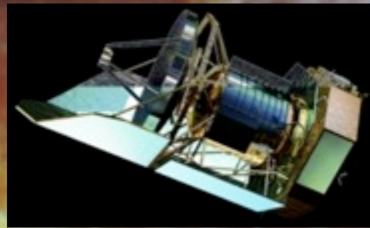
Mini-starburst ridges and "present-day" SFR in HOBYS, the *Herschel* imaging survey of OB Young Stellar objects

http://hobys-herschel.cea.fr



SPIRE

SAG3

PACS

esa

HOBYS

Coordinated by Frédérique Motte (AIM Paris-Saclay), Annie Zavagno, and Sylvain Bontemps

- 50 researchers from 10 institutes
- Management team: P. André, J. di Francesco, F. Motte, S. Pezzuto, D. Ward-Thompson
- HOBYS talks: N. Schneider, P. Tremblin, A. Zavagno
- HOBYS posters: V. Minier (A#77), Q. Nguyen-Luong, T. Rayner (#63), A. Rivera-Ingraham (#65) D. Russeil (#68), K. Rygl (#69), J. Tigé (#79)
- Special credit to: S. Bontemps, P. Didelon, A. Gusdorf, M. Hennemann, T. Hill, F. Louvet, A. Men'shchikov, V. Minier, Q. Nguyen-Luong, N. Schneider

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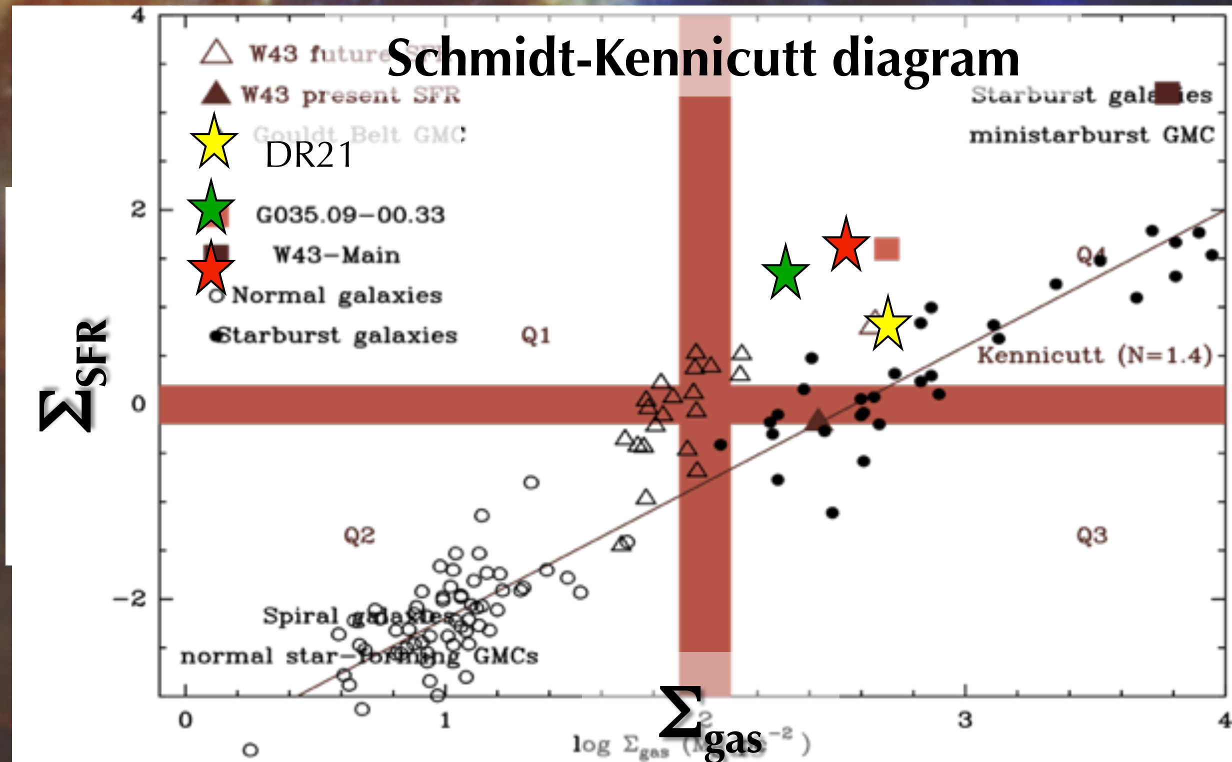
1. HOBYS specificity
2. Cloud structure study, ridge definition
3. Census of young stellar objects, SFR estimates
4. Future HOBYS work and perspectives

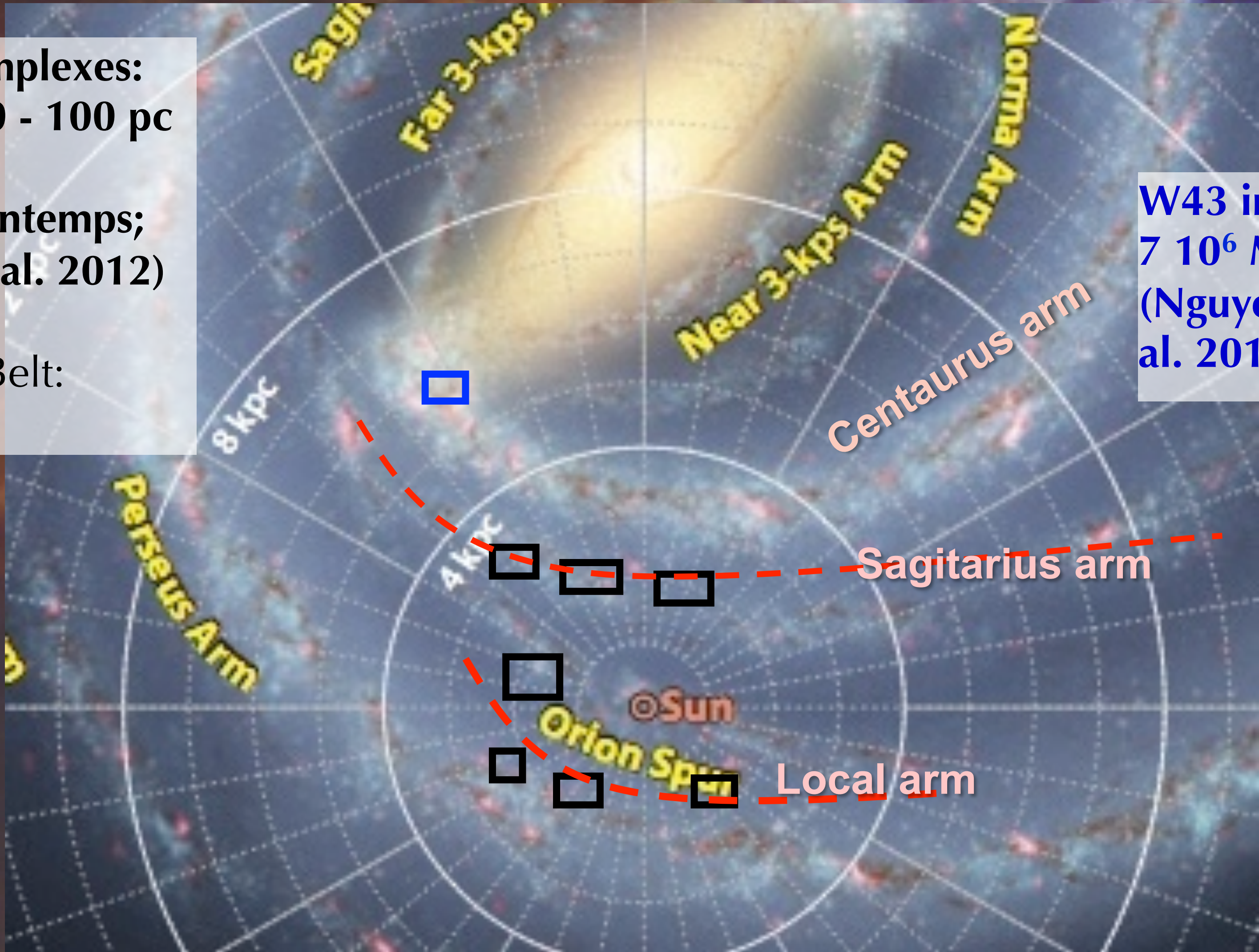


HOBYS molecular cloud complexes, pieces of the nearest spiral arms of the MW

HOBYS mol. complexes:
10^5 - 10^6 $M_\odot$ 50 - 100 pc

(catalog by S. Bontemps; see Schneider et al. 2012)

Orion in Gould Belt:
10^5 $M_\odot$ 50 pc



W43 in Hi-GAL:
7 10^6 $M_\odot$ 150 pc
(Nguyen Luong et al. 2011b)

HOBYS molecular cloud complexes, one necessary step toward nearby galaxies

HOBYS mol. complexes:
10^5 - 10^6 $M_\odot$ 50 - 100 pc

(catalog by S. Bontemps; see Schneider et al. 2012)

Orion in Gould Belt:
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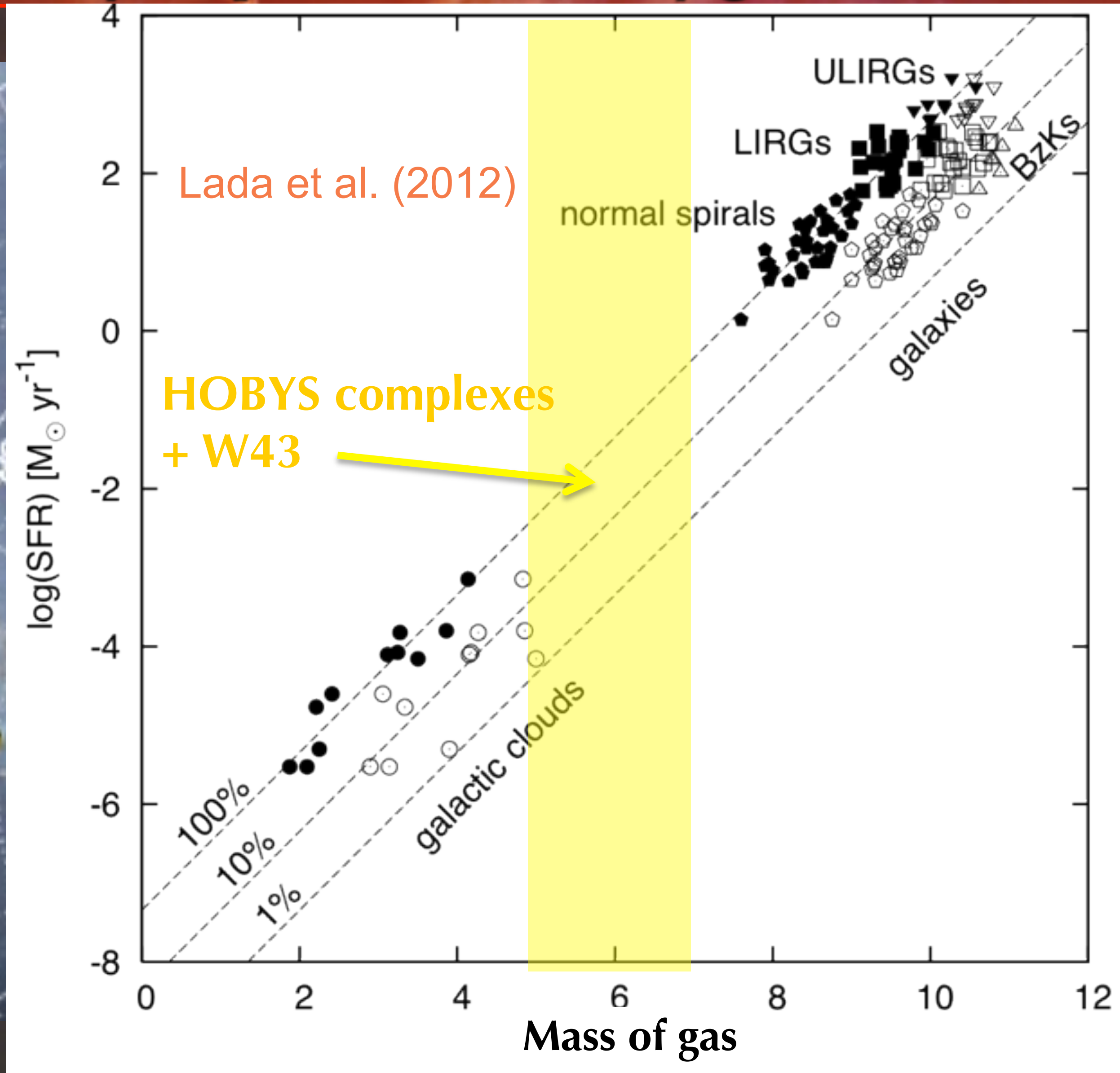


GAL:
0 pc
ng et

Herschel HOBYS suvey

- Target all molecular cloud complexes forming OB-type stars at d_{Sun} < 3 kpc
- Wide-field PACS/SPIRE imagings (70, 160, 250, 350, 500 μm) with 20''/sec

HPBW = 6''-36.9'' @ 0.7-3 kpc ➔ down to 0.03-0.2 pc dense cores

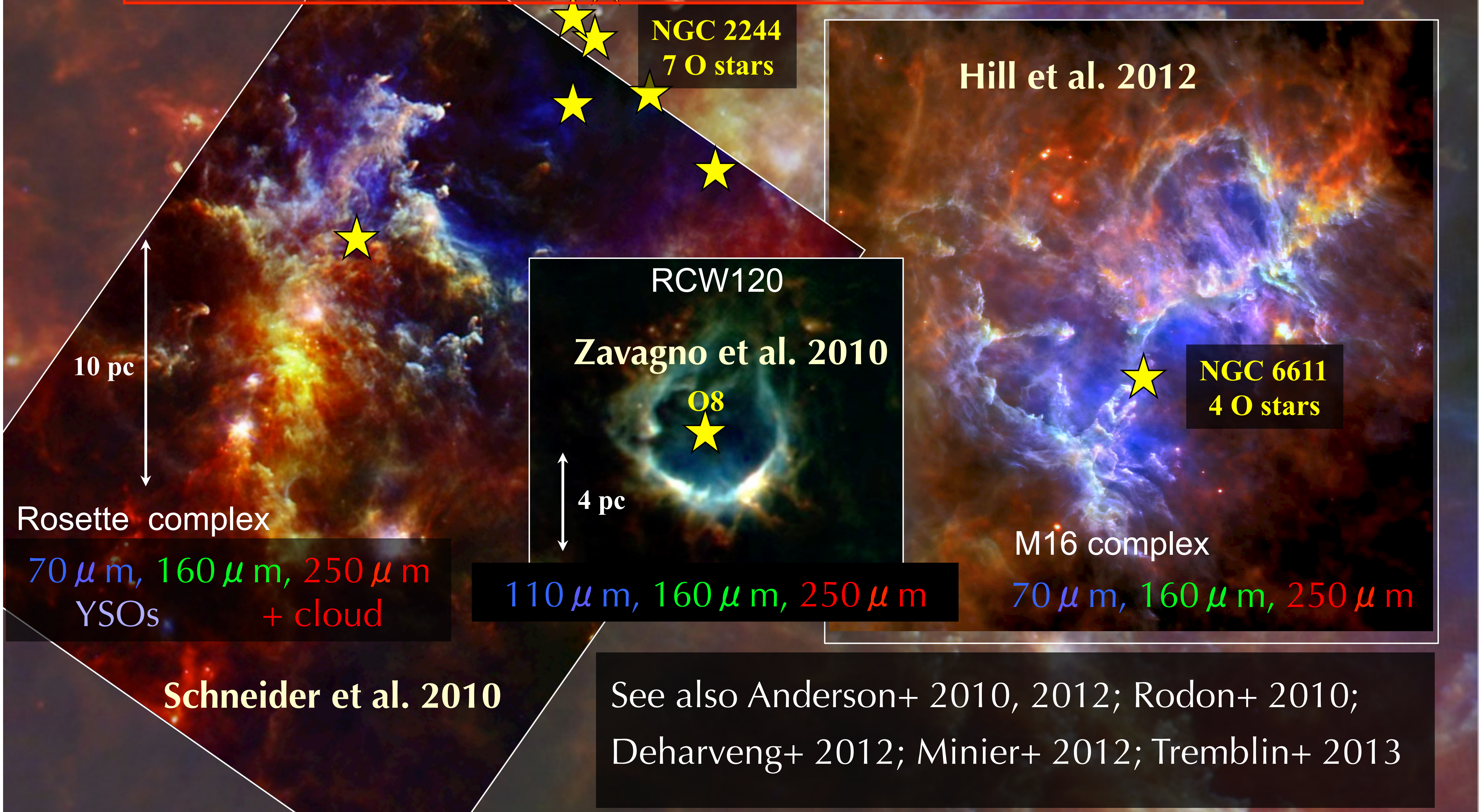
⇒ census of intermediate- to high-mass protostars

⇒ link between cloud structure and (high-mass) SF

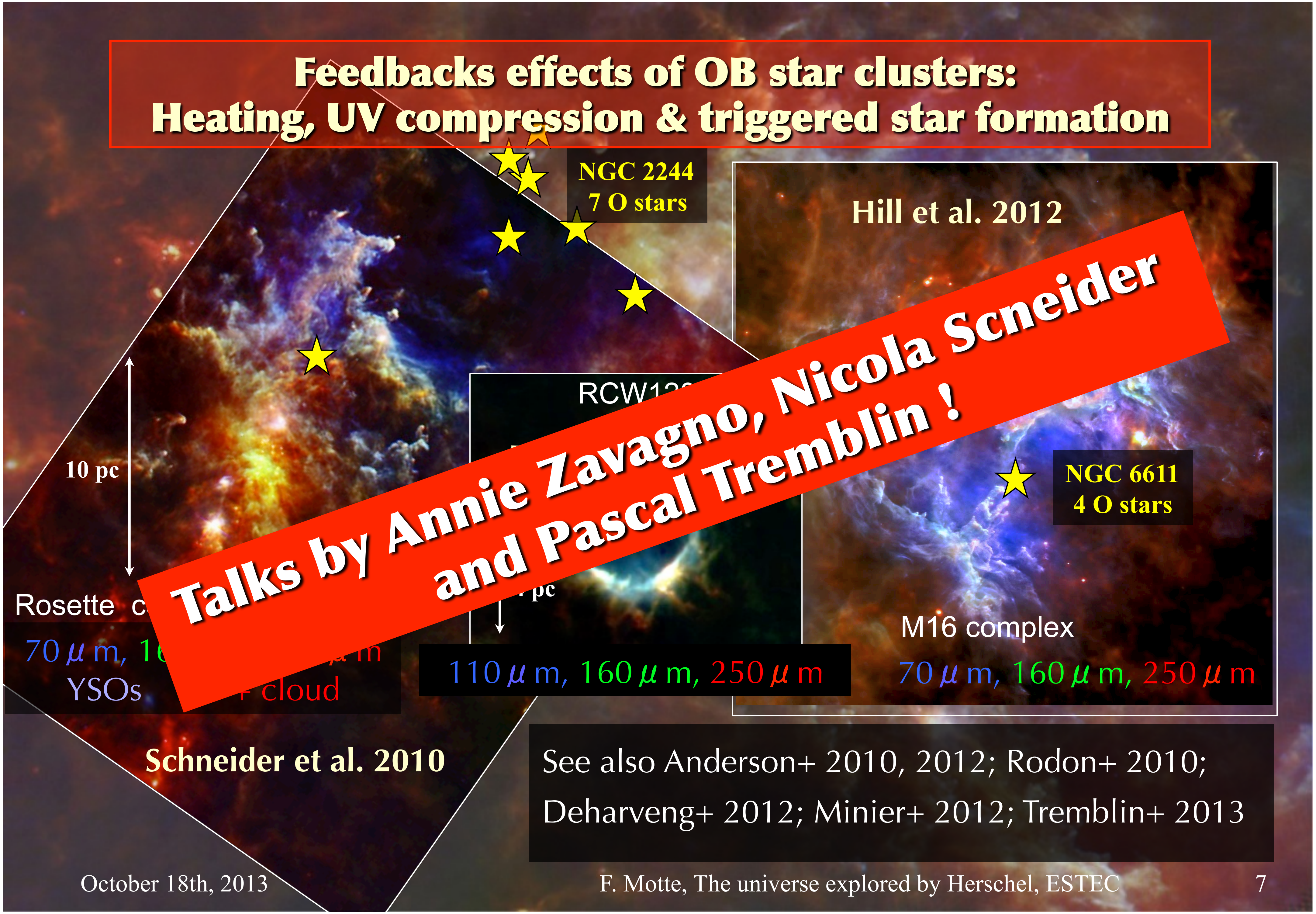
⇒ feedback effects

- Complementary to other *Herschel* KPs:
  - high-mass dense cores (small and isolated clouds) - EPOS (Krause et al.)
  - low-mass cores (~0.02 pc) – HGBS, Cold Cores and HOPS survey (André et al.; Juvela, Ristorcelli et al.; Megeath et al.)
  - protoclusters (~1 pc clumps) - Hi-GAL (Molinari et al.)

Feedbacks effects of OB star clusters: Heating, UV compression & triggered star formation

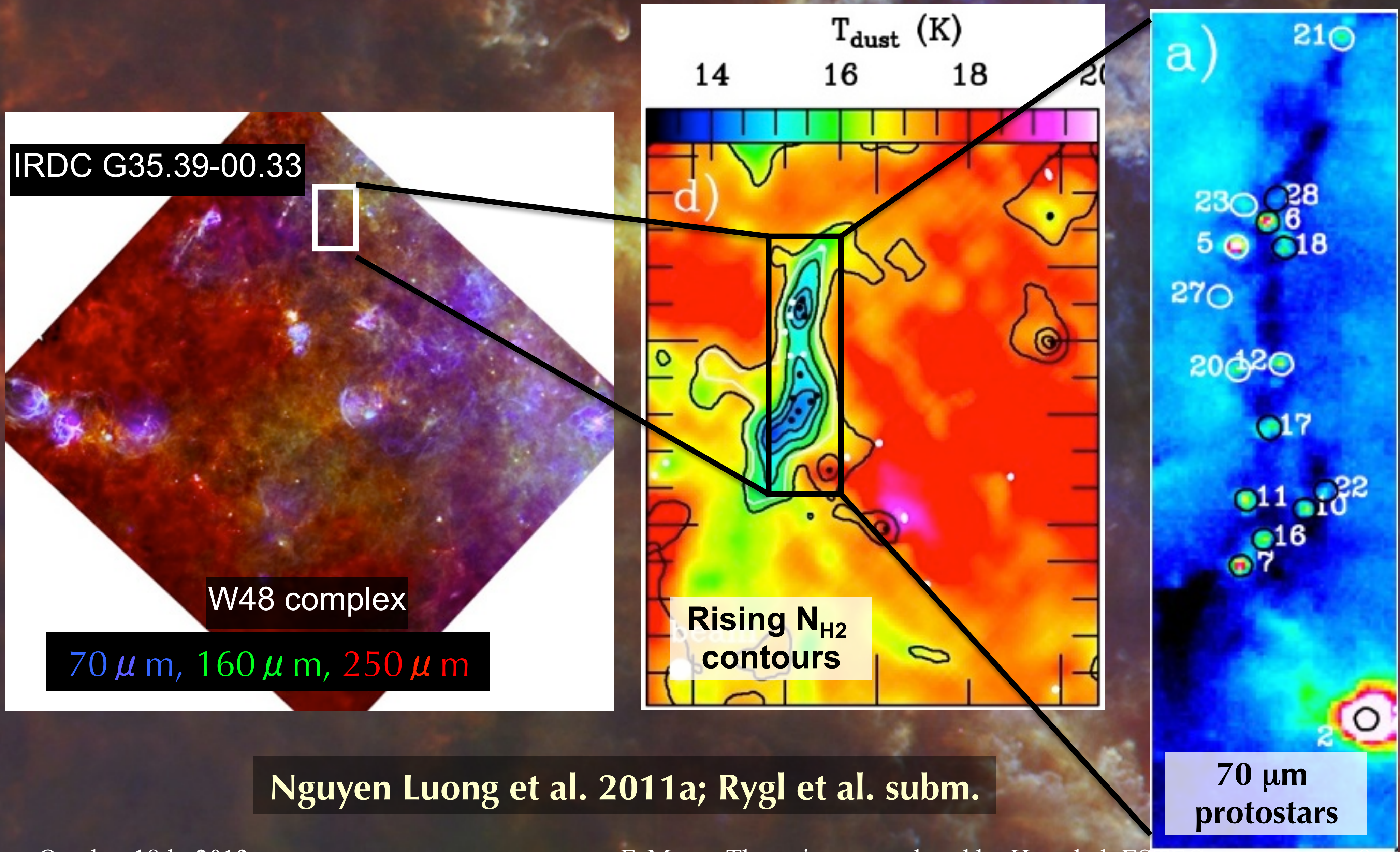


See also Anderson+ 2010, 2012; Rodon+ 2010; Deharveng+ 2012; Minier+ 2012; Tremblin+ 2013



Feedbacks effects of OB star clusters:
Heating, UV compression & triggered star formation
NGC 2244
7 O stars
Hill et al. 2012
Talks by Annie Zavagno, Nicola Scneider
and Pascal Tremblin !
RCW12
10 pc
Rosette c
70 μm, 16
YSOs
cloud
pc
110 μm, 160 μm, 250 μm
NGC 6611
4 O stars
M16 complex
70 μm, 160 μm, 250 μm
Schneider et al. 2010
See also Anderson+ 2010, 2012; Rodon+ 2010;
Deharveng+ 2012; Minier+ 2012; Tremblin+ 2013

Example cloud filament forming a stellar cluster



Nguyen Luong et al. 2011a; Rygl et al. subm.

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Ridges are extreme clumps forming clusters of high-mass stars

- ~50% of high-mass protostars are forming in clusters within high-density elongated clumps

⇒ Ridge definition : 5-10 pc^3 above 10^4-10^5 cm^{-3}

For convenience, we use the 100 A_v level to identify ridges but it is not a physical threshold

- Surrounding gas concentrates toward ridges at high column-density (seen e.g. with PDF studies of N. Schneider)

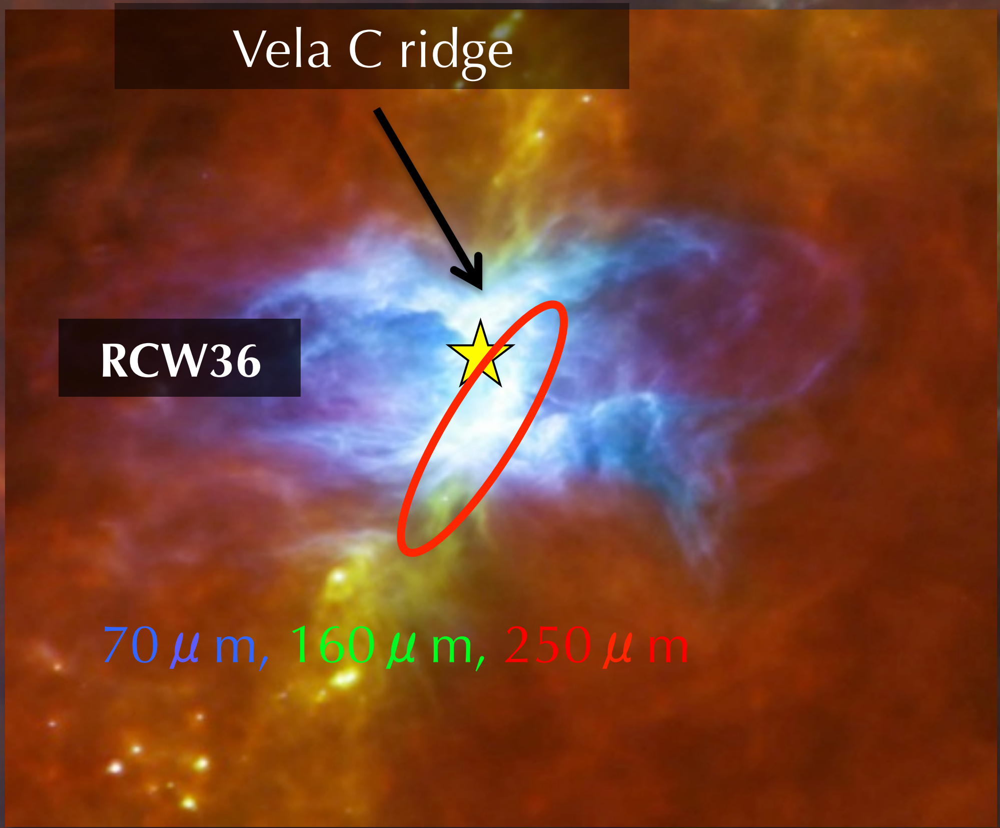
➢ Vela C ridge (Hill, Motte, Didelon et al. 2011)

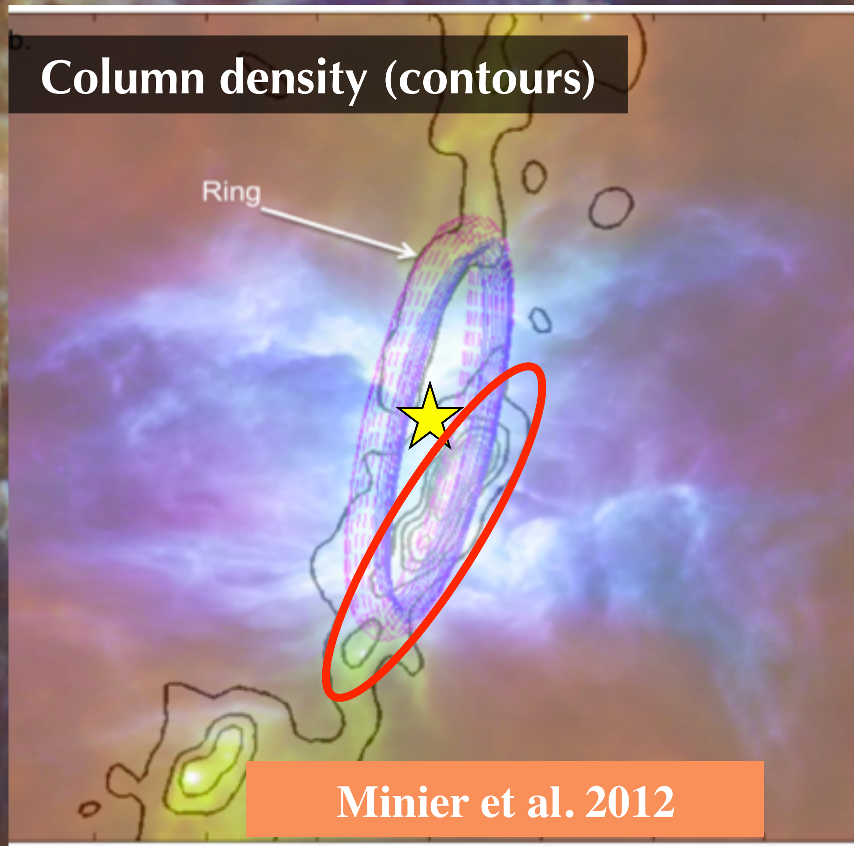
➢ DR21 ridge in Cygnus X (Hennemann, Motte, Schneider et al. 2012)

➢ IRDC G035.39-00.33 ridge (Nguyen Luong, Motte, Hennemann et al. 2011a)

➢ W43-MM1, MM2 ridges (Nguyen Luong, Motte, Carlhoff et al. 2013)

Some ridges could have formed by compression by UV radiation...

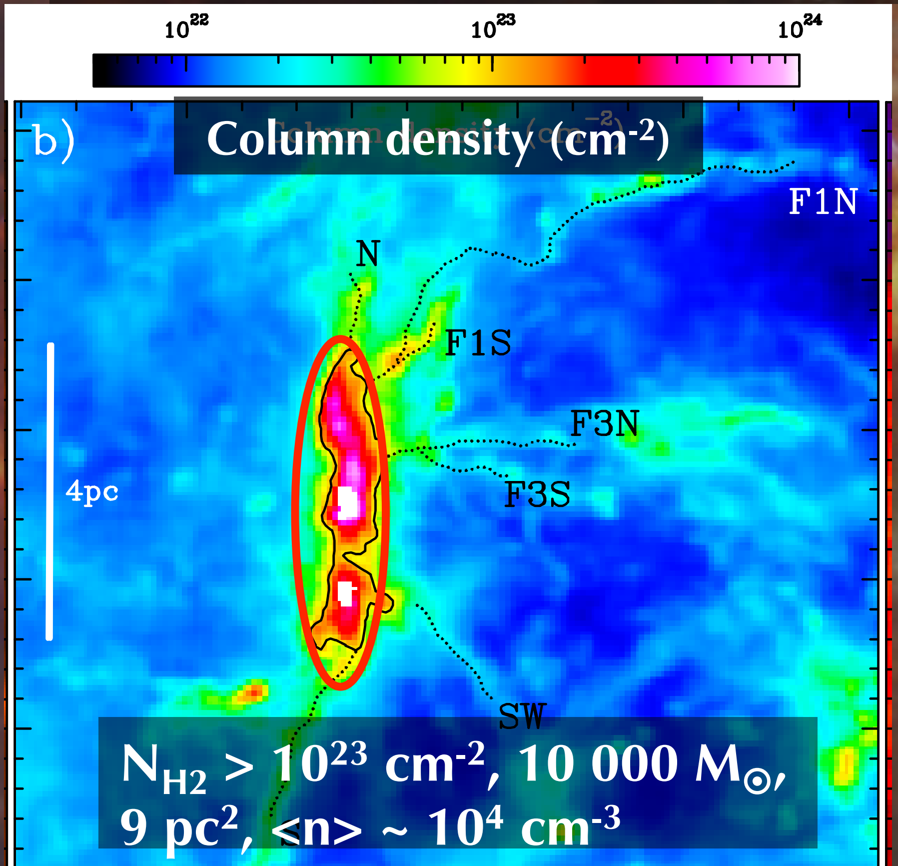




A model of ridge formation within a sheet compressed by the OB cluster UV radiation explains the observed structure and kinematics (Minier, Tremblin, Hill et al. 2012)

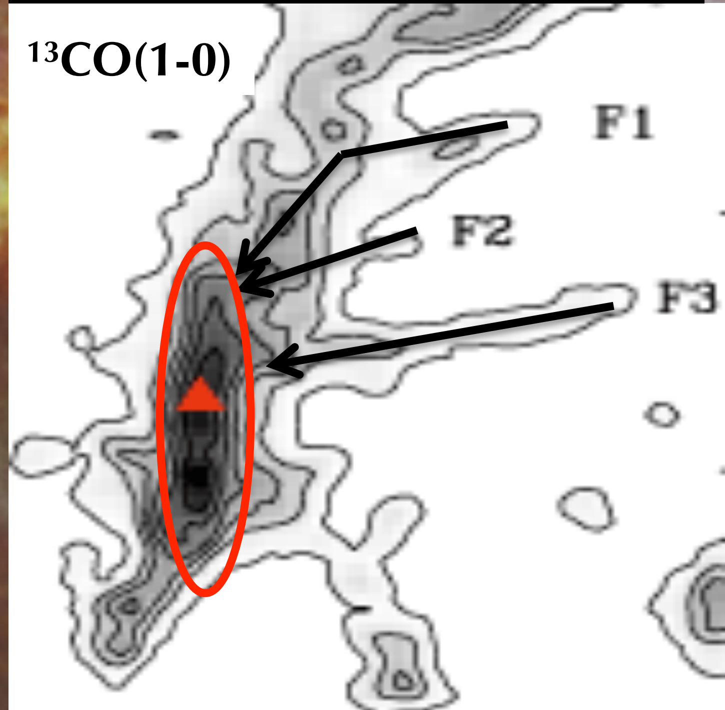
Most ridges should form by cloud global collapse

- Forced-fall (pressure-driven infall) of the DR21 ridge further fed by filaments.



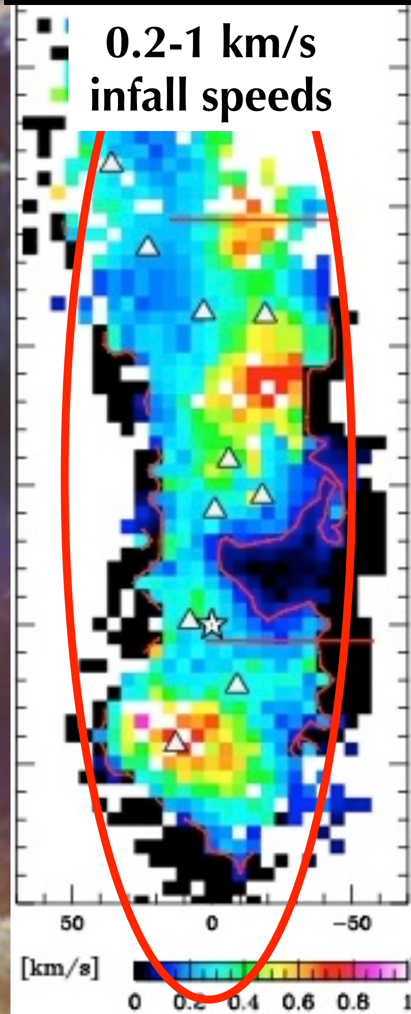
Hennemann, Motte, Schneider et al. 2012

Gas flows along sub-filaments



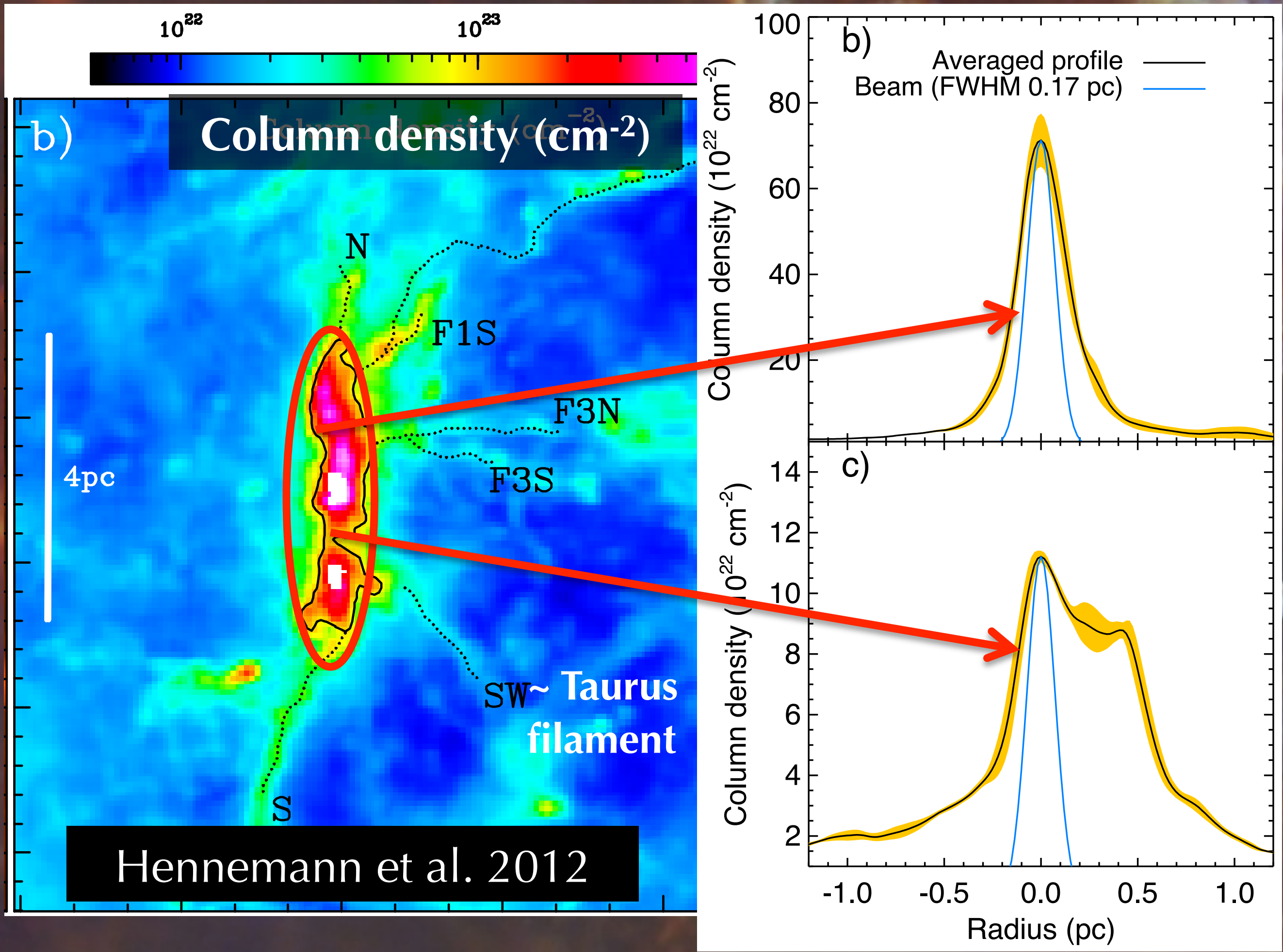
Schneider, Csengeri, Bontemps et al. 2010

Global infall



- Similar kinematics for the W43-MM1 & MM2 ridges (Motte et al. 2005; Louvet et al. in prep.)

The DR21 ridge, formed by merging of super-critical filaments?



Steps toward SF in ridges:

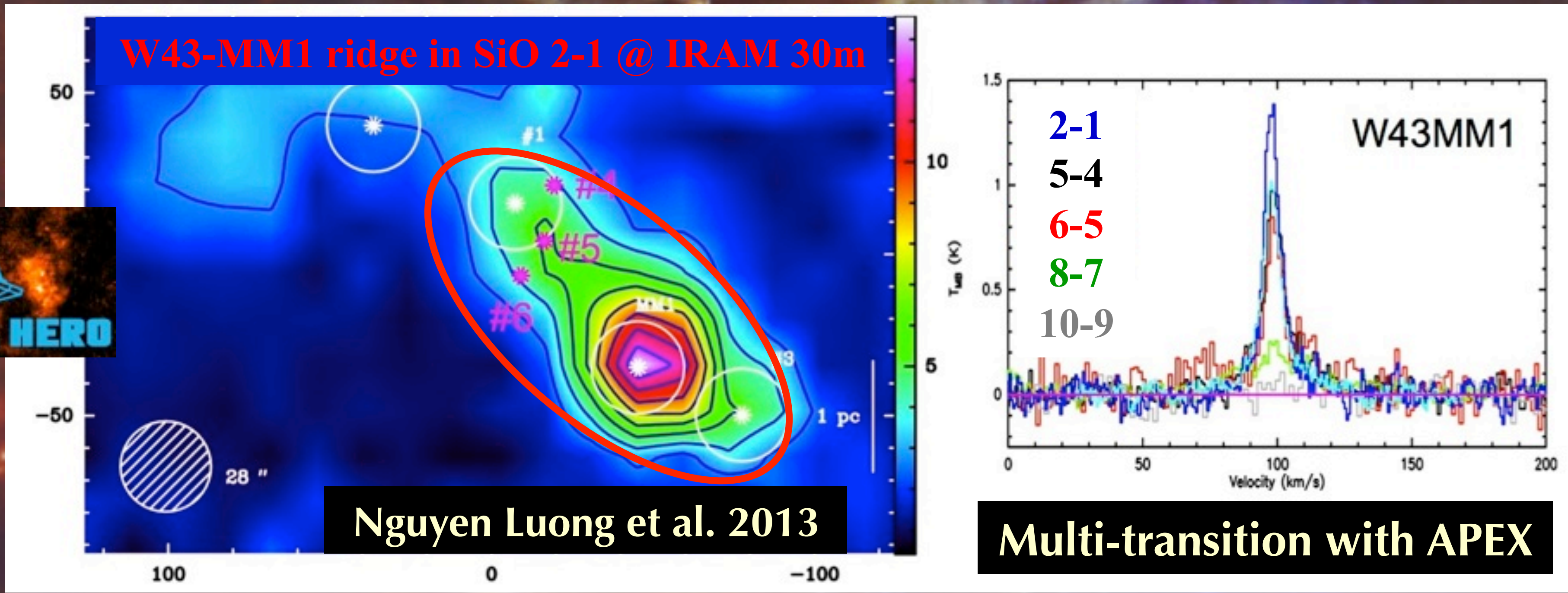
1. MHD tubulent shocks build-up filaments that gently accrete from their surrounding.
2. Gravity braids filaments in a collapsing clump attracting more filaments.
3. Stars and filaments simultaneously form. Protostar accretion is non-local & aspherical.

⇒ Prestellar cores may not exist in such environment

See Csengeri et al. 2011a-b for gas inflow shears in DR21 cores

See also Henshaw et al. 2013; Louvet et al. in prep. for other ridges

Bright & extended SiO emission along W43 ridges



SiO classically associated with protostellar outflows but here >70% is associated to 5-10 km/s shocks (Nguyen Luong et al. 2013; Louvet et al. in prep.)

Observations compared with shock models with Si in gas or SiO in grain mantles to constrain the filament merging (Gusdorf et al. in prep.).

See also Jiménez-Serra et al. 2011 for the IRDC G035.39-00.33

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HOBYS contribution to the Schmidt-Kennicutt (SFE/SFR versus M_{gas}/Σ_{gas}) relation

Making a **direct link** between protostars and their cloud, *Herschel* measures instantaneous SFE, easier to compare with statistical models of SFR (e.g. Federrath et al. 2012).

- *Herschel* or (sub)millimeter samples of protostars (lifetime ~10^5 yr) (e.g. Motte et al. 2003; Nguyen Luong et al. 2011a)

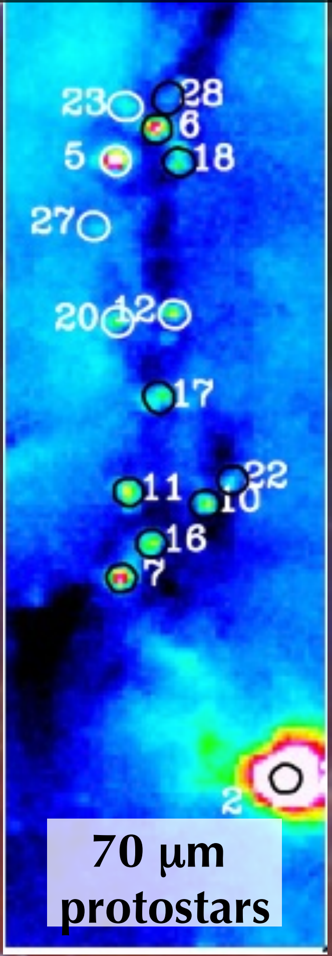
  ➔ "Present-day" SFR

- *Spitzer* sample of pre-main sequence stars (lifetime ~10^6 yr) or effect of OB stars (depletion time 2 x 10^6 yr) on the cloud (e.g. Heiderman et al. 2010; Kennicutt 1998)

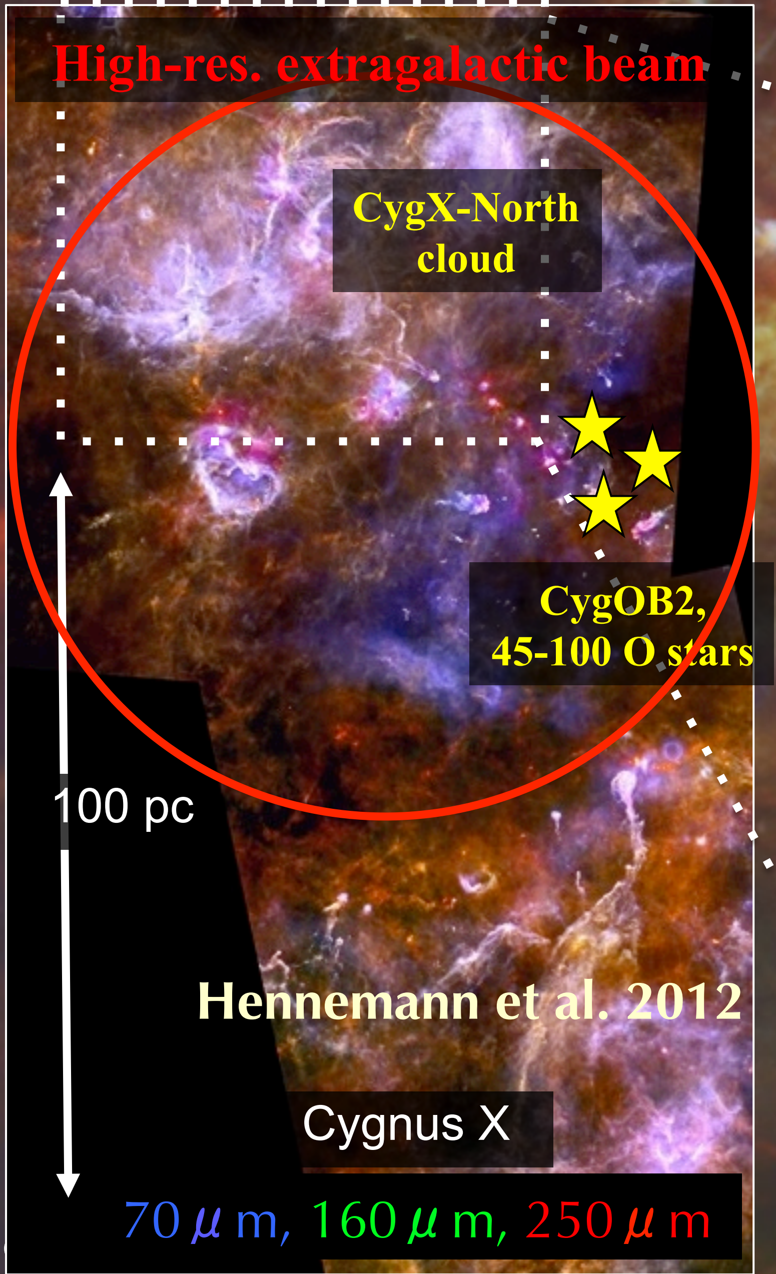
  ➔ "Past" SFR

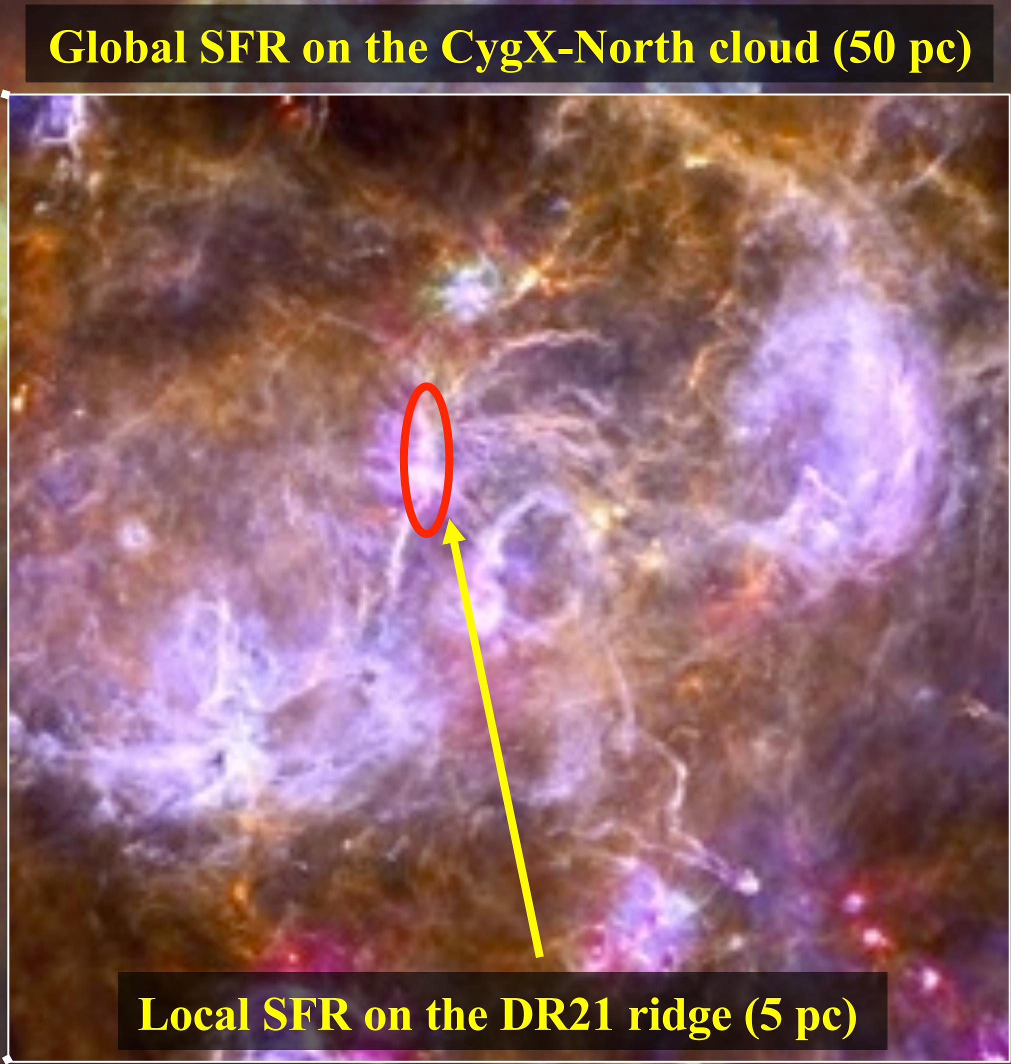
With both SFRs, one may constrain the history of star formation…

Nguyen Luong et al. 2011a

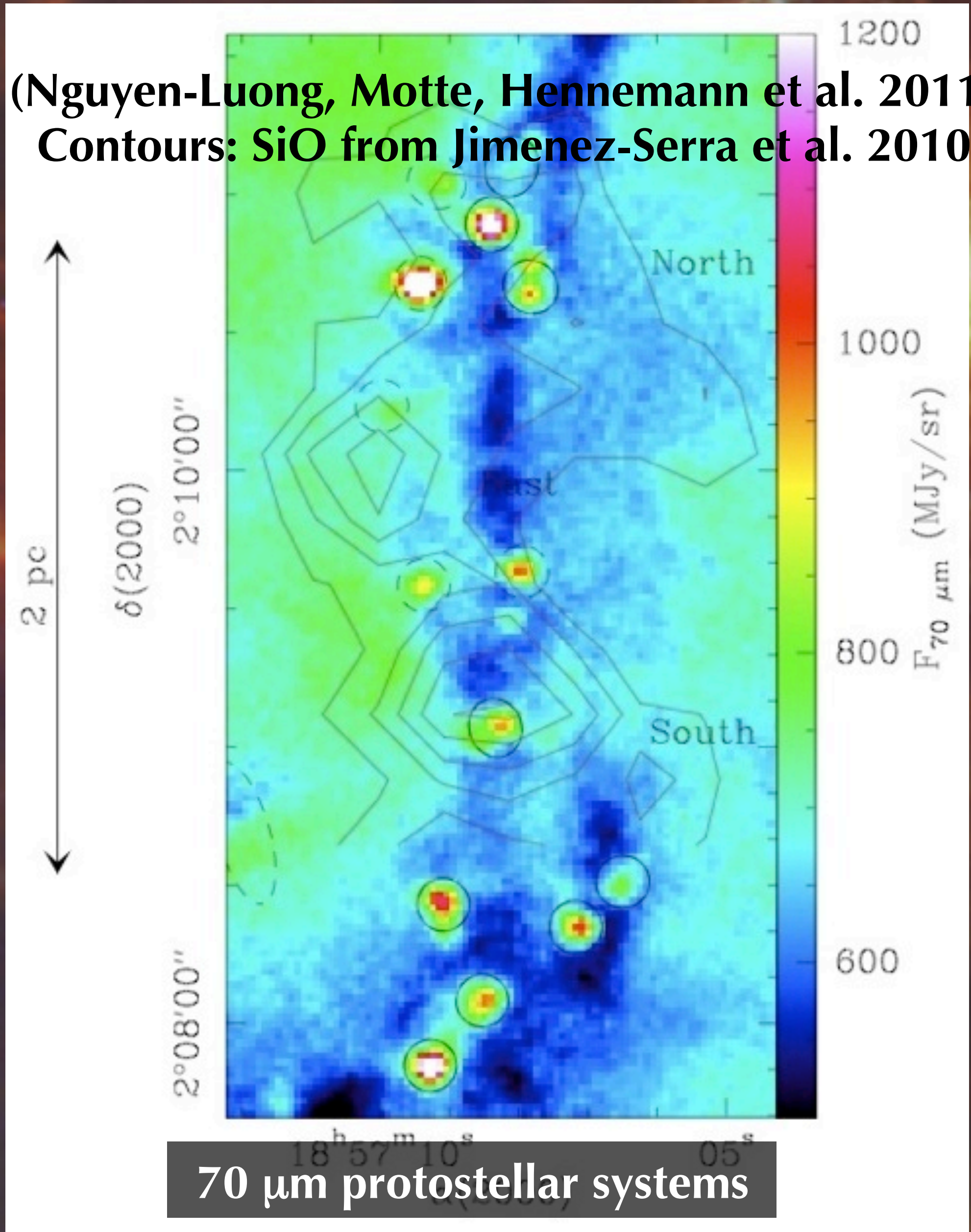


Warning: Spatial scales used for SFR/SFE estimates





Mini-starburst cluster in the G035.39-00.33 ridge



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

70 µm protostellar systems

- Herschel census:

⇒ 5 high-mass class 0 protostars or 20 protostars with 2 $M_\odot$ on the main seq.

- Assumptions:

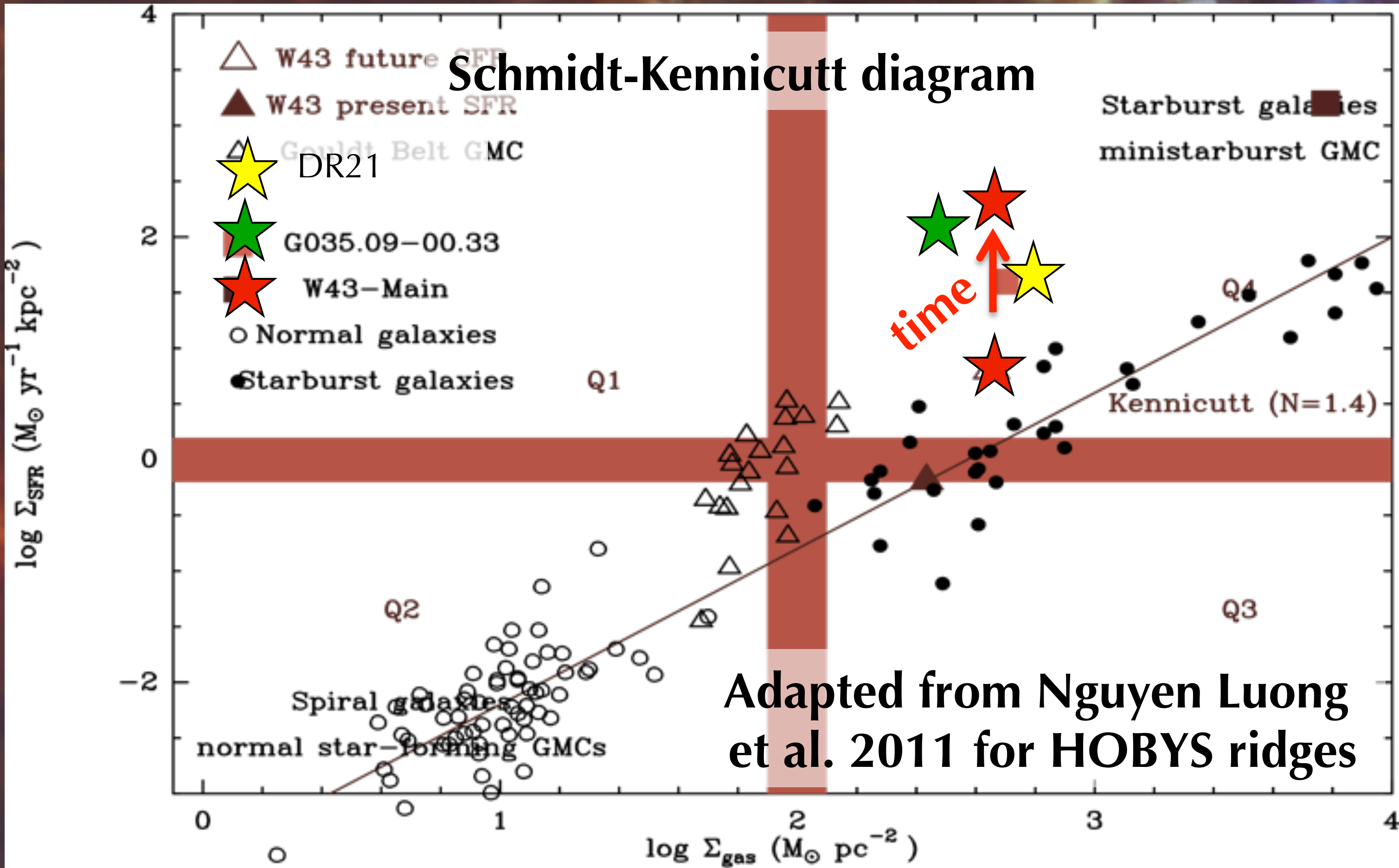
✓ **<u>Core-to-star mass efficiency</u>: ε ~ 20-40% in 0.1 pc 10^6 cm^{-3} dense cores**

✓ **<u>Protostellar lifetime</u>: 10^5 yr of IR-quiet/Class0-like massive protostars**

✓ <u>Fast episode of cloud formation</u>: 1-3 **10^6 yr**

⇒ A mini-burst of SF (SFE ~20%, SFR~300 $M_\odot$/Myr, 40 $M_\odot$/yr/kpc^2 within 8 pc^2)

Galactic mini-starburst ridges location in a SK diagram



Starburst quadrant:

$\Sigma_{SFR} > 1\ M_\odot/yr/kpc^2$

$\Sigma_{gas} > 100\ M_\odot/pc^2$

All these values must be refined with new protostar catalogs. These pioneering studies need to be generalized…

Caveats: Core-to-star formation efficiency assumed to be constant

Extrapolation of a standard IMF to mini-starburst ridges

Constraining statistical theories of SFR on W43-MM1…

An IRAM Plateau de Bure census of protostars in the W43-MM1 ridges provides an estimate of the clump to core formation efficiency (CFE, Louvet et al. in prep.).

According to models of Lada et al. 2012; Krumholz et al. 2011, 2012; Padoan & Nordlund 2012, …

$$\mathrm{SFR_{ff}} = \epsilon \int_{s_{\mathrm{crit}}}^{\infty} \overbrace{\frac{t_{\mathrm{ff}}(\rho_0)}{t_{\mathrm{ff}}(\rho)}}^{\text{freefall time}} \overbrace{\frac{\rho}{\rho_0}}^{\text{mass fraction}} p(s)\,\mathrm{d}s$$

- They predict a constant CFE = $\mathrm{SFR_{ff}} / \varepsilon$ in regions above the SF threshold (Av> 8 mag).
- It is inconsistent with first measurements!!!

Prediction of threshold models

CFE

Louvet et al. in prep.

n_{H2} (cm^{-3})

Multi-freefall models (Hennebelle et al. 2012; Federrath et al. 2012) with more realistic cloud structure should be more adequate…

Conclusion and perspectives

- Summary of HOBYS findings:

Networks of filaments among which the "ridges" are globally collapsing clumps formed through filaments merging driven by cloud or ionization compression.

Ministarburst clusters containing numerous high-mass class 0-like protostars leading to high local and present-day SFR within ridges.

Feedback effects of OB star clusters are important for cloud and star formation.

- Future prospects:

combining Herschel Galactic-scale and ALMA studies to

- Constrain the physics at the origin of the SK relation found in x-gal studies.

- Constrain the statistical SFR theories.