Evolution status of Planck Cold Dust Clumps

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1. Planck early results and follow-up studies

Planck cold dust clumps:
C3PO: 10783
updated as 13188
(Planck Collaboration 2015)
Mass: ≈1-10^5 M⊙
Td: Peaks at 13 K
Compare to PSS, IRAS, MSX,...
cold
More wavelength bands (30-857 GHz)
Herschel measurements
Images
Whole sky

To understand Planck dust cores
Molecular lines
--critical important
Early Cold Cores (ECC):
PMO 13.7 m
2. Observations

Sources:
674/915 most reliable clumps: (Planck Collaboration 2011)

CO Survey:
• J=1-0 of CO, $^{13}$CO, $^{18}$O: PMO, 13.7m, 56”, 674 Planck clumps (Dec.>-20°)
• Receiver: SIS array with Nine beam
• Velocity resolution: $^{12}$CO: 0.16 km/s $^{13}$CO, $^{18}$O: 0.17 km/s
  rms: $^{12}$CO, 0.2 K : $^{13}$CO, $^{18}$O : 0.1 K
• Single point: Position switch 2012-14

CO Mapping: OTF 630 CO cores were obtained

Further probing with dense molecular lines:
• J=1-0 of HCO$^+$, HCN PMO 2013 621 CO cores
  250 were detected: 230 with HCO+, 158 with HCN
• IRAM: J=1-0 of HCO$^+$, HCN, N$_2$H$^+$, 24 were mapped
  Several cores were observed with 2-1 of CO, $^{13}$CO, $^{18}$O at CSO

N$_2$H$^+$ (1-0), C$_2$H (1$_{3/2}$ -0$_{1/2}$) observation
  121 CO cores, 63 were detected: 48 for N$_2$H$, 57$ for C$_2$H
3. Results

1. Physical parameters

100% detected for $^{12}$CO and $^{13}$CO, 68% for $^{13}$C$^{18}$O except 39 with reference position problem. Rare with > 3 components, No blending.

**Line center velocity** (Wu et al. 2012)

- Histogram: $V_{12} - V_{13}, V_{13} - V_{18}$
- Correlation: $100%$

<table>
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<th>Peak</th>
<th>Molecule</th>
<th>$V_{lsr}$ ($km/s$)</th>
<th>$T_{MB}$ ($K$)</th>
<th>$ΔV$ ($km/s$)</th>
<th>$ΔT_{MB}$ ($K$)</th>
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</table>

6 NH3 cores in G084.81–01.09: $V_{lsr}$(CO)–$V_{lsr}$(13CO) > 1 km/s for all (Zhang et al. 2011)

Wu et al. 2012

$V_{13}$ systematic V

A basic application $\rightarrow$ D

Previously: extinction (978 objects)

Using associated IRDCs (Simon et al. 2006)
Excitation temperature: Derived from $T_{12}$
- If $^{12}$CO optical thick, the system is LTE
- The kinematic temperature $T_k$
  Range: (3.9 –27 K) $>$ Td: 7- 17 K
Higher part:
$^{12}$ with $T_k > 17$ K
Peak value –cold dark cloud
- Distribution: peak at 9-10 K

Line widths:
Most of the cores with narrow lines
Mean values and the standard deviations:
$^{12}$CO: 2.0 $\pm$ 1.3 km s$^{-1}$
$^{13}$CO: 1.3 $\pm$ 0.8,
$C^{18}$O: 0.8 $\pm$ 0.7
Non thermal motion:
$\sigma_{NT}$: With R:
  large at 5 kpc
With height $Z$:
  decrease
High again at $\sim$680 pc
related with Orion, Taurus

Wu et al 2012
**Column density $N_{\text{H}_2}$**: Wu et al. 2012

- $N_{\text{H}_2}$ and the optical depth derived from $T_{13}$ with radiation transfer equation assuming $^{13}\text{CO}$ line optical thin and LTE
- $N_{\text{H}_2}$ spans from $10^{20}$ to $4.5 \times 10^{22}$ cm$^{-2}$
- Distribution:

![Graphs showing distribution of column density and optical depth](image-url)
A comparison for cumulative of FWHM of $^{13}$CO lines and $N_{\text{H}_2}$:

Five different samples:

- IRDCs, FCRAO (Simon+06)
- Weak and Red IRAS: KOSMA (Wang+09)
- UCHII candidate PMO (Wu+02)
- CH+OH maser, PMO (Ren+13)
- EGOs, PMO (Chen+11)

Planck cores are the smallest
2). Star formation activity

Line profiles:
- Blue profile, 15 (Nb)  --2%
- Red profile, 5 (Nr)  -- 0.8%
- Blue excess: \( E = \frac{(Nb-Nr)}{Nt} = 0.01 \) (Nt=782)
  Much less than E of the SFRs:
  HMCs : 0.17
  UCHII: 0.53  (Wu et al. 2007)
  UCHII: 0.58  (Wyrowski et al. 2006)
- But blue profiles > red profiles, tending to show collapse more than driving mass outward
G192.32-11.88:
(Liu et al 2015)

Two cores:
• G192N
  $L_b \sim 0.8 \, L_{\odot}$
  Class 0
  CO outflow
• G192.S:
  $(0.08 \pm 0.01) \, L_{\odot}$
  $(2.8 \pm 0.8) \times 10^{-8} \, M_{\odot} / yr$
  Proto-Brown dwarf candidate

Red: Planck
Green: IRAS
Blue: H$\alpha$

Contours: $N_{\text{H}_2}$  B type star (blue), Variable: yellow

SMA: Continuum, 1.3 mm
Right: CO $J=2-1$
3). CO Depletion

Depletion:
Correlates with $\beta$
anti-correlates with $T_d$, $L/M$

Depletion factor:
mean value: 1.7
5.6% > 5
13%, > 3
53% < 1
(Liu, Wu, Zhang 2013)

less than that of
Nearby dark cores:
(L1544: ~10  Caselli et al. 1999)
4) A comparison of NH2+ and C2H missions

NH2+, C2H: Primary results
Detected: 40% (NH2+) and 54% (C2H)
The maps of two sources:
One: NH2+ stronger, the other C2H stronger
Colum density:
C2H: larger as a whole
NH2+: increasing
C2H: tend to decreasing
--Early stage

Model analyse
is in progress

Liu, X., Wu, Zhang
In prep.

Color:
CO Tex
Size:
NH2
5). Morphology, structure, distribution

Taurus: Meng, Wu, Liu, 2013

- 71 Clumps
- 38 cores from 27 clumps

Taurus cores:
- $n: (10^3/cm^3)$
- $(1.4-7.6) \times 10^3$
- Most cores: $M_{LTE} < M_{vir}, M_J$

Filaments
Isolated cores
Starless

Diffuse both with and without stellar objects
Filaments are more than those seen in CO maps:

Examples of 39 have Herschel + Qinghai CO indicated with circles (from Juvela)
Core multiple split:
G222.2+01.2  From PMO to CSO

G108.8-00.8a2  From CSO to IRAM
High latitude: 41 higher than 25°
- The highest 71°, previous 44°
- 5: belong to group Himas
- \( N_{\text{H}_2} \): 3\( \times \)10^{21} \text{ cm}^{-2}, \text{average,}\ 
  \( \sigma_{NT} \) smaller among the 12 regions but larger than that in Oph, Oph-Sgr
- Tex: intermediate
- Surveys: \( 16^\circ \leq b \leq 44^\circ, 117^\circ \leq l \leq 160^\circ \)
  13%: CO detected (Heithausen+93)
- \(-30^\circ - (-43^\circ)\): 110 clouds, no C^{18}O)
  not dense enough (Yamamoto+03)
- Planck cores: good guide to search gas

Grey: Hø
Red: CO (Dame)
Blue: 100 \( \mu \)m
Green: Planck clumps (Liu et al. 2012)
Possible part of dark gas

CO observations a
Extended gas space:
7 Planck cores:
Out of the New Arm extend region
by Sun et al. 2015
l=100° to 150°
Dame & Thaddeus 2011:
l=13° to 55°
(Zhang et al. 2016)
4. Summary

Studies of the 674 ECC:

- Real Cold; with extremely low luminosity stellar molecular complex
- Less dynamical layers; but turbulence is major of non-thermal motions
- Early phase with emission of C$_2$H rather common than that of N$_2$H$^+$
- Filaments is significant, and core multiple-splits were detected
- Diffuse clump may be transition between ISM and molecular cloud
- Extended CO gas regions surveyed previously
Thank You!