Weak lensing in the UNIONS survey.

Analysis with the galaxy shape measurement pipeline ShapePipe & first results.

19 January 2023

Kick-off meeting du GDR CoPhy

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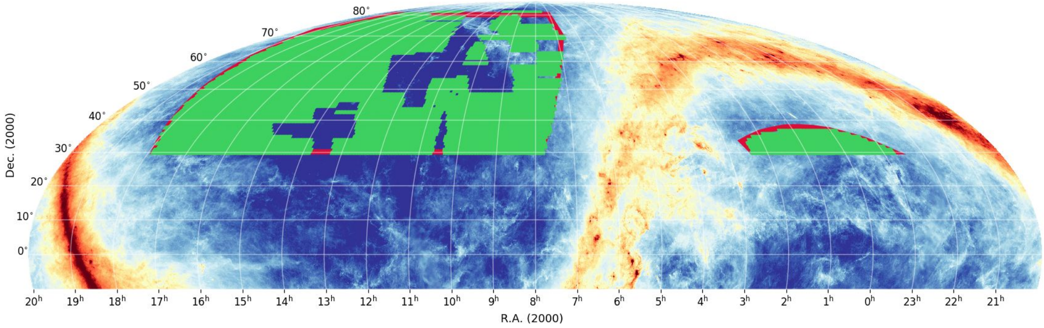
Outline

- The UNIONS survey
- ShapePipe weak-lensing data analysis pipeline
- First results

UNIONS: Ultra-violet Near-Infrared Optical Northern Survey
CFIS: Canada-France Imaging Survey

Large imaging survey (4,800 deg^2) in the Northern hemisphere with CFTH in optical bands *u*, *r* (CFIS), *i*, *z* (Pan-STARRS), *g*, *z* (HSC).
P.I.: Jean-Charles Cuillandre (DAp) & Alain McConnachie (Victoria/Canada)

- **Optical bands for Euclid for photometric redshifts**
- **Weak lensing**
- Milky Way dynamics
- Large-scale structure
- Galaxy evolution



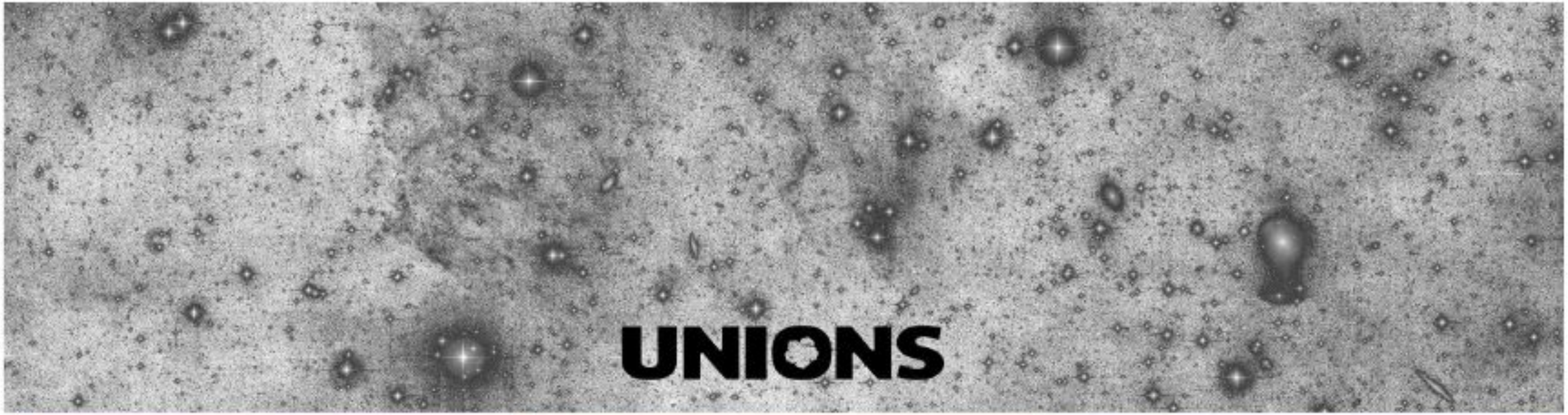
CFIS-r survey area and realized coverage as of September 2022

Total survey area: 4.800 deg.^{2}
Covered area: 4012 deg.^{2} (83%), left to cover: 788 deg.^{2} (17%)

UNIONS

CFIS
Dust map: Planck Collaboration

www.skysurvey.cc

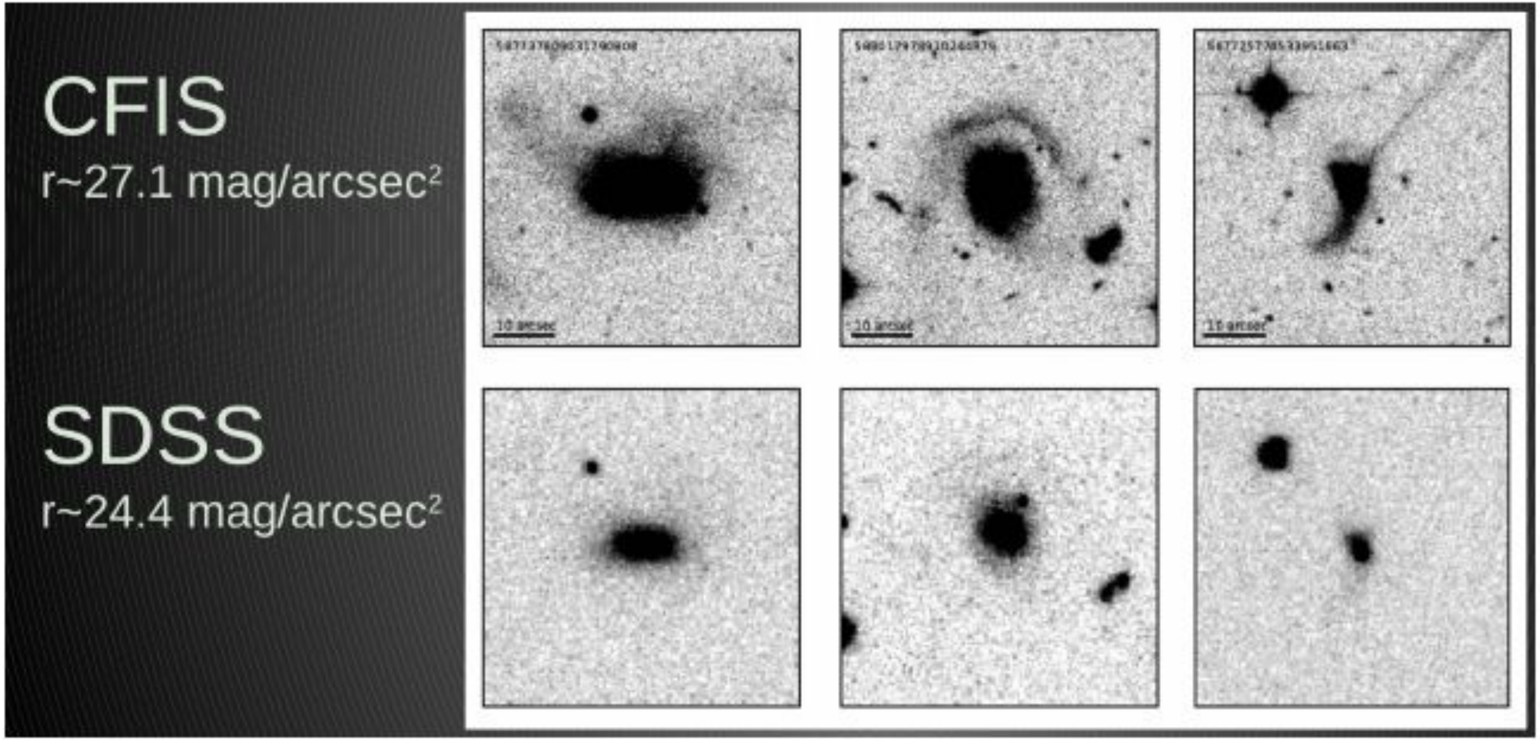

UNIONS


Canada-France-Hawaii Telescope

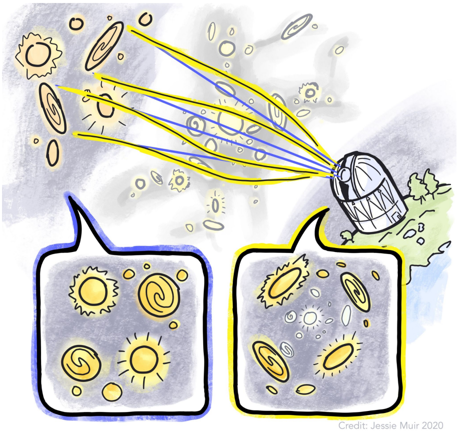

Pan-STARRS


Subaru Telescope

UNIONS/CFIS vs. SDSS

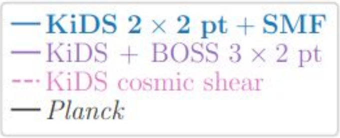


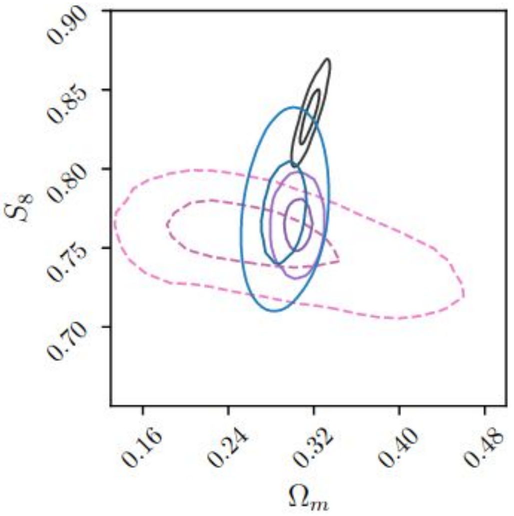
Weak gravitational lensing



- Probe of (dark) matter distribution at large scales, and in clusters and galaxies
- Measures density amount and fluctuations amplitude (“σ_8 / S_8 tension”)
- Dark-energy dominated epoch

Dvornik, Heymans, Asgari et al. 2022





- “Weak” = galaxy shape distortions at %-level
  - ≪ intrinsic galaxy shapes
  - ≪ atmosphere & telescope distortions
- ➛ Need dedicated pipeline to process massive amounts of data for high-precision galaxy shape measurements + calibration

ShapePipe

A modular weak-lensing processing and analysis pipeline

https://github.com/cosmostat/shapepipe

ShapePipe

CI passing | pages-build-deployment passing | python 3.9 | release v1.0.1

ShapePipe is a galaxy shape measurement pipeline developed within the CosmoStat lab at CEA Paris-Saclay.

See the documentation for details on how to install and run ShapePipe.

ShapePipe

A modular weak-lensing processing and analysis pipeline

Software paper

Farrens et al., 2022, [A&A, 664, 141]

ShapePipe: A modular weak-lensing processing and analysis pipeline

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ABSTRACT

We present the first public release of ShapePipe, an open-source and modular weak-lensing measurement, analysis, and validation pipeline written in Python. We describe the design of the software and justify the choices made. We provide a brief description of all the modules currently available and summarise how the pipeline has been applied to real Ultraviolet Near-Infrared Optical Northern Survey data. Finally, we mention plans for future applications and development. The code and accompanying documentation are publicly available on GitHub.

Key words. Gravitational lensing: weak – Methods: data analysis

ShapePipe

Goals

- Modular
- Easy
- Fast (enough)
- Robust

Code installation

- Conda
- Docker (in prep)
- CD/CI

Three components

Pipeline

- Arguments & config
- I/O
- Job handling (MPI, SMP)
- Errors & logging

Modules

- WL data processing
- Book-keeping

Utilities

- Scripts
- Tools
- Survey-specific stuff

ShapePipe modules

Input images are pre-processed (calibrated for astrometry and photometry)

Main processing

- Mask
- Detect objects
    - Star candidates on single exposures
    - Galaxy candidates and stacks
- Select stars
- (Select galaxies)
- Create PSF model
- Interpol PSF model to galaxy positions
- Validate PSF model
- Measure galaxy shapes

Further processing

- Process multi-band images (joint photometry)
- Match with (external) catalogue
- Create random catalogue

Masking

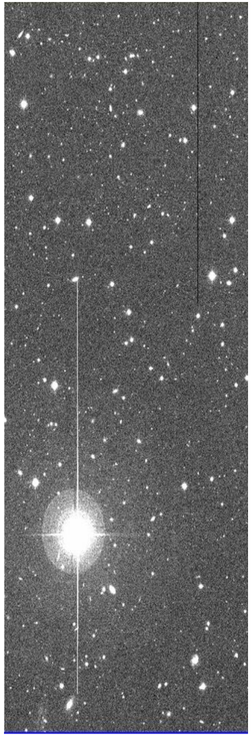
Image artefacts: spurious detections as galaxies, contaminations to weak-lensing shear (correlations).

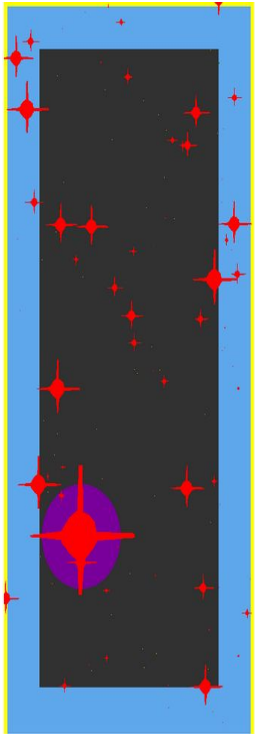
We mask:

- Halos and diffraction spikes of bright halos (from Guide Star Catalogue GSC II)
- Messier & NGC objects
- CCD borders

Already masked in pre-processing:

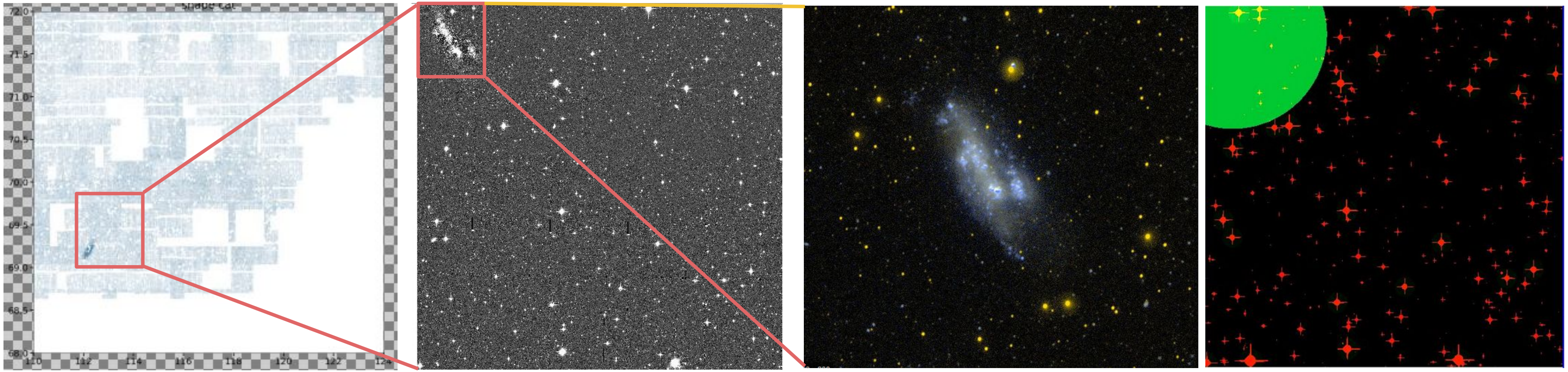
- cosmic rays (somewhat)
- bad columns





Masking: example

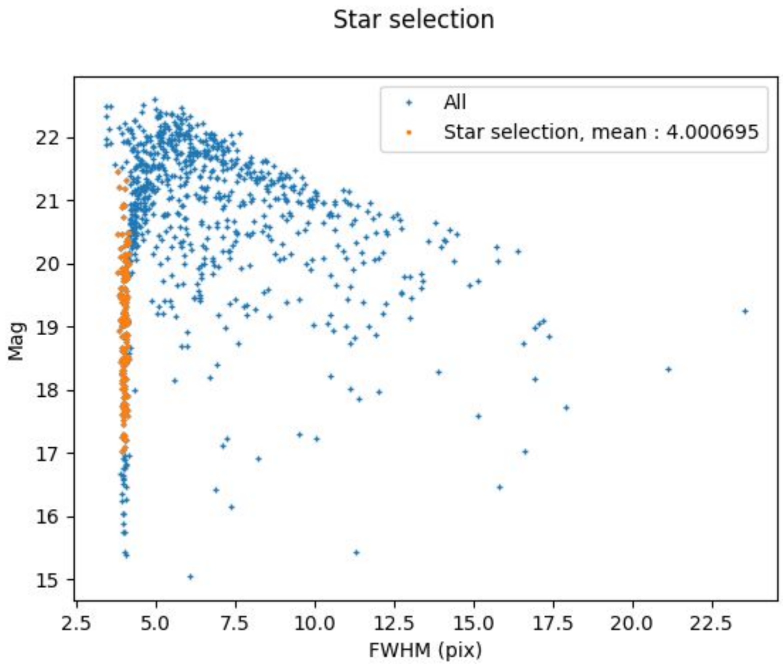
Detections in a 50 deg^2 area | Stacked image | NGC 2366 (UGC 3851) | Add mask

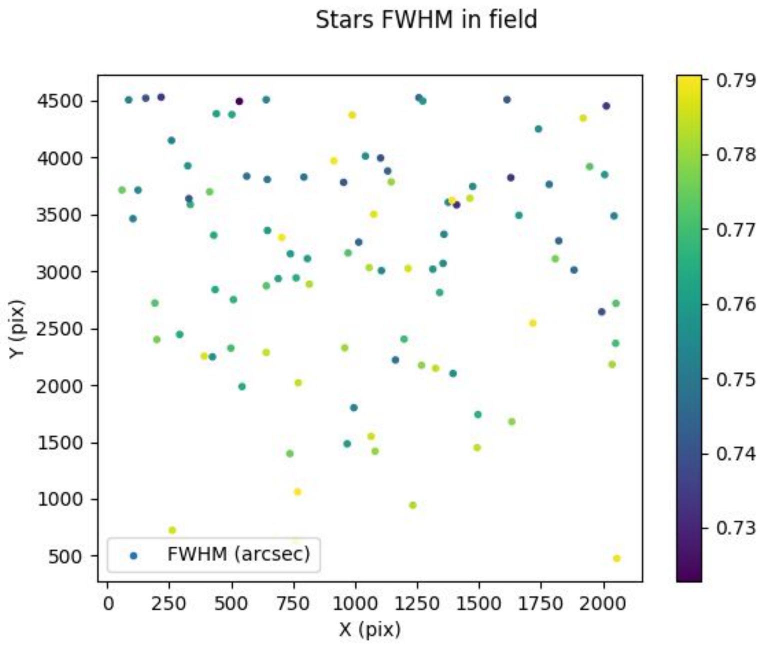


Knots in nearby galaxies create spurious detections as WL galaxies, need to be removed from analysis.

Star selection

Use stars to create PSF model.



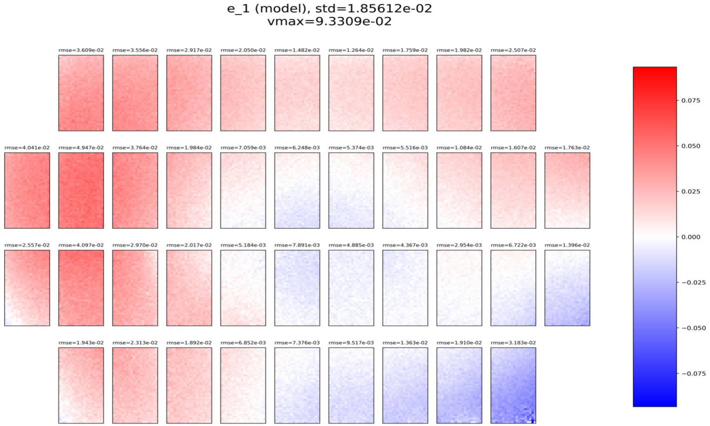


PSF model

Two models can be used:

- PSFEx, Bertin et al. 2011
- MCCD, Liaudat et al. 2021, [A&A, 646, A27]

Stacked MegaCAM focal plane

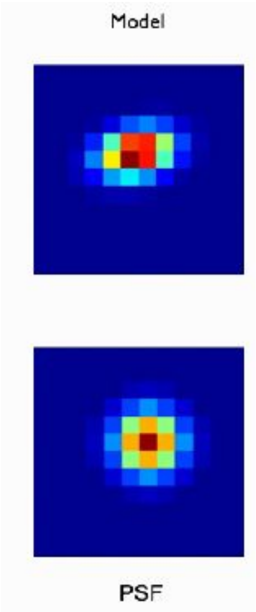


PSF ellipticity component 1

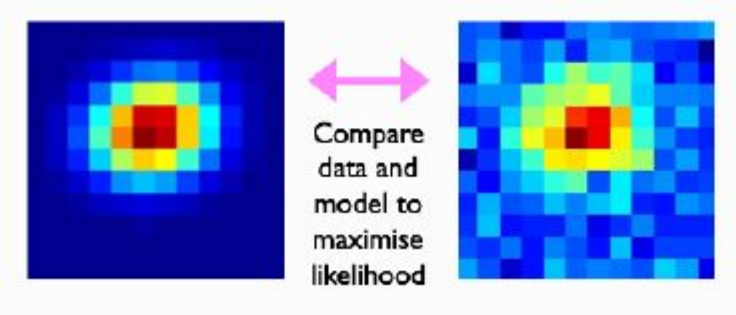
PSF ellipticity residual component 1

Galaxy shape measurement

- Simple model for galaxy light profile (Gaussian)
- Convolve model with PSF
- Fit to observed galaxy, minimise to measure shape parameters
- ngmix (DES; E. Sheldon et al.)



Convolve



(Meta-)Calibration

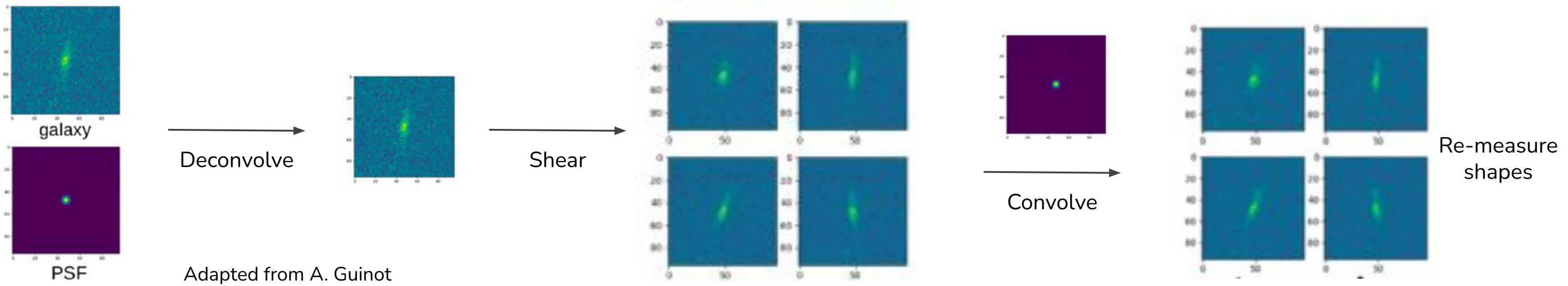
- Weak-lensing shapes are biased (noise, wrong model or PSF, blended galaxies.
- Multiplicative bias **R** most important:

$$\boldsymbol{\gamma}^{\text{obs}} = \mathbf{R}\, \boldsymbol{\gamma}^{\text{true}} + \boldsymbol{c}$$

- Interpret **R** as response of the observed shape to a (small) shear:

$$\mathbf{R} = \mathrm{d}\boldsymbol{\gamma}^{\text{obs}} / \mathrm{d}\boldsymbol{\gamma}^{\text{true}} \approx [\, \boldsymbol{\gamma}^{\text{obs}}(\boldsymbol{\gamma}^{\text{true}} + \delta\boldsymbol{\gamma}) - \boldsymbol{\gamma}^{\text{obs}}(\boldsymbol{\gamma}^{\text{true}} - \delta\boldsymbol{\gamma}) \,] / [\, 2\, \delta\boldsymbol{\gamma} \,]$$

- **R** can be measured by applying small artificial shear **δγ** to each observed galaxy.



Adapted from A. Guinot

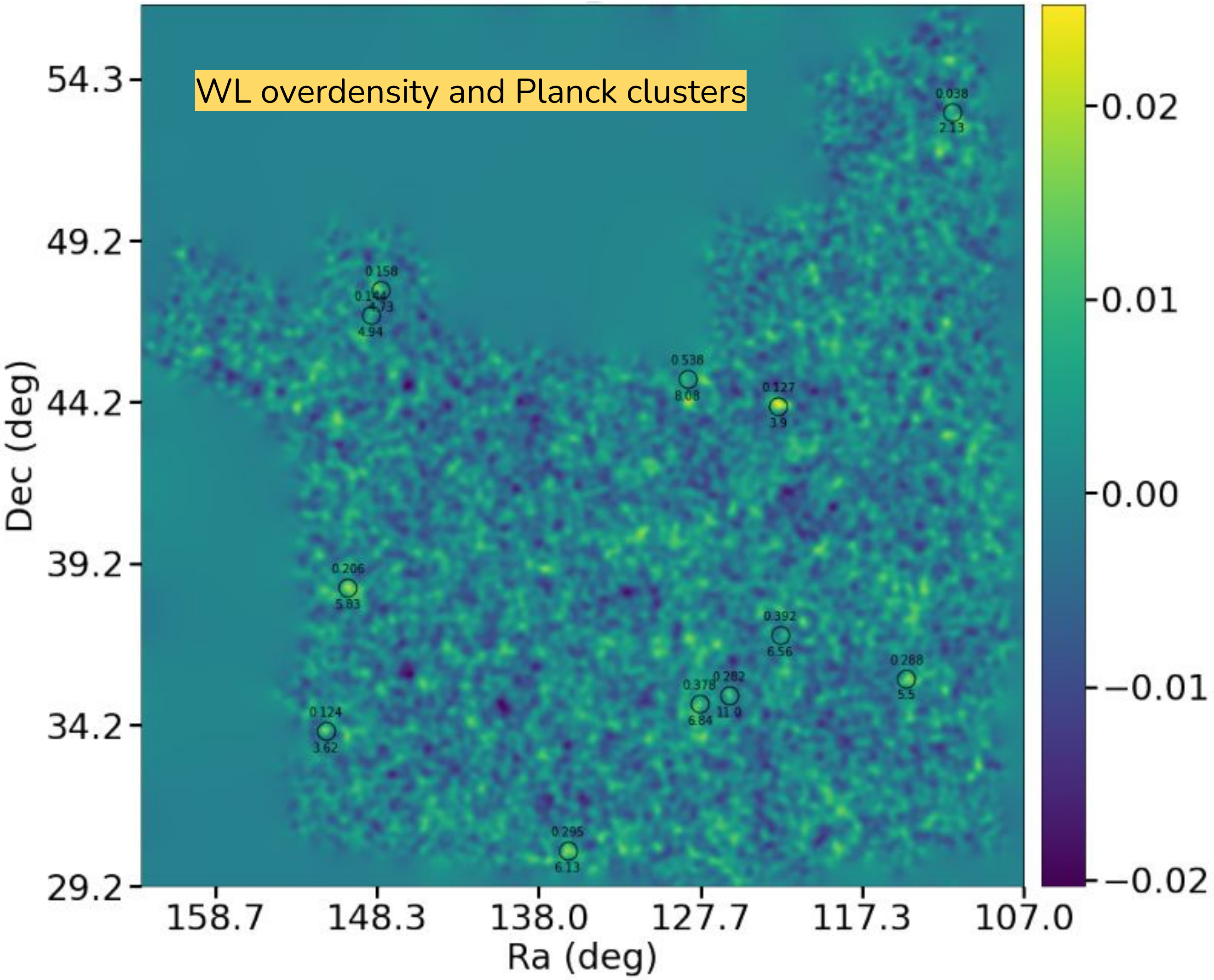
Some early results

- Mass maps, cluster convergence & masses
- Halo ellipticity
- Peak counts
- Intrinsic galaxy alignment
- Void lensing

Future publications

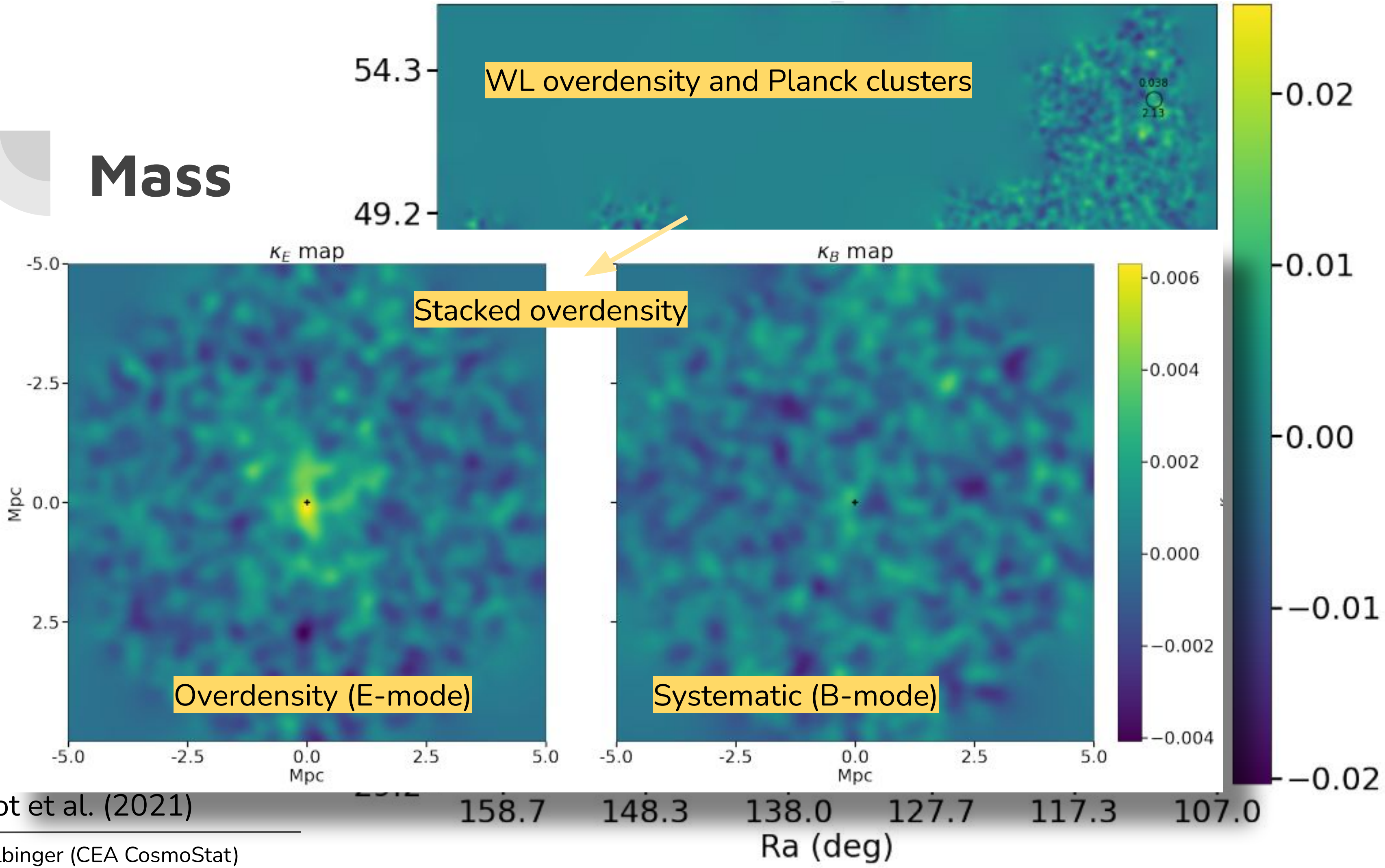
- Blinded (redshift distribution)
- Two pipelines (ShapePipe and *lens*fit)

Mass maps



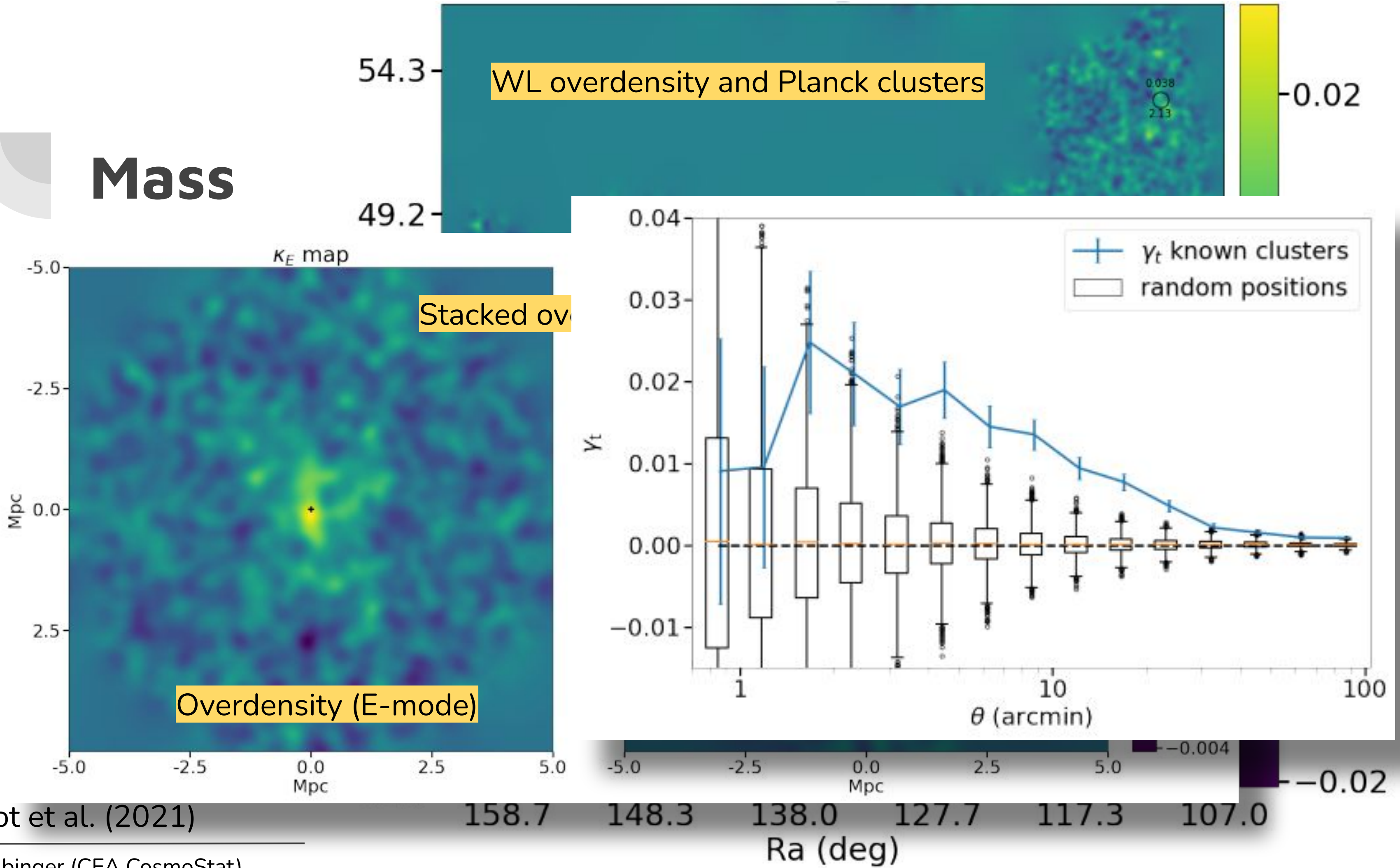
Guinot et al. (2021)

Mass



Guinot et al. (2021)

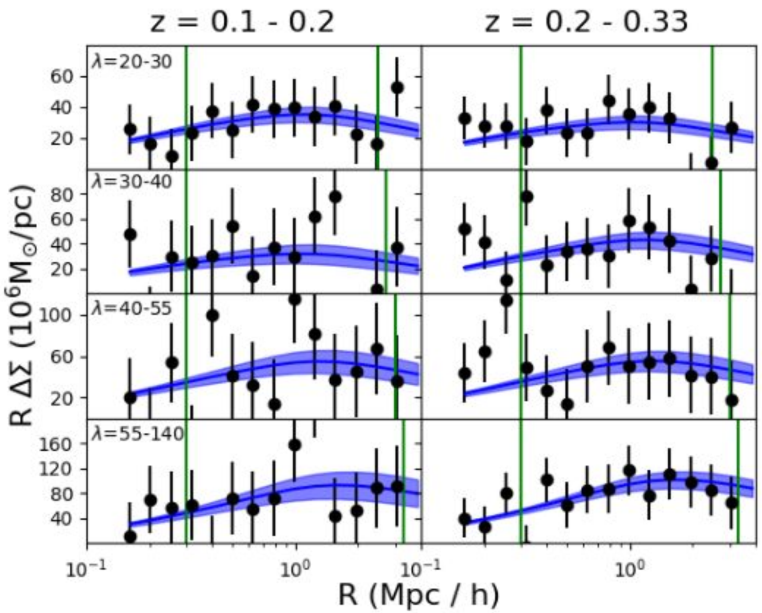
Mass

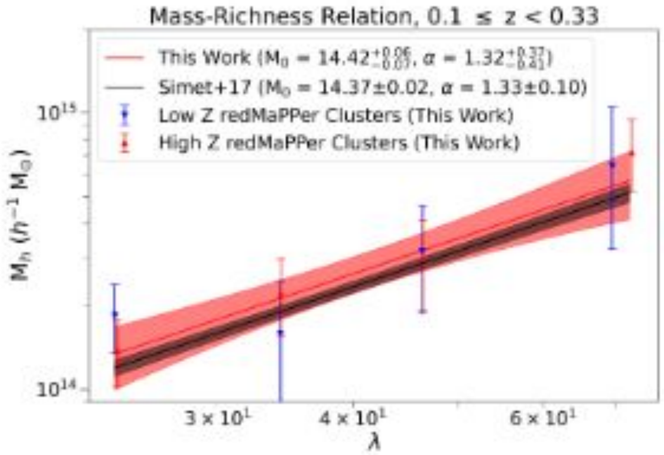


Guinot et al. (2021)

Group and cluster masses

Overdensity around SDSS redMaPPer groups



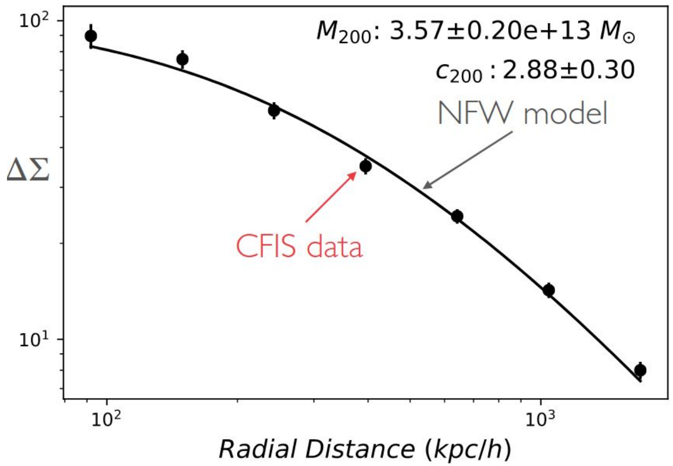


Spitzer et al. (2022)

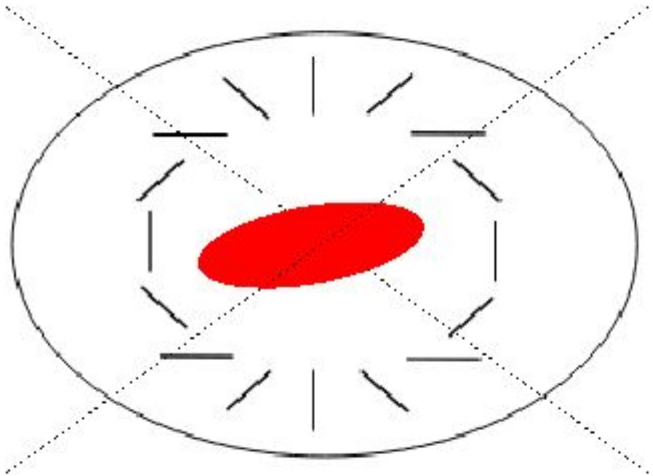
Dark-matter halo shapes

WL halo profile of 146,000 SDSS DR7 Luminous Red Galaxies (LRGs).

Monopole.



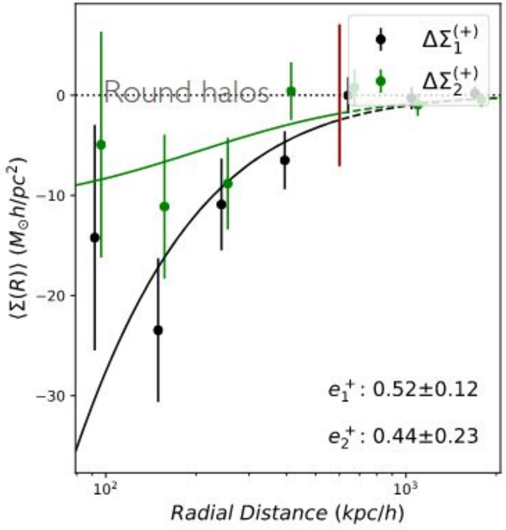
Can we measure the **quadrupole?**
→halo shape
Stack LRGs along galaxy orientation

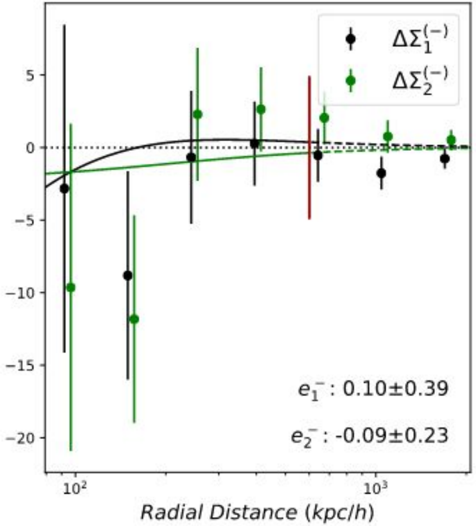


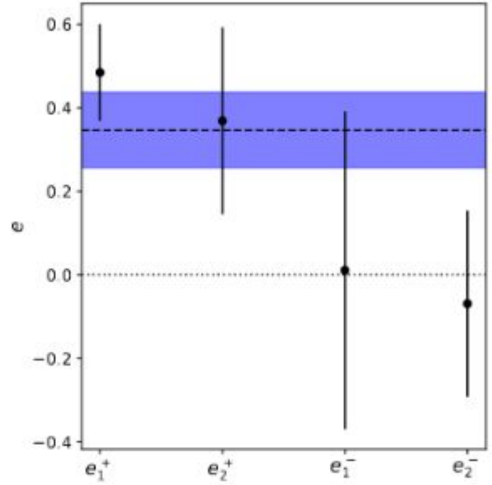
Robison et al, 2022

Dark-matter halo shapes

WL halo profile quadrupole estimators.







e = 0.35±0.09 (~4σ detection of DM halo ellipticity)

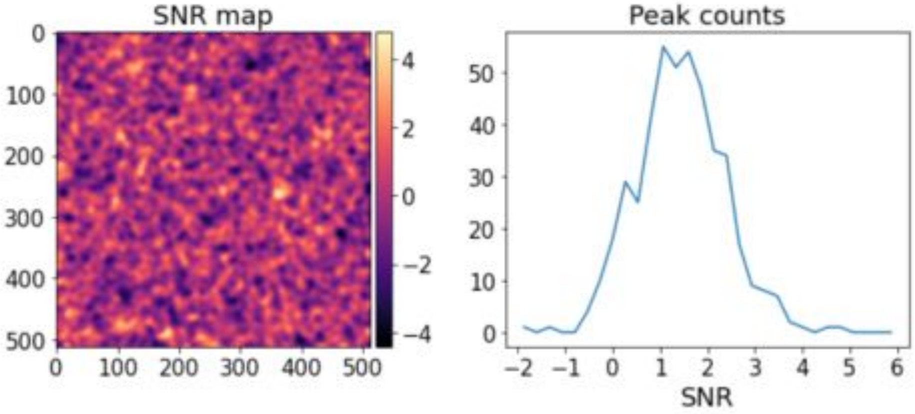
Robison et al, 2022

Peak counts

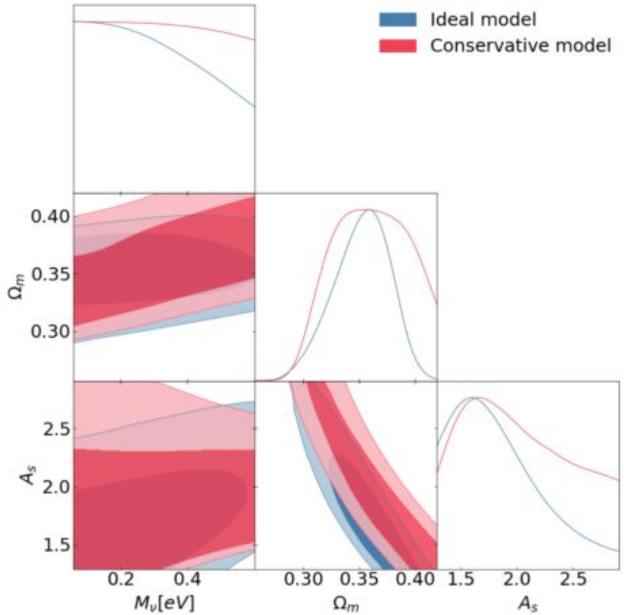
Study of systematic effects:

- Local shear calibration
- Baryonic effects
- Intrinsic alignments
- Redshift uncertainty

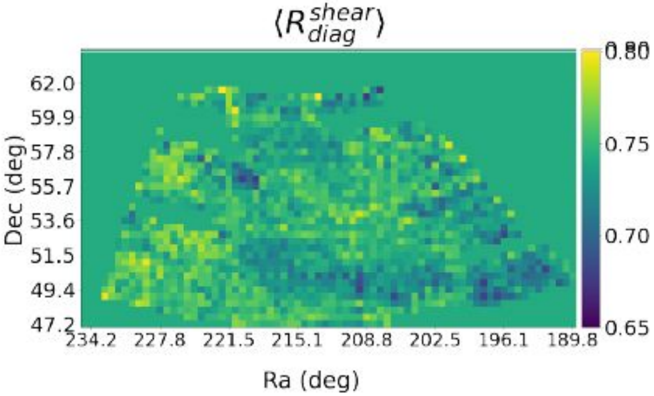
Number of peaks in WL overdensity (/ noise) map depends on cosmological parameters.

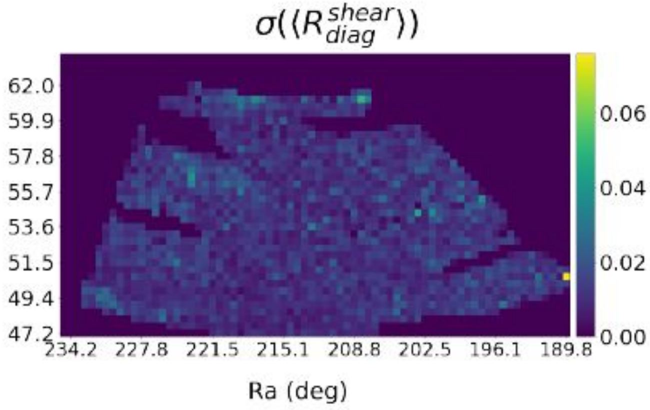


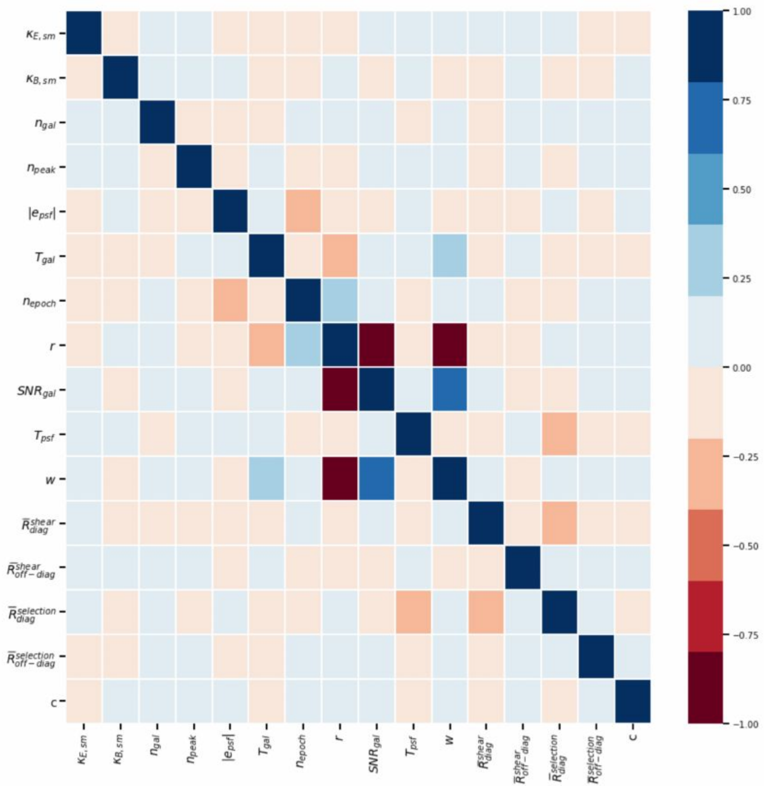
Ayçoberry et al, 2022



Peak counts & local calibration

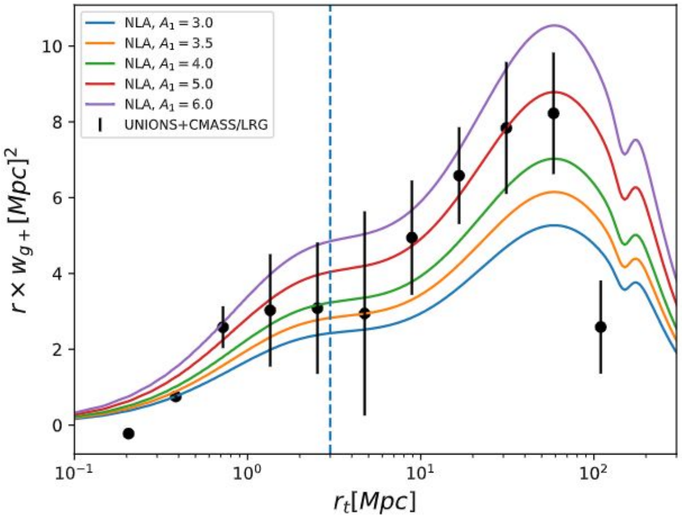




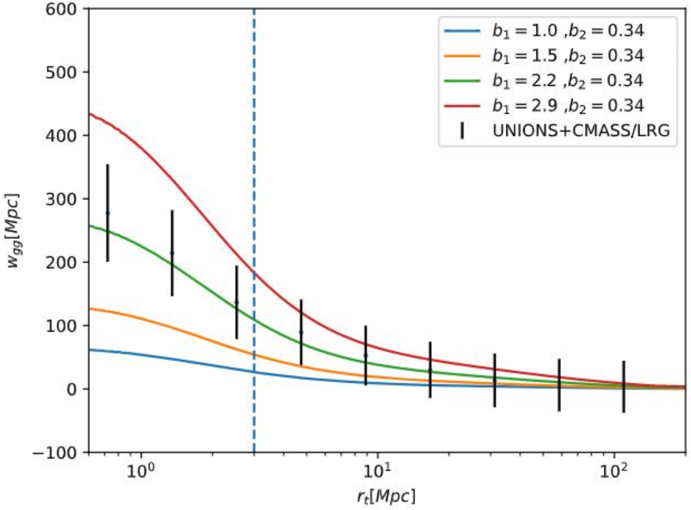


Intrinsic galaxy alignment

“Lensing” galaxies at same z as LRGs:
Measure intrinsic alignment amplitude.



“Lensing” galaxies behind LRGs:
Measure galaxy bias.



From Fabian Hervas Peters

ShapePipe

A modular weak-lensing processing and analysis pipeline

Software paper	Farrens et al., 2022, A&A, 664, 141
Code & documentations	https://github.com/cosmostat/shapepipe
UNIONS first weak-lensing analysis	Guinot et al., 2022, A&A, 666, A162
Group & cluster masses	Spitzer et al., 2022, submitted to MNRAS
Dark-matter halo shapes	Robison et al., 2022, arXiv:2209.09088
Peak counts	Ayçoberry et al., 2022, A&A in press
Multi-CCD PSF model	Liaudat et al., 2021, A&A, 646, A27

In progress

Intrinsic galaxy alignment

Void lensing

Cosmic shear, constraints on Ω_m, σ_8, DE

Peak counts II

Lensing by AGNs, M_{BH} - M_{halo} relation

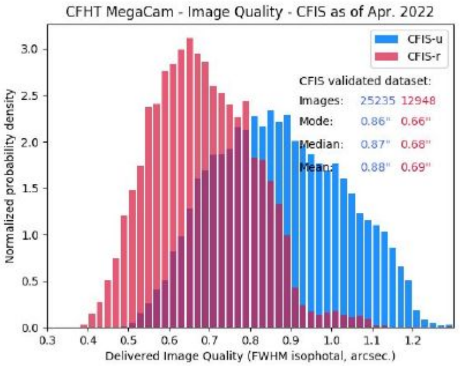
Analysis of CFHT P.I. data (rotating galaxy cluster, FRB field)

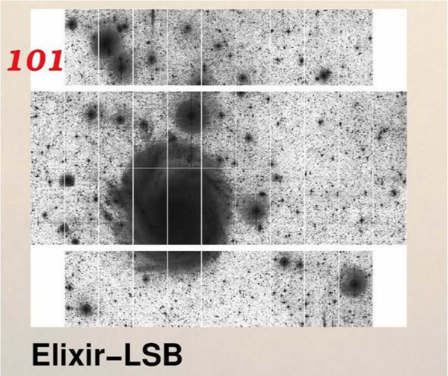
Backup slides

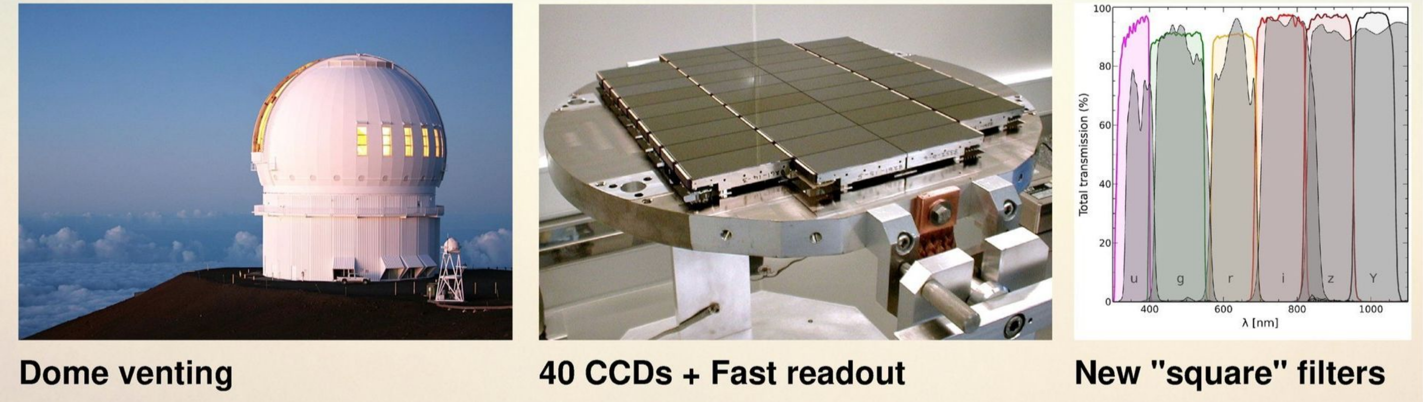
UNIONS/CFIS

Best wide-field imager on CFHT ever.

Improvements (2011 - 2014)



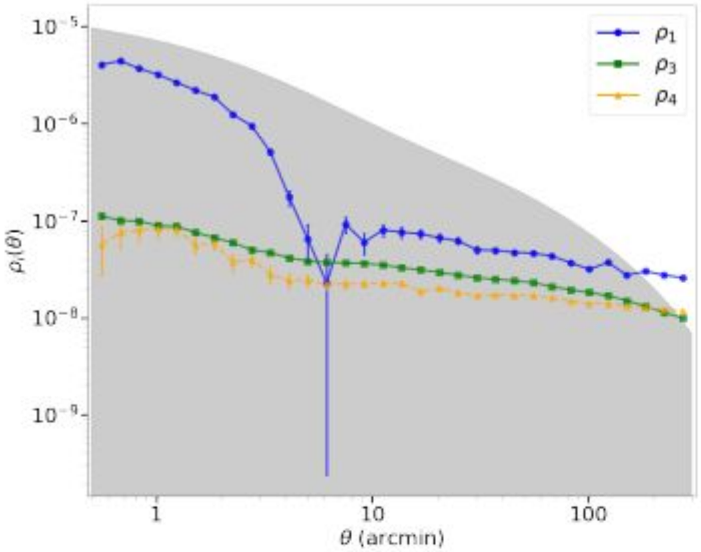




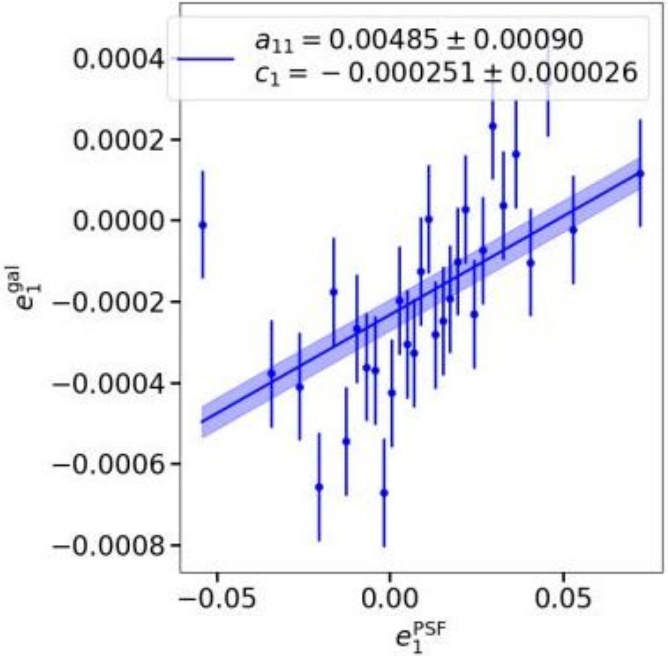
UNIONS is basically a static LSST in the North, not likely to be outperformed any time soon.

PSF diagnostics

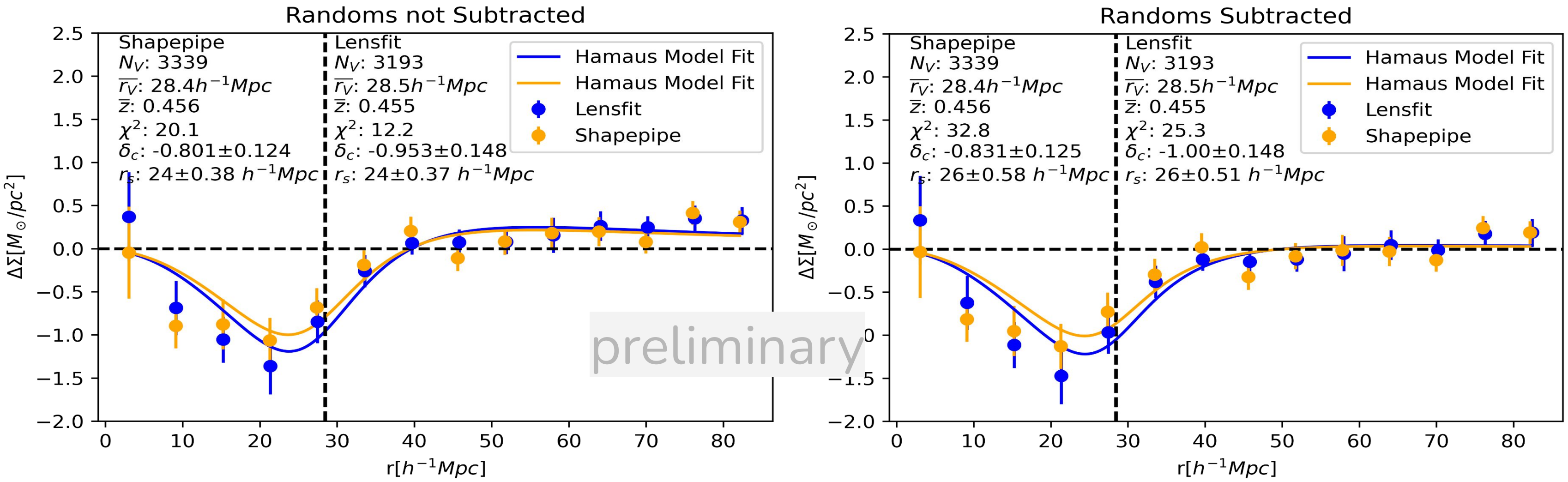
PSF residual correlation functions, propagation to cosmology.



PSF leakage into galaxy ellipticity



Void lensing (previous WL catalogues)



Void lensing

$$\frac{\rho_V(r)}{\overline{\rho}} - 1 = \delta_c \frac{1 - (r/r_s)^\alpha}{1 + (r/r_V)^\beta}$$

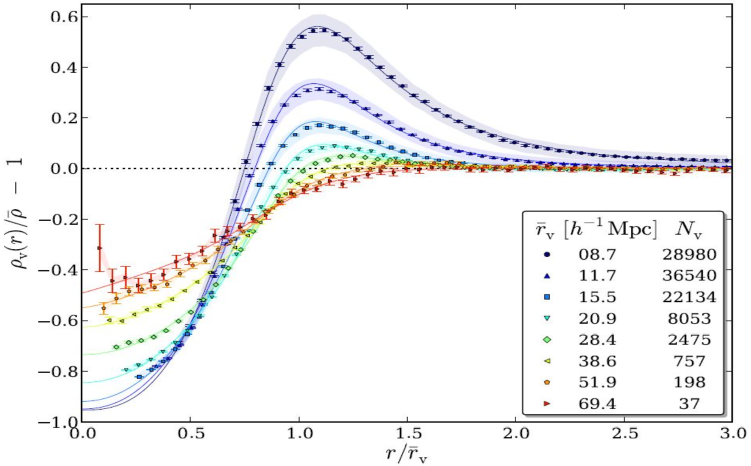
2 free parameters: δ_c and r_s

$$\Sigma_H(y) = 2 \int_y^\infty \frac{(\rho_V(r) - \overline{\rho})r}{\sqrt{r^2 - y^2}} dr$$

$$\Delta\Sigma = \overline{\Sigma(< r)} - \Sigma(r)$$

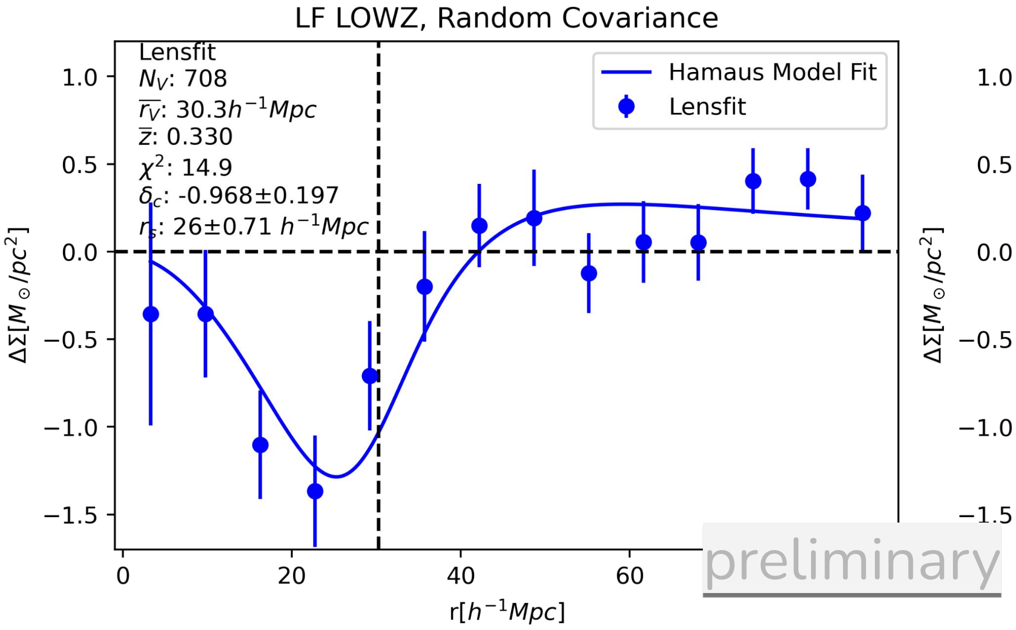
Citation: Hamaus N., Sutter P. M., Wandlet B. D., 2014, Phys. Rev. Lett., 112, 251302

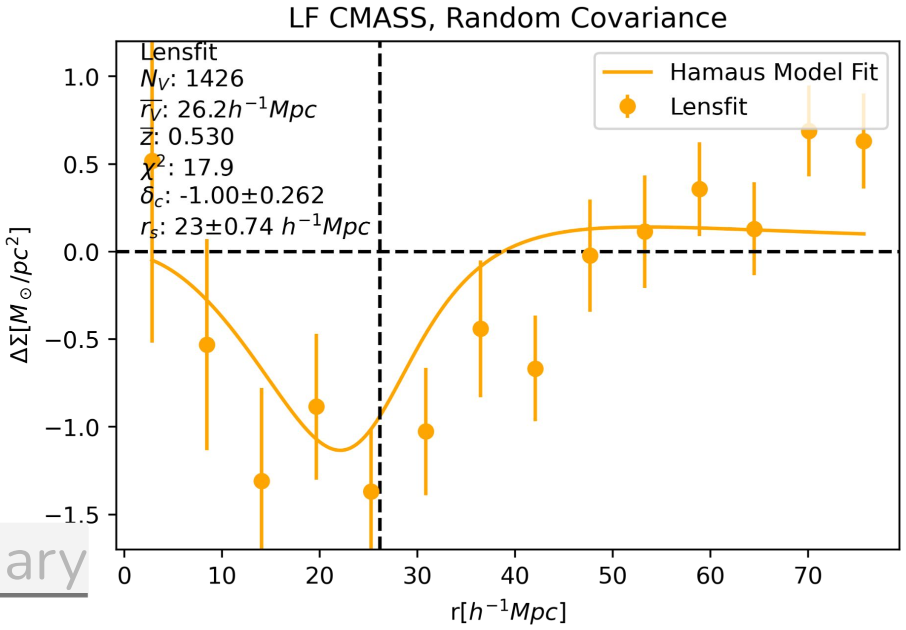
Universal density profile



Fits of overdensity profiles of stacked simulated voids at redshift of 0. Source: (Hamaus et al. 2014)

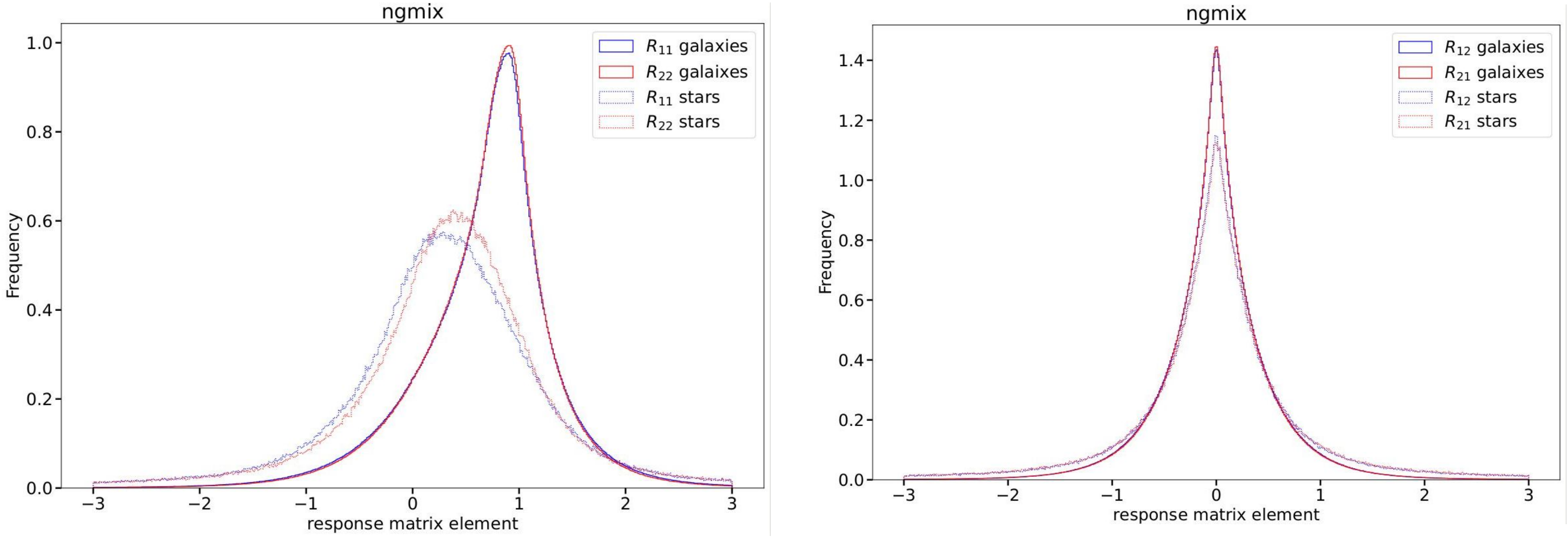
Void lensing





From Hunter Martin, Mike Hudson

Metacalibration response matrix



Galaxies: <R>~0.7, 30% bias. Stars: <R>~0-0.2, stars are point sources, no/small response to shear.