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(Haines et al. 2011, MNRAS in press)

ACCESS

A Complete CEnsus of Star formation and nuclear activity in the Shapley supercluster

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Primary aim: to detect the signatures of galaxies being transformed, using a multi-band data-set plus targeted follow-up of integral-field spectroscopy.

A galaxy’s environment has a profound effect on its global properties (morphology, SFR, colours)

morphology - density relation

(Dressler 1980, Dressler et al. 1997, Smith et al. 2005)

star formation – density relation

(Dressler et al. 1985, Balogh et al. 2000,
Lewis et al. 2002, Kauffmann et al. 2004, Haines et al. 2009)

Classes of transition galaxies

post-starburst and/or E+A galaxies

(Dressler & Gunn 1983, Poggianti et al. 1999, Mercurio et al. 2004, Mahajian et al. 2010, 2011)

interaction-induced starbursts

(Moss 2006, Fadda et al. 2008)

passive/red spirals

(Van der Bergh 1976, Bamford et al. 2009)

Mid-infrared data as key diagnostic to understand the relevance of the proposed transition galaxies

dust-obscured star formation

"optical post-starburst galaxies" → dusty starbursts
(Duc et al. 2002, Dressler et al. 2009)

population of starburst and post-starburst ~L* spirals in z~0.5 clusters
(Couch & Sharples 1987, Geach et al. 2006, Dressler et al. 2009)

interaction-induced starbusts highly obscured
(Mihos & Hernquist 1994)

some red sequence galaxies are actively star-forming
(Wolf et al. 2005, 2009, Haines et al. 2010)

Mid-IR and far-IR data: impact of the environment on the ISM and dust contents

- warm (60K) component of small dust grains in HII regions heated by the star formation

- cool (20K) cirrus component of large dust grains heated by the interstellar radiation field

IRAS+sub-mm data of the MW:
(Désert, Boulanger & Puget 1990

Herschel 24-500 μm of M33:
(Kramer et al. 2010)

Mid-IR and far-IR data: impact of the environment on the ISM and dust contents

Mid-IR Spitzer/MIPS (24μm):

dominated by dust emission from current star formation

Far-IR Spitzer/MIPS (70μm):

40% of the integrated galaxy light from dust heated by diffuse interstellar radiation from evolved stars (the general ISRF)

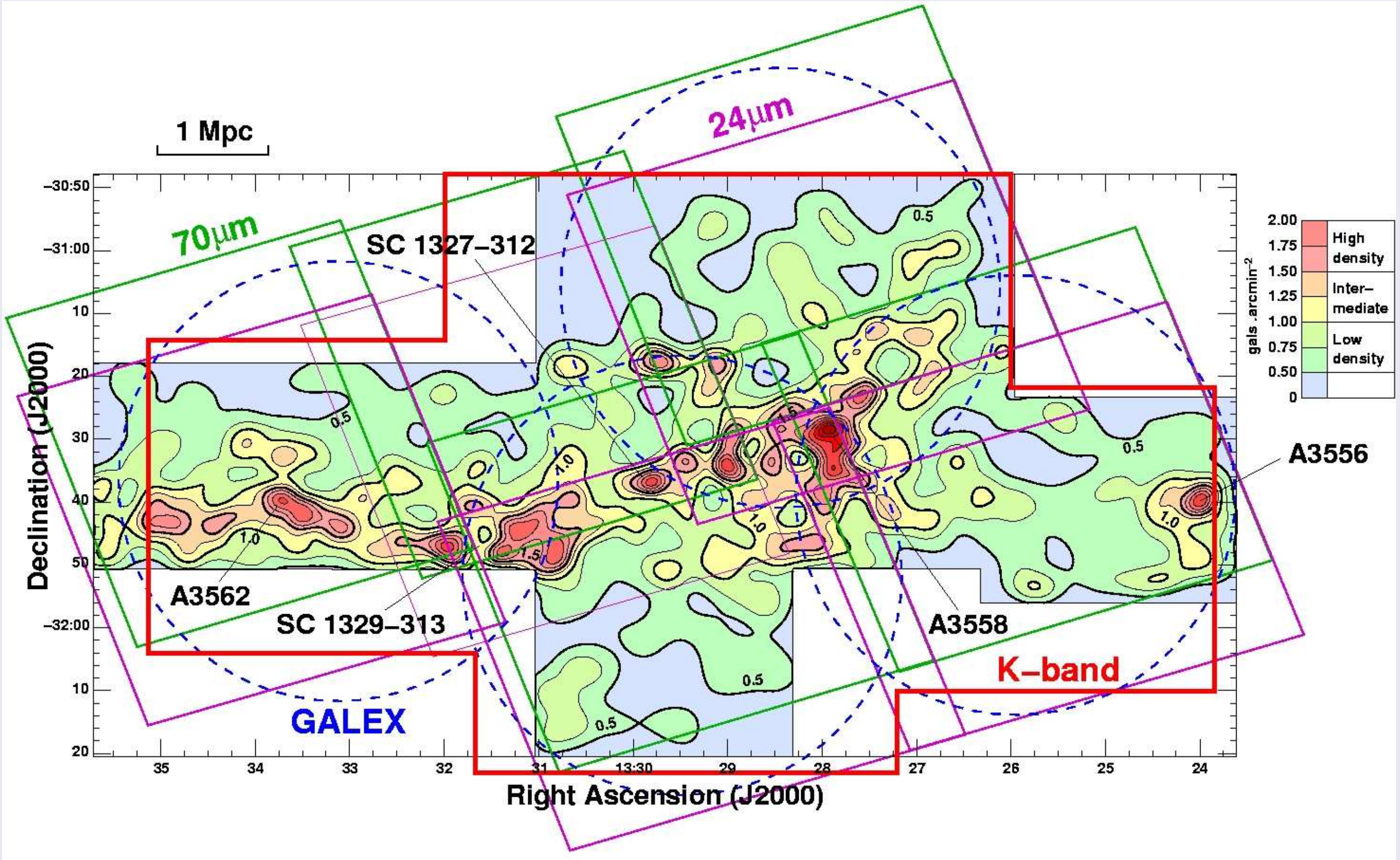
(Li et al. 2010, Bendo et al. 2010, Calzetti et al. 2010)

↓

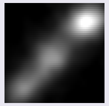
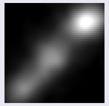
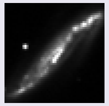
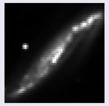
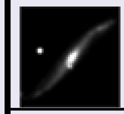
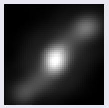
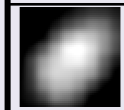
$$f_{70}/f_{24}$$

probes the dust heating sources

Shapley Supercluster Core
(z=0.048)



The data: imaging

λeff. (μm)	Instrument	Completeness limit
 0.15	GALEX	22.5 mag
 0.23	GALEX	22 mag
 0.43	2.2 WFI	22.5 mag
 0.7	2.2 WFI	22 mag
 2.2	UKIRT	18 mag
 24	Spitzer	0.35 mJy
 70	Spitzer	25 mJy

90% completeness for GALEX and Spitzer data;

50% (80%) completeness for the UKIRT data in the high (low) density environments;

100% completeness for WFI B and R data

L_{IR}=7.5 $10^8 L_{sun}$ (SFR=0.05$M_{sun}yr^{-1}$)

L_{IR}=5.7 $10^9 L_{sun}$

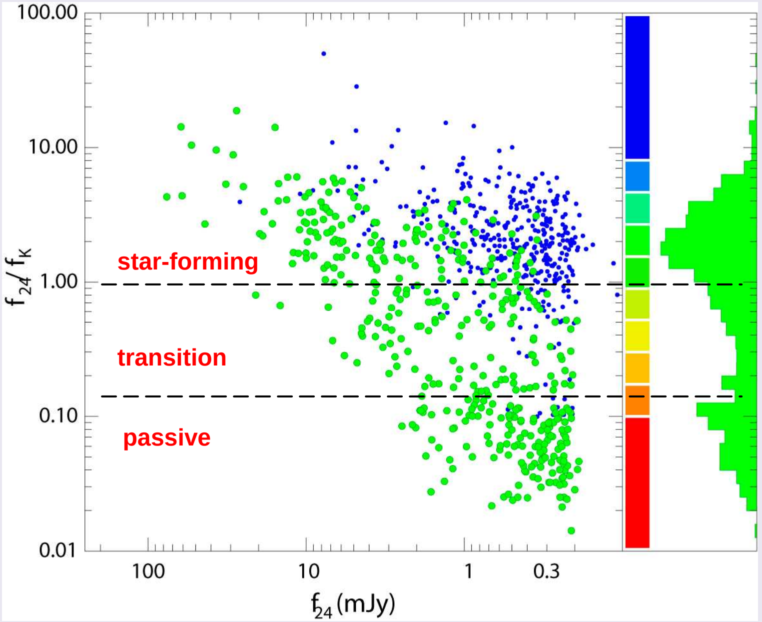
Mercurio et al. 2006, Haines et al. 2006, Merluzzi et al. 2010, Haines et al. 2011a

The data: spectroscopy

- **814** spectroscopic supercluster members:
- **396** detected at 24μm and **163** at 70μm
- **415** supercluster members with high (>60/Å) S/N spectra (Smith at al. 2007)
- IFS with WiFeS for **20** galaxies

Specific star formation rate:

passive-evolving ellipticals and star-forming spirals



Haines et al. 2011b

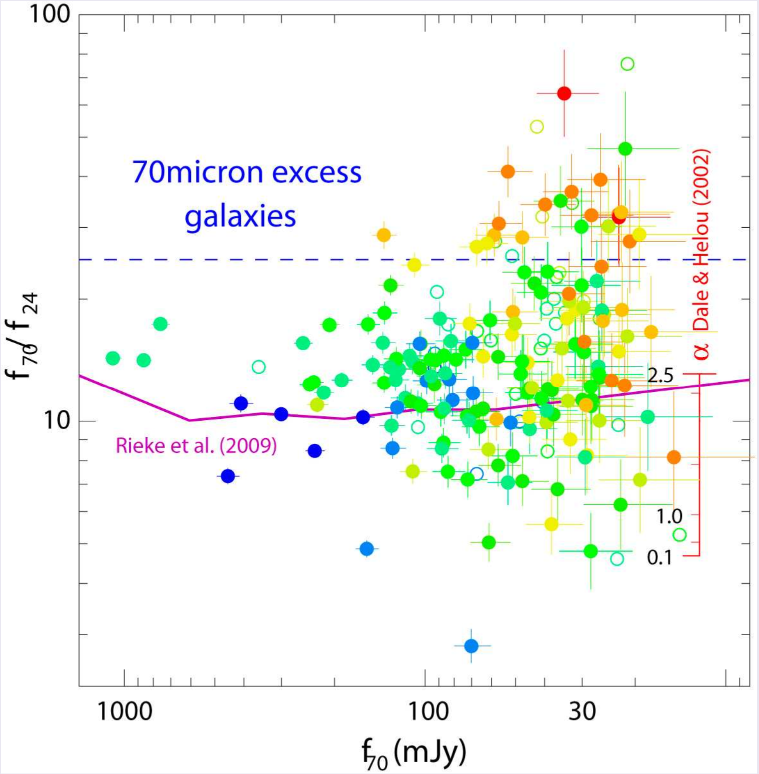
f_{24}: current SF
K band: stellar mass

- passive galaxies: **f_{24}/f_K≈0.1**
- star-forming galaxies: **f_{24}/f_K≈2**
- galaxies in the process of having their star formation quenched: **f_{24}/f_K≈0.15–1.0**

(from correlation with Hα, FUV-R, morph)

Green: confirmed supercluster members
Blue: photometric-selected supercluster galaxies

f_{70}/f_{24}



star-forming galaxies consistent with

- luminosity-dependent SEDs of Rieke et al. 2009
- models by Dale & Helou 2002 with α≥1.5

galaxies with $f_{70}/f_{24} \geq 25$

- inconsistent with standard SED models at ≥3σ

solid symbols: confirmed supercluster members
open symbol: photometric selected supercluster galaxies

70μm-excess galaxies: $f_{70}/f_{24} \geq 25$

- **22/23 galaxies with K-band photometry: ~L* (11.3≤K≤12.8, ±1 MK*)**
- **8% of all the K<13 (MK<M*+1.3) SSC galaxies**
- **23 70μm-excess galaxies 14% of the 70μm-detected SSC galaxies**
- **most of them are in the transition region between passive and SF**

- they may be related to the population of cluster galaxies with f_{100}/f_{24}>25-30 identified in LoCuSS at z=0.2-0.3
(Smith et al. 2010, Pereira et al. 2010, Rawle et al. 2010)

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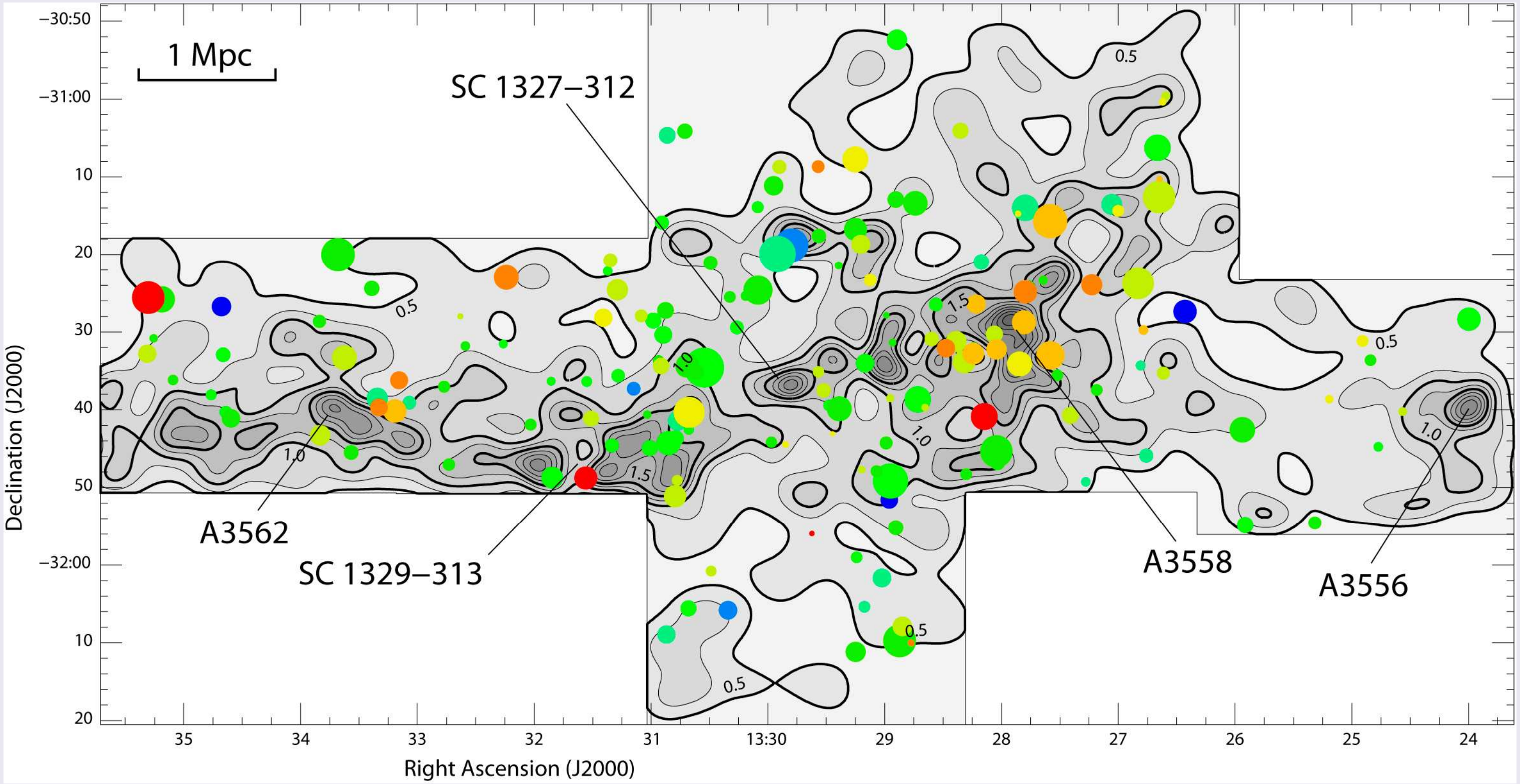
↓

Are they related to a particular environment?

The environment of 70μm-excess galaxies within the SSC



blue: $f_{70}/f_{24} \leq 7$

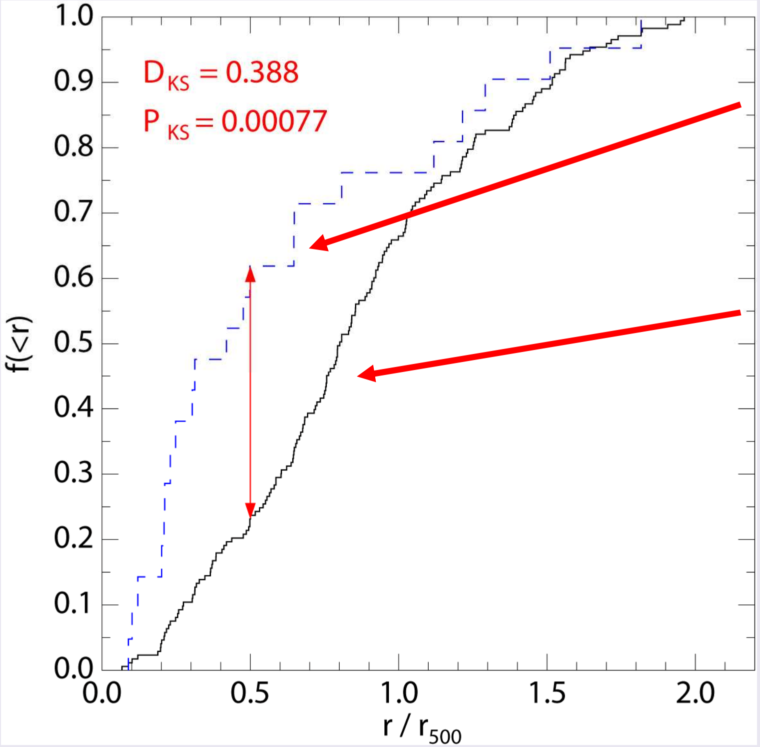
green: $f_{70}/f_{24} \leq 10$-20 normal star-forming

yellow/orange: $f_{70}/f_{24} \geq 25$ 70μm-excess

$\sigma_{70\mu m\text{-excess}} \sim \sigma_{A3558}$

The environment of 70μm-excess galaxies within the SSC

The **70μm-excess** galaxies appear much more clustered than the overall **70μm** supercluster galaxy population.



Cumulative distribution of distances of each **70μm-excess** galaxy from their nearest cluster in units of r_{500}

Corresponding distribution for all confirmed **70μm-detected** supercluster members

70μm-excess galaxies are in average at smaller cluster-centre radii: 60% within $0.5r_{500}$ (25% of the overall 70μm-detected galaxies)

also more concentrated than SSC members (P_{KS}=0.03)

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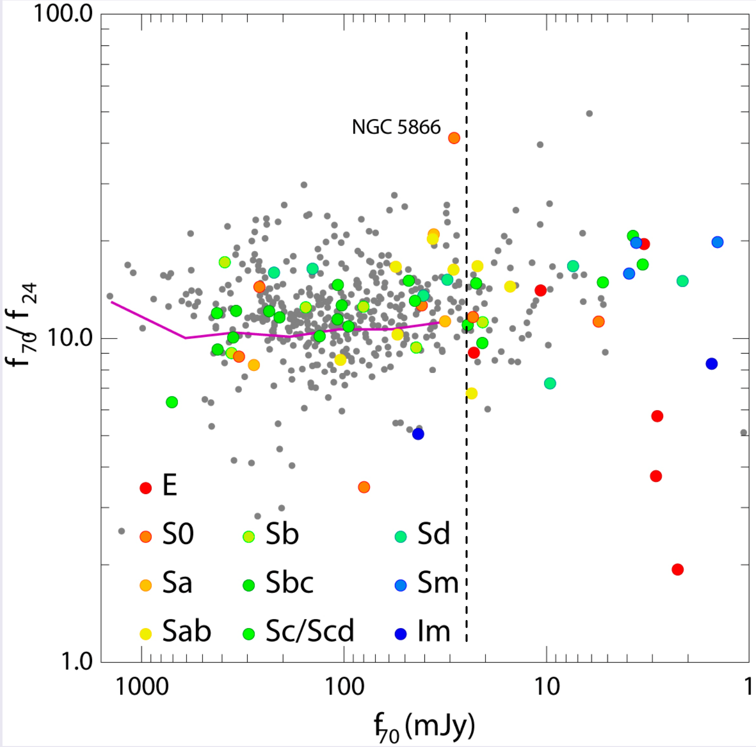
Are these 70μm-excess galaxies purely cluster phenomenon, or are they ubiquitous?

Comparison to field galaxy sample



- the bulk of SINGS galaxies have the same colours of our star-forming sequence galaxies: $\mathbf{8 \leq f_{70}/f_{24} \leq 20}$
- only one SINGS galaxy (3%) can be classified as 70µm-excess
- the SWIRE galaxies show a narrow range of f_{70}/f_{24} with a median value 12.08 (5.3-24.8 at 1α)
- only 5 SWIRE galaxies (1%) can be classified as 70µm-excess

SINGS galaxies (Kennicutt et al 2003): large coloured dots
SWIRE galaxies (Lonsdale et al. 2003): small gray dots

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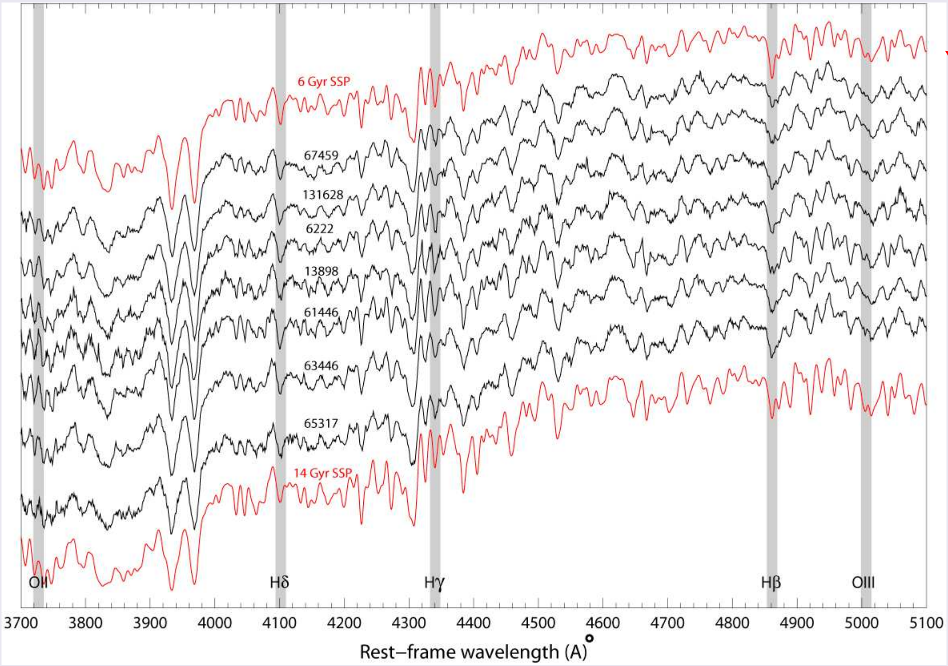
- 70μm-excess galaxies are a cluster population

Spectra of the 70μm-excess galaxies



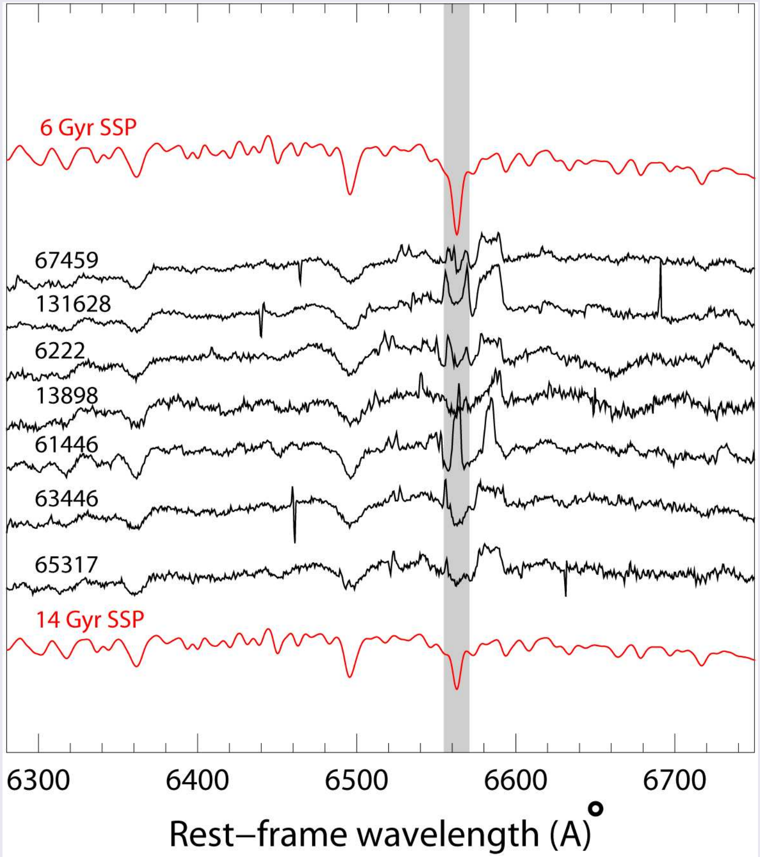
6 Gyr

solar-metallicity SSP
(MILES,Vazdekis et al. 2010)

14 Gyr

The models match well the overall continuum and the primary age features:
4000Å break, and Balmer indices ➡ **old stellar population**
4 galaxies have measured stellar ages (Smith et al. 2007) ➡ **6-11 Gyr**

Spectra of the 70μm-excess galaxies



6 Gyr

solar-metallicity SSP
(MILES,Vazdekis et al. 2010)

14 Gyr

moderate/absent on-going star formation from Hα emission (EW=0.3-3)
also confirmed by their red colours **NUV-R~4.5-6**

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70μm excess galaxies
R-band images
30 kpc

Morphologies

B- and R-band imaging of SOS (FWHM~0.7”) with the classification scheme by Thomas & Katger (2006)

23 70μm-excess SSC galaxies:

2 Es
4 E/S0s
11 S0s
2 Sa
4 later-type galaxies (K>14)

most of them (80%) B/D>0.4 → E/S0

Morphologies

B- and R-band imaging of SOS (FWHM~0.7”) with the classification scheme by Thomas & Katger (2006)

23 70μm-excess SSC galaxies:

2 Es
4 E/S0s
11 S0s
2 Sa
4 later-type galaxies (K>14)

163 70μm-detected spectroscopic members:

63 E/S0s
100 later-type galaxies than Sa

probability of 3.4×10^{-4} to extract 17 E/S0/Sa galaxies out of 23

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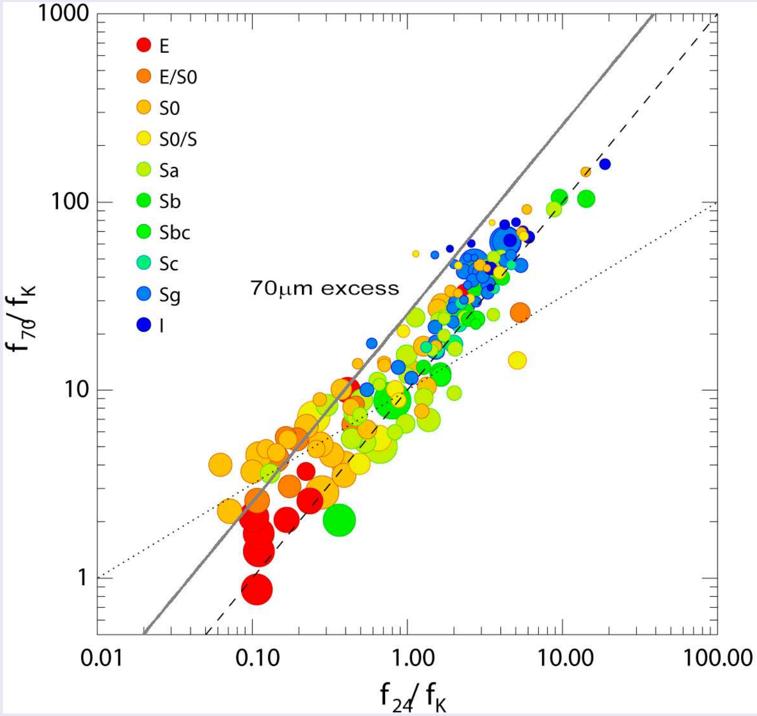
The 70μm-excess phase along the quencing sequence



f_{24}/f_K → SSFR

f_{70}/f_K → cooler dust content

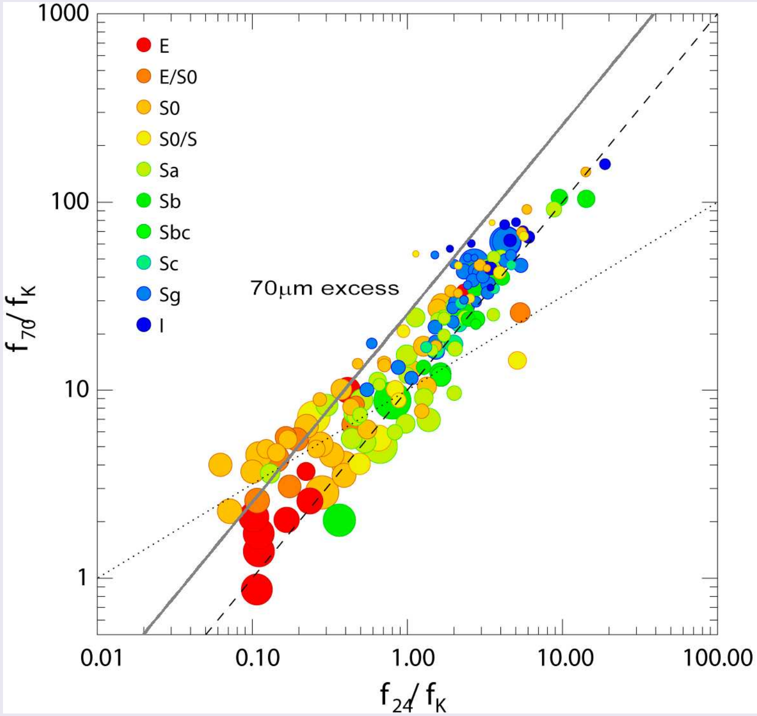
SF galaxies:
70μm emission directly proportional to 24μm emission, $\mathbf{f_{70}/f_{24}=10}$

70μm from dust heated by star formation

S0 galaxies at lower $\mathbf{f_{24}/f_K}$:
$\mathbf{f_{70}/f_K}$ ratios lie systematically above the SF sequence

70μm declines slower than the 24μm emission

The 70μm-excess phase along the quencing sequence



f_{24}/f_K → SSFR

f_{70}/f_K → cooler dust content

Deyon & Joseph (1989):
star formation decline with HI deficiency while the cool dust content declines at lower rate.

→ $f_{70}/f_K \propto (f_{24}/f_K)^{1/2}$

da Cunha et al. (2008, 2010):
star-forming galaxies

→ young stars mainly contribute to dust heating

quiescent galaxies

→ 80% of dust emission from dust heating by older stars

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- mostly early-type galaxies
- FIR emission coming from dust heated by the ISRF

The history of 70μm-excess galaxies

<u>**Ram-pressure stripping**</u>
70μm-excess galaxies concentrated in the cluster cores

Star formation is quenched *before* the morphological transformation

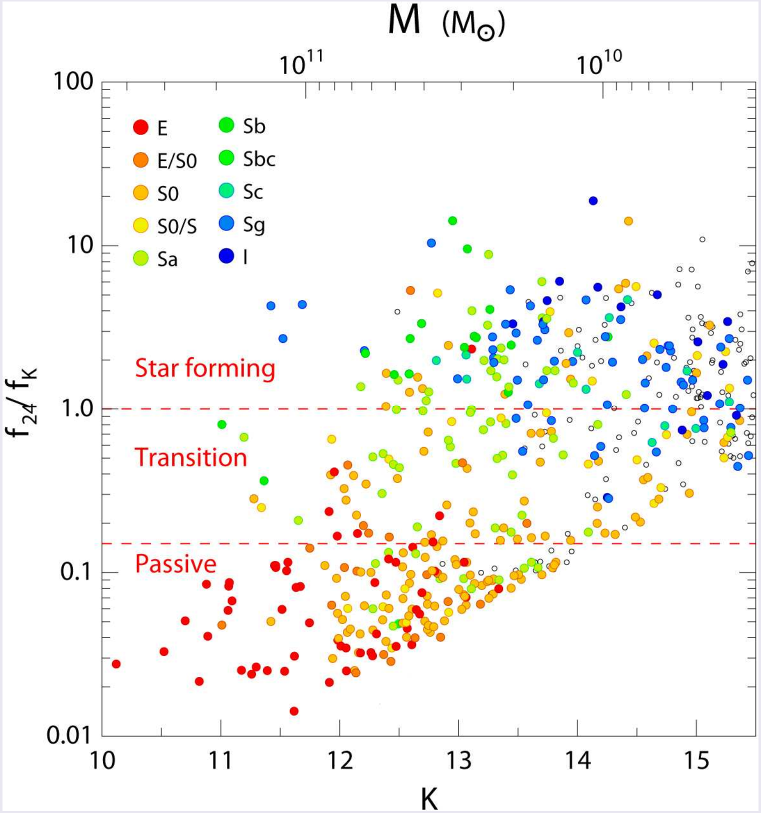
- Star formation is quenched in the outer disc, but may continued normally within the truncation radius.
- 2-3x increase in the dust-to-gas ratio or metallicity

<u>**Morphological quenching (Martig et al. 2009)**</u>
70μm-excess galaxies morphologically S0s: smooth profiles and no spiral arm

Star formation is quenched *after* the morphological transformation

- Morphological transformation makes the gas more stable against fragmentation and collapse into molecular clouds quenching the star formation.
- 24μm emission continues to decline while the interstellar radiation field into the bulge efficiently heats the interstellar dust (70μm emission).

Star-formation quenching vs. morphological transformation



Passive spirals (10% of passive)
~
star-forming early-types (18% of SF)

star formation in cluster galaxies
is quenched both before
and after morphological transformation

transition galaxies:
42% are spirals
58% are early-types

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70μm-excess galaxies reside in the ICM for some time and are not on their first infall

ram pressure stripping and/or morphological quenching

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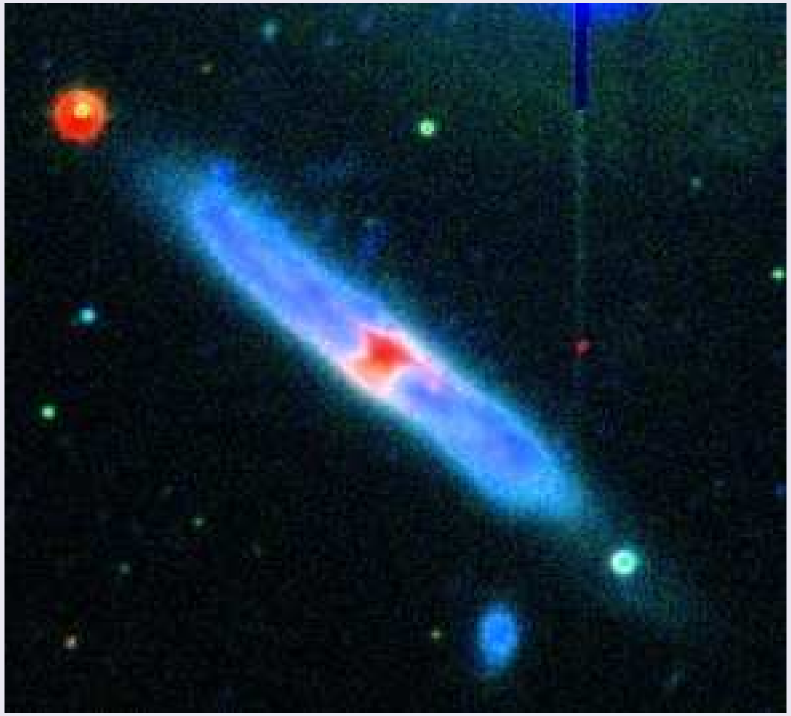
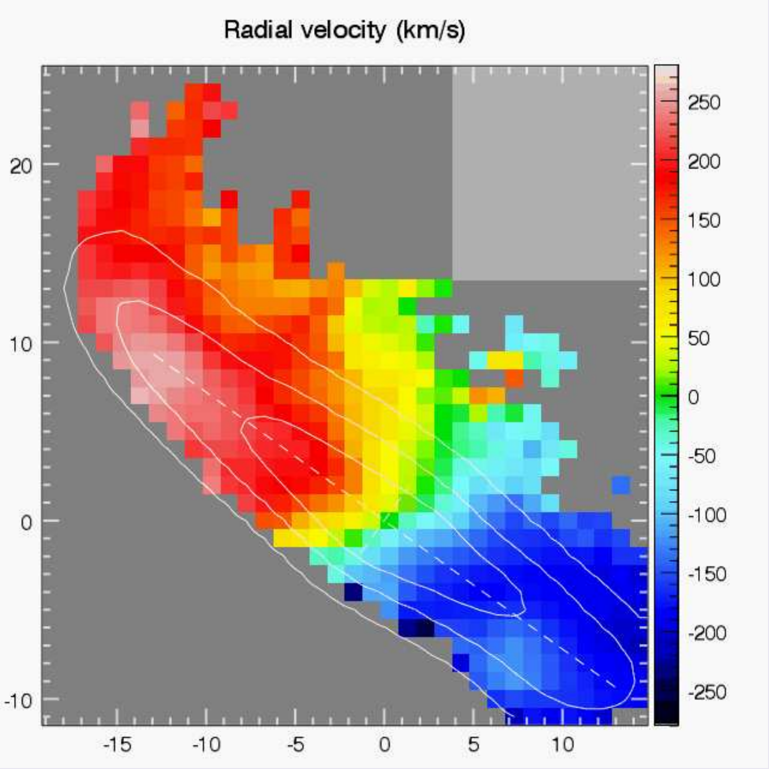
ram pressure stripping and/or morphological quenching

Are they the direct descendants of the dusty starburst and post-starburst L* galaxies abundant in cluster at z~0.4?

SOS 114372



BRK composite image



Gas velocity field

Merluzzi et al. in preparation