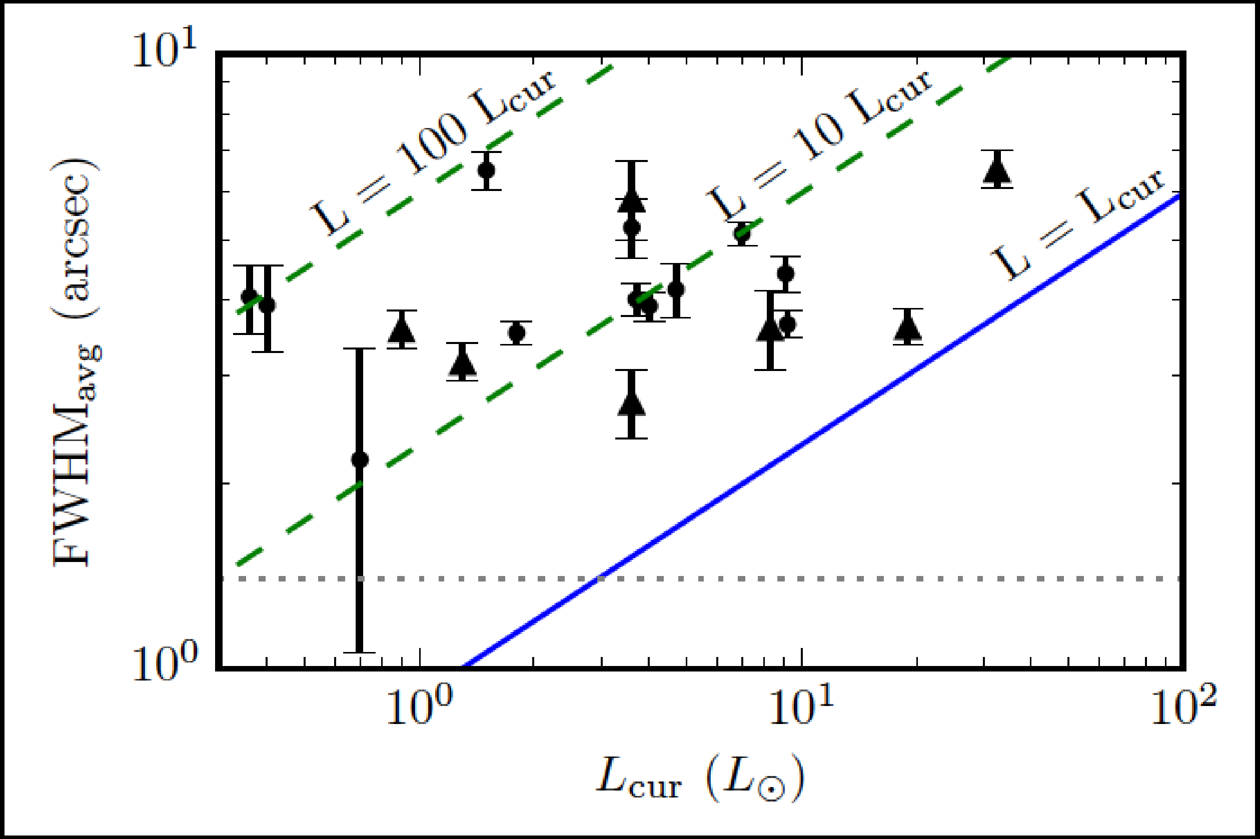
Is protostellar accretion purely gradual, or is it episodic?

- **Depending on temperature CO and $C^{18}O$ can both sublime and freeze-out with the dust grains**
- **Compare current luminosity with expected size based on chemical modeling**



Søren Frimann et al. (submitted)

Protostellar accretion traced with chemistry

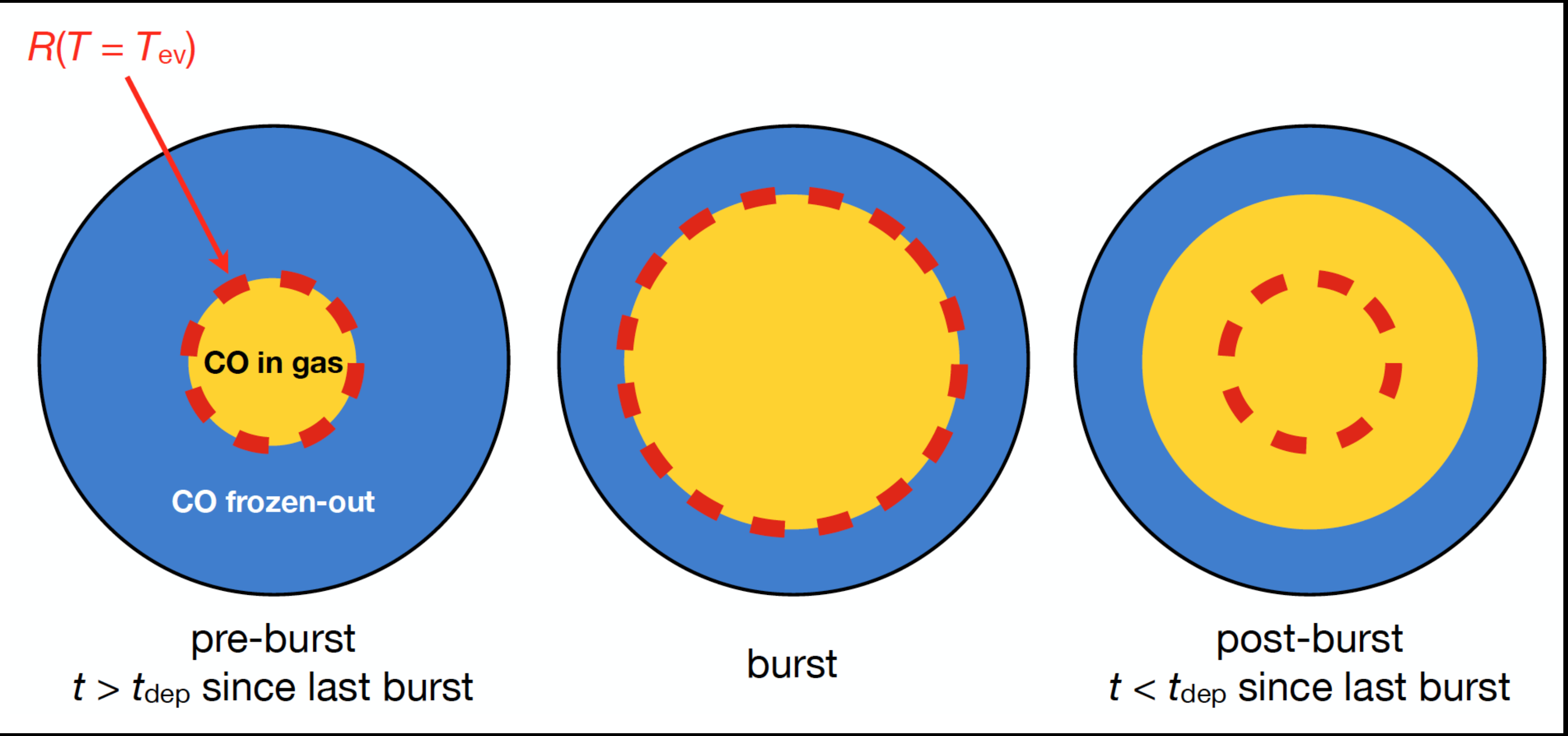


Frimann et al. (submitted)

Blue line: Expected size of $C^{18}O$ for protostars' current luminosity
Dashed Green lines: Expected size for 10 and 100 times current luminosity

Observed sizes are much larger!

Can be explained by Episodic Accretion!!!



Jørgensen et al. (2015)

Based on sizes of $C^{18}O$ sizes, accretion bursts every ~10,000 years

Multiplicity/Fragmentation

Thermal Jeans Fragmentation

Thermal Jeans Mass (Spitzer formulation):

$$M_J = \bar{\rho}\lambda_J^3$$

where $\lambda_J = \frac{\pi^{1/2}\sigma}{(G\bar{\rho})^{1/2}}$

Jeans number

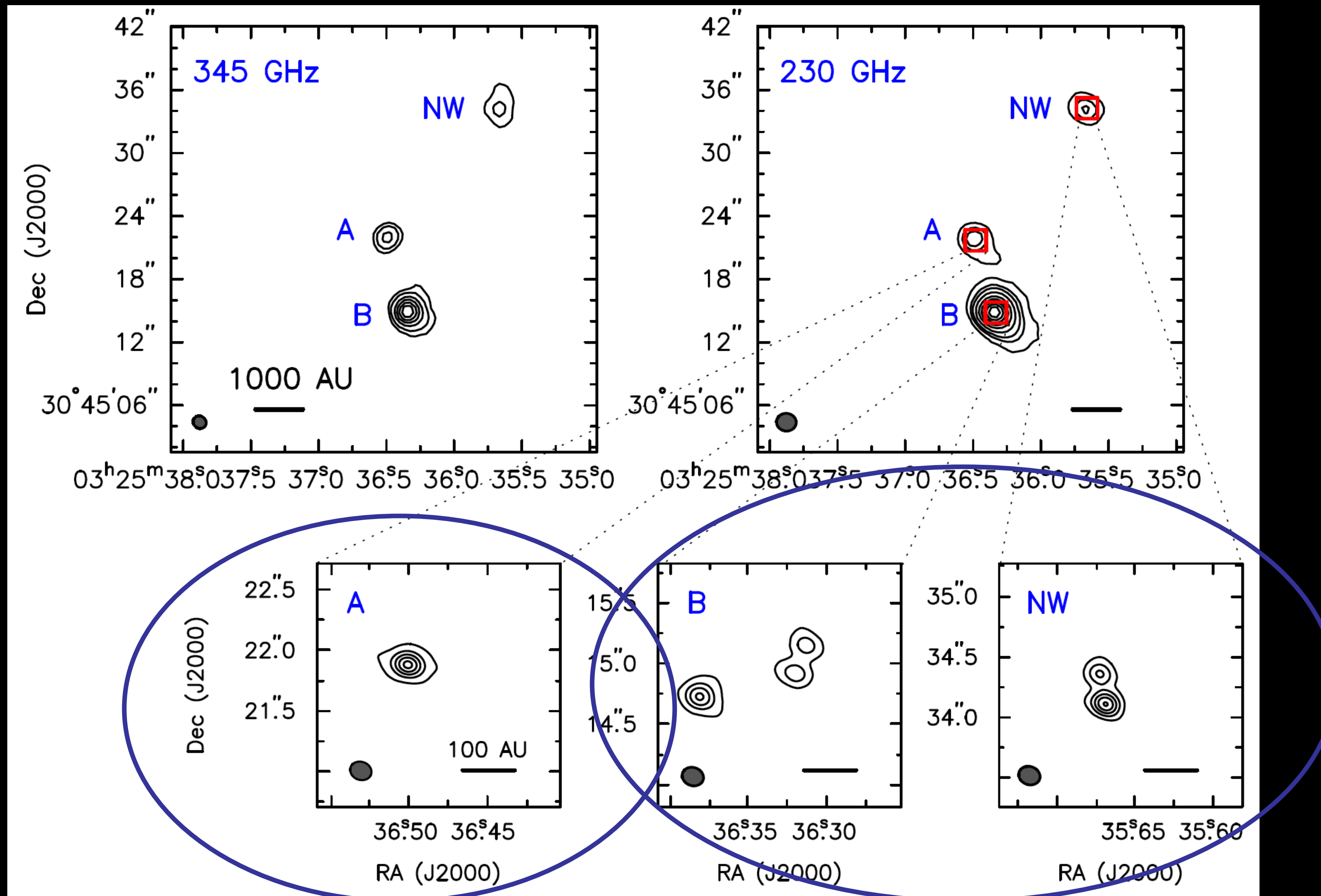
$$N_J = \frac{M}{M_J}$$

Larger N_J, fragmentation more likely

Thermal Jeans Fragmentation

MASSES
SMA

VLA



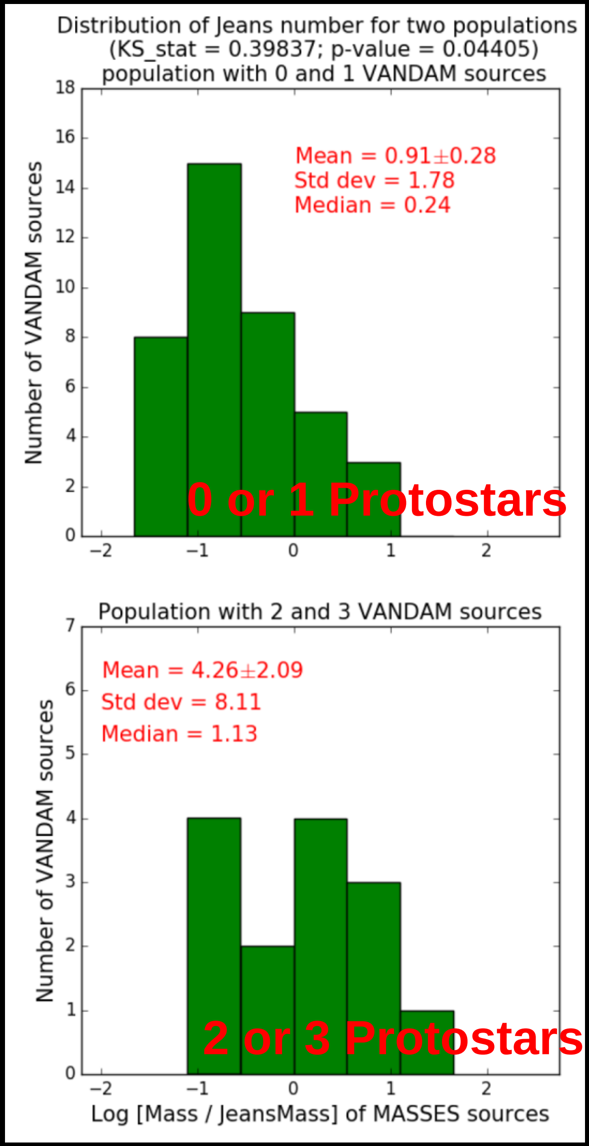
Lowest Jeans Number **Much Higher Jeans Numbers**

Lee et al. (2015)

Thermal Jeans Fragmentation

Given the Jeans number for each SMA envelope, how many protostars found with VLA?

Number in Bin



Log Jeans Number

Higher Jeans Number ➢ More Multiples!!!

Riwaj Pokrehl et al. (in prep)

Thermal Jeans Fragmentation

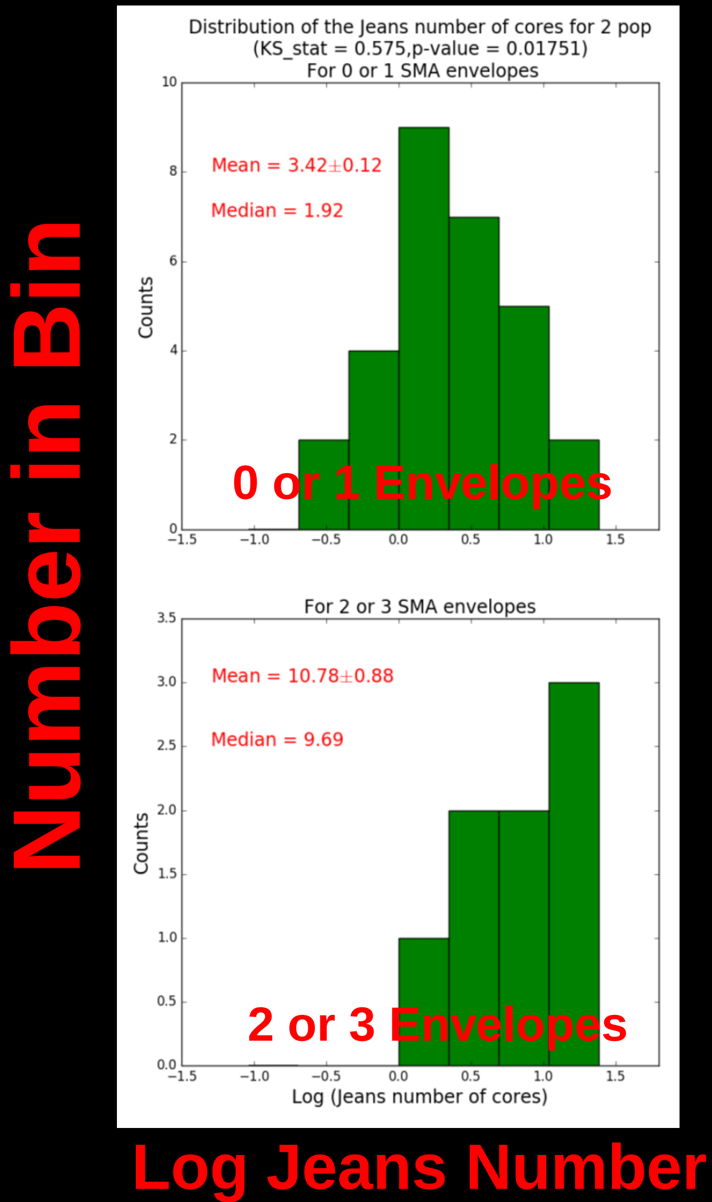
Higher multiplicity for Higher Jeans number seen at larger scales too!!

Envelope to Protostar
(few 1000 AU to 100 AU)

Core to Envelope
(~0.1 pc to few 1000 AU)

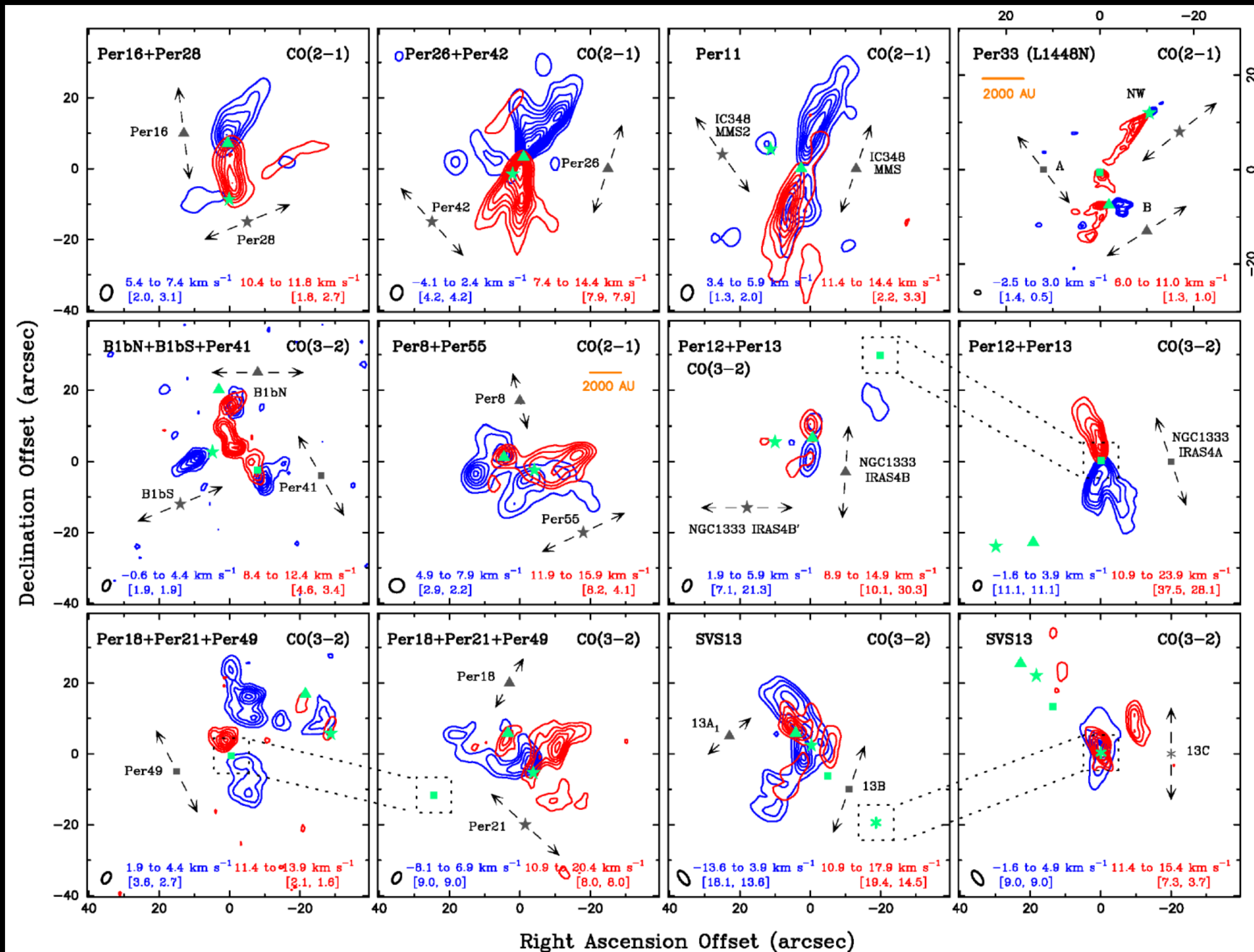
Clump to Core
(few pc to ~0.1 pc scales)

Pokrehl et al. (in prep)



Angular Momentum/Outflows

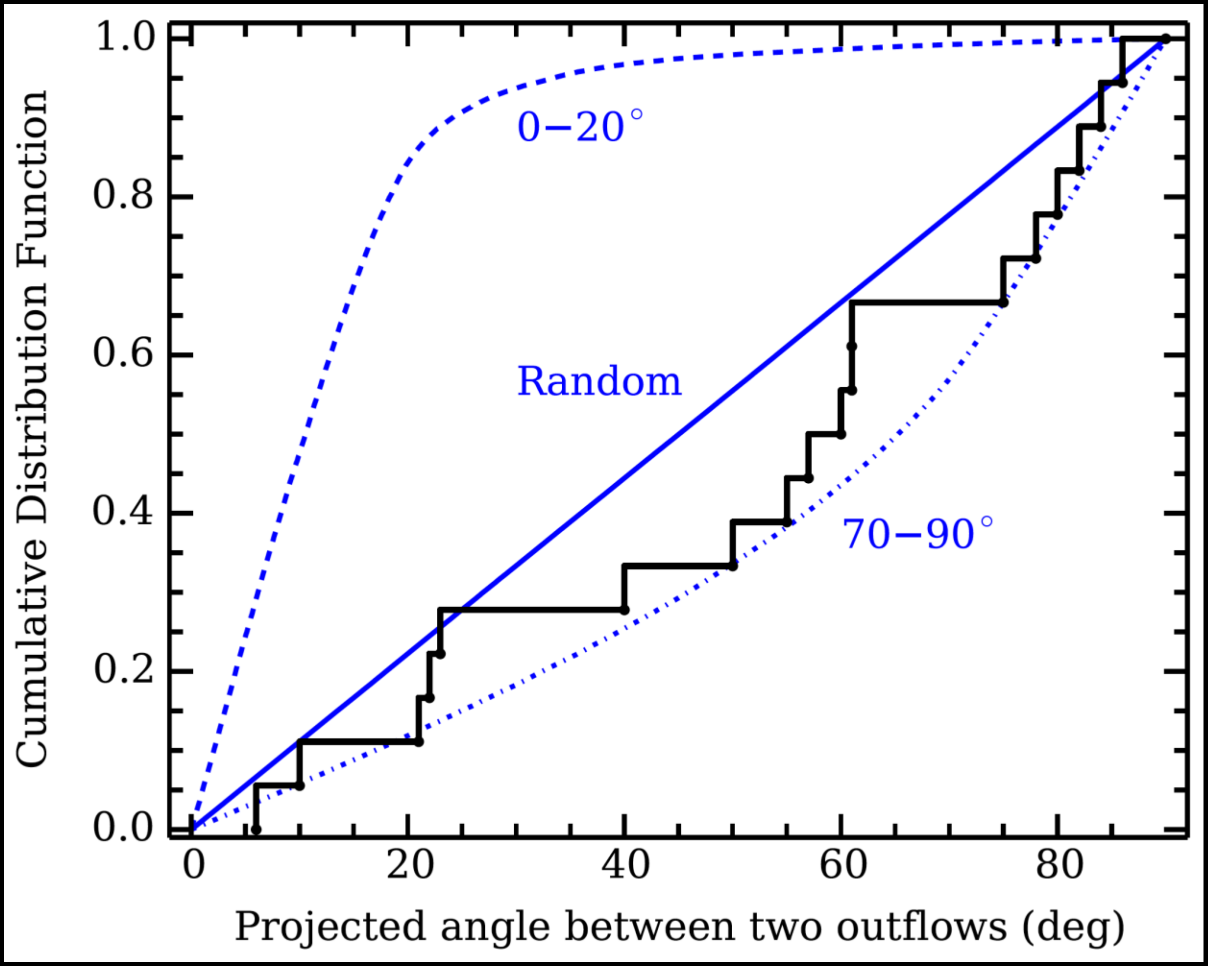
Misalignment of Outflow Axes



Wide Binaries separated by 1000 – 10000 AU

Lee et al. (2016)

Misalignment of Outflow Axes



Preferentially Perpendicular or Misaligned!

Lee et al. (2016)

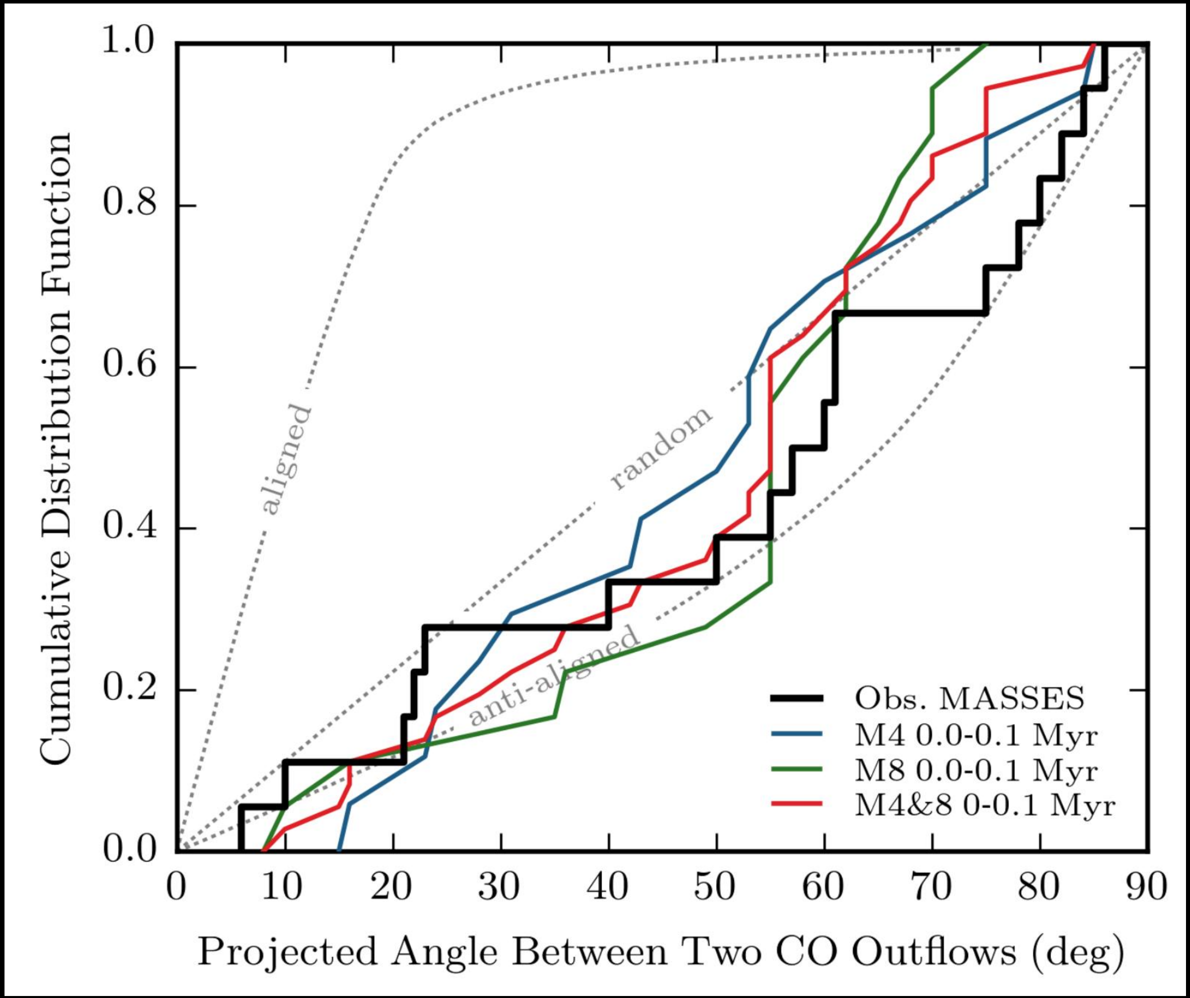
Misalignment of Outflow Axes

3D MHD Simulations

Initial uniform field with mass to flux ratio of about ~2

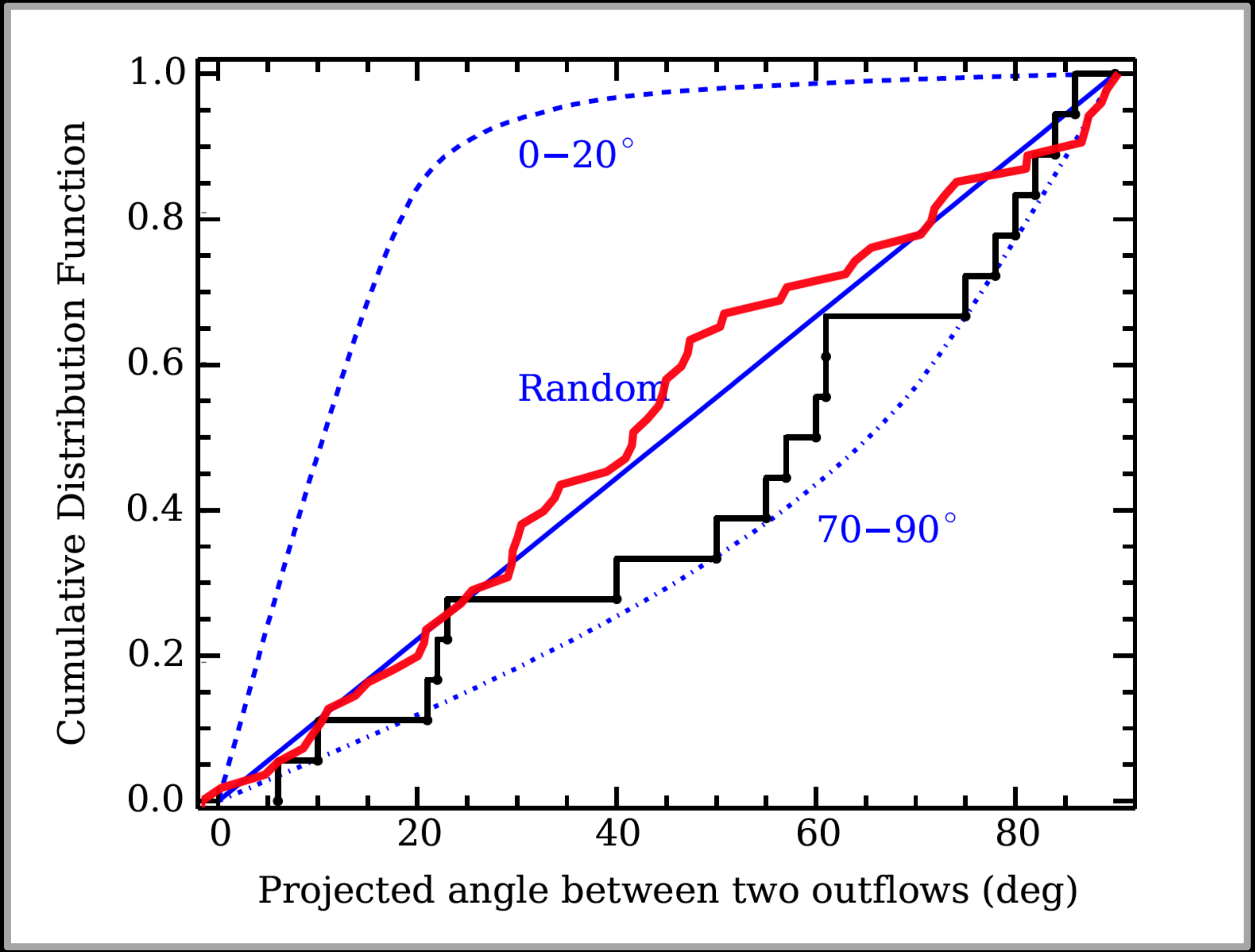
Stars form via turbulent fragmentation of cores

Signature of binary formation via turbulent fragmentation



Offner et al. (2016)

Misalignment of Outflow Axes

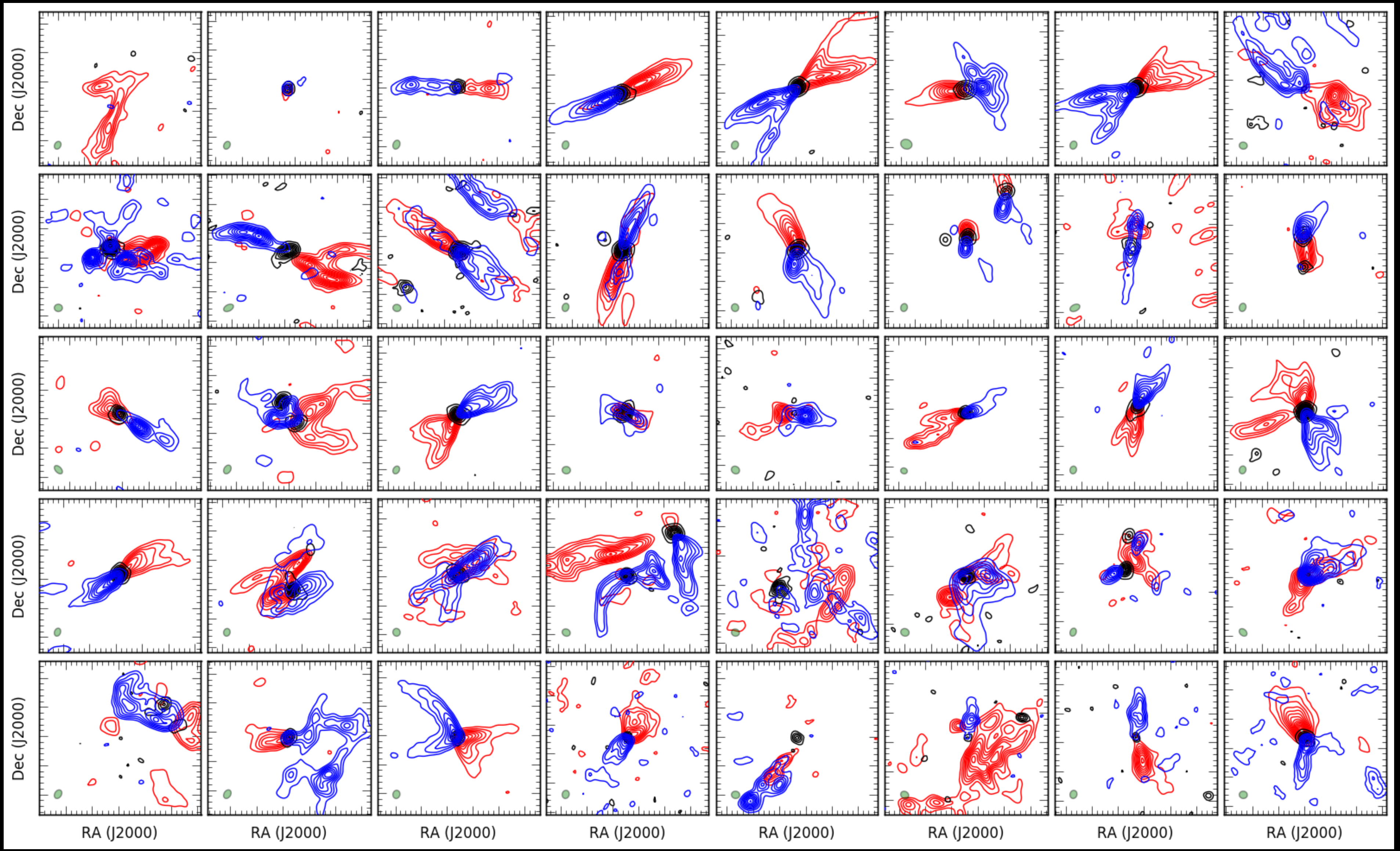


Red: Projected angle between Planck B-field and Outflow

Lee et al. (2016)

Stephens et al. (in prep)

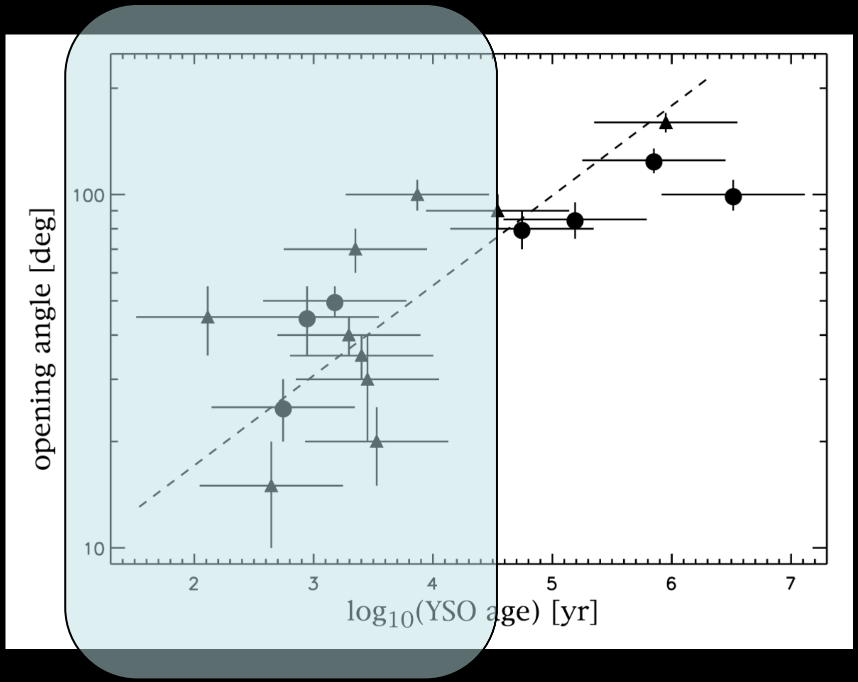
Outflow Opening Angle Versus Age



Stephens et al. (in preparation)

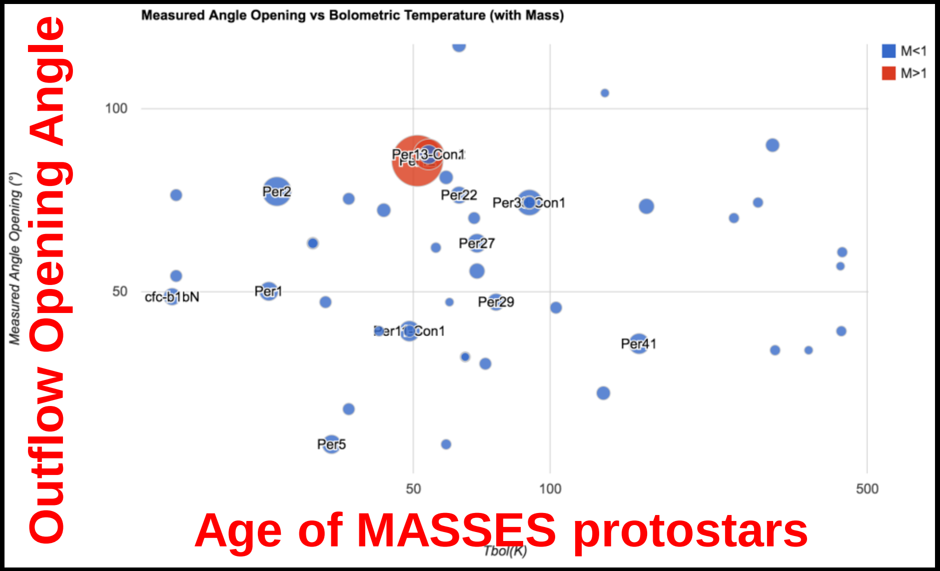
Outflow Opening Angle Versus Age

Does the opening angle of an outflow evolve with age?



Arce & Sargent (2006)

Age of MASSES protostars



Oscar de La Rosa et al. (in prep)

MASSES Summary

Survey of all 75 Class 0/I protostars in the Perseus molecular cloud

Largest molecular line survey in a single region at this resolution

Many people working on the project

Will provide major statistical constraints of outflows, multiplicity, protostellar evolution

Happy to share data: ian.stephens@cfa.harvard.edu