



Fermi

Gamma-ray Space Telescope

フェルミガンマ線衛星による カメレオン座分子雲の観測

林 克洋、水野 恒史、佐田貴幸
(広島大学)

On behalf of the Fermi-LAT
Collaboration

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Giant Molecular Cloud (GMC)

Giant molecular cloud

- 分子雲を構成する分子: 水素原子について量が多い
- Temperature $\sim 10\text{K}$, Mass $\sim 10^{4-6} M_{\text{sun}}$, density $\sim 10^{2-3} \text{ cm}^{-3}$ 、星形成の現場
- 多くは solar circle 内に存在、太陽系近傍($<1\text{kpc}$)にも存在 (Orion, Taurus, etc)
- 放射・吸収のメカニズム
 - 分子の回転遷移 (主として CO line) \rightarrow radio \longleftrightarrow H_2 (分子ガスの主成分) 直接検出できない
 - dust による吸収・放射 \rightarrow optical, infra-red
 - 宇宙線との相互作用

$p +$

“Gamma-ray = 宇宙線強度 \times 物質(ガス)”

ガンマ線放射率は物質の温度や状態に依存しない

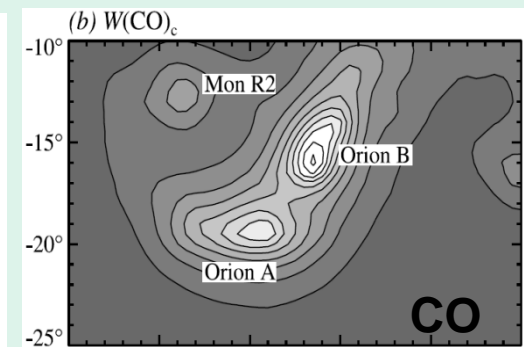
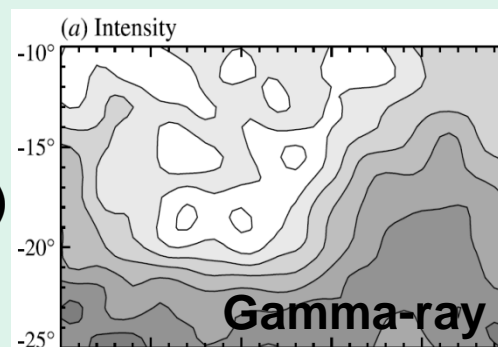
\rightarrow ガンマ線によって宇宙線スペクトルや物質の分布を明らかにできる

90' EGRET 感度が不十分

ガンマ線が検出されたGMC 少ない

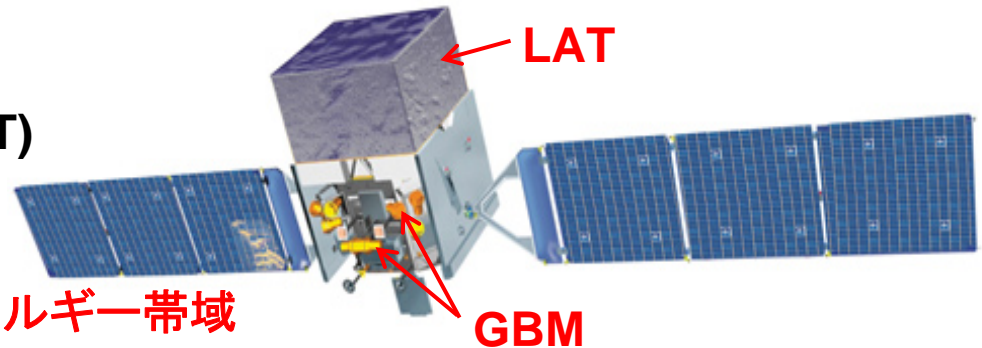
e.g; Orion MC
(Digel et al. 1999)

宇宙線や物質分布までの詳細な議論までには至らず



Fermi Gamma-ray Space Telescope

- Launched on June 11, 2008
- Two instruments:
 - Large Area Telescope (LAT)
e⁺/e⁻ pair-conversion
with silicon detectors
 - Gamma-ray Burst Monitor (GBM)



高分解能・高感度・広いエネルギー帯域

	CGRO-EGRET	Fermi-LAT
Angular resolution @100MeV	5.8 deg	3.5 deg
@1GeV	1.7 deg	0.6 deg
Effective area	1500cm ²	≥8000cm ²
Energy range	20 MeV - 30 GeV	20 MeV - 300 GeV
Detected sources (>5σ)	271 (10 years)	444 (3 months)

Motivation

With Fermi, we are able to study small ($M \leq 10^4 M_{\text{sun}}$) GMCs.

Detailed study of large GMCs ($M \sim 10^5 M_{\text{sun}}$) such as Orion
(2009 春年会 奥村講演)

多くのサンプルの中から宇宙線や物質分布を詳細に明らかにする

- Cosmic-rays

What is the distribution of local CRs?

Dependence on the star-formation activities?

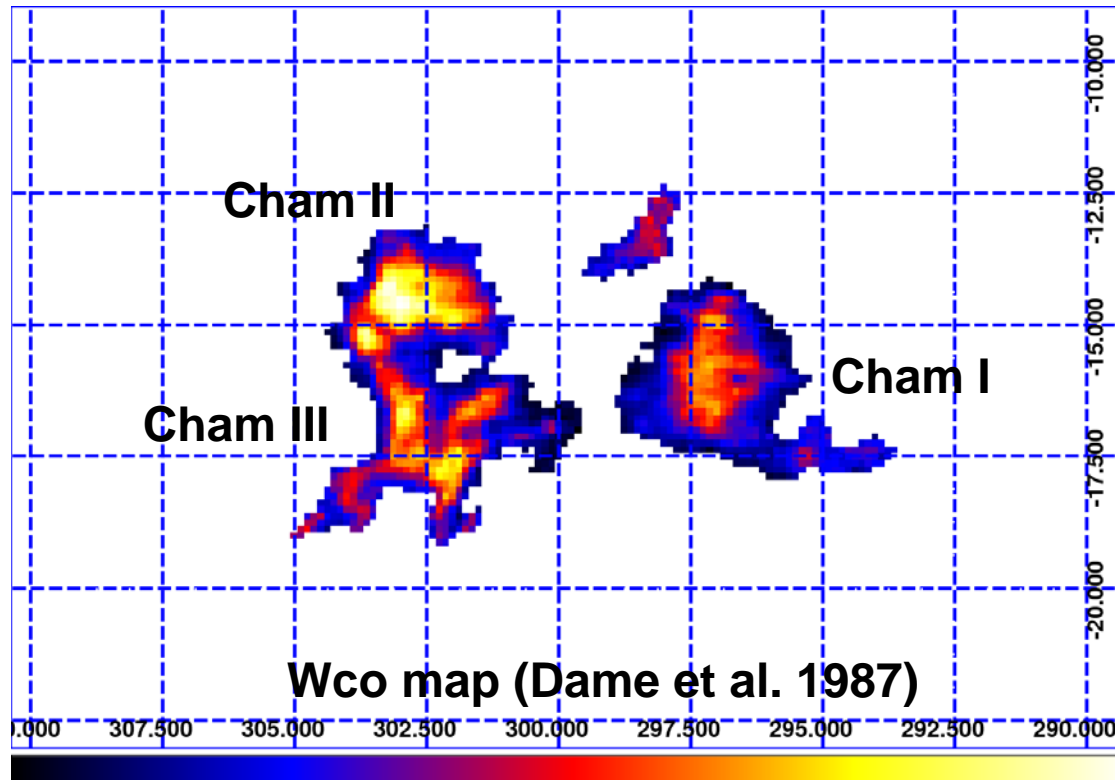
- Matter distribution

Molecular mass calibration ratio,

$X_{\text{CO}} = N(\text{H}_2)/W(\text{CO}) \sim (1-2) \times 10^{20} \text{ cm}^{-2}/(\text{K km/s})$ is highly uncertain.

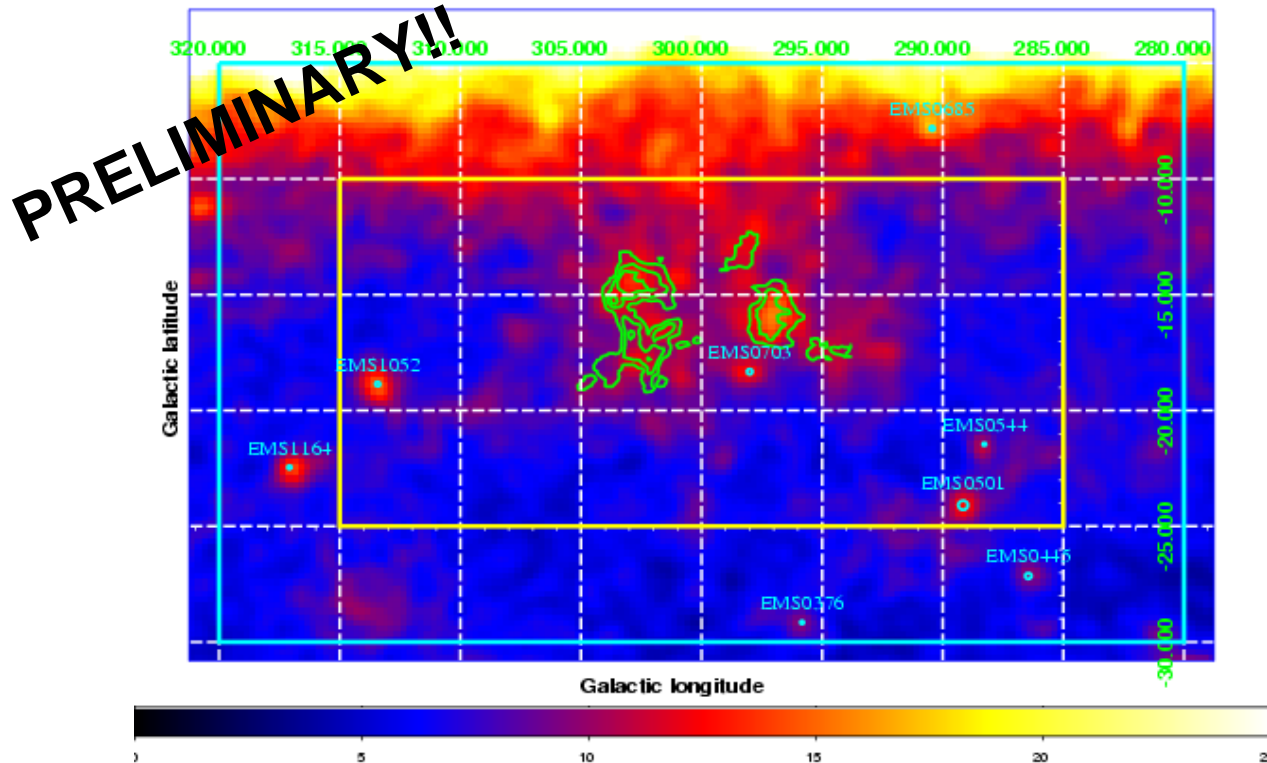
Fermi-LAT はこれらの “questions” を解き明かす最強の道具

Chamaeleon Molecular Clouds



- ~200 pc away from the Solar system (Dame et al. 1987)
- Three MCs (Cham I, II and III) with different star-formation rate
- Separated from the Galactic plane ($-19 \text{ deg} < b < -12 \text{ deg}$; $45 \text{ pc} < |z| < 70 \text{ pc}$)
- Mass of molecular gas has been estimated to be $\sim 10000 M_{\text{sun}}$ (Dame et al. 1987)
- Reported by EGRET, but detailed study not performed yet in gamma-rays

Data Count Map of Chamaeleon Region



- Data Count Map ($E \geq 200$ MeV) smoothed with a gaussian of 0.75 degree
- **Contour**: CO line intensity (Dame et al. 1987) 分子ガスの領域からガンマ線がはっきりと検出されている
- **Cyan dots**: the position of point source ($T_s \geq 100$, 11 month source list)
- **Yellow square**: the region used for the fitting

Data and Analysis Procedure

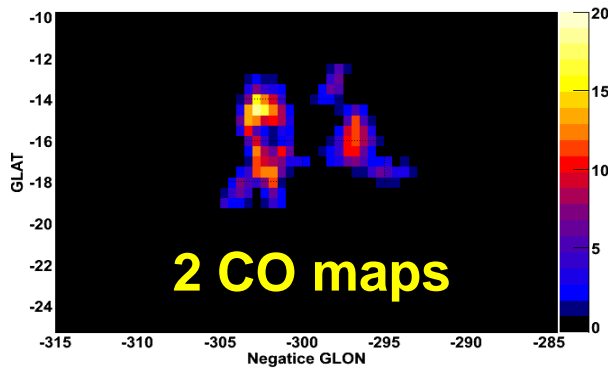
$$\gamma \text{ 線フラックス } I(l, b, E) = A(E) \times N(HI)(l, b) + B(E) \times W(CO)(l, b)$$

(宇宙線との相互作用)

+ *others ...*

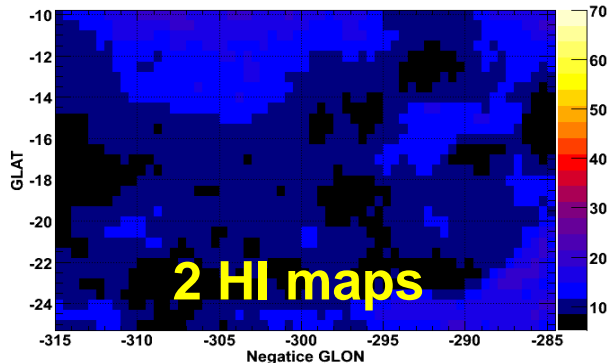
- Extra galactic diffuse (uniform)
- Inverse compton (galprop model)
- Excess of E(B-V) map (Grenier et al. 2005)
- 8 point sources (sources with $T_s \geq 1000$), 11 month source list

Wco [K km/s], R=7.5-9.5 kpc

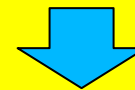


R=0-7.5kpc, 7.5-9.5kpc

HI column density [10^{20} cm^{-2}], R=7.5-9.5 kpc



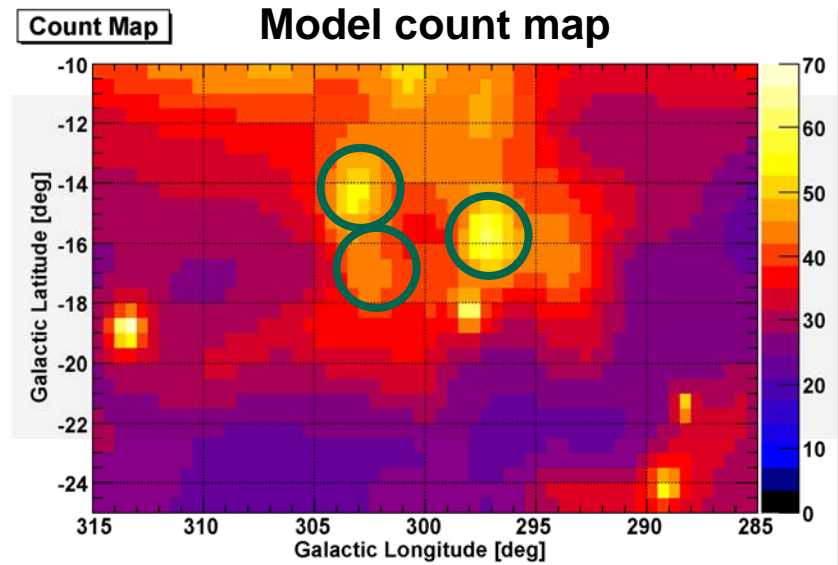
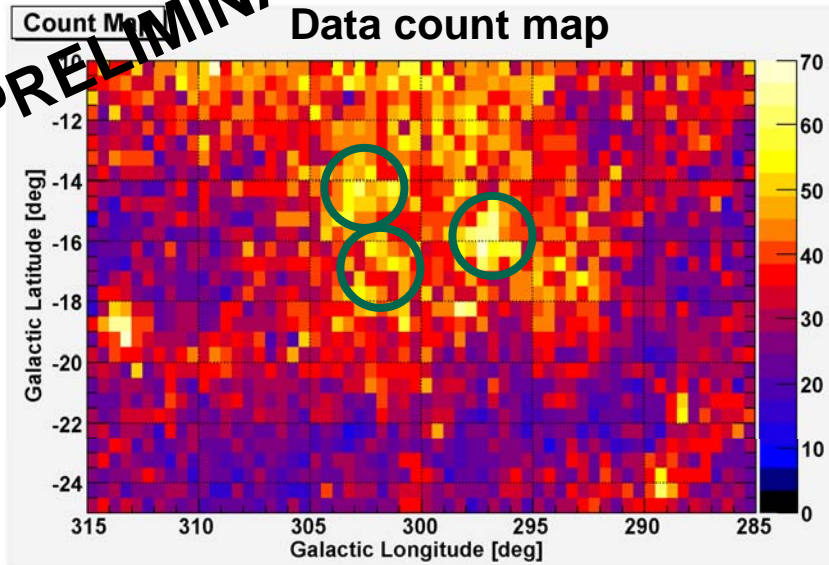
Fit data at each energy bin :
 (100~144 MeV), (144~200 MeV), ... ,
 (9.05~12.8 GeV)



Gamma-ray spectrum ($A(E), B(E), \dots$)
 of each component

Data and Model Maps ($E \geq 200$ MeV)

PRELIMINARY!!



- Clear detection of gamma-rays from the molecular cloud region.
- **Our model reproduces the gamma-ray data well.**

Detailed study of obtained spectra in progress
→ CR and matter distribution

Summary

Fermi-LAT will allow us to study the CR and matter distribution of many GMCs (e.g; orion GMC (2009春年会 奥村講演)).

- **Preliminary analysis of GMCs in Chamaeleon (距離が近い、比較的質量が小さい) region is presented.**
- **Clear detection of gamma-rays from Chamaeleon region.**
- **Fit gamma-ray data with a combination of models (gas map, IC, Isotropic and point sources)**
The model reproduces the gamma-ray data well.

Future work

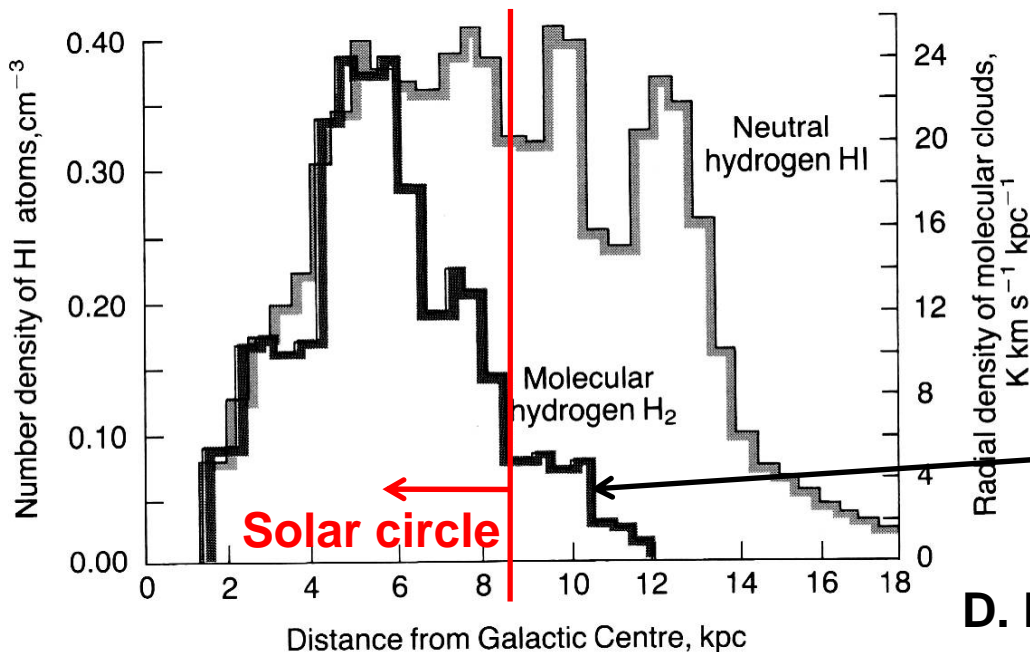
- **Detailed study of obtained spectra of each component**
→ **CR and matter distribution in detail**
- **Compare with other GMCs**

Backup Slides

Molecular Gas

The principal phase of the molecular gas

Main constituent	Detected by	Volume of interstellar matter	Fraction by mass	$N(\text{m}^{-3})$	Temp (K)
H_2 , CO, Cs, etc.	Molecular lines ; dust	~0.5%	40%	$>10^9$	10-30

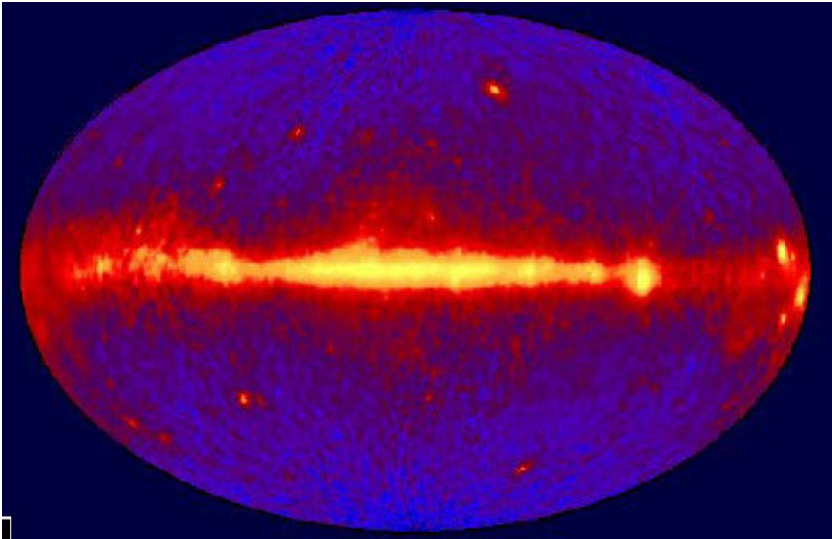


Radial density of MC.

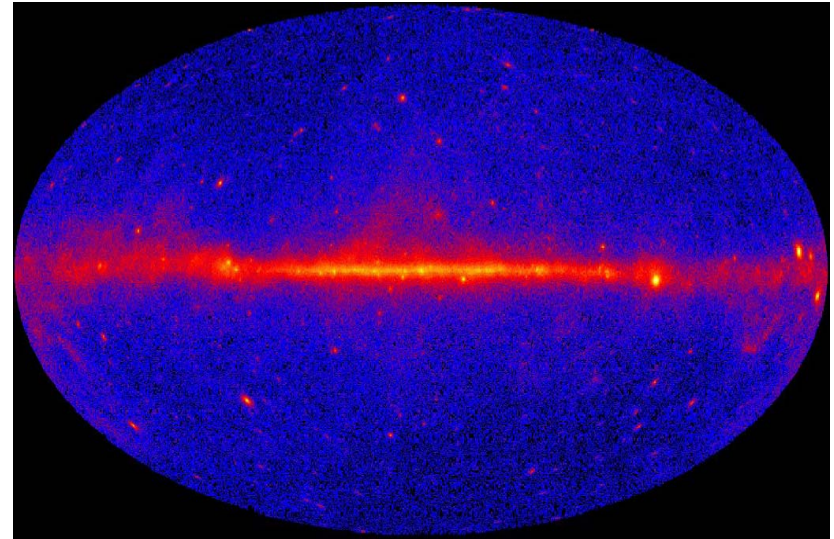
Most of MC exist within solar circle (~8.5 kpc).

D. Michalis and J. Binney (1981)

All-Sky Map



EGRET all sky map $E > 100$ MeV
(10 years)



LAT all sky map $E > 200$ MeV
(3 months)

Sample of GMCs

Dame et al. 1987

(see also Dame et al. 2005)

TABLE 2

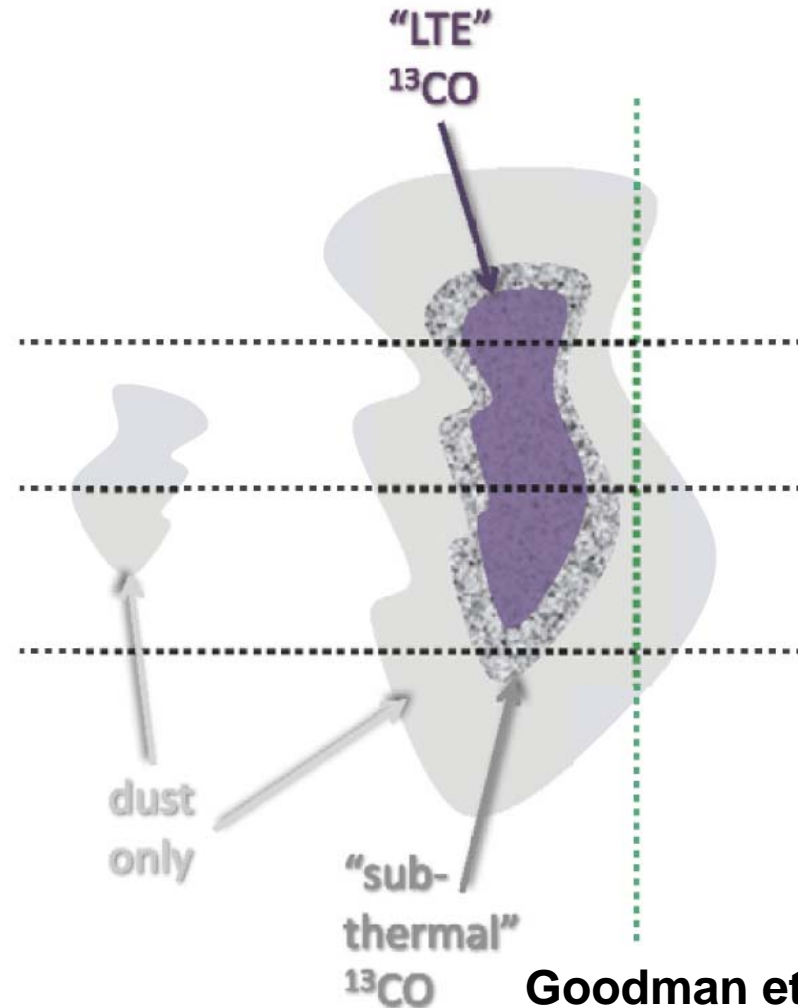
MOLECULAR GAS WITHIN 1 KILOPARSEC OF SUN

Region	l_{\min}	l_{\max}	b_{\min}	b_{\max}	v (km s^{-1})	D (pc)	Ref.	M ($10^5 M_{\odot}$)	\bar{z}^a (pc)	σ_z^b (pc)
Aquila Rift	{ 18 ^h 5	34 ^o	-6 ^o	10 ^o }	8	200	1	1.5	9	15
Cloud A	44	49.5	-4	2	27	500	1	0.4 ^c	-7	14
Cloud B	44	54	-4	5	7	300	1	0.4 ^c	0	11
Cloud C	50	55	-1	3.5	24	500	1	0.3	5	12
Vul Rift	54	63	-3	5	10	400	1	0.8	5	12
Cyg Rift	63	86.5	-4	4	7	700	1	8.6 ^d	-4	24
Cyg OB7	87	99	-3	8	-1	800	1	7.5	41	52
Lindblad Ring	100	164	-4	10	1	300	2	1.6	22	28
"-12 km/s"	102	161	-4	10	-12	800	3	8.7	44	59
Cepheus	100	120	11	22	-5	450	4	1.9	131	133
Taurus	163	178	-22	-9.5	5	140	5	0.3	-37	38
Per OB2	{ 154	162.5	-25	-7	5 }	350	5	1.3	-84	92
	{ 163	171	-9	-6	-3 }					
Mon OB1	197.5	205	-1	4	7	800	7	1.6	17	22
Orion A	208.5	218	-21	-14.5	5	500	6	1.6	-163	164
Orion B	202.5	208	-21	-6	5	500	6	1.7	-129	132
Mon R2	210	218	-14	-10	7	830	6	1.2	-182	183
Vela Sheet	272	279	-3	8	0	425	8	0.8	9	19
Cham	295	305	-20	-12	4	215	9	0.1	-60	60
Coalsack	300	307	-4	3	-4	175	10	0.04	-2	5
G317 - 4	315	320	-6	-2	-6	170	11	0.03	-11	11
Lupus	333	346	4	22	5	170	8	0.3	32	35
ρ Oph	{ 350	2	13	24 }	3	165	12	0.3	35	39
	{ 356	5	3	12.5 }						
R CrA	357	4	-22	-14	6	150	13	0.03	-55	55

Detailed analysis by EGRET (e.g; Digel et al. 1999)

Gas traced by excess of E(B-V)

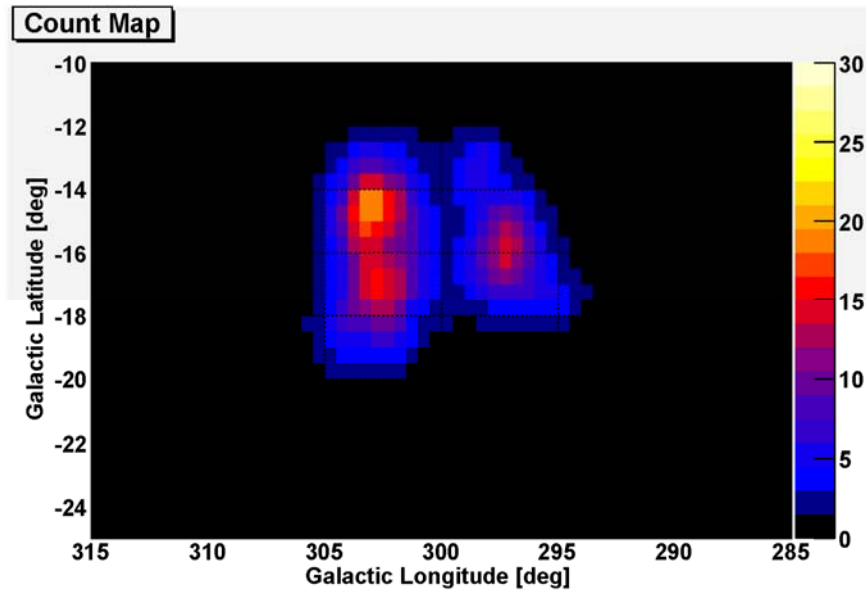
- Some fraction of gas is not detectable by 21 cm line (atomic hydrogen) and CO line (e.g; Grenier et al. 2005, Goodman et al. 2009).
- We estimated their contribution from the emission of dust



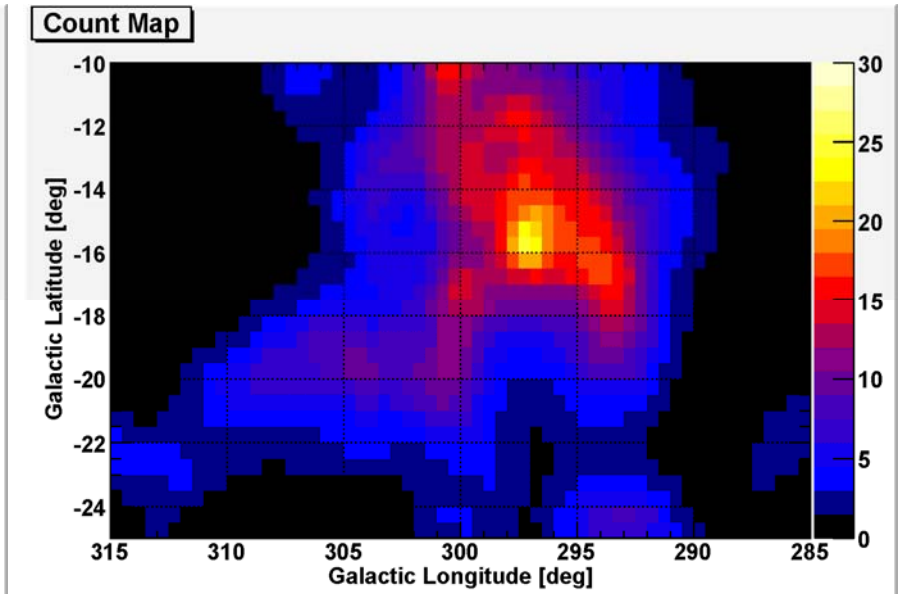
Goodman et al. 2009

Model Count Map

PRELIMINARY!!



CO model count map



Dark_gas model count map

Derivation of CR density and X_{CO}

$$X_{CO} = N(H_2)/W(CO) \sim (1-2) \times 10^{20} \text{ cm}^{-2}/(\text{K km/s})$$

Gamma-ray flux

$$I(l, b, E) = \sum_i [A_i(E) \times N(H_I)(l, b)_i + B_i(E) \times W(CO)(l, b)_i] + \dots$$

Emissivity of HI gas
 -> CR density
 -> distribution of CR

Emissivity of H₂ gas (in unit of W_{CO})
 (emissivity of H₂ is 2 × emissivity of HI)
 -> CO-to-H₂ conversion factor

$$X_{COi} = \frac{B_i}{2A_i}$$