Galaxy Clusters Hunters

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INCT do e-Universo

LSST: Brazilian Participation Group

South American Workshop on Cosmology in the LSST Era

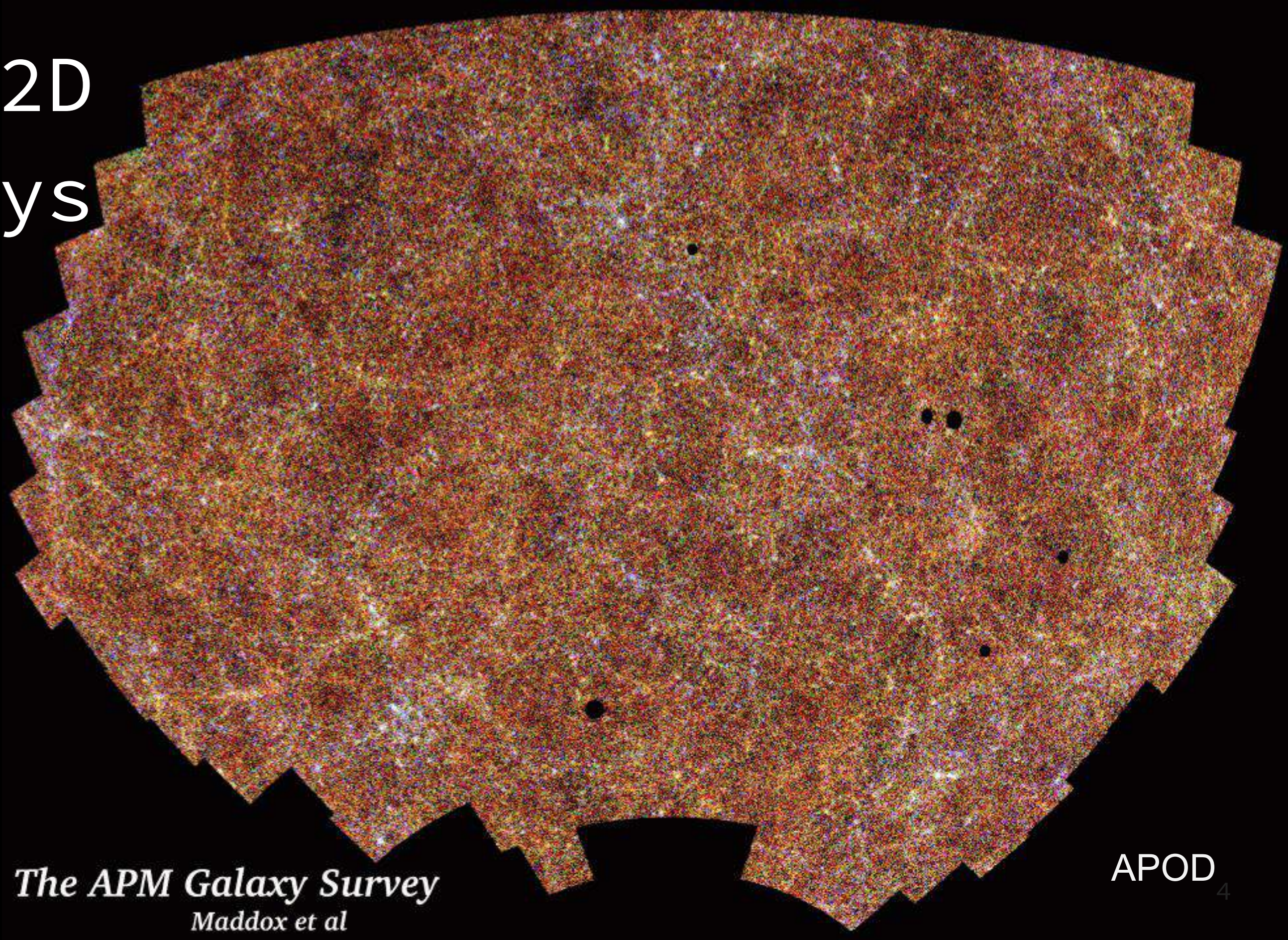
ICTP SAIFR

MATTER DISTRIBUTION IN SPACE

"São Paulo"
Thierry Cohen

90'S REVOLUTIONS

First large 2D galaxy surveys



APOD

Detailing the structures with spectra

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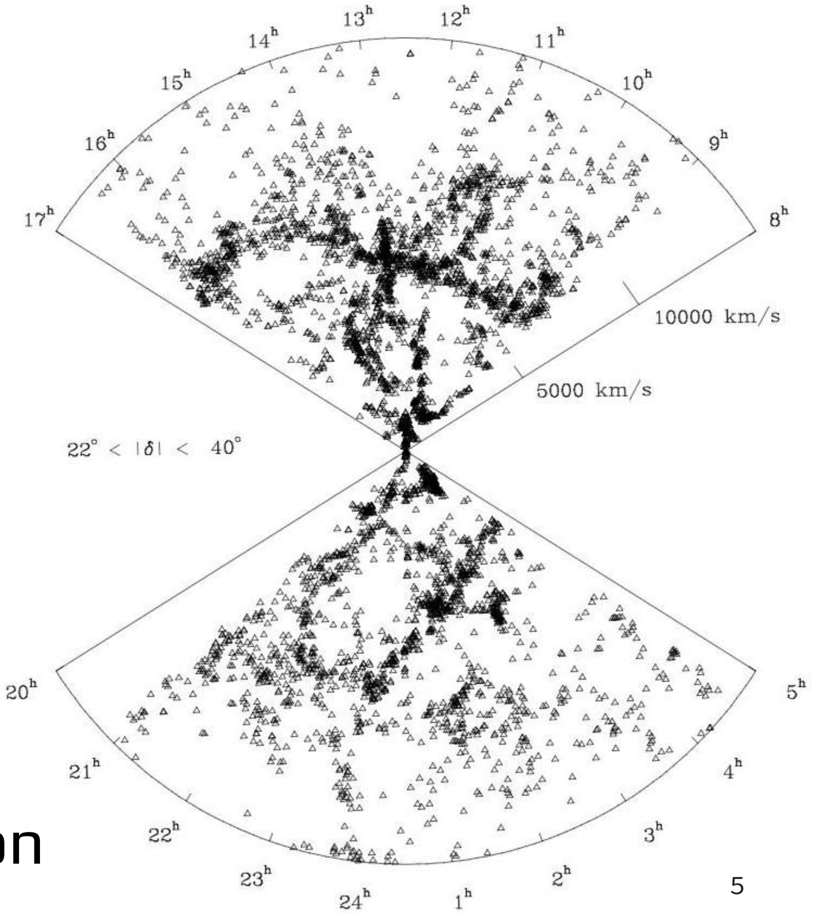
- CfA2
  - Geller & Huchra 1989
- SSRS2
  - da Costa et al. 1994

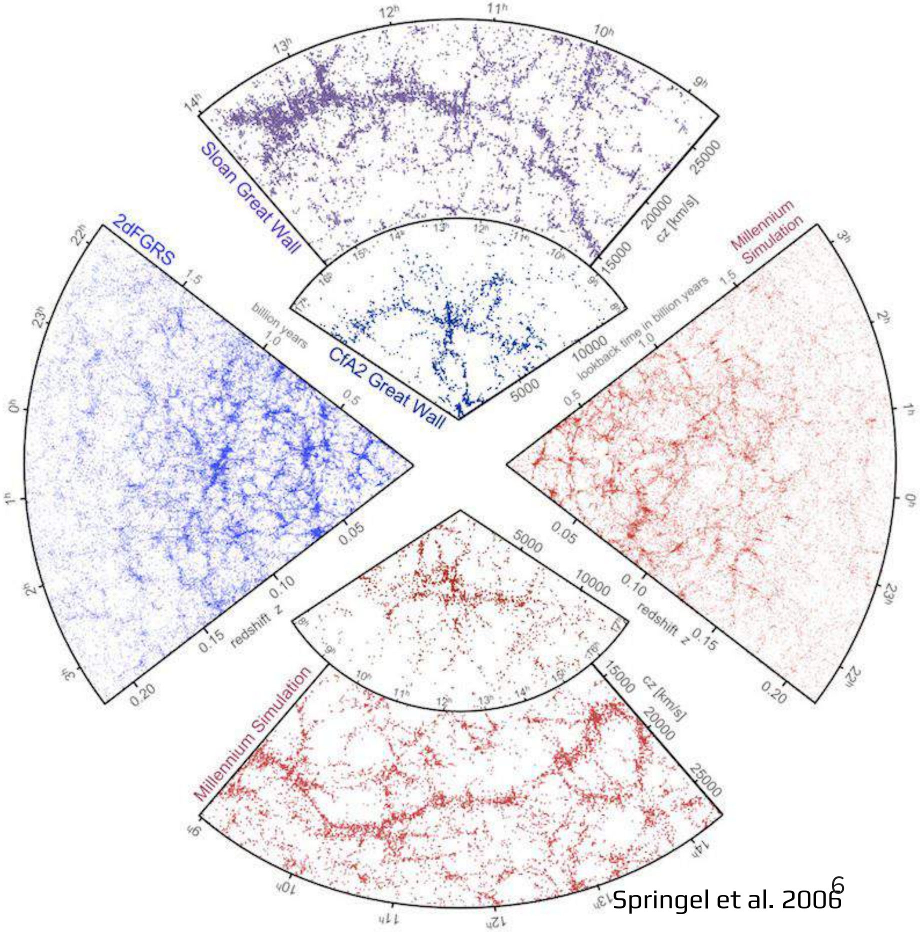
O Reticon, primeiro detector eletrônico utilizado no OAB, 1982
FONTE: LUIZ ALBERTO NICOLACI, ACERVO PESSOAL

Reticon



More observations and simulations

- 2dFGRS and SDSS
  - large samples
  - clustering versus physical properties
    - luminosity
    - color
    - stellar mass

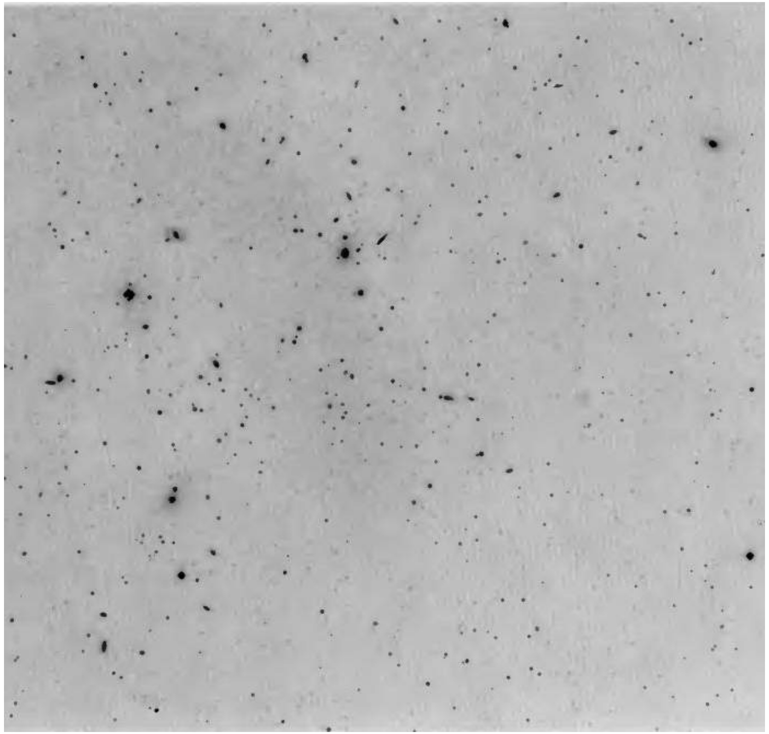


Springel et al. 2006

HOW TO DETECT A GALAXY CLUSTER?

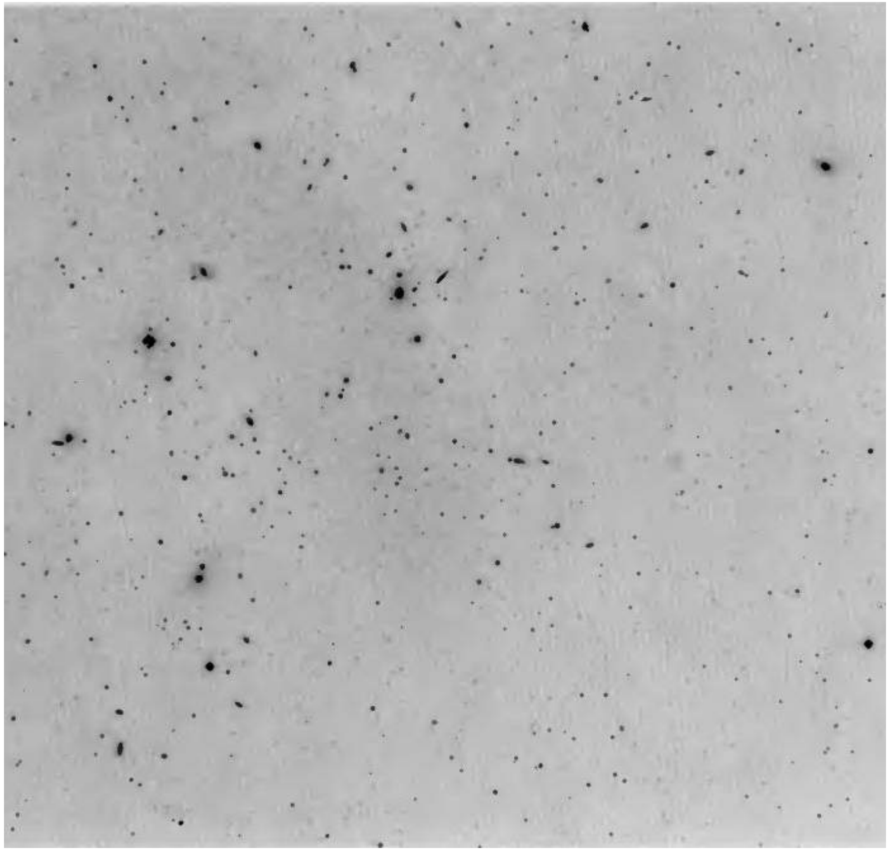
Galaxy Cluster optical samples

- Abell (1958)
  2,712 rich clusters
  $z \leq 0.2$

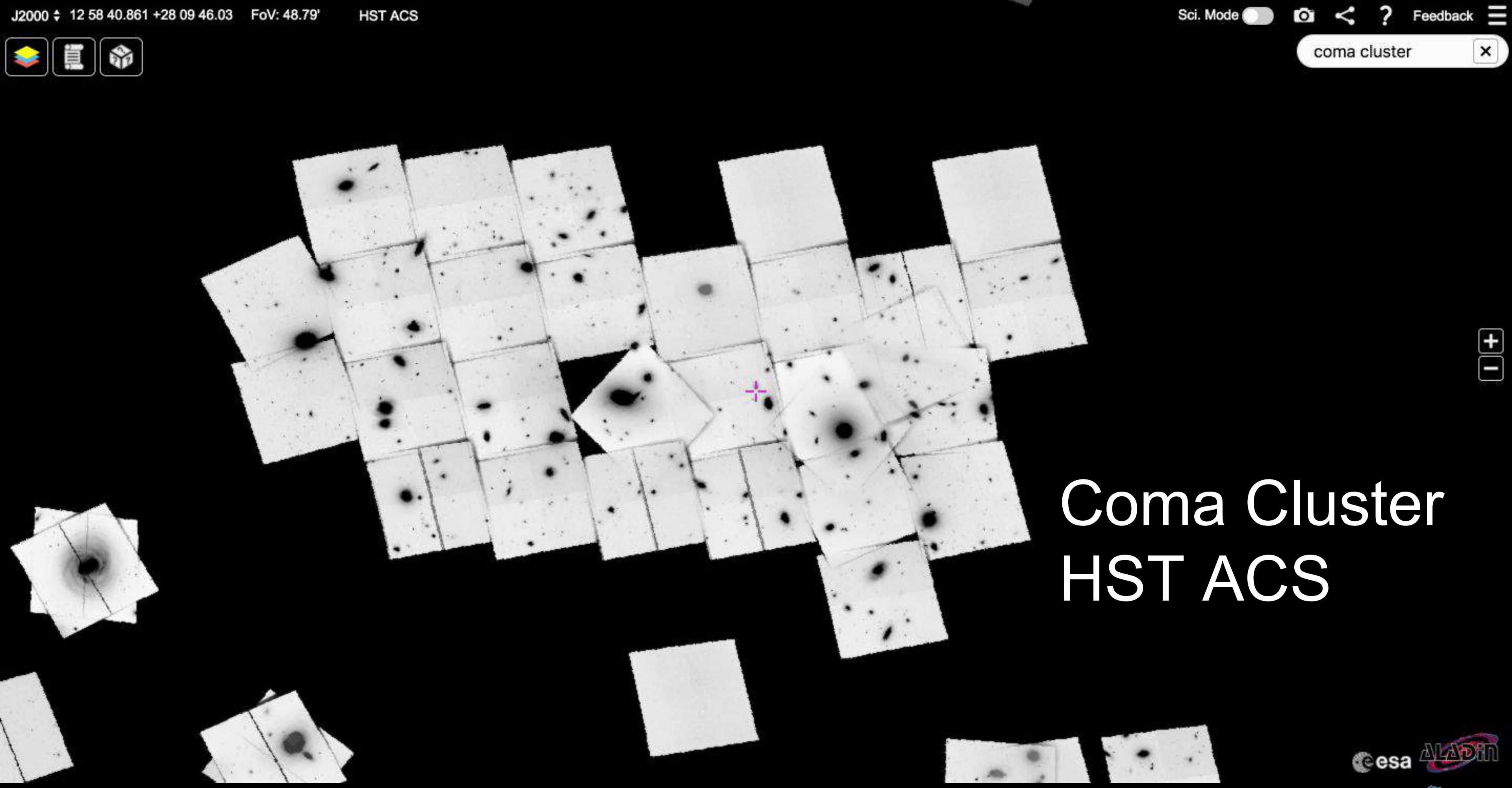


Leo Cluster.

Galaxy Cluster optical samples



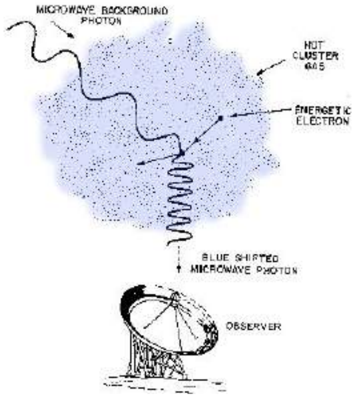
Leo Cluster. Waid Observatory

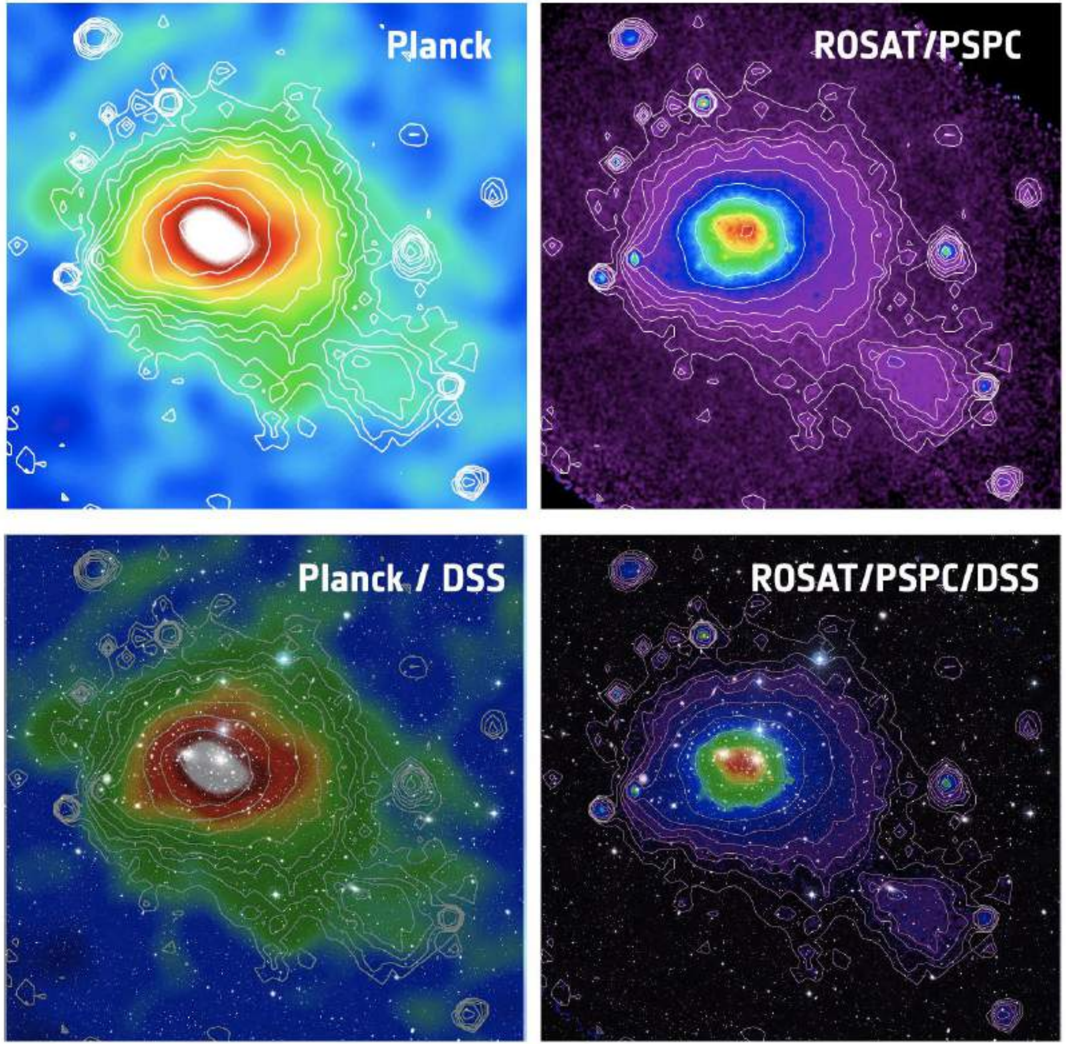


Coma Cluster
HST ACS


SDSS III
Southern Galactic Cap
Northern Galactic Cap

SZ effect

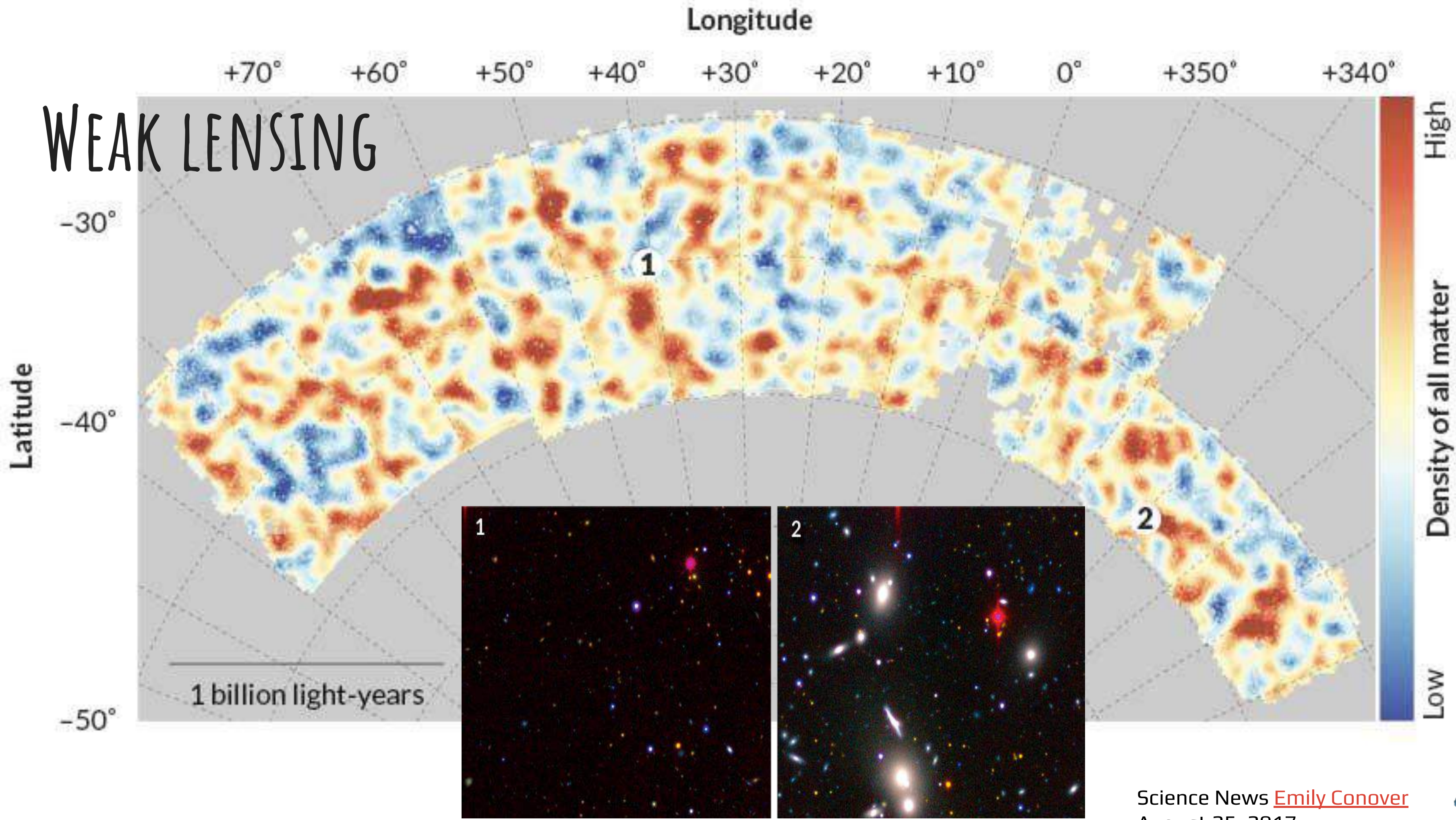




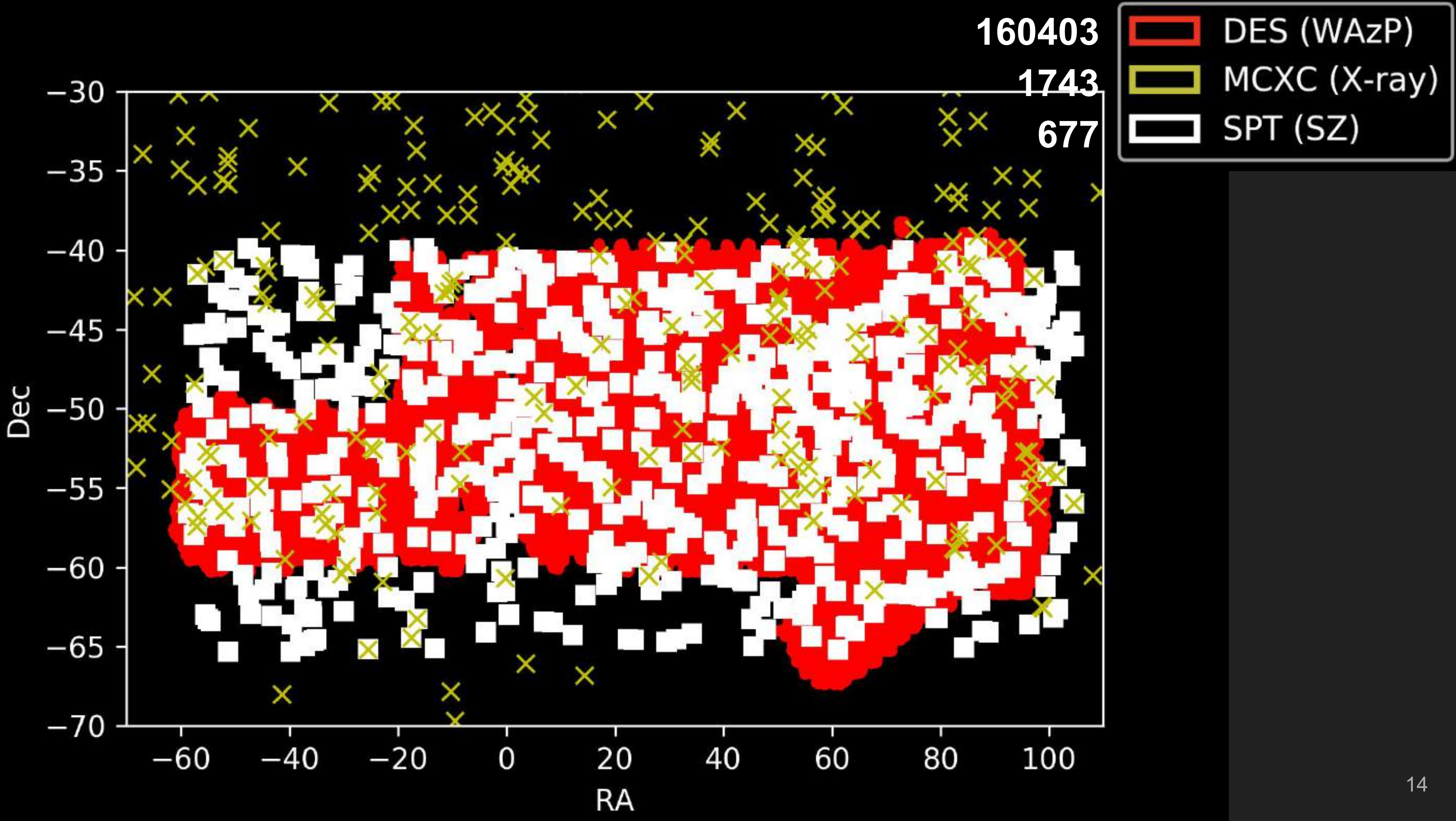
X-ray

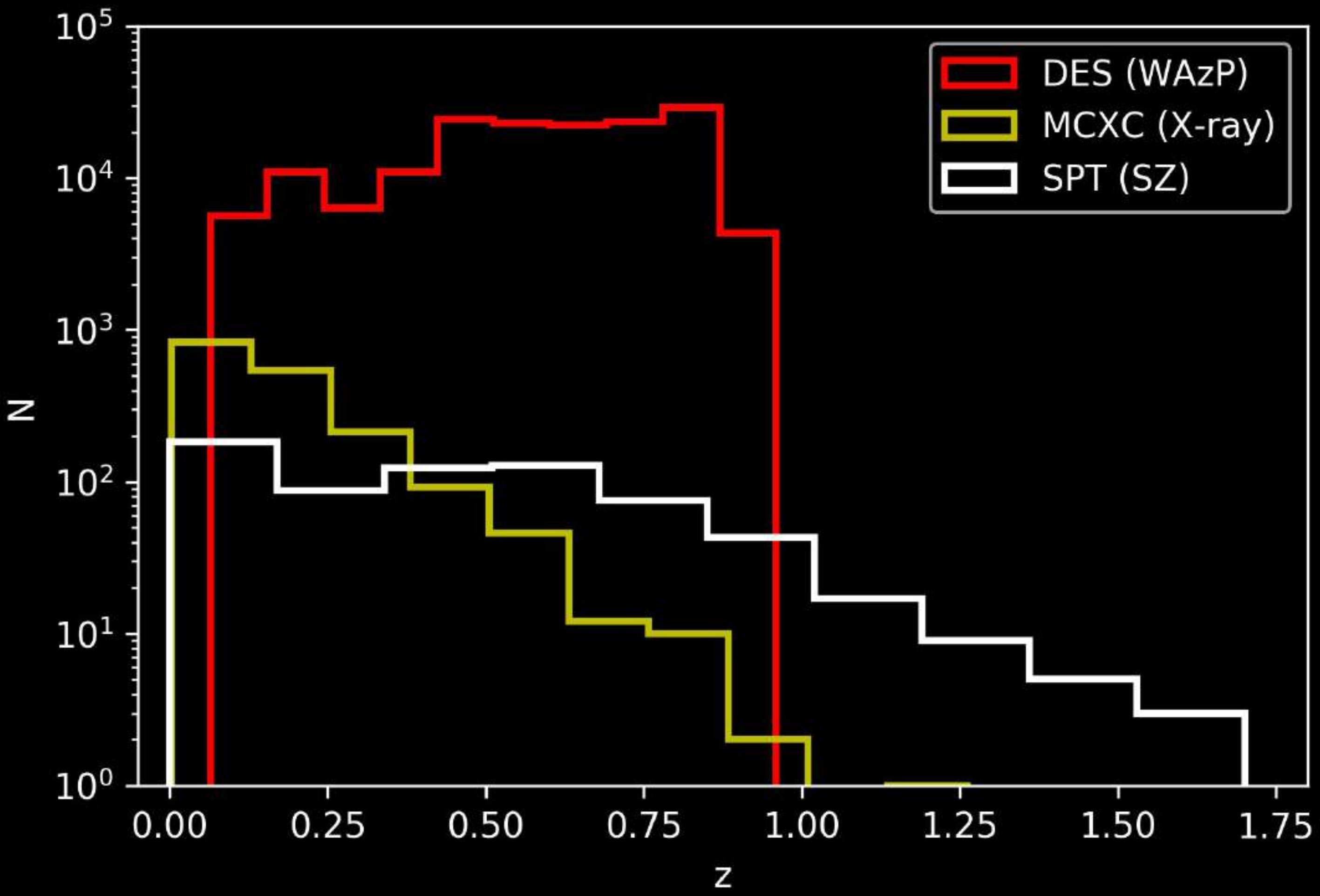
Coma cluster (Abell 1656)

Weak lensing



Science News Emily Conover
August 25, 2017


160403
1743
677
DES (WAzP)
MCXC (X-ray)
SPT (SZ)
Dec
RA
−30
−35
−40
−45
−50
−55
−60
−65
−70
−60
−40
−20
0
20
40
60
80
100



DES (WAzP)
MCXC (X-ray)
SPT (SZ)
N
z
10^0
10^1
10^2
10^3
10^4
10^5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75


Southern Galactic Cap
Northern Galactic Cap
SDSSIII

SDSS galaxy cluster Samples (all reportedly very pure and complete*)

Authors	Publication	# clusters	z max
Miller et al.	2005 AJ 130 968	750	0.17
Koester et al.	2007 ApJ 660 239	14,000	0.30
Wen et al.	2009 ApJS 183 197	40,000	0.60
Hao et al.	2010 ApJS 191 254	55,500	0.55

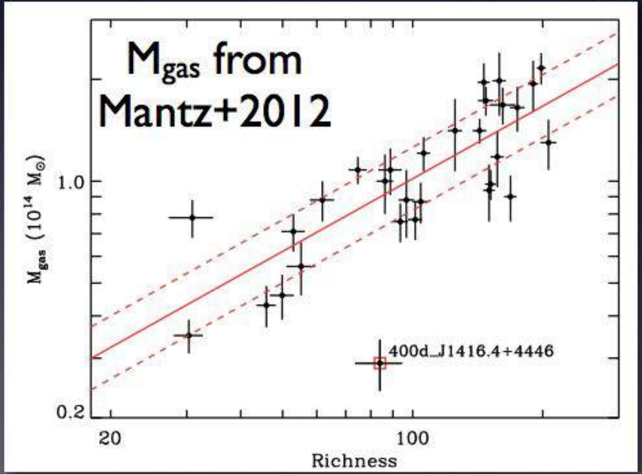
* low contamination and detect most of true clusters

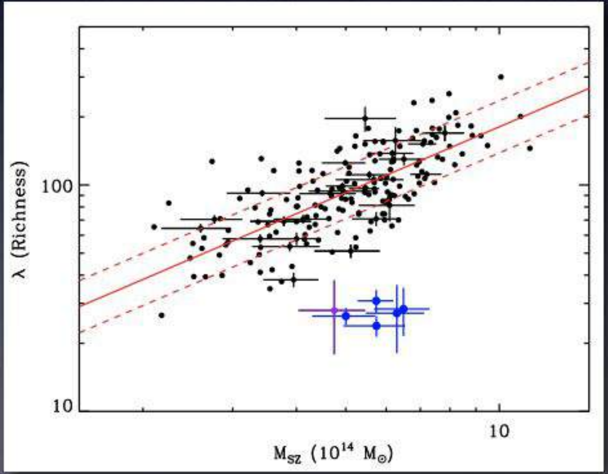
redMaPPer

- The "red-sequence Matched filter Probabilistic Percolation" algorithm has all this... and more!
  - Computationally efficient: can run on 5000 deg^2 of DES data in ~500 CPU hrs
  - Works with limiting training samples
  - High purity and completeness
  - Low scatter mass proxy, λ
  - A probabilistic centering algorithm analogous to P(z) in position space

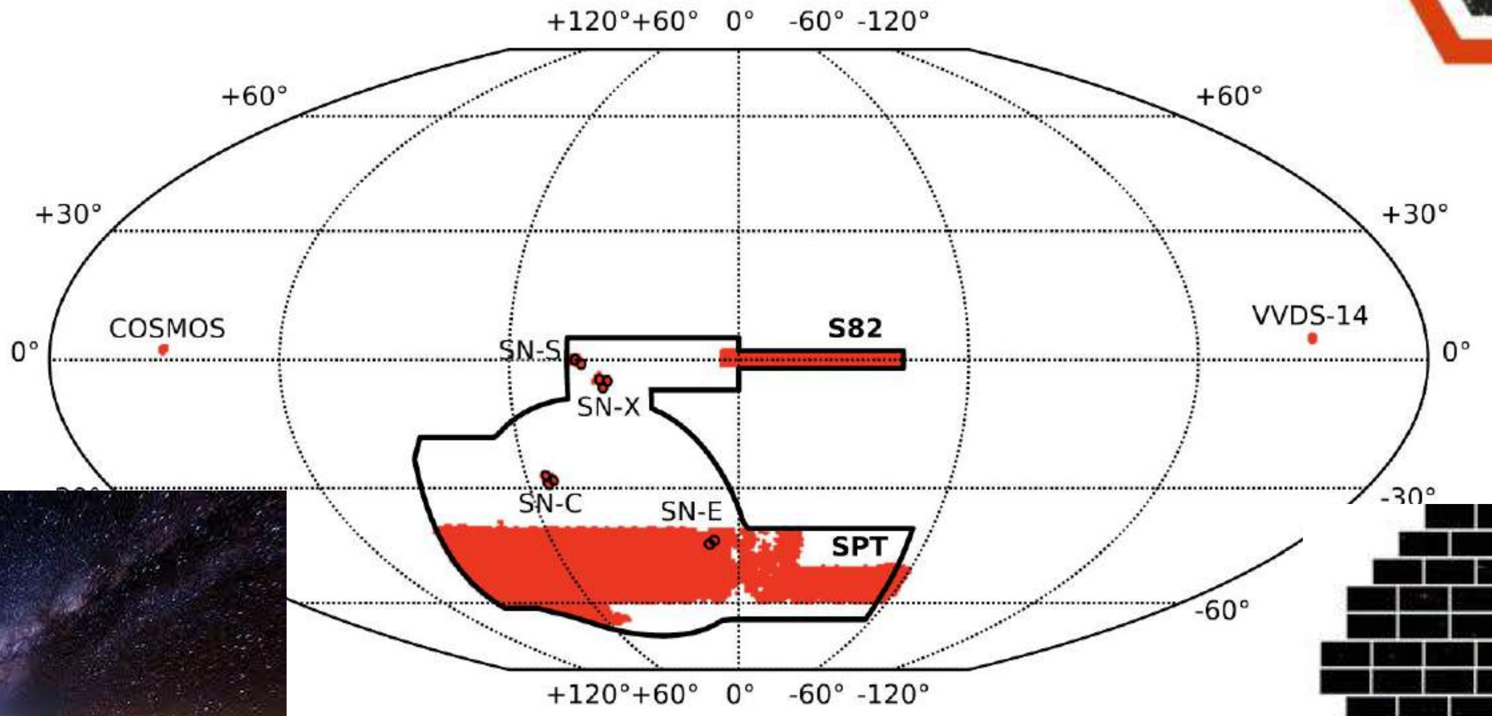
M_{gas} and M_{SZ} vs. λ

- Compare to well-measured X-ray clusters and Planck SZ clusters, mass scatter in λ is ~25%
  - Not fully corrected for optical selection





Dark Energy survey (DES)



Drlica et al. 2017

in the LSST Era

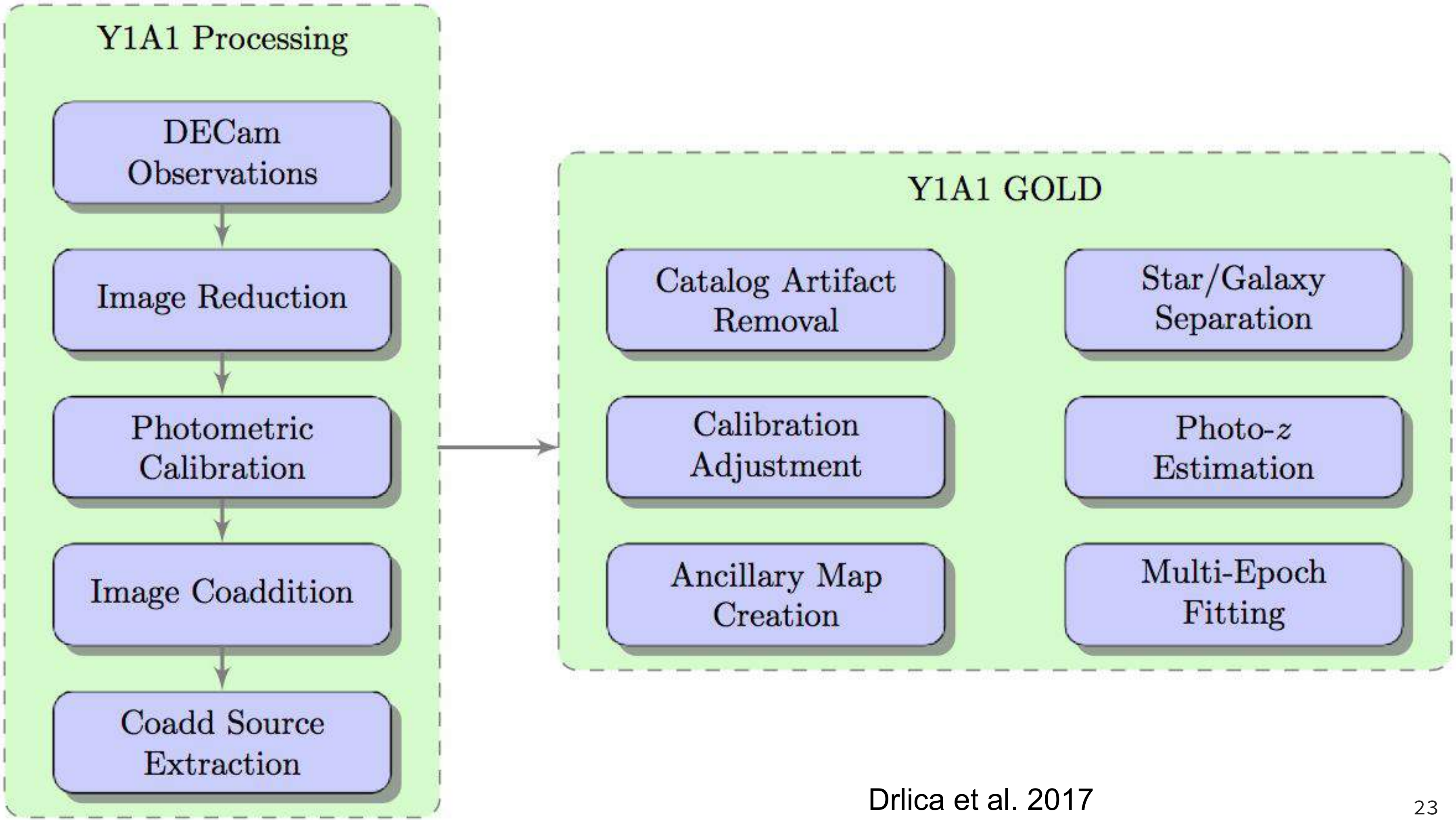
http://adsabs.harvard.edu/abs/2018ApJS..235...33D

Table 1. Y1A1 GOLD Data Quality Summary

Parameter	Band				
	g	r	i	z	Y
Median PSF FWHM	$1.25''$	$1.07''$	$0.97''$	$0.89''$	$1.07''$
Sky Coverage (in all bands)	1786 deg^2				1773 deg^2
Astrometric Accuracy	25 mas (relative); $<$ 300 mas (external)				
Absolute Photometric Uncertainty (mmag)	14	4	2	15	32
Relative Photometric Uniformity (mmag)	19	22	20	20	18
Completeness Limit (95%)	23.6	23.4	22.9	22.4	
Coadd Galaxy Magnitude Limit (10σ)[a]	$23.4^{+0.14}_{-0.40}$	$23.2^{+0.13}_{-0.37}$	$22.5^{+0.14}_{-0.34}$	$21.8^{+0.12}_{-0.37}$	$20.1^{+0.18}_{-0.33}$
Multi-Epoch Galaxy Magnitude Limit (10σ)[a]	$23.7^{+0.07}_{-0.40}$	$23.5^{+0.16}_{-0.29}$	$22.9^{+0.14}_{-0.30}$	$22.2^{+0.14}_{-0.32}$	...
Galaxy Selection ($i \leq 22$)	Efficiency $>$ 98%; Contamination $<$ 3%				
Stellar Selection ($i \leq 22$)	Efficiency $>$ 86%; Contamination $<$ 6%				

Drlica et al. 2017
https://arxiv.org/pdf/1708.01531.pdf

One year of DES superseded by couples of weeks of LSST observations 😱



Drlica et al. 2017
https://arxiv.org/pdf/1708.01531.pdf

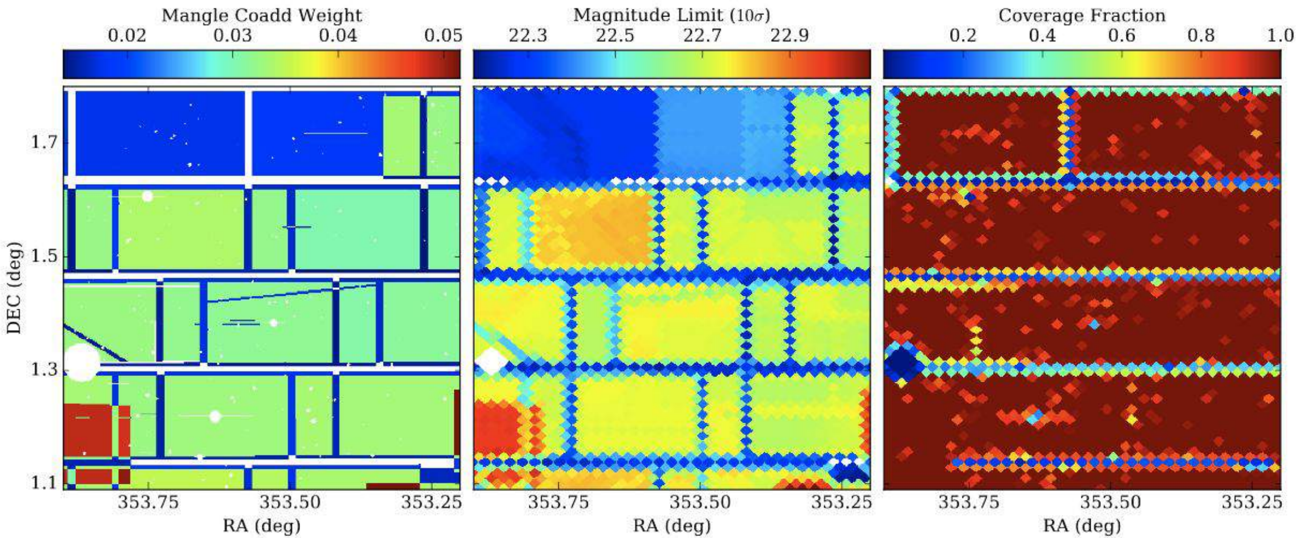
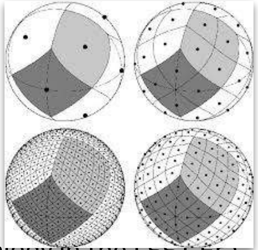
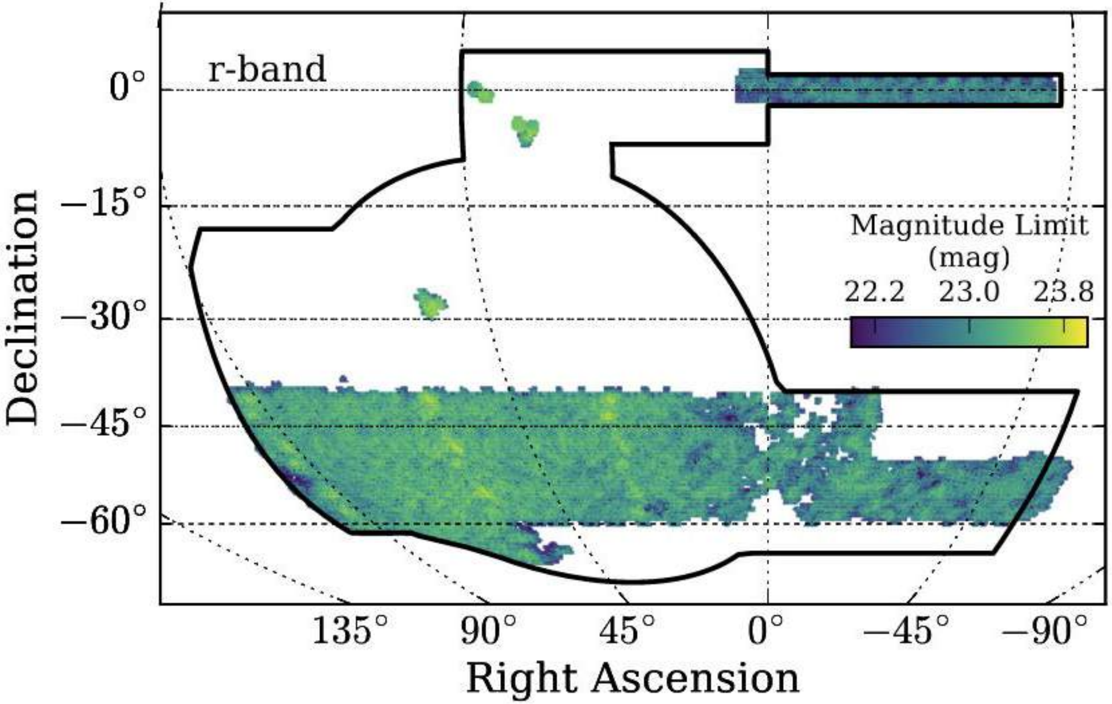


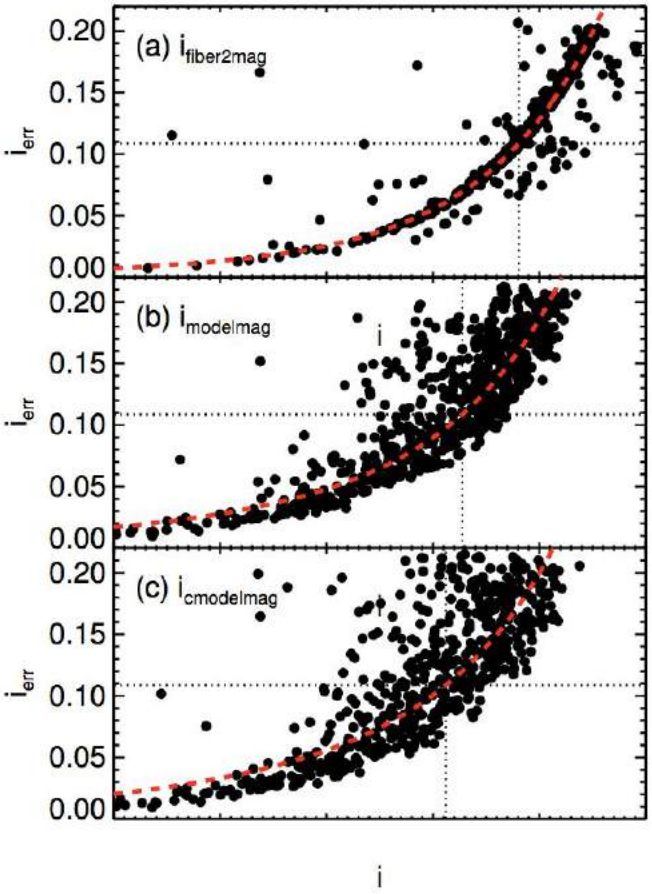
Figure 9. Coverage and depth maps for a single Y1A1 coadd tile. (Left) Vectorized **mangle** weight map for an r-band coadd tile. Satellite trails, star masks, and chip gaps are stored at full resolution. (Center) Pixelized 10σ limiting magnitude map for galaxies using **HEALPix** at **nside** $= 4096$. (Right) Pixelized map of the coverage fraction at **HEALPix nside** $= 4096$. This tile is located on the border of the Y1A1 footprint and has been chosen for illustrative purposes due to its variable depth and incomplete coverage.



Drlica et al. 2017
https://arxiv.org/pdf/1708.01531.pdf

SURVEY DEPTH





Drlica et al. 2017
https://arxiv.org/pdf/1708.01531.pdf

Rykoff et al. 2015
https://arxiv.org/pdf/1509.00870.pdf

Star Galaxy Separation

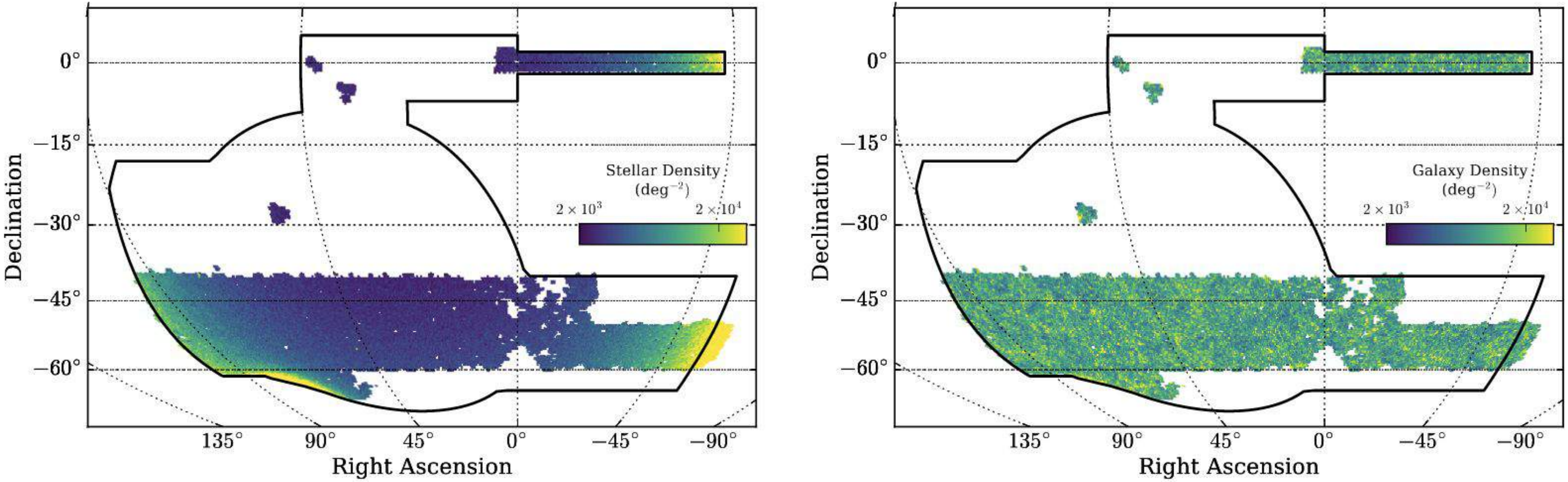


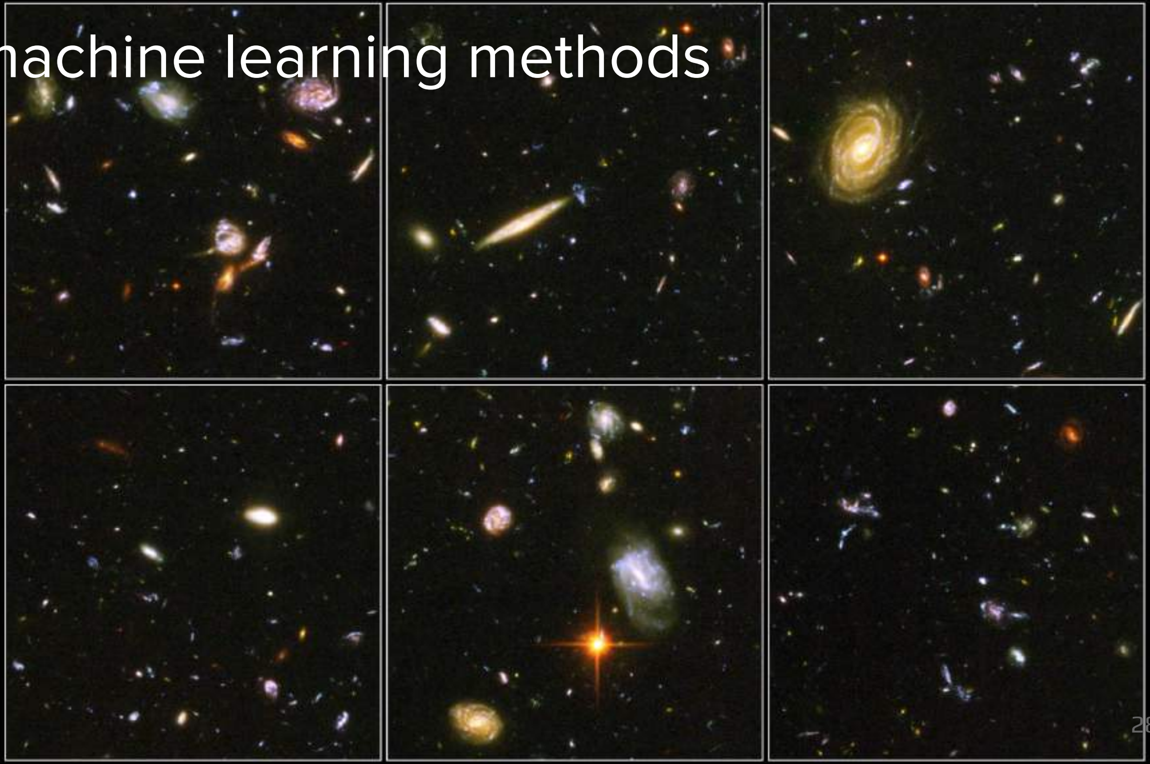
Figure 15. Density of objects with $i < 22$ passing the high-completeness star (left) and high-purity galaxy (right) MODEST_CLASS selections. The linear color scales represent the density of catalog objects and are the same for both panels. The density of objects has been corrected for the coverage fraction of each pixel (Section 7.1).

From afar, everything is a point

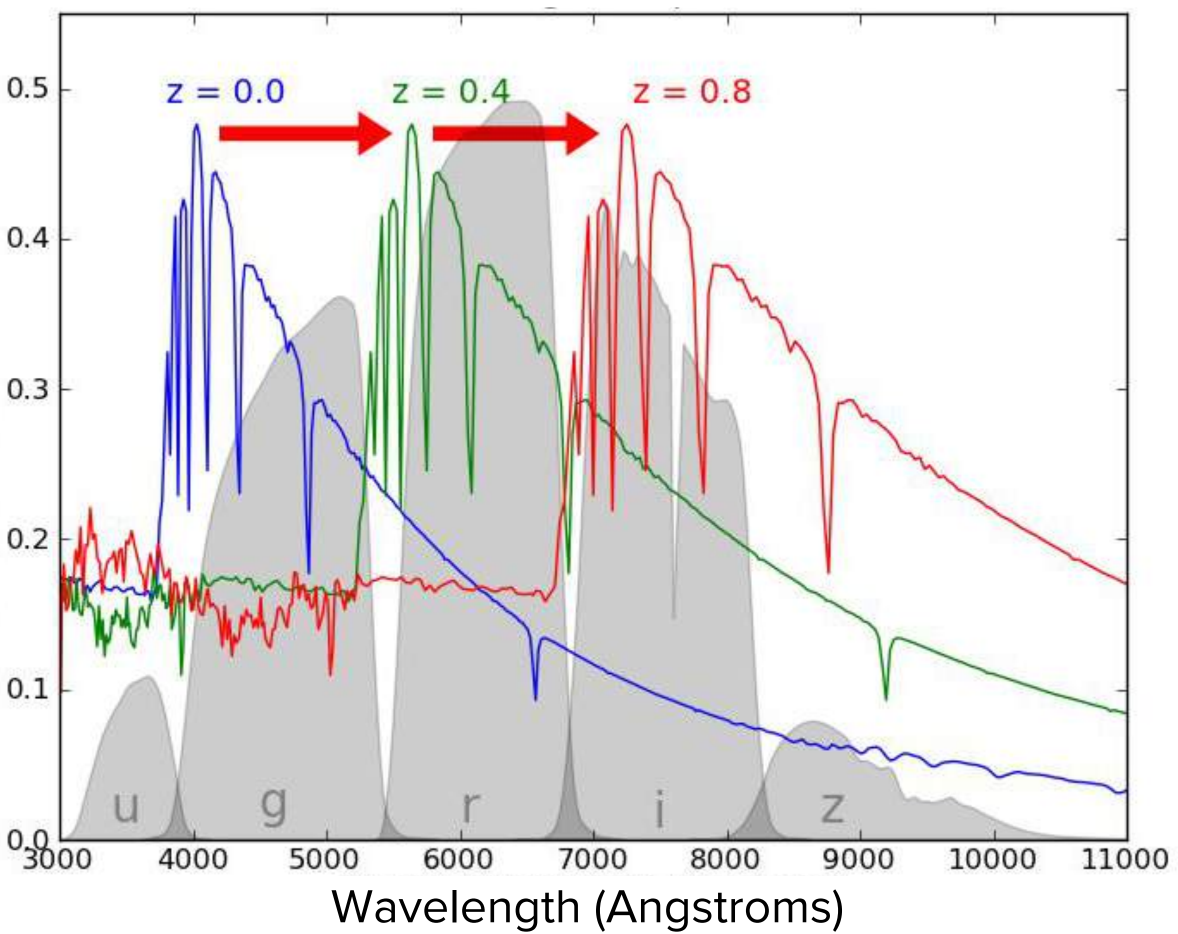
- nearby galaxies easy to distinguish from stars
- far far away galaxies appear as a point, just like stars

From afar, everything is a point

- Atmospheric seeing blurs images
- HST to aid!
- Training sample for machine learning methods



Photometric redshifts



[Gschwend et al. 2018 A&C 25 58]

Value added catalogs

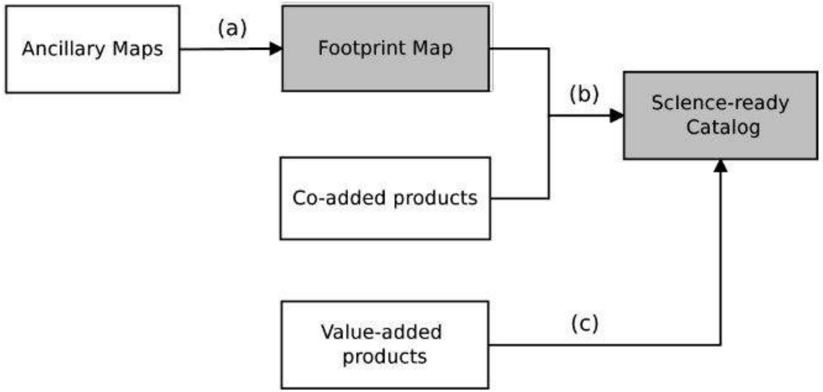
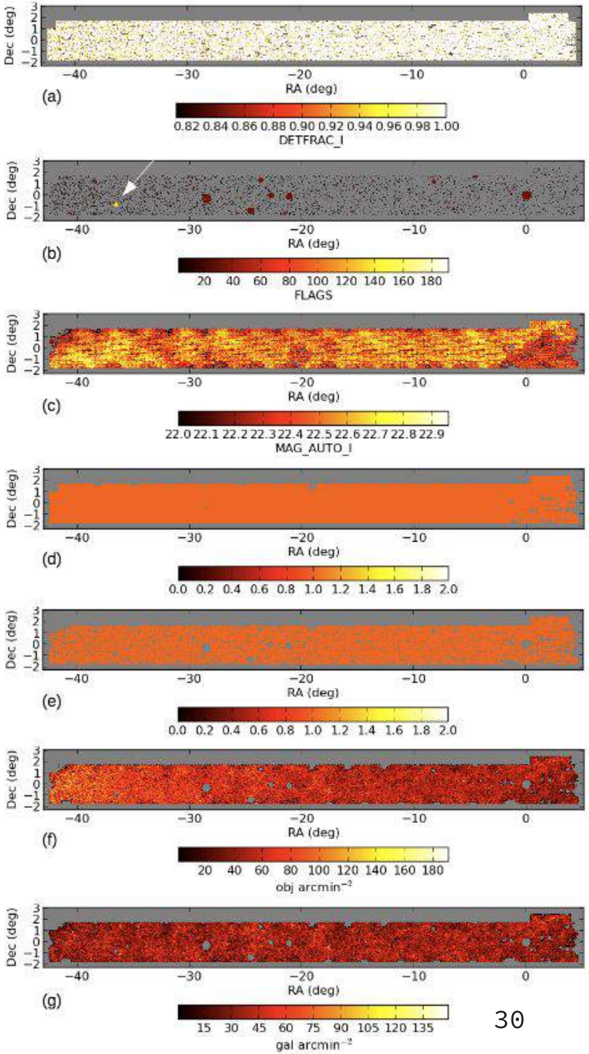


Figure A.10: Steps to create the LSS catalog as described in Section 4 for the S82 dataset. Panel (a): regions with DETFRAC_I > 0.8. Panel (b): bad region mask with FLAG=2,4,8,32, and 128. The white arrow indicates the position of the globular cluster M2 removed by the FLAG=128. Panel (c): regions with depth with $i > 22$ at 10-σ. Panel (d): binary map showing regions with EXPTIME > 90s in the *griz* filters. Panel (e): footprint map after combining the previous conditions, with a total area of 140.65 deg^2. Panel (f) map showing the density of objects after the *object selection* step with 5.89 obj/arcmin^2. Panel (g): map showing the density of galaxies after the star-galaxy separation step with 3.57 gal/arcmin^2.



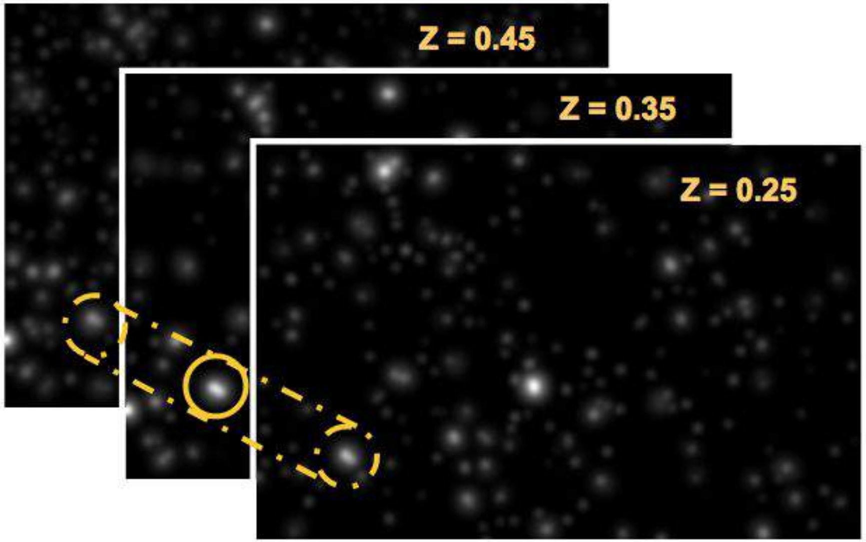
Fausti Neto et al. 2018
https://arxiv.org/pdf/1708.05642.pdf

The WaZp (Wavelet Zphotometric) Cluster Finder (B

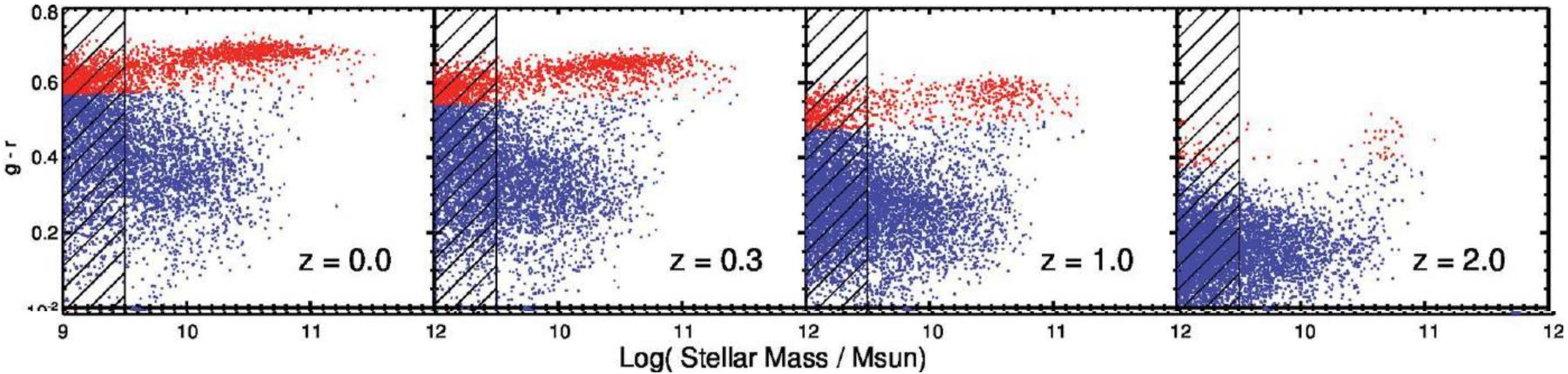
- 2D+1D method
- Density maps in redshift slices
- photo-z instead of Red Sequence
    - high-z clusters
    - "blueish" clusters

Cluster at z=0.35

Galaxy density maps in several redshift slices



The growth of red sequence galaxies



Gabor & Davé 2012

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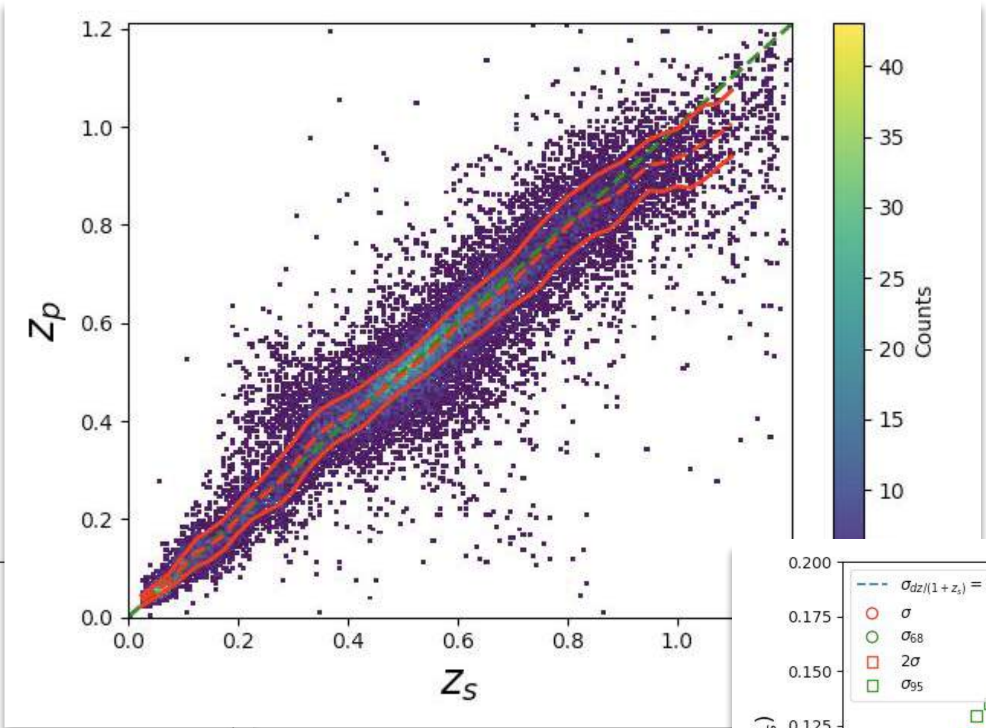
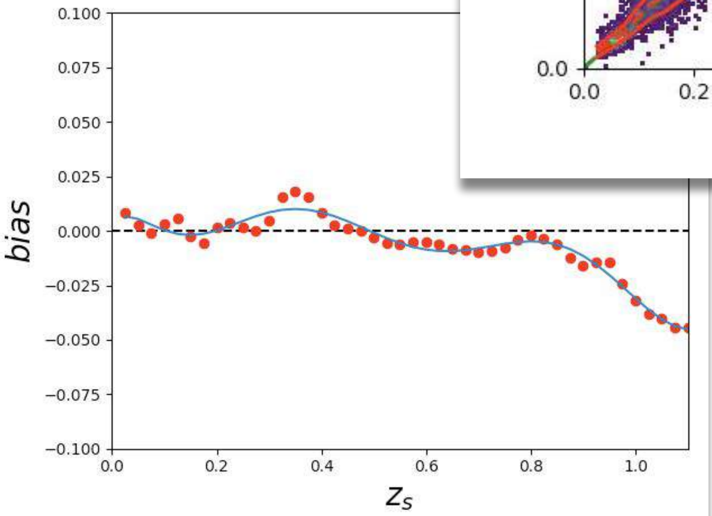
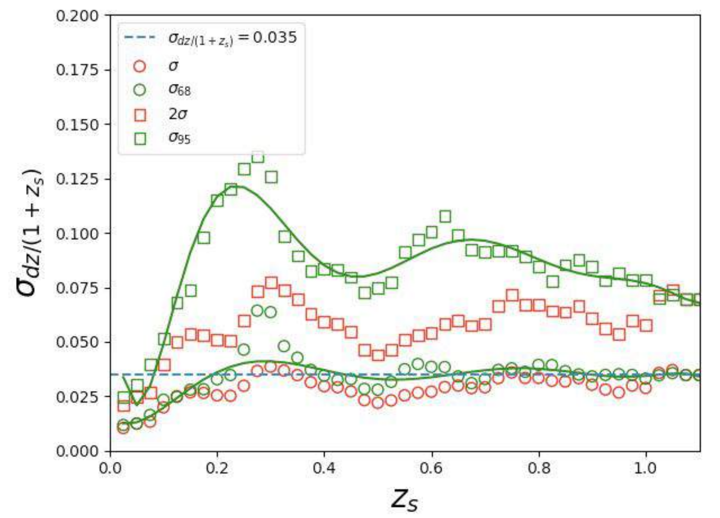
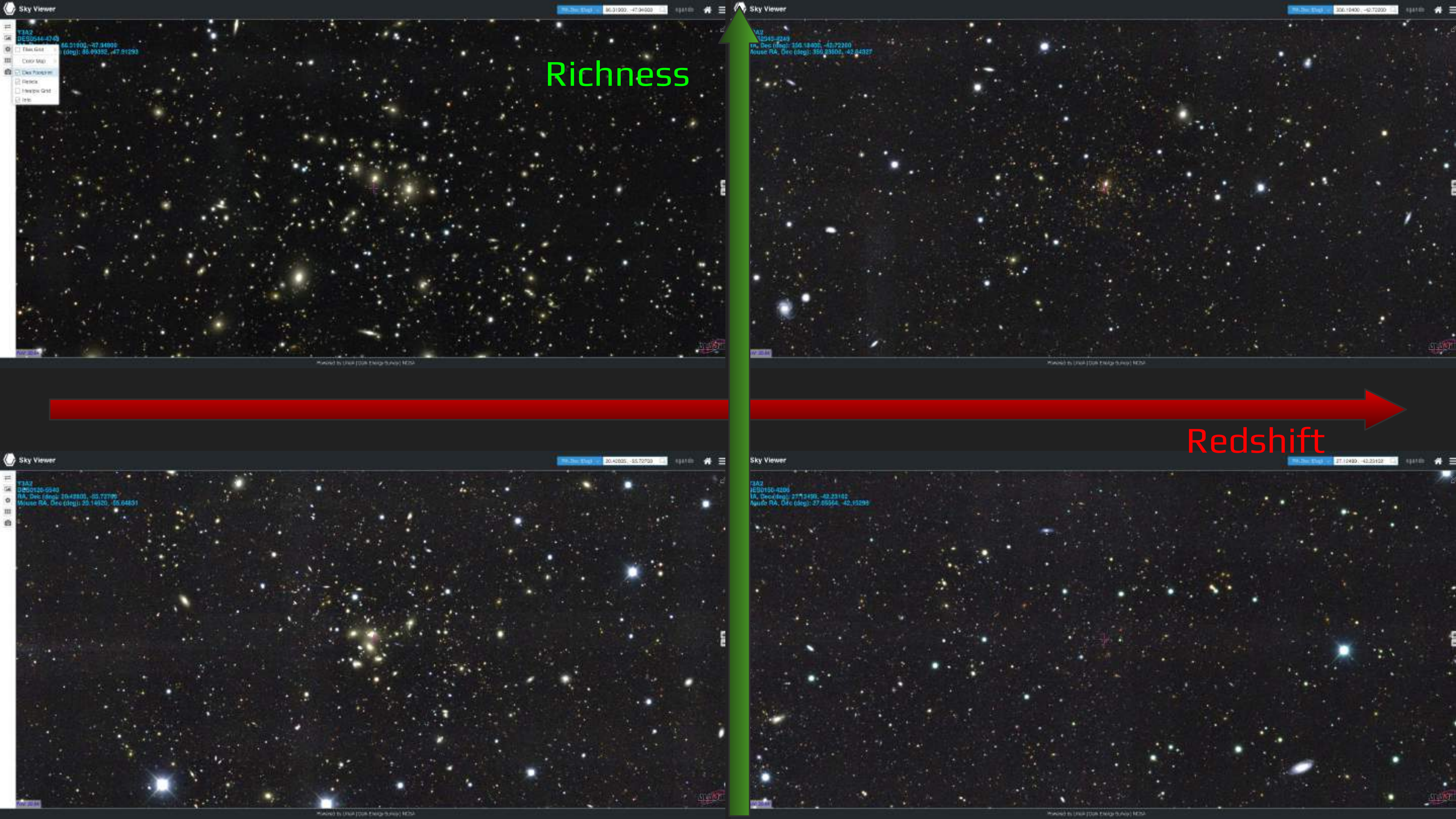






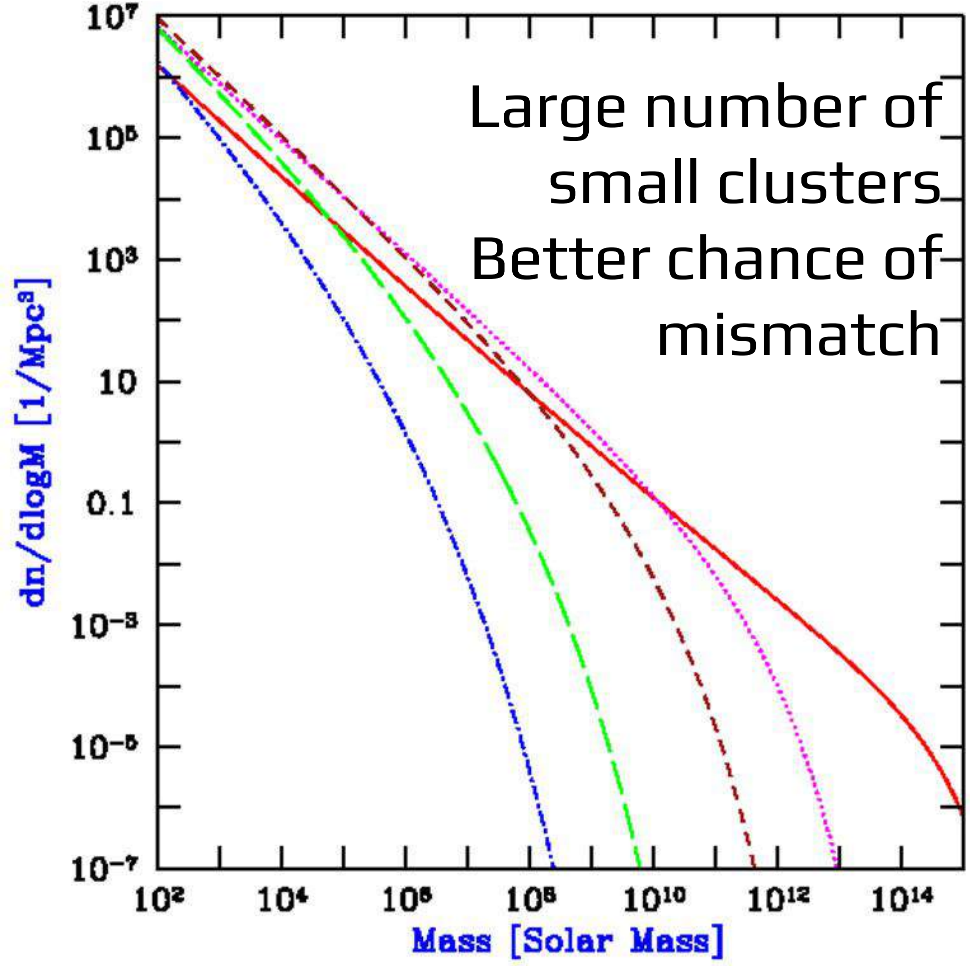


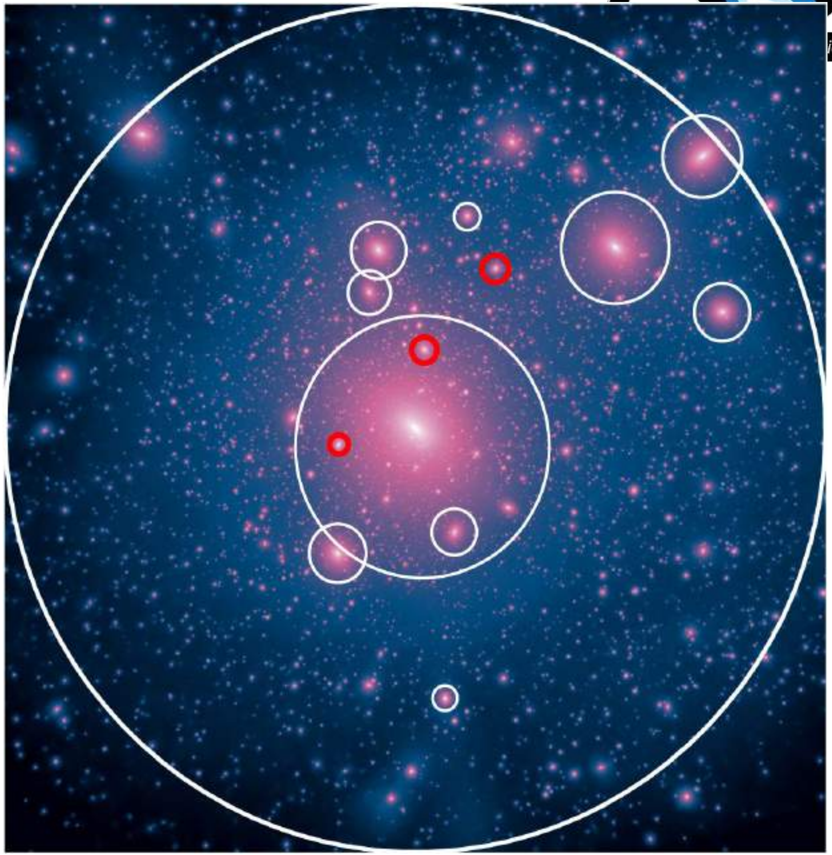
Richness
Redshift
Sky Viewer

How good is your cluster catalog?

- Matching by proximity (M. Aguena)
  - Redshift and Angular distance
- Mass proxy rank in multiple matches

Large number of small clusters
Better chance of mismatch





Consistency with other Clusters

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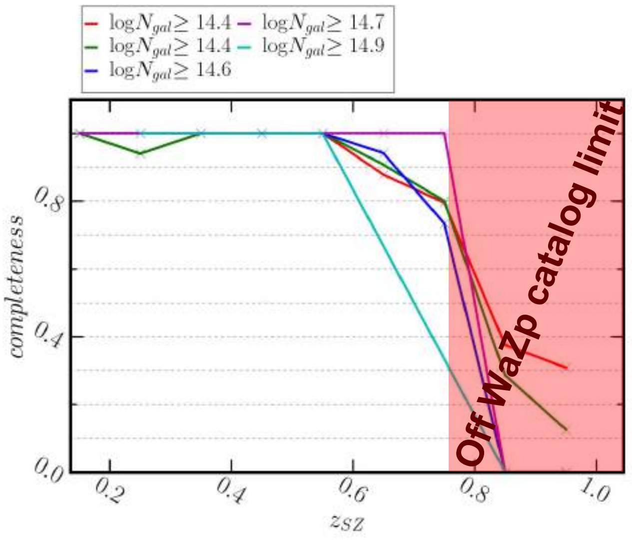
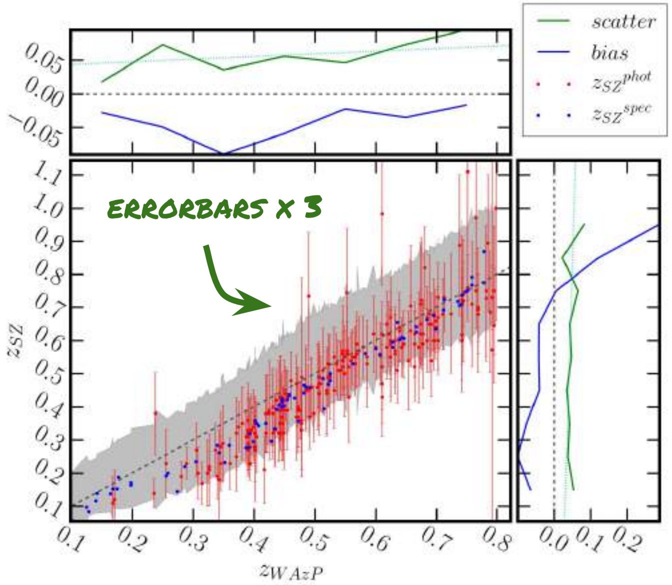
★ Matching to SPT-SZ catalogBleem et al. (2015)

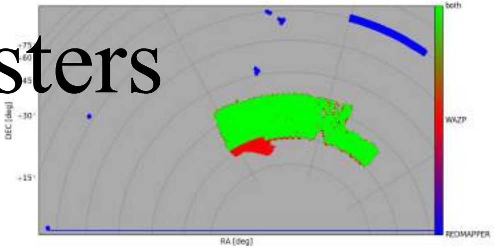




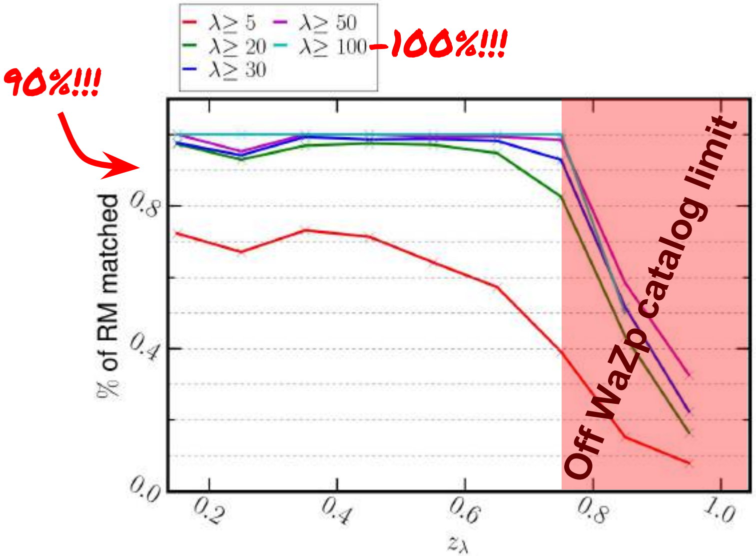
Thanks to Michel Aguena

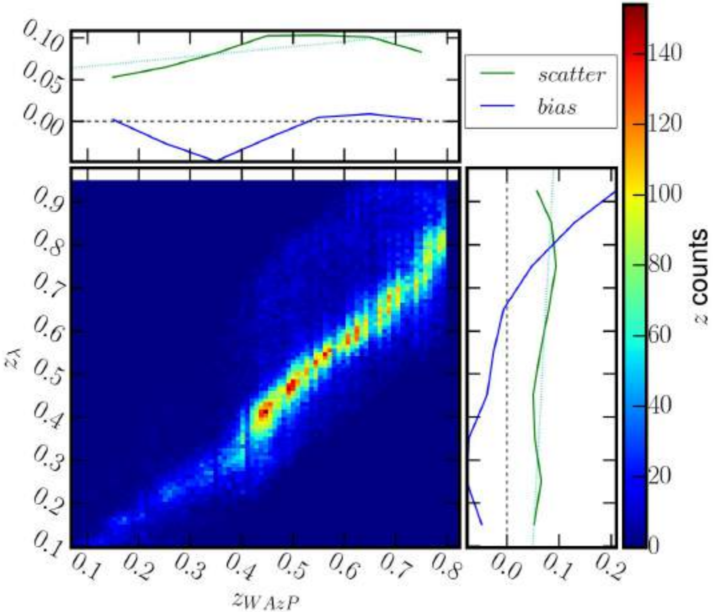
ICTP SAIFR

Consistency with other Clusters



★ Matching to RedMapper 6.4.17 full





Thanks to Michel Aguena

Questions?

Questions

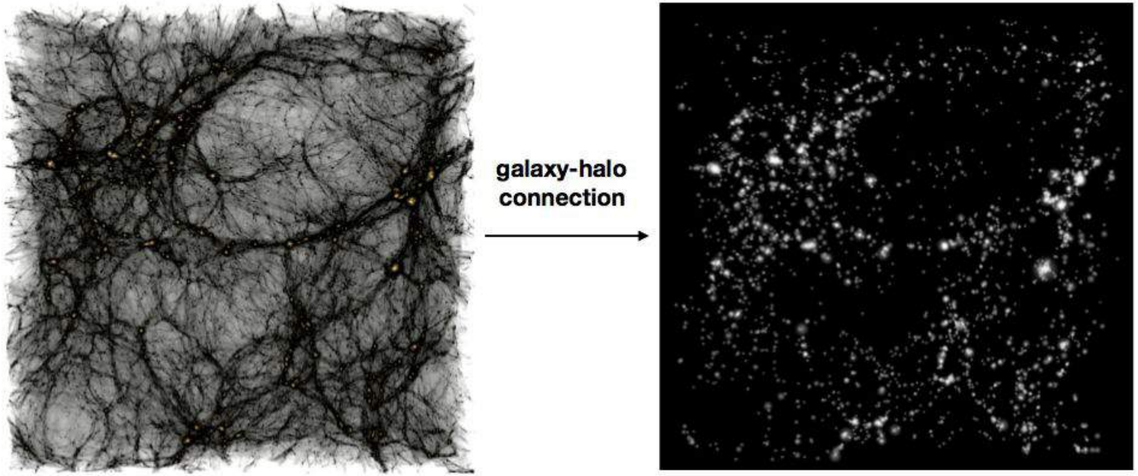
- Galaxy formation and evolution
  - gas cooling, star formation, feedback (AGN, SNe)
- Cosmology
  - lambda? dark energy? modified gravity?
  - **mass measurement**
- Dark Matter properties

GALAXY-HALO CONNECTION

- Two approaches
- empirical modeling (data)
  - get parameters evolution from data
- physical modeling (simulations)
  - simulate the physics of galaxy formation

More Expensive
More predictive

Less expensive
Less predictive
More flexibility
to constraint
unknowns



Approaches to modeling the galaxy-halo connection

← physical models | empirical models →

Hydrodynamical Simulations	Semi-analytic Models	Empirical Forward Modeling	Subhalo Abundance Modeling	Halo Occupation Models
Simulate halos & gas; Star formation & feedback recipes	Evolution of density peaks plus recipes for gas cooling, star formation, feedback	Evolution of density peaks plus parameterized star formation rates	Density peaks (halos & subhalos) plus assumptions about galaxy—(sub)halo connection	Collapsed objects (halos) plus model for distribution of galaxy number given host halo properties

Figure 1: Modeling approaches to the galaxy–halo connection. Top panel shows the dark matter distribution in a $90\times90\times30$ Mpc h^{-1} slice of a cosmological simulation *(Left)*, compared to the galaxy distribution using an abundance matching model, tuned to match galaxy clustering properties of an observed sample (*Right*). The grid highlights the key assumptions of various models

Wechsler & Tinker 2018

What is a halo?

- Basic unit of large scale structure
- Gravitationally bound and disconnected from Hubble flow
- Overdensities in dark matter n-body simulations
  - with a given mass and radius for an over density threshold (ex. 200)

$$M_{\rm vir} = \frac{4\pi}{3} R_{\rm vir}^3 \Delta \rho_m$$

Halo radius

$$M_{\rm vir} = \frac{4\pi}{3} R_{\rm vir}^3 \Delta \rho_m$$

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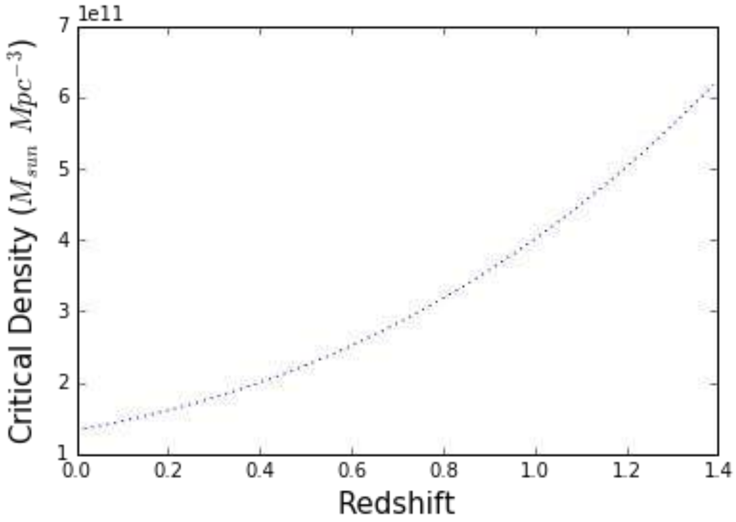
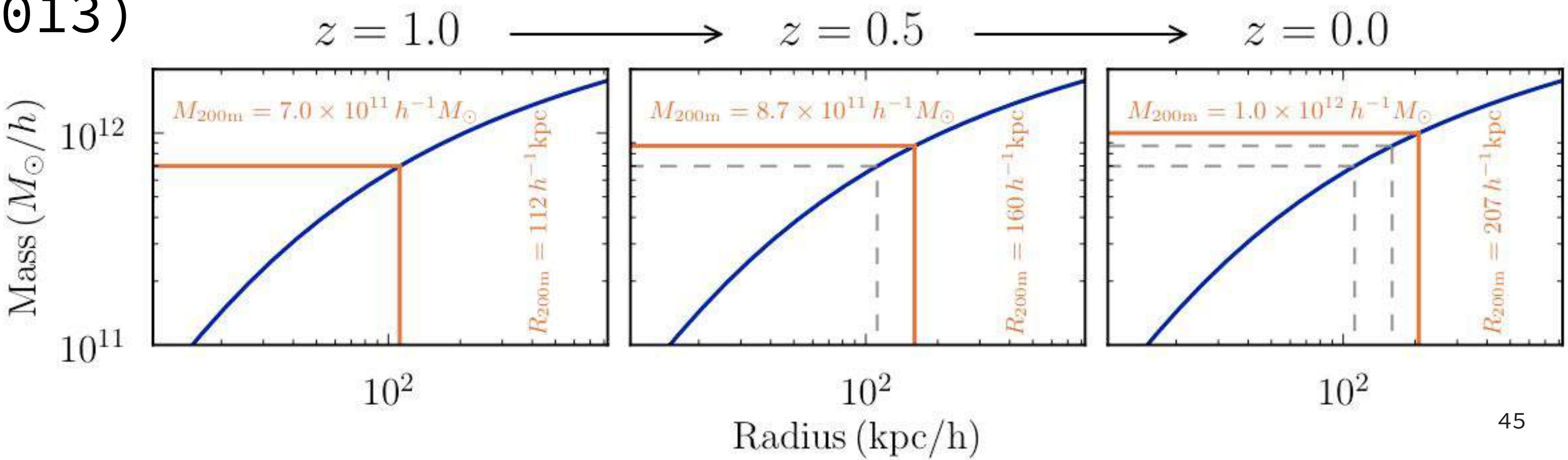
- masses and sizes are key properties of halos
- but, there are issues with this mass definition
- reference density (ρ_m) evolves with time



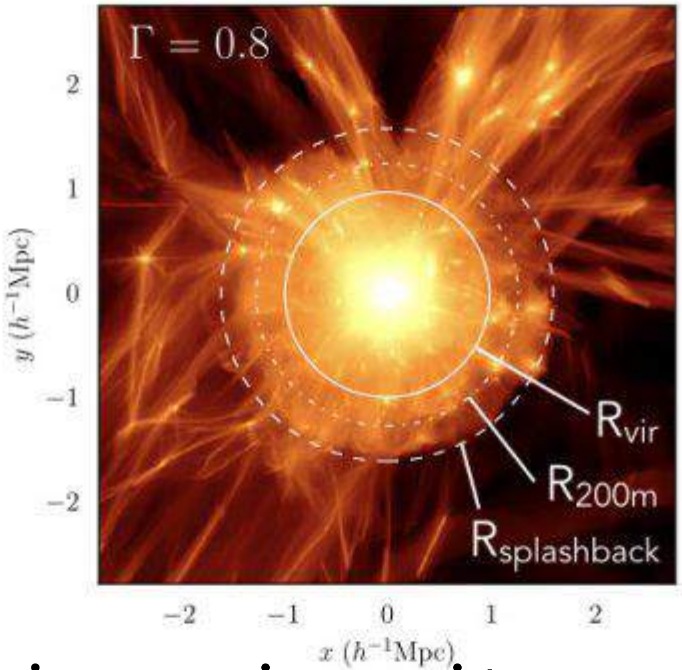
Halo radius

$$M_{\rm vir} = \frac{4\pi}{3} R_{\rm vir}^3 \Delta \rho_m$$

- Even if halo physical density profile is constant
- Mass and radius will evolve
- "pseudoevolution"(Diemer, More, & Kravtsov 2013)



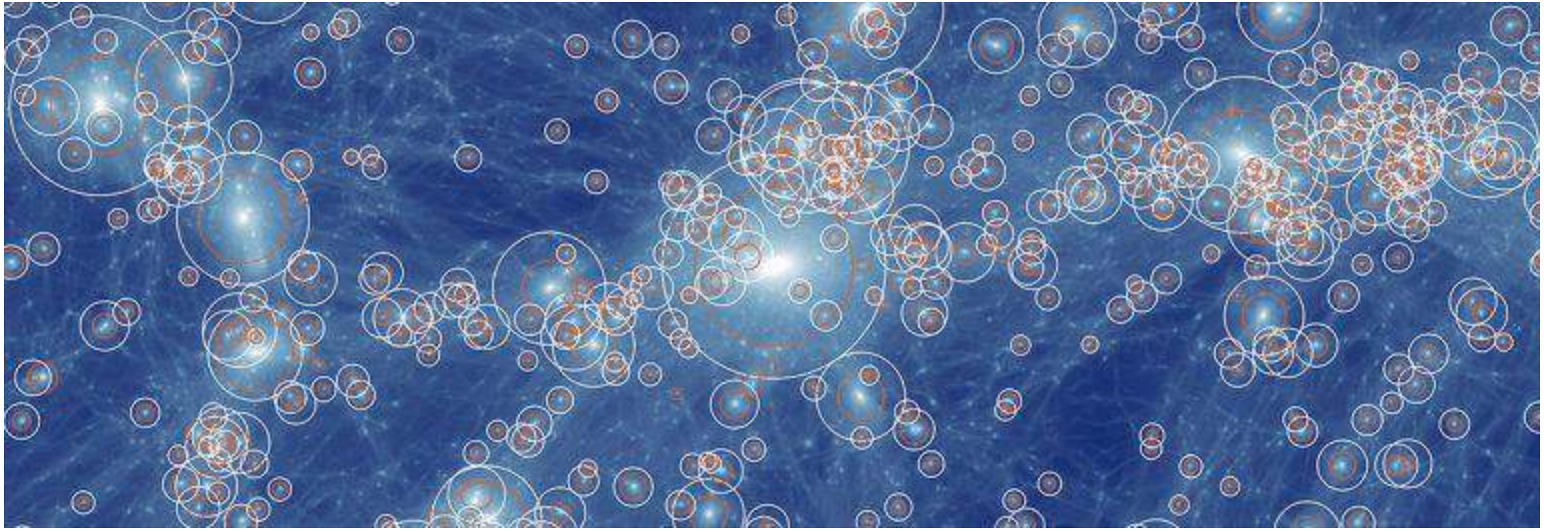
Splashback radius



- More, Diemer & Kravtsov 2015
- physically motivated radius
- separates infalling material from in orbit
- really depends on mass accretion, since it a deeper well will decrease apocenters

Comparison between splashback and virial radius

Diemer et al. 2017



What can I do with the splashback?

- assess accretion rate of halos
- verify if different populations have different Rsp (different infall times?)
  - Shin et al (arXiv 181106081)
- can we measure it on non-luminous matter?
  - Chang et al. 2018
- evolution of radius and populations w redshift?

Weighting galaxy clusters

Mass richness for SV

- Saro et al. 2015
- Redmapper cluster catalog
- Matched to SPT SZ
- **T. McClintock**

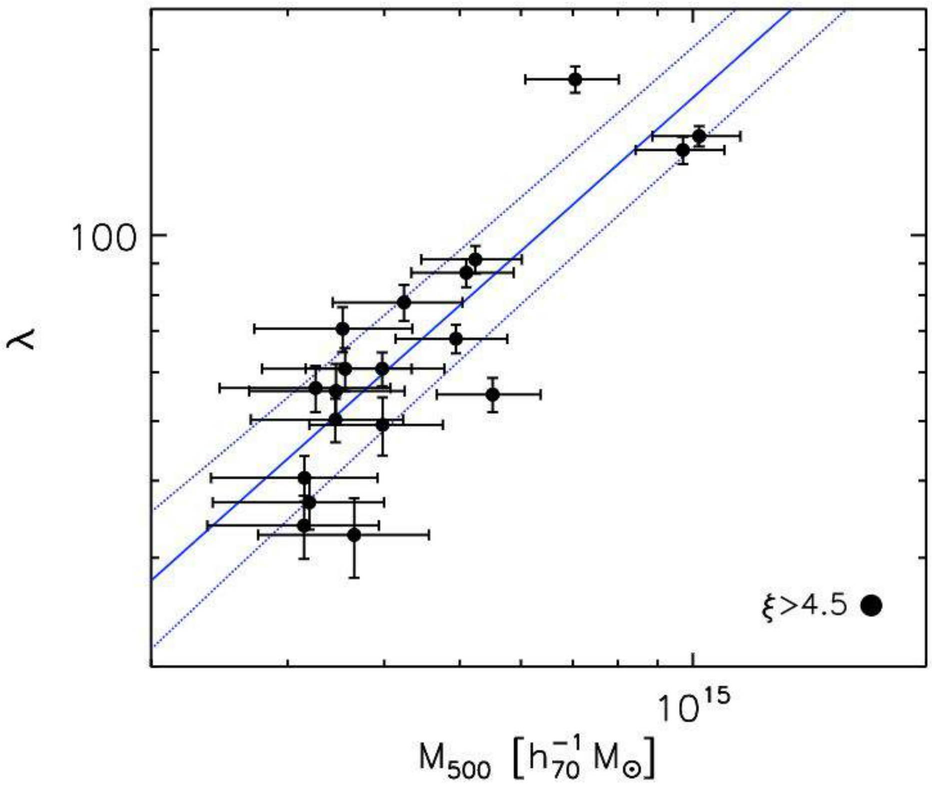
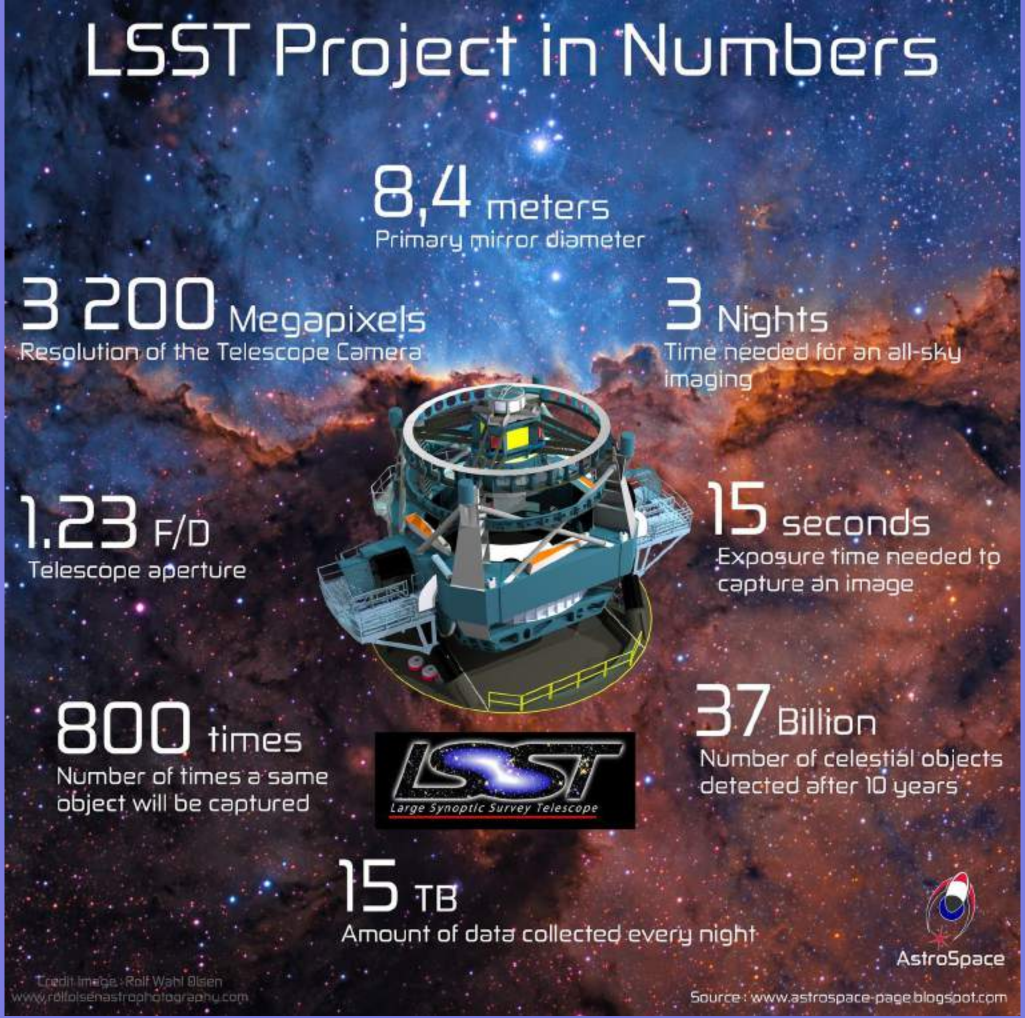


Figure 4. Richness as a function of the SPT derived masses for the calibration sample used in this analysis (Section 2.3). Blue lines show the best fit richness-mass relation and 1σ intrinsic scatter.

LSST


LSST Project in Numbers
8,4 meters
Primary mirror diameter
3 200 Megapixels
Resolution of the Telescope Camera
3 Nights
Time needed for an all-sky imaging
1.23 F/D
Telescope aperture
15 seconds
Exposure time needed to capture an image
800 times
Number of times a same object will be captured
LSST
Large Synoptic Survey Telescope
37 Billion
Number of celestial objects detected after 10 years
15 TB
Amount of data collected every night
AstroSpace
Source: www.astrospace-page.blogspot.com

Clusters of galaxies on LSST

- largest optical sample ever
- better photometry
  - weak lensing
  - photometric redshift

Thanks!

"Rio de Janeiro"
Thierry Cohen