Gravitational Lensing in an Exact, Anisotropic Model

M. A. Troxel,

with M. Ishak & A. Peel

University of Texas at Dallas

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Context

Gravitational lensing in a general cosmology

Building an exact, anisotropic galaxy cluster model

Specific lensing results for an anisotropic galaxy cluster

What are we doing?

- And why…

- Can a simple model be too simple?

- Studies of gravitational lensing by galaxy clusters
  - Spherical halos are not good enough
  - One option: Triaxiality

- On large scales: second order, nonlinear, relativistic corrections

- Other opportunities:
  - Exact, anisotropic (inhomogeneous) structure models

Gravitational lensing

- Geodesic optics - deviation of neighboring geodesics
- Directly related to the metric
- No partial derivatives of null vector

$$Y^{\mu}(\vec{\theta}, \lambda) = \gamma^{\mu}(\theta, \lambda) - \gamma_0(\theta = 0, \lambda)$$

$$Y^{\mu} = \xi_1 E_1 + \xi_2 E_2 + \xi_0 k^{\mu}$$

$$\boldsymbol{\xi}(\lambda) = \boldsymbol{\mathcal{D}}(\lambda)\boldsymbol{\theta}$$

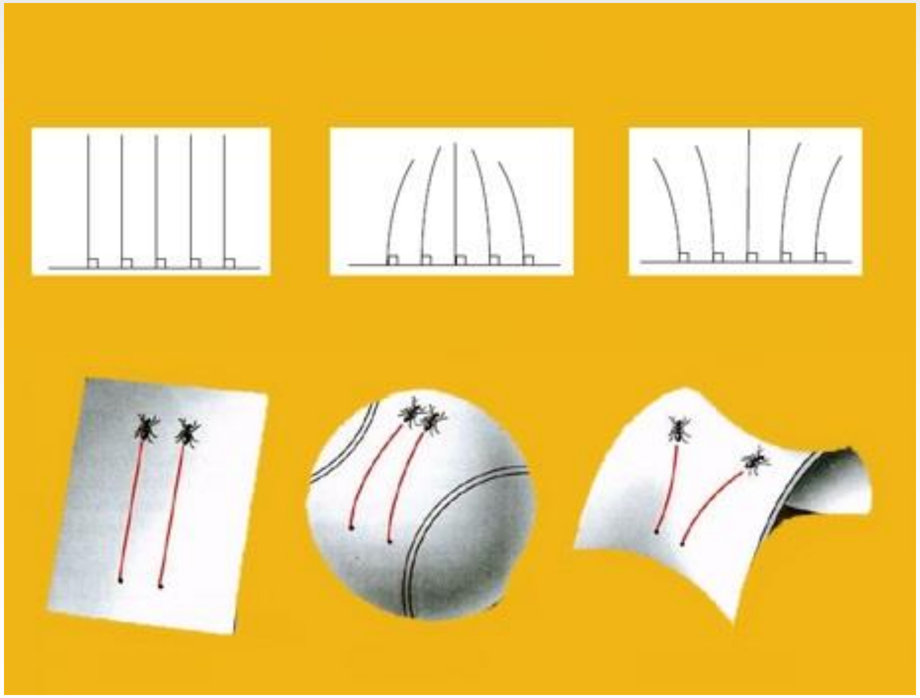
$$\ddot{\boldsymbol{\xi}} = \boldsymbol{\mathcal{T}}\boldsymbol{\xi} \qquad \ddot{\boldsymbol{\mathcal{D}}} = \boldsymbol{\mathcal{T}}\boldsymbol{\mathcal{D}}$$

$$\boldsymbol{\mathcal{T}} = \begin{pmatrix} \mathcal{R} - \Re\mathcal{F} & \Im\mathcal{F} \\ \Im\mathcal{F} & \mathcal{R} + \Re\mathcal{F} \end{pmatrix}$$

$$\mathcal{R} = -\frac{1}{2} R_{\mu\nu} k^{\mu} k^{\nu}$$

$$\mathcal{F} = -\frac{1}{2} C_{\alpha\beta\mu\nu} \epsilon^{*\alpha} k^{\beta} \epsilon^{*\mu} k^{\nu}$$

$$D_A = \sqrt{\det \tilde{\mathcal{D}}}.$$



Credit: João Nuno Tavares, CMUP

Gravitational lensing

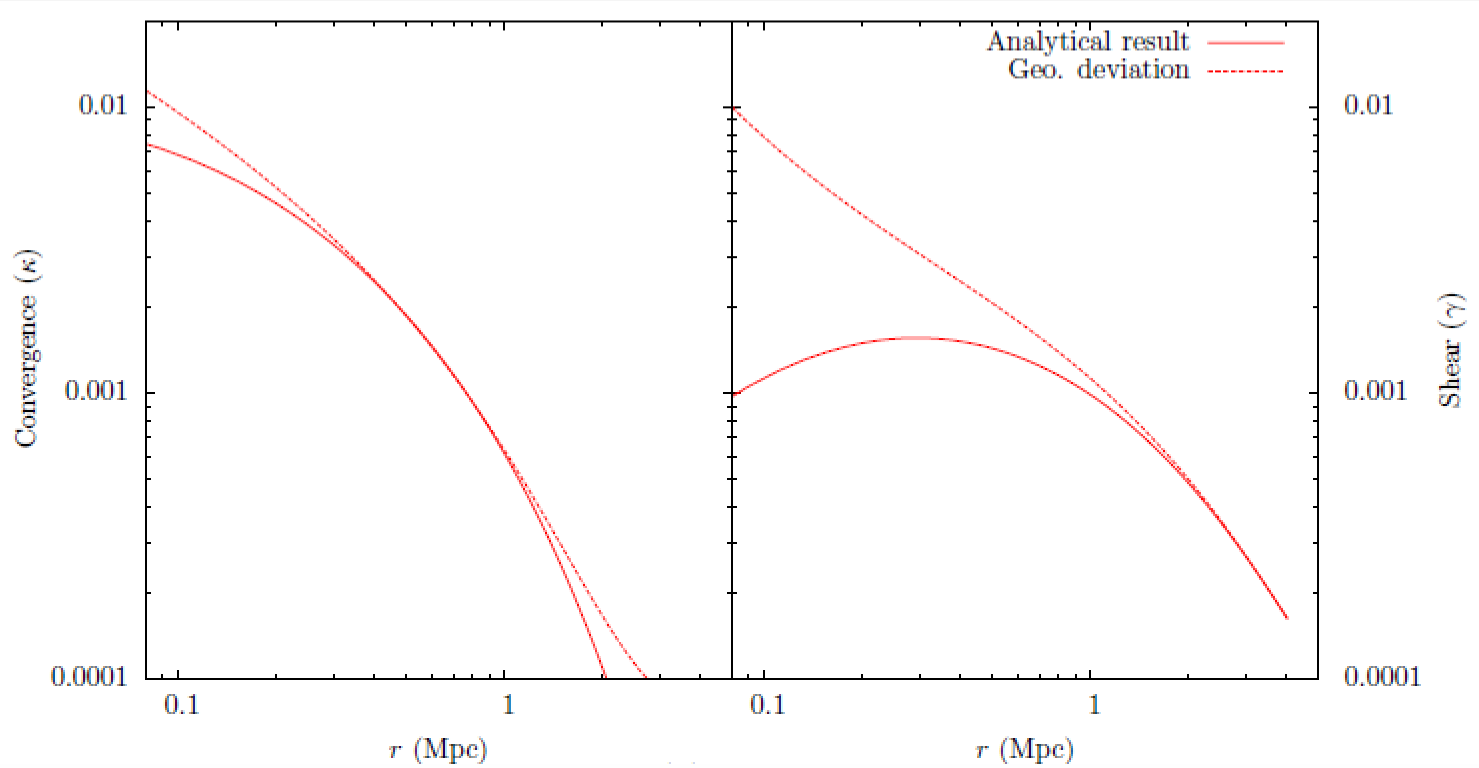
- FLRW limits…

$$\mathcal{D} = \tilde{D}_A \mathcal{A}$$

$$\mathcal{A} = \begin{pmatrix} 1-\kappa-\gamma_1 & \gamma_2 \\ \gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\mathcal{R} = -4\pi\rho_{bg}(1+z)^2 = -\frac{3}{2}H_0^2\Omega_m^0(1+z)^5$$

$$\mathcal{F} = -(2\Phi_{,ij} + \delta_{ij}\Phi_{,33})(1+z)^2$$



Building an exact, anisotropic cluster model

- Szekeres metric

$$ds^2 = -dt^2 + \frac{(\Phi_{,r} - \Phi\mathcal{E}_{,r}/\mathcal{E})^2}{\epsilon - k(r)} dr^2 + \frac{\Phi^2}{\mathcal{E}^2}(dp^2 + dq^2)$$

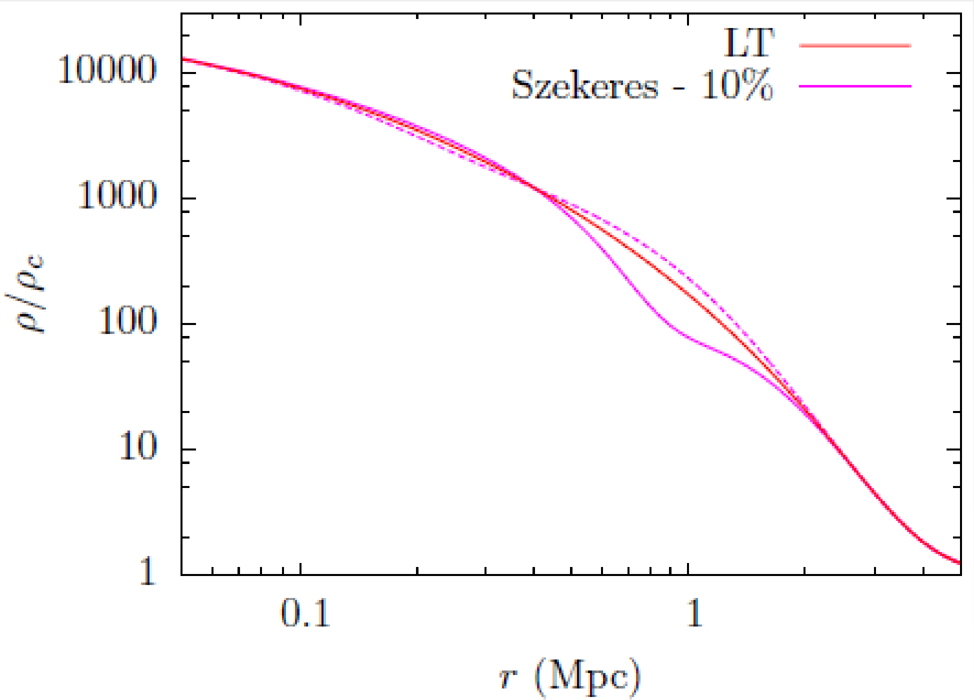
$$(\Phi_{,t})^2 = -k + \frac{2M}{\Phi} + \frac{\Lambda}{3}\Phi^2$$

$$\mathcal{E}(r,p,q) = \frac{S(r)}{2}\left[\left(\frac{p - P(r)}{S(r)}\right)^2 + \left(\frac{q - Q(r)}{S(r)}\right)^2 + \epsilon\right]$$

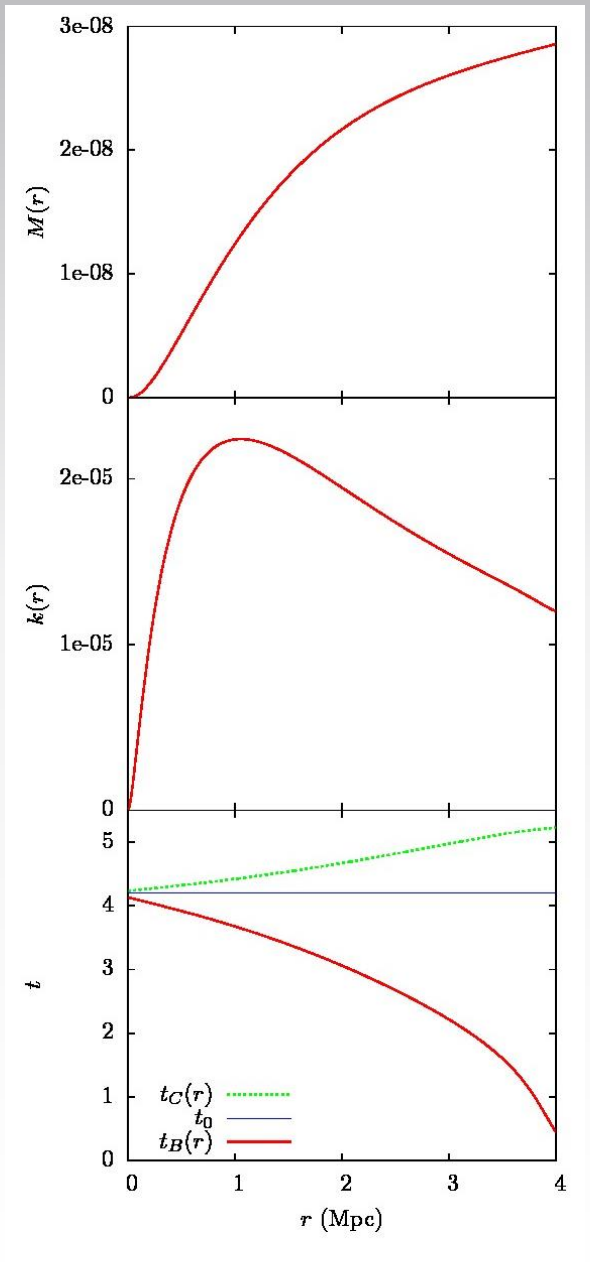
$$\kappa\rho(t,r,p,q) = \frac{2(M_{,r} - M\mathcal{E}_{,r}/\mathcal{E})}{\Phi^2(\Phi_{,r} - \Phi\mathcal{E}_{,r}/\mathcal{E})}$$

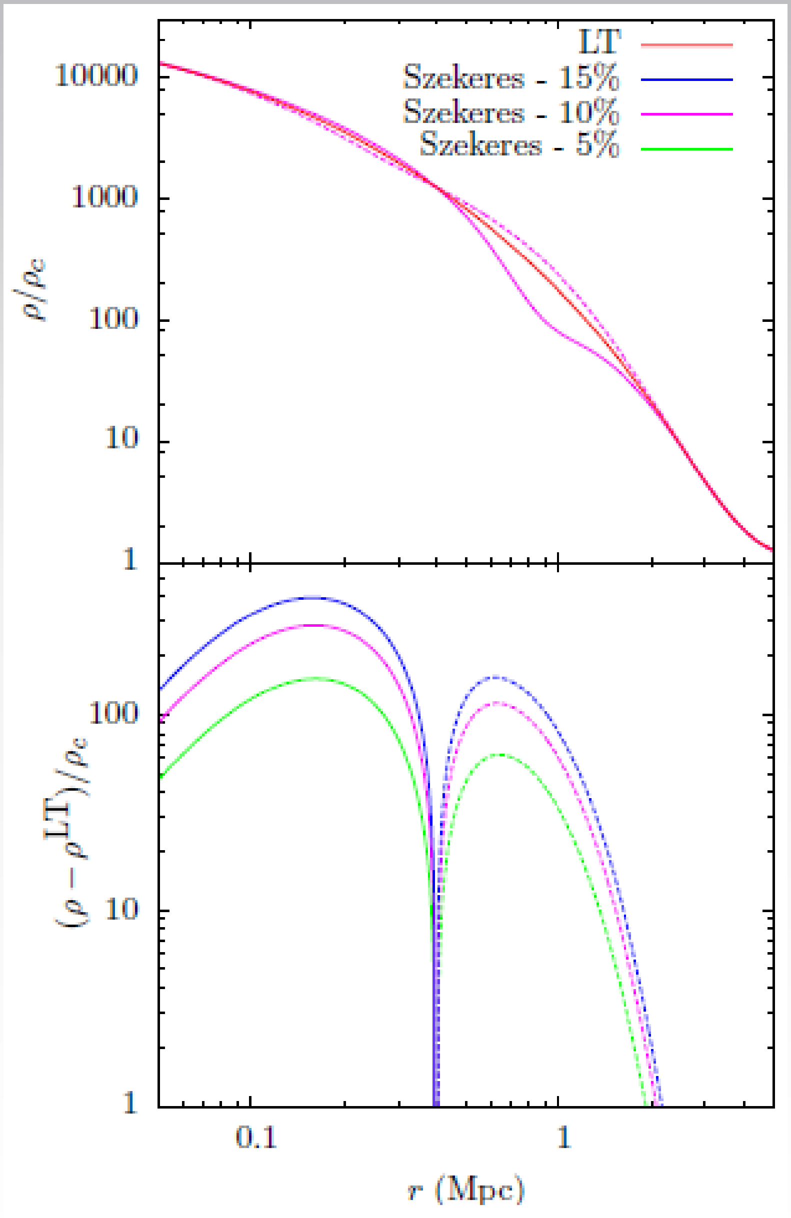
$$\rho^{\mathrm{BMO}}(x) = \frac{\delta_c \rho_c}{(\epsilon_c + x)(1+x)^2}\left(\frac{\tau^2}{x^2+\tau^2}\right)^2$$

$$Q(r) = 27e^{-5r}r^2$$



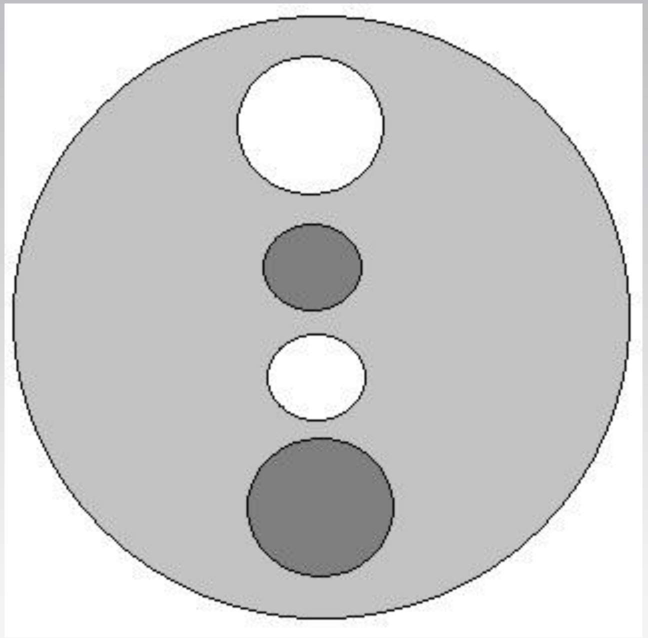
Building an exact, anisotropic cluster model





Building an exact, anisotropic cluster model

- Now what did we learn?



Building an exact, anisotropic cluster model

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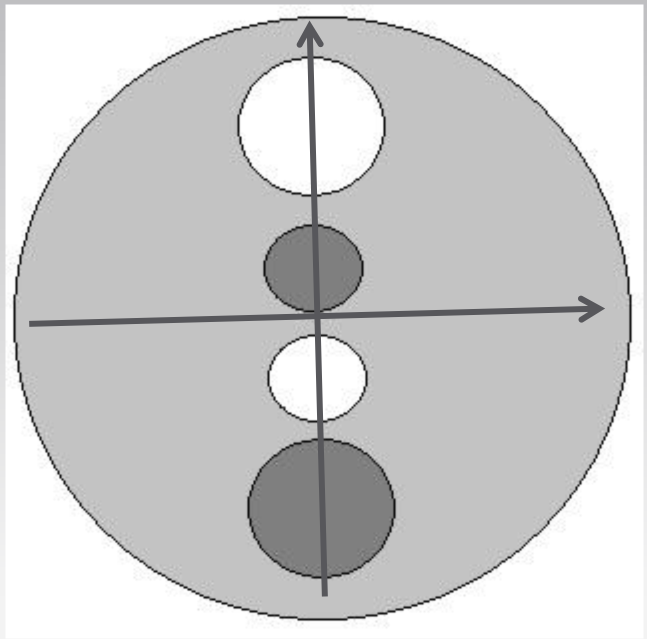

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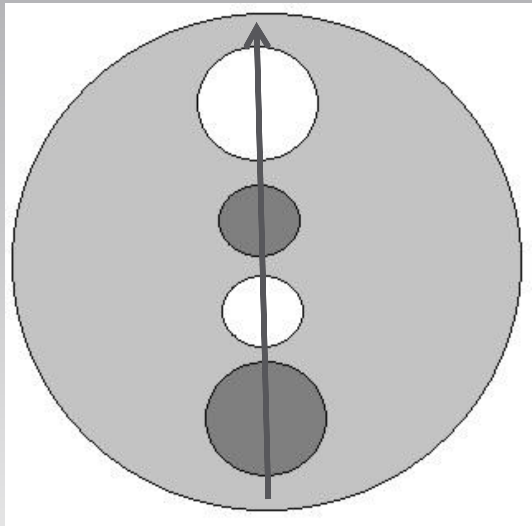

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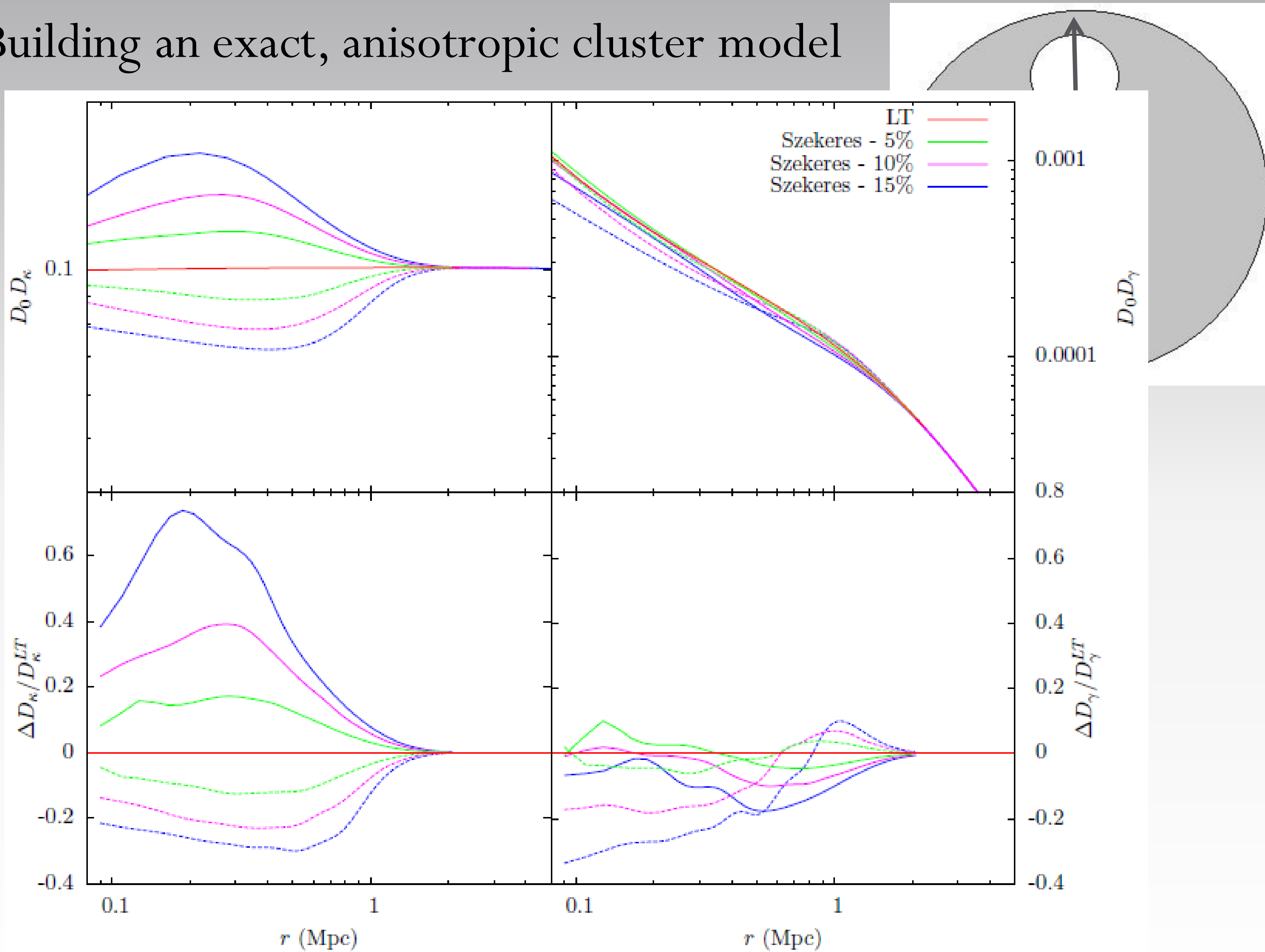

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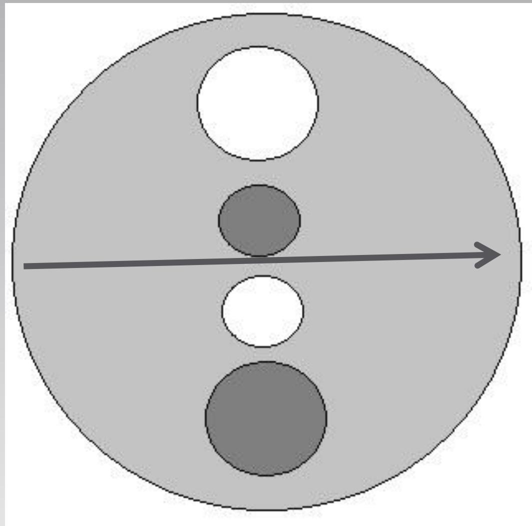

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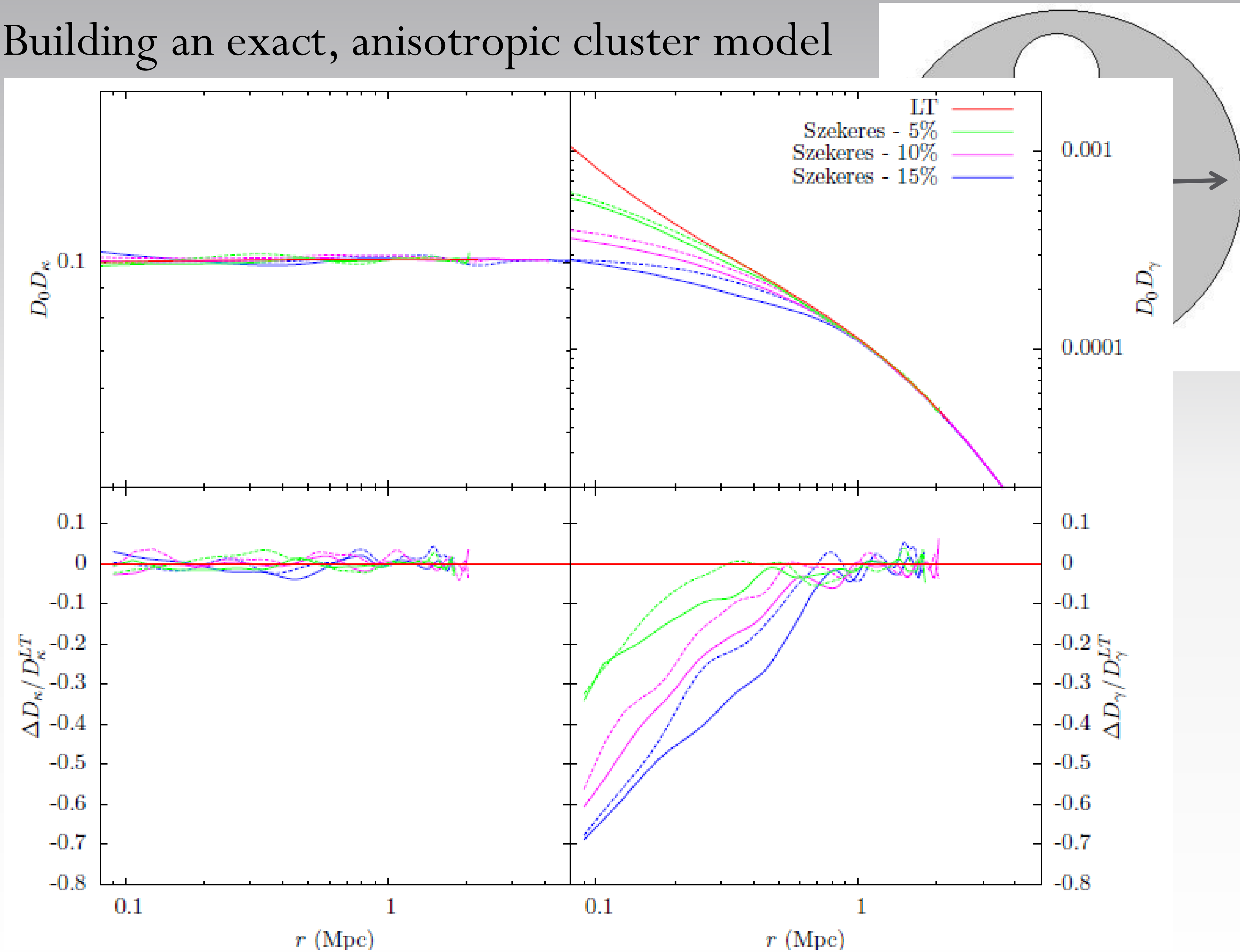

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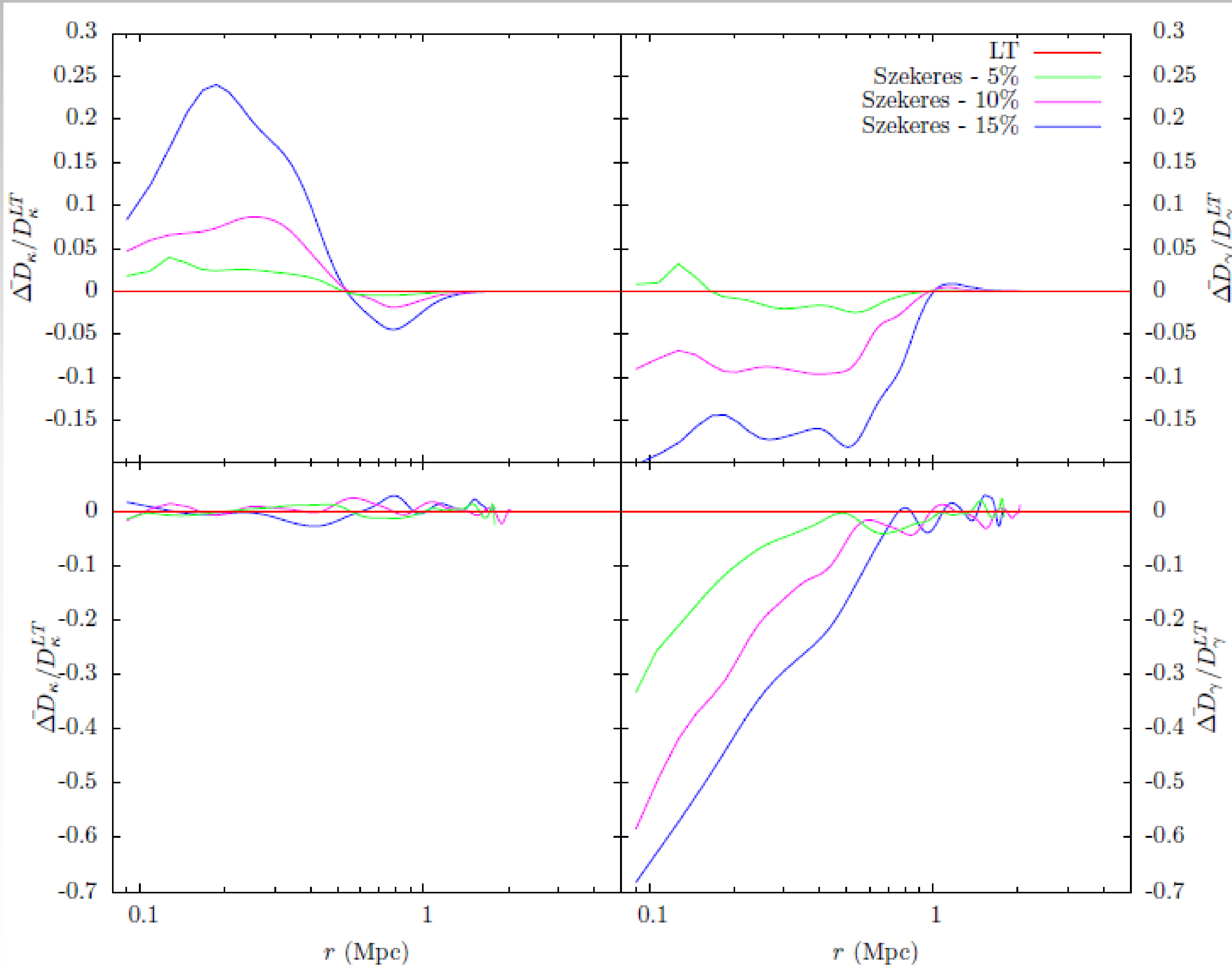

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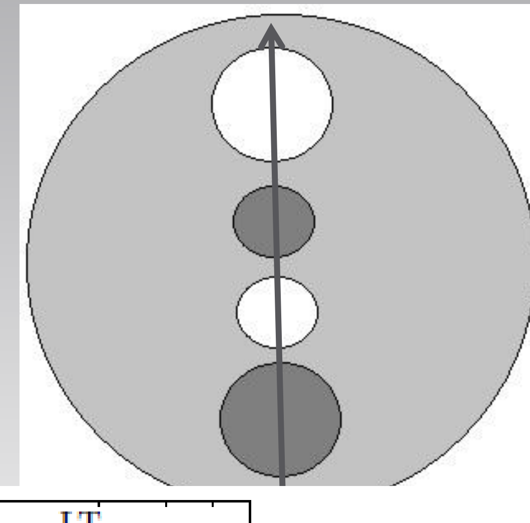

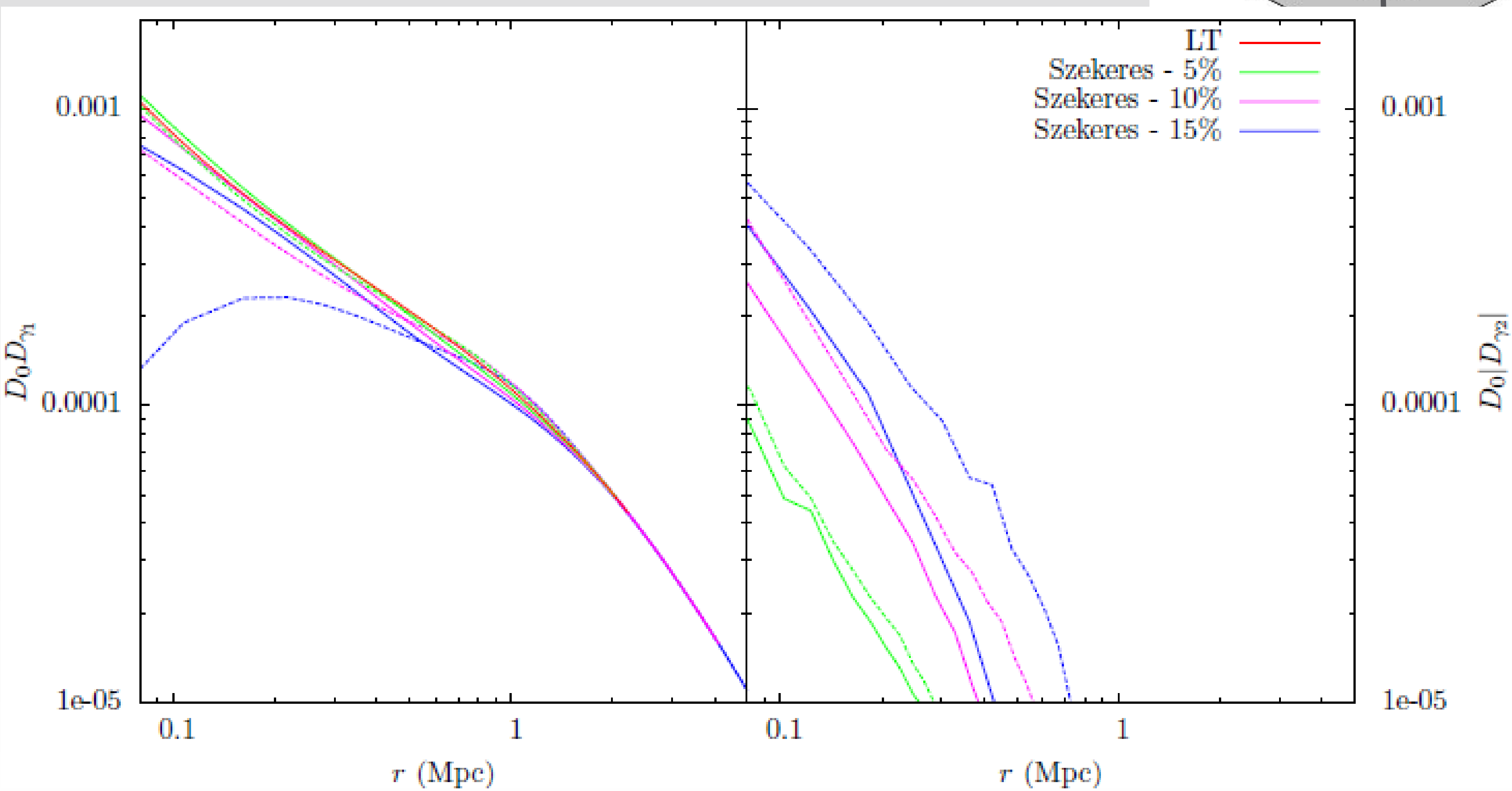

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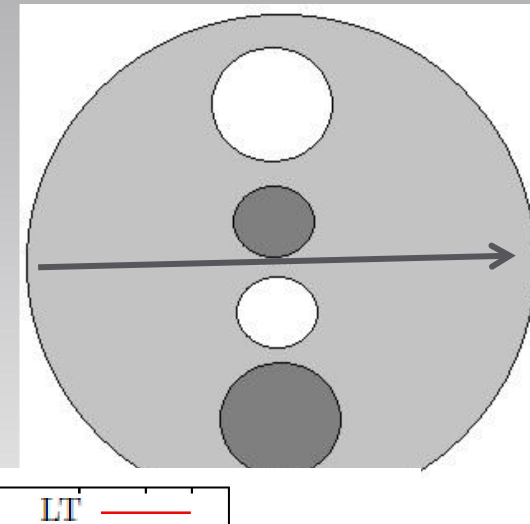

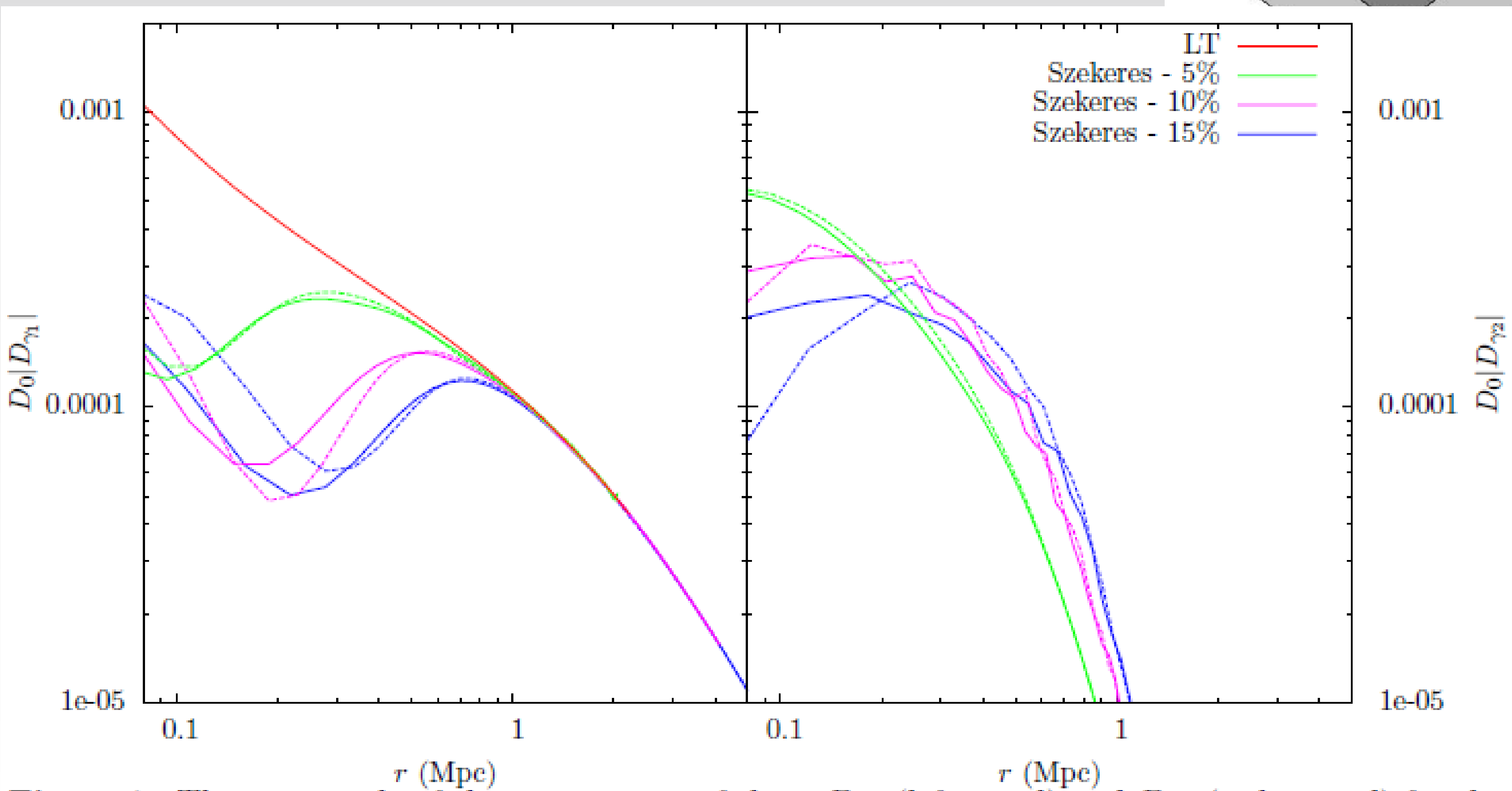

Summary

- Lensing in an exact, anisotropic galaxy cluster model
  - Simple FLRW limit outside the cluster on large scales
  - Modified NFW dark halo
- Reproduces analytical work in traditional lensing framework
  - Convergence & Shear
- Considered various levels of anisotropy by scaling parameter S
  - 5%, 10%, 15%
- Persistent systematic shifts in lensing convergence and shear measures
  - Up to 20% in 1-κ measure, 15-50% in magnitude of shear
  - Individual shear components change sign, more interesting behaviour