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Gas and Dark Matter in the Sculptor Group

Tobias Westmeier (ICRAR / UWA)

Pilot Observations of the Sculptor Group

Pilot Observations

- ATCA H I observations of the Sculptor Group
  - NGC 300
  - NGC 55

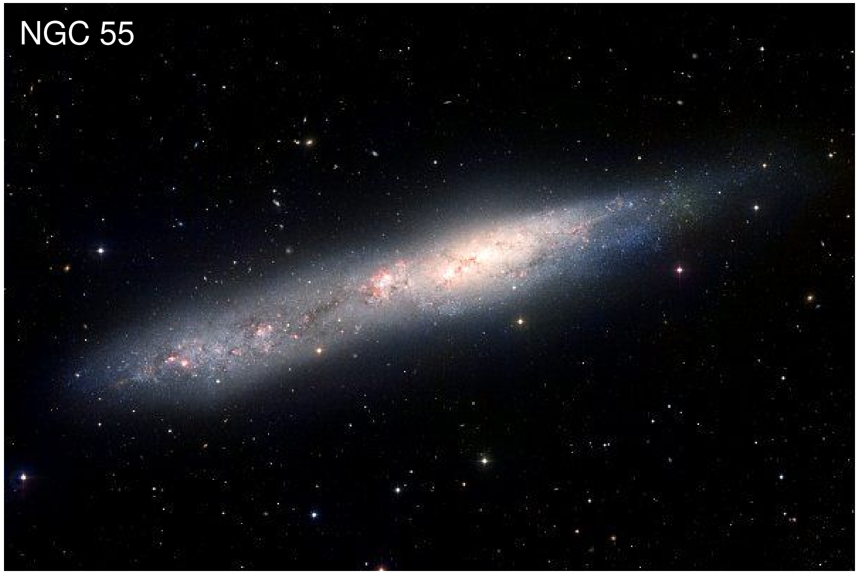


Image: ESO

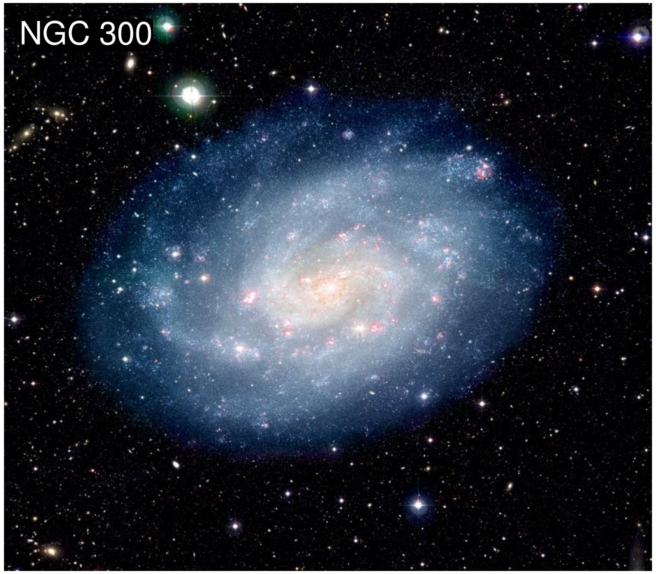


Image: ESO

Pilot Observations

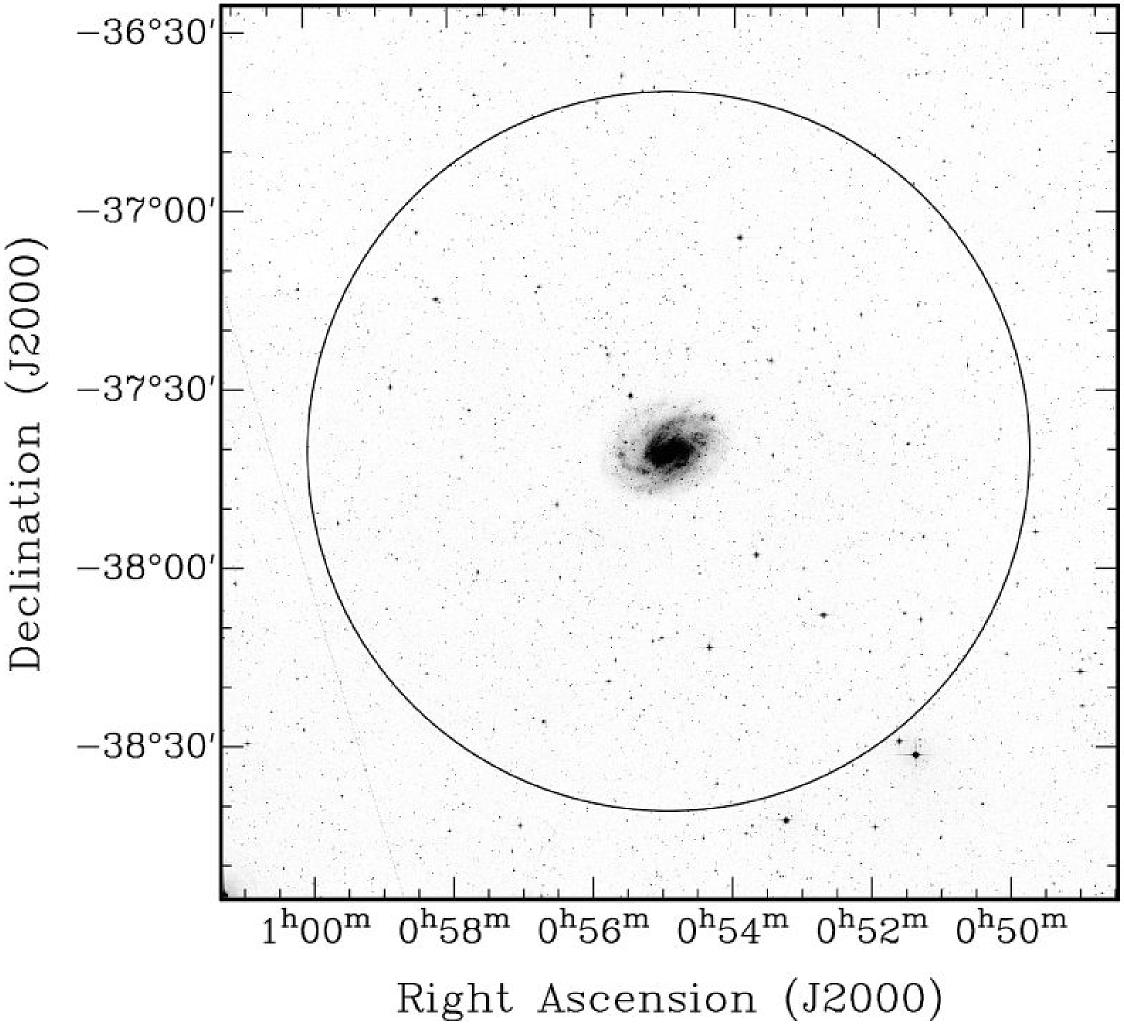
ATCA H I Observations of NGC 55 / 300

• Frequency:	1420 MHz
• Array configurations:	EW 352/367
• Covered area:	$2^\circ \times 2^\circ$
• Number of pointings:	32
• Total integration time:	96 h
• Angular resolution:	$90'' \times 180''$ 0.8×1.6 kpc
• Velocity resolution:	4 km s^{-1}
• 5σ H I sensitivity:	10^{19} cm^{-2} 10^5 $M_\odot$

Australia Telescope Compact Array

H I Observations of NGC 300

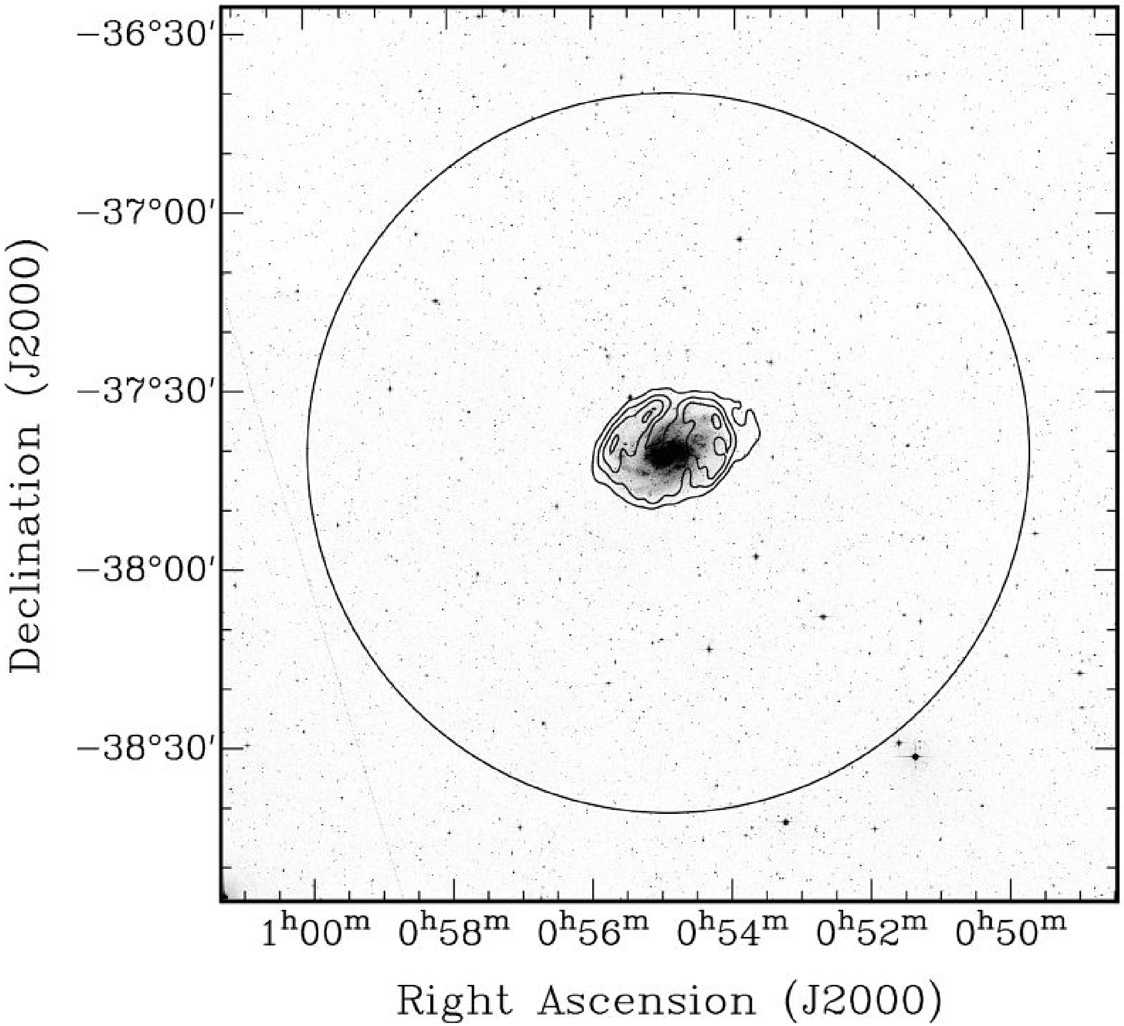
NGC 300



DSS Image of NGC 300

Westmeier, Braun & Koribalski 2010, MNRAS, in press

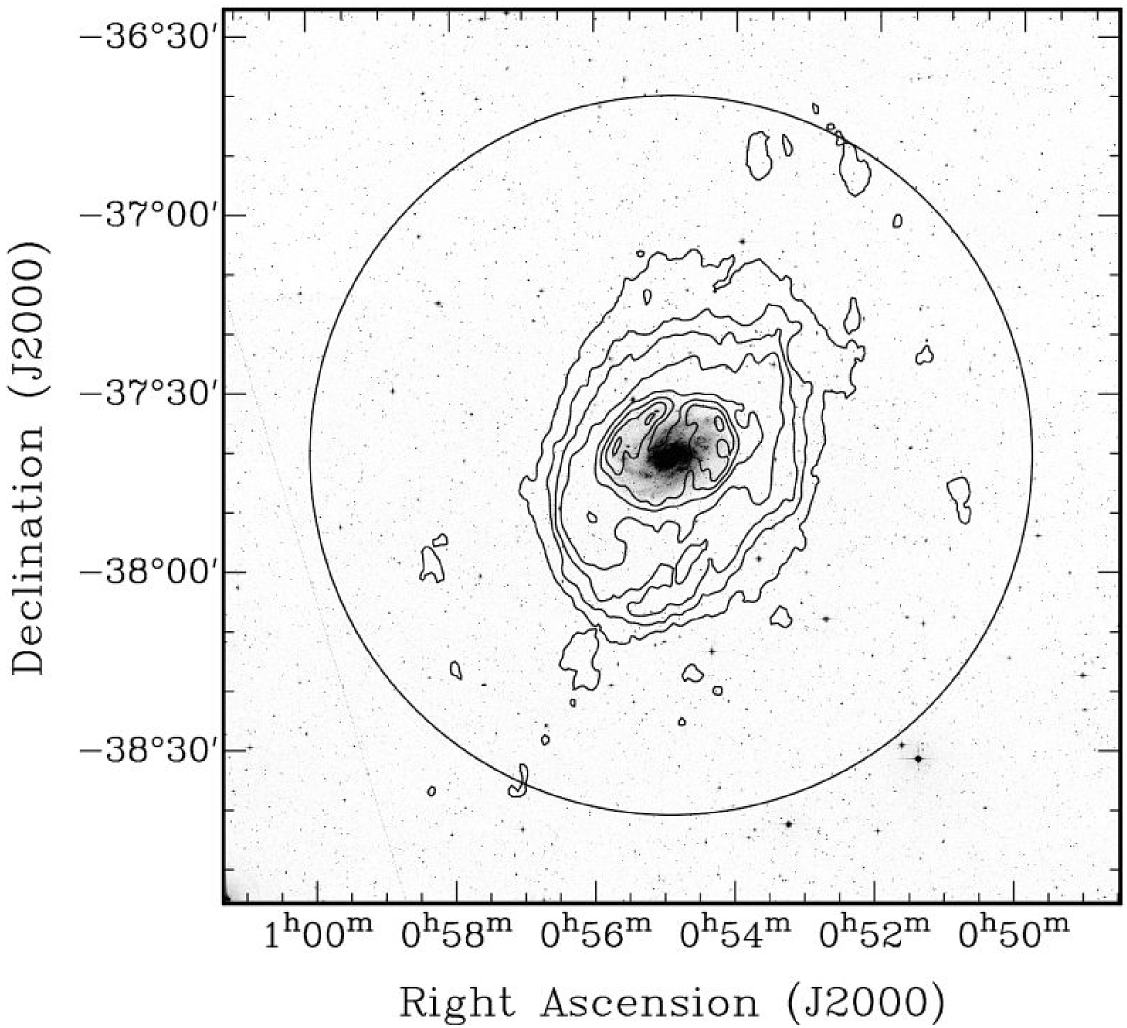
NGC 300



Lowest H I contour: $5 \times 10^{20}\ \mathrm{cm}^{-2}$

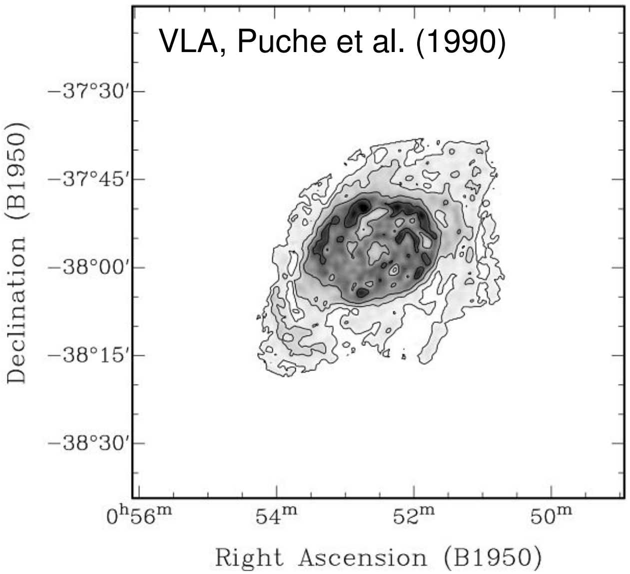
Westmeier, Braun & Koribalski 2010, MNRAS, in press

NGC 300



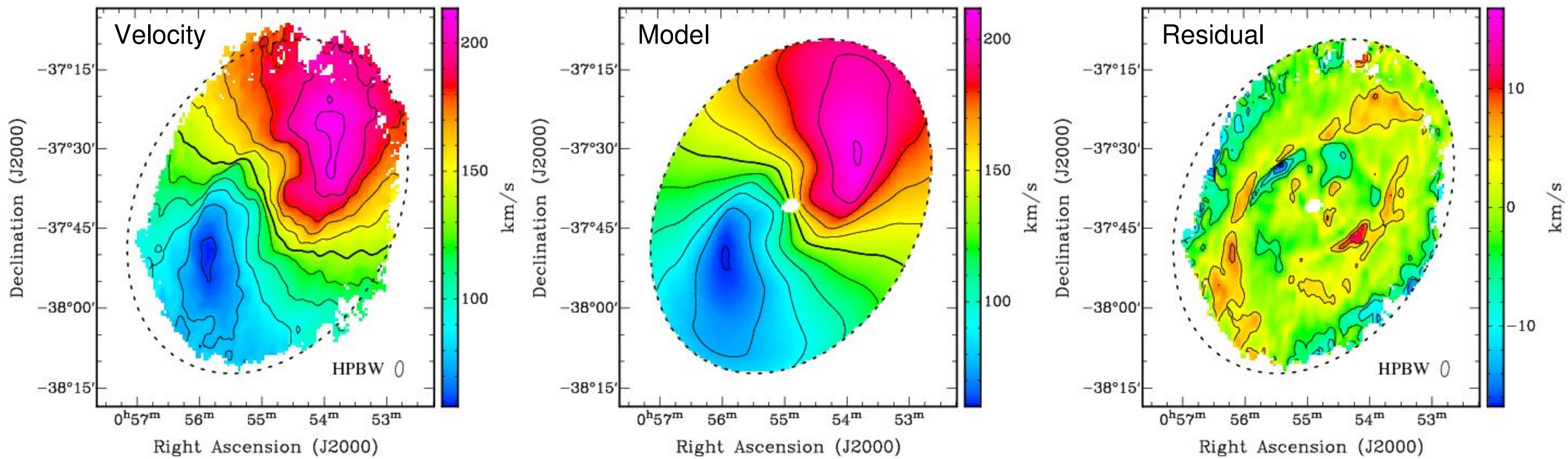
Lowest H I contour: $1 \times 10^{19}\ \mathrm{cm}^{-2}$

Very extended outer disc with different orientation angle.



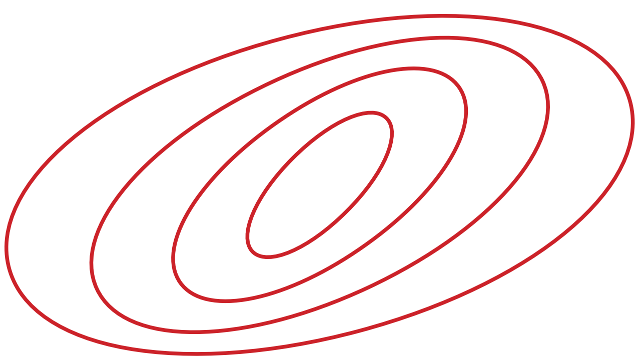
Westmeier, Braun & Koribalski 2010, MNRAS, in press

NGC 300

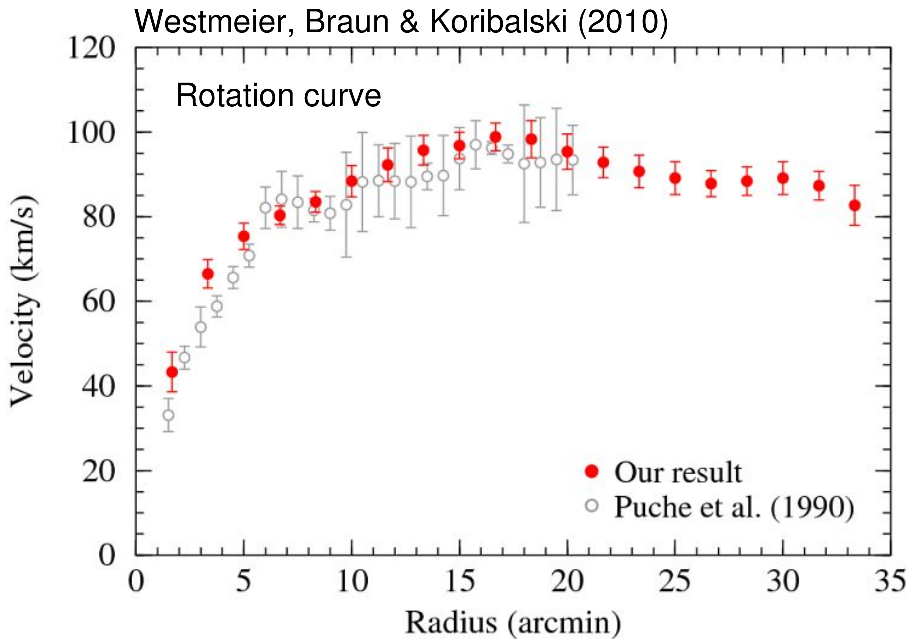


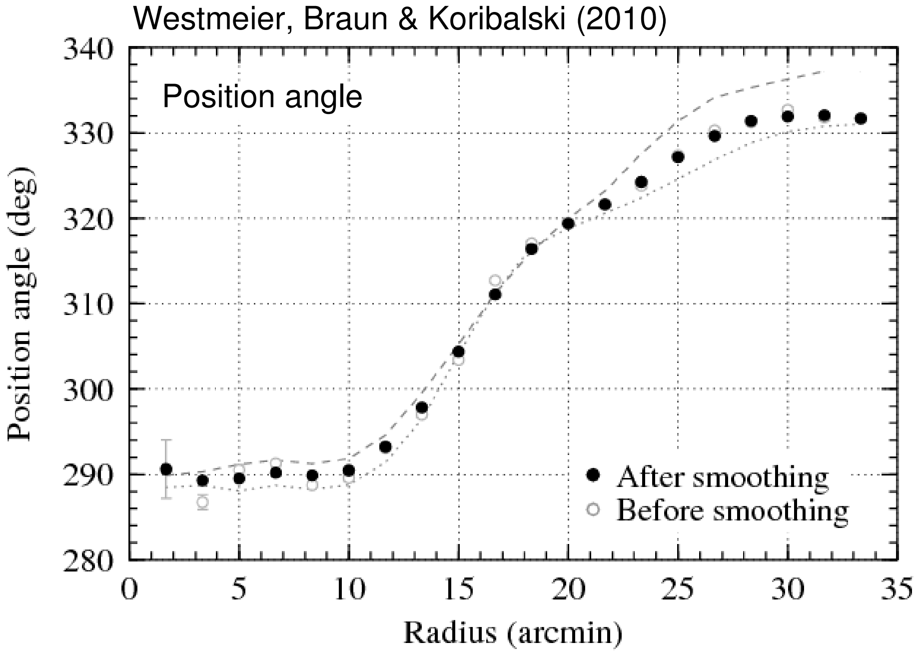
- Distortion of gas disc obvious from the velocity field.
- Fitting of tilted-ring model to velocity field to characterise disc structure.
- Radial velocity:

$$v_{\mathrm{rad}}(x,y) = v_{\mathrm{sys}} + v_{\mathrm{rot}} \sin(i) \cos(\varphi),$$
$$\varphi = \mathrm{f}(x,y,\vartheta).$$



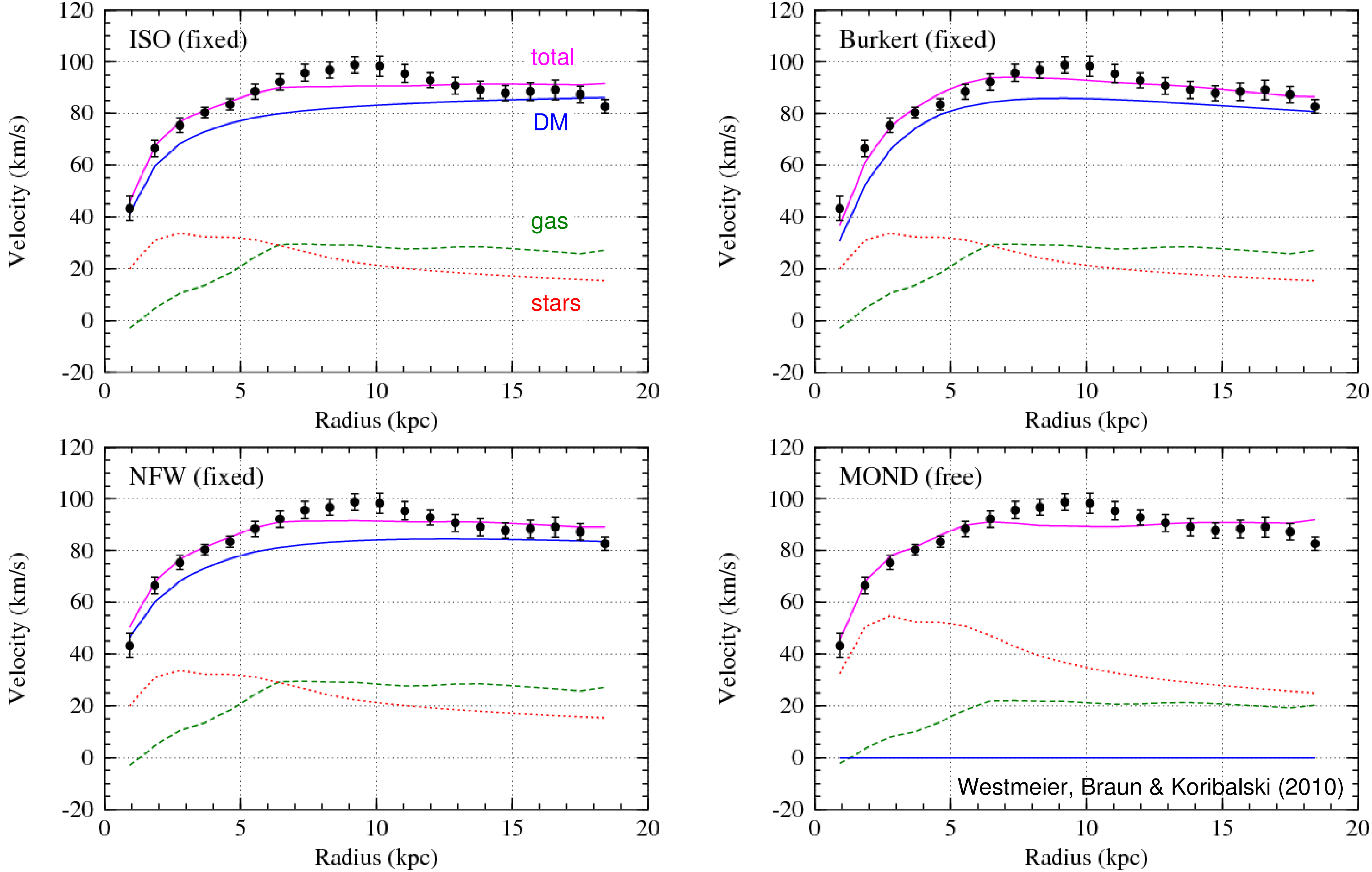
NGC 300





- Rotation curve traced out to $R \approx 20\ \mathrm{kpc}$, almost twice as far out as VLA data by Puche et al. (1990).
- Rotation curve decreases beyond $R \approx 10\ \mathrm{kpc}$.
- Mass modelling: $$v_{\mathrm{rot}}^2(r) = \underbrace{f_{\mathrm{gas}} v_{\mathrm{gas}}^2(r)}_{\textit{Gas}} + \underbrace{f_{\mathrm{stars}} v_{\mathrm{stars}}^2(r)}_{\textit{Stars}} + \underbrace{v_{\mathrm{DM}}^2(r)}_{\textit{DM}}$$

NGC 300

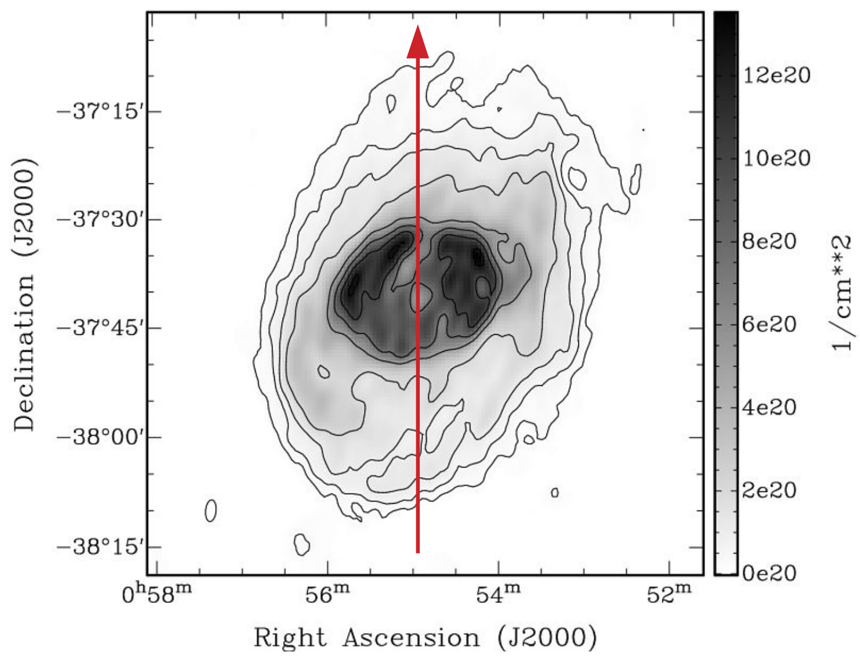

ISO (fixed)
total
DM
gas
stars
Burkert (fixed)
NFW (fixed)
MOND (free)
Westmeier, Braun & Koribalski (2010)
Velocity (km/s)
Radius (kpc)

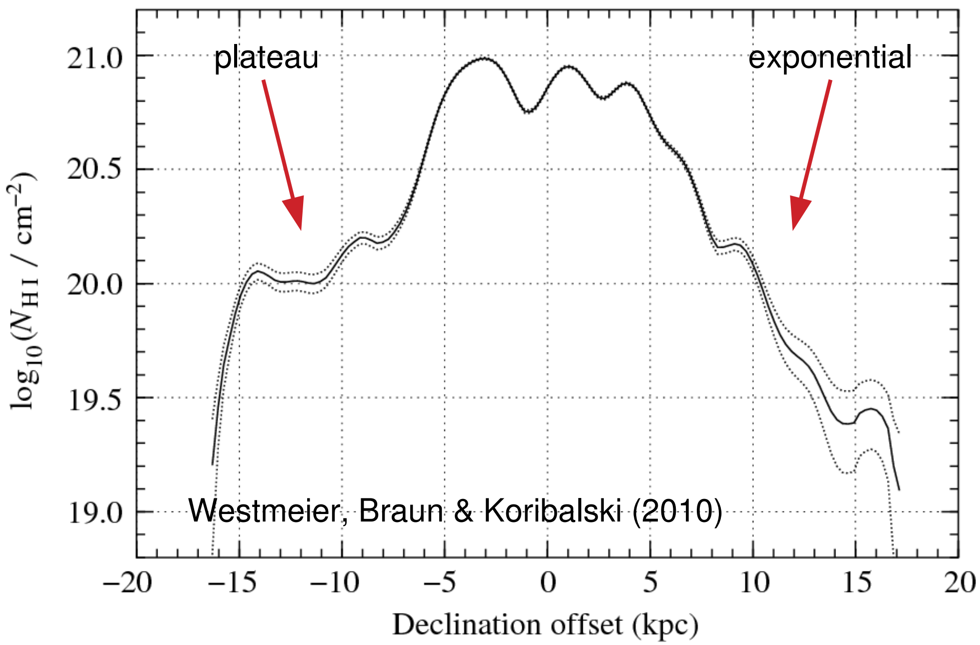
NGC 300

Halo model	$f_\star$	$f_{\rm gas}$	$r_{\rm c}$ (kpc)	ϱ_0 ($\mathrm{M_\odot\,pc^{-3}}$)	$\chi^2_{\rm red}$	$M_{\rm tot}$ ($10^{10}\,\mathrm{M_\odot}$)	$f_{\rm DM}$
ISO fixed	1	1	0.93 ± 0.14	0.170 ± 0.046	2.10	3.6	0.92
ISO gas fixed	1.6 ± 1.3	1	1.17 ± 0.61	0.107 ± 0.111	2.16	3.6	0.90
ISO free	2.3 ± 0.6	4.8 ± 1.0	0.74 ± 0.35	0.135 ± 0.119	1.17	3.3	0.65
	$f_\star$	$f_{\rm gas}$	$r_{\rm c}$ (kpc)	ϱ_0 ($\mathrm{M_\odot\,pc^{-3}}$)	$\chi^2_{\rm red}$	$M_{\rm tot}$ ($10^{10}\,\mathrm{M_\odot}$)	$f_{\rm DM}$
Burkert fixed	1	1	2.78 ± 0.14	0.081 ± 0.008	1.18	3.2	0.91
Burkert gas fixed	2.2 ± 0.9	1	3.58 ± 0.75	0.044 ± 0.021	1.20	3.3	0.88
Burkert free	3.1 ± 0.9	3.0 ± 1.4	4.04 ± 1.10	0.025 ± 0.018	1.12	3.3	0.73
	$f_\star$	$f_{\rm gas}$	$r_{\rm s}$ (kpc)	r_{200} (kpc)	$\chi^2_{\rm red}$	$M_{\rm tot}$ ($10^{10}\,\mathrm{M_\odot}$)	$f_{\rm DM}$
NFW fixed	1	1	5.81 ± 0.56	89.7 ± 2.4	1.47	3.4	0.91
NFW free	1.1 ± 1.1	3.9 ± 1.0	4.00 ± 1.53	71.9 ± 6.7	0.95	3.3	0.74

Westmeier, Braun & Koribalski (2010)

NGC 300



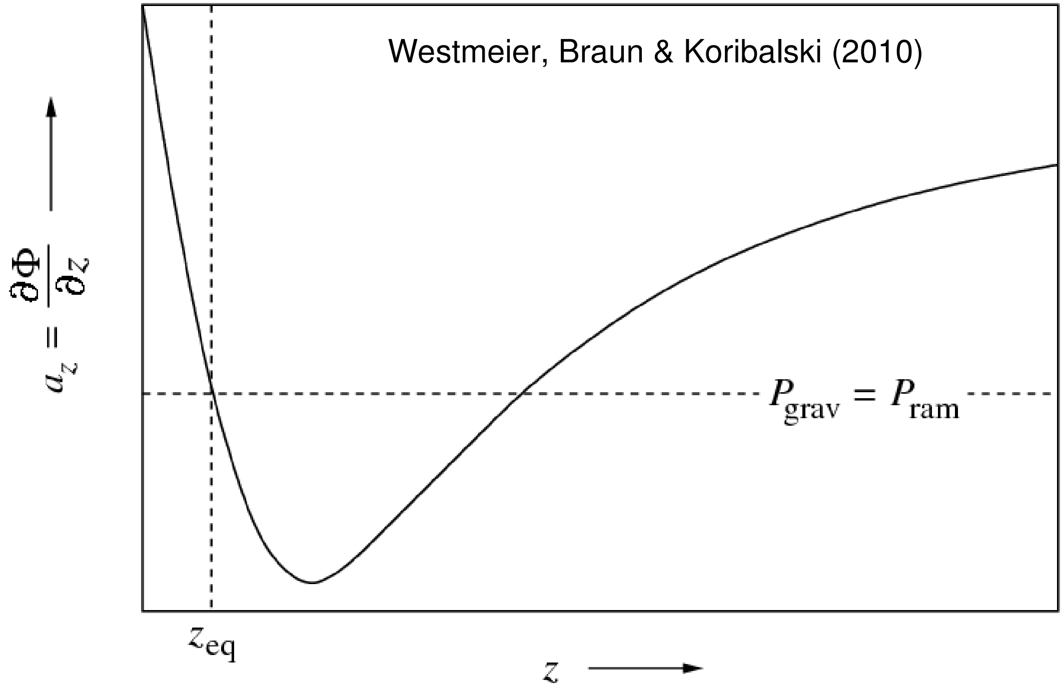


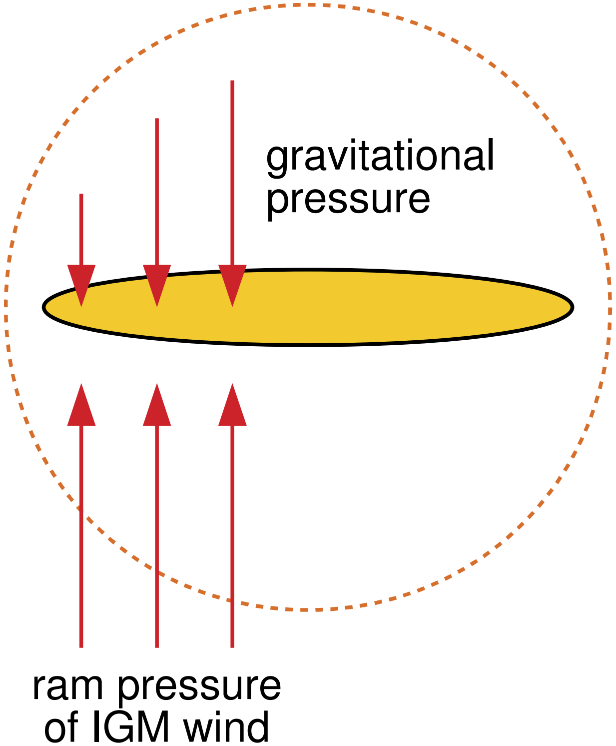
- Strong asymmetries in the H I disc of NGC 300.
- South-eastern edge sharp and smooth.
- North-western edge broad and ragged.
- Possible explanation: ram-pressure interaction while NGC 300 is moving through intergalactic medium.

Ram-pressure Stripping

Ram pressure: $P_{\text{ram}} = \varrho_{\text{IGM}} v^2$

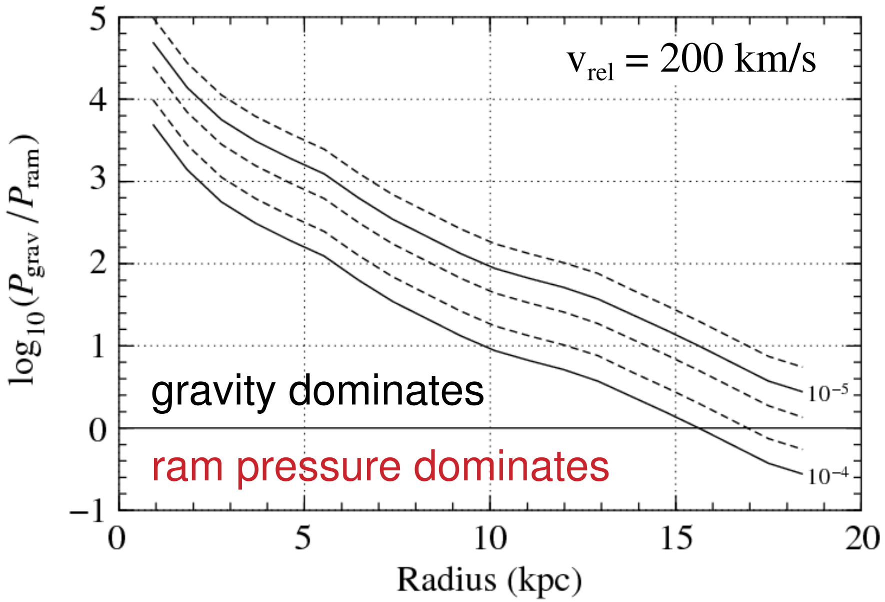
Gravitational pressure: $P_{\text{grav}} = \Sigma_{\text{gas}}(r) \left| \frac{\partial \Phi(r)}{\partial z} \right|_{\text{max}}$

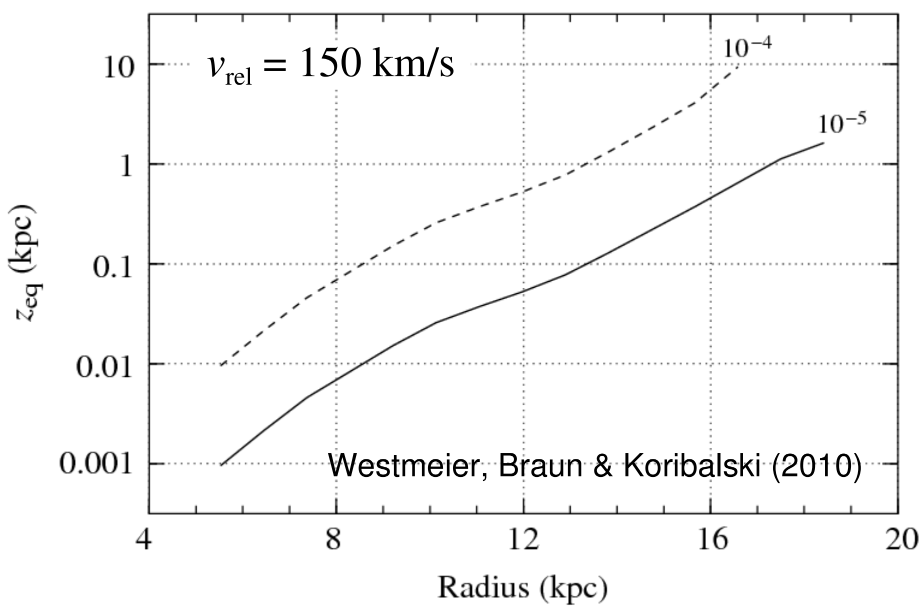




Face-on situation, but valid for inclination angles of up to 60° (Rödiger et al. 2005).

NGC 300

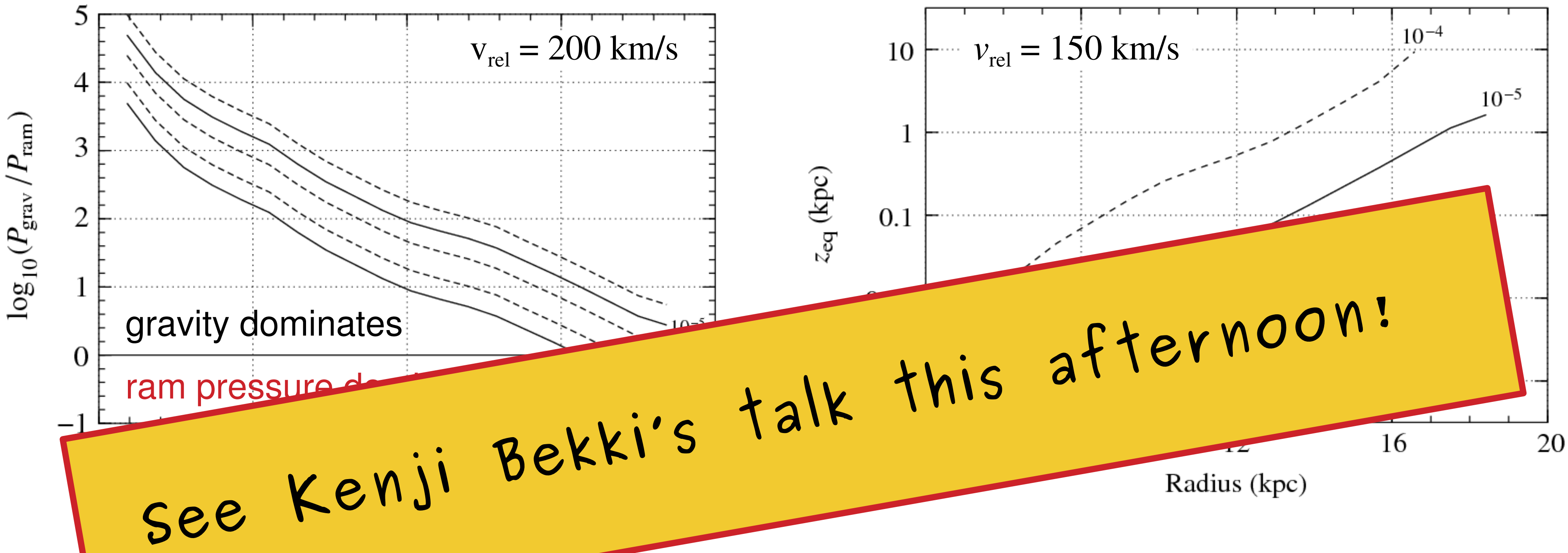




Ram-pressure stripping does occur in galaxy groups (not only in clusters) at reasonable assumptions on the IGM density (10^{-4} to 5×10^{-6} cm^{-3}) and relative velocities (100 to 300 km/s).

- It affects the faint outer gas discs of galaxies and possibly contributes to the warping observed in many galaxies (U-shaped warps?).
- A systematic study of ram-pressure stripping + simulations can be used as a probe to constrain the density of the IGM in galaxy groups.

NGC 300



Ram[illegible]pping does occur in galaxy groups (not only in clusters) at reas[illegible]able assumptions on the IGM density (10^{-4} to 5×10^{-6} cm^{-3}) and relative velocities (100 to 300 km/s).

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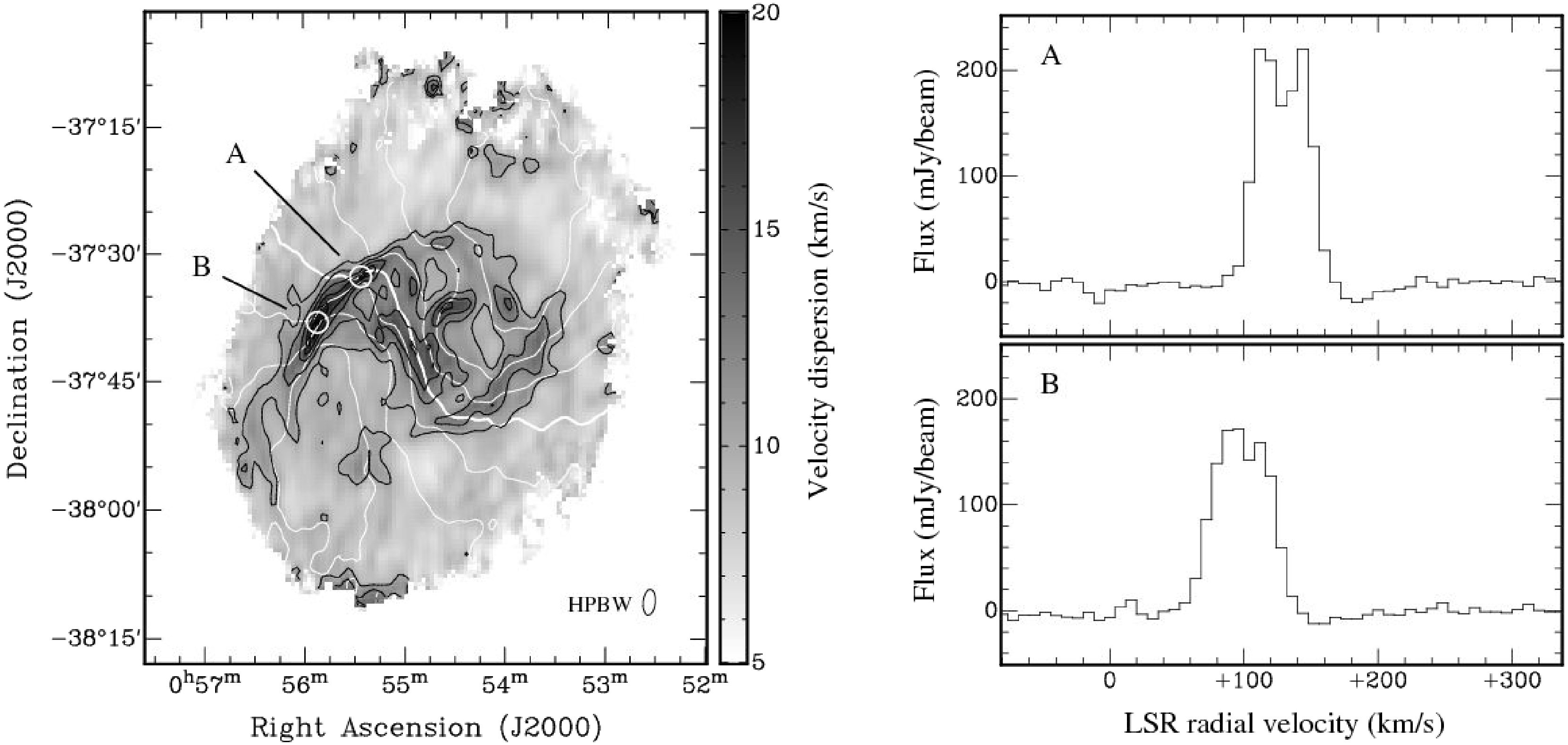
NGC 300

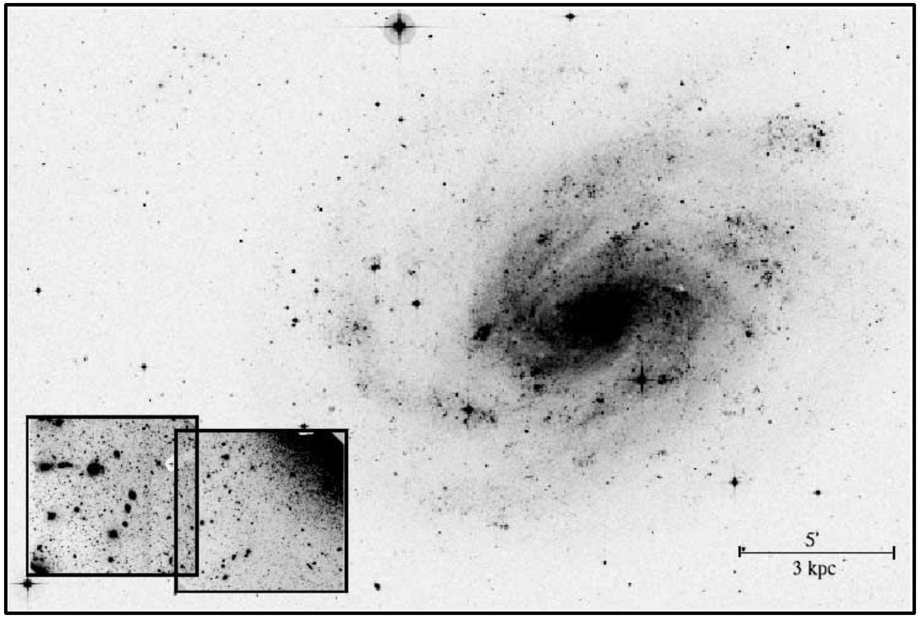


Westmeier et al. (2010)

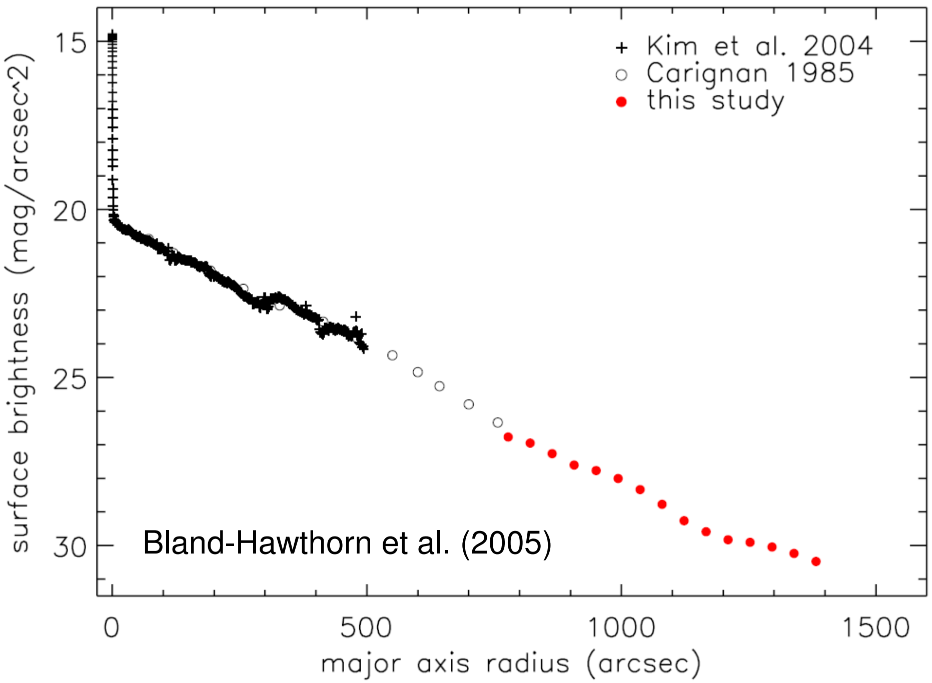
- High dispersion of $\sigma \approx 20\ \mathrm{km\,s^{-1}}$ along boundary between inner and outer disc of NGC 300.
- Double-peak profile indicates sudden transition from inner to outer disc within beam size of $\simeq 1$ kpc.

Comparison with Stellar Disc

- Optical observations of outer disc by Bland-Hawthorn et al. (2005) with the Gemini South 8-m telescope.
- Stellar disc of NGC 300 detected out to 14 kpc in two targeted fields.
- Stellar disc exponential across entire radial extent without deviation or break.



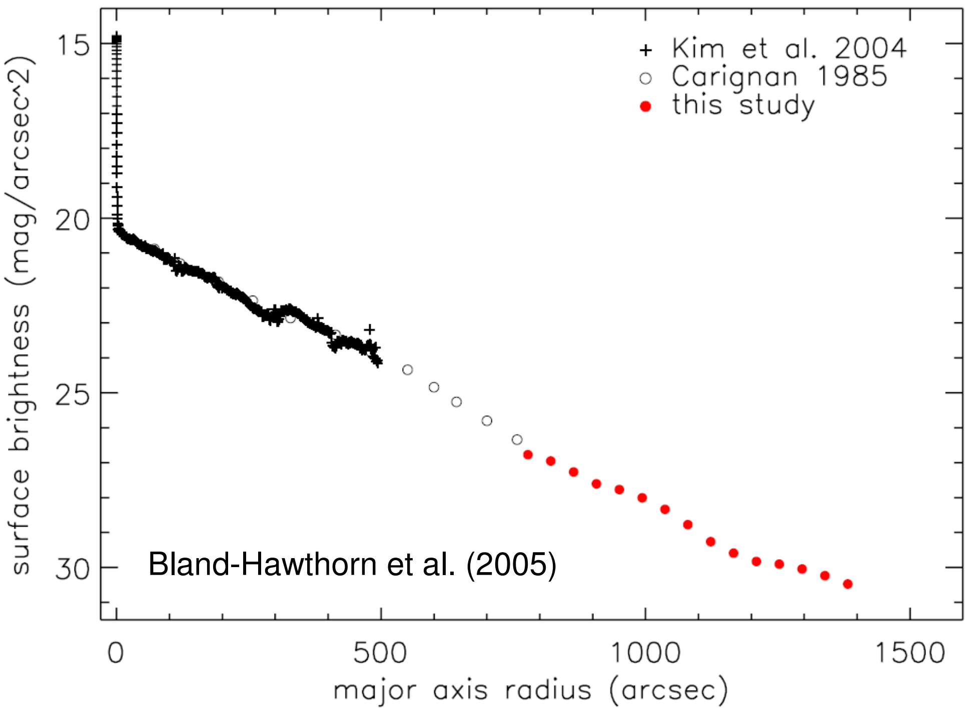
Bland-Hawthorn et al. (2005)

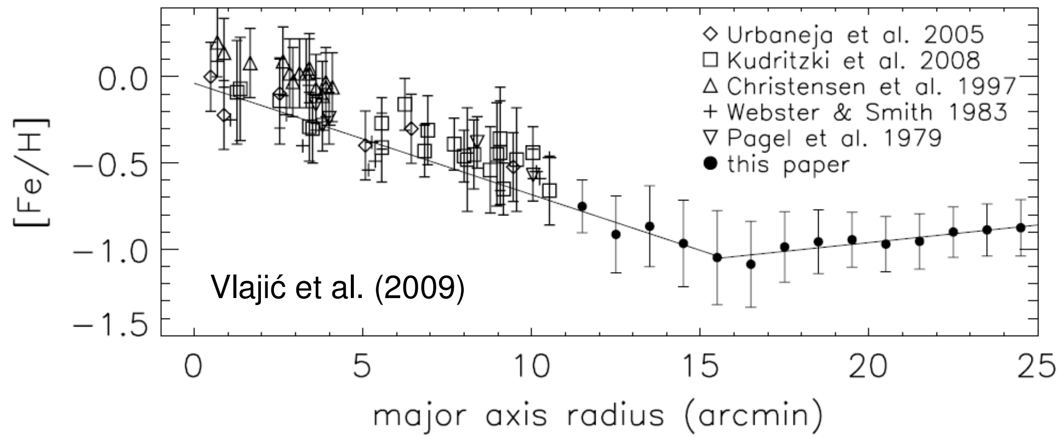


NGC 300

Comparison with Stellar Disc

- Strong radial metallicity gradient (Vlajić et al. 2009) with break near boundary between inner and outer H I disc.
- Possible explanations:
  - Star formation activity only in the inner disc, but radial mixing of stars in the disc.
  - Star formation activity slowly progressing outwards.
- Outer gas disc does not play significant role, consistent with old age of stars ($\gtrsim 1$ Ga).





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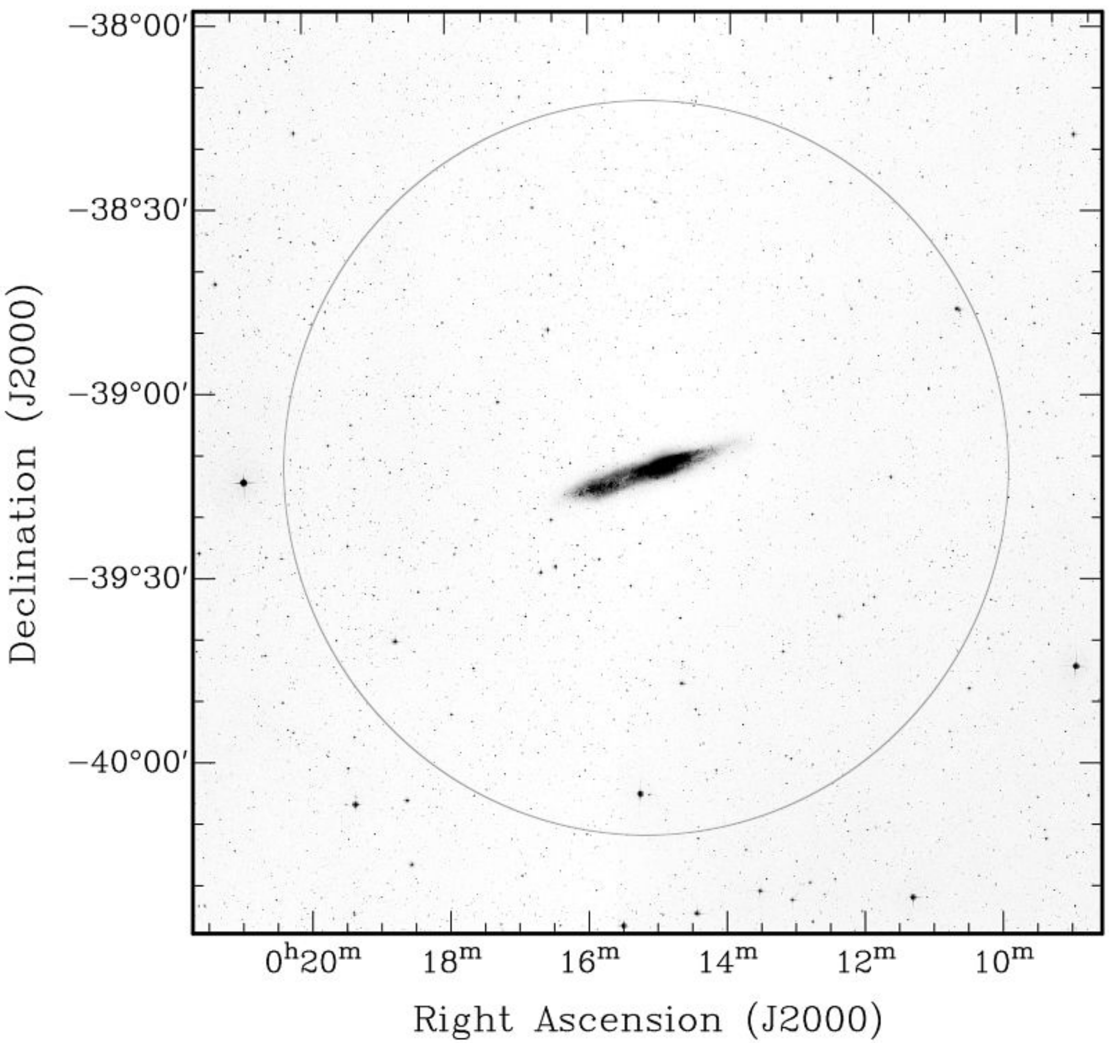
H I Observations of NGC 55

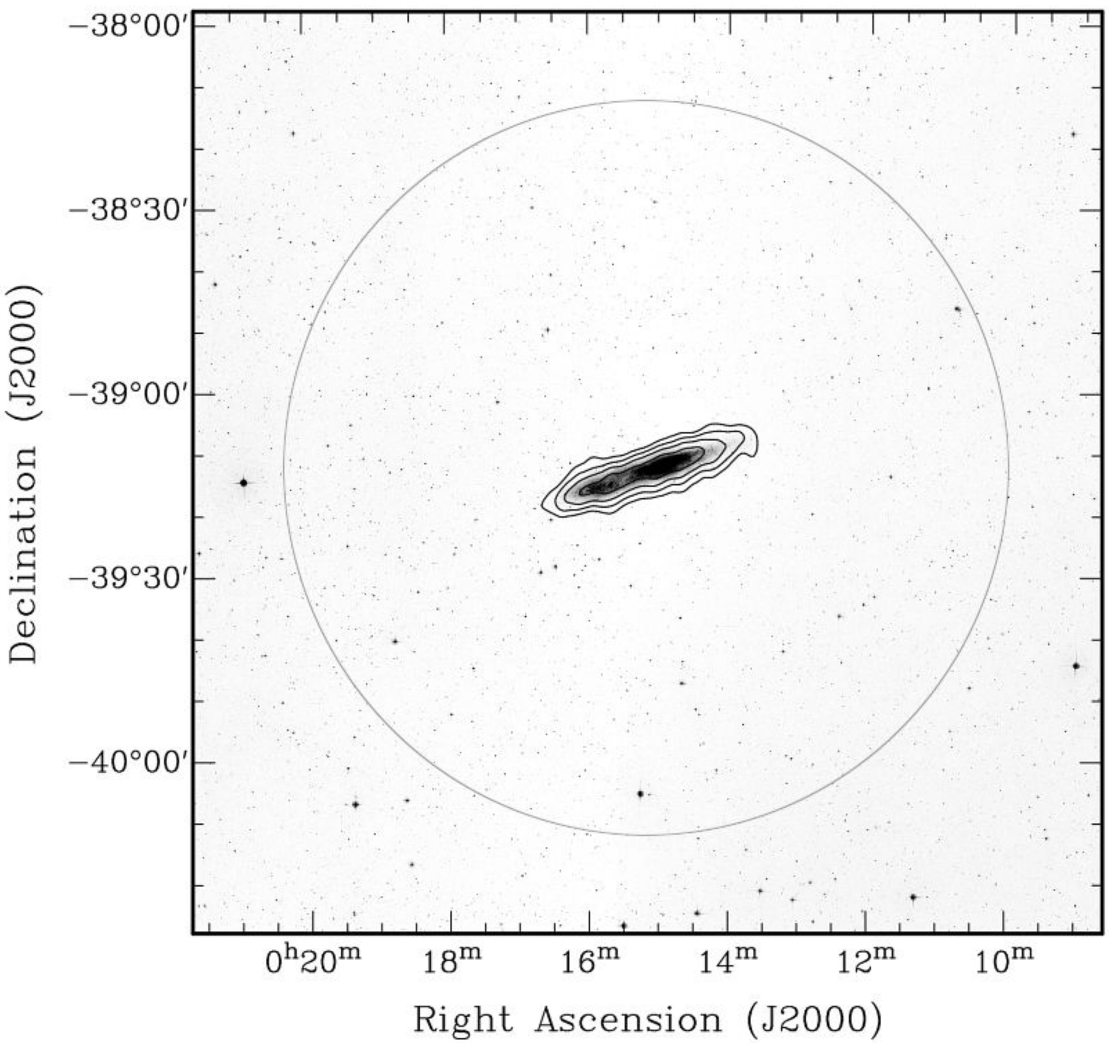
NGC 55



DSS Image of NGC 55

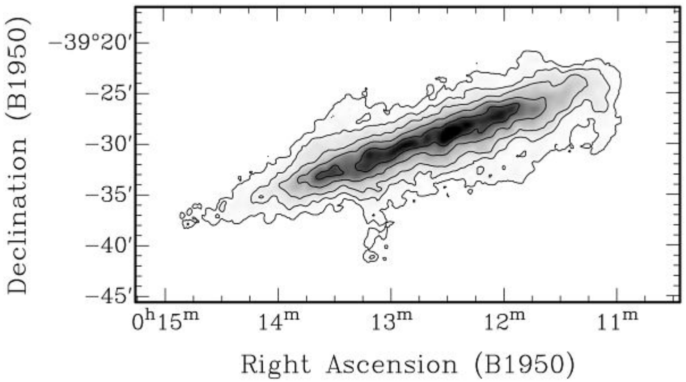
Westmeier et al., in prep.

NGC 55



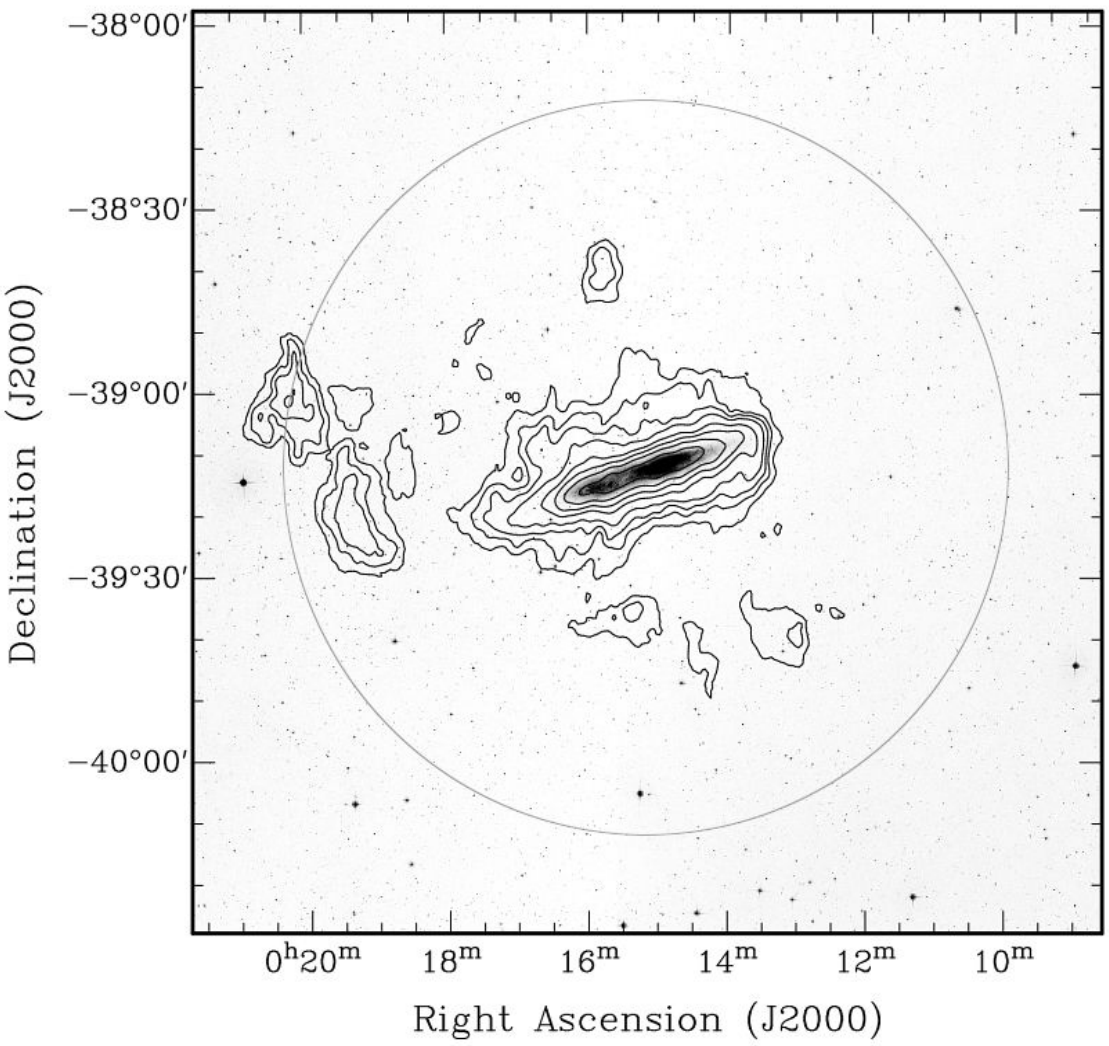
Westmeier et al., in prep.

Lowest H I contour: $5 \times 10^{20}\ \mathrm{cm}^{-2}$



VLA image, Puche et al. (1991)

NGC 55

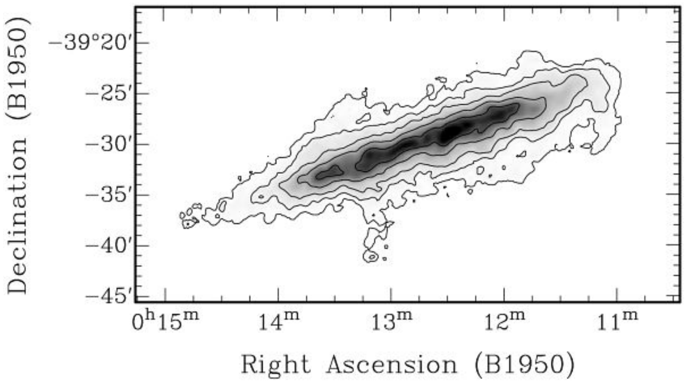


Westmeier et al., in prep.

Lowest H I contour: $1 \times 10^{19}\ \mathrm{cm}^{-2}$

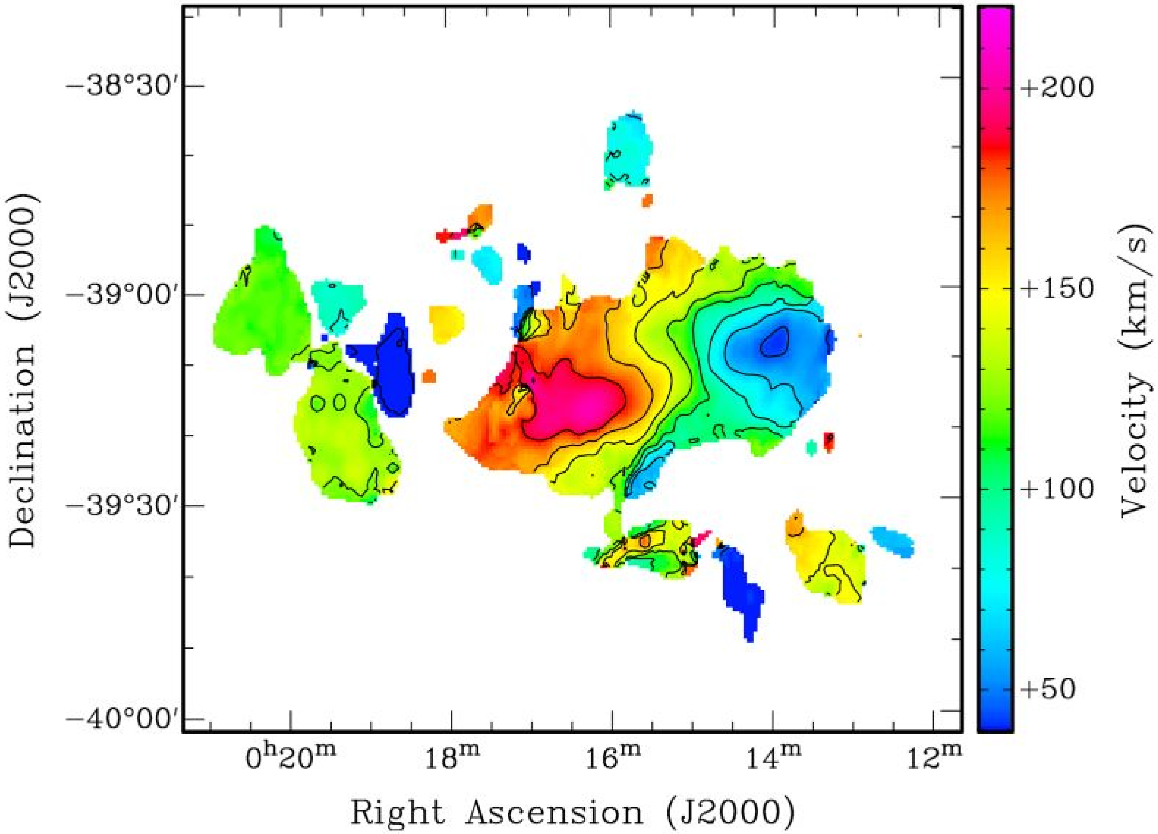
H I image of NGC 55 looks very distorted.

Extended regions of extra-planar gas as well as isolated gas clouds or HVCs of a few times $10^6\ M_\odot$.

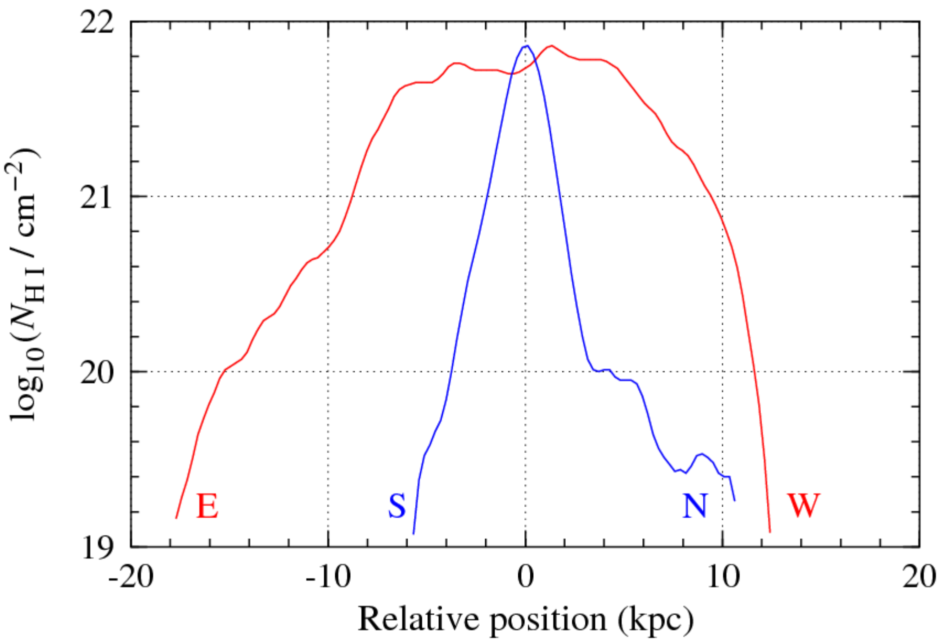


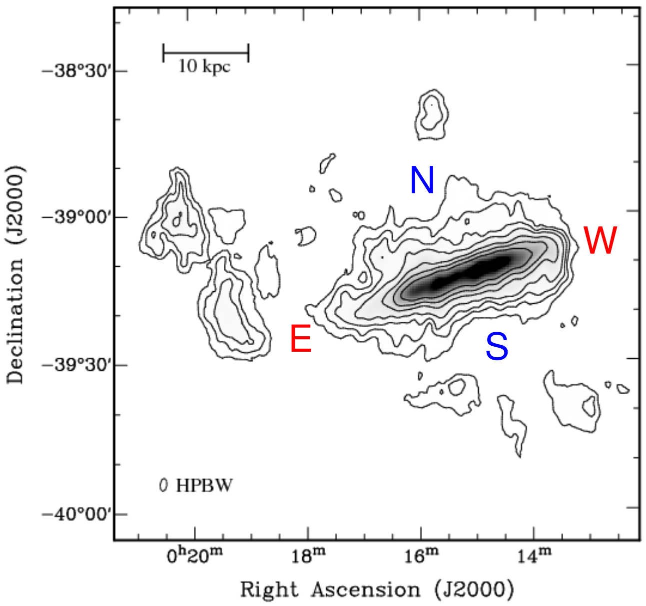
VLA image, Puche et al. (1991)

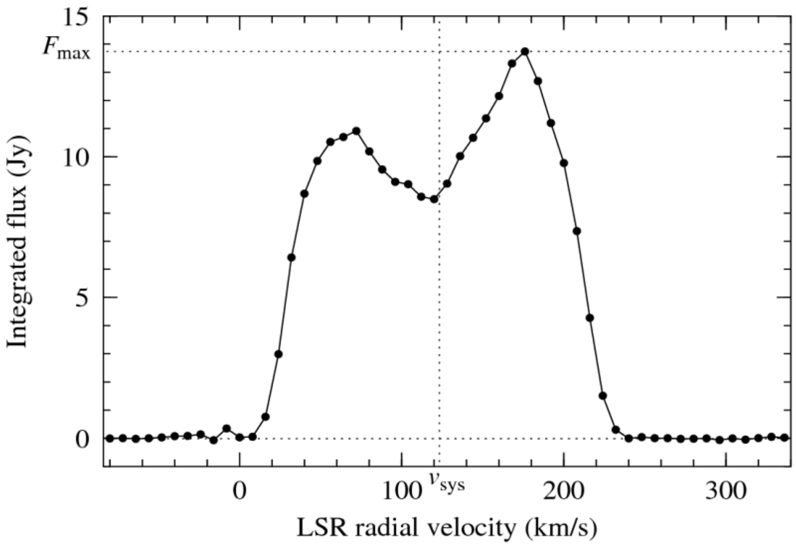
Velocity Field



- Complex velocity field with s-shaped isotachs:
  - Extended disc most likely due to warp, not outflows or extra-planar gas.
  - Velocities of isolated gas clouds different from disc gas.

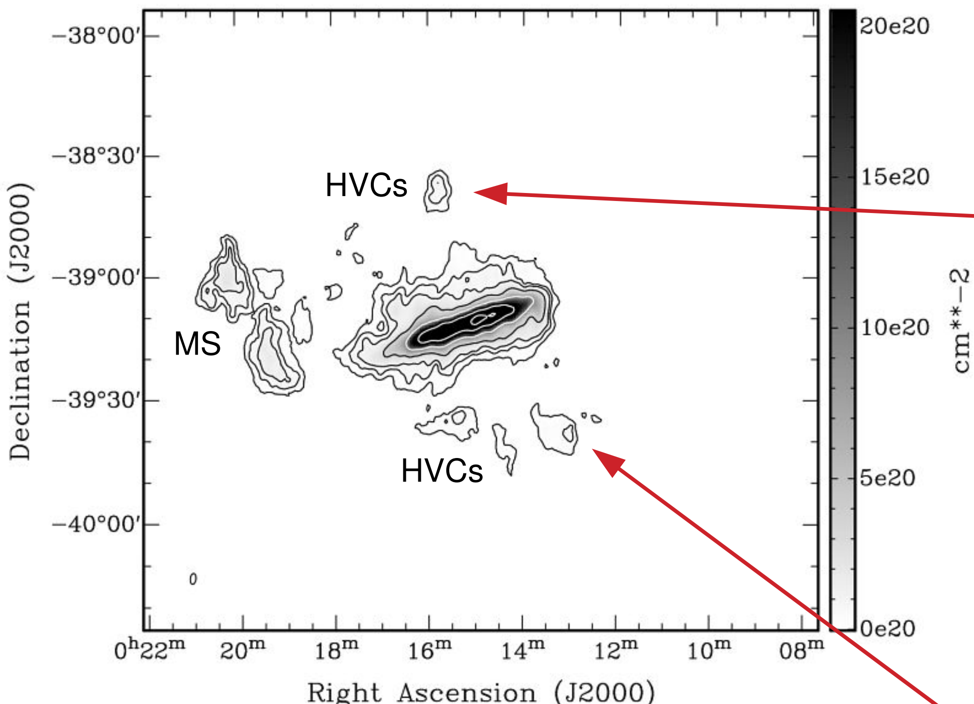


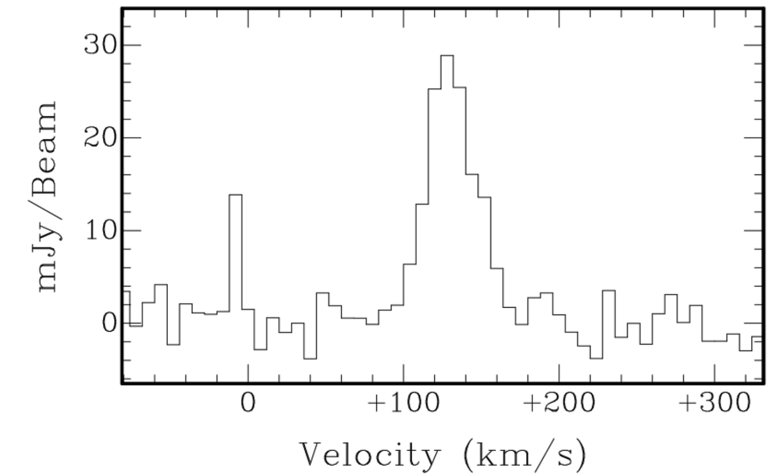


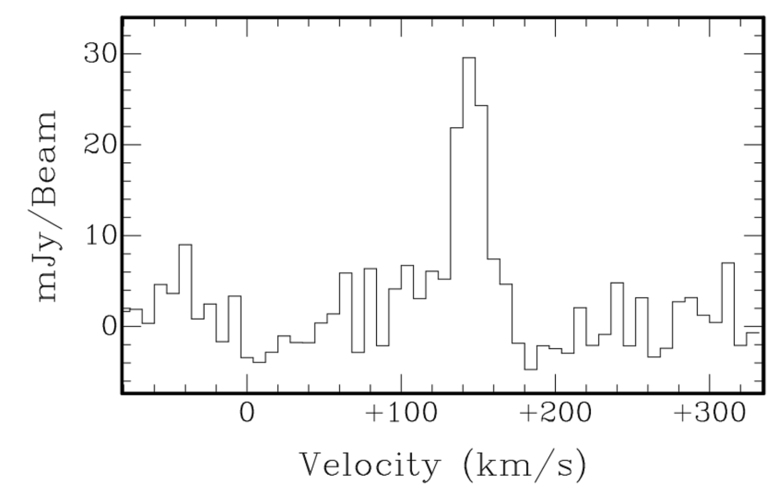


- Strong asymmetry in $N_{\rm H\,I}$ profile:
  - *East:* Exponential with $a = -0.18$.
  - *West:* Steeper than exponential.
- Asymmetry also along minor axis.
- Integrated spectrum asymmetric too.

NGC 55







- Several isolated H I clouds all around NGC 55.
- H I masses typically $5 \times 10^6 M_\odot$.
- Velocity dispersions of $\sigma \approx 10 \ldots 20$ km/s.

NGC 55

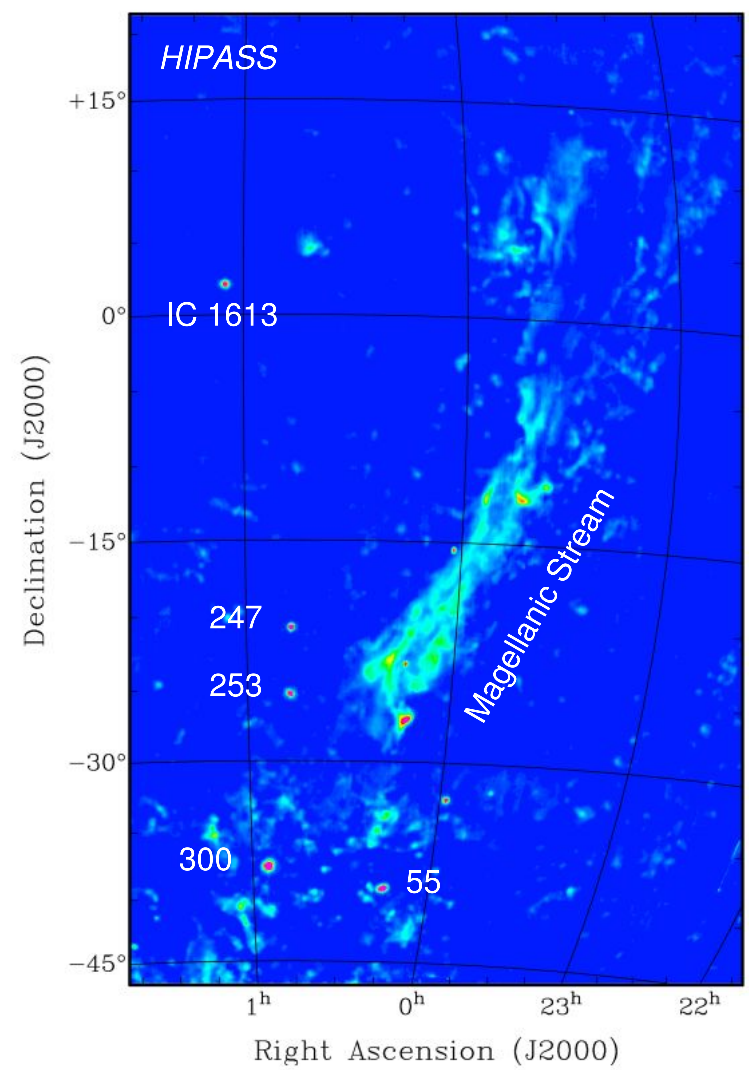
NGC 55 or Foreground?

Two possibilities:

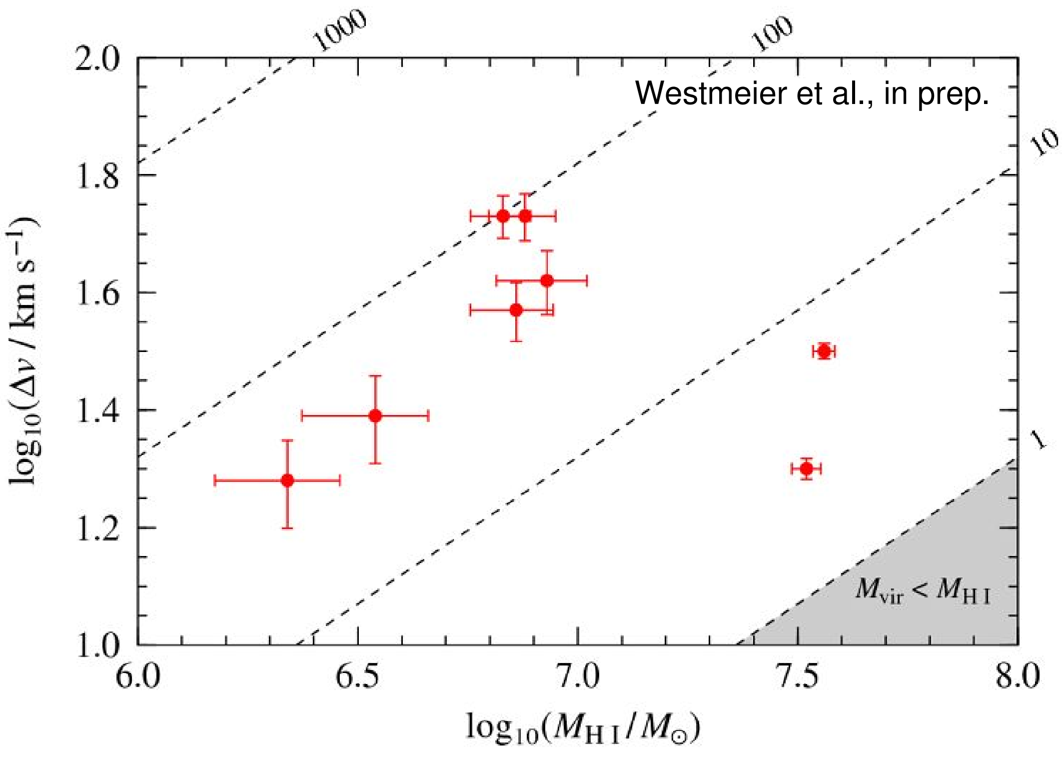
- Clouds are at the distance of NGC 55.
- Clouds are foreground from Milky Way or Magellanic Stream.

Virial mass vs. H I mass

- Virial mass: $M_{\mathrm{vir}} \propto \langle v^2 \rangle R \propto d$
- H I mass: $M_{\mathrm{H\,I}} \propto F_{\mathrm{int}} d^2 \propto d^2$
- Mass ratio: $\alpha \equiv \frac{M_{\mathrm{vir}}}{M_{\mathrm{H\,I}}} \propto d^{-1}$

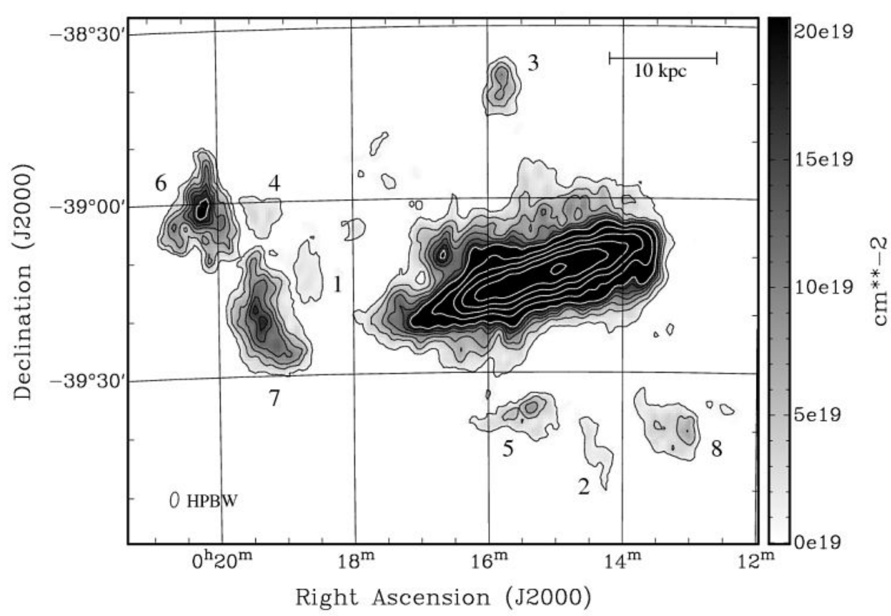


NGC 55



Virial-to-H I mass ratio

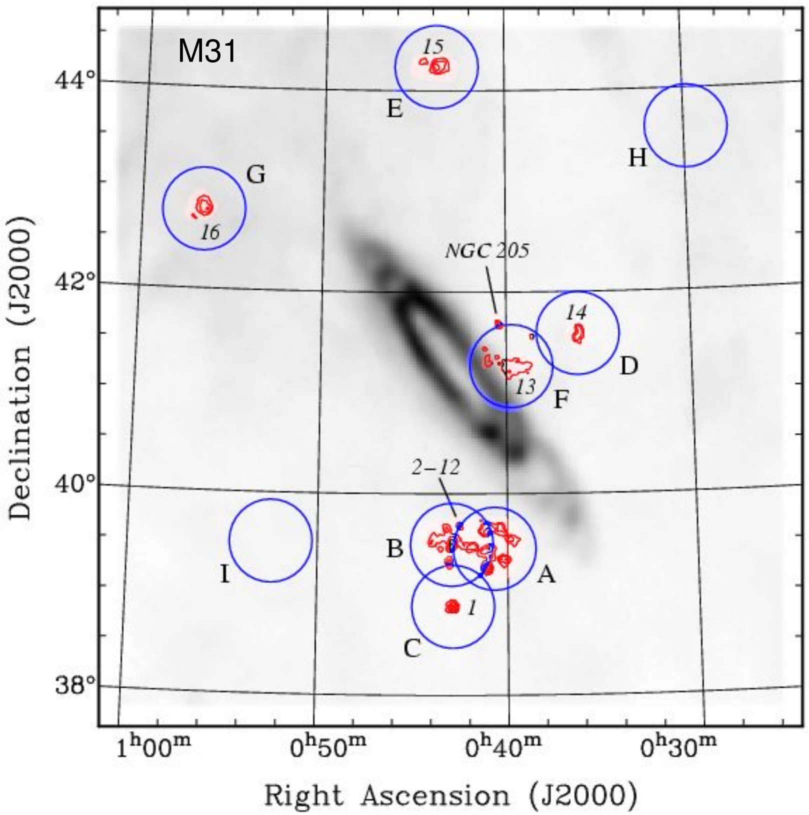
$\alpha \equiv M_{vir} / M_{H I}$



Values of $\alpha = 50$ to 100 for six clouds, but well below 10 for remaining two.

Origin of the Gas Clouds

- Origin of NGC 55 clouds currently unknown.
- Similar populations observed around other galaxies, including
  - M31 (Thilker at al. 2004, Westmeier et al. 2005, 2009)
  - M83 (Miller et al. 2009)
  - MW high-velocity clouds
- Possibly combination of different origins, including
  - Gaseous satellites
  - Outflows
  - Tidal stripping



Westmeier, Braun & Thilker (2005)
Westmeier, Brüns & Kerp (2009)

H I Observations of NGC 55 / 300

- NGC 300
  - Extended, warped H I disc with decreasing rotation curve.
  - Evidence of ram-pressure stripping by the IGM in the Sculptor group.
  - Low metallicities in the outer disc indicate lack of star formation.
- NGC 55
  - Extended, asymmetric H I disc, presumably the result of warping.
  - Population of circumgalactic H I clouds with $M_{\rm H\,I} \simeq 10^6\,M_\odot$.
- Questions arising
  - Origin of warp?
  - Origin of circum-galactic gas clouds?
  - Role of ram-pressure stripping in groups?
- WALLABY will enable us to study these questions with the help of a large sample of galaxies.

Summary

Weather Forecast for the Sculptor Group

"Mainly sunny throughout most of the Sculptor group with a few clouds near NGC 55.

Strong winds of up to 4×10^5 knots in central parts of the Sculptor group."