HOBYS: *Herschel* imaging surveys of OB Young Stellar objects

Guaranteed time key project: http://hobys-herschel.cea.fr

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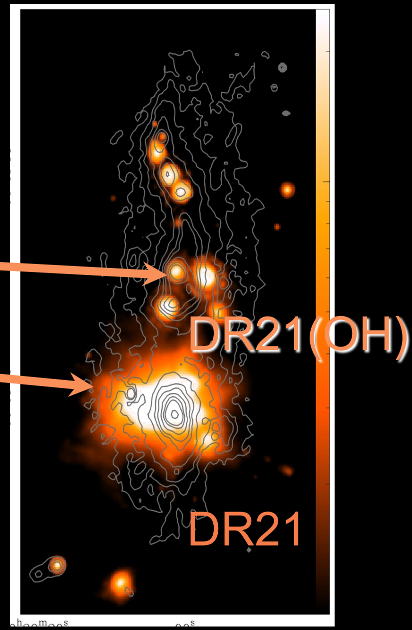
The main objectives of HOBYS

- 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

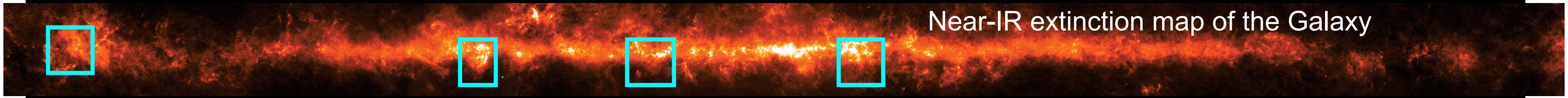
- measure their core/envelope mass and bolometric luminosity
  - to build an evolutionary diagram of high-mass protostars
  - to estimate the lifetime of each evolutionary stage

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



MAMBO 1.2 mm
Spitzer 24 μm

The HOBYS sample and observation strategy



HOBYS images all major GMCs forming OB-type stars with distance < 3 kpc

Rosette, Cygnus, Vela, NGC7538, M16/17, NGC6334, W3, W48…

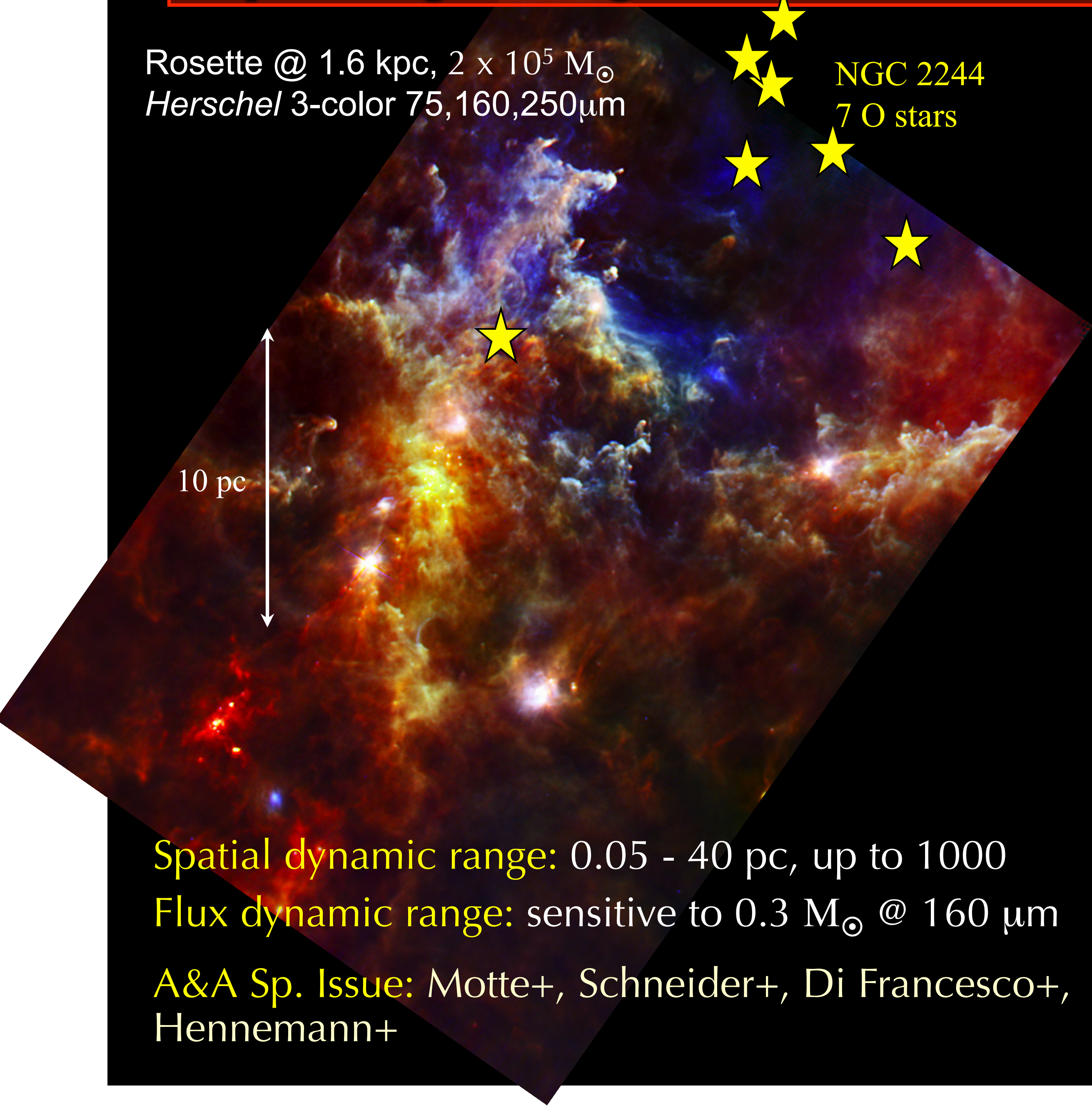
Wide-field SPIRE/PACS imaging (70, 160, 250, 350, 500 μm) in parallel-mode with 20''/sec scanning speed

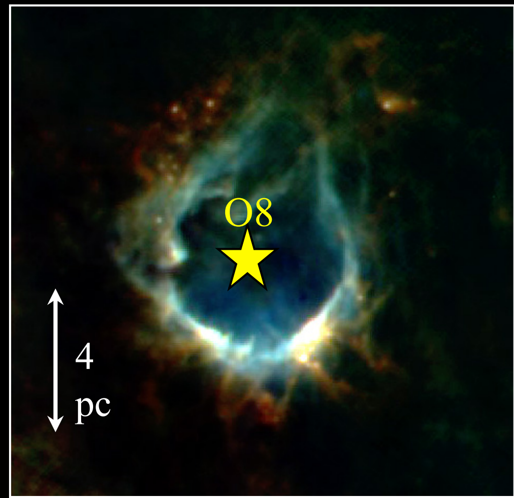
HPBW = 6''-36.9'' @ 0.7-3 kpc => down to 0.05-0.3 pc cloud structures

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.

Science Demonstration Phase
expanding HII regions with *Herschel* : Rosette and RCW120

Rosette @ 1.6 kpc, $2 \times 10^5\ M_\odot$
Herschel 3-color 75,160,250μm





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

Star formation triggered by expanding HII regions

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

Spatial dynamic range: 0.05 - 40 pc, up to 1000

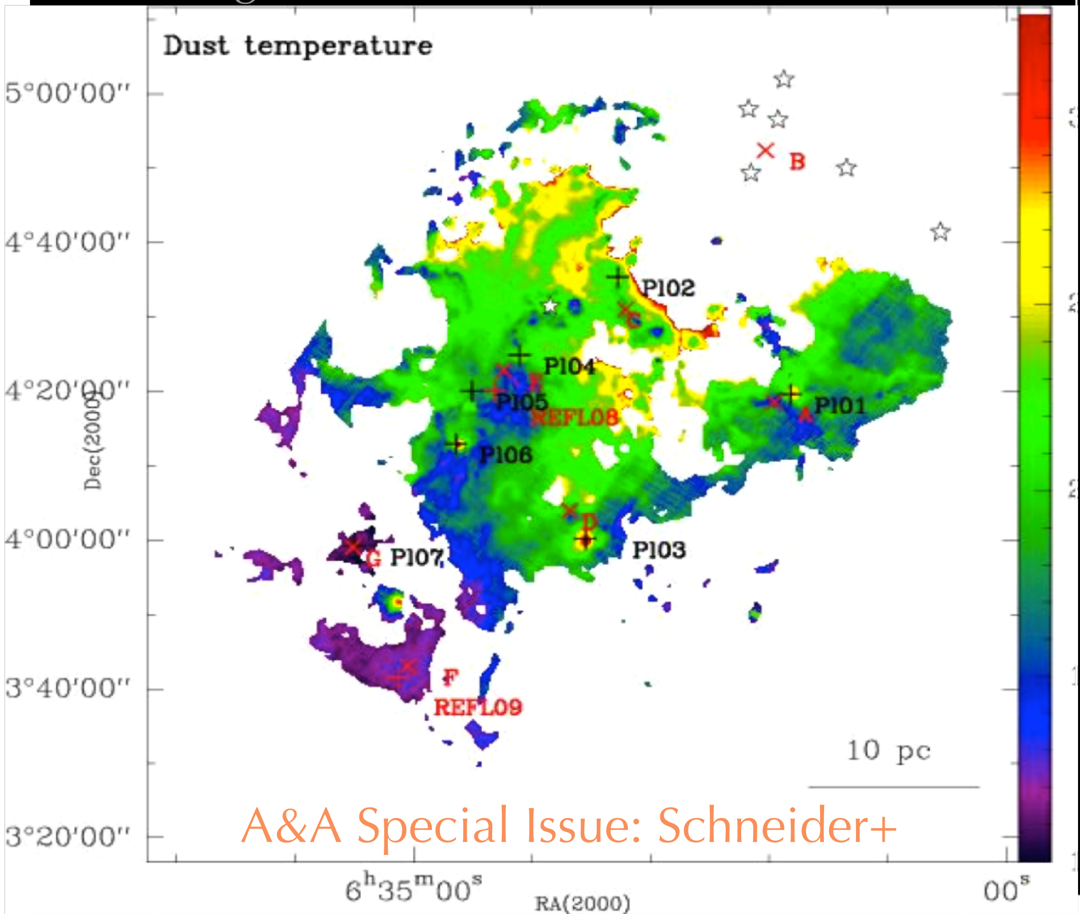
Flux dynamic range: sensitive to 0.3 $M_\odot$ @ 160 μm

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

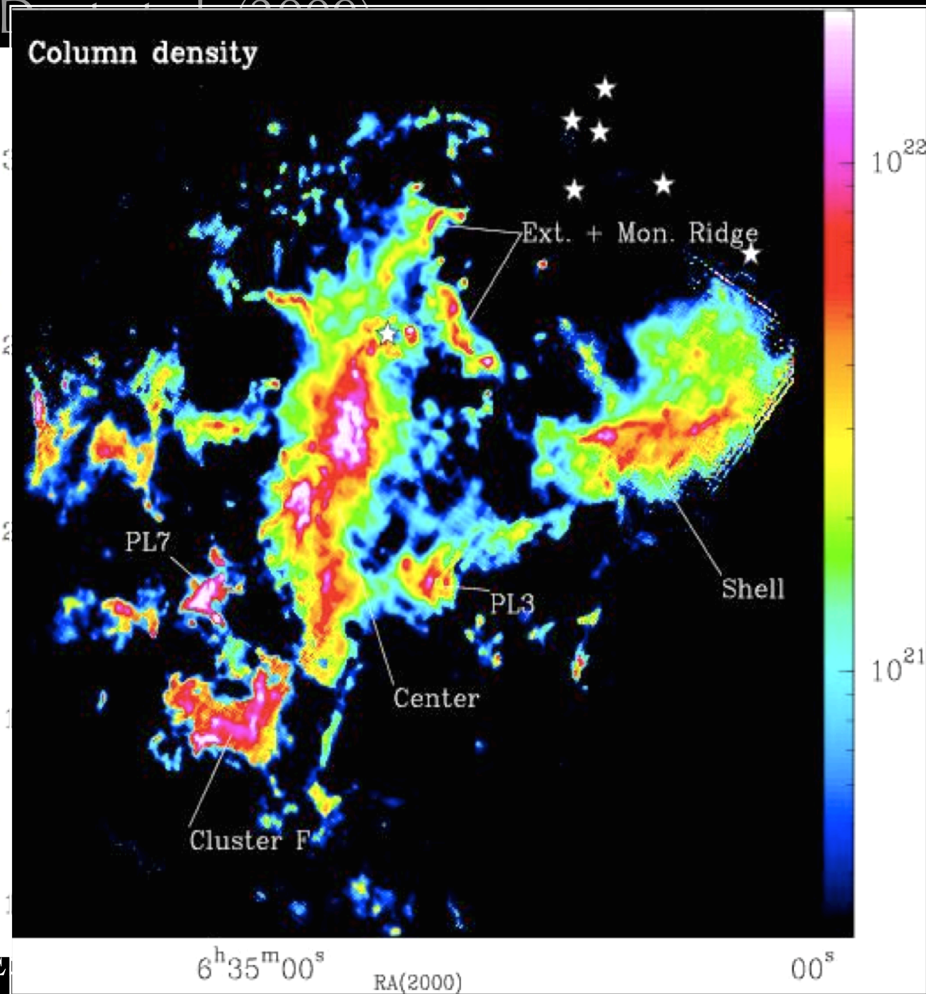
Rosette GMC under the influence of NGC 2244

Greybody 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.

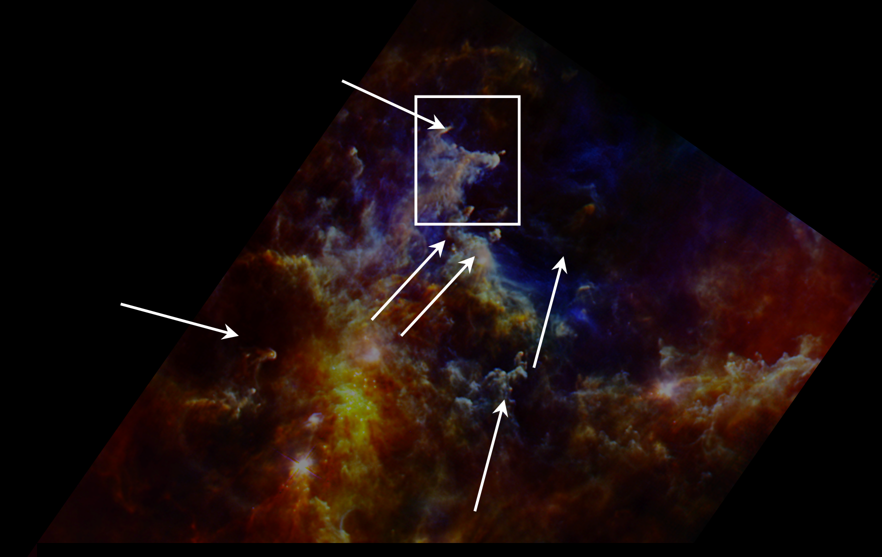
In agreement with Schneider et al. (1998), D…



A&A Special Issue: Schneider+



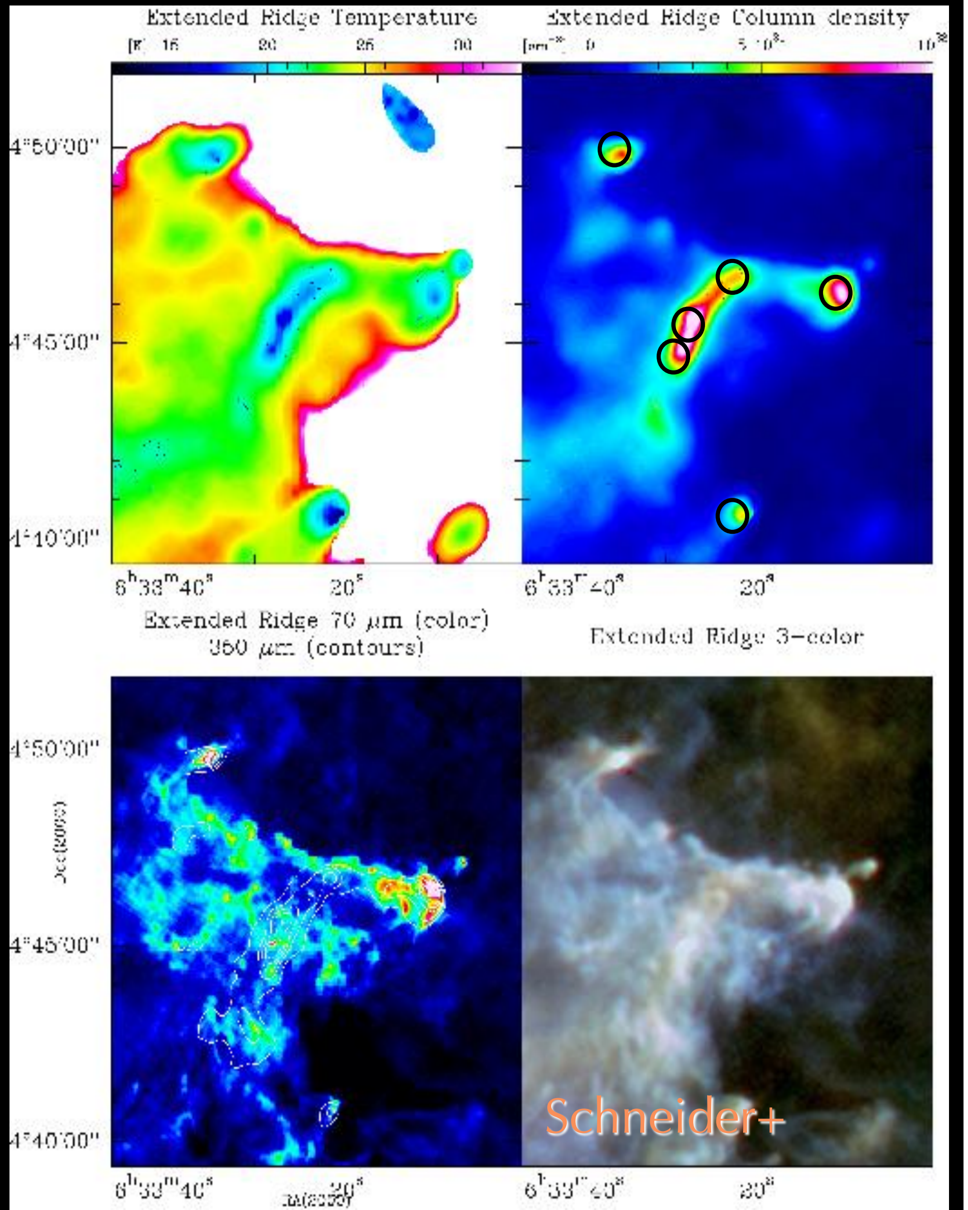
Star formation in pillars



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 sources in Rosette

Source extraction :

Testing different algorithms (Gaussclumps, Clumpfind, Csar, Fellwalker, reinhold, getsources….)

Used for HOBYS and Gould Belt:

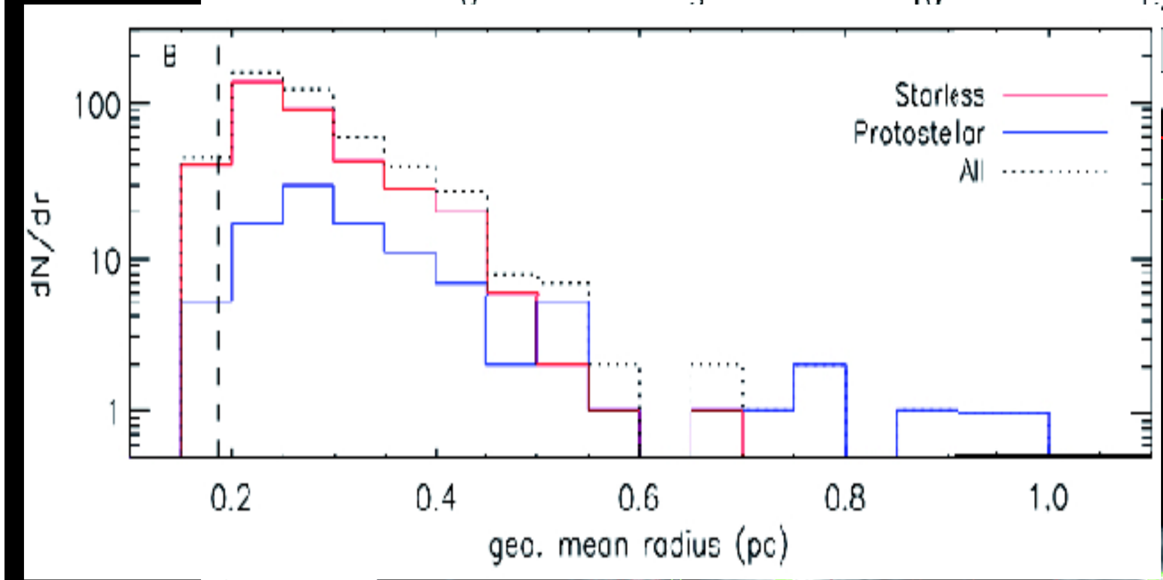
mre-gcl (Motte et al. 2007) and *getsources* (Men'shchikov et al. 2010)

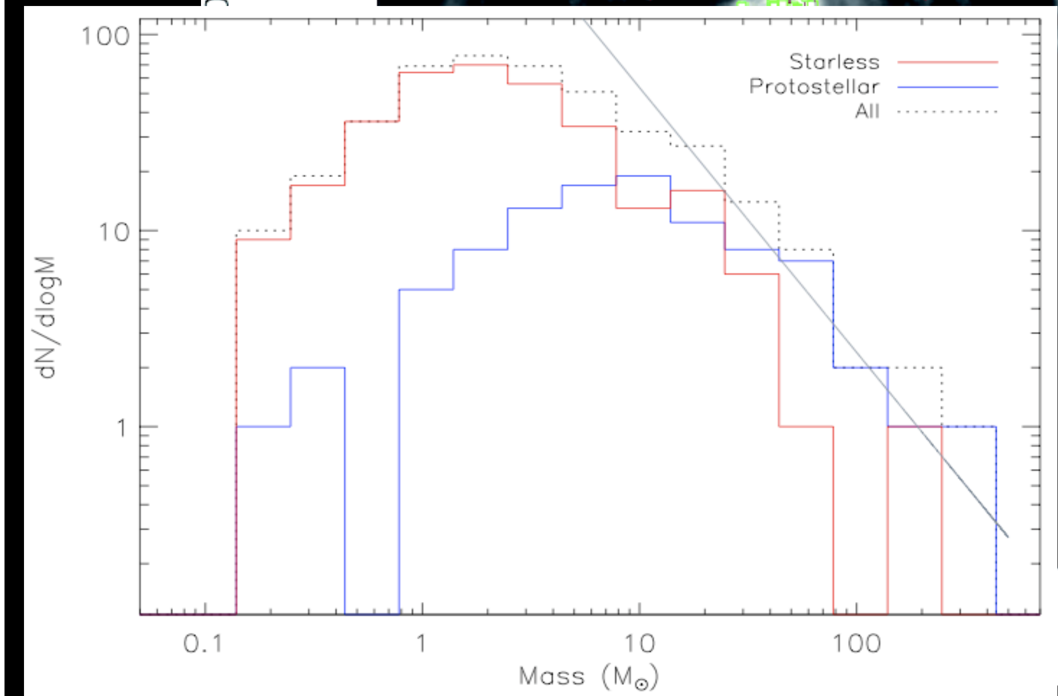
Rosette:

⇒ catalog of ~500 cluster-forming clumps (<1pc)

⇒ catalog of ~800 pre- and protostellar dense cores (0.02 – 0.3 pc)

What are the Rosette cluster-forming clumps?





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

⇒ slope α = -0.6 (all)

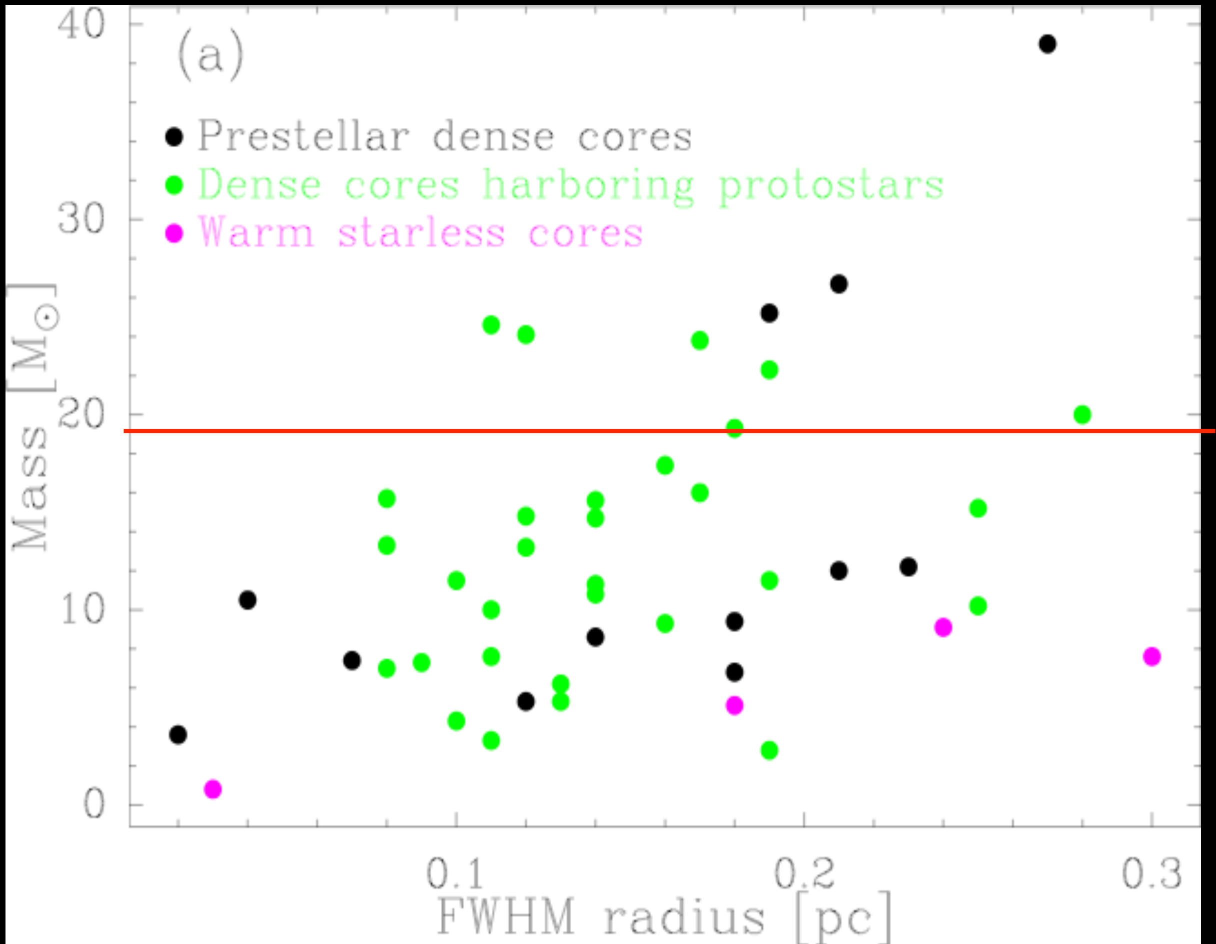
Their mass spectrum resembles that of CO clumps (Schneider et al. 1998, Dent et al. 2009).

But: no Salpeter IMF (-1.35).

A&A Special Issue: Di Francesco+

What are the dense cores in Rosette ?

They are 0.02-0.3 pc cloud structures with masses up to ~40 $M_\odot$, average 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

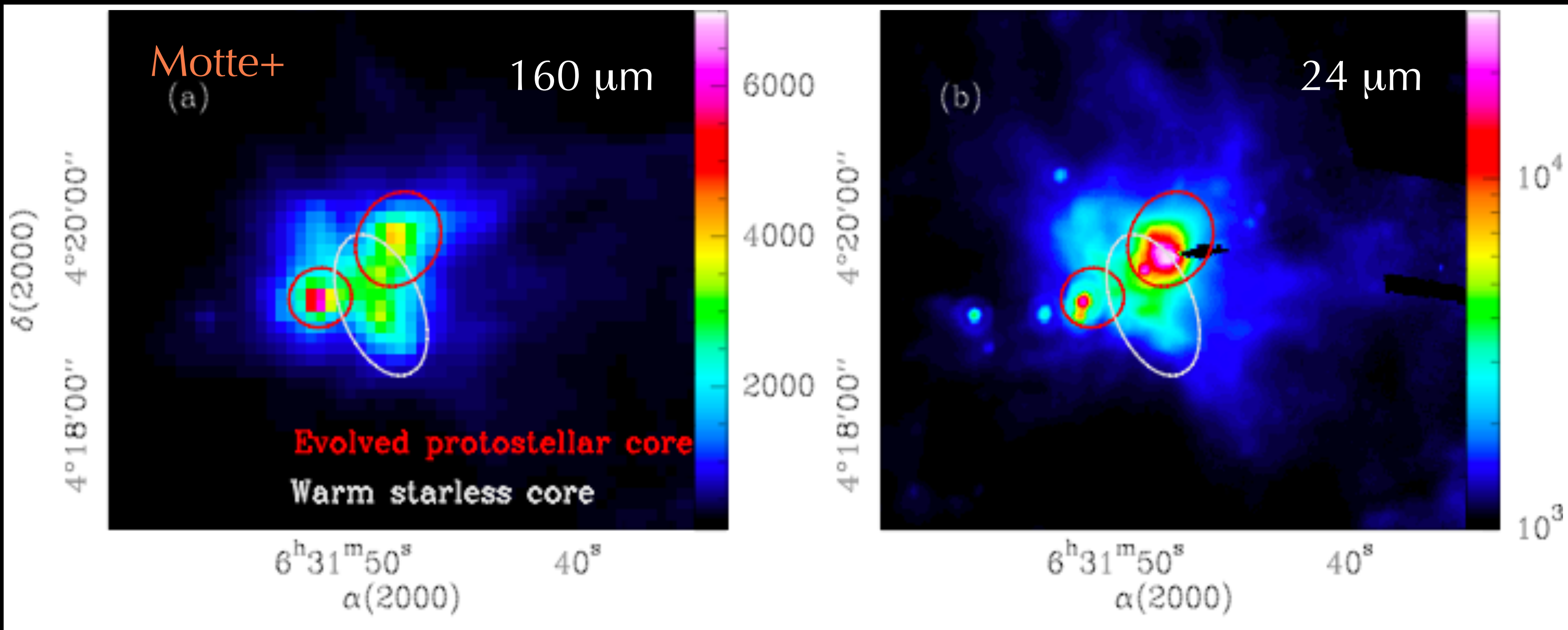
A&A Special Issue: Motte+

Where are the massive prestellar dense cores?

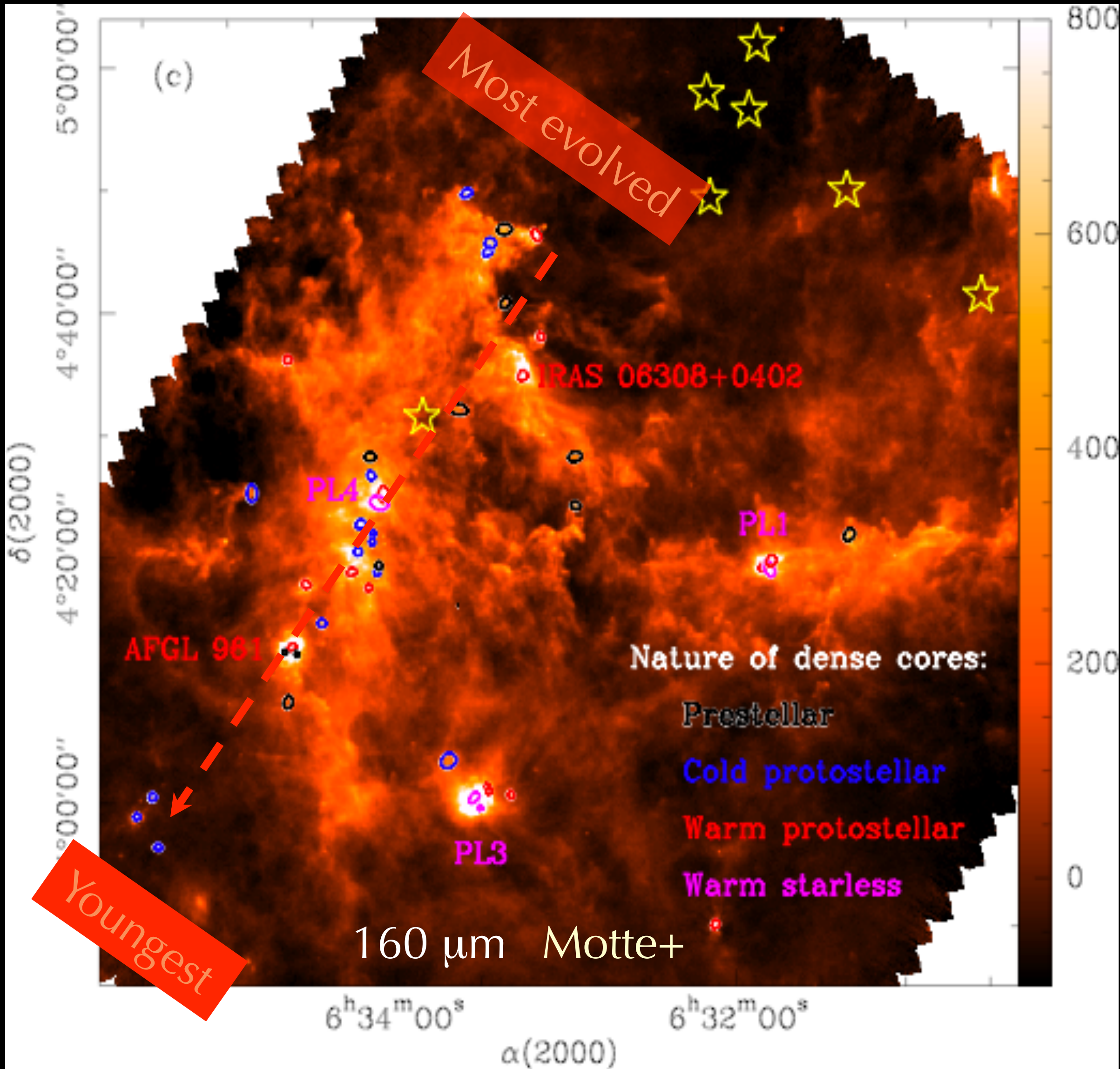
Not a single massive prestellar core has been identifed in ground-based studies of Cygnus X and NGC 6334 (Motte et al. 2007; Russeil et al. 2010).

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} diagrams to give an approximate evolutionary status for the most massive dense cores (young or evolved).

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

⇒ Triggered star formation?

Schneider+

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 resembles the CO mass spectra and differs from the stellar IMF (Di Francesco et al. 2010)

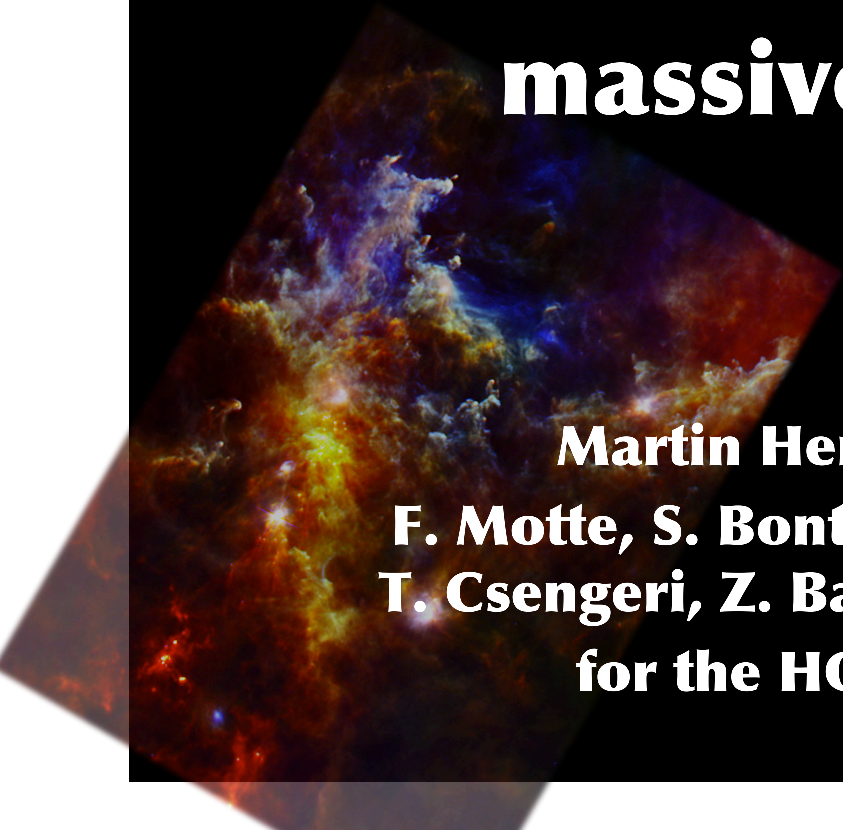
• rich protoclusters forming low- to high-mass protostars including a large number of class 0 protostars (Hennemann et al. 2010)

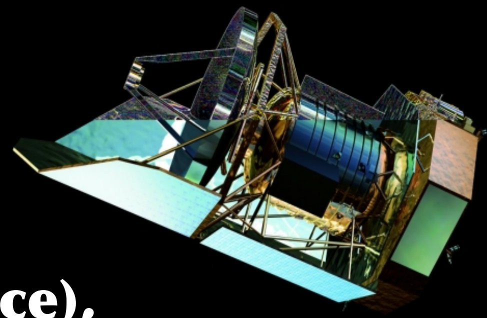
• 3 massive prestellar dense cores + a few starless warm cores that could represent the long sought precursors of high-mass protostars (Motte et al. 2010)

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

HERSCHEL AND THE FORMATION OF STARS AND PLANETARY SYSTEMS
Göteborg (Särö), Sweden, September 6, 2010

Protostellar Clusters revealed by the HOBYS *Herschel* survey of massive cloud complexes





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for the HOBYS/SPIRE SAG3 consortium

SPIRE

Outline of the talk

Early evolution of protostars

- Simple evolutionary tracks
- Constraints from *Herschel* observations

The protostars towards the Rosette Molecular Cloud

- Protostellar sample selection and resolution issues
- Resulting statistics and diagram
- Comparison to Gould Belt Aquila result

First look on M16, NGC7538, and Cygnus-X (South)

- Wealth of intermediate-mass protostars expected

Background: Early stages of star formation

Early protostellar evolution:

- SEDs of Class 0 dominated by dust thermal emission from the protostellar envelope ($M_{env} > M_*$)
- Class I possess comparatively less massive, hotter envelope ($M_{env} < M_*$)

Characteristic: Envelope mass & bolometric luminosity (➔Stellar mass)

Simple evolutionary tracks (Bontemps et al.):

- Each protostar forms from a bounded condensation of finite initial mass $M_{env}(0)$
- $L_{bol} = G\, M_*(t)\, dM_{acc}(t)/dt \,/\, R_*(t) + L_*(t)$
- Protostellar radius R_* and interior stellar luminosity L_* according to Stahler 1988, Hosokawa & Omukai 2008
- Mass accretion rate $dM_{acc}(t)/dt = \varepsilon\, M_{env}(t) / \tau$
- ε is the typical star formation efficiency for individual cores
- $\tau = 10^5$ yr is the characteristic timescale of protostellar evolution
- $dM_{acc}(t)/dt$ and $M_{env}(t)$ declining exponentially with time (Bontemps et al. 1996)

Background: Early stages of star formation

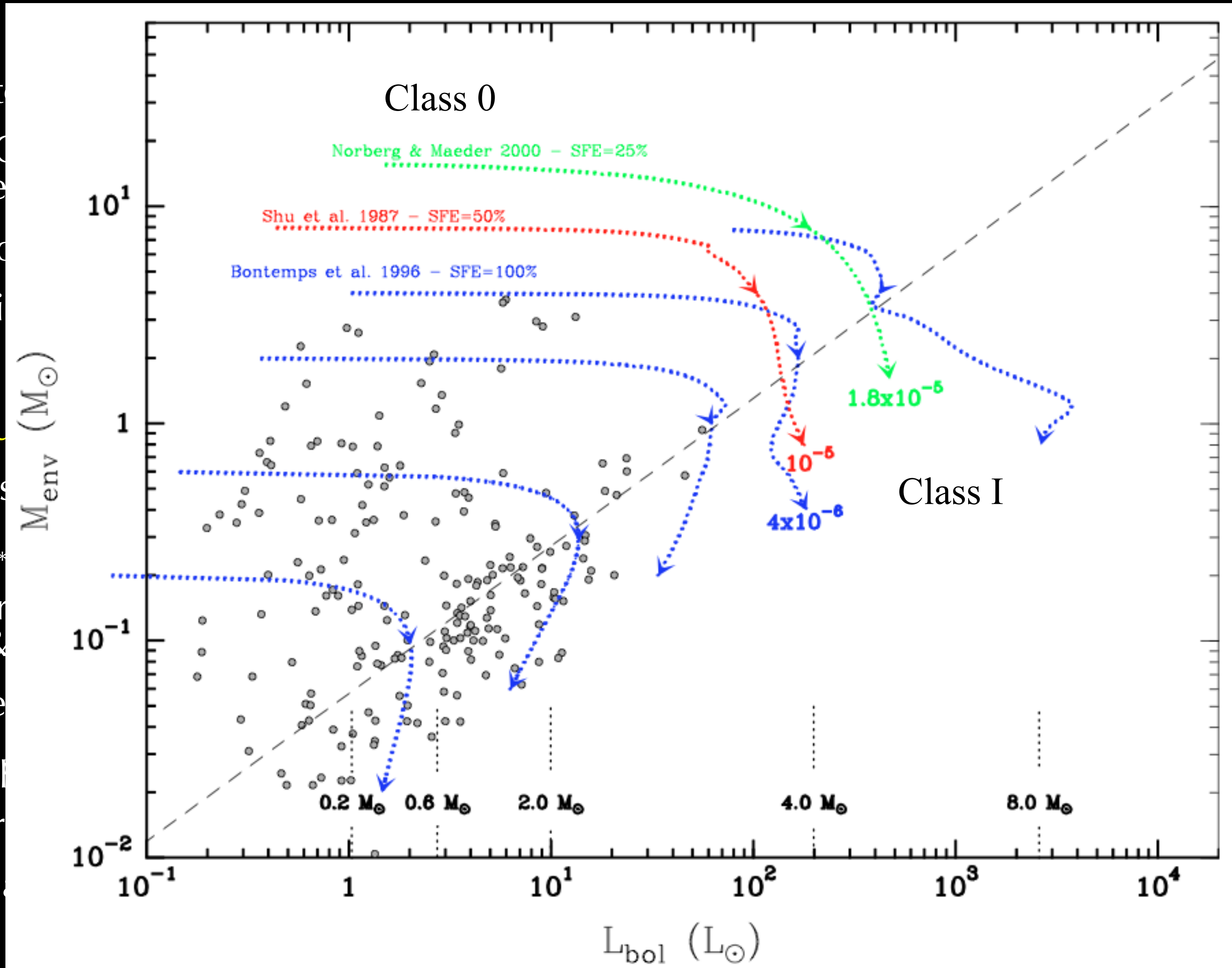
Early protost

- SEDs of C envelope
- Class I pc

Characteristi

Simple evolu

- Each protos
- L_{bol} = G M_*
- Protostellar Hosokawa &
- Mass accre
- ε is the ty
- τ = 10^5 yr
- $dM_{acc}(t)/dt$



Background: Early stages of star formation

Characteristic: Envelope mass & bolometric luminosity (➔Stellar mass)

The perspective of *Herschel*:

• *Herschel* covers the SED peak to constrain the luminosity and the envelope dust temperature

• *Herschel* mapping delivers statistical samples of protostellar objects also for the earliest stages

The Rosette molecular complex with *Herschel*

Herschel PACS & SPIRE parallel mode

70, 160, 250, 350, 500 μm

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

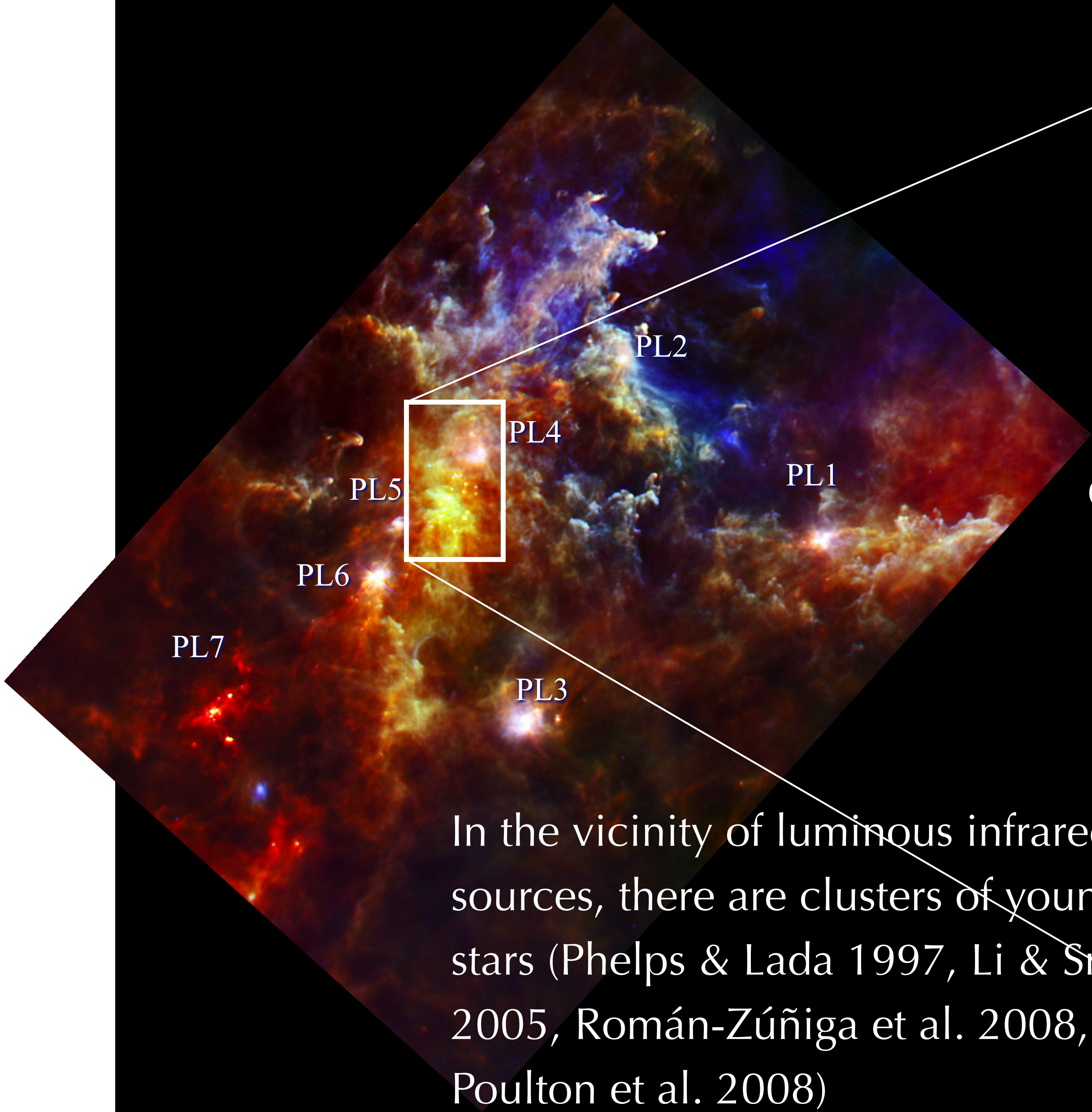
Rosette GMC 1.6 kpc, 2 x 10^5 $M_\odot$

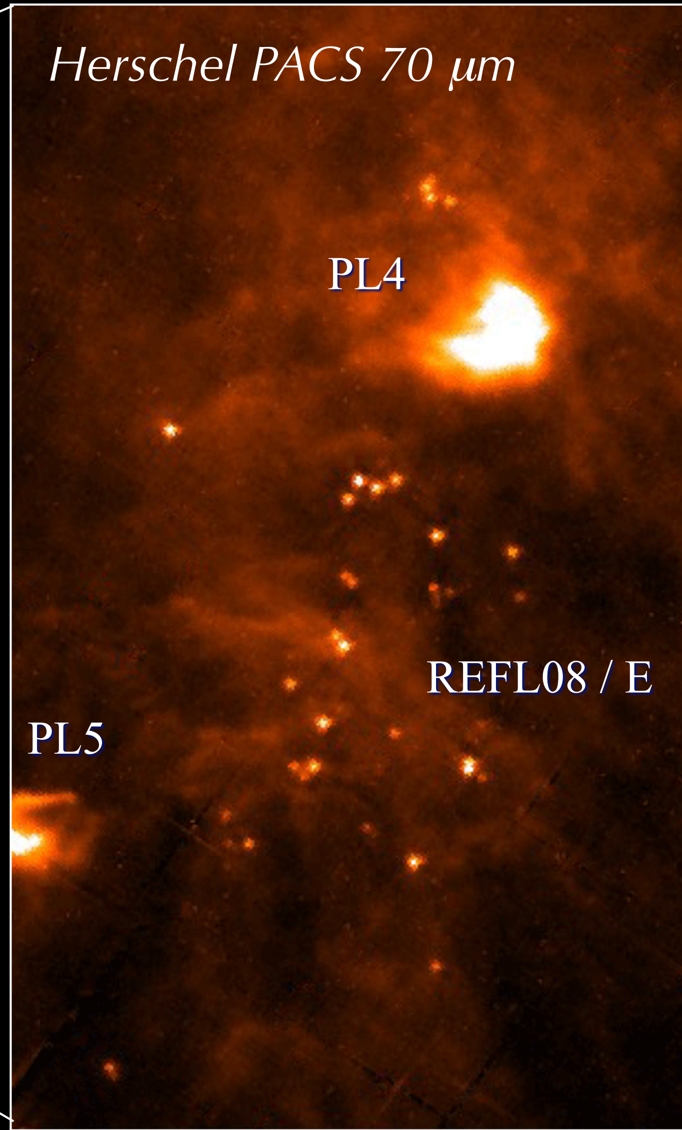
Under the influence of 7 O stars

PACS data reduction:

- HIPE scripts
- Baseline removal using the median high-pass filter with a width of one scan leg length ➔ conserve the extended emission structure
- Projection using MADmap (InvNTT table version 1)

Clusters of protostars in the Rosette





0.5 pc

In the vicinity of luminous infrared sources, there are clusters of young stars (Phelps & Lada 1997, Li & Smith 2005, Román-Zúñiga et al. 2008, Poulton et al. 2008)

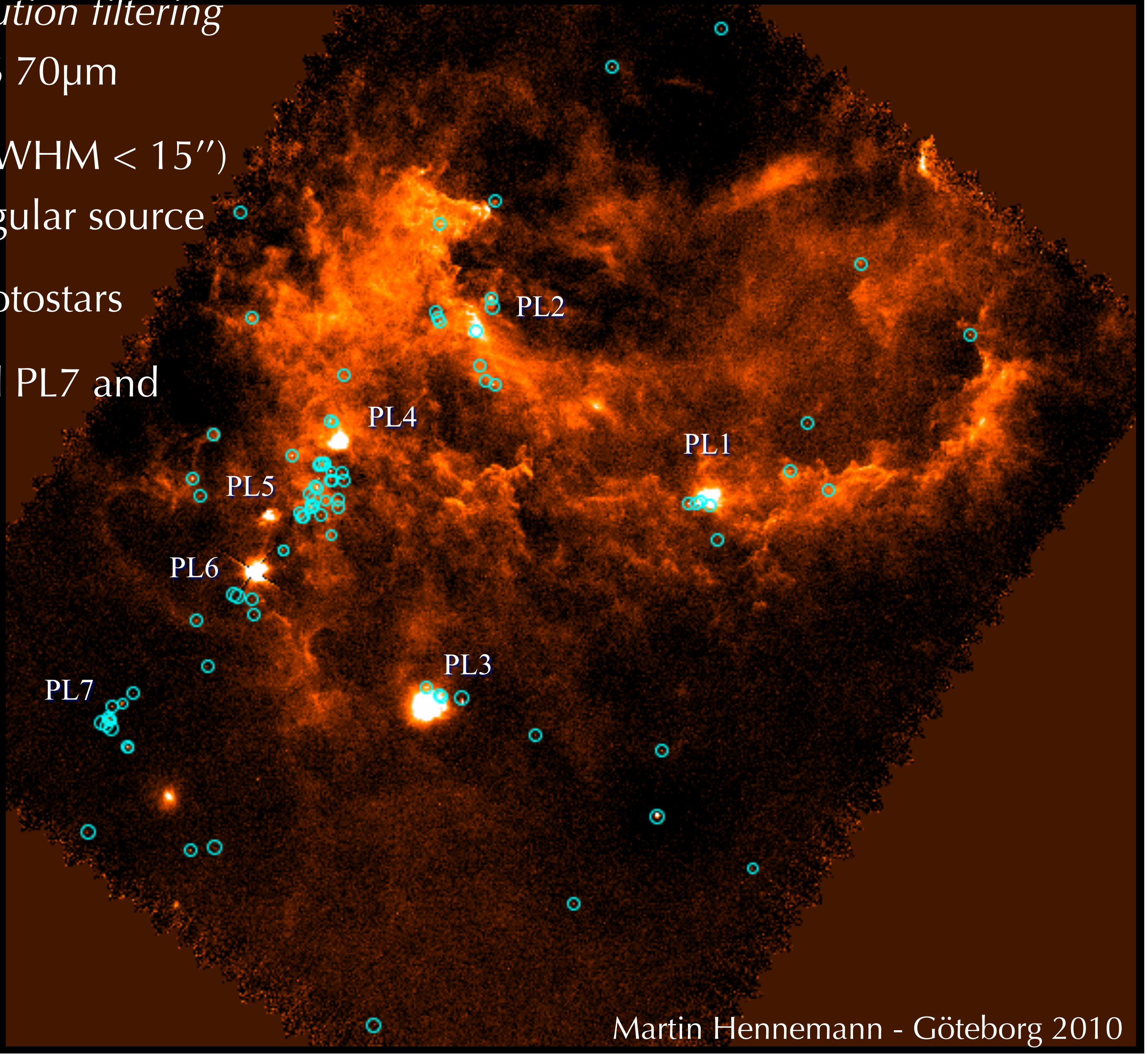
Identification of compact protostellar objects

Application of *Multi-resolution filtering* and *gaussclumps* on PACS 70µm

Filter for compact sizes (FWHM < 15″) and clear detection of singular source

Sample of 88 *Herschel* protostars

Prominent clusters around PL7 and Cloud centre



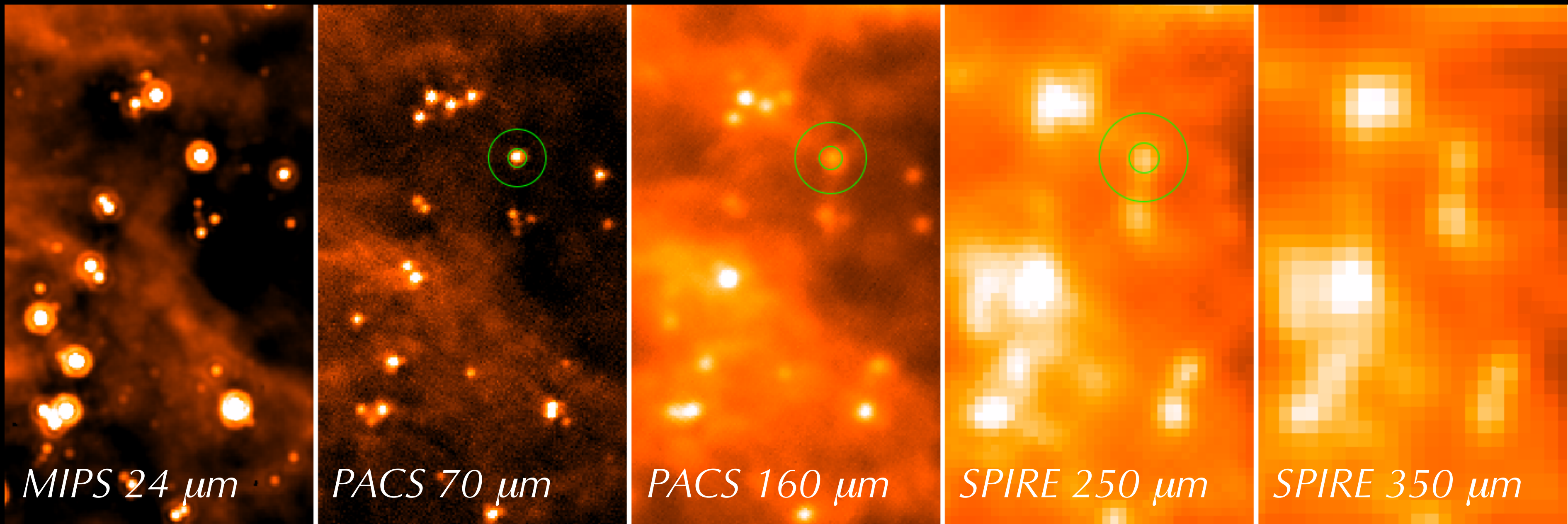
Identification of compact protostellar objects

Aperture photometry on the 70 and 160 μm maps:

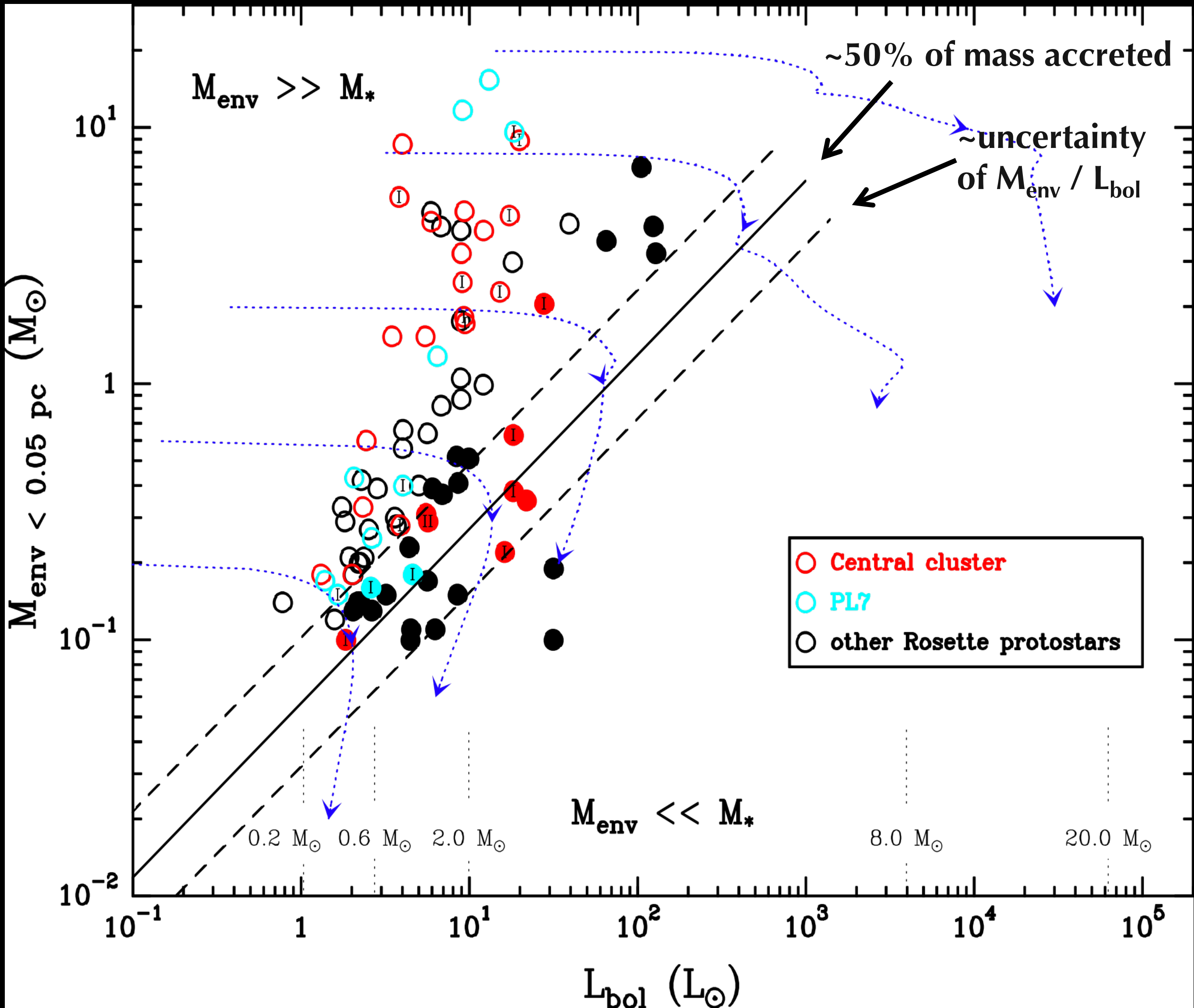
- Aperture diameter fixed to 0.1 pc convolved with (gaussian) beam, background annulus with 0.3 pc diameter ➔ FWHM size 0.05 pc ≈ size of the mass reservoir

Greybody function ($\beta = 2$) scaled to 160 μm flux, dust temperature adopted from Motte et al. (2010):

- Integrated emission on larger scales in all *Herschel* bands
- T_d = 20 K for sources where no estimate is available



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



Large fraction of Class 0 candidates (~2/3)

➔ *Herschel* finds a statistical sample of Class 0 objects

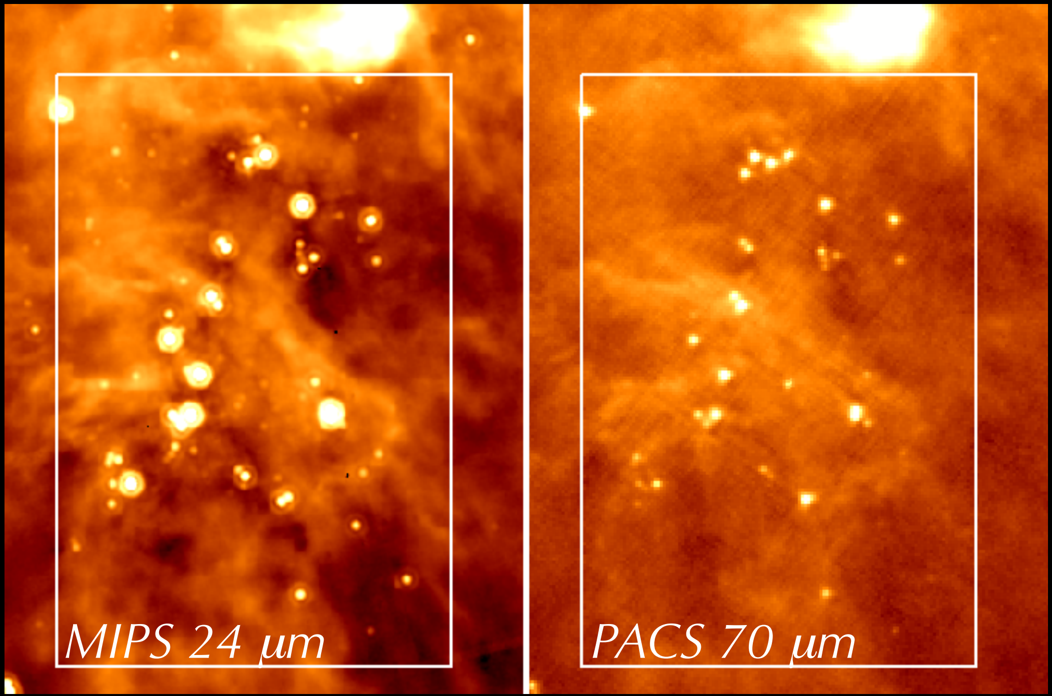
Apparently young are central cluster & PL7 (consistent with indications from NIR observations)

Comparison with NIR +*Spitzer* classification (I and II, Gutermuth et al. 2008) shows many I in Class 0 regime

FIR-submm classification of protostellars

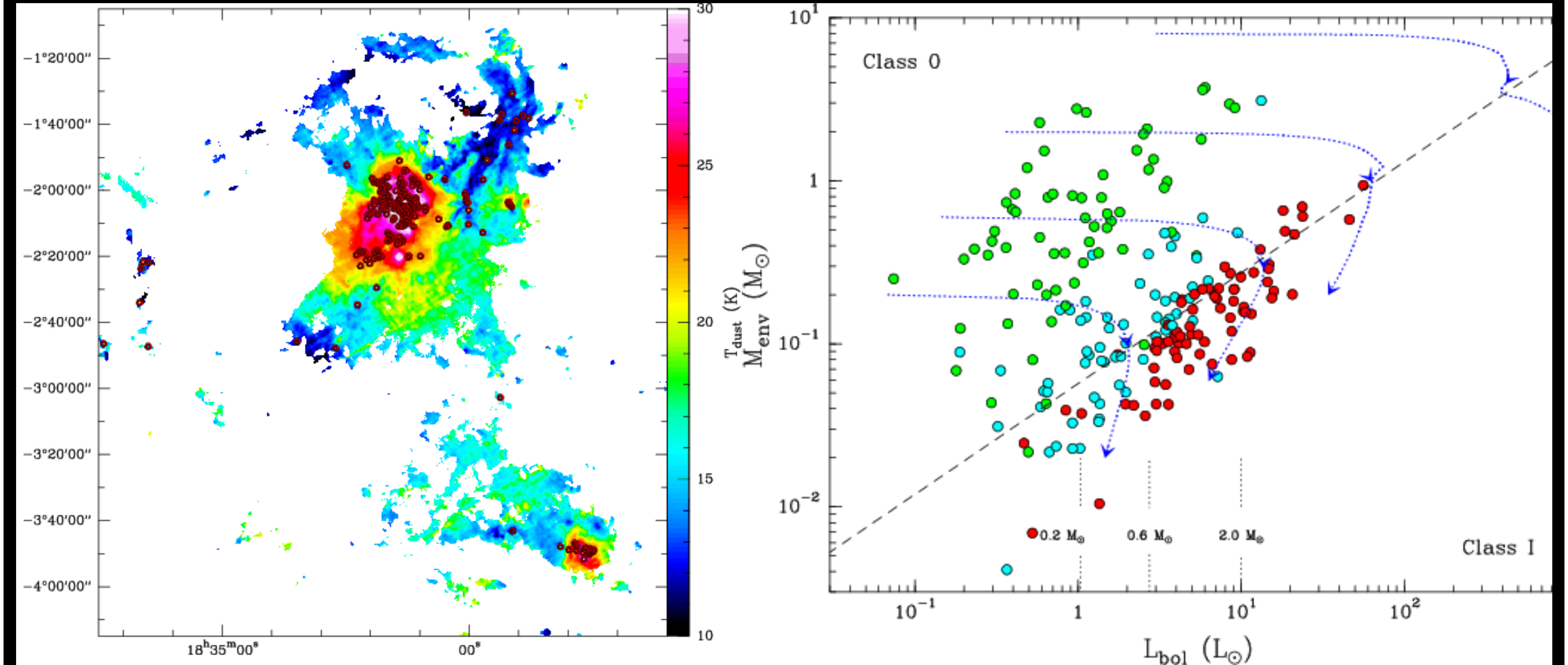
First census of detection rates in the central cluster area (excluding PL4)

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)



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

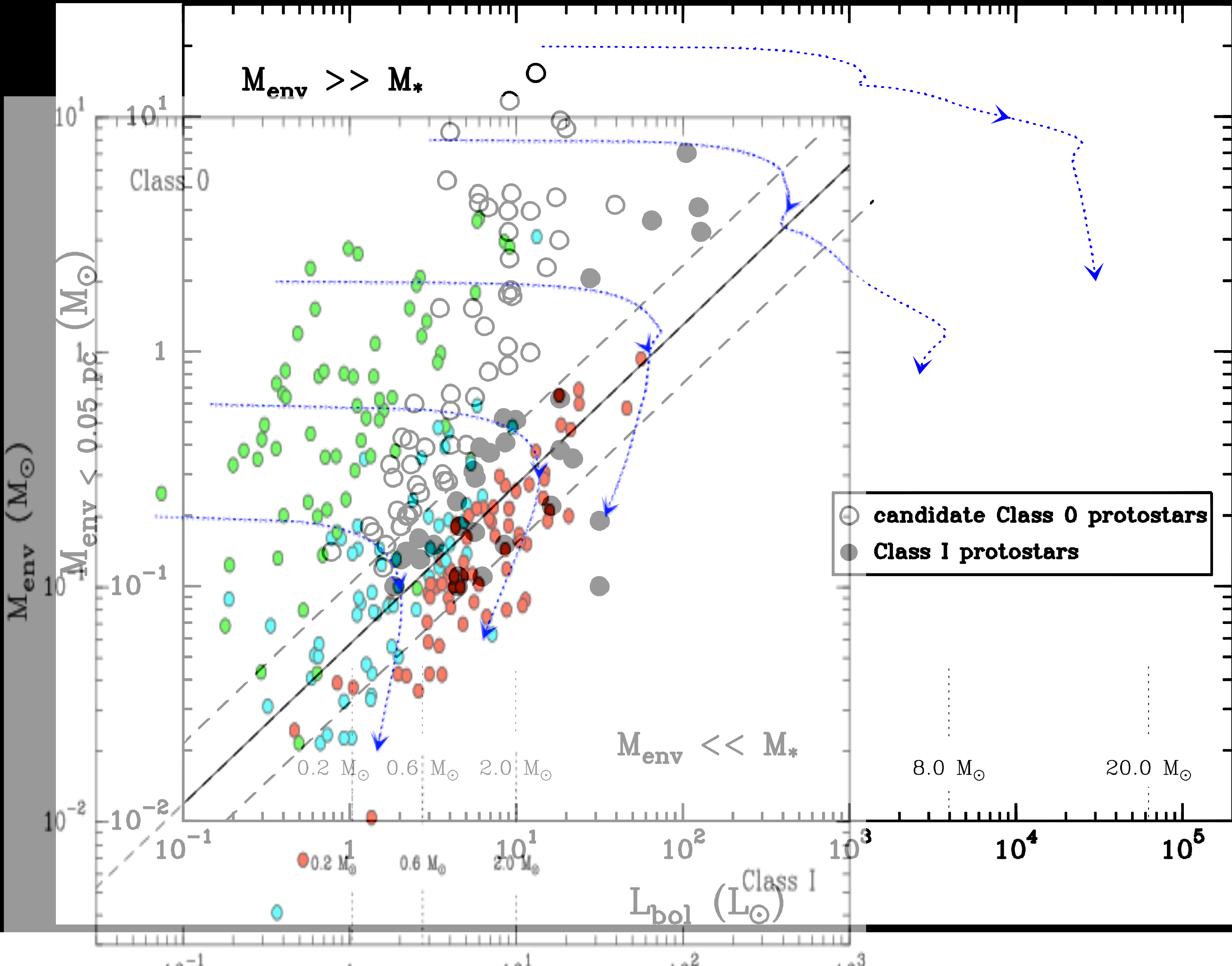
Comparison to first look on Aquila by the Gould Belt survey



Bontemps et al. 2010: *getsources* identified 201 protostars, detected as compact 70 µm sources (FWHM < 40″) present in all *Herschel* bands

- 90 % completeness level at ~0.2 $L_\odot$
- Photometry includes *Spitzer* and MAMBO bands for a fraction of the sources

Comparison to first look on Aquila by the Gould Belt survey



Protostellar clusters observed by HOBYS

Herschel traces protostars also in regions at intermediate distances

Towards the Rosette Molecular Cloud:

- clusters of low- to high-mass protostars
- among them a large number of Class 0 protostars

Herschel will provide required statistics to populate evolutionary diagrams

HOBYS *Herschel* Open Time follow-up to get PACS 100 μm coverage is pursued

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.

This work was partly supported by CNRS, CEA, and the ANR project «PROBeS».