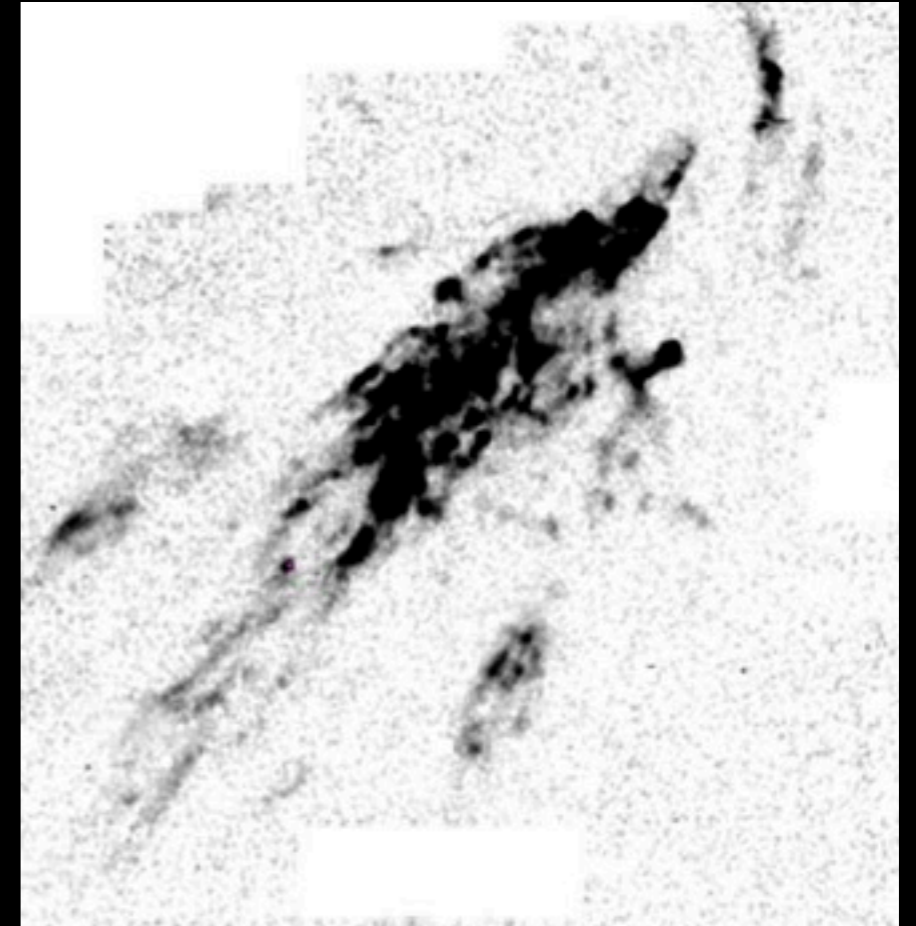
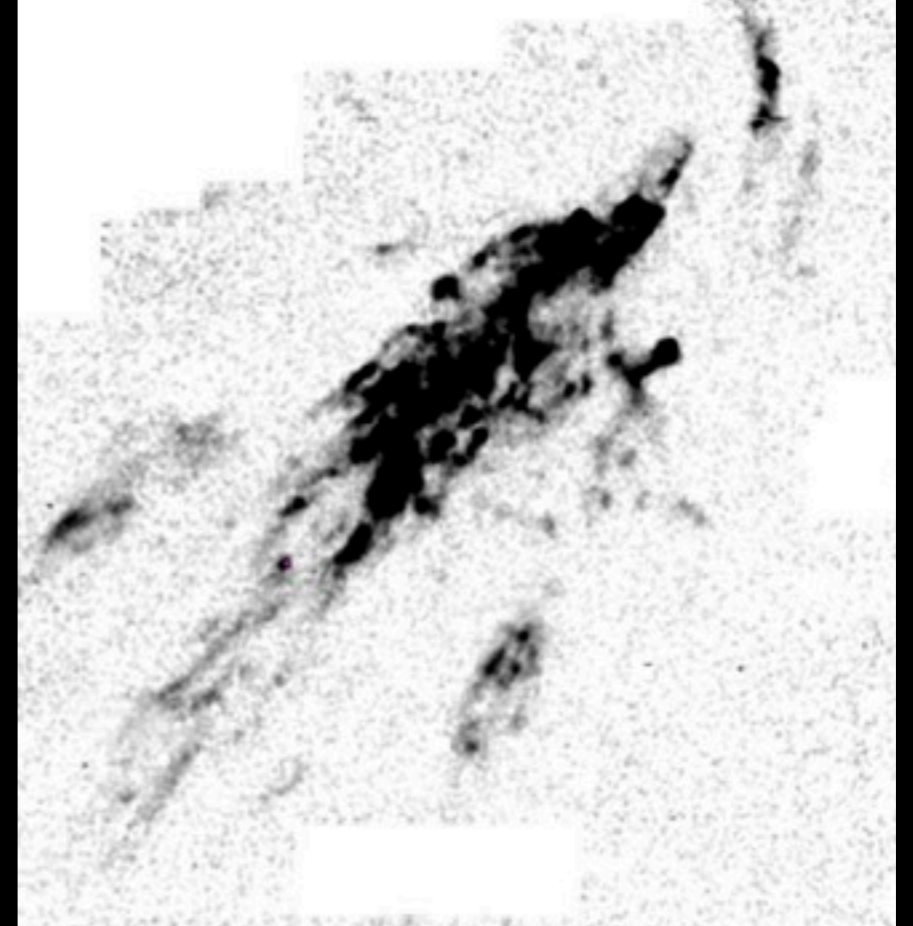
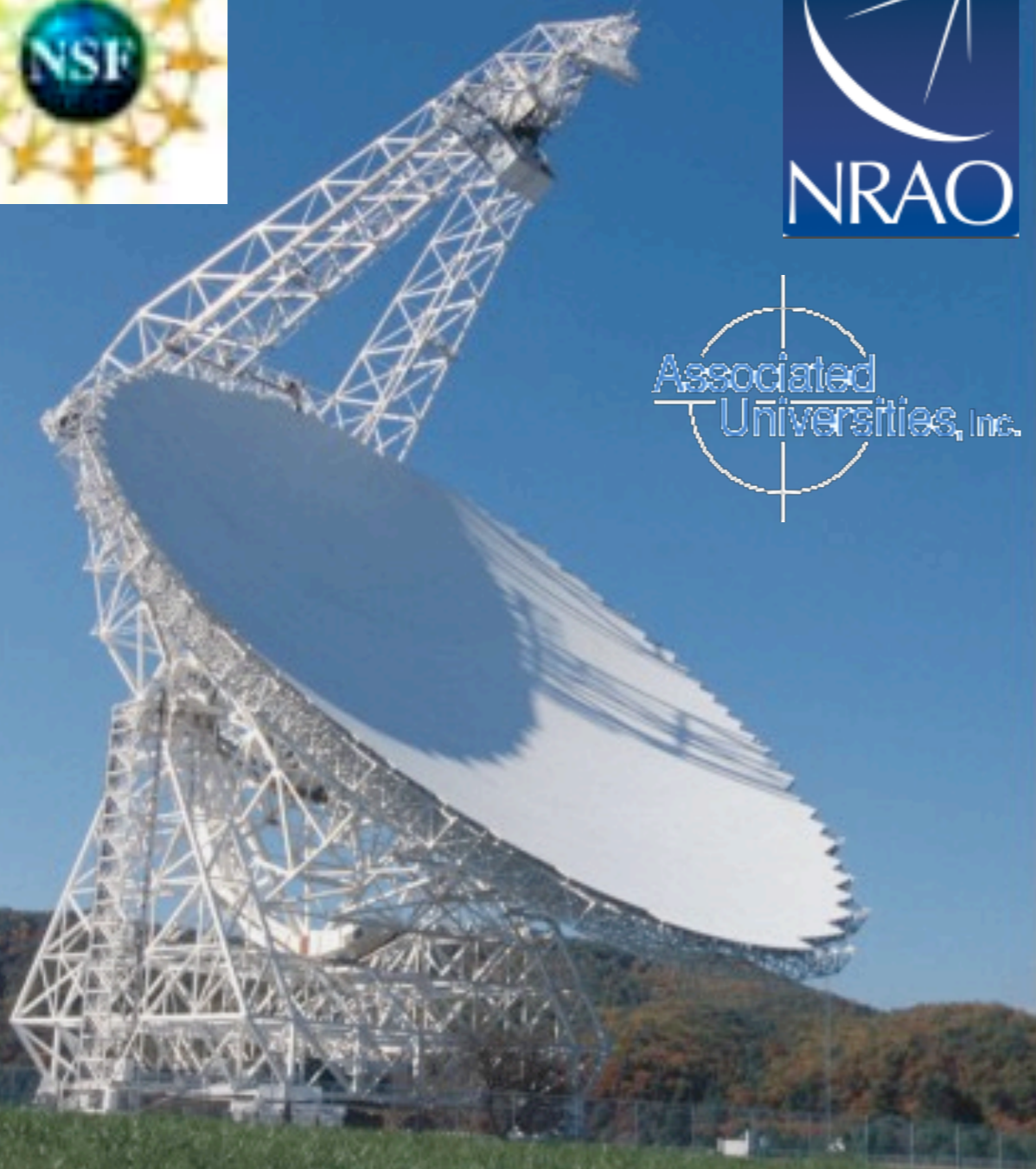


Neutral Gas Clouds in the Local Group



Felix "Jay" Lockman
NRAO, Green Bank WV
ASTRON 2015

Gas clouds where they should not be



Felix "Jay" Lockman
NRAO, Green Bank WV
ASTRON 2015

The Local Group of Galaxies

High Velocity Clouds
Remnants of Interaction
Inter-Group Gas?

Milky Way

Andromeda

Triangulum

NGC
185

NGC
147

IC 10

NGC
6822

M31 High Velocity Clouds

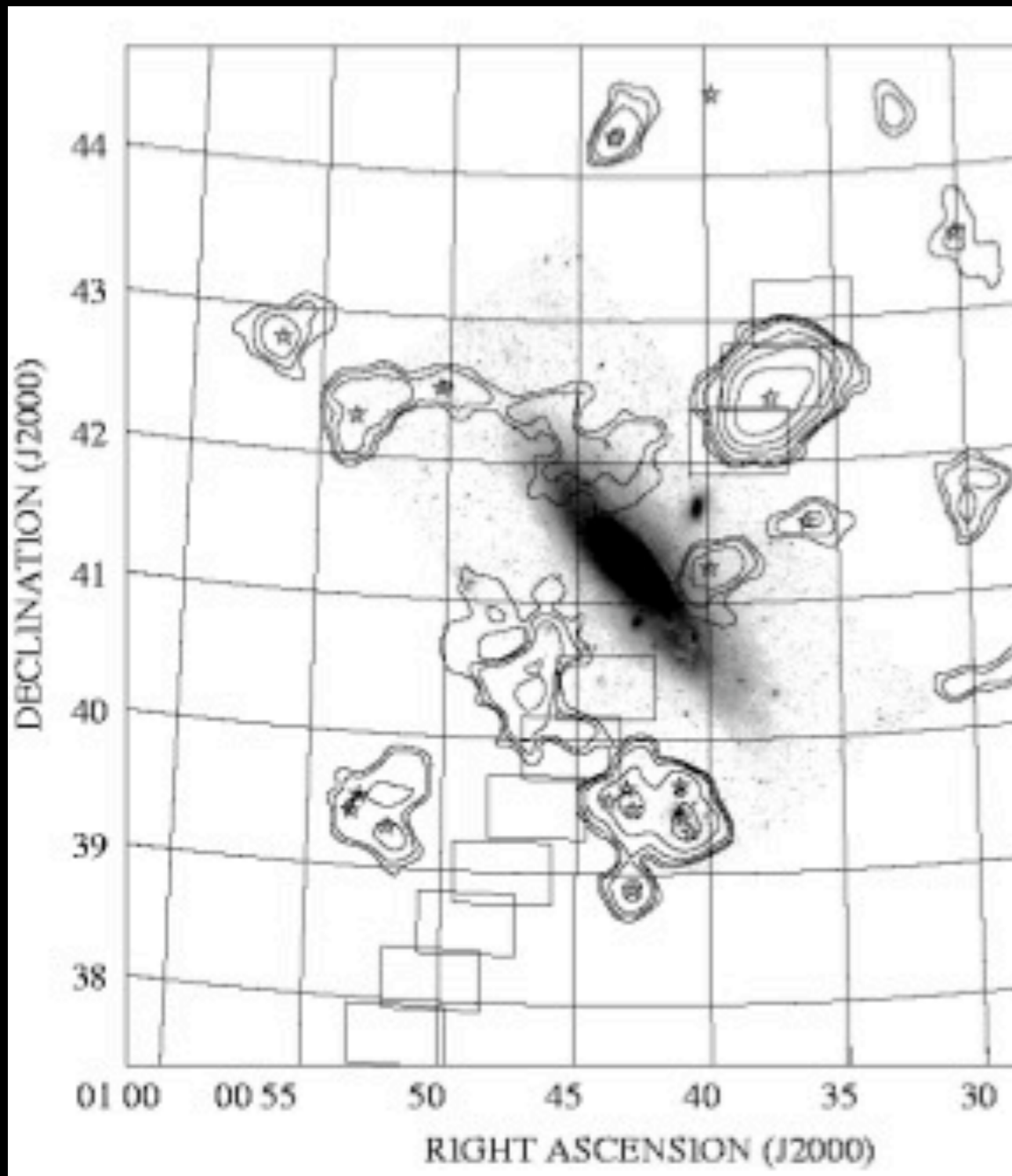
$10^{18.5}$

10 kpc

$M_{HI} = 10^{5-6} M_{\odot}$

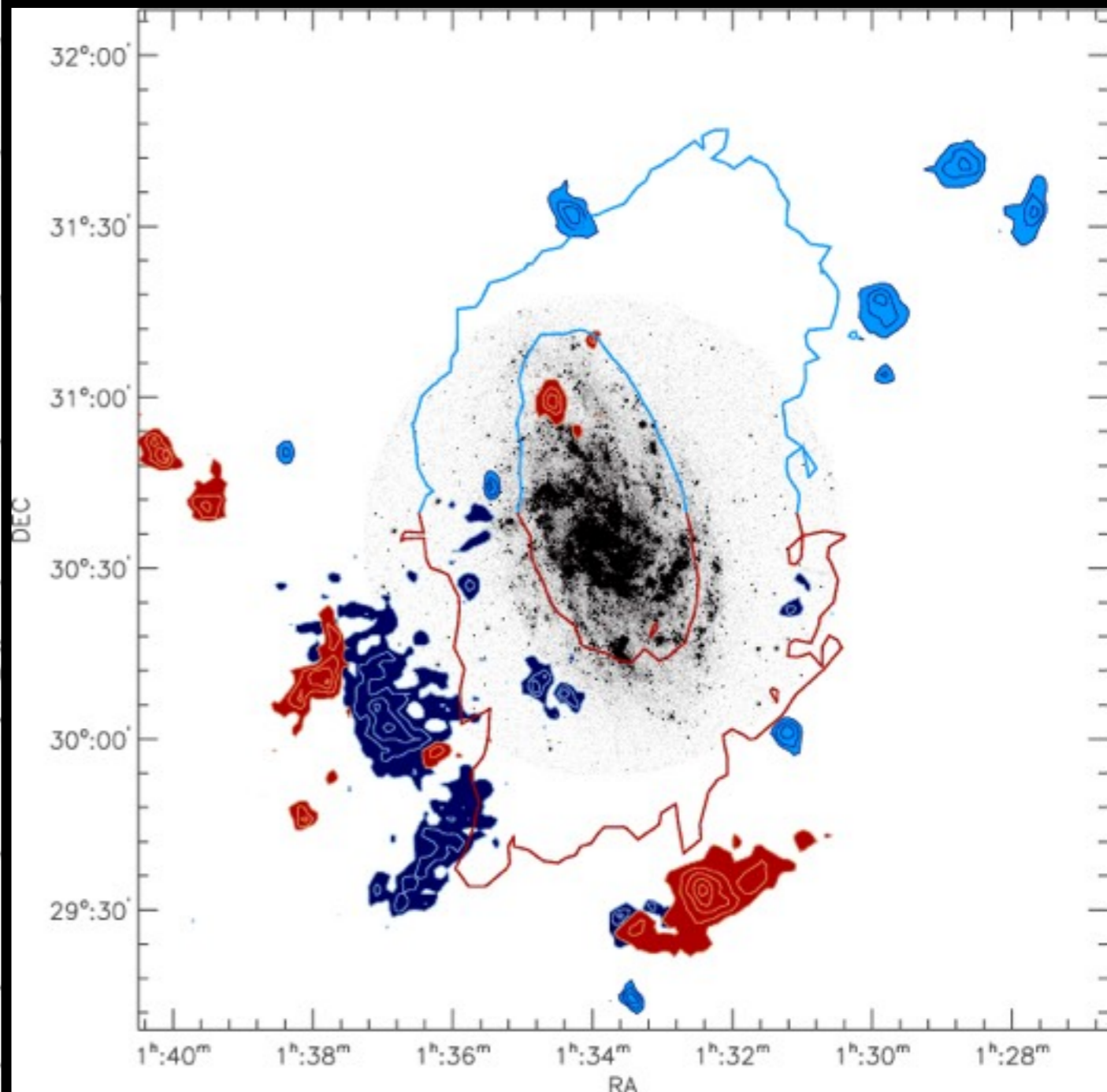
Thilker et al 2004

Local Group High Velocity Clouds



Thilker et al 2004

Westmeier et al. 2005; 2008



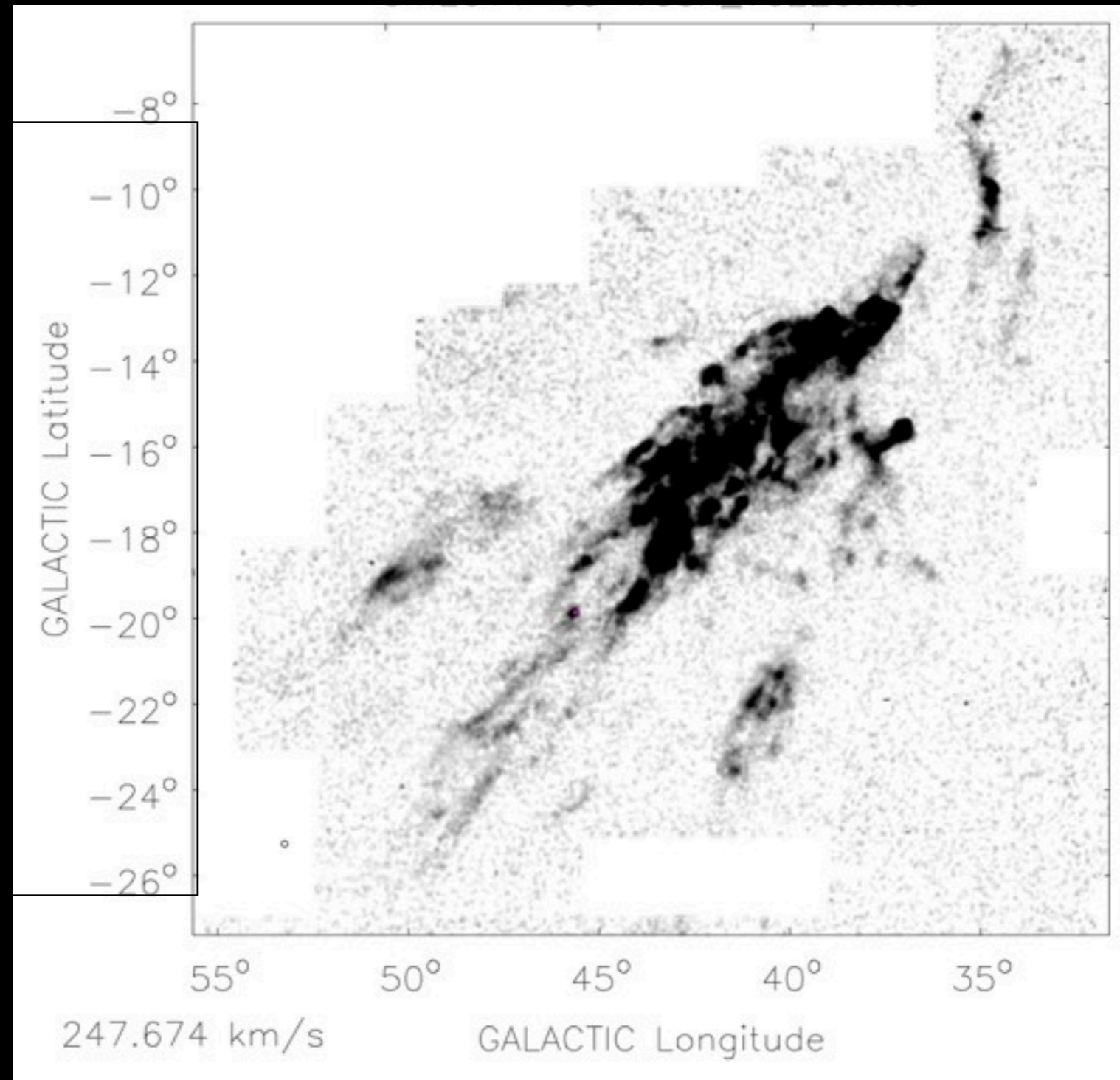
Grossi et al. 2008

Putman et al 2009

F.I. Lockman ASTRON September 2015

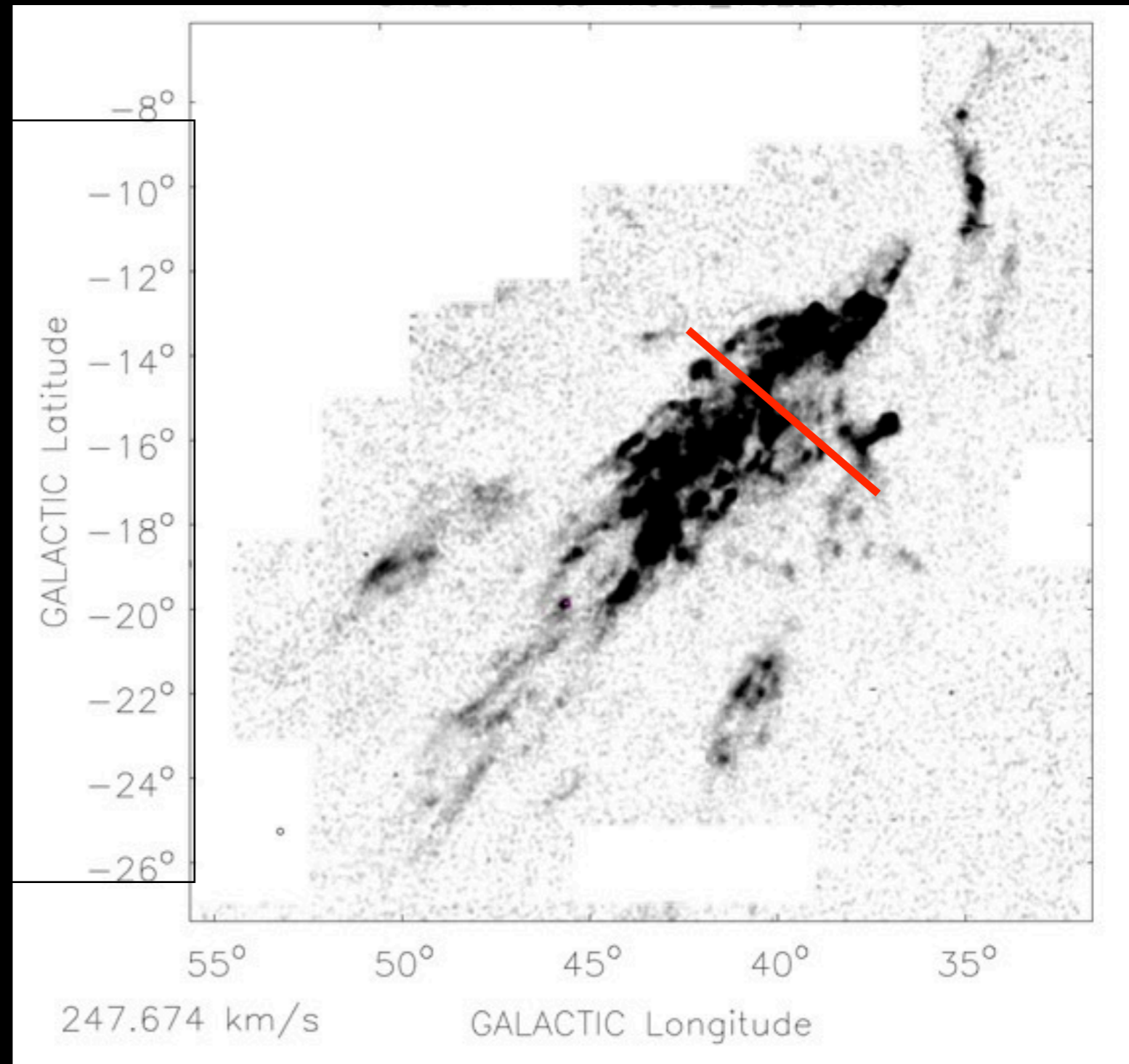
The Smith “Galactic” High Velocity Cloud

dist = 12.4 ± 1.3 kpc
R = 7.6 ± 1.0 kpc
z = -2.2 kpc
 $M_{\text{HI}} > 2 \times 10^6 M_{\odot}$
 $M_{\text{H}^+} > 1 \times 10^6 M_{\odot}$
size $> 3 \times 1$ kpc
No Stars!



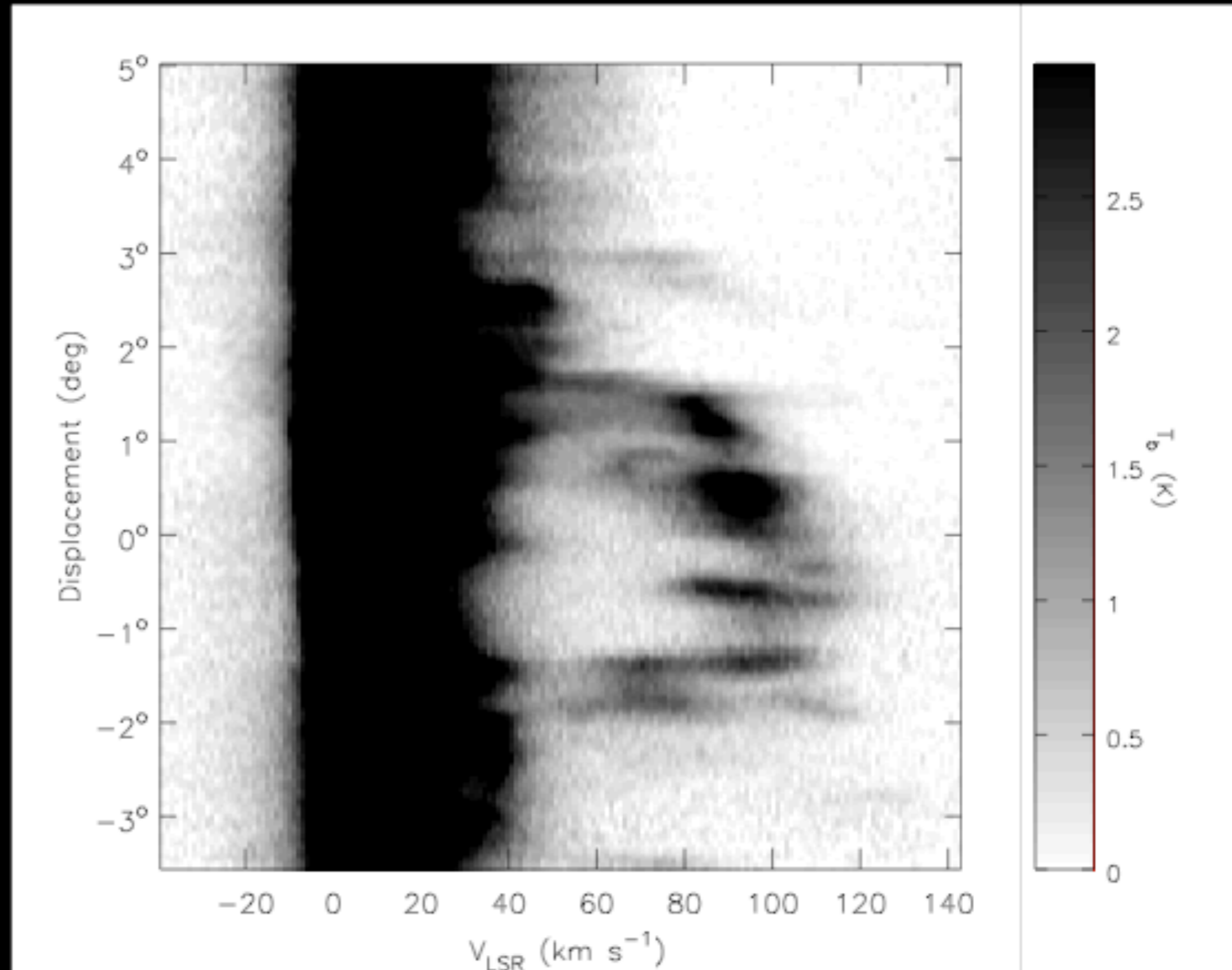
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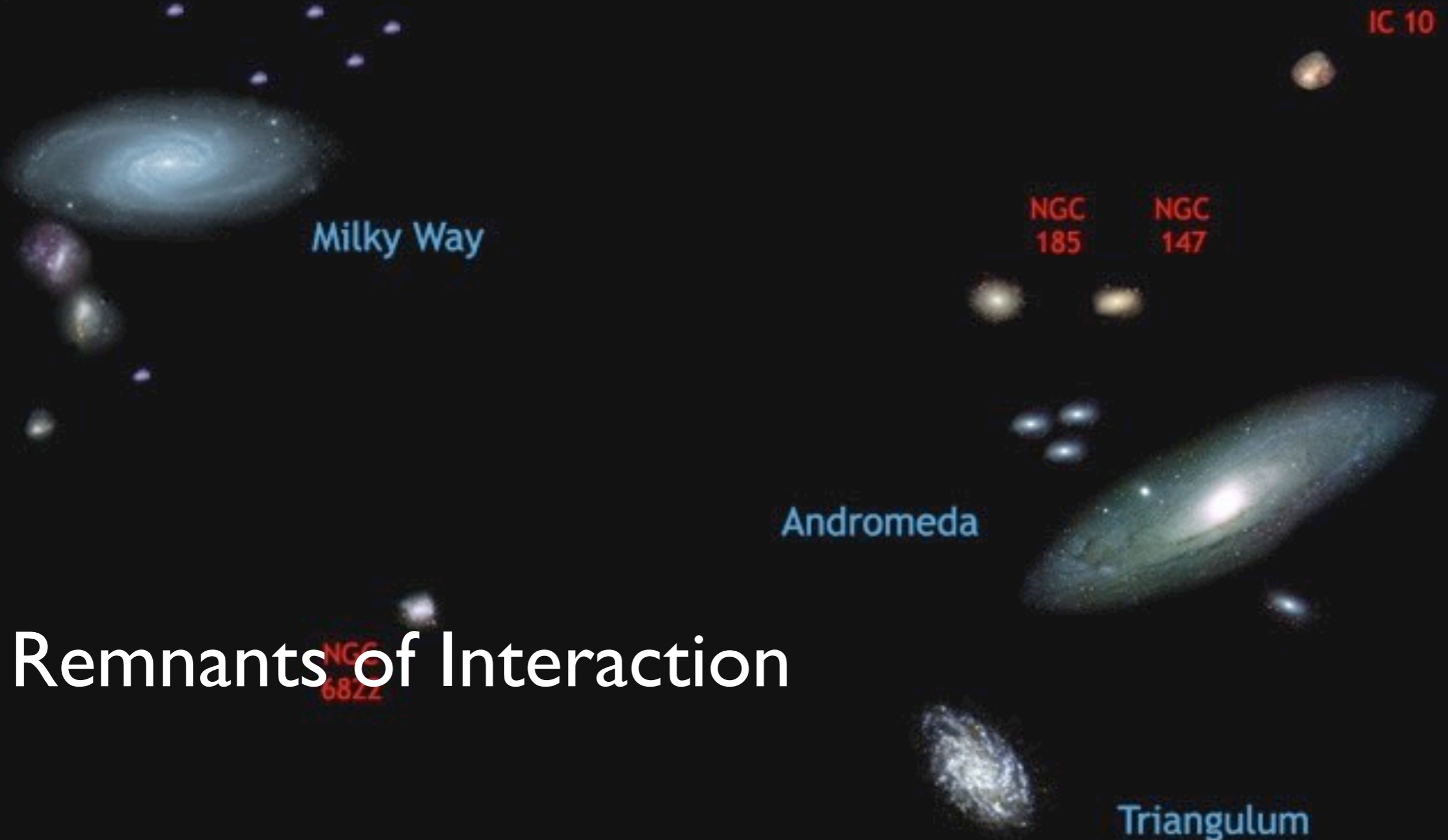
The Smith Cloud accreting onto the Milky Way

Position



Velocity

The Local Group of Galaxies



Remnants of Interaction

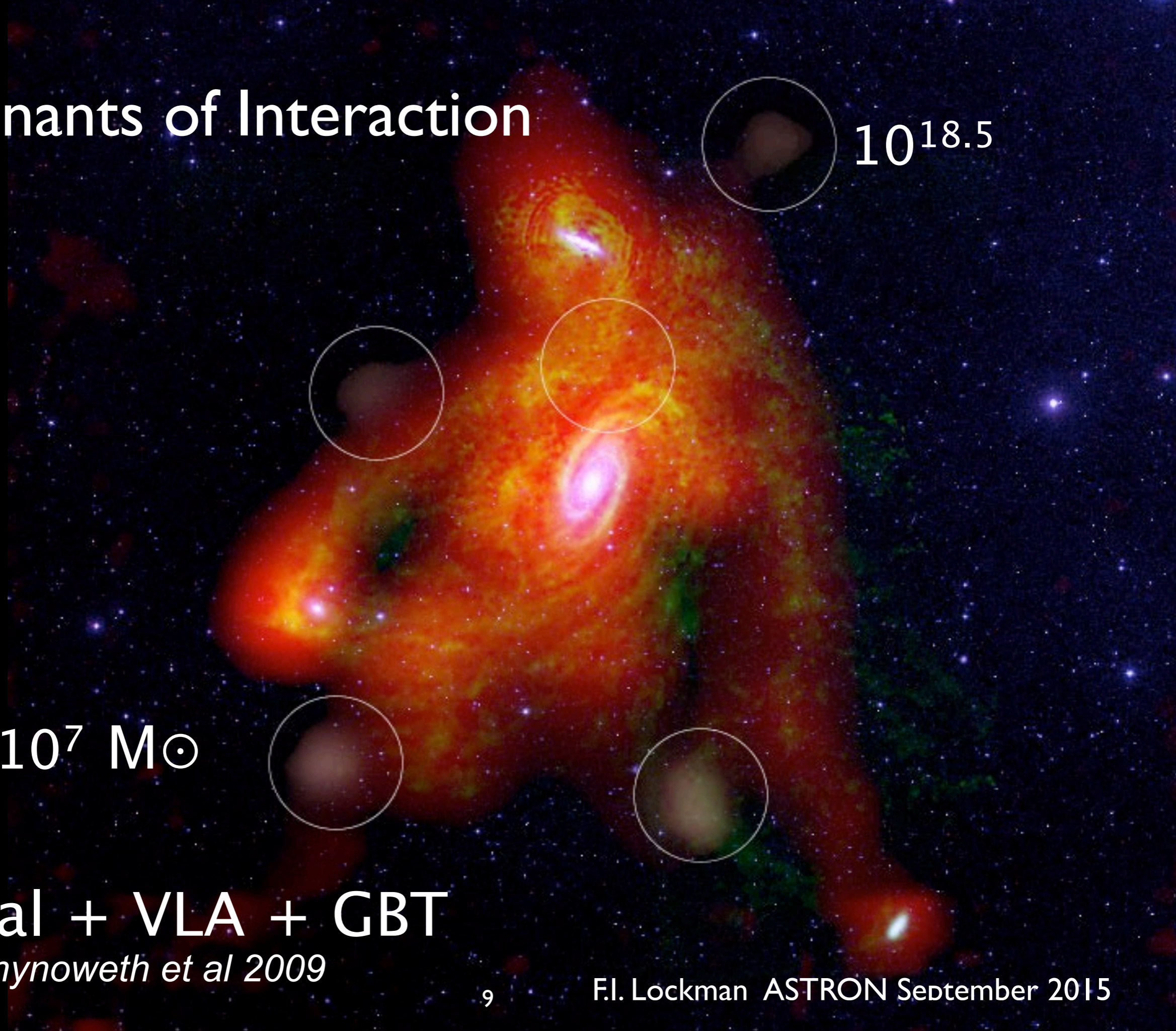
Remnants of Interaction

$10^{18.5}$

MHI $\sim 10^7 M_{\odot}$

Optical + VLA + GBT

Chynoweth et al 2009

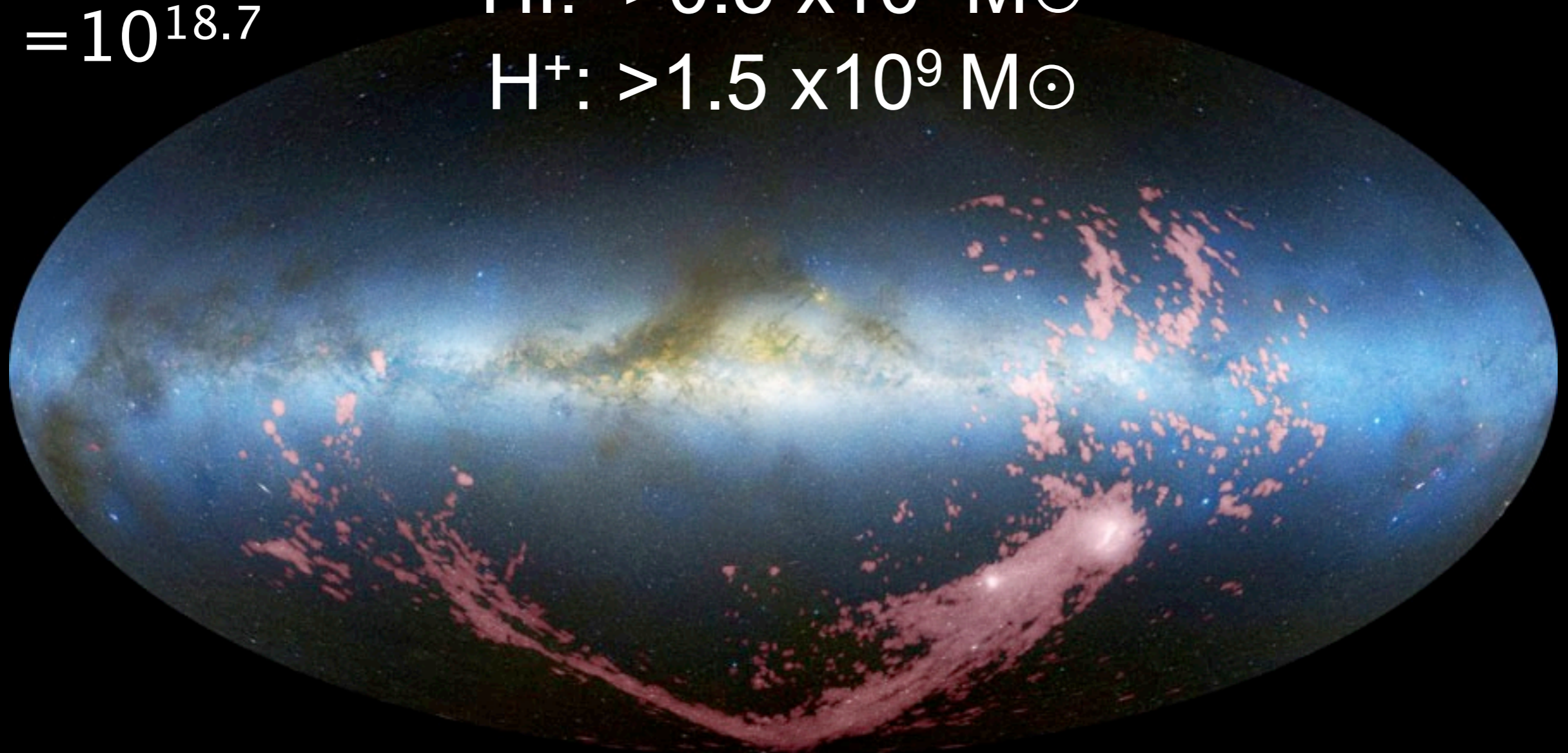


Magellanic Stream

$$3\sigma = 10^{18.7}$$

HI: $>0.5 \times 10^9 M_{\odot}$

H⁺: $>1.5 \times 10^9 M_{\odot}$



Nidever et al. 2010

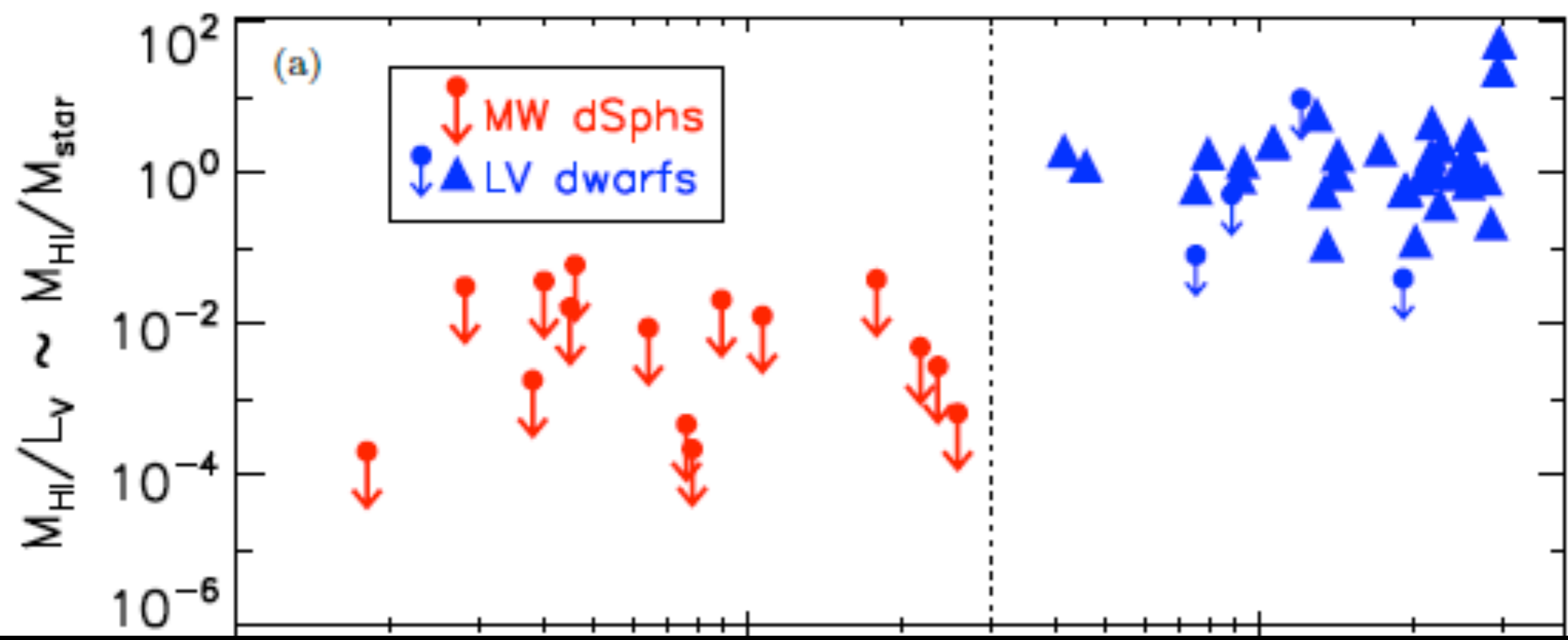
Fox et al. 2014

No Hydrogen in the Milky Way's Dwarf Galaxies



Galaxy	L (L_{\odot})	M_{HI} (M_{\odot})
Segue I	340	<11
UMa II	41,000	<74
Bootes II	1,000	<38
Coma Ber	3,700	<62
Ursa Mi	280,000	<63
Draco	280,000	<133
Spitzer Cloud		400
Hydra II	8,000	<210

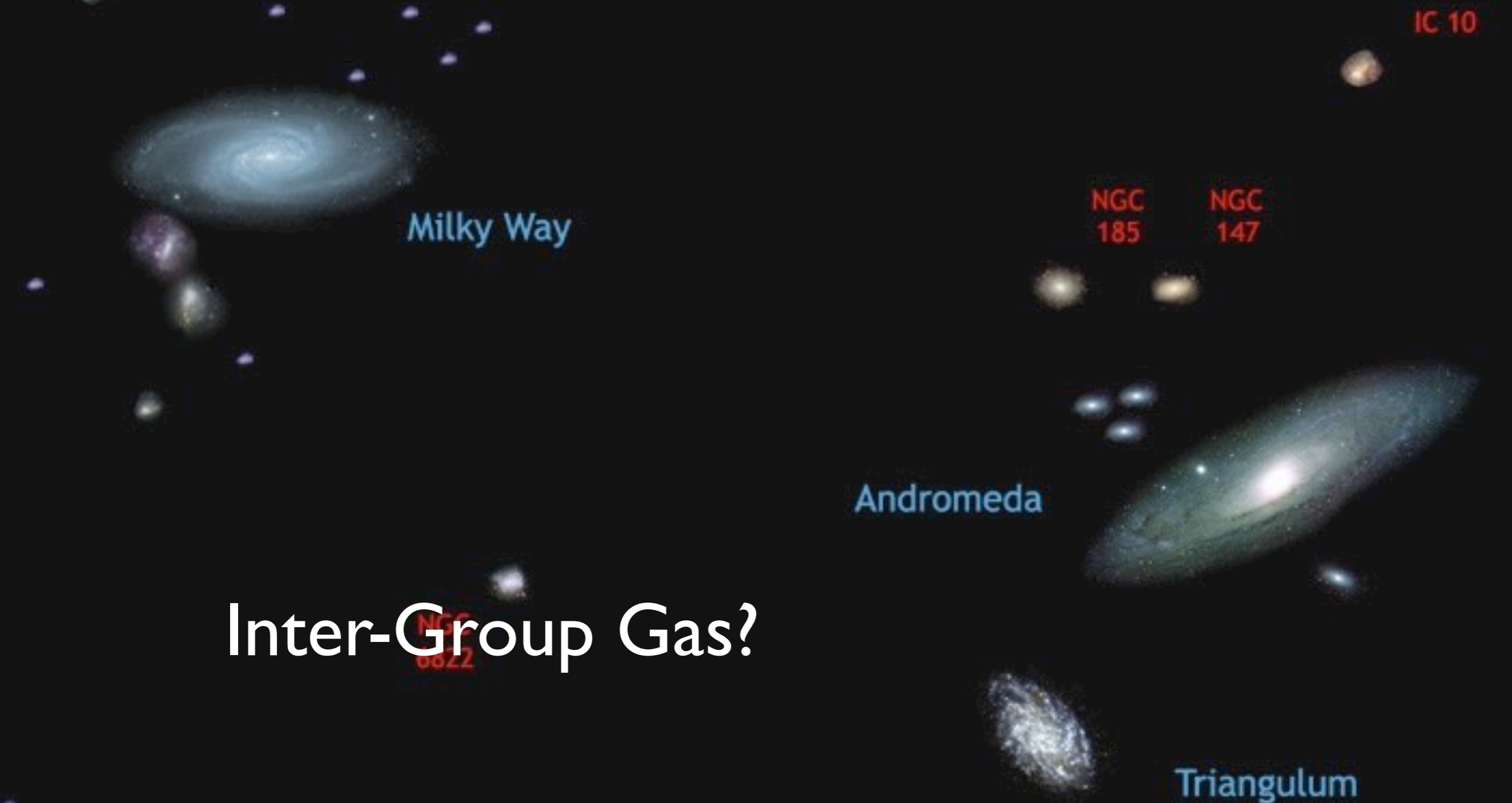
Spekkens et al. 2014
Janzen et al. 2015



Spekkens et al. 2014

Missing $\sim 3 \times 10^7 M_{\odot}$

The Local Group of Galaxies



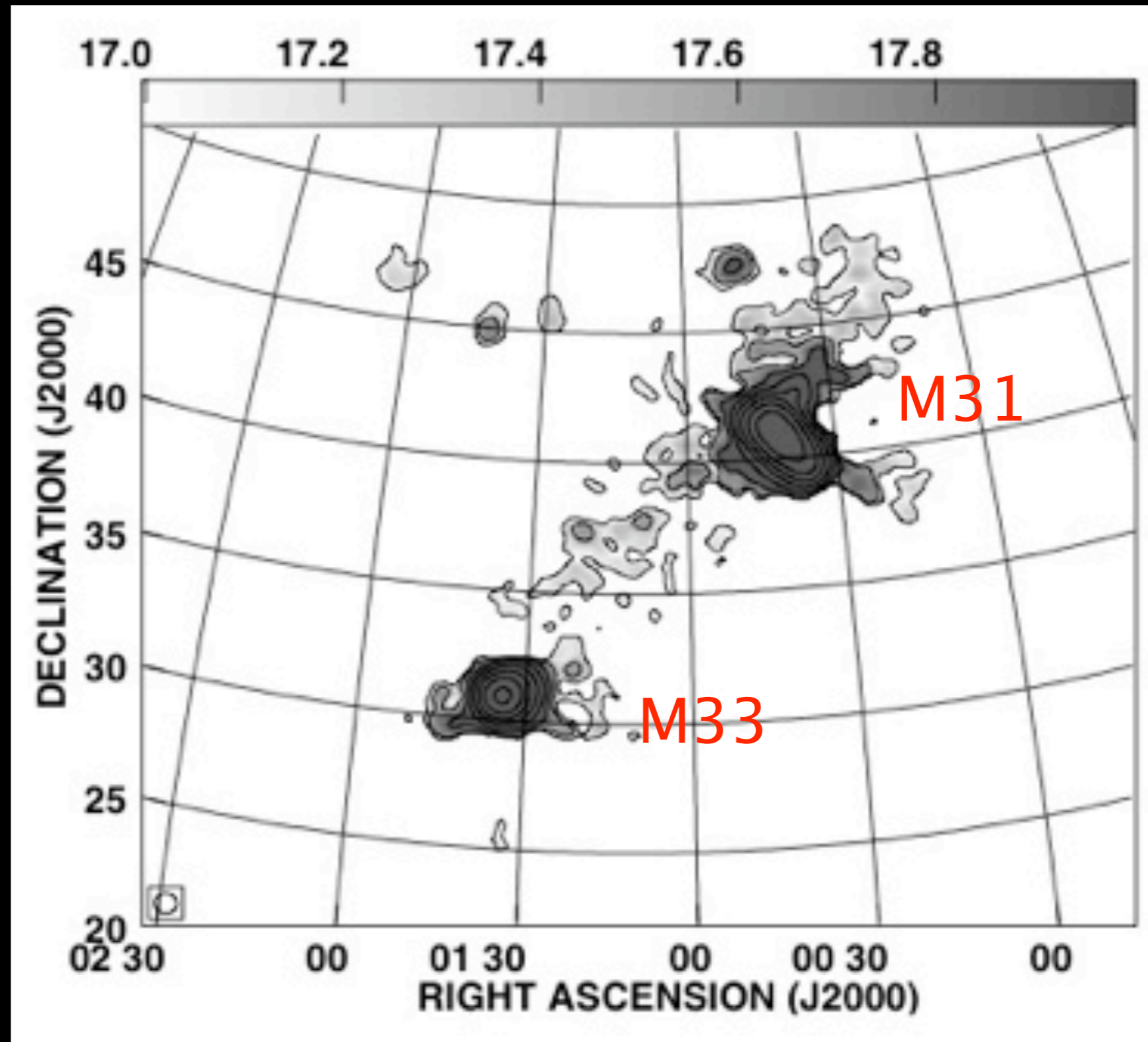
Inter-Group Gas?

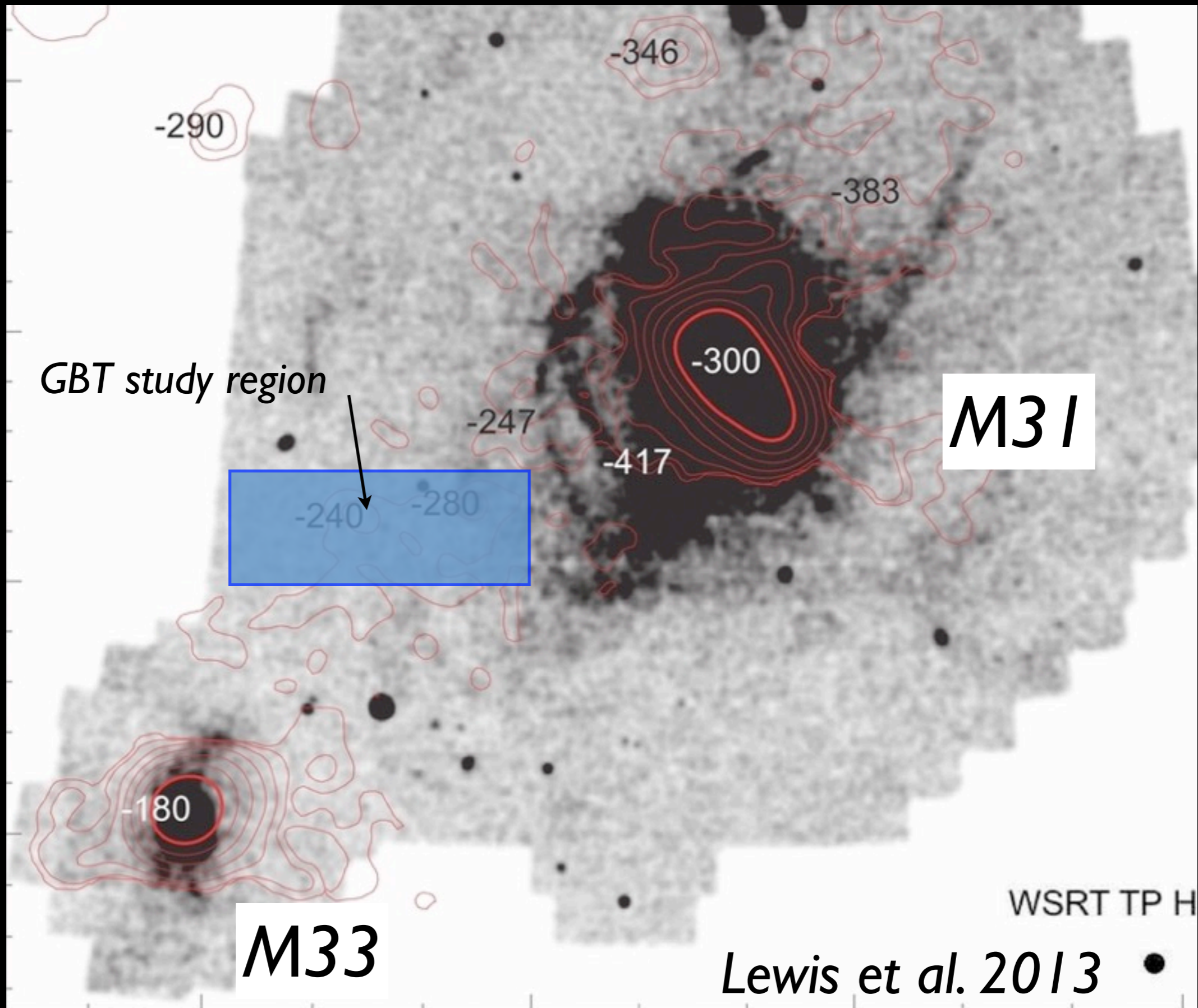
Neutral Gas in the Local Group

3σ

THINGS= 5×10^{19}

HALOGAS= 1×10^{19}



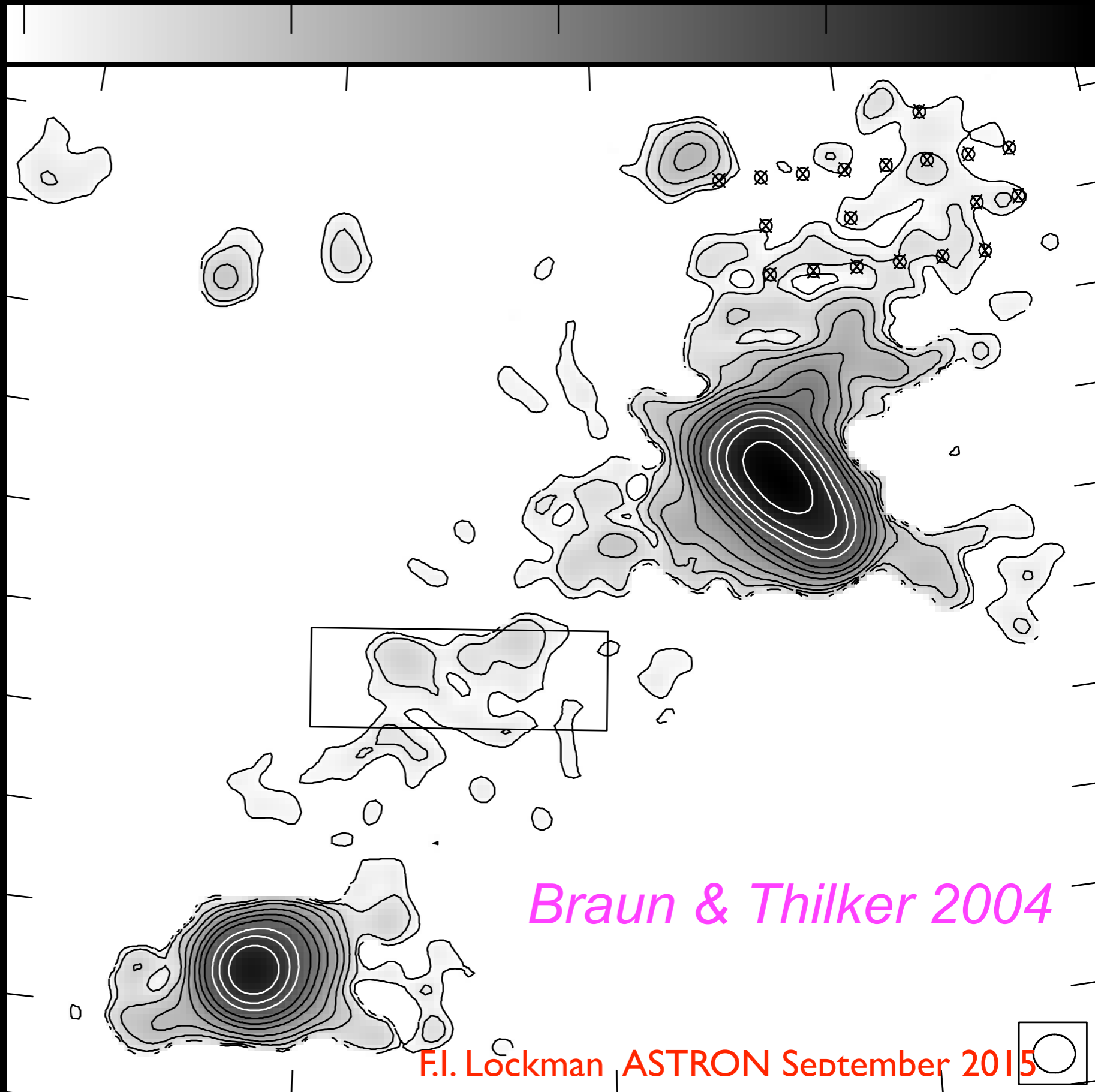


GBT Study of M31 HI



3σ

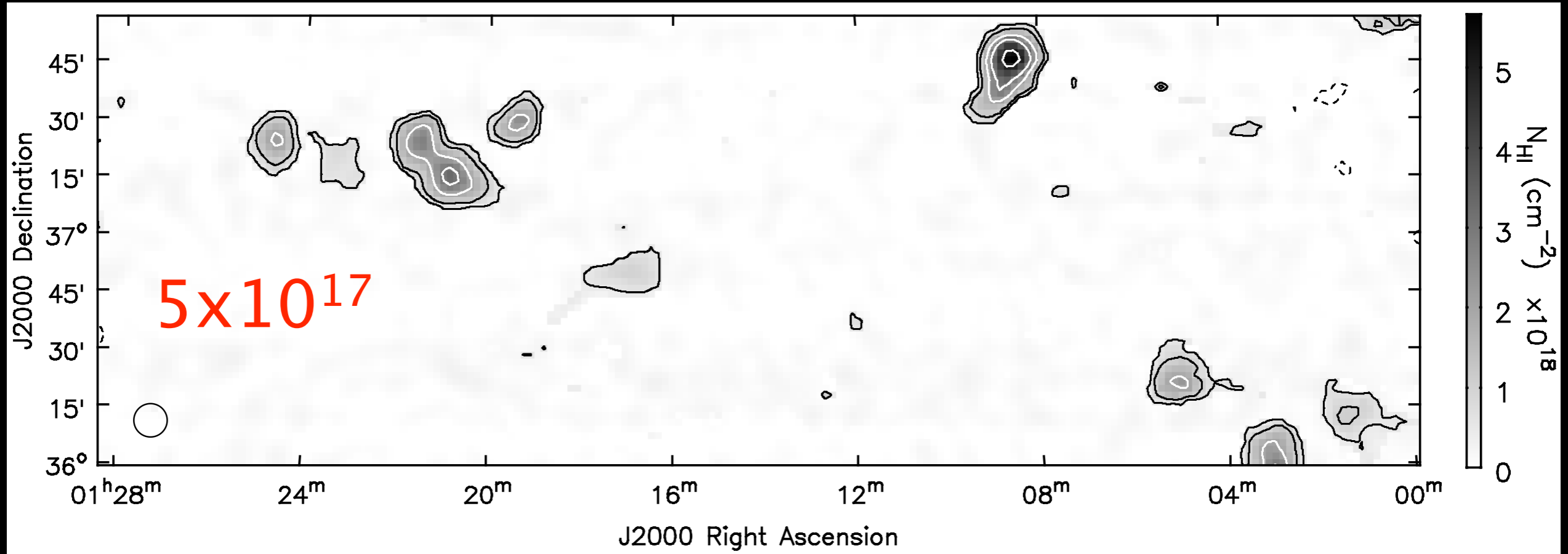
THINGS: 5×10^{19}
HALOGAS: 1×10^{19}
GBT: 2.3×10^{17}



Braun & Thilker 2004

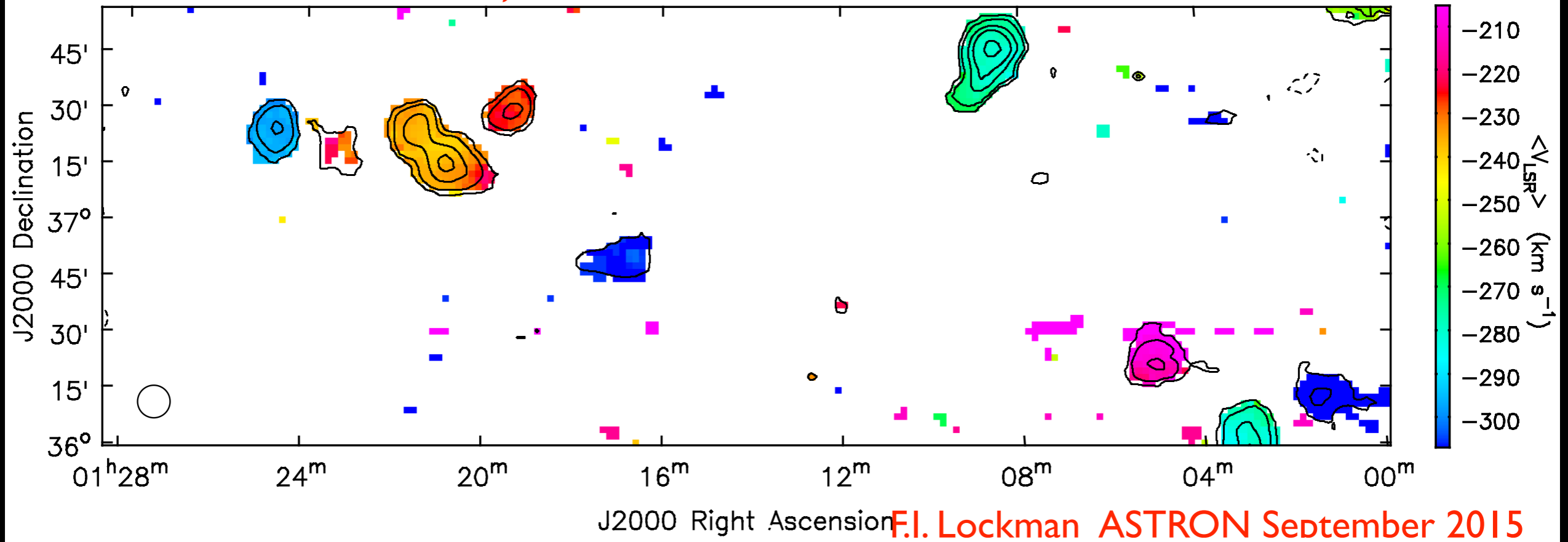
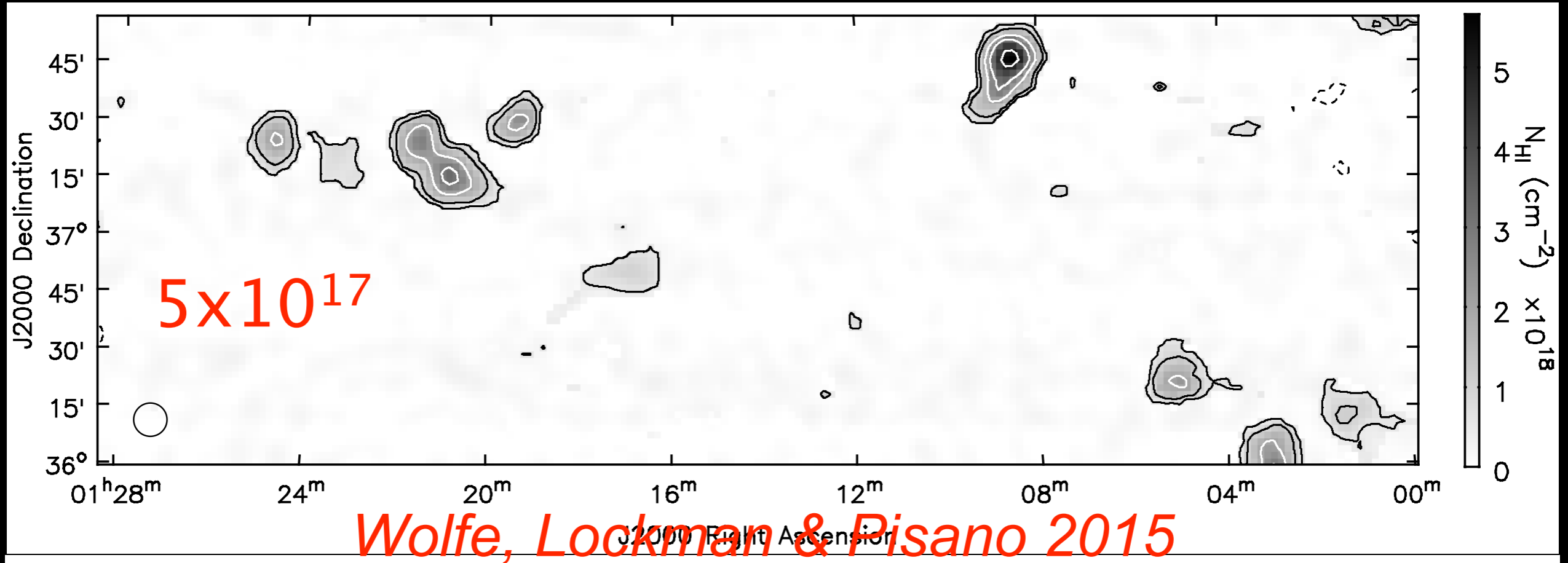


M31-M33 Clouds

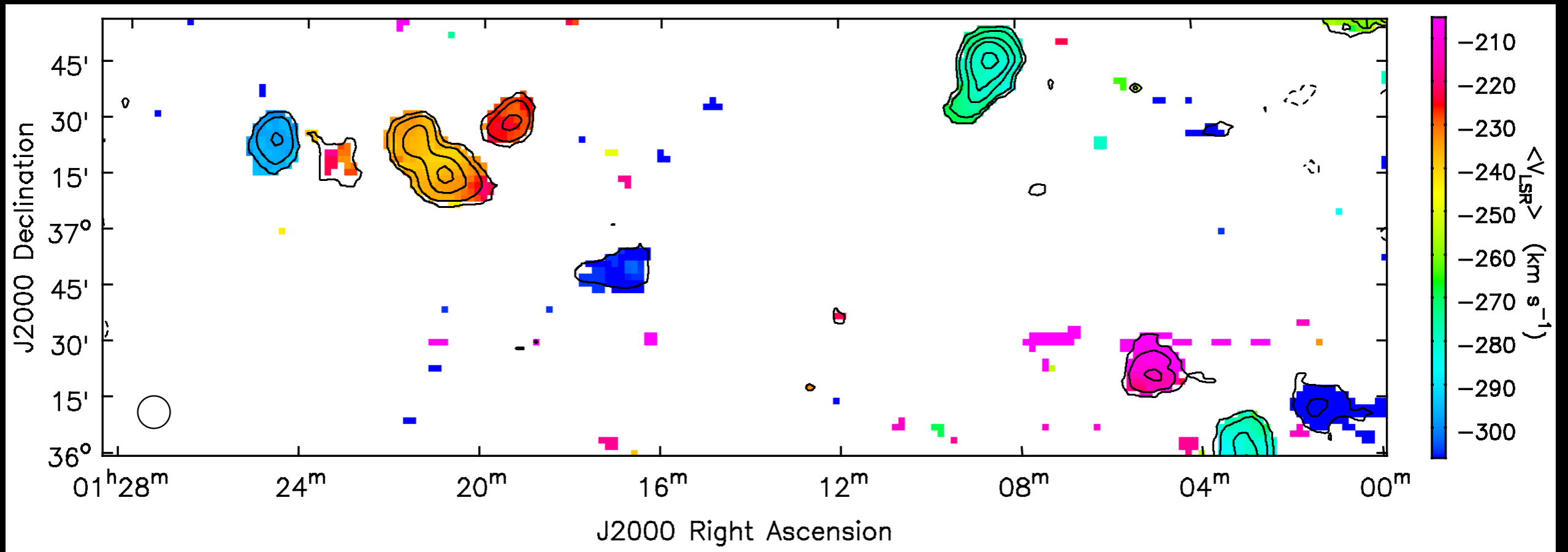


Wolfe, Lockman & Pisano 2015

M31-M33 Clouds



M31-M33 Clouds



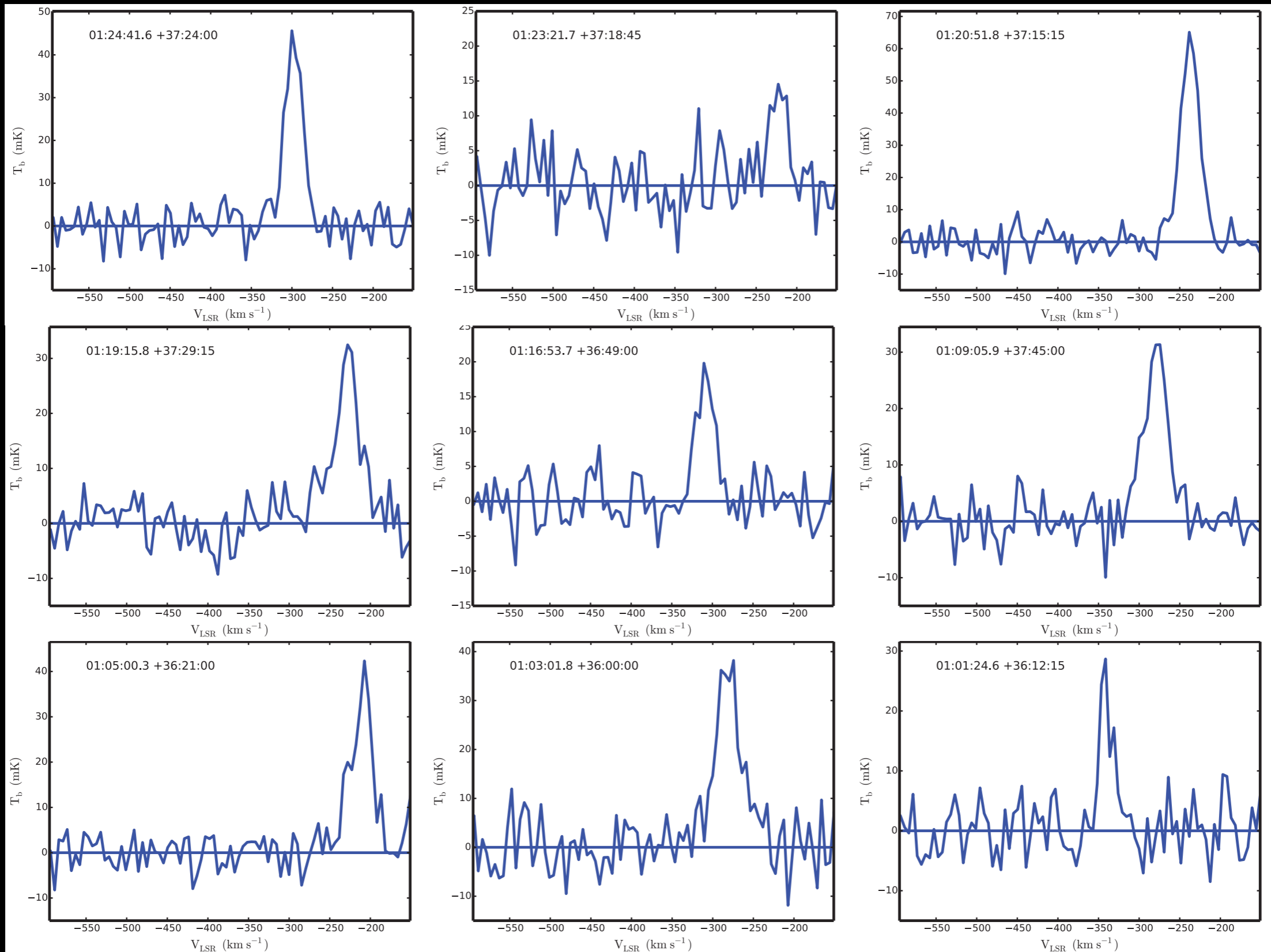
Peak NHI $2 \times 10^{18} \text{ cm}^{-2}$

FWHM 19 - 39 km/s

MHI $4.5 - 39 \times 10^4$

$r_{1/2}$ 0.4 - 1.1 kpc

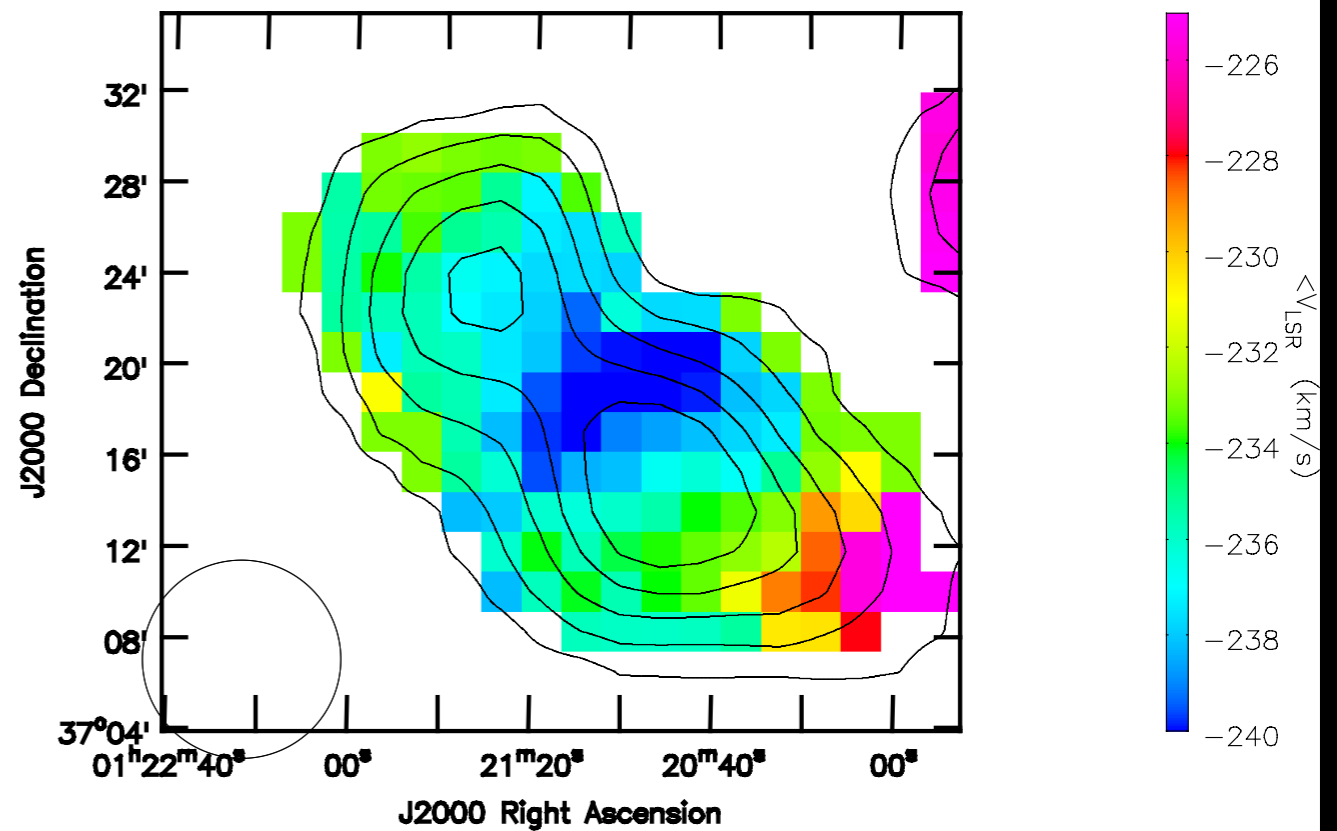
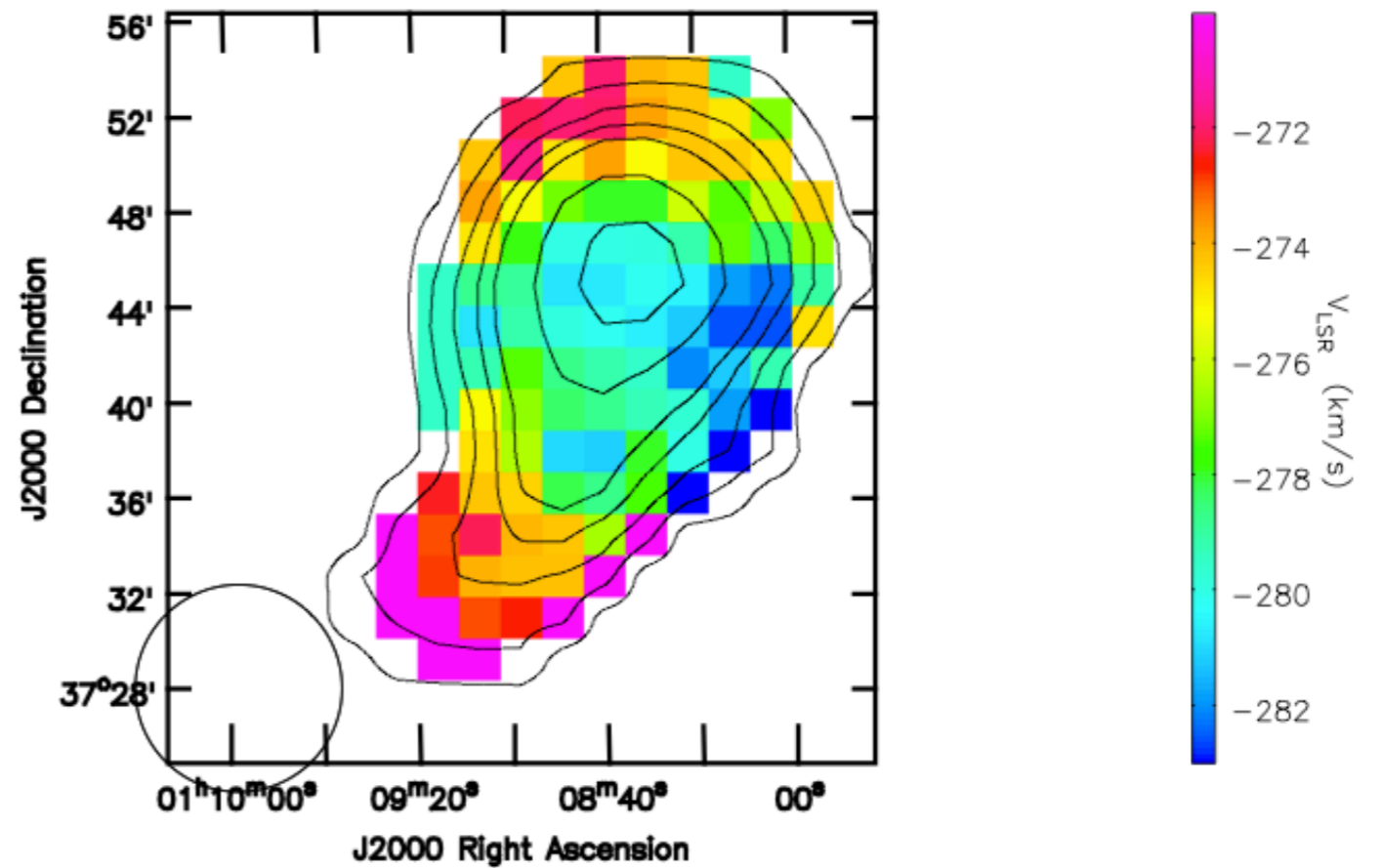
GBT Study of M3 I HI



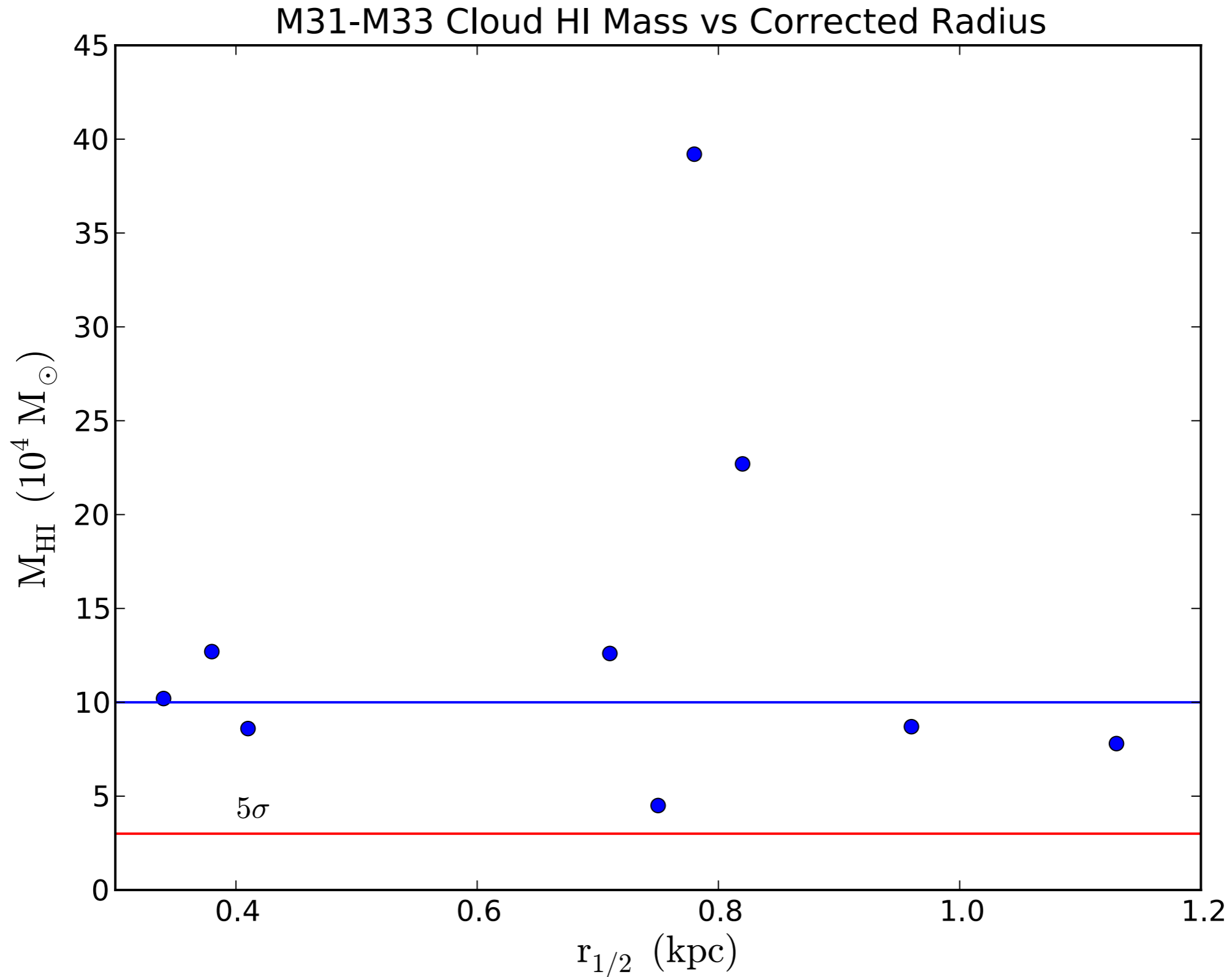
M31-M33 Clouds

$$\text{MHI} = 3.9 \times 10^5 M_{\odot}$$

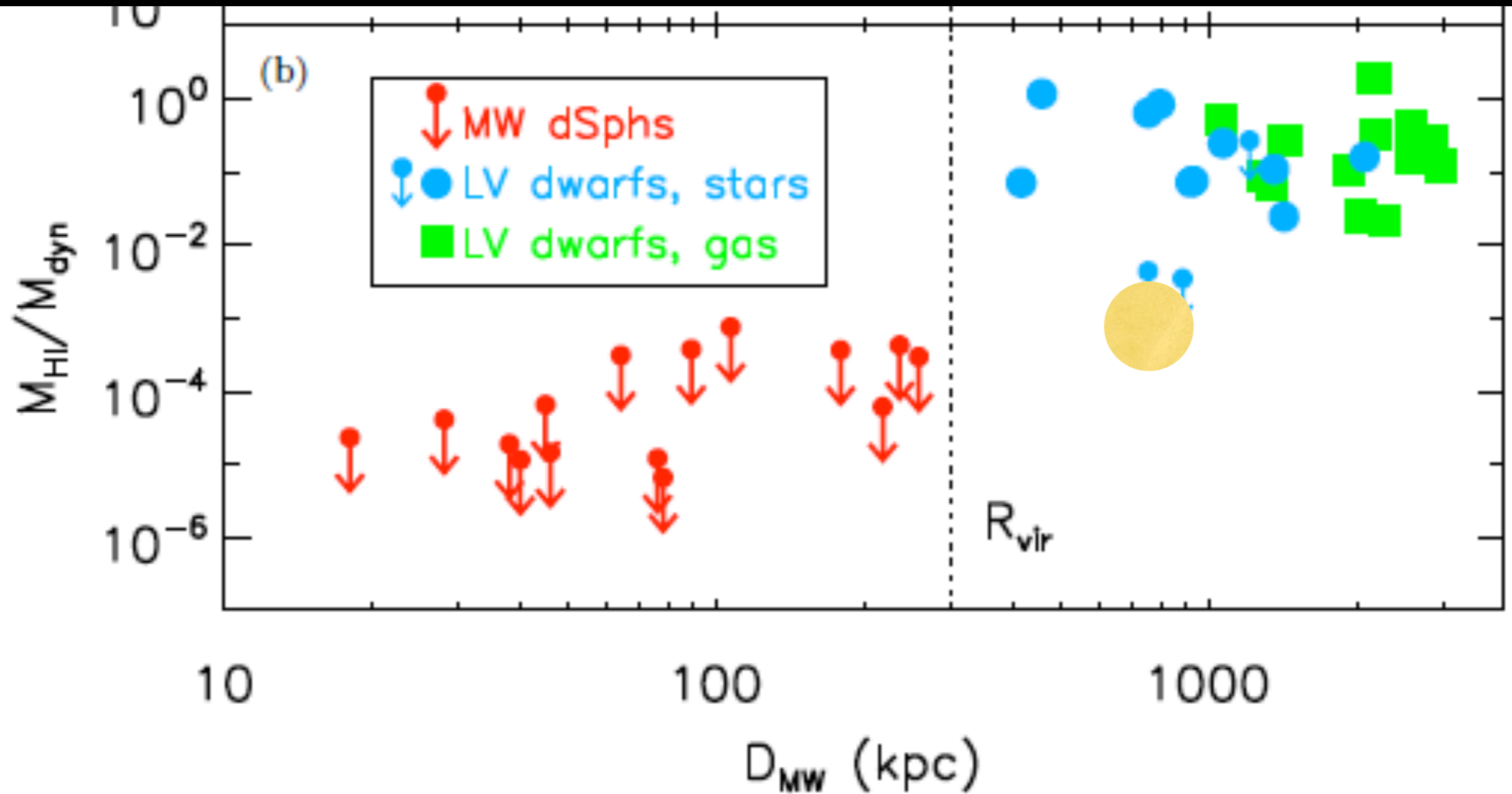
$$\text{MHI} = 3.3 \times 10^5 M_{\odot}$$



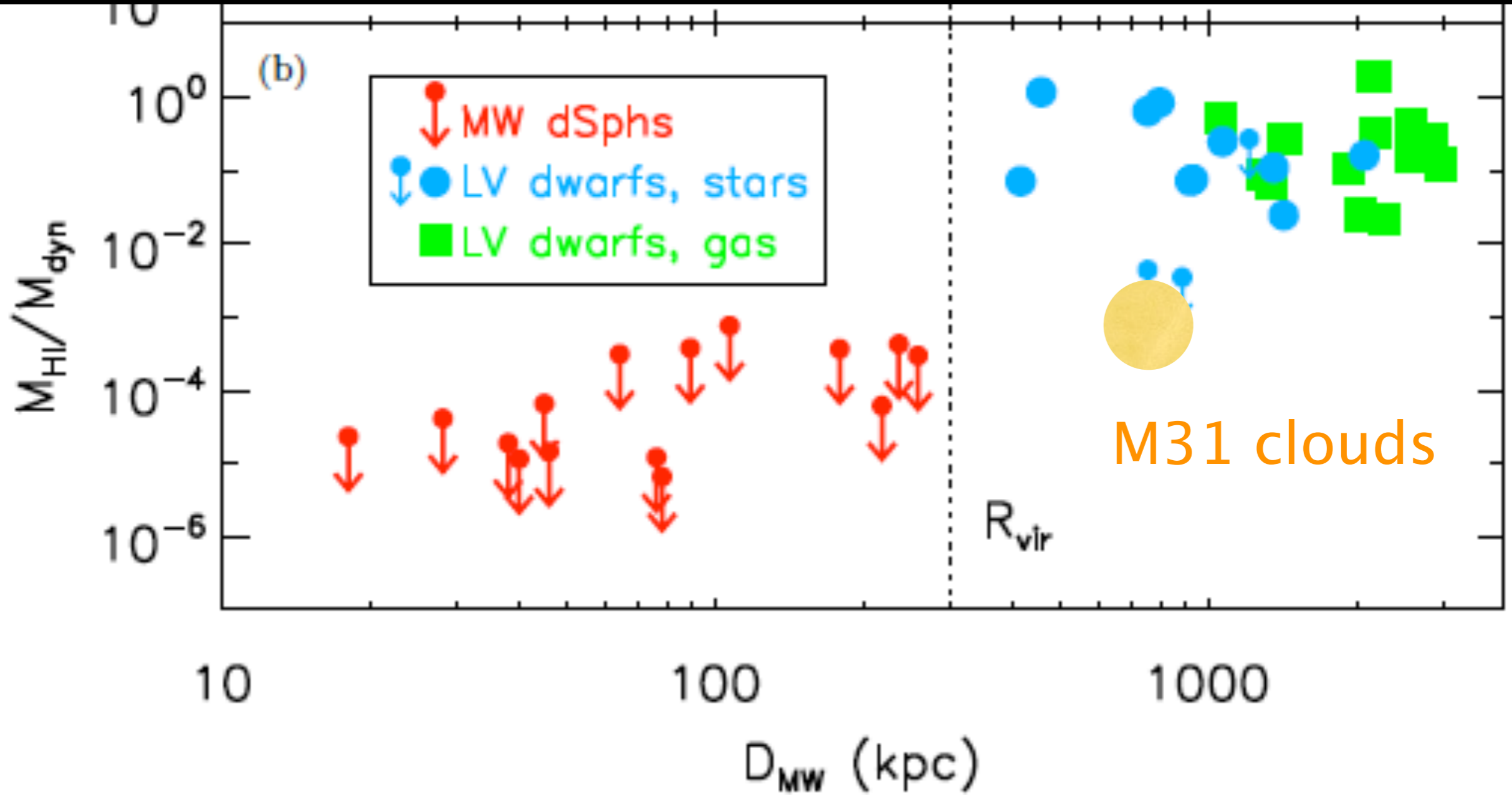
$$M_{\text{HI}_{\text{tot}}} = 1.4 \times 10^6 M_{\odot}$$



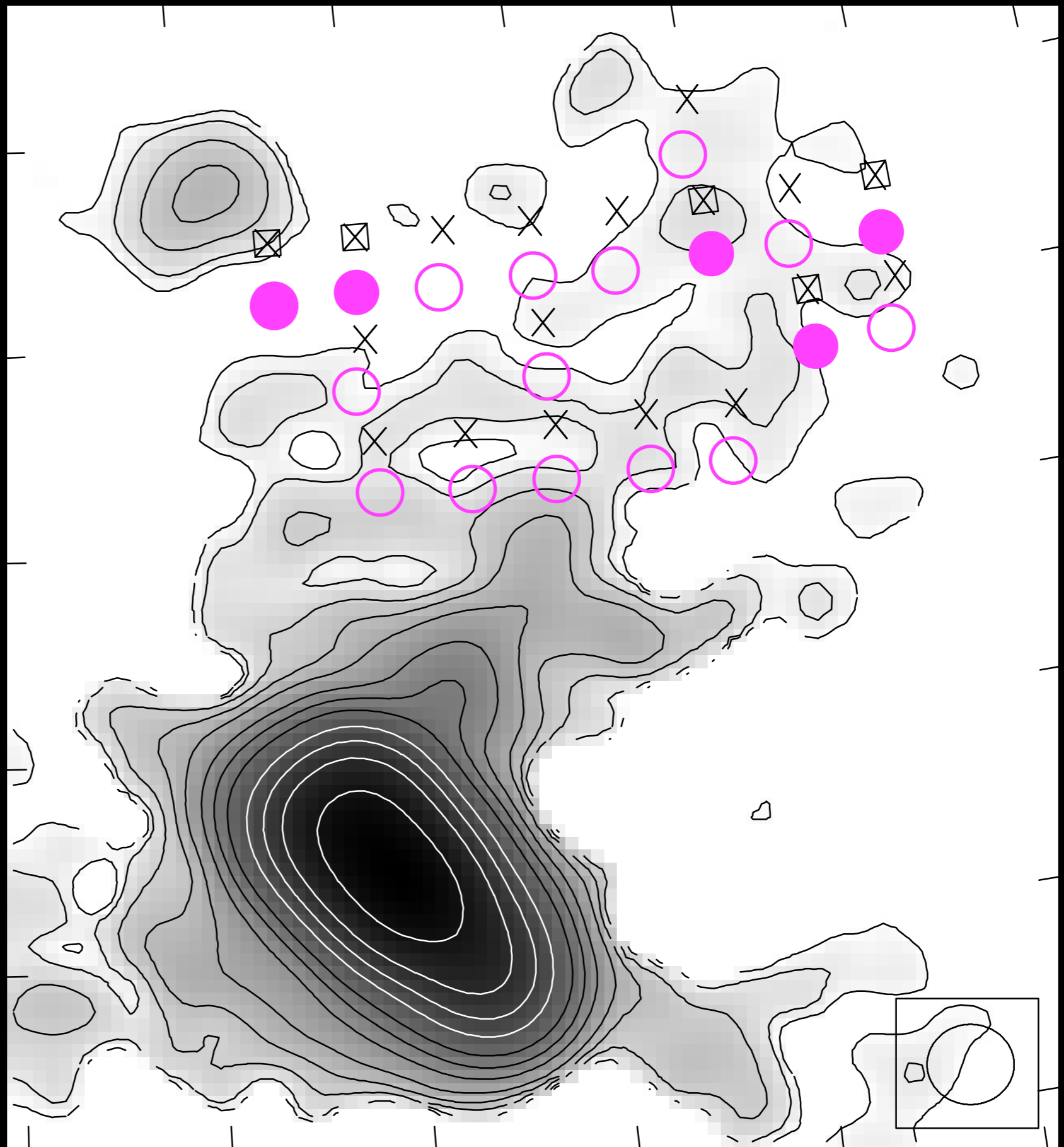
Spekkens et al. 2014



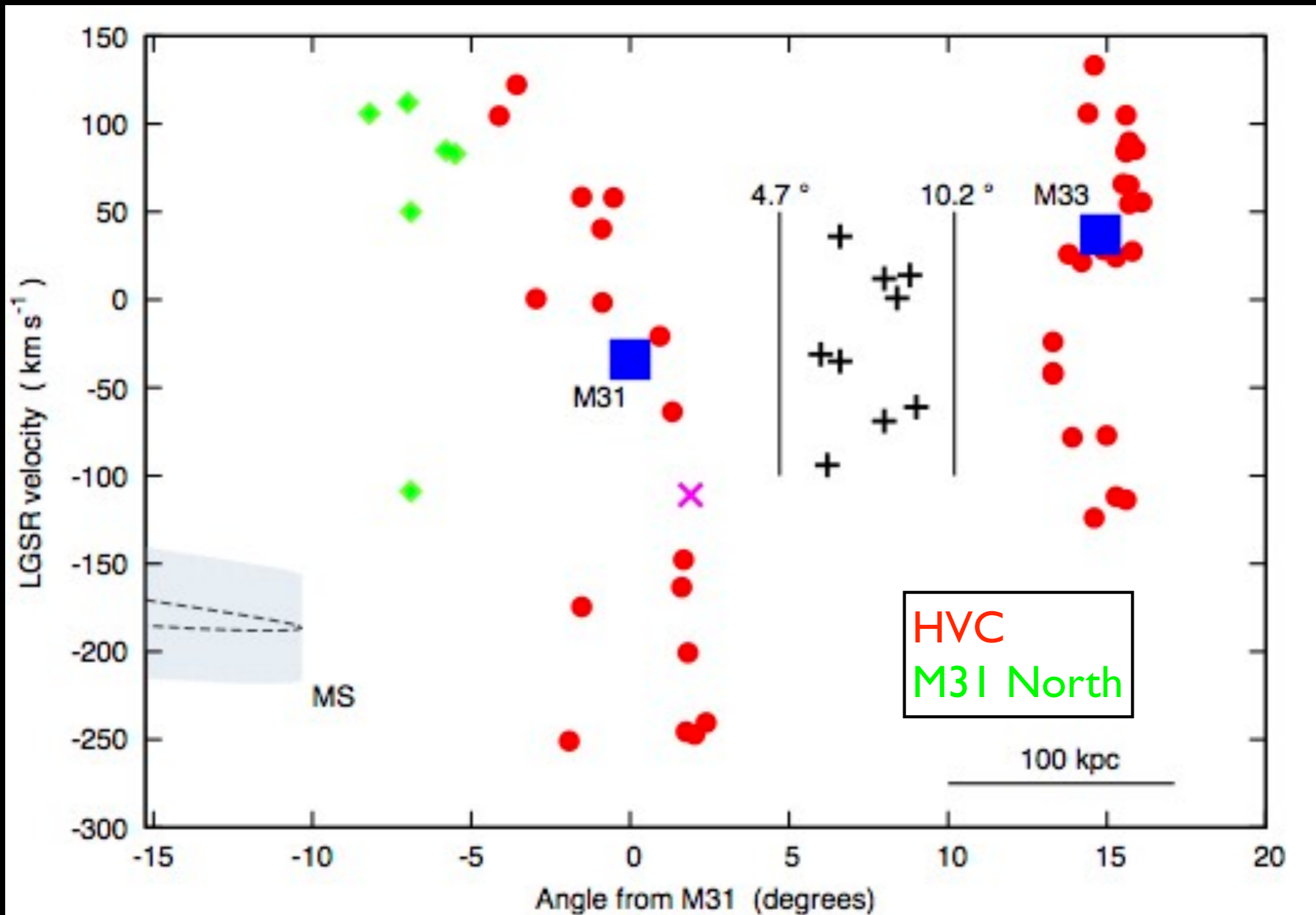
Spekkens et al. 2014



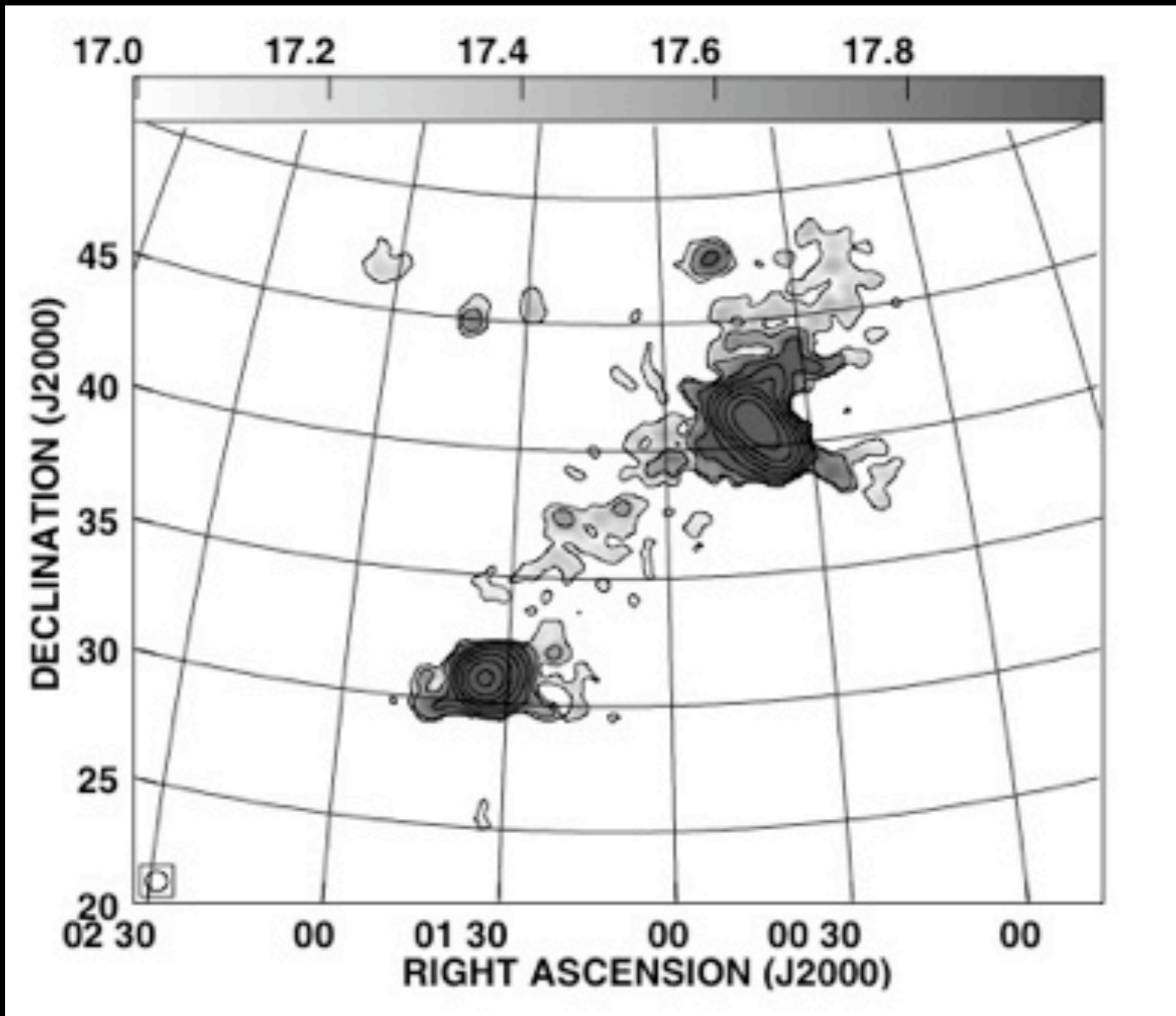
M31 North



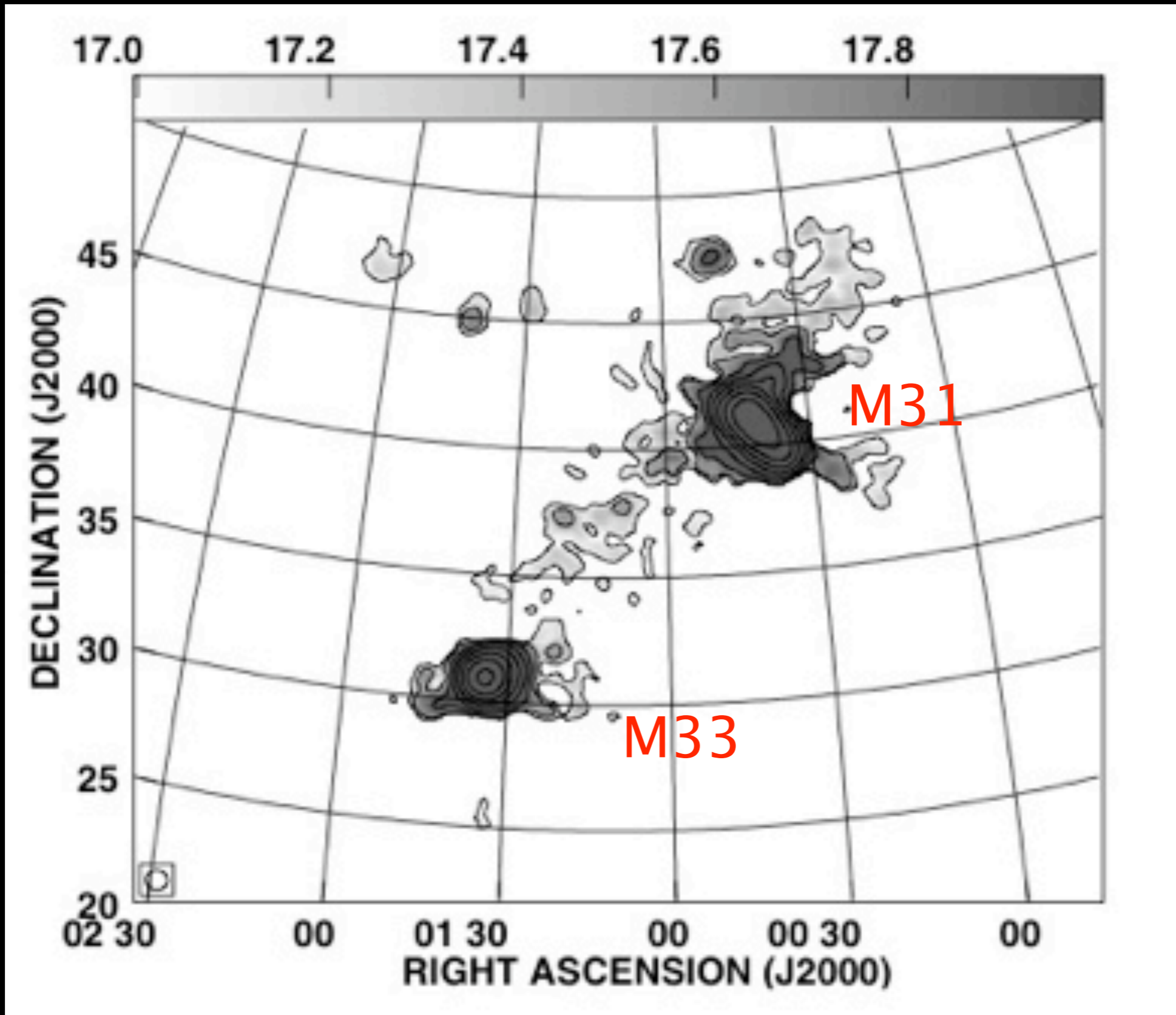
M31-M33 Cloud Kinematics



M31-M33 Interaction?

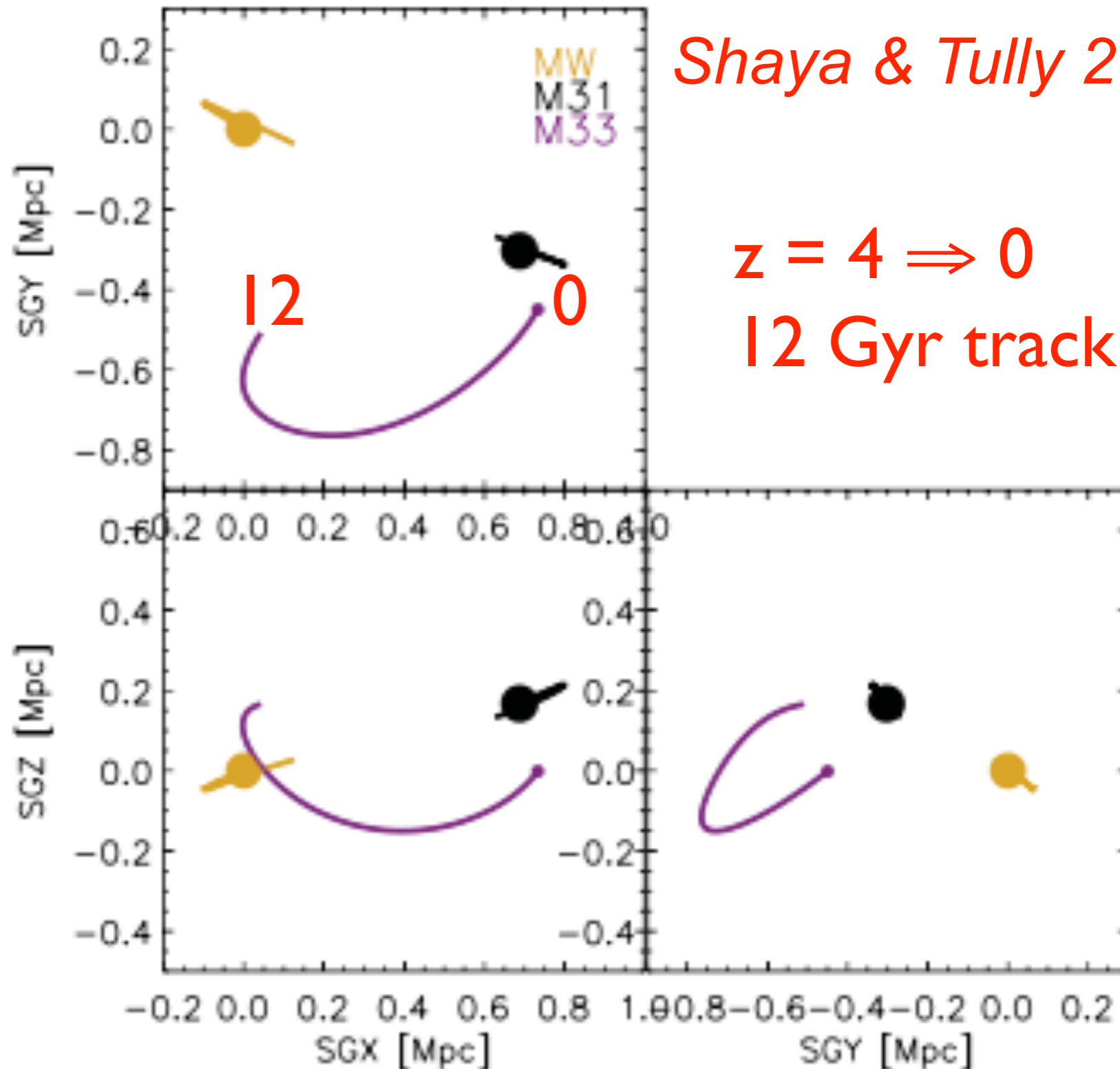


M31-M33 Interaction?



M31-M33 Interaction?

Bekki 2008
Putman et al. 2009
Lewis et al. 2013
Shaya & Tully 2013



Shaya & Tully 2013

$z = 4 \Rightarrow 0$
12 Gyr track

M31-M33 Interaction?

Shaya & Tully 2013

Bekki 2008

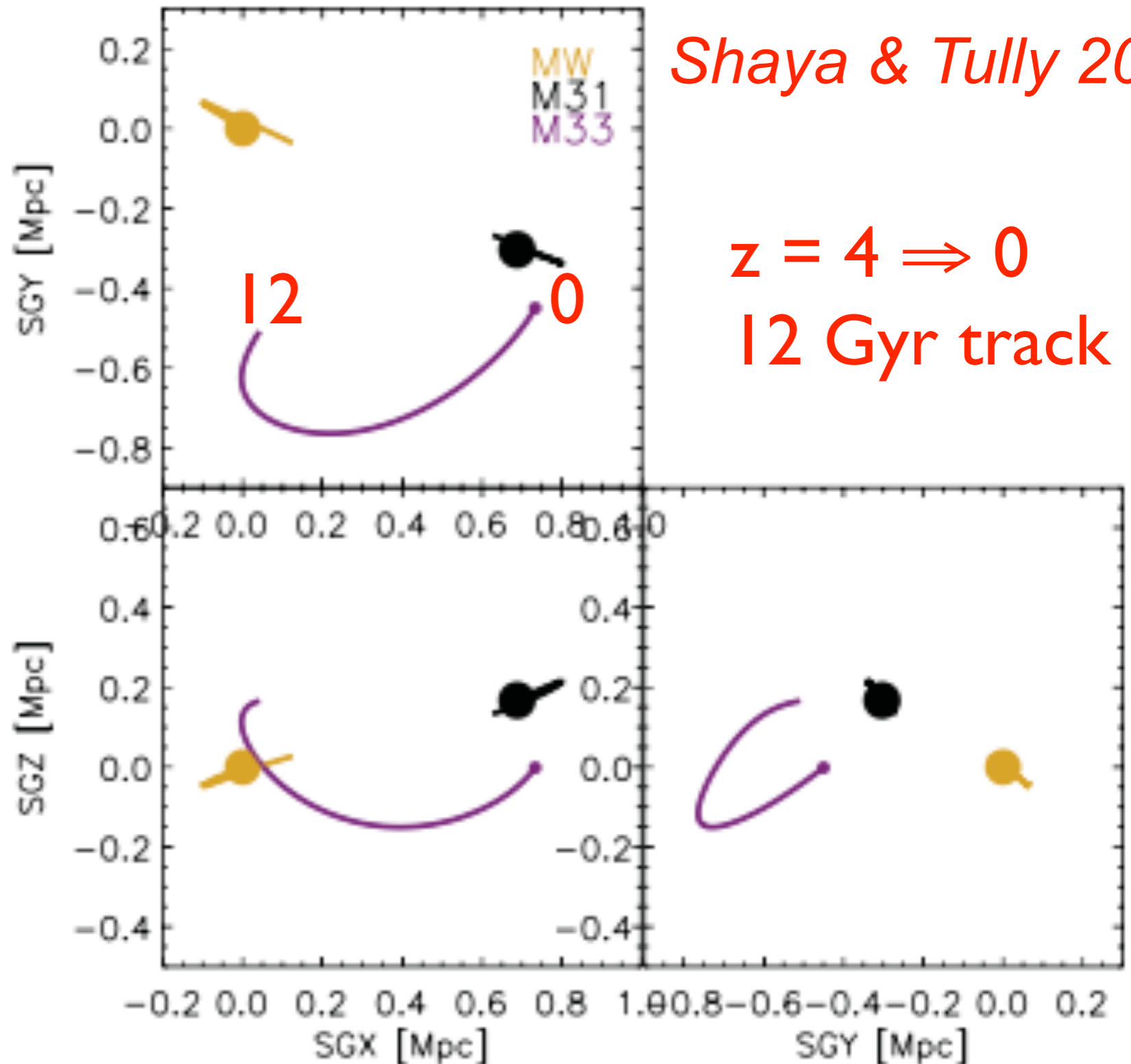
Putman et al. 2009

Lewis et al. 2013

Shaya & Tully 2013

$z = 4 \Rightarrow 0$

12 Gyr track



THERE
WAS NO
ENCOUNTER

Table 4. Comparison of an M31-M33 Cloud with Dwarf Galaxies

Object	$r_{1/2}$ (kpc)	FWHM (km s^{-1})	M_{HI} (M_{\odot})	M_{*} (M_{\odot})	M_V	M_{dyn} (M_{\odot})	References
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cloud 6	0.78	34	3.9×10^5	—	—	2.2×10^8	1
Leo P	0.25	24	9.5×10^5	5.7×10^5	-9.4	3.6×10^7	2,3,4
Leo T	0.17	16	2.8×10^5	1.4×10^5	-8.0	1.1×10^7	5,6,7,8
And XII	0.30	6	—	3.1×10^4	-6.4	2.8×10^6	9,10

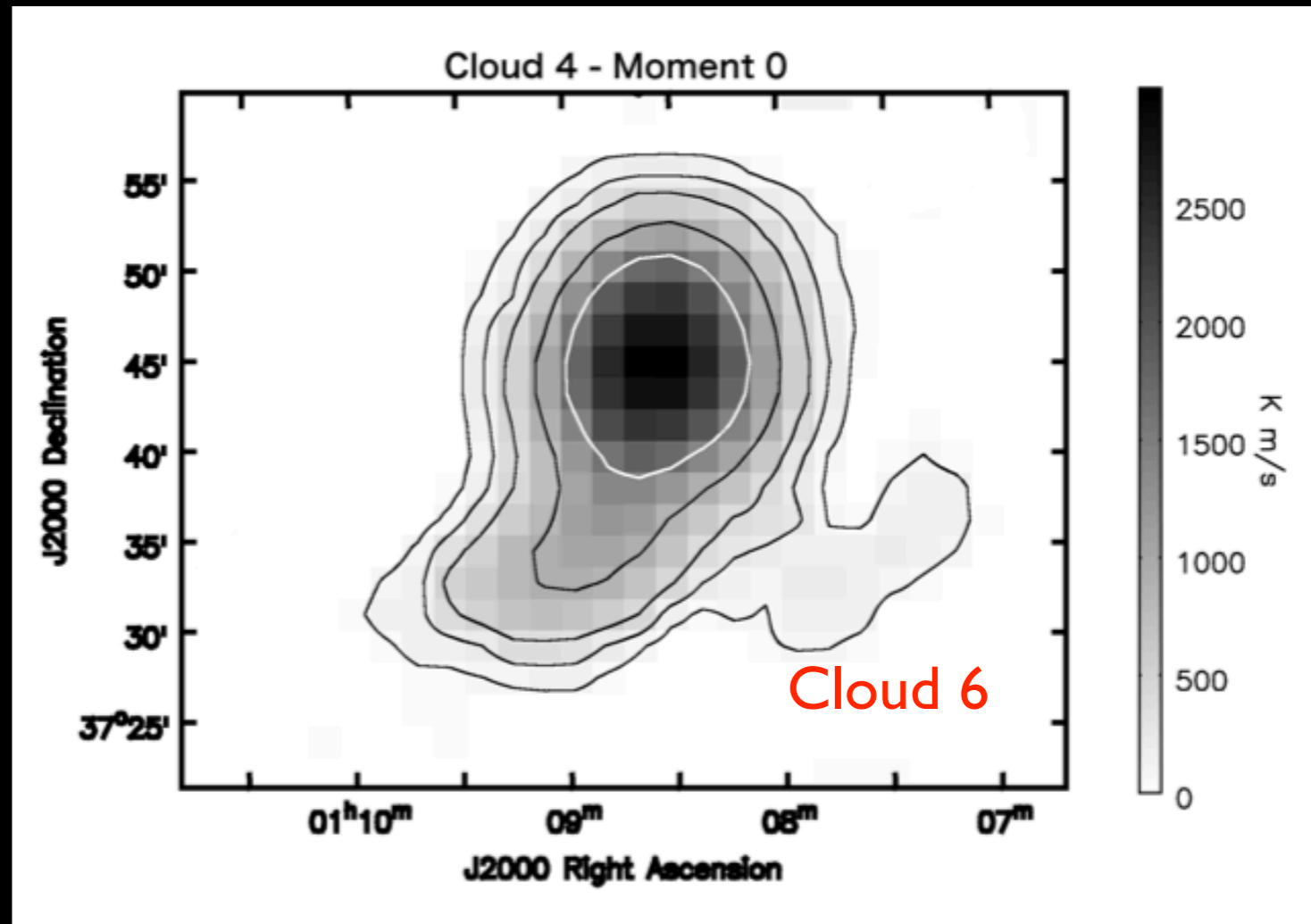
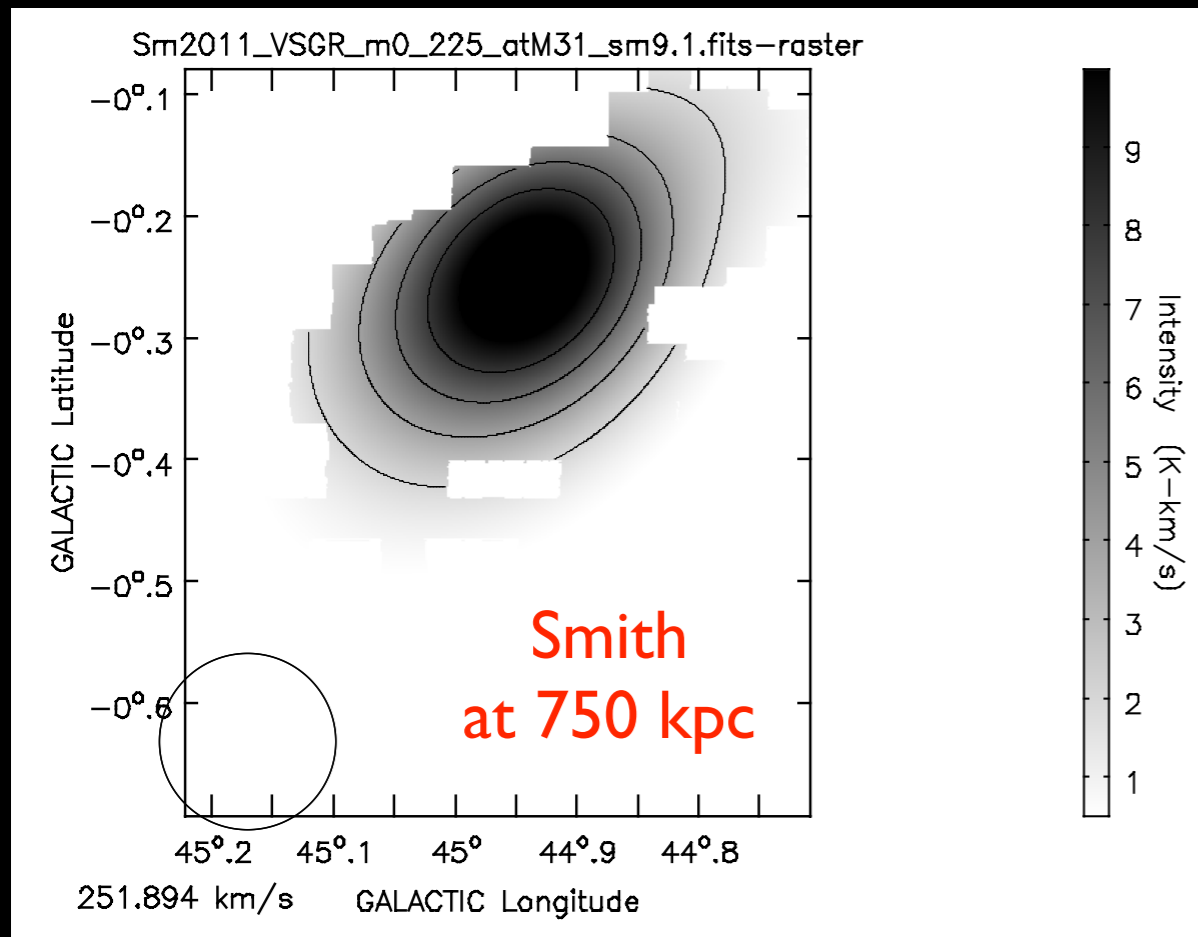
References. — (1) This Work; (2) Bernstein-Cooper et al. (2014); (3) Adams et al. (2013); (4) McQuinn et al. (2013); (5) Ryan-Weber et al. (2008); (6) Simon & Geha (2007); (7) Faerman et al. (2013); (8) de Jong et al. (2008); (9) Collins et al. (2010); (10) McConnachie (2012)

Table 5. Comparison M31-M33 Clouds with HVCs

Object	$r_{1/2}$ (kpc)	FWHM (km s ⁻¹)	M_{HI} (M_{\odot})	M_{dyn} (M_{\odot})	References
(1)	(2)	(3)	(4)	(5)	(6)
M31-M33 Clouds	0.75	27	1.2×10^5	1.4×10^8	1
M31 HVC	0.52	26	4.7×10^5	8.8×10^7	2, 3
UCHVC	1.16	23	1.2×10^5	1.5×10^8	4

Westmeier et al. 2005,2008; Adams et al. 2013

The Smith Cloud at 750 kpc and M31-M33 Cloud 6

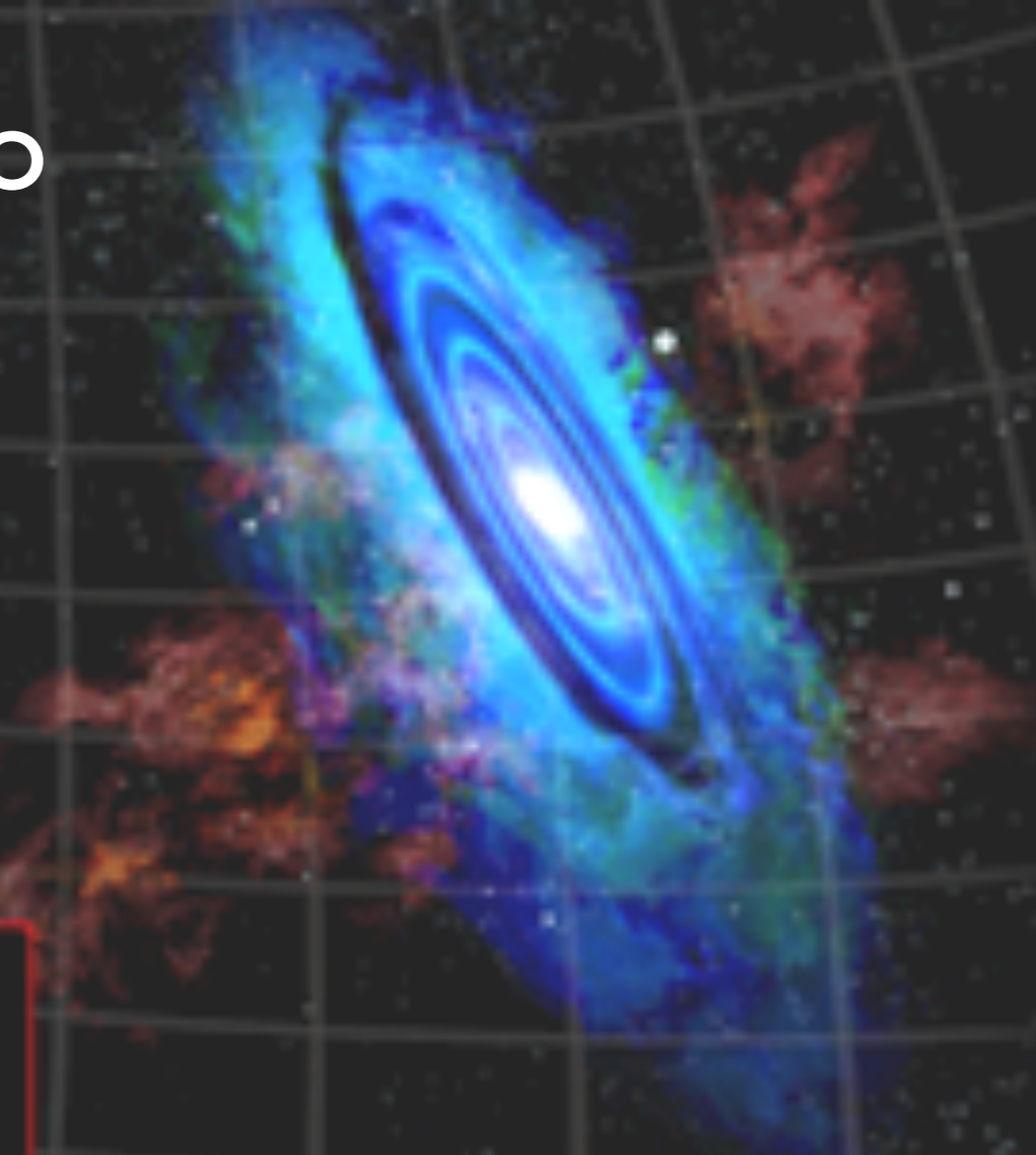


Cloud 6: $M_{\text{HI}} = 4e5$ $N_{\text{HI}} \text{ peak} \approx 5e18$
 Smith*: $M_{\text{HI}} = 2e6$ $N_{\text{HI}} \text{ peak} \approx 2e19$

M31 Massive Gaseous Halo

$>3 \times 10^9 M_{\odot}$ at $R < 60$ kpc
Lehner, Howk, Wakker (2015)

$6 \times 10^{17} \text{ cm}^{-2}$



Loose gas in the Local Group

High Velocity Clouds
Remnants of Interaction
Inter-Group Gas?

