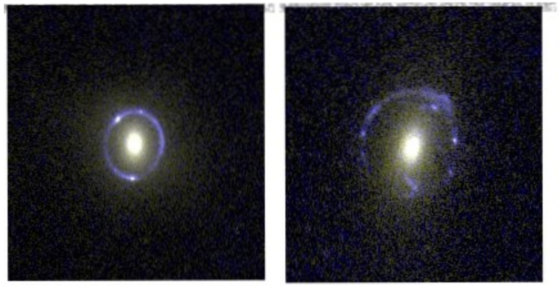
# LSST France meeting

***The small-scale dark matter content in galaxies and clusters of galaxies from weak and strong lensing***



Raphael Gavazzi
LAM / IAP

# Introduction

- Project proposed during the 2016 call for INSU-IN2P3 sharing of LSST data rights.
  - Combination of strong and weak lensing in the core of galaxies and clusters to constrain DM properties

- Between 2016 and 2020
  - I got further involved in Euclid (co-Lead of the Strong Lensing SWG)
  - Pushed a project aiming at modeling cluster weak lensing data from ground based data (AMALGAM). Merged with the CHEX-MATE cluster project
  - Focused on the ray-tracing through Hydrodynamical cosmo sims

- Worked at IAP until 2020, then spent 1 year at IoA, Cambridge. Since Sept 2021, at LAM!… busy period...

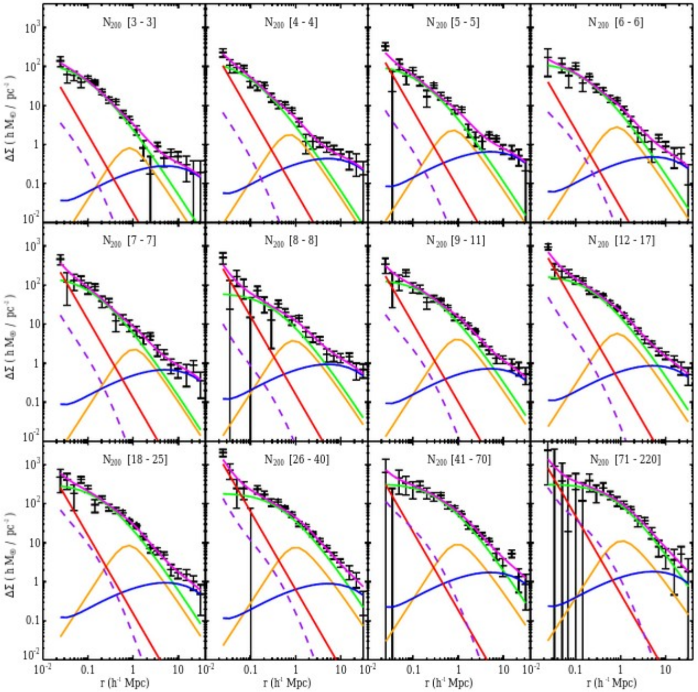
- As of yet, only weakly acquainted with LSST paradigm!
  - Should get into closer contact with C. Combet’s group and DESC-Clusters at large
  - Had a substantial contribution to the writing of Euclid – Rubin/LSST Derived Data Products proposal for Strong Lensing

# Mass content

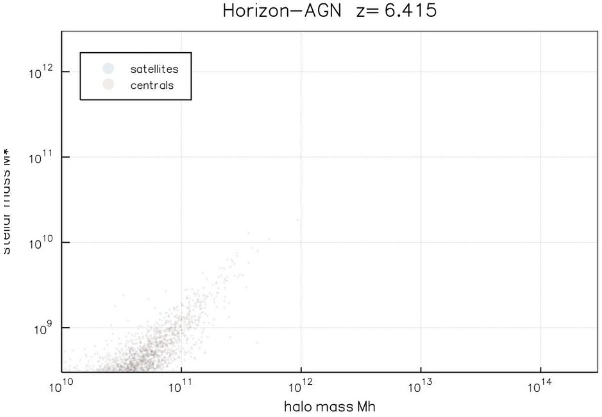
- From masses...
  - Overall halo masses and beyond (virial, turnaround, 2-halo & linear bias)
  - Relation between halo and baryons

- ... profiles & shapes ...
  - DM properties (cusp-core, ellipticity
  - Severe cross-talk with baryons

- … to substructure




$$p(M_{\rm h}, \cdots | M_*, \cdots)$$



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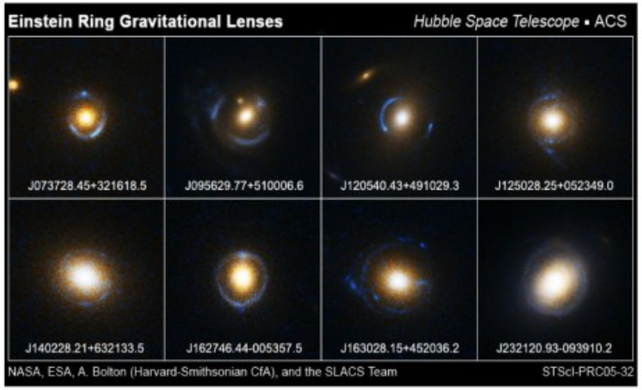
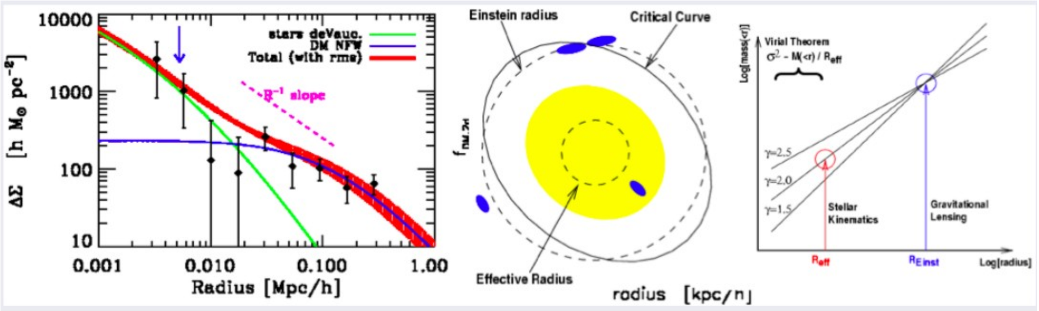
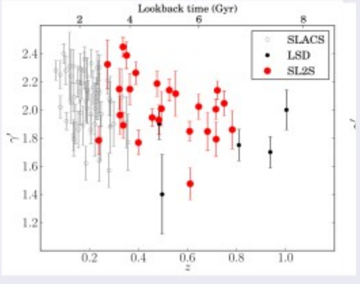


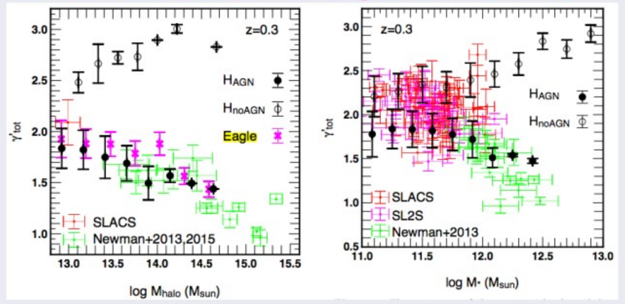




$$\gamma' = \frac{d \log \rho_{tot}}{d \log r} \sim 2.08 \pm 0.02$$

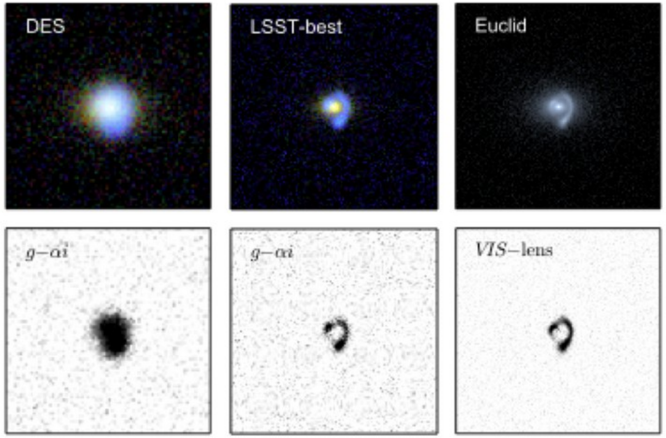
Dispersion $\sigma_{\gamma'} = 0.12 \pm 0.02$




Horizon-AGN : Dubois, Peirani, Laigle, Codis, Pichon,...



# Strong Lensing: Euclid/LSST synergies




- Replied to the call (Apr 21 - now) for sharing Derived Data Products.

W/ T Collett, P Marshall, G Smith, T Anguita, A Verma, ...

  Propose maximal sharing of pixels (3% of LSST & Euclid sky)

FND-19-SL: Combining Rubin and Euclid data is critical to strong lens discovery and exploitation
REC-31-SL: Multiband simulations of Euclid and LSST strong lenses
DDP-57-SL: Pansharpenned images of all strong lens candidates
DDP-58-SL: Deblended foreground lens and background source photometry for strong lens candidates
DDP-59-SL: A joint colour and morphology catalogue for strong lens searches
DDP-60-SL: A strong lens probability for every early type galaxy
DDP-61-SL: ugrizy-VIS-YJH postage stamps of strong lens candidates

- Coordinating spectroscopic follow-up
  - Pure SL 4MOST Proposal (PI Collett)

- SL reply for SV during Rubin commissioning
  ArXiv 2111.0021[illegible]

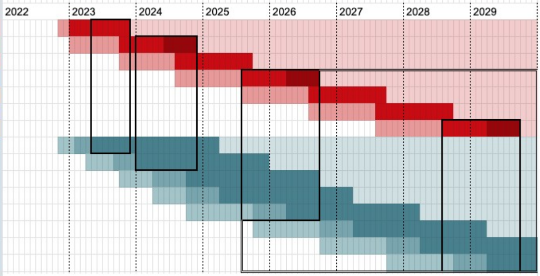
Strong Lensing Science Collaboration input to the on-sky commissioning of the Vera Rubin Observatory

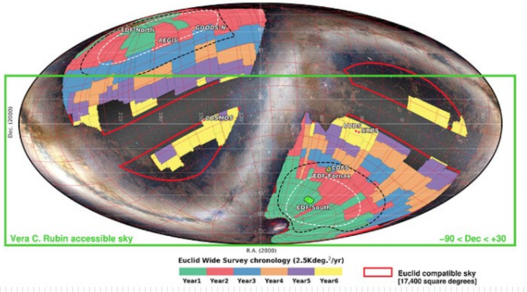
Graham P. Smith[a], Timo Anguita[b,c], Simon Birrer[d], Paul L. Schechter[e], Aprajita Verma[f], Tom Collett[g], Frederic Courbin[h], Brenda Frye[i], Raphael Gavazzi[j], Cameron Lemon[h], Anupreeta More[k], Dan Ryczanowski[a], Sherry H. Suyu[l], on behalf of the Strong Lensing Science Collaboration

ance meeting

**Rubin Euclid Data Release Timeline**

| Survey | Data Release | |
|---|---|---|
| Euclid | Q1 | Euclid Performance Verification (50 sq deg) |
| Euclid | DR1 | Euclid Y1 (2500 sq deg, << 1000 sq deg overlap) |
| Euclid | Q2 | Euclid Y2 |
| Euclid | DR2 | Euclid Y3 (7500 sq deg, ~3000 sq deg overlap) |
| Euclid | Q3 | Euclid Y4 |
| Euclid | Q4 (TBC) | Euclid Y5 |
| Euclid | DR3 | Euclid Y6 (15000 sq deg, ~7000 sq deg overlap) |
| LSST | DP1 | LSST ComCam |
| LSST | DP2 | LSST SV (~1000 sq deg, 180 visits / Y2 depth) |
| LSST | DR1 | LSST First 6 Months |
| LSST | DR2 | LSST Y1 (18000 sq deg, 90 visits) |
| LSST | DR3 | LSST Y2 (180 visits) |
| LSST | DR4 | LSST Y3 (270 visits) |
| LSST | DR5 | LSST Y4 (360 visits) |
| LSST | DR6 | LSST Y5 (450 visits) |
| **Assumptions:** | | |
| October 2022 | | Euclid mission launch date |
| October 2023 | | LSST survey start |
| **Key:** | | |
| | | Observing |
| | | Processing |
| | | Proprietary Access |
| | | Public Access |
| Notes: | | |
| | (a) | Euclid launch and LSST survey start may both slip by ~6 months |
| | (b) | LSST data release dates may move by +/3 months as the operations team adapts to circumstances. |
| | (c) | Euclid plan additional quick releases containing specific featured data products made with the Y2 ("Q2") , Y4 ("Q3") and Y5 ("Q4", TBC) data. The data from these years will be available to the consortium to use while they are being processed, there just won't be an internal release of a full data release dataset. |
| | (d) | The overlap between Euclid Y1 and LSST SV is potentially quite small, because Rubin commissioning obseravtions are needed at a wide range of latitude (and the best calibration pre-cursor data tends to be closer to equatorial). The SIT-Com team's field selection is not yet determined. |
| | (e) | LSST Y2 is when the survey depths become matched, which is important |



# Cluster mass estimation (WL)

- The case for weak lensing masses
  - Accurate total masses! (No need to assume hydrostatic nor dynamical equilibrium)
  - Wide field (multi)band imaging → $r_{500}$, $r_{200}$, $r_{vir}$, … LSS environment (ie 2-halo component)
  - Probes dark matter + baryons + …

- Weak lensing is weak
  - Shape noise mitigation requires many backgrd sources: good seeing, deep…
  - Shape noise mitigation requires many foregrd lenses: stacking, very large surveys ($10^2$ - $10^4$ deg$^2$)

- Not only total mass: access to profile, halo shape, subhalos… (possibly aided with strong lensing)

- Wealth of optical ground-based data (CFHT, DECam, Subaru, VST,…)

**Should allow to measure a lot of cluster masses in a unified way…**

# Towards an “automated” lensing pipeline

## Devise a function Lensing_pipeline( RA, Dec, Width, facilities) →

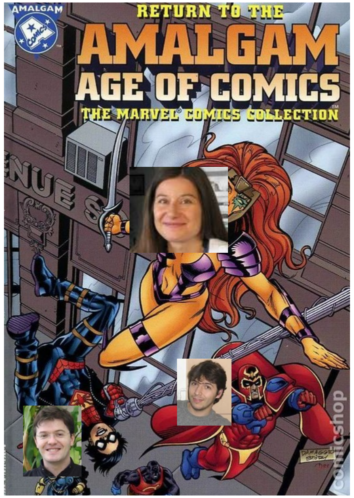
- Fetch raw or detrended images from archive of facility(ies) within “width” of a cluster
- Perform astrometric and photometric calibration against GAIA, PS1
- Build a model of the PSF and its spatial variations
- Cherry-pick the “good” exposures
- Combine exposures into “stacked images” for so many available bands (defects...)
- Detect sources on stack
- Go back to individual exposures, fit for PSF-convolved surface brightness model
- Photo/morphometric catalog → derive photo-z, and shear profile/map, mass…

# AMALGAM / CHEX-MATE project

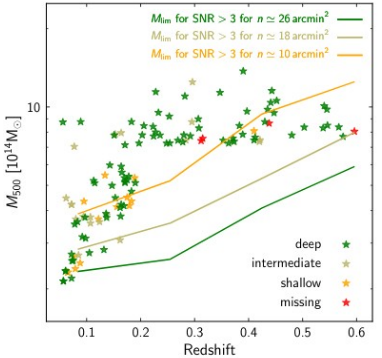
*Stands for "Ajustement de Modèles Appliqué aux Lentilles Gravitationnelles dans les AMas de galaxies",*

with A. Donnarumma & E. Bertin and CHEX-MATE Collaboration

[http://amalgam.iap.fr/](http://amalgam.iap.fr/)

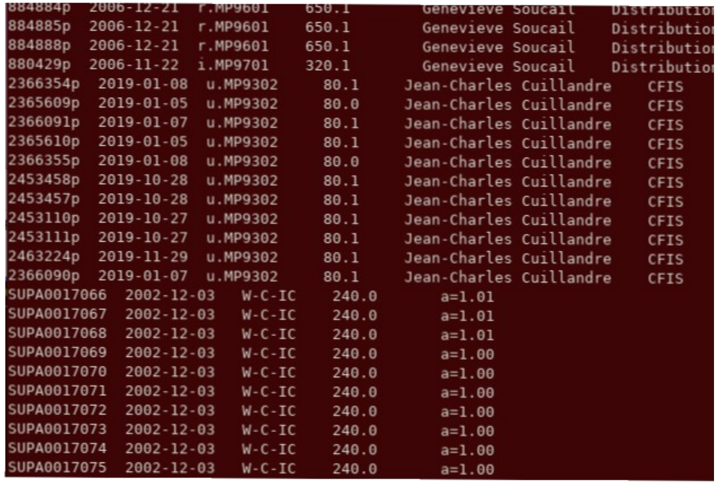



- 140 clusters in CFHT/Subaru archives (510 optical stacks, 11000 exposures, ~CFHTLS).
- 124 clusters with 2 to 9 optical bands. seeing~0.65'', depth $i_{AB}$~24 - 25, $n_{bg}$= 5-25 arcmin$^{-2}$. Substantial overlap with CCCP, LOCUSS, WtG, CLASH. But selection function is obscure
- Sample redefinition based on Planck $M_{500,SZ}$ criteria (arXiv: 2010.11972)
  - CHEX-MATE : 118 targeted by XMM Heritage 4Msec project.
  - AMALGAM U CHEX-MATE ~ 200 clusters (~130 already processed +70 ongoing)
- If lensing mass is accurate to 20-40 %, **should enable a 4% calibration of mass proxy (either HE or Yx)**
- Shapes measured with model fitting capabilities of Sextractor+PSFEx.
- Source redshifts PDFs computed with k-NN technics with COSMOS photo-z (poorman-z).
- Ongoing improvements : VST, HSC images, photometric calibration against PS1 (issue: u band)



# “automated” lensing pipeline

Lensing_pipeline( RA, Dec, Width, facilities) →



| | | | | | |
|---|---|---|---|---|---|
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| 884885p | 2006-12-21 | r.MP9601 | 650.1 | Genevieve Soucail | Distributio |
| 884888p | 2006-12-21 | r.MP9601 | 650.1 | Genevieve Soucail | Distributio |
| 880429p | 2006-11-22 | i.MP9701 | 320.1 | Genevieve Soucail | Distributio |
| 2366354p | 2019-01-08 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2365609p | 2019-01-05 | u.MP9302 | 80.0 | Jean-Charles Cuillandre | CFIS |
| 2366091p | 2019-01-07 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2365610p | 2019-01-05 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2366355p | 2019-01-08 | u.MP9302 | 80.0 | Jean-Charles Cuillandre | CFIS |
| 2453458p | 2019-10-28 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2453457p | 2019-10-28 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2453110p | 2019-10-27 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2453111p | 2019-10-27 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2463224p | 2019-11-29 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| 2366090p | 2019-01-07 | u.MP9302 | 80.1 | Jean-Charles Cuillandre | CFIS |
| SUPA0017066 | 2002-12-03 | W-C-IC | 240.0 | a=1.01 | |
| SUPA0017067 | 2002-12-03 | W-C-IC | 240.0 | a=1.01 | |
| SUPA0017068 | 2002-12-03 | W-C-IC | 240.0 | a=1.01 | |
| SUPA0017069 | 2002-12-03 | W-C-IC | 240.0 | a=1.00 | |
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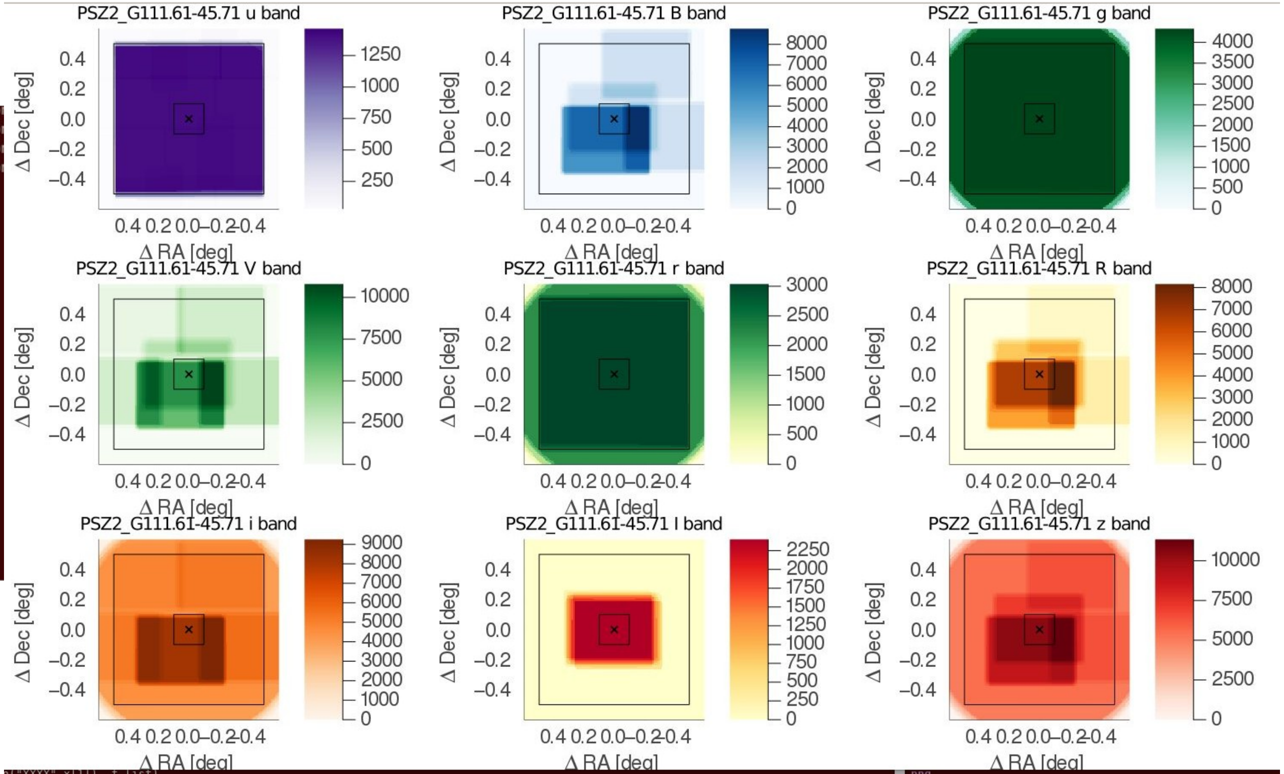
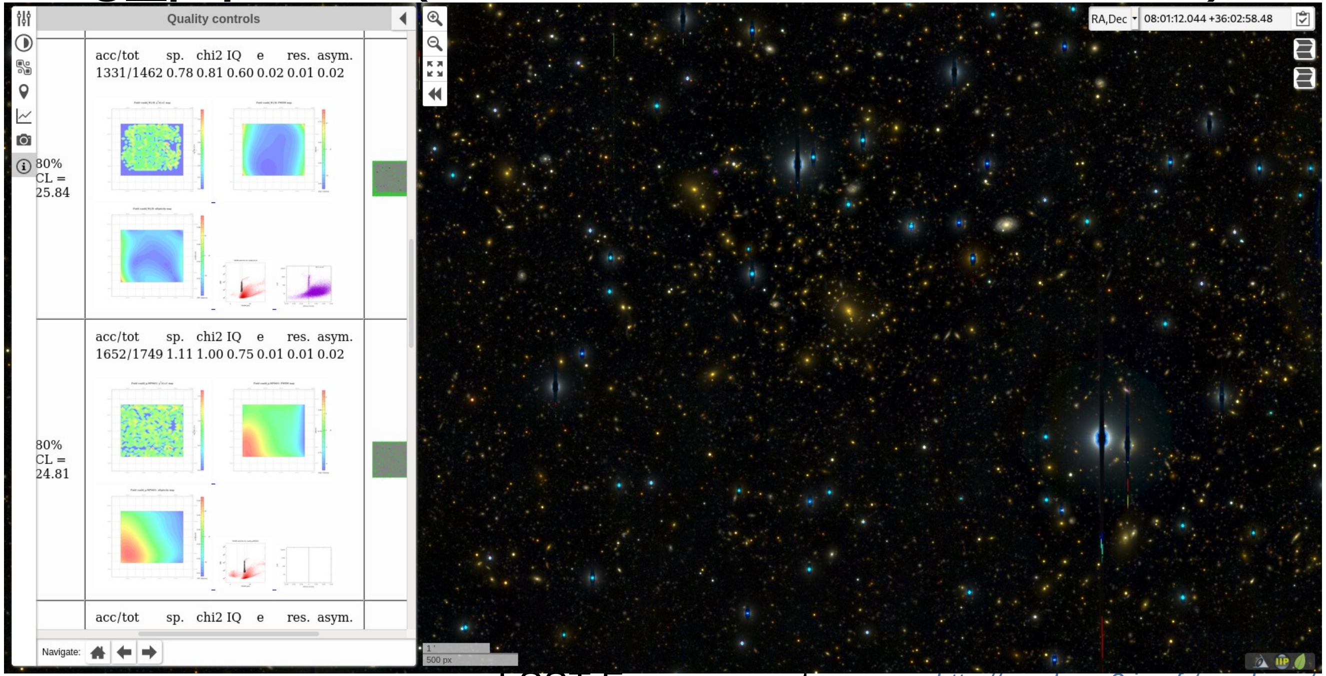



24 nov 2021

# “automated” lensing pipeline

Lensing_pipeline( RA, Dec, Width, facilities) →

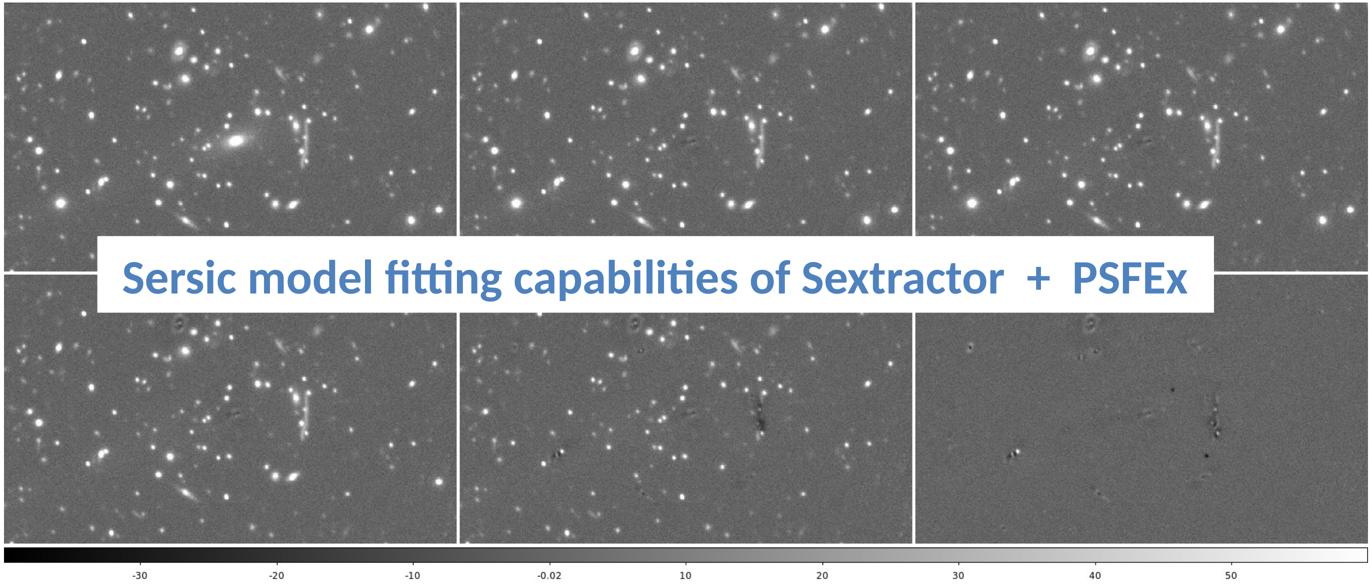





http://amalgam2.iap.fr/amalgam/show.html?tile=A611

# “automated” lensing pipeline

Lensing_pipeline( RA, Dec, Width, facilities) →



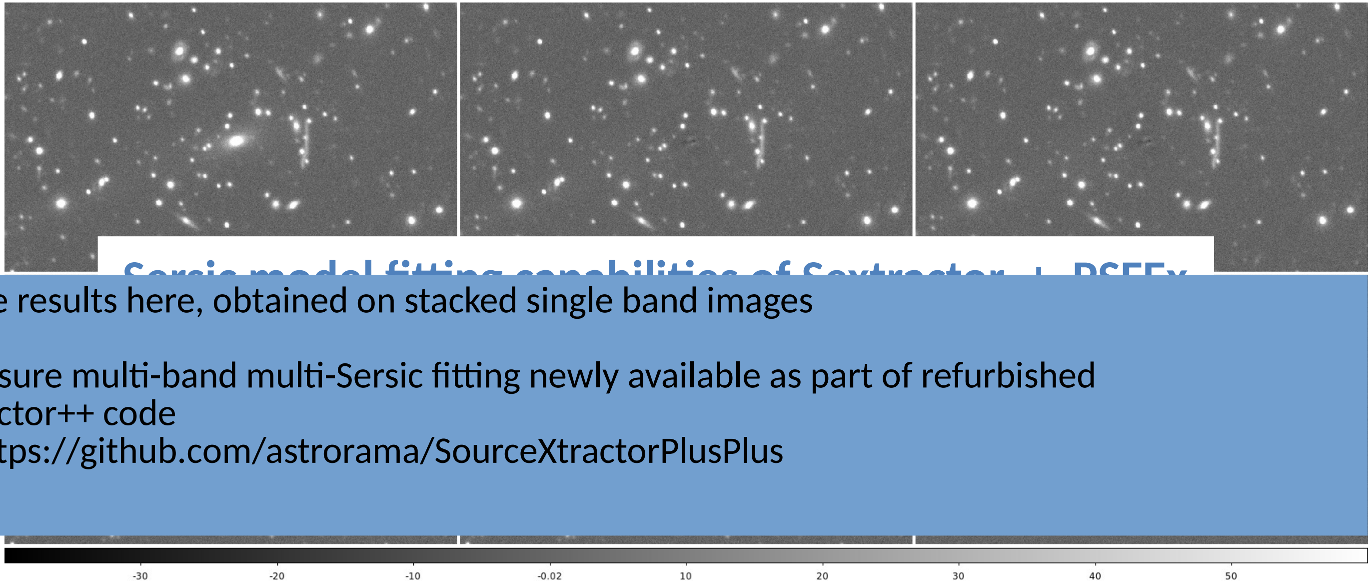

**Sersic model fitting capabilities of Sextractor + PSFEx**



http://amalgam2.iap.fr/amalgam/show.html?tile=A611

# “automated” lensing pipeline

Lensing_pipeline( RA, Dec, Width, facilities) →




Most of the results here, obtained on stacked single band images

Multi-exposure multi-band multi-Sersic fitting newly available as part of refurbished SourceXtractor++ code

https://github.com/astrorama/SourceXtractorPlusPlus

# “automated” lensing pipeline

Lensing_pipeline( RA, Dec, Width, facilities) →

multiband catalog x,y,ra,dec,… e1,e2,… {mag1, mag2… magN}

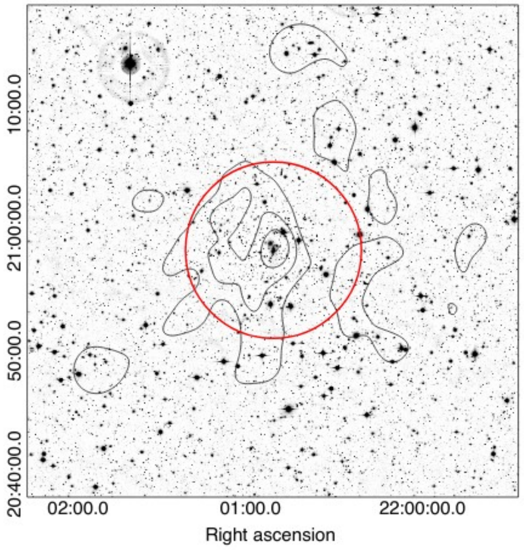
A probabilistic approach is highly desirable to get p(z|m) but standard photometric redshifts require many bands, only feasible for ~20 clusters.

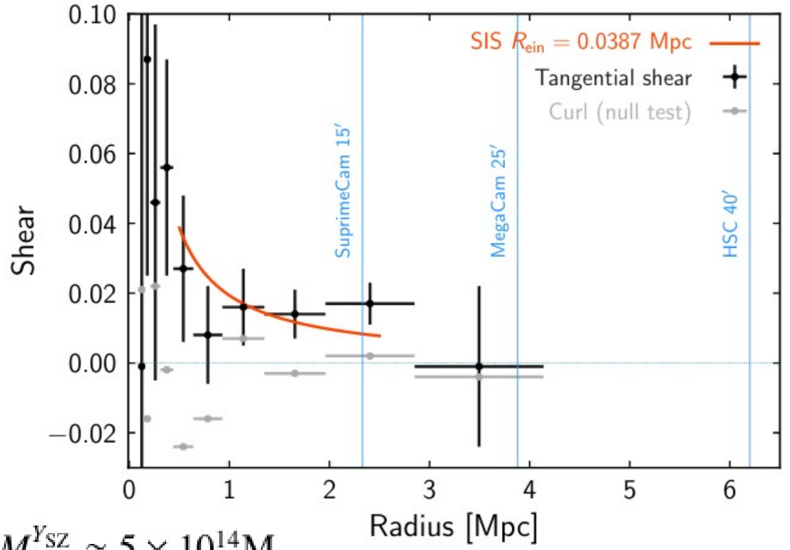
**POORMAN-Z : k-NN redshift picker from COSMOS2015 (Laigle++16) photo-z (COSMOS photometry degraded to our depth in each band)**

multiband catalog x,y,ra,dec,… e1,e2,… {mag1, mag2…}, p(z) or ($z,\sigma_z$), membership probability

# “automated” lensing pipeline

## Lensing_pipeline( RA, Dec, Width, facilities) →




$M_{500}^{Y_{SZ}} \simeq 5 \times 10^{14} M_{\odot}$

$z = 0.148$

### 2D bayesian fit

No radial binning. Accounting
- correlated LSS noise
- multimodal clusters!
- marginalizing over center, ellipticity, concentration… AND all source redshifts $p(z_s|mags)$

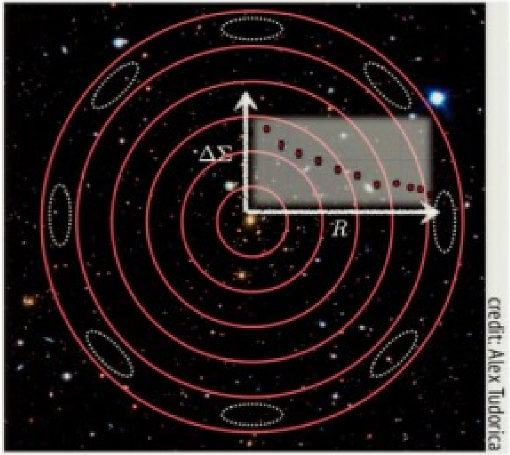
Fully non-linear shear regime, allowing for combined Strong+Weak lensing modeling.

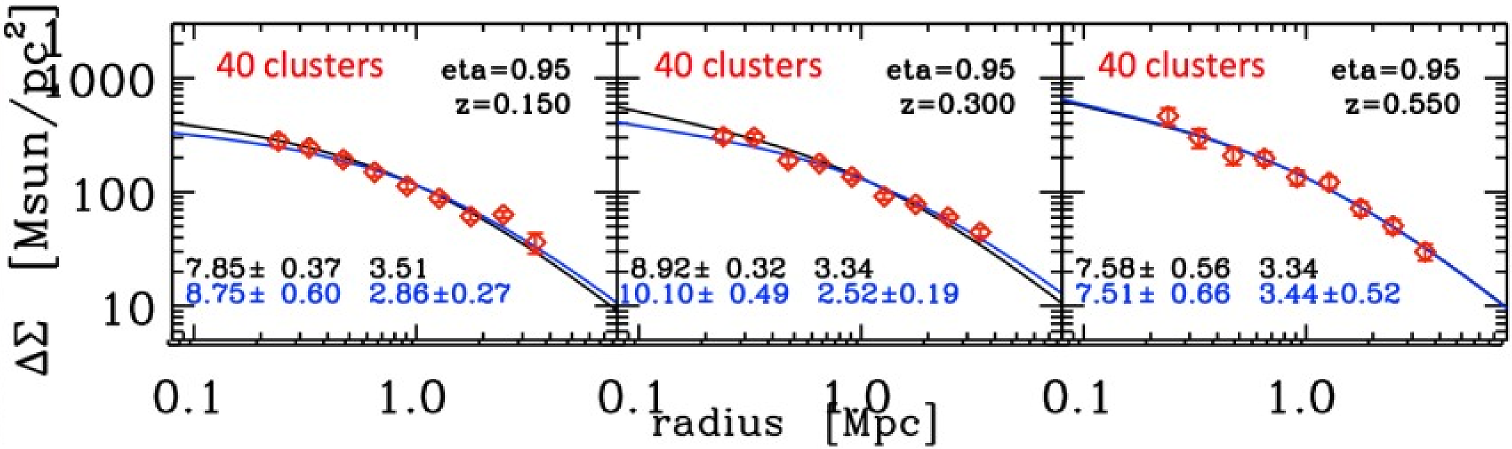
$p(z_s|mags)$ can be updated given M and richness to correct for signal dilution

# Some results

*Stacked shear profile*

$$\Delta\Sigma(R) = \frac{M(<R)}{\pi R^2} - \Sigma(R) \propto \gamma_t(R)$$

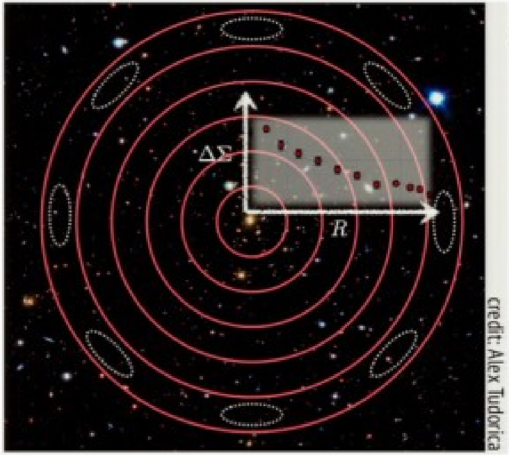


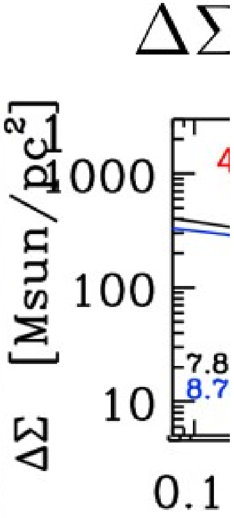




High SNR (10% accuracy per bin), typical $M_{200}$ ~ 8e14

# Some results

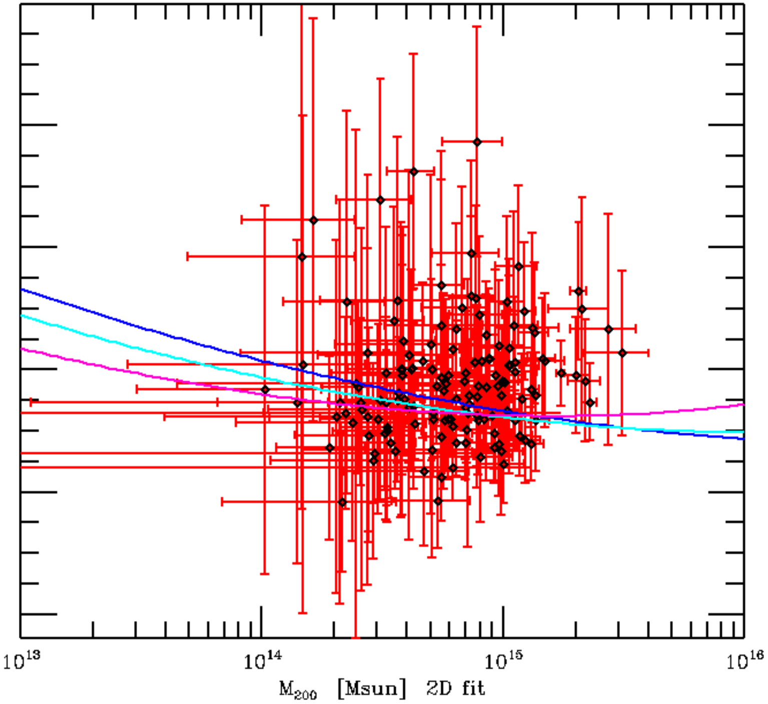
*Stacked shear profile*




NFW fit on individual clusters in the range 0.5-2 Mpc

Concentration-mass relation
Looks consistent with Klypin++16




High SNR (1

# Some results

## *Crude **preliminary** mass-observable relation for $M_{Yx}$ - $M_{WL}$*

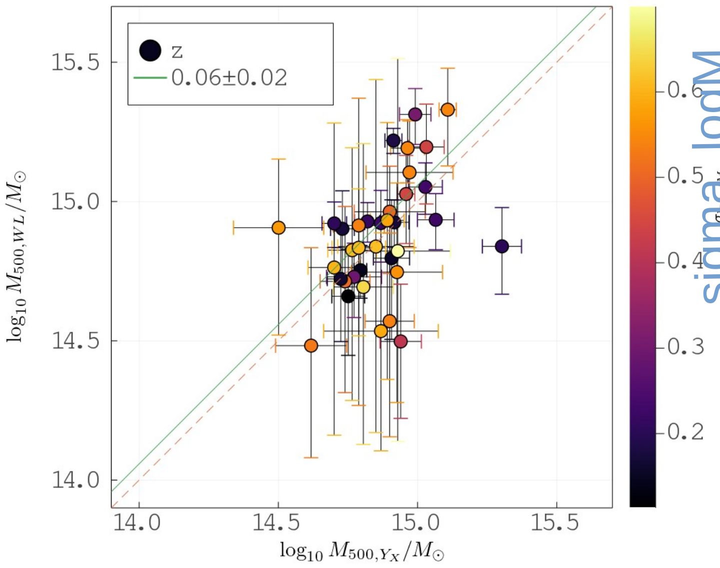
M2C Sample (36 clusters): (w/ Bartalucci, Arnaud, Pratt… to be updated with full CHEX-MATE Sample)

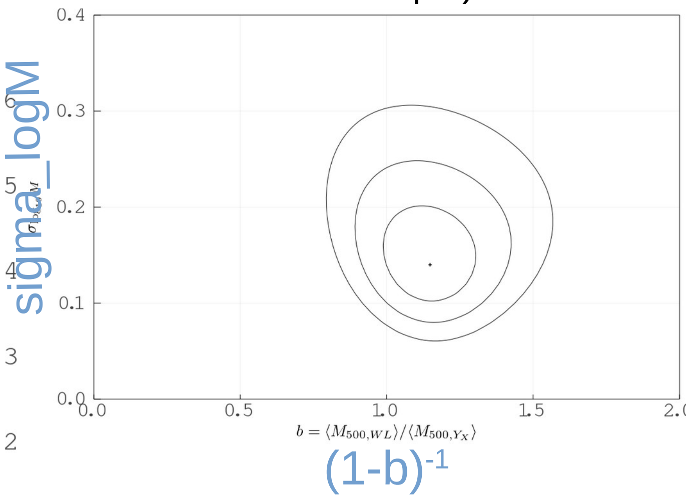
Simple regression
- assuming slope=1
- no uncertainties on $M_{Yx}$
- accounting for non-gaussian $M_{WL}$
- No redshift evolution 0.1-0.7

  $\log M_{500WL} - \log M_{500Yx} = 0.06 \pm 0.02$
- **=> 1-b ~ 0.87 ± 0.04**

  sigma_logM ~ 0.14±0.02 (but should subtract off some 7% uncertainties on X)

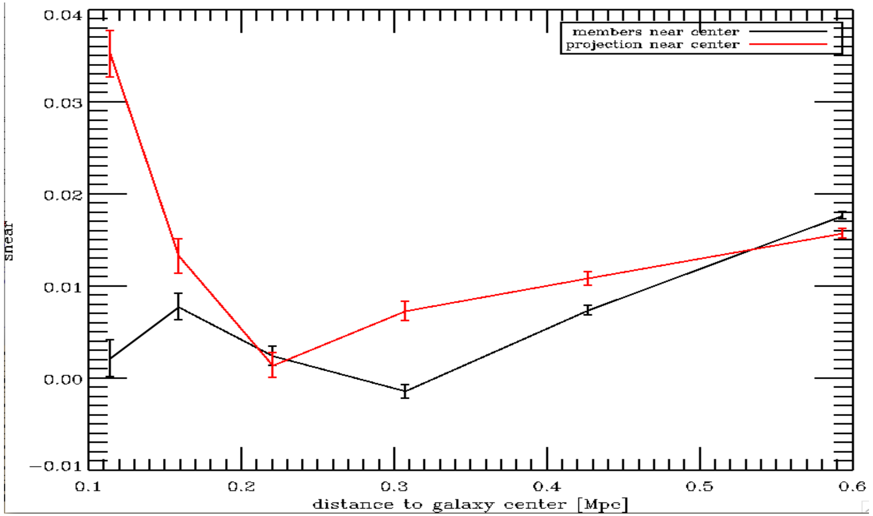
- Lensing Masses totally consistent with Herbonnet++20

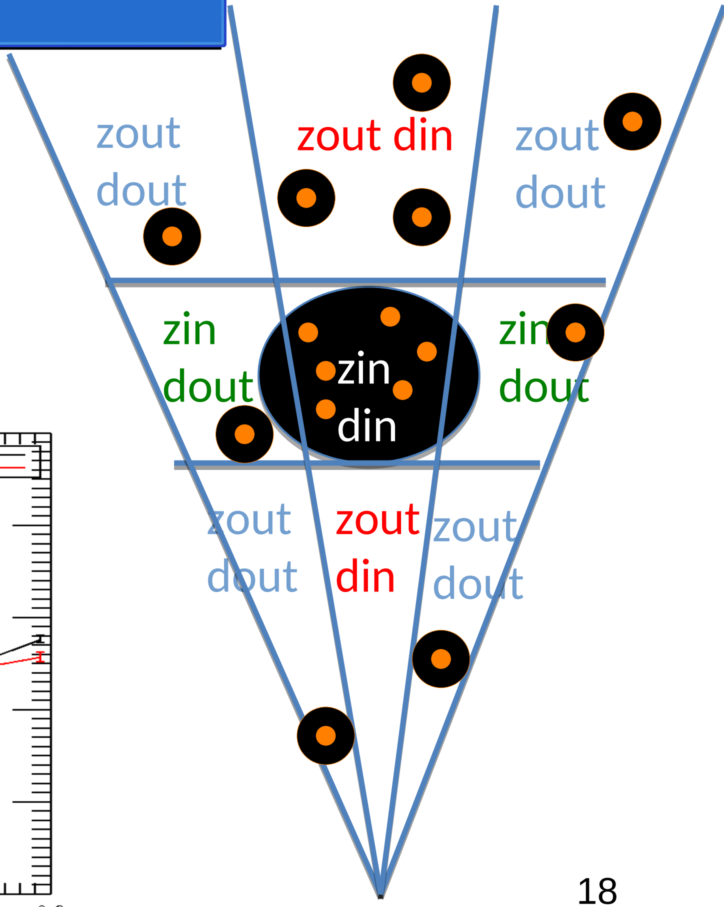


# Shear around truncated sub-halos

- Preliminary results by internship student (J Christiano)
- SDSS spectro (1e4 lenses w/ z and $150<\sigma<300$ km/s)
- AMALGAM (9e5 sources)
- At same $\sigma$ (or $M_*$), cluster member galaxies have lost ~80% of their mass



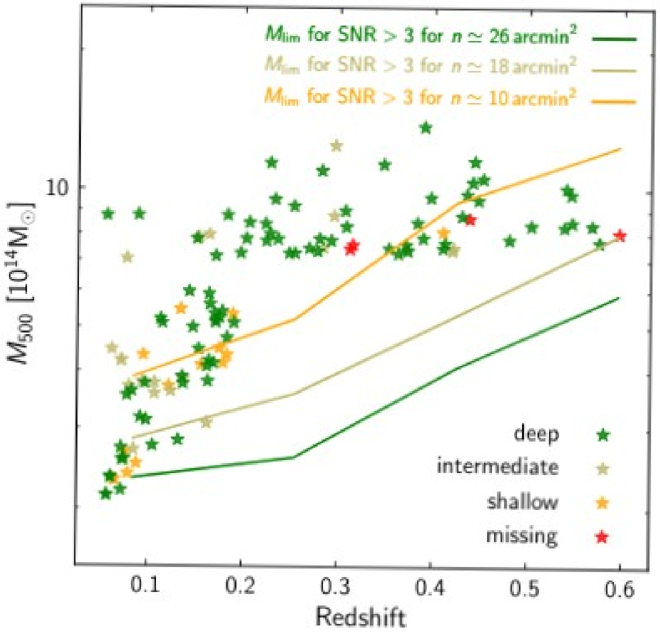




*See also Niemiec et al 17*

# Note on WL mass accuracy

- Statistical: leading factors
  - Bckgrd source density (depth, seeing)
  - Line of sight structure  (mostly for low z)
  - Ability to isolate high z sources (multiband)

- Systematics
  - Shape measurements
  - Redshift of sources (photo-z)
  - Magnification, screening & contamination by cluster members
  - Centering?!?!?
  - Range over which the mass profile is fitted (typically between 0.5 and 2 Mpc , or so…



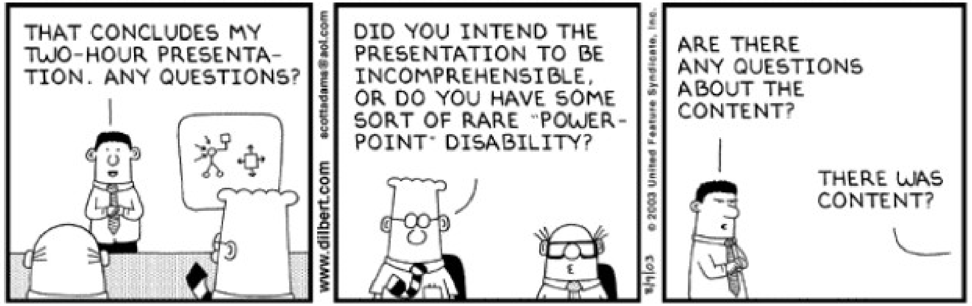
# Conclusions

- **Strong lensing activity took off**
  - Ambitious Rubin/Euclid DDP proposal (finding/modeling lenses with multiband, high resolution, time domain information)
  - Coordinating spectroscopic follow-up with Euclid. First attempt:  a joint 4MOST proposal on galaxy-scale SL.
  - Contributed to the proposition of SV targets for Rubin commissioning

- **Weak lensing mass estimates "made easy"**
  - Lensing_pipeline()  function able to ingest Megacam/SuprimeCam  data (soon HSC/VST/DECam) and deliver images, catalogs, Masses, mass map/profiles,… at almost any position!
  - Application to sizeable and well defined samples underway
  - Bayesian modeling able to fit parametric 2D clusters with substructures (mergers)   (unbinned, SL+WL possible, p($z_s$) marginalisation downweigh cluster members)
  - Ongoing effort to fold magnification in   ( angular fg/bg cross-correlation  w(theta) → magnitude,[size] shifts)  Thesis M. Shuntov
  - Able to pin down normalisation of scaling relations to within a few percents (systematics floor)

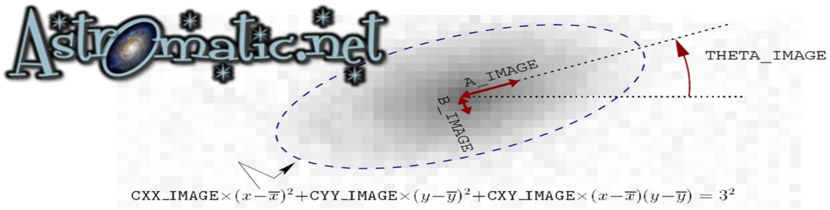
- **Willing to better understand LSST landscape and contribute on WL**
  - My recent moves did not allow me to supervise new students yet.
  - Extend my Euclid credentials at CC-IN2P3
  - Investigate the merits of my "pipeline" at catalog level on DC2 and eventually at pixel level using new (ML) features of SourceXtractor++

# Questions?


THAT CONCLUDES MY TWO-HOUR PRESENTATION. ANY QUESTIONS?
www.dilbert.com scottadams@aol.com
DID YOU INTEND THE PRESENTATION TO BE INCOMPREHENSIBLE, OR DO YOU HAVE SOME SORT OF RARE "POWERPOINT" DISABILITY?
© 2003 United Feature Syndicate, Inc.
ARE THERE ANY QUESTIONS ABOUT THE CONTENT?
THERE WAS CONTENT?

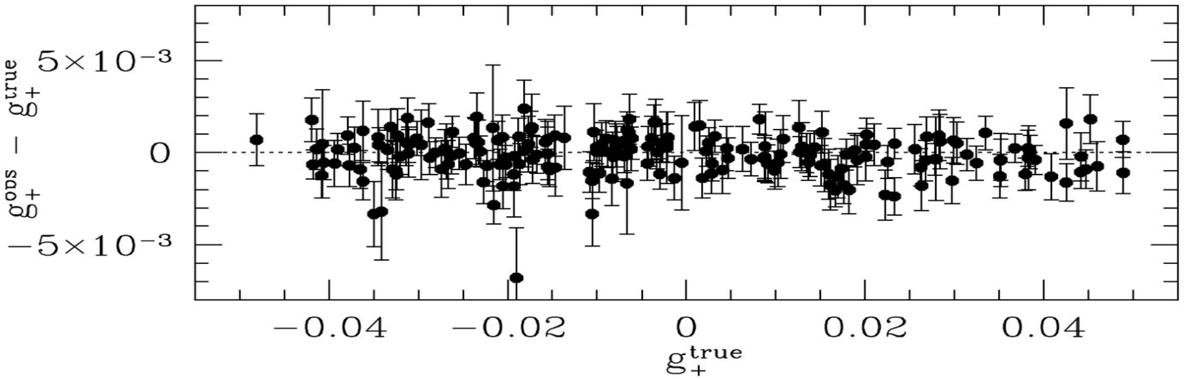
# EXTRA MATERIAL

# Shape measurements




- Great perfs in GREAT3 challenge: 2nd team out of a dozens.
- With appropriate weighting, and snr cut :
  - Multiplicative biases ~< $10^{-3}$
  - Additive biases ~<2 $10^{-4}$

*Mandelbaum et al 2015*


The Great-3 challenge is now complete and the winners decided. We h
deactivated the post-challenge leaderboards, so no more submissions can be ma

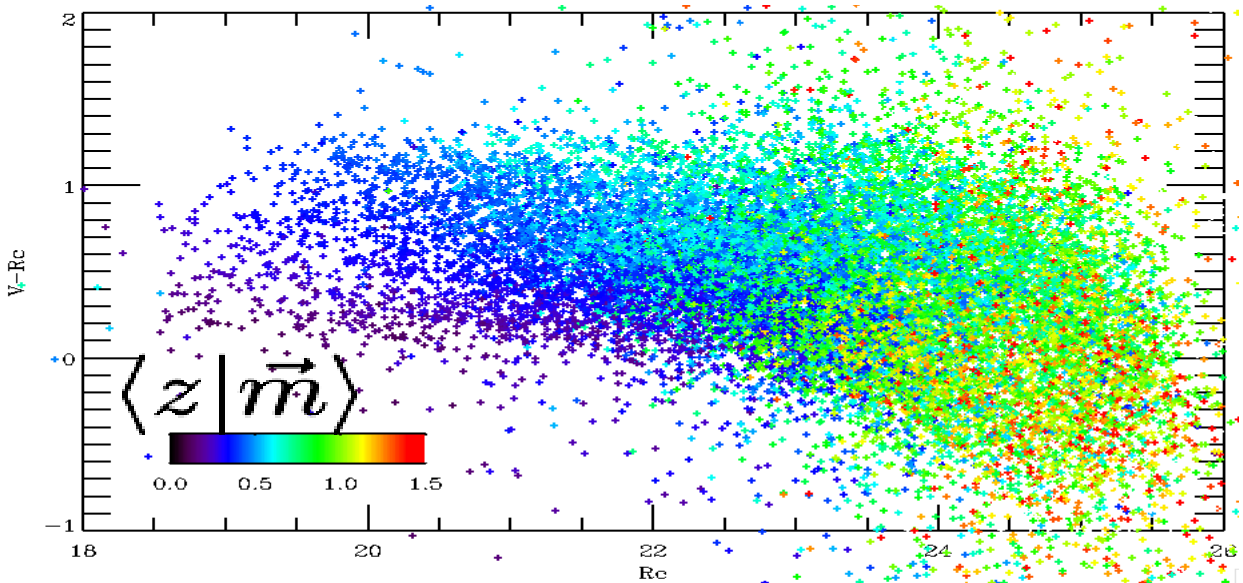
**Overall Leaderboard**

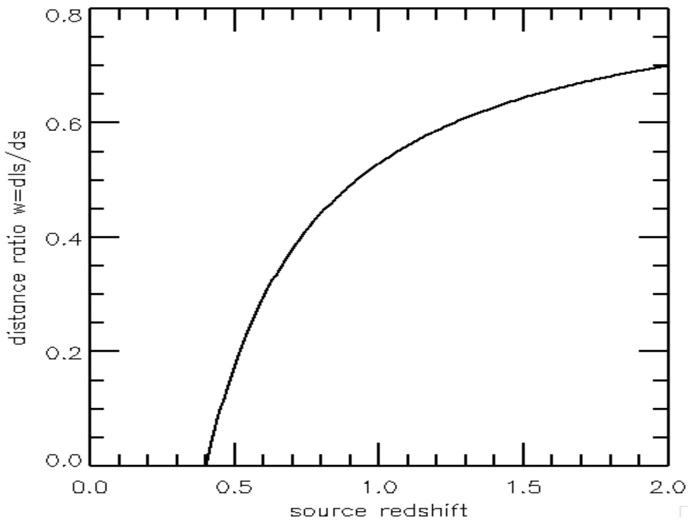
| Name | Notes | Score | Number of entries |
|---|---|---|---|
| sFIT | Modified DLS stackfit algorithm | 80001 | 162 |
| Amalgam@IAP | Some fellows developing software based around SExtractor and PSFex for real-life shape measurements. | 80000 | 215 |
| CEA-EPFL | The team wants to investigate if we could improve shear estimation by combining gfit with sparse representation methods. | 72000 | 340 |
| MegaLUT | Evolutions of the MegaLUT technique : how far can we go with SExtractor + Machine Learning ? | 52000 | 234 |
| Fourier_Quad | Our team uses the quadrupole moments of the spectral density of galaxy images in Fourier space to measure shear. | 32000 | 36 |
| EPFL_gfit | Using the gfit shear measurement method, testing how far one can go by using forward model fitting + new approaches for bias calibration | 24000 | 124 |

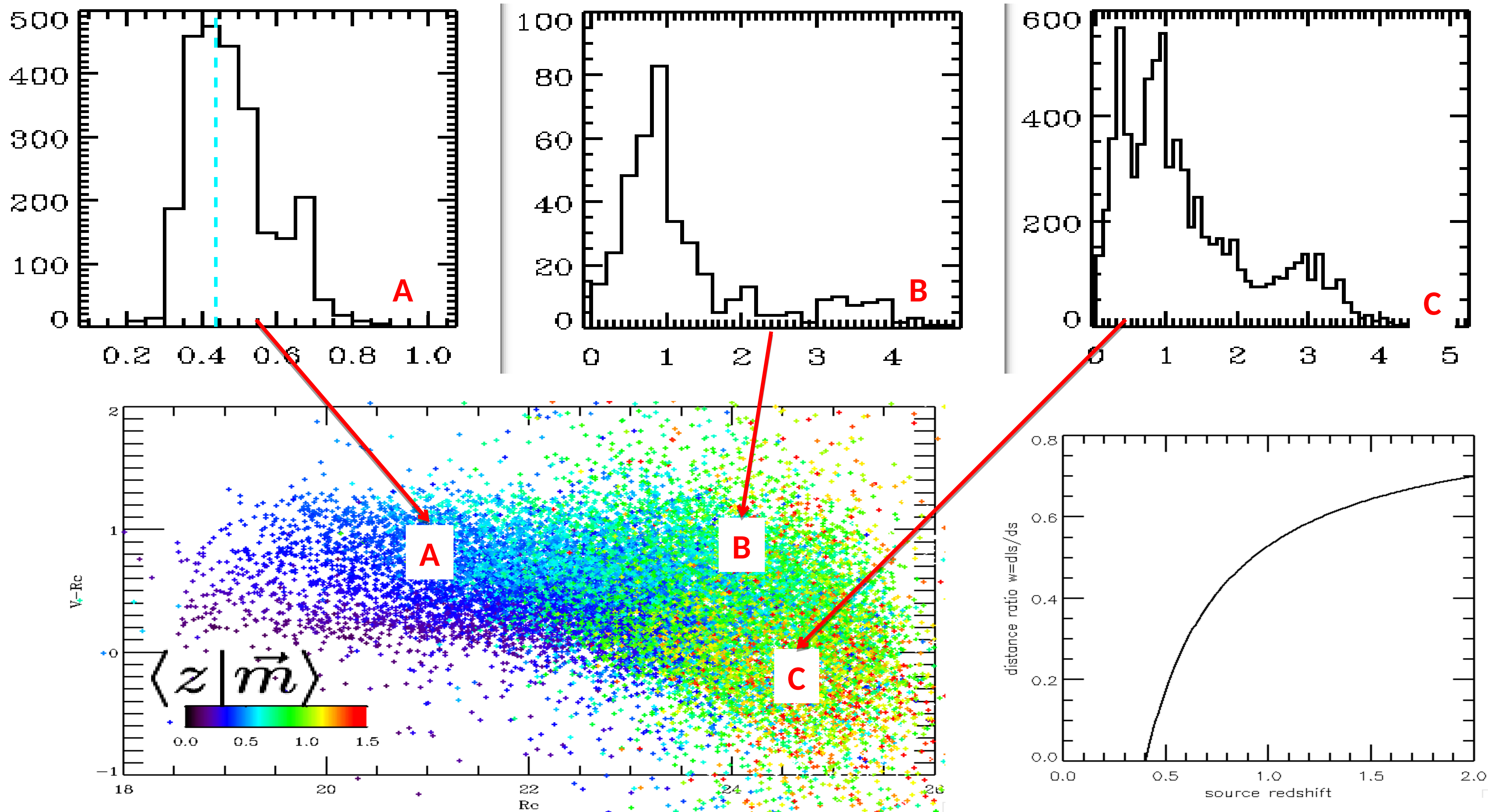
# Redshift distribution of sources

- Needed to convert shear into actual surface mass density and to discard cluster members.
- color cuts… hard to handle with different combinations of filters from one cluster to the next.
- A probabilistic approach is highly desirable to get p(z|m) but standard photometric redshifts require many bands, only feasible for ~20 clusters.

- **POORMAN-Z : k-NN redshift picker from latest COSMOS2015 (Laigle++16) photo-z (COSMOS photometry degraded to our depth in each band)**

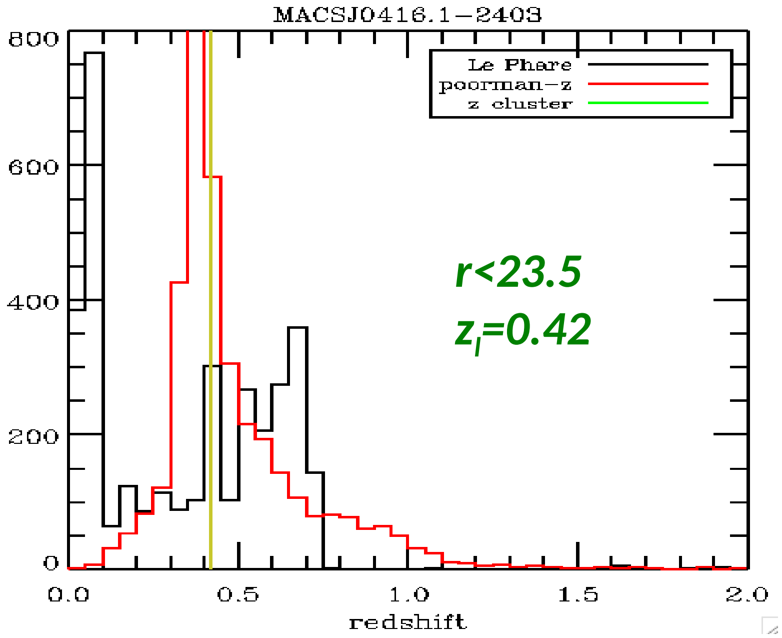


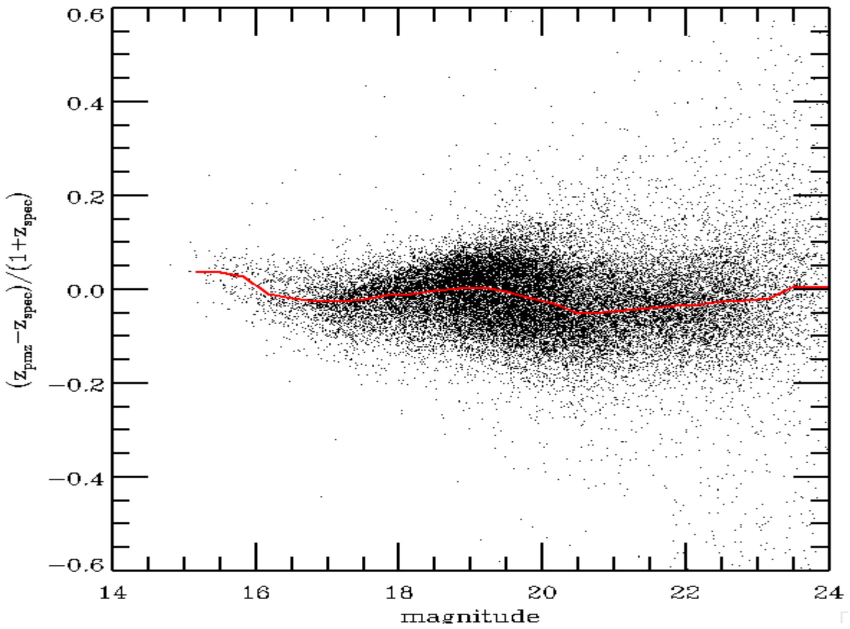





A
B
C
V-Rc
Rc
$\langle z|\vec{m}\rangle$
source redshift
distance ratio w=dls/ds

# Poorman-z

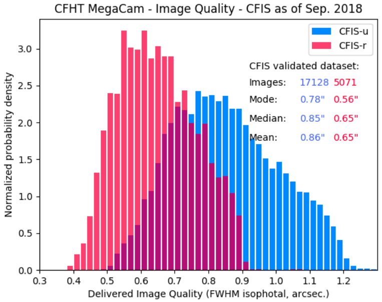


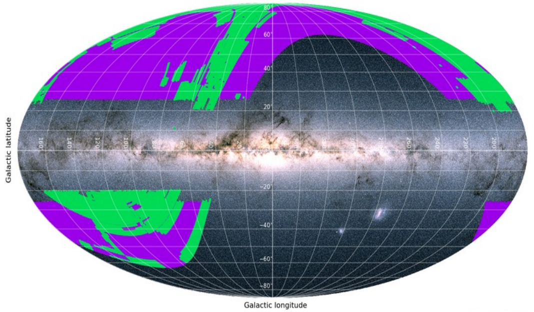




- About 20000 existing spec-z for comparison (CLASH-VLT, SDSS,…)
- Spectroscopic sample highly biased (bright).
- Cluster members are generally more luminous than field galaxies
- Sources are also magnified.

# Additional cluster Lensing in CFIS/UNIONS

- UNIONS: UV NIR Optical Northern Sky Survey
  - u,r (CFHT/Megacam) → CFIS (PI Cuillandre/McConnachie)
  - g (HSC and JPAS)
  - i (PanSTARRs) (Chambers++)
  - z (HSC) → WISHES (Oguri+)
- Main goal is to provide photometry for Euclid
- + Stand alone Science → in particular r band with 0.6" seeing
- 4500 $deg^2$ with good overlap with SDSS spectroscopy → lensing with r-band, red sequence with r+z, Galactic science with shallower u
-

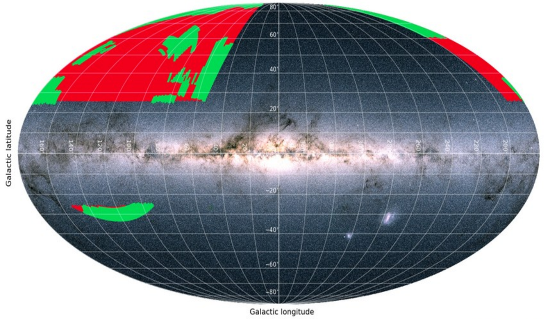



CFIS-u survey area and realized coverage as of September 2018

Total survey area: 10,000 $deg.^2$

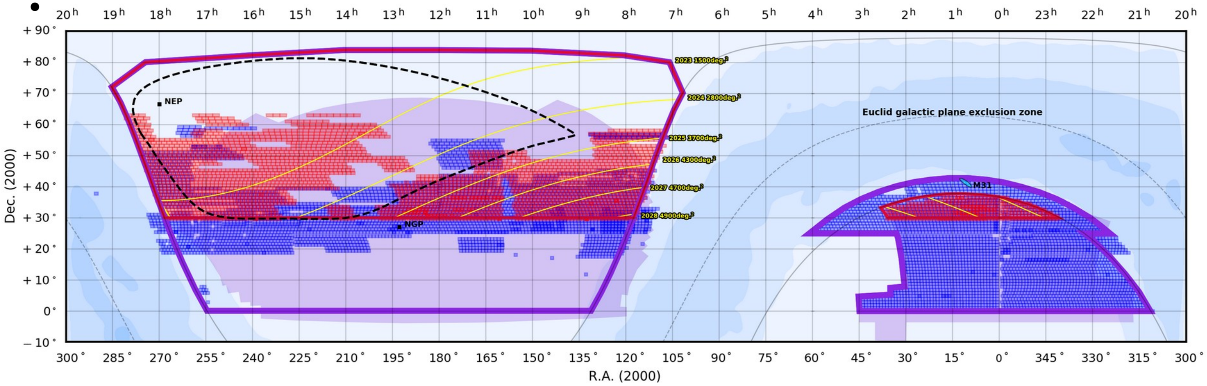
Covered area: 4446 $deg.^2$ (44%), left to cover: 5554 $deg.^2$ (56%)




CFIS-r survey area and realized coverage as of September 2018

Total survey area: 4.800 $deg.^2$

Covered area: 1501 $deg.^2$ (31%), left to cover: 3299 $deg.^2$ (69%)

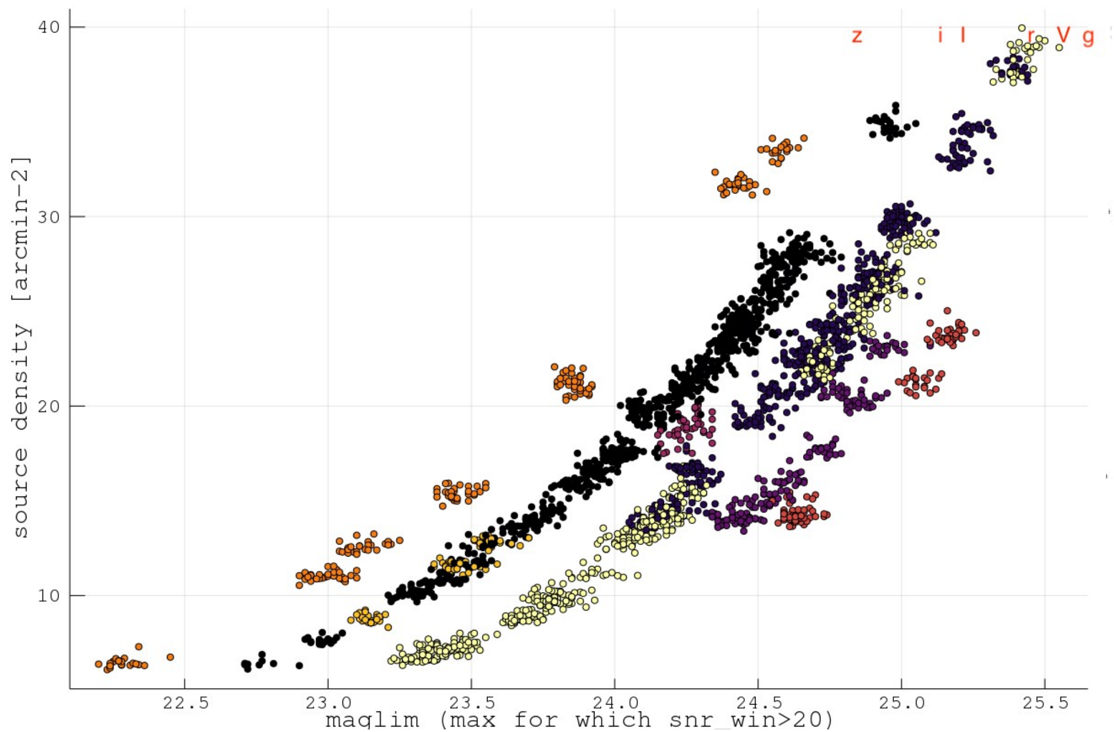


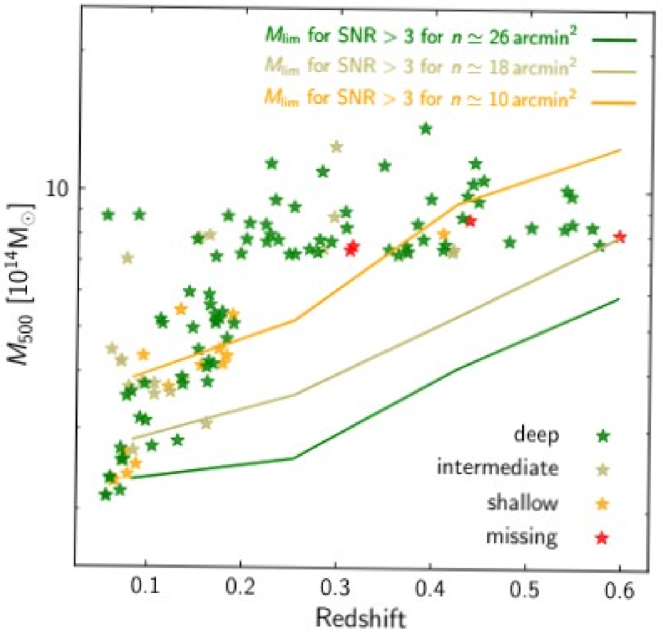

CFIS sky coverage goal with current completion (September 2020) and the high priority area

- Galactic plane
- BOSS
- CFIS−u area goal : 11,400 $deg.^2$
- CFIS−r area goal : 4,900 $deg.^2$
- CFIS−u covered with 3 exposures (full depth) : 5650 $deg.^2$
- CFIS−r covered with 3 exposures (full depth) : 2860 $deg.^2$
- CFIS priority area : Euclid space survey best northern 2600 $deg.^2$
- ⇒ yellow ecliptic isolines track in the CFIS−r area the Euclid survey coverage per year assuming a start at the ecliptic pole (NEP): total area given for both galactic caps.

# Note on WL mass accuracy

- Statistical: leading factors
  - 
  - 
  - 



# Note on WL mass accuracy

- Statistical: leading factors
  - 
  - 
  -