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High-Resolution Images of Diffuse Neutral Clouds in the Milky Way

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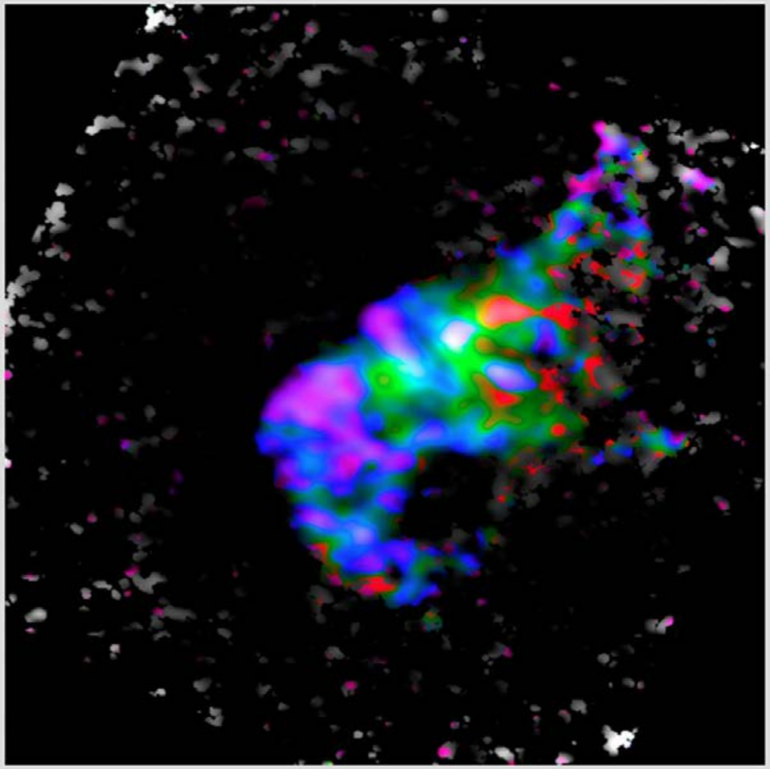

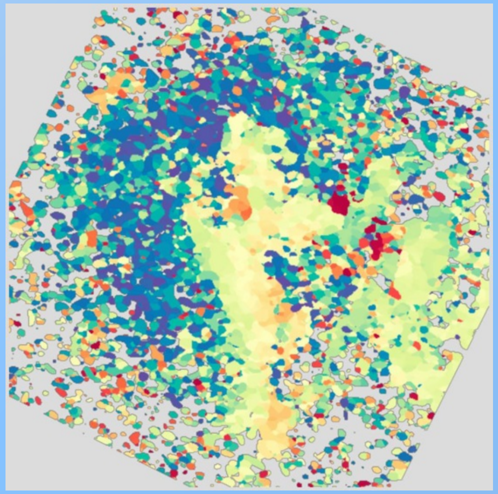

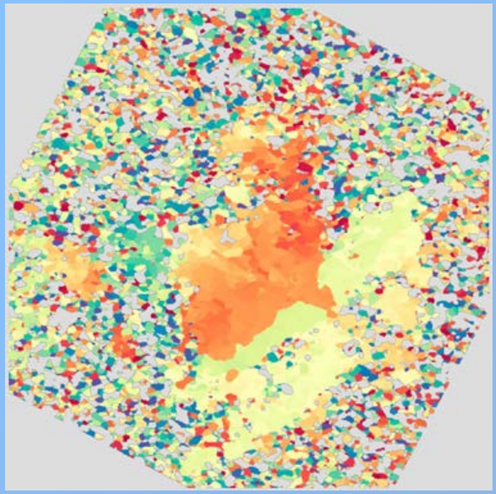

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Y. Pidopryhora, F. J. Lockman, J. M. Dickey & M. P. Rupen, ApJS, 219, 16, 2015

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High-resolution Images of Diffuse Neutral Clouds in the Milky Way. I. Observations, Imaging, and Basic Cloud Properties

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Y. Pidopryhora *et al.* 2015 *ApJS* **219** 16. doi:10.1088/0067-0049/219/2/16
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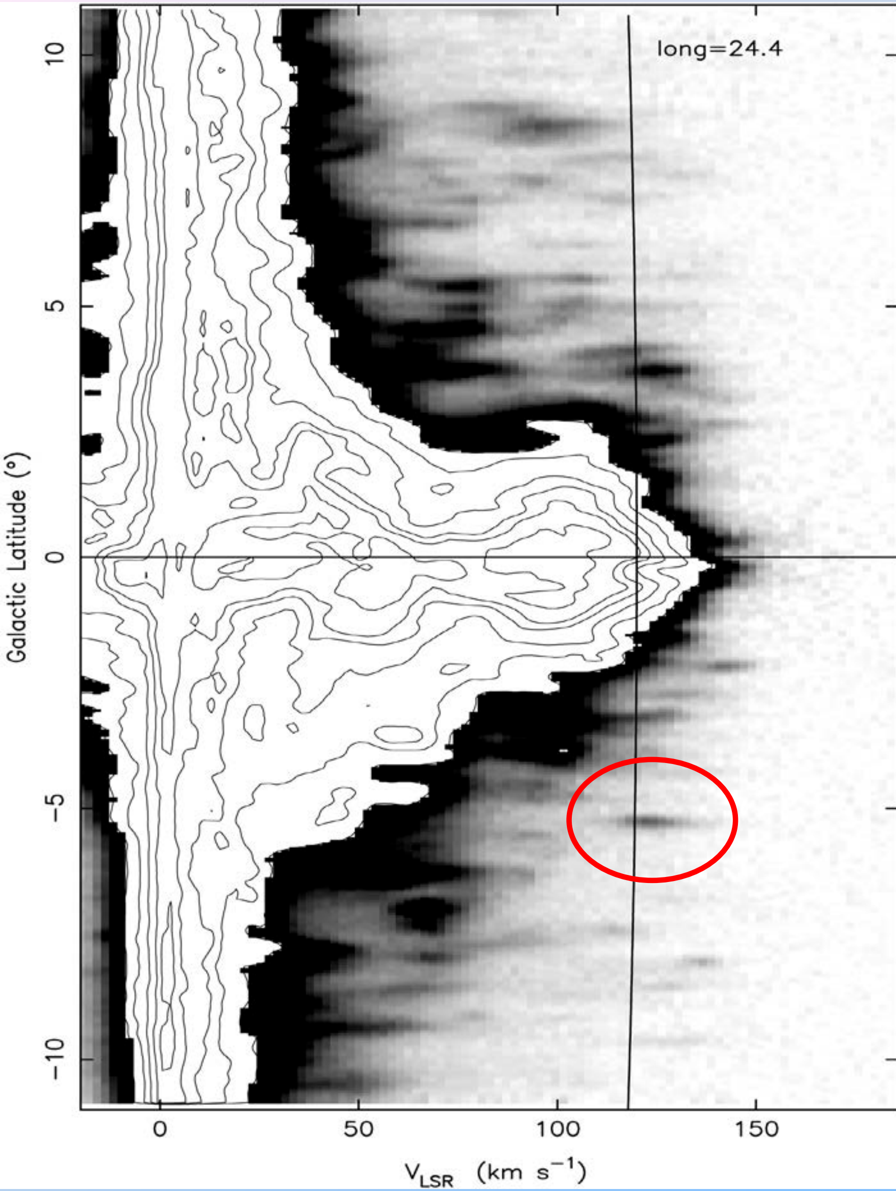
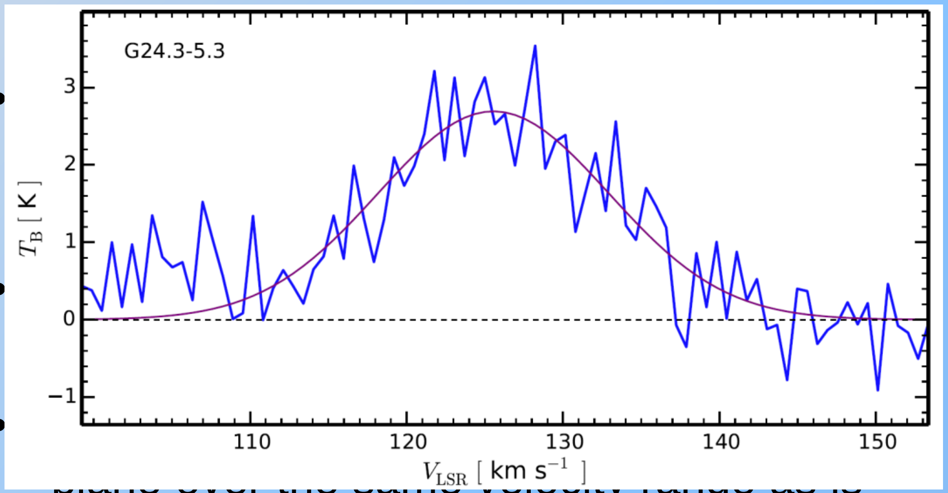
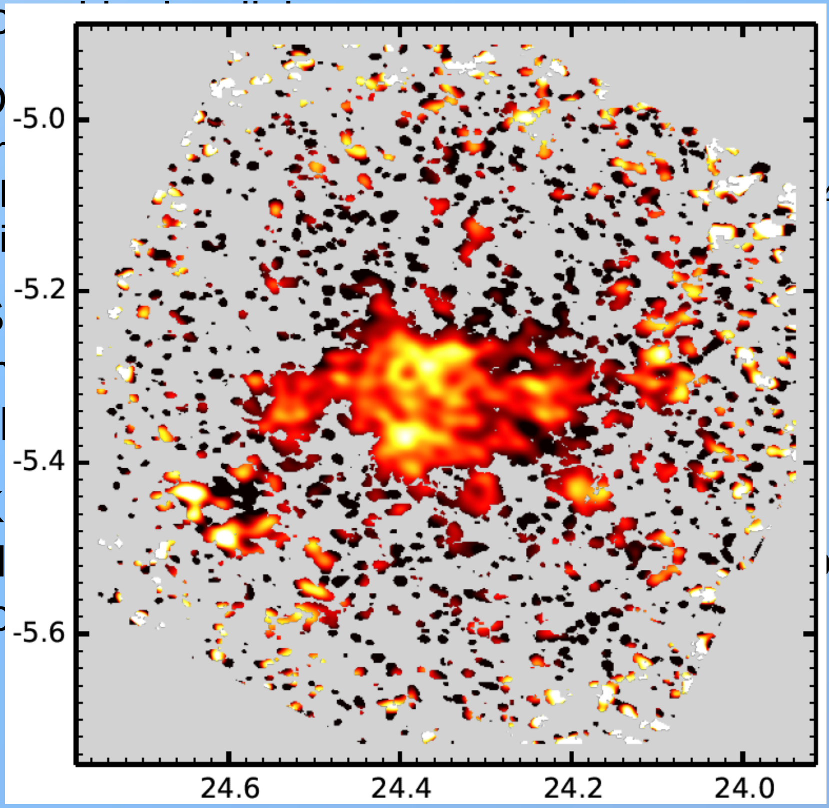
Abstract

A set of diffuse interstellar clouds in the inner Galaxy within a few hundred parsecs of the Galactic plane has been observed at an angular resolution of ≈1&farcm;0 combining data from the NRAO Green Bank Telescope and the Very Large Array. At the distance of the clouds, the linear resolution ranges from ~1.9 to ~2.8 pc. These clouds have been selected to be somewhat outside of the Galactic plane, and thus are not confused with unrelated emission, but in other respects they are a Galactic population. They are located near the tangent points in the inner Galaxy, and thus at a quantifiable distance: $2.3 \leqslant R \leqslant 6.0$ kpc from the Galactic Center and $-1000 \leqslant z \leqslant +610$ pc from the Galactic plane. These are the first images of the diffuse neutral H i clouds that may constitute a considerable fraction of the interstellar medium (ISM). Peak H i column densities lie in the range $N_{\mathrm{H\,I}}$ = 0.8–2.9 × 10^{20} cm^{-2}. Cloud diameters vary between about 10 and 100 pc, and their H i mass spans the range from less than a hundred to a few thousands $M_{\odot}$. The clouds show no morphological consistency of any kind, except that their shapes are highly irregular. One cloud may lie within the hot wind from the nucleus of the Galaxy, and some clouds show evidence of two distinct thermal phases as would be expected from equilibrium models of the ISM.





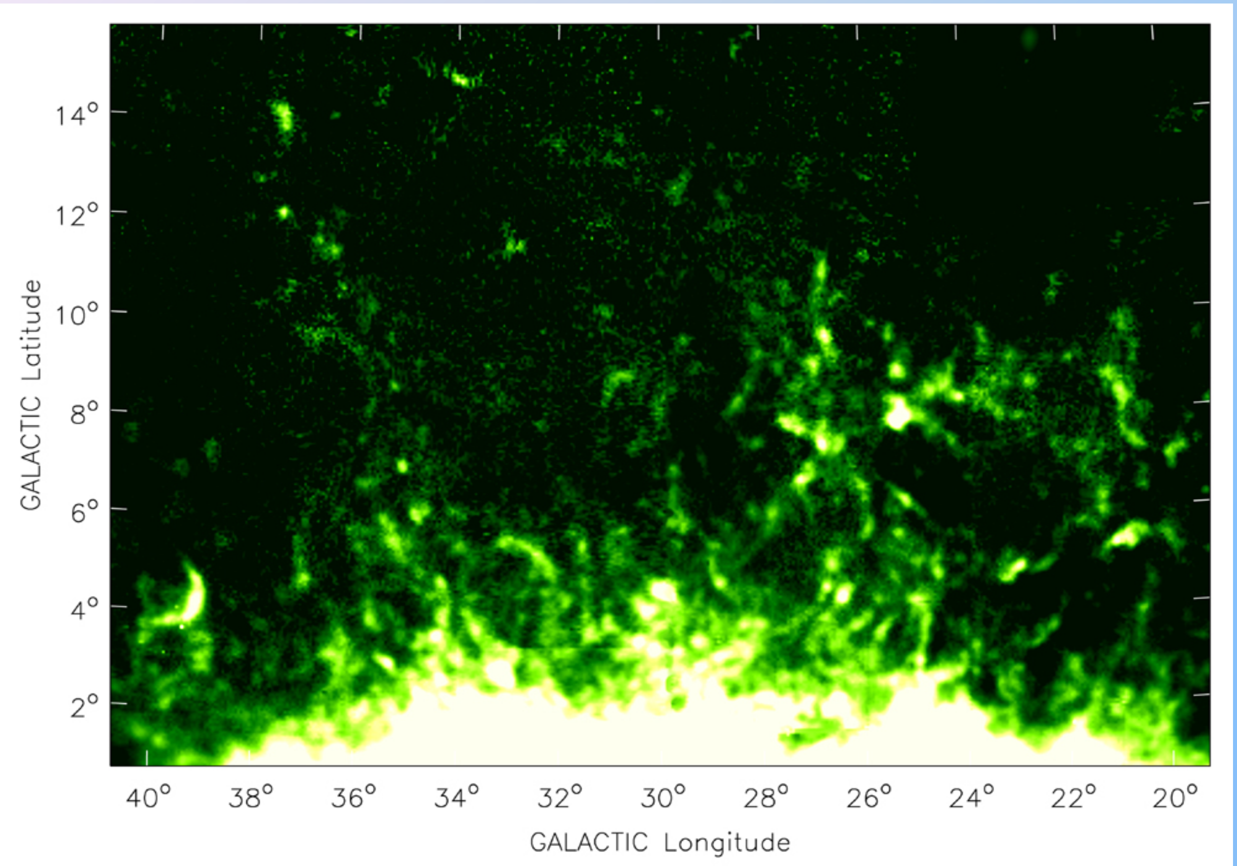


Lockman & Pidopryhora,
ASP Conference Series, 331, 59, 2005.

These clouds are Galactic objects

- Best seen a few ^{o} above and below the disk, they are also quite common IN the disk.
- They populate disk and lower halo at $b \leq 10^{o}$ and follow the Galactic rotation, with a cloud-cloud velocity dispersion $\sigma_{cc} \approx 16$ km s^{-1} (Lockman 2002, Ford et al. 2008, 2010)
- Their linear sizes are ~1-100 pc, masses ~10-10^{3} $M_{\odot}$ and as far as we know they are of pure H I
- Please do not confuse them with other types of clouds (high/intermediate velocity, giant molecular etc.)

These clouds are excellent objects for wide single dish surveys:

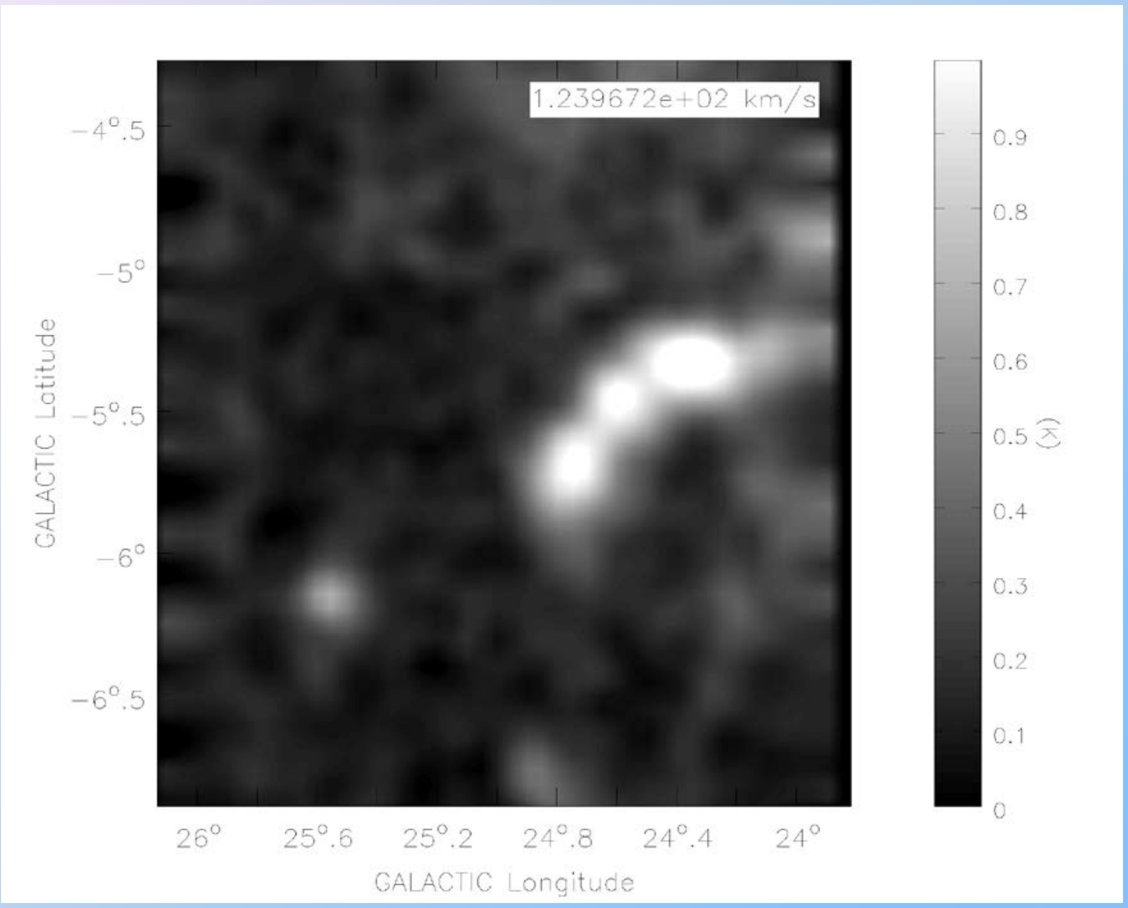


- Stanimirovic et al. ApJ 653, 1210 (2006)
- Ford et al. ApJ 688, 290 (2008)
- Dedes, PhD Thesis (2008)
- Begum et al. ApJ 722, 395 (2010)

and others have studied hundreds of such clouds with single dishes: GBT, Parkes, Arecibo, Effelsberg.

H I, integrated over 3 km s^{-1} near 95 km s^{-1}
(GBT survey, 2004-2005 by Pidopryhora & Lockman)

But to understand the structure, underlying physics and origins of these clouds one needs to achieve higher resolutions than ~9 arcmin of the largest single dishes.



100 pc long, 700 pc below the Galactic plane.

Individual clouds have identical LSR velocities to within 2 km/s

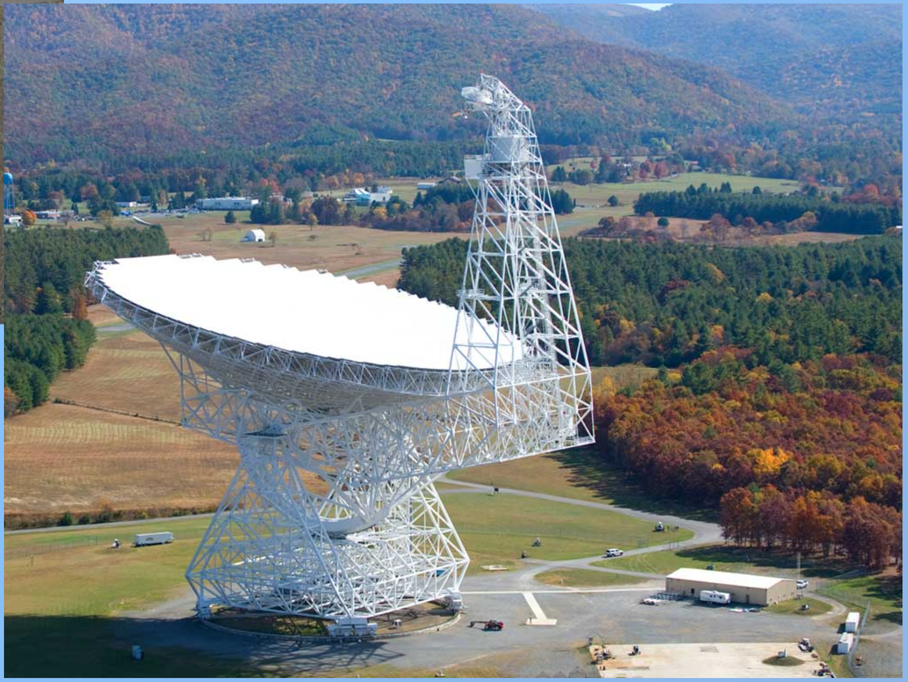
Total H I mass: 1350 $M_\odot$
- ~70 % clouds
- ~30 % diffuse envelope

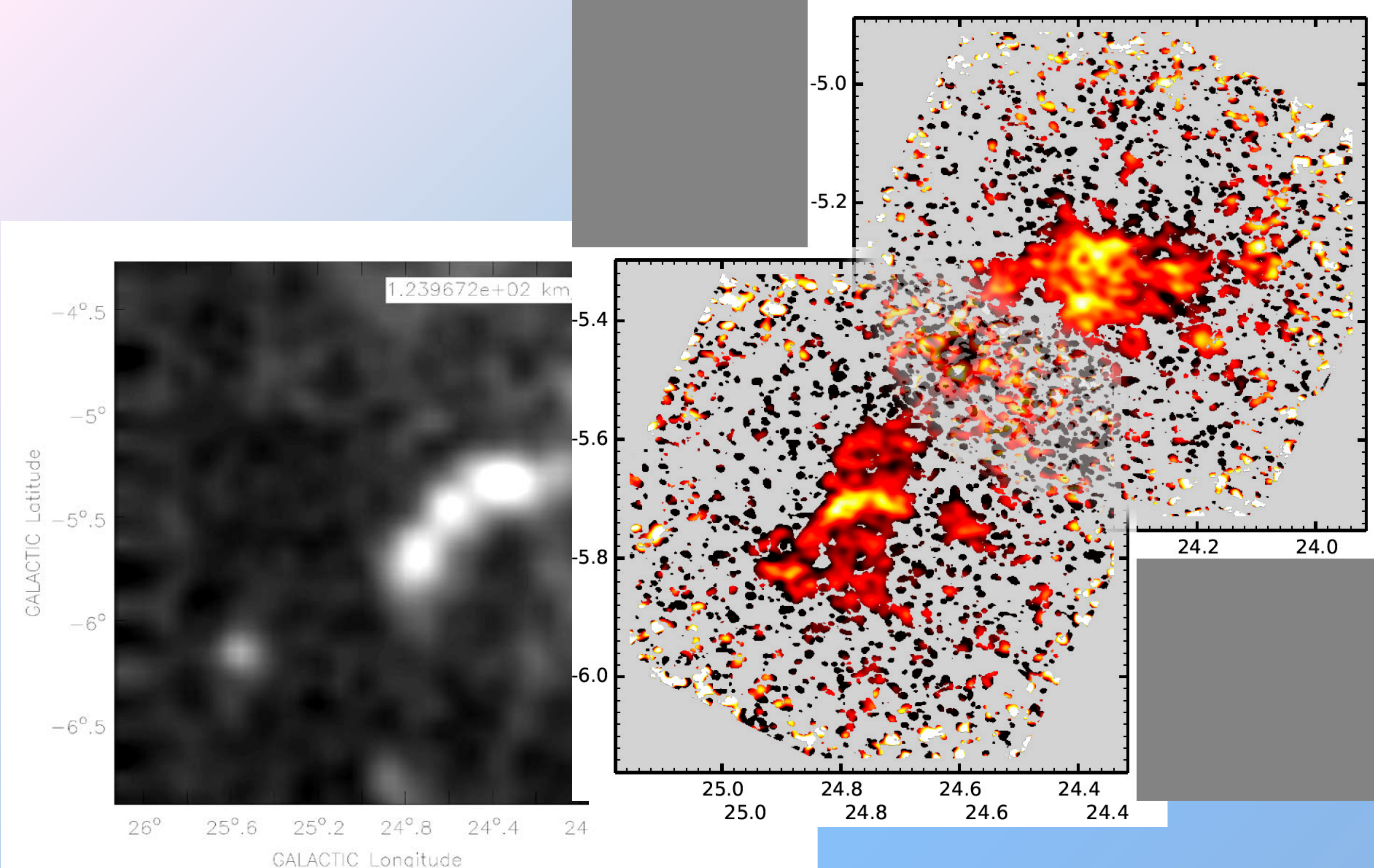
Individual clouds:
350, 170 and 410 $M_\odot$
left to right

Small cloud: 70 $M_\odot$
< 20 pc (unresolved).

Lockman & Pidopryhora,
ASP Conference Series, 331, 59, 2005.

…thus we observed ~20 of these clouds located close to tangent points with the VLA D, C and B array, complemented by the GBT providing the short spacing information



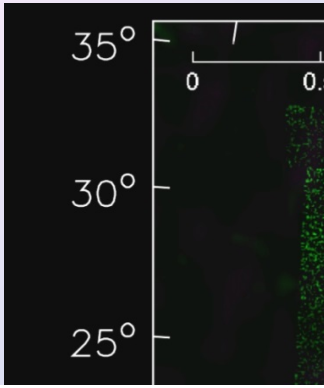


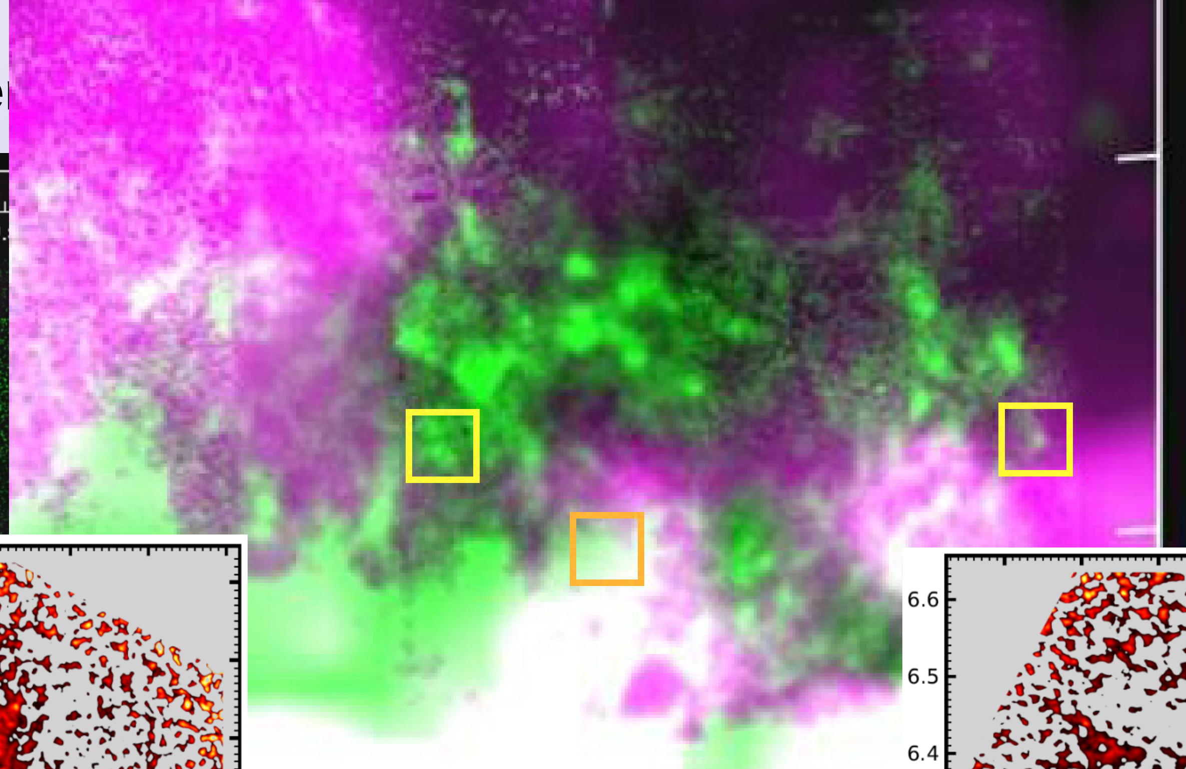
1.239672e+02 km
−4°.5
−5°
−5°.5
−6°
−6°.5
GALACTIC Latitude
26°
25°.6
25°.2
24°.8
24°.4
24
GALACTIC Longitude
-5.0
-5.2
-5.4
-5.6
-5.8
-6.0
24.2
24.0
25.0 24.8 24.6 24.4
25.0 24.8 24.6 24.4

Targets of the survey were chosen close to the tangent points, i. e. with velocity preferably higher than the terminal velocity for the given longitude. This allowed to estimate the distance.

Name	T_b (K)	V_{LSR} km s^{-1}	Distance (kpc)	z (pc)
G16.0+3.0	1.2	+143	8.2 ± 1.0	$+430 \pm 55$
G17.5+2.2	2.4	+138	8.1 ± 1.1	$+310 \pm 40$
G19.5-3.6	4.2	+122	8.0 ± 1.6	-500 ± 100
G22.8+4.3	4.9	+137	7.9 ± 1.4	$+590 \pm 105$
G24.3-5.3	1.7	+123	7.8 ± 1.5	-720 ± 140
G24.7-5.7	1.9	+127	7.8 ± 1.5	-770 ± 150
G25.2+4.5	3.2	+147	7.7 ± 1.6	$+610 \pm 125$
G26.9-6.3	4.0	+122	7.6 ± 1.7	-840 ± 190
G33.4-8.0	2.0	+102	7.2 ± 2.0	-1000 ± 280
G44.8-7.0	3.4	+94	6.1 ± 2.5	-740 ± 300

The super



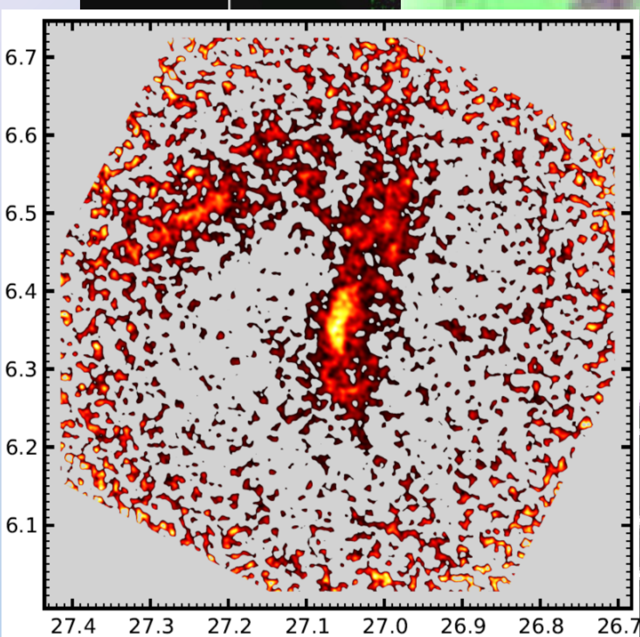


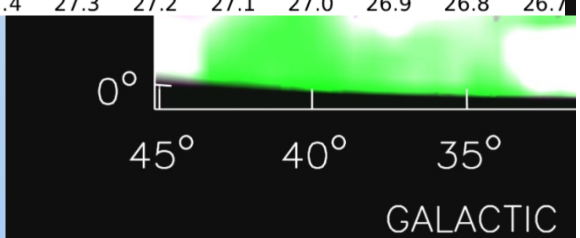
asic Facts:

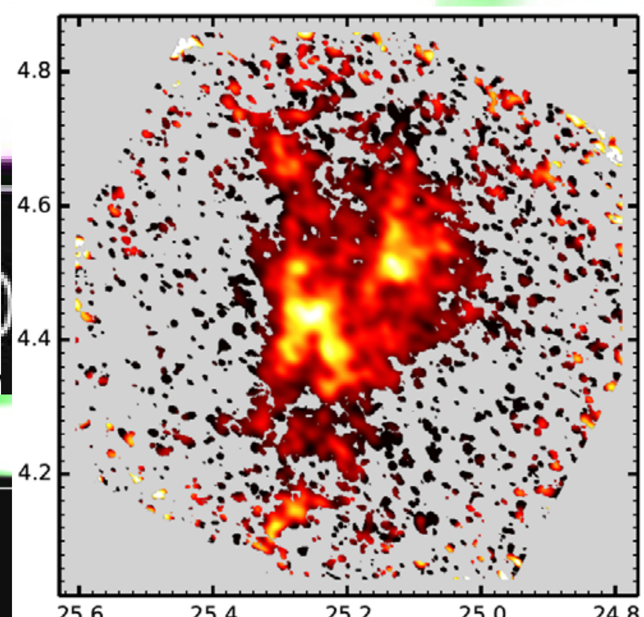
7 kpc

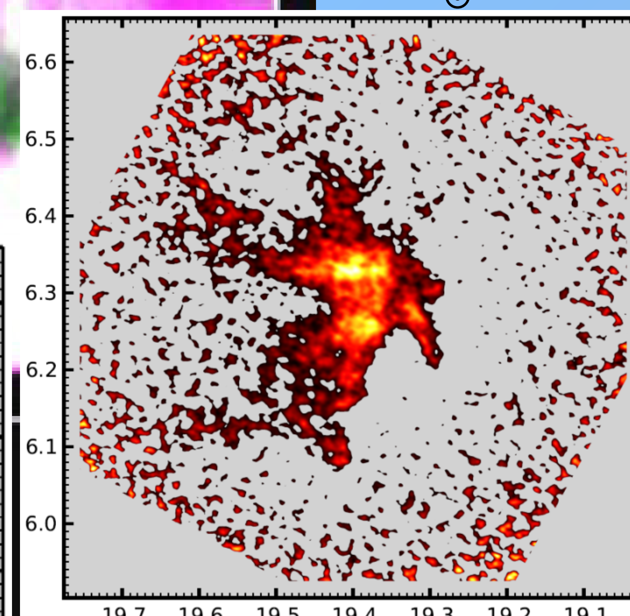
3 kpc

10^6 M$_\odot$



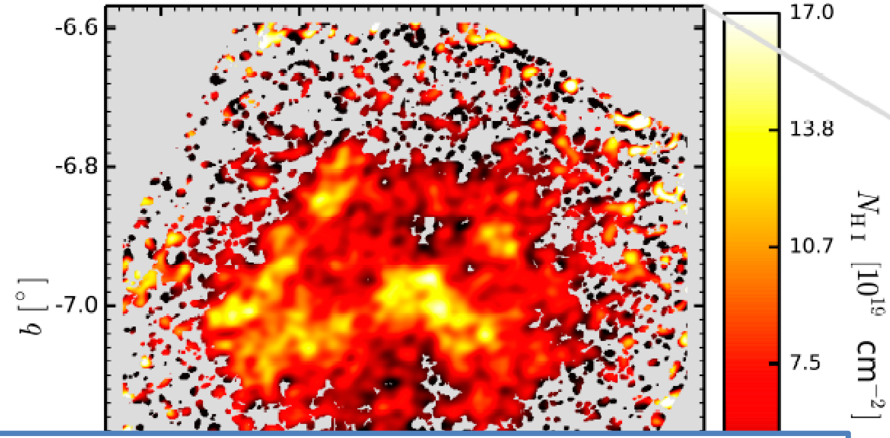


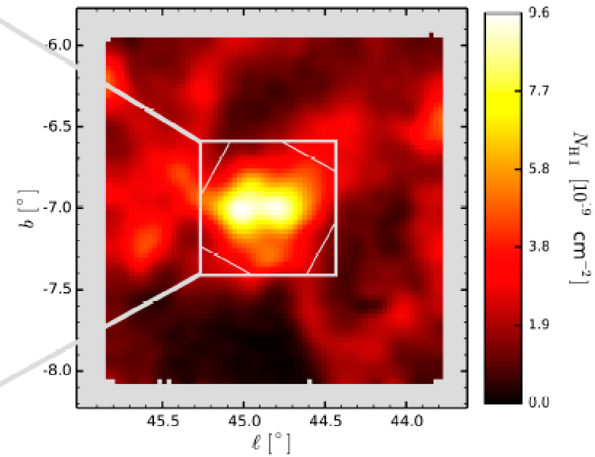




nal Energy ≤ $10^{53\text{-}54}$ erg

pryhora, Lockman & Shields
ApJ 656, 928 (2007)



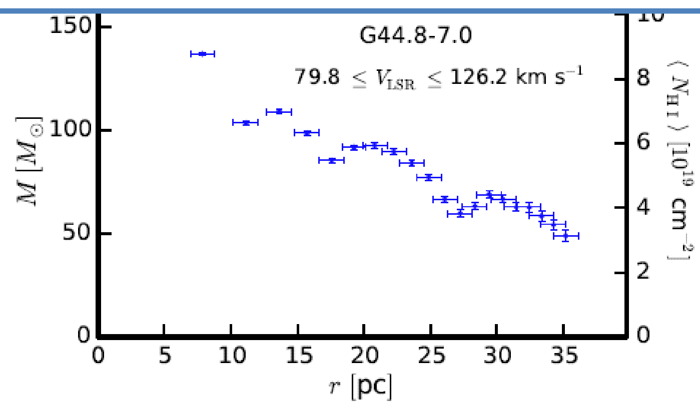


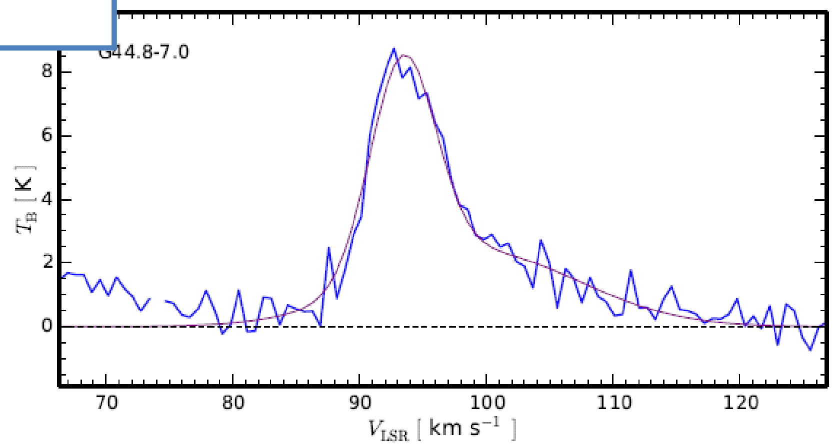
G44.8-7.0, R ≈ 6.0 kpc, z ≈ -740 pc

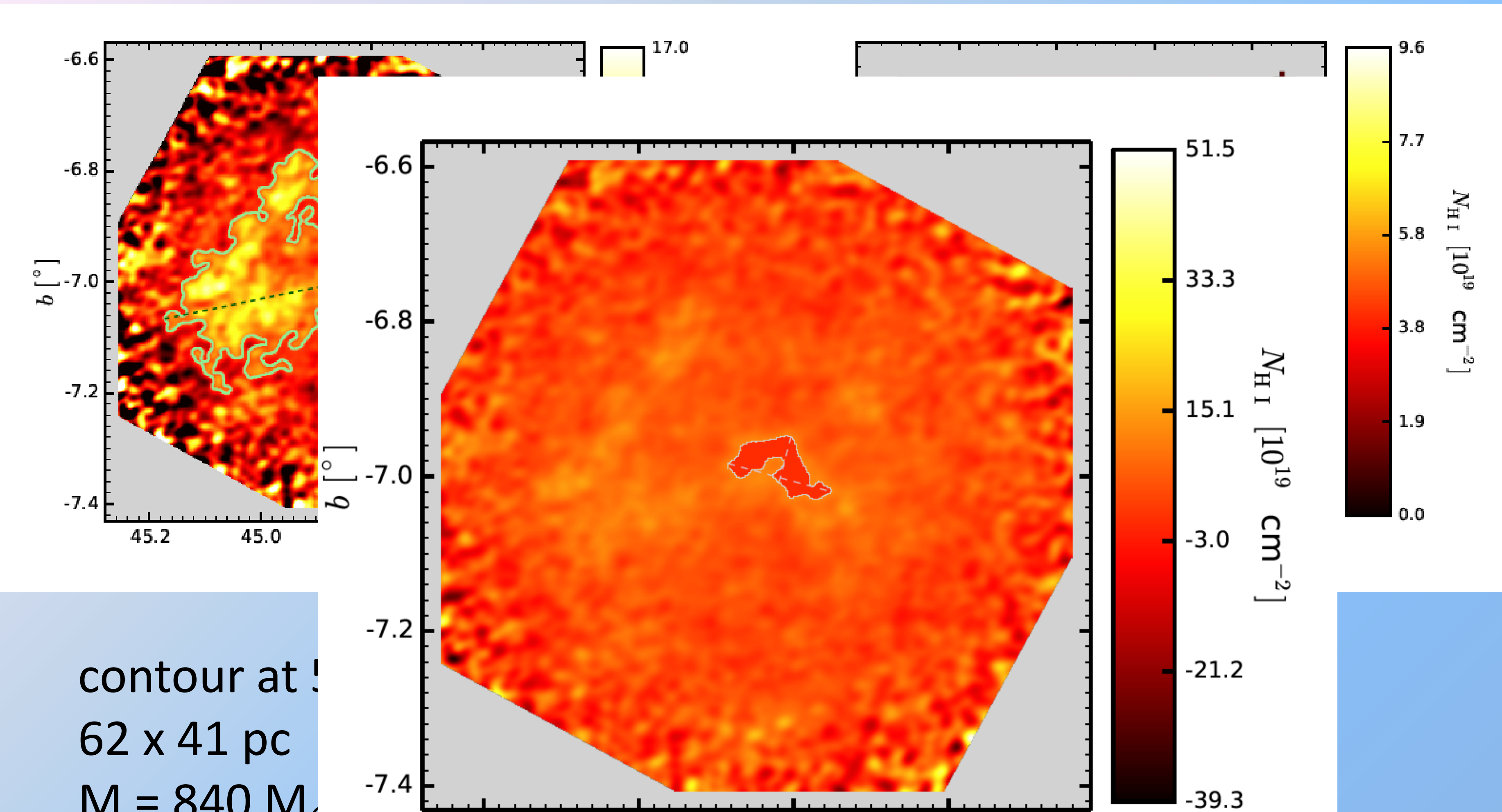
T_b = 6.8 ± 0.4 K, V_{LSR} = 93.4 ± 0.1 km s^{-1} ,
FWHM = 6.1 ± 0.4 km s^{-1}

T_b = 2.3 ± 0.3 K, V_{LSR} = 99.4 ± 1.1 km s^{-1} ,
FWHM = 18.6 ± 1.5 km s^{-1}

$N_{H\,I}$ = 1.7 x 10^{20} cm^{-2}







contour at 5

62 x 41 pc

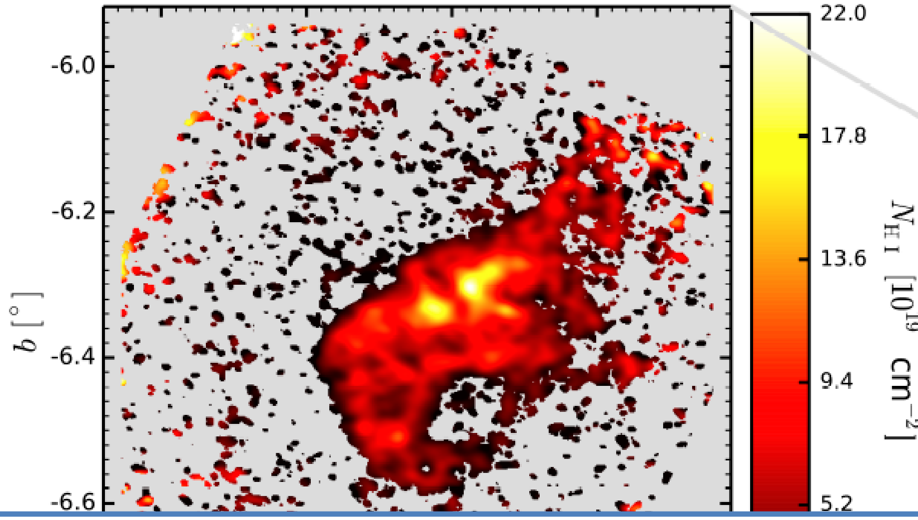
M = 840 M$_\odot$

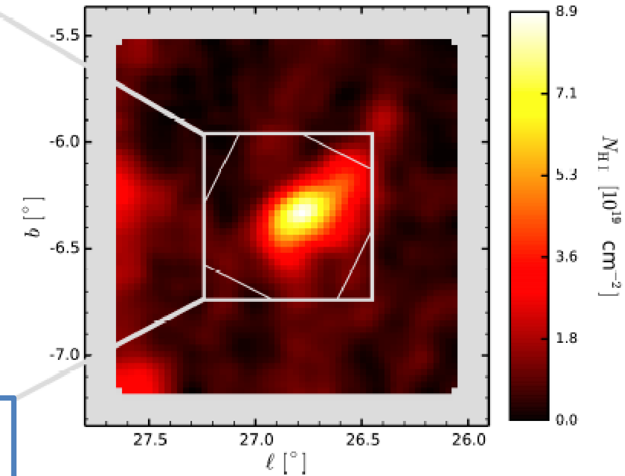
core contour at 1.2 x 10^{20}

15 x 7 pc

M = 54 M$_\odot$

n ~ 4 cm^{-3}



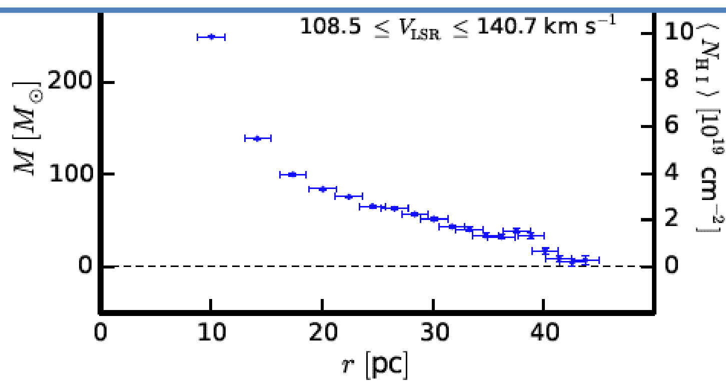


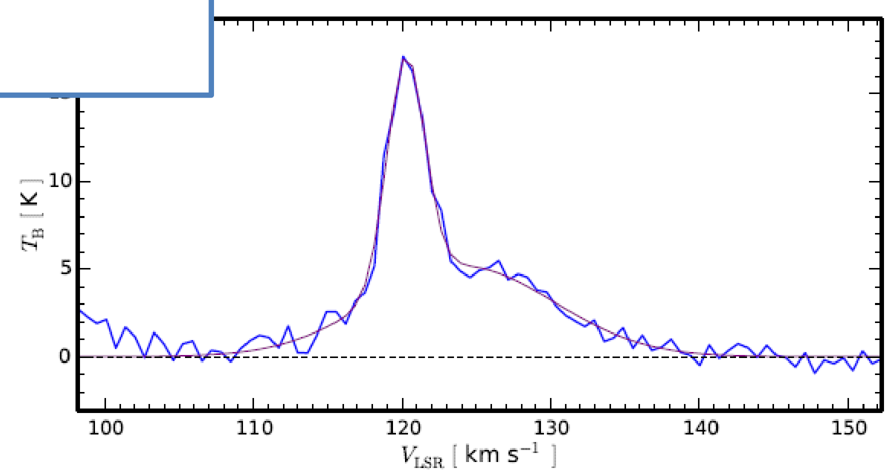
G26.9-6.3, R ≈ 3.9 kpc, z ≈ -840 pc

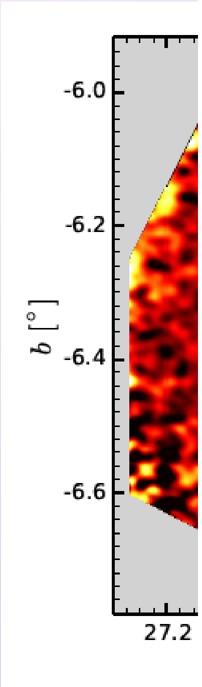
T_b = 13.0 ± 0.4 K, V_{LSR} = 120.3 ± 0.1 km s^{-1} ,
FWHM = 3.0 ± 0.1 km s^{-1}

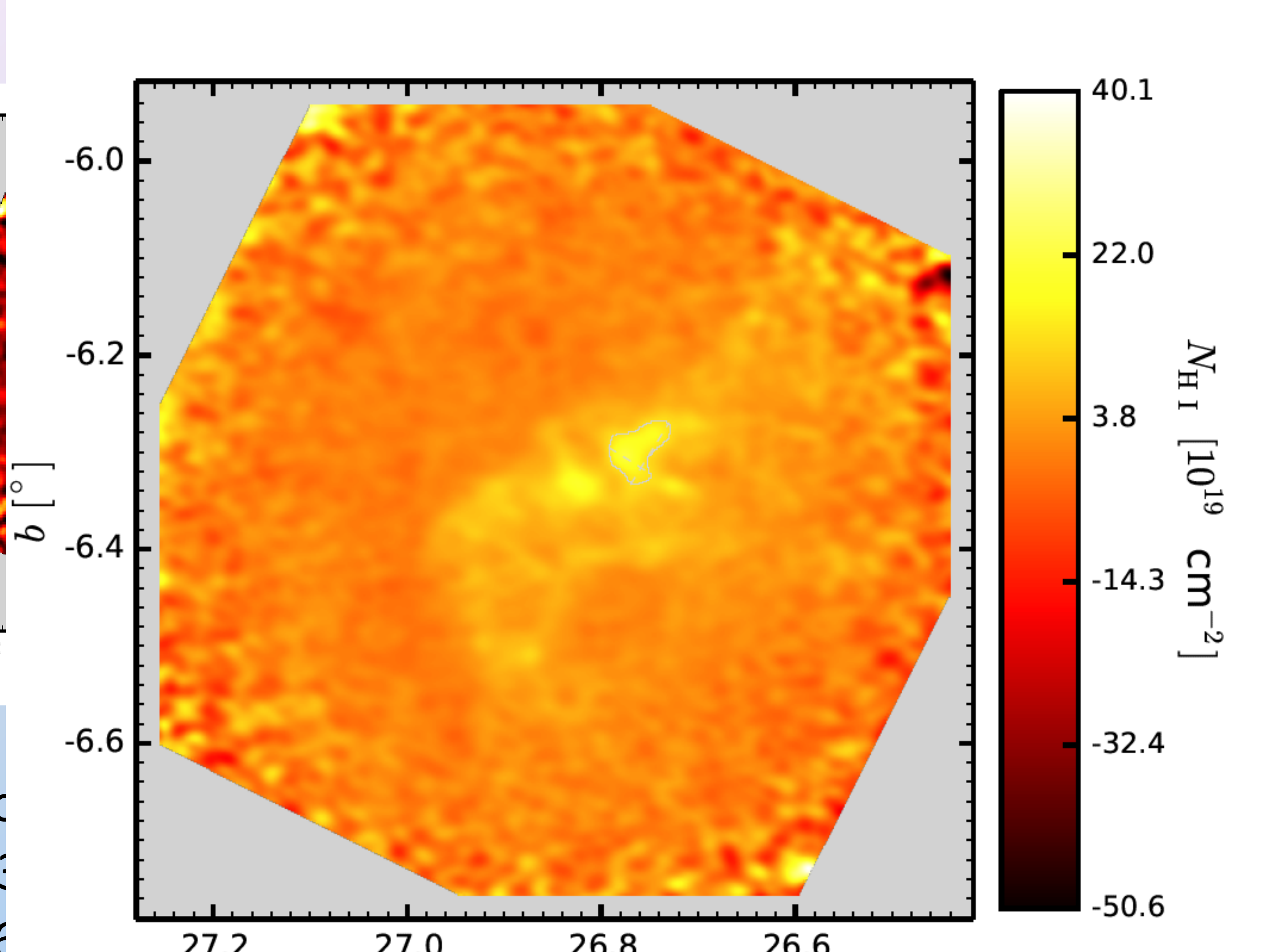
T_b = 5.2 ± 0.3 K, V_{LSR} = 124.1 ± 0.3 km s^{-1} ,
FWHM = 14.5 ± 0.6 km s^{-1}

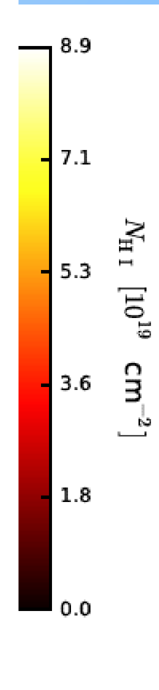
$N_{H\,I}$ = 2.2 x 10^{20} cm^{-2}











conto

66 x 3

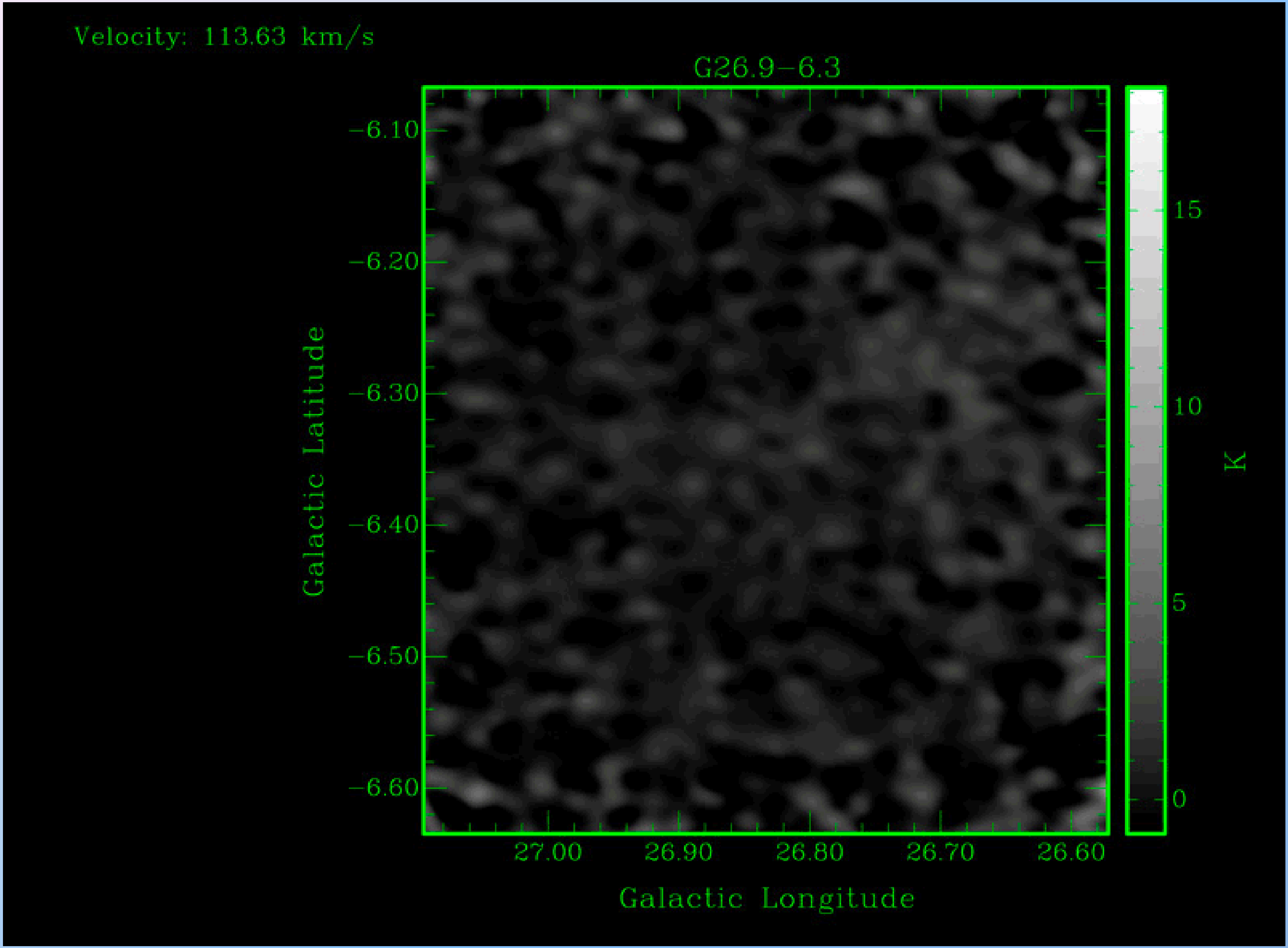
M = 6

core contour at 1.3 x 10^{20}

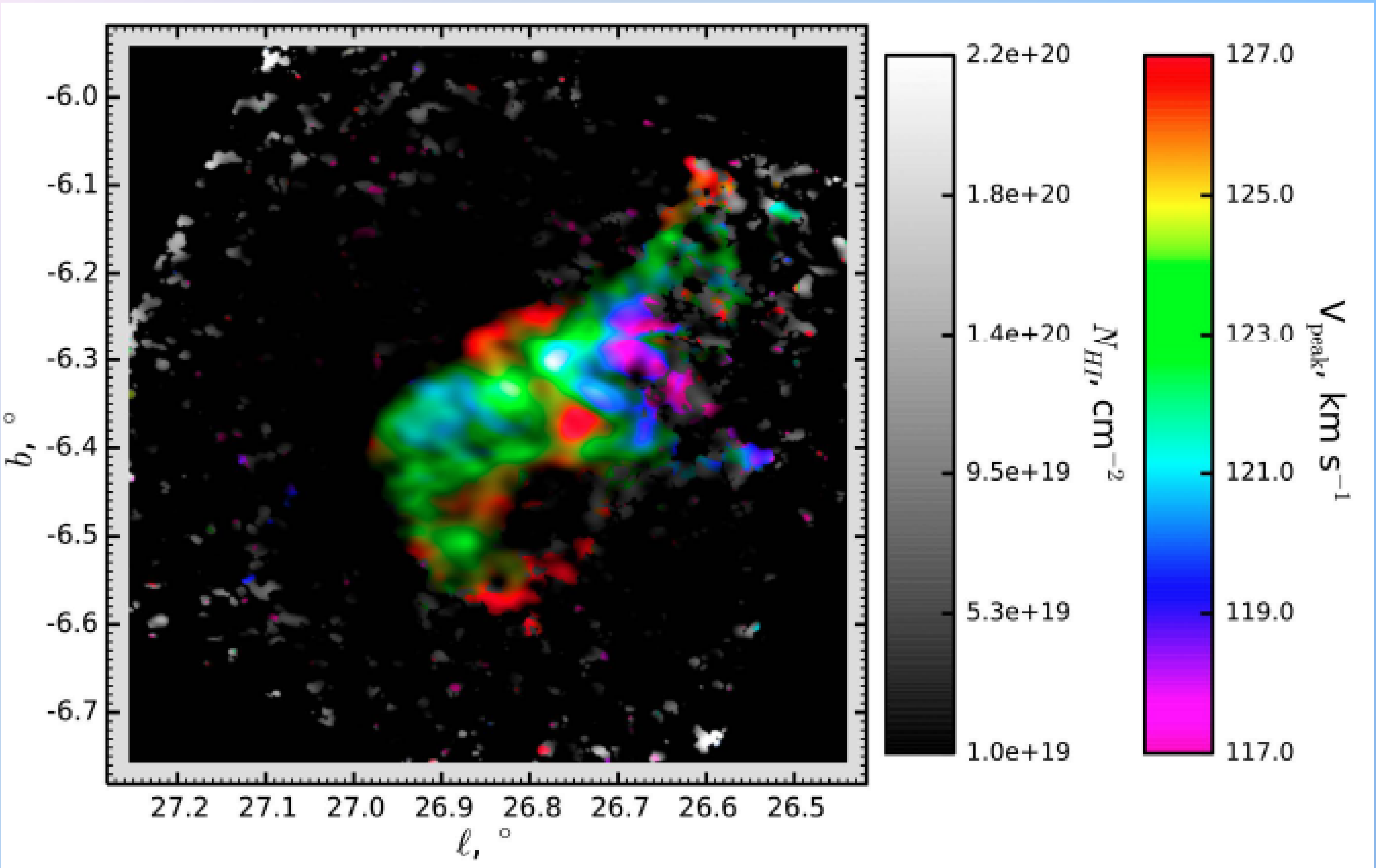
10 x 7 pc

M = 54 $M_\odot$

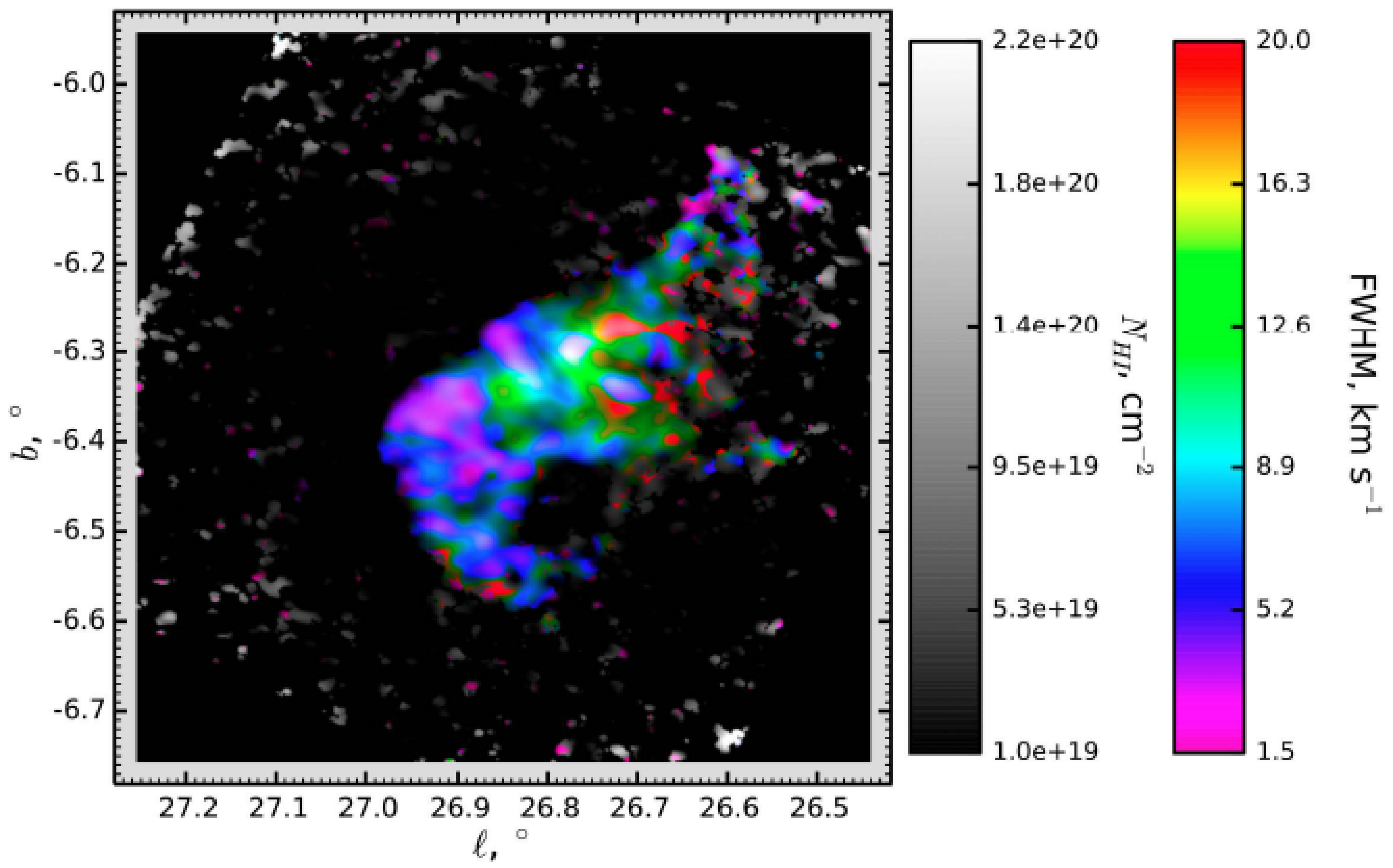
n ~ 7 cm^{-3}



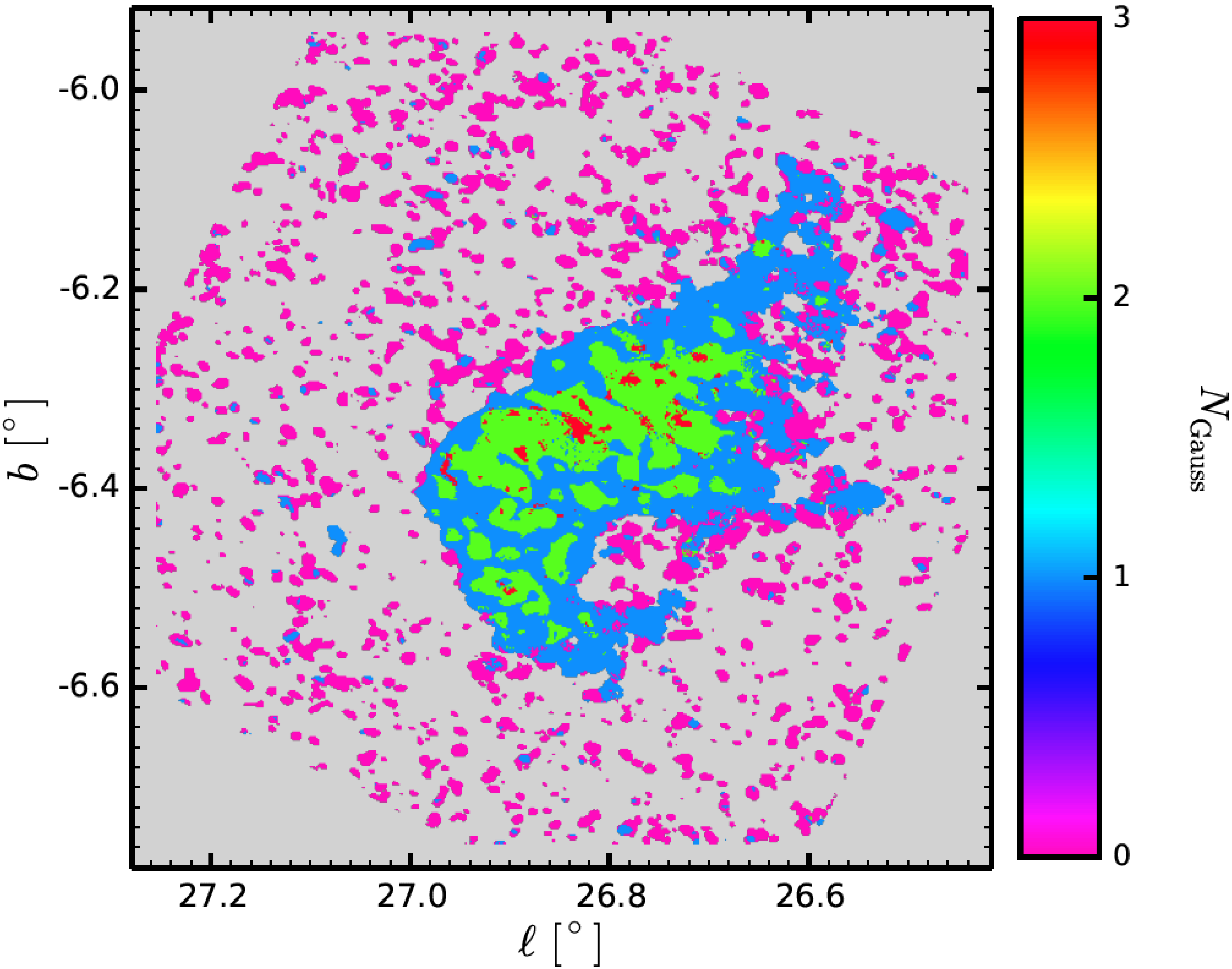
Velocity: 113.63 km/s
G26.9−6.3
Galactic Latitude
−6.10
−6.20
−6.30
−6.40
−6.50
−6.60
27.00
26.90
26.80
26.70
26.60
Galactic Longitude
15
10
5
0
K



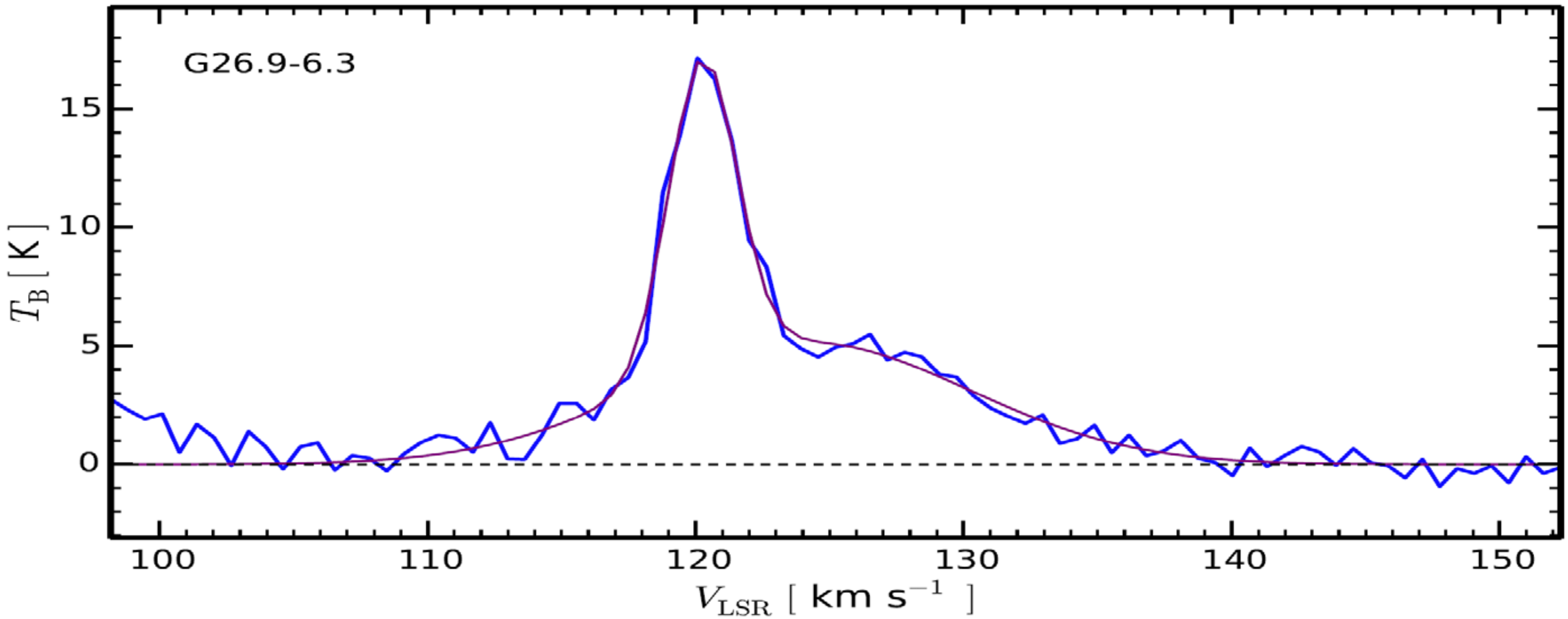
-6.0
-6.1
-6.2
-6.3
-6.4
-6.5
-6.6
-6.7
b, °
27.2
27.1
27.0
26.9
26.8
26.7
26.6
26.5
ℓ, °
2.2e+20
1.8e+20
1.4e+20
9.5e+19
5.3e+19
1.0e+19
N_HI, cm⁻²
127.0
125.0
123.0
121.0
119.0
117.0
V_peak, km s⁻¹



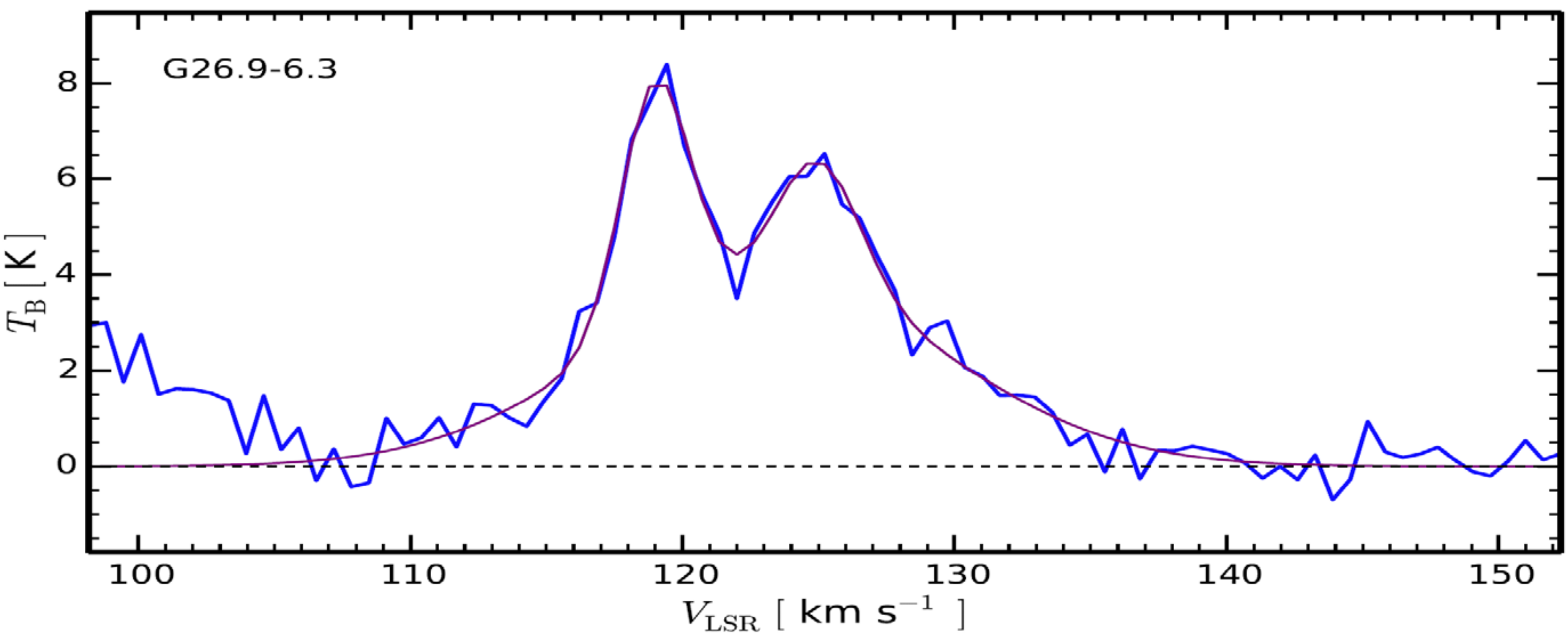
-6.0
-6.1
-6.2
-6.3
-6.4
-6.5
-6.6
-6.7
b, °
27.2
27.1
27.0
26.9
26.8
26.7
26.6
26.5
ℓ, °
2.2e+20
1.8e+20
1.4e+20
9.5e+19
5.3e+19
1.0e+19
N_HI, cm^-2
20.0
16.3
12.6
8.9
5.2
1.5
FWHM, km s^-1



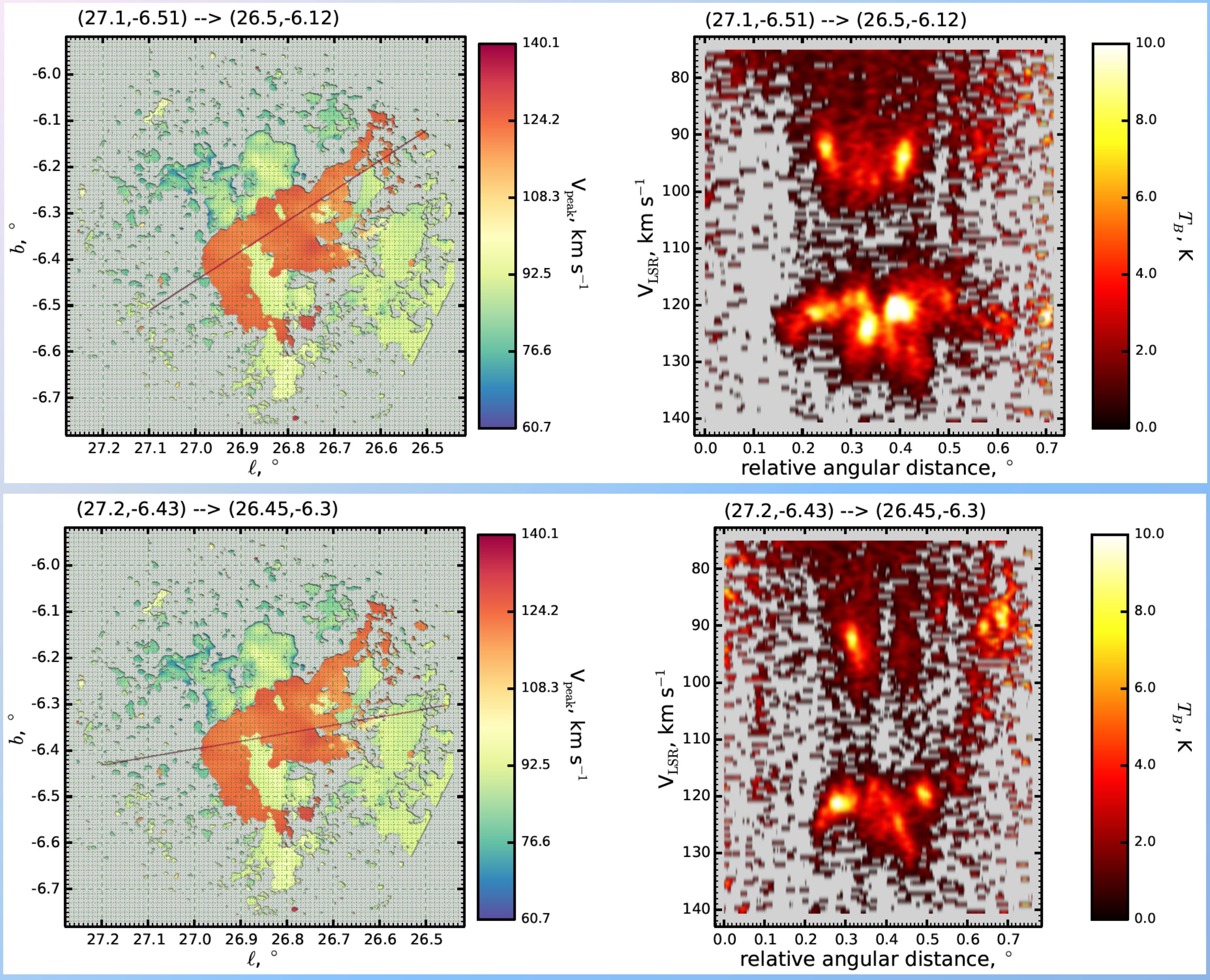
-6.0
-6.2
-6.4
-6.6
b [°]
27.2
27.0
26.8
26.6
ℓ [°]
3
2
1
0
N_Gauss

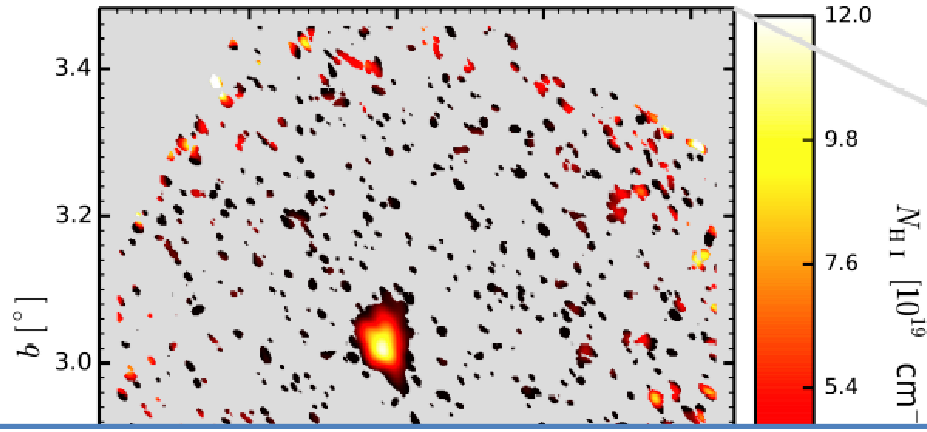


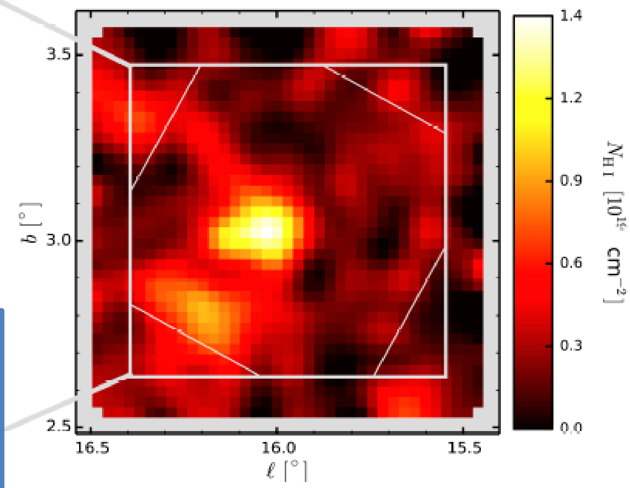
G26.9-6.3
T_B [K]
V_{LSR} [km s^{-1}]



G26.9-6.3
T_B [K]
V_{LSR} [km s^{-1}]


(27.1,-6.51) --> (26.5,-6.12)
(27.1,-6.51) --> (26.5,-6.12)
(27.2,-6.43) --> (26.45,-6.3)
(27.2,-6.43) --> (26.45,-6.3)
V_{peak}, km s^{-1}
V_{LSR}, km s^{-1}
T_B, K
b, °
ℓ, °
relative angular distance, °
140.1
124.2
108.3
92.5
76.6
60.7
10.0
8.0
6.0
4.0
2.0
0.0





G26.9-6.3, R ≈ 2.3 kpc, z ≈ +430 pc

T_b = 12.3 ± 0.3 K, V_{LSR} = 143.6 ± 0.1 km s^{-1} ,

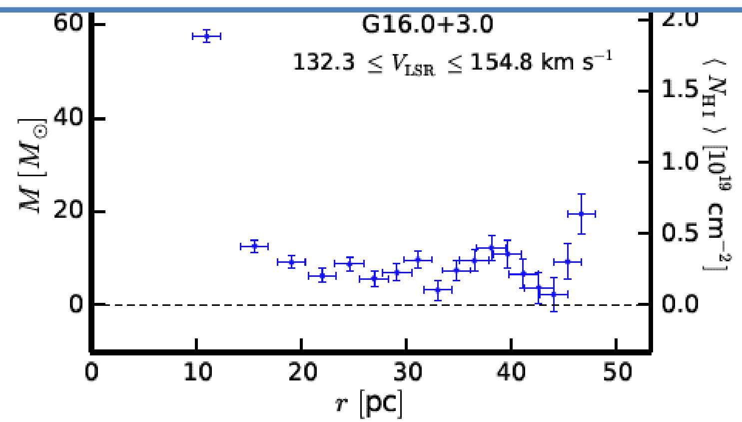
FWHM = 4.7 ± 0.1 km s^{-1}

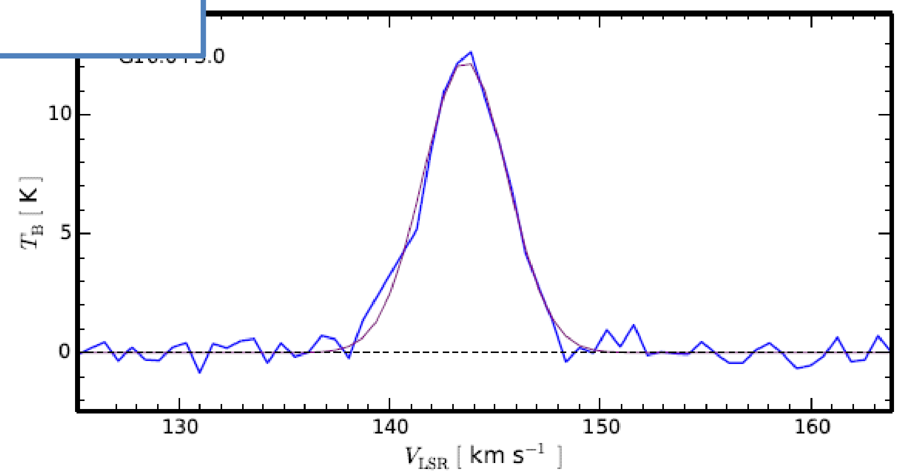
$N_{H\,I}$ = 1.2 x 10^{20} cm^{-2}

16 x 10 pc

M = 45 $M_\odot$

n ~ 1.7 cm^{-3}





Next step: GASKAP and GAMES surveys

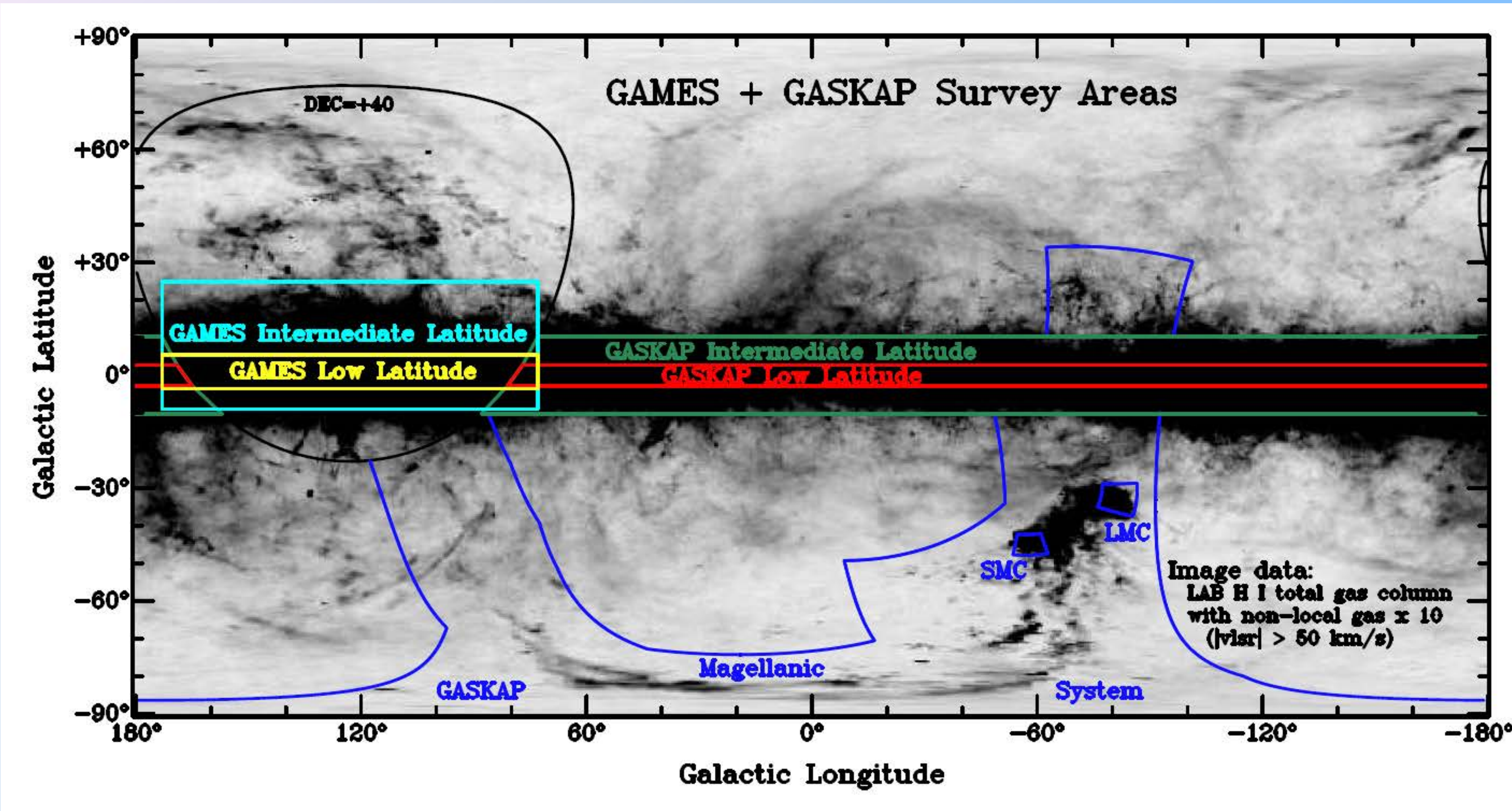
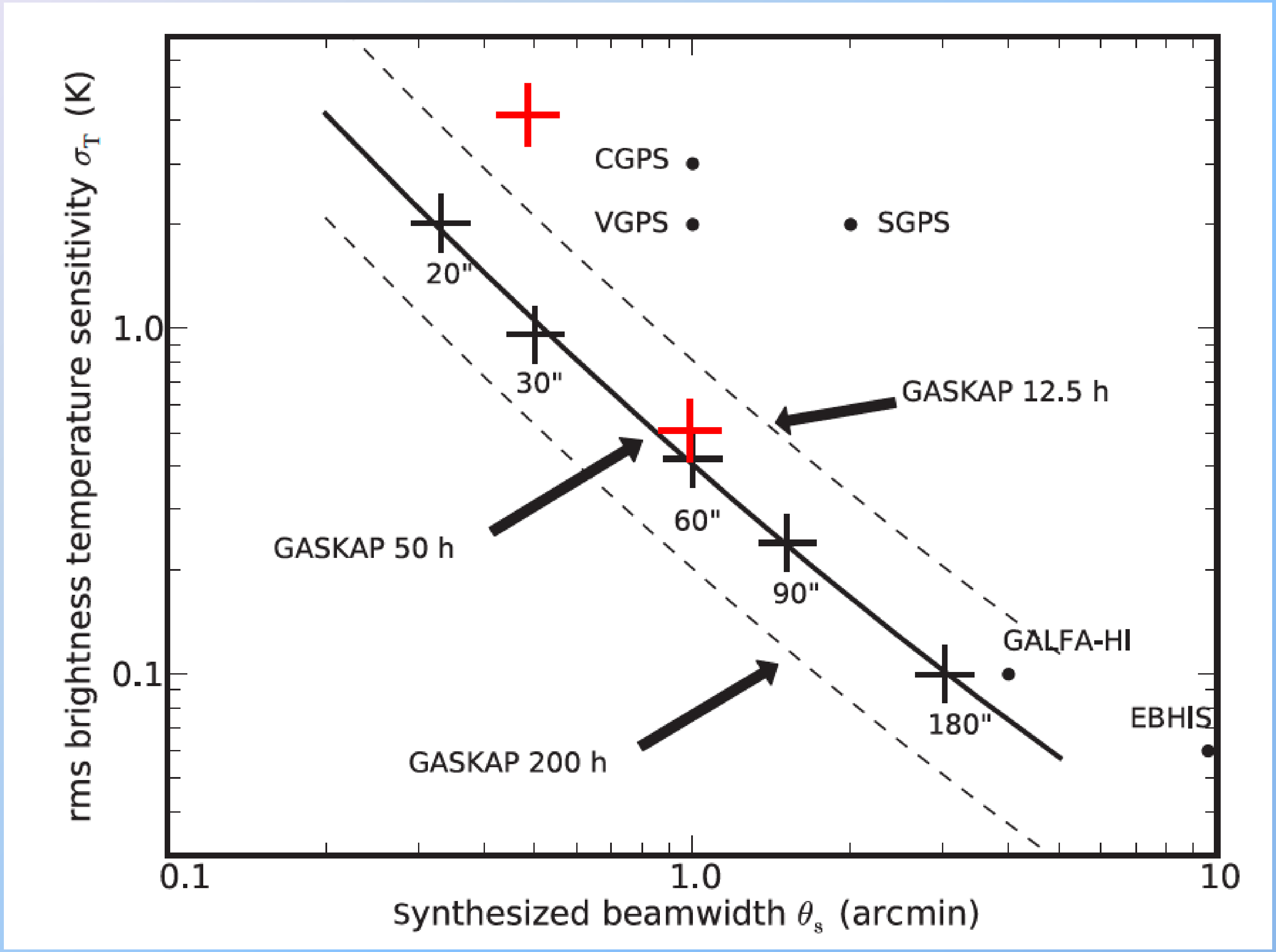


figure courtesy of N. McClure-Griffiths

GASKAP compared with our VLA+GBT survey



background figure from Dickey et al. PASA 30, 3 (2013)

Discussion

- Morphology of the clouds is very complex and difficult to interpret
- Their confinement mechanism is as enigmatic as ever
- As for their origin, we only vaguely understand that it is related to superbubbles
- We see both evidence of warm+cold two-phase system and of complex relative motion of cold “subcloudlets”