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LAT検出器による近傍原子雲領域の星間ガス・宇宙線の研究

2018年9月21日@日本天文学会
(兵庫県立大学)

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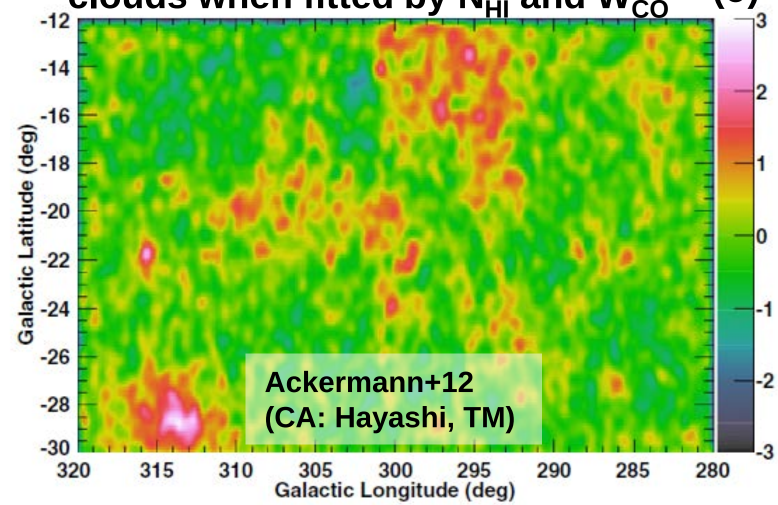
Motivation: Dark Gas

- **Significant amount of ISM gas not well traced by standard 21 cm and 2.6 mm lines (Grenier+05)**

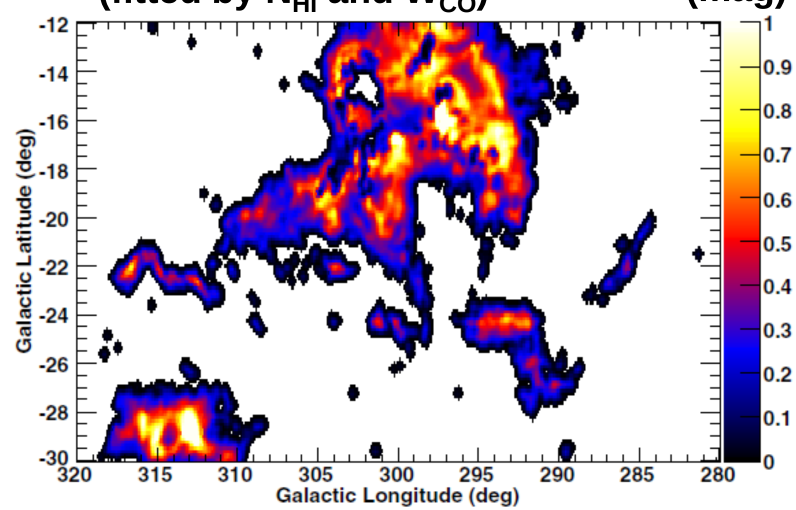
Chamaeleon Molecular Cloud:
$M_{H2,CO} \sim 5\times10^{3}\ M_{solar}$
$M_{DG} \sim 2\times10^{4}\ M_{solar}$

- **This "dark gas"(DG) usually traced by dust, but <u>the procedure not established</u>**
- **Also affect the study of cosmic rays (CRs) because** $I_{\gamma} \propto N_{\mathrm{H}} U_{\mathrm{CR}}$

Residual γ rays in the Chamaeleon clouds when fitted by N_{HI} and W_{CO}

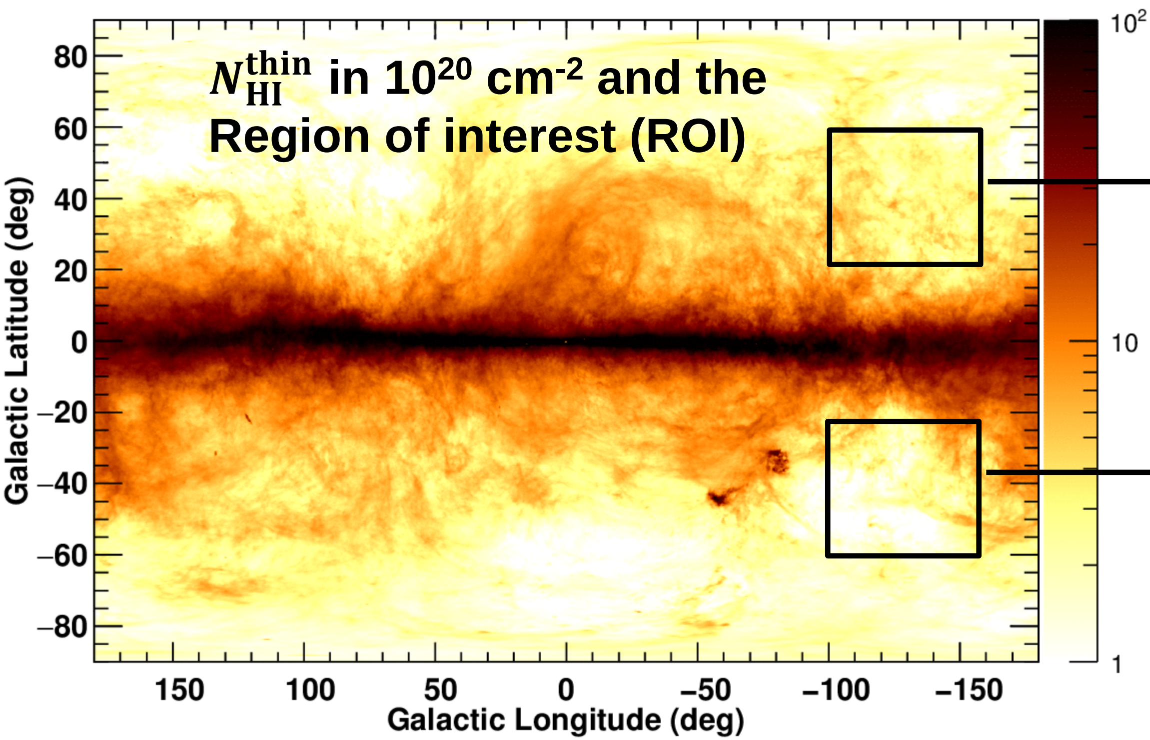


Residual gas inferred by <u>dust</u> (fitted by N_{HI} and W_{CO})

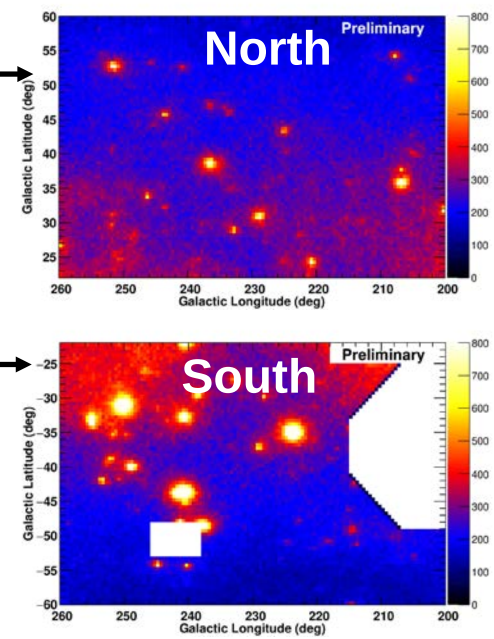


Objectives of the Study

- **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**



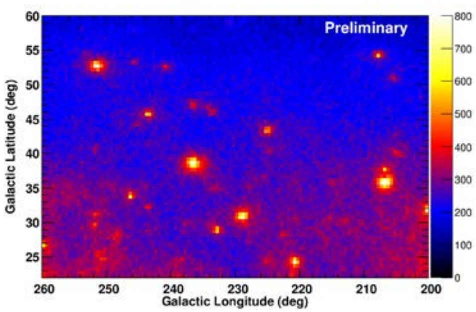
Fermi Data
(>100 MeV, P8R2_CLEAN_V6)



Fitting Procedure

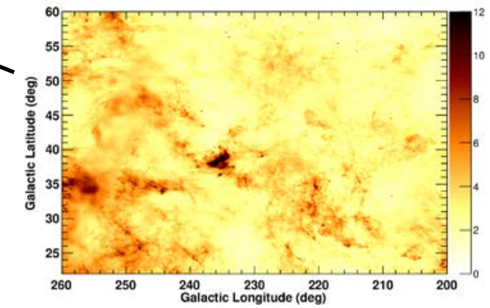
- **Uniform CR density (assumption testable by energy dependence) -> the γ-ray intensity can be modeled as a <u>linear combination of templates</u>**

Fermi Data

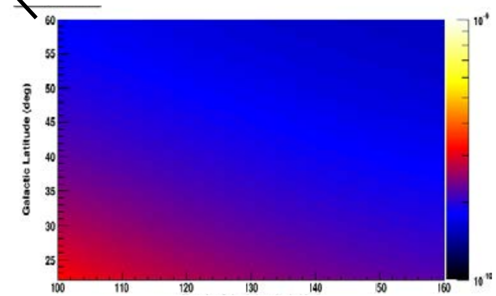


$$I_\gamma(l,b,E) = q_\gamma(E)\cdot N_{\mathrm{H}}(l,b) + I_{\mathrm{IC}}(l,b,E) + I_{\mathrm{iso}}(E) + \Sigma\, I_{\mathrm{source}}(l,b,E) + \cdots$$

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



IC model (e.g., galprop)



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

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

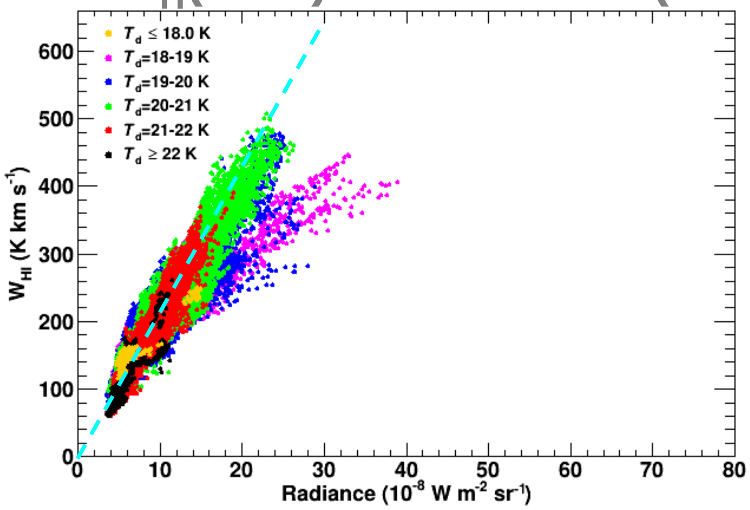
Fit quality tells us which tracer is better
Coefficients (a_i) tell us gas properties

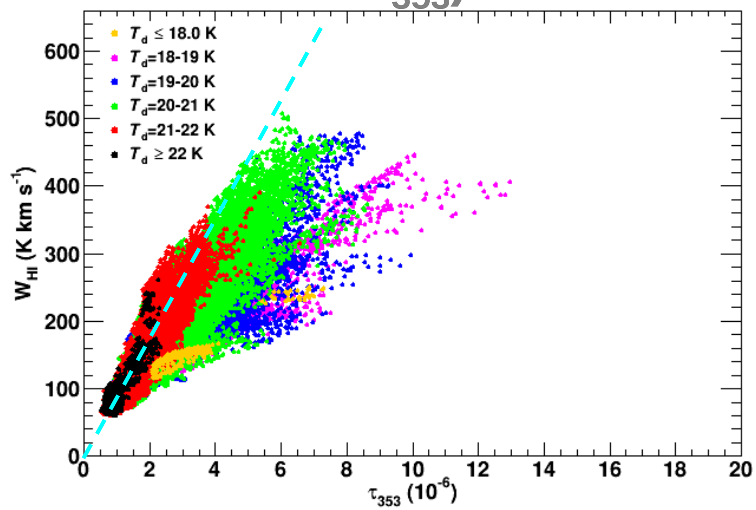
We employ "P305" data to reduce residual background toward Ecliptic/Equator while keeping high photon statistics (public data w/ stringent cut also OK)

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 $N_H \propto D_{em}$

$N_H(cm^{-2}) = 1.82\times10^{18} \times (21.1\times10^{8}\ R \text{ or } 87.2\times10^{6}\ \tau_{353})$



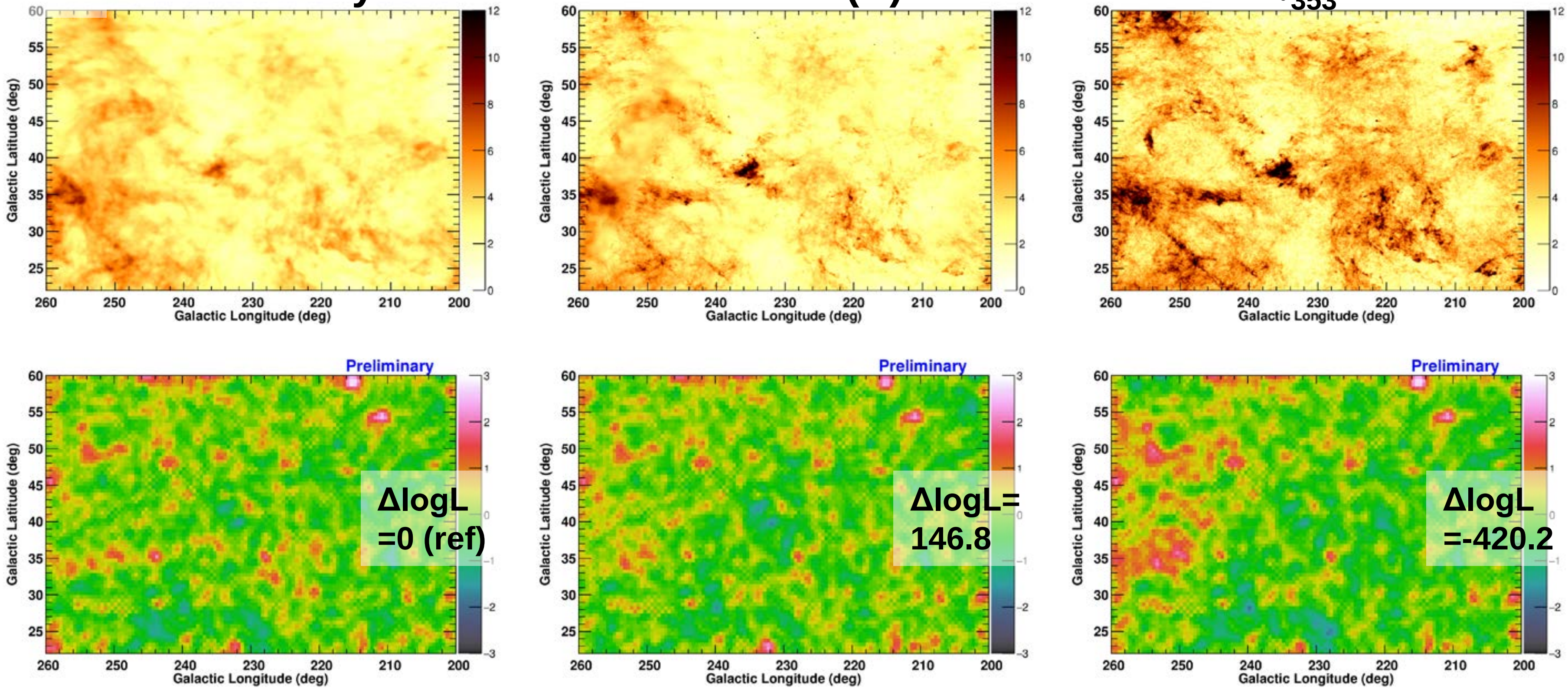


N_H Model Maps and Residuals (North)

- **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}

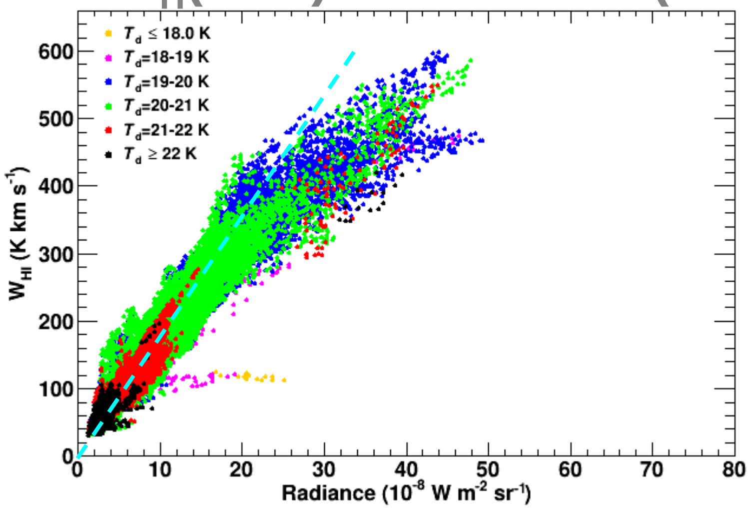
North HI4PI survey | **radiance (R)** | τ_{353}

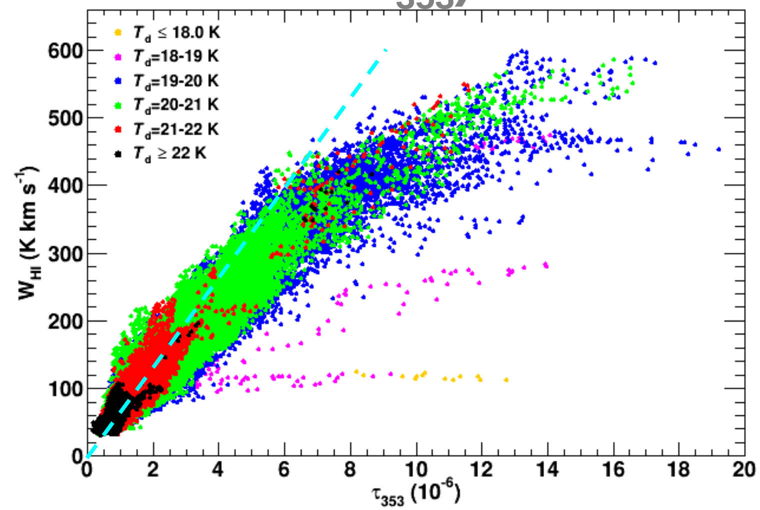


W_{HI}-Dust Relation (South)

- **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 $N_H \propto D_{em}$**

$N_H(\mathrm{cm}^{-2}) = 1.82\times10^{18} \times (17.6\times10^{8}\ R \text{ or } 66.9\times10^{6}\ \tau_{353})$



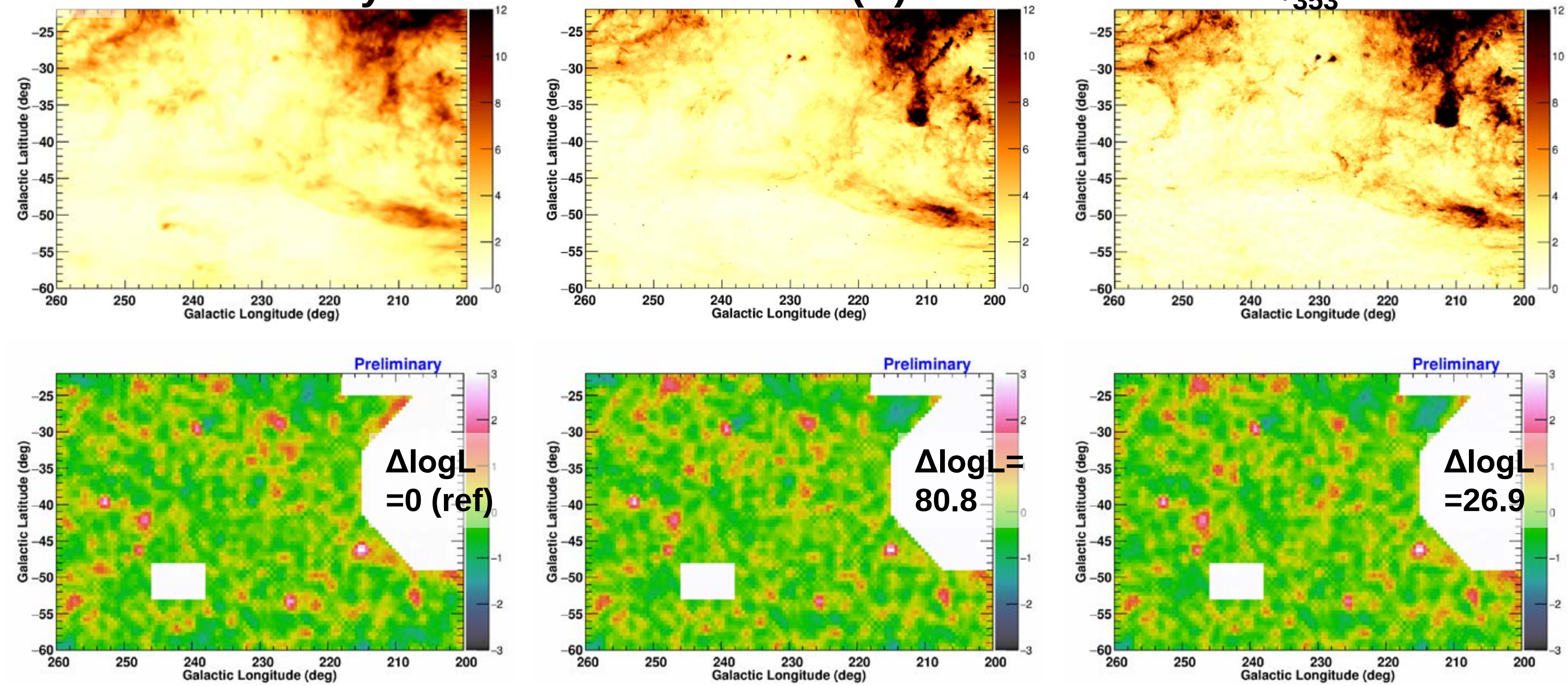


N_H Model Maps and Residuals (South)

- **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}

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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- Mori09, Astropart. Phys. 31, 341
- Planck Collaboration 2014, A&A 571, 13 (Planck 2013 Results XIII)