Molecular Gas Distribution of our Galaxy: NANTEN Galactic Plane Survey

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23-24 May 2005@SLAC

Neutral ISM in the Galactic Disk

	density	observation line
-	HI: 1-10 cm^{-3}	HI (21 cm)
-	H_2: 10^2-10^4 cm^{-3}	CO(J=1-0) (2.6 mm)

How to estimate gas mass from CO spectrum?

↓

brightness temperature ⇨ column density ⇨ gas density

assumptions

(1) depth of a cloud toward the line of sight

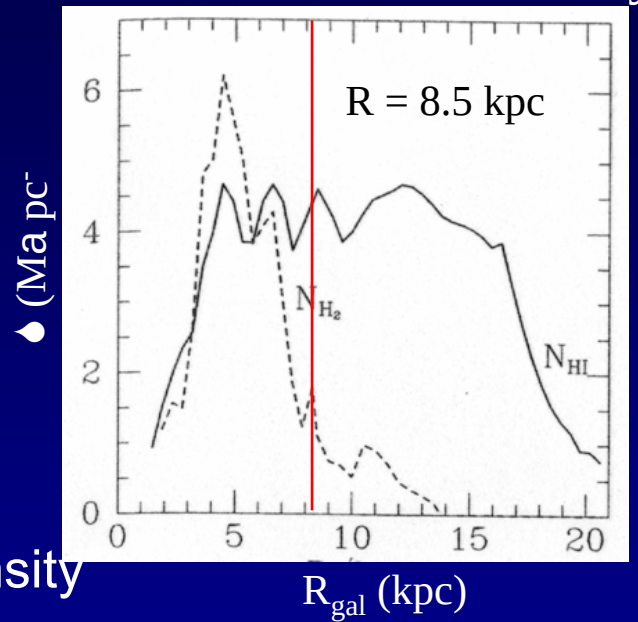
(2) distance of cloud

(3) $N(H_2)/W(CO)$ conversion ratio (X-factor)

Scale height: H_2 ~ 60 pc

HI ~ a few x 100 pc (increase with R)

Radial mass surface density

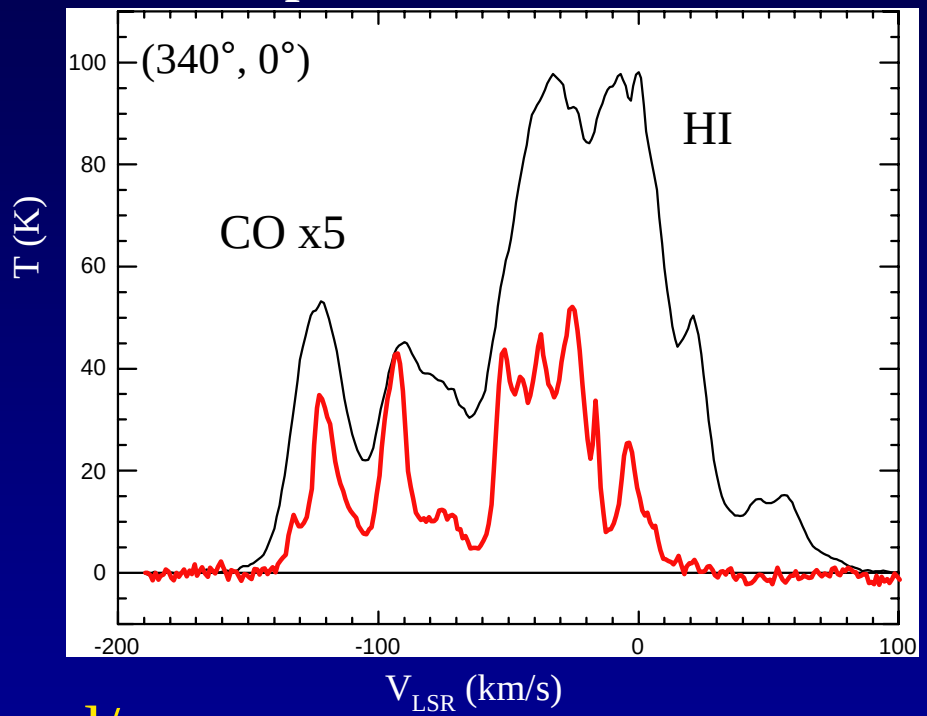


Advantages of Molecular Observations

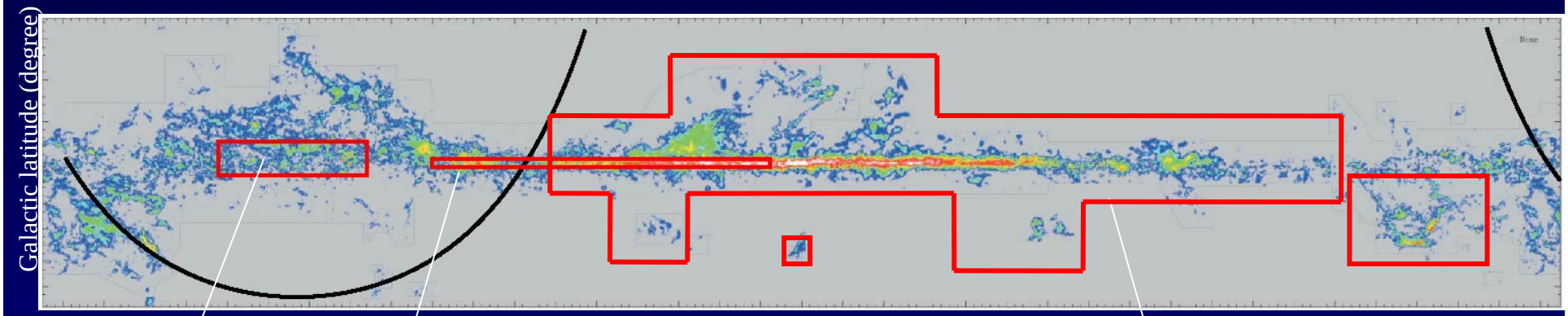
(1) better angular resolution
(2) better velocity resolution
(3) smaller line-width
⇨ less contamination
in velocity field

(4) trace more dense gas
⇨ better probe of spiral arms and/or
GMCs coupling with cosmic rays

line profiles of CO and HI



CO Galactic plane surveys



FCRAO UMassSB NANTEN

name	diameter	beam	grid	covered area	longitude range
Columbia	1.2m	8.7′	8-15’	|b| < 10-25°	(complete)
Mass.-S.B.	14m	45″	3-6’	|b| < 1°	(inner Galaxy, ^{13}CO)
FCRAO	14m	45″	50”	|b| < 4°	(outer Galaxy)
NANTEN	4m	2.6′	4-8’	|b| < 10-25°	(220°< *l* < 60°)

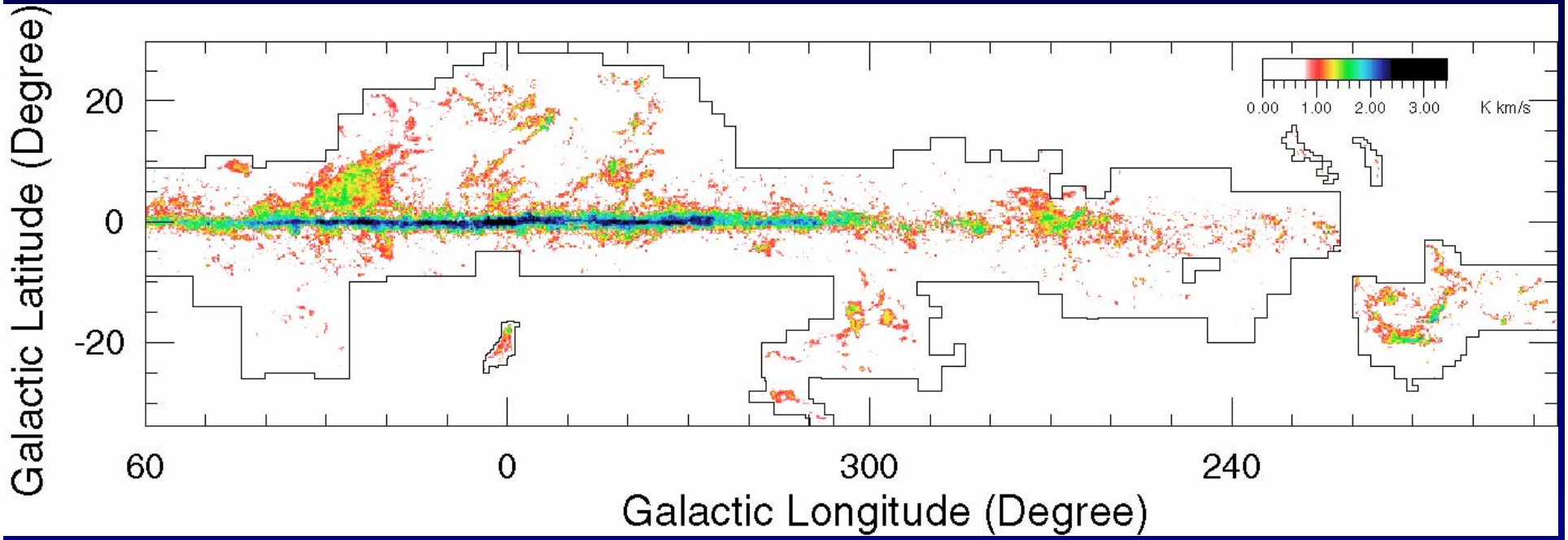
NANTEN 4m radio telescope

Las Campanas Observatory, Chile

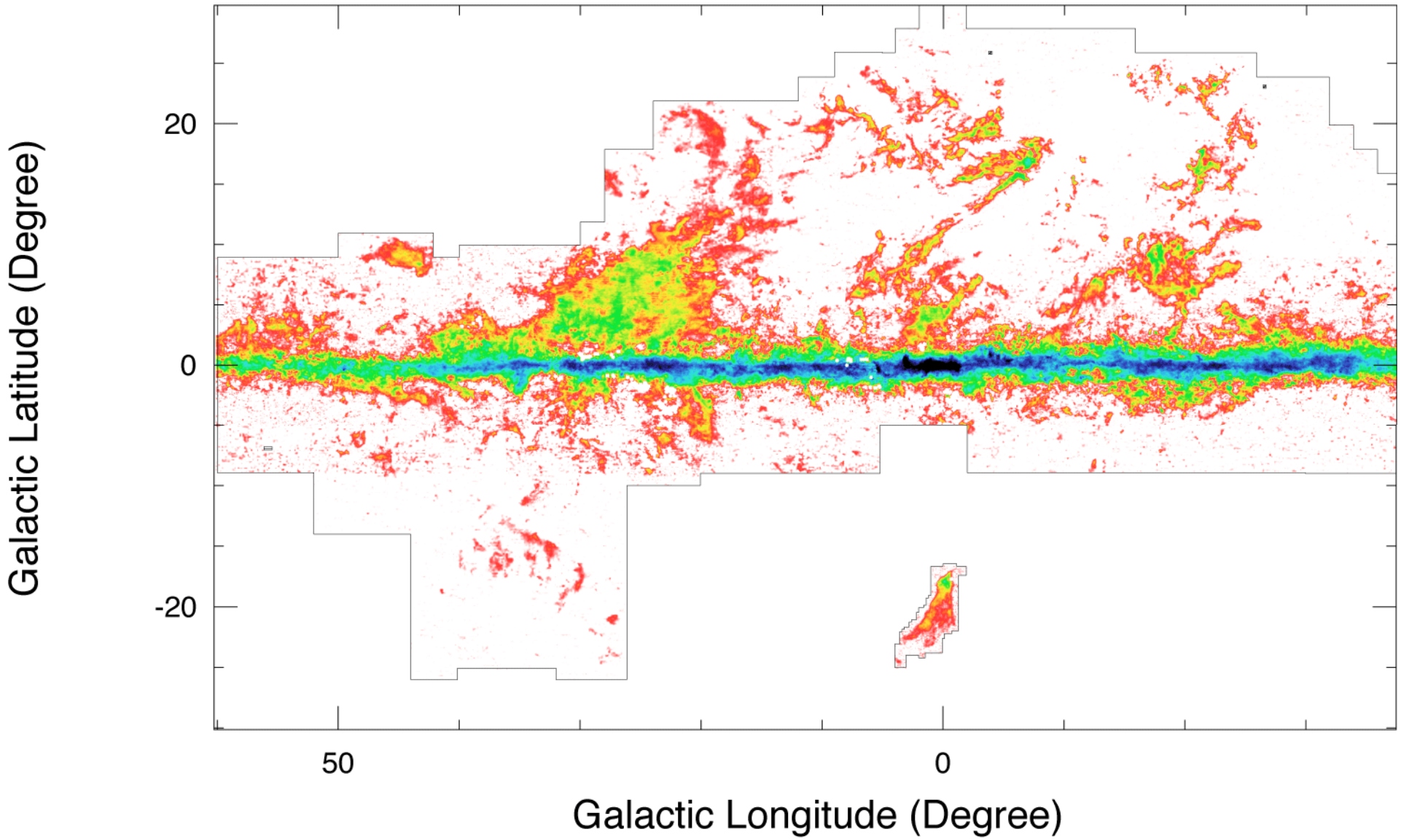
Nagoya University radio astronomy group

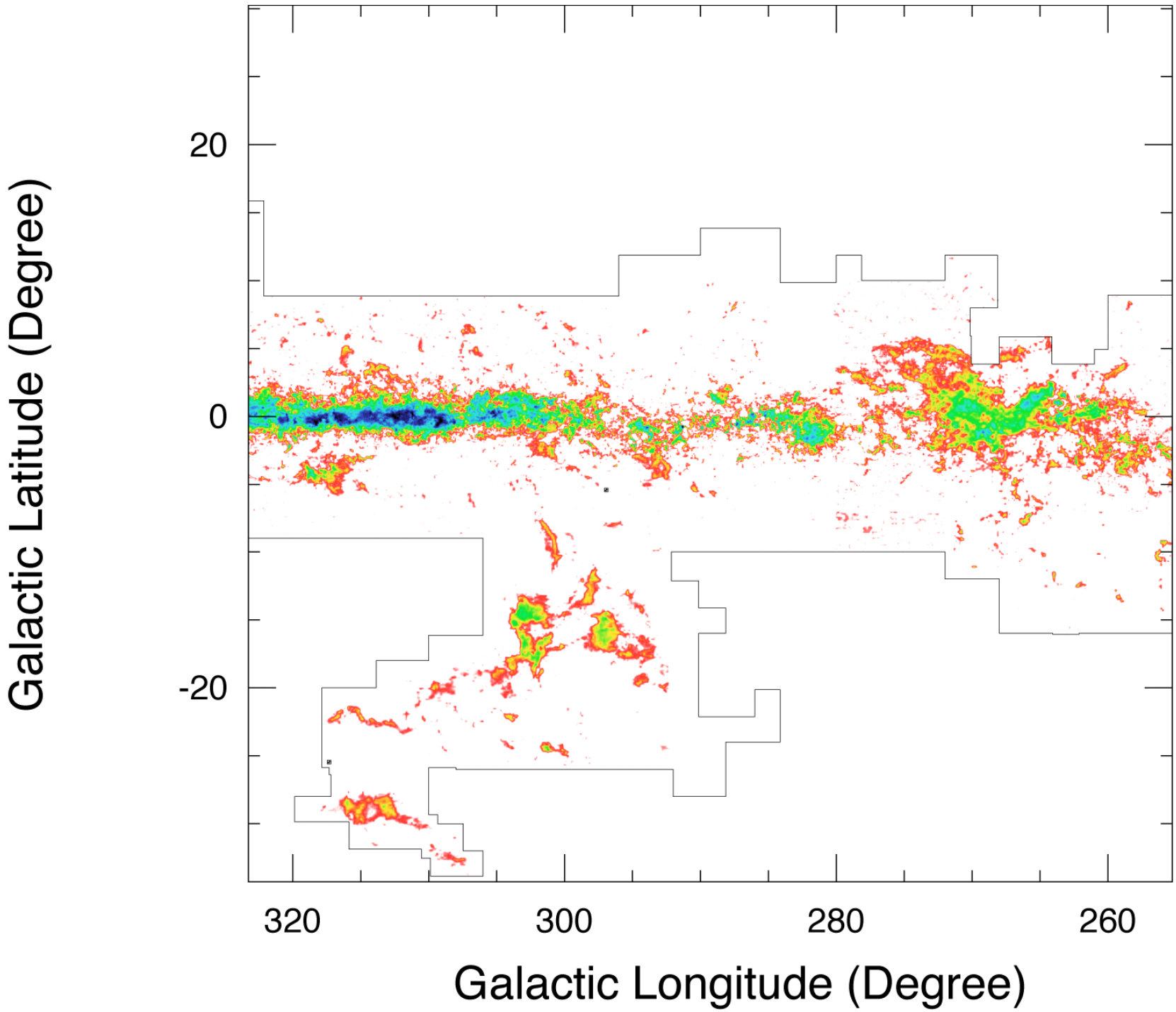
- superconductor mixer
- Frequency band : 85 -115GHz
- Beam size = 2.6′(@115GHz)
- Velocity resolution = 0.1 or 0.6 km/s
- Velocity coverage = 100 or 650 km/s
- Tsys =100-300 K

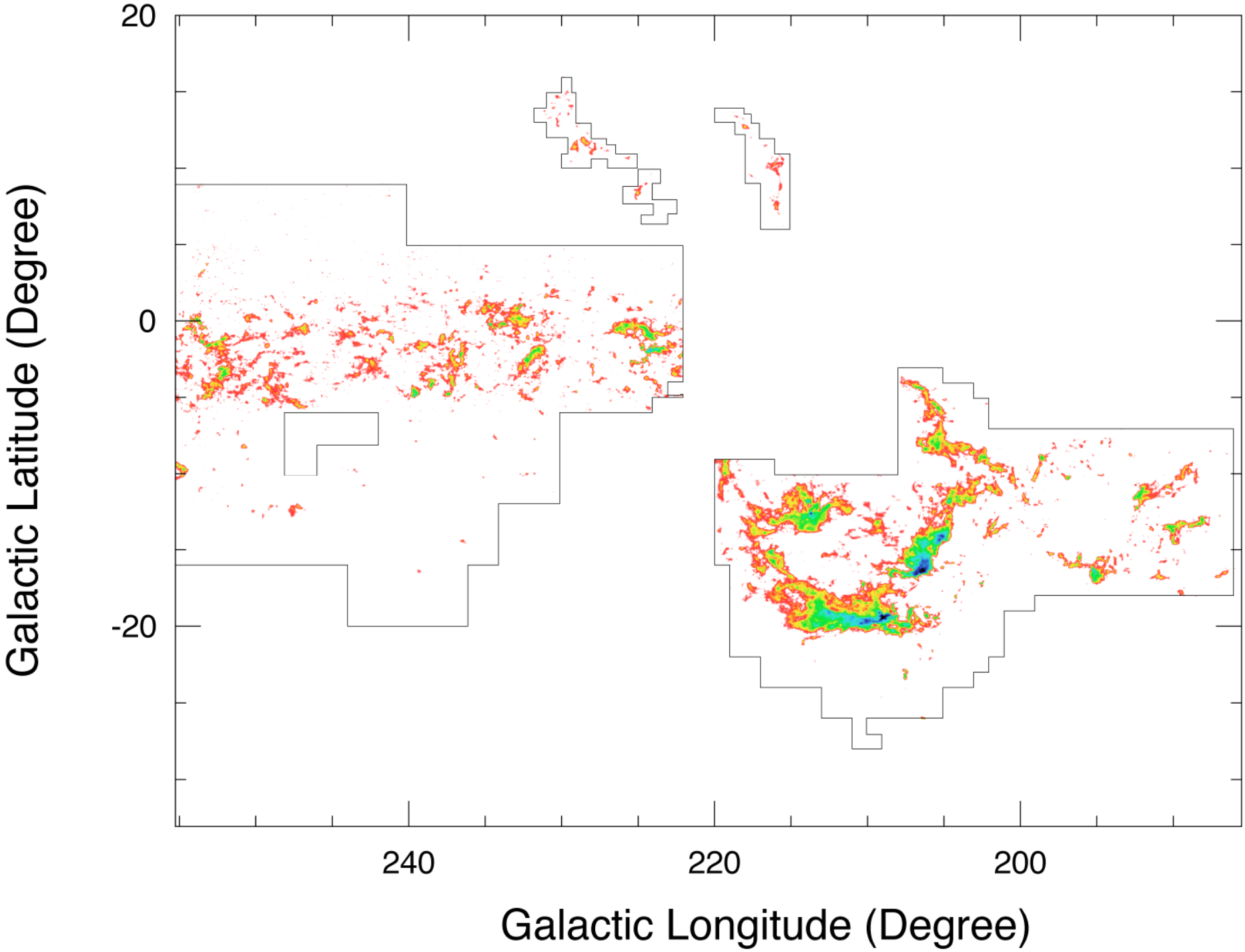
NANTEN ^{12}CO (J=1-0) Galactic Plane Survey



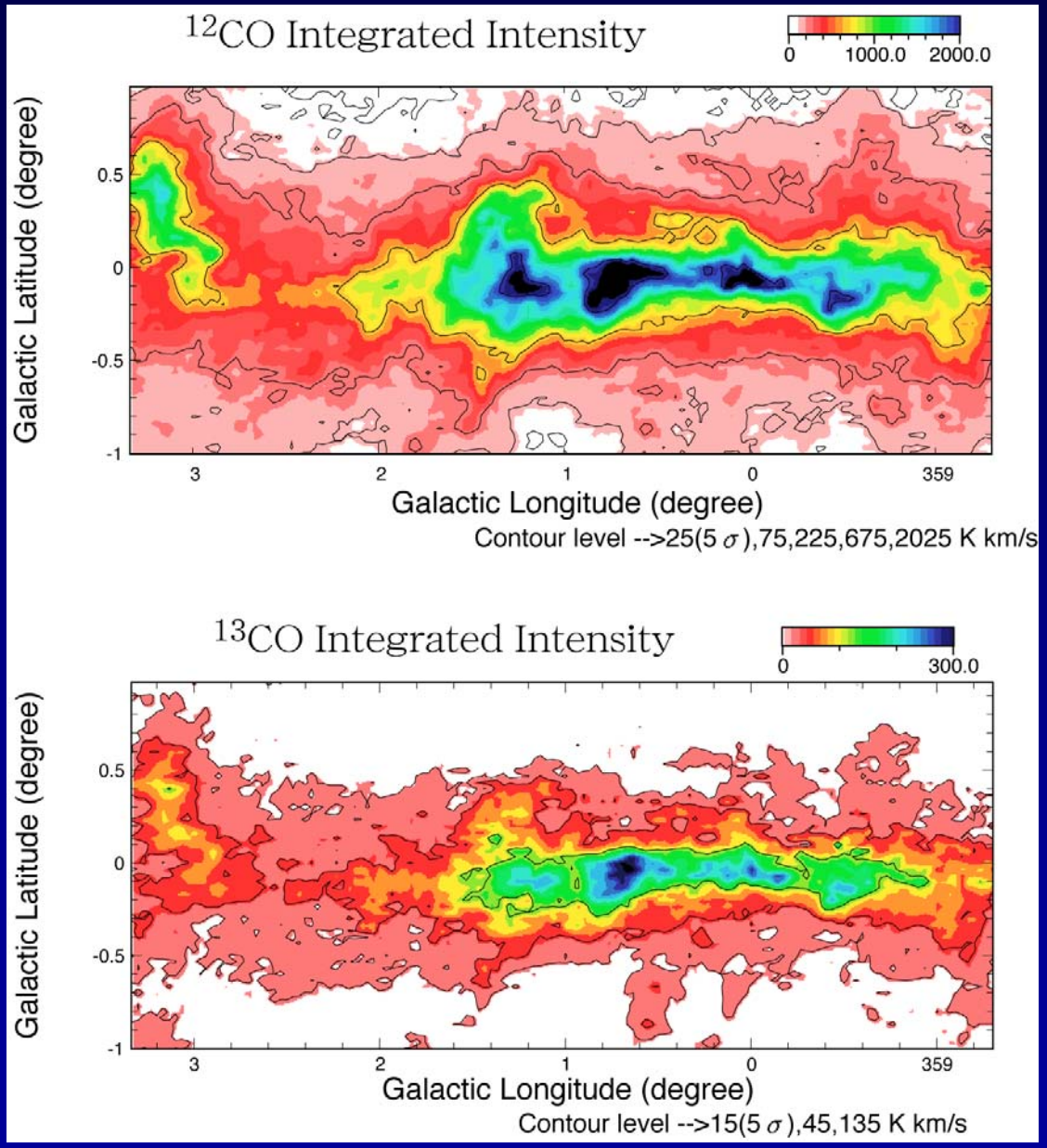
Observed area:	$220° < l < 60°$, $\|b\| < 10$-$25°$
Grid spacing:	4’ ($\|b\| < 5°$)
	8’ ($\|b\| > 5°$)
Number of spectra:	1,100,000
Sensitivity:	~ 0.4 K


Galactic Latitude (Degree)
20
0
-20
50
0
Galactic Longitude (Degree)

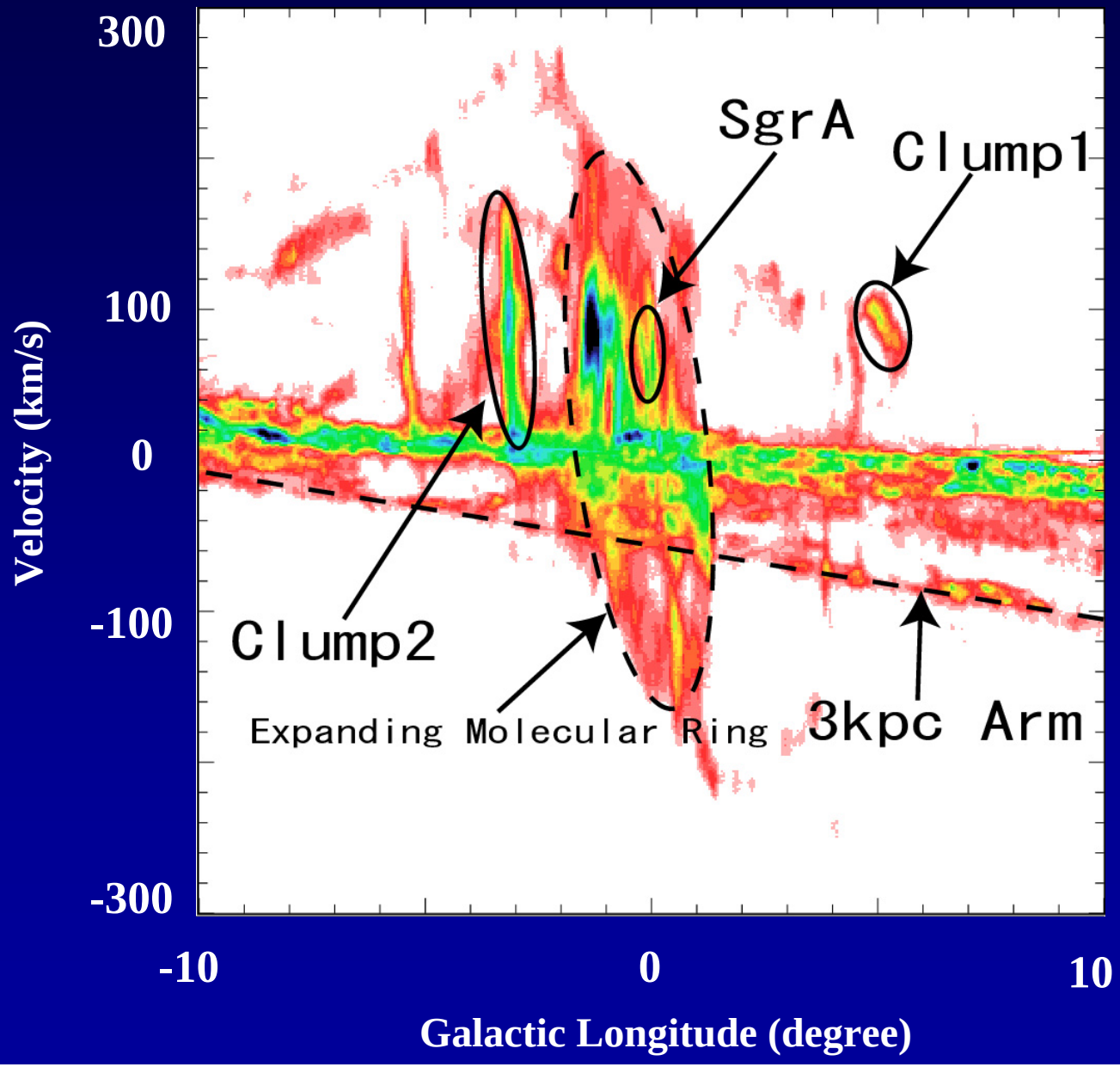

Galactic Latitude (Degree)
20
0
-20
320
300
280
260
Galactic Longitude (Degree)


20
0
-20
240
220
200
Galactic Latitude (Degree)
Galactic Longitude (Degree)

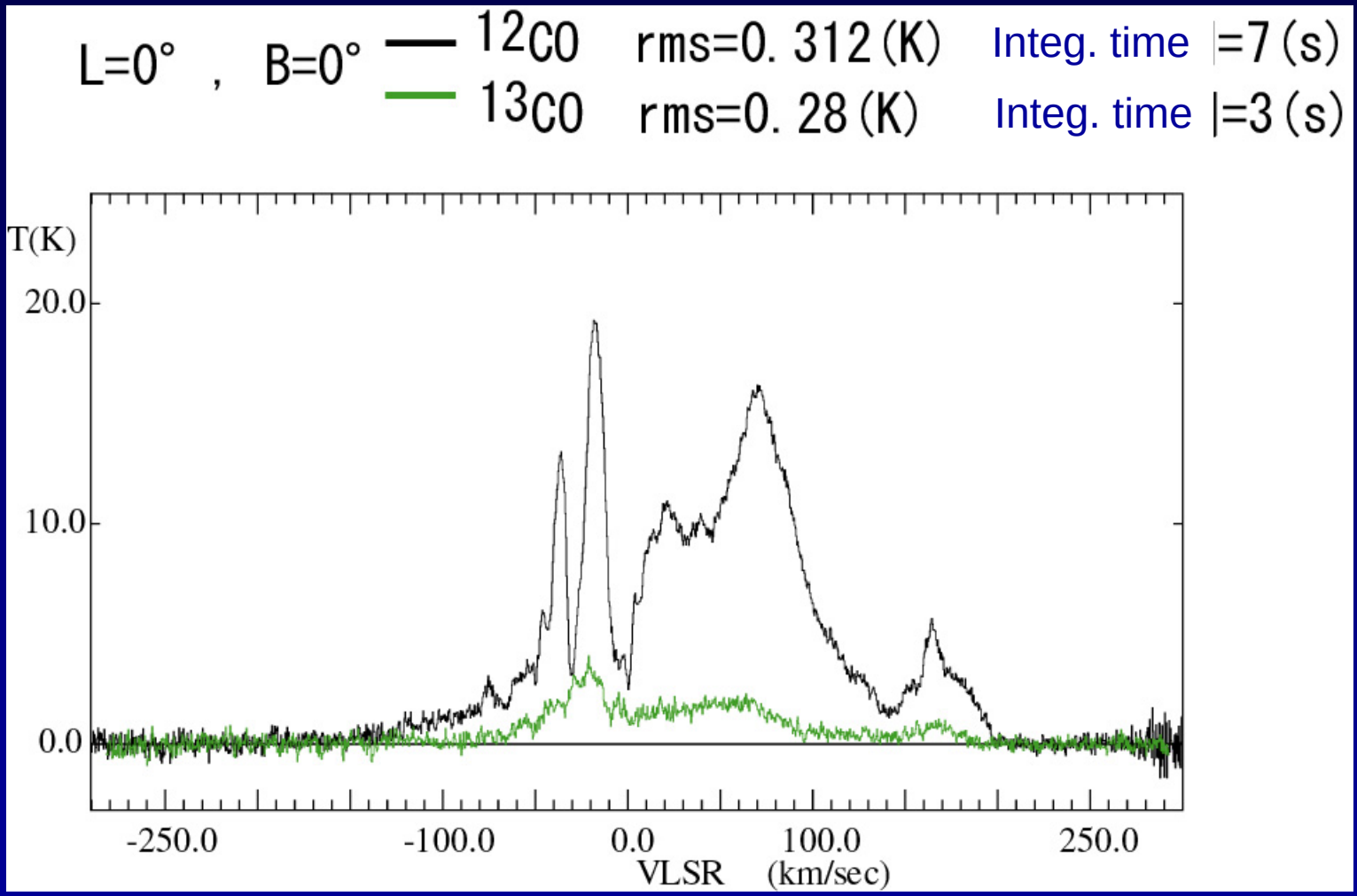
Galactic Center



Longitude-Velocity

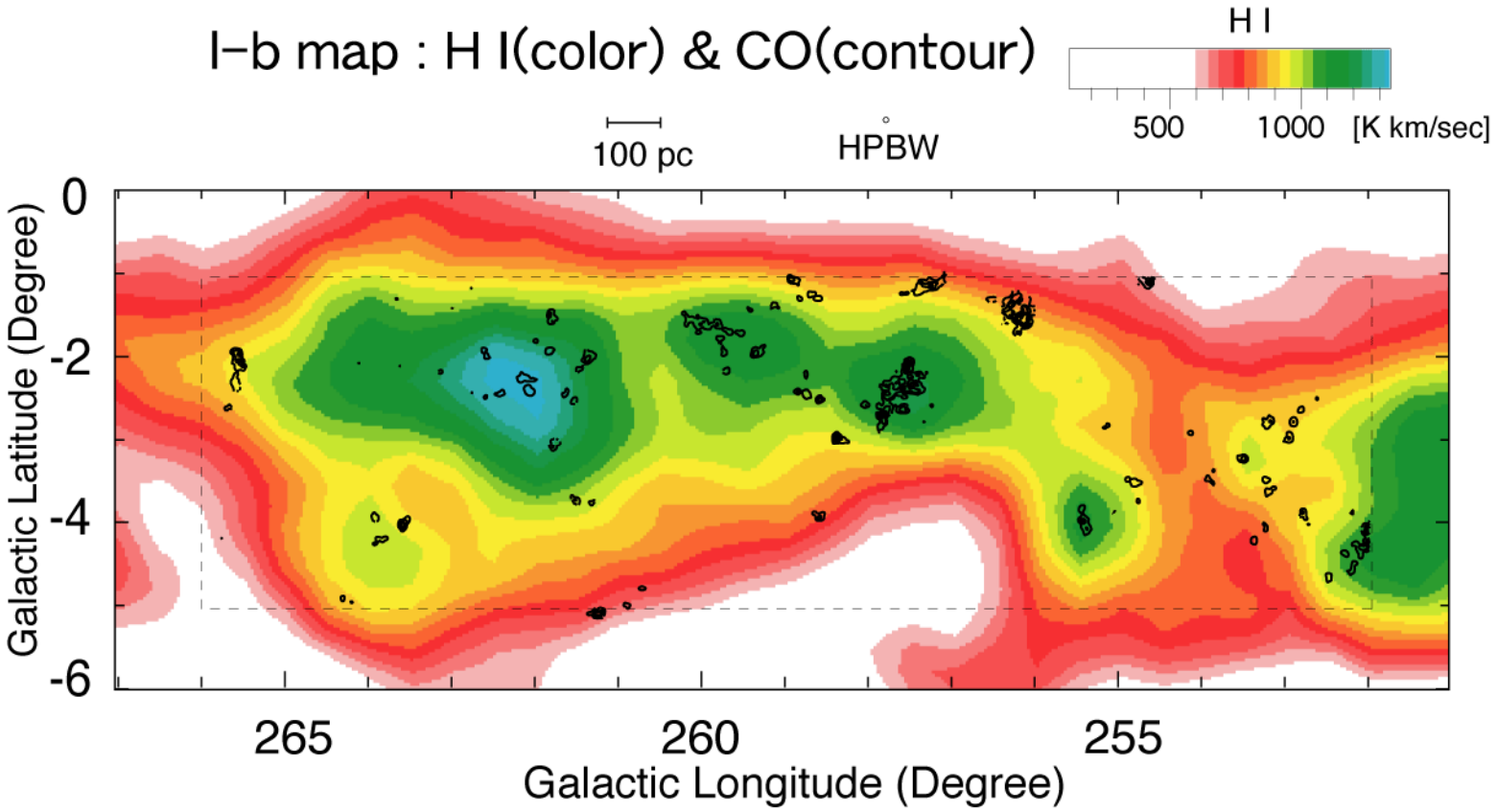


Typical Profiles



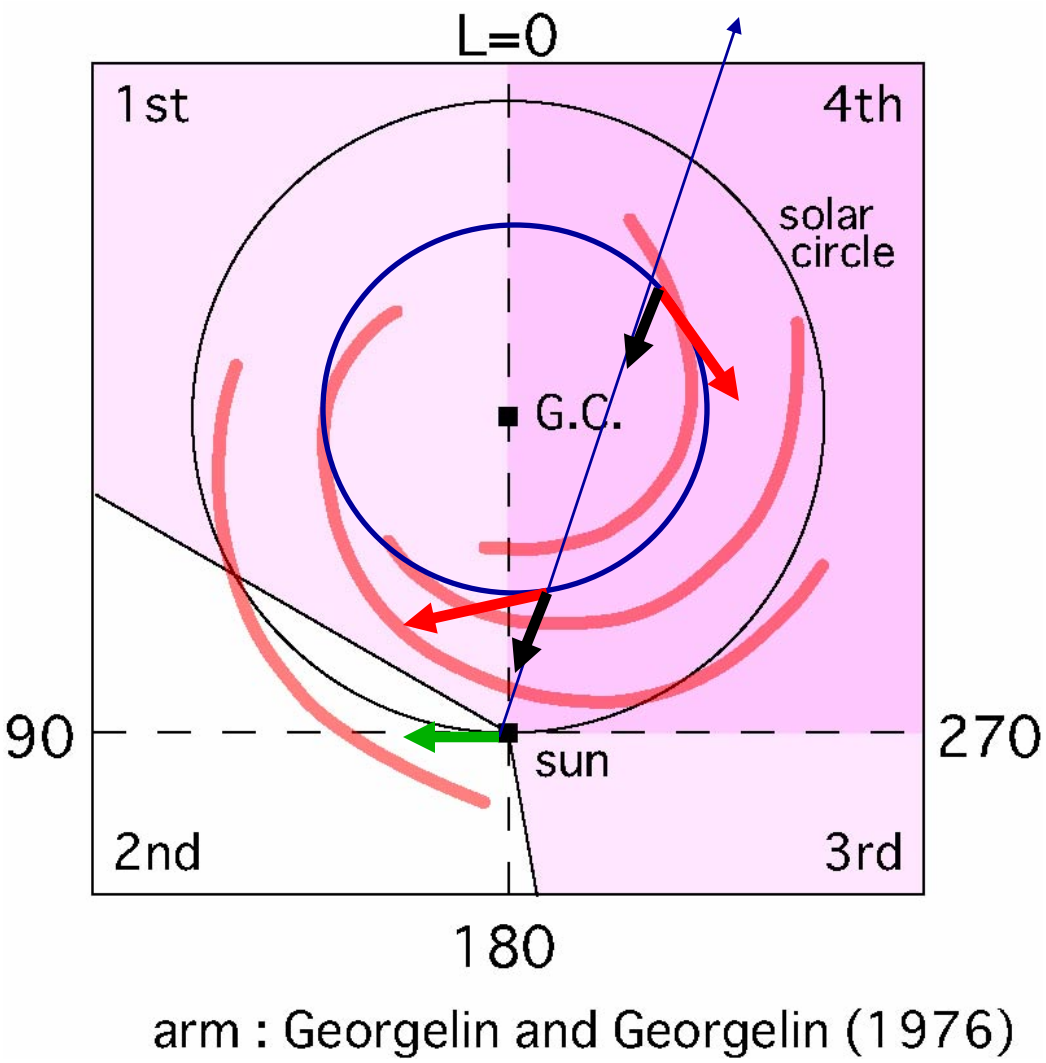
Galactic Warp

distribution of warp clouds



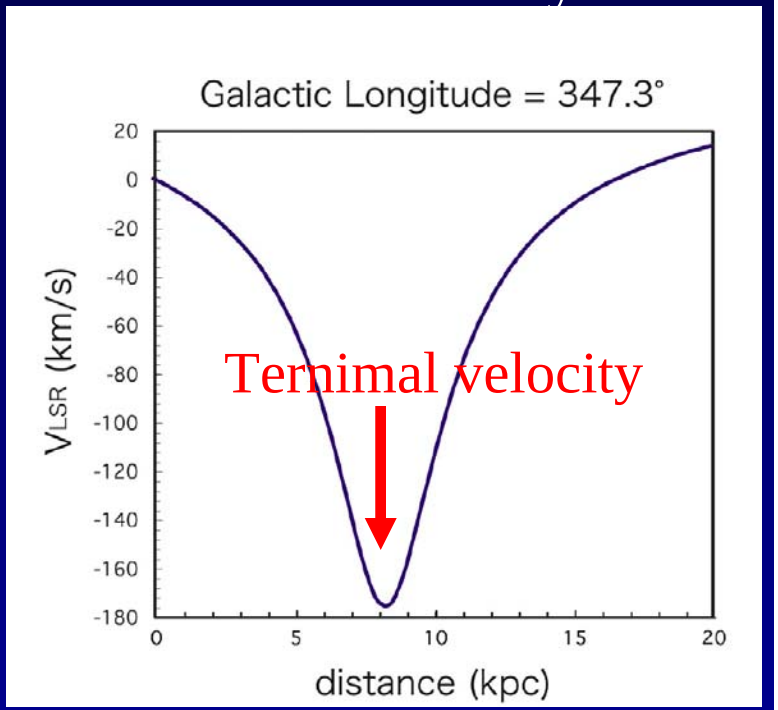
- mass range : 500(detection limit) - 50,000(max) M⊙ (<< GMC)
- total mass : $5*10^5$ >> $1*10^4$ (previously known in this region)

spiral structure and kinematic distance



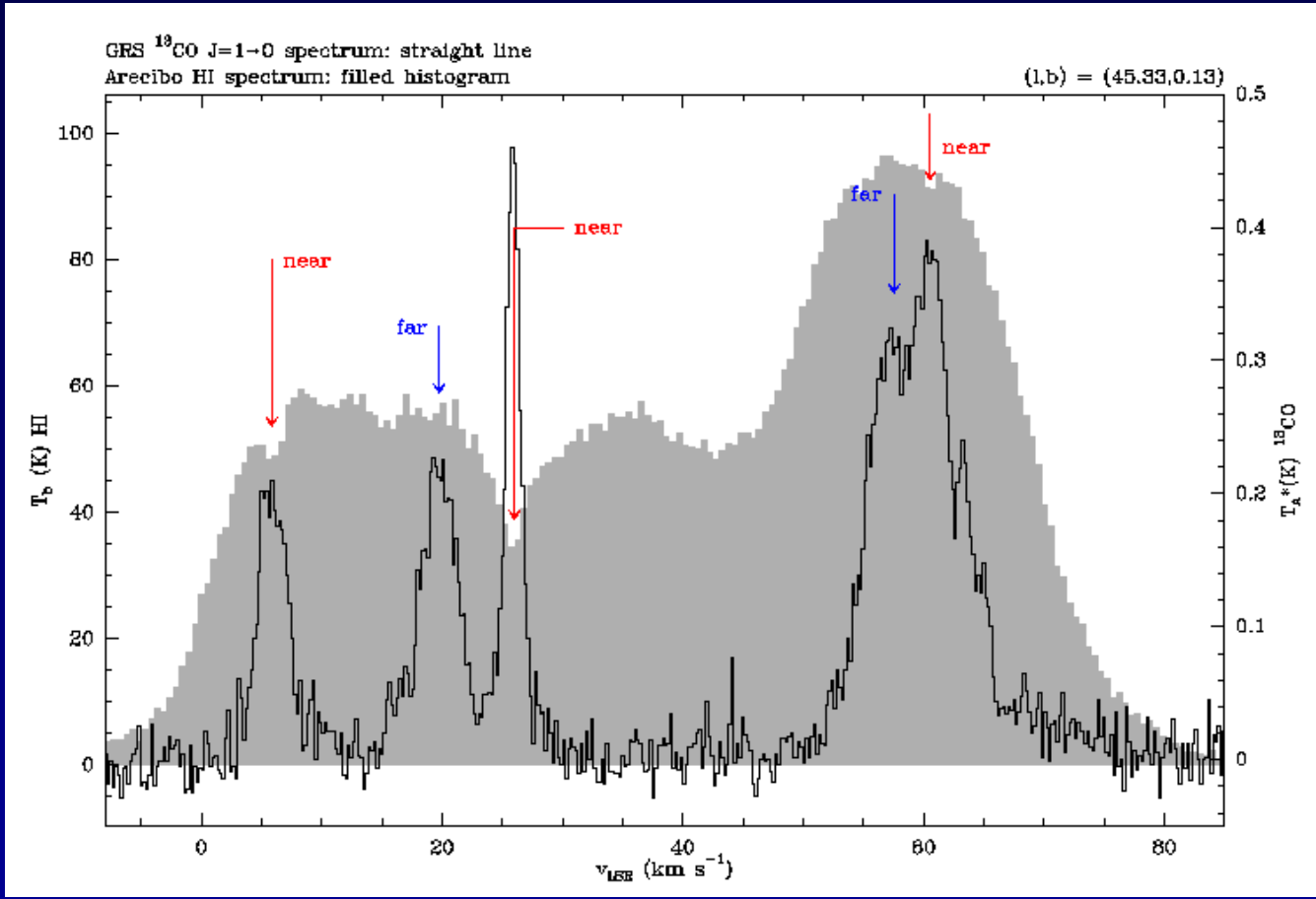
arm : Georgelin and Georgelin (1976)

two solutions for
the inner Galaxy



Assumption of
circular velocity is needed.

How to solve distance ambiguity?



(Kolpak et al. 2000)

Self absorption by cold HI gas ⇨ evidence of **Nearside** CO cloud

(HI data with high sensitivity and high resolution is necessary.)

Galactic rotation curve models

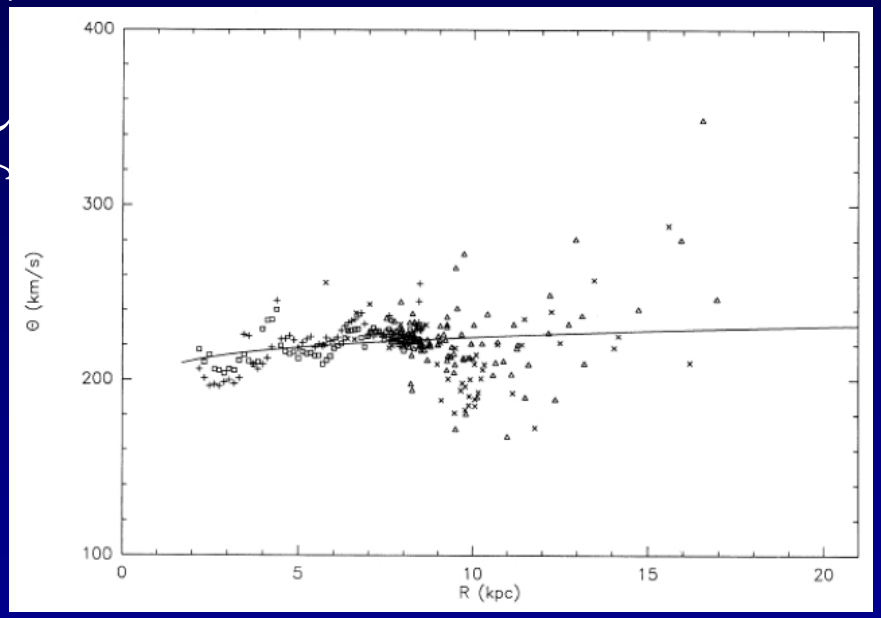
Reference	Area	data
Burton & Gordon (1978)	Quad 1	HI, CO
Clemens (1985)	$13^\circ < l < 85^\circ$	CO, HI
Fich et al. (1989)	north	HI, CO, HII
Alvarez et al. (1992)	$-10^\circ < l < 210^\circ$	CO
Merrifield (1992)	External Gal.	HI
Brand & Blitz (1993)	Outer Gal.	HI, CO, HII, Neb.

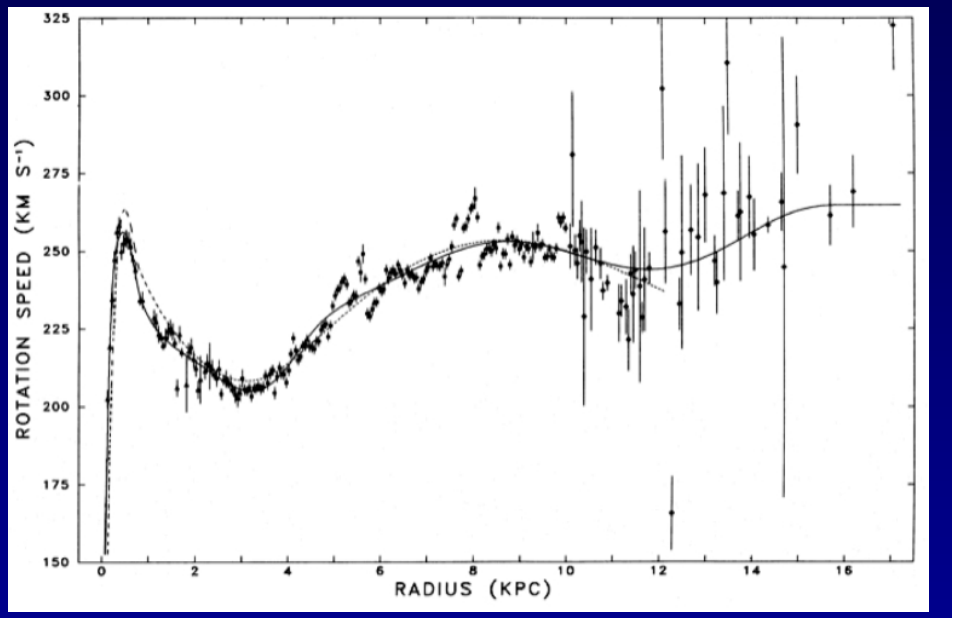
Errors of rotation curve

Brand & Blitz (1993)

Clemens (1985)

Circular velocity (km/s)





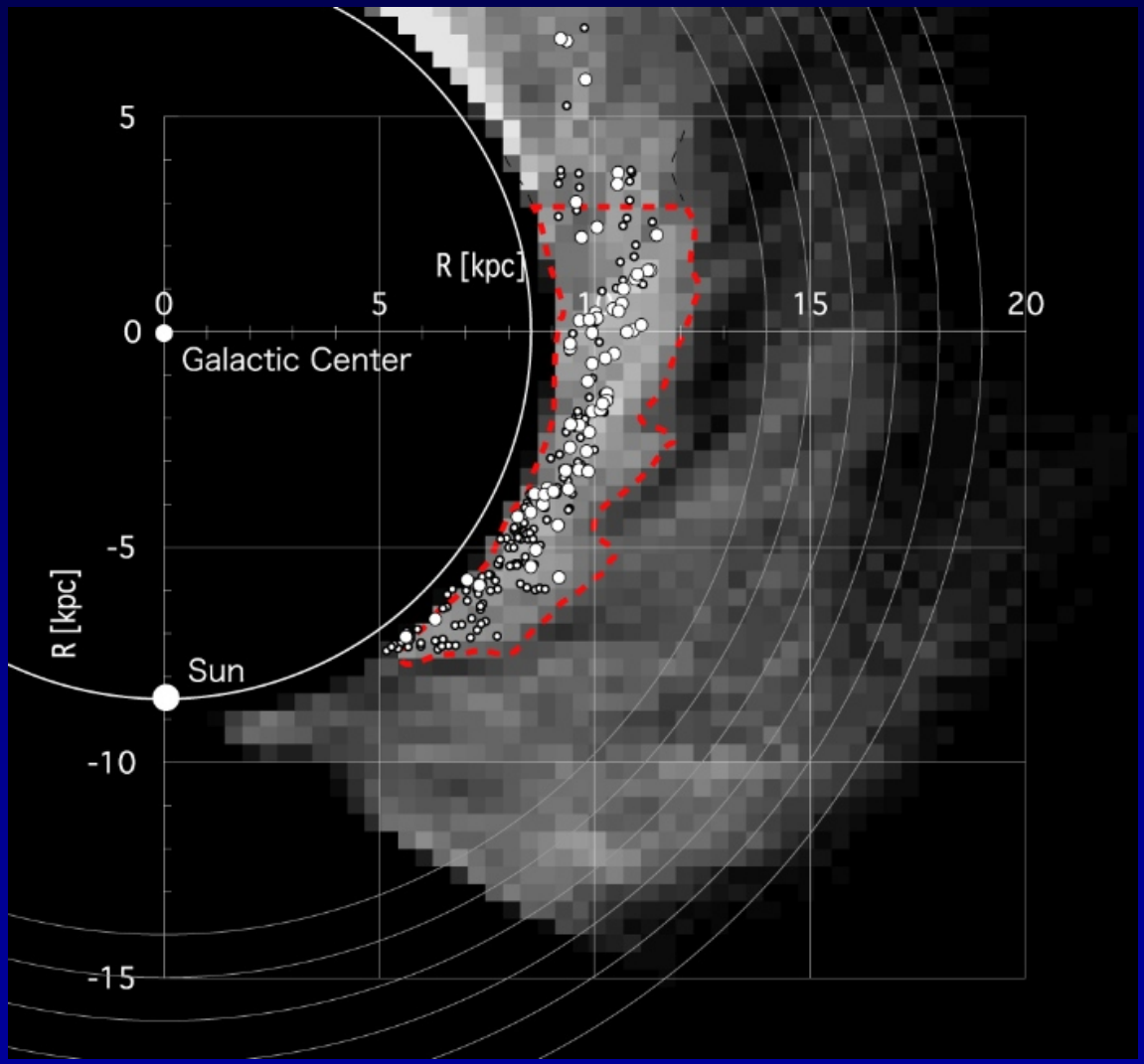
Galactocentric distance (kpc)

- dependence on models: 10 ~ 20 % error
- cloud-cloud velocity dispersion by random motion etc.:~ 10 km/s

(e.g. Stark & Brand 1989)

H_2 - HI top-view of the Galactic disk

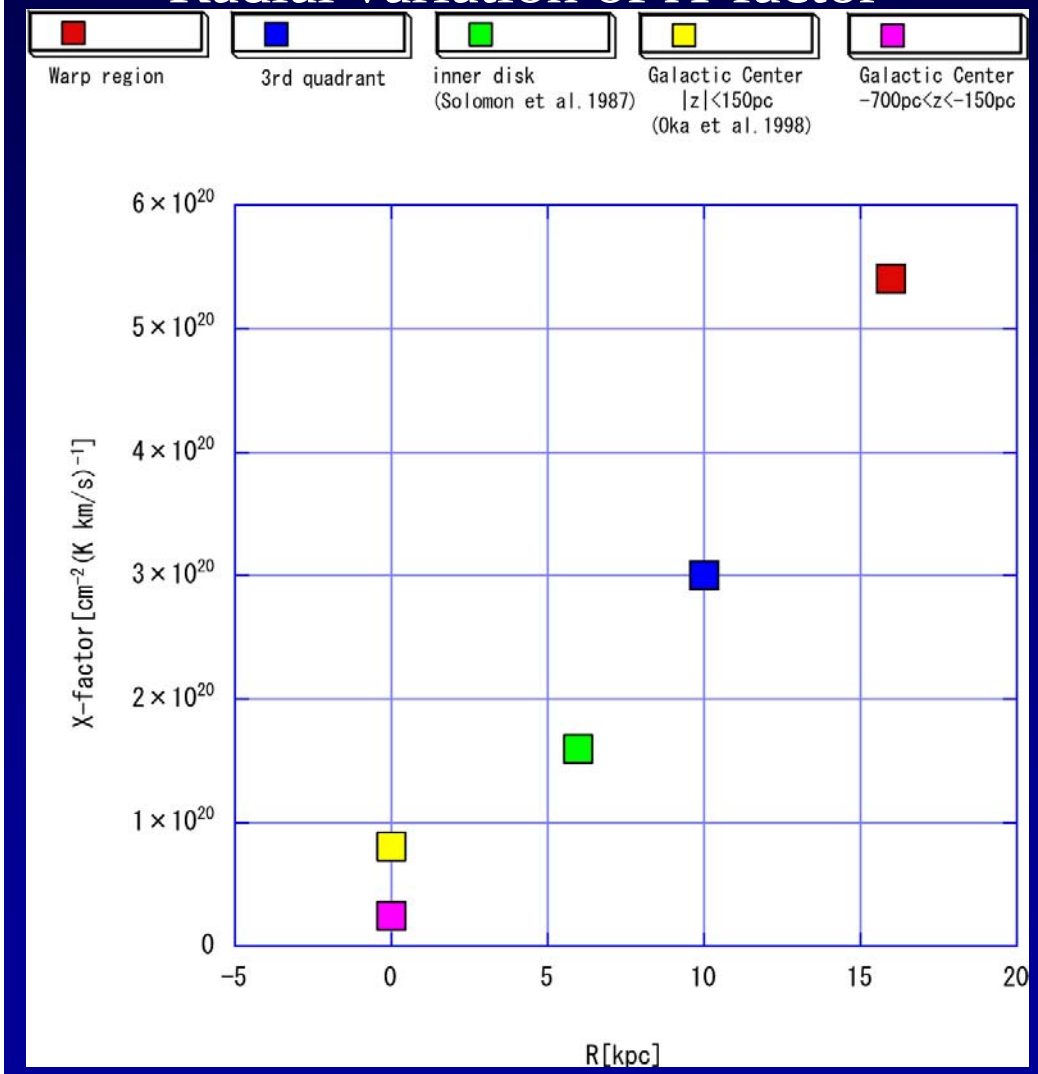
White circle: CO cloud (NANTEN) gray scale: HI (Parkes 18m, Kerr et al. 1986)



rotation curve model: Brand & Blitz (1993)

X - Factor

Radial variation of X-factor



$$n_{H_2} = \frac{X}{\Delta r} W_{\mathrm{CO}} \quad (cm^{-3})$$

How to estimate X-factor?

- far-IR/CO/HI combination
- Galactc diffuse gamma-ray
- virial mass of clouds

1.9×10^{20} (Strong & Mattox 1996)
1.3×10^{20} (Reach et al. 1998)
1.8×10^{20} (Solomon et al. 1987)
0.8×10^{20} (Oka et al. 1998)

NANTEN

$\sim 3\times10^{20}$ (3rd quad.)
$\sim 5.4\times10^{20}$ (Warp)

Verification of X-factor

- Virial mass - CO luminosity relation
  - using NANTEN (this method requires an assumption that the cloud is virialized)
- CO+HI+far IR
  - ⇨ NANTEN + SGPS + IRAS (or ASTRO-F)
  - ASTRO-F launch in 2005
- gamma-ray ⇨ GLAST + NANTEN + SGPS
  - GLAST launch in 2007

NANTEN 2 Project

4-m sub-mm telescope for extended CO/CI surveys

target frequency: 100-800 GHz (beam size = 2.6’ - 22”)

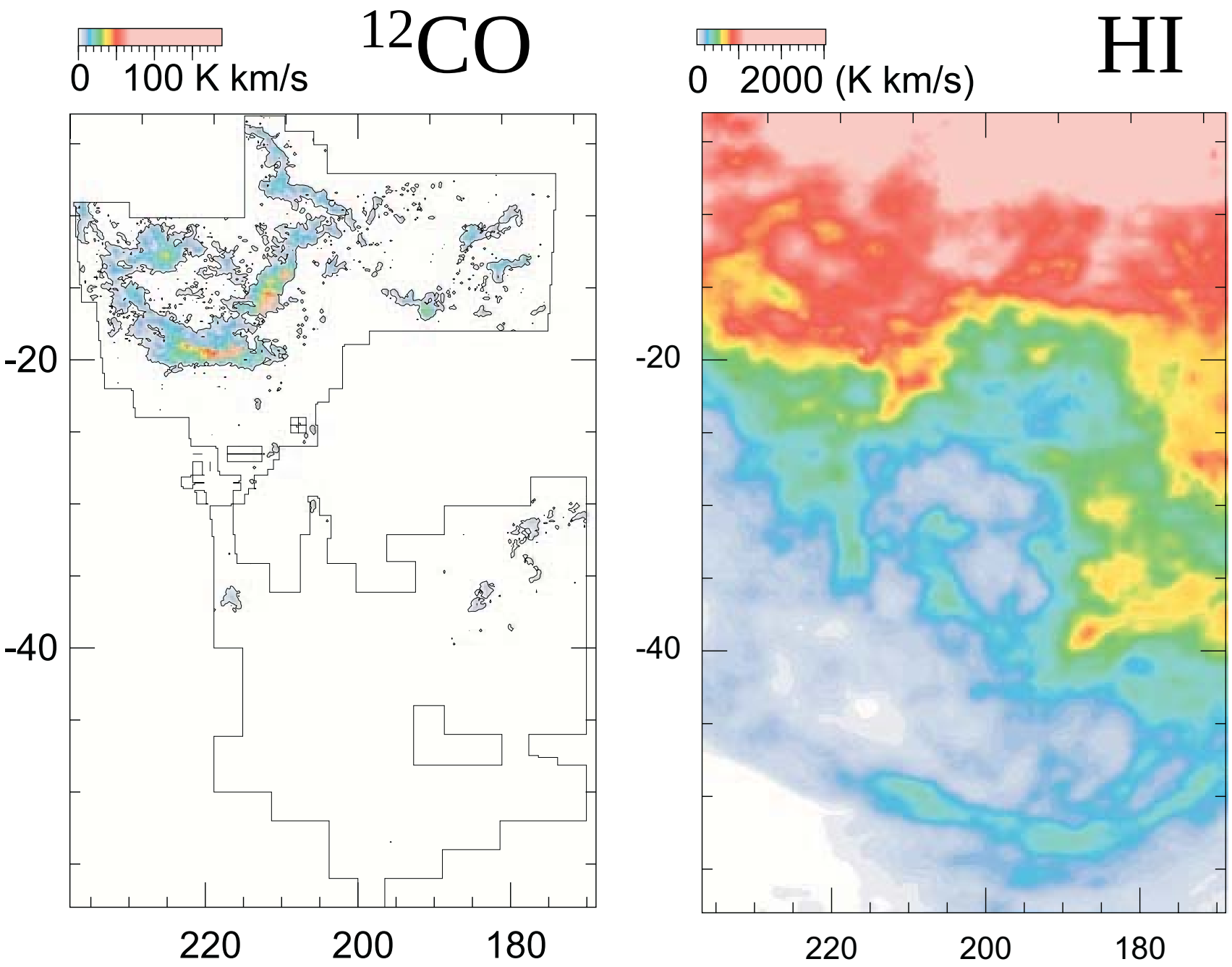
Nagoya Univ., Osaka Prefecture Univ. (Japan)
Universitaet zu Koeln, Universitaet Bonn (Germany)
Seoul National Univ. (Korea) Univ. of Chile (Chile)

Atacama, Pampa la Bola site

Starting test observations in 2005 Dec.

Summary

- NANTEN Galactic Plane Survey produces high-quality molecular maps of the southern sky
- Galactic rotation curve, X-factor
  Dependence on models should be considered.
- telescope developments: NANTEN → NANTEN2


^{12}CO
0 100 K km/s
HI
0 2000 (K km/s)
-20
-40
220
200
180
-20
-40
220
200
180