Cosmic rays & gas: Fermi & Planck

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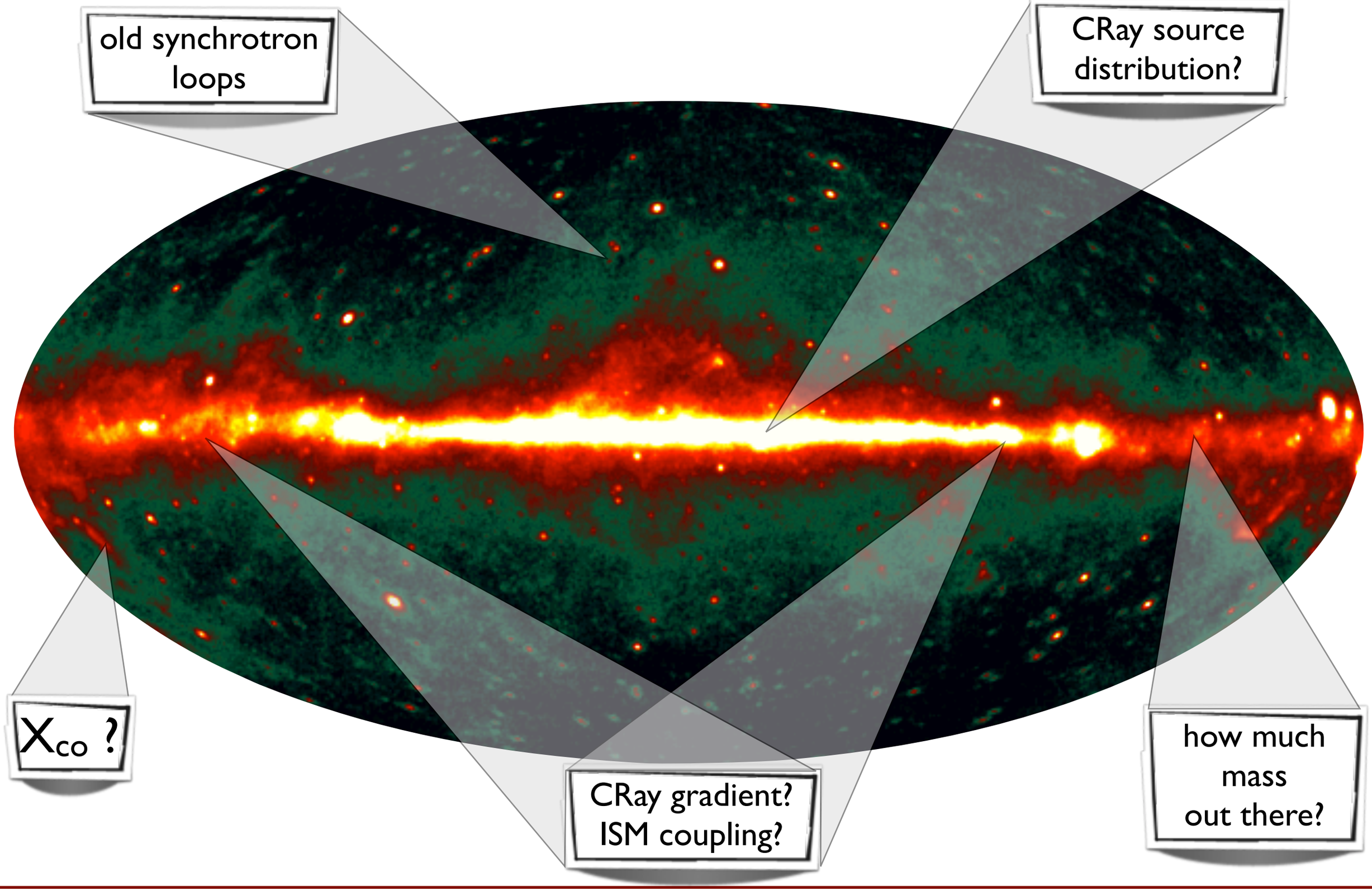
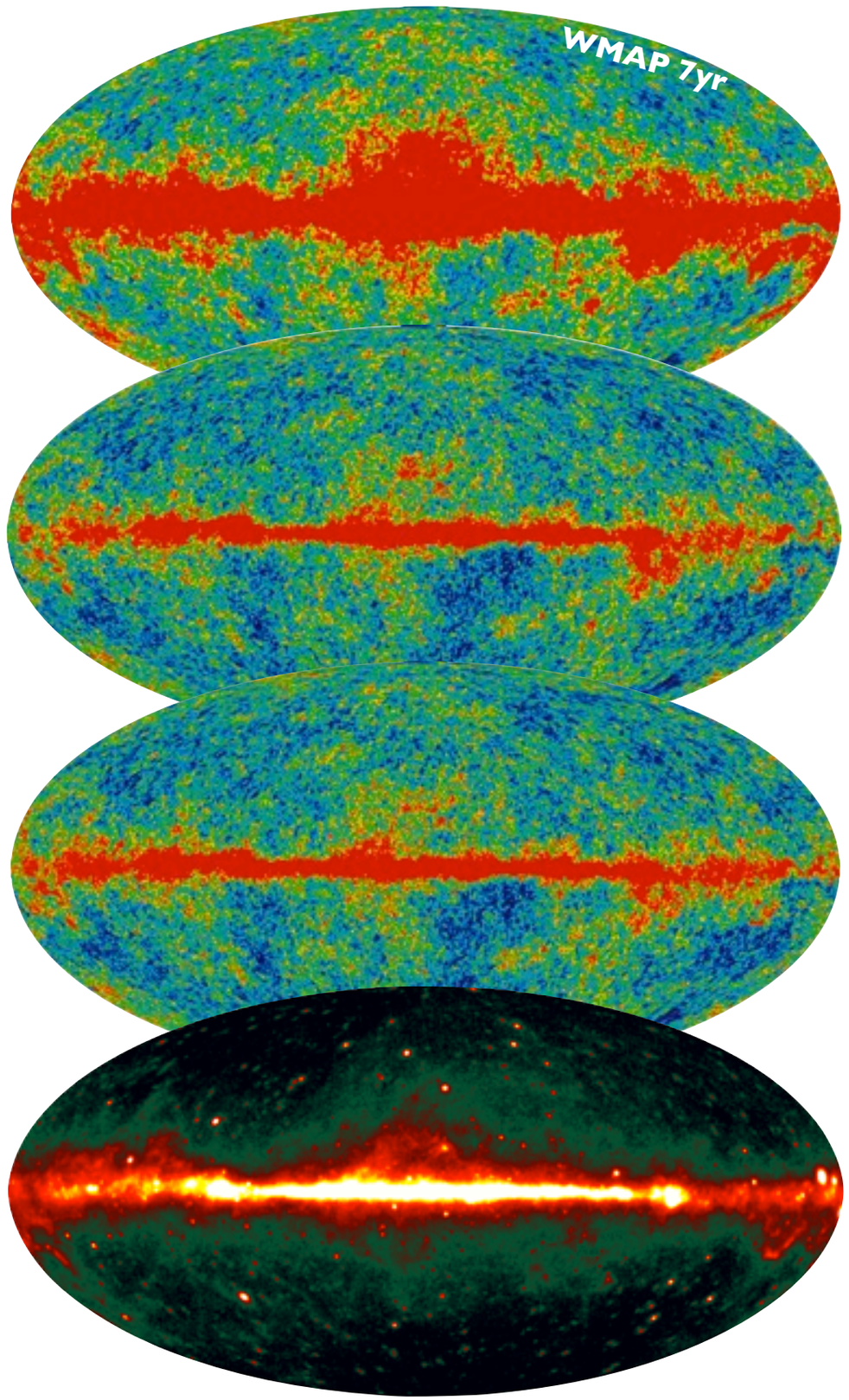
(AIM Paris Saclay)

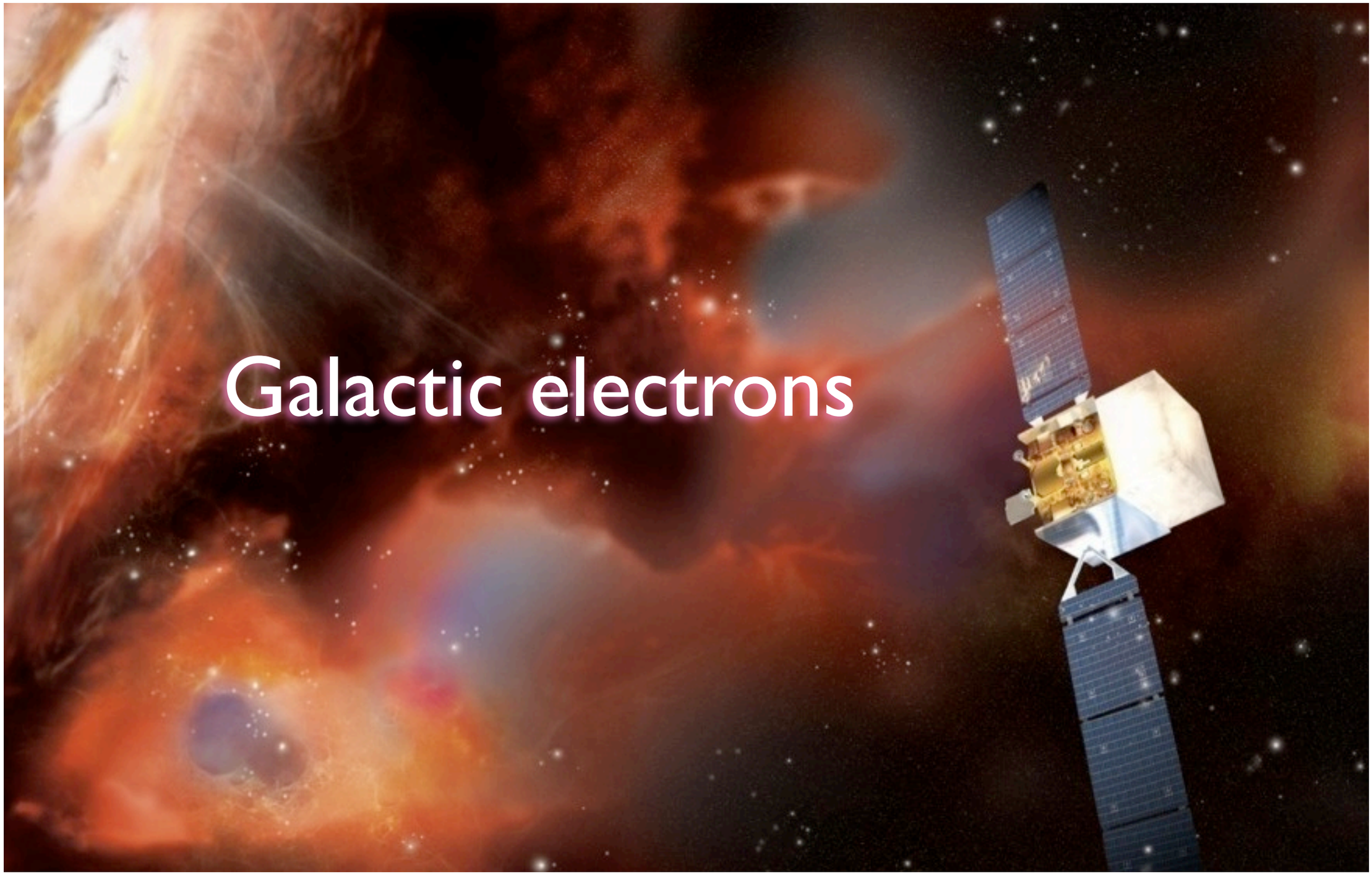
the sky seen by Fermi (> 400 MeV)



answers: Fermi & Planck

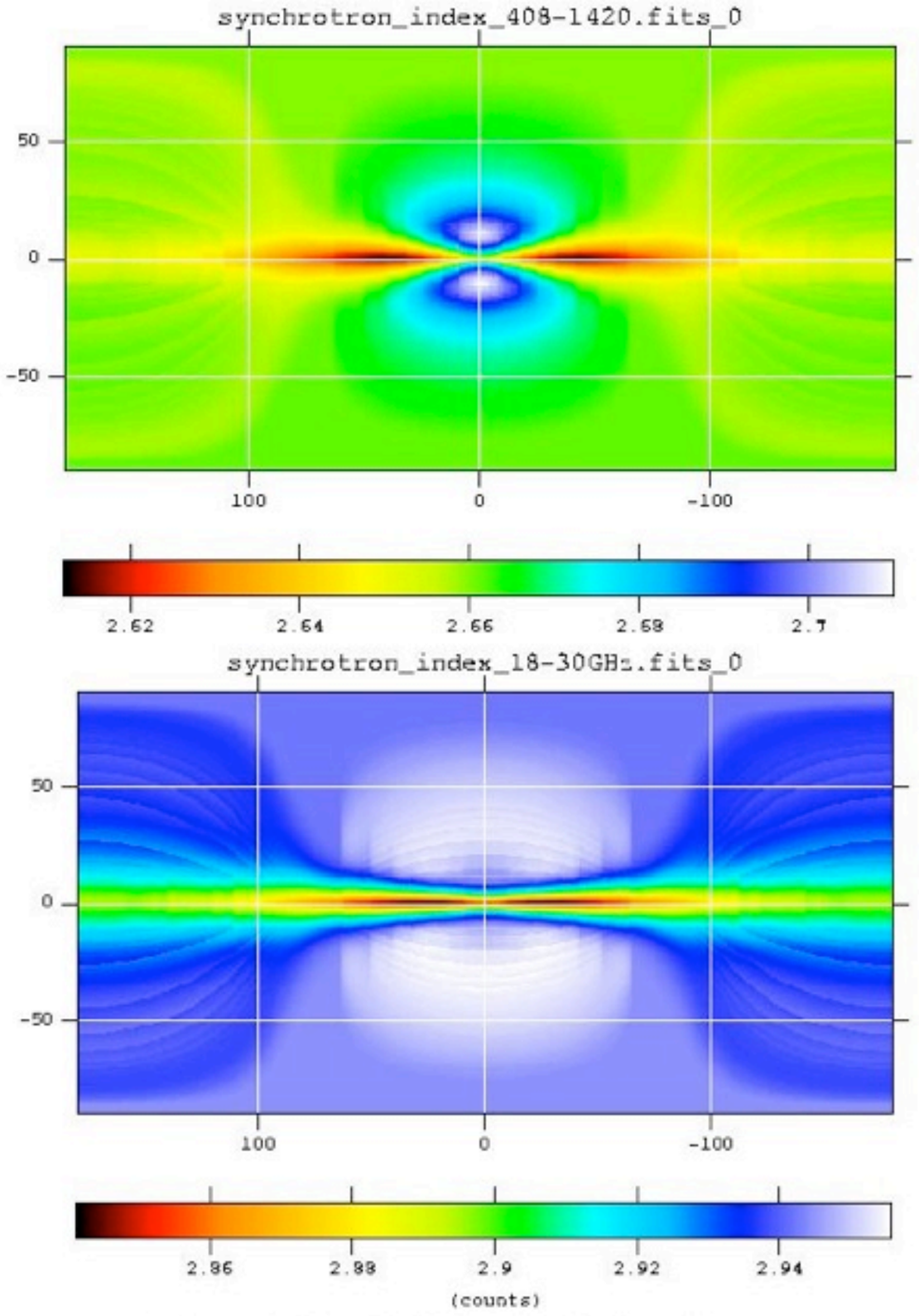
- Fermi
  - 30 MeV - 100 GeV
  - 3° → 9’ resolution
- Planck
  - 0.1 - 3.6 meV
  - 33’ → 5’ resolution
- HI + H2 + H+ + Hdark distribution
  - dust emission
  - π0 and brem. emission
  - ⇒ ISM mass census
- electron distribution
  - synchrotron radiation
  - IC and brem. emission
  - ⇒ halo size, old loops, local ISRF, B fields...




Galactic electrons

expected spectral variations

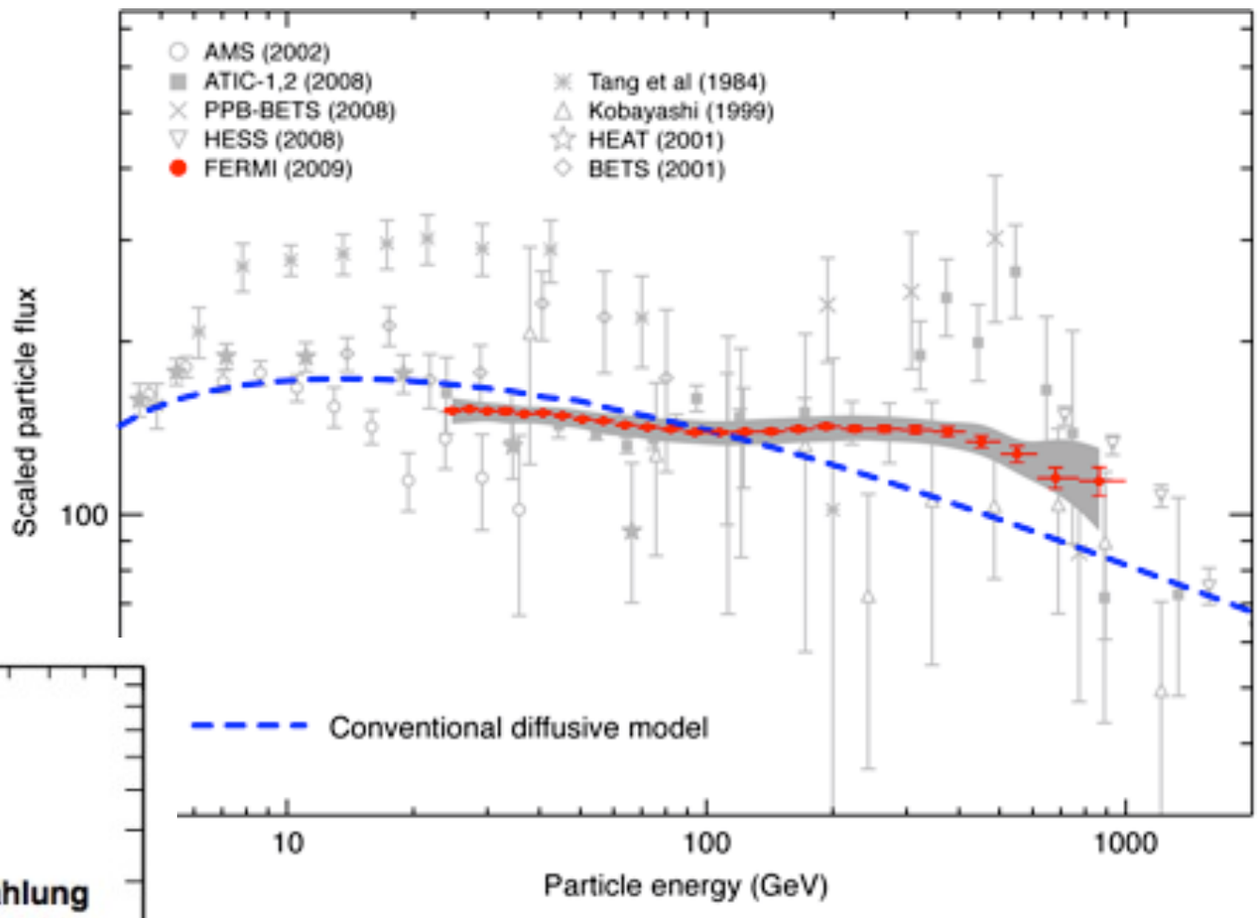
- Fermi
  - $0.1 < E_e < 100$ GeV: brem emission in gas (mostly < 0.3 GeV)
- Planck
  - $1 < E_e < 10$ GeV: synchrotron emission in B
- Fermi
  - $E_e \sim$ few 100 GeV: IC emission in ISRF
  - $E_e < 3$ TeV: direct calorimeter measurement
- Galprop modelling in plane & halo



Fermi news: harder local spectrum

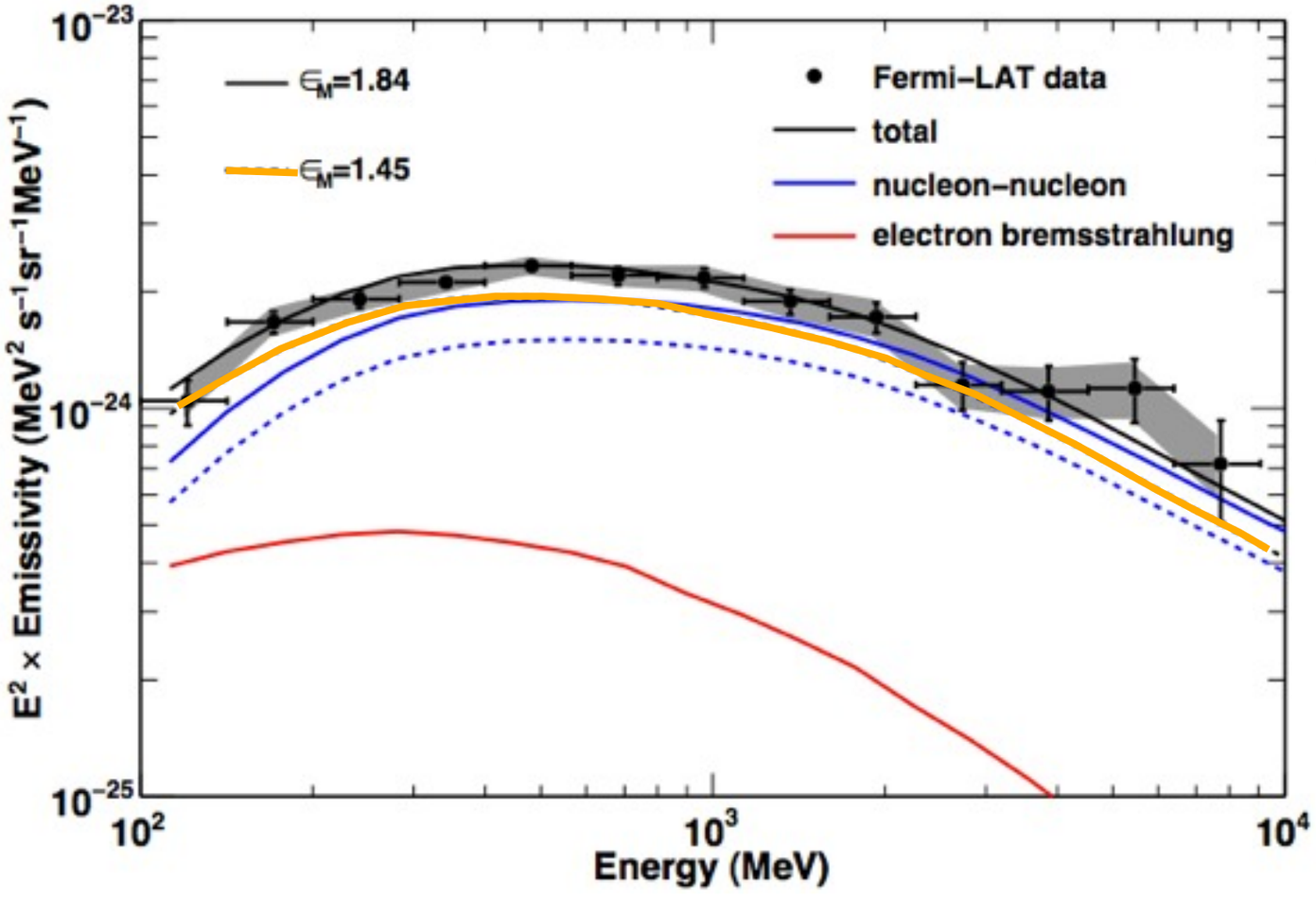
- E_e < TeV: at the Earth

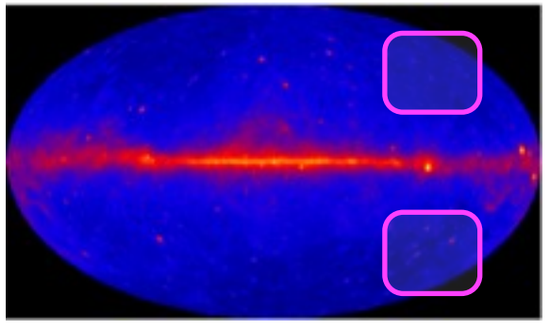
- E_e < GeV: ~ 150 pc away
  - no GeV excess, Earth-like spectrum



Abdo et al. '09, PRL, 102, 181101

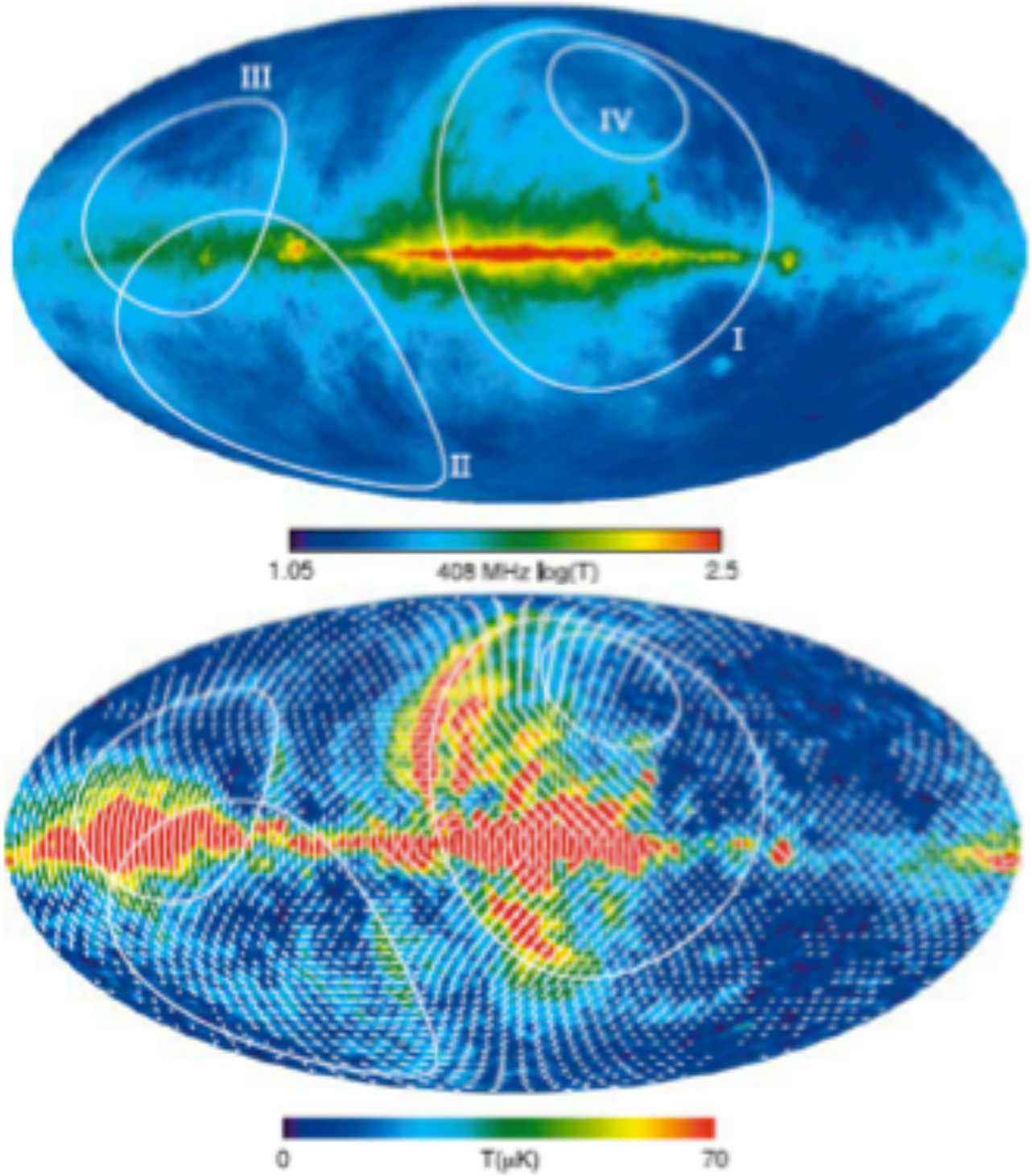
Abdo *et al.*, ApJ 703, 1249 (2009)





old loops: hollow or filled ?

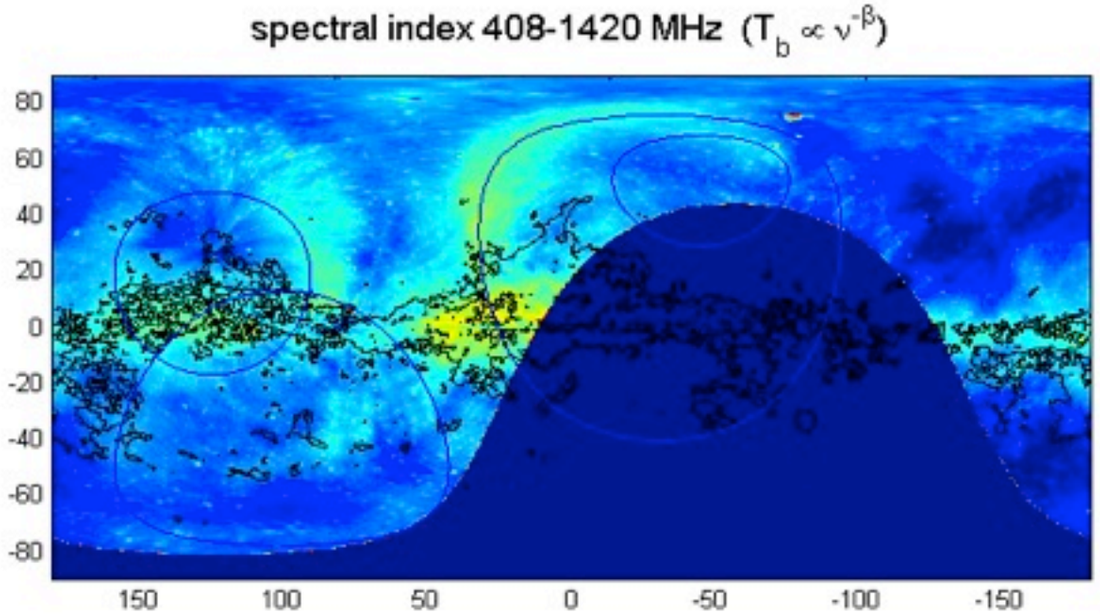
- 408 MHz

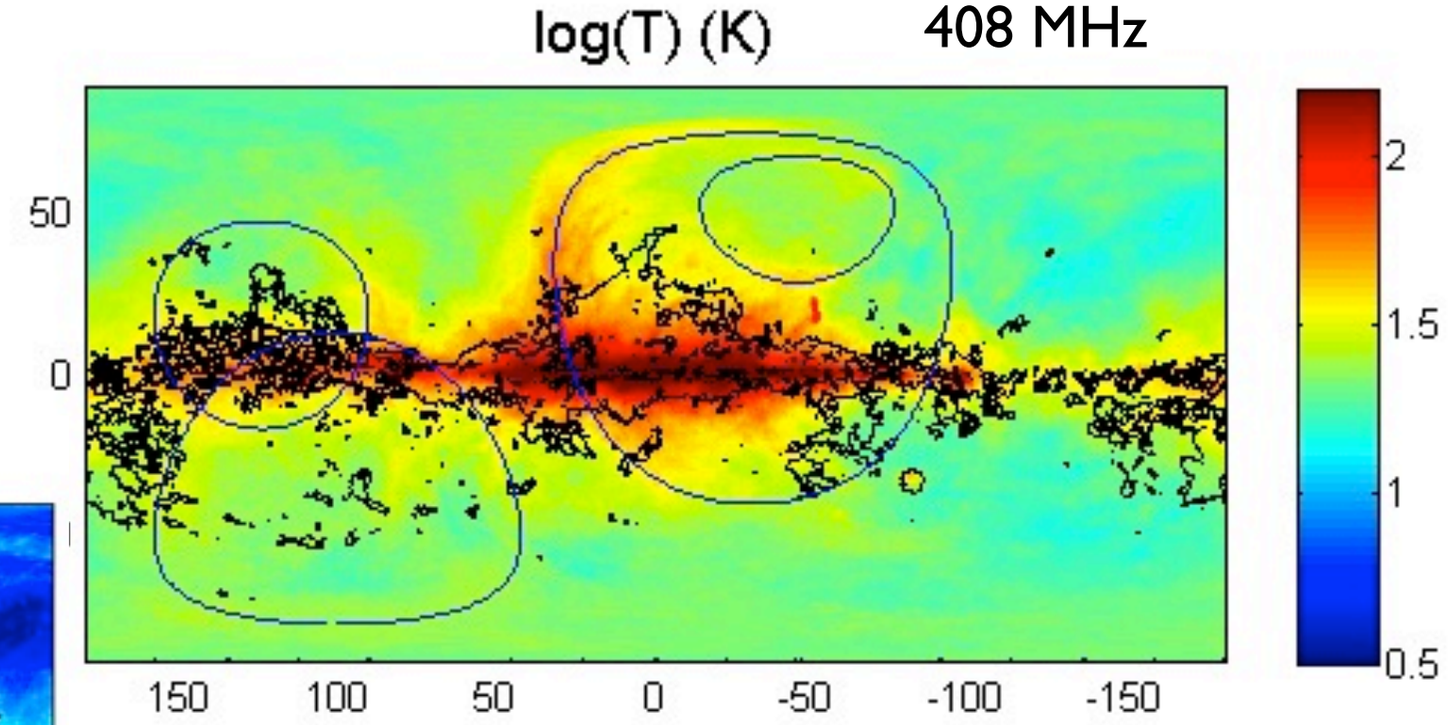


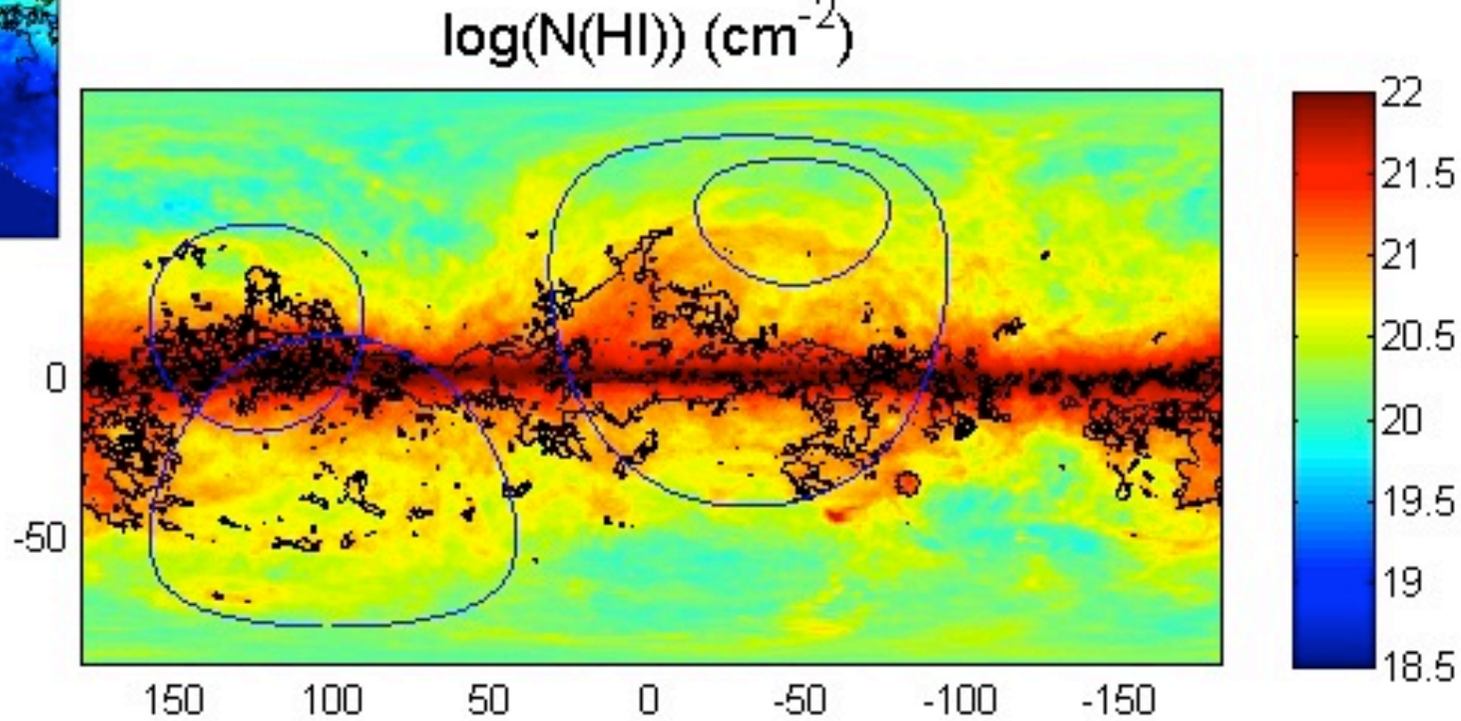
- WMAP K band

local loops

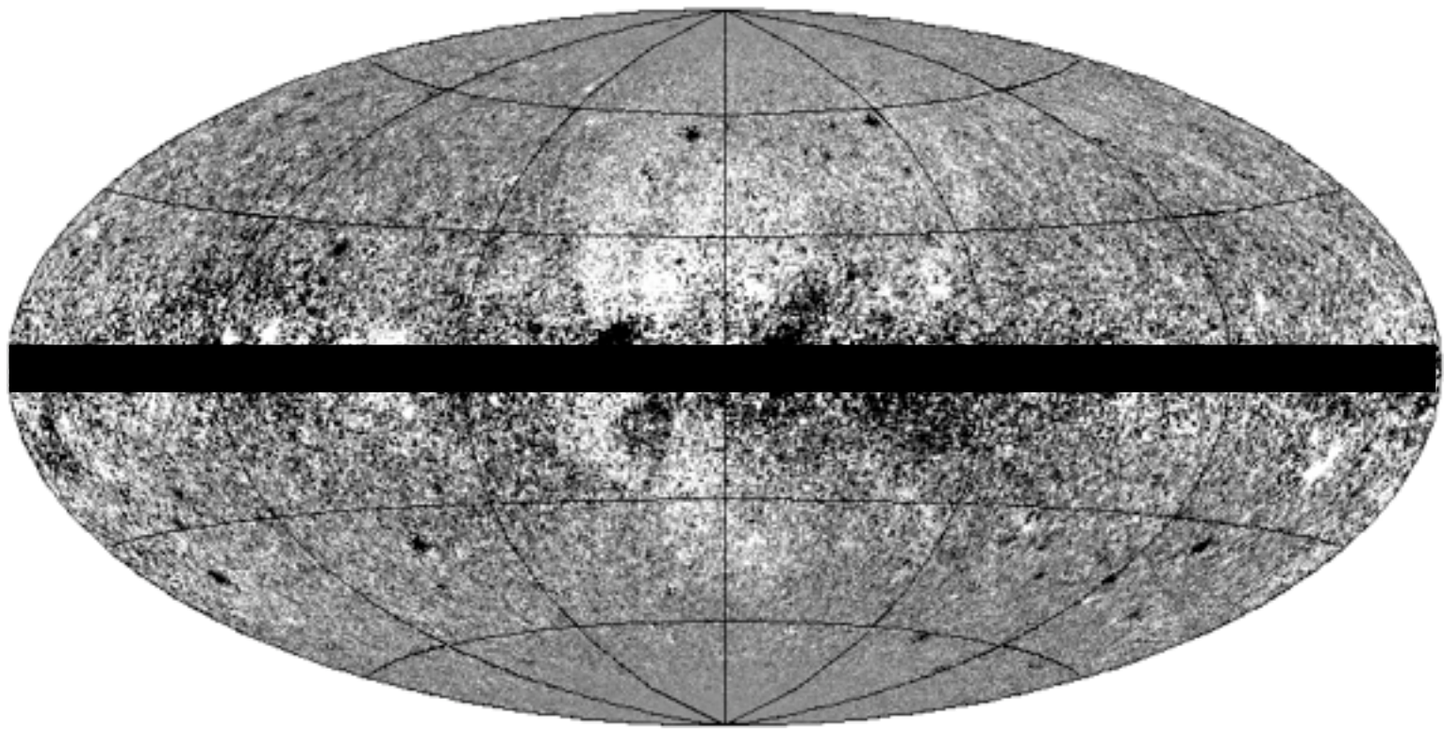
- how to trace them?
  morphology changes with ν
- N(HI) front ≠ radio front
  ⇒ brem ≠ synchrotron ≠ IC ...



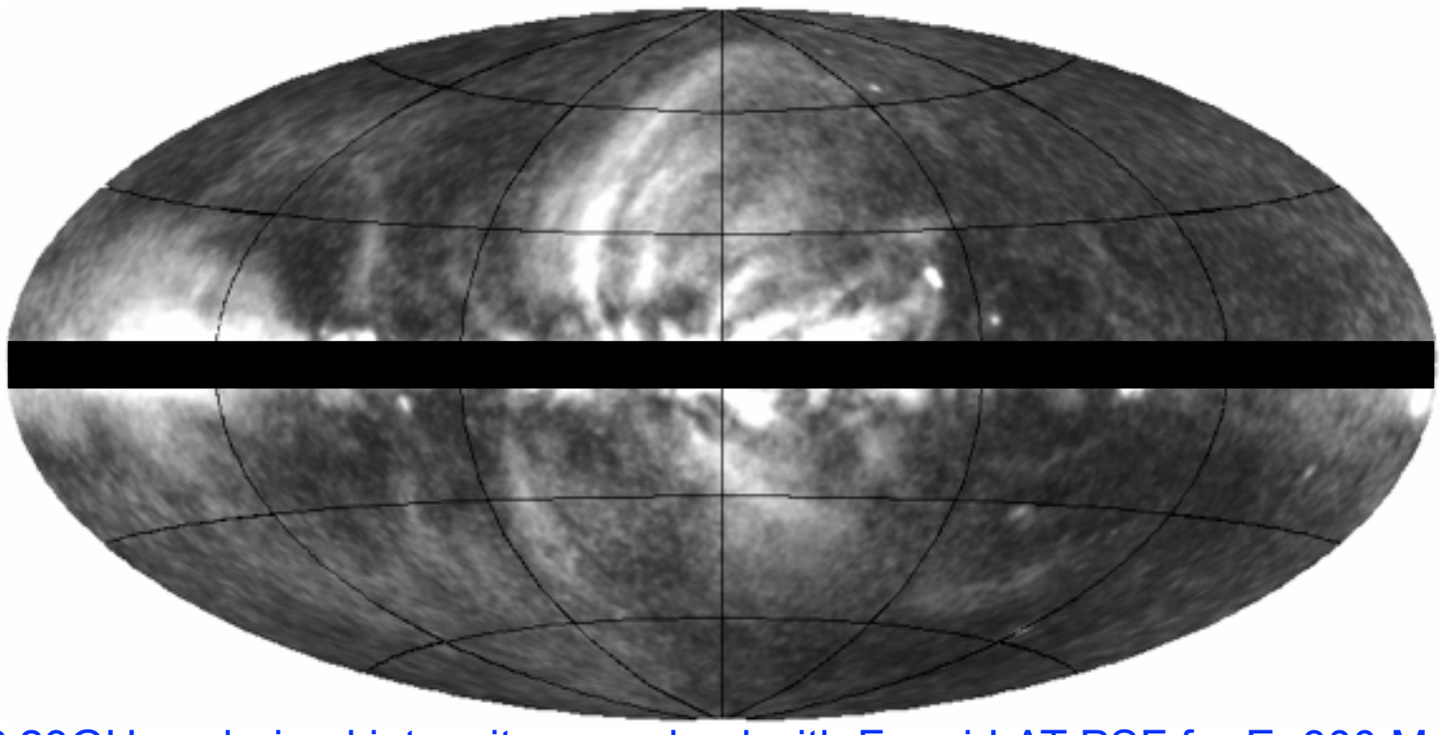




no haze, but loop I + “bubbles”



Residual map (data-model) for photons with E>300 MeV



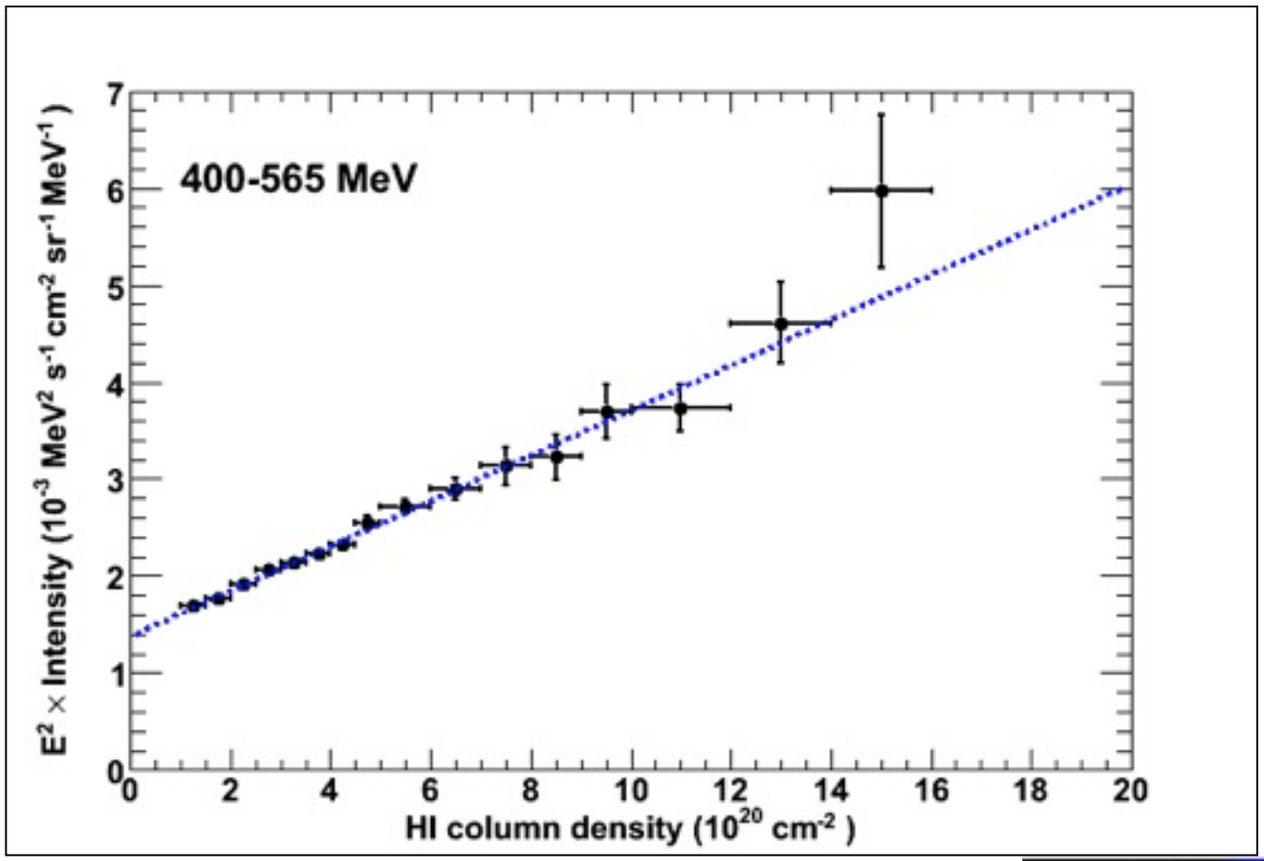
WMAP 23GHz polarized intensity convolved with Fermi-LAT PSF for E>300 MeV

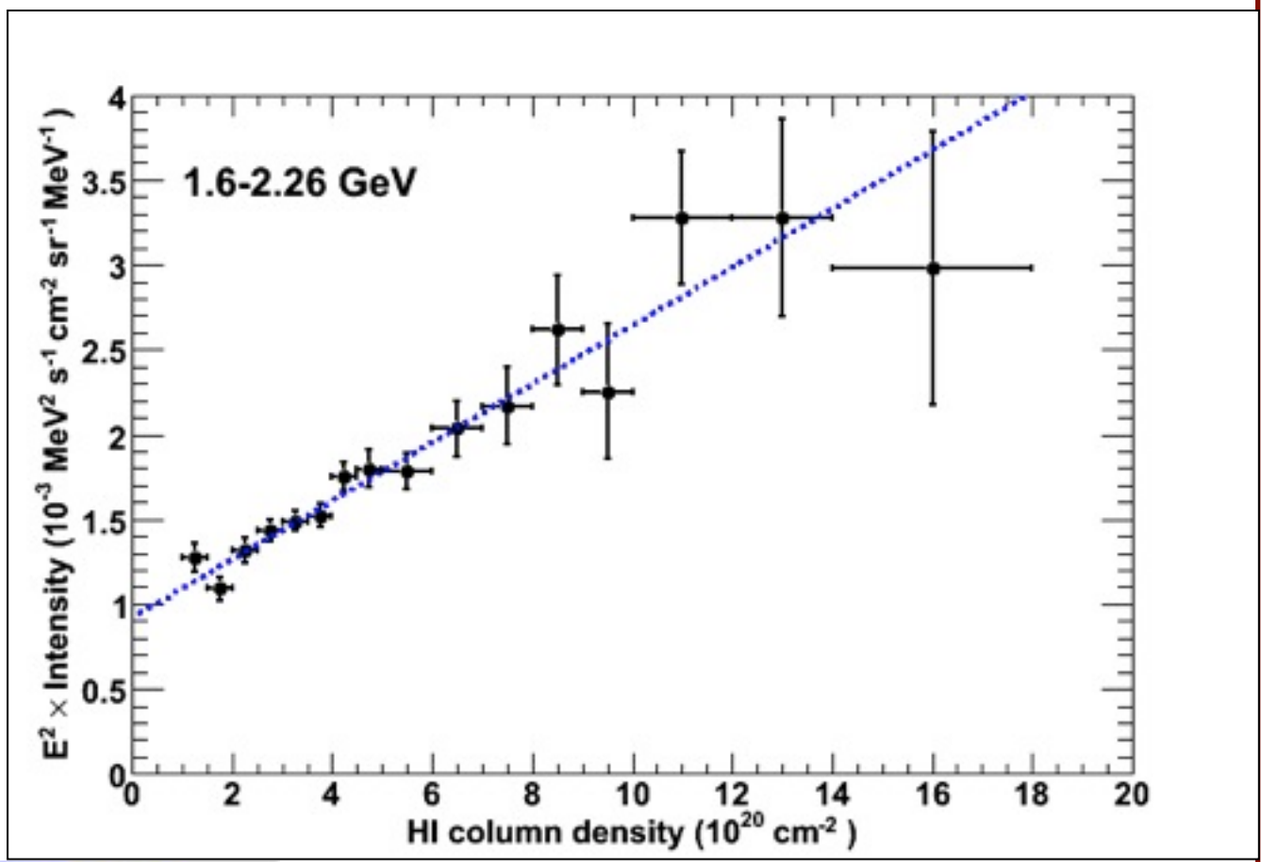
arXiv:0912.3478

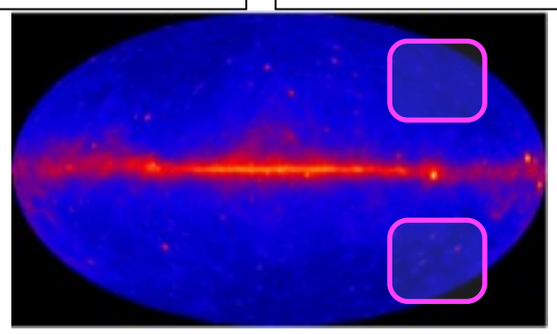

Galactic nucleons

local HI emissivity

- proportional to N(HI) where no CO



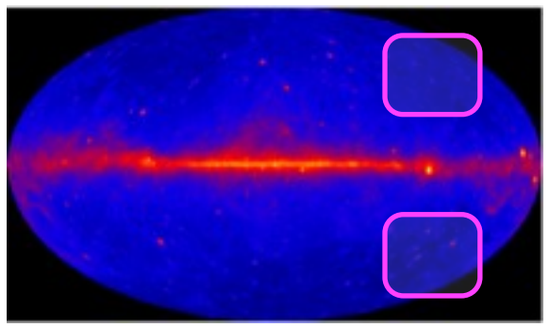




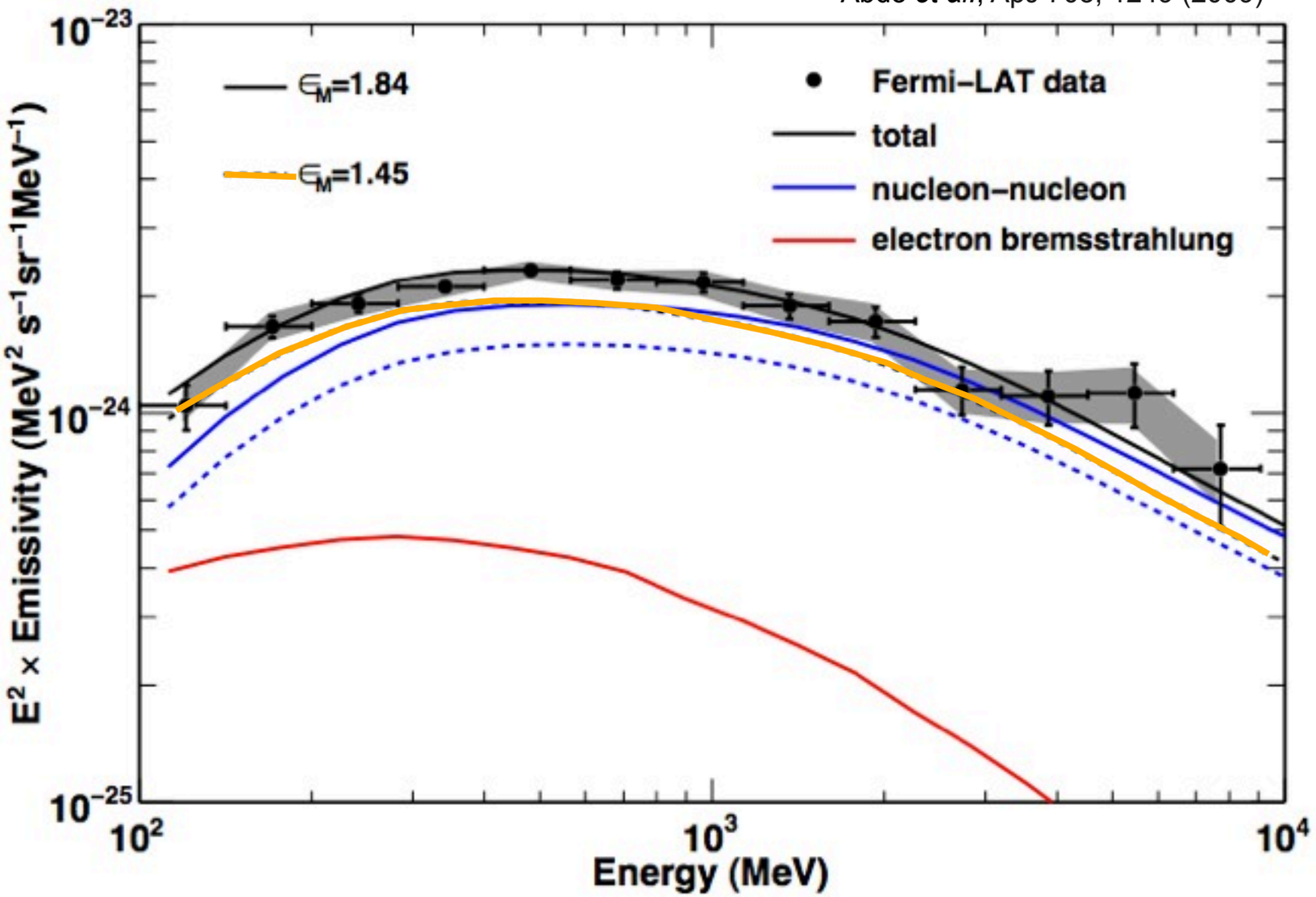
Abdo *et al.*, ApJ 703, 1249 (2009)

local HI emissivity

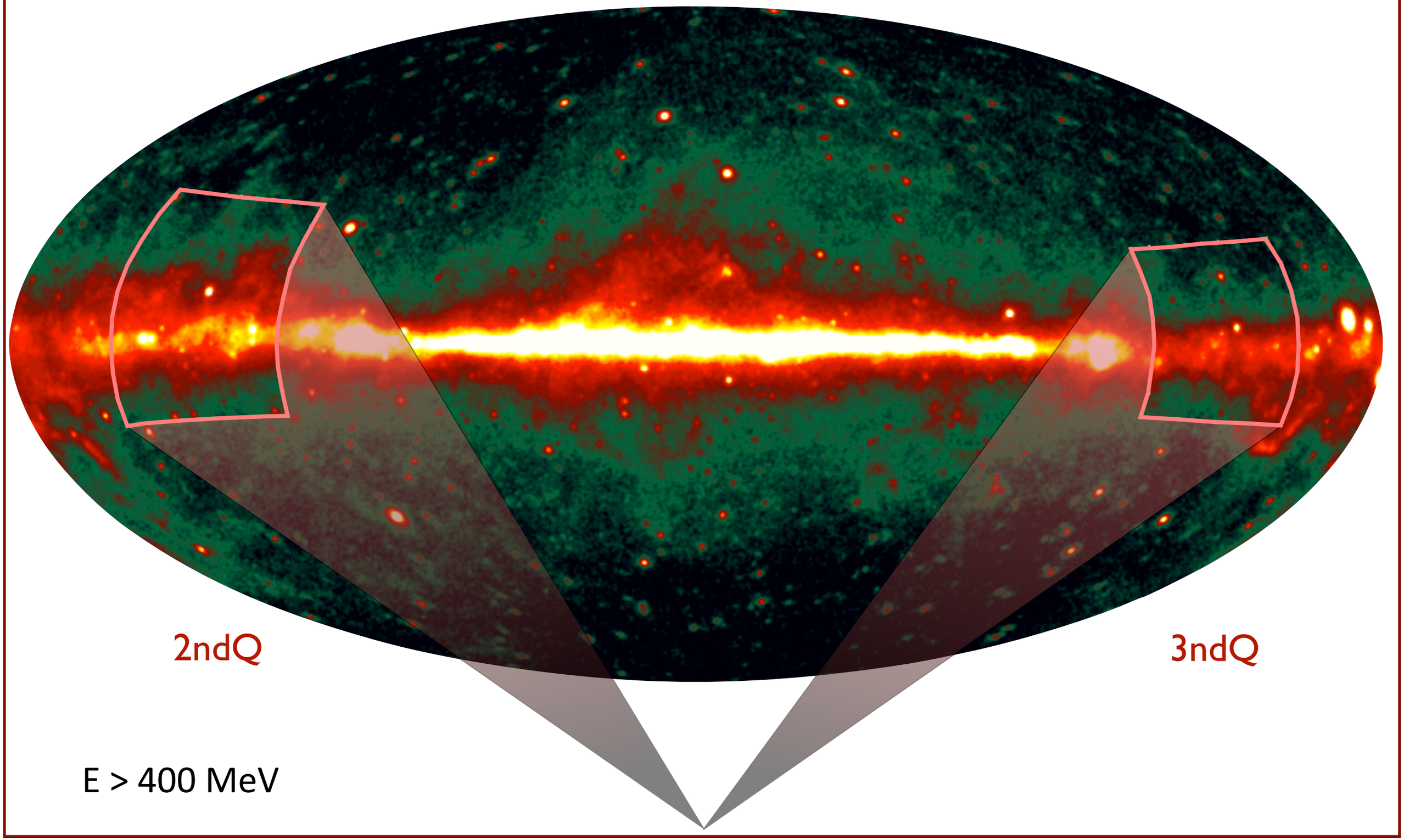
- ≤ 1 kpc and in Cep+Cas local clouds: consistent with CR spectra at Earth
- larger nuclear enhancement factor for p-Z and Z-p → π^0 interactions



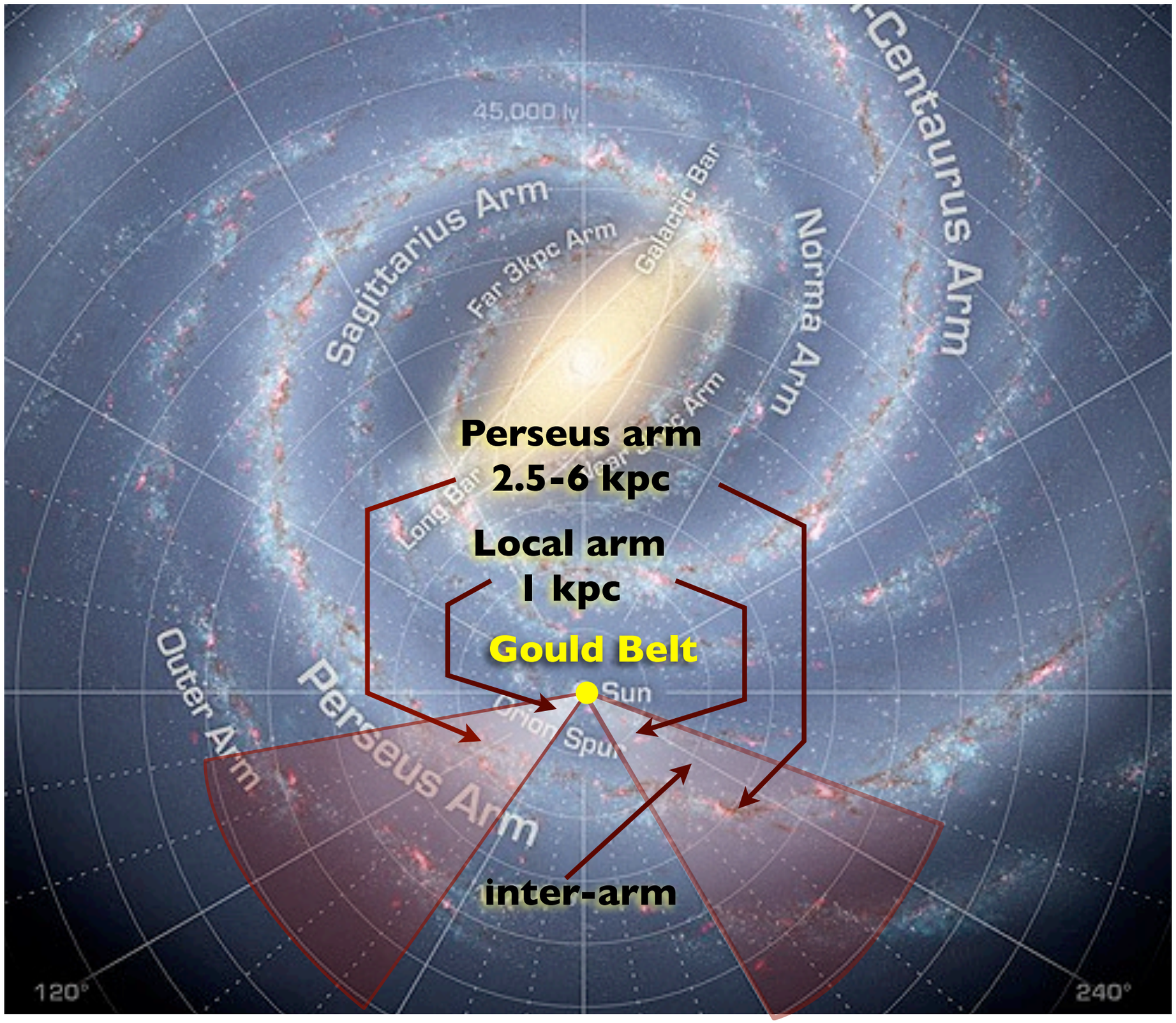
Abdo *et al.*, ApJ 703, 1249 (2009)



trip to the outer Galaxy

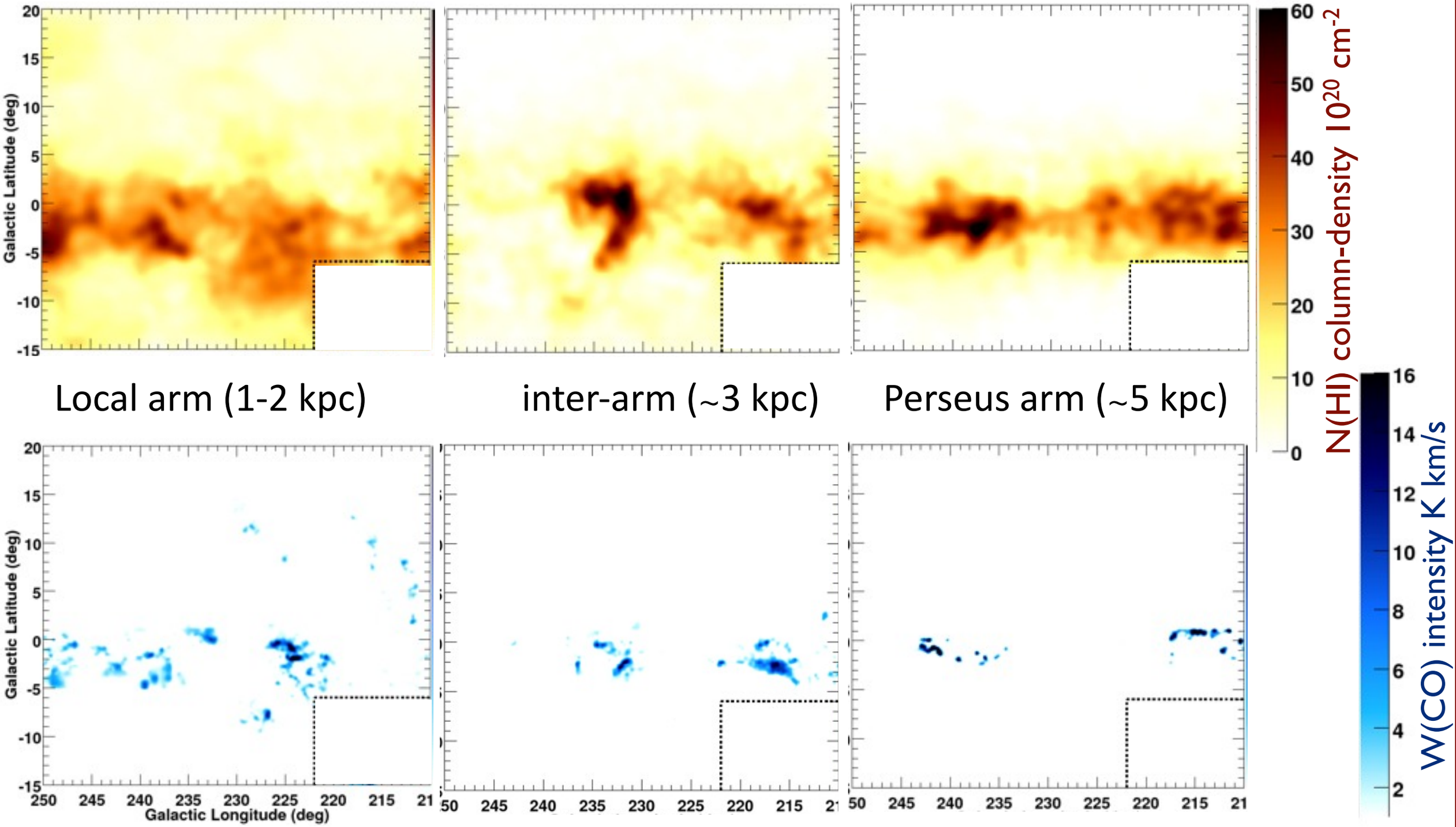


probing the outer Galaxy



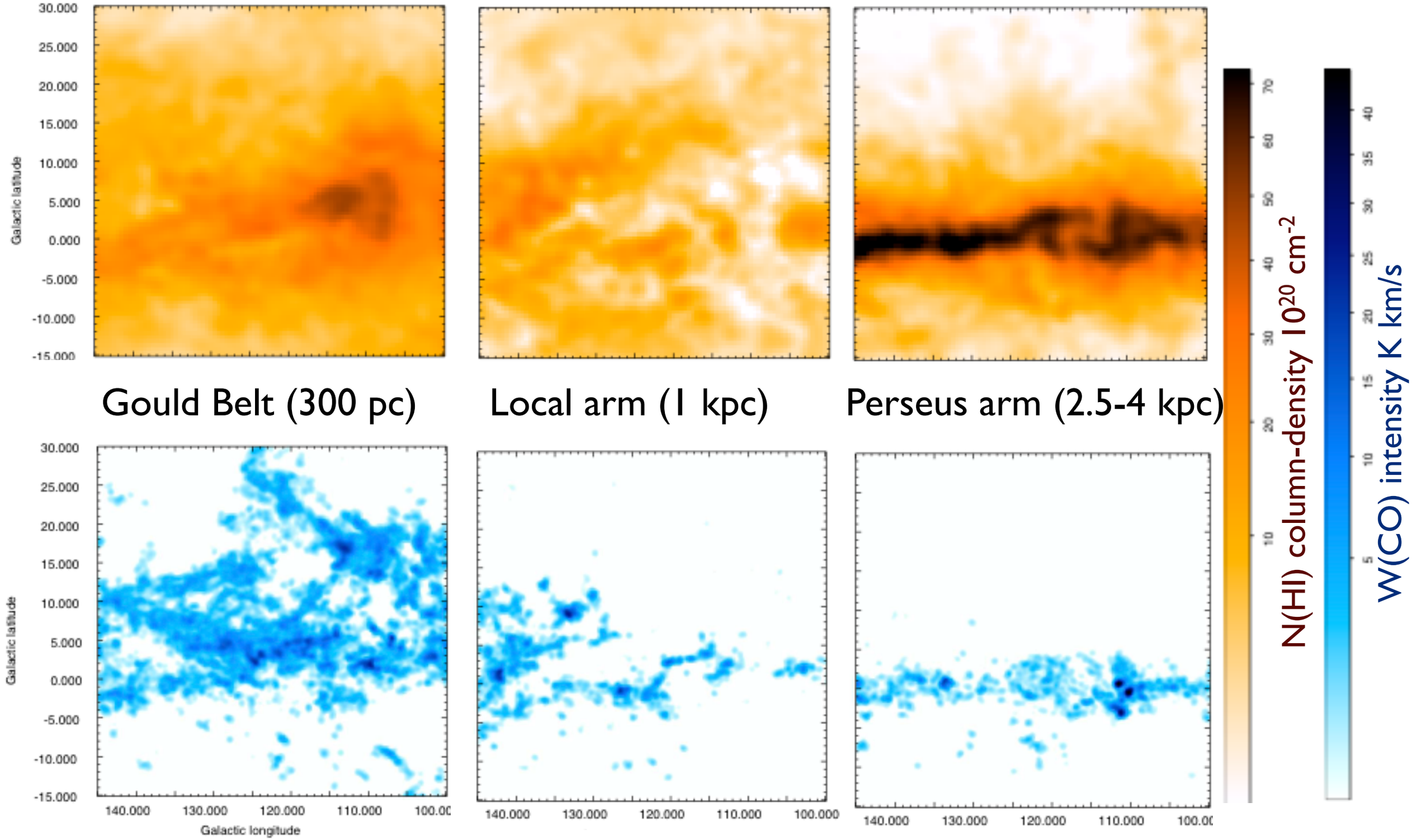
cloud complexes in the 3rd quadrant

- careful kinematical separation of the clouds along the lines of sight (HI and CO line fitting + spill-over correction between regions)



cloud complexes in the 2nd quadrant

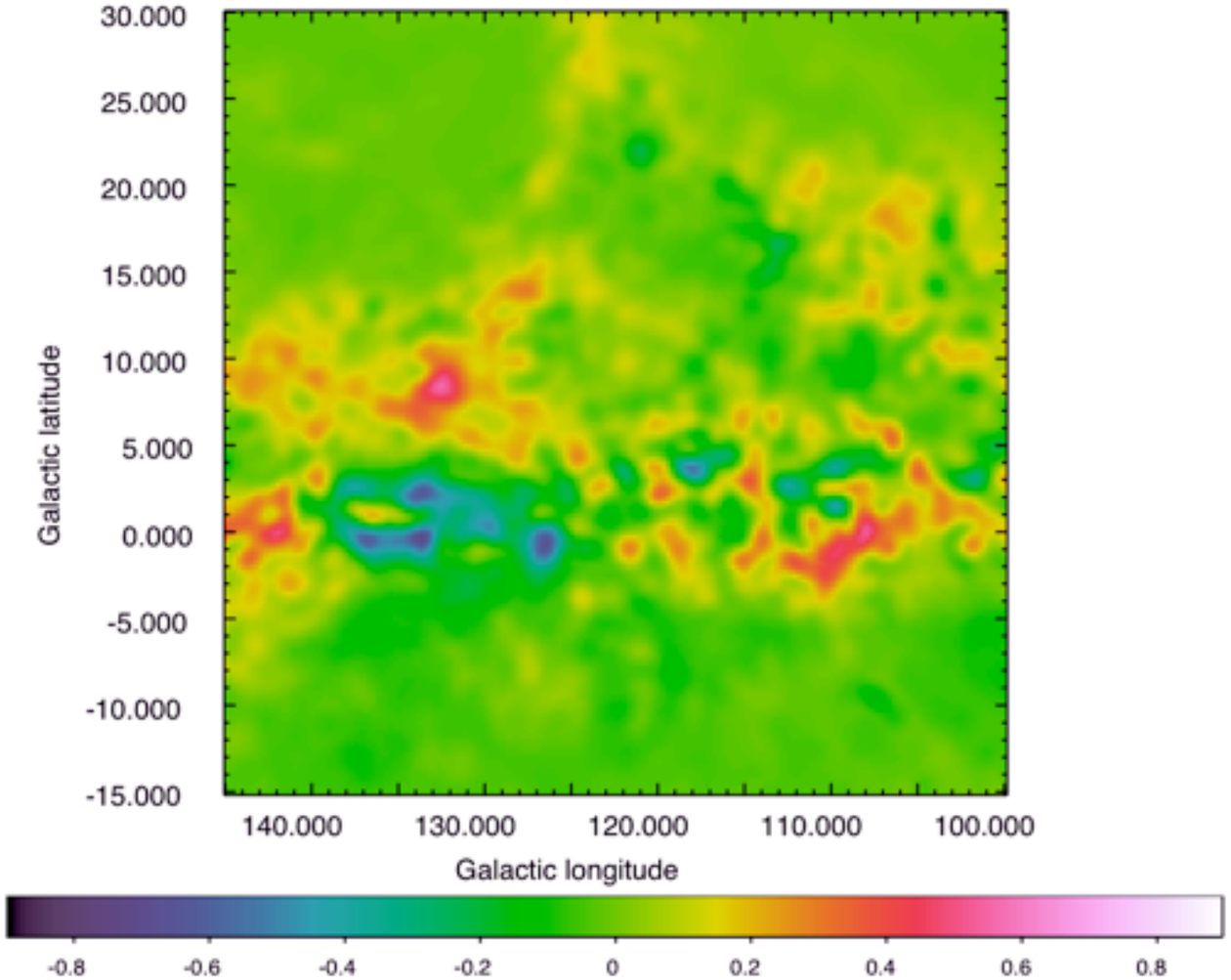
Abdo *et al.*, '10, ApJ 710, 133



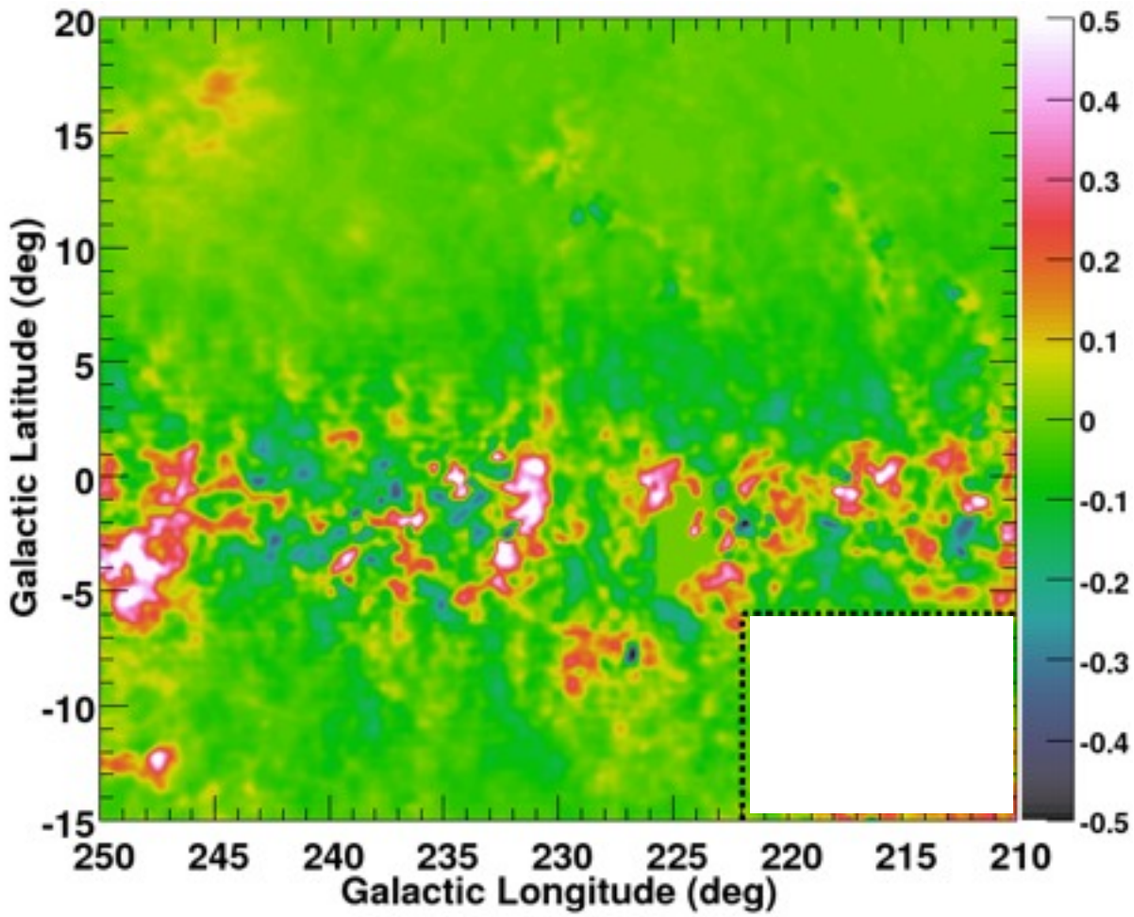
dark molecular gas

- adding in the analysis a dust reddening template (Schlegel et al. ’98) to account for the nearby dark, presumably H_2, gas

Abdo *et al.*, ’10, ApJ 710, 133

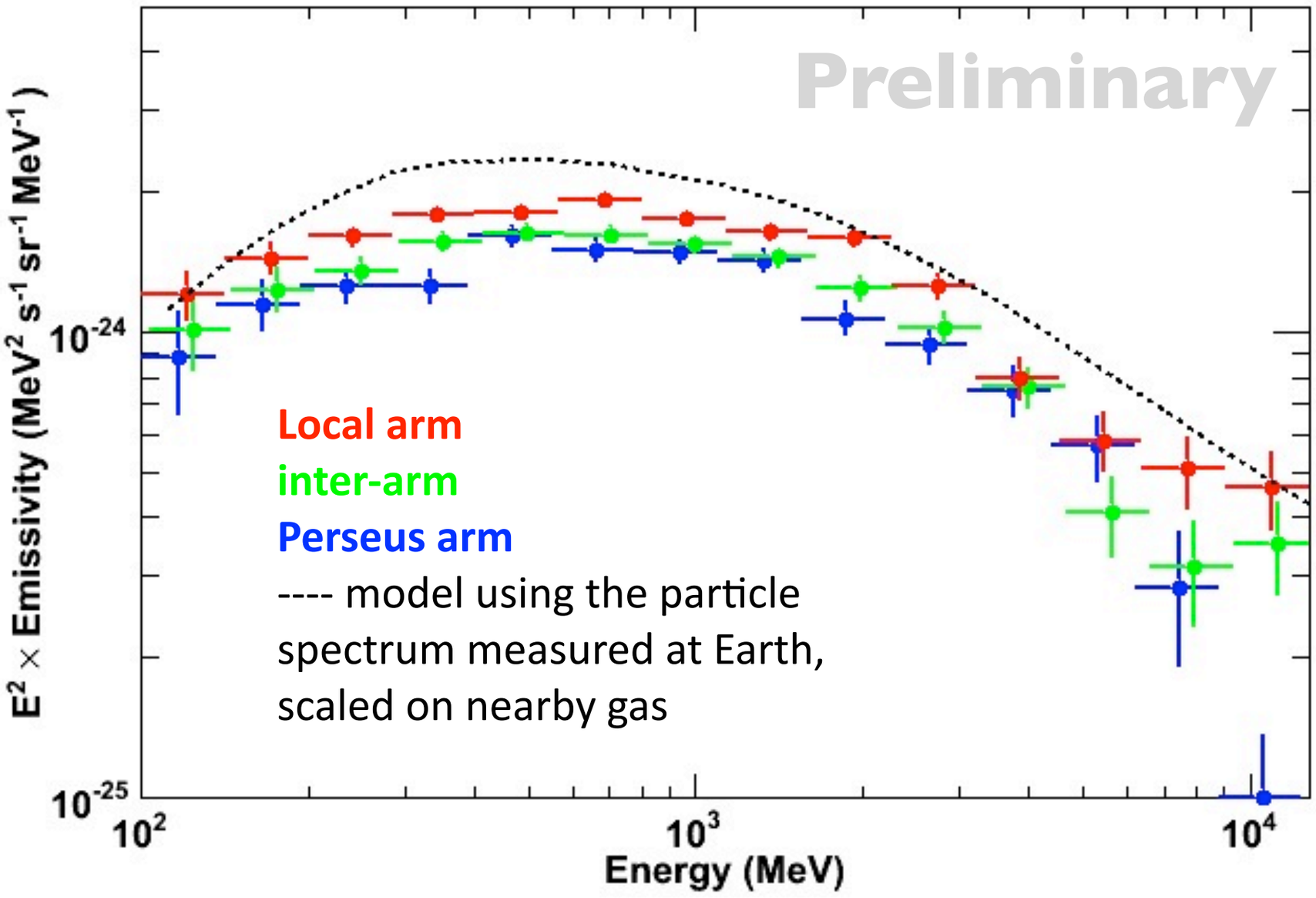


in preparation



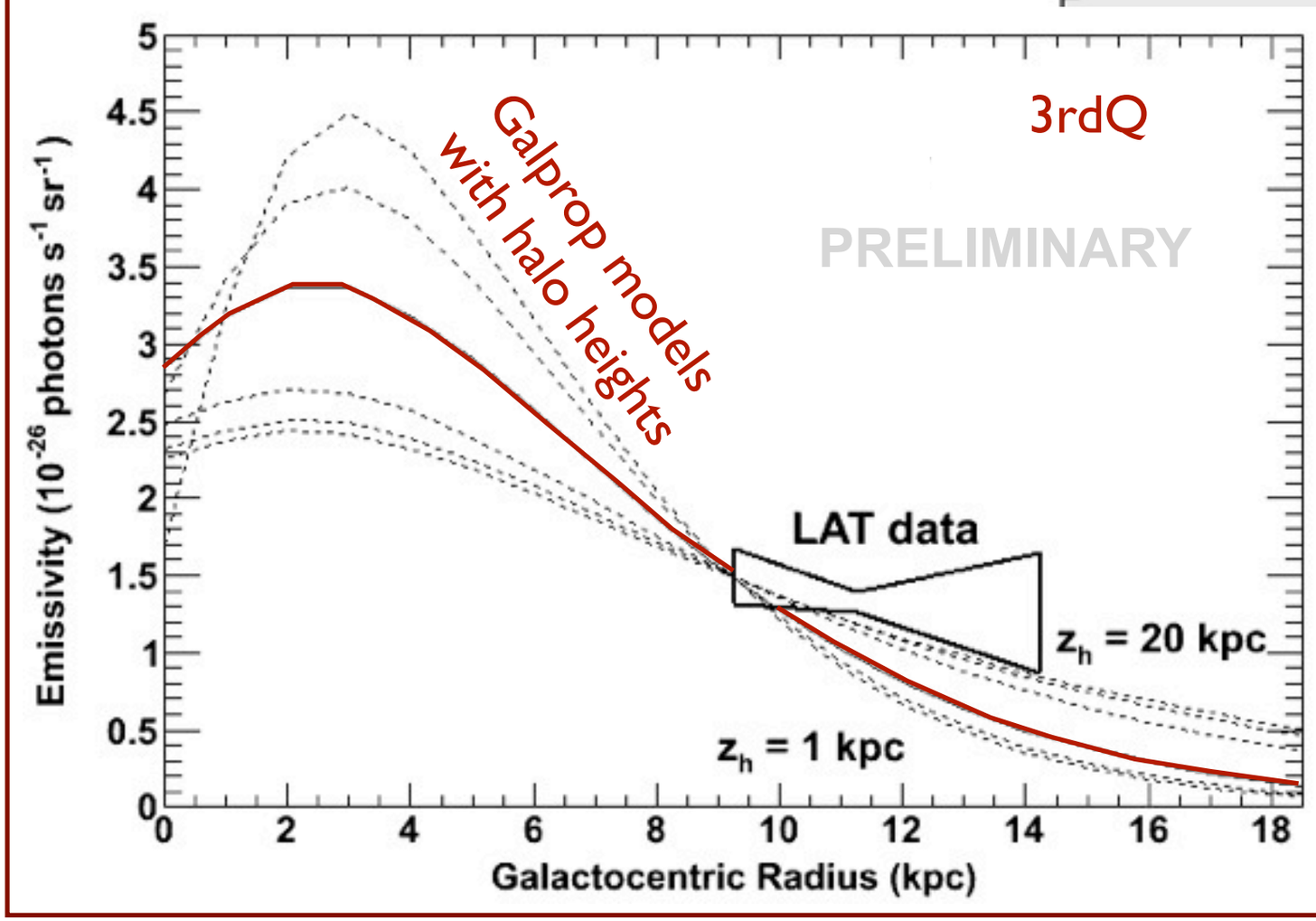
cosmic-ray spectra

- no change in emissivity spectra per H atom up to the Perseus arm
  ⇒ ~ uniform spectra of the $10^{9\text{-}11}$ GeV cosmic rays over several kpc
- little arm/interarm contrast
  ⇒ loose coupling with the kpc-scale average ISM surface density

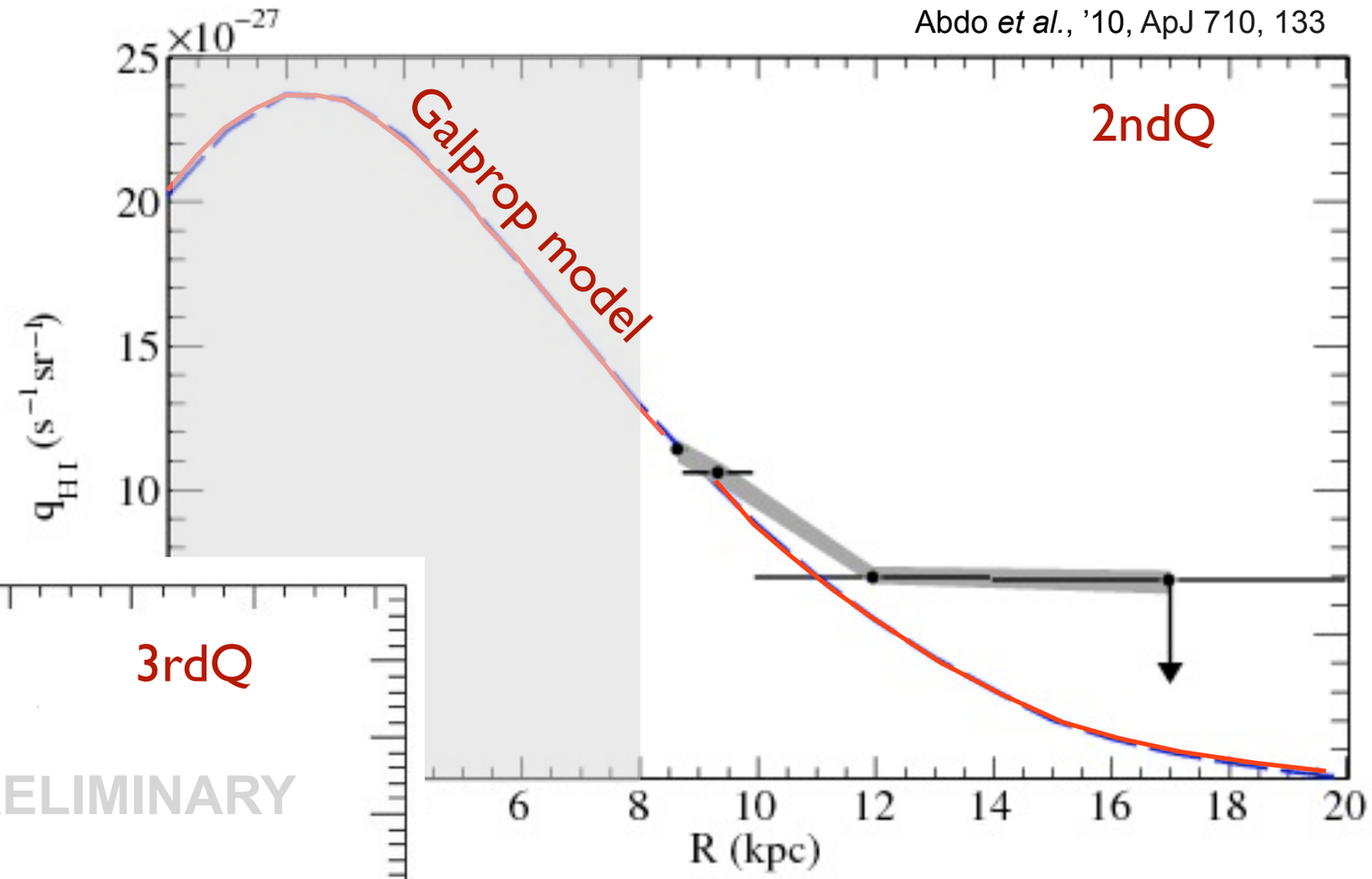


cosmic-ray density gradient

- flat emissivity gradient beyond the Solar circle
- HI bow-tie uncertainty: $100 > T_{spin}(HI) < 400$ K



Abdo *et al.*, '10, ApJ 710, 133



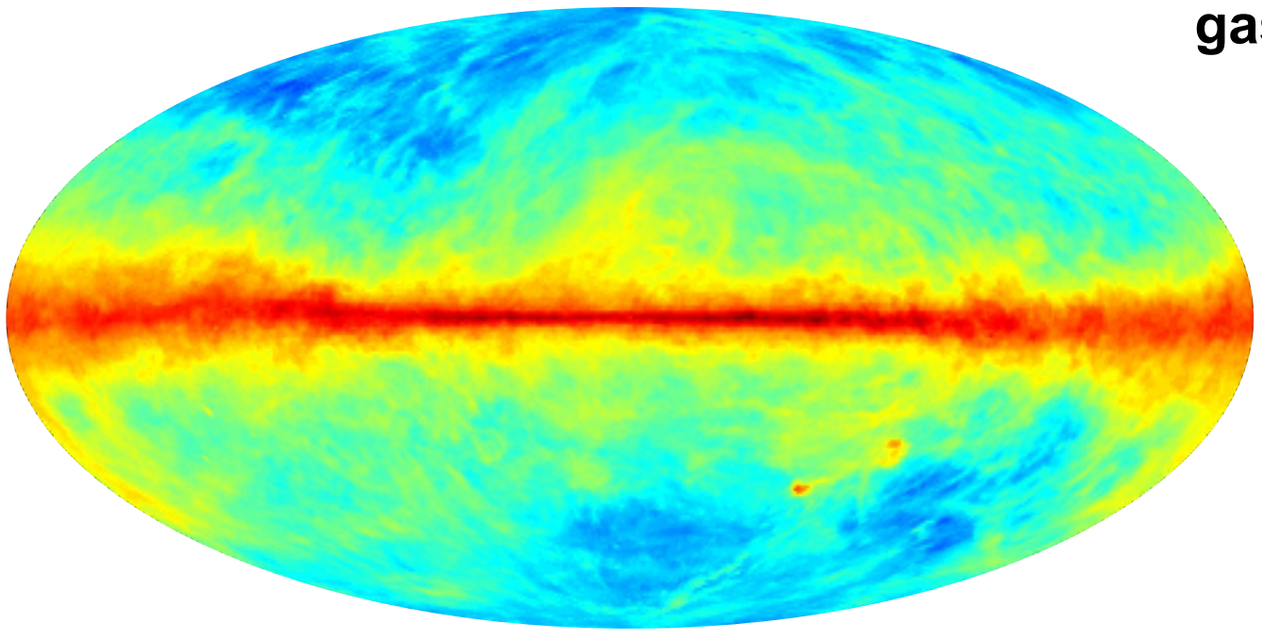
gradient flatter than expectations from CR diffusion from SNR or pulsar like source distributions, with uniform diffusion

⇒ large halo height, or flat source distribution at R > R⊙, or large amounts of missing gas


the ISM

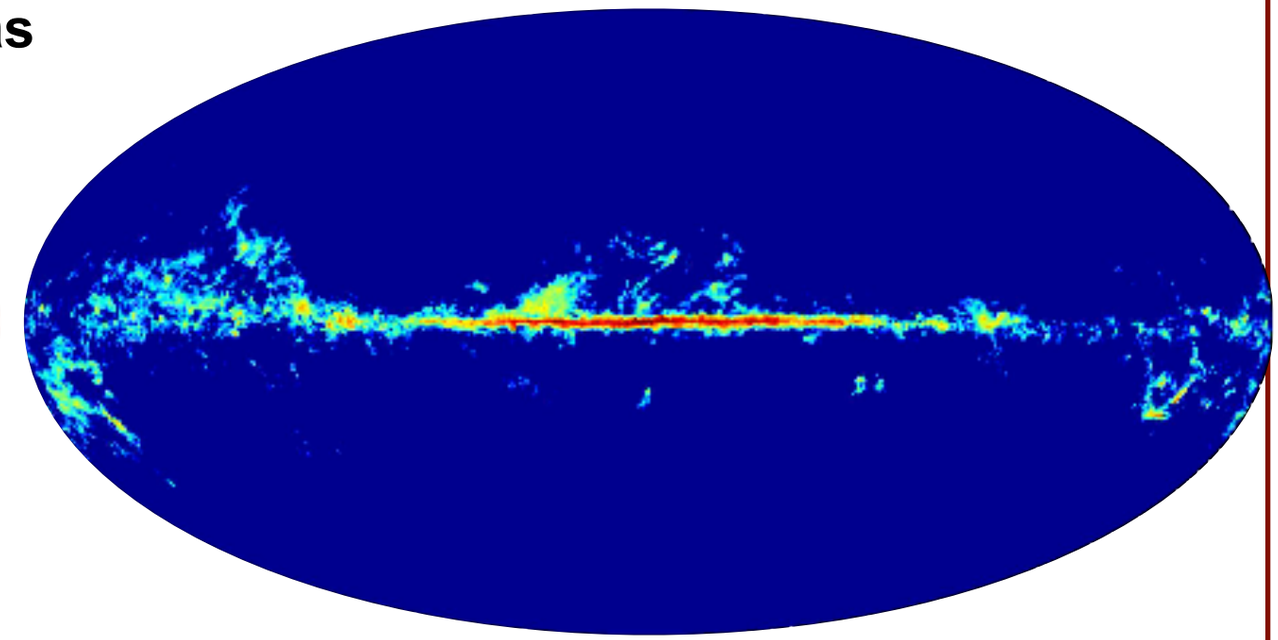
interstellar medium

HI (LAB) Kalberla '05

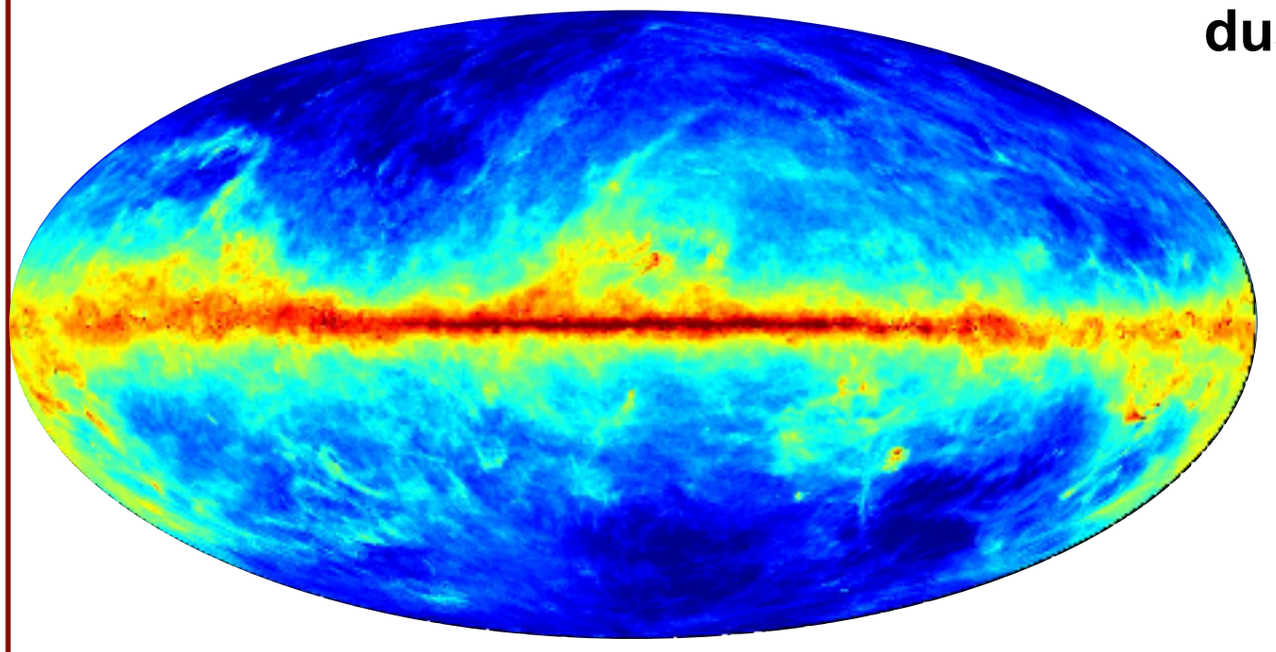


HII << gas

CO (CfA) Dame '01

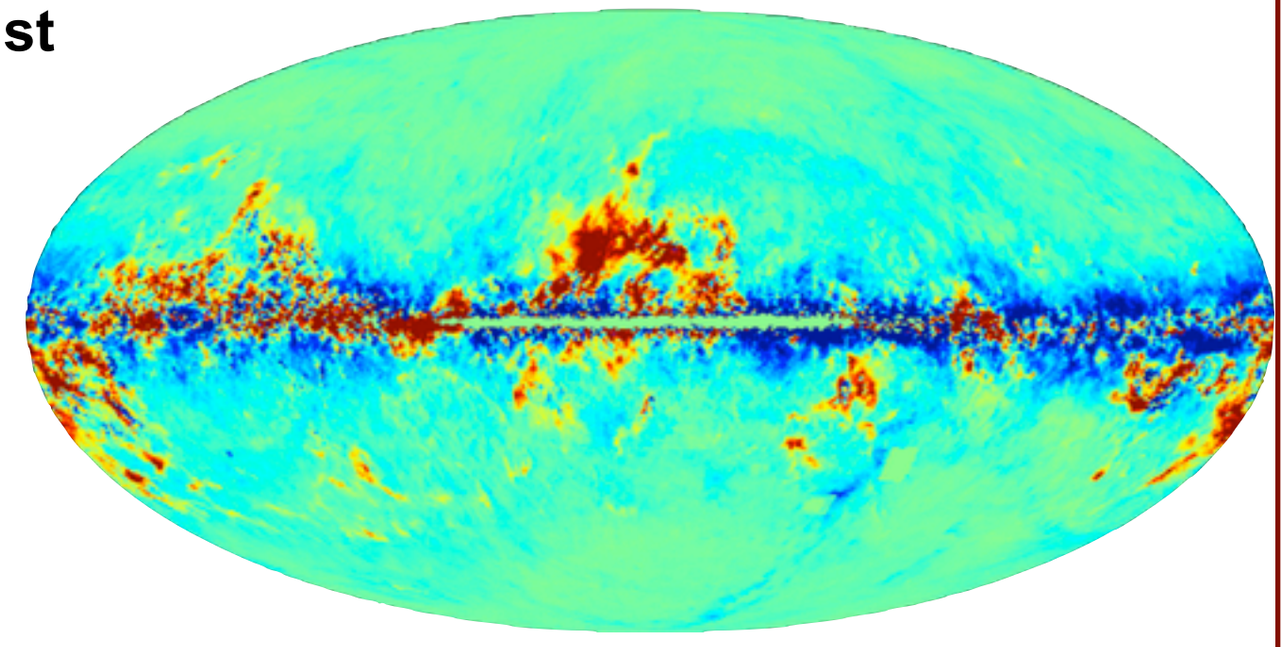


E(B-V) Schlegel '98



dust

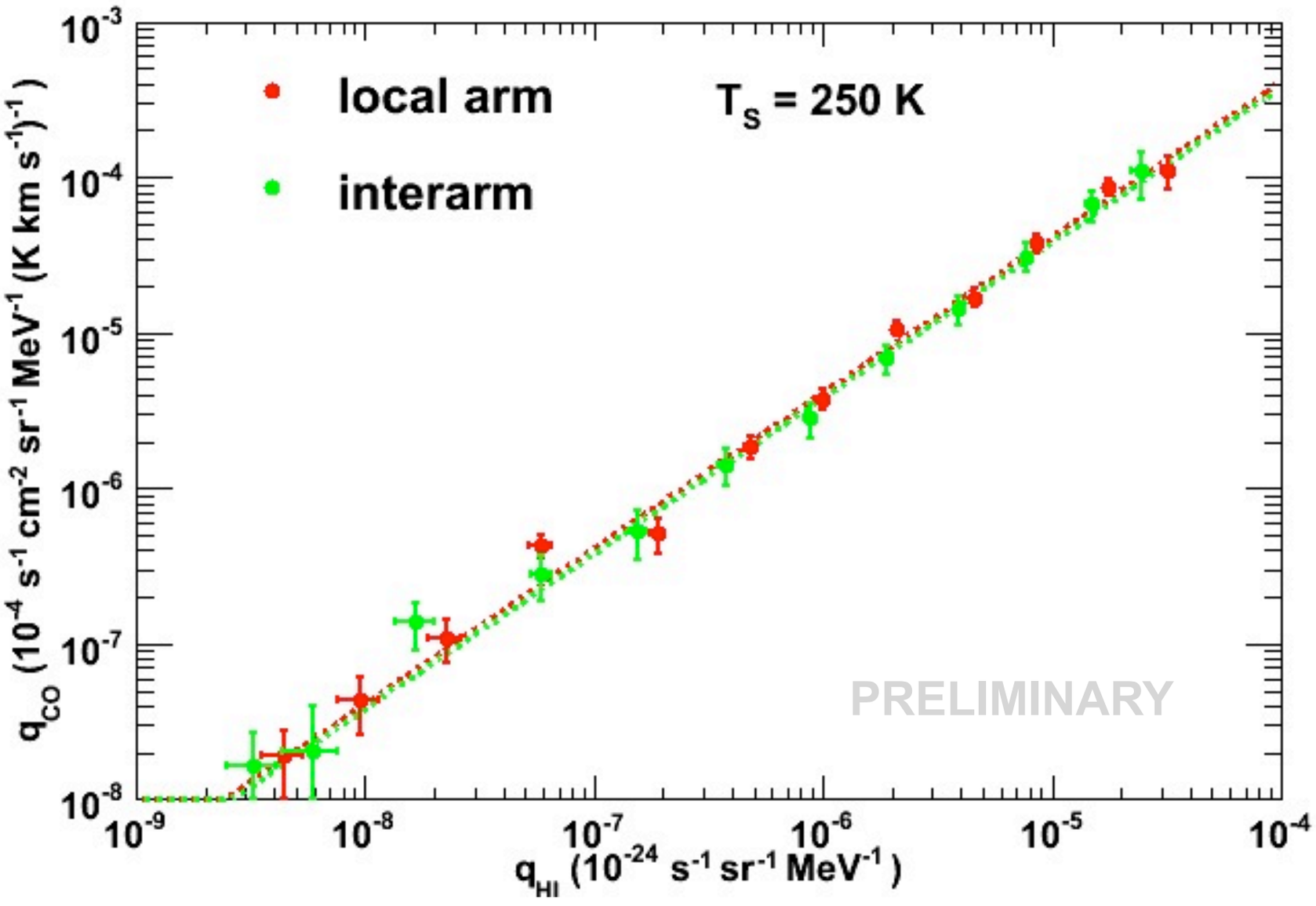
dark gas Grenier '05



IR emission → N_{dust}: temperature correction

CO-to-H_2 conversion factor

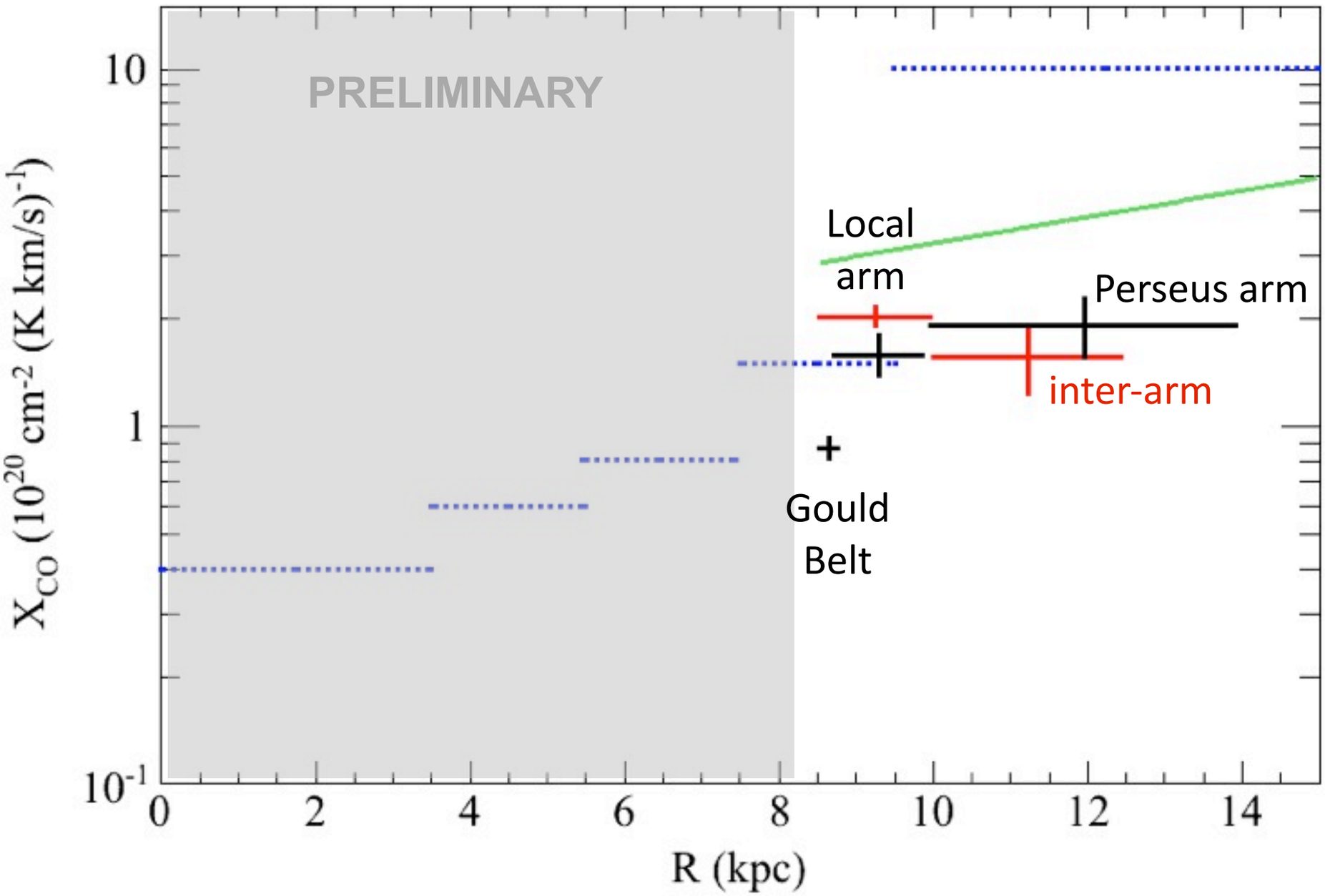
- linear relation between the HI and CO γ-ray emissivities over 12 energy bands > 200 MeV ⇒ cosmic rays penetrate rather uniformly to the dense cloud cores, with little spectral change



- the correlation yields an estimate of the $X_{CO} = q_{CO}/(2q_{HI})$ conversion factor

flat X_{CO} gradient

- kpc-average: $X_{CO} \sim 2\ 10^{20}\ H_2\ cm^{-2}\ K^{-1}\ km^{-1}\ s$ in the outer Galaxy, rather uniform
- pc-scale sampling: $X_{CO} = (0.87 \pm 0.05)\ 10^{20}$ in well-resolved Cepheus and Cassiopeia



GALPROP assumed profile Strong et al. '04

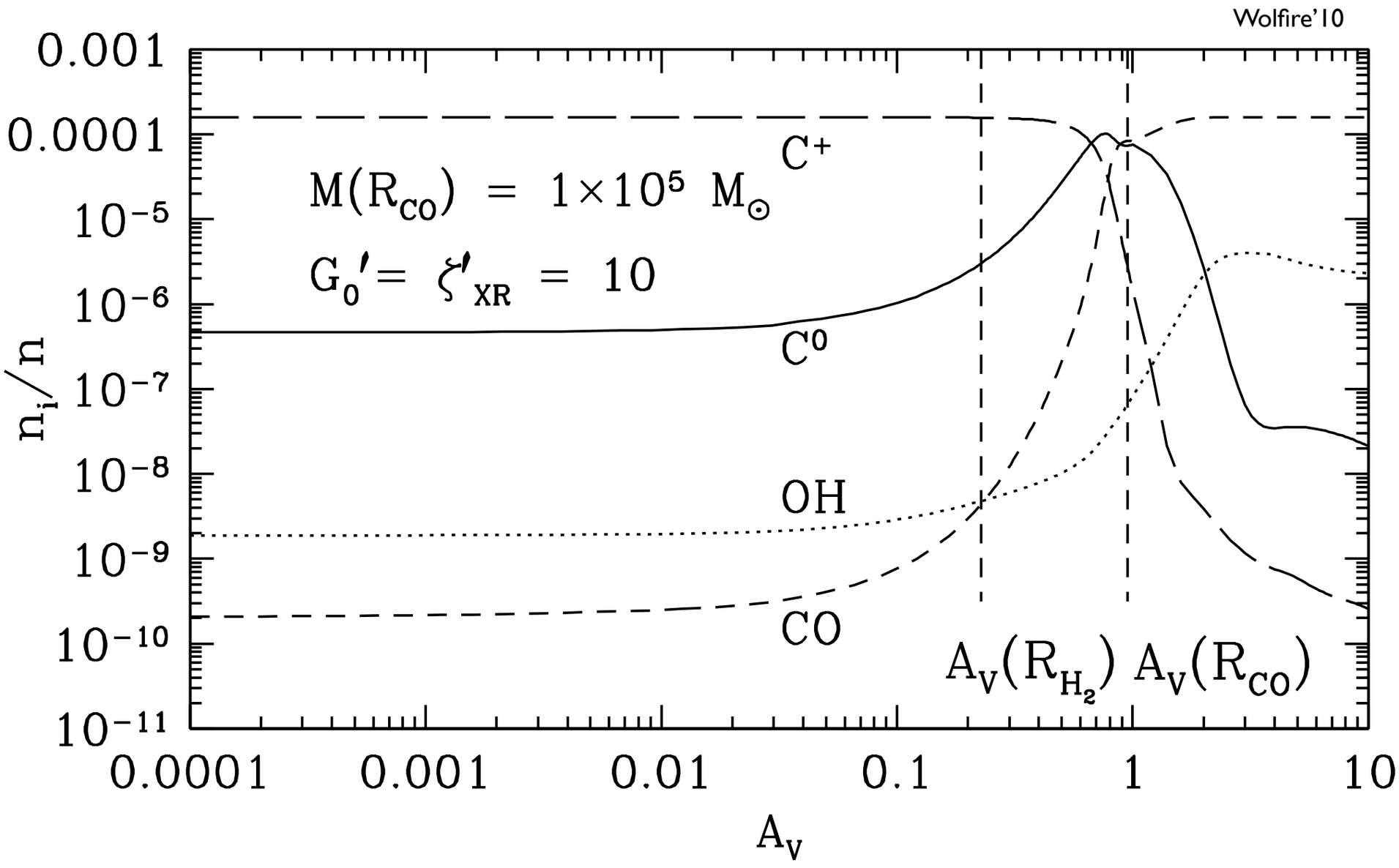
Virial analysis
Nakanishi & Sofue '06

2ndQ

3rdQ

CO-quiet H_2 gas

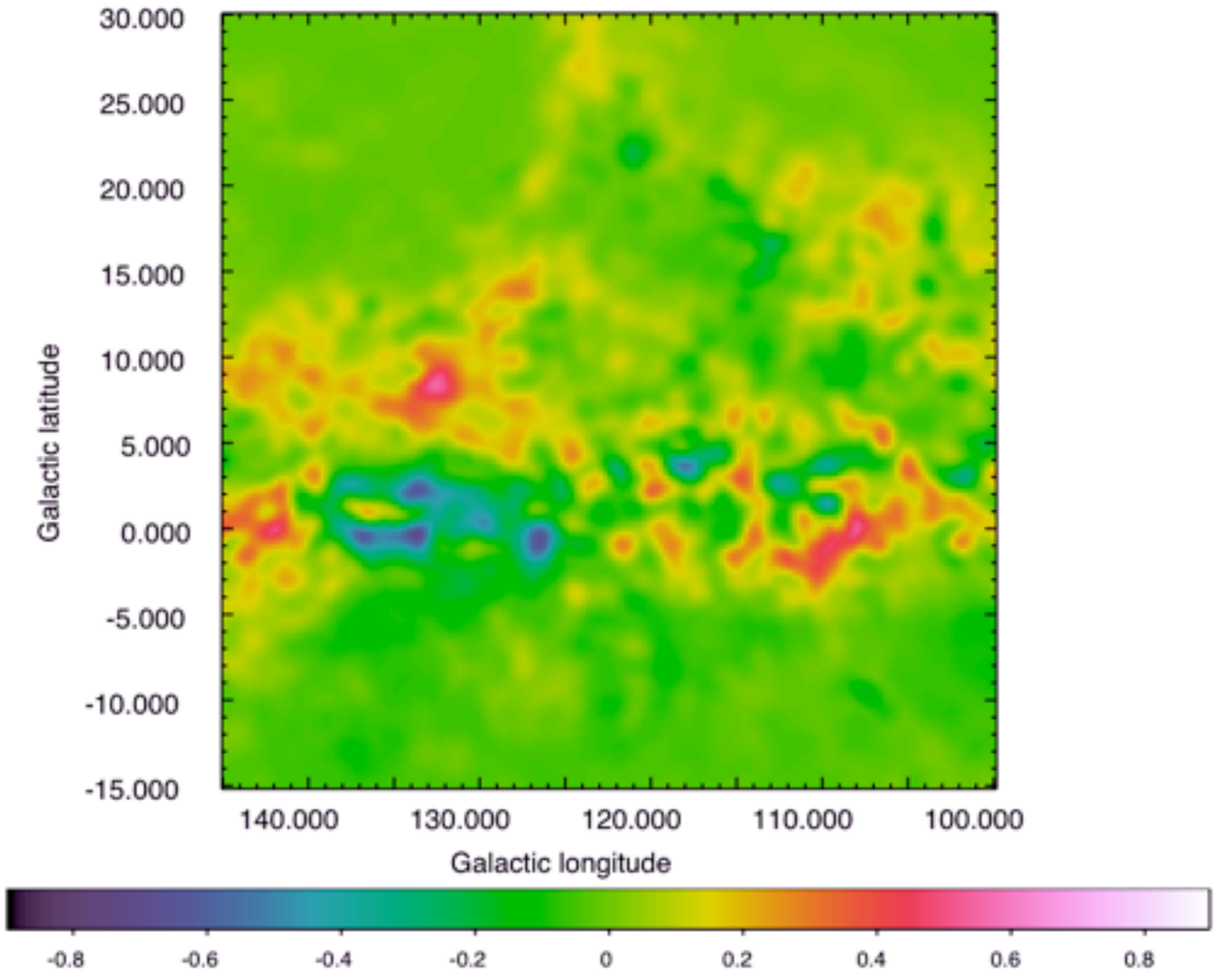
- dark H_2 gas with little or no CO, but C and C^+



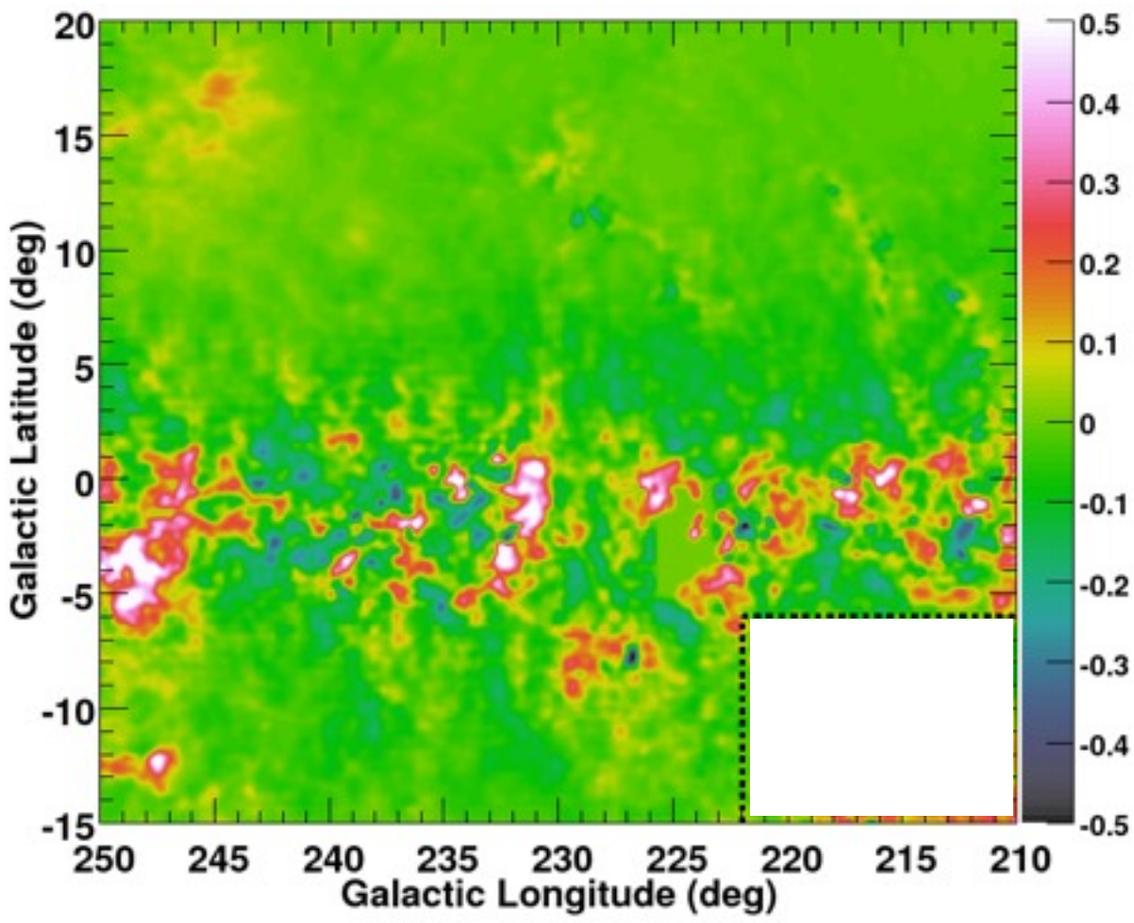
dark H_2 gas

- excess dust from SFD'99

2ndQ

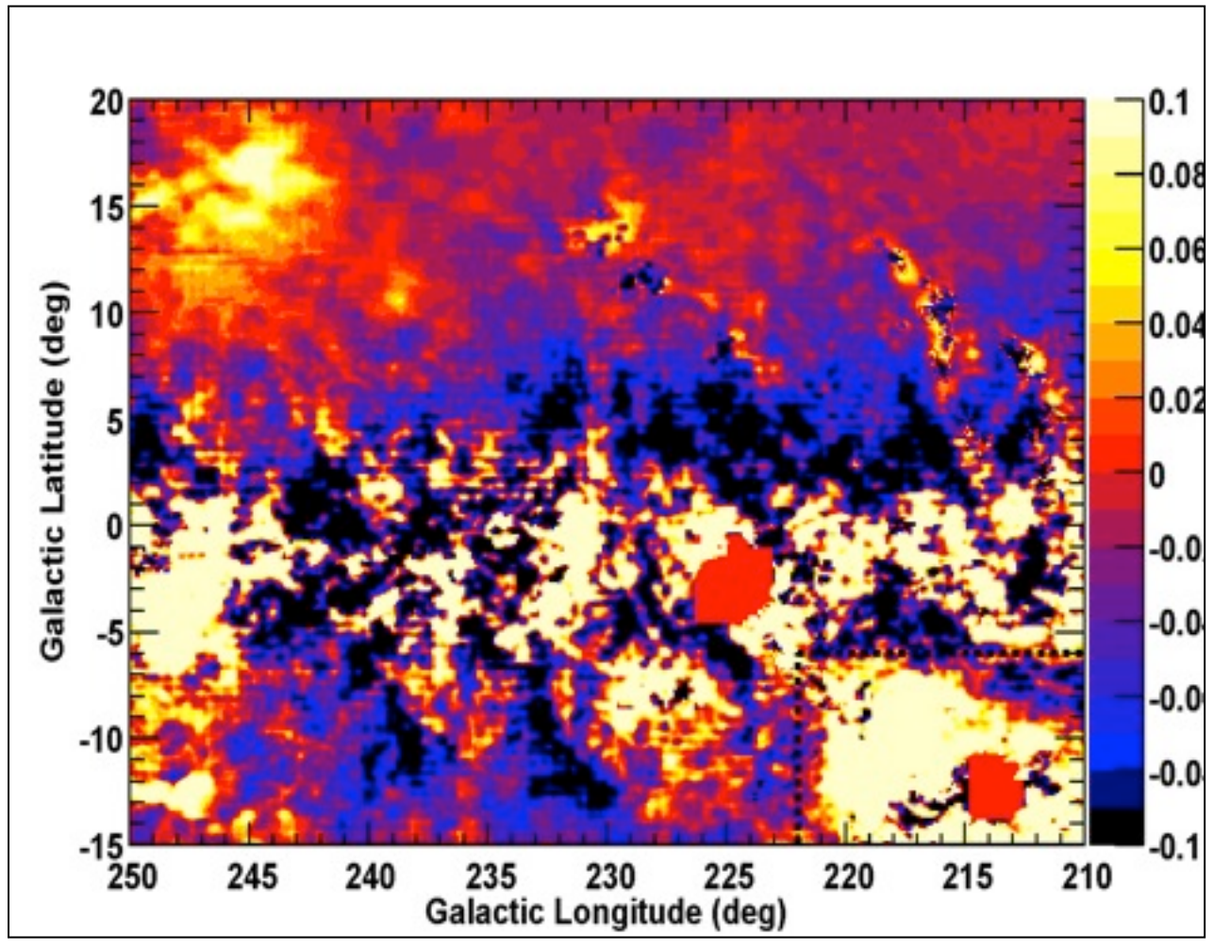


3rdQ

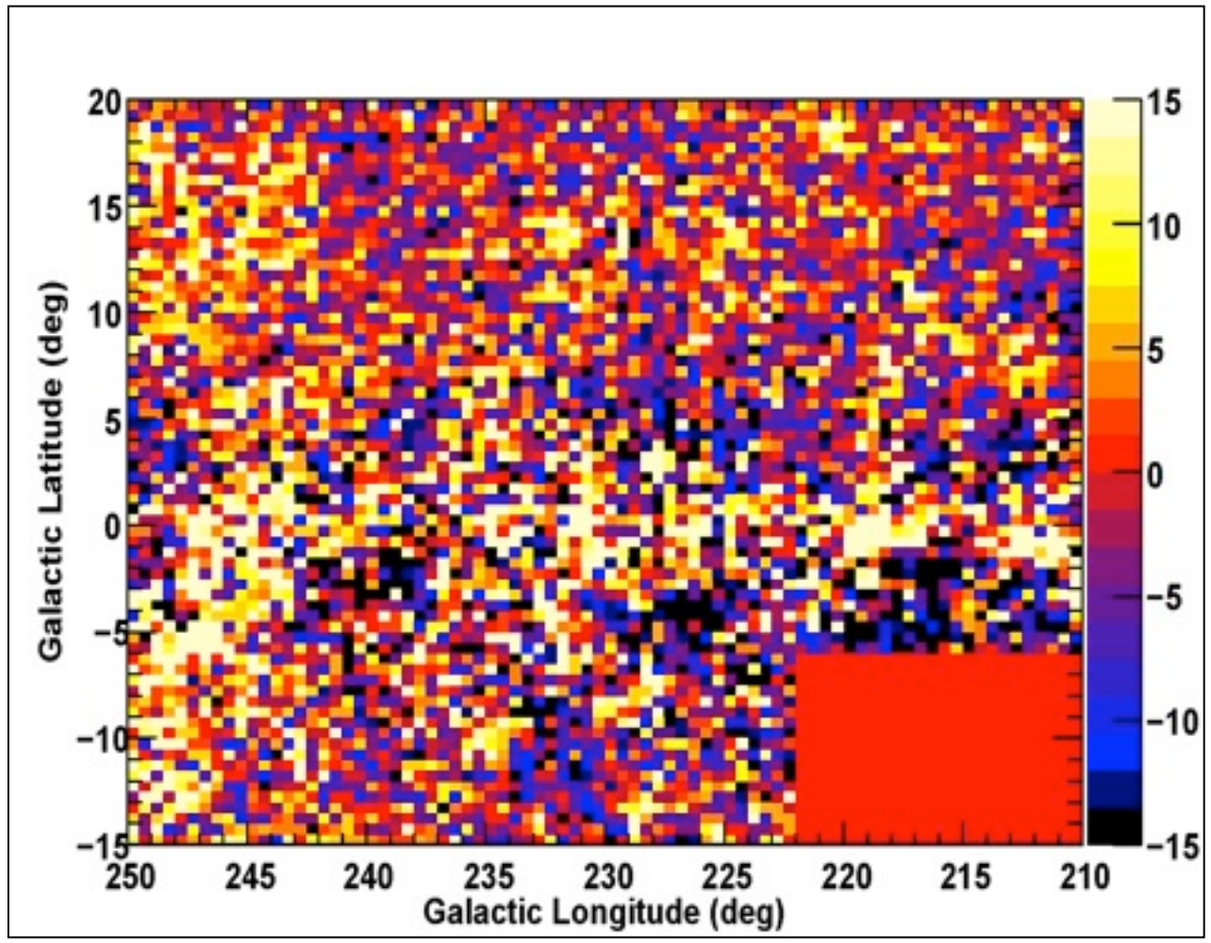


3rd quadrant

- E(B-V) - a.N(HI) - b.W(CO)

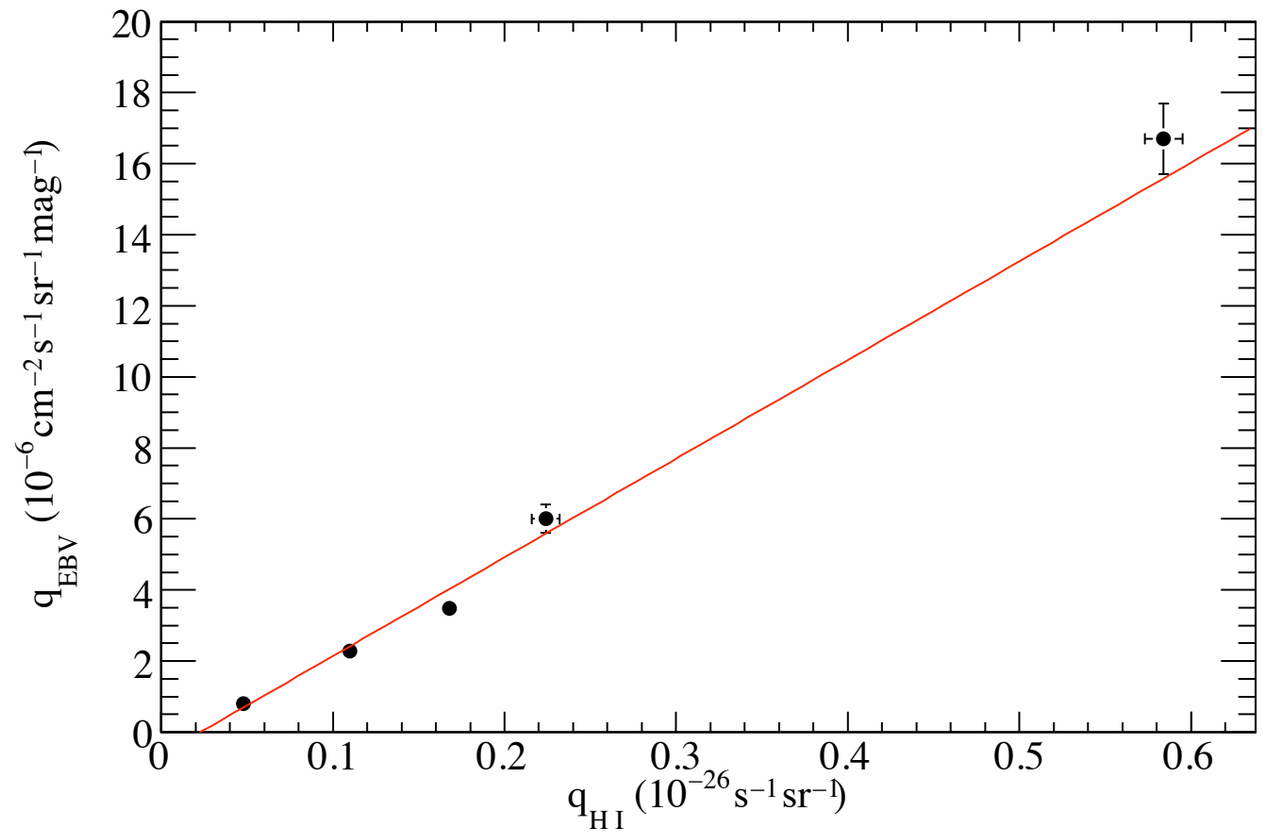


- γ - a.N(HI) - b.W(CO)



dark H_2 gas

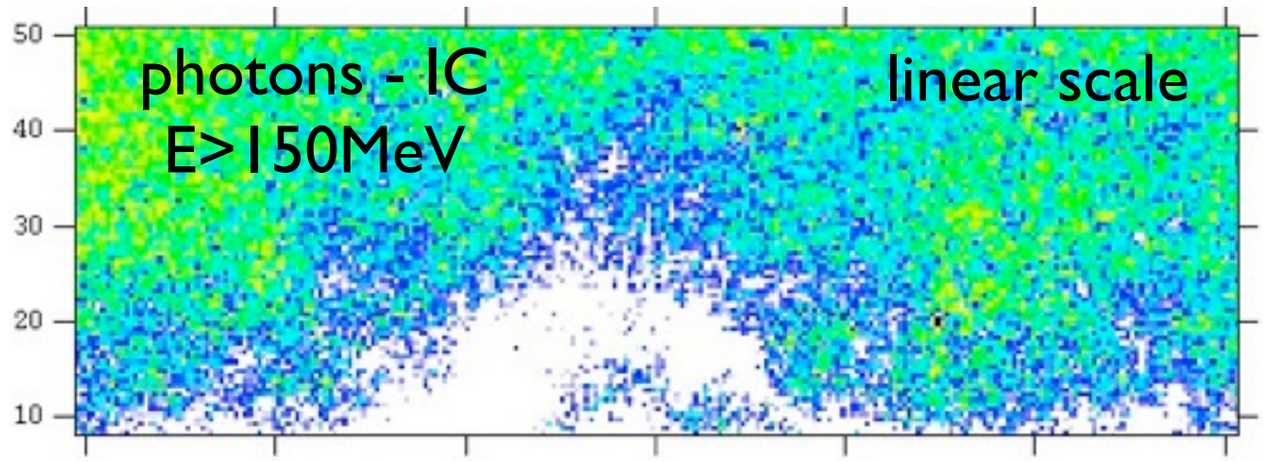
- strong correlation of excess dust with γ rays
- same spectrum as HI emission (from π^0 decay)
- 40-60% of the CO-bright H_2 mass in Cepheus, Cassiopeia, Polaris

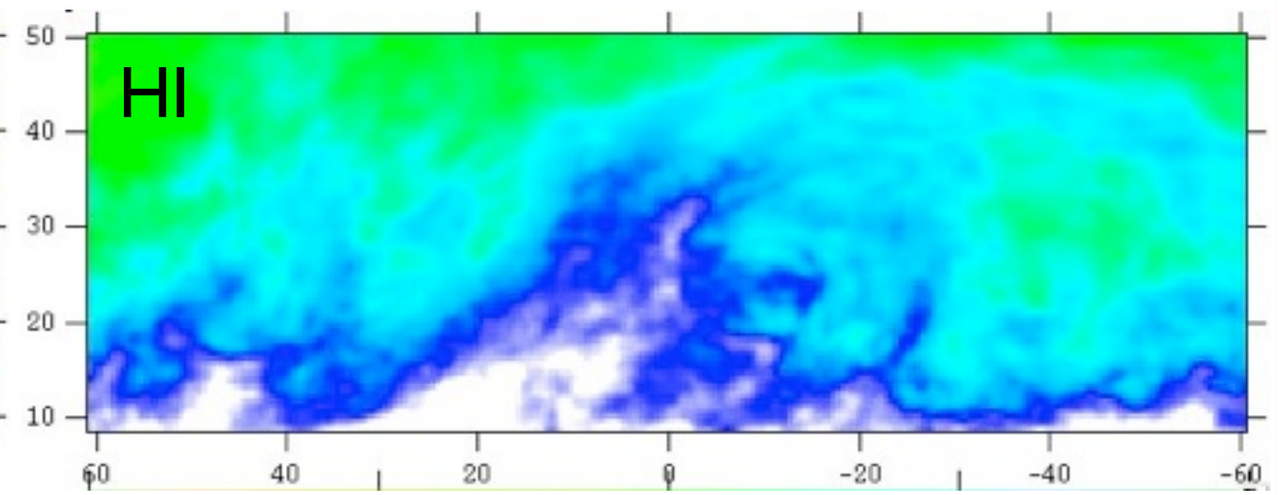


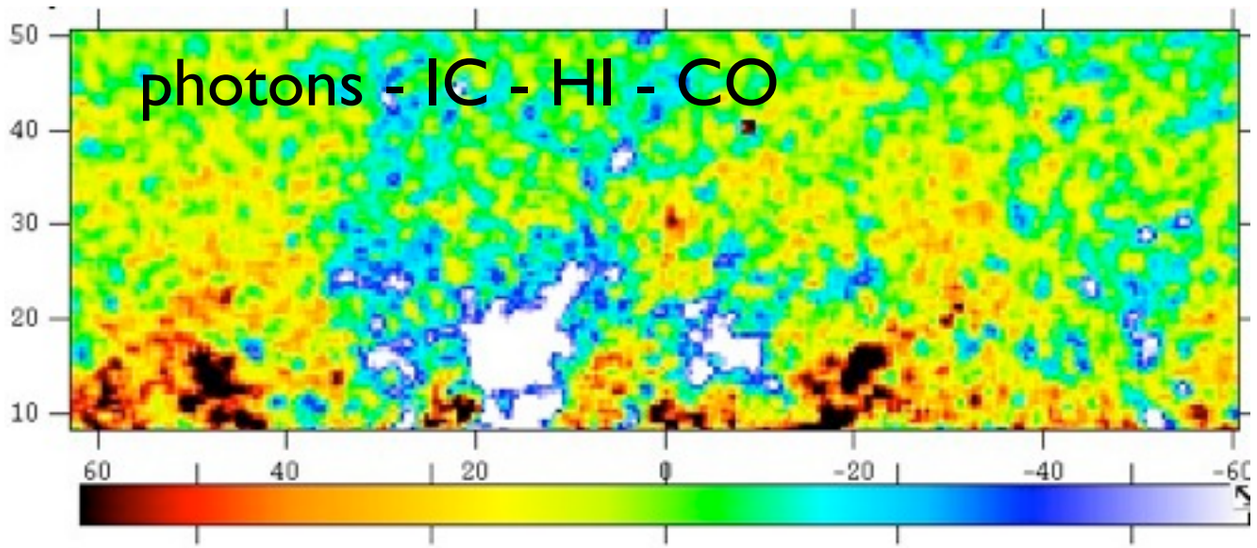
Abdo *et al.*, '10, ApJ 710, 133

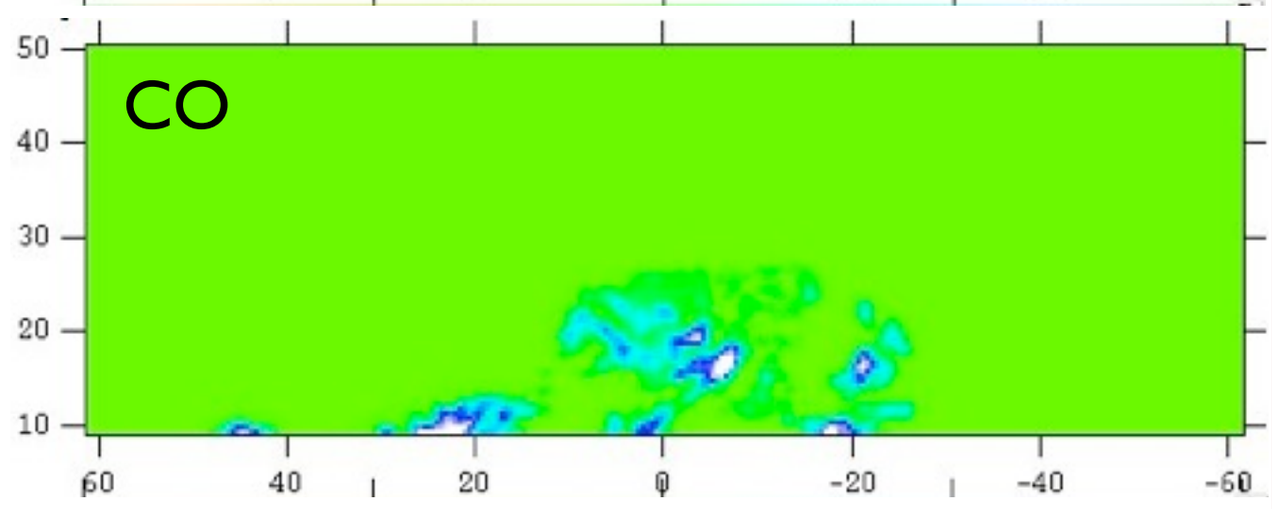
	l	b	d (kpc)	$M_{\rm CO}$	$M_{\rm vir}(r_A)$	$M_{\rm vir}(\langle r \rangle)$	$M_{\rm dark}$
Cepheus	$[100, 117]$	$[6, 22]$	0.3[a]	0.37 ± 0.02	0.687	0.903	0.160 ± 0.011
Polaris	$[117, 129]$	$[18, 30]$	0.25[b]	0.052 ± 0.003	0.208	0.159	0.031 ± 0.002
Cassiopeia	$[117, 145]$	$[2, 18]$	0.3[a]	0.61 ± 0.03	0.893	1.062	0.34 ± 0.02
Gould Belt	$[100, 145]$	$[-15, 30]$	0.3	1.47 ± 0.08			
NGC 7538	$[107, 115]$	$[-5, 5]$	2.65[c]	20 ± 2			
NGC 281	$[120, 125]$	$[-9, -5]$	3.0[d]	0.79 ± 0.08	1.205	1.047	
Perseus arm	$[100, 145]$	$[-10, 10]$	3.0	57 ± 6			

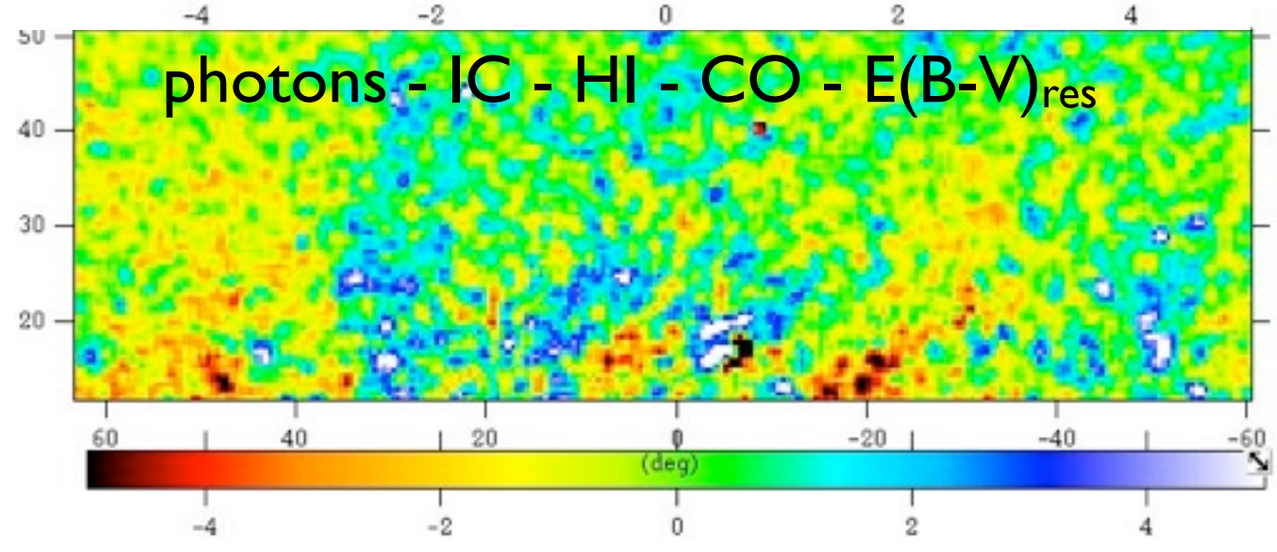
dark gas

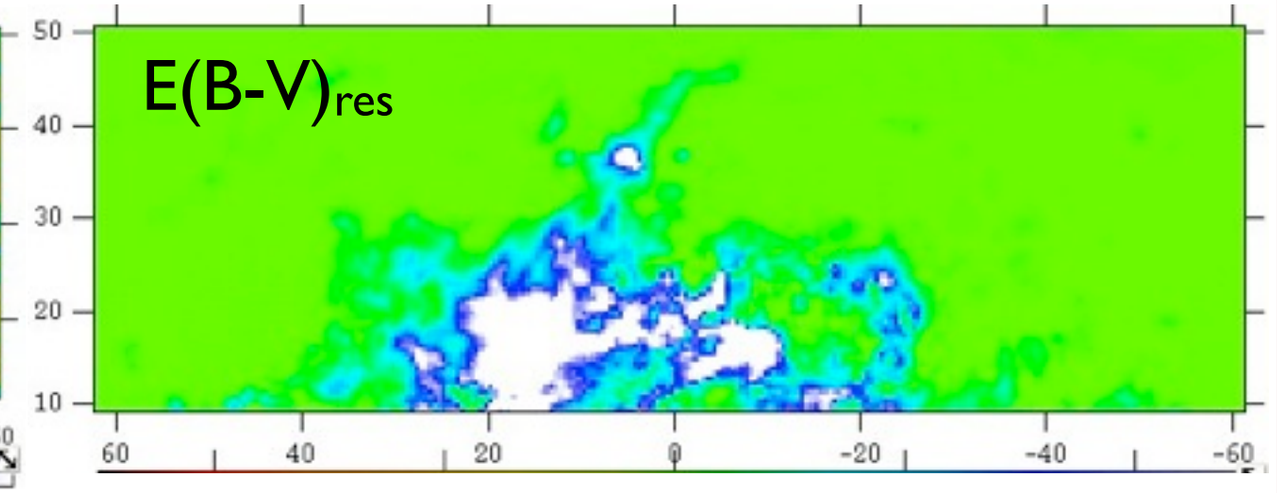

photons - IC
E>150MeV
linear scale


HI


photons - IC - HI - CO


CO


photons - IC - HI - CO - E(B-V)res
(deg)


E(B-V)res

much more soon...