Cluster Cosmology at LSST

Rance Solomon
Postdoc @ LAPP
solomon@lapp.in2p3.fr

Assemblée Générale Enigmass2
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About Rance:

Ph.D. in Oct-2022 from University at Buffalo.
Doctoral work in theoretical cosmology and AGN variability.

Began postdoc contract at LAPP on 15-Feb-2023.

Work focuses on contributions to cluster cosmology pipeline for LSST and photometric calibrations on the auxiliary telescope at Rubin Observatory.

This talk will cover my work in:

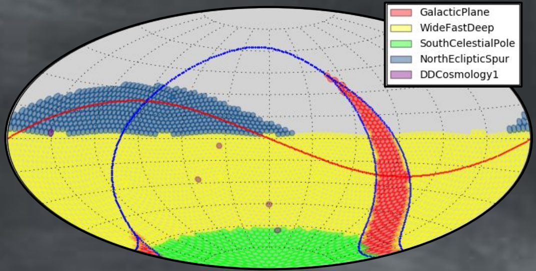
1. Cluster finders
2. Dark matter halo mass estimation
3. Photometric studies on the Auxtel CCD

Why LSST?

1. LSST will run a synoptic Wide-Fast-Deep survey
   - ➢ **Wide**: covering 18 000 deg^2 of Southern sky
   - ➢ **Fast**: can cover full footprint every ~3 days on average
   - ➢ **Deep**: to a depth r = 27.5 for coadd visits
2. It is largely complementary to other surveys:
3. The survey expects to observe ~10^{10} galaxies and ~10^5 clusters.

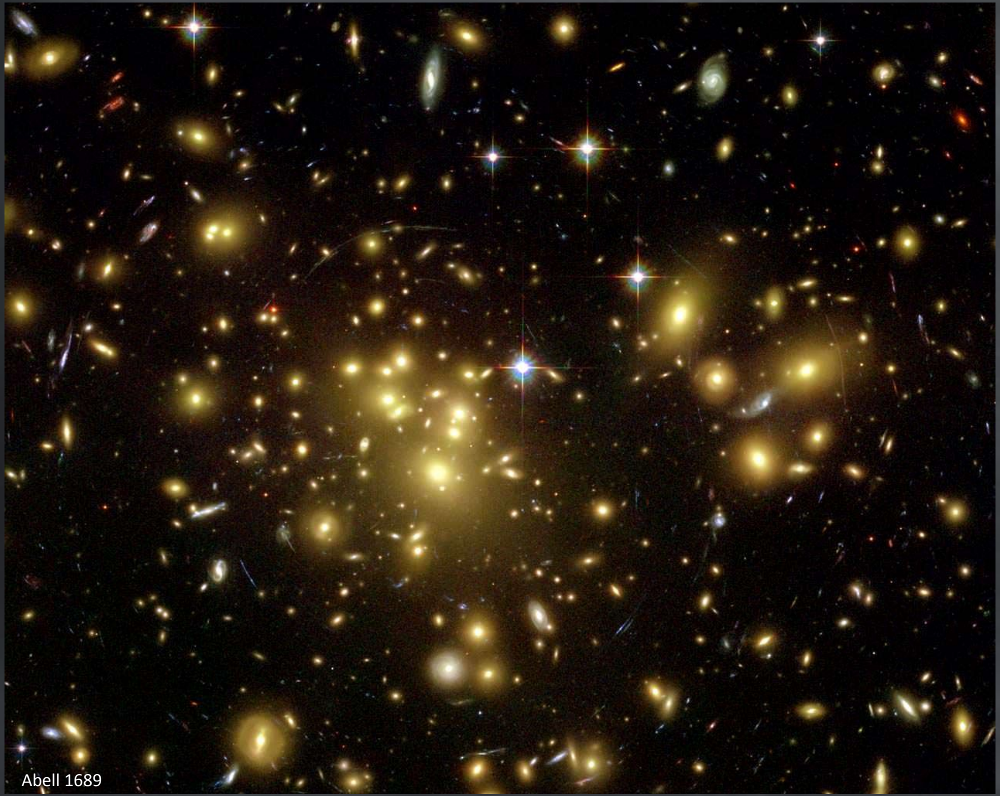
With this many objects we need to turn our attention to systematic uncertainties that have been ignored in previous surveys.

The LSST key probes: WL, SL, LSS, **galaxy clusters**, and Type Ia SNe.



first light on main telescope

12-Nov-2024



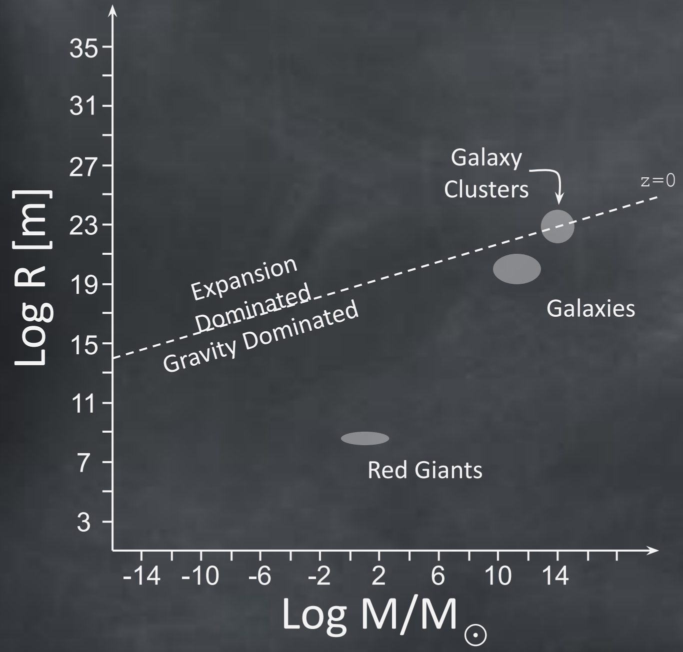
Galaxy Clusters

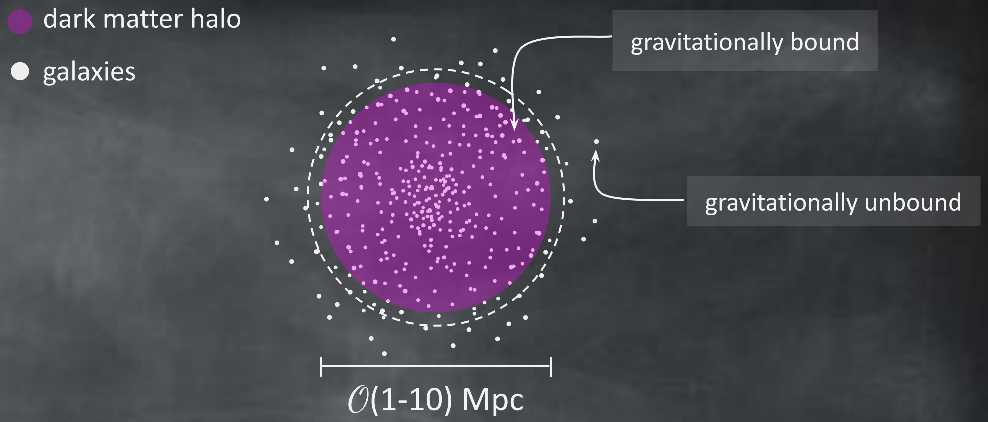
- Largest virialized structures
- Typical Mass: $10^{14-15} M_{\odot}$
- Typical Size: 1-2Mpc (~10^6c yr.)

Contents:

- Galaxies	4%
- Hot gas (2-10keV)	15%
- Dark Matter	81%

Why galaxy clusters?





1) clusters trace dark matter halos
2) rich clusters ~ massive halos
3) clusters exist on boundary of expansion/gravity domination:

expansion: $[\,H_{(z)}\,] = T^{-1}$

contraction: $[\,G\,] = L^3 / M \times T^2$

$$R^3 \sim \frac{G}{H_{(z)}^2} M$$

Dark Energy from counting…

Counting clusters as a function of M and redshift provides a strong cosmological probe.

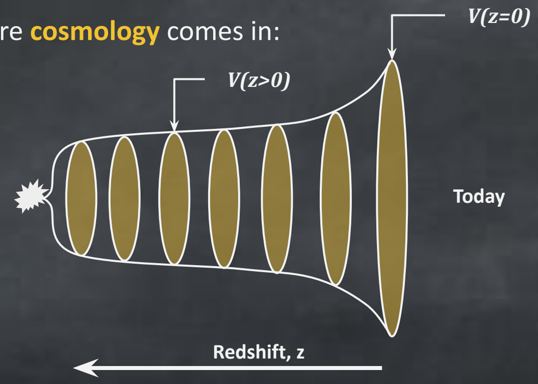
$$\bar{N}(M_a, z_i) \equiv \bar{N}_{ai} = \frac{\Delta\Omega}{4\pi} \int_{z_i}^{z_{i+1}} dz \frac{dV}{dz} \int_{\ln M_a}^{\ln M_{a+1}} d\ln M \frac{dn}{d\ln M}.$$

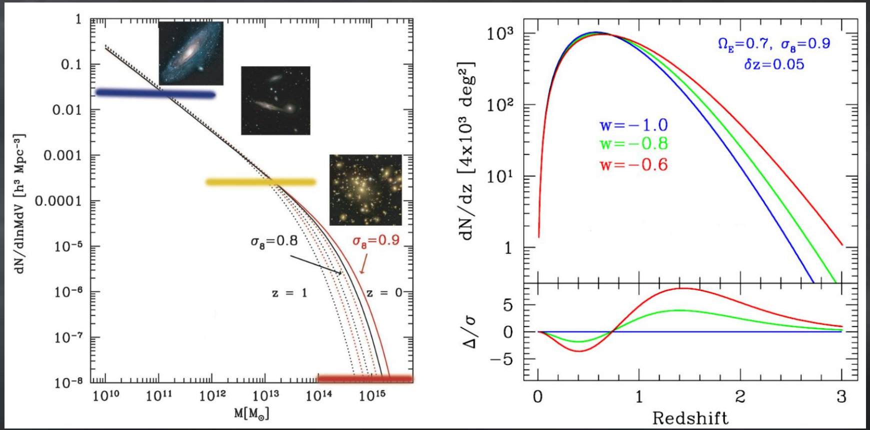
Mass function:

Number density, *n*
- **cosmology** also comes in here
- N° of clusters provided by the "cluster finder"
  - e.g. redMaPPer, WaZP, AMICO, YOLO

Halo mass, *M*
- assuming some halo profile
  - Einasto, NFW
- it is given either by:
  1. gravitational shear (CLMM)
  2. mass proxy relations (i.e. richness)

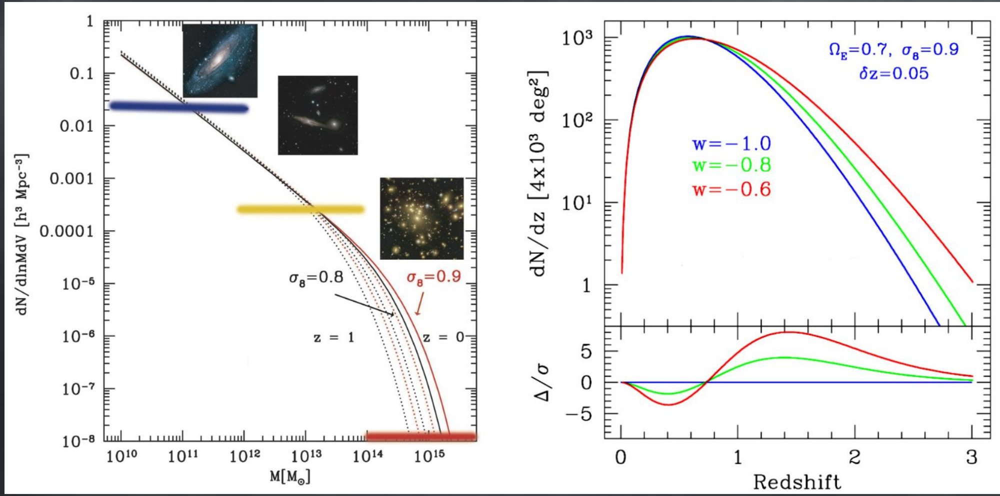
This is where **cosmology** comes in:





from LSST Science Book

Dark Energy from counting… (closer look)



Clusters are sensitive to σ_8.

Dominated by volume effect (i.e. small volume gives less clusters)

Growth rate sensitive

What are these parameters?

$\boldsymbol{\sigma_8}$: Amplitude of matter fluctuations at $8h^{-1}$Mpc scale

- currently there is a >3σ tension between CMB and cluster measurements

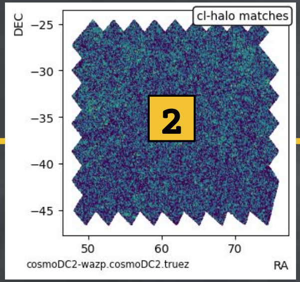
w: the equation of state for dark energy, $p = w\rho$

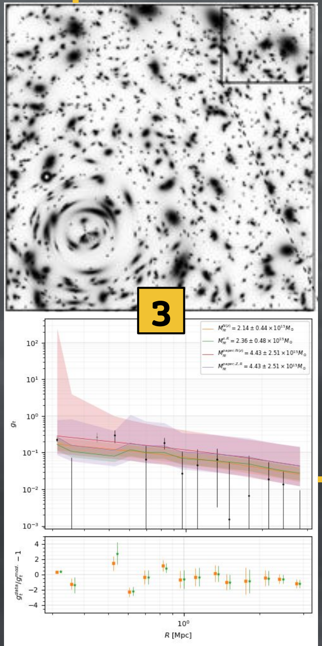
- if concordant w=-1 then DE is constant and we ask how this can be
- if w≠-1 then DE is more complex and cosmic history could change

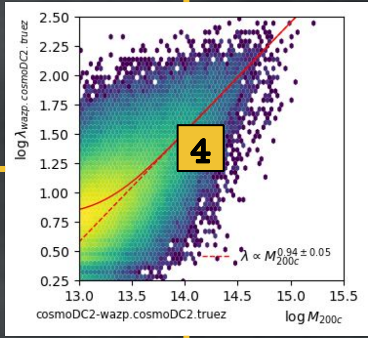
But clusters can do much more:

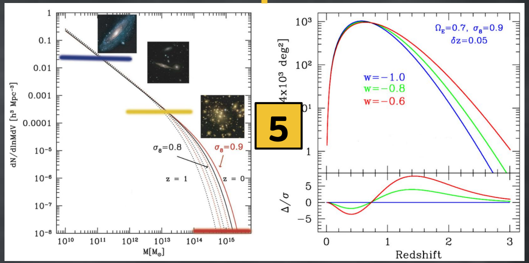
- sum of neutrino masses
- constrain modified gravity
- probe dark matter properties
- structure formation
- …

Cluster cosmology…









1. Start with galaxy catalogs.
2. Find clusters and determine richness.
3. Use weak lensing to estimate halo mass for a subset of clusters.
4. Use WL masses to calibrate richness-mass relation.
5. Bin cluster count in (z, richness) Constrain cosmology by counting halos in mass and redshift.

Cluster cosmology in practice…

There is a lot that goes into the cluster pipeline.

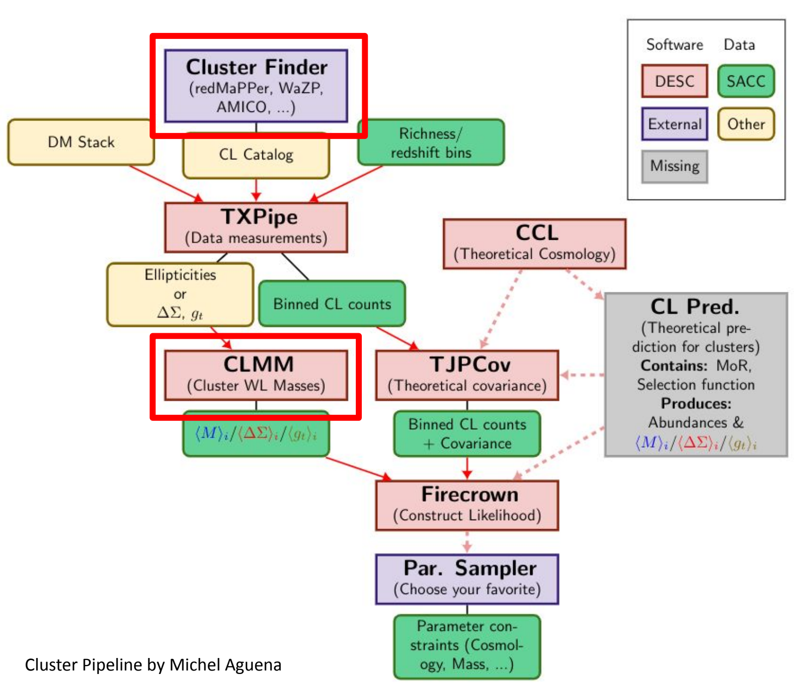
Focusing on just two parts:

➢ Cluster Finders: algorithms designed to find galaxy clusters

- includes WaZP, redMaPPer, AMICO, YOLO …
- can be spatial density based or astrophysical
- provides richness (N° of galaxies in a cluster) which serves as mass proxy

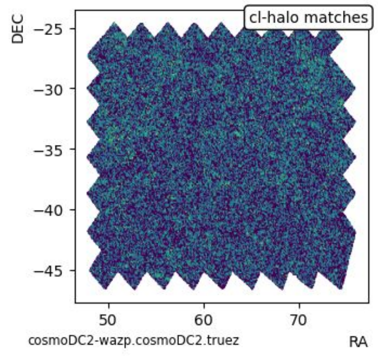
➢ CLuster Mass Modeling (CLMM): DESC module for estimating the halo mass

- uses weak lensing shear measurements to determine the halo mass
- used to calibrate richness-mass relation



Cluster Pipeline by Michel Aguena

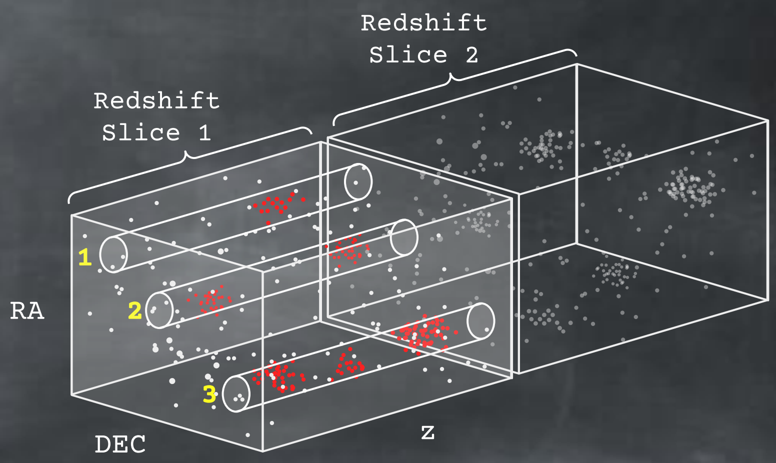
Ongoing work with Cluster Finders



In collaboration with:
Michel Aguena (APC)
Christophe Benoist (OCA)
Dominique Boutigny (LAPP)
Luiz da Costa (LineA)
Thibault Guillemin (LAPP)

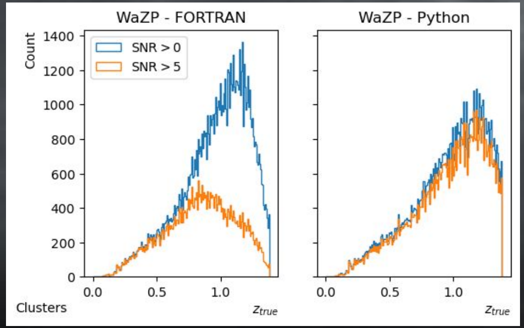
Ongoing work with Cluster Finders

WaZP-Py (github)
- WaZP is a cluster finder based on spatial over-densities.
- Like other cluster finders it will be used not only to find clusters in the galaxy catalogs but also will determine the cluster richness, an observable proxy for the halo mass.



This work is two step:

1. WaZP has been recently moved from FORTRAN to Python so the resulting catalogs need to be validated.
2. Further enhancements need to be made to the code. For instance, upgrade from using the modes of the photoz pdf's to the full pdf.



In collaboration with:
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Dominique Boutigny (LAPP)
Thibault Guillemin (LAPP)

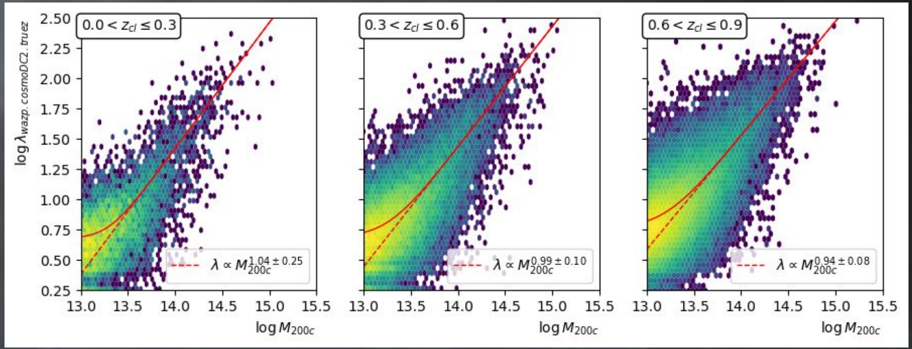
Ongoing work with Cluster Finders

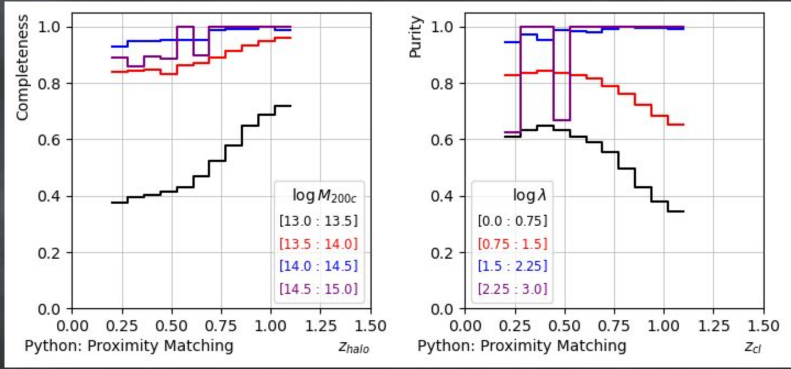
Cluster Challenge (github)
The performance of a cluster finder can have strong effects on our cosmological constraints. Thus, this project aims at:

- building a workbench to bridge gap between the various Cl. finders and the rest of the Cl. pipeline
- make performance studies of Cl. finders on simulated cosmoDC2 and DC2 image

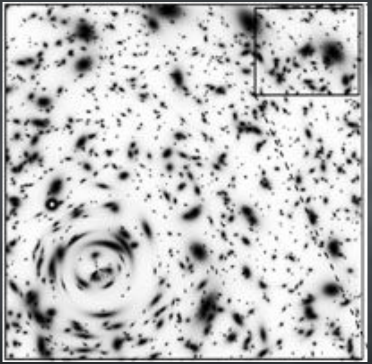
With cosmoDC2 and DC2 (akin to truth and reco for HEP people) we are building towards real onsky data.

Currently studies are on AMICO, redMaPPer, and WaZP with the intent to be extendable to other cluster finders.





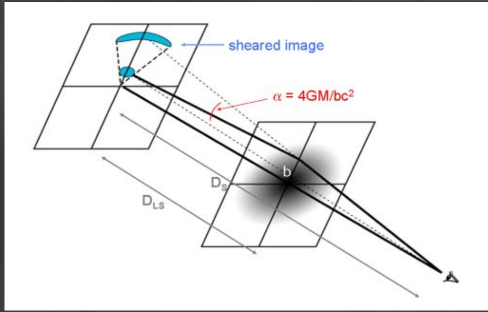
Ongoing work with CLMM



In collaboration with:
Akum Gill (UMI)
Shenming Fu (NOIRLab)
Radhakrishnan Srinivasan (SBU)
Tae-hyeon Shin (SBU)

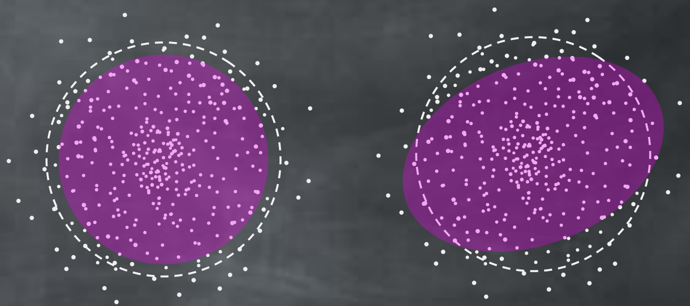
Ongoing work with CLMM

CLMM uses the sheared images of background galaxies to map out density profile of the lensing DM halo.



It is commonly assumed (as is the case in CLMM) that halos are spherical even though simulations prefer projected ellipticities of ε~0.4.

ε = 0 ε = 0.4



Assumed True

Also by stacking shear profiles we can get better statistics in redshift bins. However, if this is done without attention to alignment then it will force the stacked elliptical halos to appear spherical.

Overall, not accounting for ellipticity can cause a deficit in the estimated halo mass by a few percent – at the sensitivity level of LSST.

Ongoing work with CLMM

In collaboration with:
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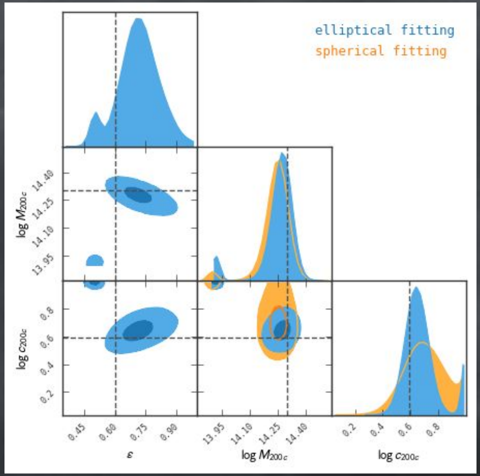
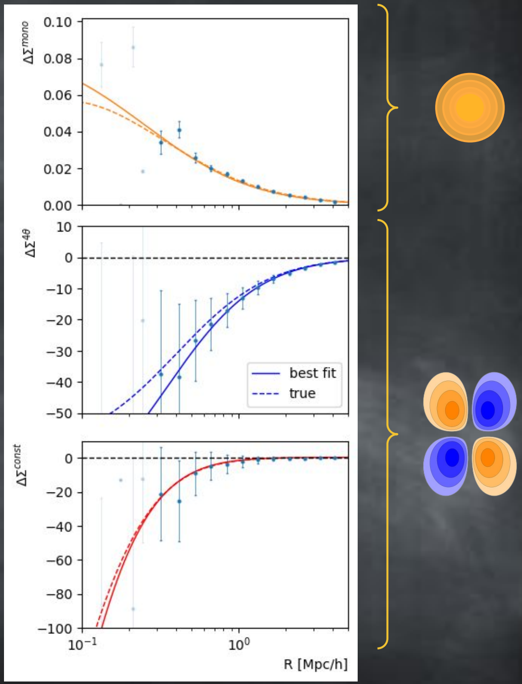
Radhakrishnan Srinivasan (SBU)
Tae-hyeon Shin (SBU)

Using multipole expansion the ellipticity can be accounted for with promising results both in mass estimation and in cluster concentration.

Some work remains before implementing into CLMM:

- practical details of stacking
- bias at high ellipticity
- study sensitivity to shape noise
- study sensitivity to miscentering





Commissioning

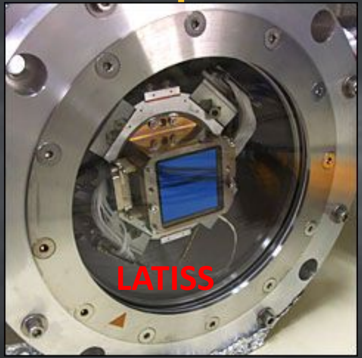
Commissioning

Delays in installing the main telescope have lead to a compression of the commissioning timeline and a reduction in the onsky commissioning.

But an identical CCD is already installed *and* onsky in Auxtel.

Auxtel has been designed such that it serves as a scaled down test bed of what will come on the main telescope.

So with Auxtel we can start some onsky commissioning early



Auxtel - photometric calibrations

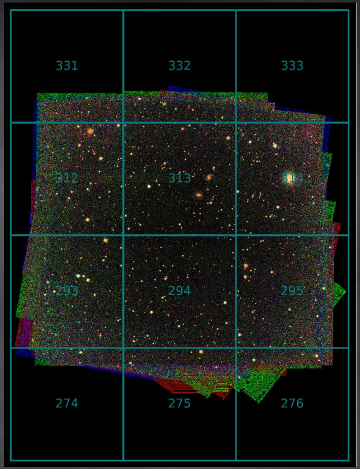
In calibrations we have the standard Dark, Flat, and Bias frames – each plays a part in reducing the noise from electronics and optics and manufacturing defects.

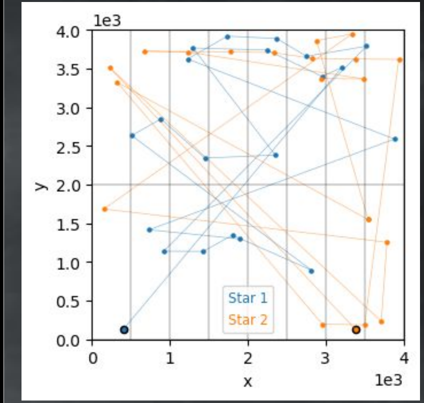
Another frame which can be produced is a **star flat**.

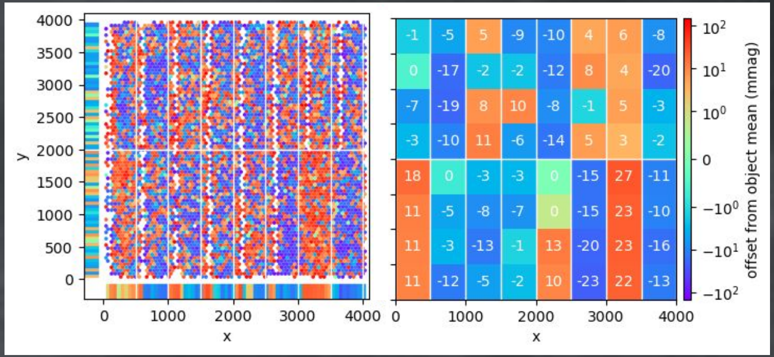
A star flat uses the idea that since stars are very constant in magnitude one can monitor the variations of a star at different positions on the CCD.

Random fluctuations are expected but observing correlated structures would point towards failure in calibrations.

As can be seen, there is some correlated structure on the CCD but some investigation is needed to find the cause.







Future work…

Cluster finder:

- complete validation of WaZP on cosmoDC2 and DC2 datasets (1-2 papers)
- finish the construction of the Cluster Challenge project (1 paper)
- advise an M1 student in a WaZP related project with Thibault Guillermin
- implement the utilization of photoz's into WaZP

CLMM:

- integrate triaxiality code into the CLMM module
- apply triaxiality analysis to Hyper Supreme Cam (HSC) data (1 paper)
- investigate radial dependence of ellipticity in halos (1 paper)

Commissioning:

- continue investigation into photometric calibrations to ensure first light is very nice light.