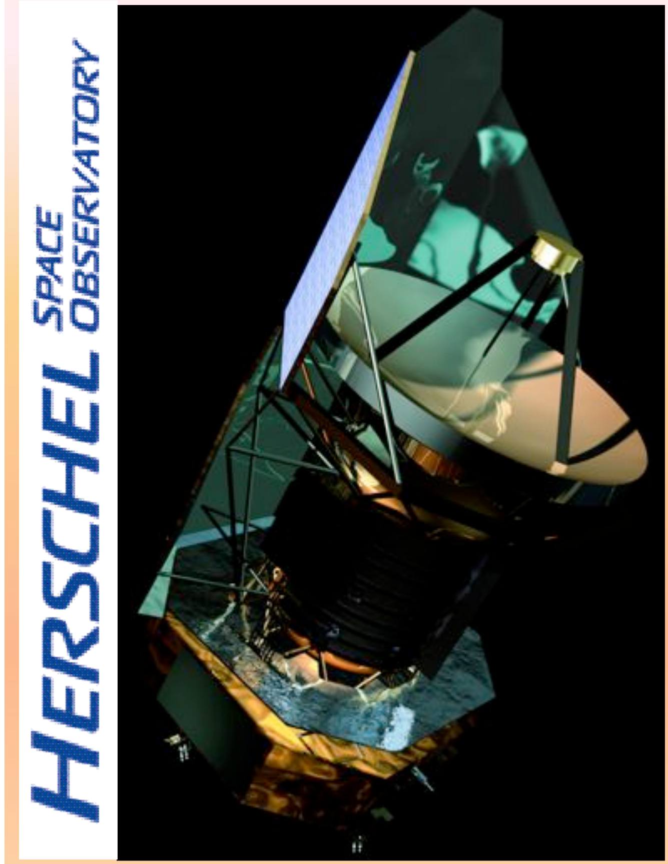
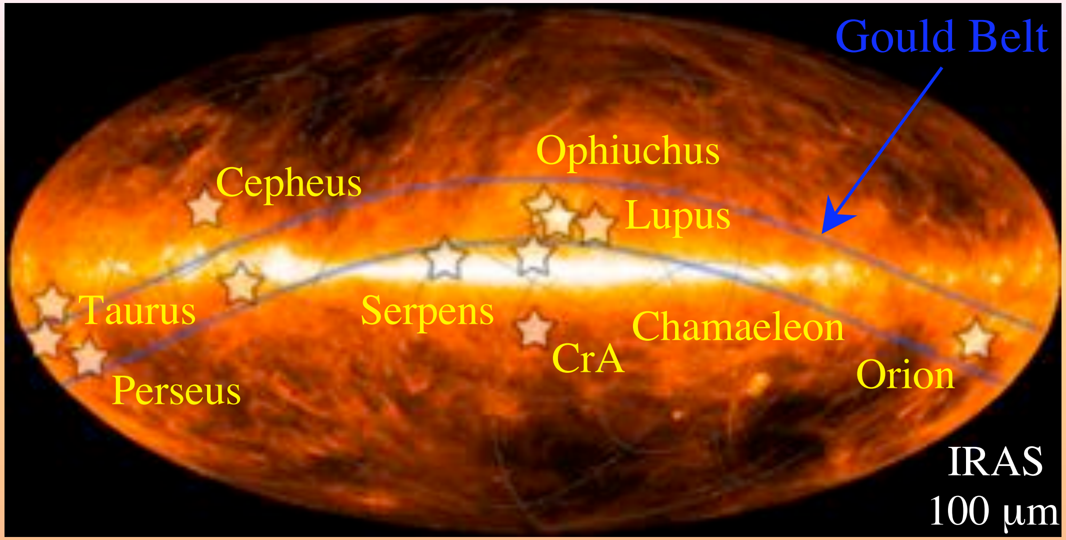
Herschel SPIRE/PACS Star Formation Surveys

Philippe André, CEA/SAp Saclay



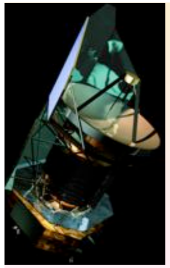


Herschel : Major Far-IR & Submm Space Observatory (ESA 'cornerstone') 3.5 m telescope

Launch : 2008

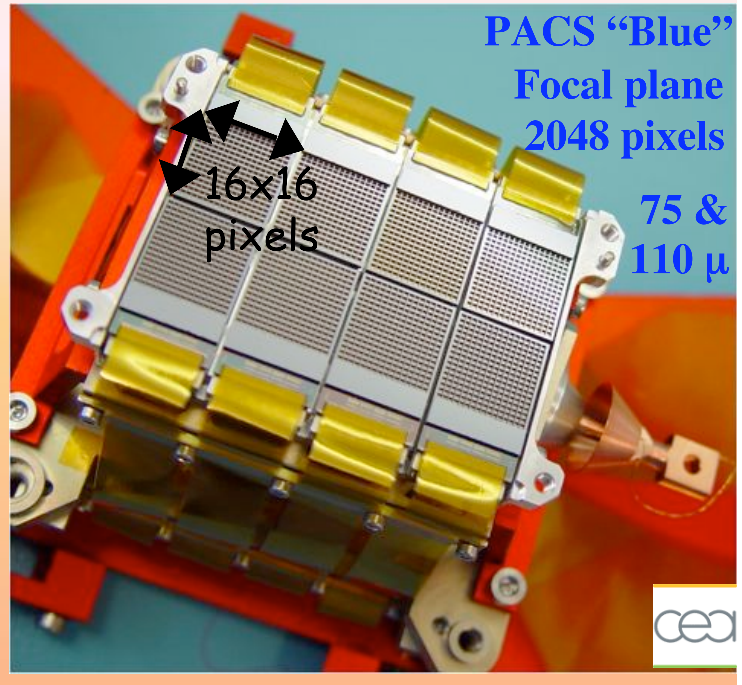
Outline

- Overview of Herschel imaging instruments and star formation KPs
- « Gould Belt » survey
- « OB star formation » survey
- Conclusions



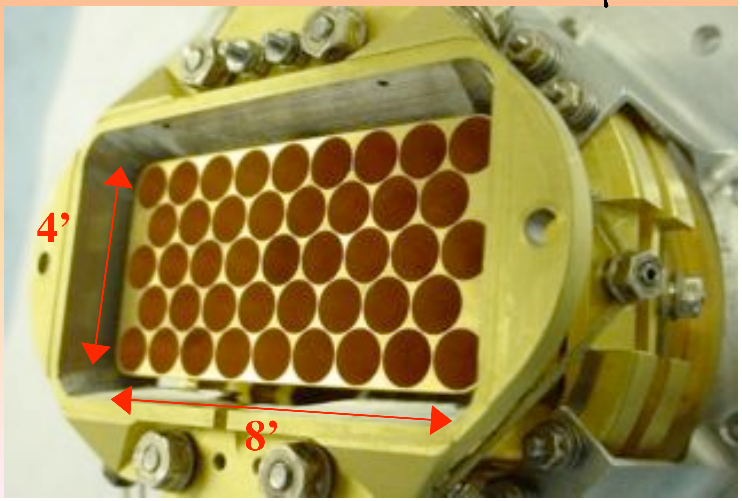
Herschel imaging instruments

- **PACS - Photodetector Array Camera and Spectrometer**
  - **PI: Albrecht Poglitsch, MPE, Garching**, Germany
  - imaging photometry in 2 bands simultaneously:
75 or 110 μm (blue) and 170 μm (red)
  - 2 filled bolometer arrays (64x32 and 32x16 pixels)
--> full beam sampling over **3.5’x1.75’ field of view**
  - **Angular resolution: ~ 5”, 8’’, 13” (HPBW)**
  - **Expected sensitivity: ~ 3-4 mJy/beam (5σ, 1hr)**
  - Integral-field line spectroscopy from 57 to 210 μm



- **SPIRE - Spectral and Photometric Imaging Receiver**
  - **PI: Matt Griffin, Cardiff University**, UK
  - 3-band imaging bolometer array: **250, 350, 500 μm** (simultaneous)
  - **8’x4’ field of view** (2Fλ feedhorns - cf. SCUBA)
  - **Angular resolution: 18”, 25”, 36” (HPBW)**
  - **Expected sensitivity: ~ 2-8 mJy/beam (5σ, 1hr)**
  - Spectro-imaging FTS from 200 to 670 μm

SPIRE 43 detectors @ 500 μm



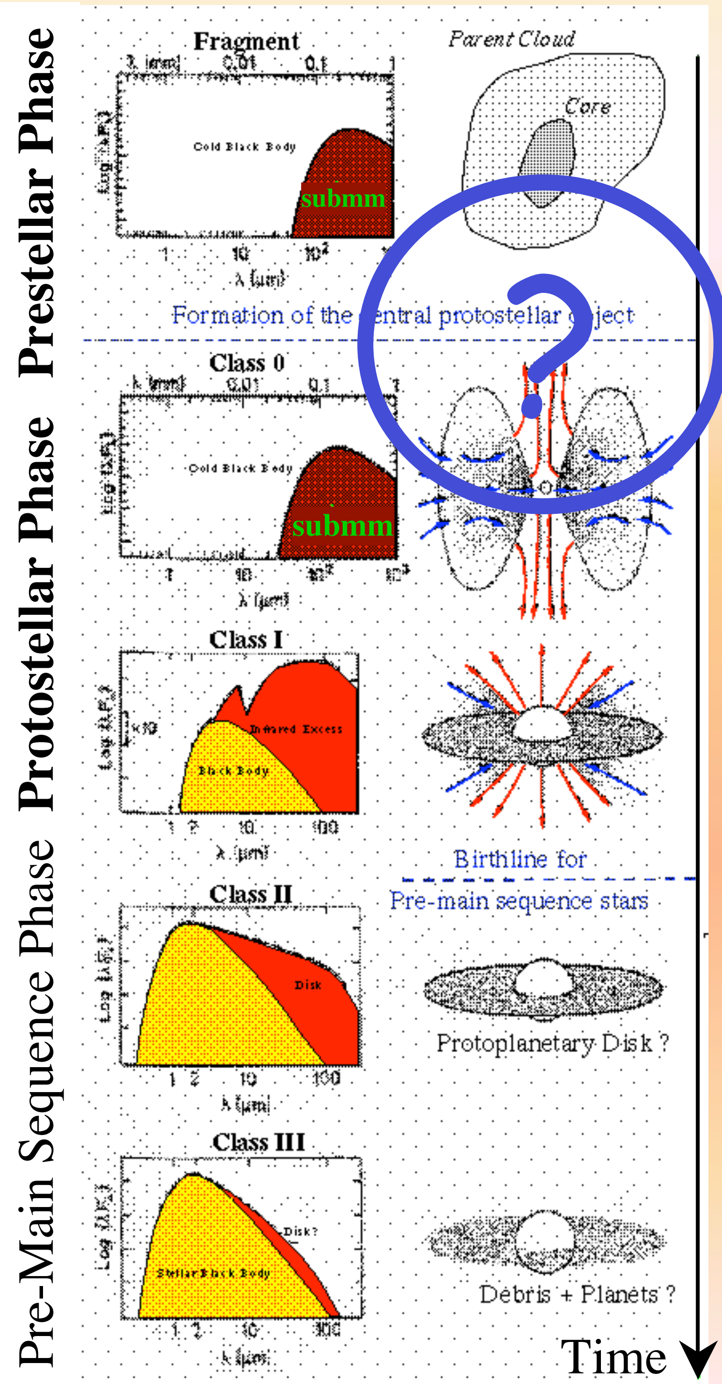
Overview of Herschel SPIRE/PACS SF KP Surveys

• ***Probing the origin of the stellar IMF*** **(Gould Belt** survey)
Coordinators: Ph. André (CEA/Saclay) and P. Saraceno (IFSI/Rome)
Wide-field (~160 deg^2) photometric imaging of nearby (d < 0.5 kpc) molecular clouds **461 hr of GT (SPIRE+PACS consortia+HSC)**

• ***The birth of high-mass stars*** **(OB star formation** survey)
Coordinators: F. Motte (CEA/Saclay), A. Zavagno, and S. Bontemps
Multi-band imaging survey of high-mass star-forming complexes at intermediate (d < 3 kpc) distances **125 hr of GT**

• ***The earliest phases of low- to high-mass star formation***
Coordinators: Th. Henning & O. Krause (MPIA/Heidelberg)
Detailed, small-scale mapping of individual objects **118 hr of GT**

• ***Herschel Infrared Galactic Plane Survey*** ***(HIGAL)***
Coordinator: S. Molinari (IFSI/Rome) **Open Time KP**



Lada (1987) + André (1994, 2002)

Formation of solar-type stars

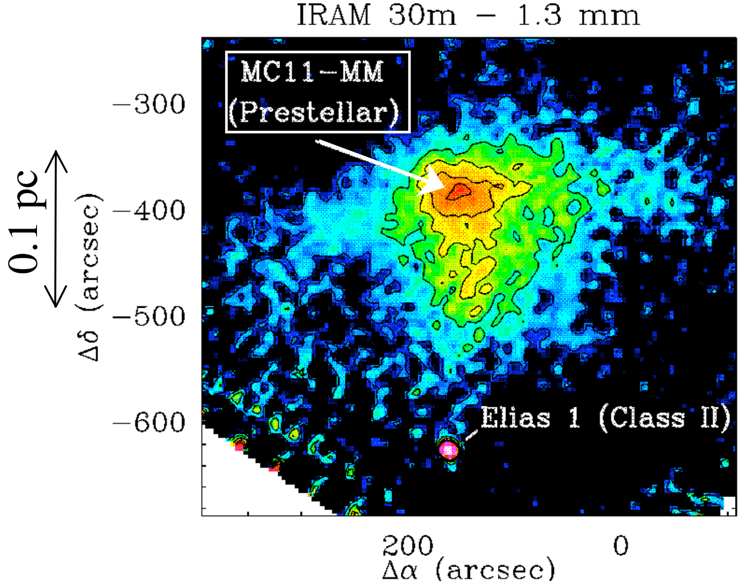
Reasonably well established evolutionary sequence but physics of early stages unclear

Motivation for the GB survey
Key questions on the early stages

- **What determines the distribution of stellar masses = the IMF ?**
- **What generates prestellar cores & what governs their evolution to protostars ?**
- **Timescale of core/star formation ? Quasi-static or dynamic process ?**

Prestellar Cores (t < 0) → Class 0 protostars (t > 0)

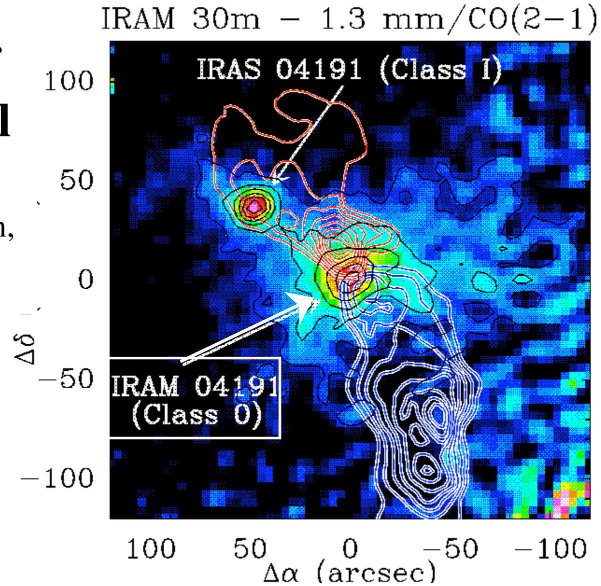
The progenitors of protostars



Representative of the collapse initial conditions
(cf. André, Ward-Thompson, Barsony 2000 PPIV)

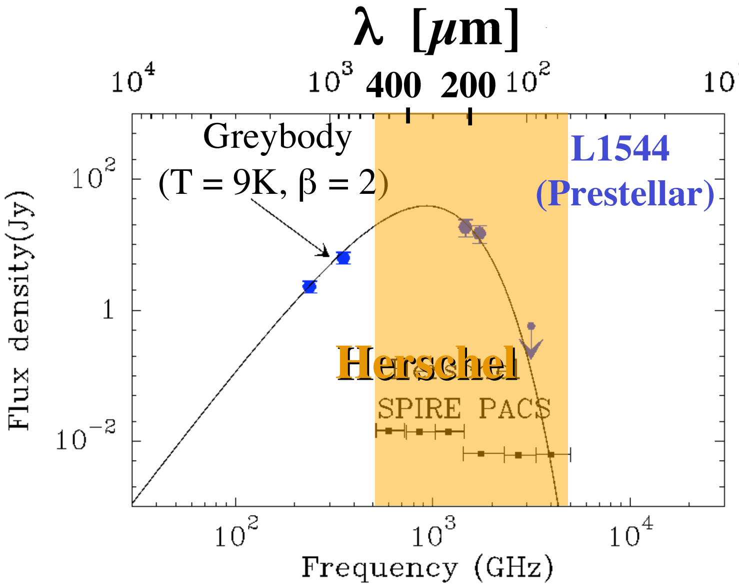
Sizes: ~ 0.01 pc to ~ 0.1 pc
Resolved by *Herschel* up to ~ 0.5 kpc

Protostars in the build-up phase



Gravitationally bound ($M \sim M_{VIR}$, $M_* = 0$)

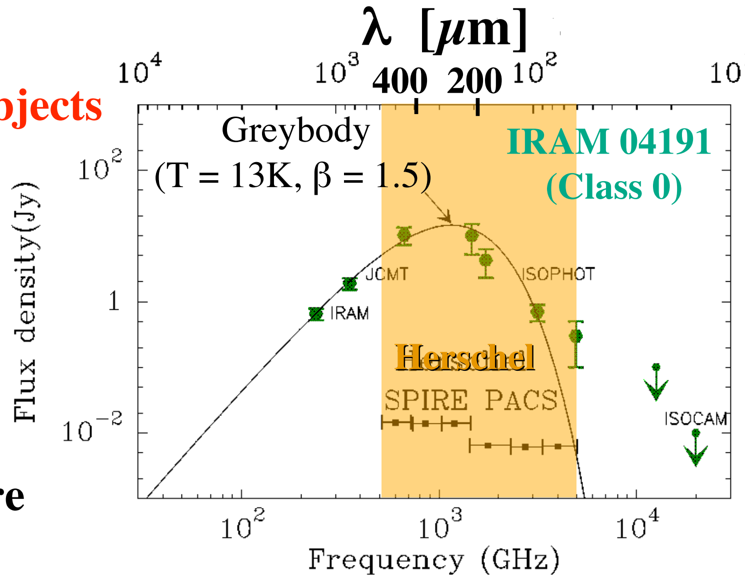
Massive envelopes ($M_{env} > M_*$)



Submm-only objects

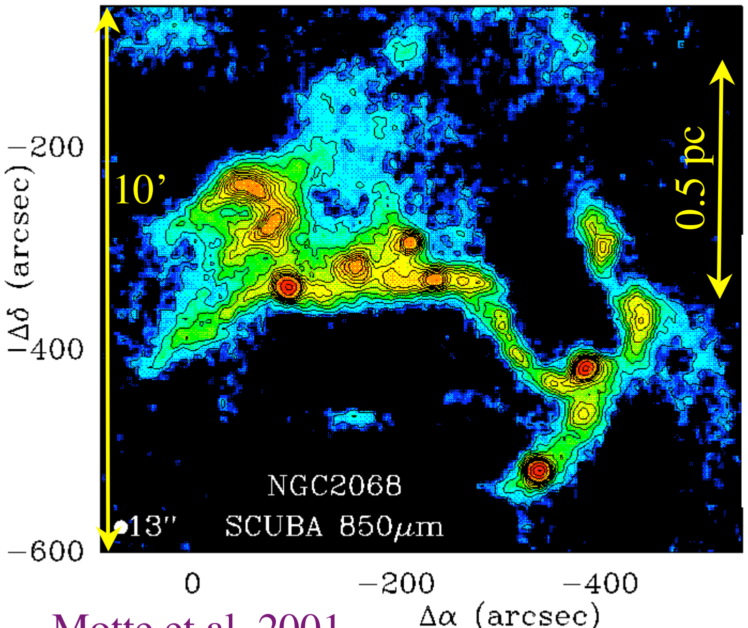
↓

***Herschel* bands essential**
for **luminosity** and **temperature** determinations

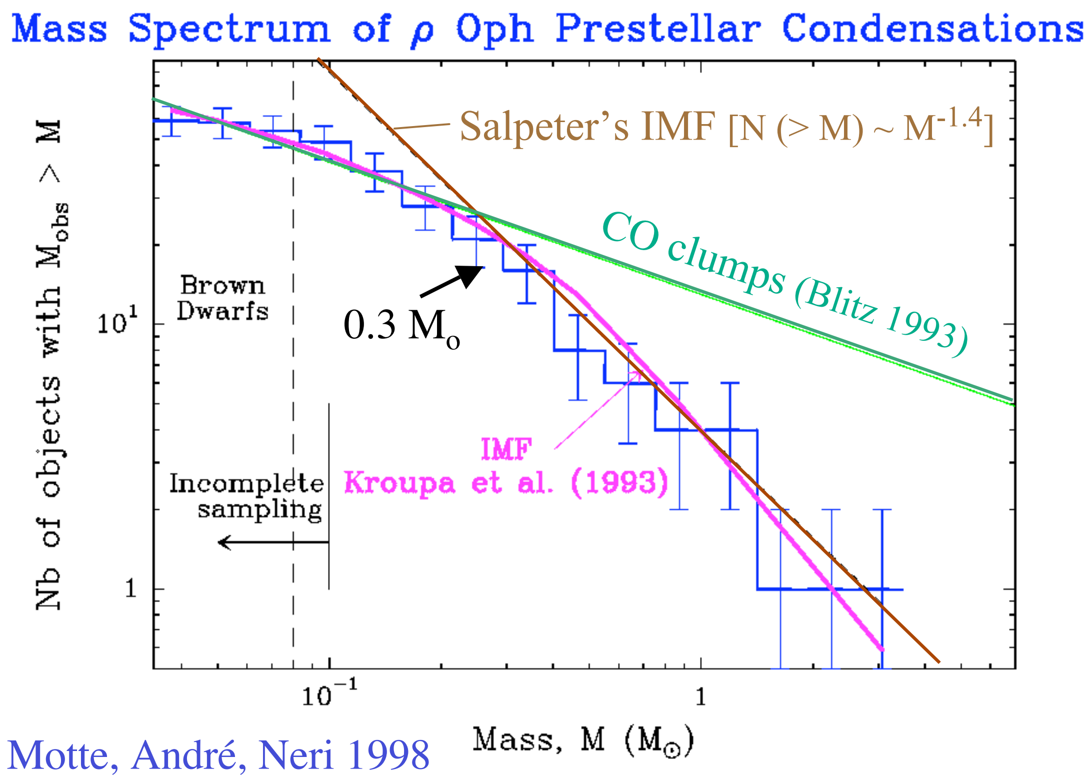


The prestellar core mass function (CMF) resembles the IMF

NGC2068 at 850 µm



Motte et al. 2001



Motte, André, Neri 1998

➜ The IMF is at least partly determined by pre-collapse cloud fragmentation (~ 0.1 - 5 M_O)

• **Limitations:** Small-number statistics, incompleteness at low-mass end (?) + assume constant dust properties

➜ *Herschel* & ALMA needed to confirm/extend conclusions toward lower/higher masses

See also: Testi & Sargent 1998; Johnstone et al. 2001; Stanke et al. 2006; Alves et al. 2007

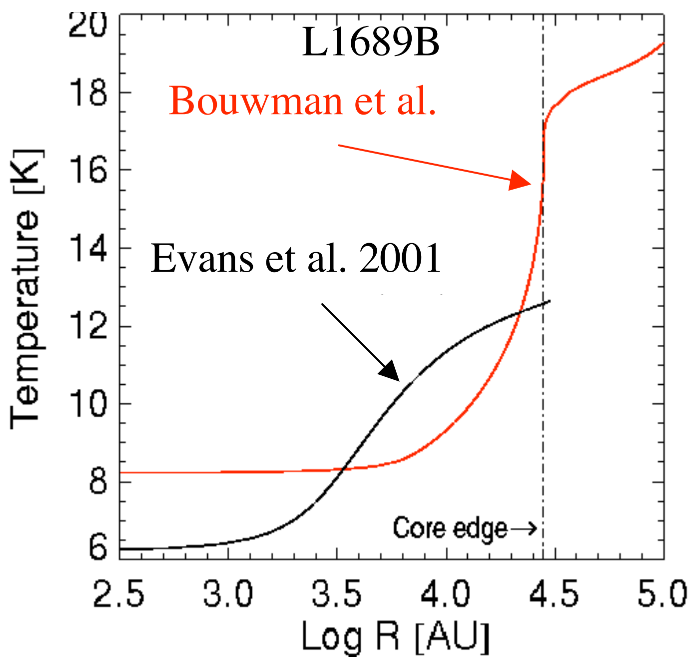
And for massive cores: Beuther & Schilke 2004

Importance of direct determinations of T_{dust}

- Current mass estimates assume constant dust properties (T_{dust} , κ_{dust})
- But both T_{dust} and κ_{dust} are uncertain and may vary from object to object

Expectations: T_{dust} ↘ and κ_{dust} ↗ in the core interiors as N_{H2} (or A_V) ↗

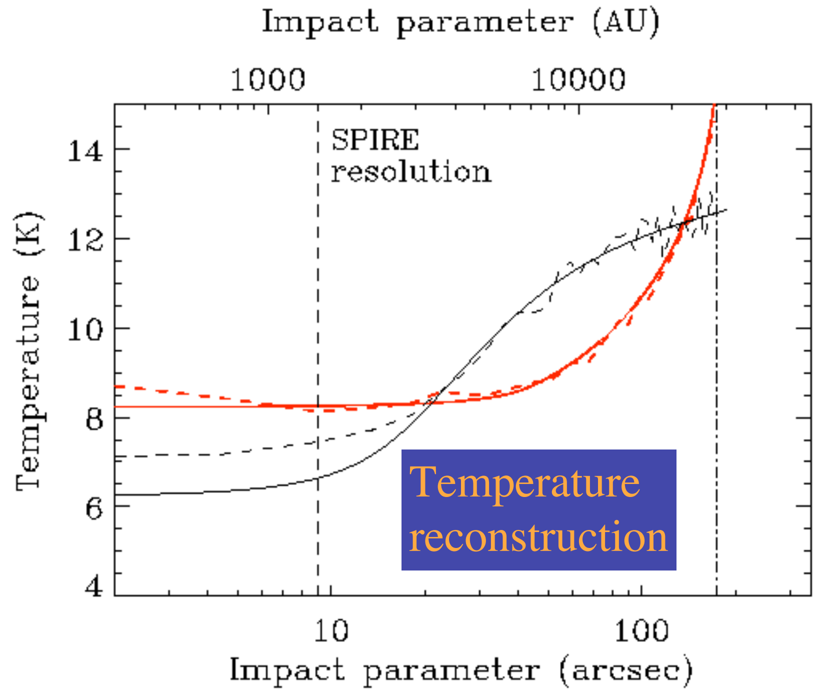
Model Core Temperature Profiles



(see also Zucconi et al. 2001, Stamatellos et al. 2004)

NB: $B_{1mm}(15\ K)/\ B_{1mm}(5\ K) \sim 10$

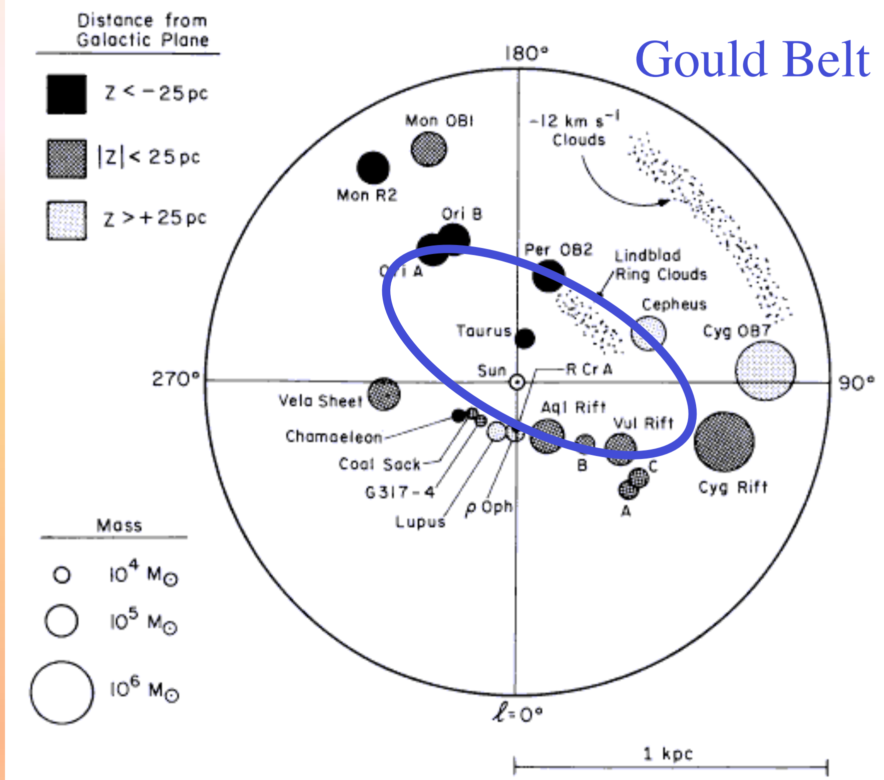
With Herschel, simultaneous determination of the temperature and column density profiles from images in 5 bands (110-500 µm)



A wide-field *Herschel* survey of nearby clouds (d < 500 pc)

A ~ 460 hr SPIRE/PACS GT Key Project:

- SPIRE 250-500 µm survey of $A_v > 3$ portion of **Gould belt** (~ 160 deg^2)
- PACS 110-170 µm imaging of ~ 65 deg^2 (~ $A_v > 6$ regions)
- rms sensitivity: ~ 10 mJy/beam (1σ)
- Col. density sensitivity (5σ): $A_v \sim 1$
- see **http://starformation-herschel.iap.fr**



Expected immediate outcome of the survey:

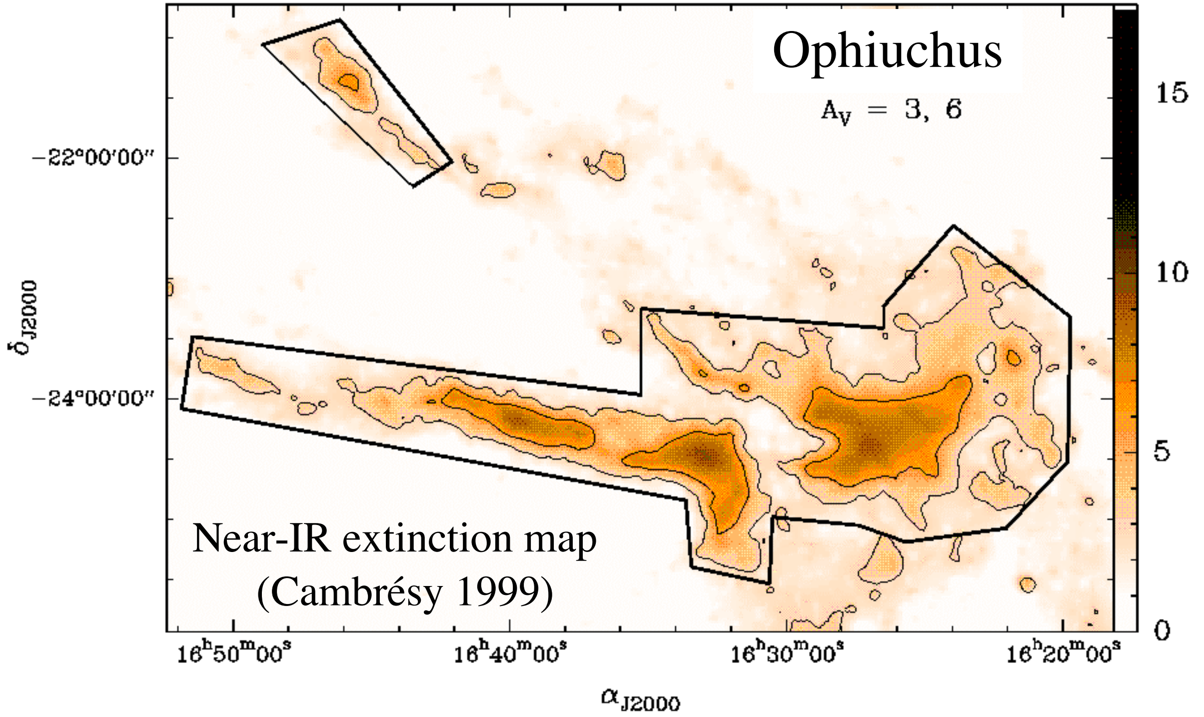
- ~ 350 Class 0 protostars and ~ 3500 prestellar cores with well-characterized temperatures, luminosities, masses (+ profiles in many cases)

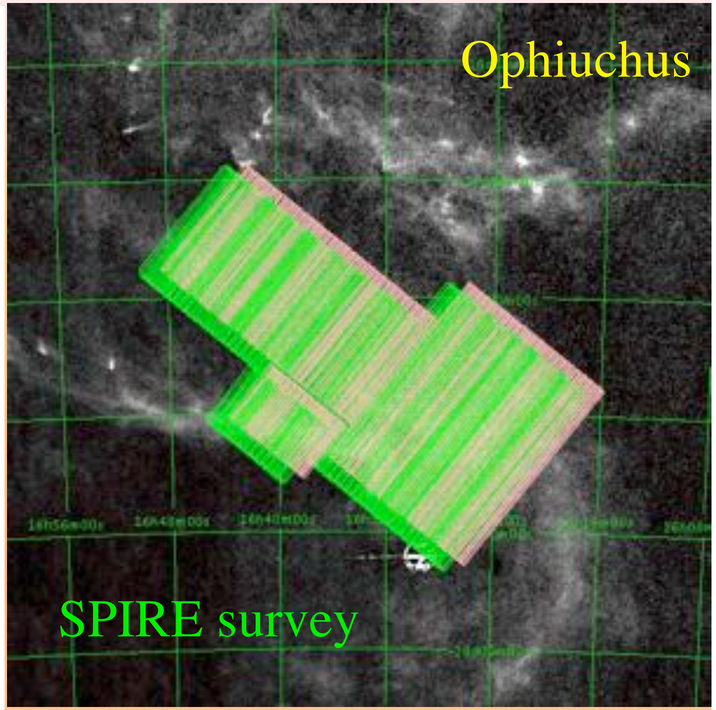
→ Good sampling of the prestellar core mass function from the substellar to the intermediate-mass regime; lifetimes as a function of mass, density, environment

→ Unique database for follow-up kinematical/multiplicity studies with ALMA

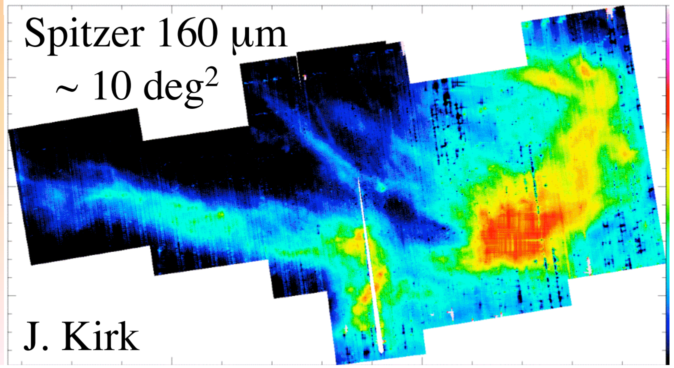
Careful definition of the target fields using near-IR extinction maps

(See http://starformation-herschel.iap.fr/gouldbelt/ for all fields)





N. Evans' Spitzer c2d project



--> ~ 17 deg² scanning @ 60''/sec with SPIRE

Sensitivity level < cirrus confusion noise:

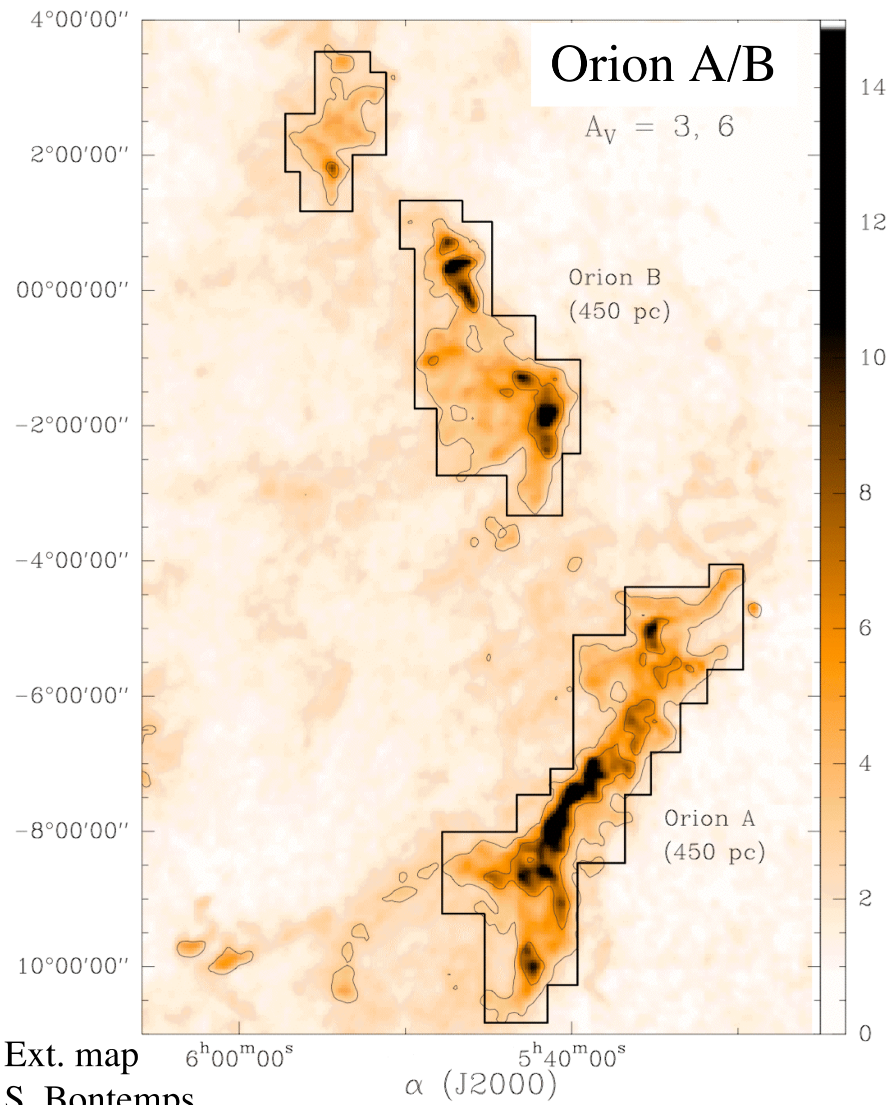
σ_{250} ~ 9 mJy/18''-beam @ 250 μm

~ 6 deg² @ 20''/sec with PACS

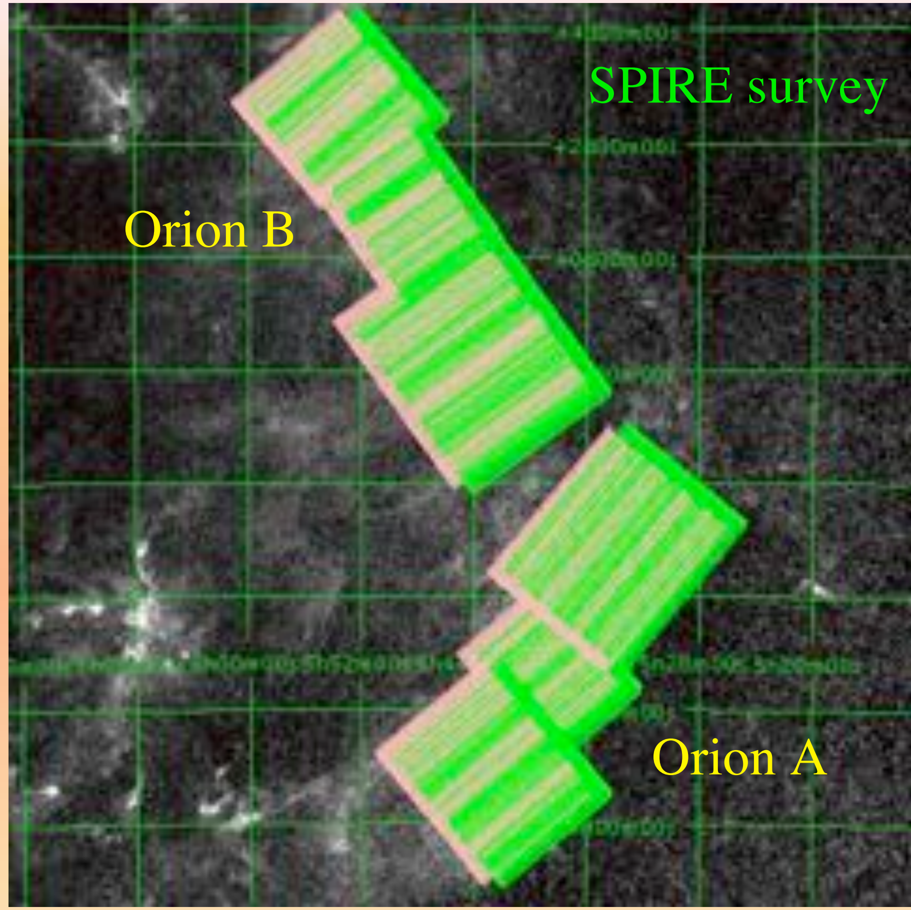
σ_{110} ~ 7.5 mJy/8''-beam @ 110 μm

Careful definition of the target fields using near-IR extinction maps

(See http://starformation-herschel.iap.fr/gouldbelt/ for all fields)



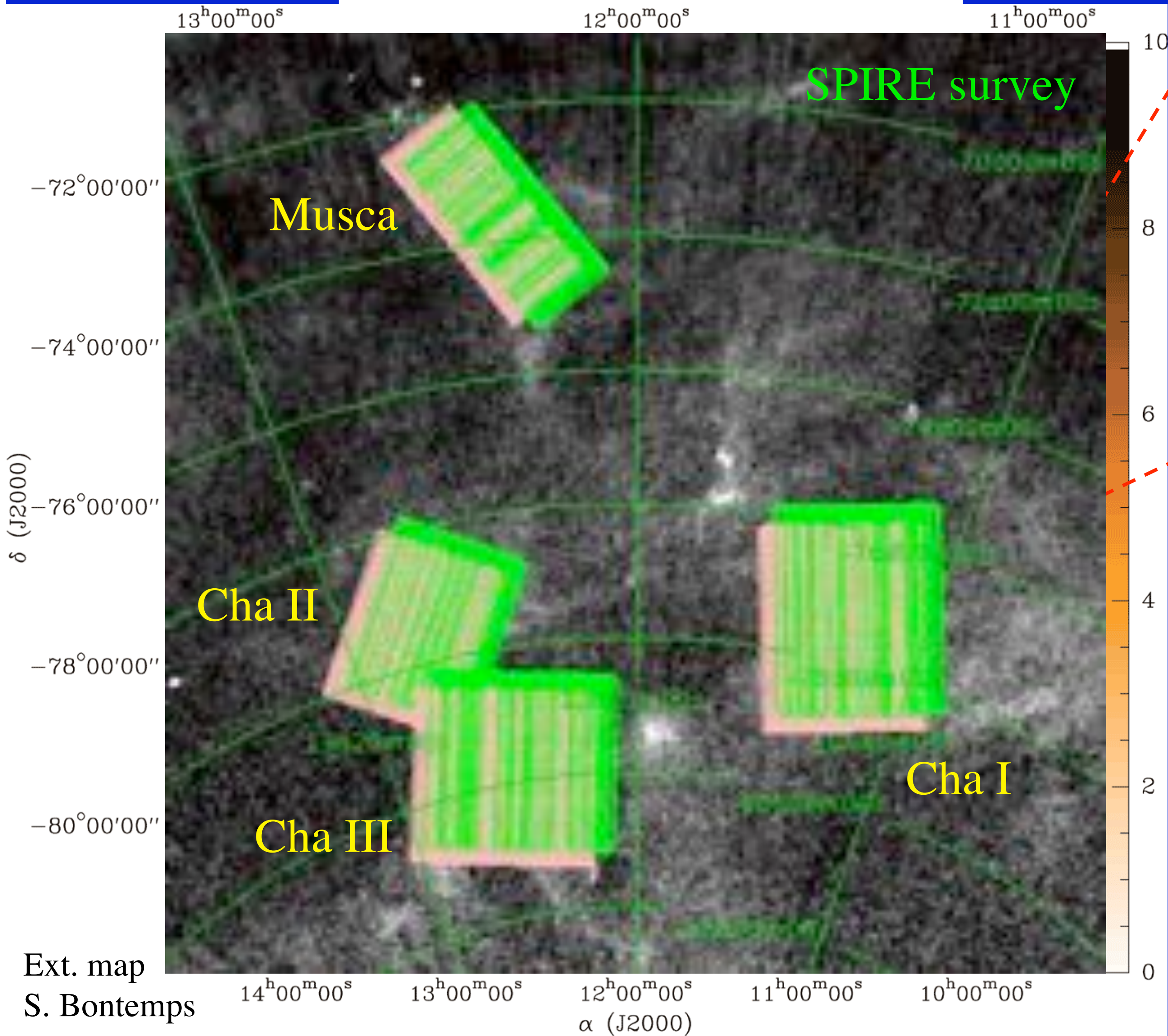
Ext. map
S. Bontemps



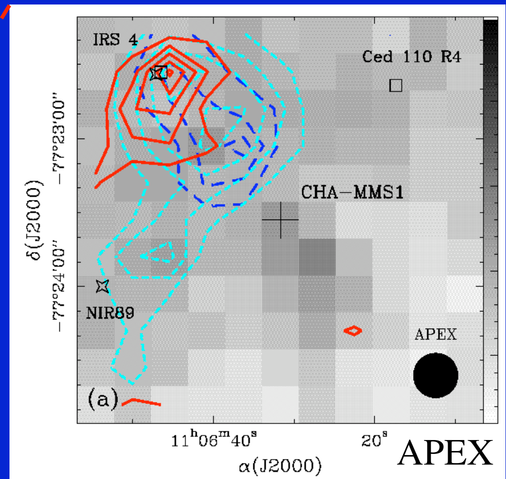
→ ~ 30 = 15+15 deg^2 in scan-map mode @ 60''/sec with SPIRE

Sensitivity ~ 10 mJy (< cirrus noise)

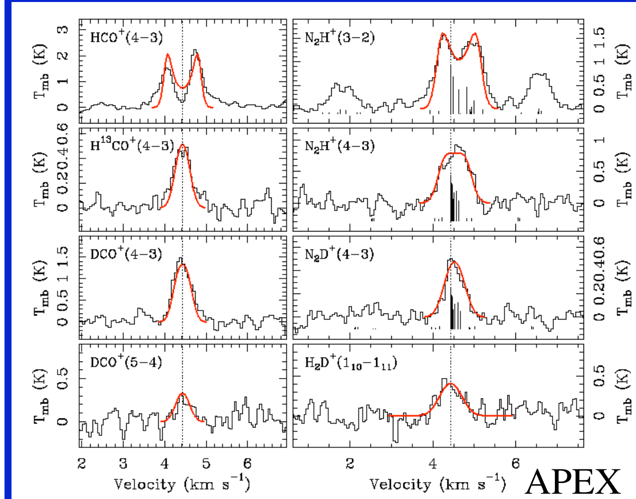
Chamaeleon + Musca clouds



Ext. map
S. Bontemps



Cha-MMS1 (Class 0) (Reipurth et al. 1996, Belloche et al. 2006)



→ ~ 16 deg^2 to rms$_{250}$ ~ 9 mJy/18''-beam scanning @ 60''/sec with SPIRE

✚ ~ 7 deg^2 to rms$_{110}$ ~ 7.5 mJy/8''-beam @ 20''/sec with PACS

Need to go beyond the Gould Belt and sample a few kpc in radius to study the formation of massive protostars

Object	**Total Gould Belt**	**Total < 3 kpc**	B3-B1	O9-O7	O6-O3	O3-O1
	> 8 M_o	**> 8 M_o**	8-20 M_o	20-50 M_o	50-100 M_o	> 100 M_o
Prestellar core	**20 ?**	**700 ?**	480 ?	150 ?	40 ?	30 ?
Class 0 -like protostar	**2**	**70**	48	15	4	3

Requirements to derive the basic properties (Mass + Luminosity) of massive protostars:

- SED coverage: 75-500 μm
- Spatial resolution: ~ 0.1 pc
- Sensitivity: not a serious issue

➜ The "3 kpc opportunity" for Herschel

« HOBYS » SPIRE/PACS GT KP Survey:

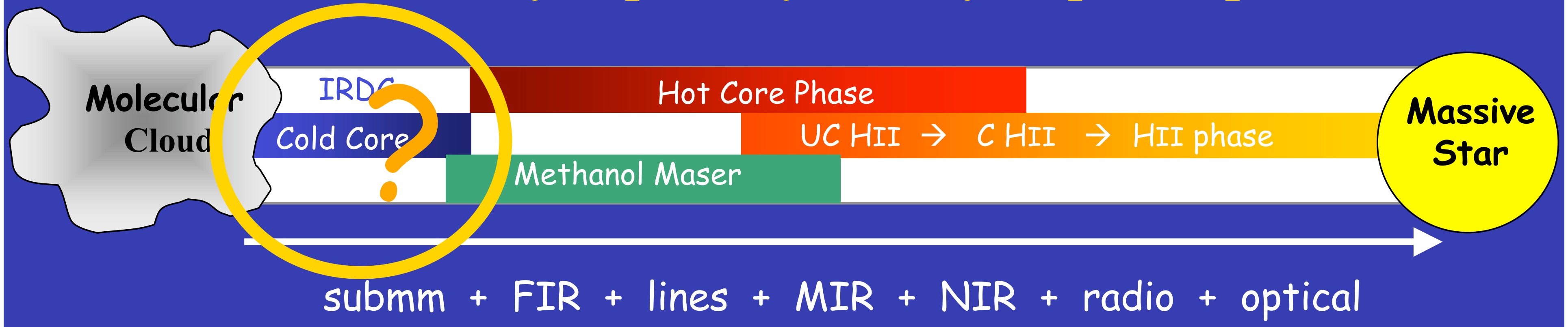
- SPIRE/PACS parallel-mode survey of most massive star-forming clouds at d < 3 kpc (~22 deg^2)
- rms sensitivity: ~ 10 mJy/beam (1σ)
- Coordinators: F. Motte, A. Zavagno, S. Bontemps
- see **http://starformation-herschel.iap.fr**

Motivation for the OB Star Formation Survey

• Importance of OB stars for evolution & energy budget of galaxies

• High-mass star formation poses a specific theoretical problem (radiation pressure expected to stop accretion when $M_* > 8\ M_o$)

• No clear evolutionary sequence yet; Only empirical phases



Key questions on massive star formation

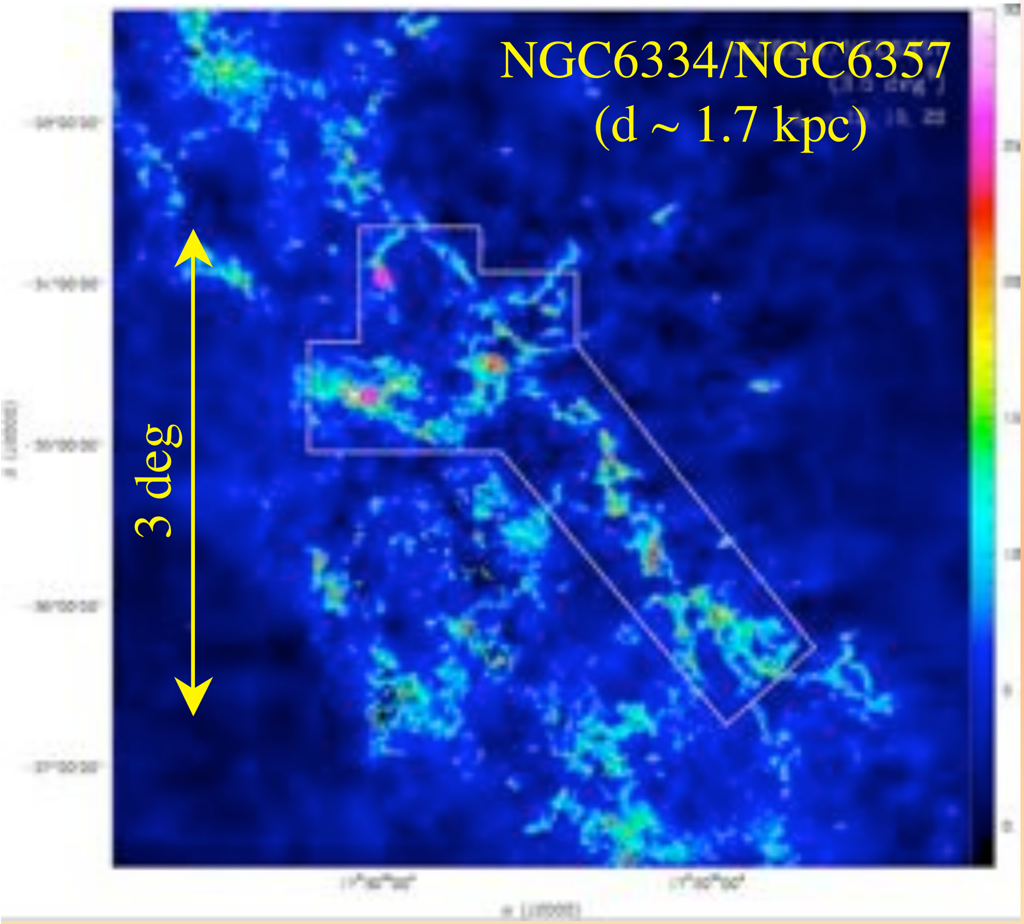
• Initial conditions and evolutionary sequence ?

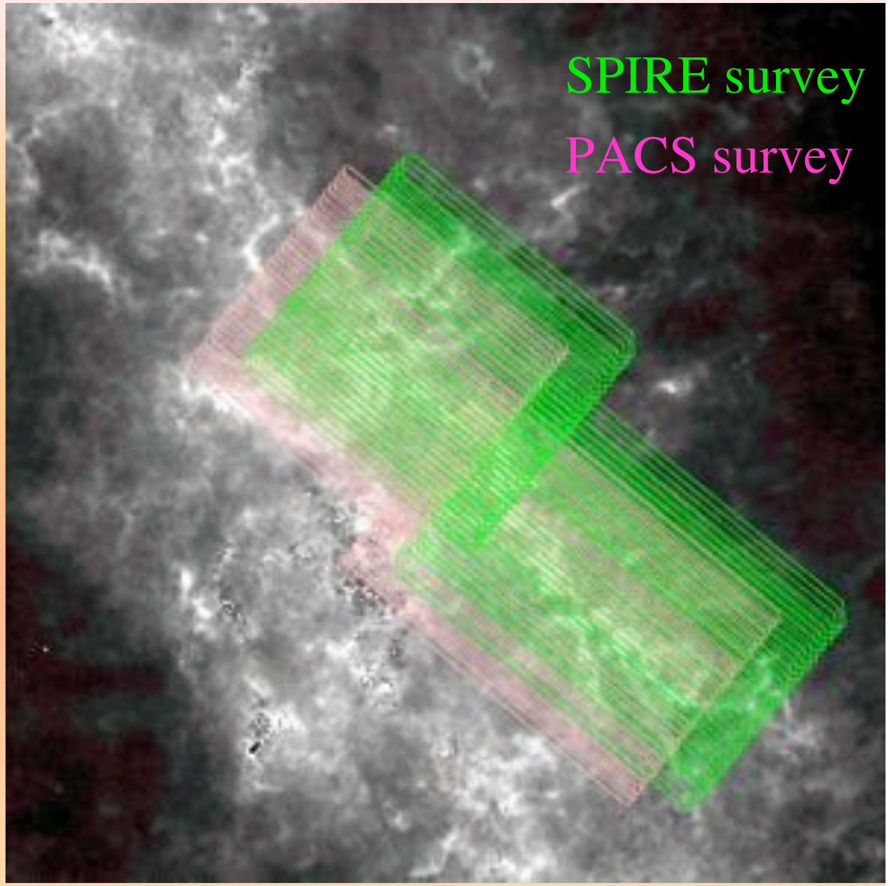
• Direct collapse/accretion or other mechanism (e.g. coalescence) ?

• Role of external triggers ?

Example of « HOBYS » survey field

Near-IR extinction map (S. Bontemps)



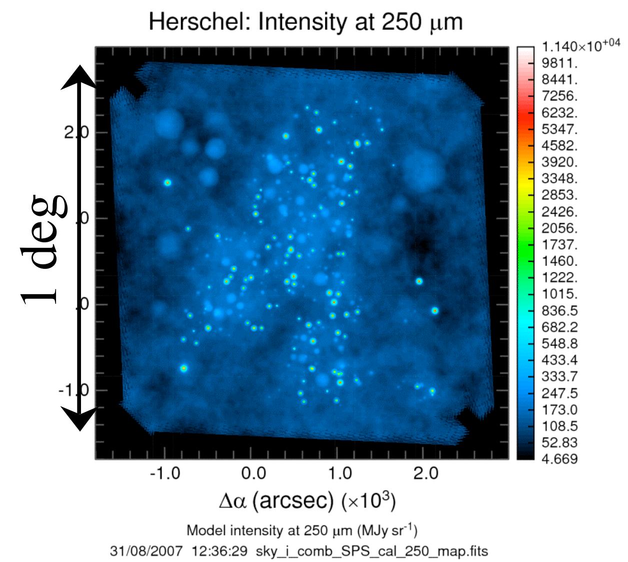


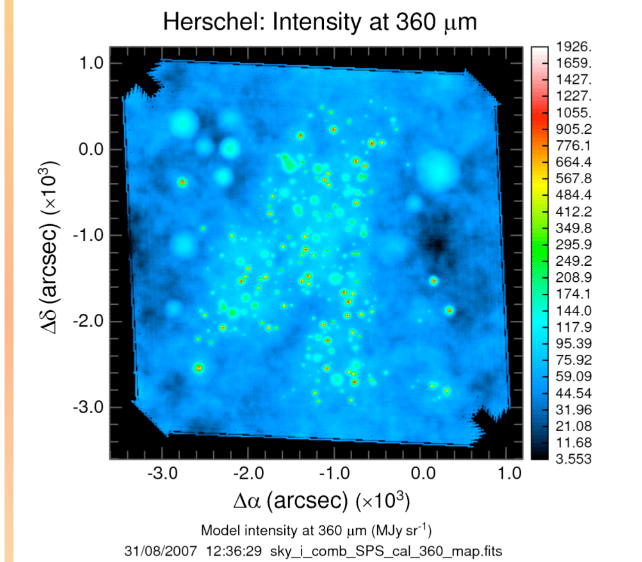
→ ~ 3.2 deg^2 in parallel-mode @ 20''/sec with SPIRE/PACS

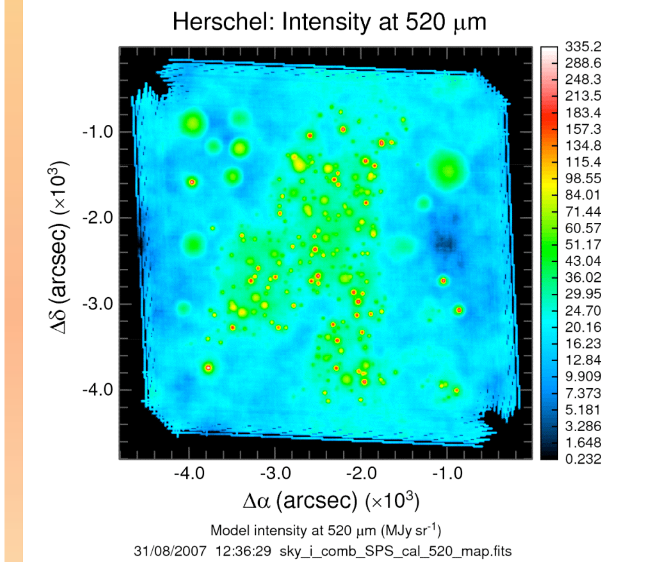
See http://starformation-herschel.iap.fr/hobys for all fields

Simulations of the Herschel SPIRE/PACS mapping

- Synthetic molecular cloud including ISM structure and populations of prestellar cores & protostars with realistic radiative transfer (A. Menshchikov)
- Processing with the SPIRE simulator (B. Sibthorpe, Cardiff) and the PACS simulator (R. Gastaud, Saclay)

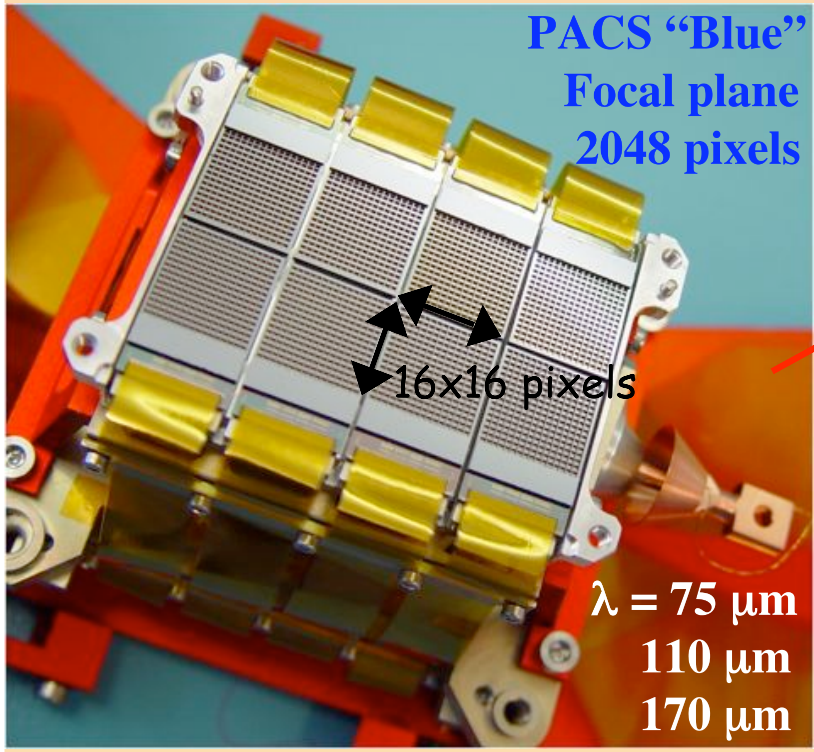


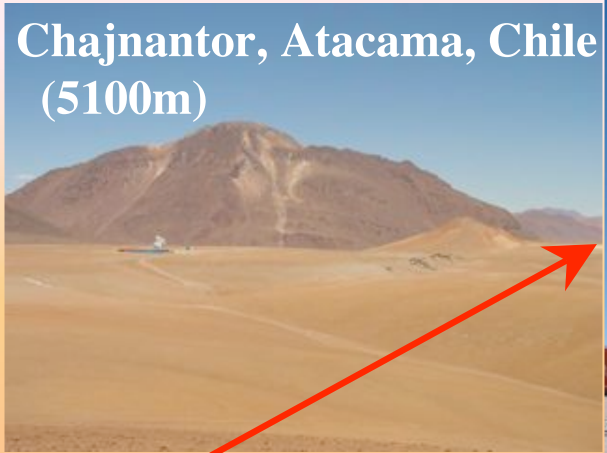


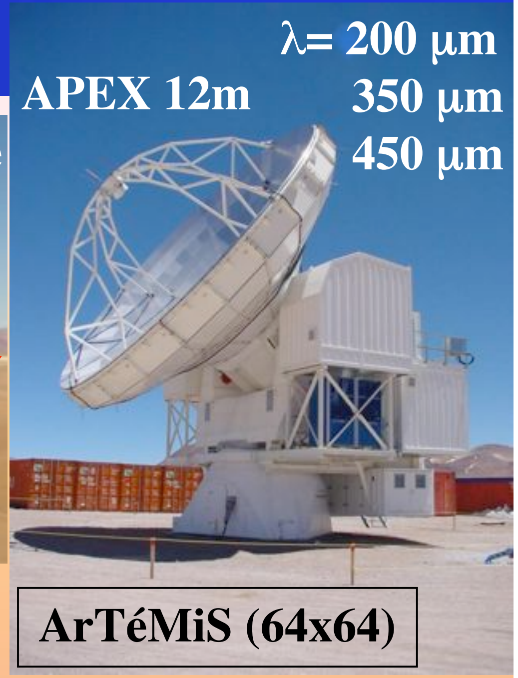


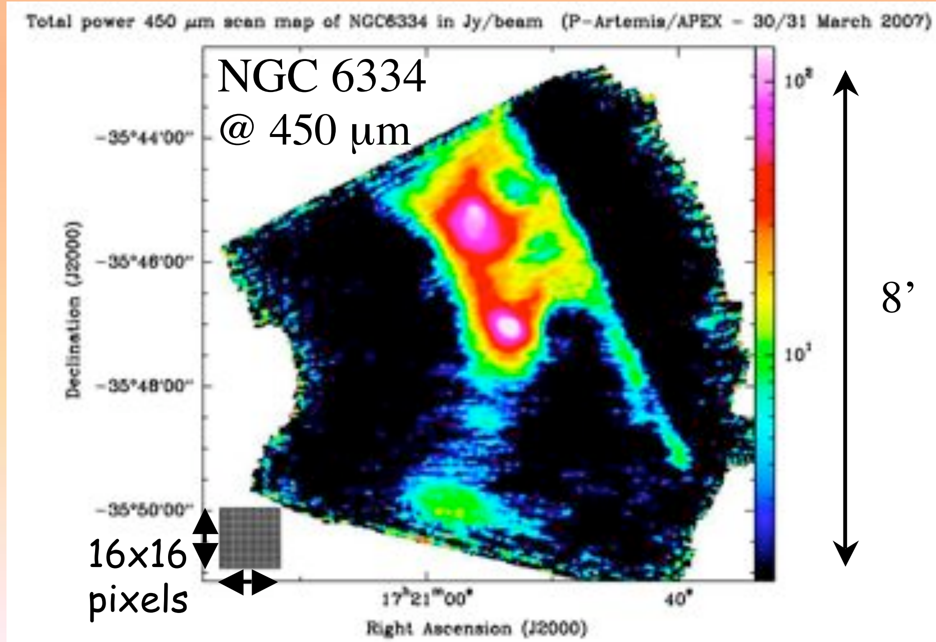
Tests of various background-subtraction and « clump-finding » algorithms (N. Schneider, P. Didelon)

ArTéMiS : Large-format submm bolometer arrays for ground-based telescopes









Driver: Embedded phases of star formation throughout the Universe

Prototype : P-ArTéMiS (16x16) λ = 450 μm

Conclusions: *Herschel* as a pathfinder for ALMA

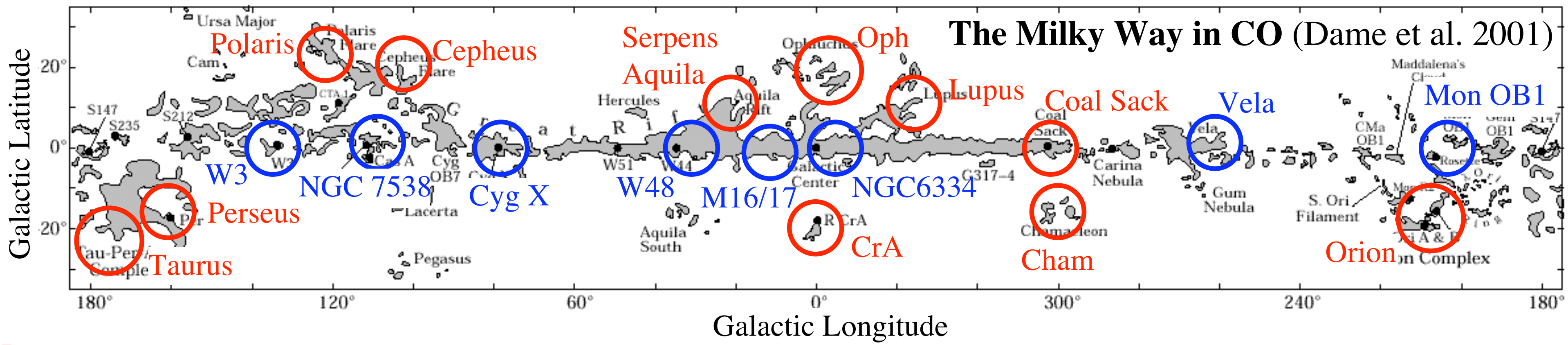
Wide-field unbiased surveys with *Herschel* (SPIRE/PACS) at $\lambda \sim$ 75-500 μm will soon provide complete samples of prestellar cores and young protostars in nearby cloud complexes.

See http:starformation-herschel.iap.fr for details

→ First versions of source catalogs available as early as ~ 2010 (i.e., at the end of the proprietary period)

→ Unique database for follow-up detailed studies with ALMA

Regions to be mapped in the Gould Belt and HOBYS surveys



Many thanks to

Main groups : SPIRE SAG 3
(eg. S. Bontemps, J. Di Francesco,
D. Ward-Thompson, C. Wilson,
A. Abergel, M. Griffin,
P. Martin, G. Olofsson, G. White)

PACS Institutes
- **CEA Saclay (**F. Motte, V. Minier, A. Menshchikov, N. Schneider)
- **IFSI Rome** (eg. S. Molinari) & **INAF Arcetri** (eg. L. Testi)
- **OAMP Marseille** (A. Zavagno, J.P. Baluteau, D. Russeil)
- **KU Leuven** (eg. J. Blommaert & C. Waelkens)
- **MPIA Heidelberg** (eg. T. Henning, R. Launhardt)

+ ESA HSC (eg. T. Prusti, S. Leeks, R. Vavrek)