# A map of CO extracted from Planck

### The Planck Collaboration

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Planck Conference - Bologna

14/02/12

## HOW PLANCK HFI SEES CO AND HOW THE CO MAP WAS EXTRACTED?

- ★ Emission of the CO lines in HFI
- ★ Calibration of HFI bolometer responses to CO
- ★ Building the CO map

#### THE FIRST ALL SKY CO MAP

- \* Comparison to ground observations in molecular clouds
- \* Comparison to ground observations at high Galactic latitudes
- **\*** Discovery of unobserved CO clouds
- **\*** Conclusions





## Emission of the CO lines in HFI





## Calibration of HFI bolometer responses to CO



- ★ Each HFI bolometer has a different transmission at the CO line frequency
- Pre-flight measurement of the HFI filters were done at IAS, but with a coarse spectral sampling (0.5 GHz, 0.017 cm<sup>-1</sup>) with respect to the CO line width
- \* Incertitudes arise from interpolation of a sampled signal around a single spectral line [Spencer et al.]
- \* "Effective" response is a combination of the one of <sup>12</sup>CO and <sup>13</sup>CO (~10-20% of the <sup>12</sup>CO in intensity)
- \* A calibration scheme was designed on the sky using the Dame survey as an absolute calibrator [Aumont et al.]
- Component separation residual maps were correlated to Dame in several molecular cloud regions, giving responses that vary by ~3% at 100 GHz and ~10% at 217 GHz among the fields
- Sky calibration was chosen as it better describes the CO in Planck than ground calibration

[Pajot et al., A&A, 2010, **520**, 10] [Planck HFI Core Team, A&A, 2011, **536**, 6] [Dame, Hartmann & Thaddeus, ApJ, 2001, **547**, 792]





## Building the CO maps

★ Two approaches were used:

[Hurier et al., submitted to A&A, 2010, astro-ph/1007.1149] [Eriksen et al., ApJ, 2008, **676**, 10]

MILCA 100 GHz

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MULTI-BOLOMETER: exploits the diversity of individual bolometer responses to a CO line inside a frequency band (ex: MILCA algorithm [Hurier, Combet, Macías-Pérez])

- very weakly contaminated by Galactic residuals
- noisy
- give 3 independent CO maps at 100,
- 217 and 353 GHz

MULTI-FREQUENCY: transmitted line ratios is exploited to perform a multi-frequency component separation (ex: Commander [Górski, Pietrobon, Colombo et al.], Linear System [Aumont & Boulanger], multi-MILCA [Hurier, Combet, Macías-Pérez])

- very high signal to noise
- subject to potential contamination by other Galactic components
- Can be solved to recover 2 independent maps at 100 and 217 GHz





## The Planck full sky CO map

#### Dame et al. CO (J=1-0)



[Dame, Hartmann & Thaddeus, ApJ, 2001, **547**, 792]





## The Planck full sky CO map

#### Commander 100 GHz



First high-resolution full sky CO emission map





## Comparison to ground observations in molecular clouds



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## Validation with ground observations at high Galactic latitudes

- \* Commander map was compared to the high Galactic latitude CfA  $^{12}$ CO (*J*=1-0) surveys
- ★ These surveys sample the sky with 15,377 equally spaced (~1°), |b| > 30°, 8 arcmin resolution observations
- \* On this grid, 159 observation points showed a detection and 15,218 didn't
- Very good agreement between Planck and CfA on the detection positions

[Hartmann, Magnani & Thaddeus, 1998, ApJ, **492**, 205] [Magnani, Hartmann, Holcomb et al., 2000, ApJ, **535**, 167]







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- Planck measurements on no-detection positions is compatible with zero

HMT (1998) and MHHST (2000) grids (blue) and detections (red)



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## Discovery of unobserved CO clouds



 The Planck map reveals a lot of unobserved CO emitting clouds over wide areas of the sky



[Yamamoto, Onishi, Mizuno & Fukuii, 2003, ApJ, **592**, 217] [Dame, Hartmann & Thaddeus, ApJ, 2001, **547**, 792]

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## Discovery of unobserved CO clouds

★ Comparison between the Planck map and NANTEN and Dame <sup>12</sup>CO (J=1-0) ground observations in the region of MBM 53-54-55 clouds

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[Yamamoto, Onishi, Mizuno & Fukuii, 2003, ApJ, **592**, 217] [Dame, Hartmann & Thaddeus, ApJ, 2001, **547**, 792]

#### PLANCK COMMANDER 100 GHz

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## Map characterization



Commander CO 100 GHz, N<sub>wide</sub> = 16, Kkm's<sup>-1</sup>



- \* Noise rms is 0.24 K·km·s<sup>-1</sup> in the Commander map for the (J=1-0) line
- ★ Weak large scale features (~0.1 K·km·s<sup>-1</sup>)
- ★ CO emission level is statistically compatible with zero for the regions having a I<sub>857GHz</sub> less than 5 MJy·sr<sup>-1</sup>





#### FIRST ALL-SKY CO MAP

- \* Maps produced with various assumptions and component separation methods give very similar results
- ★ Good correspondence with ground based observations. Variations within the combined uncertainties in the absolute calibration of ground based data and the varying <sup>13</sup>CO/<sup>12</sup>CO line ratio

#### THE MAP REVEALS NEW EMISSION REGIONS

- ★ It could be used to search for faint CO emission associated with the dark-gas
- \* Finding chart to guide ground-based follow-up observations of CO emitting gas at high Galactic latitude
- \* Work still needed to improve the quality of our maps and to produce separated maps of the higher order CO lines that could be used to study the line ratio variations all over the sky





The scientific results that we present today are the product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

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