Gregory Horndeski, 'Horndeski Scalar Theory, Past, Present and Future'

Towards Void-Lensing as a Cosmological Observable

I. How To Optimize Void-Lensing Measurements

II. How To Interpret the Measurement

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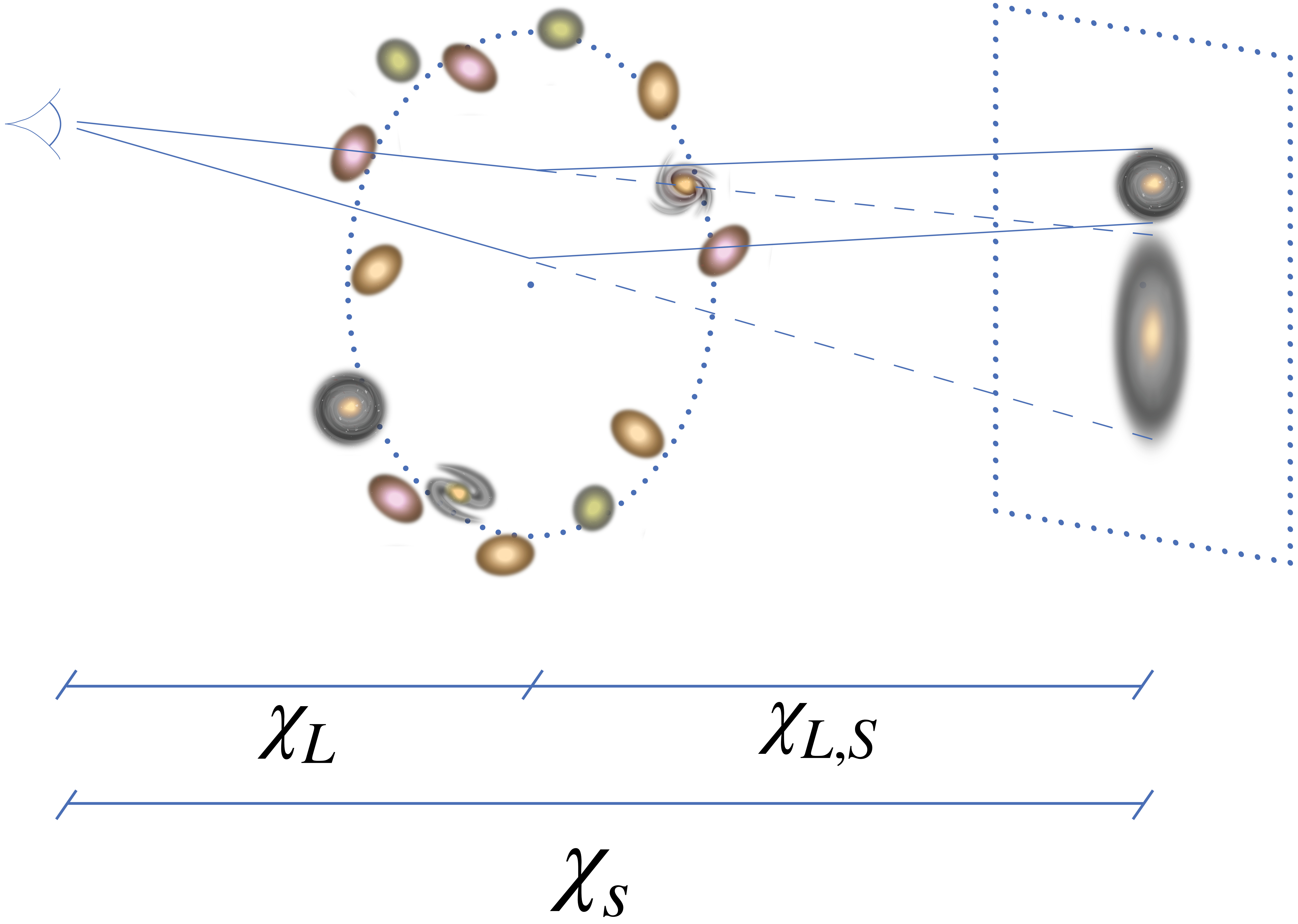
WL Voids



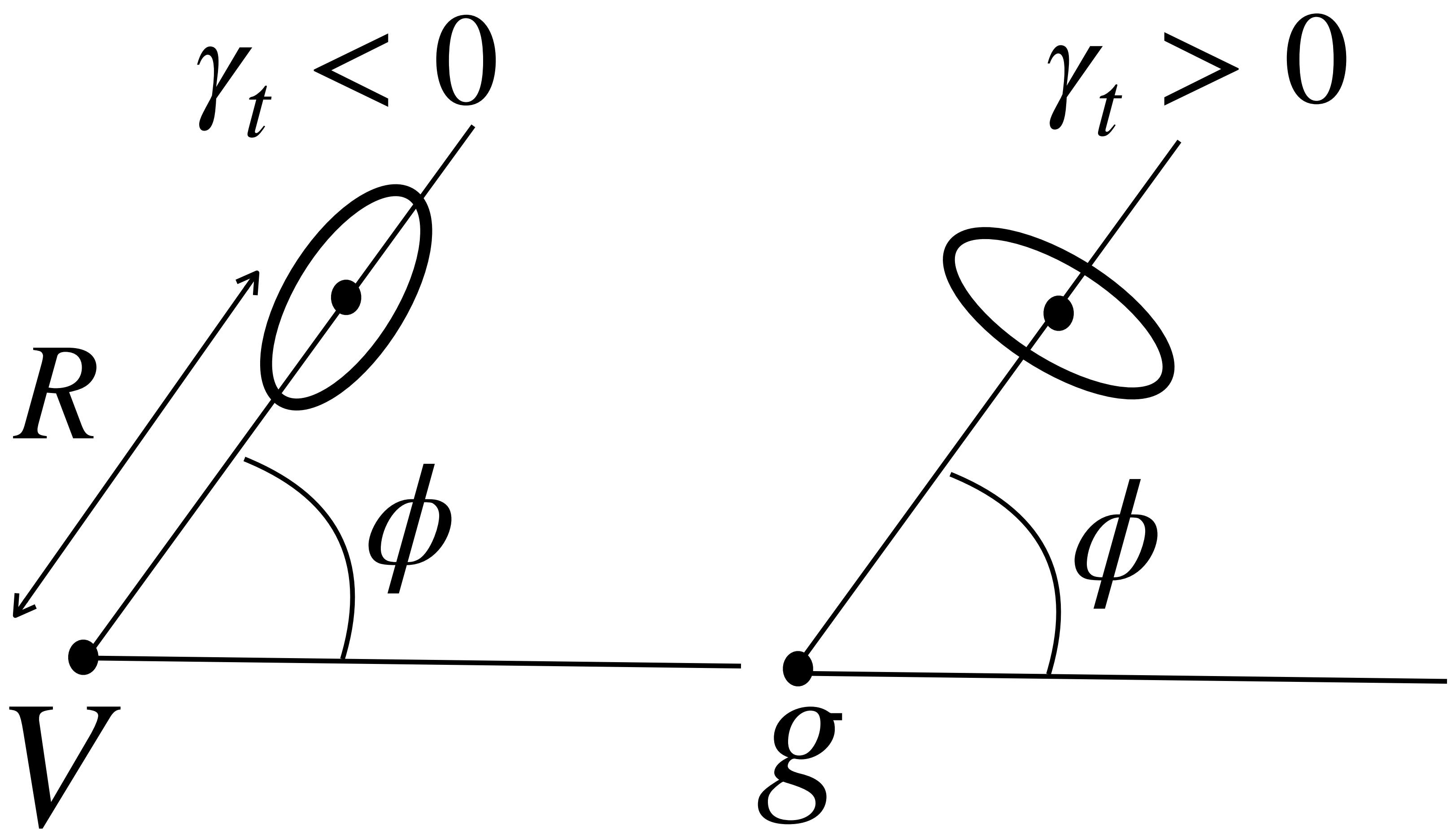
Differential surface mass density:

$$\Delta\Sigma(R, z_L) = \Sigma_{crit}(\bar{\kappa}(<R) - \kappa(R))$$

$$= \Sigma_{crit} \times \gamma_t(R)$$

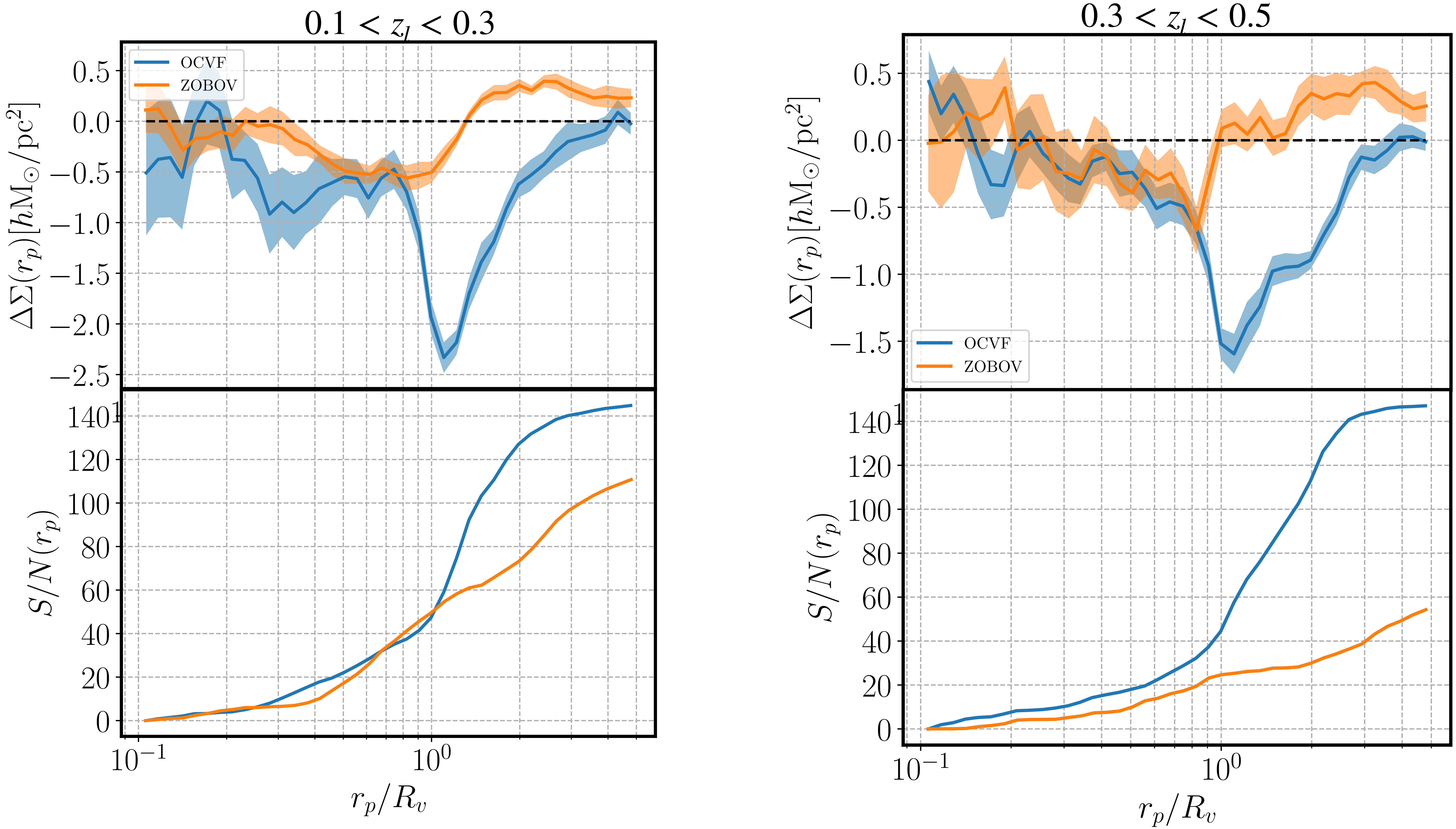
$$\kappa(R) = \int d\chi \Sigma_{crit}^{-1} \bar{\rho} \delta(\chi, R) \simeq \Sigma_{crit}^{-1} \Sigma(R) \text{ (TL)}$$

$$\Rightarrow \Delta\Sigma(R) = \bar{\Sigma}(<R) - \Sigma(R)$$

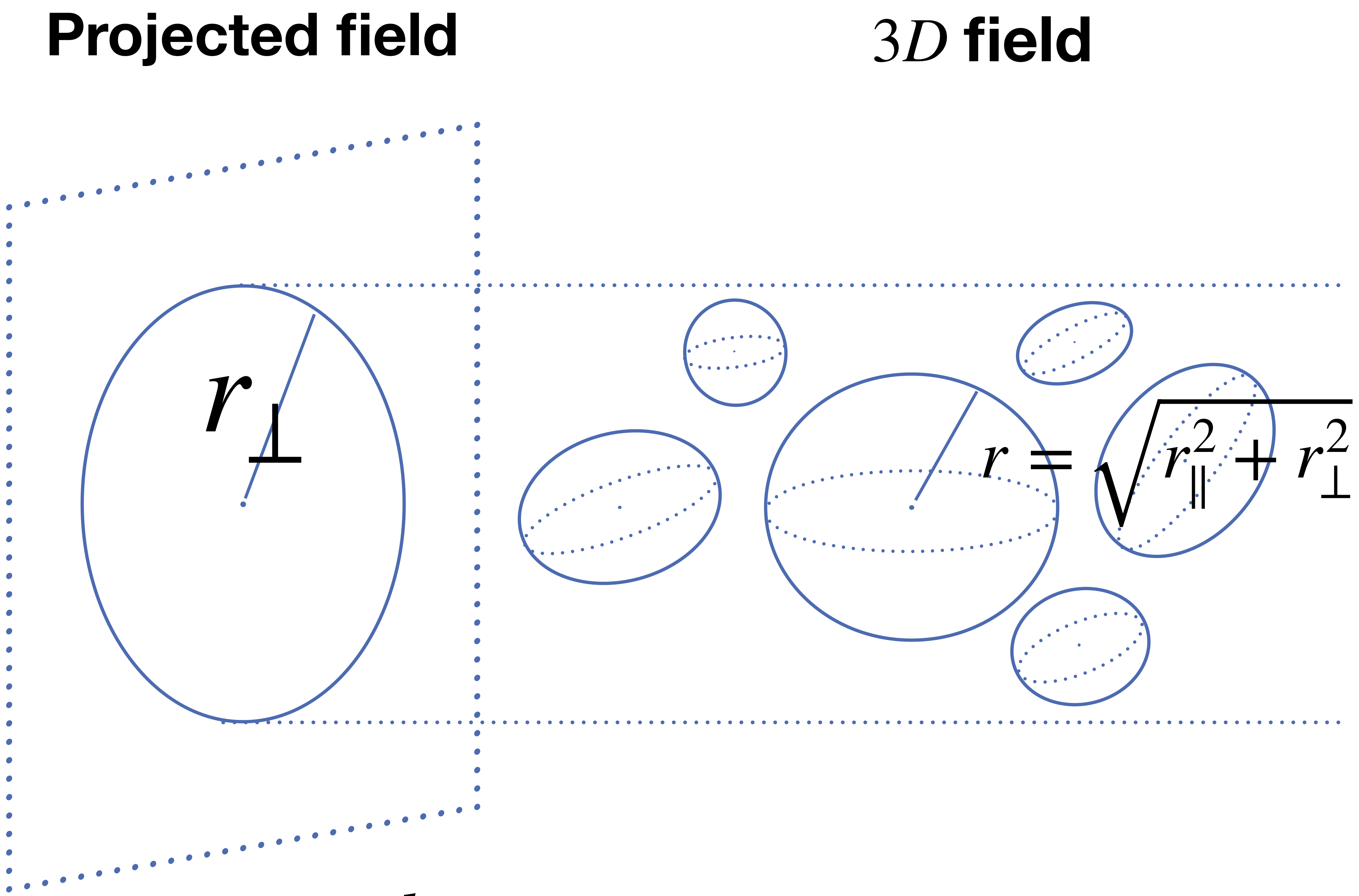


Performance on VL

$10 < R_v < 15[h^{-1}\textbf{Mpc}]$ 10^4degrees^2



The Void-Lensing Model



$$\Sigma(r_\perp \,|\, R_{2D}) = \int d\ln R_{3D} \frac{dn_v}{d\ln R_{3D}} \int dx_\perp (1 + \xi(x_\perp)) \int dr_\parallel \, \delta_{3D}(r_\perp, r_\parallel \,|\, \alpha, R_{3D})$$

$$= \int dr_\parallel \delta^{eff}(r_\perp, r_\parallel \,|\, \alpha, R_{3D})$$

$$\Rightarrow \Delta\Sigma(r_\perp) = \bar{\Sigma}(< r_\perp) - \Sigma(r_\perp)$$

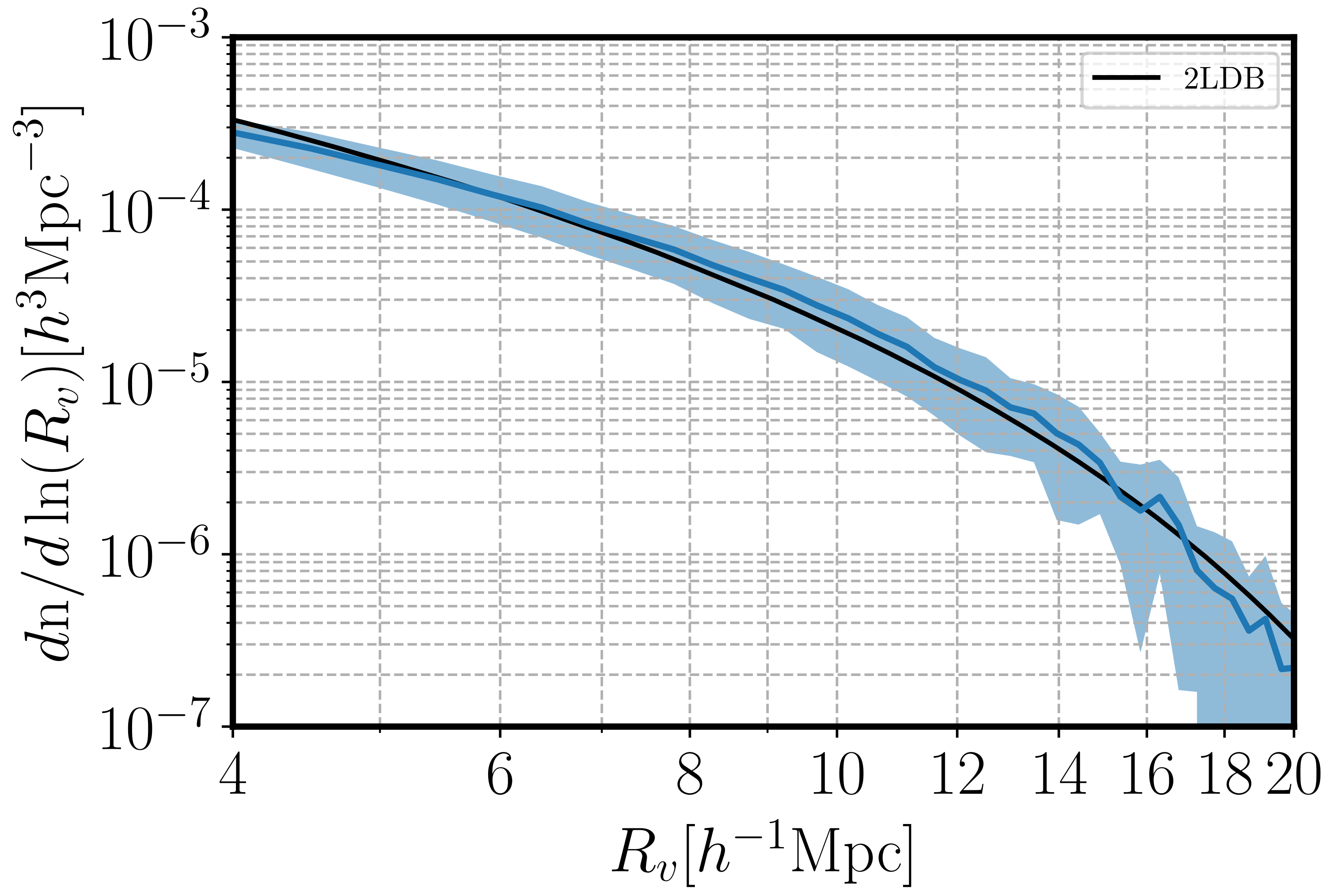
The Void-Lensing Model

$$\Sigma(r_\perp \,|\, R_{2D}, \Delta_{2D}) = \int dR_{3D} \frac{dn_v}{dR_{3D}}(R_{3D} \,|\, \Delta_{3D}) \int dx_\perp dx_\parallel d\alpha P(x_\perp, x_\parallel, \alpha \,|\, R_{3D}, R_{2D}, \Delta_{3D}, \Delta_{2D}) \int dr_\parallel\, \delta_{3D}(r_\perp - x_\perp, r_\parallel - x_\parallel \,|\, \alpha, R_{3D}, \Delta_{3D})$$

$$\simeq$$

$$\Sigma(r_\perp \,|\, M_{2D}) = \int d\ln R_{3D} \frac{dn_v}{d\ln R_{3D}} \int dx_\perp (1 + \xi(x_\perp)) \int dr_\parallel\, \delta_{3D}(r_\perp, r_\parallel \,|\, \alpha, R_{3D})$$

$$\frac{dn_v}{d\ln R} = \frac{f(\sigma)}{V(R)} \frac{d\ln \sigma^{-1}}{d\ln R}$$, **where** $$\sigma^2(R) \equiv \int \frac{dk}{2\pi^2} k^2 P^L_{mm}(k) \,|\, \tilde{W}(k \mid R) \,|^2$$



The Void-Lensing Model

$$\Sigma(r_\perp | R_{2D}, \Delta_{2D}) = \int dR_{3D} \frac{dn_v}{dR_{3D}}(R_{3D} | \Delta_{3D}) \int dx_\perp dx_\parallel d\alpha P(x_\perp, x_\parallel, \alpha | R_{3D}, R_{2D}, \Delta_{3D}, \Delta_{2D}) \int dr_\parallel \rho_{3D}(r_\perp - x_\perp, r_\parallel - x_\parallel | \alpha, R_{3D}, \Delta_{3D})$$

$$\simeq$$

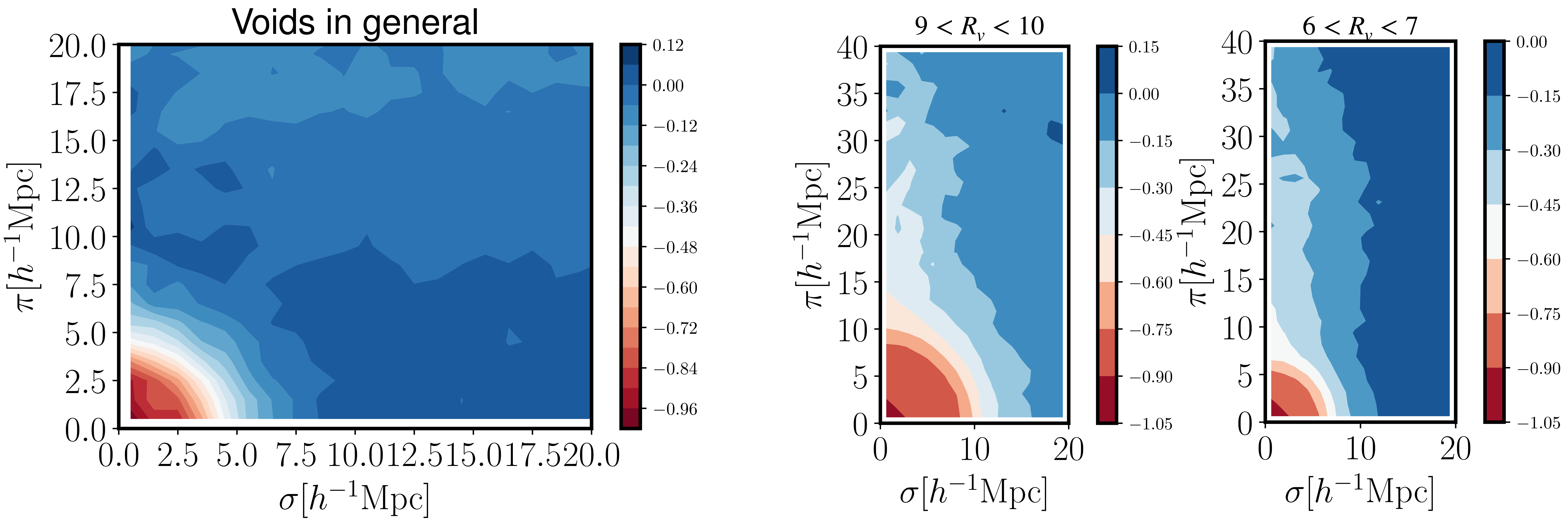
$$\Sigma(r_\perp | R_{2D}) = \int d \ln R_{3D} \frac{dn_v}{d \ln R_{3D}} \int dx_\perp (1 + \xi(x_\perp)) \int dr_\parallel \delta_{3D}(r_\perp, r_\parallel | \alpha, R_{3D})$$

The Void-Lensing Model

$$\Sigma(r_\perp | R_{2D}, \Delta_{2D}) = \int dR_{3D} \frac{dn_v}{dR_{3D}}(R_{3D} | \Delta_{3D}) \int dx_\perp dx_\parallel d\alpha P(x_\perp, x_\parallel, \alpha | R_{3D}, R_{2D}, \Delta_{3D}, \Delta_{2D}) \int dr_\parallel \, \delta_{3D}(r_\perp - x_\perp, r_\parallel - x_\parallel | \alpha, R_{3D}, \Delta_{3D})$$

$$\simeq$$

$$\Sigma(r_\perp | M_{2D}) = \int d\ln R_{3D} \frac{dn_v}{d\ln R_{3D}} \int dx_\perp (1 + \xi(x_\perp)) \int dr_\parallel \, \delta_{3D}(r_\perp, r_\parallel | \alpha, R_{3D})$$

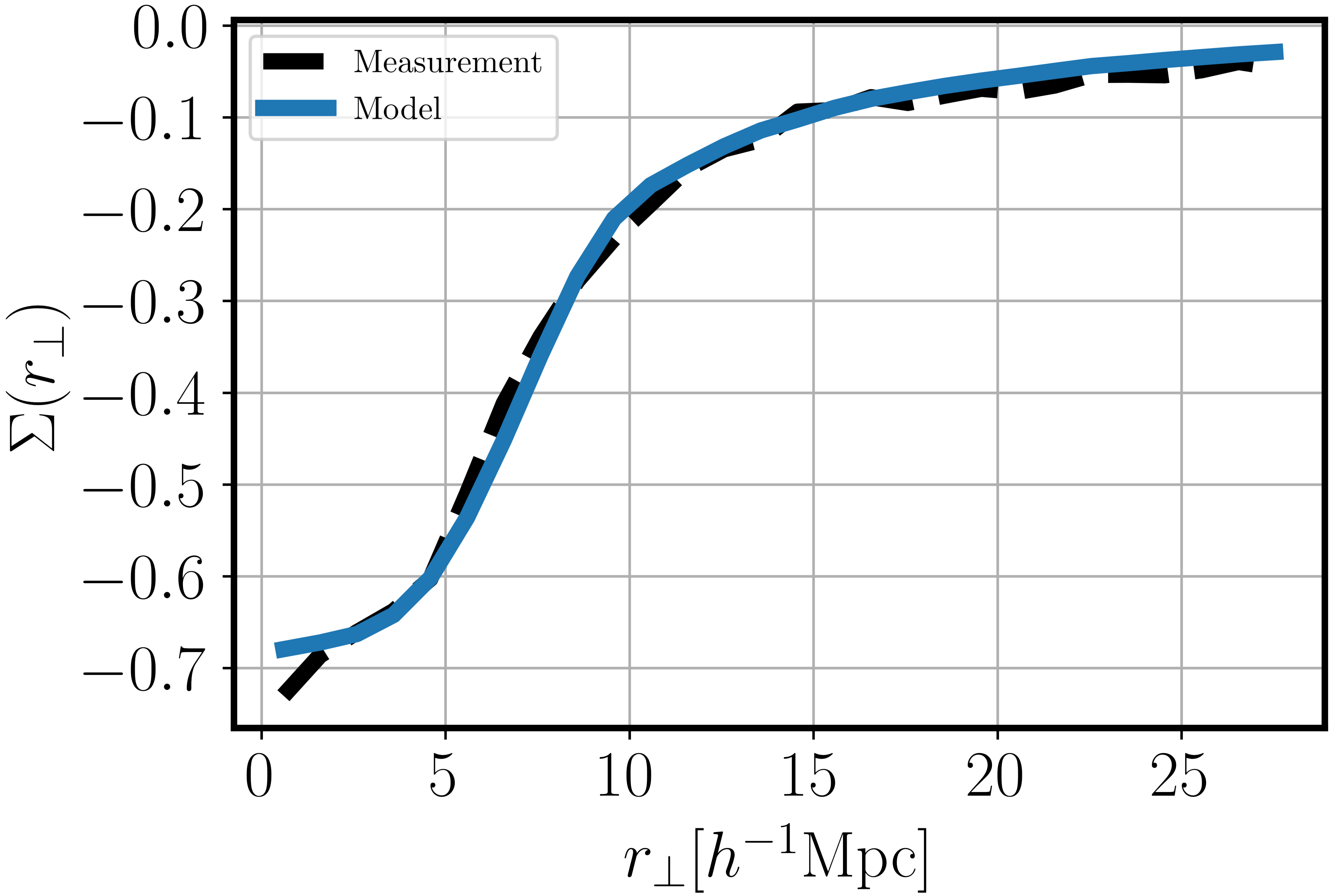


Preliminary Result

$$\Sigma(r_\perp | R_{2D}, \Delta_{2D}) = \int dR_{3D} \frac{dn_v}{dR_{3D}}(R_{3D} | \Delta_{3D}) \int dx_\perp dx_\parallel d\alpha P(x_\perp, x_\parallel, \alpha | R_{3D}, R_{2D}, \Delta_{3D}, \Delta_{2D}) \int dr_\parallel \, \delta_{3D}(r_\perp - x_\perp, r_\parallel - x_\parallel | \alpha, R_{3D}, \Delta_{3D})$$

$$\simeq$$

$$\Sigma(r_\perp | R_{2D}) = \int d\ln R_{3D} \frac{dn_v}{d\ln R_{3D}} \int dx_\perp (1 + \xi(x_\perp)) \int dr_\parallel \, \delta_{3D}(r_\perp, r_\parallel | \alpha, R_{3D})$$

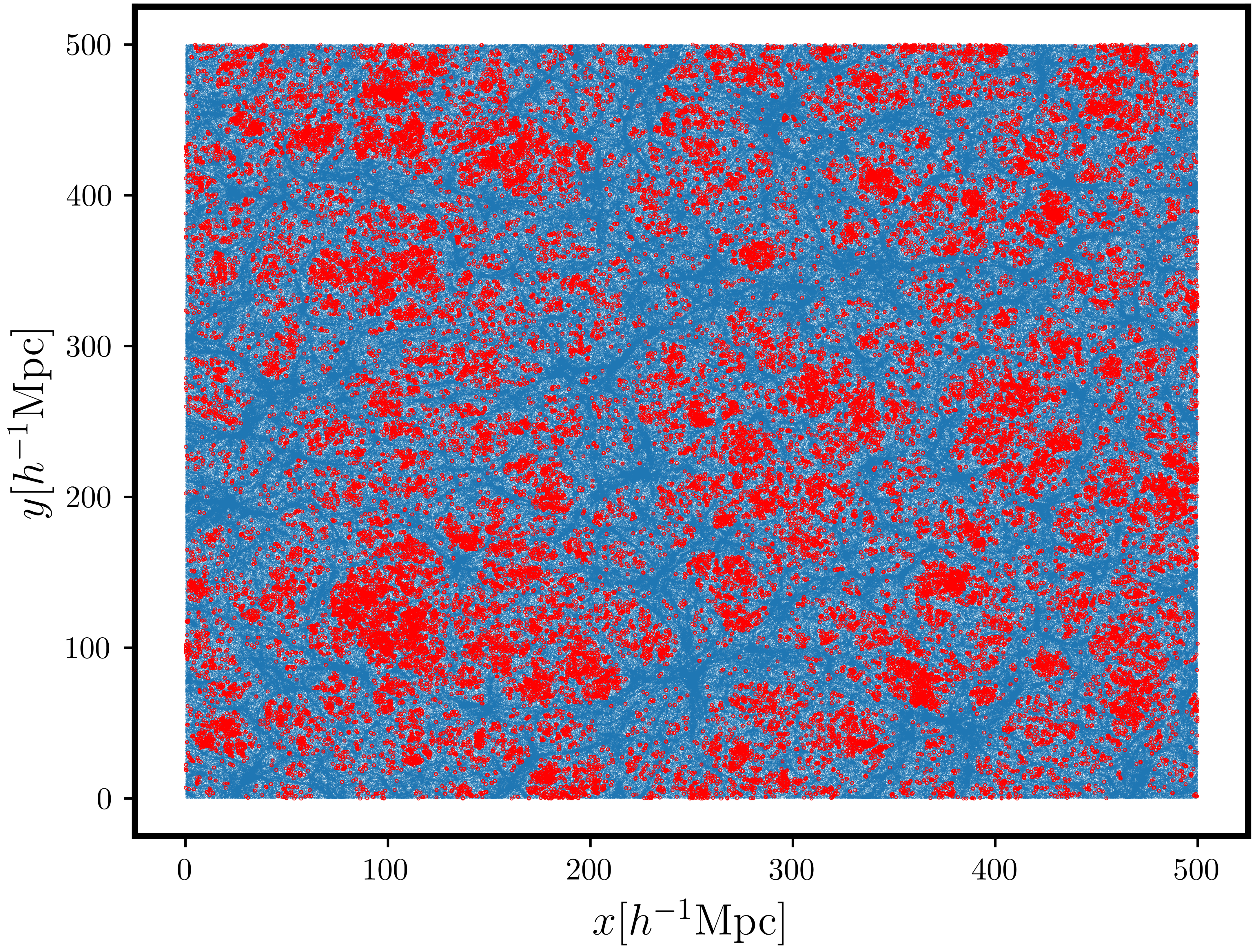


Conclusions and Prospects

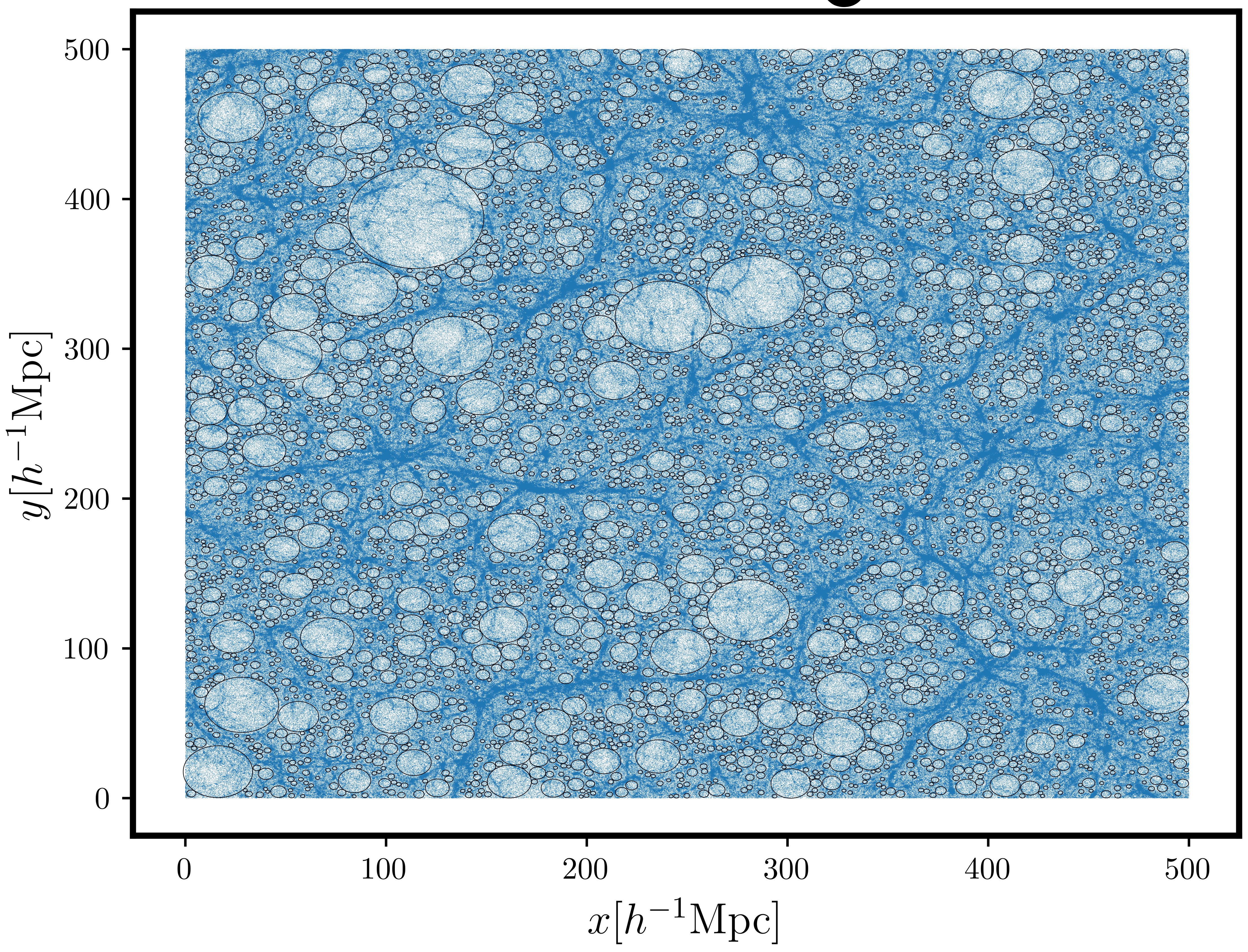
- Void-Lensing can be measured with a significant S/N
- Interesting phenomenology
- Is the Void intrinsic alignment sensitive to cosmology, modifications to gravity or neutrinos?
- What is exactly the cosmological information in Void-Lensing?

Optimum Centering Void Finder

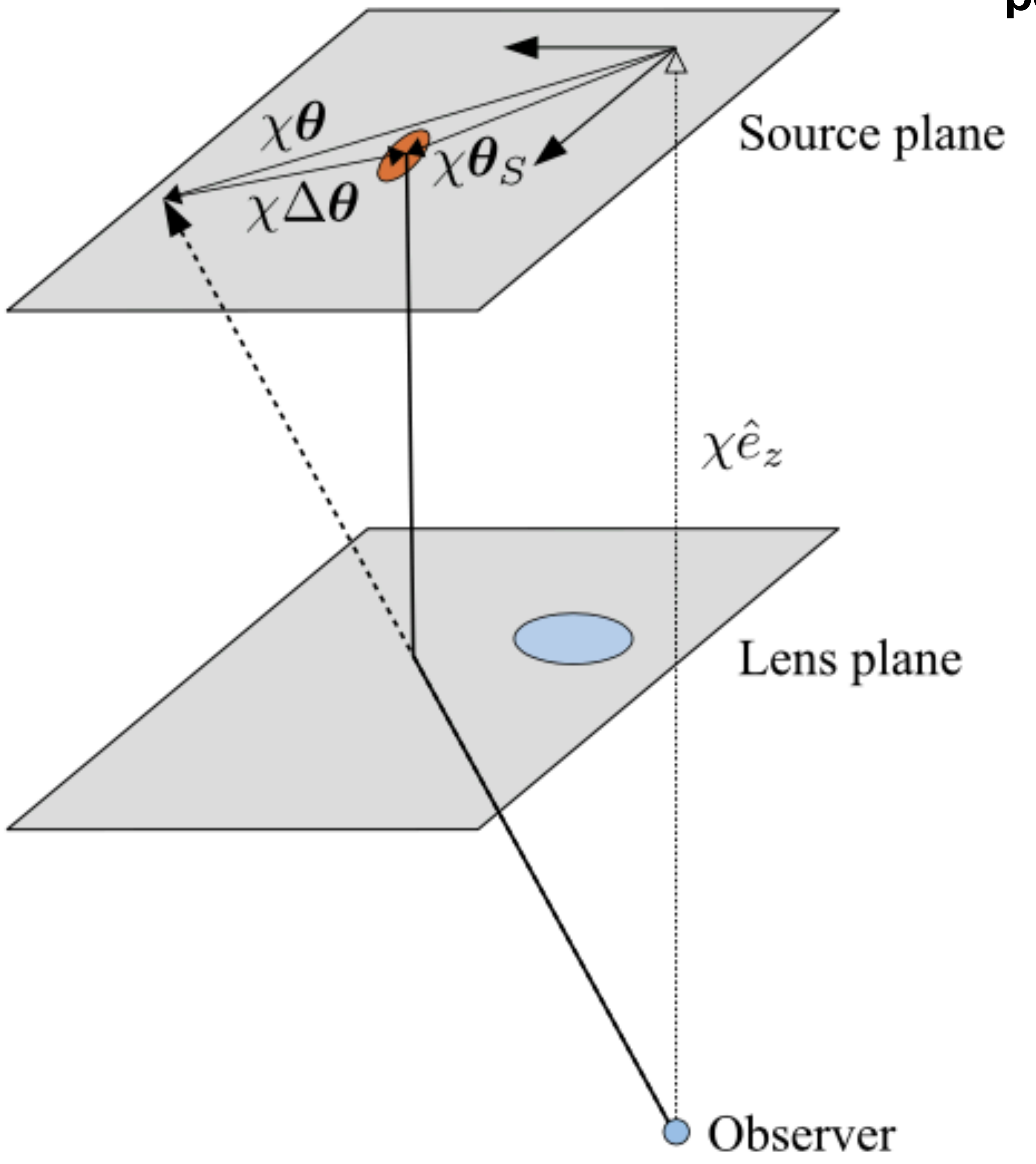
Candidates



Final Catalogue



WL



Dodelson and Schmidt (2021)

Geodesic equation + scalar perturbations $\Rightarrow$

$$\theta^i = \theta^i_s + \Delta\theta^i$$

$$\Delta\theta^i(\boldsymbol{\theta}) = \frac{2}{c^2}\int_0^{\chi} d\chi' \Phi_{,i}\left(\boldsymbol{x}\left(\boldsymbol{\theta},\chi'\right)\right)\chi'\left(1-\frac{\chi'}{\chi}\right)$$

$$\psi_{ij} \equiv \frac{\partial \Delta\theta^i}{\partial\theta^j} = \frac{\partial^2}{\partial\theta^i\partial\theta^j}\phi_{\rm L}(\boldsymbol{\theta}) = \frac{2}{c^2}\int_0^{\chi} d\chi' \Phi_{,ij}\left(\boldsymbol{x}\left(\boldsymbol{\theta},\chi'\right)\right)\chi'\left(1-\frac{\chi'}{\chi}\right)$$

$$A_{ij} \equiv \frac{\partial\theta^i_S}{\partial\theta^j} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$A_{ij} = \delta_{ij} + \psi_{ij}$$

$$\kappa = \psi_{11} + \psi_{22} = \frac{2}{c^2}\int_0^{\chi} d\chi' \nabla^2\Phi\left(\boldsymbol{x}\left(\boldsymbol{\theta},\chi'\right)\right)\chi'\left(1-\frac{\chi'}{\chi}\right)$$

$$\gamma_1 = -\frac{\psi_{11}-\psi_{22}}{2} \qquad \gamma_2 = -\psi_{12}$$

Intuition

Motivation

- The new field act as an extra source of stress-energy (fifth force)

$$\nabla^2\Phi = 4\pi G\left(\rho_M + \rho_{\rm eff}\right)$$

- The Bardeen potentials are not equal in general:

$$\mathrm{d}s^2 = -(1+2\Phi)\mathrm{d}t^2 + a^2(t)(1-2\Psi)\mathrm{d}\mathbf{x}^2$$

$$\Phi_{len} = (\Phi+\Psi)/2 \neq \Psi$$