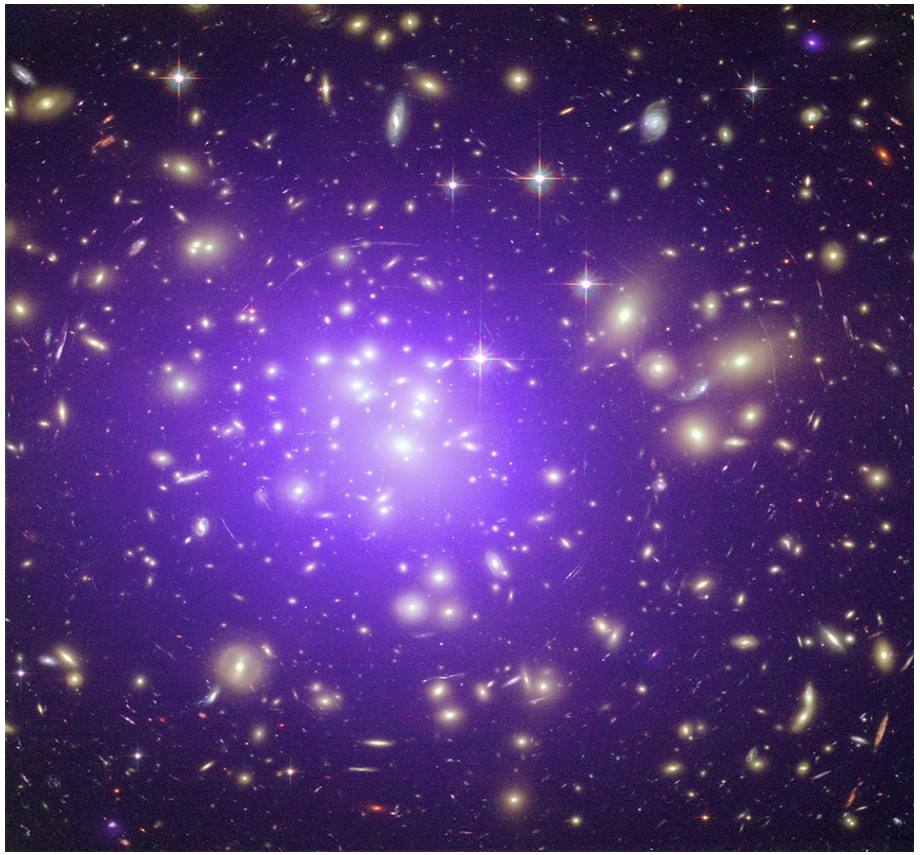
***[quick and biased] Overview of cluster cosmology** [C. Combet]*

***Galaxy clusters analysis with the LSST stack outputs** [N. Chotard]*

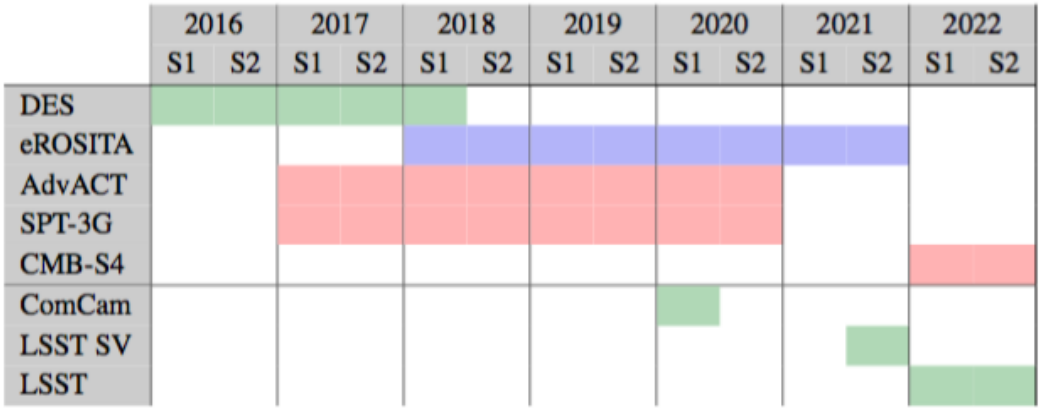
***Organisation of the work within DESC + topics of discussion** [C. Combet, all :)]*

Main properties of galaxy clusters



Abell 1689 – X-ray: NASA/CXC/MIT/E.-H Peng et al;
Optical: NASA/STScI

- Largest gravitationally bound structures in the universe
- **Total mass** : 10^{14} – 10^{15} M_{sun}
- **Composition**
  - Dark matter [~88%]
  - Diffuse hot gas [~10%]
  - Galaxies [~2%]
- **Observations**
  - Optical
  - X-rays
  - mm (SZ effect)



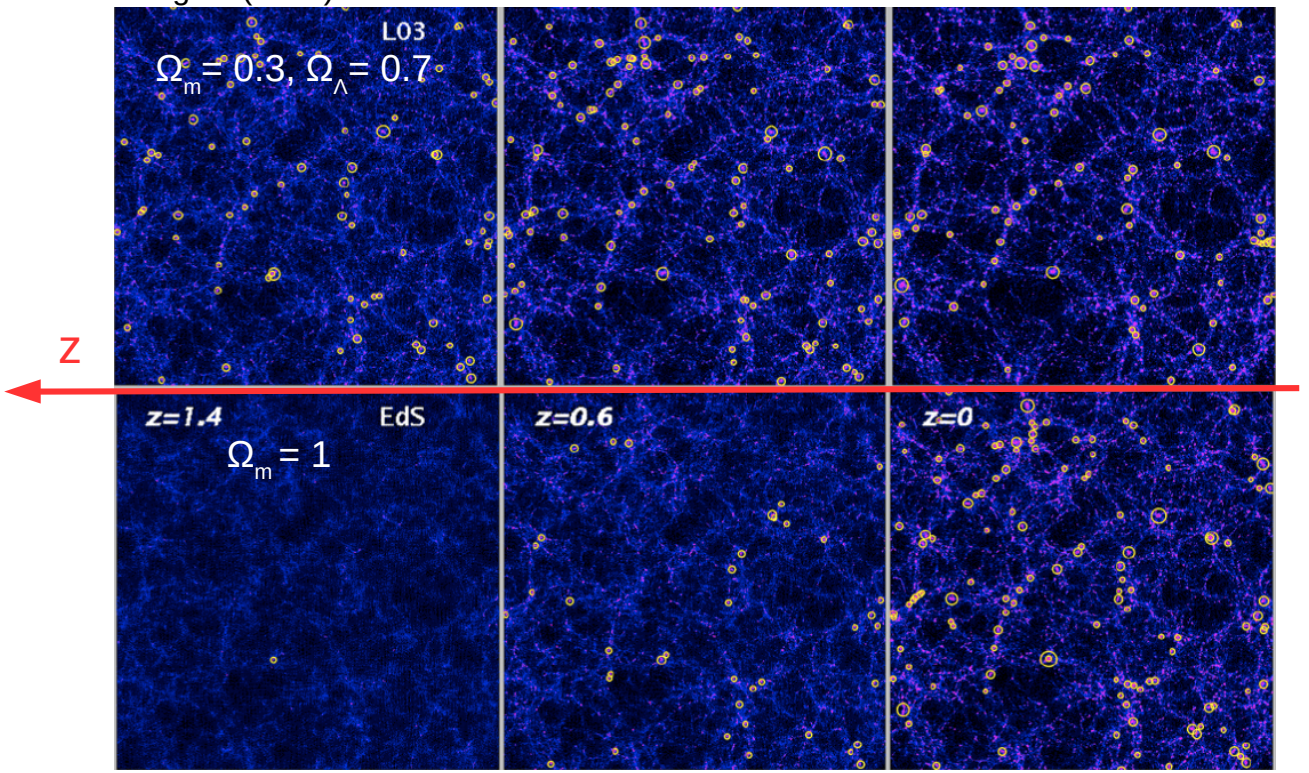
Cluster cosmology with cluster counts

- Halo mass function = number density of haloes (clusters) as a function of mass and redshift $n(M,z)$

- $n(M,z)$ depends on cosmology
  - Expansion history
  - Growth of structures

➡ Cluster counts are at the core of cluster cosmology

Borgani (2001)



In mass bin a and redshift bin i

$$N(M_a, z_i) = \frac{\Delta\Omega}{4\pi} \int_{z_i}^{z_{i+1}} dz \frac{dV}{dz} \int_{M_a}^{M_{a+1}} dM\ n(M,z)$$

1. predict mass function $n(M,z) = f$(cosmology)
2. build cluster catalog ('cluster observable' + redshift)
3. determine cluster masses
4. cosmological parameters from likelihood analysis

Cluster cosmology is currently limited by mass estimation

Determining cluster masses

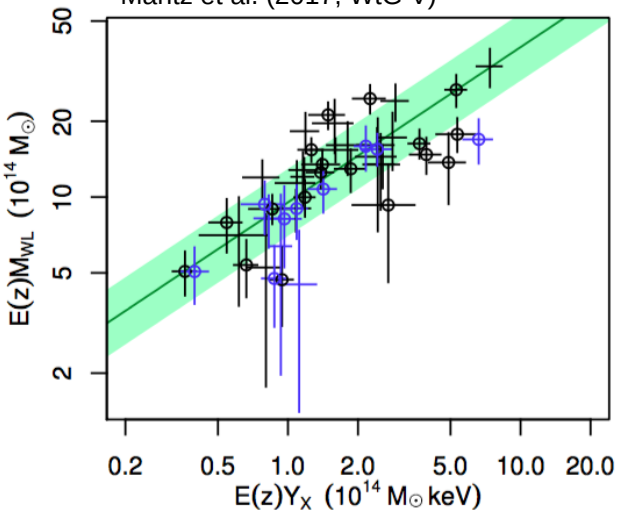
Cluster observable – mass proxies

- X-rays (XMM, Chandra): L_X, kT_X, Y_X *[baryons]*
- mm (Planck, SPT, etc.): Compton parameter Y_{SZ} (SZ effect) *[baryons]*
- Optical (DES,LSST): richness (N_{200} , # of galaxies in cluster), [weak lensing (shear) → M_{tot}]
- [If spectroscopy: velocity dispersion → M_{tot}]

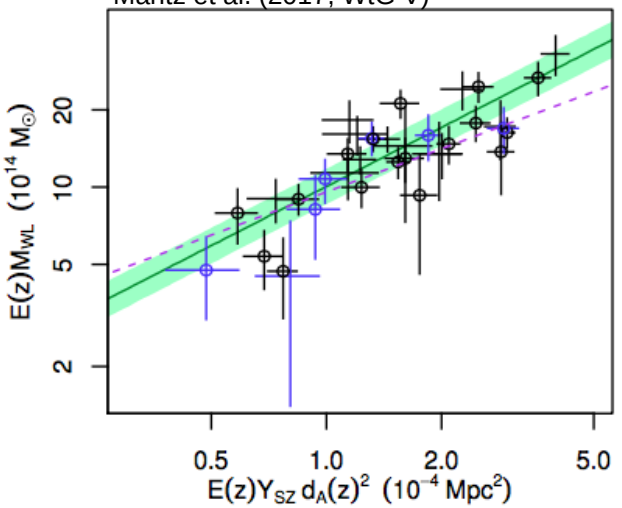
$$M_{obs} \neq M_{true}$$

➡ Scaling relations are necessary to go from cluster observable to cluster mass

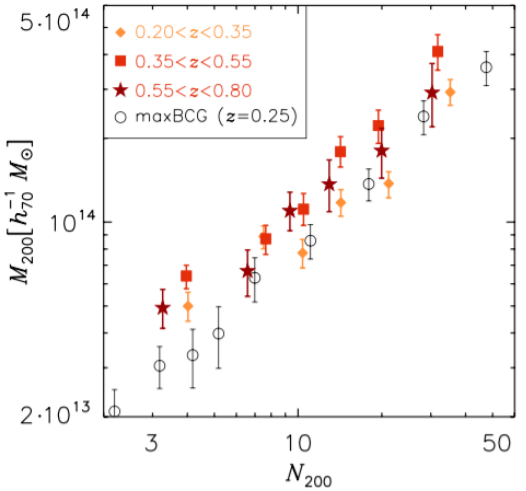
Mantz et al. (2017, WtG V)



Mantz et al. (2017, WtG V)



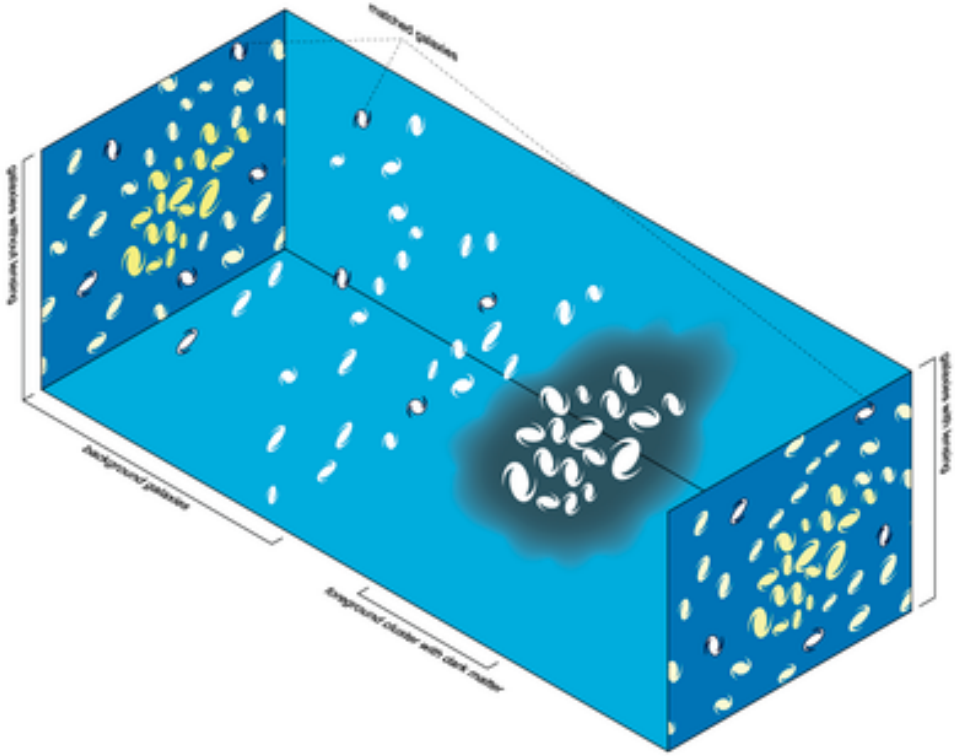
Van Huitert et al. (2016)



➡ Weak lensing is the best approach to determine the absolute mass calibration

- Shear is sensitive to total mass
- Noisy and high scatter mass proxy for individual clusters
- But, **precise and robust mean mass calibration for ensemble of clusters**
- Requires calibration of the shear measurement

WL cluster mass from shape measurements



Images of background galaxies are

- coherently distorted (shear γ),
- magnified (convergence κ)

by the cluster gravitational potential. Lensing Jacobian:

$$A = (1-\kappa)\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} - \gamma\begin{bmatrix}\cos 2\phi & \sin 2\phi\\ \sin 2\phi & -\cos 2\phi\end{bmatrix}$$

Weak lensing limit: $\gamma = < e^{obs} >$, e^{obs} = observed ellipticity

Shape measurements, PSF deconvolution : KSB, HSM,...

Several methods already available in **LSST DM stack**

Simulations needed to calibrate the shear likelihood $P(\hat{g}|g(z,M))$

From C. Heymans

WL cluster mass from shape measurements

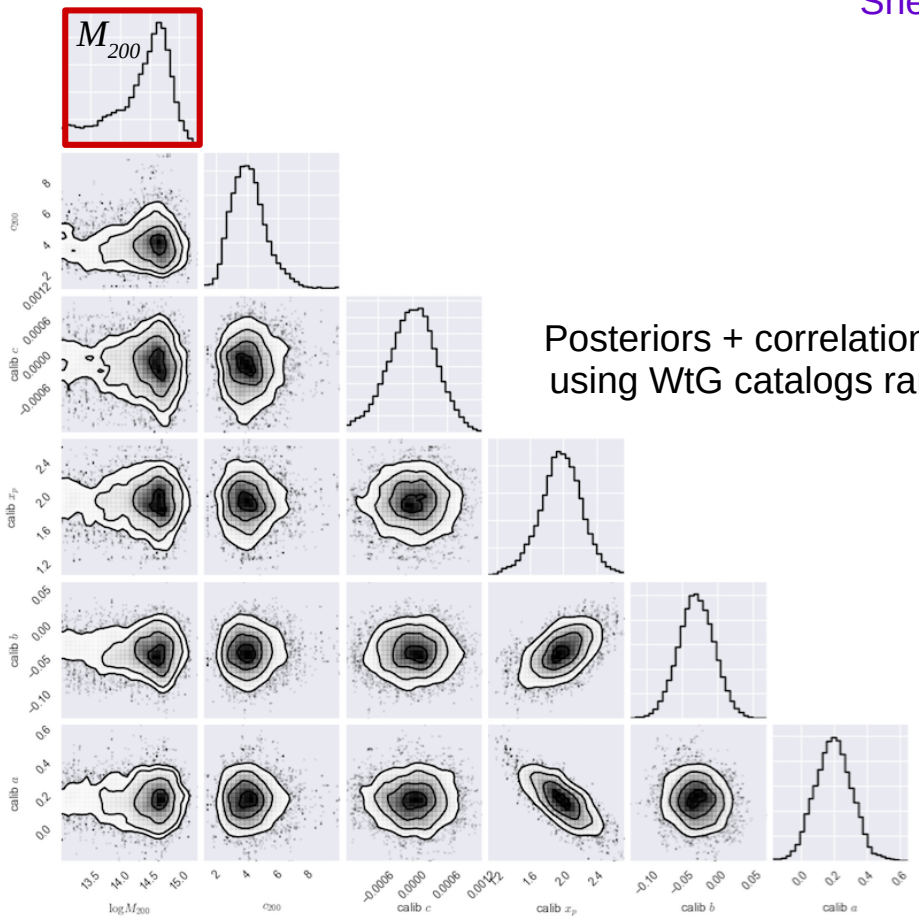
Mass determination ("standard" approach):

- Assume spherical symmetry
- Assume DM radial profile (NFW) – normalised w.r.t to mass (via concentration)
- Compute the expected shear and "compare" to observations, e.g. WtG "P(z) method"

$$P(M|\hat{g}) = P(M) \int_{\vec{\alpha}} P(\vec{\alpha}) \prod_i \int_0^\infty \underbrace{P(\hat{g}_i|g(z,M),\vec{\alpha})}_{\text{Shear likelihood}} P_i(z)\, dz\, d\vec{\alpha}$$

Shear calibration parameters

Redshift distribution function



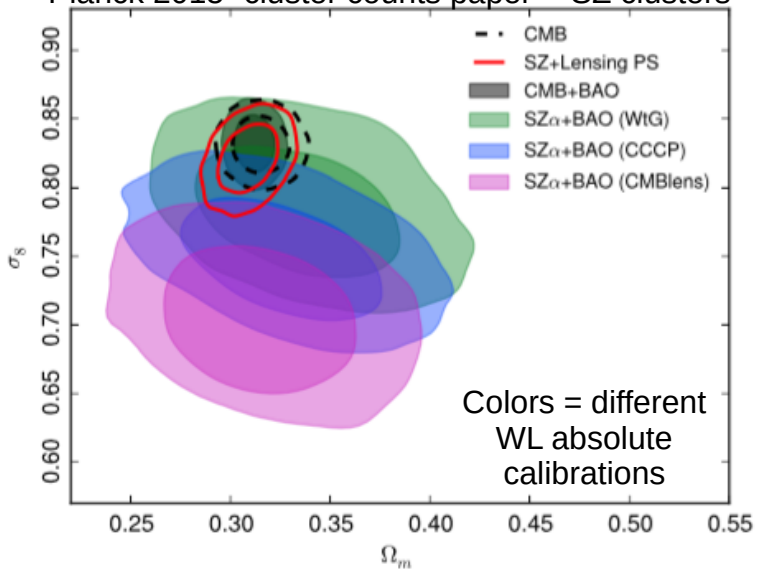
Posteriors + correlations MACSJ2243.3-0935 using WtG catalogs ran with "clusters_mass"

Need to have automatised way to compute the WL masses for the large cluster catalog that LSST will provide → **Clusters pipeline**

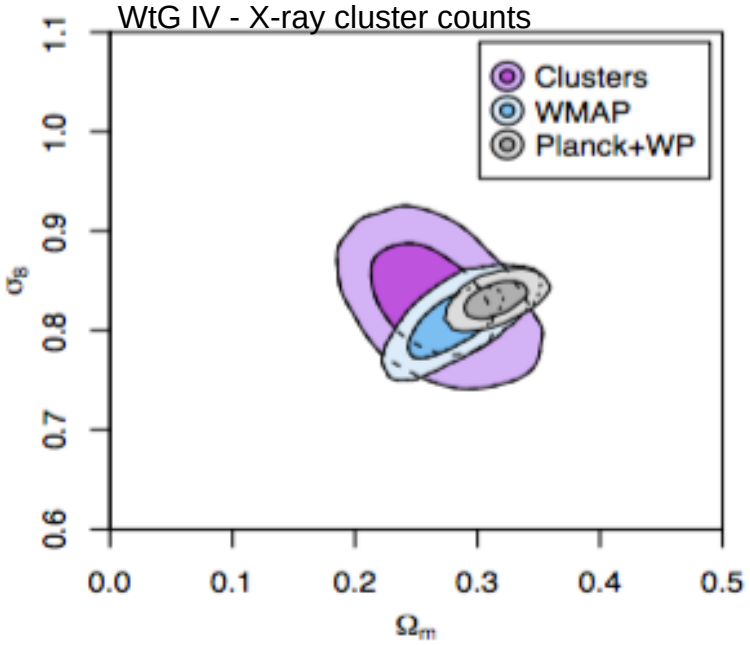
See Nicolas' talk

Using clusters for cosmology

Planck 2015 “cluster counts paper” - SZ clusters



WtG IV - X-ray cluster counts



- + contraints on dark energy, neutrinos, etc...
- distinguishing power between dark energy and modified gravity scenarios
- other cluster cosmological observables:
  - cluster clustering (using clusters, not galaxies, as tracers of LSS)
  - cluster gas fraction (**f_{gas} proposal, P. Astier, D. Boutigny + WtG people**)
  - tomography: z-dependent lensing of background galaxies

Clusters are becoming/will become a competitive cosmological probe!

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DESC Clusters WG

- **WG coordinators** : Anja von der Linden, Ian dell'Antonio (stepping down)

- **Monthly telecon** : ~ 15 – 20 people connected, 1 – 2 presentations/telecon
  - Any cluster-related work. A lot of expertise!
  - Not necessarily LSST-related work, discussion.

- **Bi-monthly cluster 'sub-telecon'** : linked to 'Clusters' pipeline development
  - N. Chotard, D. Boutigny, C. Combet (DM stack reprocessing + pipeline development)
  - Anja von der Linden, D. Applegate, A. Wright (WtG expertise)
  - I. dell'Antonio, Robert Liu (DM stack users, cluster expertise)
  - *[Collaboration started at DESC hack week, November 2016… These are great opportunities!]*

Work is organised around the Science Roadmap

Clusters Science Roadmap

Galaxy Clusters Key Projects:

DC1 Key Project **CL1**: Cluster finding and characterization via red-sequence methods	56
DC1 Key Project **CL2**: Absolute mass calibration I	59
DC2 Key Project **CL3**: Absolute mass calibration II	62
DC2 Key Project **CL4**: Relative Mass Calibration	65
DC1&DC2&DC3 Key Project **CL5**: Cosmology Likelihood Module (CLCOSMO)	67
DC3 Key Project **CL6**: Analysis of **`DC3 Mock Lightcone`** and pre-cursor data. CC/SV observing plan	68
Deliverable CX1.2CL (DC1 DP: Measure the impact of blends on cluster shear profiles)	111
Deliverable CX1.6CL (DC2 DP: Shear Deblending including galaxy colors and clustering)	113
Deliverable CX12.6CL (DC3 DP: On the use of the DDFs to reduce cluster mass systematics)	143

Clusters Science Roadmap: where we (LAPP/LPSC) contribute

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Deliverable **CL3.5** (**09/18**) – DC2 DP: Apply refined results to existing cluster lensing data (CLABSMASS)

Objective: We will use the results of CL3.1, CL3.2 and CL3.4 to further improve mass measurements from available "LSST-like" cluster weak-lensing datasets (both currently existing and gathered in CL2.6). On this timescale, we will also look towards converting our data processing pipelines to DM stack.
Prerequisite Deliverables: CL2.6,CL3.1,CL3.2,CL3.4

Key Task CL3.5.1 (**ongoing**): Obtain additional "LSST-like" cluster weak-lensing datasets

Key Task CL3.5.2 (**12/17**): Analyze data; adopt DM stack (where ready) for parts of pipeline processing

Key Task CL3.5.3 (**03/18**): Measure cluster masses

Clusters Science Roadmap: where we (LAPP/LPSC) will probably contribute

Galaxy Clusters Key Projects:

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Deliverable **CL6.5** (**03/20**) – DC3 DP,VA: Cluster masses from Project re-processed survey data

Objective: We will use the DESC algorithms to process project reprocessed "LSST-like" survey data sets to extract cluster masses. Survey data sets that may be available at the time include CFHTLS, DES, and HSC.

Prerequisite Deliverables: CL2.6, CL3.5, CLMASSMOD, CLSHEAR, CLSMURFS, CLABSMASS

Key Task CL6.5.1 (**09/19**): Analyze Project reprocessed data sets using DESC algorithms.

Key Task CL6.5.2 (**12/19**): Measure cluster masses.

Key Task CL6.5.3 (**03/20**): Provide feedback to DM and relevant DESC groups.

Clusters Science Roadmap: where we (IN2P3) could contribute? Discussion...

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- Cluster cosmology needs accurate *p(z) :* CL3.4 → overlap with photoz-WG
- Improve shear measurement methods : see A. Guyonnet's talk, LSST-France 06/16
- Magnification?

CLABSMASS	Provide accurate absolute mass calibration	**CL2 Gather and analyze LSST-like cluster data sets**	**CL3 Continue DC1**; develop magnification	**CL6 Test DM Stack and apply to existing cluster data**^{DM}; develop CMB lensing

- Likelihood module, cosmological parameters CL5? (cluster cosmology with CAMEL?)
- Cluster finding methods CL1? Others?