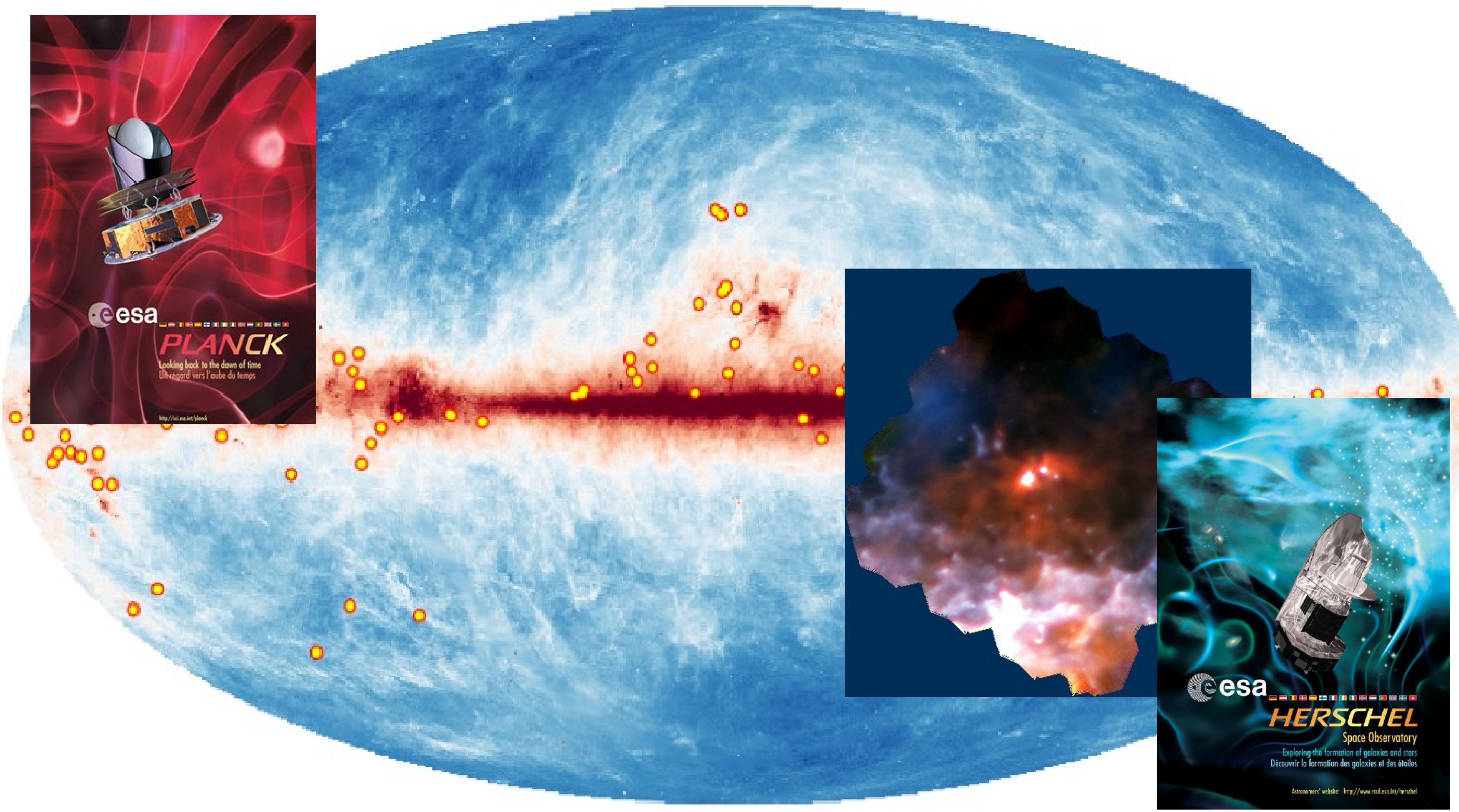
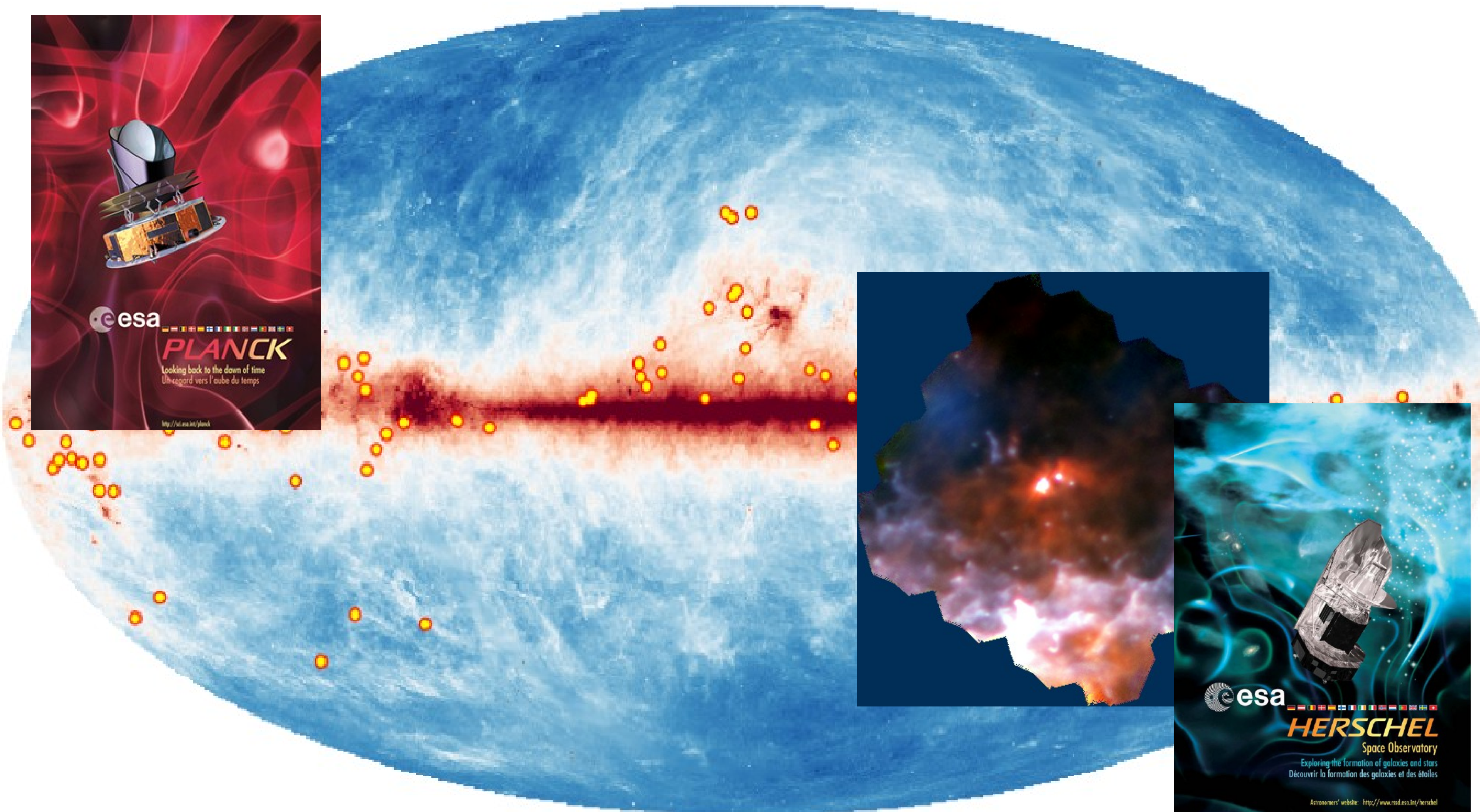
Herschel observations of selected Planck cold clumps

Mika Juvela, on behalf of the Planck and Herschel projects on cold cores

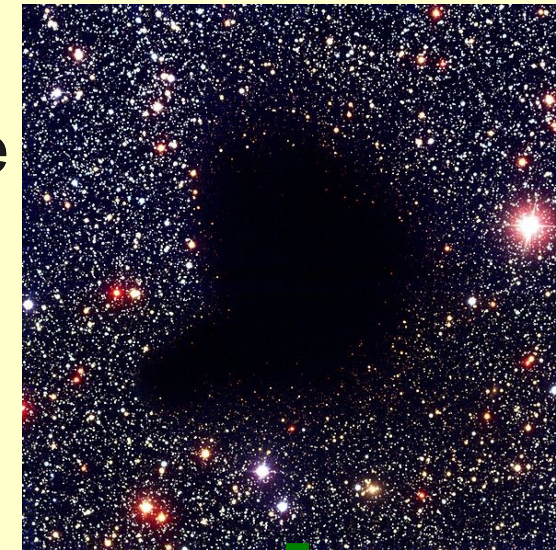


Herschel observations of selected Planck cold clumps

Mika Juvela, on behalf of the Planck and Herschel projects on cold cores



Galactic Cold Cores



- Sub-millimetre dust emission probes dense molecular clouds, also the **hidden cold** phase
- Tracer of the **earliest phases of star formation**
  - What creates **cores**, what determines evolution to **protostars**, stars, clusters
  - Origin of the global stellar **initial mass function** (IMF)

- Part of the life **cycle of dust**
  - from diffuse medium to protostars

We need **large samples** of cores in different environments

Cold Cores & Planck

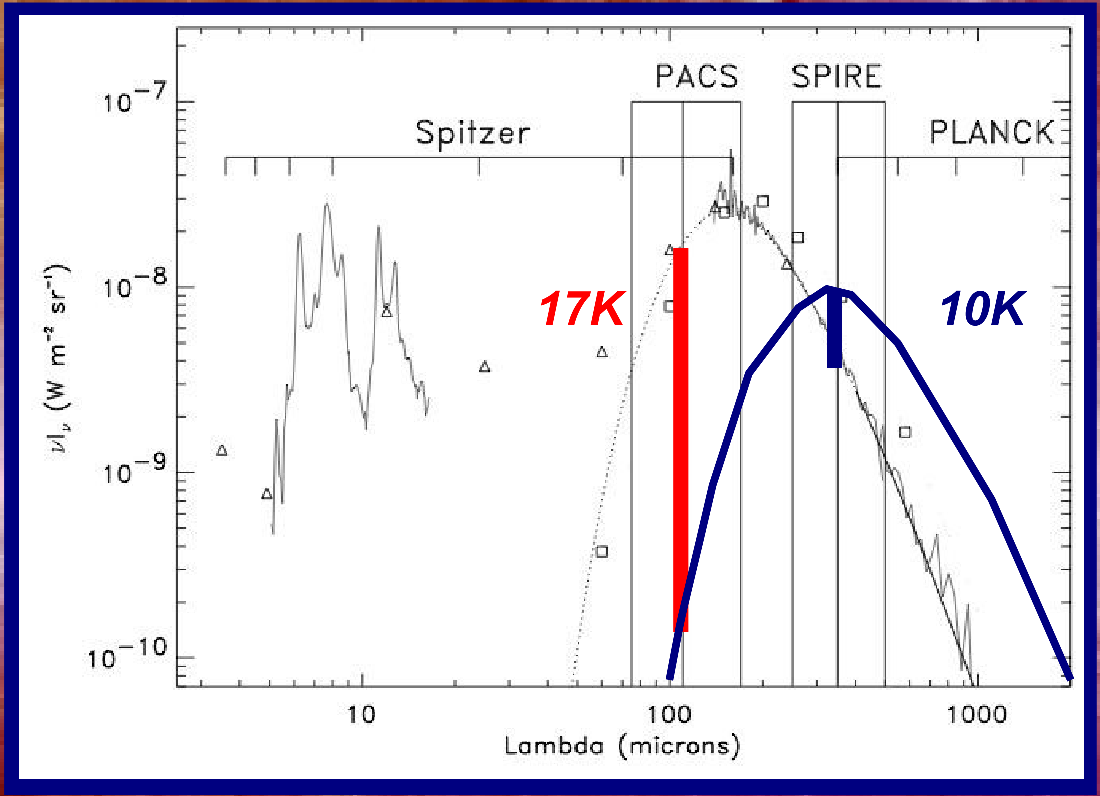
The Planck satellite is mapping the sky at 9 frequencies between 857GHz and 30 GHz

- **350, 550, 850**, 1380, 2100, ...,10000 µm
- **better than 5'** resolution in the sub-mm

This enables the **detection of cold clumps**!

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

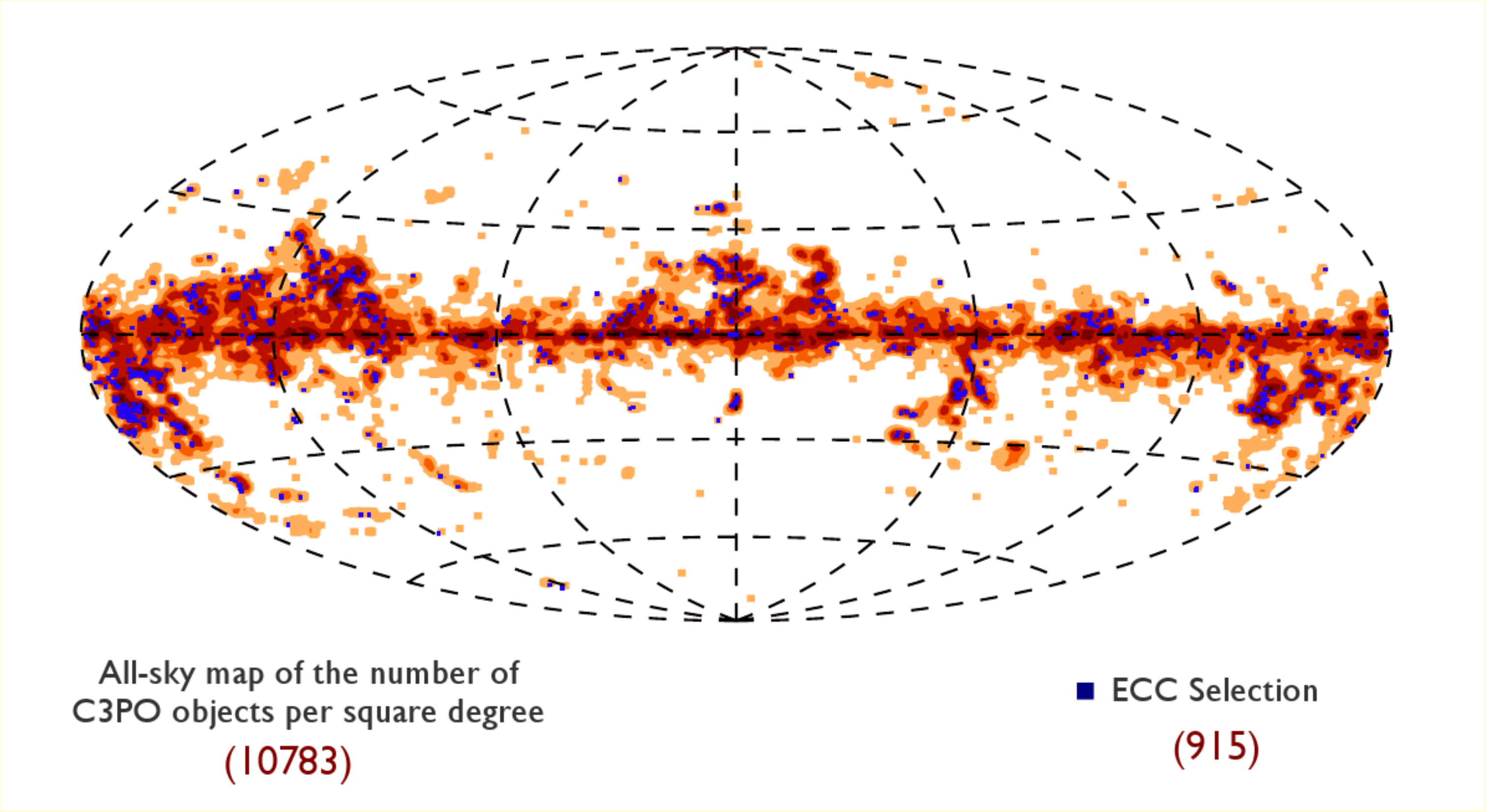
- all-sky
- sub-millimetre wavelengths
- sufficient resolution
- excellent sensitivity



Cold Cores & Planck

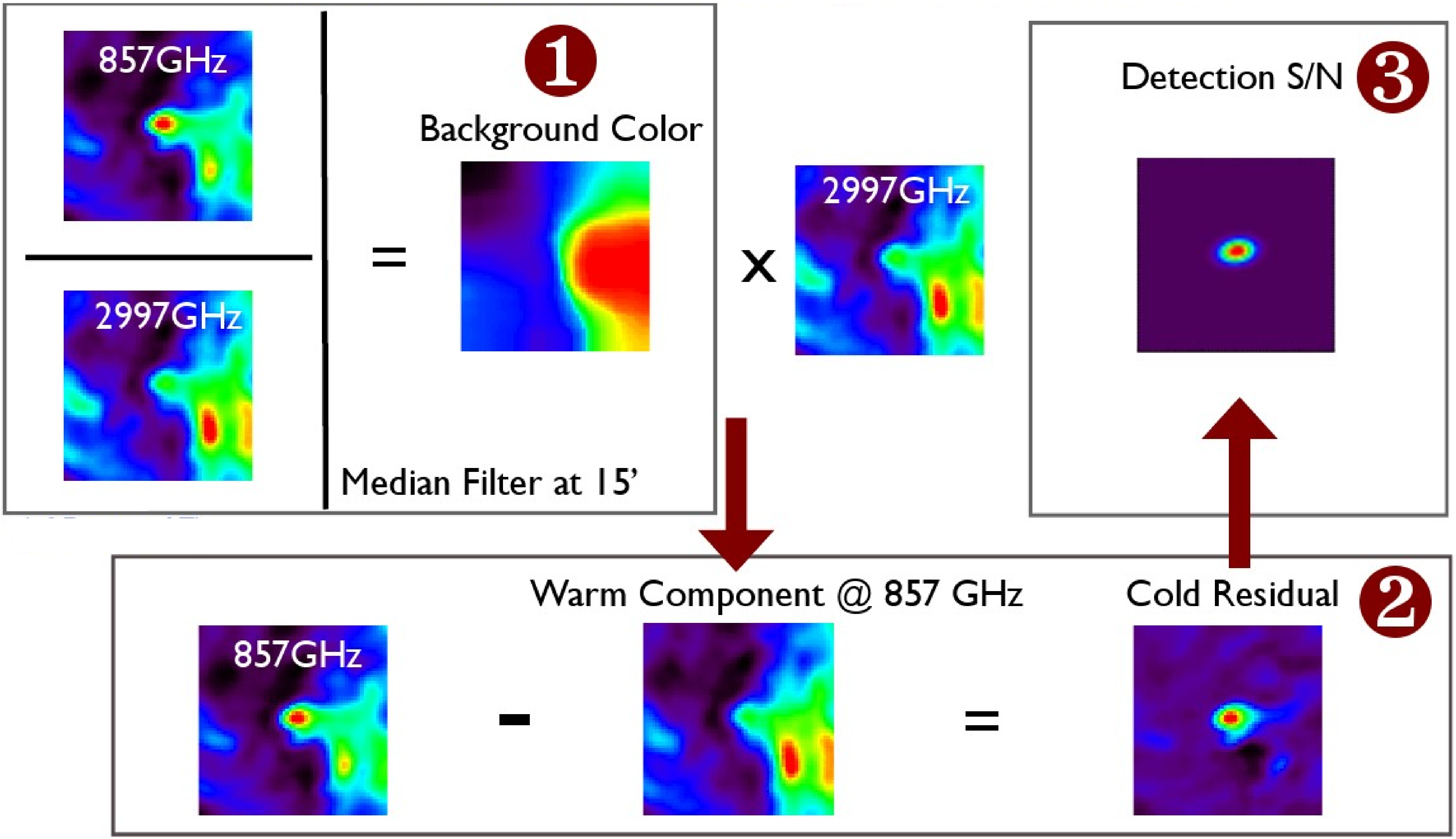
The **Planck early papers** included **cold clump** studies

- Planck XXIII: ***The Galactic Cold Core Population revealed by the first all-sky survey***, A&A 536, A23
- Planck XXII: *The submillimetre properties of a sample of Galactic cold clumps*, A&A 536, A22



Detection based on the **cold dust excess**

Montier et al. 2010, Planck XXIII



Distance estimates have been obtained for one third of the catalog

- distances from ~100pc to 7kpc
- Galactic heights at least up to ± 400pc

From cold clumps to cold cores

We want to *understand* star formation

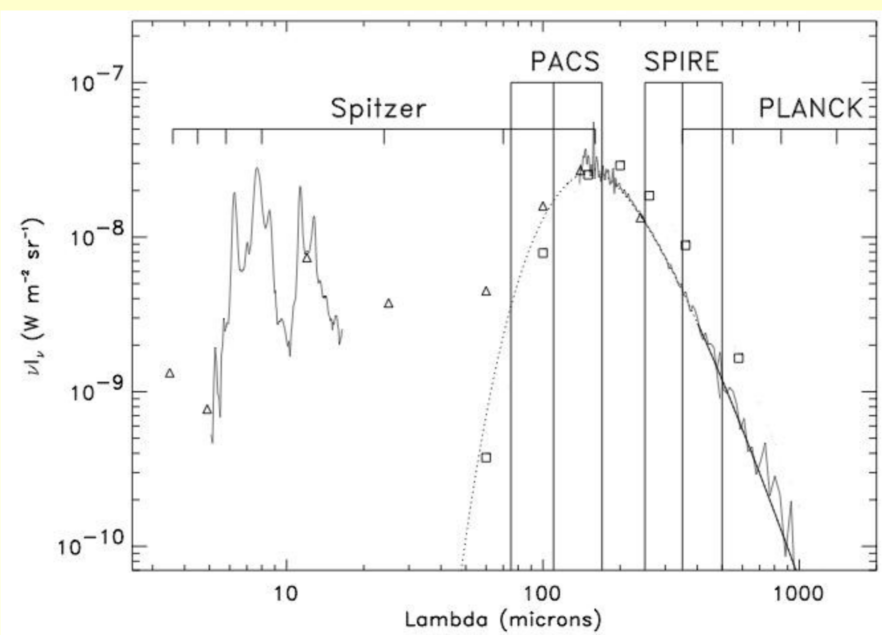
- what forms the gravitationally bound cores
- how do the cores evolve
- what is the connection with the surrounding cloud
- what is the morphology of the regions
- what is the structure of the cores themselves
- how do the dust properties vary in the cores
- how does the star formation affect the cores
- ...

... we need **higher resolution**, and better coverage of the **far-infrared** wavelengths

Cold Cores & Herschel

Herschel Open Time Key Programme
Galactic Cold Cores (151 hours)

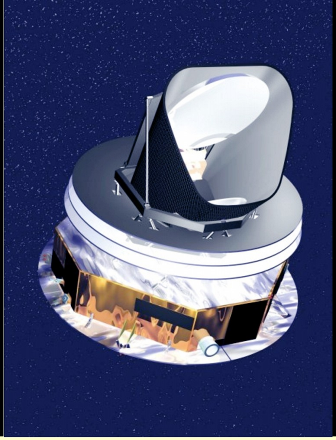
- PACS and SPIRE maps of 100+ fields with clumps **detected by Planck**
- a **cross-section** of the Galactic cold core population
  - **temperature**, **mass**, **density**, **size**, **location** (high/low latitudes, inner/outer Galaxy), **environment** (clustered vs. isolated sources, magnetic fields), **dust** properties (emissivity index, signs of anomalous microwave emission, polarization)

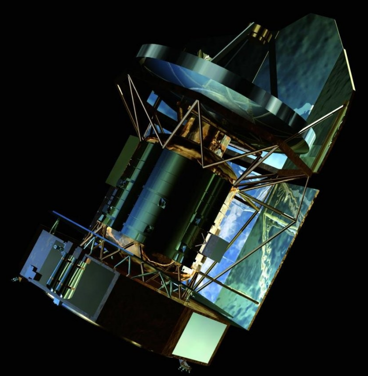


Cold Cores

on Planck[1, 2] and Herschel [1]

on behalf of the Planck collaboration





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

Planck

Desert, Dupac, **Falgarone**, 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, **Pagani**, Puget, Reach

Herschel

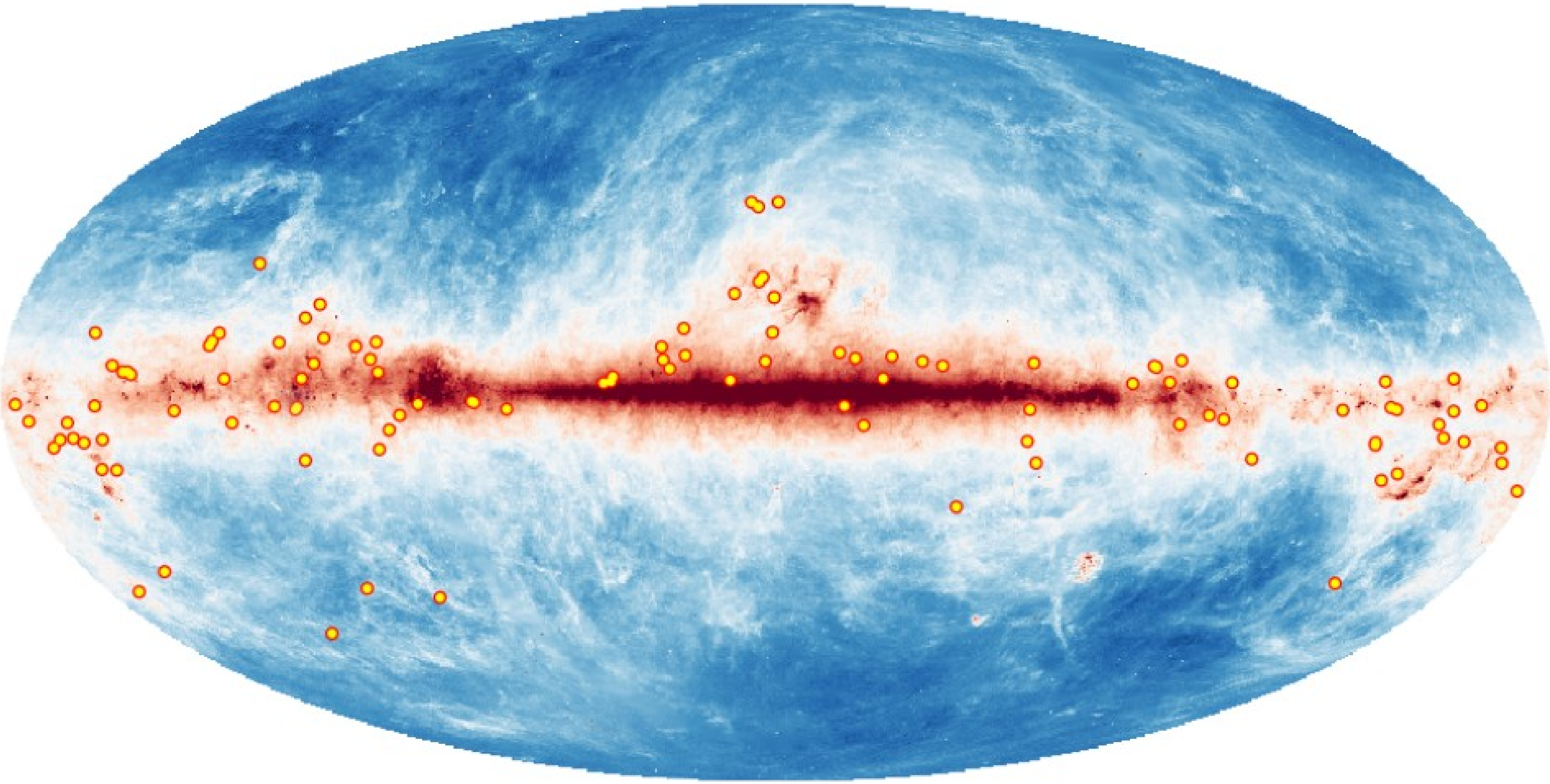
Andre, Kiss, Klaas, Krause, Molinari, **Motte**, Schneider, **Toth**, Ward-Thompson, **Zavagno**

External

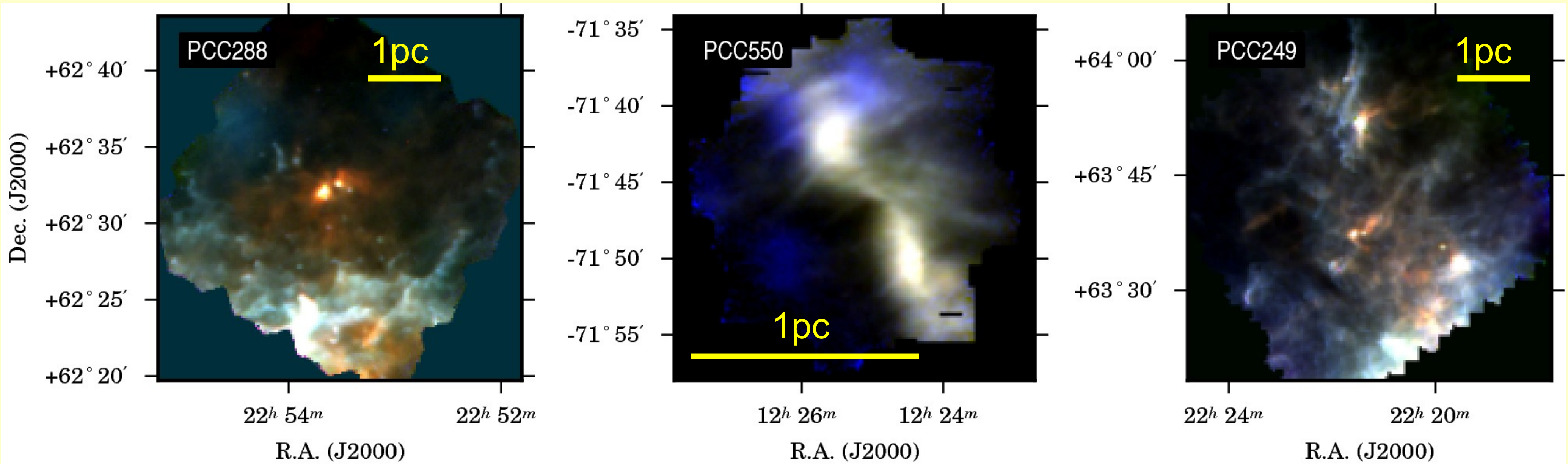
Doi, Ueno, Kitamura, Nikeda, Kawamura, Onishi

With acknowledgement to ESA[1] and the Planck HFI & LFI consortia[2]

Distribution of the ~110 Herschel target fields
including ~350 Planck clumps



The Herschel SDP fields



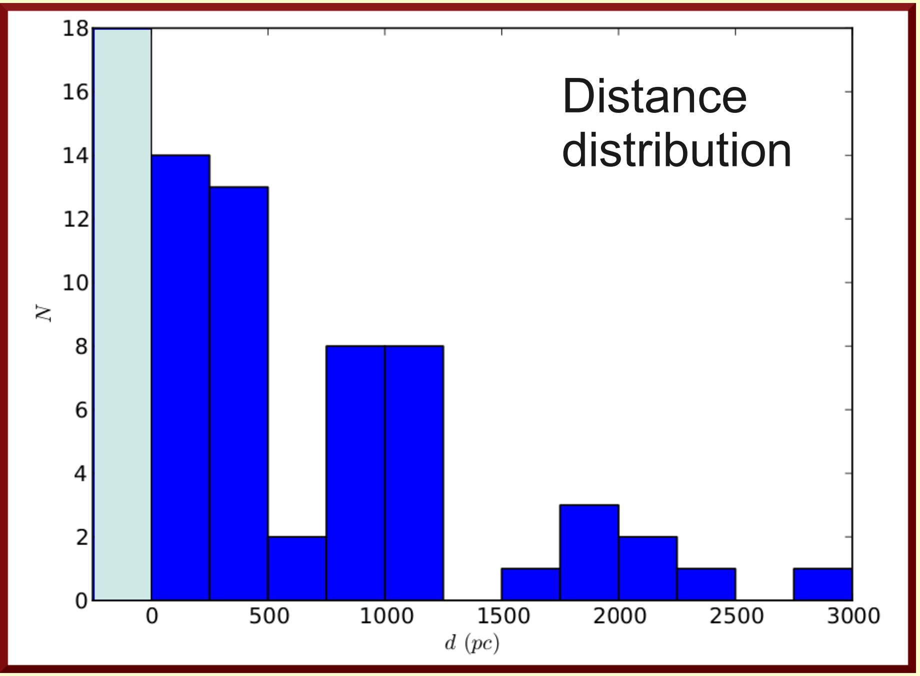
PCC288 at 800 pc
- ~14K clump in Cepheus with ~140 Msun
- Several compact objects with FIR/submm colour temperatures above 20K
- One Fu Ori type protostar with a molecular outflow
- Between a young stellar group and a molecular cloud – triggered SF?

PCC550 at 225 pc
- Piece of a long filament in Musca
- Two ~11K cores, both about 10 Msun
- Quiescent with density profiles similar to stable Bonnor-Ebert spheres

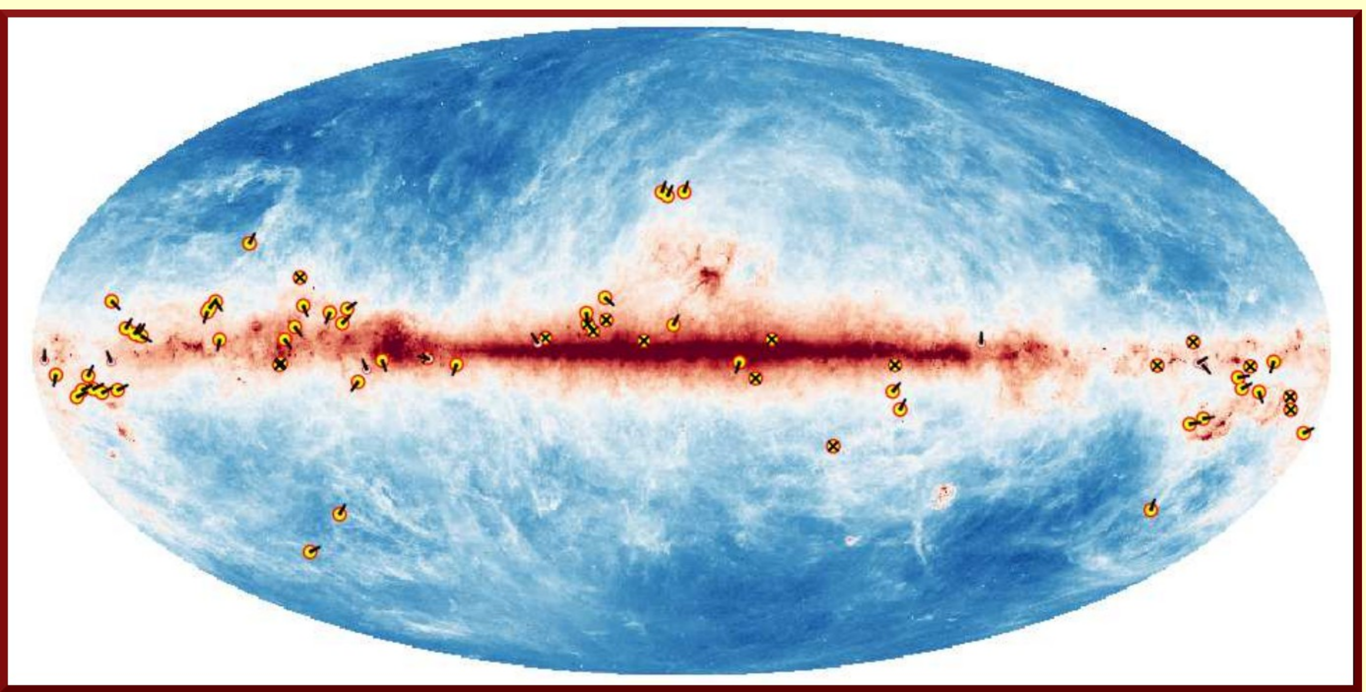
GCC-I, GCC-II
(Juvela et al. 2010, 2011)

PCC249 at 900 pc
- Very active star forming region
- Average temperature high, the Planck detections correspond to ~100 Msun regions at ~17K
- Colder smaller clumps (~13K) between the hot cores – possibly pre-stellar?

GCC-III: General cloud properties



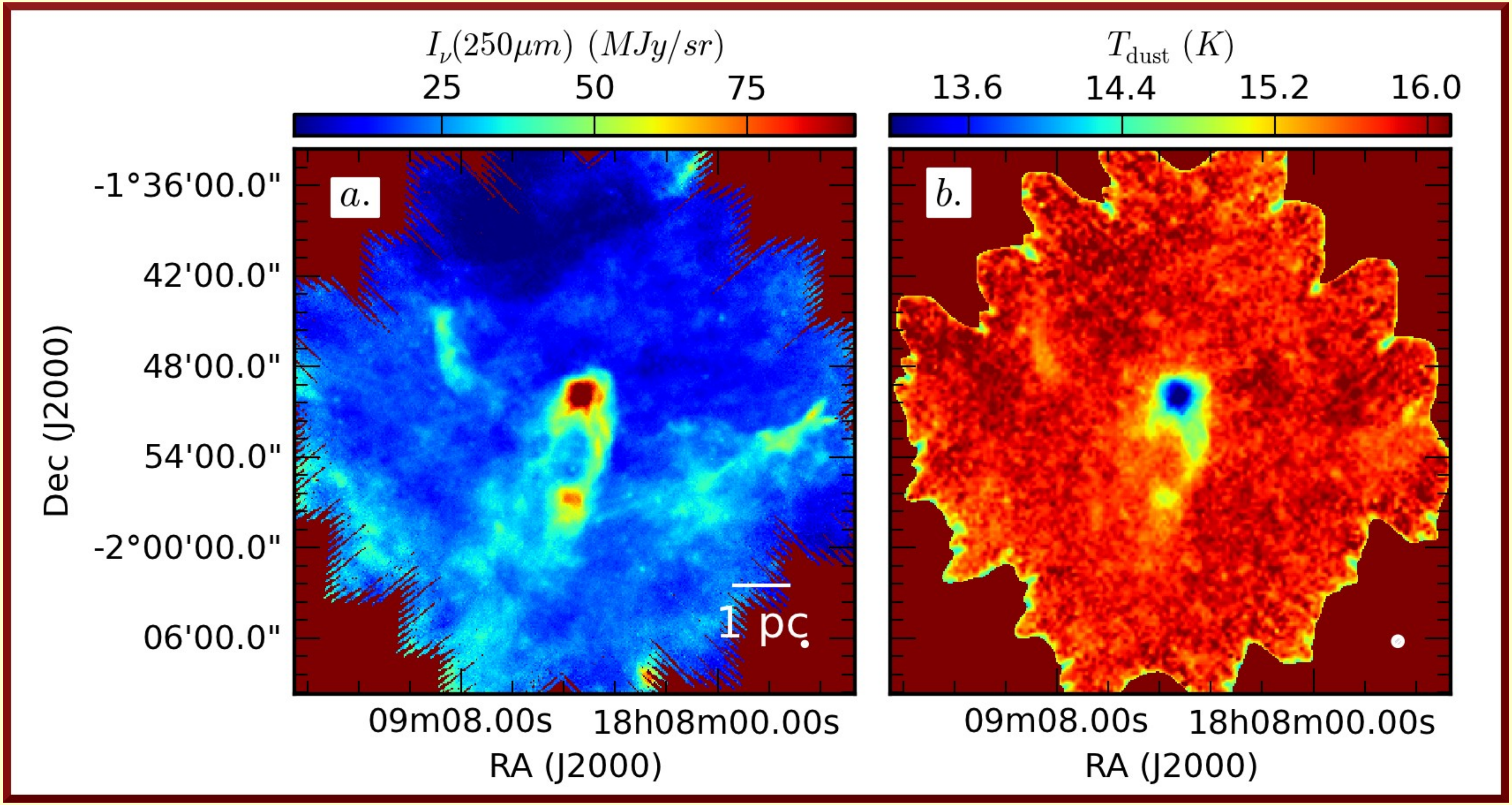
- Study of **71 fields** covered with Herschel SPIRE (250, 350, 500μm) by May 2011
  - **temperatures, column densities, masses, IR data**



Morphology

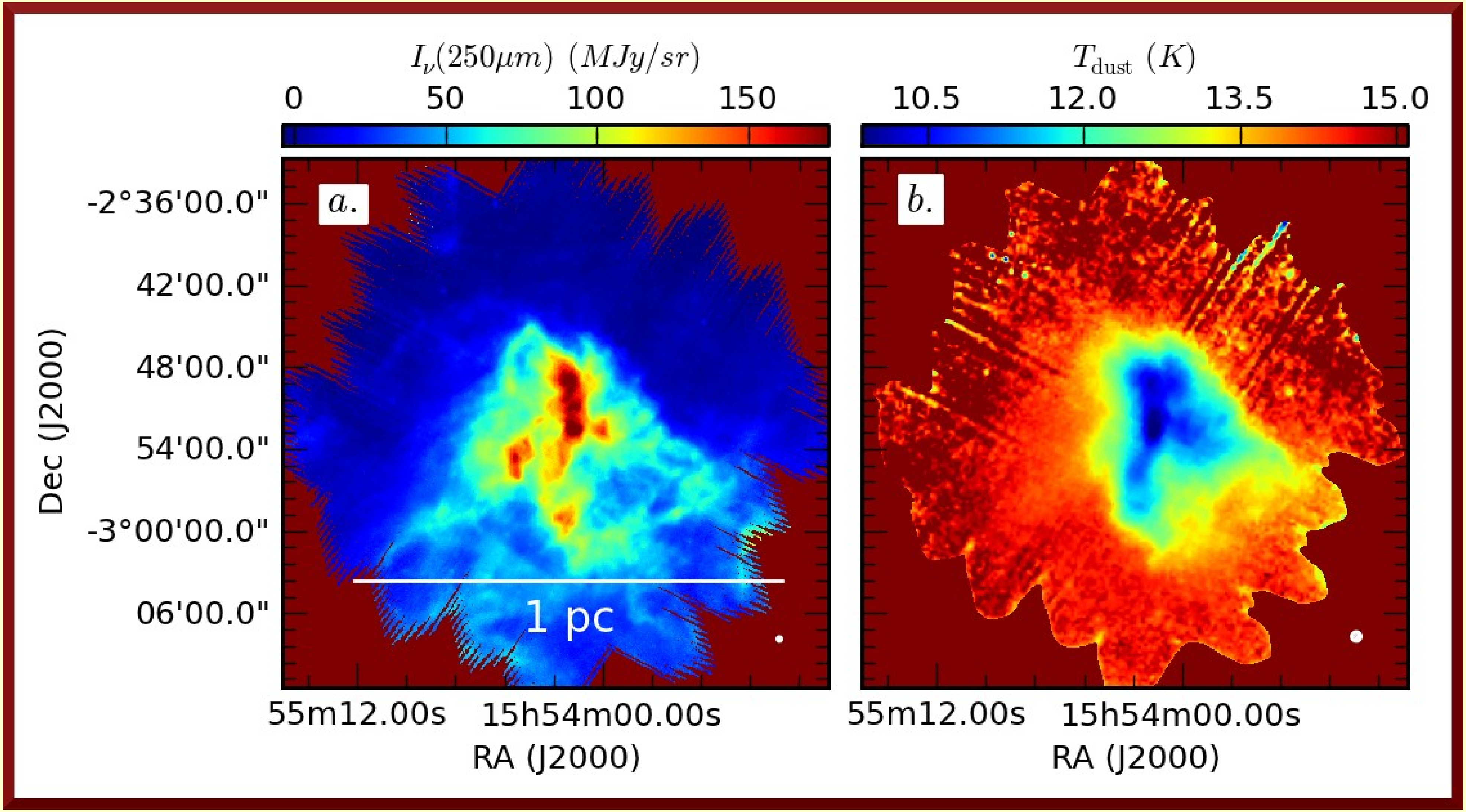
- Round, cometary, filamentary, and more complex shapes
  - The clouds are rarely of a single morphological type
  - There are occasionally indications of dynamic **interaction** with the environment
    - sharp boundaries, cometary shapes etc.
    - not the dominant feature: only one field in ten
  - ~50% have a clear **filamentary** structure

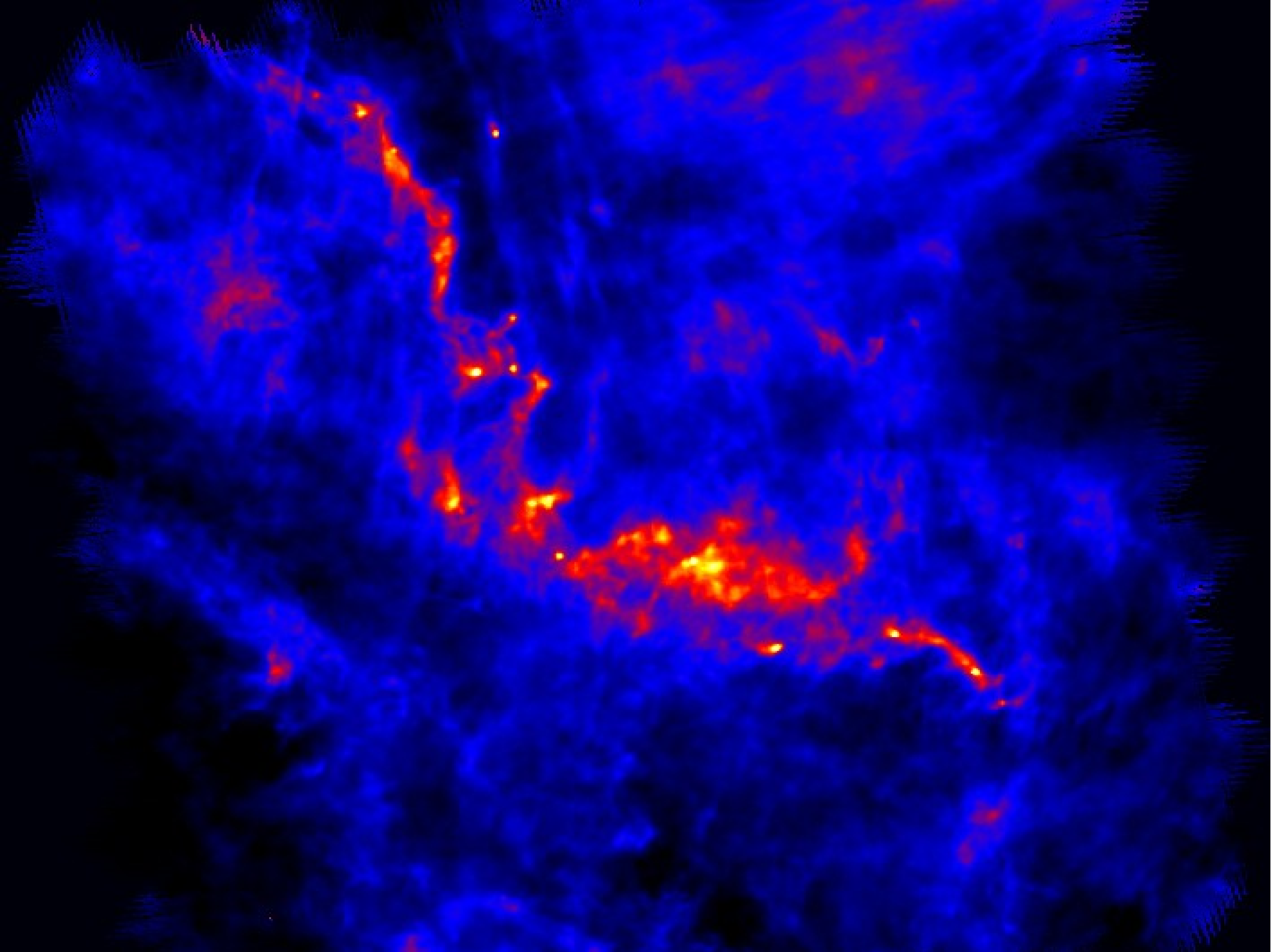
Blobs ...

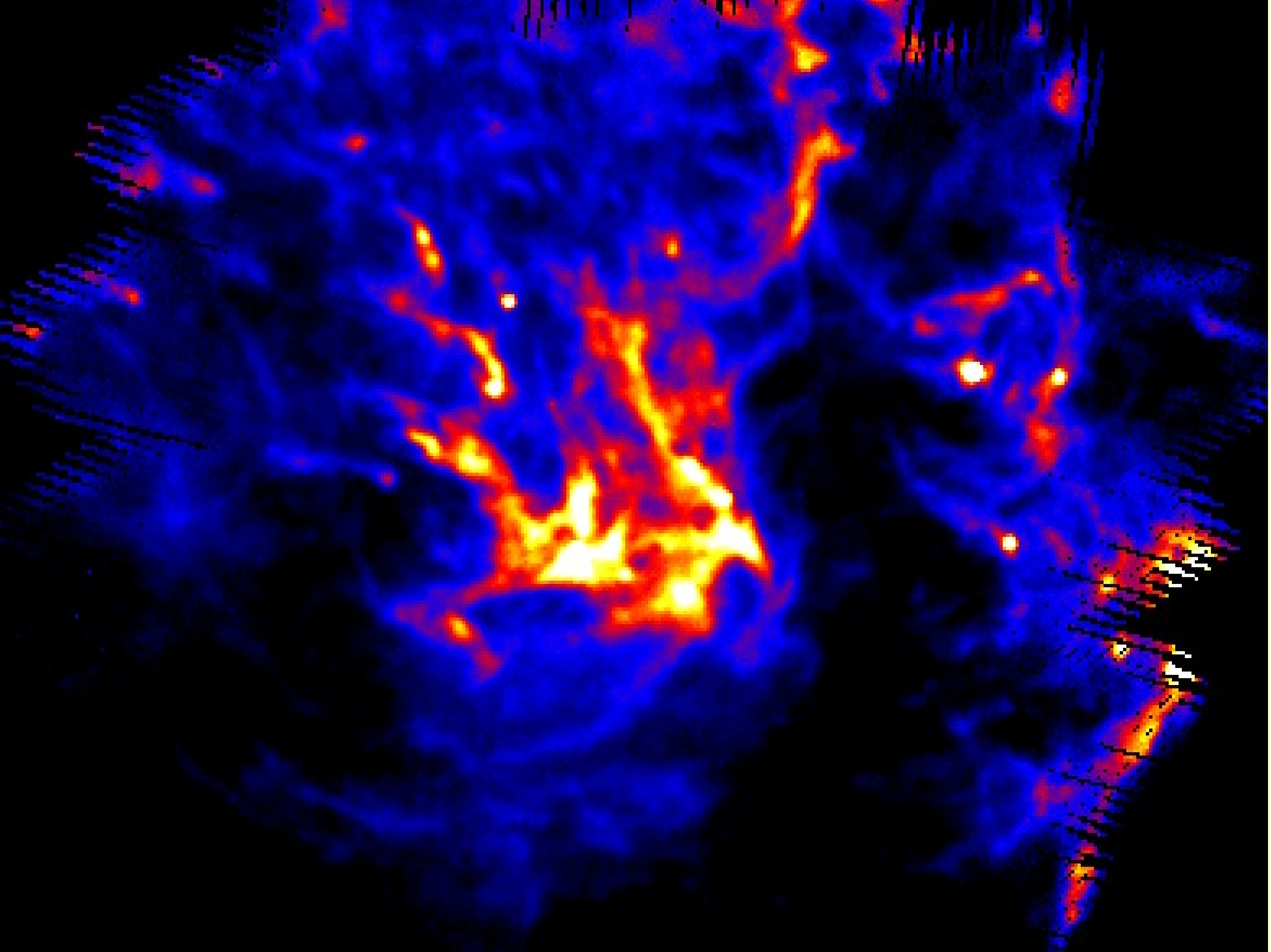


$I_\nu(250\mu m)\ (MJy/sr)$
25
50
75
$T_{\rm dust}\ (K)$
13.6
14.4
15.2
16.0
a.
b.
-1°36'00.0"
42'00.0"
48'00.0"
54'00.0"
-2°00'00.0"
06'00.0"
Dec (J2000)
1 pc
09m08.00s
18h08m00.00s
RA (J2000)
09m08.00s
18h08m00.00s
RA (J2000)

Cometary clouds...





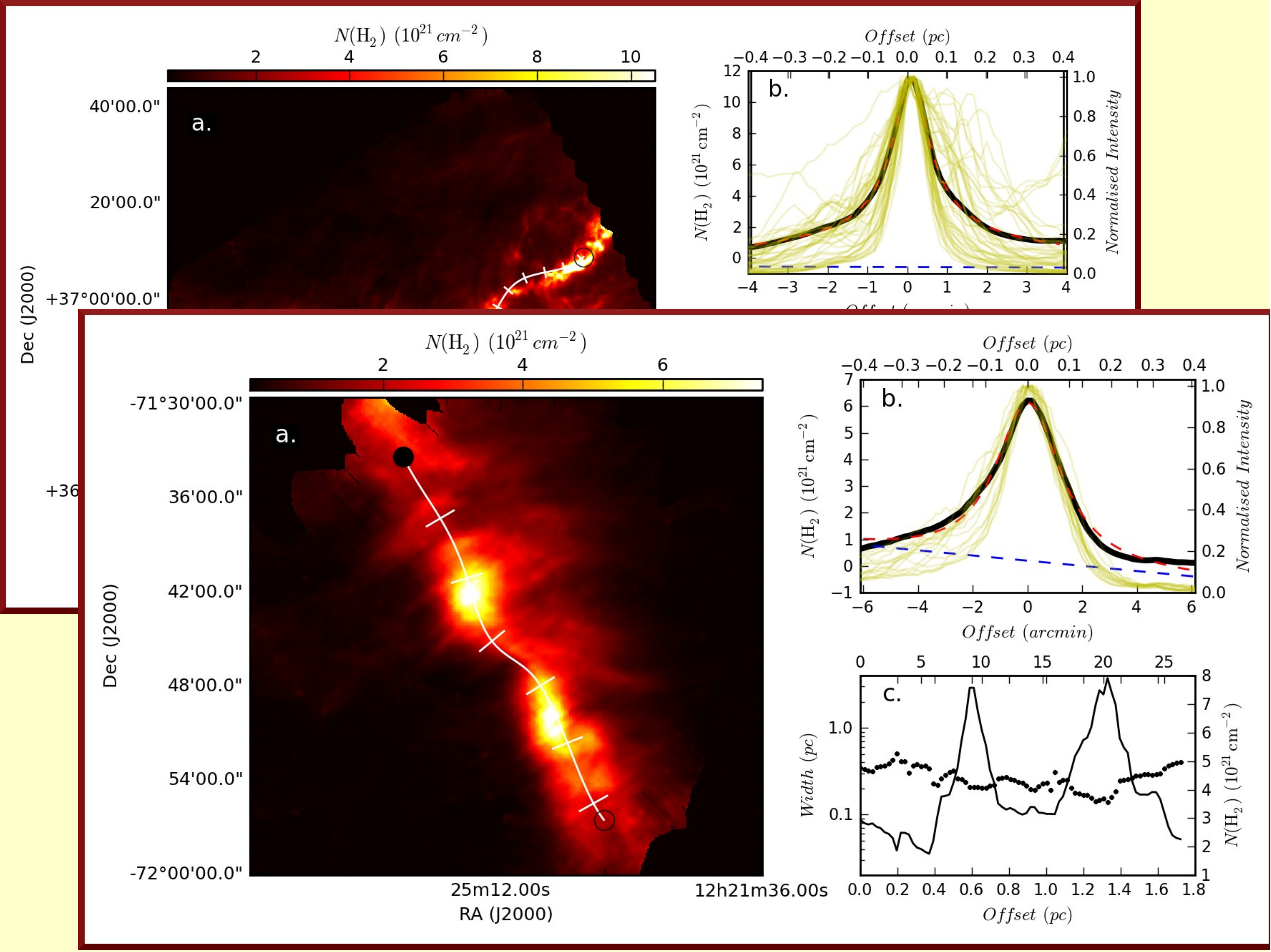


Filaments

- Half of the fields contain very distinct filamentary structures
  - We examined the widths and the profiles of the filaments
    - FWHM (from gaussian fits)
    - fit of Plummer profiles
    - masses

$$\rho_p(r) = \frac{\rho_c}{[|1 + (r/R_{\rm flat})^2|^{p/2}]}$$

  - Caveats
    - also filaments can form hierarchical system – it is a decision what constitutes 'a filament'
    - filaments are not continuous and reside on top of a sometimes strongly varying background



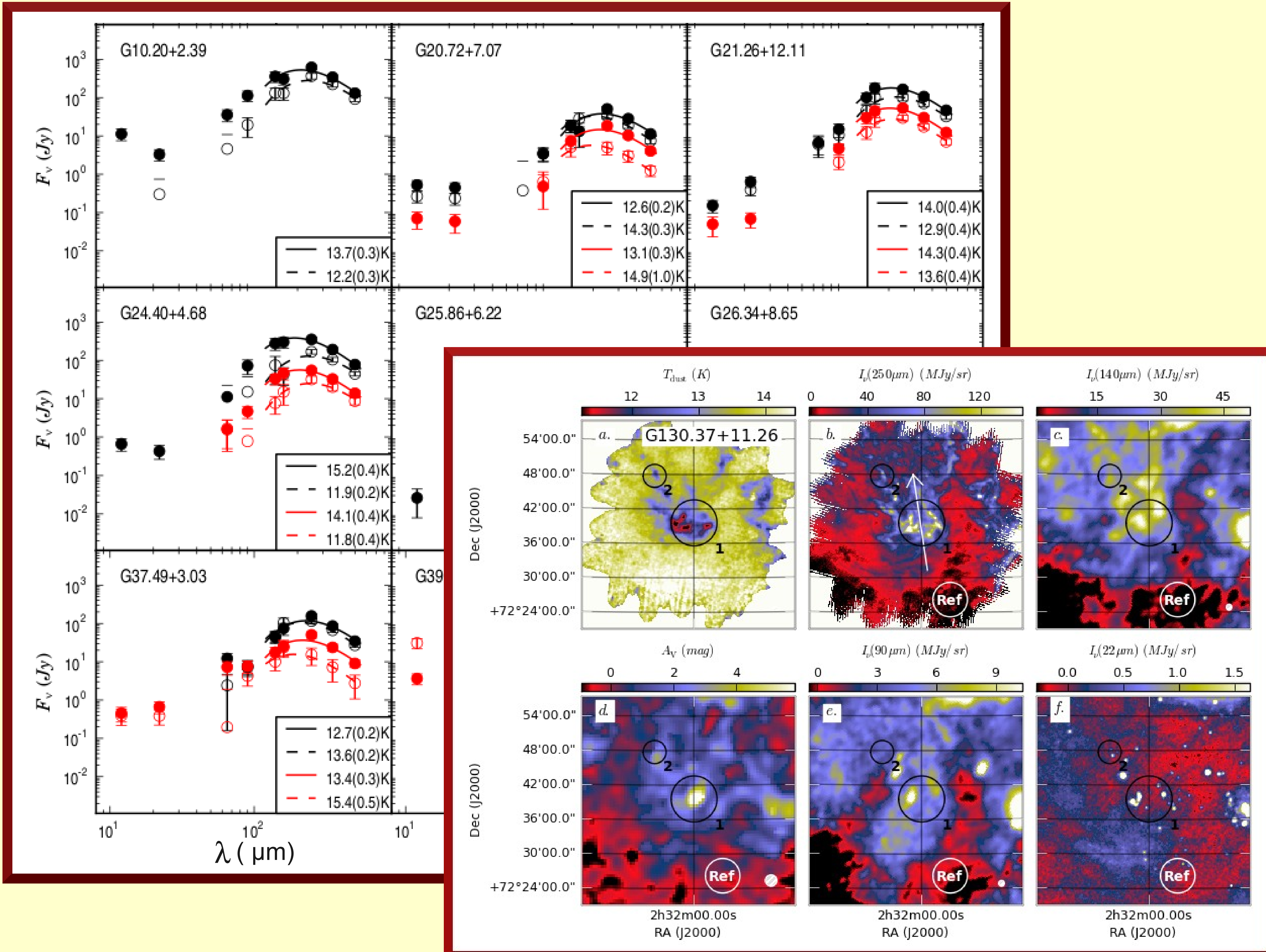
N(H2) (10^21 cm^-2)
a.
40'00.0"
20'00.0"
+37°00'00.0"
+36
Dec (J2000)
b.
Offset (pc)
Normalised Intensity
Offset (arcmin)
-71°30'00.0"
36'00.0"
42'00.0"
48'00.0"
54'00.0"
-72°00'00.0"
25m12.00s
12h21m36.00s
RA (J2000)
c.
Width (pc)

Name	Length (pc)	Width (pc)	Mass ($M_\odot$)	N_{H_2}	$\sigma(N(H_2))$ (10^{21}/cm^2)	L_{Jeans} (pc)	FWHM (pc)	ρ_c (H_2/cm^3)	R_{flat} (pc)	p	M_{line} ($M_\odot$/pc)
G1.94+6.07	2.49	0.40	19.4	1.7	0.2	0.32/0.24	0.21	2.41e+03	0.06	1.5	7.0
G82.65-2.00	14.94	0.40	2931.7	19.2	3.9	0.03/0.02	0.24	3.70e+04	0.06	2.0	116.4
G89.65-7.02	17.83	0.80	2283.9	7.1	2.7	0.08/0.04	0.30	6.56e+03	0.10	1.7	61.9
G94.15+6.50	2.46	0.40	47.2	4.0	0.9	0.13/0.09	0.11	1.23e+04	0.08	6.6	7.0
G98.00+8.75	5.78	0.40	606.7	7.4	2.1	0.07/0.05	0.22	5.11e+04	0.02	1.6	42.8
G105.57+10.39	3.64	0.40	237.7	4.3	0.5	0.12/0.11	0.20	1.63e+04	0.03	1.7	24.3
G126.63+24.55	0.78	0.40	3.5	1.9	0.4	0.28/0.19	0.12	3.97e+03	0.06	2.6	7.0
G149.67+3.56	6.54	0.40	691.1	5.3	0.6	0.10/0.09	0.25	4.88e+03	0.05	1.3	42.2
G157.08-8.68	3.47	0.40	209.5	11.5	2.6	0.05/0.03	0.63	3.45e+04	0.04	2.1	51.6
G157.92-2.28	27.66	0.40	3151.8	3.7	1.0	0.14/0.09	0.35	9.85e+03	0.04	1.5	38.9
G159.34+11.21	6.69	0.80	307.7	2.9	0.6	0.19/0.13	0.31	1.37e+03	0.15	1.4	30.0
G161.55-9.30	2.41	0.40	92.7	4.4	0.7	0.12/0.09	0.65	7.36e+03	0.05	1.6	29.1
G163.82-8.44	8.22	0.40	344.7	11.4	9.5	0.05/0.01	0.65	4.03e+04	0.03	1.9	39.4
G164.71-5.64	2.36	0.40	23.0	2.4	0.4	0.22/0.16	0.16	6.10e+03	0.02	1.4	6.3
G167.20-8.69	3.29	0.40	51.6	2.1	0.5	0.25/0.18	0.67	5.14e+03	0.03	1.5	7.9
G176.27-2.09	13.25	0.80	1808.6	8.6	2.7	0.06/0.04	0.37	1.15e+04	0.09	1.8	82.0
G181.84-18.46	2.70	0.40	58.1	3.3	0.7	0.16/0.12	0.66	6.55e+03	0.04	1.5	19.3
G198.58-9.10	5.78	0.40	820.2	14.9	4.7	0.03/0.02	0.29	2.34e+04	0.06	1.7	123.5
G203.42-8.29	2.87	0.40	61.6	4.0	1.1	0.13/0.08	0.14	1.34e+04	0.03	1.6	17.1
G205.06-6.04	5.46	0.40	142.2	2.2	0.5	0.24/0.15	0.52	1.74e+03	0.08	1.4	20.1
G210.90-36.55	1.34	0.40	12.9	4.8	1.4	0.11/0.07	0.17	8.39e+03	0.07	2.1	17.5
G212.07-15.21	6.23	0.40	77.3	0.9	0.1	0.59/0.48	0.41	1.29e+03	0.05	1.4	7.3
G215.44-16.38	3.31	0.40	80.7	4.6	1.7	0.12/0.07	0.32	6.93e+03	0.10	2.6	28.1
G276.78+1.75	12.91	0.80	925.6	3.0	1.1	0.18/0.10	0.49	1.54e+03	0.55	9.1	34.2
G298.31-13.05	1.11	0.40	10.8	3.8	0.5	0.14/0.10	0.11	1.08e+04	0.04	2.2	10.8
PCC550	1.74	0.40	42.6	6.3	1.0	0.09/0.07	0.19	1.07e+04	0.10	3.5	27.9

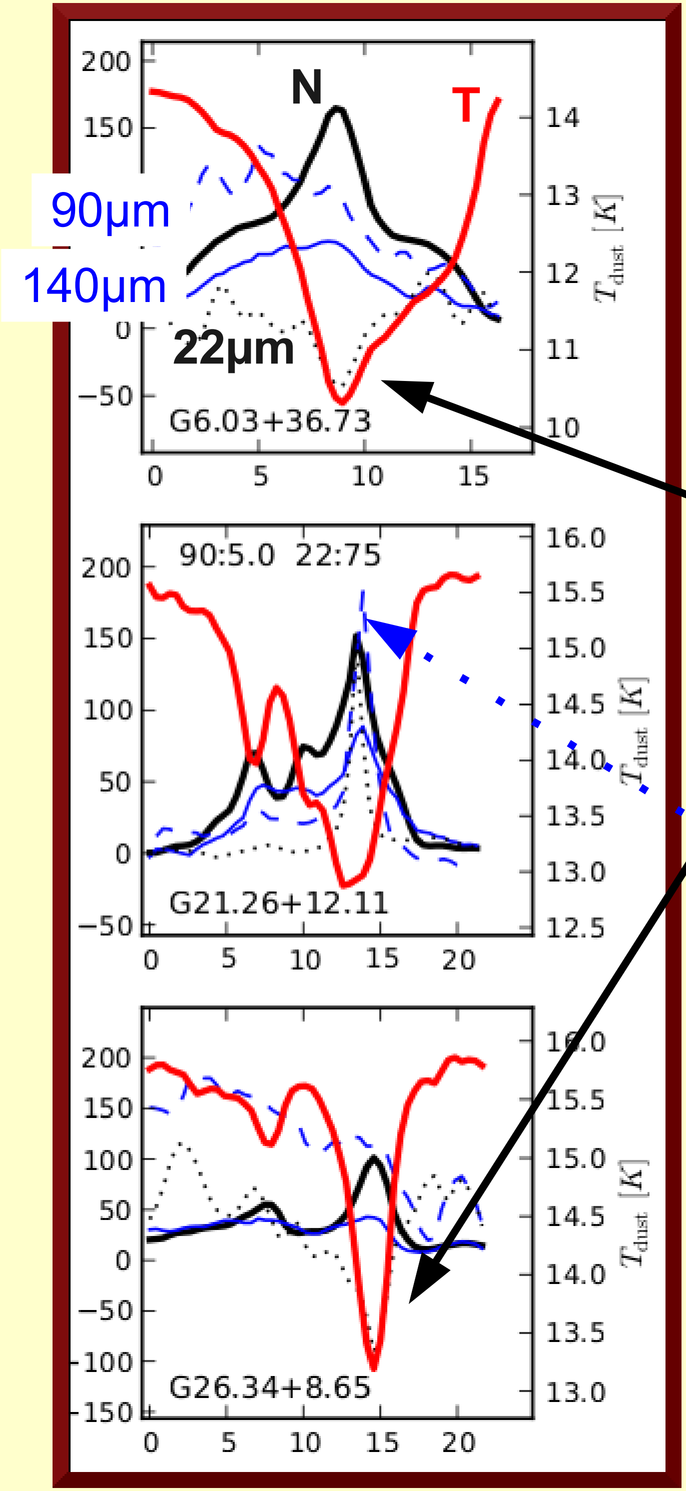
Spectral energy distributions

- There are additional infrared data available
  - AKARI (65, 90, 140, 160μm)
    - will become public later this year
  - WISE (3.4, 4.6, 12.0, 22.0μm)
    - using the first public data release of 2011

- The fields **do** contain cold cores
  - Colour temperatures derived from the **total** intensity are not extreme, typically ~12-14K
- Lots of MIR point sources, some warm even in FIR
  - YSOs and protostars at different stages

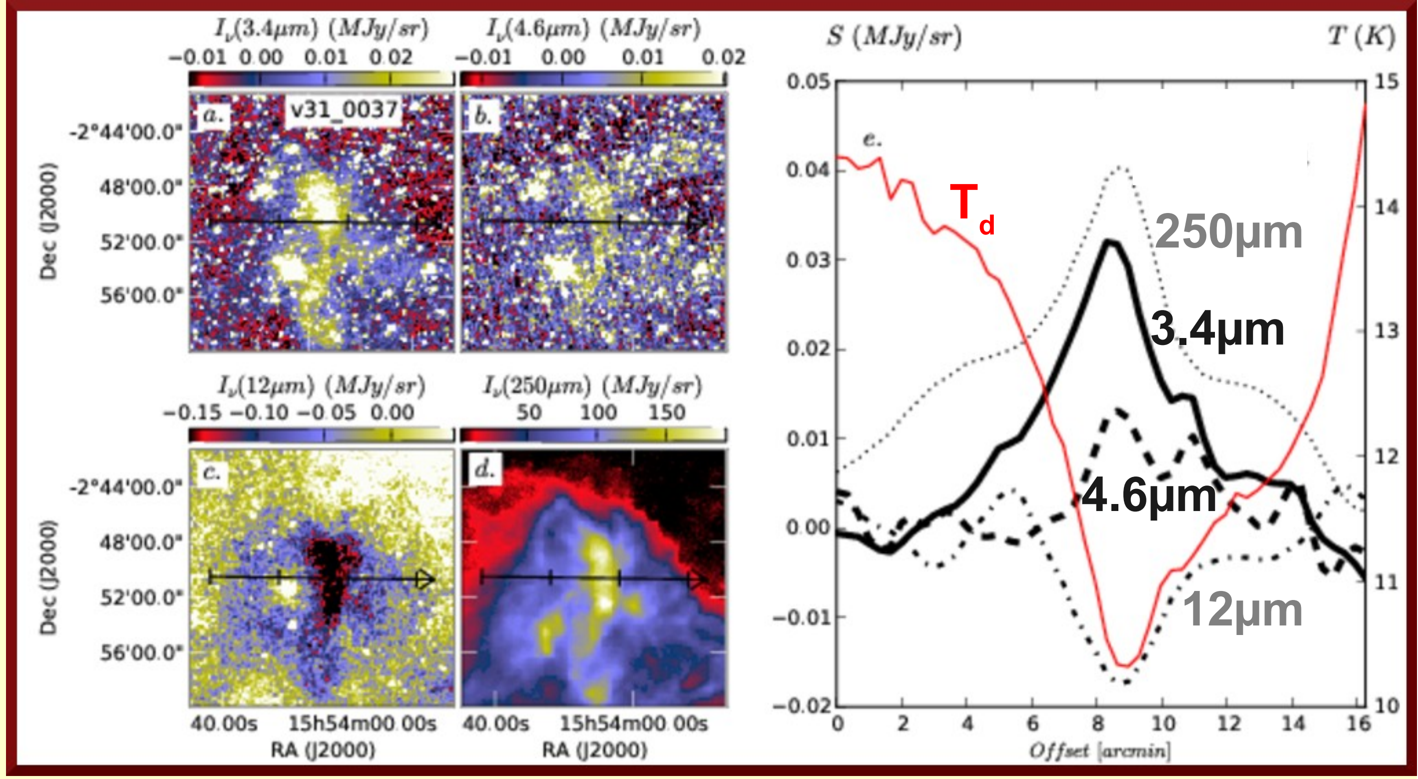


G10.20+2.39
G20.72+7.07
G21.26+12.11
G24.40+4.68
G25.86+6.22
G26.34+8.65
G37.49+3.03
13.7(0.3)K
12.2(0.3)K
12.6(0.2)K
14.3(0.3)K
13.1(0.3)K
14.9(1.0)K
14.0(0.4)K
12.9(0.4)K
14.3(0.4)K
13.6(0.4)K
15.2(0.4)K
11.9(0.2)K
14.1(0.4)K
11.8(0.4)K
12.7(0.2)K
13.6(0.2)K
13.4(0.3)K
15.4(0.5)K
F_ν (Jy)
λ (μm)
G130.37+11.26
T_dust (K)
I_ν(250μm) (MJy/sr)
I_ν(140μm) (MJy/sr)
A_V (mag)
I_ν(90μm) (MJy/sr)
I_ν(22μm) (MJy/sr)
Dec (J2000)
RA (J2000)
2h32m00.00s
+72°24'00.0"
Ref



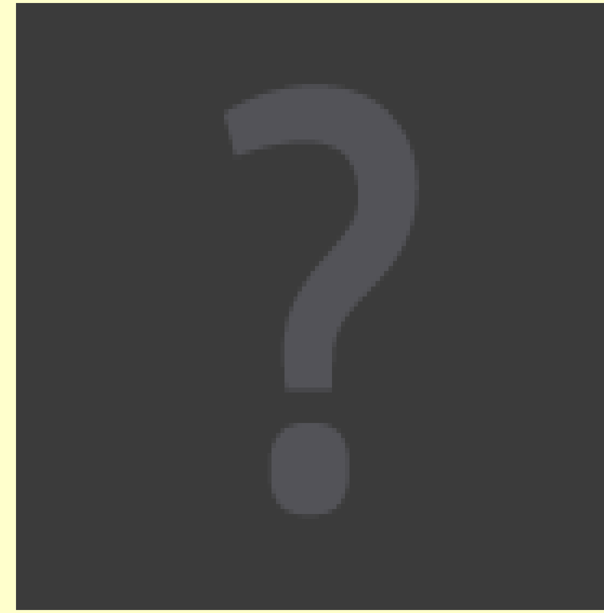
- Cold cores often show reduced MIR emission
  - Decrease of the radiation field or depletion of small grains?
- … and often FIR/MIR sources within the cold clumps

Coreshine



- ~3.5μm signal from light scattering caused by the grain growth (Steinacker et al. 2010, Pagani et al. 2010)
- 56 fields examined with public WISE 3.4μm data, relative to the other MIR and sub-mm bands
- The result: **four detections**, six tentative detections
  - the visibility depends on the background sky, the presence of point sources, the source size, the survey sensitivity etc.

Summary



- We have examined the first 71 fields of the Cold Cores survey
  - The **distances** range from ~100pc to several kpc, masses from a few solar masses up to ~10^5 M_0
  - Half of the fields are strongly **filamentary**, one in ten shows signs of **external forces** (e.g., cometary shape)
  - Filaments have widths 0.1-1pc, most are gravitationally **unstable**
  - Fields are often associated with active **star formation**
  - 4 (+6) out of 56 examined fields show signs of increased grain sizes in the form of **coreshine**

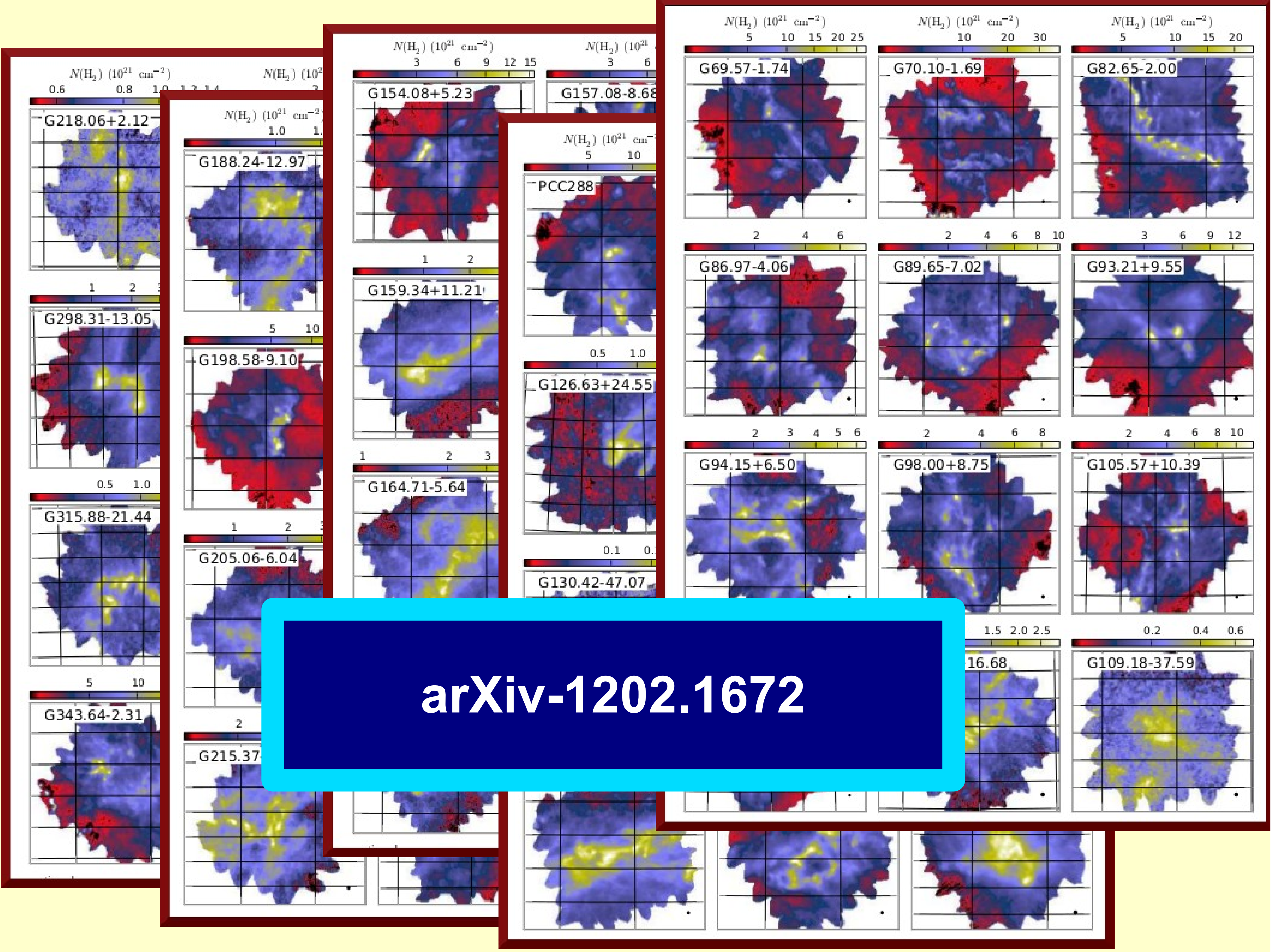
Outlook I

- There are several on-going studies
  - Properties of the **clumps** (mass spectra, structure, etc.)
  - **Star formation** associated with the cold clumps
  - Detailed studies of **individual fields**
  - Studies of **dust properties**
    - the PACS data reduction is in progress
  - Ground-based **follow-up** studies for further characterisation of individual clumps
    - radio observations with APEX, IRAM, Effelsberg, Green Bank, Onsala, CSO, Kitt Peak, etc.
    - NIR observations with CFHT, VLT
  - There is a **Spitzer** programme (166h, PI R. Paladini) to look for coreshine in 90 ECC sources

Outlook II

- The **Herschel** survey is **near completion**
  - The final sources selected last week
  - Time to make the conclusions on the correlations between the clouds, the clumps, the star formation, and the environment

- Work is going on to interpret **Planck** **polarisation** data on the fields
  - the role of magnetic fields in the evolution of the clouds and the regularisation of star formation
- ECC published January 2011, the complete **Planck** C3PO **catalogue** will be published in 2013


arXiv-1202.1672
G218.06+2.12
G298.31-13.05
G315.88-21.44
G343.64-2.31
G188.24-12.97
G198.58-9.10
G205.06-6.04
G154.08+5.23
G157.08-8.68
G159.34+11.21
G164.71-5.64
PCC288
G126.63+24.55
G130.42-47.07
G69.57-1.74
G70.10-1.69
G82.65-2.00
G86.97-4.06
G89.65-7.02
G93.21+9.55
G94.15+6.50
G98.00+8.75
G105.57+10.39
G109.18-37.59