STAGES: revealing galaxy evolution in dense environments

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the STAGES collaboration
Gomez et al. 2002 (SDSS)
Kodama et al. 2001
Lewis et al. 2002 (2dF)
Kauffmann et al. (2004)
Dressler (1980)
morphology-density
AGN fraction
colour-density
SF-density

Kodama et al. 2001

Gomez et al. 2002 (SDSS)
1. Galaxy-cluster gas interactions
   - e.g. ram-pressure stripping (Gunn & Gott 1972, Larson et al 1980)

2. Galaxy-cluster gravitational interactions
   - e.g. tidal truncation of galaxy dark matter halos (Merrett 1983, 1984)

3. Galaxy-galaxy interactions
   - mergers (low-speed interactions; Bekki 1998);
   - harrassment (high-speed interactions; Moore et al 1999)

Distinct observational effects on galaxy properties:
- star-formation (induce, truncate, or suffocate)
- AGN activity (modify gas supply to central engine)
- structural parameters (destroy disks, create tidal features)

\[ \textbf{effective on different timescales and in different regimes} \]
Nature or nurture?

An experiment to understand galaxy evolution in dense environments satisfy the following criteria:

• completely map environment: mass, gas and galaxies
• choose unrelaxed structure (info not yet erased)
• cover wide dynamic range in density: cluster cores to field
• probe luminous and dwarf galaxies: SF, structure, and AGN

STAGES:
Space Telescope A901/902 Galaxy Evolution Survey
(PI: Gray)
STAGES:
A multiwavelength (X-ray--radio) survey to dissect the A901/902 supercluster

A901a
A901b
A902

$z = 0.17; \sim 5 \times 5$ Mpc

COMBO-17 image
### Hubble Space Telescope

**80-orbit mosaic with 3 cameras:**
- morphologies, weak gravitational lensing

<table>
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<tr>
<th>Instrument</th>
<th>Description</th>
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<td>COMBO-17 survey</td>
<td>17-band optical imaging: photo-zs + SEDs for 15000 objects</td>
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<td>Omega2000 @ Calar Alto (Meisenheimer)</td>
<td>near-infrared extension (Y, J1, J2, H): M*, photo-zs</td>
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<td>2dF spectrograph</td>
<td>spectroscopy of ~300 cluster galaxies: dynamics, star-formation histories</td>
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<td>XMM-Newton</td>
<td>90 ks X-ray imaging/spectroscopy: ICM, AGN</td>
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<td>Spitzer (Bell)</td>
<td>infrared imaging (8 and 24 μm): obscured star formation, AGN</td>
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<td>GALEX (GALEX team)</td>
<td>NUV + FUV imaging: unobscured star formation</td>
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<tr>
<td>GMRT</td>
<td>radio imaging (610 and 1400MHz): obscured SF, AGN</td>
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<tr>
<td>constrained simulations (van Kampen)</td>
<td>N-body + hydro + semi-analytic models: dark matter, gas, galaxies</td>
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</tbody>
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*Meghan Gray, University of Nottingham*
Two-pronged attack

1. galaxy evolution and environment with COMBO-17++: the story so far

2. STAGES: results in progress
The story so far (I): X-ray selected AGN


- 11 confirmed + 1 possible COMBO-17 counterparts in supercluster
- one Type I AGN with $L_X = 1.55 \times 10^{44}$ erg/cm$^2$/s (…but not BCG)
- 6/8 with optical spectra would not otherwise have been identified as AGN:

![Image of emission lines]
The story so far (I): X-ray selected AGN

Supercluster AGN hosts:

- are all massive galaxies with R<20
- have morphologies from E \(\rightarrow\) Sb
- populate all photometric classes (red/dusty/blue)

live in areas of moderate galaxy number density

The story so far (II): truncation of SF

star-formation--density relation (Gray et al 2004)

ground-based mass map of Gray et al (2002)
The story so far (III): “trimodality”

Using COMBO-17 to split the cluster red sequence:
“third population”: dusty red star-forming galaxies; make up >30% of the cluster red sequence

Wolf, Gray & Meisenheimer 2005
The story so far (III): “trimodality”

composite 2dF spectra: visual morphologies:

Wolf, Gray & Meisenheimer 2005

Lane, Gray, Aragón-Salamanca et al 2007, MNRAS submitted
The story so far: action in the suburbs

Intermediate densities: preferred habitat for

- AGN: (Gilmour, Gray, Almaini et al, 2007, submitted)
- truncation of star-formation (Gray et al 2004)
- “third population”: dusty red star-forming galaxies (Wolf, Gray & Meisenheimer 2005); with intermediate morphologies (Lane, Gray et al 2007, MNRAS submitted)
Beyond the morphology-density relation….

age-density relation @ fixed morphology

Beyond the morphology-density relation….

age-density relation
@ fixed morphology


age-morphology relation
@ fixed density
Beyond the morphology-density relation…

age-density relation @ fixed morphology


age-morphology relation @ fixed density

morphology-density relation @ fixed age
Beyond the morphology-density relation

no morphology-density at fixed age/colour

→ age-density relation of primary importance:
“head start” + longer time to experience environmental effects

see also Quintero et al (2006)…but also Park et al (2006)
First summary

• results to date from COMBO-17++
  – intermediate densities sites of activity (Gilmour et al 2007)
  – “trimodal” population of dusty red gals discovered, intermediate morphology (Lane et al 2007)
  – age-density, not morphology-density, of primary importance (Wolf et al 2007)

• However…only reach $M_V = -18$ from the ground
  ➔ STAGES + HST = morphologies
• 80 orbit mosaic
• ACS + WFPC2/NIC3 parallels
• data reduction complete; science exploitation underway
• largest non-public HST mosaic
• sister survey to GEMS/CDFS

Collaborators

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C Wolf

UBC
C Heymans

UMass
D McIntosh

ESO/Chile
R Gilmour

Innsbruck
E van Kampen
M Barden

Arizona
C Papovitch

Columbia
B Johnson

Waterloo
M Balogh

image: COMBO-17
contours: mass
STAGES: revealing morphologies

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STAGES: Galaxy Evolution in Dense Environments
The need for HST

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STAGES: Galaxy Evolution in Dense Environments
STAGES Einstein ring

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STAGES Einstein ring

Aragón-Salamanca et al, in prep

lensed background galaxy @ $z = 1.55$

1.25 arcsec

lensing supercluster galaxy @ $z = 0.168$
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STAGES: Galaxy Evolution in Dense Environments

**Lens model (courtesy Chien Peng)**

- SIE + external shear
- Bulge well-fit by single profile
- Complex core
- B/T ~ 85%

ACS image | lens model
---|---
residuals | reconstructed source

Lens model (courtesy Chien Peng)

ACS image

residuals

reconstructed source
Meghan Gray, University of Nottingham

STAGES: Galaxy Evolution in Dense Environments

- standard KS93 reconstruction
- are attempting more sophisticated methods,
  40 gal/sq arcmin $\rightarrow$ 100 gal/sq arcmin
- + independent flexion (w/David Bacon) $\rightarrow$
  filaments and the cosmic web

with Catherine Heymans (UBC)
mass

X-ray gas

galaxy number density
galaxy luminosity density
number density: all
luminosity density: all
luminosity density: red sequence
luminosity density: old red sequence
number density: all
luminosity density: all
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number density: all
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Aside: STAGES 1 dSph

9 arcsec

cf. Apples 1
(Pasquali et al 2004)
Conclusions

• **COMBO-17++ shows us:**
  - trimodality (young, dusty & red gals with intermediate morphologies)
  - supercluster AGN hosts, truncation of SF at critical density
    ➔ **intermediate densities key sites for galaxy transformation**
  - beyond the red sequence: age-morphology-density
    ➔ **age-density relation primary importance**

• **STAGES + HST is providing:**
  - high-resolution weak lensing mass map: visualizing the cosmic web
    ➔ **luminosity density of old red galaxies maps to mass peaks, faint blue galaxies in filaments**
  - serendipitous Einstein Ring (S0 M/L)
  - visual morphologies and profile fitting in progress
  - additional foreground/background science (e.g. AGN hosts, local dSph)