Galaxy transformation in dense environments

A multi-wavelength study of superclusters at z ~ 0.1 - 0.5

- Galaxy transformation in the supercluster environment
  - transformation scenarios, time scales, location
- GALEV evolutionary synthesis models
  - modelling star formation histories and transformation scenarios
- A multi-wavelength approach
  - optical/NIR imaging, spectroscopy, HI imaging
- The nearest of the superclusters: Abell 1437 (z ~ 0.135)
  - initial results from GALEV modeling and GMRT observations

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Deep, wide
Area
Study of
Superclusters at
Intermediate
Epochs

dassie (hyrax)

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Evidence for transformation

Central regions of local **rich clusters** dominated by **S0 galaxies**. Dwarf galaxies (**dEs, dS0s, dSphs**) are twice as numerous as the luminous galaxies (Coma cluster; de Lucia et al. 2004).

→ Distinctly different morphological mix from the **low-density field population** in the local Universe (**predominantly spirals and irregulars**)

Increased fraction of blue galaxies in distant clusters (Butcher-Oemler effect).

→ Blue galaxy fraction increased by a factor of 5 from z = 0 to z = 0.5 (van Dokkum 2001, Dahlen et al. 2004) (corresponds to a t_{LB} = 5 Gyr)

→ Population of blue galaxies in intermediate redshift clusters (z = 0.5) consists of spirals and irregulars with ongoing star formation (Smail et al. 1997)

→ Fraction of ellipticals in clusters (from z = 0.5 to 0) remains approx. constant, fraction of spirals decreases by factor of 5, fraction of S0s increases by same factor (Fasano et al. 2000, 2001).

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Transformation scenarios

Harrassment (Moore et al. 1995, 1998; Moran et al. 2007):
Fast galaxy-galaxy encounters which destabilize the disks of infalling spirals (dragging out short-lived tidal tails, inner parts → **dE**, **S0** (low-L), **dSph** on time-scale of few Gyr)

Ram-pressure stripping (Cayatte et al. 1990; Bravo-Alfaro et al. 2000):
Truncated and displaced HI disks due to interaction with ICM → truncated star formation. Observed in Coma cluster and inferred in Norma cluster (Vollmer et al. 2001; Kraan-Korteweg et al. 2009).

Galaxy mergers (van Dokkum et al. 1999):
Merging of galaxies (within groups before or during infall into the cluster, relatively low velocity is required) → changing morphology: high-L **S0** due to major mergers of gas-rich spirals (Fritze-von Alvensleben 1998, 1999). MS 1054-03 (z = 0.83) enhanced merging in infalling groups (van Dokkum et al. 1999)

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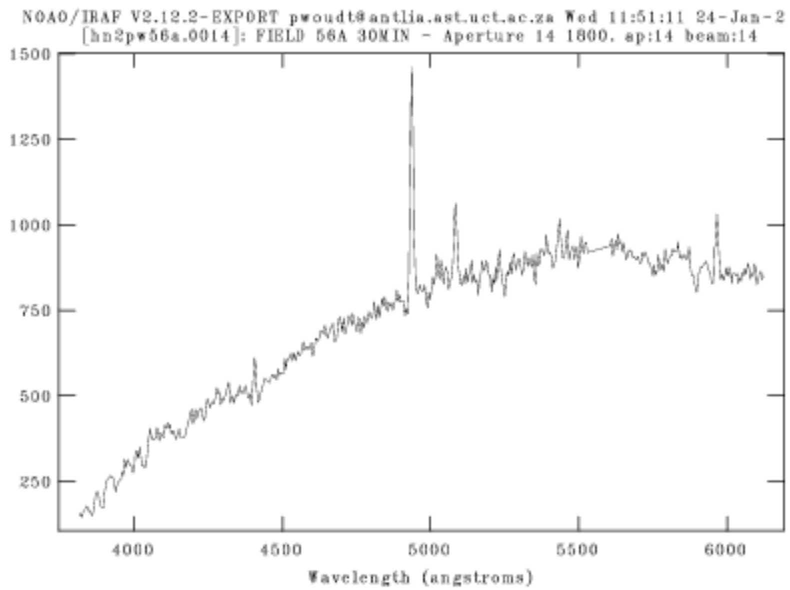
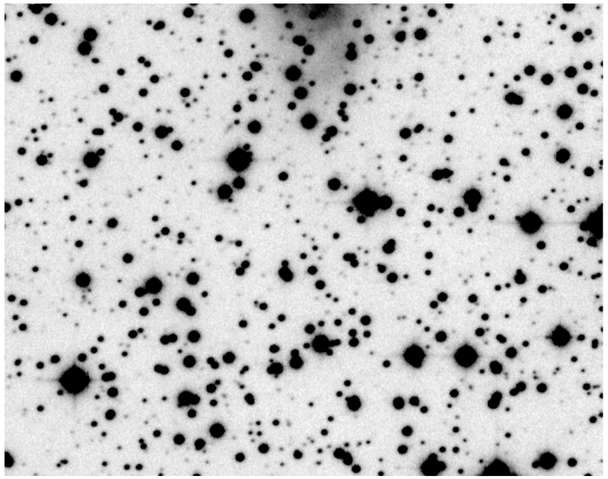
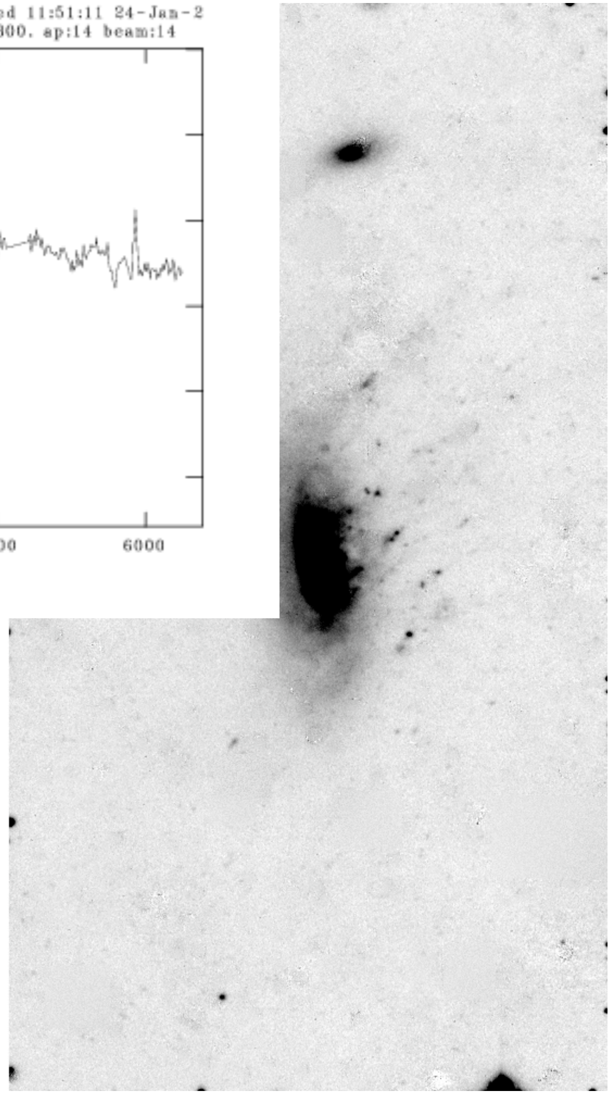
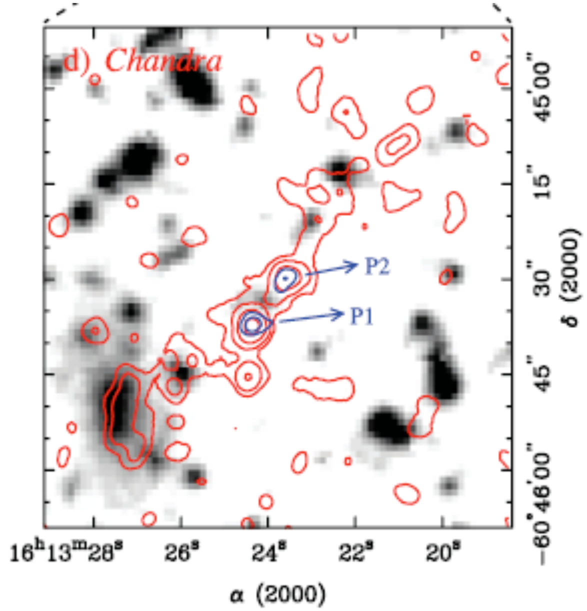
Example of RAM pressure stripping (low z example in Great Attractor)









Chandra X-ray Tail
From: Sun et al. 2006)

Close to the core
of the cluster (0.34 Mpc)

R band image of WKK6176 (2.2' x 4' = 43 x 77 kpc) before & after star subtraction (Woudt et al. 2008).

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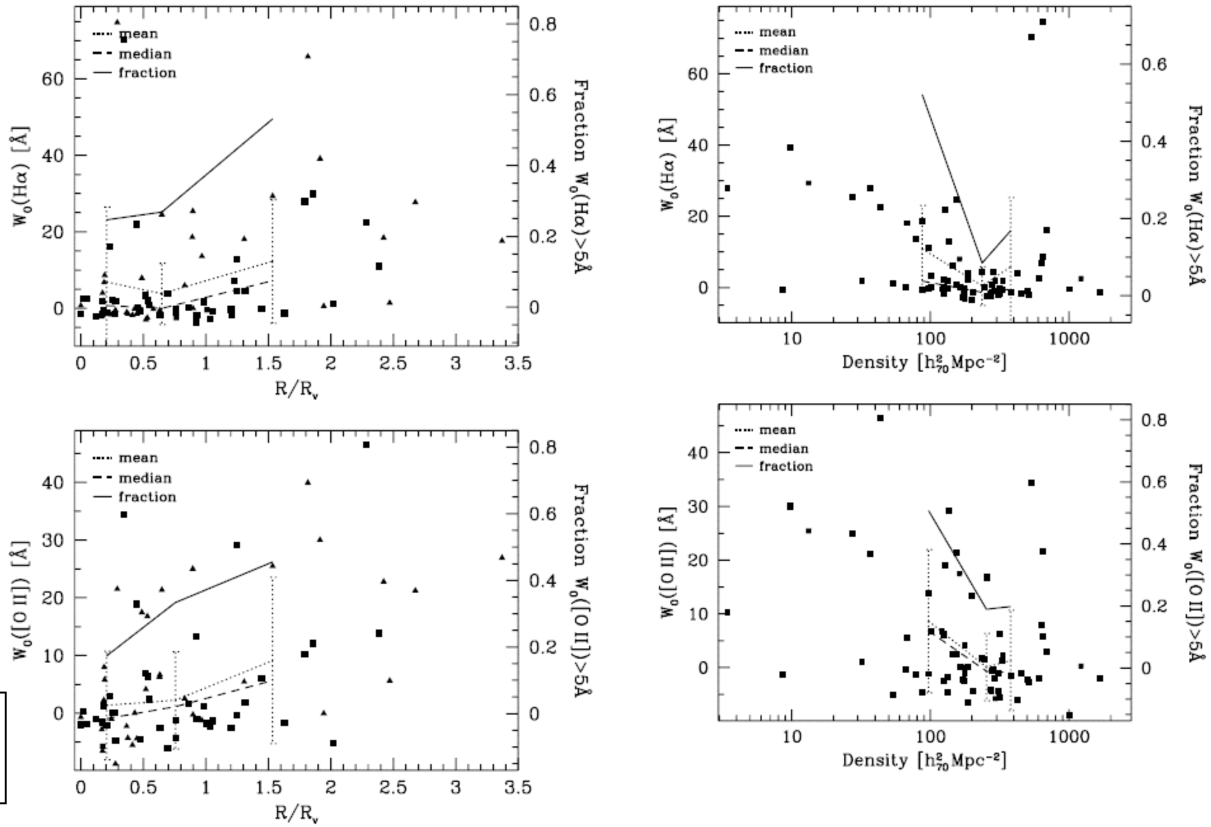
Location of transformation

Recent observations (Lewis et al. 2002; Gomez et al. 2003; Balogh et al. 2004; Gerken et al. 2004) indicate that galaxy populations in clusters start to deviate from the `field' population (in terms of star formation activity) relatively far from the cluster centres, at **~3-4 virial radii**

→ ICM densities high enough at these distances to drive away low-density gas of infalling galaxy halos, leading to **star formation strangulation**.



Picture from:
Gerken et al. (2004)

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GALEV: Evolutionary Synthesis Models (www.galev.org)

What are the respective transition stages, end products and what are the time scales involved?

GALEV: Evolutionary Synthesis Models (Kotulla et al. 2009, MN – arXiv:0903.0378)

Large grid of models undisturbed galaxies (**E**, **S0**, **Sa**, **Sb**, **Sc**, **Sd**), as well as for galaxies undergoing **various kinds of transformation processes** affecting their **star formation histories at various stages in their evolution.**

→ Follow time evolution of **galaxy spectra** (incl. gaseous emission in terms of continuum and lines and stellar abs. features), **luminosities**, and **colours** from the onset of starbursts (of various strengths), star formation truncation (short time scales), star formation strangulation (longer time scales), and merging, until present time.

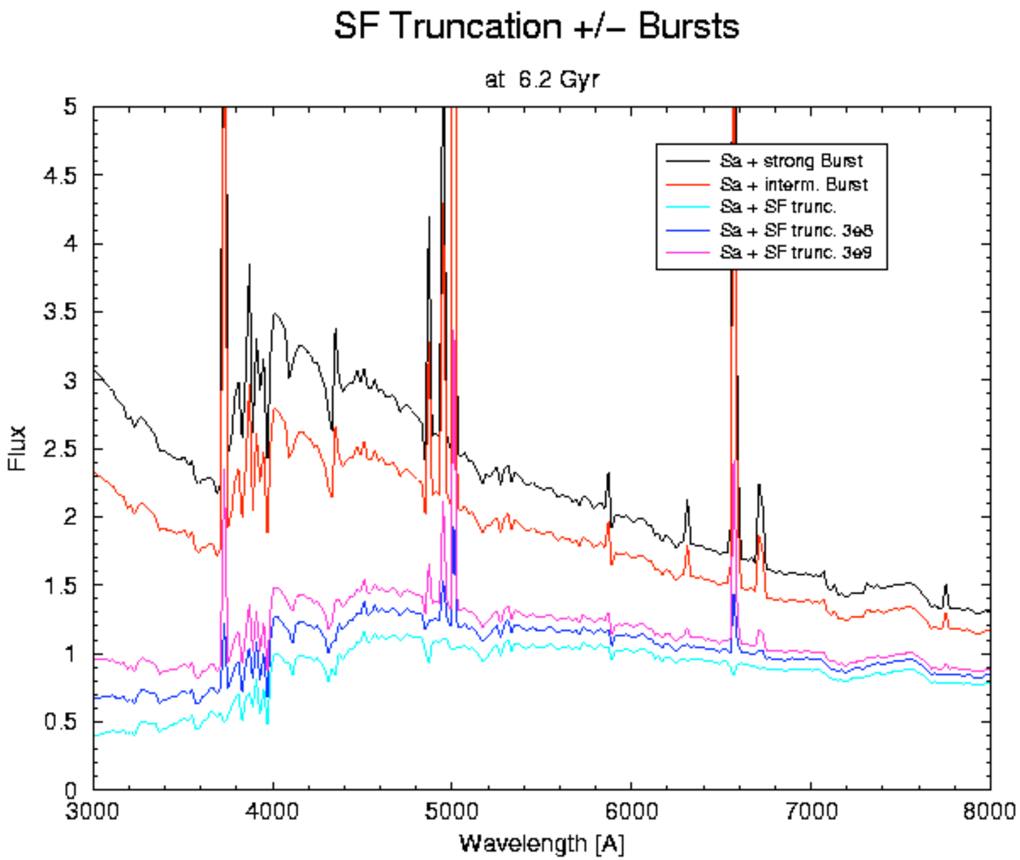
Chemically-consistent models.

Application to E+A and post-starburst galaxies (Falkenberg et al. 2009a,b, MN arXiv: 0901.1665 and arXiv: 0905.0909)

Galaxy transformation in dense environments

GALEV: Evolutionary Synthesis Models – modeling truncation / bursts

Input physics: stellar evolutionary tracks (Padova group) for 5 different metallicities, BaSeL library of model atmospheres (based on Kurucz), gaseous emission, stellar yields, ejection rates (chemical evolution of galaxies), dust extinction, cosmological model, intergalactic attenuation.



Sa galaxy + undisturbed SFR for 6 Gyr

Various effects imposed:

- strong SF burst
- intermediate SF burst
- SF truncation on different time scales

Plotted at 6.2 Gyr after different effects were imposed.

Picture from:
Fritze & Woudt (2006)

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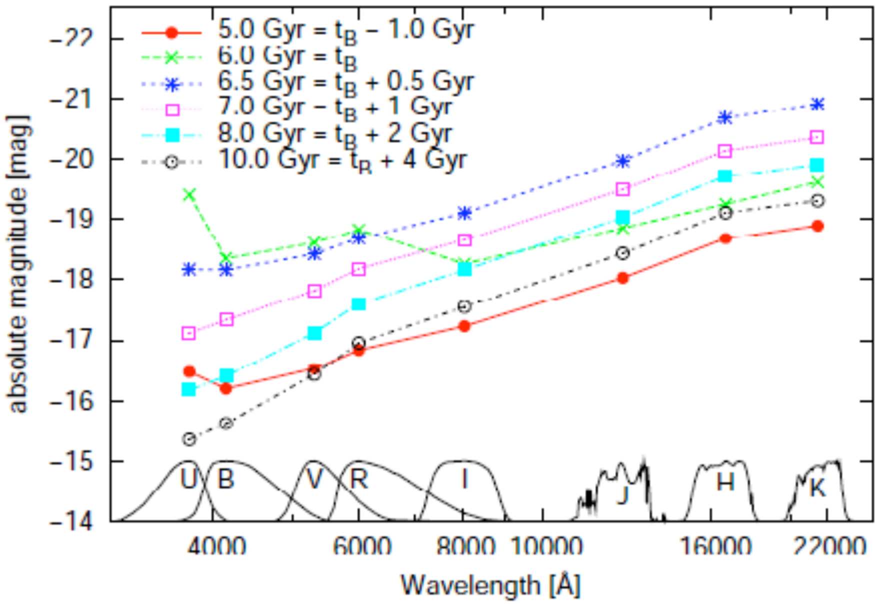
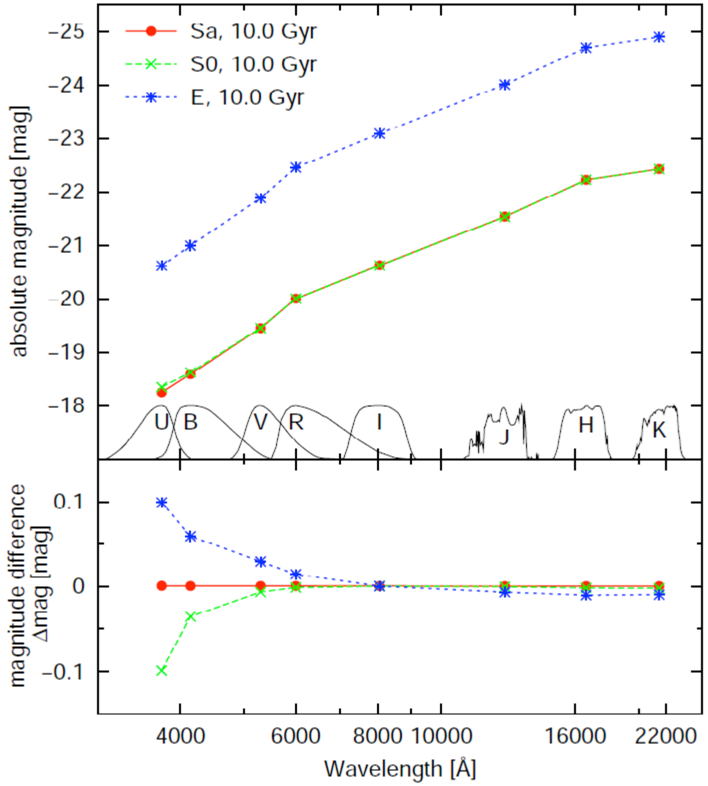
GALEV: Evolutionary Synthesis Models – SED variations

Sd galaxy + burst at 6 Gyr

70% burst strength
Exponential decay time 0.1 Gyr



Sa galaxy + burst at 6 Gyr
50% burst strength
Exponential decay time 0.1 Gyr
E / **S0** undisturbed



Pictures from: Falkenberg, Kotulla and Fritze (2009, arXiv: 0905.0909)

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Multi-wavelength perspective

Optical (SALT, SDSS, skymapper + VO):

1. Deep imaging in UBVRI (ugriz)

   Desired completeness limit: m_B ~ 24 mag, m_V ~ 23.5 mag, m_R ~23 mag

   At z ~ 0.15 (m–M = 38.8 mag), complete coverage down to **L* + 6 mag**
   At z ~ 0.55 (m–M = 41.8 mag), complete coverage down to L* + 3 mag

   → With the inclusion of the U band (**strong point of SALT**), accurate photometric redshifts with GALEV.
   → Multi-band photometric data: exploration of galaxy transformation processes with GALEV.

2. Medium resolution (grating: 1800 l/mm or 2300 l/mm) multi-object spectroscopy (R ~ 3000 – 4000). 100 galaxies per 8 x 8 arcmin field

   → redshifts, absorption line indices and galaxy velocity dispersions
   → **star formation diagnostics**.

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Multi-wavelength perspective

Near-infrared (IRSF: SA / UKIDSS: UK)

3. Deep imaging in JHK_s.

    Completeness limit: $m_{Ks} \sim 17.5 - 18$ mag

    At z ~ 0.15 (m–M = 38.8 mag), complete coverage down to **L* + 3 mag**
    At z ~ 0.55 (m–M = 41.8 mag), complete coverage down to $K_s \sim -24$ mag
    UKIDSS (large area survey) limits: $m_{Ks} = 18.4$

MeerKAT/GMRT:

4. HI imaging at intermediate redshifts.

    GMRT: z ~ 0.15 (45 hours: $\sigma = 0.094$ mJy/beam, 32 MHz, 256 channels centred on 1251 MHz)
    MeerKAT: z ~ 0.15 (120 hours, 5σ detection of L* galaxy)

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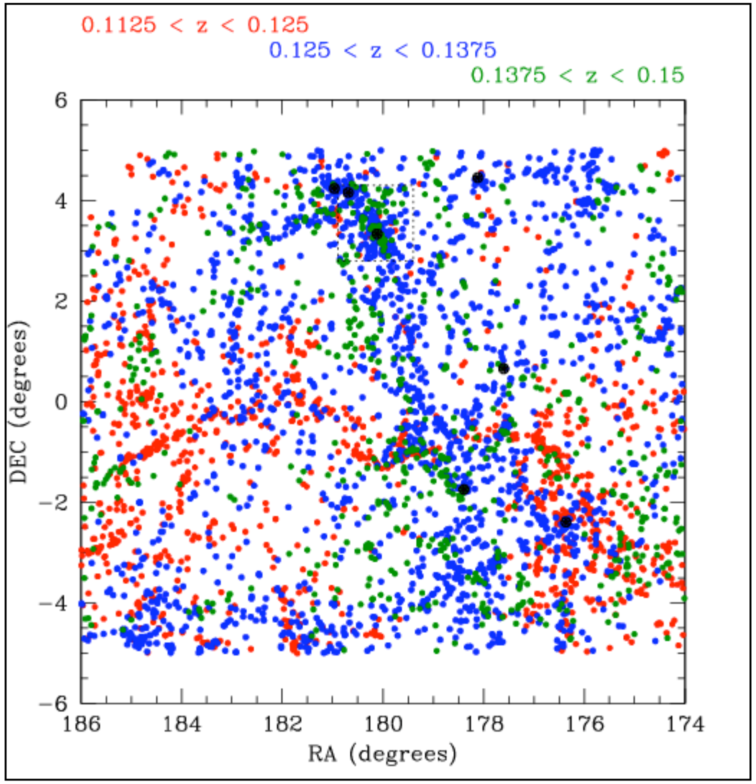
The nearest supercluster: Abell 1437

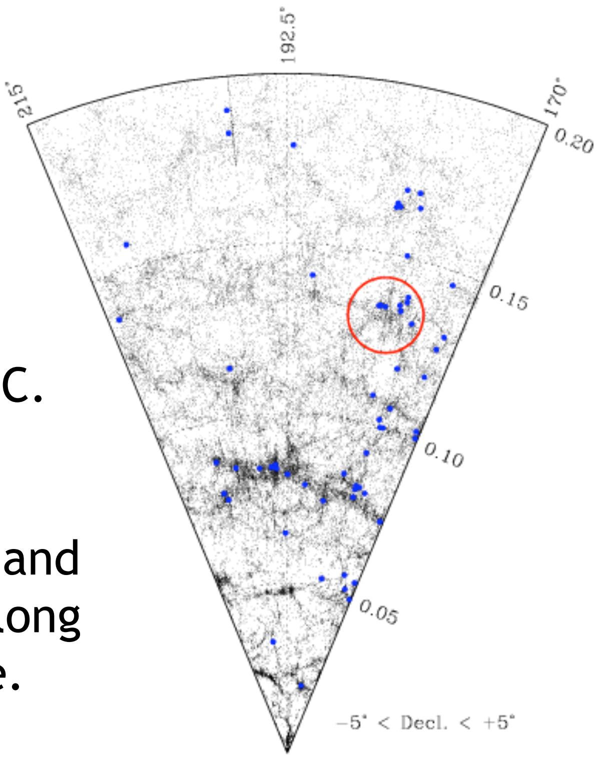
First supercluster in lowest redshift bin ($z \sim 0.15$, $m-M = 38.7$, $t_{LB} = 1.7$ Gyr)

SDSS photometry and **2dF spectroscopy** available (Pimbblet et al. 2006) – no need to wait for SALT to get started on redshifts.



Abell 1437: massive cluster in extended SC. (σ_z = 1152 km/s).

X-ray: very luminous and elongated NE/SW - along filamentary structure.



At z ~ 0.135, 1 degree ~ 8.3 Mpc

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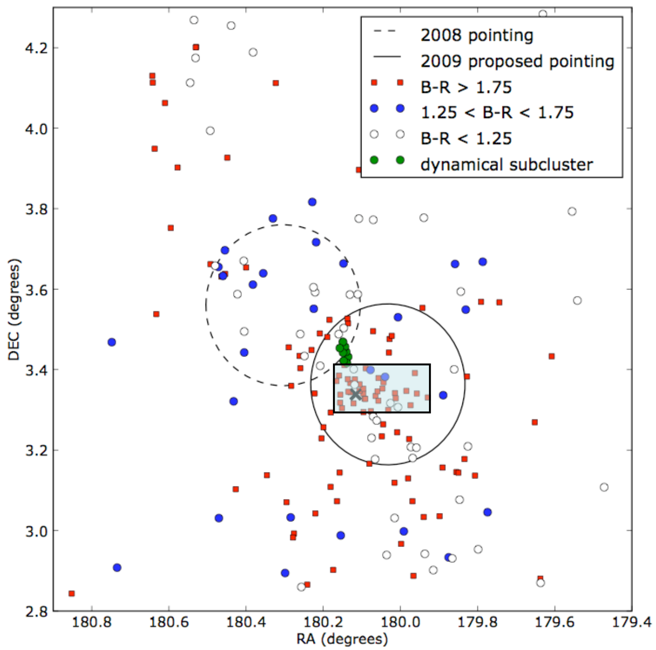
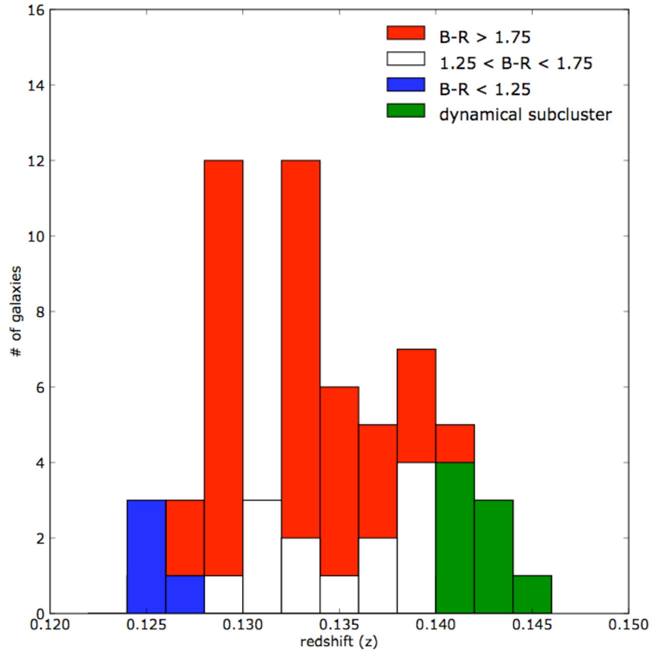
The nearest supercluster: Abell 1437

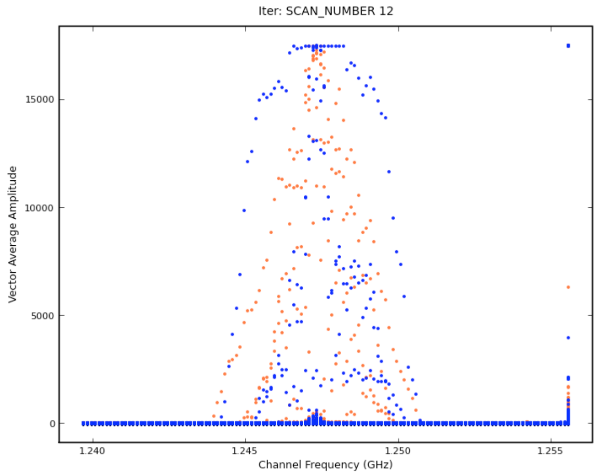




128 channels:
1240-1256 MHz
0.127 > z > 0.115
Δv = 30 km/s

GMRT: 45 h in 2008, 45 h in 2009 (2 separate pointings)

- Expected rms: ~0.1 mJy/beam
- Data reduction complicated by RFI: in progress
- HI stacking possible (note: SALT spectroscopy)



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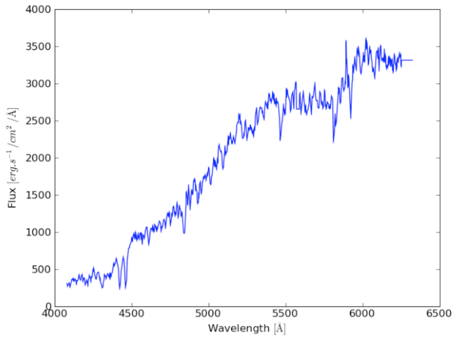
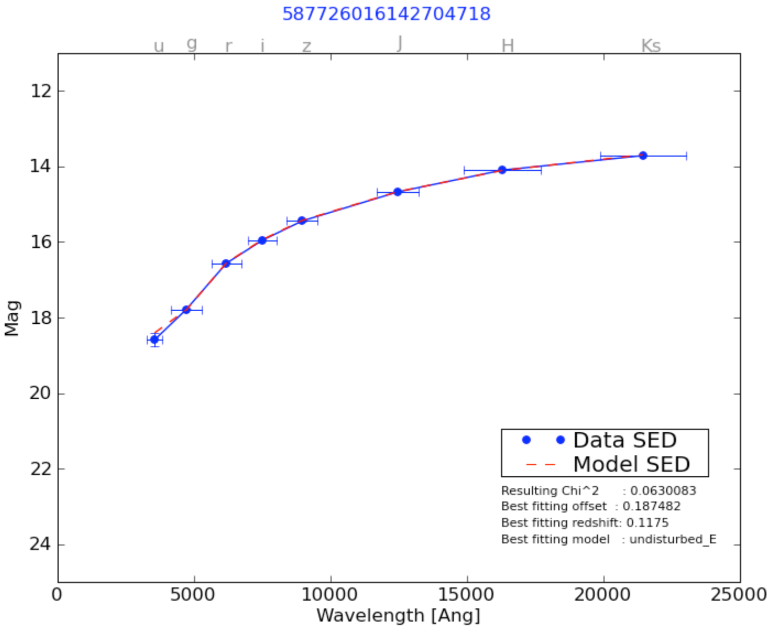
Abell 1437: Some examples of GALEV modelling

100" x 100"   z = 0.124 sersic index = 1.77





Initial sample of 37 galaxies with SDSS and IRSF photometry and 2dF spectroscopy in central 15 x 8 arcmin.

Focus of this part of the study: refine model grid and test reliability of photometric redshifts.

Note: SDSS photometry redone (recall Wim van Driel's talk on Tuesday).

<u>GALEV models:</u>

Type	Burst	Epoch
E	-	-
Sa	- 30% 70%	10.2 11.2 Gyr
Sd	- 30% 70%	10.2 11.2 Gyr

Exponential decay of burst time: 250 Myr

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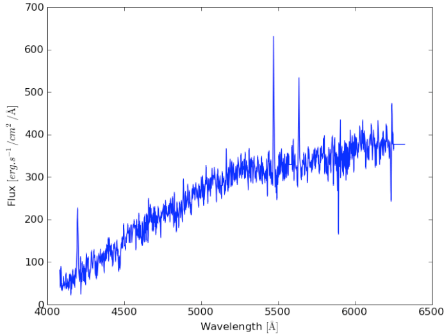
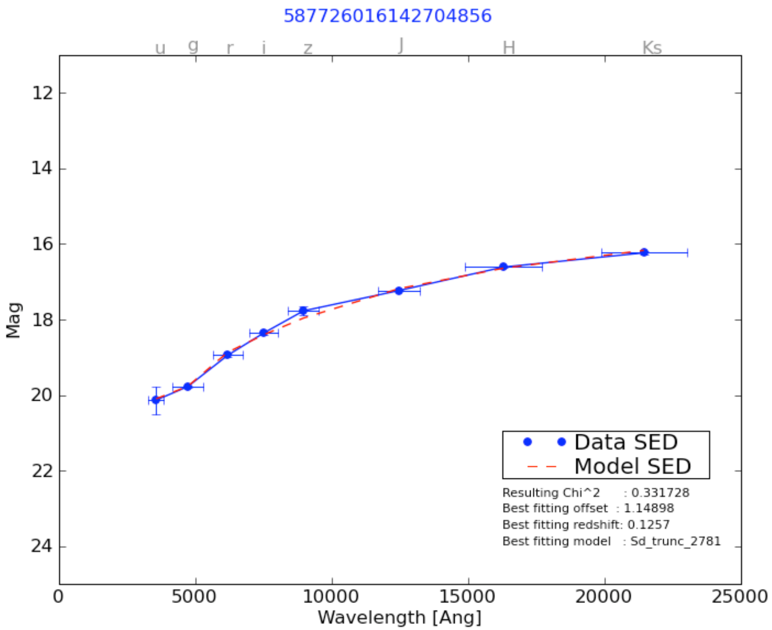
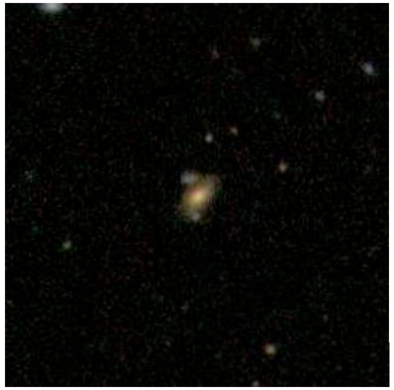
Abell 1437: Some examples of GALEV modelling

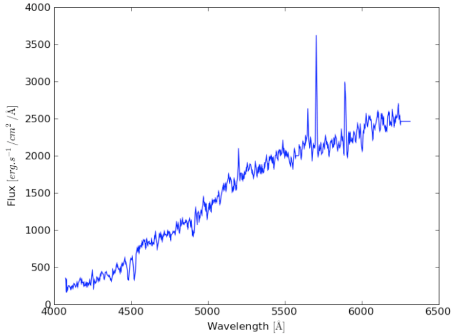
100" x 100" z = 0.126 sersic index = 0.96

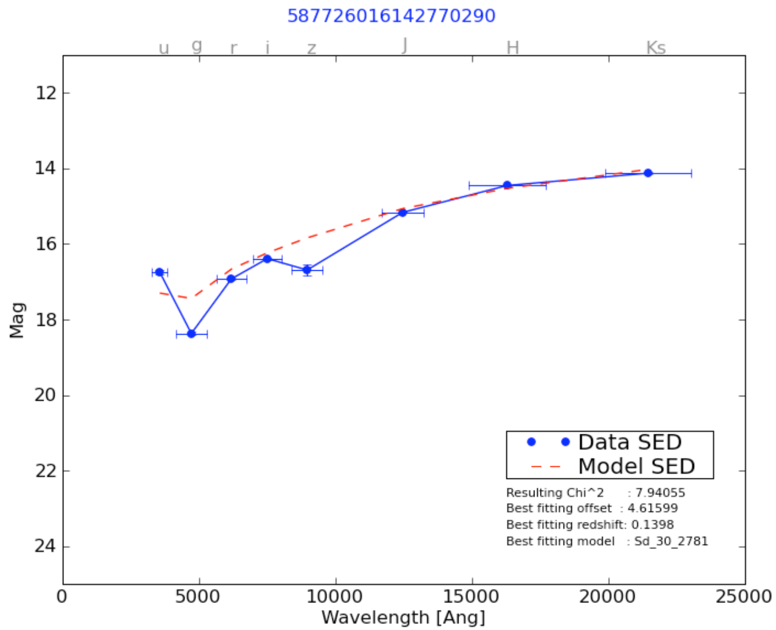




100" x 100" z = 0.140 sersic index = 2.11







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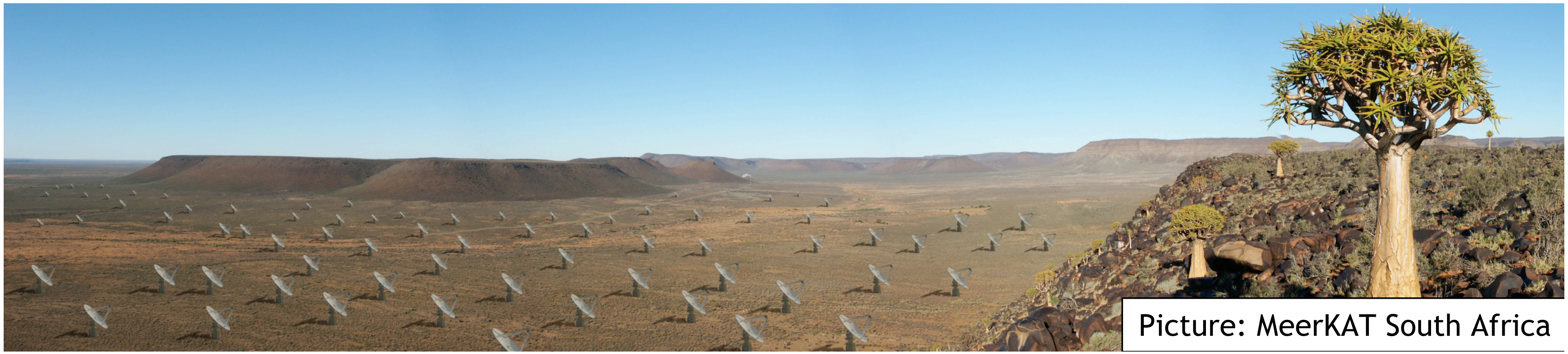
MeerKAT planned observations

80 dishes of D = 12 metres, maximum baseline 8 km (beam width ~6"), T_{sys} = 30 K

Assumptions: noise = 0.6 mJy in 8 h observation, W = 200 km/s
(top-hat profile, 5 sigma peak flux)

5-σ detection of an M_{HI}* galaxy (Zwaan et al. 2005) at z = 0.135
(e.g. Abell 1437 at distance 550 Mpc) in 120 hours of observations.

Stacking: average properties for carefully selected sample



Picture: MeerKAT South Africa

Galaxy transformation in dense environments

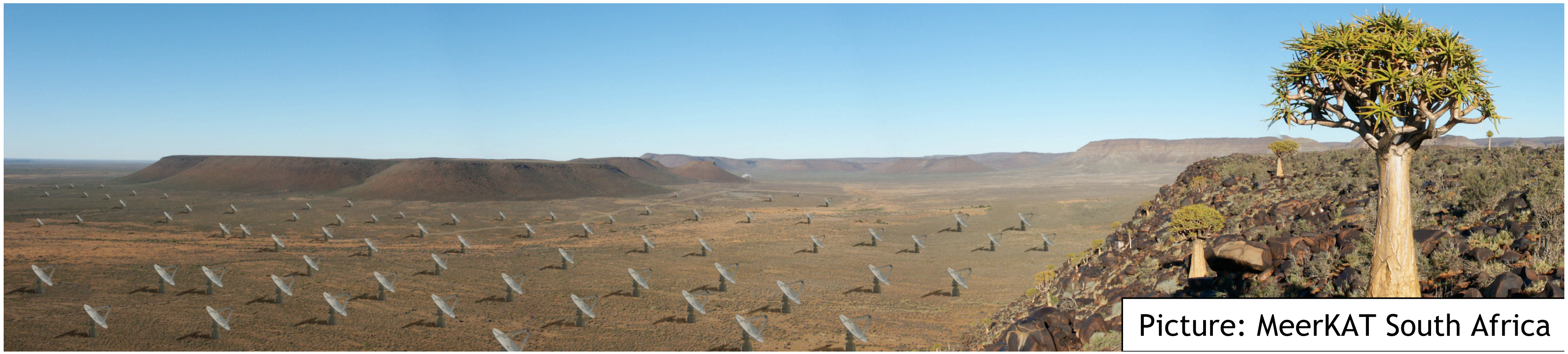
Summary

Through **HI line emission** observations, optical/near-infrared photometry, spectroscopy & **modelling** over a **wide area**, constrain galaxy transformation scenarios, galaxy (end) products and time scales, over a range of intermediate redshifts (z ~ 0.15 – 0.45).

Current status: characterizing GALEV models, SED fitting and HI observations (GMRT) for the nearest redshift range.

GALEV – observed SED / spectroscopy — **refining burst parameters**
GALEV – HI observation — **model / observed gas content**

HI observations will give: HI content at z = 0.15 – 0.45 (Ω_{HI}) and HI mass function as a function of redshift, location (overdensity)



Picture: MeerKAT South Africa