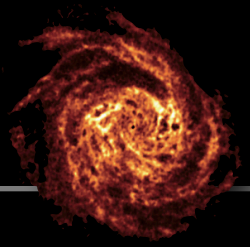
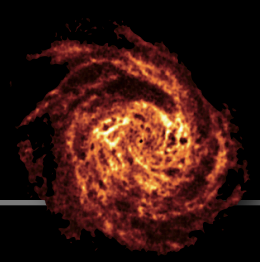


Cold Gas in Galaxies

a concise HI perspective

Marc Verheijen

university of groningen / Kapteyn Astronomical Institute

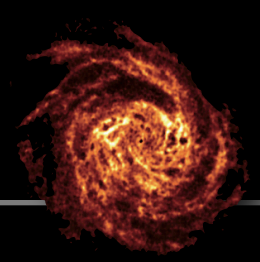


Characteristics of HI imaging data

A limited number of 21cm aperture synthesis imaging telescopes.

array	dishes	T_{sys}	BL_{min}	BL_{max}	configuration	Θ
EVLA	27x 25m	35 K	35 m	36 km	Y zoomable	1.3"
WSRT	14x 25m	27 K	36 m	2.7 km	EW moveable	15"
GMRT	30x 45m	73 K	100 m	25 km	Y fixed	2"
ATCA	6x 22m	22 K	31 m	6.0 km	EW zoomable	6"

Field-of-view : 20' – 40' FWHM
Useful resolutions : 5"– 45" x few km s^{-1}
Column density sensitivities : $N_{HI} \approx 10^{19} - 10^{22}$ atoms cm^{-2}
HI mass limits : $M_{HI} \approx 10^{6}$ M_{sun} at D=10 Mpc
Maximum redshifts : Z<0.25



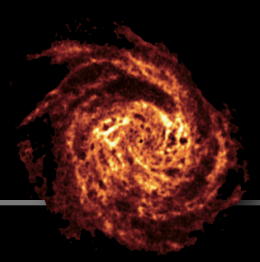
major HI imaging surveys

Targeted Surveys of selected samples:

- WHISP (350) northern spirals with F>100 mJy
- VIVA (53) SFR-selected Virgo spirals
- UMa (85) Ursa Major group with $M_B < -18.5$
- THINGS (34) HI follow-up of SINGS sample
- LittleTHINGS (42) Local dIm and BCDs
- FIGGS (47) Faint Irregular galaxies
- ATLAS^{3D} (166) HI follow-up of northern early-types
- HALOGAS (22) the deepest HI survey of spirals
- VLA-ANGST (36) HI follow-up of HST/ACS survey

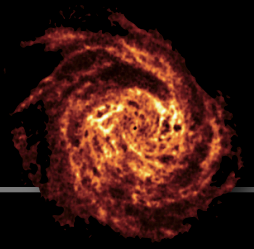
Blind Surveys of different environments:

- Coma (WSRT)
- Perseus-Pisces (VLA)
- Ursa Major (VLA)
- CVn (WSRT)



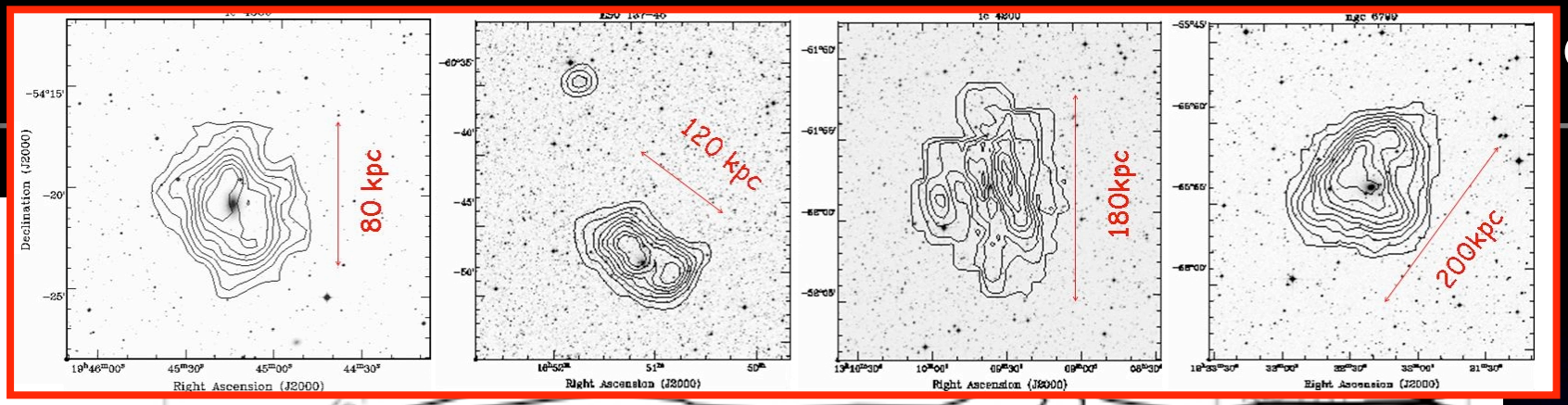
HI science topics

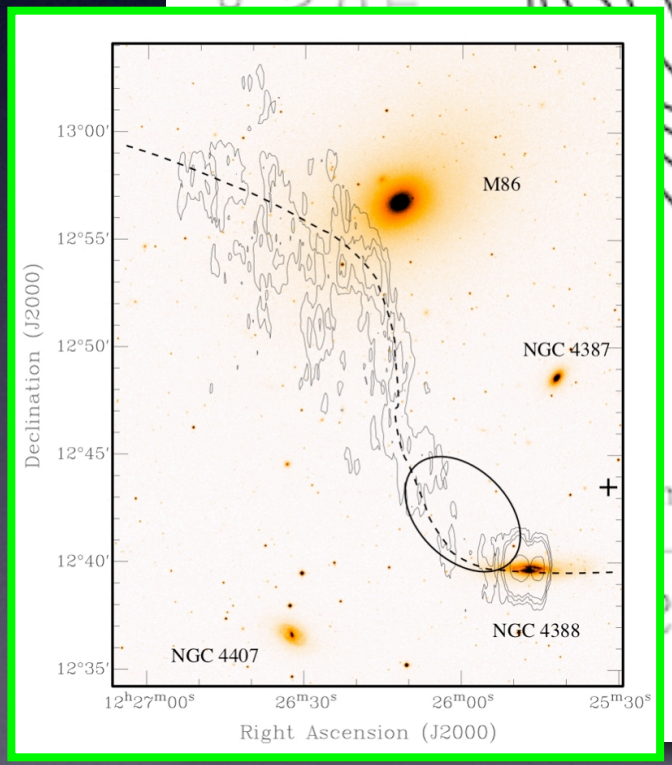
- Galactic and galaxy structure & kinematics.
  - the ISM, warps, lopsidedness, rotation curves, angular momentum, non-circular motions...
- Accretion and depletion of gas onto galaxies.
  - minor mergers, cold accretion, ram-pressure stripping, outflows and feedback...
- Formation of galaxies and large scale structure.
  - HIMF, major mergers, spin alignments, void population, cosmic web, TF distances...
- Cosmic evolution of gas in galaxies.
  - $\Omega_{HI}(z)$, gas fractions vs mass, role of gas in downsizing...



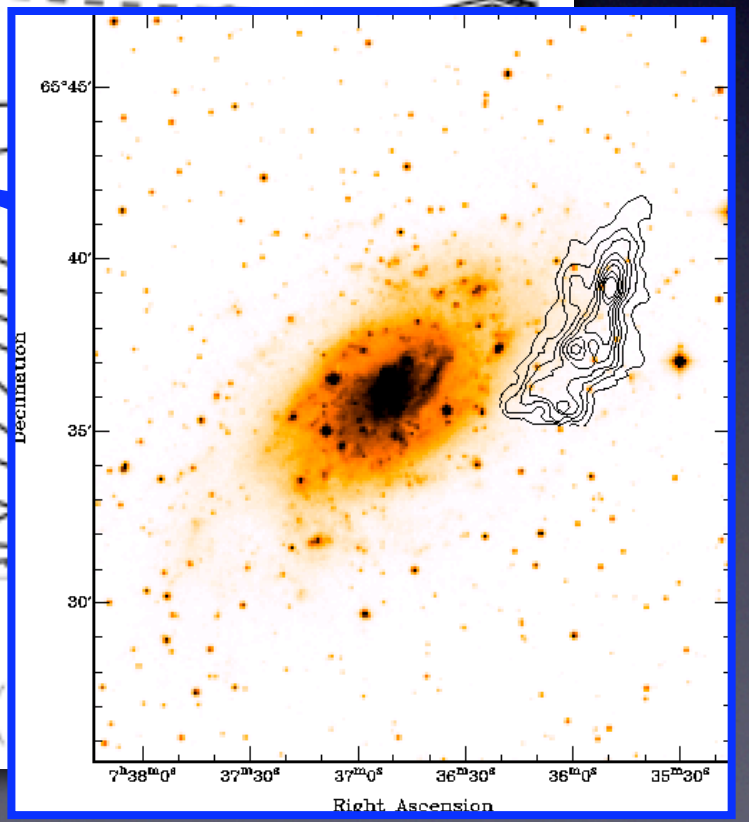
Oosterloo et al 2007

on





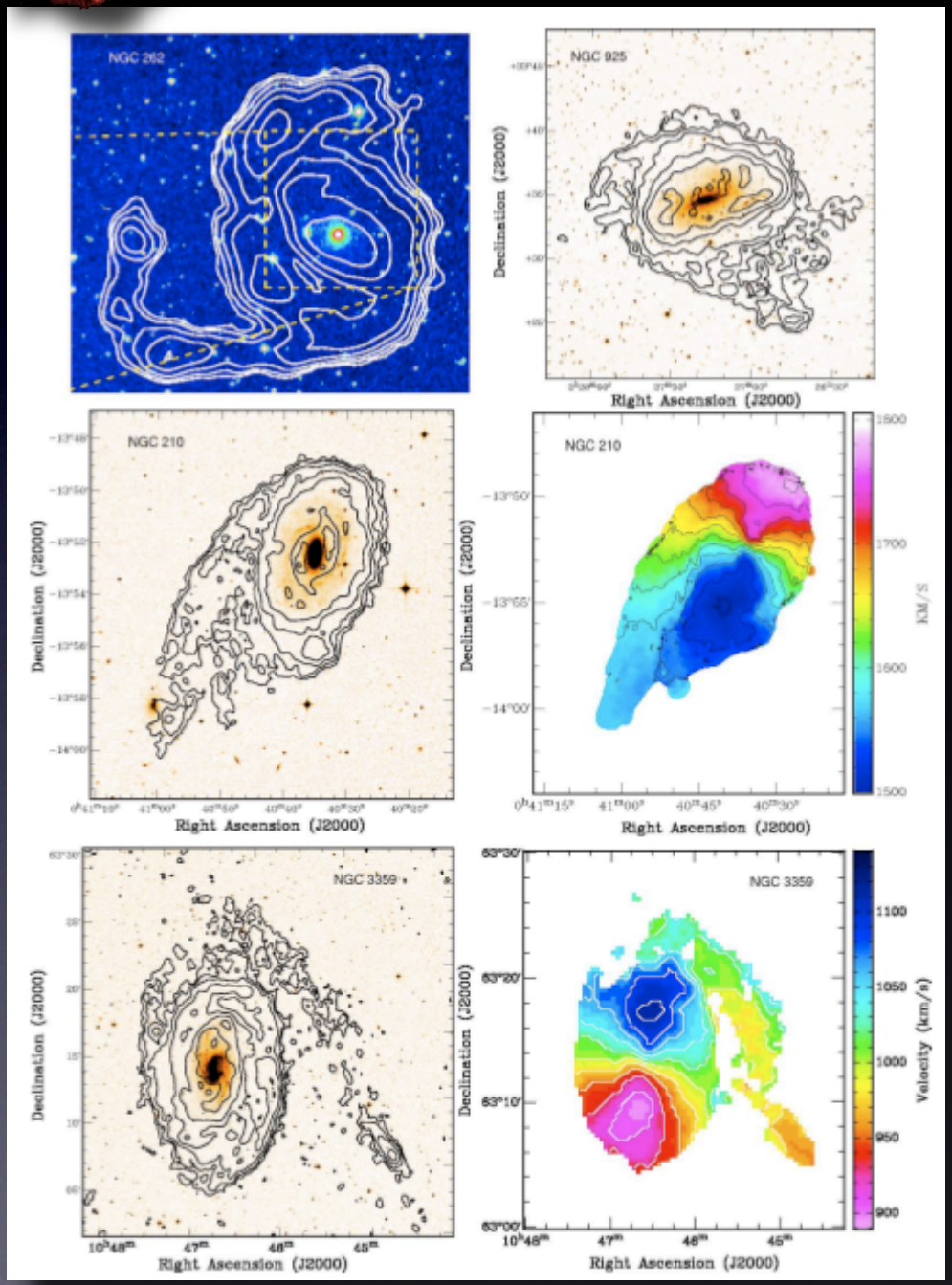
Oosterloo & van Gorkom 2005



Fraternali et al 2002

Fueling the Blue Cloud

Simkin+ 1987



Sancisi+ A&A Rev. 2008

sustaining star formation

-

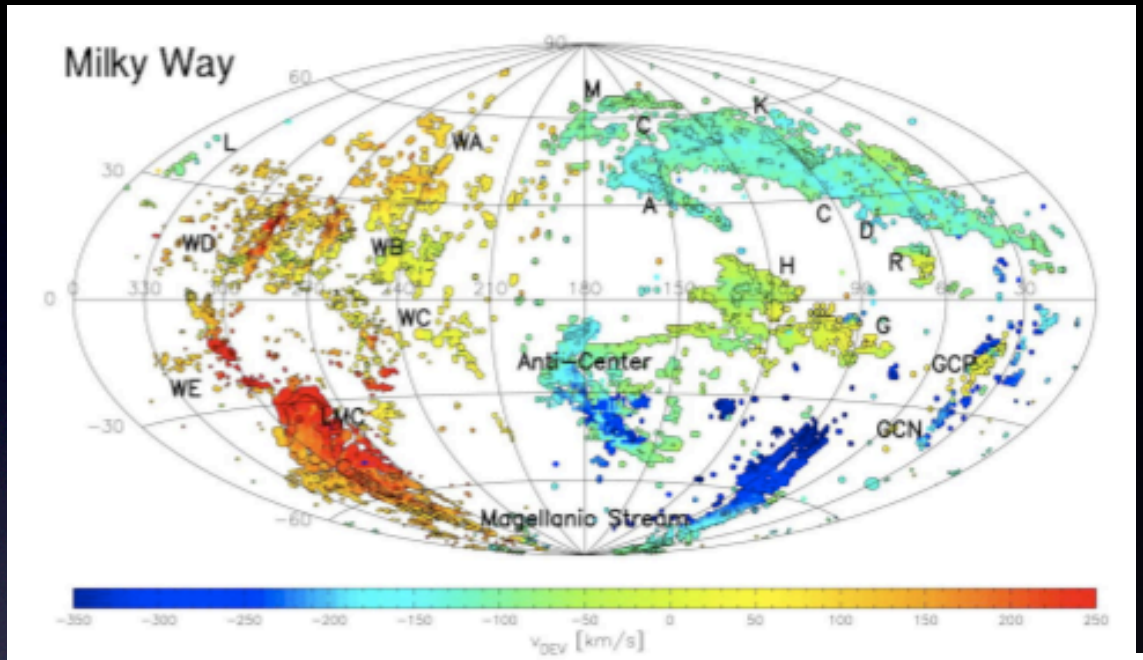
building up stellar mass

Gas accretion with minor mergers.

Inspection of 300+ HI images shows minor mergers or tidal interactions for 25% of the galaxies.

Typical gas accretion rate $\approx 0.2\ M_{\odot} yr^{-1}$ per galaxy.

Fueling the Blue Cloud



van Woerden+ 2004

sustaining star formation

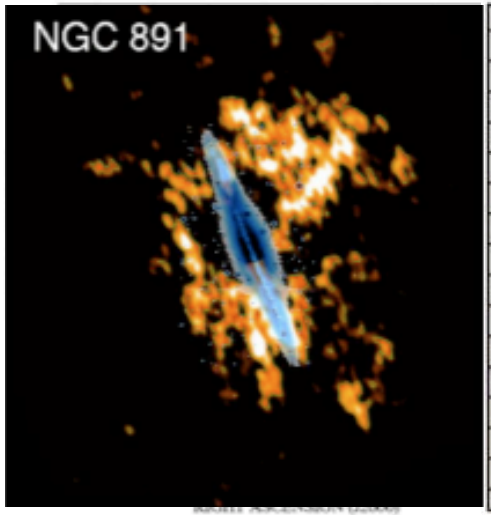
-

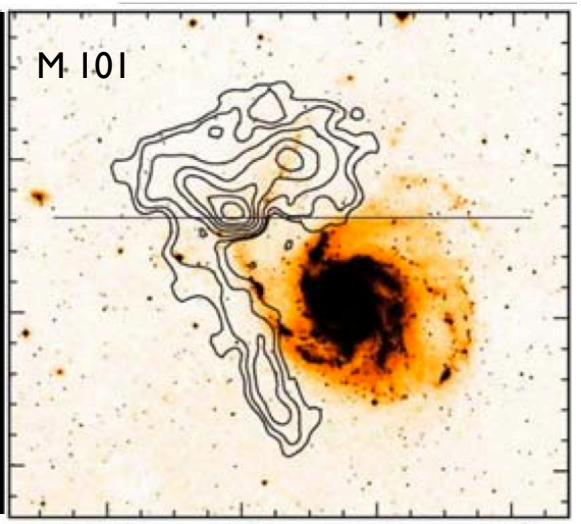
building up stellar mass

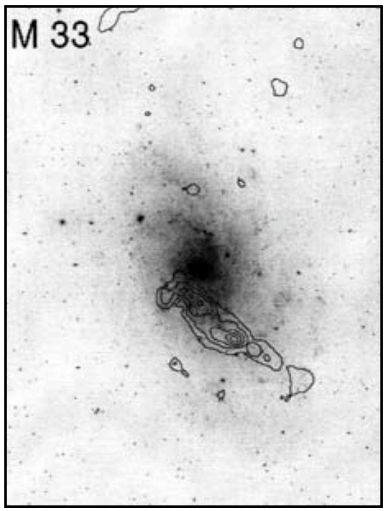
Evidence for cold accretion

or

Galactic Fountain / Fallback?

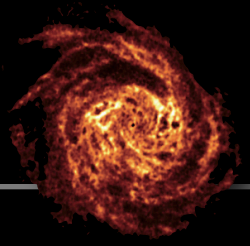






Thilker+ 2004

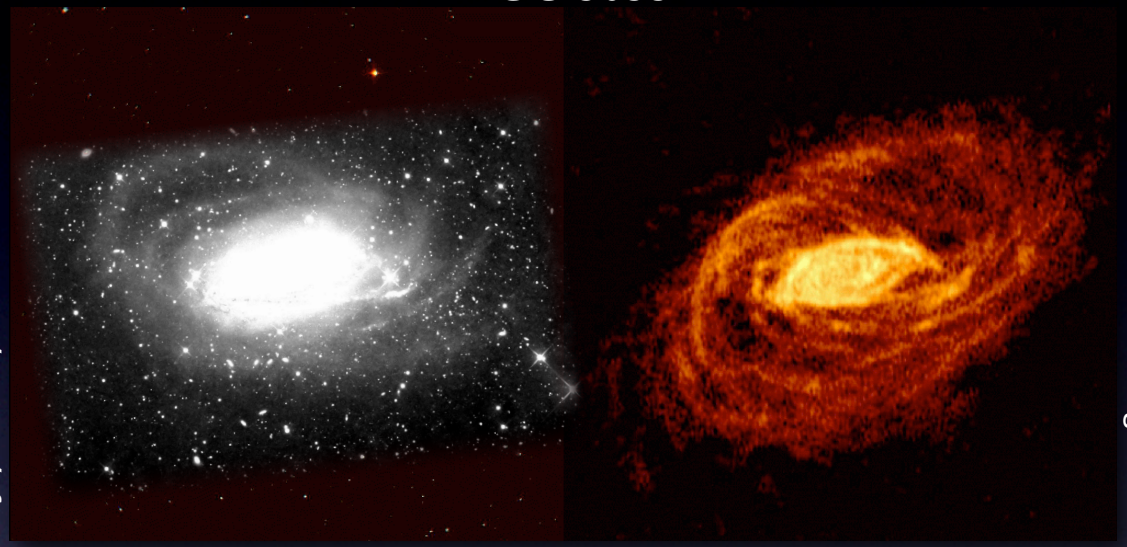
Oosterloo+ 2007



Warps and stellar streams

Is there a link?

NGC 5055



R. Jay GaBany

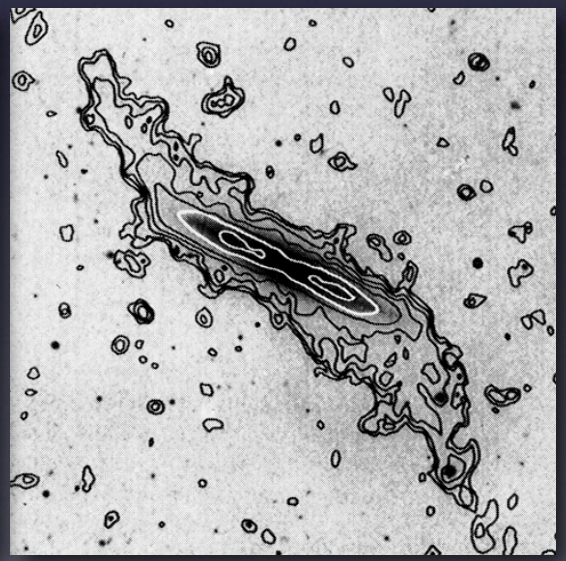
Battaglia+ 05

NGC 5907

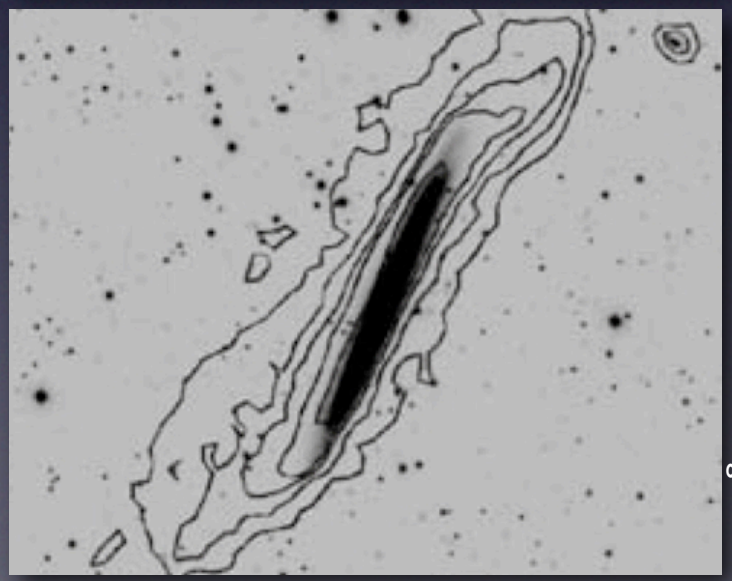
R. Jay GaBany

NGC 4013

R. Jay GaBany



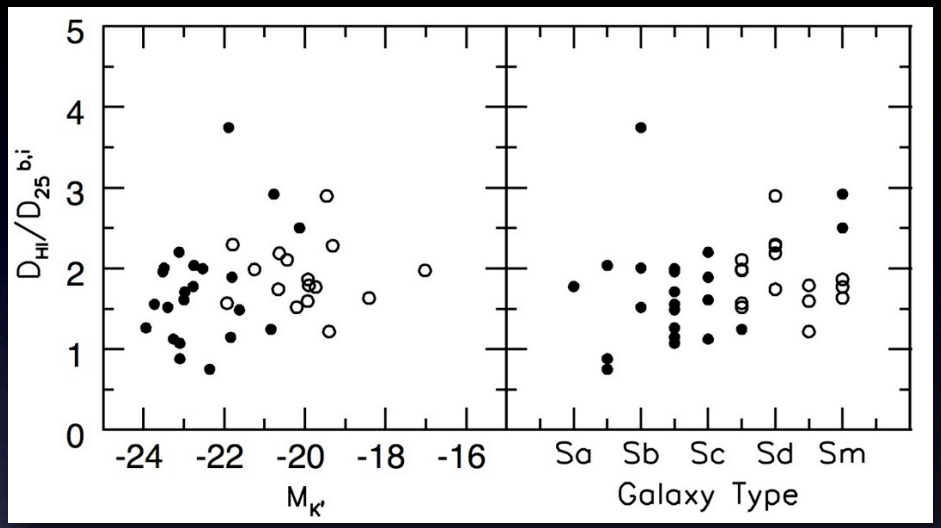
Bottema 95



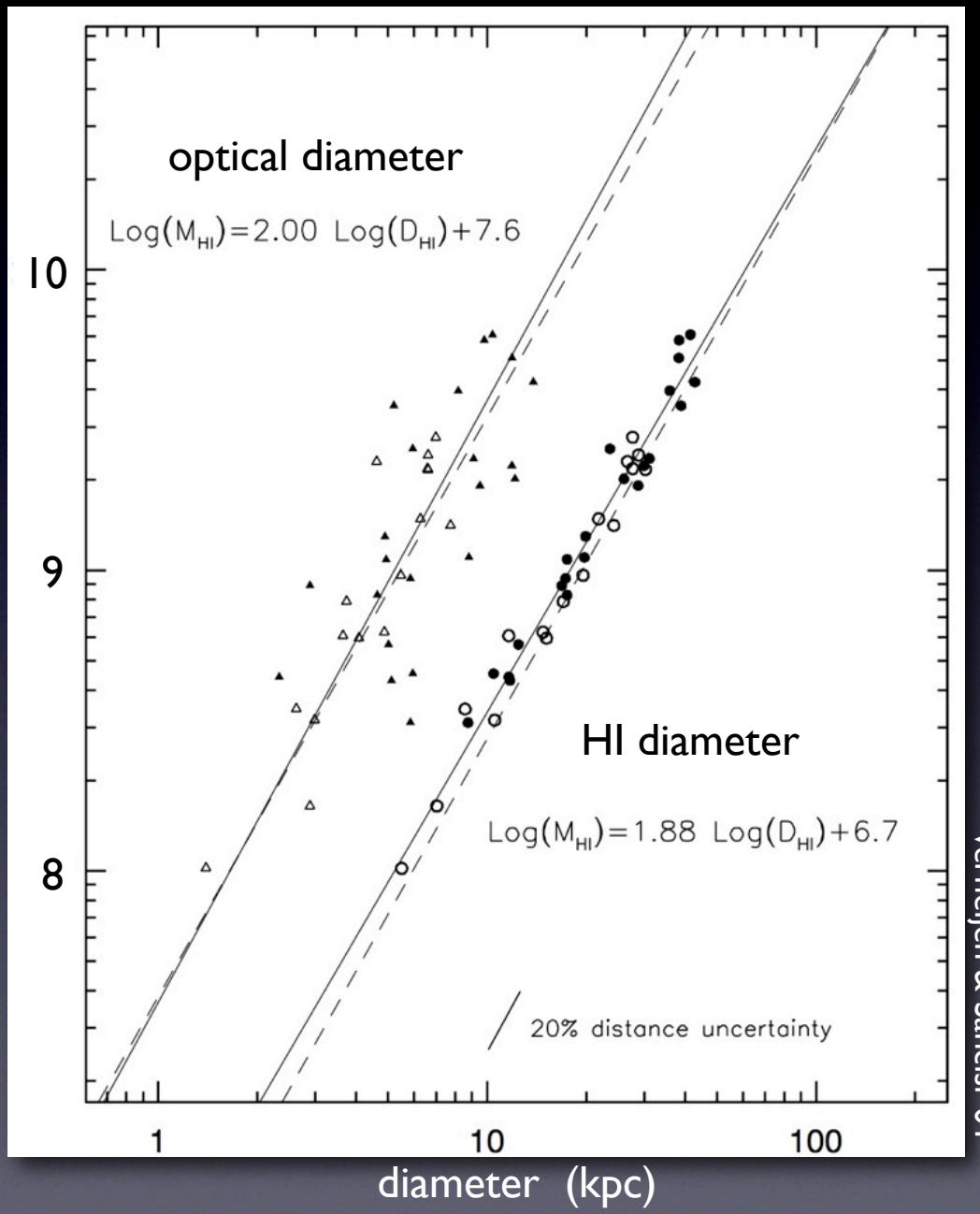
Shang+ 98

HI scaling relations

HI to optical diameters (UMa)



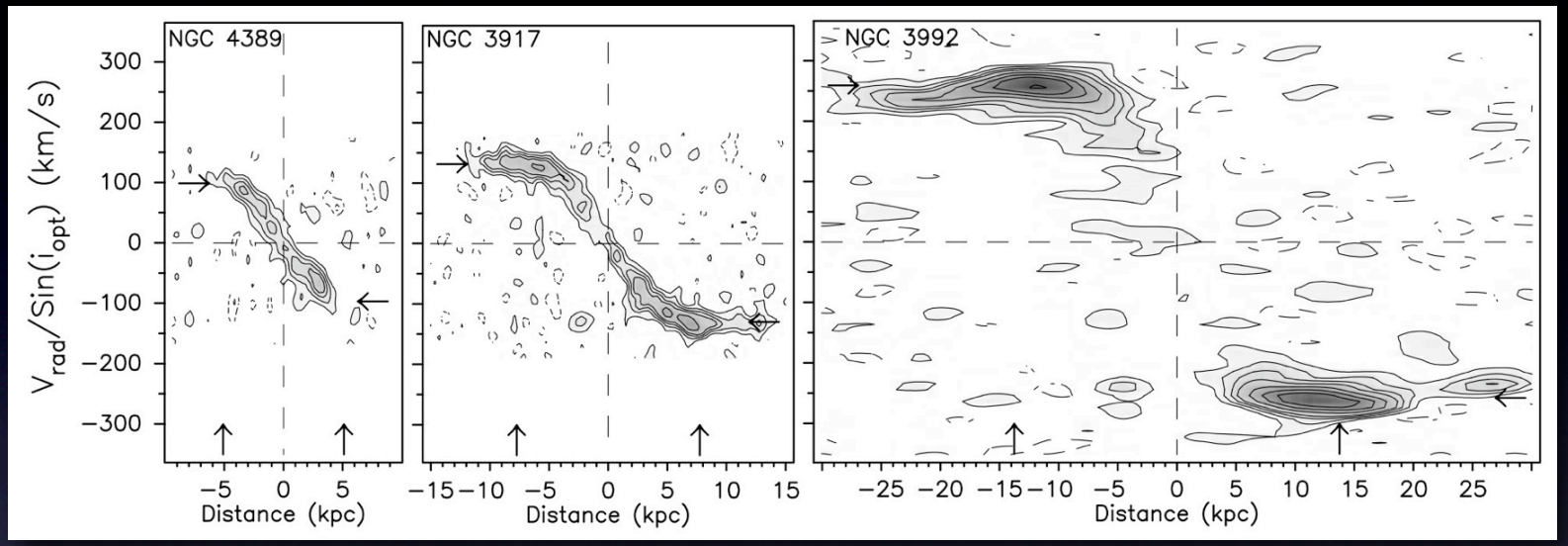
Verheijen & Sancisi '01

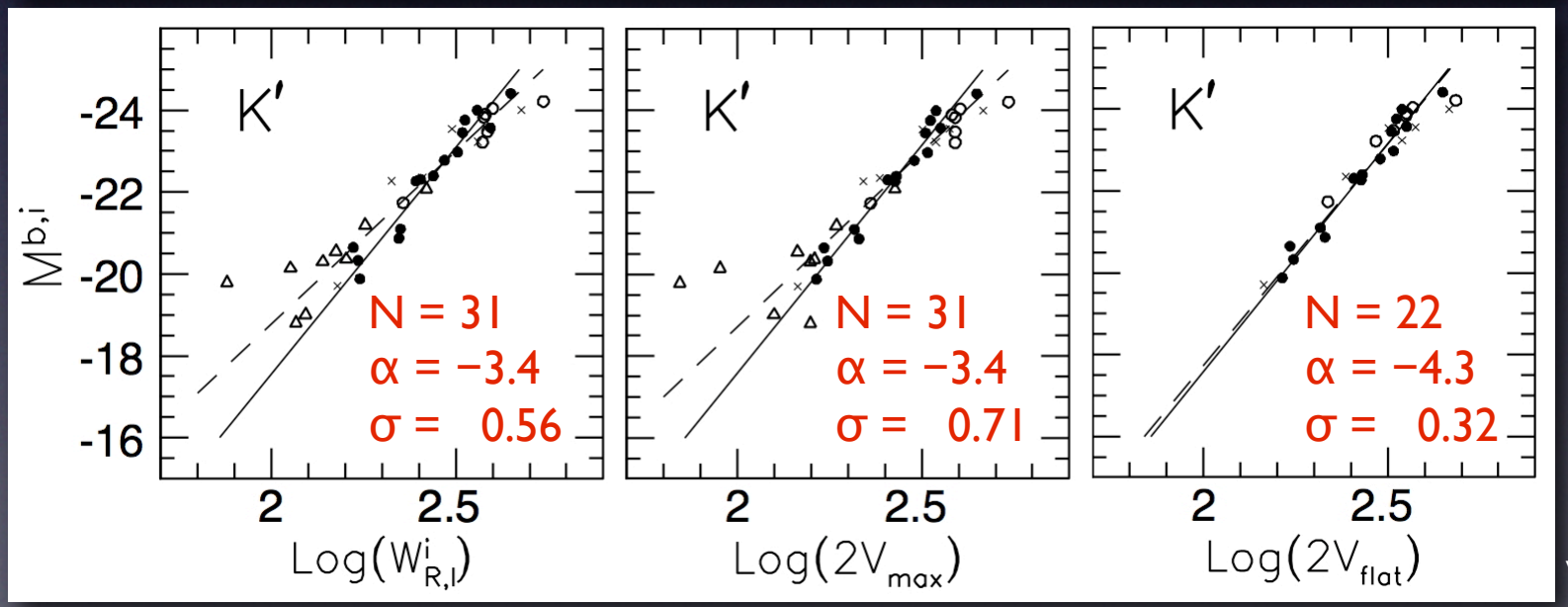


Although $\langle N_{HI} \rangle$ within D_{25} varies significantly, it is nearly invariant within D_{HI} (1 $M_\odot pc^{-2}$).

Rotation curves and the Tully-Fisher relation

rising flat declining





MV01

Verheijen '01

Rotation curves *beyond the optical radius* (R_{25}) provide the relevant kinematic measure.

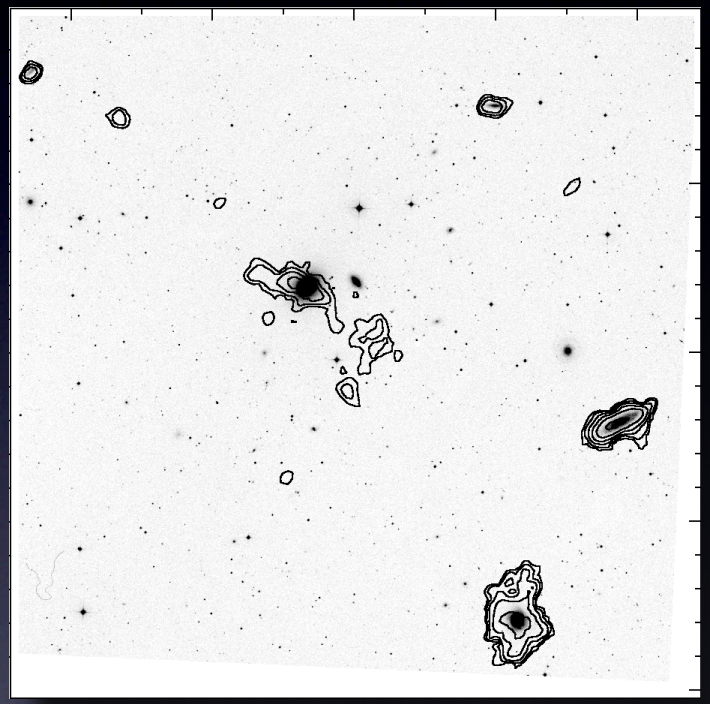
Extent of Hα rotation curves is insufficient to measure V_{flat} consistently.

W_{20} V_{max} V_{flat}

Crossing the Green Valley

The brightest lenticulars in Ursa Major - hot action in a cool group

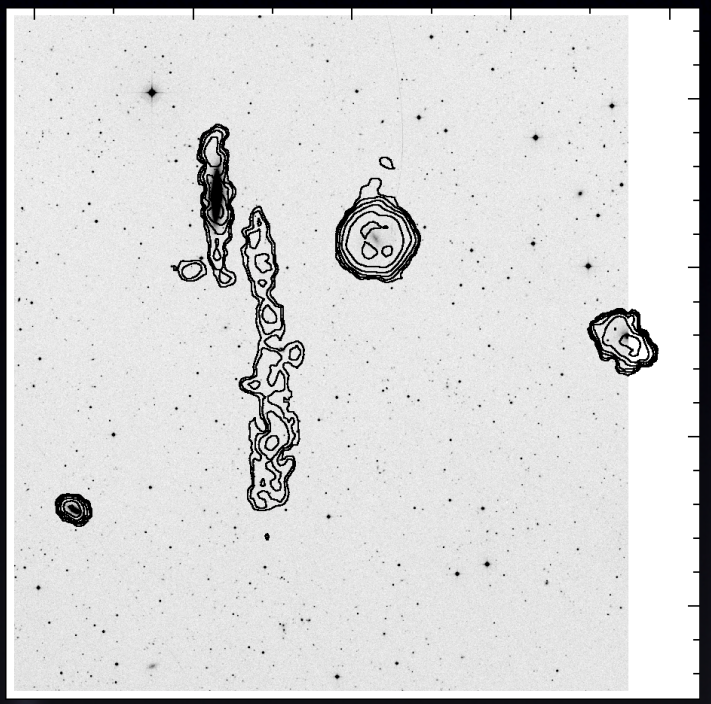
NGC 3998



$M_R = -21.84$ (mag)

$M_{HI} = 5.8 \times 10^8 (M_\odot)$

NGC 4026

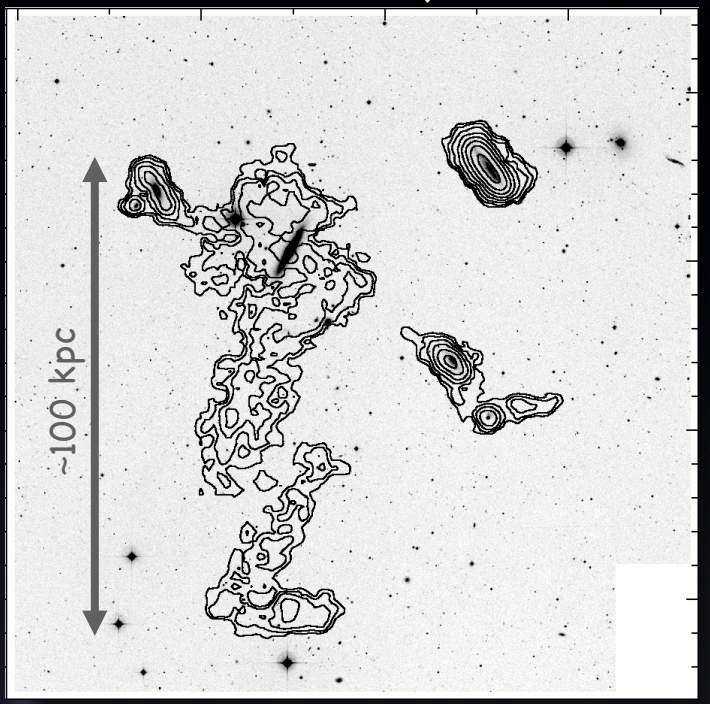


$M_R = -21.16$ (mag)

$M_{HI} = 1.2 \times 10^9 (M_\odot)$

NGC 4111

Verheijen et al, 2001



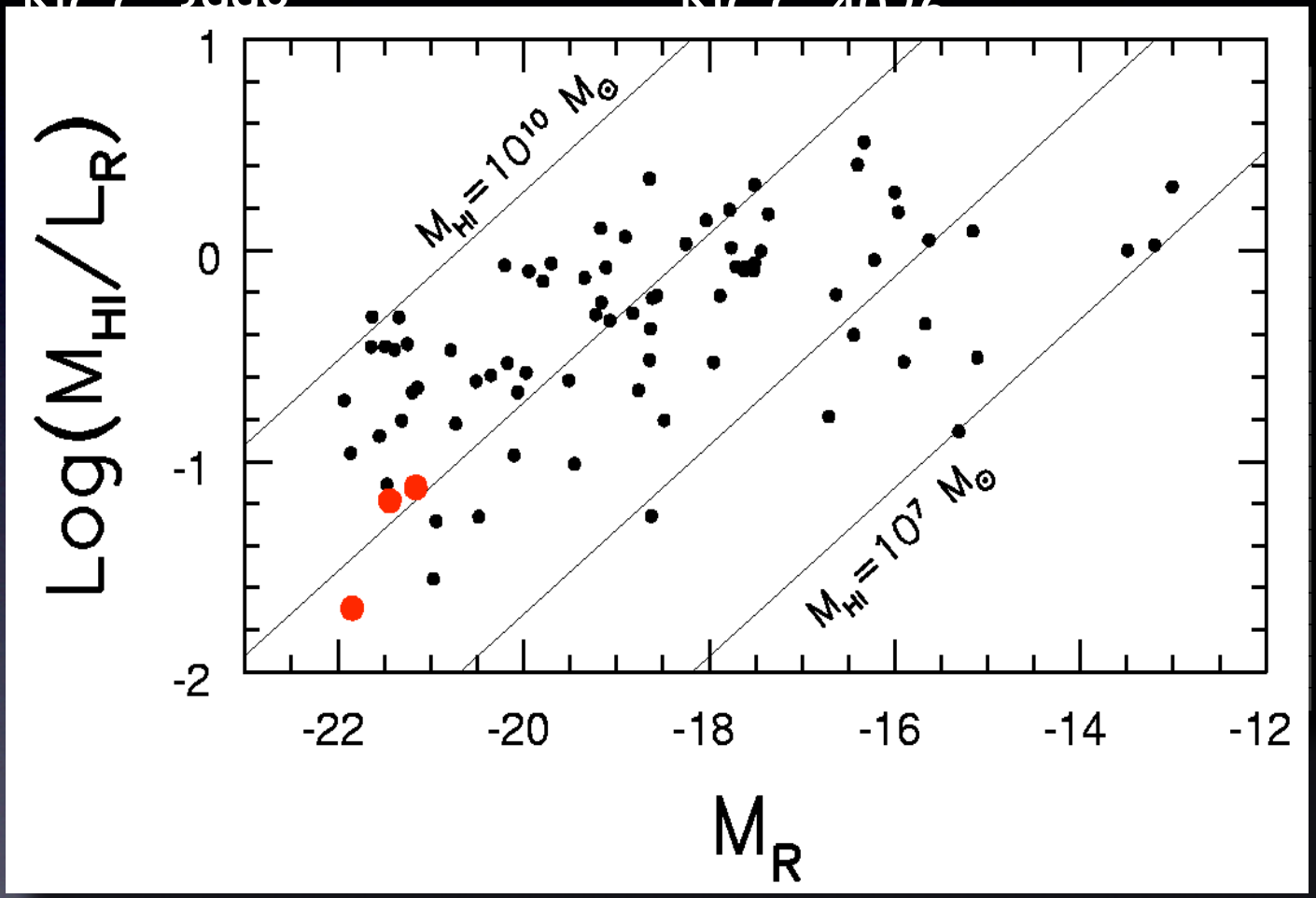
$M_R = -21.44$ (mag)

$M_{HI} = 1.3 \times 10^9 (M_\odot)$

Crossing the Green Valley

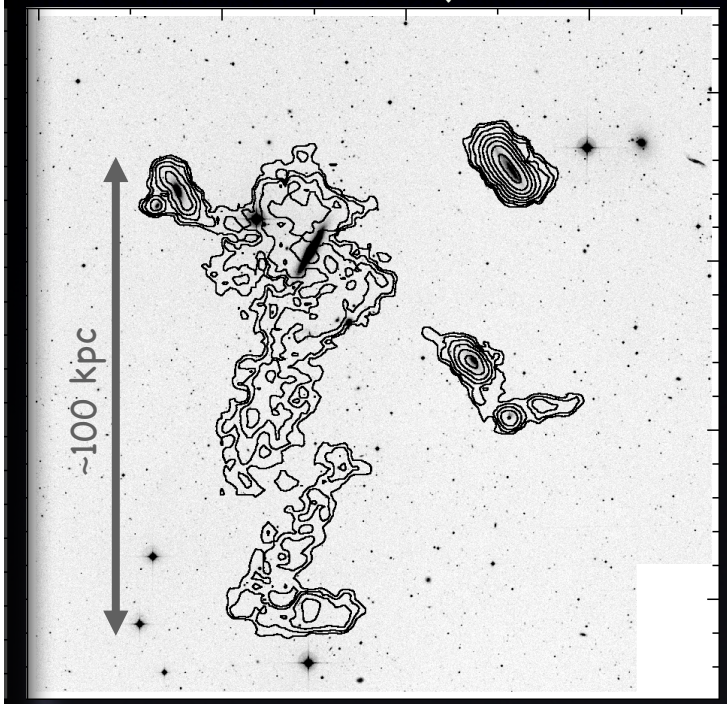
The brightest lenticulars in Ursa Major - hot action in a cool group

NGC 3998 NGC 4026



NGC 4111

Verheijen et al, 2001



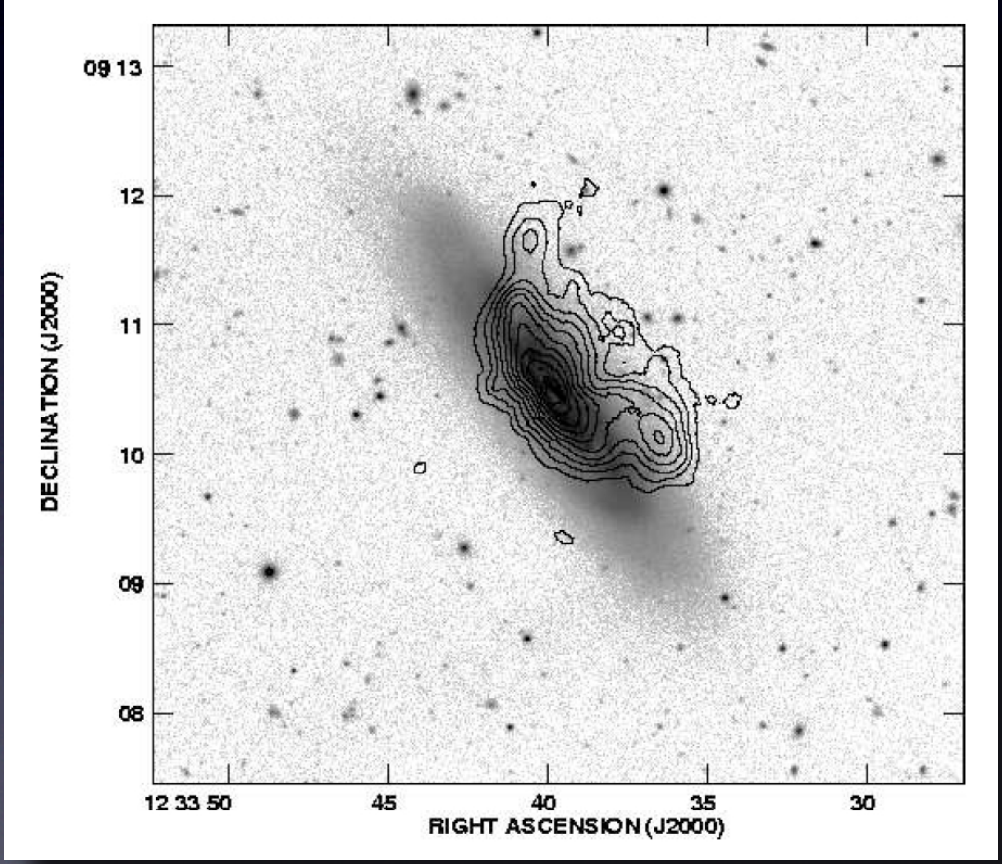
$$M_R = -21.44\ (\mathrm{mag})$$
$$M_{HI} = 1.3 \times 10^9 (M_\odot)$$

From Spiral to Lenticular through tidal interactions?

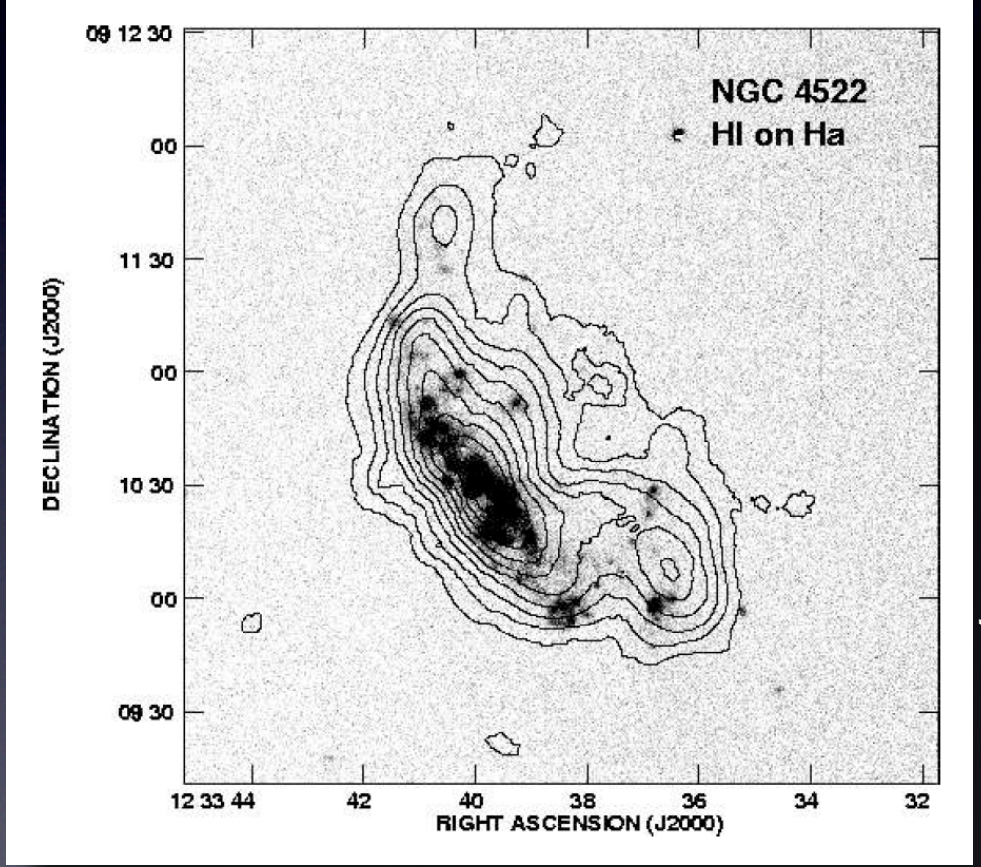
Crossing the Green Valley

NGC 4522 in Virgo - stripping in action

HI contours on optical image



HI contours on Hα image



Kenney et al, 2004

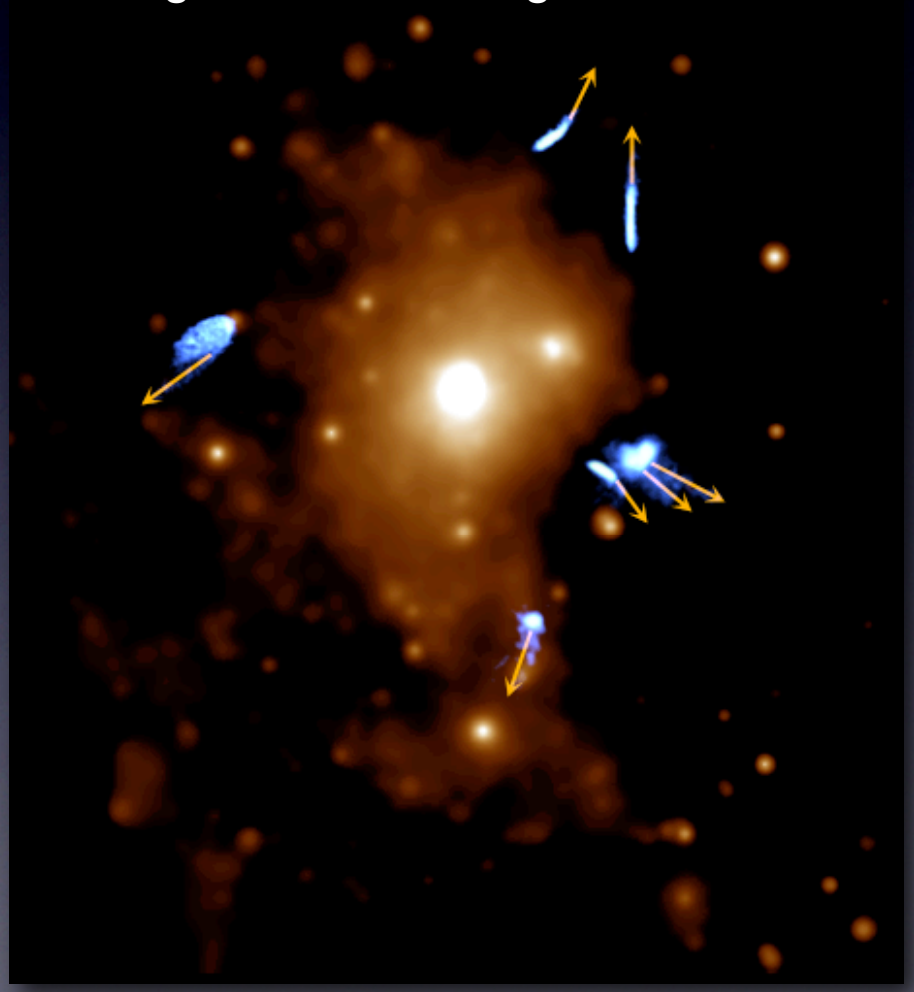
➢ Ram-pressure induced (and truncated?) star formation

Crossing the Green Valley

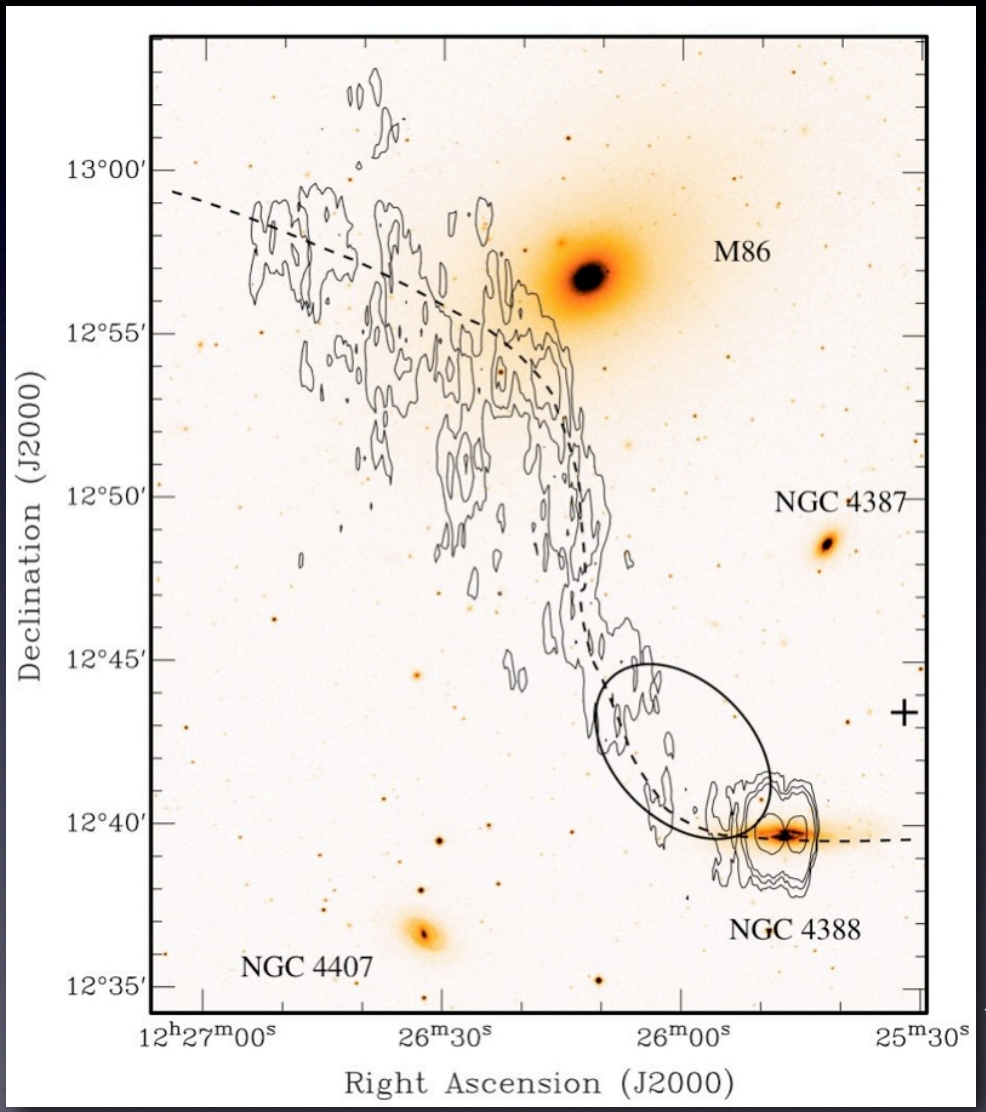
VLA

WSRT

VIVA : VLA Imaging of Virgo galaxies in Atomic gas



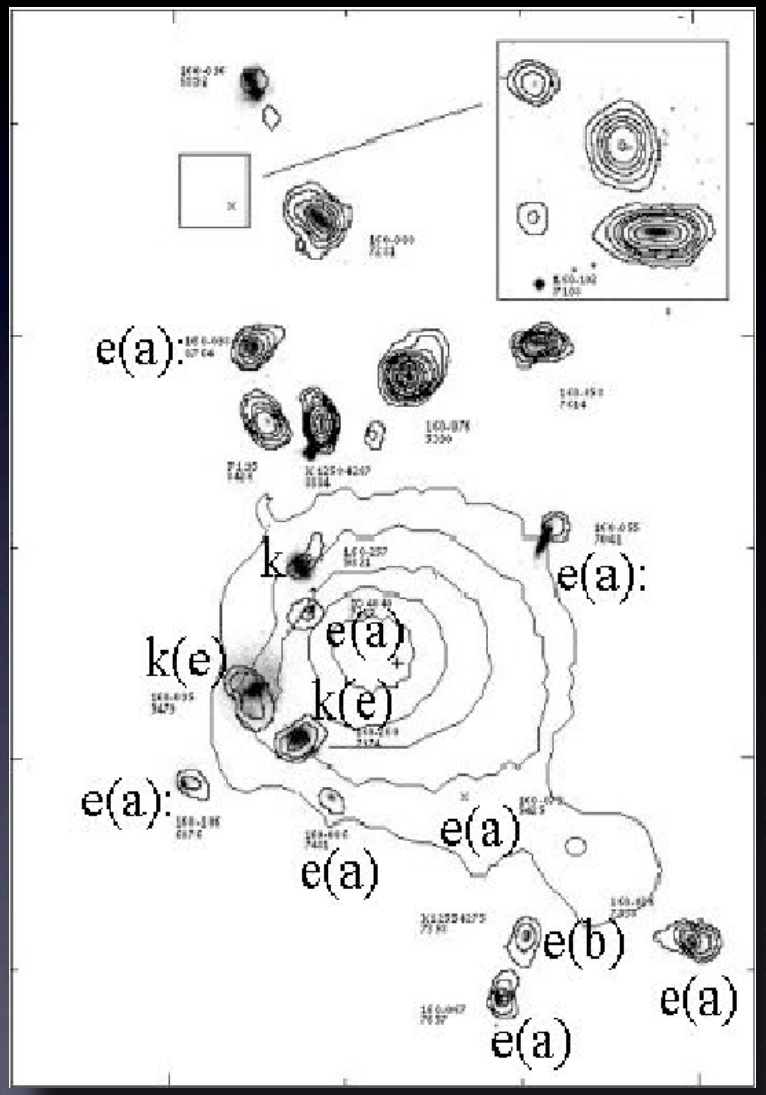
Chung, van Gorkom, Kenney & Vollmer, 2007



Oosterloo & van Gorkom, 2005

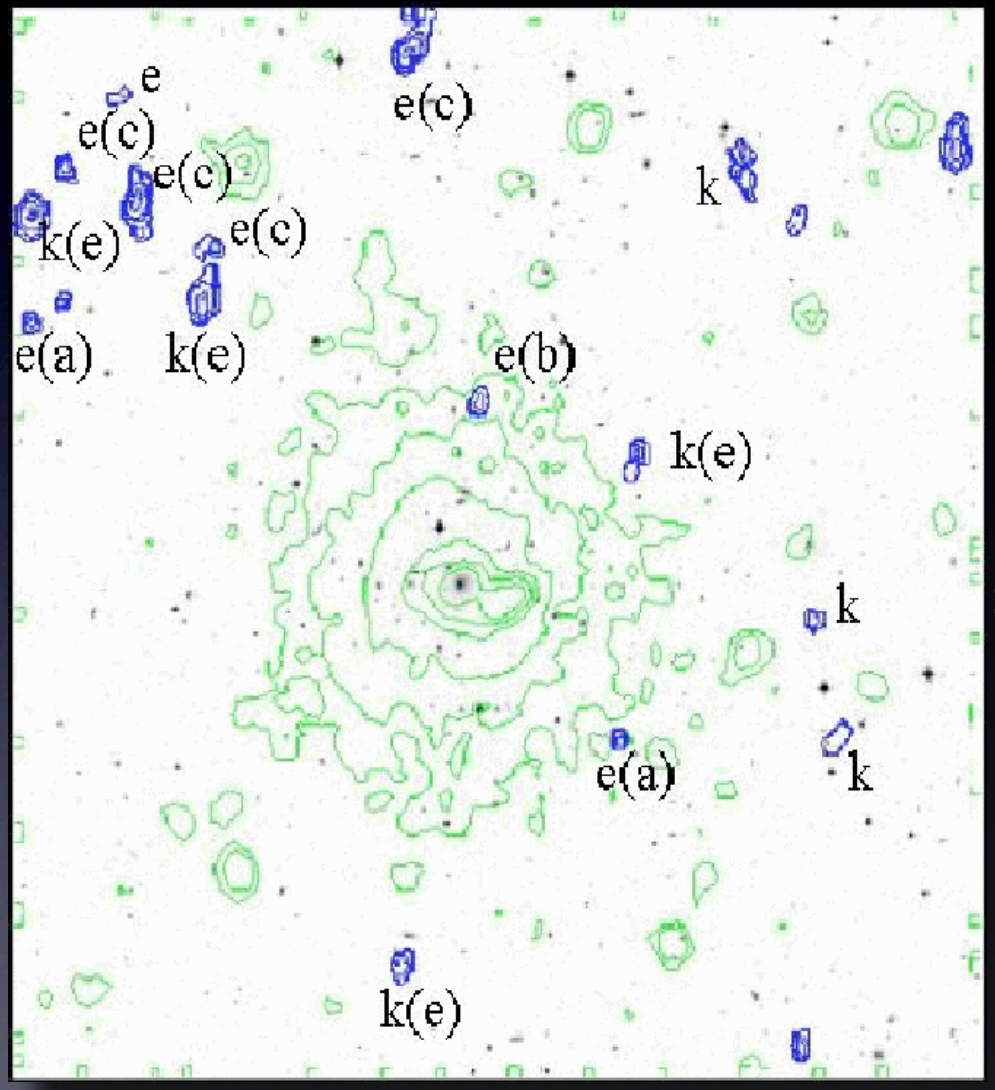
HI, ICM, SFR, SP interrelations

Coma



Bravo-Alfaro+ 01

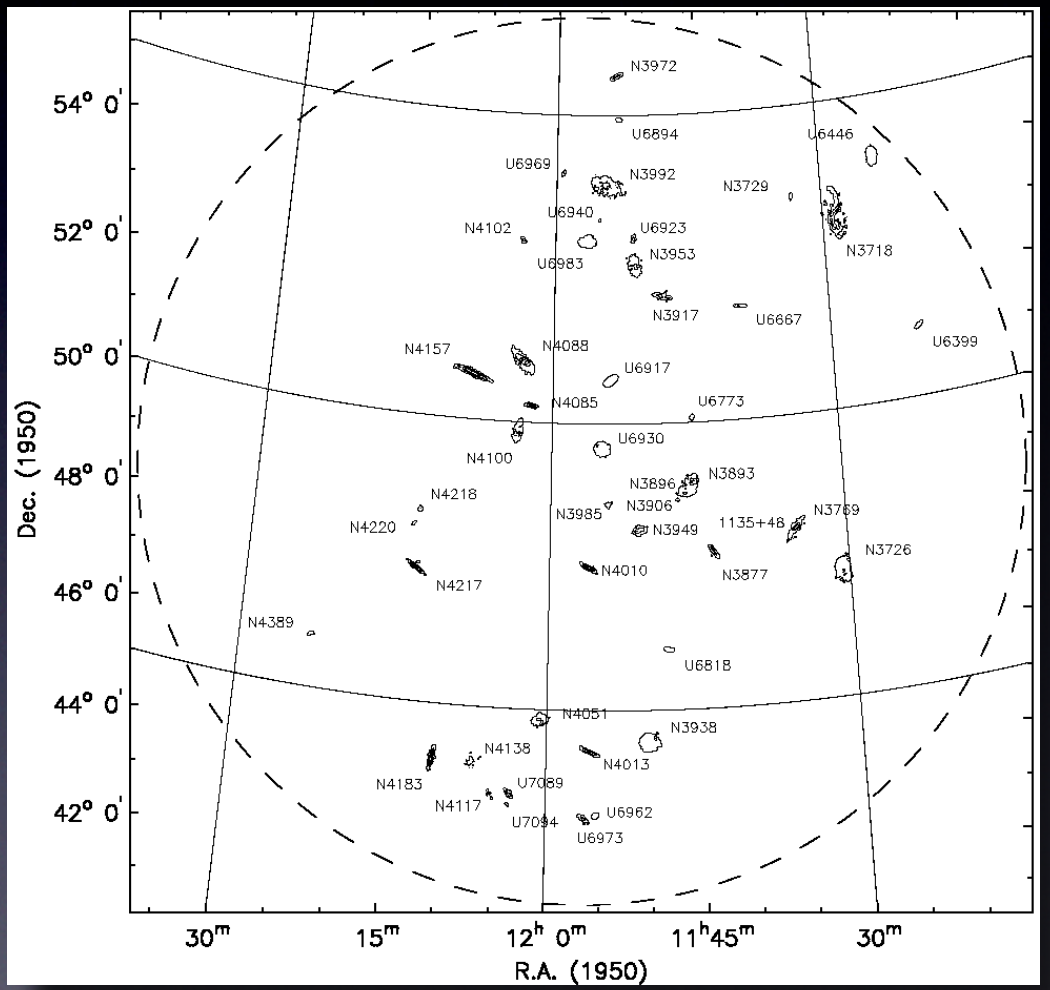
Abell 2670



Poggianti & van Gorkom, 01

Environmental dependence of gas content

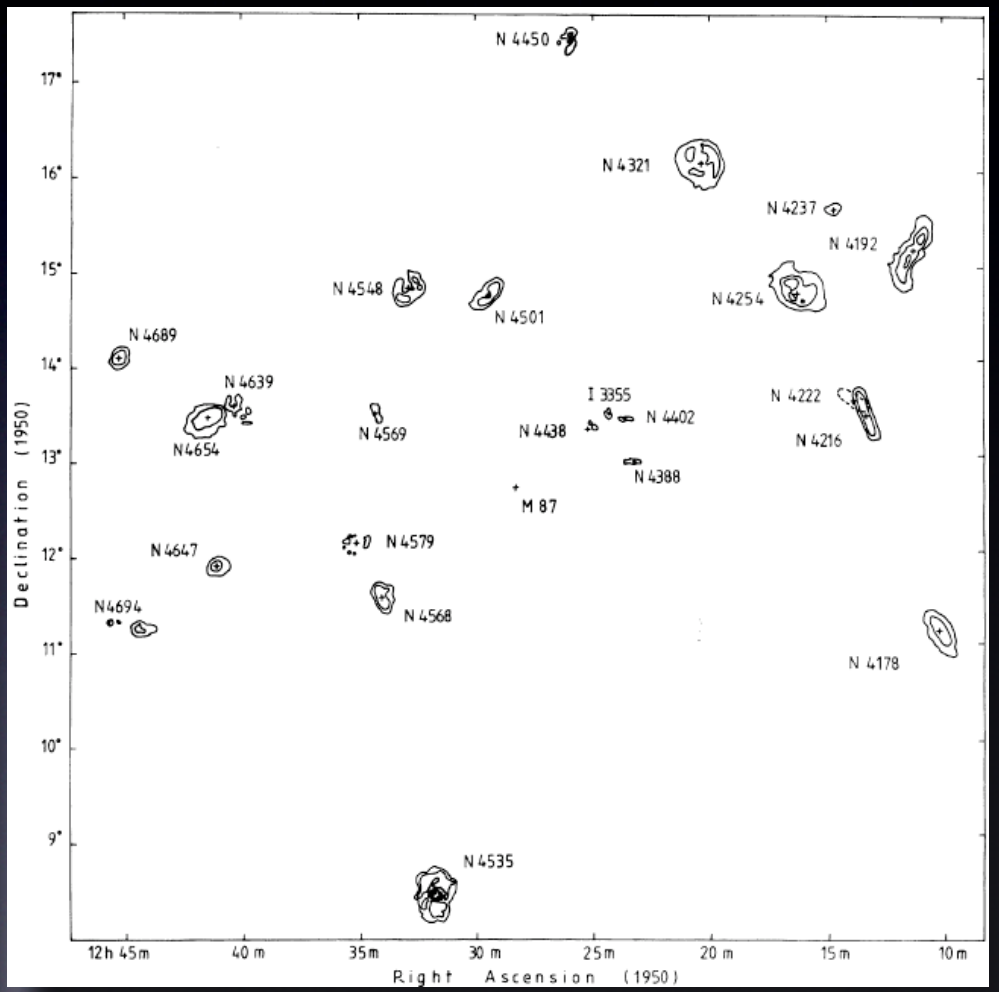
Ursa Major



Verheijen & Sancisi 2001

Westerbork

Virgo



Cayatte et al 1993

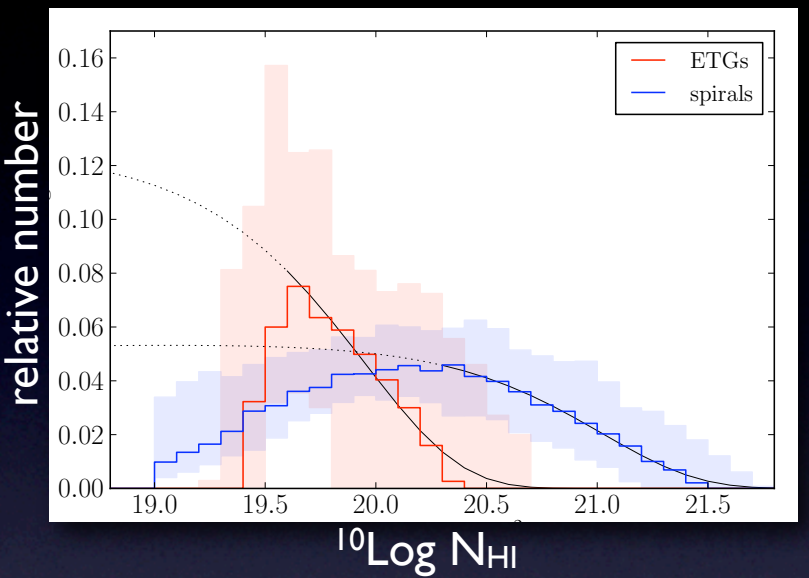
Very Large Array

Atlas^{3D} : HI follow-up of Early-types

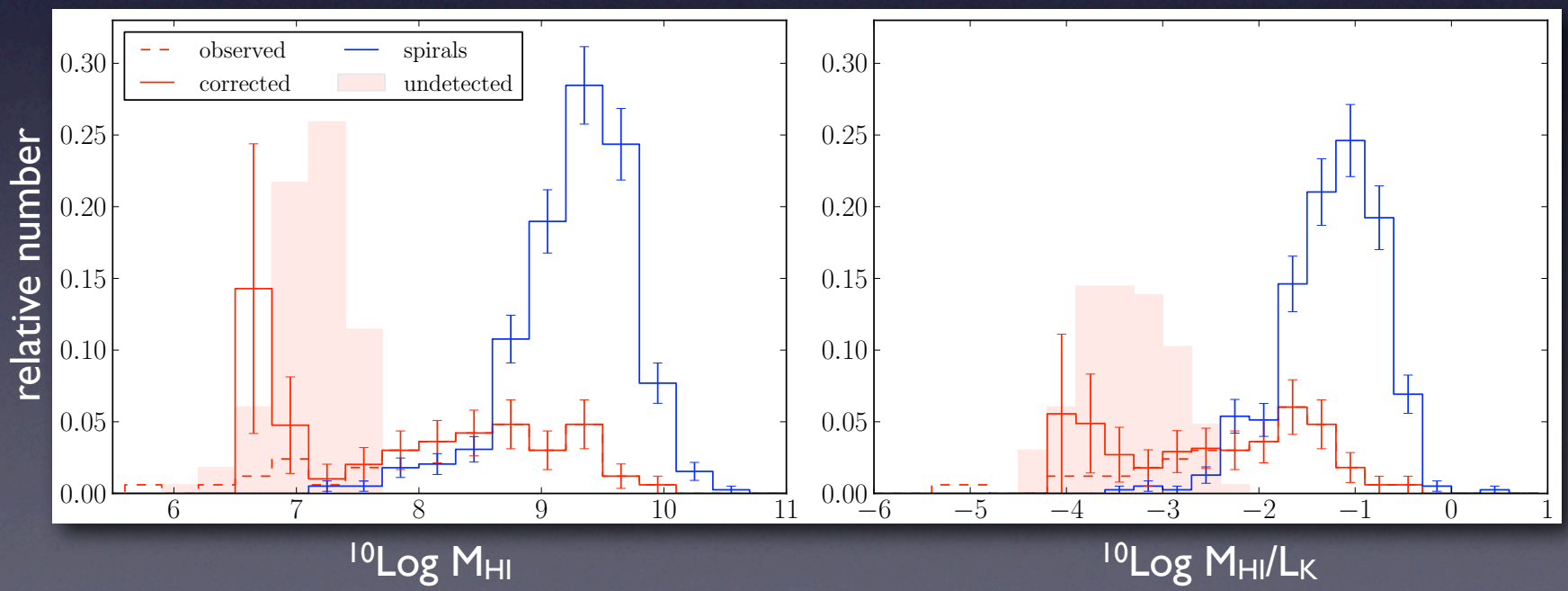
Serra et al. 2011, *in prep*

- 166/260 E-types (no spiral structure)
- 1/3 detected ($M_{HI}^{min} \approx 10^7\ M_{sun}$)
  40% of E-types outside Virgo
- lower column densities
- broader distribution of M_{HI}/L_K

Column density distribution



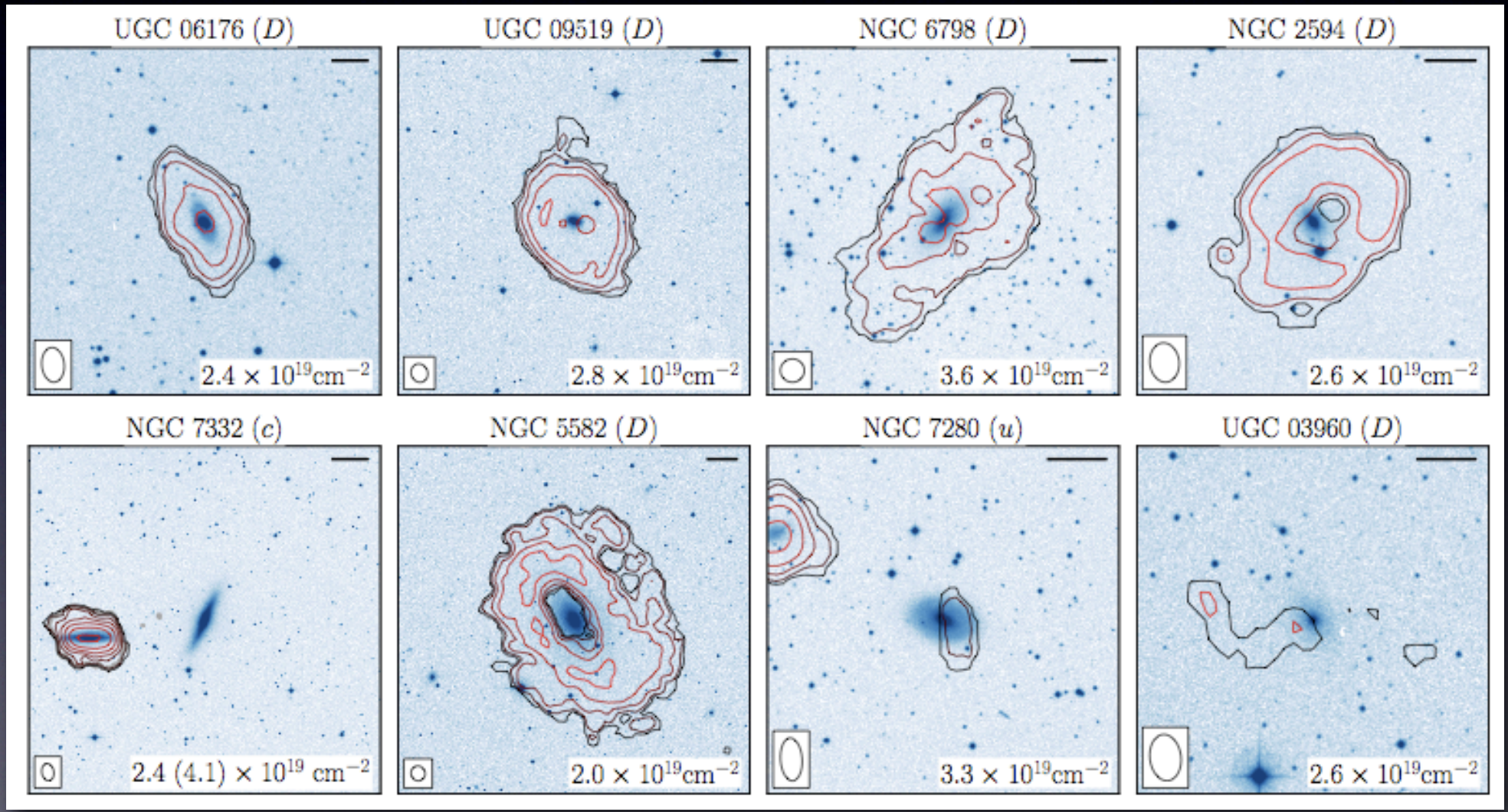
(relative) HI masses



Atlas^{3D} : HI follow-up of Early-types

Serra et al. 2011, *in prep*

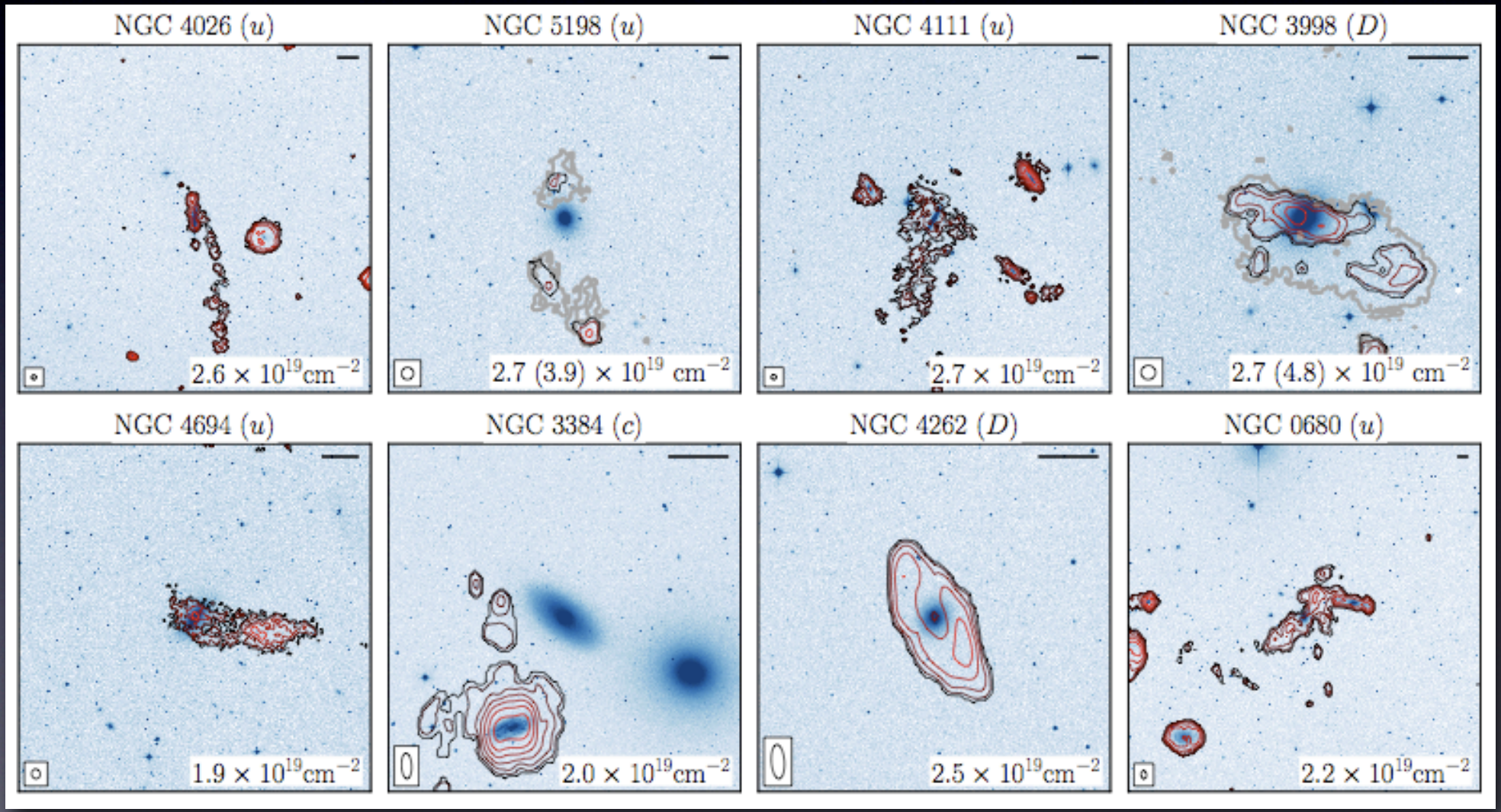
Lower density regions : extended and regular HI disk



Atlas^{3D} : HI follow-up of Early-types

Serra et al. 2011, *in prep*

Higher density regions : clumpy and unstructured



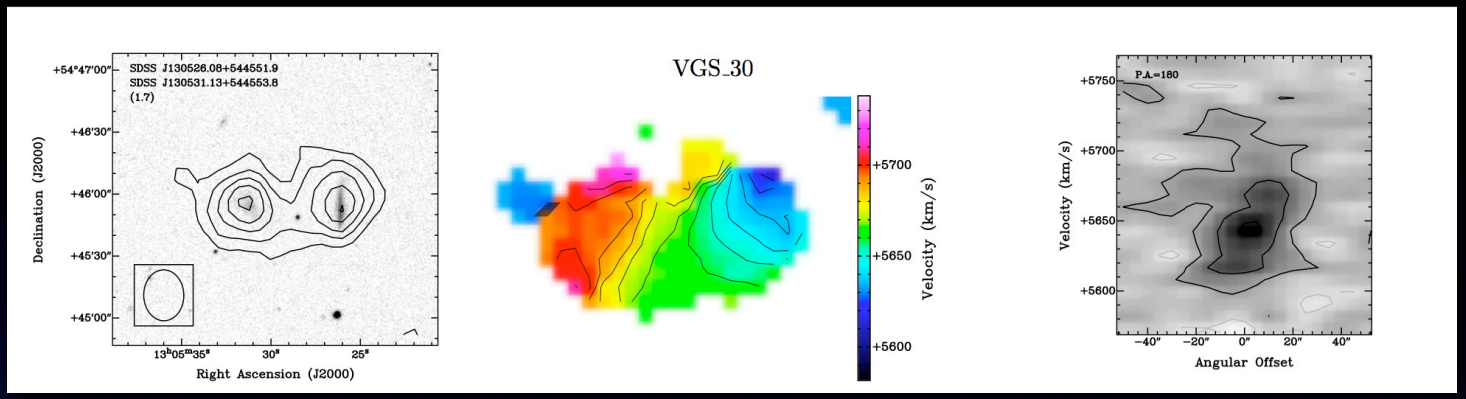
Void Galaxy Survey

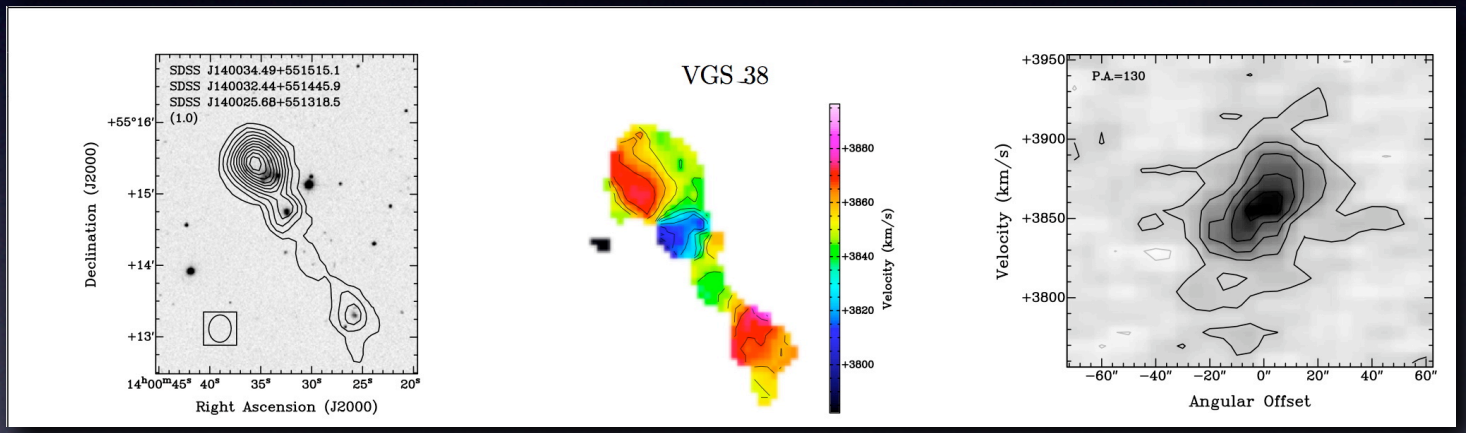
Kreckel+ 11

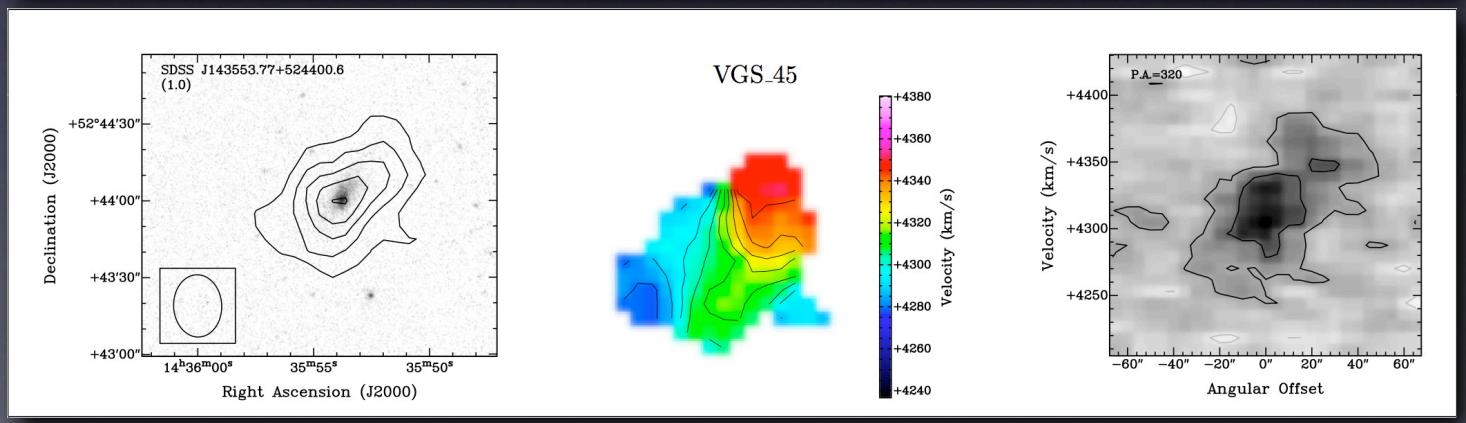
A pilot study of 15 void galaxies.

4/15 are strongly perturbed

Void galaxies seem to be gas-rich with evidence for ongoing gas accretion, major & minor interactions, and alignment along filaments.

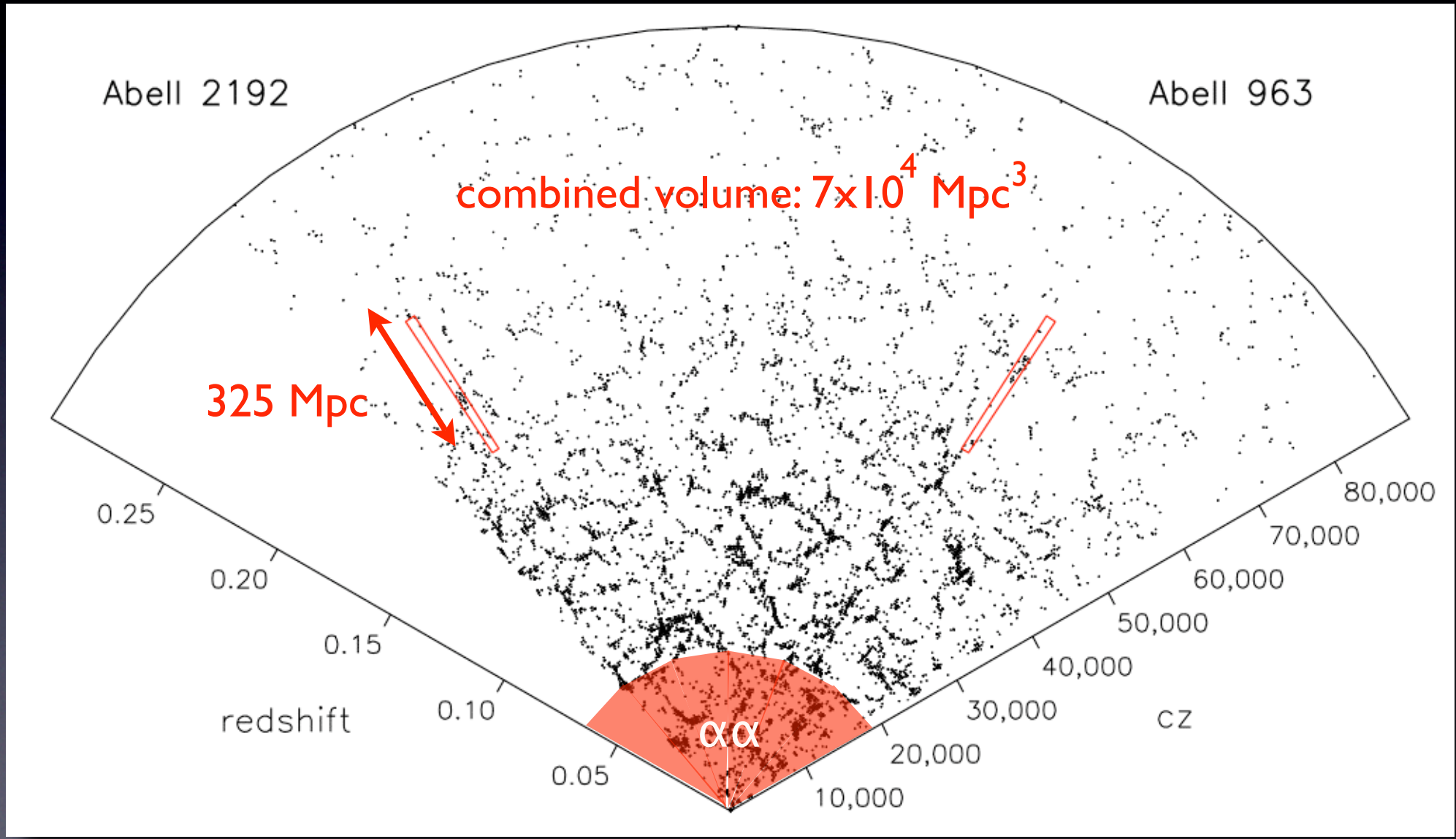






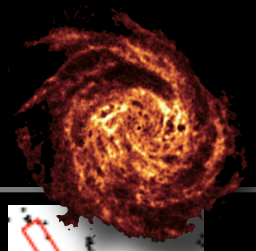
The push to higher redshifts

WSRT ultra-deep HI survey of galaxy clusters at z=0.2



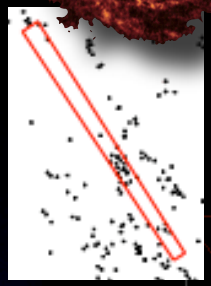
SDSS redshift cone

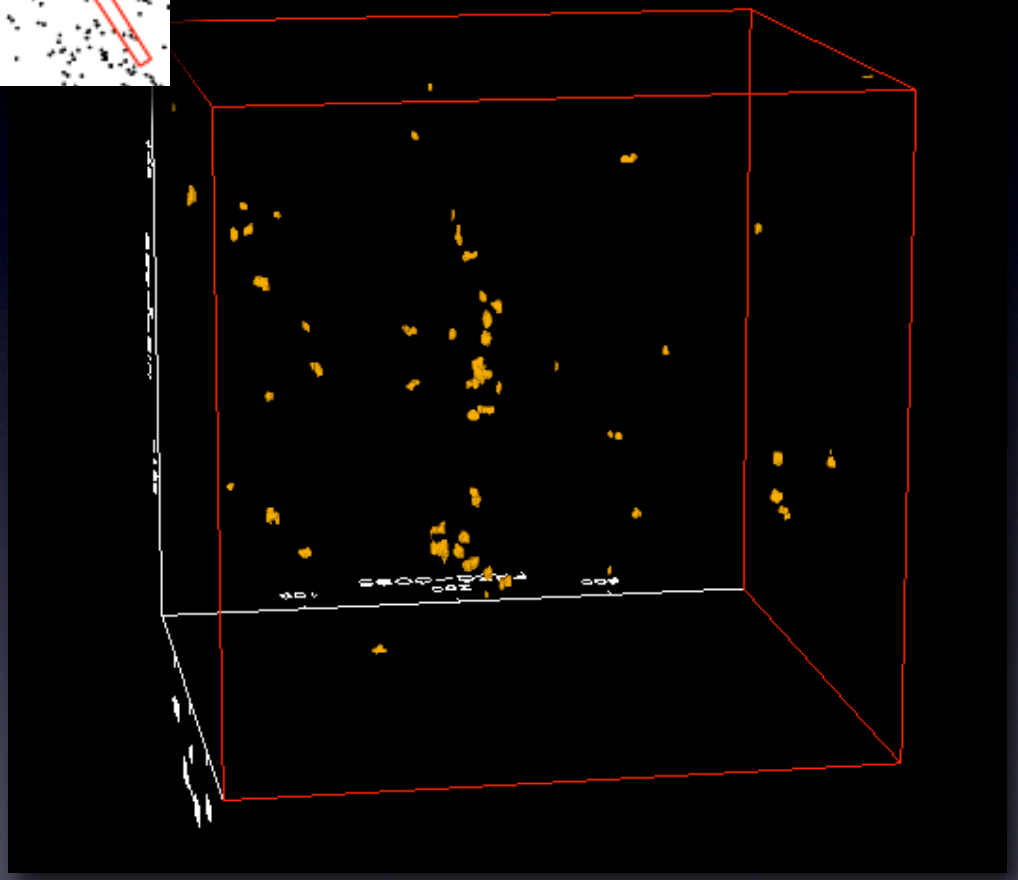
The push to higher redshifts



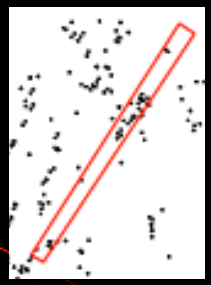
Verheijen+, in prep

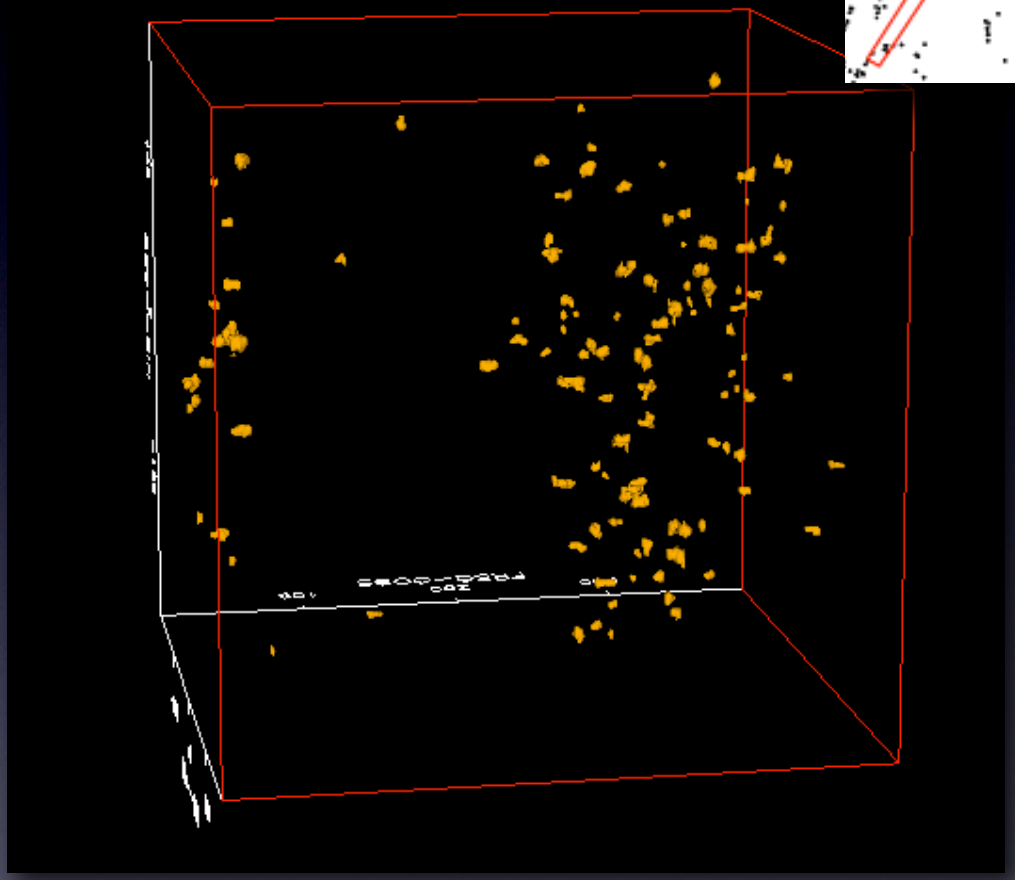
Abell 2192





Abell 963



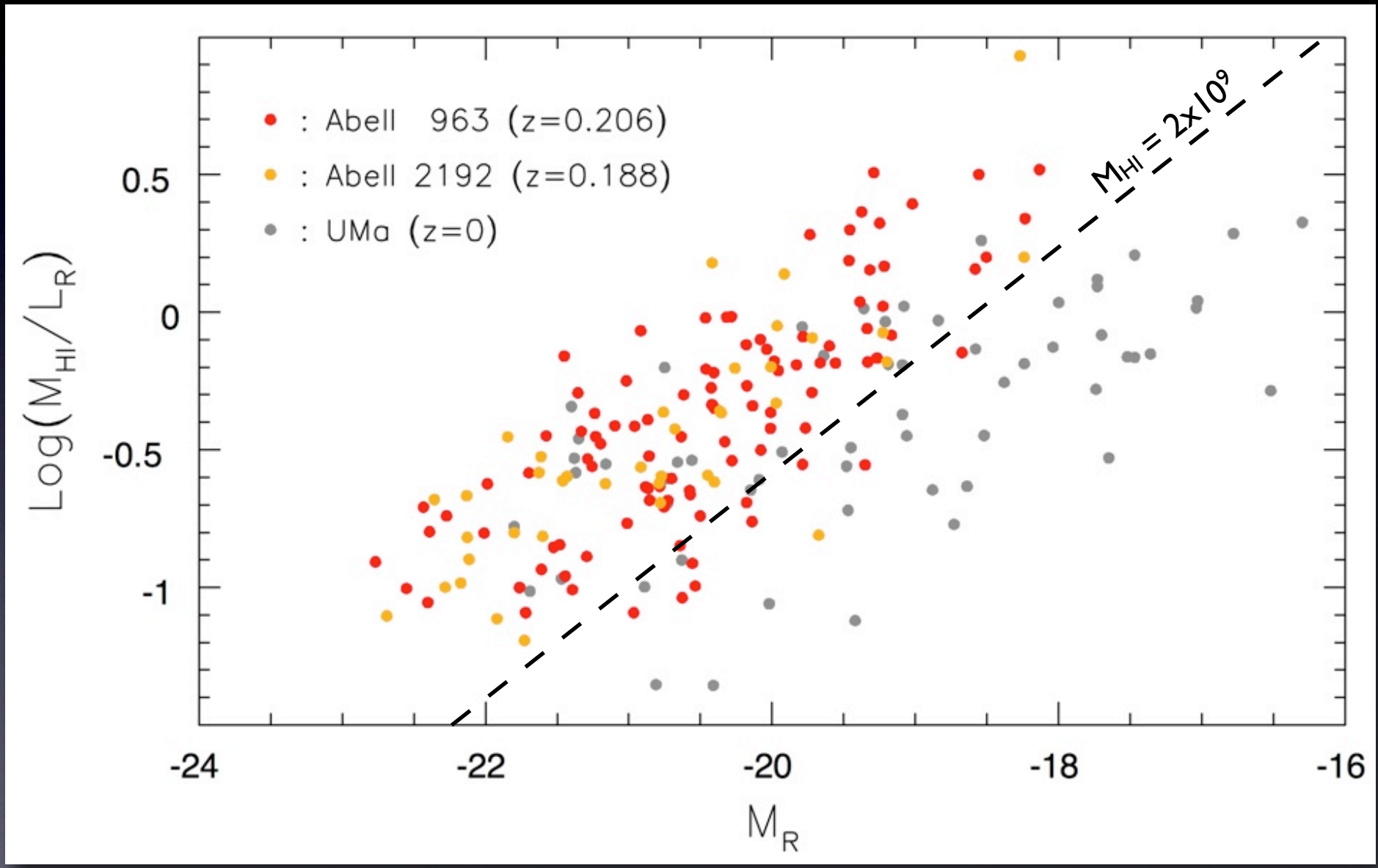


Cube size : 9.5 x 9.5 x 325 Mpc^3
Beam size : 65 x 80 kpc^2 x 80 km/s

Are Butcher-Oemler clusters accreting a more gas-rich field population?

The push to higher redshifts

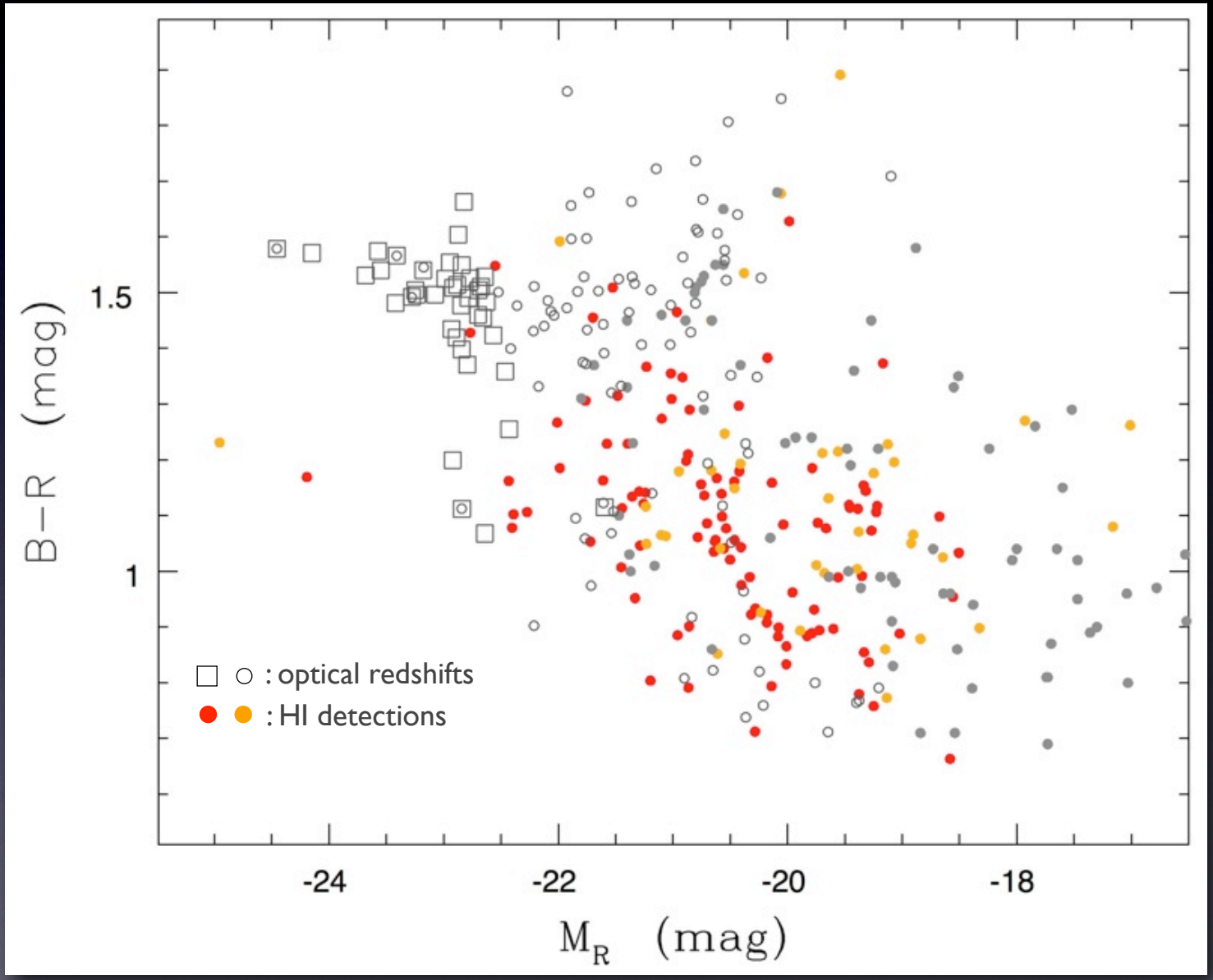
Relative HI gas mass fractions



Verheijen+, in prep

The push to higher redshifts

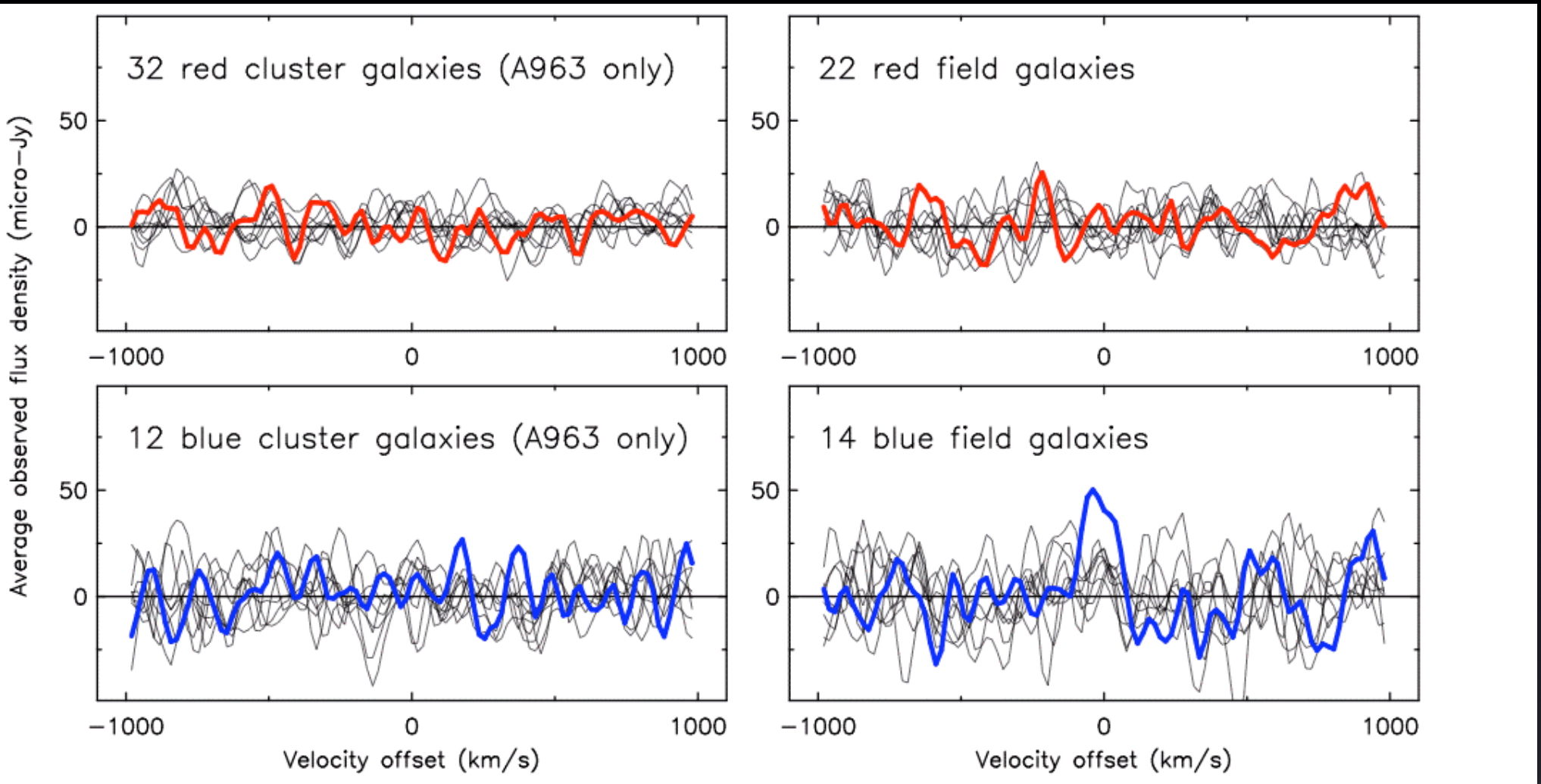
Colour-Magnitude diagram



Verheijen+, in prep

The push to higher redshifts

Stacking HI spectra (based on pilot data)

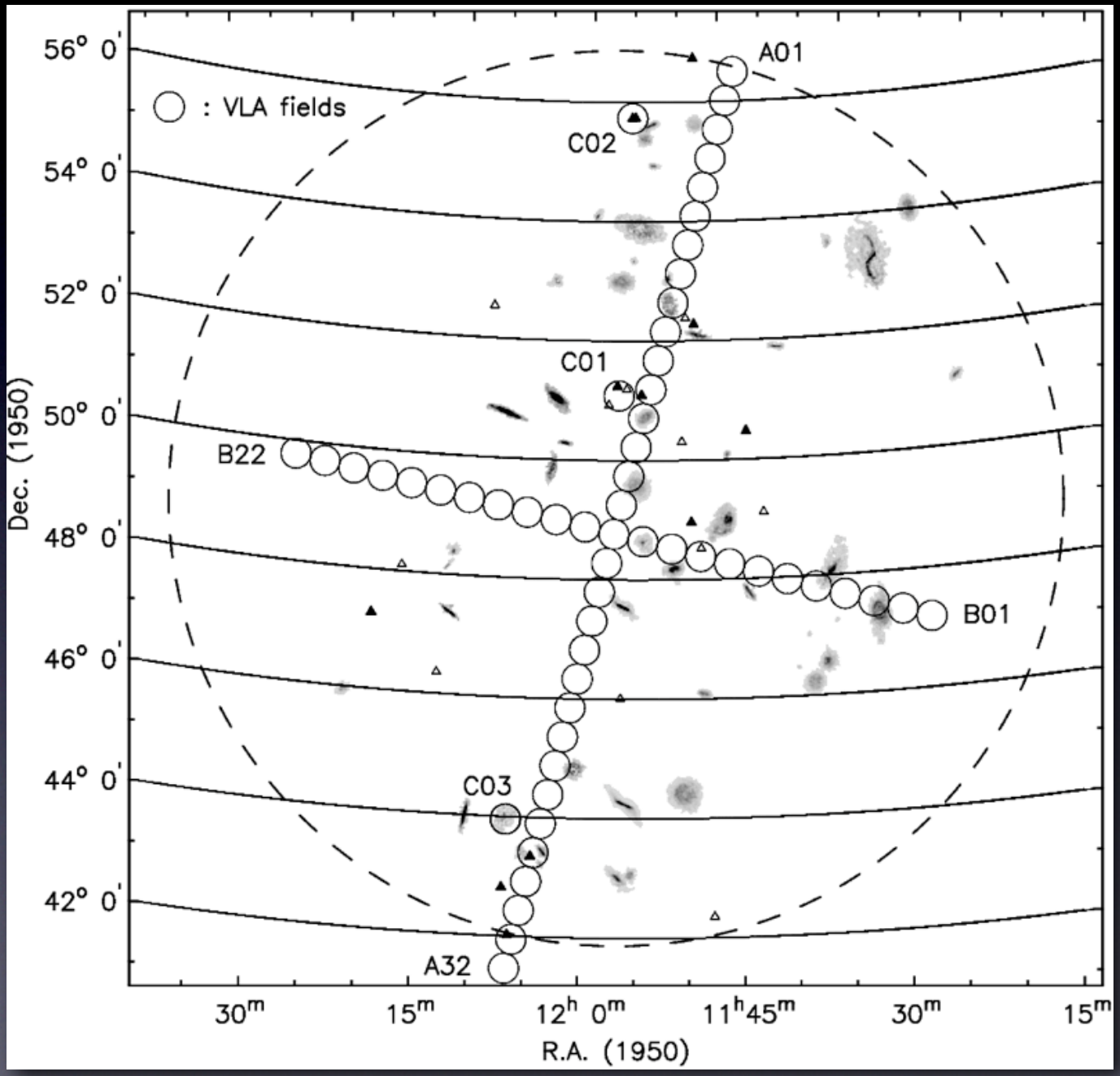


Verheijen+ '07

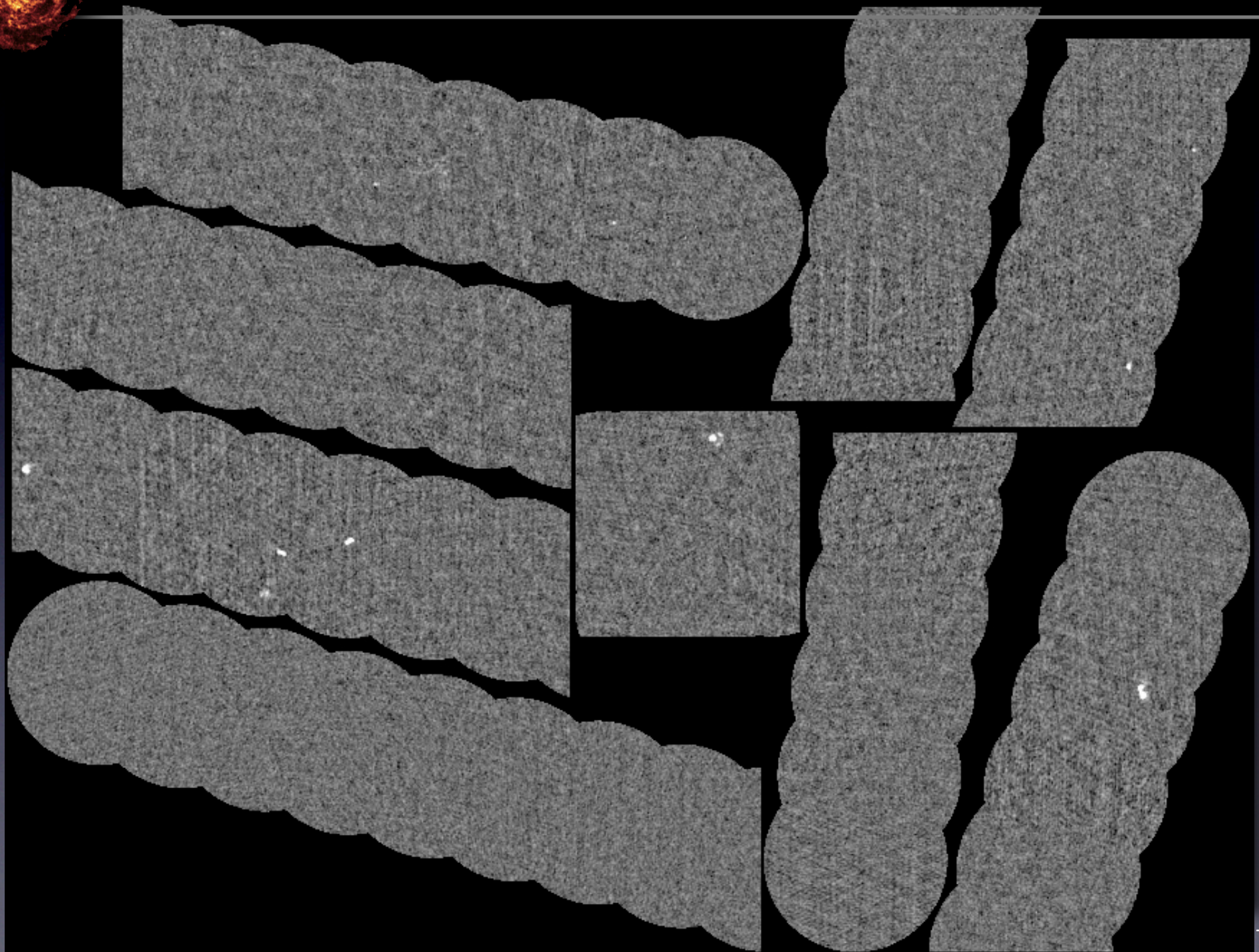
Average HI mass ≈ 2×10^9 $M_\odot$

Coming soon : all-sky blind HI imaging surveys

Blind
VLA-D survey
of Ursa Major



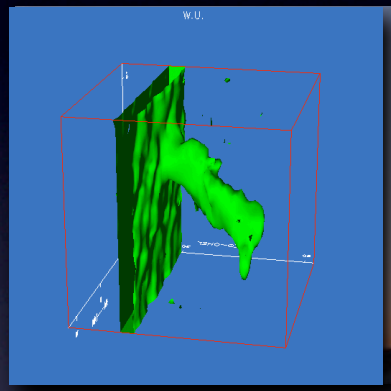
Coming soon : all-sky blind HI imaging surveys

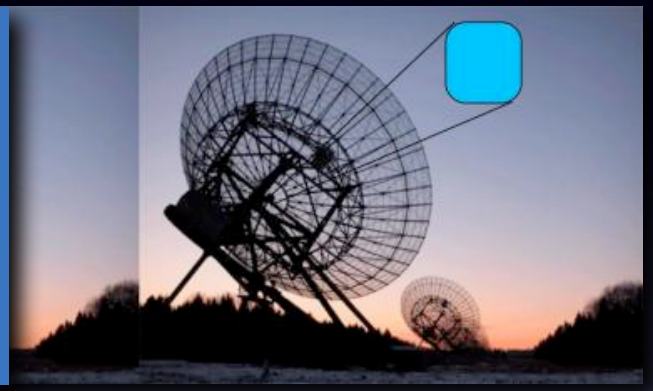


Coming soon : HI imaging survey facilities

APERTIF

Westerbork
12x 25m
8 deg^2 FoV
2015





New Mexico
27x 25m
0.25 deg^2 FoV
2012

EVLA

MeerKAT

South Africa
64x 13m
1 deg^2 FoV
2018

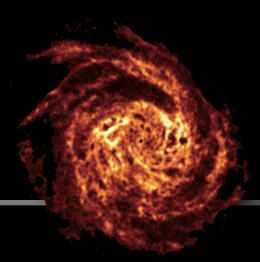
ASKAP

W. Australia
36x 12m
30 deg^2 FoV
2015

Image 10^5 galaxies in HI out to z=0.6

Coming soon : HI imaging survey facilities

www . SKAtelescope . org



Closing Remarks

Imaging of HI morphologies and kinematics
reveals a wealth of information on physical processes
relevant for galaxy (trans)formation mechanisms
not detectable otherwise.

Small samples sizes and heterogeneous selection effects.

Pathological phenomenae hold the clues
but objective quantification is challenging.

Future (all-sky) blind surveys with SKA pathfinders
will yield ~10^5 HI images/cubes across all environments.