Relativistic effects with cross-correlations

Enea Di Dio

in collaboration with
Francesco Montanari, Ruth Durrer, Julien Lesgourgues,
Matteo Viel, Vid Irsic

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Relativistic Astrophysics

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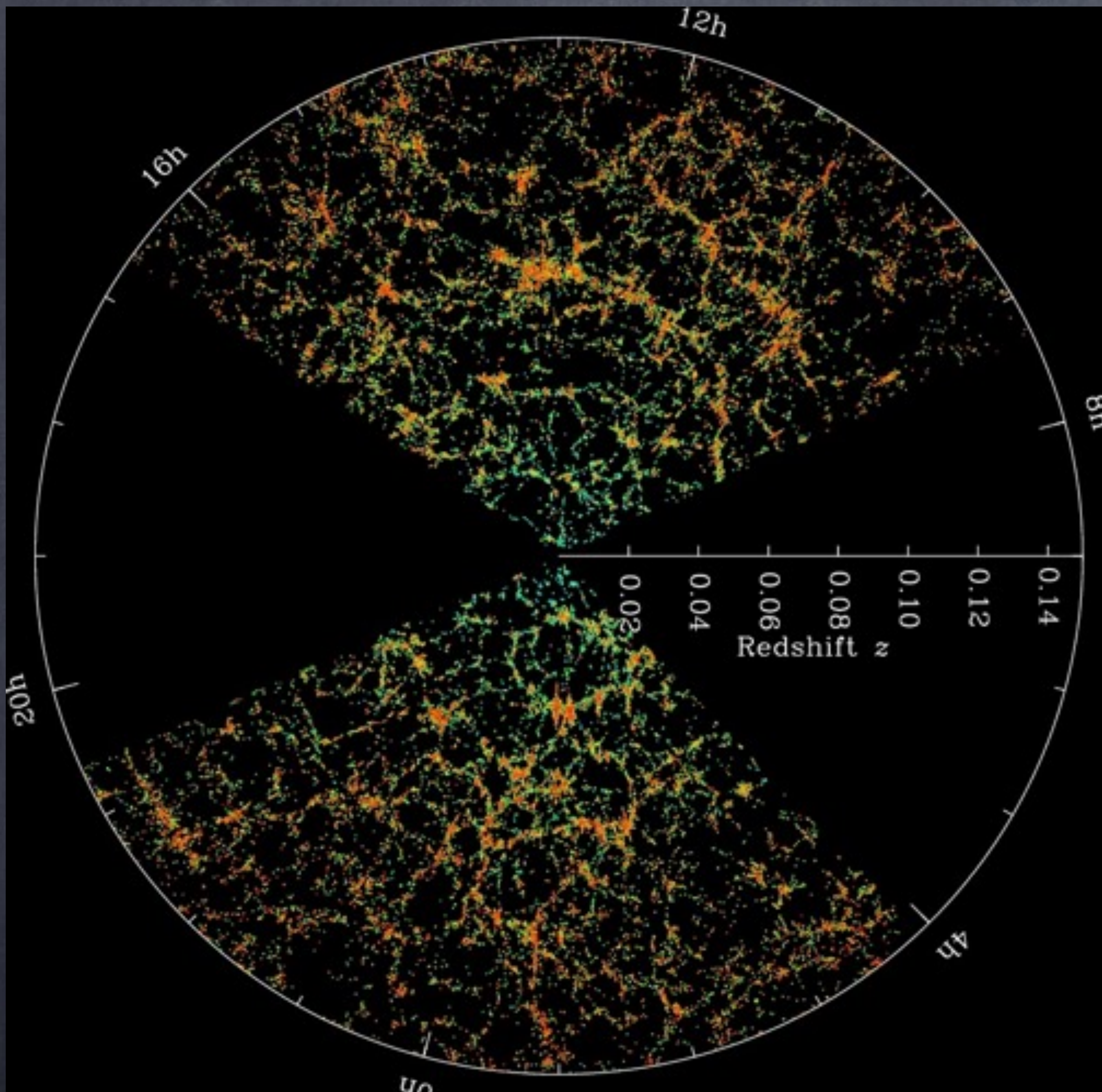
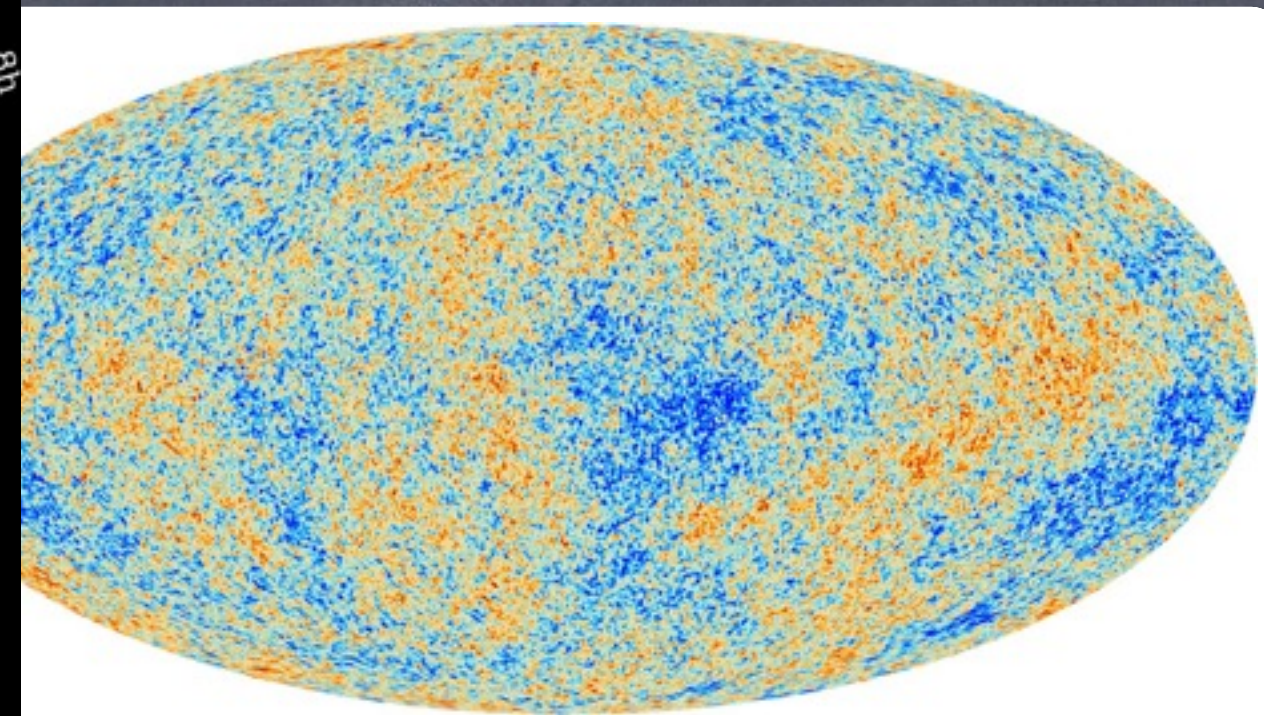
Large Scale Structures



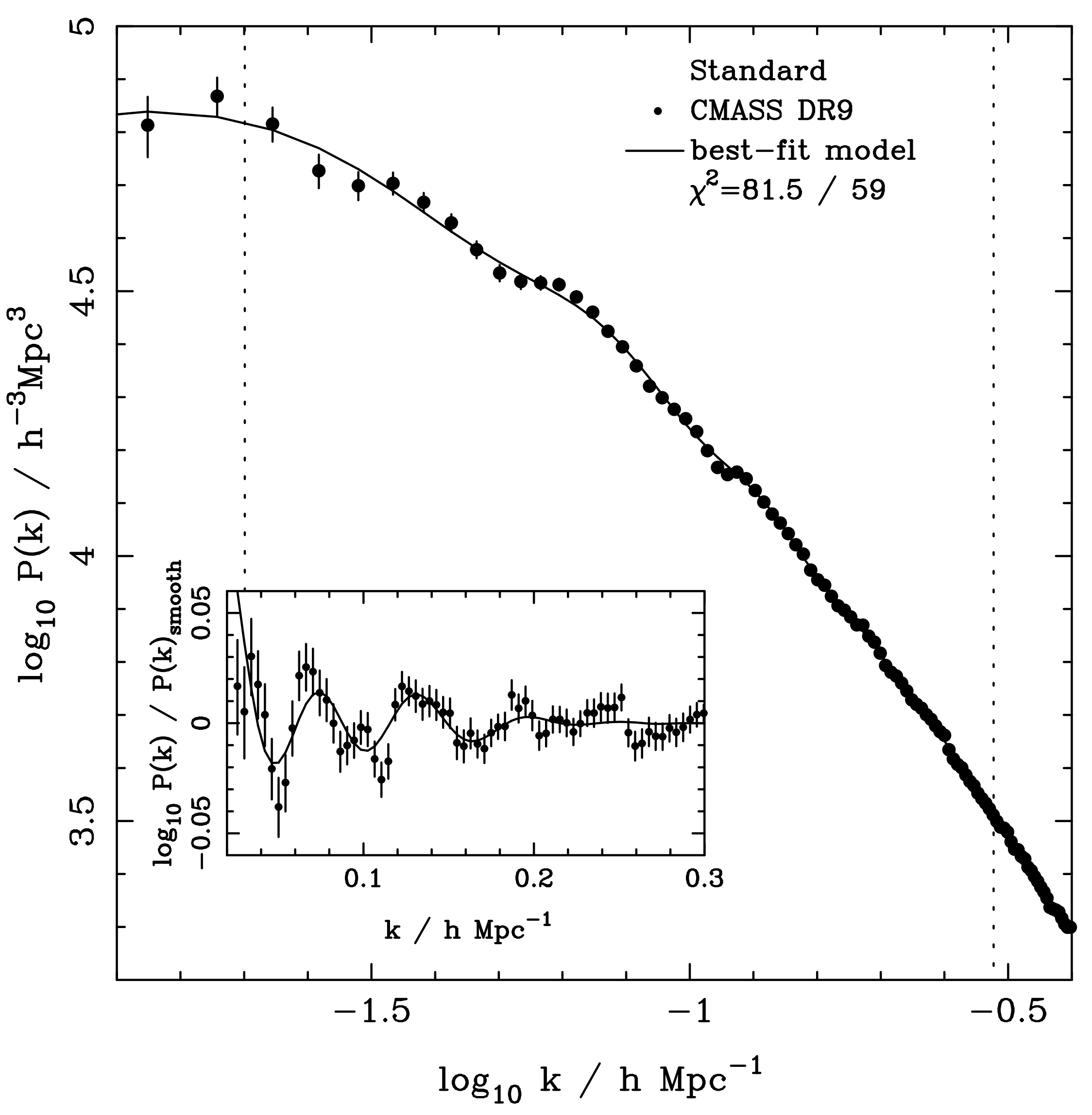
$$2 \sum_{\ell=2}^{2500} (2\ell + 1) \sim 10^7$$



Planck Collaboration

$$(3000)^3 = 2.7 \times 10^{10}$$

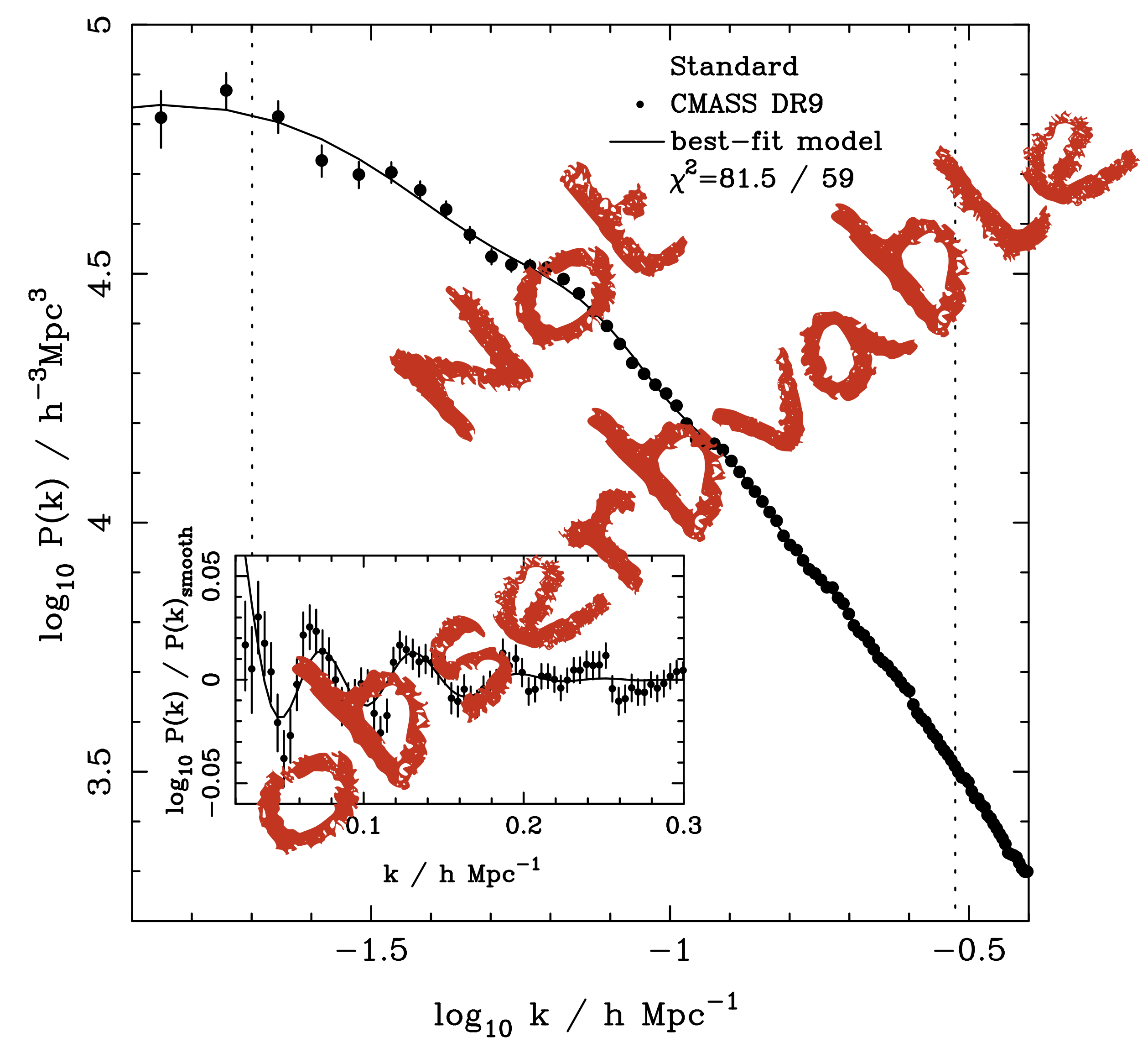
Large Scale Structures



Anderson et al ’12 [arXiv:1203.6594]

$$P_{\rm obs}\left(k,\mu,z\right)=b\left(z\right)^2\left(1+\beta\left(z\right)\mu^2\right)^2P\left(k,z\right)$$

Large Scale Structures



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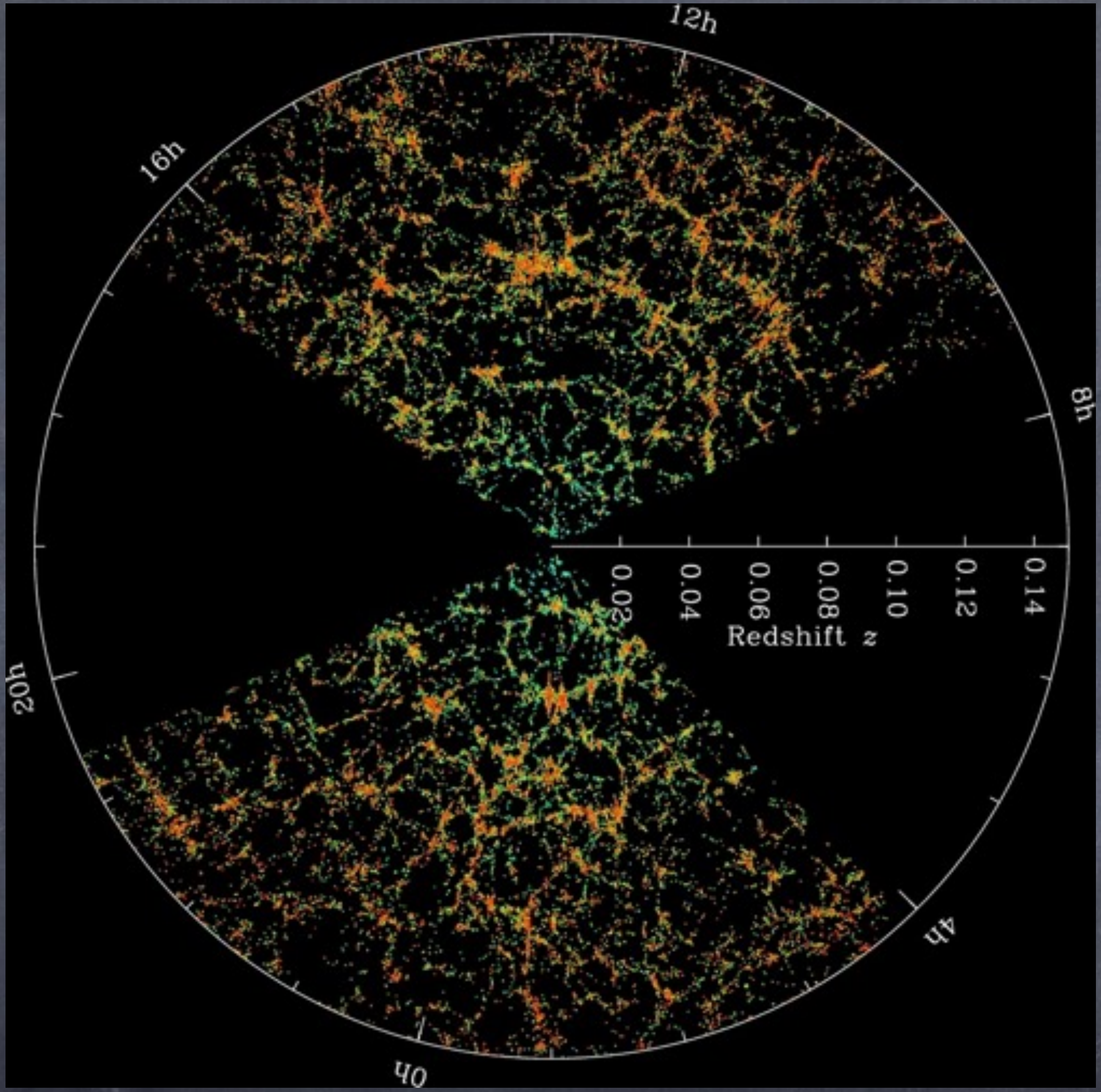

Angular position $\mathbf{n}$ Redshift z

$$N\left(\mathbf{n}, z\right) d\Omega_{\mathbf{n}} dz$$

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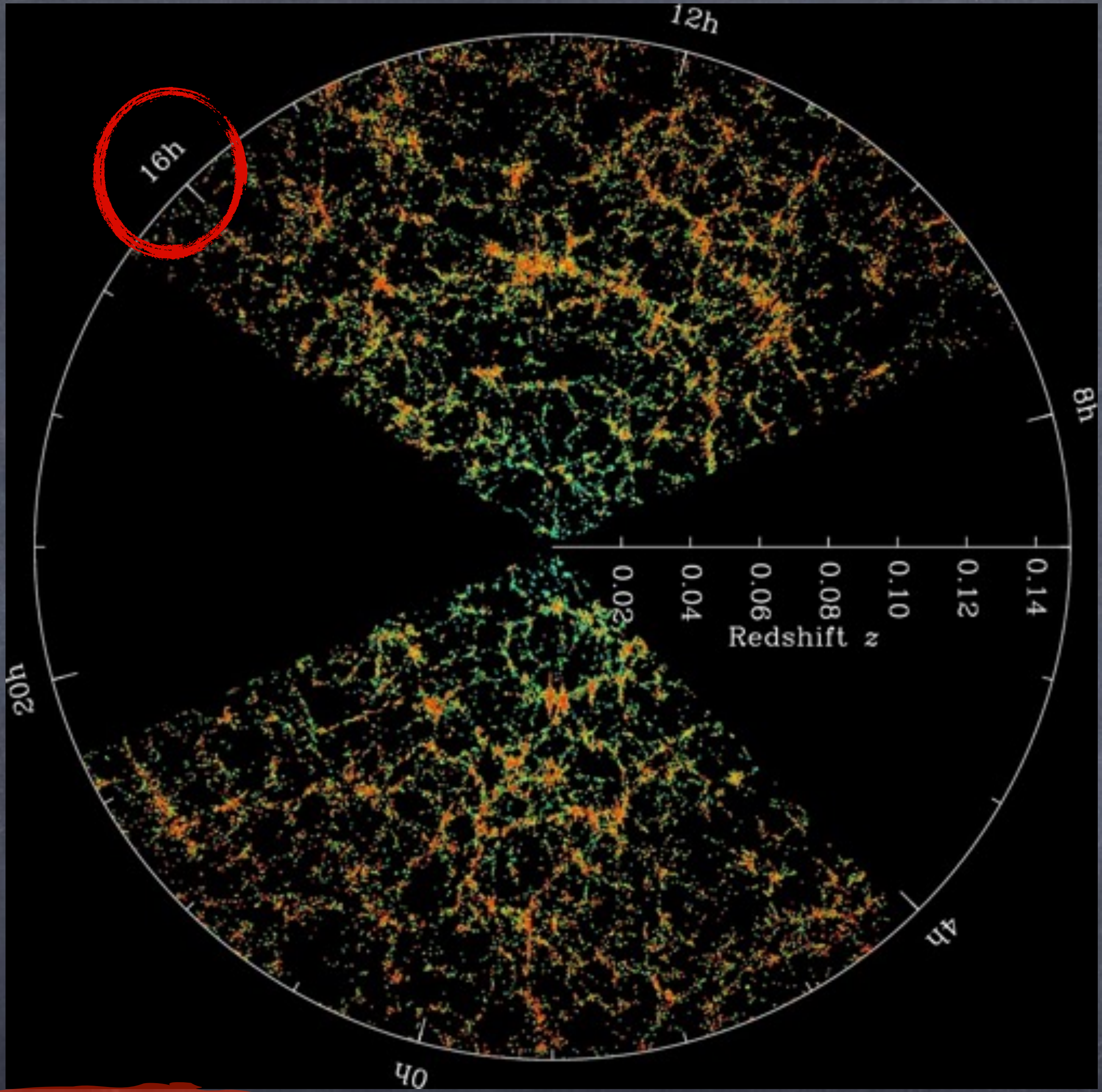

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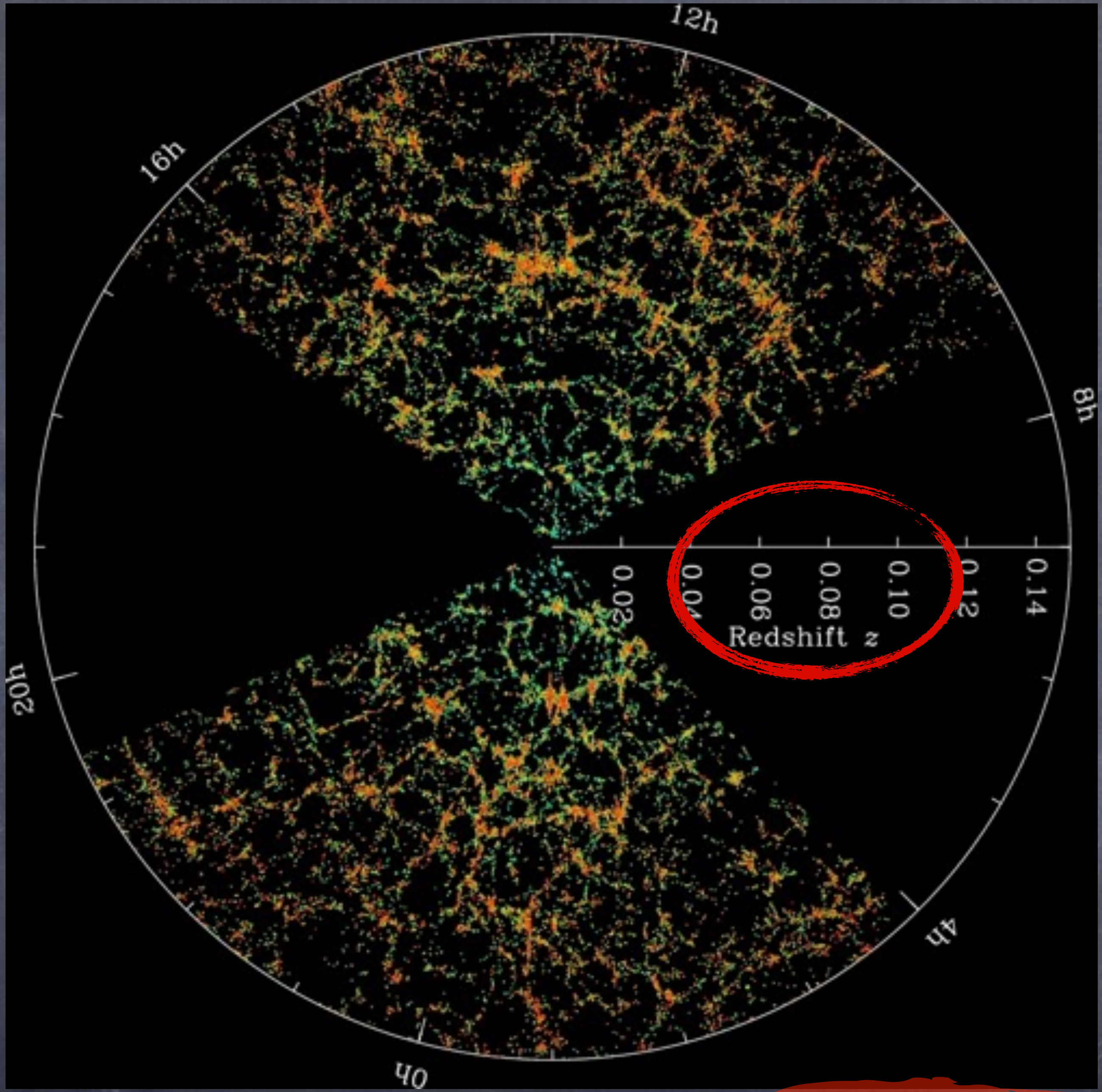

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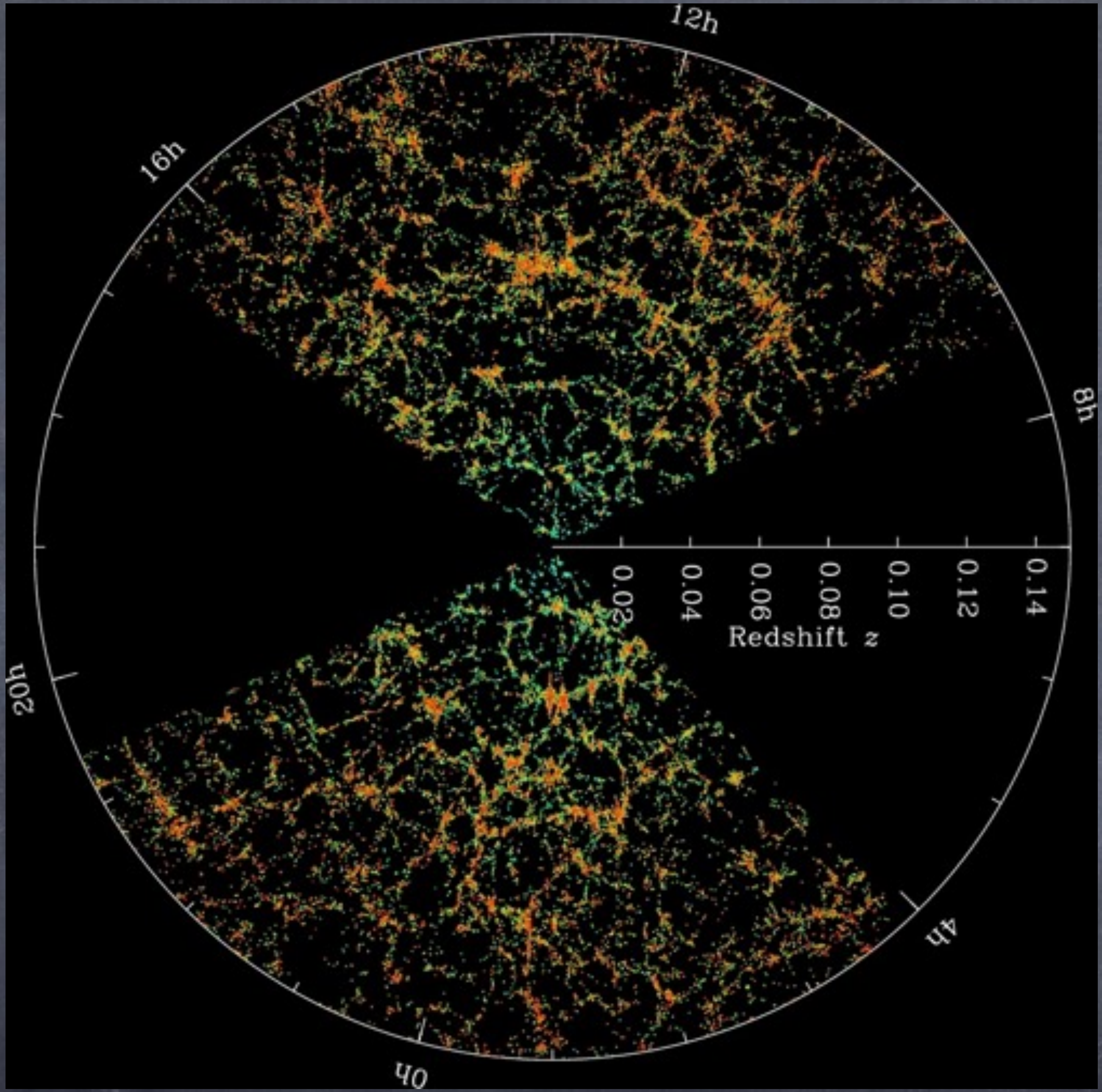

Info about mass, spectral type, ...

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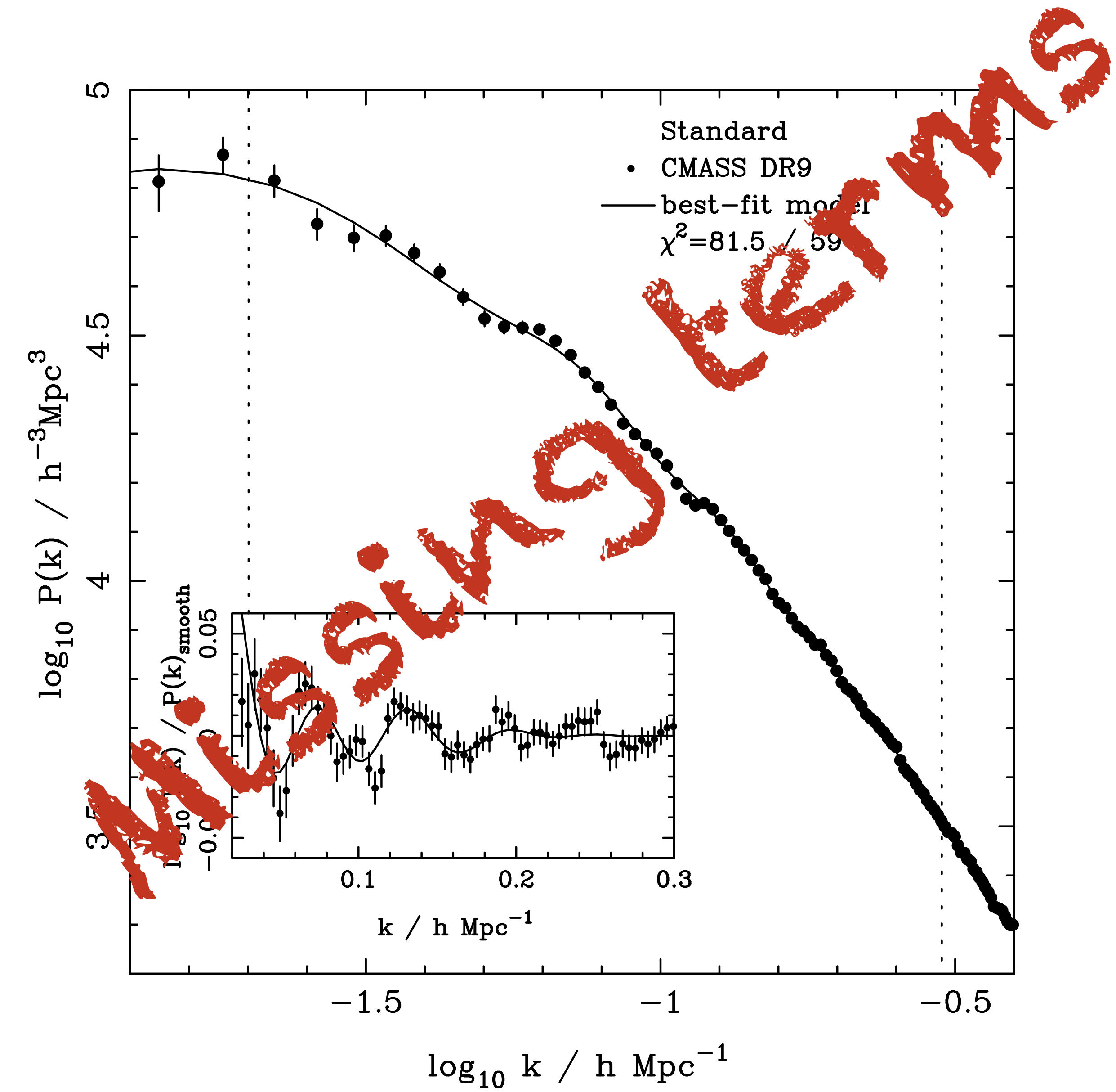

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Large Scale Structures

$$\Delta_N(\mathbf{n}, z, m_*) = b(z) D_{cm}\left(L > \bar{L}_*\right) + \mathcal{H}^{-1}\partial_r \mathbf{n}\cdot\mathbf{v}$$

Standard

$$- \frac{2-5s}{2}\int_0^r \frac{r-r'}{rr'}\Delta_\Omega(\Psi+\Phi)\,dr'$$

$$+ \left(5s + \frac{2-5s}{\mathcal{H}r} + \frac{\dot{\mathcal{H}}}{\mathcal{H}^2} - f^N_{\mathrm{evo}}\right)\mathbf{n}\cdot\mathbf{v} + (f^N_{\mathrm{evo}} - 3)\mathcal{H}v$$

$$+ \left(5s + \frac{2-5s}{\mathcal{H}r} + \frac{\dot{\mathcal{H}}}{\mathcal{H}^2} - f^N_{\mathrm{evo}}\right)\int_0^r \left(\dot{\Psi} + \dot{\Phi}\right) dr'$$

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Relativistic Effects

Bonvin & Durrer [arXiv:1105.5280],
Challinor & Lewis [arXiv:1105.5292],
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What do we really observe?

To compute $\Delta(\mathbf{n}, z) \equiv \dfrac{N(\mathbf{n}, z) - <N> (z)}{<N> (z)}$
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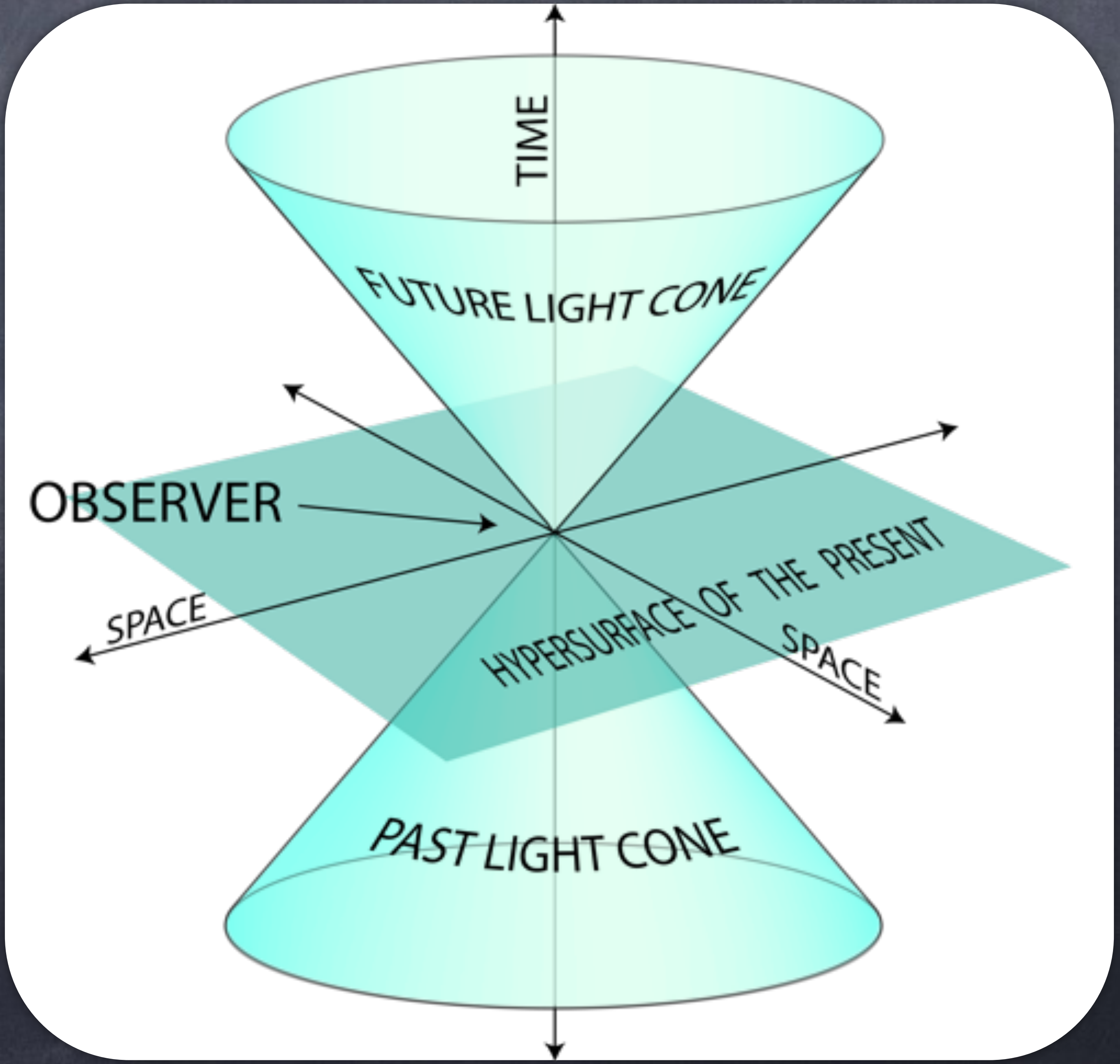

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To compute $\Delta(\mathbf{n}, z) \equiv \dfrac{N(\mathbf{n}, z) - <N>(z)}{<N>(z)}$
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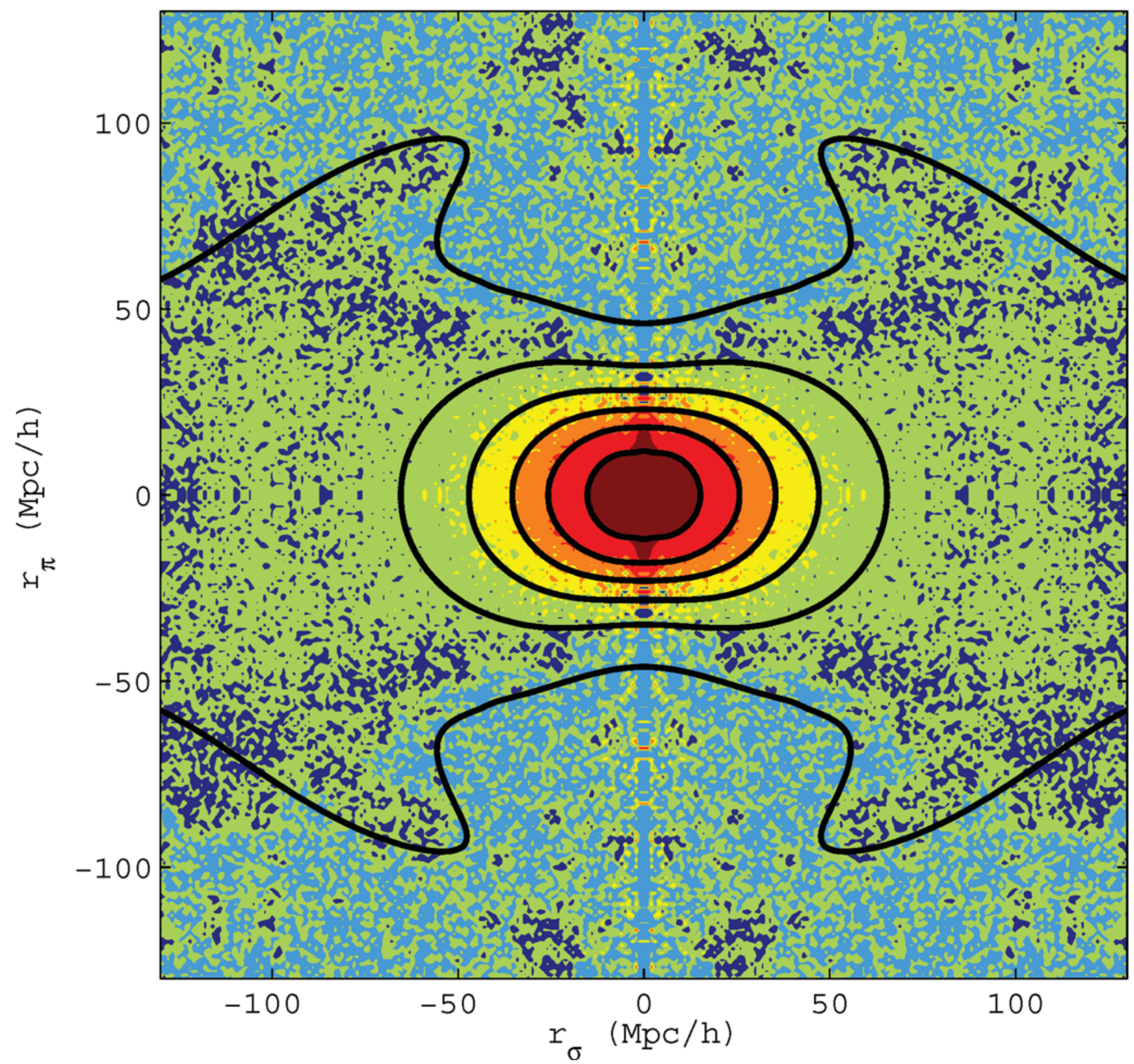

Reid et al '12 [arXiv:1203.6641]

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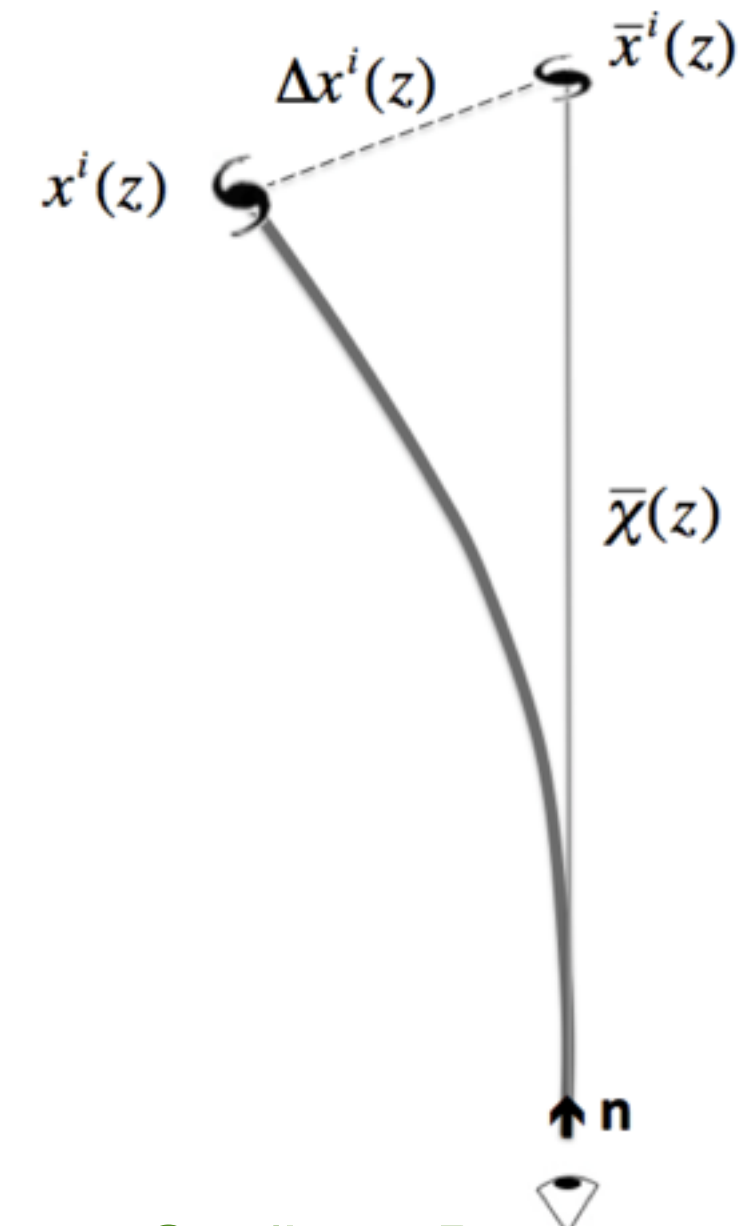
To compute $\Delta(\mathbf{n}, z) \equiv \dfrac{N(\mathbf{n}, z) - <N>(z)}{<N>(z)}$
we have to consider:

- observation on the past lightcone
- redshift perturbed by peculiar velocity
- light deflection



Credits to Bertacca

Large Scale Structures

$$\Delta_N(\mathbf{n}, z, m_*) = b(z) D_{cm}\left(L > \bar{L}_*\right) + \mathcal{H}^{-1}\partial_r \mathbf{n}\cdot\mathbf{v}$$

$$\sim D$$

$$- \frac{2-5s}{2}\int_0^r \frac{r-r'}{rr'}\Delta_\Omega(\Psi+\Phi)\,dr'$$

$$+ \left(5s + \frac{2-5s}{\mathcal{H}r} + \frac{\dot{\mathcal{H}}}{\mathcal{H}^2} - f^N_{\text{evo}}\right)\mathbf{n}\cdot\mathbf{v} + (f^N_{\text{evo}} - 3)\mathcal{H}v$$

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$$\sim \frac{\mathcal{H}}{k} D \qquad + \left(5s + \frac{2-5s}{\mathcal{H}r} + \frac{\dot{\mathcal{H}}}{\mathcal{H}^2} - f^N_{\rm evo}\right)\mathbf{n}\cdot\mathbf{v} + (f^N_{\rm evo} - 3)\mathcal{H}v$$

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$\sim \left(\frac{\mathcal{H}}{k}\right)^2 D$

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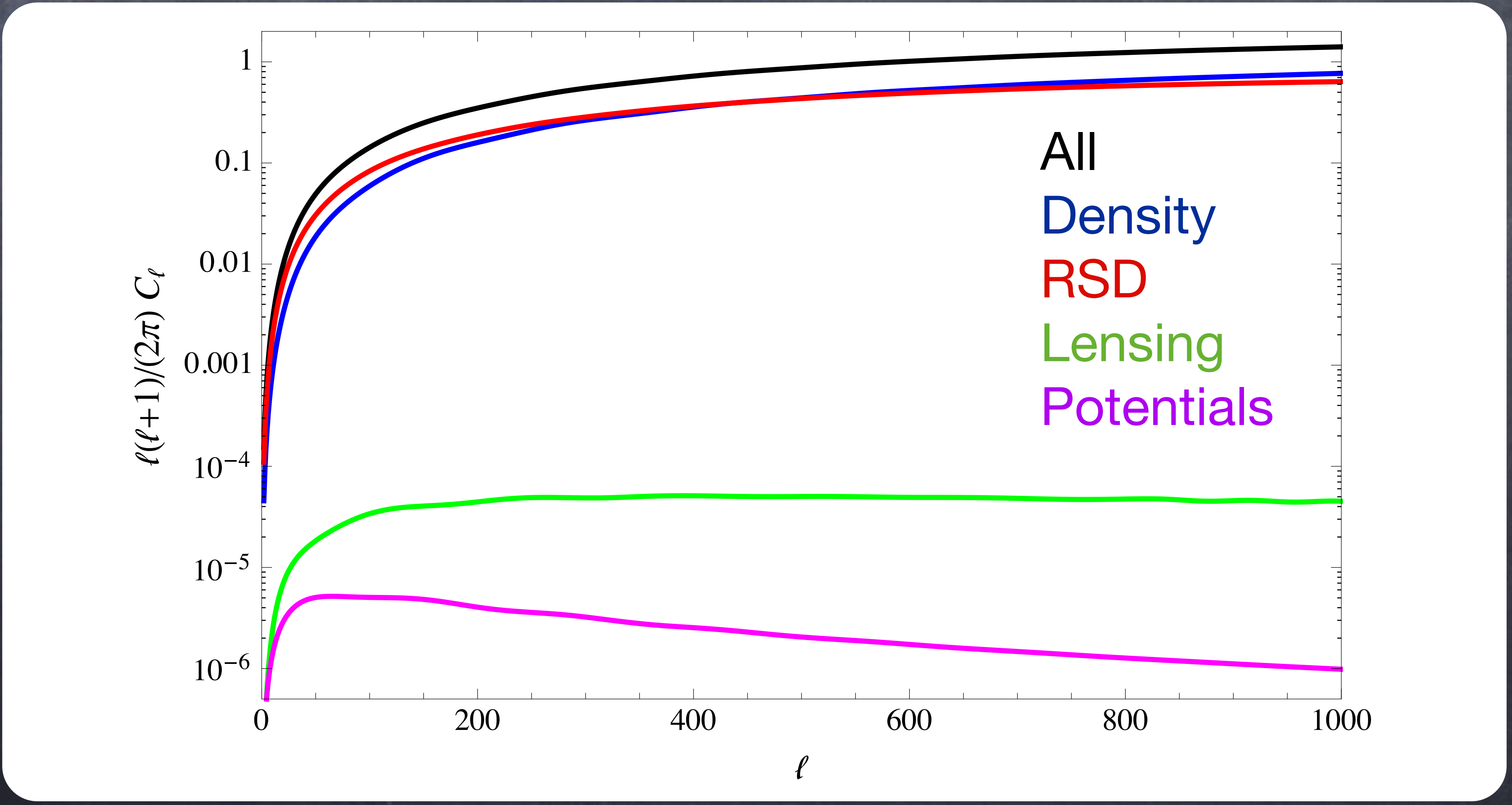
z-dependent angular power spectrum

Power spectrum

$$c_\ell(z_1, z_2) = < a_{lm}(z_1) a_{lm}(z_2) > = 4\pi \int \frac{dk}{k} \mathcal{P}(k) \Delta_\ell(z_1, k) \Delta_\ell(z_2, k)$$

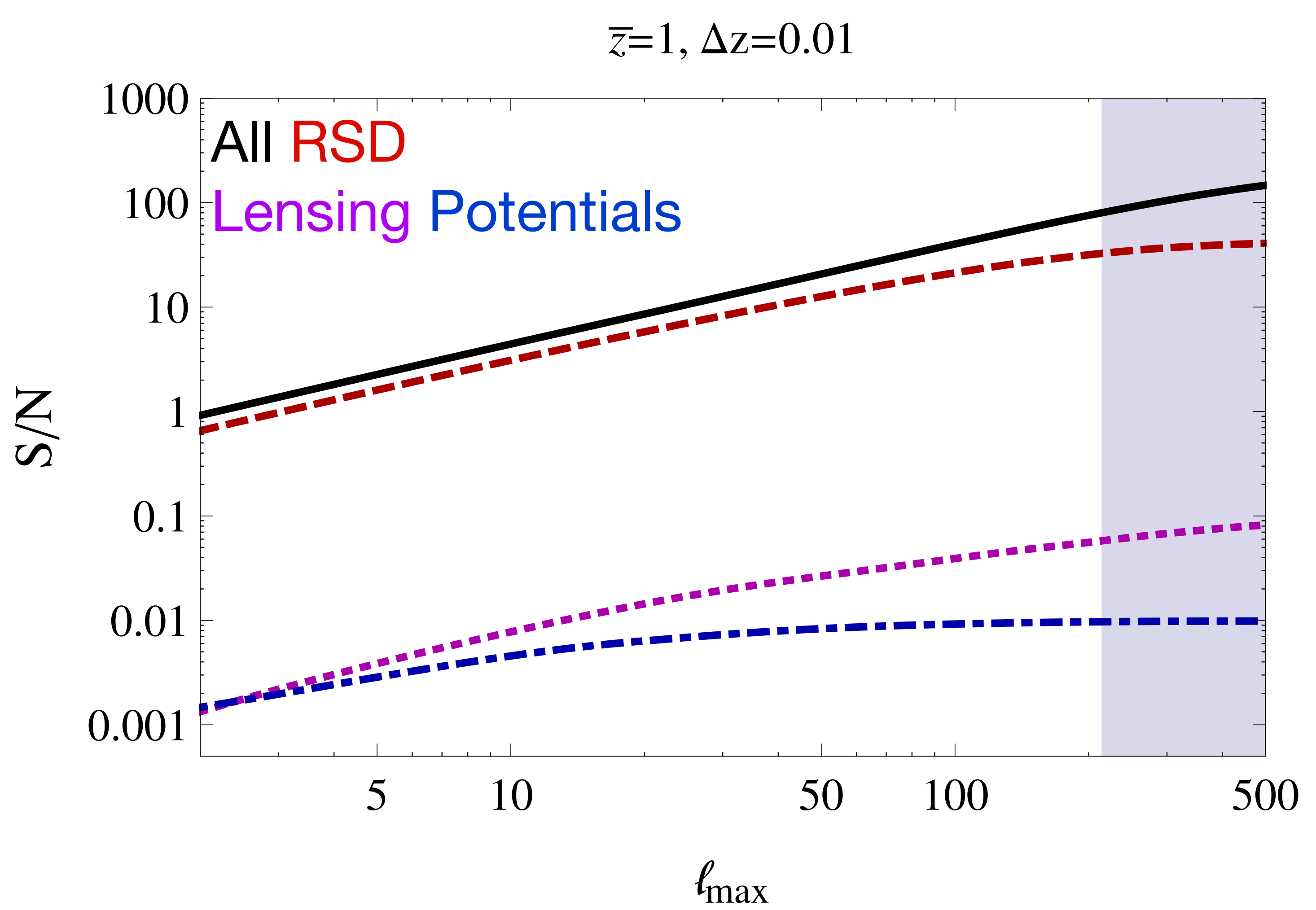


Lensing Potential

Cumulative Signal to Noise

$$\left(\frac{S}{N}\right)^2 = \sum_{\ell=2}^{\ell_{\max}} \left(\frac{C_\ell - \tilde{C}_\ell}{\sigma_\ell}\right)^2$$

Euclid



ED, Montanari, Durrer, Lesgourgues [arXiv:1308.6186]

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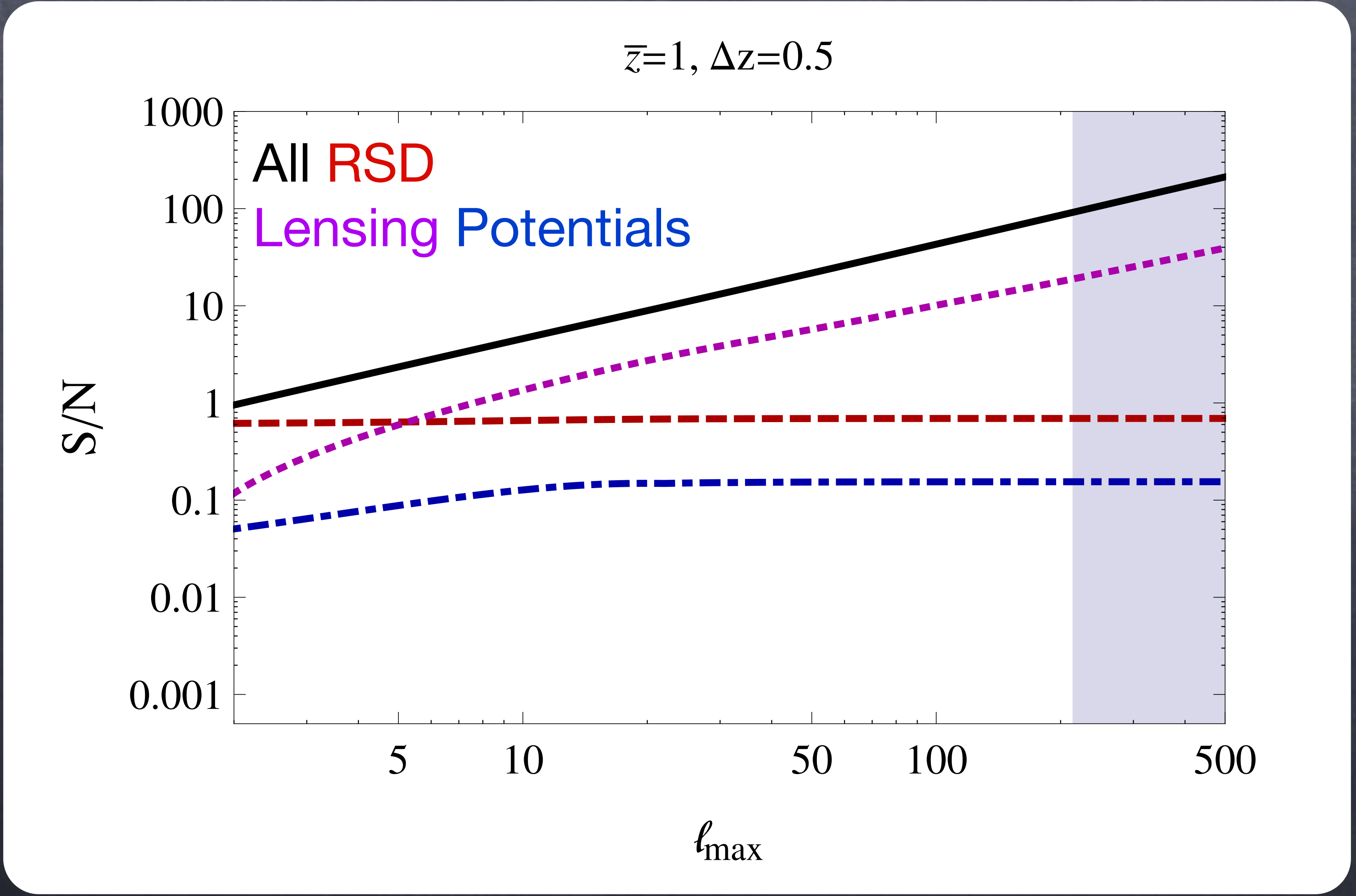

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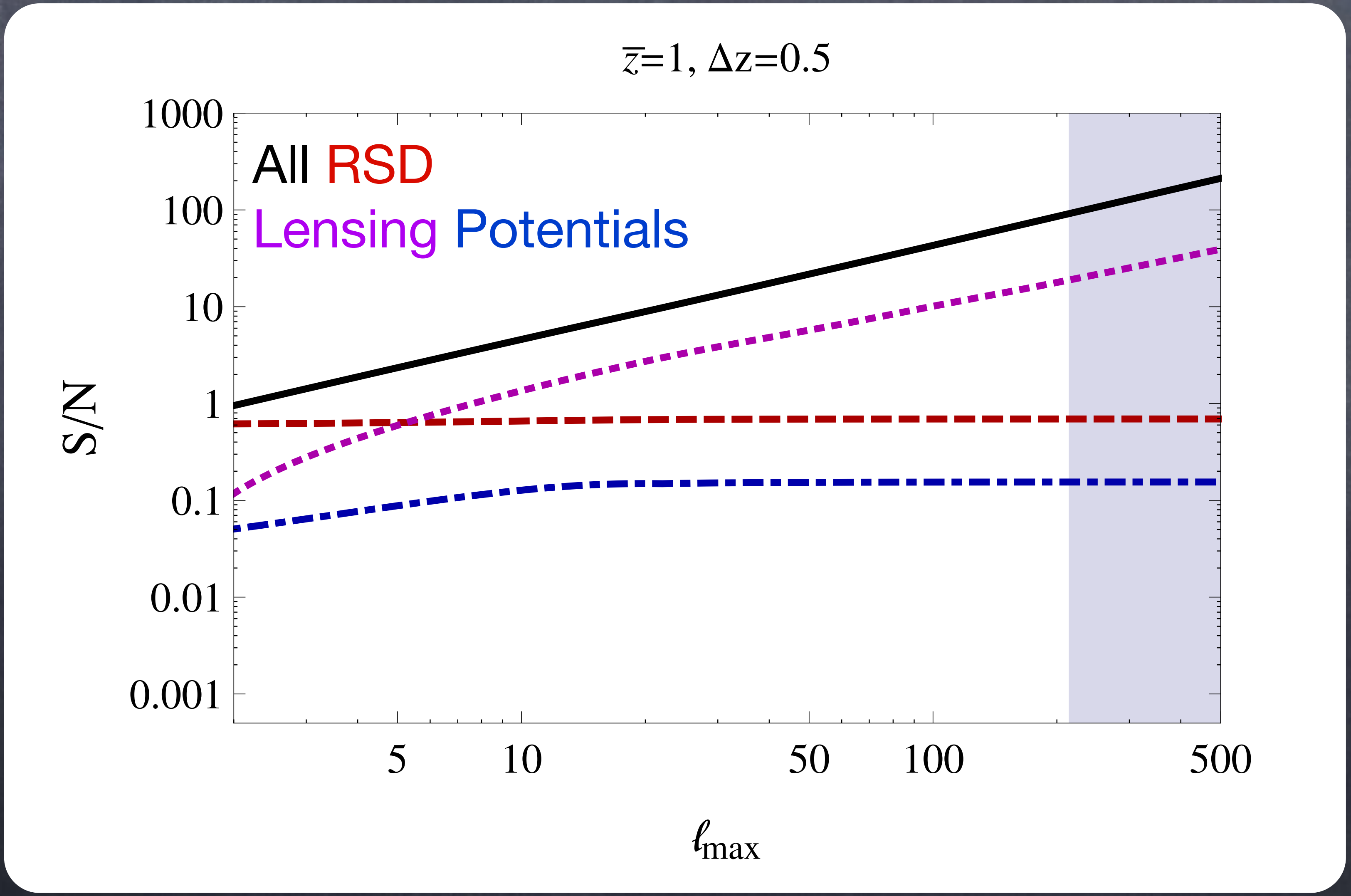

See Montanari's Talk

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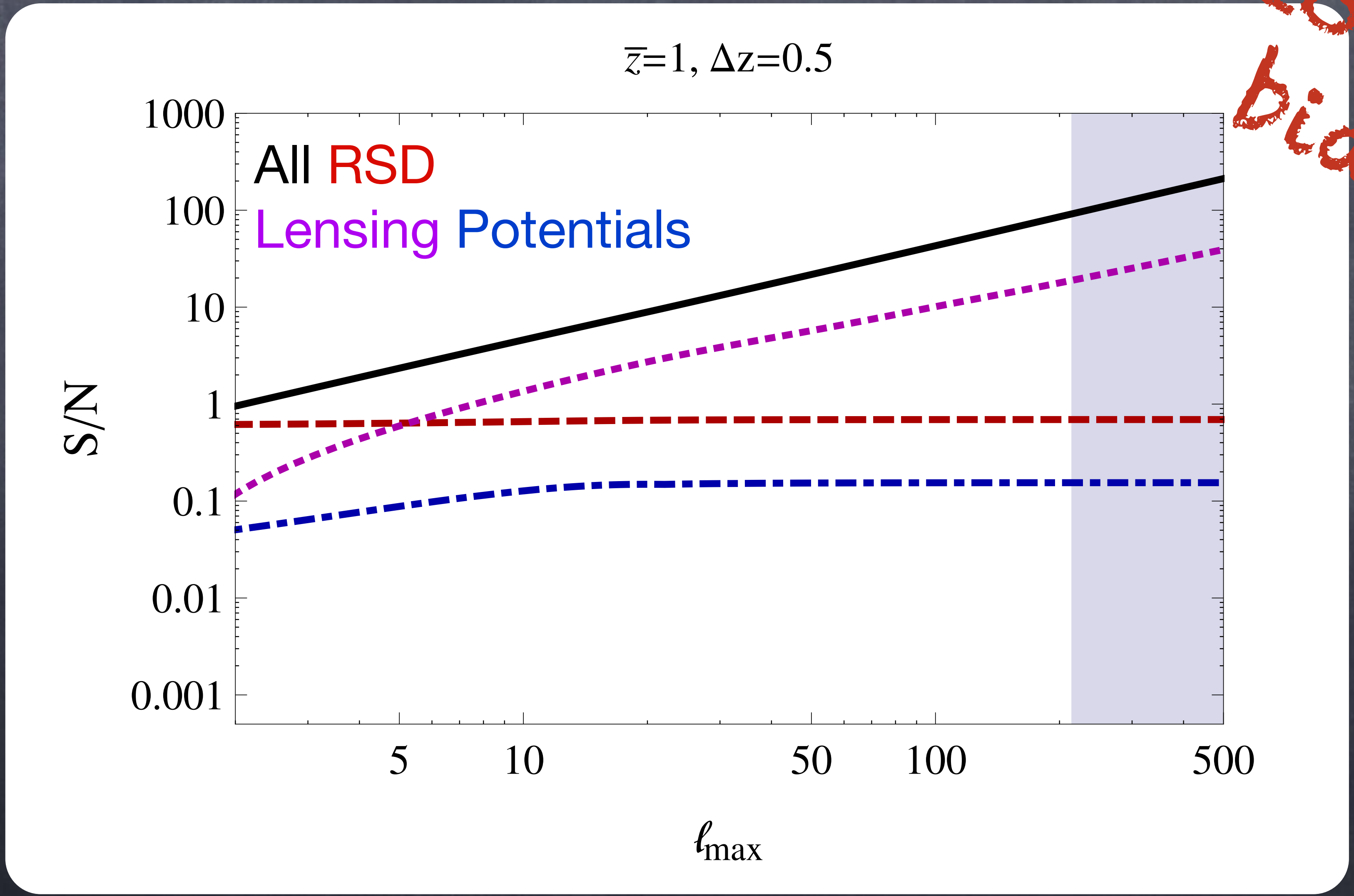
Theoretical bias?

Euclid



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Relativistic Effects

Relativistic Effects

Are relativistic effects relevant for the standard analysis?

- No, but.. (Yoo and Seljak [ArXiv:1308.1093], Yoo et al [arXiv:1206.5809], Alonso et al [1505.07596])
- cosmic magnification for deep survey
  (see also Raccanelli et al [ArXiv:1311.6813], Alonso et al [1505.07596], Montanari and Durrer [ArXiv:1506.01369])

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If not relevant in standard analysis, can we think to an alternative analysis to measure them?

- imaginary power spectrum (McDonald [Arxiv:0907.5220])
- dipole and octupole in galaxy correlation functions (Raccanelli et al [ArXiv:1306.6646], Bonvin et al [Arxiv:1309.1321])
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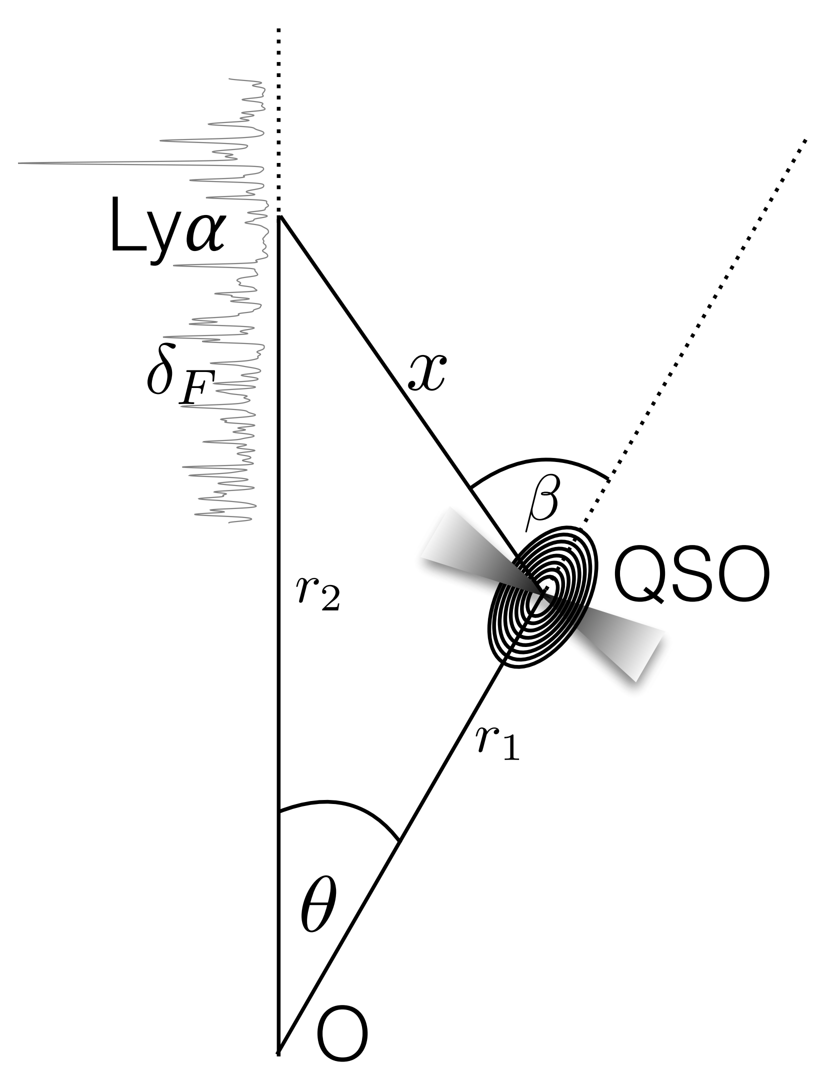
Multi-tracers

Quasars x Ly-alpha correlation

Irsic , ED, Viel [arXiv:1510.03436]



$$\xi_{Q\alpha}\left(z_1, z_2, \theta\right) = \left\langle \Delta_Q\left(\mathbf{n}_1, z_1\right) \delta_F\left(\mathbf{n}_2, z_2\right)\right\rangle$$

Large bias factor difference

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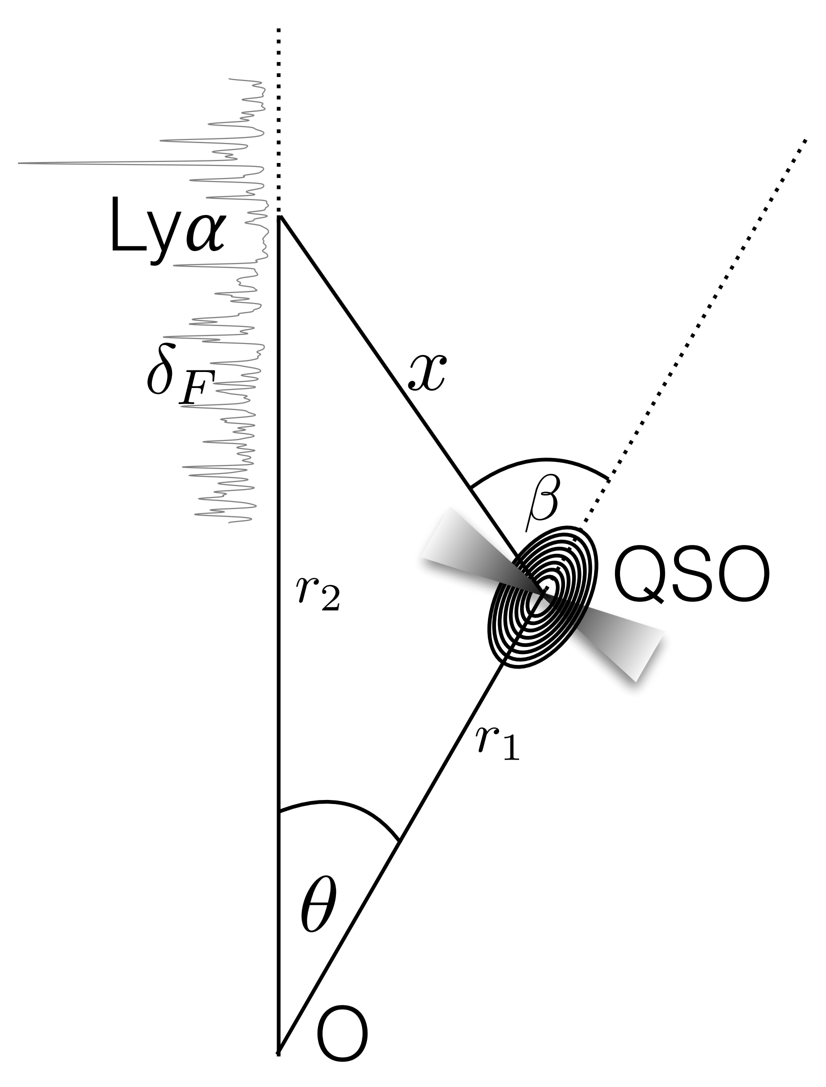

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Large bias factor difference

$$\delta_F\left(\mathbf{n}, z\right) = b_\alpha \delta^{\rm sync} + b_v \mathcal{H}^{-1}\partial_r \mathbf{n}\cdot\mathbf{v} - \bar{\tau}\left(z\right)\left[-\left(2 + \frac{\dot{\mathcal{H}}}{\mathcal{H}^2}\right)\frac{\delta z}{1+z} + \mathbf{n}\cdot\mathbf{v} + \Psi + \mathcal{H}^{-1}\dot{\Phi} - 3\mathcal{H}v\right]$$

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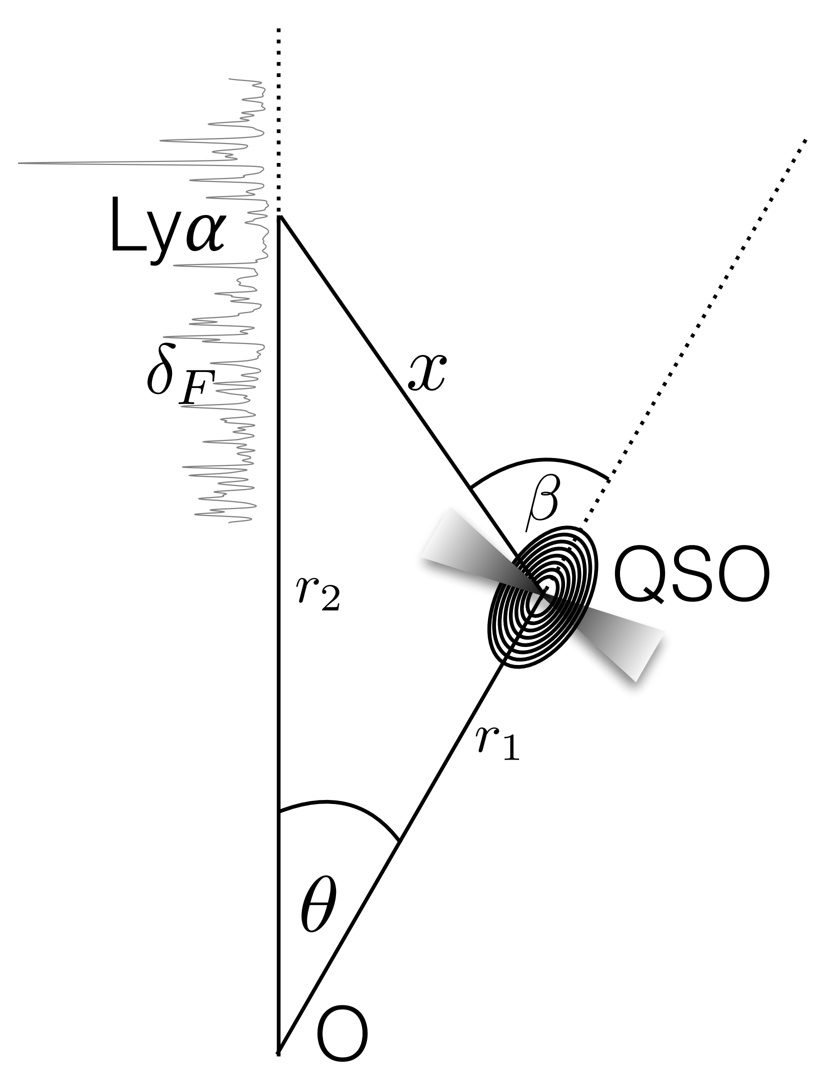

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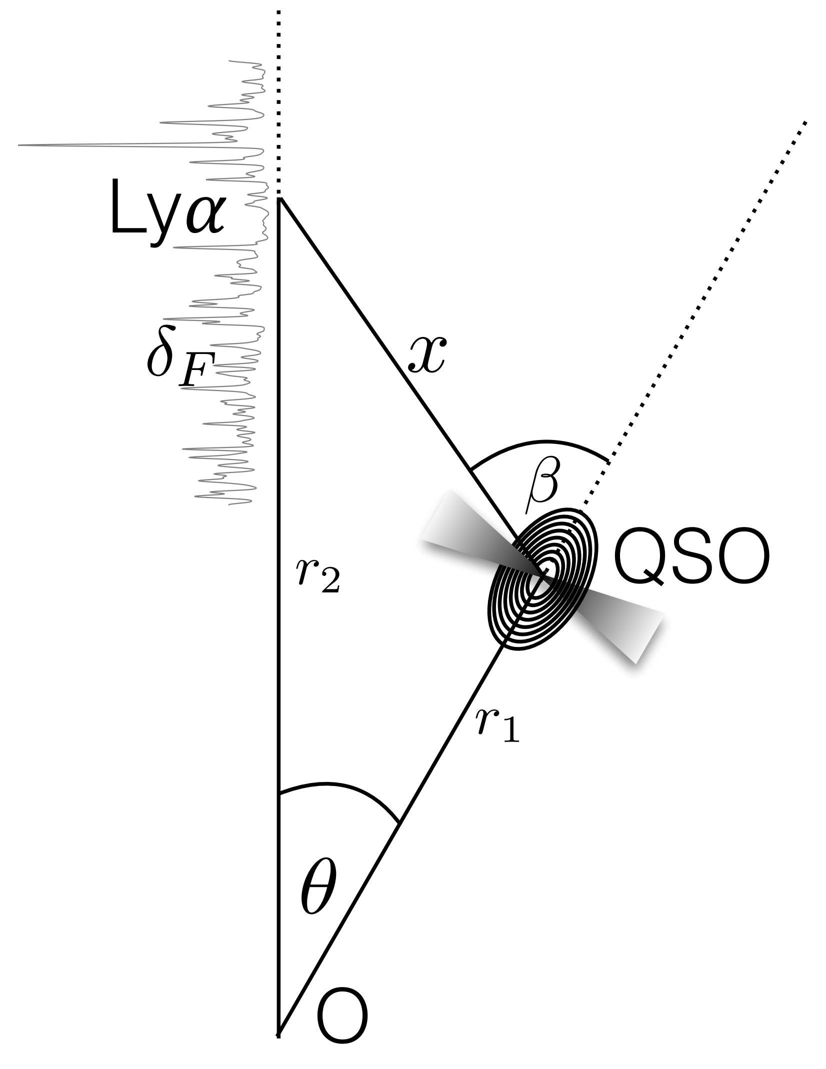
Standard

Quasars x Ly-alpha correlation

Irsic , ED, Viel [arXiv:1510.03436]

$$\xi_{Q\alpha}(z_1, z_2, \theta) = \langle \Delta_Q(\mathbf{n}_1, z_1)\, \delta_F(\mathbf{n}_2, z_2) \rangle$$



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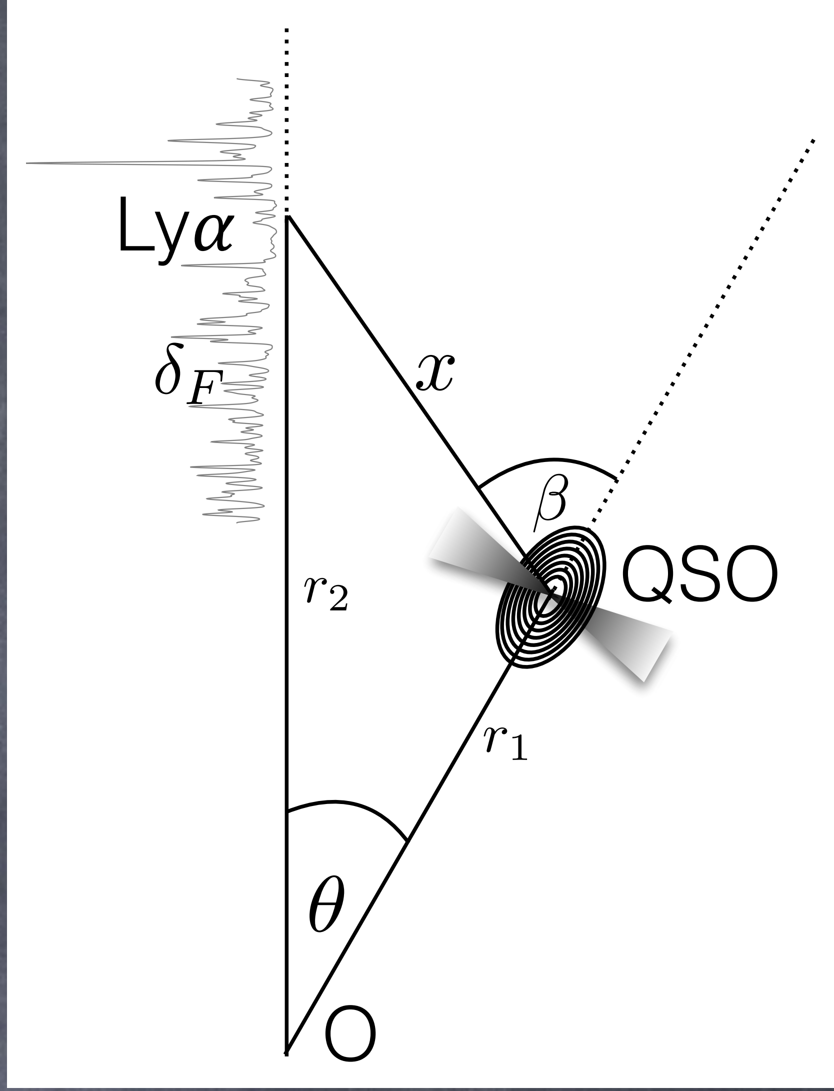

$$\xi_{Q\alpha}\left(z_1, z_2, \theta\right) = \left\langle \Delta_Q\left(\mathbf{n}_1, z_1\right) \delta_F\left(\mathbf{n}_2, z_2\right)\right\rangle$$

$$\xi_{Q\alpha} = \xi_{Q\alpha}^{\text{newt}} + \xi_{Q\alpha}^{\text{magnification}} + \xi_{Q\alpha}^{\text{relativistic}}$$

Quasars x Ly-alpha correlation

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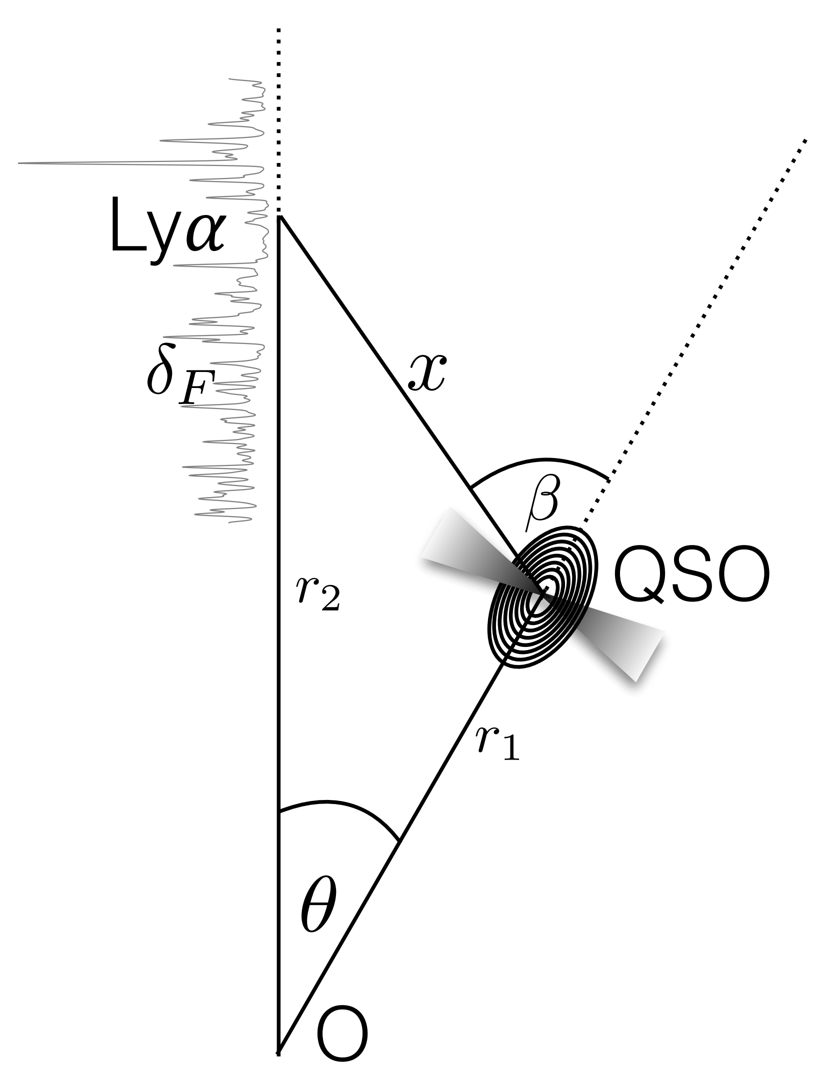

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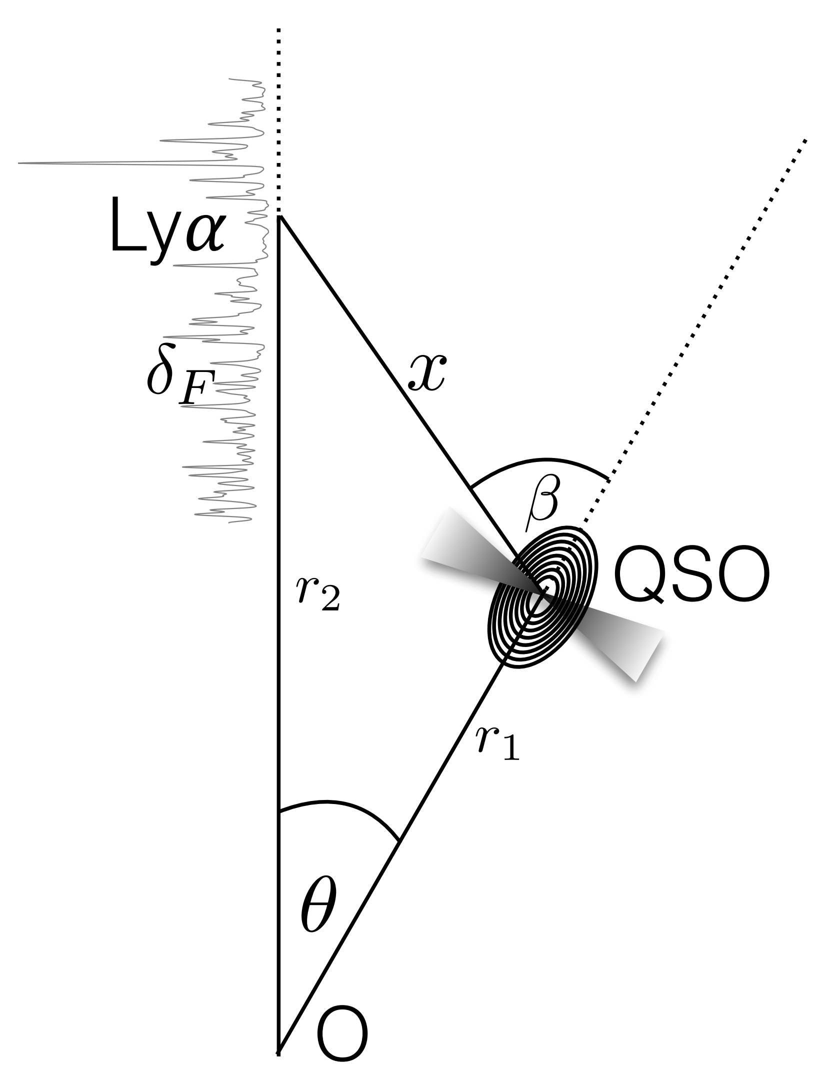
$$\xi_{Q\alpha}^{\rm newt} \sim b_Q b_\alpha \int \frac{dk}{2\pi^2} k^2 P\left(k\right) j_0\left(kx\right)$$
$$+ b_v \int \frac{dk}{2\pi^2} k^2 f^2 P\left(k\right) \left[\frac{1}{5} j_0\left(kx\right) - \frac{4}{7} j_2\left(kx\right) + \frac{8}{35} j_4\left(kx\right)\right]$$
$$+ \left(b_Q b_v + b_\alpha\right) \int \frac{dk}{2\pi^2} k^2 f P\left(k\right) \left[\frac{1}{3} j_0\left(kx\right) - \frac{2}{3} j_2\left(kx\right)\right]$$

Order $\mathcal{O}(1)$

Even spherical Bessel functions

Quasars x Ly-alpha correlation

Irsic , ED, Viel [arXiv:1510.03436]



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$$\xi_{Q\alpha} = \xi_{Q\alpha}^{\text{newt}} + \xi_{Q\alpha}^{\text{magnification}} + \xi_{Q\alpha}^{\text{relativistic}}$$

$$\xi_{Q\alpha}^{\text{Doppler}} \sim \left(-b_Q\mathcal{R}_\alpha + \mathcal{R}_Q b_\alpha\right)\int \frac{dk}{2\pi^2}k^2 f P\left(k\right) j_1\left(kx\right)\frac{\mathcal{H}}{k}$$
$$+ \left(-\mathcal{R}_\alpha + \mathcal{R}_Q b_v\right)\int \frac{dk}{2\pi^2}k^2 f^2 P\left(k\right)\left[\frac{3}{5}j_1\left(kx\right) - \frac{2}{5}j_3\left(kx\right)\right]\frac{\mathcal{H}}{k}$$
$$+ \mathcal{R}_\alpha\mathcal{R}_Q\int \frac{dk}{2\pi^2}k^2 f^2 P\left(k\right)\left[\frac{1}{3}j_0\left(kx\right) - \frac{2}{3}j_2\left(kx\right)\right]\left(\frac{\mathcal{H}}{k}\right)^2$$

Order $\mathcal{O}\left(\mathcal{H}/k\right)$

Odd spherical Bessel functions

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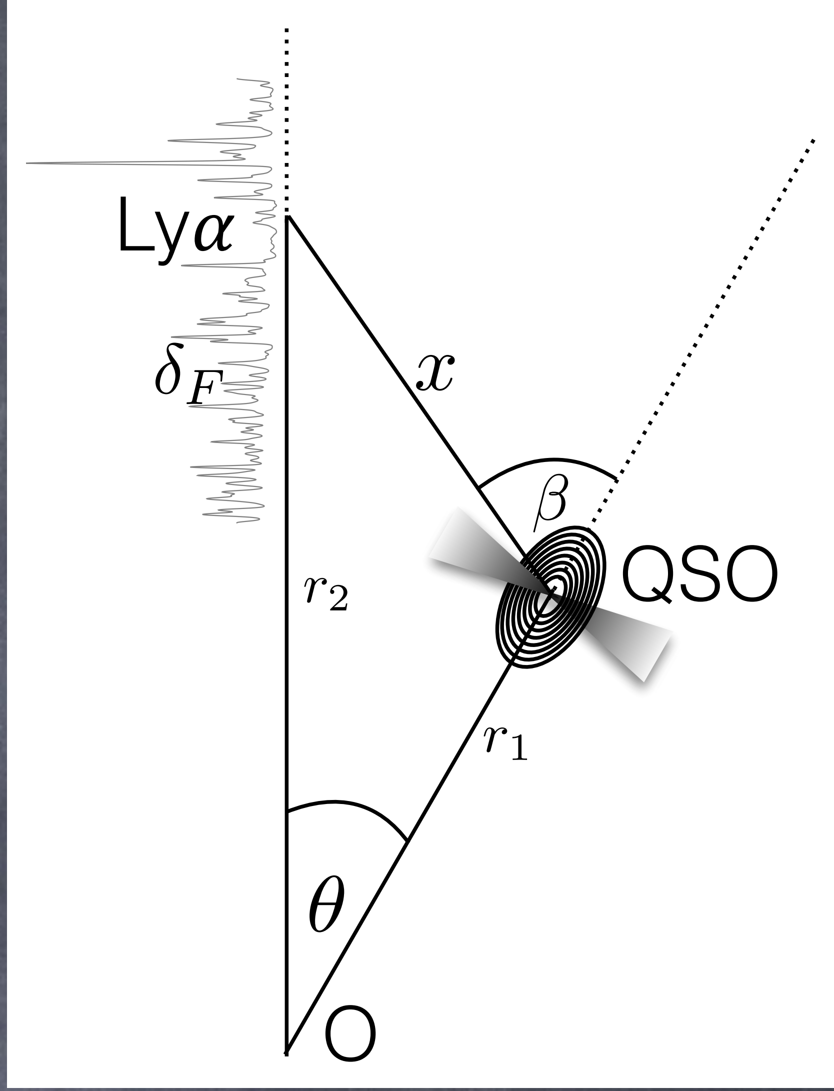


$$\xi_{Q\alpha}\left(z_1, z_2, \theta\right) = \langle \Delta_Q\left(\mathbf{n}_1, z_1\right)\delta_F\left(\mathbf{n}_2, z_2\right)\rangle$$

$$\xi_{Q\alpha} = \xi_{Q\alpha}^{\rm newt} + \xi_{Q\alpha}^{\rm magnification} + \xi_{Q\alpha}^{\rm relativistic}$$

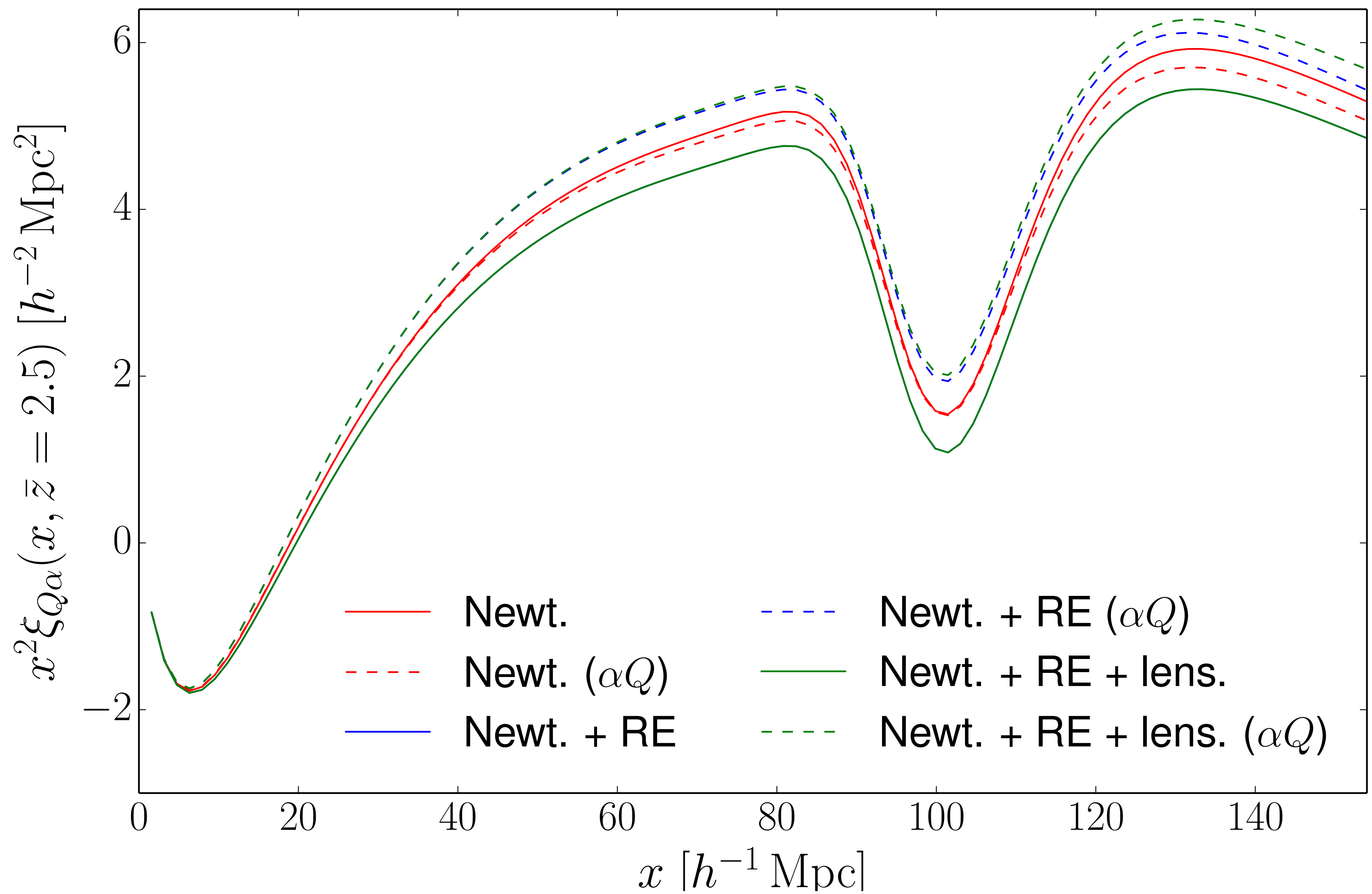
$$\xi_{Q\alpha}^{\rm Doppler} \sim \cancel{\left(-b_Q\mathcal{R}_\alpha + \mathcal{R}_Q b_\alpha\right)}\int \frac{dk}{2\pi^2}k^2 f P\left(k\right) j_1\left(kx\right)\frac{\mathcal{H}}{k}$$
$$+\cancel{\left(-\mathcal{R}_\alpha + \mathcal{R}_Q b_v\right)}\int \frac{dk}{2\pi^2}k^2 f^2 P\left(k\right)\left[\frac{3}{5}j_1\left(kx\right) - \frac{2}{5}j_3\left(kx\right)\right]\frac{\mathcal{H}}{k}$$
$$+\mathcal{R}_\alpha\mathcal{R}_Q\int \frac{dk}{2\pi^2}k^2 f^2 P\left(k\right)\left[\frac{1}{3}j_0\left(kx\right) - \frac{2}{3}j_2\left(kx\right)\right]\left(\frac{\mathcal{H}}{k}\right)^2$$

Order $\mathcal{O}\left(\cancel{\mathcal{H}/k}\right)$ $\mathcal{O}\left(\mathcal{H}^2/k^2\right)$

even

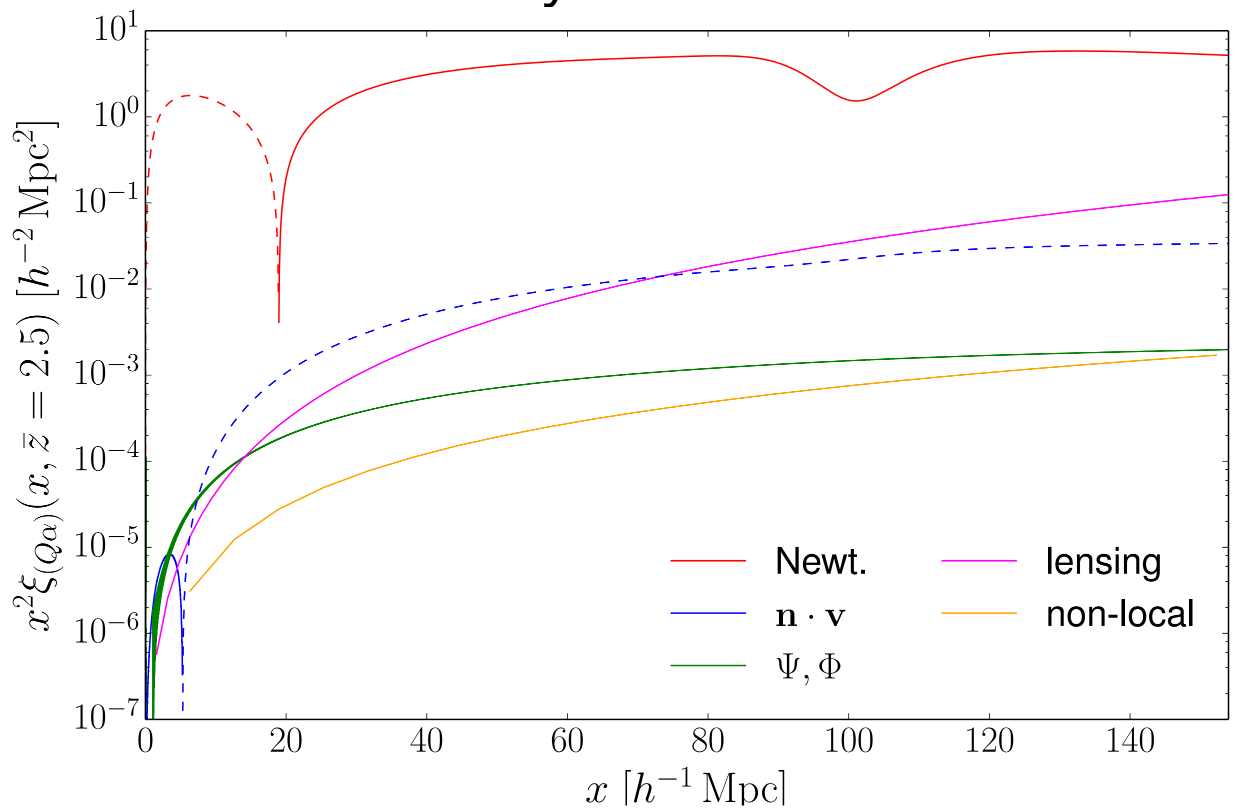
~~Odd~~ spherical Bessel functions

Relativistic effects on Lyman-α forest

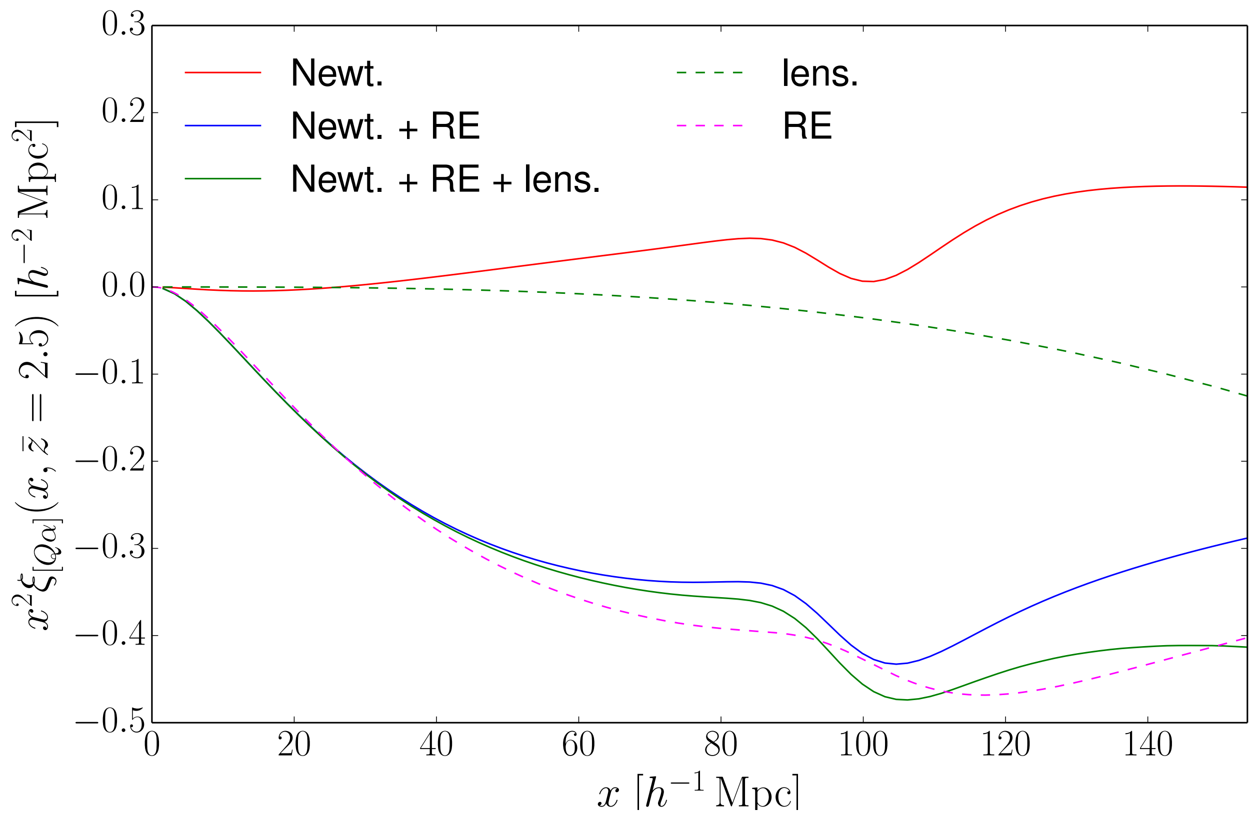


Irsic , ED, Viel [arXiv:1510.03436]

Symmetric

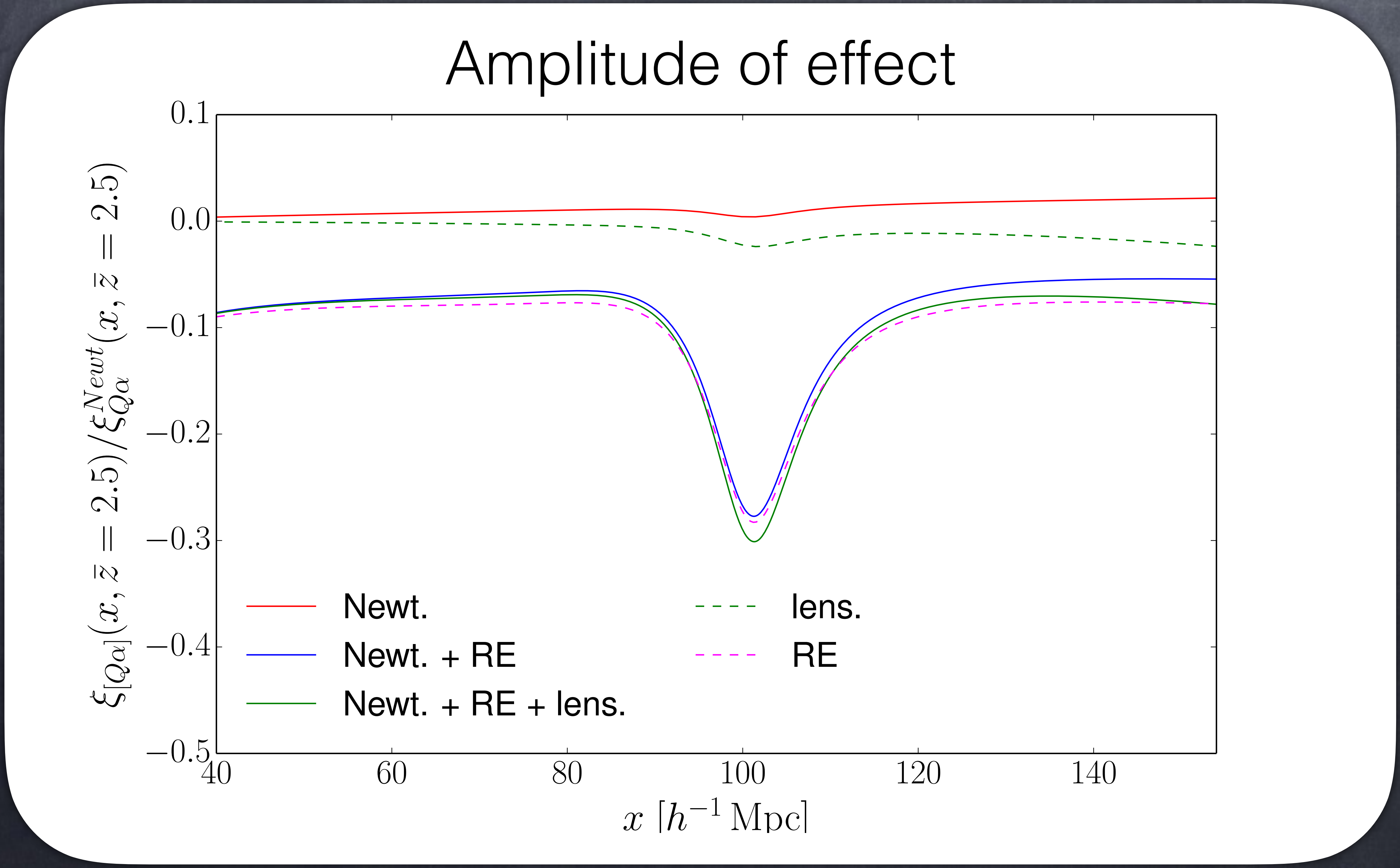


Anti-Symmetric



Irsic , ED, Viel [arXiv:1510.03436]

Relativistic effects on Lyman-α forest



Irsic , ED, Viel [arXiv:1510.03436]

Single tracer vs multi-tracers

	single	multi
Leading order correction	$\mathcal{O}\left(\mathcal{H}^2/k^2\right)$	$\mathcal{O}\left(\mathcal{H}/k\right)$
Parity	even	odd
Relevant scales	super-Hubble	all
Limited by	cosmic variance	shot noise
Forecasted detection	No	Yes