水素原子-水素分子の転移観測の最前線

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分子雲と原子雲の境界

分子雲　ー　CO (H_2) 密度　1000cm^{-3}以上：星形成

原子雲　ー　HI　密度　10cm^{-3}以下：分子雲形成

ダーク・ガス　CO or HI で見えない？：ガンマ線、ダスト放射・減光

分子雲と原子雲の境界（10−100cm^{-3}）は見えるか（定量できるか）？

ー H_2 without CO?

ー CI emission?

ー 相転移、Hはダスト表面でH_2になり、放出される

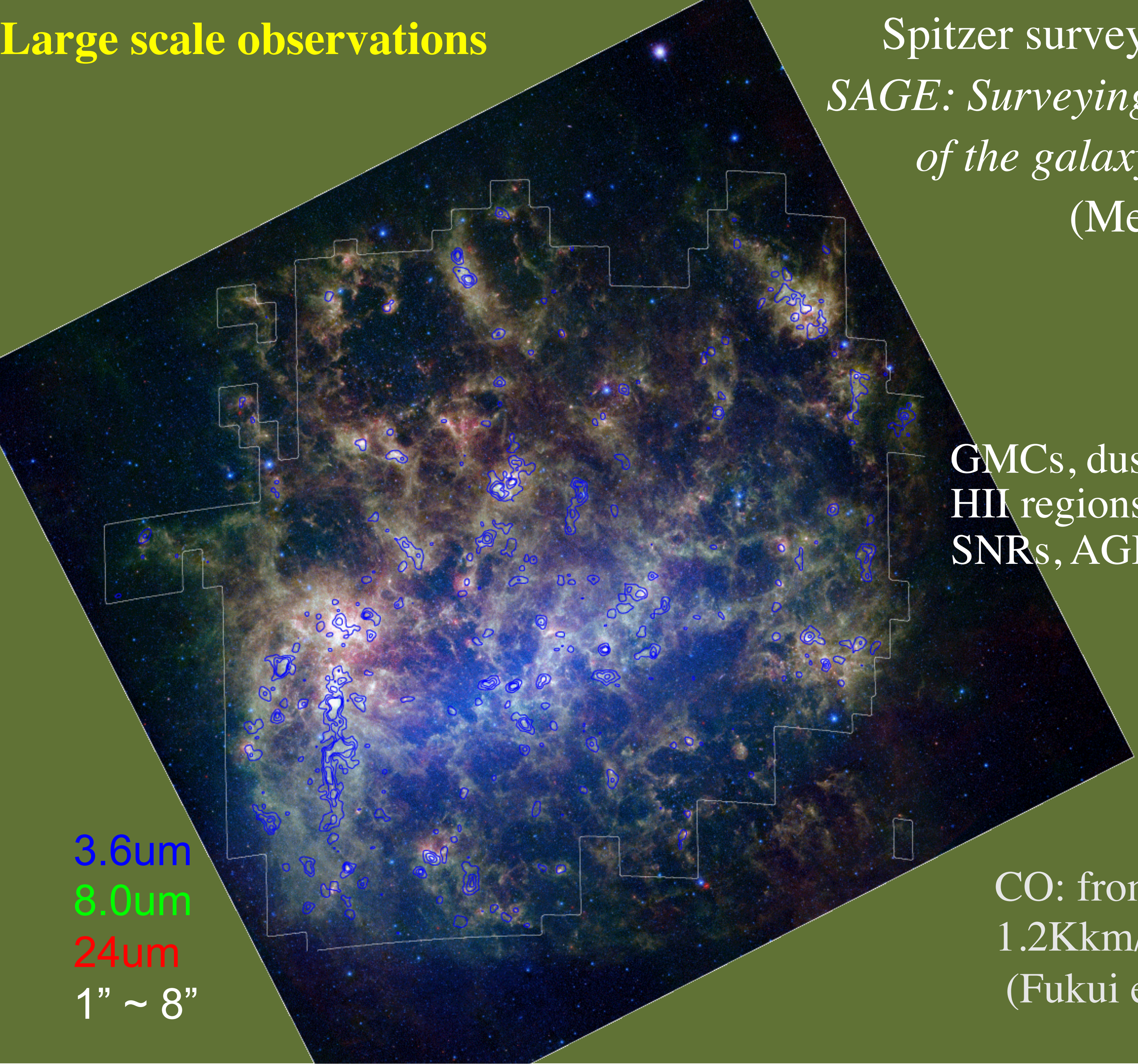
最大の仮定「HIは光学的に薄い」

Large scale observations

Spitzer survey of the LMC

SAGE: Surveying the Agency of the galaxy's evolution

(Meixner et al.)

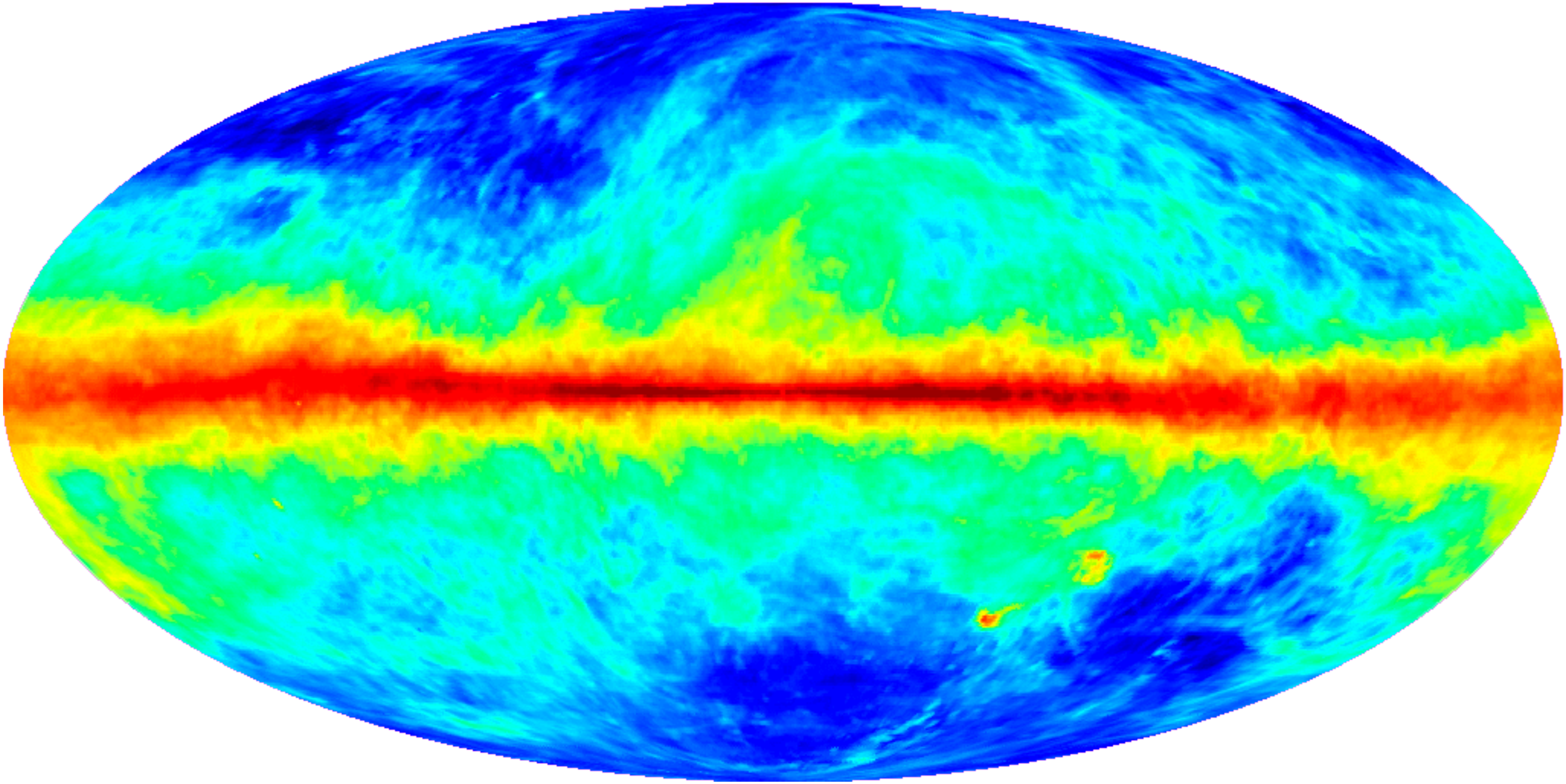


GMCs, dust, YSOs,
HII regions,
SNRs, AGBs,,…

3.6um
8.0um
24um
1" ~ 8"

CO: from 1.2 Kkm/s
1.2Kkm/s intervals
(Fukui et al. 2008)

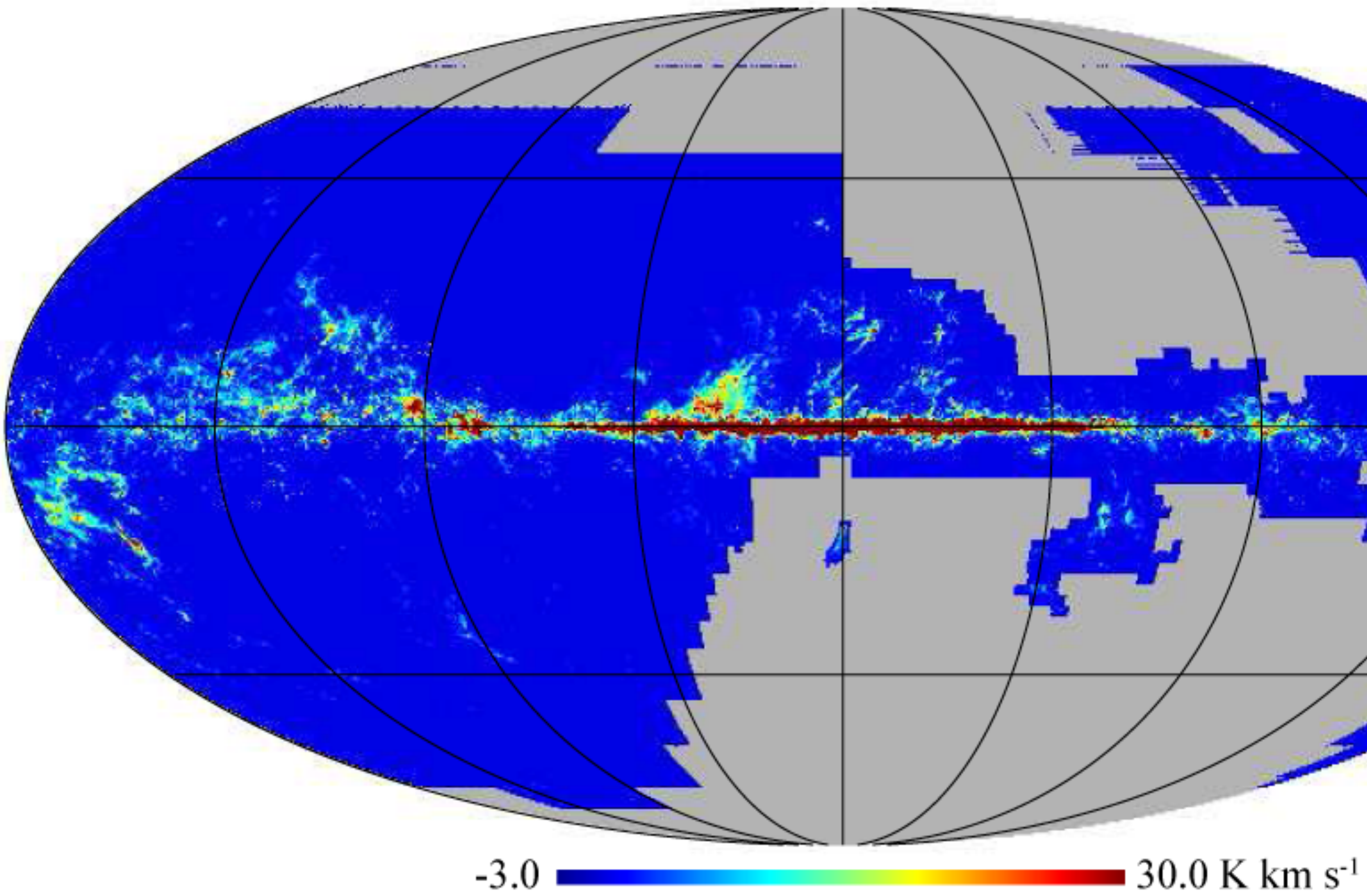
HI LAB



The Leiden/Argentine/Bonn Galactic HI Survey

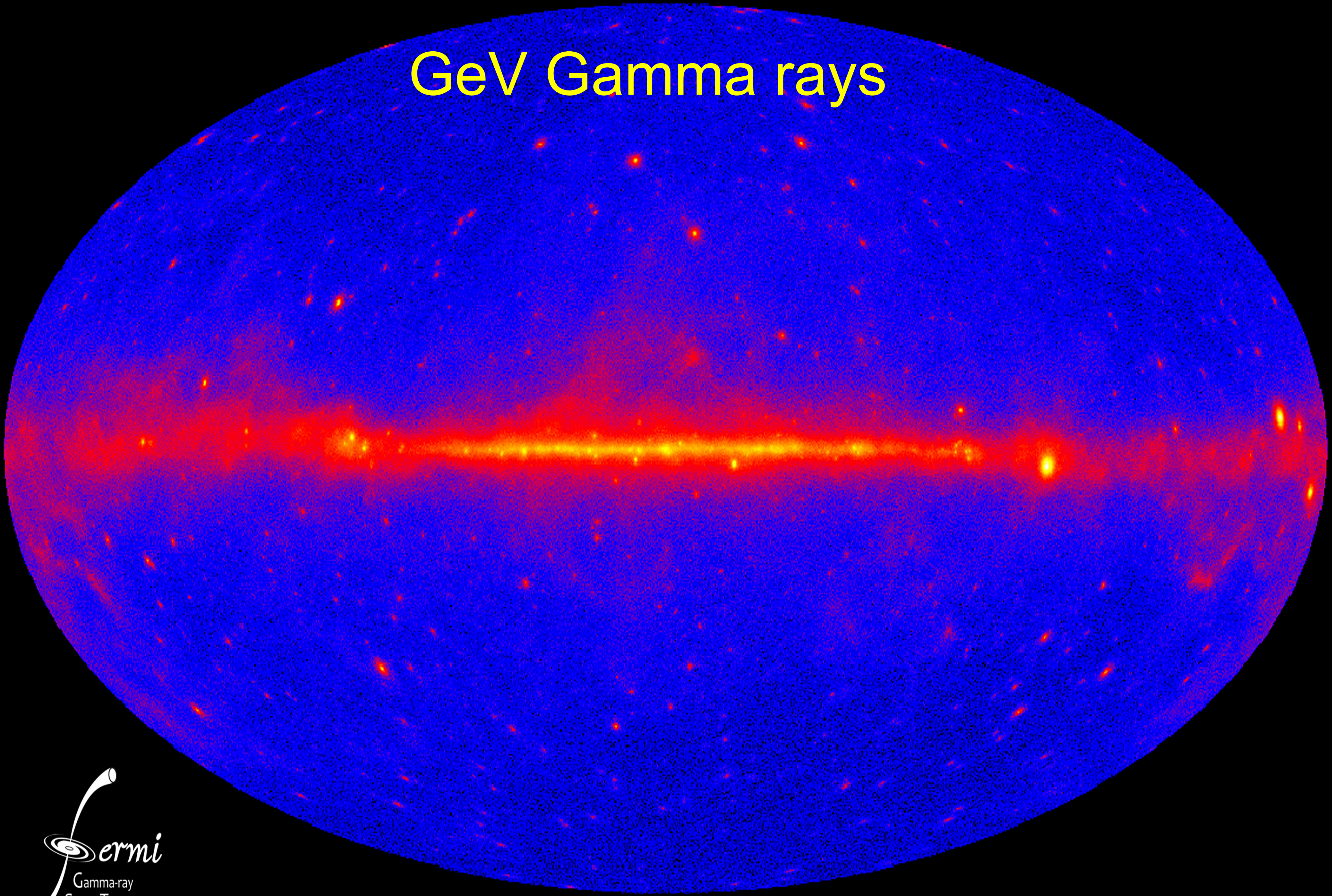
Kalberla+ 2005
Courtesy of Legacy Archive for Microwave Background Data Analysis

CO surveys : CfA + NANTEN



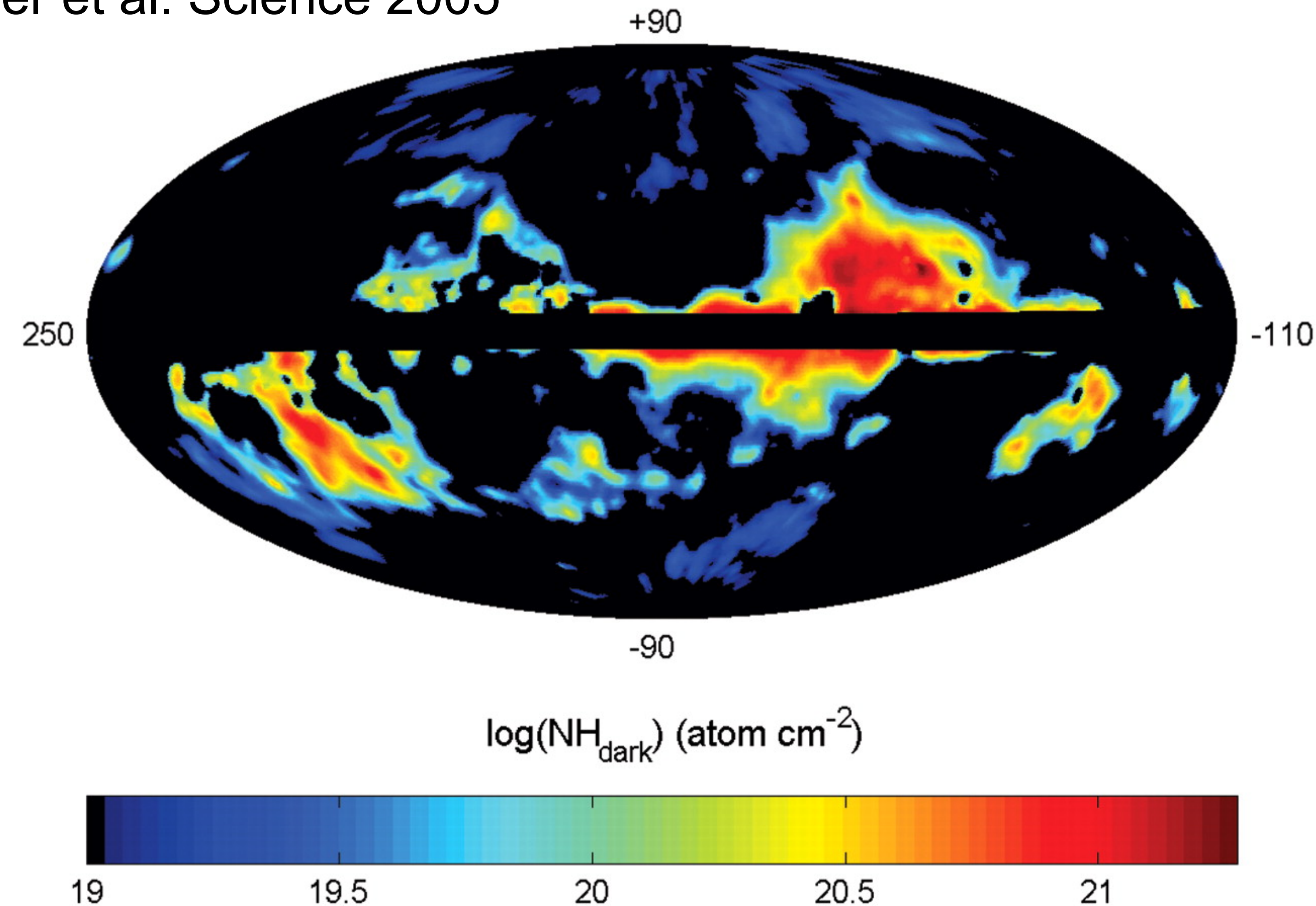
Planck Collaboration, arXiv:1101.2029

GeV Gamma rays



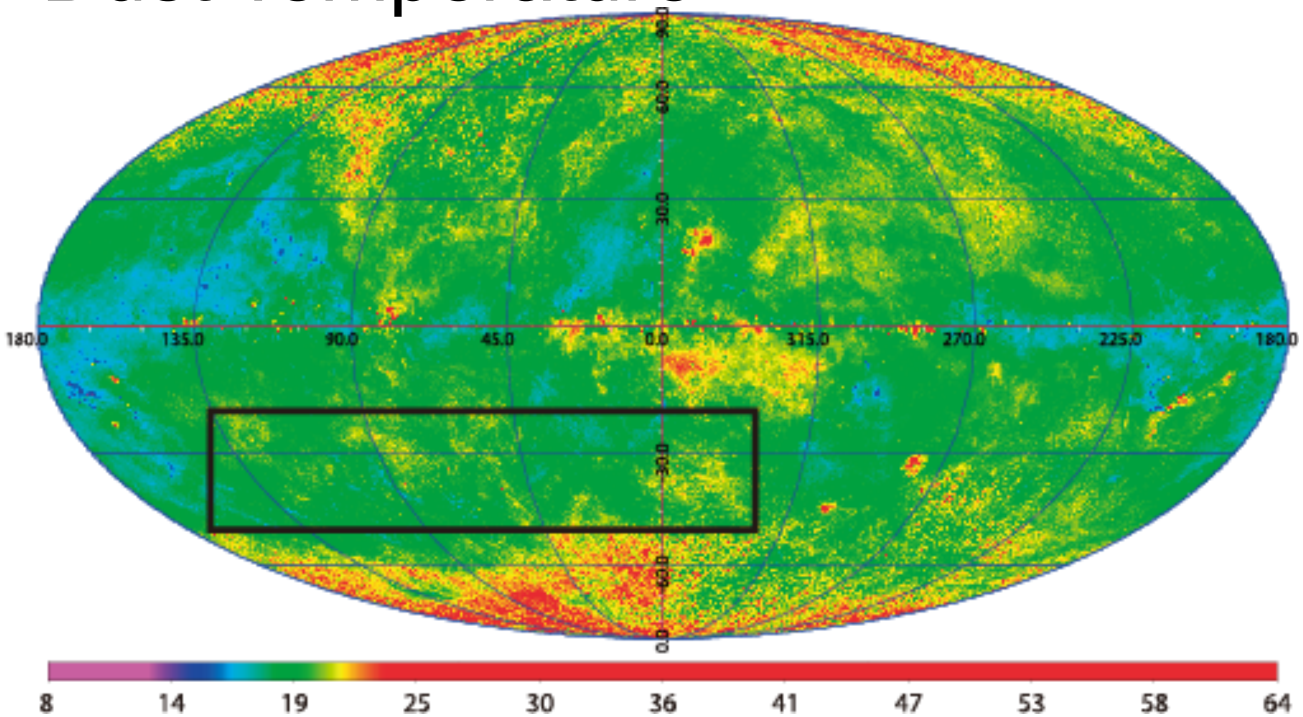
fermi
Gamma-ray
Space Telescope

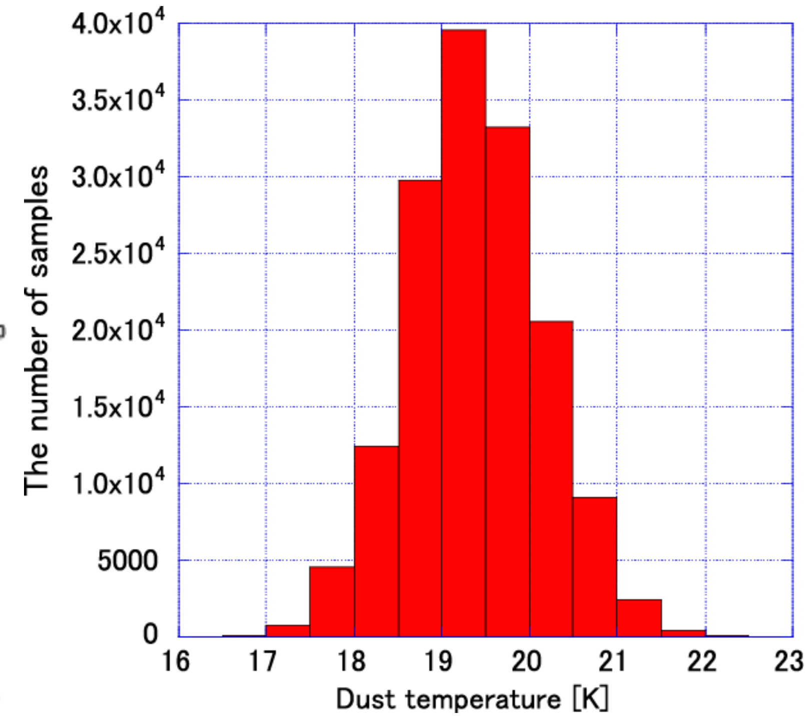
Grenier et al. Science 2005



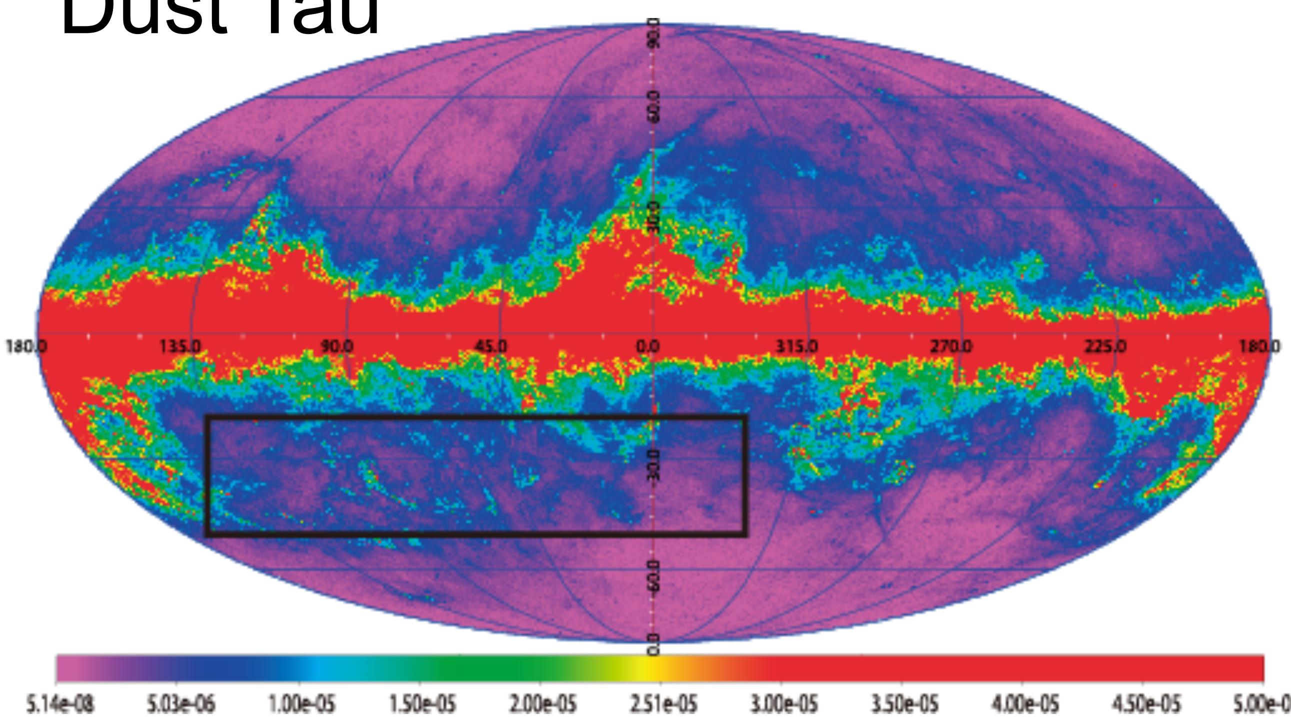
Column density of dark gas ~ $10^{20.5}$-$10^{21.5}$ /cm^2

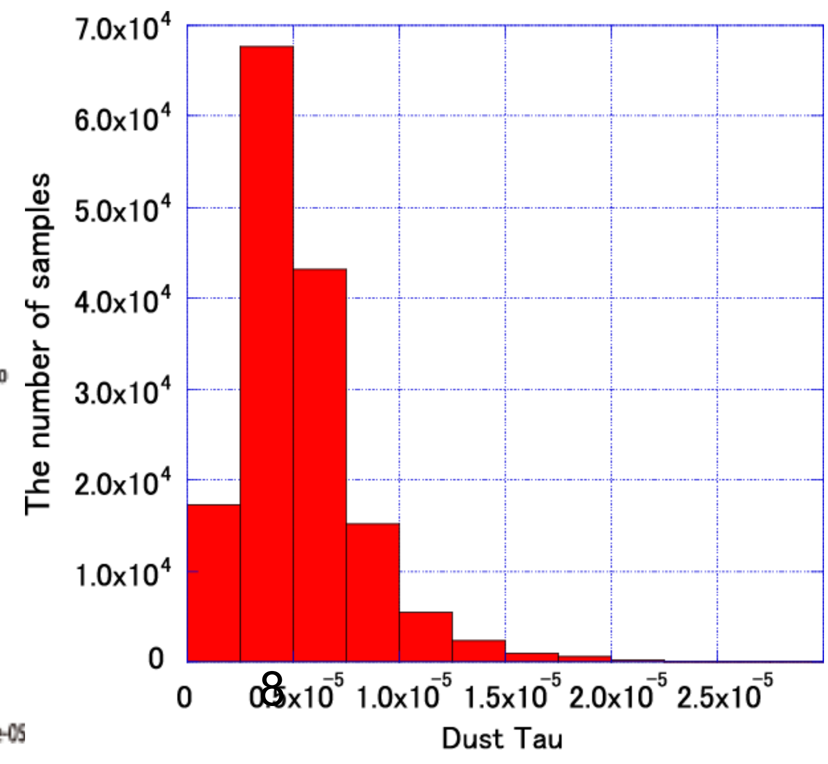
Dust Temperature

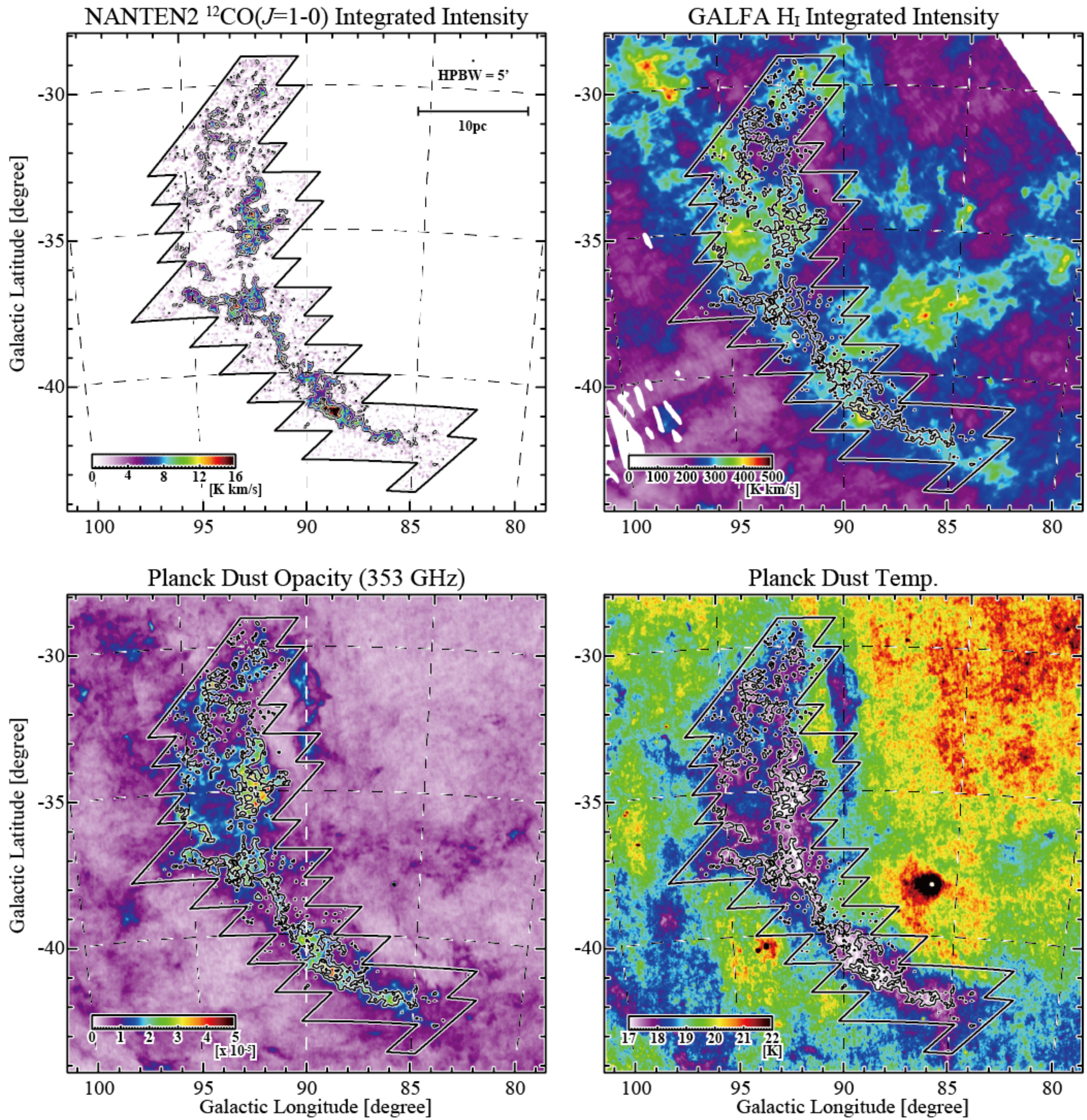




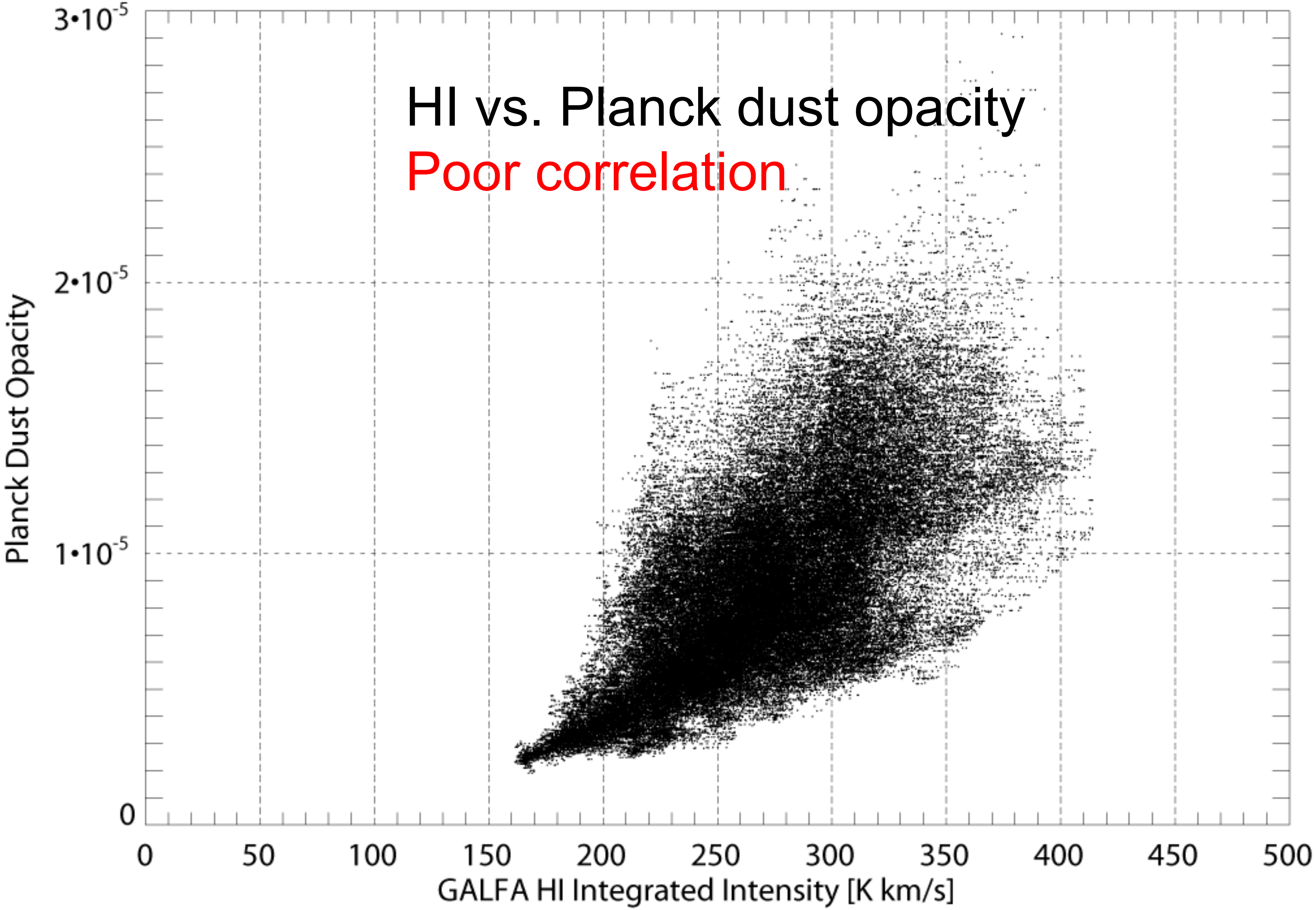
Dust Tau







NANTEN2 12CO(J=1-0) Integrated Intensity
GALFA HI Integrated Intensity
Planck Dust Opacity (353 GHz)
Planck Dust Temp.
HPBW = 5'
10pc
Galactic Latitude [degree]
Galactic Longitude [degree]
-30
-35
-40
100
95
90
85
80
0 4 8 12 16
[K km/s]
0 100 200 300 400 500
[K km/s]
0 1 2 3 4 5
[x 10-5]
17 18 19 20 21 22
[K]


HI vs. Planck dust opacity
Poor correlation
Planck Dust Opacity
3•10^-5
2•10^-5
1•10^-5
0
0
50
100
150
200
250
300
350
400
450
500
GALFA HI Integrated Intensity [K km/s]

HI 21cm line

In the thermodynamic equilibrium

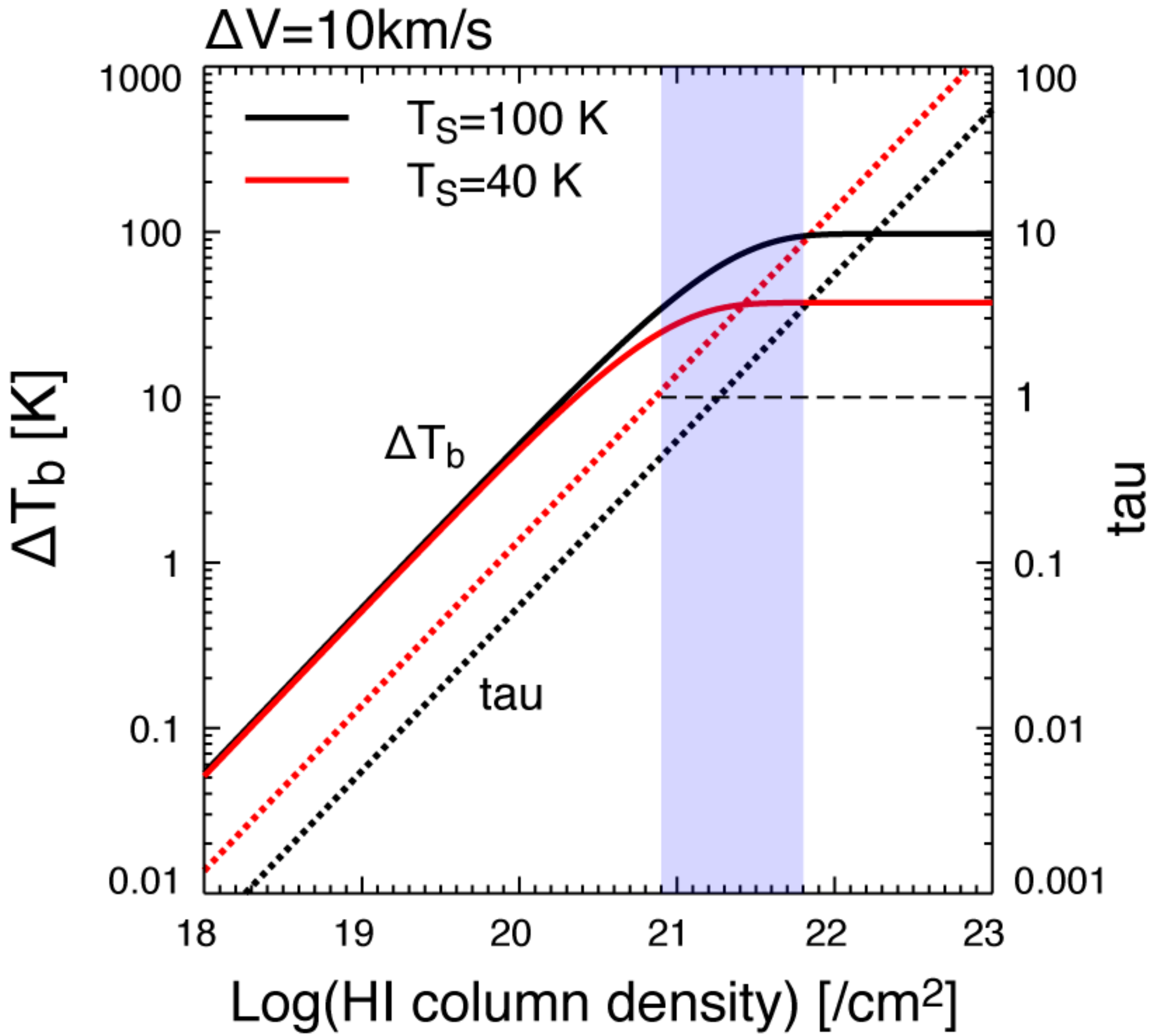
$$\frac{N_2}{N_1} = \frac{g_2}{g_1} \exp\left(-\frac{h\nu}{kT}\right) \approx \frac{g_2}{g_1} = 3$$

$$N_{\rm HI} = N_2 + N_1 = 4N_1$$

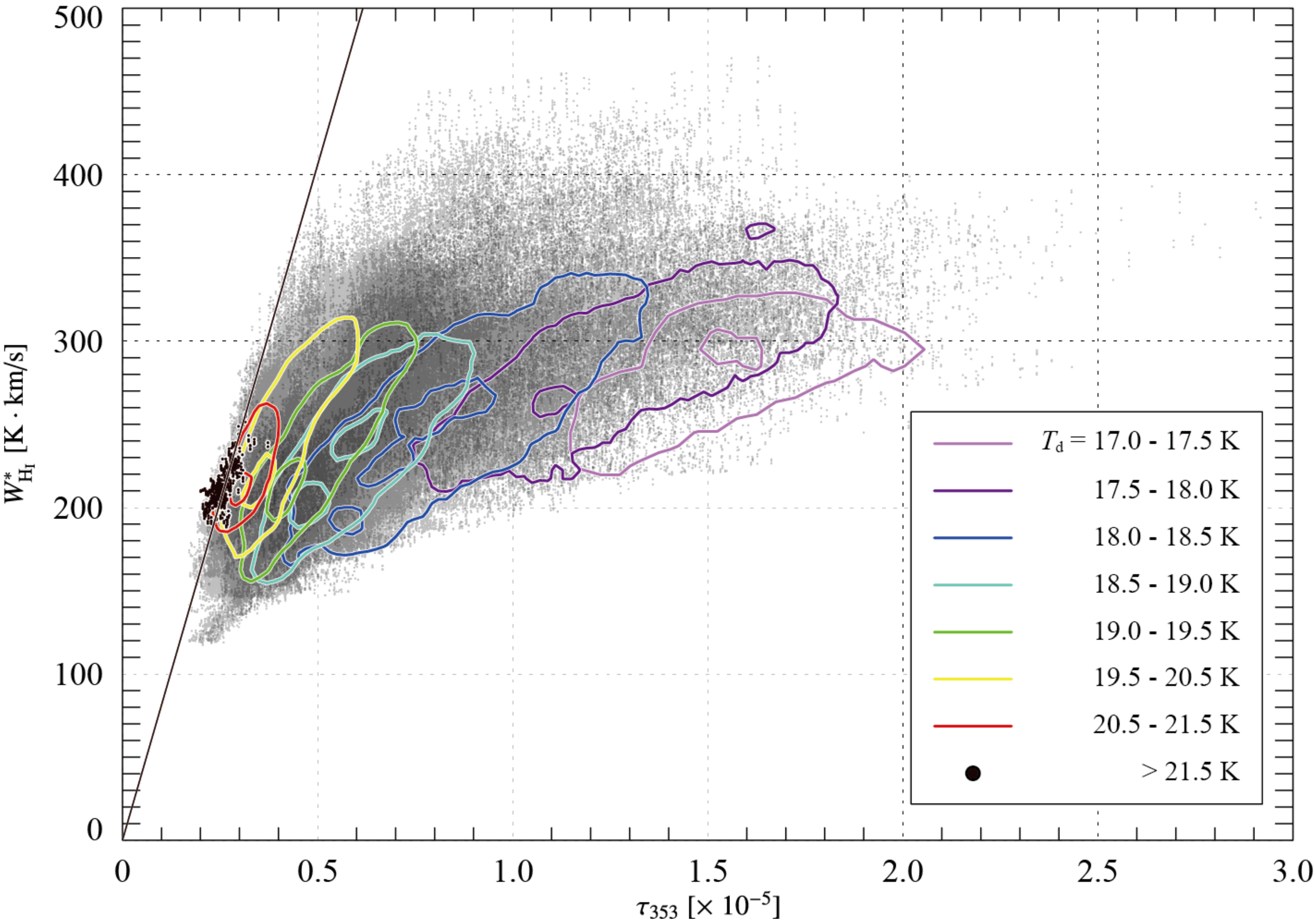
Optically thin approximation

$$N_{\rm HI} = 4 \times \frac{8\pi\nu^2 g_1 k}{c^3 h g_2 A_{21}} \int \Delta T_b dv$$

$$= 1.82 \times 10^{18} \int \Delta T_b dv \quad ({\rm cm}^{-2})$$



$$\Delta T_{\rm b} = (T_{\rm s} - T_{\rm bg})(1 - \exp(-\tau))$$



500
400
300
200
100
0
$W^*_{\mathrm{H_I}}$ [K · km/s]
0
0.5
1.0
1.5
2.0
2.5
3.0
τ_{353} [× 10^{-5}]
T_d = 17.0 - 17.5 K
17.5 - 18.0 K
18.0 - 18.5 K
18.5 - 19.0 K
19.0 - 19.5 K
19.5 - 20.5 K
20.5 - 21.5 K
> 21.5 K

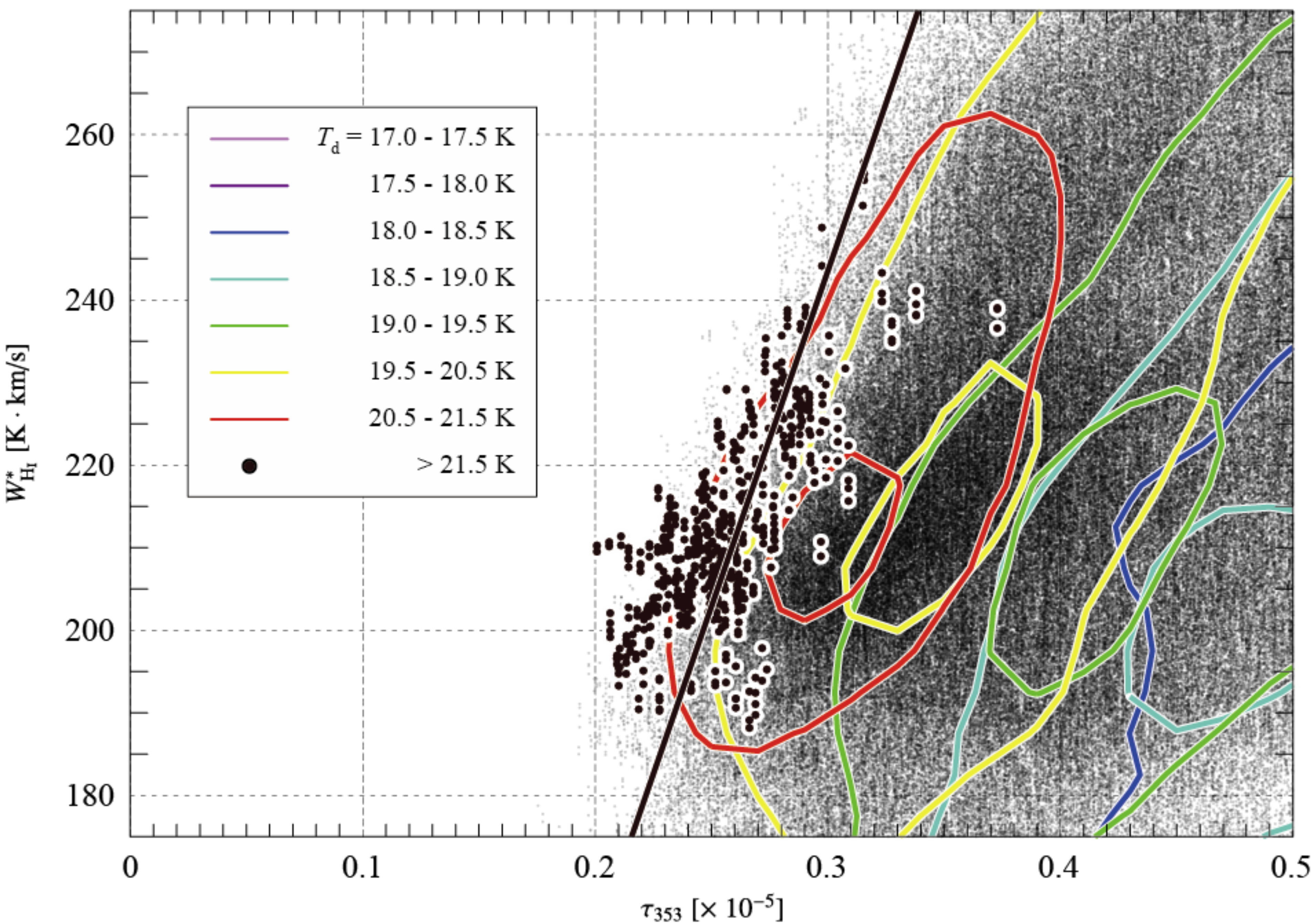


Fig. 3 クローズアップ

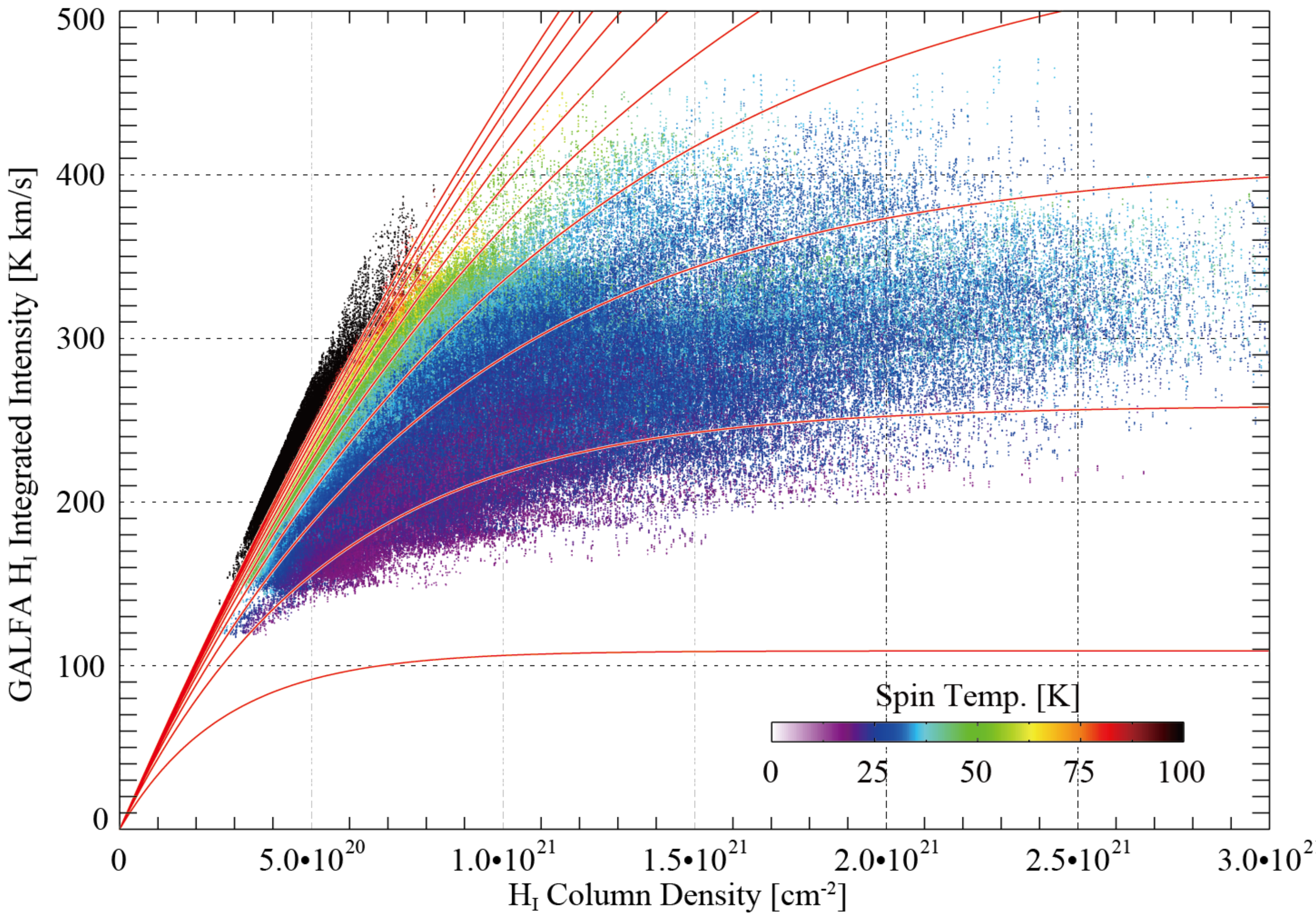
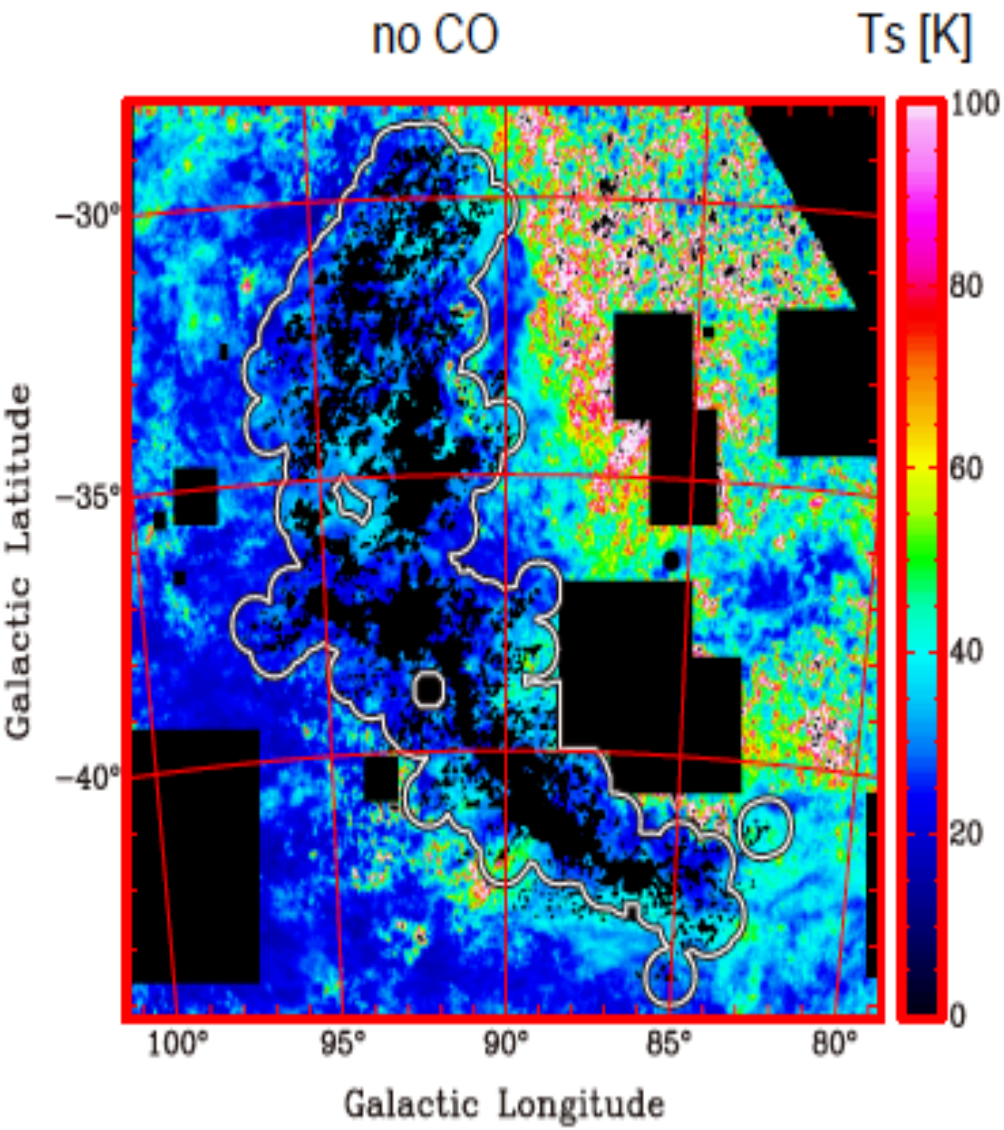
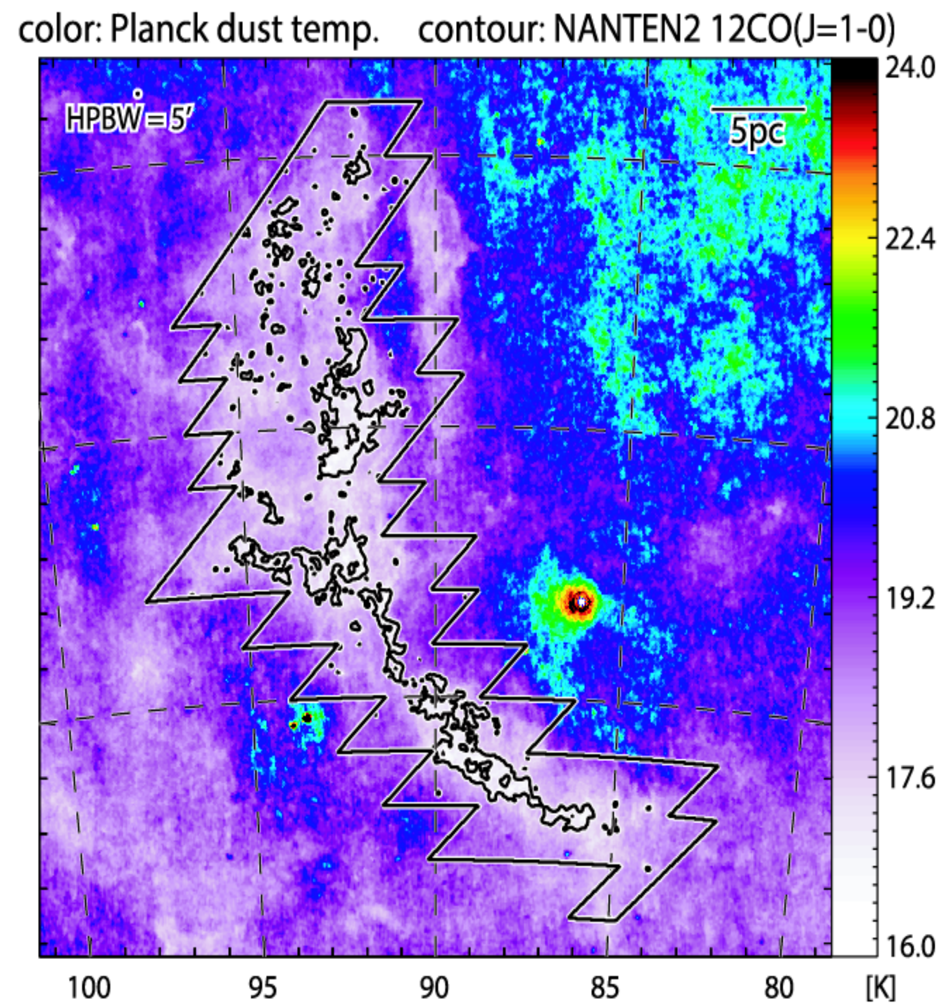
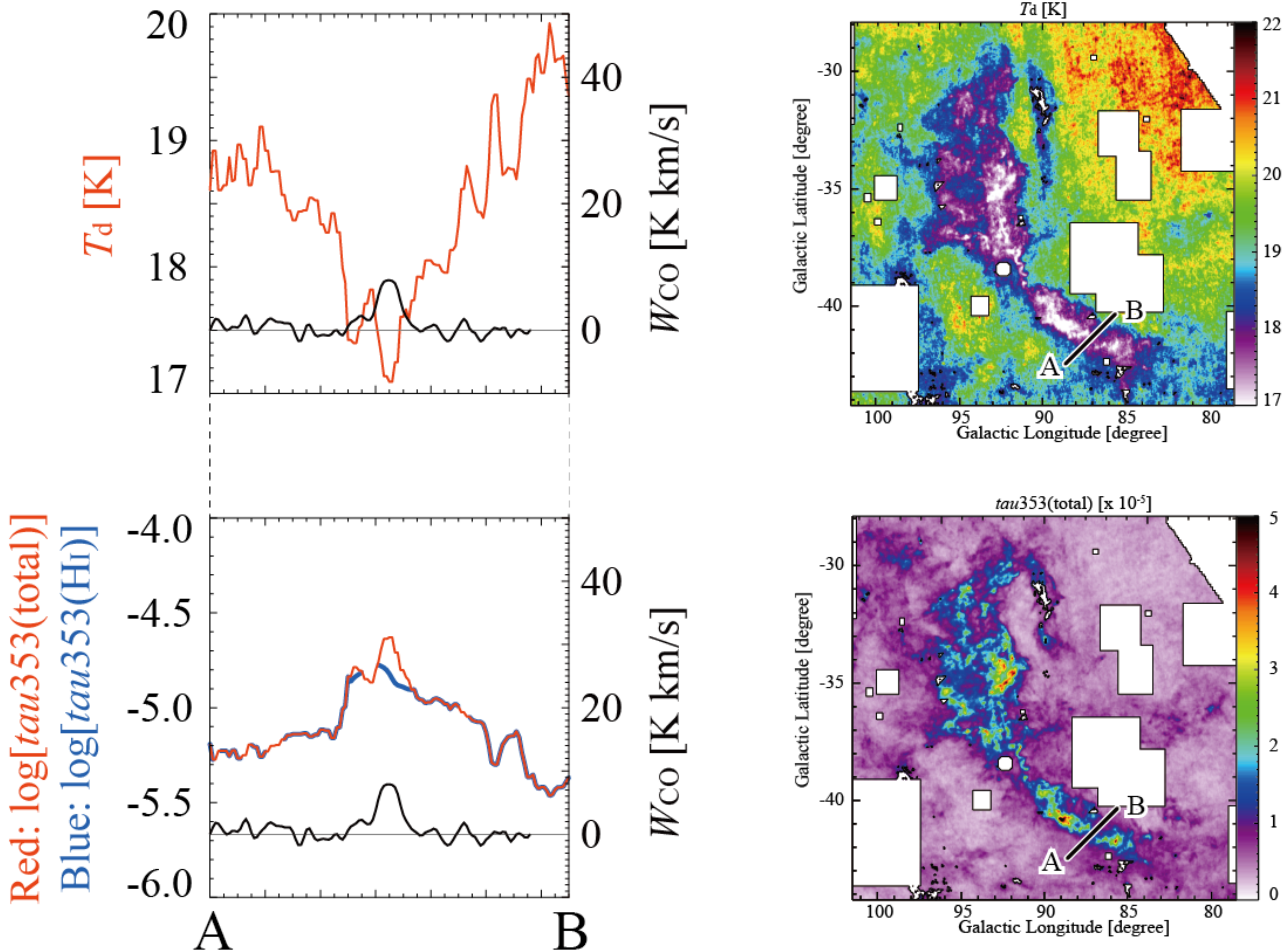


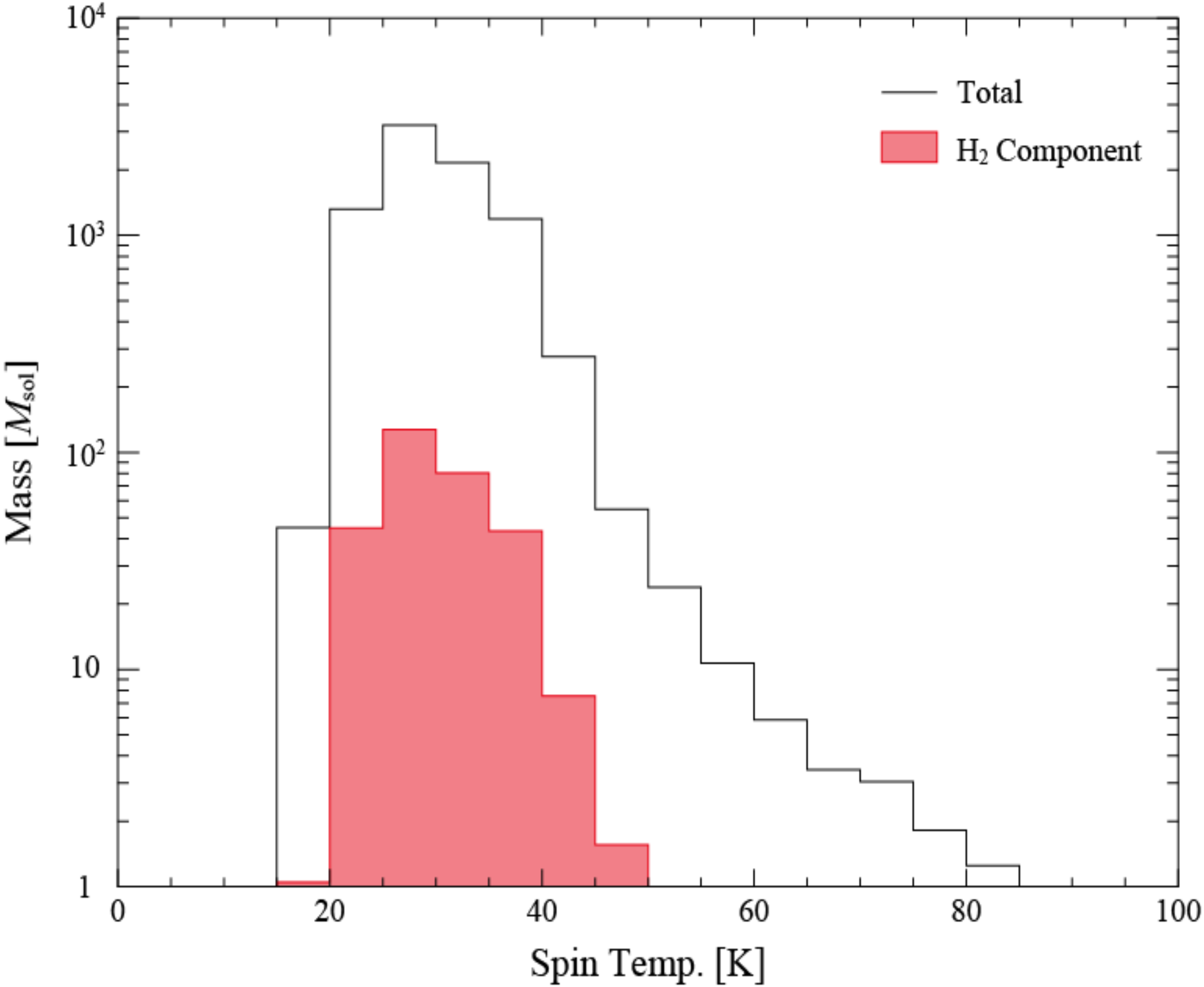
Fig. 3
赤の曲線は等Ts線(理論線)
下から10, 20, 30, …, 100 K


no CO
Ts [K]
100
80
60
40
20
0
-30°
-35°
-40°
100°
95°
90°
85°
80°
Galactic Latitude
Galactic Longitude

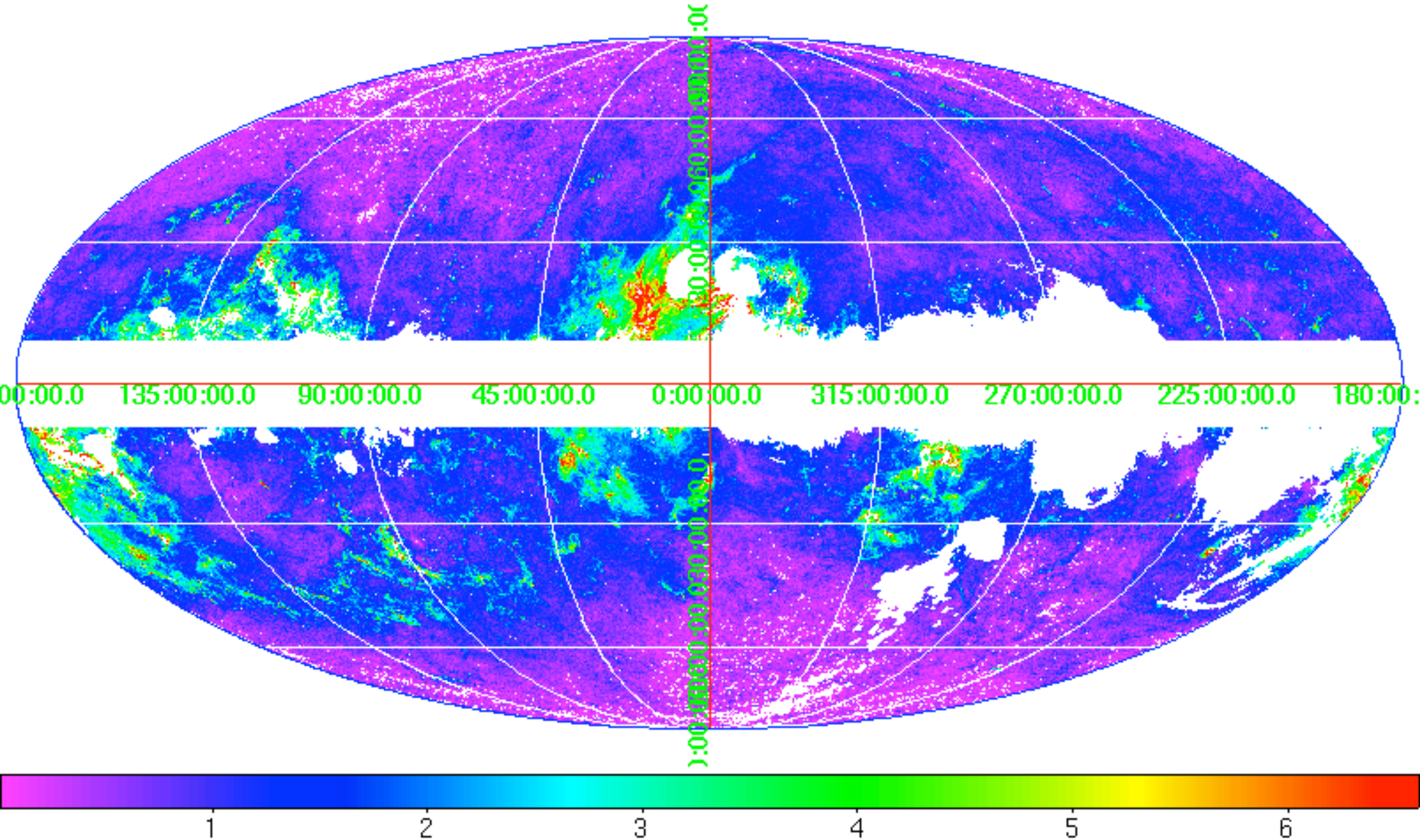

color: Planck dust temp.
contour: NANTEN2 12CO(J=1-0)
HPBW=5′
5pc
24.0
22.4
20.8
19.2
17.6
16.0
[K]
100
95
90
85
80

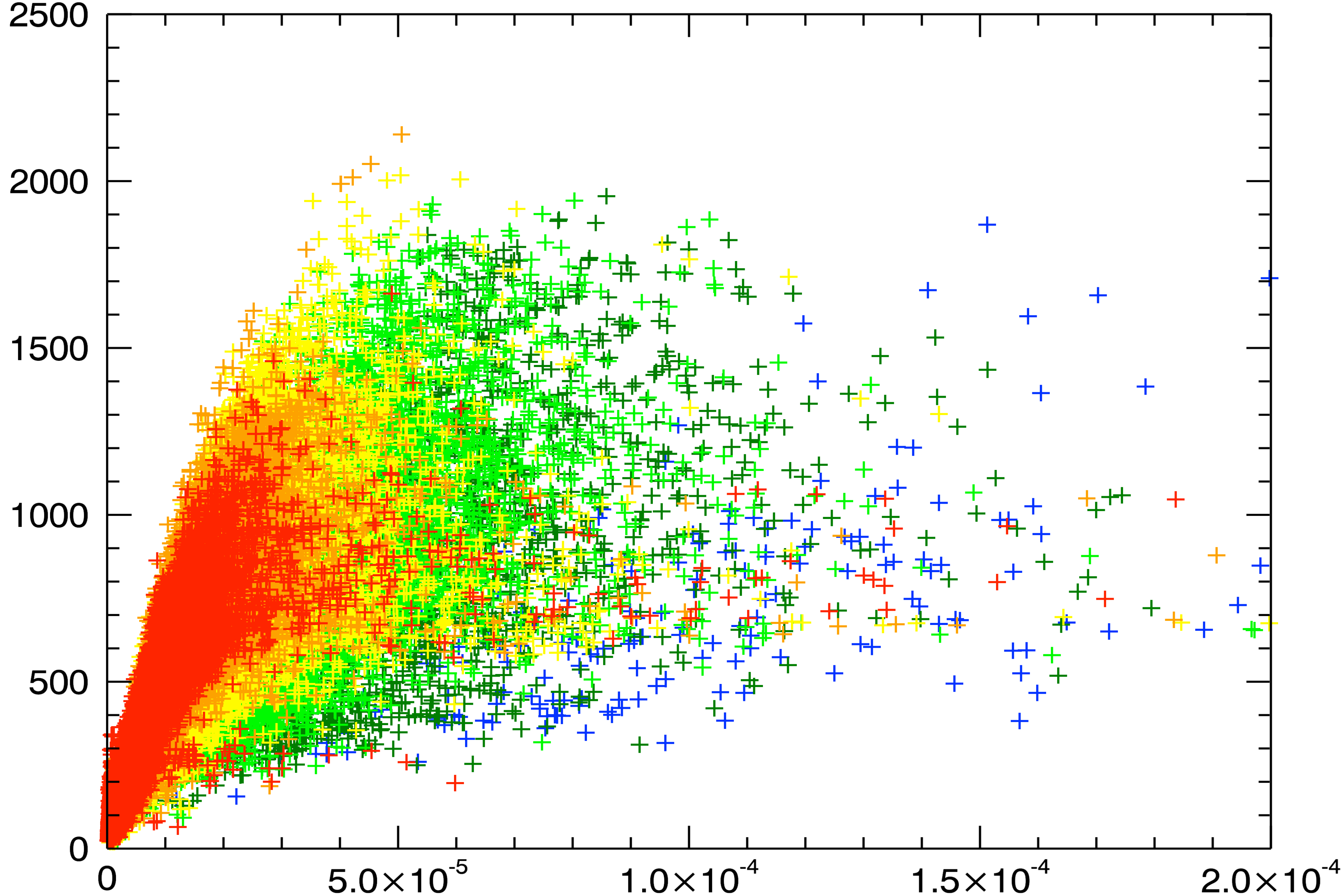


A-B 線に沿ったTdとtau353のプロット。



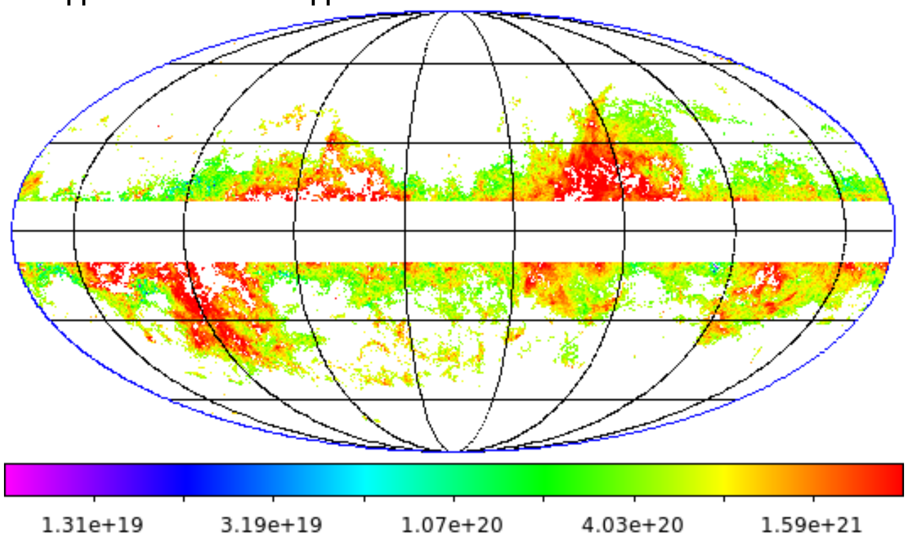
Total
H_2 Component
Mass [M_{sol}]
10^4
10^3
10^2
10
1
0
20
40
60
80
100
Spin Temp. [K]


135:00:00.0
90:00:00.0
45:00:00.0
0:00:00.0
315:00:00.0
270:00:00.0
225:00:00.0
1
2
3
4
5
6


2500
2000
1500
1000
500
0
0
5.0×10-5
1.0×10-4
1.5×10-4
2.0×10-4

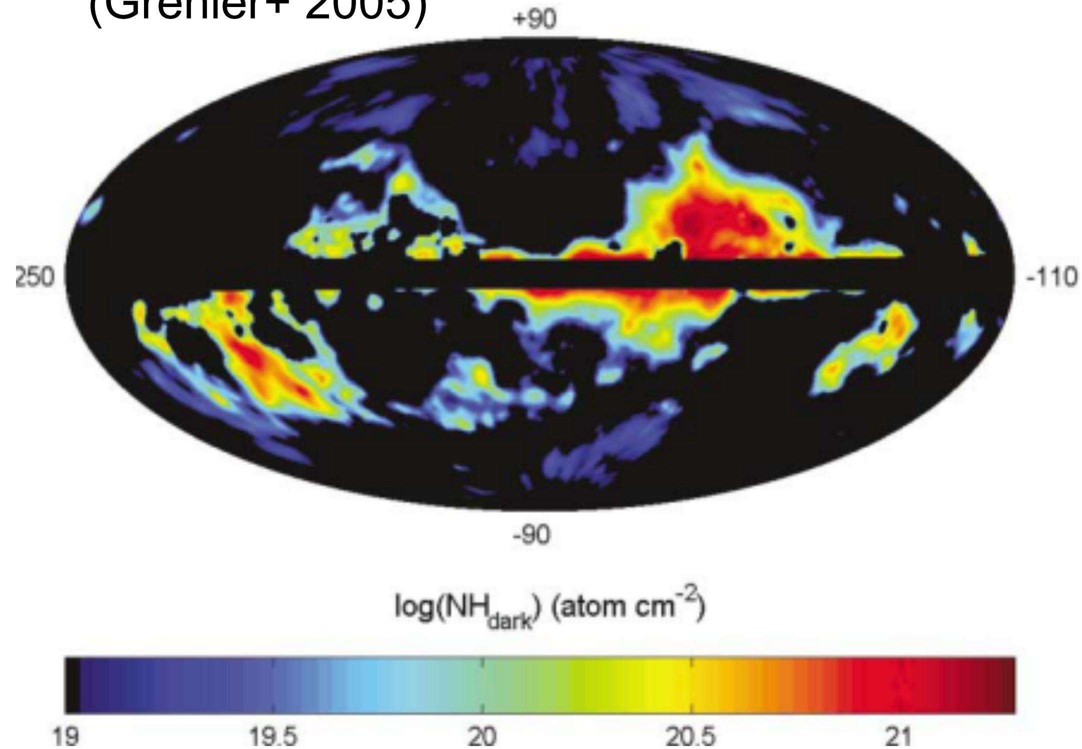
"Dark gas"

$N_H^{corrected} - N_H^{conventional}$



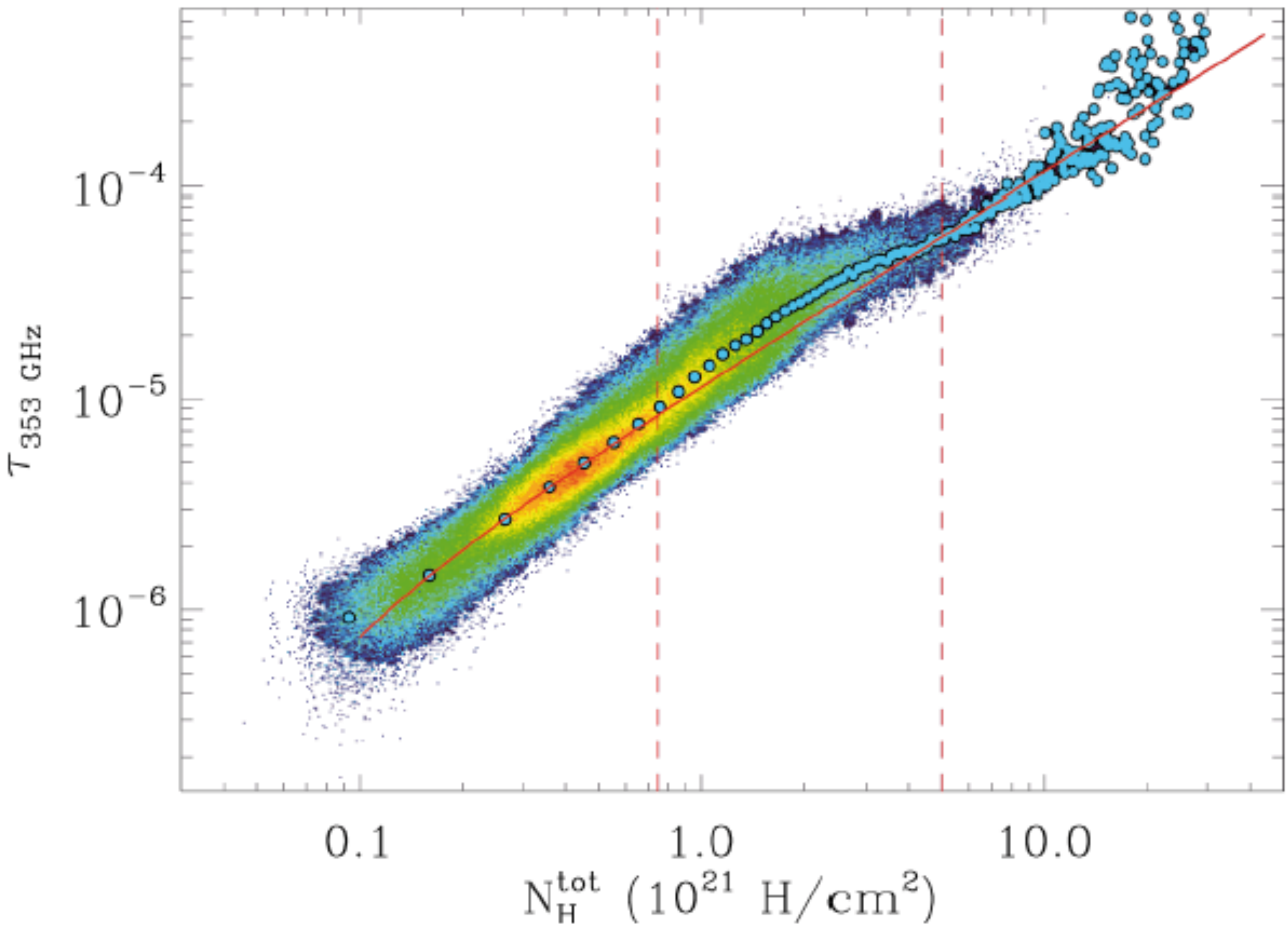
※ Grenier+ (2005)に合わせて*l*=70 °を中心に投影している

Column densities of "dark gas"
(Grenier+ 2005)

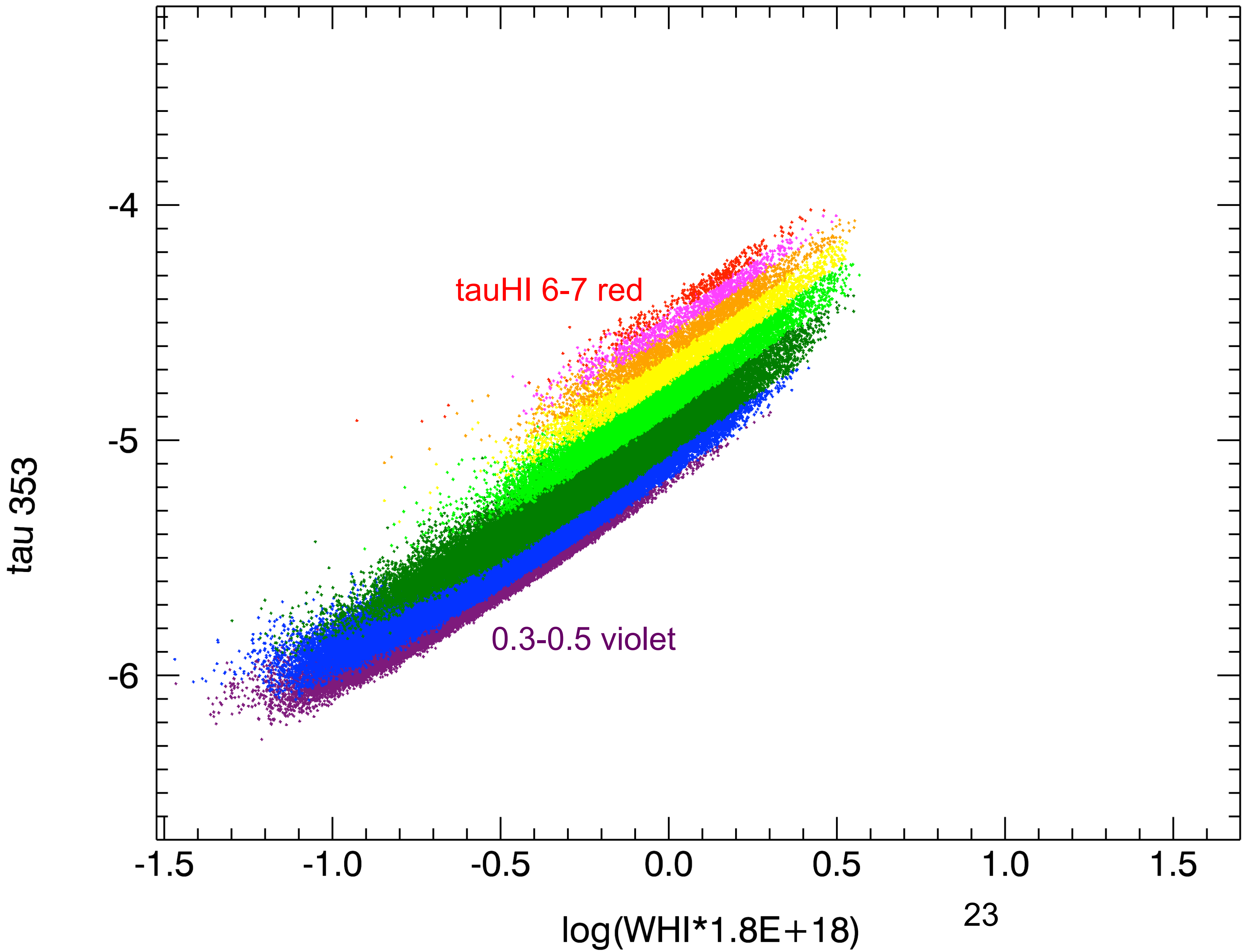


$N_H^{dark} = N_H^{corrected} - N_H^{conventional}$ で再現可能

- $N_H^{conventional} = W_{HI} \times 1.82 \times 10^{18}$ [cm^{-2} /(K km/s^{-1})]
- $N_H^{corrected} = N_H^{conventional} \times$



10^{-4}
10^{-5}
10^{-6}
$\tau_{353\ GHz}$
0.1
1.0
10.0
N_H^{tot} (10^{21} H/cm^2)


tauHI 6-7 red
0.3-0.5 violet
-4
-5
-6
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
tau 353
log(WHI*1.8E+18)

HIは光学的に厚い（τ=1−5以上）

- HI、スピン温度50以下に大量に存在する
  水素原子密度は、ほぼ2倍になる（太陽系近傍）
  （Dickey 2003; Heiles & Troland 2003は連続波の吸収から同様の示唆）

- ガス・ダストの性質の精密な定量、従来よりも１桁向上
  [SKA+ALMA]
  分子雲の力学（dense HIの動圧大）
  分子雲の成長（銀河規模も含めて）
  SNRにおけるガンマ線の起源、dense HIがハドロン起源
- ダスト表面の水素原子の挙動、水素の相転移の理解
  ダスト表面での粒子の挙動の理解
- 宇宙線のエネルギー密度の見直し（Fermi collaboration)
- 宇宙背景放射の前景の理解（Planck collaboration）
- 世界は「薄いHI」で築かれている　大幅かつ広範な改訂が必要

H2 formation timescale

Formation time scale of H_2

$$\frac{dn_2}{dt} = \frac{1}{2}\gamma\langle v_1\rangle n_g n_1 \langle \sigma_g \rangle$$

(Hollenbach & Salpeter 1971; Jura 1974)

γ: sticking probability for incident H atoms.

$<v_1>$: mean thermal velocity of H atoms.

$<\sigma_g>$: average grain cross section.

n_1, n_2 & n_g: number density of HI, H_2 and grains, respectively

$$t_{\mathrm{form}} = n_2 \left(\frac{dn_2}{dt}\right)^{-1} \sim 10^7 \left(\frac{10^2\ \mathrm{cm}^{-3}}{n_1}\right)\ [\mathrm{yr}]$$

Workshop
Birth and death of high-mass stars: Lesson on newly explored phases of the interstellar medium

January 8-11, 2014
Nagoya University

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