Combining Weak and Strong Lensing in Galaxy Cluster Mass Reconstruction

Julian Merten

Institut für Theoretische Astrophysik
Zentrum für Astronomie
Universität Heidelberg

January 15th, 2009

with:
Matthias Bartelmann (ZAH/ITA Heidelberg)
Massimo Meneghetti (INAF Bologna)
Peter Melchior (ZAH/ITA Heidelberg)
Matteo Maturi (ZAH/ITA Heidelberg)
Holger Israel (AIfA Bonn)

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

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

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

The Reconstruction Method

In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

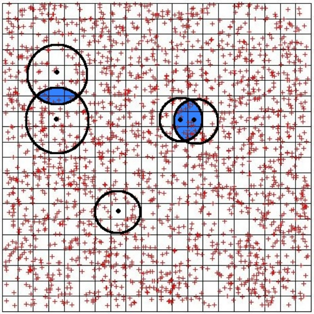
- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

Weak Lensing

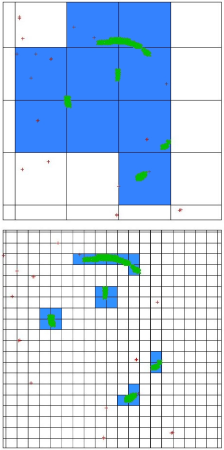
- State-of-the-art observations allow only for a ($\sim$ 10x10) pixel reconstruction grid
- Furthermore galaxies are not distributed homogeneously over the field
- Solution:
  Adaptive-averaging-process
  Problem:
  Grid points become correlated



$$\chi^2_w(\psi) = \sum_{i,j} \left(\varepsilon - \frac{Z(z)\gamma(\psi)}{1 - Z(z)\kappa(\psi)}\right)_i \mathcal{C}^{-1}_{ij} \left(\varepsilon - \frac{Z(z)\gamma(\psi)}{1 - Z(z)\kappa(\psi)}\right)_j$$

Strong Lensing

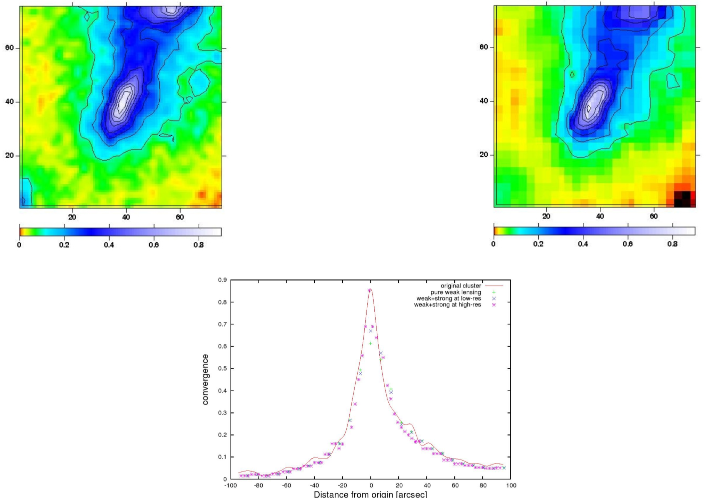
- The exact position of the critical curve is not observable
- Position of arcs is a very good approximation for the location of the critical curve
- Arc positions are known with high accuracy
- Using weak lensing grid resolutions would result in information loss



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

ARI ITA LSW

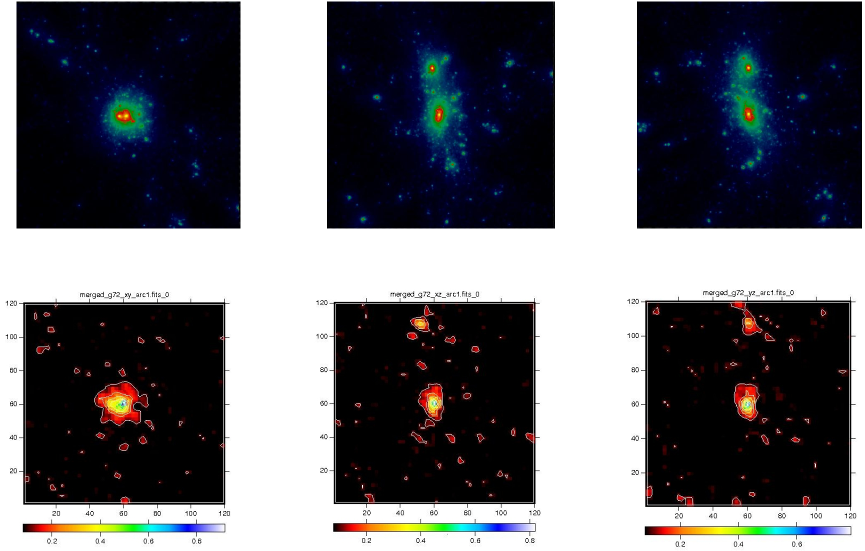
A Synthetic Test



(JM et al. 2008)

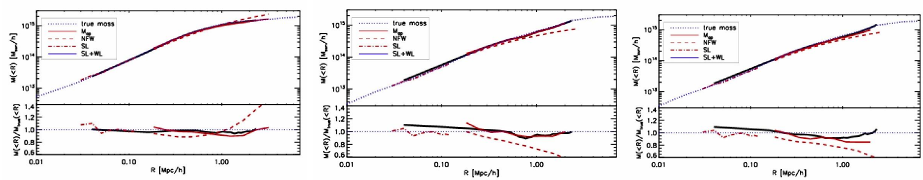
A Realistic Test: g72

For details about SkyLens, please see Massimo Meneghetti's talk.



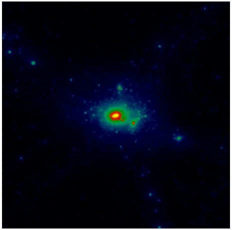
A Realistic Test: g72

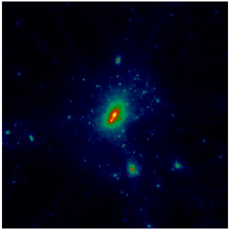
For details about SkyLens, please see Massimo Meneghetti's talk.

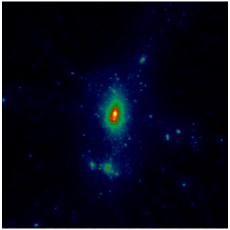


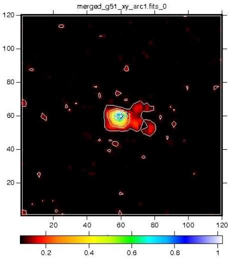
(Meneghetti, JM et al. in prep.)

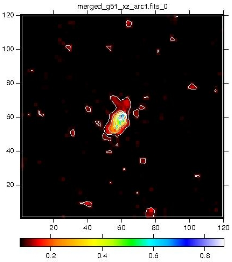
A Realistic Test: g51

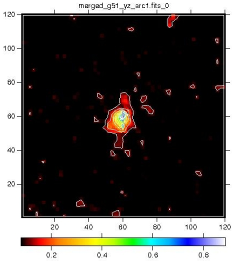








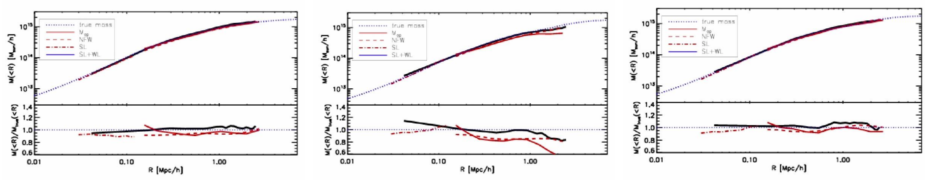




(Meneghetti, JM et al. in prep.)

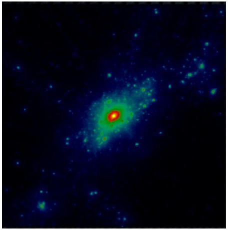
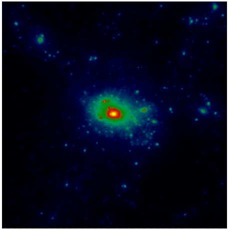
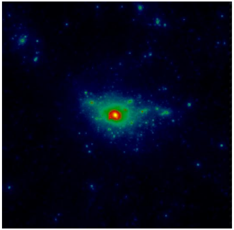
ARI ITA LSW

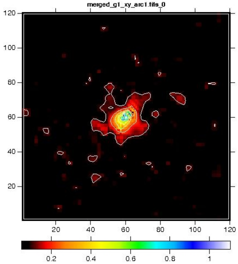
A Realistic Test: g51

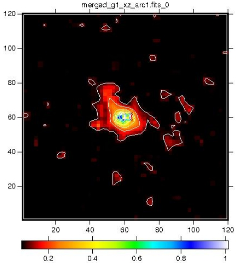


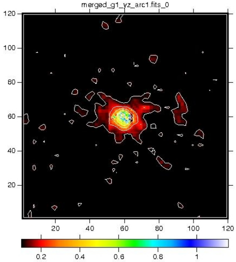
(Meneghetti, JM et al. in prep.)

A Realistic Test: g1

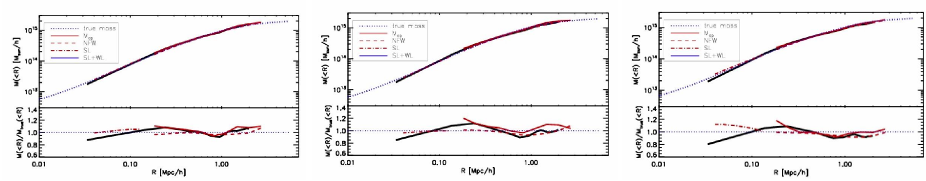






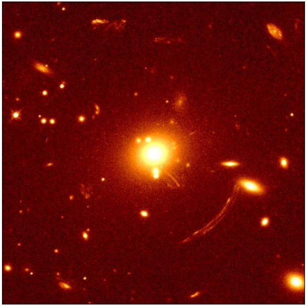
(Meneghetti, JM et al. in prep.)

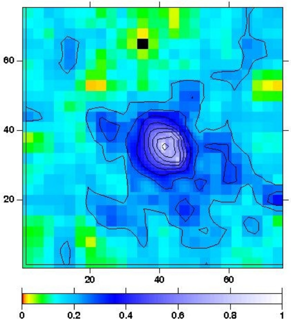
A Realistic Test: g1



(Meneghetti, JM et al. in prep.)

MS 2137





(JM et al. 2008)

Conclusions

1. We developed a method which successfully combines weak and strong lensing.
2. We use adaptive grid resolutions to take full advantage of both lensing regimes.
3. Tests of the method with synthetic and realistic lensing simulations show promising results.
4. The case of the galaxy cluster MS 2137 shows the applicability of our method to real data.
5. In the future the method will include lensing constraints of three different orders. (Multiple image systems, critical-curve estimators, shear and flexion).
6. The method may provide a useful tool for testing image-analysis pipelines.

HGSFP