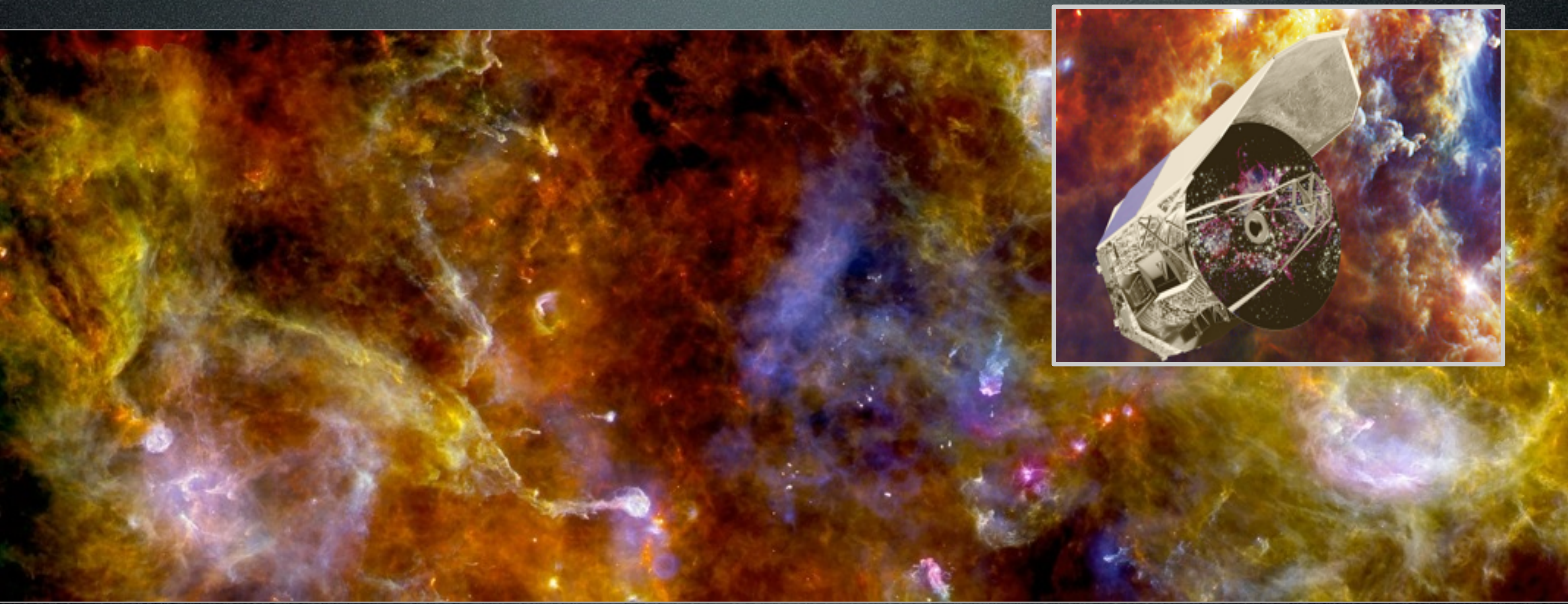
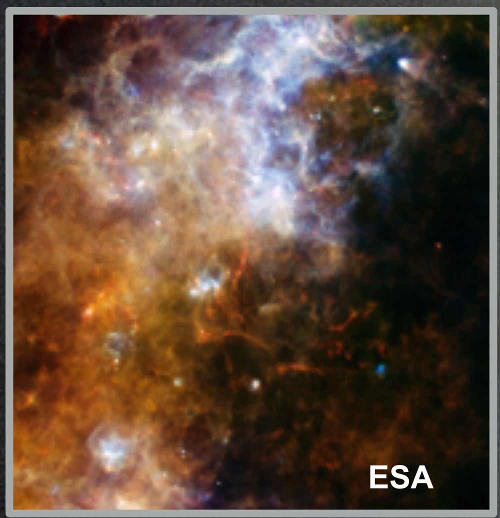
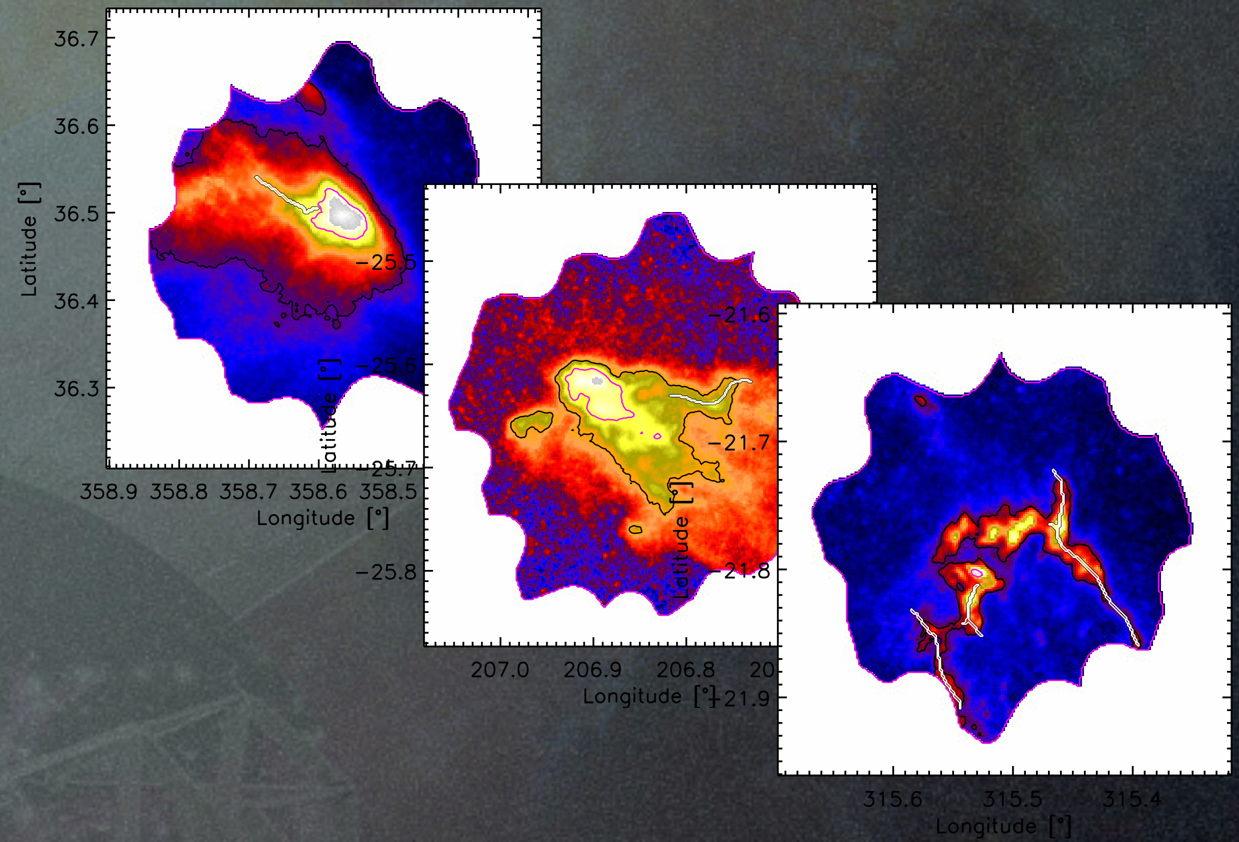
Extreme Star Formation: Environments & Processes

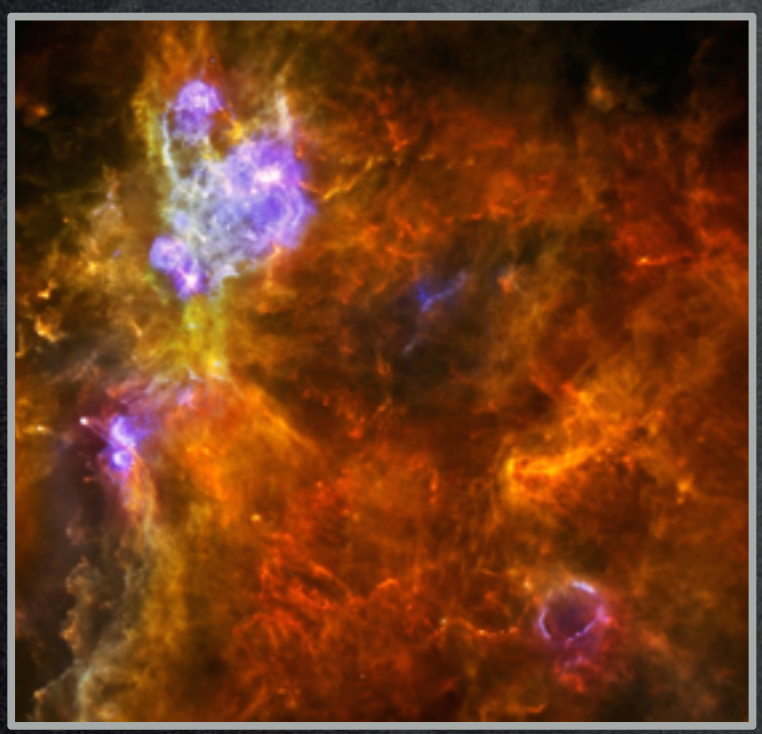


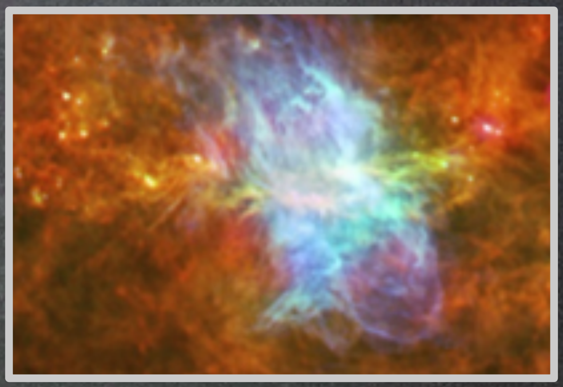
- **WHAT? WHY?**
- **Diffuse Environments: Low-Mass Case**

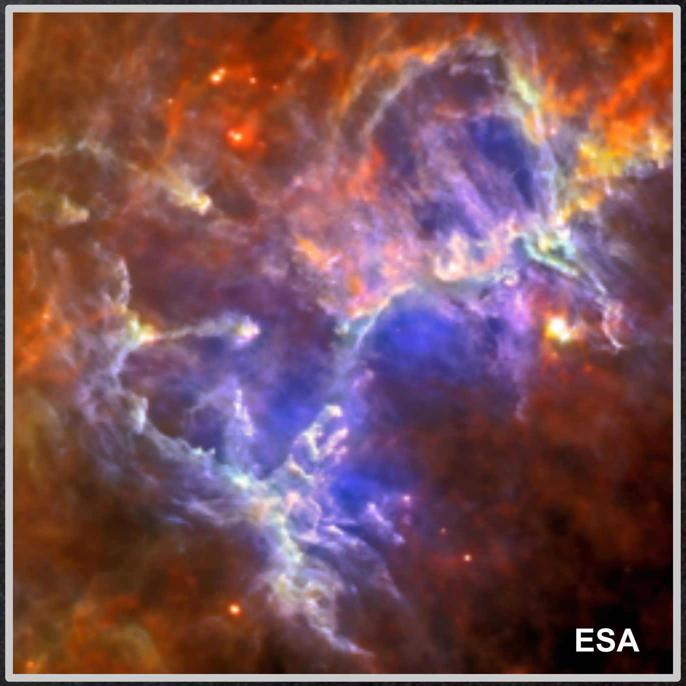




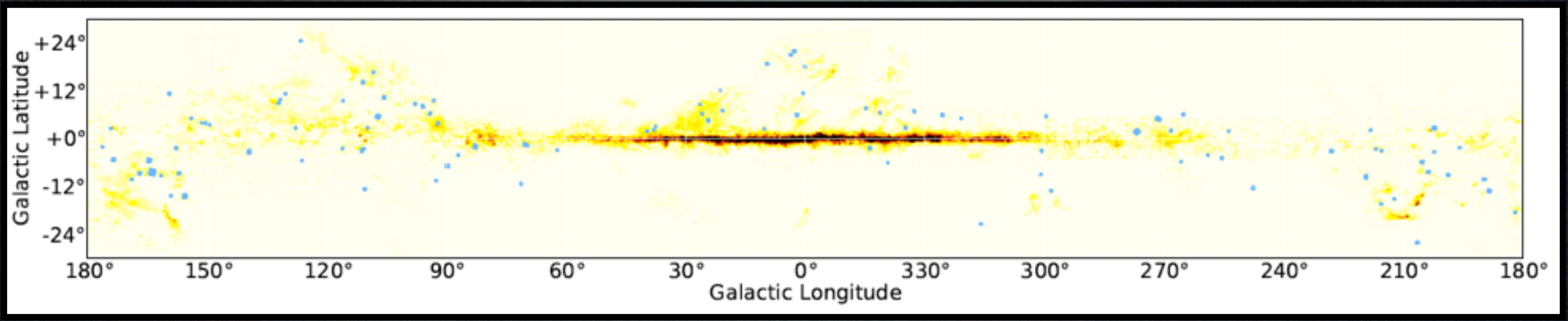
- **Dense Environments: High-Mass Case**







- The GCC Programme
- Low-Mass Case



Montillaud et al. 2015

Probes various galactic positions and environments

<u>'Classical' Local Star Formation</u>
probing filament formation an evolution, sites of on-going star formation

<u>'Anomalous' Star Formation</u>
star formation in diffuse environments - high-galactic latitudes

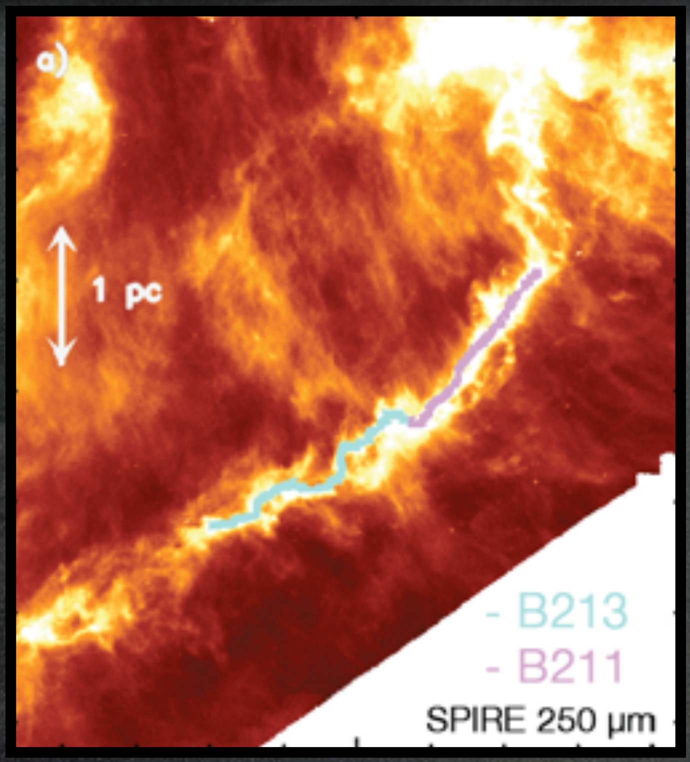
Low-Mass Case [Filaments]

[Rivera-Ingraham et al. 2015; submm]

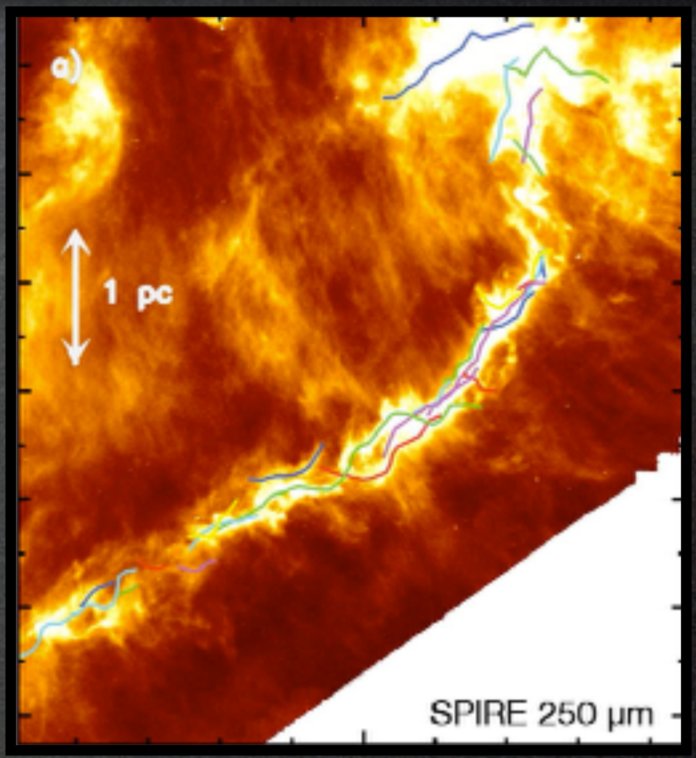
TARGET: The ultimate and final link between the filamentary 'environment' and the cores hosting/forming young stellar objects

(the last step in the hierarchical ladder)

Large scale filament



Small scale

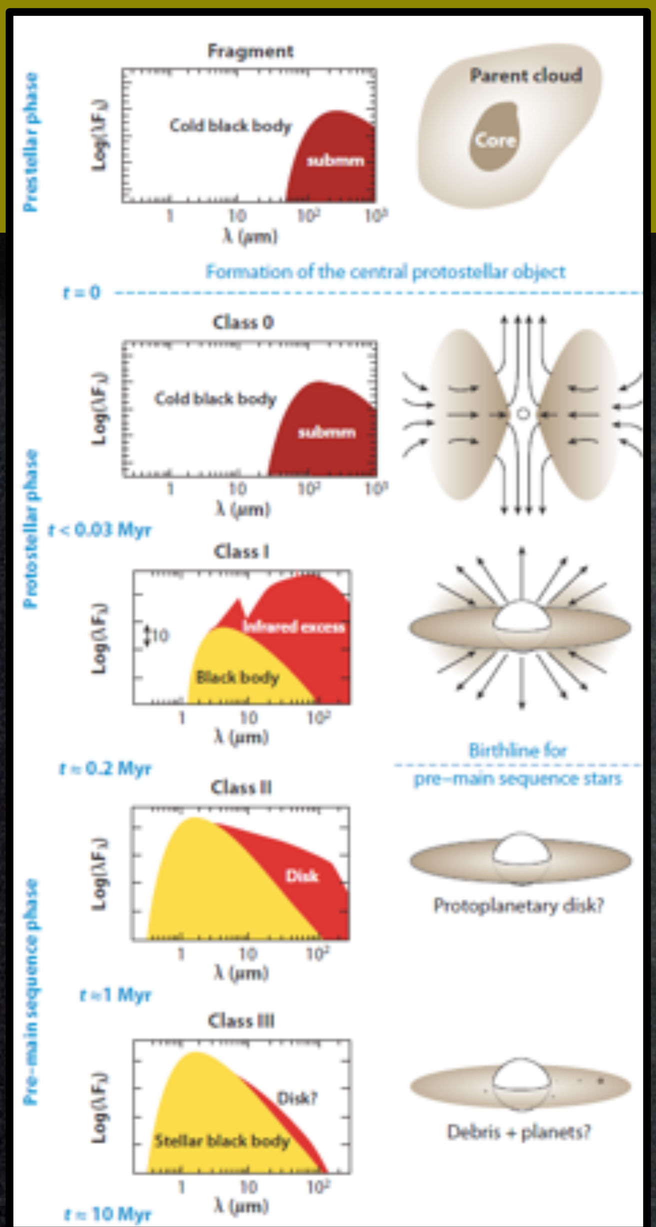


Palmeirim et al. 2013

Low-Mass Case [Filaments]

[Rivera-Ingraham et al. 2015; submm]

GOAL: Evolution of core-bearing filaments (= SF) in the ISM combining observational and theoretical models based on accretion under different conditions



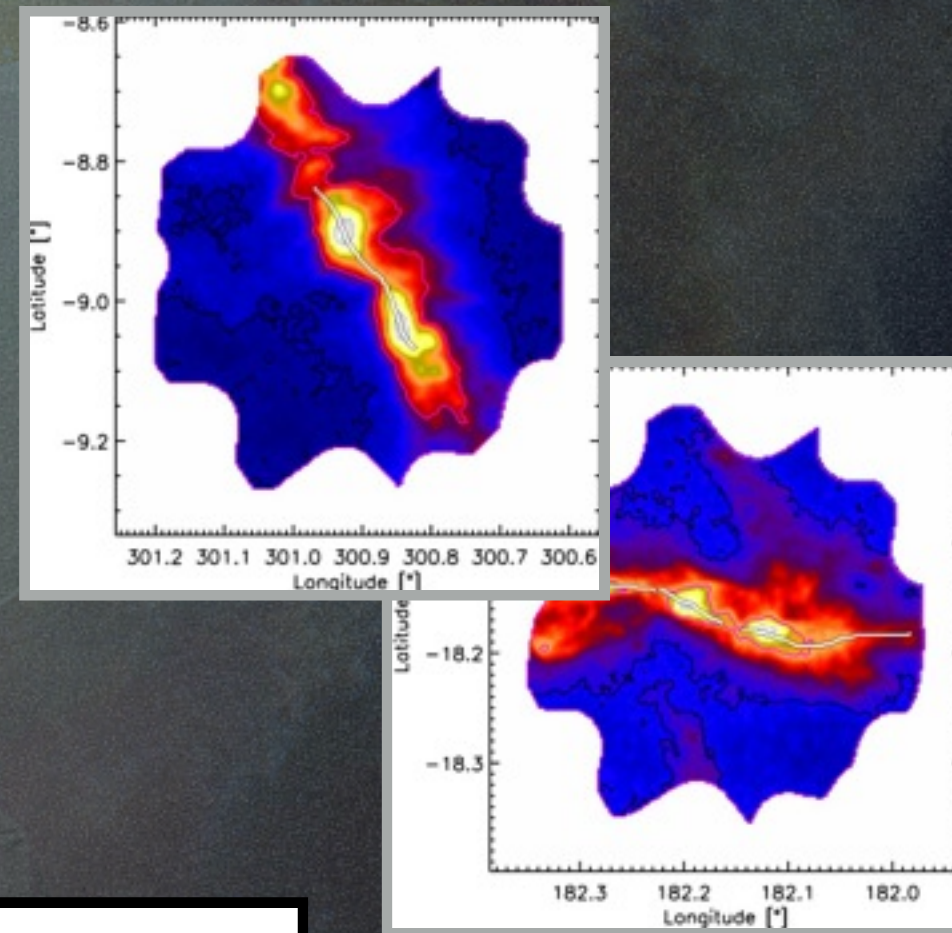
<u>Evidence for key role of accretion (mass increase) & gravity:</u>

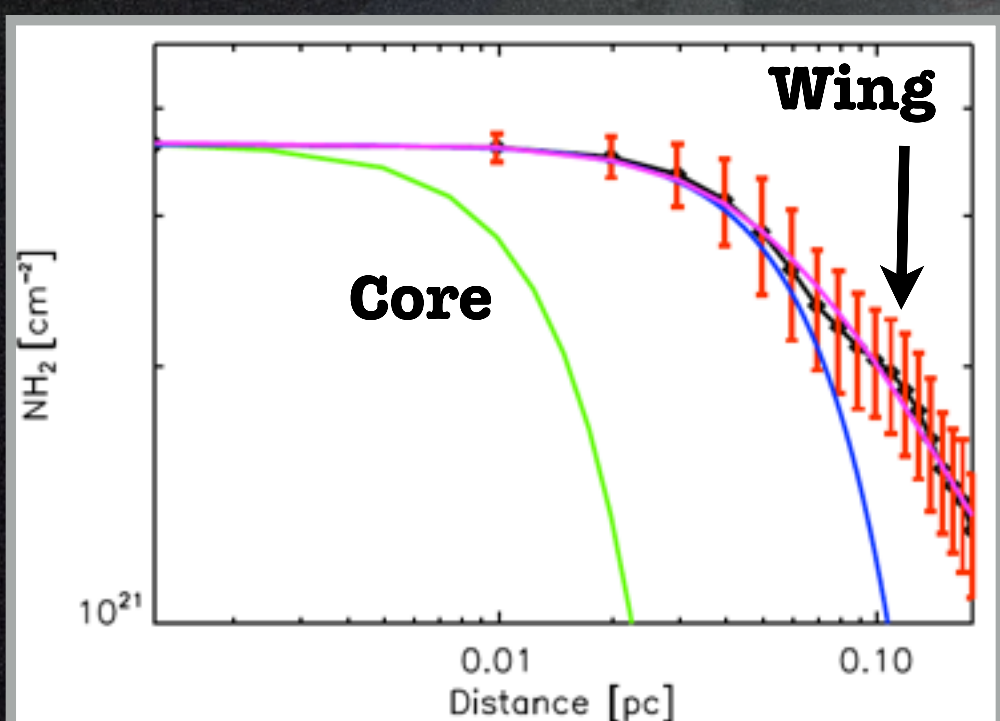
- Direct observations (e.g., Palmeirim et al. 2013):
- More massive protostellar filaments than prestellar filaments (e.g., Schisano et al. 2014).
- Accreting, supercritical self-gravitating filaments increase <u>central density</u> and <u>linear mass</u> at c<u>onstant width</u> with accretion/ collapse (Arzoumanian et al. 2011; 2013)

METHODOLOGY

- **GETSOURCES** [Men’shchikov et al. 2012]
  - Multi-scale, multi-wavelength source extraction algorithm
- **GETFILAMENTS** [Men’shchikov et al. 2013]

Extracts and removes (multi-scale) filaments from the images (more accurate source detection and measurements).



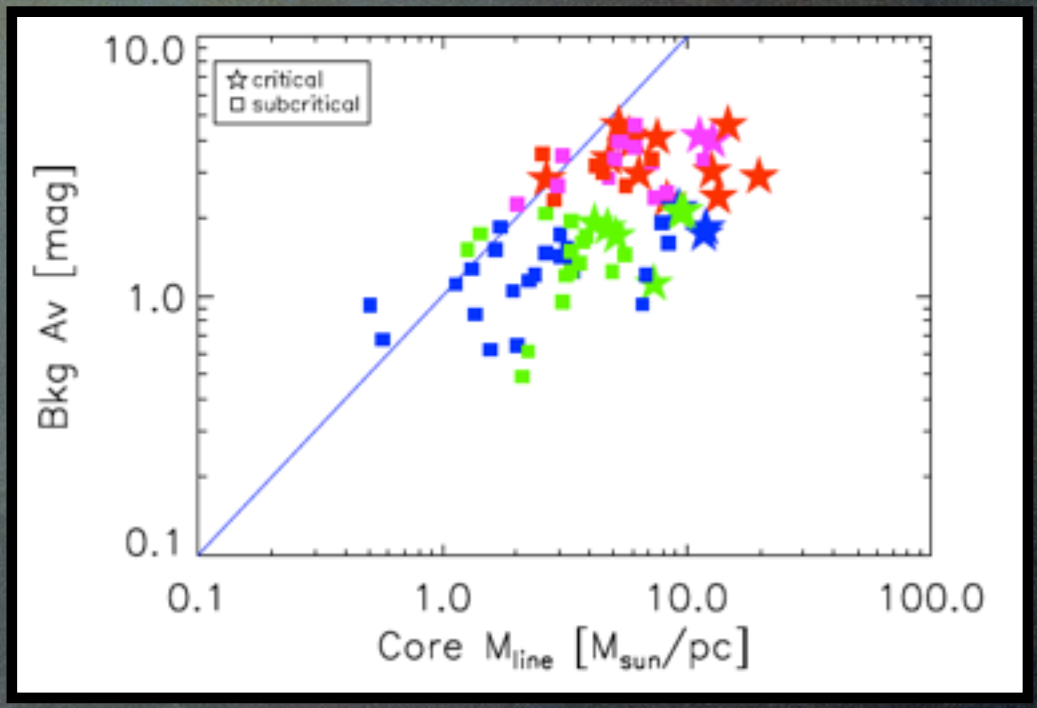


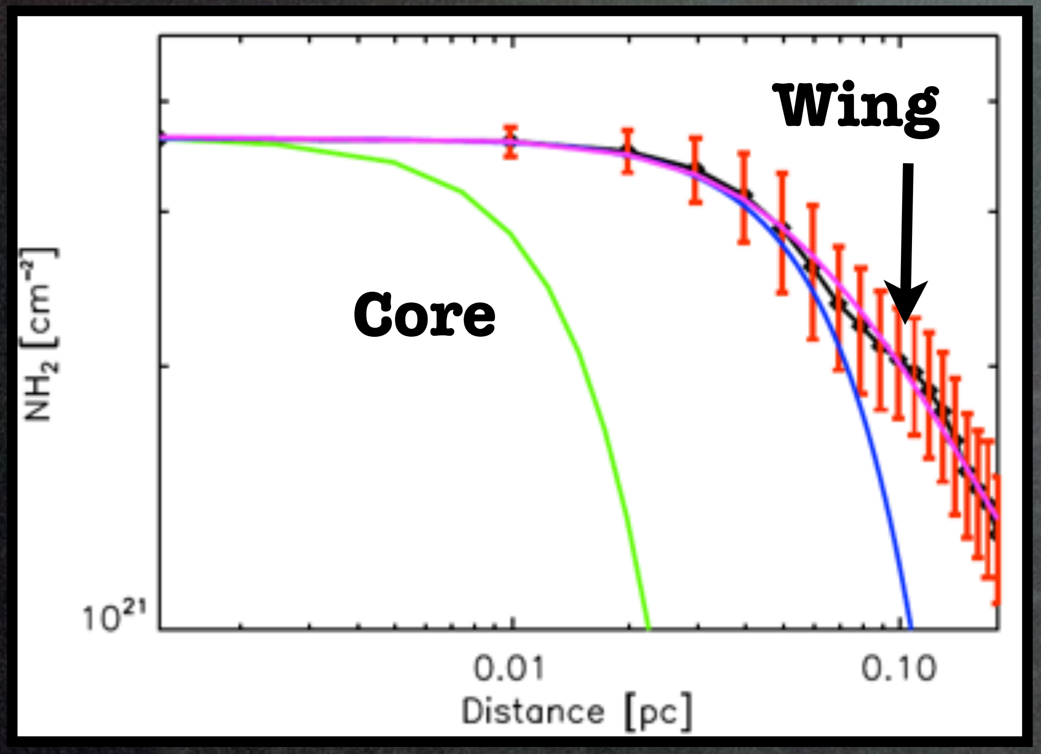
$$\rho_p(r) = \frac{\rho_c}{\left[1 + (r/R_{\rm flat})^2\right]^{p/2}}$$

$$M_{\rm line,crit} = 2\, c_s^2/G$$

$$M_{\rm line} = M_{\rm core} + M_{\rm wing}$$

OBSERVATIONAL RESULTS





CRITICAL | HB WING | LB WING

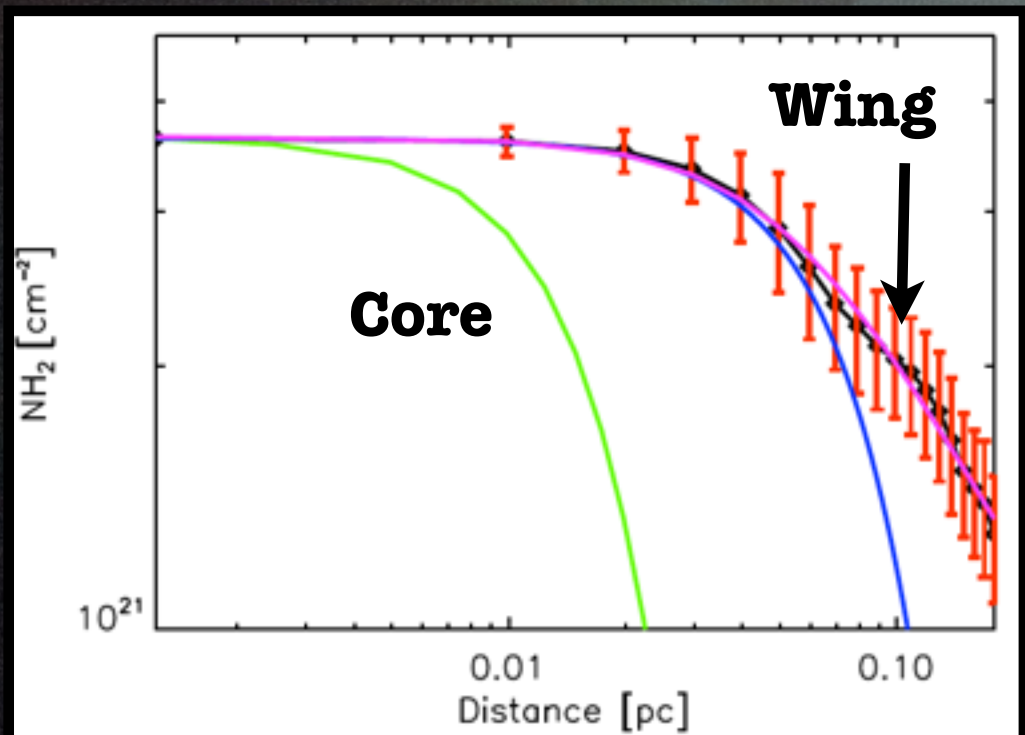
SUBCRITICAL | HB CORE | LB CORE

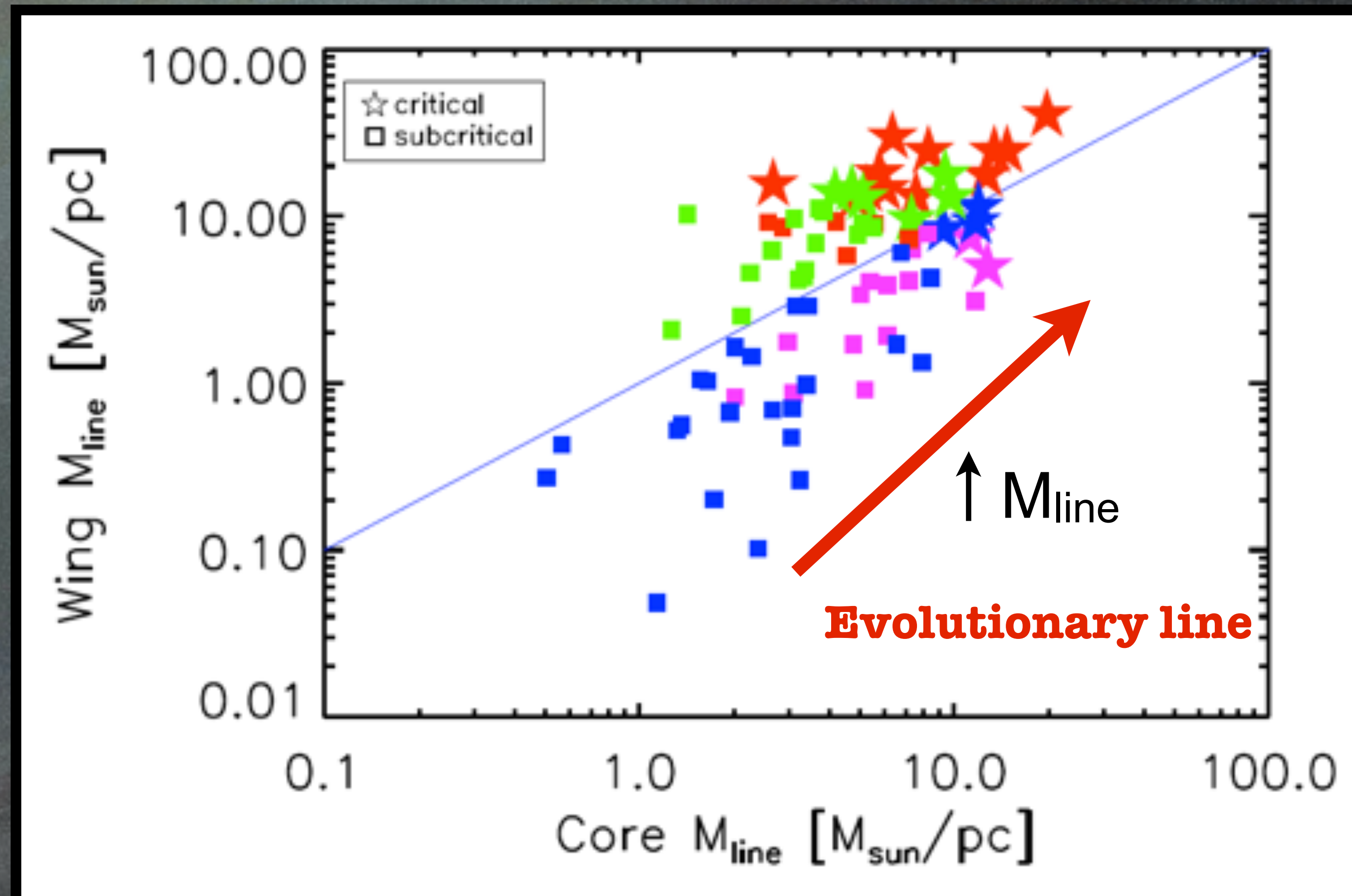
Filaments in dense environments reach systematically higher M_{core}

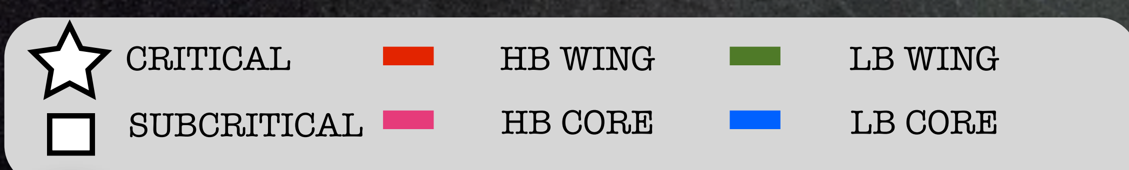
Typical value for supercritical filaments: Av~3 mag

transition to typical turbulent 'cloud' environment (based on PDF analysis; GTKP HOBYS - Rivera-Ingraham et al. 2015; submm)

OBSERVATIONAL RESULTS







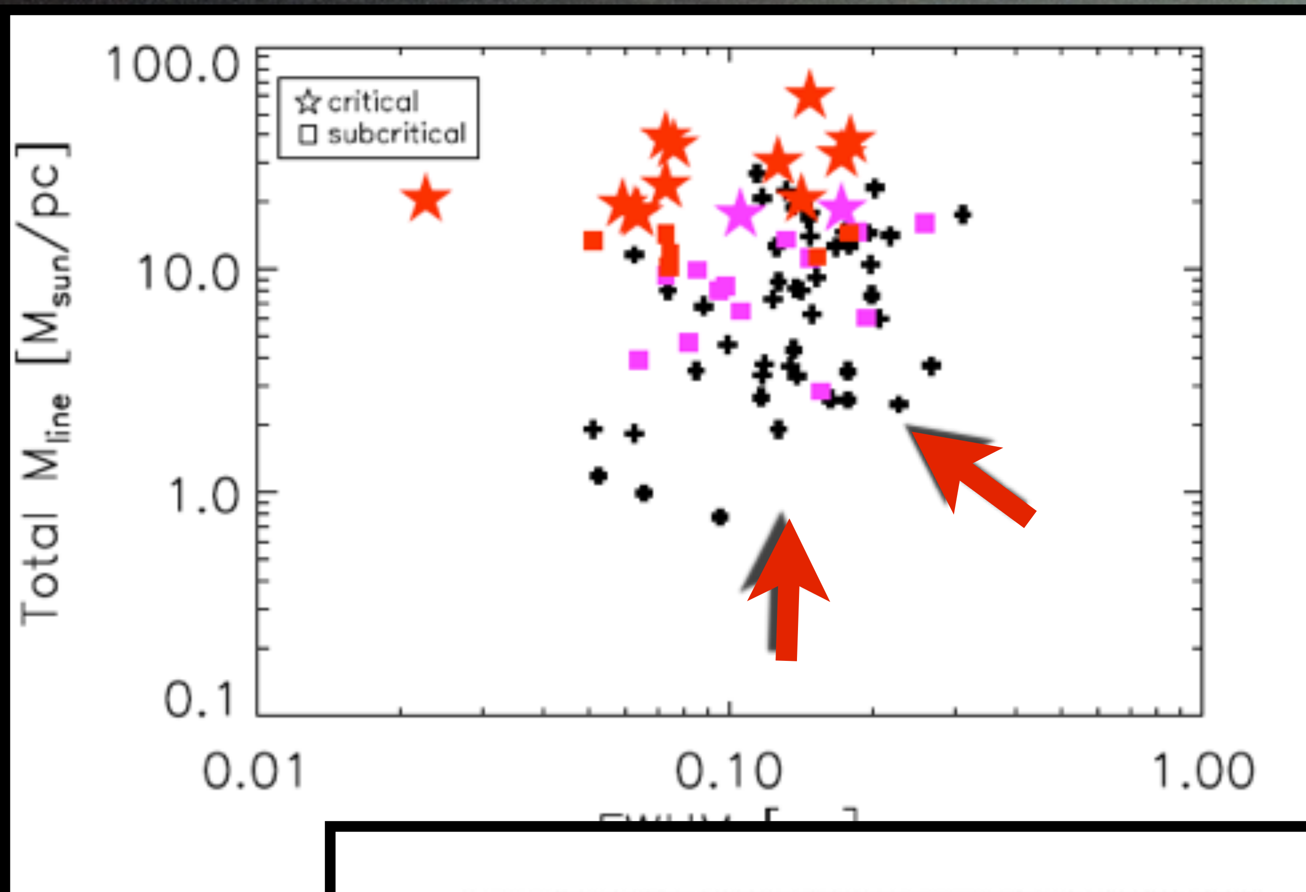
a) The wing dominates at later stages of evolution

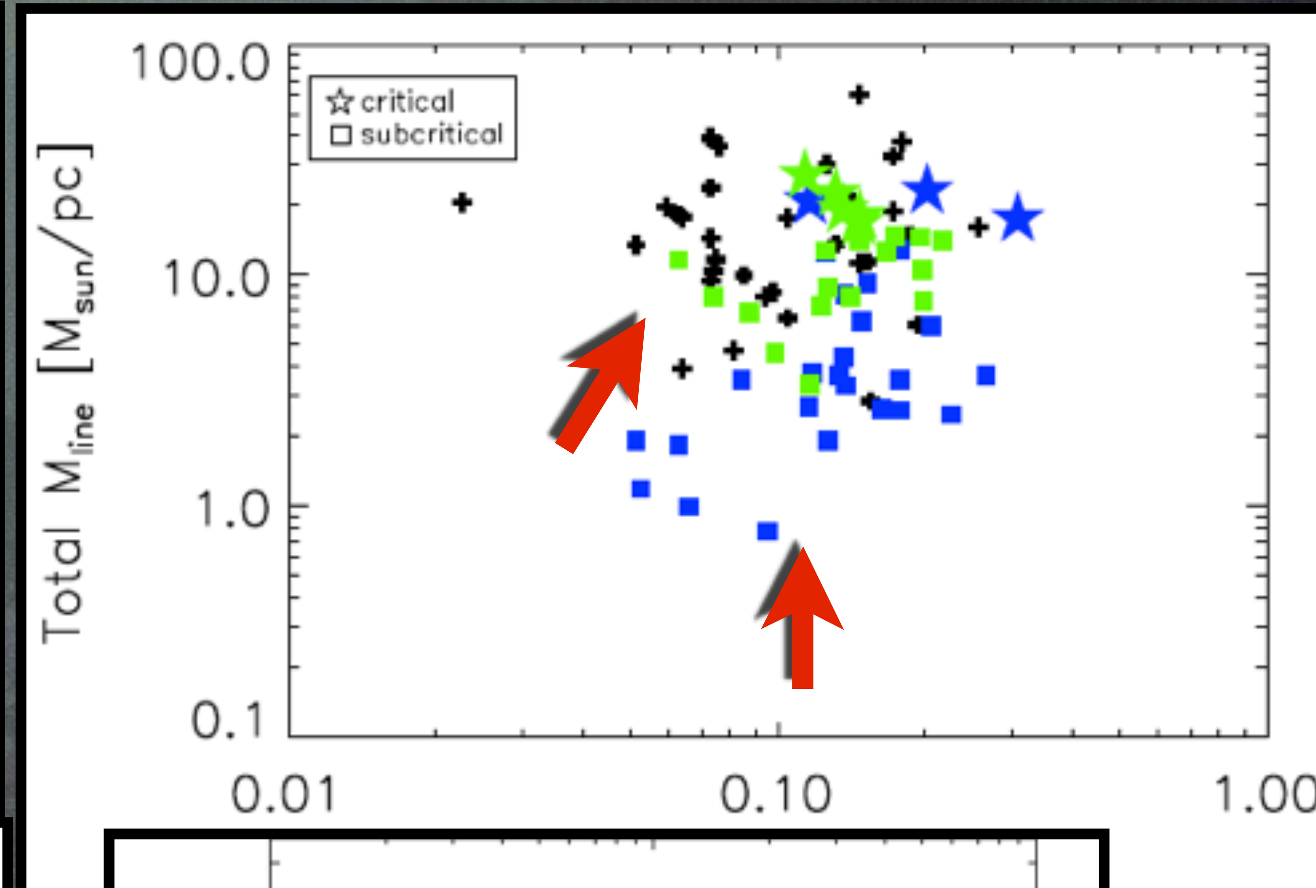
b) 'Decent' wings are associated with the most massive cores

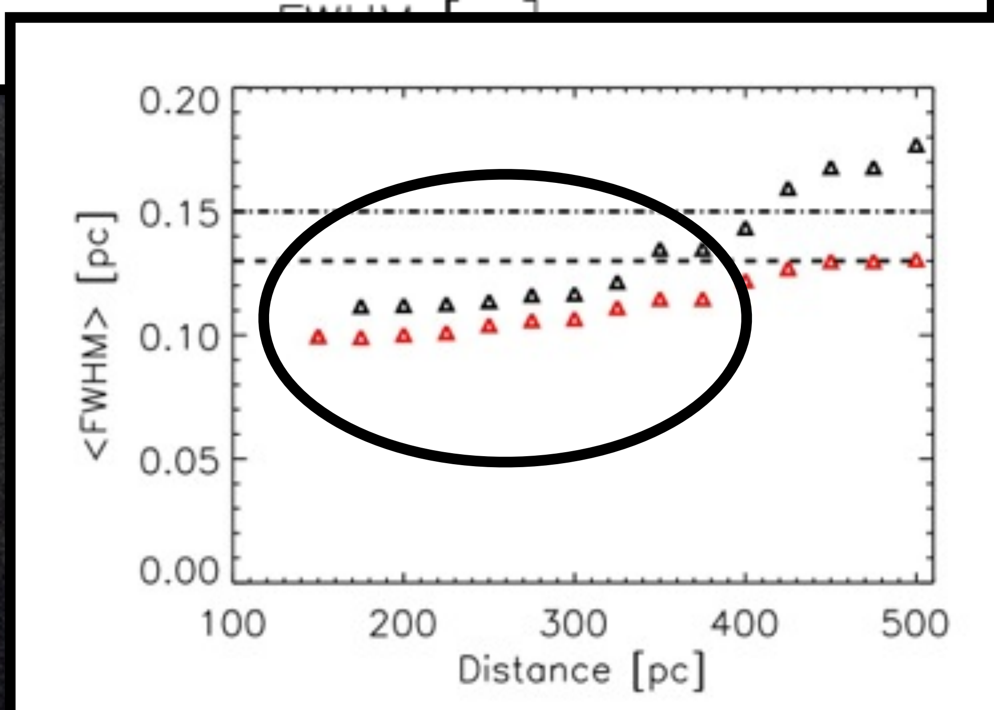
c) = associated with the highest BKGs

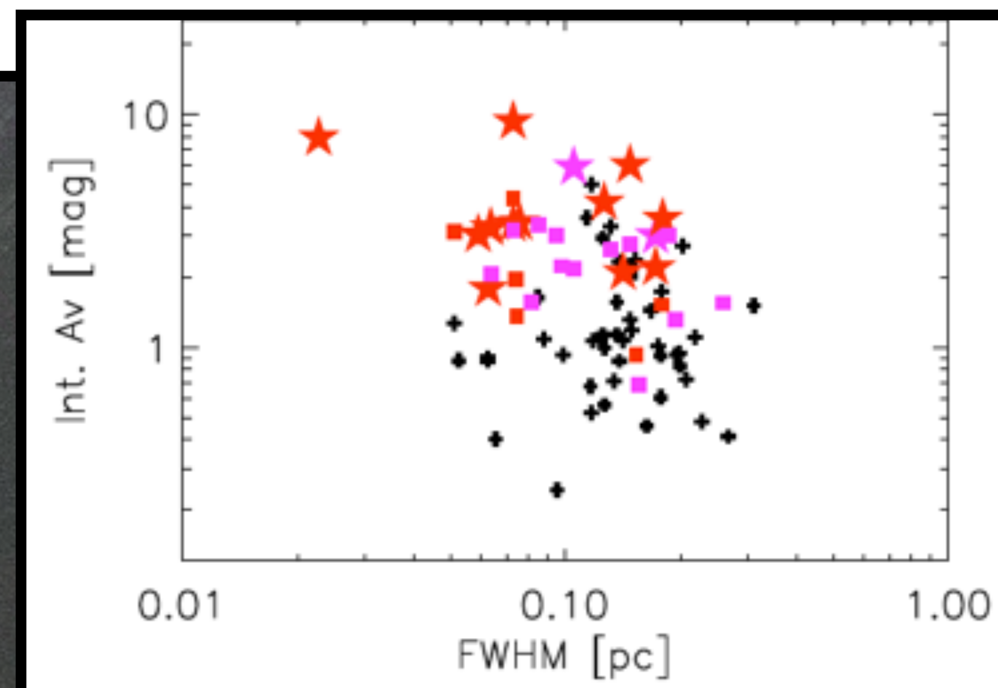
2 - LOCAL STAR FORMATION: FILAMENTS

OBSERVATIONAL RESULTS





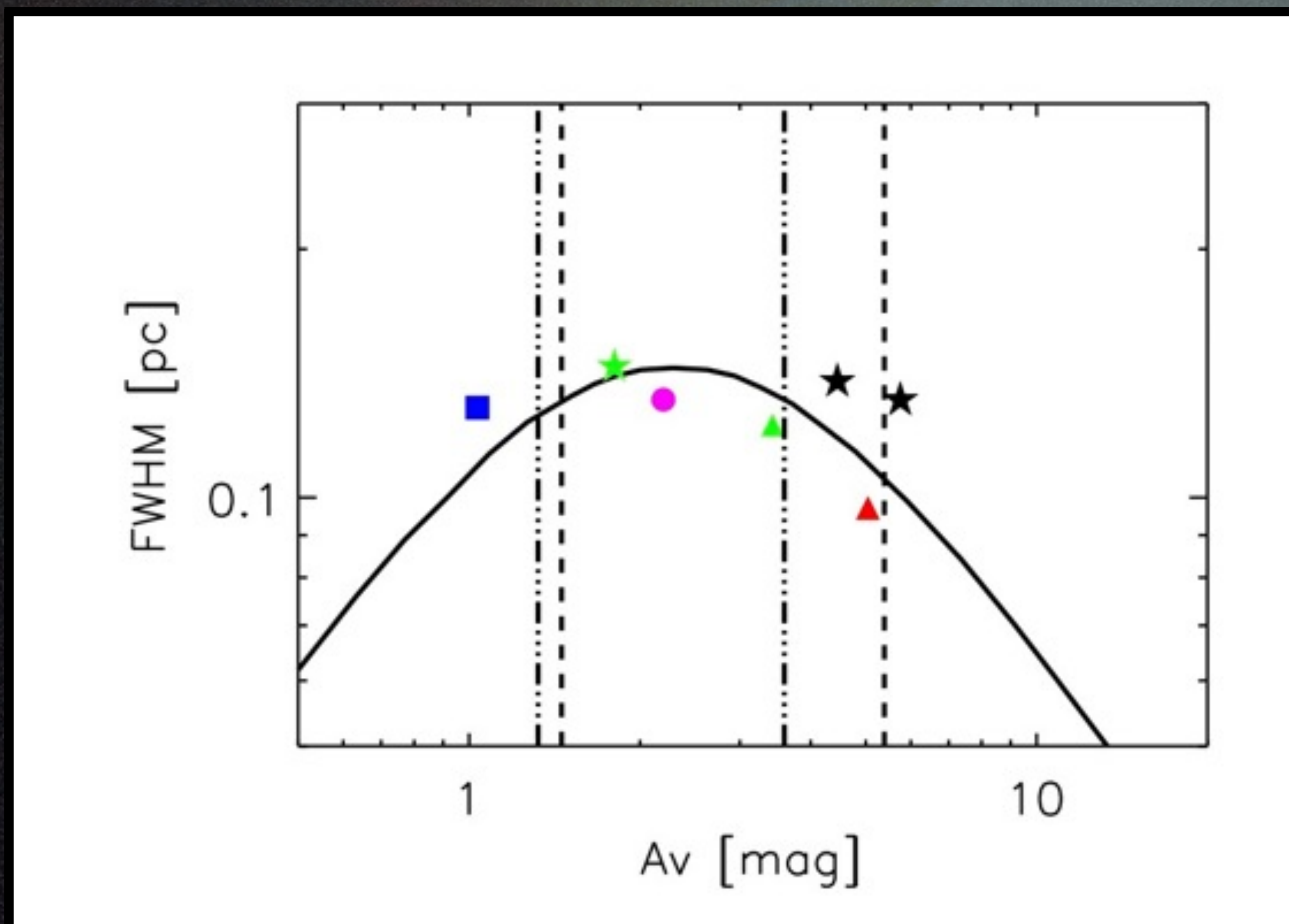


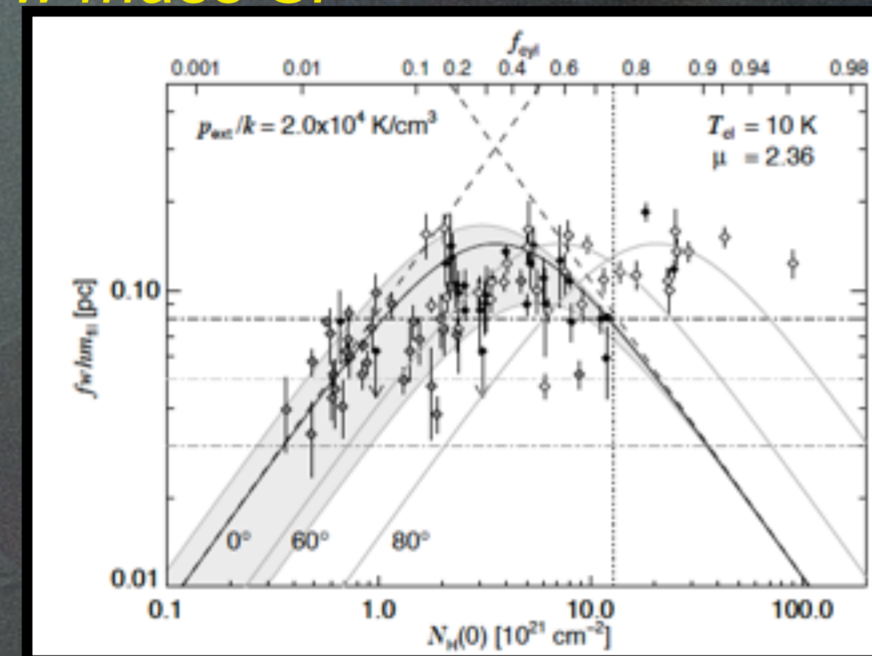


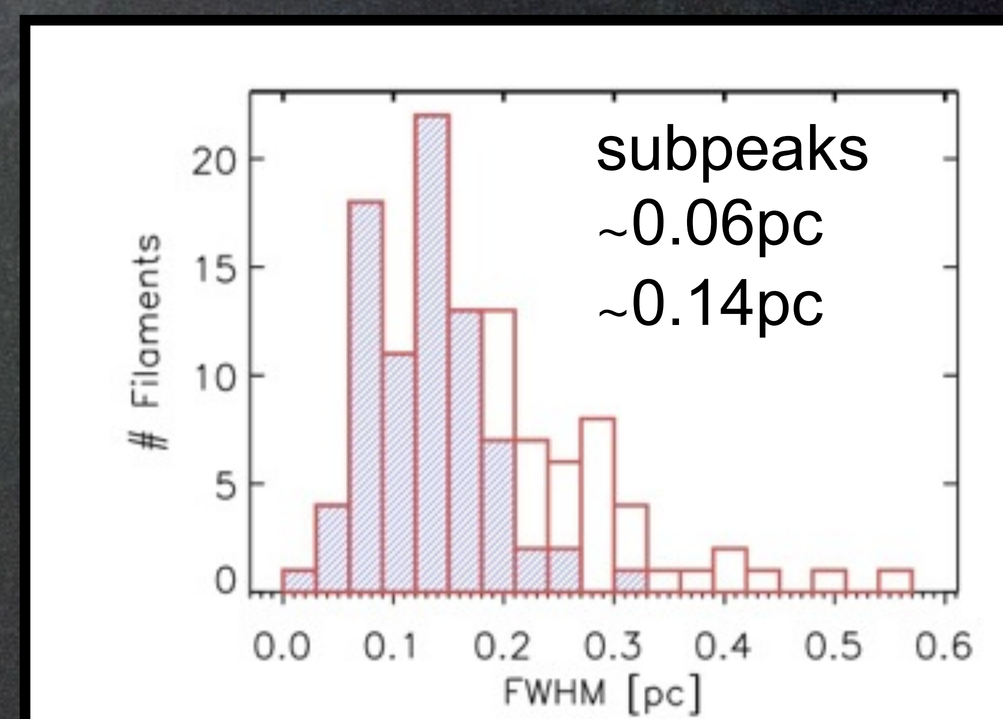
- THEORETICAL RESULTS
- ENVIRONMENTALLY-DEPENDENT GRAVITY-DOMINATED FILAMENT EVOLUTION:

Towards a complete model of filament evolution in low mass SF

Fischera & Martin 2012

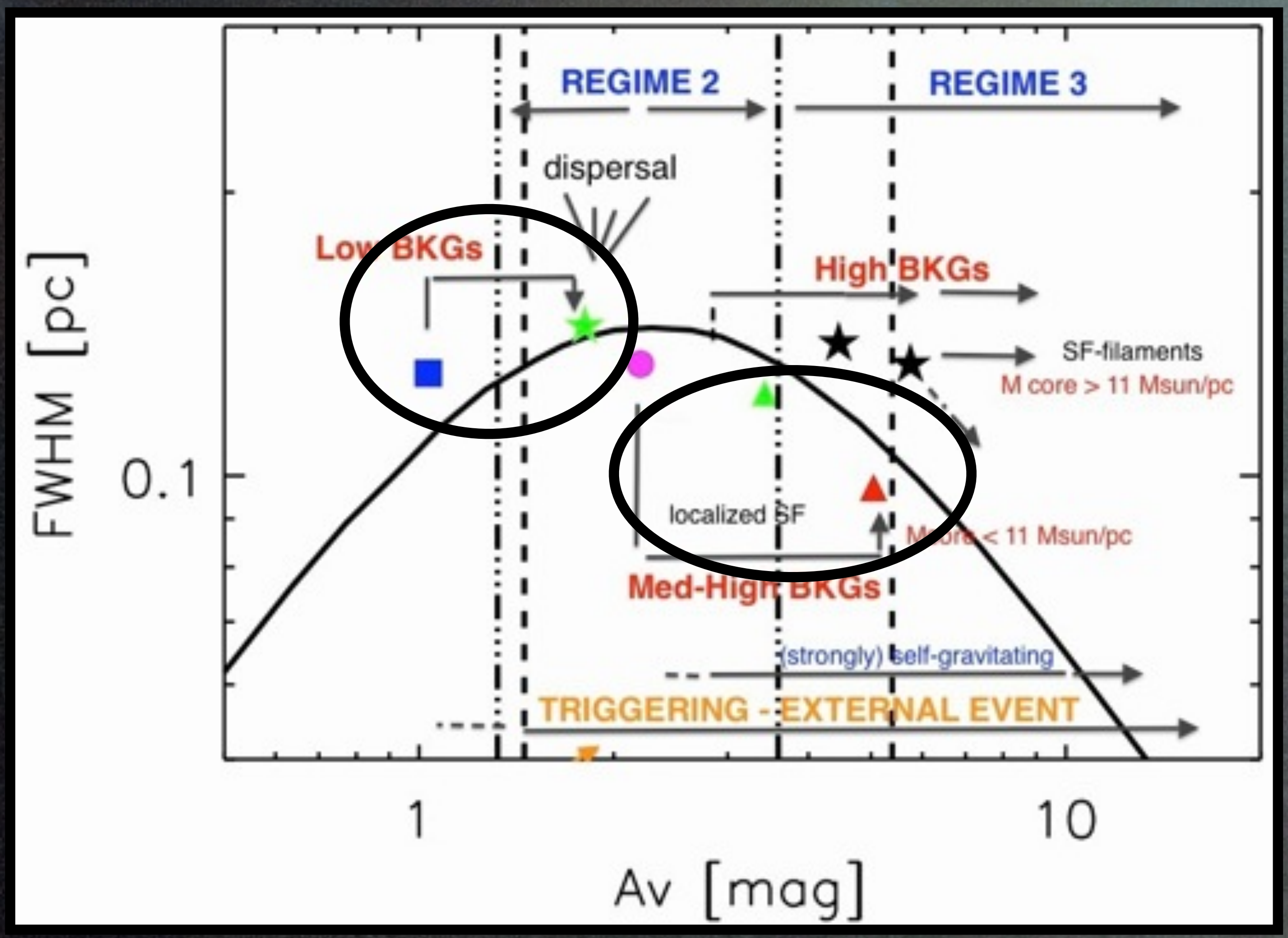






Width changes within 0.1pc (~2 range) characteristic width for SF-filaments (e.g., Gould Belt Studies)

THEORETICAL RESULTS



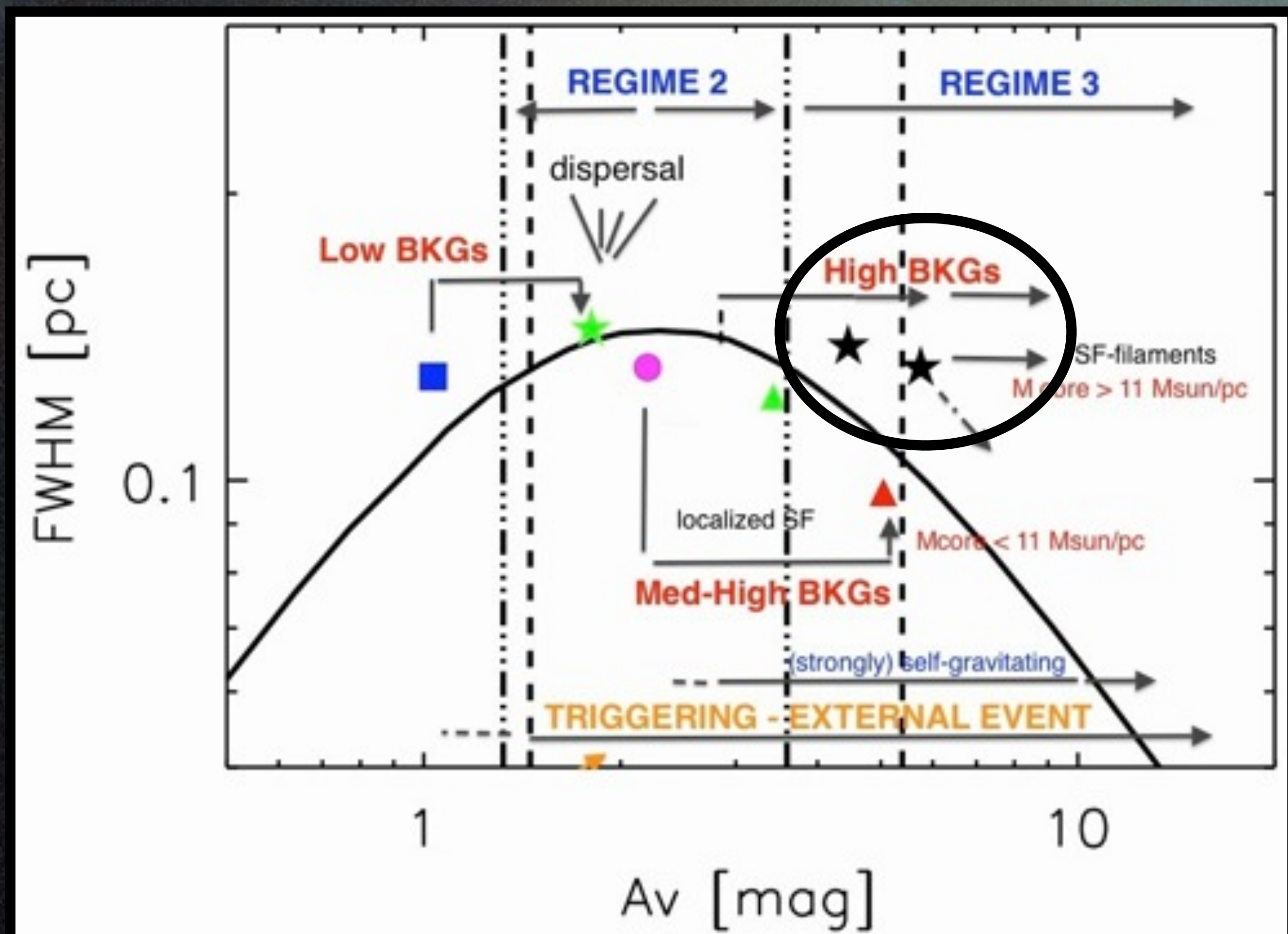
No filaments at low BKGs can evolve into SF-filaments

At LB: low M_{core}, low availability of material, leads to self-limited accretion, fragmentation, and dispersal without SF

At intermediate BKG: higher Mcore possible: formation in the turnover point or contracting regime. Self-gravitating enough, but still limited.

Not SF-filaments, but capable of localized SF.

THEORETICAL RESULTS



SF-filaments:

more stable width: collapse stopped due to star formation and global collapse[?]

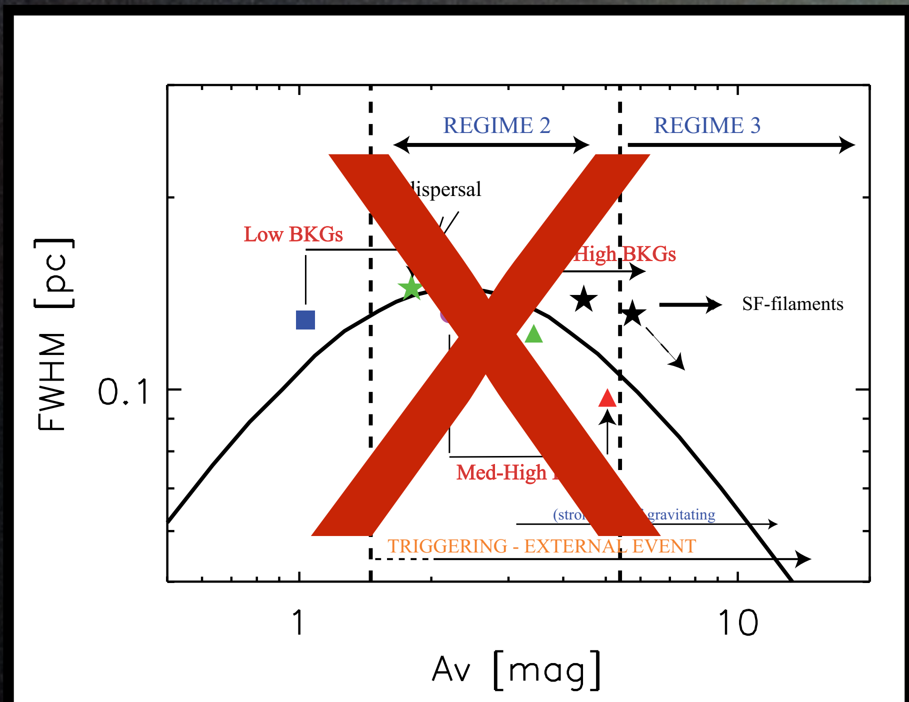
Formed from subcritical filaments close to supercritical state at core level: i.e. with M_{core}>7M_{sun}/pc, + the highest BKGs (based on our results = most massive cores+availability of material)

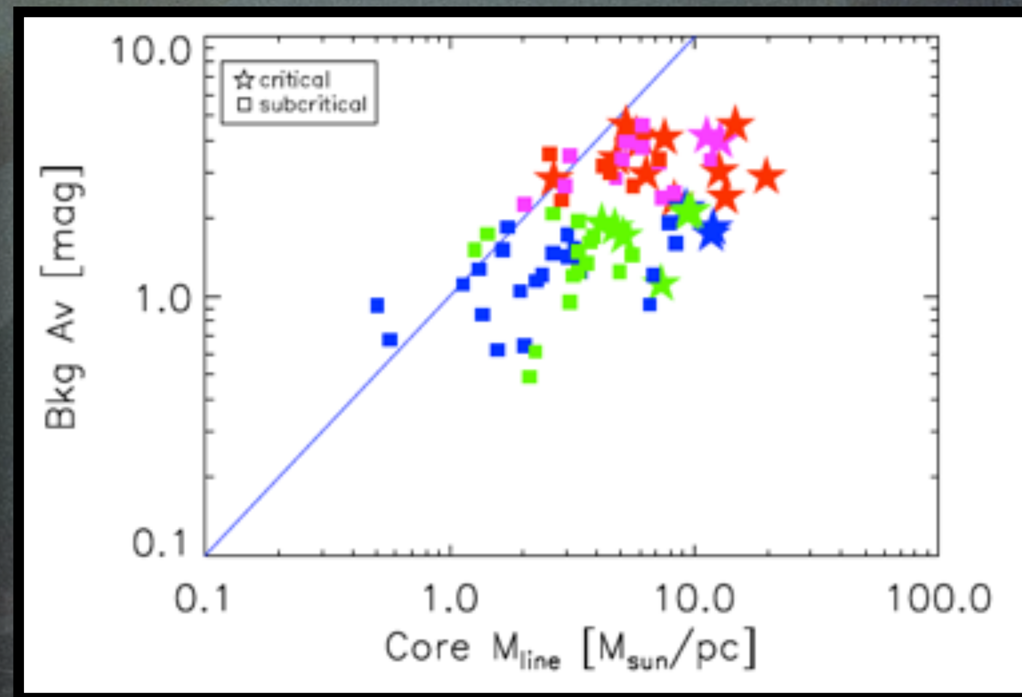
- **Faster accretion**, shorter accretion timescales> For accretion rate of 10^{-4} M_{sun}/pc/yr (Schisano et al. 2014) -> filament reaches supercritical level in 10^5 yrs (10^6 yrs for accretion rate of 10^{-5} M_{sun}/pc/yr; Andre et al. 2013):

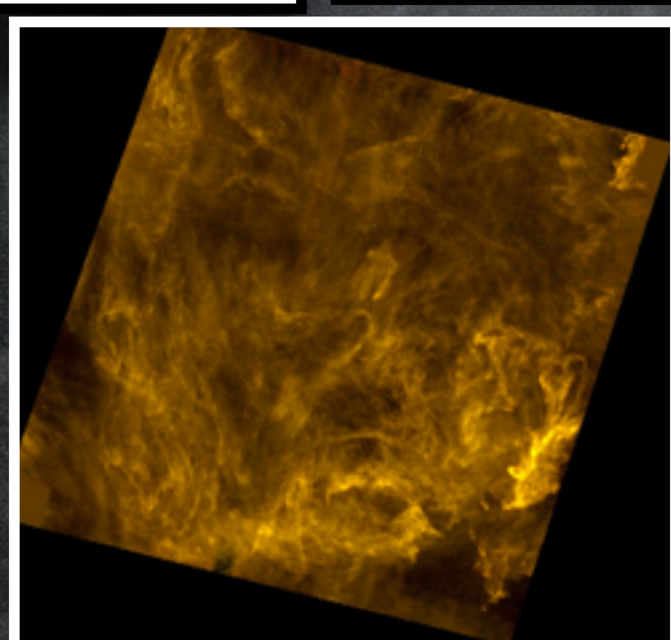
- Filament formation as fast as fragmentation timescale [fragmentation occurs while filament still forming] > **YSOS in filaments still forming (accreting)**

IMPLICATIONS: THE CASE OF EXTREME STAR FORMATION

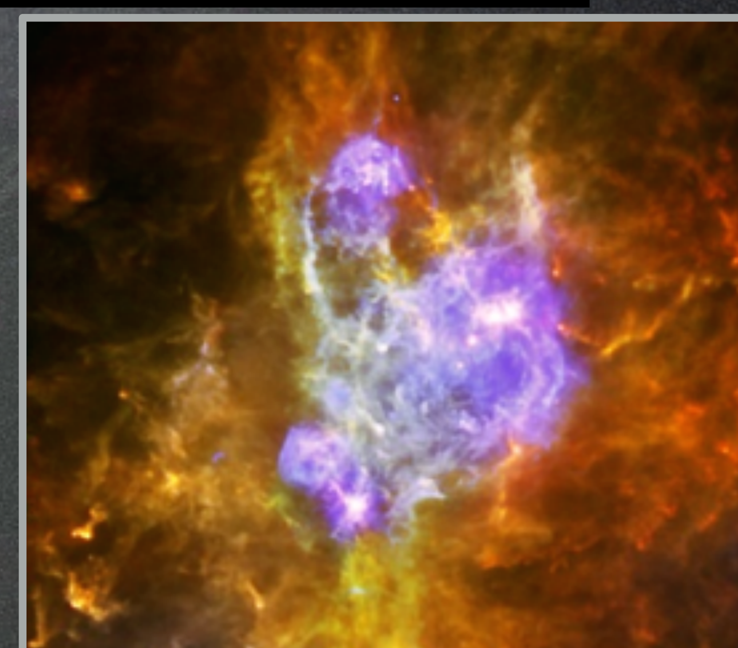
- Key role of environment:







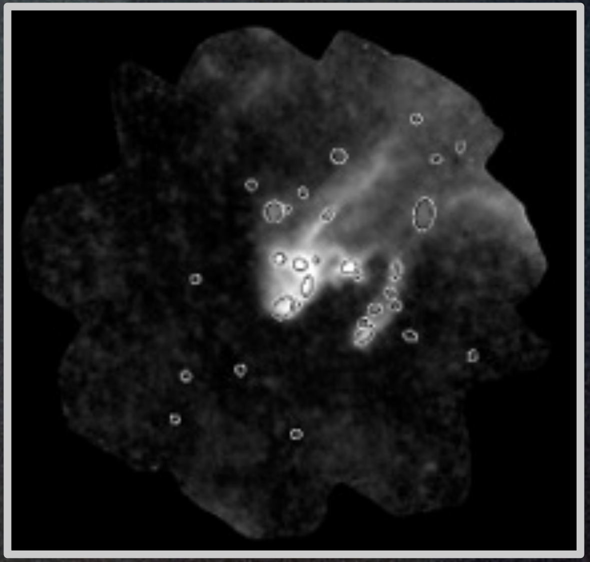
ESA, Andre, Abergel (G. Belt, Evol. Int. Dust)



ESA, Rivera-Ingraham (

STAR FORMATION AT HIGH-GALACTIC LATITUDES

[Rivera-Ingraham et al.; in progress]



- Goal: Investigation of star formation process, structural properties, and efficiency in the diffuse (accretion-limited) environments (|b|>30 deg; nearby <d>~185 pc, but poorly characterized -> the most detailed study up to date.)

- Methodology
  - Environmental:
    - Clouds & Filaments (NH2)
  - Substructural (Cores and Clumps): Catalog, physical characterisation, dynamics [molecular], classification, and evolution
  - Comparative analysis with low-galactic latitude fields and with/out triggering [HMSF]

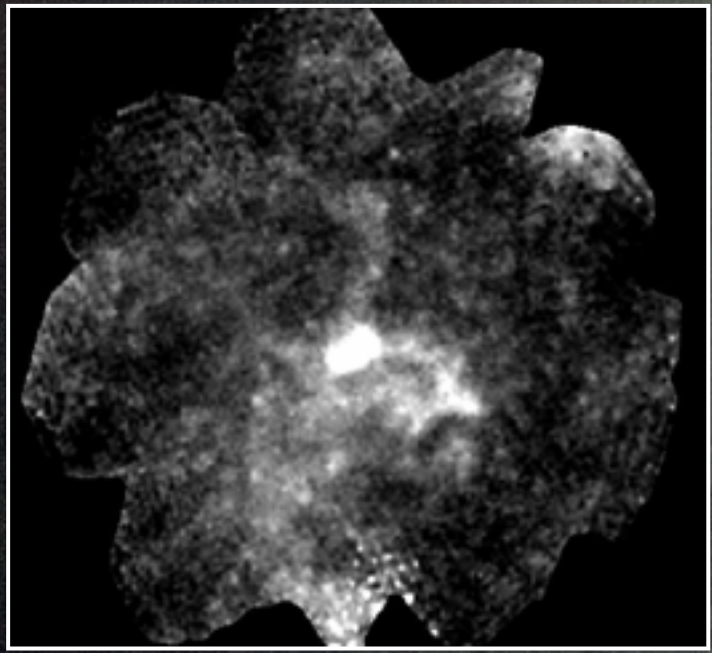
Sample: v31_0035, v31_0037, G128.78-69.46, G130.42-47.07, G91.09-39.46, G171.35-38.28, G109.18-37.59, G210.90-36.55, G4.18+35.79, G141.25+34.37, G159.23-34.51, G206.33-25.94

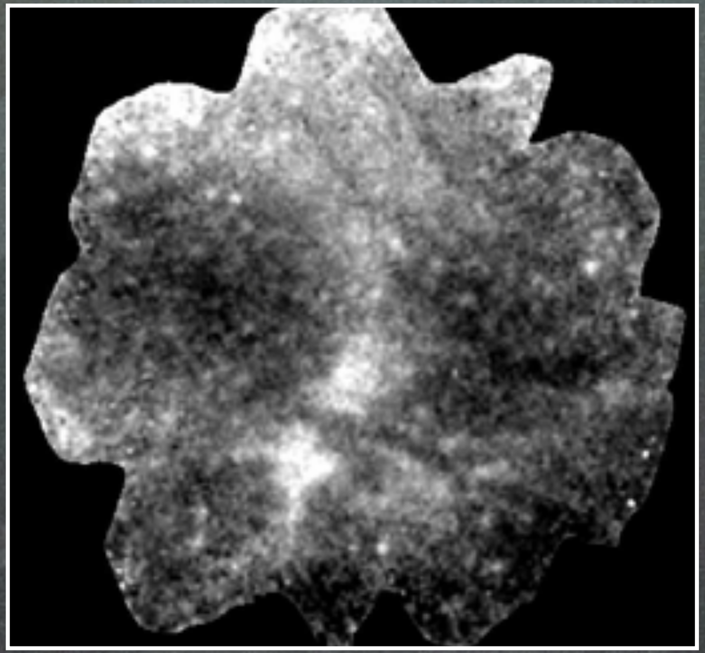
STAR FORMATION AT HIGH-GALACTIC LATITUDES

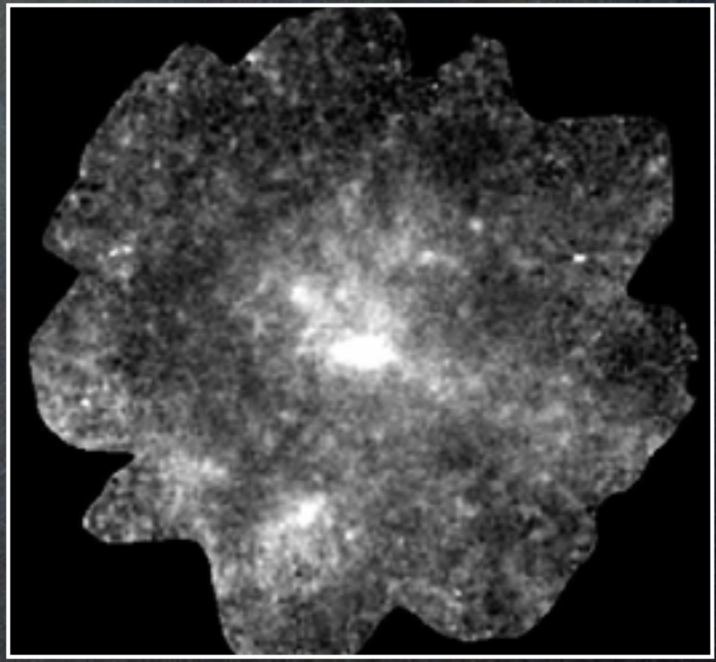
G91.09-39.46
d~295 pc
Un-classified

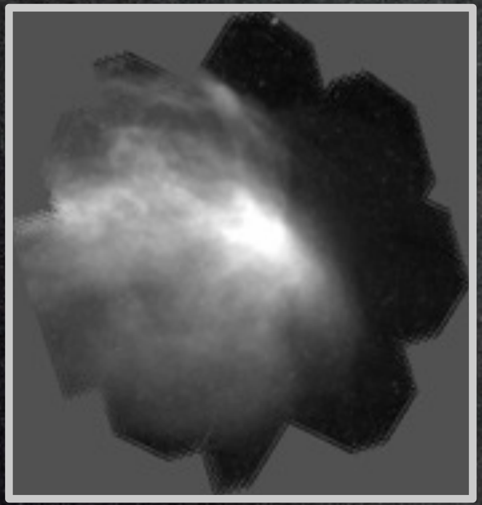
G171.35-38.28
d~80 pc
Un-classified

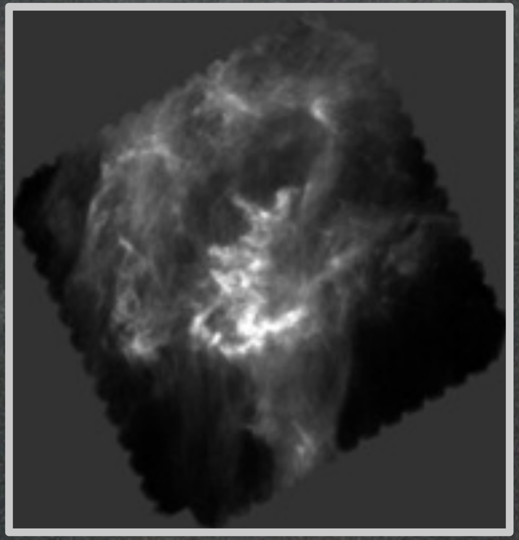
G109.18-37.59
d~160 pc
Un-classified

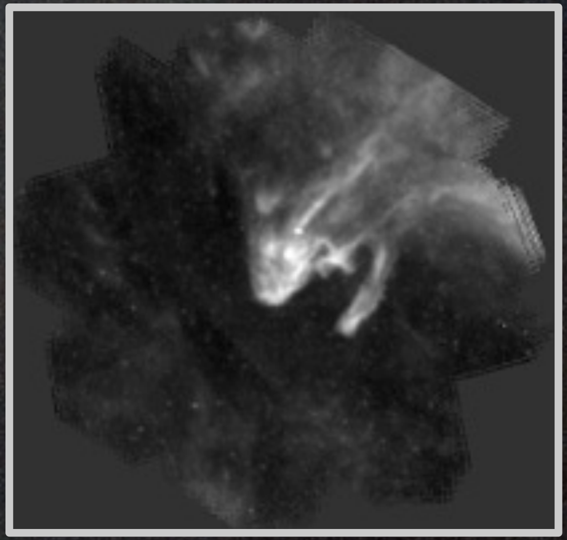












4 - EXTREME [HM] STAR FORMATION

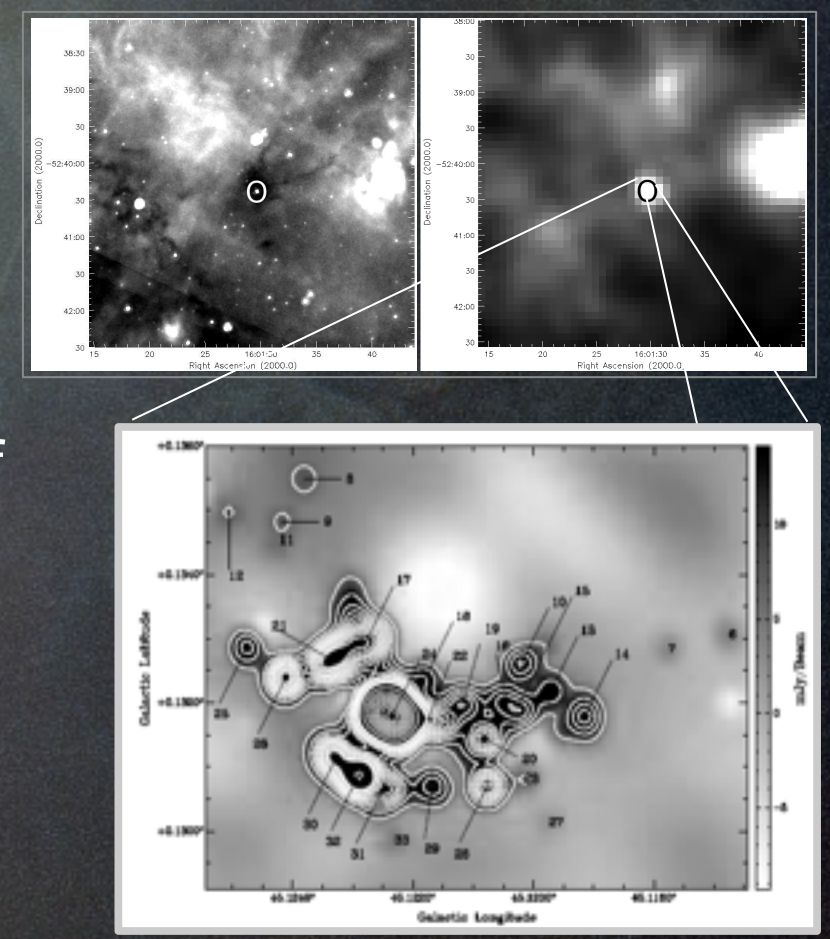
HIGH-MASS STAR FORMATION

[Rivera-Ingraham et al. 2015; in prep]

- Goal:

  Investigation of formation and early evolution of rare dense environments
  -> Efficiency and modes of HMSF

- Methodology
  - Environmental and substructural self consistent study of regions of HMSF in the Outer Galaxy [Herschel-based + multiple collaborations]

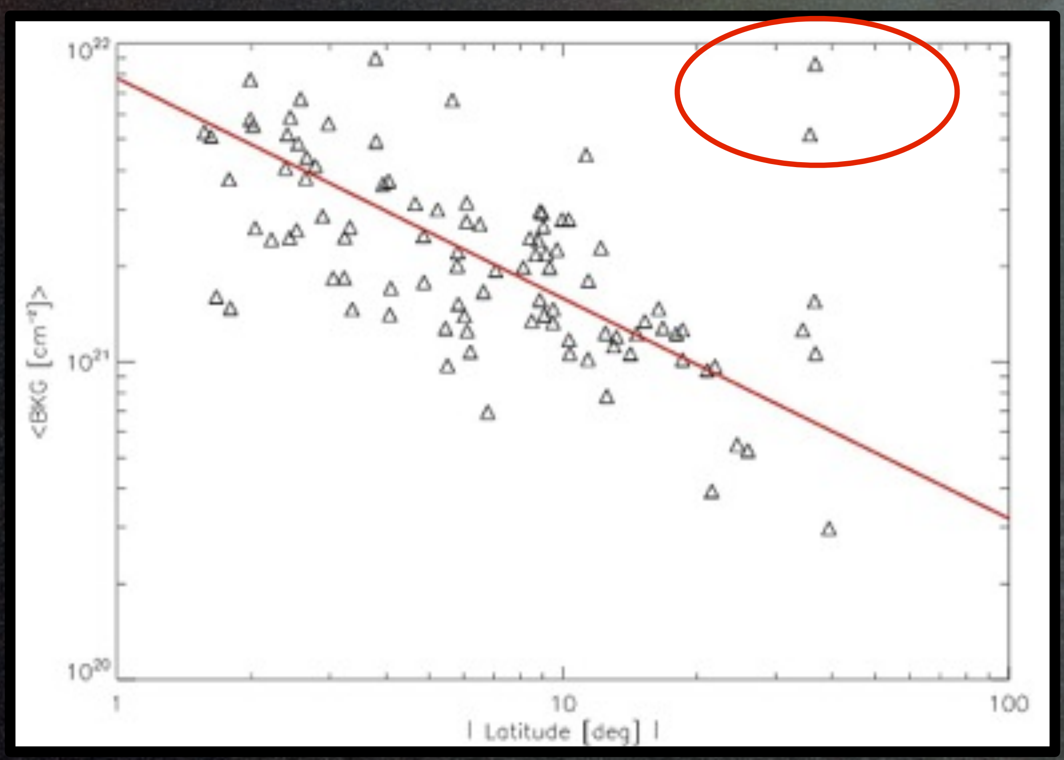


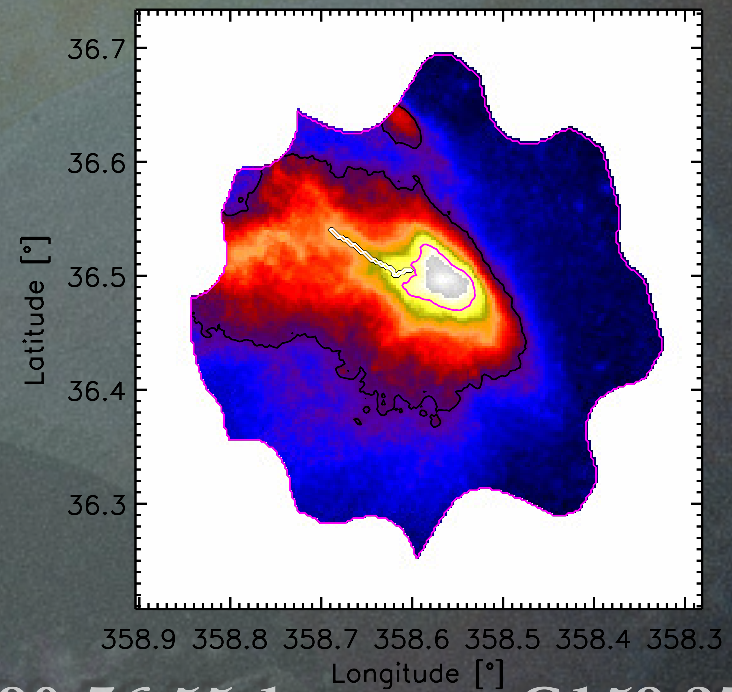
ESA - HOBYS

…the environmental factor in Galactic Star Formation

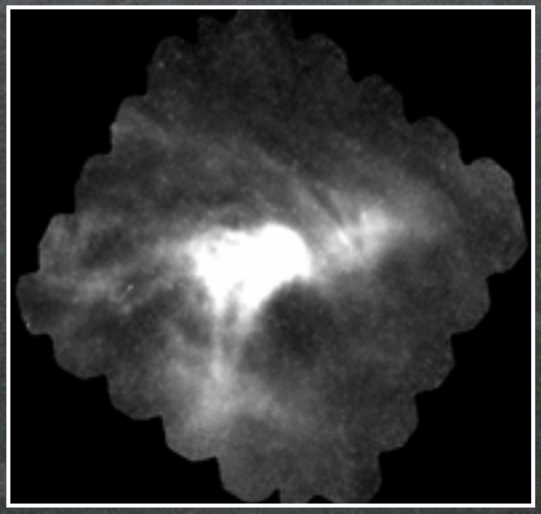
[Rivera-Ingraham et al.; in progress]

Taking SF to the extreme: The Key Role of Triggering and External Events



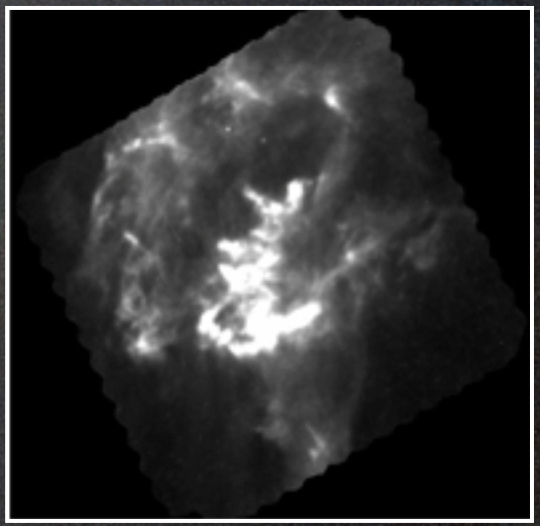


G210.90-36.55-1
d~140 pc

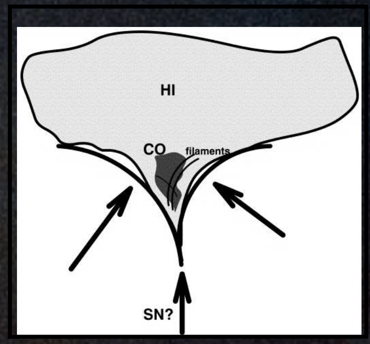


LDN 1642 (MBM 20) - Member of Orion outlying clouds

G159.23-34.51-1
d~360 pc



LDN 1457 (MBM 12)

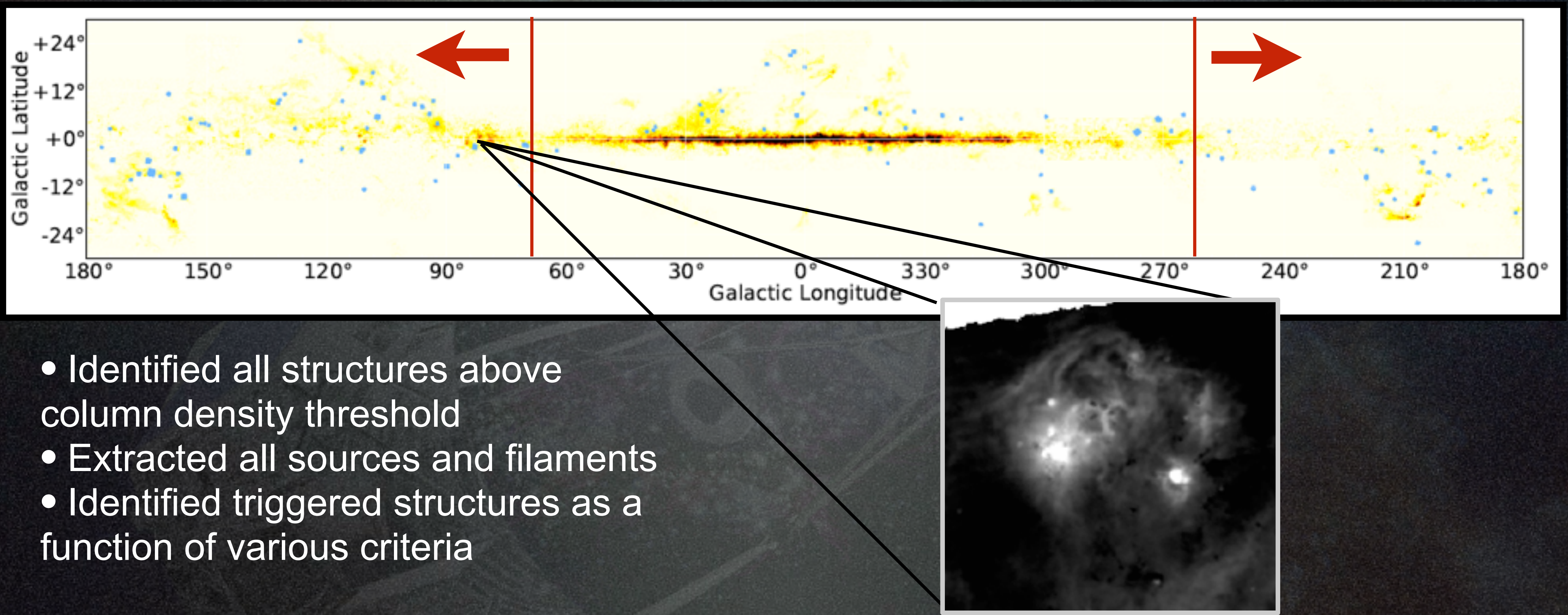


Moriarty - Schieven et al. 1997

…the environmental factor in Galactic Star Formation

[Rivera-Ingraham et al 2015.; in prep]

<u>Taking SF to the extreme: </u>The Key Role of Triggering and External Events



- Identified all structures above column density threshold
- Extracted all sources and filaments
- Identified triggered structures as a function of various criteria

<u>Dynamic SF key for dense environment formation [quick, effective cf. bypass limitations of accretion-models]</u> e.g., Schneider et al. 2010; Hill et al. 2011; Hennemann et al. 2012 Peretto et al. 2012; <u>and high-mass star and cluster (c.f., isolated) formation</u> (e.g., CCF - Rivera-Ingraham et al. 2013).

[Completed] Filament Analysis

• (Sub)critical filaments increase their total linear mass by increasing that of their core and wing components. Both appear to be linked to local environment, with filaments at higher background levels systematically reaching more massive core and wing components. The distribution of core and wing-dominated filaments suggests a wing origin linked to accretion, driven by the gravity exerted by the mass of the core and the local availability of material.

• Results constrain a tentative accretion-based evolutionary process in which supercritical filaments are formed from subcritical, contracting, self−gravitating filaments with a minimum core component greater than $7M_{sun}/pc$ (half M_{crit}). Formation of such star−forming filaments would be aided by a dense environment with Av~3mag

[On-going] Extreme Environments: High-Galactic Latitude and HMSF

•_ Need for high BKG emphasises the need of triggering and active SF modes (coll flows vs turb) as alternative methods to bypass the limitations of gravity at early stages/formation and form (or strengthen) core-dominated structures by sweeping/compression: Diffuse environments, or birthplaces of HMS