Filaments, Ridges and Mini-Starbursts,

HOBYS' view of high mass star formation

SPIRE

PACS

AIM

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MARIE CURIE ACTIONS

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Eurotalents

BACKGROUND: MASSIVE STAR FORMATION

Open Questions:

How do High Mass (OB > 8$M_\odot$) stars form?

- Quasi-static vs dynamic scenario
- powerful gas (competitive) accretion vs coalescence
- Scaled up low mass star formation?

What are the initial conditions (density, temperature, kinematics) for high-mass star formation?

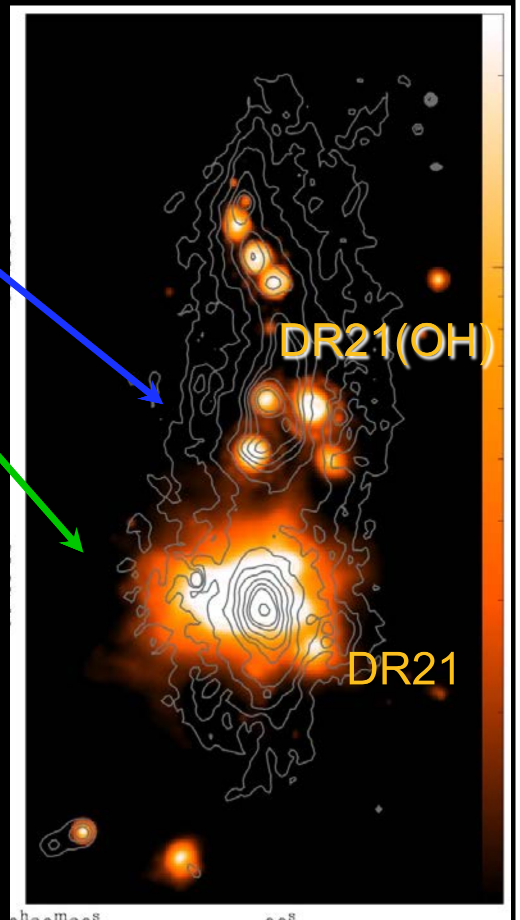
Observational evolutionary sequence:

- HII regions -> UC HII -> HII
- High mass protostars: evolving from envelope-dominated to star-dominated.
  - (e.g. Molinari et al. 1998, Bontemps et al. 2010)
  - Associated with hot cores, masers, powerful outflows, no radio cm
  - Identified within: IR-quiet protostellar dense cores (e.g. Hill et al., 2005, Motte et al. 2007), IR-bright protostellar dense cores or HMPOs or Hot Molecular Cores (e.g Beuther et al. 2002, Cesaroni et al. 2005)
- Massive prestellar cores (?) in IRDCs (e.g. Peretto & Fuller 2009)

Evolution

HOBYS OBJECTIVES

- Identify & characterise the precursors of OB stars
  - High-mass analogues of prestellar cores – do they exist?
  - Massive IR-quiet protostellar dense cores
  - Massive IR-bright protostellar dense cores
- Measure core/envelope mass & bolometric luminosity
  - Build an evolutionary diagram
  - Estimate lifetime of each evolutionary stage
- Make the link between cloud structure and star formation
  - Differentiate low & high-mass star-forming filaments.
- Assess the importance of triggering
  - By comparing well-behaved HII regions to more common HMSF regions



MAMBO 1.25 mm
Spitzer 24 μm

Sample & Observations

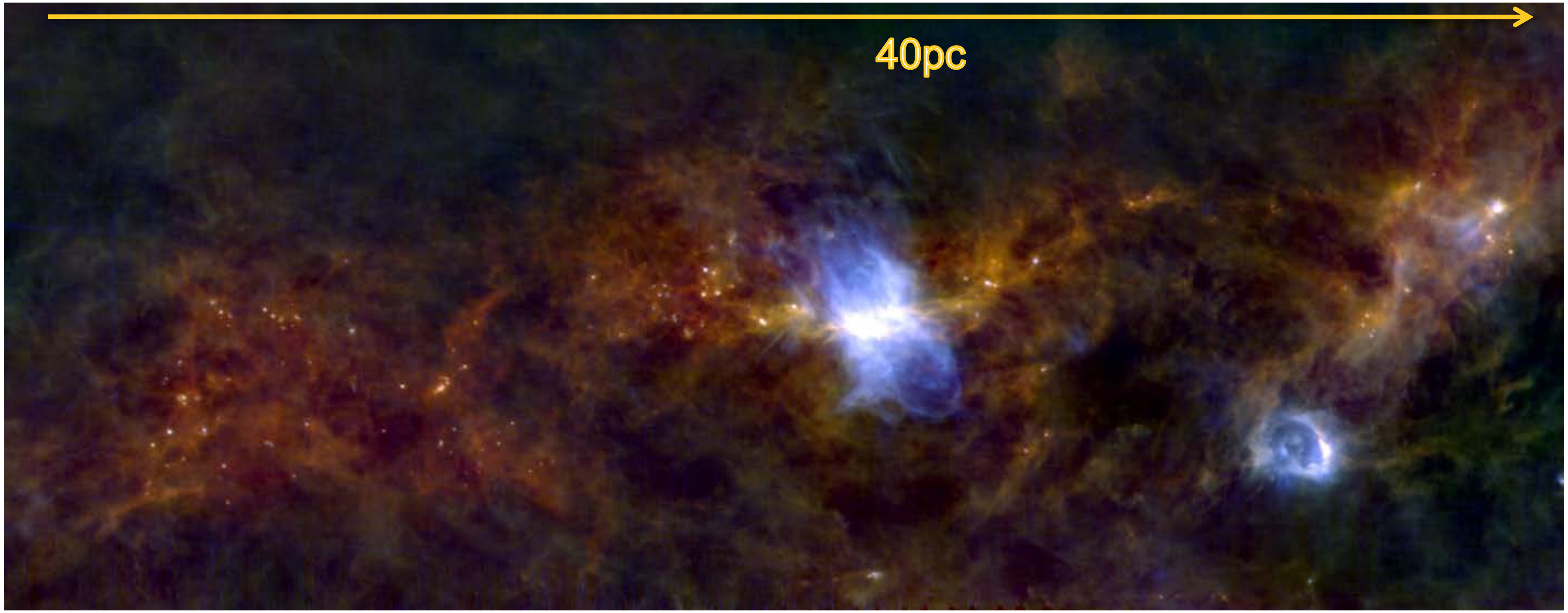
- Image all molecular cloud complexes forming OB-type stars < 3pc – 10 regions
  - Expect ~250 high-mass protostars
  - Statistical importance
  - Study precursors of stars up to $20 M_{\odot}$
- Wide-field PACS/SPIRE images (70, 160,250, 350, 500μm)
  - HPBW = 6''-36.9'' @ 0.7-3 kpc => down to 0.05-0.3 pc cloud structures
- Complementarity
  - Progenitors of low mass stars – Gould Belt Survey (André et al)
  - Precursors of OB stellar clusters – HI-GAL Survey (Molinari et al)

The First Herschel images reveal:

- Extensive networks of filaments, among which "ridges" (dominating super critical filaments) are forming high mass stars.
  - The Vela C Ridge – Hill et al., 2011
    - Giannini et al., in press. Minier et al., in prep.
  - The IRDC G35.39-00.33 in W48 – Nguyen Luong et al., 2011
  - DR21 – Hennemann et al., in prep
- Feedback of OB star clusters on molecular cloud structure, such as heating, pillars and triggered star formation.
  - Reid et al., NGC 7538, Hill et al., M16; Schneider et al., Rosette
- Clusters of protostars
  - Among which a few good candidates are high-mass class 0 protostars and starless cores.

VELA C

70um, 160µm,250µm

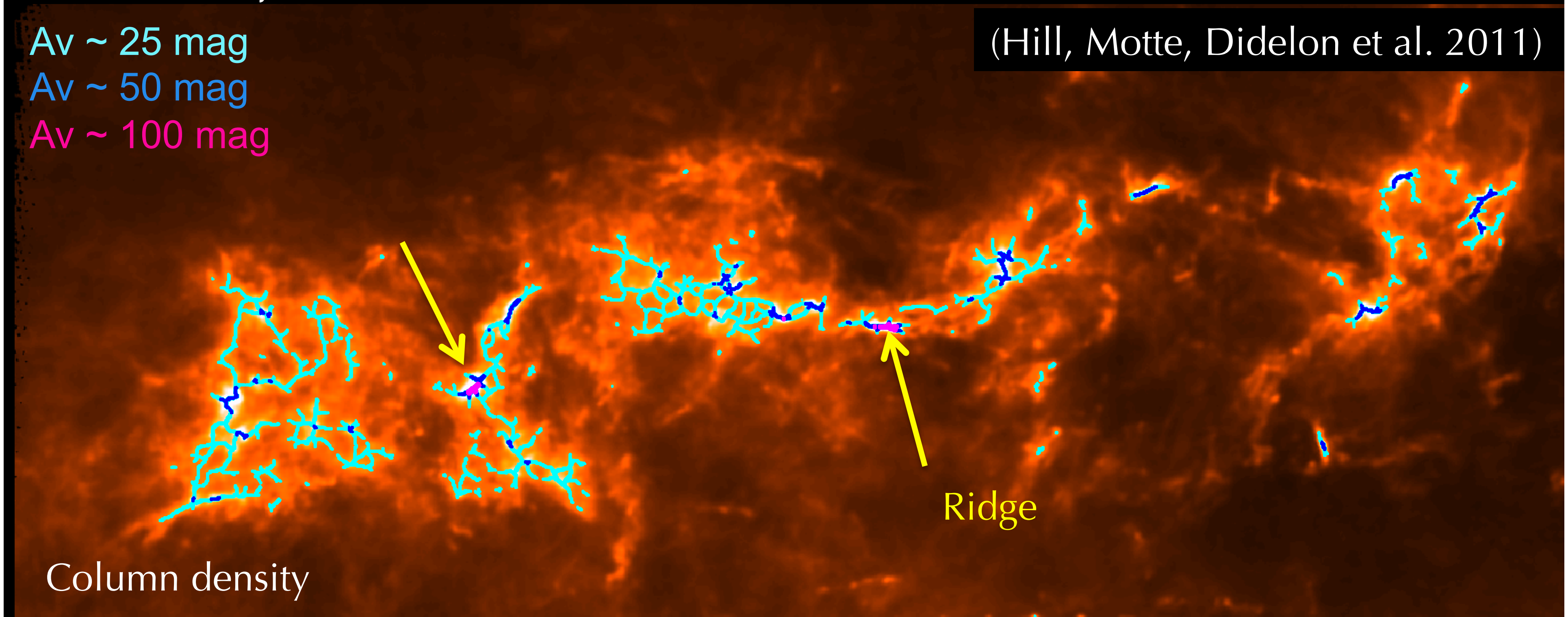


- May 18, 2010, 700pc, Parallel scan-mode, 3 deg^2
- Sources extracted with getsources (multi-wavelength, multi-resolution) sources extraction algorithm.
- Conservative S:N, gives 13 high-mass sources – 14-70$M_\odot$
- ~ 0.04 pc, these sources correspond to protostellar or prestellar cores, i.e., the direct progenitors of individual high-mass stars.


See also
Minier et al., in prep

IDENTIFYING FILAMENTS & RIDGES

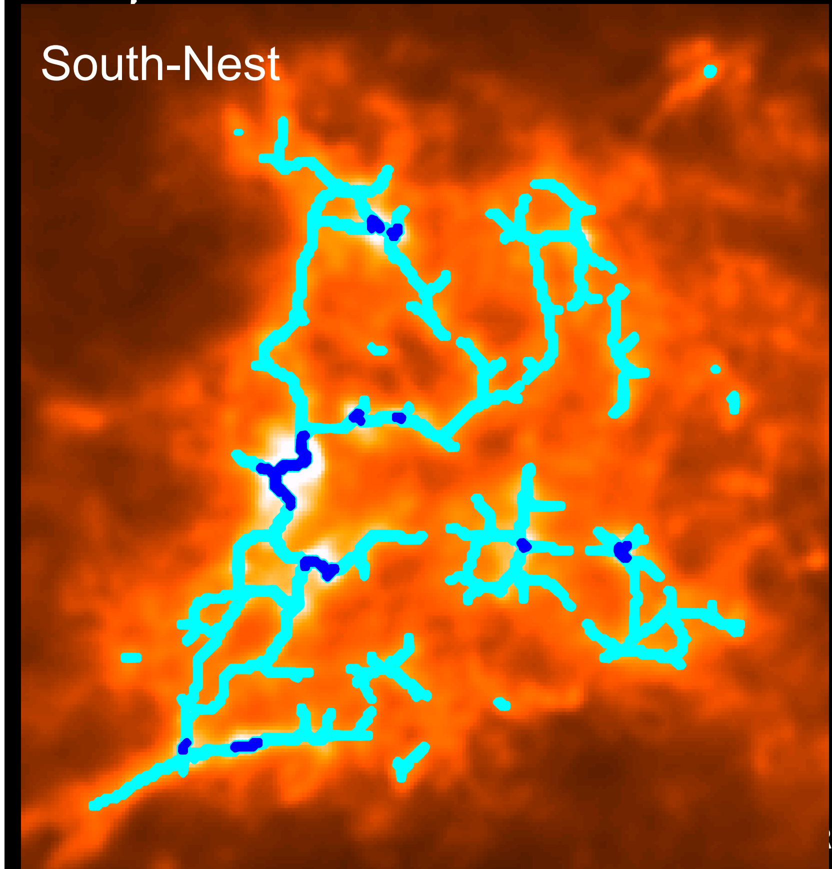
- Dust temperature and column density from greybody fits (37’ ’)
- Census of filaments: DisPerSE (Sousbie 2011)
- Above Av > 50 mag all filaments identified have supercritical masses per unit length and are thus likely forming stars

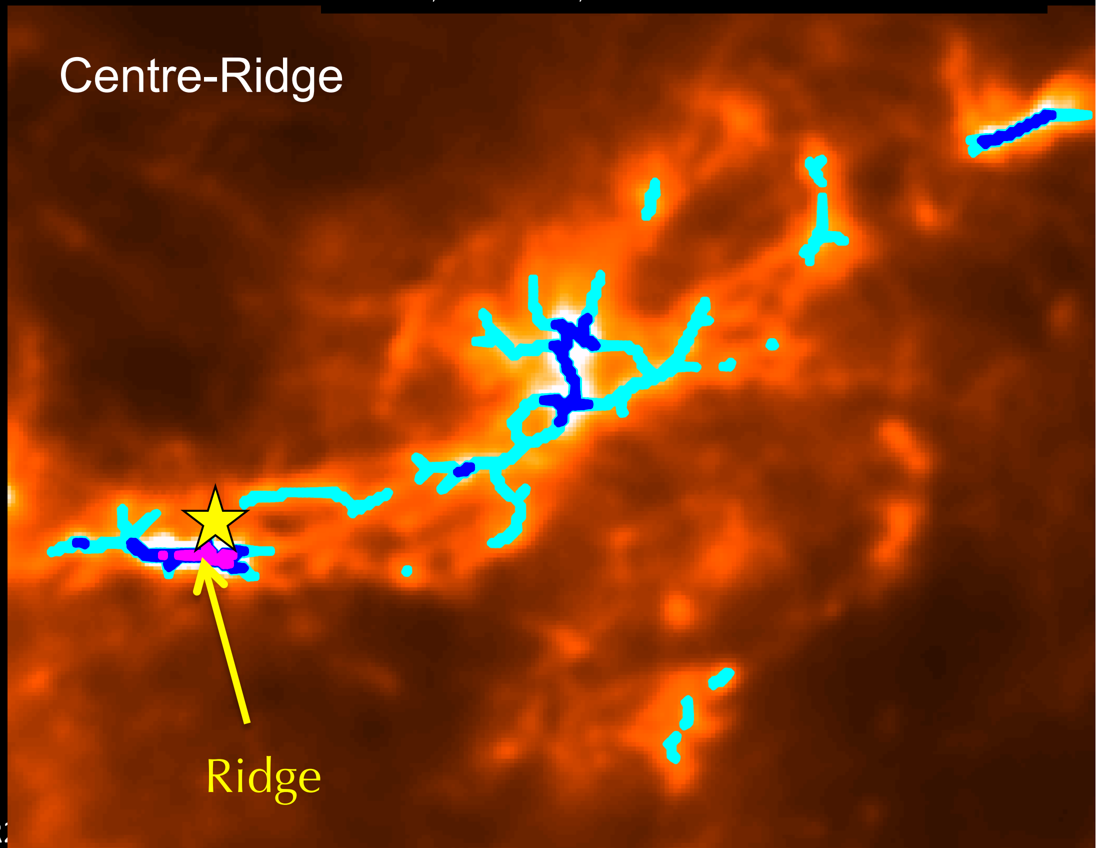


CLOUD STRUCTURE IN SUB-REGIONS

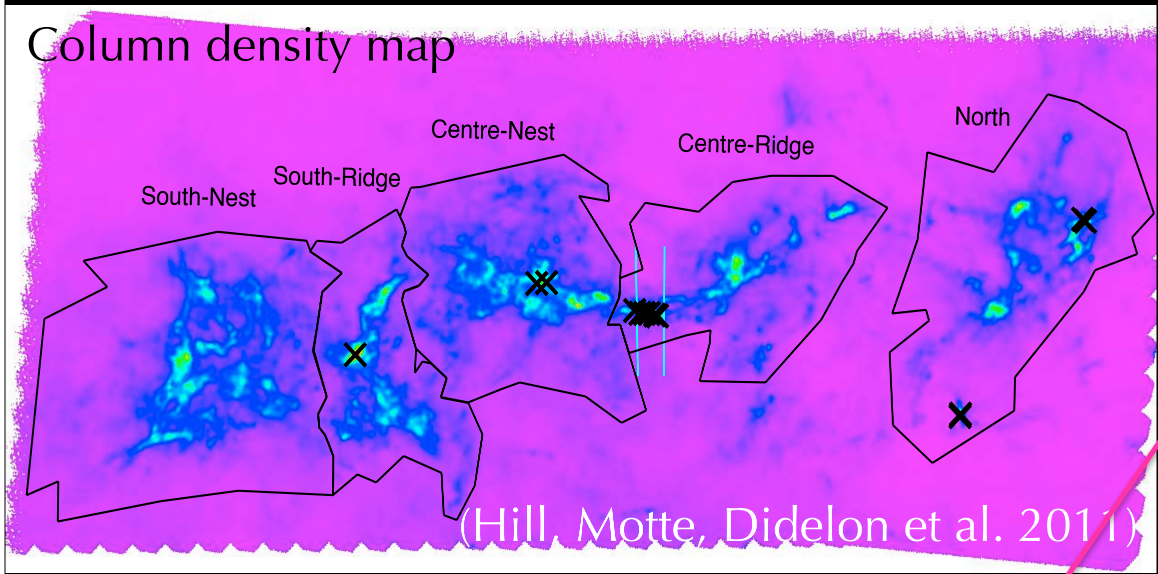
- Disorganised network of filaments vs single dominating ridge.
- High-mass stars form preferentially in ridges, high-column density (Av > 100 mag), wide (>0.3 pc) filaments present in specific regions.

(Hill, Motte, Didelon et al. 2011)

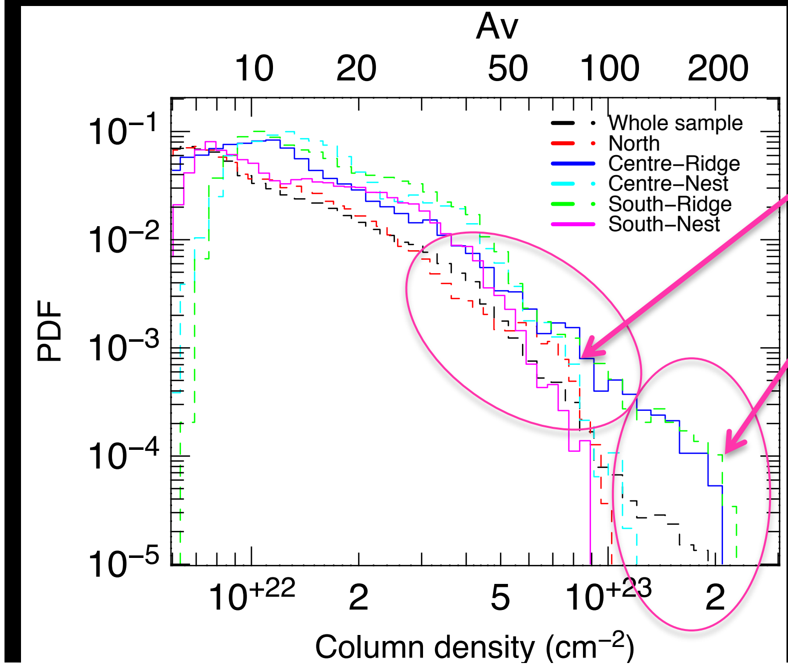




GRAVITY VS TURBULENCE



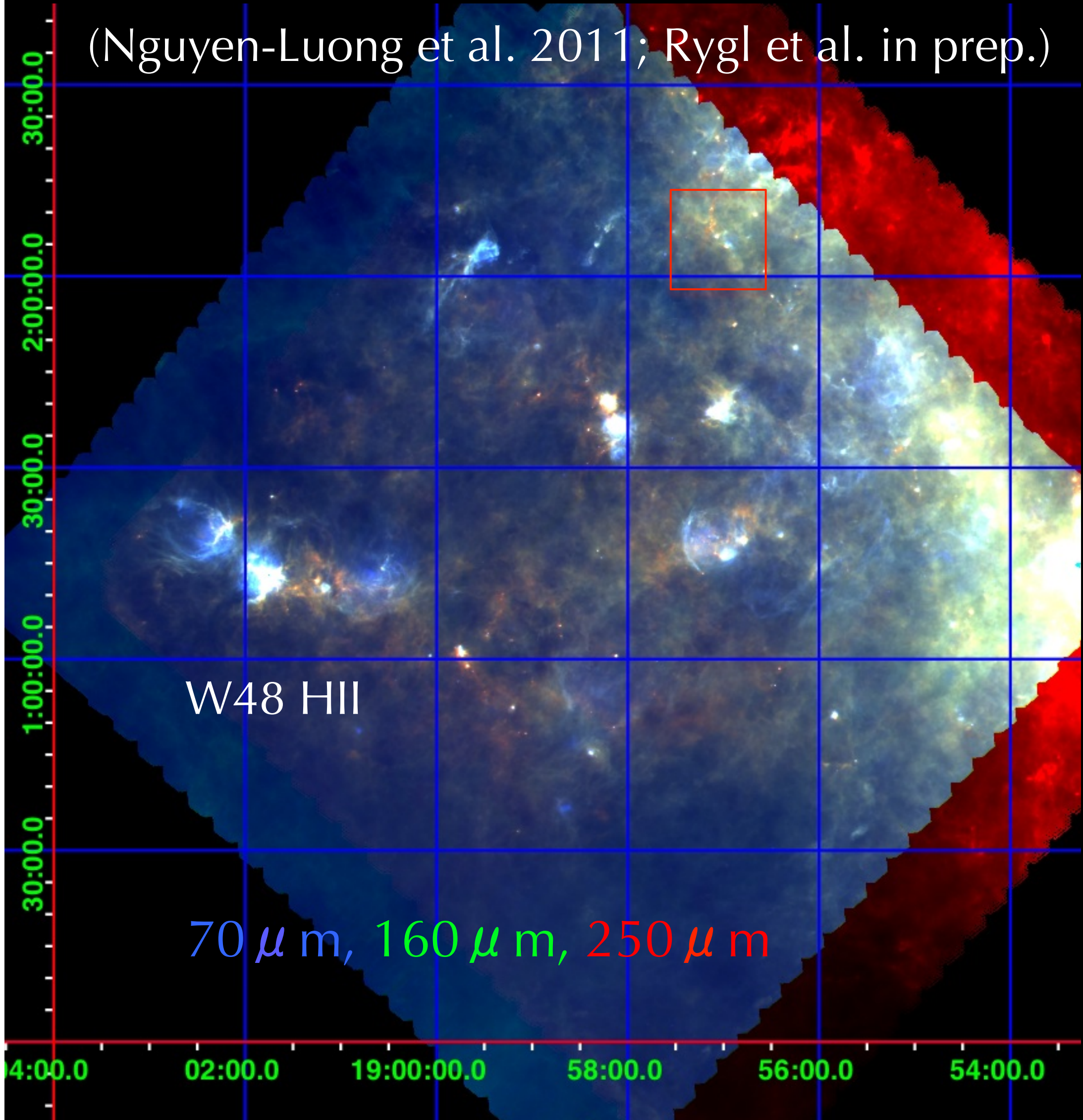
- At Av~ 7 mag, Vela C segregates into 5 sub-regions of similar mass
- CR has a high CD tail
  - May suggest gravity rather than turbulence is shaping the cloud.

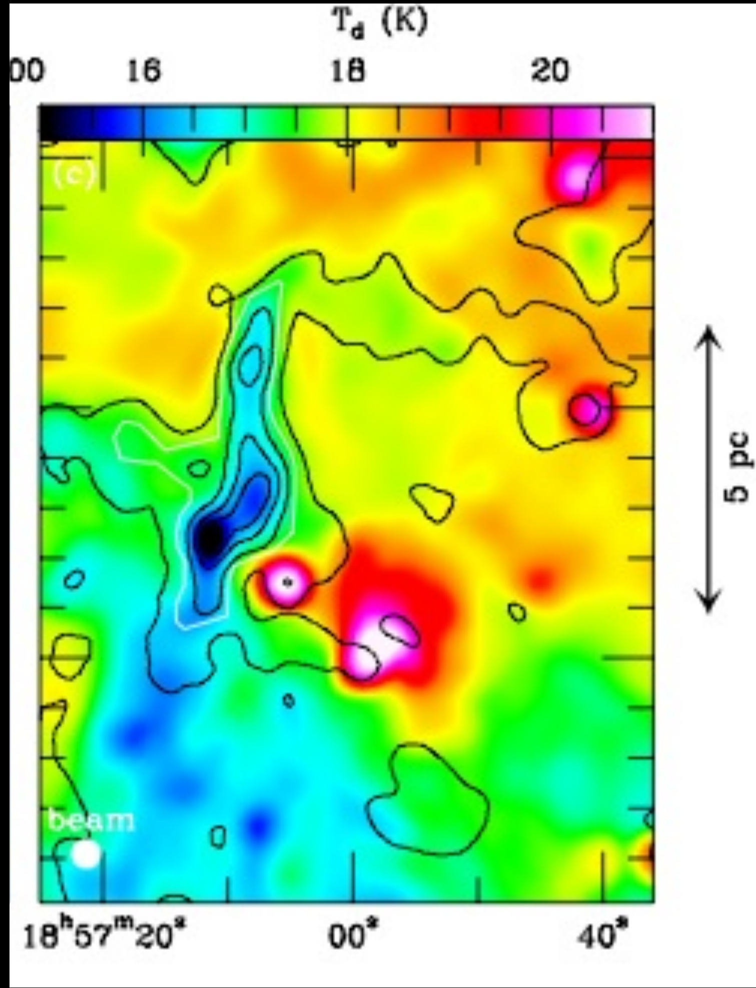


- Flatter PDF (CR) observed for coherent structures created via constructive large-scale flows in some numerical simulations (Federrath et al., 2010)

- The Ridge is dominated by gravity and large-scale converging flows.

IRDC G035.39-00.33, A RIDGE IN W48



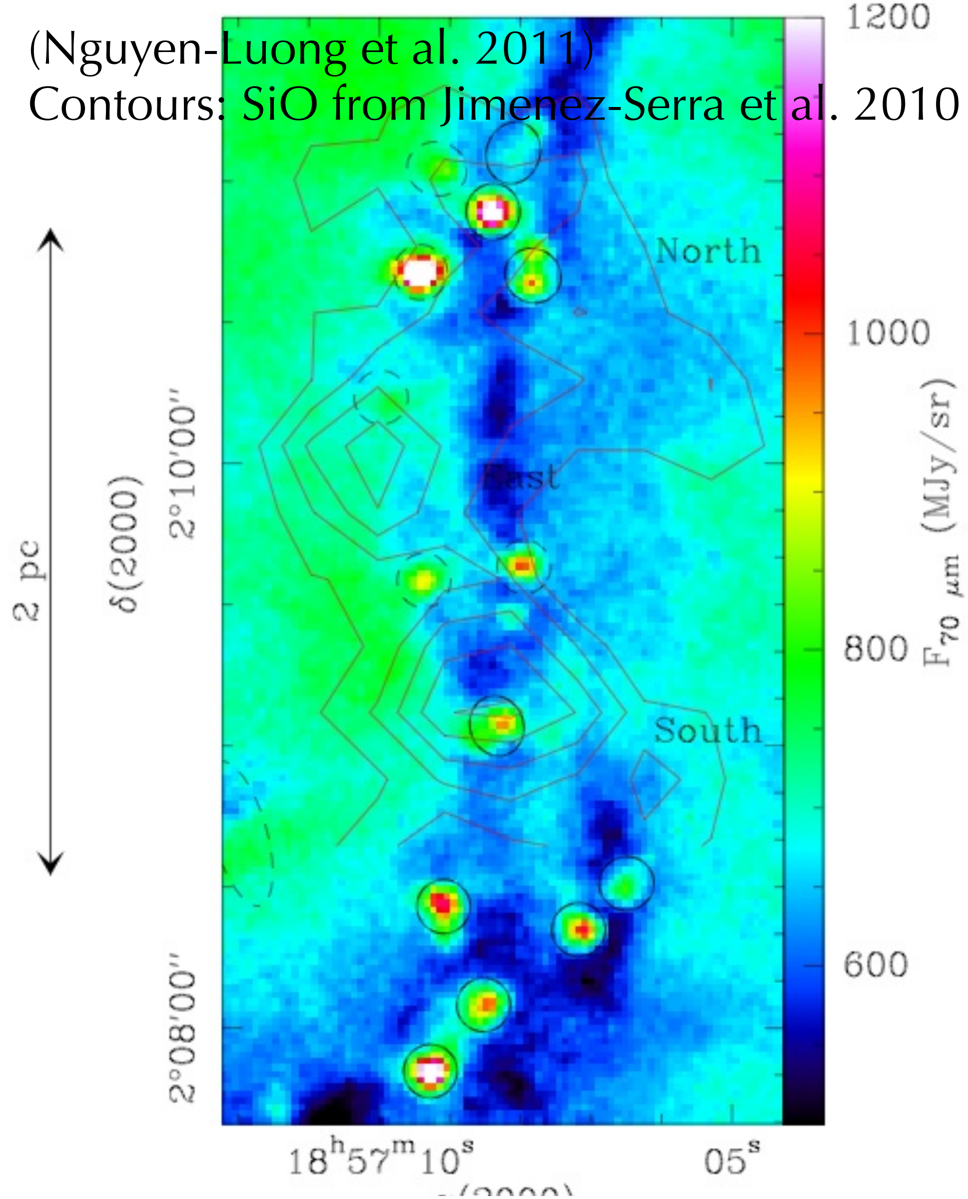


Density contours

- W48, 3kpc, $1 \times 10^6 M_\odot$, ~1.5-8 10^{22}cm^{-2}, 16K

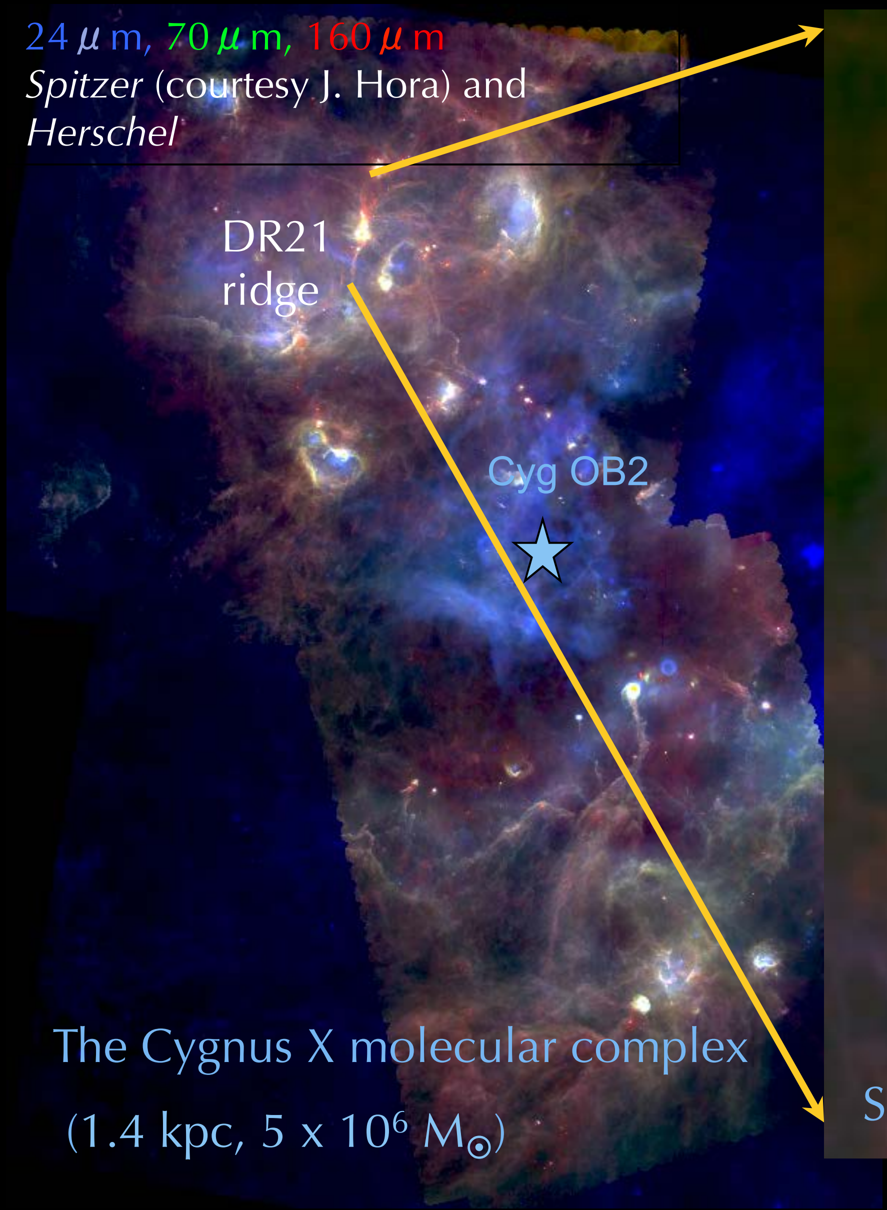
HIGH-MASS STAR FORMATION IN G0.35.39-00.33

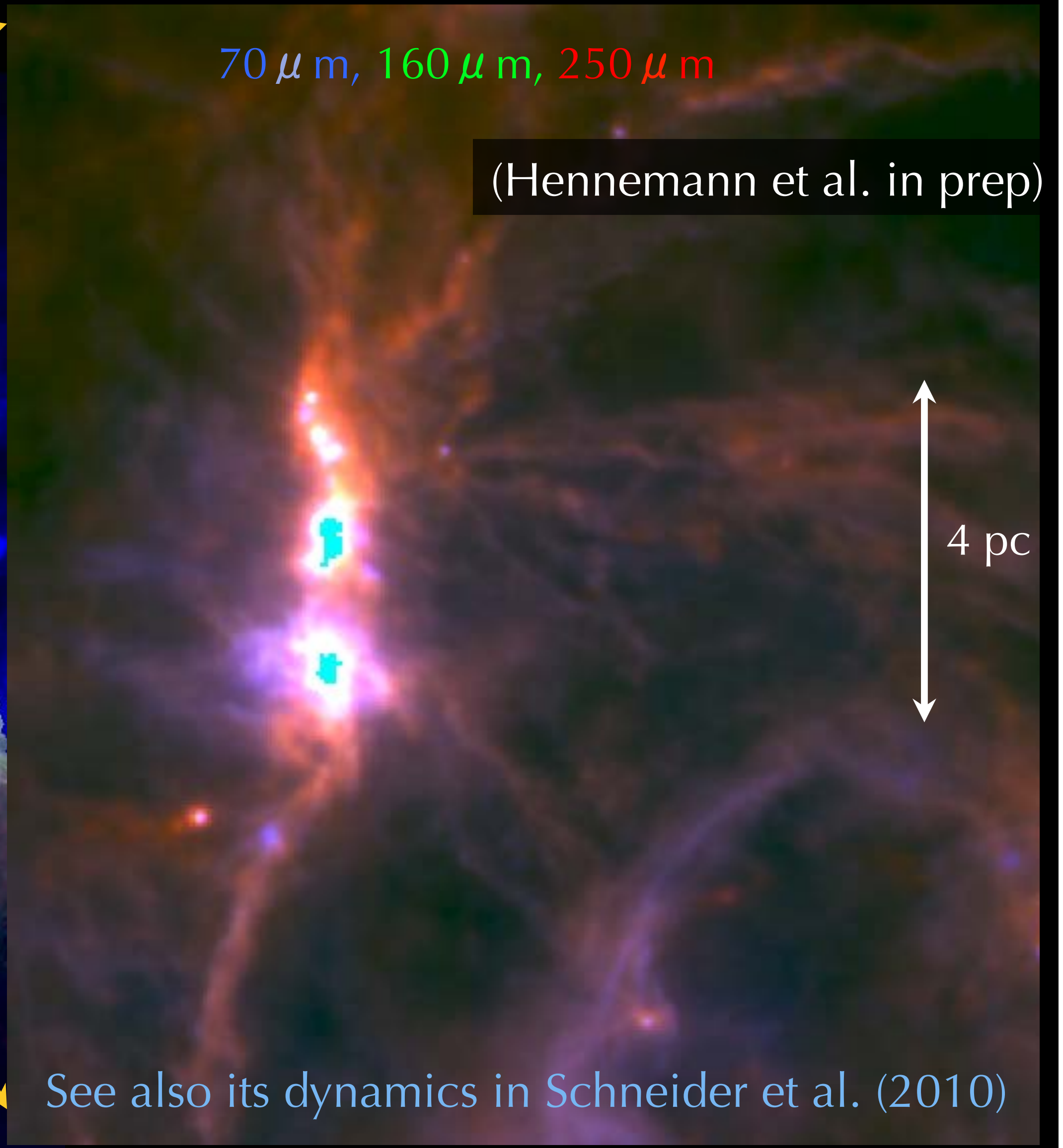
(Nguyen-Luong et al. 2011)
Contours: SiO from Jimenez-Serra et al. 2010



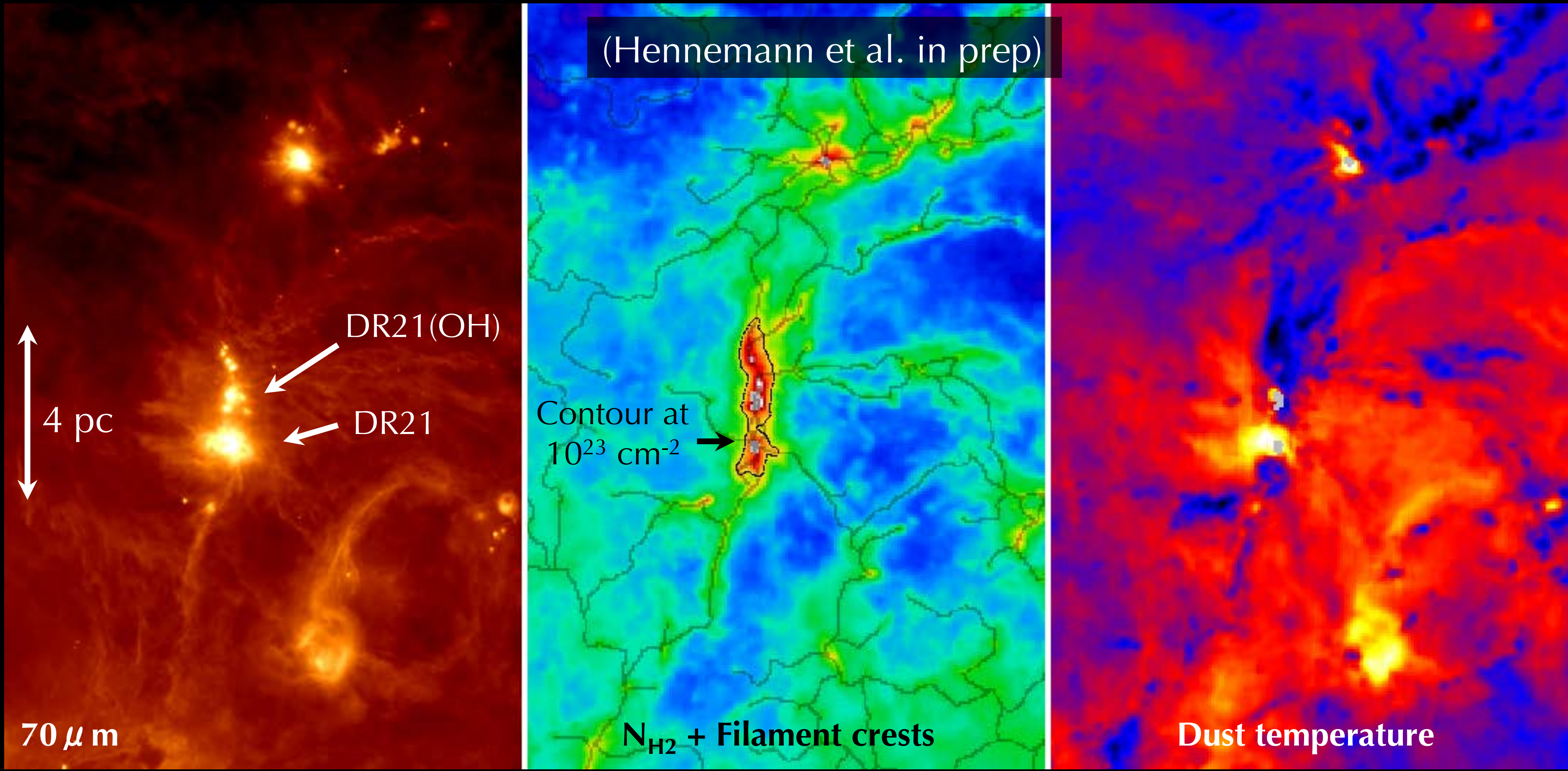
- From the Herschel column density map, IRDC mass = 4000$M_\odot$
- Greybody fitting
  - A cluster of 9 MDC, (0.1-0.2pc, 30-1000$M_\odot$) harbouring class 0 objects
- Part of the SiO may be tracing low velocity shocks assoc. with converging flows.
- A burst of star formation (SFE ~15%) after the fast cloud formation?

DR21, A RIDGE IN CYGNUS X





The DR21 Ridge and its sub-filaments



DR21, a prototypical ridge at 1.4 kpc

$N_{H2} > 10^{23}$ cm^{-2}, 4 pc, 15 000 $M_{\odot}$, $\langle n \rangle \sim 10^4$ cm^{-3}

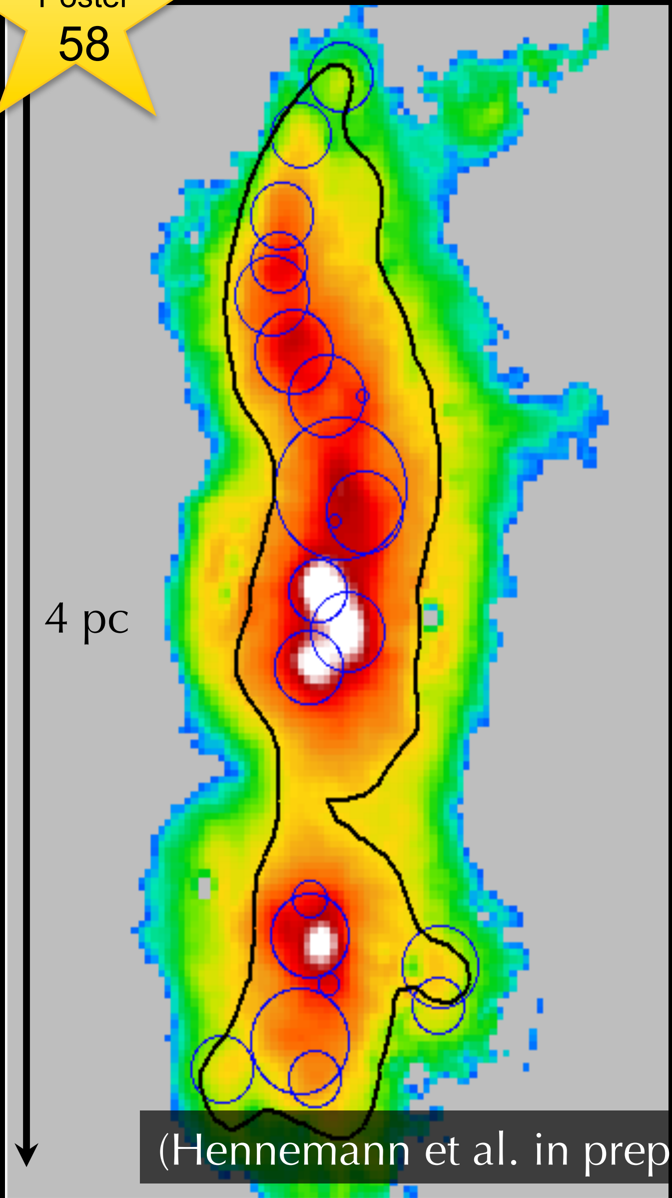
Dominating its surrounding and forming many high-mass stars

Complex substructure, suggestive of a junction/merging of filaments

Poster 58

THE DR21 RIDGE, FORMED BY MERGING OF SUPER-CRITICAL FILAMENTS?

Poster 58



- dominates its environment (and Cygnus X North), linked to supercritical, massive sub-filaments

-Burst of Star Formation?

- 7 MDCs containing 1-3 high-mass protostars

- = 14 high-mass protostars

- +a Kroupa IMF ⟶ A burst with SFE ~ 7%

-Assuming 10^5 yr protostellar lifetime:

⇒ Present SFR ~ 1000 $M_\odot$/Myr on ~9 pc^2

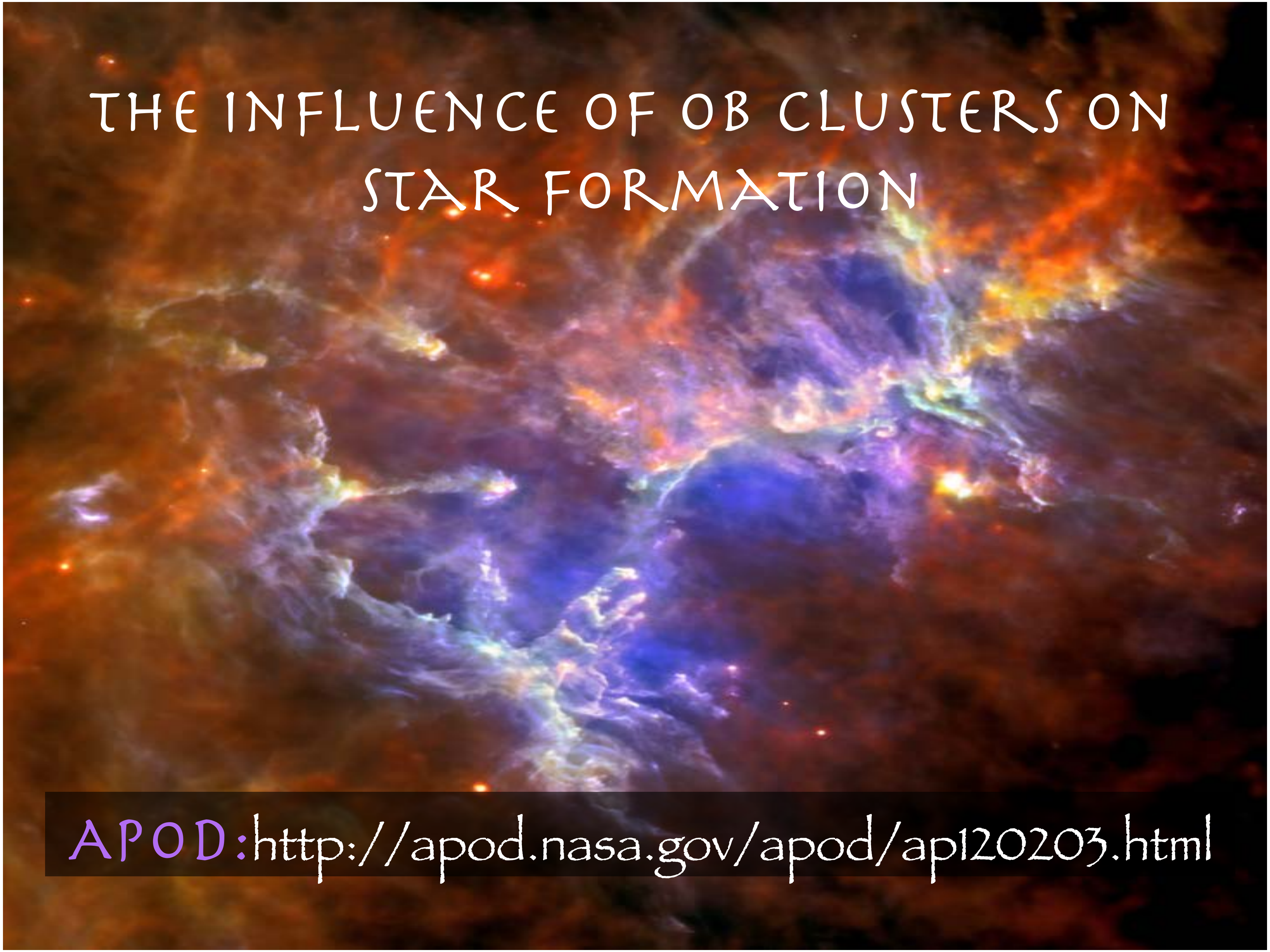
⇒Σ SFR ~ 100 $M_\odot$/yr /kpc^2 (mini-starburst)

Mass accumulation and fate of the DR21 ridge:

- Junction/merging of filaments, collapse of a filamentary network?

- Incoming flows through sub-filaments built up massive DR21 / DR21 (OH) clumps and cores

THE INFLUENCE OF OB CLUSTERS ON STAR FORMATION

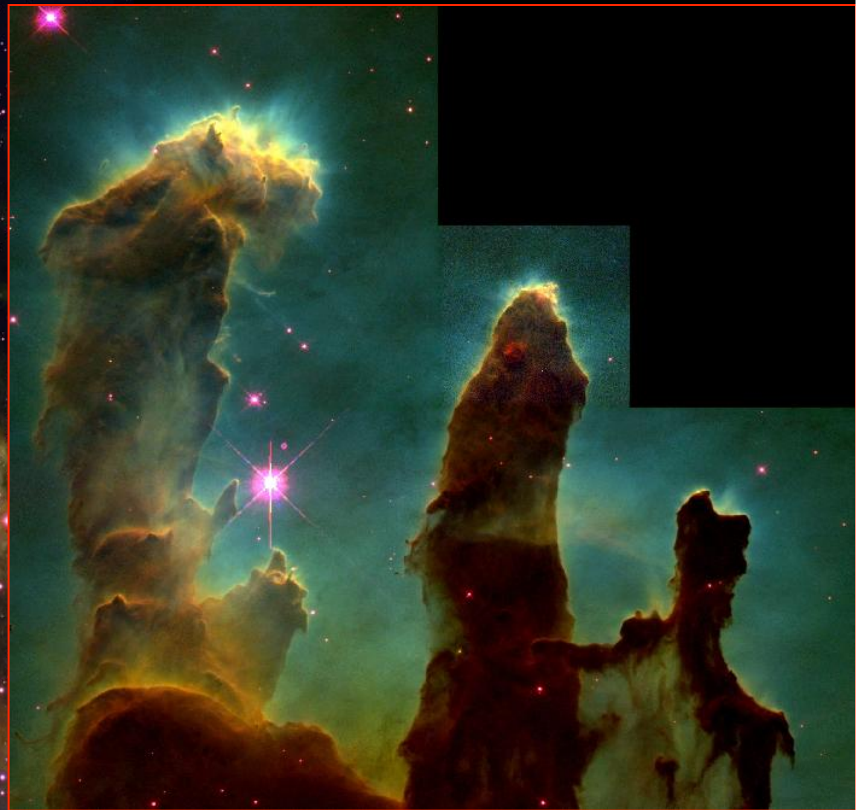


APOD:http://apod.nasa.gov/apod/ap120203.html

M16 UNDER THE INFLUENCE OF NGC6611

Picture credit: T.A. Rector & B.A. Wolpa

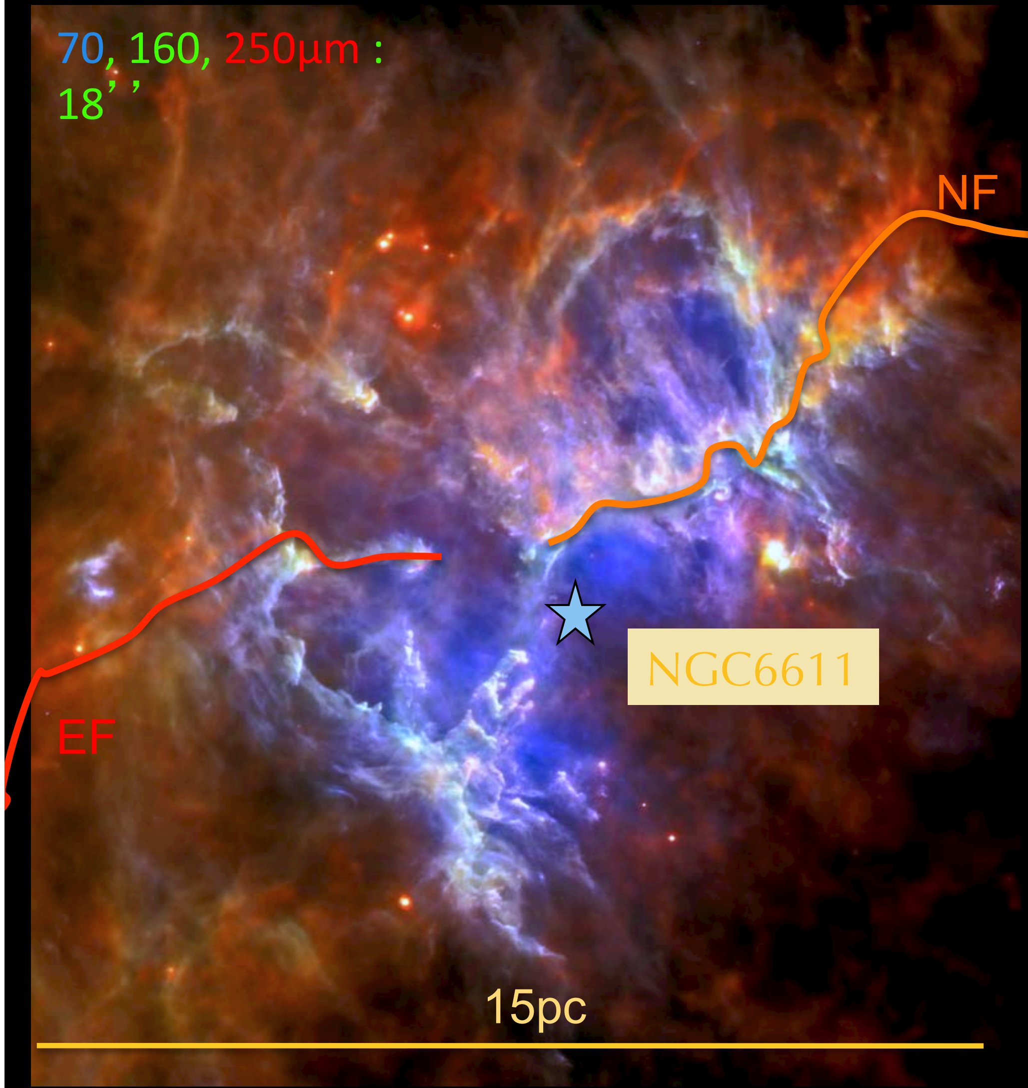
Picture Credit: J. Hester & P. Scowen



Pillars of Creation

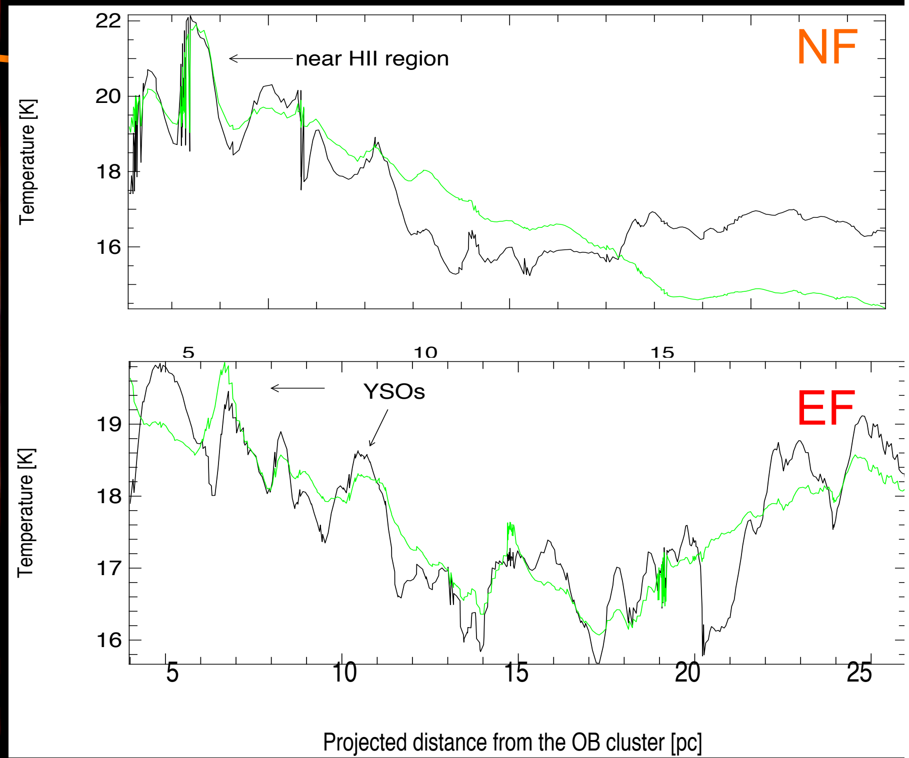
H-alpha, Oxygen [OIII], Sulfur [SII]

Filamentary structure



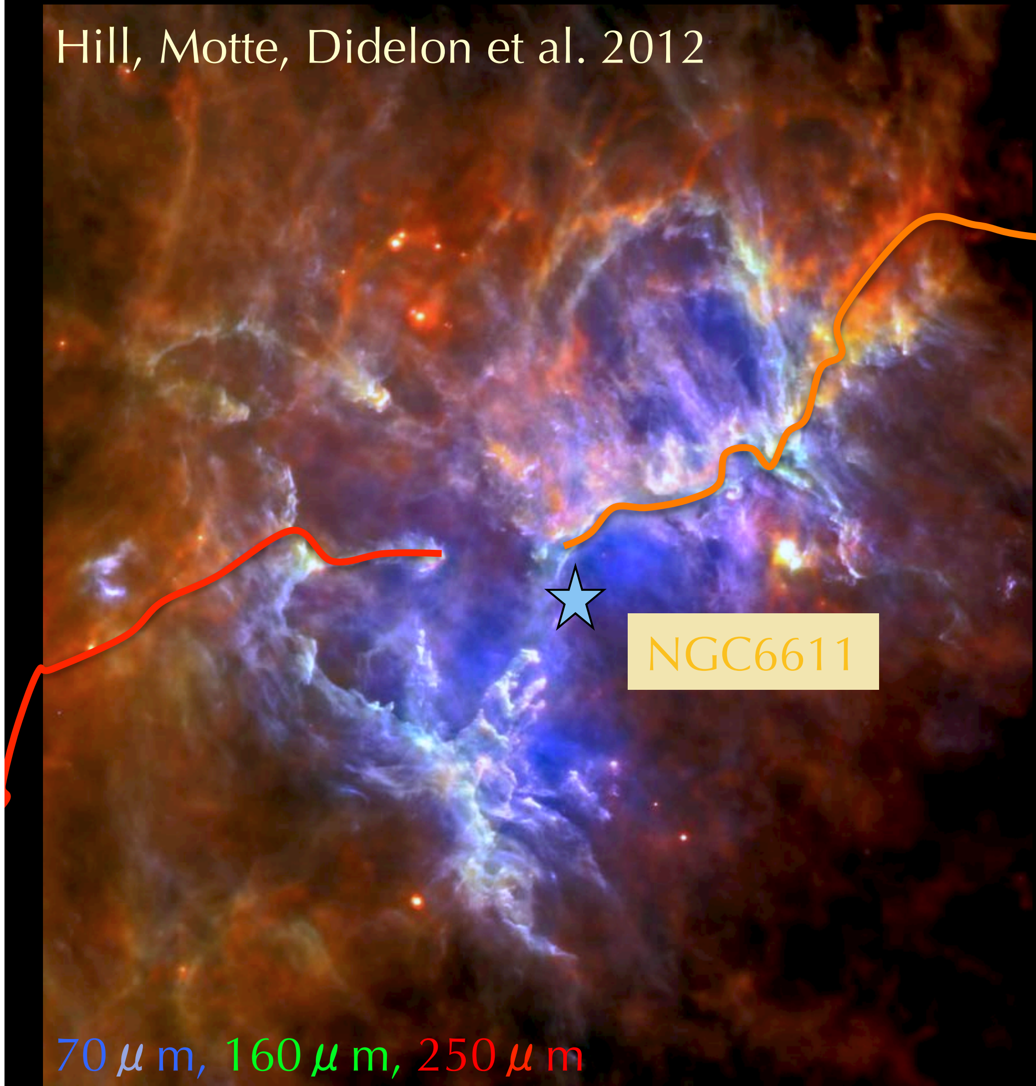
Hill, Motte, Didelon et al. 2012

- Two main filaments identified.



The NGC6611 cluster (several O stars) is heating the cloud up to 10 pc in >10^{22} cm^{-2} filaments which are forming stars

Feedback of OB clusters on surroundings is strong!



The M16 molecular complex (2 kpc)

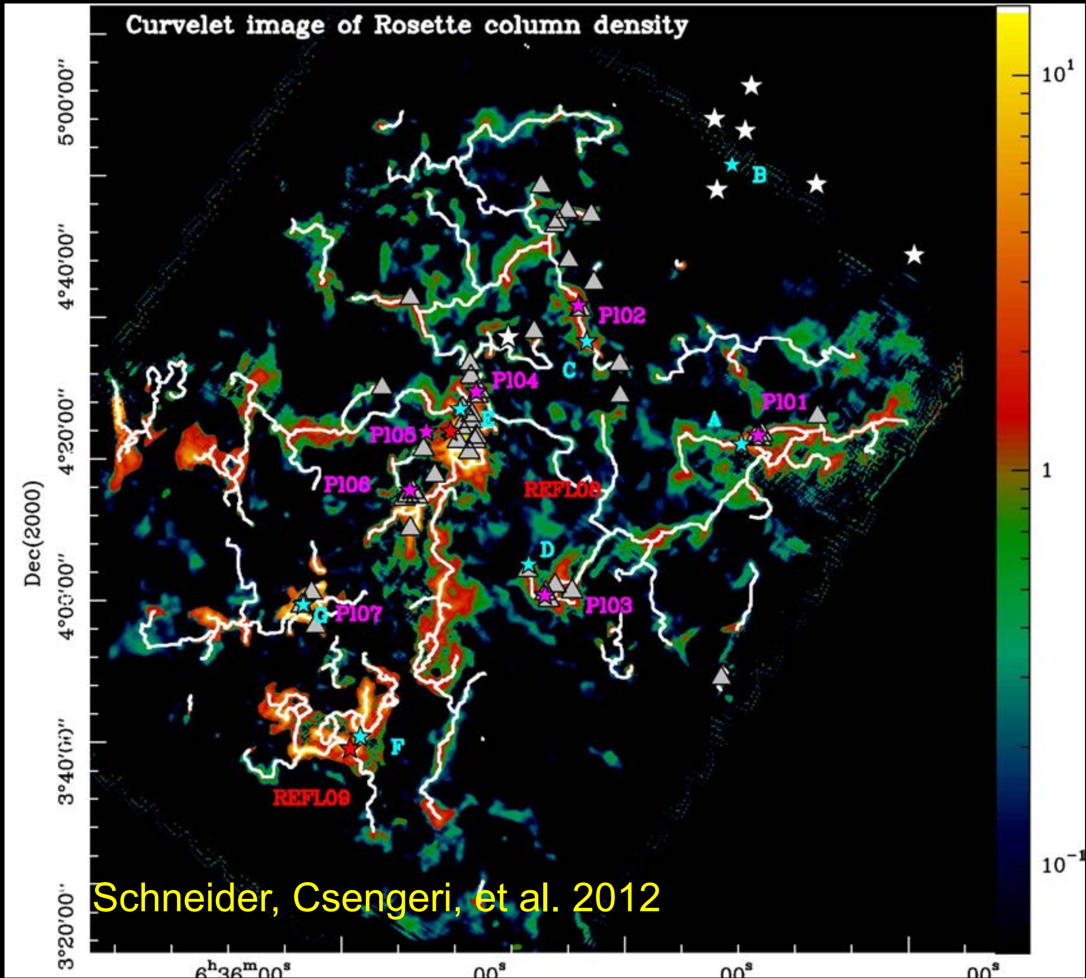
Decreasing temperature with increasing distance from cluster

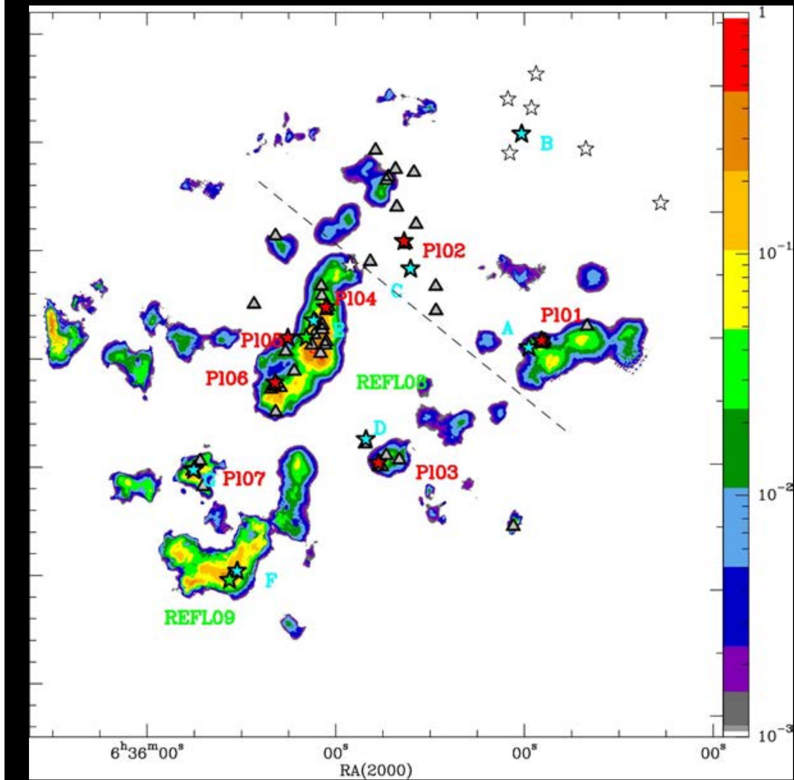
Heating from cluster able to penetrate to ~10pc.

(High-mass) star-forming sites are subject to variations of heating (10 K to 20 K) in HOBYS clouds...

➔ using T_{dust} values and M_{env} vs L_{bol} diagrams to give an approximate evolutionary status for massive dense cores can be biased in high-mass star-forming regions.

Rosette clusters and its filamentary structure

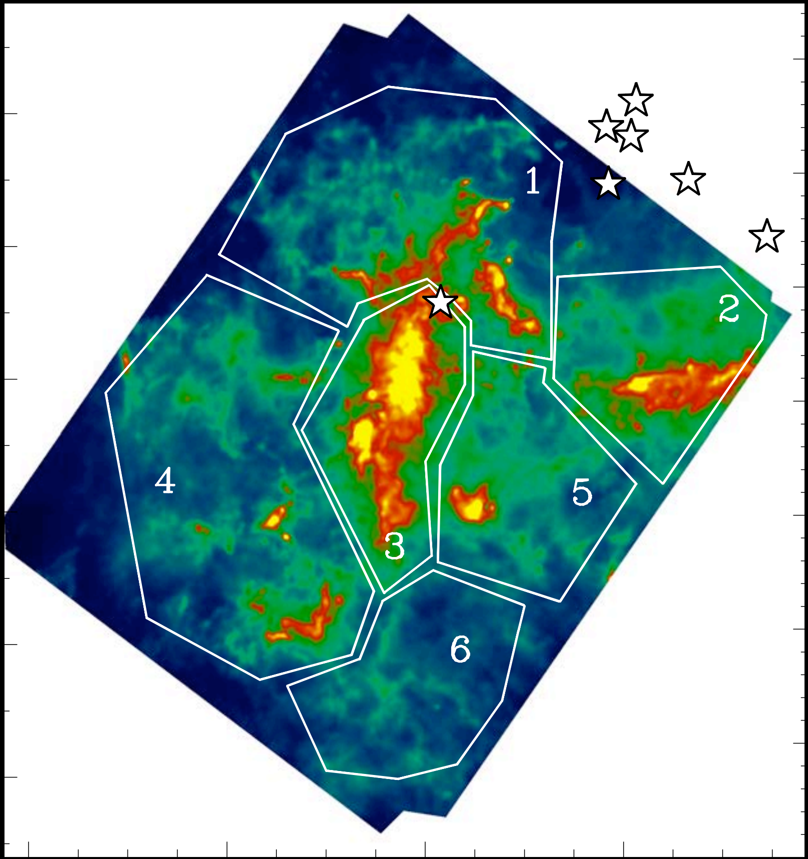


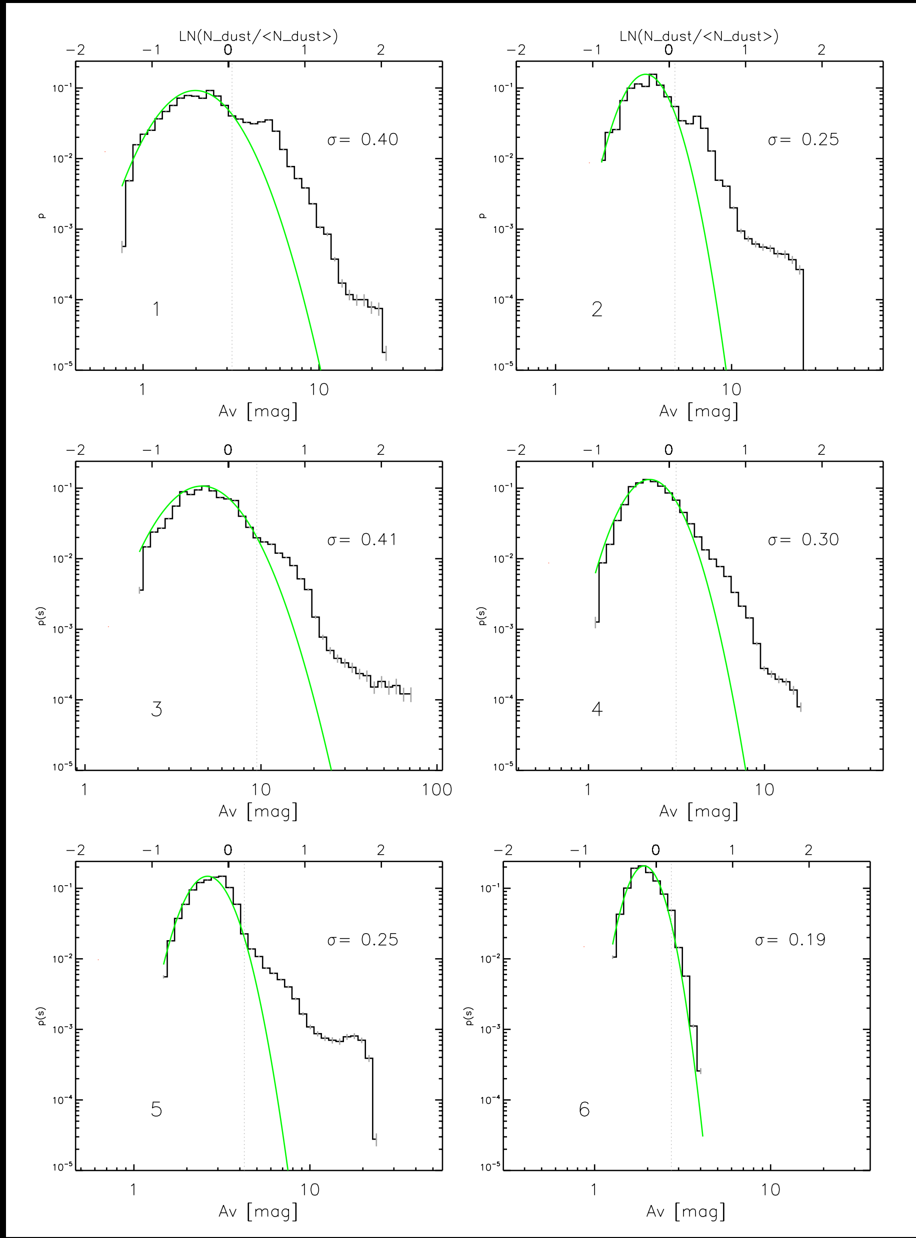


"Probability" to find a cluster/dense core at a junction of filaments

Clusters are preferentially forming at the junction of supercritical filaments, in agreement with the predictions of Dale & Bonnell (2011)

A STAR FORMATION THRESHOLD?





Schneider, Csengeri, et al. 2012

The *Herschel* images of HOBYS reveal

- Networks of filaments among which "ridges" which are forming high-mass stars

Ridge = well-ordered, sub-structured, high-N_{H2} dominating filament, that may host mini-starbursts

Turbulence could have formed most filaments, more dynamic scenario (converging flows? filaments merging?) are proposed to form ridges.

- Feedback effects of OB star clusters on molecular clouds such as heating, pillars and triggered star formation

- The temperature of high-mass star forming sites is subject to variations due to the proximity of OB clusters
    - Can affect the parameters derived from SED fitting

HOBYS POSTERS

10 Tige, Russeil, Schneider et al., NGC 6334

11 Didelon, André, Motte, et al.,

18 Russeil, Tige, Schneider et al., NGC 6334

58 Hennemann, Motte, Schneider et al., DR21

Others from our Group

20 Louvet, Motte, Nguyen Luong , W43