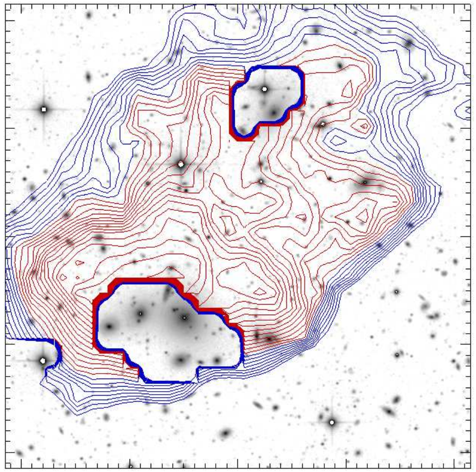
Heidelberg University

Zentrum für Astronomie

Cosmology with galaxy cluster counts in weak lensing surveys



Matteo Maturi

Angrick C., Pace F., Bartelmann M.

Overview

Cosmology and structure formation

Gravitational lensing: looking at dark matter

Detecting non-linear structures

An analytic approach to predict WL cluster counts

Do we really need clean sample of clusters for cosmology?

Cosmology and structure formation

You already know all about it....

Enlighting the dark: gravitational lensing

Eigentime

$$ds^2 = c^2 dt^2 - d\boldsymbol{x}^2$$

$$ds^2 = \left(1 + \frac{2U}{c^2}\right) c^2 dt^2 - \left(1 - \frac{2U}{c^2}\right) d\boldsymbol{x}^2 = 0$$

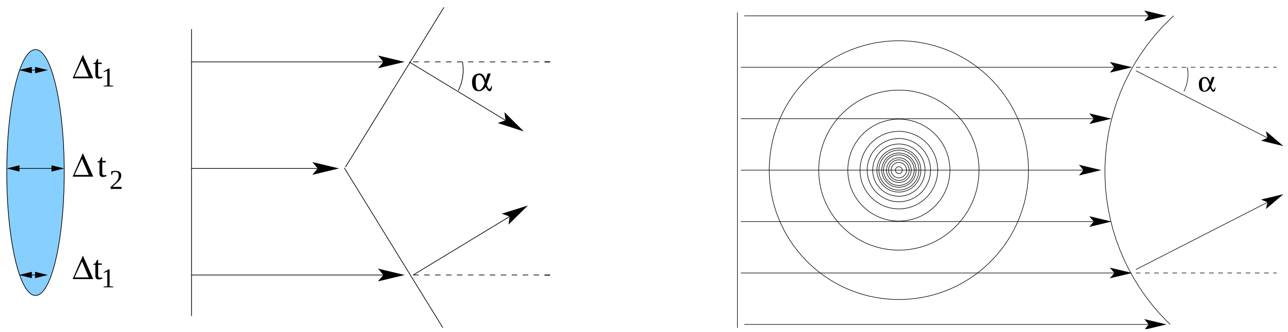
$$\left[v^2 = \frac{dx^2}{dt^2} \right]$$

Diffraction index

$$n \equiv \frac{c}{v} = 1 + \frac{2}{c^2}|\Phi| \geq 1 \qquad \Delta t = \int_o^s \frac{2}{c^3}|\Phi|\, dz$$

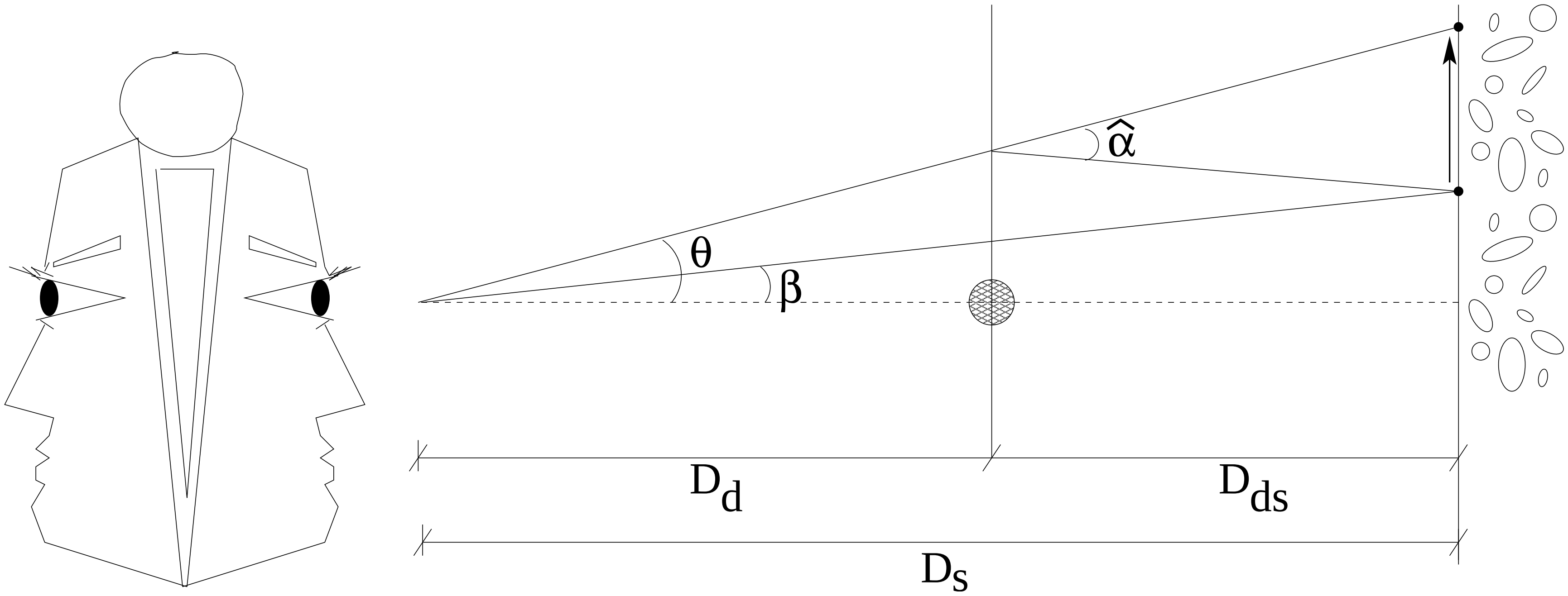
Deflection angle

$$\hat{\alpha} = -\int \nabla_\perp n\, dz = \frac{2}{c^2}\int \nabla_\perp \Phi\, dz$$



Avoid Barions as tracers of DM

Gravitational lensing



Lens equation

$$\boldsymbol{\beta}(\boldsymbol{\theta}) = \boldsymbol{\theta} - \frac{D_{ds}}{D_s}\boldsymbol{\alpha}(\theta) = \boldsymbol{\theta} - \widehat{\boldsymbol{\alpha}}(\theta)$$

Lensing quantities (first oreder)

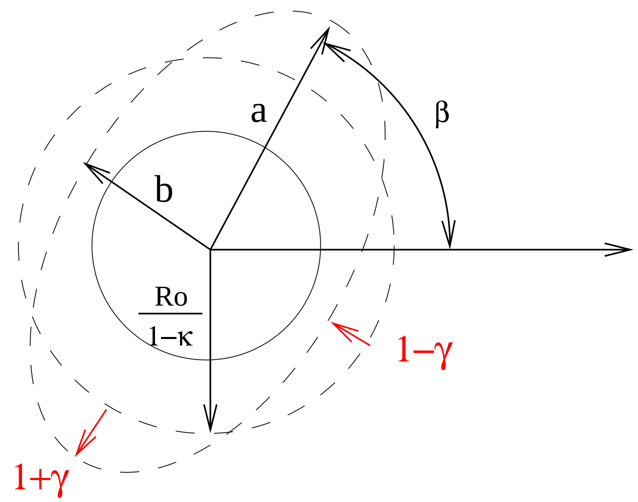
Linearized LE $$\boldsymbol{\beta}(\boldsymbol{\theta}) \simeq \boldsymbol{\beta}(\boldsymbol{\theta}_0) + A(\boldsymbol{\theta}_0)(\boldsymbol{\theta} - \boldsymbol{\theta}_0) \qquad (\alpha \ll 1)$$

Jacobian of the LE $$A \equiv \frac{\partial \boldsymbol{\beta}}{\partial \boldsymbol{\theta}} = (1-\kappa)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} - \begin{pmatrix} \gamma_1 & \gamma_2 \\ \gamma_2 & -\gamma_1 \end{pmatrix}$$

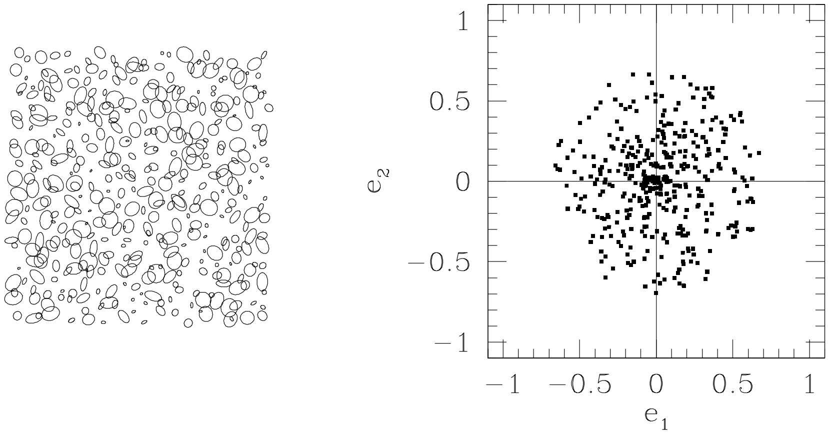
The convergence $$\kappa(\boldsymbol{\theta}) \equiv \frac{\Sigma(\boldsymbol{\theta})}{\Sigma_{cr}} \qquad \Sigma_{cr} \equiv \frac{c^2}{4\pi G}\frac{D_s}{D_d D_{ds}}$$

The shear $$\gamma = \gamma_1 + i\gamma_2 = |\gamma| e^{2i\phi}$$

The reduced shear $$g = \frac{\gamma}{1-\kappa}$$



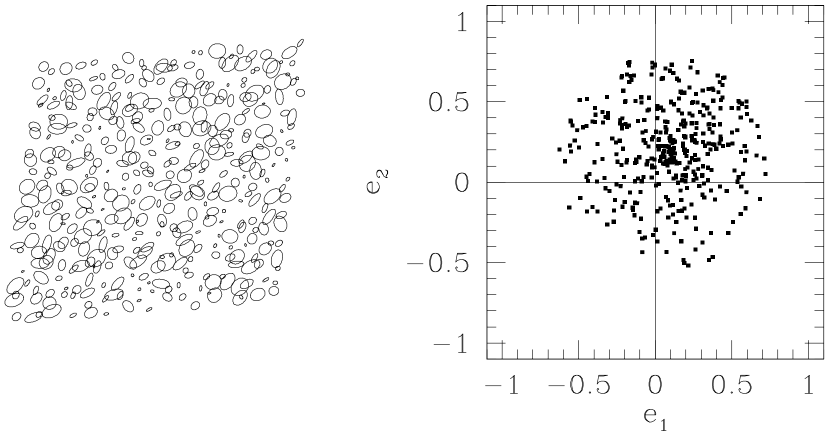
Weak Lensing on background galaxies



Distant galaxies $(z \sim 1 - 2)$

Typical size $r \sim 1'' - 10''$

Typical density $n \sim 10 - 100 \, \frac{gal}{arcmin^2}$

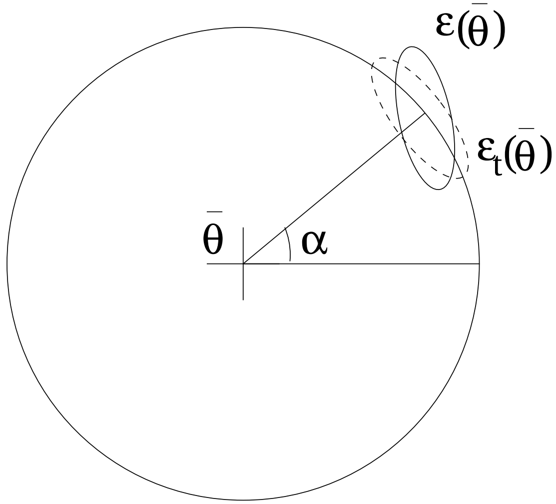


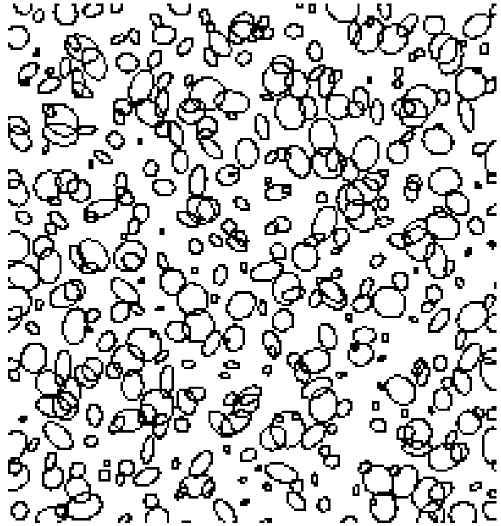
Distorted ellipticity $\epsilon = \dfrac{\epsilon^{(s)} + g}{1 + g^* \epsilon^{(s)}}$

Hypothesis: $\langle \epsilon^{(s)} \rangle = 0 \quad \rightarrow \quad \langle \epsilon \rangle = g$

Non linear structures: an optimal filter

$$M_{\rm ap}(\boldsymbol{\theta}) = \int d^2\theta' \, \gamma_t(\boldsymbol{\theta}')Q(\boldsymbol{\theta} - \boldsymbol{\theta}')$$





Data $D(\boldsymbol{\theta}) = A\tau(\boldsymbol{\theta}) + N(\boldsymbol{\theta})$

Estimate $A_{\rm est}(\boldsymbol{\theta}) = \int D(\boldsymbol{\theta}')\Psi(\boldsymbol{\theta} - \boldsymbol{\theta}')\, d^2\theta'$

$\Downarrow$

Bias to vanish $b \equiv \langle A_{\rm est} - A \rangle$

Variance to be minimal $\sigma^2 \equiv \left\langle (A_{\rm est} - A)^2 \right\rangle$

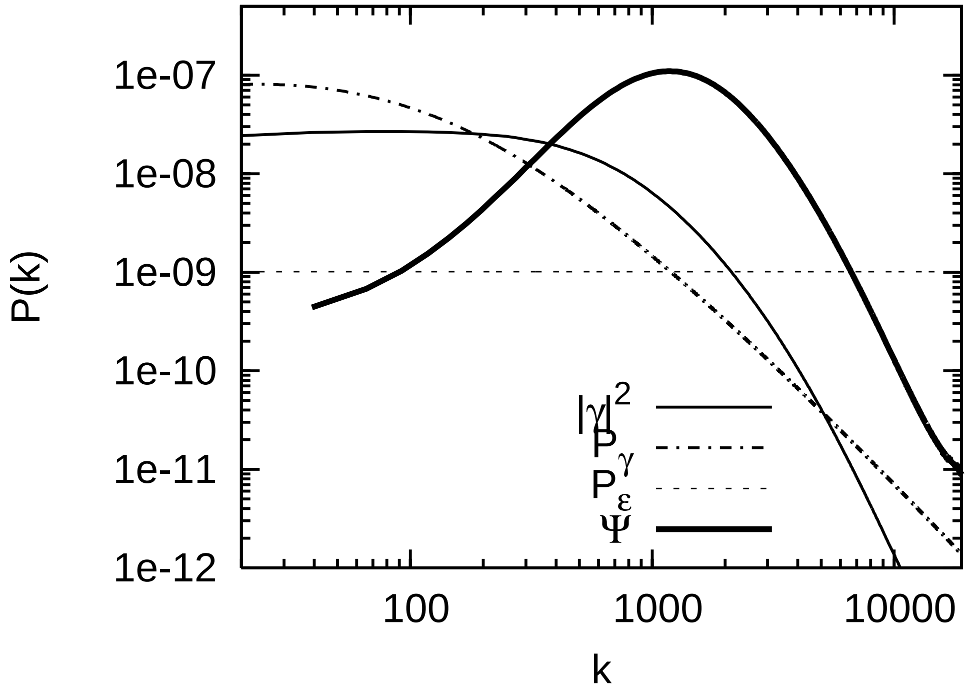
$\Rightarrow$

Optimal matched filter

$$\hat{\Psi}(\boldsymbol{k}) \propto \frac{\hat{\tau}(\boldsymbol{k})}{P_N(k)}$$

Maturi et al. 2005

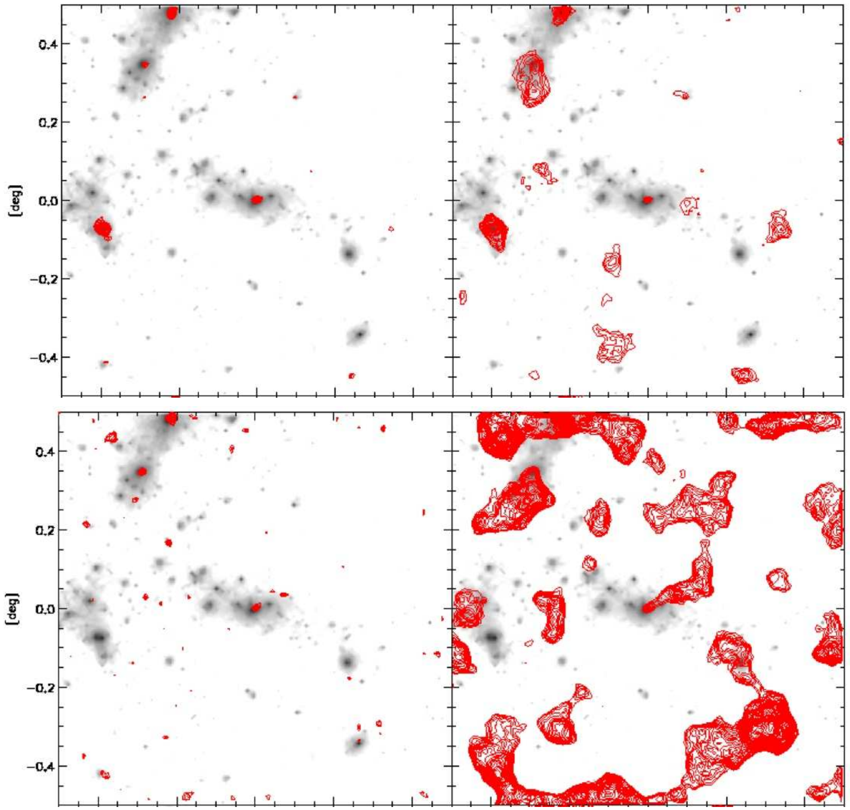
How does it work?



$$\hat{\Psi}(\boldsymbol{k}) \propto \frac{\tau(\boldsymbol{k})}{P(k)}$$

Maturi et al. 2005

An example of application



Optimal filter Aperture mass

Gray background image: Convergence of one cube

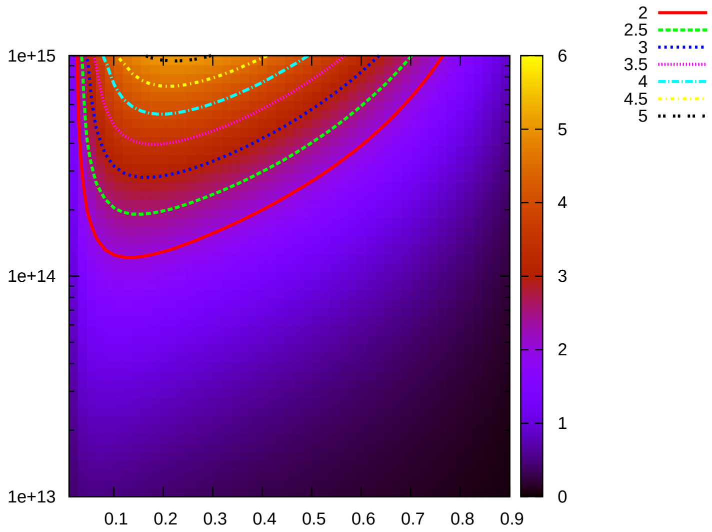
Red Isocontours:

- left: optimal filter
- right: aperture mass, Schneider (1996)

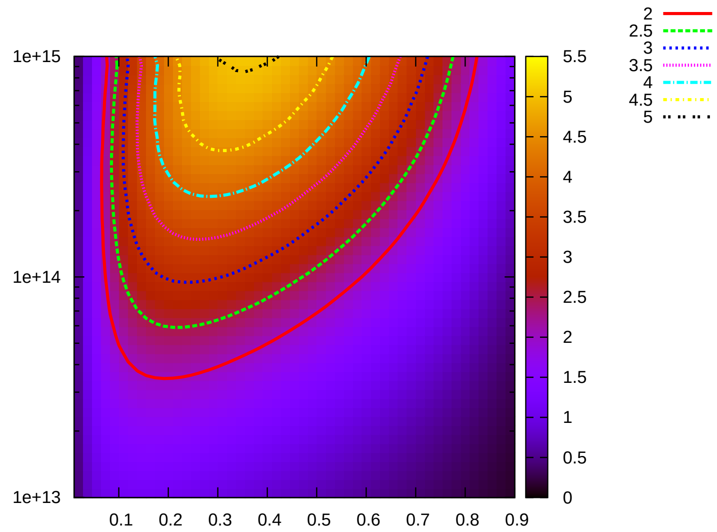
Upper (bottom) panels: redshift $z = 1$ ($z = 2$)

Maturi et al. 2005

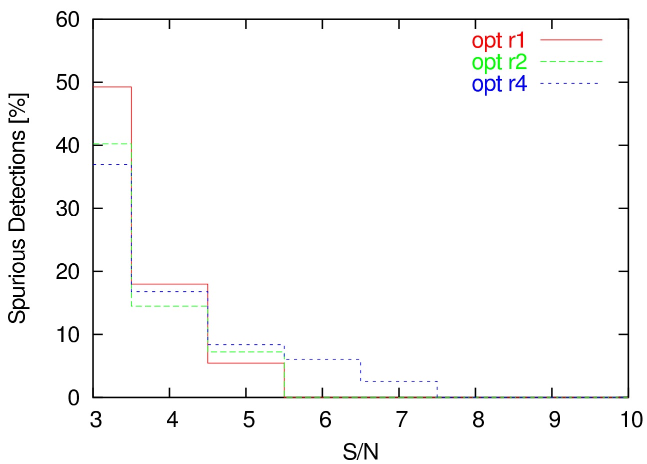
More quantitatively... selection function

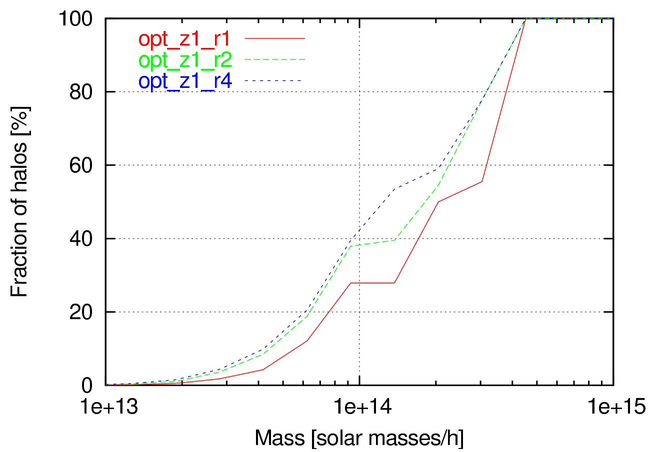


NFW filter



NFW optimal filter





Pace et al. 2007

With this approach...

...we can find clusters

- Create a clusters sample with a different selection criteria (with respect to optical, X-rays)
- Enlarge the cluster sample (not only for cosmology)
- Study the clusters mass function $\longrightarrow$ cosmology

But...

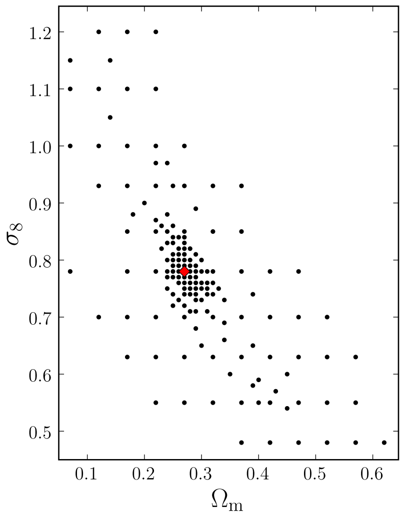
- ...we have to measure the clusters mass (and possibly redshift)
- ...what about the sample contamination?

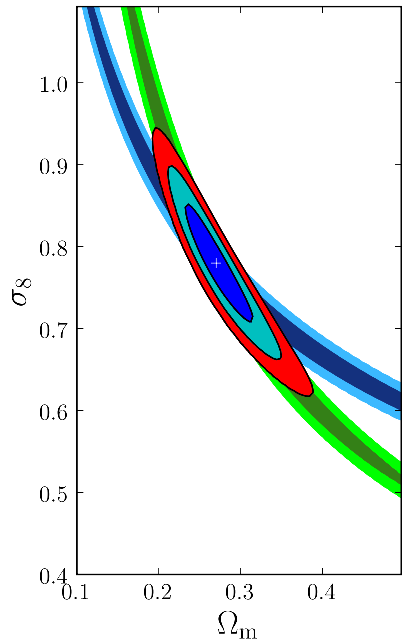
Let's rather use a statistical approach

- instead of distinguisching clusters from the rest, lets just count all detections
- instead of measuring masses (difficult) let's measure S/N

Cosmological constraints from weak lensing peak counts

- 128 Numerical simulations (ΛCDM) with different σ_8 and Ω_m
- Counted weak lensing detections with $S/N > 3.5$
- Cosmological constraints





Dietrich & Artlap (2009)

Lensing signal as a Gaussian random field

- LSS and noise (filtered) are well represented by a Gaussian random field with power spectrum:
$P(k) = P_{LSS}(k) + P_{noise}(k)$

- Joint probability distribution of the 2D gaussian random field
(Bardeen et al. 1986, Van Waerbeke, 2000)

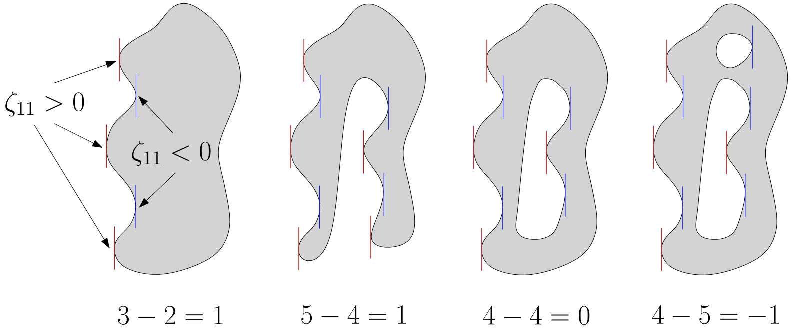
$$\mathcal{P}(y_1, \ldots, y_\mathrm{p})\, \mathrm{d}y_1 \cdots \mathrm{d}y_\mathrm{p} = \frac{1}{\sqrt{(2\pi)^p \det(\mathcal{M})}} \mathrm{e}^{-Q}\, \mathrm{d}y_1 \cdots \mathrm{d}y_\mathrm{p}$$

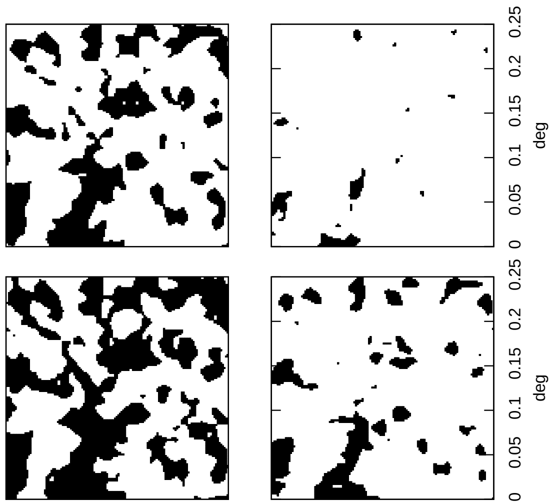
where $Q := \frac{1}{2} \sum_{\mathrm{i,j}=1}^{p} \Delta y_\mathrm{i} \left(\mathcal{M}^{-1}\right)_\mathrm{ij} \Delta y_\mathrm{j}$, $\mathcal{M}_{ij} := \langle \Delta y_i \Delta y_j \rangle$

and $\boldsymbol{y} = (\kappa, \eta_i, \eta_2, \xi_{11})$

- $\mathcal{M}$ Contains the spectral moments
$\sigma_j^2 = \int \frac{k^{2j+1}\,\mathrm{d}k}{2\pi} P(k) \hat{W}^2(k) |\hat{Q}(k)|^2$

Detections definition: the deblended up-crossing criteria





- The upcrossing criteria: count all points with $F(\boldsymbol{r}_{\rm up}) = \kappa_{\rm th}\ , \quad \eta_1(\boldsymbol{r}_{\rm up}) = 0\ , \quad \eta_2(\boldsymbol{r}_{\rm up}) > 0\ .$
- Number density of detection given by

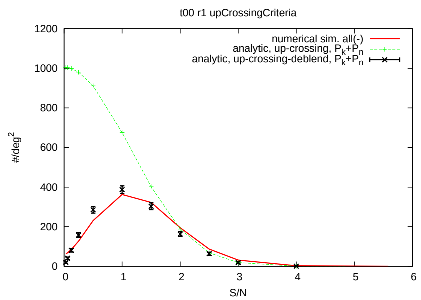
$n_{\rm det}(\kappa_{\rm th}) = n_{\rm pos}(\kappa_{\rm th}) - n_{\rm neg}(\kappa_{\rm th})$ with

$$n_{\rm pos}(\kappa_{\rm th}) = \int_0^\infty d\eta_2 \int_0^\infty d\zeta_{11} |\eta_2 \zeta_{11}| p(\kappa = \kappa_{\rm th}, \eta_1 = 0, \eta_2, \zeta_{11})$$

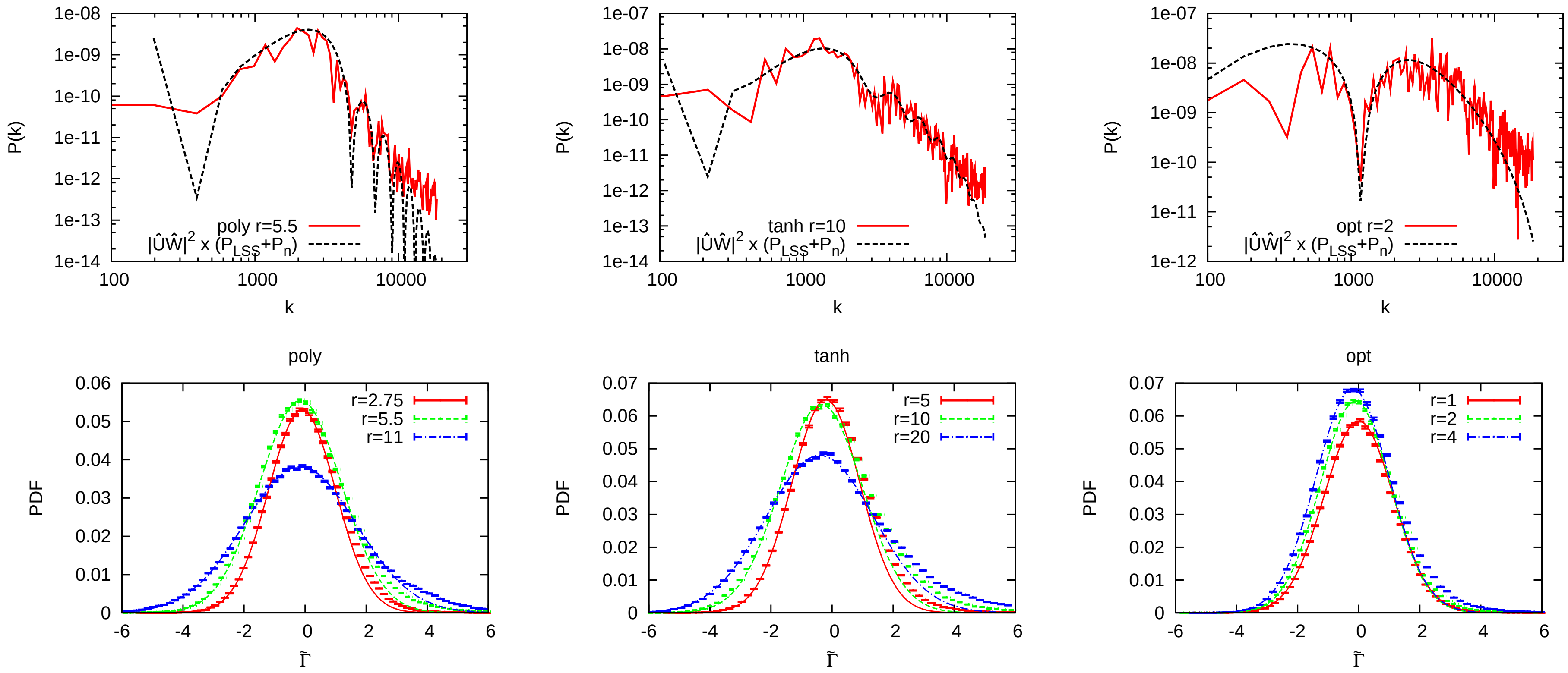
The resulting number of detections:

$$n_{\rm det}(\kappa_{\rm th}) = \frac{1}{4\sqrt{2}\,\pi^{3/2}} \left(\frac{\sigma_1}{\sigma_0}\right)^2 \frac{\kappa_{\rm th}}{\sigma_0} \exp\left(-\frac{\kappa_{\rm th}^2}{2\sigma_0^2}\right)$$

Maturi et al. 2009



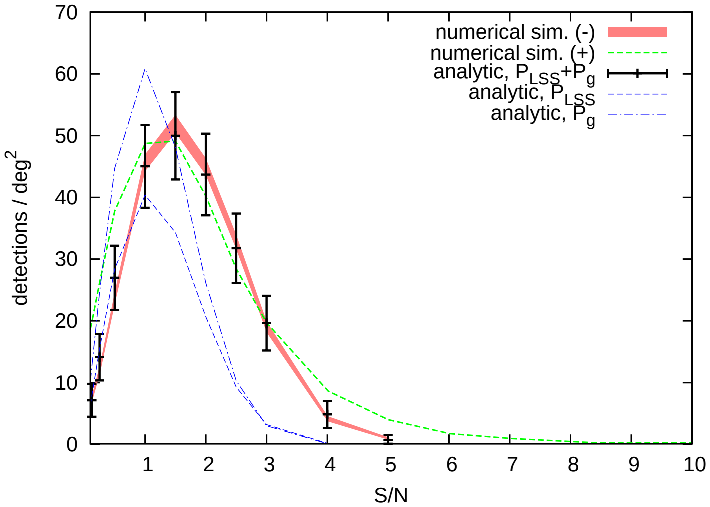
How good is our approximation?

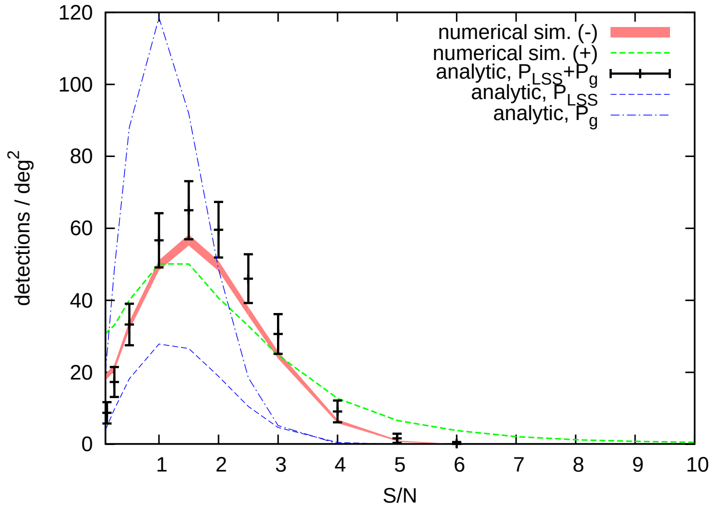


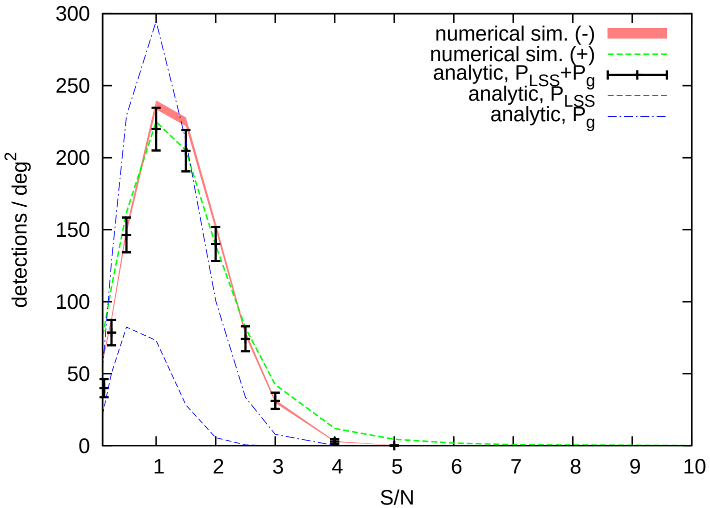
The negative end is Gaussian

The positive end has an extended tail because of non-linear structures

Comparison with num. Simulations

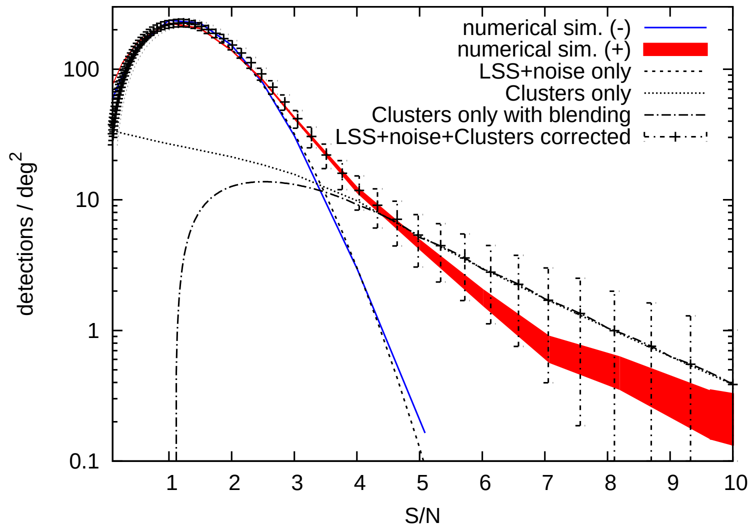






Maturi et al. 2009

Adding galaxy clusters



Prediction for:

- Noise peaks, Large Scale Structures (linear), Galaxy clusters (non-linear)
- Convinient to know what is in your WL cluster catalogues

Compare theory with real observables:

- No mass estimates are necessary
- No problem with contamination (LSS are part of the signal)
- We relate theory to Signa-to-noise ratios

Conclusions

Searching for DM haloes? Use an optimized filter:

- To maximize sensitivity
- To minimize LSS contamination

$\Rightarrow$ Obtain better calaogues

+ There is a Simple recipy to know what is in your WL sample

Do we really need to identify clusters for cosmology?

- It would be good but it is not necessar
- Instead, we could study the statisticas of S/N maps (which contain clusters)
- We can use a S/N function instead of a mass function
- The S/N function, i.e. the number of lensing detections, can be evaluated with our model.

. *Optimal filter: Maturi et al. 2005*

Numerical simulations: Pace et al. 2007

Analytic method: Maturi et al. 2009