



NRO Galactic Plane Survey (FUGIN) Legacy Project

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and
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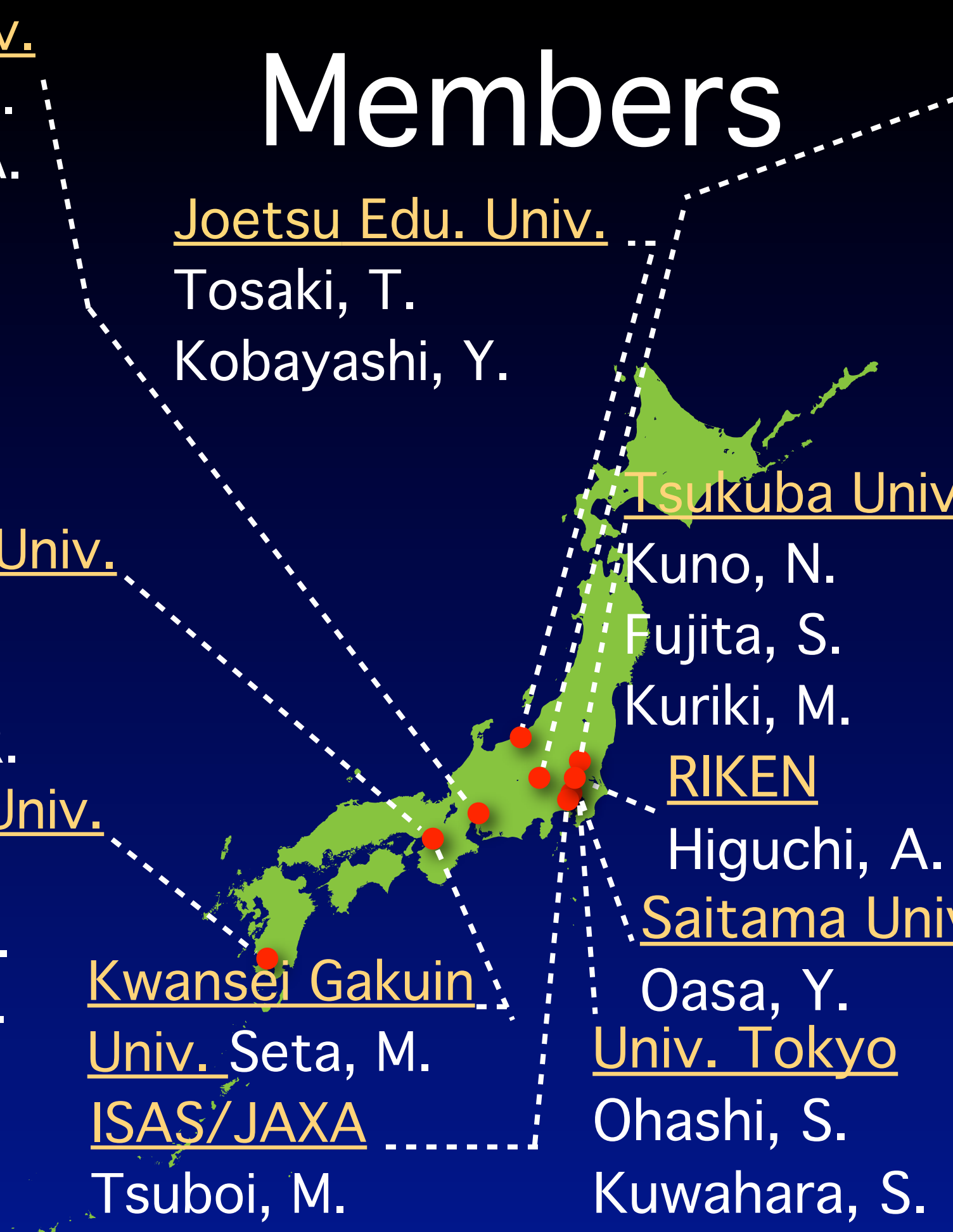
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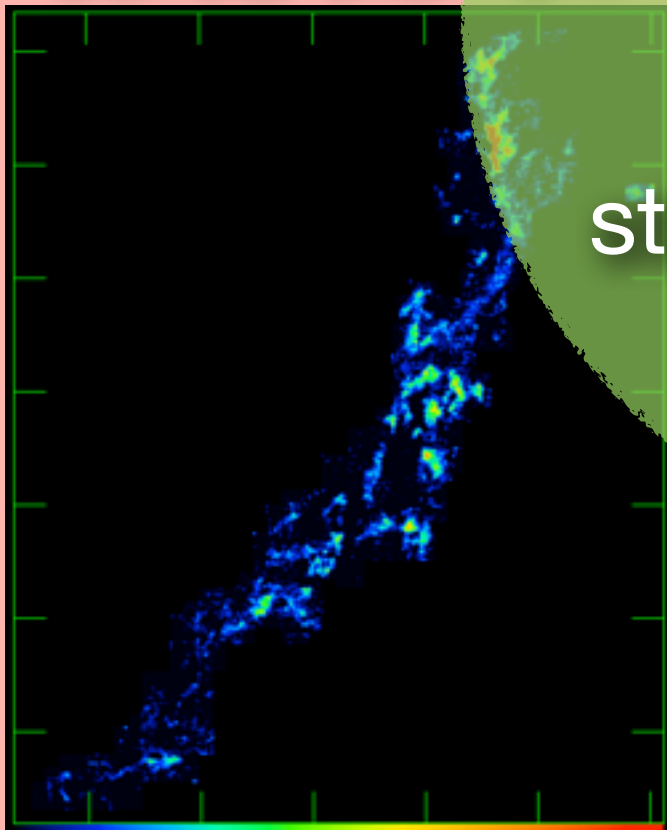
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Missing Link

Formation process of dense clumps
studied in nearby GMCs in the Galaxy

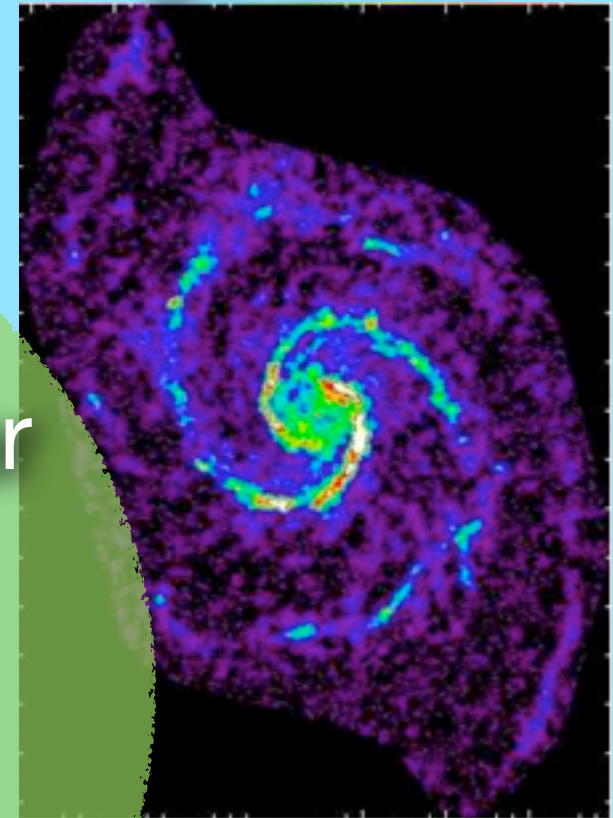
cores/clumps



Tatematsu +1993

Linkage between star
formation study
in the Galaxy
and
study of molecular gas
in galaxies

galaxies

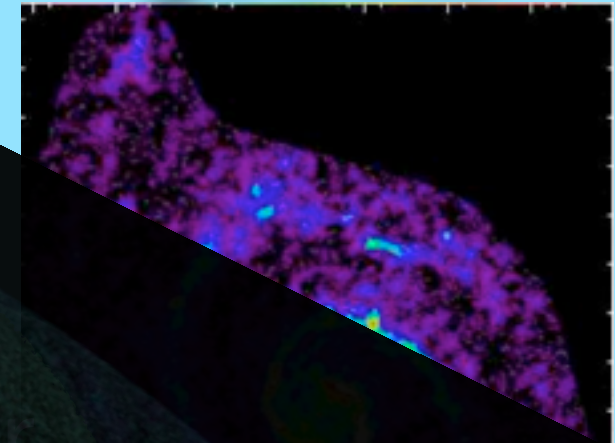


Koda+ 2011

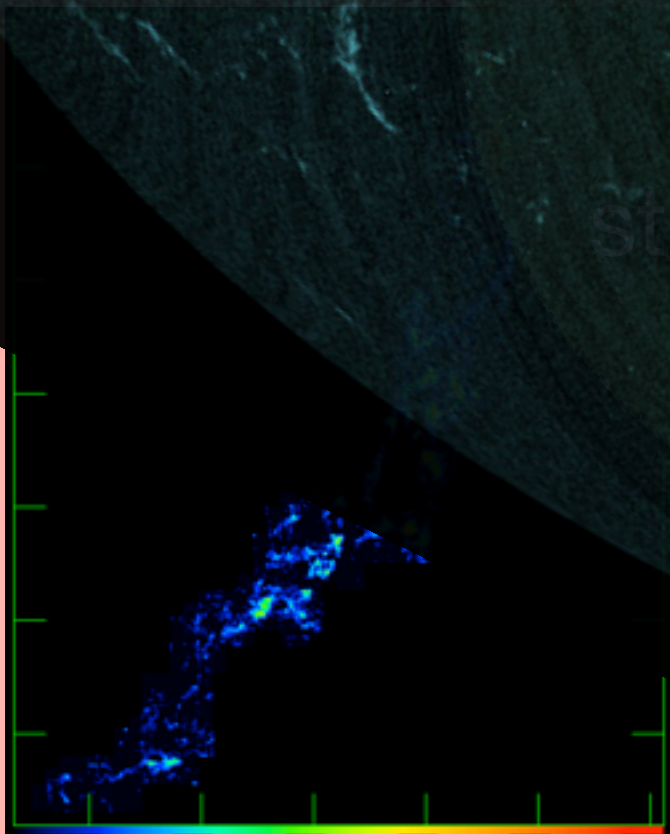
Evolutionary process of ISM studied in
GMC scale

Missing Link

All-sky image of molecular gas seen by Planck



galaxies

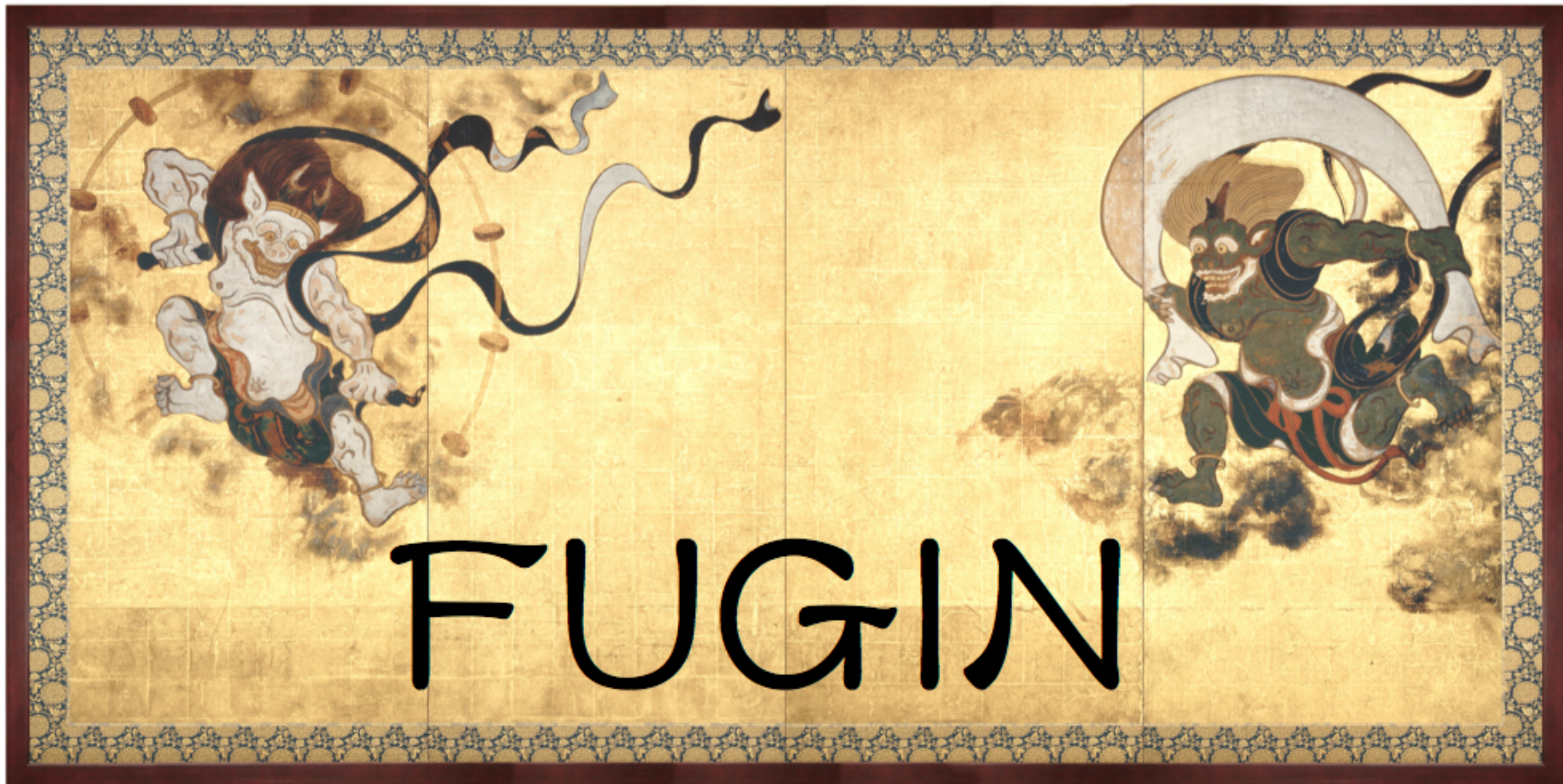


Tatematsu +1993



Multi-line survey of the Galactic plane with high angular resolution by the 45m

FUGIN Project



FOREST Ultra-wide Galactic-plane survey In Nobeyama

“Wind god and Thunder god” by Ogata Korin

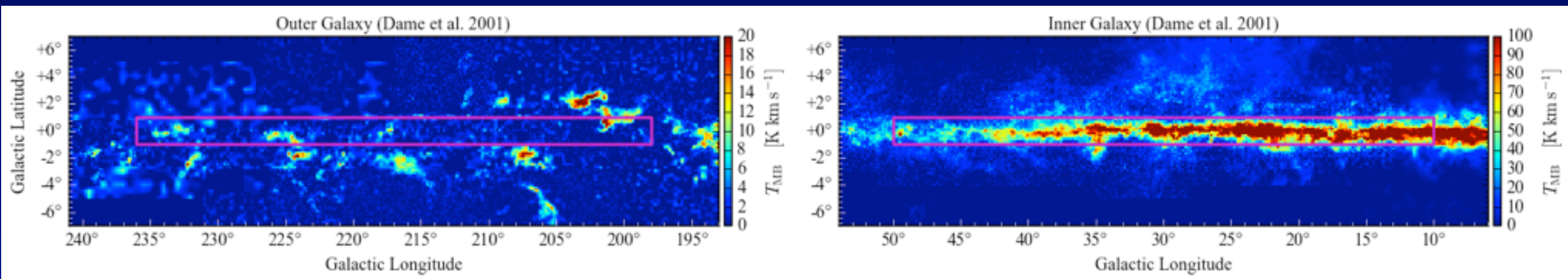
FUGIN Project

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

The CO Galactic Plane Survey by simultaneous
3CO lines
with the highest angular resolution($\sim 15''$)!

FUGIN Project

- Using multi-beam receiver **FOREST**, OTF mapping of the Galactic plane in $^{12}\text{CO}(1-0)$, $^{13}\text{CO}(1-0)$, $\text{C}^{18}\text{O}(1-0)$, **simultaneously**
- **Large** mapping area
 - Inner Galaxy l: $10^\circ \sim 50^\circ$ b: $\pm 1^\circ$ (80 deg^2)
 - Outer Galaxy l: $198^\circ \sim 236^\circ$ b: $\pm 1^\circ$

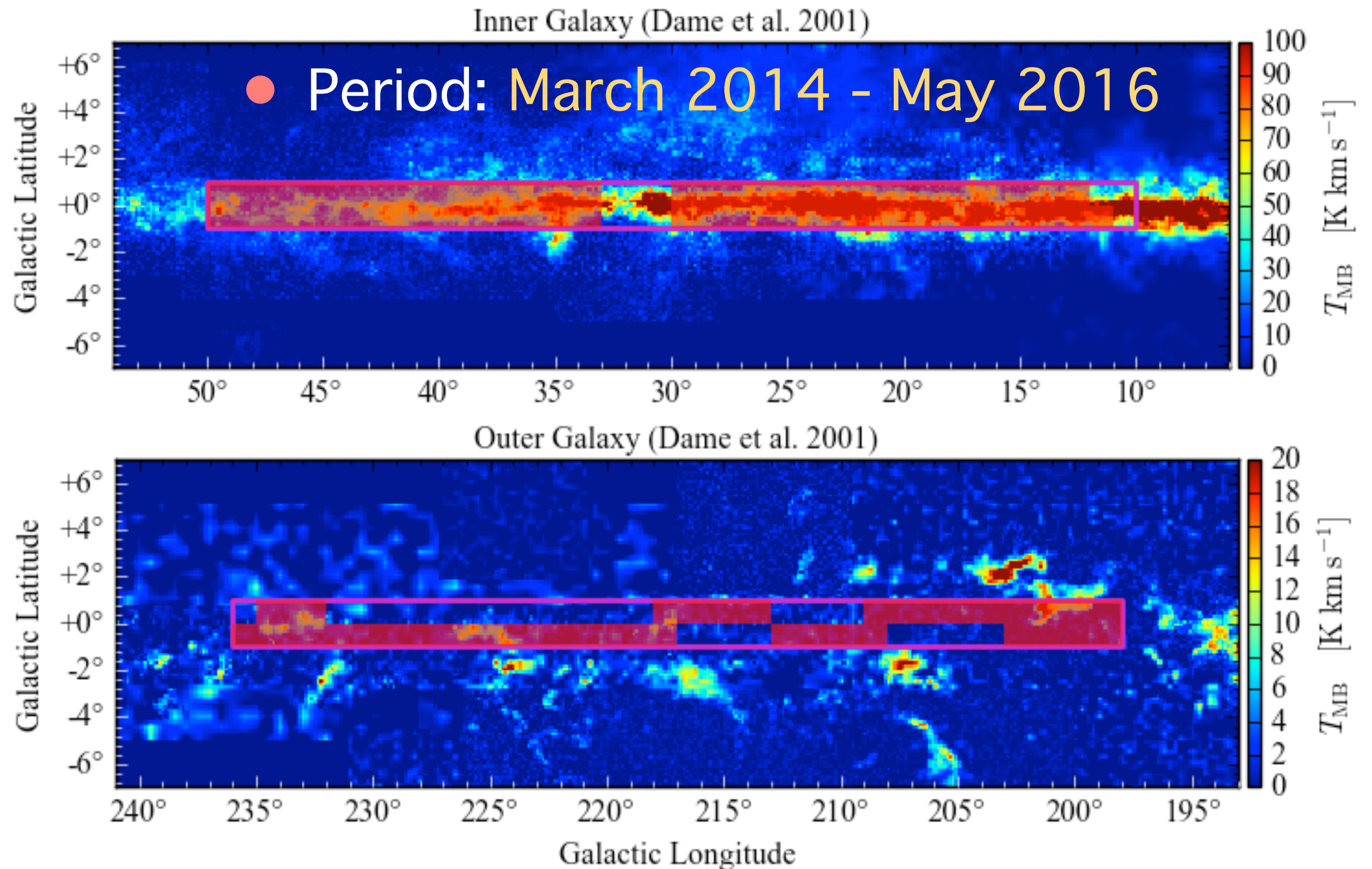


FUGIN Project

- Using multi-beam receiver **FOREST**, OTF mapping of the Galactic plane in $^{12}\text{CO}(1-0)$, $^{13}\text{CO}(1-0)$, $\text{C}^{18}\text{O}(1-0)$, **simultaneously**
- **Large** mapping area Obs.Time : **1,200h**(3 yeras)
 - Inner Galaxy $l: 10^\circ \sim 50^\circ$ $b: \pm 1^\circ$ (80 deg²)
 - Outer Galaxy $l: 198^\circ \sim 236^\circ$ $b: \pm 1^\circ$
- Sensitivity
 - $T_{\text{rms}}(T_{\text{a}^*}) = 0.12\text{K}$ @ ^{13}CO $dv = 1.3$ km/s
 - $T_{\text{rms}}(T_{\text{a}^*}) = 0.12\text{K}$ @ ^{12}CO $dv = 5$ km/s (~ 0.24 K $dv = 1.3$ km/s)

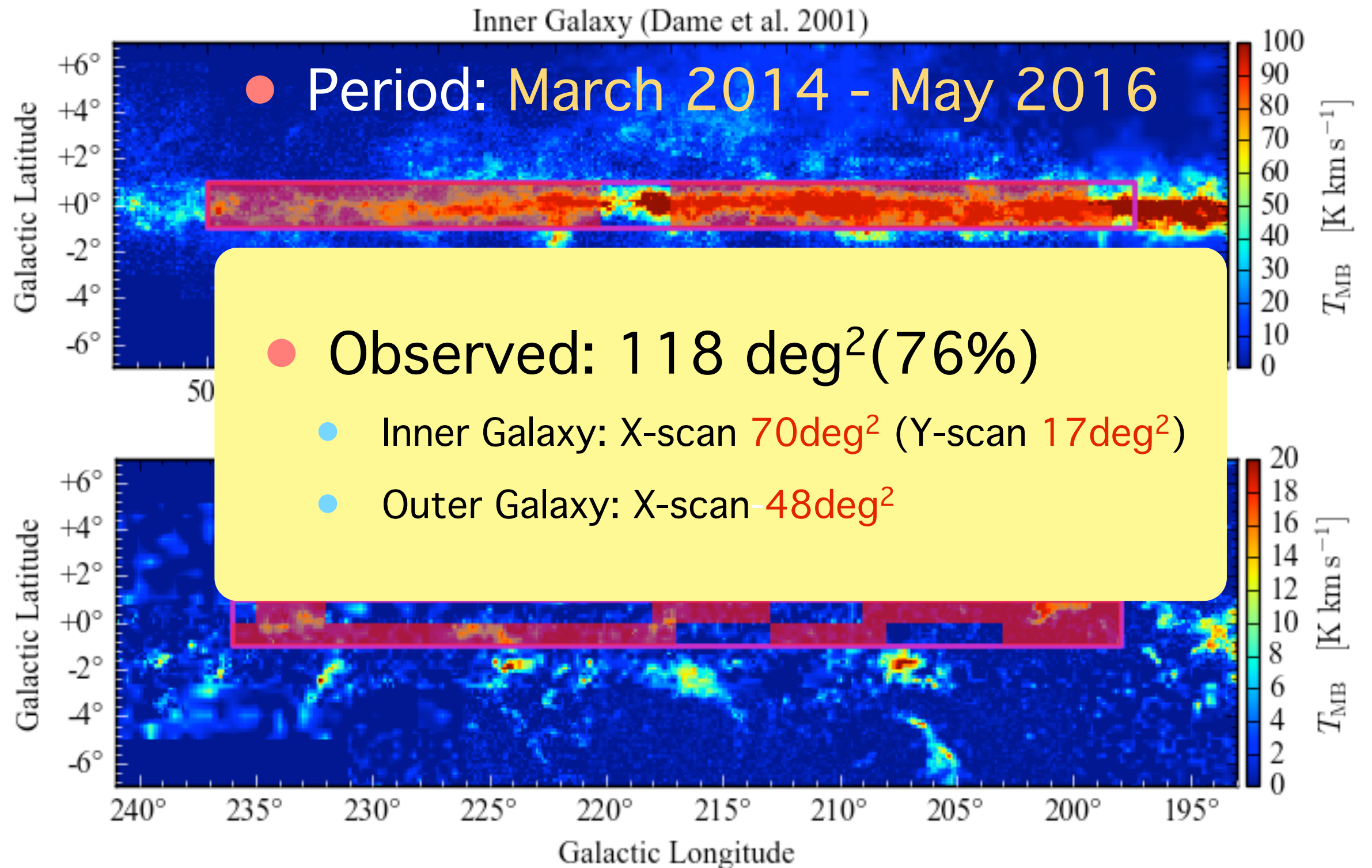
Observed Regions To Date

- magenta: planned, red: observed



Observed Regions To Date

- magenta: planned, red: observed



Optical

Image: Axel Mellinger

FUGIN

R: ^{12}CO
G: ^{13}CO
B: C^{18}O

Spitzer

R: $24\mu\text{m}$
G: $8\mu\text{m}$
B: $5.4\mu\text{m}$

W33

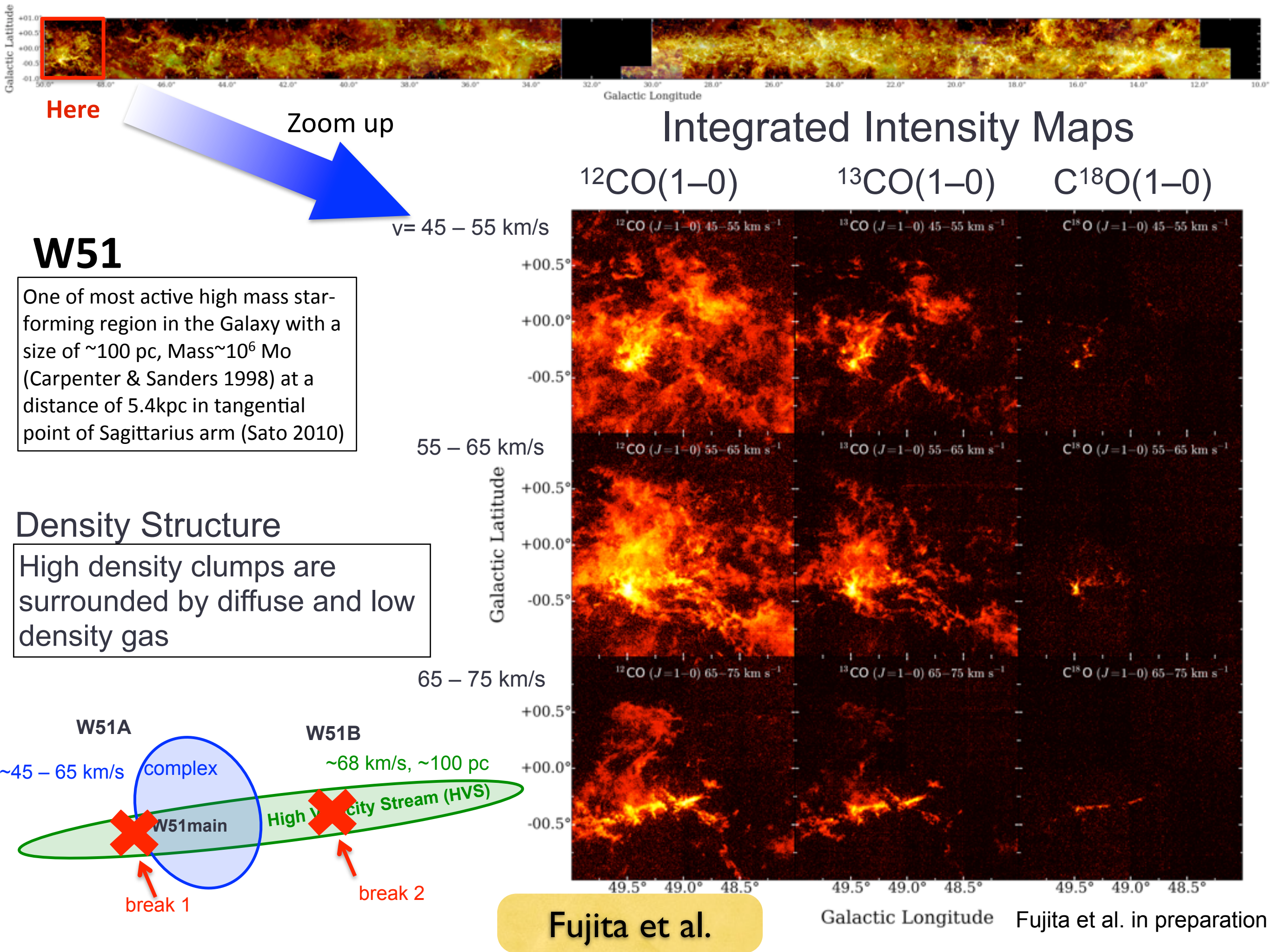
MI7

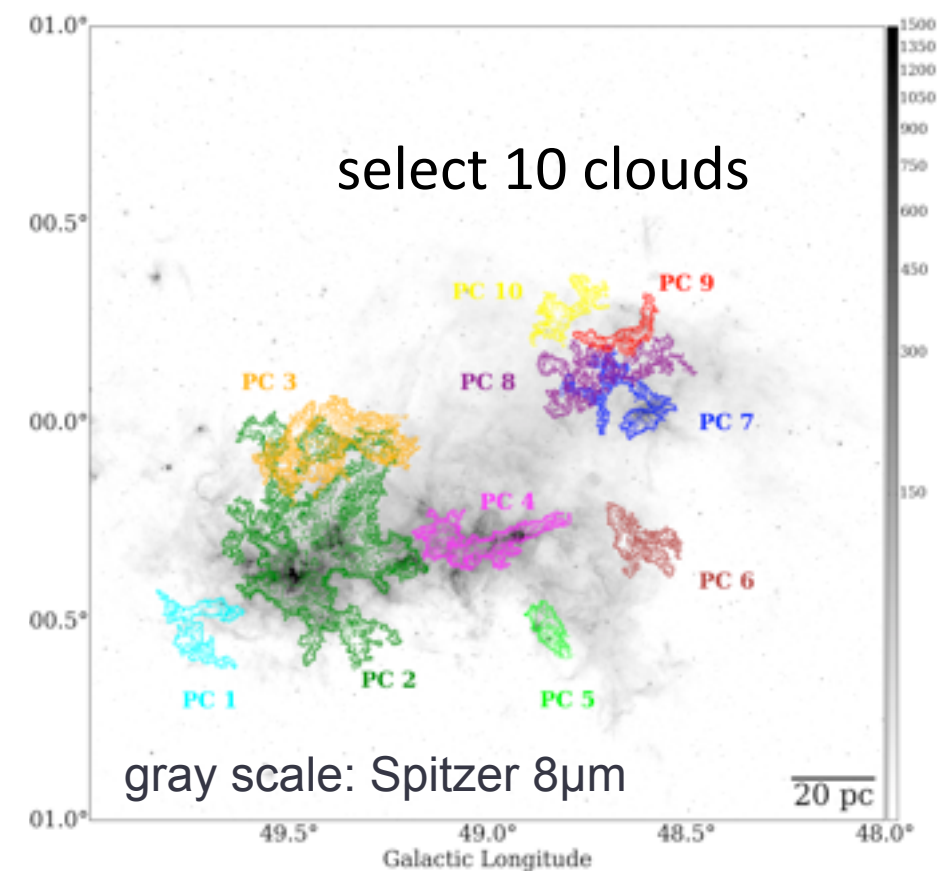
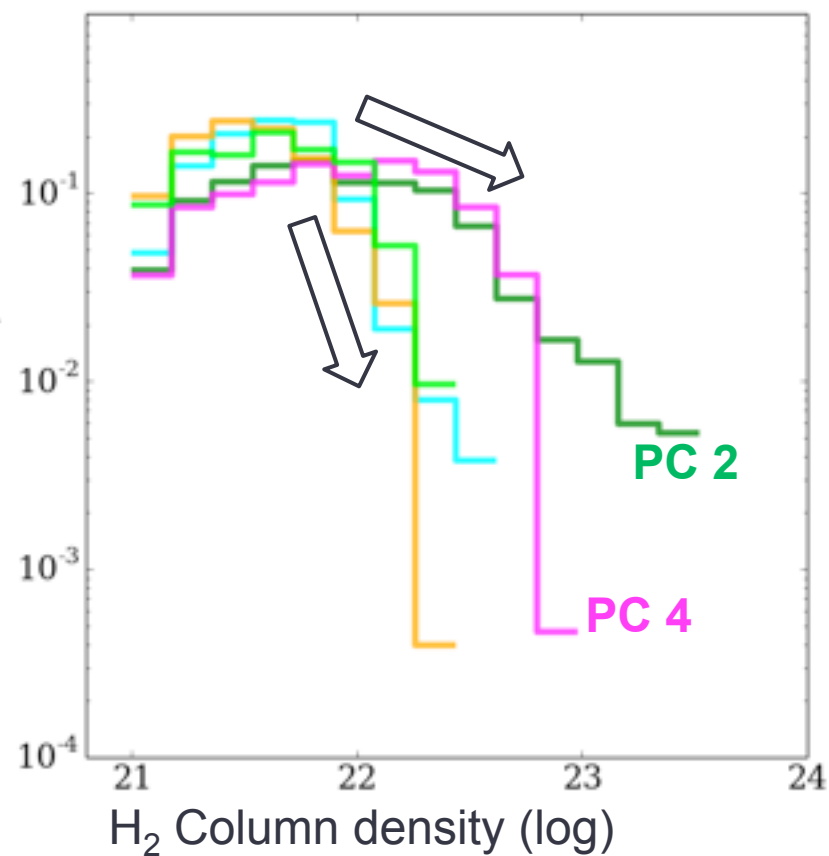
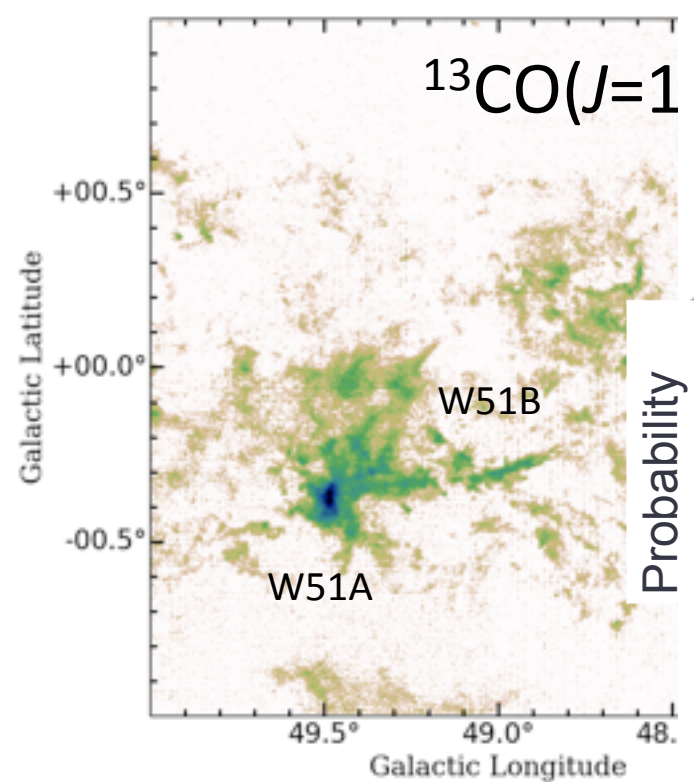
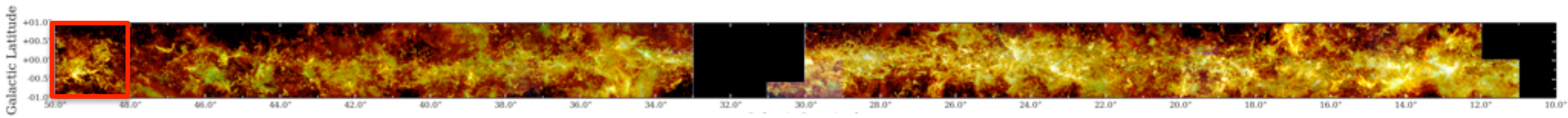


国立天文台 野辺山宇宙電波観測所

NOBEYAMA

FOREST





Characteristics of the clouds

Name	V_{rms} [km/s]	radius [pc]	M_{LTE} [$10^4 M_{\text{sun}}$]	$\frac{^{13}\text{CO}(1-0)}{^{12}\text{CO}(1-0)}$	$\frac{^{13}\text{CO}(3-2)}{^{13}\text{CO}(1-0)}$	$N(\text{H}_2)$ max [cm^{-2}]	$8\mu\text{m}$ intensity [MJy/sr]	number of YSOs ($>8M_{\odot}$)
PC1	1.8	4.4	1.4	0.30 ± 0.03	0.66 ± 0.05	3.5×10^{22}	31.2	0
PC2	6.6	9.4	44	0.35 ± 0.06	0.75 ± 0.11	33×10^{22}	122.7	active 22
PC3	1.9	6.0	3.5	0.36 ± 0.06	0.20 ± 0.03	2.0×10^{22}	37.3	3
PC4	3.4	3.4	6.0	0.28 ± 0.05	0.99 ± 0.14	6.7×10^{22}	174.5	active 14
PC5	1.1	4.4	0.8	0.39 ± 0.07	0.52 ± 0.07	2.5×10^{22}	56.2	1

Discussion – 1. The structure of GMC in W51

1.1 Collisions of internal clouds

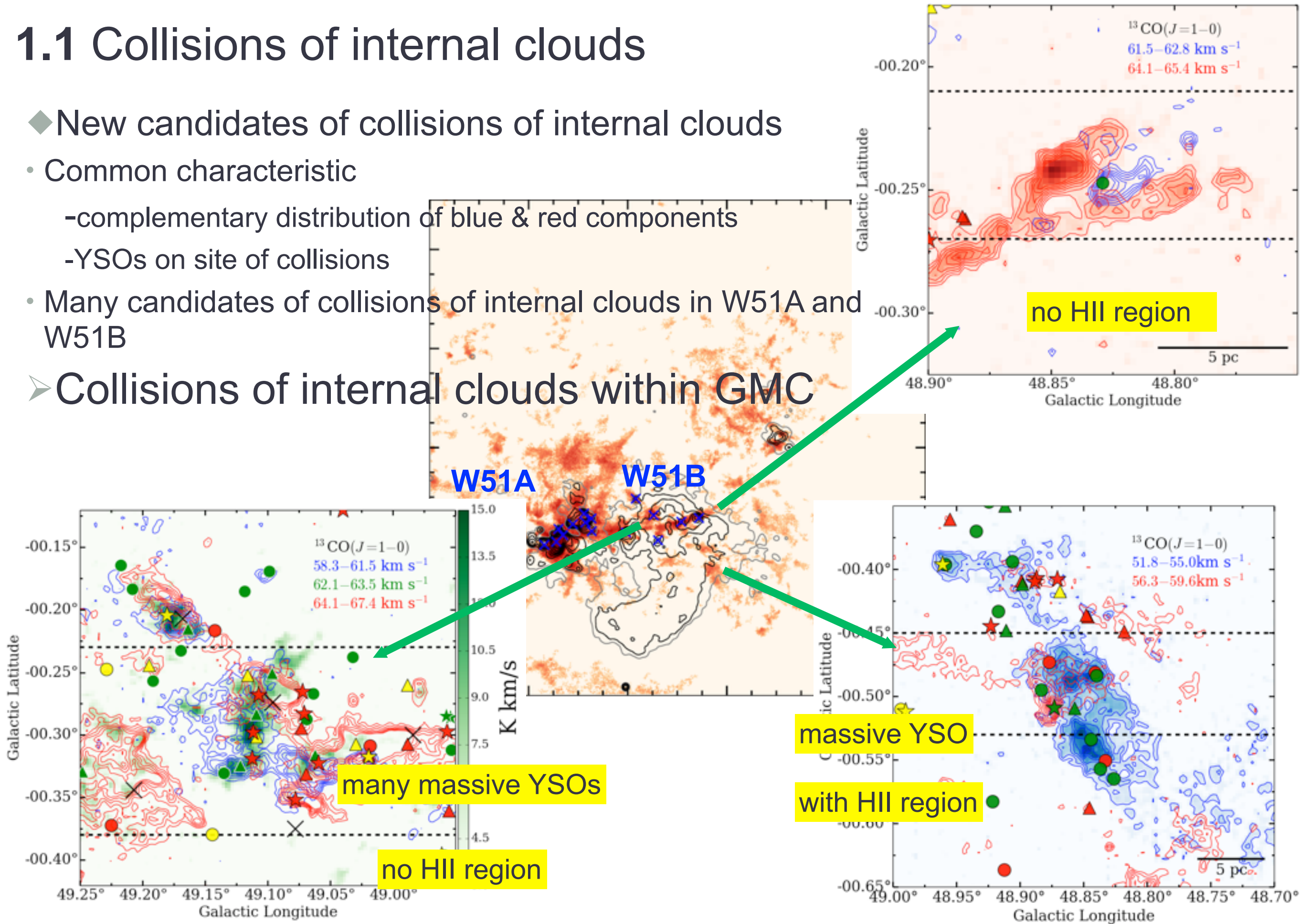
◆ New candidates of collisions of internal clouds

- Common characteristic

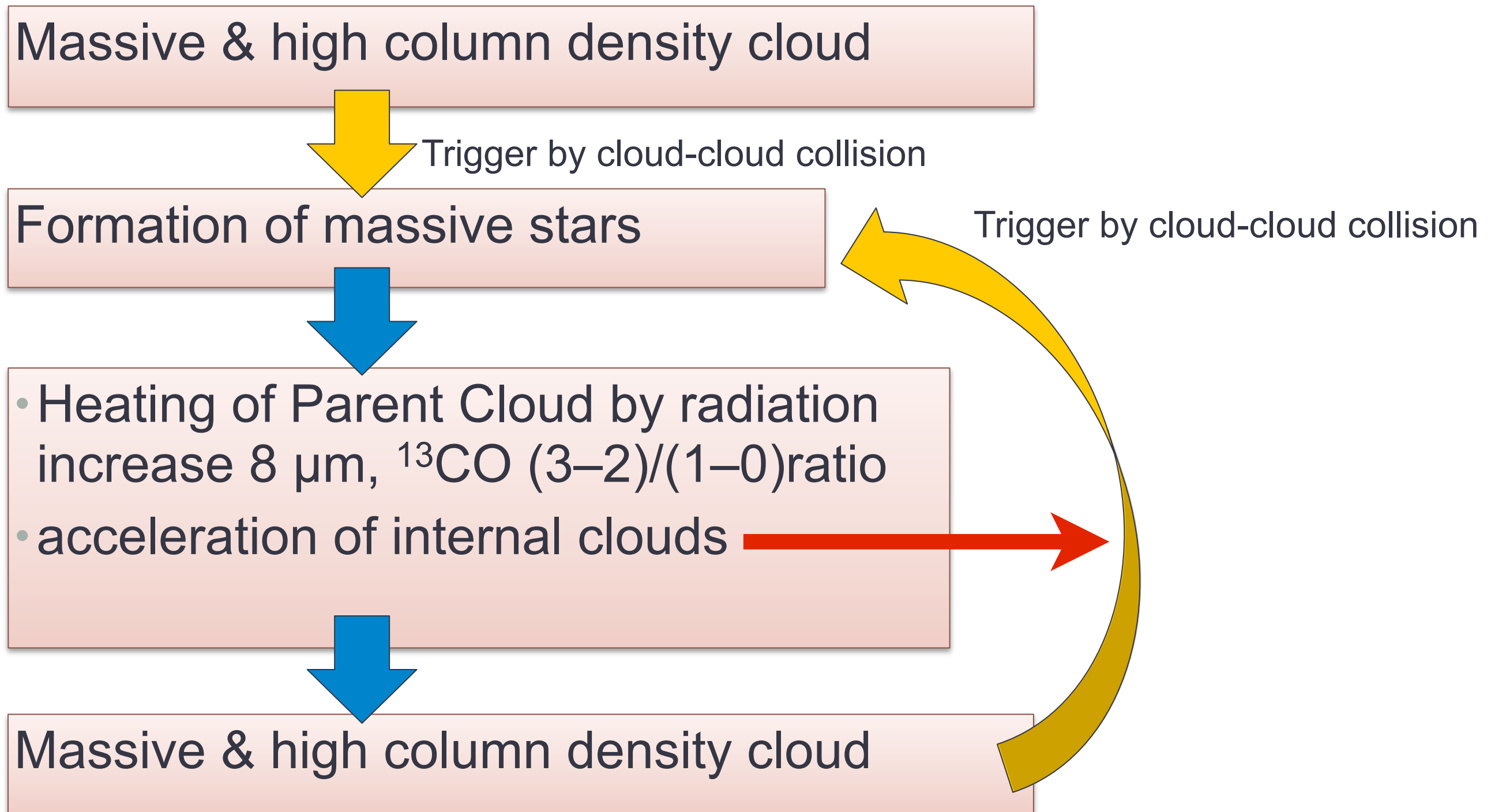
- complementary distribution of blue & red components
- YSOs on site of collisions

- Many candidates of collisions of internal clouds in W51A and W51B

➤ Collisions of internal clouds within GMC



Feedback scenario of massive star formation



Interaction of SNR G33.6+0.1 (Kes79)

Kuriki et al.

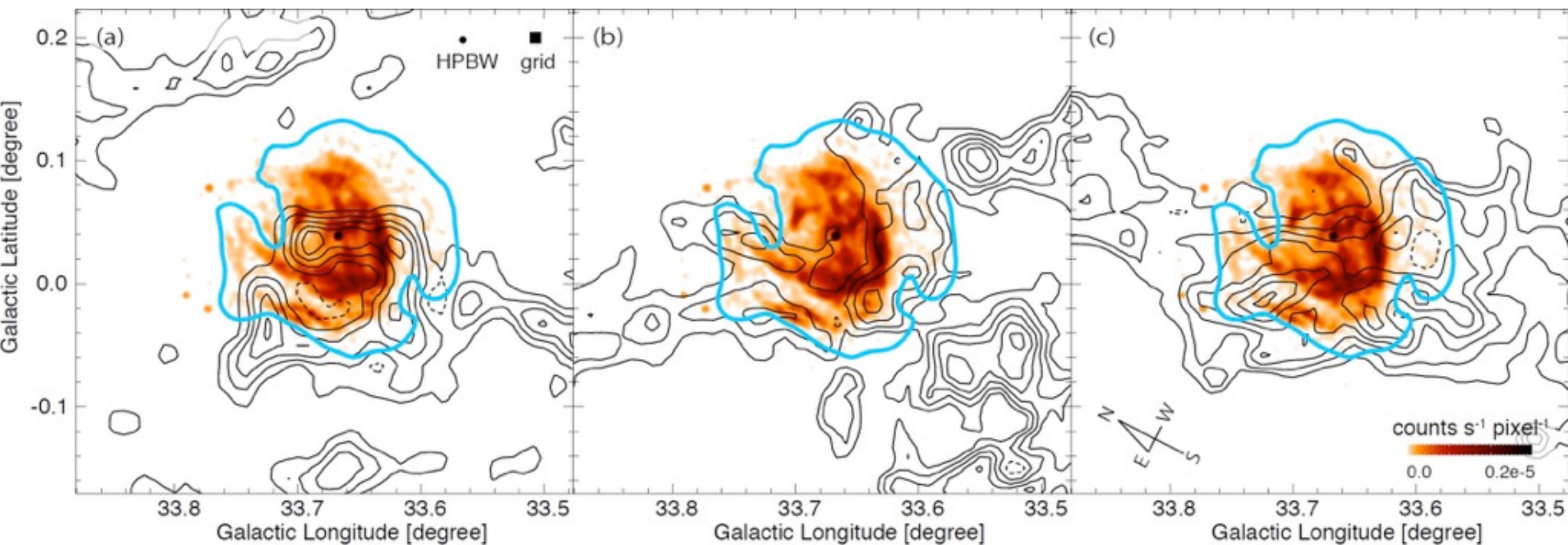
$^{12}\text{CO}(J=1-0)$

Integrated Intensity (black contour) HPBW $\sim 18''$

30 km/s cloud

80 km/s cloud

100 km/s cloud



積分範囲:

$V_{\text{LSR}} = 30.5 - 39.5 \text{ km/s},$

$82.5 - 86.5 \text{ km/s},$

$99.5 - 112.5 \text{ km/s}$

Color :

X-ray (0.3 – 10 keV)

blue contour :

radio continuum (1.4 GHz)

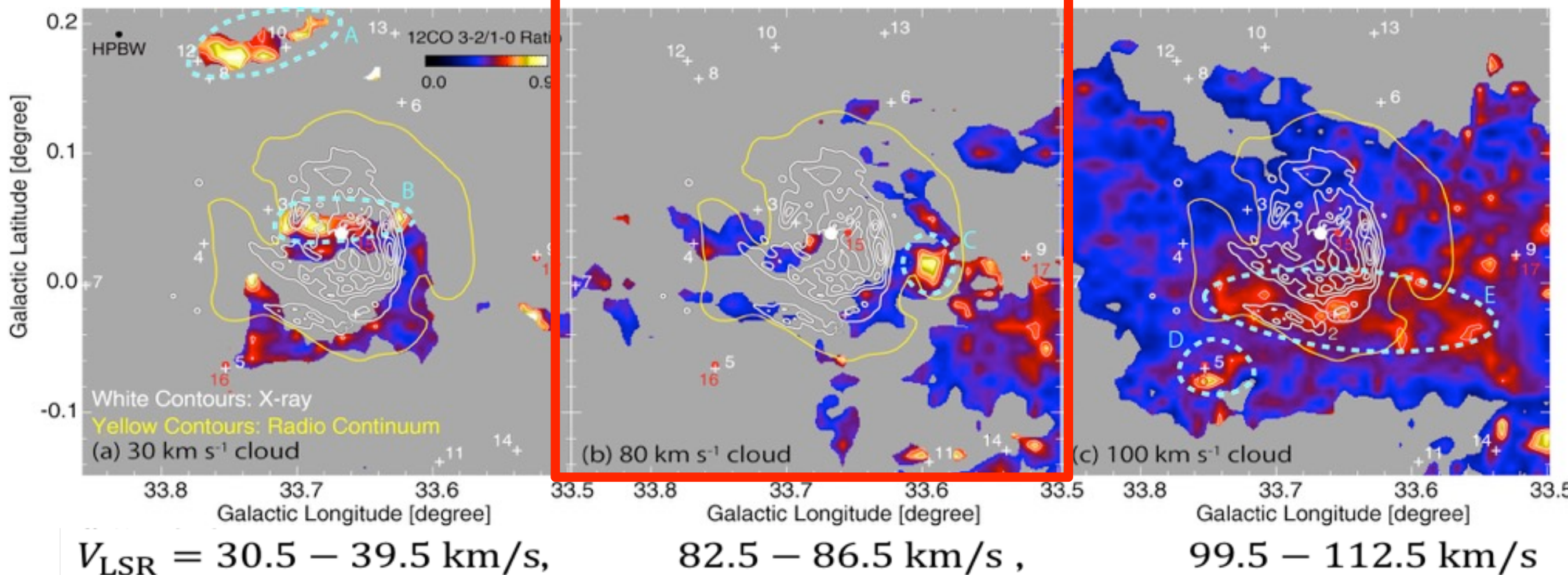
$^{12}\text{CO}(J=3-2)/^{12}\text{CO}(J=1-0)$ Ratio Map

$^{12}\text{CO}(J=1-0)$ と $^{12}\text{CO}(J=3-2)$ の
強度比 ($>10\sigma$)

30 km/s cloud

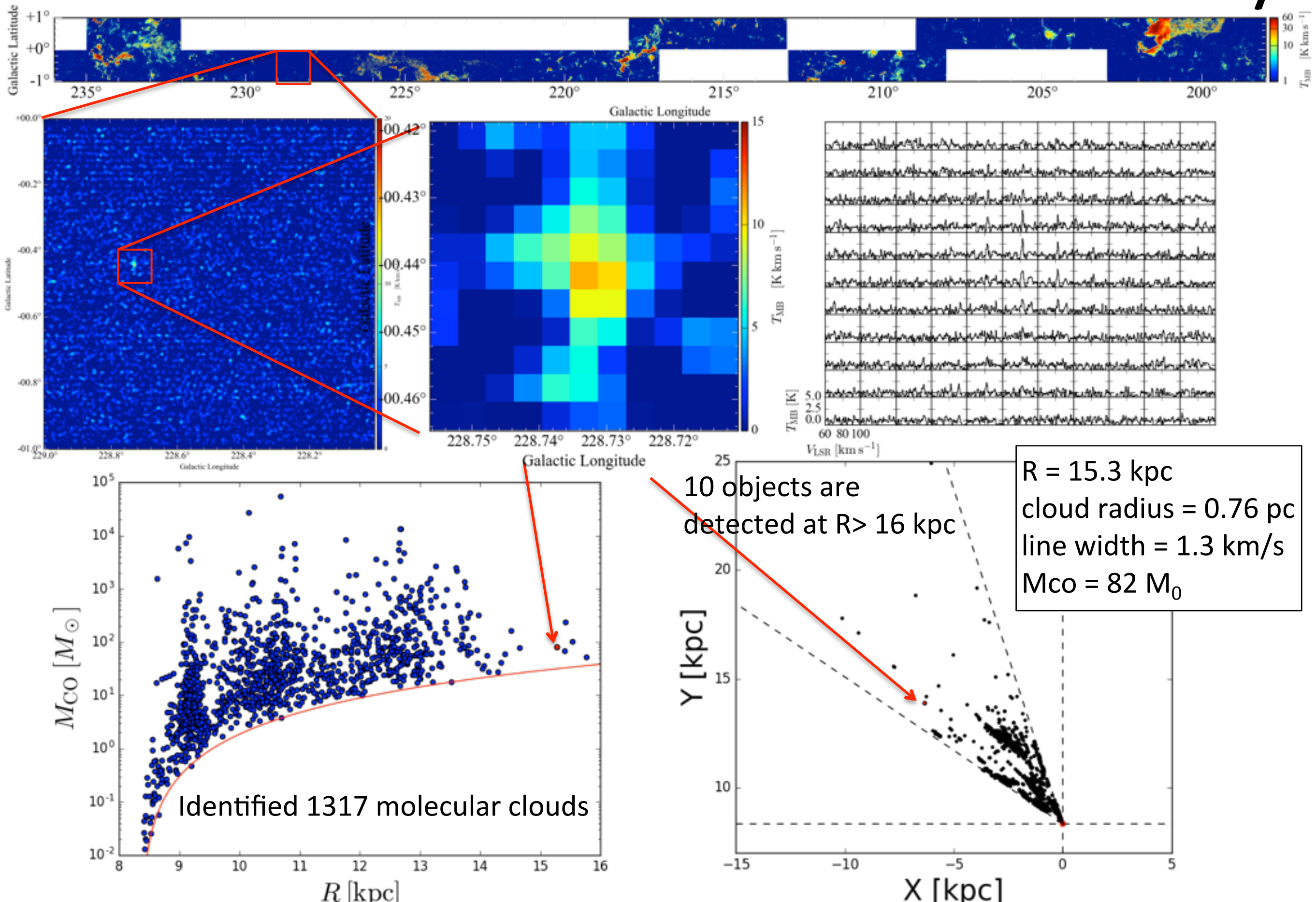
80 km/s cloud

100 km/s cloud



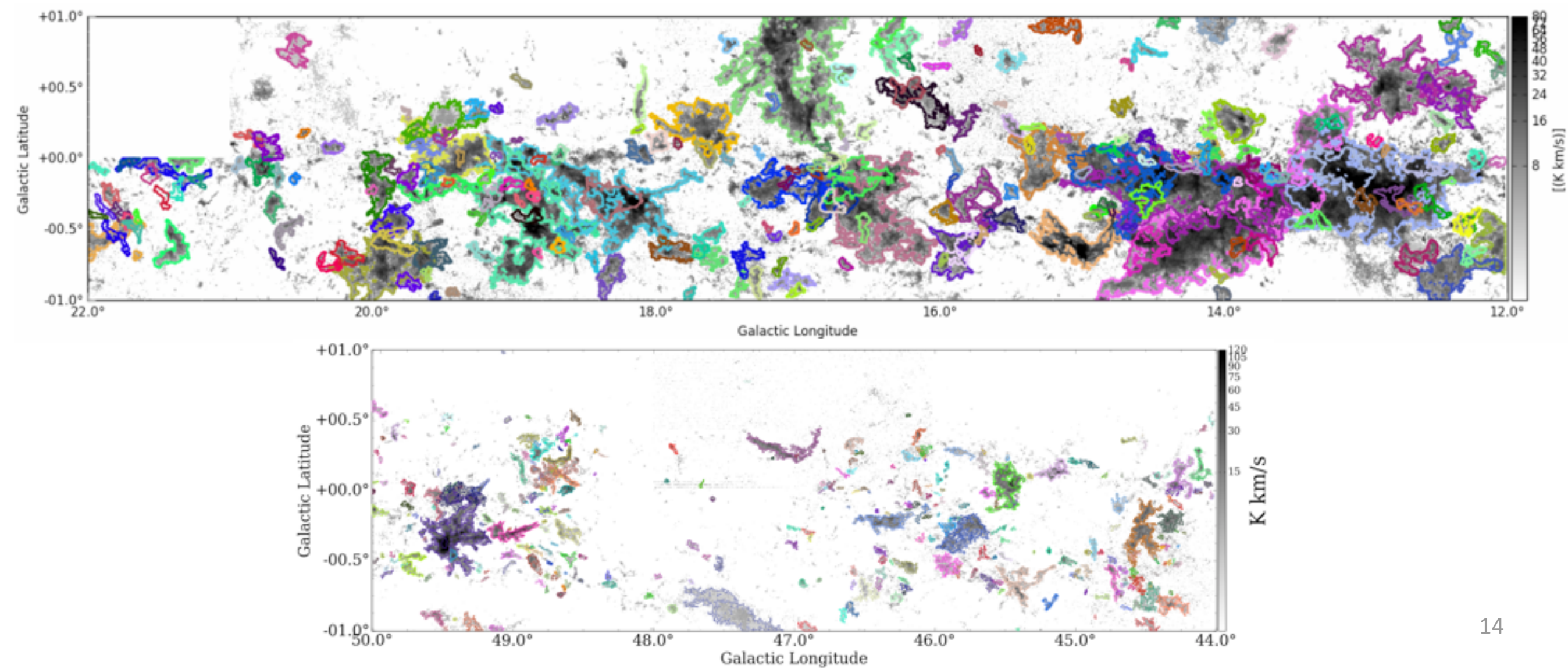
- the molecular cloud complementary distributed with X-ray radiation
 - an expanding shell structure
 - the large CO 3-2 to 1-0 ratio region around the SNR
- Possibility of interaction with the molecular cloud at $V_{\text{LSR}} \sim 80 \text{ km/s}$

Molecular clouds in the Outer Galaxy



Identification of Molecular Clouds

- Apply to IR2.1 ^{13}CO cube data for the Inner Galaxy
 - 1180+310 clouds were found (within 31 deg^2)
 - determination of the distance and mass (not yet)



Publication Status

Theme	PI	Status
Project overview	T. Umemoto	submitted
Star formation in M17 region	A. Nishimura	writing
Dense cores in M17 region	T. Tosaki	writing
PDR in M17 region	M. Yamagishi	will be published
Cloud-cloud collision in W33 region	M. Kohno	writing
Molecular clouds in W51 region	S. Fujita	writing
Shells	Y. Tsuda	in preparation
Molecular clouds in outer Galaxy	M. Matsuo	writing
Cloud-cloud collision in Spitzer bubbles	K. Torii	writing
Interaction between molecular clouds and SNRs	M. Kuriki & Sano	writing
PDF	T. Handa	in preparation
NH3 survey towards cores	T. Handa	in preparation

Data Release Policy

- Open all after 1 yr from the end of the observations of this project
- Calibrated data
 - 3-D FITS (overall map and/or sub-maps within several degree)
 - Open on the project website (in preparation)
- Many catalogs
 - molecular clouds, clumps, filaments, shells
 - Provide original catalogs to the detailed observations by ALMA
- Open widely to the community, the researchers of various wavelengths utilize these data, and generate new science

Summary

- We are conducting the Galactic Plane Survey with the highest angular resolution by **simultaneous** ^{12}CO , ^{13}CO and C^{18}O J=1-0 lines (**FUGIN**) as the NRO legacy project using the **FOREST** installed on the Nobeyama 45m telescope.
- To date, we have covered **118 deg²** (**76%** of the plan).
- We have revealed a **wide range** and **detailed** structures of molecular clouds not seen in previous surveys.
- In ALMA era, this project must make a **linkage** between the study of star formation in the Milky Way Galaxy and study of molecular gas in galaxies.
- After the end of the project, open **all** data, 3-D fits, catalogs of clouds/clumps etc.. We hope the researchers of **various wavelengths** utilize these data.
+theorist