Simulating the Cluster Weak Lensing Signal

Joe Hollowed

Physics 526 Final Presentation
University of Michigan
December 10 2019

Cosmology from galaxy cluster masses

High mass end of the halo population is sensitive probe of cosmology:

For the case of a power-law spectrum of density fluctuations, $P(k) \propto k^{n_{\rm eff}}$, the Press-Schechter mass function can be written as

$$\frac{dn_{\rm PS}(M,z)}{d\ln M} = \frac{\alpha}{\sqrt{2\pi}} \, \frac{\bar{\rho}_{m,0}\nu_c(M,z)}{M} \, e^{-\nu_c^2(M,z)/2}, \tag{3}$$

where $\alpha = (n_{\rm eff}+3)/6$, $\bar{\rho}_{m,0}$ is the present mean mass density, and $\nu_c(M,z)$ is the Gaussian-normalized critical collapse threshold,

$$\nu_c(M,z) = \frac{\delta_c}{\sigma(M,z)}. \tag{4}$$

$$\sigma(M,z) = \sigma(M,0)\, D(z)/D(0),$$

Observable mass proxies:

- ➔ X-ray temperature
- ➔ Optical richness
- ➔ Thermal CMB distortion (SZ)
- ➔ Distortion of background sources (gravitational lensing)

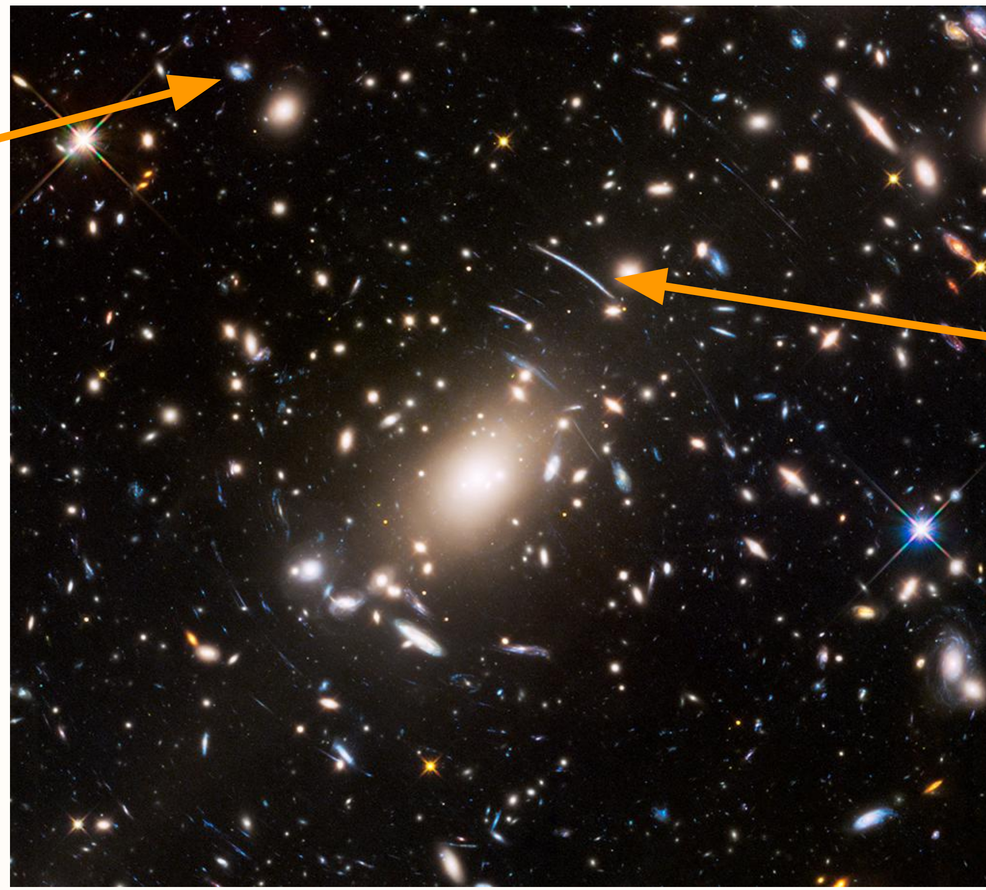
Figure 7: Images of Abell 1835 ($z = 0.25$) at X-ray, optical and mm wavelengths, exemplifying the regular multi-wavelength morphology of a massive, dynamically relaxed cluster. All three images are centered on the X-ray peak position and have the same spatial scale, 5.2 arcmin or ~ 1.2 Mpc on a side (extending out to $\sim r_{2500}$; Mantz et al. 2010a). Figure credits: *Left*: X-ray: Chandra X-ray Observatory/A. Mantz; *Center*, Optical: Canada France Hawaii Telescope/A. von der Linden et al.; *Right*, SZ: Sunyaev Zel'dovich Array/D. Marrone.

Cosmological Parameters from Observations of Galaxy Clusters, Allen, Evrard & Mantz, Annual Rev. of A&A, 2011

Weak Gravitational Lensing and the Halo Profile

Abell S1063

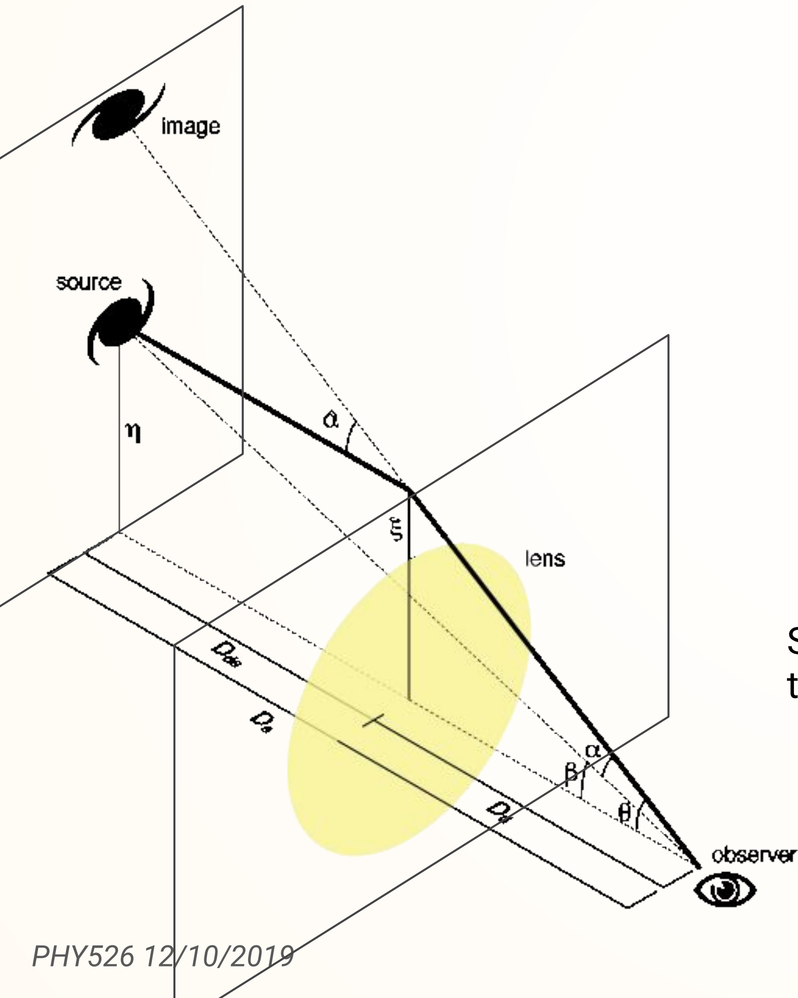
Weakly lensed



Strongly lensed arc

Image: ESA

Weak Gravitational Lensing and the Halo Profile



Projec

Conve

Shear r ... y of
the len

Gravitational Lensing by NFW Halos

Candace Oaxaca Wright & Tereasa G. Brainerd
Boston University, Department of Astronomy, Boston, MA 02215

arXiv:astro-ph/9908213v1 19 Aug 1999

$$\gamma_{\rm nfw}(x) = \begin{cases} \frac{r_s \delta_c \rho_c}{\Sigma_c} g_<(x) & (x < 1) \\ \frac{r_s \delta_c \rho_c}{\Sigma_c} \left[\frac{10}{3} + 4 \ln\left(\frac{1}{2}\right) \right] & (x = 1) \\ \frac{r_s \delta_c \rho_c}{\Sigma_c} g_>(x) & (x > 1) \end{cases}$$

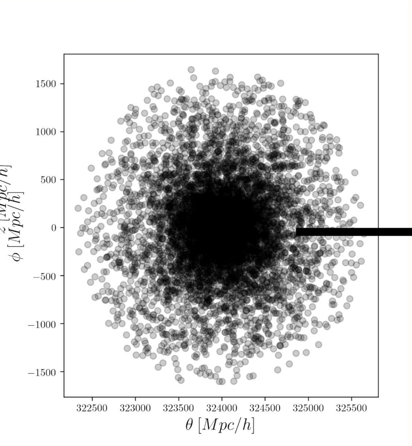
$$g_<(x) = \frac{8 \mathrm{arctanh} \sqrt{\frac{1-x}{1+x}}}{x^2 \sqrt{1-x^2}} + \frac{4}{x^2} \ln\left(\frac{x}{2}\right) - \frac{2}{(x^2-1)} + \frac{4 \mathrm{arctanh} \sqrt{\frac{1-x}{1+x}}}{(x^2-1)(1-x^2)^{1/2}}$$

$$g_>(x) = \frac{8 \arctan \sqrt{\frac{x-1}{1+x}}}{x^2 \sqrt{x^2-1}} + \frac{4}{x^2} \ln\left(\frac{x}{2}\right) - \frac{2}{(x^2-1)} + \frac{4 \arctan \sqrt{\frac{x-1}{1+x}}}{(x^2-1)^{3/2}}.$$

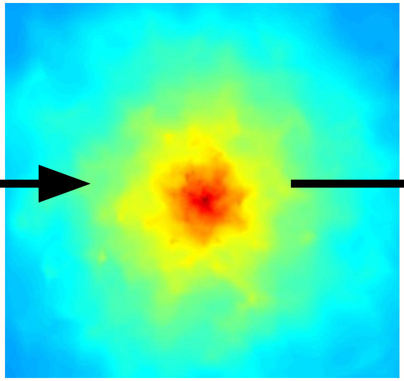
$$\gamma(r) \propto \frac{\bar{\Sigma}(r) - \Sigma(r)}{\Sigma_c} \qquad \Sigma_c \equiv \frac{c^2}{4\pi G} \frac{D_s}{D_d D_{ds}}$$

Pipeline

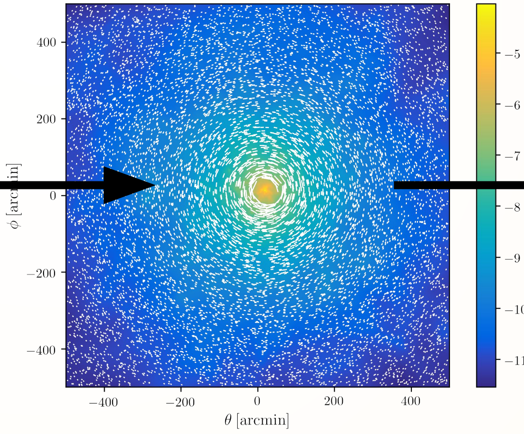
Generate a particle-sampled NFW halo realization



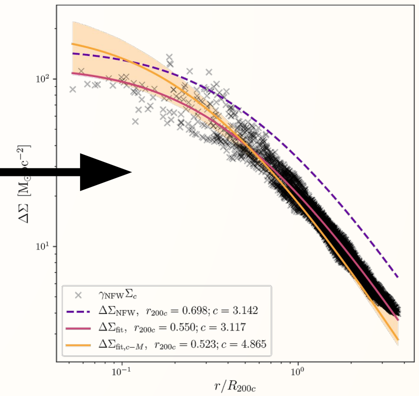
Obtain continuous expression of the density field



Compute lensing quantities, esp. shear field



Fit shear profile to NFW form to recover input parameters



Random realizations of NFW halos

FORWARD MODELING OF LARGE-SCALE STRUCTURE:
AN OPEN-SOURCE APPROACH WITH HALOTOOLS

ANDREW P. HEARIN[1,2], DUNCAN CAMPBELL[3], ERIK TOLLERUD[3,4]
AND
PETER BEHROOZI[5,6], BENEDIKT DIEMER[7], NATHAN J. GOLDBAUM[8], ELISE JENNINGS[9,10], ALEXIE LEAUTHAUD[11],
YAO-YUAN MAO[12,13], SURHUD MORE[11], JOHN PAREJKO[14], MANODEEP SINHA[15,16], BRIGITTA SIPŐCZ[17,18], ANDREW ZENTNER[13]

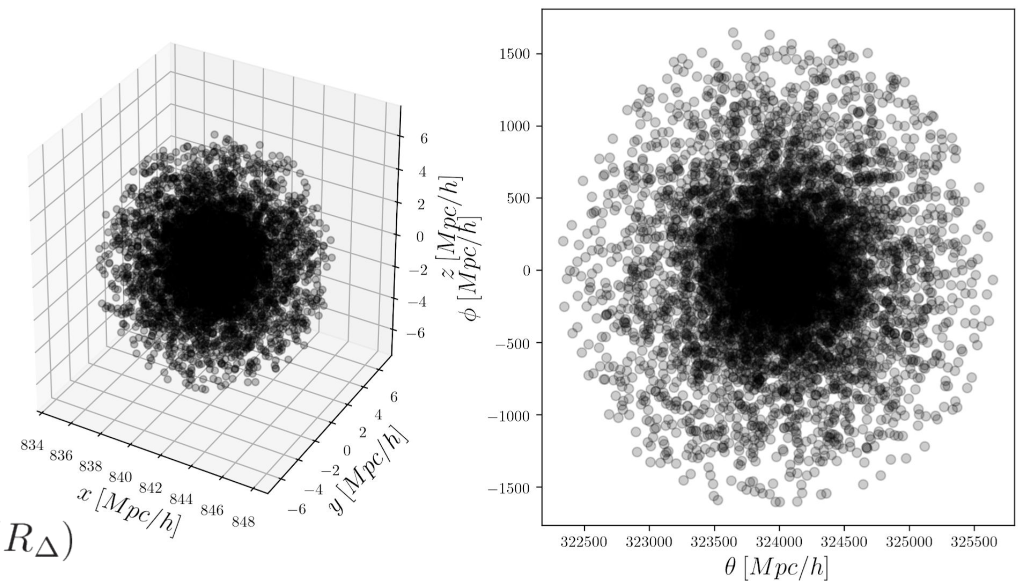
$$\rho_{\rm NFW} = \rho_{\rm crit} \frac{\delta_c}{r/r_s(1+r/r_s)^2}$$

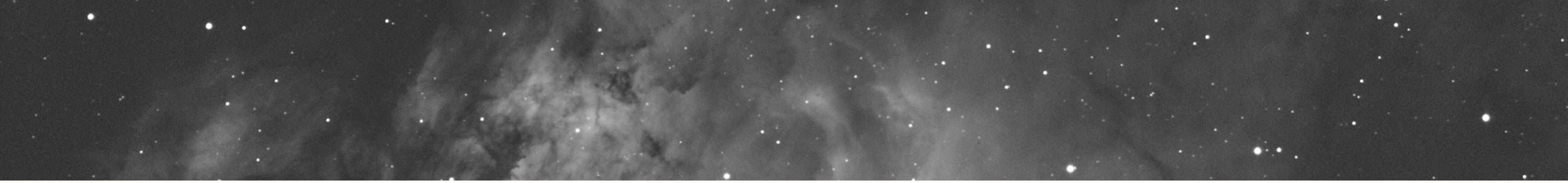
$$\delta_c \equiv \frac{200}{3} \frac{c^3}{ln(1+c) - c/(1+c)}$$

$$P(<r) = M(<r)/M_\Delta$$

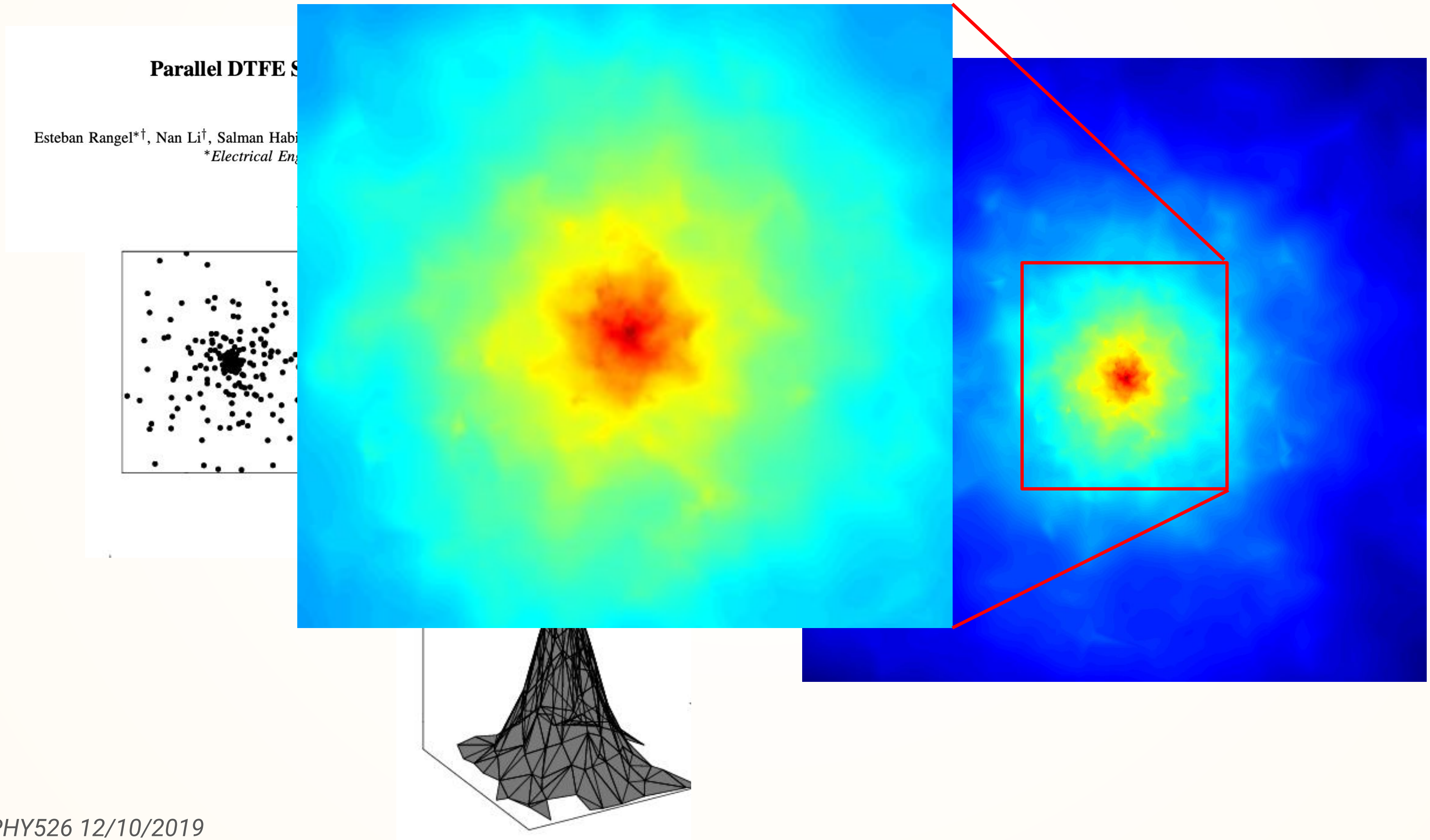
$$M(<r) = 4\pi\Delta\rho_{\rm ref} \int_0^r dr' r'^2 \rho_{\rm NFW}(r')$$

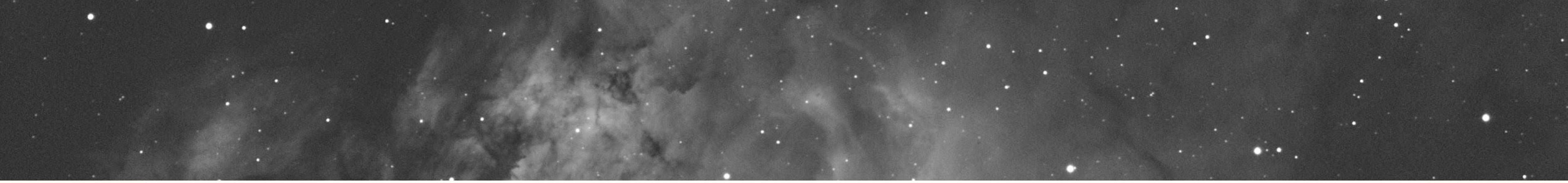
$$\implies P(<r) = \frac{\ln(1+c\tilde{r}) - c\tilde{r}(1+c\tilde{r})}{\ln(1+c) - c(1+c)} \quad (\tilde{r} \equiv r/R_\Delta)$$



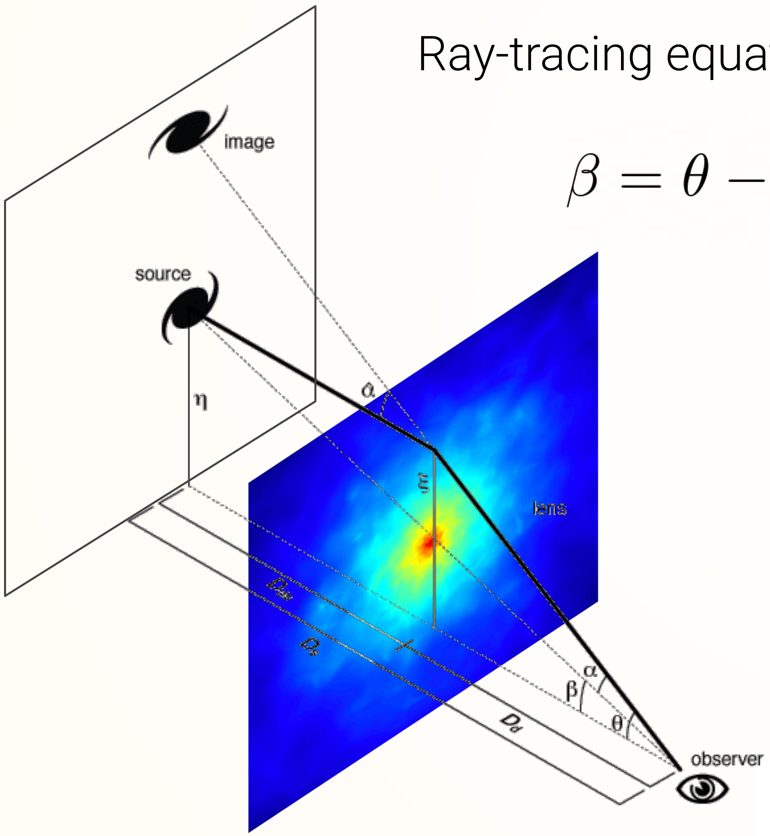


Projected density estimation via Delaunay triangulation





Ray-tracing through the integrated density field



Ray-tracing equation:

$$\beta = \theta - \frac{D_{ds}}{D_d}\alpha(D_d, \theta)$$

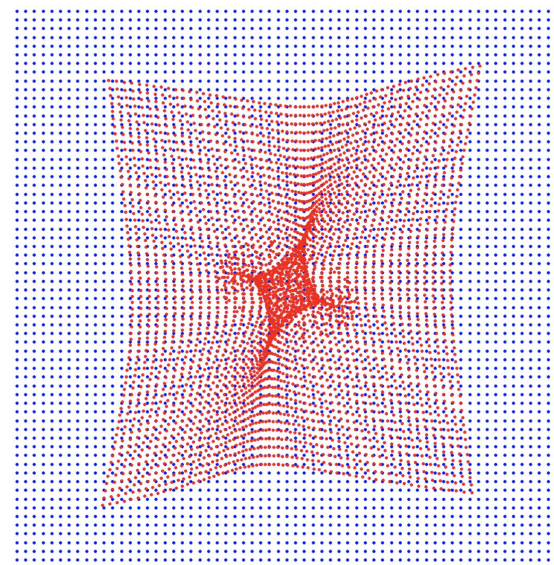


Figure 2. Illustration of mapping the lens plane to the source plane. Blue points show the positions of the intersection between light rays which start from the observer, and the image plane. To produce the lensed images using Fourier methods, we sample the blue points on regular grids. Red points illustrate the intersection between the deflected light rays and the source plane.

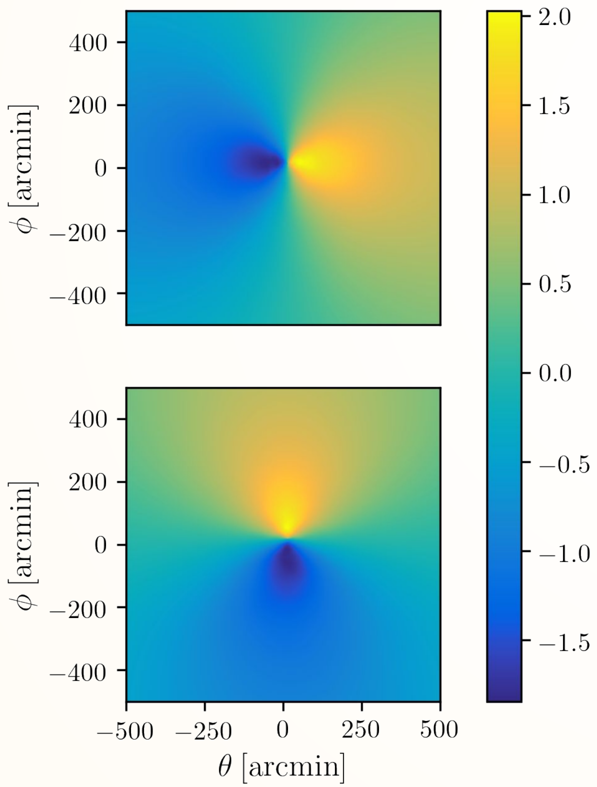
PICS: SIMULATIONS OF STRONG GRAVITATIONAL LENSING IN GALAXY CLUSTERS

NAN LI[1,2,3]; MICHAEL D. GLADDERS[1,3]; ESTEBAN M. RANGEL[2,5]; MICHAEL K. FLORIAN[1,3]; LINDSEY E. BLEEM[2,3]; KATRIN HEITMANN[2,3]; SALMAN HABIB[2,3], AND PATRICIA FASEL[4]

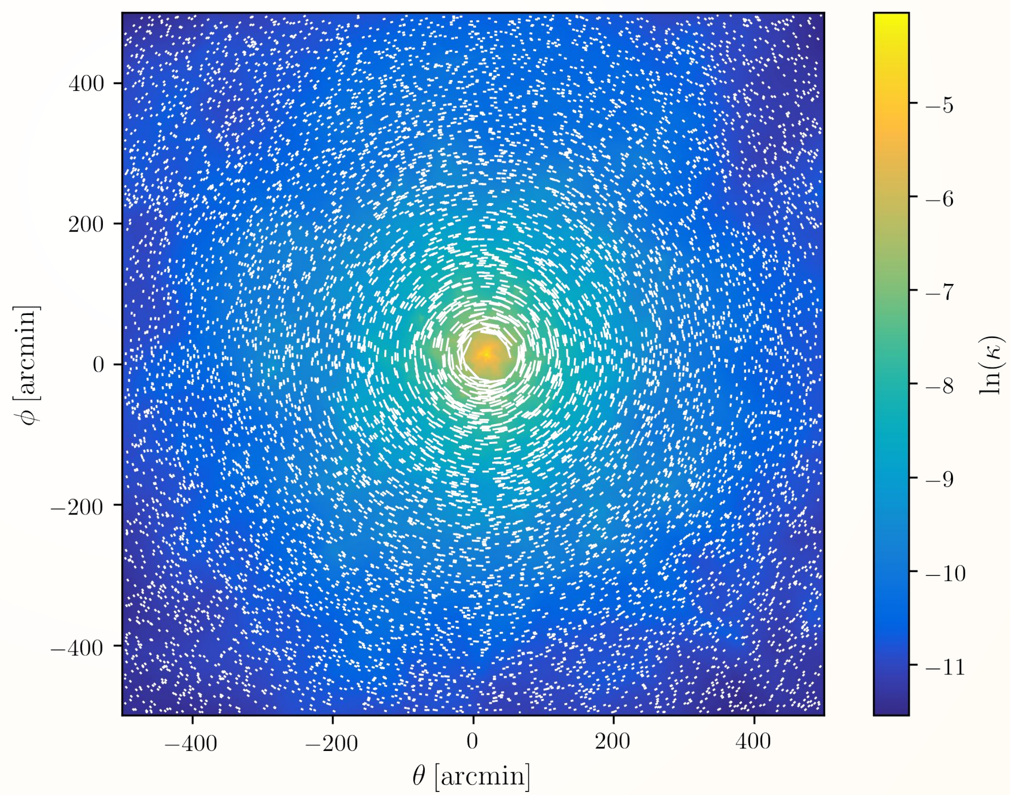
Preparing to submit to to ApJ: draft date September 30, 2016

Ray-tracing through the integrated density field

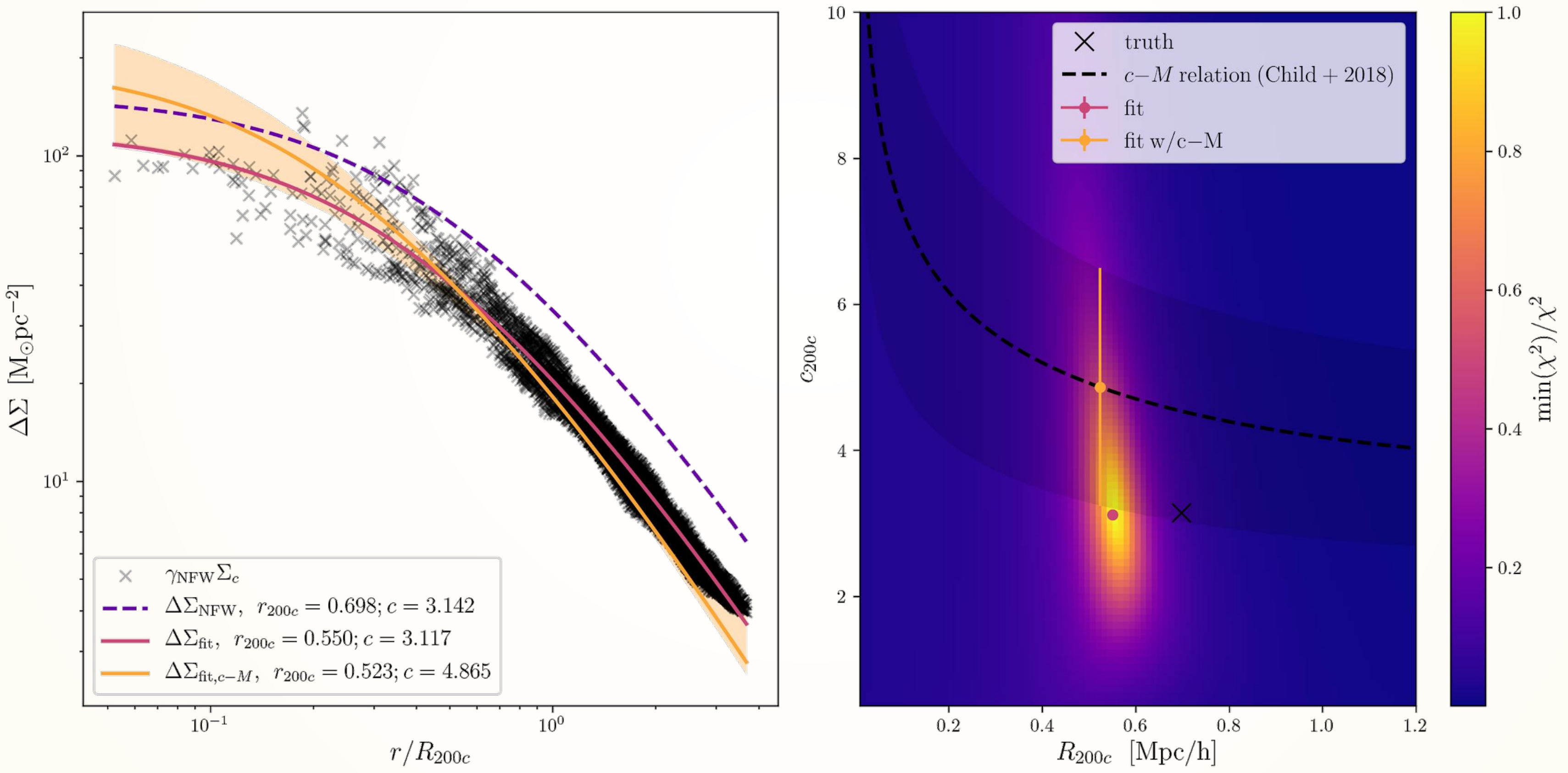
Deflection components:



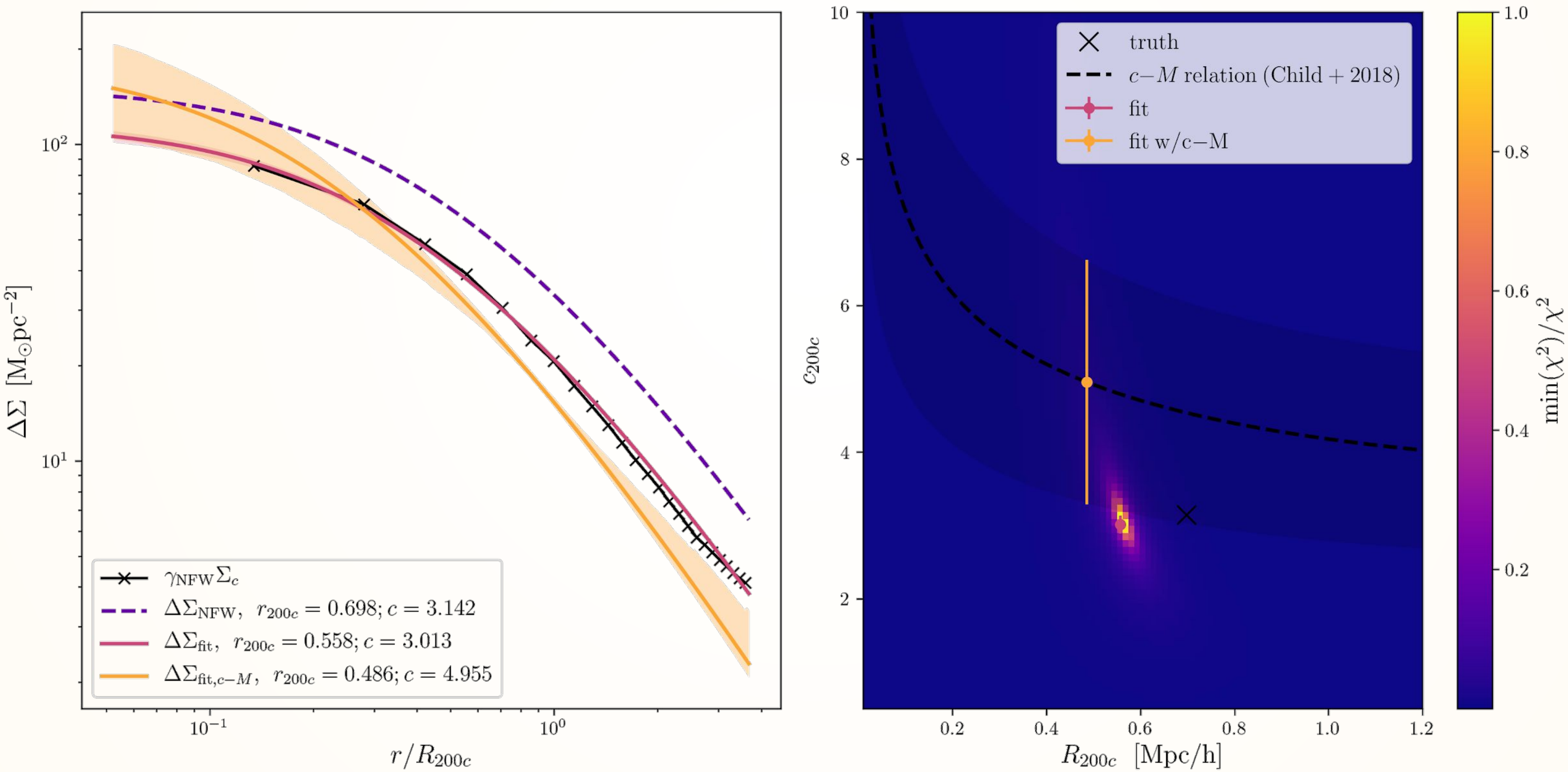
Interpolated shear field:



Recovering the input NFW form



Recovering the input NFW form



Recovering the input NFW form