Study of the ISM and CRs in the MBM 53-55 Clouds and the Pegasus Loop (2)

Sep. 12th, 2017@ASJ meeting in Hokkaido

T. Mizuno (Hiroshima Univ.) on behalf of the Fermi-LAT Collaboration

(Mizuno+16, ApJ 833, 278)

フェルミ衛星によるMBM 53-55分子雲・Pegasus Loop領域の星間ガスと宇宙線の研究(2)

Sep. 12th, 2017@北海道大学(日本天文学会)

水野恒史 (広島大学) on behalf of the Fermi-LAT Collaboration

(Mizuno+16, ApJ 833, 278)

Introduction: Dark Gas

- **A significant amount of ISM (interstellar medium) gas not traced by standard 21 cm and 2.6 mm radio lines has been recognized recently**

Chamaeleon Molecular Cloud:

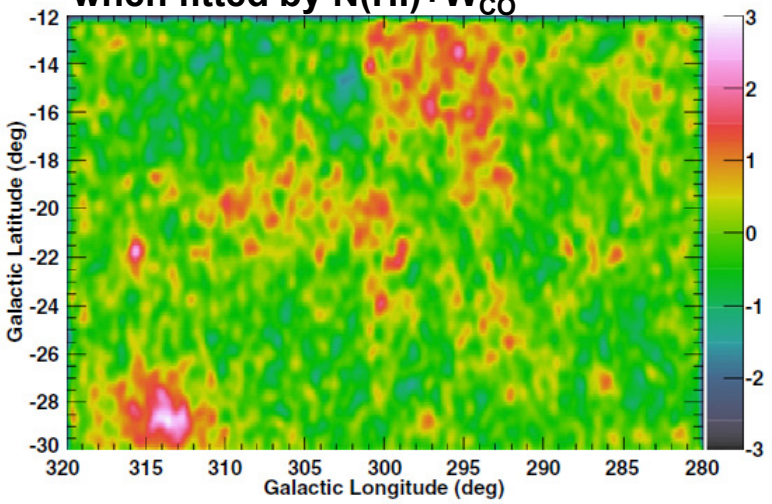
$M_{H2,CO} \sim 5 \times 10^3 M_{solar}$

$M_{DG} \sim 2 \times 10^4 M_{solar}$

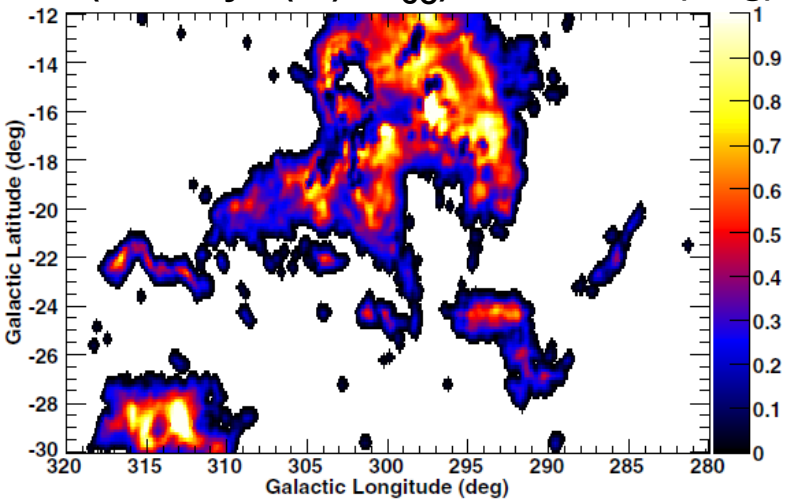
Ackermann+12, ApJ 755, 22 (CA: Hayashi, TM)

- **These "dark gas"(DG) can be traced by infrared (IR) and γ-ray observations, but <u>the procedure has not been established yet</u>**

Residual γ rays in Chamaeleon when fitted by $N(HI)+W_{CO}$



Residual gas inferred by dust (fitted by $N(HI)+W_{CO}$)



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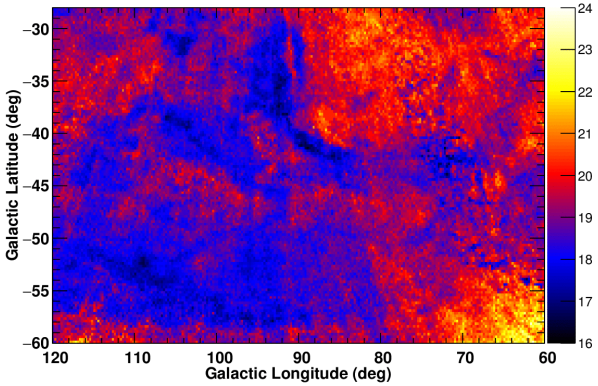
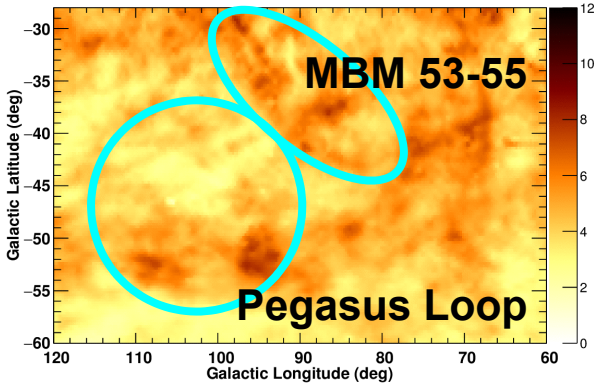
Study of ISM (and CRs) using Fermi-LAT

- The procedure to convert dust distribution into $N(H_{tot})$ has not been established yet, giving uncertainty in dark gas distribution
- Here we present the study of MBM53-55 and the Pegasus loop by using γ-rays as a robust tracer of $N(H_{tot})$
  - Under the assumption of uniform cosmic-ray (CR) density, we can trace $N(H_{tot})$ by γ-rays since $I_\gamma \propto N(H_{tot})U_{CR}$

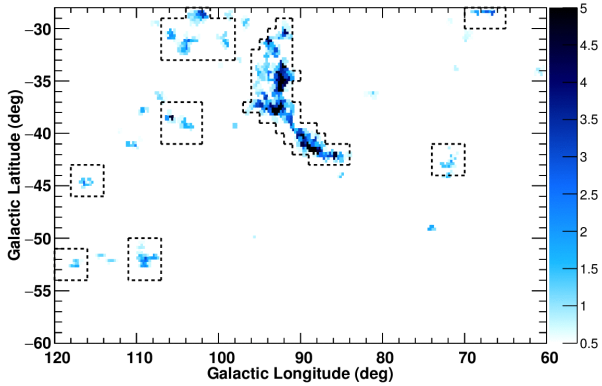
dust temperature (T_d)



$N(HI_{thin})$ (10^{20} cm^{-2})



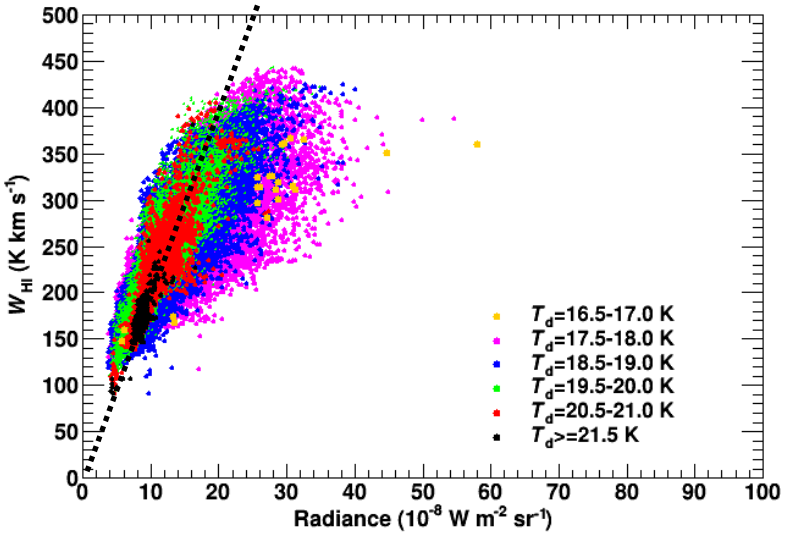
W_{CO} (K km s^{-1})

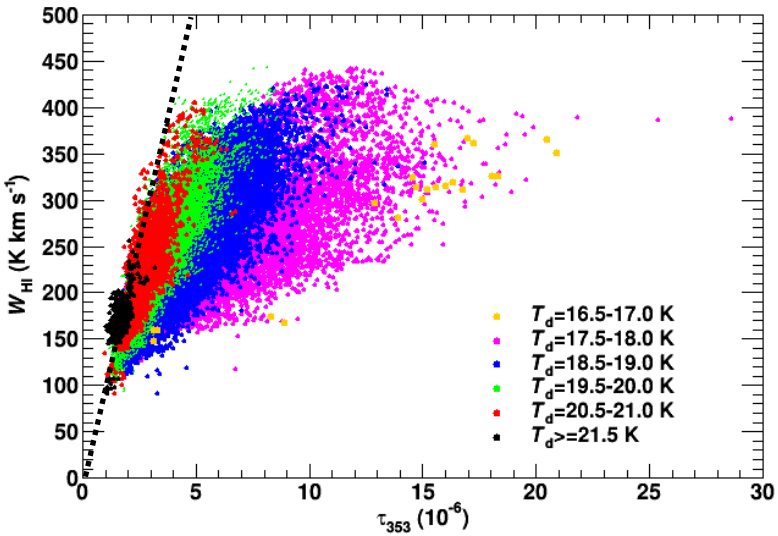


W_{HI}-Dust Relation (1)

- **Dust is mixed with gas and has been used as a tracer of $N(H_{tot})$**
  - **But what kind of quantity should we use?**
- **We examined correlations btw. W_{HI} and two dust tracers (radiance (R) and opacity at 353 GHz (τ_{353})) (see also Fukui+14,15, Planck Collab. 2014)**
  - **Two tracers show different and T_d-dependent correlations with W_{HI}**

(Areas with W_{co}>1.1 K km/s are masked)
(Lines show best-fit linear relations in T_d>21.5 K)





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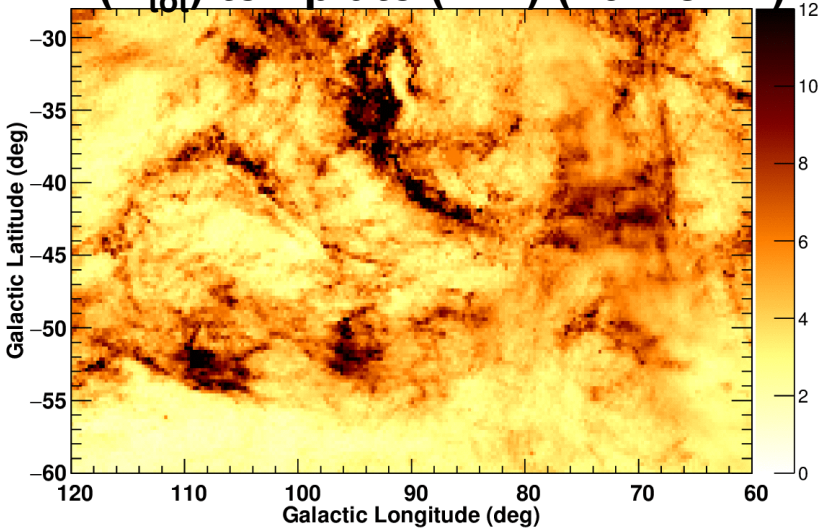
W_{HI}-Dust Relation (2)

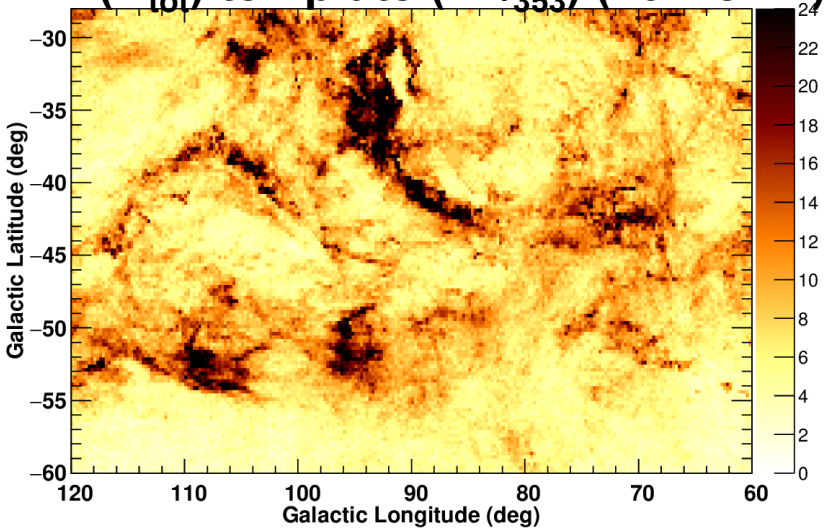
- Dust is mixed with gas and has been used as a tracer of $N(H_{tot})$
  - But what kind of quantity should we use?
- We examined correlations btw. W_{HI} and two dust tracers (radiance (R) and opacity at 353 GHz (τ_{353})) (see also Fukui+14,15, Planck Collab. 2014)
  - Two tracers show different and T_d-dependent correlations with W_{HI}

    => Different contrast in $N(H_{tot})$ template maps ($\propto$ R, τ_{353}). The map $\propto$ R gives better fit to γ-ray data

$N(H_{tot})$ template ($\propto$ R) (10^{20} cm^{-2})



$N(H_{tot})$ template ($\propto \tau_{353}$) (10^{20} cm^{-2})



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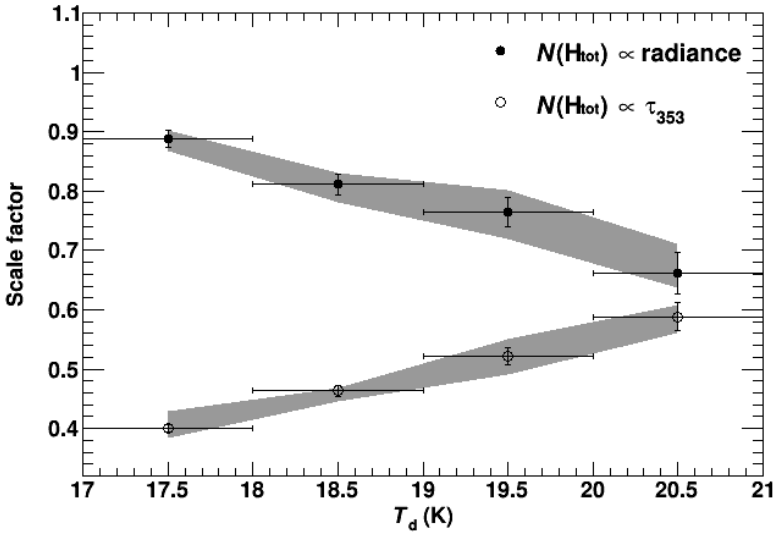
T_d-Sorted Modeling

- Even though R-based $N(H_{tot})$ is preferred by γ-ray data, true $N(H_{tot})$ could be appreciably different
- Therefore we split $N(H_{tot})$ template map into four based on T_d and fit γ-ray data with scaling factors freely varying individually
  - Scale factors should not depend on T_d if $N(H_{tot}) \propto D$ (R or τ_{353}) and U_{CR} is uniform
- Fit improves significantly but scale factors depends on T_d
  - Negative correlation with R implies underestimate of $N(H_{tot})$ in low T_d

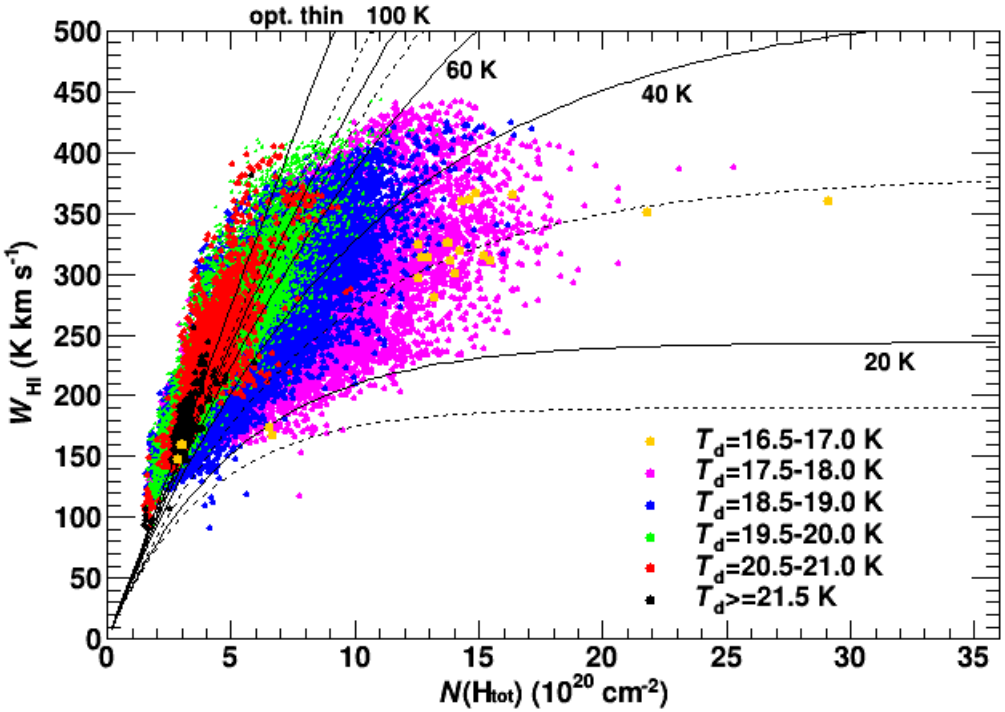


We propose to use γ-ray data to compensate for the dependence

$$N(\mathrm{H_{tot,mod}}) = \left(1 + 0.1\,\frac{20.5\ \mathrm{K} - T_d}{1\ \mathrm{K}}\right) N(\mathrm{H_{tot,}}_R)$$

Discussion of the ISM (1)

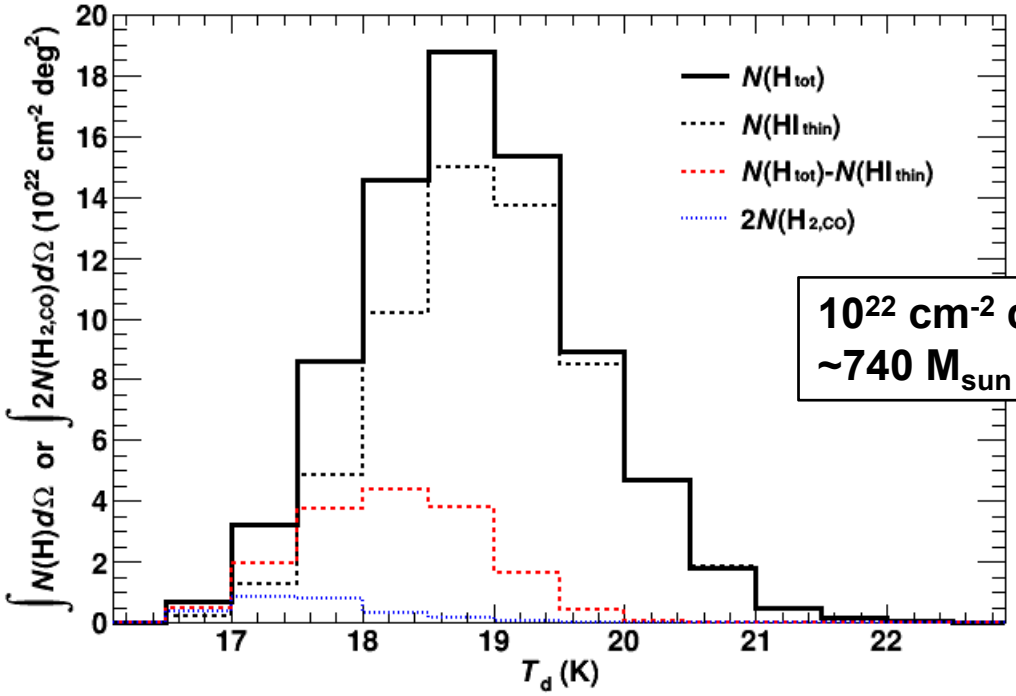
- **The correlation between W_{HI} and the "corrected" $N(H_{tot})$ map**
  - **Scatter due to dark gas (DG). T_s<100 K is inferred in the scenario that optically thick HI dominates**



Discussion of the ISM (2)

- **Integral of gas column density ($\propto M_{gas}$) as a function of T_d for $N(H_{tot})$, $N(HI_{thin})$, $N(H_{tot})$-$N(HI_{thin})$(~N(H) for dark gas) and $2N(H_{2,CO})$**
  - **M_{DG} is ~25% of $M_{HI,thin}$ and ~ 5 x $M_{H2,CO}$, larger than model predictions of CO-dark H_2 scenario (NB: different physical conditions)**
  - **M_{DG} differs by a factor of ~4 if we use only R (or τ_{353}); The correction based on γ-ray data is crucial**

M(DG,γ) = ~ 4 x M(DG, R)
~1/4 x M(DG, τ_{353})



10^{22} cm^{-2} deg^2 corresponds to ~740 M_{sun} for d=150 pc

Summary

- An accurate estimate of ISM densities is important
- Diffuse GeV γ rays are a powerful probe to study the ISM (and CRs)
- We present a joint Planck & Fermi-LAT study of MBM 53-55 clouds and the Pegasus loop for the first time
  - We propose to use γ rays as a robust tracer of $N(H_{tot})$, and obtained the ISM (and CR) properties
  - We obtained physical quantities of the ISM and CRs (e.g., T_s for HI dominant scenario, mass of dark gas)

- Systematic study of other high-latitude regions is important and underway

Thank you for your Attention