Galactic Cold Cores

M.Juvela
On behalf of the *Galactic Cold Cores* project

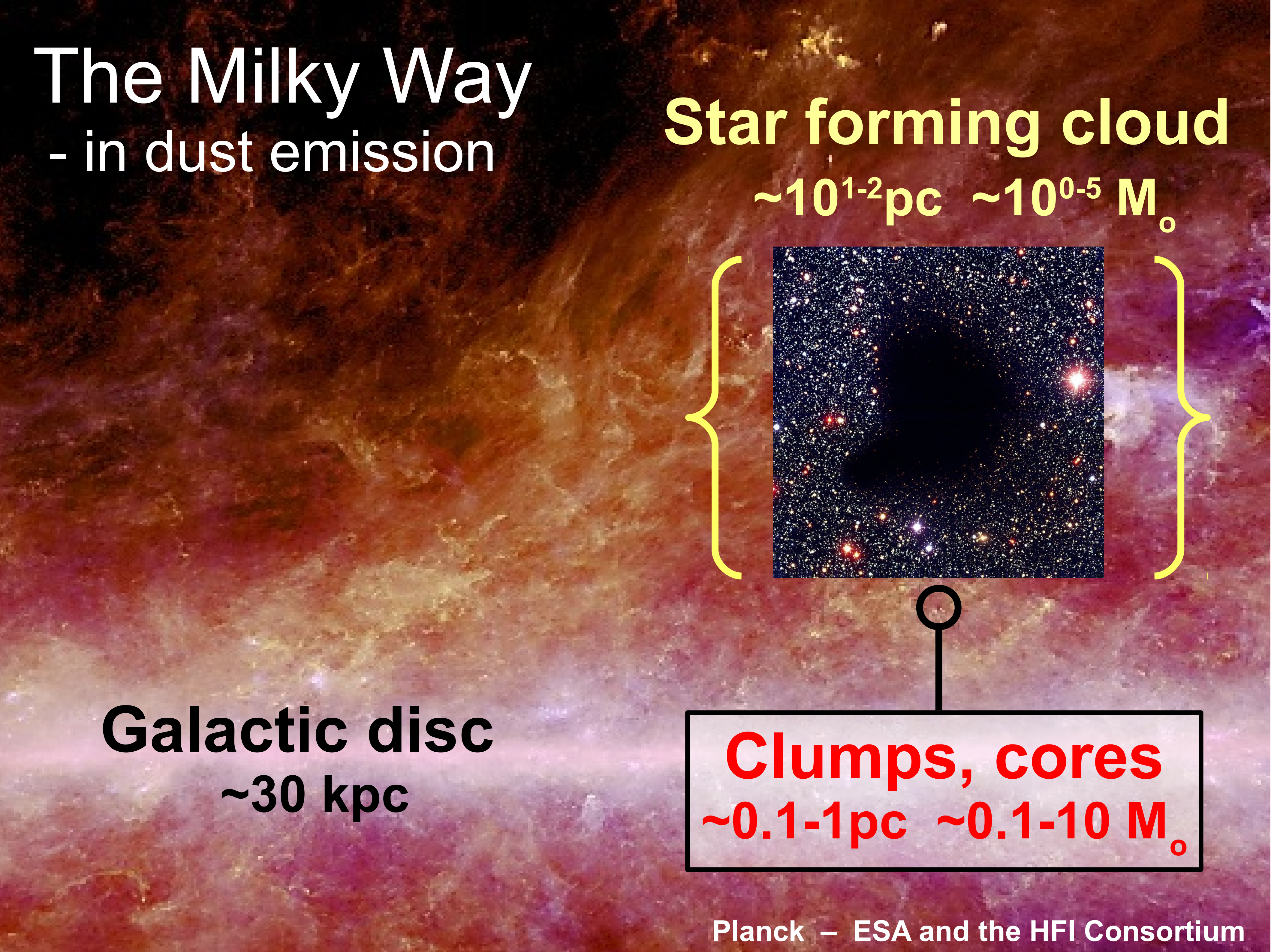
M. Juvela, **I. Ristorcelli** (coord.)

Desert, Dupac, Giard, **Harju**, Harrison, Joncas, Jones, Lagache, Lamarre, Laureijs, Lehtinen, Maffei, Martin, **Marshall**, **Malinen**, Mattila, **McGehee**, **Montier**, Pajot, **Paladini**, **Pelkonen**, Tauber, Taylor, Valenziano, Verstraete, **Ysard**

Abergel, **Bernard**, Boulanger, Cambresy, Davies, Dickinson, Fischera, Macias-Perez, Meny, Miville-Deschenes, Nartallo, Puget, Reach

Andre, Kiss, Klaas, **Krause**, Molinari, Motte, **Pagani**, Schneider, **Toth**, Ward-Thompson, **Zavagno**, Marton, Verebelyi

Doi, Ueno, Kitamura, Nikeda, Kawamura, Onishi

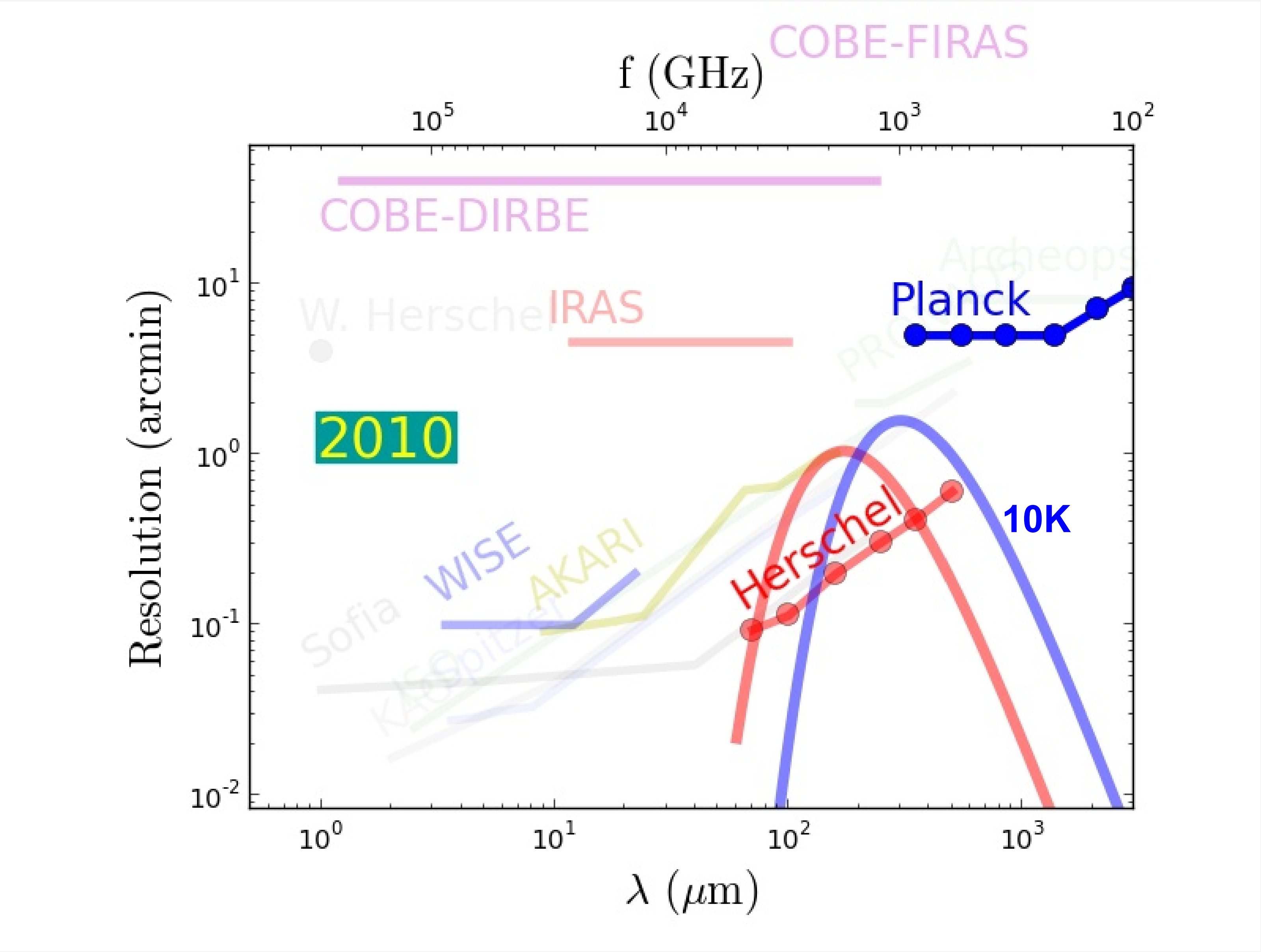

The Milky Way
- in dust emission
Star forming cloud
~10^{1-2}pc ~10^{0-5} M_{o}
Galactic disc
~30 kpc
Clumps, cores
~0.1-1pc ~0.1-10 M_{o}
Planck – ESA and the HFI Consortium

The objects

- **Cold** cloud cores, where the stars are born
  - ***T*** down to 6K? (Evans et al.2001, Galli et al. 2002; Pagani et al. 2003; Crapsi et al. 2007; Harju et al. 2008)
- We want to **understand** the physics
  - Density → the origin of the density field
  - Temperature → factors affecting thermal balance
  - Velocity field → core formation and evolution

The tools

- Observations of **spectral lines**
- Observations of **dust**
  - **thermal dust emission**
  - light scattered by dust
  - light extinction

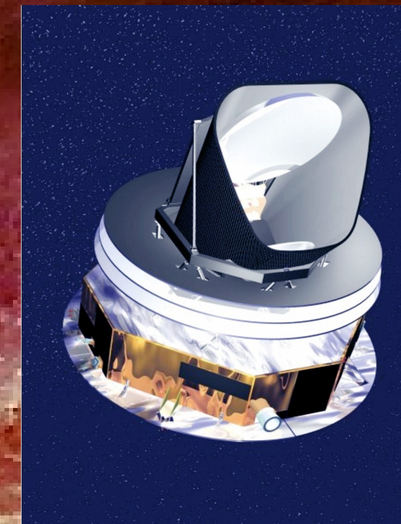

COBE-FIRAS
f (GHz)
10^5
10^4
10^3
10^2
COBE-DIRBE
Planck
IRAS
W. Herschel
2010
10K
Herschel
WISE
AKARI
Sofia
Resolution (arcmin)
10^1
10^0
10^-1
10^-2
10^0
10^1
10^2
10^3
λ (μm)

Cold Cores & **Planck**

The Planck satellite mapped the sky at nine sub-millimetre and radio wavelengths

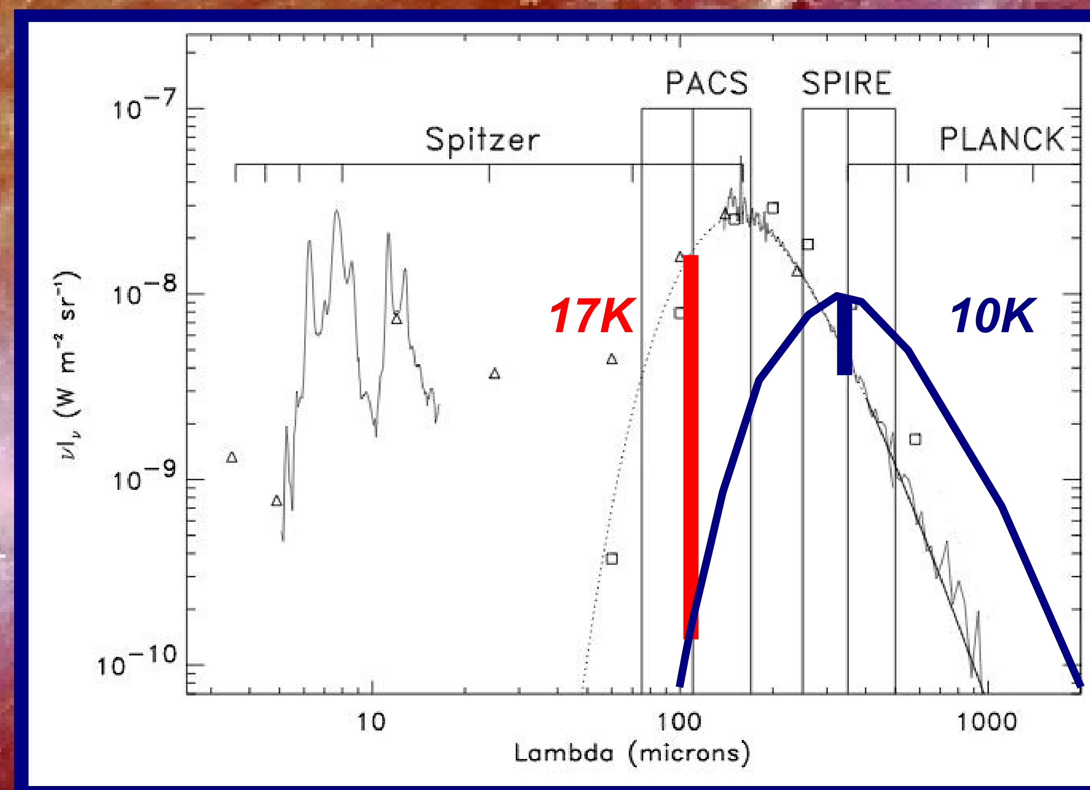
- **350µm, 550µm, 850µm**, ...,1cm
- **better than 5'** resolution in the sub-mm

Enables the **detection of cold clumps**!



Planck is also **the first** mission capable of a full survey

- full sky coverage
- sub-millimetre bands
- sufficient resolution
- excellent sensitivity

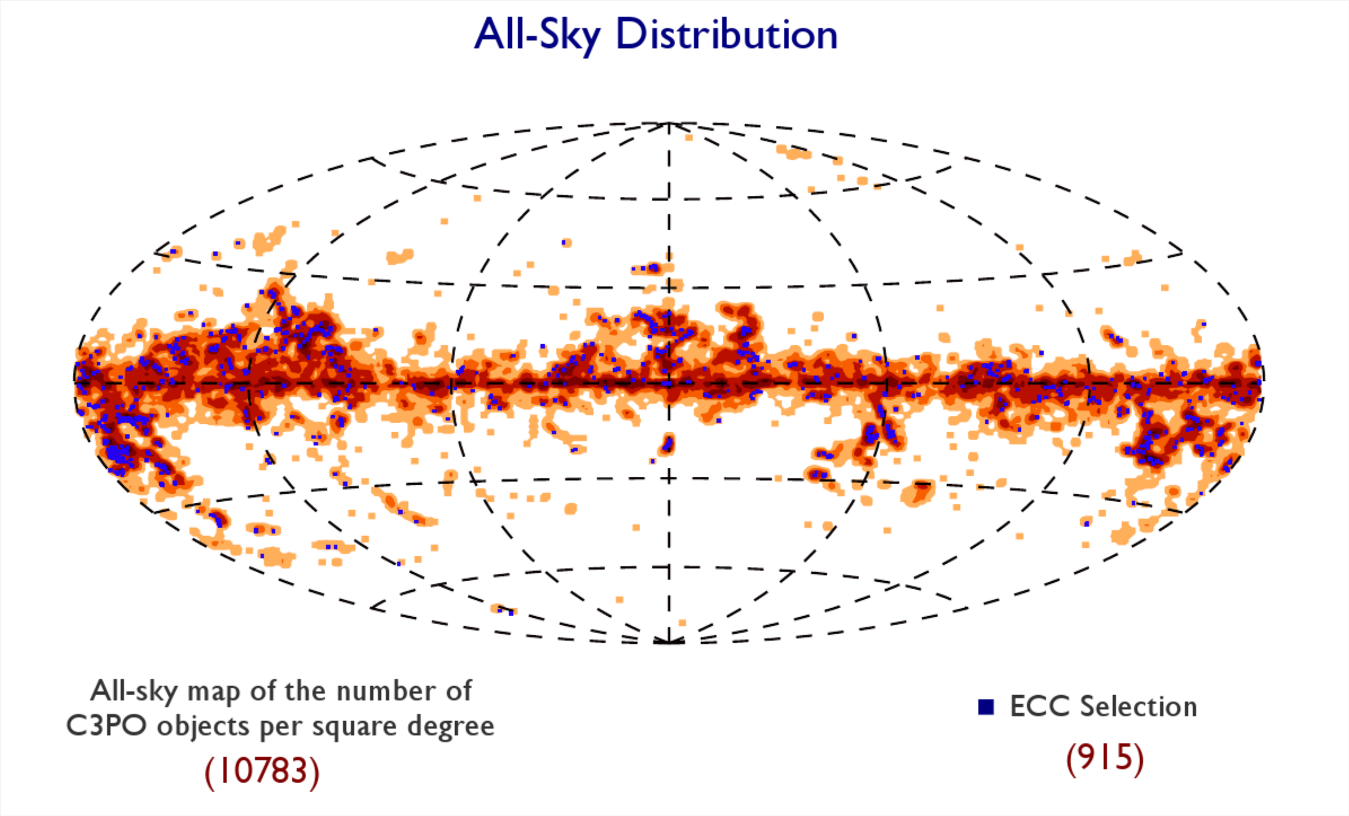


Preliminary catalog **C3PO** had >10000 sources

Some 900 were included in the Early Cold Clumps catalogue

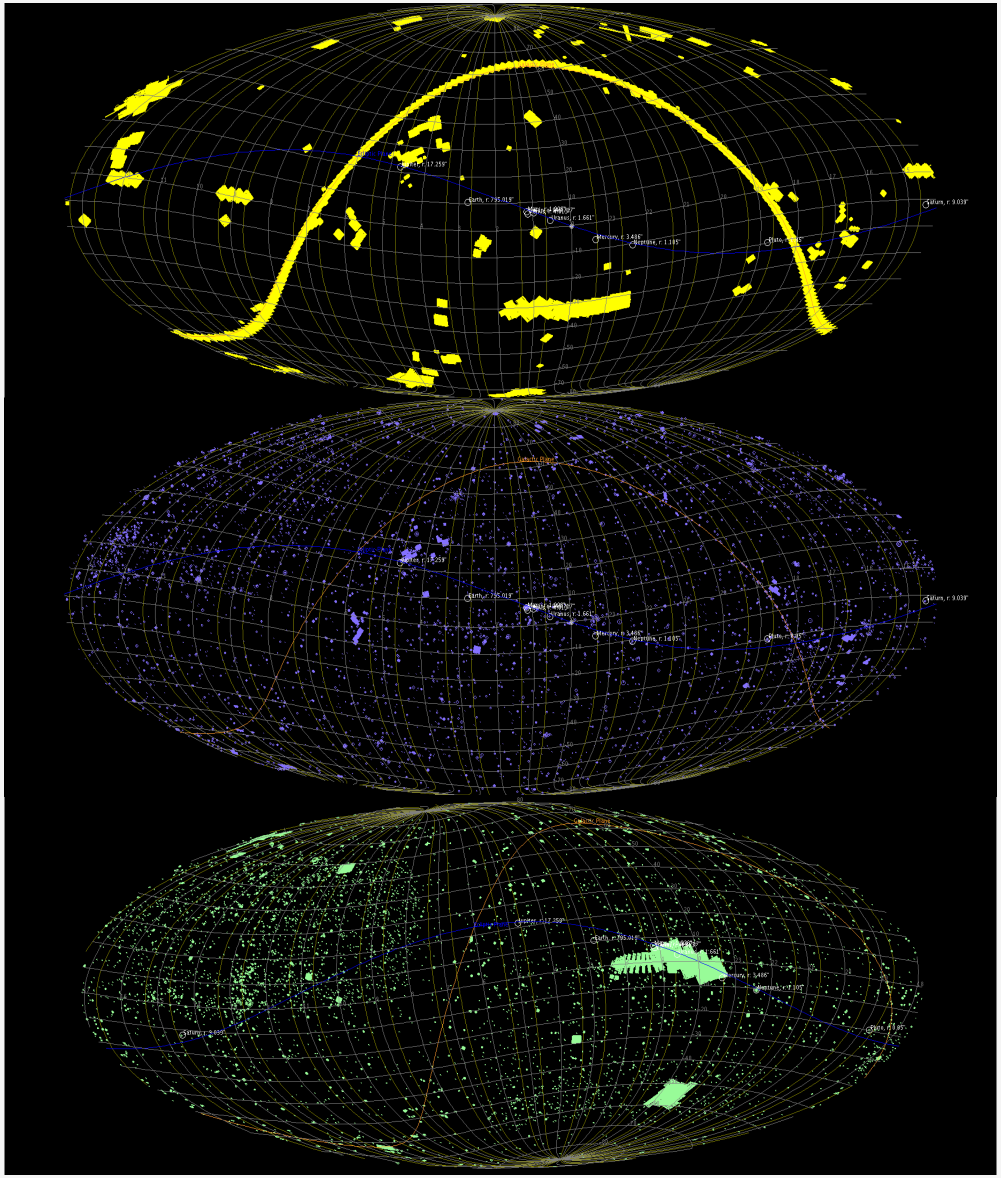
for methods, see L. Montier, V.-M. Pelkonen et al. (2010)

- distances from 100pc to 8kpc, Galactic heights up to ± 400pc



Planck Collaboration (2011)
Planck early results XXIII, A&A 536, A23

Herschel covered almost 10% of the full sky!



Totals (uncert +/- 5%)

• S/P parallel	6.44
• PACS phot	0.67
• SPIRE phot	2.28
• PACS spec	<0.01
• SPIRE spec	<0.01
• HIFI	0.06
• Total Herschel	9.45

These numbers are %-ages of the entire sky (~41,000 sq deg)

Herschel (SPIRE) has observed almost 10% of the entire sky!

By performing about 23,500 hr of science observing!

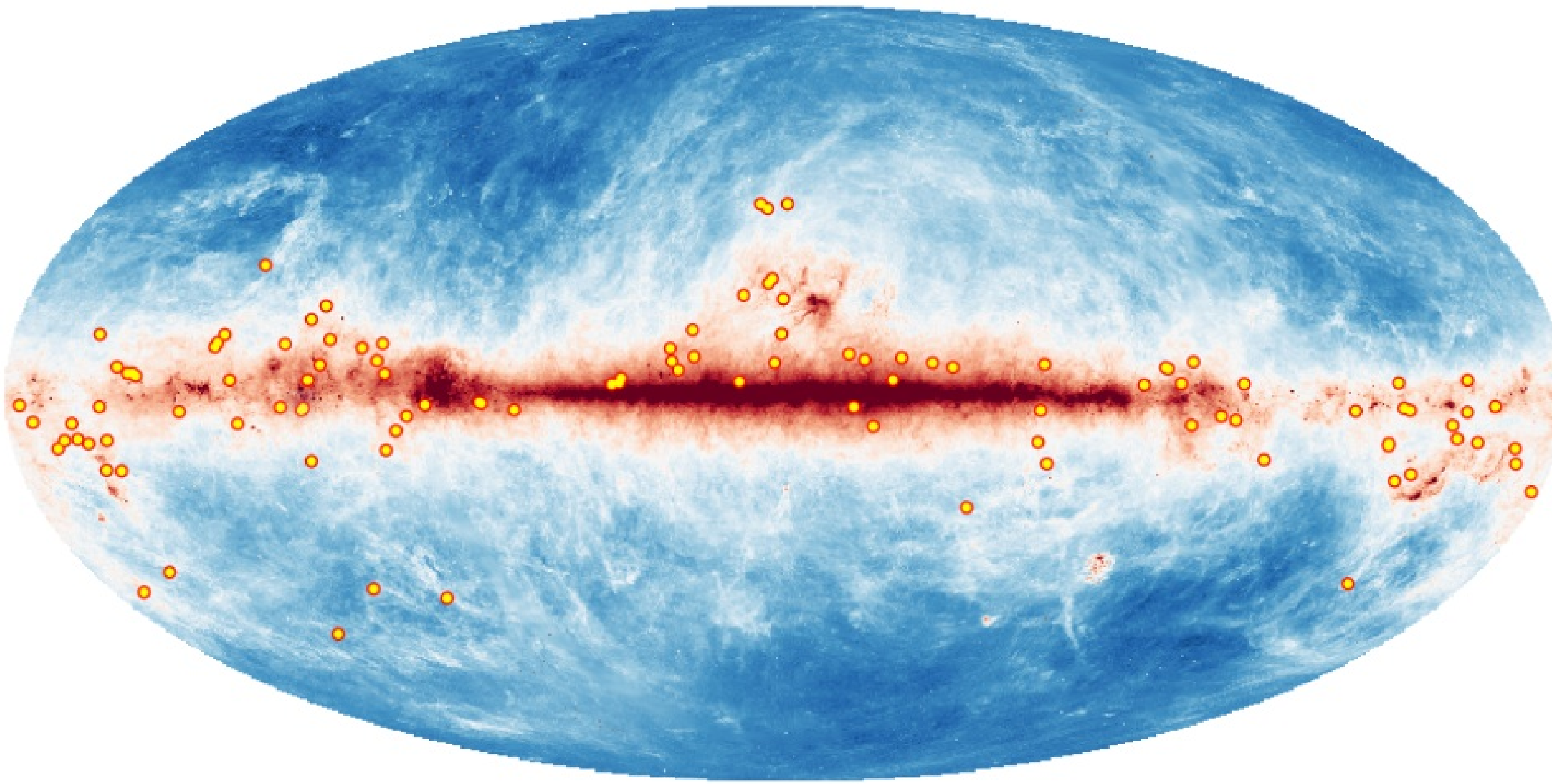
Cold Cores & **Herschel**

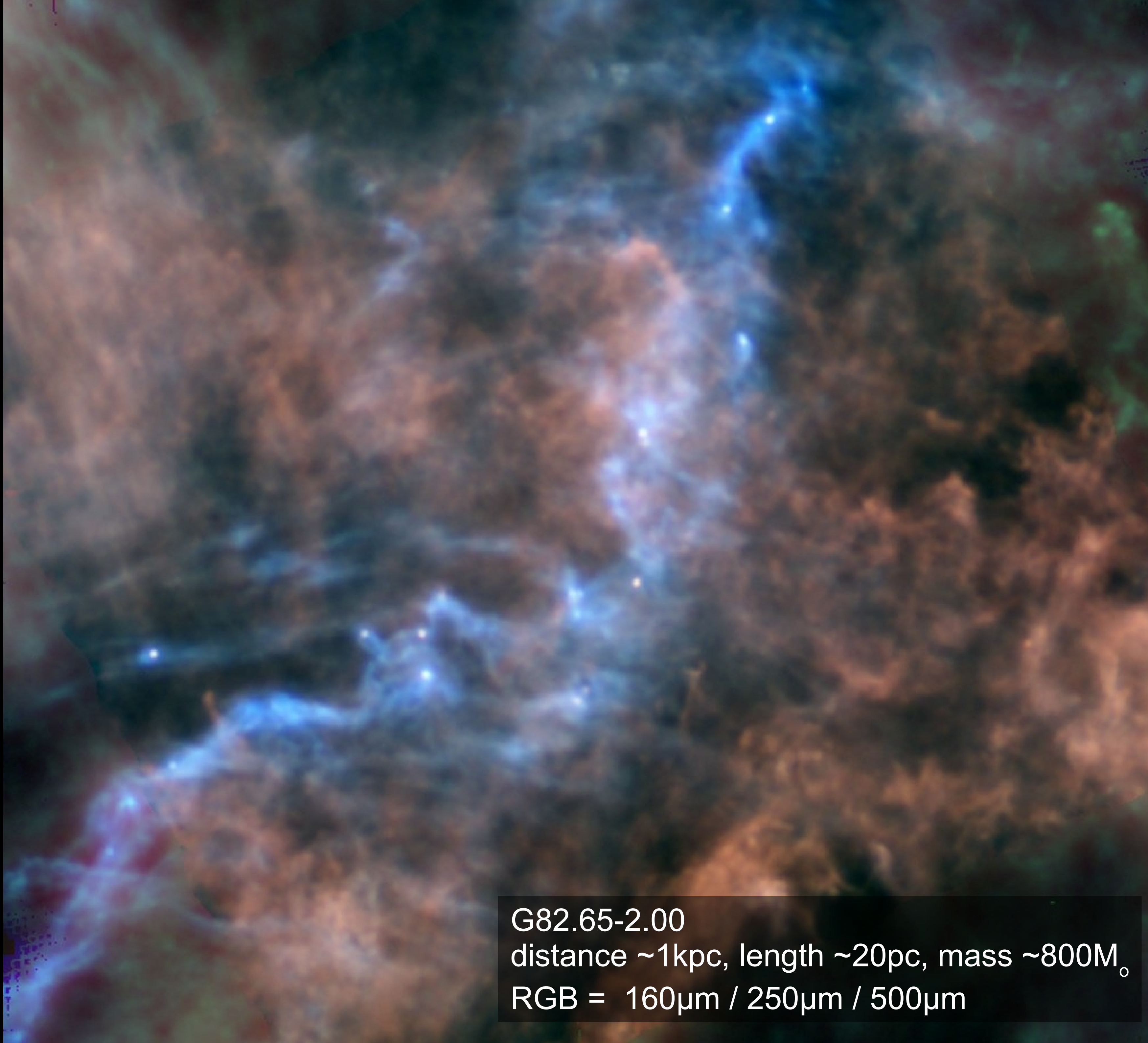
Galactic Cold Cores

- Herschel open time key programme (151h)
- 116 fields with cold Planck clumps
- a **cross-section** of the full source population (*T*, *M*, *n*, *R*, *l*, *b* etc.)
  - Monte Carlo sampling of 108 parameter bins
    - Galactic longitude 0-60, 60-120, 120-180
    - Galactic latitude 1-5, 5-10, 10-90
    - Temperature 6-9, 9-11, 11-14, >14 K
    - Mass **0**, 0.01-2, 2-500, >500 M_{Sun}

- complementary to other Herschel programmes → includes high latitudes, outer regions of molecular cloud complexes, large distances
  - cf. **Gould Belt Survey** (Andre), **HIGAL** (Molinari), **EPOS** (Krause), **HOBYS** (Motte) and many other key/normal programmes

Distribution of the 115 Herschel target fields (100-500μm) that include over 350 Planck-detected cold clumps



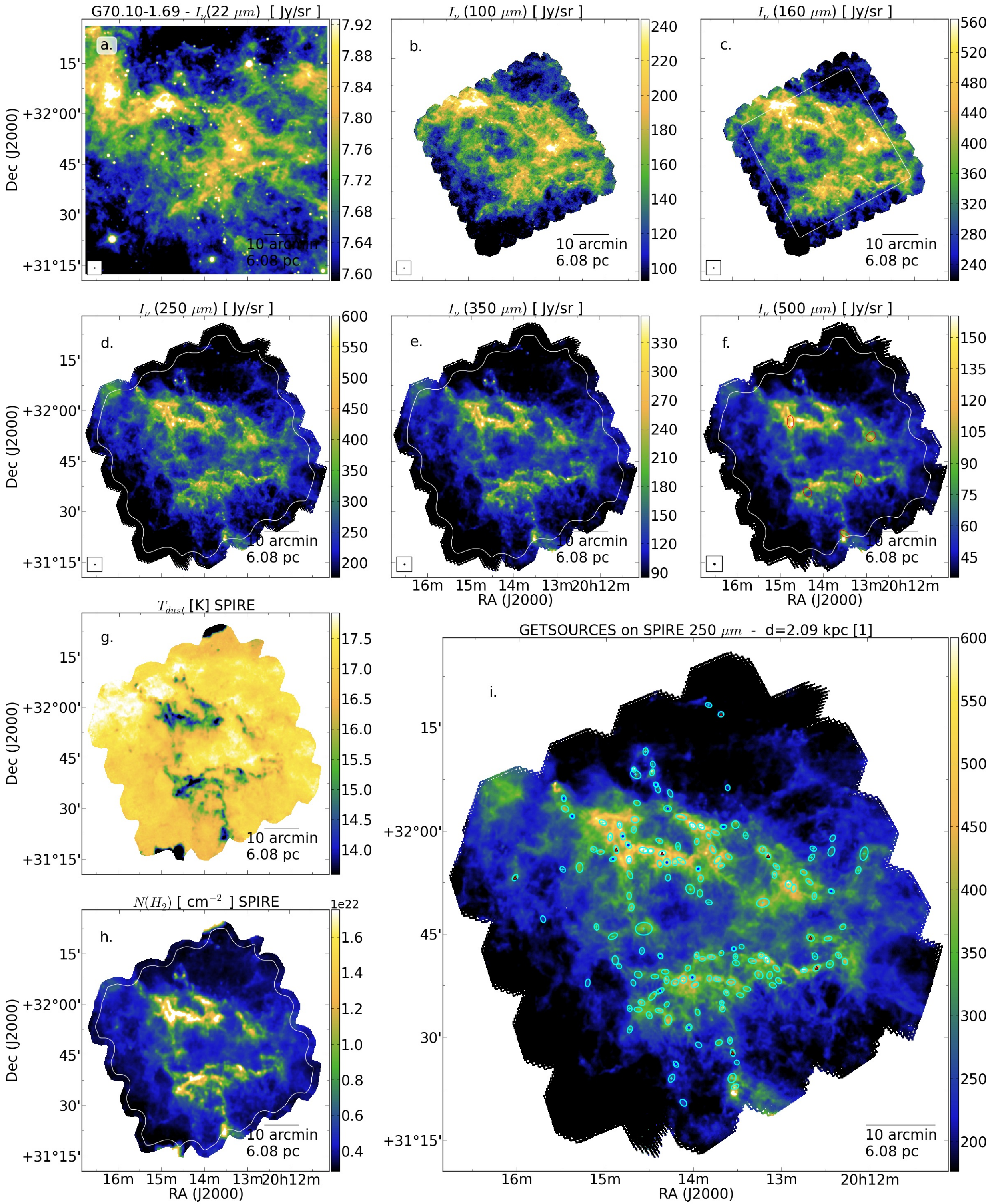

G82.65-2.00
distance ~1kpc, length ~20pc, mass ~800M$_o$
RGB = 160µm / 250µm / 500µm

Star formation

Extraction of clumps and cores

- *getsources* run on 160-500μm and column density: ~4500 sources
  - dropped ~500 potential extragalactic sources
  - protostellar sources were identified with help of WISE and AKARI point source catalogs
    - Koenig et al. (2012) criteria; additional Class 0 objects from 22μm and/or 65μm detections
- detailed investigation of the effect of distance
- analysis of clump properties
  - starless vs. protostellar, vs. Galactic location

J. Montillaud et al. (in prep.)



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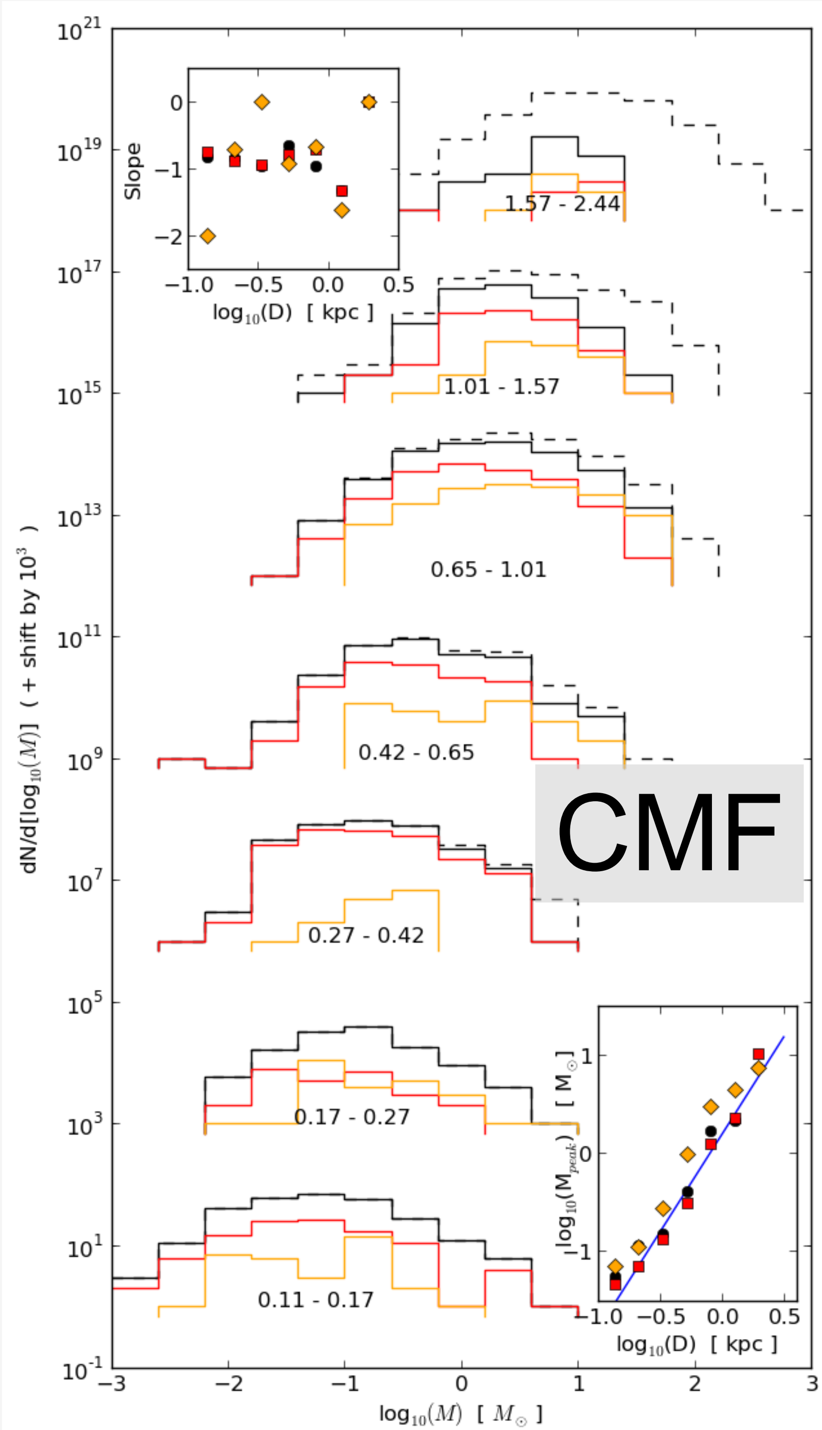

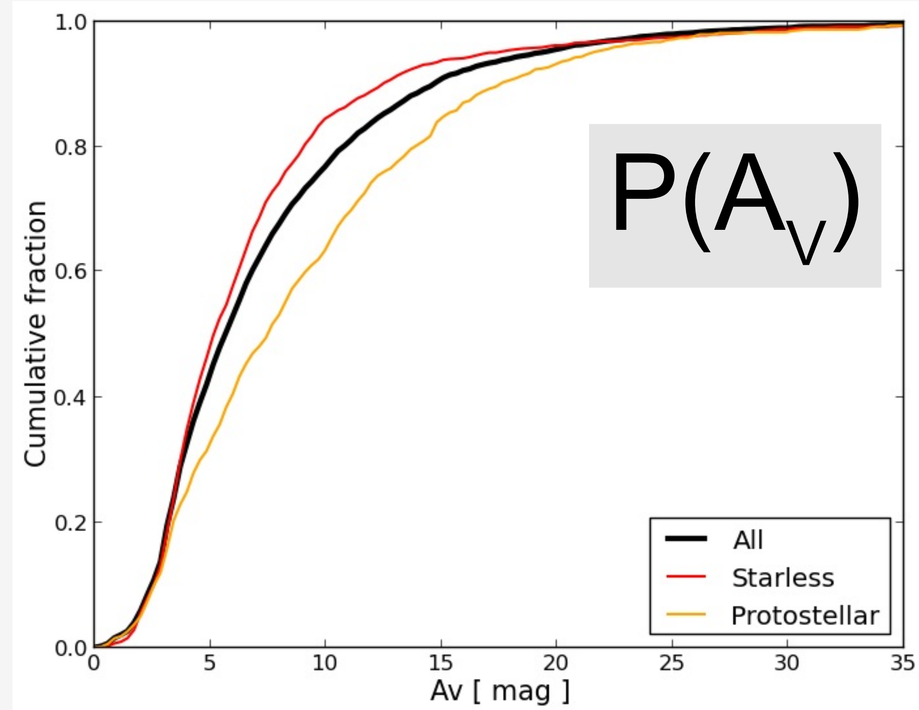

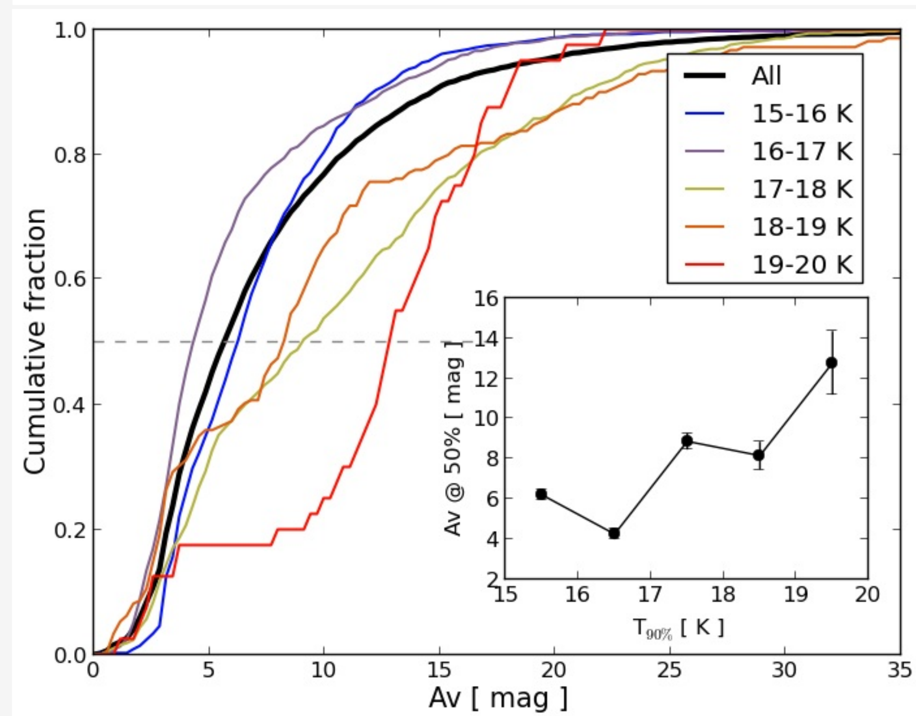

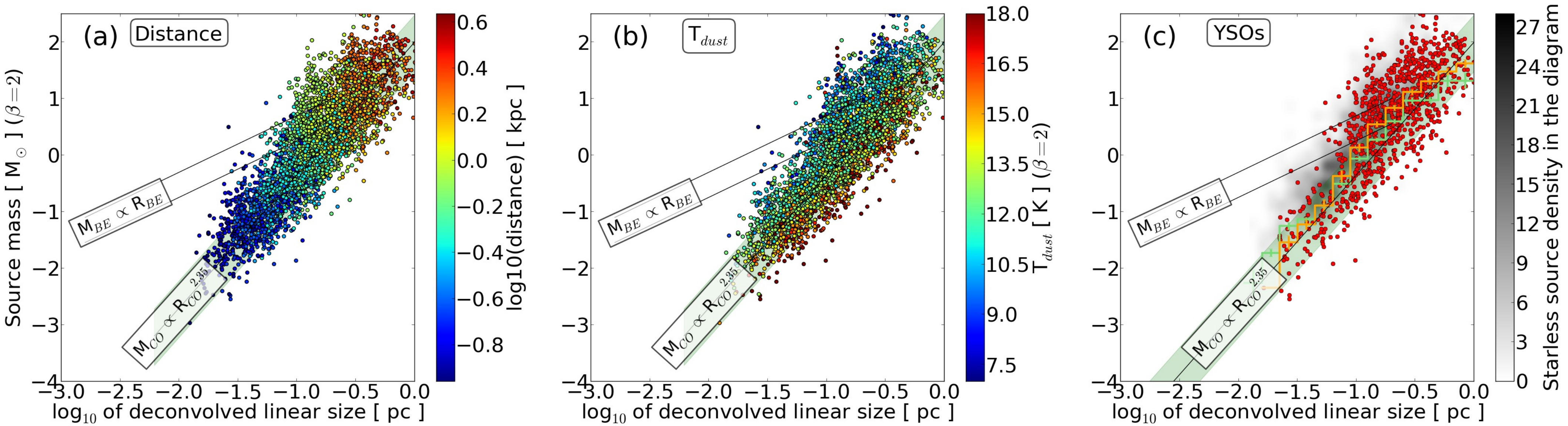

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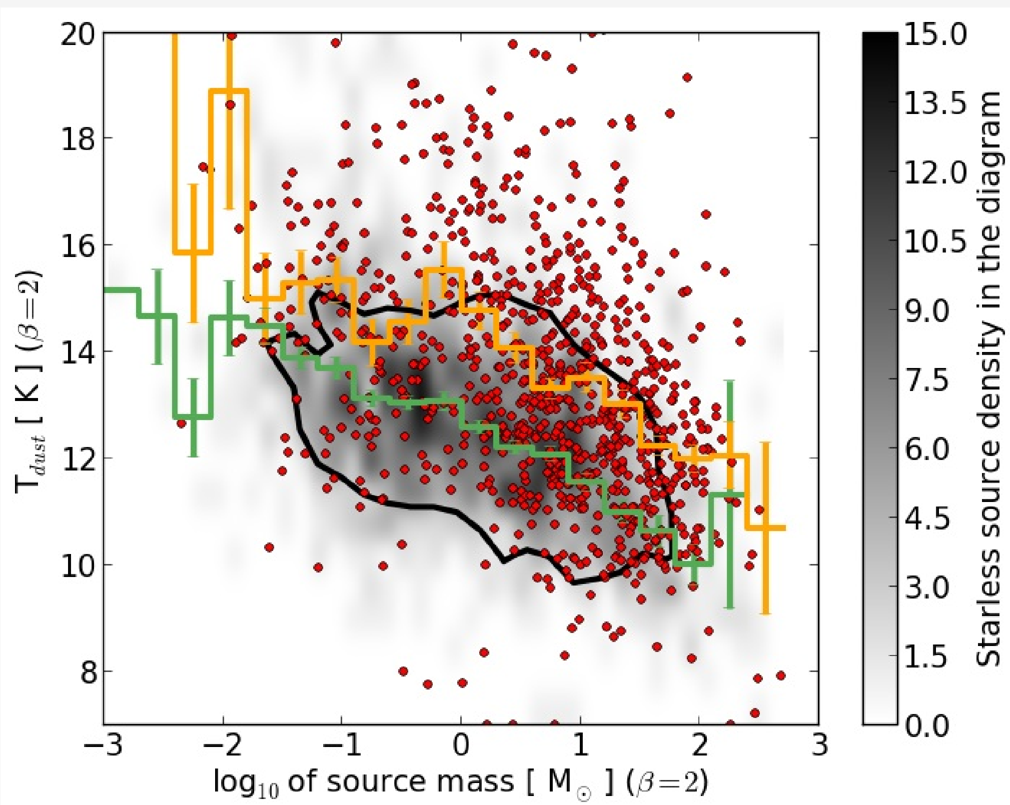


Mass-Size relation consistent with that of CO clumps, $M \sim R^{2.3}$

more massive objects tend to be more distant (and colder)

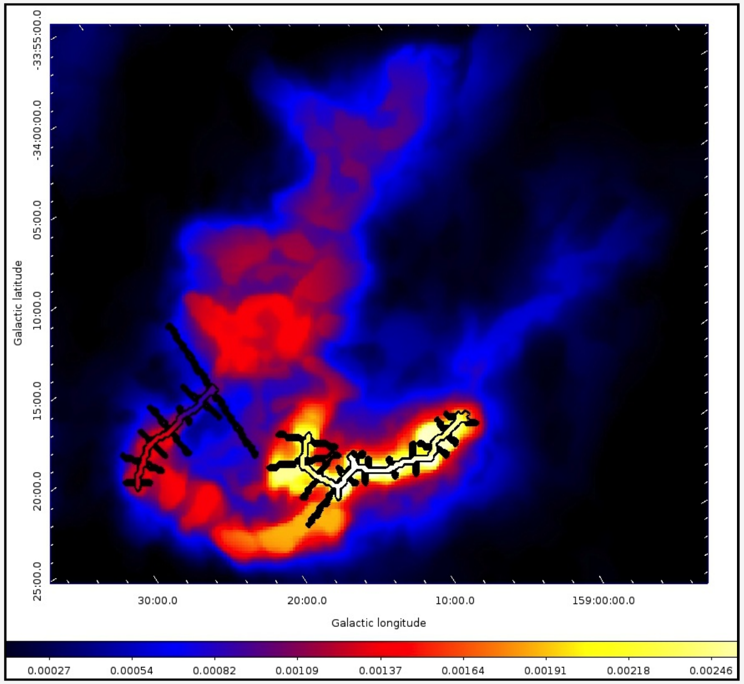
Protostellar cores are warmer (~1K) and have on average higher density

Weak dependence on Galactocentric distance and Galactic height

High latitude clouds

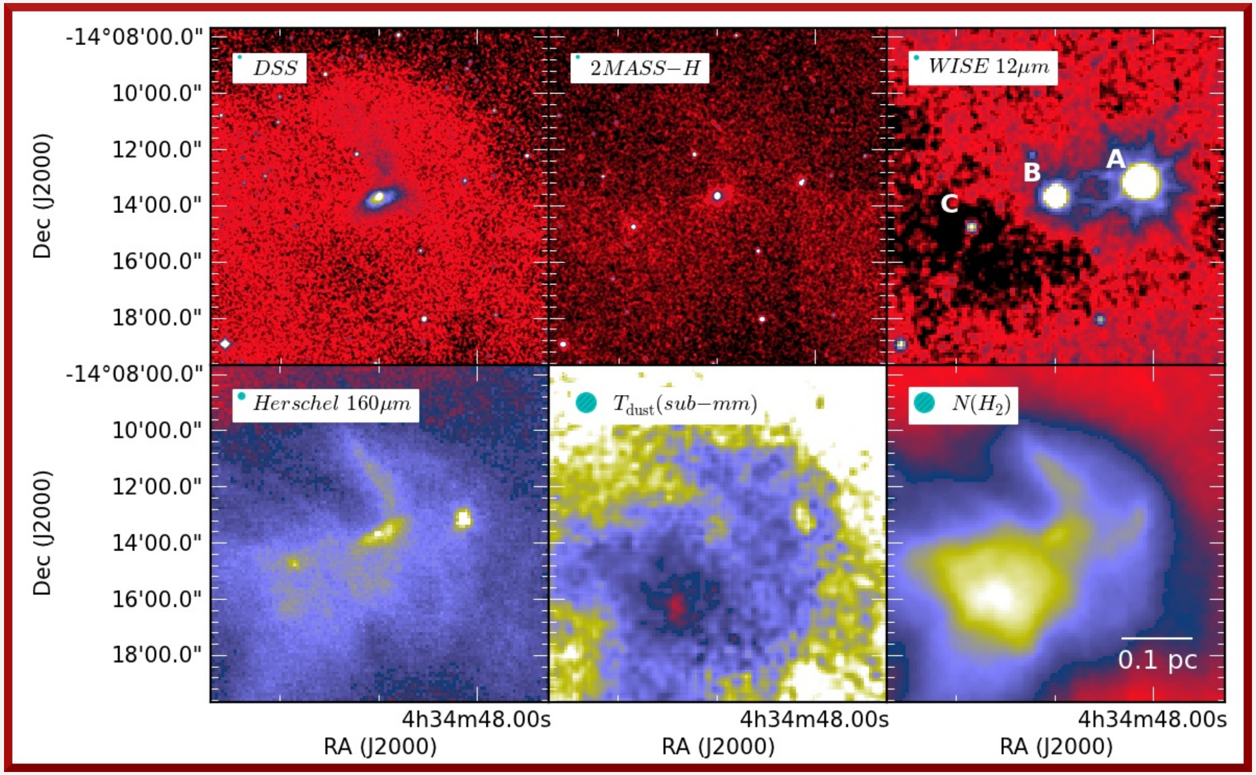
Star and core formation remains poorly constrained in the diffuse environments at high latitudes |b|>25^{o}. Cold Cores fields are used to study of the star/core formation in the most extreme diffuse environments

- Constraining global core/stellar characteristics
    - intrinsic properties through multi-structural analysis
    - external influences
    - evolutionary stages, activity, dust properties
- To examine filamentary structure
    - profiles vs. environment, age, core/star characteristics

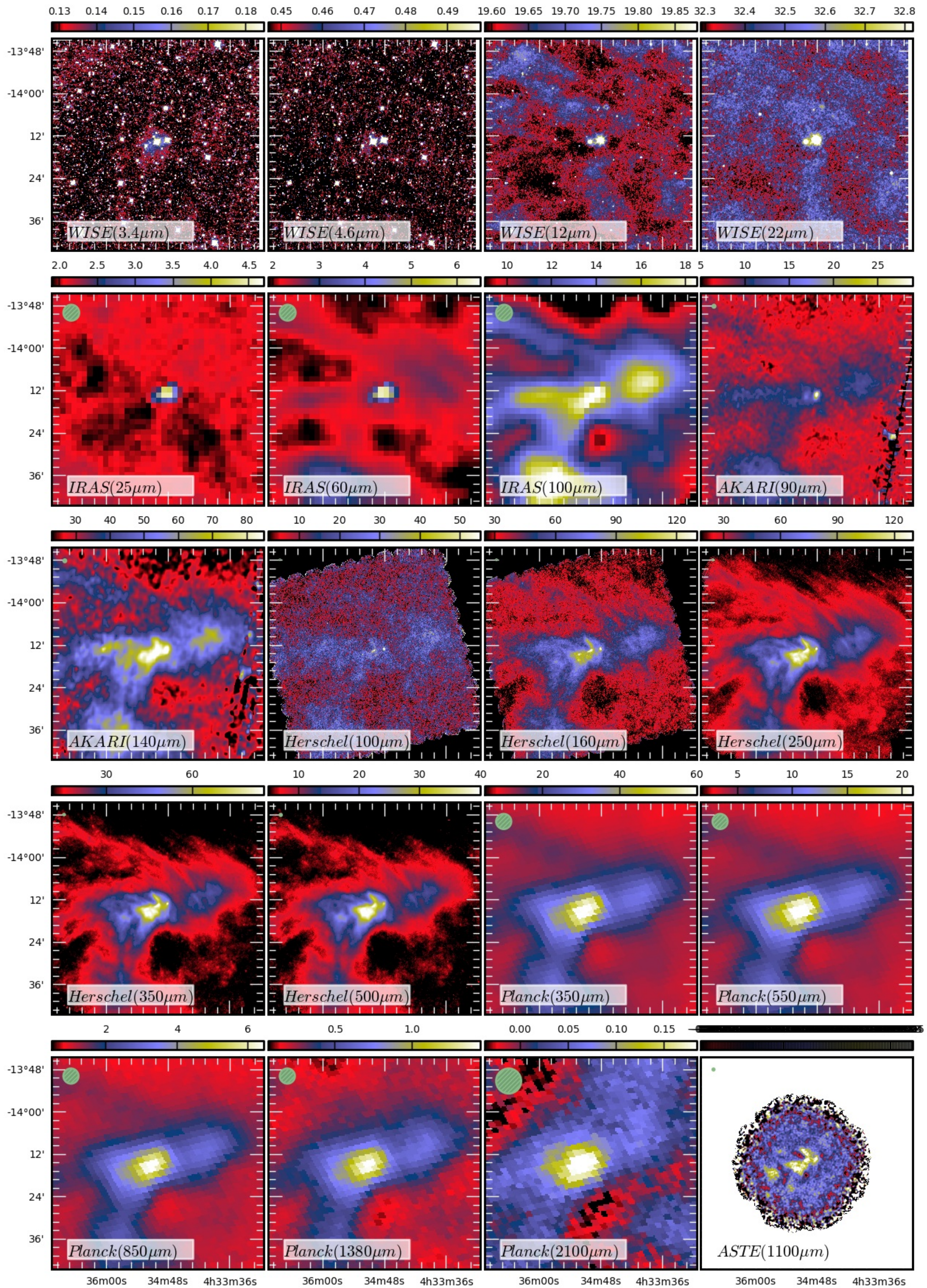


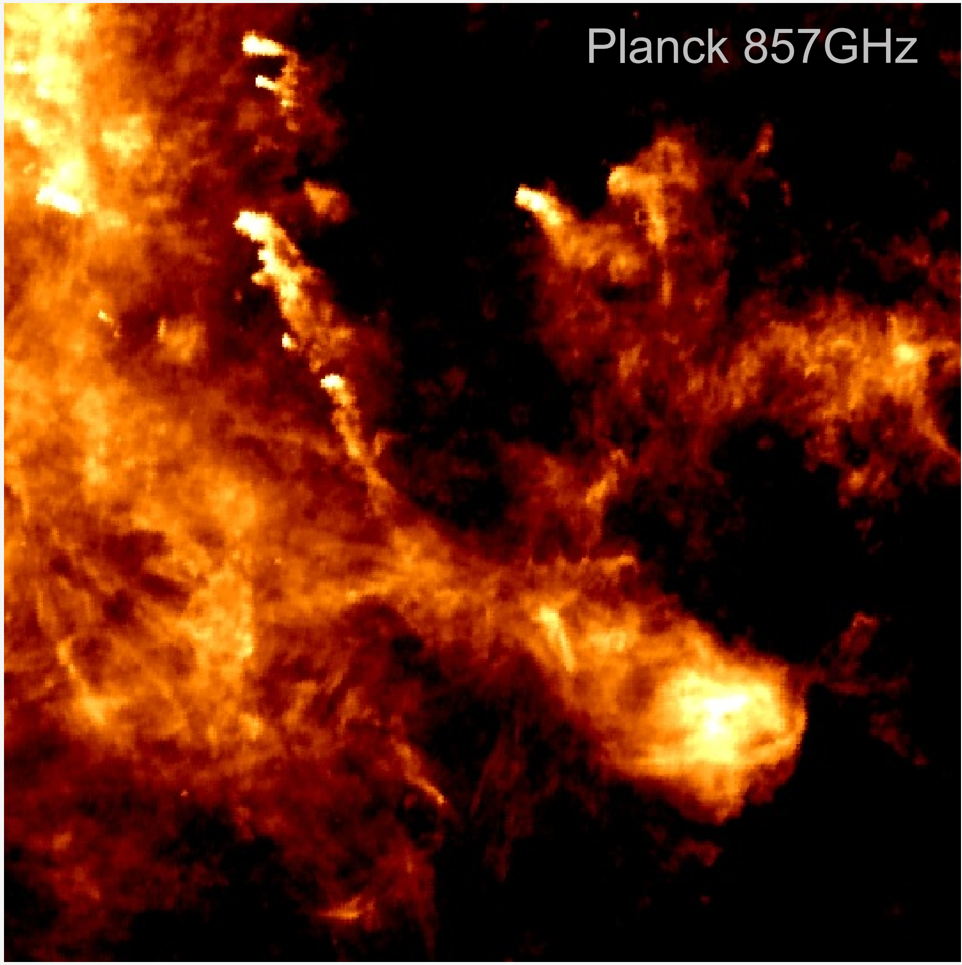
Rivera-Ingraham et al., poster P65/B
Galactic Cold Cores + HOBYS targets

- “Polaris Bear” (I. Ristorcelli et al., in prep.)
  - G126.65+24.55, cometary cloud **without** any star formation
  - Ristorcelli et al., poster P64/B
- LDN1642 (J. Malinen et al., in prep.)
  - apart from MBM12, the only star forming cloud at |*b*|>30°
  - cometary cloud with two previously known binary YSOs (one with bipolar outflow and associated Herbig-Haro objects)
  - third probable YSO (Class-III) detected
  - one cold starless core – not gravitationally bound



L1642 – G210.90**-36.55**





Dust physics

Dust evolution during the star formation process

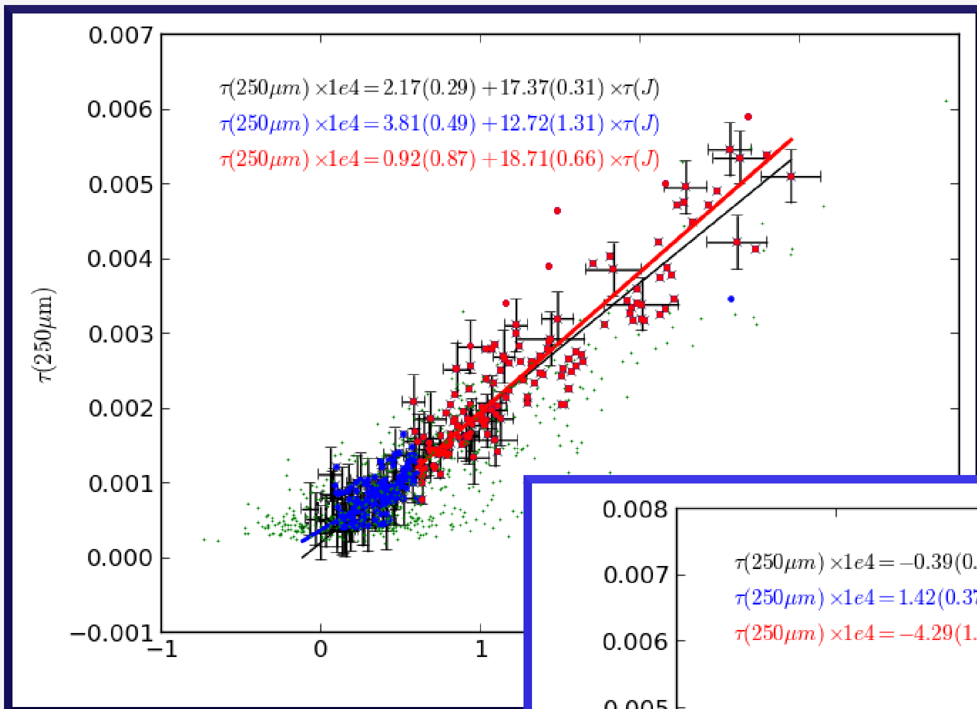
- Diffuse medium vs. dense clouds, different layers of the clumps and cores

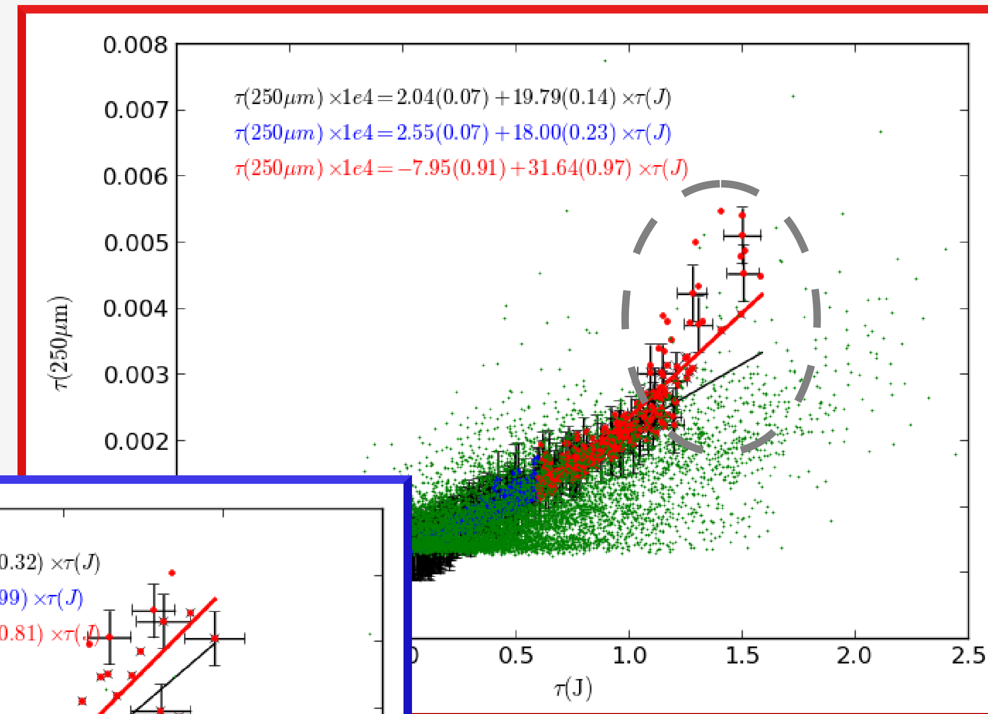
Main parameters

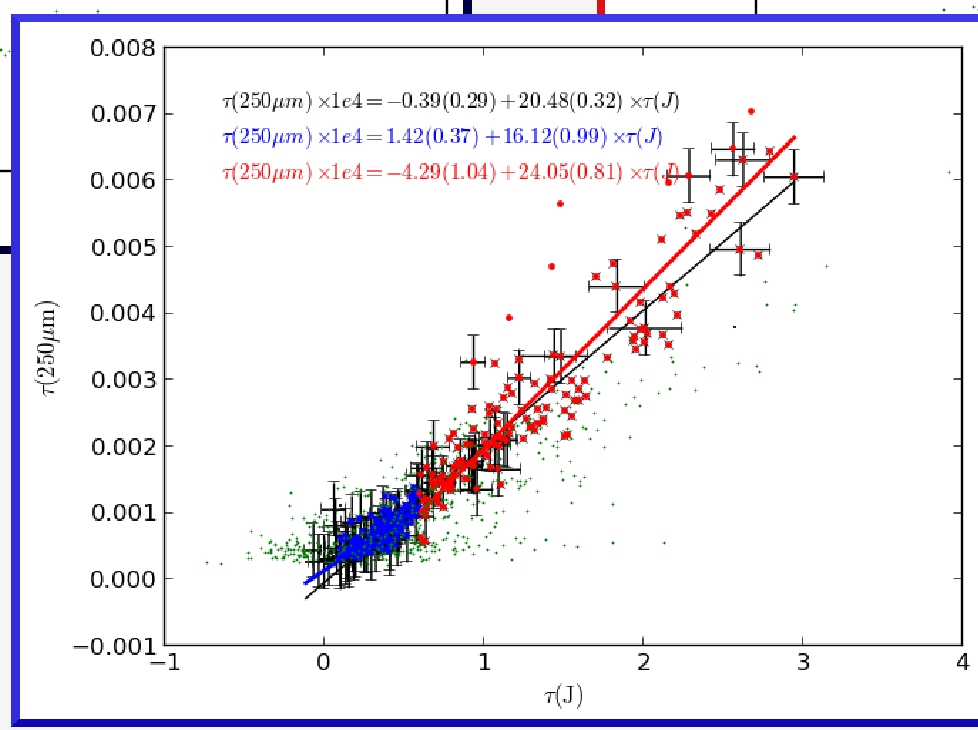
- Dust opacity κ
  - submillimeter wavelengths (Herschel) vs. NIR/MIR extinction and scattering (2MASS,Spitzer, WISE)
    - see Ysard et al. (2013); Juvela, Malinen,Lunttila (2013); Juvela & Montillaud (2013)
- Dust emissivity spectral index β
  - as function of dust temperature, as function of wavelength (Juvela et al. 2011)
    - see also Juvela et al. (2012a,b), Juvela, Montillaud, Ysard, Lunttila (2013)

Variations in dust submillimetre opacity?

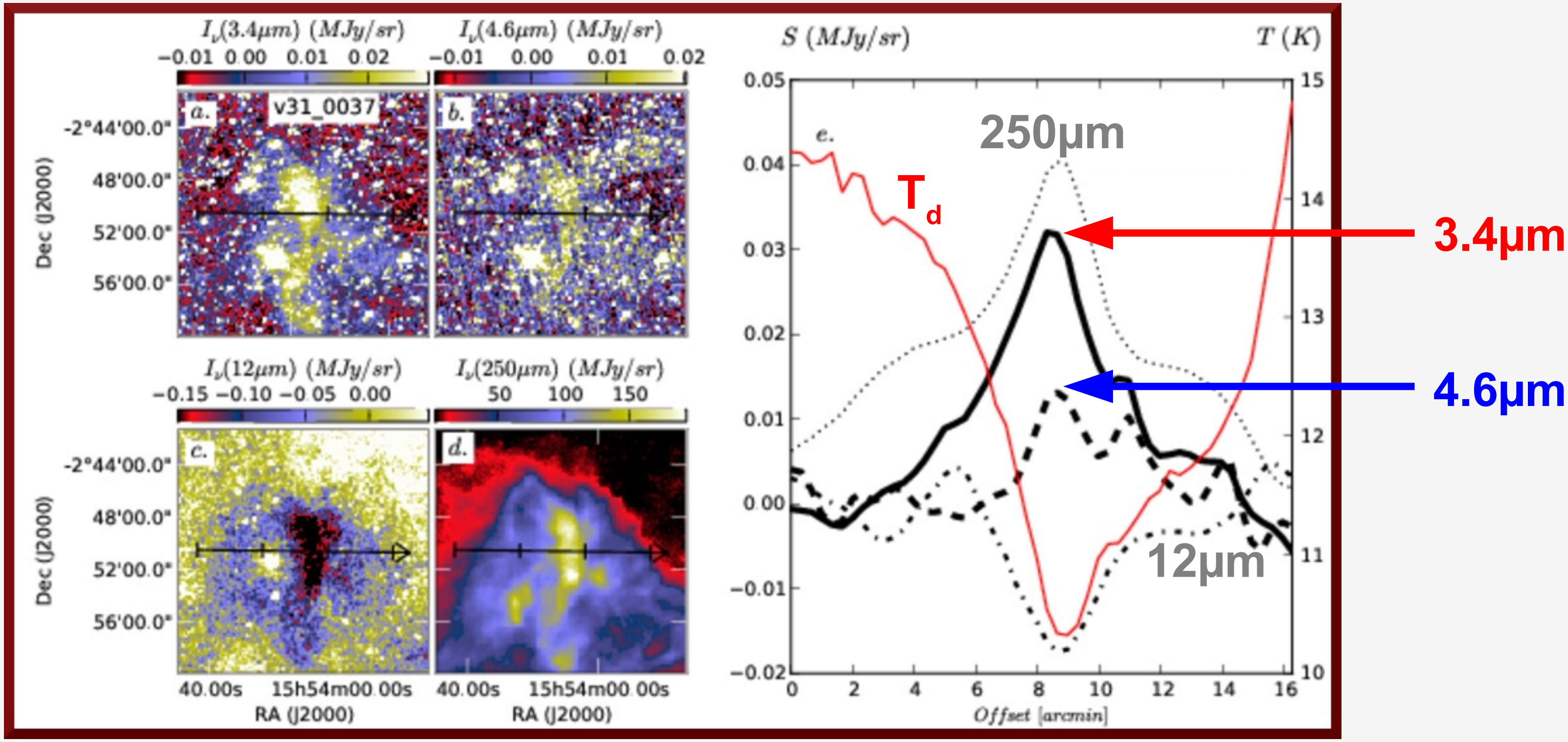
- **most** fields close enough for estimation of NIR optical depth (2MASS) → $\tau_{250}/\tau_J \sim 1.8\times10^{-3} \pm 50\%$







Juvela et al. (in prep.)



Juvela et al. (2012d)

- In dense cloud cores **scattered light** sometimes seen even at ~3.5μm (***Coreshine*** Steinacker et al. 2010, Pagani et al. 2010)
- Out of 56 fields, WISE gave four detections (+6 tentative)
  - Spitzer programme on 90 Planck clumps, PI **R. Paladini**

Molecular line follow-ups...

Toth et al., poster P80/B

Summary

115 "Cold Cores" fields mapped with PACS and SPIRE

- 100μm-500μm; data (HIPE 10.0) all *available in the archive*
- Half of the fields star forming – little activity at high latitudes

Clump catalog in preparation

- ~4000 submillimetre sources (starless and protostellar)
- YSO clumps slightly warmer and denser; little variation as function of Galactic location

Signs of dust evolution

- increase in κ (τ_{250}/τ_J), inverse $\beta(T)$ relation, coreshine, ...

To-do

- density and temperature structure of clumps and cores, final estimation of the interdependence of T and β