The M31–M33 "Bridge"

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But first, an example of accretion of gas by the Milky Way,
then considerations of the detectability of faint HI lines

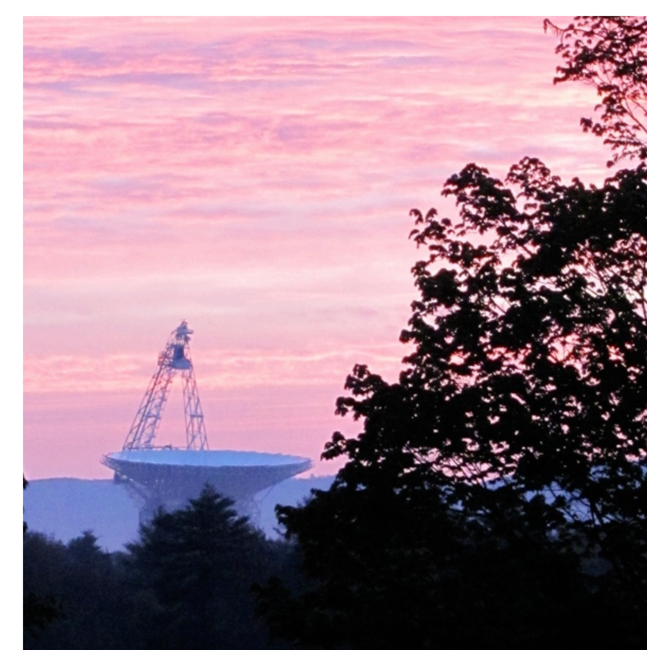
The “Smith” High-velocity Cloud

An HVC being absorbed by the Milky Way

dist = 12.4 ± 1.3 kpc
R = 7.6 ± 1.0 kpc
z = -2.2 kpc
$M_{HI} > 10^6\ M_\odot$
$M_{H+} \approx 3\times10^6\ M_\odot$
size ≈ 3 x 1 kpc
[N\H] = 0.14 - 0.44

$V_{tot} \approx 300$ km/s
Will impact the disk
in 30 Myr

Lockman et al. 2008
Hill et al 2009



Practical issues when observing the 21cm line in emission

time for a 3σ detection

$$t = 1.6 \times 10^{-2}\ f^{-2}\ \Omega^{-2}\ \mathrm{N}_{\mathrm{HI20}}^{-2}\quad \mathrm{(s)}$$

$f \leq 1$ is surface brightness efficiency
$\Omega \leq 1$ is beam dilution

Assumptions:

$\tau \ll 1$

Tsys = 20 K

5 km/s channel width

3σ detection

ΔV=25 km/s

no bandpass noise or other issues

Surface brightness efficiency factors

Instrument	f
GBT	~1
Arecibo	~1
EVLA-D	$\sim 10^{-2}$
EVLA-C	$\sim 10^{-3}$
EVLA-B	$\sim 10^{-4}$
ATA	$\sim 10^{-2}$
ASKAP	$\sim 10^{-3}$

$$t = 1.6 \times 10^{-2}\ f^{-2}\ \Omega^{-2}\ \mathrm{N}_{\mathrm{HI20}}^{-2}\ \ (\mathrm{s})$$

Deep 21cm Surveys *(therefore are all done with single dishes)*

from Popping (2010)

$4\sigma < 10^{18}$

Survey	Beam [']	Area [deg^2]	δv [km s^{-1}]	rms(Flux)^a	rms(N_{HI})^b	Ref
AHISS	3.3	13	16	0.7	3.5e17	*c*
ADBS	3.3	430	34	3.3	1.7e18	*d*
WSRT WVF	49	1800	17	18	4.1e16	*e*
Nancay CVn	4 × 20	800	10	7.5	5.2e17	*f*
HIPASS	15.5	30000	18	13	3.0e17	*g*
HI-ZOA	15.5	1840	18	13	3.0e17	*h*
HIDEEP	15.5	32	18	3.2	7.4e16	*i*
HIJASS	12	1115	18	13	5.0e17	*j*
J-Virgo	12	32	18	4	1.5e17	*k*
AGES	3.5	200	11	0.7	3.2e17	*l*
ALFALFA	3.5	7074	11	1.7	7.7e17	*m*

Table 1.1: Comparison of Blind H I Surveys: *(a)*: mJy beam^{-1} at 18 km s^{-1}, *(b)*: cm^{-2} over 18 km s^{-1}, *(c)*: Zwaan et al. (1997), *(d)*: Rosenberg & Schneider (2000), *(e)*: Braun et al. (2003), *(f)*: Kraan-Korteweg et al. (1999), *(g)*: Barnes et al. (2001), *(h)*: Henning et al. (2000), *(i)*: Minchin et al. (2003), *(j)*: Lang et al. (2003), *(k)*: Davies et al. (2004), *(l)*: Minchin et al. (2007), *(m)*: Giovanelli et al. (2007)

The ragged edges of HI disks

$N_{HI} = 10^{19}$
$T_b = 0.2$ K
$t \approx 2 f^{-2}$ s

HALOGAS WSRT Survey -- Heald et al (2011)
15" resolution to N_{HI} limit few 10^{19}
120 hours per galaxy

G. Heald et al.: The WSRT HALOGAS survey. I.

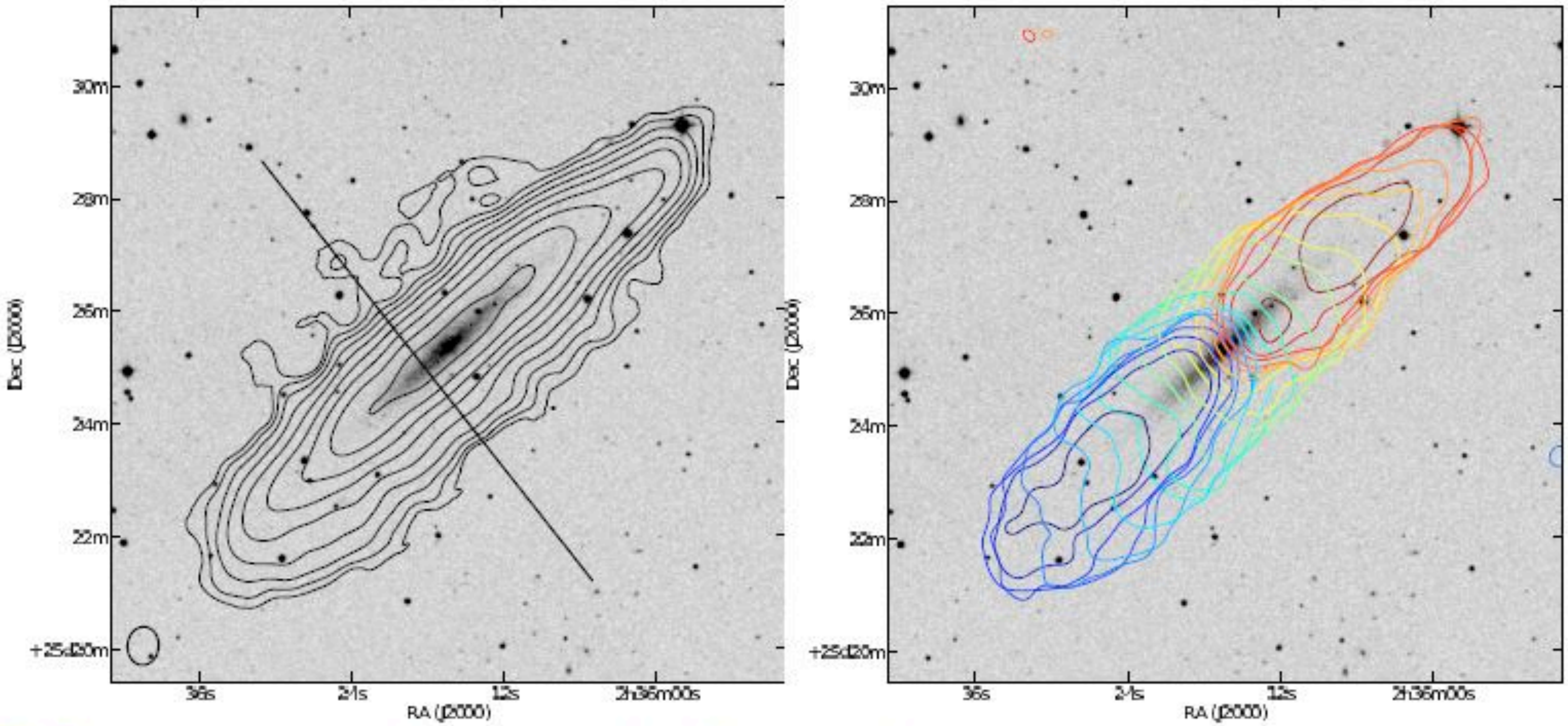


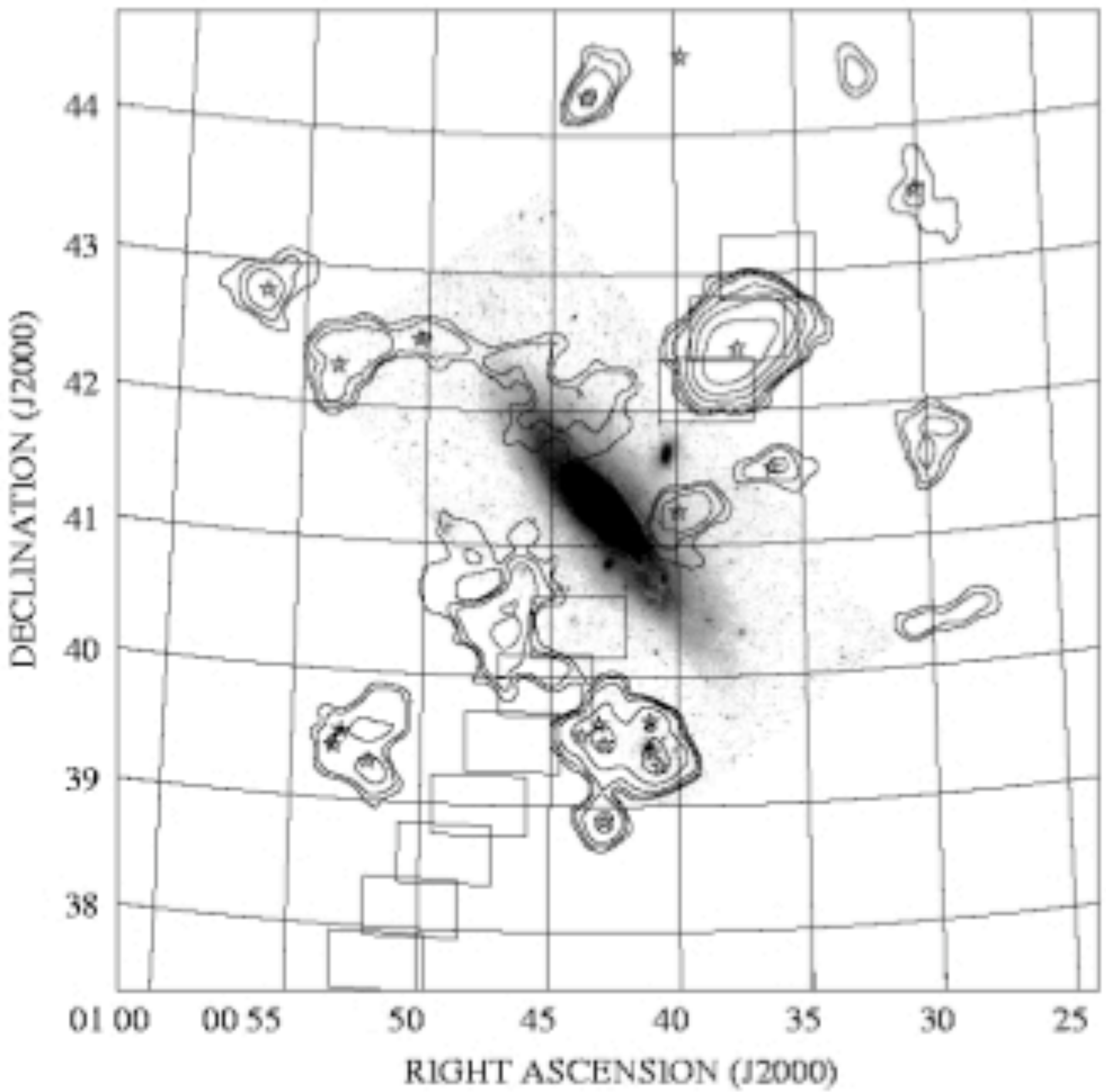
Fig. 1. Overview of the HALOGAS observations of UGC 2082. The *left panel* shows the H I total intensity overlaid on the DSS *R*-band image. The H I contours originate from the 30″-tapered image, begin at $N_{HI} = 1.0 \times 10^{19}$ cm^{-2} and increase by powers of two. The straight line shows the orientation of the PV slice shown in Fig. 2. The *right panel* shows an overlay of several channels in the lowest resolution data cube, all at a level of 0.9 mJy beam^{-1} ($\approx 3.75\sigma$). The contours are separated by 12.4 km s^{-1}, begin at 593 km s^{-1} (dark blue) and range upward to 815 km s^{-1} (dark red). *Both panels* show the same area of the sky. The beam size of the H I data is shown in the *lower left* corners of the *left panel*.

HVCs around other galaxies

$N_{HI} = 10^{18.5}$
$T_b = 0.065$ K
$t \approx 16 f^{-2}$ s

M31 -- GBT
Thilker et al (2004)

0.5,1,2,10,20 x 10^{18}
HI Mass = 10^{6-7} M⊙



M33 -- Arecibo
Grossi et al. (2008)
lowest contour 2x10^{18}

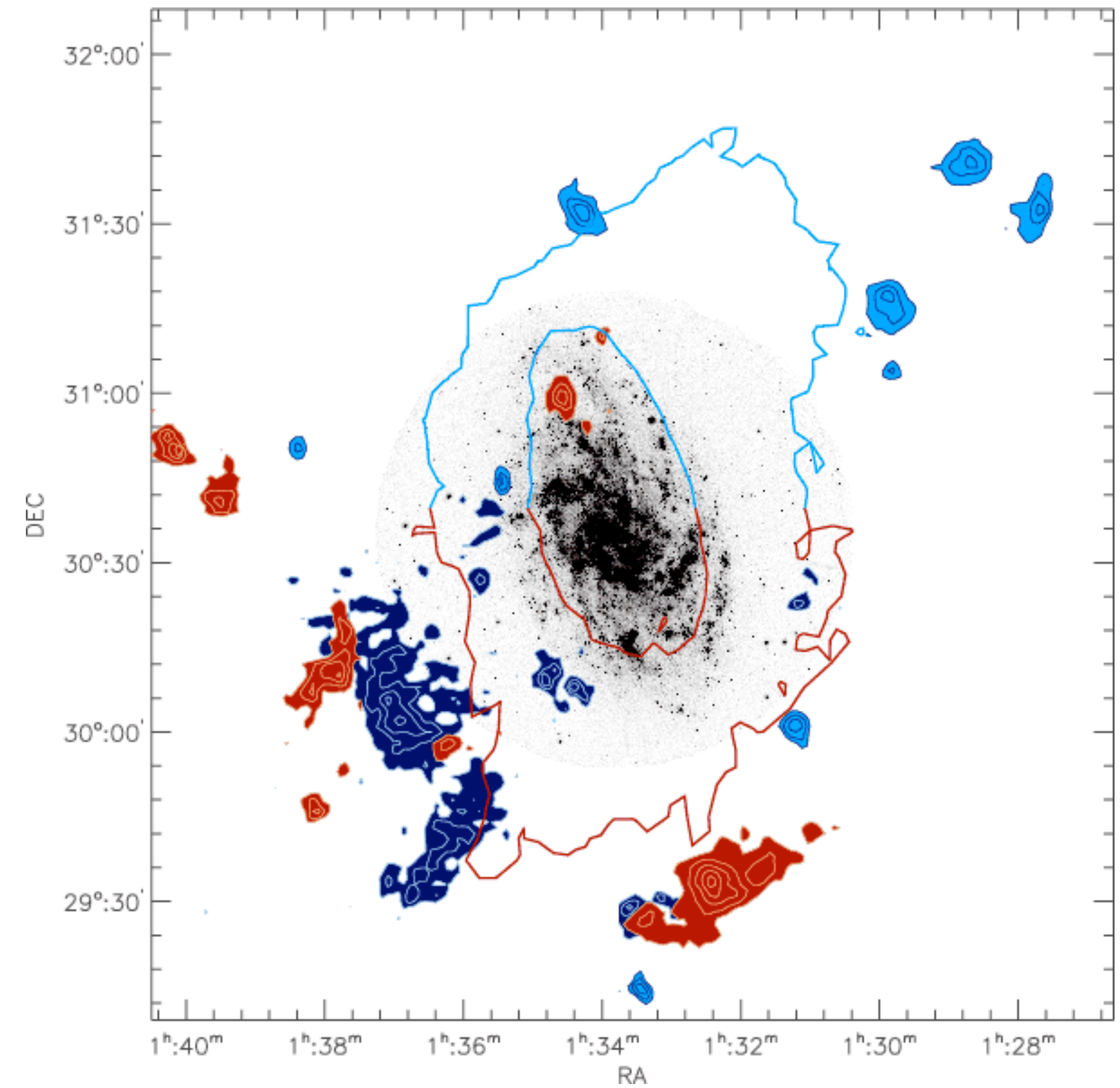


Fig. 2.— Total column density for discrete and diffuse high-velocity H I in the M31 GBT field, after masking emission from Andromeda's inclined, rotating disk. Contours were evaluated at (3 kpc, 72 km s^{-1}) resolution and rendered at 0.5, 1, 2, 10, and 20 × 10^{18} cm^{-2}, then overlaid

The M31-M33 stream

$N_{HI} = 10^{17}$
T_b=2 mK
$t \approx 16\,000 f^{-2}$ s

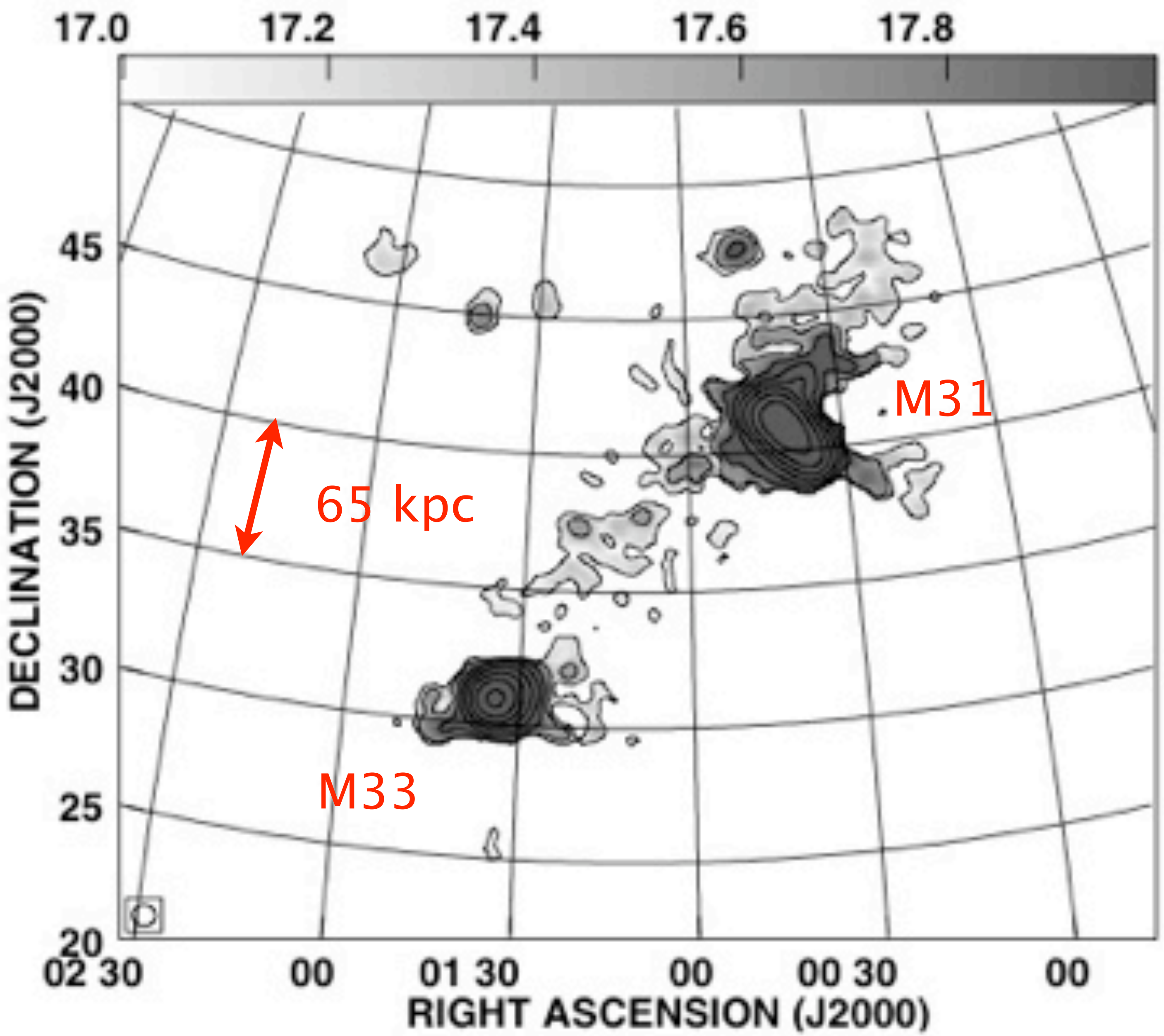


Fig. 9. Integrated H I emission from the subset of detected features apparently associated with M 31 and M 33. The grey-scale varies between $\log(N_{HI})$ = 17–18, for N_{HI} in units of cm^{-2}. Contours are drawn at $\log(N_{HI})$ = 17, 17.5, 18, … 20.5.

Braun & Thilker (2006)
using WSRT as single dishes
49' Resolution
16 km/s channels

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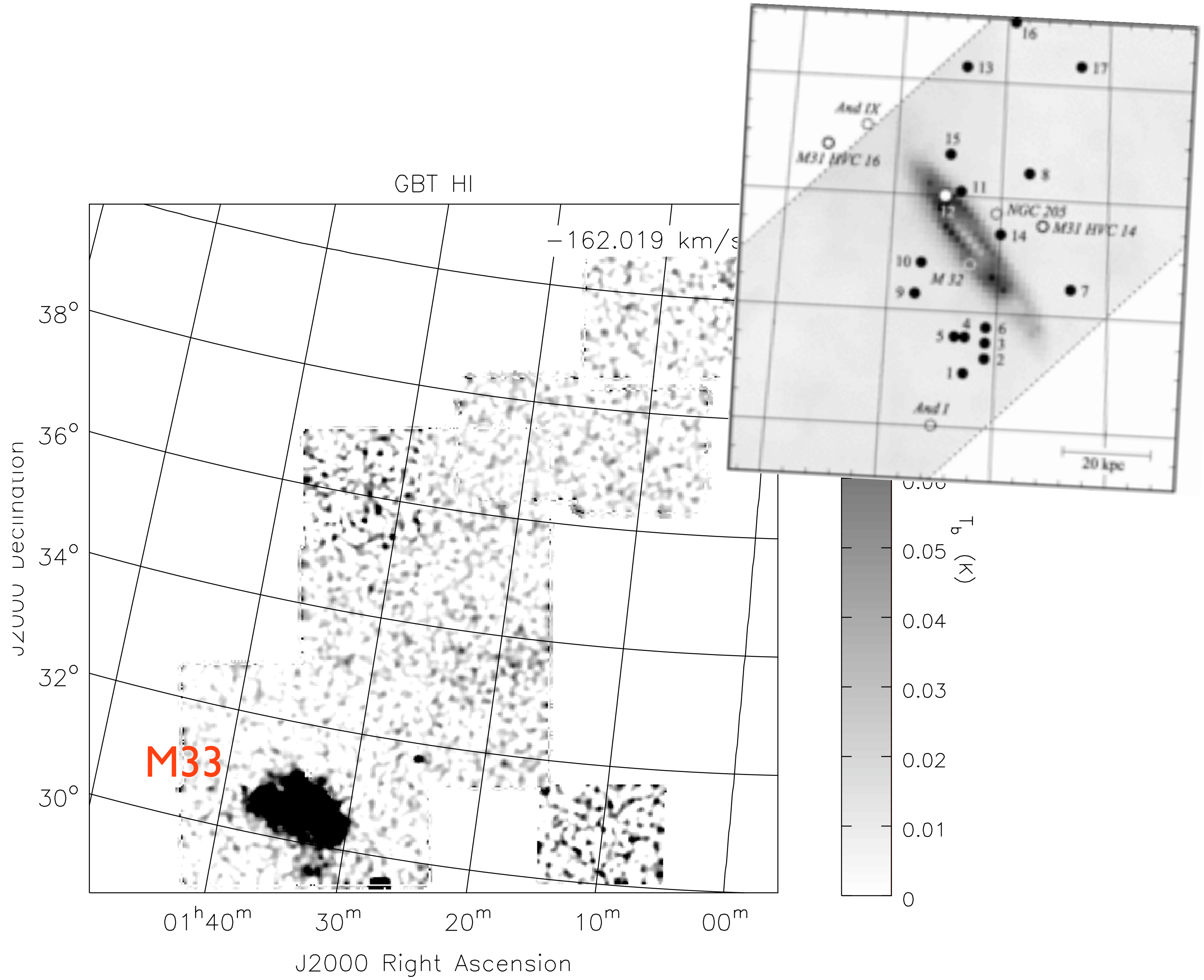
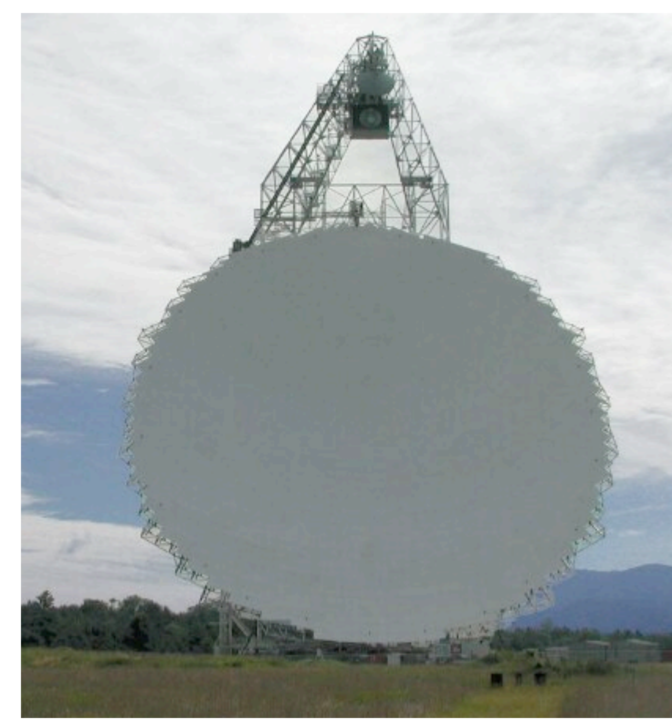
GBT Observations of the M31–M33 stream





GBT Observations of the M31-M33 stream

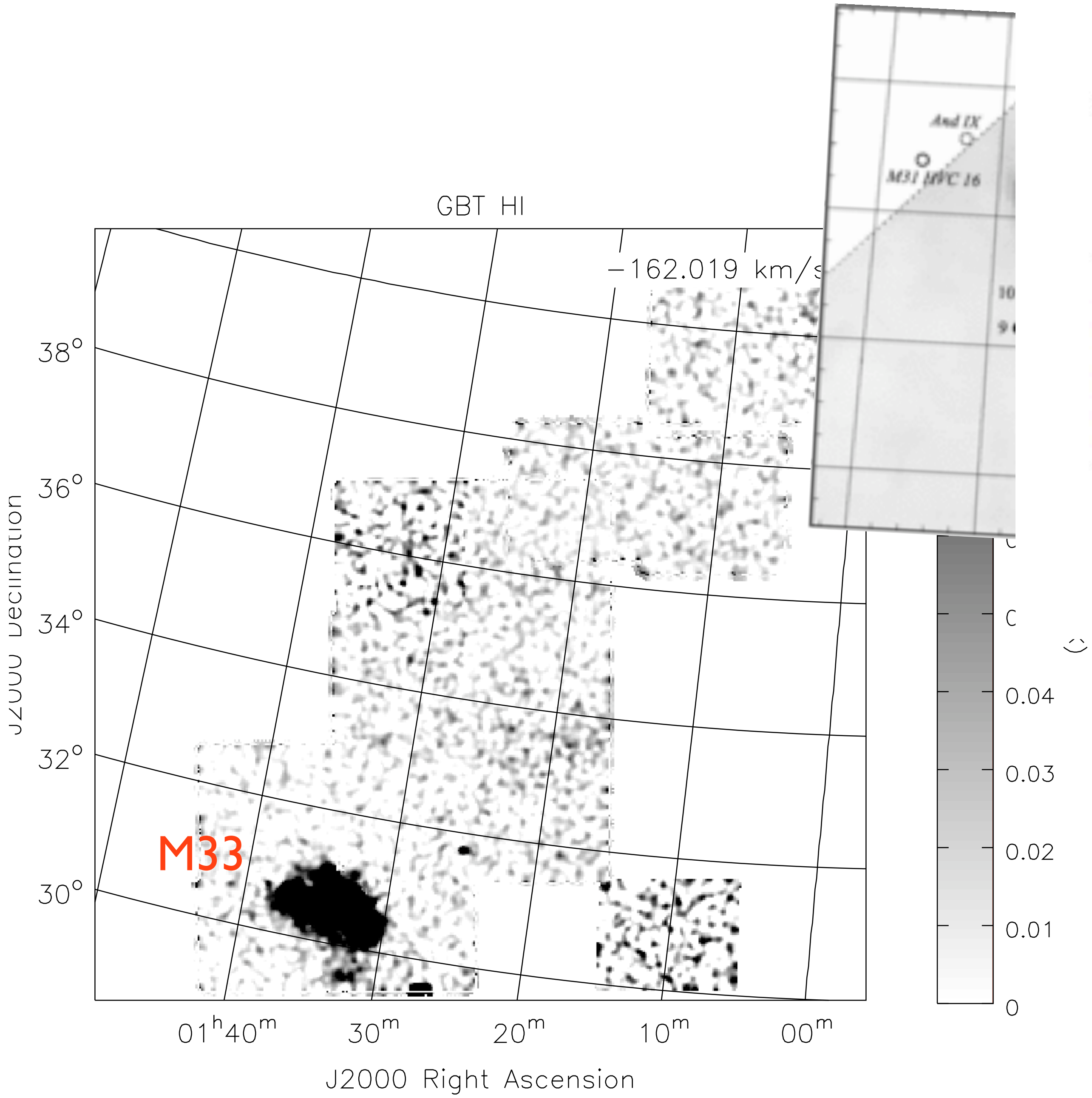


Table 1. 5σ Detection Limits[1]

Data Set	N_{HI} (cm^{-2})	M_{HI}[2] ($M_\odot$)
Map	1.5×10^{18}	4.2×10^{4}
Follow Up	5.0×10^{17}	1.4×10^{4}
Deep Pointings	$1.0 - 1.4 \times 10^{17}$	$2.8 - 4.1 \times 10^{3}$

[1]For a line width of 25 km s^{-1} (FWHM).

[2]Mass of H I within a single GBT beam at 0.8 Mpc distance.

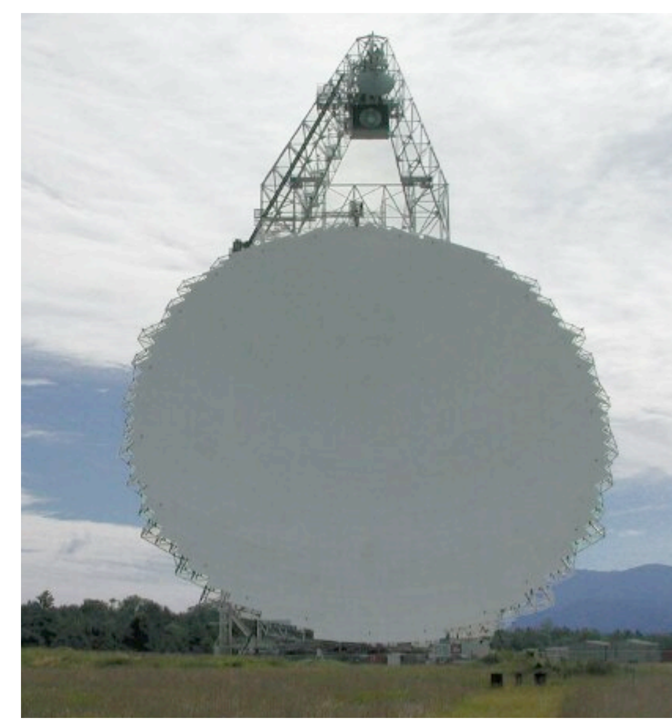


Table 2. Observations of M31 Satellites

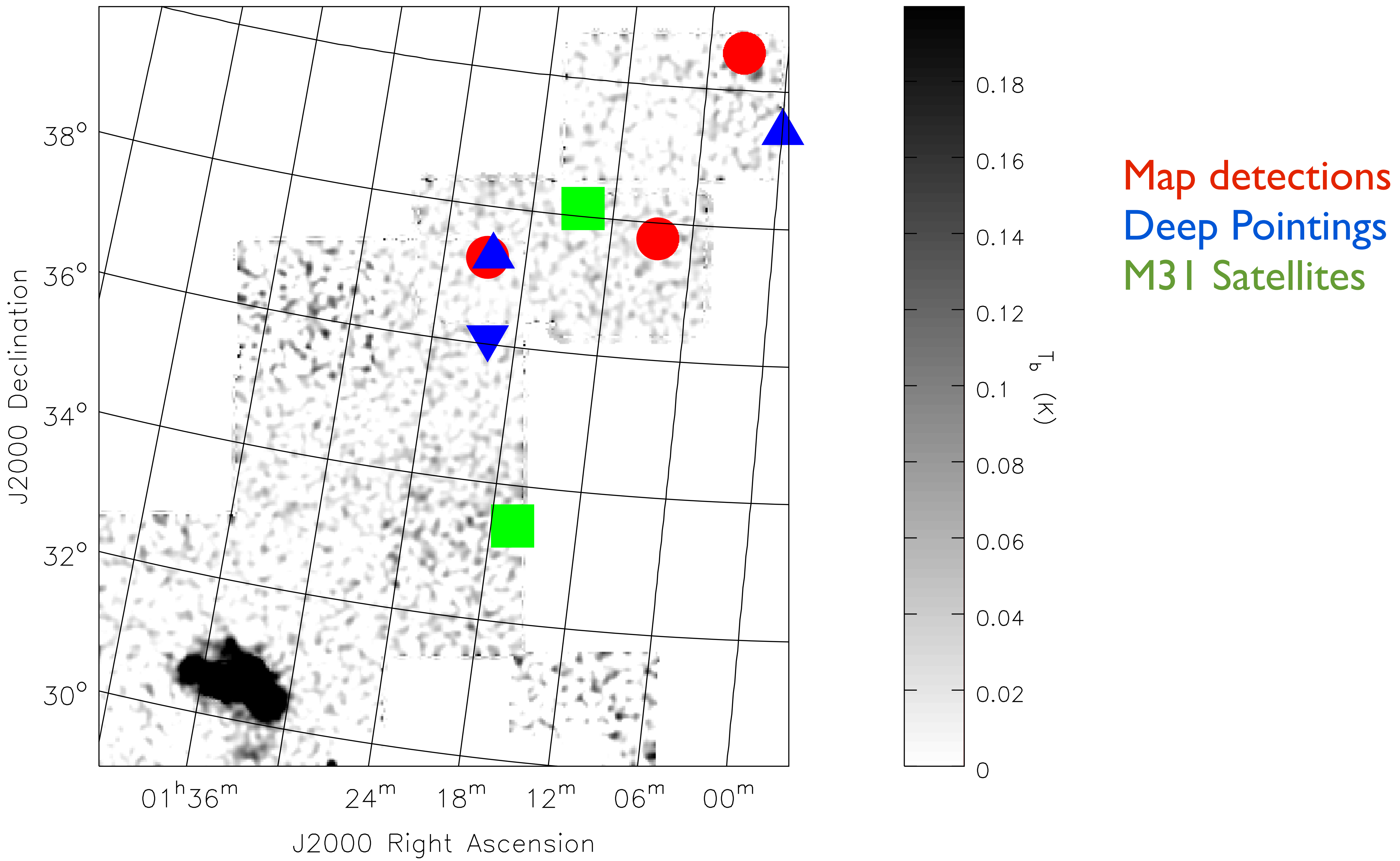
J2000 (hh:mm:ss.s dd:mm)	V_{LSR} (km s^{-1})	V_{LGSR} (km s^{-1})	σ_b [1] (mK)	N_{HI} [2] (10^{17} cm^{-2})	M_{HI} (10^3 $M_\odot$)	Object	Ref
01:14:18.7 +38:07	−322 (1.4)	-79 (13)	4.4	< 3.6	< 9.3	And XV	1
01:16:29.8 +33:25	−187 (3.0)	+46 (14)	9.4	< 7.7	< 14	And II	2

References. — (1) Tollerud et al. (2011); (2) Côté et al. (1999).

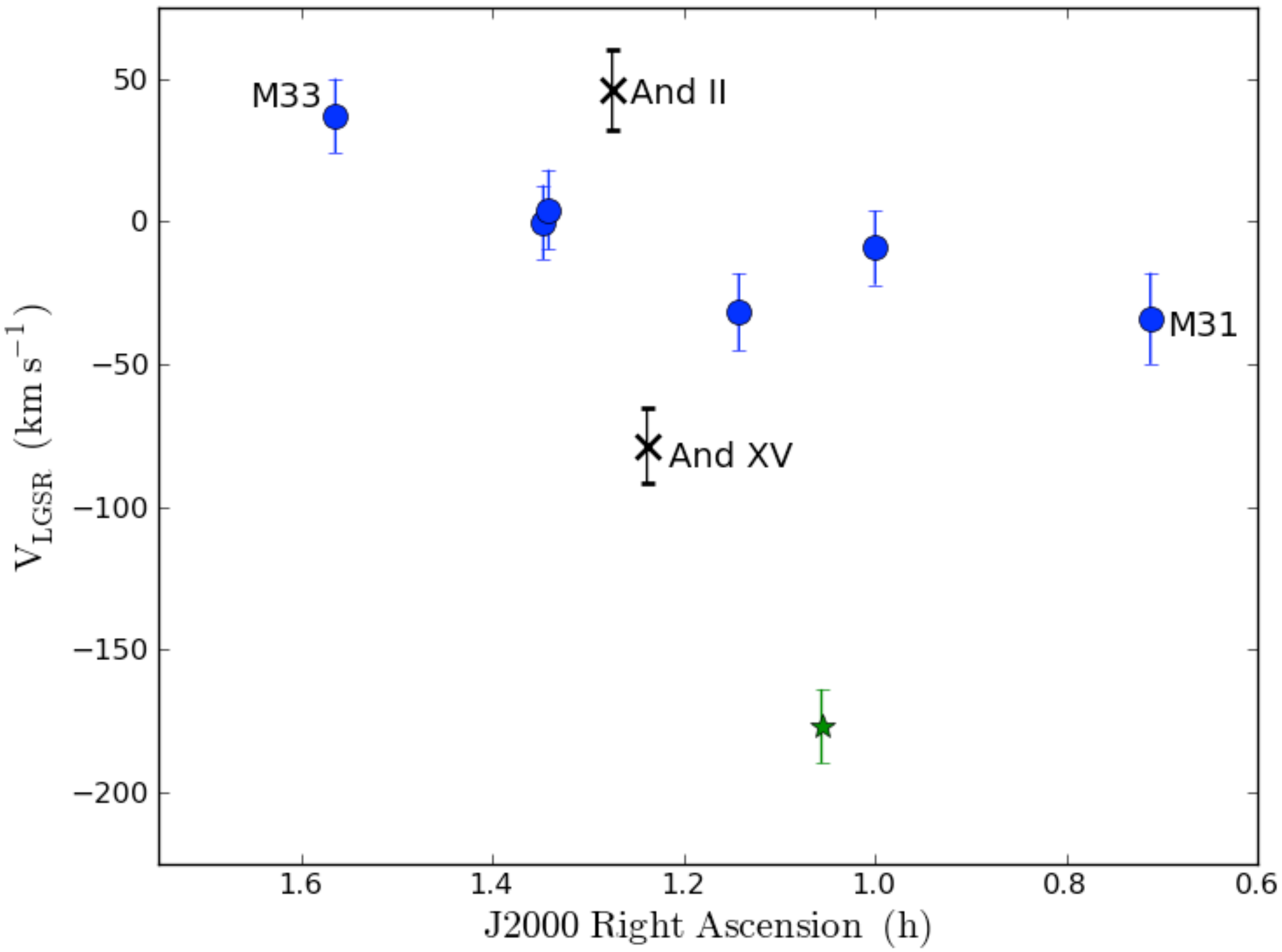
[1] Noise in a 3.2 km s^{-1} channel

[2] For a 25 km s^{-1} line width.

GBT Observations of the M31–M33 stream

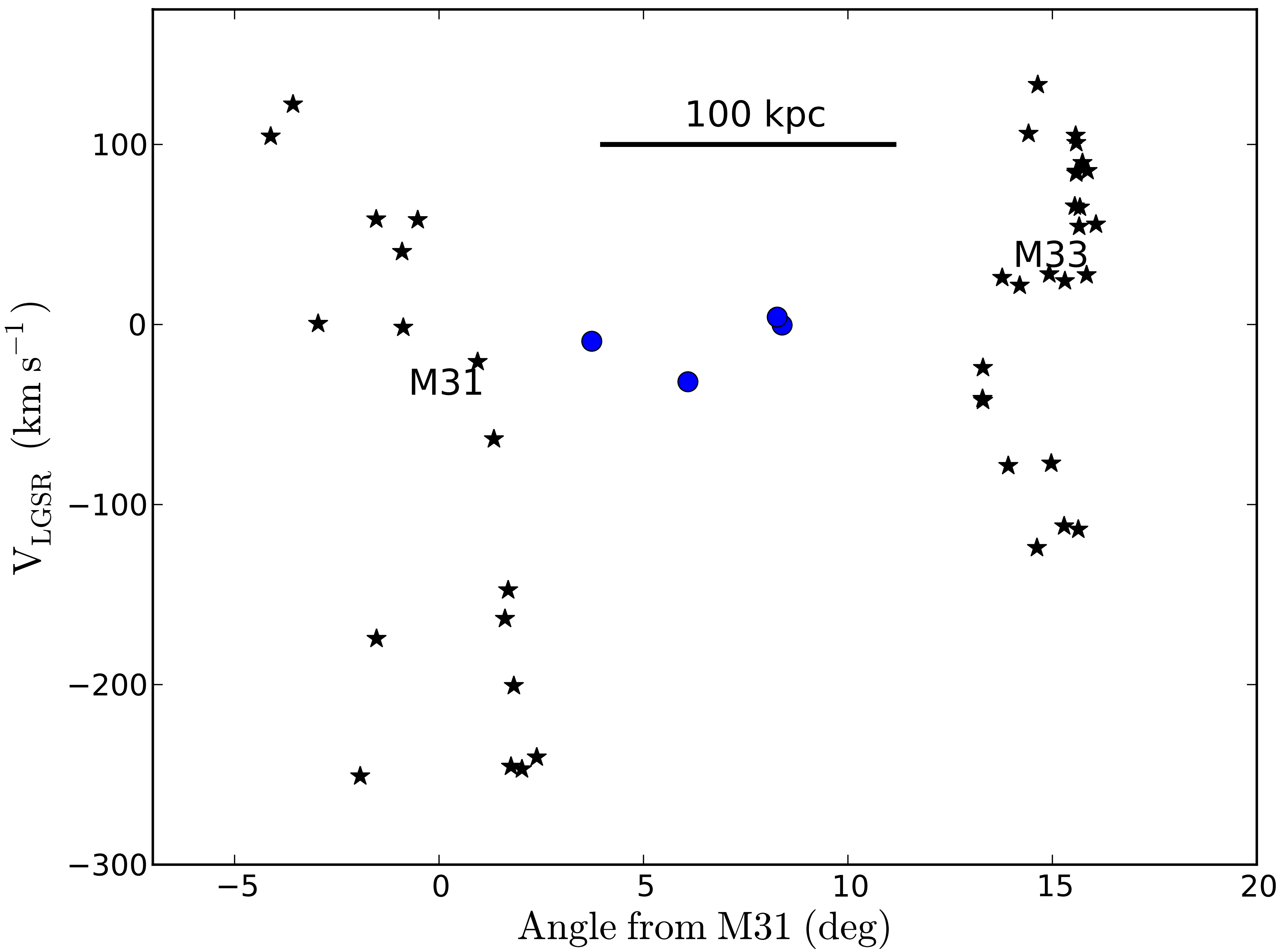


Detected lines: V_{LGSR} vs RA



The new detections lie between the position and velocity of M31 and M33, and confirm the existence of the "bridge"

Detected lines: V_{LGSR} vs angle from M31



Stars mark the HVCs of M31 and M33.
Circles are the newly detected HI clouds

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Table 3. Summary of Measurements of the M31-M33 Bridge

J2000 (hh:mm:ss.s dd:mm) (1)	T_L (mK) (2)	FWHM (km s^{-1}) (3)	V_{LSR} (km s^{-1}) (4)	σ_b[1] (mK) (5)	N_{HI} (10^{17} cm^{-2}) (6)	V_{LGSR} (km s^{-1}) (7)	Notes (8)
01:00:00.0 +39:30	4.4(0.4)	34.4(4.0)	−262.4(1.7)	1.3	2.9(0.2)	−9 (13)	Deep
01:03:21.9 +40:33	86 (4)	24.1 (1.2)	−430 (0.5)	8.7	40 (1)	−177 (13)	Map[2]
01:08:32.5 +37:46	106 (3)	38.0 (1.2)	−278 (0.5)	8.6	78 (1)	−32 (13.5)	Map
01:20:00.0 +36:00	≤ 9			1.8	≤ 1.5		Deep
01:20:28.3 +37:22	6.1 (0.9)	20.8 (3.6)	−235.1 (1.5)	1.3	2.5 (0.2)	+4 (14)	Deep
01:20:48.5 +37:15	75 (4)	23.3 (1.3)	−239 (0.6)	7.2	34 (1)	−0.3 (13)	Map
00:42:44.3 +41:16			−296 (4)			−34 (16)	M31
01:33:50.9 +30:39			−180 (3)			+37 (13)	M33

Note. — Uncertainties are 1σ, limits are 5σ. Values for M31 and M33 were taken from NED: http://ned.ipac.caltech.edu.

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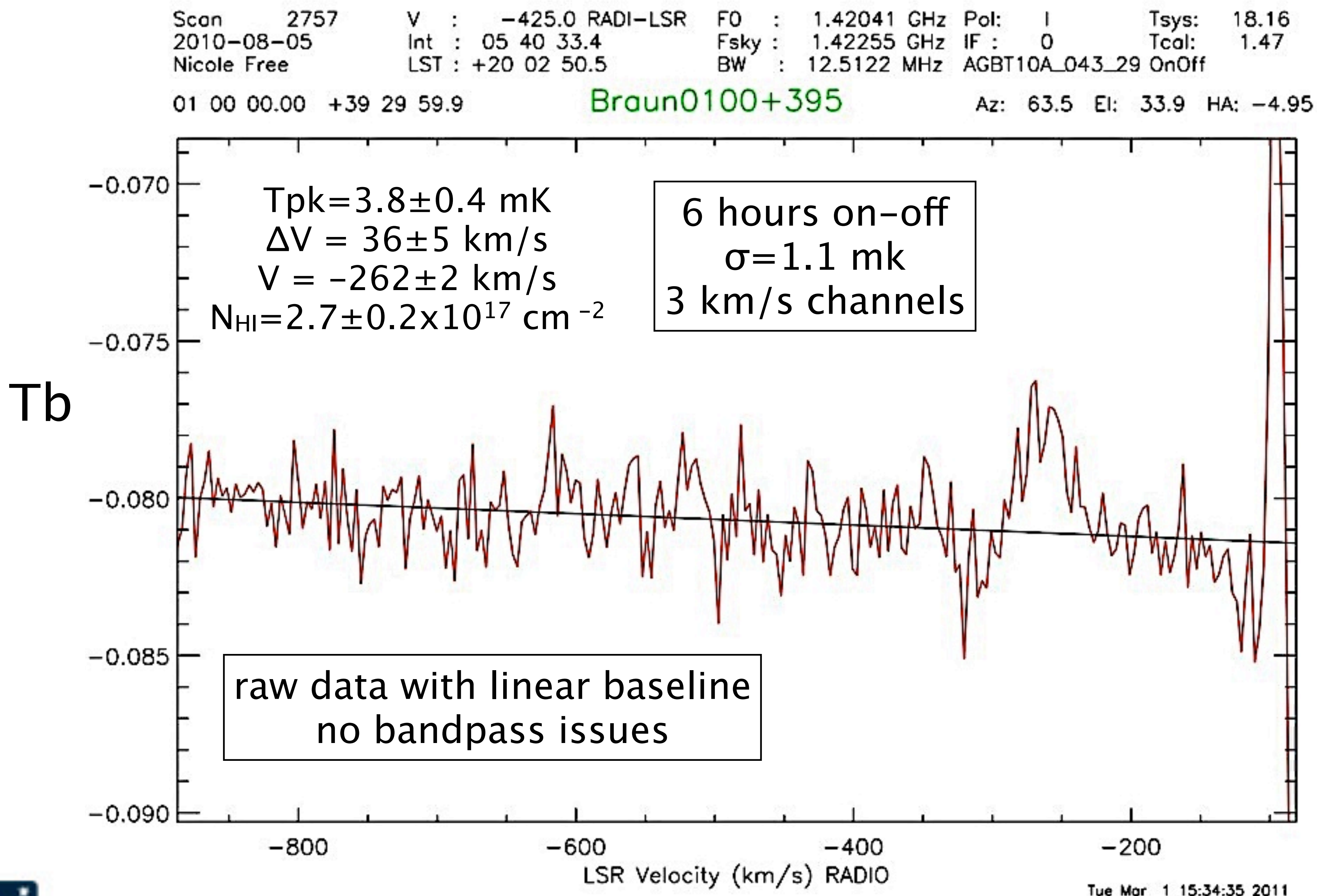
GBT spectrum of the M31-M33 stream



- The challenge of studies at $N_{HI}=10^{17}$ What's out there?
  - Signals are very weak, and yet likely extended
  - Possible with current instruments, it just takes time
- Near term
  - Better receivers -- Tsys=10 K?
  - Phased array feed receivers -- still not competitive, but...
  - EVLA-E -- f≈0.25
- Medium Term
  - FAST
- Long term ????
  - SKA -- HPBW=2.5' reaches 1.6 mK over 25 km/s in 1 hour
  - (but GBT at 9' now reaches 0.7 mK over 25 km/s in 1 hr)

The GBT is the instrument of choice for the foreseeable future!

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