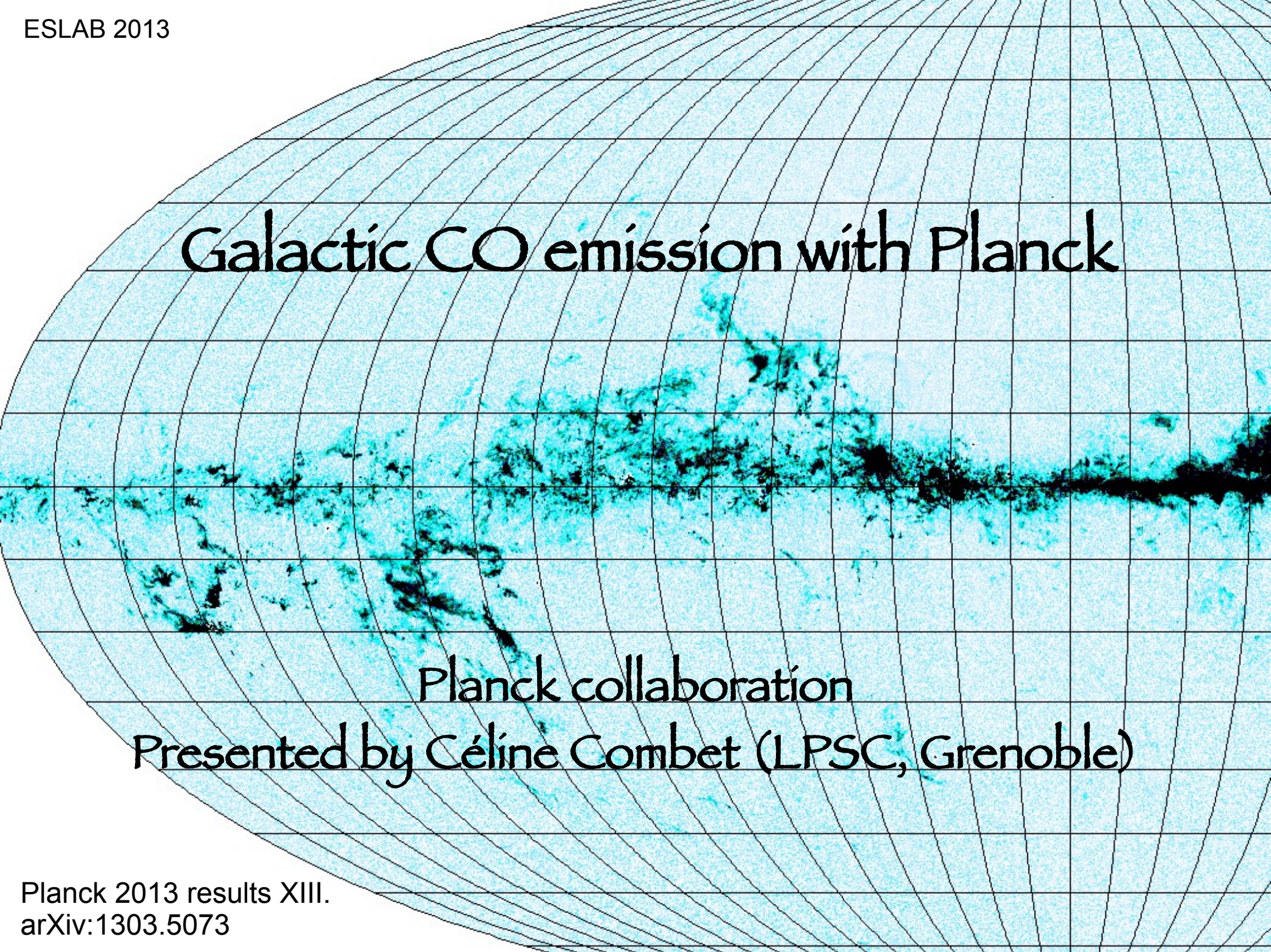
ESLAB 2013

Galactic CO emission with Planck

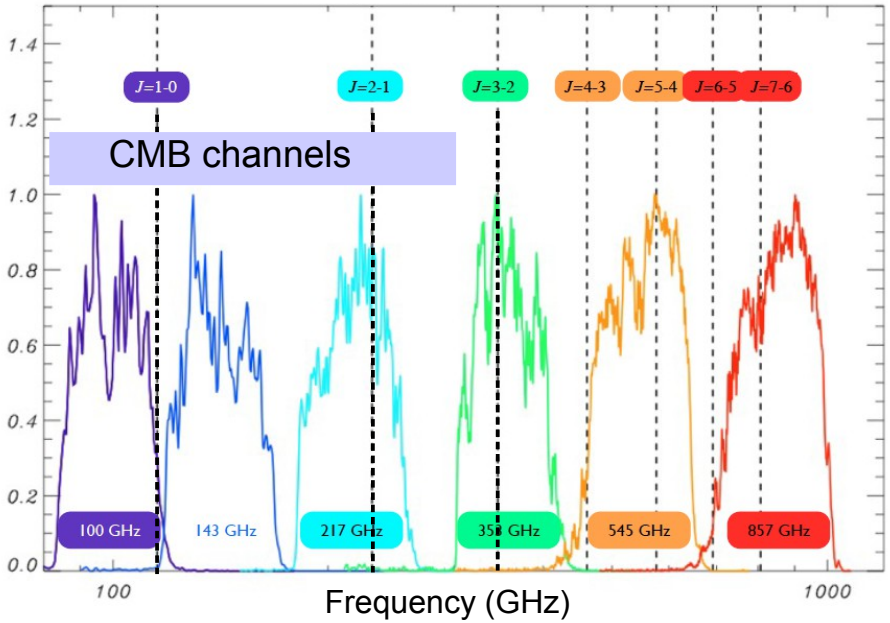


Planck collaboration
Presented by Céline Combet (LPSC, Grenoble)

Planck 2013 results XIII.
arXiv:1303.5073

Motivation and outline

HFI filters and ^{12}CO lines

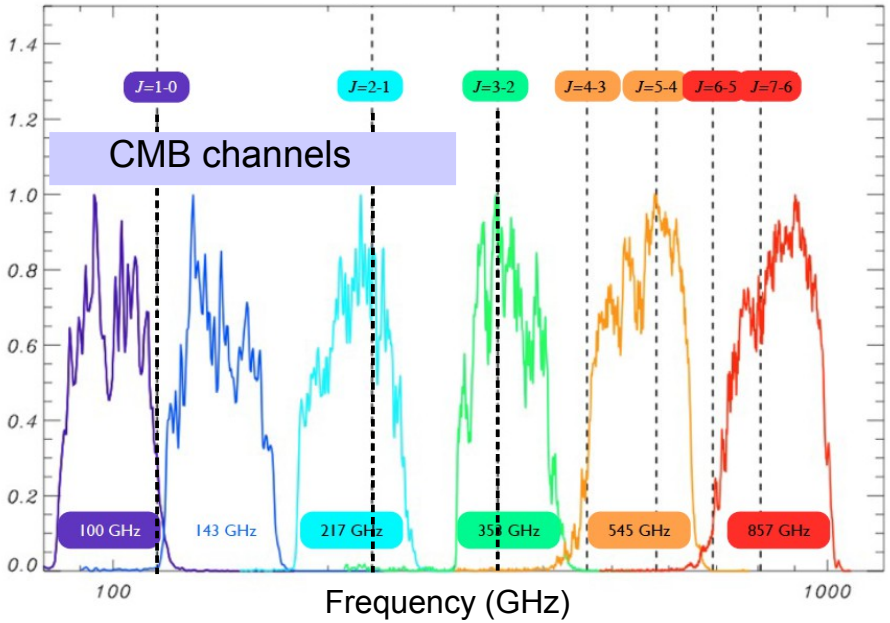


- **Significant CO transmission** @ 100, 217, 353 GHz
- ^{12}CO, but ~ 10-20% ^{13}CO as well
- **Contaminant foreground** for:
  → Intensity + CMB studies
  → Polarisation because of leakage

CO in Planck must be characterized

Motivation and outline

HFI filters and ^{12}CO lines



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CO in Planck must be characterized

Variety of HFI channels → extract fullsky CO maps of [1-0], [2-1] and [3-2]

NEW !

Internal validation
→ between methods
→ on simulated data

Validation using external datasets
[1-0]: CfA 1.2m, NANTEN II, FCRAO 14m, COBE/FIRAS
[2-1]: Tokyo-NRO, COBE/FIRAS, IRAM-30m, CSO
[3-2]: JCMT/HARP,COBE/FIRAS, CSO

Systematics charaterization
→ dust
→ free-free
→ other isotopologues (^{13}CO)

+ preview of Planck's CO science paper results

3 CO products from 3 approaches

- **Single-channel approach** TYPE 1 product

  → Use diversity of individual bolometer maps to extract independent maps : **[1-0], [2-1], [3-2]**
  → **Little contamination** by other foregrounds, but **noisy**
  → Suitable for the Galactic plane region

- **Multi-channel approach** TYPE 2 product

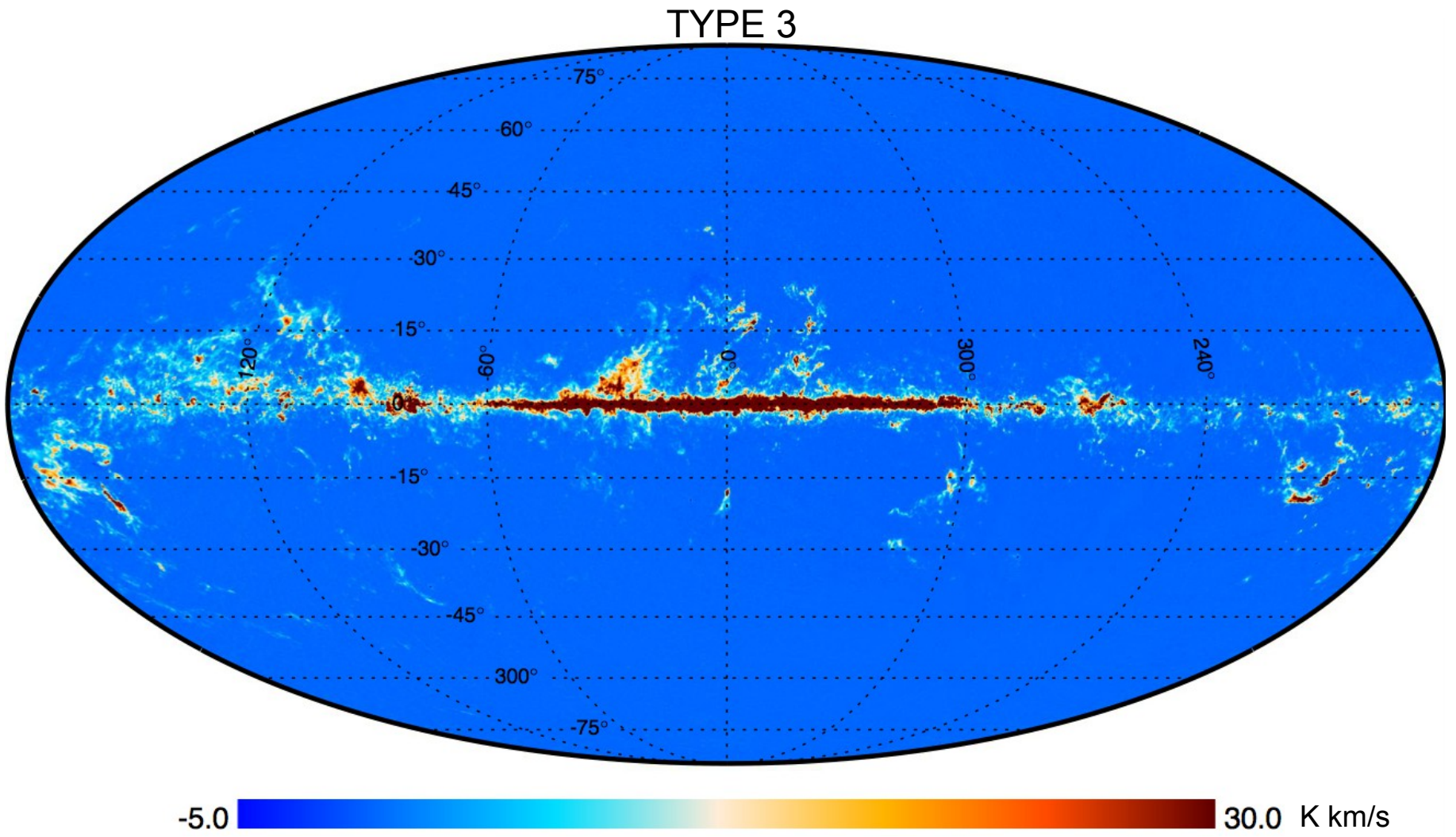
  → Use multi-channel information to extract independent maps: **[1-0], [2-1]**
  → **High S/N but foreground contamination** (in the plane)
  → Suitable at high Galactic latitudes

- **Multi-line approach** TYPE 3 product

  → Combine frequency channels assuming fixed CO line ratios to get the **highest S/N map**
  → Useful to detect high-latitude faint CO-emitting regions and guide ground-based follow-up observations

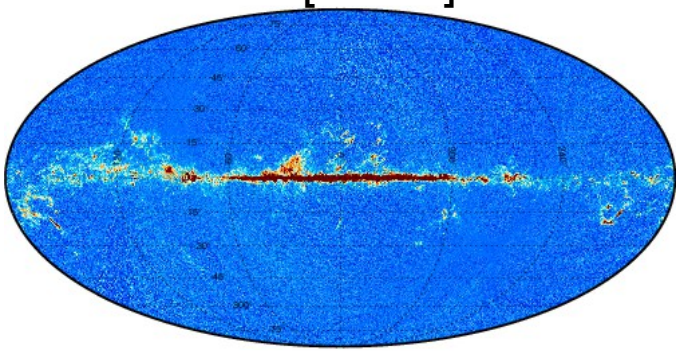
The Planck CO maps

- Velocity-integrated CO brightness temperature map W(CO)
- Healpix pixellisation scheme (N_{side} = 2048)

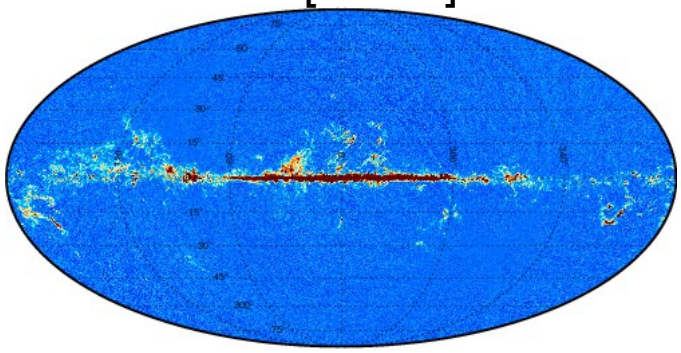


The Planck CO maps

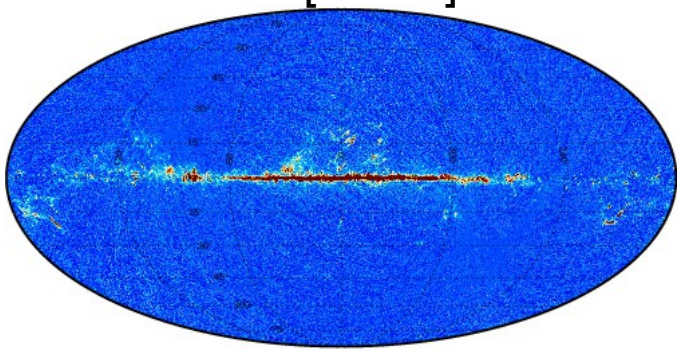
CO [1 → 0]



CO [2 → 1]

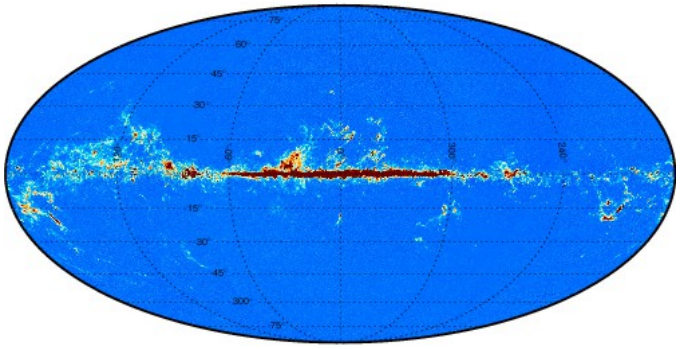


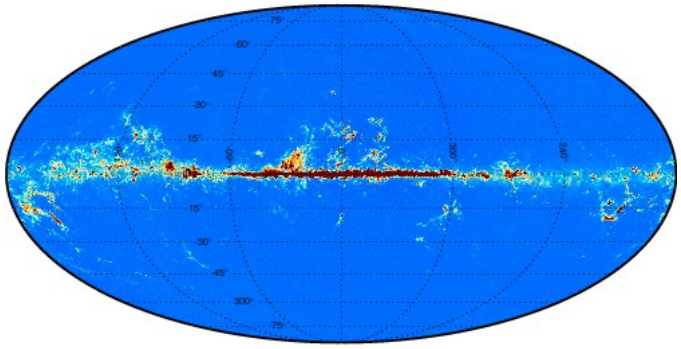
CO [3 → 2]



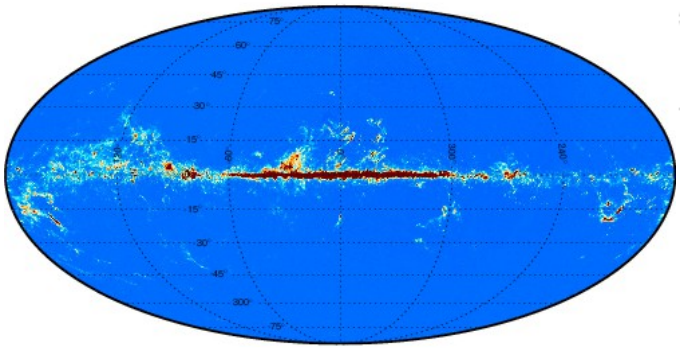
TYPE 1

TYPE 2





TYPE 3



Type	Line	Resolution [′]	Noise / 15′pix [K km s^{-1}]	Components considered
TYPE 1	CO[1→0]	9.65	1.77	CO, CMB
TYPE 1	CO[2→1]	4.99	0.74	CO, CMB, dust
TYPE 1	CO[3→2]	4.82	0.73	CO, dust
TYPE 2	CO[1→0]	15	0.45	CO, CMB, dust, free-free
TYPE 2	CO[2→1]	15	0.12	CO, CMB, dust, free-free
TYPE 3	-	5.5	0.16	CO, CMB, dust, power-law Gal. emission

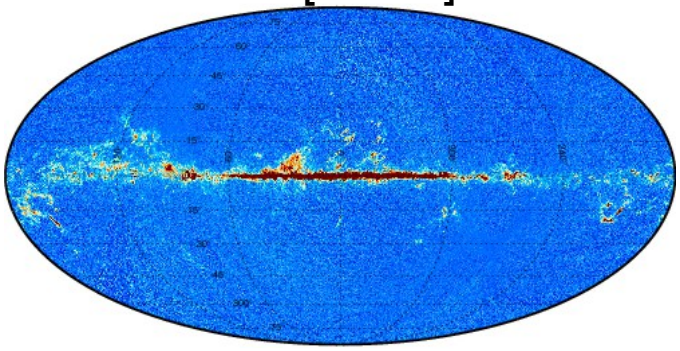
The Planck CO maps

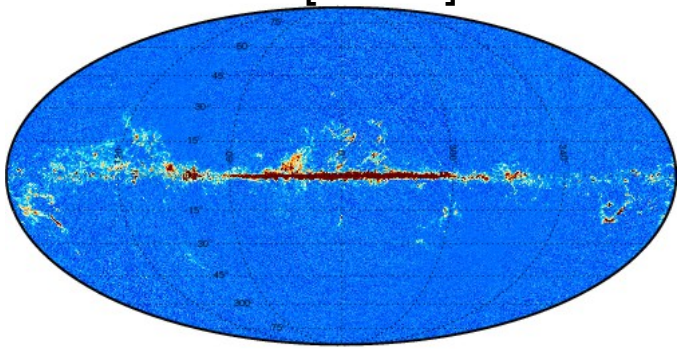
CO [1 → 0]

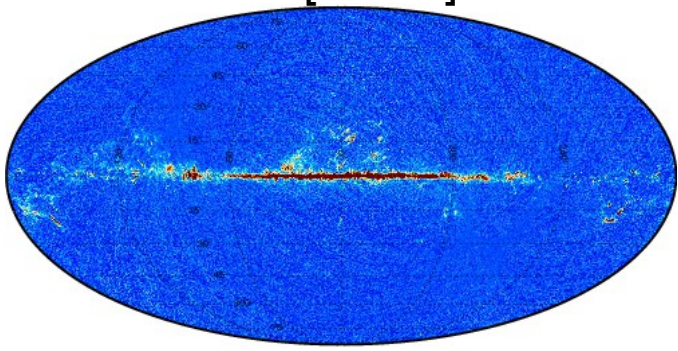
CO [2 → 1]

CO [3 → 2]

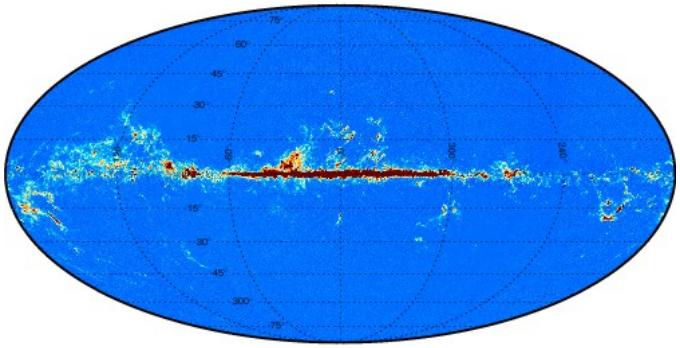
TYPE 1

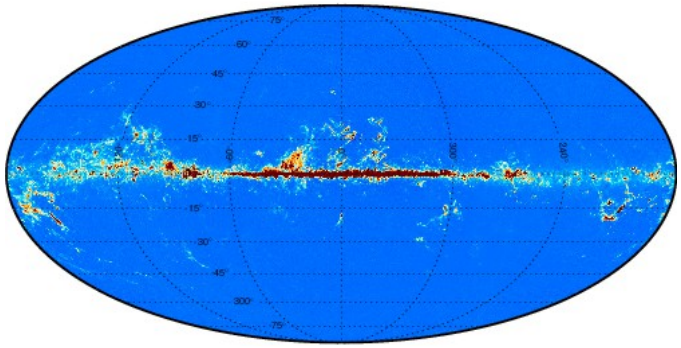






TYPE 2

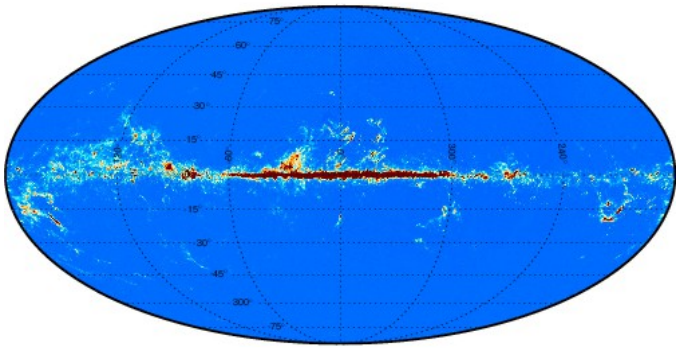




The Planck CO product:

- CO map
- stddev map
- noise map
- mask

TYPE 3

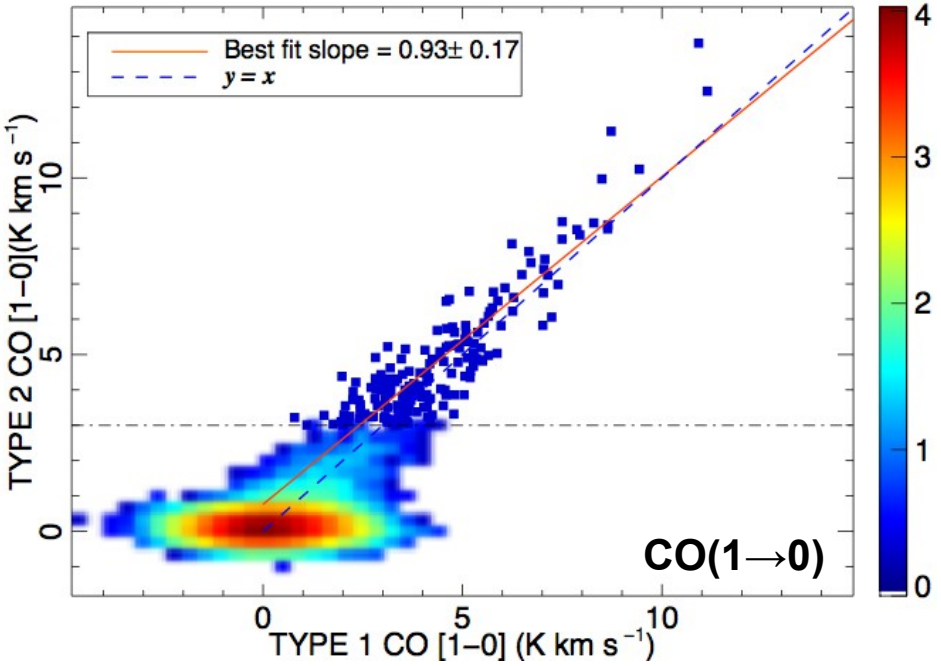


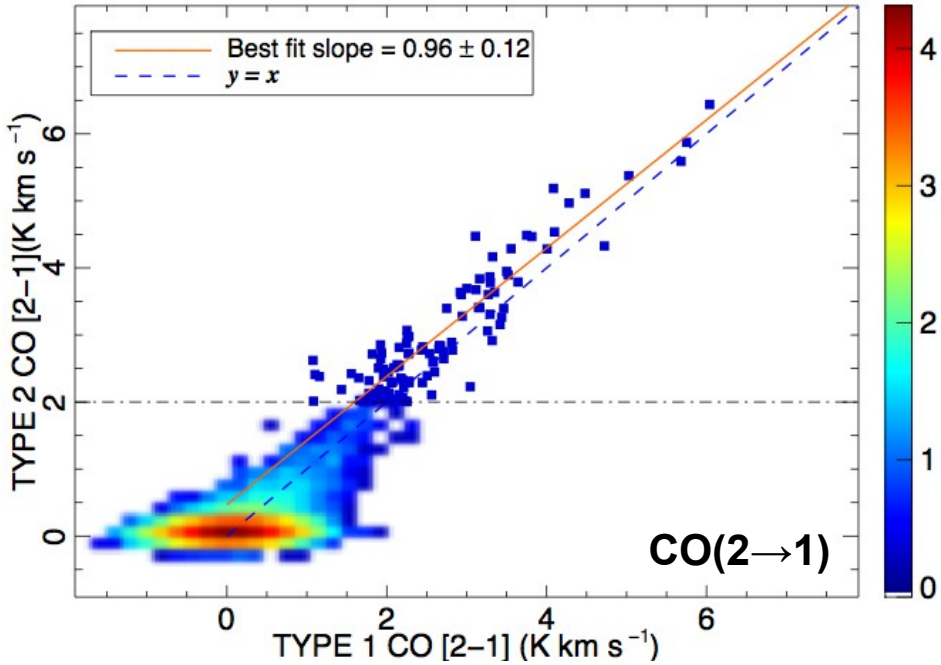
The full set of maps can be retrieved from the Planck Legacy Archive

`www.sciops.esa.int/index.php?page=Planck_Legacy_Archive&project=planck`

Internal validation

High latitude checks (where little dust contamination is expected)

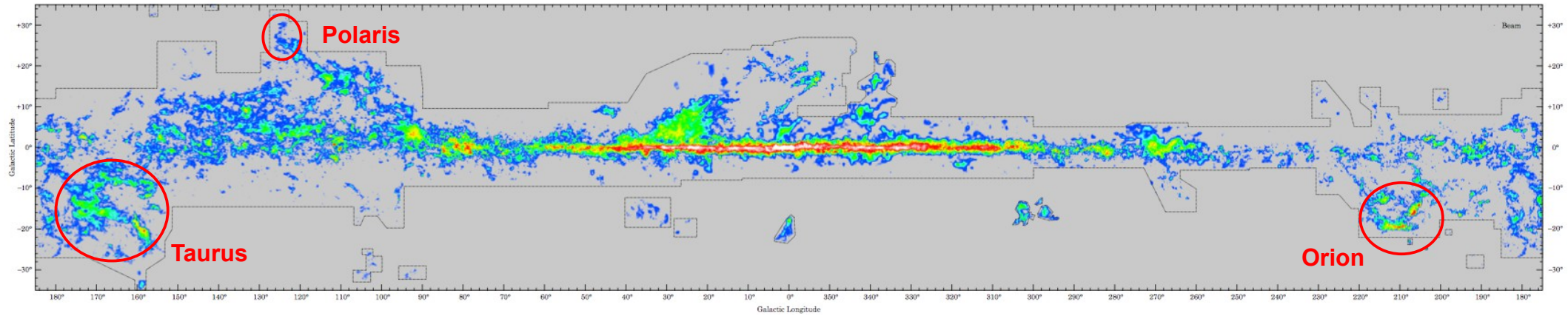


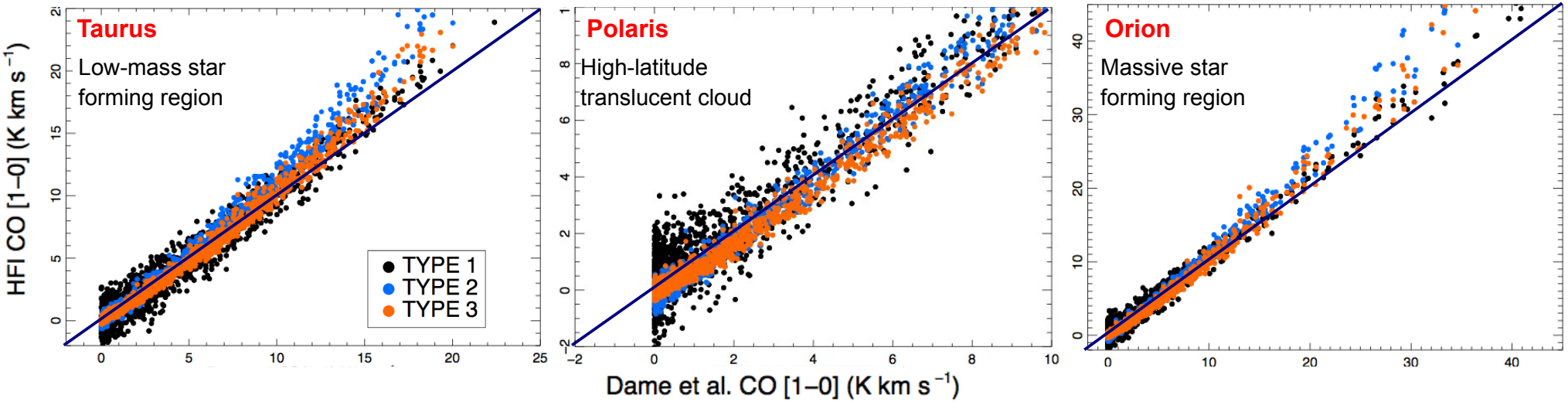


- Slope compatible with 1 in all cases
- Component separation methods used for the 3 CO products have also been validated using FFP-2013 simulations

Validation on external data CO [1-0]

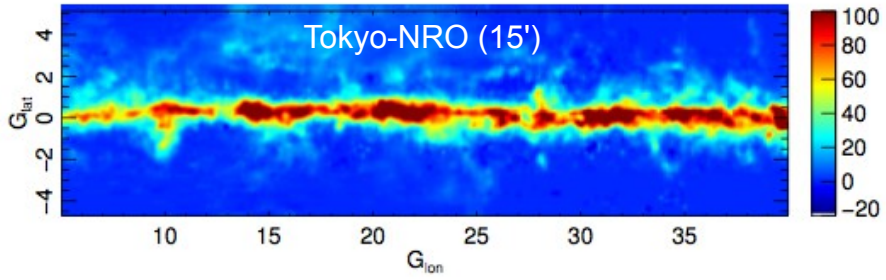
Dame et al. (2001) CfA CO(1-0) Galactic survey

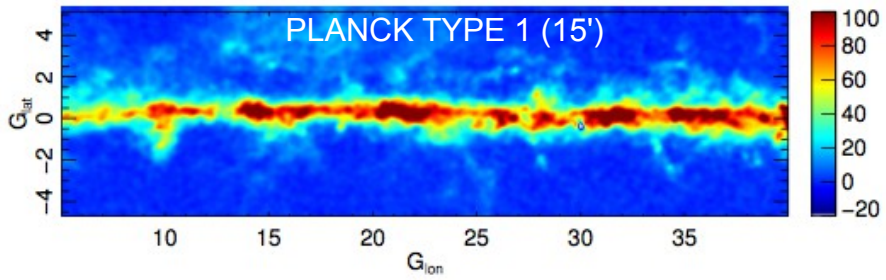




- All Planck CO maps show tight correlation with Dame et al. (much tighter than correlation with dust) → **we are seeing CO**
- **TYPE 1 (black dots) map is the most robust**
- **TYPE 2 and TYPE 3** maps suffer from **dust contamination**

Validation on external data CO [2-1]

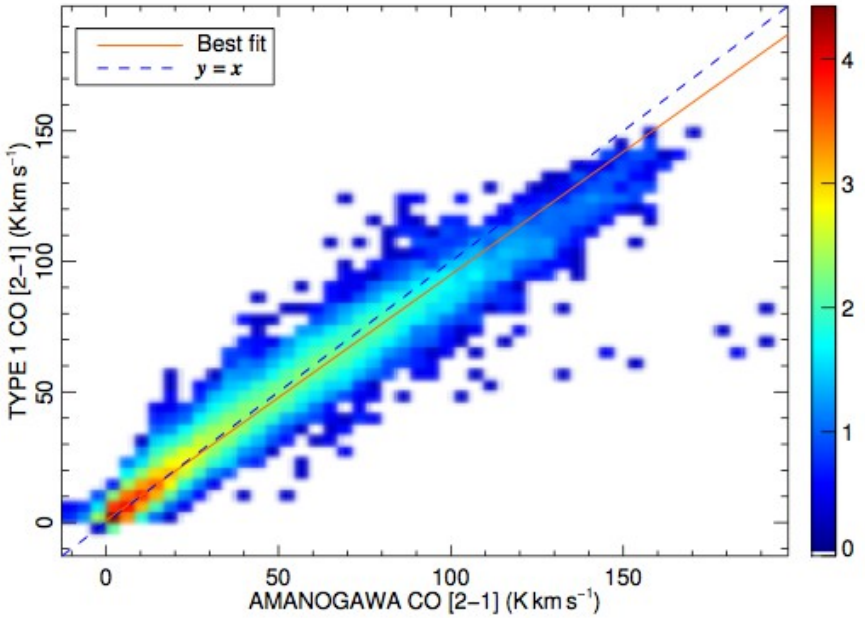


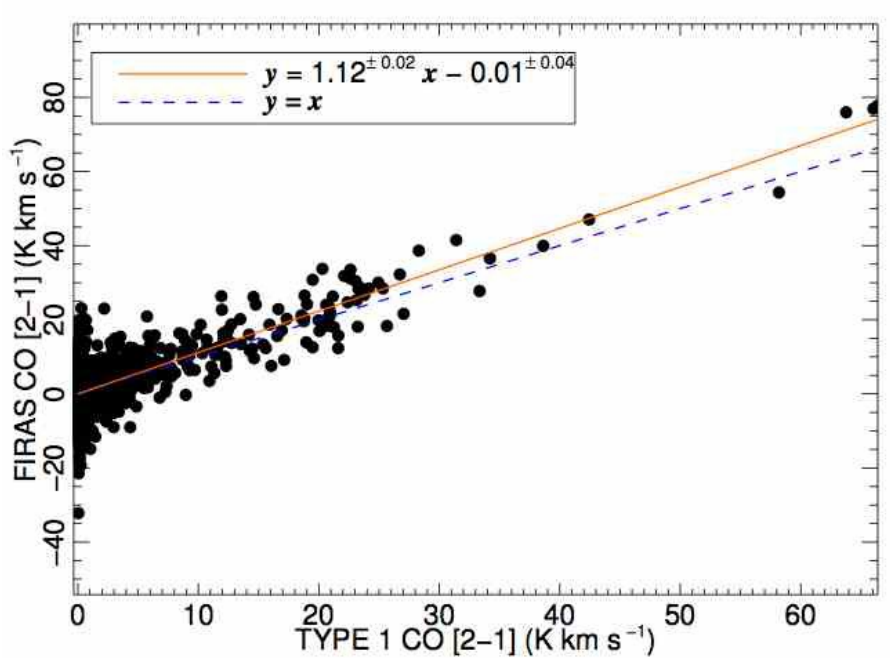


Available data for [2-1] transition are rare:

- Tokyo-NRO (AMANOGAWA data, plane)
- FIRAS fullsky map (7° beam)
- IRAM Polaris flare (43' x 33' field, high lat.)

In all cases, agreement is found within calibration uncertainty





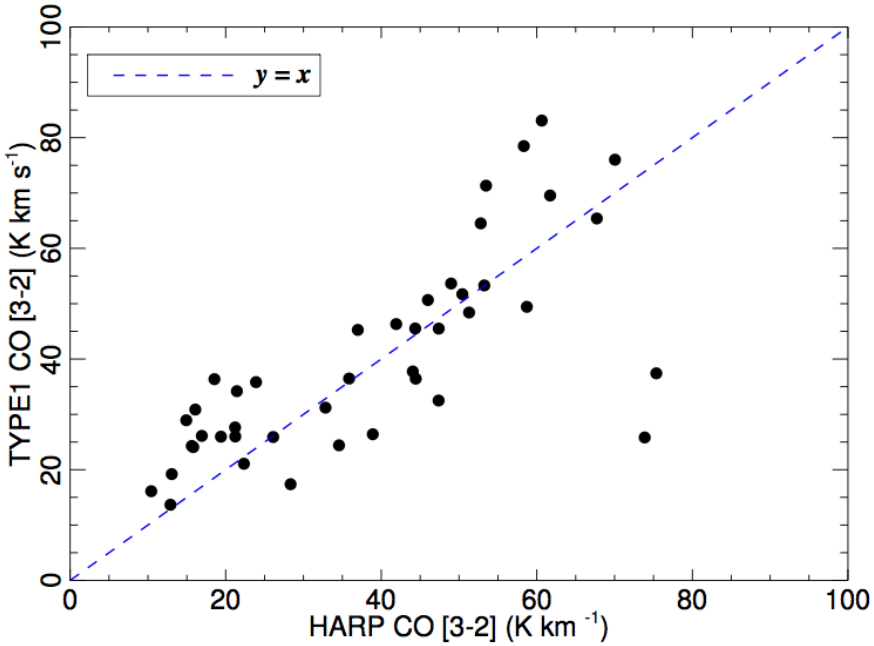
Validation on external data CO [3-2]

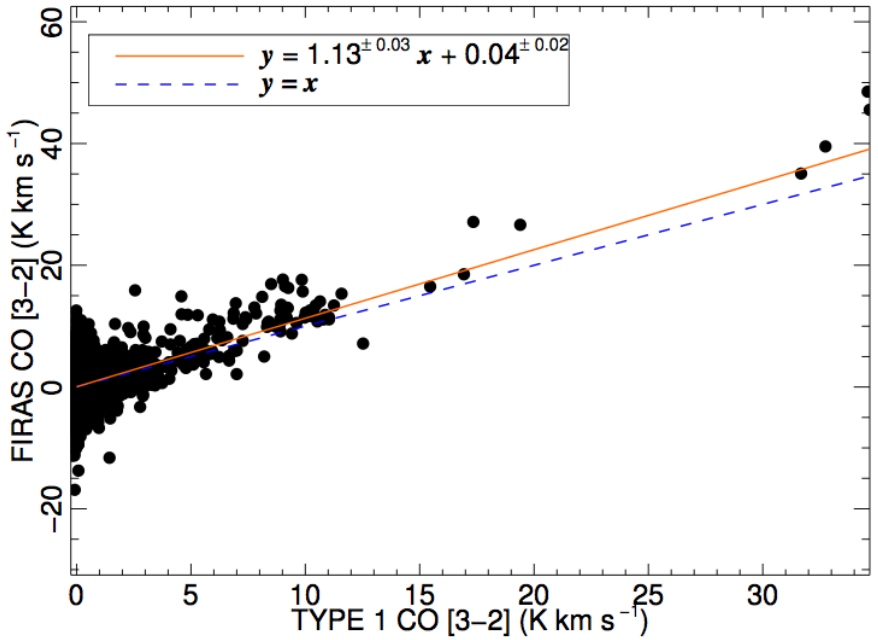
Very few data available for comparison

→ Full-sky FIRAS CO(3→2) map (7° beam)

→ JCMT HARP/ACSIS ^{12}CO(3→2) Galactic plane data. Small 2°x1° field around ℓ = 13.5°

Agreement is found within calibration uncertainty





More extensive characterization of this map is in progress

^{13}CO contamination

^{13}CO is the main other contributing isotopologue
Not separated in this release but we can estimate its contribution

CO content of TYPE 1 maps:

$$\mathrm{CO}^{X}_{\mathrm{type1}} = {}^{12}\mathrm{CO}^{X} \sum_{i}^{N_{\mathrm{bolo}}} w_i F^i_{12} + {}^{13}\mathrm{CO}^{X} \sum_{i}^{N_{\mathrm{bolo}}} w_i F^i_{13}$$

X = transition

0.53 for CO[1→0]

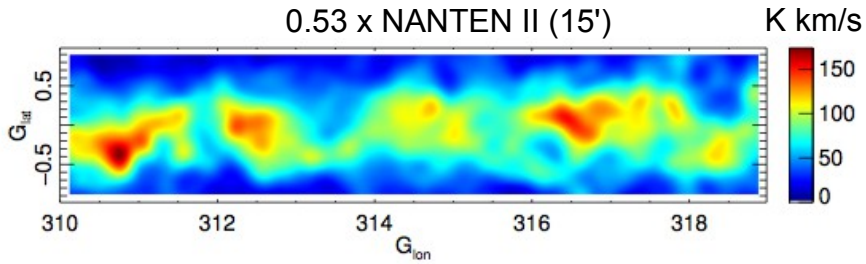
0.01 for CO[2→1]

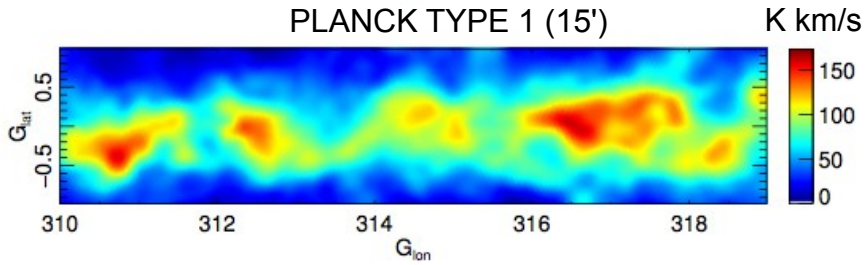
^{13}CO contamination depends on ^{13}CO/^{12}CO

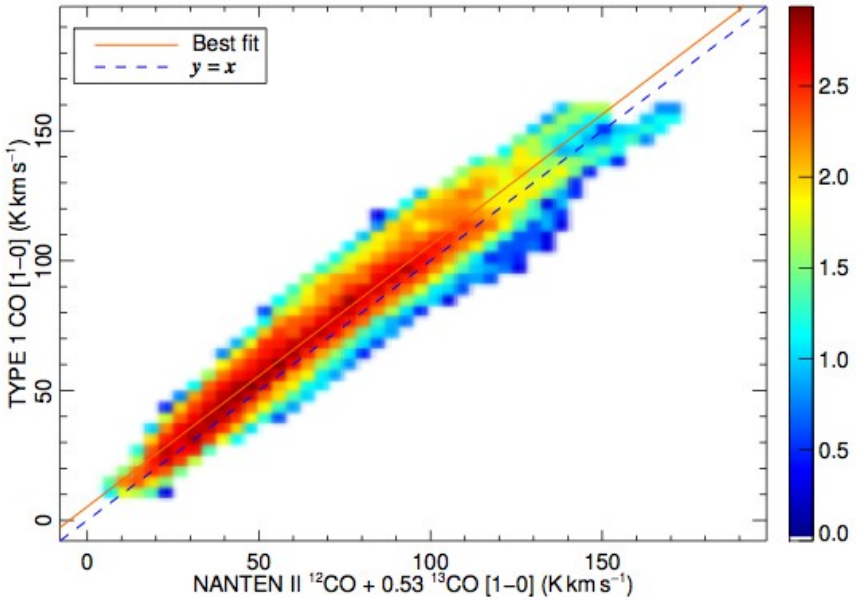
→ Assuming ^{13}CO/^{12}CO = 0.2

$\mathrm{CO}[1\rightarrow0]_{\mathrm{TYPE1}}$ ~ 1.10 ^{12}CO[1→0]
$\mathrm{CO}[2\rightarrow1]_{\mathrm{TYPE1}}$ ~ 1.02 ^{12}CO[2→1]
$\mathrm{CO}[3\rightarrow2]_{\mathrm{TYPE1}}$ ~ 1.07 ^{12}CO[3→2]

$\mathrm{CO}[1\rightarrow0]_{\mathrm{TYPE2}}$ ~ 1.20 ^{12}CO[1→0]
$\mathrm{CO}[2\rightarrow1]_{\mathrm{TYPE2}}$ ~ 1.20 ^{12}CO[2→1]

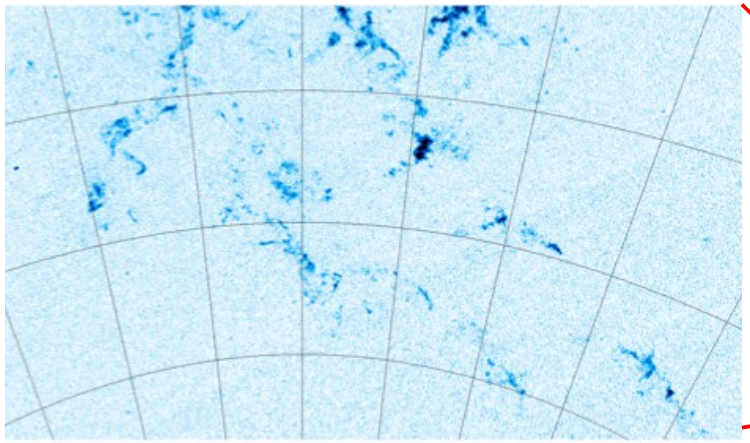




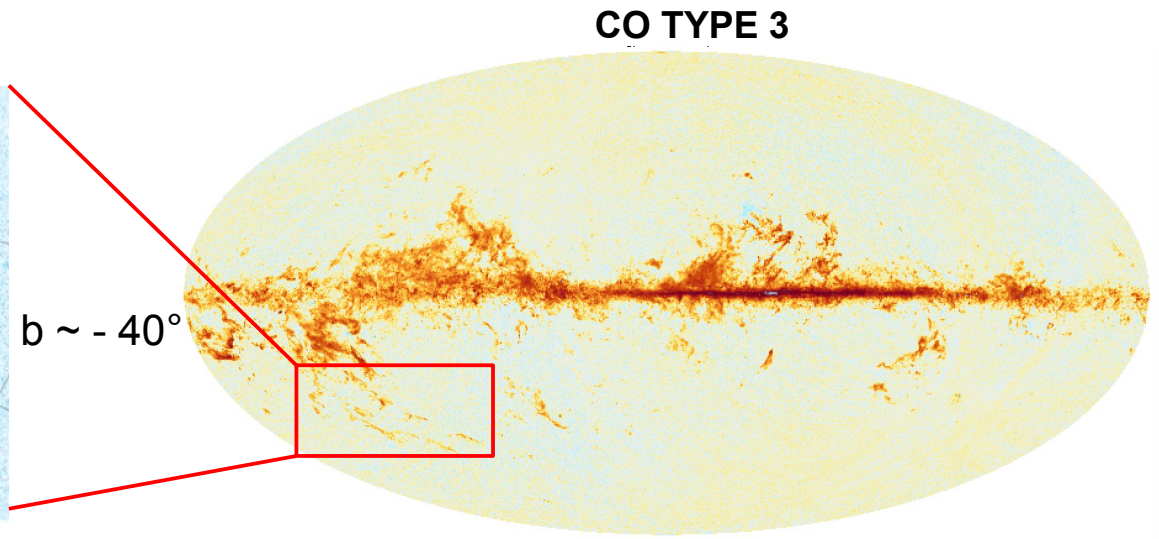


The high-latitude CO sky

Large extensions of cloud complexes



Environment of the Taurus complex
If distance ~ 100 pc → ~ 50 pc extension

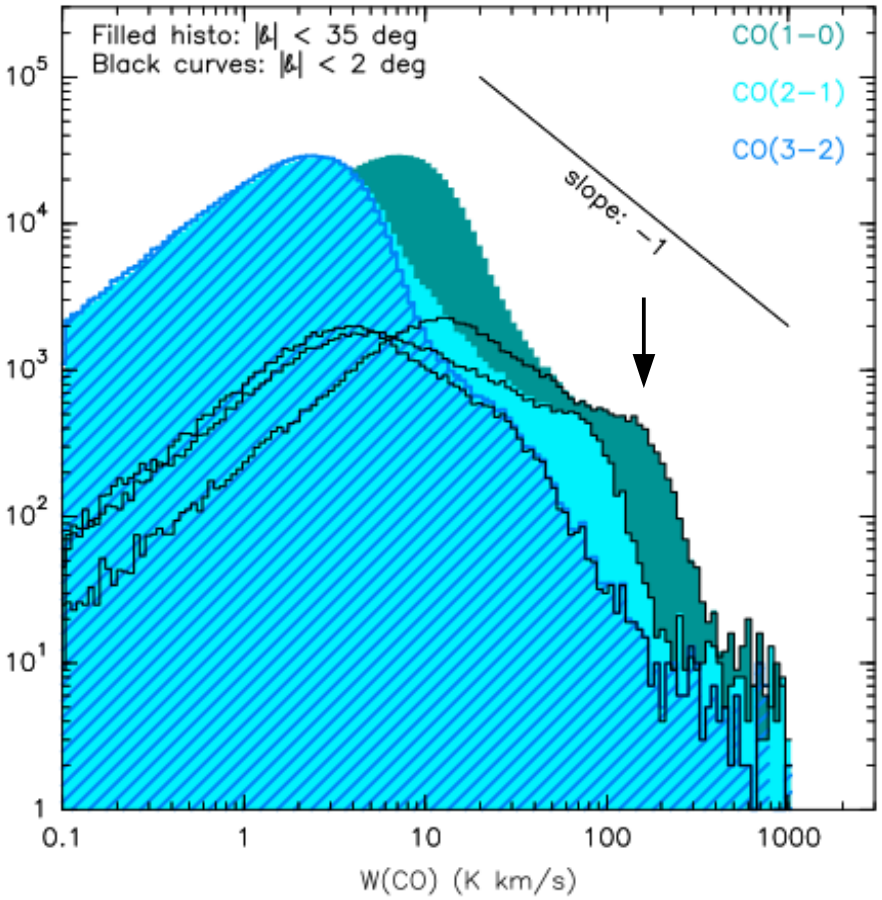


Automated search of new CO ”patches” outside previously known regions

- Patchy distribution
- Large extension of known clouds
  → catalogue of new ”patches”
- Power-law distribution of size and flux
  → no characteristic scale

The gas that builds up the CO mass

CO brightness distribution



- The bulk of the mass traced by CO(1→0) in the Milky Way has W(CO) ~ 160 K km/s

- Line ratios at the shoulders:
  $R_{2\text{-}1/1\text{-}0} = 0.50 \pm 0.05$
  $R_{3\text{-}2/1\text{-}0} = 0.20 \pm 0.05$

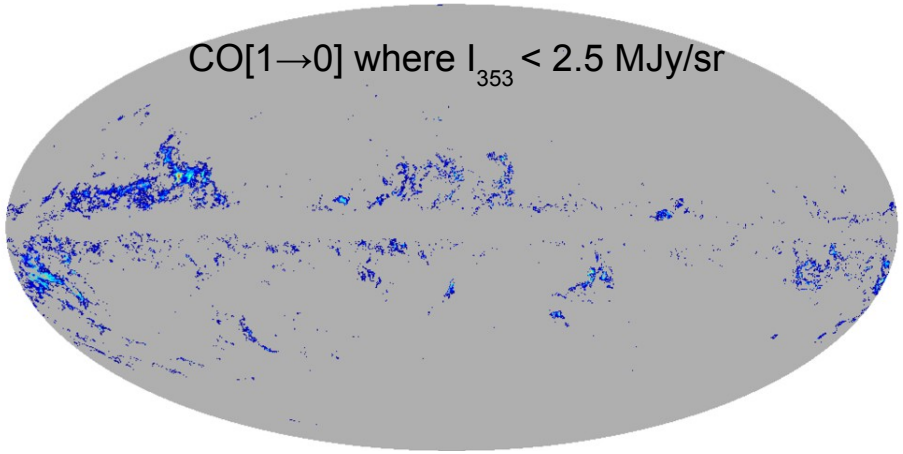
  → Analyzed in the Large Velocity Gradient approximation

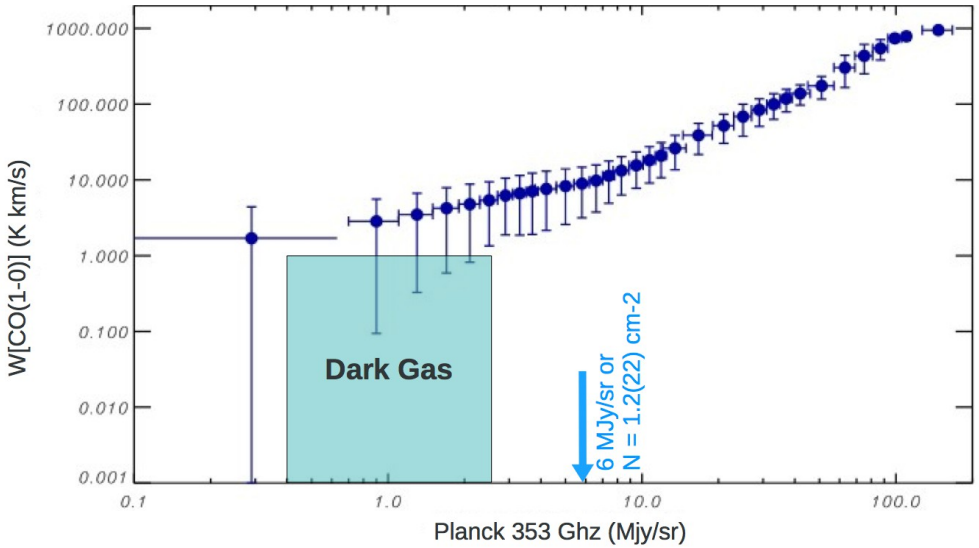
- The bulk of the molecular gas traced by CO is more dilute than 10^3 cm^{-3}
- It is located in the Molecular Ring (shoulder inexsistant at |v| < 35 km/s)

CO emission of the "dark gas"

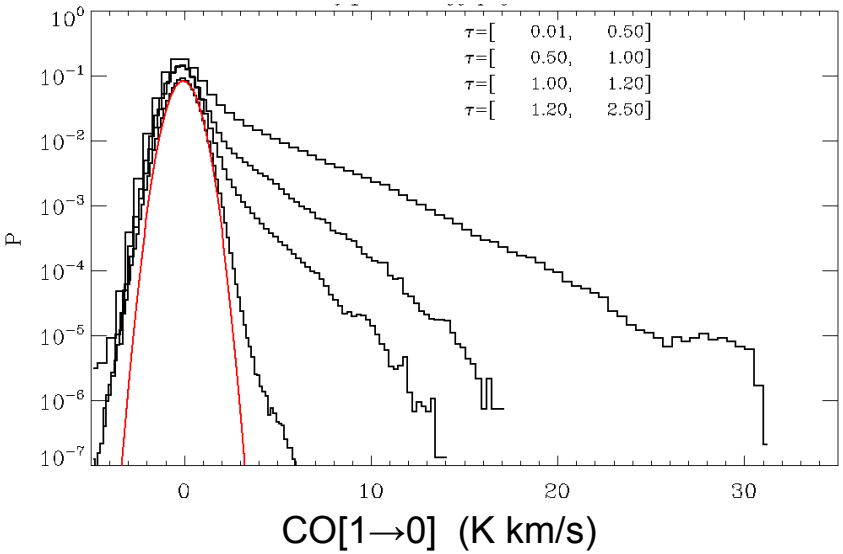
"Dark gas": not traced by CO above 1 K km/s or HI (Planck early results XIX, I. Grenier's talk tomorrow)

0.4 MJy/sr < I_{353} < 2.5 MJy/sr or 0.35 mag < A_v < 2.5 mag





CO distribution in 4 dark gas bins



- Non-Gaussian distribution of the CO emission in the weakest I_{353} regions
- The large values in the non-Gaussian tail of the PDF are well above theoretical predictions for such low column densities

The so-called dark gas emits in CO

Conclusions

- Full-sky CO maps of J = 1→0, J = 2→1 and J = 3→2 using Planck data have been delivered to the community.
  → Enables a multitude of ground-based follow-up studies

- Maps have been systematically compared to and found in agreement with external datasets.

- Systematic effects have been identified (dust, ^{13}CO) → no major limitations

- Full sky high-sensitivity map → discovery of large and weak extensions of known molecular clouds, catalogue of new patches of CO emission

- First 3 CO line survey of the Inner Galaxy: moderate density of gas traced by CO

- Non-Gaussian distribution of the CO emission of the "dark gas"

Thank you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cnes
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cnrs
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