3D weak lensing Application to galaxy clusters

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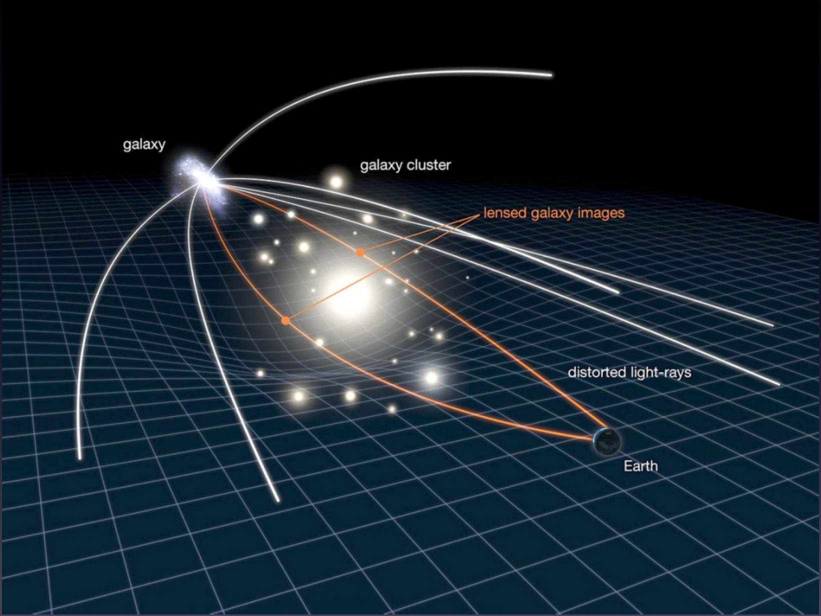
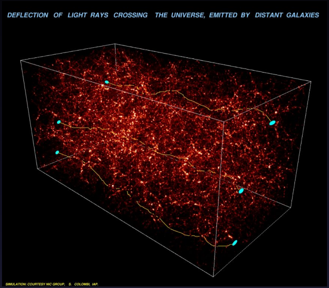
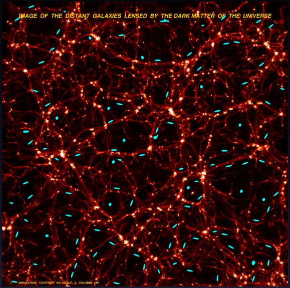
Layout

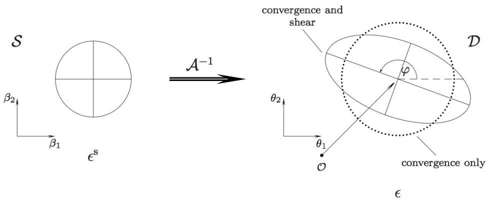
1. 3D Weak Gravitational Lensing
   - Gravitational Lensing
   - Probing the Universe in 3D
   - State of the art 3D weak lensing reconstruction methods
2. The GLIMPSE algorithm
   - Sparse regularisation
   - The algorithm
3. Test on simulated NFW profiles
   - Assessing the performance of the algorithm
   - Redshift estimation
   - Mass estimation
   - Detection efficiency


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth



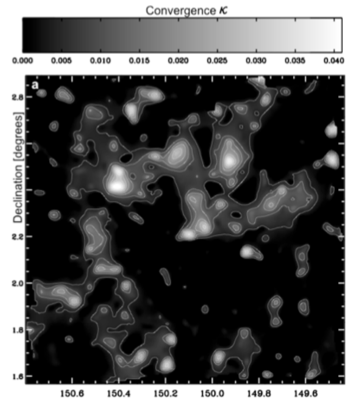


Impact on galaxy shapes: Convergence κ and Shear γ



$$\epsilon = \epsilon_i + \gamma \text{ with } < \epsilon_i >= 0$$

$$\Longrightarrow \quad < \epsilon >= \gamma$$



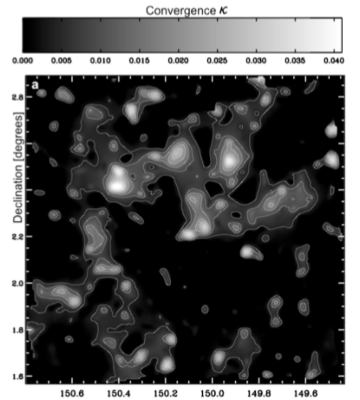
Convergence map of the COSMOS field, Massey et al. (2008)

- Weak lensing **mass mapping** $\equiv$ map the convergence from the measured shear.

- Why map the convergence ?

$$\kappa = \int Q(\chi)\delta(\chi)$$

$\Rightarrow$ Projection of the **3D matter density contrast** δ



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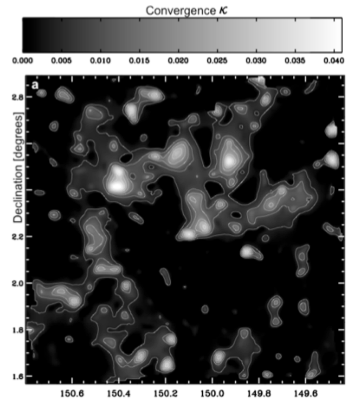

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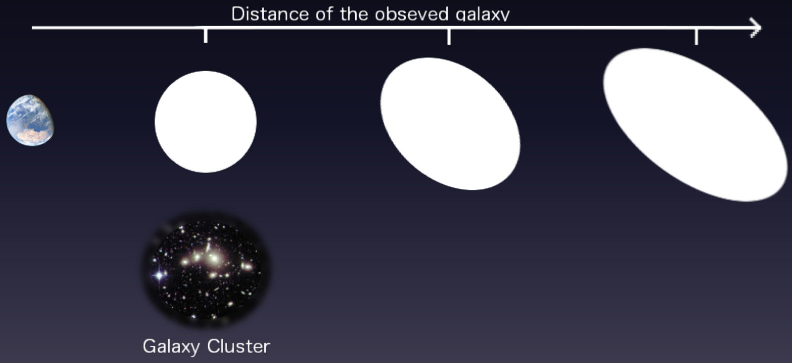
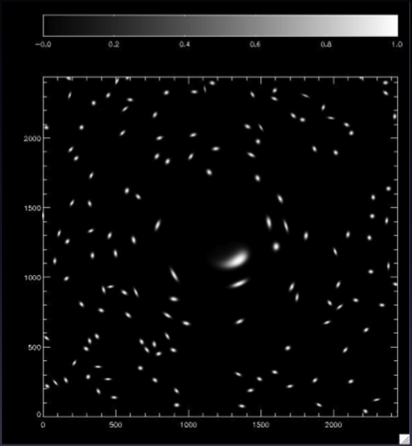
Limits of the projected convergence map alone

Degeneracy between mass and distance of structures due to the projection

The intensity of the lensing effect depends on the **ratio of distances** between observed galaxy, lensing source and observer.



What are we trying to do ?



$\Longrightarrow$

From measurements:

- shear
- **redshift**

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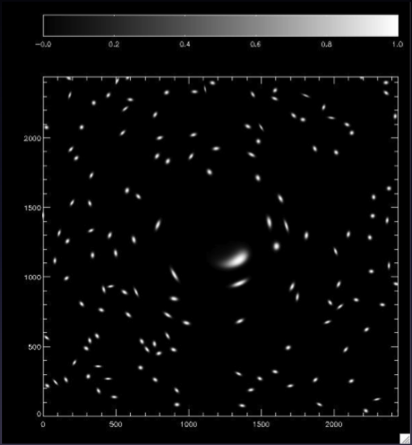

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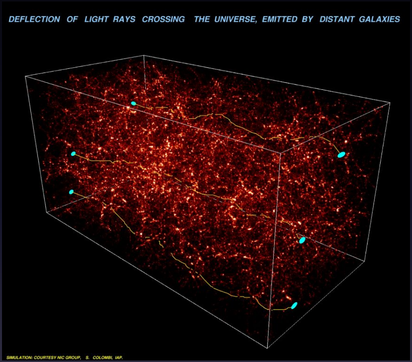

Deproject the lensing signal and **infer the 3D distribution** of dark matter

- **The 3D Reconstruction Problem:**

$$\underbrace{\gamma}_{\text{shear}} = \mathbf{P} \quad \mathbf{Q} \quad \underbrace{\delta}_{\text{overdensity}} + \underbrace{n}_{\text{noise}}$$

P and Q are the **tangential** and **line of sight** lensing operators

On the bright side:

- linear problem

On the other side:

- **ill-posed** inverse problem
- extremely noisy shears
- **photometric redshifts** errors
- missing data

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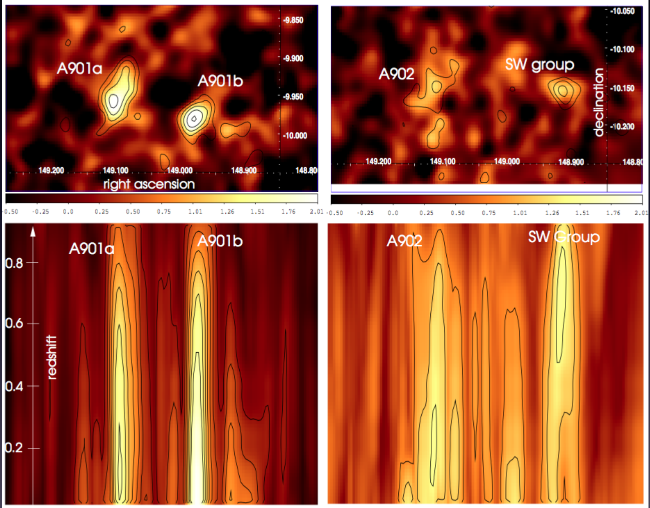
- 2 **linear methods** where introduced to address the inversion problem:
  - Wiener filtering, *Simon et al.* (2009)
  - SVD regularisation, *VanderPlas et al.* (2011)

- In both cases:
  - very poor redshift accuracy (structures are smeared in l.o.s.)
  - systematic bias in reconstructed redshift
  - overall noisy reconstructions

- These methods **do not reconstruct the dark matter overdensity** δ, only Signal to Noise Ratios.

Wiener filter reconstruction of the STAGES Abell A901/2 superclusters, from *Simon et al.* (2012)



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Why are the results for 3D lensing so poor ?

- The lensing kernel $\mathbf{Q}$ degrades the information too much.
- Usual linear methods are not powerful enough to recover the information.

Our approach

Introduce a new non-linear **sparsity** based reconstruction method.

Considering a general linear problem of the form:

$$Y = \mathbf{A}X_0 + N$$

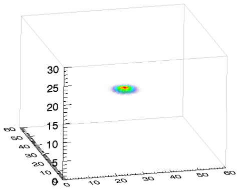
An approximation of X_0 can be recovered by imposing a sparsity promoting penalty on the solution in a dictionary Φ.

$$\boxed{\min_{\alpha} \frac{1}{2} \parallel Y - \mathbf{A\Phi}\alpha \parallel_2^2 + \lambda \parallel \alpha \parallel_1} \qquad \text{with } \tilde{X} = \Phi\alpha$$

Simple example: **Deblurring**

The 2 ingredients of the **GLIMPSE** reconstruction technique:

- a **wavelet based dictionary** adapted to dark matter halos.



- a **Fast Iterative Soft Thresholding Algorithm** to solve the optimisation problem:

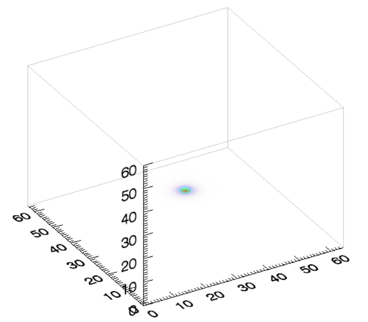
$$\min_{\alpha} \frac{1}{2} \underbrace{\| \boldsymbol{\Sigma}^{-1/2} [\gamma - \mathbf{P}\mathbf{Q}\boldsymbol{\Phi}\alpha] \|_2^2}_{\text{Data fidelity}} + \underbrace{\lambda \| \alpha \|_1}_{\text{Sparsity constraint}}$$

Leonard, Lanusse, Starck (2014) [arxiv:1308.1353]

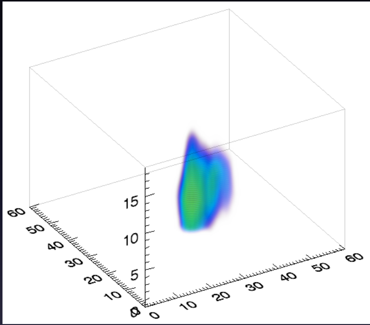
The algorithm in action on an N-body simulation:

(Loading Video...)

Comparison to previous methods on a single halo field:



(a) Input **simulated density contrast** for an NFW halo



(b) **SNR map** thresholded at 4.5σ using **Transverse Wiener Filtering**

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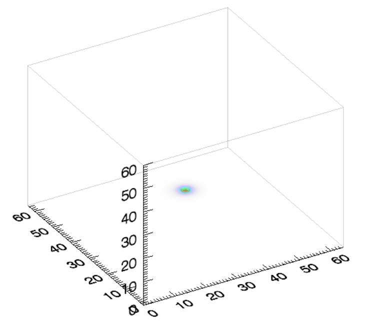

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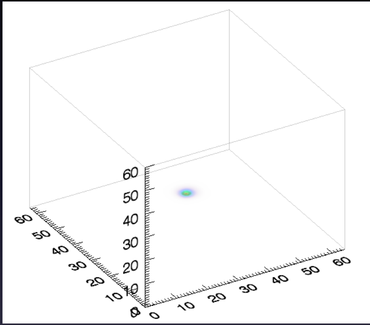

(b) **Density contrast** reconstruction using **GLIMPSE**

Improvement over linear methods:

- GLIMPSE reconstructs the density contrast and not only SNR maps.
- No redshift bias
- No smearing of structures
- No damping in amplitude of the reconstructed halos.

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Single halo simulations

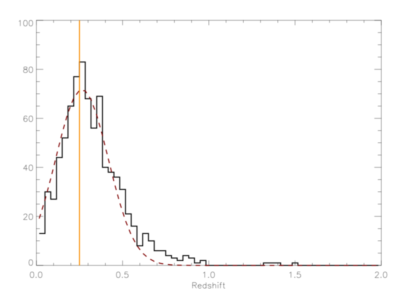
- One NFW profile at the center of a 60x60 arcmin field
- Noise and redshift errors corresponding to an Euclid-like survey
- Mass varying between 3.10^{13} and $1.10^{15}\ h^{-1}M_{\odot}$
- Redshifts between 0.05 and 1.55

We ran 1000 noise realisations on each of the 96 fields.

Redshift Estimation

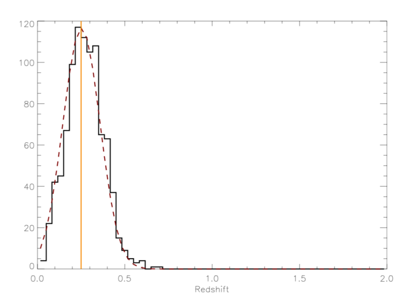
Example of 2 NFW halos at z=0.25

$m_{vir} = 4.10^{14} h^{-1} M_\odot$



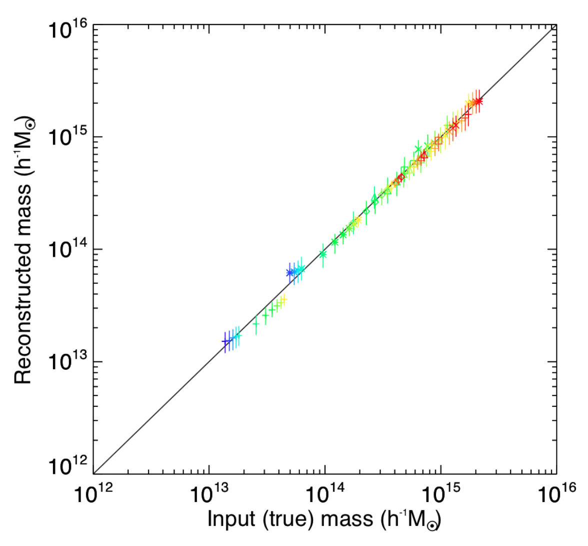
$\sigma_z = 0.15$

$m_{vir} = 8.10^{14} h^{-1} M_\odot$

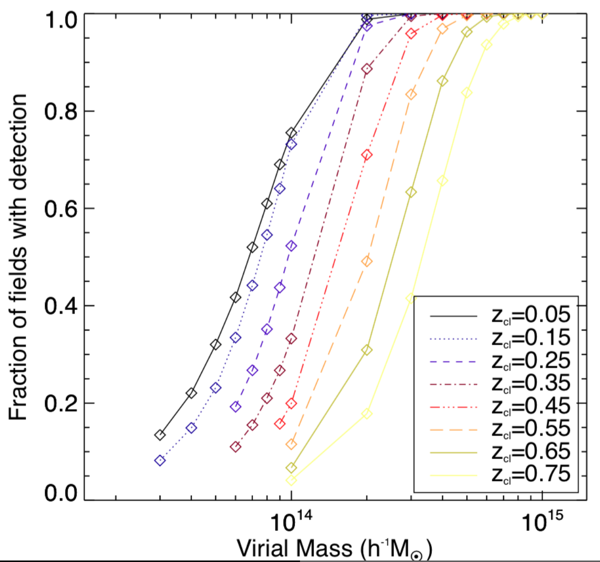


$\sigma_z = 0.1$

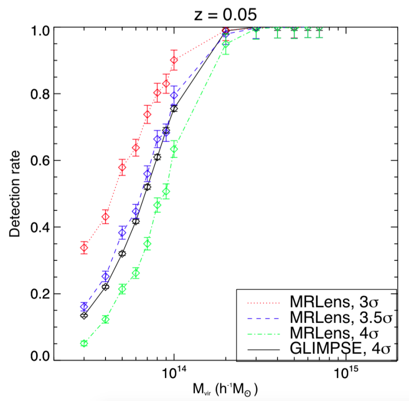
Mass estimation

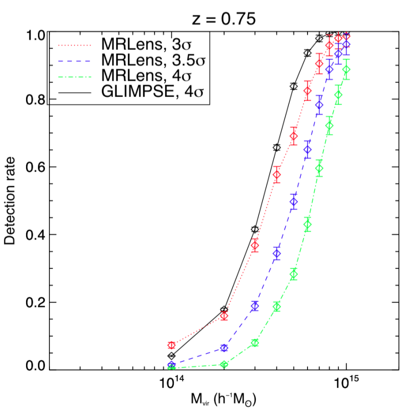


Detection efficiency



Comparison between 2D (MRLens) and 3D detection efficiency





$\Longrightarrow$ 3D lensing seems more efficient than 2D to detect "high" redshift clusters.

Conclusion

- 3D lensing mass mapping can now become a useful probe
- We expect 3D lensing to complement optical cluster finders for large scale surveys

Ongoing work:

- High resolution 3D map of the STAGES Abell A901/2 clusters
- Validation of the algorithm on the MICE N-body simulation
- Process the CFHTLenS data and produce 3D lensing detected catalog of objects (with mass and redshifts)

http://www.cosmostat.org/research/wl/glimpse

arxiv:1308.1353