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

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on behalf of the Planck Collaboration
Understand the star formation

- **Cold dust** is a tracer of dense, hidden regions of star-forming clouds, that are part of the cycle of dust, form diffuse medium to dense clouds.

- **Many questions are still open on the earliest phases of star formation:**
  - What generates pre-stellar cores?
  - What governs their evolution to protostars?
  - What is the origin of the global initial mass function (IMF)?

- **Planck** is very well designed to track the cold component of our Milky-Way: resolution, sensitivity, frequency coverage (especially in HFI bands).

- Two catalogues of cold cores have been built:
  - **C3PO:** Cold Core Catalogue of Planck Objects (Legacy)
  - **ECC:** Early Cold Core Catalogue (part of the ERCSC) (planck2011c)

- **Planck** is exploring the all-sky distribution of this large population of cold objects to investigate their intrinsic properties and provide hints to understand the processes of star-formation.
Building the C3PO

Principle of Detection

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)
Building the C3PO

Algorithm of the Warm Background Subtraction

1. Background Color

2. Warm Component @ 857 GHz

3. Detection S/N

(cf Poster 17)

857GHz

2997GHz

Median Filter at 15'

2997GHz

Cold Residual

857GHz

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Building the C3PO

X-check between Planck Bands

IRAS 100 um

857GHz

545GHz

353GHz

857GHz Catalog 33819 objects

545GHz Catalog 24719 objects

353GHz Catalog 15164 objects

Final Catalog 10783 objects

Increase Robustness

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Building the C3PO and ECC

C3PO & ECC Catalogues

C3PO:
- 10,783 high photometric reliability sample: 7,608
- Distance estimates: 3,644

ECC:
- 915
- Early Cold Core Selection:
  - SNR > 15
  - $T < 14$ K

Sample used to derive all physical properties

Sample used to derive $T$, $N_H$, $L/M$
All-sky map of the number of C3PO objects per square degree

(10783)  (915)

ECC Selection

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The C3PO sources are highly correlated with the molecular component of the Milky-Way.

(Dame et al. 2001, NANTEN)
X-Correlation with Ancillary Data

Cross-Correlation with Simbad Query

ISM Objects:
- IRAS sources
- IRDCs
- Dark Clouds

- 49% Stars
- 2% Galaxies
- 2% Radio / QSO
- 2% No match
- 41% No match

... and chance alignment?

Colour-Colour selection rejects only a few extragalactic objects

> 50% of C3PO objects are new!

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Spatial Distribution

Distance Estimates

IR Extinction Signature (2MASS, GLIMPSE)
(978)

Optical Extinction Signature (SDSS)
(1452)

Association with 14 known Molecular Complexes
(1152)

Association with IRDCs
(Simon et al. 2006b, Jackson et al. 2008, Peretto et al. 2009)
(315)
Spatial Distribution

3D Distribution

- Mainly Local Solar Neighbourhood (D<2kpc)
- A few objects at greater distance (D > 5kpc)
- Completeness of the sample is very difficult to probe.
- Heterogeneous due to the bias introduced by distance estimates
Temperature & Dust Spectral Index

Temperature Properties

- Data are not consistent with a constant value of $\beta$
- Cold Core distribution: $8 \text{ K} < T < 16 \text{ K}$
- $\beta=2$
- $\chi^2$ increases with low T:
- Multiple T components?
- $\beta(T)$?
- Lab: (Boudet et al. 2005, Coupeaud et al. 2010)
Temperature Properties

Temperature & Dust Spectral Index

\[ \beta \text{ free} \]

- T distribution:
  \[ 7 \text{ K} < T < 17 \text{ K} \]
  \[ \sigma T/T \sim 7\% \]
  \[ \sigma \beta/\beta \sim 20-30\% \]

Monte-Carlo Simulation

- Monte Carlo Simulations with realistic (calibration + pixel) errors and constant \( \beta \) cannot reproduce data.
- Data errors + Fit Degeneracy does not explain the observed relation:
  \[ \beta = (\delta + \omega T)^{-1} \]
C3PO sources are quite extended:
\[ \theta \sim 1.4 \times \theta_{\text{PSF}} \]

C3PO sources are elongated:
\[ \varepsilon \sim 1.5 \times \varepsilon_{\text{PSF}} \]

- Sources are linked to hierarchical extended structures with power-law density profiles (Enoch et al. 2007)

- Sources associated to filaments and elongated sub-structures of cold clouds

- The distribution of physical sizes is highly heterogeneous, due to the bias introduced by the distance estimates methods.

\[ 0.2 \text{ pc} < \text{FWHM} < 20 \text{ pc} \]
**Nature of the C3PO Objects**

**Physical Properties**

### Column density

- **Cold Cores** *(Pronaos, Herschel)*
  - $<N_H> = 2 \times 10^{21} \text{ H.cm}^{-2}$
  - lower than for cold cores or IRDCs

- **IRDCs** *(Rathborne et al. 2010)*

### Luminosity / Mass

- Early Stage (E): external heating is dominant
- Accretion Stage (A): mechanism driven by accretion *(Roy et al. 2010)*

- 85% of C3PO sources are **potential pre-stellar objects**.
  - Presence of stars inside the objects is still uncertain due to Planck limited resolution.

**Mass**

- Mass spectrum quite heterogeneous
  - $1 \, \text{M}_\odot < \text{Mass} < 10^5 \, \text{M}_\odot$
The C3PO sources match mainly the cold clump domain. They are intermediate sub-structures between molecular clouds and dense cores.
Nature of the C3PO Objects

Physical Analysis

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

- Each C3PO Object contains **2 to 15 IRDCs** from MSX & SPITZER.
  Simon et al. 2006
  Peretto et al. 2009

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
Medium & Large Scale Properties

Groups, Filaments and Loops

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

Medium scale
(cf talk by G. Marton)

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)
Conclusion

The Cold Cores Catalogues:
• Legacy: C3PO (10783)
• Early: ECC (915)
• Local Solar neighbourhood

Medium & Large scale distribution:
• Organised in Groups and Filaments
• Aligned on Large Scale Loops

Perspectives:
• Unprecedented statistical all-sky view of potential pre-stellar clumps.
• Unique opportunity for classification in terms of intrinsic properties and environment
• Legacy Catalogue scheduled in 2013.
• Follow-up with Herschel / PACS-SPIRE
  • Key Program Herschel Cold Core (cf talk by M. Juvela)
  • Open Time based on the ECC for the whole community.

Physical Properties:
• Cold: 7K < T < 17K
• Extended & Elongated
• Low to high Mass
• <NH> = 2.10^{21} \text{ H.cm}^{-2}
• Cold Clumps: Intermediate sub-structures between clouds and cores
Planck Collaboration Cold Cores Papers

- *Planck* Early Results: The Galactic Cold Core Population revealed by the first all-sky survey
  corresponding author: Ludovic.Montier@cesr.fr (Planck 2011s)

- *Planck* Early Results: the submillimetre properties of a sample of Galactic cold clumps
  corresponding author: Isabelle.Ristorcelli@cesr.fr (Planck 2011r)