# HI clouds in the outskirts of M33: a potential supply for fueling star formation?

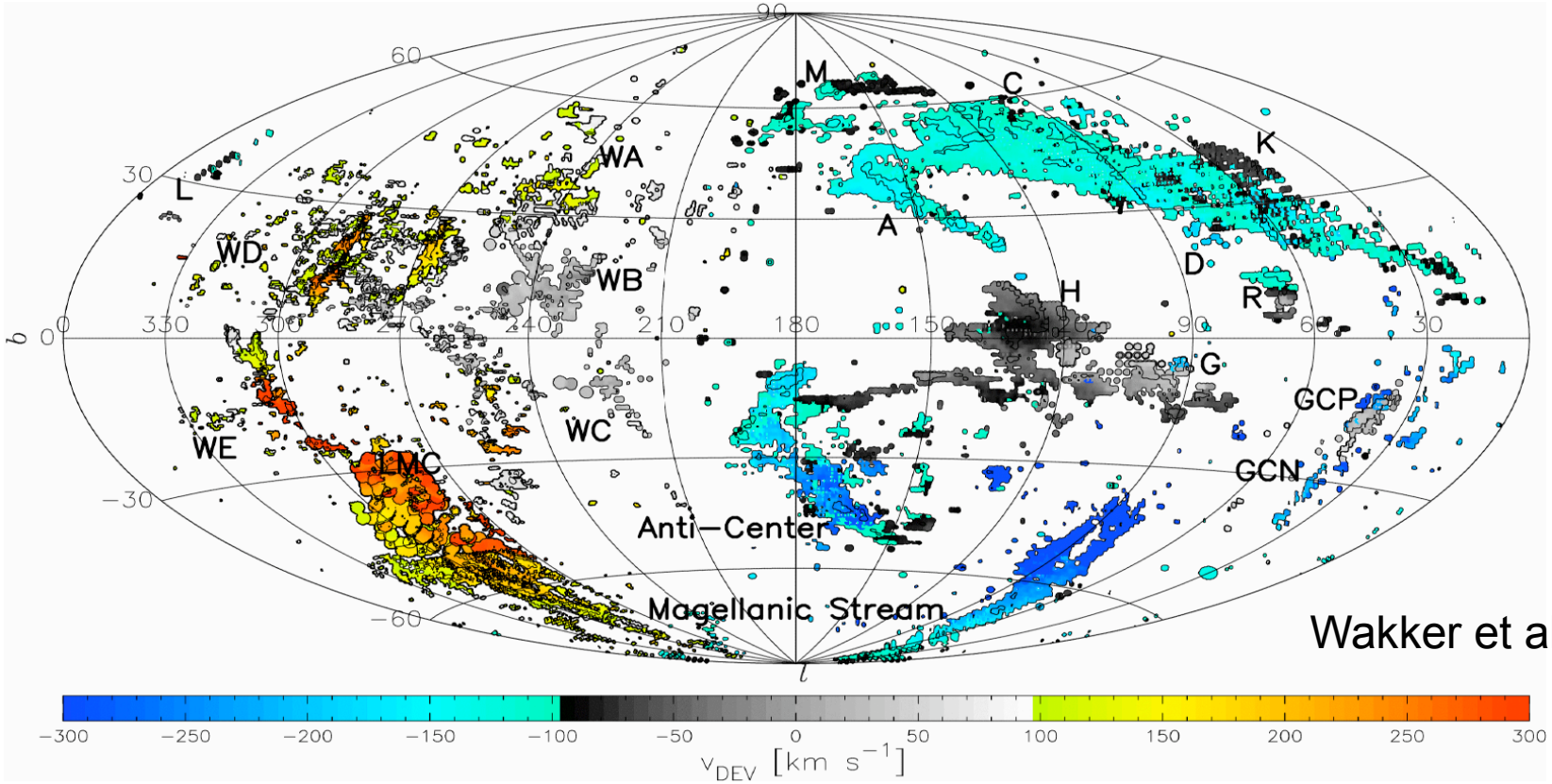
M. Grossi, C. Giovanardi, E. Corbelli,
R. Giovanelli, M. Haynes

# Overview

• High Velocuty clouds (HVC) are gas clouds observed all over the sky in the 21-cm line of H I.

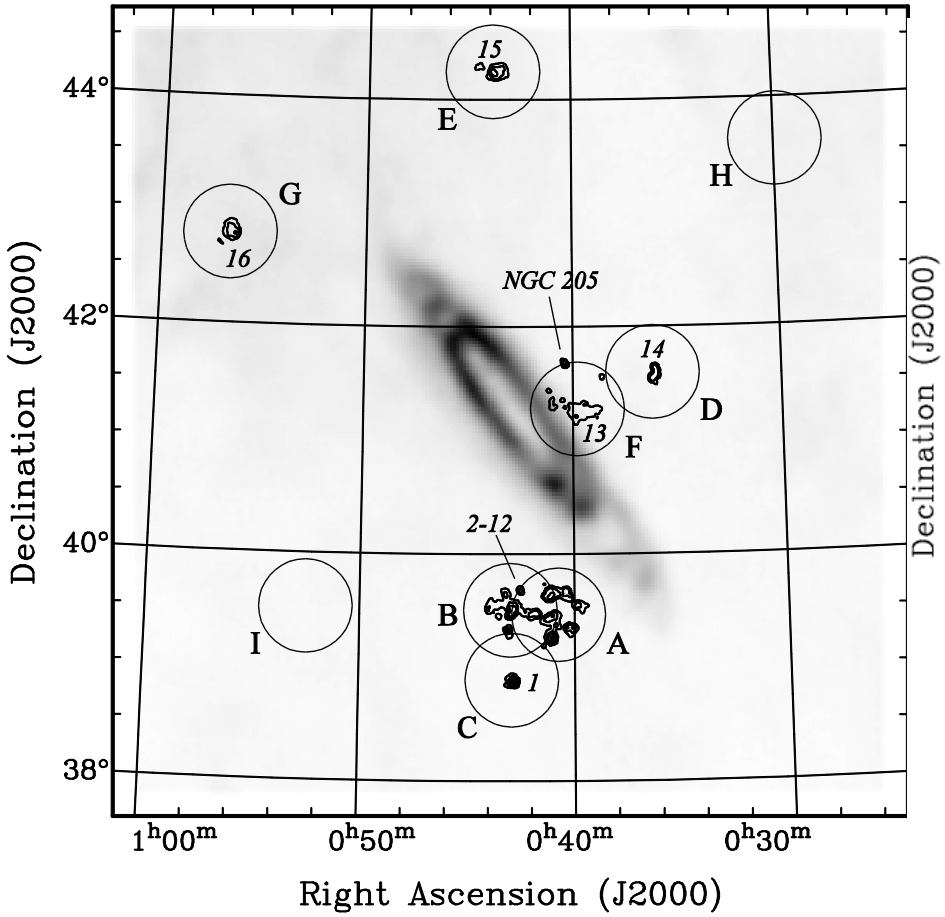
• They are characterised by high radial velocities of tipycally $|V_{LSR}| > 100$ km/s

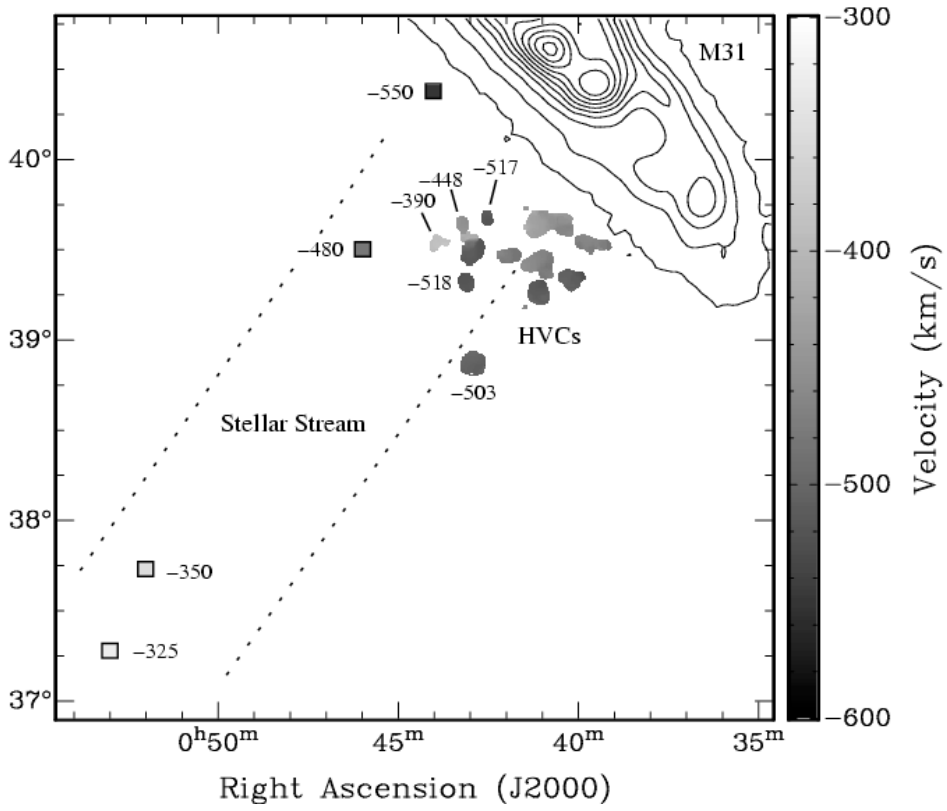
• They may form large complex extended for few degrees (complex A;C, in the MW) or appear as compact, isolated clouds (CHVCs)




Wakker et al. 2000

# HVCs in other galaxies: the example of Andromeda




Andromeda hosts a population of HVCs with masses between 10^5 and 10^7 Msun within 50 kpc (Thilker et al. 2004, Westmeier et al. 2005)

Some of the clouds are related to a giant stellar stream to the south of the galaxy.
Others appear compact and isolated.

# Open issues: why searching for HI clouds (in M33)?

• What is the origin of HI clouds?

• Compact HVCs as gaseous counterparts of dark matter mini-halos →
The test of CDM models of galaxy formation

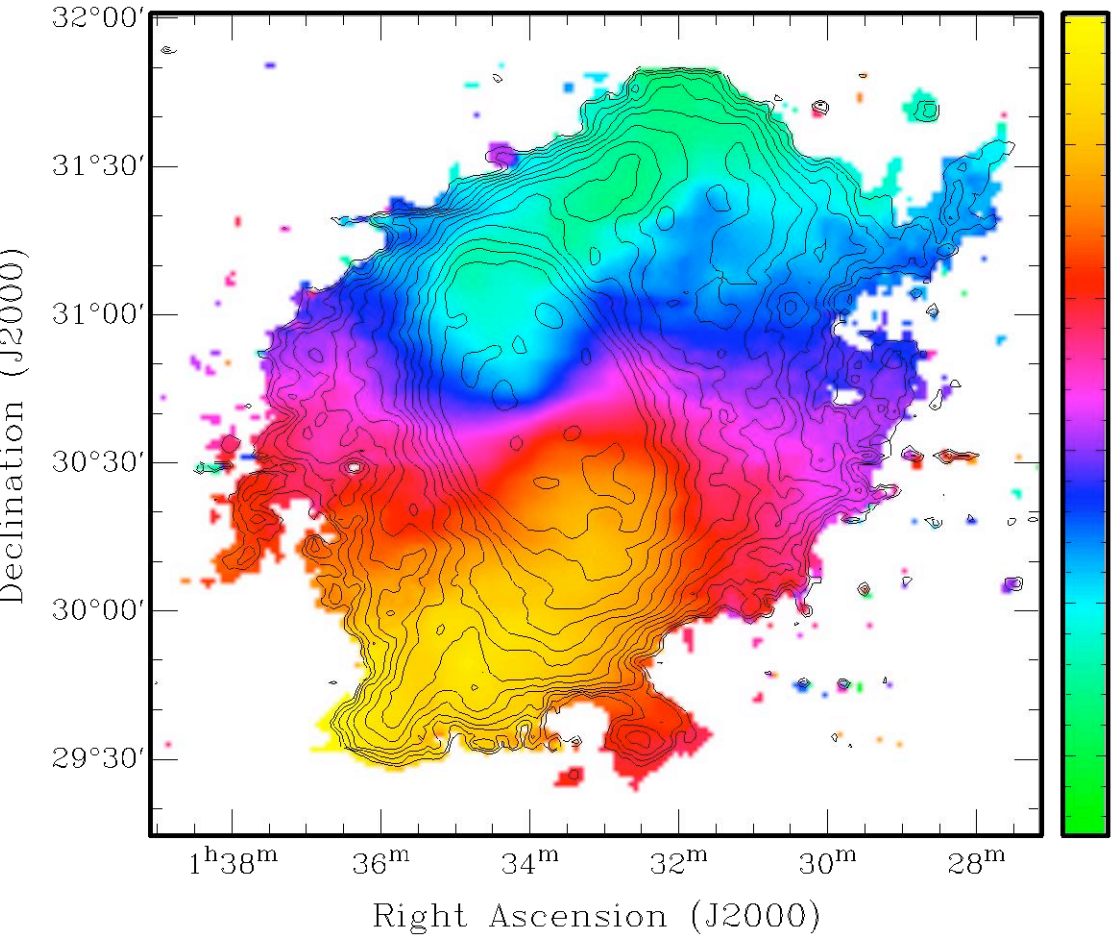
•Extragalactic origin? Clouds as remnants of gas stripped by previous interaction with smaller companions. Is there a gaseous component giving evidence of satellite accretion in M33?

• Can HVCs affect the evolution scenario of the galaxy. IS THERE A RELATION BETWEEN THE PRESENCE OF HI CLOUDS AND THE SFR OF A GALAXY?
an HI clouds provide fuel for star formation?
In M33 for example, the present star formation rate of 0.5 Msun/yr, implies an inflow of gas at a rate of about 1 Msun/yr (Magrini et al. 2007, Barker & Sarajedini 2008).

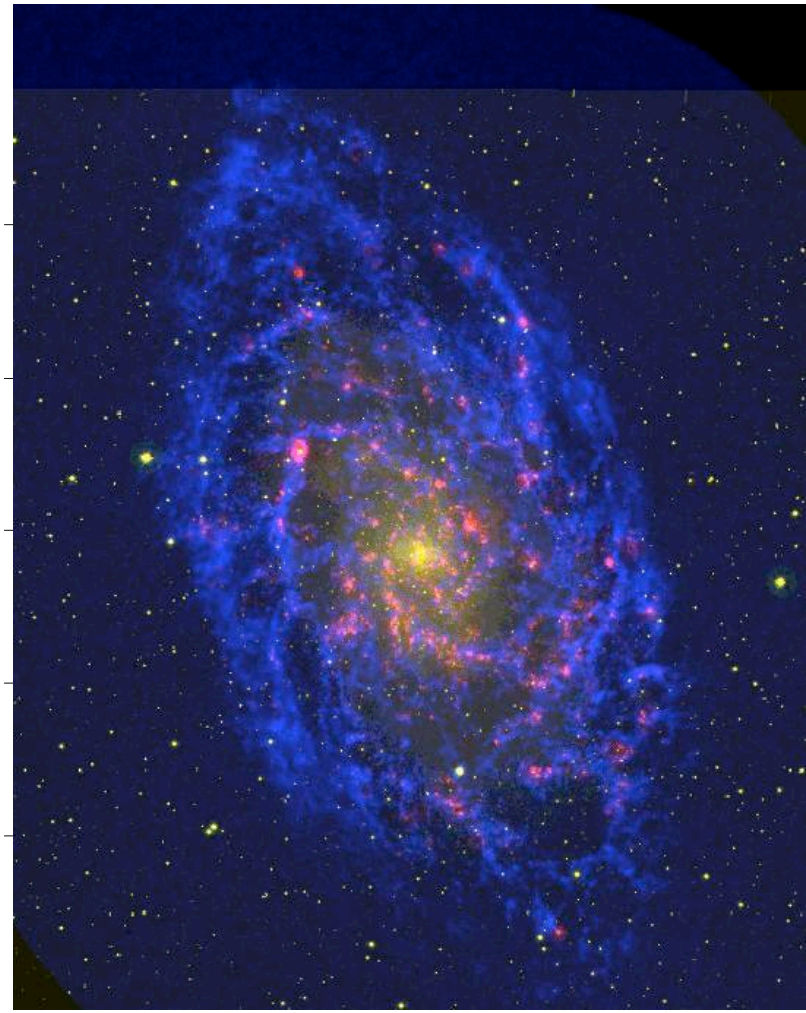
# M33

MHI= 1.4 x 10^9 M_sun  ~ 20 % is found beyond the SF disc

Main HI features: warped disc (Corbelli & Schneider 1997), extended HI distribution out to 20 kpc, northern arc of gas from the warp to the disc (Putman et al. 2008), a large HI cloud in the southern disc (Westmeier et al. 2005)




Putman et al. 2008

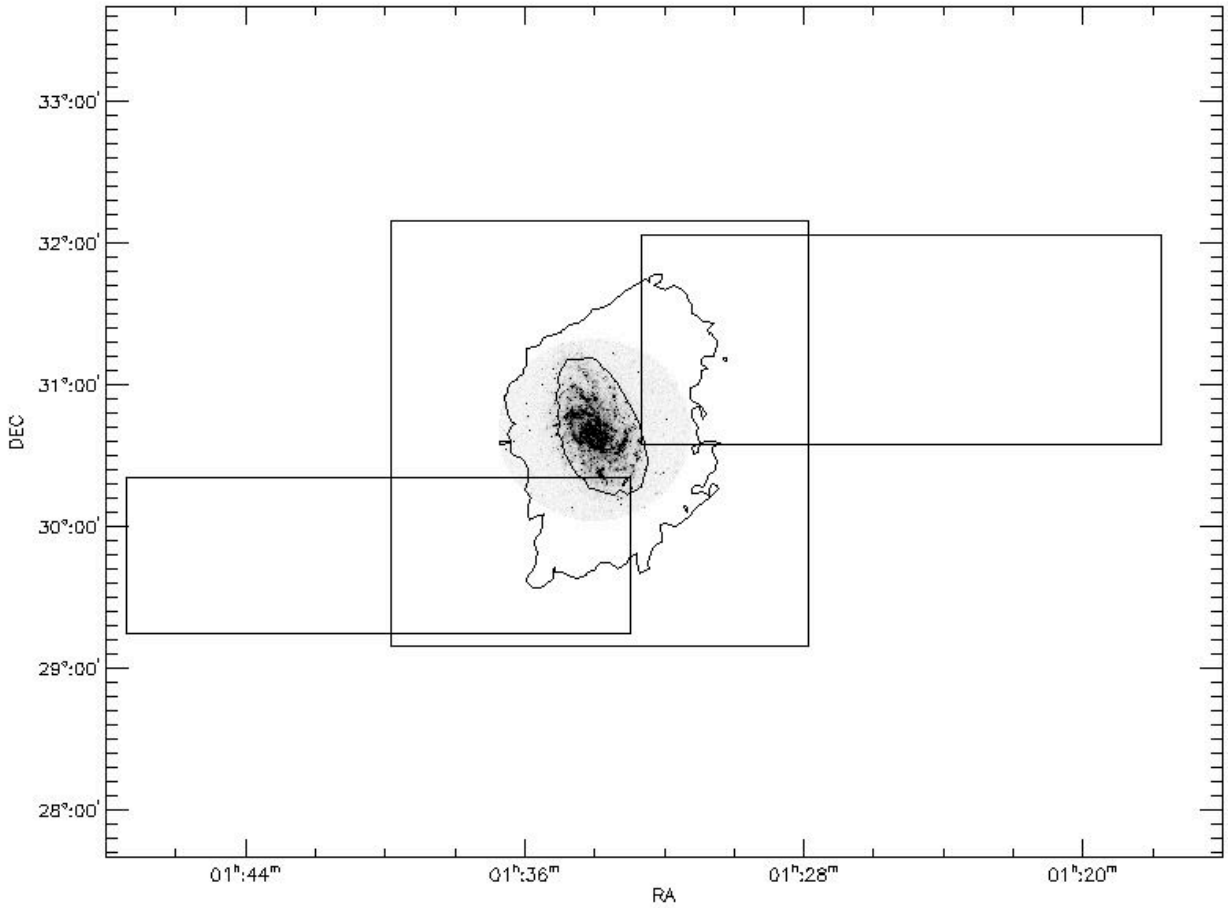


Braun & Thilker 2002, 2007

# 21-cm data sets.

1. The Arecibo Legacy Fast Alfa (ALFALFA) survey (Giovanelli et al. 2005)
   (3 deg x 3 deg ) rms ~ 2.5 mJy/channel ; Δv = 10 km/s (after hanning smoothing)

2. Deeper pointed observations with the Arecibo Telescope of two fields (Sparse Mode, roughly 5 sq deg each) rms ~ 1.5 mJy/channel ; Δv = 2 km/s (after hanning smoothing)



# Results: 21 candidate HI clouds/complexes around M33

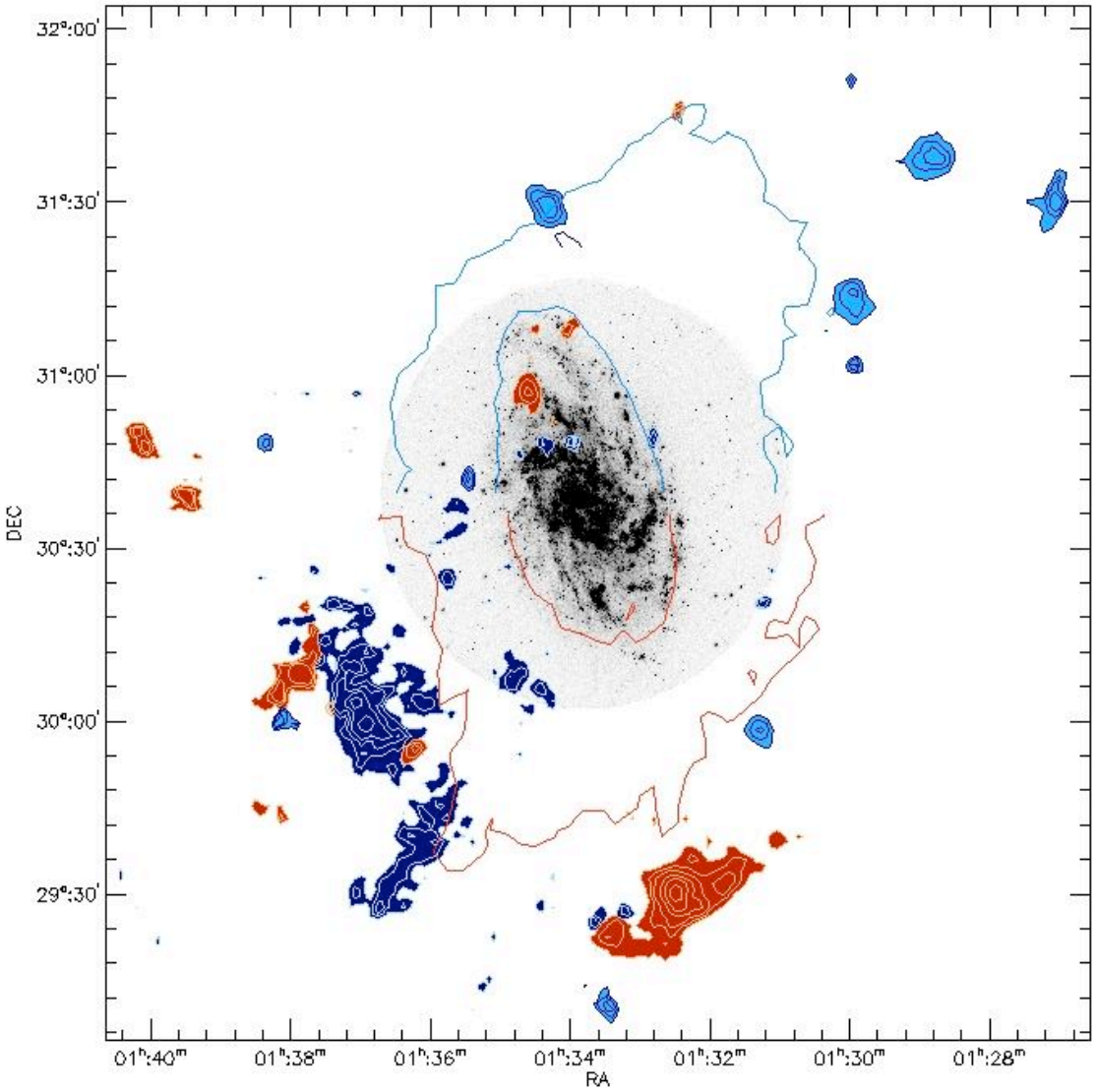
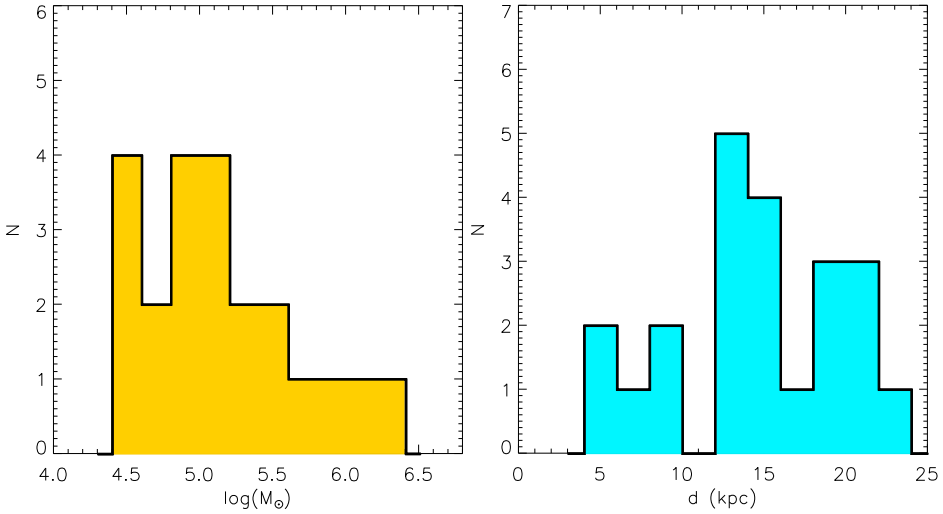


**Table 1.** Catalog of HI detections in the ALFALFA cube

| ID | RA J2000 | DEC J2000 | $V_{hel}$ km s$^{-1}$ | $\Delta V$ km s$^{-1}$ | flux Jy km s$^{-1}$ | $M_{HI}$ $10^5 \times M_\odot$ | $R_{half}$ (kpc) | S/N | d (kpc) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 01:34:36.9 | 30:59:35 | -83 | 22 | 0.63 | 1.0 | 0.78 | 9 | 5.3 |
| 2 | 01:40:13.2 | 30:50:57 | -107 | 31 | 0.67 | 1.0 | 0.68 | 6 | 20.3 |
| 3 | 01:34:02.9 | 31:12:12 | -111 | 23 | 0.38 | 0.58 | 0.8 | 6 | 8.0 |
| 4 | 01:37:56.4 | 30:10:15 | -122 | 29 | 5.43 | 11.9 | 1.7 | 51 | 14.9 |
| 5 | 01:39:31.4 | 30:41:30 | -128 | 25 | 0.57 | 0.91 | 0.68 | 9 | 18.0 |
| 6 | 01:32:30.6 | 29:26:56 | -140 | 26 | 7.3 | 12.1 | 1.5 | 76 | 18.6 |
| 7 | 01:38:11.8 | 29:47:11 | -155 | 19 | 0.38 | 0.46 | 0.75 | 5 | 19.0 |
| 8 | 01:36:15.0 | 29:58:10 | -158 | 15 | 0.34 | 0.56 | 0.79 | 5 | 12.7 |
| 9 | 01:33:27.8 | 29:14:49 | -185 | 22 | 0.40 | 0.7 | 0.97 | 8 | 21.0 |
| 10 | 01:31:15.2 | 30:01:14 | -188 | 13 | 0.56 | 0.86 | 0.61 | 14 | 12.6 |
| 11 | 01:38:26.0 | 30:50:37 | -189 | 13 | 0.21 | 0.44 | 0.38 | 4.3 | 14.7 |
| 12 | 01:29:54.6 | 31:16:36 | -194 | 15 | 0.59 | 0.98 | 0.86 | 7 | 15.3 |
| 13 | 01:34:16.7 | 31:31:25 | -196 | 25 | 1.28 | 2.75 | 1.42 | 20 | 12.7 |
| 14 | 01:27:51.3 | 31:31:21 | -246 | 29 | 0.92 | 1.5 | 0.7 | 18 | 22.5 |
| 15 | 01:28:46.3 | 31:41:02 | -264 | 26 | 1.25 | 1.97 | 0.75 | 24 | 21.9 |
| 16 | 01:35:28.9 | 30:43:17 | -292 | 15 | 0.23 | 0.4 | 0.46 | – | 5.2 |
| 17 | 01:29:52.0 | 31:04:23 | -298 | 14 | 0.24 | 0.41 | 0.4 | 5.4 | 13.9 |
| 18 | 01:33:40.7 | 29:27:31 | -328 | 21 | 0.96 | 2.02 | 1.96 | 10 | 17.8 |
| 19 | 01:34:39.9 | 30:09:20 | -333 | 25 | 1.56 | 2.65 | 2.07 | 15 | 7.9 |
| 20 | 01:31:12.5 | 30:24:04 | -341 | 25 | 0.38 | 1.09 | 1.48 | 7 | 9.2 |
| 21a | 01:36:56.6 | 30:02:43 | -372 | 27 | 3.66 | 11.5 | 3.3 | 23 | 13.5 |
| 21b | 01:36:07.2 | 29:42:39 | -383 | 25 | 2.12 | 7.7 | 2.8 | 20 | 15.9 |

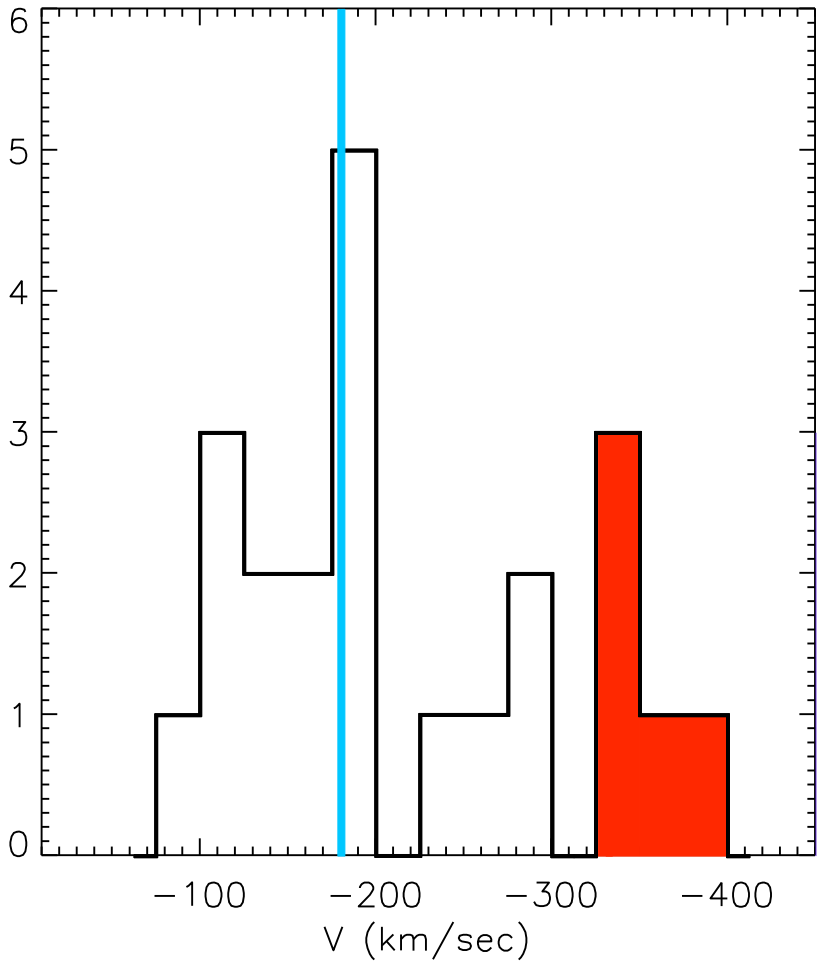
# Cloud properties

- **HI masses** 3x10^4 <MHI < 3x10^6 M_sun
- **Galactocentric dist** 5 kpc < d < 22 kpc
- **Velocity** -80 km/s < v < -400 km/s
- **Sizes** 0.4 kpc < R < 1.5 kpc



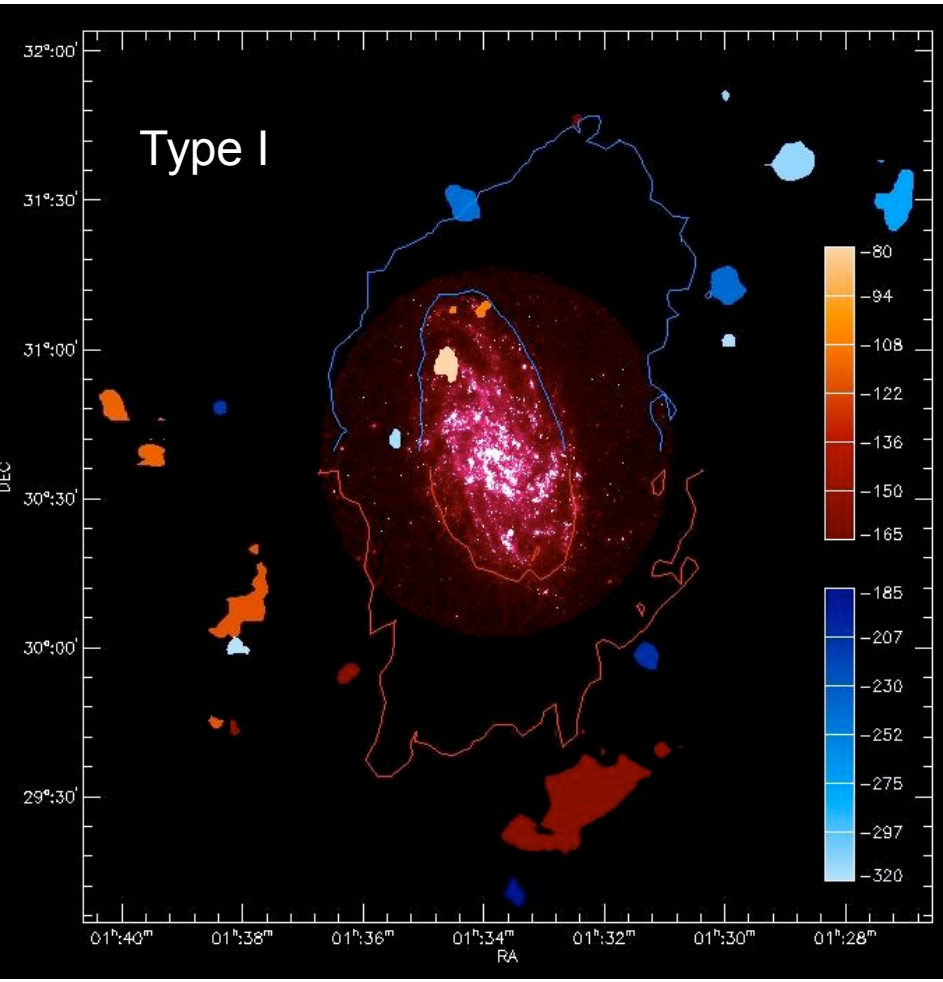


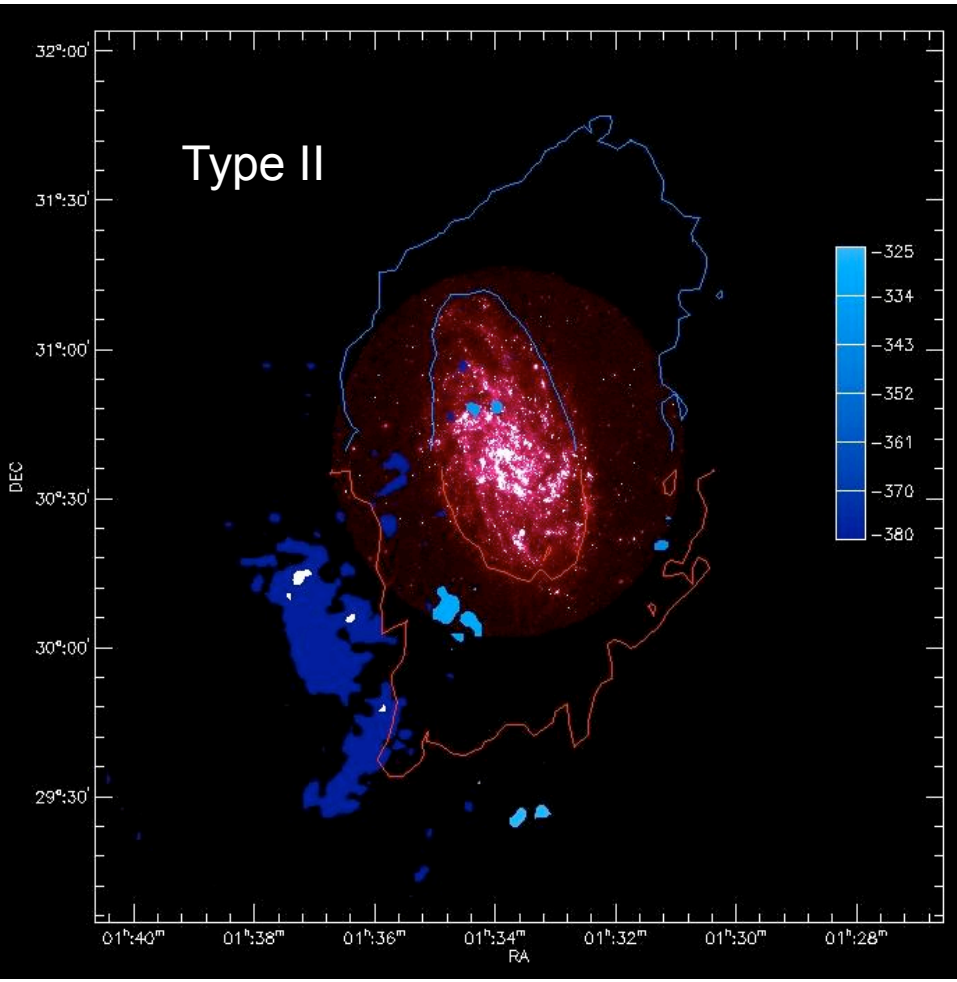




The velocity of the clouds is correlated with the rotation of the disc

Except few complexes with v ≈ -400 km/s

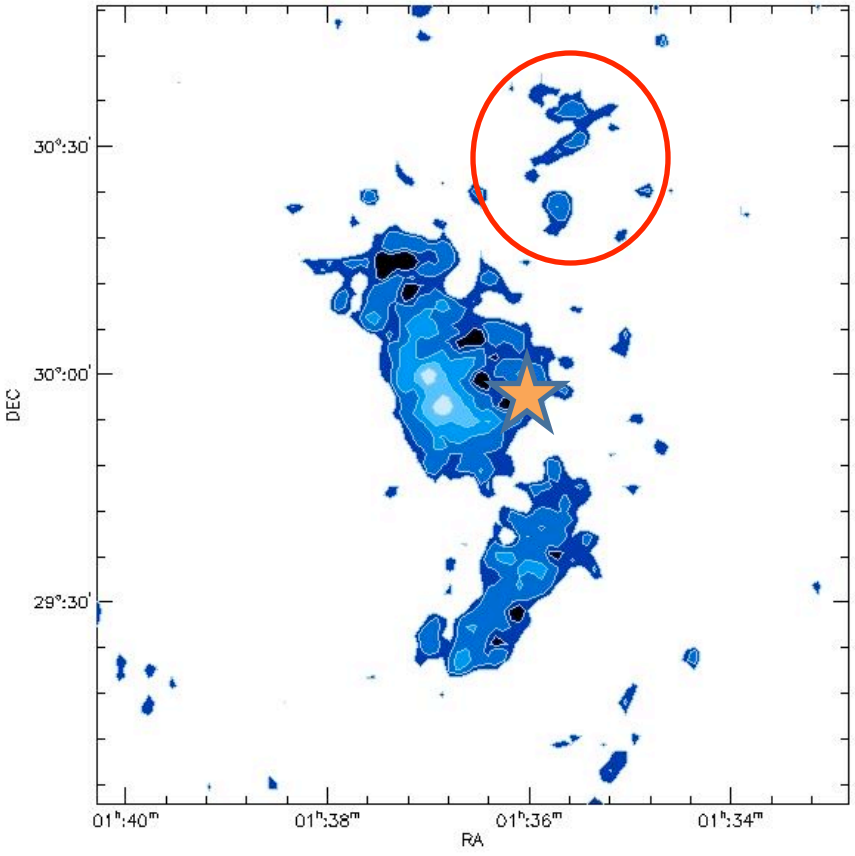



**V_M33** = -180 km/s --

- The maximum rotation velocity derived from the rotation curve is ±140 km/s (Corbelli 2003)
- Clouds with -320 km/s < V < -400 km/s might not be gravitationally bound to M33

# An extended HI complex related to M33 or a local HI cloud?



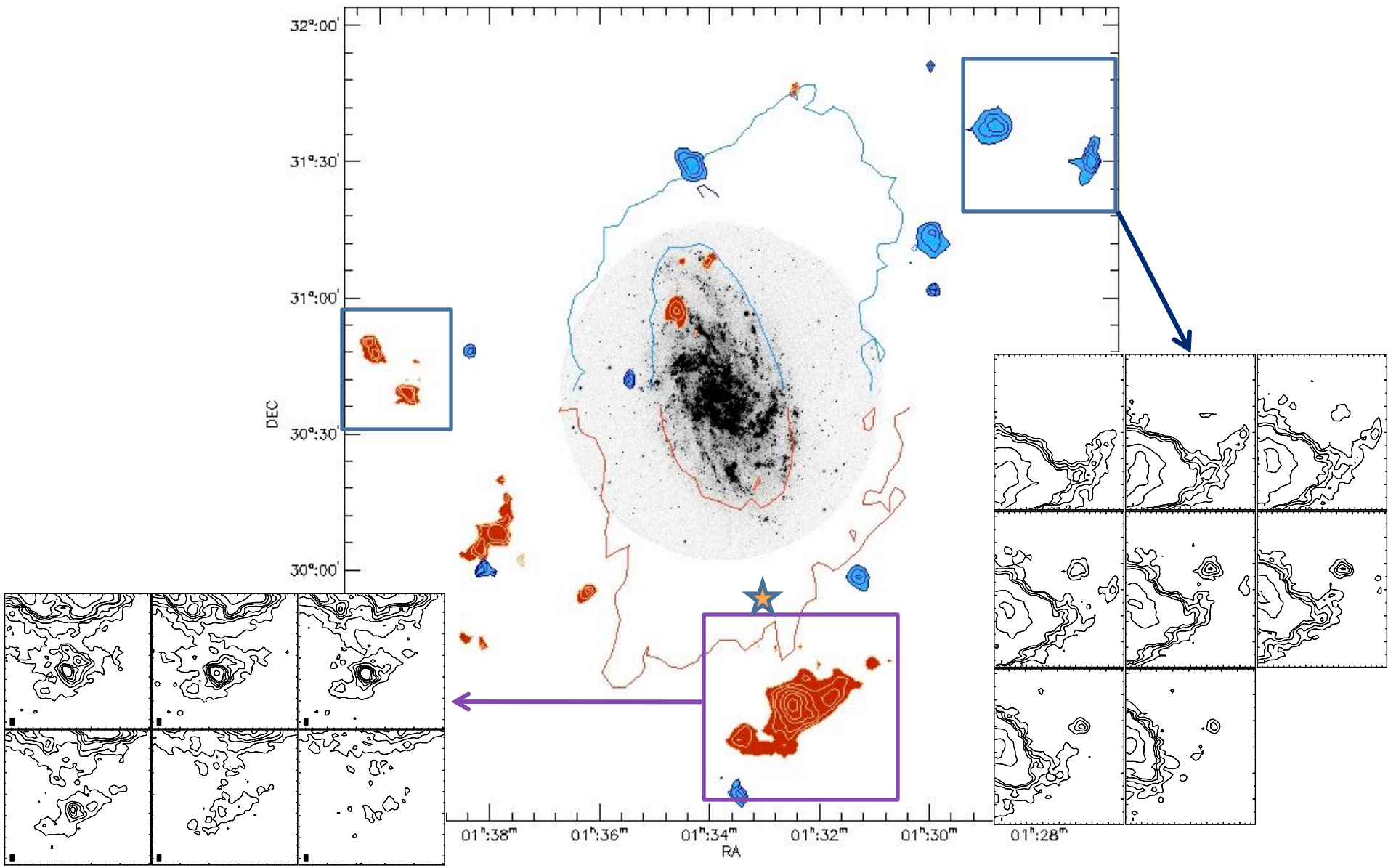

MHI = 2 x $10^6$ $M_{SUN}$
V_helio = -380 km/s
V_GSR = -240 km/s.
Clouds with similar velocity are found within 10 degrees from M33
(LDS catalog: de Heij et al. 2002; Wakker et al. 2004).

T_cr = 2R/Δv = 0.6 Myr (d/kpc)

Possible evidence for interaction/tidal disruption?

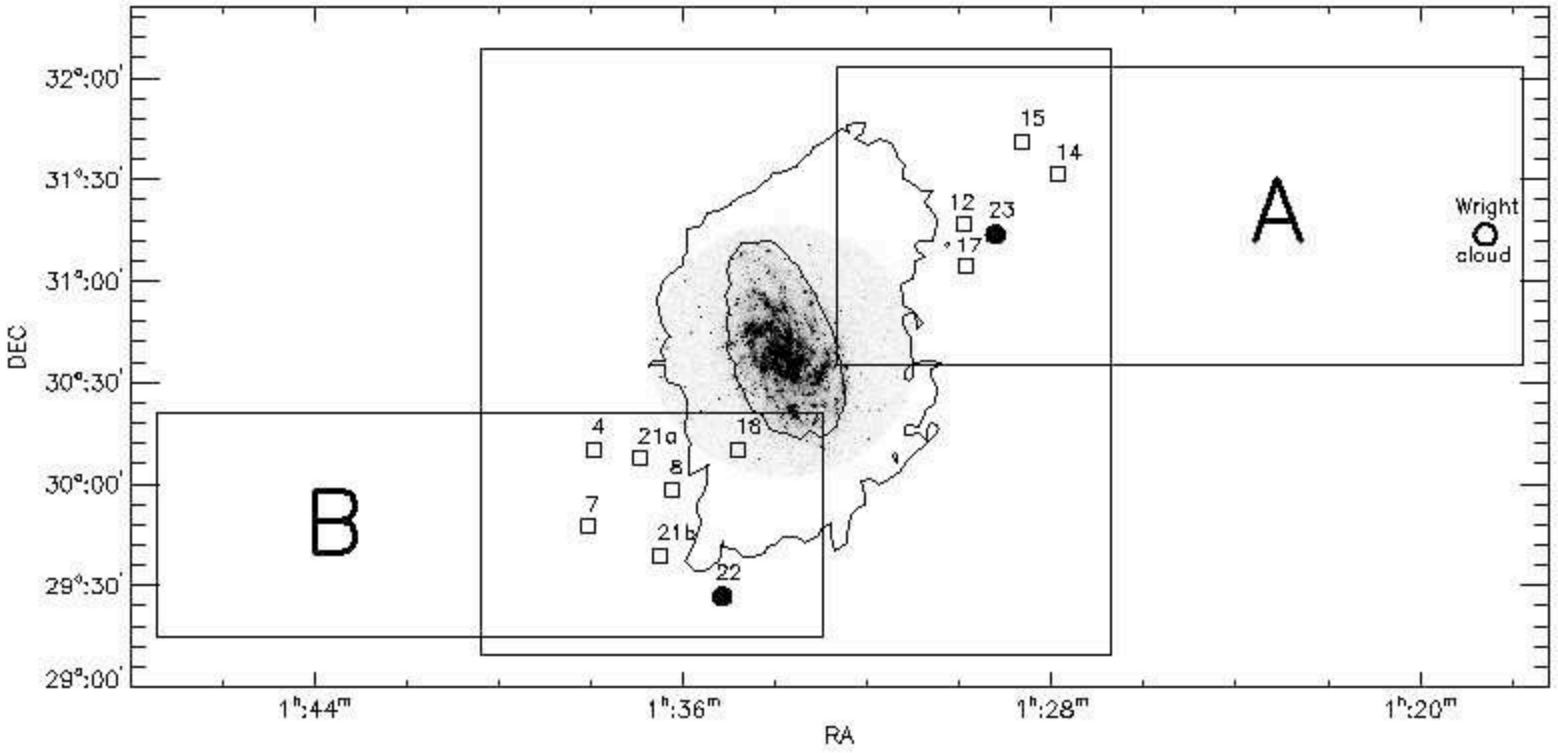
Huxor et al. (2009) found an extended globular cluster in the same region ( ★ )
EGCs are considered as possible remnants of accreted dwarf galaxies (Stonkute et al. 2008)

# HI clouds associated to the disc (Type I)



# The lack of a low mass cloud population

The additional pointed observations reach a 3σ mass limit of MHI ~ 10^4 (Δv/20km/s) Msun)
Only one low mass cloud per field has been detected.
No clouds are found at the edges of the fields, neither in proximity of the Wright cloud.
A fully sampled survey of the area would not largely increase the number of low mass clouds.



# Cloud formation scenarios

1. Dark matter mini halos
2. Tidal  interaction between M31 and M33
3. Gas stripped by nearby companions
4. Galactic fountain
5. Accretion from cosmic filaments

# 1. Dark matter dominated clouds

If the clouds are self-gravitating their halo mass would be around $10^7$ - $10^8$ $M_{sun}$, implying a total to HI mass ratio as high as $f \approx 2000$ (dark matter + **ionised gas**)

$G f M_{HI}/5R = \sigma^2$

The number of sub-halos within a distance *d* of a parent galaxy with virial mass greater than $10^8$ $M_{sun}$ can be estimated from CMD simulations (Sternberg et al. 2002)

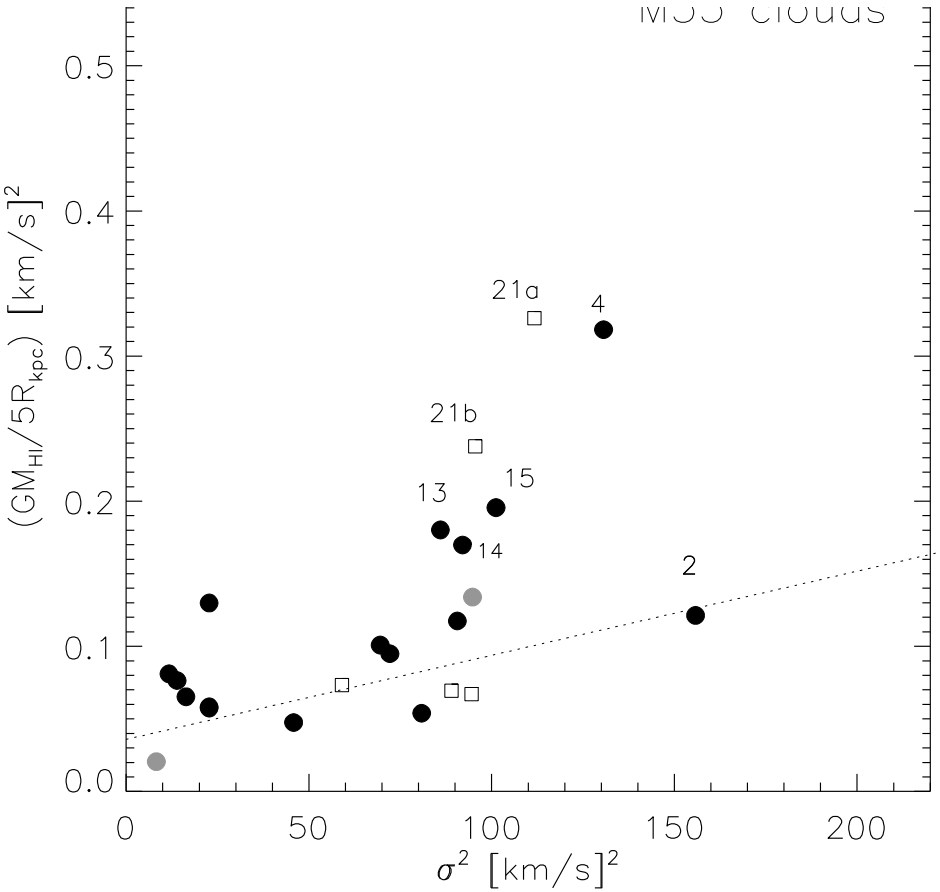
→ N = 25 (d < 50 kpc)

The simulations of Sterneberg et al. (2002) provide models of gas clouds confined in a DM mini-halo for different cloud parameters, at different external bounding pressures.

If we assume an average type of cloud with $M_{HI} = 10^5$ $M_{sun}$ ; $M_{vir,cl} = 3x10^8$ $M_{sun}$ ; $R_{HI} = 0.6$ kpc

→ $M_{gas}/M_{HI} = 50$ with $R_{gas} = 3$kpc

A large fraction of the gas is ionised
NHI < 5 x $10^{19}$ $cm^{-2}$



# Estimate of the gas accretion rate (DM halos)

The total HI mass associated to Type I clouds is $5 \times 10^6 M_{sun}$

Adding the ionised component → $M_{gas} = 1.5 \times 10^8 M_{sun}$

assuming that the gas is distributed within 20 kpc and it is falling towards the disc at 100 km/s

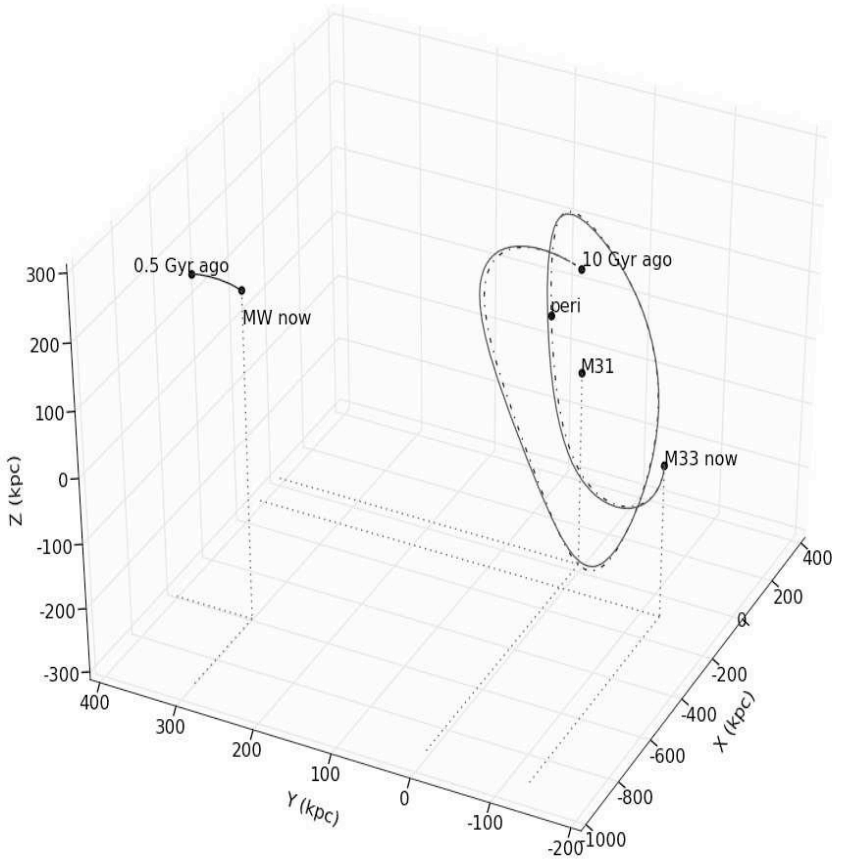
$$dM/dt = 0.8 M_{sun} yr^{-1} (V/100 \text{ km } s^{-1}) (d/20 \text{ kpc})^{-1}$$

# 2. Tidal remnants from an interaction with M31

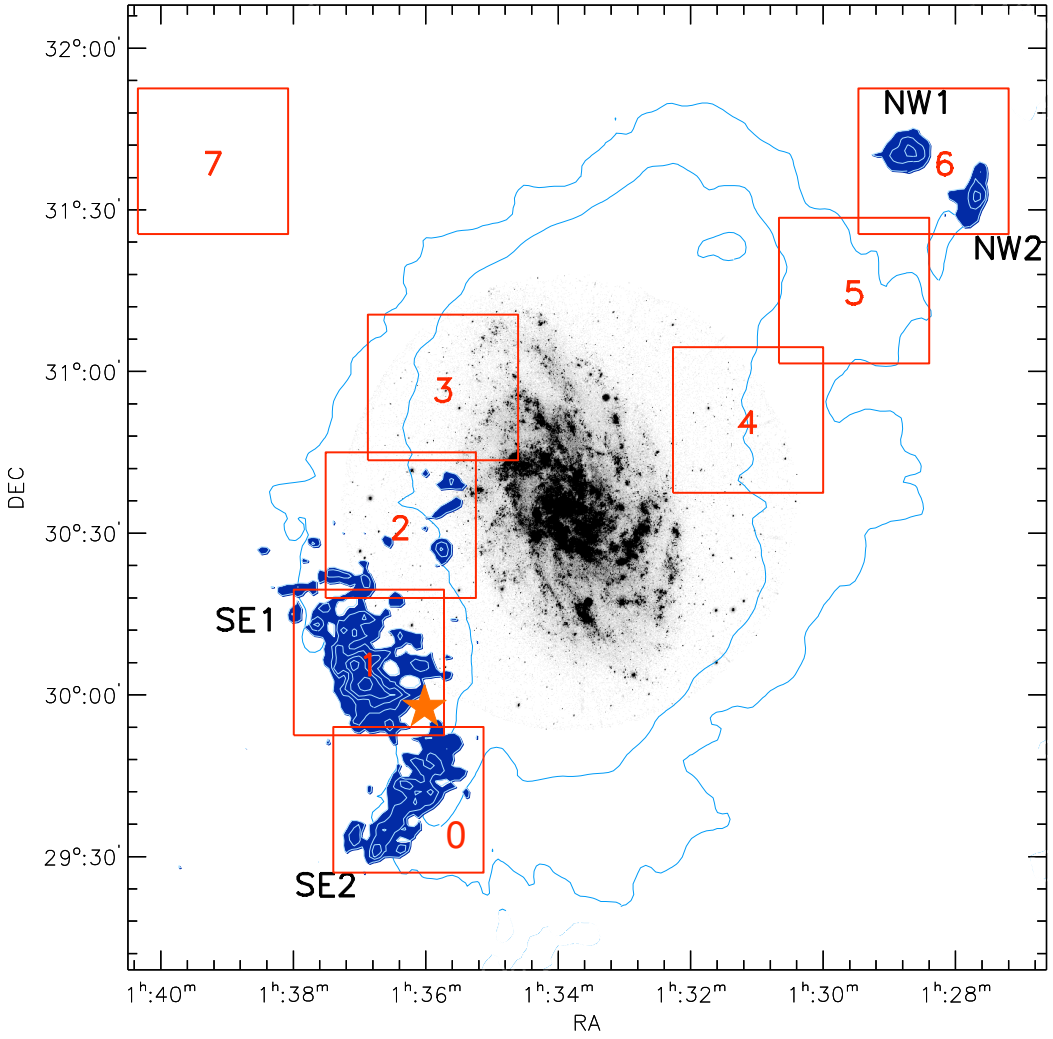
•Simulations of the motion of the system M31/M33 (Loeb et al. 2005; Bekki et al. 2008, Putman et al. 2008) predict that there may have been a close encounter between the galaxies in the recent past (between 1 and 3 Gyr).

•The stellar disc remains unperturbed during the encounters (tidal radius ~ 15 kpc).

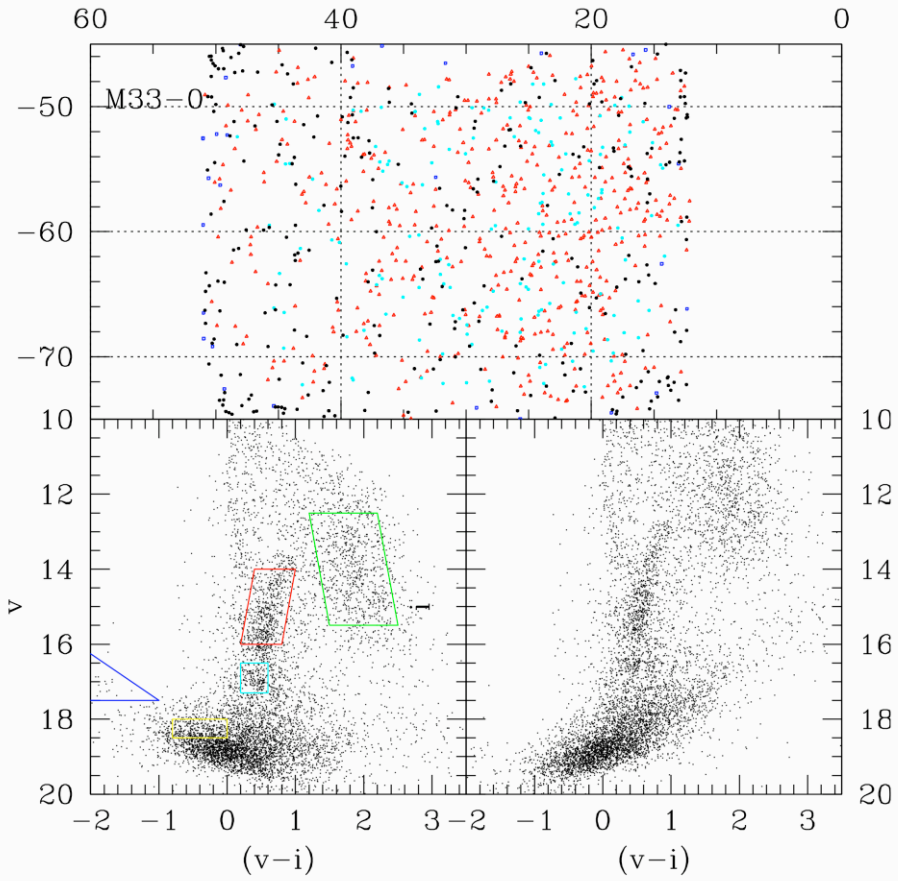
•A tidal interaction with M31 may produce the observed gaseous features. As M33 passes through the extended halo of M31, ram pressure may cause the loss of angular momentum and the gas fall back towards M33's disk (Putman et al. 2008)

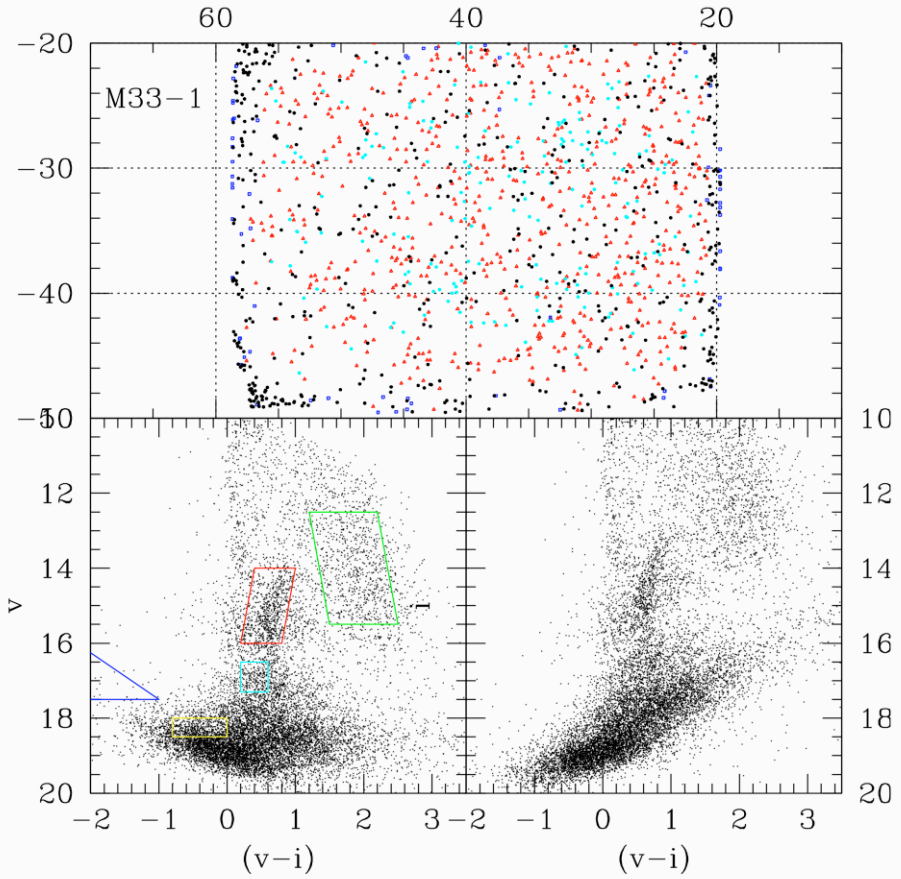


# A search for optical counterparts with Subaru/Suprime-Cam



# Preliminary Color Magnitude Diagrams



# CONCLUSIONS

1.We have detected a population of HI cloud in M33 within a projected radius of 20 kpc
2.The HI masses range within $10^4$ and $10^6$ $M_{sun}$
3. A large fraction of the gas is expected to be ionised, implying a total gas reservoir as high $10^8$ $M_{sun}$ .
4. The consequent accretion rate would be around 1 M_sun/yr

5. Possible formation scenarios include:

- Gaseous satellites confined in dark mini-halos around M33
- Remnants of a tidal encounter with M31

- Deep VI CMDs will be used to check whether the gas clouds are associated with stellar streams /substructure.