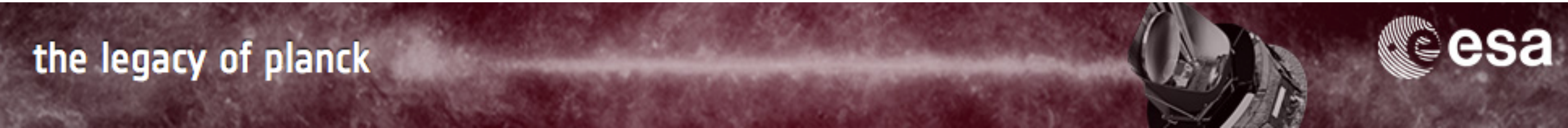
Mass content around Galactic VHE sources

Emma de Oña Wilhelmi[1], Giovanna Pedaletti[1], Diego F. Torres[1,2] & Giovanni Natale[3,4]
[1]Institute for Space Sciences, CSIC-IEEC, Barcelona
[2]ICREA, Barcelona
[3]MPIK, Heidelberg
[4]Jeremiah Horrocks Institute, Preston



Outlook

Why do we care about the mass content about VHE sources

- Acceleration of CRs in Galactic sources
- Distribution of VHE sources in the Galactic Plane

Distribution of gas and mass estimation

- Mass estimation through dust and CO line observations

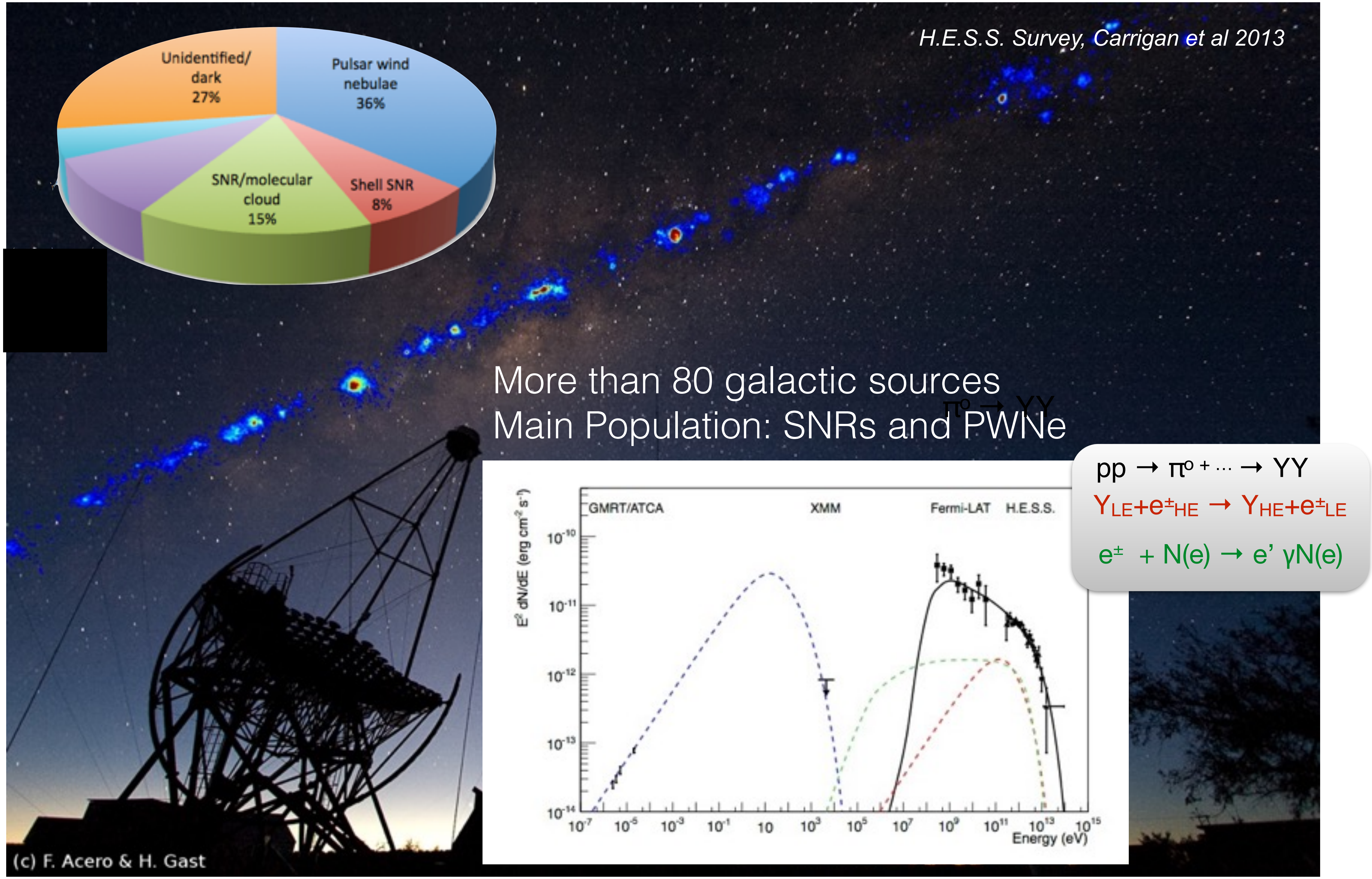
Statistical correlation between VHE and molecular enhancement

- Tracers and estimation of CR enhancement

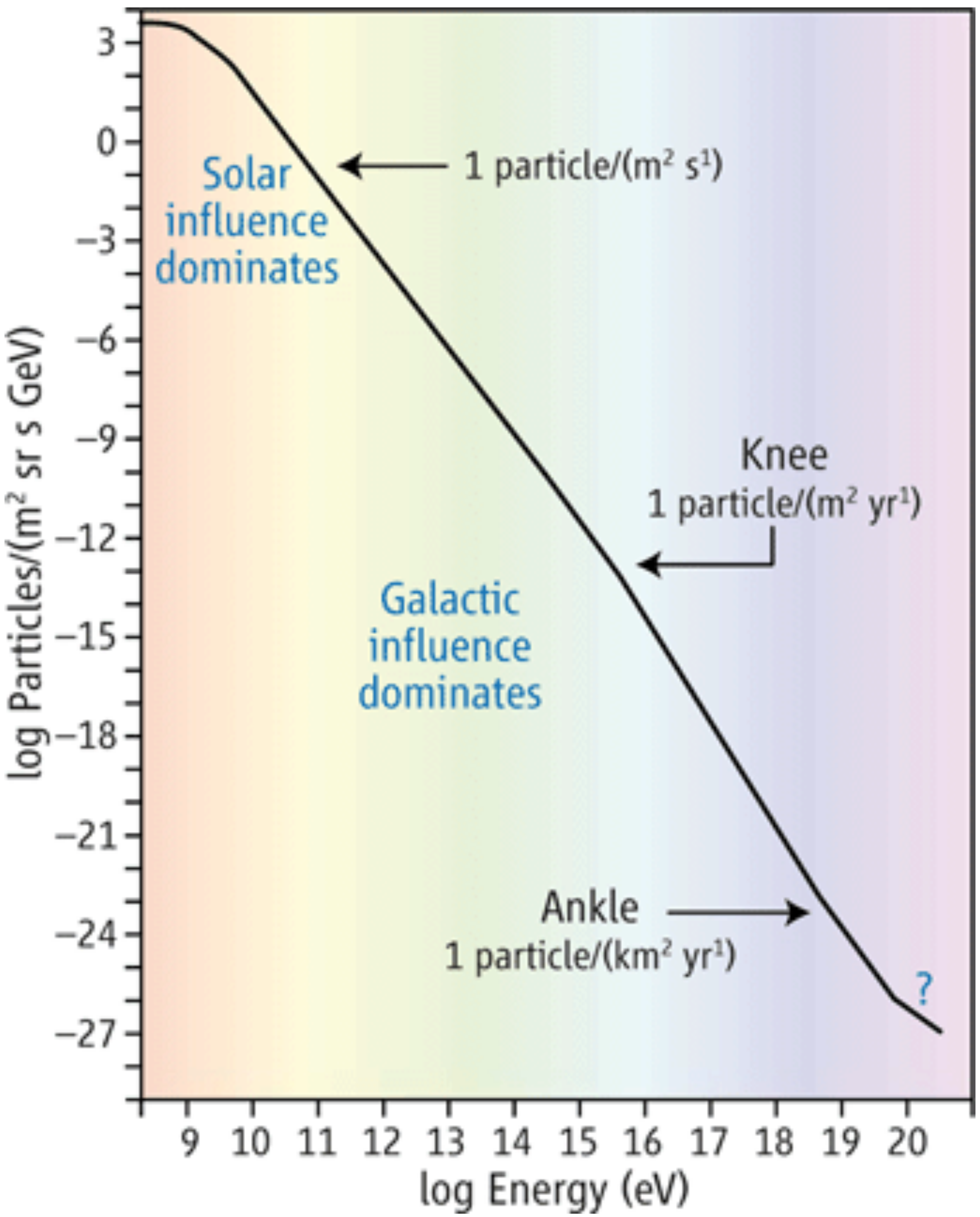
Comparison of different tracers

On the possible correlation of Galactic very-high energy source locations and enhancements of the surface density in the Galactic plane, G. Pedaletti, EOW et al, A&A 565, A118, 2014
Estimating Galactic gas content using different tracers: Compatibility of results, dark gas and unidentified TeV sources, G. Pedaletti, EOW, et al, JHEAp 5-6 15-21, 2015

Galactic VHE sources



CRs Observations



Direct observations

- At low energies, largely affected by solar wind modulations
- At high energies, limited by the satellites effective area

Indirect observations

- Detection of by-products

$$p + p \rightarrow \pi^o + X + \ldots + \pi^\pm$$

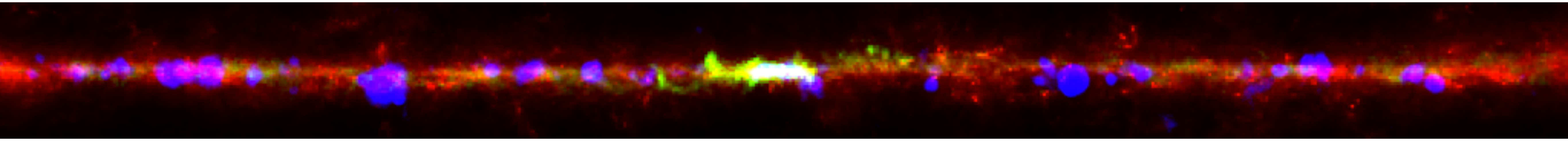
$$\pi^o \rightarrow Y + Y$$

$$\pi^\pm \rightarrow \nu_{e,\mu}$$

- Crucial to understand the target Planck!

Galactic VHE sources

Planck



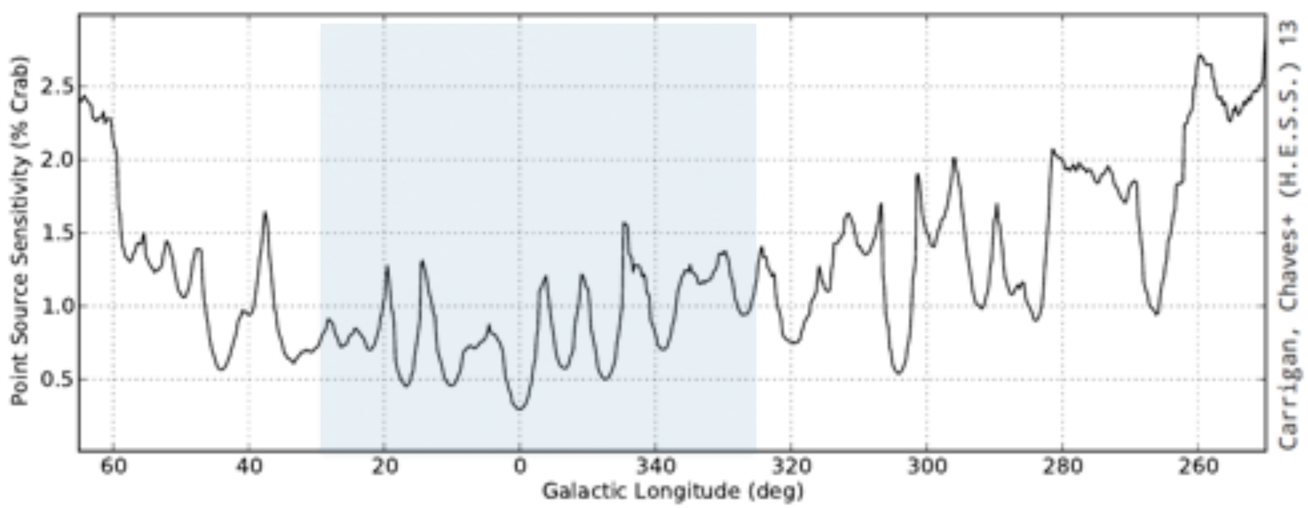
VHE emission is believed to be associated to regions of massive star formation, usually traced by a dust content enhancement.

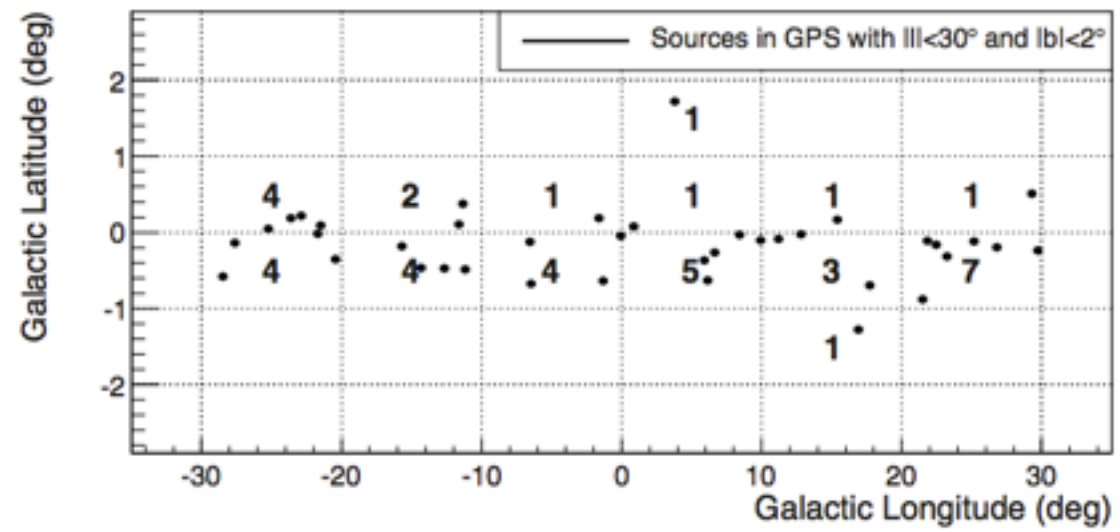
Tracing of material through:

- 2.6mm line of ^{12}CO → Dame+01 galactic survey & Planck all-sky map
- Dust → Planck all-sky map (353+545+857)GHz+100μm (3THz IRAS)

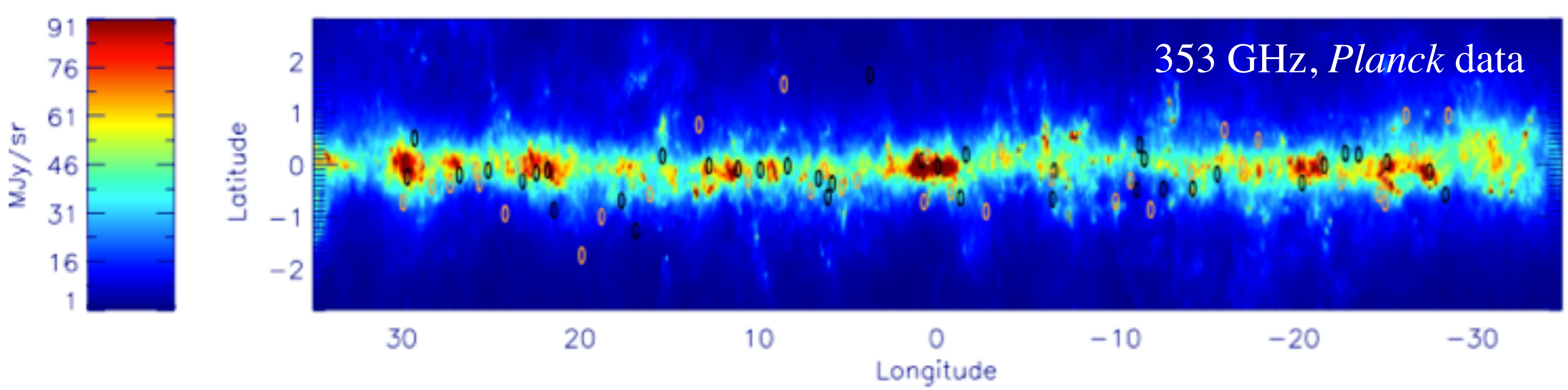
Galactic VHE sources

- We select the inner part of the HESS GPS to ensure a ~homogenous exposure
- 39 sources in the $|l| < 30^{o}$ and $|b| < 2^{o}$ range
- Binning size $\delta l = 10^{o}$ and $\delta b = 1^{o}$ selected to obtain a sufficient source density





- For each bin, randomise the position of the sources in that bin
- 10^{5} fake distribution of TeV sources



Estimating the molecular material

Estimation of material via ^{12}CO line intensity

- Using CfA data (Dame-deep, Dame 1987, 2001) integrated to all velocities.
- Planck data (which includes <10% contribution from ^{13}CO) provides compatible information - not used to have two independent estimators

$$M_{\mathrm{CO}} = \mu m_{\mathrm{H}} D^2 \Delta\Omega_{\mathrm{px}} X_{\mathrm{CO}} \sum_{\mathrm{px}} W_{\mathrm{CO}}. \quad (1)$$

Estimation of material via dust

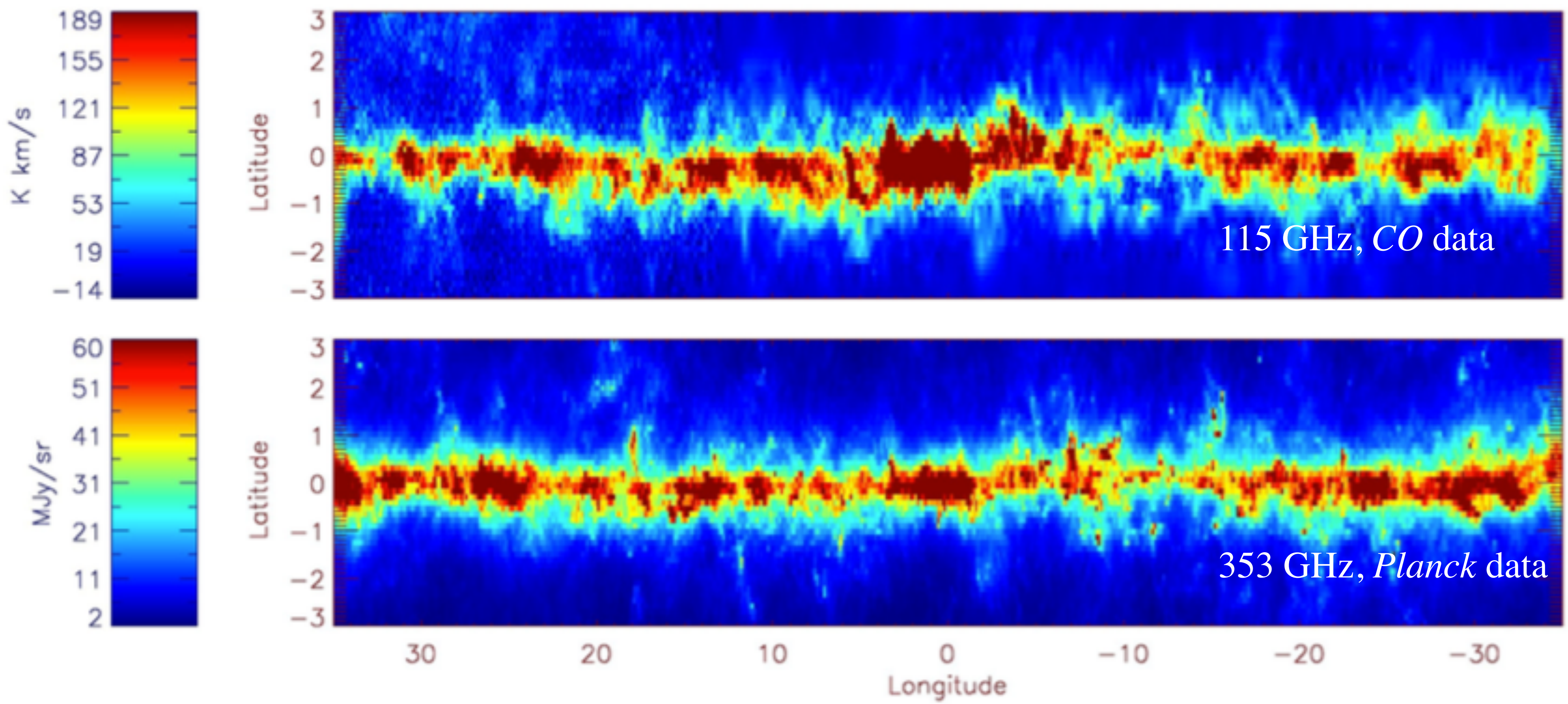
- Using Planck all-sky map (353+545+857) GHz + 100 µm (IRAS)

$$M_{\mathrm{dust}} = \Delta\Omega_{\mathrm{px}} D^2 \kappa_{\nu_0}^{-1} \sum_{\mathrm{px}} \frac{I_\nu}{B_\nu(T)} \left(\frac{\nu}{\nu_0}\right)^{-\beta}, \quad (2)$$

$$\tau_\nu = \frac{I_\nu}{B_\nu(T)} = A \left(\frac{\nu}{\nu_0}\right)^{\beta}. \quad (3)$$

$$\Sigma = \left(\frac{M}{M_\odot}\right)\left(\frac{A}{\mathrm{pc}^2}\right), \quad (4)$$

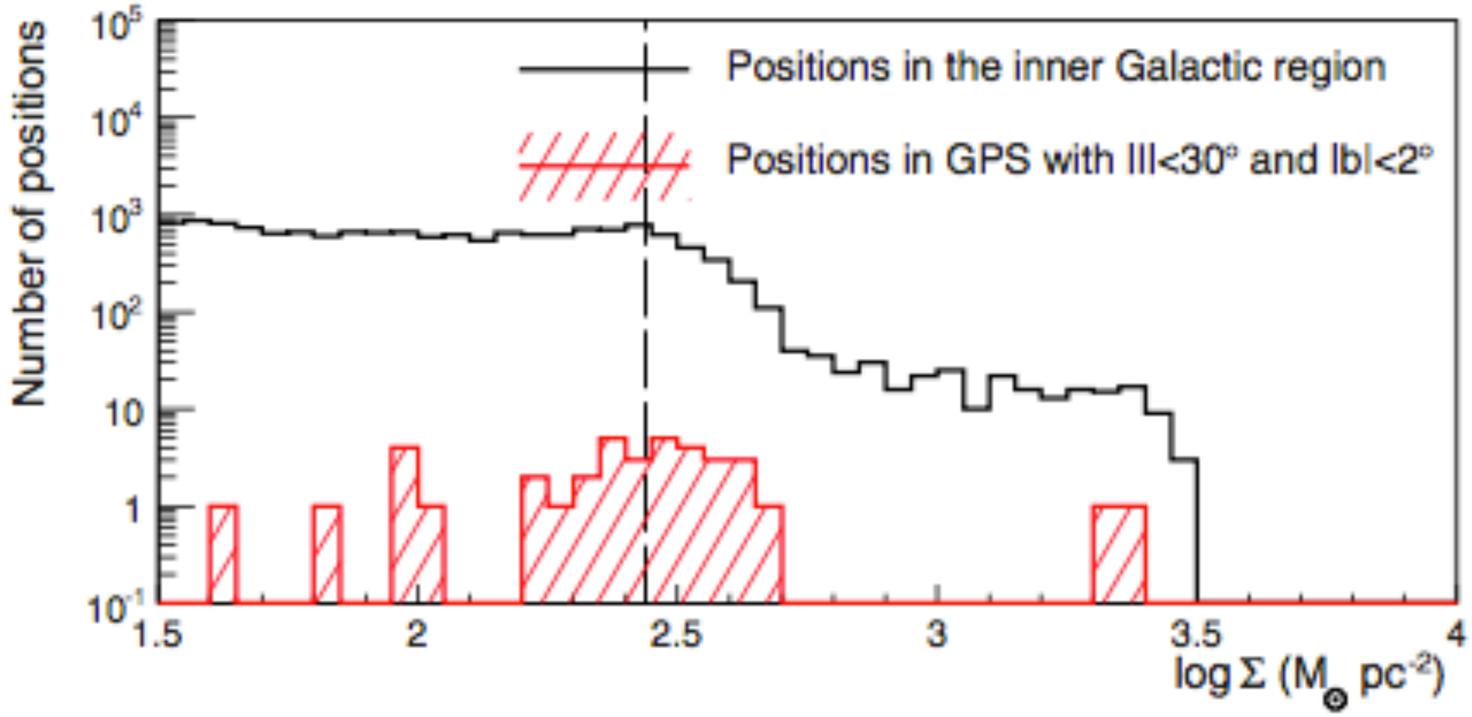
Estimating the molecular material



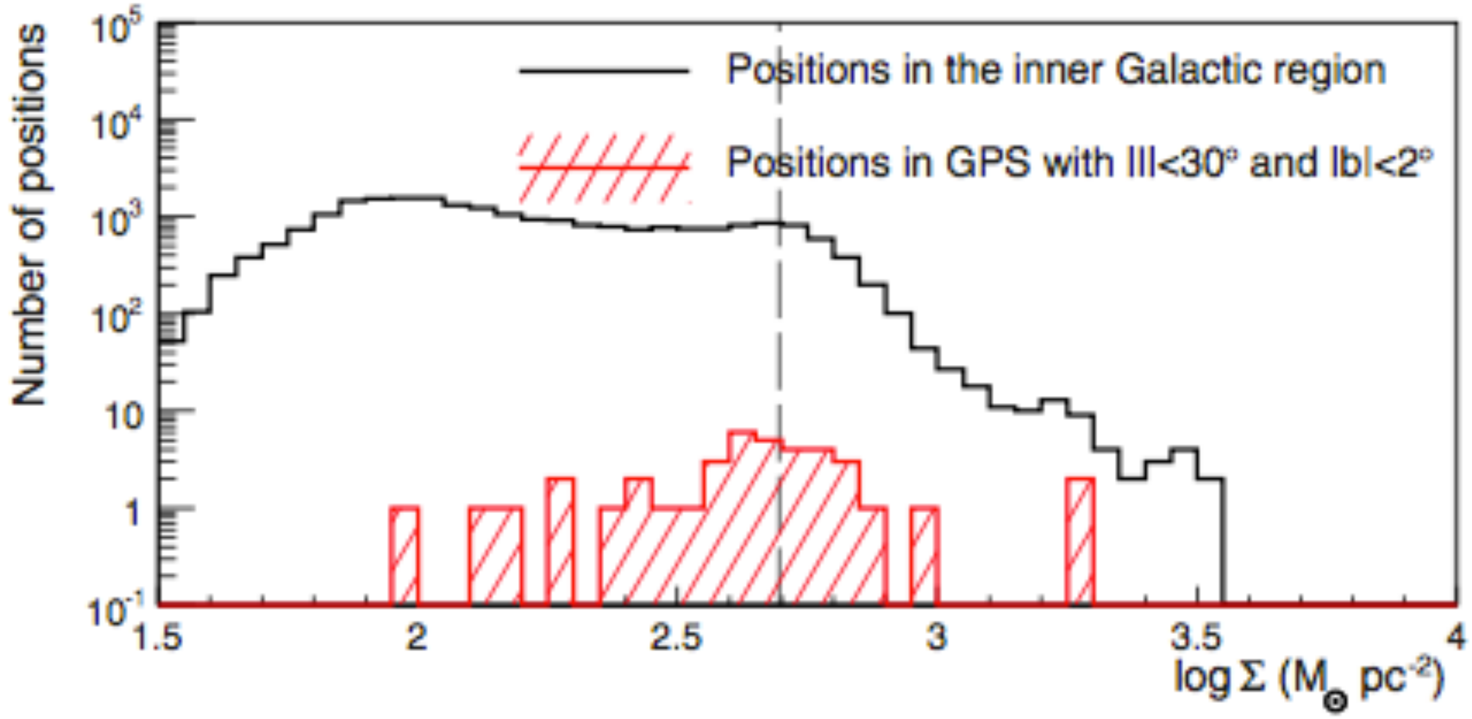
- Rebin at same resolution (healpix package):1pix = 0.125^o
- For each VHE source, select a 3x3 bin (0.375x0.375deg), similar in extension to 0.22deg radius for source discovery in HESS

Correlations

CO



Planck

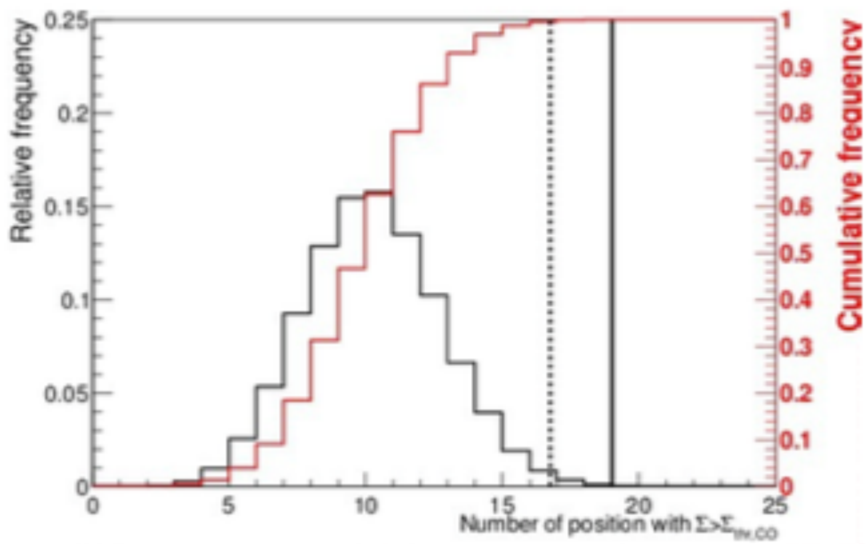


To quantify the correlation, we calculate the probability of having a certain number of positions of the GPS sources associated with a surface density estimate above a chosen threshold, thus defining the enhancement.

The threshold is defined equivalent to a surface density that is exceeded by 10% of the positions in the inner Galaxy.

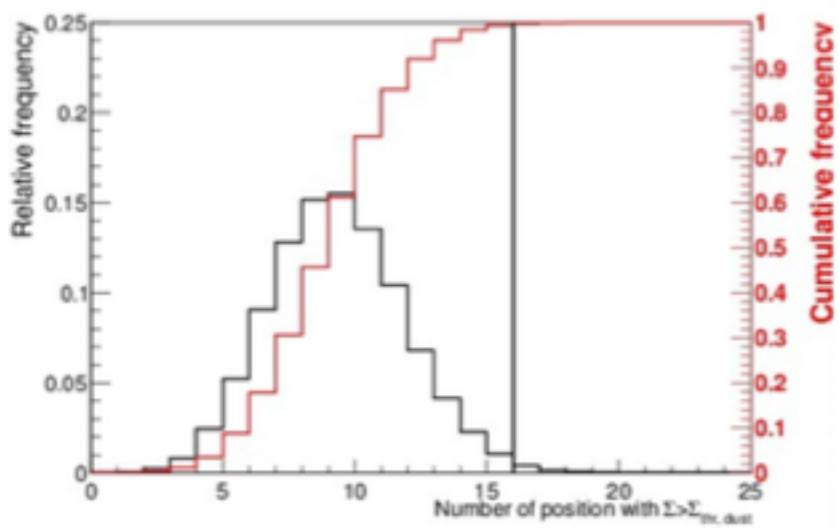
$$\Sigma_{thr}=\Sigma_{10}$$

Correlations



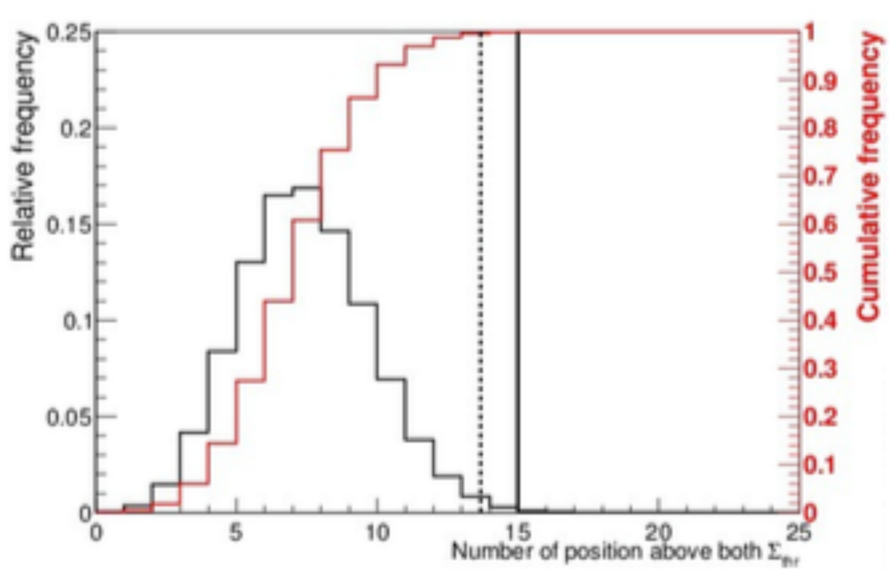
CO

there are 19 sources in the inner GPS associated with positions of surface density above Σ_{thr} corresponding to 3.9σ.



Dust

16 sources above Σ_{thr} corresponding to 3.0σ



Combined CO+Dust

Positions that are above the threshold for both map), 15 positions → 3.9σ.

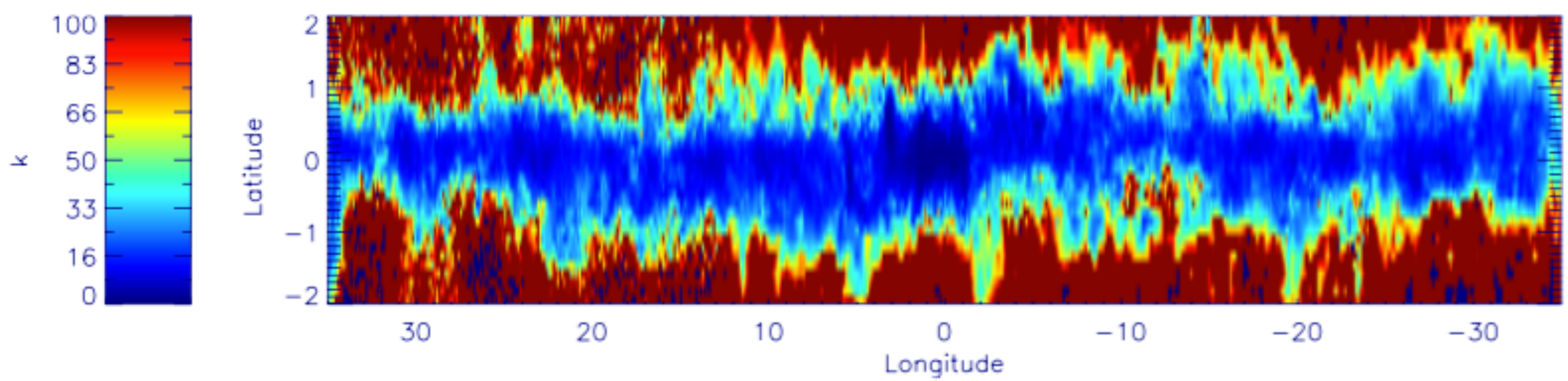
CR accelerators?

- We found a (weak) correlation between VHE source & Mass enhancement
- VHE emission from clouds?

$$F\left(E > E_\gamma\right) \sim 1 \times 10^{-13} \kappa E_\gamma^{-1.7} M_5 D^{-2}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1},$$

Aharonian et al 1991

κ is the enhancement factor of CRs, which is assumed to be unity for passive clouds and larger in the presence of a nearby accelerator.



Map of the enhancement κ over the Galactic CR background necessary to reach detection with 50 h of CTA observations ($2\mathrm{x}10^{-13}$ $\mathrm{erg/cm^2/s}$).

Comparing mass estimators

$$M_{\rm CO} = \mu m_{\rm H} D^2 \Delta\Omega_{\rm px} X_{\rm CO} \sum_{\rm px} W_{\rm CO}.$$

Xco = {0.5 - 4.8} x10^{20} cm^{-2} $(K\ Km/s)^{-1}$

$$M_{\rm dust} = \Delta\Omega_{\rm px} D^2 \kappa_{\nu_0}^{-1} \sum_{\rm px} \frac{I_\nu}{B_\nu(T)} \left(\frac{\nu}{\nu_0}\right)^{-\beta},$$

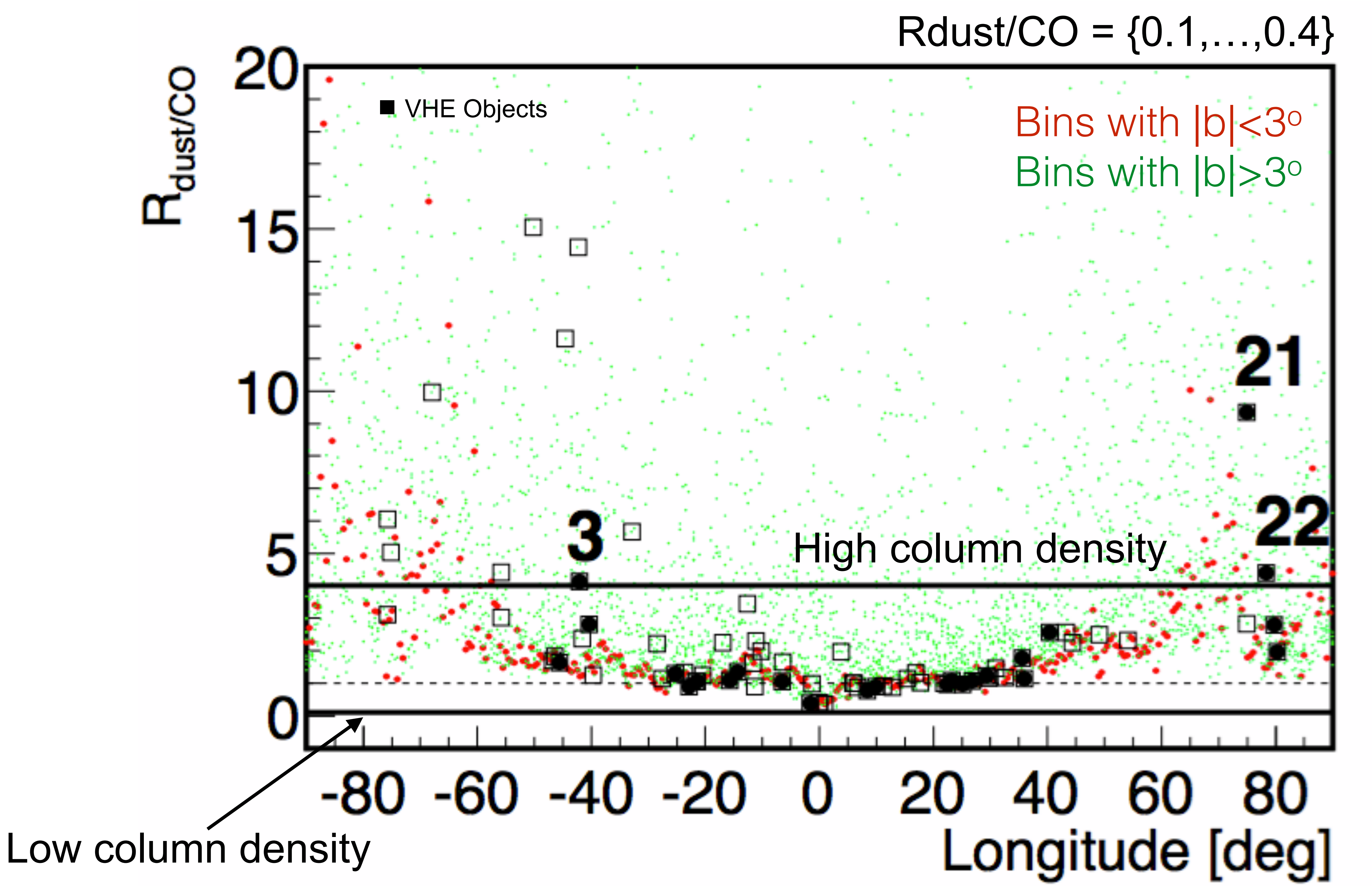
$$\sigma_\nu = \mu m_{\rm H} \kappa_\nu$$

σ(353 GHz) = {1. - 4.1} x10^{-26} cm^2 H^{-1}

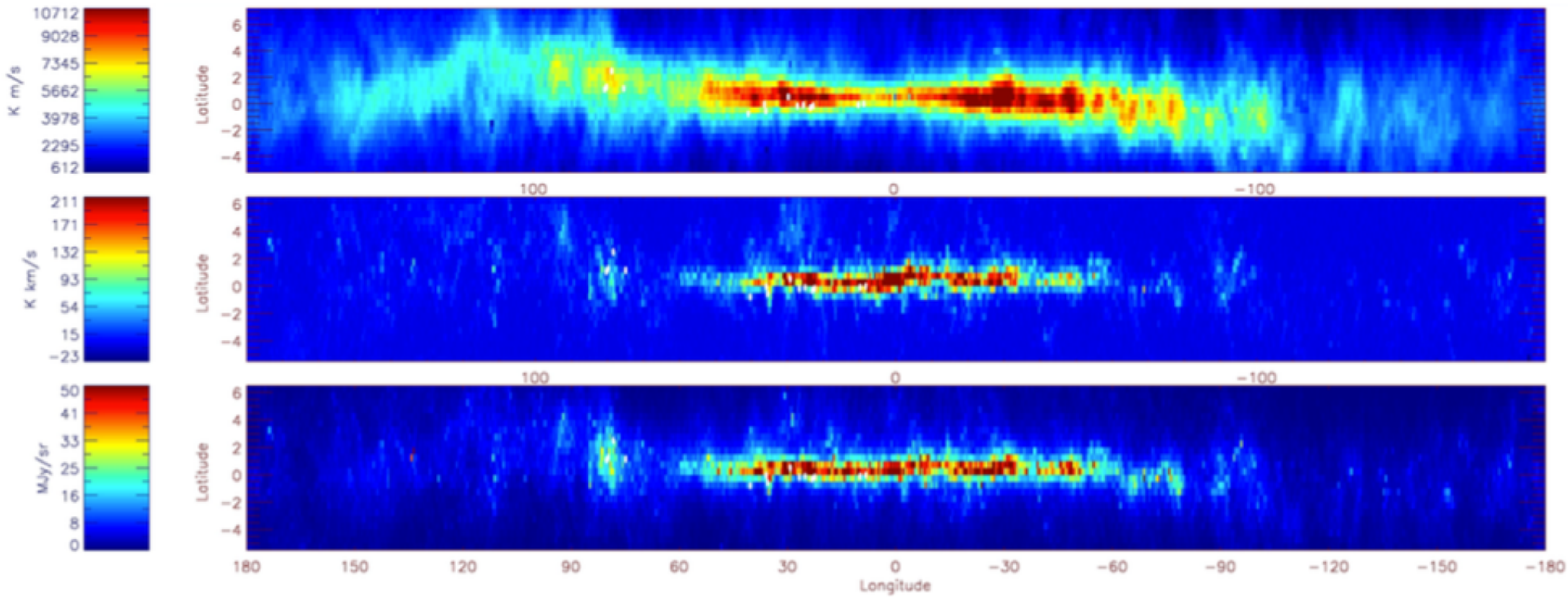
- Xco increases with galactocentric distance and σ(353 GHz) decreases with column density
- Take minimum and maximum values from literature and normalize to average values

$$\Sigma_{\rm dust} = \eta \Sigma_{\rm CO}, \longrightarrow R_{\rm dust/CO} \equiv \eta X_{\rm CO} \sigma_{\nu_0} = \frac{\sum_{px} \tau_\nu (\nu/\nu_0)^{-\beta}}{\sum_{px} W_{\rm CO}},$$

Comparing mass estimators



Comparing mass estimators

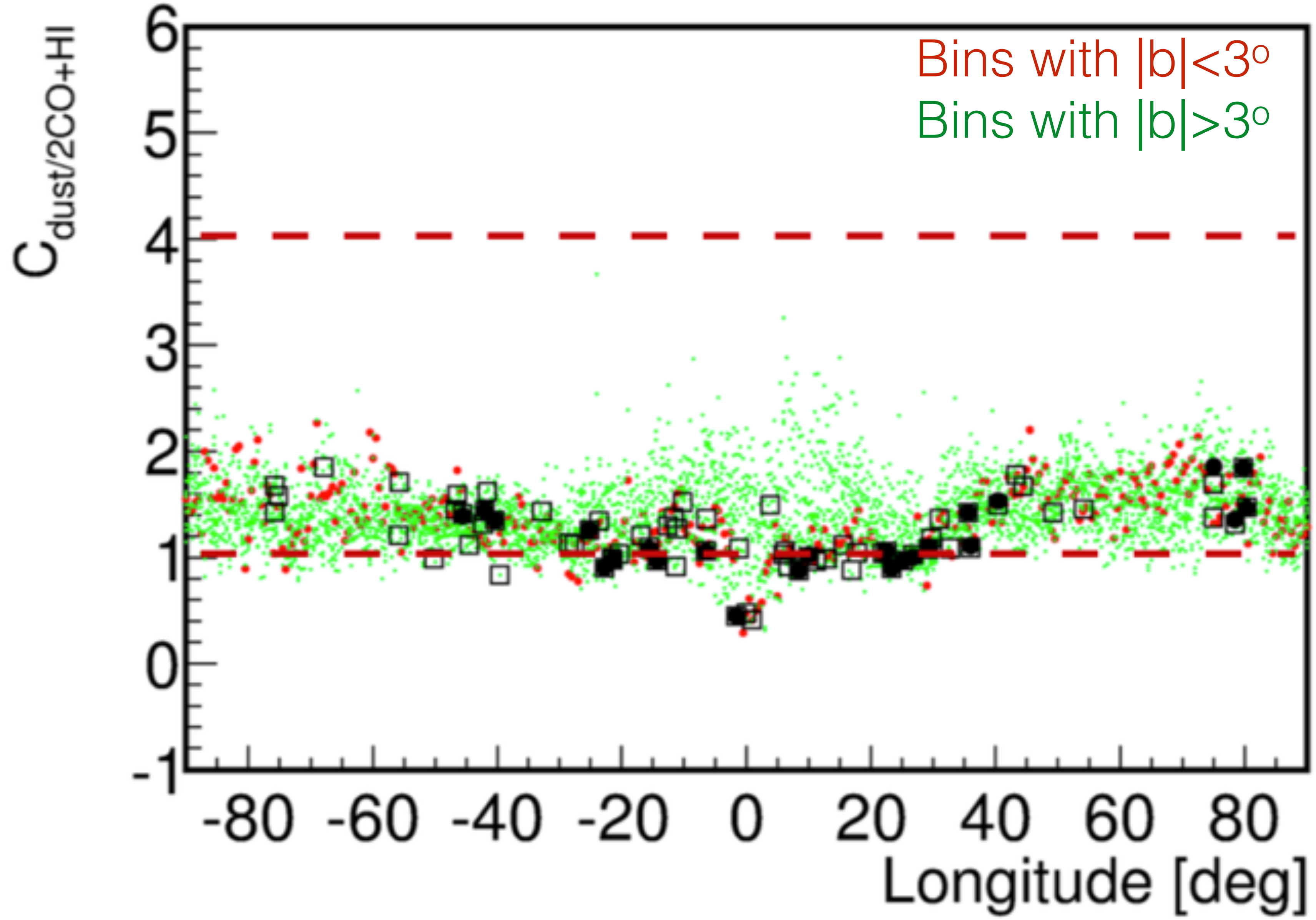


Use Planck CO and dust map, use LAB survey for HI.

Rebin at same resolution (0.5 deg).

$$C_{\mathrm{dust/2CO+HI}} = \frac{N_{\mathrm{H}}}{2N_{\mathrm{H2}} + N_{\mathrm{HI}}}$$

Comparing mass estimators



Summary

- We establish a (still weak) correlation between VHE sources and material enhancement on the Galactic plane
- At large scale, the molecular content obtained using Planck data requires a ~tens to ~hundred enhancement factor of CRs to be observed by the next generation of Cherenkov telescopes (CTA)
- Comparing different tracers and including limits in the conversion factors, we don't find a privilege conditions on the direction of the VHE sources in the inner part of the Galaxy (such dark gas not traced by dust/CO/HI)
- For sources located in the outer Galaxy, such i.e. Cygnus region, the molecular component is not dominant.

On the possible correlation of Galactic very-high energy source locations and enhancements of the surface density in the Galactic plane, G. Pedaletti, EOW et al, A&A 565, A118, 2014
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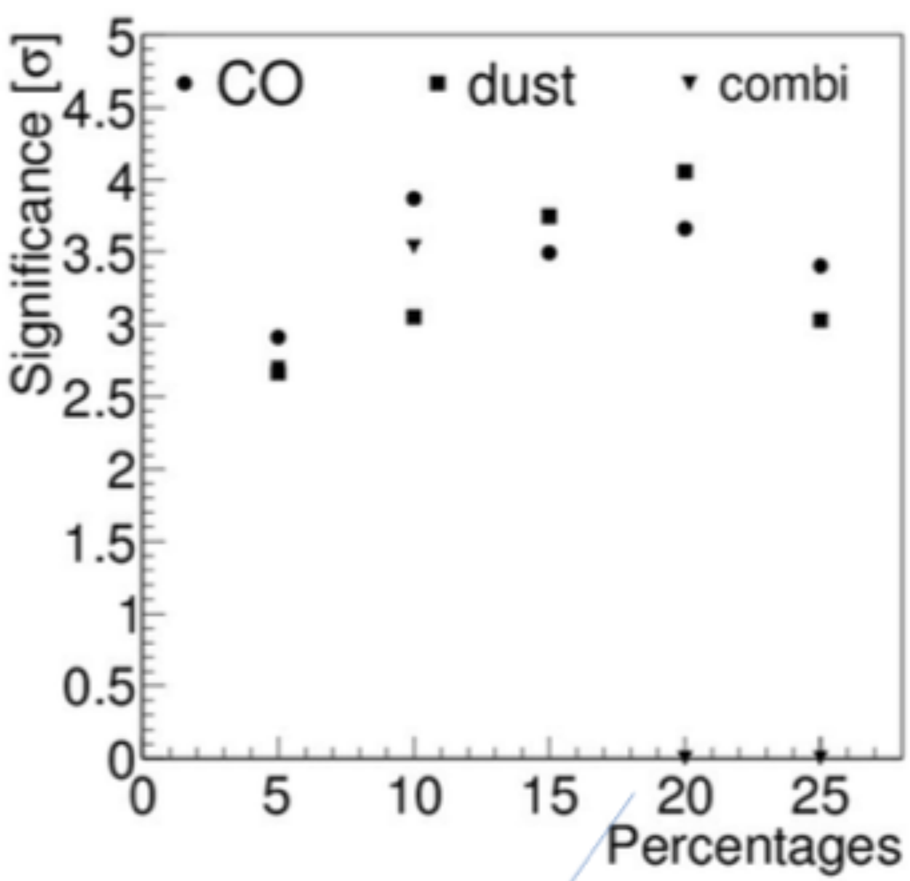
Thanks!

Backups

We made best guess assumptions in the set up of the problem.
But how much is the correlation affected by changing those?



Zero significance means that we did not have enough randomized smaples to construct the high end tail of the distribution

Case	Tracer	$\Sigma_{\rm thr}$ $M_{\odot}{\rm pc}^{-2}$	#	Probability	S
A	Dust	496	16	0.9977	3.05σ
A	CO	274	19	0.9999	3.89σ
A	Combined	–	15	0.9995	3.52σ
B	Dust	496	16	0.8366	1.39σ
B	CO	274	19	0.9822	2.37σ
B	Combined	–	15	0.9610	2.06σ
C	Dust	266	4	0.8804	1.55σ
C	CO	137	4	0.9170	1.73σ
C	Combined	–	4	0.9663	2.12σ

A: initial case
B: reduced binning in latitude
C: |b|>0.5º