# Particle Based Lensing (PBL)


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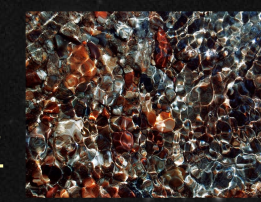
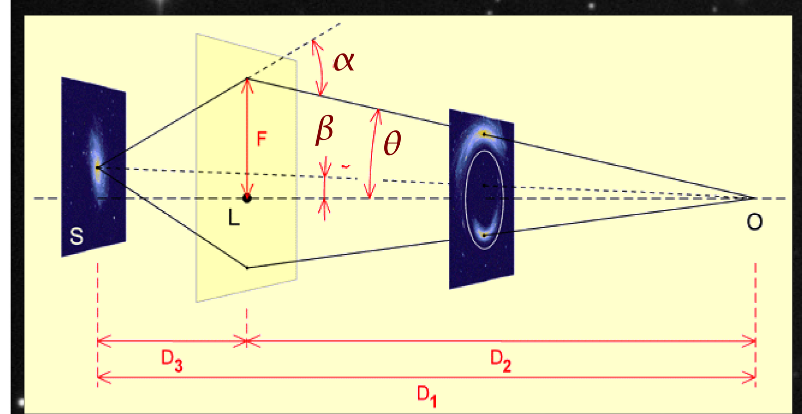


## Abstract


Combining weak and strong(W+S) lensing is becoming an important tool in mass measurements of clusters. Determining mass maps of clusters using W+S analysis can be challenging because of the difference in length scales associated with the different signals. Traditionally researchers have used grid based methods to reconstruct the density fields. In this poster we develop a particle based method that incorporates these two scales without the necessity of regularization. The accuracy of the method is determined by the smoothing scale used. We apply the particle based method to do mass reconstruction using ellipticities only. This can be easily generalized to include strong lensing information as well. There are also complexities with images in the semi strong or semi weak regimes which is resolved by smoothing the ellipticity function. We apply these techniques to a number of test cases and find excellent agreement between the reconstructed and input mass distribution.


## Introduction



Gravitational lensing is the bending of light rays from distant sources by intervening massive bodies.

Fig. 1: Lensing geometry

## Weak Lensing

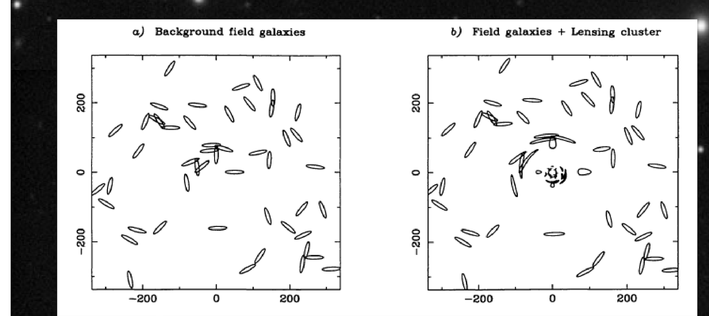


Fig. 2: Weak distortions of background galaxies by the lens.

Weak Lensing is the statistical distortion of background galaxies by foreground lens, like a galaxy cluster. Lensed galaxy images preferentially align tangentially to a lens, as illustrated in Fig. 2.

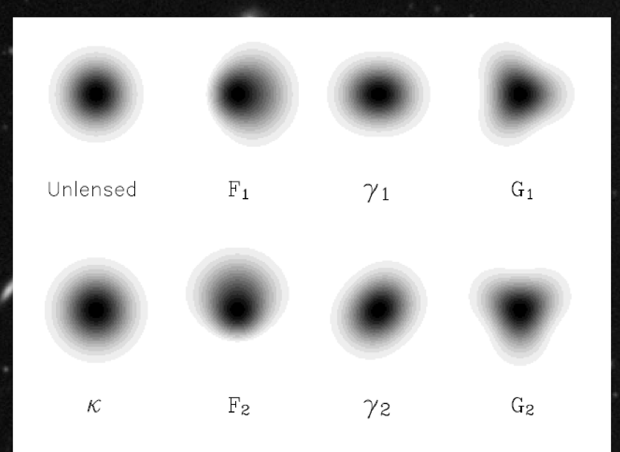
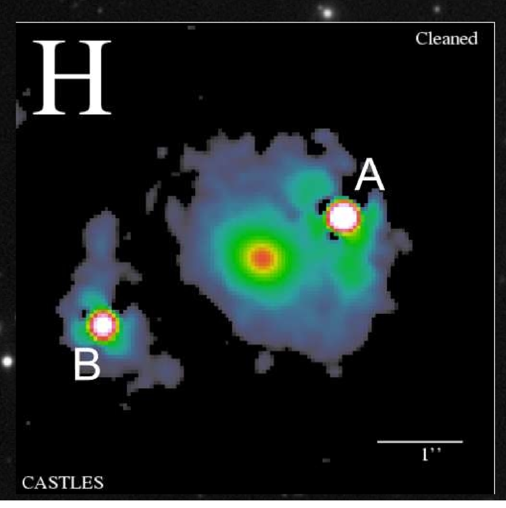


Fig. 3: Weak lensing distortions with increasing spin values. Here an unlensed Gaussian galaxy with radius 1 arcsec has been distorted with 10% convergence/shear, and 0.28 arcsec$^{-1}$ flexion.

## Strong Lensing: Parity



When a background source and the lens are very nearly aligned, the source may be multiply imaged.

Fig 4: Gravitational lens HE1104-1805 discovered by the Hamburg/ESO Survey. A and B are images of the quasar. In the center the lensing galaxy

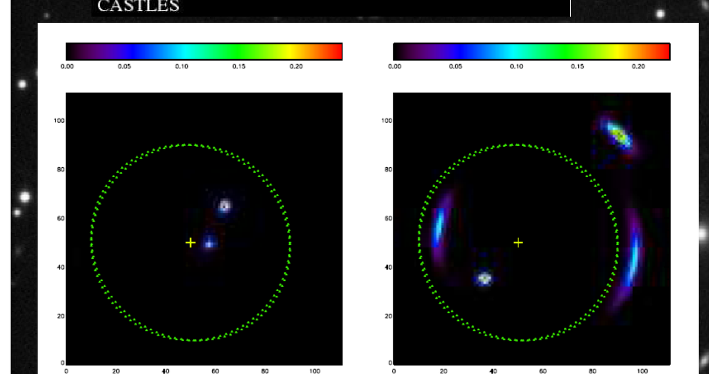
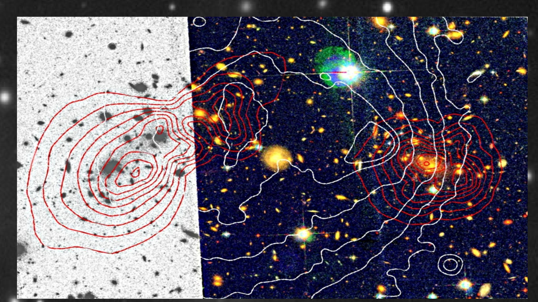


Fig 5: Multiple images are often formed such that one of the images get flipped or parity reversed. Unless there is some distinct structure visible in the source this parity reversal cannot be determined from the image.

## Weak+Strong Lensing



Recent studies of weak+strong lensing have produced some excellent results.

Fig. 6: Mass reconstruction of the "Bullet Cluster" by Bradac et al. 2006.

The mass reconstruction is done via a $\chi^2$ minimization process. Finite differencing methods are used for calculating derivatives.

Regularization

$$\chi^2 = \chi^2_W + \chi^2_S + \chi^2_R \quad (eq.\ 1)$$

| | | |
|---|---|---|
| | 1/2 (i-1,j) | |
| 1/2 (i,j-1) | -2 (i,j) | 1/2 (i,j+1) |
| | 1/2 (i+1,j) | |

Fig. 7: Finite Differencing Scheme between neighboring grid-cells

$$\chi^2_W = \sum_i \frac{\left(\frac{G_{ij}\psi_j}{1-\kappa_i^{(n-1)}} - \epsilon_i\right)^2}{\sigma_i^2}$$

$$\chi^2_S = \sum_{i,\ pairs} \frac{\left((\alpha^A(\{\psi\}) - \alpha^B(\{\psi\})) - (\theta^A - \theta^B)\right)^2}{\sigma_i^2}$$

Strong lensing occurs within a few arc-seconds of the lens center whereas weak lensing resolution is larger than ~30". Regularization schemes are used to smooth the result in weak regime and resolve the strong lensing structure. Though these methods have been very successful in reconstructing the cluster cores the choice of the regularization is arbitrary.

## More Information !!!

- Flux Ratios: $\frac{\mu_A^2 - \mu_B^2}{\mu_A^2 + \mu_B^2} = \frac{f_A^2 - f_B^2}{f_A^2 + f_B^2}$
- Ellipticity Differences: $\epsilon_a - \epsilon_b$

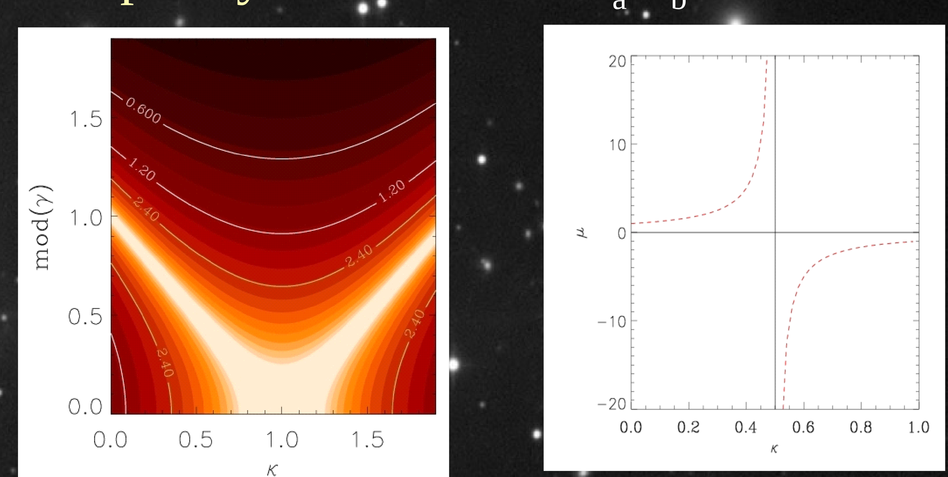


Fig. 8: The magnification as a function of shear and convergence. The right panel is a simple slice through the left, along the diagonal. derivatives are a continuous function. One of the images in a two image system will have negative parity. Thus, a solution to the potential field which is found using standard relaxation methods will not normally converge to a negative parity estimate for any magnification.

## Particle Based Lensing

We introduce a new method Particle Based Lensing (PBL, pronounced as "pebble") which combines the disparate scales of weak and strong lensing with the help of a smoothing scale $w_{mn}$. This is a variant of SPH in which the potential field is defined at the position of each lensed galaxy, $\{\psi_n\}$. In order to make the field as continuous as possible, we may expand the local potential field around that point to arbitrary order:

$$\psi(\theta) = \psi_n + \theta_j \psi_{n,j} + \frac{1}{2}\theta_j\theta_k\psi_{n,jk} + \ldots$$

$\psi_{n,i}$

$$\chi^2 = \sum (\psi_m - w_{mn}[\psi_n + A^i_{nl}\psi_l \Delta\theta_i^{nm} + \ldots])^2$$

This method replaces the finite differencing scheme. The beauty of PBL is that it does not require a regularization term in the $\chi^2$ expression of Eqn. 1. $w_{mn}$ can be set according to the signal to noise at each image which depends on the density of information and the type of constraint (weak or strong).

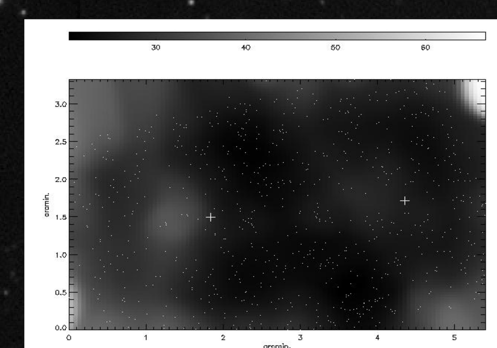


Fig. 9: A visualization of the weight function for the data in bullet cluster. The dots represent the image galaxies and the "+" represent the centers of the multiple images close to the two peaks.

## Interpolated Ellipticities

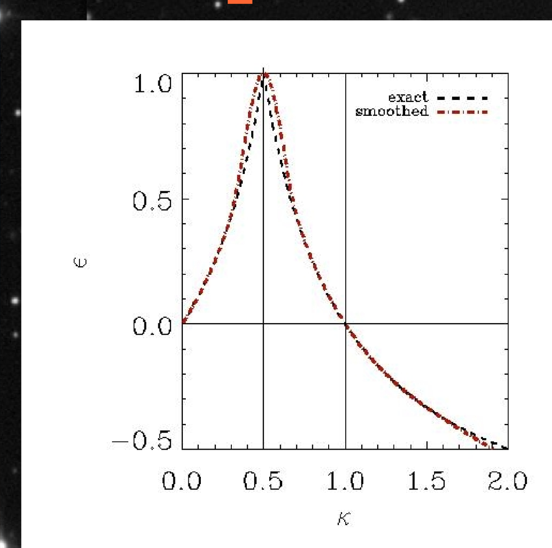


Fig. 10: Plot of the ellipticity vs κ. The red dashed line represents the interpolated ellipticities.

The ellipticities are defined by two different functions inside and outside the critical curve(cc). The functions are continuous at the cc's but their derivatives are not. This makes fitting to the ellipticity via a $\chi^2$ difficult. We have replaced this cuspy ellipticity function with a smooth function. This helps us to avoid getting stuck at a local minimum close to the global minimum

## Results

We implement PBL on a softened isothermal sphere and compare it with the grid based method.

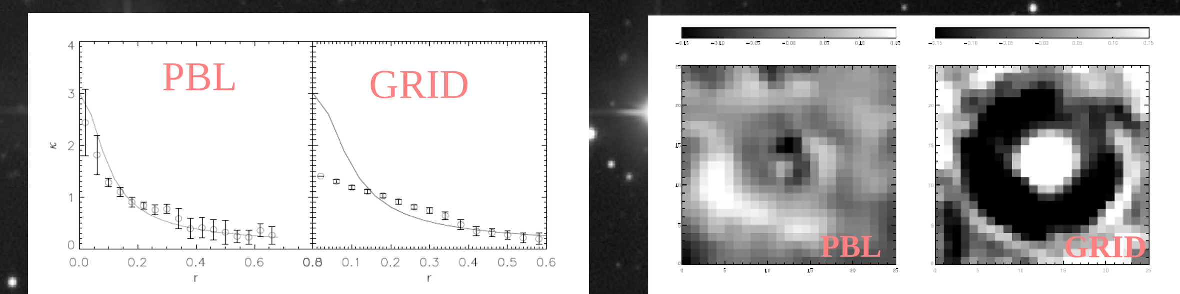


Fig. 11: Mass reconstruction of a softened isothermal sphere using "PBL" and grid based method( $\chi^2_{PBL} < \chi^2_{GRID}$ ). 600 background galaxies were lensed by a softened isothermal sphere. The data has been created by using the resulting ellipticities of the galaxies. Left panel is a radial plot of the mass profile and right panel is a difference map between the original mass map and the reconstructed mass map.

As an application to data, we have done the mass reconstruction of the bullet cluster using PBL. This is a weak lensing only mass reconstruction using data from Bradac et al. (2006; Clowe,private communication).

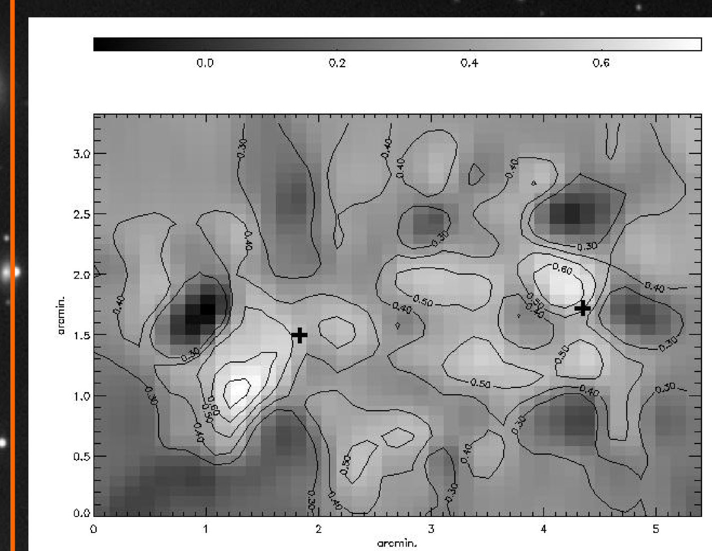


Fig. 12: A weak-lensing only reconstruction of the bullet cluster using PBL. This figure is a zoom into the inner few arcmins. of the cluster Note that both substructure peaks are identified.

## References


Bradac, M., Schneider, P., Lombardi, M.\& Erben, T., 2005, A&A437, 39

Bradac, M., Clowe, D., Gonzalez, A.H., Marshall, P., Forman W., Jones, C.,Markevitch, M., Randall, S., Schrabback, T., & Zaritsky, D. 2006, ApJ 652, 937

Cacciato, M., Bartelmann, M., Meneghetti, M.,& Moscardini, L.,2006, A\& A 458, 349

Diego, J.M., Protopapas, P., Sandvik, H.B. & Tegmark, M., 2005,MNRAS 360, 477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Website:http://www.physics.drexel.edu/~deb/PBL.htm