Combining Weak and Strong Lensing in Galaxy Cluster Mass Reconstruction

Julian Merten

Institut für Theoretische Astrophysik
Zentrum für Astronomie
Universität Heidelberg

December 9th, 2008

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

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

Weak lensing

- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

Strong lensing

- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Gravitational Lensing

- Deflection of light by massive objects, described by general relativity.
- The lensed images of background sources contain information about the lens.

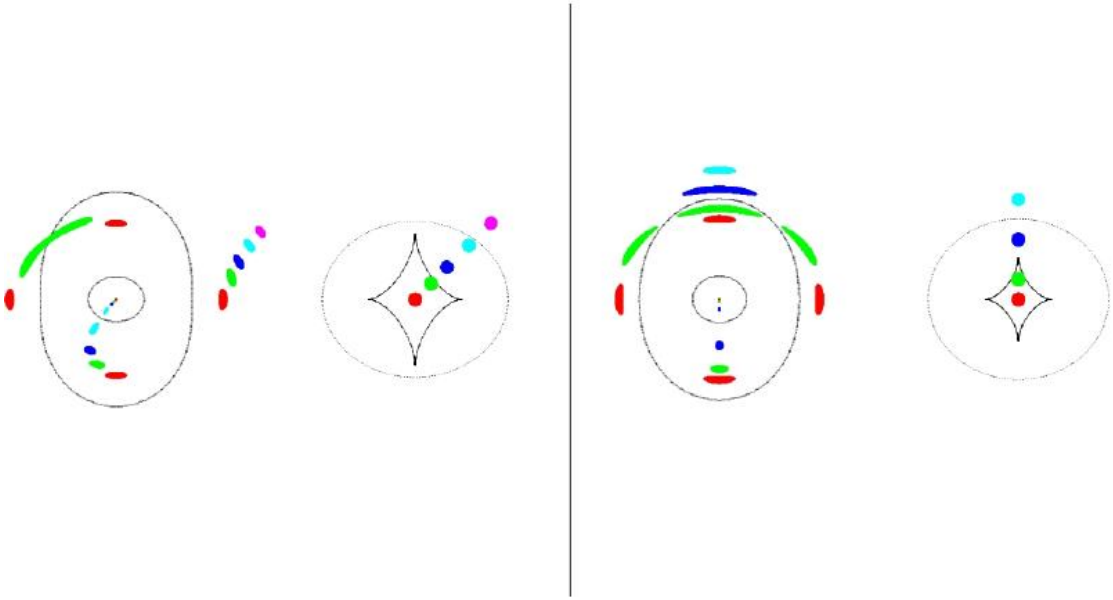
Weak lensing

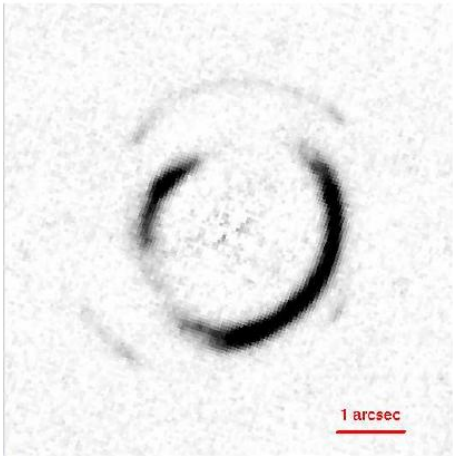
- Slight image distortions of background galaxies.
- Point sources would appear elliptical.
- Galaxies also carry intrinsic ellipticity.
  $\Rightarrow$ Weak lensing has to be treated statistically.
- Observable over a wide field.

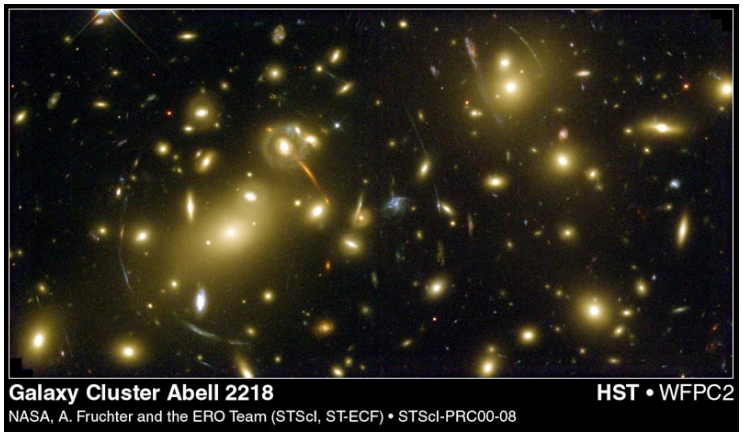
Strong lensing

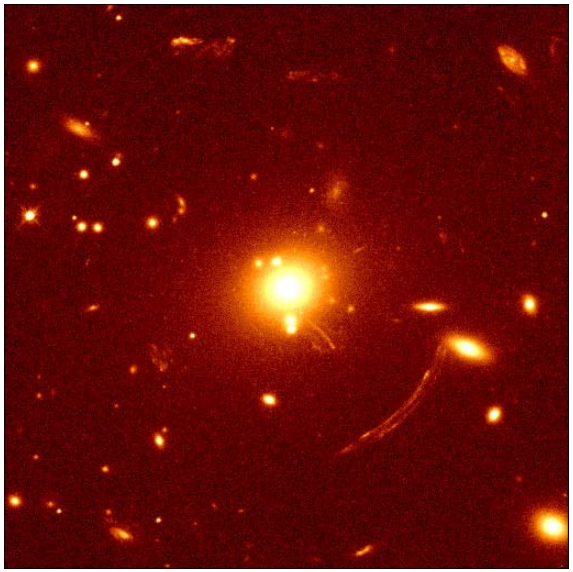
- Spectacular distortion of background galaxies to giant arcs or even rings.
- Well resolved and observable effect.
  $\Rightarrow$ No statistics necessary
- Takes place only near the cores of massive objects.
- No reconstruction of extended objects possible.

Some Lensing Pictures









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.

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

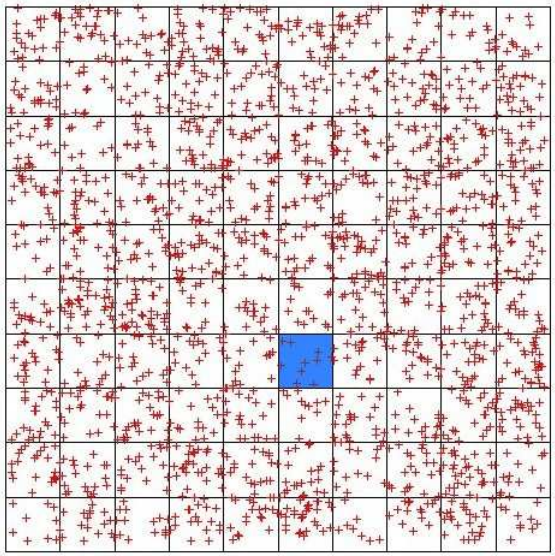
In our reconstruction method we try to combine the advantages of both lensing regimes into a joint method:

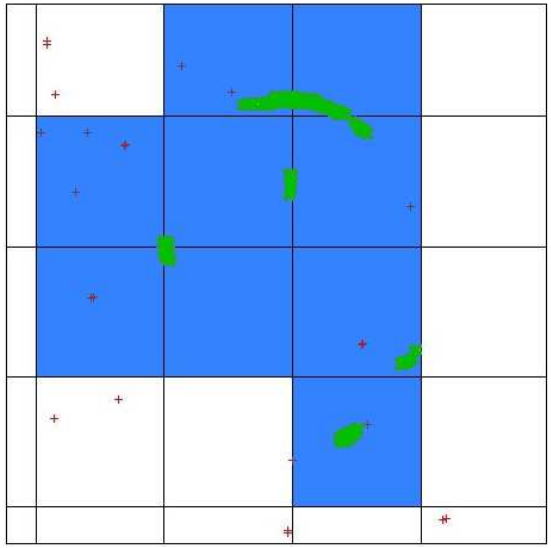
- Fully non-parametric, adaptive grid method using finite differences.
- Reconstruction quantity is the lensing potential ψ.
- Maximum-likelihood method. We are searching for that lensing potential which is most likely to have caused the observations:

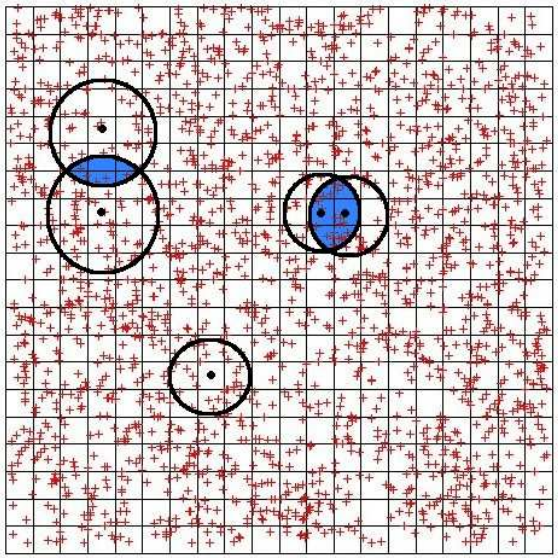
$$\chi^2(\psi) = \chi^2_w(\psi) + \chi^2_s(\psi)$$

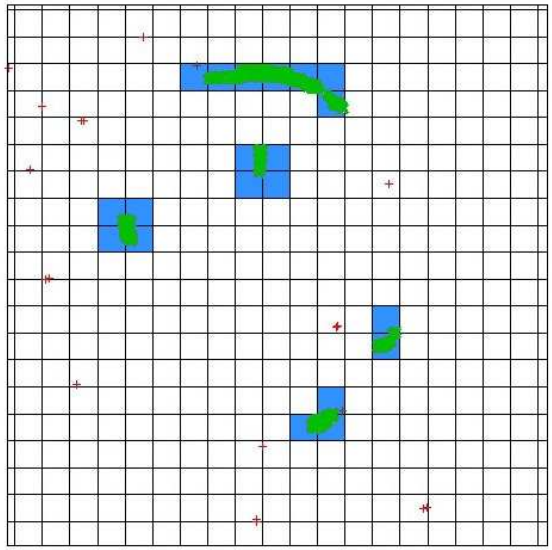
- Input data are:
  1. Ellipticity catalogue
  2. Arc positions
  3. Flexion catalogue (given a reliable measurement, work in progress)
  4. Multiple image positions (Bradač et al. 2005-08)
- χ^2-function is the minimised with respect to the potential on every grid position.

Two different kinds of Grids

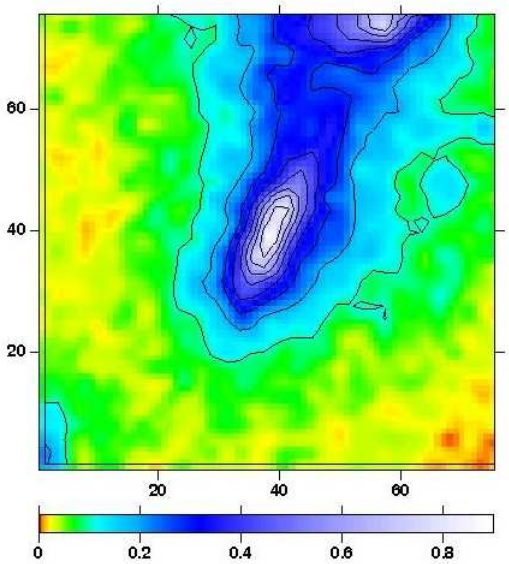


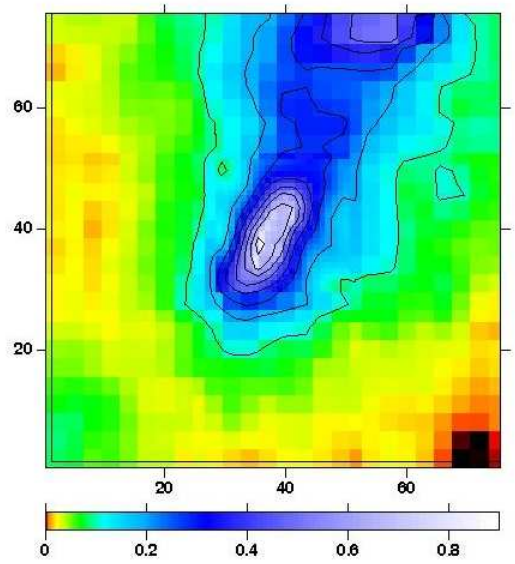


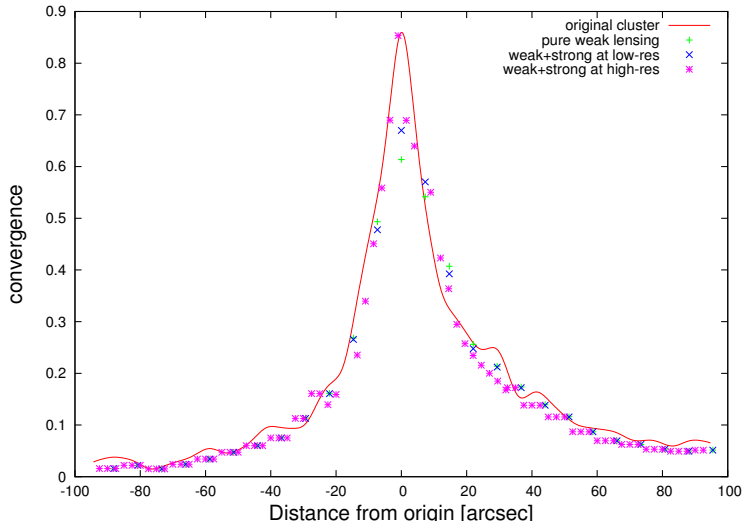




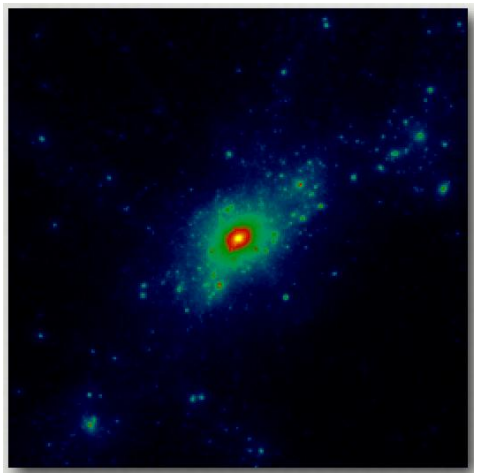
A Synthetic Test

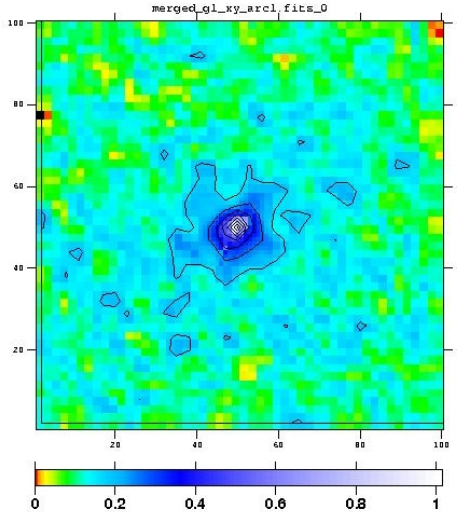


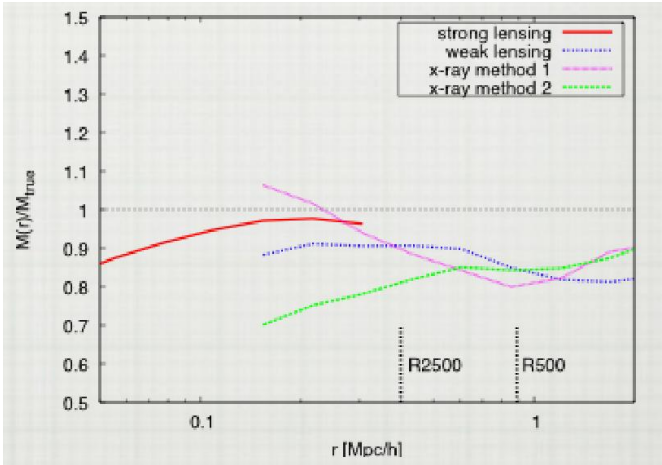


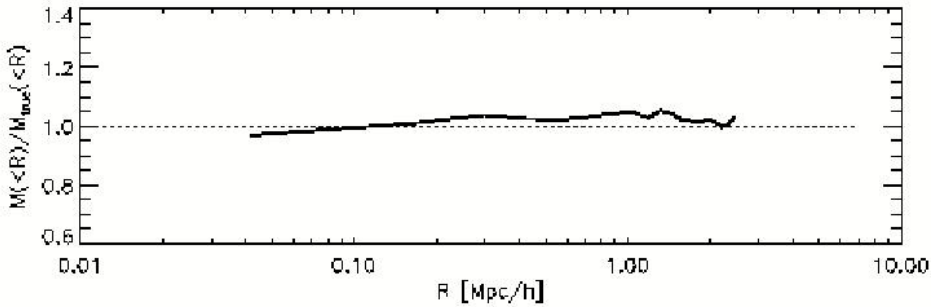


One Example of a Realistic Test



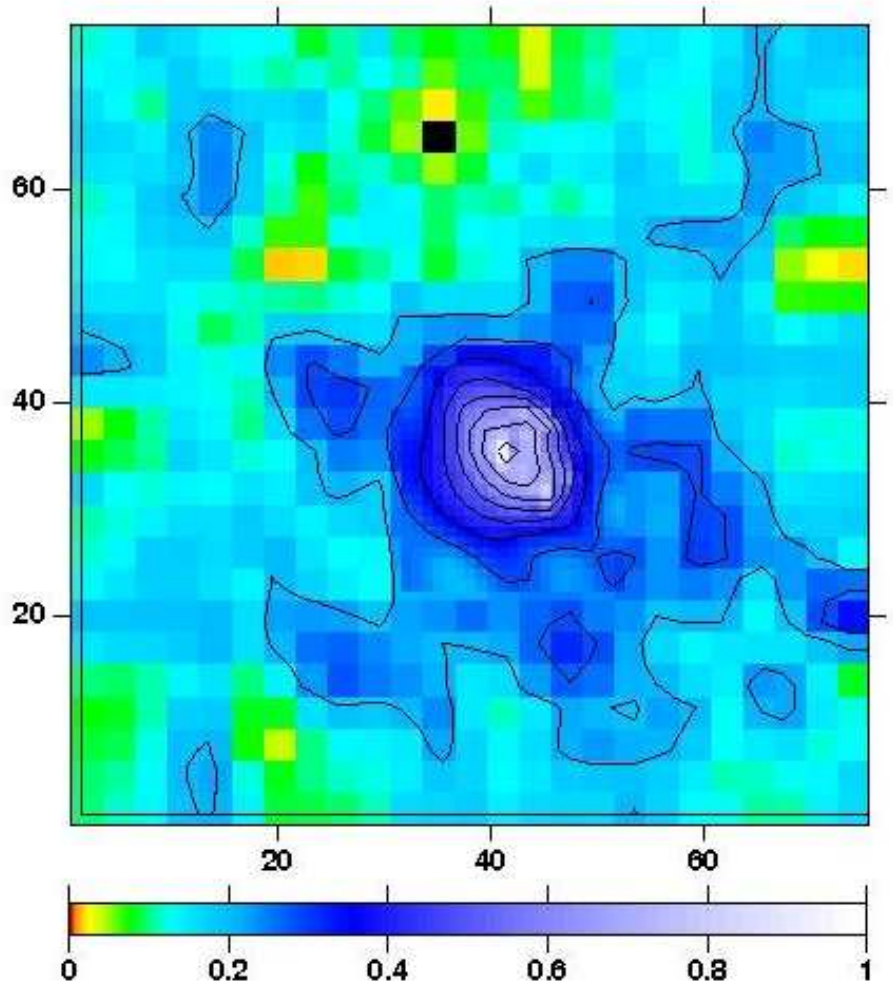






(Meneghetti, JM et al. in prep.)

MS 2137



Sorry for the missing total mass, but we wanted to be sure about the calibration (JM et al. in prep.).