Combining Weak and Strong Lensing in Galaxy Cluster Mass Reconstructions

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Abstract

While weak lensing cannot resolve cluster cores and strong lensing is almost insensitive to density profiles outside the scale radius, combinations of both effects promise to constrain density profiles of galaxy clusters well, and thus to allow testing the CDM expectation on dark-matter halo density profiles.
We develop an algorithm further that we have recently proposed for this purpose. It recovers a lensing potential optimally reproducing observations of both strong and weak-lensing effects by combining high resolution in cluster cores with the larger-scale information in weak lensing.

Introduction

Weak Lensing

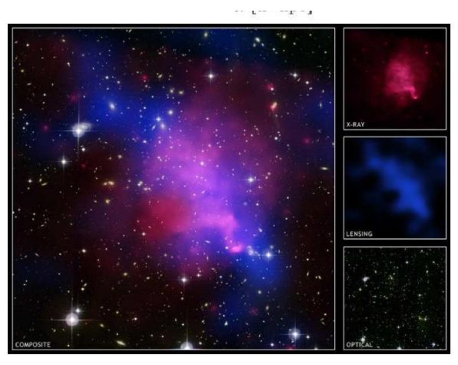


Figure: The "Cosmic Train Wreck" Abell 520 (Mahdavi et al., 2007)

The main features of weak lensing:

- Slight image distortions of background galaxies.
- Round sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity. ⇒ Weak lensing has to be treated statistically.
- Observable over a wide field, so it allows a very complete reconstruction.

Strong Lensing

The main features of strong lensing:

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect. ⇒ No statistics necessary.
- Confined to the inner core of cluster.
- Therefore, the area in which one can perform a reliable reconstruction is limited.

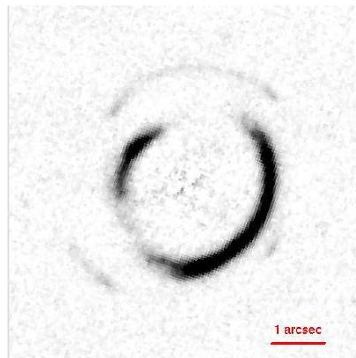


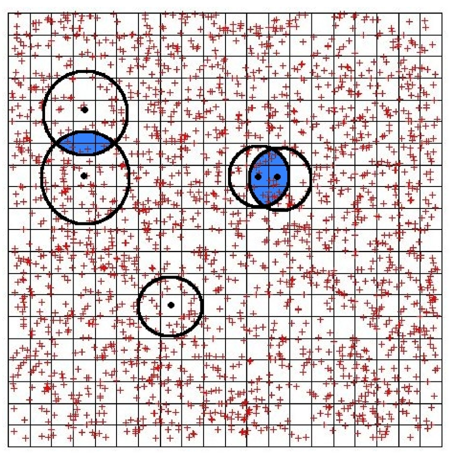
Figure: The first discovered double Einstein ring by HST/ACS (Gavazzi et al., 2008)

The Reconstruction Method

Combining Weak and Strong Lensing

Regarding the advantages and disadvantages of both methods, it seems clear that an ideal reconstruction method based on gravitational lensing should make use of both lensing effects. There have been several attempts to implement a joint reconstruction method. We refer here to Bradač et al. (2005); Cacciato et al. (2006); Diego et al. (2007).
In the following we summarise the main ideas of our combined weak and strong lensing reconstruction method. For a more detailed description, see Merten et al. (2008).

This figure shows an adaptive averaging process for the background galaxies. This procedure is necessary for a efficient weak lensing reconstruction at a reasonable resolution. Since the averaging areas may overlap, one has to take into account correlations in the weak lensing χ^2, as shown in this formula.



$$\chi_w^2(\psi)=\sum_{i,j}\left(\varepsilon-\frac{Z(z)\gamma(\psi)}{1-Z(z)\kappa(\psi)}\right)_i C_{ij}^{-1}\left(\varepsilon-\frac{Z(z)\gamma(\psi)}{1-Z(z)\kappa(\psi)}\right)_j$$

Features:

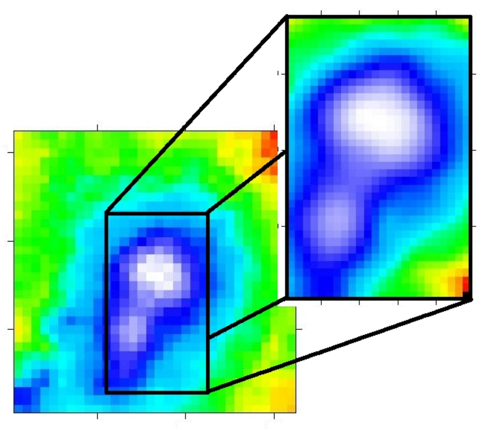
- Maximum-likelihood method
- Fully non-parametric
- Reconstruction quantity is the lensing potential ψ
- Minimising χ^2-function leads to the result

Input data:

- Ellipticity catalogue
- Arc positions
- Flexion catalogue
- Multiple image positions

$$\chi^2(\psi)=\chi_w^2(\psi)+\chi_w^2(\psi)$$

$$\frac{\partial\chi^2(\psi)}{\partial\psi_l}=\frac{\partial\chi_w^2(\psi)}{\partial\psi_l}+\frac{\partial\chi_s^2(\psi)}{\partial\psi_l}\overset{!}{=}0$$



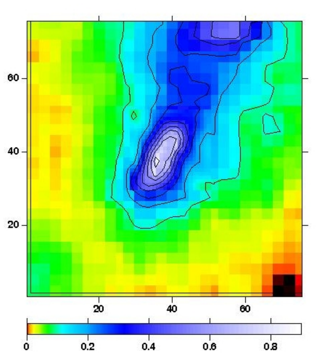
Since strong lensing constraints can be resolved very well by observations, using the coarse weak lensing reconstruction grid would result in a waste of information. Thus, we refine the grid resolution in the centre of the cluster, until the reconstruction can follow strong lensing features like arcs.

$$\chi_s^2(\psi)=\sum_i\frac{|\det A(\psi)|_i^2}{\sigma_i^2}=\sum_i\frac{|(1-Z(z)\kappa(\psi))^2-|Z(z)\gamma(\psi)|^2|_i^2}{\sigma_i^2}$$

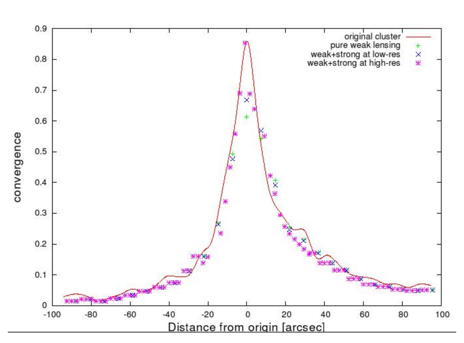
Results

Simulated Clusters

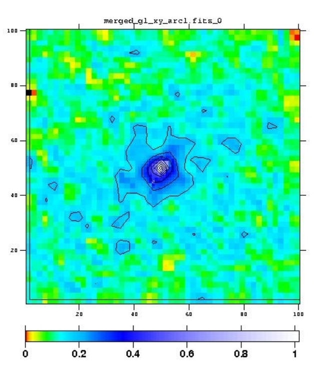
This figure shows the reconstructed density distribution of a simulated galaxy cluster. Perfect input data was used here as a proof of concept.

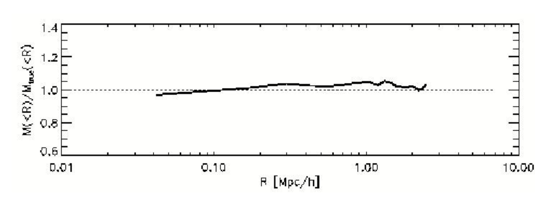


Since we used perfect data, also the reconstruction should yield results which contain almost no error. This radial density plot shows exactly this.



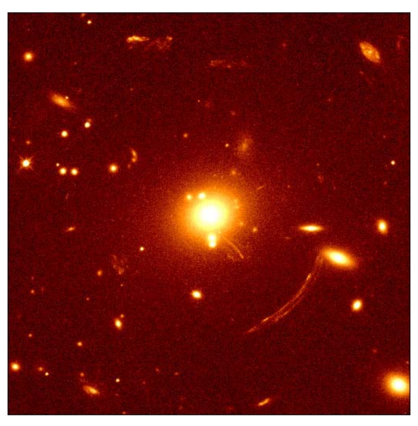
In this reconstruction we used a simulated lensing scenario, which includes most of the important measurement errors. We used the simulator code described in Meneghetti et al. (2008).

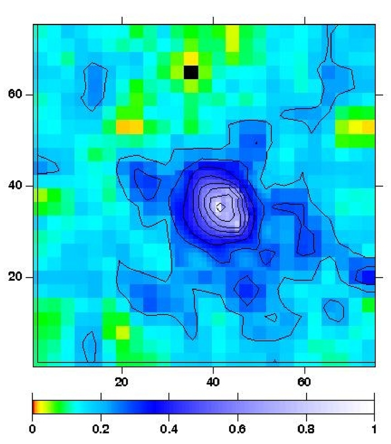




Ratio of the reconstructed mass against the real mass within a given radius. Also here we achieve a fairly good result.

MS 2137





Here we show an HST image and the reconstruction of the galaxy cluster MS2137. The cluster is suspected to be fairly relaxed, with a spherical shape. Our reconstruction supports this statement.

References

Bradač, M., Schneider, P., Lombardi, M., & Erben, T. 2005, A&A, 437, 39
Cacciato, M., Bartelmann, M., Meneghetti, M., & Moscardini, L. 2006, A&A, 458, 349
Diego, J. M., Tegmark, M., Protopapas, P., & Sandvik, H. B. 2007, MNRAS, 375, 958
Gavazzi, R., Treu, T., Koopmans, L. V. E., et al. 2008, ArXiv e-prints, 0801.1555v1
Mahdavi, A., Hoekstra, H., Babul, A., Balam, D. D., & Capak, P. L. 2007, ApJ, 668, 806
Meneghetti, M., Melchior, P., Grazian, A., et al. 2008, A&A, 482, 403
Merten, J., Cacciato, M., Meneghetti, M., et al. 2008, ArXiv e-prints, 0806.1967v1

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