Galaxy Clusters with Euclid

Probing Cosmology and Physical processes in dense environments

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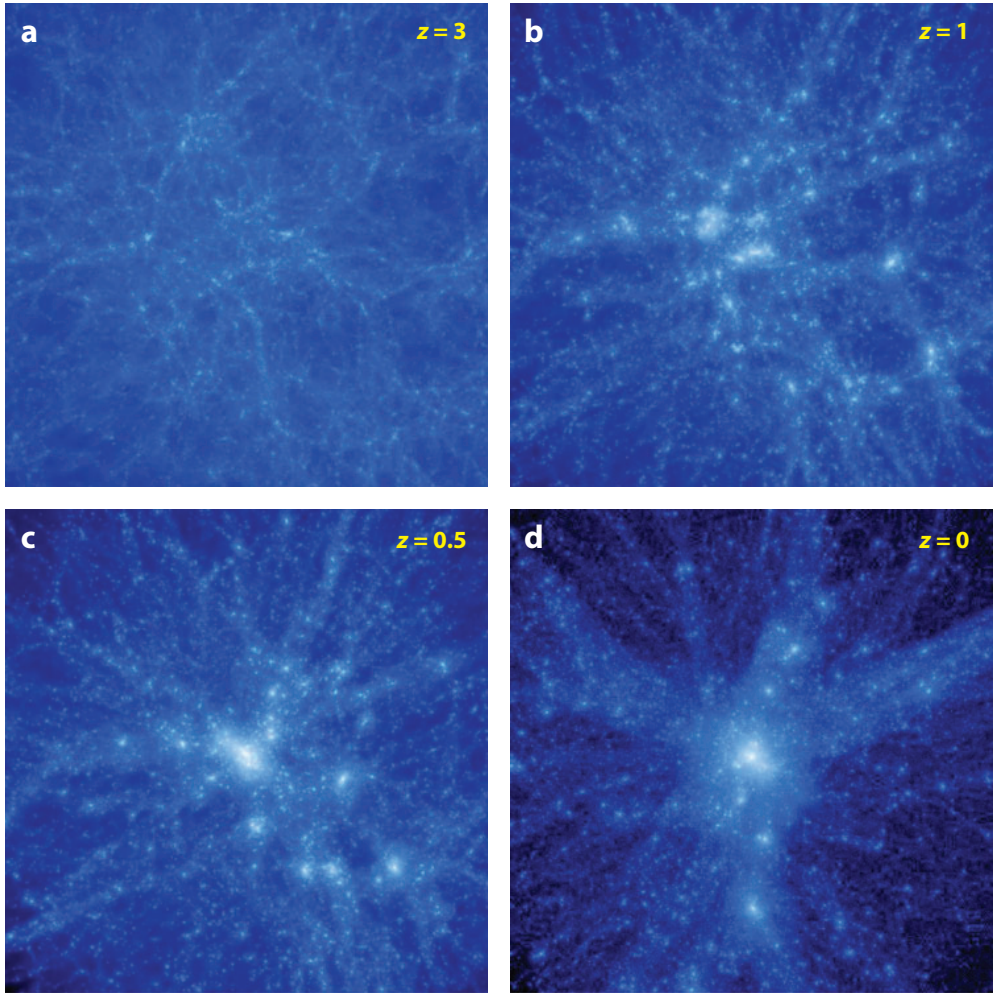
In collaboration with J. Bartlett, L. Moscardini, J. Weller, A. Biviano
and the Clusters of galaxies SWG and OU-LE3 WPs

Why galaxy clusters?



Kravtsov and Borgani, 2012

- LSS results from growth of primordial density fluctuations under the influence of gravity and expansion
- Clusters of galaxies are the highest peaks of the large-scale matter density, most massive (typically several 10^{14} $M_{\odot}$) bound structures

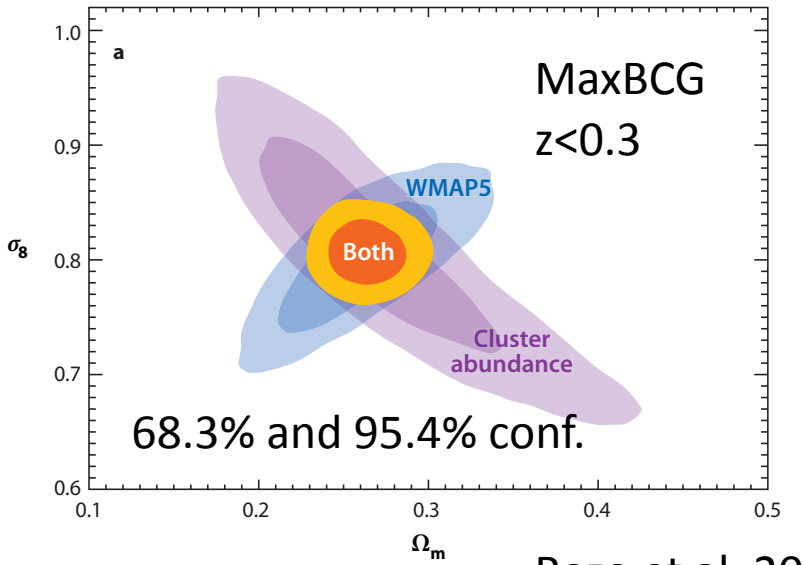
  Easy tracers of the growth of structure
- Since long used as tracers of underlying cosmology, in particular of Ω_M and σ_8

Why galaxy clusters ?

Complementary probe to CMB, SNe, GC and WL:

Different systematics and degeneracies

Sensitive to the growth of structure (as WL): Combined with a purely geometrical probe can be used to test the validity of our theory of gravity

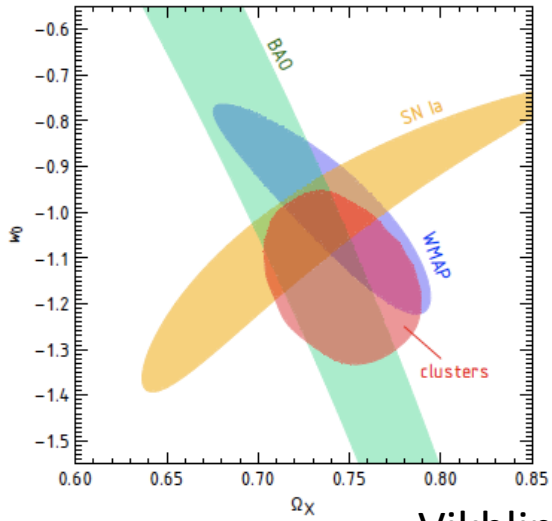


Rozo et al. 2010

BUT

Complex astrophysics objects:
mix of galaxies, gas, dark matter
Interactions between these components

Need to understand the physics at work and the evolution of these objects to constrain cosmology correctly.

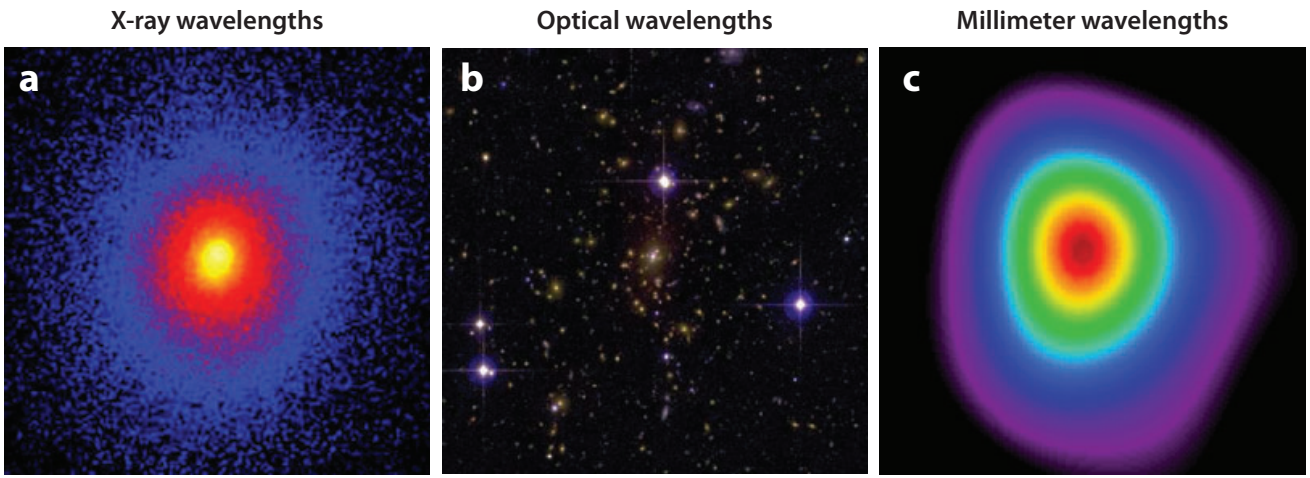


400 sq deg sample
z<0.9

Vikhlinin et al. 2009

39.3% conf.

Multiwavelength analysis



Chandra/ A. Mantz CFHT/ A. von der Linden SZ array/D. Marrone

Properties of the different components can be adressed using a multi-wavelength approach:

- UV/Optical/NIR/IR: properties of galaxies (distribution, dynamics, star-formation, stellar masses,…)
- X-Ray/SZ: physics of the thermal gaz
- Radio: non-thermal processes

Abell 1835 @z=0.35
from Allen, Evrard and White 2011

Galaxy clusters as probes of dark energy

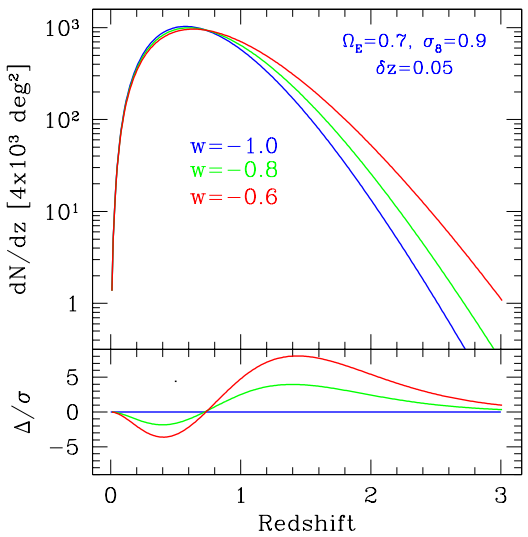
Cluster redshift distribution:

$$\frac{dN}{dz} = \Delta\Omega \frac{dV}{dz d\Omega}(z) \int_0^\infty f(M,z) \frac{dn(M,z)}{dM} dM$$

comoving volume element selection function halo mass function

Sensitive to DE:

- Growth rate of density perturbation
- Volume element



Mohr et al. 2002

Constraining dark energy from large cluster surveys

Becomes possible thanks to the recently completed/ forthcoming large cluster surveys:

optical/NIR: SDSS, Pan-STARRS, DES, KIDS, HSC, LSST, Euclid

X-Ray: XMM serendipitous, XXL, eROSITA

mm: SPT, ACT, Planck SZ catalogs

- Counts abundances: $$\overline{N}(M_a, z_i) \equiv \overline{N}_{ai} = \frac{\Delta\Omega_i}{4\pi} \int_{z_i}^{z_{i+1}} dz \frac{dV}{dz} \int_{\ln M_a}^{\ln M_{a+1}} d\ \ln M \frac{dn}{d\ \ln M}$$

- Cluster – clustering: $$P_c(k,z) = b^2(z) P_{DM}(k) = A b^2 g^2(z) k^n T^2(k)$$

  Clusters are strongly biased: high amplification factor!

  Search for BAOs in cluster distribution

Main challenges

- Mass is not a direct observable: assume proxies of mass
  - Scaling relation: Mass/observable

- One has in general to deal with a redshift estimate
  - improved photometric redshifts

- Control systematics in detection: purity/completeness
  - well controlled selection function

Mass proxies and Scaling relations

- Multiwavelength approach:

  Mass proxies: N_{opt}, shear signal, L_X, T_X, Y_X, M_{gas}, Y_{SZ}

- Beware of systematics:

  Impact of survey selection function and cluster mass function on scaling relations (Mantz et al. 2010)

  correction for Malmquist bias (Pratt et al. 2010)

- Assumptions: Estimates of mass often rely on hydrostatic equilibrium

  Lensing based estimates free of assumptions on dynamical state

  Stacked weak lensing very useful when individual signal is too low

- Dispersion and Evolution with z

How to overcome these difficulties?

Use statistical properties of clusters sensitive to mass and simultaneously fit for cosmology and M-Obs relation (cluster clustering or other): Self-Calibration

Majumdar and Mohr, 2003, Schuecker et al. 2003, Estrada et al. 2008

- Requires a large sample in the redshift range sensible to DE [0,2]

  Caveat: assumes knowledge of evolution of cluster structure !
- Best combined with detailed follow-up of a sub-sample of clusters with precise mass and redshift determination

enabled by EUCLID !

Cluster activity in Euclid

- Science Working Group

Coords.: J. Weller, L. Moscardini, J. Bartlett
~ 100 members (Mar. 2013)

Tasks:

Fix the science objectives
Requirements: pipeline products
Requirements: pipeline performances
Verify that the requirements are met
Final science analyses

Cluster activity in Euclid

- OU-LE3 WP Clusters of Galaxies

Implementation:
Coords: A. Biviano, S. Maurogordato
~ 50 members (May 2013)

Validation:
Coords.: T. Giannantonio, R. Pello
~ 20 members (May 2013)

Tasks: Implement/validate algorithms

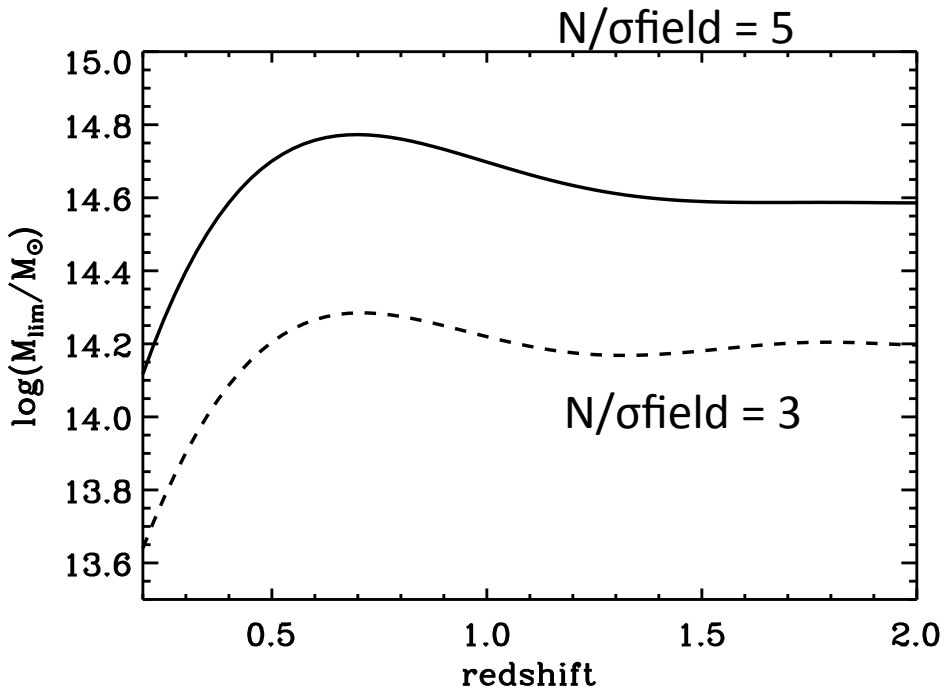
- Cluster detection & Selection Function
- Mass proxy estimates: richness – velocity dispersion
- Cluster Clustering

Clusters in Euclid from the photometric survey

Selection function: Analytical estimate based on:

Ks cluster Schechter LF Lin et al(2003)
Ks* passive evolution
No evolution of α nor ϕ*
HAB LF varying with z
Estimate N(r<r200) function of M200 and z

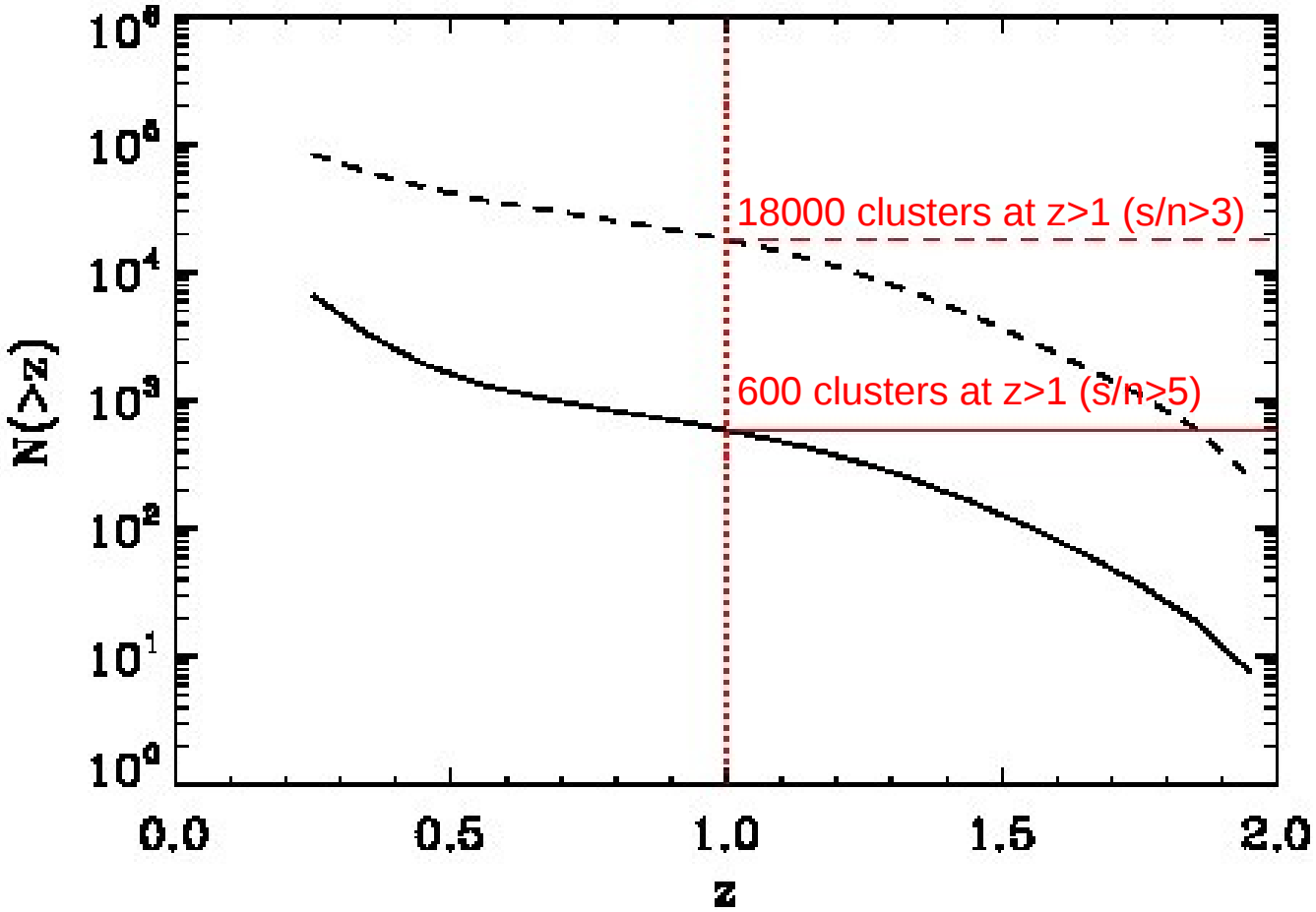
Density of field galaxies:
H-band counts: Metcalfe et al. 2006
z distribution: K20 survey Cimatti et al. 2002
Estimate of N/σfield



Clusters with $M_{200} > 1.6\ 10^{14}\ M_{\odot}$ detected at 3σ for all z

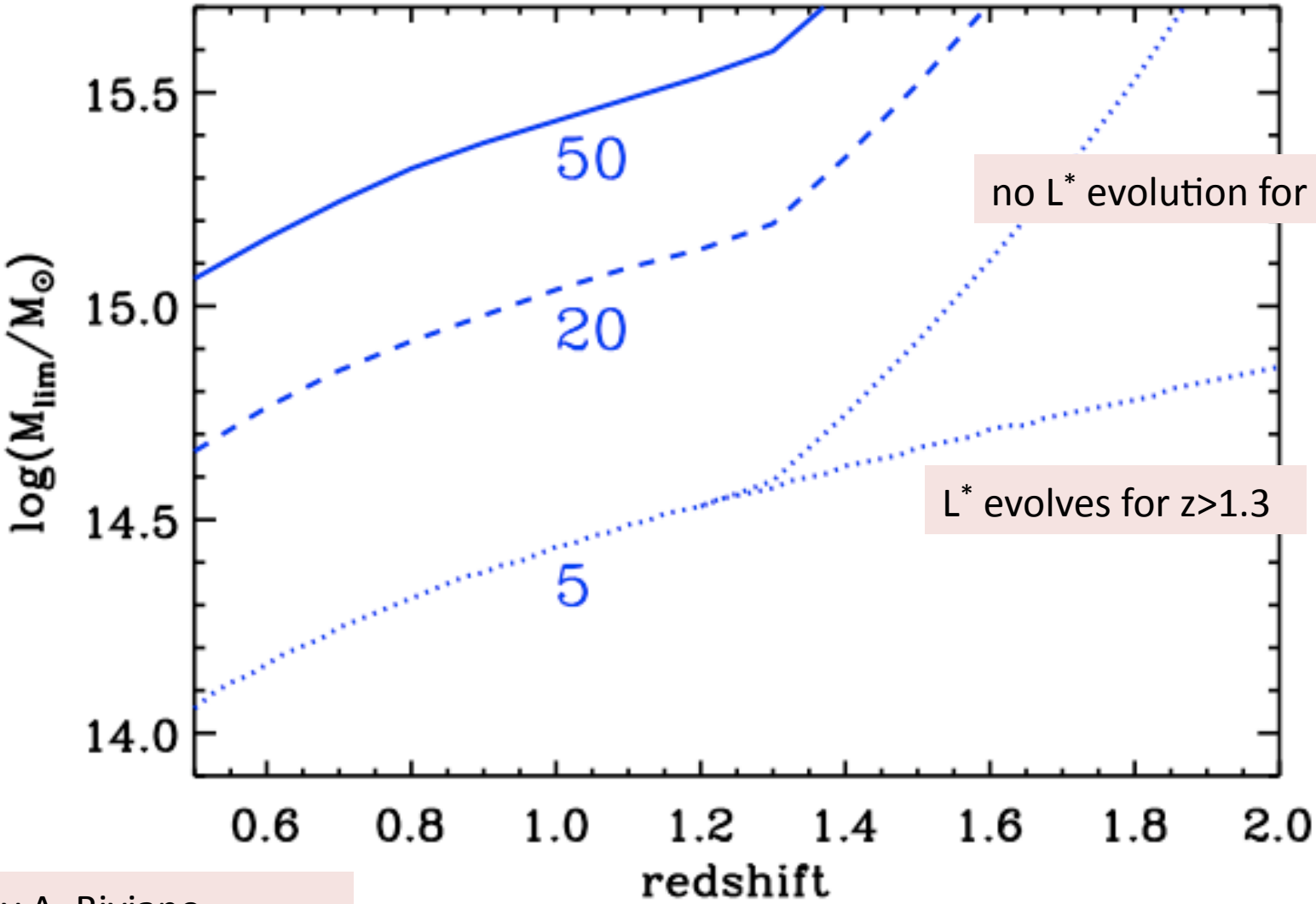
courtesy A. Biviano

Number of clusters expected



Courtesy A. Biviano

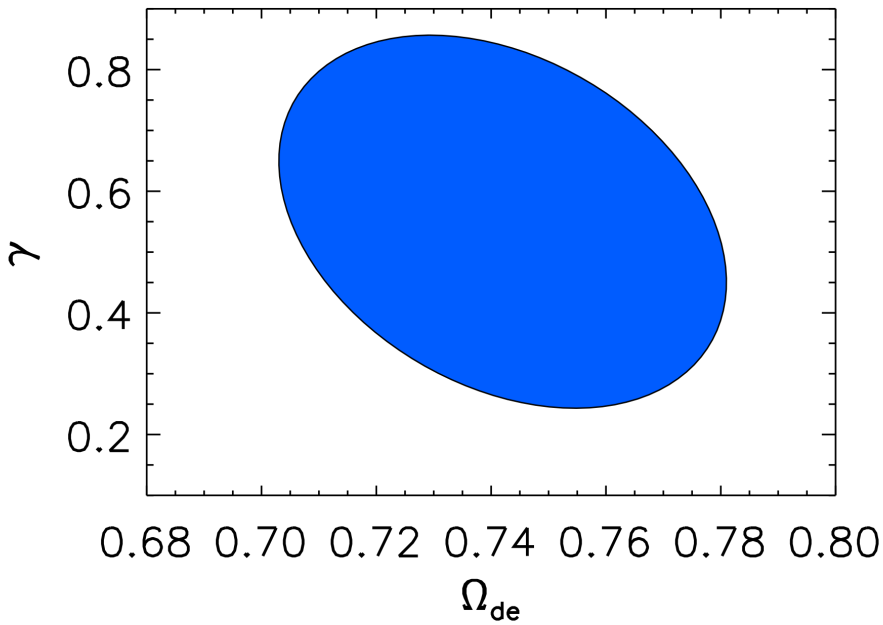
Cluster selection function: spectroscopy



Courtesy A. Biviano

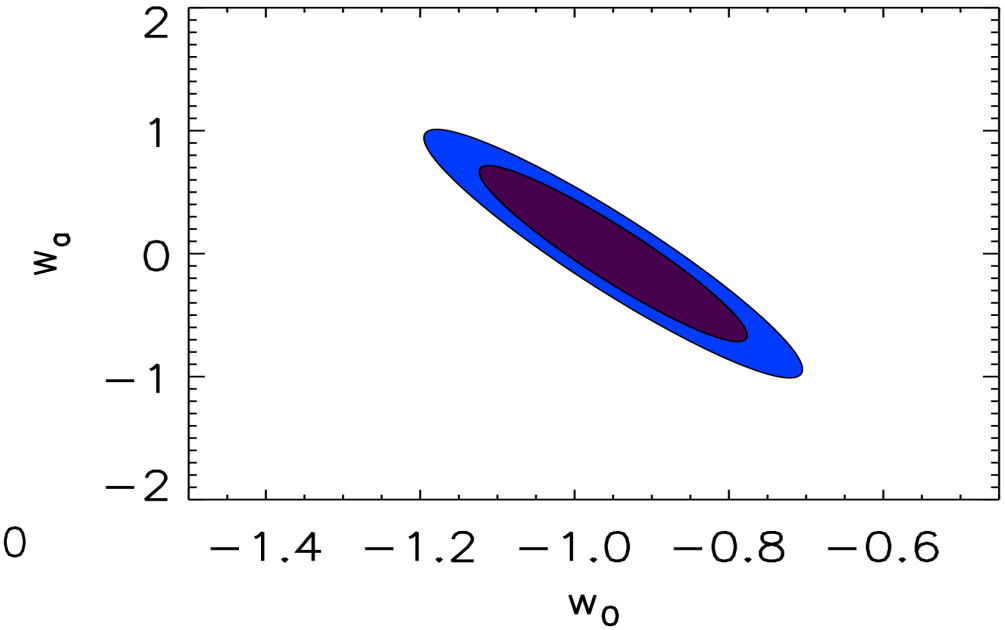
Forecasts from Euclid clusters

Modified Gravity



$$\frac{d\ln(\delta/a)}{d\ln a} = \Omega_m^{\gamma} - 1$$

DE parameters



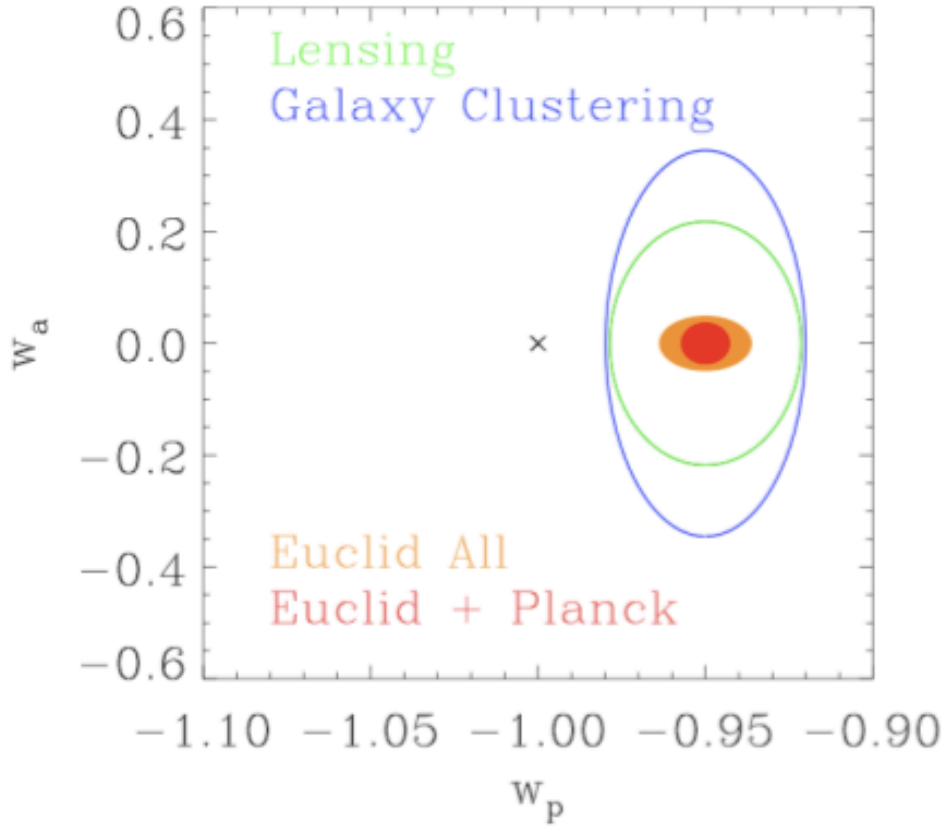
Evolving DE: $w(a) = w_0 + w_a(1-a)$

$f(z)=\Omega_m(z)^{\gamma}$ $\gamma \neq 0.55$ Modified gravity

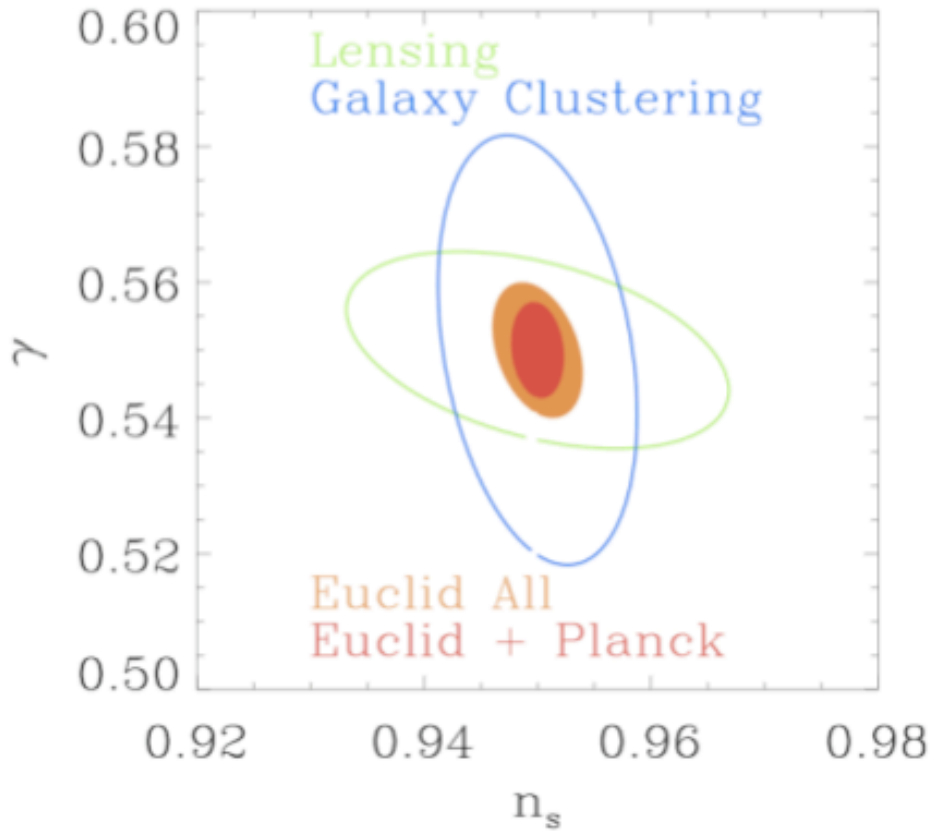
courtesy of J. Weller

Euclid WL+GC combined: predicted performances

Euclid Consortium



DE constraints from Euclid: 68% confidence contours in the (w_p, w_a).



Constraints on the γ and n_s. Errors marginalised over all other parameters.

Ref: Euclid RB arXiv:1110.3193

Cosmology with Clusters in Euclid

- Large sky coverage, Strong statistics, sampling the high z tail

  Analytical estimated selection function of the photometric catalog nearly flat:

  All ΛCDM clusters with $M > 2\ 10^{14}\ M_{\odot}$ detected at 3σ up to z=2!

  - Needs an optimized cluster finder (purity & completness) with well controlled selection function

- Calibration of the mass-observable relation and scatter:
  - State of the art WL mass estimates
  - Multiwavelength Synergy for scaling relations: e-Rosita, Athena+, Planck,…

Cluster detection in Euclid

Ongoing activity in OULE3 WP Clusters

Detection from photometric and spectroscopic surveys:
8 codes currently challenging

✓ Density field based: 2D & (2+1)D

Percolation - FOF: Farrens et al. 2011
Voronoi Tessellation: Cucciati et al. 2012
Overdensities in 2D+1D (z phots): Mazure et al 2007, Adami et al. 2009
Wavelets: WAZP Benoist et al. 2012, Eisenhardt et al. 2008

✓ Based on « filters » derived from the « known » properties of clusters:

- Luminosity function, radial profiles (1 band or more)
  Optimal matched filter detection, Bellagamba et al. 2011

- Colours : Red Sequence (at least 2 bands): Mei & Licitra 2013
  MaDCoWS: Gettings et al. 2012

What is expected for a good cluster finder?

- Algorithm automated and objective
- Well understood selection function as a function of redshift and mass
  - Optimized purity and completness
- Minimal constraints on cluster properties (avoid selection bias)
- Large coverage of the mass function (in particular at the low end)
- Output: Basic physical properties of clusters:
  - z estimate
  - Luminosity, Richness > mass proxy

Detection from gravitational lensing

- Weak lensing: see talk by J.L Starck

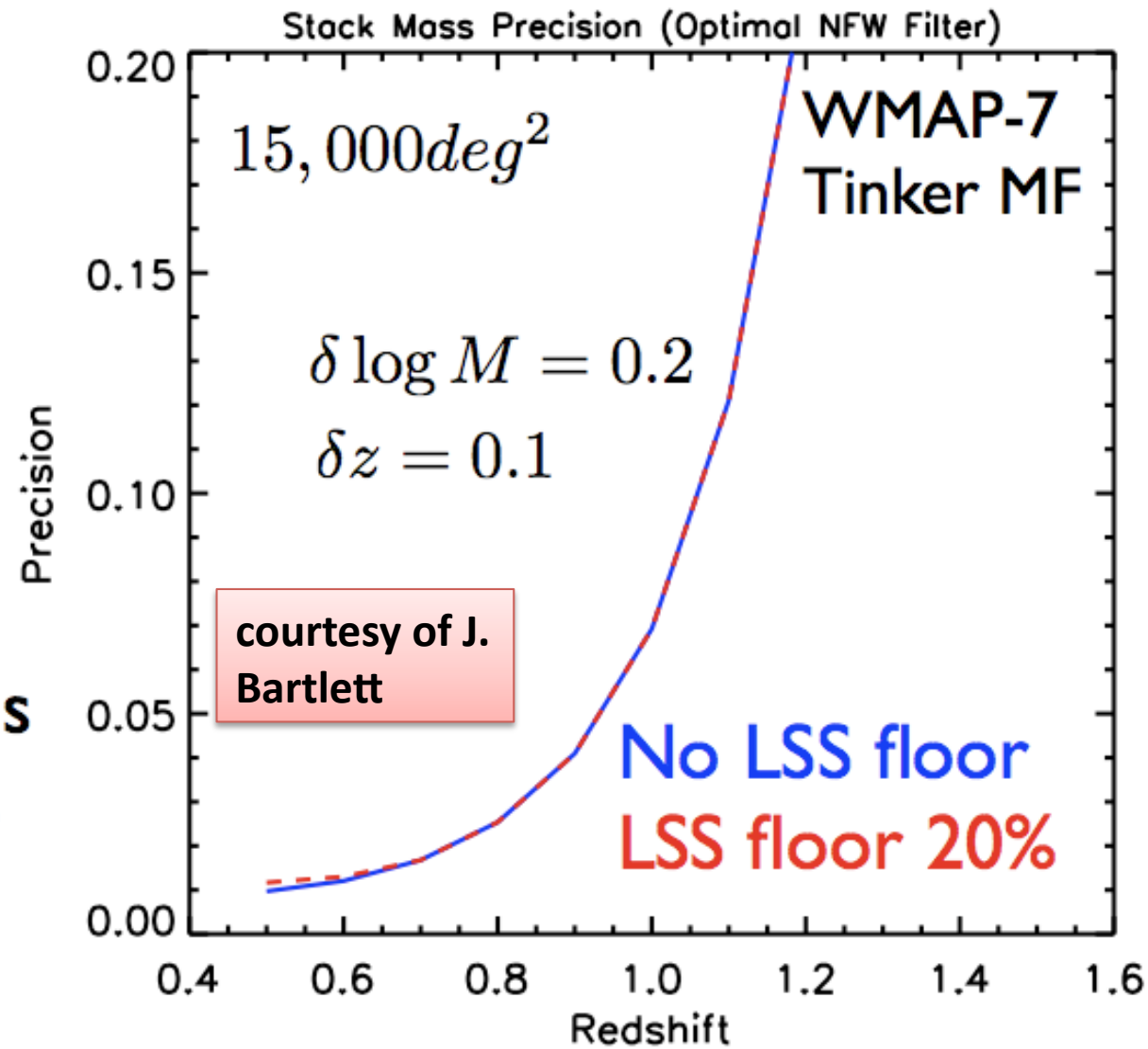
  Recent developments in the WL WP based on:
  Weak lensing galaxy cluster field reconstruction (Jullo et al. 2013)
  3D reconstruction with GLIMPSE (Leonard et al. 2013)

  see also:
  - shapelets: Bergé et al. 2008
  - shear peaks: Abate et al. 2009, Geller et al. 2010, Shan et al. 2012

- Strong lensing: see talk by R. Gavazzi
  - Cabanac et al. 2007, Limousin et al. 2009

Euclid Cluster WL Stack

- Statistical precision attainable from WL stack at NIP catalog mass limit
- $M_{5\sigma}(z)$ detection limit for NIP from A. Biviano
- Stack clusters at this mass at each redshift in bins of indicated size



Galaxy clusters in Euclid: Astrophysical issues

- Evolution of galaxies in dense environments
- Physical processes in clusters
- Detection of protoclusters (astrophysical & cosmological issue)

Euclid: Evolution of galaxy properties in dense environment

- Evolution of the Morphology-density relation:
  thanks to the high spatial resolution in the VIS channel
  reachs ~M* +2 at z≤1.4 , ~M*for higher z
  ~5000 galaxies in ~700 clusters at z≥1
  ~1800 galaxies with zspec

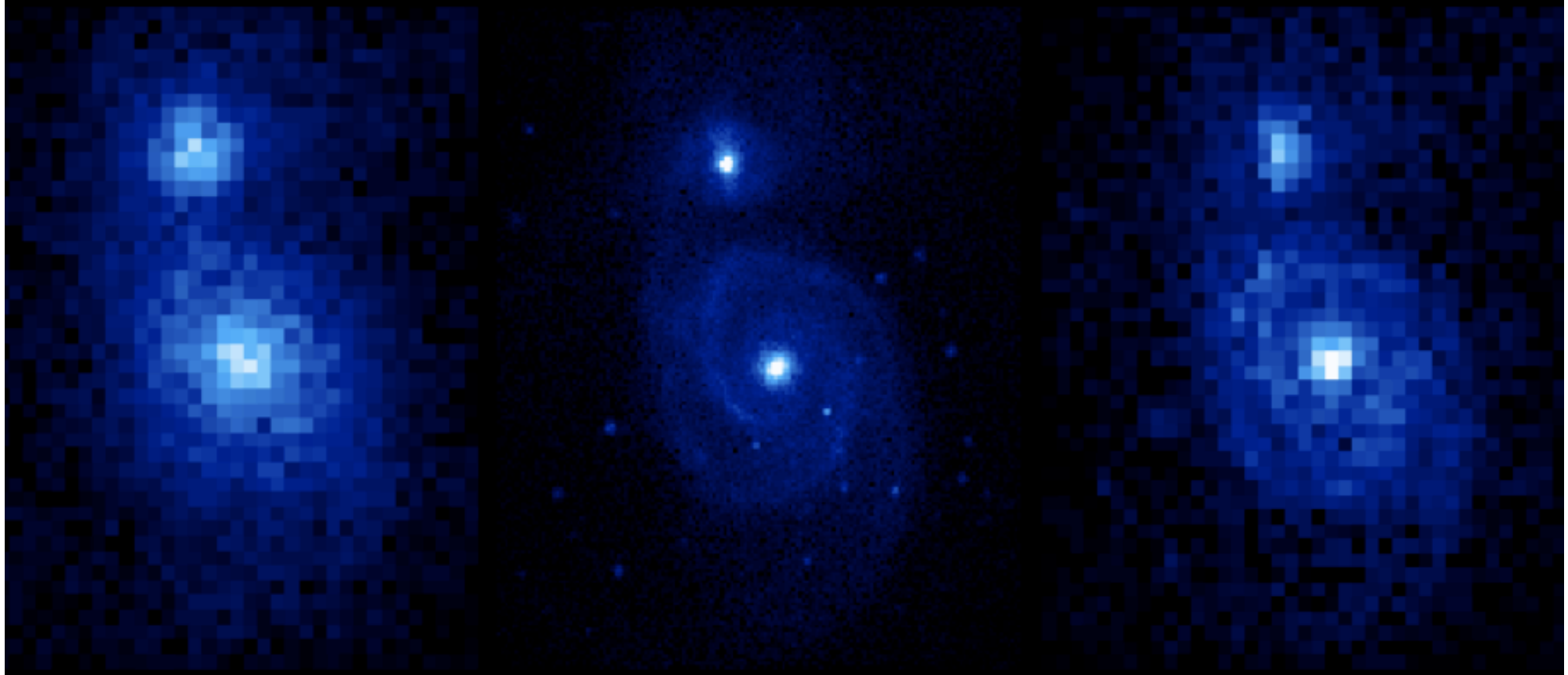
- Evolution of the cluster RS to ~HAB*+2 out to z~2
  ~700 clusters at z≥1 (~30000 galaxies)
  ~100 clusters at z≥1.5 (~4000 galaxies)

- Evolution of star formation rate per mass in clusters:
  SFR from Hα line: SFR/M with 1000 galaxies in z>1 clusters

Euclid:optimised for shape measurements

Euclid Consortium

M51



SDSS @ z=0.1 | Euclid @ z=0.1 | Euclid @ z=0.7

- Euclid images of z~1 galaxies: same resolution as SDSS images at z~0.05 and at least 3 magnitudes deeper.
- Space imaging of Euclid will outperform any other surveys of weak lensing.

Cluster with Euclid VIS+NIS imaging

Euclid Consortium

Euclid combined VIS+Y+J+H images of a simulated cluster

Courtesy of M. Meneghetti

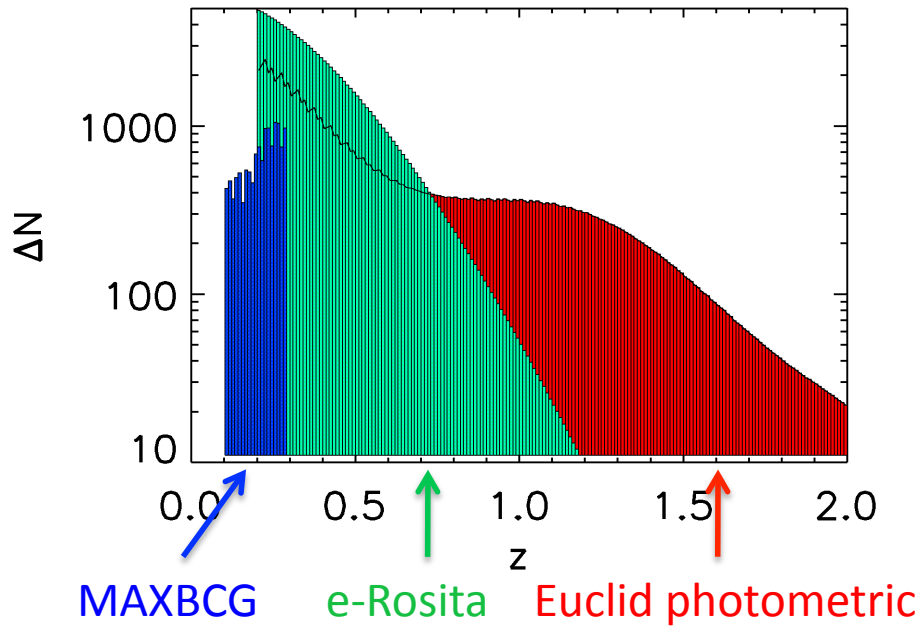
Euclid + e-Rosita : Physical processes in clusters

Synergy with future X-ray observatories:
Unprecedently detailed analysis of the gas/galaxy properties: Clues on physics of baryons in clusters

Comparison with e-Rosita up to z=1
(most e-Rosita clusters detected in the photometric survey, with > 5 redshifts measured from the spectroscopic one)

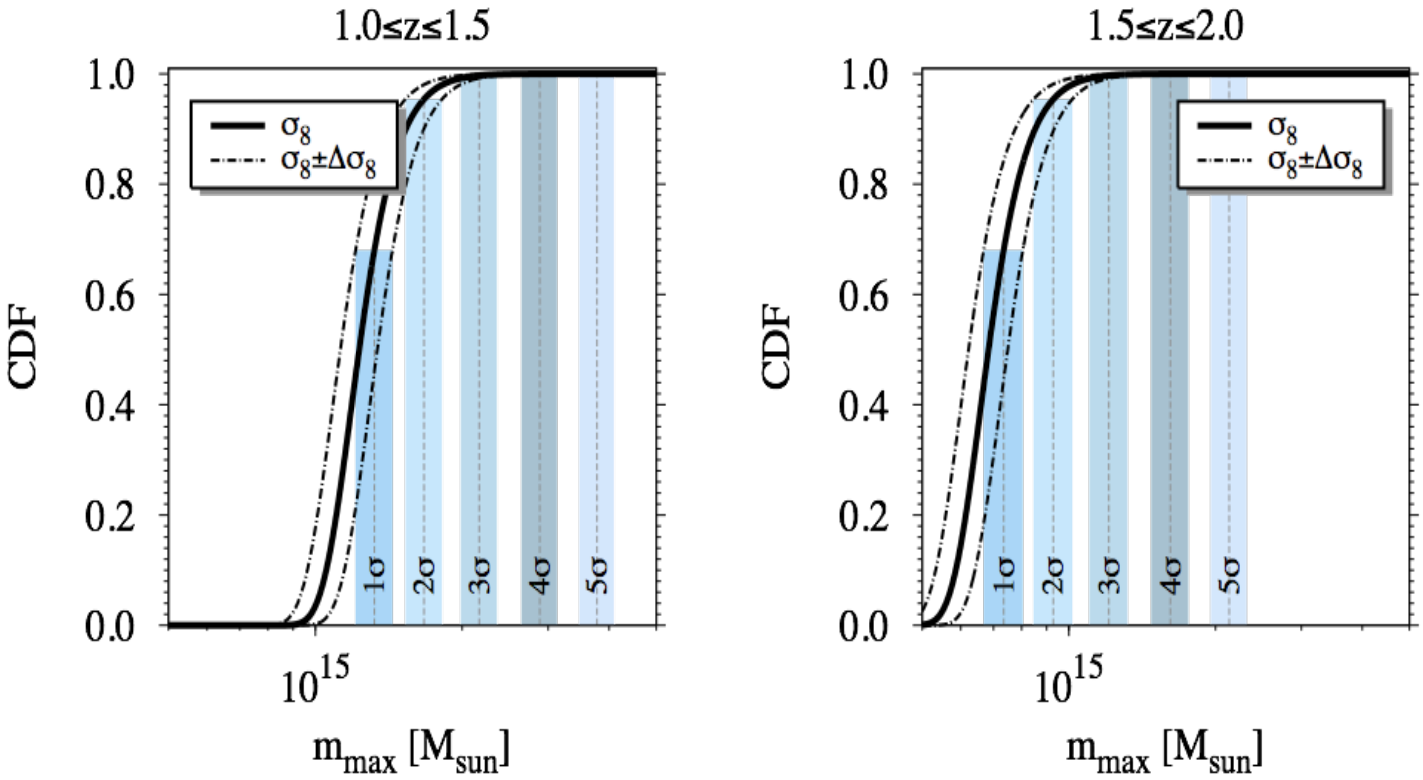
Scaling relations between L_{opt}, L_X, Y_X, M_{gas}, stacked WL mass

Future ESA Athena high-energy mission, extending to high z ?



Cortesy J. Weller

Very high-mass high redshift clusters



Tension with LCDM (>3σ) if **Euclid** will find:
a cluster of M>2.2 10^{15} M_{sun}(like ACT-CL J0102) in 1<z<1.5 or
a cluster of M>1.2 10^{15} M_{sun} (like SPT-CL J2106) in 1.5<z<2

Cortesy Lauro Moscardini

Waizmann et al. 2011, 2012

Conclusions (1)

➢Clusters of galaxies: A secondary Cosmological Probe complementary to primary Probes: WL shear maps and Galaxy Clustering to constrain Dark Energy equation of state and test our theory of gravity.

➢Main challenge will be to control the selection function of the cluster catalog and the calibration of the mass-proxy relation and its scattering.

-- Large number of clusters: accurate determination of cluster clustering

-- CC + WL mass estimates + multi-wavelength proxies + spectroscopic follow-up for part of the data should provide an efficient Self-Calibration

Conclusions (2)

- A lot of work ongoing in the SWG and OU-LE3 WPs:

Cosmological forecasts, Constraints on non gaussianity of primordial fluctuations, on neutrinos …

Cluster challenge for comparing cluster finders, selection functions and mass-proxies...

- Besides the cosmological aspects, Euclid data combined to other wavelength experiments will strongly improve our knowlege of physical processes at work in clusters, and the interplay between galaxies and gas.

Thanks!

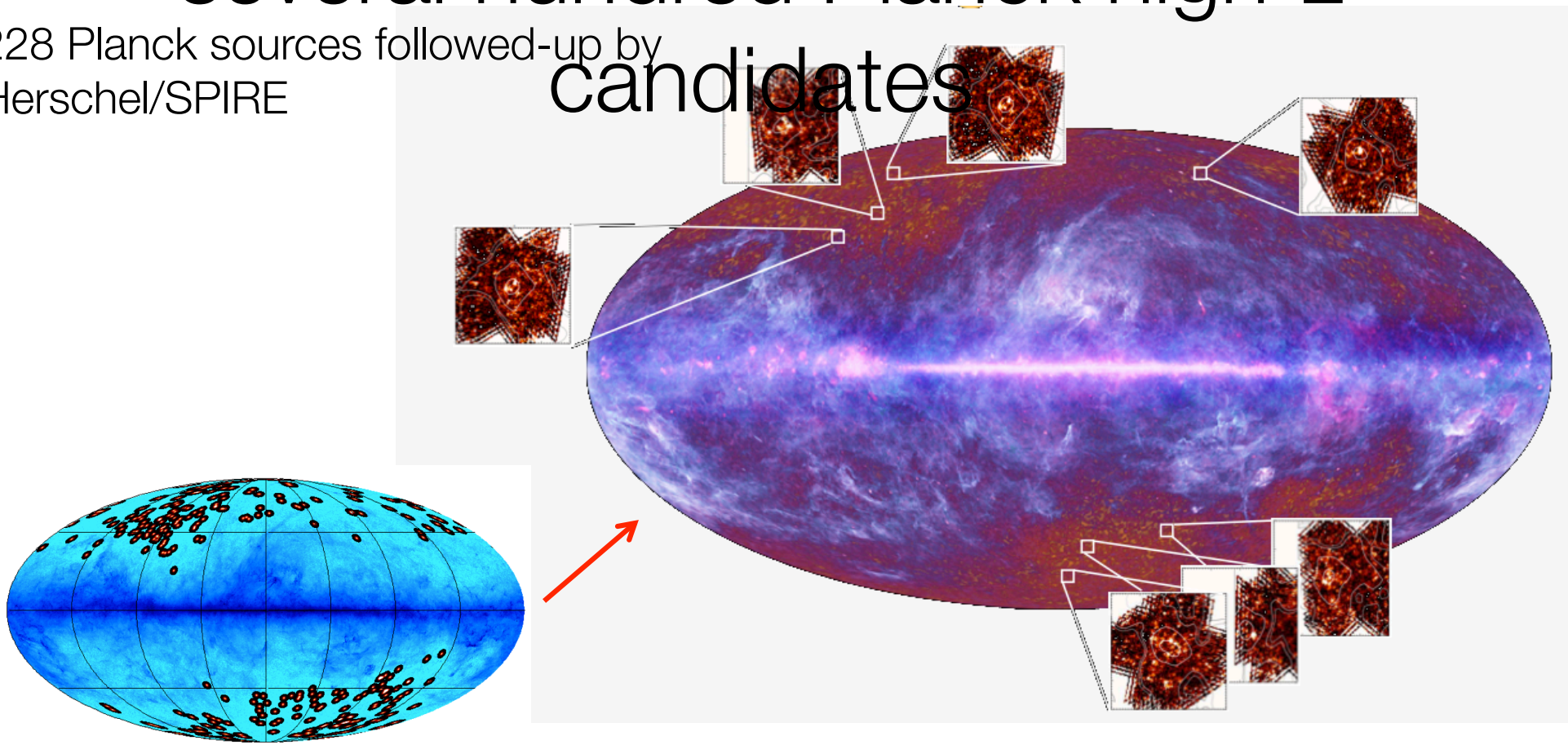
Galaxy clusters w/ Euclid and Planck, and other

Hervé Dole

Institut d'Astrophysique Spatiale, Orsay, France
Université Paris Sud & CNRS
Institut Universitaire de France
http://www.ias.u-psud.fr/dole/

several hundred Planck high-z candidates

228 Planck sources followed-up by Herschel/SPIRE

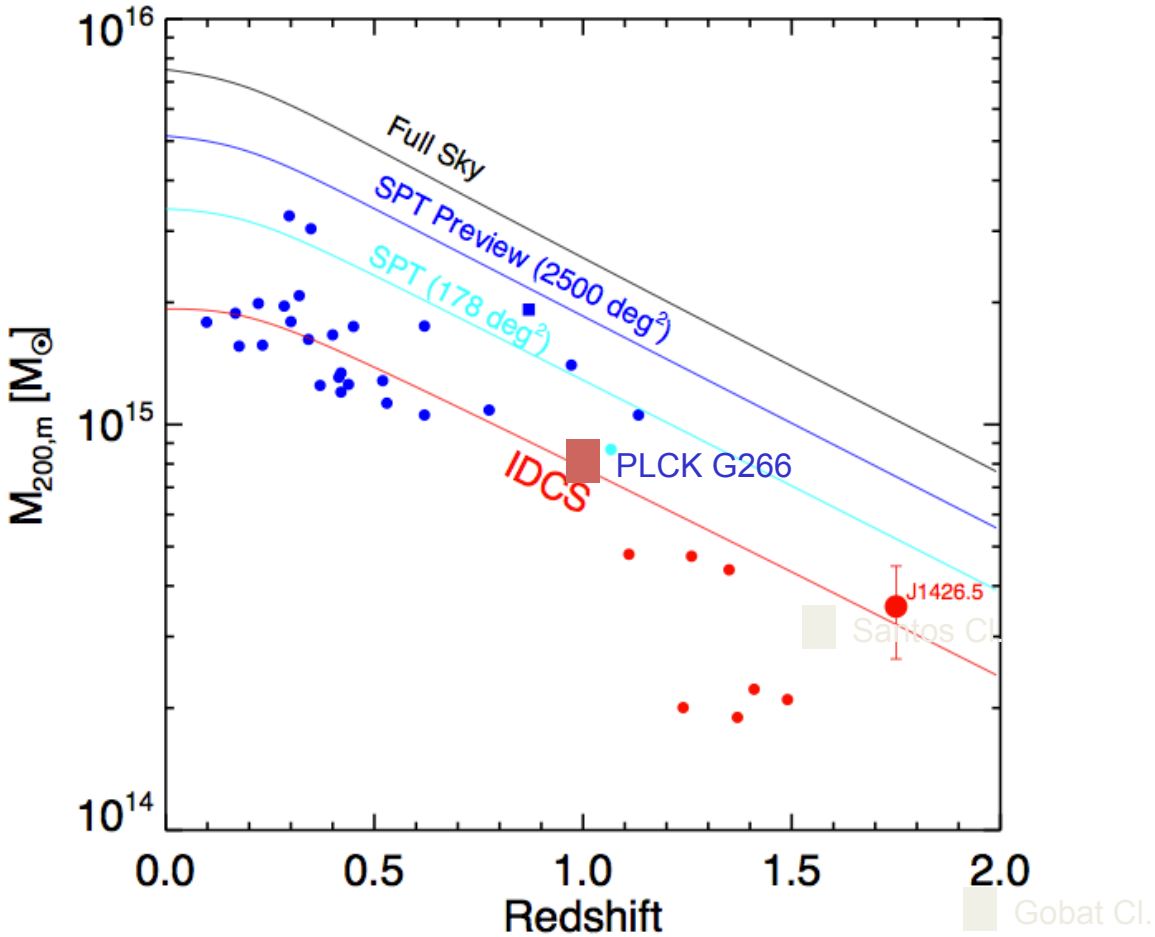


these z>1.5 clusters candidates contain luminous FIR galaxies: clusters in their burst phase ?

Dole et al., in prep

LCDM & NG. LSS formation

Predictions de masse des amas en fonction du redshift (et de la surface)



Predictions of maximum cluster mass vs redshift from Mortonson et al., 2011 (black line), with few data points (symboles).
high-z massive clusters: likely very rare on the sky. Need for all-sky surveys, à la Planck & Euclid to complement deep searches.

Brodwin et al, 2012
Mortonson et al., 2011

LCDM & NG: LSS formation

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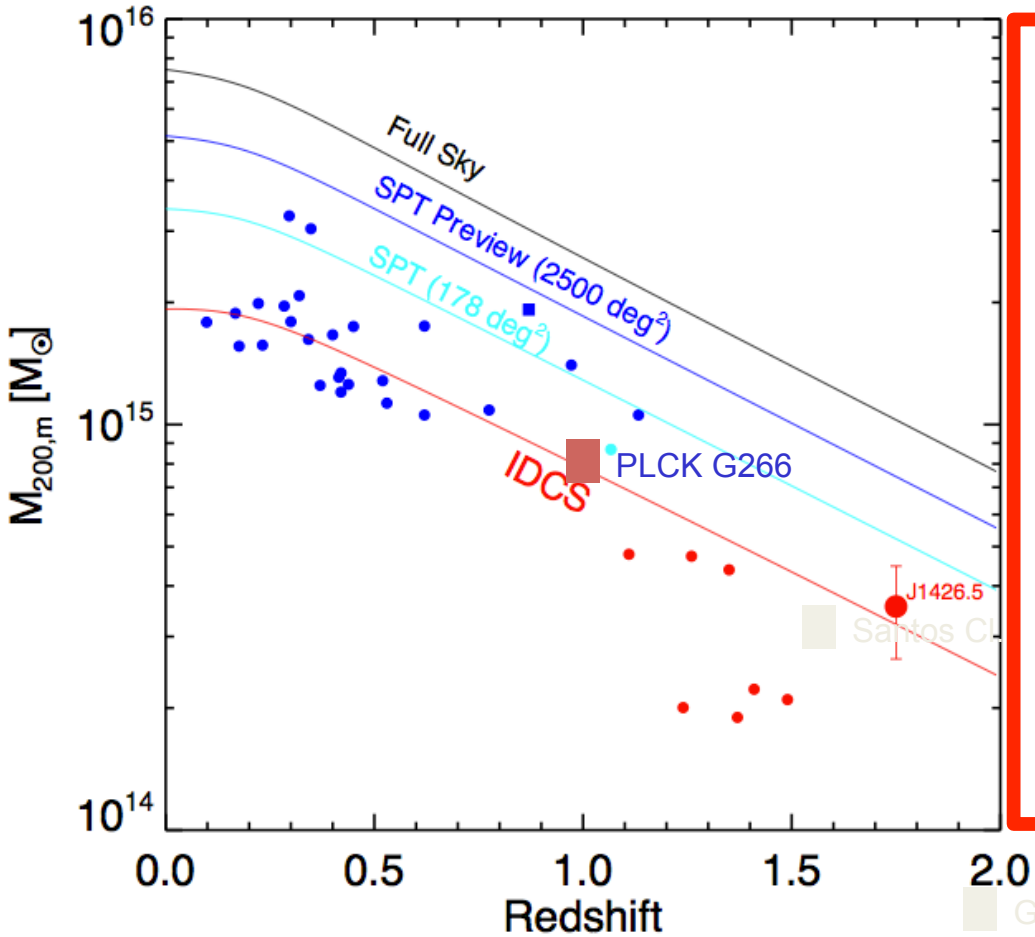

z > 2
Planck
(star formation)

then Euclid
(stellar mass)

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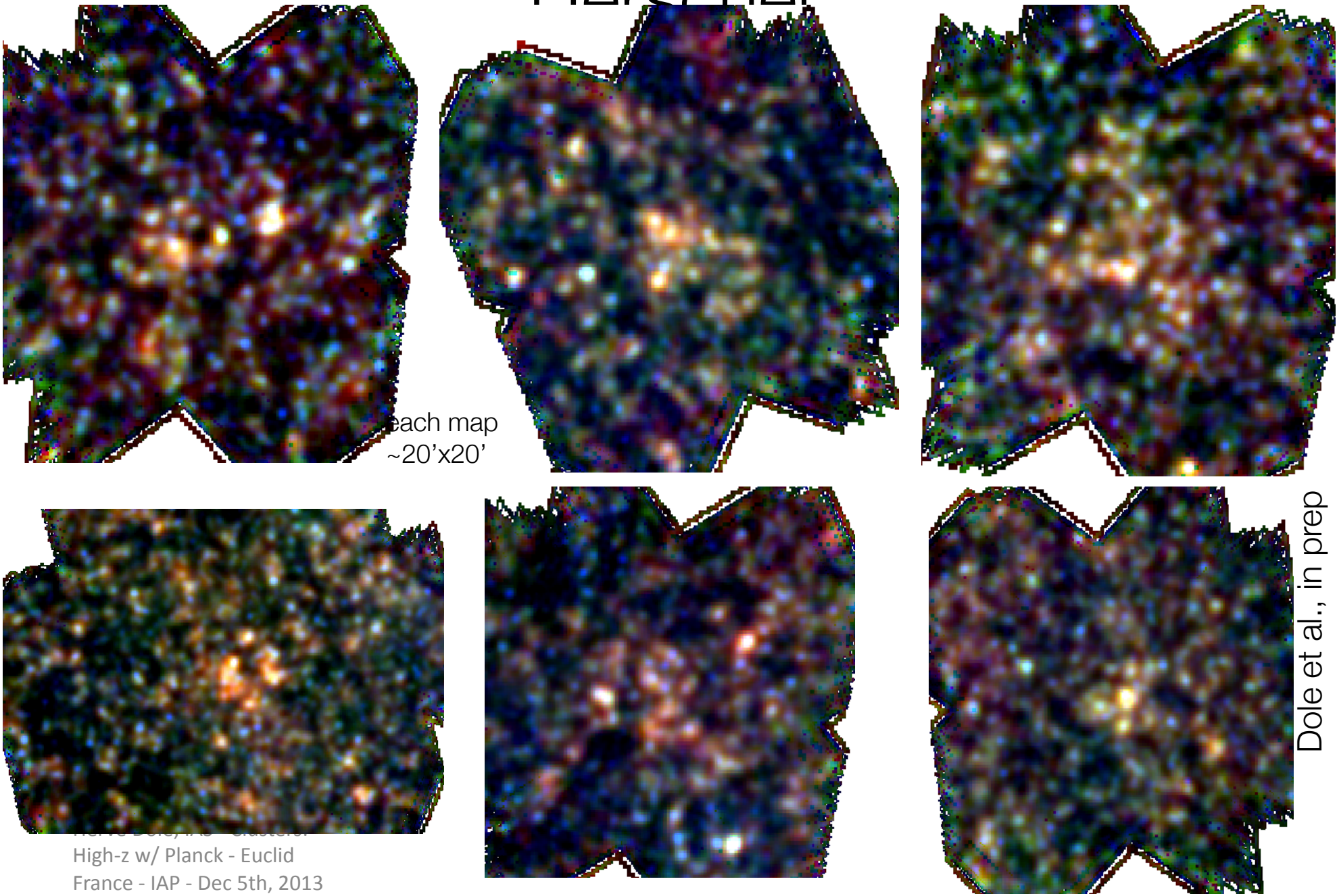
high-z massive clusters: likely very rare on the sky. Need for all-sky surveys, à la Planck & Euclid to complement deep searches.

Brodwin et al, 2012
Mortonson et al., 2011

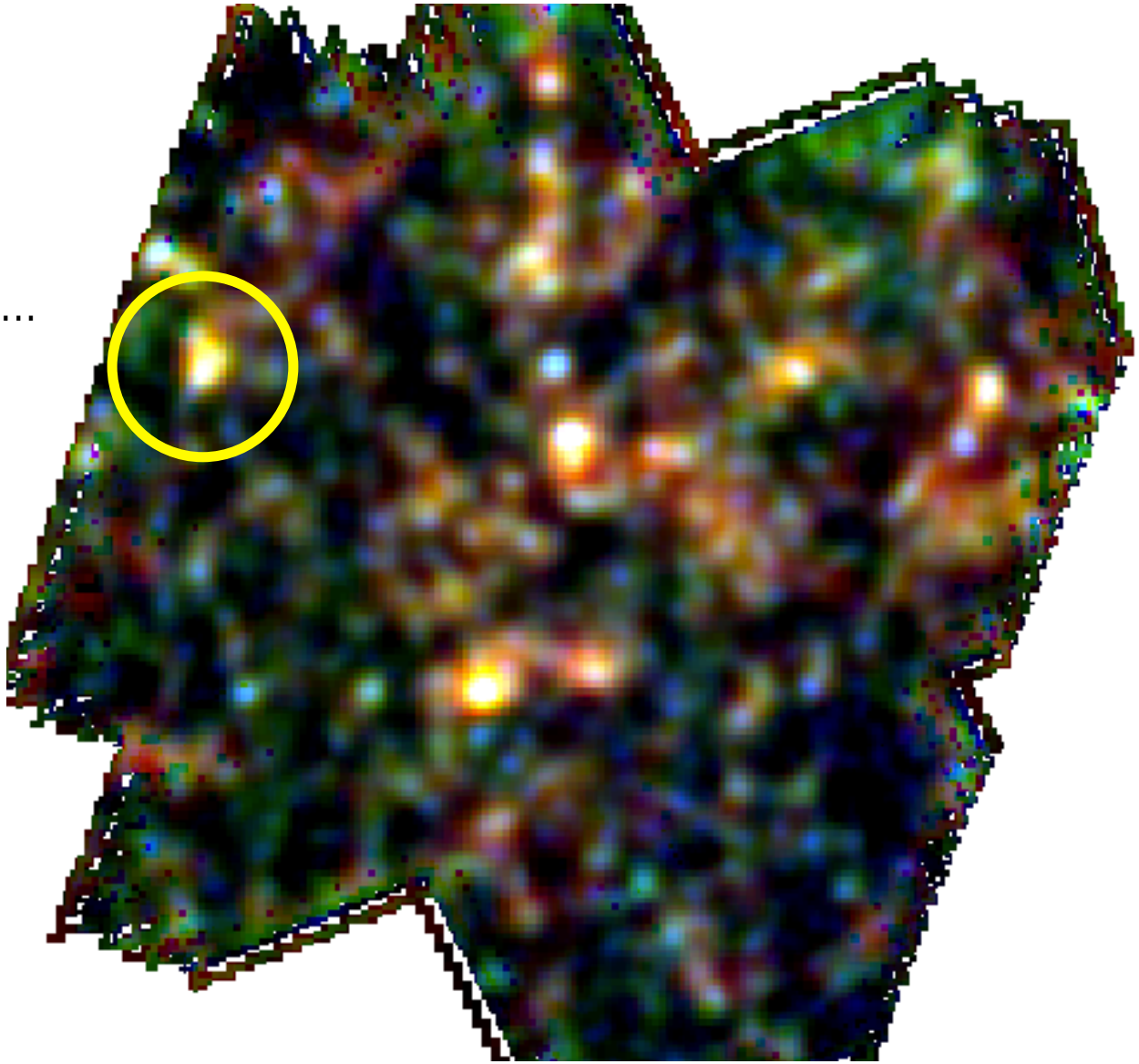
a remarkable dataset: 200+ Planck/ Herschel



Dole et al., in prep

the case of XMMU J0044.0-2033

we serendipitously found this source, slightly off our main target.
And it appears to be...



Dole et al., in prep

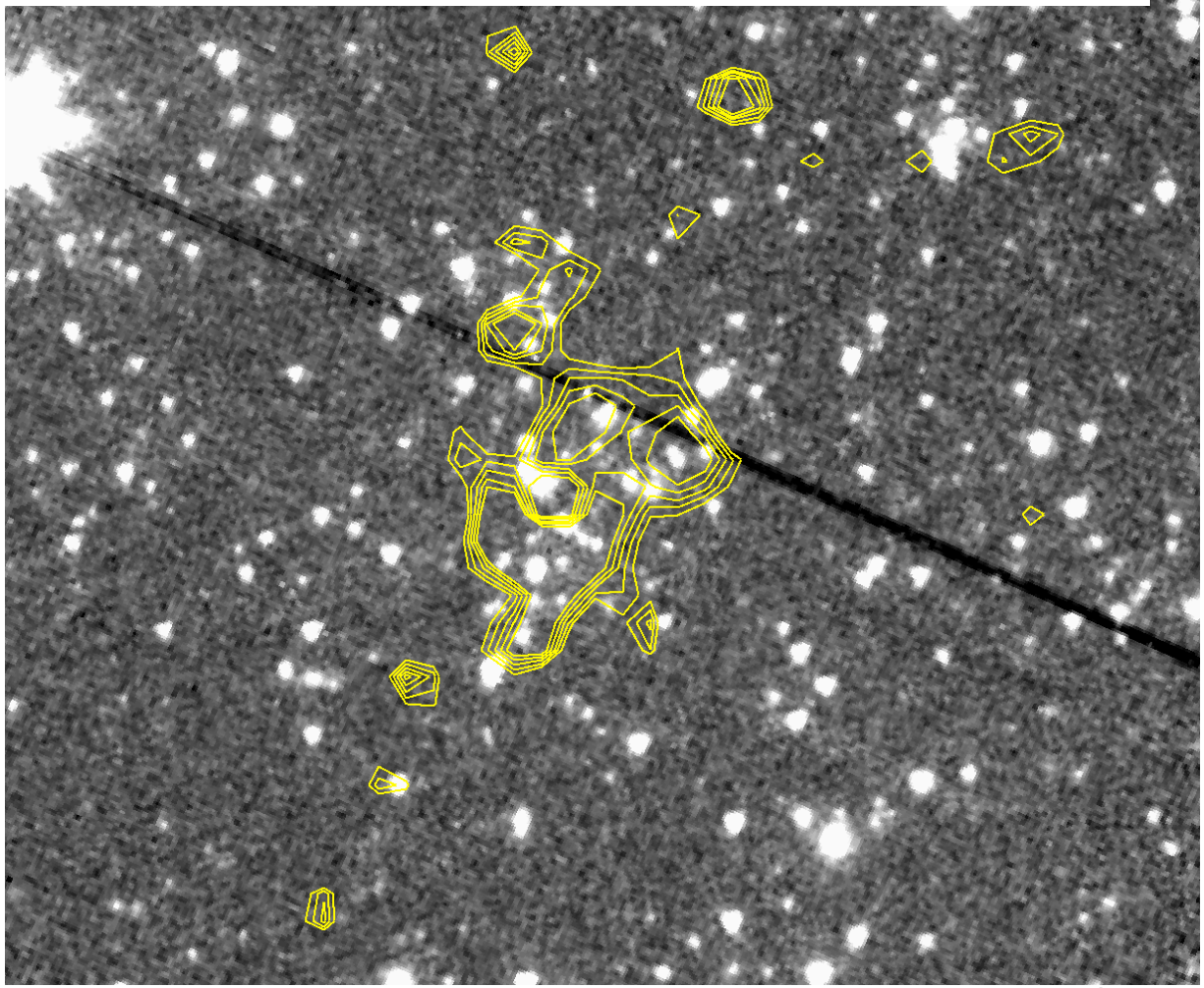
the case of XMMU J0044.0-2033

Discovery of a massive X-ray luminous galaxy cluster at $z = 1.579^{\star}$

J. S. Santos[1], R. Fassbender[2], A. Nastasi[2], H. Böhringer[2], P. Rosati[3], R. Šuhada[2], D. Pierini[2,**], M. Nonino[4], M. Mühlegger[2], H. Quintana[5], A. D. Schwope[6], G. Lamer[6], A. de Hoon[6], and V. Strazzullo[7]

We report on the discovery of a very distant galaxy cluster serendipitously detected in the archive of the *XMM-Newton* mission, within the scope of the *XMM-Newton* Distant Cluster Project (XDCP). XMMUJ0044.0-2033 was detected at a high significance level (5σ) as a compact, but significantly extended source in the X-ray data, with a soft-band flux $f(r < 40'') = (1.5 \pm 0.3) \times 10^{-14}$ erg s^{-1} cm^{-2}. Optical/NIR follow-up observations confirmed the presence of an overdensity of red galaxies matching the X-ray emission. The cluster was spectroscopically confirmed to be at $z = 1.579$ using ground-based VLT/FORS2 spectroscopy. The analysis of the $I-H$ colour–magnitude diagram shows a sequence of red galaxies with a colour range $[3.7 < I-H < 4.6]$ within 1′ from the cluster X-ray emission peak. However, the three spectroscopic members (all with complex morphology) have significantly bluer colours relative to the observed red-sequence. In addition, two of the three cluster members have [OII] emission, indicative of on-going star formation. Using the spectroscopic redshift we estimated the X-ray bolometric luminosity, $L_{\rm bol,40''} \sim 5.8 \times 10^{44}$ erg s^{-1}, implying a massive galaxy cluster. This places XMMU J0044.0-2033 at the forefront of massive distant clusters, closing the gap between lower redshift systems and recently discovered proto- and low-mass clusters at $z > 1.6$.

M~3-5 10^{14} Ms



another good candidate using IRAC

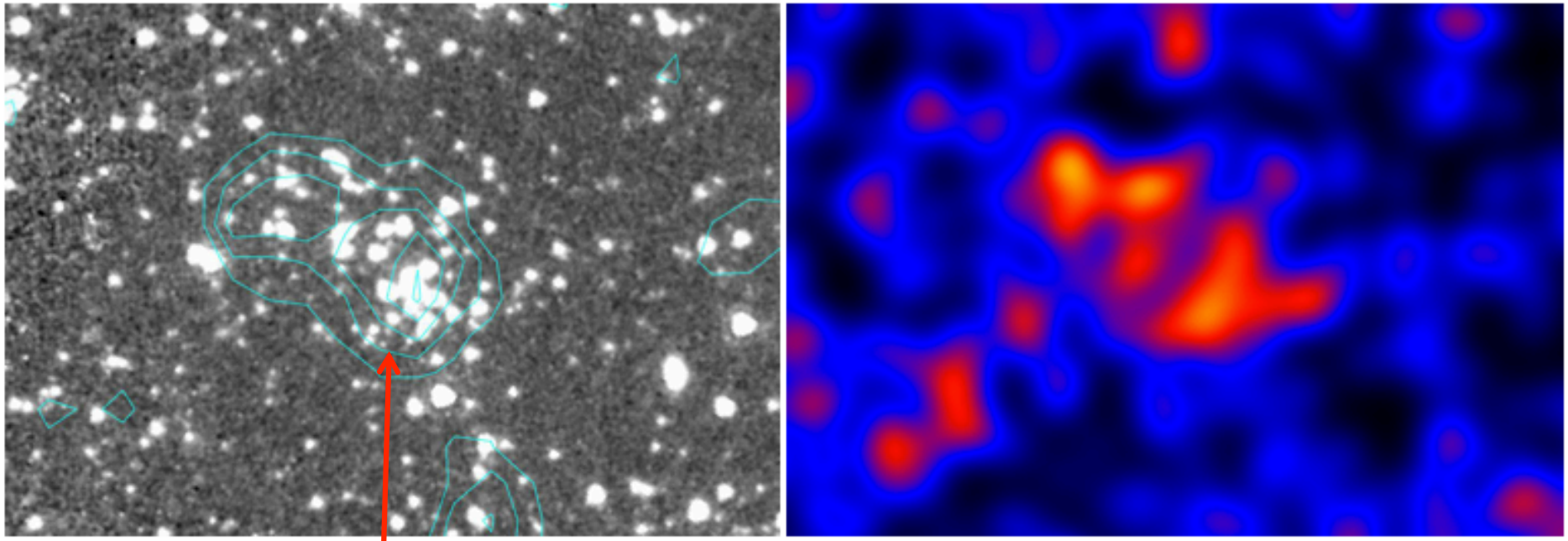
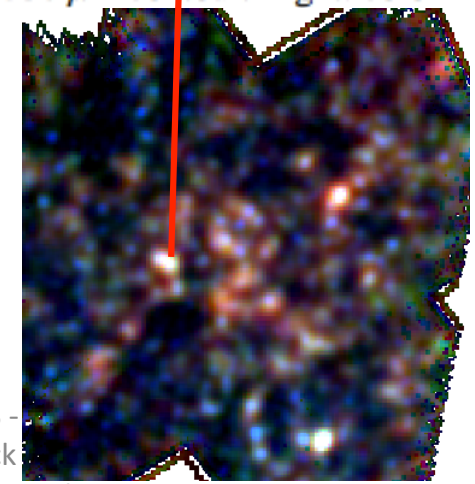


Figure 10. A high-z cluster candidate observed by *Planck*, Herschel, and here Spitzer-IRAC (3.5′ × 2.3′). Left: IRAC channel 2 (4.5 μm) with SPIRE 350 μm contour. Right: color image of the 4.5/3.6 color ratio, showing the red color of the sources within the cluster candidate.



...and Euclid in the future over the whole sky

Dole et al., in prep