Recovering the Intracluster Light from LSST

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Outline

- Evolution of the stellar mass in brightest cluster galaxies (BCGs) at the centres of rich X-ray clusters through mergers
- Feeding the Intracluster Light (ICL) with mergers – towards a consistent picture of stellar mass evolution in clusters
- Properties of BCGs using SPIDERS Clusters
- Measuring the ICL with LSST & existing data Properties

Overall Scientific Goals: Merging and the ICL

- How rapid is the build up of stellar mass in the centres of clusters?
- Major or Minor mergers with redshift (see DeMaio et al. 2015)?
- What is the contribution from ICL since z=1?
- How does the build up of ICL depend on host cluster properties?
- What is the relation between ICL and BCG morphology?

Brightest Cluster Galaxies at high redshift

BCG 7 billion years ago
z~0.9

BCG today

A lot of work done on how cluster properties relate to the stellar content in cluster cores?

(Hoessel et al., 1987,Collins & Mann 1995,
Brough et al., 2005, 2008, Lin et al., 2004, 2006, Furnell et al., 2017)

Sample 1:

BC 13

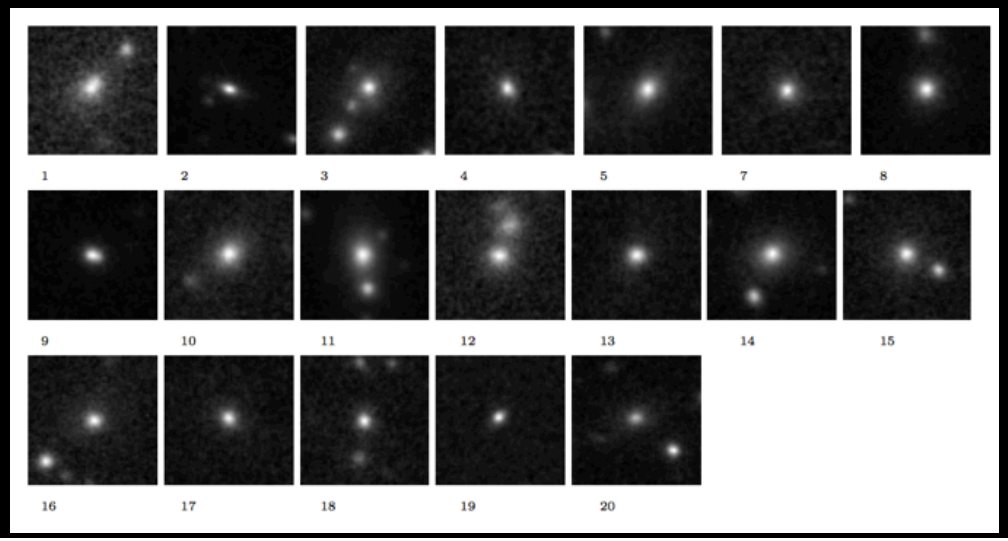
20 High z X-ray Selected BCGs (e.g. XCS)

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

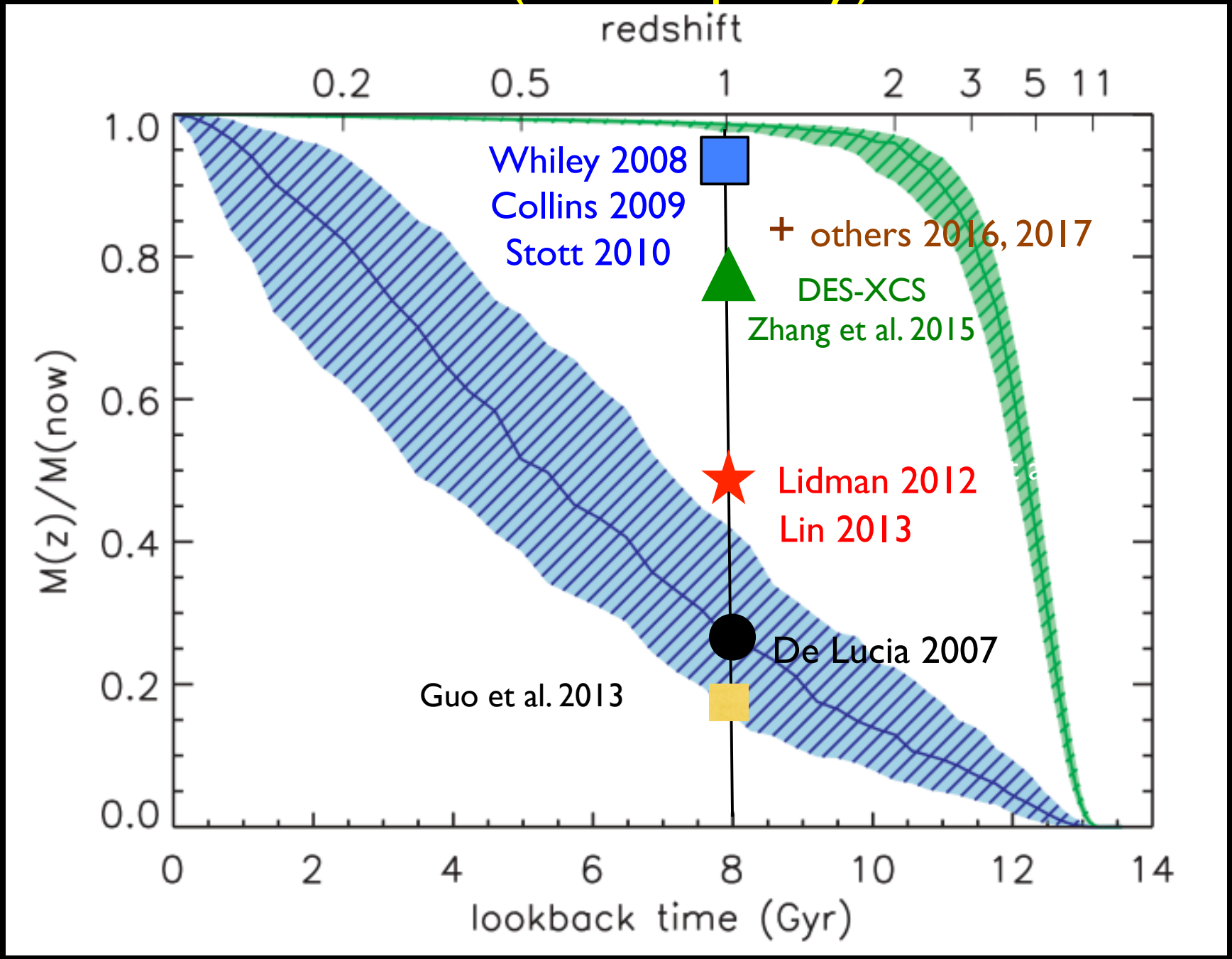
$0.18<z<0.89, T_x > 5$ keV

16 Band HST photometry

SB 26 - 27 mag arcsec^{-2}

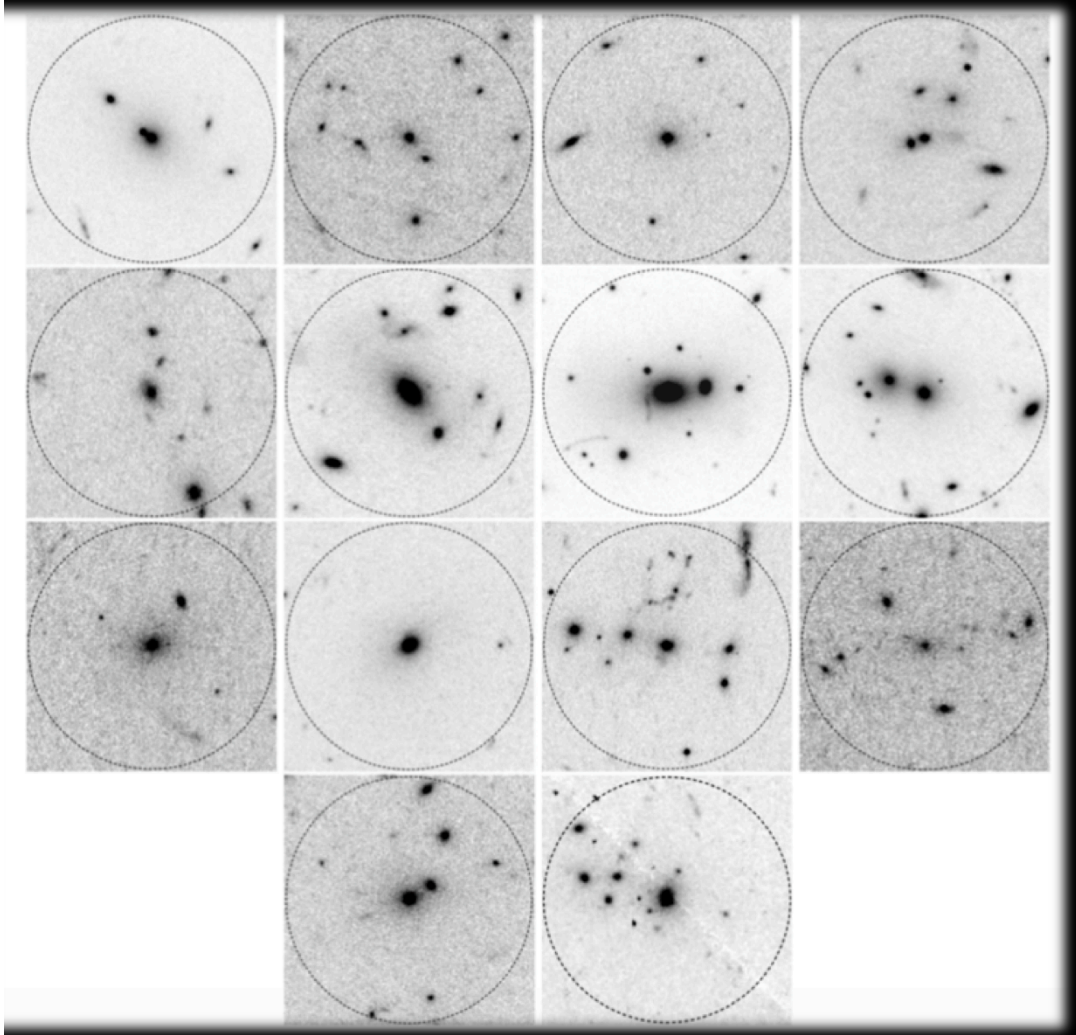
(B band)

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?

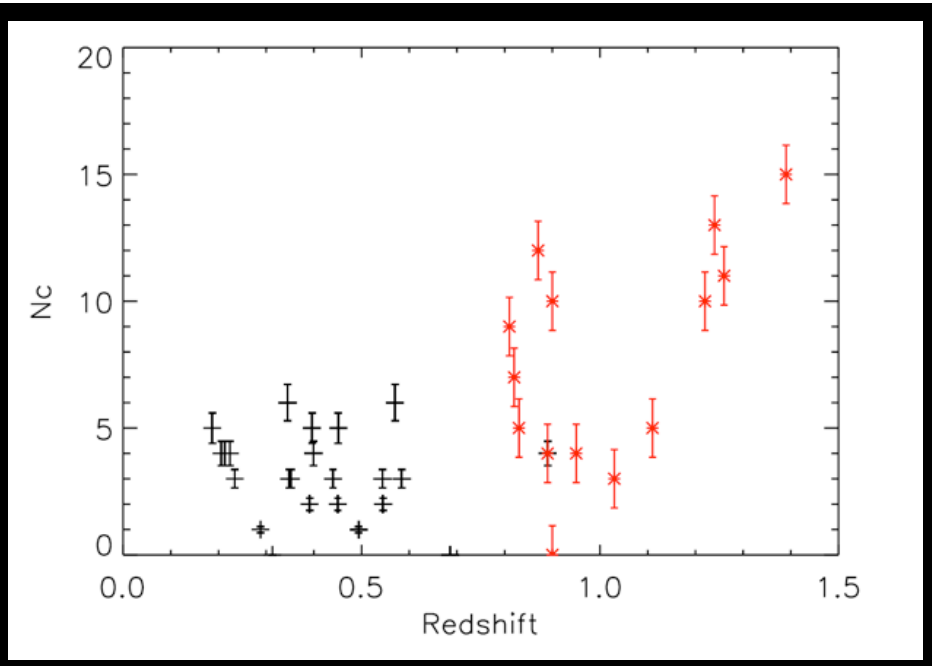


- Examine growth of BCGs via mergers:
- 14 BC13 clusters 0.8<z<1.4 + 23 CLASH clusters 0.2 <z<0.9
- all with HST imaging data

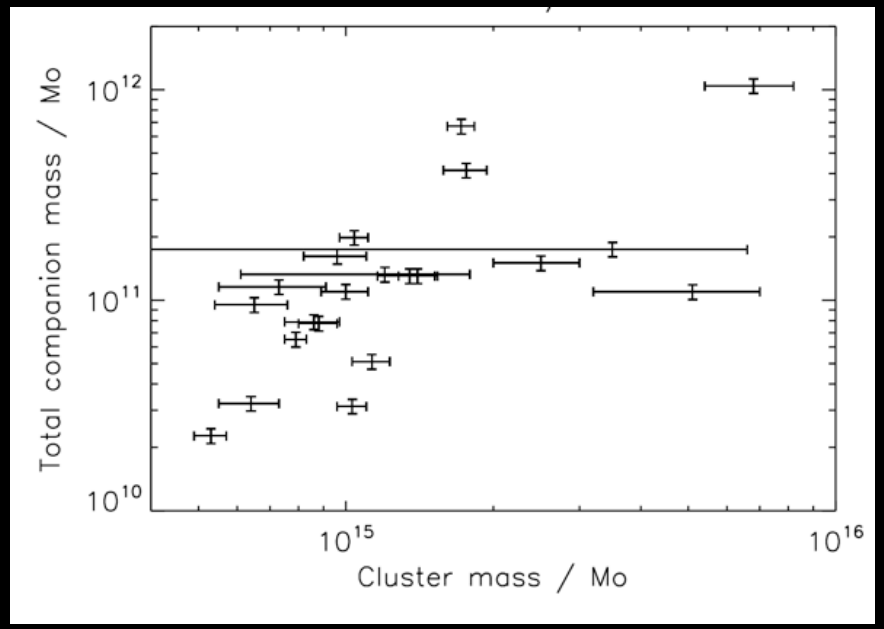
Calculate dynamical friction timescale:

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

SED fitting to companions

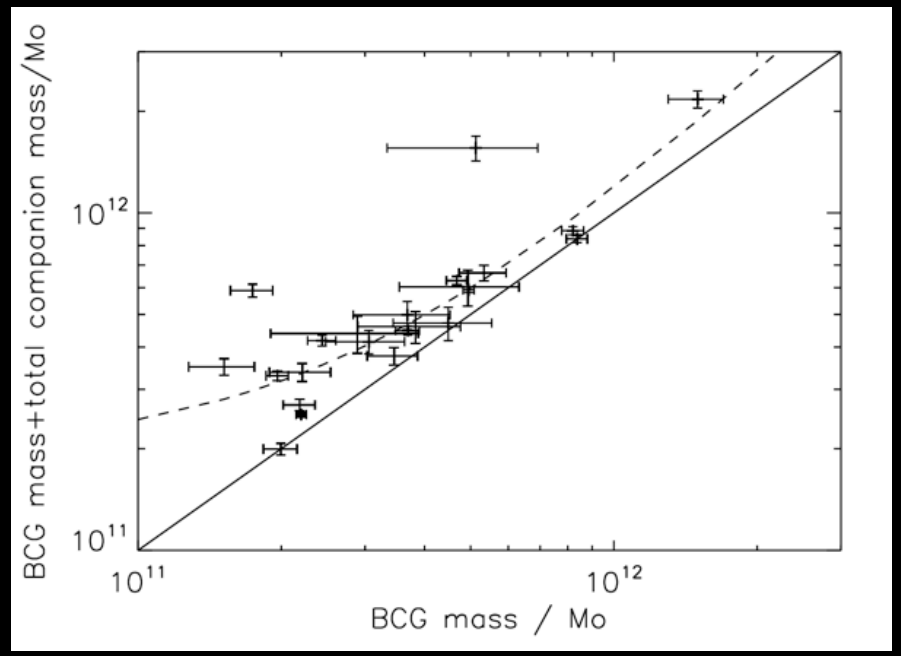


Number of BCG companions vs z from: CLASH (black); BC13 (red) – detection limit consistent



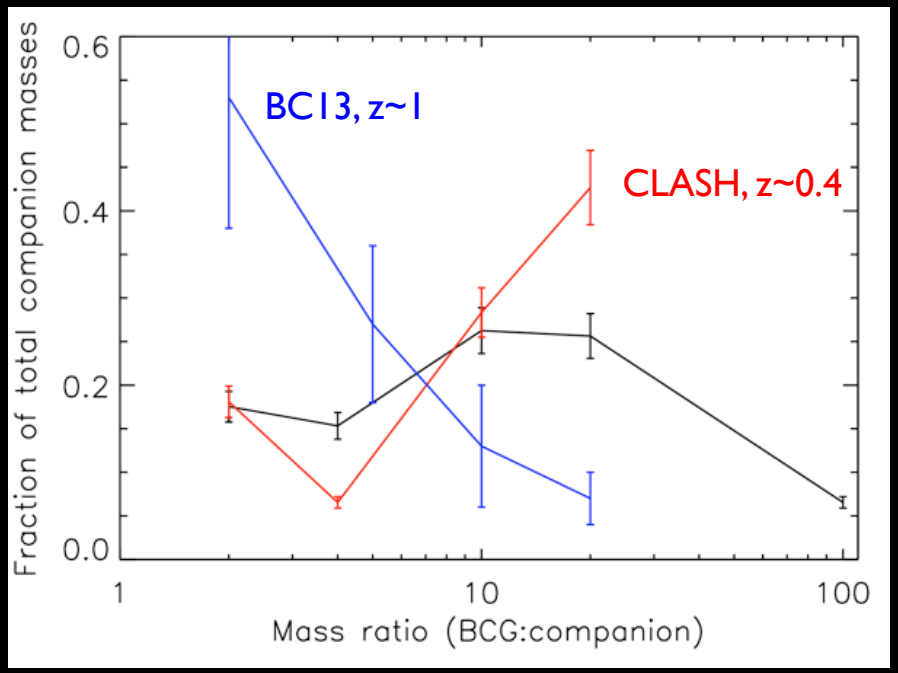
Total mass of BCG companions which will merge vs cluster mass

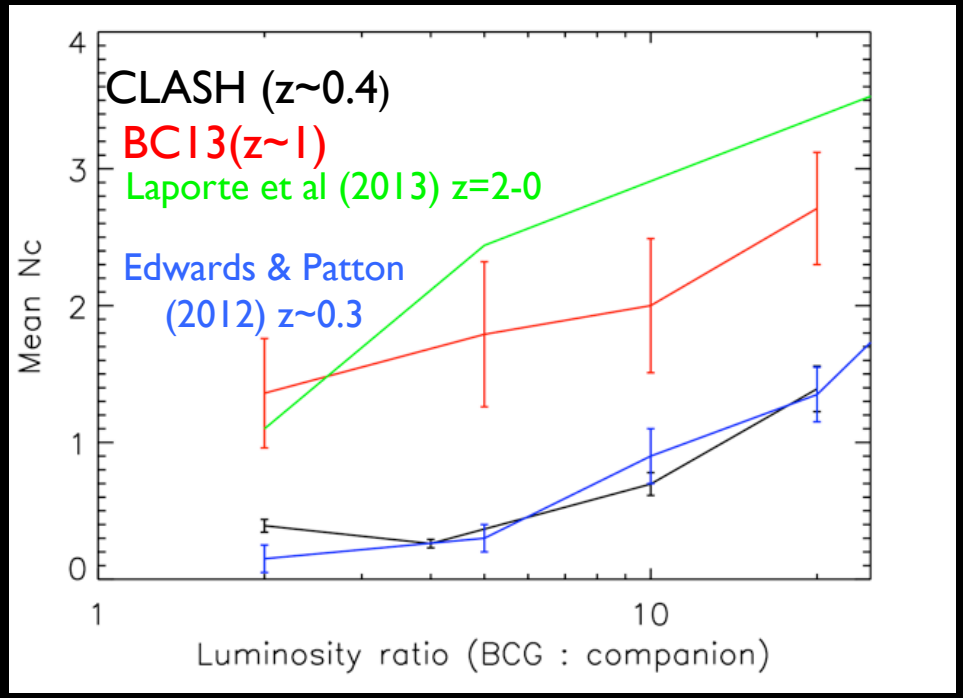
BCG + companion mass likely to merge vs BCG mass.



Between z=1 and now predict:

Fractional contribution to BCG ~40-50% (assuming 100% merger)



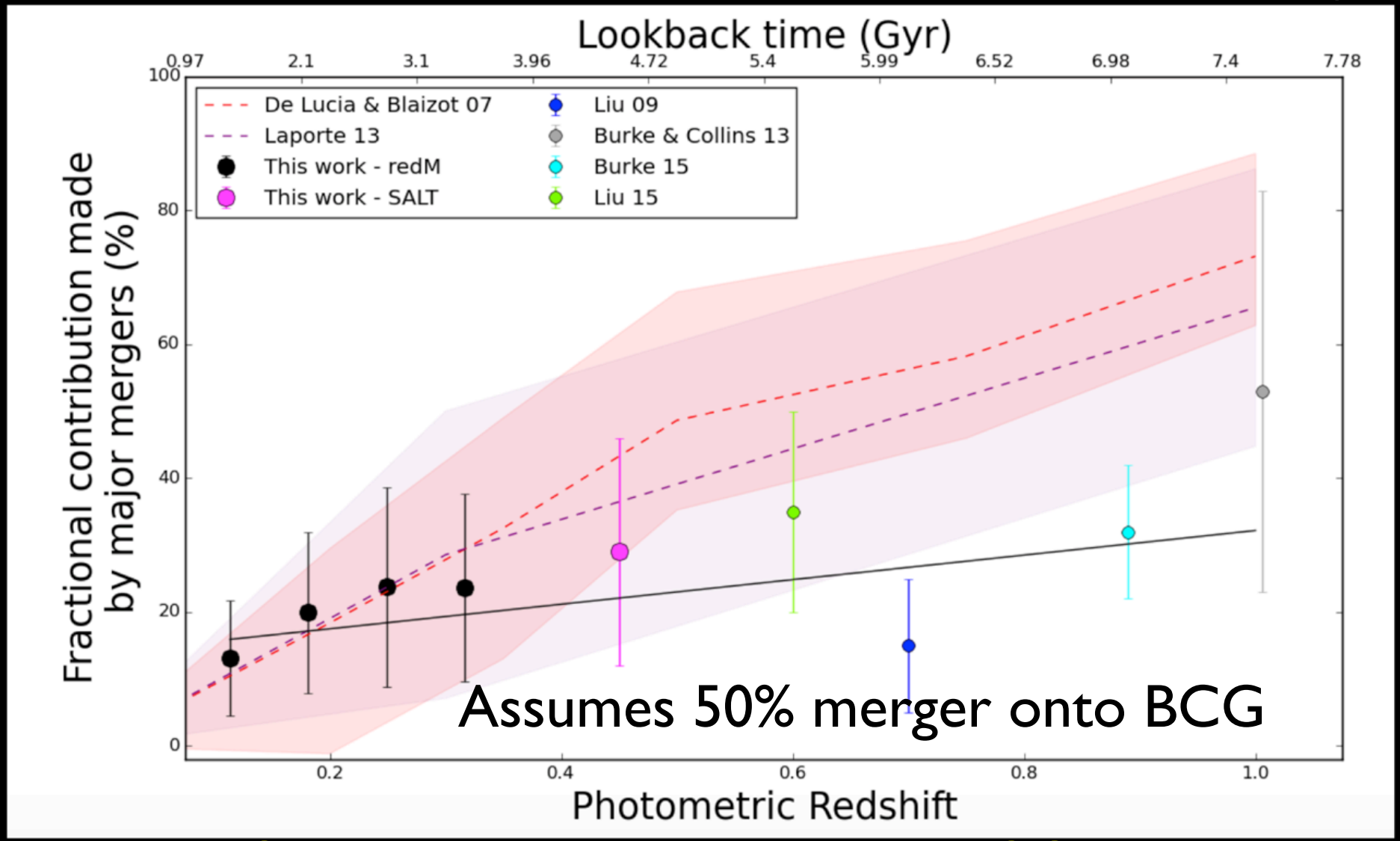


Fraction of total companion mass vs mass ratio with BCG for CLASH (red) and BC13 (blue) at same detection limit

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

- Major mergers (~1:1 – 1:2) dominate at z~1, whereas by z~0.4 major mergers rare and minor mergers (>1.2 - 1:20) dominate

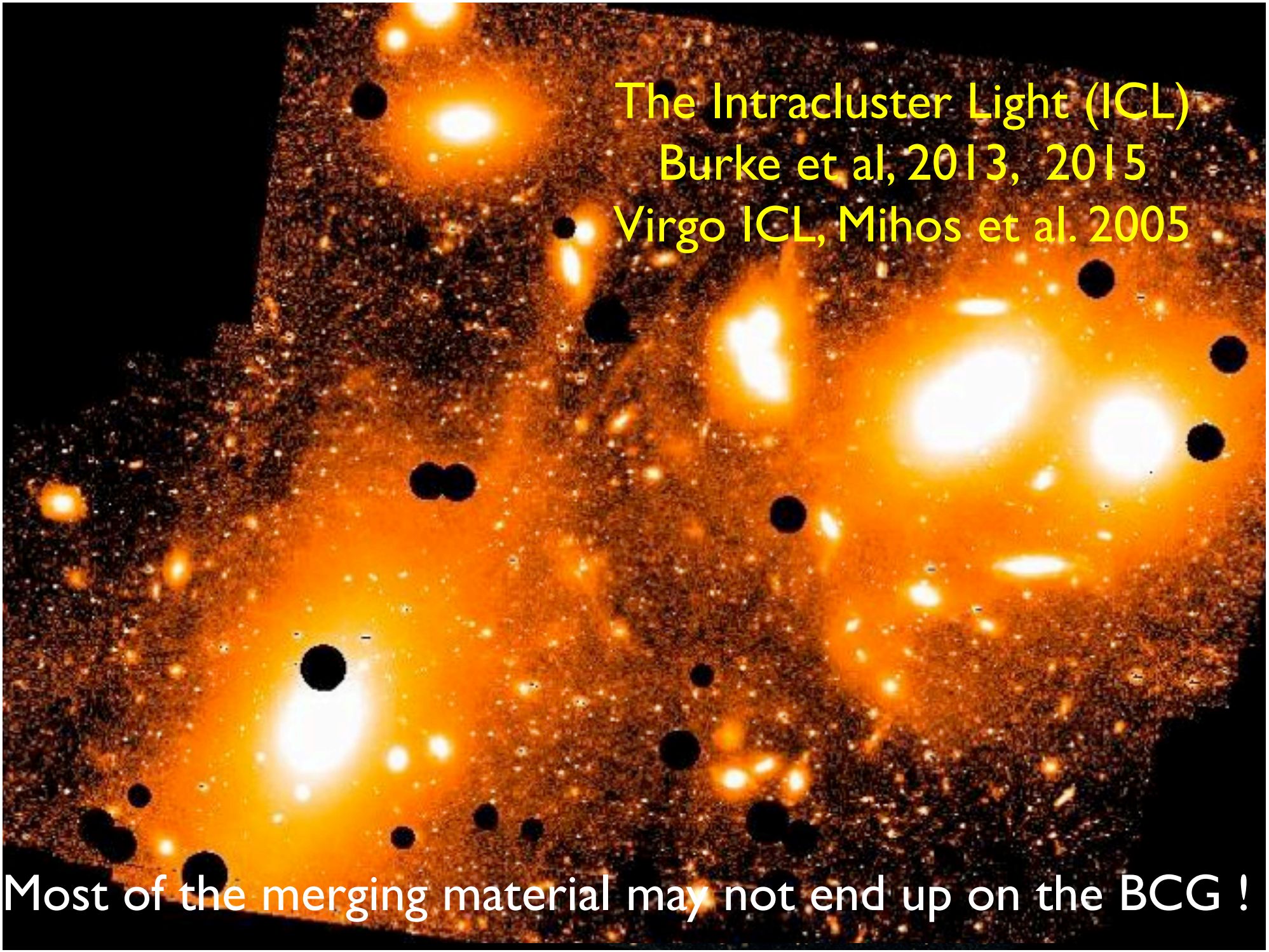
Groenewald et al 2017; BCG fraction of major mergers



Contribution to present day BCG mass:

20 - 40% mass growth of BCG from mergersSuffic

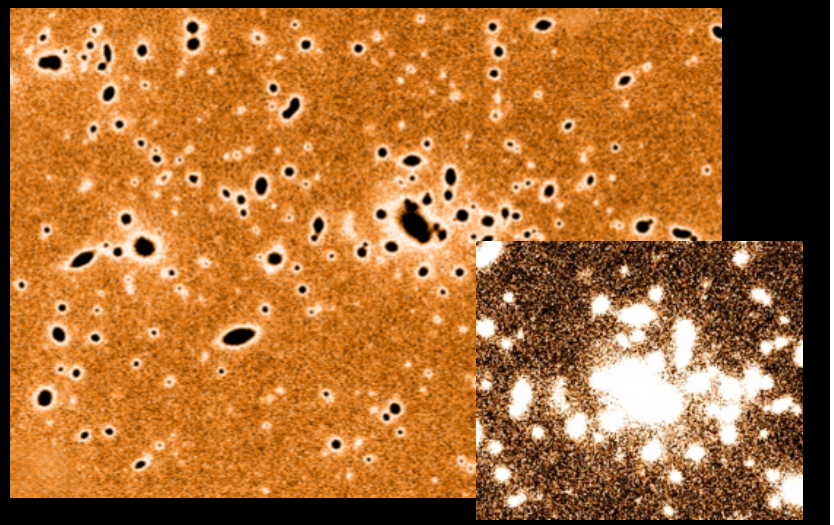
Sufficient material available for ICL growth : 10^{11}-10^{12}Mo


The Intracluster Light (ICL)
Burke et al, 2013, 2015
Virgo ICL, Mihos et al. 2005
Most of the merging material may not end up on the BCG !

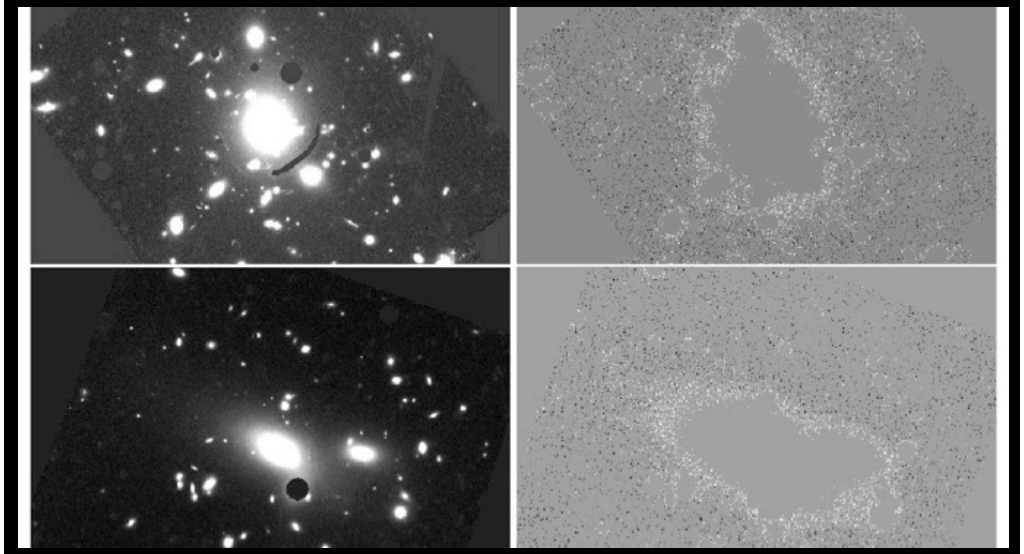
ICL in z~1 clusters

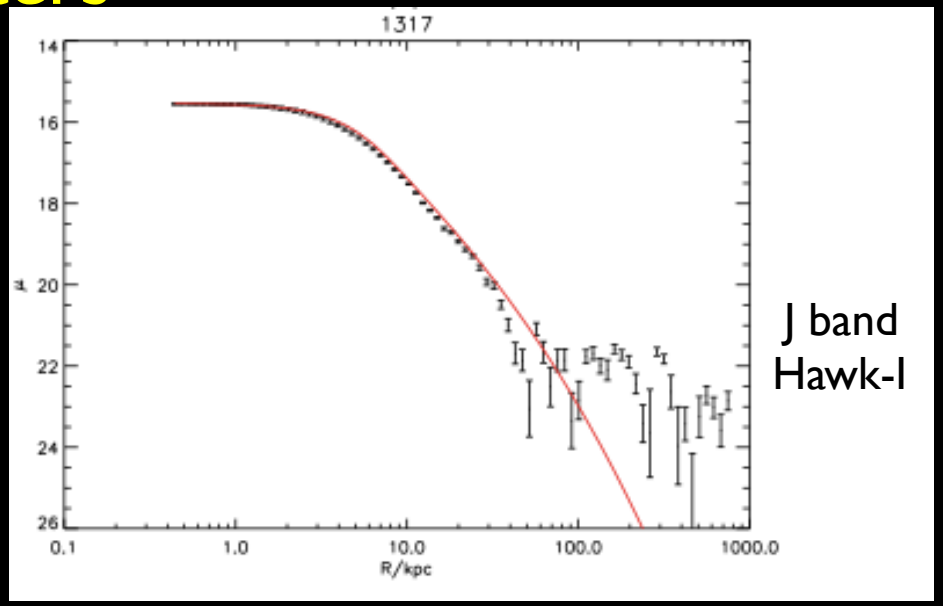
3-4 hr VLT, Hawk-I, J band

800 kpc



ICL in 0.2<z<0.9 CLASH clusters



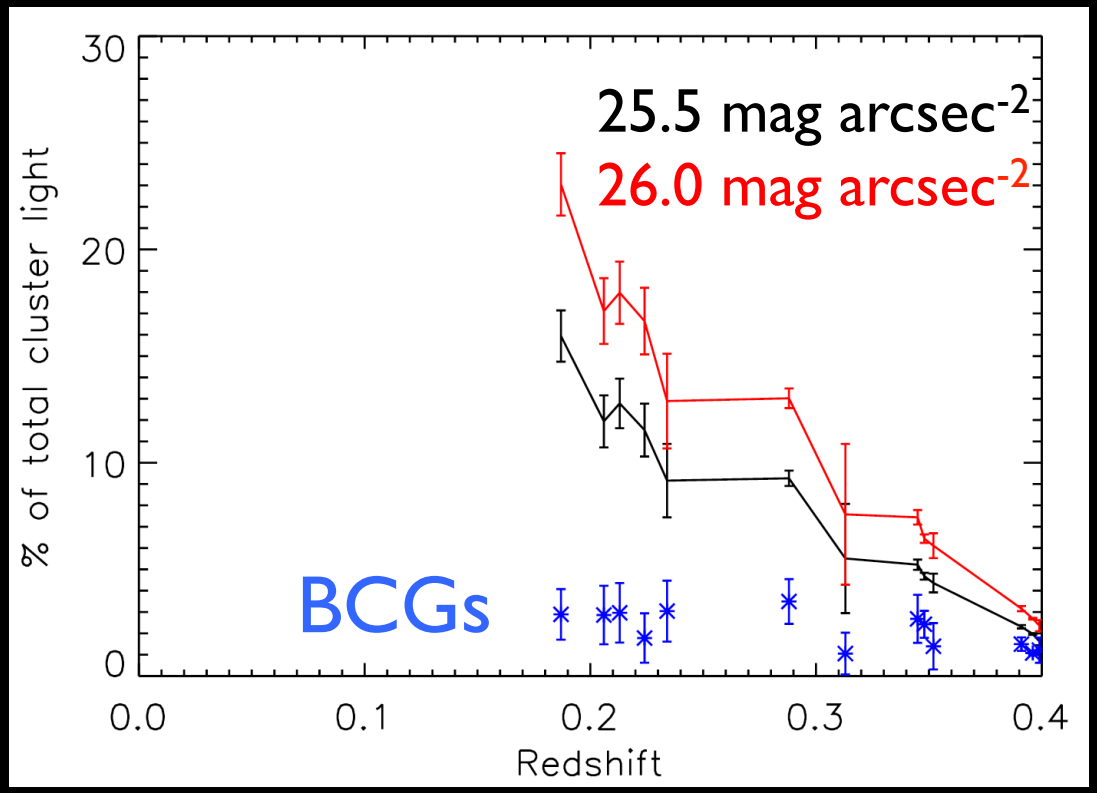


J band
Hawk-I

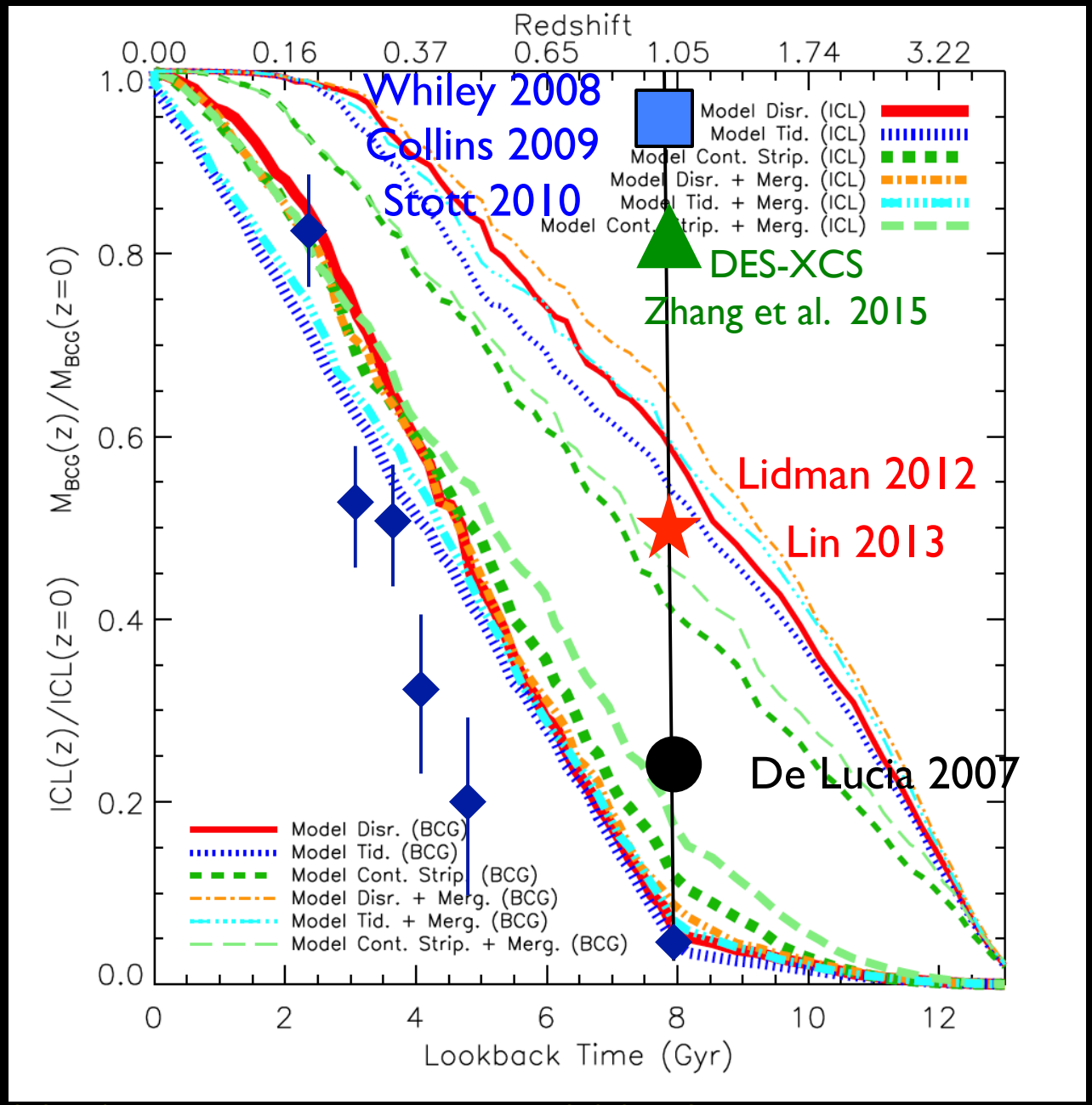
For clarity ICL Defined as all pixels below limiting SB e.g. 25 mag arcsec^{-2} (B)

We do not fit profiles !

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)
- Comparable contributions at higher z (Burke et al. 2013)



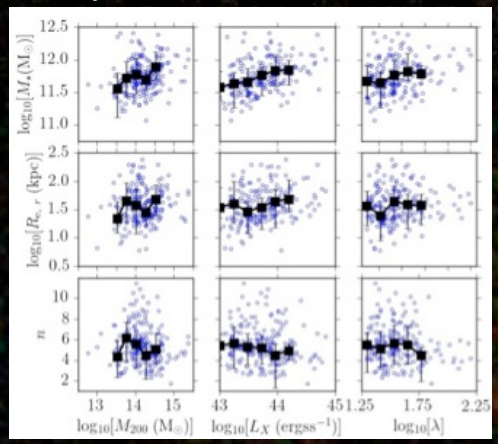
Contini et al. 2014 – updated De Lucia 2007 SAM predictions

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

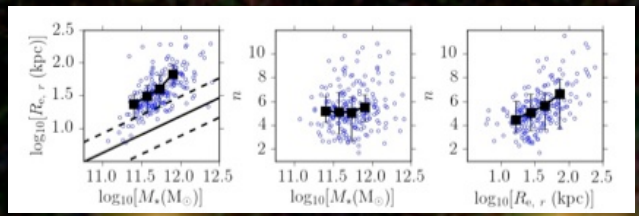
BCGs and the Cluster Environment

Furnell, Collins et al., 2017 (in collaborative review): SEE POSTER

- SPIDERS is a survey as a part of SDSS-IV dedicated partially to spectroscopic follow-up observations on X-ray clusters (eventually eROSITA) in eBOSS footprint - currently CODEX
- Created visually-inspected sample of 329 BCG candidates from SPIDERS data, which were then fitted with Sersic profiles using the SIGMA pipeline (see Kelvin et al, 2012)
- Tested fit reliability thoroughly using simulated profiles in SDSS data
- Computed cluster velocity dispersions as a proxy for mass, alongside X-ray luminosity and redMaPPer richness
- Found *strong correlations* between BCG size and stellar mass and between BCG mass and cluster environment
- However, *little influence of environment on mass-size relation*



Left: Correlations between BCG and cluster properties. As is visible, there is a correlation present with stellar mass, but little evidence for any independent environmental influence on the structural parameters.



Above: Correlations between intrinsic BCG properties. The leftmost plot is the mass-size relation, with the line marking the general relation for SDSS n > 2.5 galaxies from Shen et al., (2003)

Background: examples of BCGs from SPIDERS

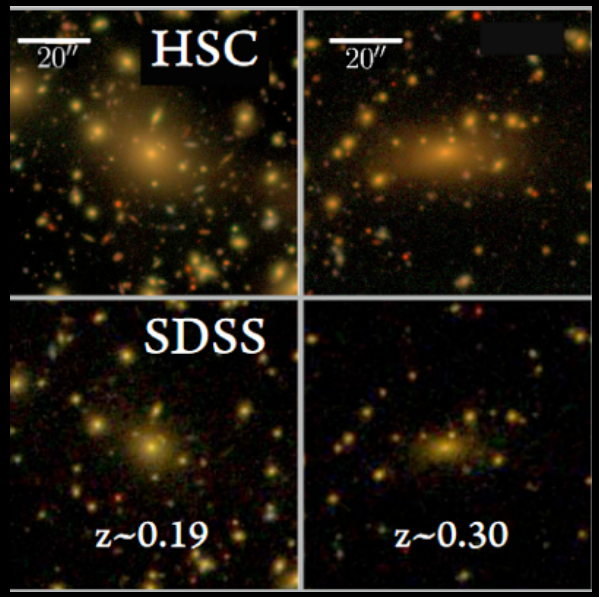
Similar results to Zhao et al 2015

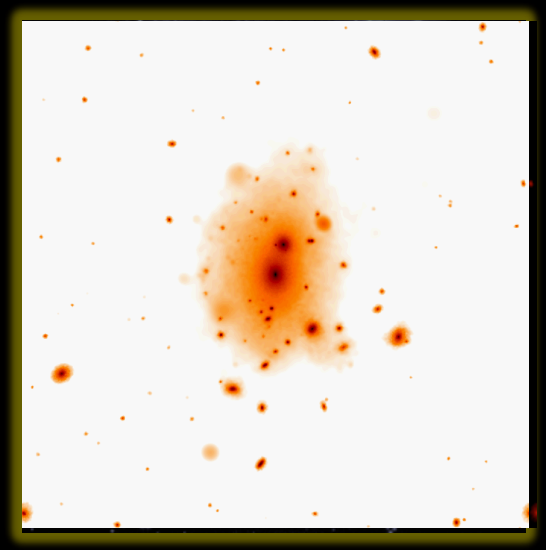
The ICL in XCS-HSC & C-EAGLE

Furnell, Collins, McCarthy et al., (in prep)

- The XMM-Cluster survey (XCS-DR2) has an overlapping sample of 202 $0 < z < 0.8$ clusters in the Hyper-Suprime Cam footprint (179 with GMPHorCC photo-z, 79 with SDSS spec-z)
- Clusters have X-ray luminosities, centroids and temperatures from deep XMM imaging.
- The HSC-DR1 release consists of deep optical data (~26 mag/arcsec in WIDE-*i*), with the potential to probe the ICL
- Comparisons between self-similar measurements from HSC data and mock images/X-ray data from C-EAGLE will provide direct constraints on the formation and nature of the ICL

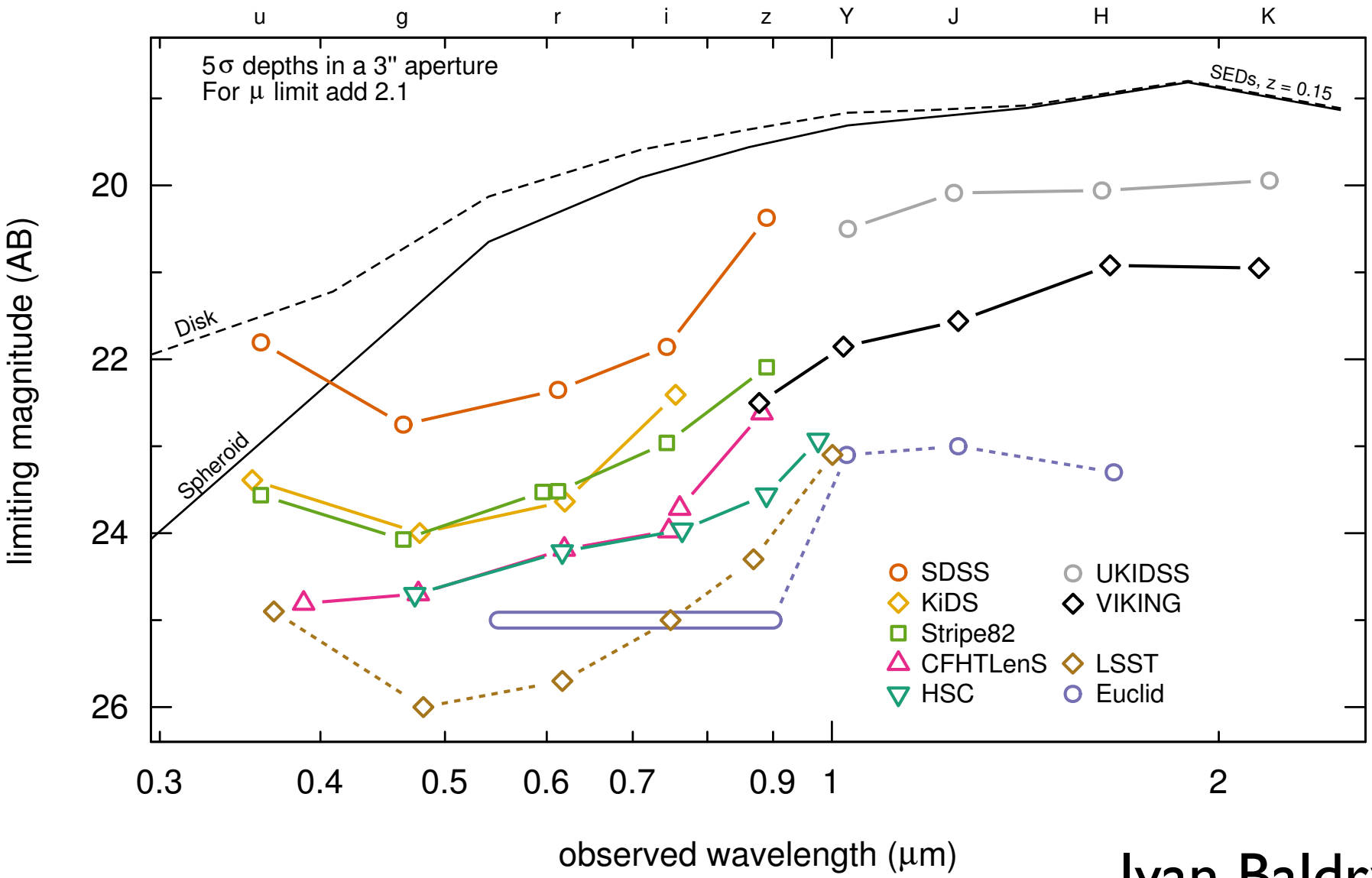
Comparison between BCGs in HSC and SDSS data, Huang et al., (2017)





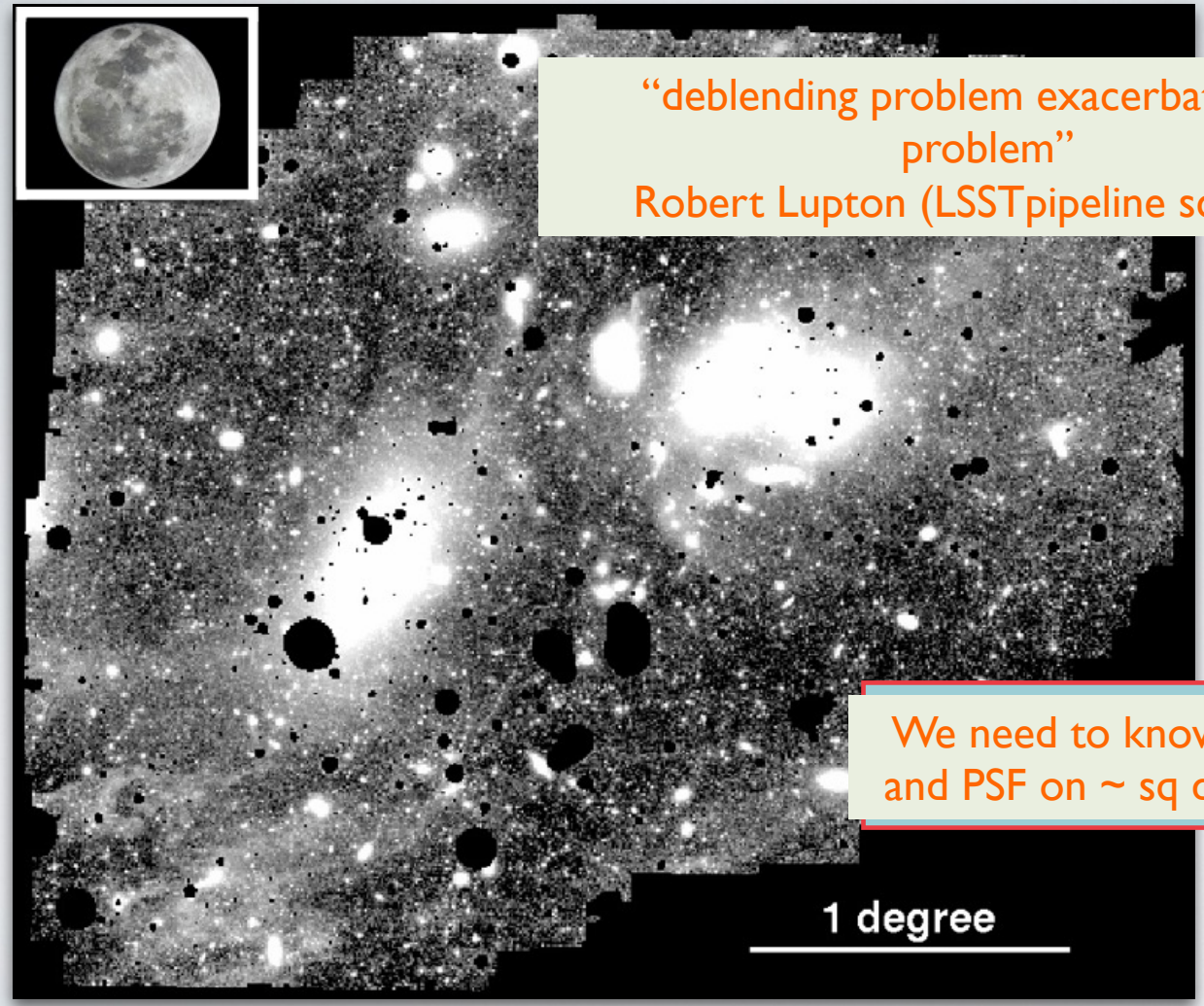
Example cluster (stellar surface brightness) from C-EAGLE

SURVEY LIMITING SURFACE BRIGHNESS



Ivan Baldry

LSST – extracting low SB extragalactic structure will be hard



"deblending problem exacerbates ICL problem"
Robert Lupton (LSSTpipeline scientist)

Virgo seen by LSST in a few exposures

We need to know FF pattern and PSF on ~ sq degree scales

[Mihos et al., 2005]

Maintaining Integrity of low SB flux with LSST

•Observing strategy: running median to detrermine sky, psuedo random dithering with rotation pointings – determine sky close in time and space to science observations, see Burke et al., 2013; VST Fornax Cluster Survey (Iodice at al., 2016)

•Clever sky subtration e.g colours, difference imaging to identify artifacts, scattered light, PSF control

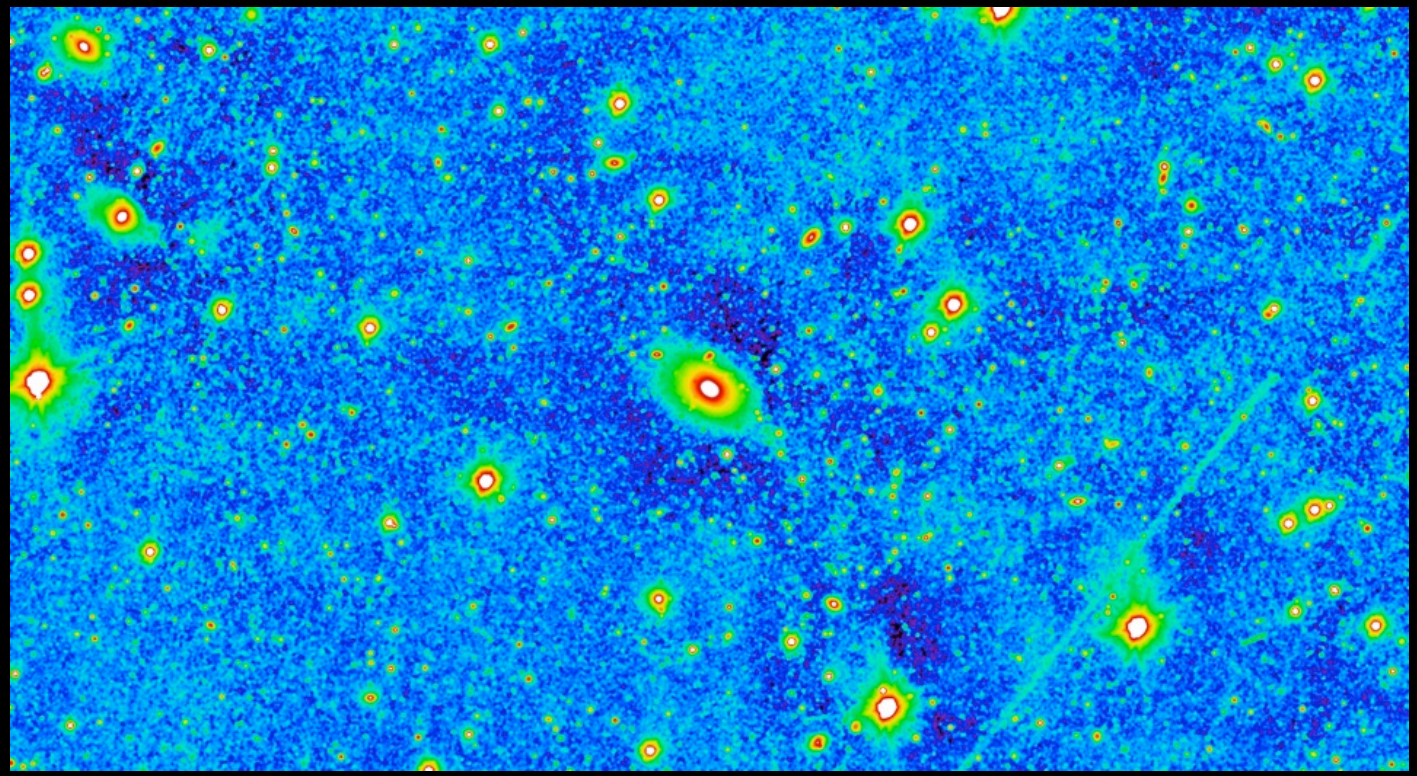
We have the ability to change the above for LSST but fixed for existing datasets, therefore we've developed

➡ Post divot correction (Kelvin et al. 2017)

"Divot Problem"

e.g. KiDS ~500x200 arcsecs; R band

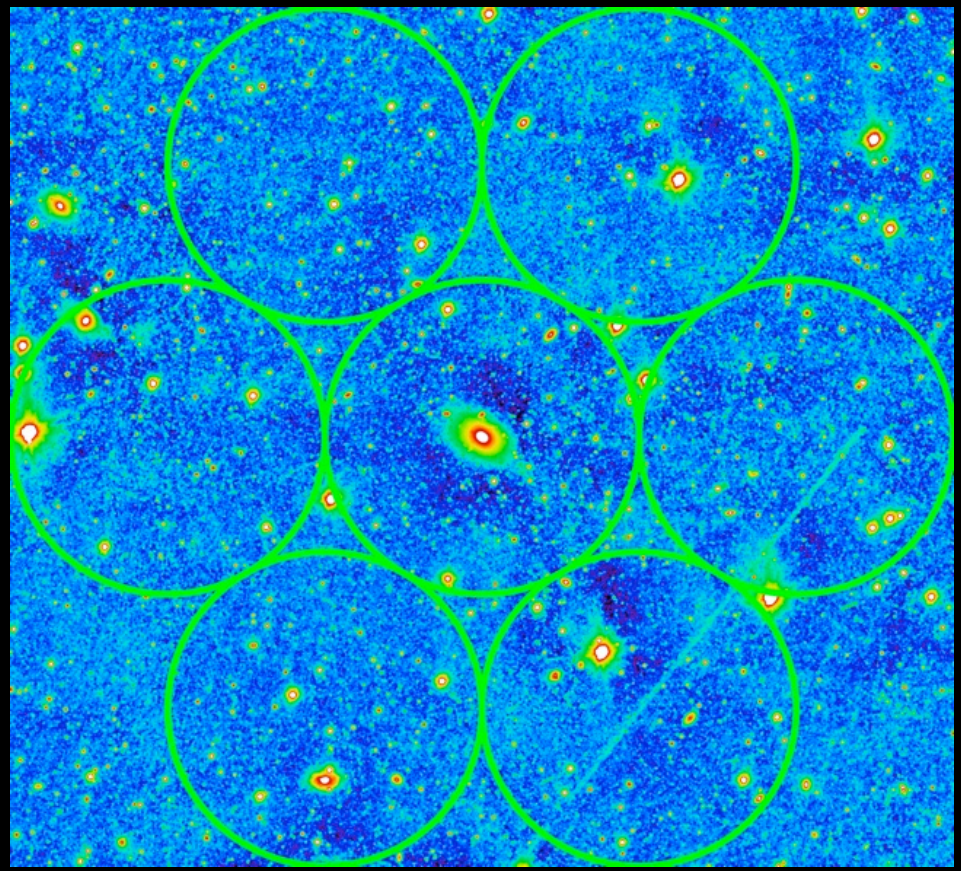
Lee Kelvin (2017, in prep)



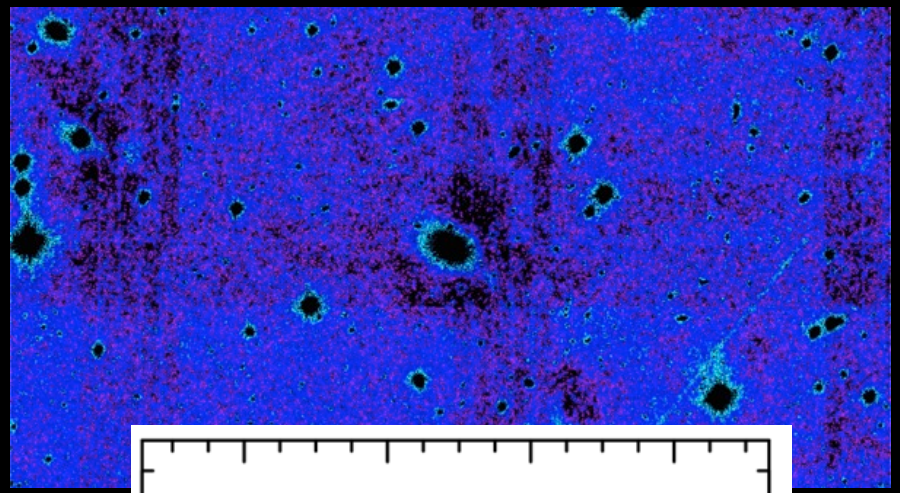
Biased background: over aggressive sky subtraction within KiDS AstroWISE pipeline. Worse for bright & LSB sources. Seen also in SDSS, Stripe82, CFHTLenS, UKIDSS and Viking

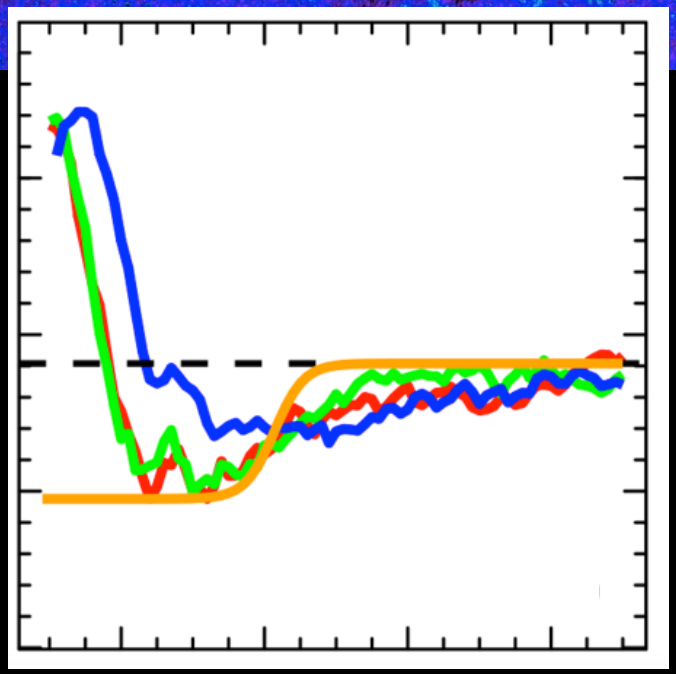
KiDS post divot correction

Lee Kelvin (2017, in prep)



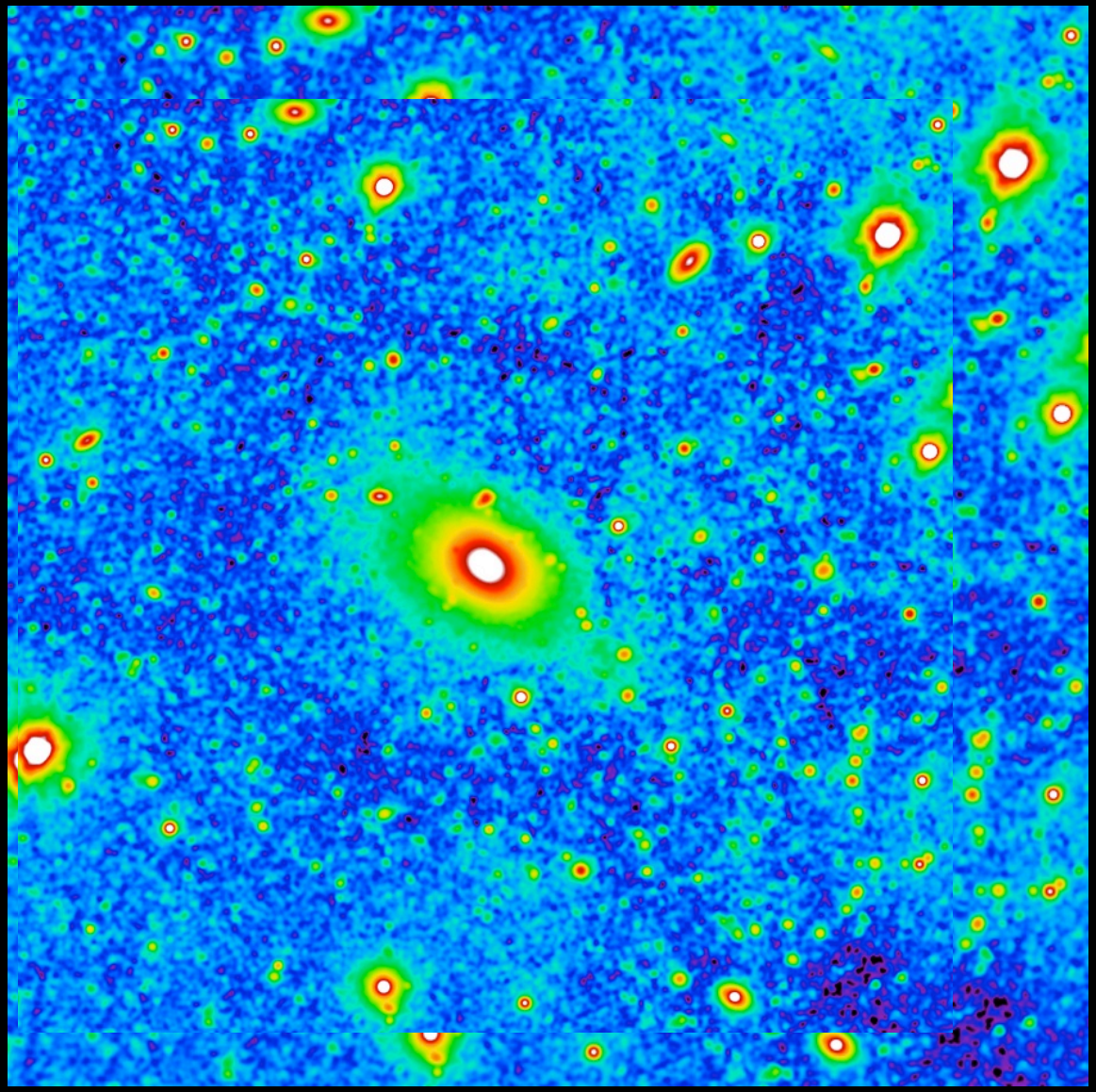
Sigma-clipped image



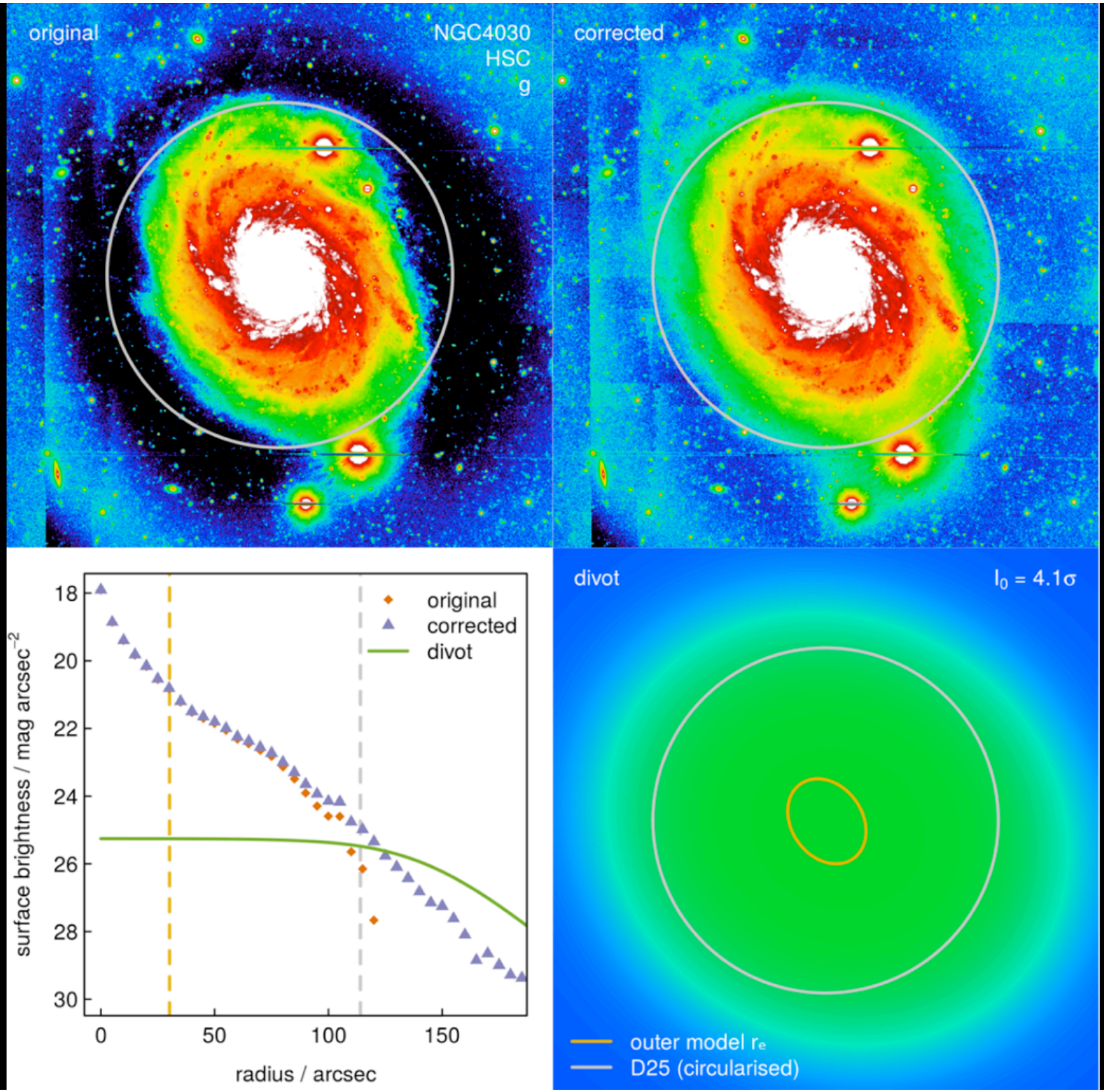


Fit "tanh function" to each divot

Lee Kelvin (2017, in prep)

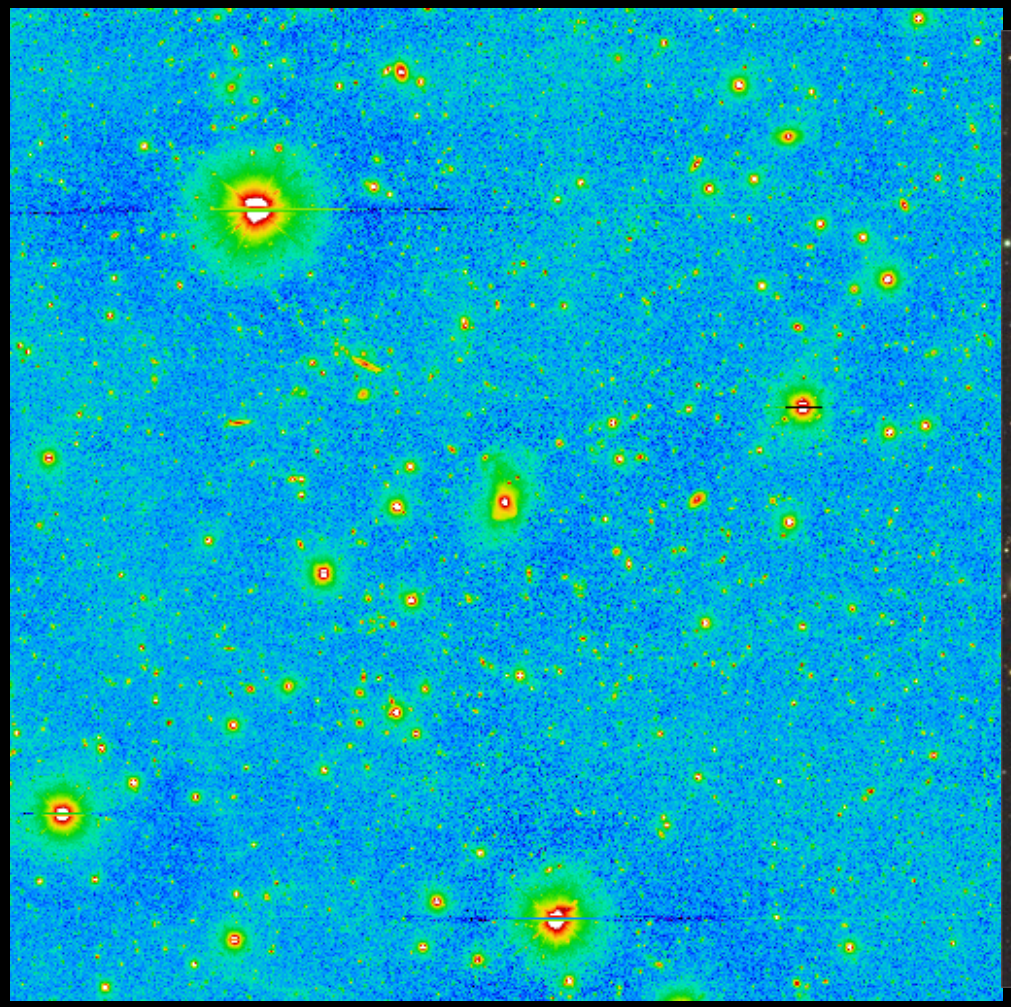


sky profile correction


original
NGC4030
HSC
g
corrected
original
corrected
divot
surface brightness / mag arcsec^{-2}
radius / arcsec
18
20
22
24
26
28
30
0
50
100
150
divot
I_0 = 4.1σ
outer model r_e
D25 (circularised)

LSST divot problem needs to be quantified

HSC DRI R band 10 arc mins reduced with current LSST pipeline



SDSS DR9 colour image

Summary/Future Work

- Major mergers dominate mass growth at z~1, whereas Minor mergers are more significant at lower z.
- Large fraction of this mass appears as diffuse ICL rather than BCG photospheric light.
- ICL forms late (z<1), reaching ~ few 10^{11} M_o , even 10^{12} M_o.
- Analysis of parameters for 329 SPIDERS BCGs shows little environmental dependence
- Direct comparisons of HSC data with C-EAGLE mocks
- Need ICL simulations using HSC data and feedback to LSST pipeline team