Filamentary Flows

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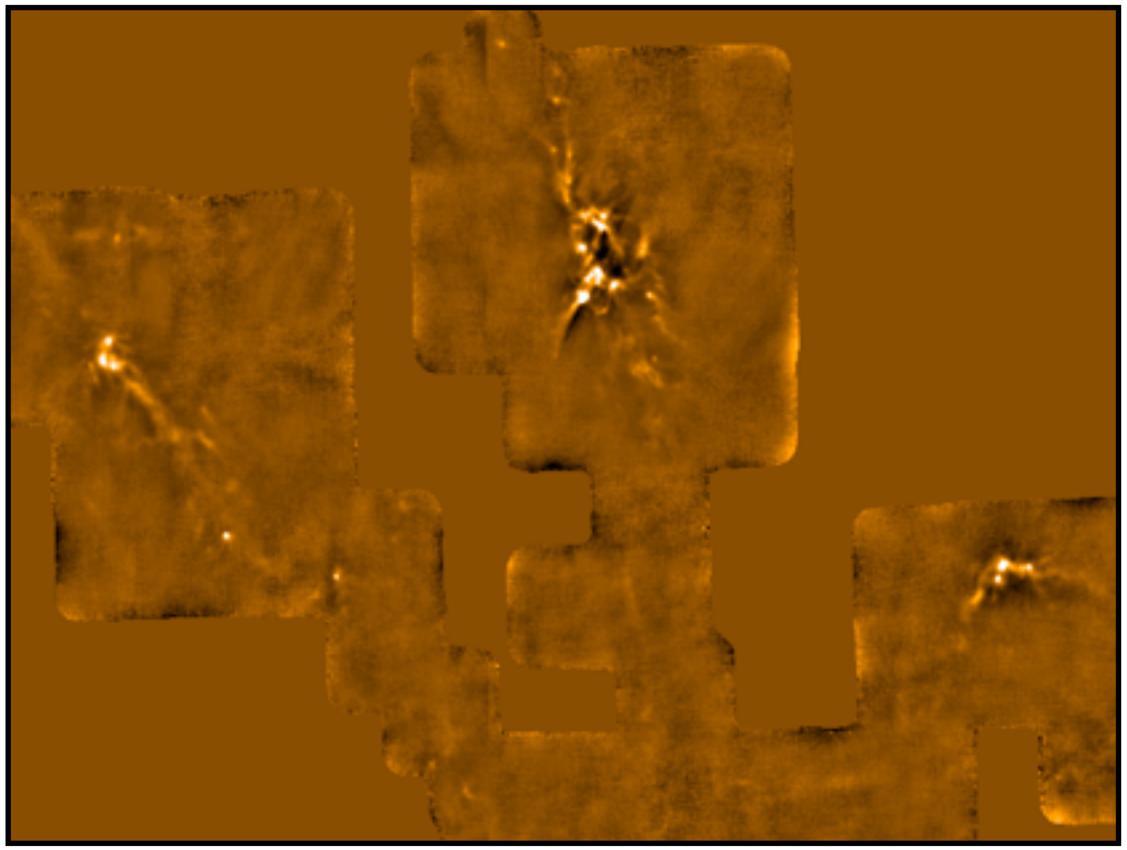
thanks to:
Phil Myers, Tyler Bourke & Rob Gutermuth (Serpens South)
Mikhail Klassen, Ralph Pudritz, & Sam Pillsworth (simulations)

NSERC Banting PDF & Smithsonian Scholarly Studies Program
(fellowships)

Filaments Everywhere!

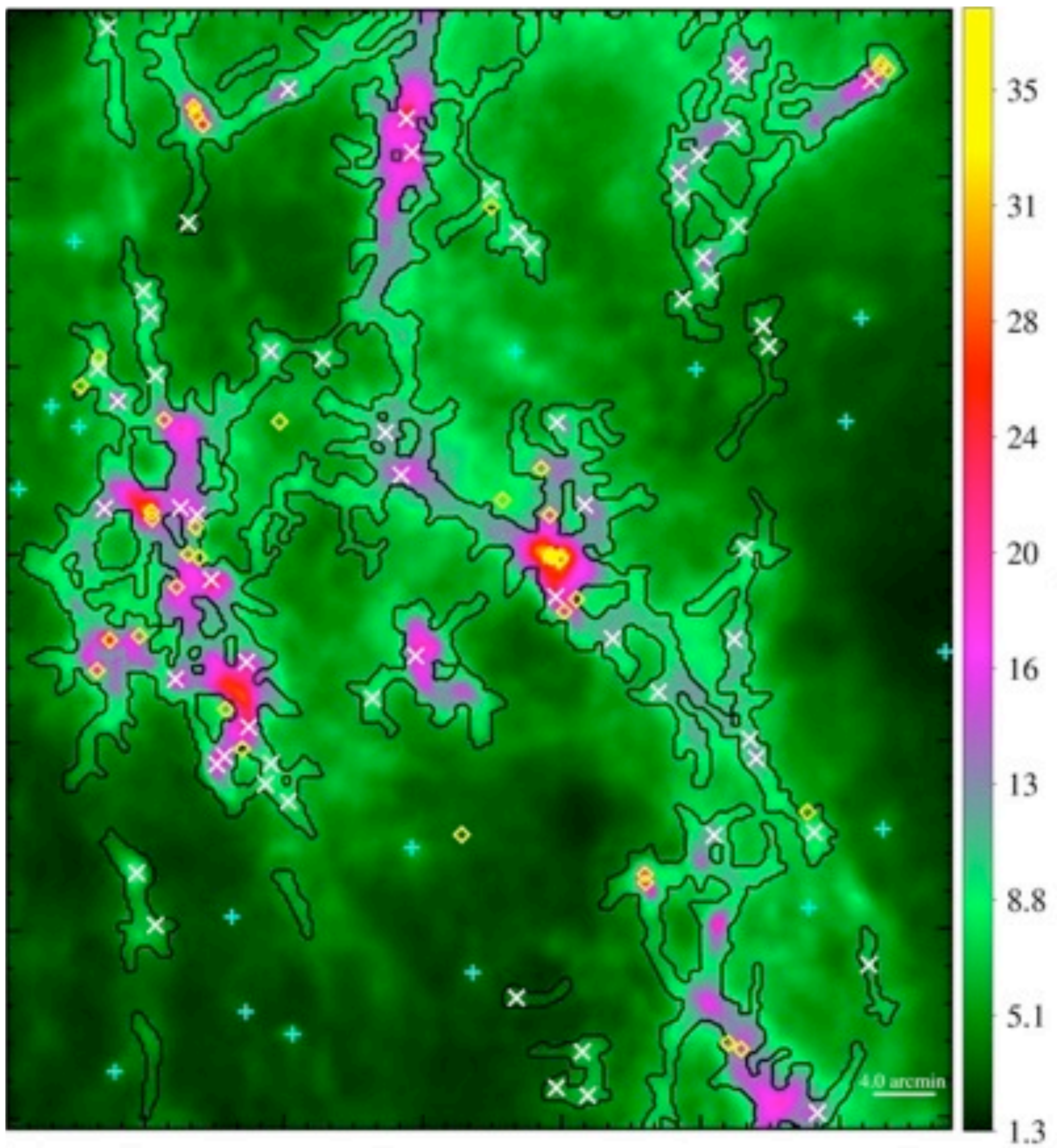


western Perseus as seen by SCUBA, Kirk et al 2006

western Perseus as seen by Herschel, Sadavoy et al 2012

Filaments seen in star formation for decades, but Herschel reveals ubiquity (Andre)

Filaments and Star Formation



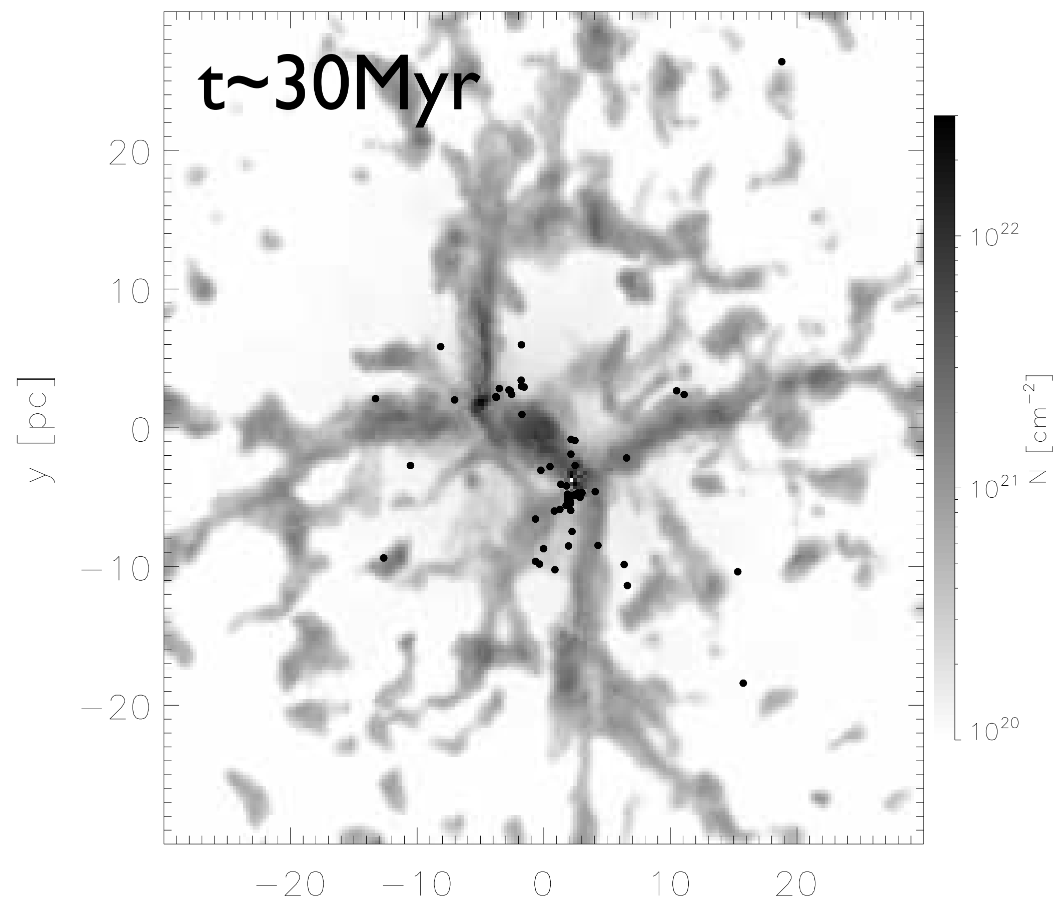
Polychroni et al 2013: L1641/OrionA - most cores are on filaments (x vs +)

Myers 2009: forming clusters tend to be associated with radiating filaments

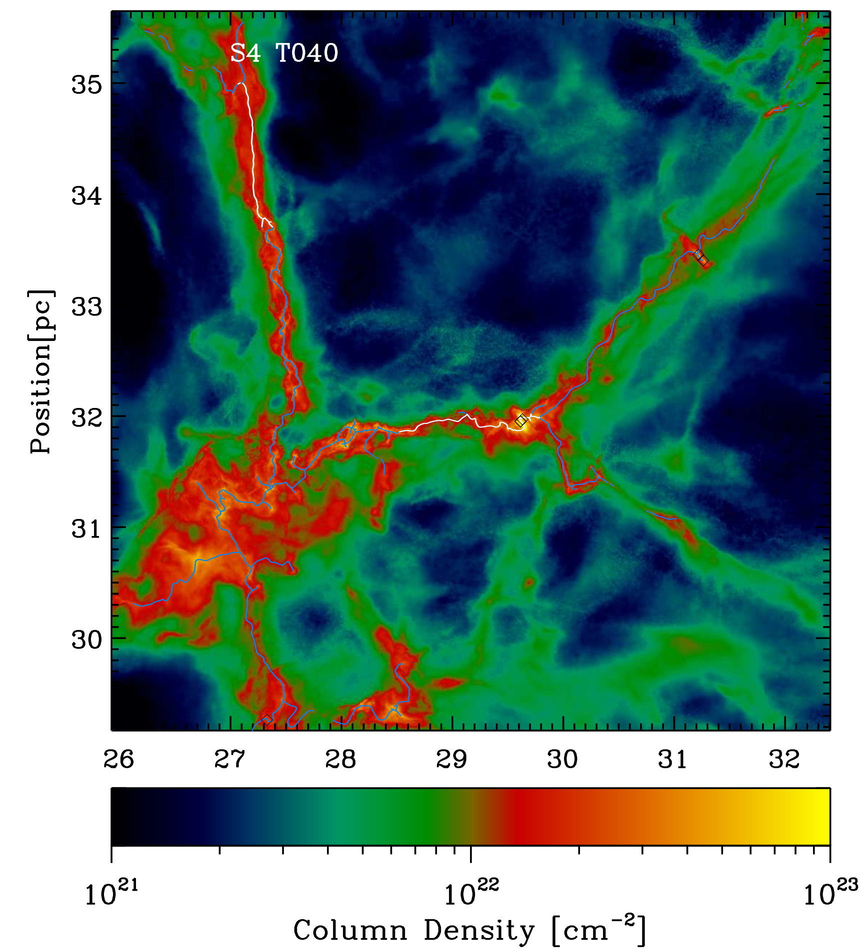
Observations suggest filaments an integral part of most dense core & cluster formation

see also Di Francesco

Insights from Simulations / Theory



Gomez & Vazquez-Semadeni 2014
colliding flows



Smith et al 2014
decaying turbulent box

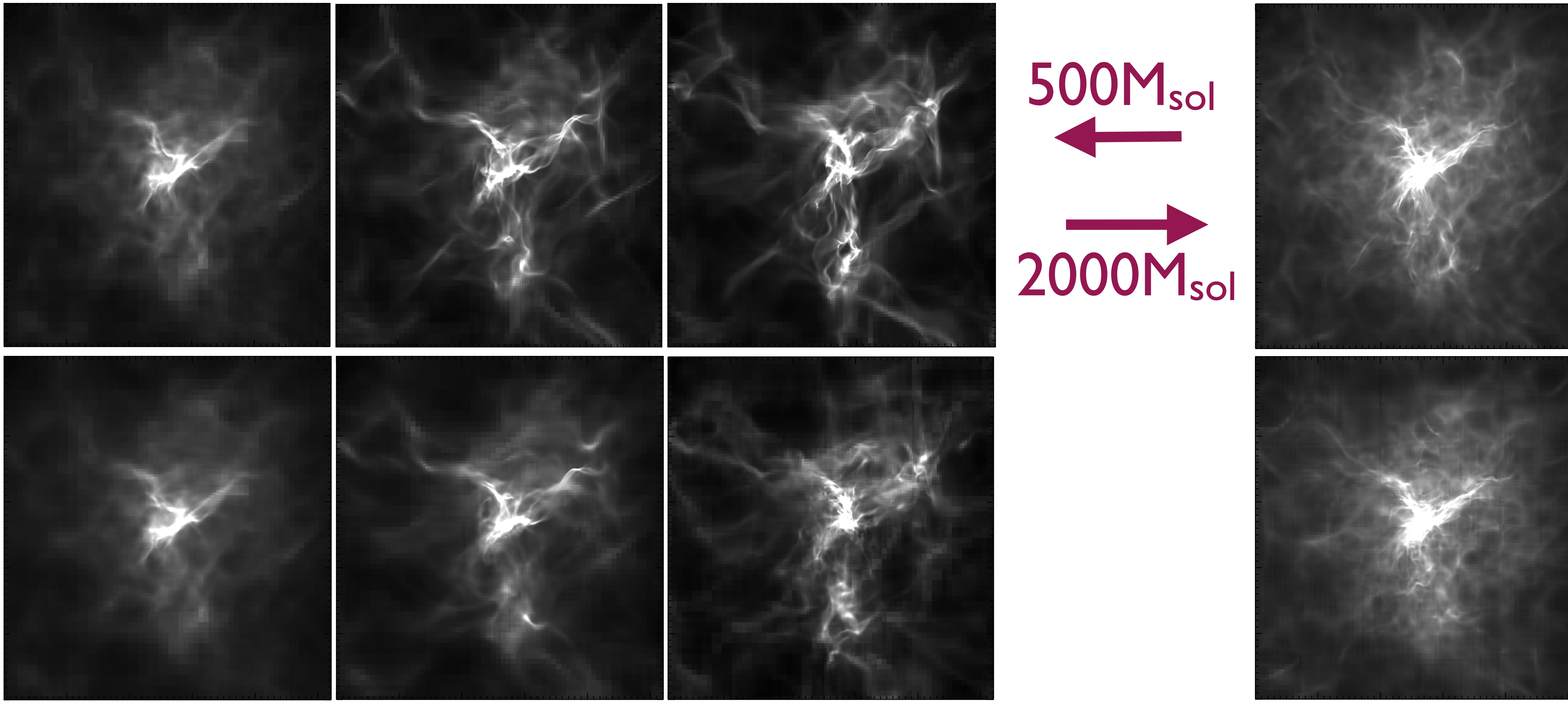
Variety of simulations which match (at least) some observations

p<4 profiles for magnetic fields (Fiege & Pudritz '00), accretion (Heitsch '13), non-isothermal (Recchi ea '13), rotation (Recchi ea '14), turbulence (Smith ea '14)

Simulations with MHD & G

HD

MHD



0.05Myr 0.1Myr 0.15Myr 0.05Myr

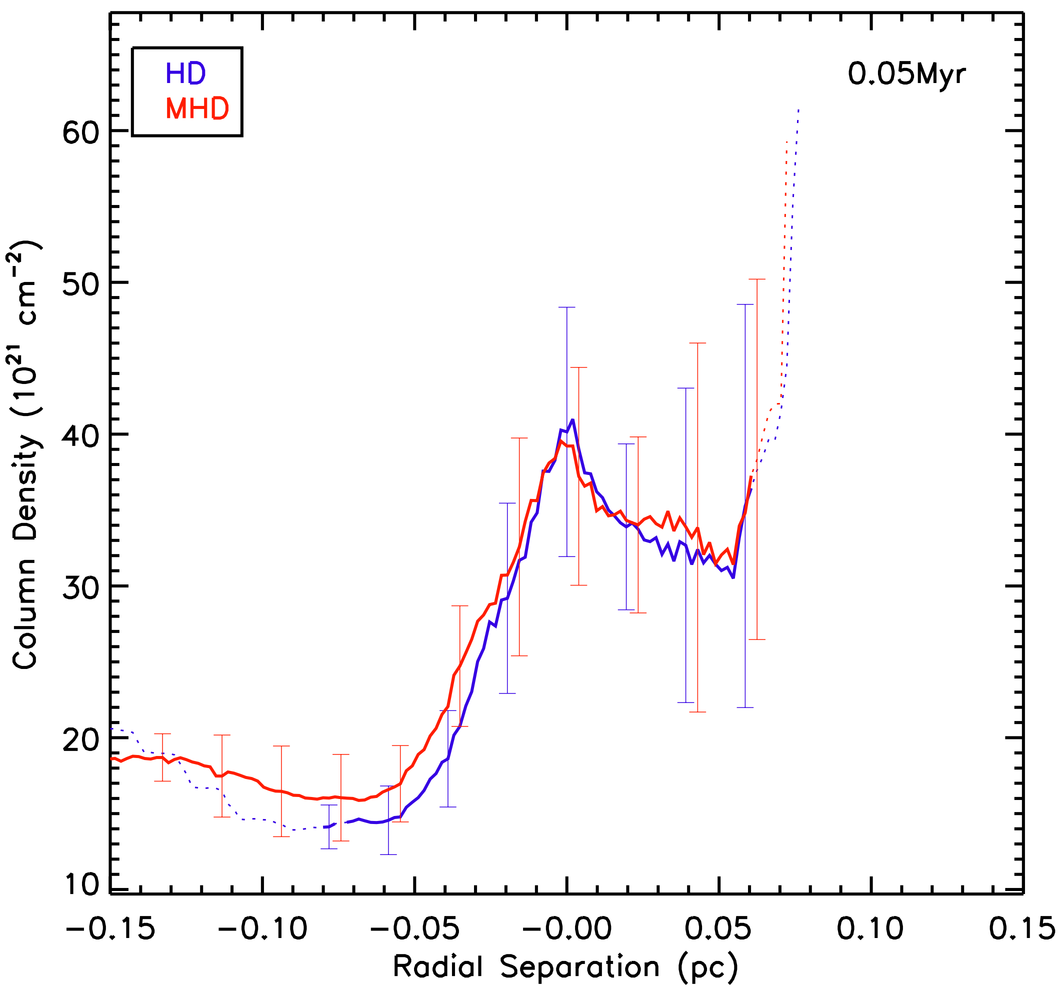
white ~ $5x10^{22}cm^{-2}$

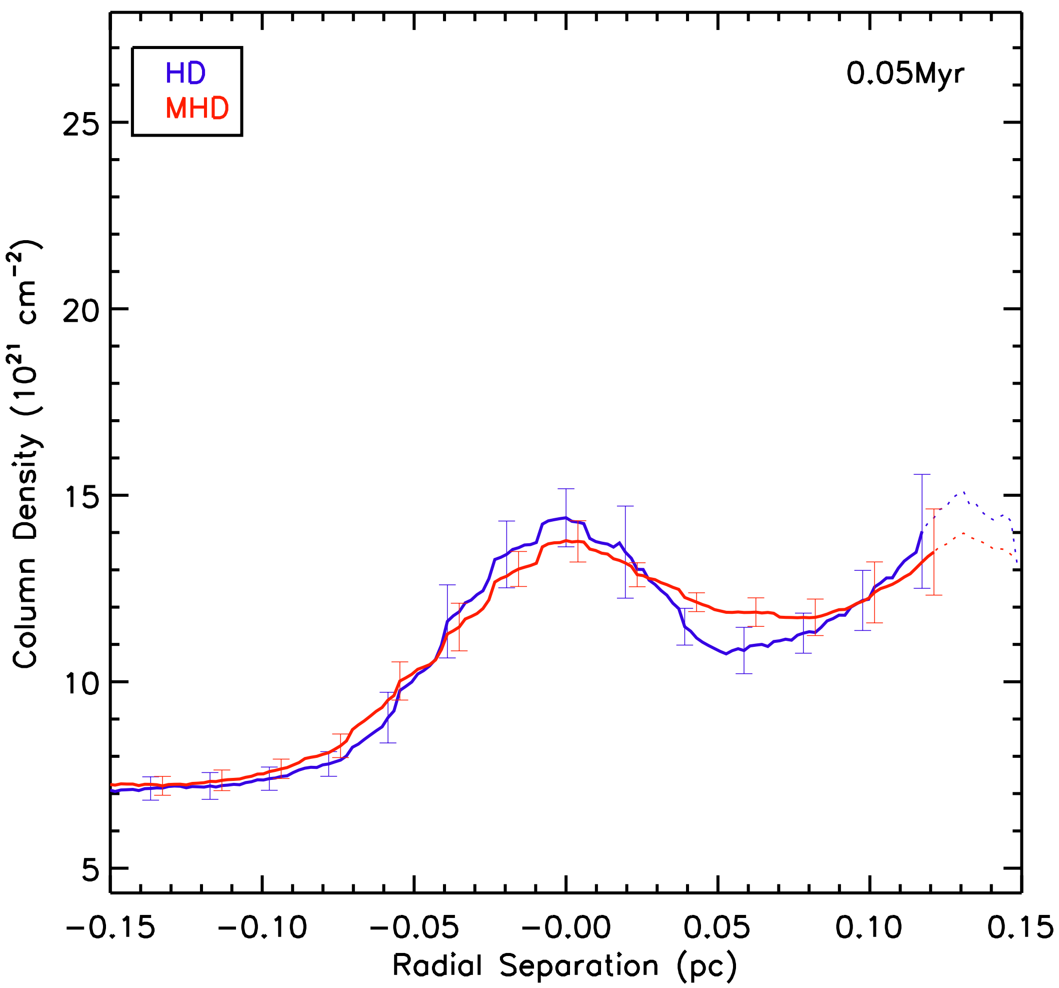
white ~ $2x10^{23}cm^{-2}$

Kirk, Klassen, Pudritz, & Pillsworth, ApJ submitted

- weak B slows dense structure formation
- higher density evolves faster

Filament evolution

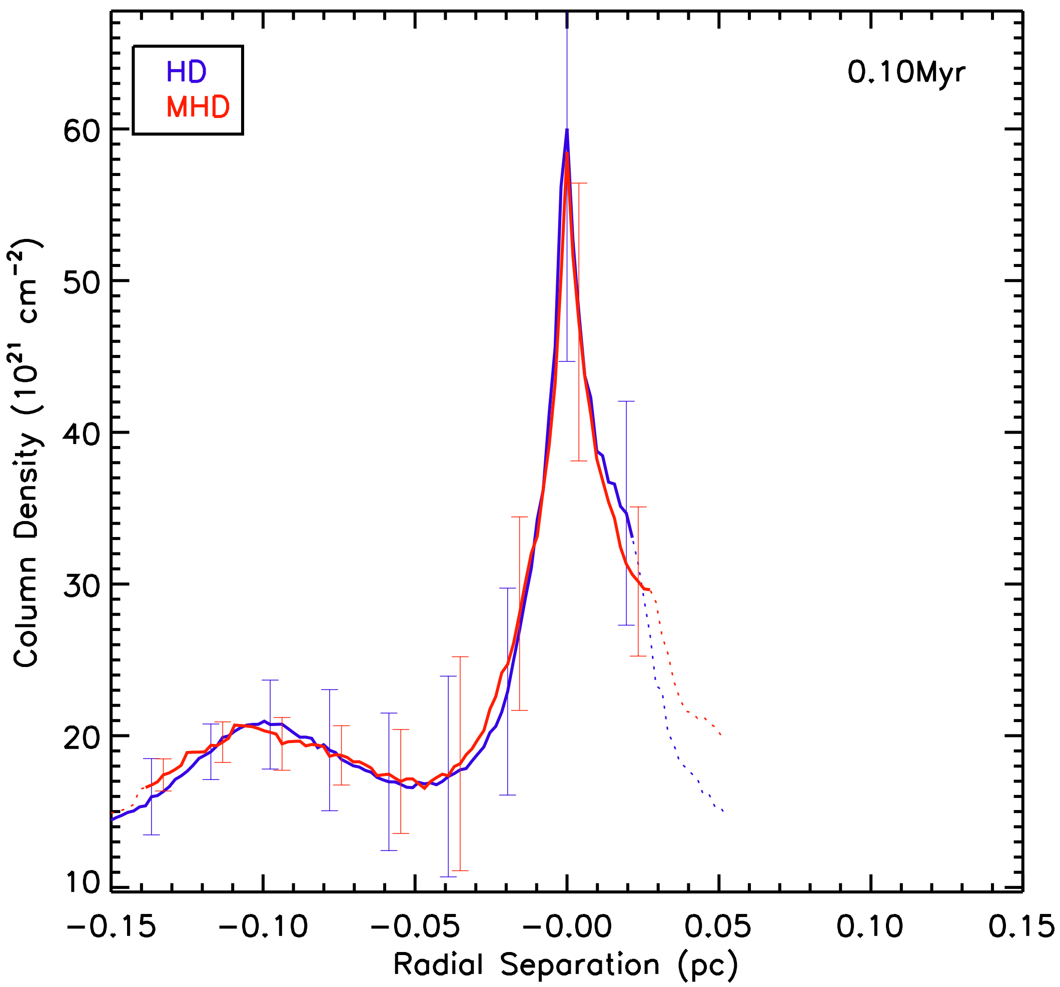


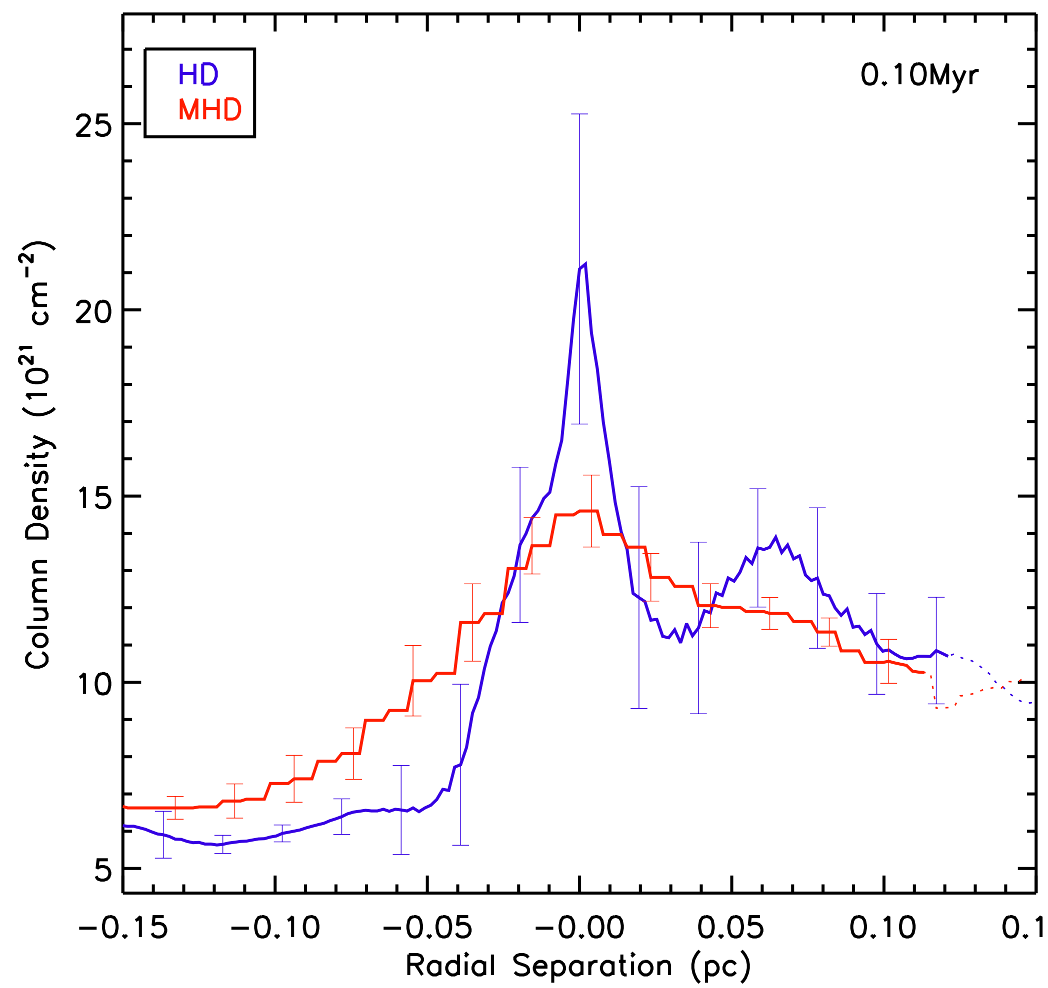


Kirk et al subm.

- MHD filaments are ‘puffier’
- not all filaments collapse

Filament evolution





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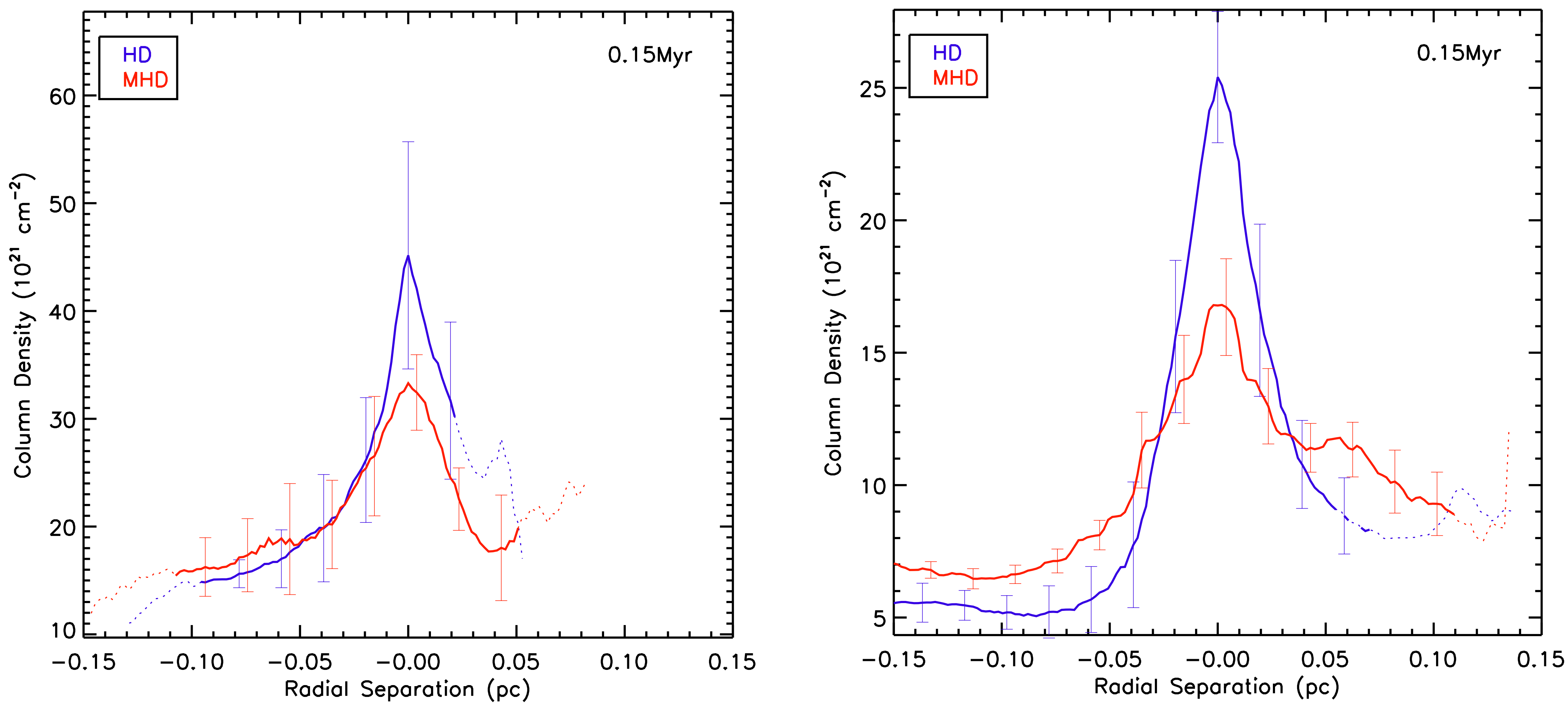

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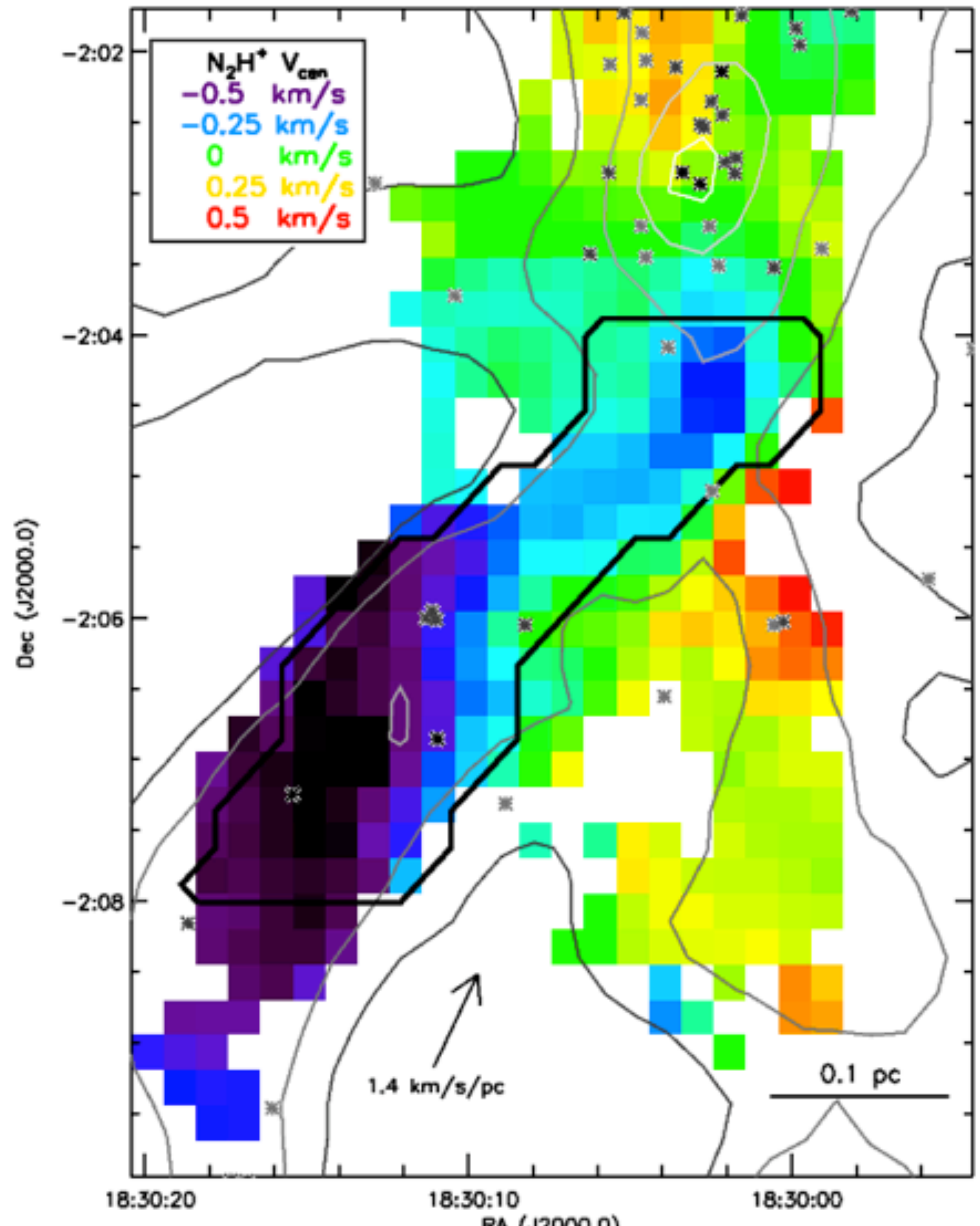
Gradients along filaments

- large-scale velocity gradient along long axis of filaments observed since early 1980's (e.g., McCutcheon et al 1982, Bally et al 1987, Dobashi et al 1992)
- Interpret as rotation? infall? outflow? shear?

(see Dirienzo, Lee, Mundy, Storm)

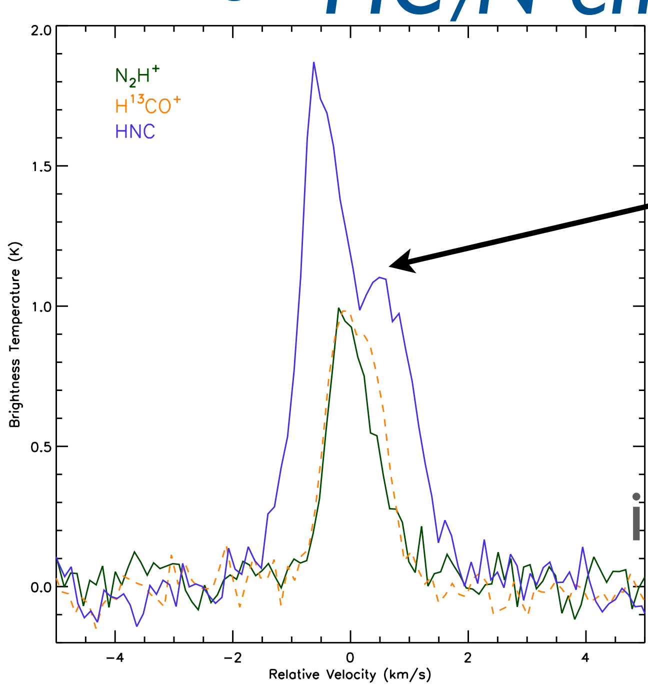


velocity gradient along Serpens South: Kirk et al 2013

Motion Across Filaments

Range of evidence for accretion onto filaments:

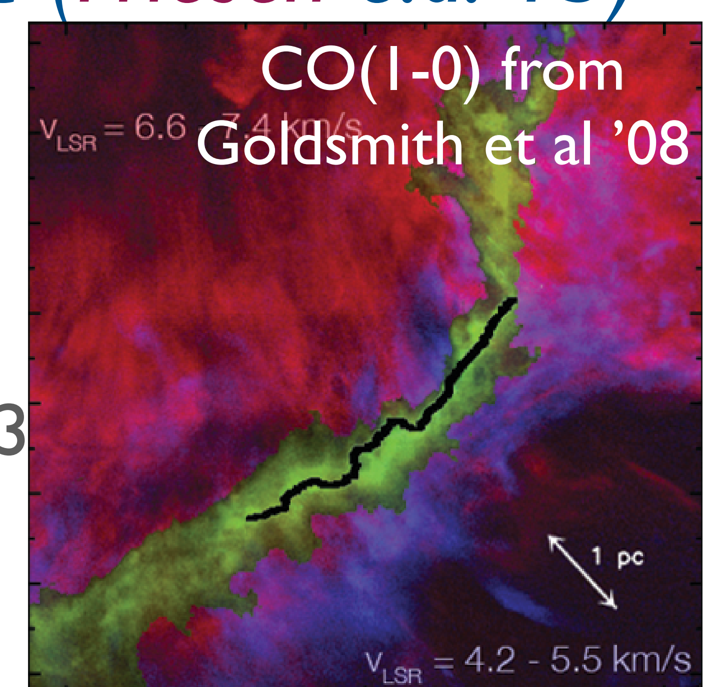
- infall (self-absorption) signatures in gas (e.g., Schneider et al 2010, Kirk et al 2013, Friesen et al 2013, Battersby, ...)
- increased linewidth in dense gas attributable to infall (Arzoumanian et al 2013, Friesen et al 2013,...)
- hints of velocity gradient across filaments (Dobashi et al 1992, Palmeirim et al 2013, CLASSY,...)
- *HC_7N emission where it should have depleted (Friesen e.a. '13)*



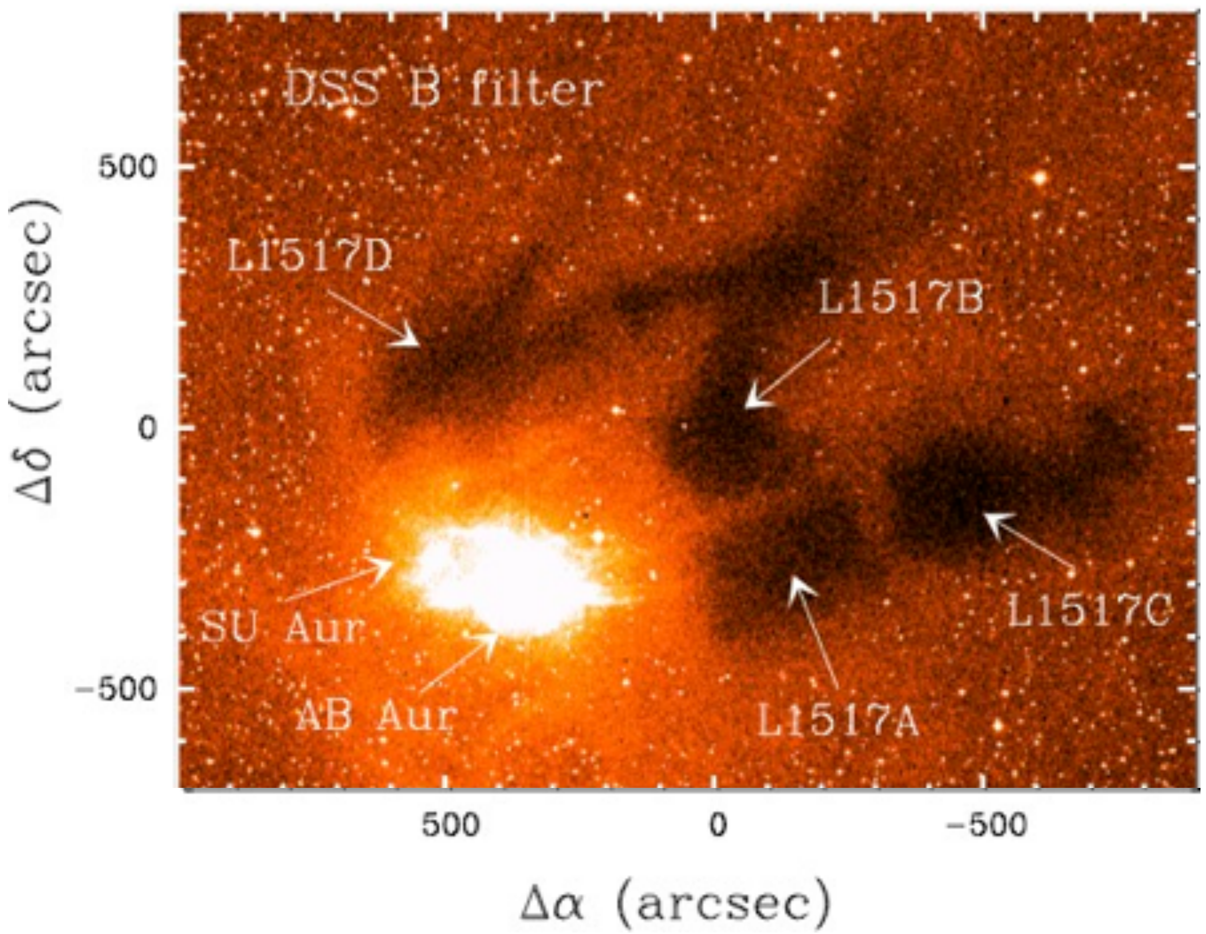
optically thick line self absorbed where optically thin lines peak

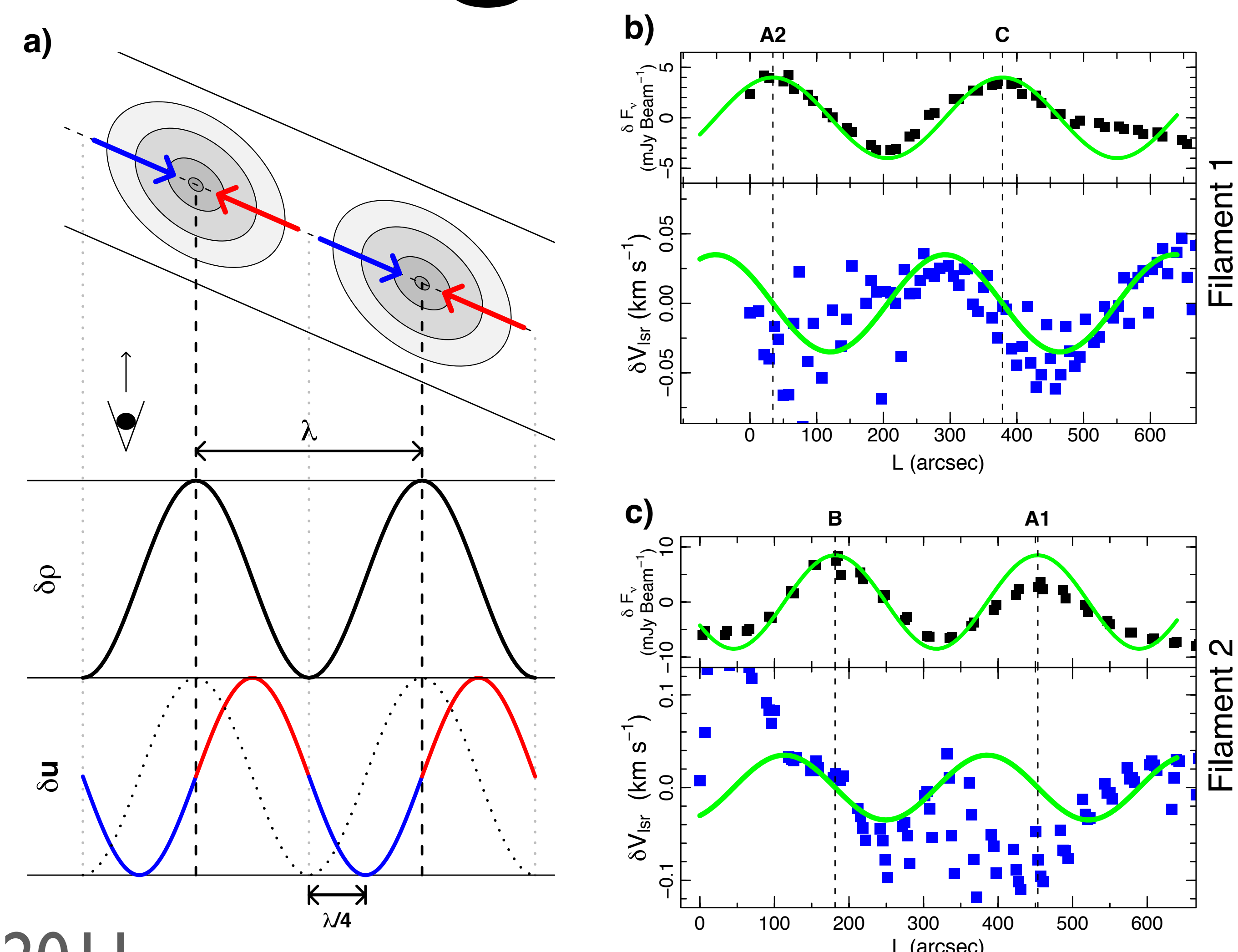
infall in Serpens South: Kirk et al 2013

velocity gradient across Taurus filament parallel to wispy striations: Palmeirim et al 2013



Filaments feeding cores



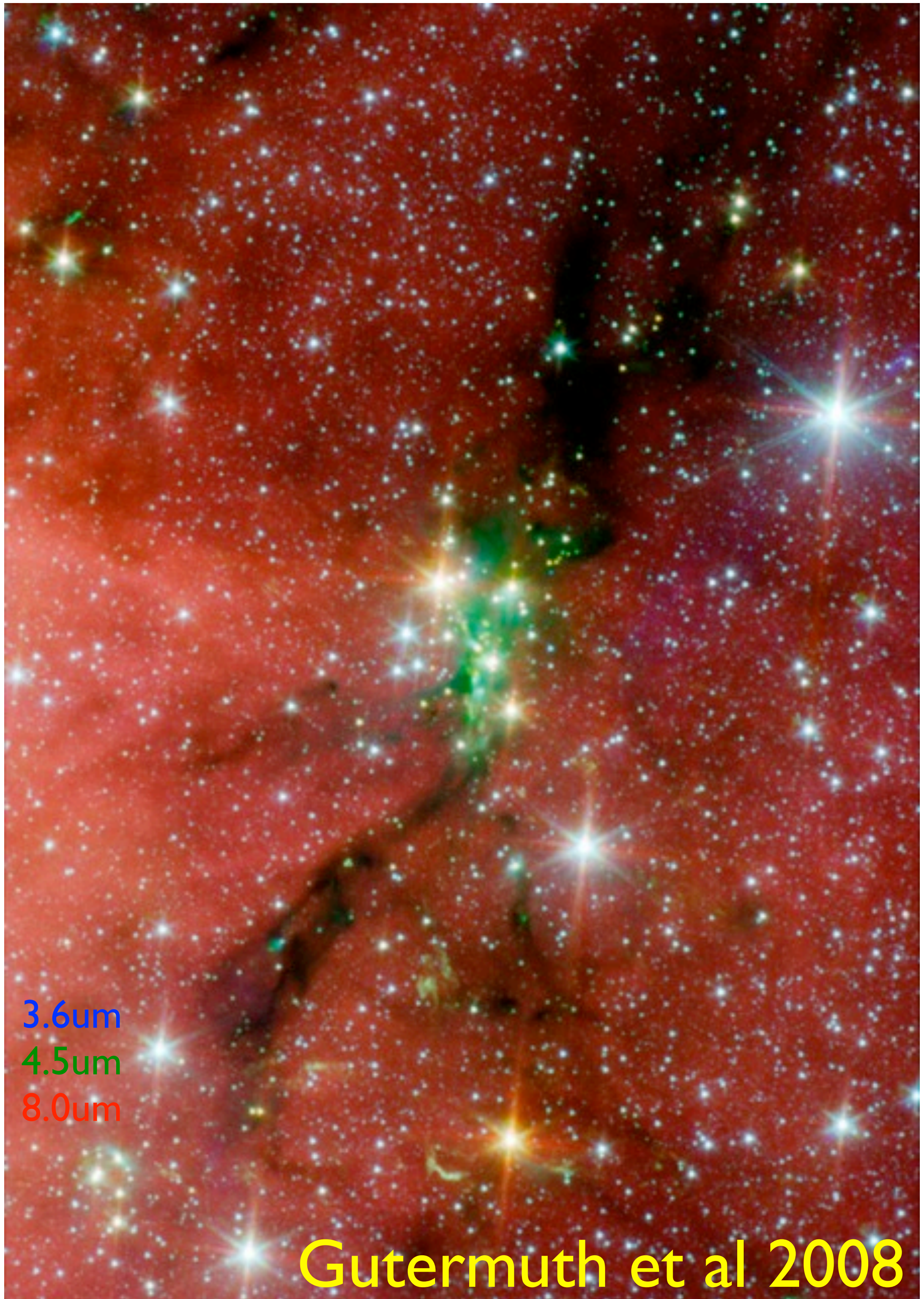


Hacar et al 2011

Taurus: oscillations in density and velocity along quiescent filaments suggest filaments accreting onto embedded cores

(see also Anderson)

Filaments Feeding Clusters



Serpens South properties

- very young cluster (v. low ratio of class II/I sources vs other nearby regions - Gutermuth et al 2008, 2009)
- B perpendicular to filaments (Sugitani et al 2011)

Southern filament:

- M/L > thermal (~60M_{sol}/pc; Kirk et al 2013)
- clear velocity gradient along filament & strong infall onto the filament (Kirk et al 2013)

see also Friesen, Plunkett, Storm

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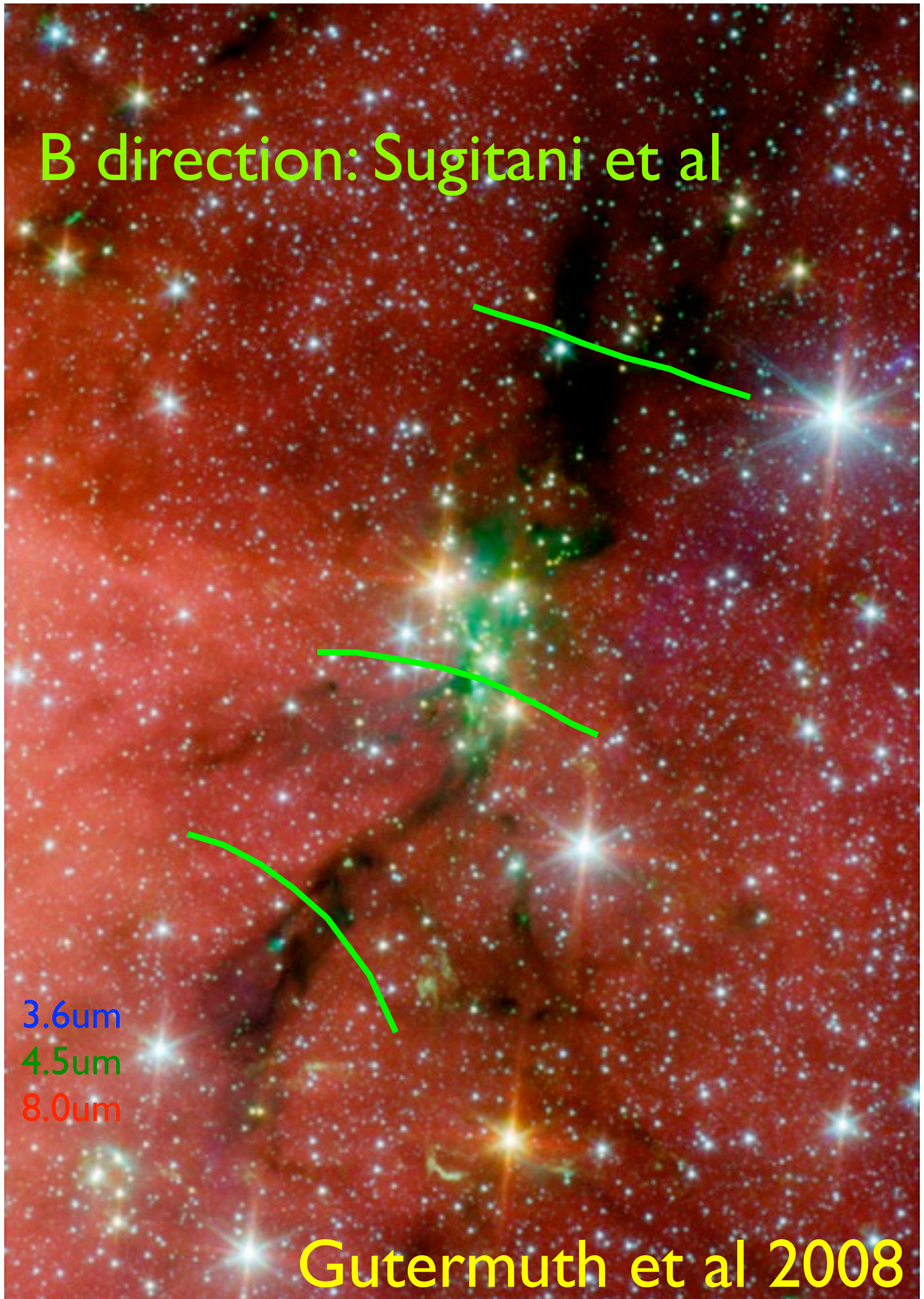

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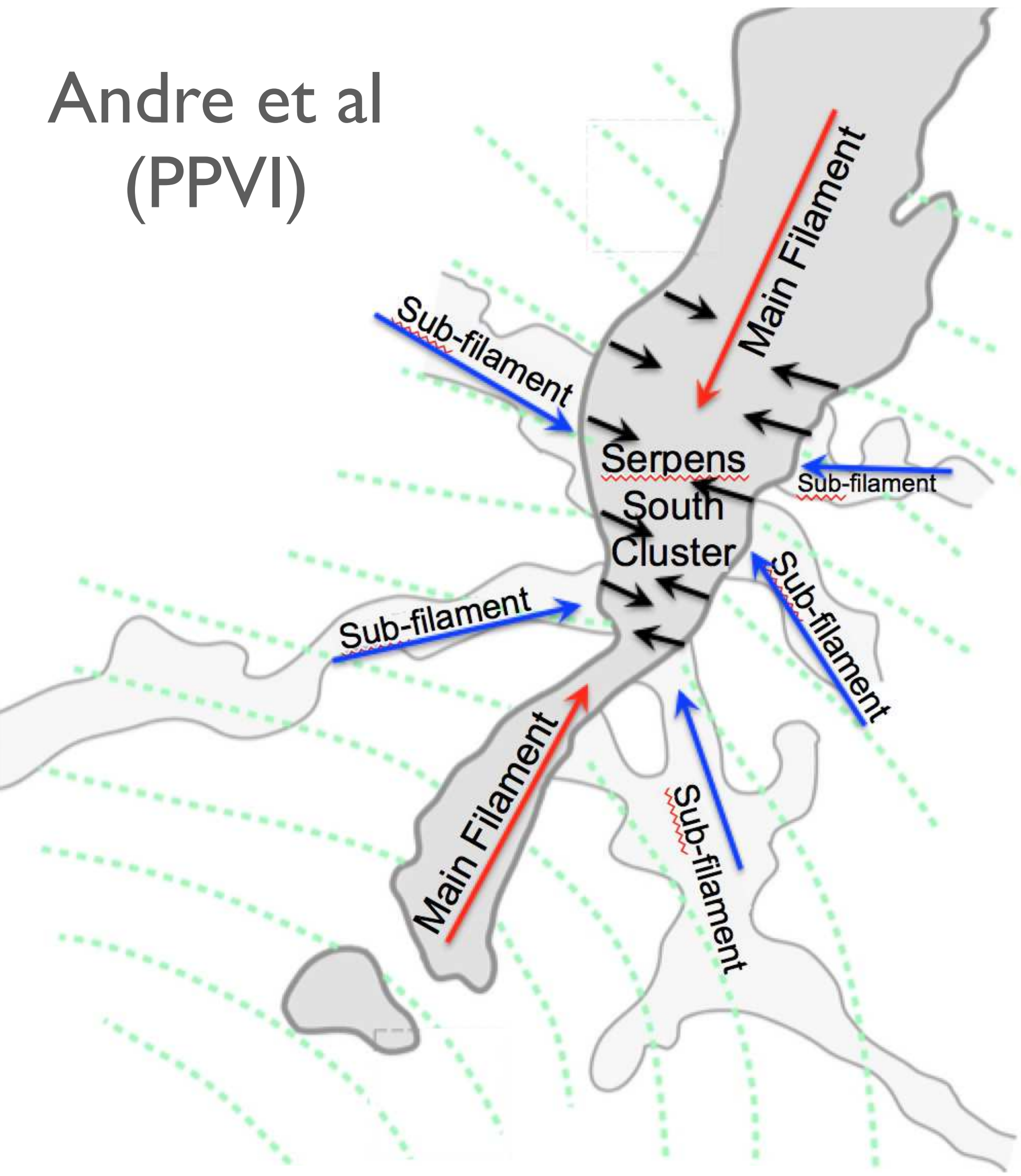
Filaments Feeding Clusters

Andre et al
(PPVI)



Serpens South
schematic model

NB: local vs global filament collapse (Pon e.a. '11 &'12)

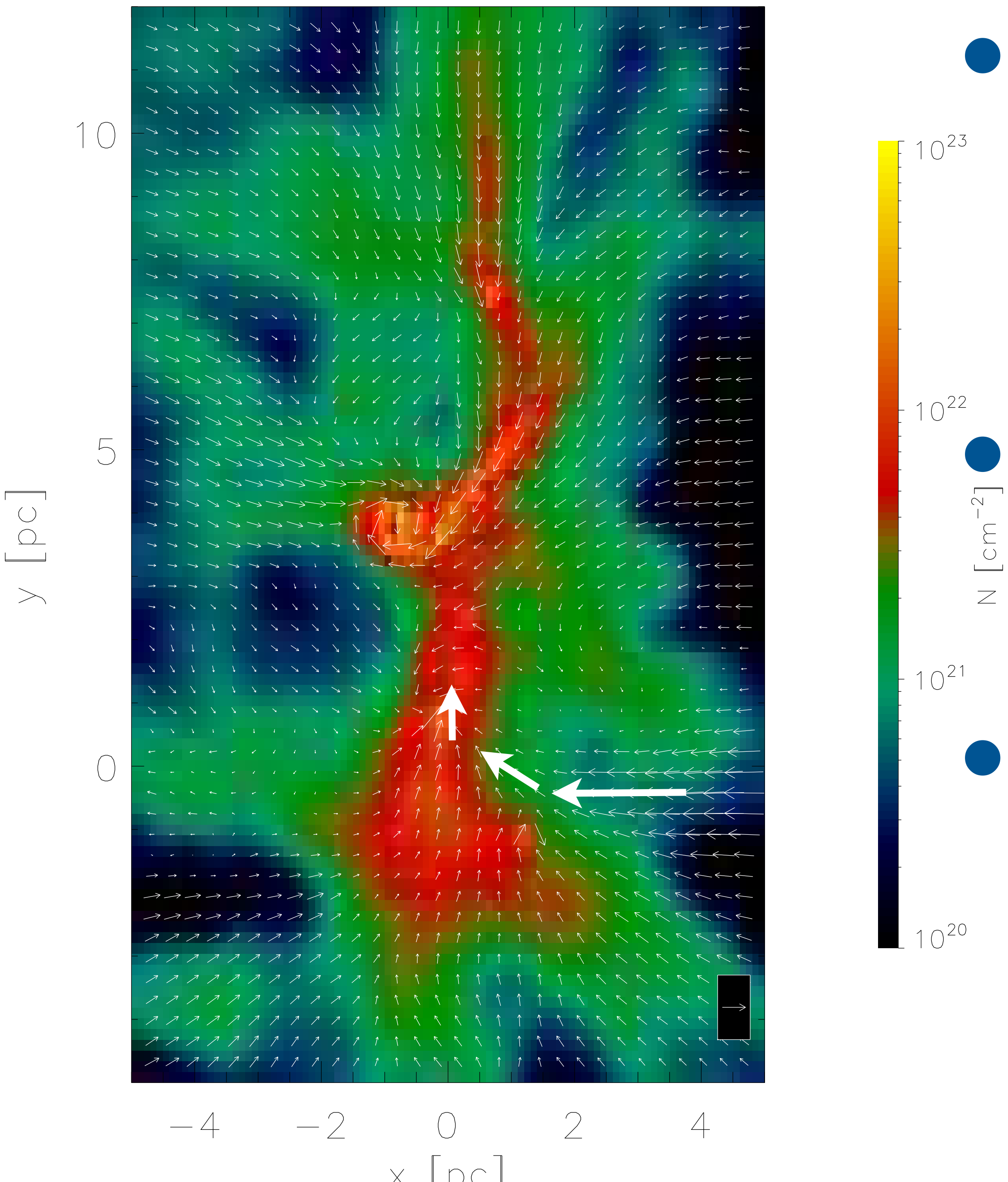
Best evidence to date for filamentary accretion onto central cluster:

- gradients & infall motions (south & north of cluster) - Kirk / Friesen '13
- inferred accretion rates: 30/130 M_{sol}/Myr
- consistent with formation rate inferred in cluster (90 M_{sol}/Myr; Gutermuth et al 2008)

NB: evidence also gathering in Taurus (Palmeirim et al 2013), DR21 (Schneider et al 2010), SDC335 (Peretto et al 2013), SDC13 (Peretto et al 2014), Fuller...

see Nakamura et al 2014 for alternate SerpS interpretation

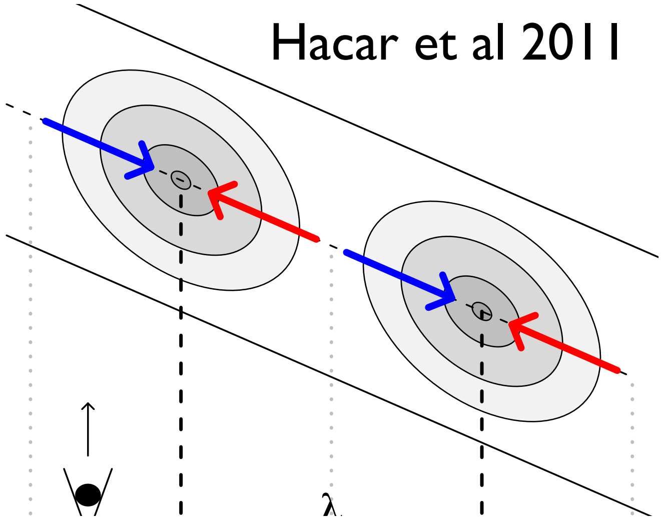
Accretion Flows in Simulations



Gomez & Vazquez-Semadeni 2014:

- Gomez & Vazquez-Semadeni 2014 (colliding flows): material accretes onto filament, along fil to cluster, + localized core accretion
- Predict different velocity structure at different density regimes (/gas tracers)
- see also Smith ea'14 for HD, Chen for MHD flows, Testi for synthetic observations, Wu for cloud collisions, Heitsch for different velocity profiles for different viewing angles, (Kirk, Klassen & Pudritz in prep for MHD vs HD filamentary flows)

Hacar et al 2011



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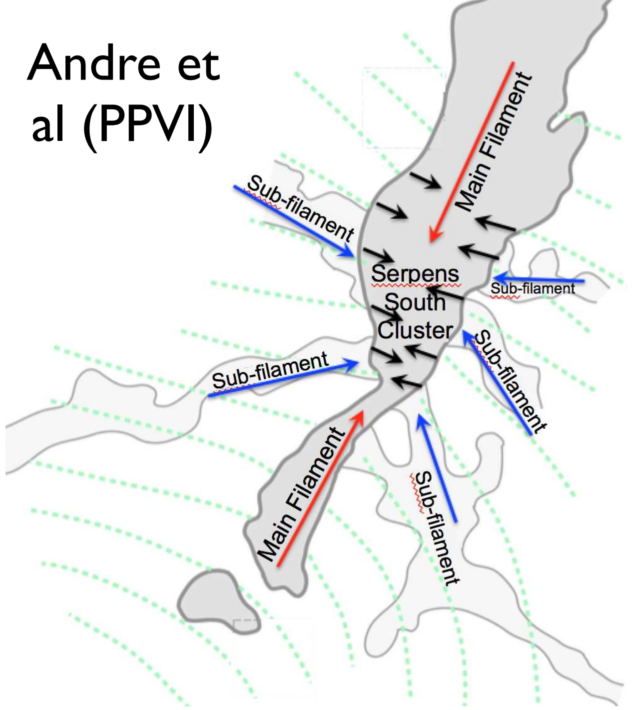
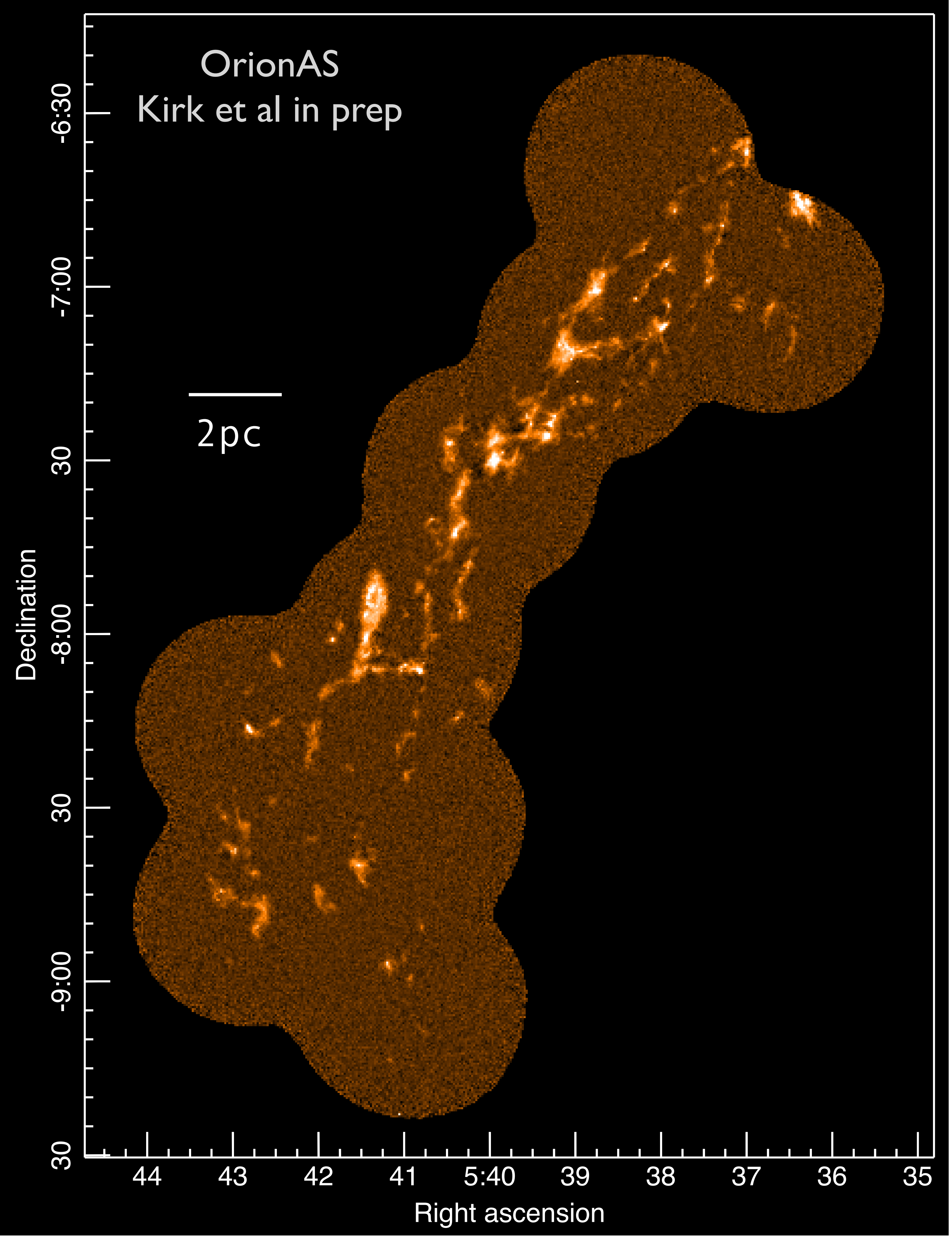


Conclusions

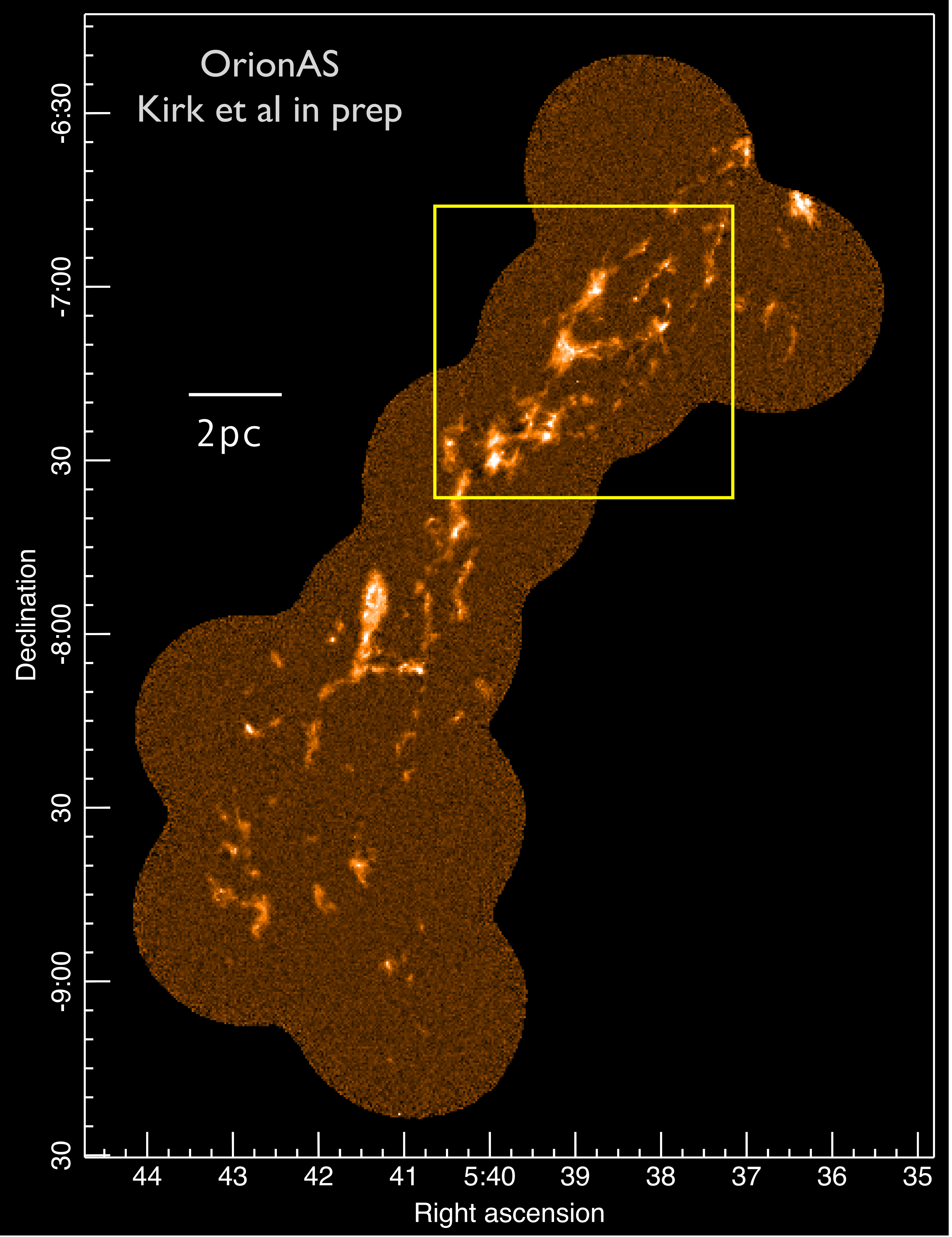
- filaments closely tied to star & cluster formation
- observations suggest filaments may provide significant mass reservoir for cores & clusters
- variety of processes may be influencing filament evolution including large-scale turbulent flows, magnetic fields, gravity, heating/cooling,...
- analytic work & simulations starting to make predictions for the effect of various physics on filament (column) density & velocity structure
- observations beginning to characterize the diversity of filaments and can test / constrain theoretical work (see also Shirley)
- complications: e.g., viewing angle (Heitsch), filament bundles (Hacar)



Future Directions: JCMT GBLS

quantitative results coming soon!

e.g., Salji et al MNRAS submitted



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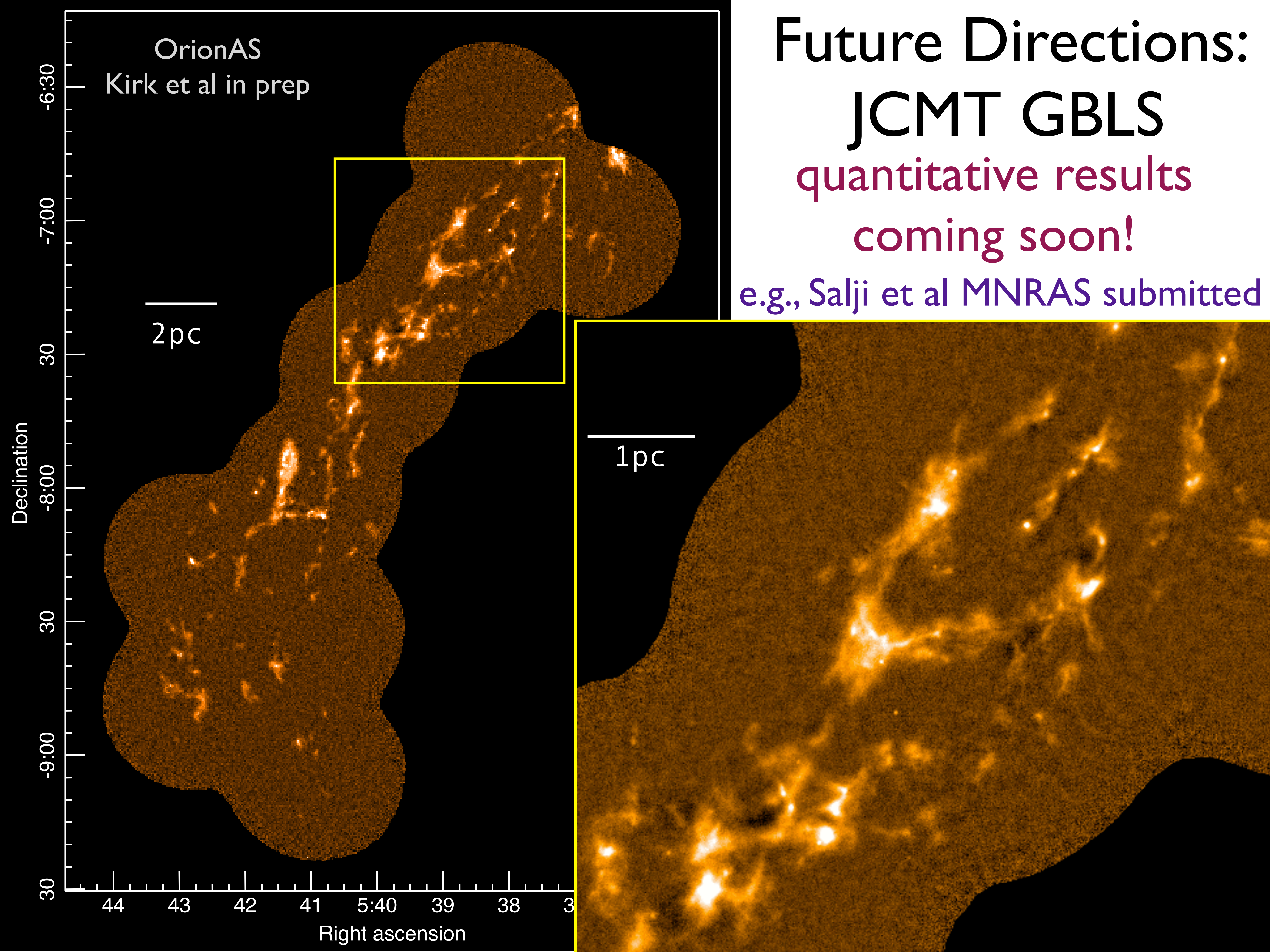

Thank You!