Build up of Stellar Mass in Cluster Cores

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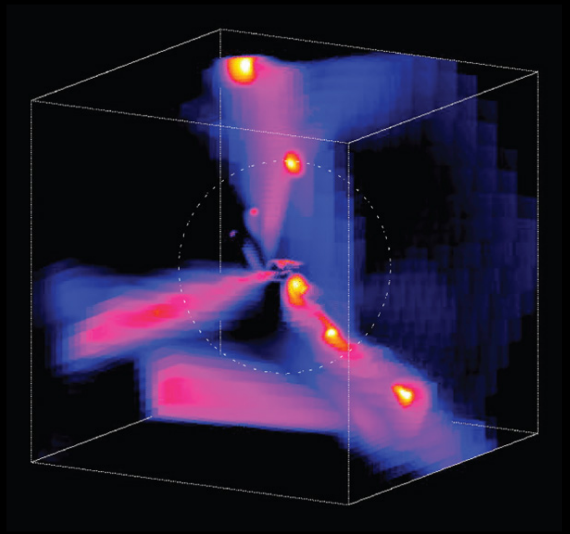
Overview

Plea for LSS All-Sky Working Group

How do cluster properties relate to the stellar content in cluster cores?

What is the evolutionary history of
(i) BCGs (ii) companion galaxies and (iii) ICL?

And can we make a consistent picture

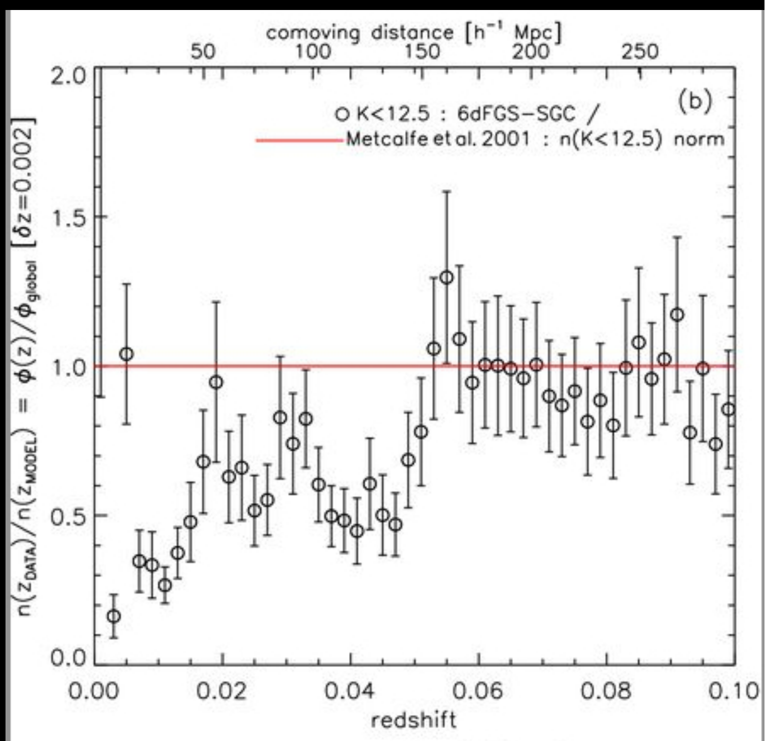


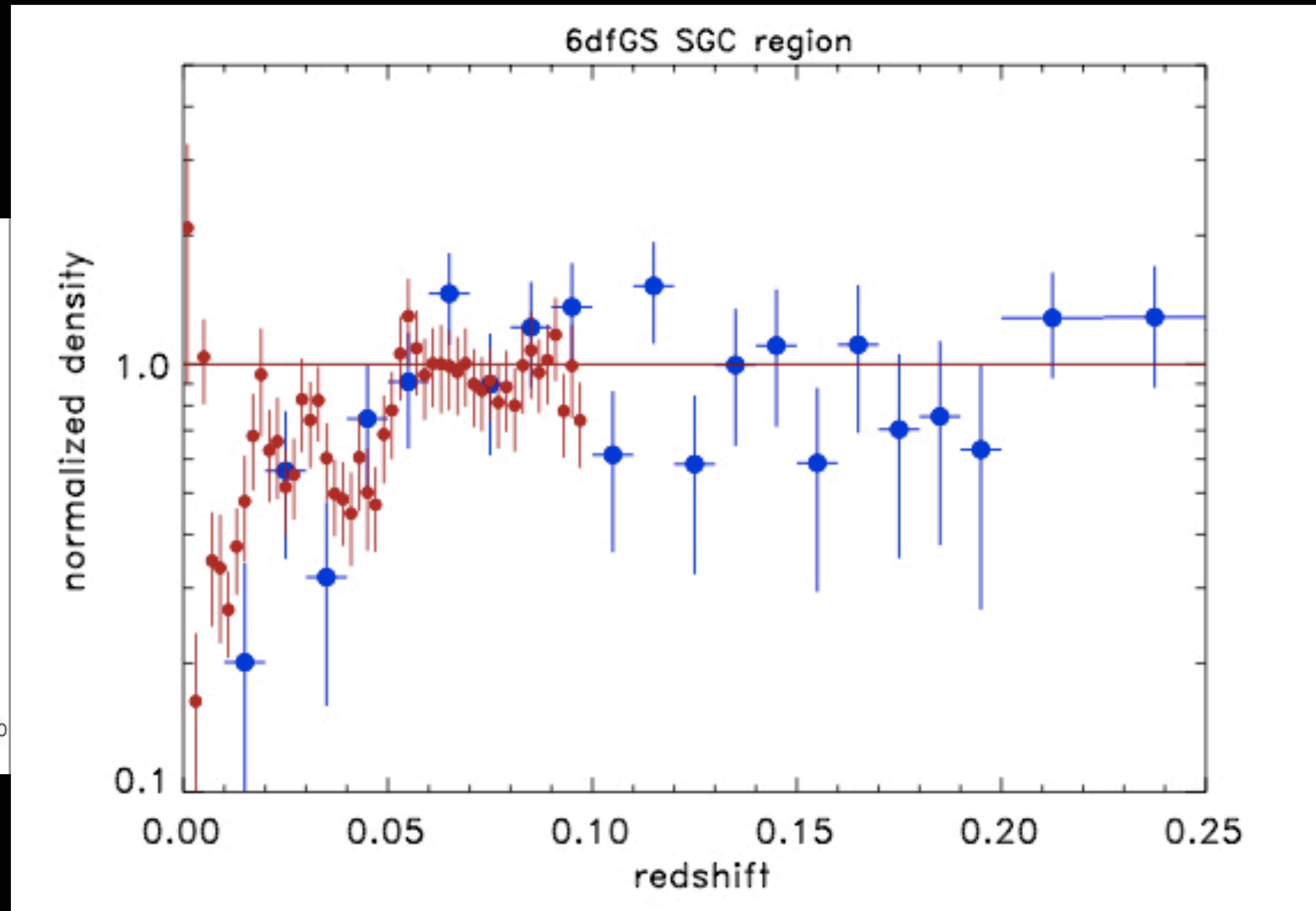
SPIDERS and LSST

eROSITA Clusters and Large-Scale Structure

- e.g. Presence of local and super voids probe cosmological parameters, neutrino mass, non-standard cosmologies etc…
- ASTRONET 2008: 20 year vision for European Science

Comparison of REFLEX II with galaxies at the SGC

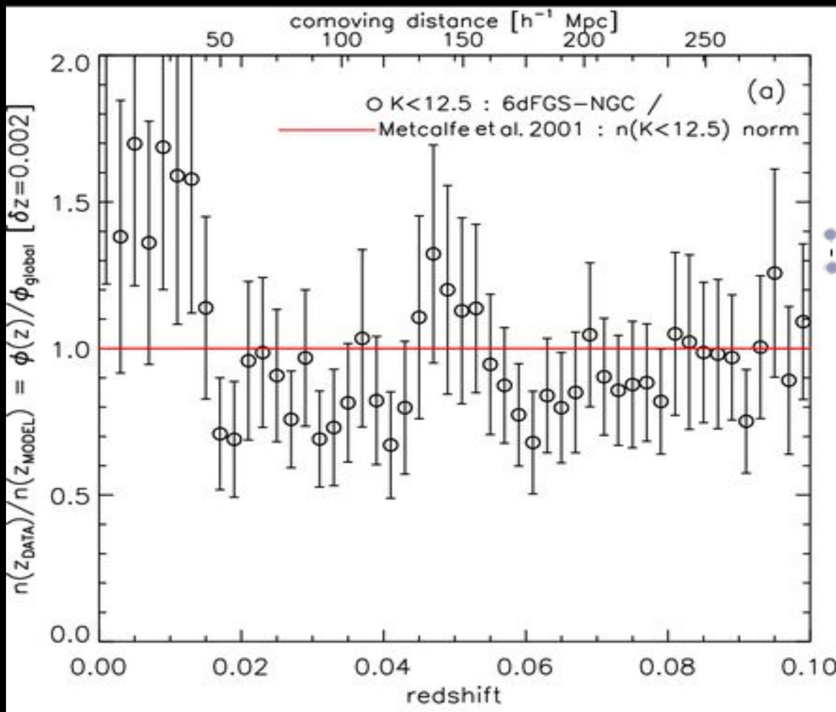




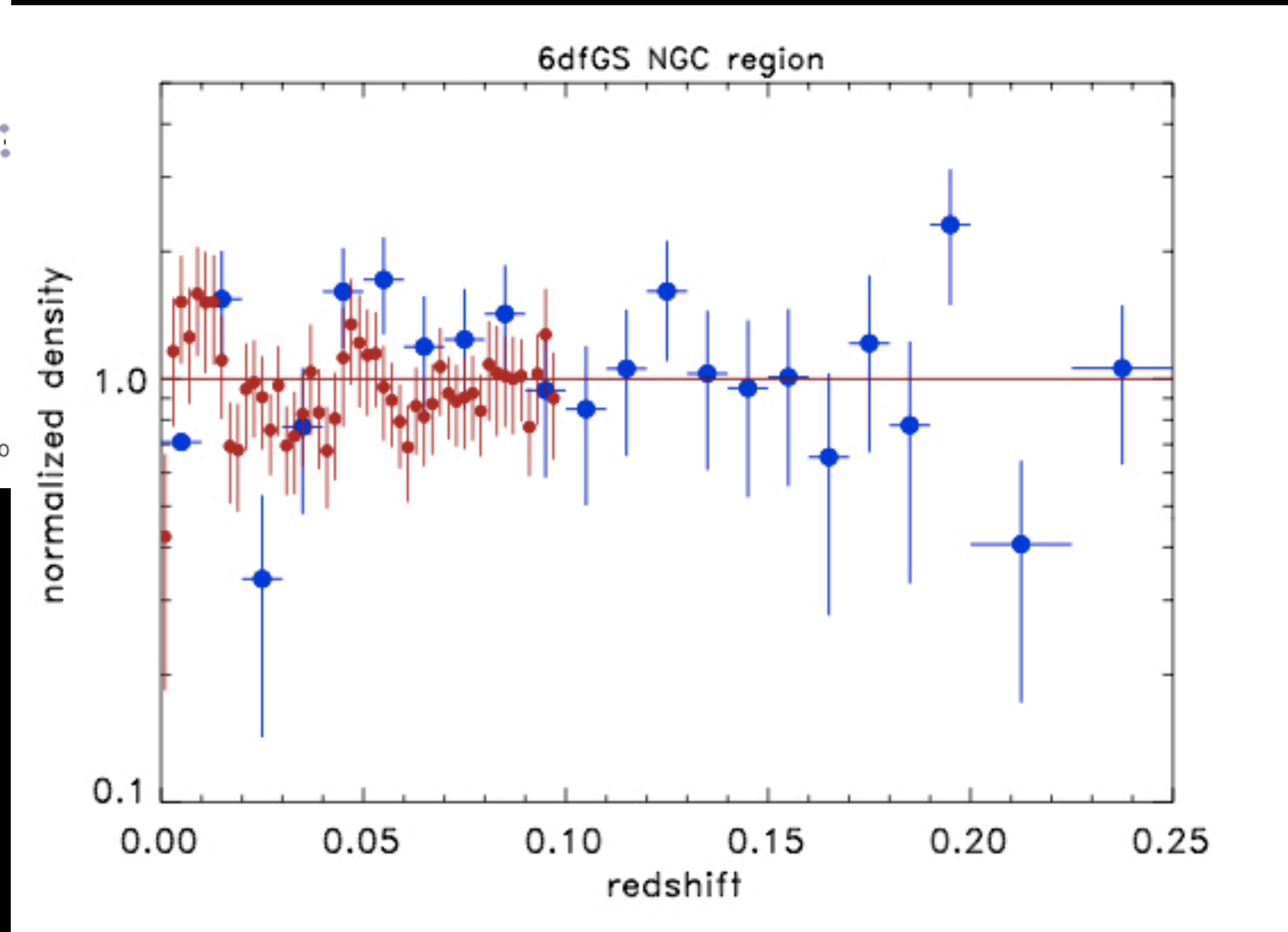
Whitbourn & Shanks data also shown

Field	Redshift limit	Underdensity	
6FGS-SGC	$z < 0.05$	0.60 ± 0.05 W&S	0.45 ± 0.10 REFLEX II
6FGS-SGC	$z < 0.1$	0.75 ± 0.04 W&S	0.84 ± 0.09 REFLEX II

Comparison of REFLEX II with galaxies at the NGC



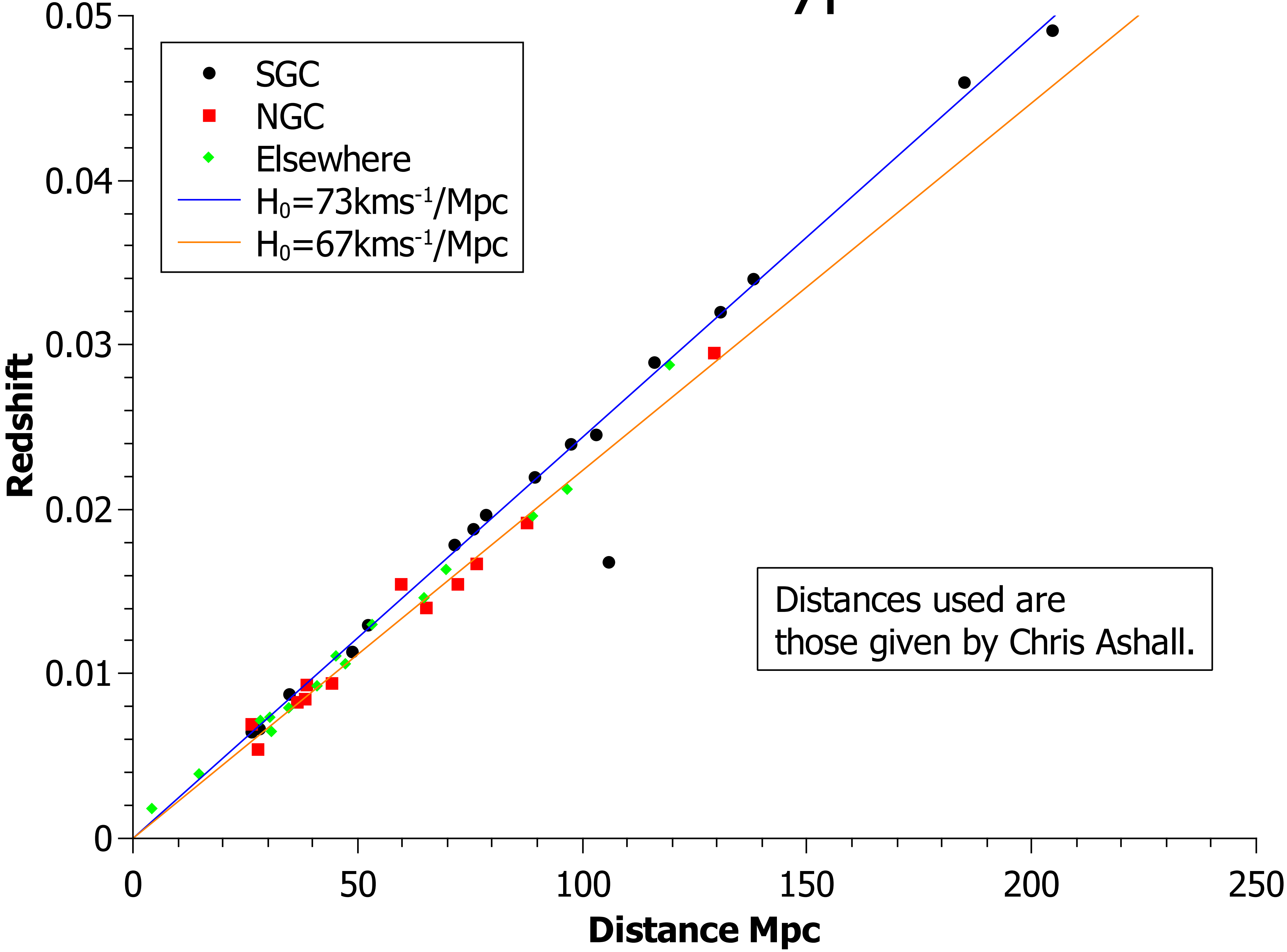
z limit	SGC	NGC
0.02	0.17(±0.12)	1.41(±0.41)
0.03	0.37(±0.12)	0.86(±0.22)
0.04	0.35(±0.10)	0.83(±0.18)
0.05	0.45(±0.10)	1.02(±0.17)
0.06	0.54(±0.09)	1.15(±0.16)
0.07	0.69(±0.10)	1.16(±0.15)
0.08	0.72(±0.09)	1.17(±0.14)
0.10	0.84(±0.09)	1.18(±0.12)



Whitbourn & Shanks data also shown

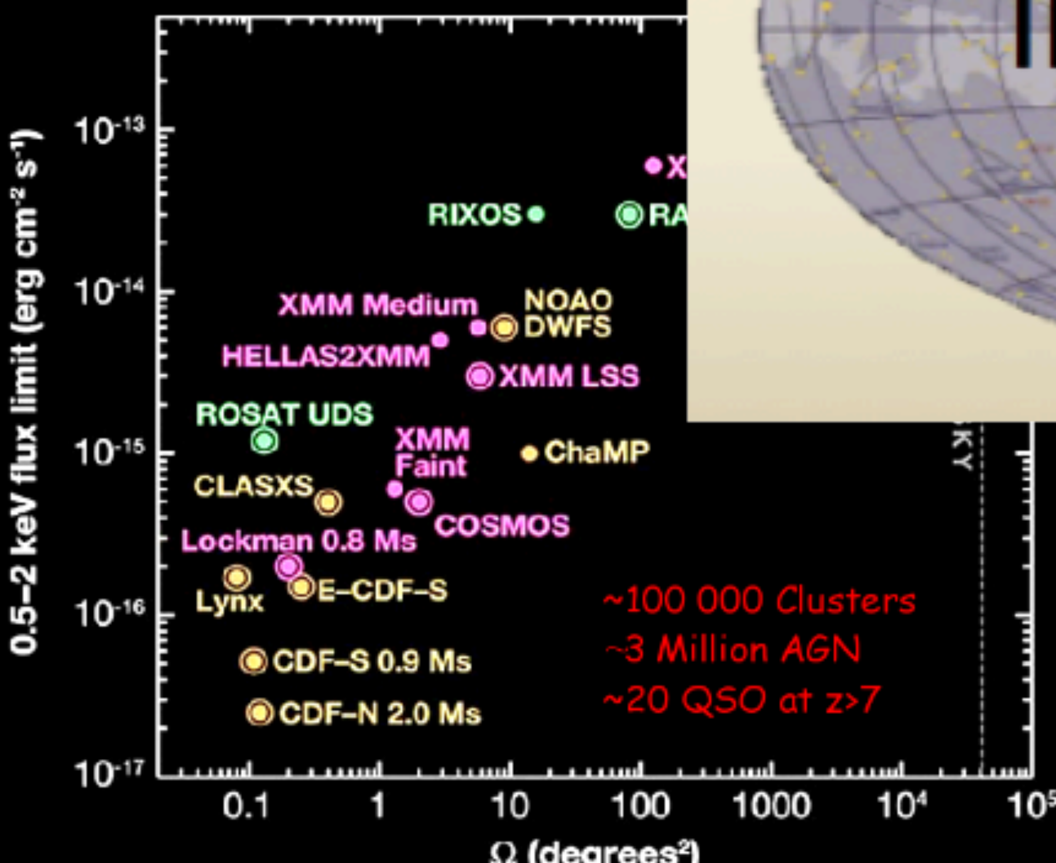
Field	Redshift limit	Underdensity	
6FGS-NGC	$z < 0.05$	0.96 ± 0.10 W&S	1.02 ± 0.17 REFLEX II
6FGS-NGC	$z < 0.1$	0.94 ± 0.07 W&S	1.18 ± 0.12 REFLEX II

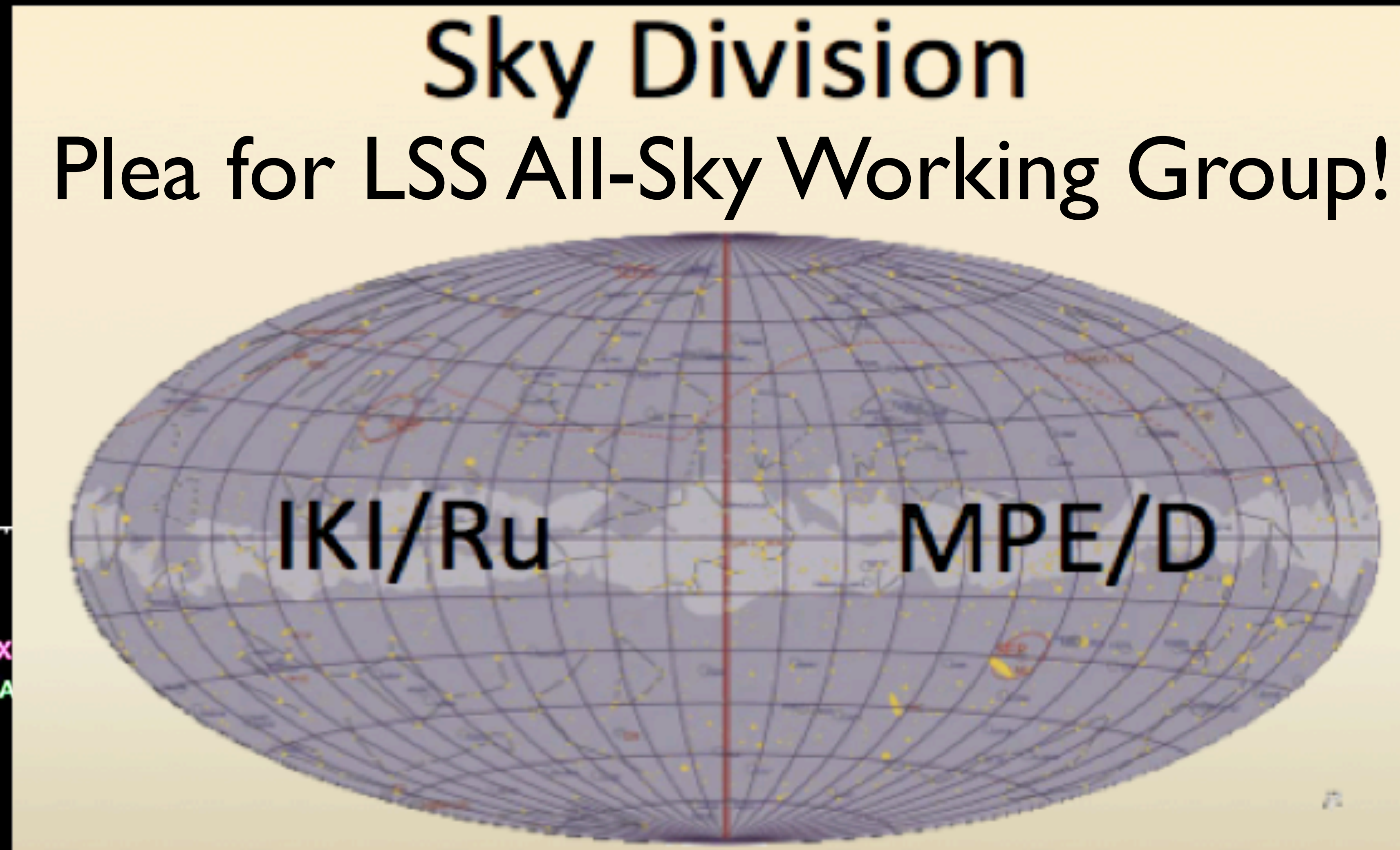
Potential Importance: tension in Local/Global Hubble Constant From SNe Type 1A

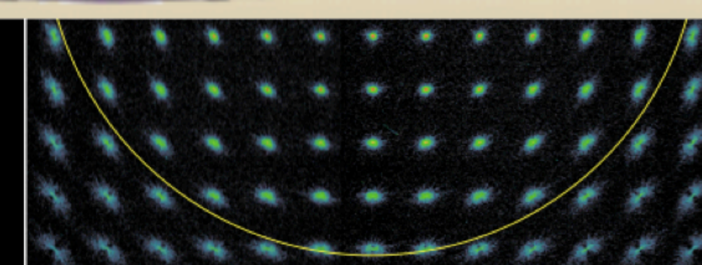


Future Prospects

- eROSITA







Energy 0.5 - 10 keV; FoV 0.8 deg;
PSF ~15 arc sec on axis (28 for survey)

All-Sky Survey (4 yrs) – 30 x deeper than ROSAT, DE probe + baryon physics;
100,000 clusters out to z~1.5 (inc. essentially all massive clusters in the Universe)

Sample 1:

BC 13

20 High z X-ray Selected BCGs (e.g. XCS)

X-ray luminous clusters

HST (ACS, WPFC2);

HAWK-I VLT

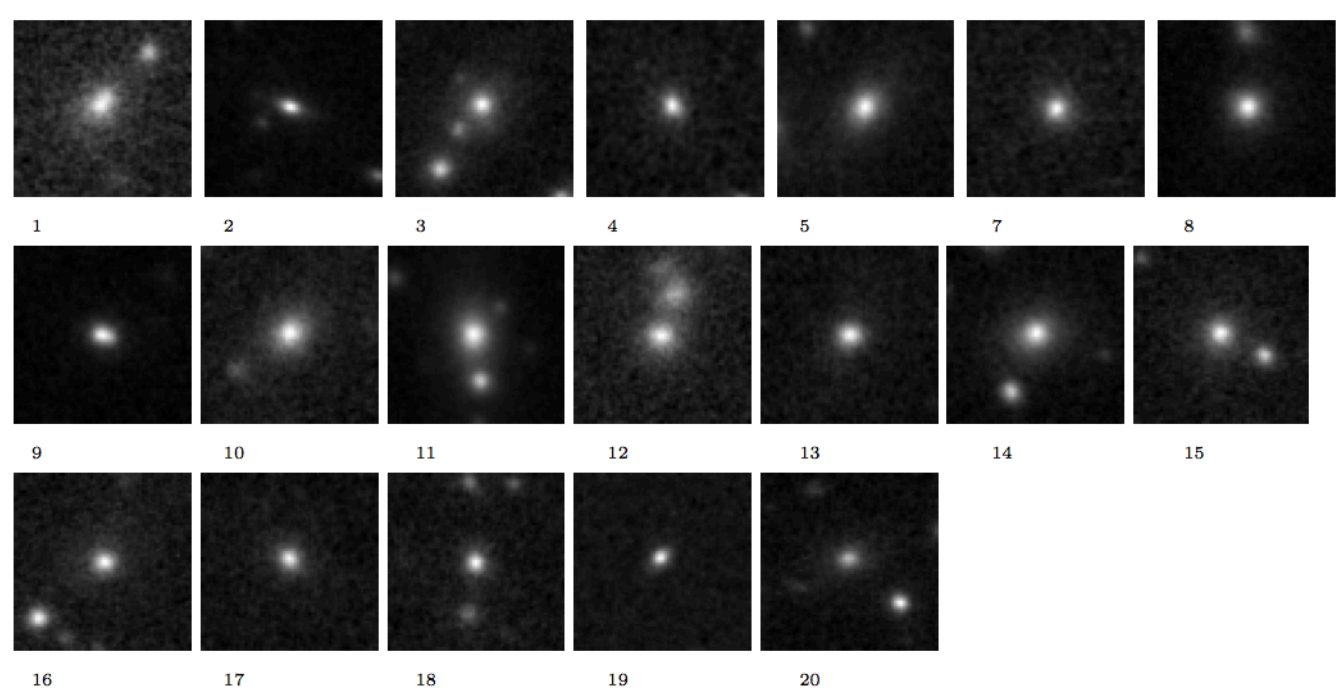
3-4 hrs, J=1.2μm

SB 24.4 mag arcsec^{-2}

TABLE 1

THE CLUSTER SAMPLE

Cluster	R.A. (J2000)	Dec. (J2000)	z	T_X keV	Cluster Mass $10^{14}M_\odot$	BCG m_{K_s}	BCG Stel. Mass[a] $10^{12}M_\odot$
1. CL J0152.7-1357	01h52m41s	-13d57m45s	0.83	$5.4^{+0.9}_{-0.9}$	$4.5^{+2.7}_{-2.2}$	16.96±0.08	0.58±0.11
2. XLSS J022303.0 − 043622[b]	02h23m53.9s	-04d36m22s	1.22	$3.5^{+0.4}_{-0.4}$	$1.8^{+0.9}_{-0.7}$	17.72±0.01	0.61±0.08
3. XLSS J022400.5 − 032526[b]	02h24m00s	-03d25m34s	0.81	$3.6^{+0.4}_{-0.4}$	$2.3^{+1.4}_{-0.8}$	16.49±0.10	0.85±0.18
4. RCS J0439 − 2904	04h39m38s	-29d04m55s	0.95	$1.5^{+0.3}_{-0.2}$	$0.5^{+0.4}_{-0.2}$	17.70±0.08	0.40±0.07
5. 2XMM J083026 + 524133	08h30m25.9s	52d41m33s	0.99	$8.2^{+0.9}_{-0.9}$	$8.5^{+4.1}_{-3.4}$	16.58±0.05	1.24±0.22
6. RX J0848.9 + 4452[c]	08h48m56.3s	44d52m16s	1.26	$6.2^{+1.0}_{-0.9}$	$4.7^{+2.8}_{-2.0}$	17.00±0.02	1.30±0.15
7. RDCS J0910 + 5422	09h10m44.9s	54d22m09s	1.11	$6.4^{+1.5}_{-1.2}$	$5.3^{+4.1}_{-2.5}$	17.88±0.05	0.48±0.08
8. CL J1008.7 +5342	10h08m42s	53d42m00s	0.87	$3.6^{+0.8}_{-0.6}$	$2.2^{+1.6}_{-1.0}$	16.42±0.08	1.06±0.21
9. RX J1053.7 + 5735 (West)	10h53m39.8s	57d35m18s	1.14	$4.4^{+0.3}_{-0.3}$	$2.7^{+1.4}_{-1.0}$	17.21±0.06	1.03±0.19
10. MS1054.4 − 0321	10h57m00.2s	-03d37m27s	0.82	$7.8^{+1.0}_{-0.9}$	$8.5^{+4.9}_{-3.2}$	16.04±0.10	1.35±0.29
11. CL J1226 + 3332	12h26m58s	33d32m54s	0.89	$10.6^{+1.1}_{-1.1}$	$13.9^{+6.6}_{-5.4}$	16.00±0.06	1.66±0.31
12. RDCS J1252.9 − 2927	12h52m54.4s	-29d27m17s	1.24	$7.2^{+0.4}_{-0.6}$	$6.1^{+2.3}_{-2.4}$	17.36±0.03	0.89±0.11
13. RDCS J1317 + 2911	13h17m21.7s	29d11m18s	0.81	$4.0^{+1.3}_{-0.8}$	$2.7^{+2.9}_{-1.3}$	17.27±0.15	0.41±0.10
14. WARPS J1415.1 + 3612	14h15m11.1s	36d12m03s	1.03	$6.2^{+0.8}_{-0.7}$	$5.2^{+2.9}_{-1.9}$	16.76±0.04	1.15±0.19
15. CL J1429.0 + 4241	14h29m06.4s	42d41m10s	0.92	$6.2^{+1.5}_{-1.0}$	$5.5^{+5.3}_{-2.0}$	17.43±0.20	0.47±0.13
16. CL J1559.1 + 6353	15h59m06s	63d52m60s	0.85	$4.1^{+1.4}_{-1.0}$	$2.8^{+3.2}_{-1.5}$	17.21±0.09	0.49±0.10
17. CL 1604+4304	16h04m25.2s	43d04m53s	0.90	$2.5^{+1.1}_{-0.7}$	$1.2^{+1.6}_{-0.6}$	17.61±0.09	0.38±0.07
18. RCS J162009 + 2929.4	16h20m09.4s	29d29m26s	0.87	$4.6^{+2.1}_{-1.1}$	$3.4^{+5.5}_{-1.4}$	17.63±0.12	0.35±0.07
19. XMMXCS J2215.9 1738[d]	22h15m58.5s	-17d38m03s	1.46	$4.1^{+0.6}_{-0.9}$	$2.1^{+1.9}_{-0.8}$	18.72±0.01	0.39±0.05
20. XMMU J2235.3 − 2557	22h35m20.6s	-25d57m42s	1.39	$8.6^{+1.3}_{-1.2}$	$7.7^{+4.4}_{-3.1}$	17.34±0.01	1.26±0.14



Z= 0.8 – 1.5

Sample 2: 23 CLASH Clusters

Cluster	z	Observed waveband for ICL measurement	$M_{ev}(z) - M_{rf}(z)$	dK	Surface brightness dimming correction $2.5\log(1+z)^3$	Corrected surface brightness equivalent to 25 mag/arcsec^2 at $z = z$(cluster)
Abell 383	0.187	F606W	-0.68	-0.49	0.56	25.06
Abell 209	0.206	F606W	-0.62	-0.41	0.61	25.20
Abell 1423	0.213	F606W	-0.55	-0.34	0.63	25.29
Abell 2261	0.224	F606W	-0.55	-0.33	0.66	25.33
RXJ2129+0005	0.234	F606W	-0.44	-0.21	0.68	25.48
Abell 611	0.288	F606W	-0.39	-0.11	0.82	25.71
MS 2137-2353	0.313	F606W	-0.27	0.03	0.89	25.91
RXJ1532+30	0.345	F606W	-0.20	0.12	0.97	26.09
RXJ2248-4431	0.348	F606W	-0.20	0.13	0.97	26.10
MACSJ1115+01	0.352	F606W	-0.20	0.13	0.98	26.11
MACSJ1720+35	0.391	F625W	-0.23	0.13	1.07	26.21
MACSJ0416-24	0.396	F625W	-0.23	0.14	1.09	26.22
MACSJ0429-02	0.399	F625W	-0.23	0.14	1.09	26.23
MACSJ1206-08	0.440	F625W	-0.01	0.39	1.19	26.58
MACSJ0329-02	0.450	F625W	-0.01	0.40	1.21	26.61
RXJ1347-1145	0.451	F625W	-0.01	0.40	1.21	26.61
MACSJ1311-03	0.494	F625W	0.25	0.69	1.31	27.00
MACSJ1149+22	0.544	F625W	0.49	0.96	1.41	27.37
MACSJ1423+24	0.545	F775W	-0.78	-0.30	1.42	26.11
MACSJ2129-07	0.570	F775W	-0.73	-0.24	1.47	26.23
MACSJ0647+70	0.584	F775W	-0.68	-0.18	1.5	26.31
MACSJ0744+39	0.686	F775W	-0.50	0.07	1.7	26.77
CLJ1226+3332	0.890	F850LP	-0.89	-0.20	2.07	26.88

$0.18<z<0.89, T_x > 5$ keV

16 Band HST photometry

SB 26 - 27 mag arcsec^{-2}

(B band)

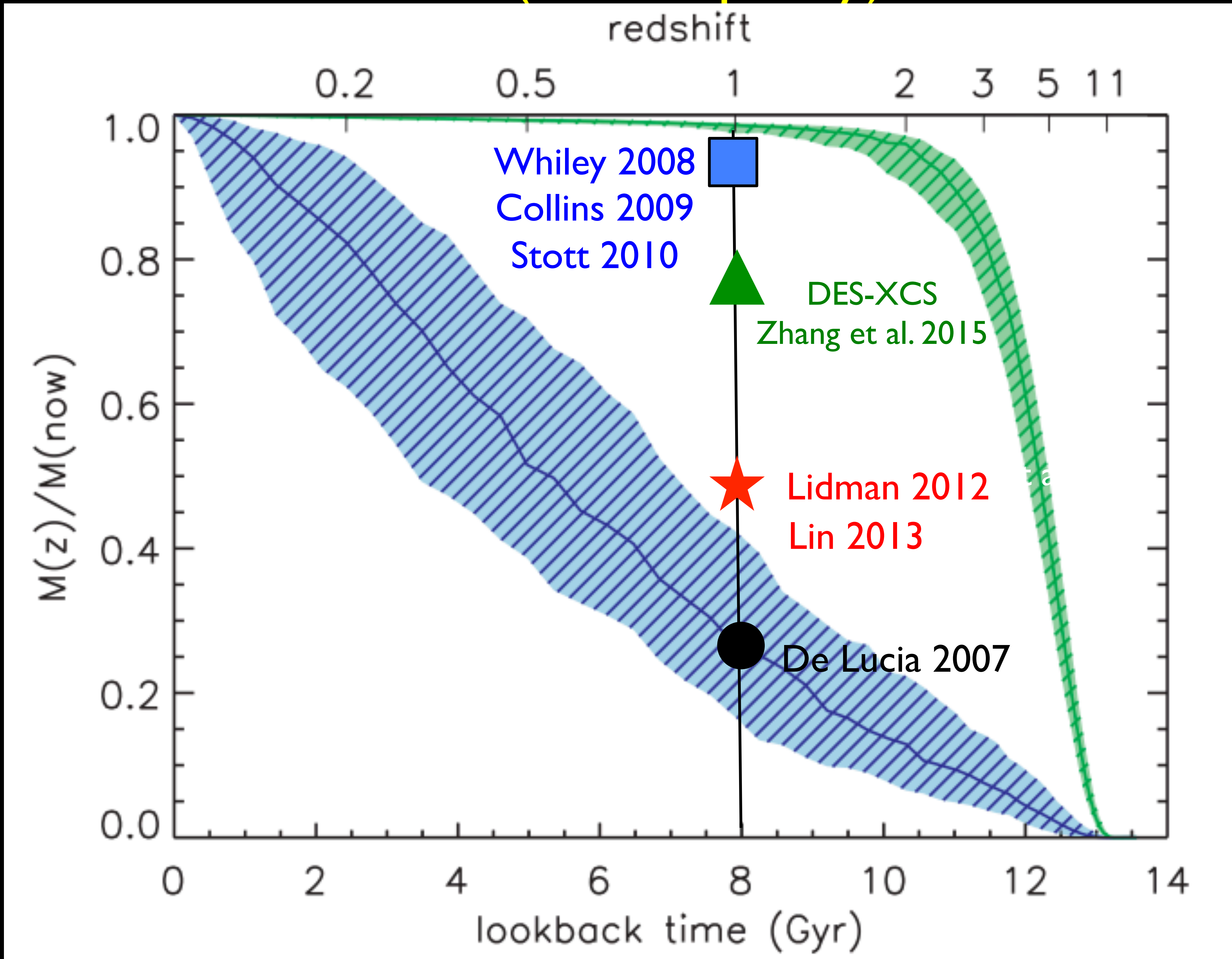
Brightest Cluster Galaxies at high redshift

BCG 7 billion years ago
z~0.9

BCG today

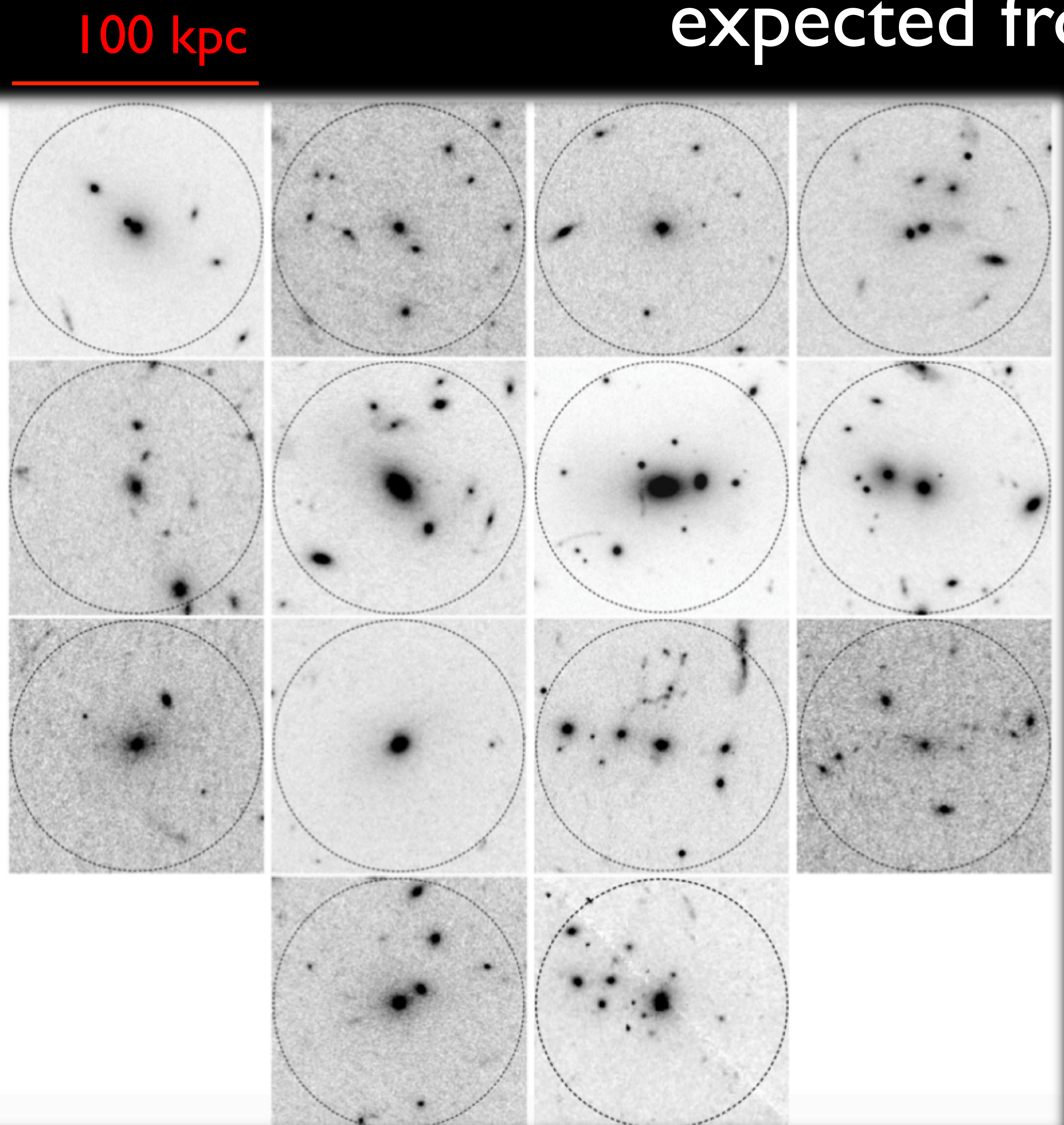
BCGs are the sites of AGN feedback in clusters

Mass Growth (k-band proxy) of BCGs



Burke et al., 2015

If BCG mass assembly is due to merging then what growth is expected from companion galaxies since z=1?

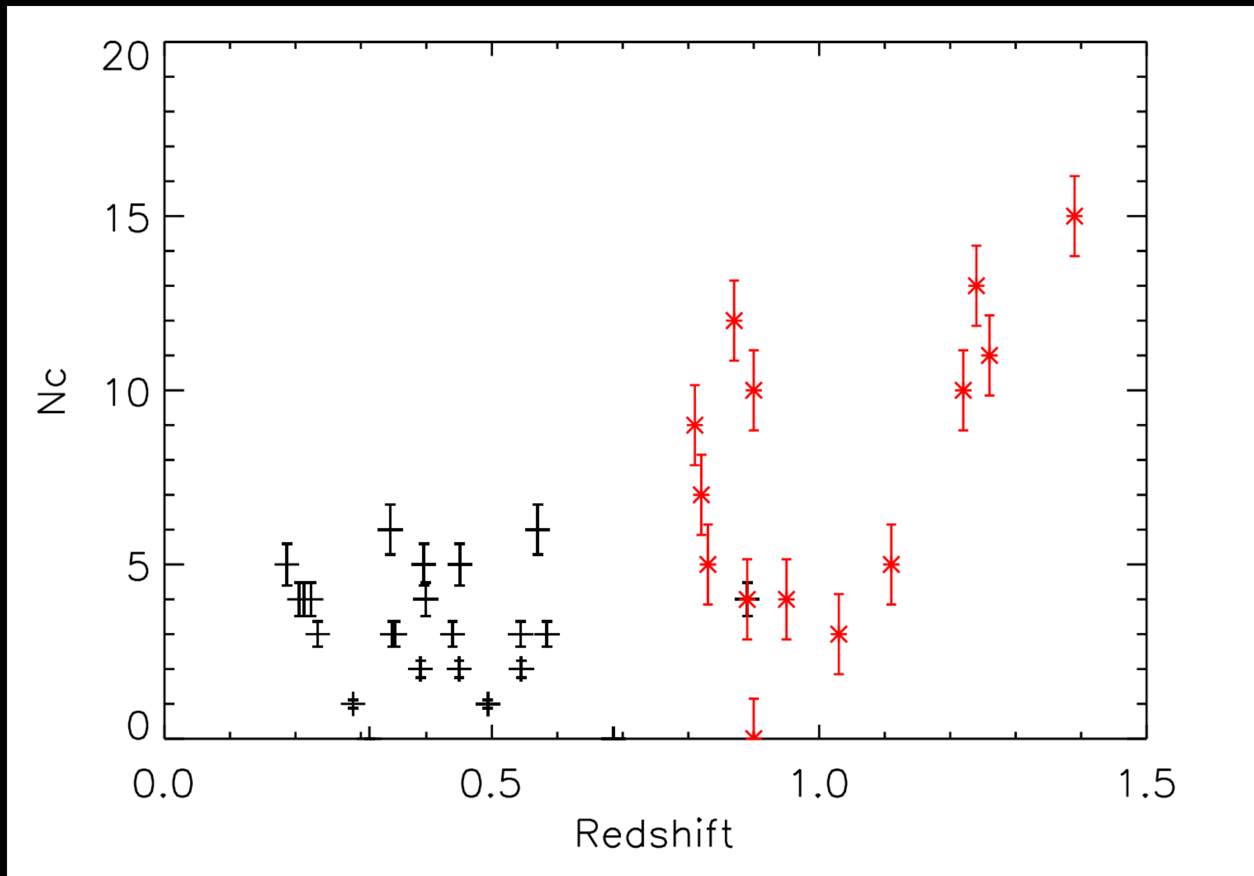


- Examine growth of BCGs via mergers:
- 14 BC13 clusters 0.8<z<1.4 + 23 CLASH clusters 0.2 <z<0.9
- all with HST imaging data

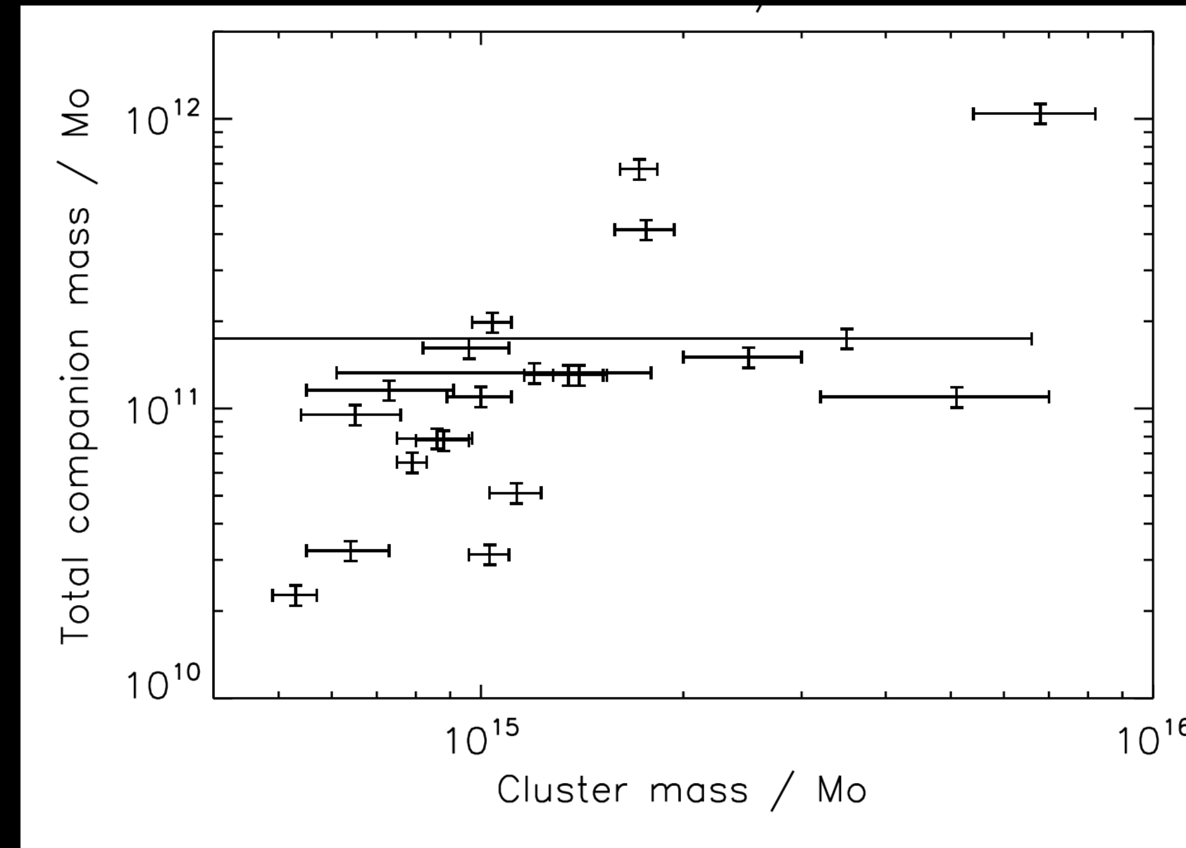
SED fitting to companions

Calculate dynamical friction timescale:

$$T_{\rm fric} = 1.17 \frac{r^2 v_{\rm c}}{G \mathcal{M}_{\rm c} \ln(\Lambda)}$$



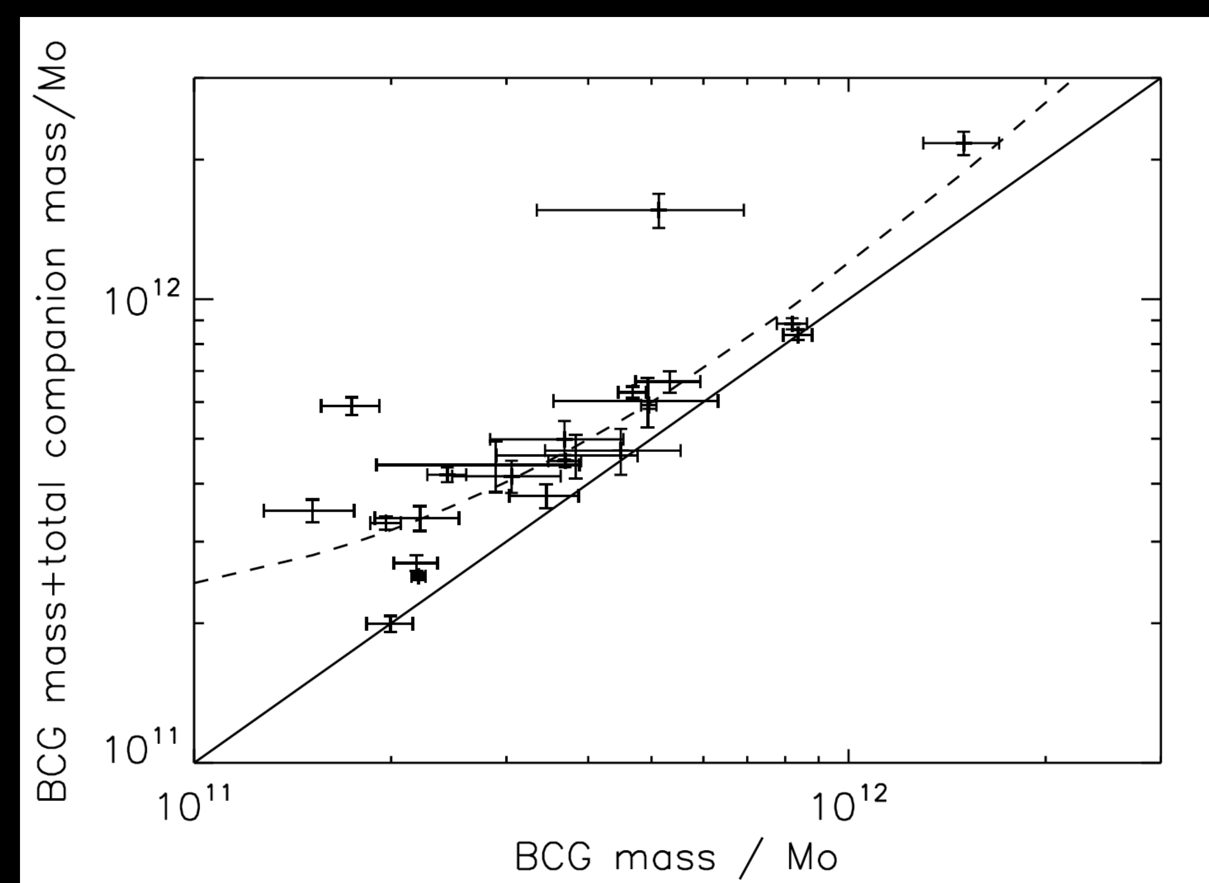
Number of BCG companions vs z from: CLASH (black); BC13 (red) – detection limit consistent

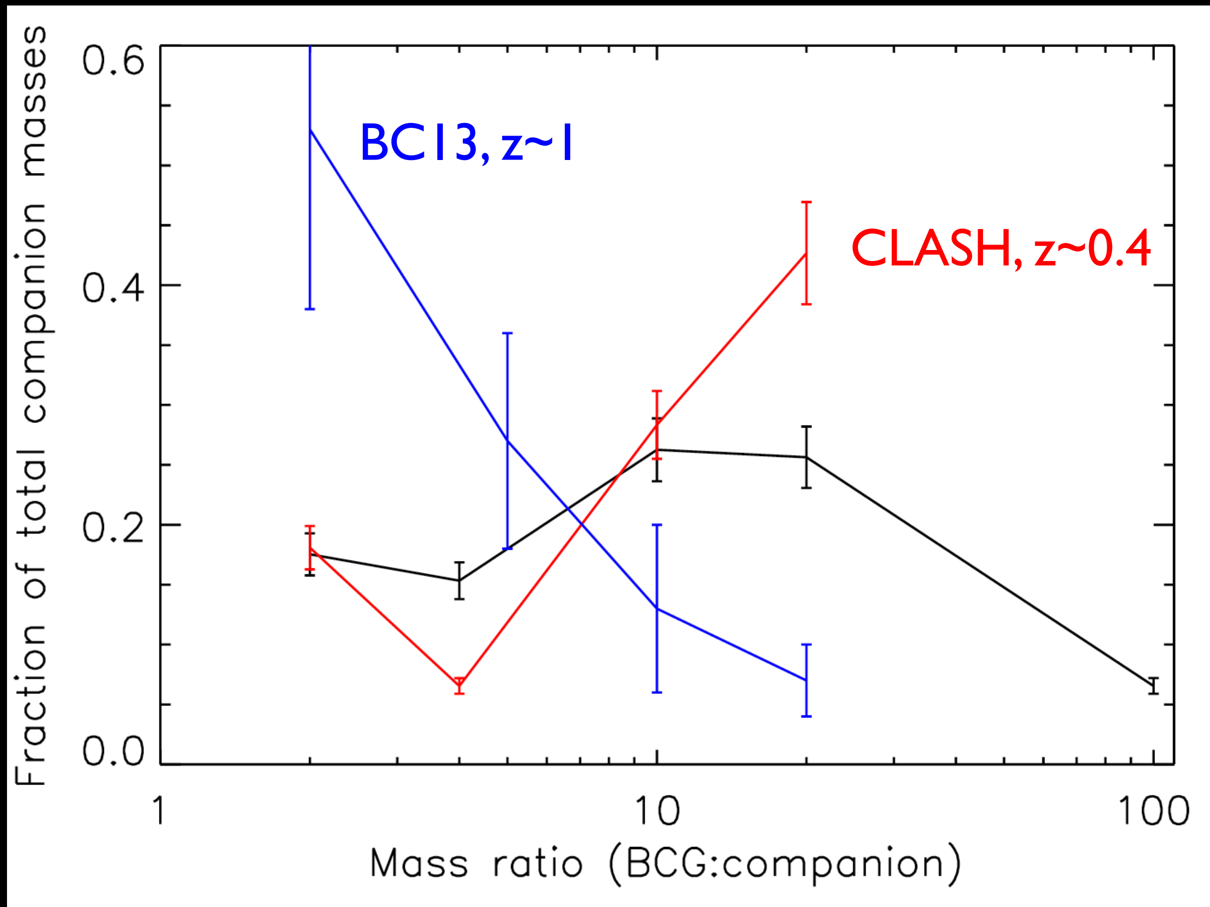


Total mass of BCG companions which will merge vs cluster mass

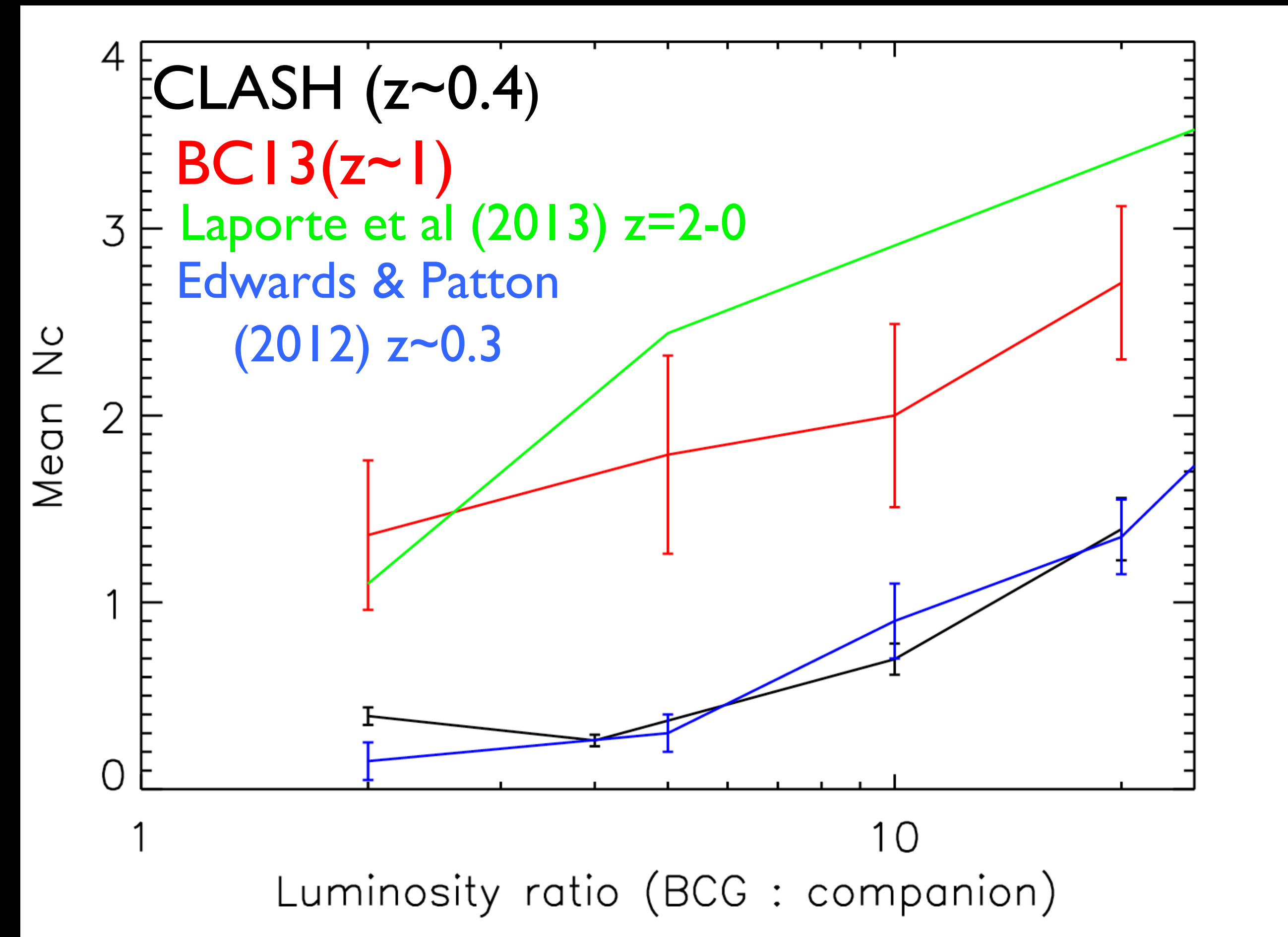
BCG + companion mass likely to merge vs BCG mass.

- Predict BCG mass growth of ~1.4 between z=1 and now from mergers





Fraction of total companion mass vs mass ratio with BCG for CLASH (red) and BC13 (blue) at same detection limit

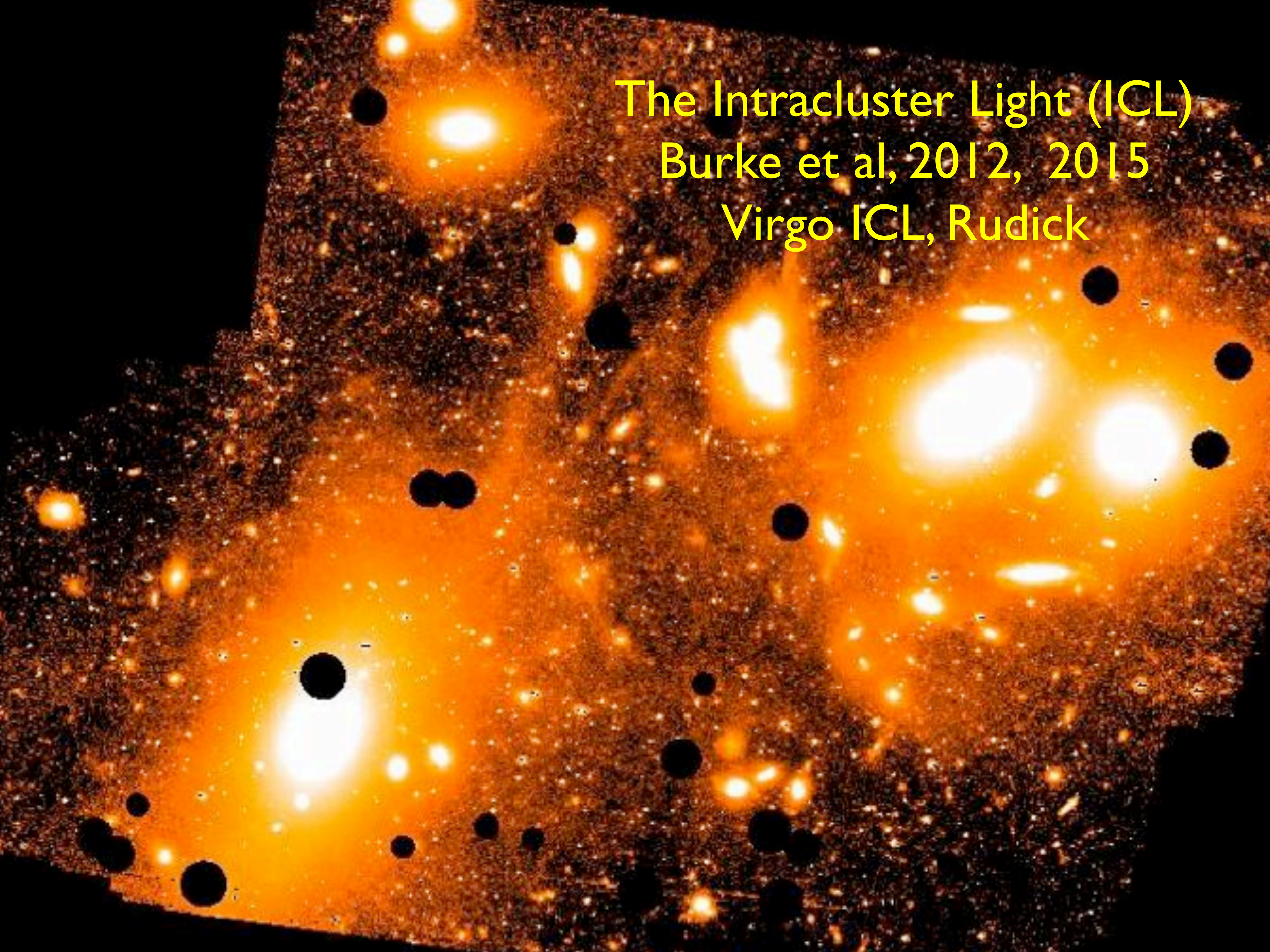


The number of BCG companions split by luminosity ratio with BCG and two literature results

- Major mergers (~1:3) dominate at z~1, whereas by z~0.4 major mergers rare and minor mergers (~1:20) dominate

- Major merging responsible for mass build up in cores since z~1

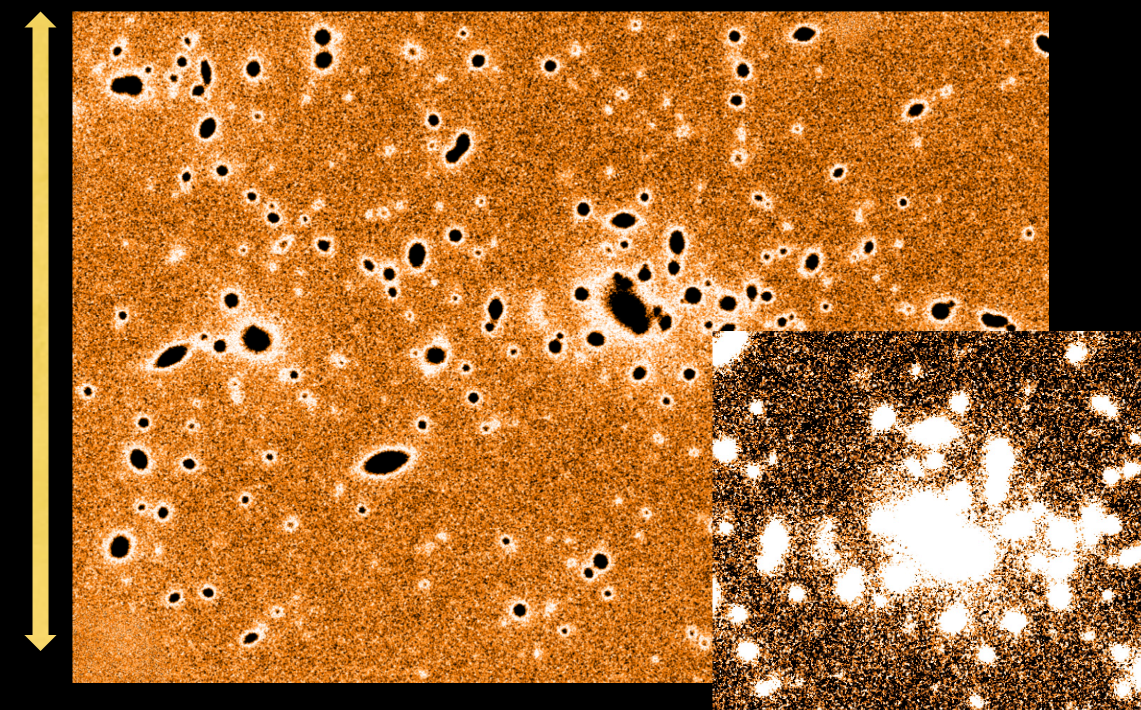
However the stellar mass growth since z~1 may not end up in the core


The Intracluster Light (ICL)
Burke et al, 2012, 2015
Virgo ICL, Rudick

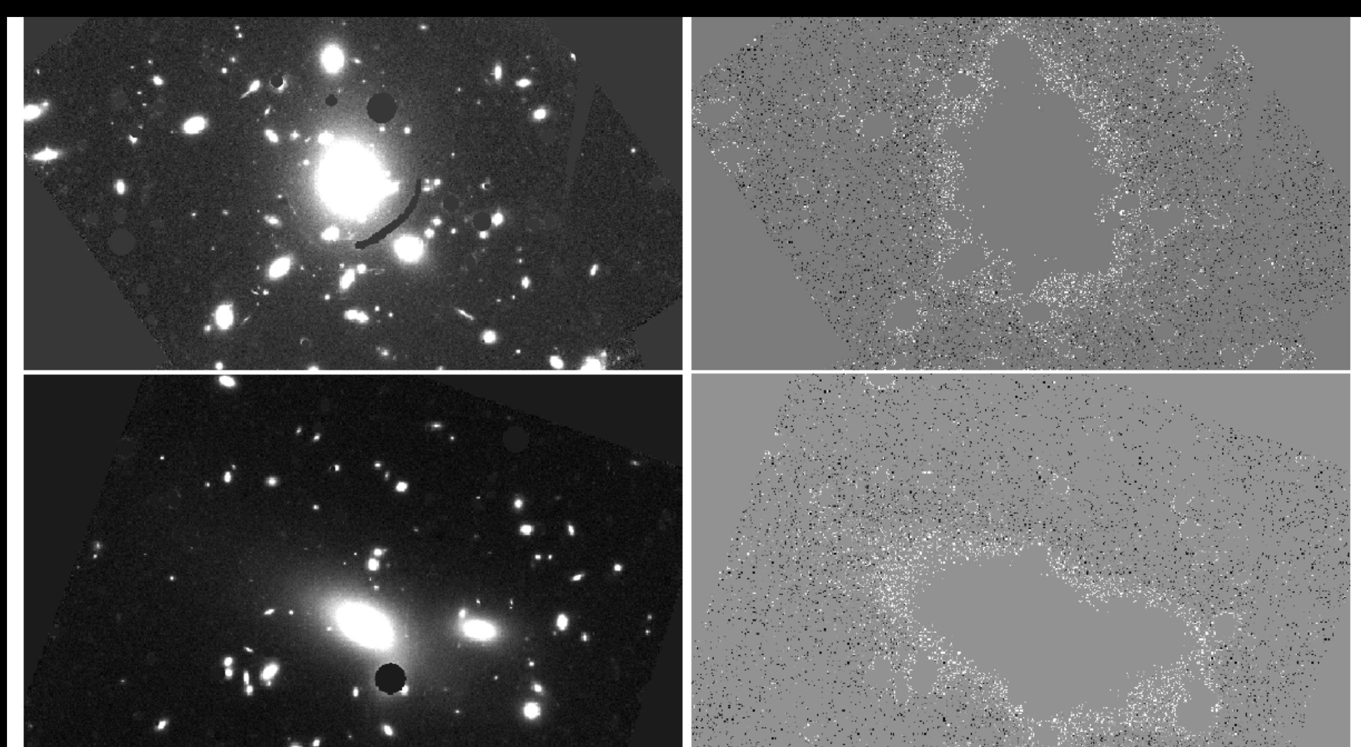
ICL in z~1 clusters

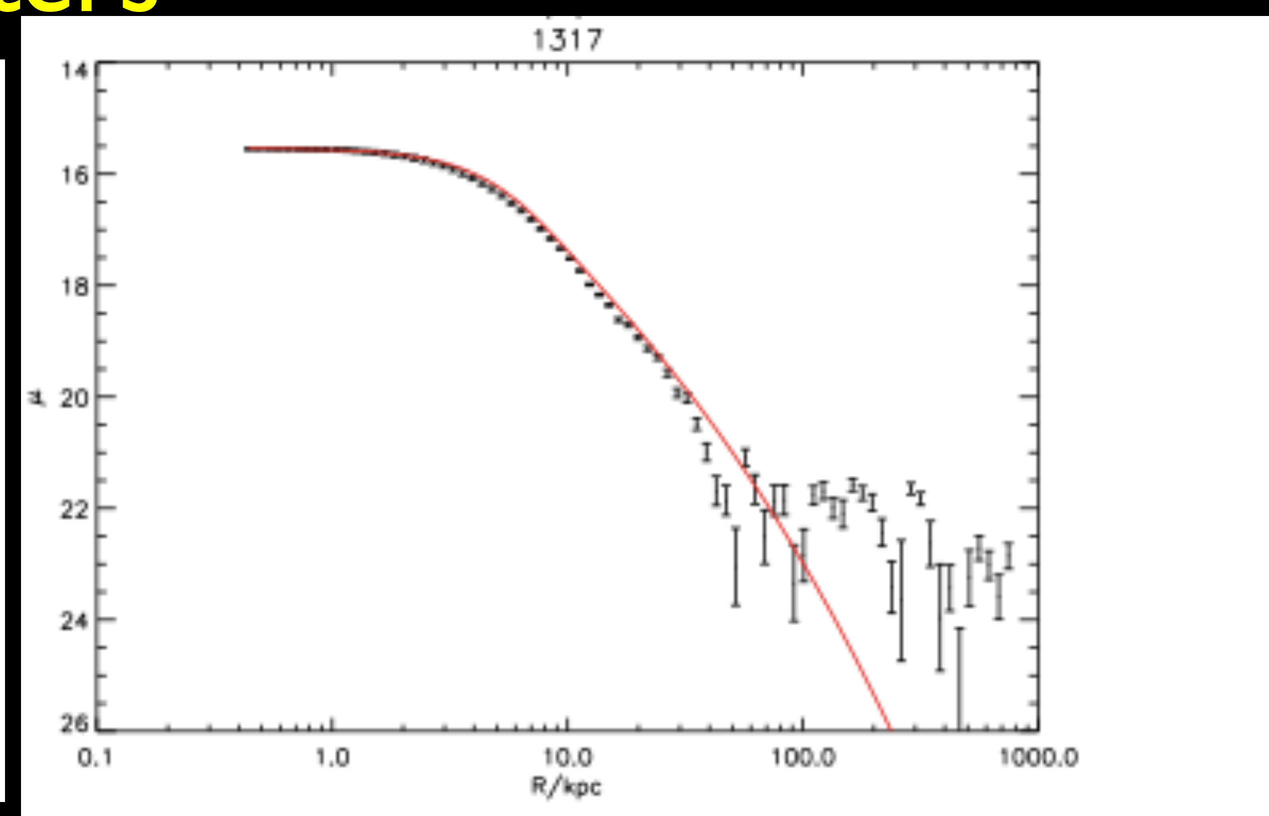
3-4 hr VLT, Hawk-I, J band

800 kpc



ICL in $0.2<z<0.9$ CLASH clusters



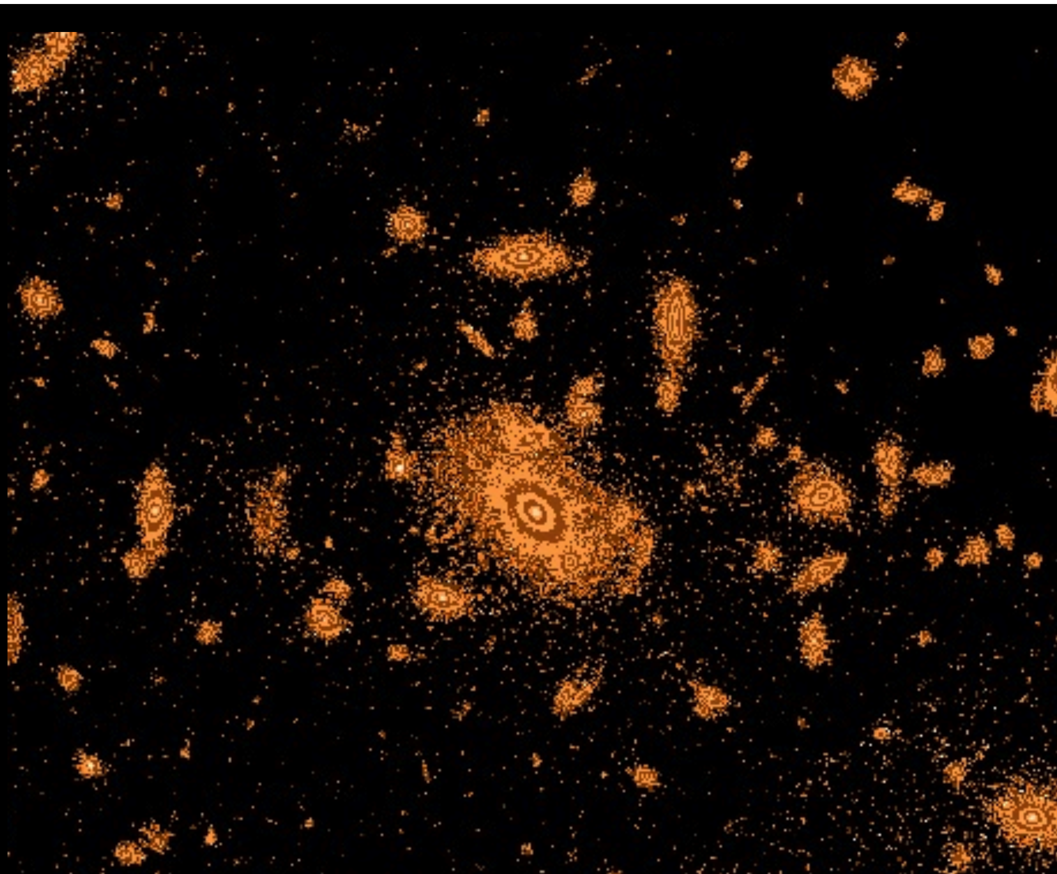


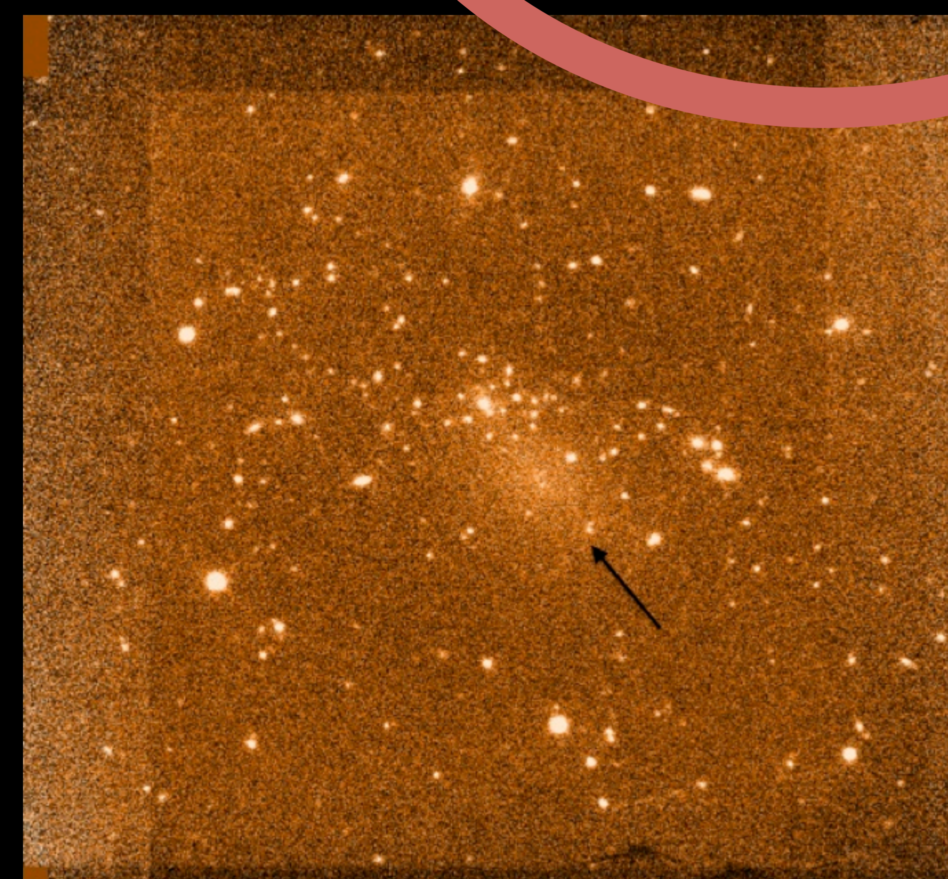
For clarity ICL Defined as all pixels below limiting SB e.g. 25 mag arcsec^{-2}

We do not fit profiles !

Table 3. ICL percentages of the total cluster light in our cluster sample measured above surface brightness limits [illegible] We also show percentages of the total cluster light contained in the BCG using two different measurements for com[illegible]on with previous st[illegible]

Cluster	% cluster light at surface brightness limit μ_J							% cluster light in BCG	
	18	19	20	20.5	21	21.5	22	DeVaucouleurs model	50 kpc aperture
CL J0152	84.7 ± 5.2	73.6 ± 35.2	51.6 ± 3.1	32.5 ± 2.9	13.6 ± 1.9	$5.4 \pm$ [illegible]	2.7 ± 0.4	3.8 ± 0.6	2.0 ± 0.2
XLSS J0223	90.9 ± 4.2	82.0 ± 21.9	55.6 ± 2.5	29.9 ± 1.0	10.1 ± 0.8	$3.6 \pm$ [illegible]	2.5 ± 0.4	2.0 ± 0.5	1.6 ± 0.2
XLSS J0224	89.2 ± 27.4	77.6 ± 12.4	34.7 ± 11.6	8.7 ± 2.0	5.3 ± 0.9	$2.6 \pm$ [illegible]	1.3 ± 0.4	6.3 ± 0.7	3.7 ± 0.3
RCS J0439	80.0 ± 5.3	70.1 ± 13.0	47.2 ± 3.5	25.7 ± 3.7	9.3 ± 1.4	$2.8 \pm$ [illegible]	1.5 ± 0.7	3.3 ± 0.4	1.3 ± 0.2
MS 1054	69.2 ± 7.9	60.2 ± 15.1	41.1 ± 4.2	23.3 ± 1.5	11.3 ± 2.7	$6.2 \pm$ [illegible]	3.8 ± 0.2	4.7 ± 0.7	1.8 ± 0.3
RDCS J1317	78.5 ± 14.9	66.0 ± 12.6	32.4 ± 1.0	12.4 ± 5.6	4.6 ± 1.1	2.5 ± 0.4	1.5 ± 0.4	2.5 ± 0.5	1.3 ± 0.2

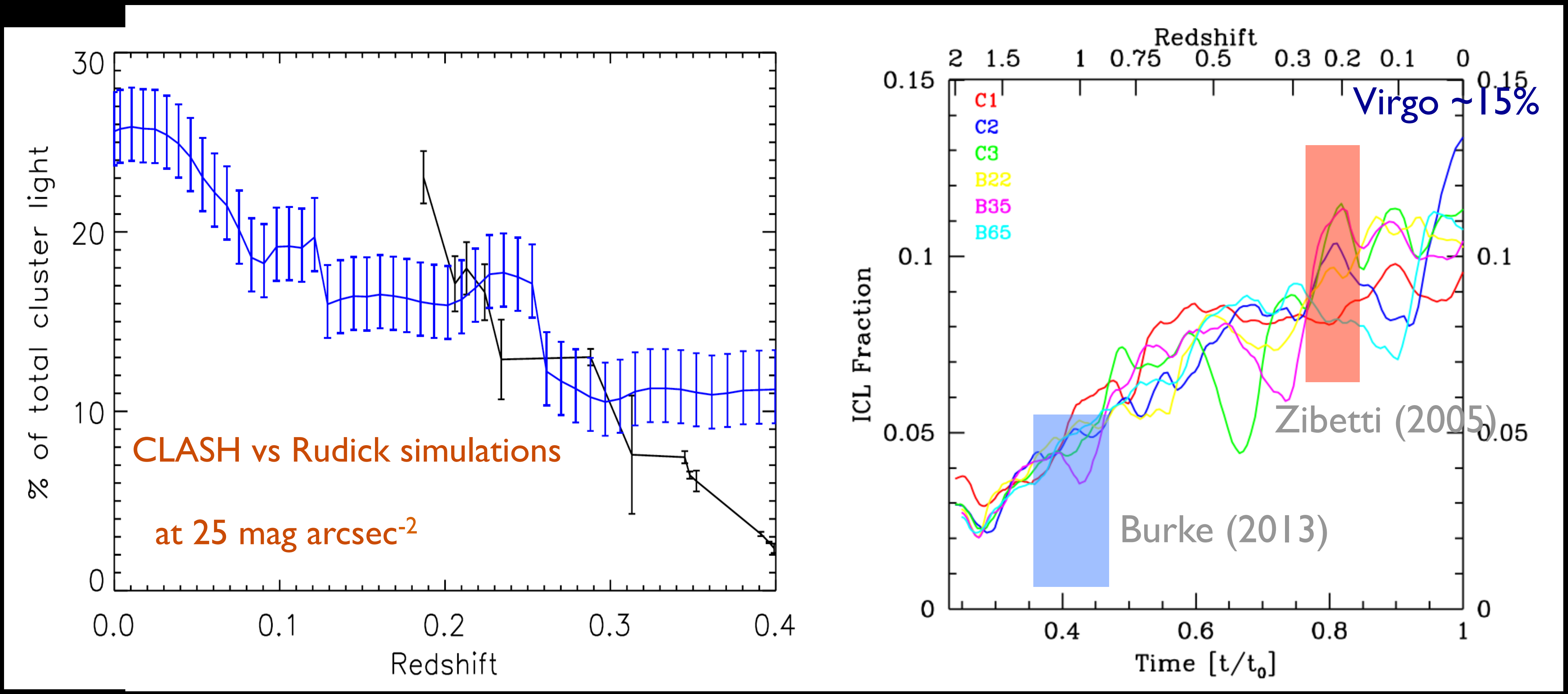




Determine final isophotal limit from simulations;
Significant mass growth outside of 50 kpc at z=1

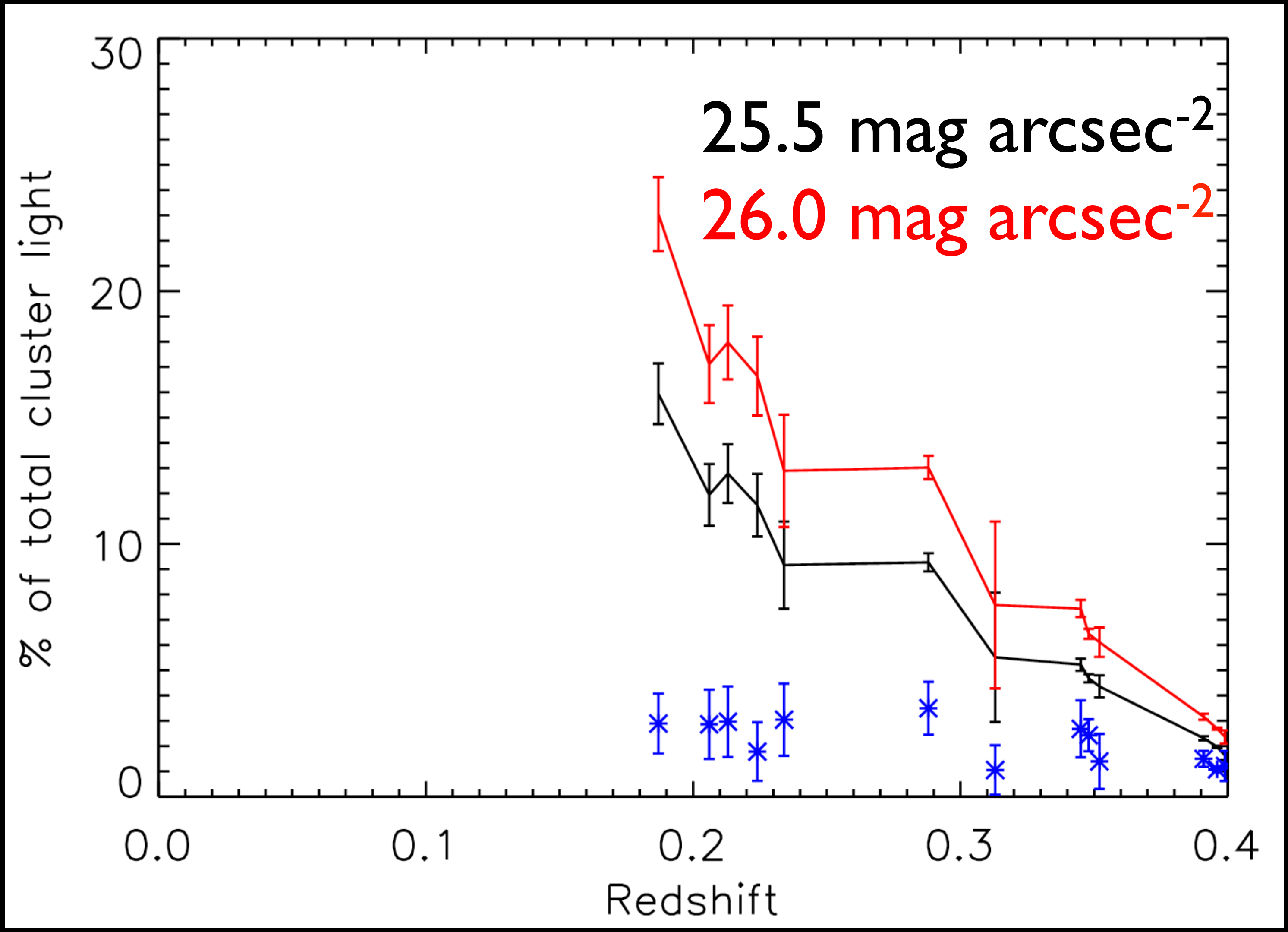
ICL Results

Compare with N-body GADGET simulations using simple SB cut definition (Rudick et al 2011)



- Detect the ICL (>100 kpc) at z=1 (~2-4% of cluster light)
- ICL increases rapidly since z=1 by factor ~5 to ~20% total cluster light
- Most of ICL growth occurs very late z< 0.1 (e.g. Contini et al 2014)
- ICL close to galaxies - stripping rather than merging

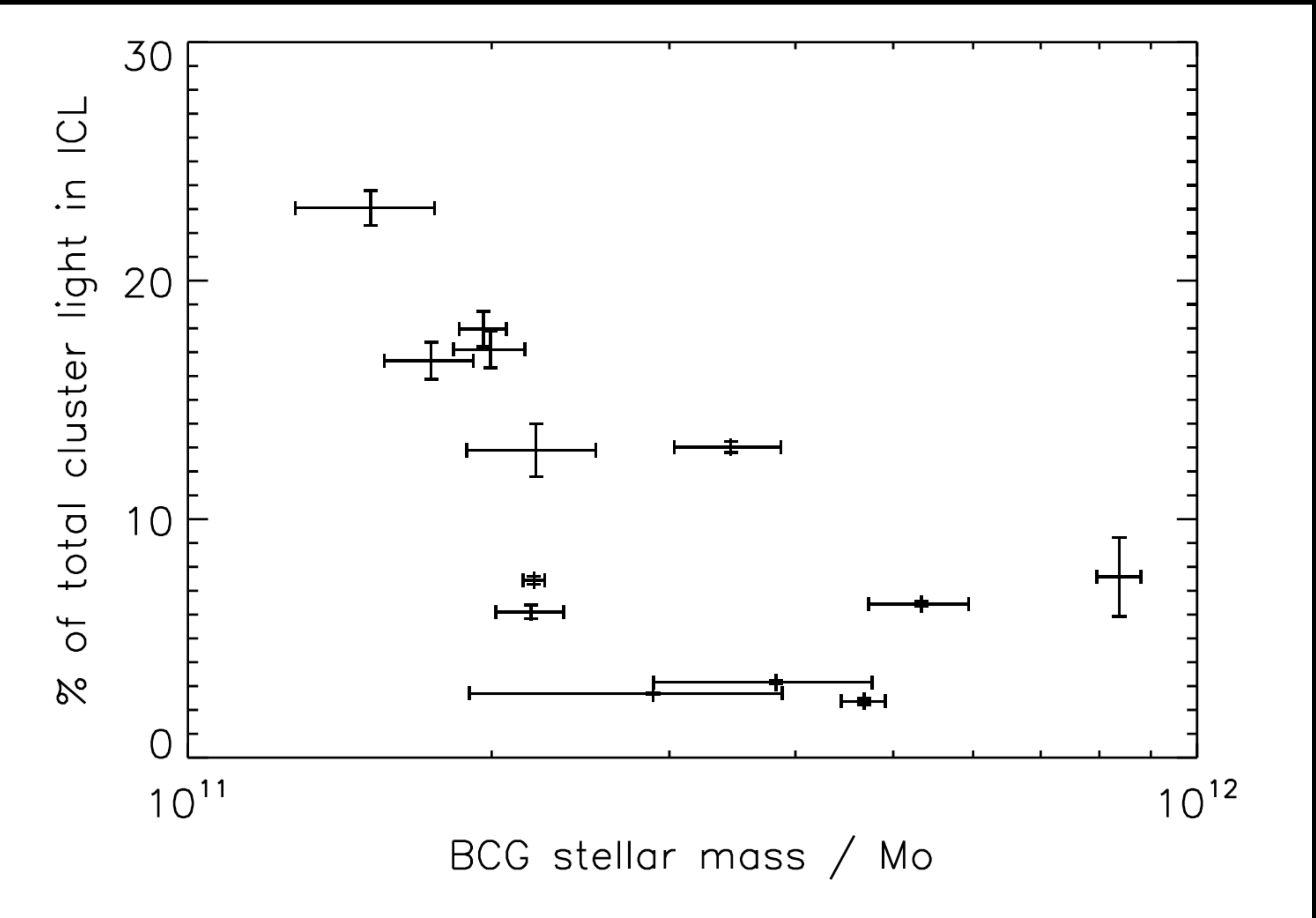
Fraction of ICL light in CLASH Clusters at z=0.2-0.4



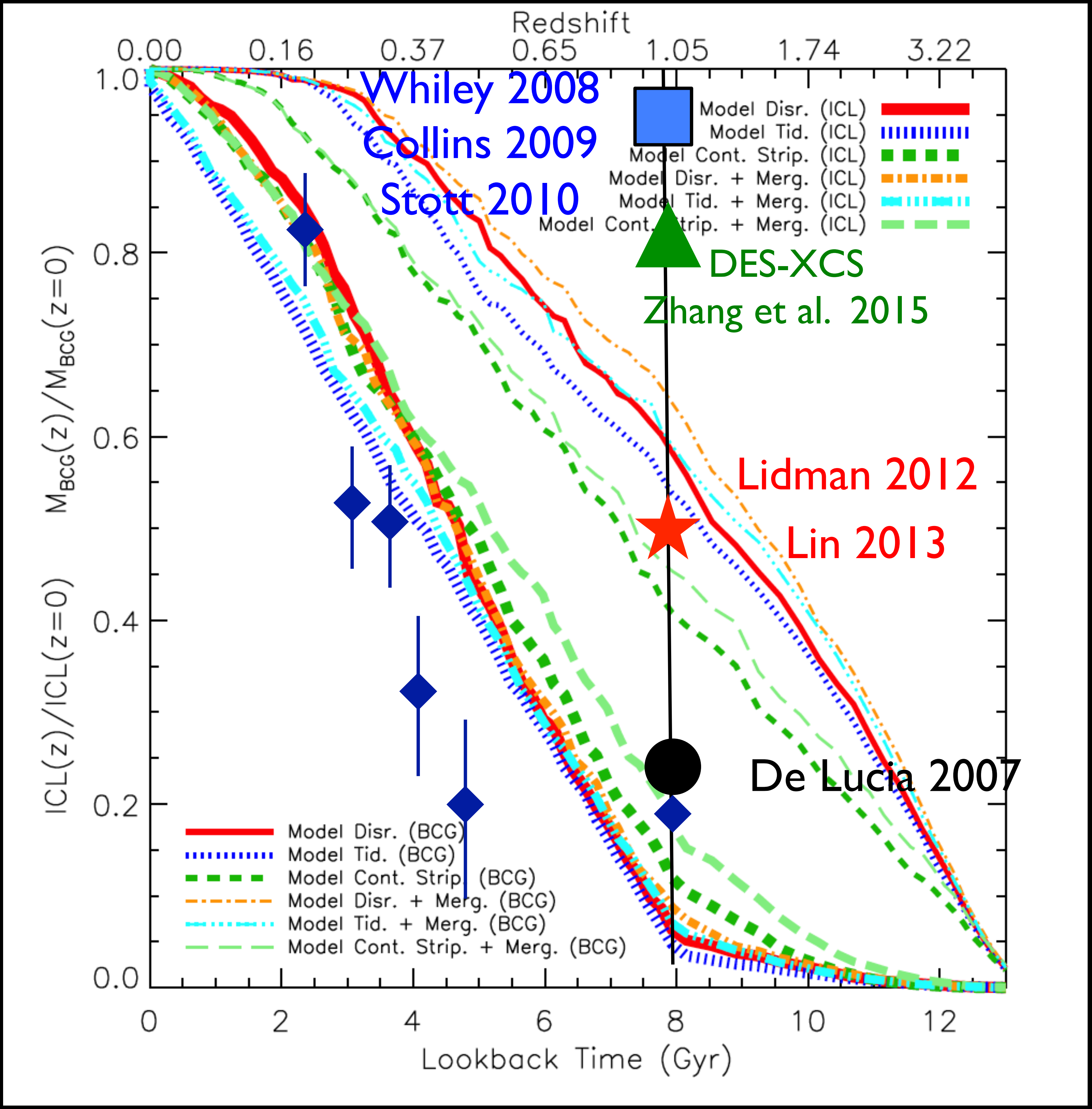
- Mass growth occurring in ICL not BCG (see Puchwein et al. 2010)
- ICL dominates stellar mass of BCG ~ 4-5:1 at low z in massive clusters
- (e.g. Gonzalez et al. 2007, 2013)
- (e.g. Comparable contributions at z~1, Burke et al. 2012)

ICL fraction is correlated with z independent of BCG mass

but NO correlation between ICL and BCG mass at constant z



Spearman Rank	Partial Spearman rank
$R_{BCG\ ICL} = -0.7$	$R_{BCG\ ICL,z} = 0.2$
$R_{ICL\ z} = -0.9$	$R_{ICL\ z,BCG} = -0.8$



Contini et al. 2014 – updated De Lucia 2007 SAM predictions

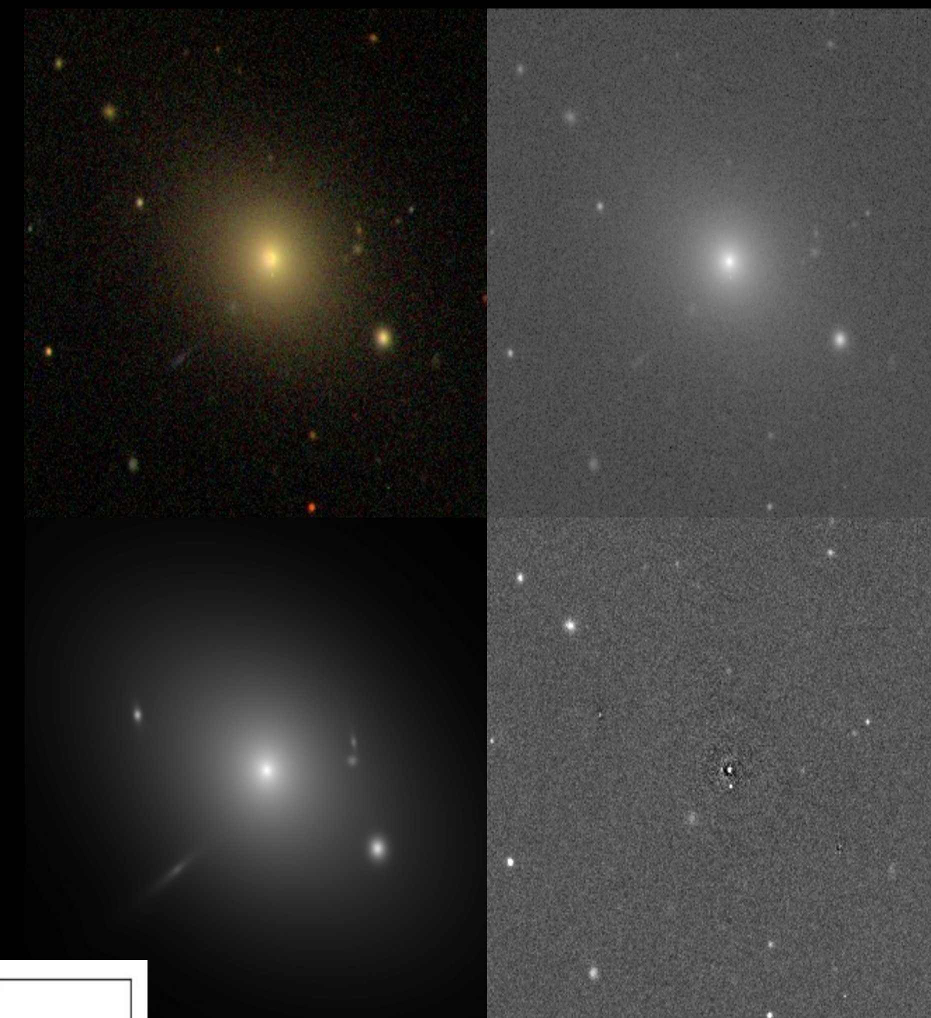
Caveat: observations not well matched to predictions: e.g. apertures, SB limits

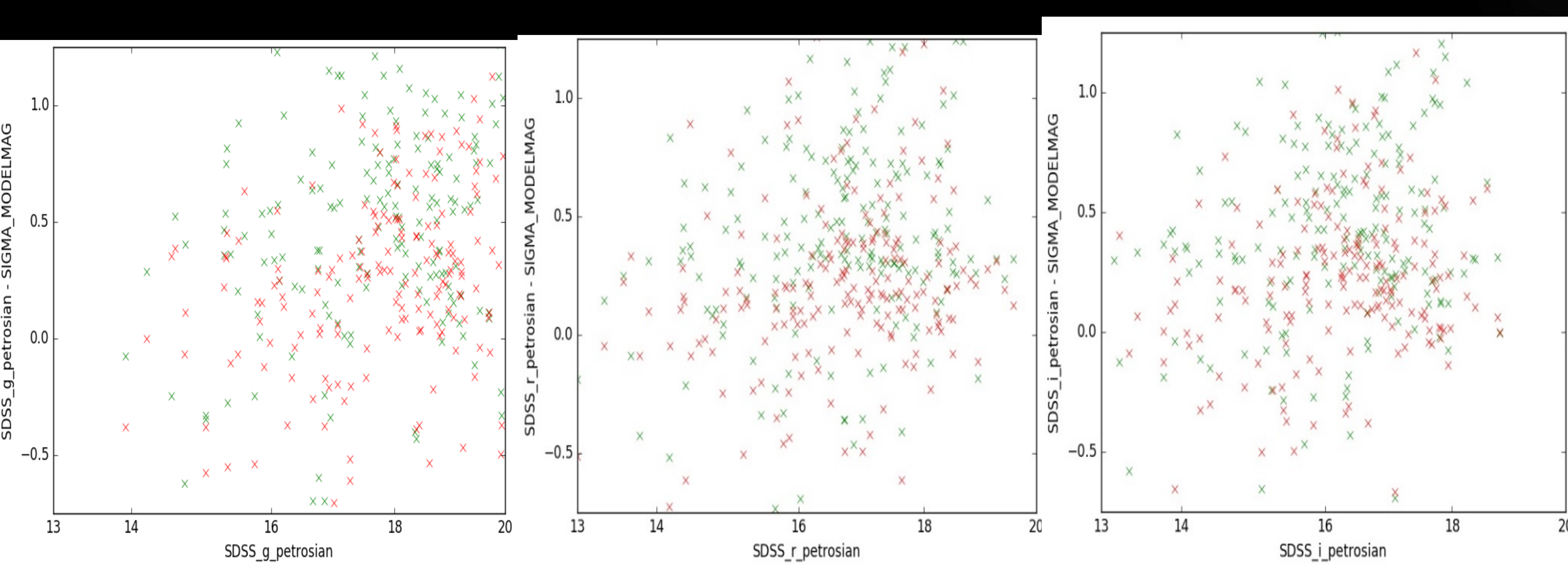
eROSITA: SPIDERS BCG Sample: Linking Morphology and Environment
SPIDERS spectroscopically prioritises BCGs

- ~240 BCGs (0.05 < z < 0.55) selected from SPIDERS cluster catalogues (Nic's talk yesterday, Clerc et al. 2016).

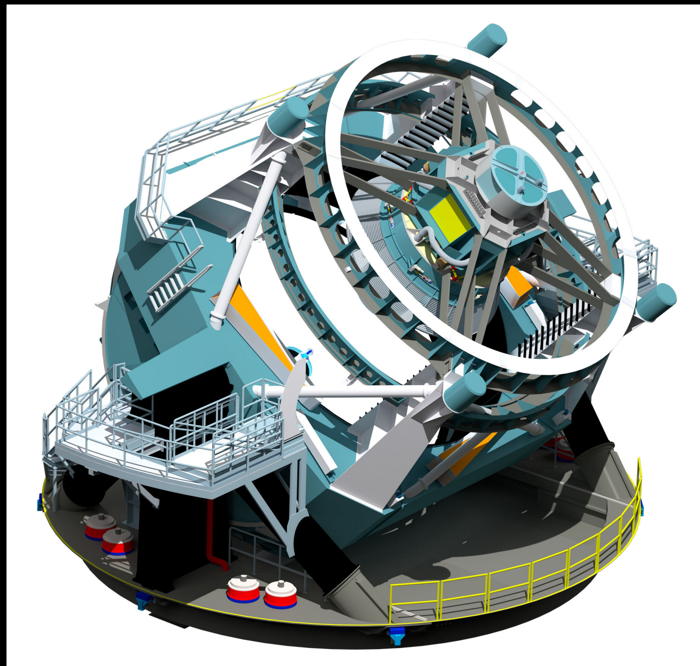
- (Currently) examining BCG morphology profiles (SIGMA; Kelvin et al., 2012) fit in SDSS bands (g,r,i) with respect to cluster X-ray/dynamical properties of host cluster

- Accurate SPIDERS redshifts for cluster member galaxies allows for robust studies of merger histories => link to prevalence of ICL





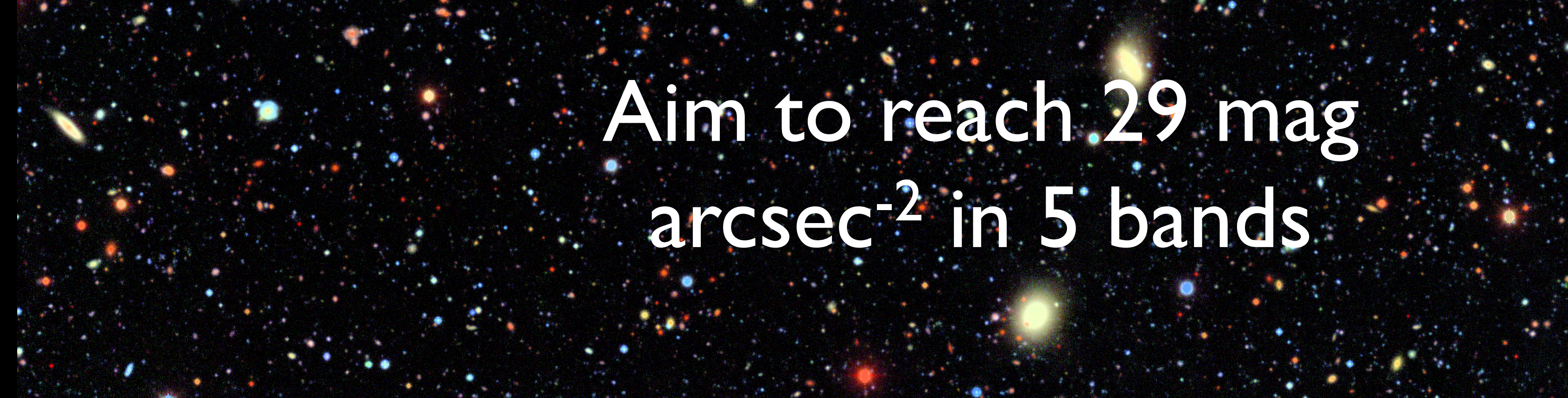
ABOVE: TL: gri SDSS composite, TR: SDSS r data, BL: Model (SIGMA), BR: Residual for z ~ 0.05 BCG
LEFT: Comparison of SDSS gri Petrosian magnitude with respect to fit. Green = Sersic, Red = Sersic + Exponential



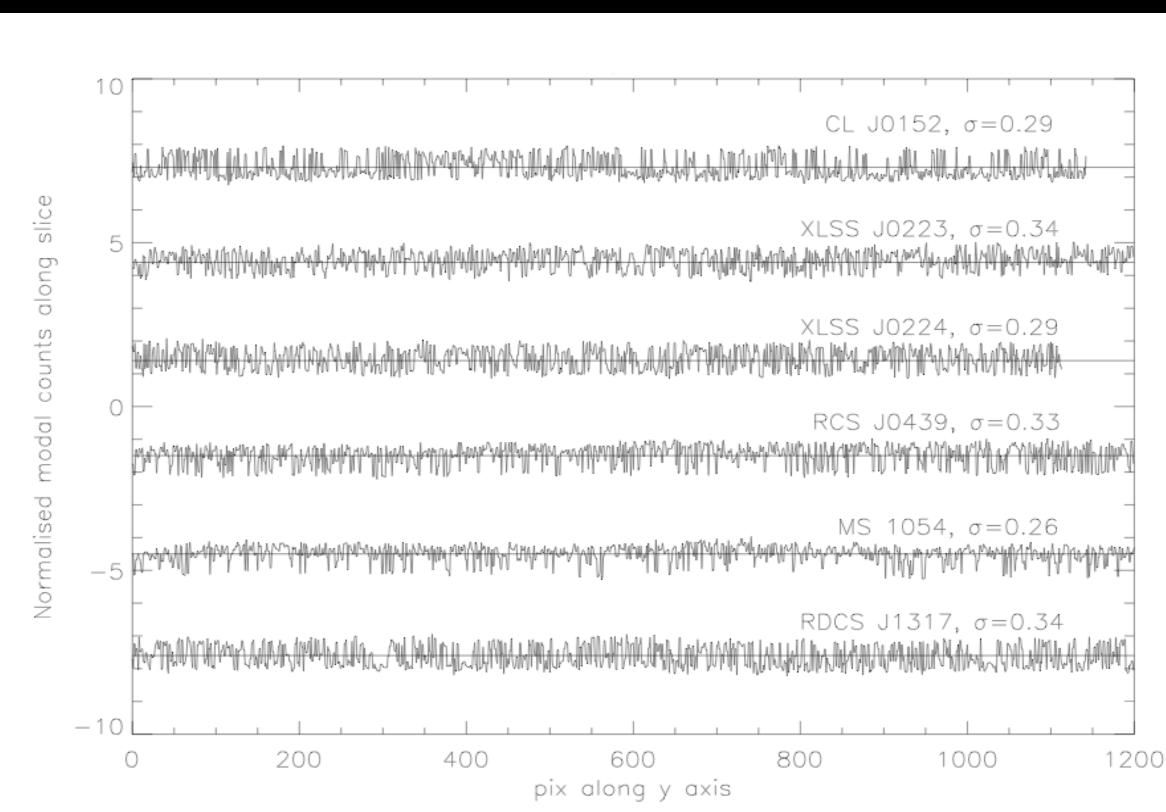
LSST

History of stellar mass in cluster cores tied up in LSB ICL component.

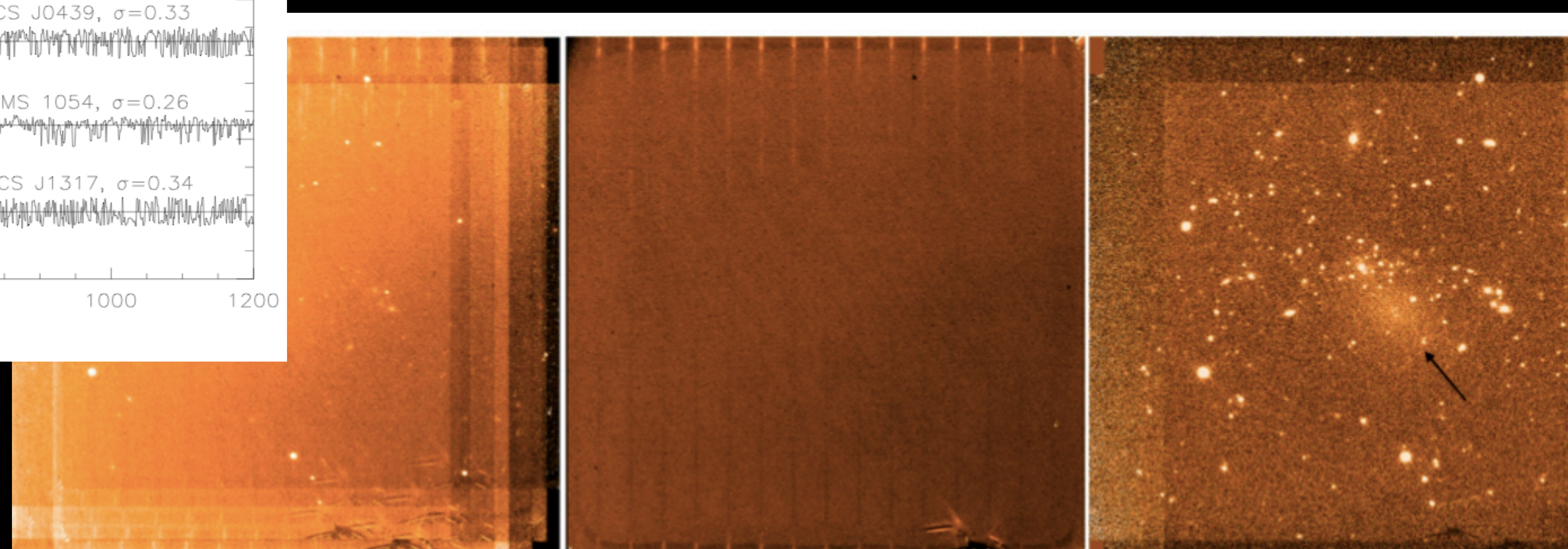
Current data too shallow c.f. simulations



Aim to reach 29 mag arcsec^{-2} in 5 bands



Essential to optimise sky background estimation and FF techniques for ICL work



e.g. VLT Hawk-I FF pattern using running median consistent with noise

Summary and Discussion Points

- ICL appears to form late ($z<1$) through stripping of major mergers, reaching ~ 2×10^{12} Mo – dominating BCG stellar mass
- There is Improving consistency between slow BCG mass growth and predictions
- Selection effects (e.g. Cluster sample bias, observational SB limits not fully accounted for in comparisons with predictions)
- SPIDERS will consist of 4-5 thousand clusters z=0.2-0.5, BCG morphology work underway
- eROSITA need to maximise impact on LSS Science