HI in Galaxy Clusters at z=0.2

Marc Verheijen
Jacqueline van Gorkom
Boris Deshev

Hector Bravo-Alfaro
Aeree Chung
K.S. Dwarakanath
Raja Guhathakurta
Glenn Morrisson
Bianca Poggianti
David Schiminovich
Arpad Szomoru
Eric Wilcots
Min Yun
Ann Zabludoff

Kapteyn Astronomical Institute
University of Groningen RuG

Why observe HI in galaxy clusters?

- Galaxy clusters are largest bound structures and continue to accrete from their environments.
- Blind, volume limited HI surveys provide optically unbiased inventory of all gas-rich galaxies.
- HI surveys provide redshifts revealing substructure.
- Presence of cold gas is prerequisite for star formation.
- Cold HI disks are very responsive to galaxy-galaxy and galaxy-ICM interactions.

Physical Processes & Observational Clues

- Ram-pressure stripping,
  turbulent viscous stripping
- Harassment
  many hi
- Tidal int
  effective low velocity encounters
- Consumption & Exhaustion
- Starvation
- Thermal conduction
  Ionization, Evaporation

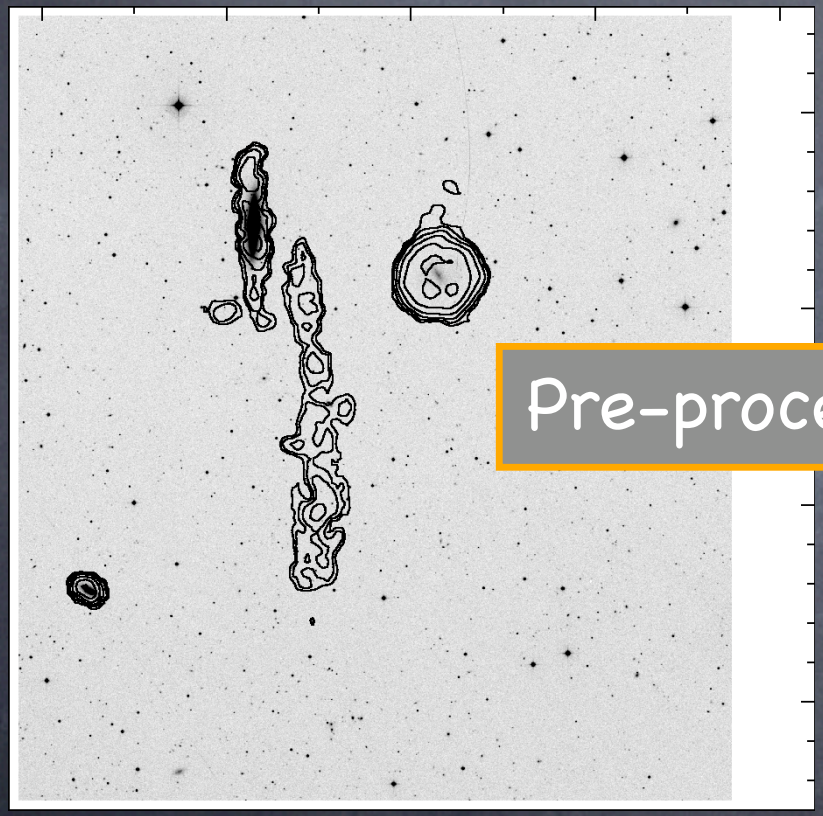
- Asymmetric & offset disks
- Truncated & disturbed disks
- streamers
- HI deficiencies in highest density regions
- HI Mass Function depends on morphology & environment

Which gas removal mechanism dominates where?

The brightest lenticulars in Ursa Major

Hot action in a cool group

NGC 4026

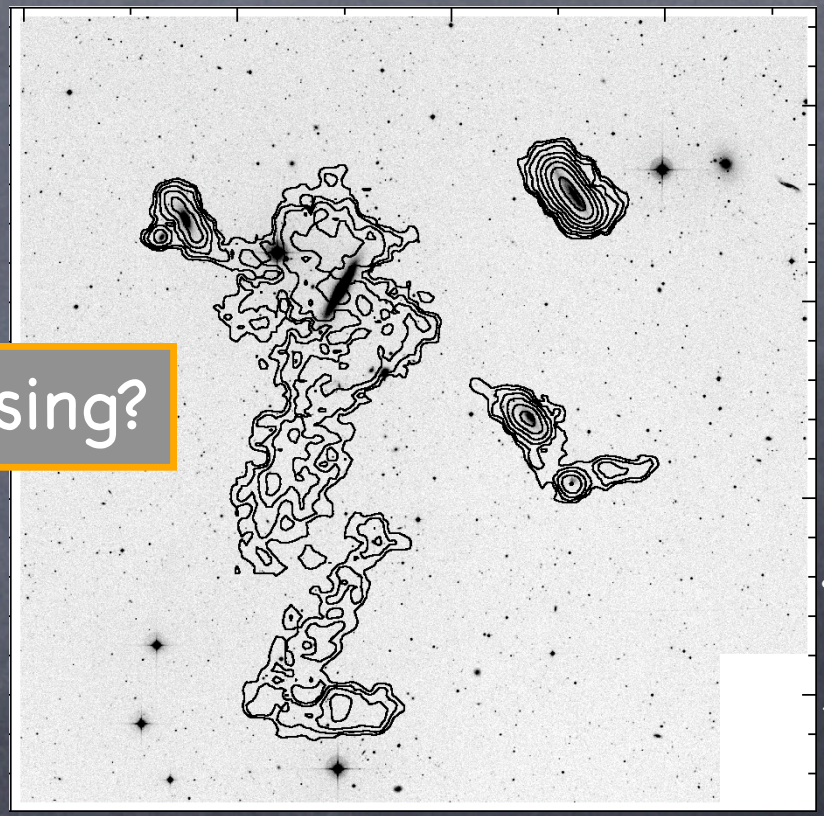


$M_R = -21.16$ (mag)

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

Pre-processing?

NGC 4111



$M_R = -21.44$ (mag)

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

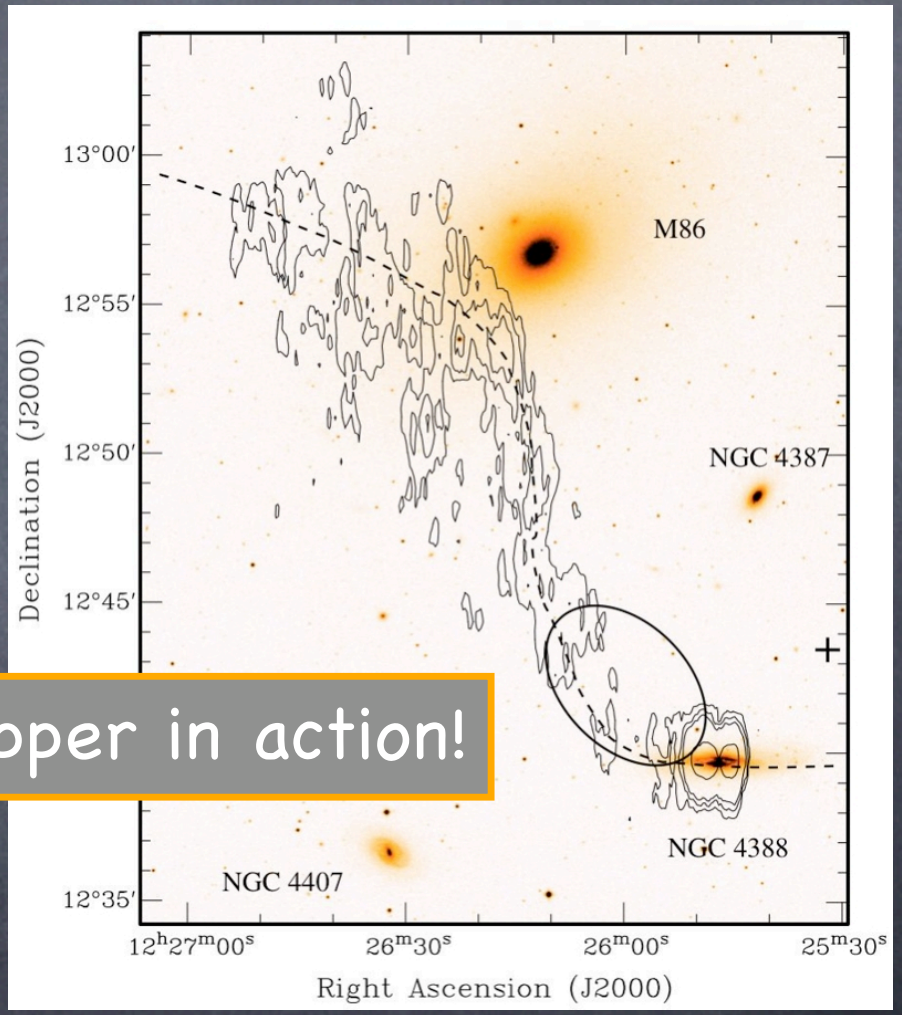
Verheijen et al, 2001

HI in the Virgo cluster

VLA

Chung et al, 2005

WSRT

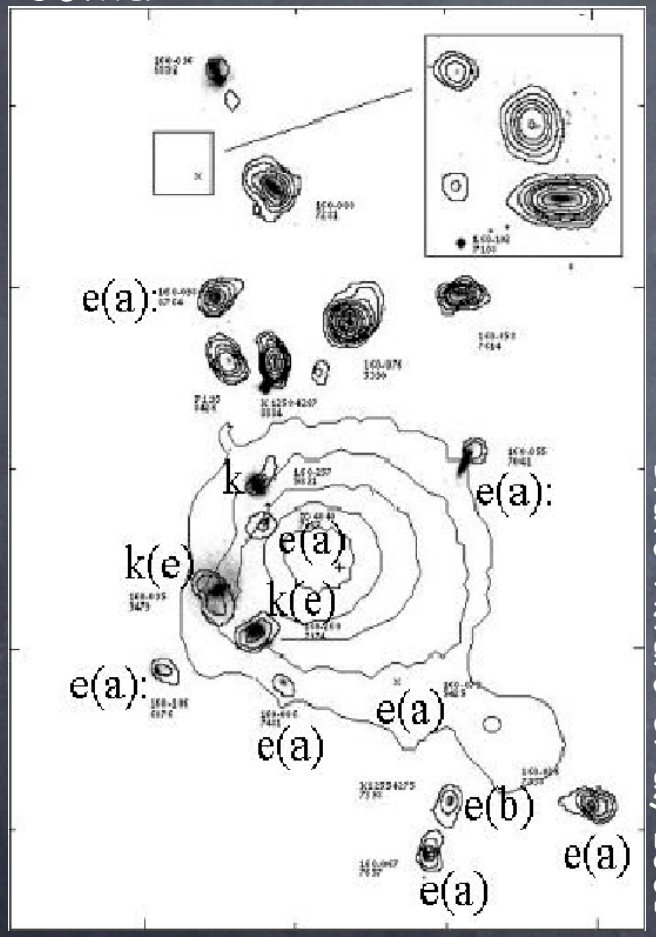


Oosterloo & van Gorkom, 2005

Stripper in action!

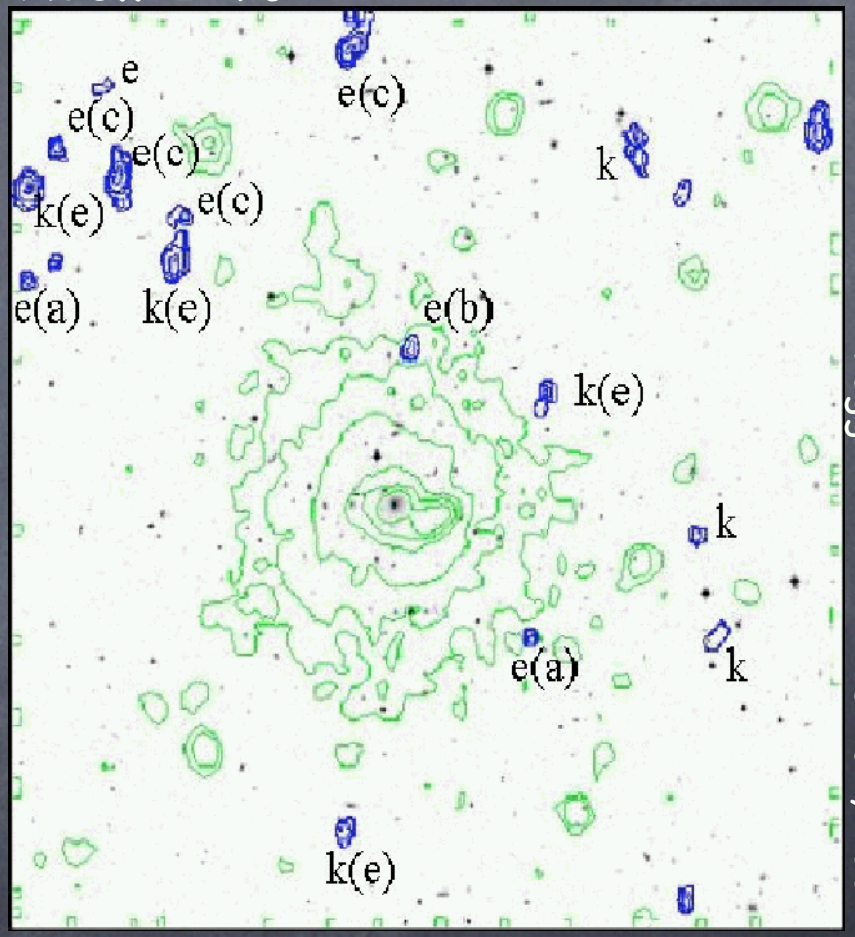
HI, ICM, SFR, SP interrelations

Coma



Bravo-Alfaro et al, 2001

Abell 2670



Poggianti & van Gorkom, 2001

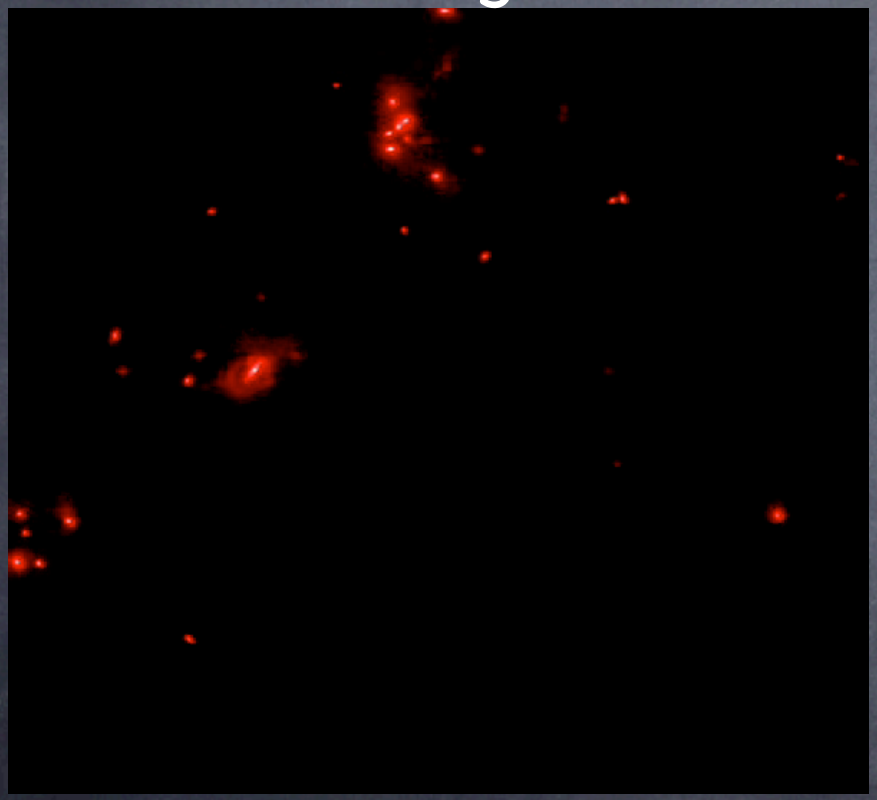
Infalling galaxies are clustered in space and velocity

➢ relates to substructures in redshift space

Simulations of cluster growth

galaxies in (trans)formation

Total gas



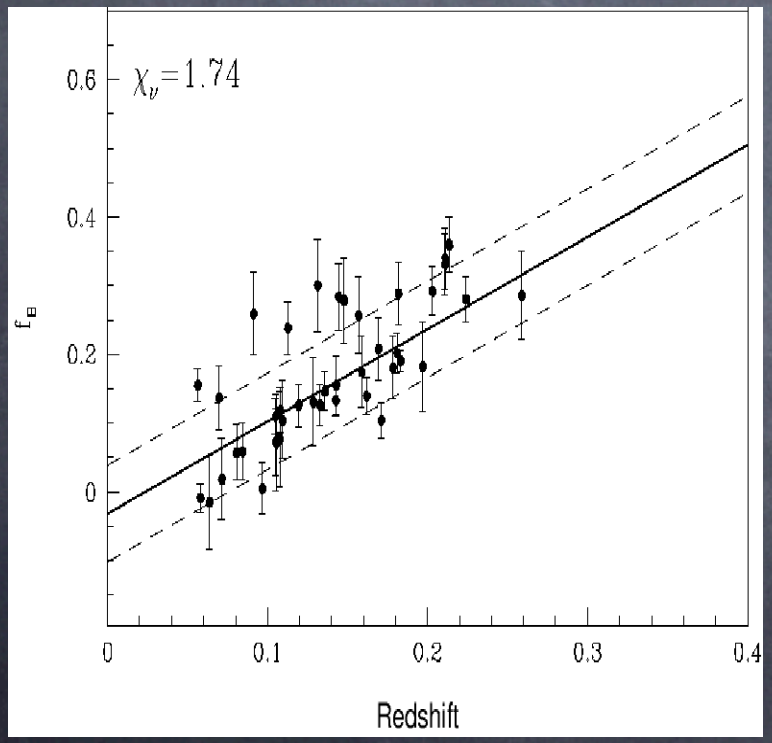
Cold gas

courtesy: Greg Bryan - Columbia University

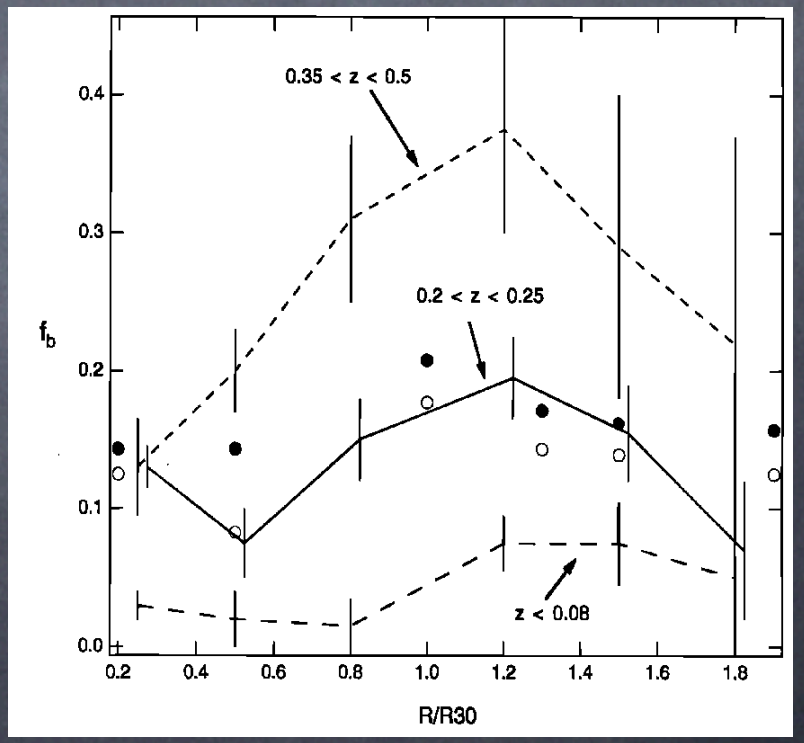
Why clusters at z~0.2 ?

- Highest redshift for practical HI imaging with existing arrays
- Lowest redshift where cosmological evolutionary effects are seen

The fraction of blue (starforming?) galaxies in clusters increases with redshift and peaks in cluster outskirts.



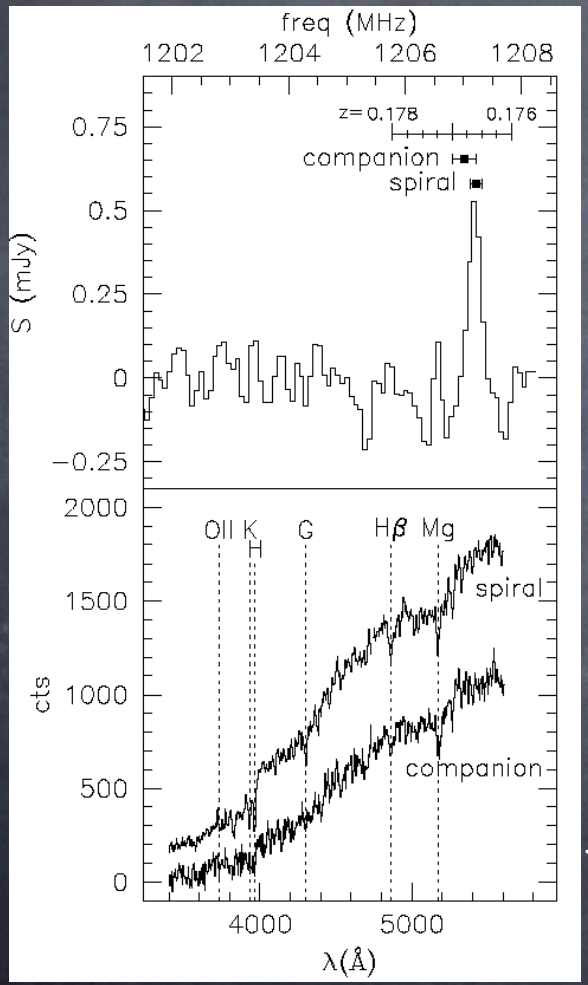
Margoniner et al, 2001



Abraham et al, 1996

First detection at intermediate Z

HI emission in the outskirts of Abell 2218 at Z=0.1766



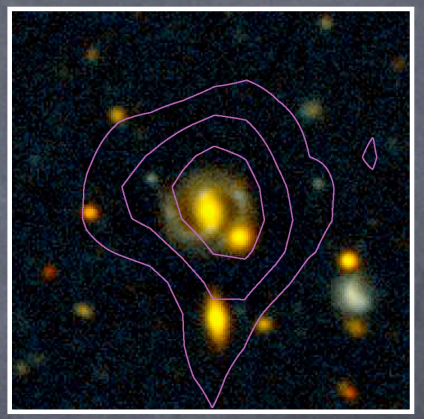
Zwaan et al, 2000

Westerbork upgrade commissioning data

$$M_{HI} = 4.7 \times 10^9 (M_\odot)$$

$$M_R = -20.8 \ (mag)$$

$$SFR_{M>5M_\odot} < 1.9 \ (M_\odot/yr)$$



Current efforts

Catinella: Arecibo detecting individual galaxies (z=0.15-025)

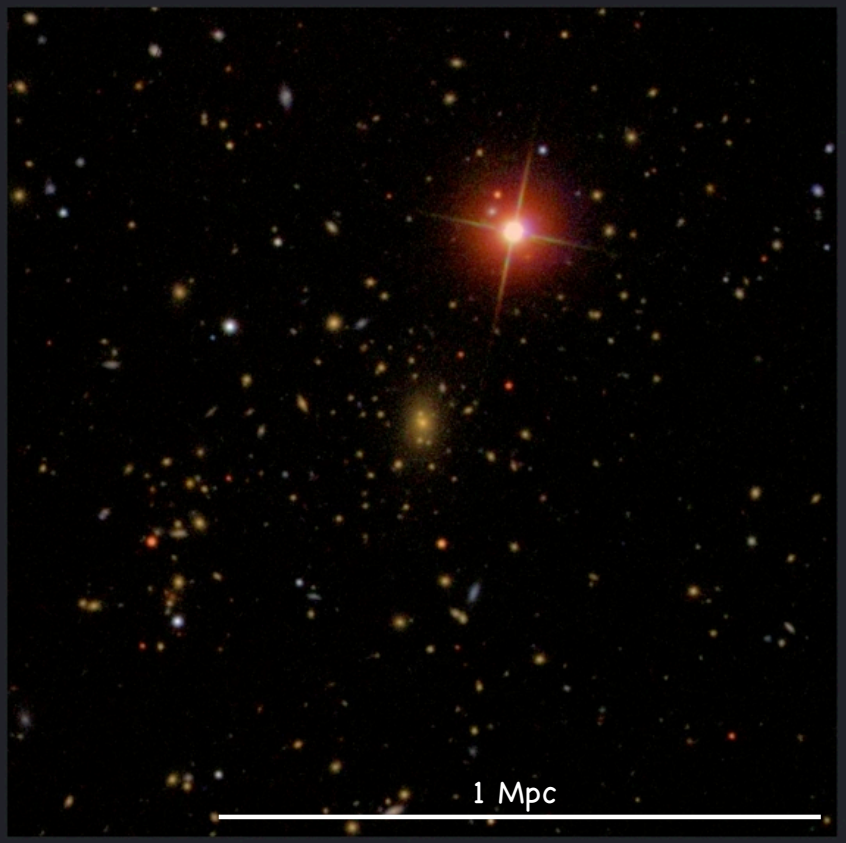
Lah : stacking 100s GMRT spectra

→ statistical detection (z=0.24)?

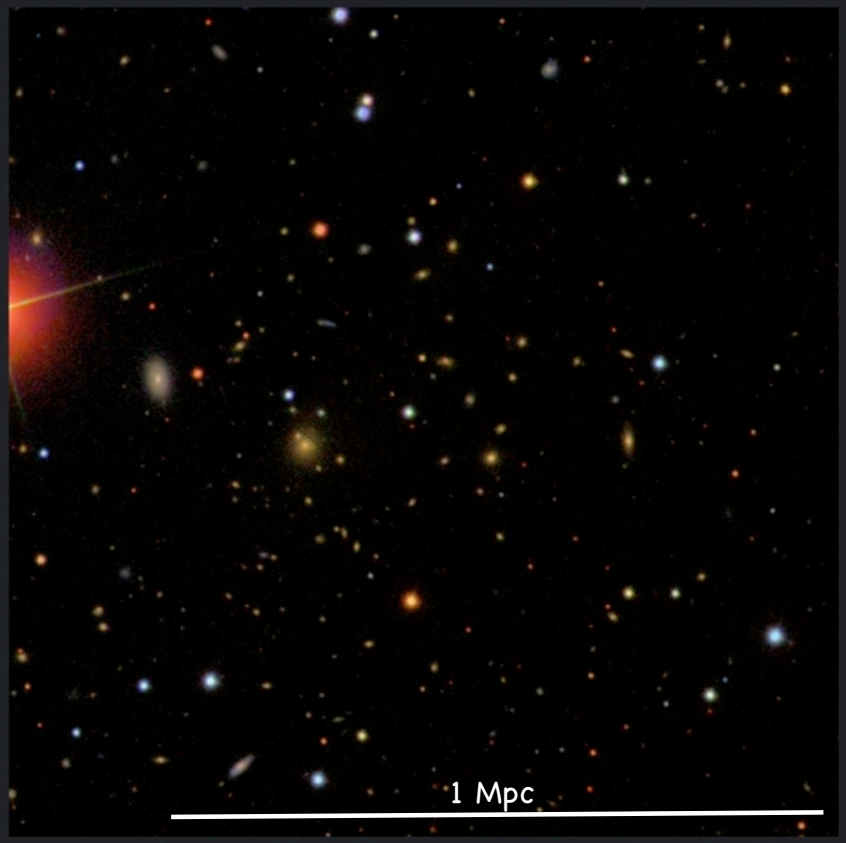
A tale of two clusters

prologue

Abell 963



Abell 2192



SDSS images

z=0.206

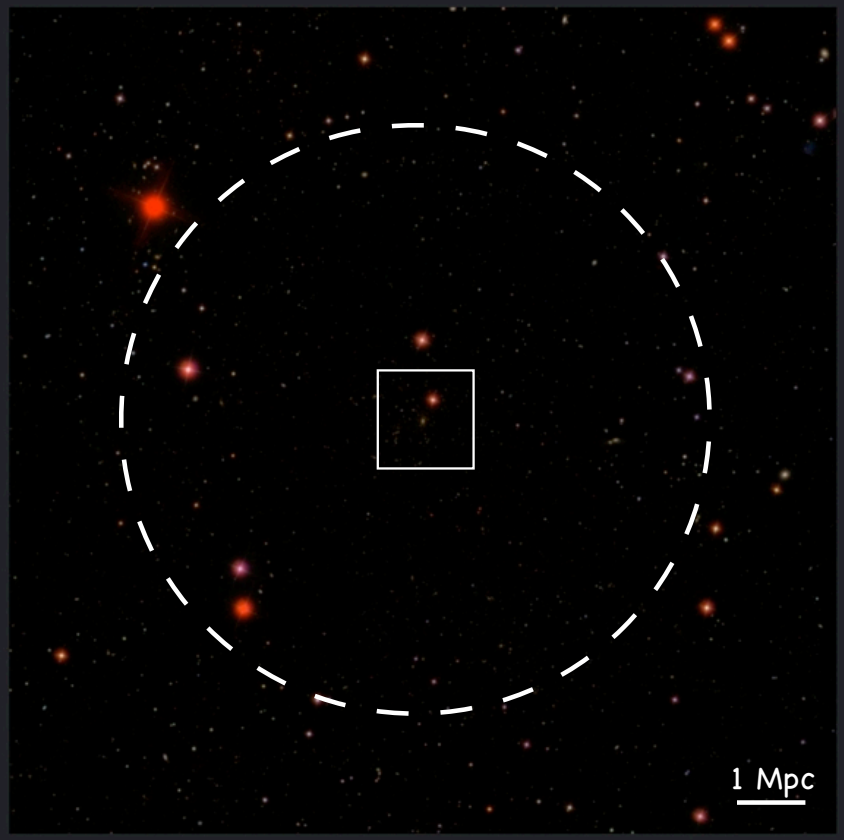
z=0.188

look-back time ≈2.5 Gyr or ~20% of the Hubble time

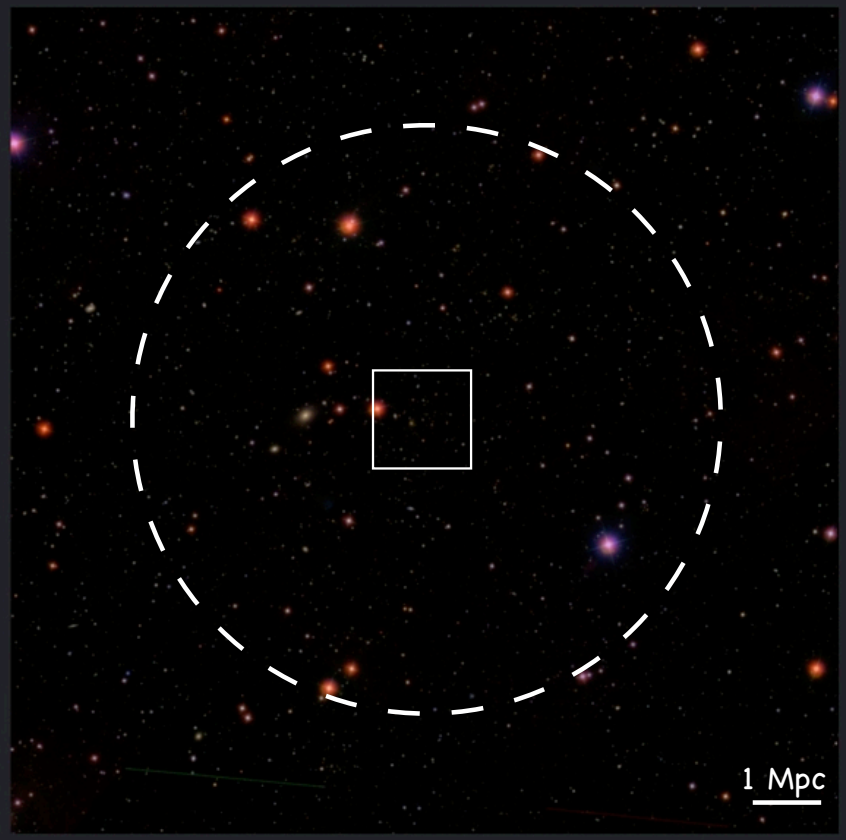
A tale of two clusters

prologue

Abell 963



Abell 2192



SDSS images

z=0.206

z=0.188

look-back time ≈2.5 Gyr or ~20% of the Hubble time

Ultra-Deep WSRT observations

- Minimum measurable HI mass:

  2×10^9 $M_\odot$ over 150 km/s profile width,
  with 4σ in each of 3 resolution elements.

- Corresponding limiting column density:

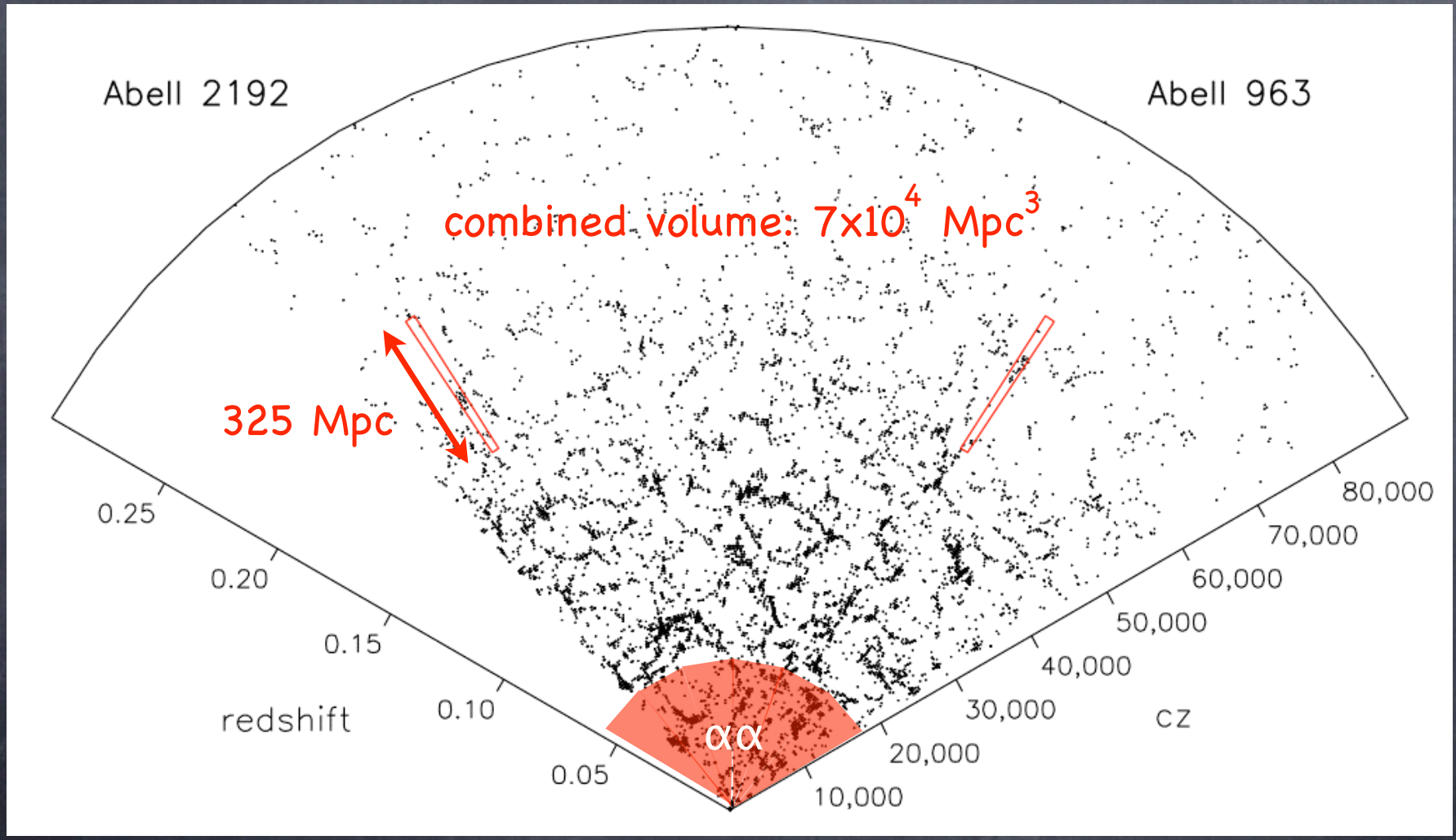
  3×10^{19} (cm^{-2}) over 75 km/s profile width at 7σ.

This requires: 73×12^{hr} for A2192
117×12^{hr} for A963

WSRT pilot observations

- 8x10MHz bands, overlapping to cover 1160-1220 MHz
  Z = 0.164-0.224, surveyed volume ≈ 70,000 Mpc^3
- 8x256 channels, covering 18,000 km/s velocity range
  24 km/s velocity resolution (after Hanning smoothing)
- dual polarisation, 2-bit correlation, recirculation
- $20x12^{hr}$ on Abell 963, $15x12^{hr}$ on Abell 2192
- rms noise per channel: 68 μJy and 91 μJy
- ~5% lost to RFI

Survey Volume & Large Scale Structure



SDSS redshift cone

Abell 963

38 channels (ΔV=24 km/s)

ν : 1175.3 - 1172.4 MHz

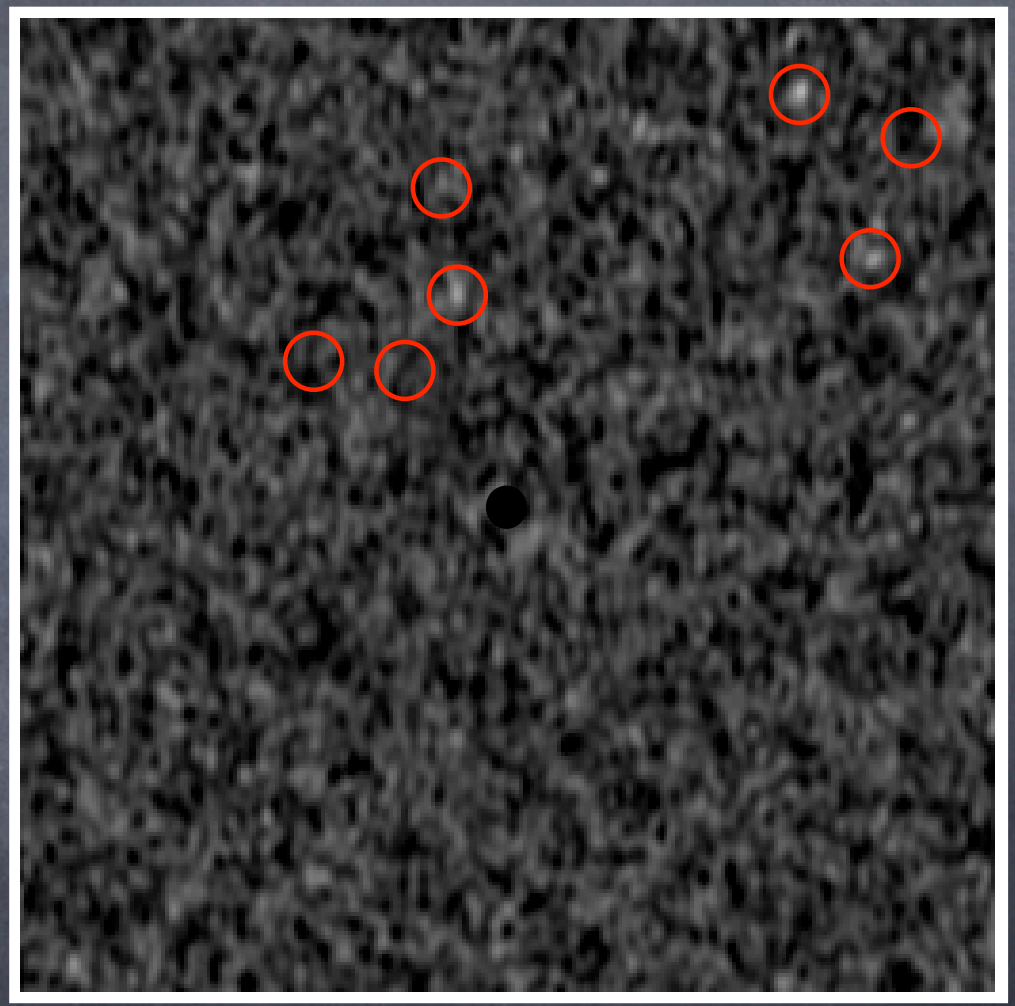
Z : 0.2085 - 0.2115

cz : 62,507 - 63,406 km/s

39 galaxies detected in two clusters

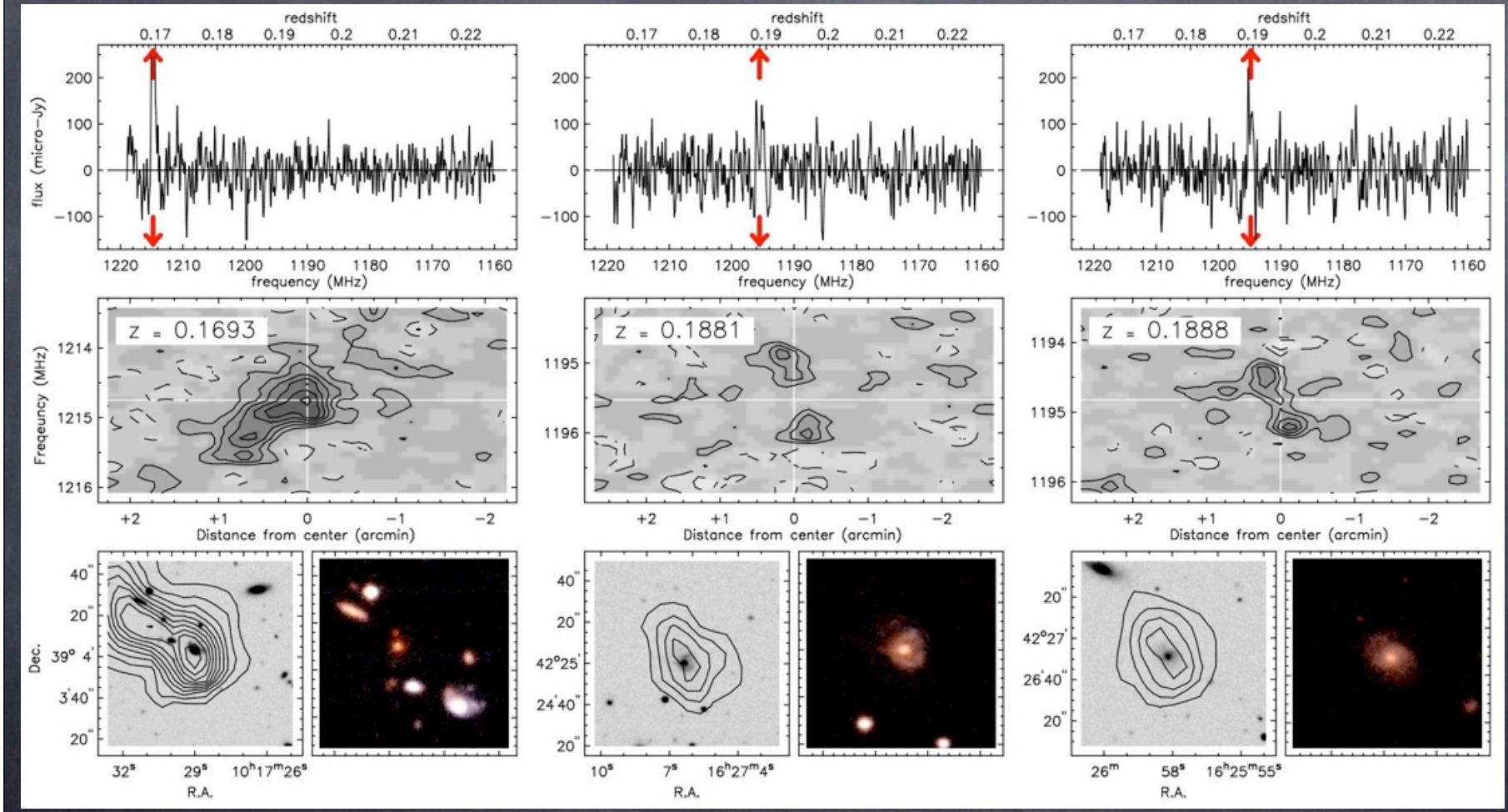
$5 \times 10^9 - 4 \times 10^{10} M_\odot$

WSRT data cube

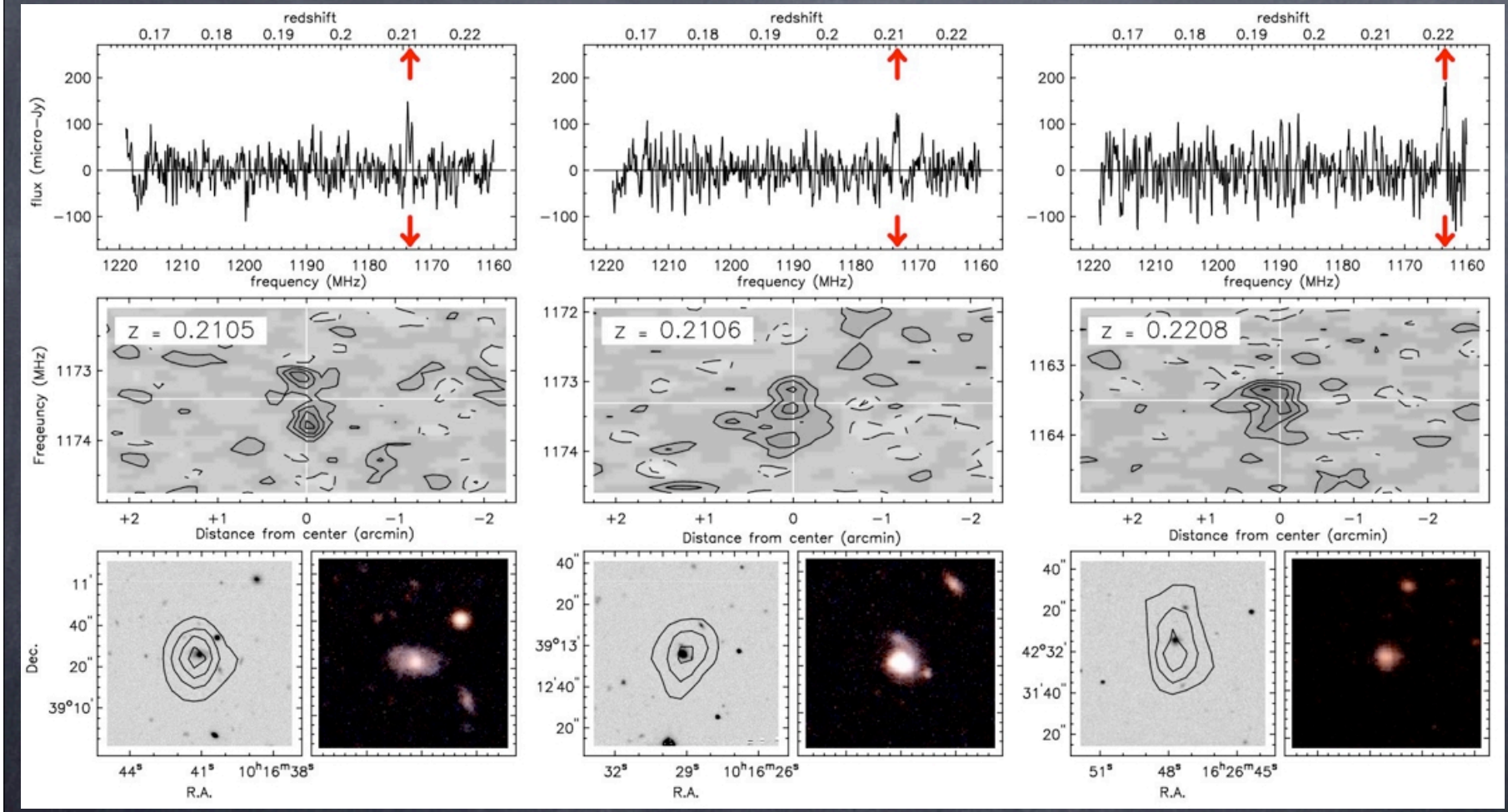


4.3 x 4.3 Mpc

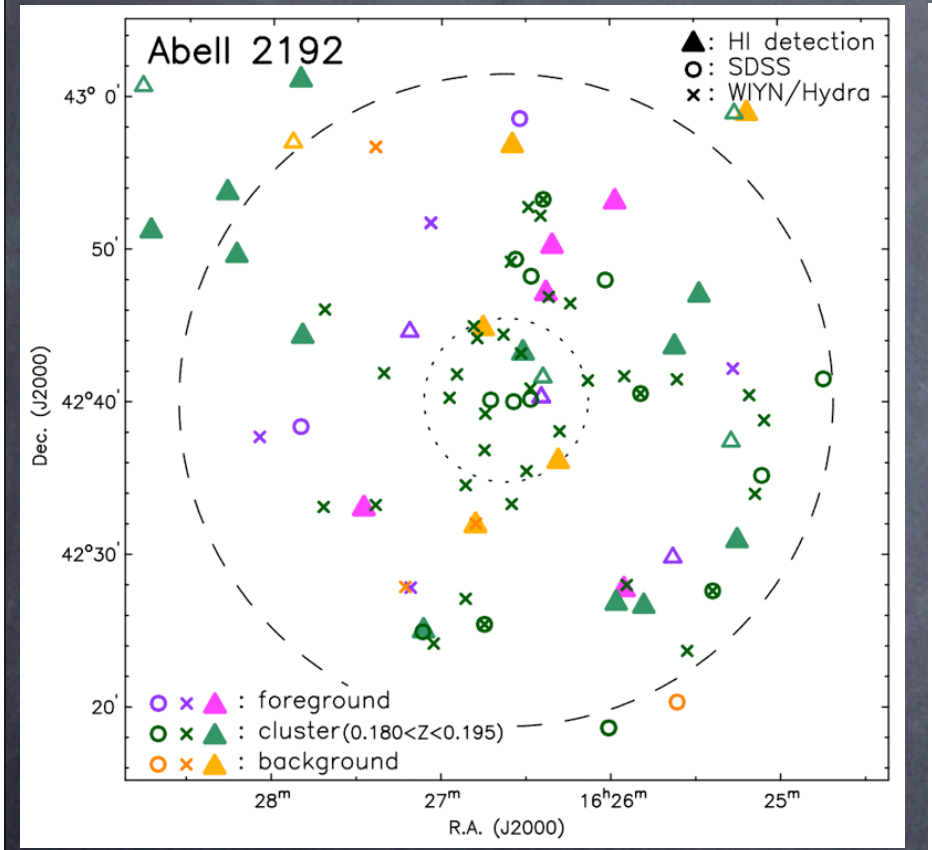
Pilot observations - First results

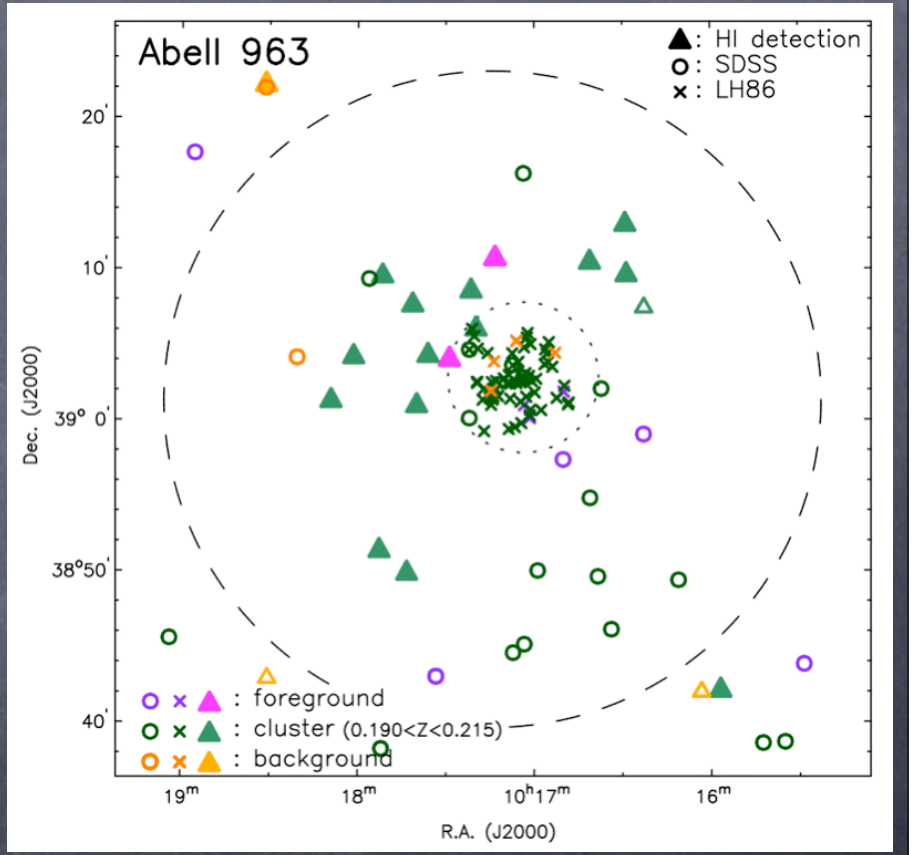


Pilot observations - First results

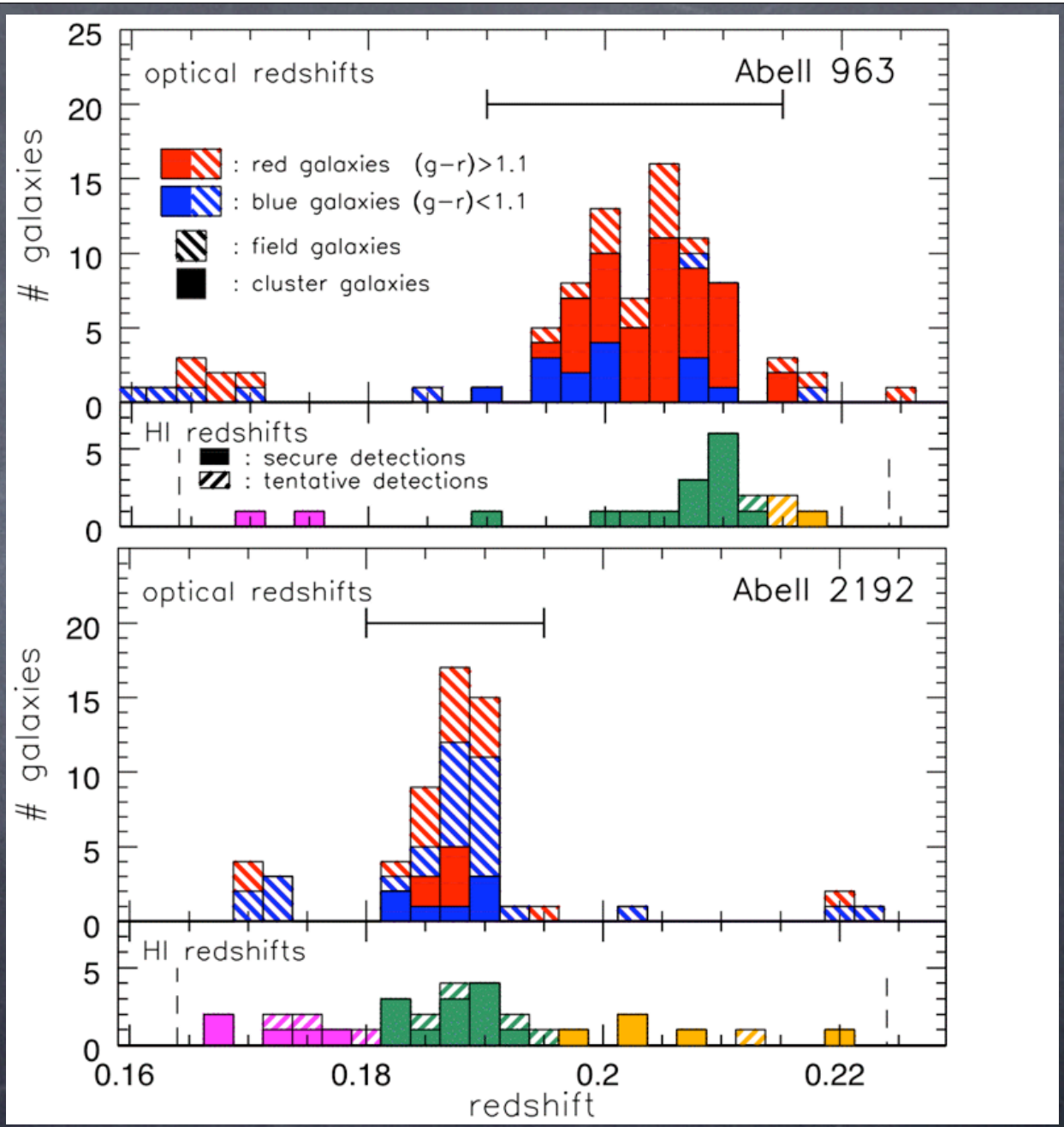


Revealing the surrounding field





Redshift distributions



Colour-Magnitude diagrams

Galaxies with known redshifts only

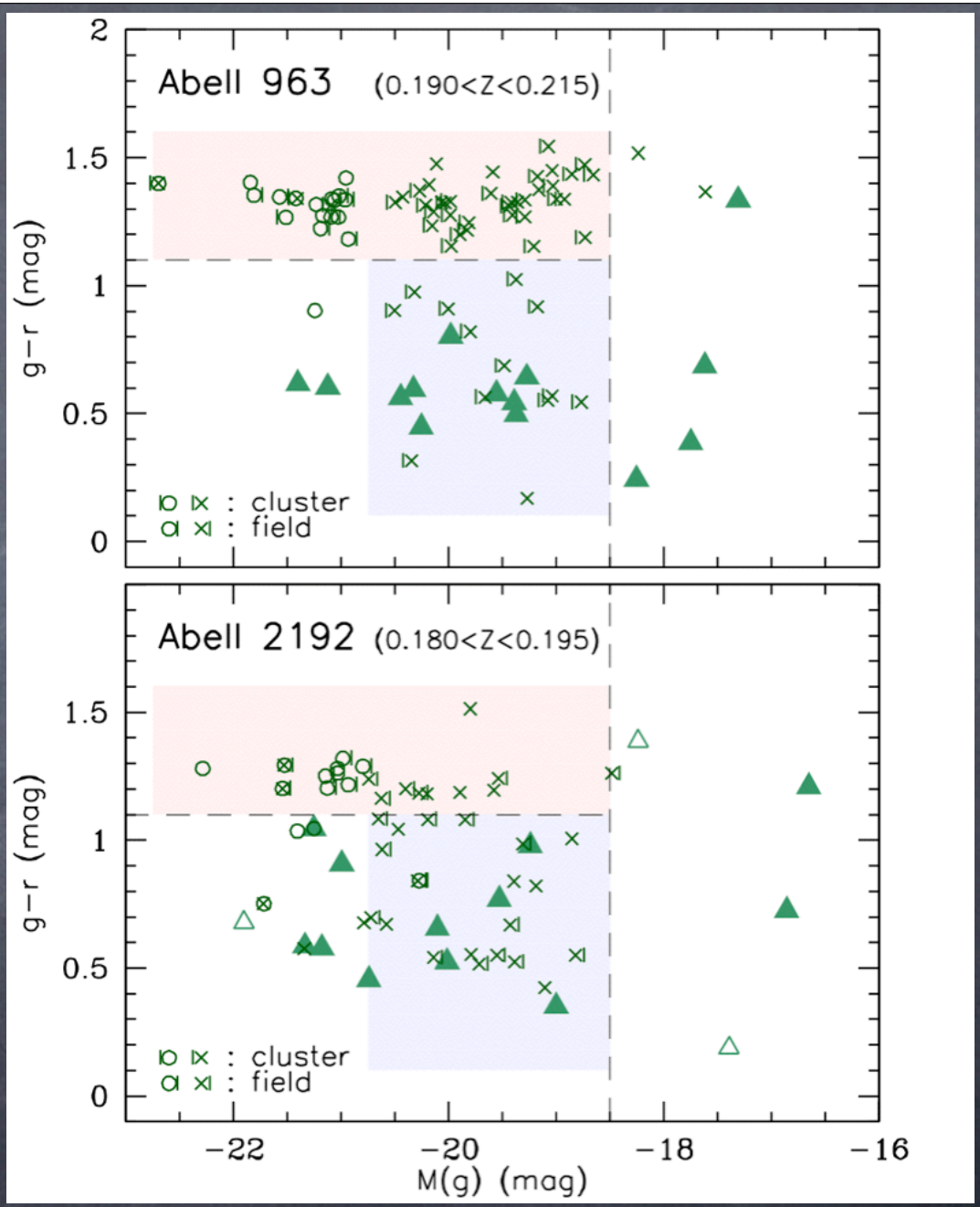
optical redshifts

○ : SDSS

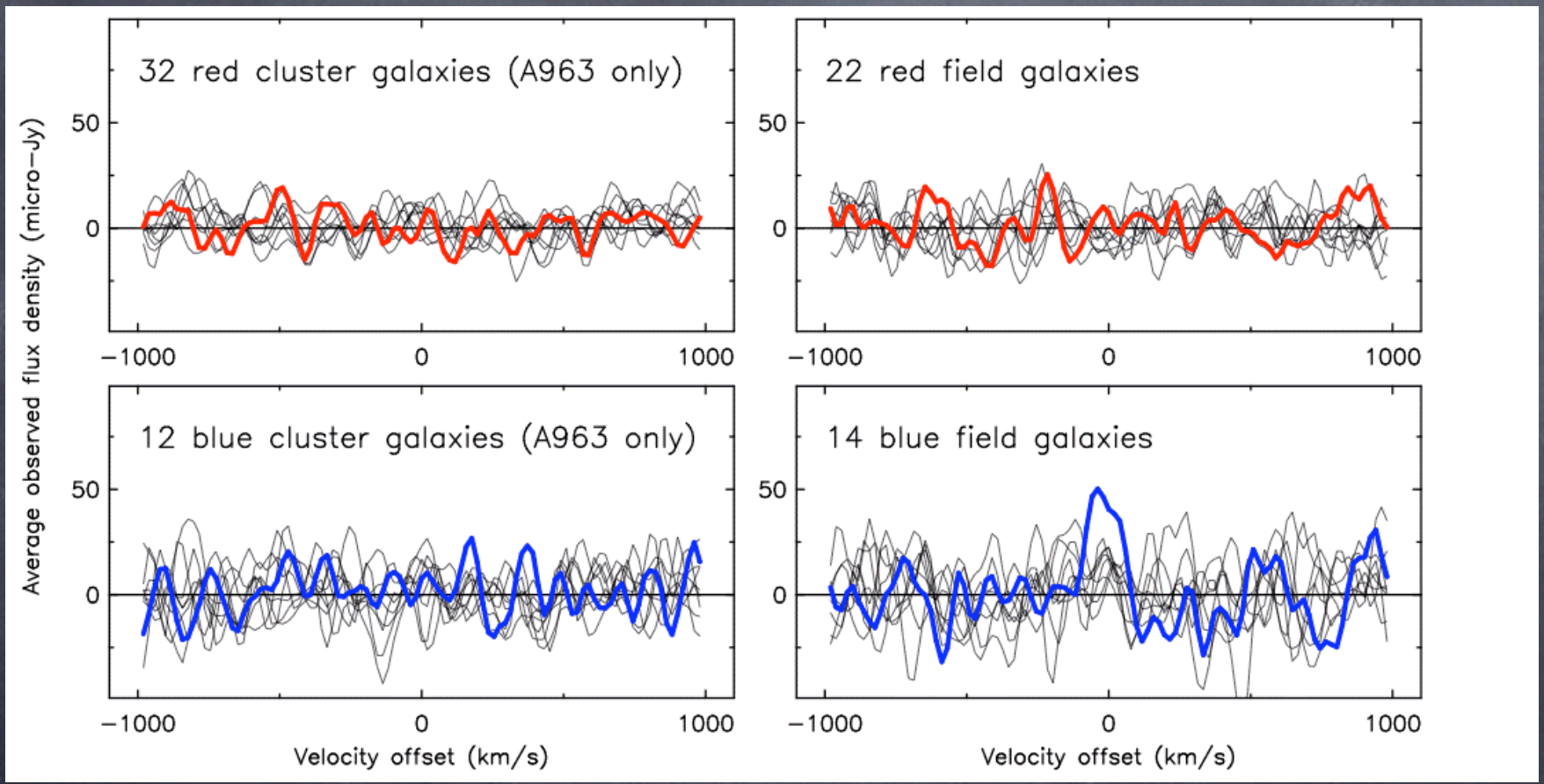
× : other

HI redshifts

▲ : WSRT



Stacking HI spectra



Average HI mass: ~ 2×10^9 $M_\odot$

Summary & Outlook

- HI reveals physical processes unseen otherwise
- Westerbork has a powerful and unique receiver
- HI emission from 39 galaxies at z≈0.2
- Blind HI survey uncovers LSS unseen by SDSS
- Blue 'BO-galaxies' gas-poor wrt similar field galaxies
- Long-term program on WSRT + Spitzer, CO, UV ..... (>200 detections expected)

Only SKA can image this at z=1