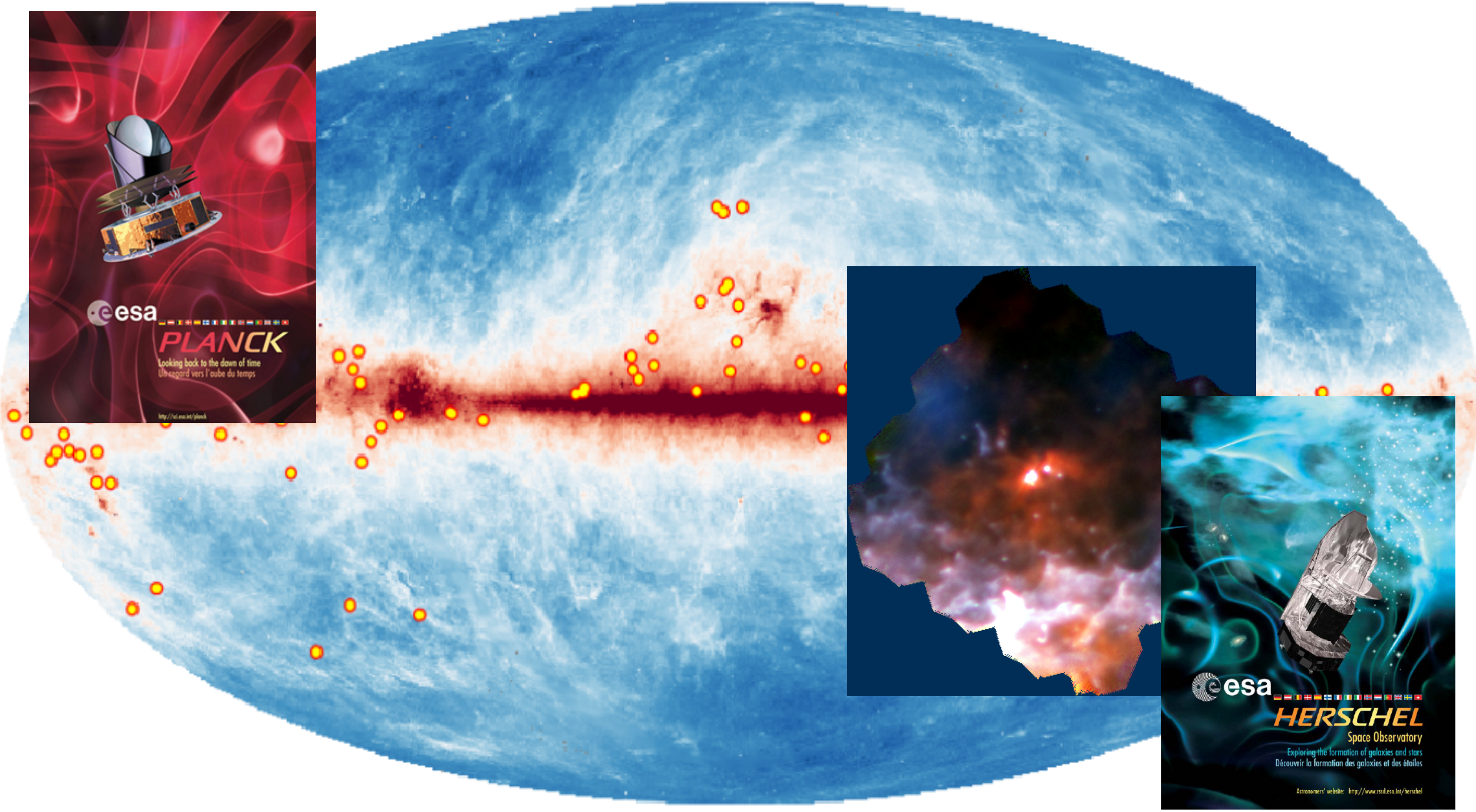
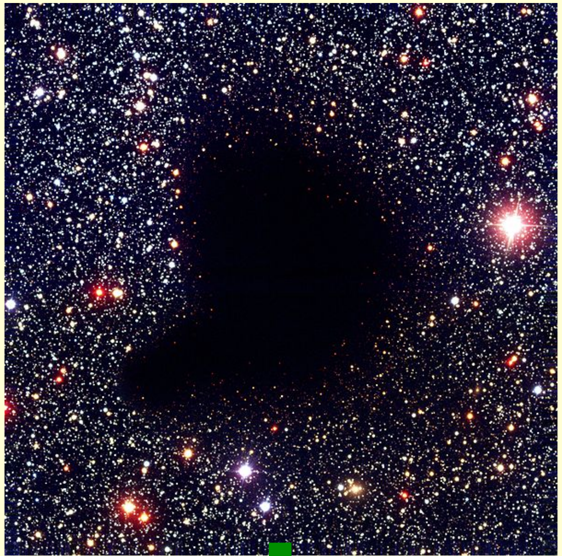
Galactic Cold Cores

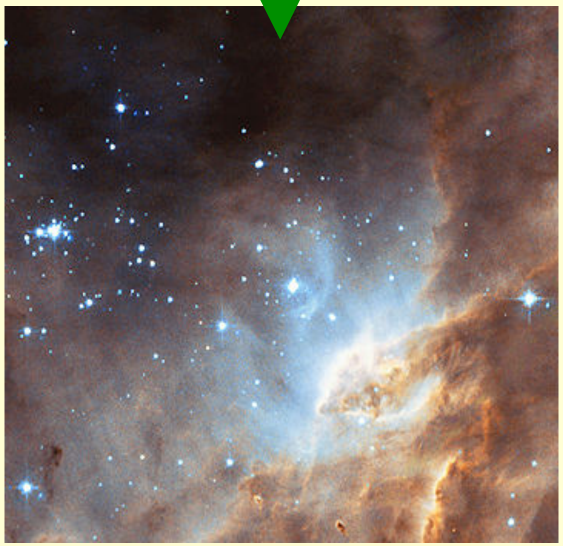
Mika Juvela, on behalf of the Planck and Herschel projects on cold cores



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
different environments

Cold Cores & Planck

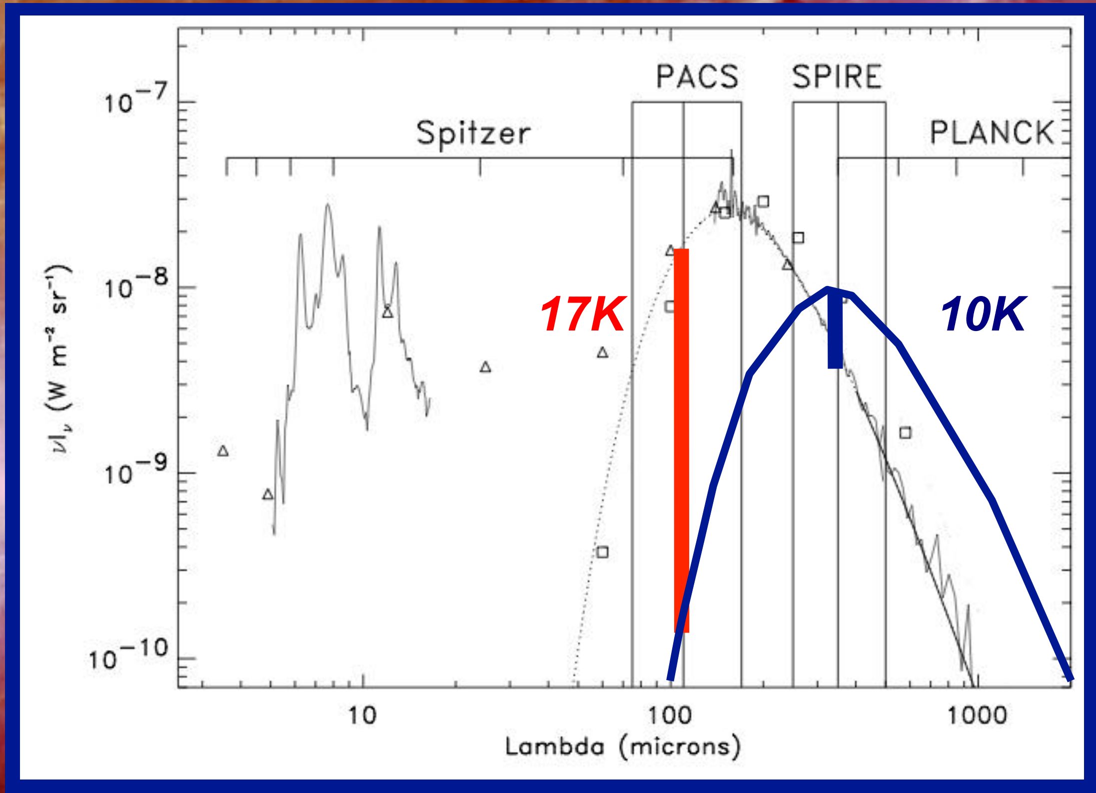
The Planck satellite is mapping the sky at 9 frequencies between 857GHz and 30 GHz

- **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

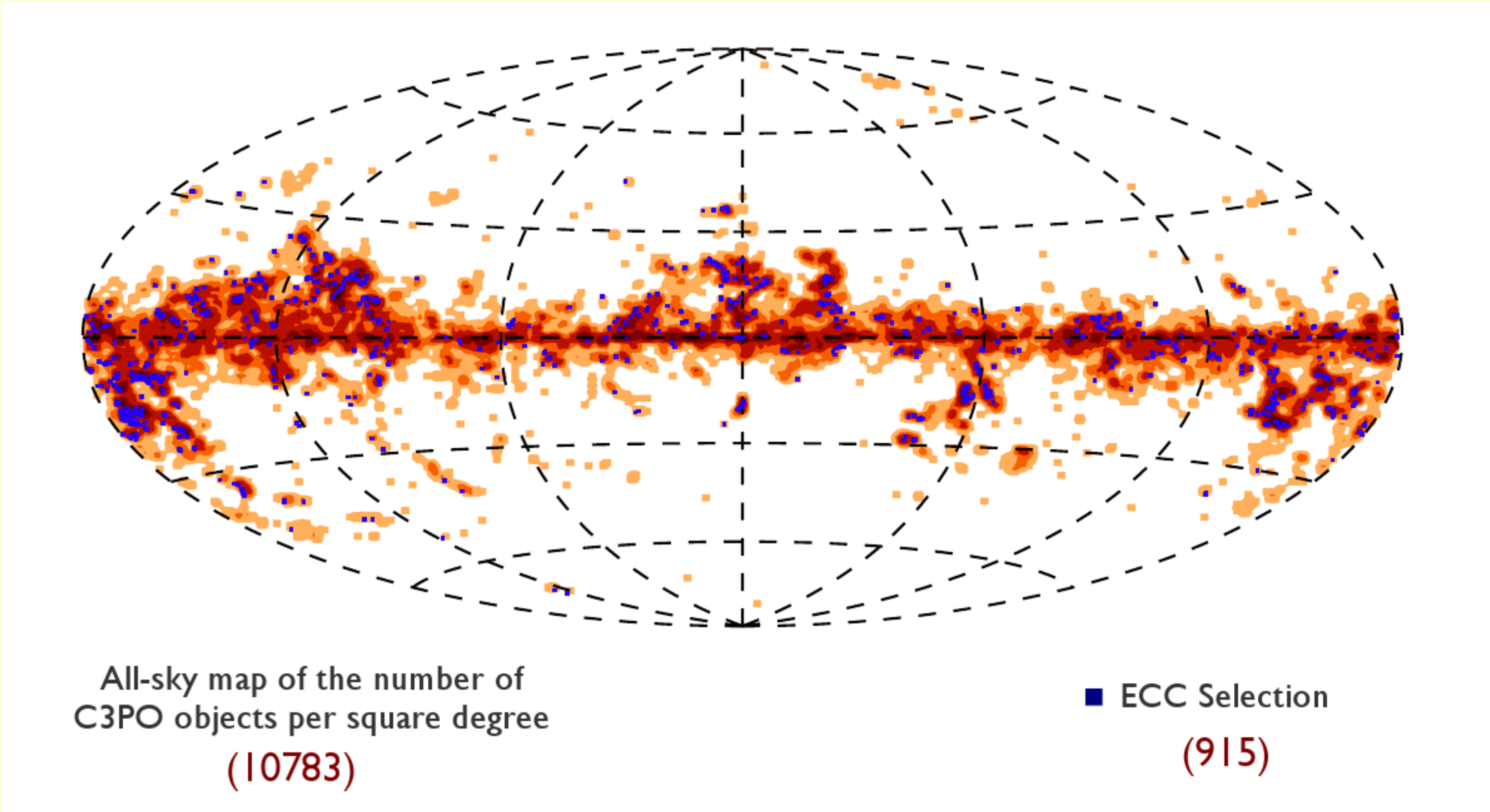
- all-sky
- sub-millimetre wavelengths
- sufficient resolution
- excellent sensitivity



Cold Cores & Planck

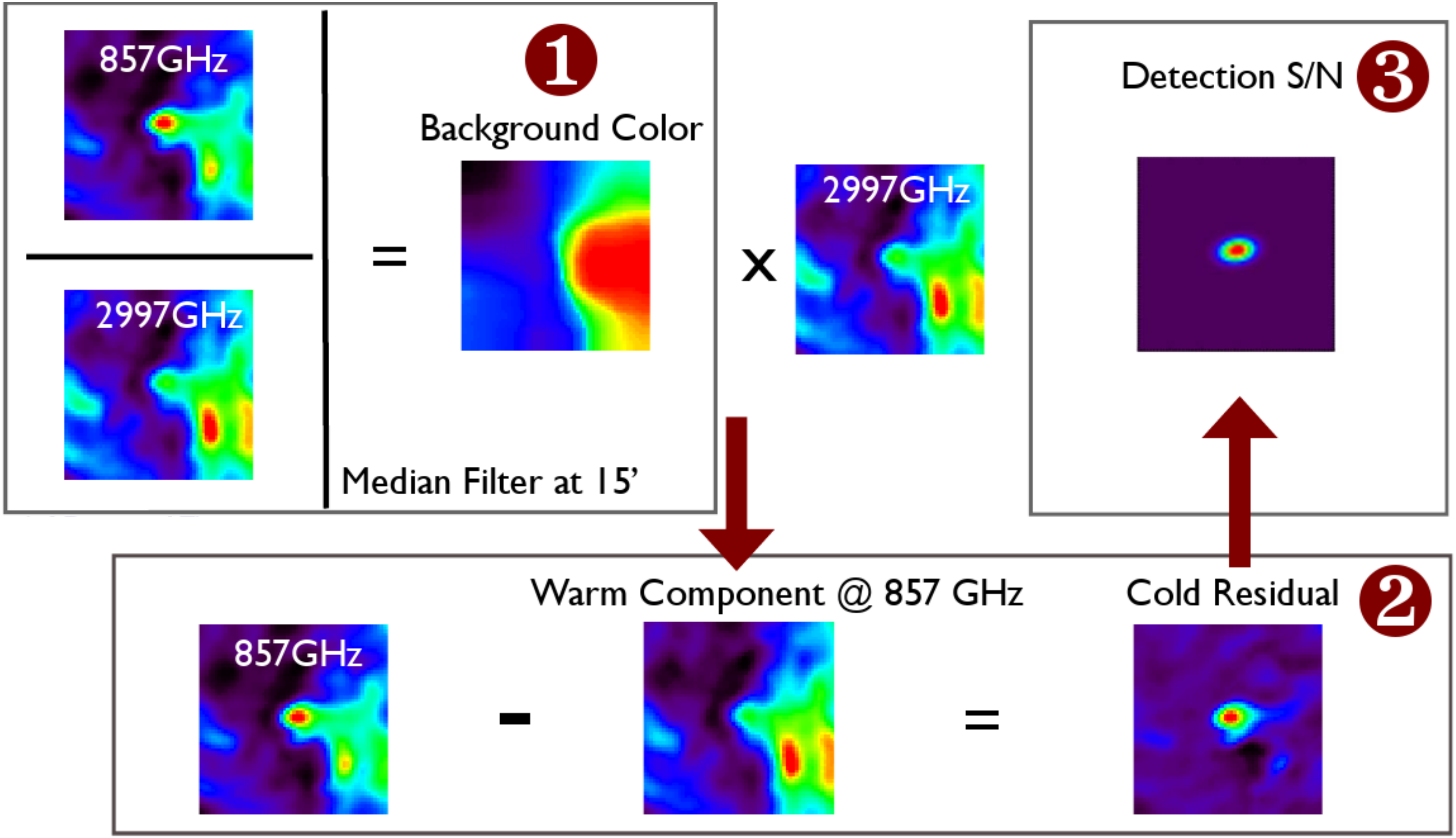
The **Planck early papers** included **cold clump** studies

- 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



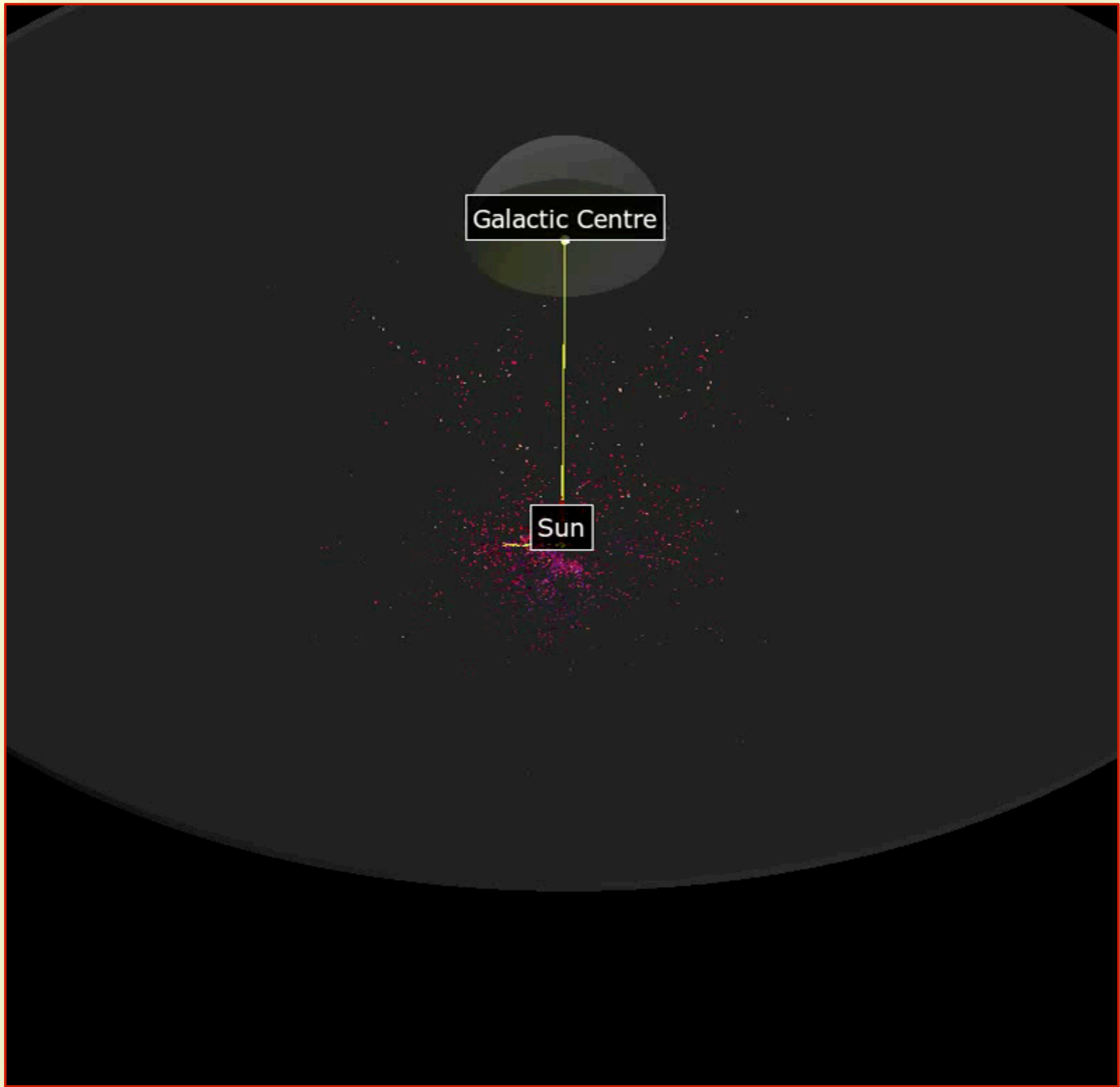
Detection based on the **cold dust excess**

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

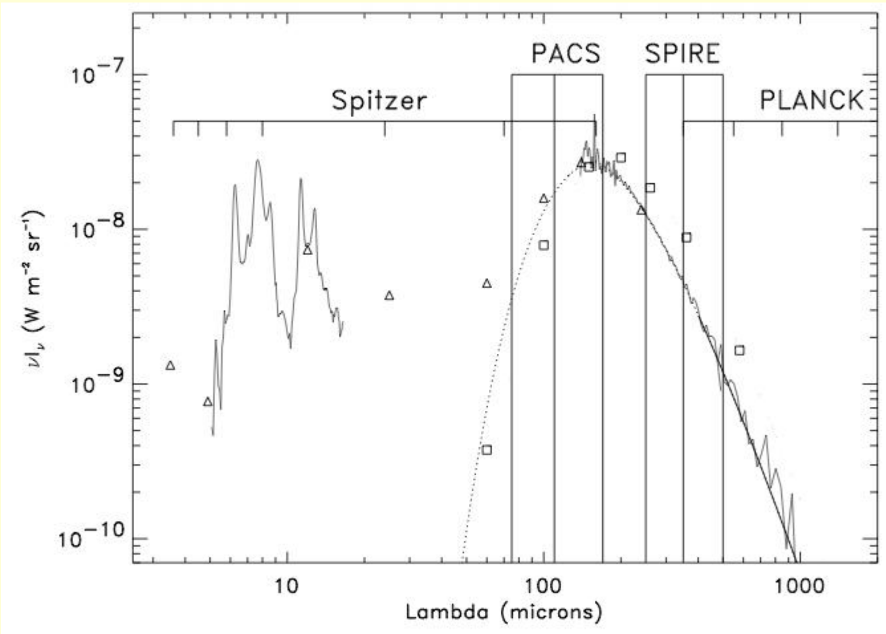
- what forms the gravitationally bound cores
- how do the cores evolve
- what is the connection with the surrounding cloud
- what is the morphology of the regions
- what is the structure of the cores themselves
- how do the dust properties vary in the cores
- how does the star formation affect the cores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

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)

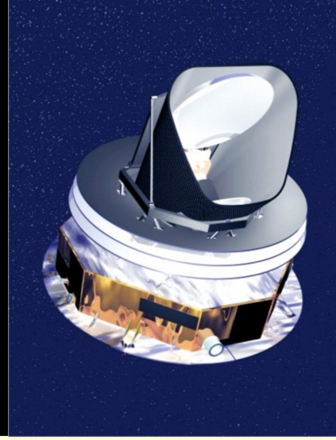
- PACS and SPIRE maps of 100+ fields with clumps **detected by Planck**
- a **cross-section** of the Galactic cold core population
  - **temperature**, **mass**, **density**, **size**, **location** (high/low latitudes, inner/outer Galaxy), **environment** (clustered vs. isolated sources, magnetic fields),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

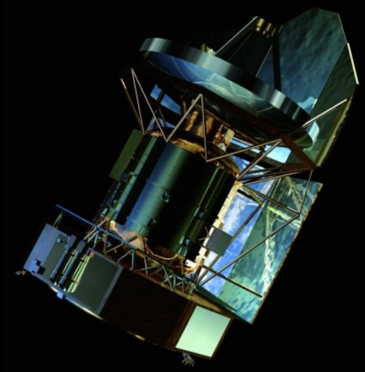


Cold Cores

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

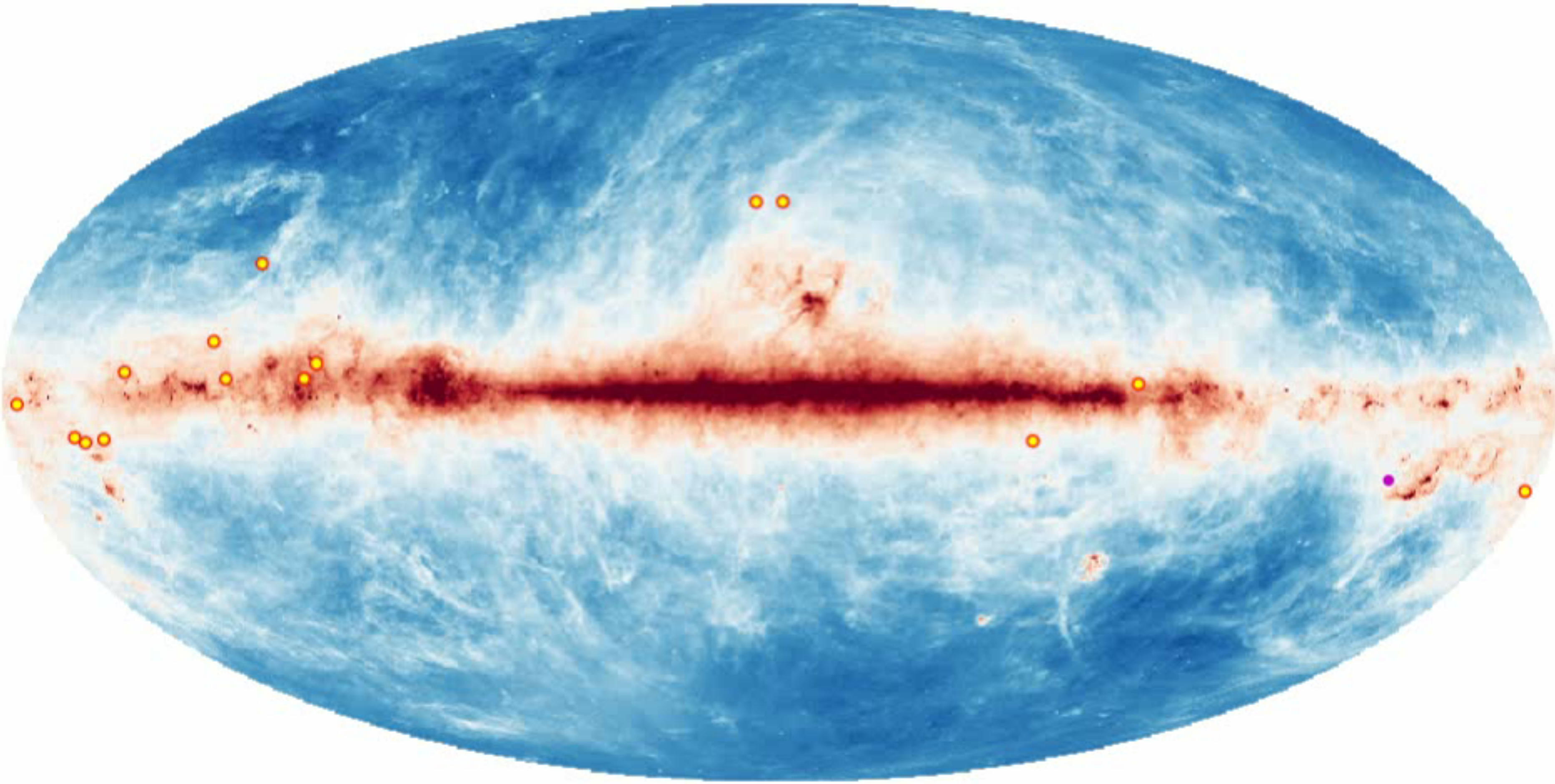
Herschel

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

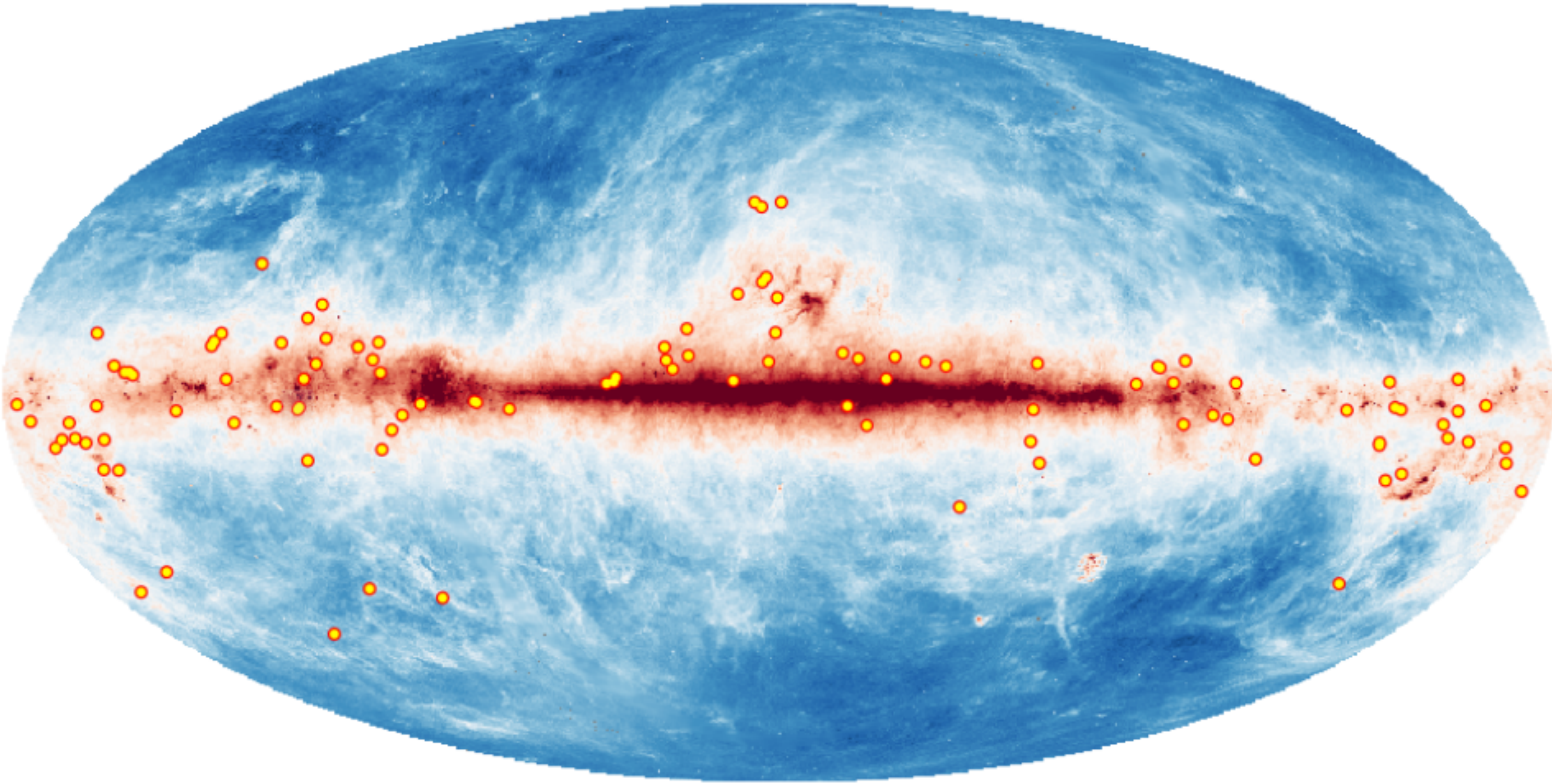
External

Doi, Ueno, Kitamura, Nikeda, Kawamura, Onishi

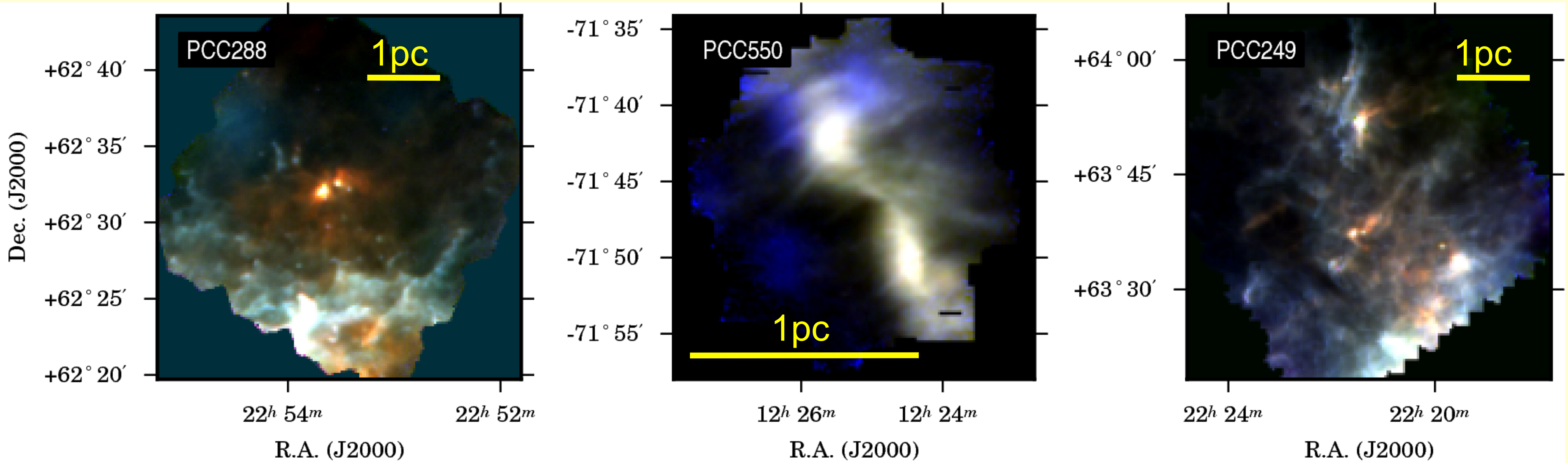
With acknowledgement to ESA[1] and the Planck HFI & LFI consortia[2]



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



The Herschel SDP fields



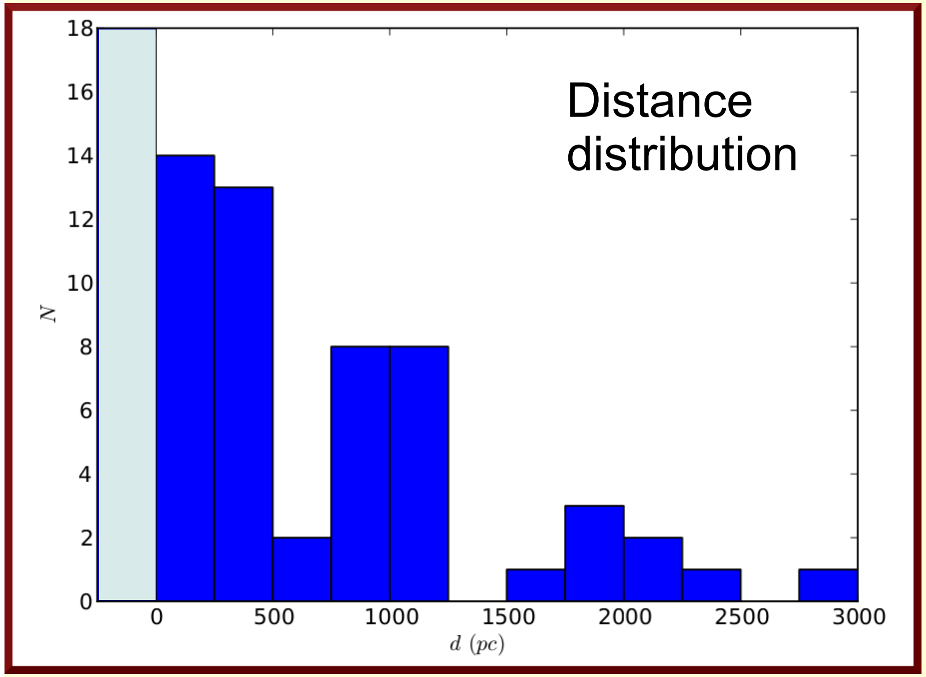
PCC288 at 800 pc
- ~14K clump in Cepheus with ~140 Msun
- Several compact objects with FIR/submm colour temperatures above 20K
- One Fu Ori type protostar with a molecular outflow
- Between a young stellar group and a molecular cloud – triggered SF?

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

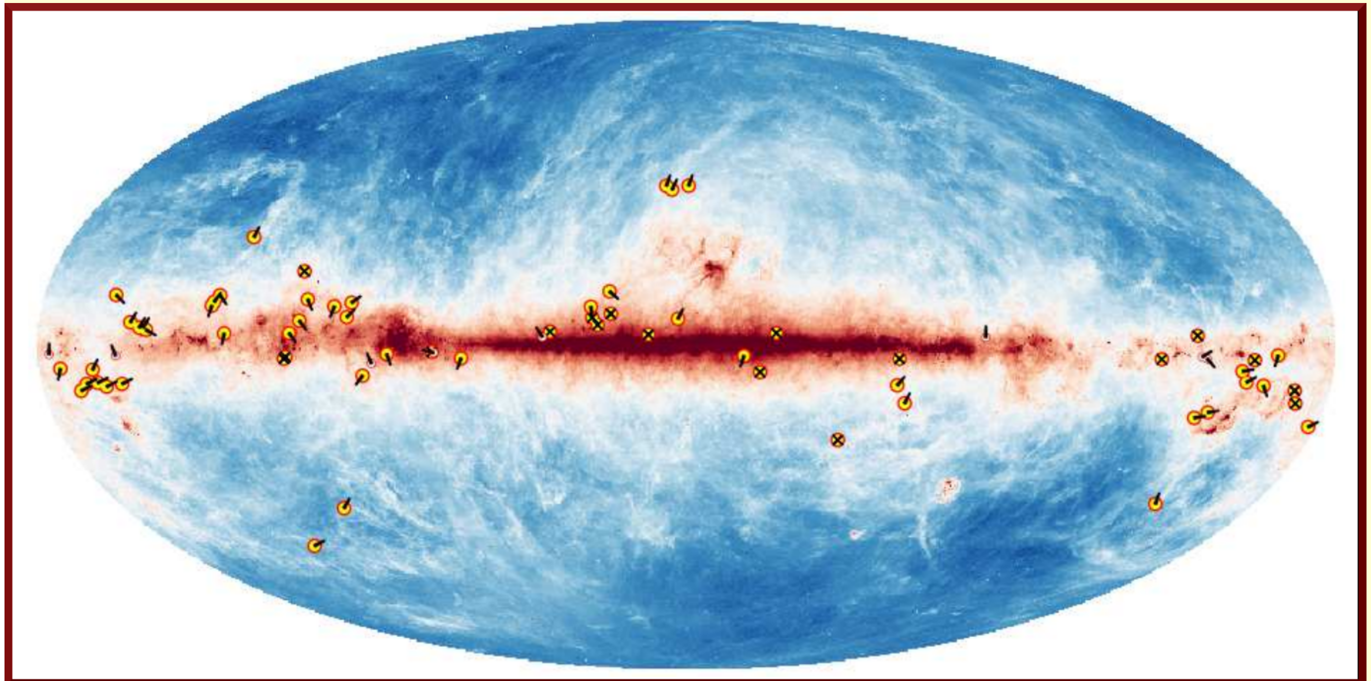
GCC-I, GCC-II
(Juvela et al. 2010, 2011)

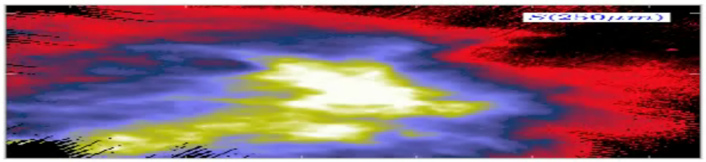
PCC249 at 900 pc
- Very active star forming region
- Average temperature high, the Planck detections correspond to ~100 Msun regions at ~17K
- Colder smaller clumps (~13K) between the hot cores – possibly pre-stellar?

GCC-III: General cloud properties



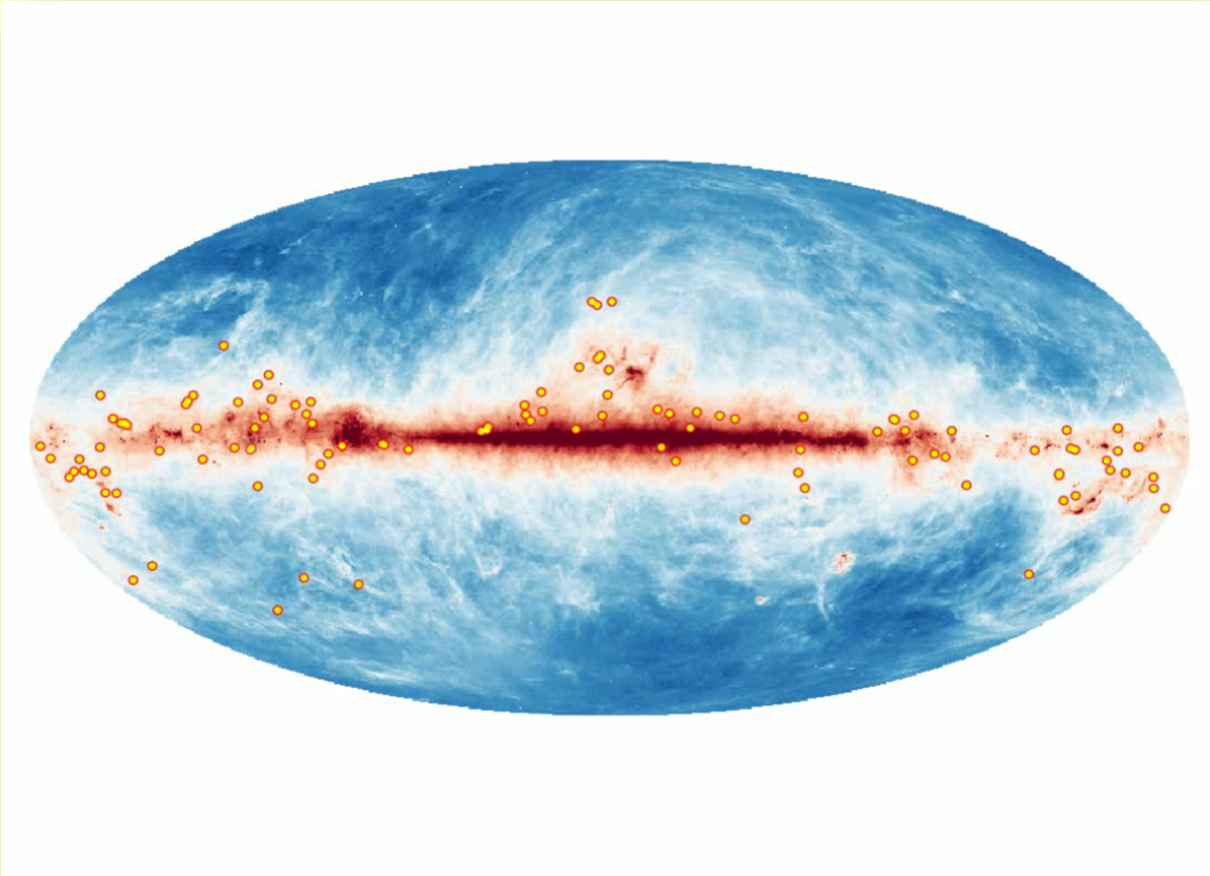
- Study of **71 fields** covered with Herschel SPIRE (250, 350, 500μm) by May 2011
  - **temperatures, column densities, masses, IR data**



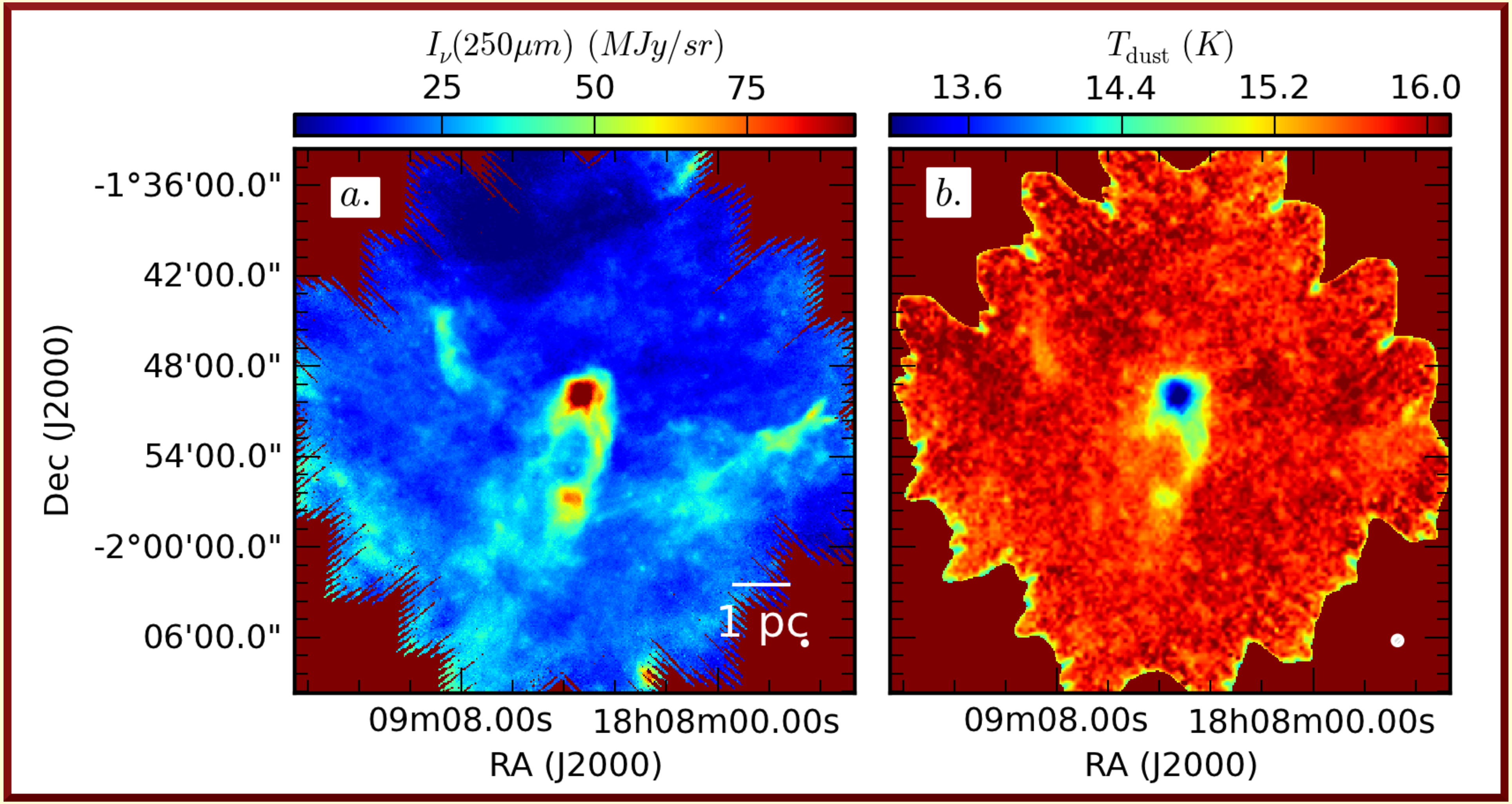


Morphology

- 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

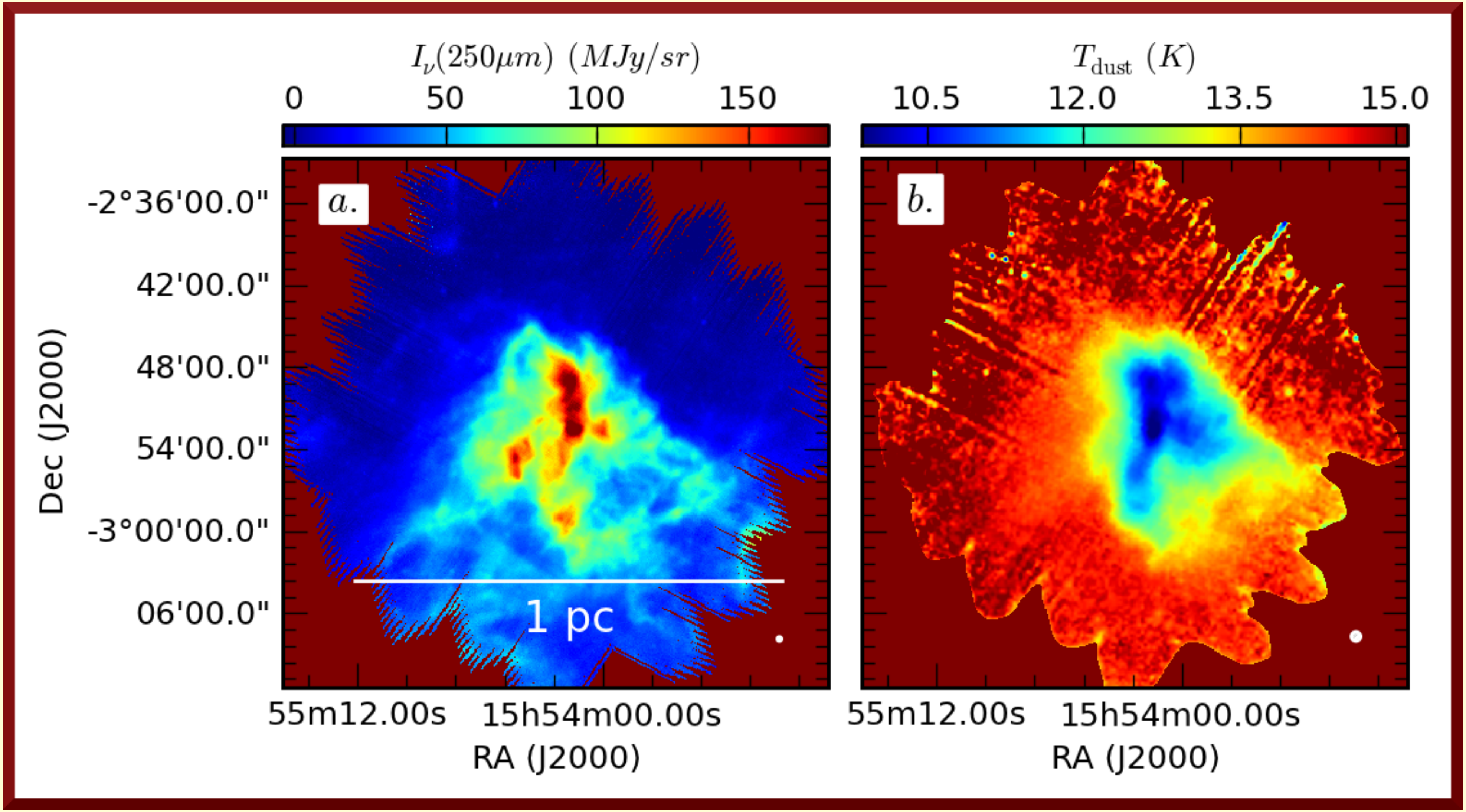


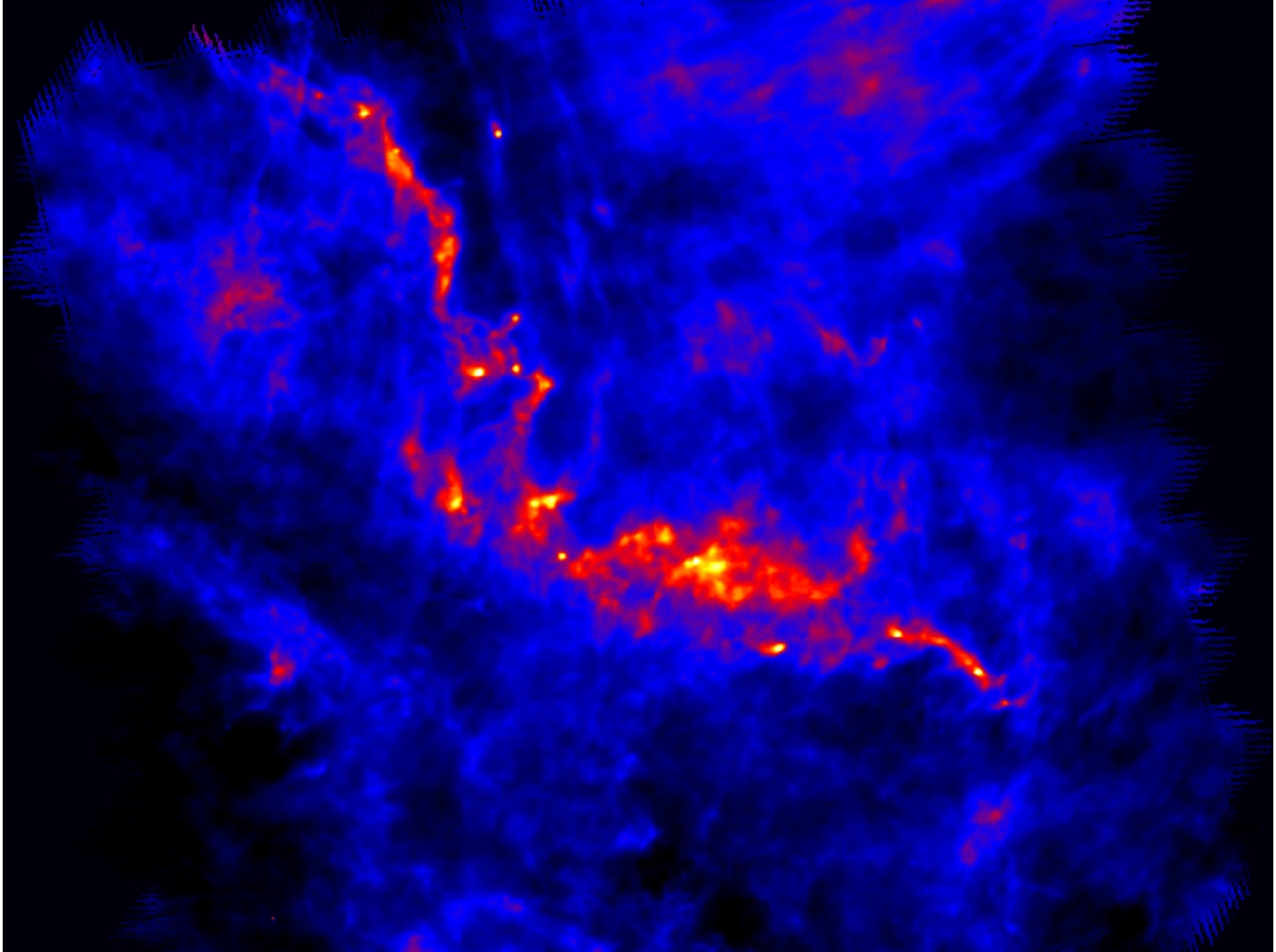
Blobs ...

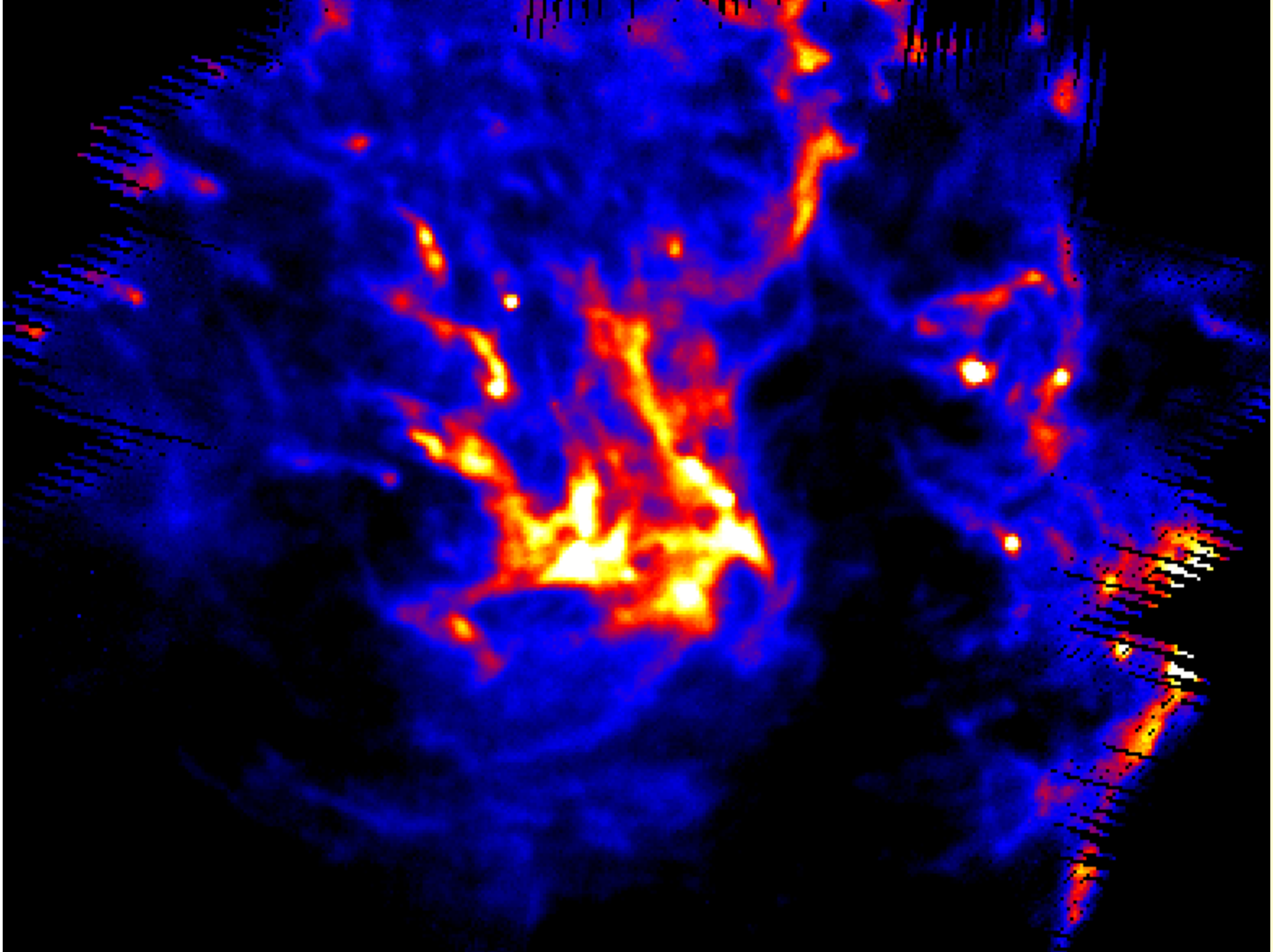


$I_\nu(250\mu m)$ (MJy/sr)
25
50
75
$T_{\rm dust}$ (K)
13.6
14.4
15.2
16.0
a.
b.
-1°36'00.0"
42'00.0"
48'00.0"
54'00.0"
-2°00'00.0"
06'00.0"
Dec (J2000)
1 pc
09m08.00s
18h08m00.00s
RA (J2000)
09m08.00s
18h08m00.00s
RA (J2000)

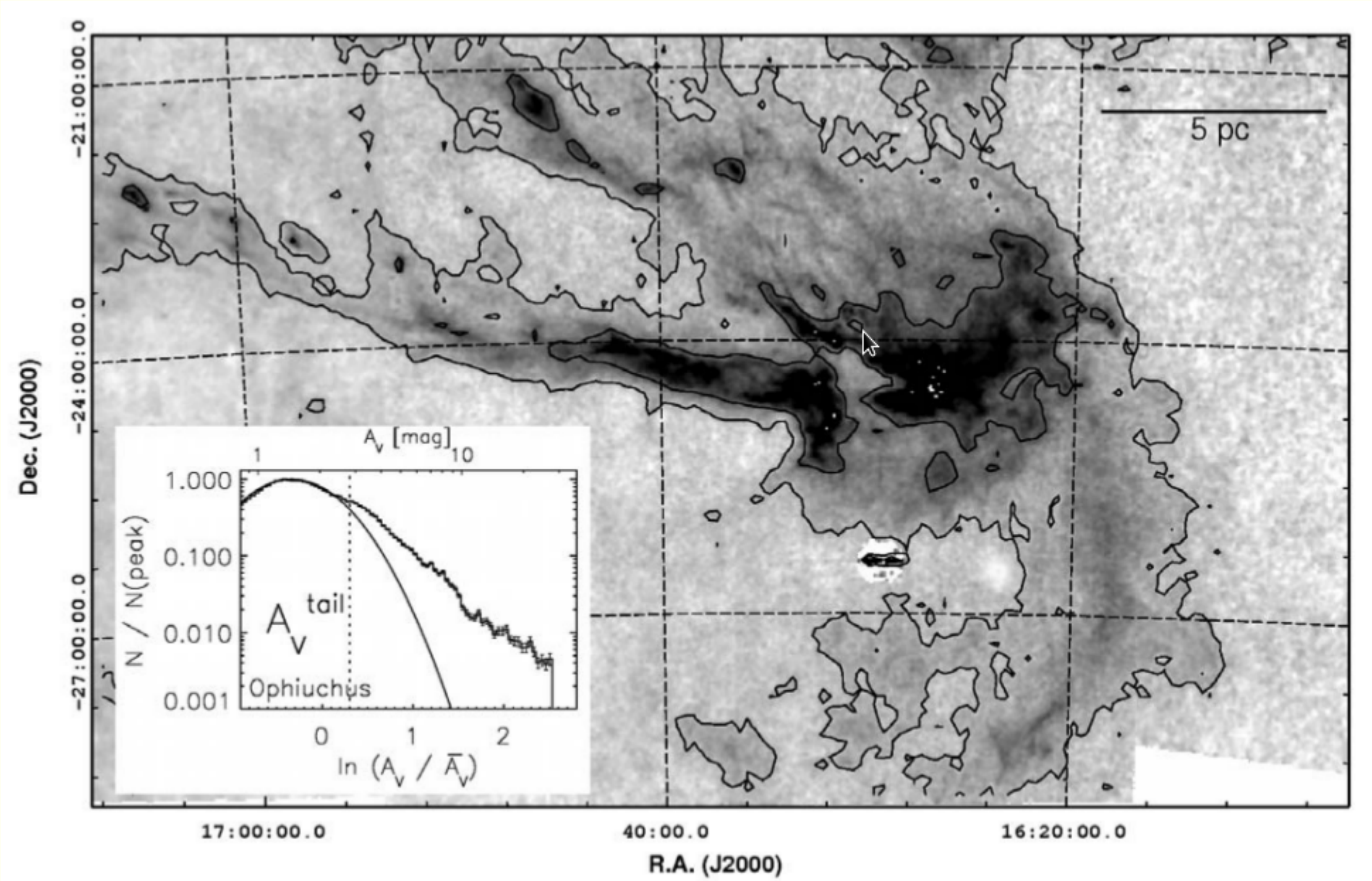
Cometary clouds...



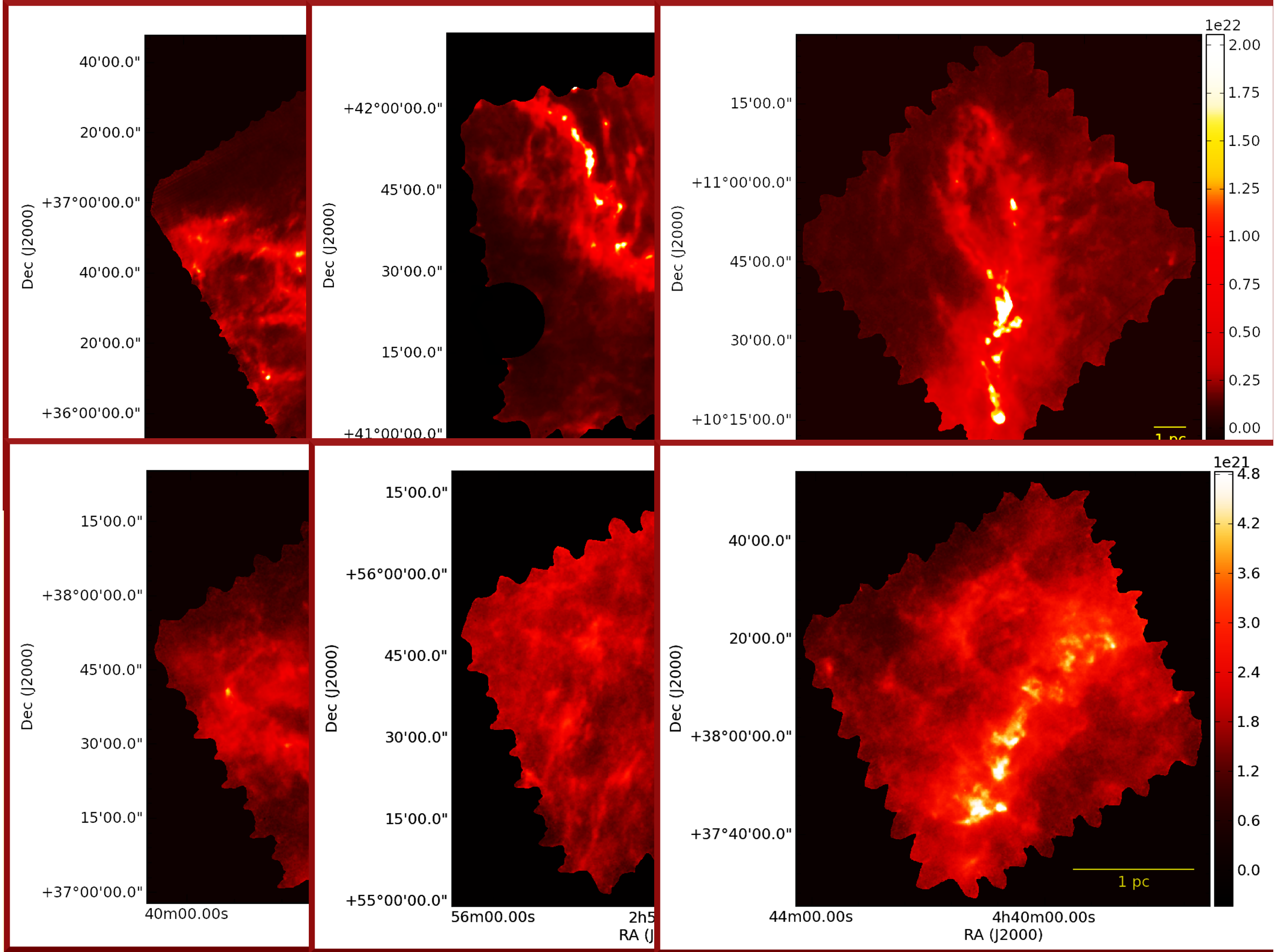




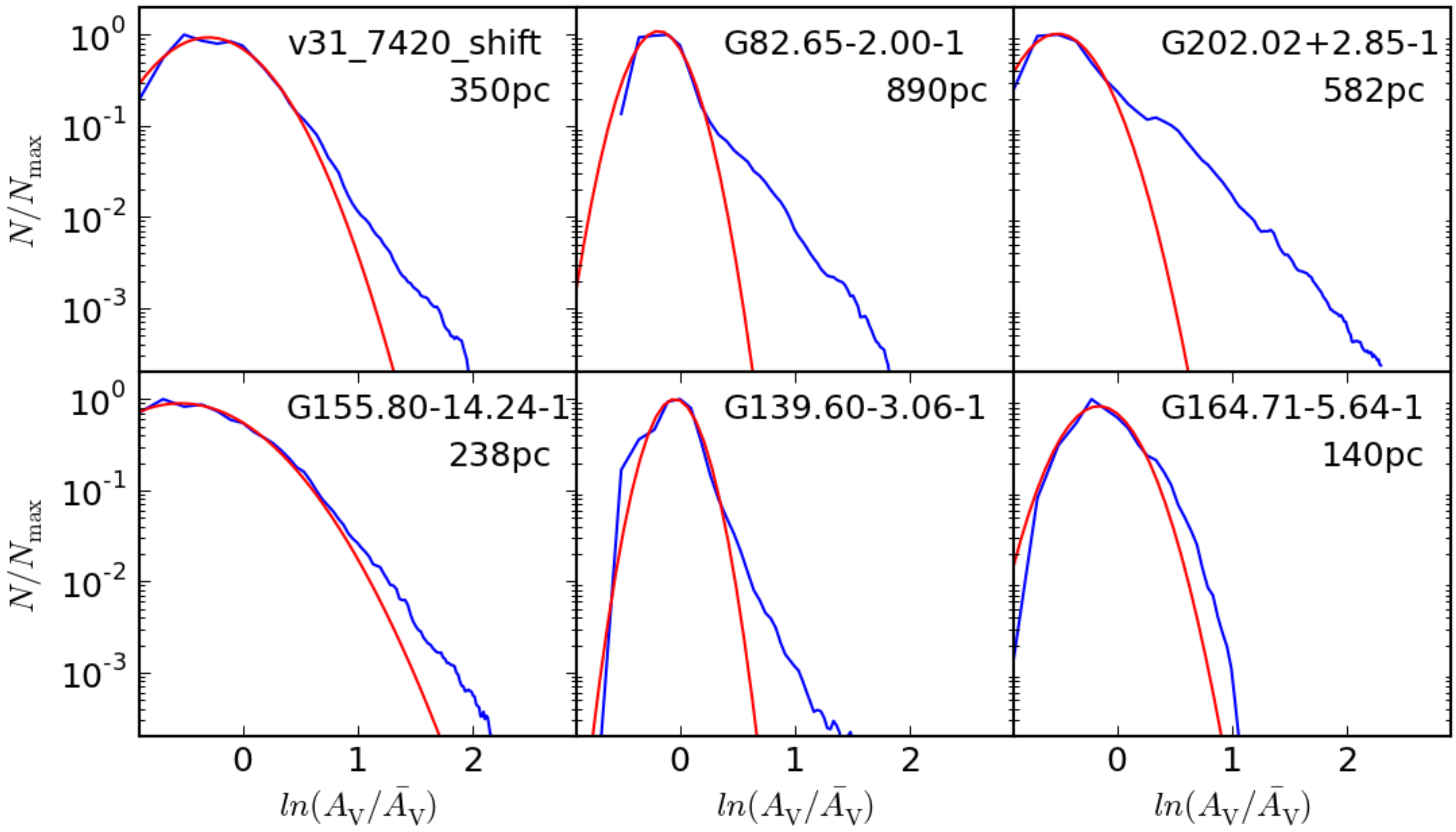
P(A_V) analysis



Kainulainen et al. (2009, 2010)



40'00.0"
20'00.0"
+37°00'00.0"
40'00.0"
20'00.0"
+36°00'00.0"
Dec (J2000)
+42°00'00.0"
45'00.0"
30'00.0"
15'00.0"
+41°00'00.0"
Dec (J2000)
15'00.0"
+11°00'00.0"
45'00.0"
30'00.0"
+10°15'00.0"
Dec (J2000)
1e22
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
15'00.0"
+38°00'00.0"
45'00.0"
30'00.0"
15'00.0"
+37°00'00.0"
Dec (J2000)
40m00.00s
15'00.0"
+56°00'00.0"
45'00.0"
30'00.0"
15'00.0"
+55°00'00.0"
Dec (J2000)
56m00.00s
40'00.0"
20'00.0"
+38°00'00.0"
+37°40'00.0"
Dec (J2000)
1 pc
44m00.00s
4h40m00.00s
RA (J2000)
1e21
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0

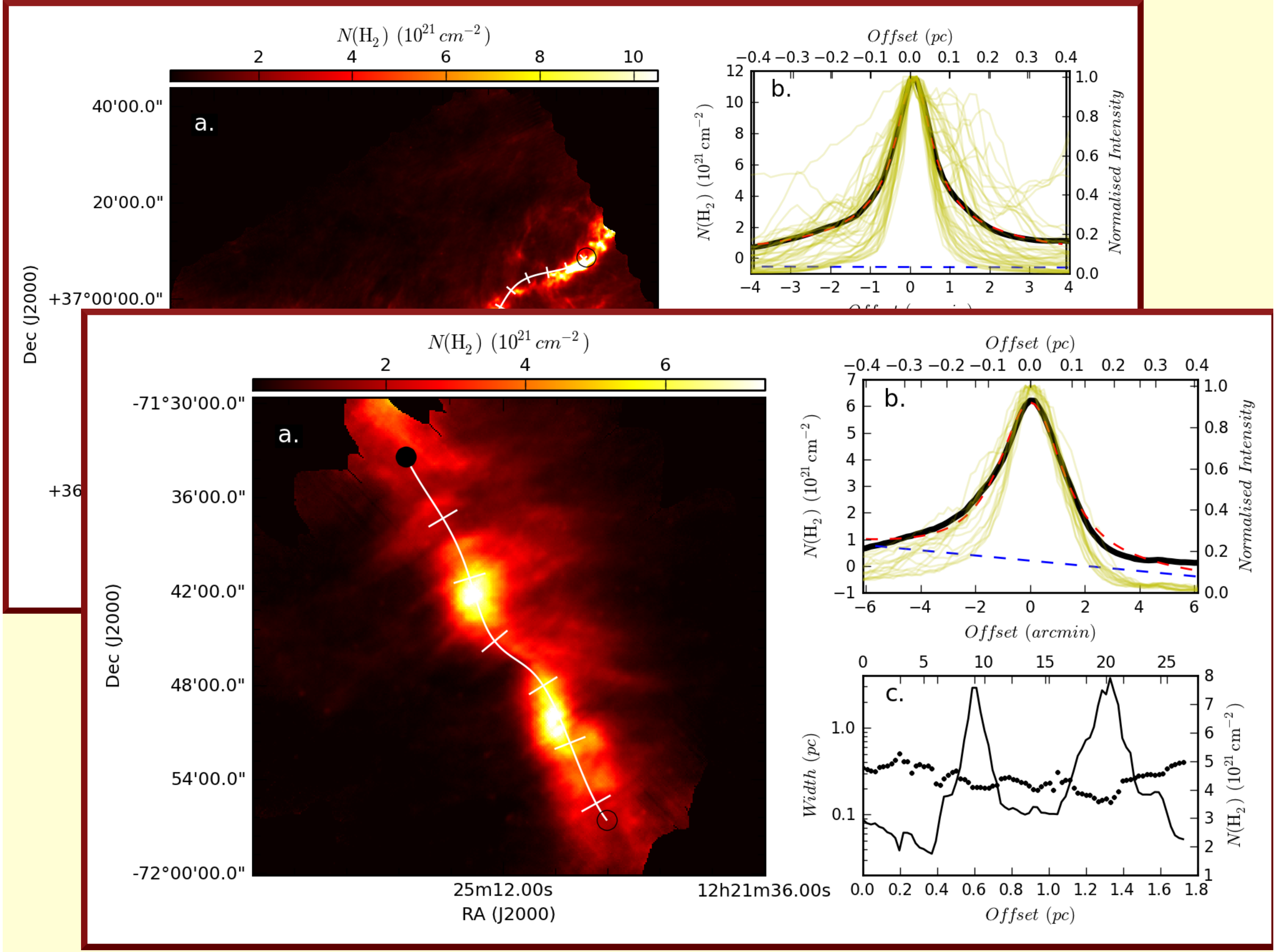

v31_7420_shift
350pc
G82.65-2.00-1
890pc
G202.02+2.85-1
582pc
G155.80-14.24-1
238pc
G139.60-3.06-1
G164.71-5.64-1
140pc
N/N_{max}
$ln(A_V/\bar{A}_V)$

Filaments

- Distinct filamentary structures are seen in half of the fields
  - We examined the **widths** and the **profiles** of the filaments
    - FWHM (from gaussian fits)
    - fit of Plummer profiles →
    - masses

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

  - 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

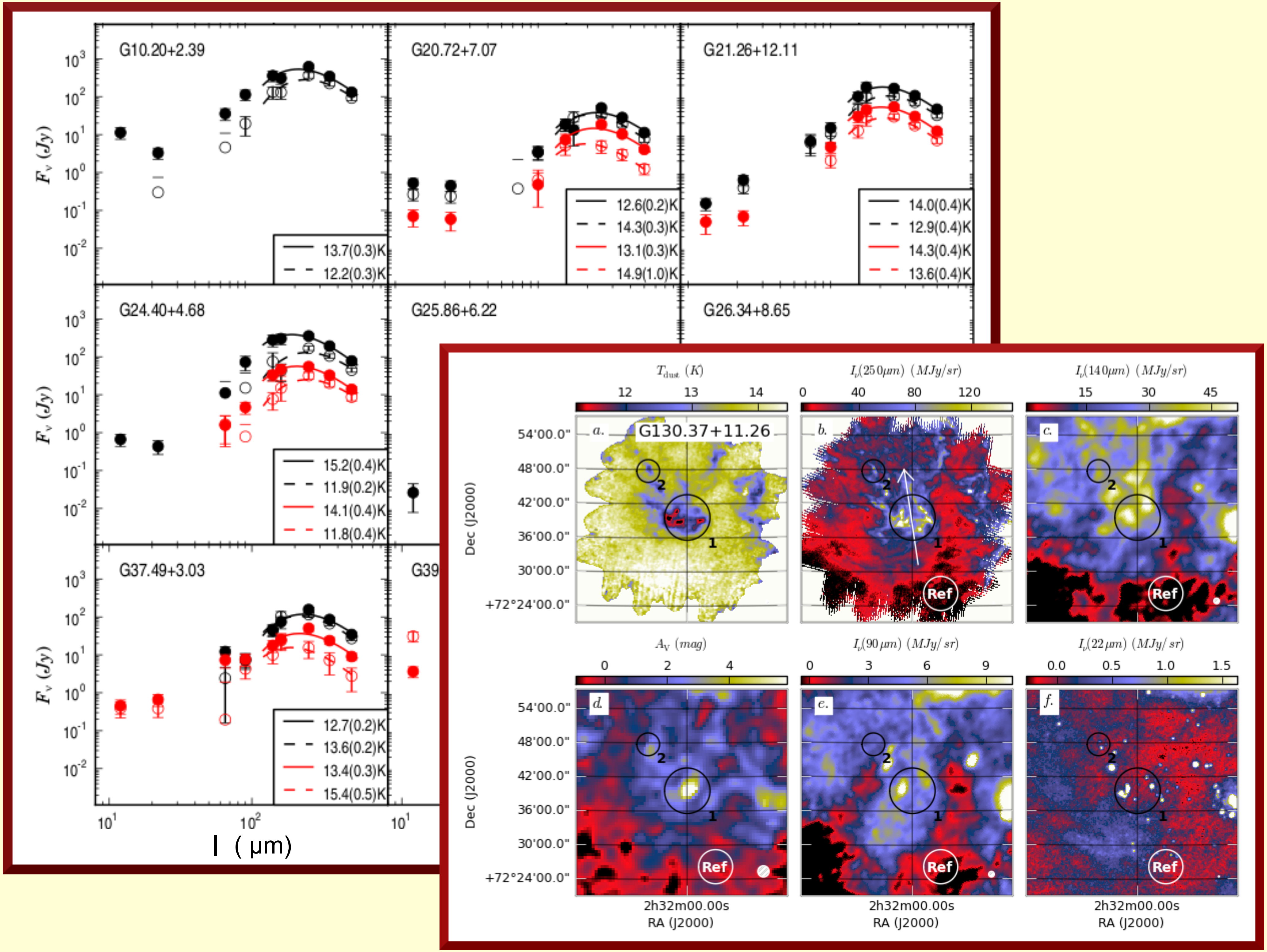


N(H2) (10^21 cm^-2)
a.
b.
c.
Offset (pc)
Offset (arcmin)
Normalised Intensity
N(H2) (10^21 cm^-2)
Width (pc)
Dec (J2000)
RA (J2000)
40'00.0"
20'00.0"
+37°00'00.0"
+36
-71°30'00.0"
36'00.0"
42'00.0"
48'00.0"
54'00.0"
-72°00'00.0"
25m12.00s
12h21m36.00s

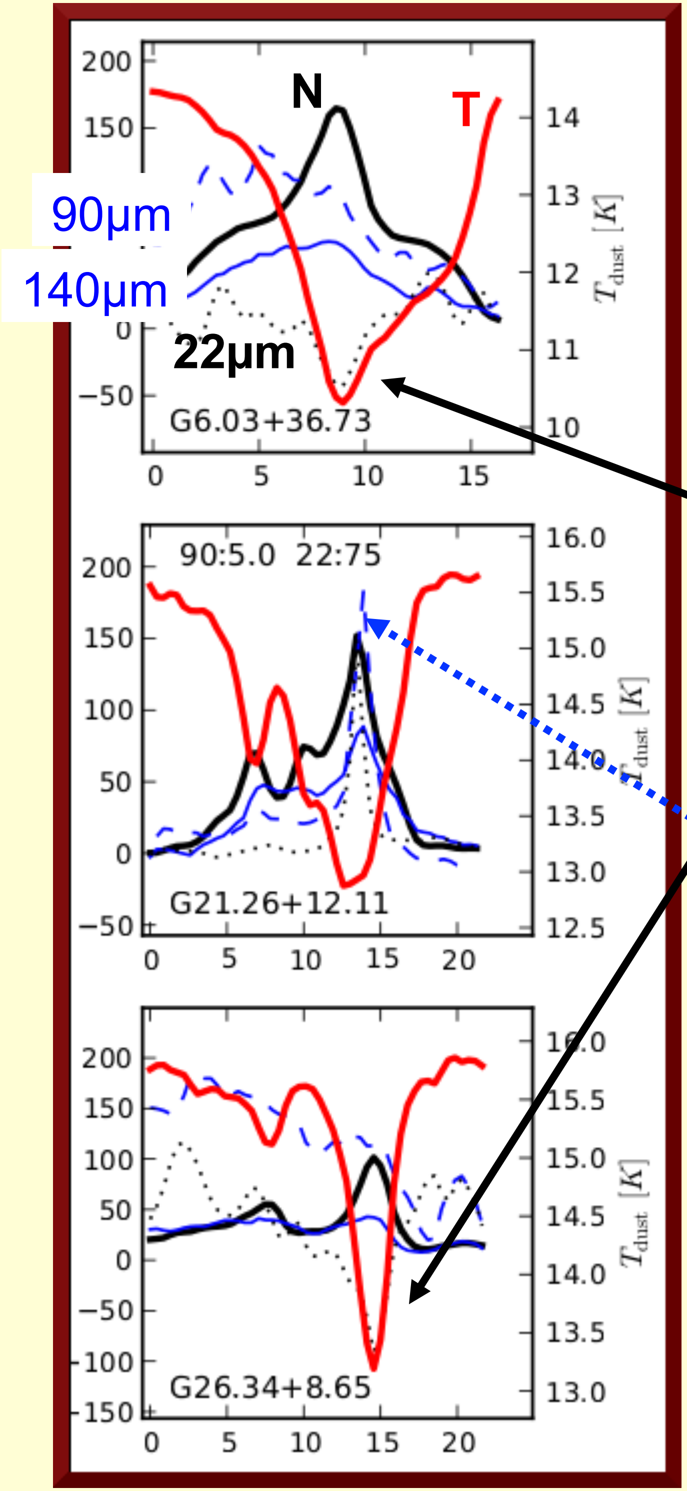
Name	Length (pc)	Width (pc)	Mass ($M_\odot$)	N_{H_2}	$\sigma(N(H_2))$ (10^{21}/cm^2)	L_{Jeans} (pc)	FWHM (pc)	ρ_c (H_2/cm^3)	R_{flat} (pc)	p	M_{line} ($M_\odot$/pc)
G1.94+6.07	2.49	0.40	19.4	1.7	0.2	0.32/0.24	0.21	2.41e+03	0.06	1.5	7.0
G82.65-2.00	14.94	0.40	2931.7	19.2	3.9	0.03/0.02	0.24	3.70e+04	0.06	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

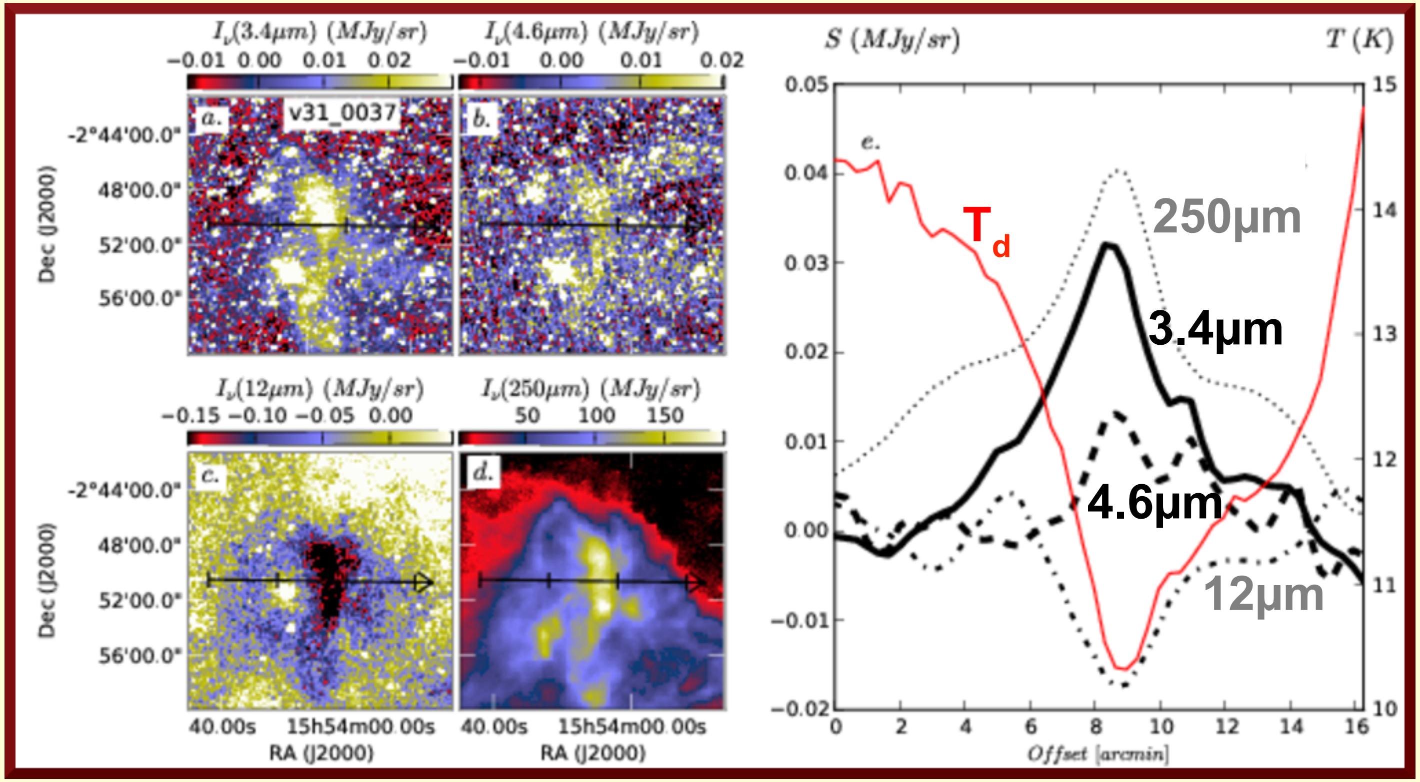


G10.20+2.39
G20.72+7.07
G21.26+12.11
G24.40+4.68
G25.86+6.22
G26.34+8.65
G37.49+3.03
13.7(0.3)K
12.2(0.3)K
12.6(0.2)K
14.3(0.3)K
13.1(0.3)K
14.9(1.0)K
14.0(0.4)K
12.9(0.4)K
14.3(0.4)K
13.6(0.4)K
15.2(0.4)K
11.9(0.2)K
14.1(0.4)K
11.8(0.4)K
12.7(0.2)K
13.6(0.2)K
13.4(0.3)K
15.4(0.5)K
F_ν (Jy)
λ (μm)
T_{dust} (K)
$I_\nu(250\mu m)$ (MJy/sr)
$I_\nu(140\mu m)$ (MJy/sr)
A_V (mag)
$I_\nu(90\mu m)$ (MJy/sr)
$I_\nu(22\mu m)$ (MJy/sr)
G130.37+11.26
Ref
Dec (J2000)
RA (J2000)
2h32m00.00s
+72°24'00.0"
30'00.0"
36'00.0"
42'00.0"
48'00.0"
54'00.0"



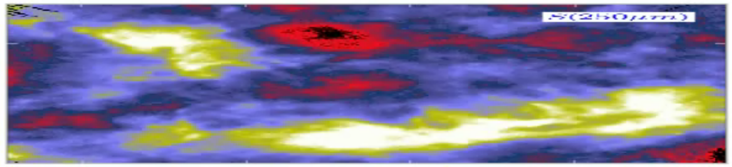
- Cold cores often show reduced MIR emission
  - Decrease of the radiation field or depletion of small grains?
- … and often FIR/MIR sources within the cold clumps

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 typically width a few 0.1pc, 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

- Studies in progress
  - 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 catching up
  - 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
  - **Hunting Coreshines with Spitzer** (166h, PI R. Paladini) to look at futher 90 ECC sources

Outlook II

- The GCC **Herschel** survey is **near completion**
  - The final AORs submitted last week
  - Time to make conclusions about 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 was published January 2011, the complete **Planck** C3PO **catalogue** will be published in 2013

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