Study of the Cosmic Rays and Interstellar Medium in Local HI Clouds using Fermi-LAT Gamma-Ray Observations

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On behalf of the Fermi-LAT collaboration

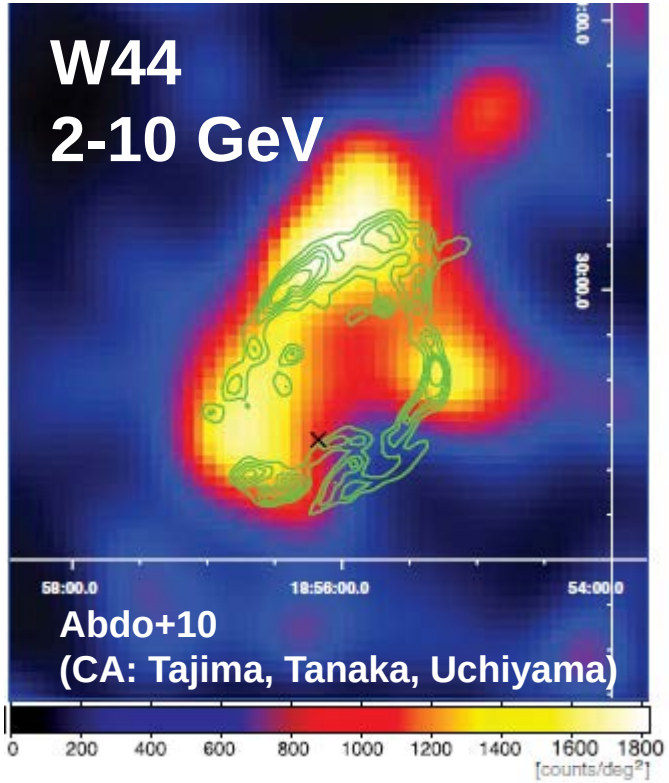
フェルミ衛星による太陽系近傍原子雲の宇宙線・星間ガスの研究(2)

2018年9月17日@日本物理学会
(信州大学)

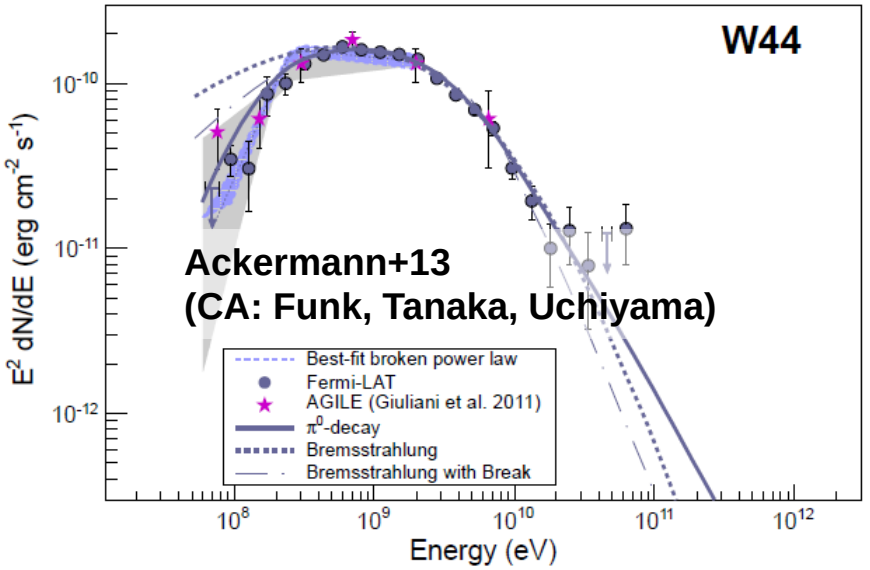
水野　恒史(広島大学)ほか
Fermi-LAT Collaboration

Motivation: ISM as a Tracer of CRs

γ-ray image
w/ 4.5 μm contours



low-energy cutoff
= signature of pi^0-decay

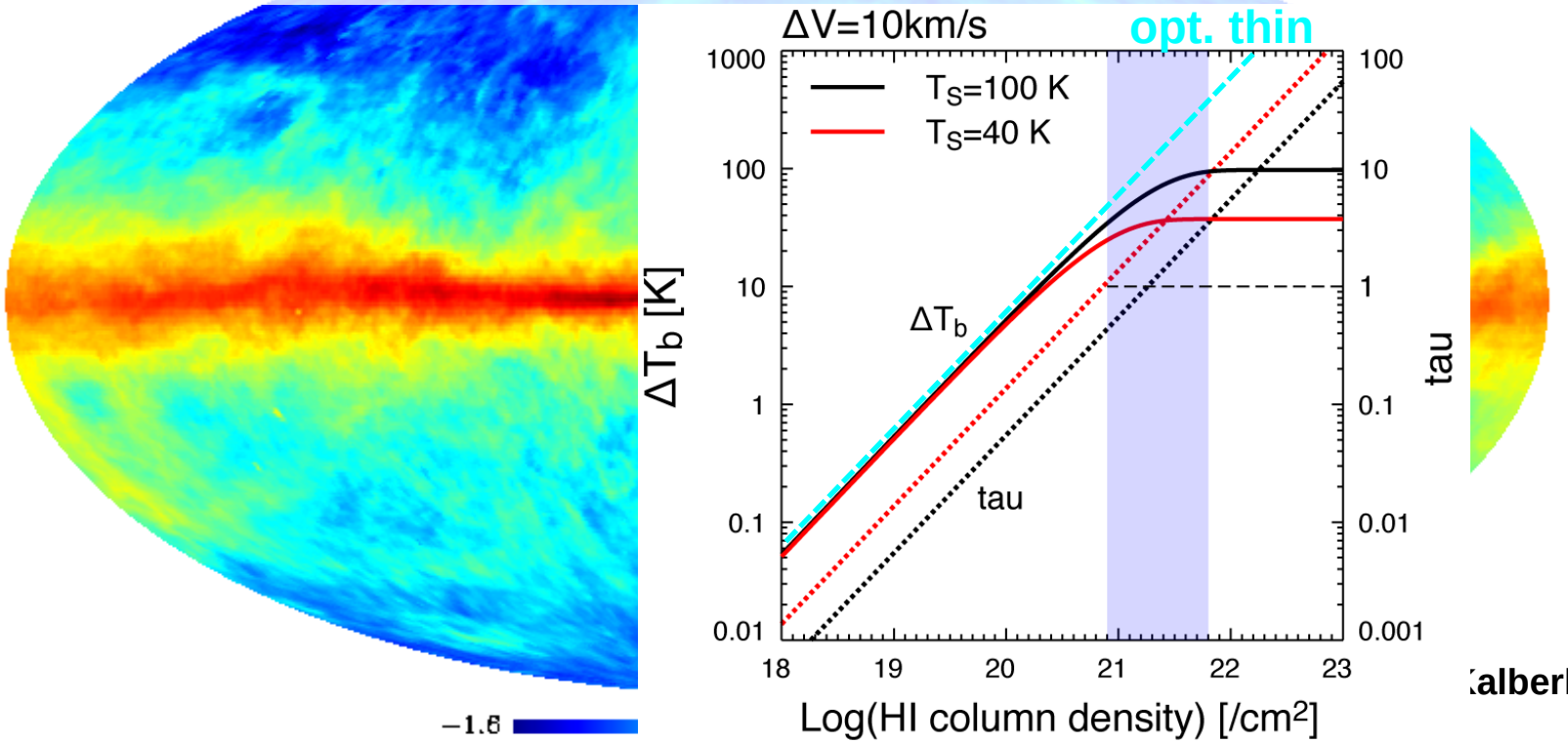


W_{SN}	5×10^{51} erg
W_{CR}	4×10^{49} $(n/100\ \mathrm{cm}^{-3})^{-1}$ erg

Accurate estimate of the interstellar medium (ISM) gas densities is crucial to study Galactic cosmic rays (CRs), because $I_\gamma \propto N_H U_{CR}$

Atomic Gas

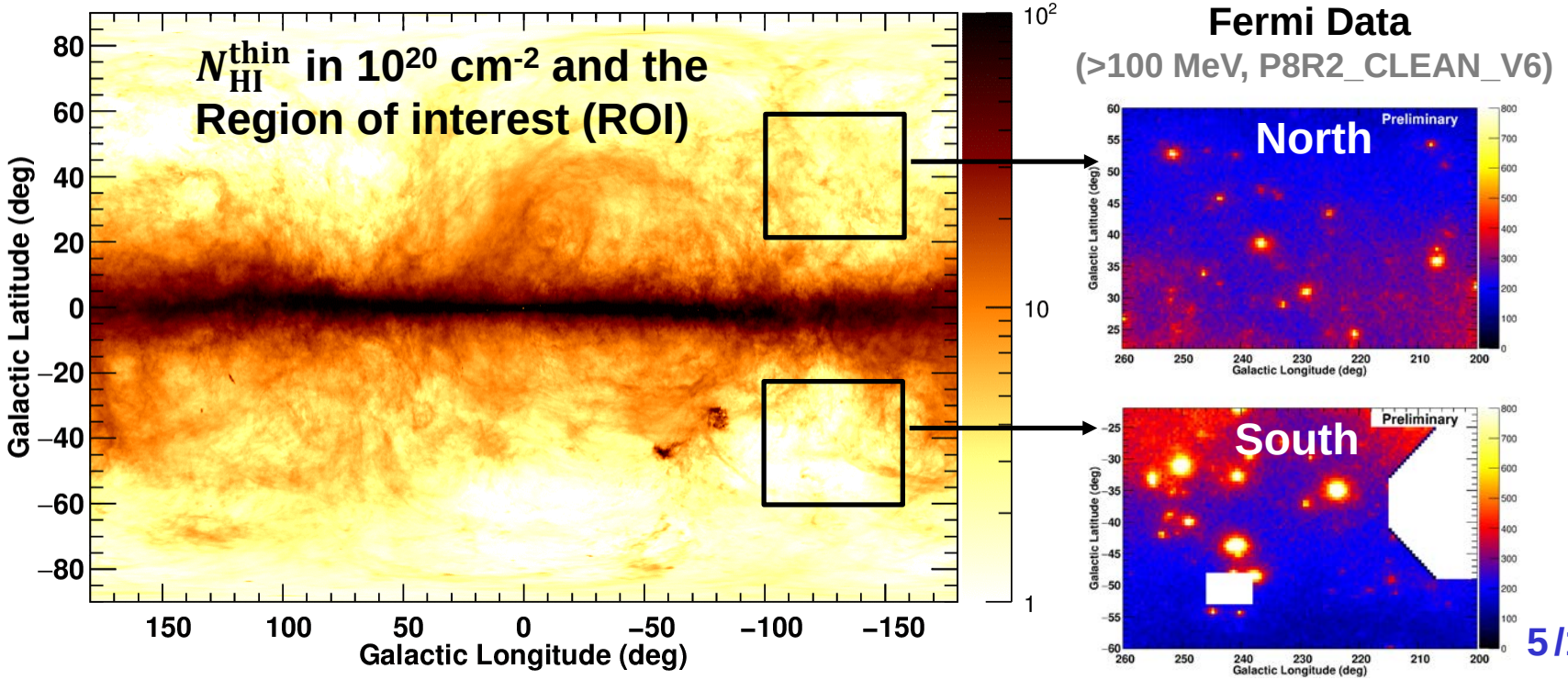
- **Main component of ISM, scale height ~ 200 pc**
- **Traced by 21 cm line (W_{HI})**
  - **True N_{HI} is uncertain due to the uncertainty of the spin temperature (T_S)**



(Kalberla+05)

Objectives of the Study

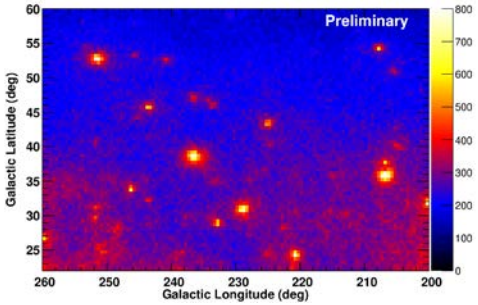
- **Accurate estimate of the ISM gas densities is crucial to understand the ISM and Galactic CRs**
- **Procedure to trace the "dark gas" (gas not properly traced by HI and CO line surveys (Grenier+05)) not established yet => detailed study of nearby clouds**



Fitting Procedure

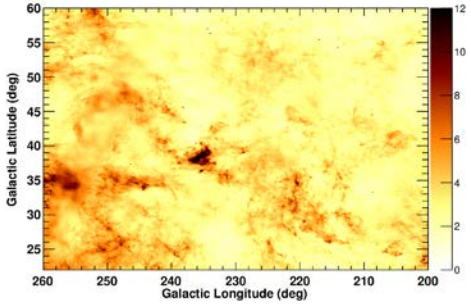
- **Uniform CR density (assumption testable by energy dependence) -> the γ-ray intensity can be modeled as a <u>linear combination of templates</u>**

Fermi Data

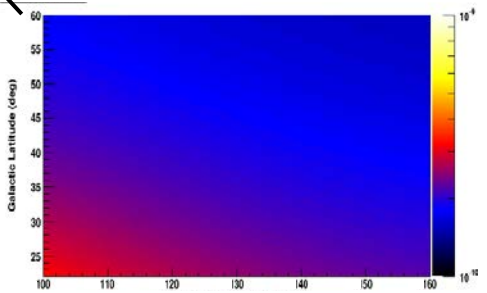


$$I_\gamma(l,b,E) = q_\gamma(E)\cdot N_{\mathrm{H}}(l,b) + I_{\mathrm{IC}}(l,b,E) + I_{\mathrm{iso}}(E) + \Sigma\, I_{\mathrm{source}}(l,b,E) + \cdots$$

Planck dust, LAB H_I, W_{CO}, etc.



IC model (e.g., galprop)



$q_\gamma(E)$ tells us CR density/spectrum

$$N_{\mathrm{H}} = \Sigma_i\ a_i \cdot N(\mathrm{H}_i)$$
$$(\mathrm{e.g.}, N(\mathrm{H_I}) + 2X_{\mathrm{CO}}\cdot W_{\mathrm{CO}} + X_{\mathrm{DG}}\cdot N(\mathrm{H_{DG}}))$$

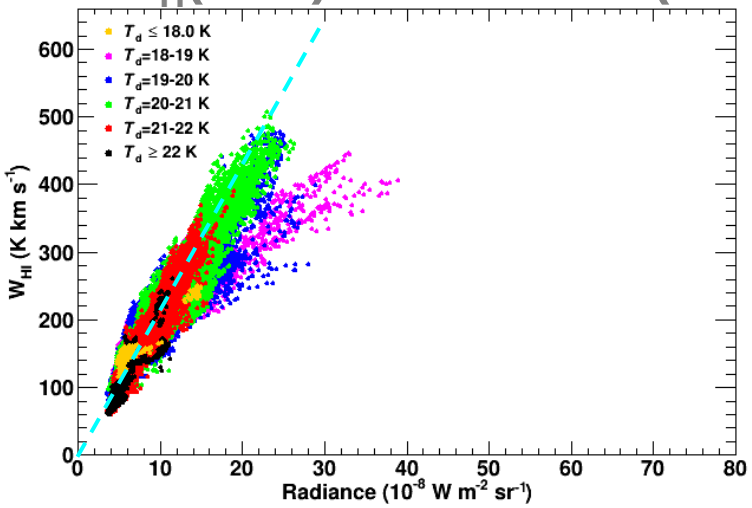
Fit quality tells us which tracer is better
Coefficients (a_i) tell us gas properties

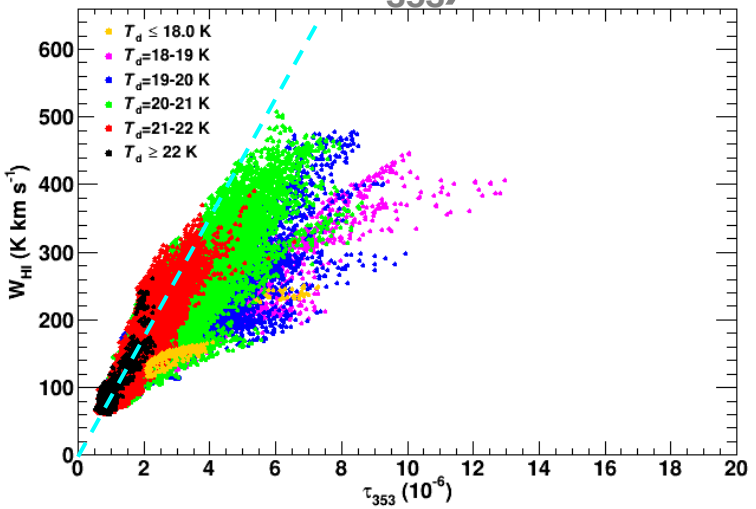
We employ "P305" data to reduce residual background toward Ecliptic/Equator while keeping high photon statistics (public data w/ stringent cut also OK)

W_{HI}-Dust Relation (North)

- Correlation btw. W_{HI} and dust emission D_{em} (R or τ_{353})
- Dust temperature (T_d) dependence is seen in W_{HI}-τ_{353} correlation
- Linear curves that follow trends in high T_d area are used to construct N_H model maps assuming $N_H \propto D_{em}$

$N_H(cm^{-2})=1.82x10^{18}$ x ($21.1x10^8$ R or $87.2x10^6$ τ_{353})



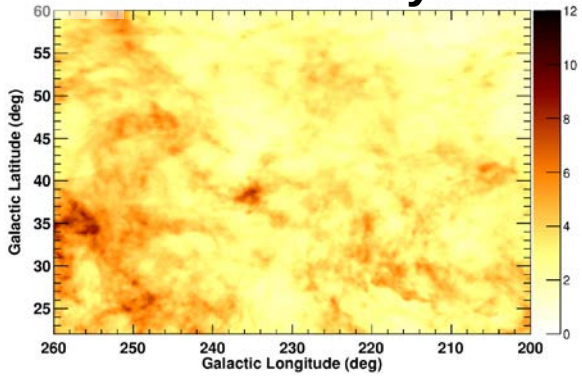


N_H Model Maps and Residuals (North)

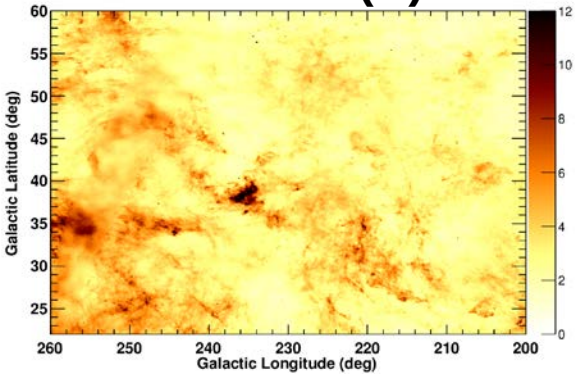
- **We prepared N_H model maps ($\propto W_{HI}$ or D_{em}) and used them in a fit of γ-ray data -> R gives the best fit.**

N_H in 10^{20} cm^{-2}

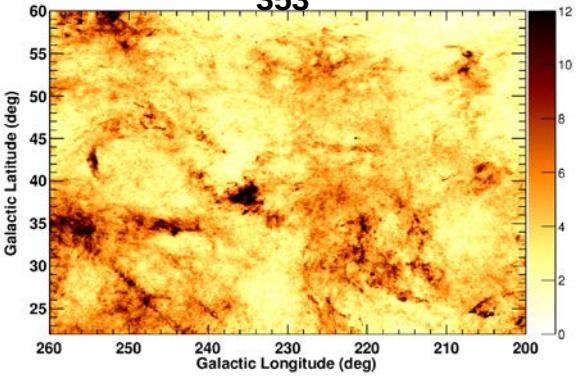
North HI4PI survey

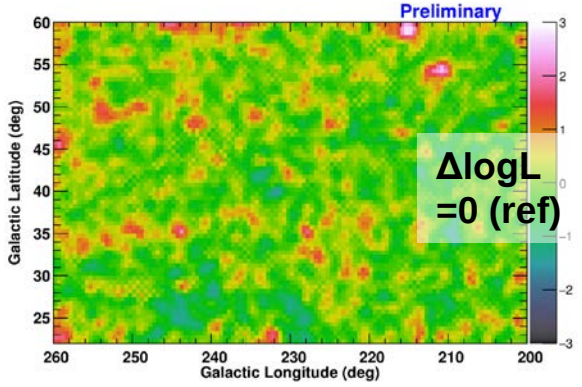


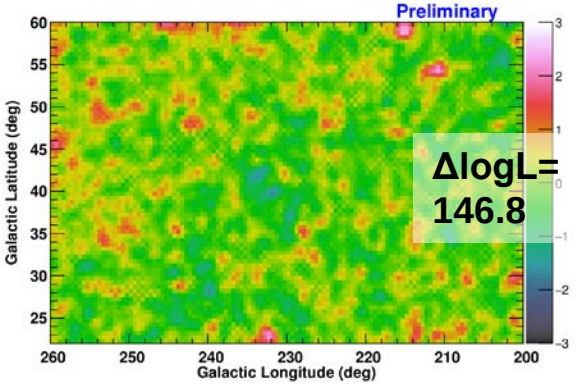
radiance (R)

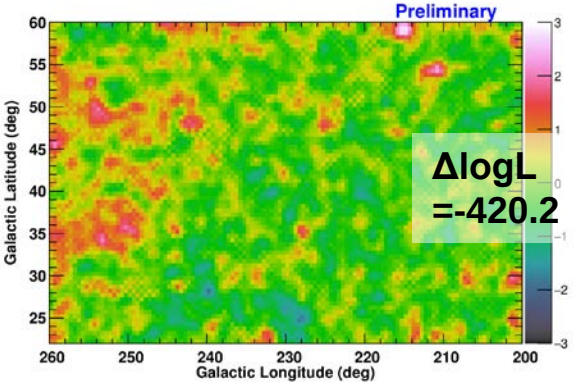


τ_{353}





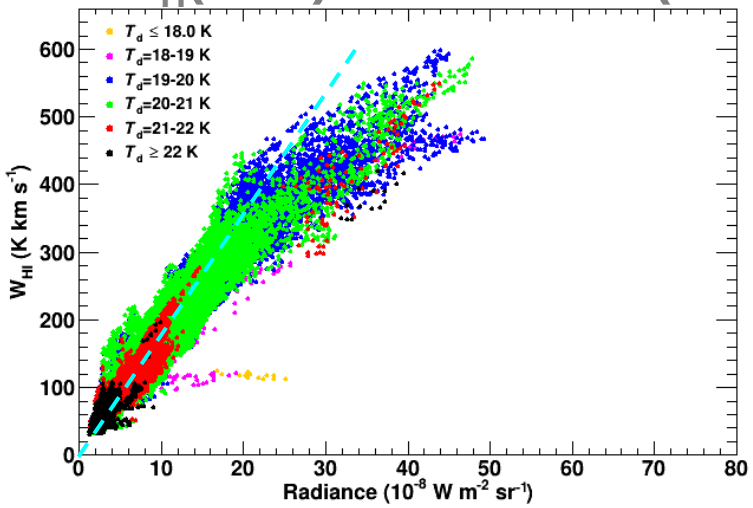


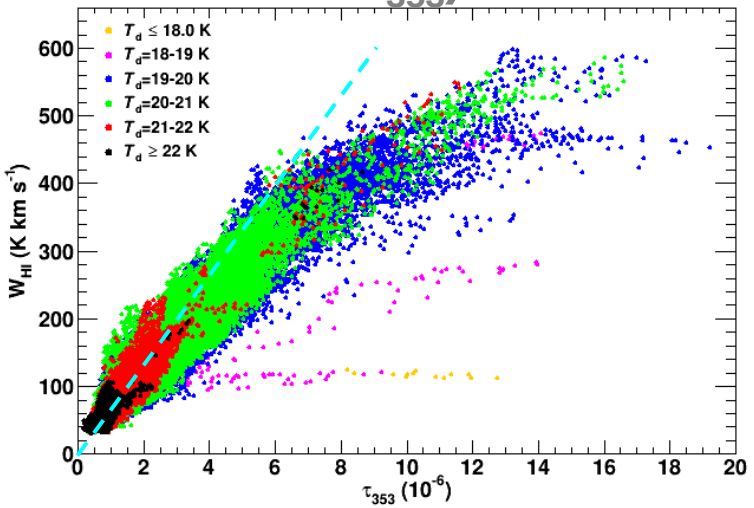


W_{HI}-Dust Relation (South)

- Correlation between W_{HI} and D_{em} (R or τ_{353})
- Weak T_d dependence, non-linear W_{HI}-D_{em} relations (N_H/D_{em} and/or N_H/N_{HI} not uniform)
- Linear curves that follow trends in (high T_d & low W_{HI}) area are used to construct N_H model maps assuming $N_H \propto D_{em}$

$N_H(cm^{-2})=1.82x10^{18}$ x ($17.6x10^8$ R or $66.9x10^6$ τ_{353})





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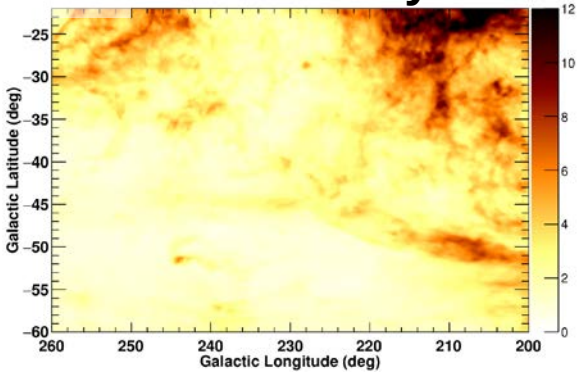
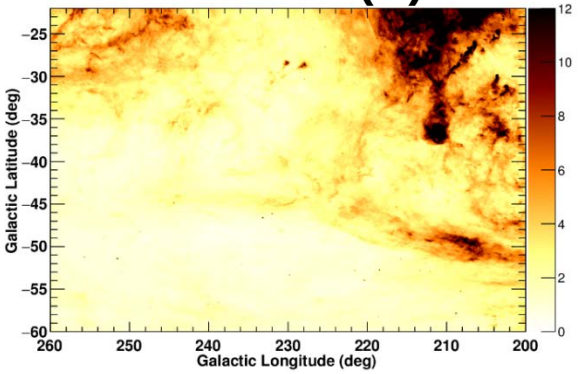
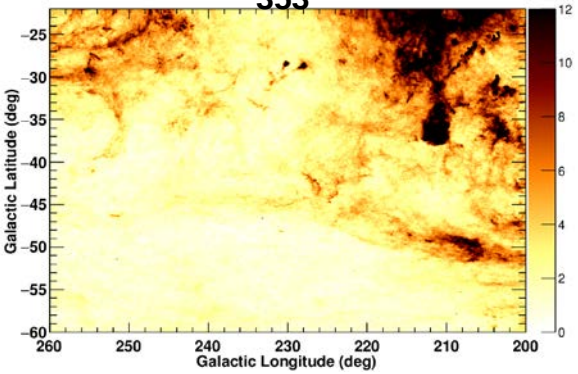
South HI4PI survey

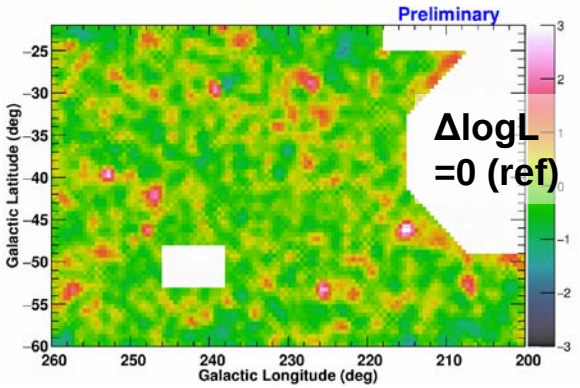
radiance (R)

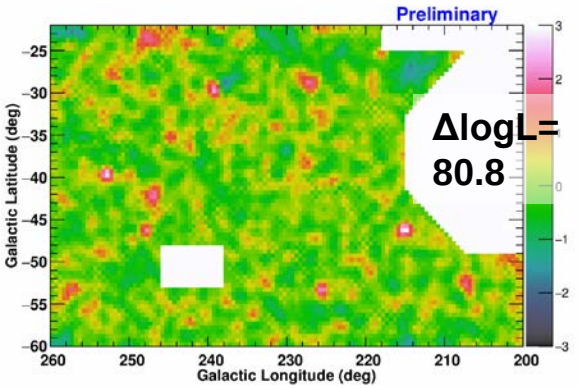
τ_{353}

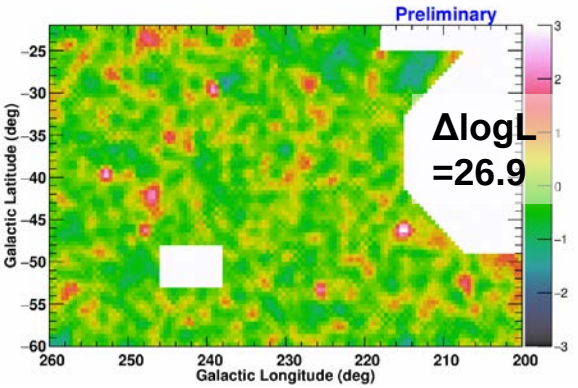












Summary & Future Prospect

- **We have been studying CRs and ISM in mid-latitude region of the 3rd quadrant.**
  - **Establish the procedure to convert D_{em} to N_H, constrain CRs and ISM gas properties**
  - **Employ P305 data to suppress residual background**
- **ISM gas tracer investigation (W_{HI}-D_{em} relationship):**
  - **T_d dependence in North, D_{em} dependence in South**
- **γ-ray data analysis:**
  - **R gives best fit (North and South)**

- **Now evaluating T_d/D_{em} dependence with systematic uncertainties into account to discuss CR/ISM properties**

Thank you for your Attention

Reference

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- Abdo+10, Science 327, 1103
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- Grenier+05, Science 307, 1292
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- Planck Collaboration 2014, A&A 571, 13 (Planck 2013 Results XIII)