Kinematic Signatures of Mass Inflows in Molecular Cloud Filaments

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SUMMARY

The DR21 ridge is a dense, massive (~10^4 $M_\odot$) filament in the Cygnus X complex undergoing large-scale gravitational collapse, with mass accretion occurring along a network of filaments. Our kinematic modeling finds systematically low inclination angles for these filaments, inconsistent with strong free-fall motions, indicating a more regulated or complex collapse process.

INTRODUCTION

Filaments are ubiquitous in molecular clouds[1]

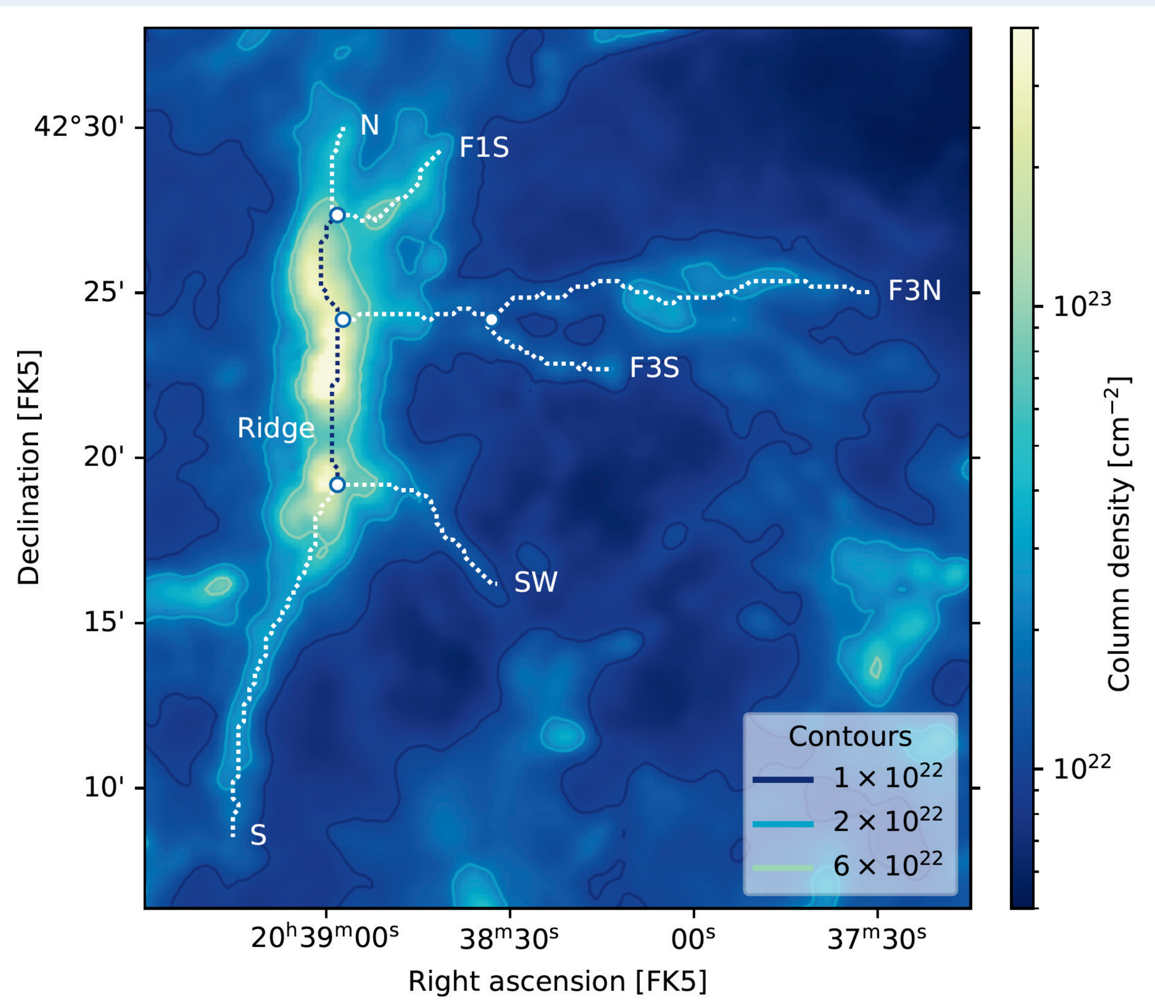
- Funnel gas into dense hubs, providing continuous supply of material for star formation

Relative importance of gravity vs other forces on filament kinematics is unknown

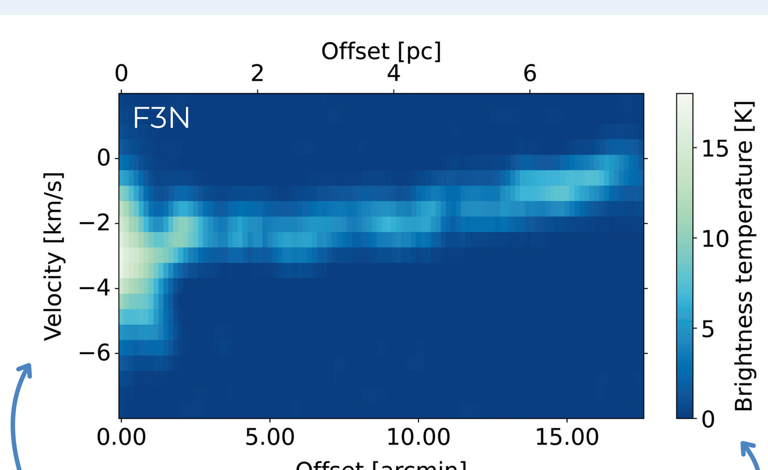
- Gravitational infall models have not been well-tested against observational data
- Expect to see free-fall velocity trajectory along filaments unless impeded by external forces

METHODS

Use FilFinder[2] to get filament spines



Extract position-velocity (PV) plots[3]



Velocity distribution at each offset

Spatial offset from DR 21 ridge

Brightness temperature shows amount of material at each (position, velocity) coordinate

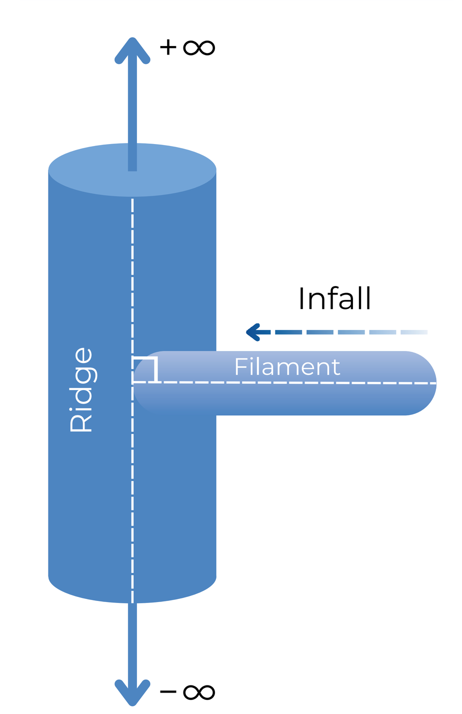
Velocities derived from ^{13}CO emission data from LEGO survey[4]

Expect to see an increasing or decreasing velocity gradient with distance from the ridge as infalling gas accelerates

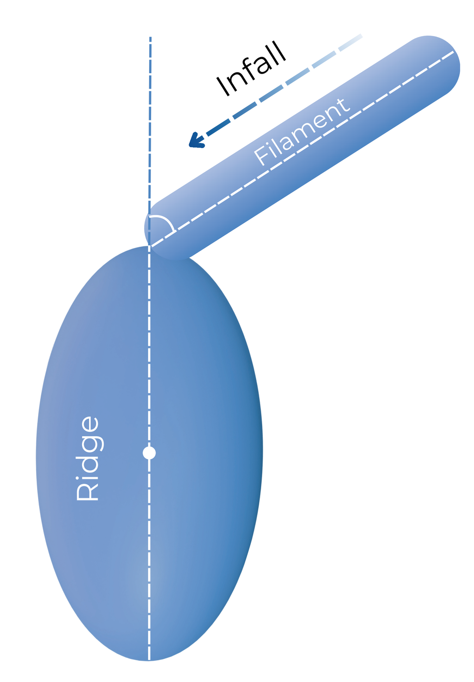
RESULTS

Two gravitational infall models are tested against observational data

Infinite cylinder



Finite ellipsoid



Free parameters

- ϑ ⟶ Filament inclination
- v_0 ⟶ Velocity offset
- $\Delta\ell$ ⟶ Length adjustment
- Δx ⟶ Position offset
- δ ⟶ Ridge inclination*

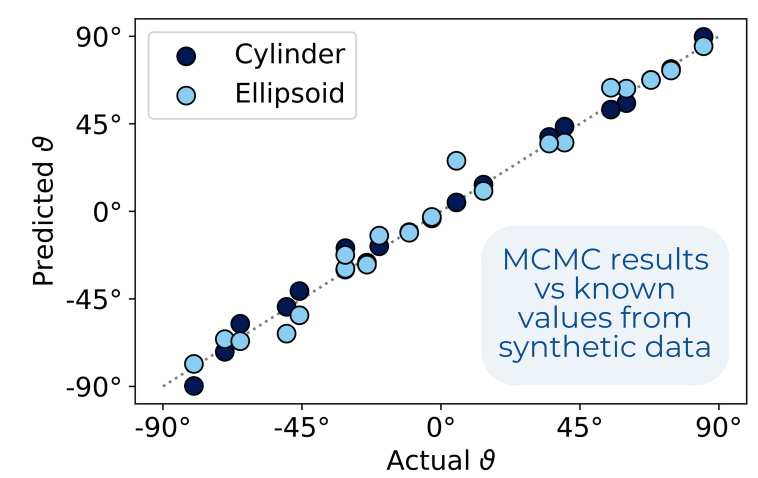
Observed parameters

- $r_{\rm ini}^{\rm obs}$ ⟶ Length of filament (projected)
- $d_0^{\rm obs}$ ⟶ Distance to center of ridge (projected)*
- α ⟶ Position angle relative to ridge (E of N)*

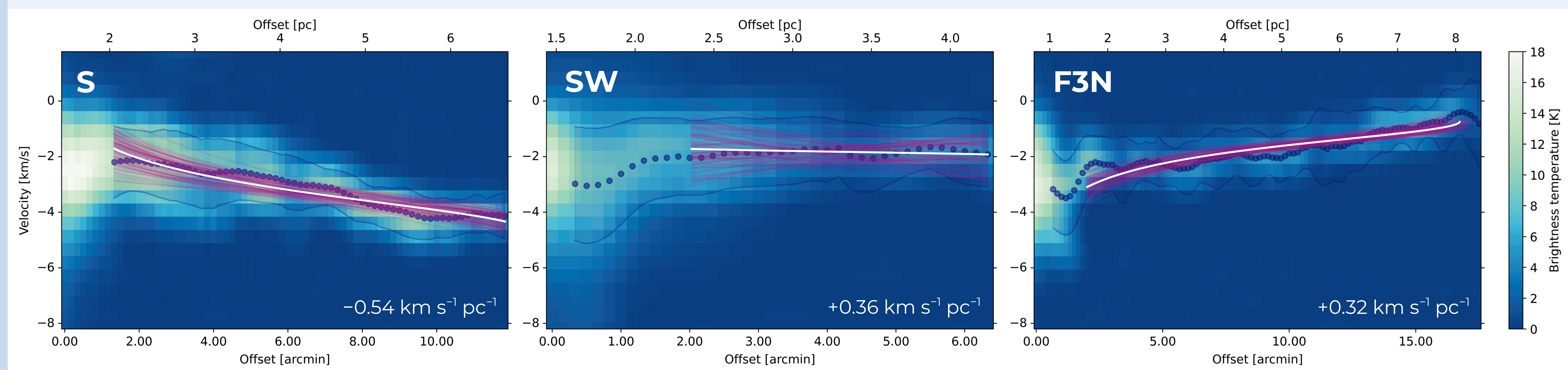
*Ellipsoid model only

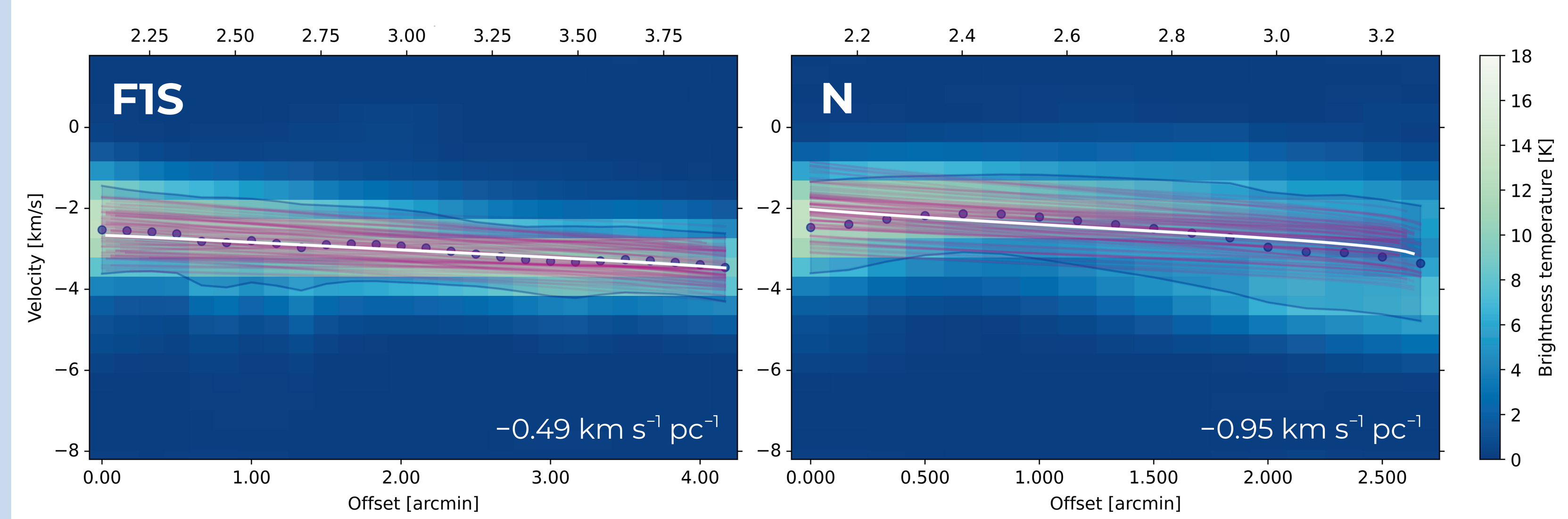
Fitting procedure

Condense PV plot into three 1D arrays
↓ x, y, yerr
Initial guesses from `least_squares`
↓ p0
Final parameters from MCMC[5]



Low inclination angles likely inconsistent with purely gravitational infall





MCMC sampling results for finite ellipsoid model

- Observed velocities
- Observed velocity errors
- MCMC samples
- Median MCMC model

Regions of high column density (N_{H_2} > 10^{23} cm^{-2}) excluded from fit

Filament	Inclination angles ϑ	
	Infinite cylinder	Finite ellipsoid
N	+4.29°	+9.52°
F1S	+4.18°	+9.57°
F3N	−9.87°	−14.99°
SW	−4.45°	−0.88°
S	+13.45°	+27.51°

Values above are median best-fit parameter estimates from MCMC sampling

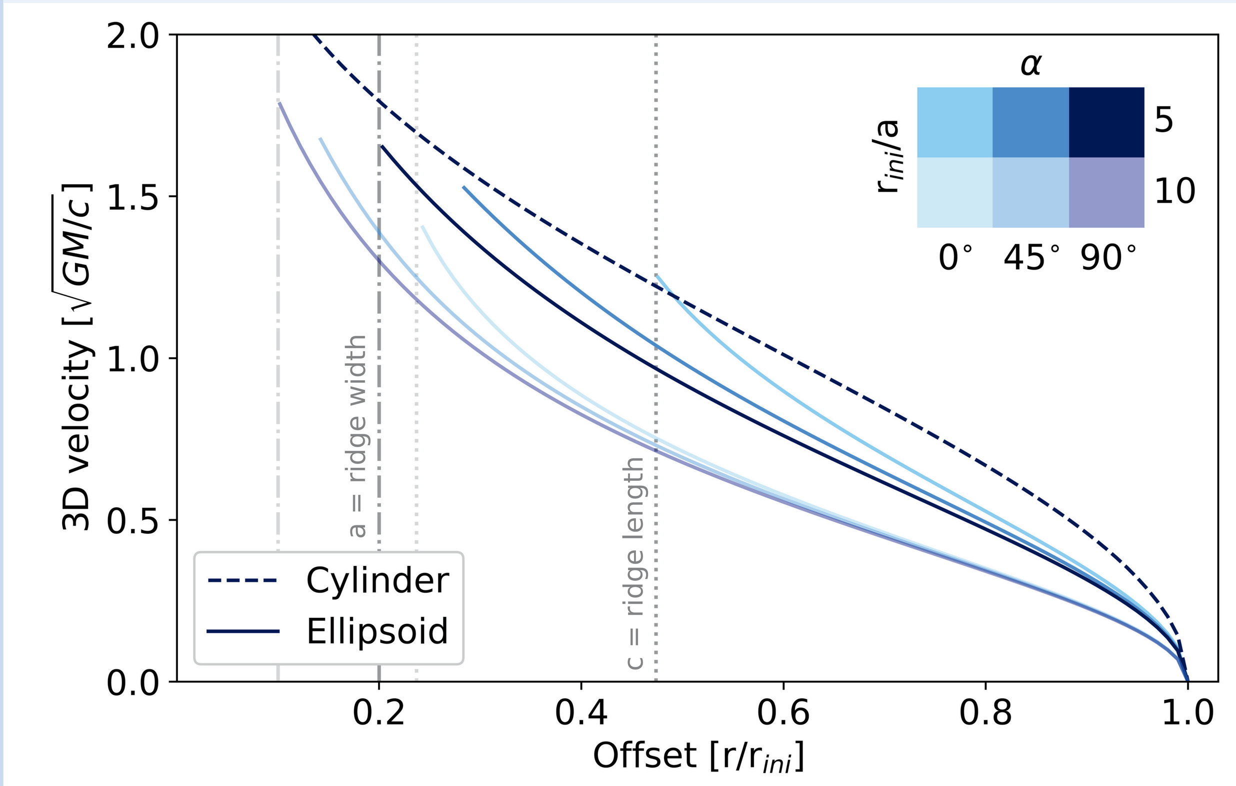
Calculate probability of observed inclinations[6]

$$P(\vartheta \le \vartheta_p) = \sin(\vartheta_p)$$

- Use 16th/84th percentile values determined via MCMC sampling
- Assume filaments are randomly oriented vectors in 3D space

Infinite cylinder	Finite ellipsoid
$P \sim 0.04\%$	$P \sim 0.83\%$

Infall model velocities



Cylinder model generally predicts higher velocities

- Trajectory independent of filament length
- Ellipsoid model is more physically realistic

CONCLUSIONS

Several potential scenarios could explain low estimated inclinations

1. **DR21 happens to be relatively flat in the plane of the sky**
   - Test infall models on filaments in other molecular clouds
2. **Filaments are not experiencing free-fall collapse**
   - Magnetic field orientations in 3D could support gas flows
3. **Filaments were formed recently**
   - In the process of being accelerated to free-fall motions
   - Calculate free-fall timescales

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