Herschel Lensing Survey

Local Cluster Substructure Survey

Far-infrared survey of BCGs with Herschel

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HLS + LoCuSS collaborations

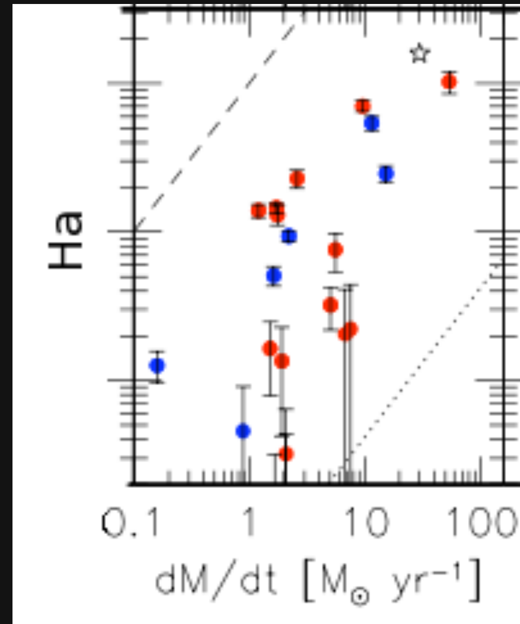
Cool cores and star forming BCGs

- Hot $T \sim 10^7$-10^8 K X-ray emitting gas constitutes the bulk of baryonic matter in rich galaxy clusters
- In central regions, ICM densities and pressures can be sufficiently high that cooling to stellar temperatures occurs on timescales shorter than the cluster lifetime (Cowie & Binney '77, Edge+92)
- X-ray observations fail to find temperatures as low as expected from the inferred mass accretion rates - heating required
  - Solved by AGN feedback - rising bubbles in nearby central galaxies

- The brightest cluster galaxies (BCGs) often lie at the minimum of the cluster potential well
- In contrast to the majority of massive cluster galaxies, some BCGs contain significant cool gas and exhibit signs of star formation
- Cluster cooling could be responsible for star formation in BCGs
- The origin of fuel for star formation is hotly debated with the impact of cooling flows disputed as well as plausible alternate sources presented, e.g. stellar mass loss (Voit & Donahue '11)

Cool cores and star forming BCGs

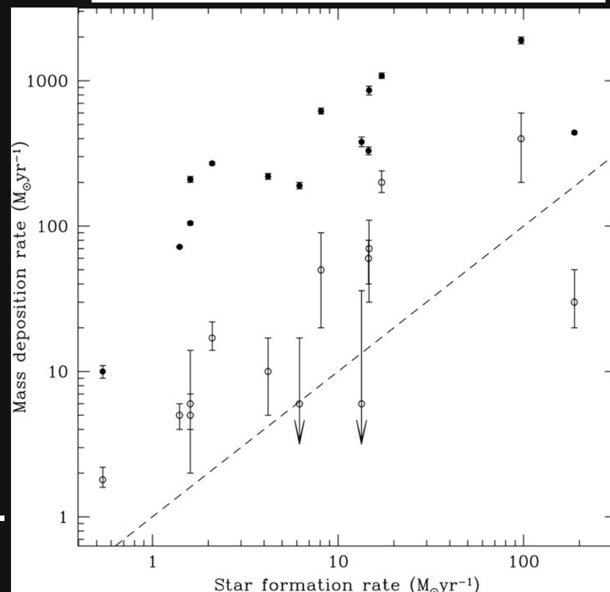
McDonald+10



- BCGs signatures of cool gas and star formation include
  - Optical emission line ratios typical of HII regions (e.g. Crawford+99, Conselice+01)
  - Molecular hydrogen at cool temperatures (via H_2, CO, Hα emission)

    (e.g. Edge+02, Egami+06, Johnstone+07, Cavagnolo+08, Edge+10)
  - Far-infrared dust continuum (obscured star formation), extrapolated from the mid-infrared

    (e.g. Egami+06, Quillen+08, O'Dea+08)
- Molecular line strength (e.g. McDonald+10) and infrared luminosity (e.g. O'Dea+08) correlate with X-ray cooling time (or mass deposition rate)

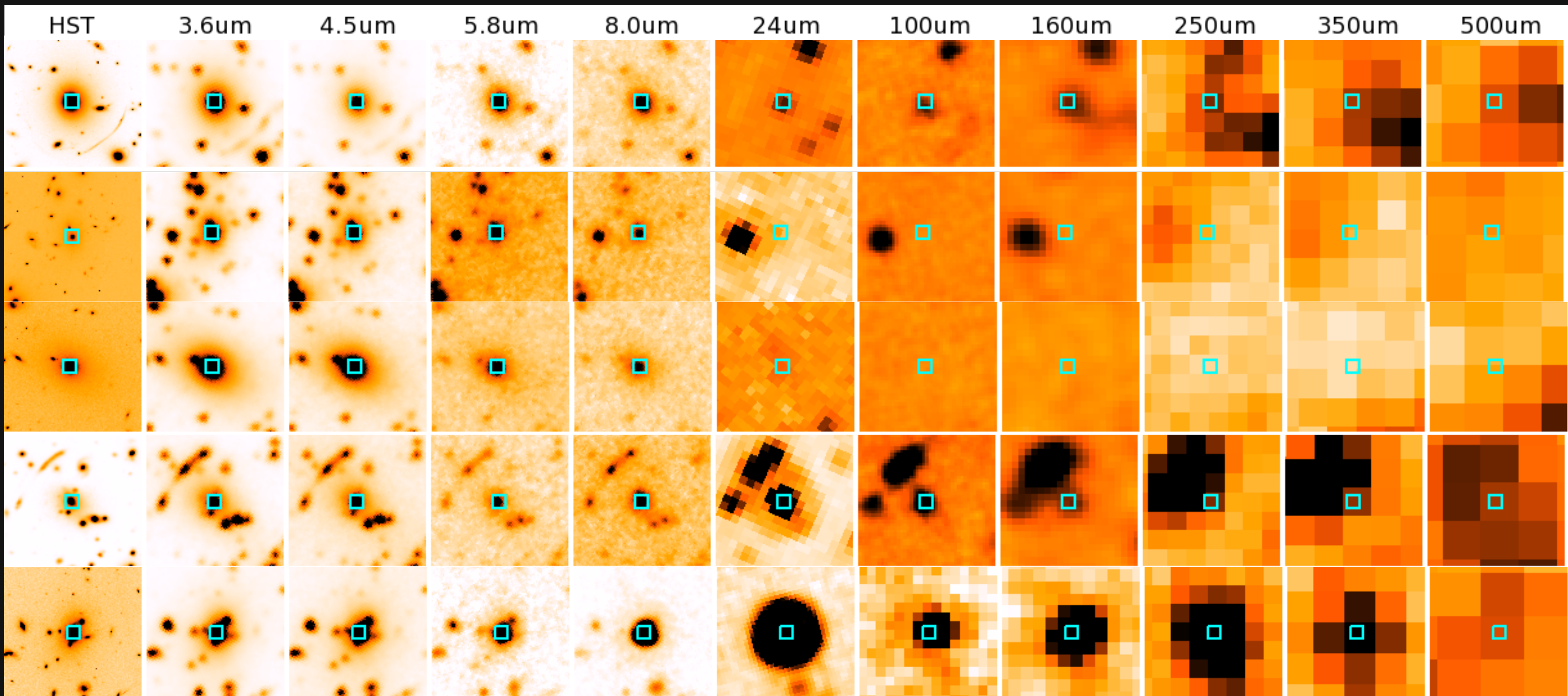


O'Dea+08

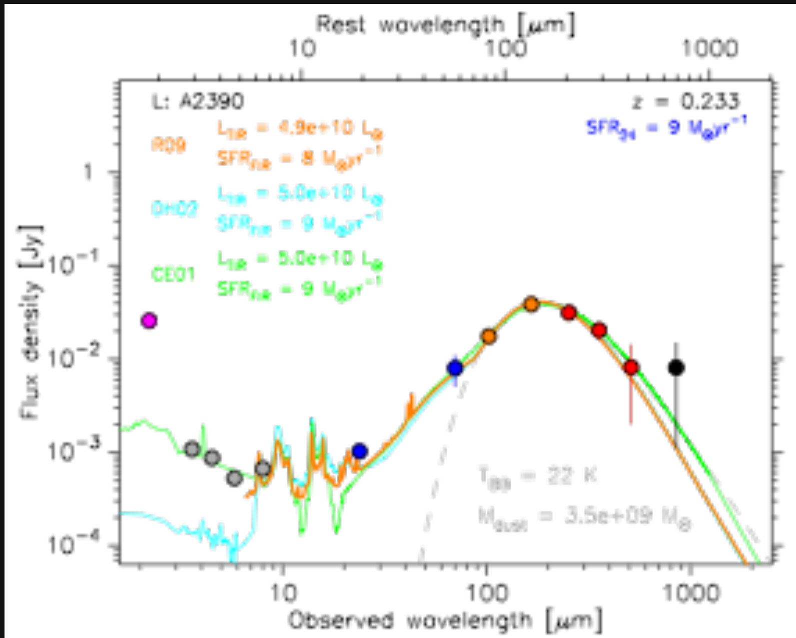
- Until now, far-infrared luminosity has only been measured directly for a small number of BCGs
- Using sensitive Herschel photometry we want to...
  - fully constrain the far-infrared component of BCGs
  - quantify star formation for a large sample

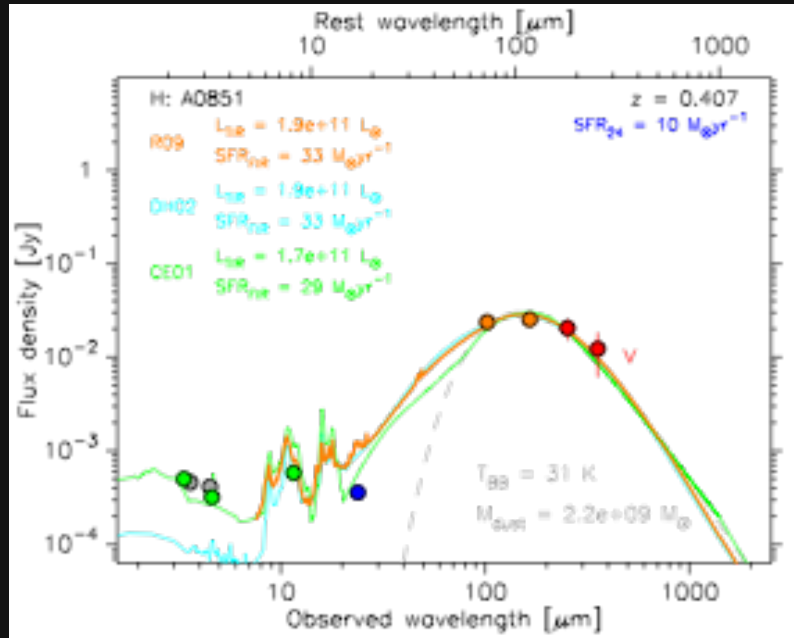
The Herschel BCG sample

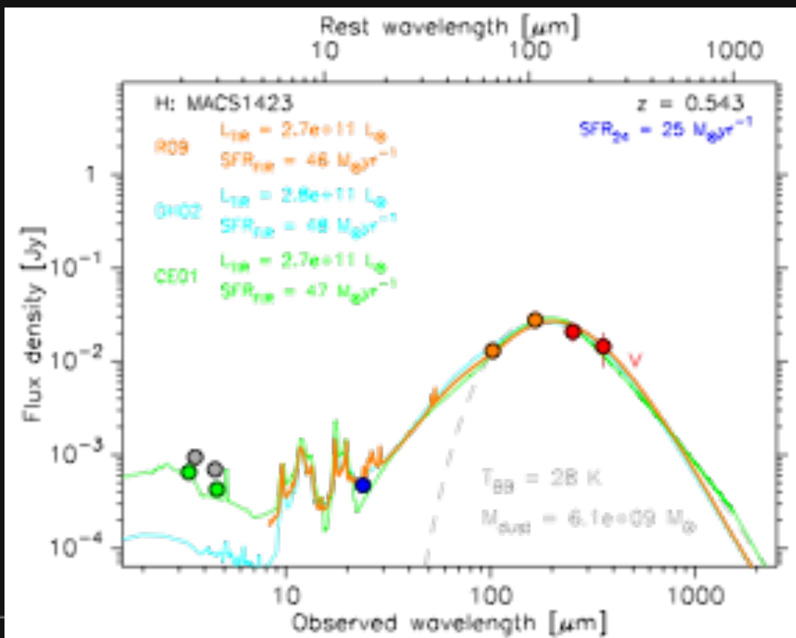
- 46 BCGs in HLS (0.15 < z < 1.0)
- 21 BCGs in LoCuSS (11 also have deeper HLS data) (z ~ 0.2)
- 3 BCGs from Edge+10 (z < 0.3)
- 70 BCGs TOTAL

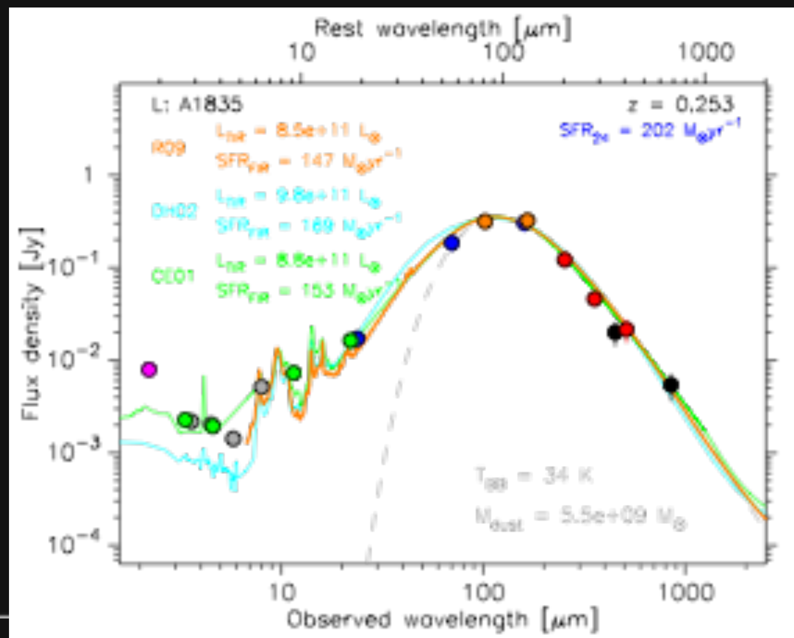


FIR detected BCGs (SEDs)

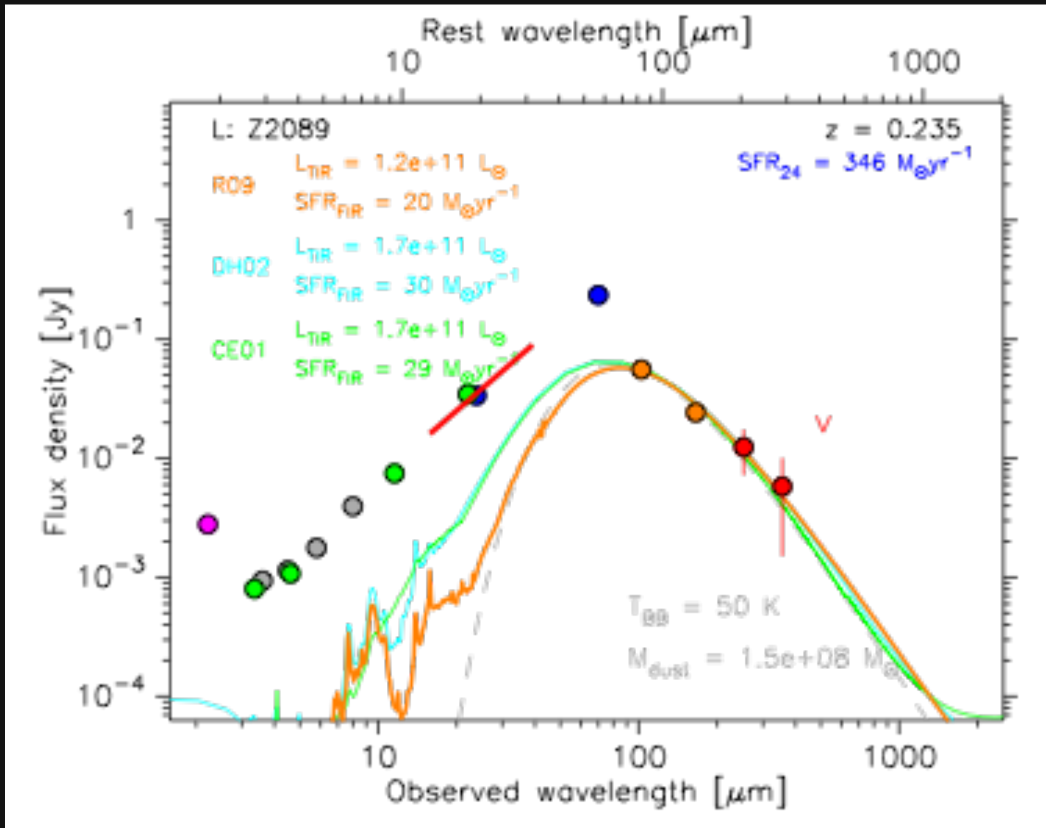


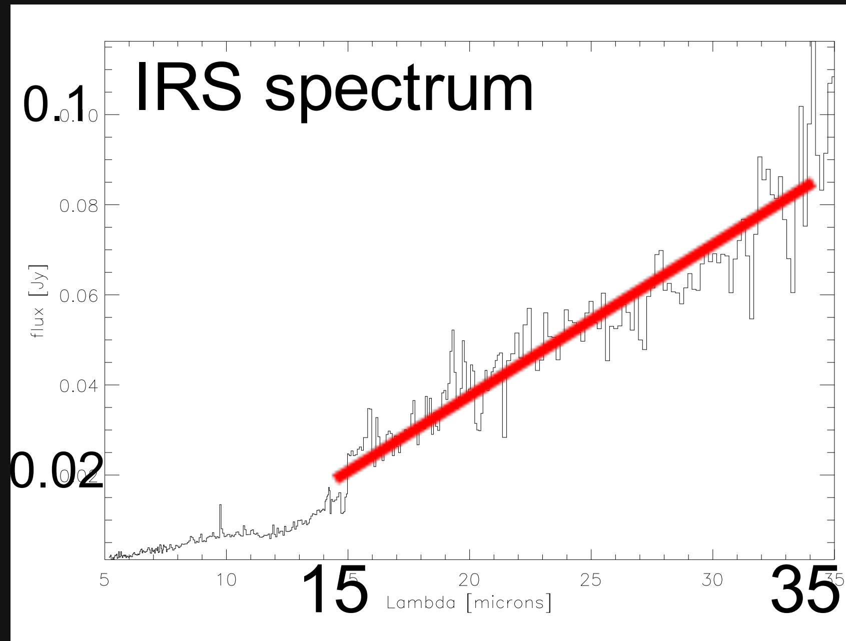






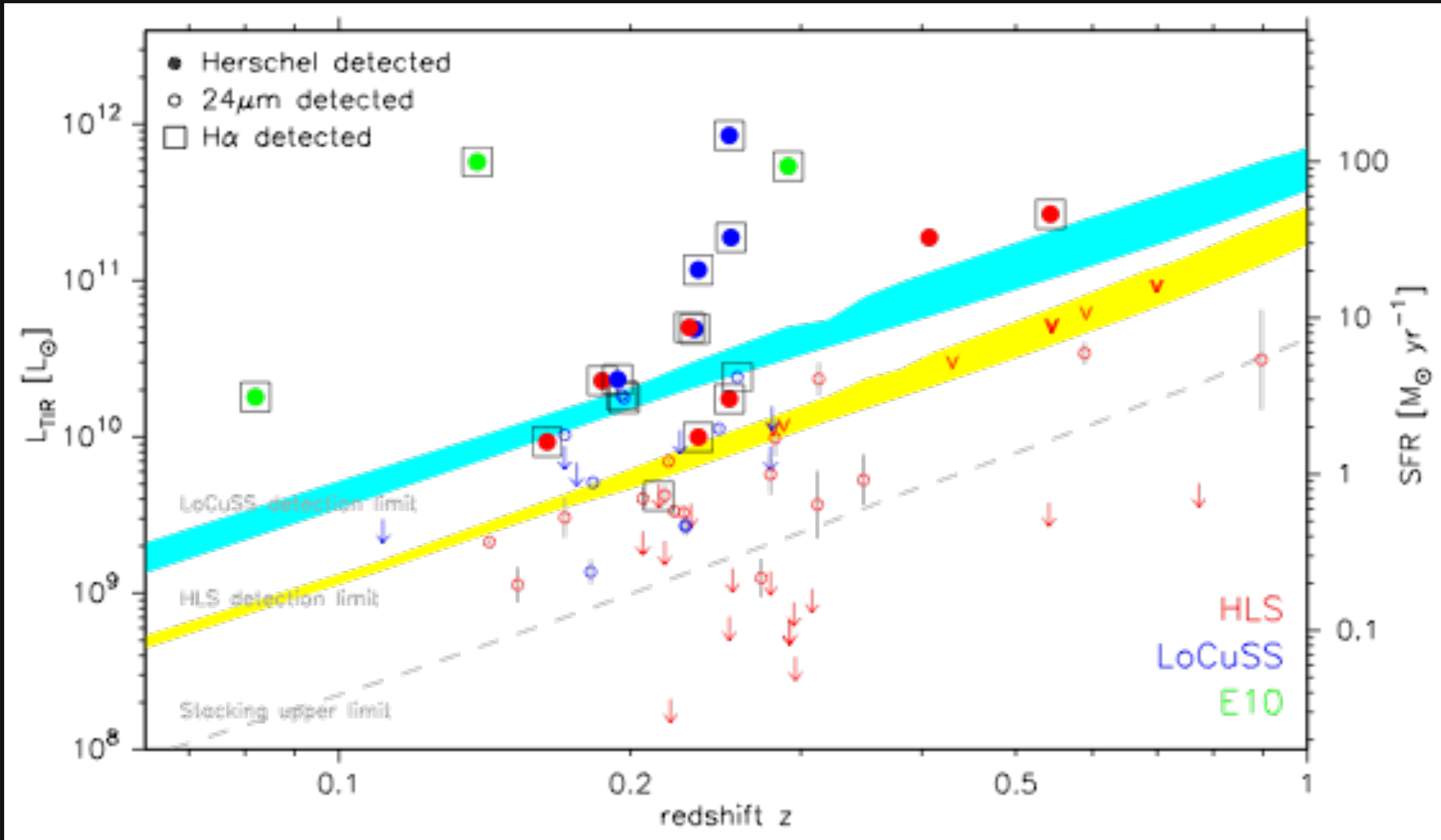
Z2089 - powerful AGN host





- The majority of BCGs do not exhibit the properties of a powerful AGN (e.g. optical lines, X-ray emission, strong MIR continuum)
- AGN feedback is thought to be responsible for reduced cooling in cluster cores
- Short AGN phase in duty cycle - but the scarcity makes further analysis difficult
- PACS 70μm photometry and line spectroscopy to investigate energetics and determine AGN effect on gas within the BCG itself (Z2089 + 3 others; OT2 PI: Edge)

L_{TIR} for the full sample



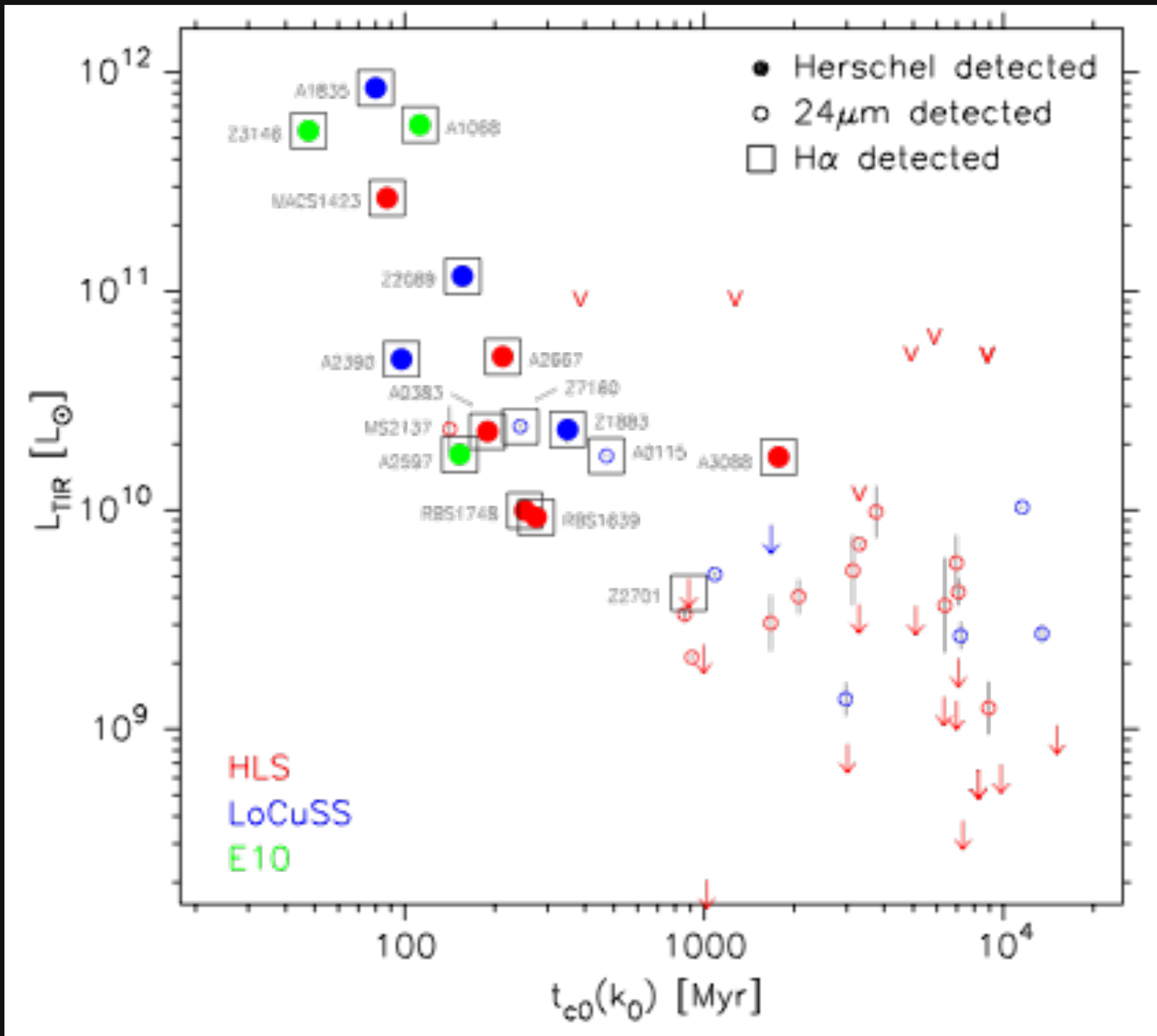
- 22% (15/70) of the BCGs are detected by Herschel (SFR ≳ 2 $M_\odot yr^{-1}$)
- Biased by redshift dependent detection limits and inclusion of Edge+10
- LoCuSS is a volume limited sample selected on X-ray luminosity (Smith+10)

8/32 BCGs detected (25%)

Star formation fueled by cooling ICM?

$$t_{c0}(K_0) \sim 10^8 \mathrm{yrs} \left(\frac{K_0}{10\,\mathrm{keV\,cm^2}} \right)^{3/2} \left(\frac{kT_X}{5\,\mathrm{keV}} \right)^{-1}$$

(Donahue+05)



Entropy profiles from the ACCEPT Chandra archival survey (Cavagnolo+09)

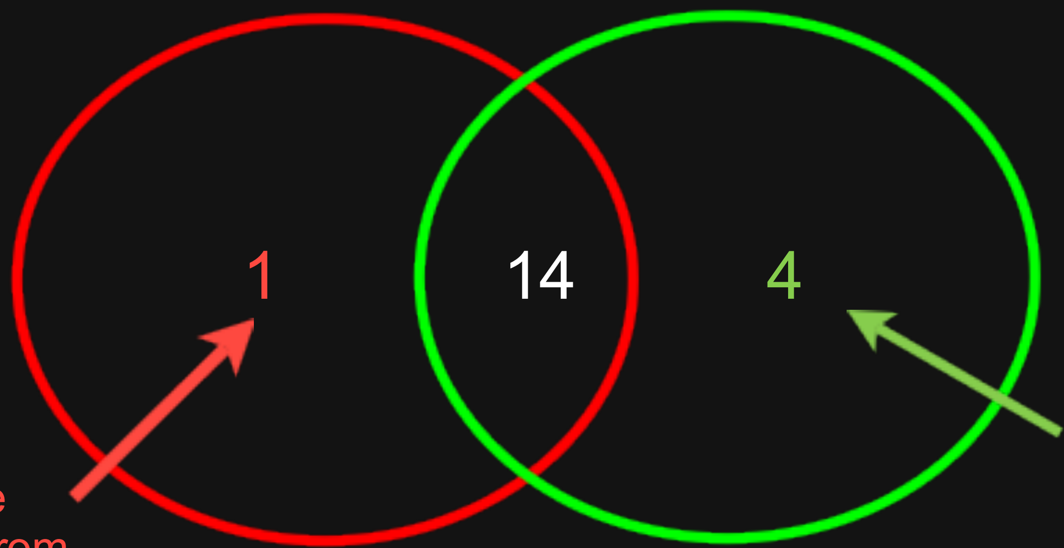
- Tight relation for Herschel detected BCGs and the cooling times
- MS2137 the only BCG undetected by Herschel or Hα with t_{co}<300 Myr (although the 24µm-estimated L_{TIR} matches trend well)

L_{TIR} compared to L(Hα) - qualitative

Total: 70 BCGs (46 HLS + 21 LoCuSS + 3 from Edge)

Herschel detected: 15 BCGs

Hα detected: 18 BCGs



A851 has a large projected offset from X-ray peak (~280 kpc; Bildfell+08)

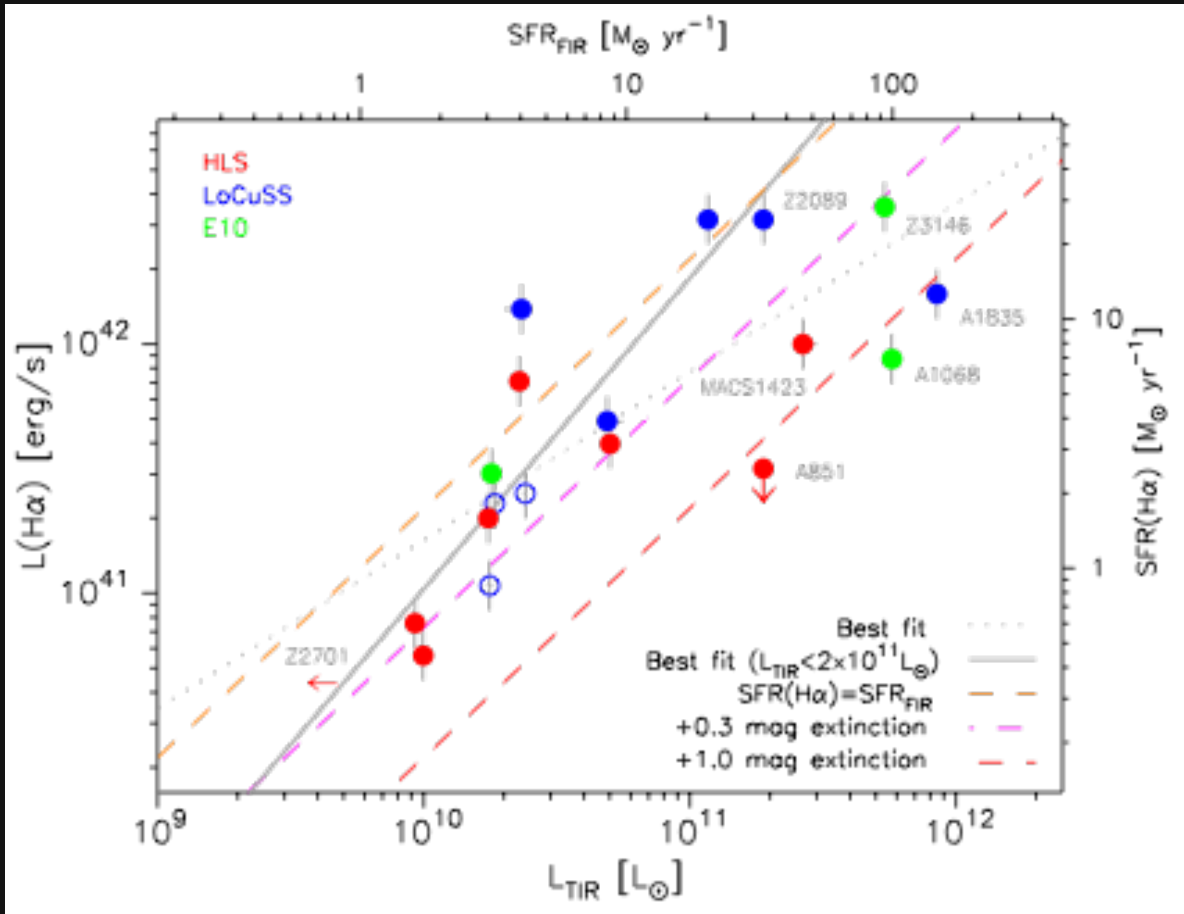
HST imaging shows large tidal tail - galaxy-galaxy interaction rather than cool-core BCG?

51 non detections

3 have 24μm detections which place L_{TIR} just below the LoCuSS Herschel limit

The remaining source (Z2701) has a very low L(Hα)

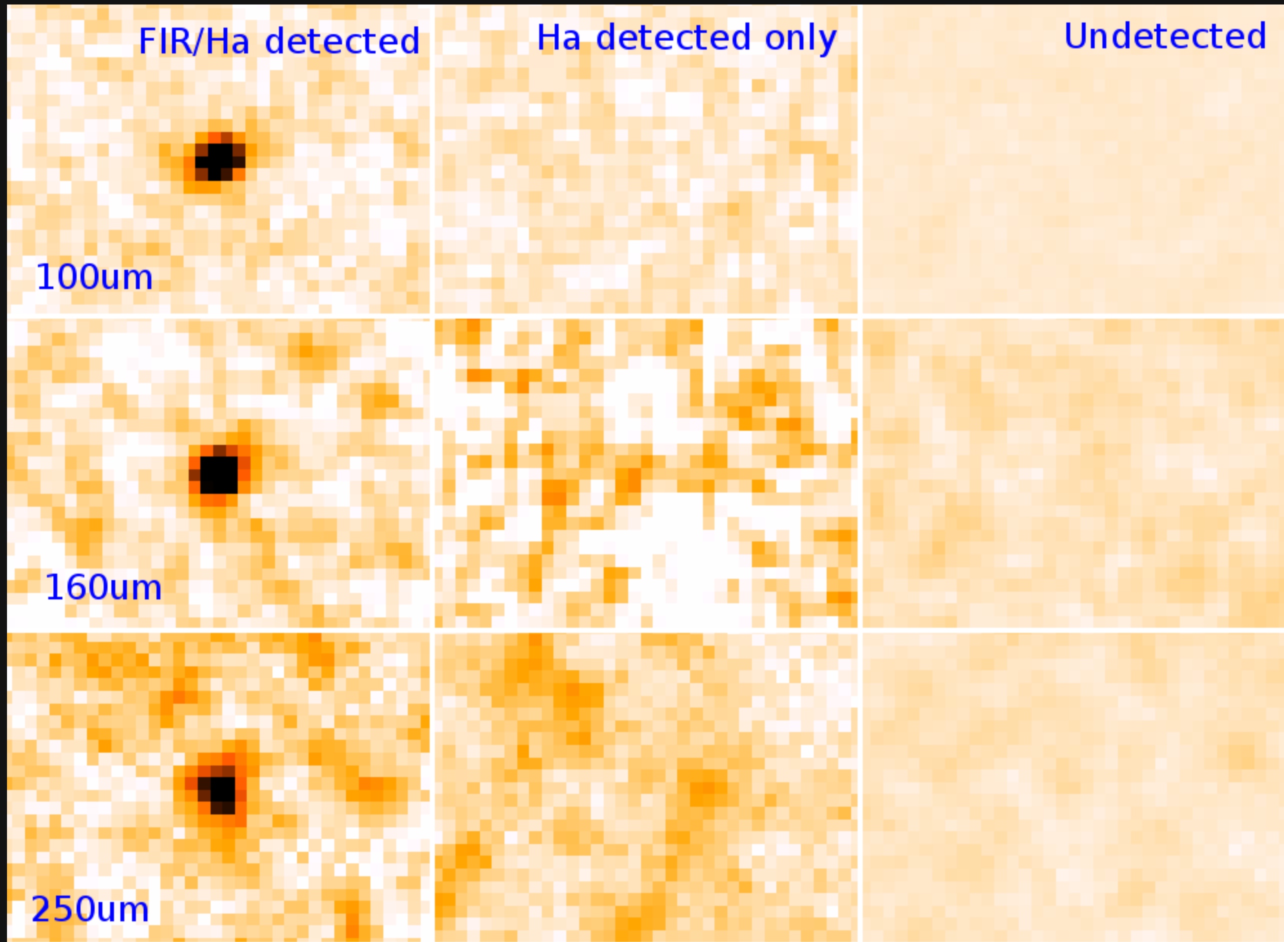
L_{TIR} compared to L(Hα) - quantitative



- L(Hα) uncorrected for reddening
- Low L(Hα) for Z2701 is consistent with Herschel non-detection
- A1068, A1835, Z2089, Z3146 all show signs of sub-dominant AGN (optical, IRS spectra)
- A851 does not lie in the cluster potential well

- Generally, SFR(Hα) and SFR_{FIR} agree with only modest reddening (<0.3mag)
- The most IR-luminous BCGs have the most obscured star-formation (~1 mag reddening) and/or dominant AGN

Stacking analysis

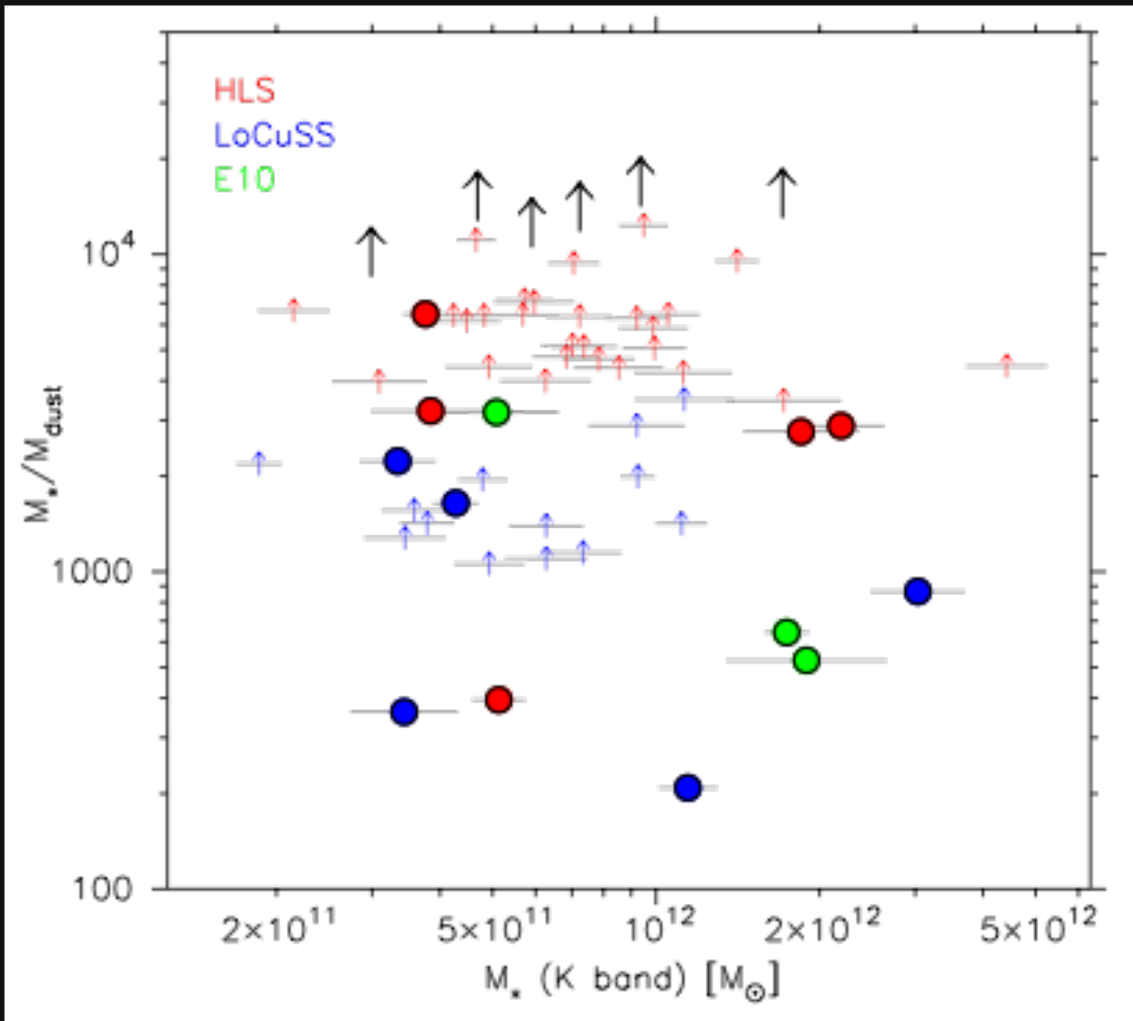


11 BCGs 4 BCGs 51 BCGs

Mean SFR limit for a non-cool-core cluster BCG at…

- z=0.2: SFR < 0.17 $M_{\odot}yr^{-1}$
- z=0.3: SFR < 0.42 $M_{\odot}yr^{-1}$

Stellar-to-dust mass ratio



$$M_{\mathrm{dust}} = \frac{4\pi D^2 f_{500}}{\kappa_{\mathrm{abs}} 4\pi B_\lambda(T_{\mathrm{dust}})}$$

$\kappa_{abs} = 0.95\ cm^2\ g^{-1}$

(Draine+05)

$$\log(M/L_K) = (-0.27 \pm 0.03)z - (0.05 \pm 0.03)$$

(Arnouts+07)

- Black arrows show binned (stacked) limit for non-Herschel detected BCGs at fixed stellar mass
- If stellar mass loss, rather than cooling cluster gas, fuels star formation, M_*/M_{dust} would vary with M_* (unless triggered, but not fueled, by cluster processes)

Summary

- Herschel 5-band photometry of 70 BCGs to constrain the far-infrared dust component and hence star formation
- 15/70 (22%) are detected by Herschel (SFR > 2 $M_\odot yr^{-1}$)
- L_{TIR} for FIR-bright BCGs are well correlated with cluster X-ray cooling time - circumstantial evidence that cool gas in the cluster fuels star formation in the BCG
- Stacking Herschel images for BCGs undetected in FIR reveals that the mean non-cool-core cluster BCG at z=0.2 has SFR < 0.17 $M_\odot yr^{-1}$
- FIR and Hα correspond well, with only moderate reddening required to correct Hα for obscuration (generally <0.3 mag)
- The most IR-luminous BCGs (L_{TIR} > 2x10^{11} $L_\odot$) have the most obscured star-formation (~1 mag reddening required for Hα) and/or dominant AGN

Coming soon - Rawle et al Herschel BCG paper on a pre-print archive near you