

Westerbork ultra-deep HI observations at $z=0.2$

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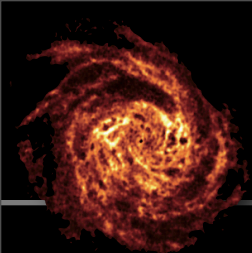
Marc Verheijen

Eric Wilcots

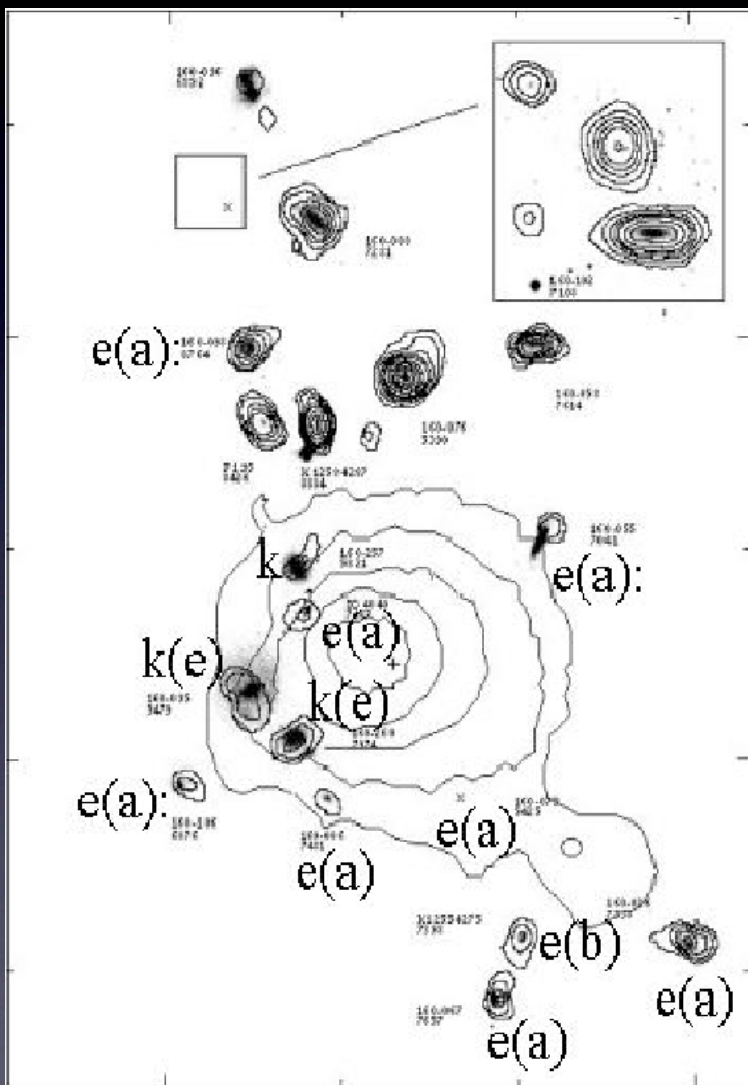
Min Yun



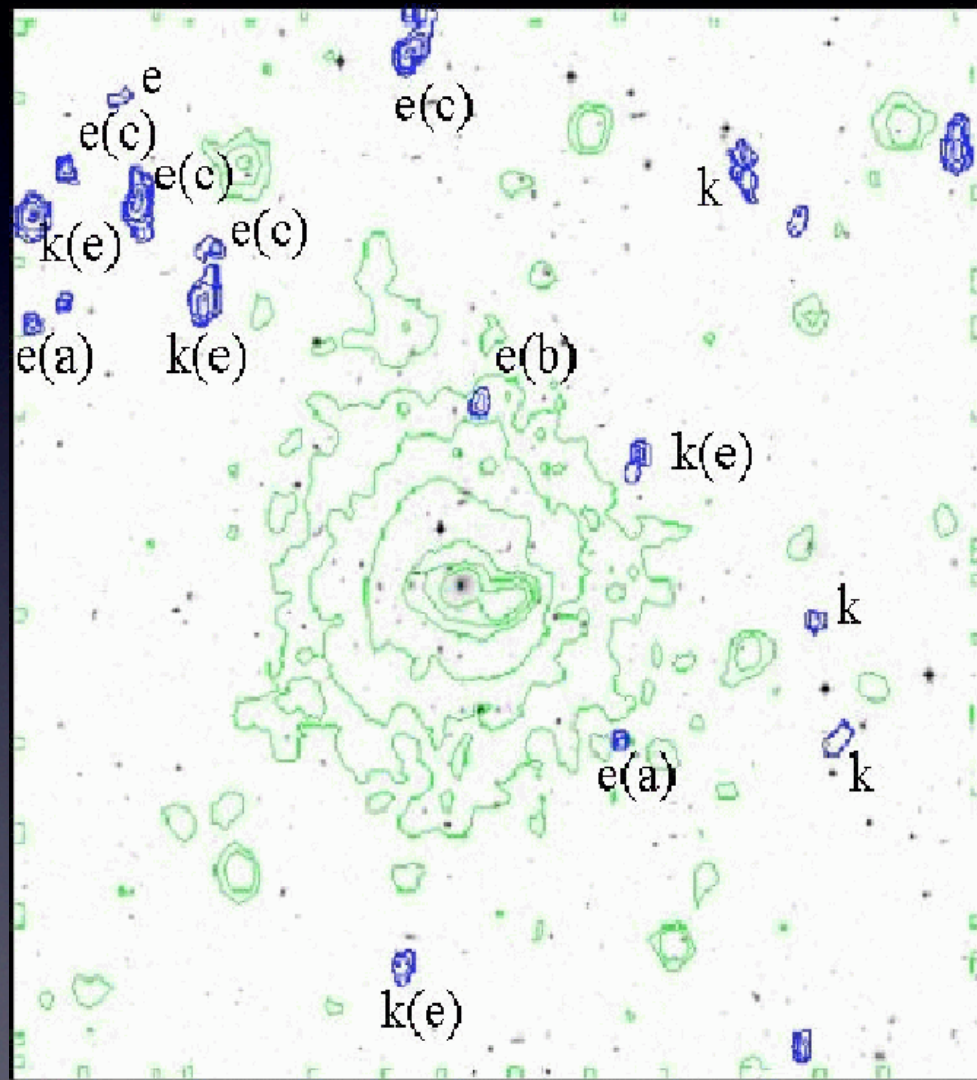
HI, ICM, SFR, SP interrelations



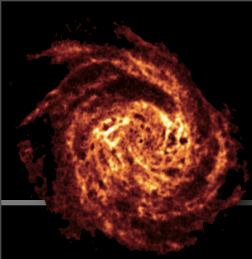
Coma



Abell 2670

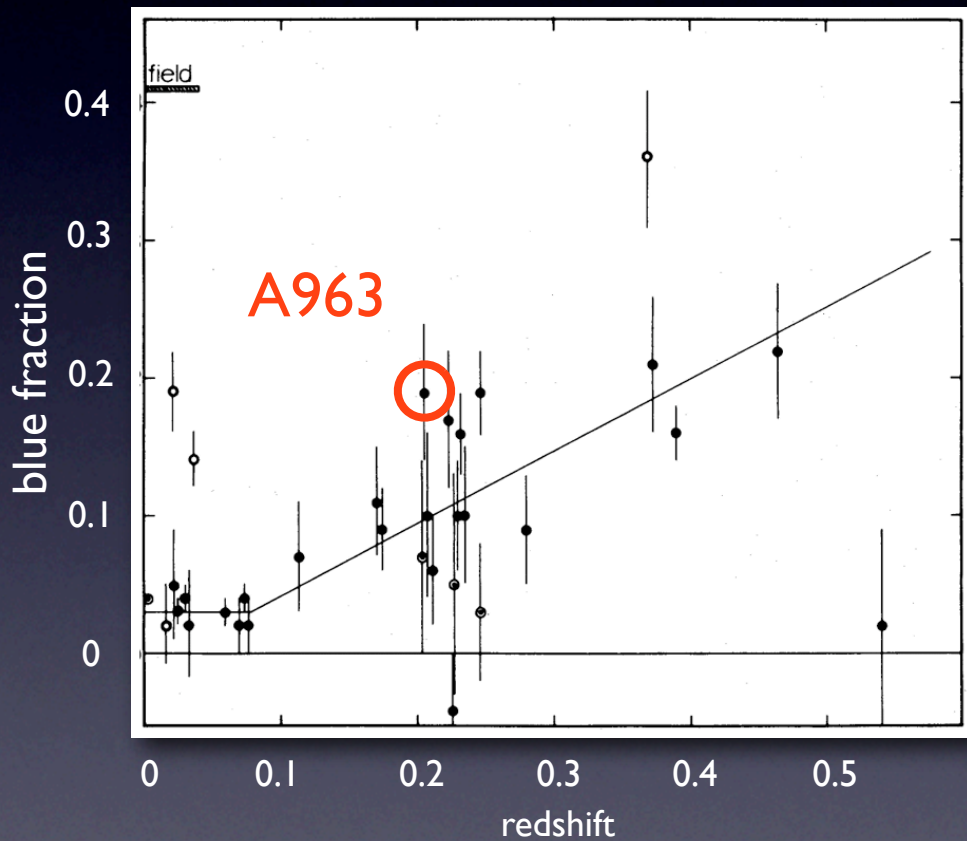


Role and fate of HI in galaxy (trans)formation & evolution

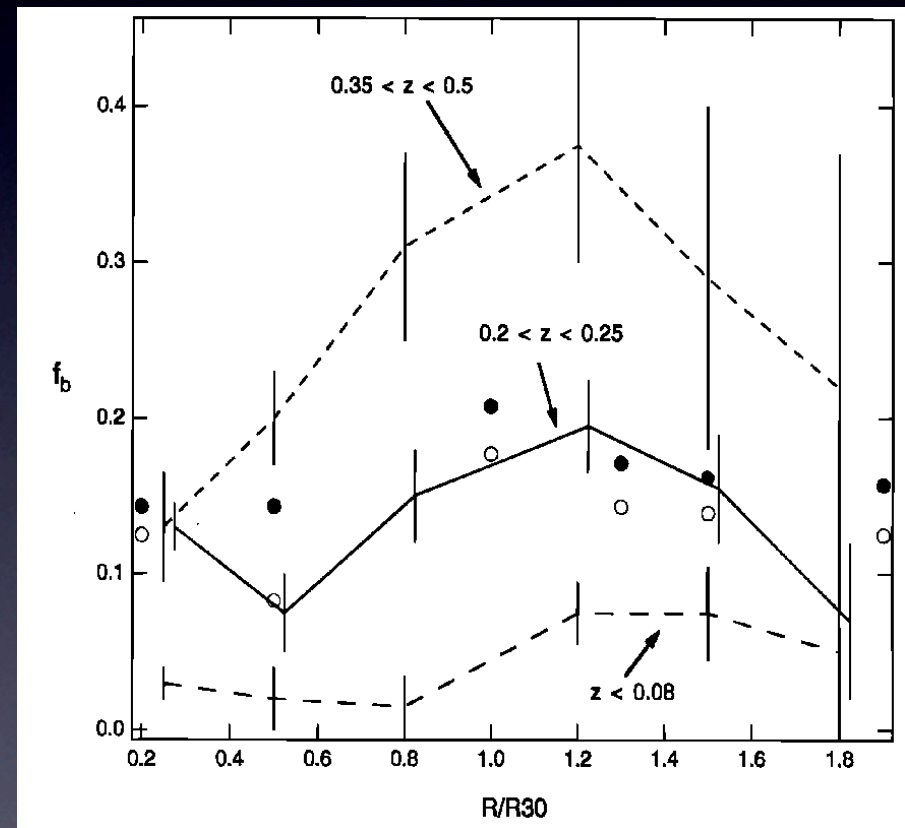


Butcher-Oemler effect

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

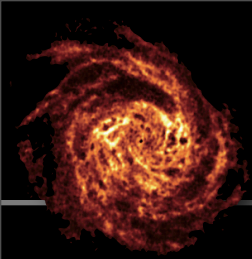


Butcher & Oemler, 1984

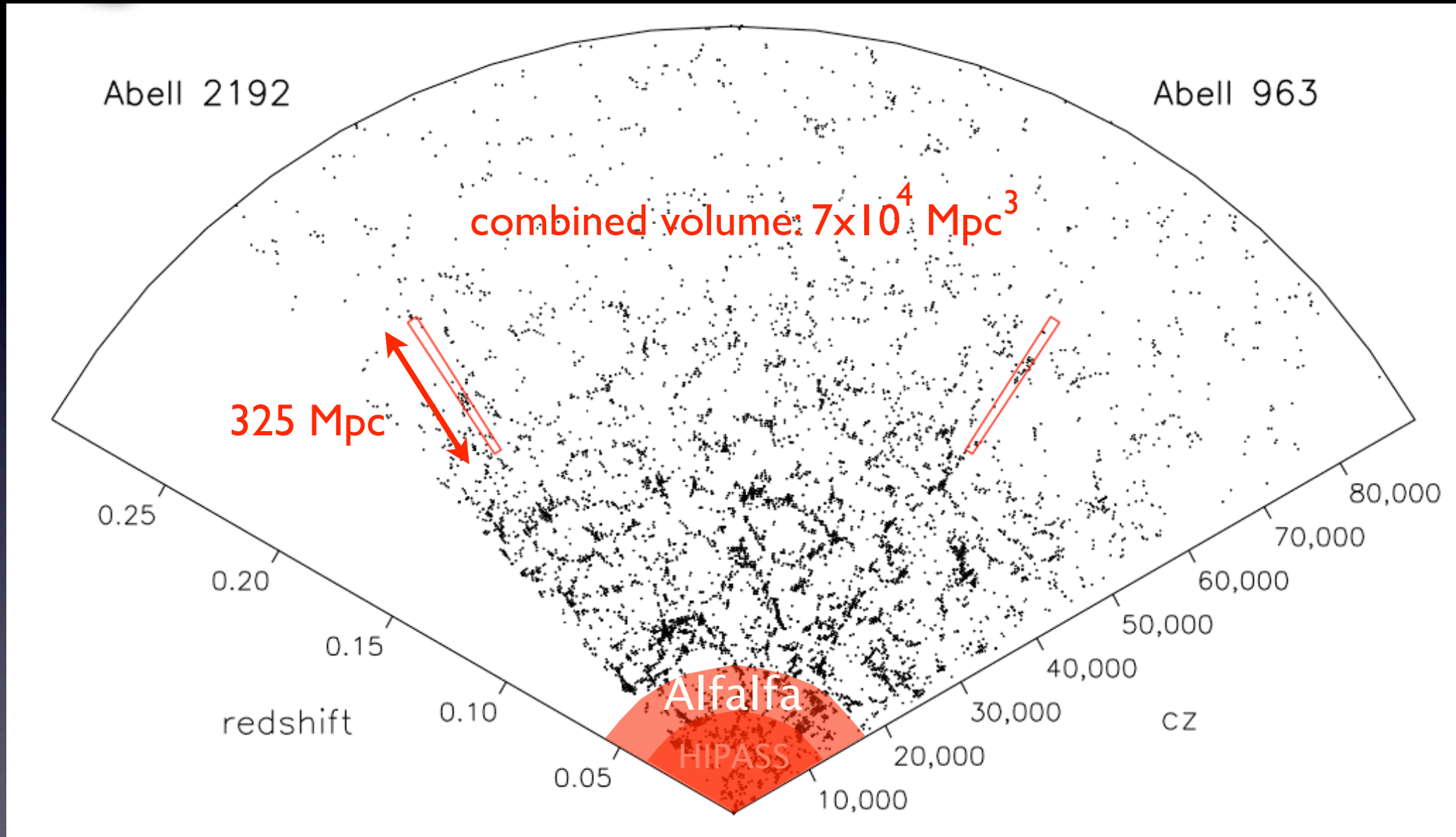


Abraham et al, 1996

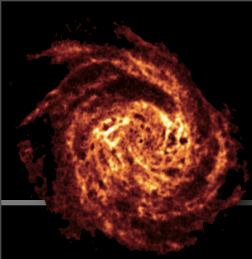
Different accretion rate/efficiency or different field population?



WSRT Survey Volume & Large Scale Structure



SDSS redshift slice

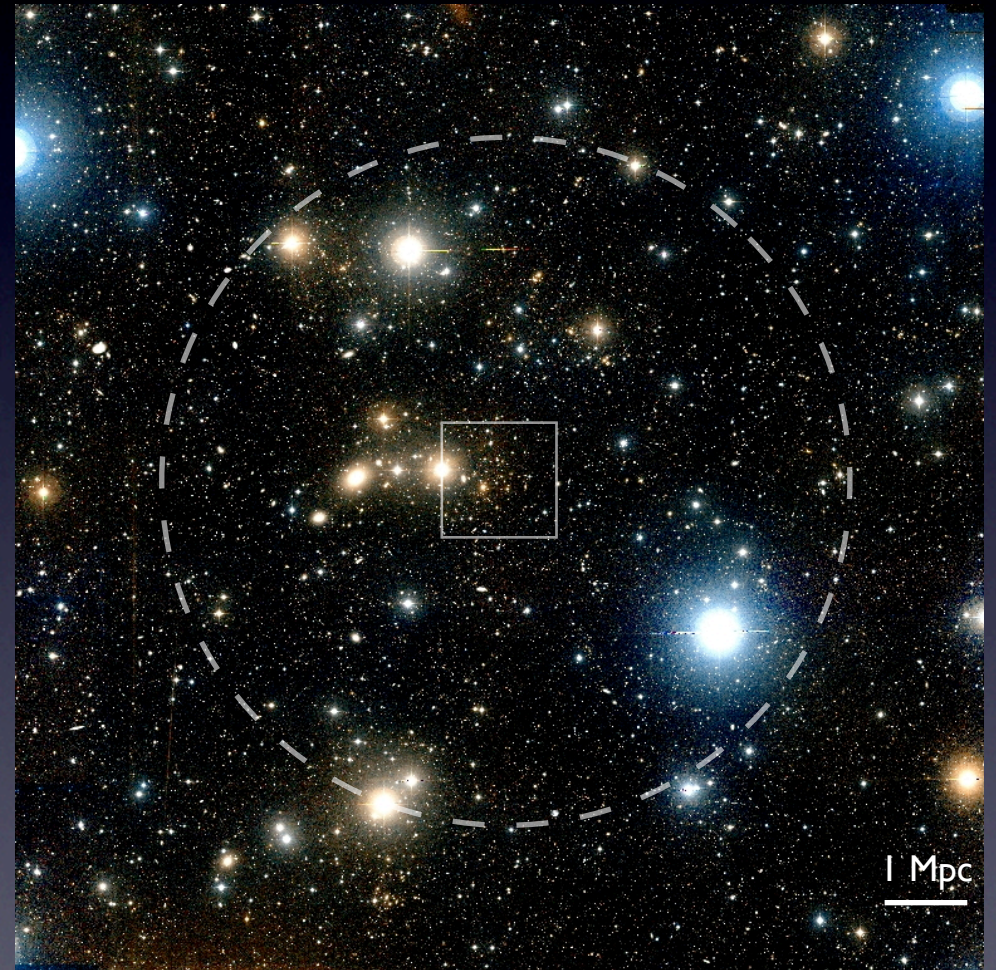
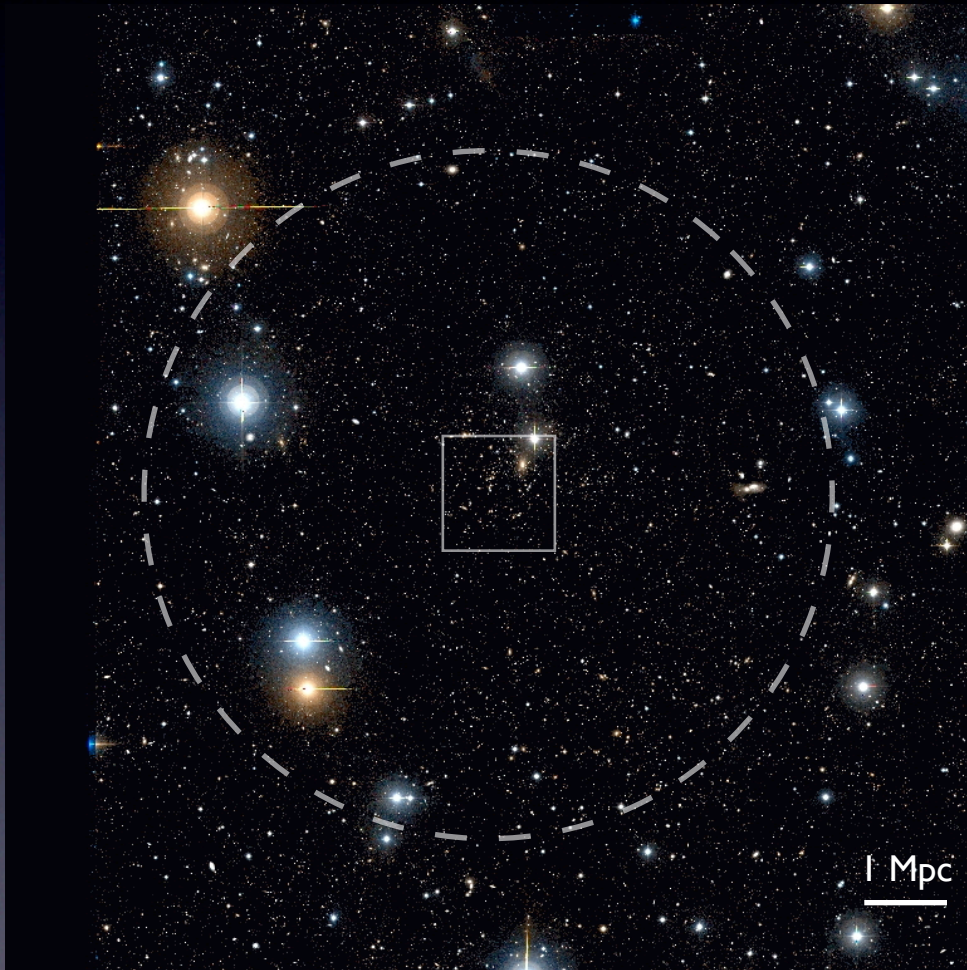


A tale of two clusters

work in progress

Abell 963

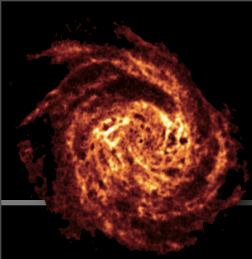
Abell 2192



INT - B,R

$z=0.206$

$z=0.188$

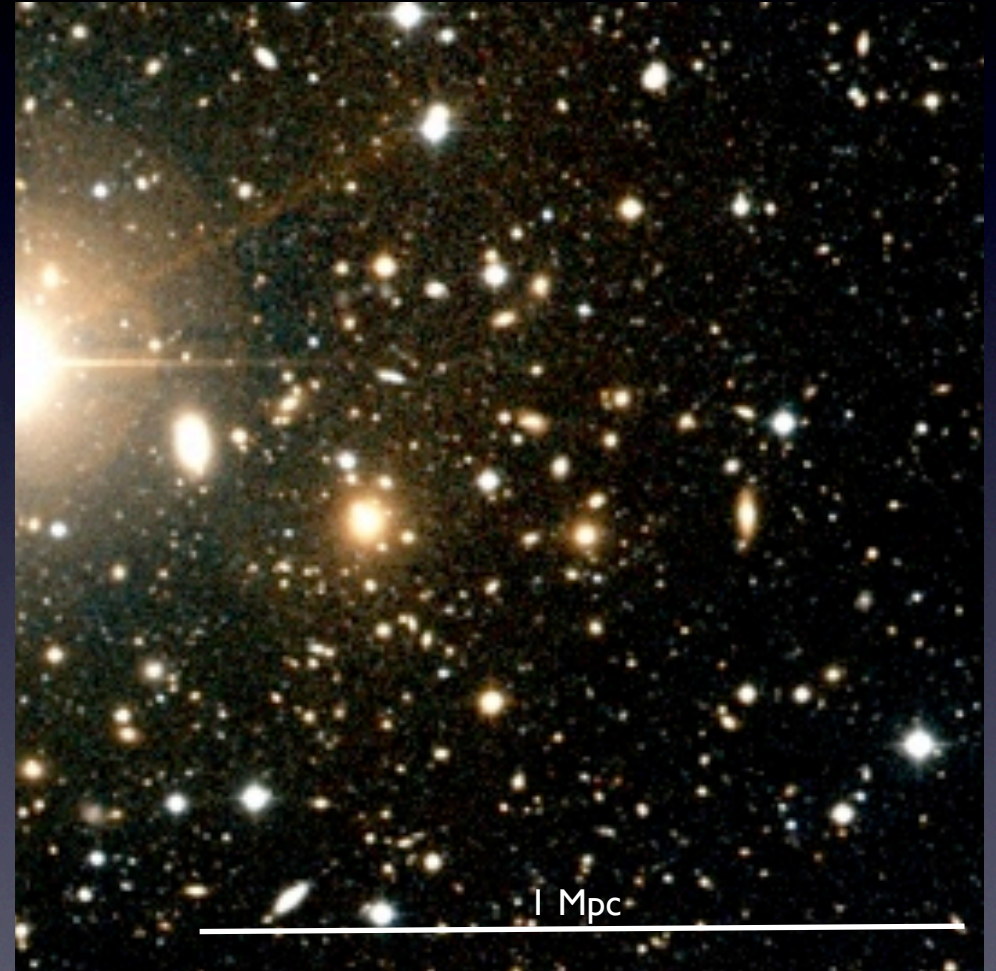
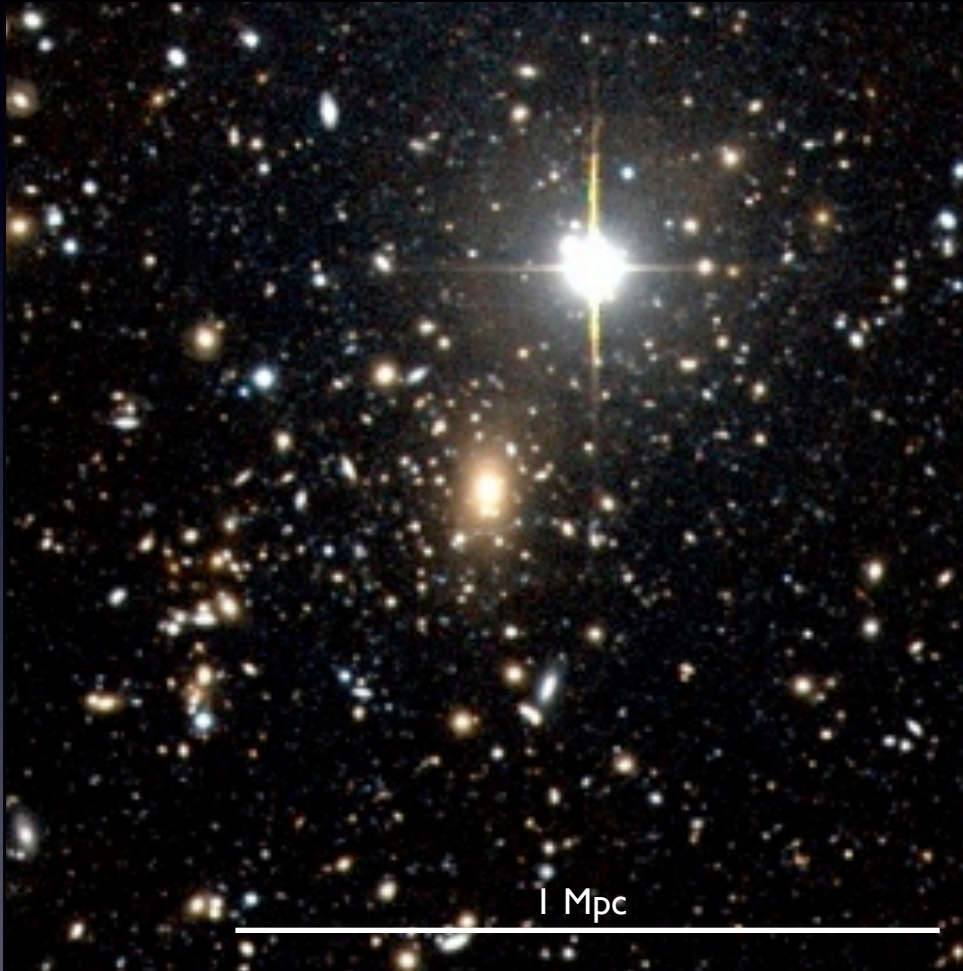


A tale of two clusters

work in progress

Abell 963

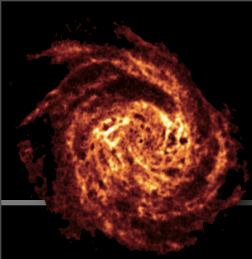
Abell 2192



INT - B,R

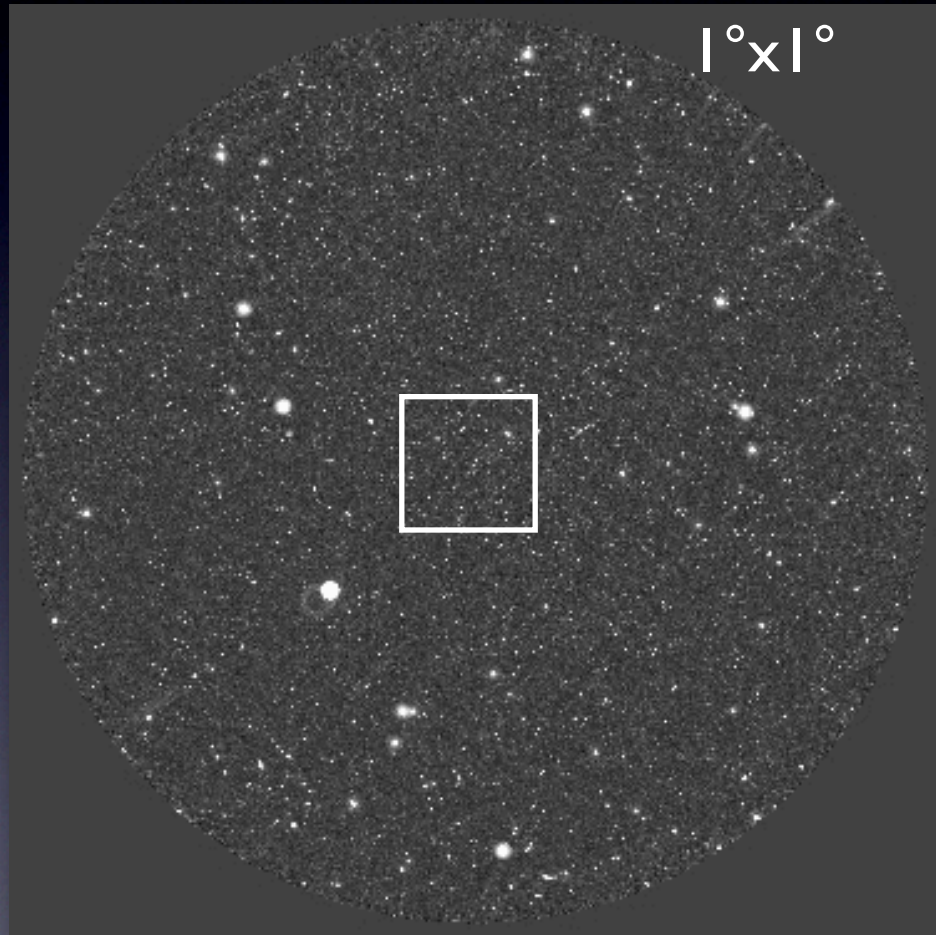
$z=0.206$

$z=0.188$

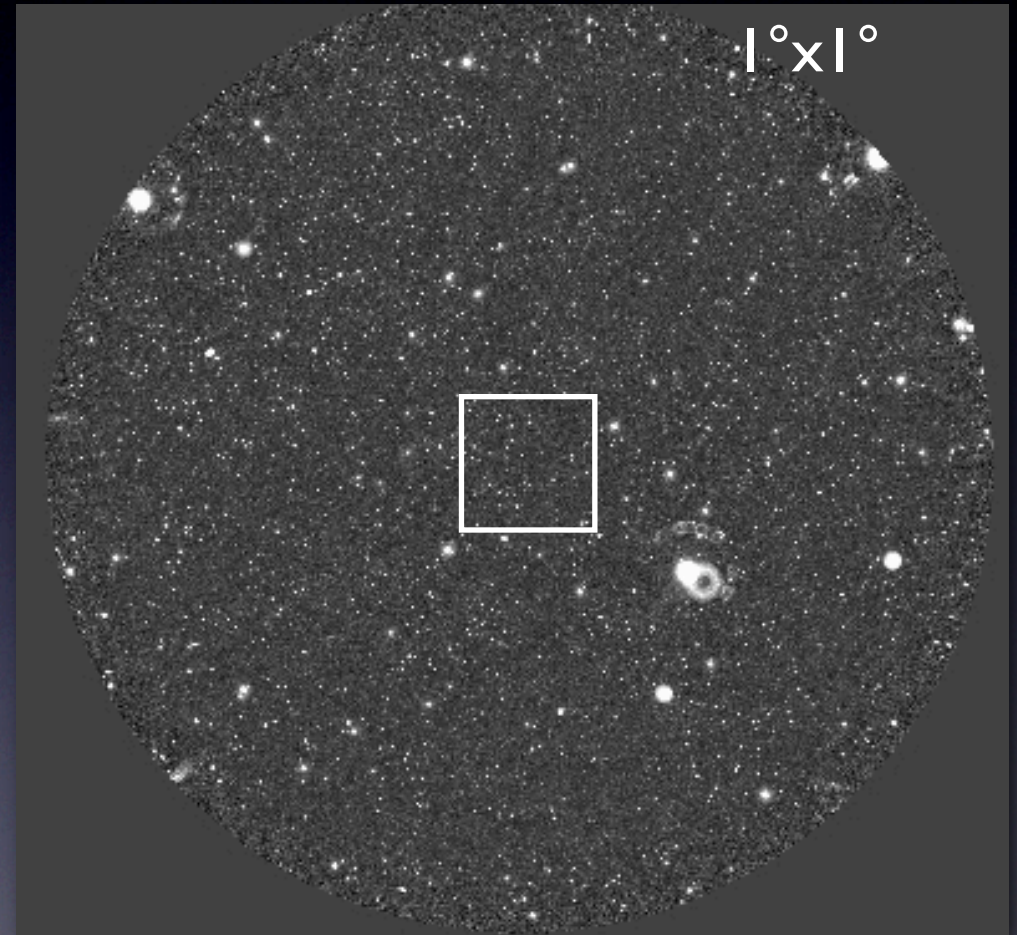


GALEX NUV / FUV imaging

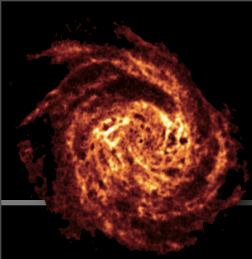
Abell 963



Abell 2192

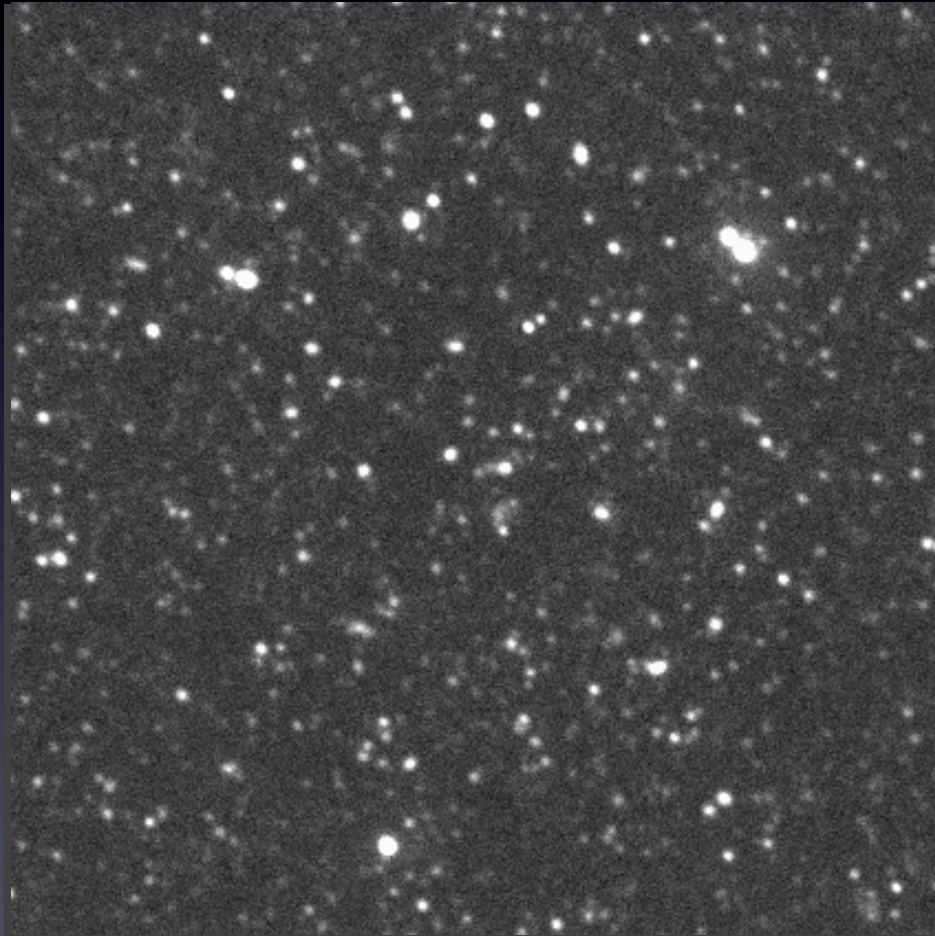


Sensitive to the youngest stellar populations



GALEX NUV / FUV imaging

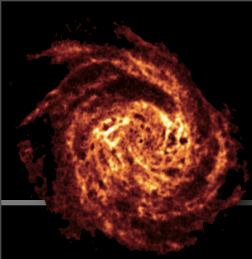
Abell 963



Abell 2192

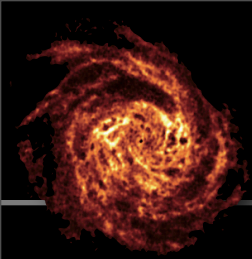


Sensitive to the youngest stellar populations



Ancillary data

- GALEX FUV & NUV
- INT B & R imaging
- SDSS ugriz photometry (shallow)
- UKIRT zYJHK (allocated)
- Spitzer 3.6, 5.0, 24, 70 micron
- Herschel PACS & SPIRE imaging (pending)
- WIYN / WHT optical spectroscopy
- Nobeyama / LMT CO masses (pending)

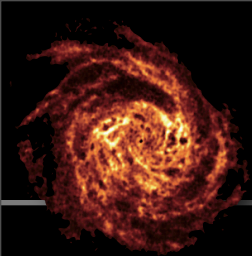


ultra-deep WSRT observations

- Minimum detectable HI mass:
 $2 \times 10^9 M_{\odot}$ over 150 km/s profile width,
with 4σ in each of 3 resolution elements.
- Corresponding limiting column density:
 $3 \times 10^{19} \text{ (cm}^{-2}\text{)}$ over 80 km/s profile width at 7σ .

This requires: $78 \times 12^{\text{hr}}$ for A2192 at $z=0.188$

$117 \times 12^{\text{hr}}$ for A963 at $z=0.206$



WSRT observational setup

Long-term program over 8 semesters

8x1		A963	A2192
7	semester	# measurements	
8x	2005 -A	20	15
	-B	<i>pilot study</i>	
20	2006 -A	33	15
	-B		5
1	2007 -A	33	12
	-B		3
rms	2008 -A	31	8
	-B		15
~5%	total	117	73
	hours	1404	876

over 1160-1220 MHz
 volume $\approx 70,000 \text{ Mpc}^3$

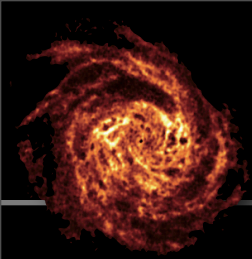
km/s velocity range
 (annular smoothing)

on, recirculation

2 hr ' on Abell 2192

7 μJy ($\Delta V=80 \text{ km/s}$)

(APERTIF prototype)



WSRT observational setup

Long-term program over 8 semesters

8x10MHz bands, overlapping to cover 1160-1220 MHz
 $Z = 0.164-0.224$, surveyed volume $\approx 70,000 \text{ Mpc}^3$

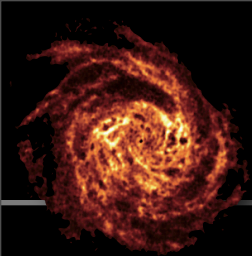
8x256 channels, covering 18,000 km/s velocity range
20 km/s velocity resolution (after Hanning smoothing)

dual polarisation, 2-bit correlation, recirculation

117x '12^{hr}' on Abell 963, 73x '12^{hr}' on Abell 2192

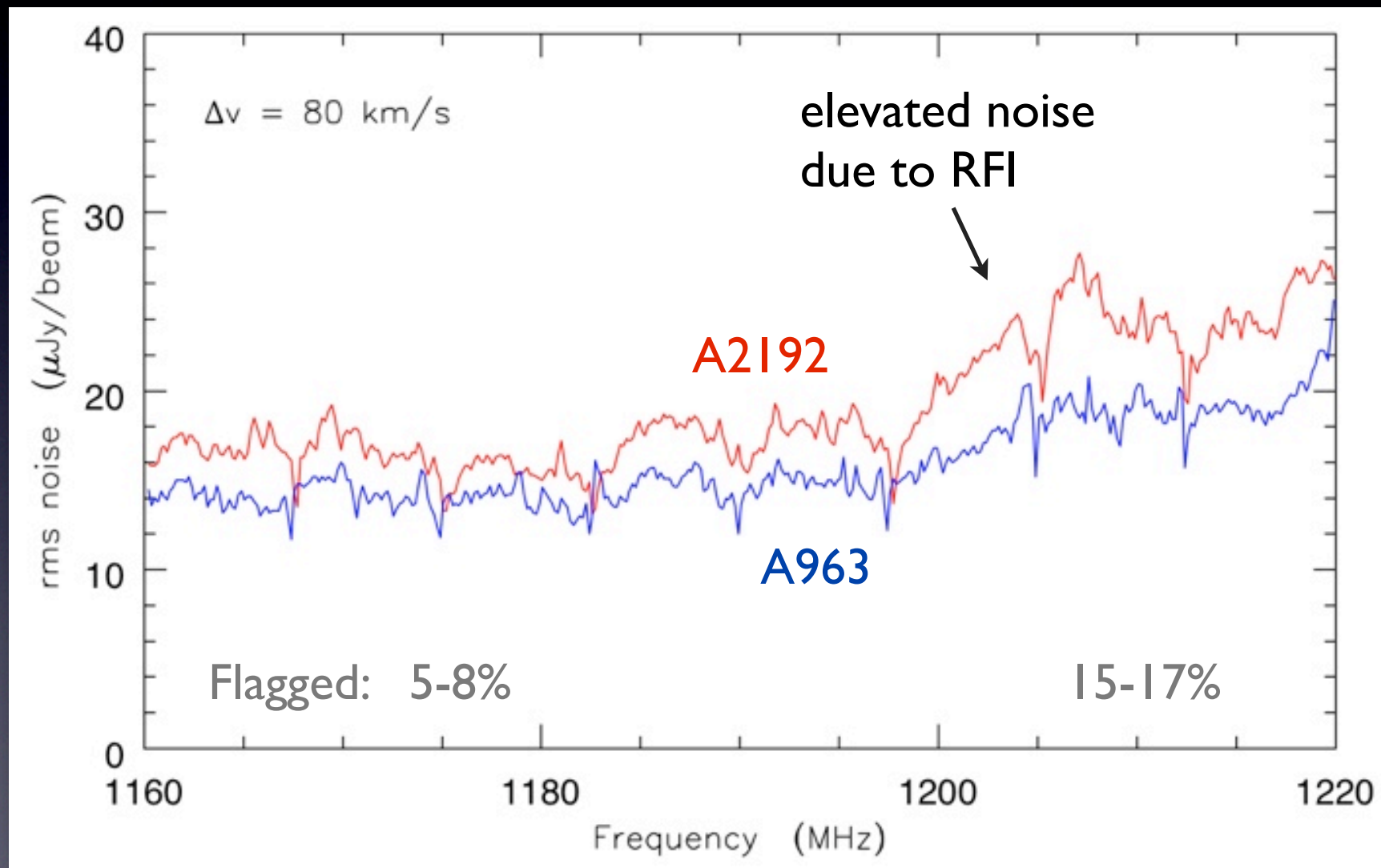
rms noise per channel: 14 μJy and 17 μJy ($\Delta V=80 \text{ km/s}$)

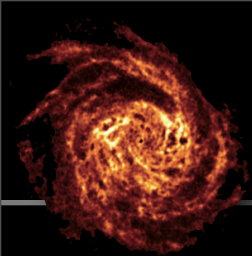
~5% lost to RFI, antenna 5 offline (APERTIF prototype)



achieved rms noise in line cubes

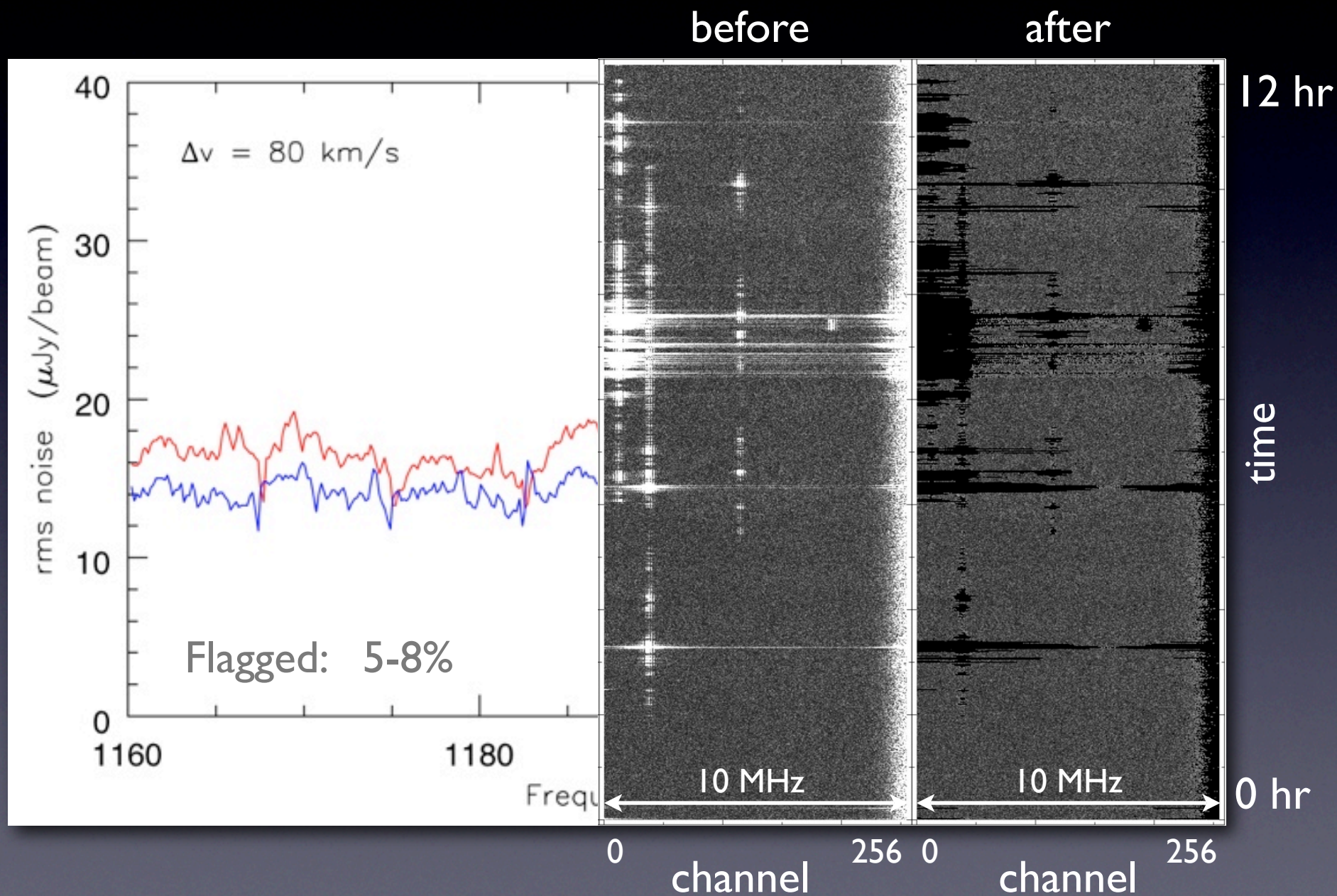
slightly better than predicted due to lower T_{sys} at $\nu < 1200$ MHz



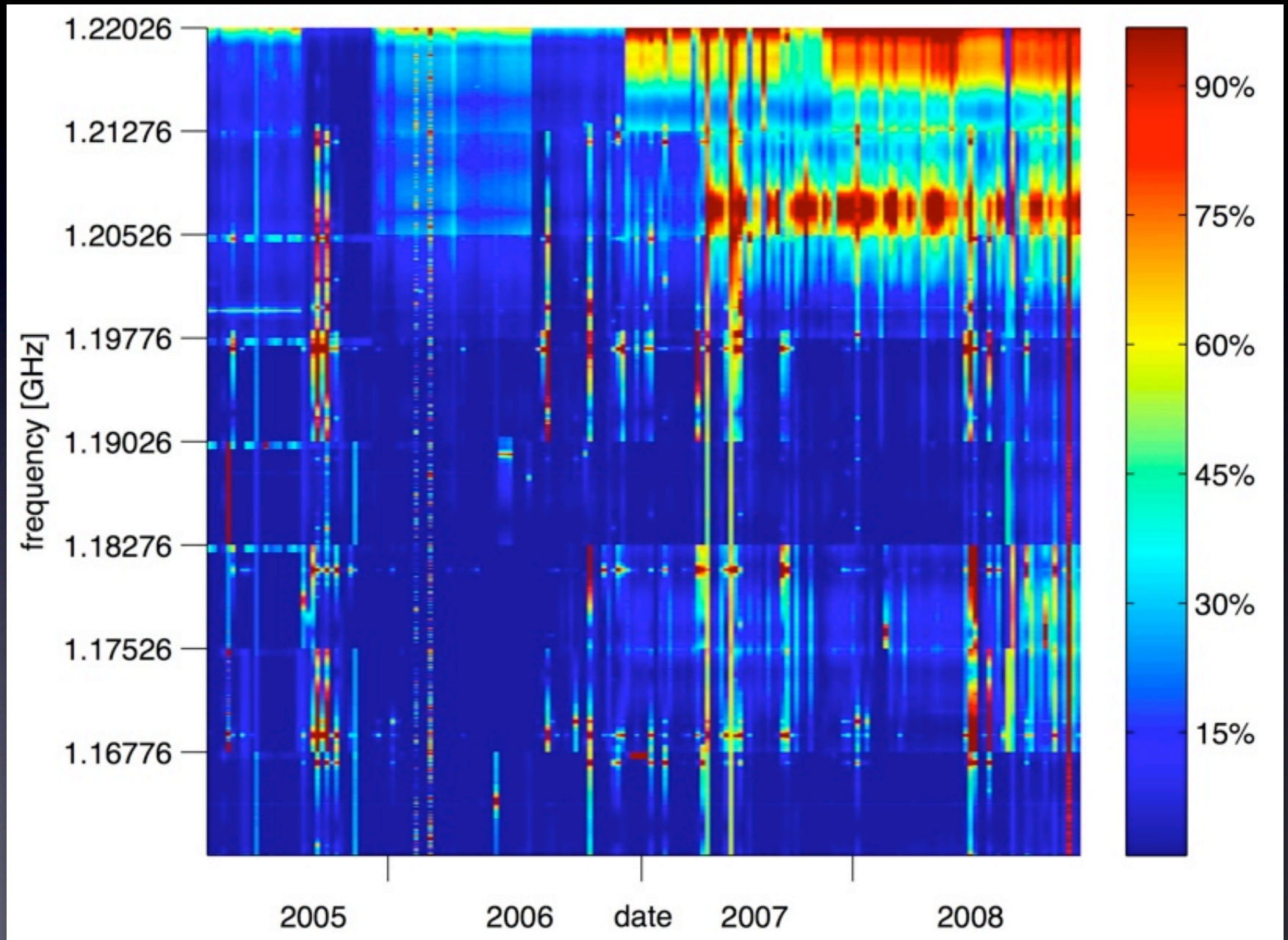


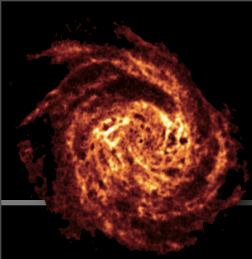
achieved rms noise in line cubes

slightly better than predicted due to lower T_{sys} at $\nu < 1200$ MHz



RFI increasing over the years ...



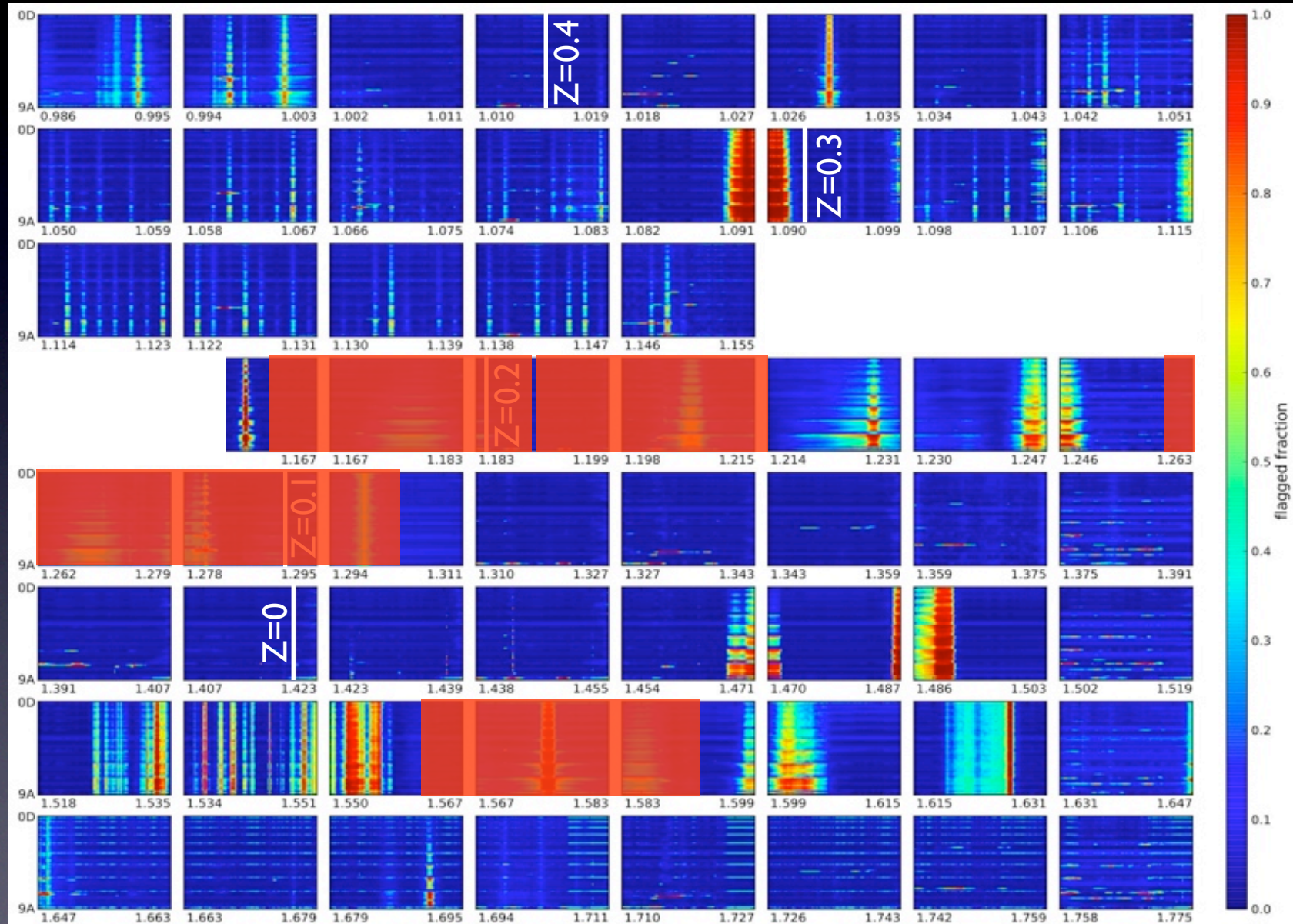


A few words on RFI

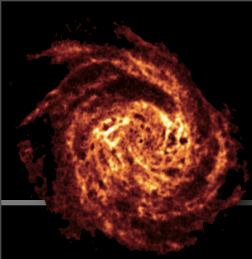
RFI
monitoring
campaign
at WSRT

Galileo

986 MHz



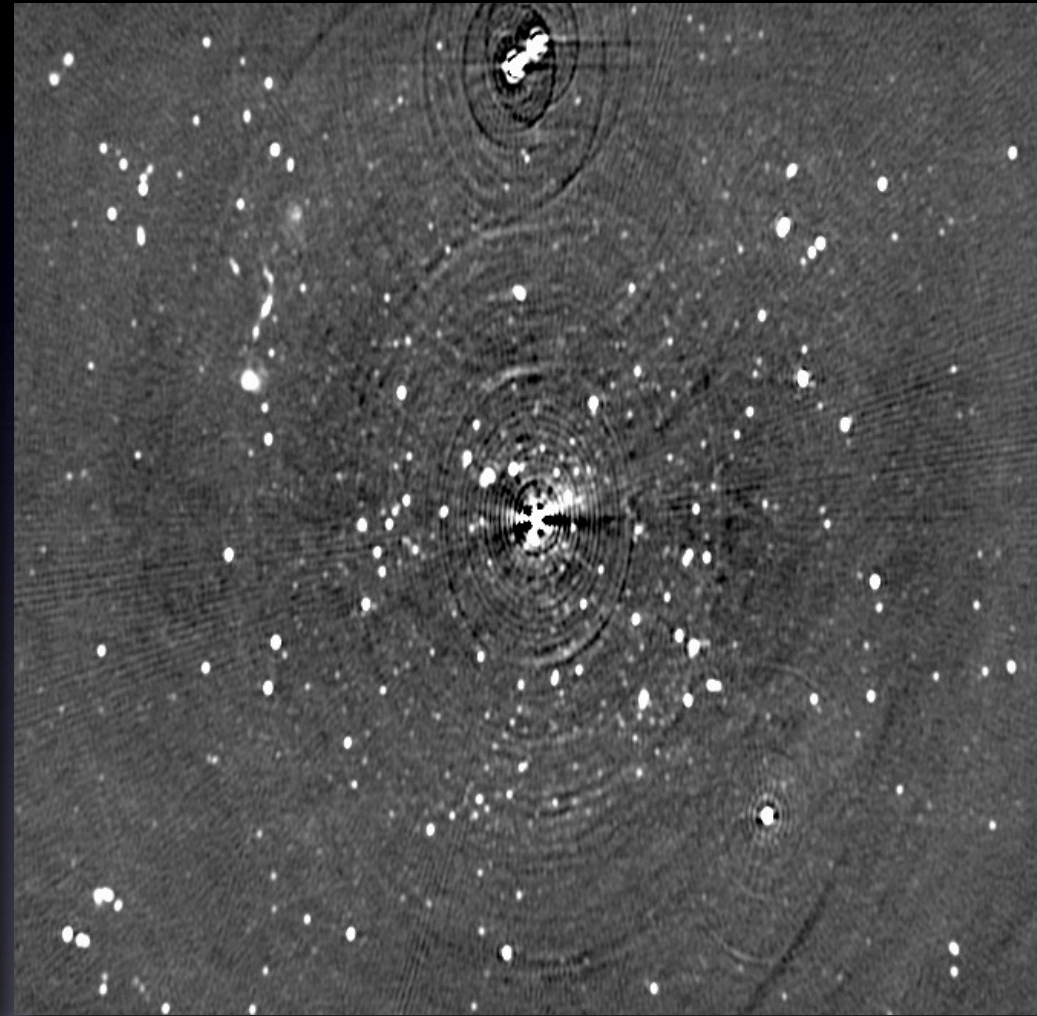
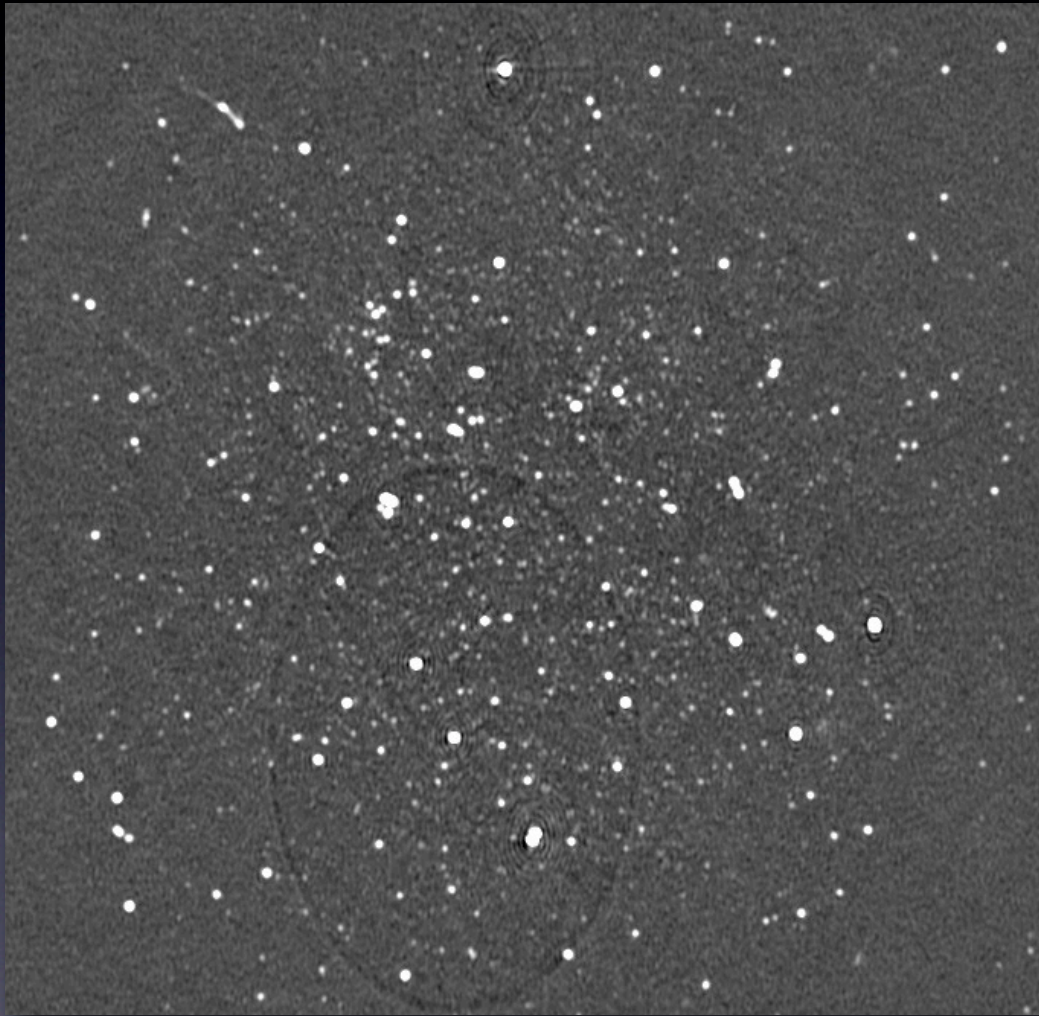
1775 MHz



continuum maps

Abell 2192

Abell 963



$\sigma = 7 \mu\text{Jy}/\text{beam}$ (confusion limited)

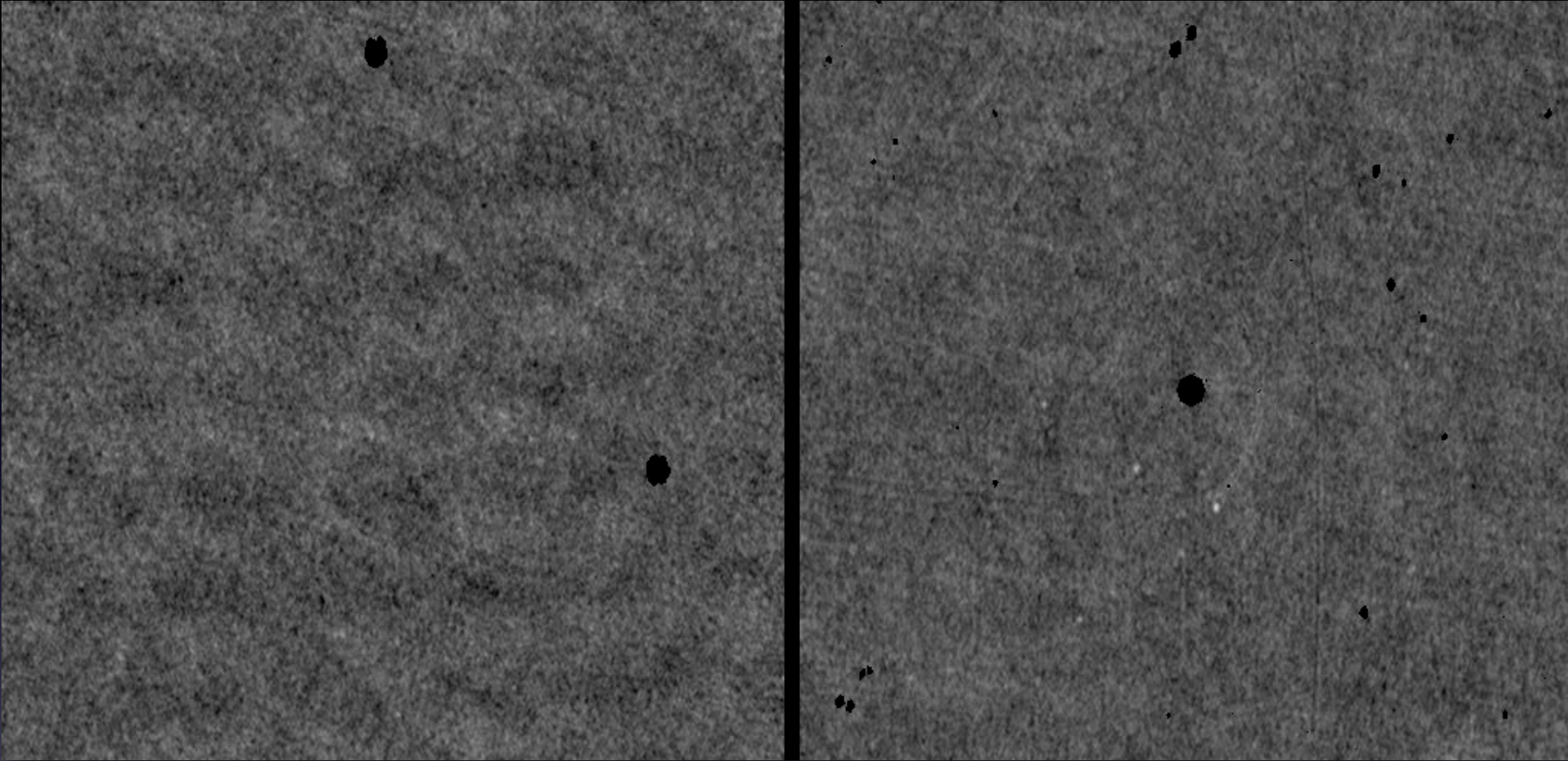
$\sigma = \sim 12 \mu\text{Jy}/\text{beam}$ (DR limited)

$\text{SFR} \approx 10 M_{\text{sun}}/\text{yr}$

(deep GALEX data more sensitive)

Abell 2192

Abell 963

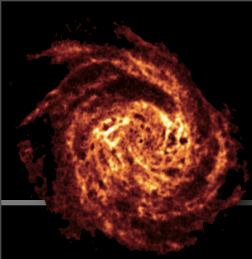


$\sigma = 17 \mu\text{Jy}/\text{beam}$

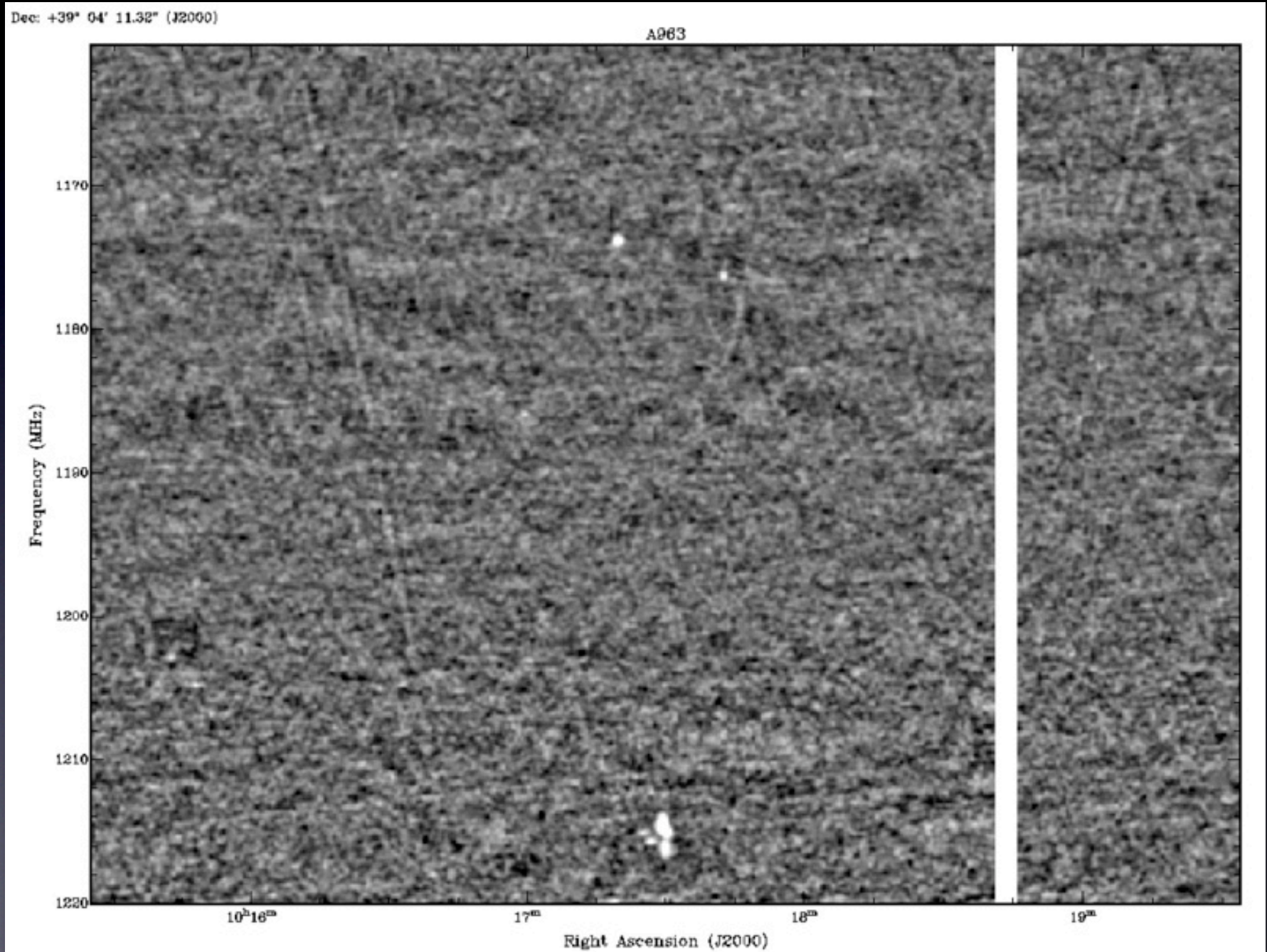
$\Delta V = 80 \text{ km/s}$

$\sigma = 14 \mu\text{Jy}/\text{beam}$

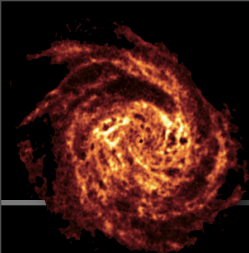
Detection criteria: 1 $\times 8\sigma$,
or 1.5 $\times 6\sigma$,
or 2 $\times 5\sigma$,
or 3 $\times 4\sigma$ in N consecutive spectral resolution elements.



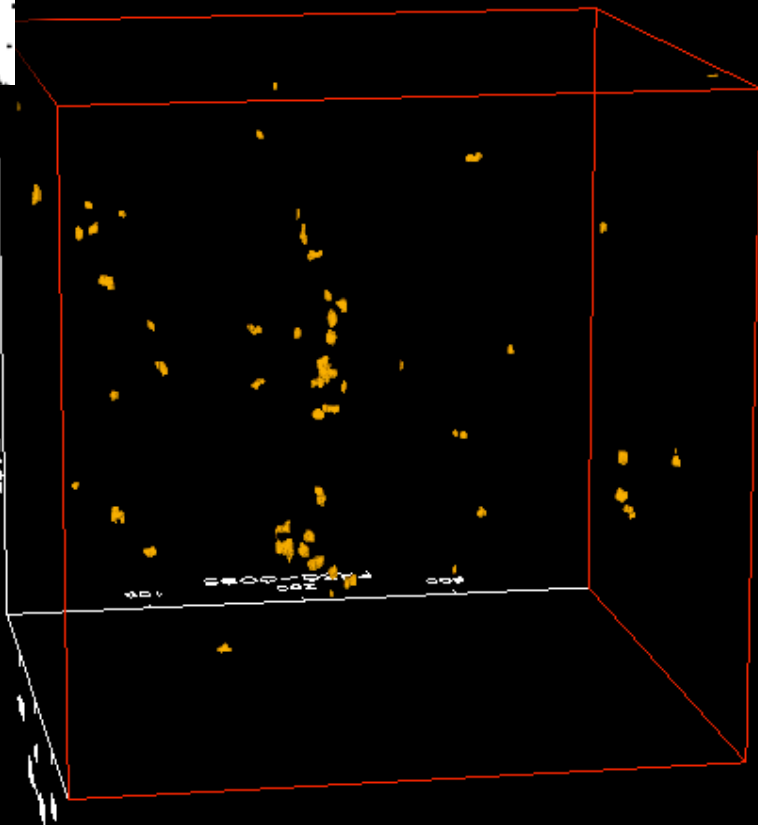
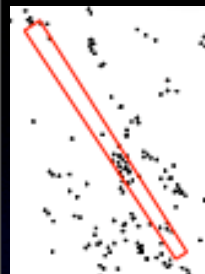
continuum subtraction



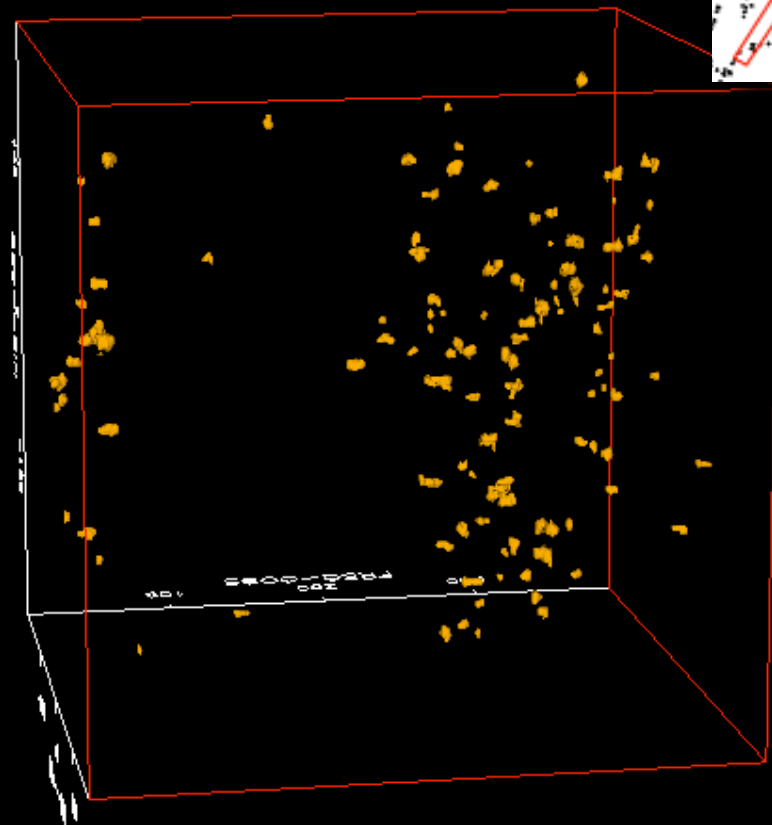
current state-of-the-art



Abell 2192



Abell 963



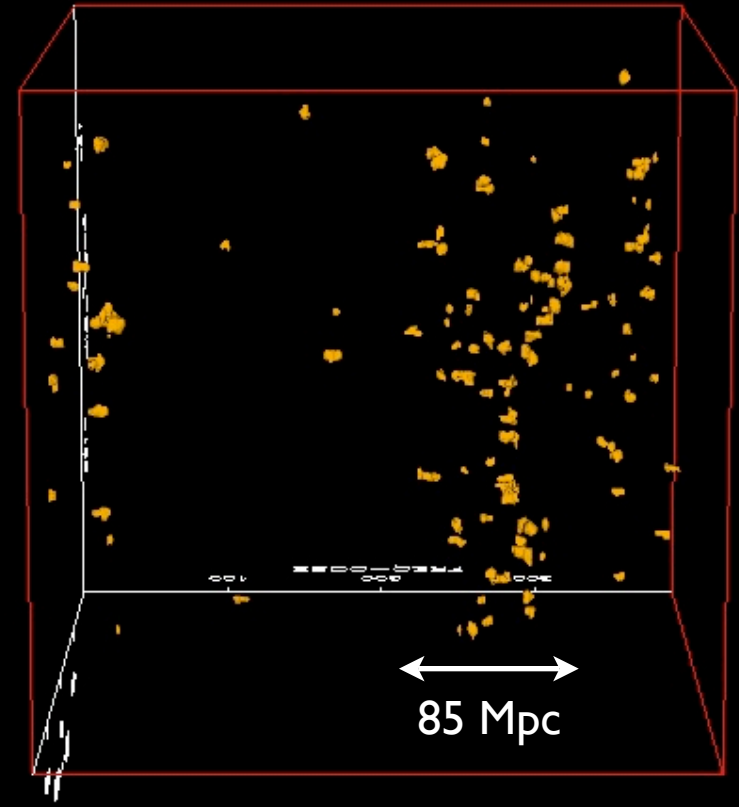
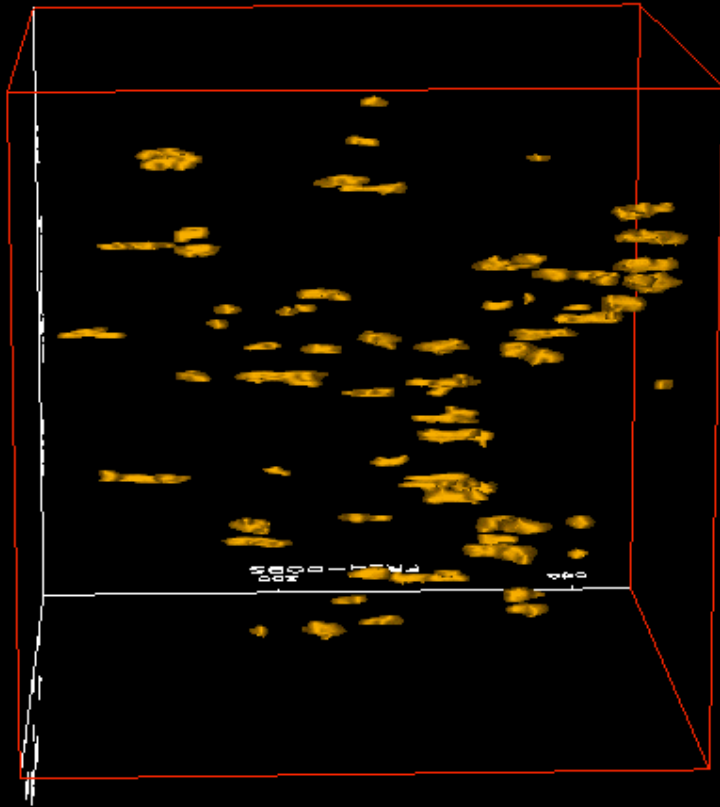
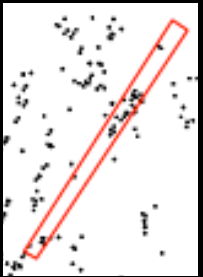
Verheijen+, in prep

Cube size : $9.5 \times 9.5 \times 325 \text{ Mpc}^3$

Beam size : $65 \times 80 \text{ kpc}^2 \times 80 \text{ km/s}$

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

surroundings of Abell 963



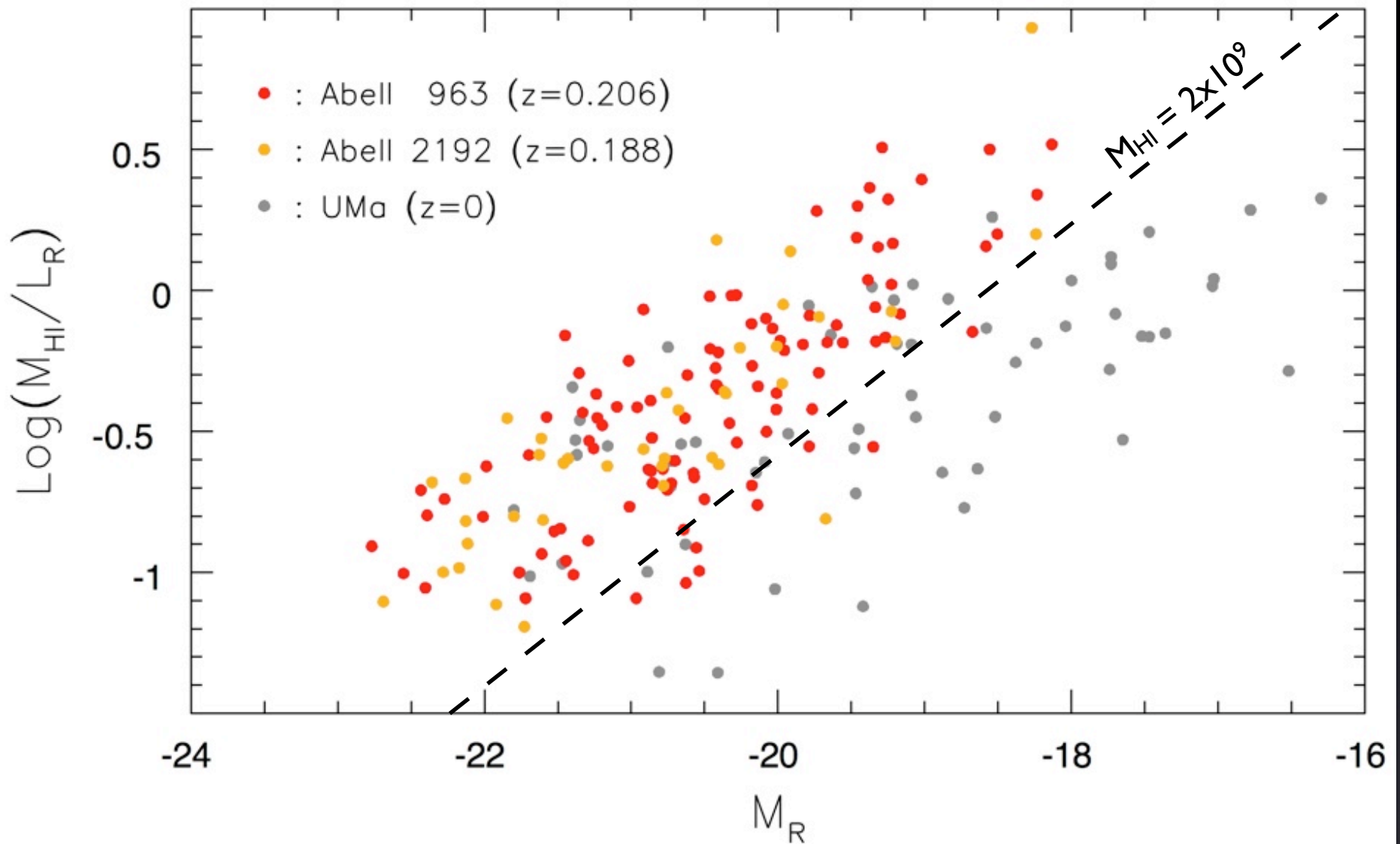
Cube dimensions: $9.5 \times 9.5 \times 85 \text{ Mpc}^3$

0.164

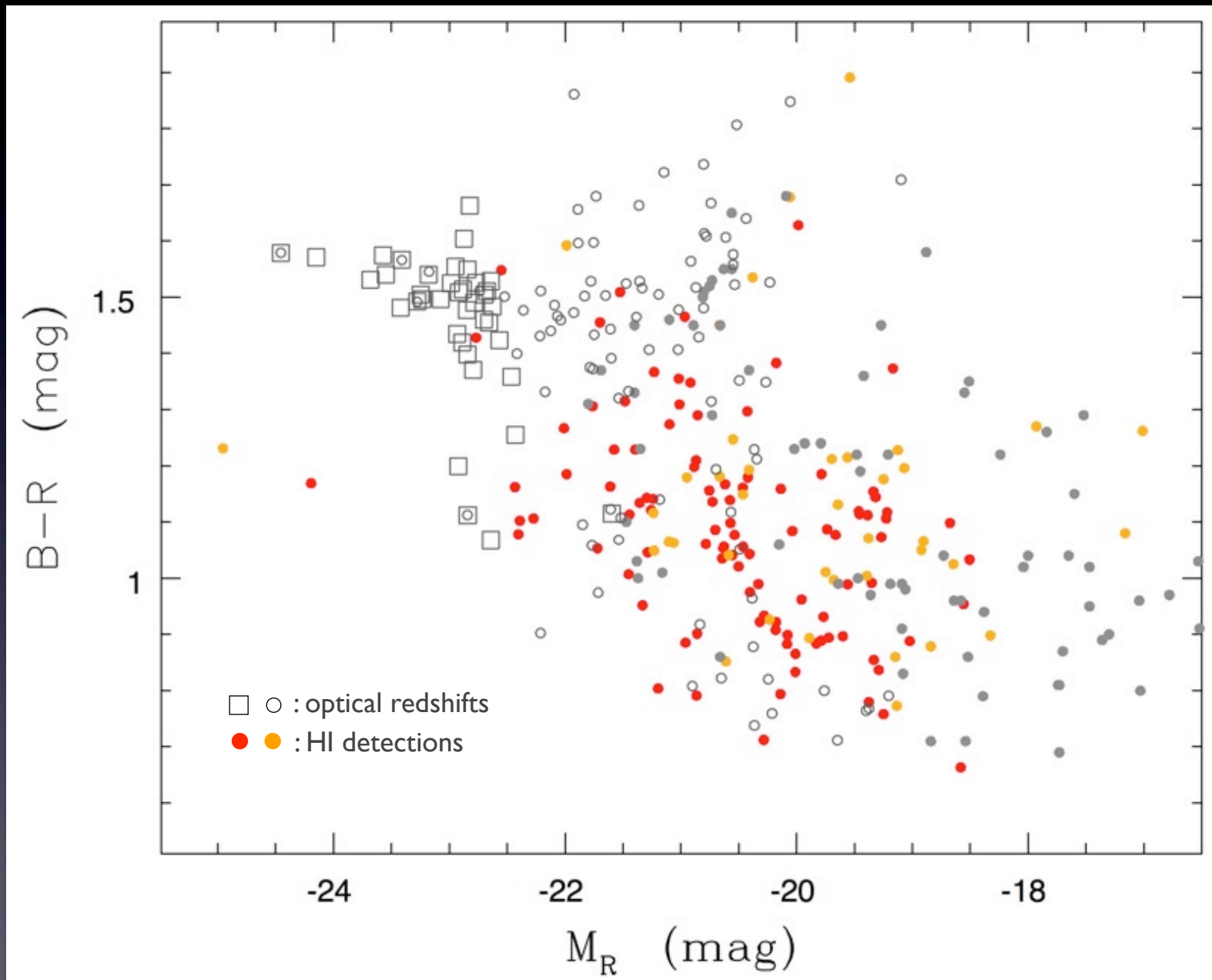
redsihft

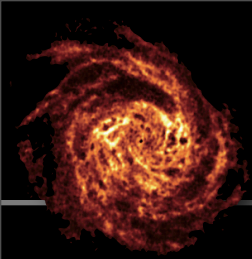
0.224

Relative HI gas mass fractions



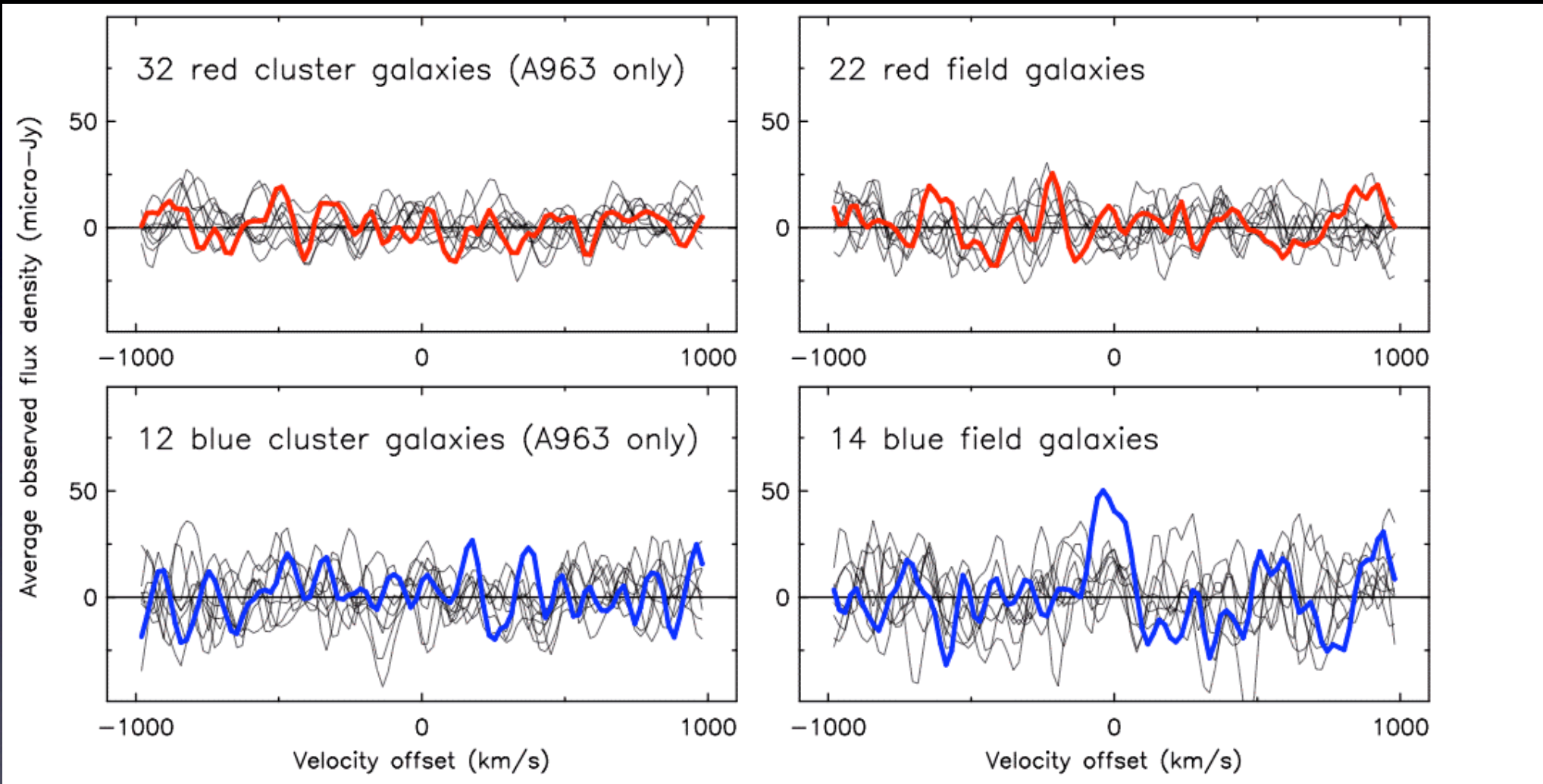
Colour-Magnitude diagram





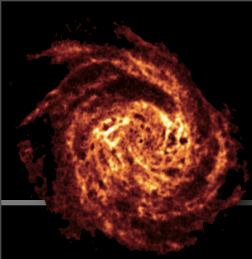
Stacking HI spectra

(based on pilot data)



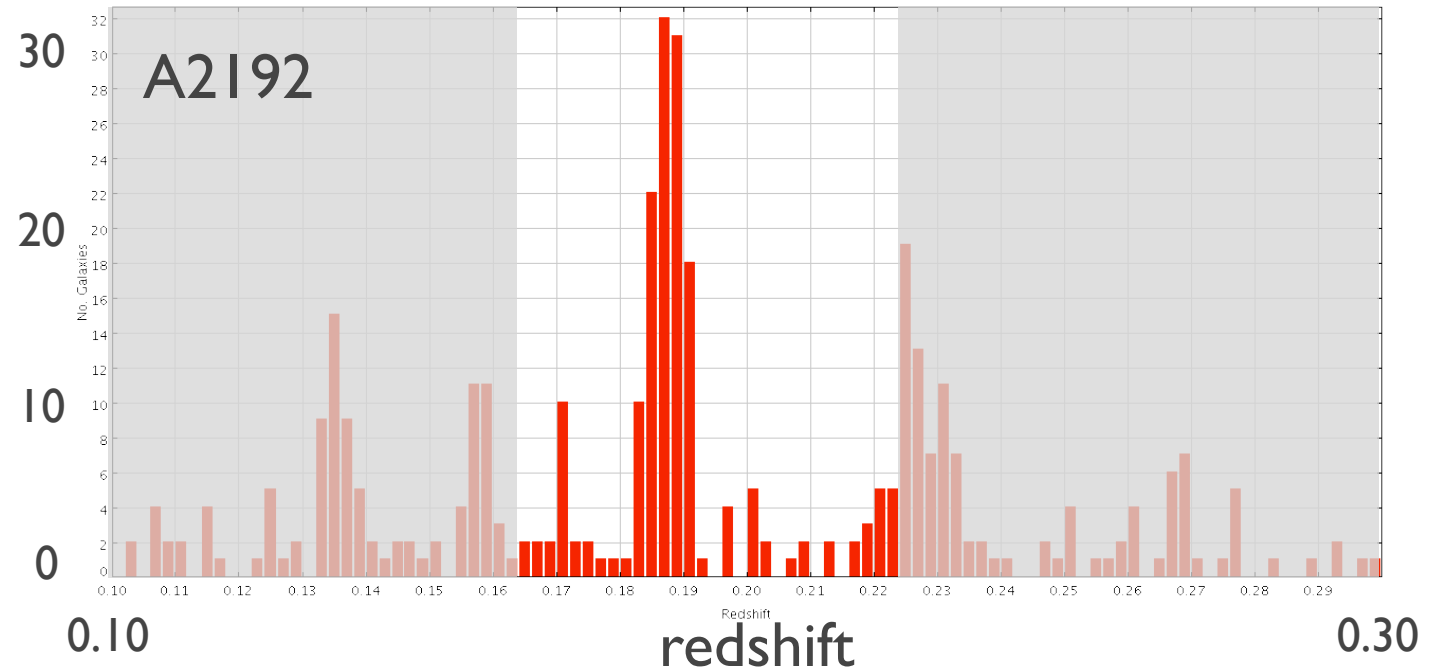
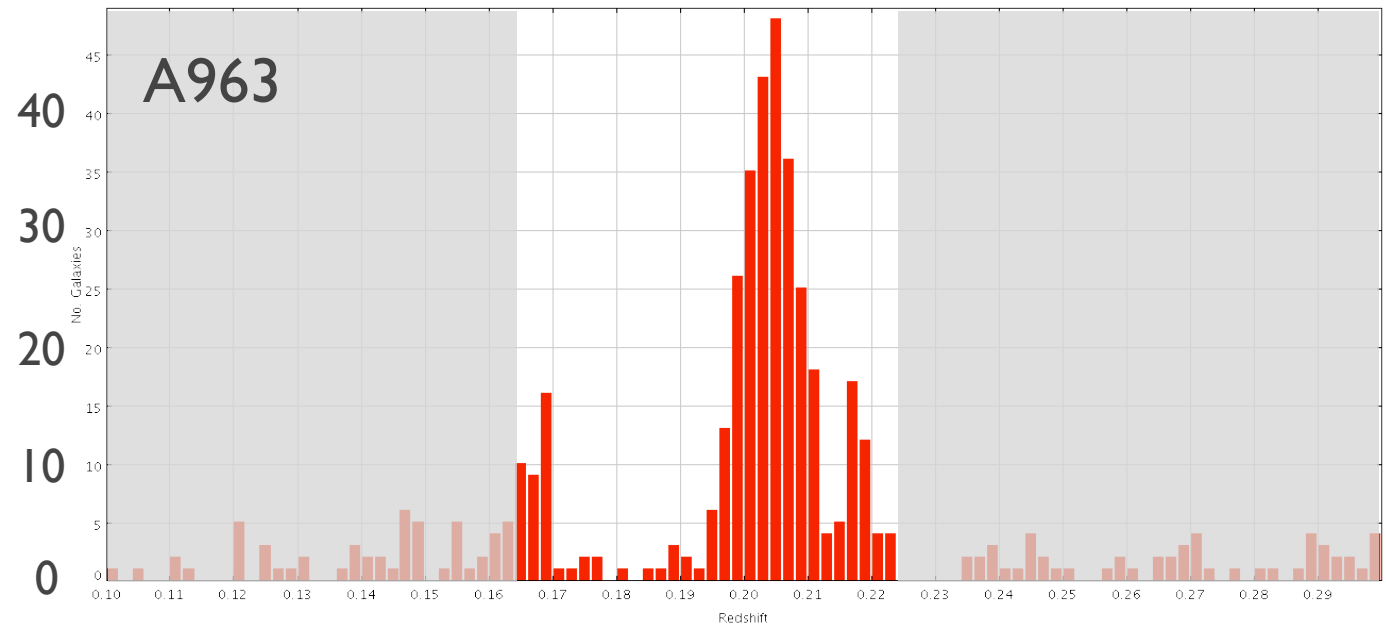
Verheijen+ '07

Average HI mass $\approx 2 \times 10^9 M_{\odot}$



new WHT/AF2 spectroscopy

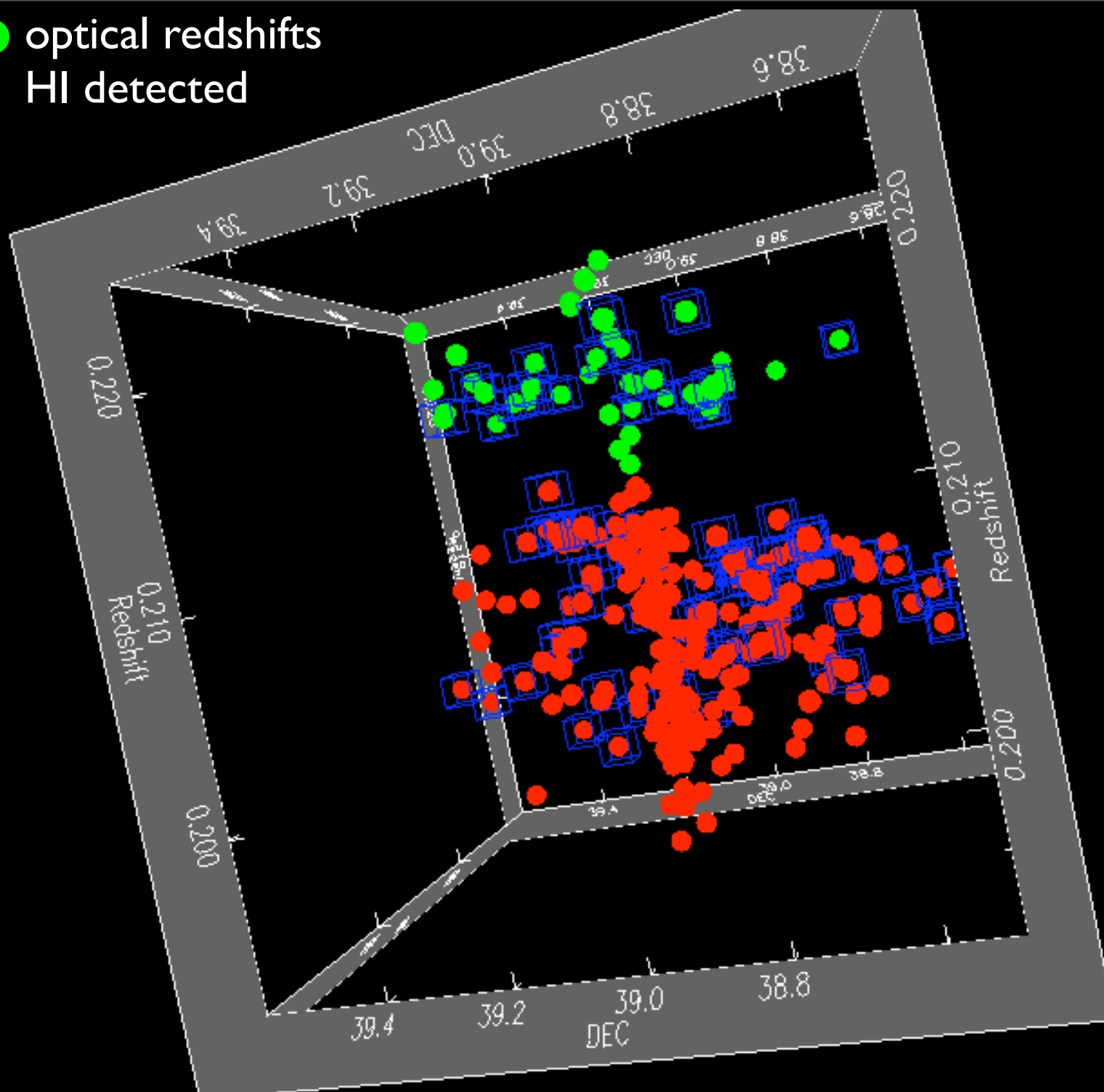
pre-selected
from CMD







Abell 963

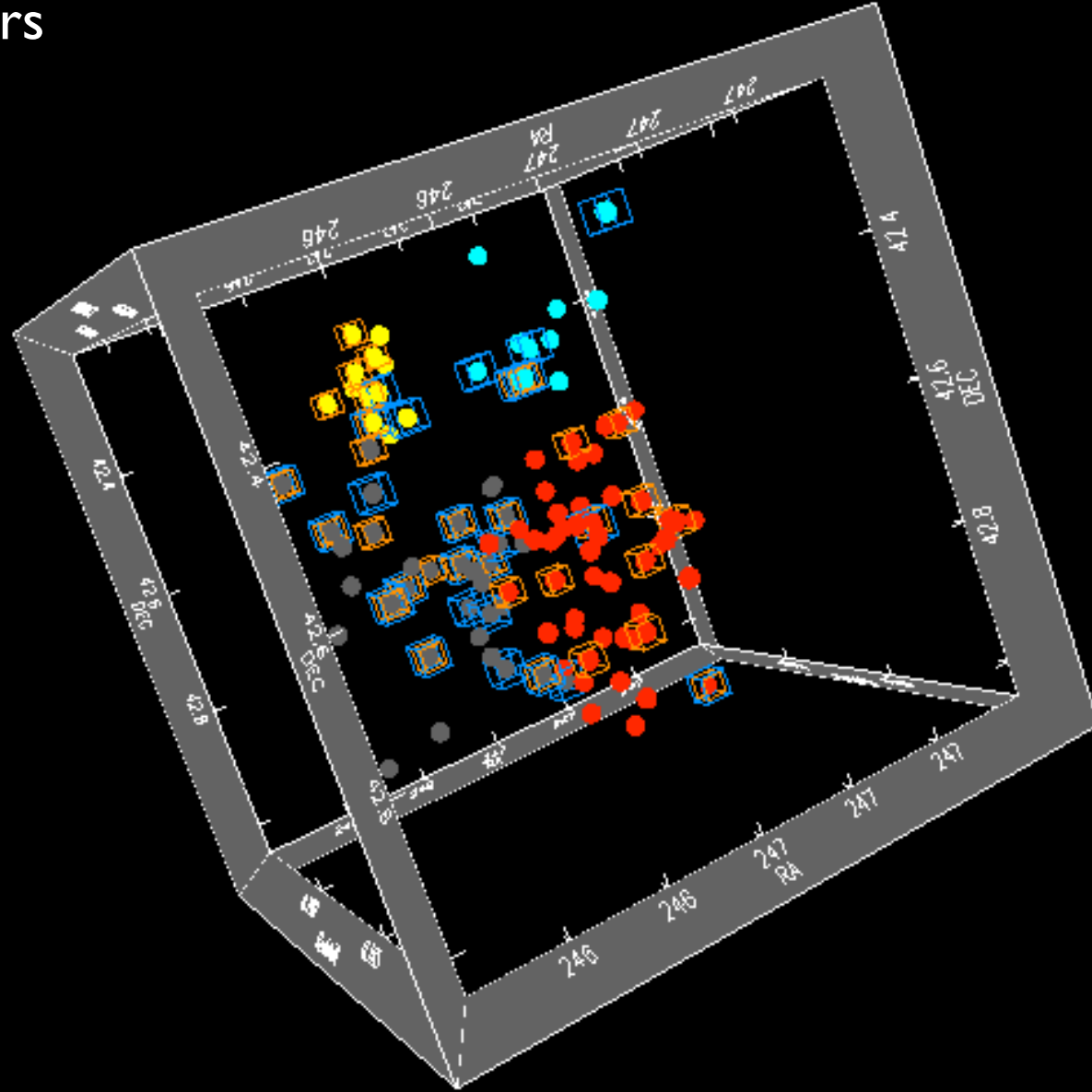
●● optical redshifts

□ HI detected

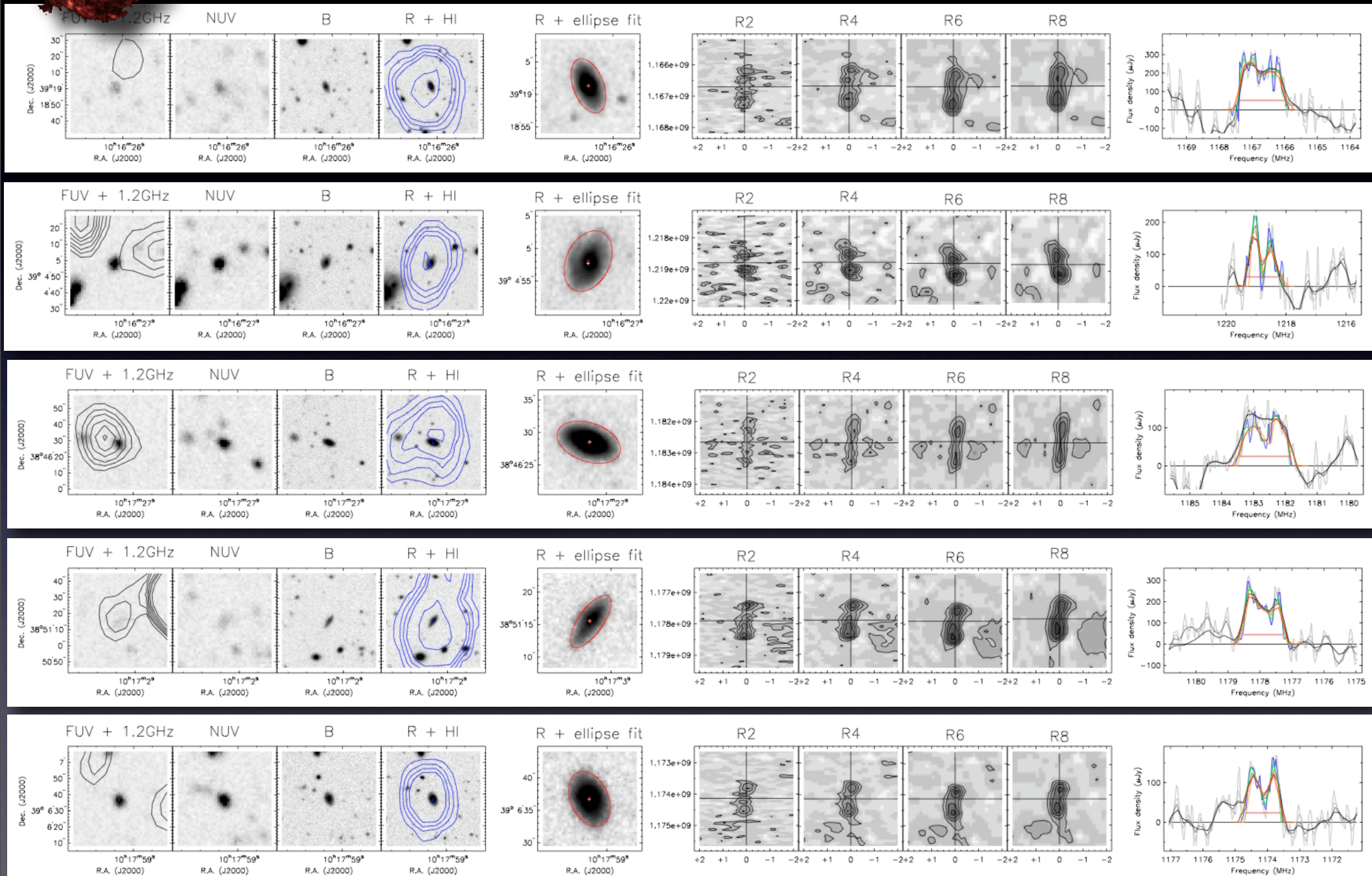
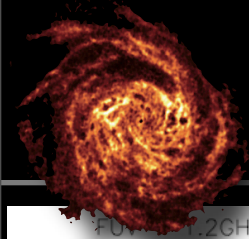


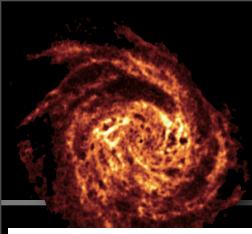
Abell 2192

-  optical redshifts
-  HI detected
-  HI detected
-  [OII] emitters

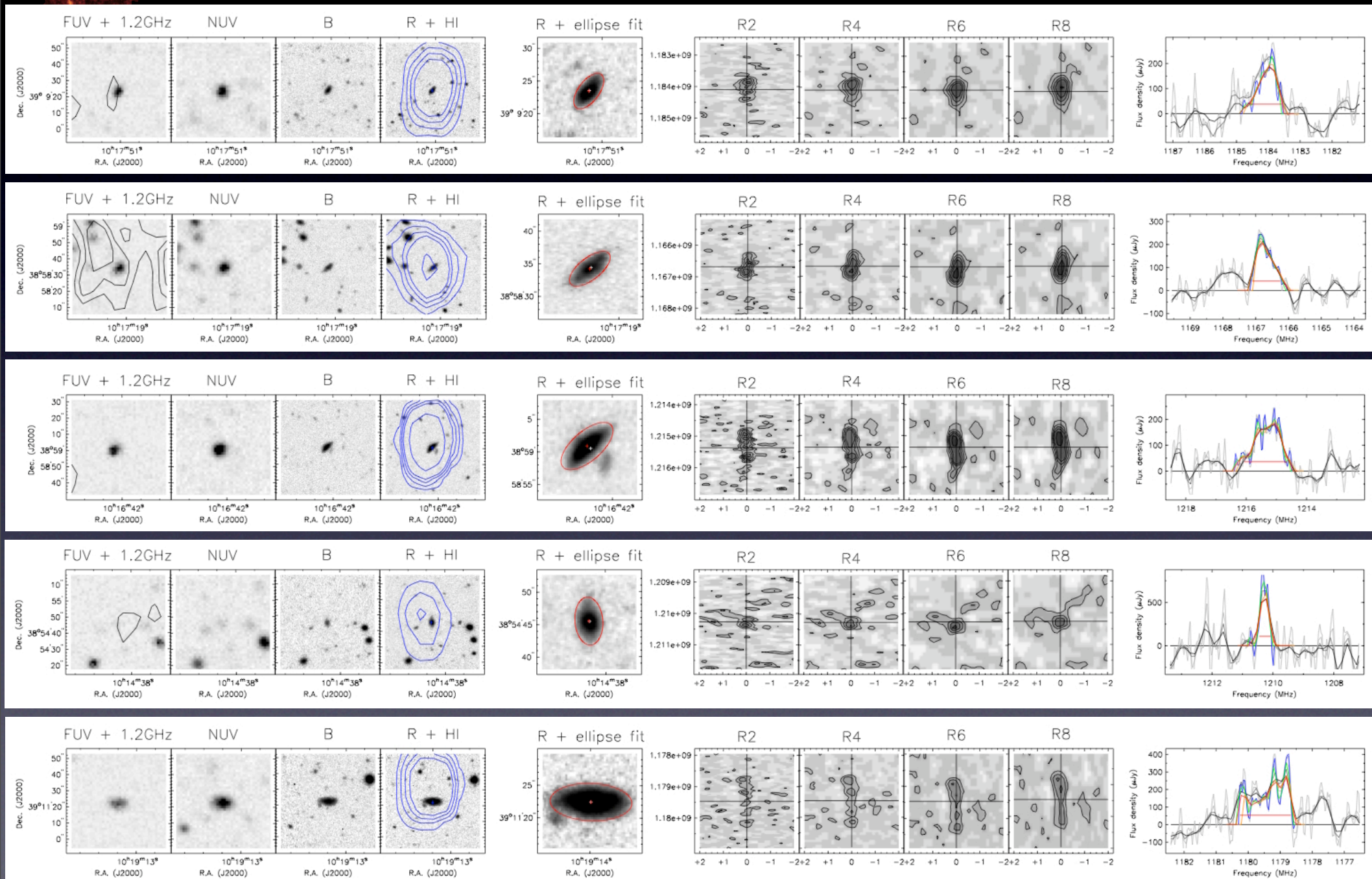


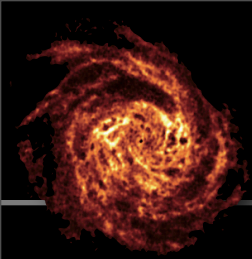
examples of 18 galaxies useful for TF study



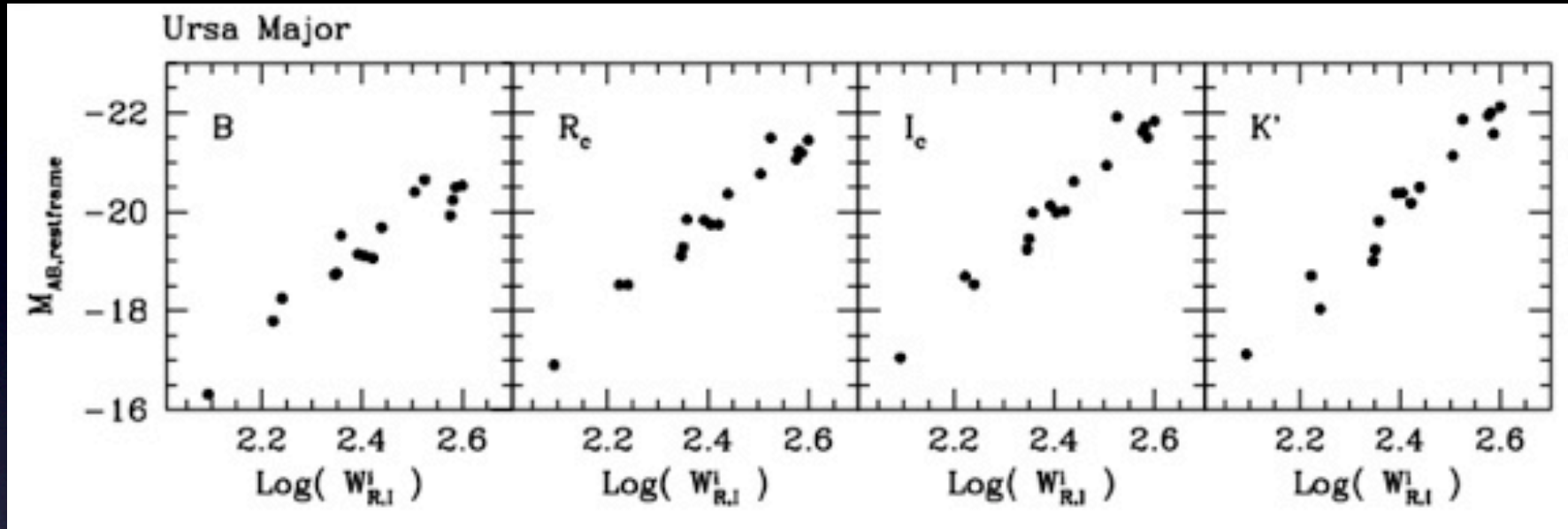


examples of galaxies rejected for TF study





TF relations - UMa revisited

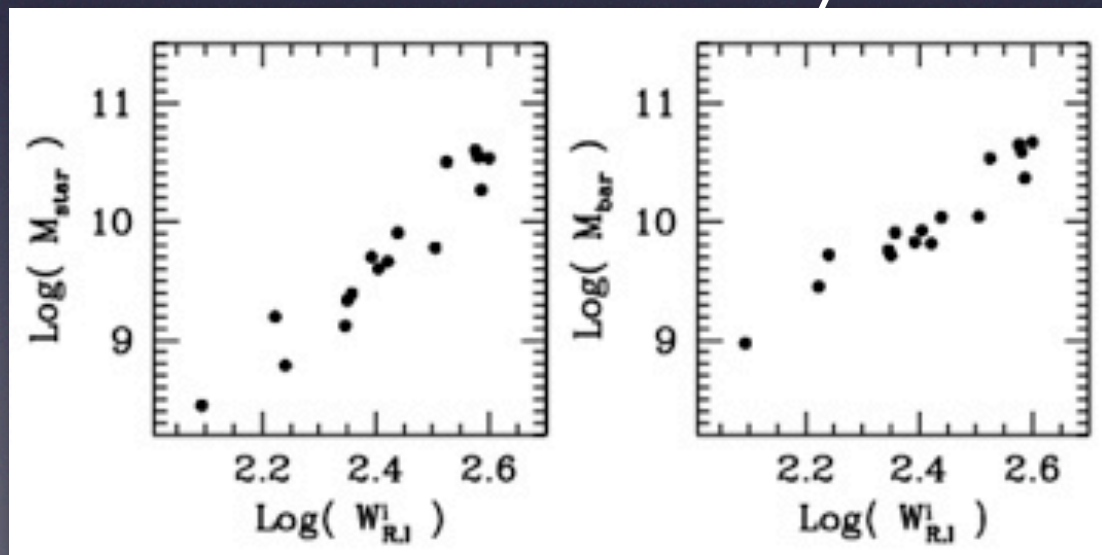


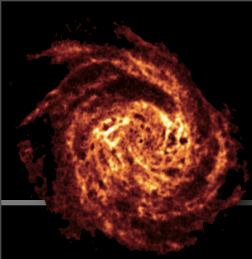
stellar mass

baryonic mass

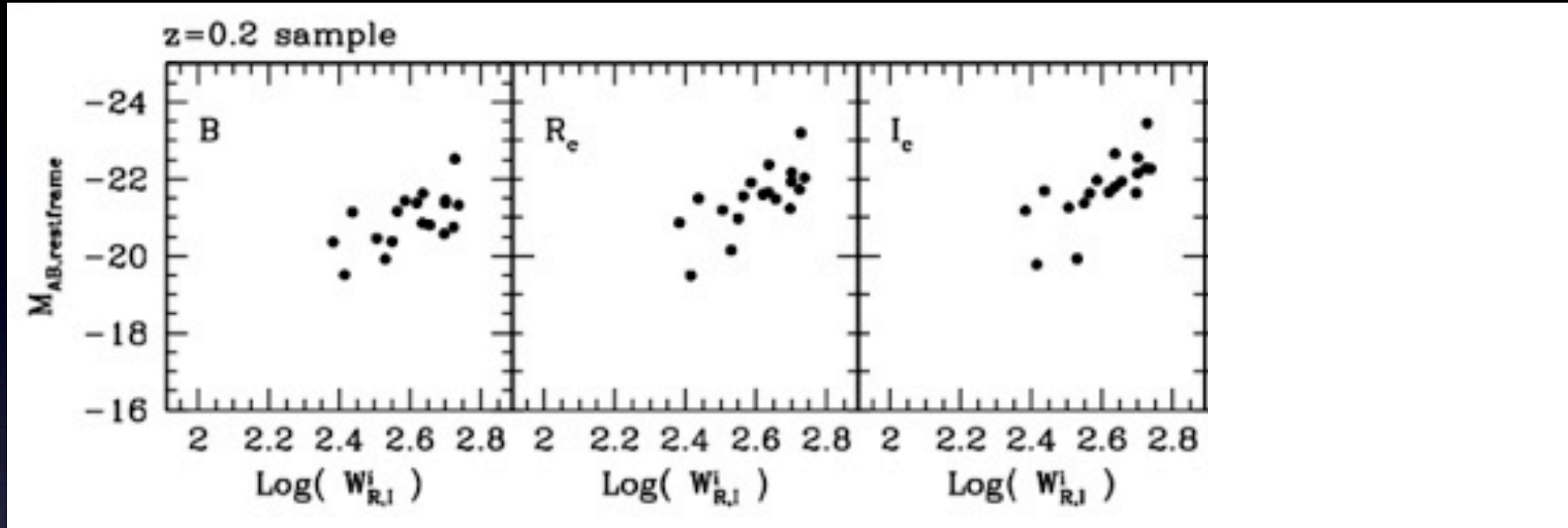
M_{star} from BRIK
photometry and
Zibetti models.

$$M_{bar} = M_{star} + 1.4M_{HI}$$





TF relations - galaxies at $z=0.2$

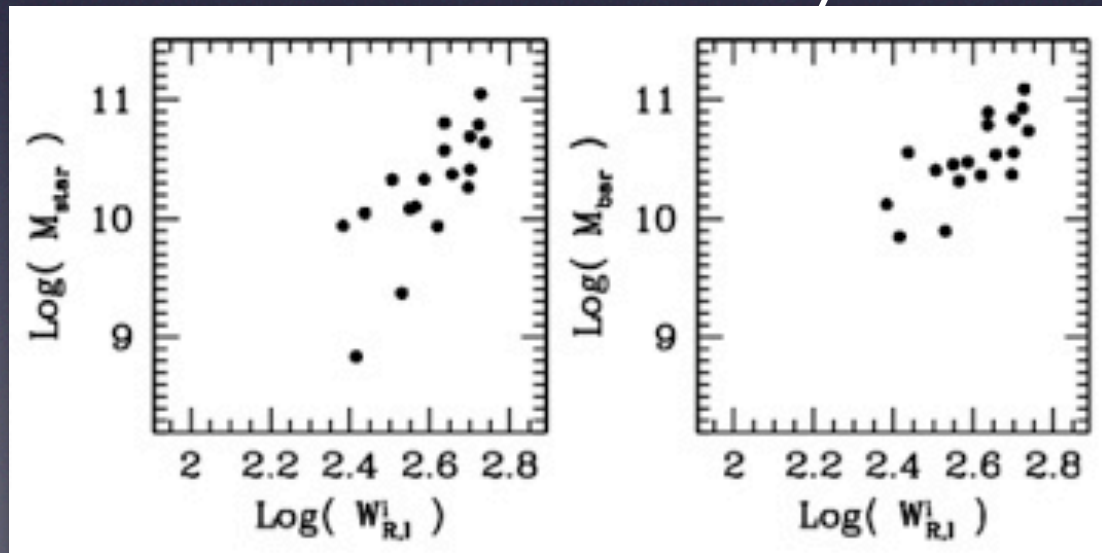


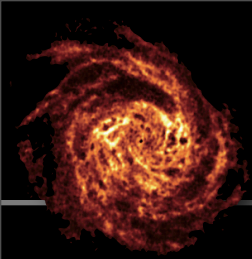
BRI mags from
dereddened SDSS
photometry
(InterRest)

M_{star} from BRI
photometry and
Zibetti models.

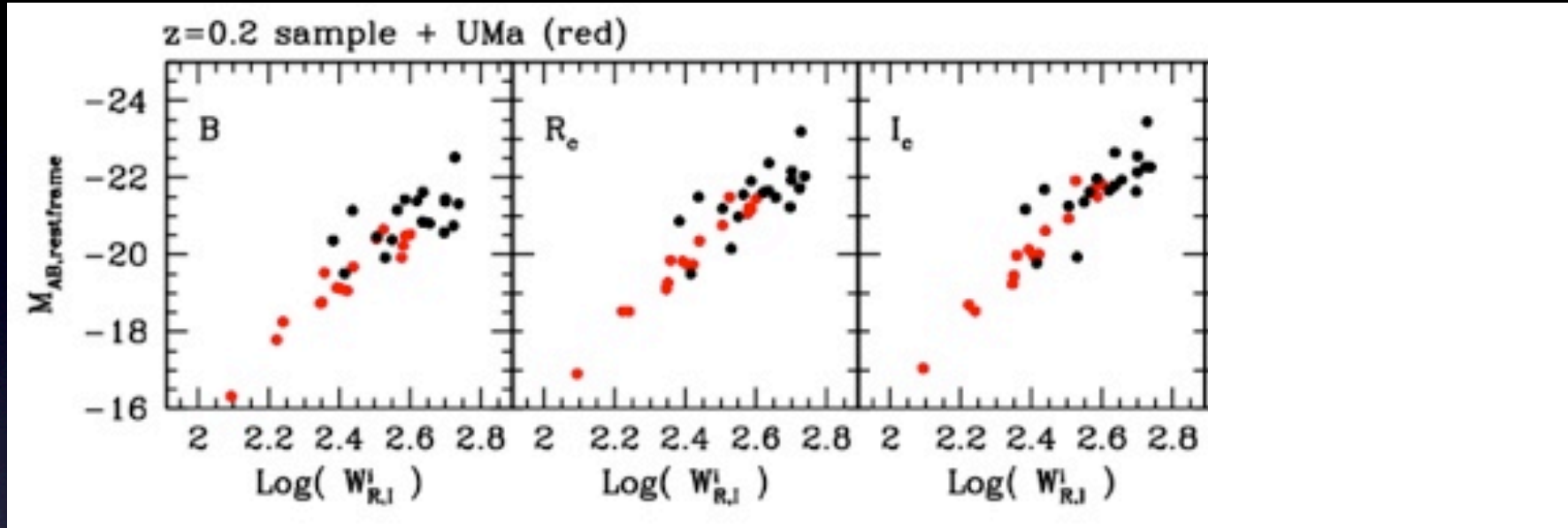
stellar mass

baryonic mass





TF relations - $z=0$ vs $z=0.2$

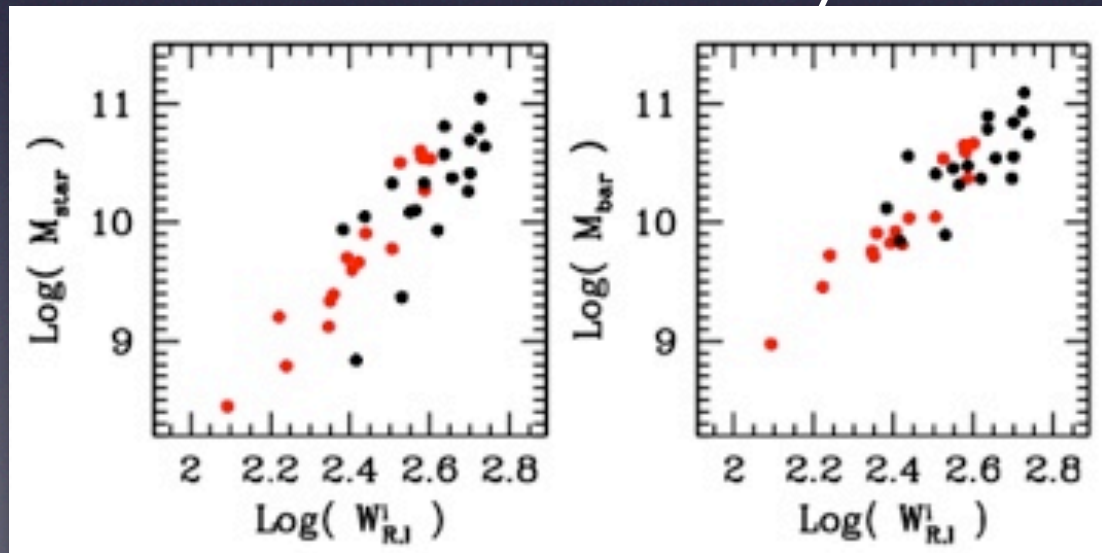


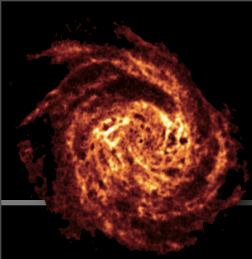
stellar mass

baryonic mass

- larger scatter
- no appreciable offset

error/statistical
analysis is pending





summary & outlook

Expected rms achieved, but significant imaging artifacts

HI emission from ~ 140 individual galaxies at $Z \approx 0.2$

Blind HI survey uncovers LSS not seen by SDSS

Blue 'BO-galaxies' gas-poor wrt similar field galaxies

$$TF_{z=0.2} \approx TF_{z=0}$$

Characterization of environments is ongoing

Collection and compilation of ancillary data is ongoing