Mapping Dark Matter

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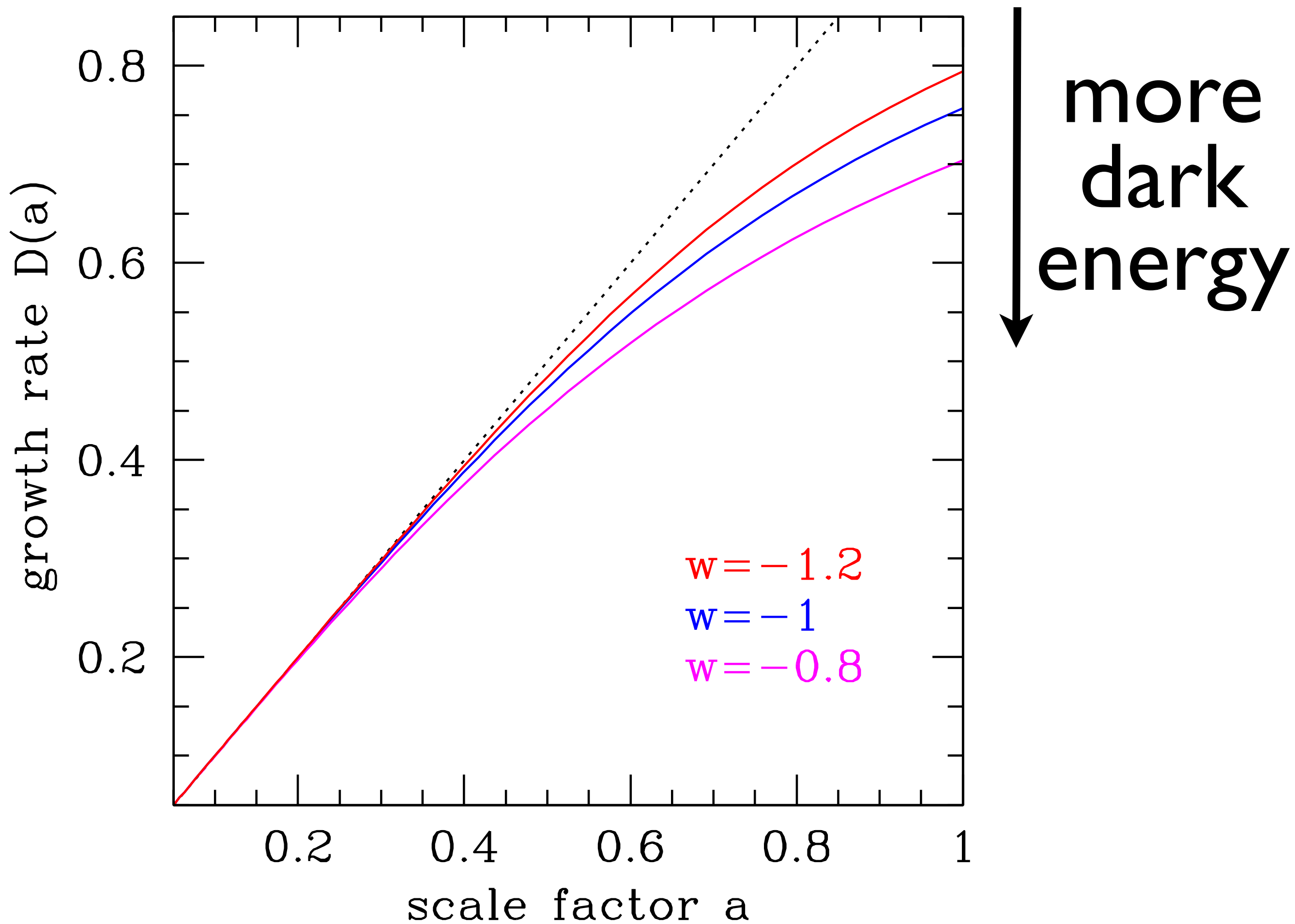
2015/9/20 Why does the Universe accelerate? @ Kavli IPMU

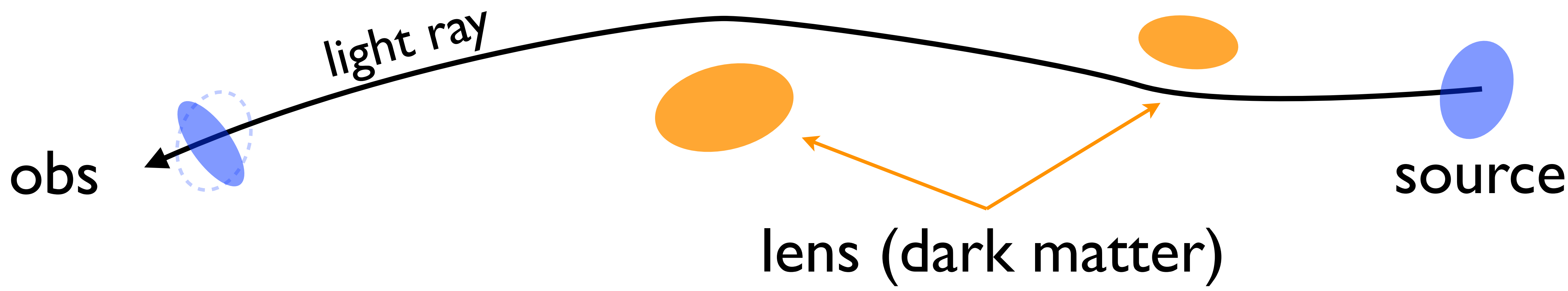
Accelerating Universe

- dark energy suppresses the growth of density fluctuations
- time evolution of dark matter dist. tells us how the Universe is accelerating



growth rate of density fluctuations

Weak gravitational lensing



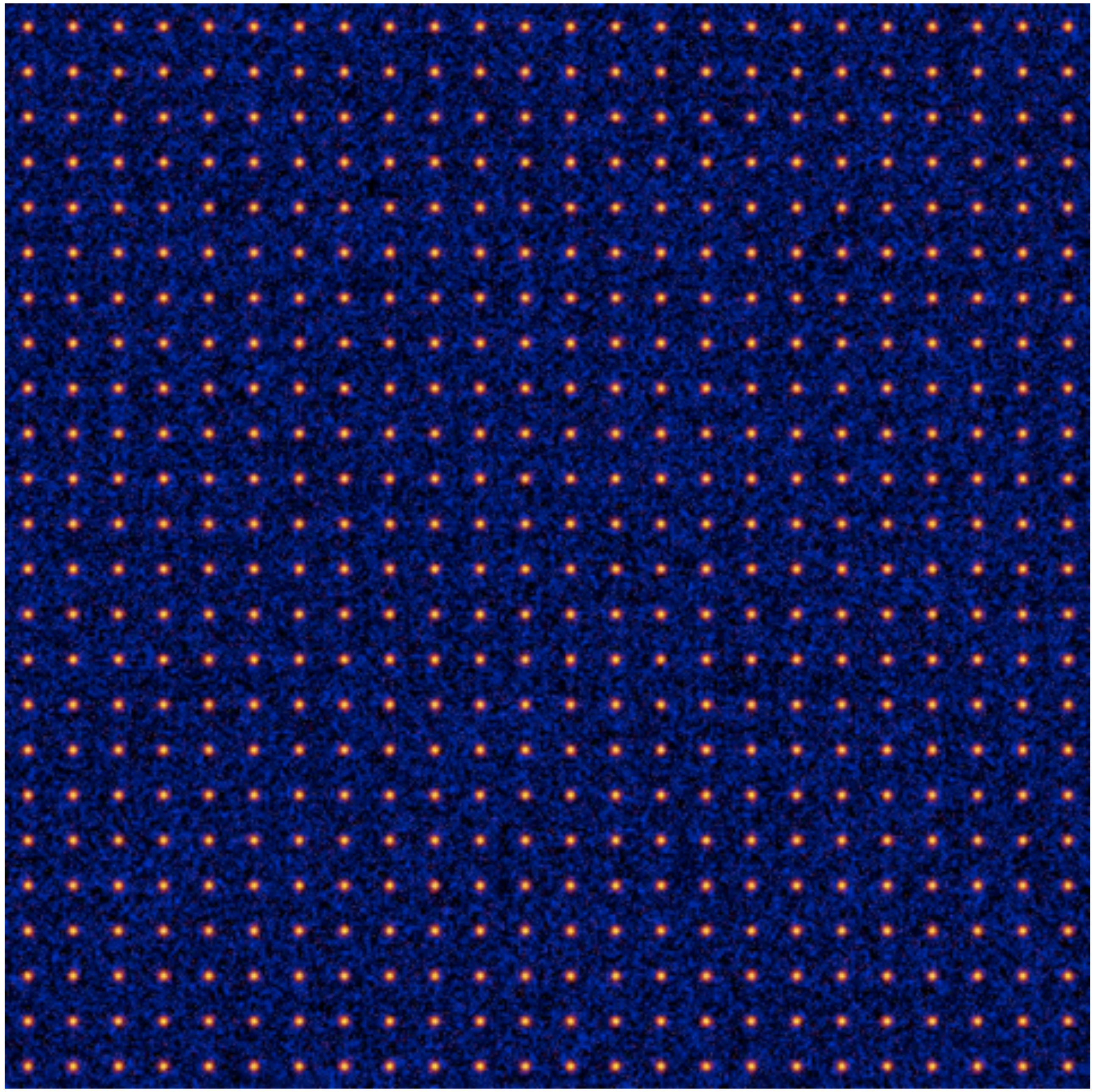
lens potential $$\phi = \int d\chi W(\chi)\Phi$$

deflection $$\alpha_i = \partial_i \phi$$

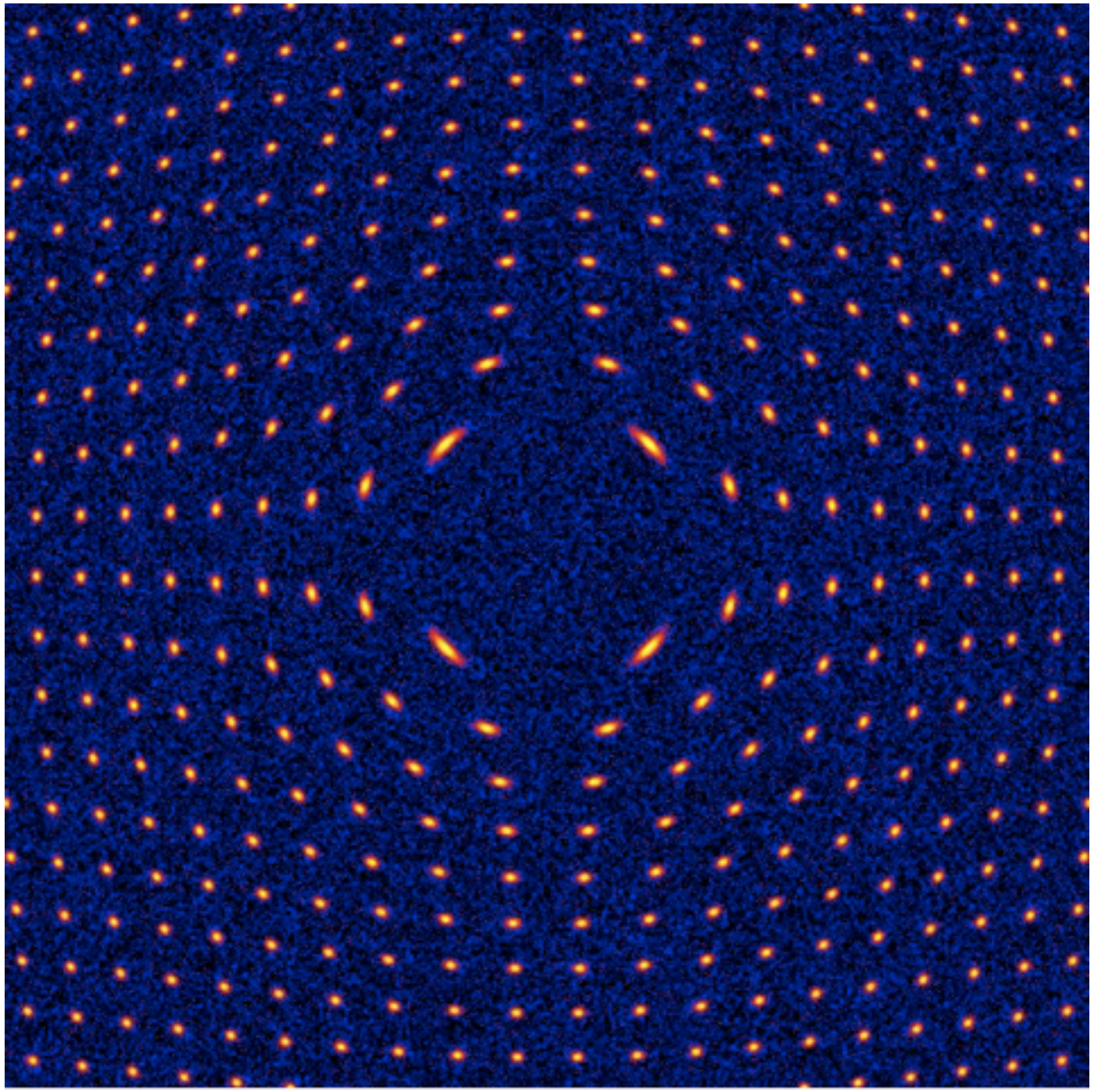
shape distortion $$\delta_{ij} - \partial_j \alpha_i = \delta_{ij} - \underline{\partial_i \partial_j \phi}$$

simulated by *glafic*

Lensing effect on galaxies

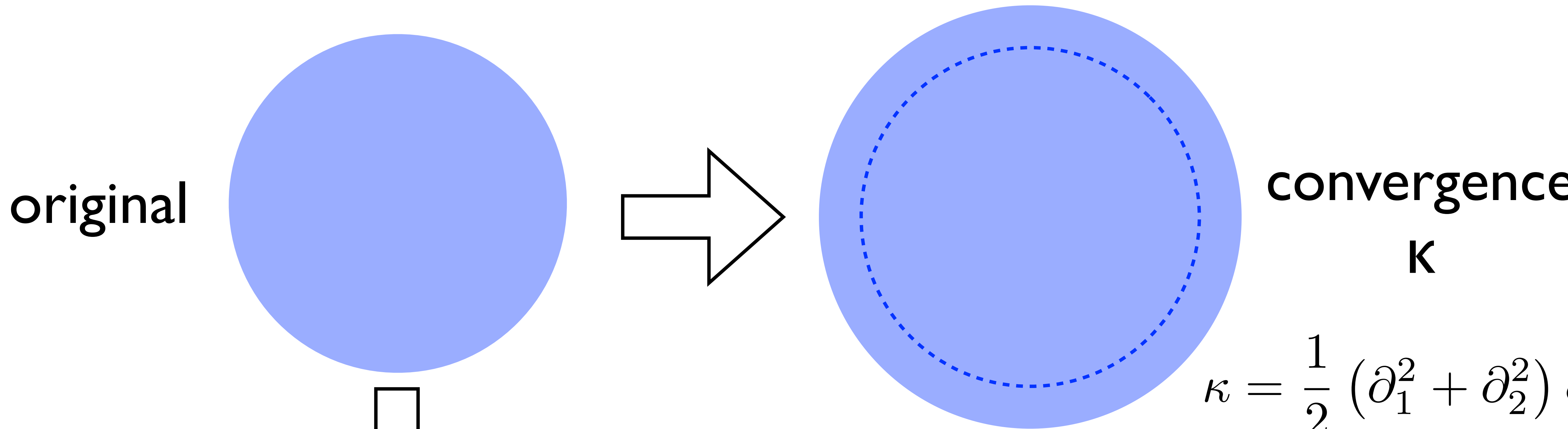


no lensing

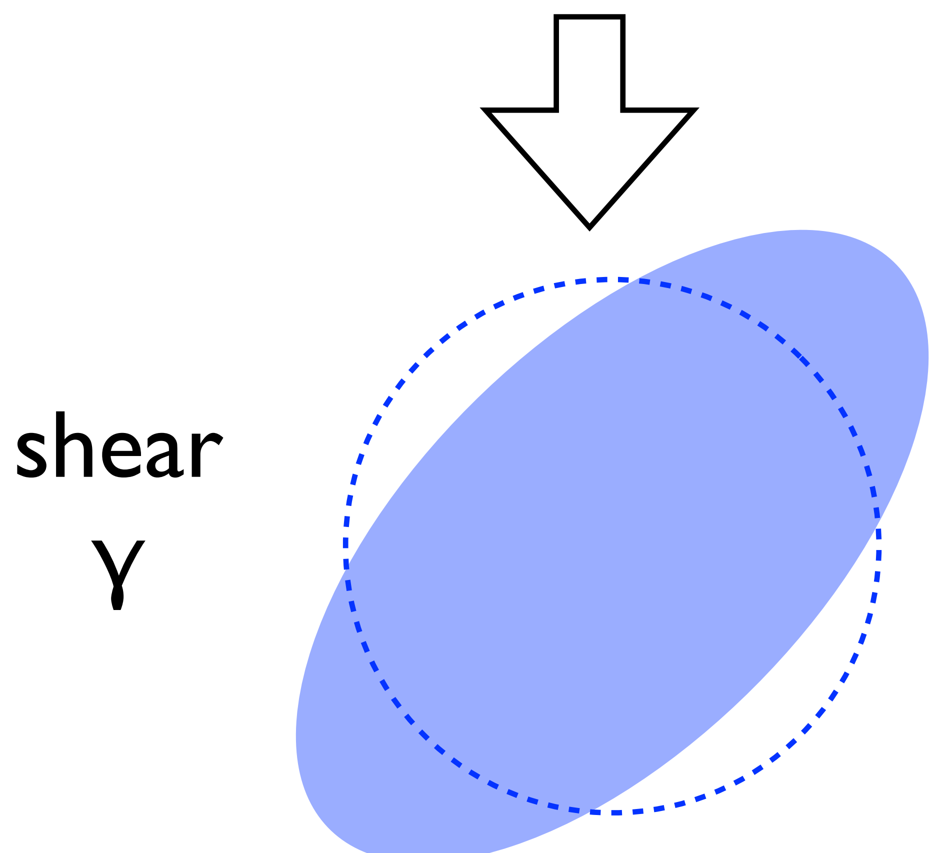


lens potential at the center

Convergence and shear



$$\kappa = \frac{1}{2}\left(\partial_1^2 + \partial_2^2\right)\phi$$



$$\gamma_1 = \frac{1}{2}\left(\partial_1^2 - \partial_2^2\right)\phi \quad \gamma_2 = \partial_1\partial_2\phi$$

- κ is related to mass dist. via Poisson eq.

$$\kappa \propto \int d\chi W(\chi)\rho$$

- we observe γ by averaging many galaxies' shapes

Mass reconstruction

- both κ and γ are second derivatives of ϕ, so their relation is simple in Fourier space

$$\tilde{\kappa}(\boldsymbol{\ell}) = e^{-2i\psi}\tilde{\gamma}(\boldsymbol{\ell})$$

- suggests that κ and γ are related to each other by convolution in real space (γ is non-local)

$$\kappa(\boldsymbol{\theta}) = \int d\boldsymbol{\theta}' D^*(\boldsymbol{\theta} - \boldsymbol{\theta}')\gamma(\boldsymbol{\theta}')$$

- need filtering to suppress shot noise

HSC survey

- ~20% of observations completed

  (talk by Satoshi Miyazaki)

- analysis ongoing....

- mass map for ~25 deg^2 HSC wide patch

E-mode and B-mode

Mass selected cluster sample

- from mass map we can select massive clusters of galaxies (using purely gravitational effect)
- this is totally different from traditional cluster finding using member galaxies, X-ray, SZ
- HSC survey will be the first survey to provide a significant number of mass-selected clusters

  (e.g., Miyazaki, Oguri, et al. 2015, ApJ, 807, 22)

HSC mass reconstruction to-do's

- HSC data look great and preliminary analysis has shown promising results!
- more tests on shape measurements
  - try multiple methods, various systematics tests (star-galaxy cross-correlation, ...), quantify the accuracy with image simulations

    (w/ HSC WL working group)
- check effects of source galaxy clustering
- mock catalogs from all-sky ray-tracing sims

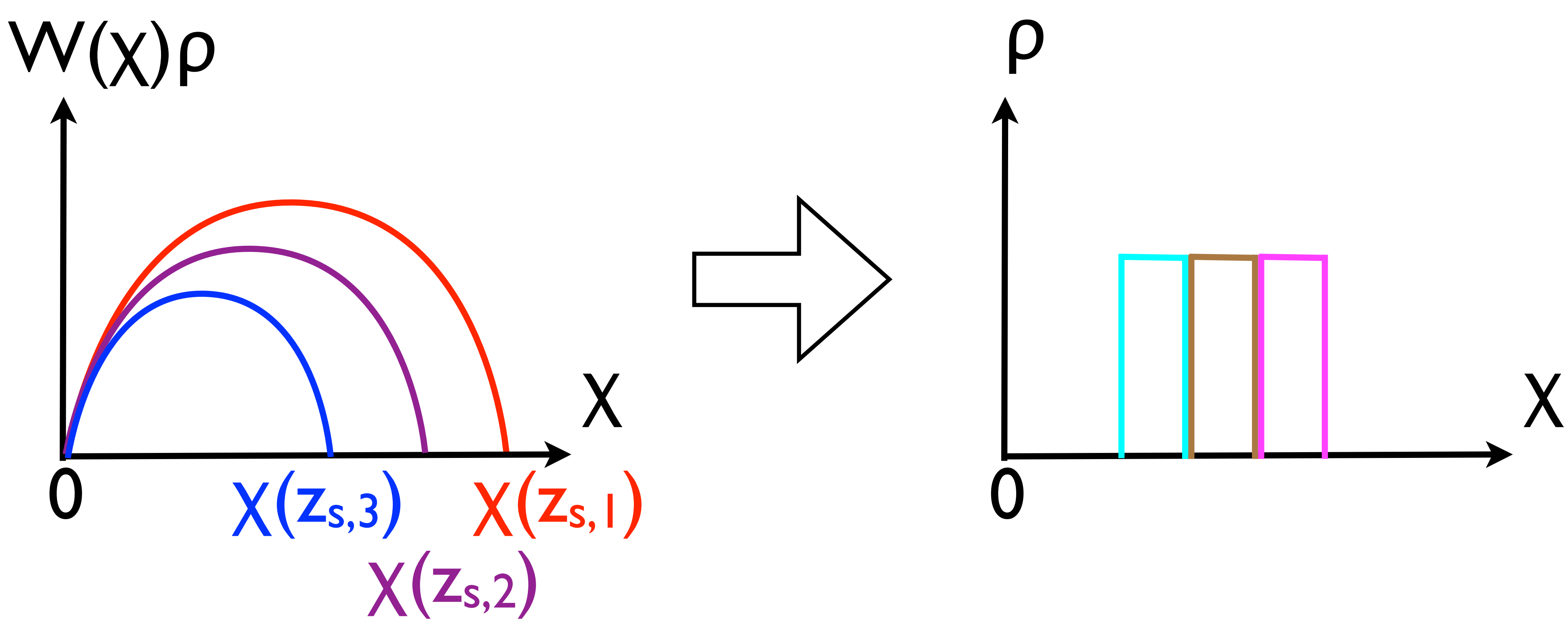
  (w/ F. Irie, N. Katayama, T. Hamana, et al.)

3D mass reconstruction

- weak lensing probe projected mass distribution

$$\kappa \propto \int d\chi W(\chi)\rho$$

- source galaxies at different redshifts probe different lens redshift range
  → 3D mass reconstruction possible



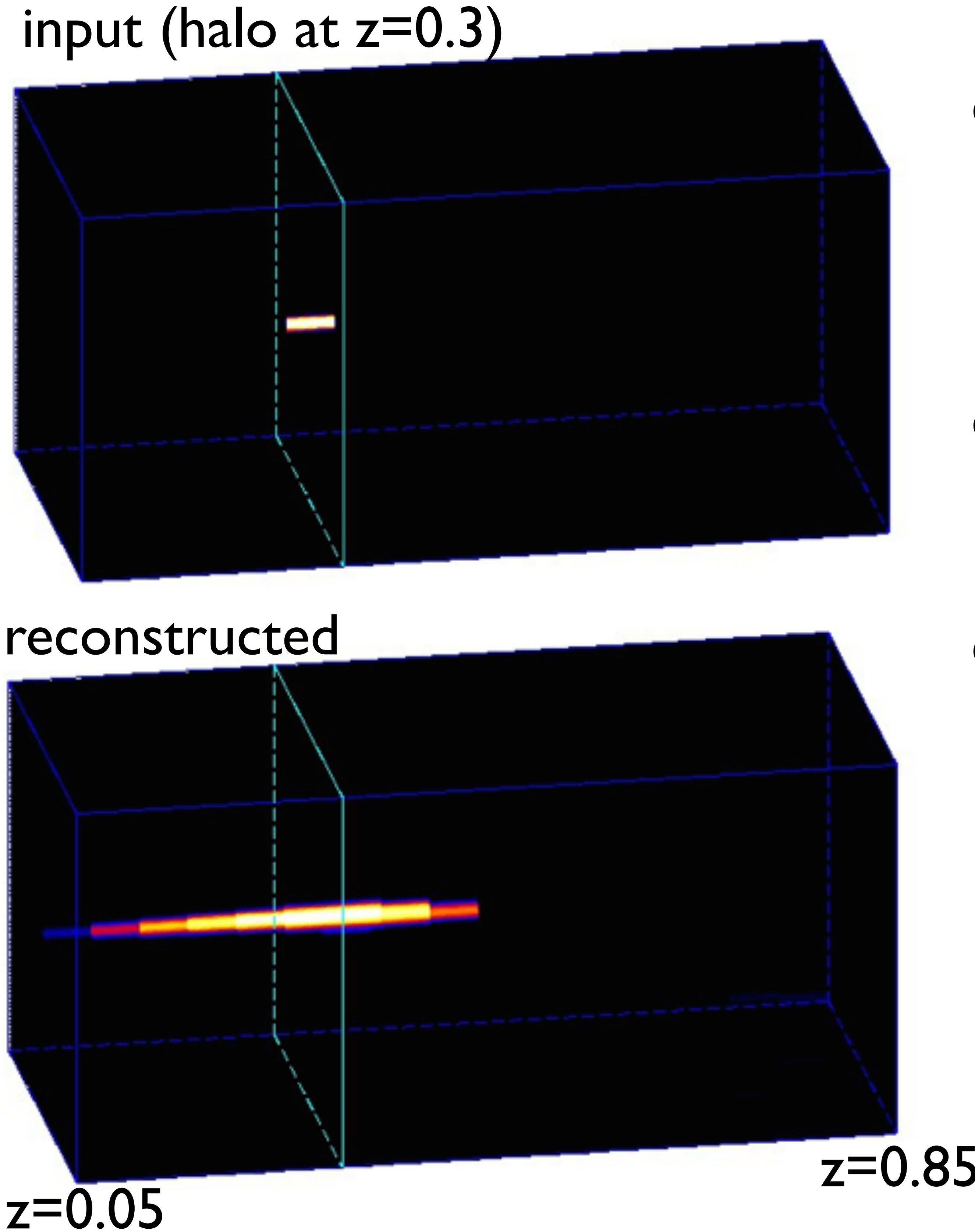
3D mass reconstruction method

- essentially it is a linear inversion problem

$$\kappa(\boldsymbol{\theta}, z_{s,i}) = \sum_j R(z_{s,i}, z_{l,j})\rho(\boldsymbol{\theta}, z_{l,j}) \quad \Rightarrow \quad \rho(\boldsymbol{\theta}, z_{l,j}) = \sum_i \left[R^{-1}\right]_{ij} \kappa(\boldsymbol{\theta}, z_{s,i})$$

- 3D mass reconstruction is very noisy, thus needs efficient filtering using e.g., Wiener filter
  (e.g., Hu & Keeton 2003)

Test example



- 3D reconstruction w/ transverse Wiener filter (e.g., Simon et al. 2009)
- recover position and redshift of input halo
- smearing in radial direction

HSC (very preliminary)

Challenges in 3D mass map

- accurate photo-z's
  (talk by Masayuki Tanaka)

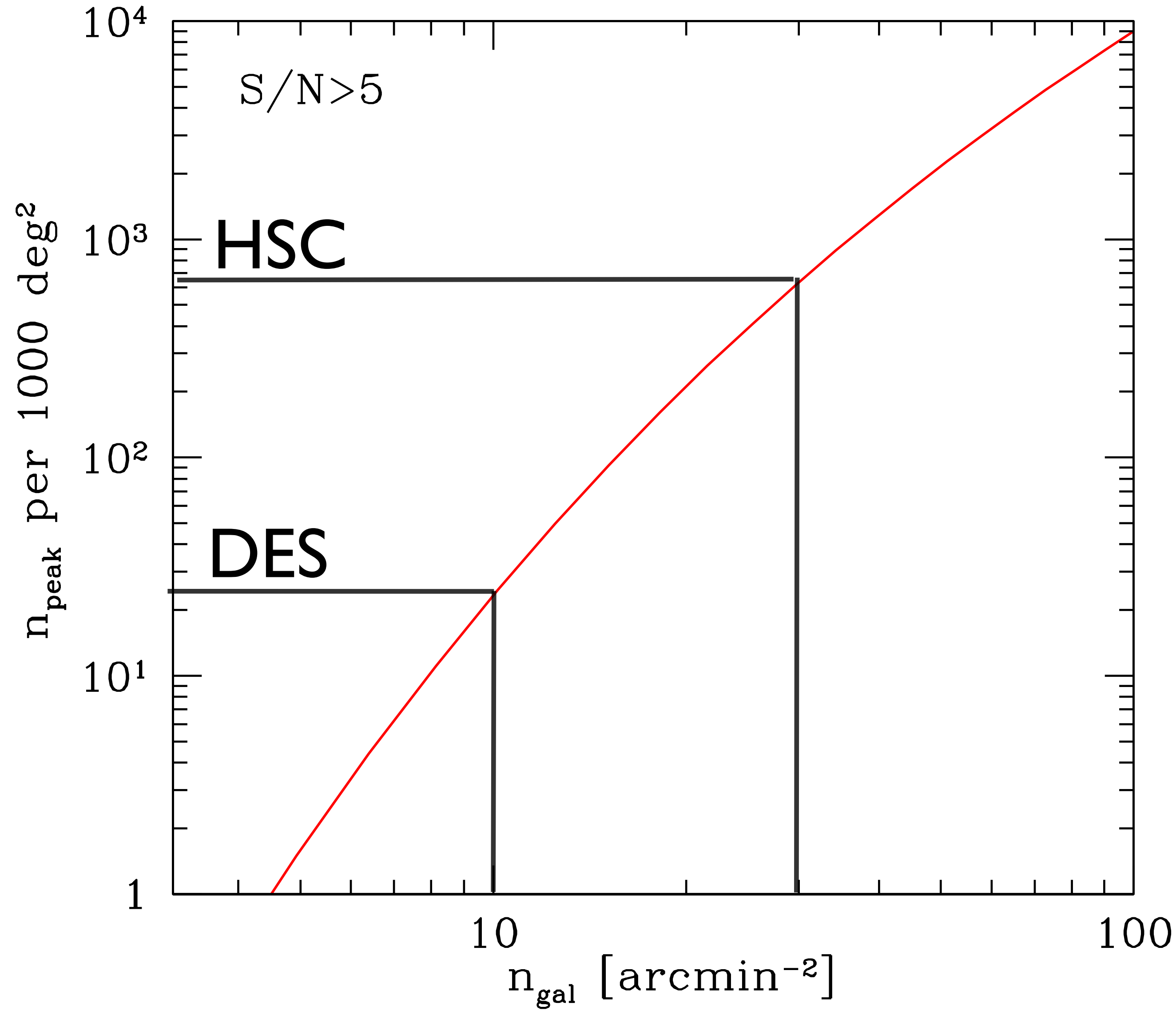
- increase galaxy number density → CMOS??
  (talk by Satoshi Miyazaki)

- improve algorithm
  radial filter? deconvolution?
  priors from galaxy distribution??

Summary

- weak gravitational lensing enables direct mapping of dark matter distribution
- HSC survey data look great and preliminary results are promising
- need more work for careful systematic checks and improving algorithms

Importance of deep imaging



- high source number density is crucial for efficient survey of mass-selected clusters