[N II] 1.46 THz 輝線による銀河面サーベイ

梅本智文 (国立天文台野辺山)

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FUGIN Project

(Umemoto et al. 2017 PASJ, 69,78)

- Using multi-beam receiver FOREST, OTF mapping of the Galactic plane in ^{12}CO, ^{13}CO, $C^{18}O$(J=1-0), simultaneously

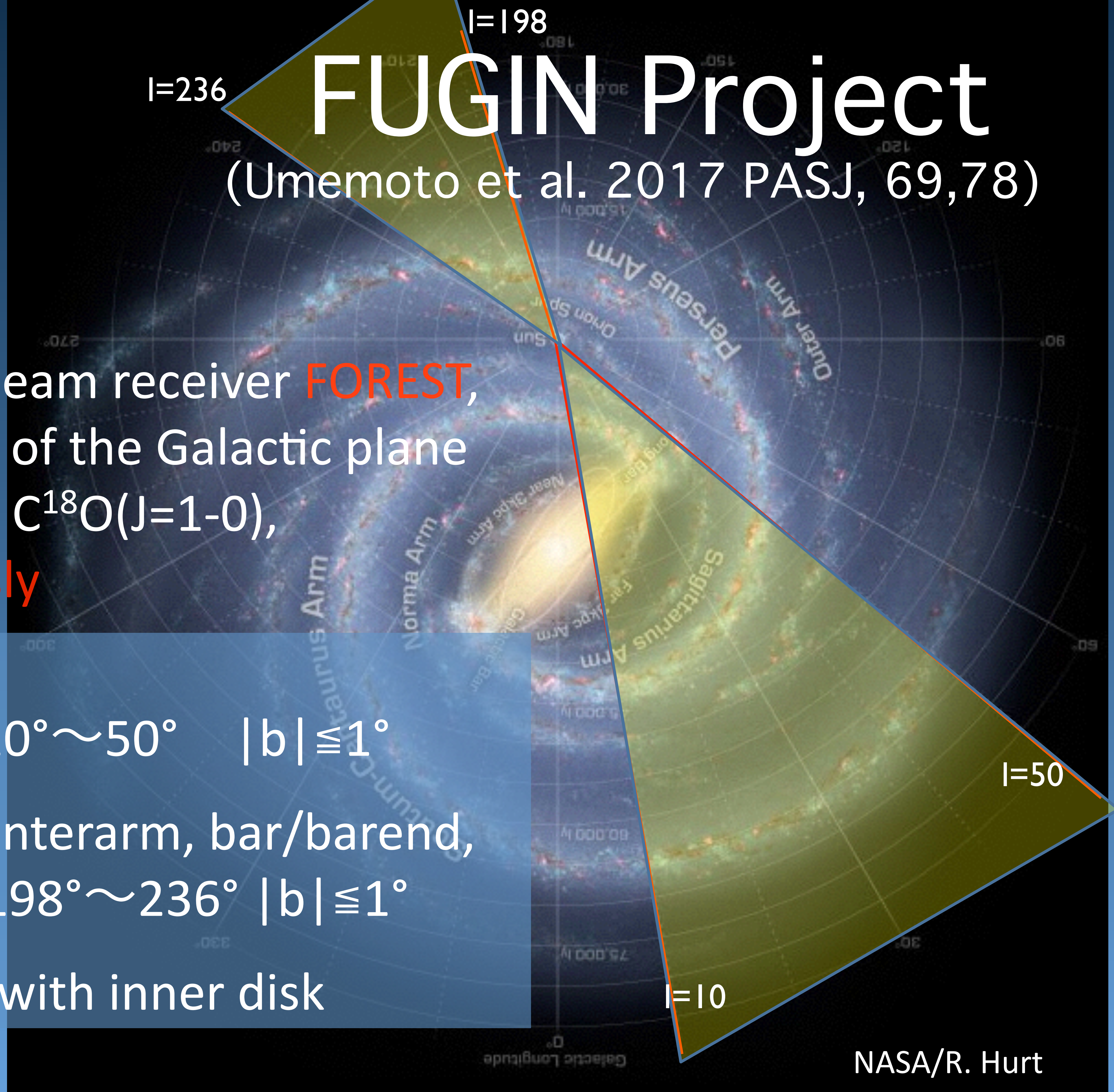
Mapping area:

inner disk: l = 10°～50°　|b|≦1°

Spiral arms, interarm, bar/barend,

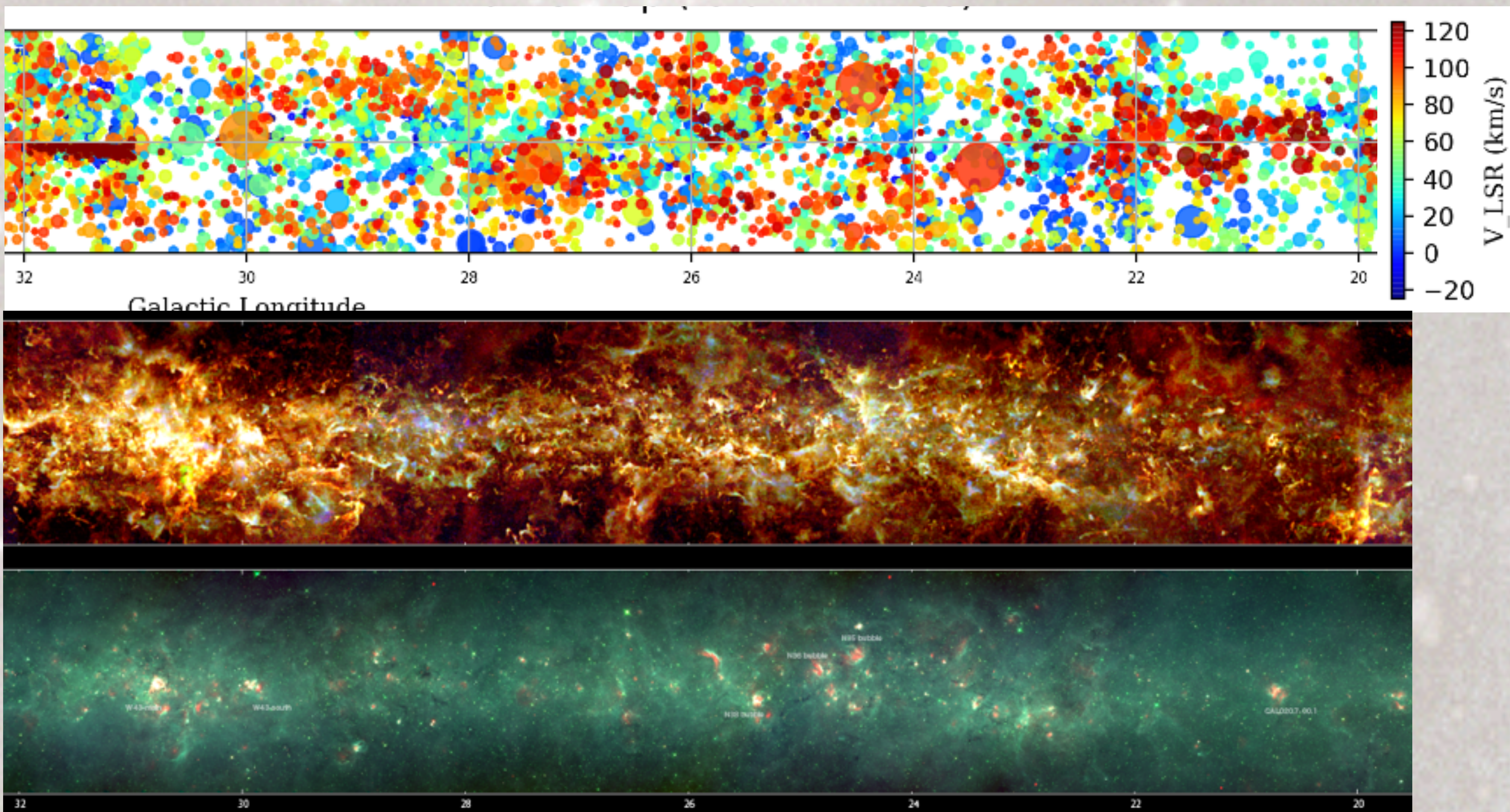
outer disk: l = 198°～236° |b|≦1°

Comparison with inner disk



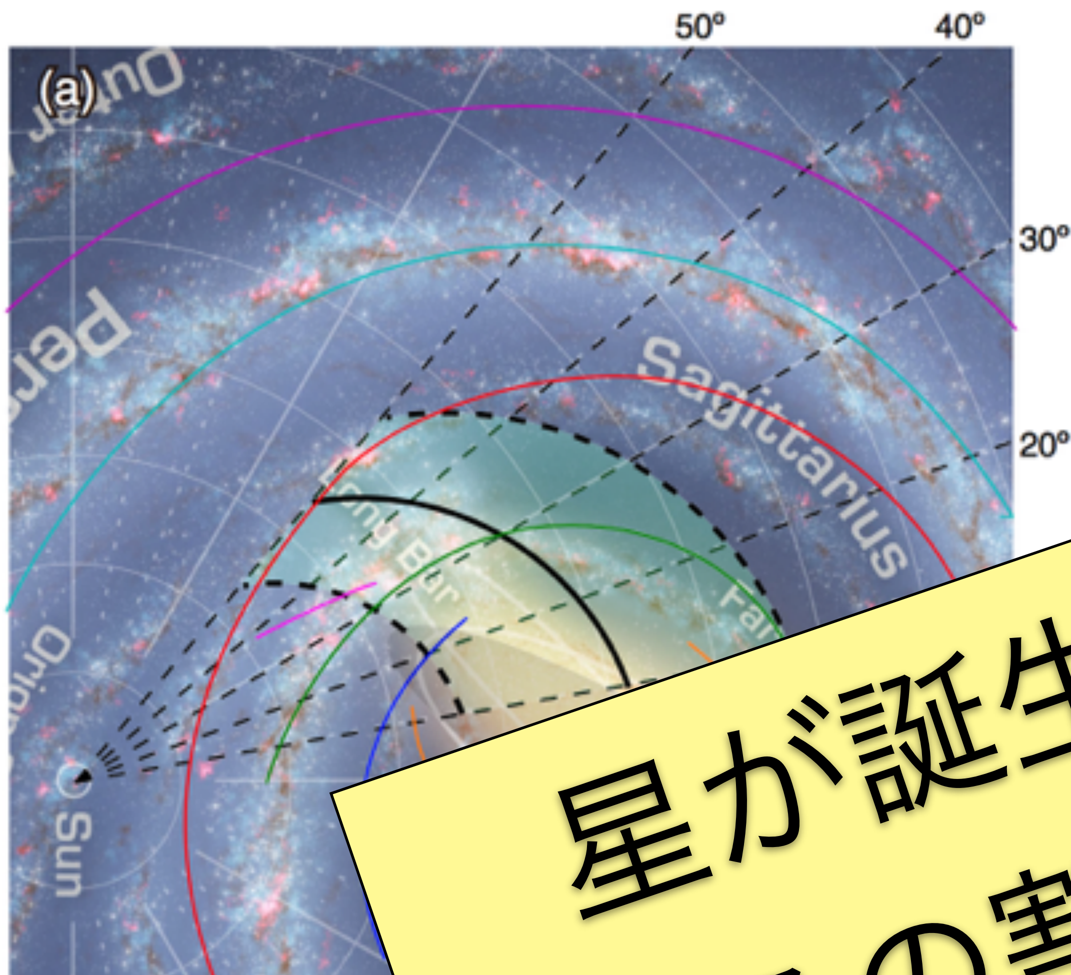
01 Molecular Cloud Identification

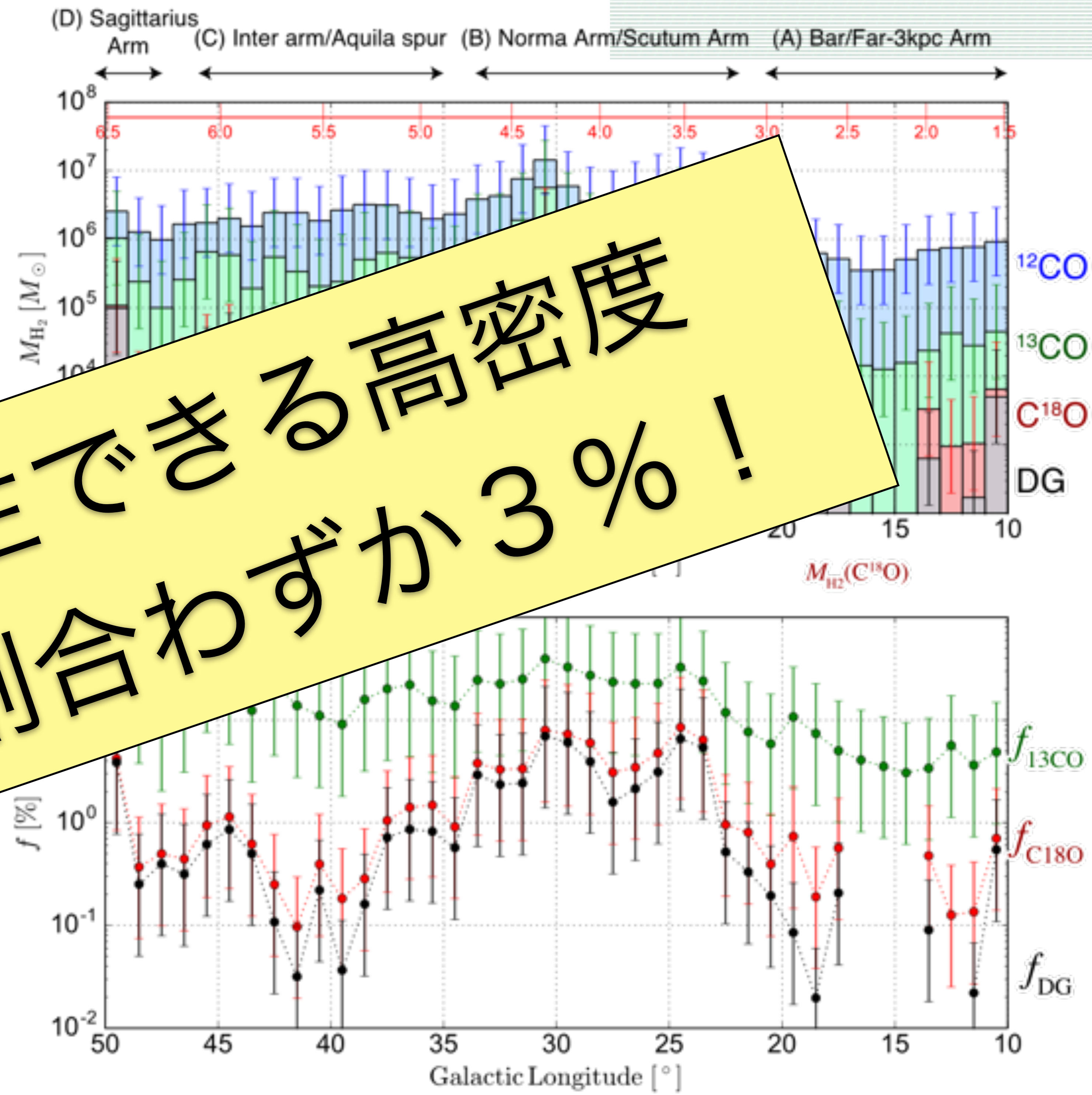
Identified Strunctures by Dendrogram (Fujita et al. in prep.)



銀河面における高密度ガスの割合

K.Torii et al. 2019, PASJ, 71,



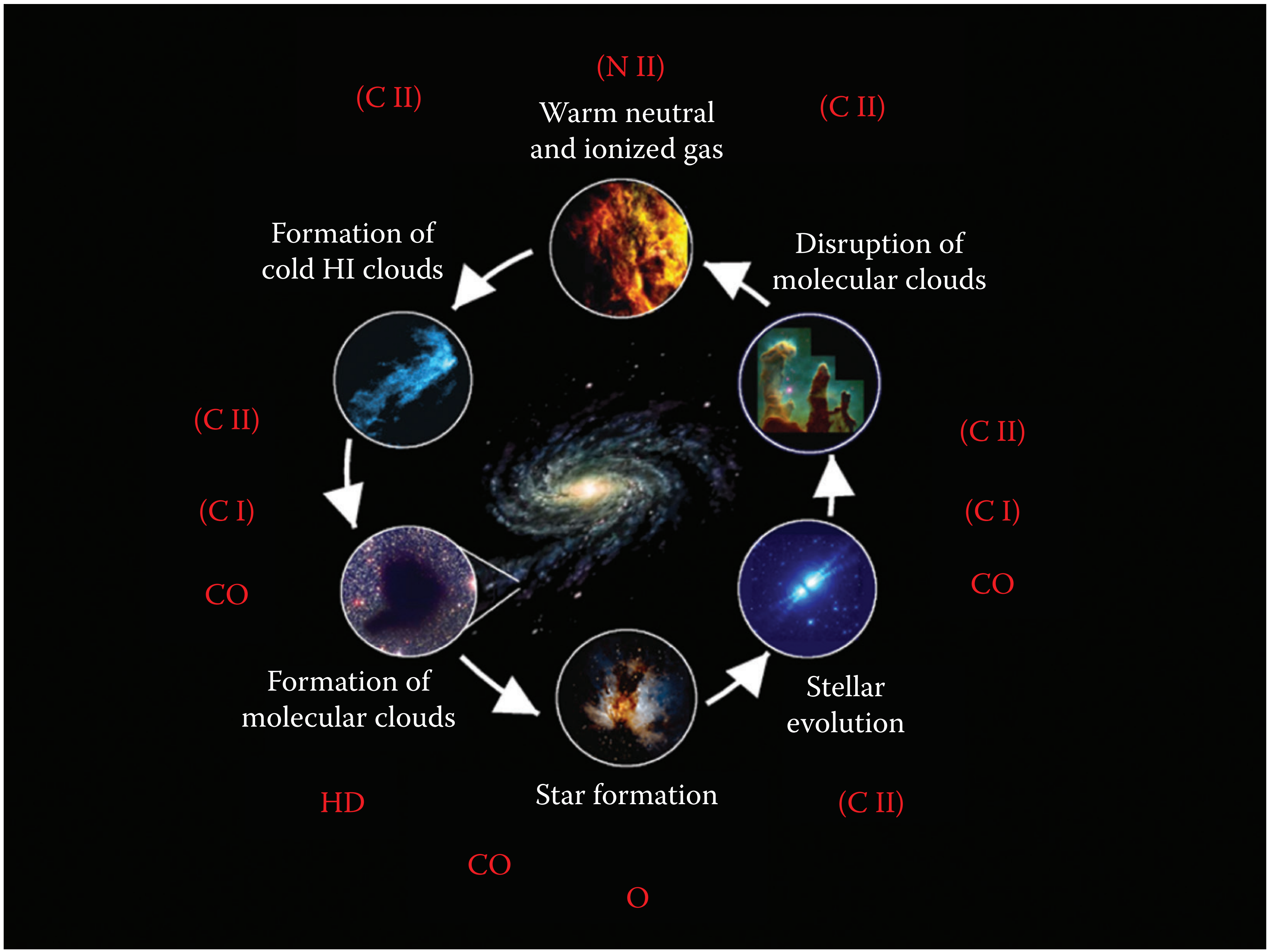


星が誕生できる高密度ガスの割合わずか３％！

- 5kpcにわた…の割合～3%
- 渦状腕では～5%に対し*bar* 領域や渦状腕の間では～0.1-0.4%
  - これらの領域での星形成率の違いか?

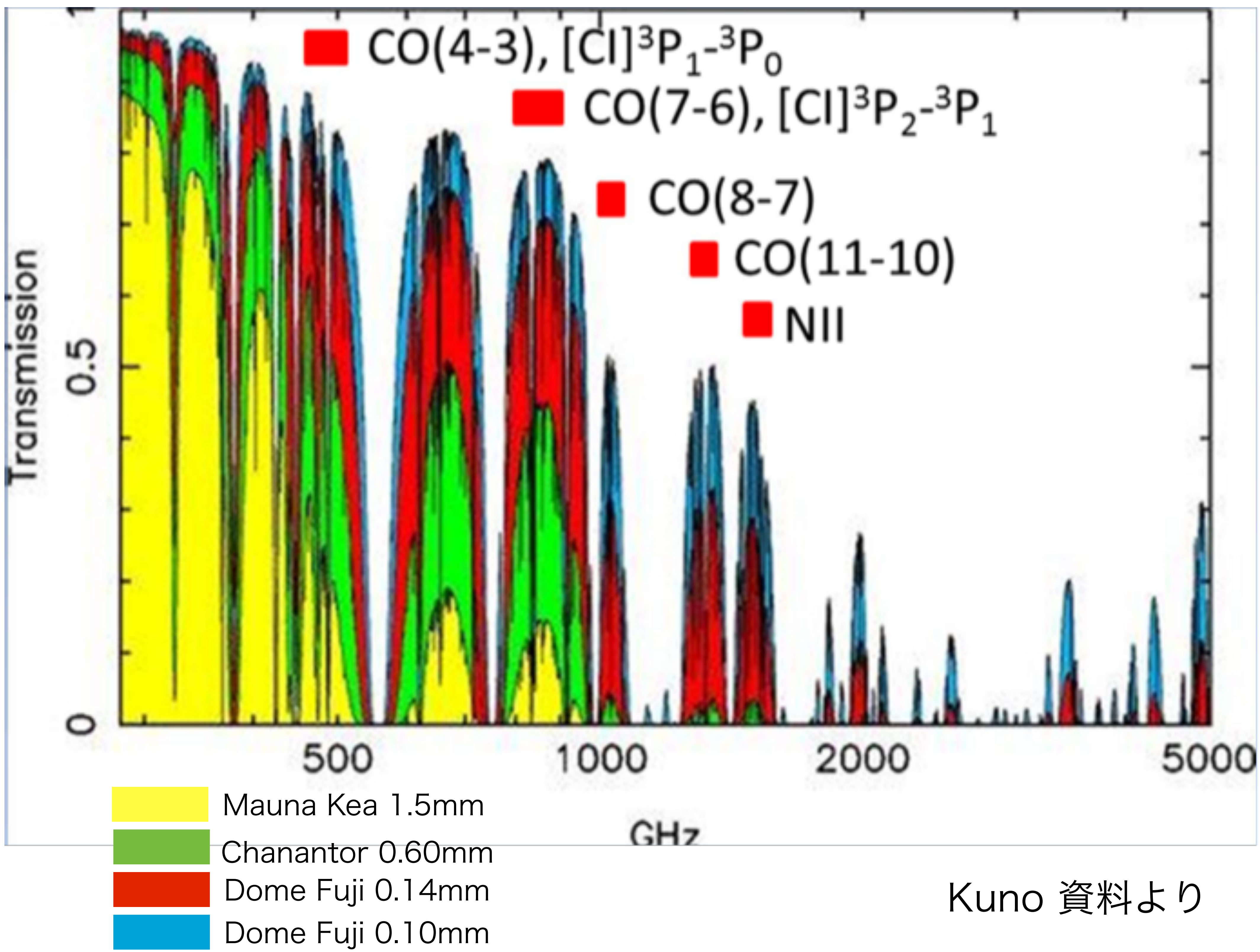
- 距離～5.5–8kpc⇄~1pcの分解能
- FUGIN データは分子雲の総質量を求め高密度ガスが集中する星形成領域を検出できる

Lifecycle of the ISM



Walker (2016)

Atomic and molecular lines at THz



Kuno 資料より

[N II] as Probe of SFR and L_{IR}

- [N II] emission line
  - An **excellent probe** of star formation rate (**SFR**) and infrared dust luminosity (**L_{IR}**) (Zhao et al. 2013) because the [N II] is less contaminated from the emission of older star due to an ionization potential higher than hydrogen.
  - Therefore, **$L_{[N\ II]}$** may be a more accurate indicator of **SFR** the the more conventional L_{IR} -derived estimates.

$$\log \mathrm{SFR} = (-5.31 \pm 0.32) + (0.95 \pm 0.05) \log L_{[\mathrm{NII}]}$$

$$\log L_{\mathrm{IR}} = (4.51 \pm 0.32) + (0.95 \pm 0.05) \log L_{[\mathrm{NII}]}$$

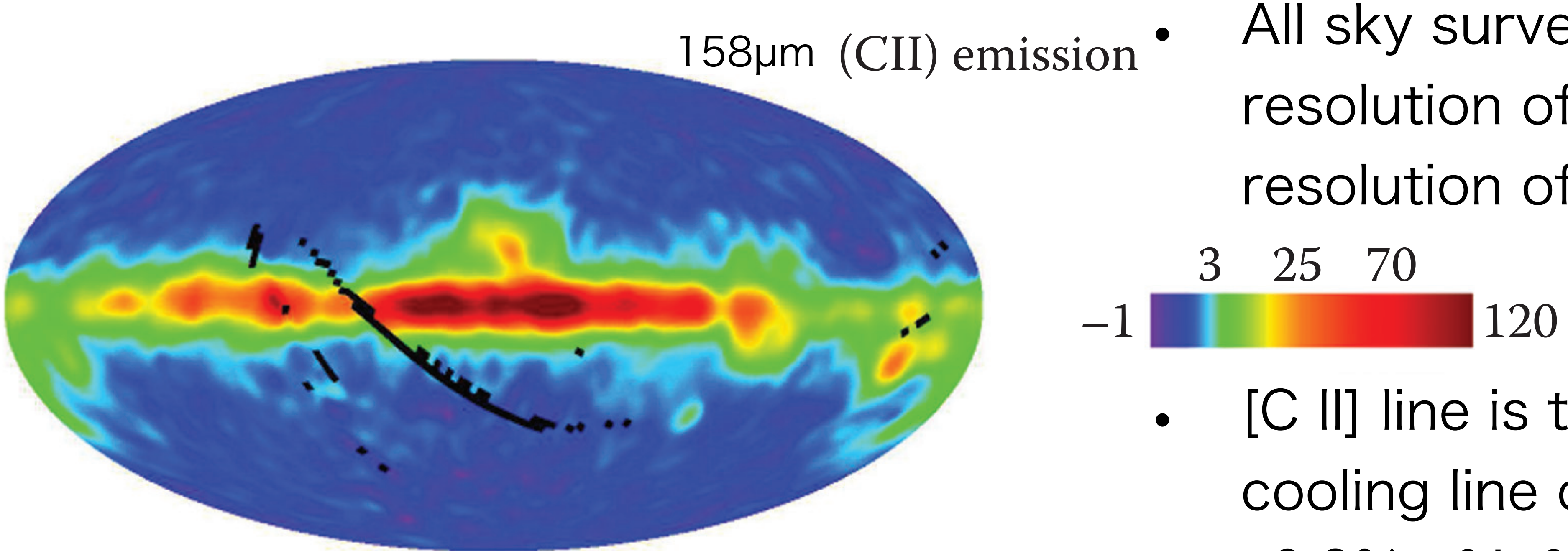
where

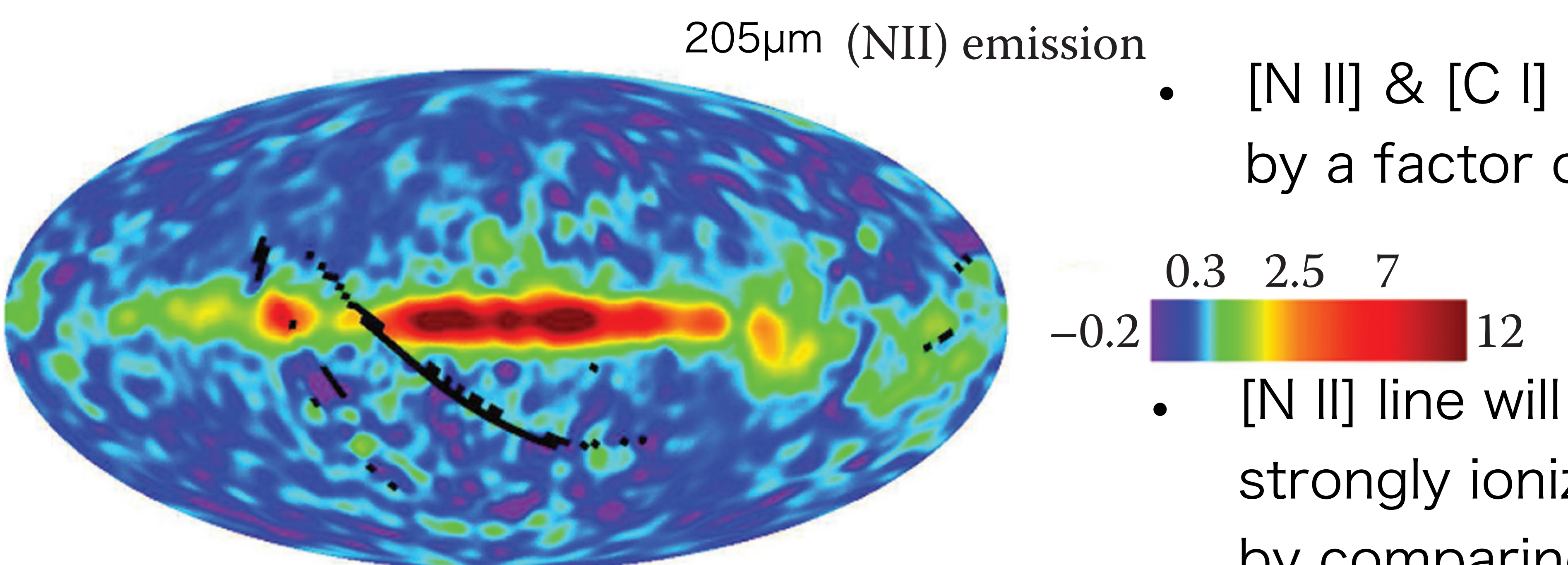
SFR = star formation rate ($M_\odot$ yr^{-1})

$L_{[\mathrm{NII}]}$ = luminosity of [NII] line ($L_\odot$)

L_{IR} = luminosity of dust in IR ($L_\odot$)

COBE/FIRAS maps of [C II] & [N II]



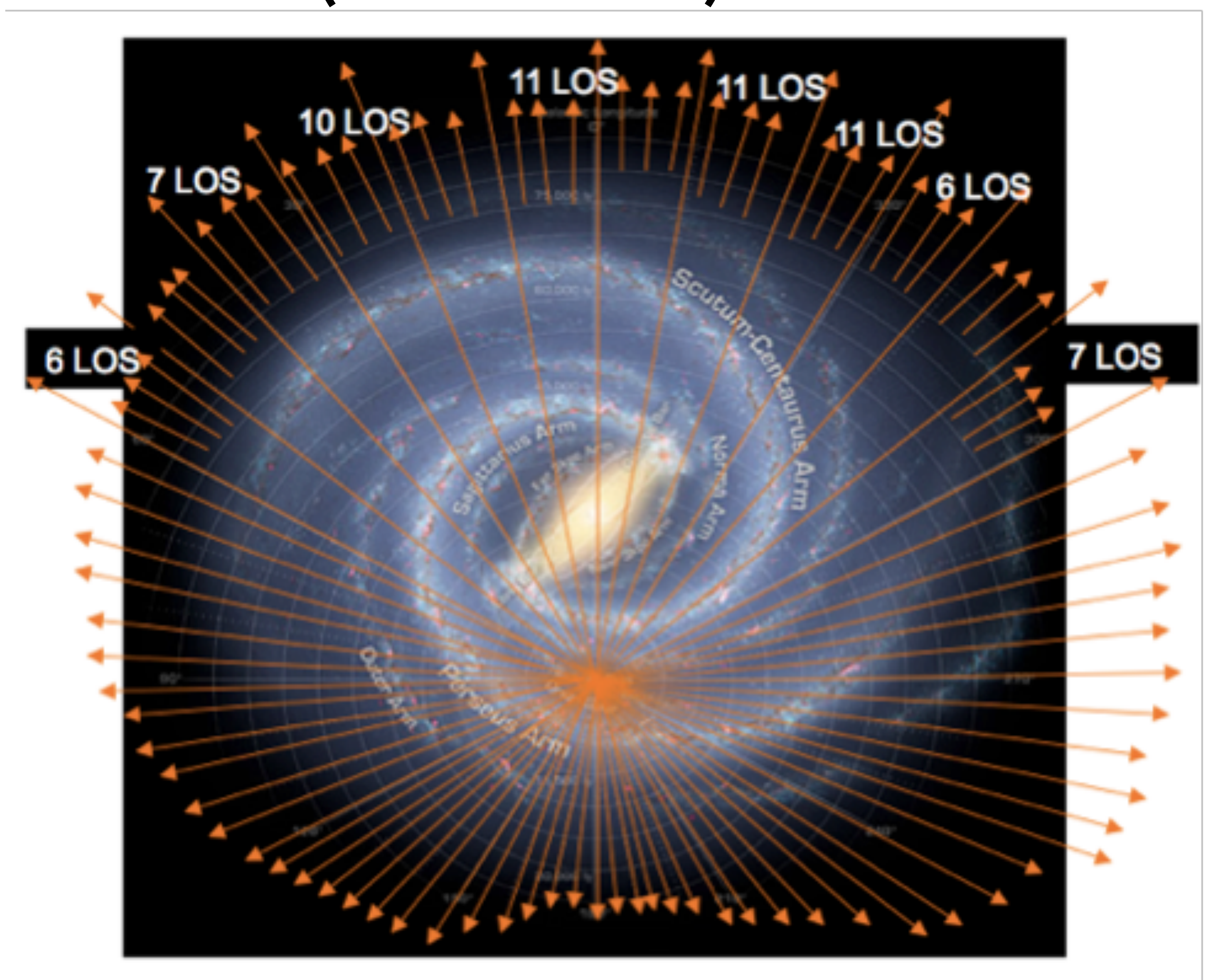


Fixsen, Bennett, & Mather (1999)

- All sky survey with a special resolution of 7° & a velocity resolution of 1000km/s
- [C II] line is the dominant cooling line of the ISM at ~0.3% of infrared continuum
- [N II] & [C I] are less intense by a factor of 10 & 100
- [N II] line will appear at strongly ionized regions --> by comparing [C II] &[N II], determine if [C II] is arising from ionized or neutral gas

Herschel [C II] Galactic plane survey

- Galactic Observations of Terahertz C+ (GOT C+)

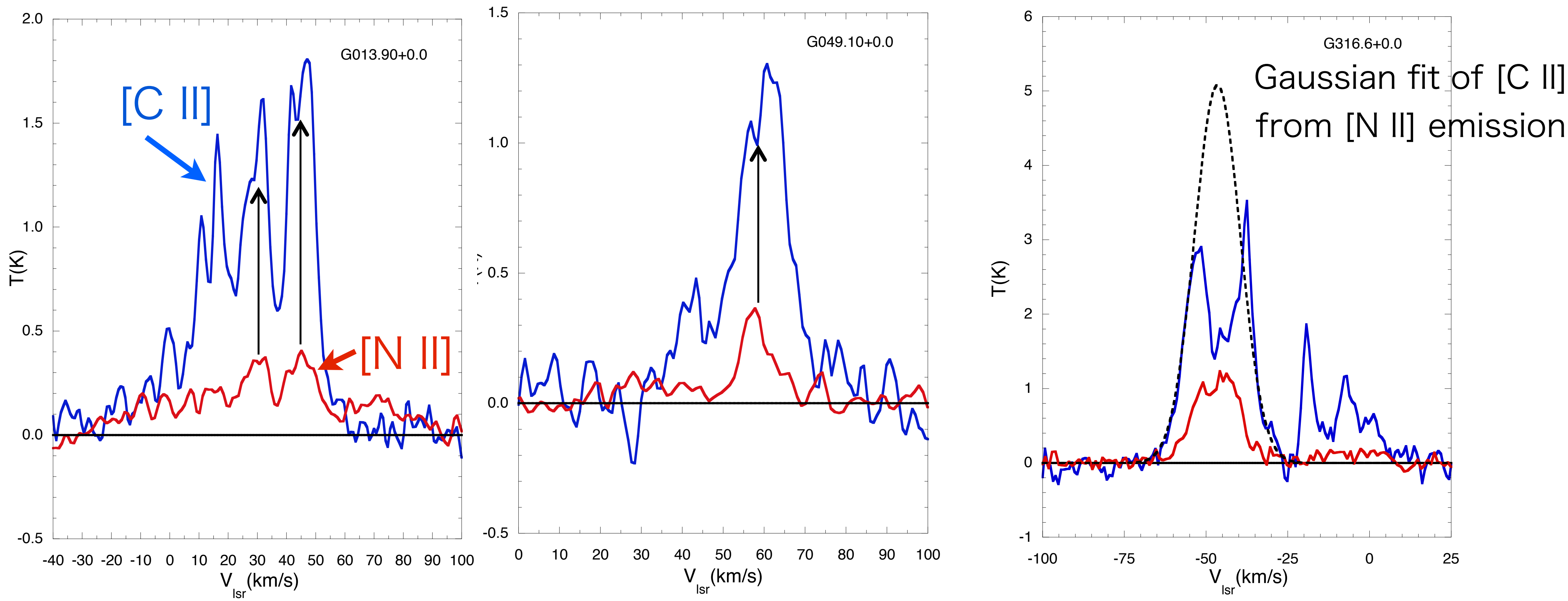


- [C II] survey by Herschel(3.5m)/HIFI with 12" angular resolution & 0.1 km/s velocity resolution
- 452 LOSs volume-weighted sample of the Galactic plane
- Every 0.87° (|l|<60°), 1.3° (30°< |l| <60°), 4.5° (60°< |l| <90°), and 4.5° to 13.5°(|l| >90°)
- b=0°, ±0.5°, and ±1.0°, ±2.0 (|l| >90°)

Langer et al. (2010), Pineda et al. (2013), Langer et al. (2014)

[C II] and [N II] by Herschel/HIFI

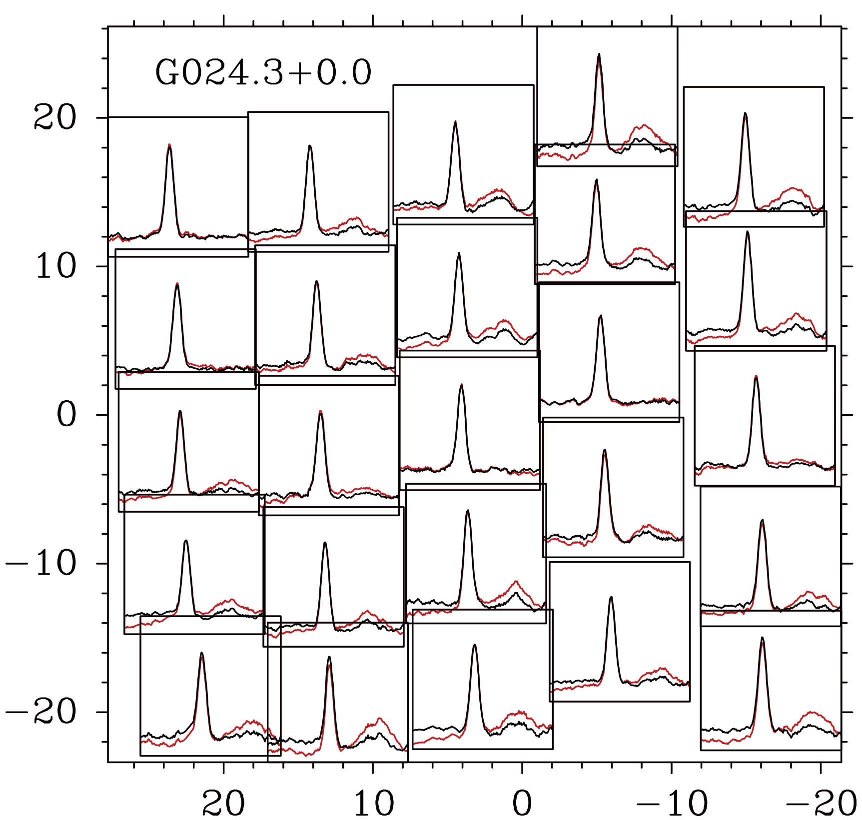
- [N II] emission to the GOT C+
  - Can separate the contributions from highly ionized and weakly ionized gas to the [C II] emission
  - [C II] emission arising from strong sources of [N II] emission is frequently absorbed by foreground gas --> **underestimate** highly ionized gas by only [C II] observations

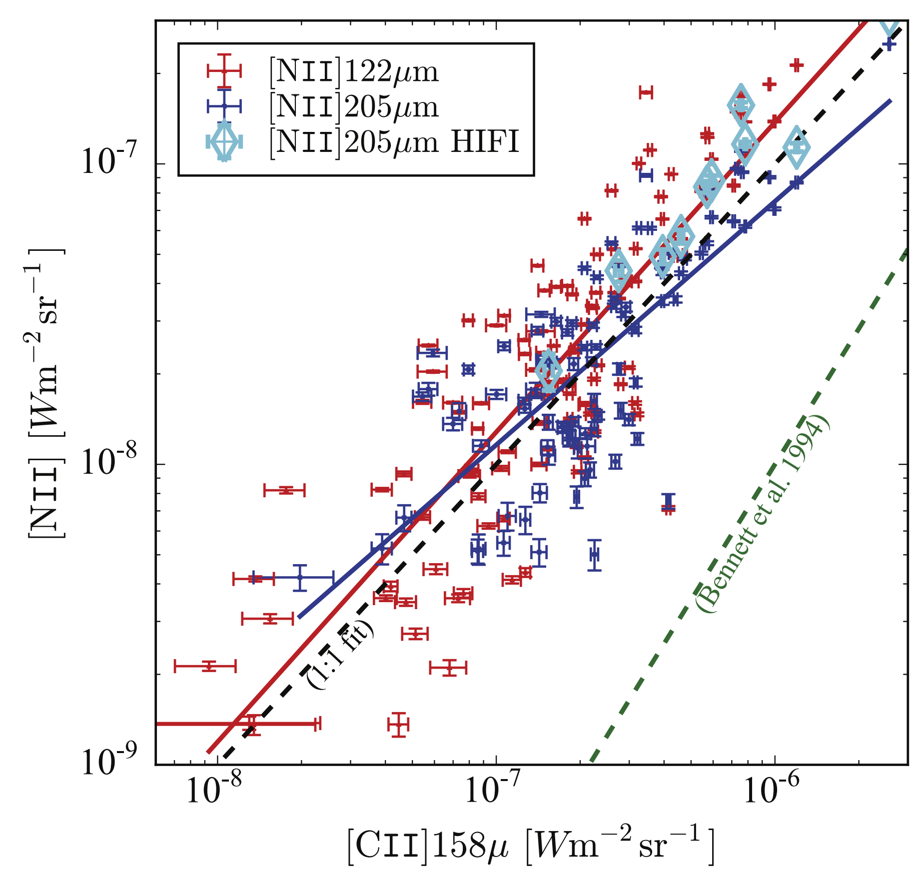


Langer, Goldsmith & Pineda (2016)

Herschel [N II] Galactic plane survey

- [N II] at 122 & 205 μm with PACS(5x5)
  - 149 LOSs selected from GOT C+, 10”(122um),15”(205μm)
  - Bothe lines are detected in the range -60°≤ l ≤60°
  - [N II] emission highly correlated with that of [C II]
  - High electron density--> extended envelopes of H II regions, and low-filling factor high-density fluctuations of WIM





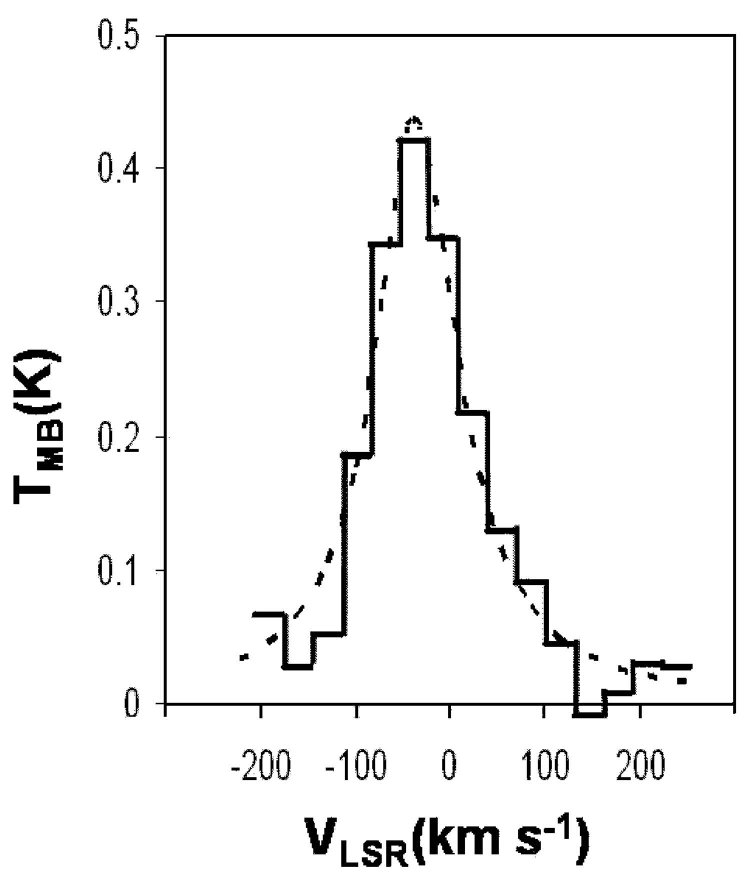
Goldsmith et al. (2015)

[N II] 1.46 THz Galactic plane survey

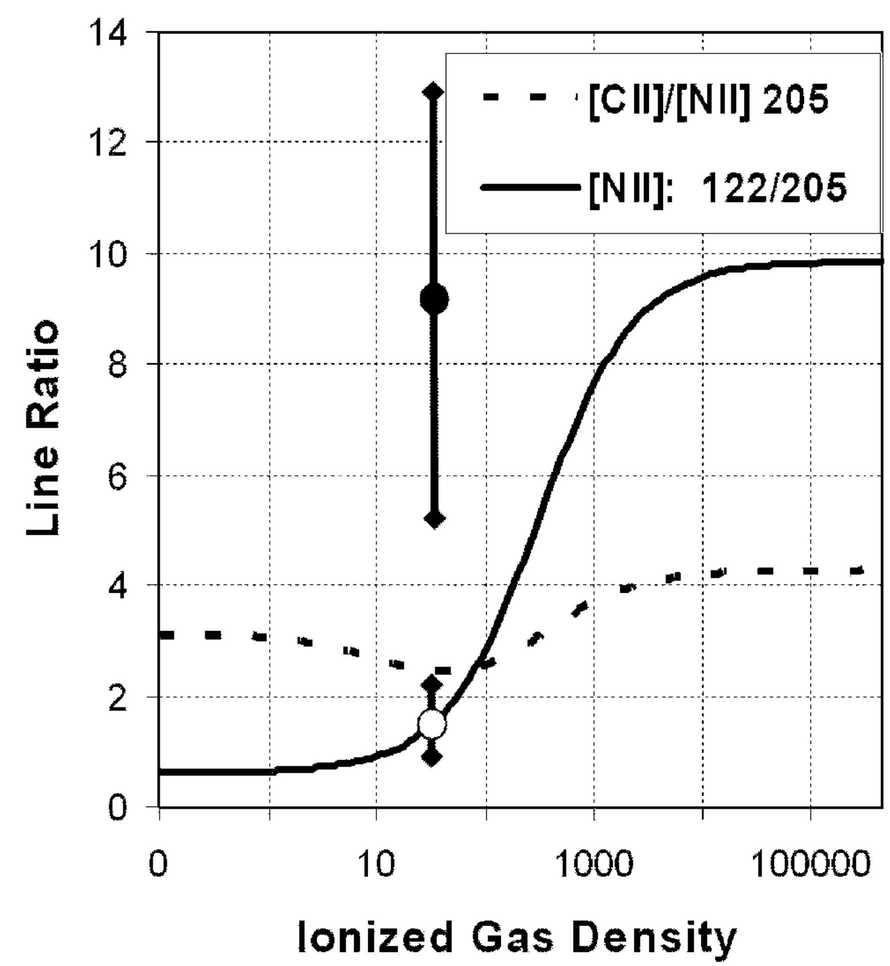
- [N II] emission line
  - [N II] line will appear at **strongly ionized** regions --> by comparing [C II] &[N II] maps, it is possible to determine whether [C II] is arising from **ionized or neutral** gas
  - [C II] emission is frequently **absorbed** by foreground gas --> underestimate highly ionized gas by only [C II] observations
  - An **excellent probe** of star formation rate (**SFR**) and infrared dust luminosity (L_{IR}) (Zhao et al. 2013) because the [N II] is less contaminated from the emission of older star due to an ionization potential higher than hydrogen
- [N II] 1.46 THz Galactic plane survey @S.P.
  - **Wide area mapping of the Milky Way --> evolutionary process of interstellar medium not only neutral gas but also ionized gas**

Detection of 205μm [N II] from Ground

- AST/RO at South Pole (1.7m)
  - The first detection of 205μm [N II] line from ground-base
  - [N II] emission reveals the fraction of [C II] emission arises from the ionized gas and the neutral ISM
  - **27% of [C II] arises from the low-density ionized gas but 73% from the neutral ISM!**

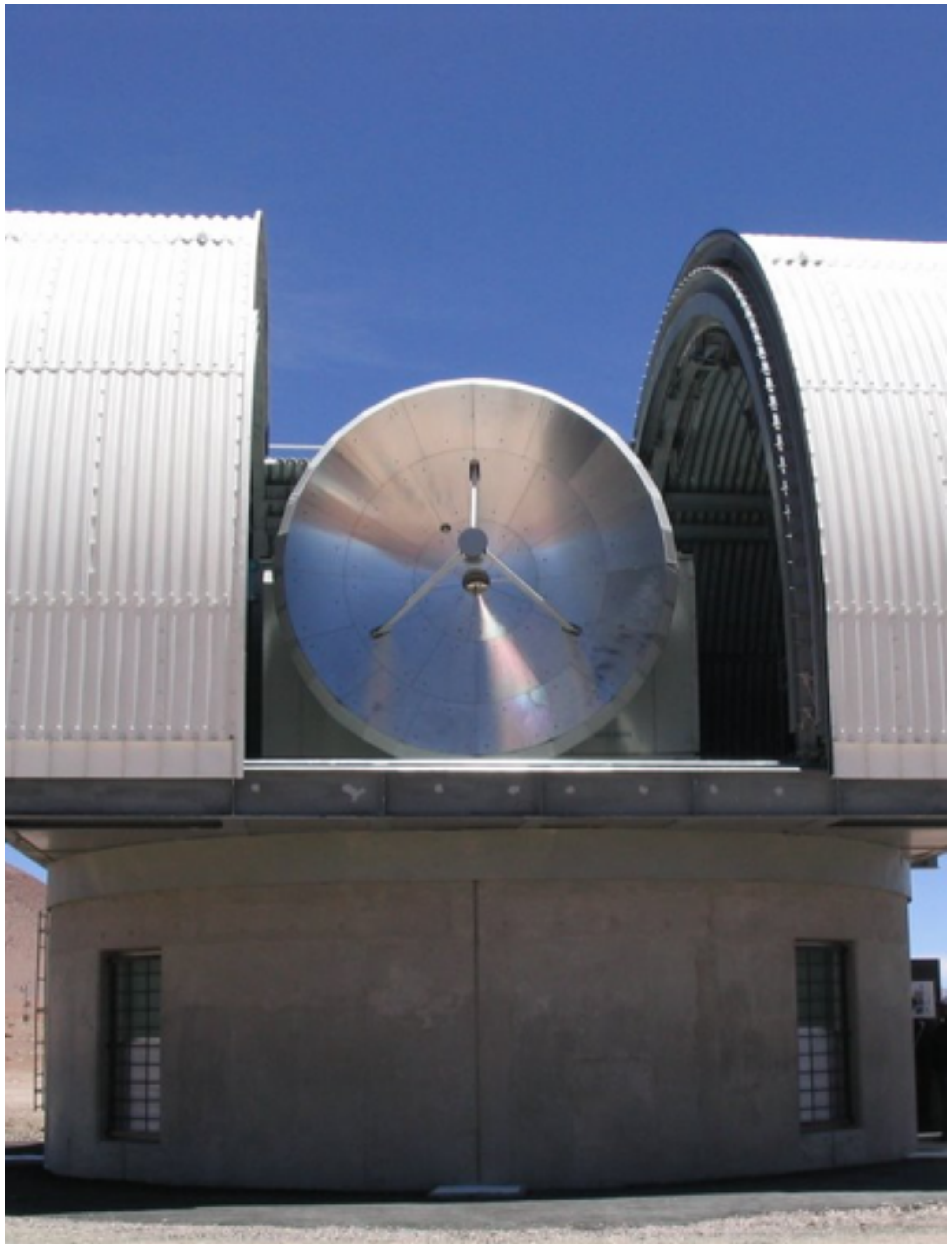


[N II] emission from Carina nebular
with velocity resolution of 60 km/s



Oberst et al. (2006)

Small Telescope Designed as Survey



NANTEN II (4m)

- Diameter: 3-6 m
- Surface accuracy: < 20μm
  - For the detection of 205μm [N II] line from ground-base, < 10μm?
- Wide field heterodyne receiver camera
  - For wide area mapping, 100-250 multi-beam receiver

Angular resolution

GHz	3m	4m	6m
460	55”	41”	27”
850	29”	22”	15”
1500	17”	13”	8.5”

Visible Sky

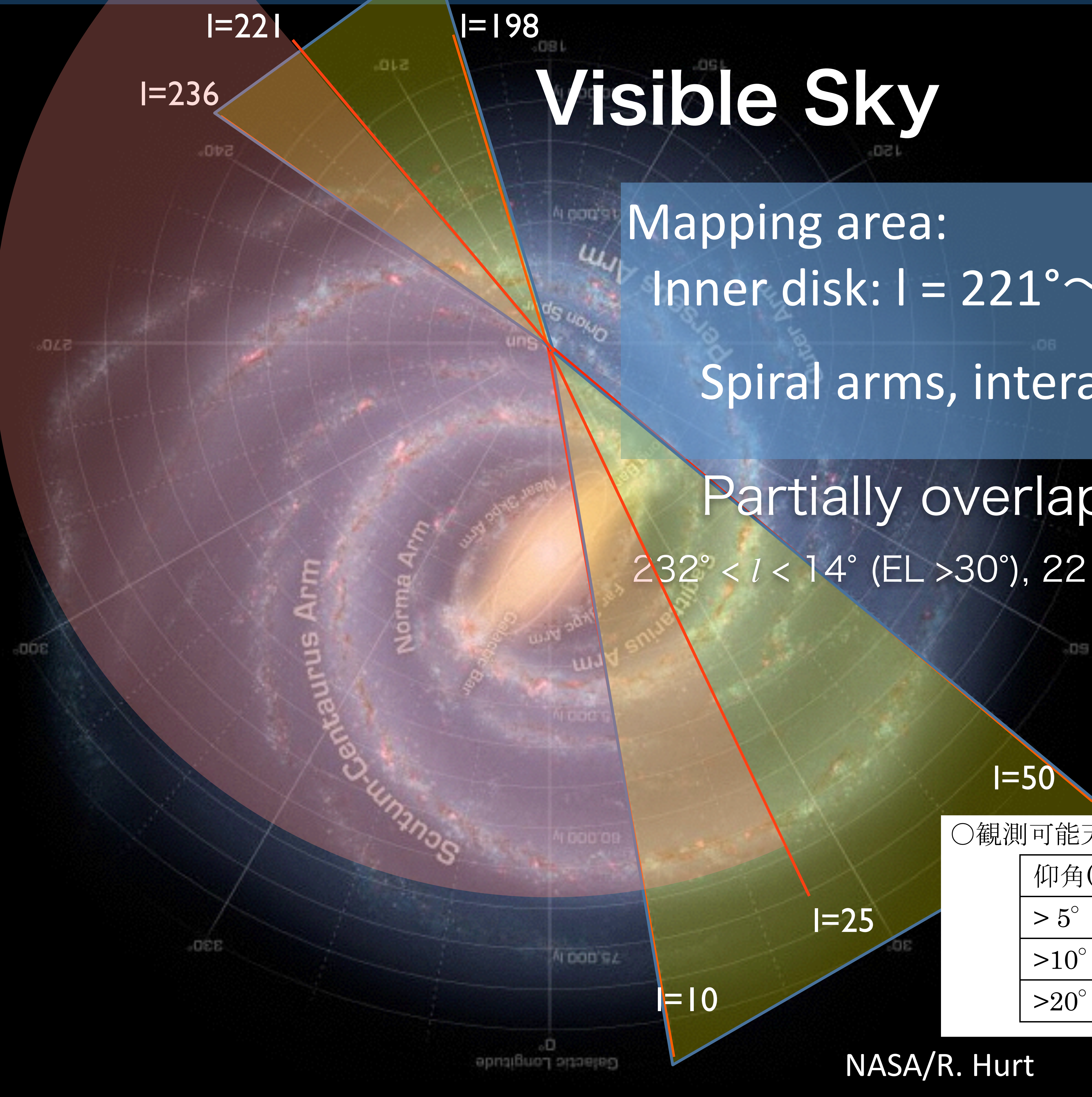
Mapping area:

Inner disk: l = 221°〜25° |b|≦1°

Spiral arms, interarm, bar, G.C.

Partially overlap FUGIN area

232° < l < 14° (EL >30°), 221° < l < 25° (EL>20°)



NASA/R. Hurt

〇観測可能天域（@新ドームふじ）

仰角(EL)	赤緯(Decl.)
> 5°	<+8°
>10°	<+3°
>20°	<−7°

Survey with Small Telescope

- [N II] 1.46THz Galactic plane survey
  - [N II] emission reveals the fraction of [C II] emission arises from the ionized gas and the neutral ISM
  - [C I] 809GHz observation when the weather is not good
  - Mapping area: l = 221°- 25° (EL>20°), $|b|$ ≤1° ($|b|$ ≤2°)
  - 20" grid, $\Delta T(5\sigma)$=0.76K, 10x10 beams —> 20,000h (OTF)
    >> more low noise receiver and more beams (or smaller D)

Freq. band (GHz)	Freq. range (GHz)	Lines	Beam	Sensitivity (5σ) (τ=10min, Δv=1km/s)	Angular Resolution (D=4m)
460	385-540	CO (J=4-3), [C I] $^3P_1$-$^3P_0$	250	0.054 K	41.3"
650	575-735	HCl, D_2H^+	250	0.092 K	28.5"
850	775-965	CO (J=7-6), [C I] $^3P_2$-$^3P_1$	250	0.14 K	21.7"
1000	1000-1060	CO (J=8-7), NH^+	100	0.35 K	18.7'
1300	1250-1380	CO (J=11-10), H^2D^+	100	0.47 K	14.2"
1500	1450-1550	[N II]	100	0.76 K*	12.7"

(*:Tsys=6000K) From Kuno's document

Survey with ~~Small Telescope~~

- [N II] 1.46THz Galactic plane survey
  - [N II] emission reveals the fraction of [C II] emission arises from the ionized gas and the neutral ISM
  - [C I] 809GHz observation when the weather is not good
  - Mapping area: l = 221°- 25° (EL>20°) some strip scans
  - 20” grid, $\Delta T(5\sigma)$=0.76K, 10x10 beams —> 55h (OTF)/strip
    >> some strip scans at latitude b

Freq. band (GHz)	Freq. range (GHz)	Lines	Beam	Sensitivity (5σ) (τ=10min, Δv=1km/s)	~~Angular Resolution (D=4m)~~
460	385-540	CO (J=4-3), [C I] $^3P_1$-$^3P_0$	250	0.054 K	~~41.3”~~
650	575-735	HCl, D_2H^+	250	0.092 K	~~28.5”~~
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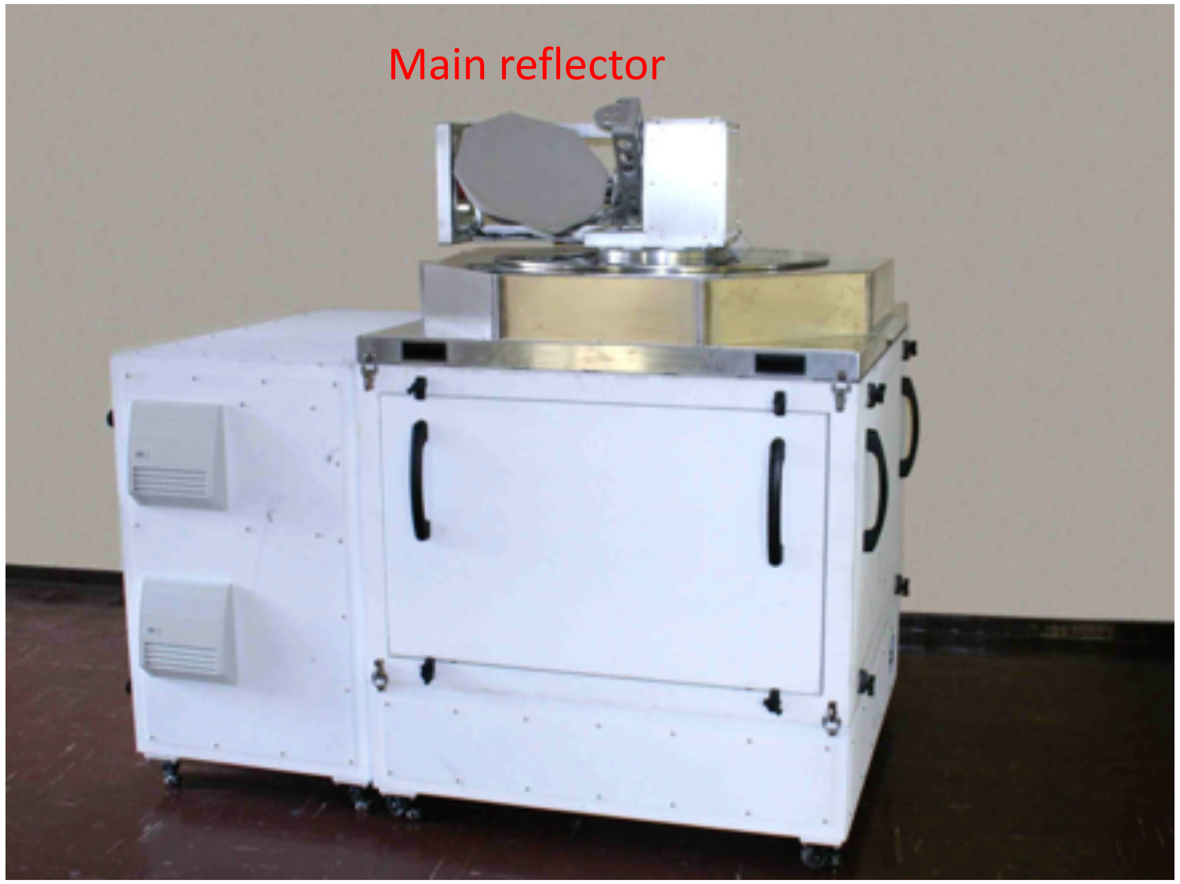
1300	1250-1380	CO (J=11-10), H^2D^+	100	0.47 K	~~14.2”~~
1500	1450-1550	[N II]	100	0.76 K*	~~12.7”~~

(*:Tsys=6000K) From Kuno’s document

Survey with 30cm Telescope

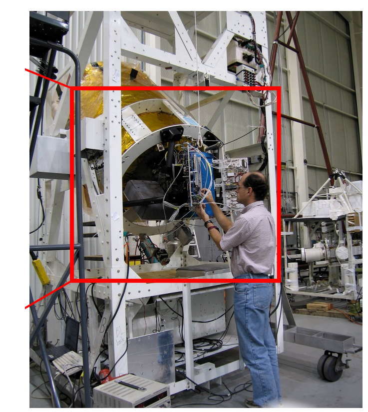
- [N II] 1.46THz Galactic plane survey



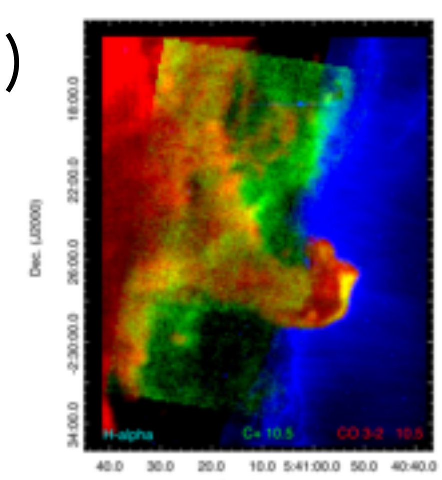
  - Mapping area: l = 221°- 25° (EL>20°), $|b|$ ≤1° ($|b|$ ≤2°)
  - Angular resolution of 2.8' at 1.46THz
  - 3' grid, $\Delta T(5\sigma)$=0.76K at 10min, **10 beams** —> 3400h (6800h)

THz Survey Telescopes

- FIRSPEX (~1m) (Rigopoulou et al. 2015)
  - Small satellite from LEO by ESA and CAS(China)
  - [C II] 1.9THz, [NII] 1.46THz, [C I] 809GHz, CO(6-5) 690 GHz
- STO (80cm) (Walker et al. 2016)
  - The Stratospheric TeraHertz Observatory by Balloon
  - [C II] 1.9THz and [NII] 1.46THz at 1 arcmin. angular resolution



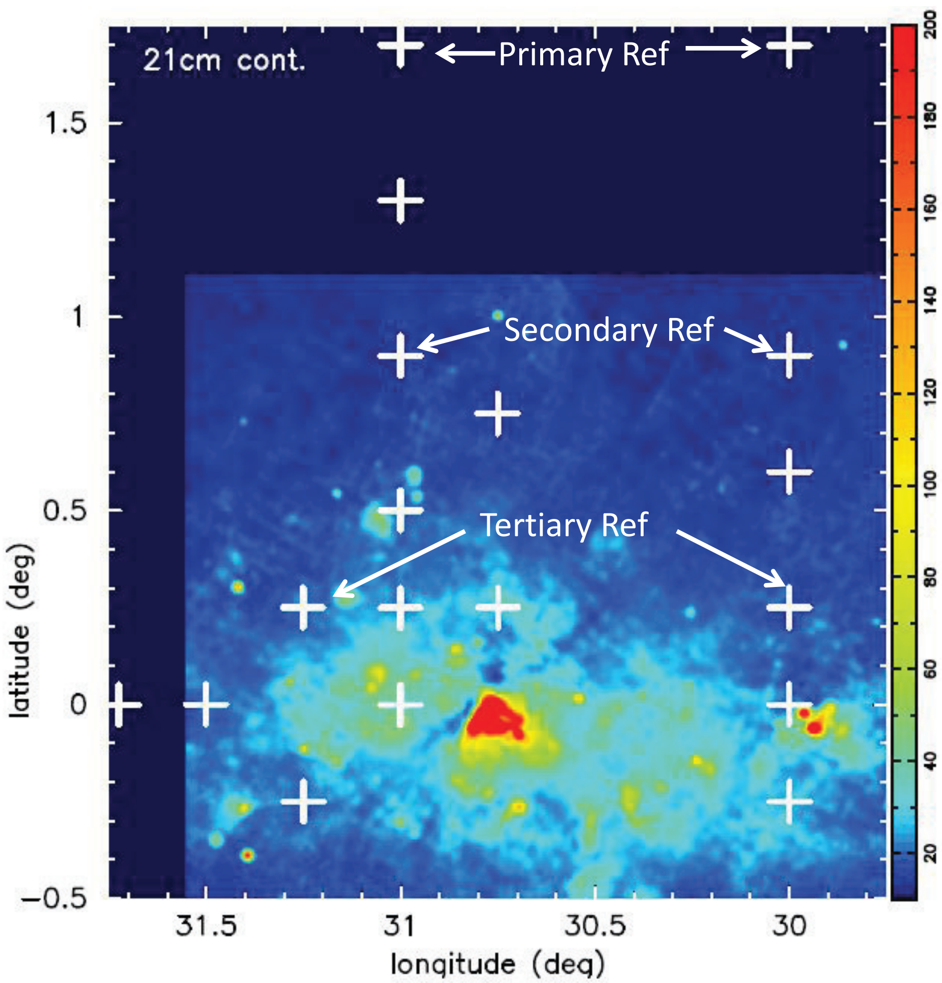
- SOFIA(2.5m)/GREAT (Young et al. 2012)
  - GREAT: 60–240μm (Heyminck et al. 2012)
  - 1.25~5 THz ([N II] 1.46THz, [C II] 1.90THz, [O I] 2.06, 4.74THz)

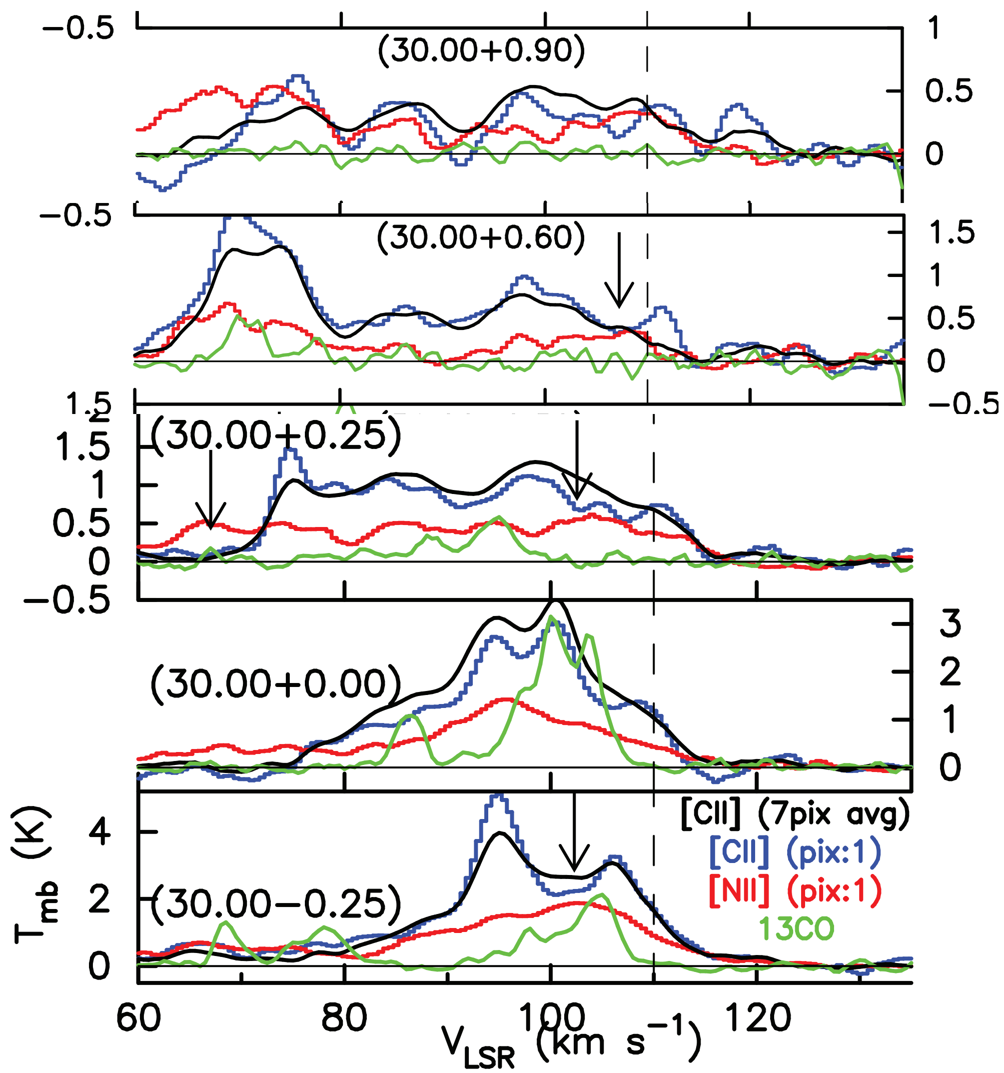


Hα, [C II}], CO(3-2)

Ionized Gas in the Scutum Arm

- [C II]158μm & [N II]205μm obs. by SOFIA
  - Highly ionized gas of the WIM at the inner edge of the Scutum arm tangency sampled along18 LOS (l=30.0-31.75°)
  - Strong [N II] emission throughout the Scutum tangency and decreases exponentially with latitude with a scale height~55pc

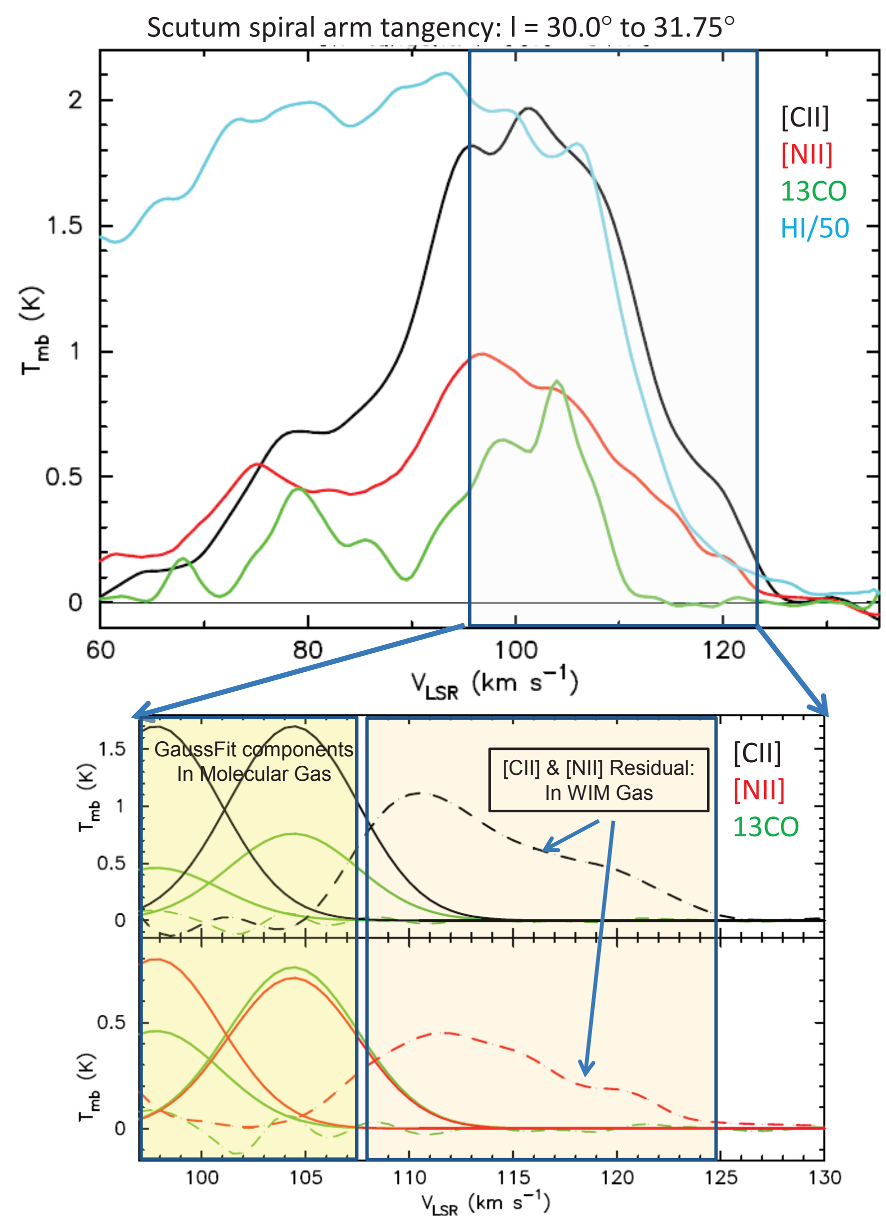


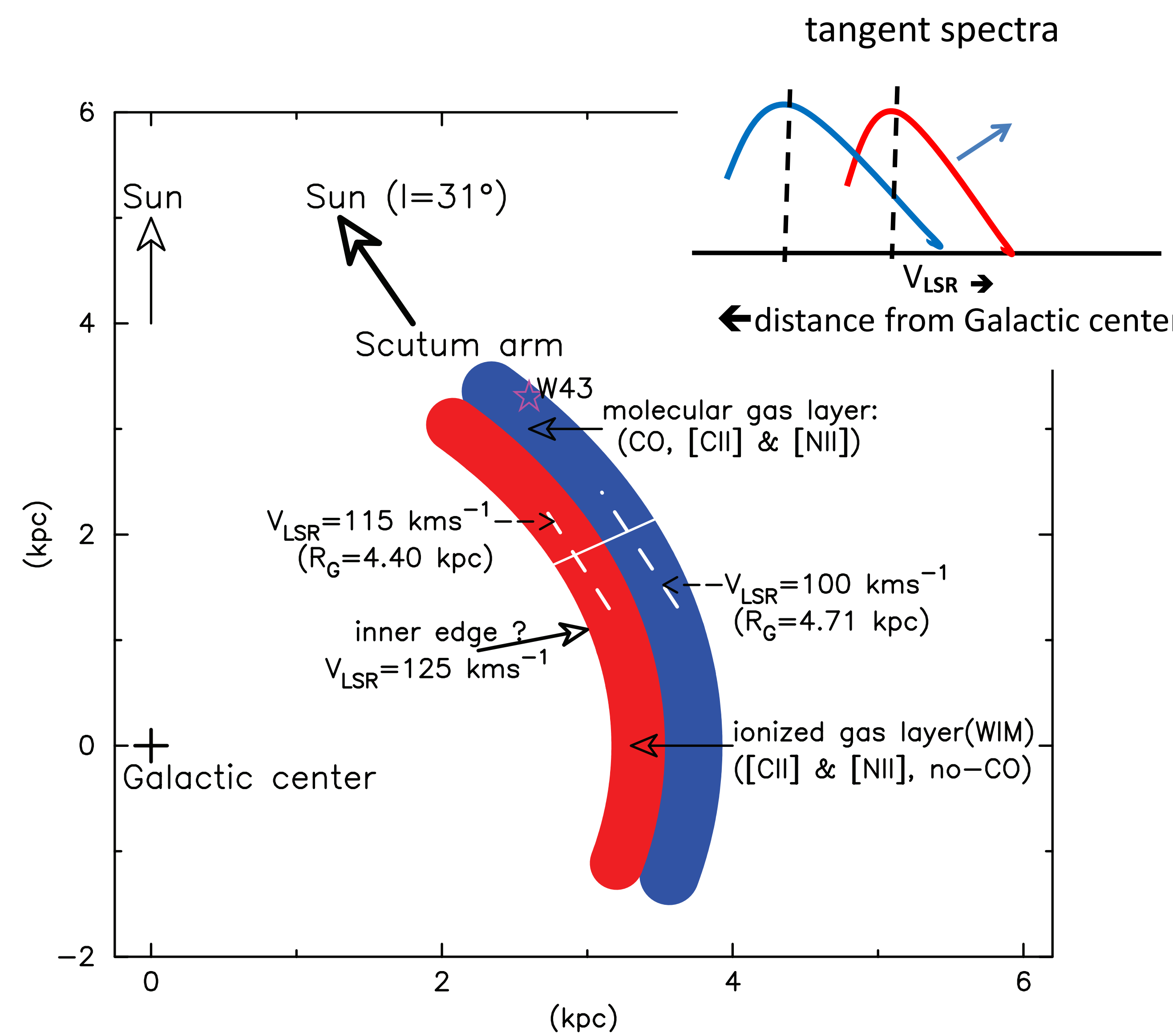


Langer et al. (2017)

Ionized Gas in the Scutum Arm

- There is highly ionized gas within the arm with 1-20 times electron density of the interarm WIM
- [N II] emission arises from shock compression layers of the WIM, accelerated by the gravitational potential of the arm





Langer et al. (2017)

Summary

- To understand the evolutionary process of interstellar medium not only **neutral gas** but also i**onized gas**, the observations of **atomic lines at THz** are criuctial
- [N II] is an **excellent probe** of star formation rate (**SFR**) and infrared dust luminosity (**L_{IR}**), and [N II] emission reveals the fraction of [C II] emission arises from the **ionized** gas and the **neutral** ISM.
- So I would like to propose the [N II] 1.46THz Galactic plane survey with the heterodyne receiver camera at South Pole. There is difficulty to survey entire the Milky Way, but it is good to observe the limited area (strips) or to survey by 30cm telescope.