

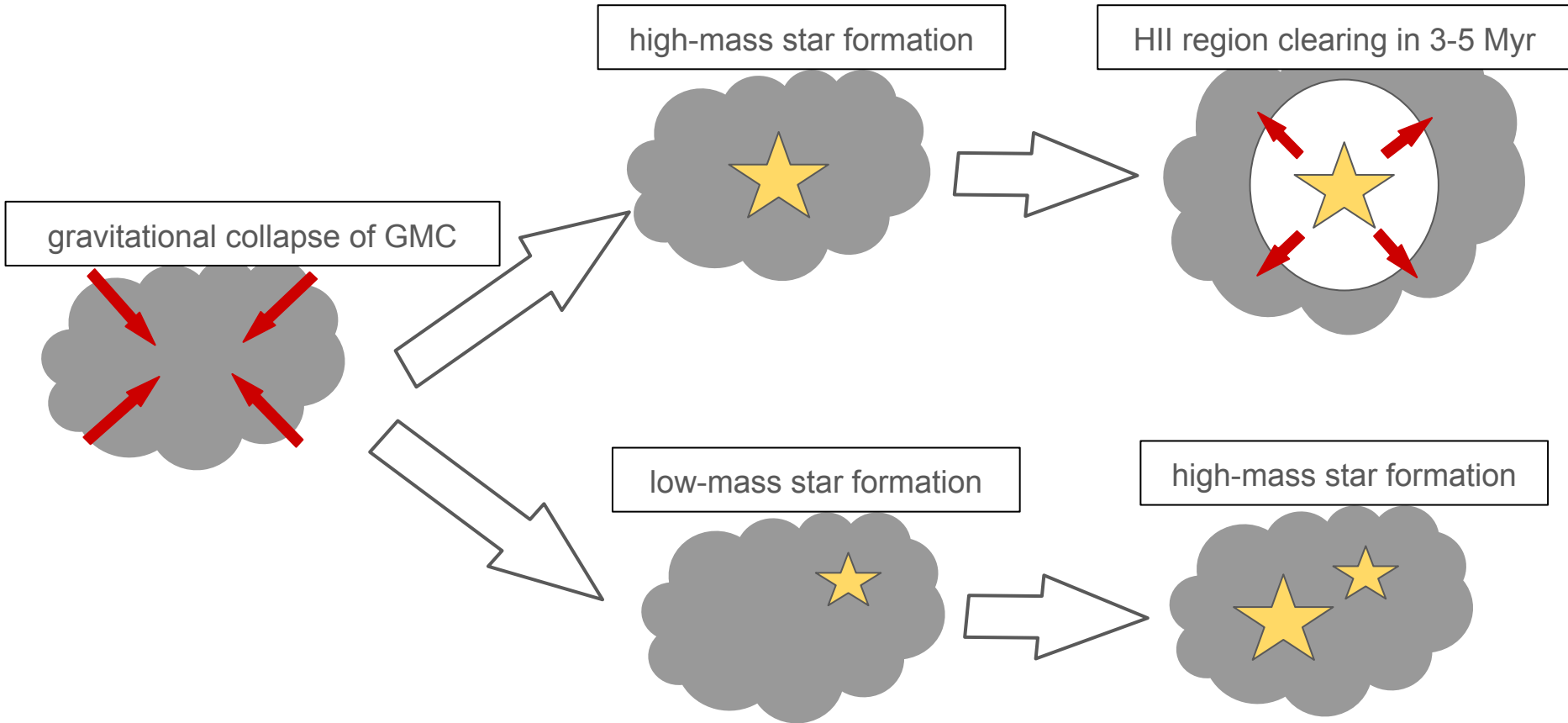
Review:

## **Unifying low- and high-mass star formation through density-amplified hubs of filaments**

**The highest mass stars ( $>100 M_{\odot}$ ) form only in hubs?**

M. S. N. Kumar, P. Palmeirim, D. Arzoumanian, and S. I. Inutsuka

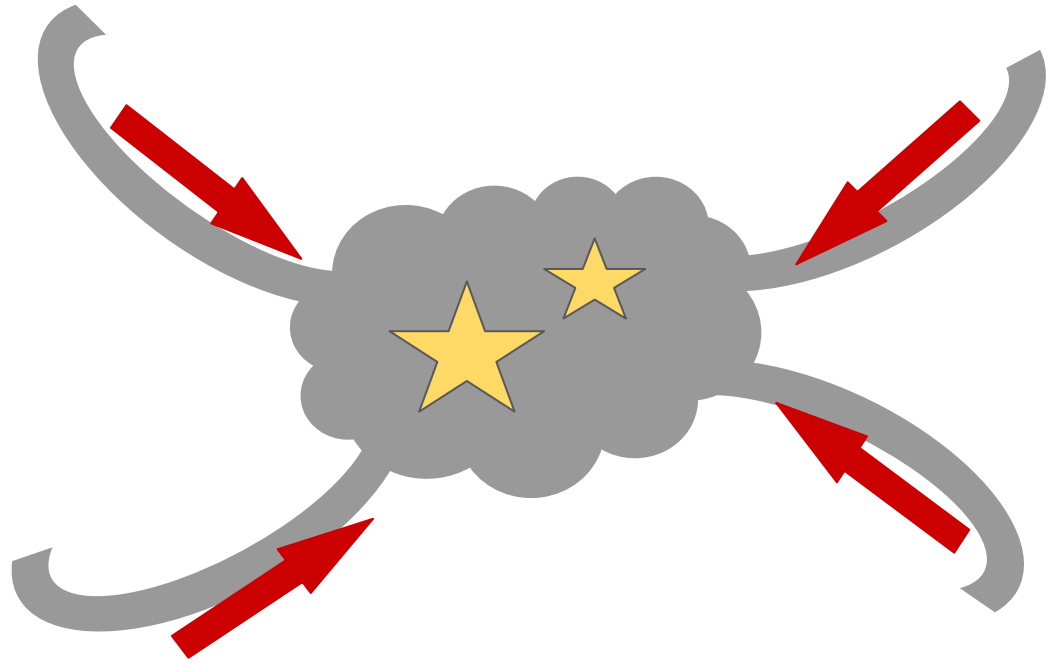
# Introduction: star formation in GMC



# Introduction: hub-filament systems (HFSs)

The nearest young stellar groups are associated with hubs that radiate multiple filaments (Myers 2009).

Observations of HFSs have uncovered longitudinal flows within filaments (Chen+2019). The flow, triggered by a hierarchical global collapse, provides sufficient flow rates to form massive stars.



# Introduction: aims

What is the difference between such HFSs with few filaments and large network of filaments?

Are the flows driven by a pre-existing massive star / clusters gravitational potential drives or if the formation of the massive star is a consequence of the flows?

**asking whether or not the highest luminosity (therefore, highest mass) stars that have recently formed are associated with HFSs, and if so, what it is that makes these regions unique**

identifying candidate HFSs towards the inner Galactic plane using Hi-GAL data

# Observational data, Identifying filamentary structures

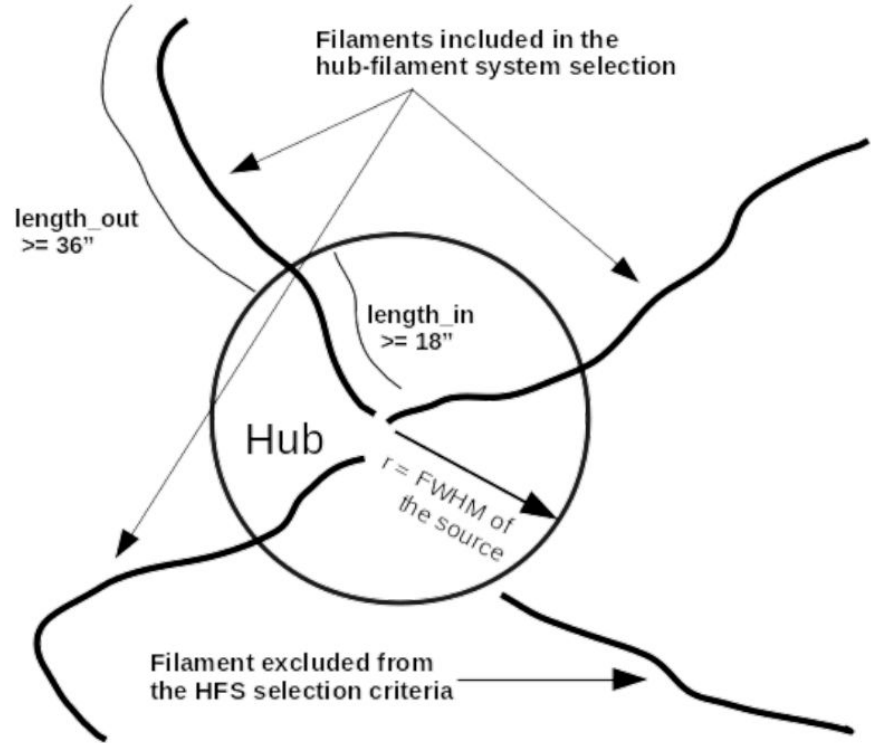
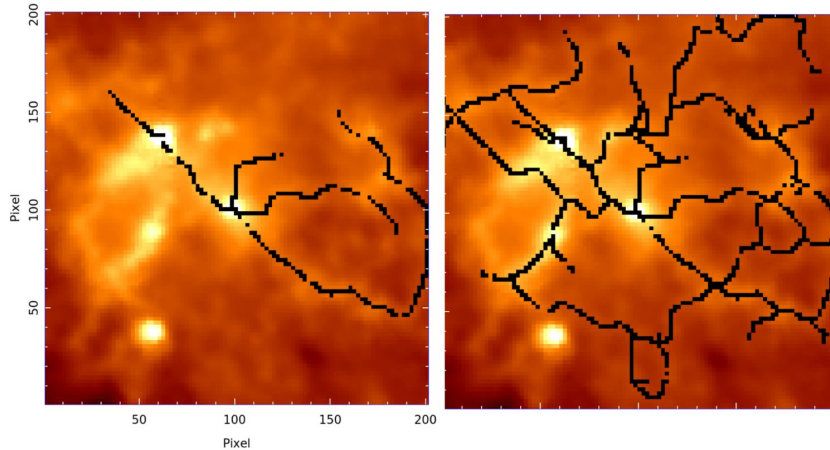
Herschel Infra-red Galactic plane survey (Hi-GAL; Molinari+2010, 2016) covered the inner part of the Galactic Plane using PACS (Poglitsch et al. 2010) 70 and 160  $\mu\text{m}$  and SPIRE (Griffin et al. 2010) at 250, 350, and 500  $\mu\text{m}$  simultaneous imaging in all five bands.

- 250  $\mu\text{m}$  maps
- column density and dust temperature maps (from 160-500  $\mu\text{m}$ )
- catalogue of Hi-GAL clumps (Elia+2017), which contain  $\sim 105$  sources

The Discrete Persistent Structures Extractor (DisPerSE) software (Sousbie 2011) works by connecting critical points such as maxima and minima with lines.

# Identifying hubs

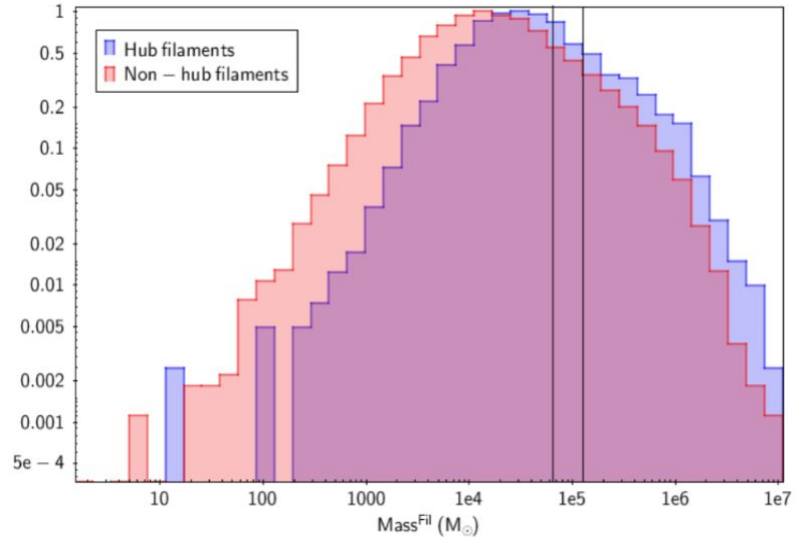
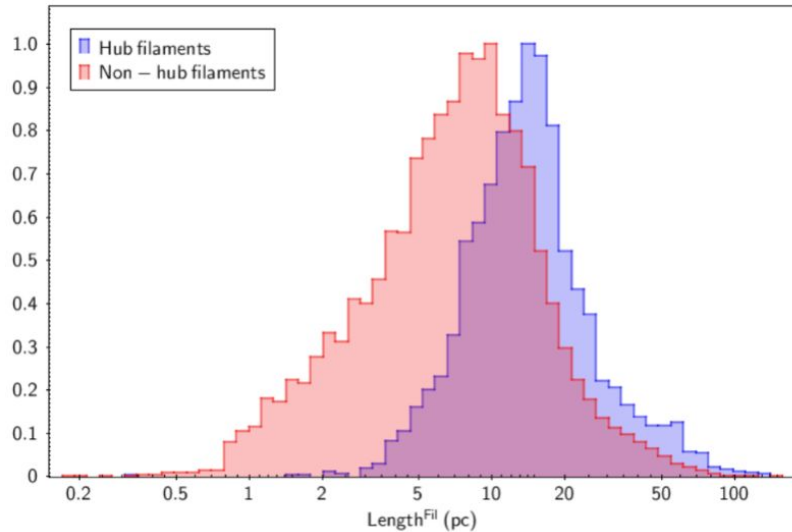
At the outset, a hub is defined as a junction of three or more skeletons at the source centre. Any filament is considered to meet at the source if at least one beam width falls within the source FWHM.



# Results: length and mass of filaments

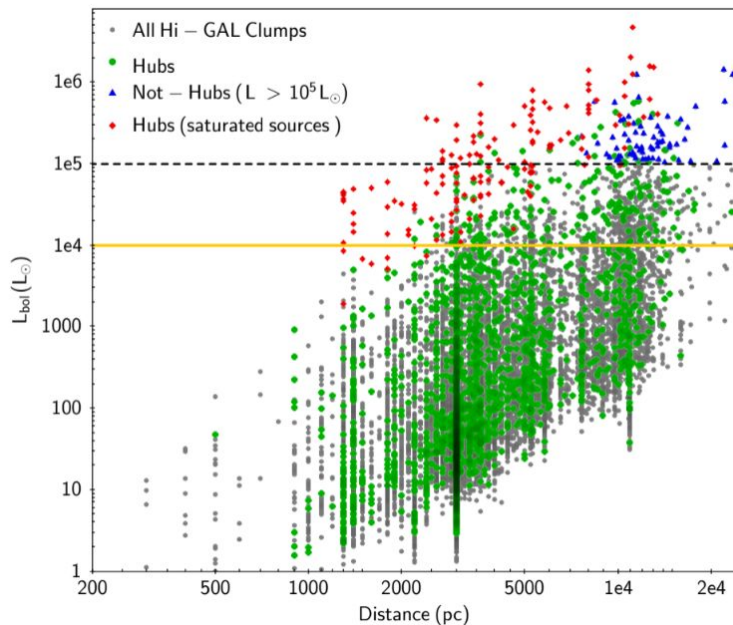
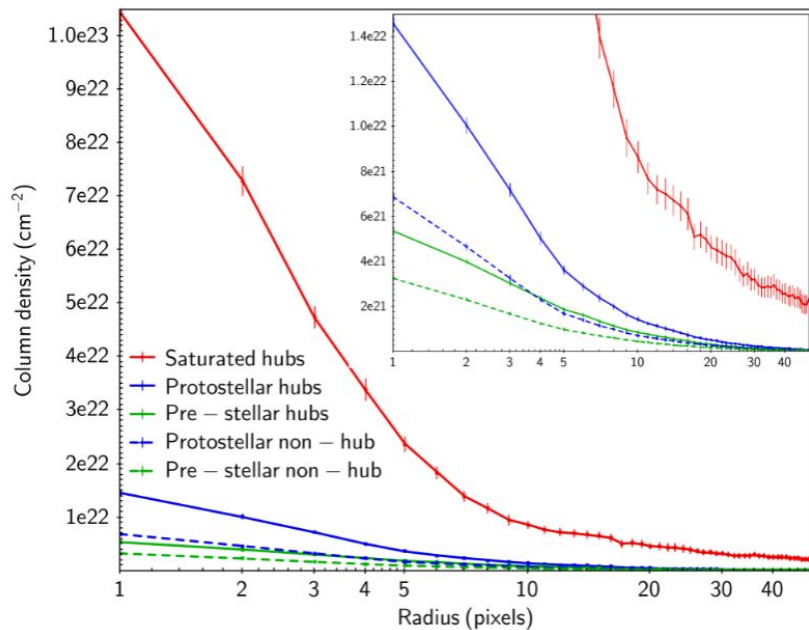
3704 HFSs / 34575 Hi-GAL clumps

starless: 156 (4%), pre-stellar: 2010 (54%), proto-stellar: 1537 (41%)



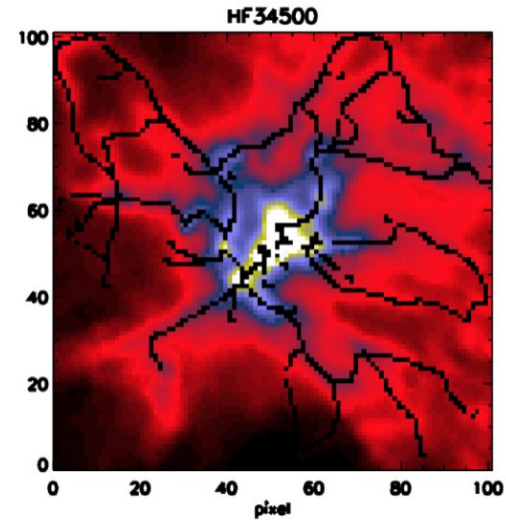
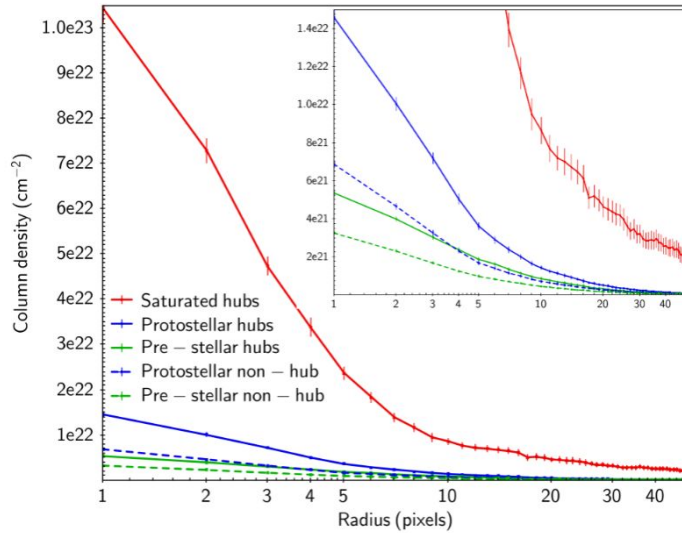
Filaments belonging to the hub are longer and more massive than those not belonging to the hub.

# Results: density enhancement and star formation in hubs



- Clumps forming hubs have greater column density
  - All massive stars form in hubs
- The most natural conditions to form the massive stars arise only when multiple filaments join to form a hub.

# Results: the number of filaments



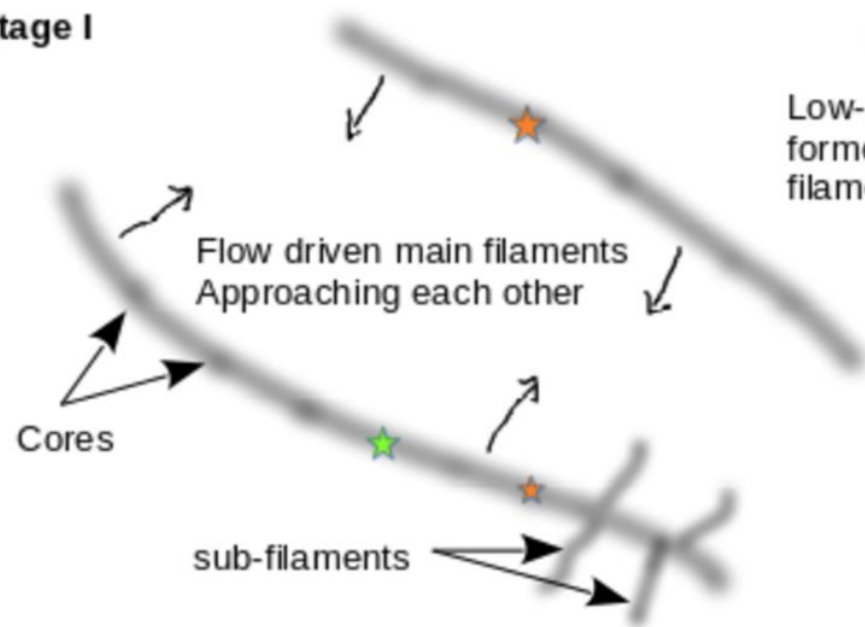
unsaturated: 3-7

saturated: 6-12

HFSs with the largest density increase at the hub (saturated sources) are the result of larger networks of criss-crossing filaments.

# Filaments to clusters: a paradigm for star formation

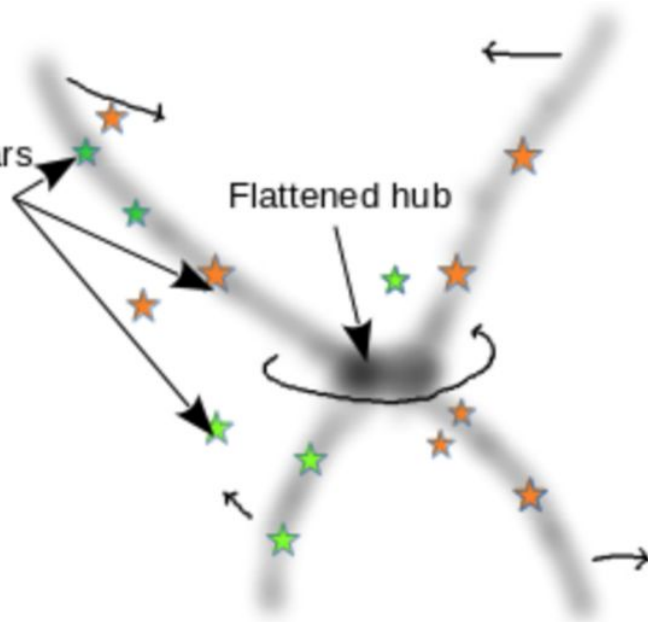
**Stage I**



**Stage II**

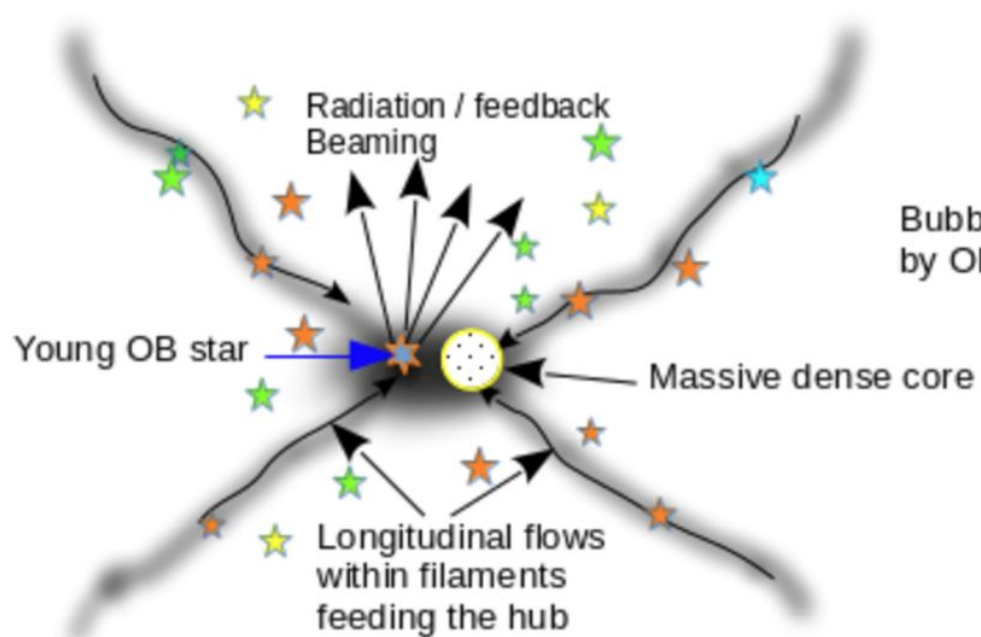
Low-mass stars  
formed in the  
filaments

Flattened hub

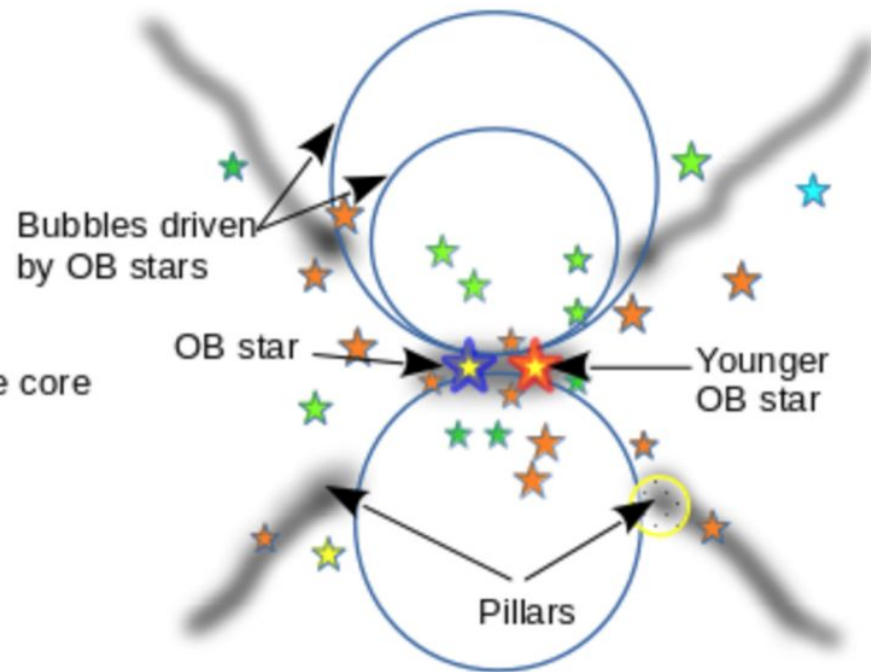


# Filaments to clusters: a paradigm for star formation

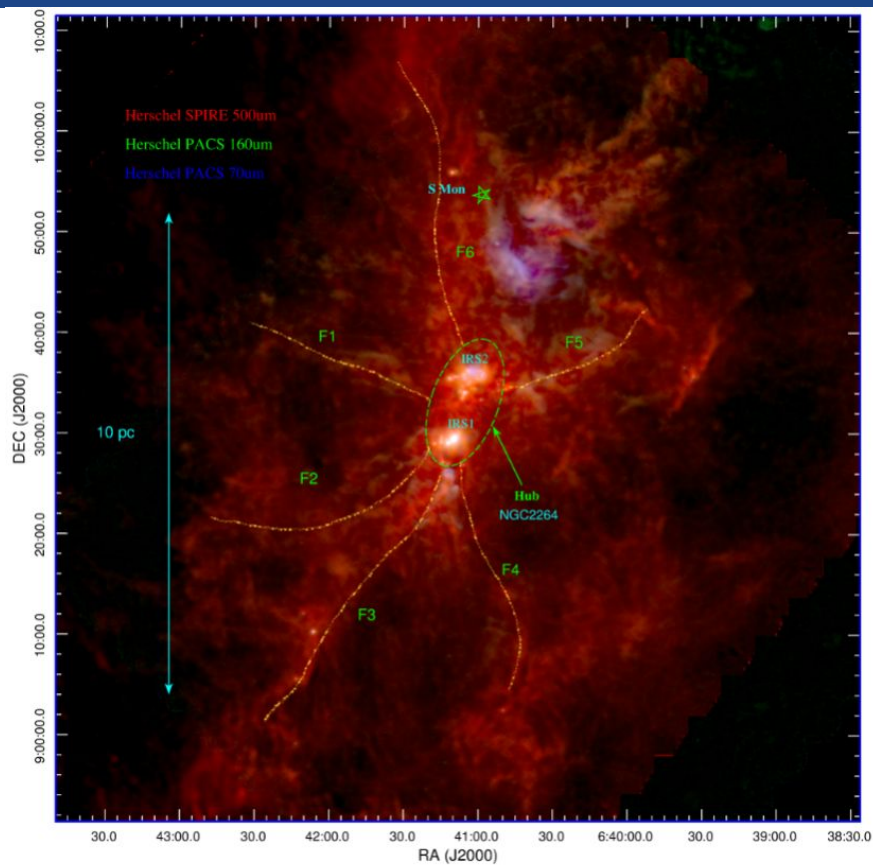
Stage III



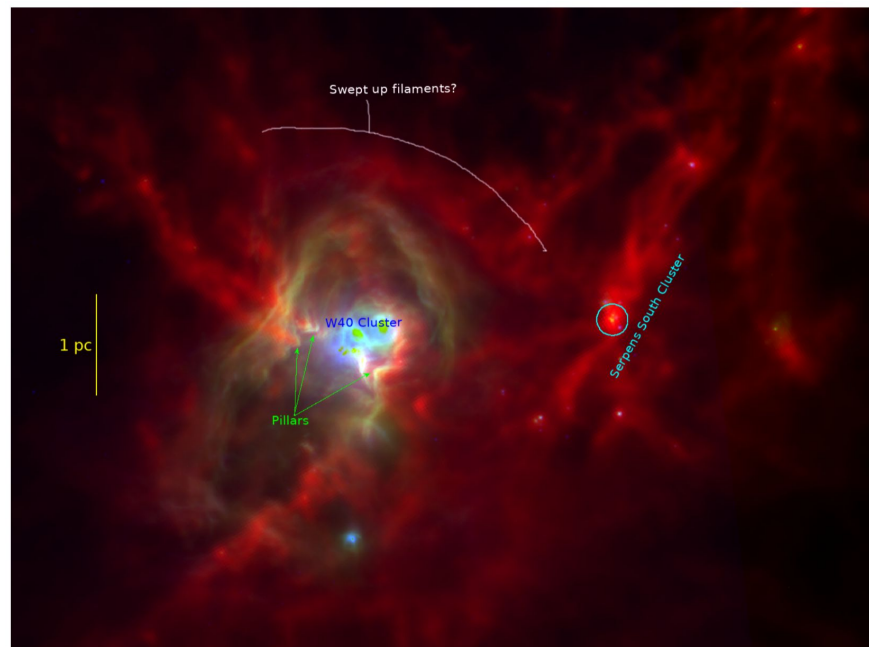
Stage IV



# Comparison of the HFS paradigm with NGC2264 and W40



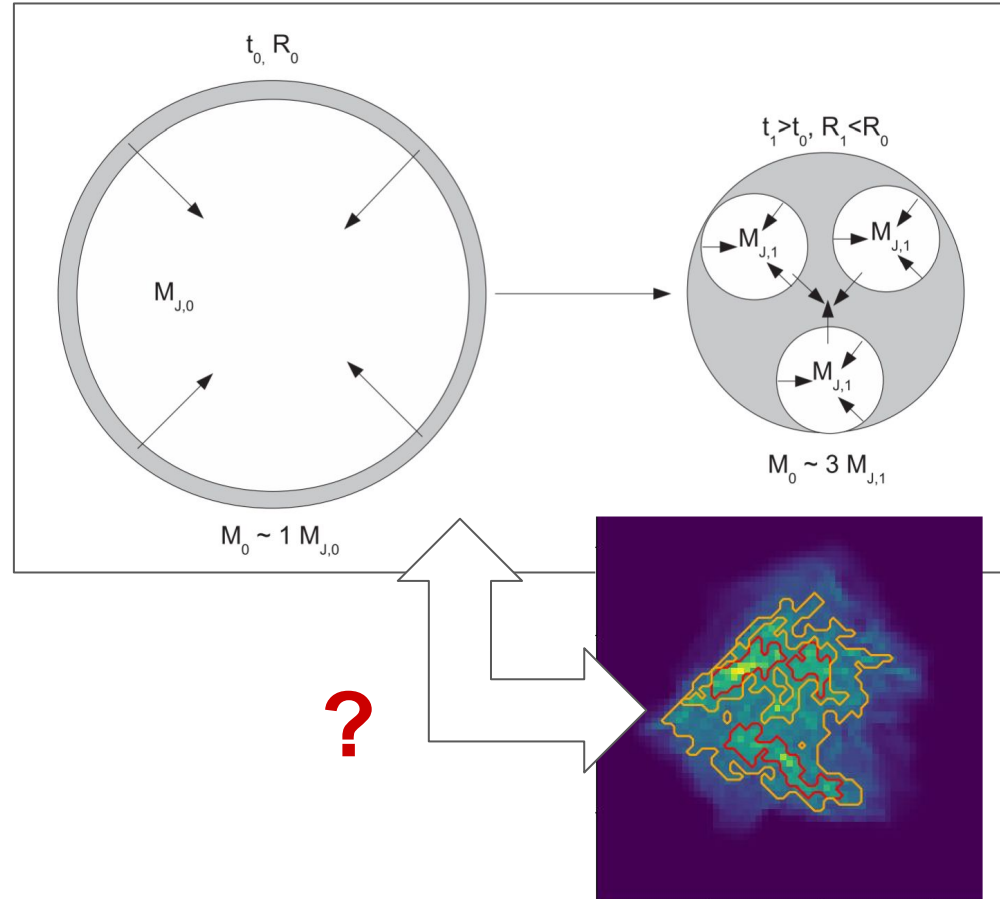
NGC2264: stage III



W40: stage IV

# The hub-filament system compared with GHC

The Global Hierarchical Collapse (GHC) reproduces the order of star formation in which low-mass stars are prioritized over high-mass stars, which corresponds to star formation occurring at the hub.



# Discussion

- A few caveats are associated with the present selection of HFS candidates, specifically the classification of HFS based on line-of-sight junctions; Therefore, not all of the selected candidates are real junctions.
- Low-mass stars are easily generated by the fragmentation of filaments, etc., whereas the formation of high-mass stars requires a three-stage mass transfer process from filament to hub to disk. Gas constantly accretes from the filaments, and high-mass stars are formed in the hub or disk, where fragmentation is suppressed by the magnetic field.
- The HFS candidate catalogue presented here includes many clumps that are located on the rim or edge of bubbles and also represent a hub.

# Summary

- HFS candidates were searched for in the Milky Way's inner disk by searching for filamentary structures around 35,000 clumps in the Hi-GAL catalogue.
- Filaments belonging to the hub are longer and more massive than those not belonging to the hub.
- HFS clumps were denser than non-filament clumps, and the density increase was steeper with increasing number of filaments.
- Since all of the nearby luminous clumps are hubs, it is thought that most massive stars are formed at the hub.
- The formation of a hub through the merger of filaments is the most natural condition for the formation of massive stars, and we considered scenarios in which a hub may form.