Kinematics of molecular cloud cores in driven and decaying turbulence: Comparison with Observations

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KITP 11/16/07

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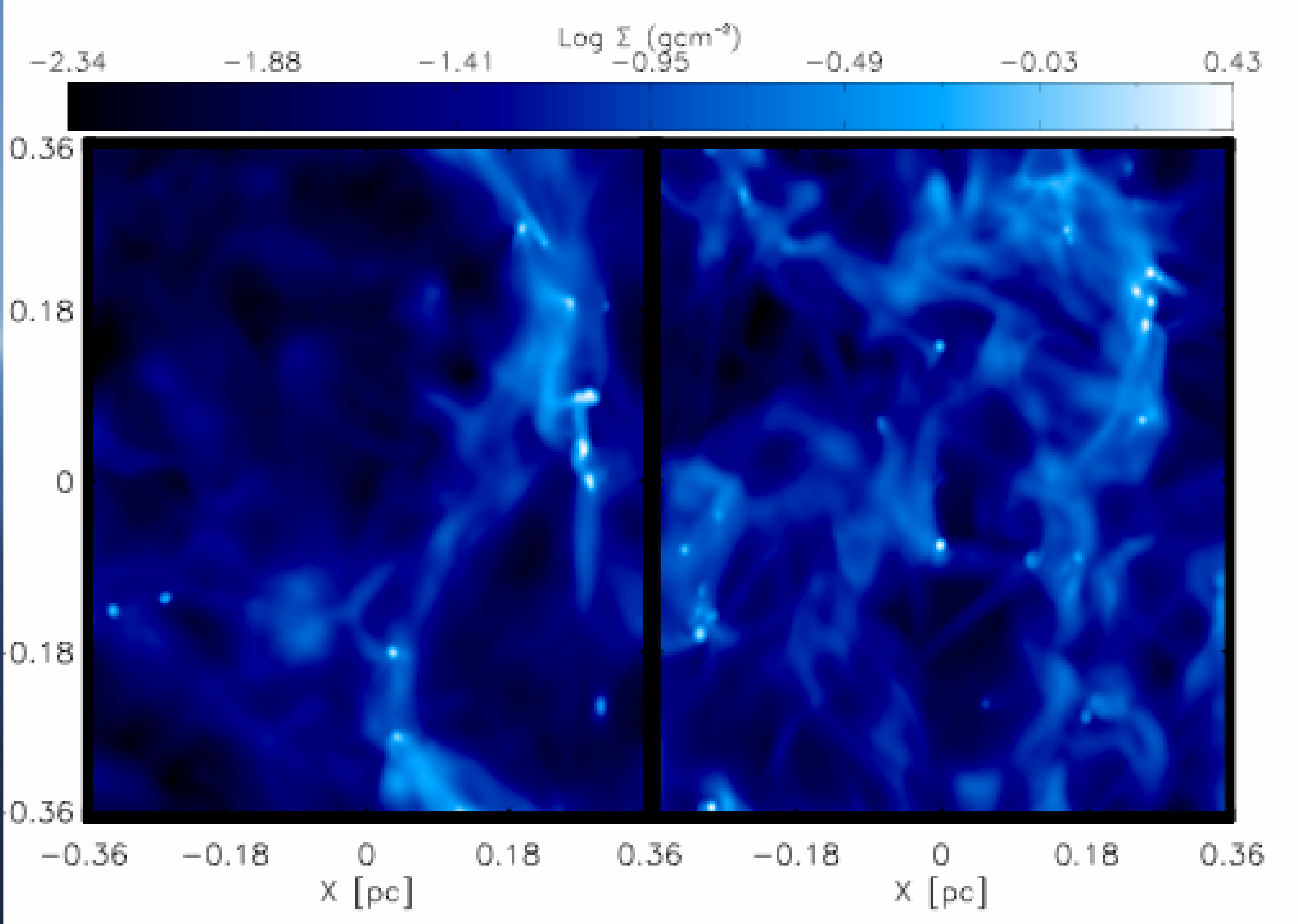
Outline

- Simulations
- Post-processing
- Kinematic information
  - Core velocity dispersions (2nd moments)
  - Core centroid velocities (1st moments)
  - Dispersion of the centroids
- Observational comparisons

Simulations

- 3D isothermal hydrodynamic AMR with self-gravity
- Effective resolution of 2048^3
- Mach=5, k=3..4
- Sink particles
- T=20K, M=1150Msun, L=2pc
- Initialization: drive turbulence for $2t_c$ without self-gravity
- Compare statistics at $1t_{ff}$ for two cases:
    - Continually driven: Mach number is constant,α~1
    - “Decaying”: turbulent driving is halted

Simulations

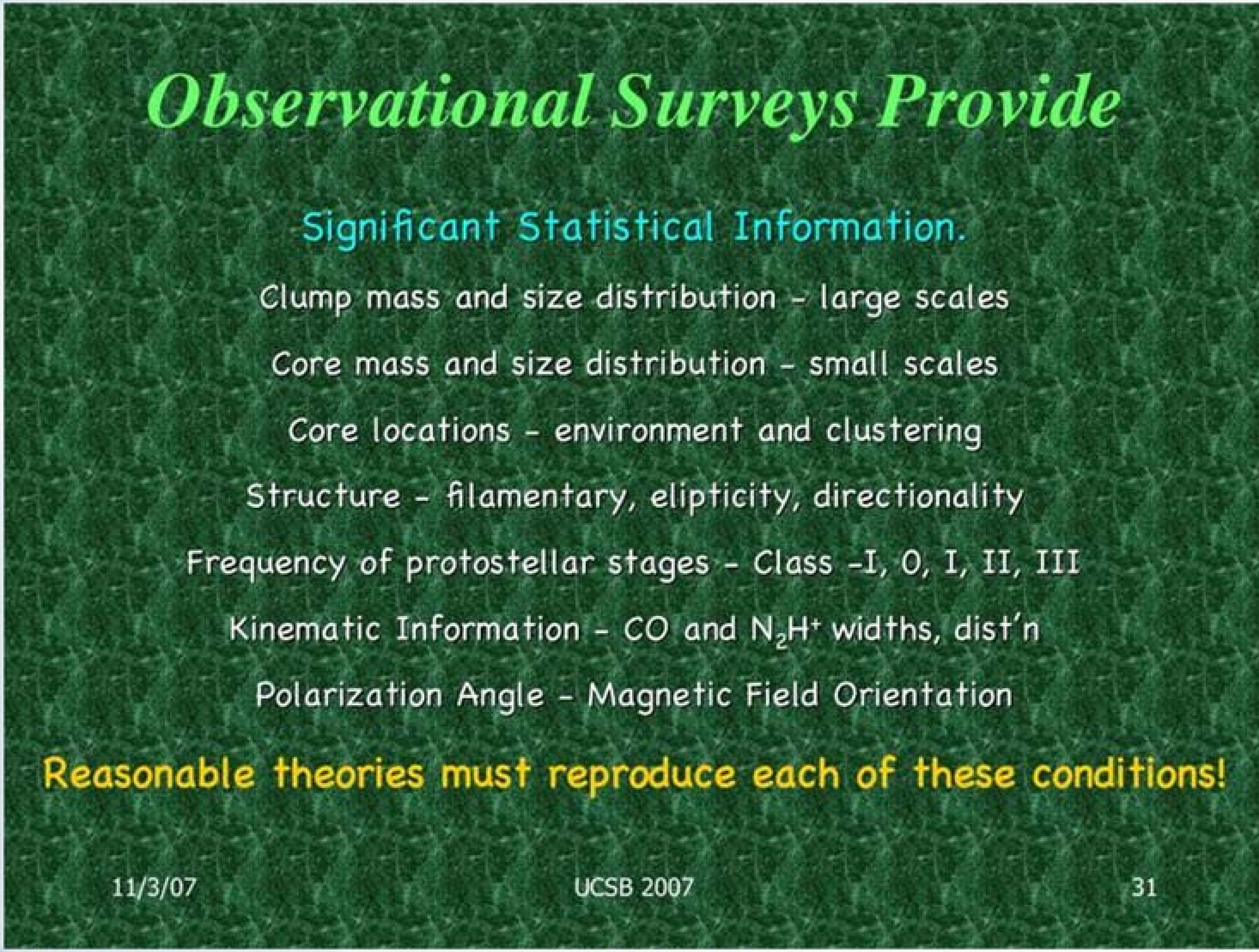


Decaying Driven

$1t_{ff}$: “Observed” at a distance of 150 pc with beam size of 26"

Observational Metrics

Doug Johnstone



Observational Surveys Provide

Significant Statistical Information.

Clump mass and size distribution – large scales

Core mass and size distribution – small scales

Core locations – environment and clustering

Structure – filamentary, elipticity, directionality

Frequency of protostellar stages – Class –I, 0, I, II, III

Kinematic Information – CO and N_2H^+ widths, dist'n

Polarization Angle – Magnetic Field Orientation

Reasonable theories must reproduce each of these conditions!

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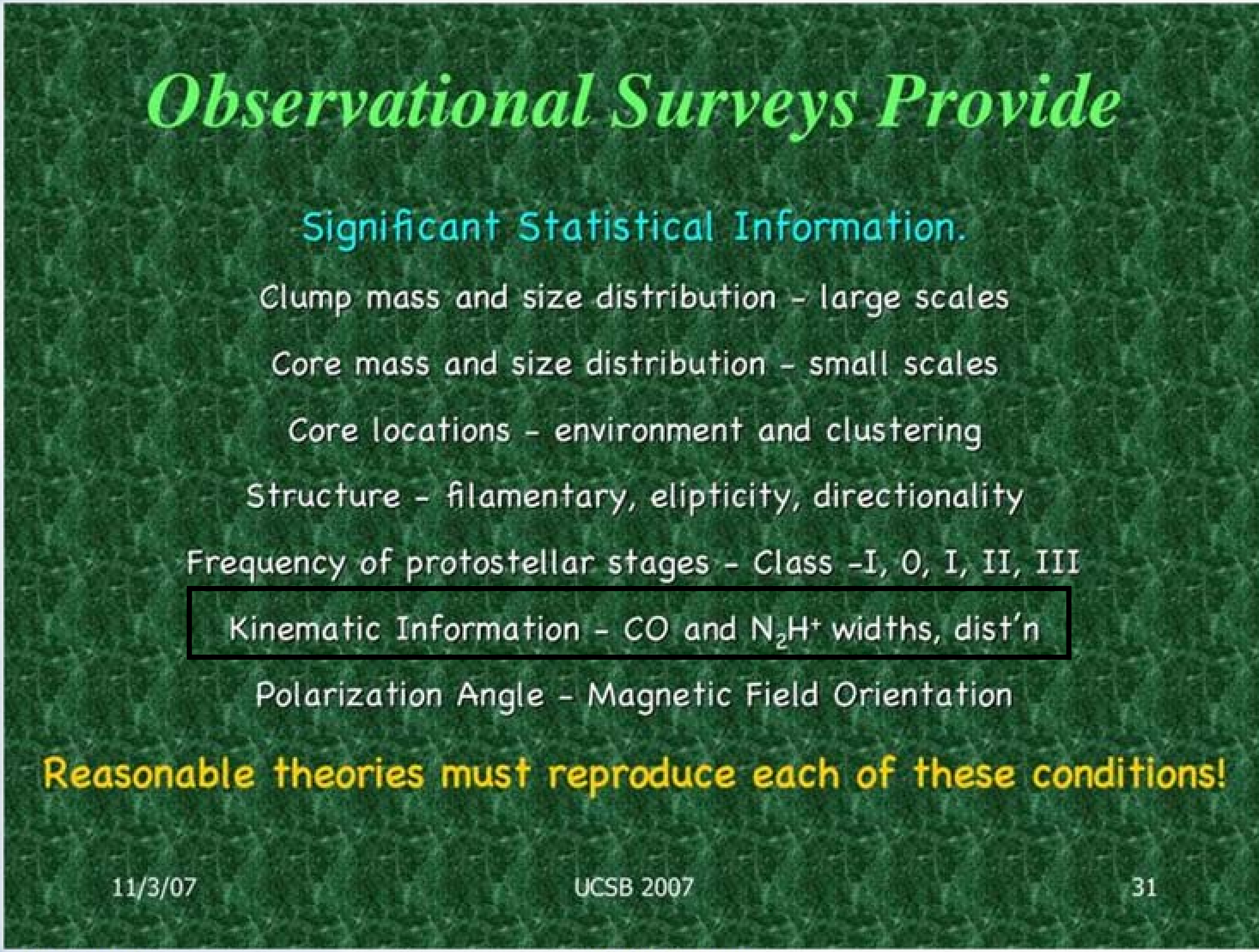
Observational Metrics

Doug Johnstone

Recent papers:

- Andre et al. 2007
  - ρ Ophiuchus
- Kirk et al. 2007
  - Perseus
- Rosolowsky et al. 2007
  - Perseus



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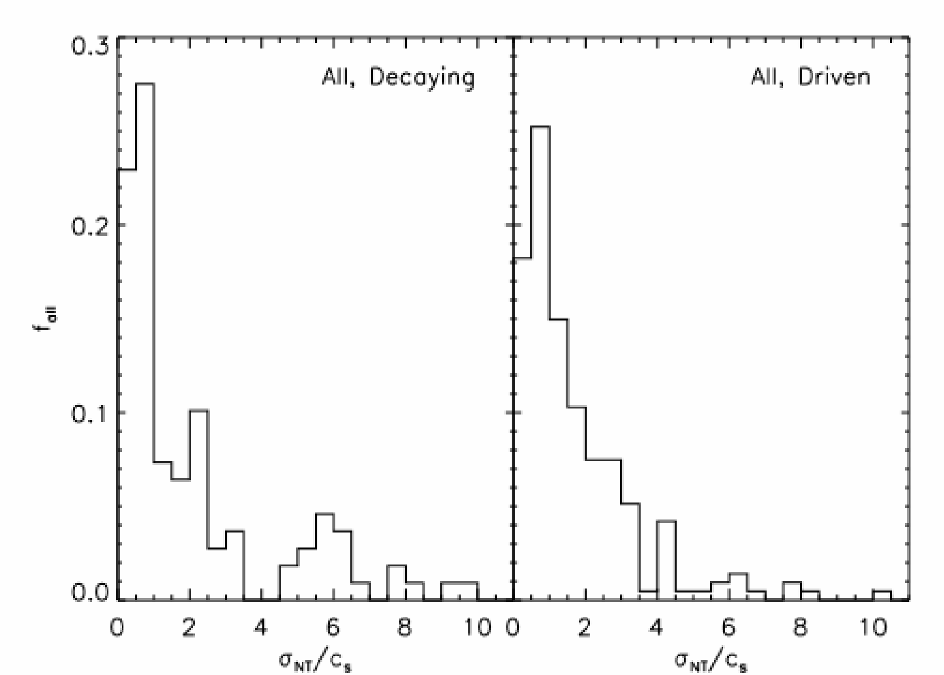
Radiative post-processing

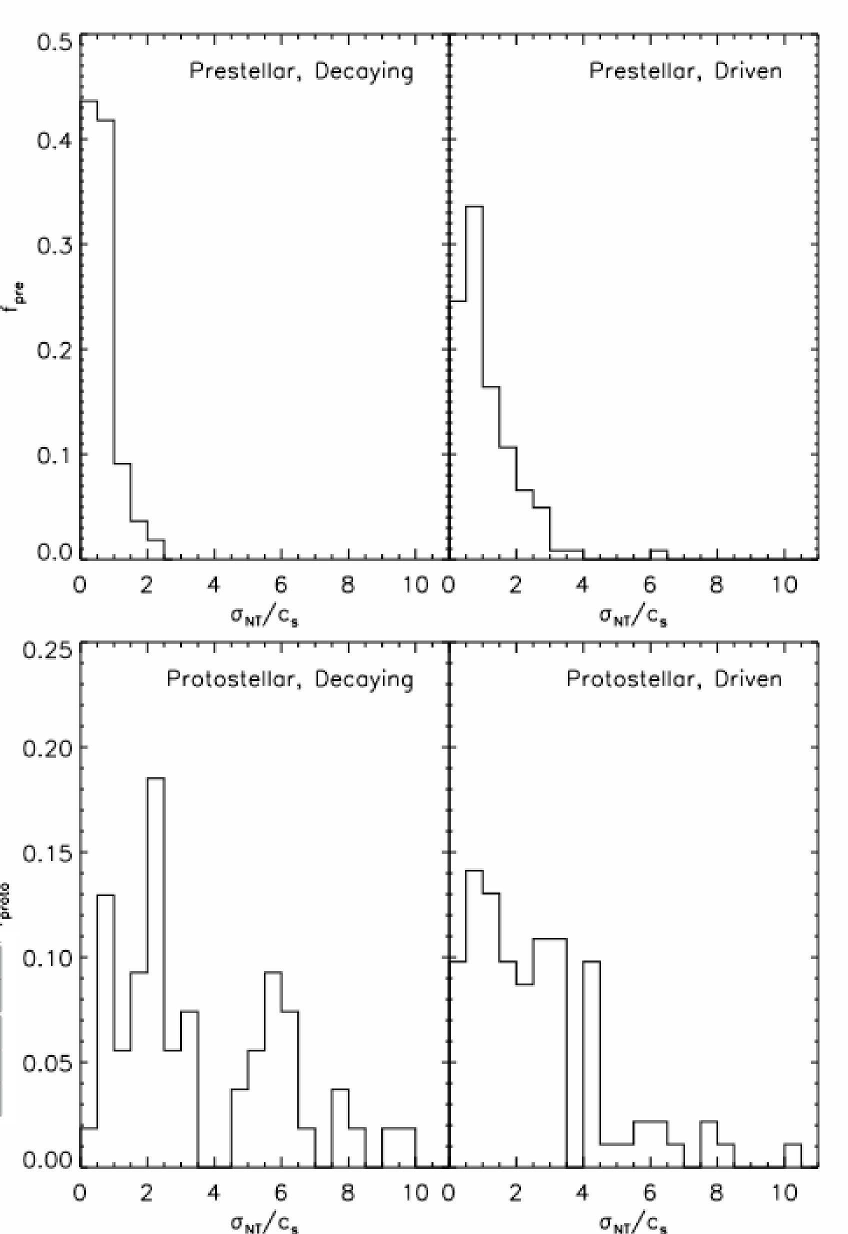
- Dust continuum map:
  - domain is optically thin at 1mm
  - dust intensity is proportional to the column density
  - convolve the column density map with appropriate beam size
  - identify cores as local maxima in this map

- Molecular line observations:
  - consider the tracers $C^{18}O$, N_2H^+, NH_3
  - mostly optically thin in low mass star-forming regions
  - assume gas is in statistical equilibrium
  - radiative pumping is negligible (except for excitation and de-excitation from the CMB)
  - calculate the emergent intensity in each pixel in each velocity channel
  - Compute the channel-averaged specific intensity along each line of sight
  - Smear the data for the beamsize and generate a PPV cube

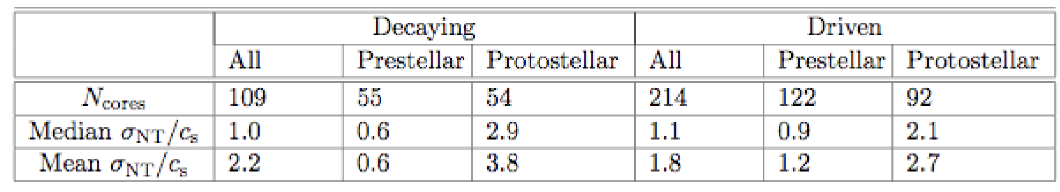
- Depletion model:
  - adopt an abundance, χ, and depletion cutoff, above which $\chi=0$
  - e.g $C^{18}O$, $\chi = 10^{-7}$ mol/H_2 with depletion at $n_{H2} = 5\times10^{4}$ cm^{-3}

Velocity Dispersions: 2nd Moments



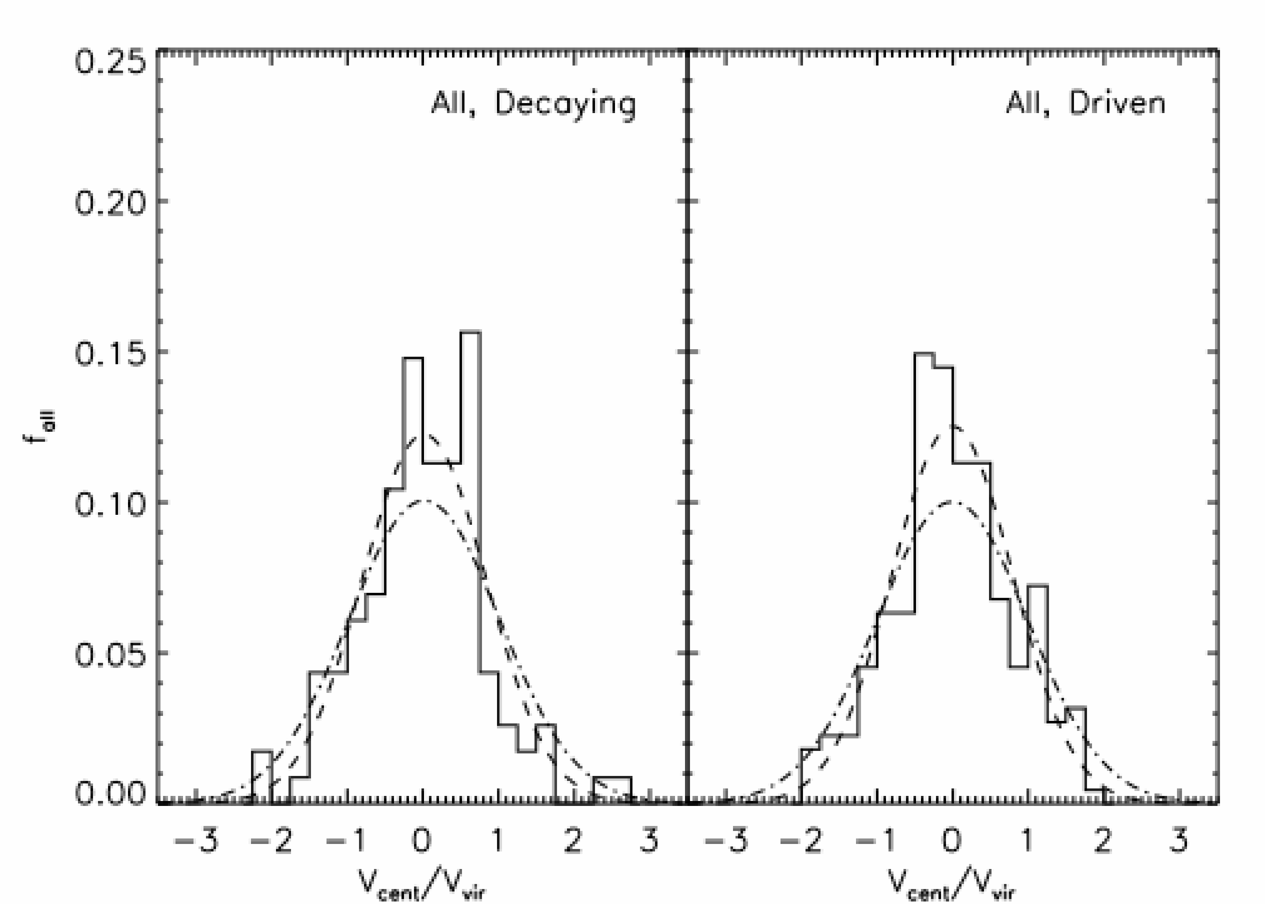


- N_2H^+:
  - Prestellar subsonic 2nd moments
  - Protostellar transonic 2nd moments



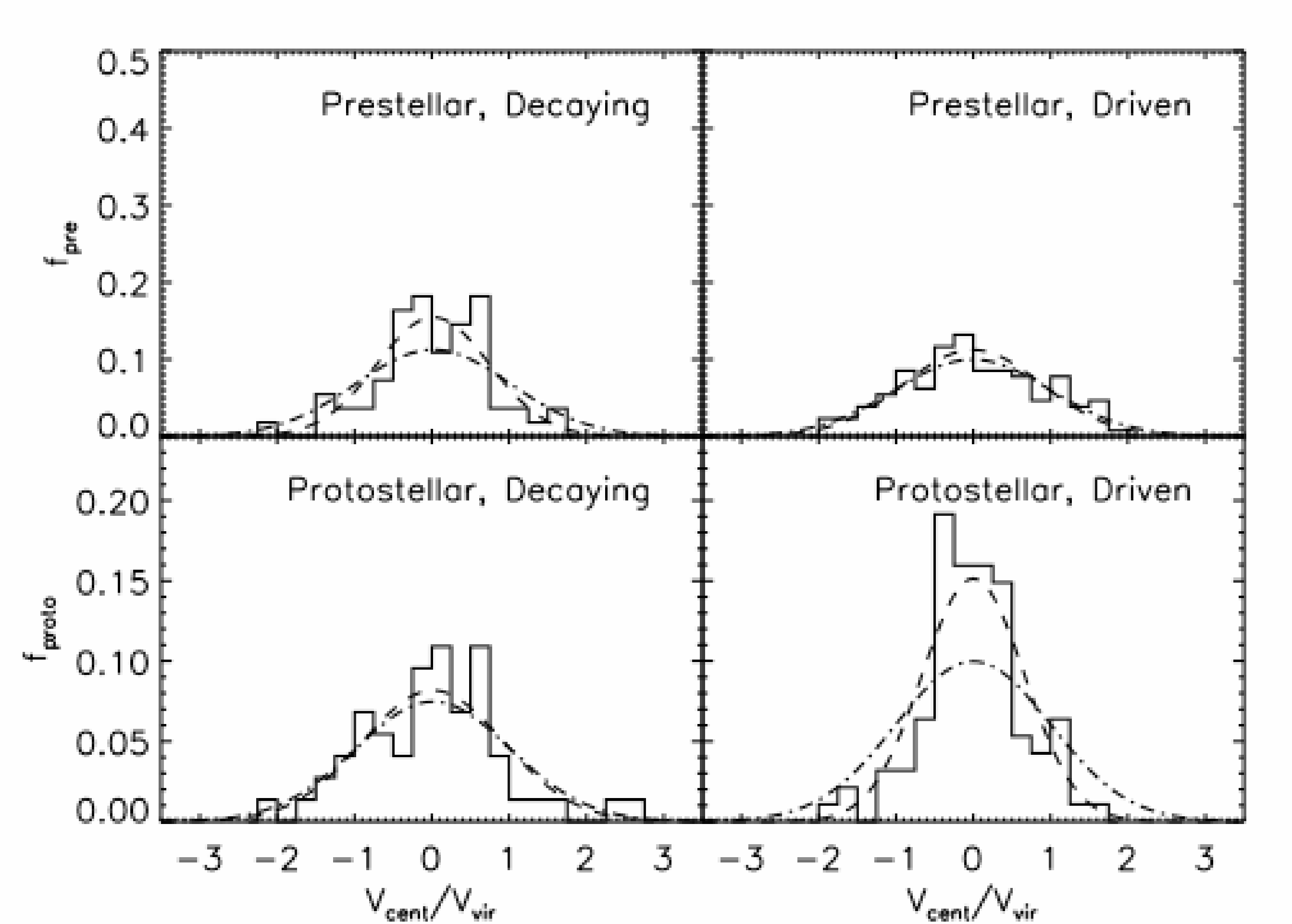
	Decaying			Driven		
	All	Prestellar	Protostellar	All	Prestellar	Protostellar
N_{cores}	109	55	54	214	122	92
Median σ_{NT}/c_s	1.0	0.6	2.9	1.1	0.9	2.1
Mean σ_{NT}/c_s	2.2	0.6	3.8	1.8	1.2	2.7

Centroid Velocities: 1st Moments



- N_2H^+:
  - Normalize to the gas dispersion (Decaying, $V_{vir}=2.1c_s$; Driven, $V_{vir}=4.9c_s$)
  - Sub-virial dispersion of centroids

Centroid Velocities: 1st Moments



- N_2H^+:
  - Normalize to the gas dispersion (Decaying, V_{vir}=2.1c_s; Driven, V_{vir}=4.9c_s)
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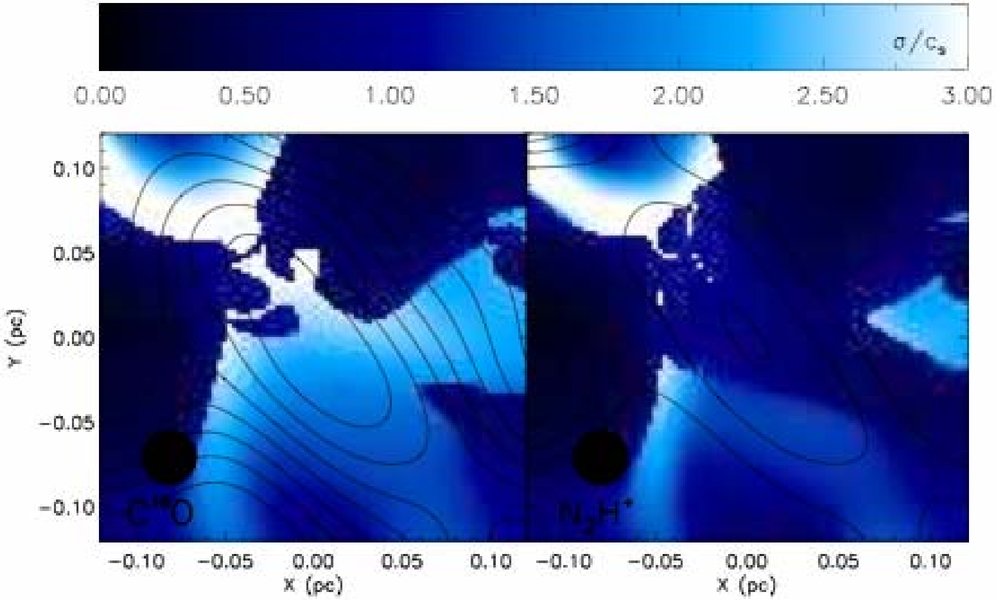
Core Envelope Dispersions

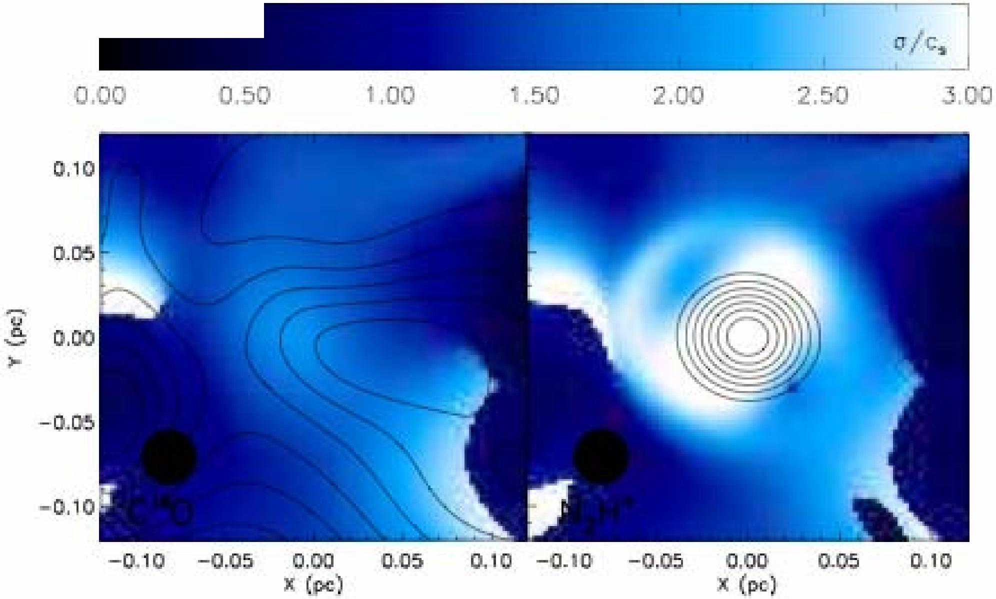
Prestellar



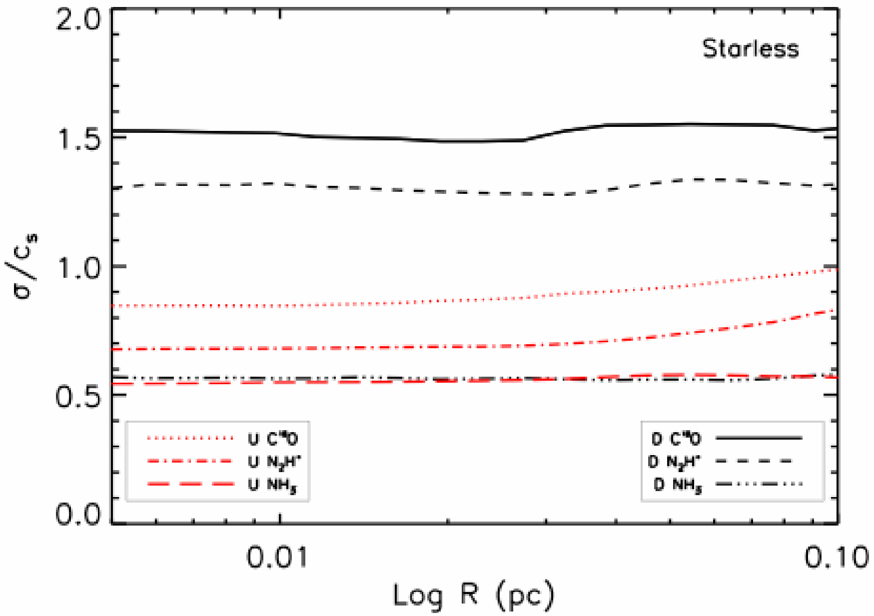
Individual core velocity dispersion map with density contours.

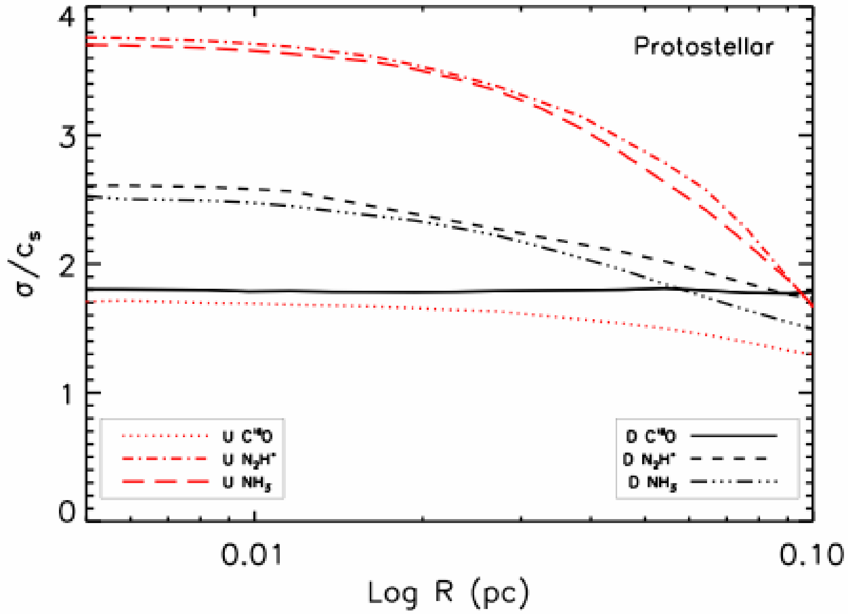
- Upper plot:
  - No infall, sub-sonic interior
  - Highest velocity gas is in the envelope
- Lower plot:
  - Strong supersonic infall
  - Envelope is transonic

Protostellar

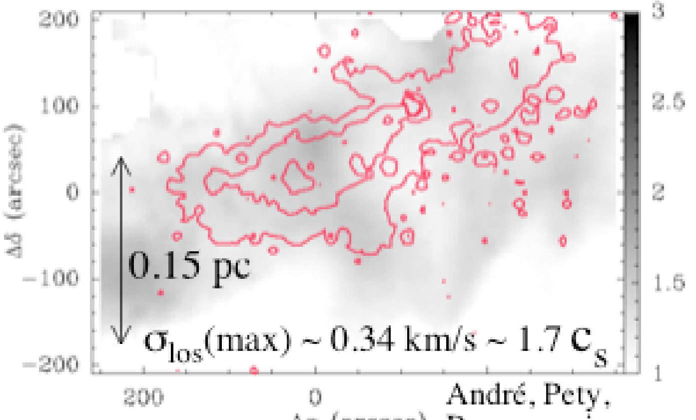


Core Envelope Dispersions





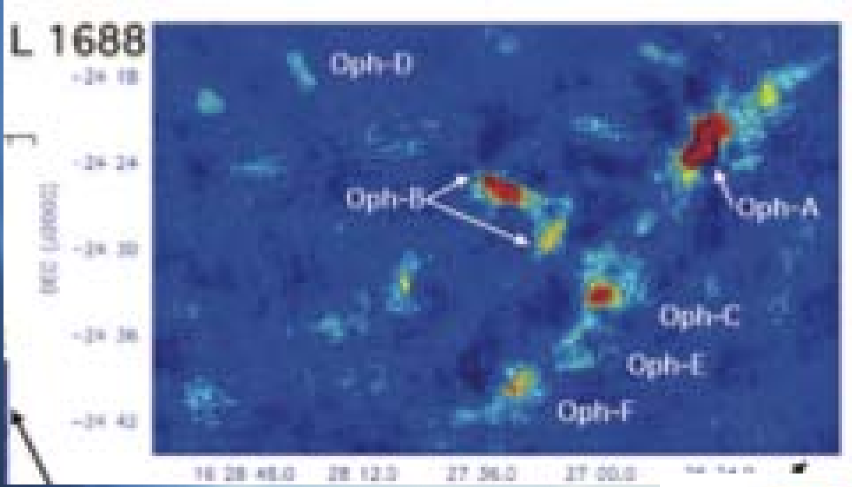
L1689B Contours: Column density (ISO)
Greyscale: ^{13}CO(1-0) Linewidth



André, Pety, Bacmann, in prep.

- Prestellar cores are "coherent"
- Prestellar cores have sonic to transonic envelopes
- C^{18}O traces lower density gas around the core, which is distinct from infall or regional gas dispersion.
- Protostellar cores have larger envelope dispersions (transonic-supersonic), in part due to infalling gas.
- Decaying protostellar cores have strongly increasing dispersion with decreasing radius.

Observed Regions

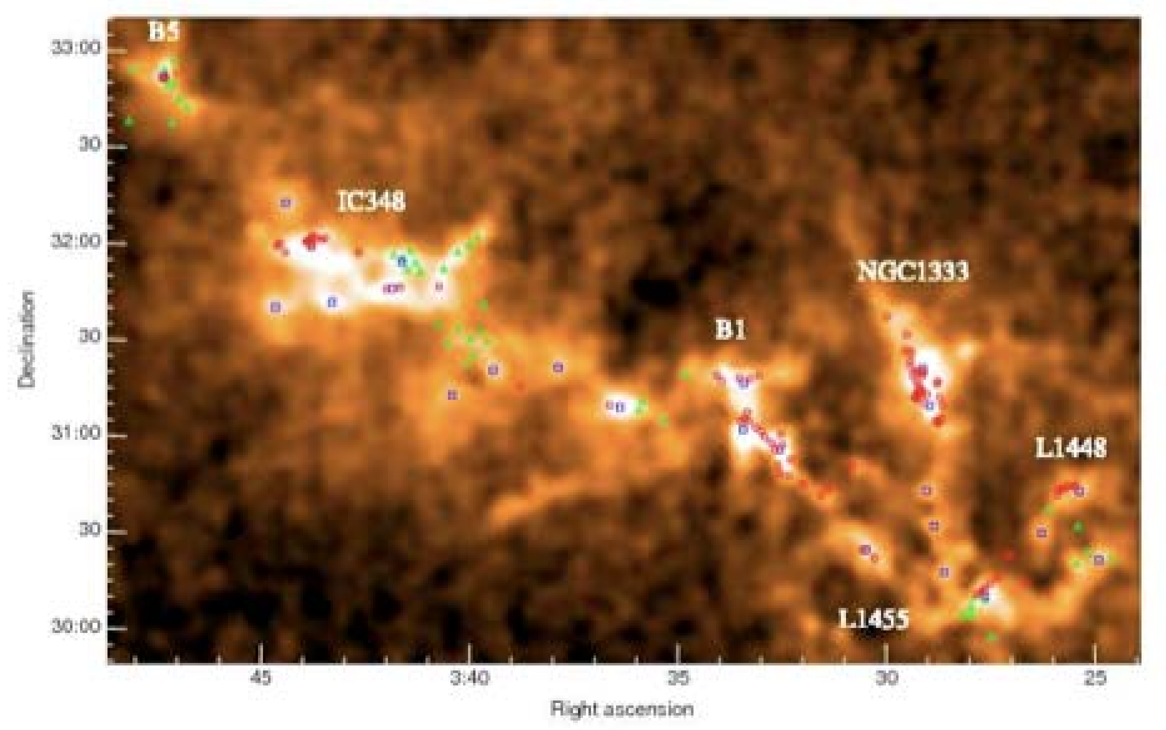


1.1mm Bolocam map (Young et al. 2006)

ρ *Ophiuchus*:
A ~ 1pc x 1pc
n_H ~ 2.2 x 10^4 cm^{-3}
D ~ 150 pc
M ~ 550 Msun

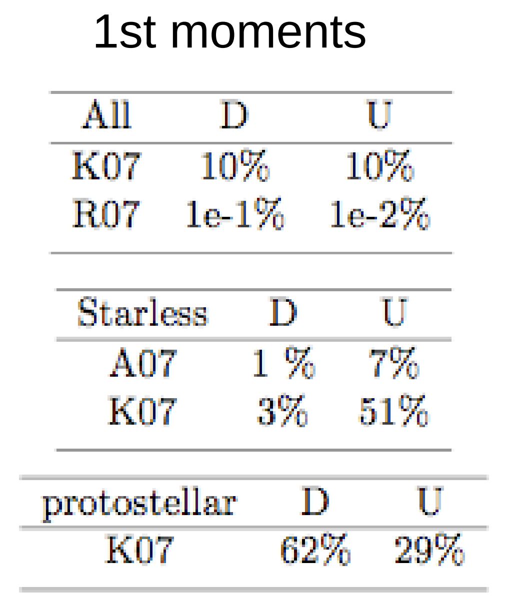
Perseus:
A ~ 5pc x 25pc
n_H ~ 1.5 x 10^3 cm^{-3}
D ~ 260 pc
M ~ 18,500 Msun

2-MASS extinction map (Kirk et al. 2007)



KS Tests

- Andre et al. 2007 (A07): ρ Oph, N_2H^+, starless
- Kirk et al. 2007 (K07): Perseus, N_2H^+, starless, protostellar
- Rosolowsky et al. 2007 (R07): Perseus, NH_3, starless + protostellar

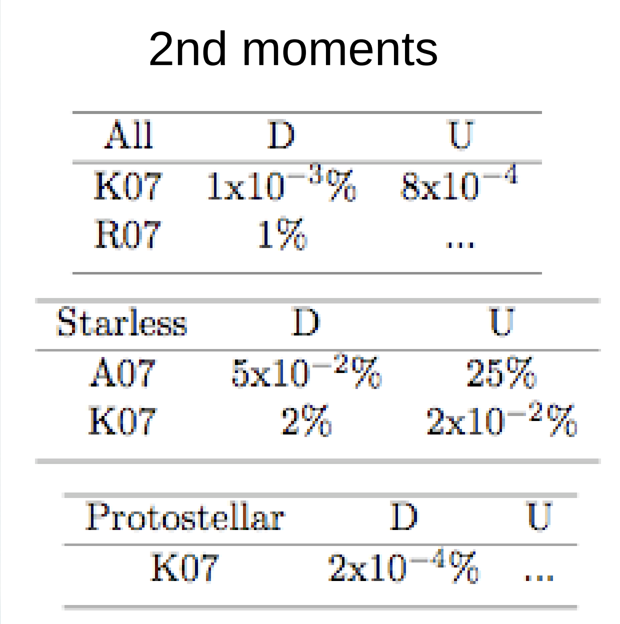


1st moments

All	D	U
K07	10%	10%
R07	1e-1%	1e-2%

Starless	D	U
A07	1 %	7%
K07	3%	51%

protostellar	D	U
K07	62%	29%



2nd moments

All	D	U
K07	$1x10^{-3}$%	$8x10^{-4}$
R07	1%	...

Starless	D	U
A07	$5x10^{-2}$%	25%
K07	2%	$2x10^{-2}$%

Protostellar	D	U
K07	$2x10^{-4}$%	...

Summary

- 2nd Moments
  - Both simulations find sonic prestellar 2nd moments
  - Decaying simulation has supersonic protostellar 2nd moments, while the driven simulation has ~transonic 2nd moments
- 1st Moments
  - The simulation distributions are statistically similar
  - Both simulations are slightly sub-virial
  - Driven simulation has ~ virial prestellar 1st moments, while the decaying simulation has ~ virial protostellar 1st moments
  - Both simulations and observations are statistically similar
- Core envelopes
  - Both simulations have coherent prestellar cores
  - Driven simulation has transonic protostellar envelopes that are flat with radius; Decaying simulation has supersonic protostellar envelopes that increase with decreasing radius
  - Driven simulations are a better fit to observations of core envelopes