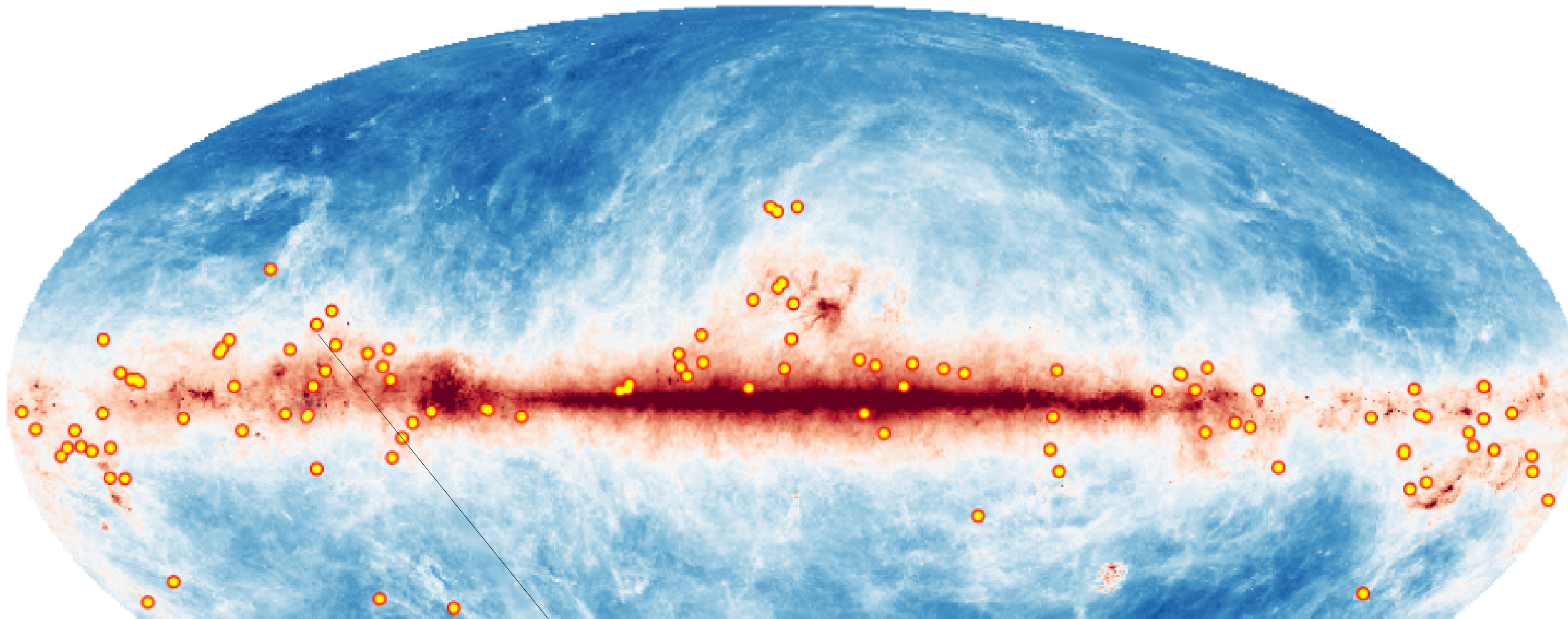
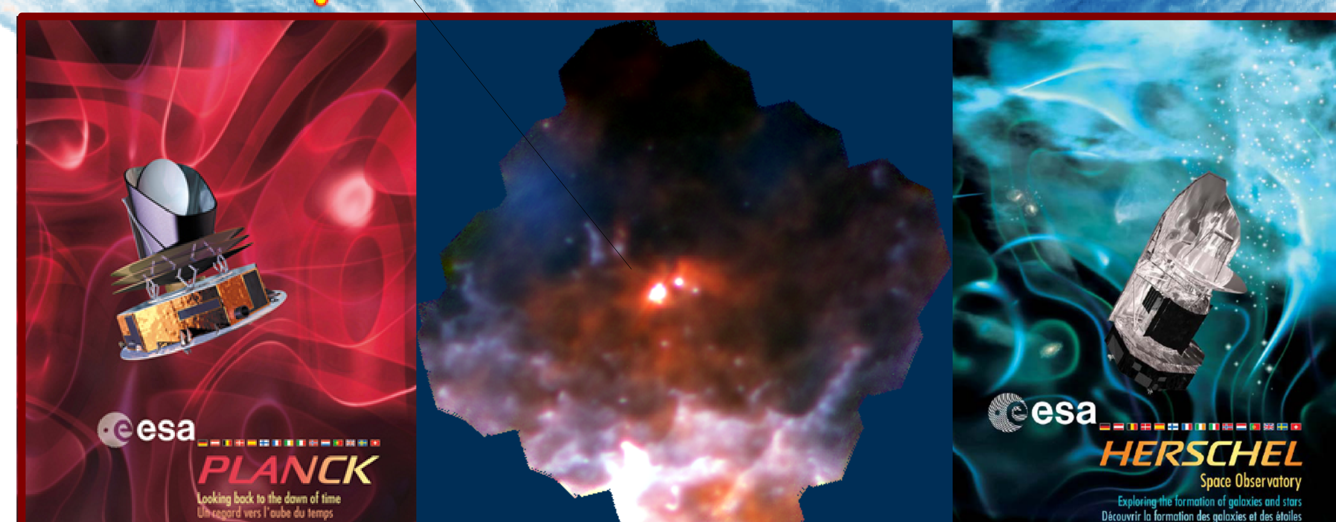
Cold Cores as seen with **Planck** and **Herschel**

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

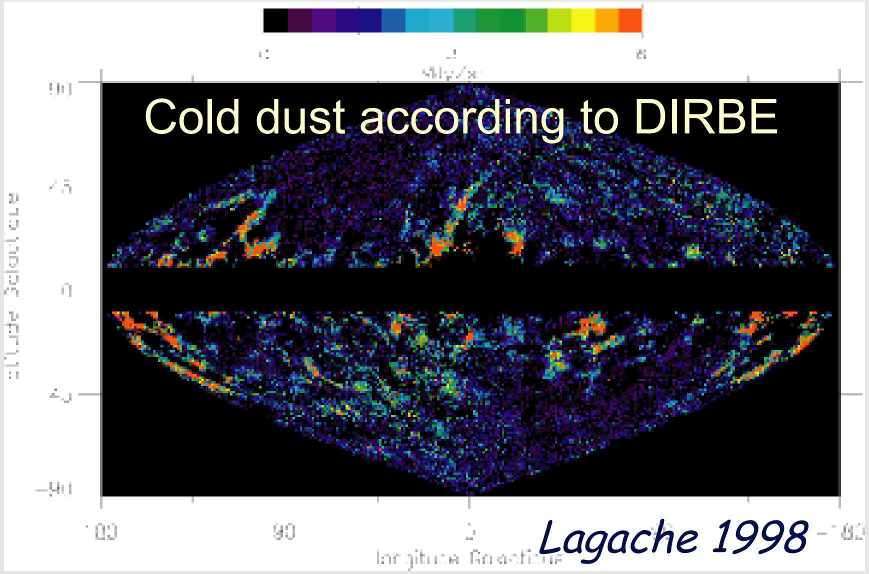




With acknowledgement to ESA and the Planck HFI & LFI consortia

Galactic Cold Cores

- Sub-millimetre dust emission **probes the hidden** dense and very cold regions of molecular clouds
- Tracer of the **earliest phases of star formation**
  - What creates the pre-stellar **cores**, what governs their evolution?
  - Origin of the global stellar **initial mass function** (IMF)
- Part of the life **cycle of dust**
  - from diffuse medium to dense clouds

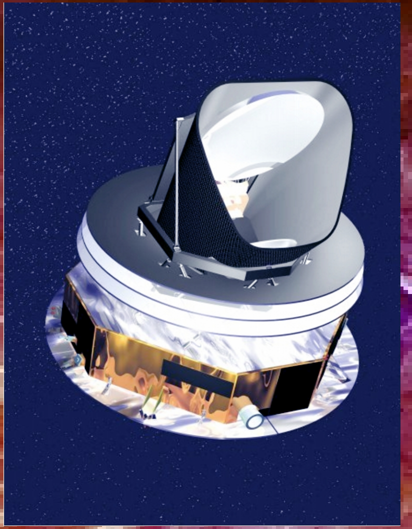


Cold Cores & Planck

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

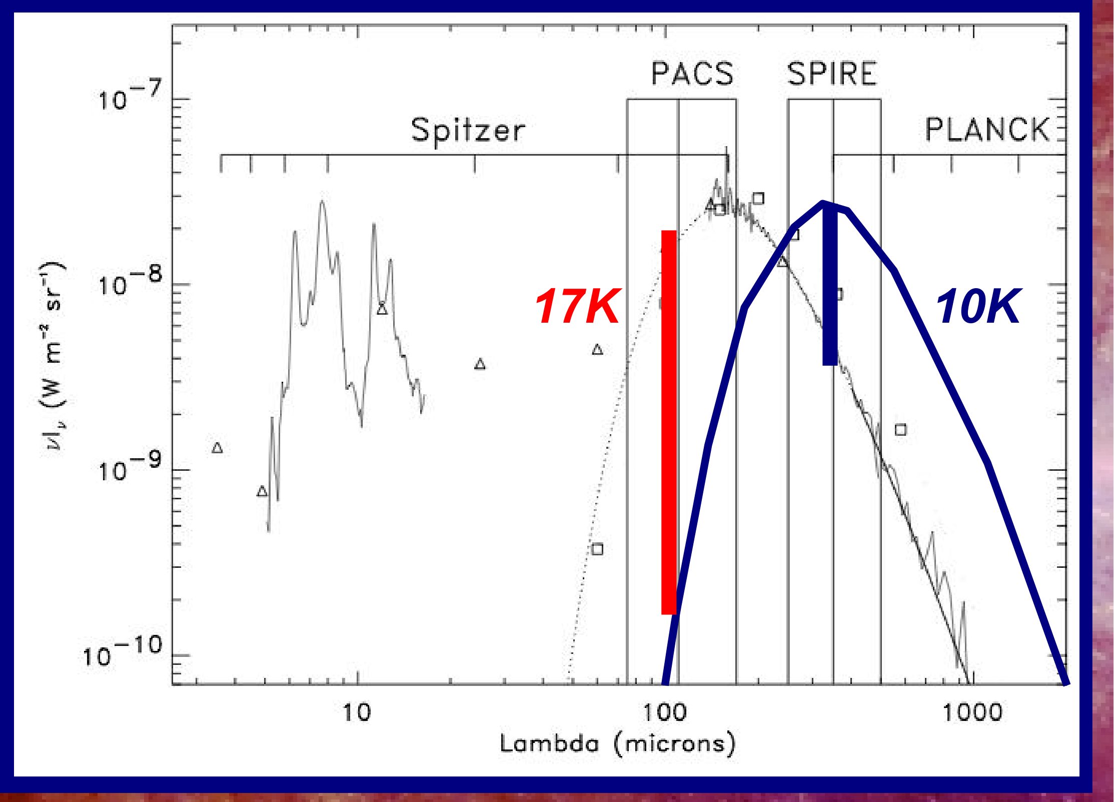
- **350, 550, 850**, 1380, 2100, ...,10000 µm
- **better than 5'** resolution in the sub-mm

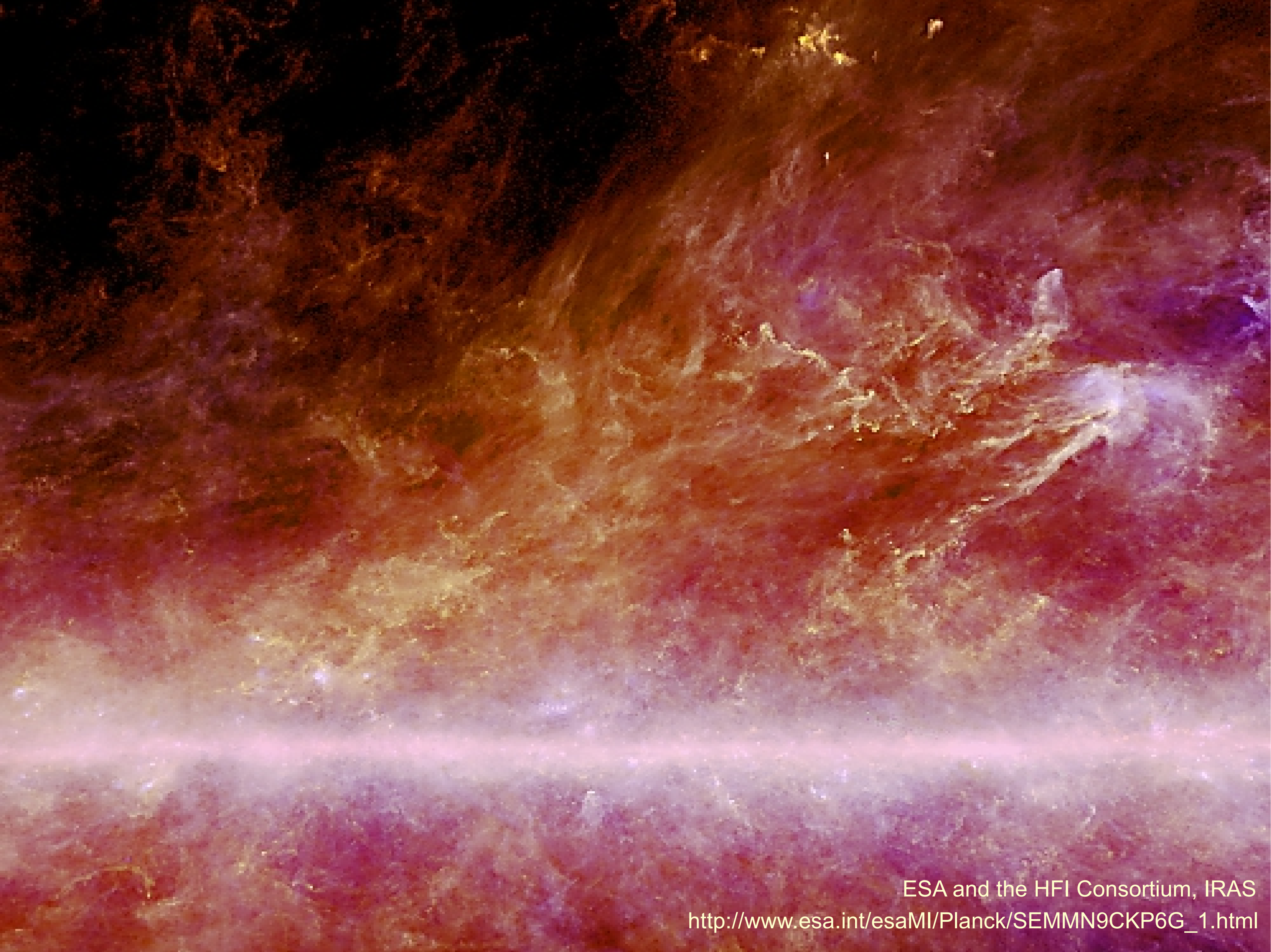
This enables the **detection of cold cores**!



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

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




ESA and the HFI Consortium, IRAS
http://www.esa.int/esaMI/Planck/SEMMN9CKP6G_1.html

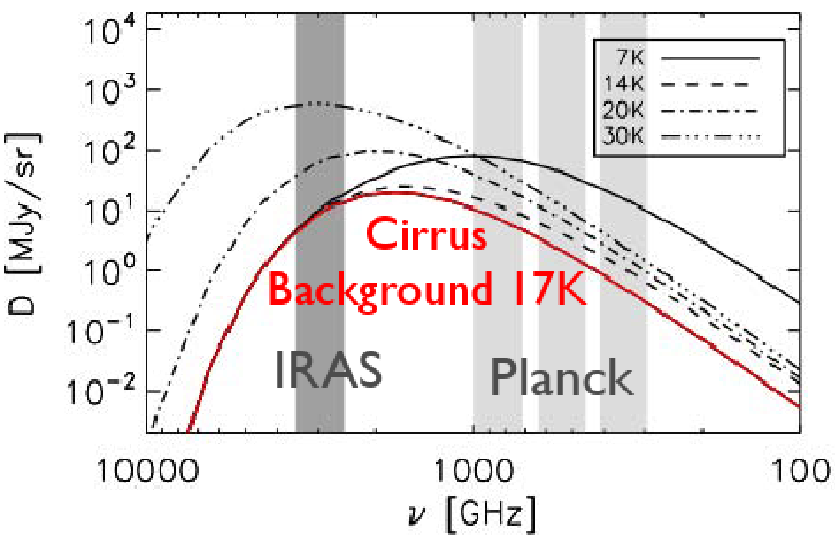
Planck Early Results: The Galactic Cold Core Population revealed by the first all-sky survey

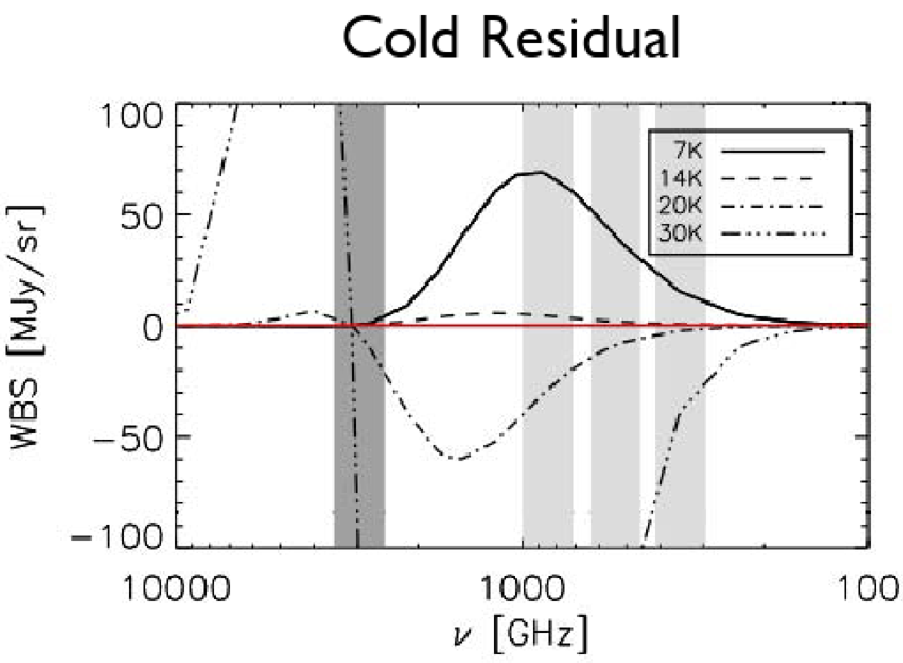
Planck Collaboration: P. A. R. Ade[68], N. Aghanim[45], M. Arnaud[55], M. Ashdown[53,74], J. Aumont[45], C. Baccigalupi[66], A. Balbi[27], A. J. Banday[72,6,60], R. B. Barreiro[50], J. G. Bartlett[3,51], E. Battaner[76], K. Benabed[46], A. Benoît[46], J.-P. Bernard[72,6], M. Bersanelli[25,40], R. Bhatia[33], J. J. Bock[51,7], A. Bonaldi[36], J. R. Bond[5], J. Borrill[59,69], F. R. Bouchet[46], F. Boulanger[45], M. Bucher[3], C. Burigana[39], P. Cabella[27], C. M. Cantalupo[59], J.-F. Cardoso[56,3,46], A. Catalano[3,54], L. Cayón[18], A. Challinor[75,53,8], A. Chamballu[43], R.-R. Chary[44], L.-Y Chiang[47], P. R. Christensen[63,28], D. L. Clements[43], S. Colombi[46], F. Couchot[58], A. Coulais[54], B. P. Crill[51,64], F. Cuttaia[39], L. Danese[66], R. D. Davies[52], R. J. Davis[52], P. de Bernardis[24], G. de Gasperis[27], A. de Rosa[39], G. de Zotti[36,66], J. Delabrouille[3], J.-M. Delouis[46], F.-X. Désert[42], C. Dickinson[52], K. Dobashi[14], S. Donzelli[40,48], O. Doré[51,7], U. Dörl[60], M. Douspis[45], X. Dupac[32], G. Efstathiou[75], T. A. Enßlin[60], E. Falgarone[54], F. Finelli[39], O. Forni[72,6], M. Frailis[38], E. Franceschi[39], S. Galeotta[38], K. Ganga[3,44], M. Giard[72,6], G. Giardino[33], Y. Giraud-Héraud[3], J. González-Nuevo[66], K. M. Górski[51,78], S. Gratton[53,75], A. Gregorio[26], A. Gruppuso[39], F. K. Hansen[48], D. Harrison[75,53], G. Helou[7], S. Henrot-Versillé[58], D. Herranz[50], S. R. Hildebrandt[7,57,49], E. Hivon[46], M. Hobson[74], W. A. Holmes[51], W. Hovest[60], R. J. Hoyland[49], K. M. Huffenberger[77], A. H. Jaffe[43], G. Joncas[11], W. C. Jones[17], M. Juvela[16], E. Keihänen[16], R. Keskitalo[51,16], T. S. Kisner[59], R. Kneissl[31,4], L. Knox[20], H. Kurki-Suonio[16,34], G. Lagache[45], J.-M. Lamarre[54], A. Lasenby[74,53], R. J. Laureijs[33], C. R. Lawrence[51], S. Leach[66], R. Leonardi[32,33,21], C. Leroy[45,72,6], M. Linden-Vørnle[10], M. López-Caniego[50], P. M. Lubin[21], J. F. Macías-Pérez[57], C. J. MacTavish[53], B. Maffei[52], N. Mandolesi[39], R. Mann[67], M. Maris[38], D. J. Marshall[72,6], P. Martin[5], E. Martínez-González[50], G. Marton[30], S. Masi[24], S. Matarrese[23], F. Matthai[60], P. Mazzotta[27], P. McGehee[44], A. Melchiorri[24], L. Mendes[32], A. Mennella[25,38], S. Mitra[51], M.-A. Miville-Deschênes[45,5], A. Moneti[46], L. Montier[72,6] ⋆, G. Morgante[39], D. Mortlock[43], D. Munshi[68,75], A. Murphy[62], P. Naselsky[63,28], F. Nati[24], P. Natoli[27,2,39], C. B. Netterfield[13], H. U. Nørgaard-Nielsen[10], F. Noviello[45], D. Novikov[43], I. Novikov[63], S. Osborne[71], F. Pajot[45], R. Paladini[70,7], F. Pasian[38], G. Patanchon[3], T. J. Pearson[7,44], V.-M. Pelkonen[44], O. Perdereau[58], L. Perotto[57], F. Perrotta[66], F. Piacentini[24], M. Piat[3], S. Plaszczynski[58], E. Pointecouteau[72,6], G. Polenta[2,37], N. Ponthieu[45], T. Poutanen[34,16,1], G. Prézeau[7,51], S. Prunet[46], J.-L. Puget[45], W. T. Reach[73], R. Rebolo[49,29], M. Reinecke[60], C. Renault[57], S. Ricciardi[39], T. Riller[60], I. Ristorcelli[72,6], G. Rocha[51,7], C. Rosset[3], M. Rowan-Robinson[43], J. A. Rubiño-Martín[49,29], B. Rusholme[44], M. Sandri[39], D. Santos[57], G. Savini[65], D. Scott[15], M. D. Seiffert[51,7], G. F. Smoot[19,59,3], J.-L. Starck[55,9], F. Stivoli[41], V. Stolyarov[74], R. Sudiwala[68], J.-F. Sygnet[46], J. A. Tauber[33], L. Terenzi[39], L. Toffolatti[12], M. Tomasi[25,40], J.-P. Torre[45], V. Toth[30], M. Tristram[58], J. Tuovinen[61], G. Umana[35], L. Valenziano[39], P. Vielva[50], F. Villa[39], N. Vittorio[27], L. A. Wade[51], B. D. Wandelt[46,22], N. Ysard[16], D. Yvon[9], A. Zacchei[38], S. Zahorecz[30], and A. Zonca[21]

Planck Collaboration, arXiv:1101.2035

Detection principle

(slides by L. Montier)





A simple example:

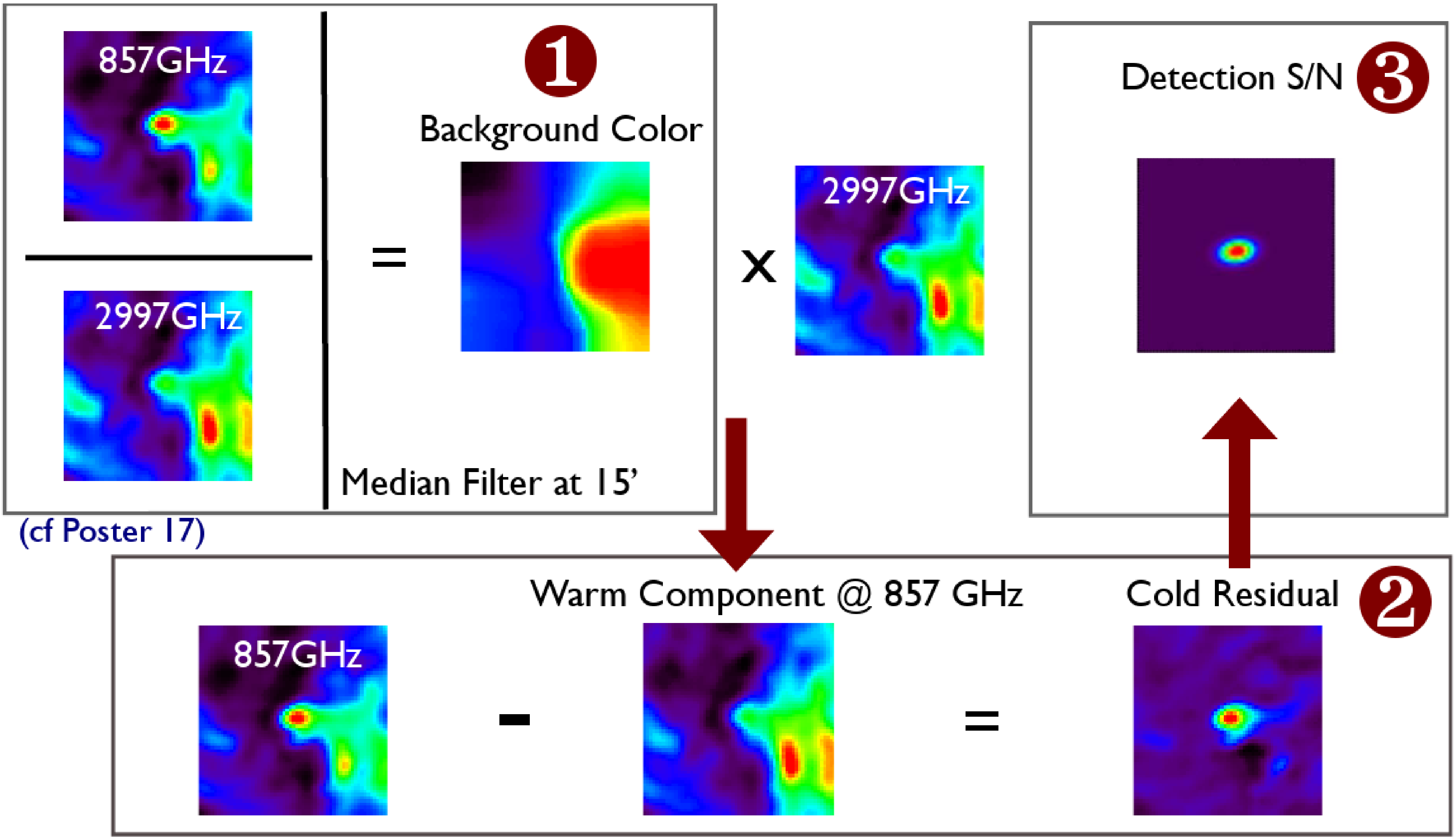
Spectra of 4 sources (from 7K to 30K) upon a galactic cirrus background at 17K

Idea:

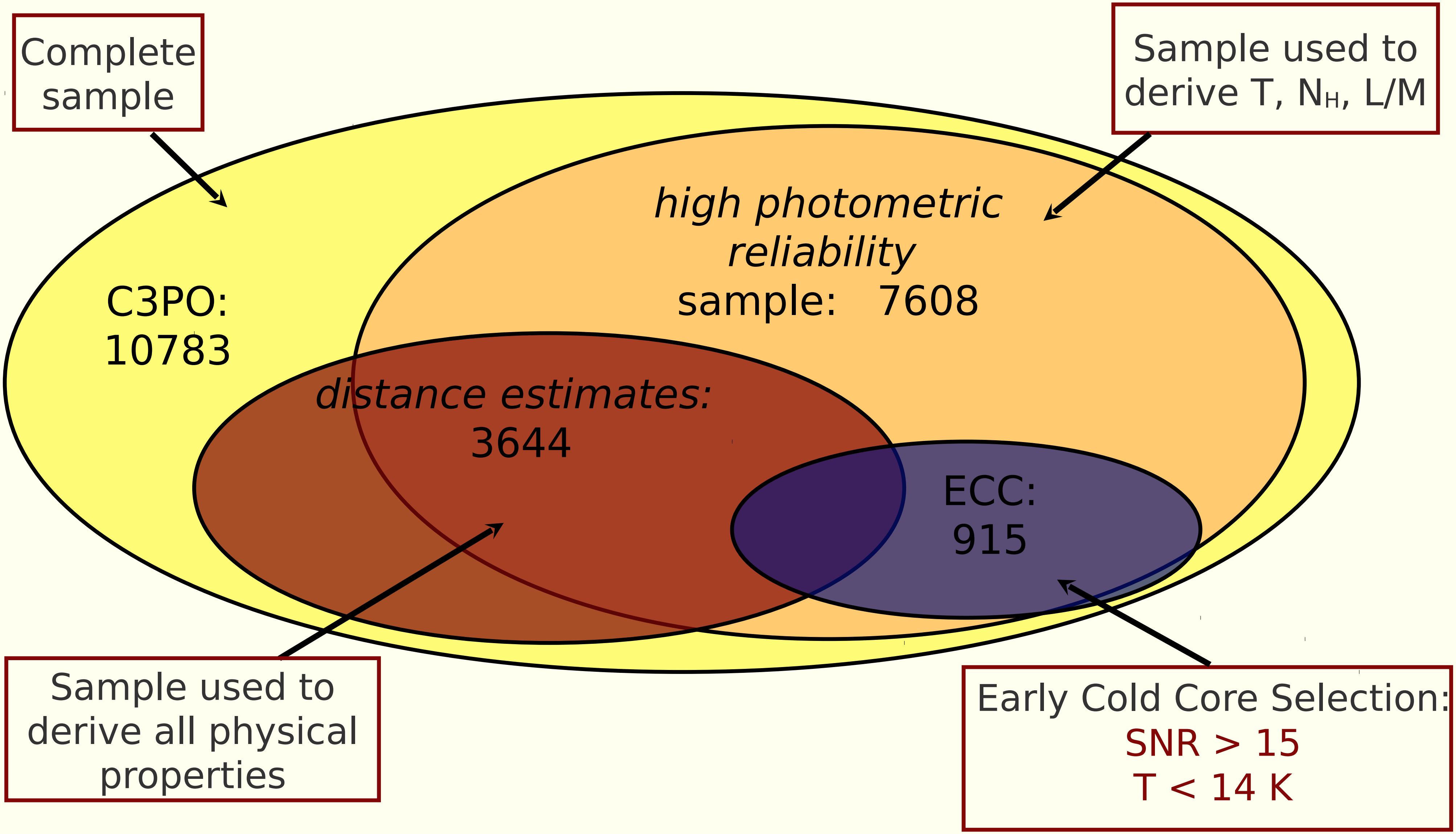
- Choose a '*warm*' frequency : IRAS 100um
- Extrapolate the *warm* component to lower frequencies
- Perform Detection on Cold Residual

(Montier et al. 2010)

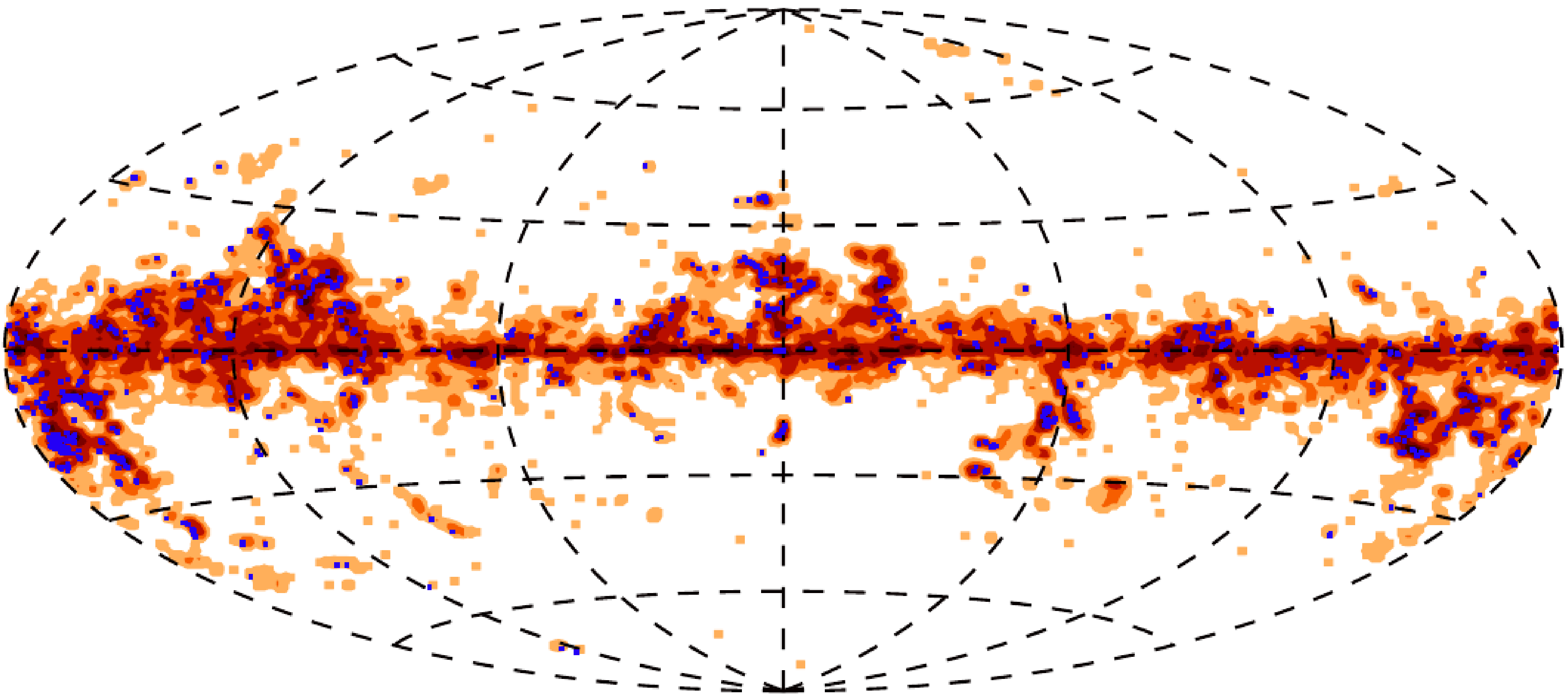
The source detection algorithm



C3PO and ECC Catalogues



All-sky distribution

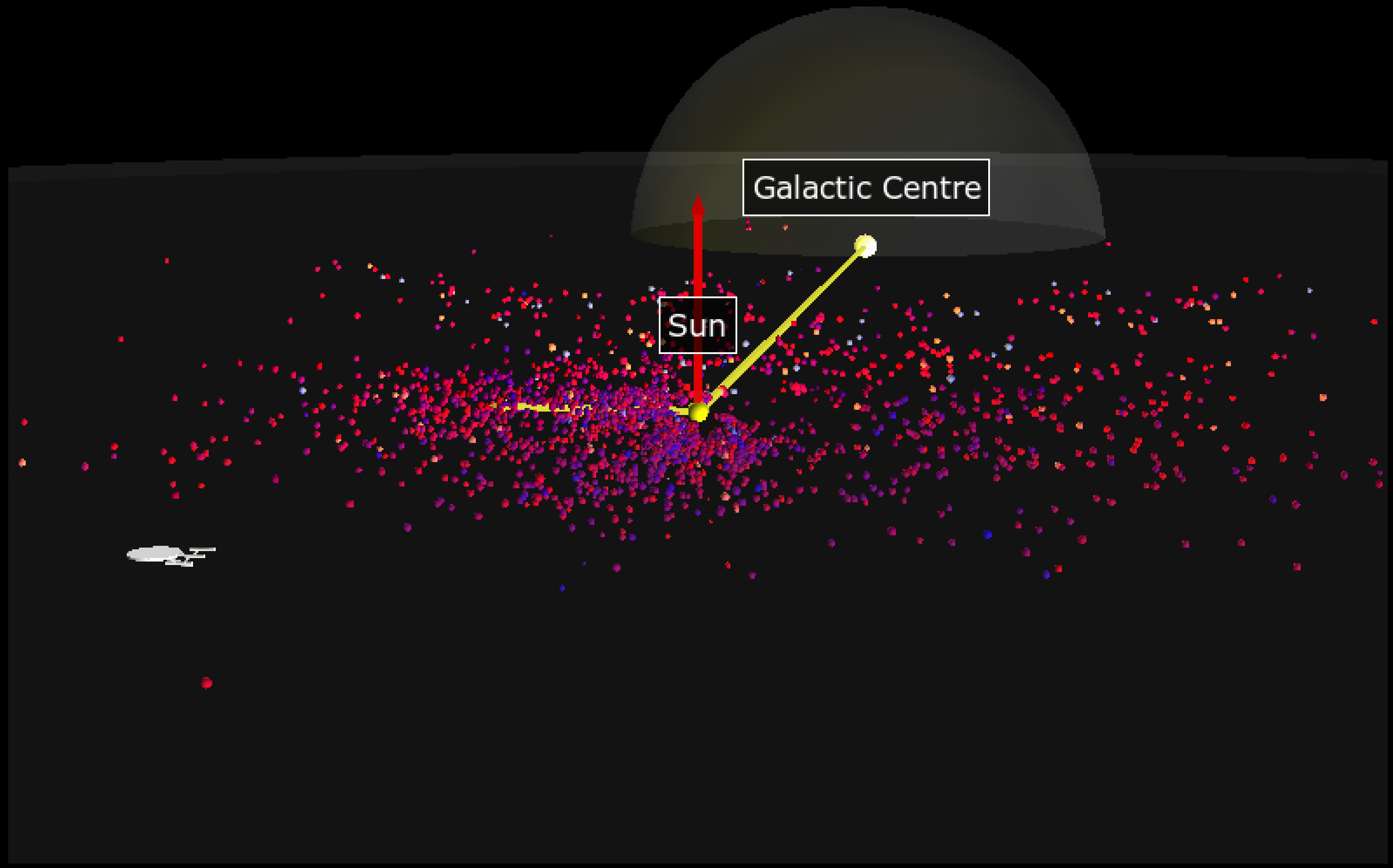


All-sky map of the number of C3PO objects per square degree

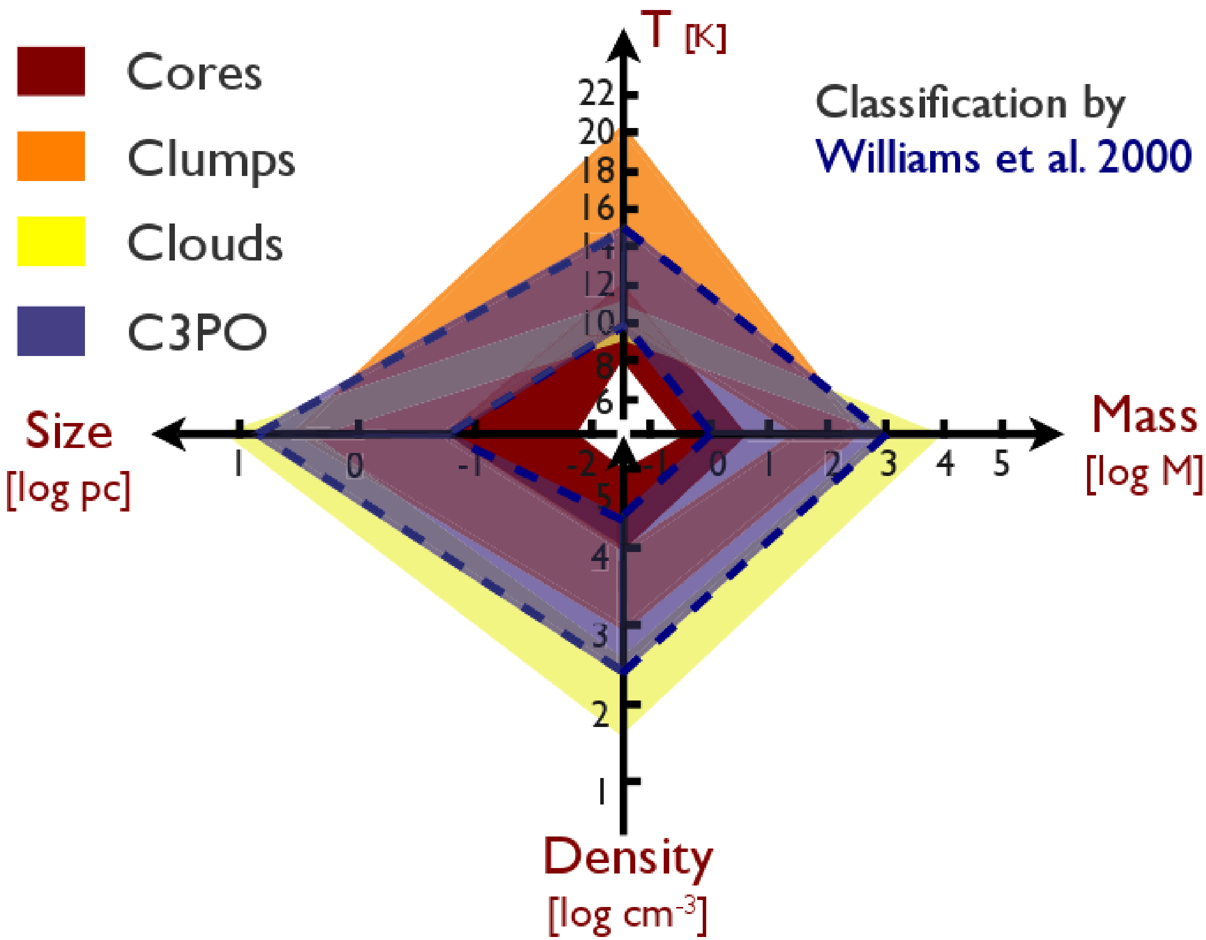
(10783)

■ ECC Selection

(915)

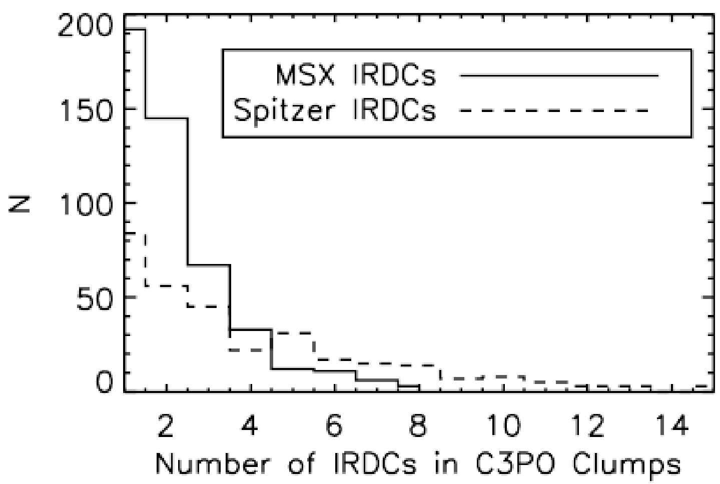

Galactic Centre
Sun

Physical Analysis



Classification by
Williams et al. 2000

Comparison with IRDCs

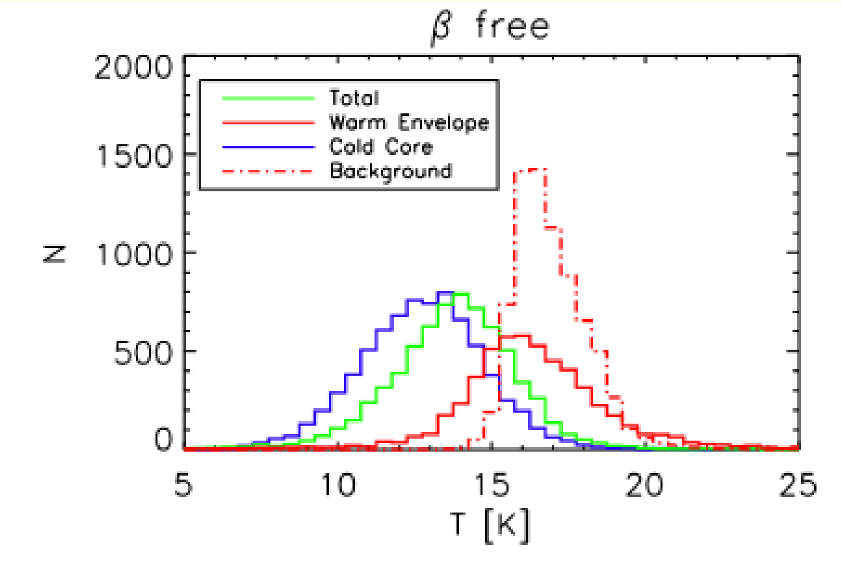


- Each C3PO Object contains **2 to 15 IRDCs** from MSX & SPITZER.

Simon et al. 2006
Peretto et al. 2009

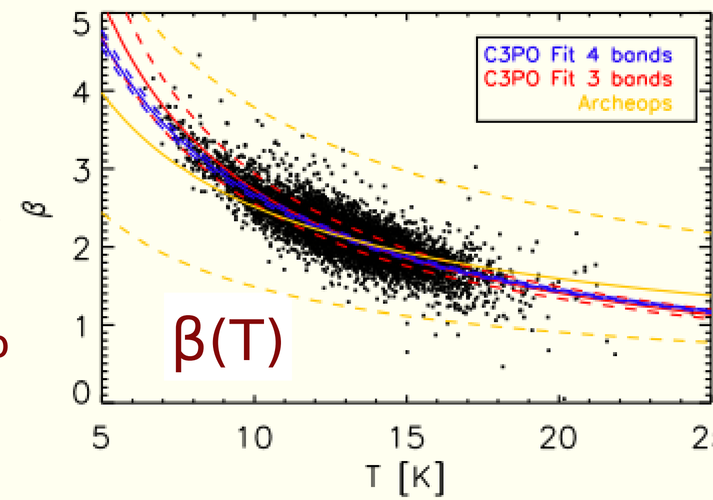
- The C3PO sources match mainly the ***cold clump*** domain.
  They are intermediate sub-structures between molecular clouds and dense cores

Temperature and spectral index



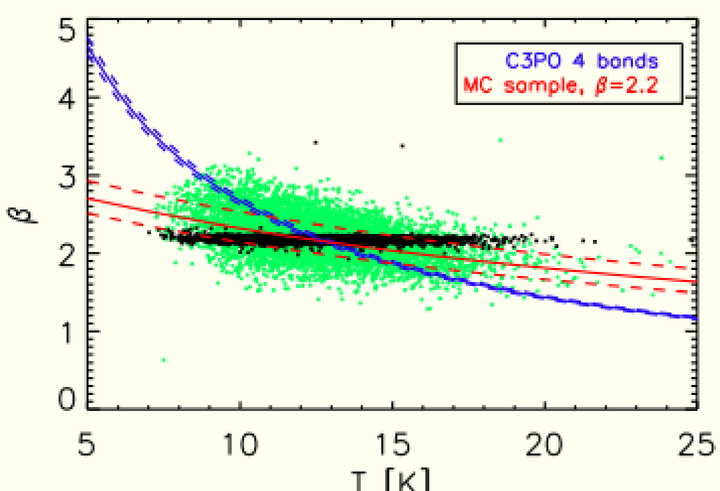
β free

- T distribution:
  7 K < T < 17 K
  σT/T ~ 7%
  σβ/β ~ 20-30%



see also Planck 2011t,u

Monte-Carlo Simulation



- Monte Carlo Simulations with realistic (calibration + pixel) errors and constant β cannot reproduce data.
- Data errors + Fit Degeneracy does not explain the observed relation: $\beta = (\delta + \omega T)^{-1}$

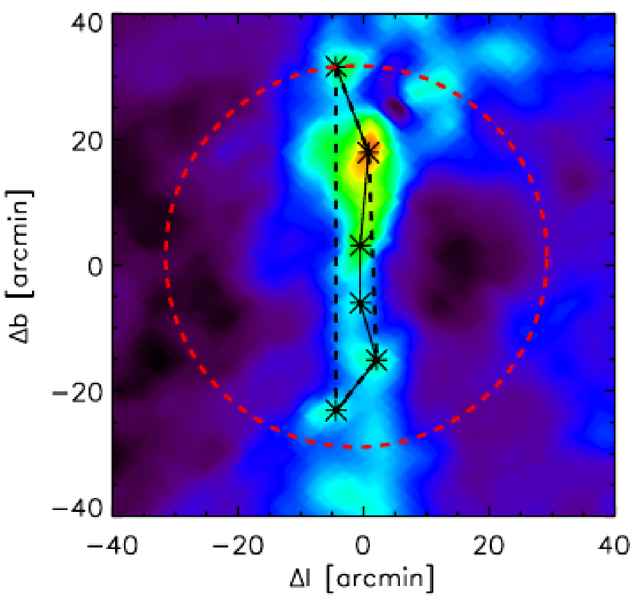
Groups, Filaments and Loops

Medium scale

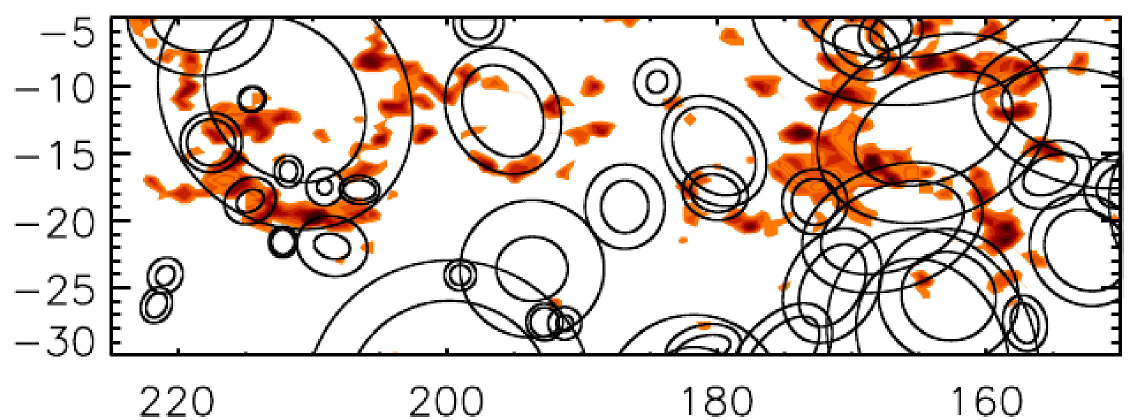
- Statistical analysis on all-sky and Tau-Aur-Per-Or regions
- Cold Clumps are preferentially organised in groups and filaments

Large Scale

- Correlation with HI shells Loops
  Correlation with IRAS Loops
- Cold clumps are preferentially located on the edges of these loops



IRAS Loops and C3PO clumps in TAPO



(Konyves et al. 2006)

Cold Cores (... clumps?)

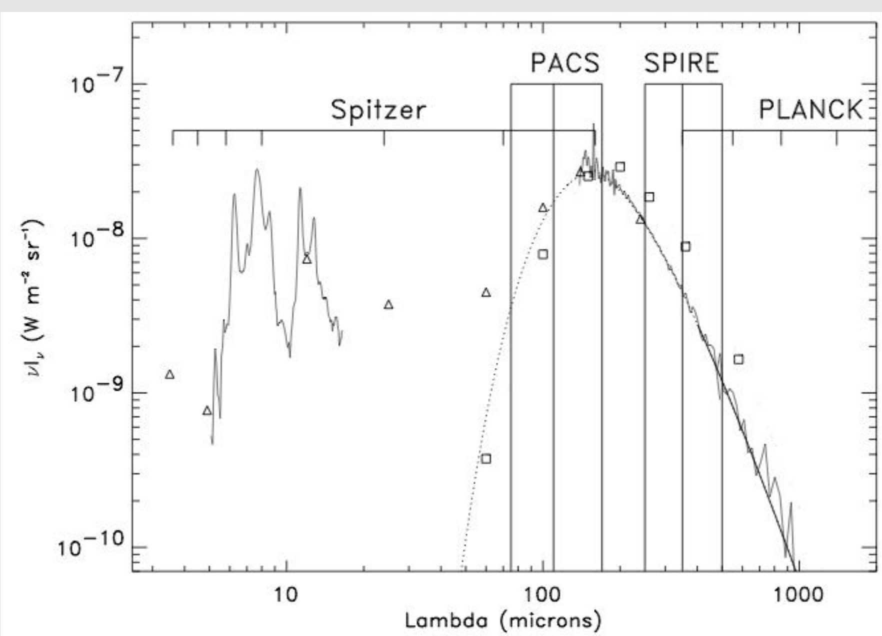
We want to *understand* star formation

- 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 dust properties vary in the cores
- how does the star formation affect the cores
- ...

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

Cold Cores & Herschel

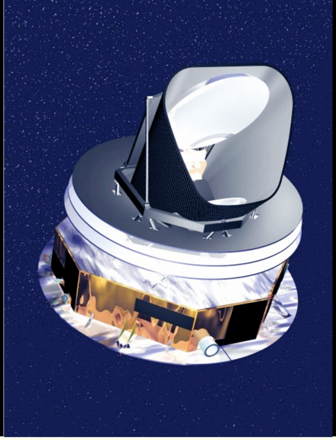
- OT KP ***Galactic Cold Cores***
- PACS and SPIRE maps of cores **detected by Planck**
- a **cross-section** of the Galactic cold core population
    - **temperature**, **mass**, **density**, **size**, **location** (high/low latitudes, inner/outer Galaxy), **environment** (clustered vs. isolated sources, magnetic fields), **dust** properties (emissivity index, signs of anomalous microwave emission, polarization)
    - 151 hours ~ 110 fields

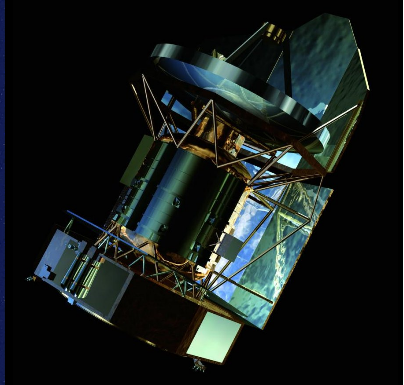


Cold Cores

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

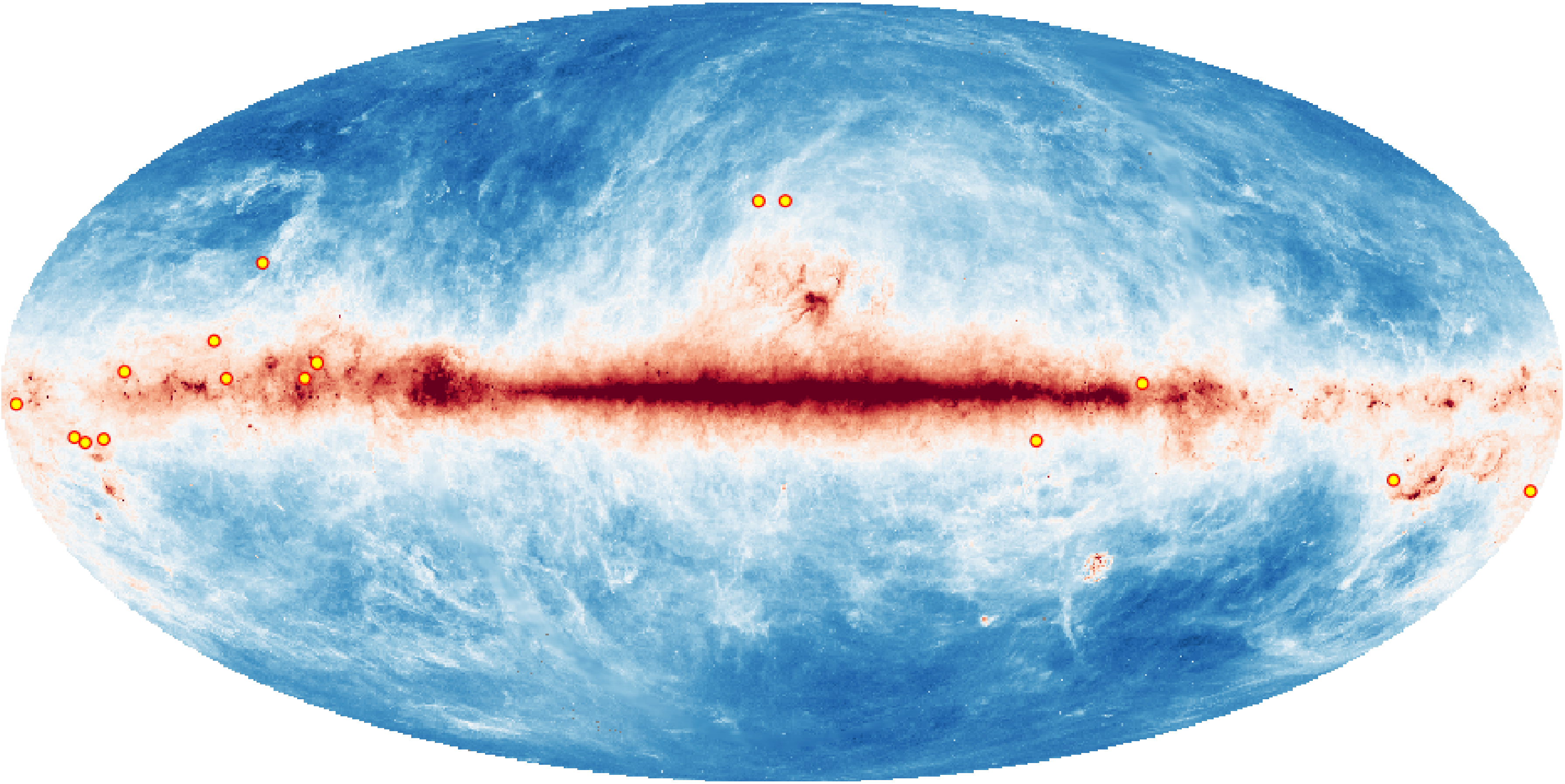
Herschel

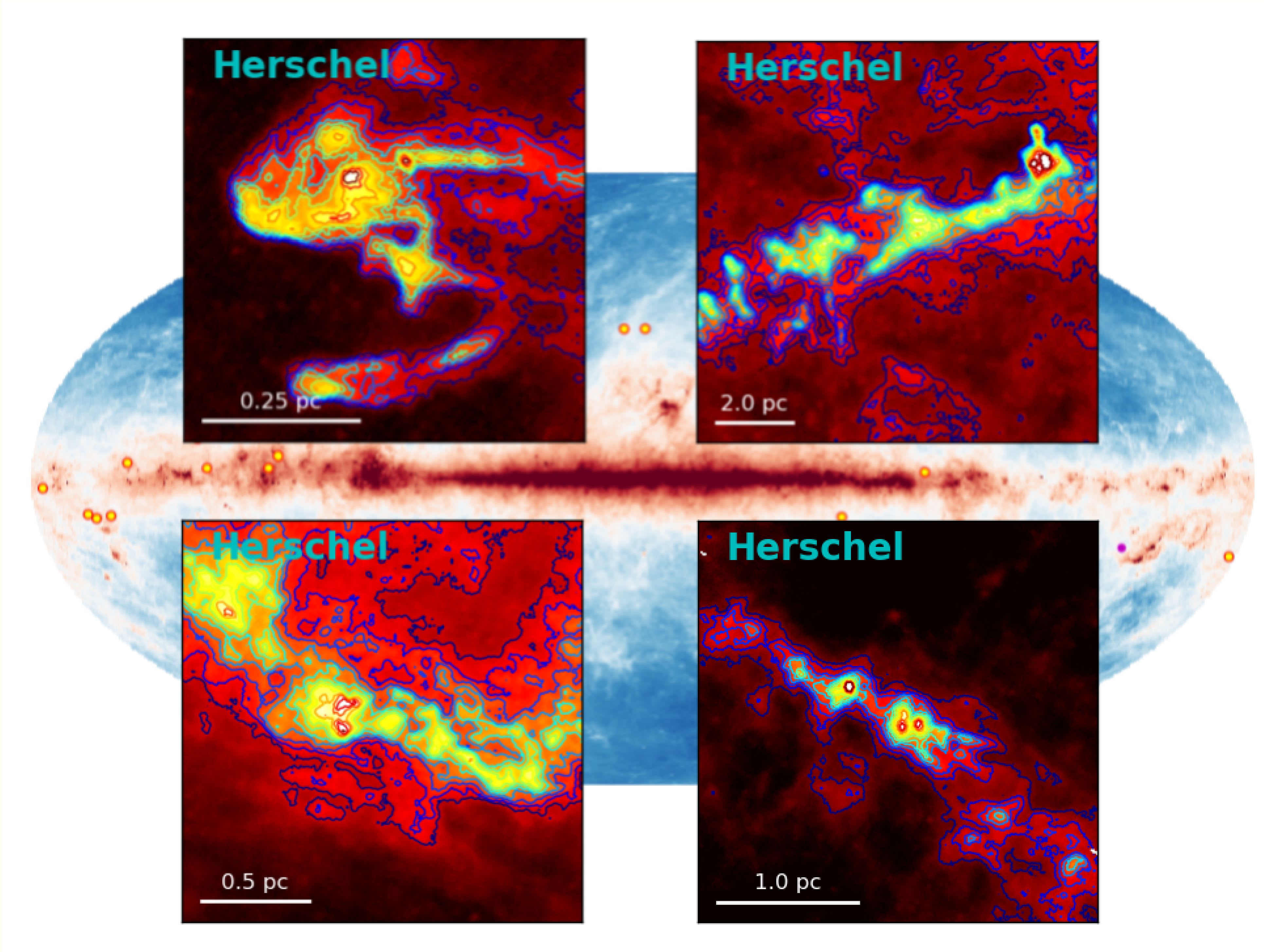
Andre, Kiss, Klaas, **Krause**, Molinari, Motte, Schneider, **Toth**, **Ward-Thompson**, **Zavagno**

External

Doi, Ueno, Kitamura, Nikeda, Kawamura, Onishi

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



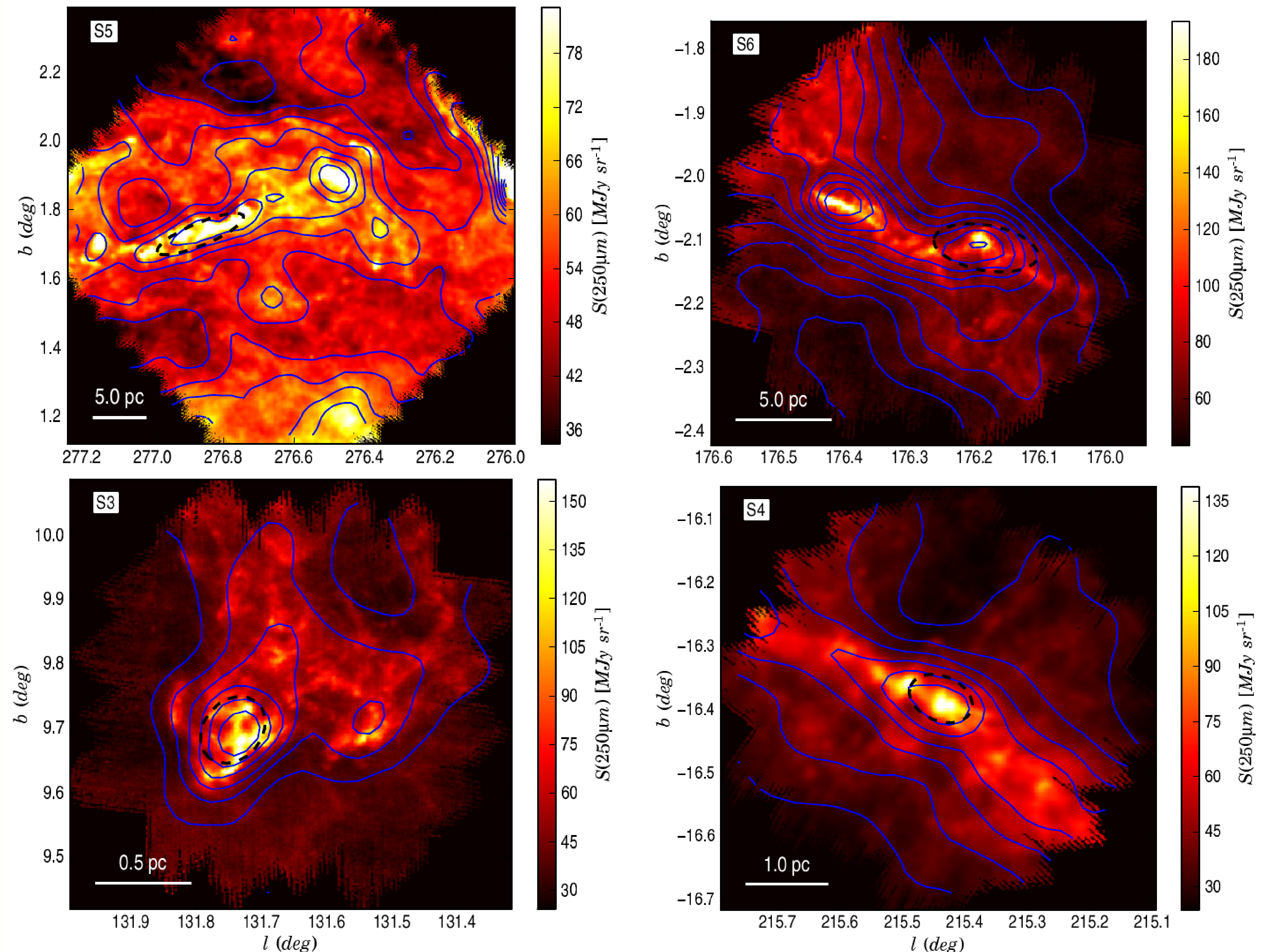

Herschel
0.25 pc
Herschel
2.0 pc
Herschel
0.5 pc
Herschel
1.0 pc

Planck Early Results: The submillimetre properties of a sample of Galactic cold clumps

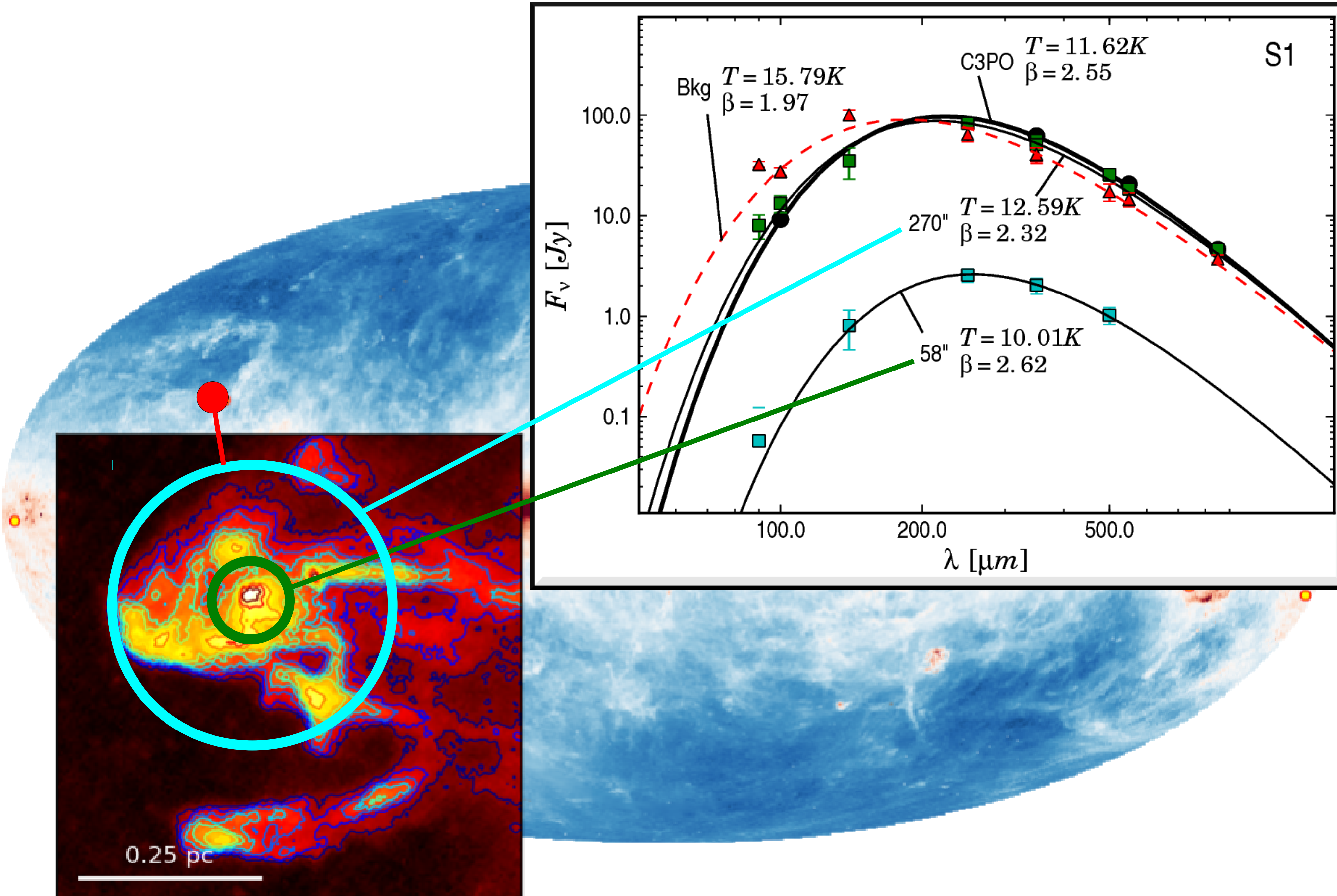
Planck Collaboration: P. A. R. Ade[68], N. Aghanim[44], M. Arnaud[55], M. Ashdown[53,74], J. Aumont[44], C. Baccigalupi[66], A. Balbi[26], A. J. Banday[72,6,60], R. B. Barreiro[50], J. G. Bartlett[3,51], E. Battaner[76], K. Benabed[45], A. Benoît[45], J.-P. Bernard[72,6], M. Bersanelli[24,39], R. Bhatia[32], J. J. Bock[51,7], A. Bonaldi[35], J. R. Bond[5], J. Borrill[59,69], F. R. Bouchet[45], F. Boulanger[44], M. Bucher[3], C. Burigana[38], P. Cabella[26], C. M. Cantalupo[59], J.-F. Cardoso[56,3,45], A. Catalano[3,54], L. Cayón[17], A. Challinor[75,53,8], A. Chamballu[42], L.-Y Chiang[46], P. R. Christensen[63,27], D. L. Clements[42], S. Colombi[45], F. Couchot[58], A. Coulais[54], B. P. Crill[51,64], F. Cuttaia[38], L. Danese[66], R. D. Davies[52], P. de Bernardis[23], G. de Gasperis[26], A. de Rosa[38], G. de Zotti[35,66], J. Delabrouille[3], J.-M. Delouis[45], F.-X. Désert[41], C. Dickinson[52], Y. Doi[13], S. Donzelli[39,48], O. Doré[51,7], U. Dörl[60], M. Douspis[44], X. Dupac[31], G. Efstathiou[75], T. A. Enßlin[60], E. Falgarone[54], F. Finelli[38], O. Forni[72,6], M. Frailis[37], E. Franceschi[38], S. Galeotta[37], K. Ganga[3,43], M. Giard[72,6], G. Giardino[32], Y. Giraud-Héraud[3], J. González-Nuevo[66], K. M. Górski[51,78], S. Gratton[53,75], A. Gregorio[25], A. Gruppuso[38], F. K. Hansen[48], D. Harrison[75,53], G. Helou[7], S. Henrot-Versillé[58], D. Herranz[50], S. R. Hildebrandt[7,57,49], E. Hivon[45], M. Hobson[74], W. A. Holmes[51], W. Hovest[60], R. J. Hoyland[49], K. M. Huffenberger[77], N. Ikeda[47], A. H. Jaffe[42], W. C. Jones[16], M. Juvela[15], E. Keihänen[15], R. Keskitalo[51,15], T. S. Kisner[59], Y. Kitamura[47], R. Kneissl[30,4], L. Knox[19], H. Kurki-Suonio[15,33], G. Lagache[44], J.-M. Lamarre[54], A. Lasenby[74,53], R. J. Laureijs[32], C. R. Lawrence[51], S. Leach[66], R. Leonardi[31,32,20], C. Leroy[44,72,6], M. Linden-Vørnle[10], M. López-Caniego[50], P. M. Lubin[20], J. F. Macías-Pérez[57], C. J. MacTavish[53], B. Maffei[52], J. Malinen[15], N. Mandolesi[38], R. Mann[67], M. Maris[37], D. J. Marshall[72,6], P. Martin[5], E. Martínez-González[50], S. Masi[23], S. Matarrese[22], F. Matthai[60], P. Mazzotta[26], P. McGehee[43], A. Melchiorri[23], L. Mendes[31], A. Mennella[24,37], C. Meny[72,6], S. Mitra[51], M.-A. Miville-Deschênes[44,5], A. Moneti[45], L. Montier[72,6], G. Morgante[38], D. Mortlock[42], D. Munshi[68,75], A. Murphy[62], P. Naselsky[63,27], F. Nati[23], P. Natoli[26,2,38], C. B. Netterfield[12], H. U. Nørgaard-Nielsen[10], F. Noviello[44], D. Novikov[42], I. Novikov[63], S. Osborne[71], L. Pagani[54], F. Pajot[44], R. Paladini[70,7], F. Pasian[37], G. Patanchon[3], V.-M. Pelkonen[43], O. Perdereau[58], L. Perotto[57], F. Perrotta[66], F. Piacentini[23], M. Piat[3], S. Plaszczynski[58], E. Pointecouteau[72,6], G. Polenta[2,36], N. Ponthieu[44], T. Poutanen[33,15,1], G. Prézeau[7,51], S. Prunet[45], J.-L. Puget[44], W. T. Reach[73], R. Rebolo[49,28], M. Reinecke[60], C. Renault[57], S. Ricciardi[38], T. Riller[60], I. Ristorcelli[72,6] ⋆, G. Rocha[51,7], C. Rosset[3], M. Rowan-Robinson[42], J. A. Rubiño-Martín[49,28], B. Rusholme[43], M. Sandri[38], D. Santos[57], G. Savini[65], D. Scott[14], M. D. Seiffert[51,7], G. F. Smoot[18,59,3], J.-L. Starck[55,9], F. Stivoli[40], V. Stolyarov[74], R. Sudiwala[68], J.-F. Sygnet[45], J. A. Tauber[32], L. Terenzi[38], L. Toffolatti[11], M. Tomasi[24,39], J.-P. Torre[44], V. Toth[29], M. Tristram[58], J. Tuovinen[61], G. Umana[34], L. Valenziano[38], P. Vielva[50], F. Villa[38], N. Vittorio[26], L. A. Wade[51], B. D. Wandelt[45,21], N. Ysard[15], D. Yvon[9], A. Zacchei[37], and A. Zonca[20]

Planck Collaboration, arXiv:1101.2034

(see also Juvela et al. 2010, A&A 518, 93L; Juvela et al. 2011, A&A 527, 111)

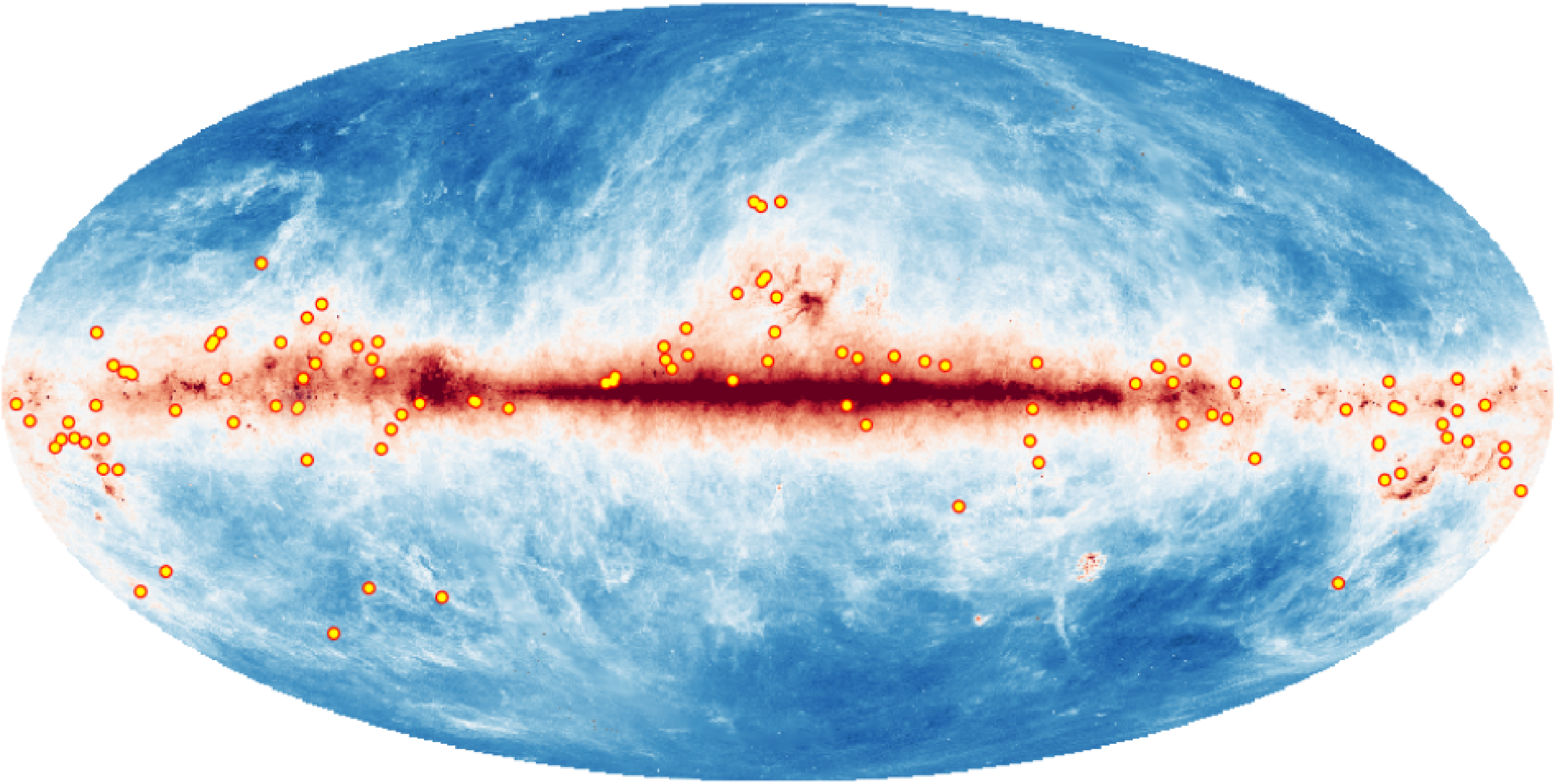


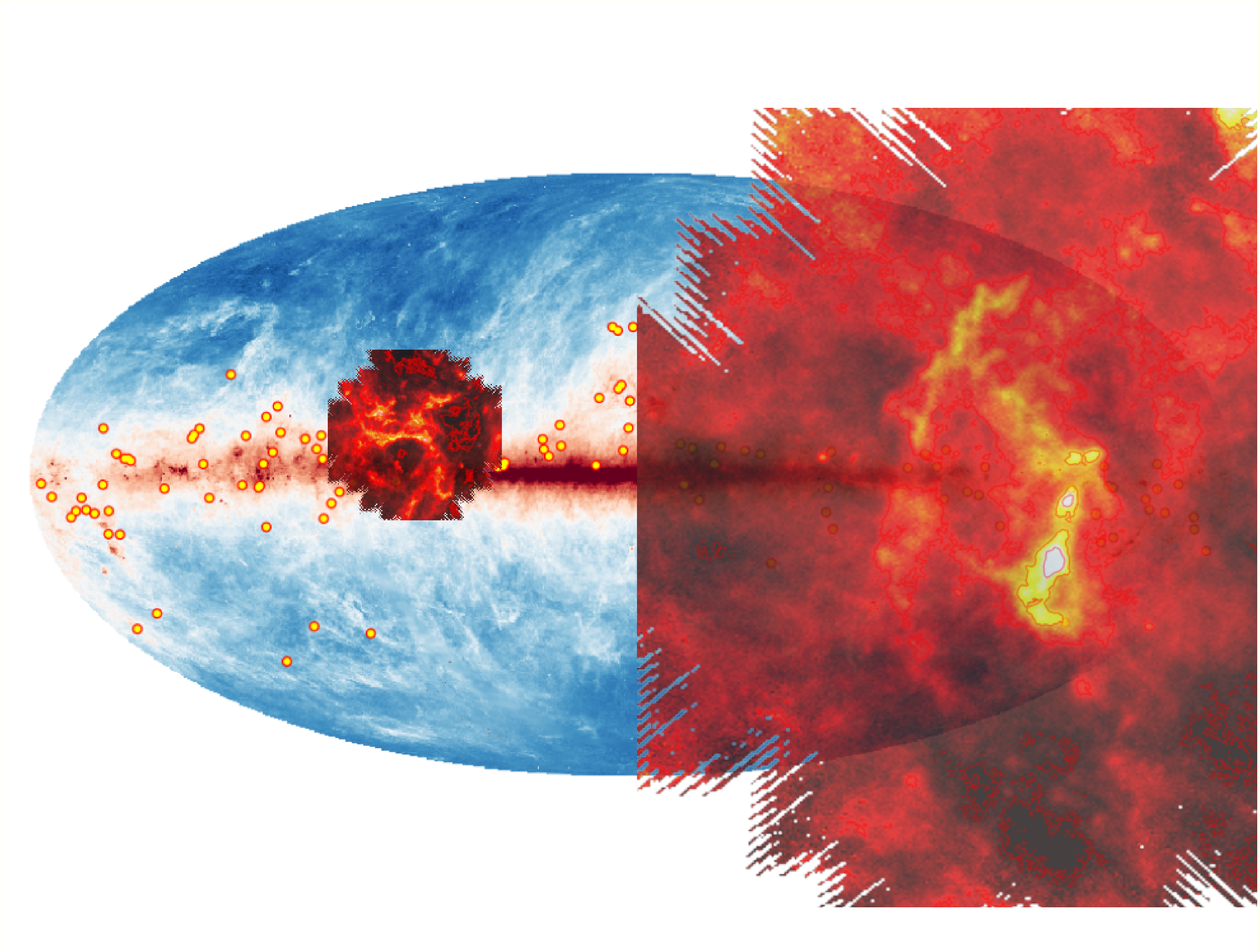
S5
5.0 pc
b (deg)
S(250μm) [MJy sr^-1]
S6
5.0 pc
S3
0.5 pc
S4
1.0 pc
l (deg)

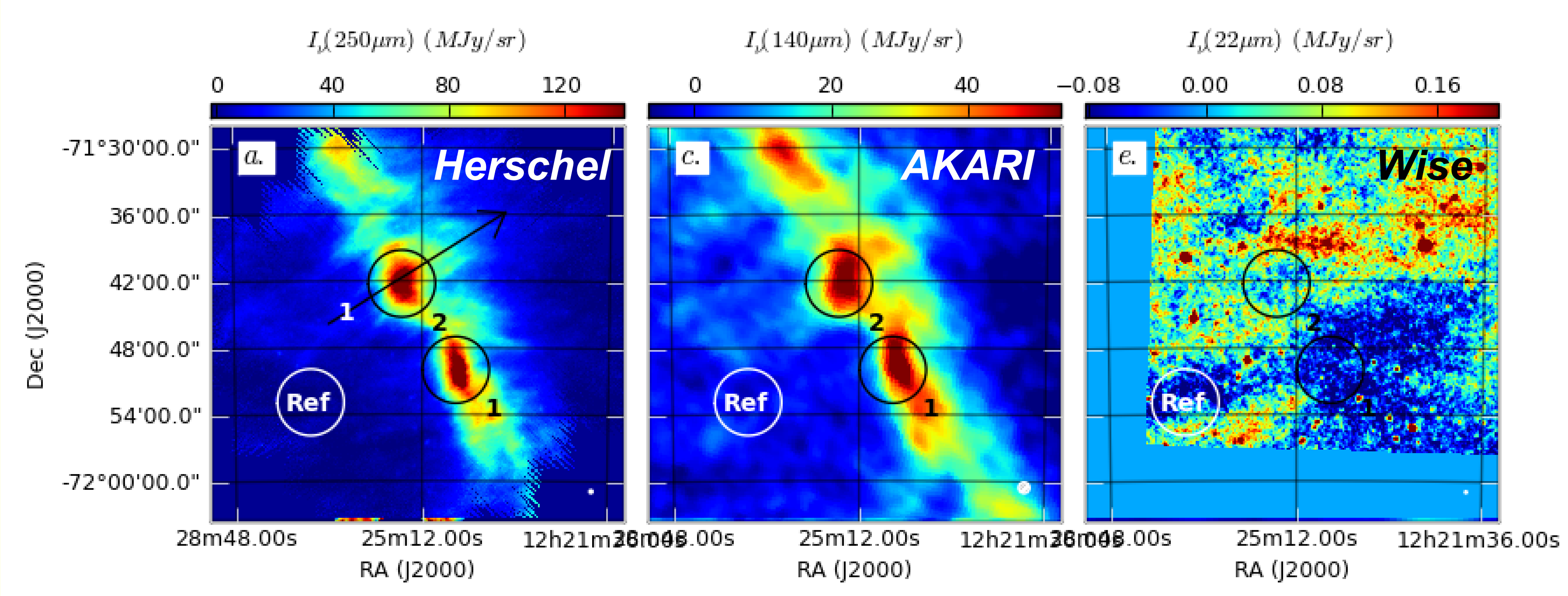


Cold **clumps** containing colder (and sometimes warmer) **cores**

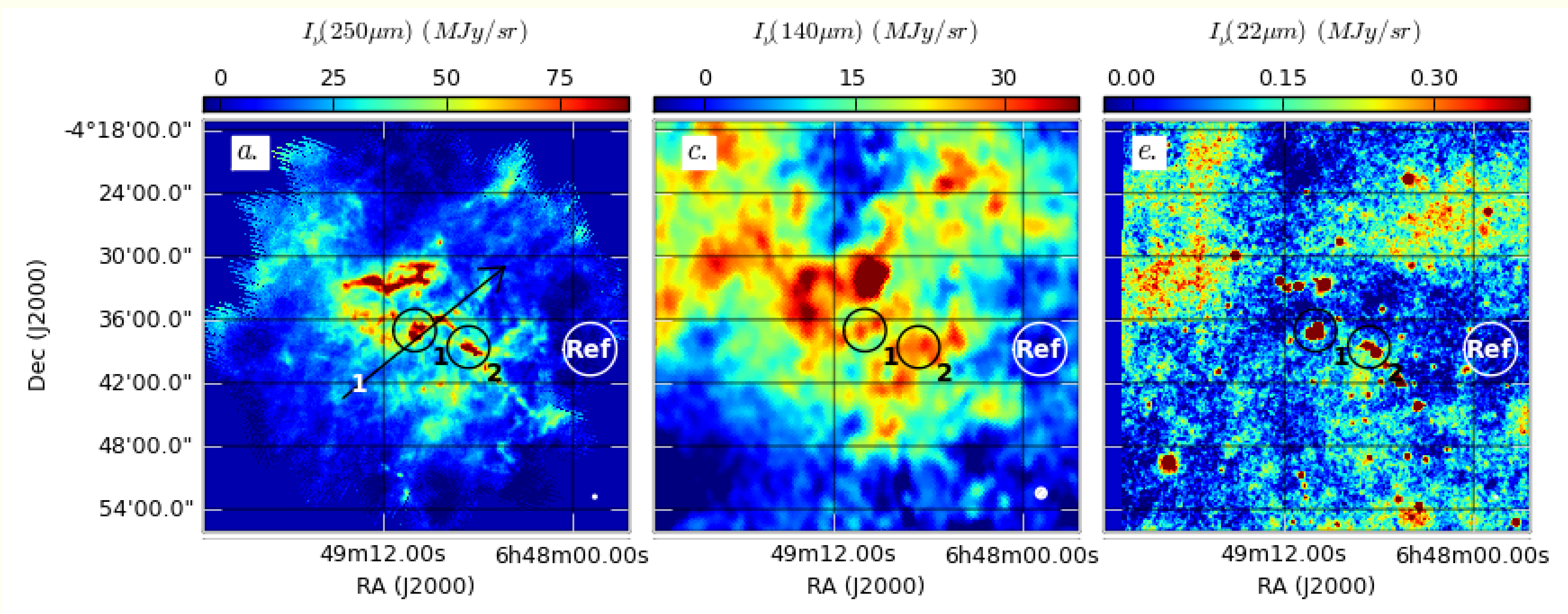
... April 2011





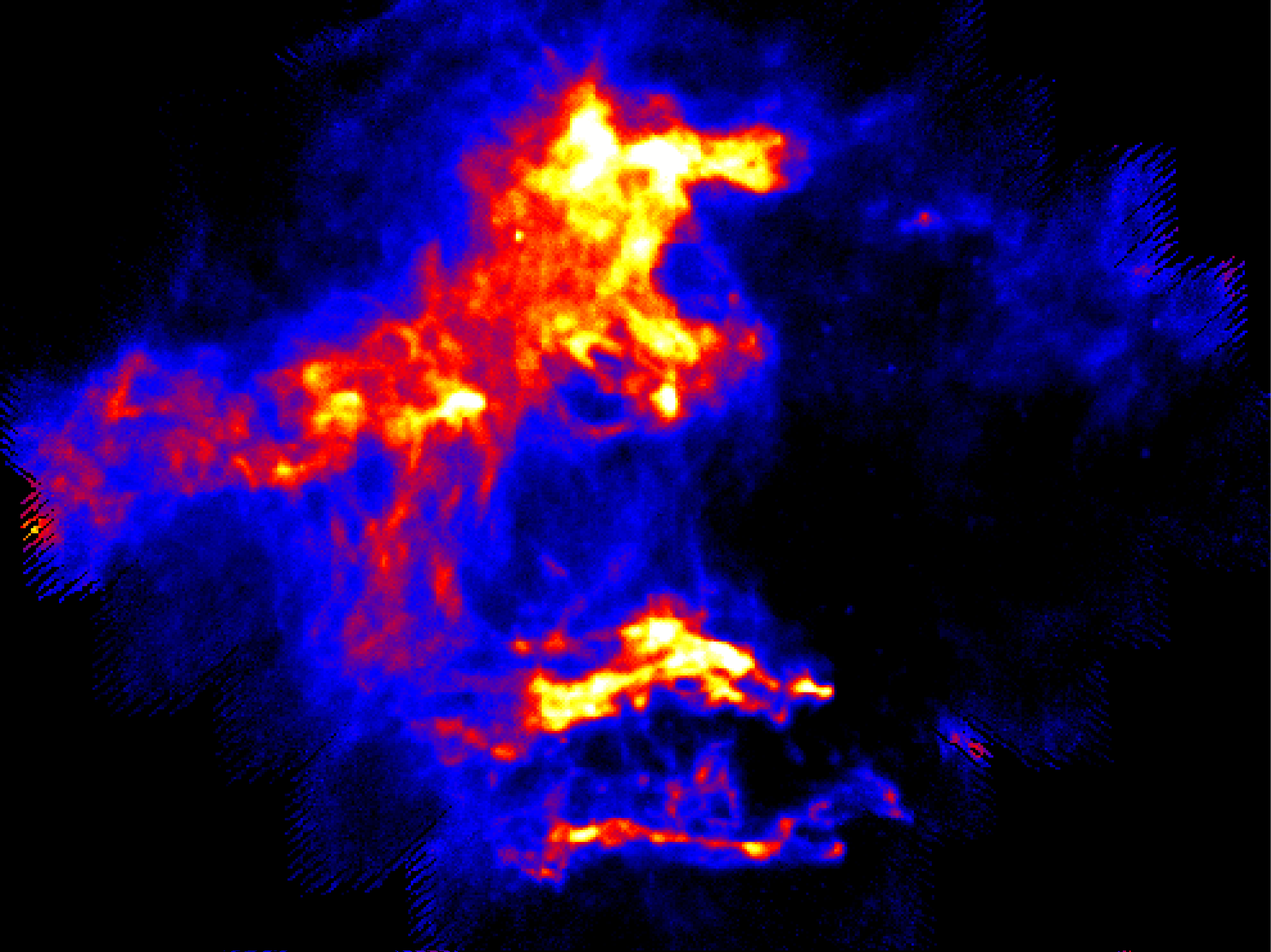


Quiescent and already star-forming clumps



Cold Cores (Clumps) and **magnetic fields**

- the Herschel fields will be interesting targets for magnetic field studies
  - isolated cores, simple filaments, fragmented and twisted filaments, cometary clouds, etc.
  - Galactic plane vs. high latitudes, inner vs. outer Galaxy, violent vs. quiescent region



Cold Cores (Clumps) and **magnetic fields**

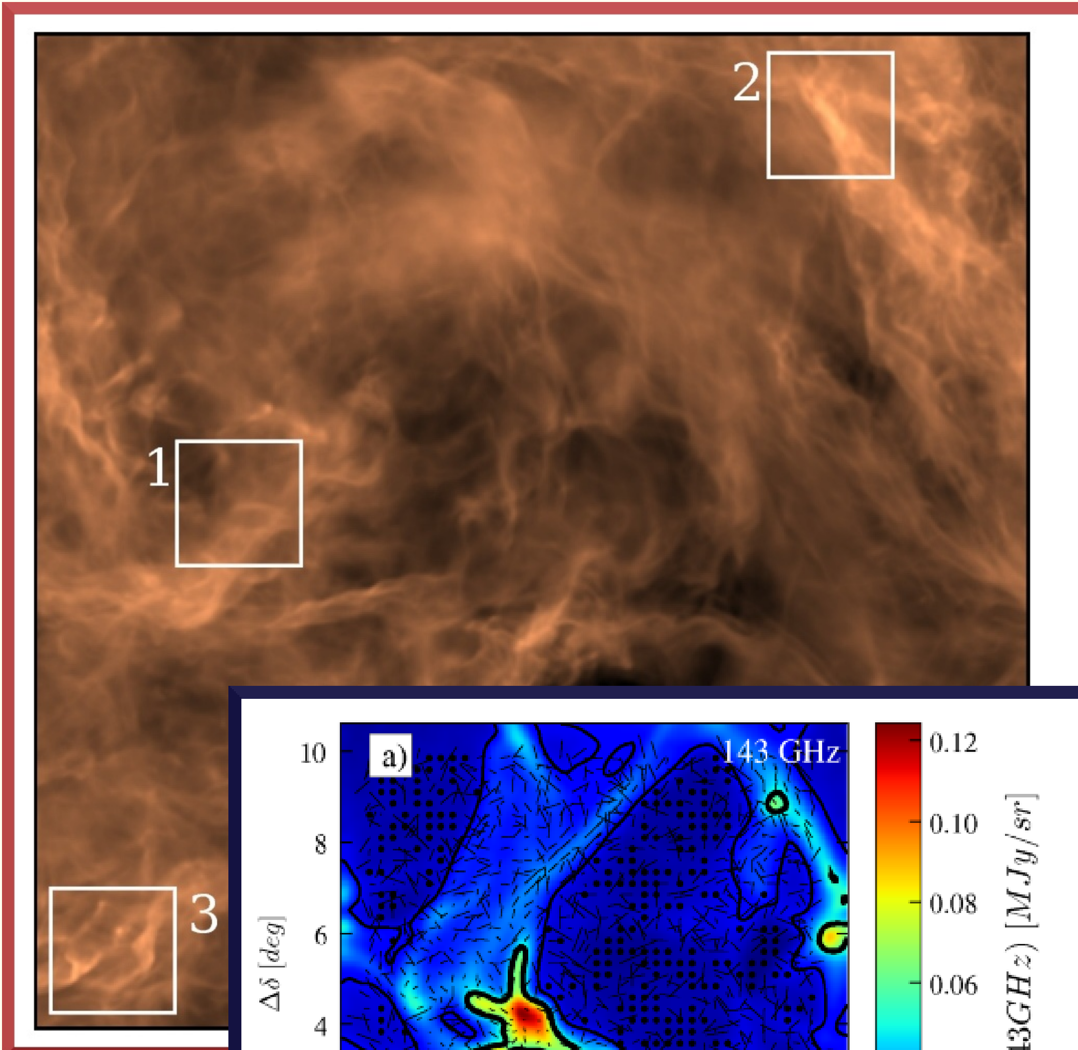
- Planck will produce all-sky maps of dust polarisation
  - resolution down to 5´
  - wavelengths down to 850μm

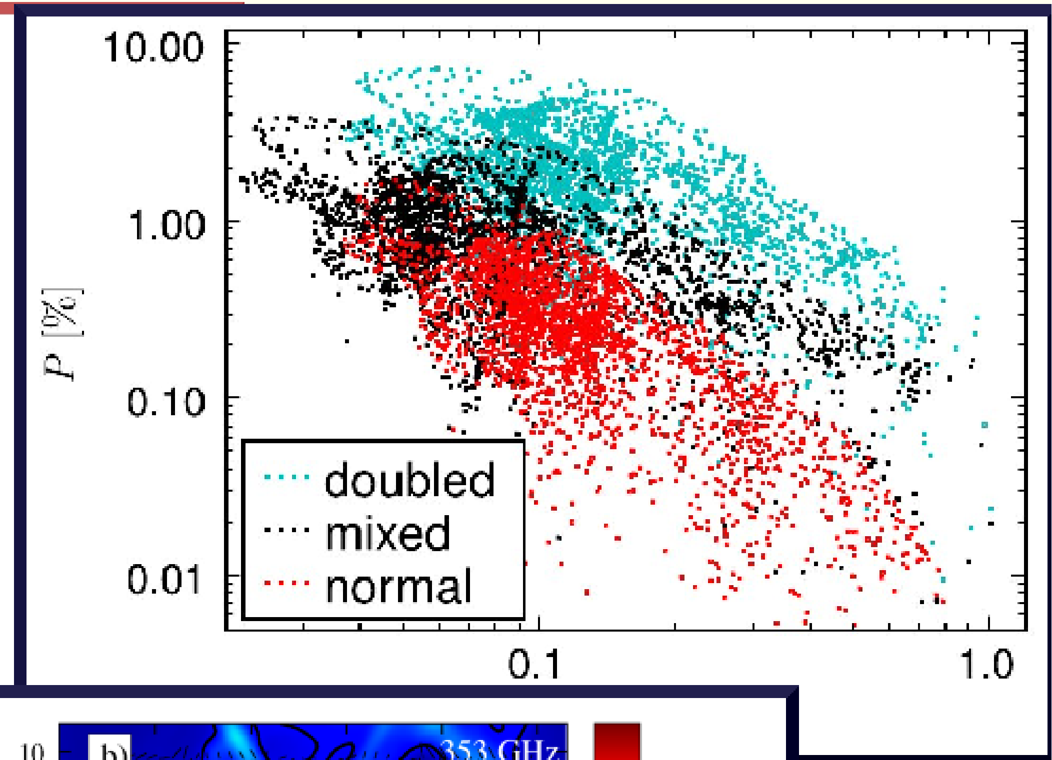
SUMMARY OF PLANCK INSTRUMENT CHARACTERISTICS

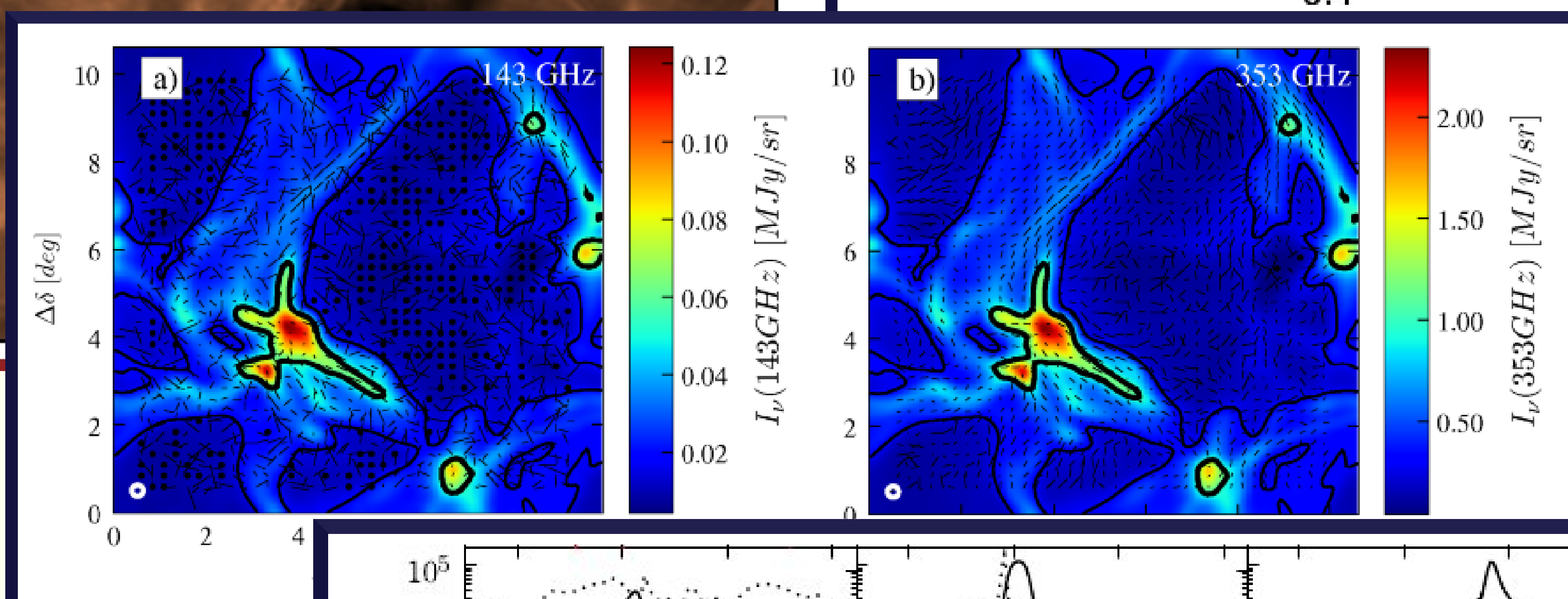
INSTRUMENT CHARACTERISTIC	LFI			HFI					
Detector Technology	HEMT arrays			Bolometer arrays					
Center Frequency [GHz]	30	44	70	100	143	217	353	545	857
Bandwidth ($\Delta\nu/\nu$)	0.2	0.2	0.2	0.33	0.33	0.33	0.33	0.33	0.33
Angular Resolution (arcmin)	33	24	14	10	7.1	5.0	5.0	5.0	5.0
$\Delta T/T$ per pixel (Stokes I)[a]	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
$\Delta T/T$ per pixel (Stokes Q &U)[a]	2.8	3.9	6.7	4.0	4.2	9.8	29.8	...	...

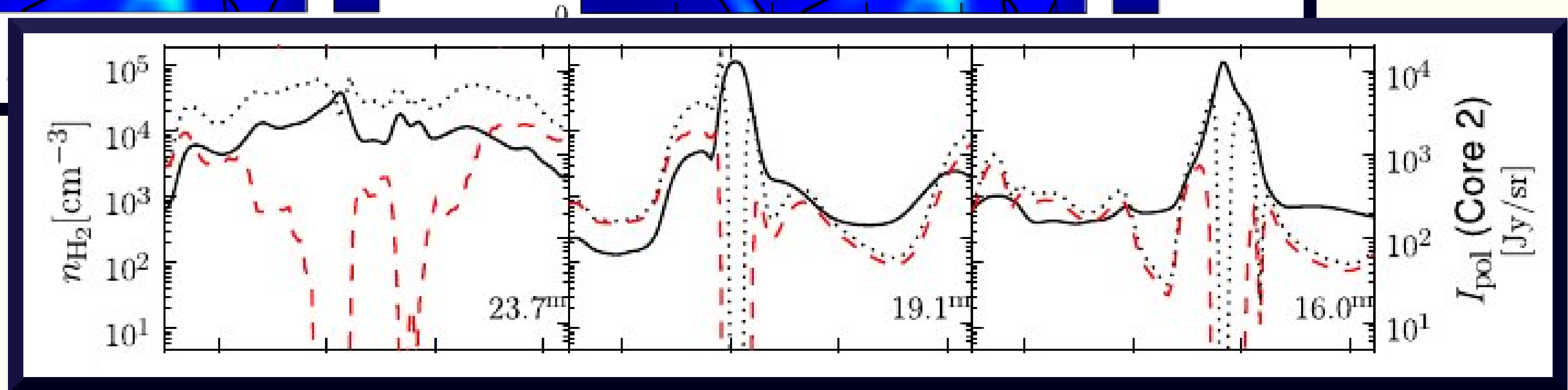
[a] Goal (in μK/K) for 14 months integration, 1σ, for square pixels whose sides are given in the row "Angular Resolution".

Bluebook-ESA-SCI(2005)









Pelkonen et al. (2009)

Conclusions

- The Cold Cores project **complements** other Herschel programmes by picking sources from all over the sky, including high latitudes and areas outside currently active SF
- The study of the first fields has **confirmed** the Planck detections and has demonstrated the variety of the cold core / clump population
- The Herschel survey will be completed within one year. The results will be used to characterize the initial stages of the Galactic star formation – for a **global view**
- The Planck and Herschel surveys provide interesting **targets** for polarization studies
- First **Planck polarisation** results will come out probably in 2013, characterising the magnetic field geometry around the cold clumps