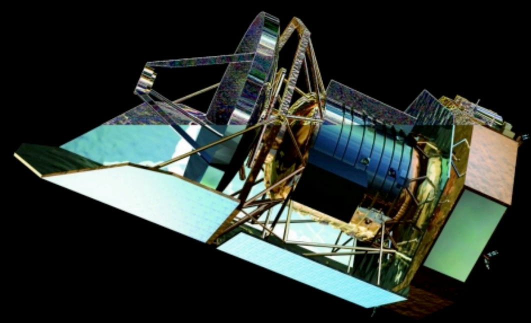
Initial highlights of HOBYS, the *Herschel* imaging survey of OB Young Stellar objects

http://hobys-herschel.cea.fr



F. Motte, A. Zavagno, S. Bontemps, N. Schneider, M. Hennemann, J. Di Francesco,
Ph. André, P. Saraceno, M. Griffin, A. Marston, D. Ward-Thompson, G. White,
V. Minier, A. Men'shchikov, T. Hill,
and A. Abergel, L. D. Anderson, Z. Balog, J.-P. Baluteau, J.-Ph. Bernard, P. Cox,
T. Csengeri, L. Deharveng, P. Didelon, A.-M. di Giorgio, P. Hargrave, M. Huang,
J. Kirk, S. Leeks, J. Z. Li, P. Martin, S. Molinari, Q. Nguyen-Luong, G. Olofsson,
N. Peretto, P. Persi, S. Pezzuto, H. Roussel, D. Russeil, S. Sadavoy, M. Sauvage,
B. Sibthorpe, L. Spinoglio, L. Testi, D. Teyssier, R. Vavrek, C. D. Wilson,
A. Woodcraft + other new comers

Talks by Zavagno+, Bontemps+, posters by Schneider+, Hennemann+, Reid+

Background: High-mass star formation

Open questions: How do high-mass (OB-type, $M_* > 8\ M_\odot$) stars form?

through a quasi-static or a dynamic scenario?

through powerful accretion of gas or coalescence of protostars?

Observational evolutionary sequence:

- **HII regions**: expanding from UltraCompact HII --> developped 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…

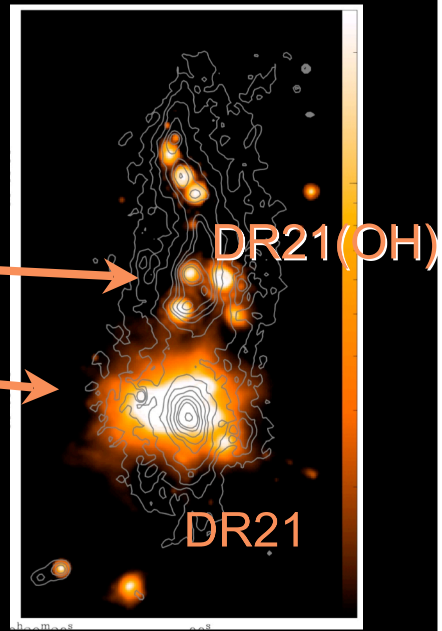
Identified within: IR-quiet protostellar dense cores (e.g. Motte et al. 2007)

IR-bright protostellar dense cores or HMPOs or Hot molecular cores (e.g. Beuther et al. 2002; Cesaroni 2005)

- **Massive prestellar cores** (?) in Infrared-dark clouds (IRDCs, Peretto & Fuller 2009)

The main objectives of HOBYS

- identify and characterize the precursors of OB stars:
    - high-mass analogs of prestellar cores: do they exist?
    - massive *IR-quiet* protostellar dense cores
    - massive *IR-bright* protostellar dense cores

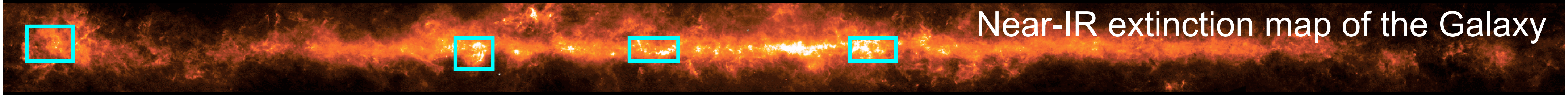


MAMBO 1.25 mm
Spitzer 24 µm

- measure their core/envelope mass and bolometric luminosity
    - directly by constraining the submm component of their SEDs
    - to build an evolutionary diagram of high-mass protostar
    - to estimate the lifetime of each evolutionary stages

- assess the efficiency of feedback to trigger (high-mass) star formation
    - by comparing well-behaved HII regions
    - to more common high-mass star-forming regions

The HOBYS sample and observation strategy



- HOBYS will image essentially all of the molecular complexes forming OB-type stars at less than 3 kpc from the Sun (cf. extinction maps by S. Bontemps)

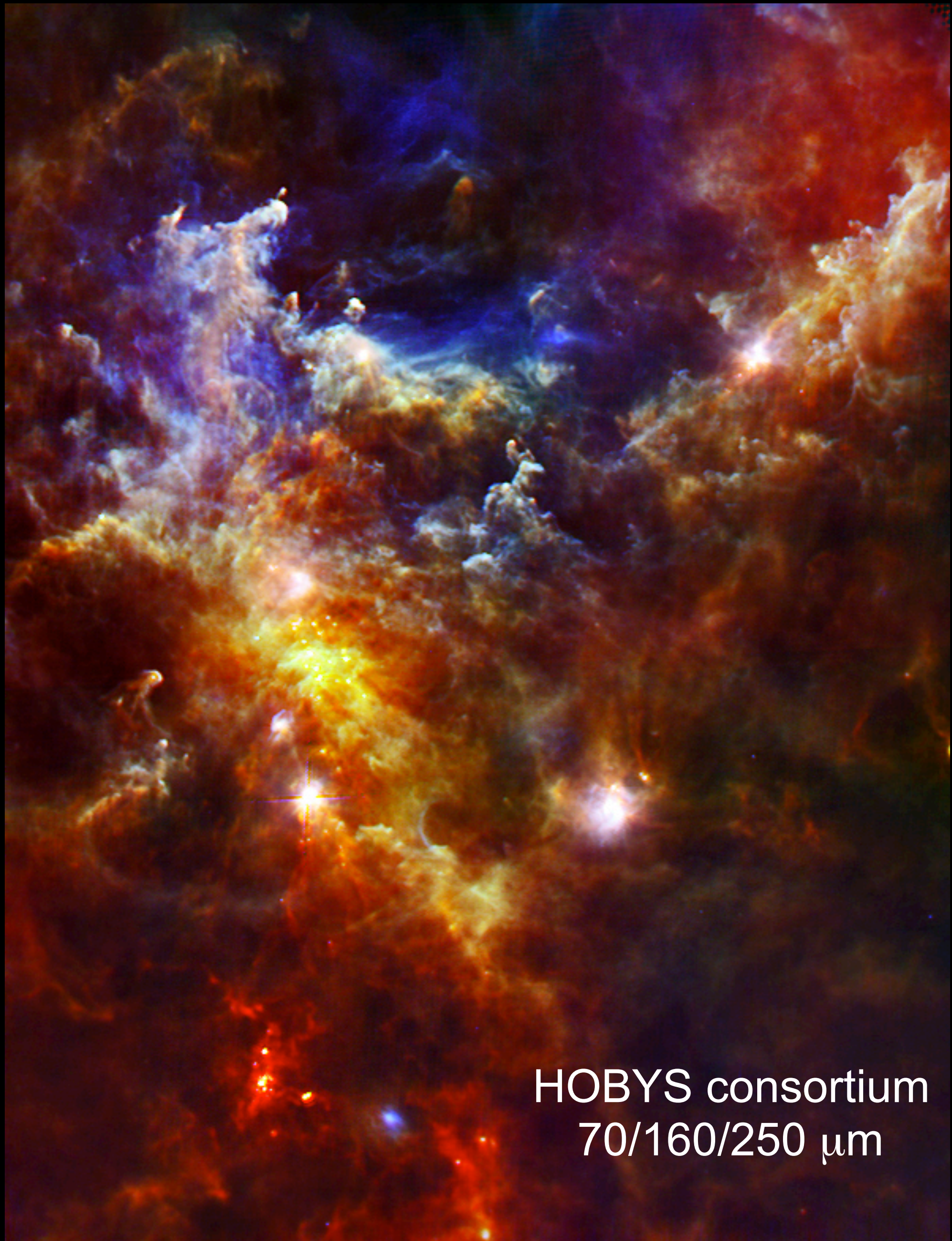
We expect them to contain ~250 high-mass protostars. HOBYS thus has enough statistics to study the precursors of stars up to 20 $M_\odot$.

- Wide-field SPIRE/PACS imagings (70, 160, 250, 350, 500 μm) in parallel-mode with 20''/sec scanning speed

HPBW = 6''-36.9'' @ 0.7-3 kpc => down to 0.05-0.3 pc cloud structures

- HOBYS makes the link between
* the progenitors of individual low-mass stars (~0.02 pc protostellar envelopes forming ~1 $M_\odot$ stars) of the Gould Belt survey and
* the precursors of OB stellar clusters (1 pc clumps able to form stars with up to 100 $M_\odot$) of the Hi-GAL survey.

The Rosette molecular complex with *Herschel*



- 1^ox1^o scan-map (5.3 hrs)

Rosette GMC 1.6 kpc, 2 x 10^5 $M_\odot$

Under the influence of 7 O stars

- Data reduction

HIPE scripts with baseline removal and MadMAP for PACS data

- Spatial dynamic range:

0.05 - 40 pc, up to 1 000 (PACS)

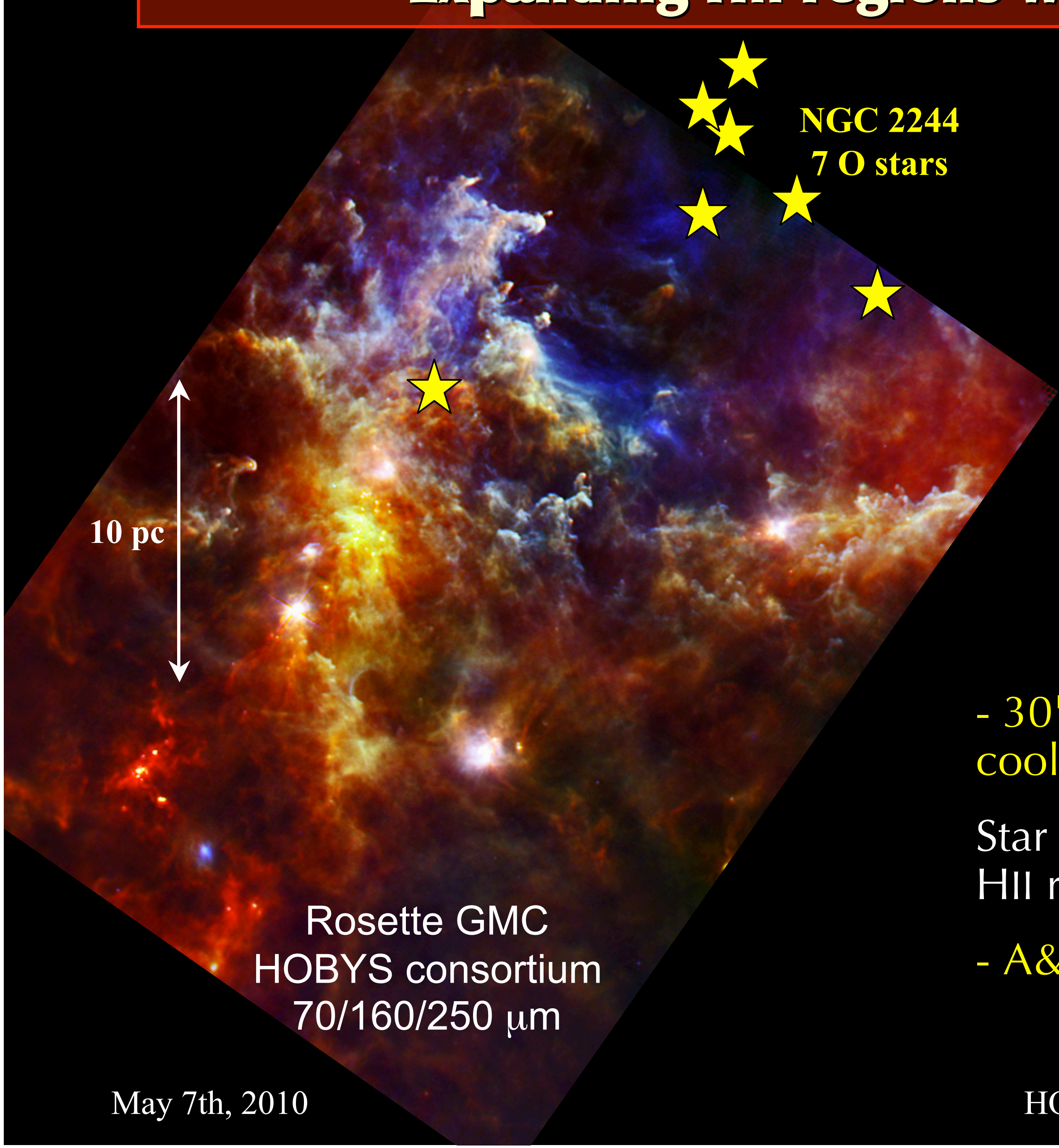
- Flux dynamic range

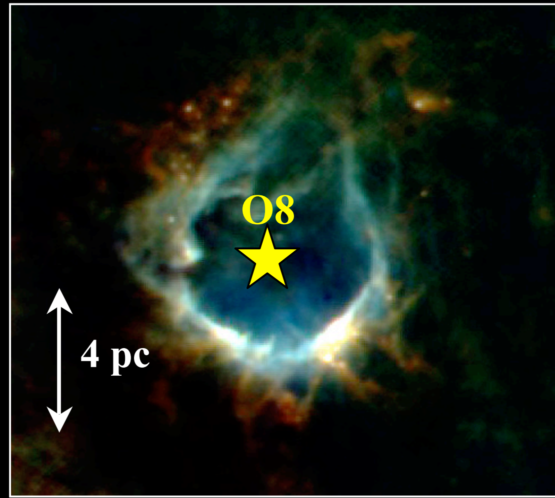
σ = several x instrumental sensitivity

Sensitive to 0.3 $M_\odot$ @ 160 μm

- A&A Sp. Issue: **Motte+, Schneider+, Di Francesco+, Hennemann+**

Expanding HII regions with *Herschel*





RCW120 @ 1.3 kpc
Herschel 3-color 110/160/250 μm

- 30''x30'' scan-maps (1.6 h) + PDR & cooling lines with SPIRE-FTS and PACS

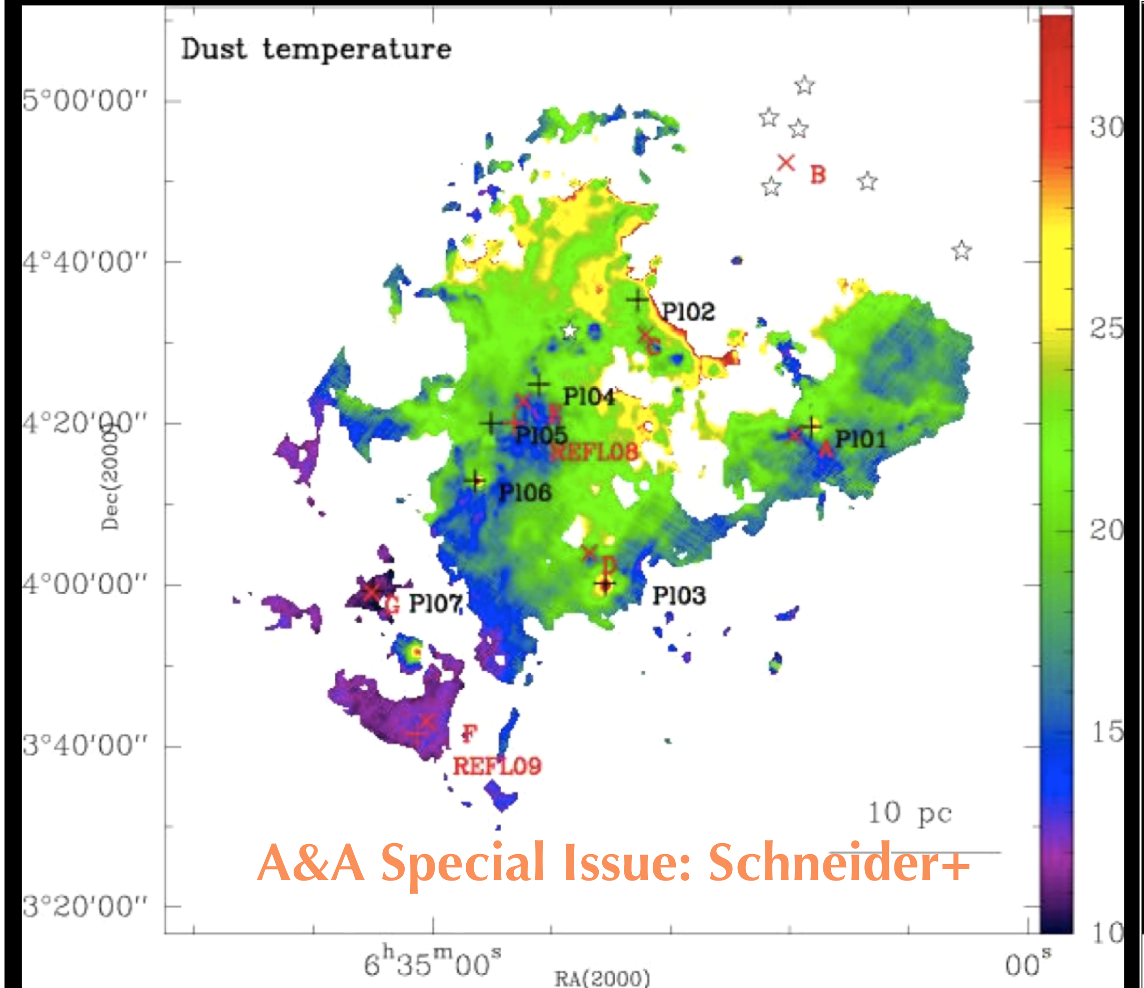
Star formation triggered by expanding HII regions

- A&A Sp. Issue: **Zavagno+, Anderson+**

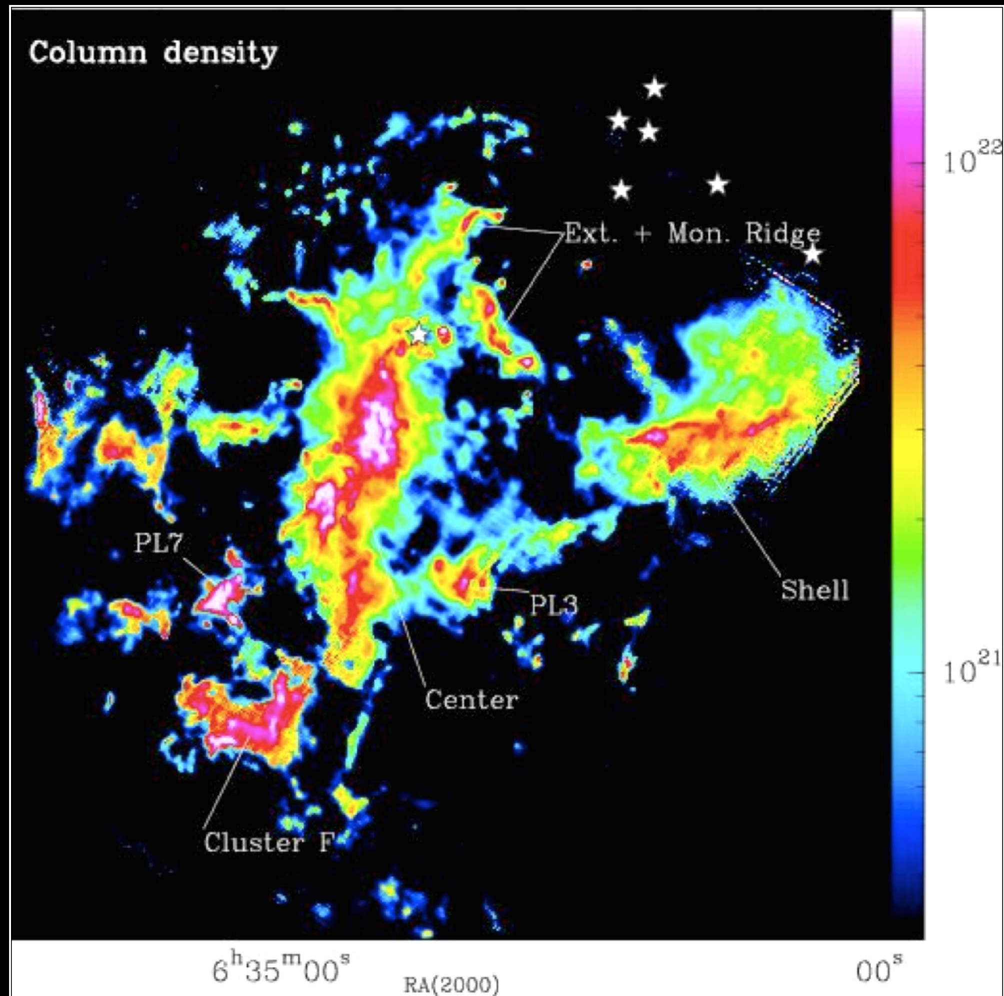
Rosette GMC under the influence of NGC 2244

Graybody fits: Temperature (30 K to 10 K) and Column density gradients (5 x 10^{21} to 2 x 10^{22} cm^{-2}) running from the HII region/cloud interface into the cloud.

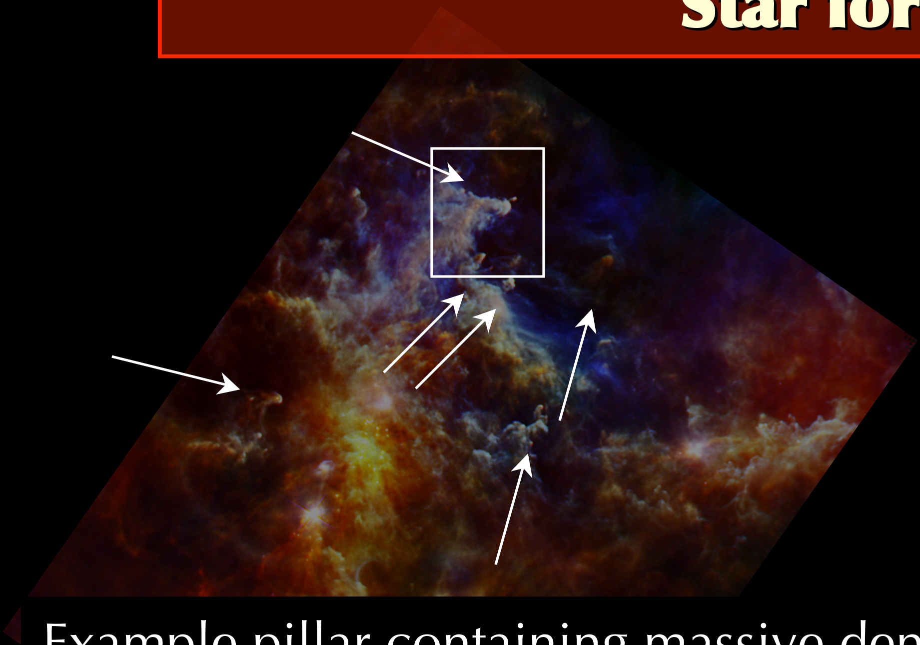
In agreement with Schneider et al. (1998), Dent et al. (2009)



A&A Special Issue: Schneider+



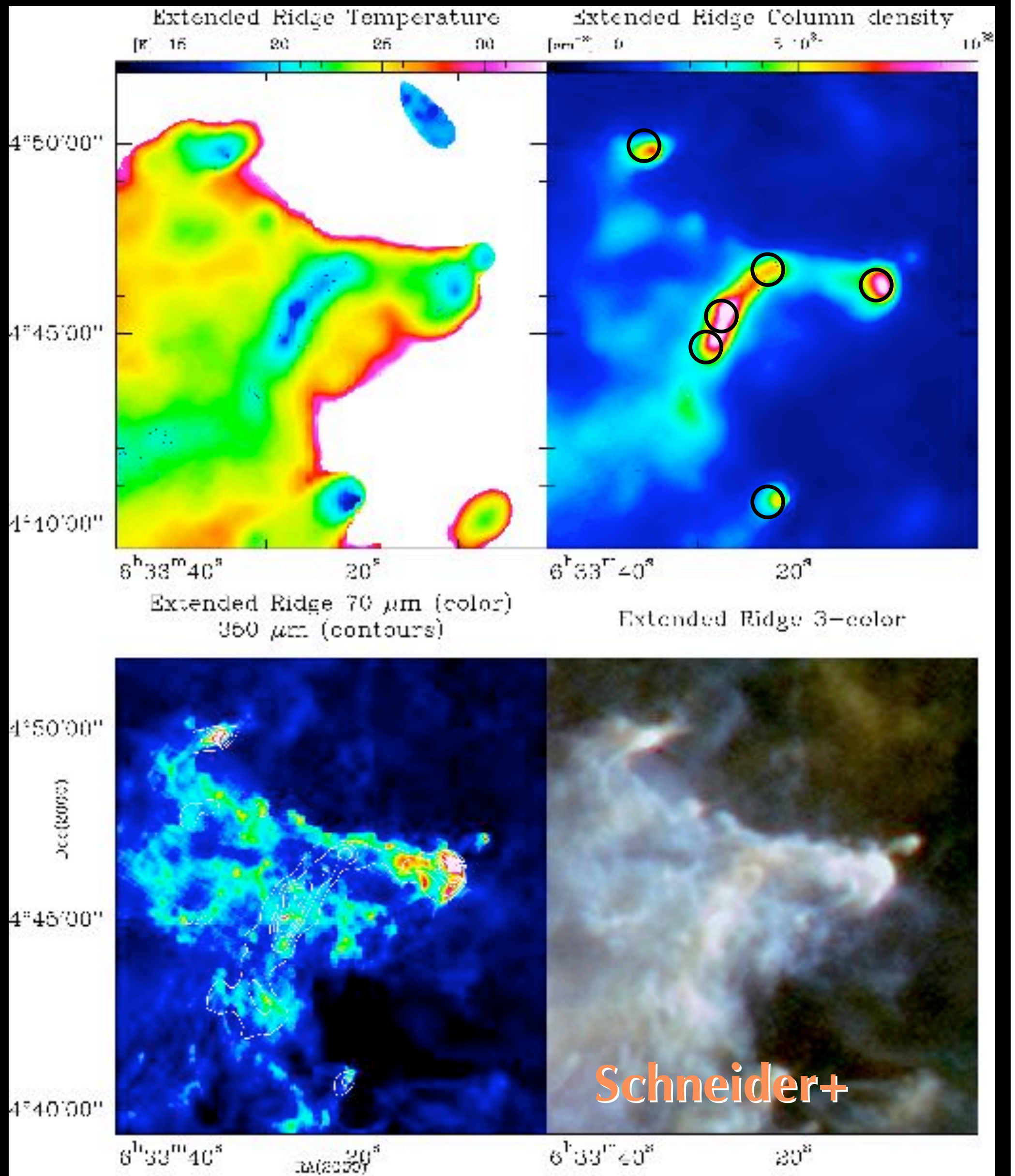
Star formation in pillars



Example pillar containing massive dense cores with ~0.17 pc, ~16 $M_{\odot}$, ~16 K, 20-170 $L_{\odot}$

Dense cores seem to survive in the high-density tips of pillars that are shaped by the strong UV field of O stars.

The cloud was most probably pre-existing but star formation could be induced by the increase of pressure…



Compact cloud structures in Rosette

« With SPIRE, we detect 0.3 pc protoclusters, with PACS 0.05 pc protostars. »

- Large clumps identified in SPIRE bands and smoothed PACS images

  Using *getsource* (Men'shchikov et al. 2010)

  => catalog of ~500 cluster-forming clumps

- Dense cores identified with emphasis put on detection at 160 µm (i.e. where the envelope of protostars is observed with the best spatial resolution)

  Using *mre-gcl* (Motte et al. 2007) => 5 catalogs crosslinked

  => a merged catalog of ~800 pre- and protostellar dense cores

- Binary protostars identified at 70 µm within 160 µm dense cores

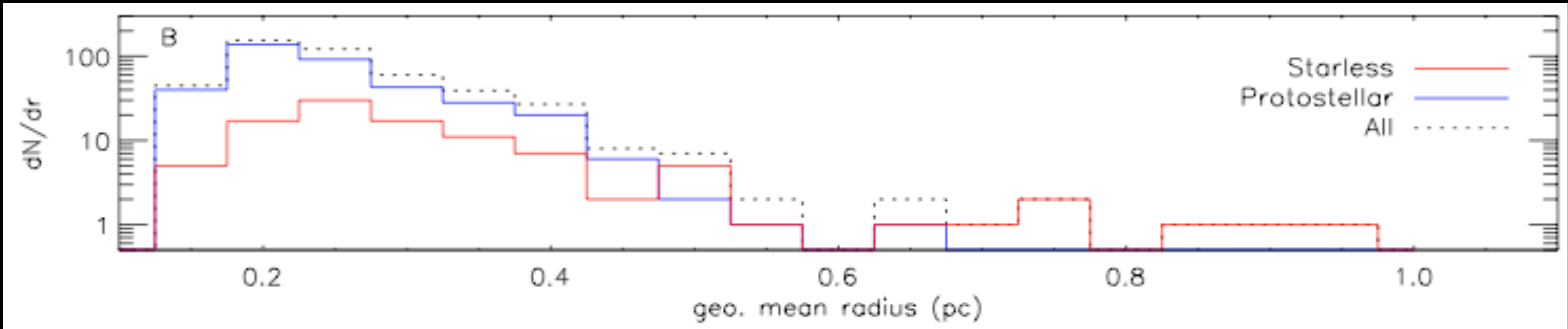
  Using aperture photometry

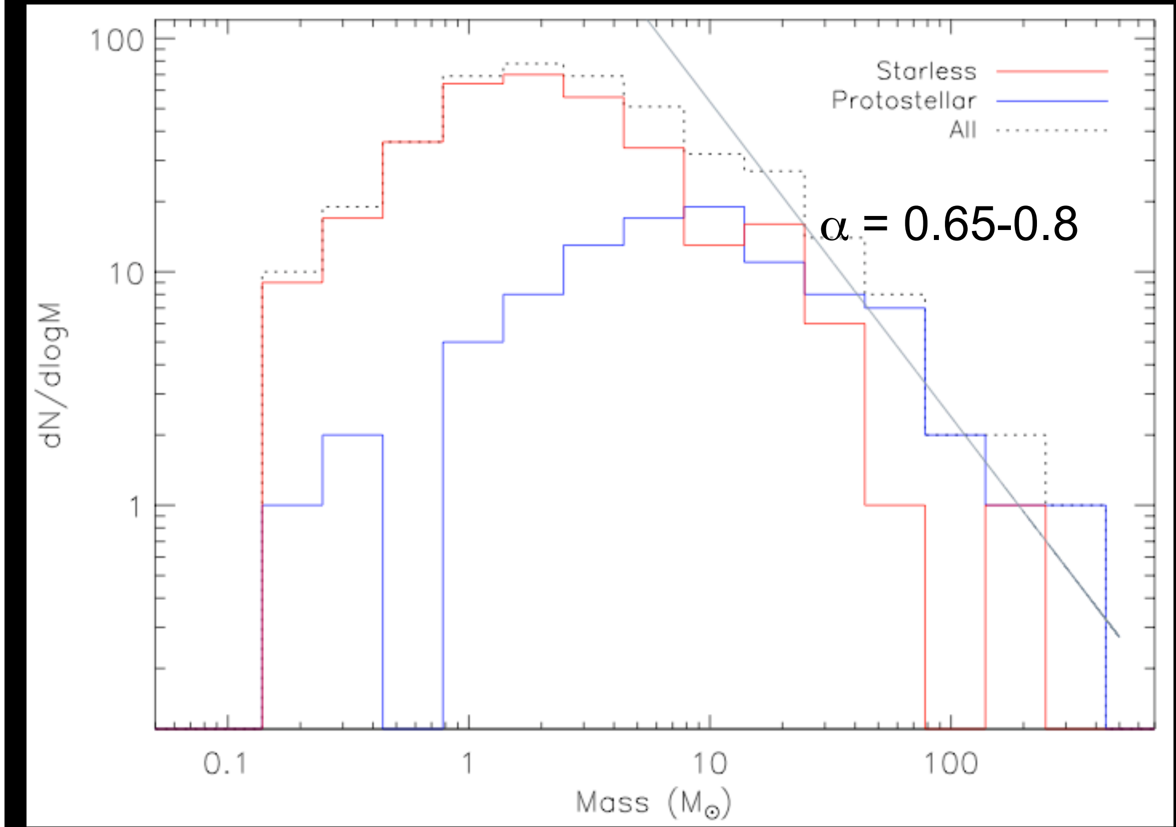
  => 70 µm flux of selected protostars

A&A Special Issue: Di Francesco+, Motte+, Hennemann+

Cluster-forming clumps

What are the Rosette cluster-forming clumps?





In average, they are ~0.3 pc cloud structures with ~0.2 - 400 $M_\odot$

Compared to *Spitzer* images

⇒ starless or protostellar nature

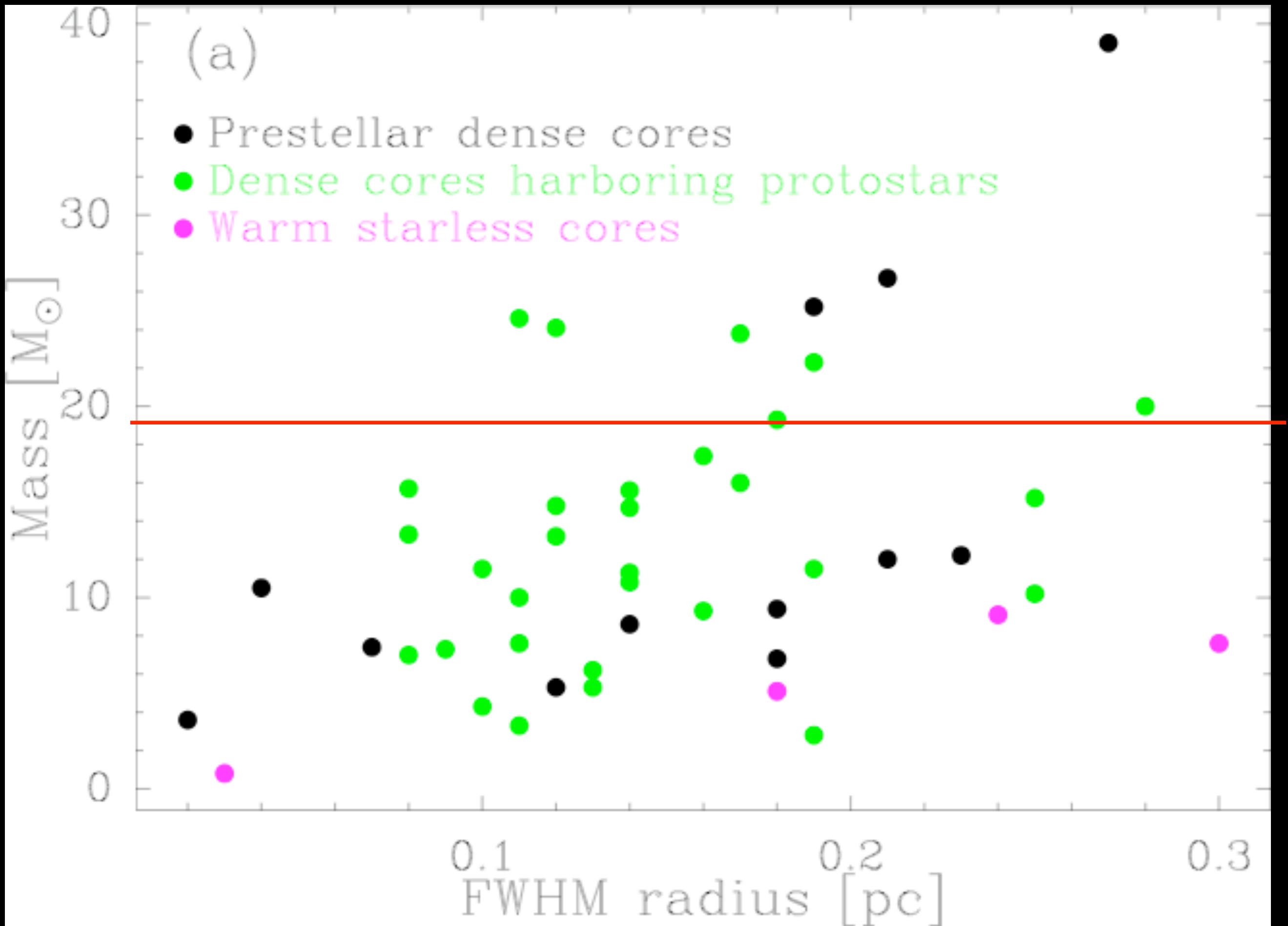
Their mass spectrum ressembles that of CO clumps (Dent et al. 2008)

A&A Special Issue: Di Francesco+
See Posters P1.24 Di Francesco+ and P2.16 Reid+

Dense cores

What are the Rosette dense cores?

They are 0.02-0.3 pc cloud structures with masses up to ~40 $M_\odot$, averaged density up to a few $x10^5$ cm^{-3}, mass-averaged temperature of 12-40 K.



The 46 most massive cores

were compared to 24 μm *Spitzer* images (Balog et al.)

⇒ starless or protostellar

Nine good candidates to form high-mass stars

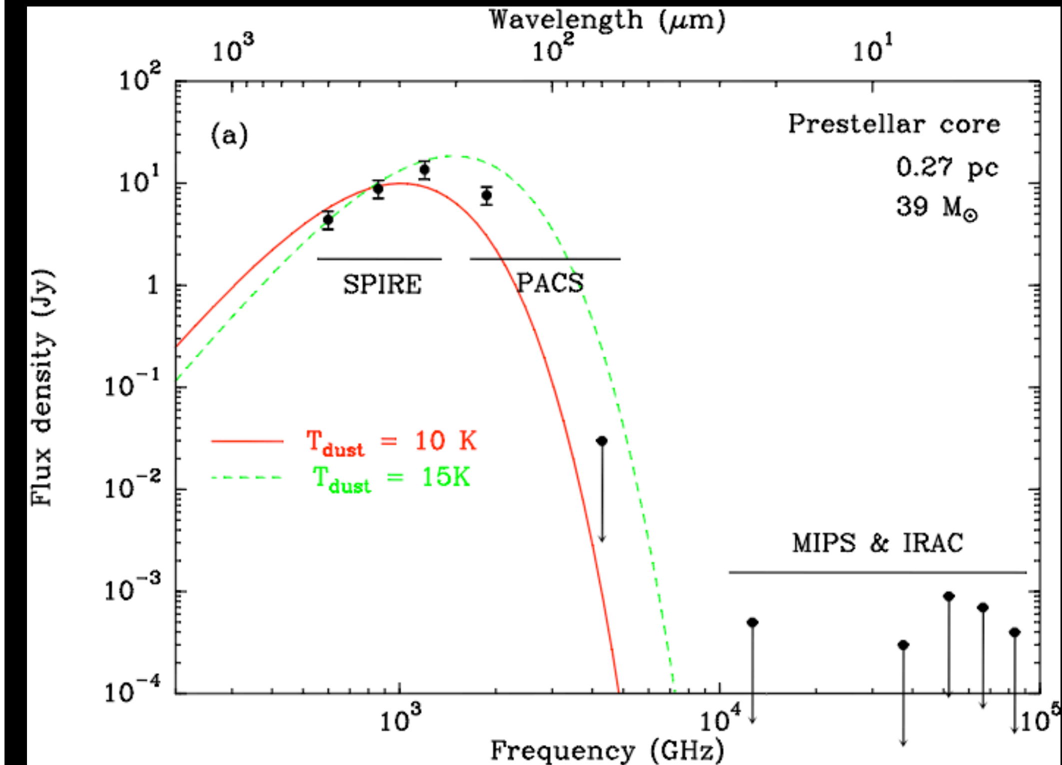
2 IR-bright protostellar cores
+ 4 IR-quiet protostellar cores
+ 3 prestellar cores

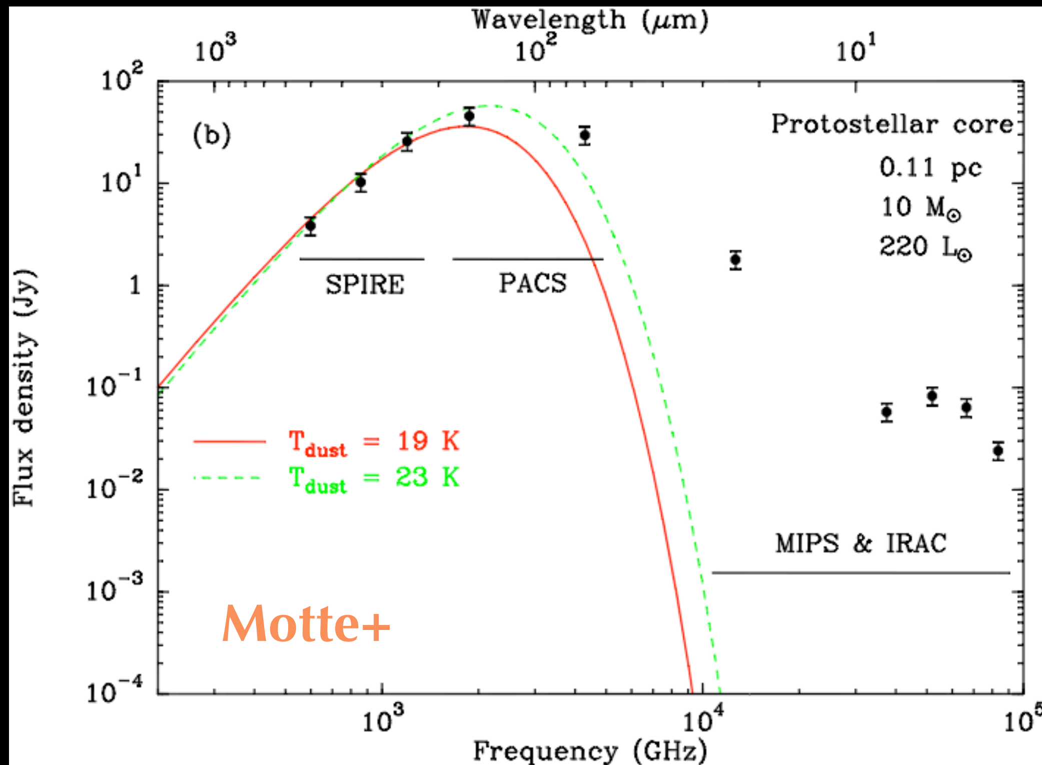
A&A Special Issue: Motte+

Analysis of complete SEDs for massive dense cores

In clustered environment (like most of the HOBYS fields), the analysis at the best spatial resolution is critical => dense cores are defined at 160 μm.

SED built with 5 *Herschel* fluxes and 5 *Spitzer* fluxes (only 4+0 for cold prestellar cores) => T_{dust} =12-40 K, M_{env}= 1-40 $M_\odot$, L_{bol} = 10-4000 $L_\odot$



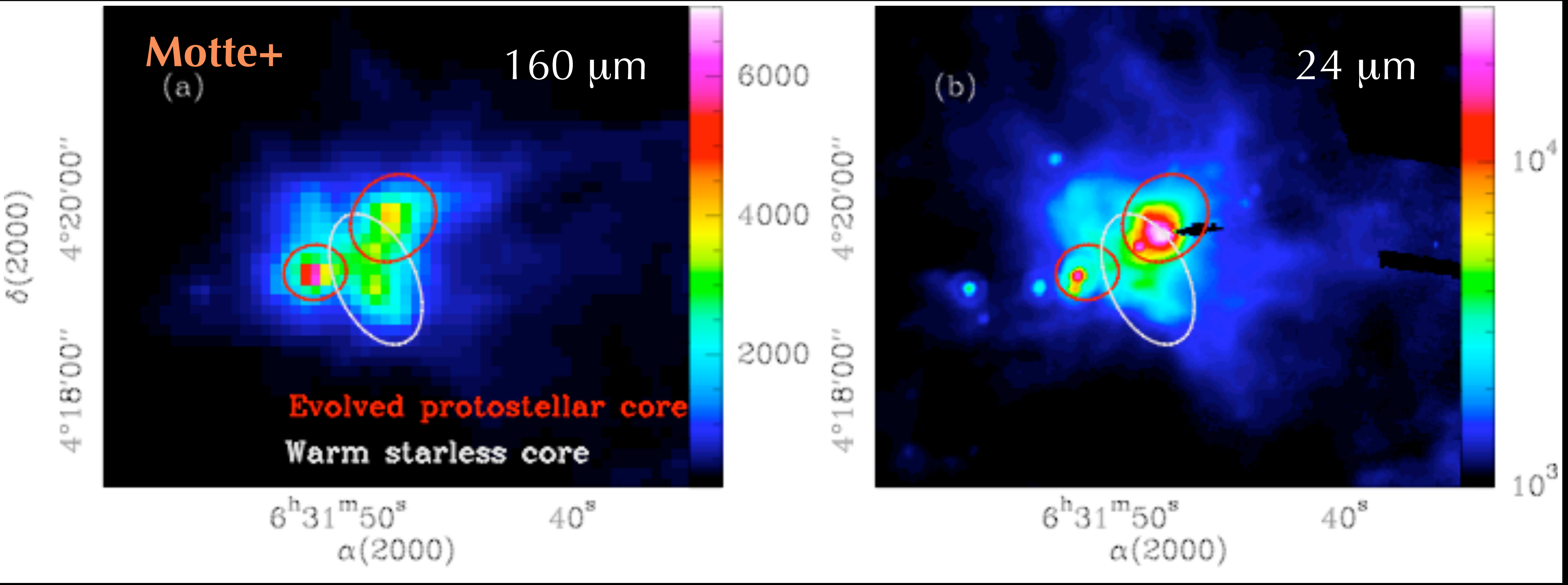


Where are the massive prestellar dense cores?

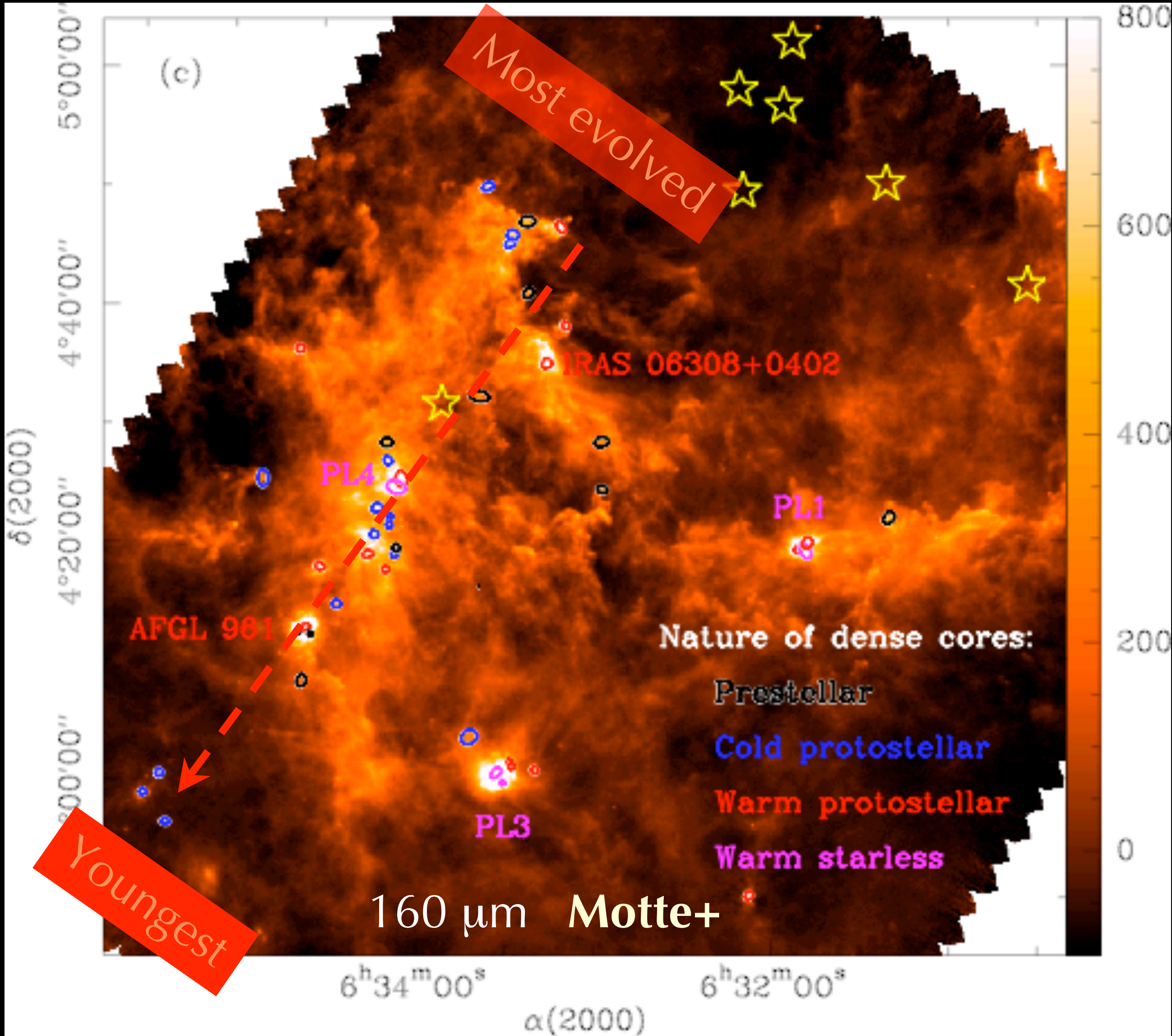
Not a single massive prestellar core has been identifed in the Cygnus X and NGC 6334 molecular complexes (Motte et al. 2007; Russeil et al. 2010).

In Rosette, we find 3 massive prestellar dense cores: ~0.22 pc, ~30 $M_\odot$. They are cold (~13 K) and dense (~10^5 cm^{-3}) and may thus form high- to intermediate-mass stars. Statistical lifetime ~ 8 x 10^4 yr, > in Cygnus X, < in nearby clouds.

We also discovered a handful of warm starless cores: ~0.14 pc, 1-9 $M_\odot$, **27 K**



Is star formation triggered in Rosette?



We used T_{dust} values and M_{env} vs L_{bol} diagram to give an approximate evolutionary status for the most massive dense cores (young or evolved).

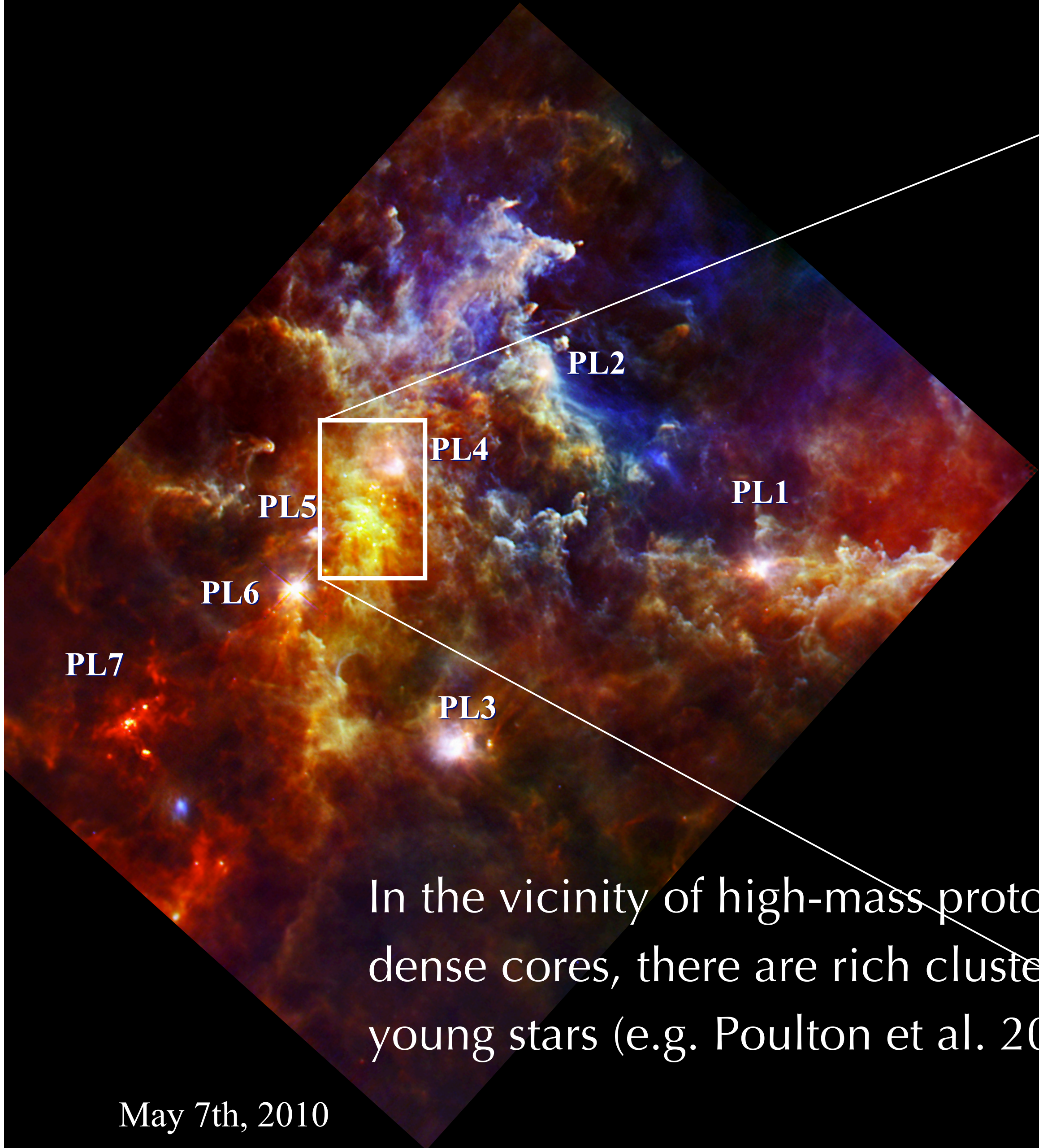
A temptative age gradient is seen for the progenitors of the most massive stars.

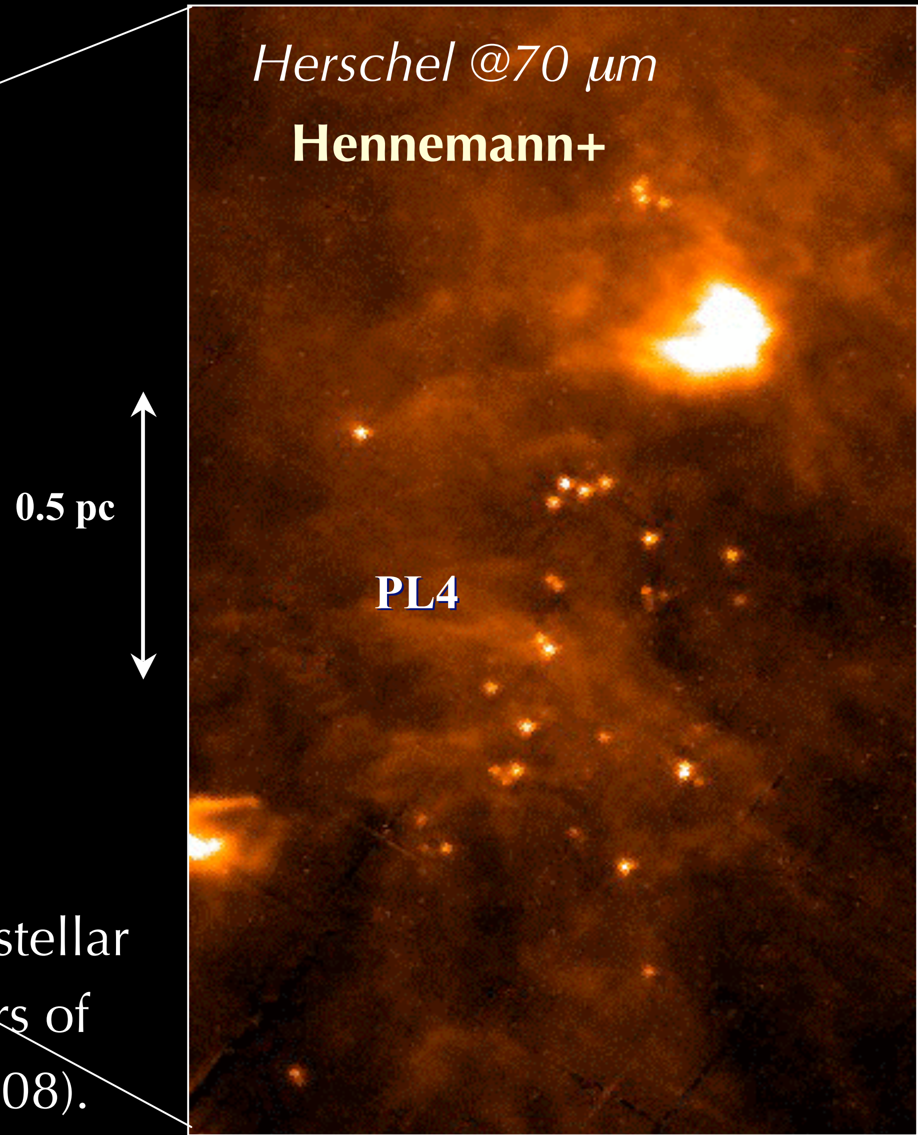
⇒ Triggered star formation?

Schneider+

Single protostars

Rich clusters of protostars in the Rosette





In the vicinity of high-mass protostellar dense cores, there are rich clusters of young stars (e.g. Poulton et al. 2008).

FIR-submm classification of protostellars

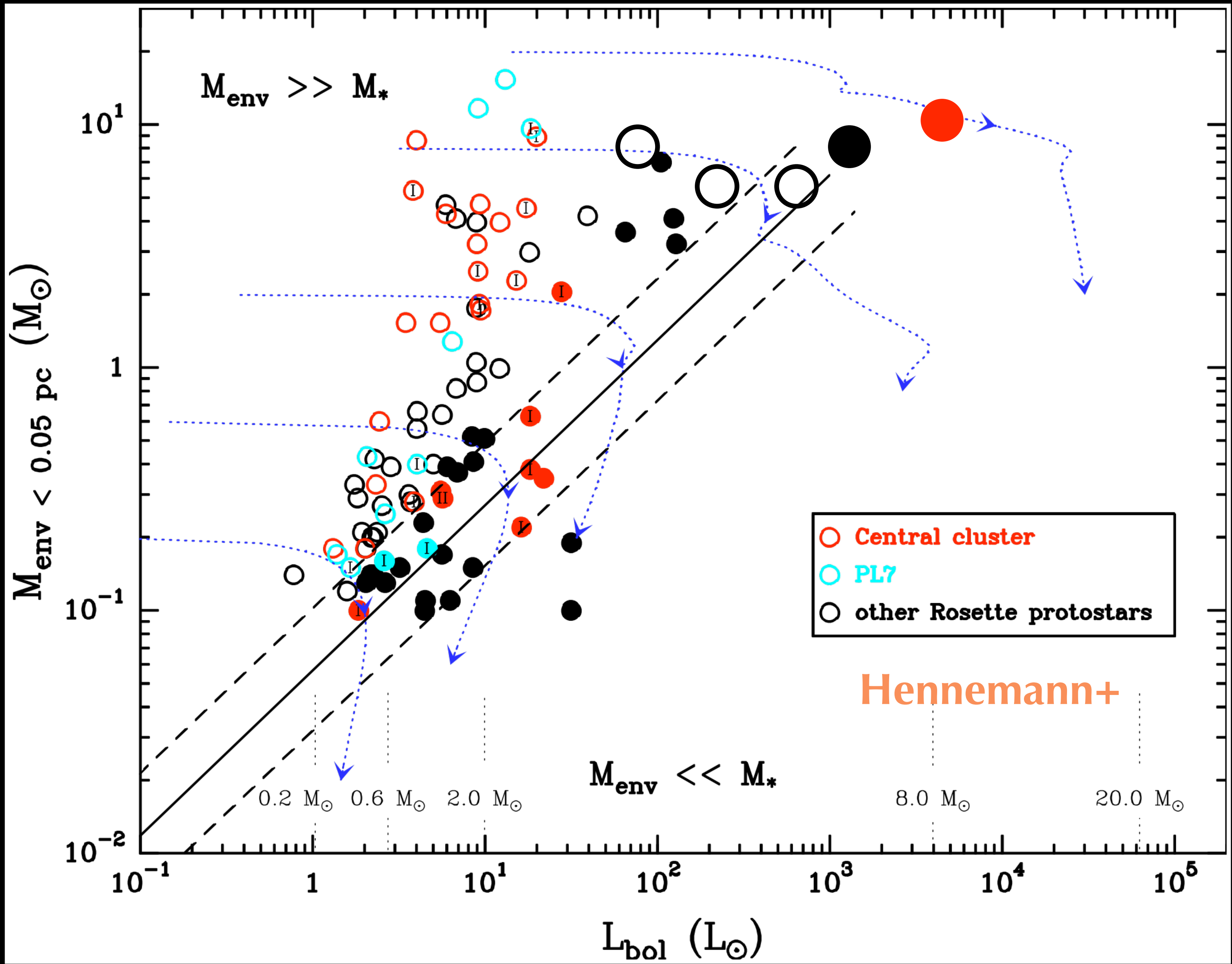
With *Herchel*, these clusters of intermediate- to low-mass protostars can be better characterized => M_{env} = 0.1-15 $M_{\odot}$, L_{bol} = 1- 150 $L_{\odot}$, L_{submm}/L_{bol} (proxy of M_{env}/M_{*}, e.g. André et al. 2000)

Extending the evolutionary status of protostars: From the NIR + *Spitzer* classification of protostars to the *Herschel* classification of Class 0 (young) versus Class I (evolved)

A&A Special Issue: Hennemann+, See Poster P1.25

NIR+ *Spitzer* classification	# total	# Class II	# Class I	# unclassified
Spitzer 24 μm YSOs	83	39	26	18
Spitzer 24 μm YSOs visible @ 70 μm	40 (±3)	10 (±1)	19 (±1)	11 (±1)
Herchel candidate Class 0s	14	0	7	7

M_{env} vs L_{bol} evolutionary diagram of protostars



For a selected number of protostar clusters, unusually large number of Class 0s compared to Class Is.

⇒ Statistical lifetimes different for intermediate-mass star-forming clouds? for a star-forming cloud under the influence of HII?

First conclusions from HOBYS

The *Herschel* data of Rosette have revealed:

- a clear temperature gradient and a tentative age gradient, running from the HII region/cloud interface into the cloud **(Schneider et al. 2010)**
- the mass spectrum of the Rosette clumps ressembles the CO mass spectra and differs from the stellar IMF **(Di Francesco et al. 2010)**
- rich protoclusters forming low- to high-mass protostars, among which a large number of class 0 protostars **(Hennemann et al. 2010)**
- 3 massive prestellar dense cores + a few starless warm cores that could represent the long-lasting searched precursors of high-mass protostars **(Motte et al. 2010)**

The *Herschel* data of RCW120 have discovered the first high-mass class 0 formed by the means of the collect-and-collapse process **(Zavagno et al. 2010)**

Near future of HOBYS and acknowledgement

As of today, *Herschel* has imaged:

- 3 molecular complexes of HOBYS: Rosette, NGC 7538, and M 16
- 4 HII regions of HOBYS: RCW120, Sh104, RCW79, and RCW82

This corresponds to only 9% of the time awarded for the full HOBYS project.

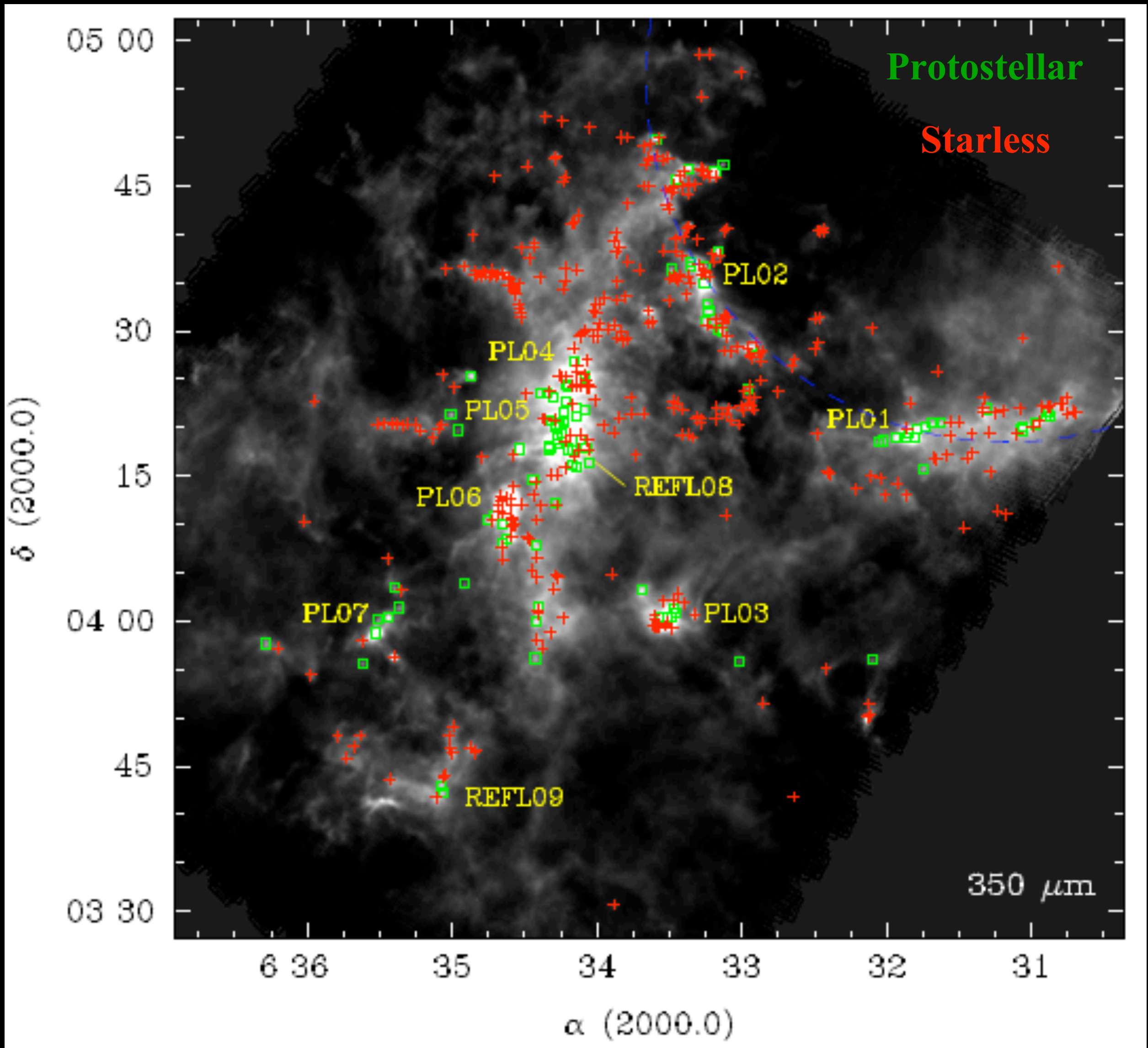
⇒ More exciting science to come!

The HOBYS team is very grateful to the *Herschel* project science team, the SPIRE Science group « Star formation » (SAG3) and the PACS and SPIRE ICC groups.

I'd like here to thank and congratulate the HOBYS members for their excellent work!

This work was partly supported by CNRS, CEA, and the ANR Probes.

Where are the Rosette cluster-forming clumps?



2 structures drawing most of the attention:

- the periphery of the HII region expanding from NGC 2244

- the densest part of the molecular cloud

PL and REFL are embedded star clusters

Di Francesco+