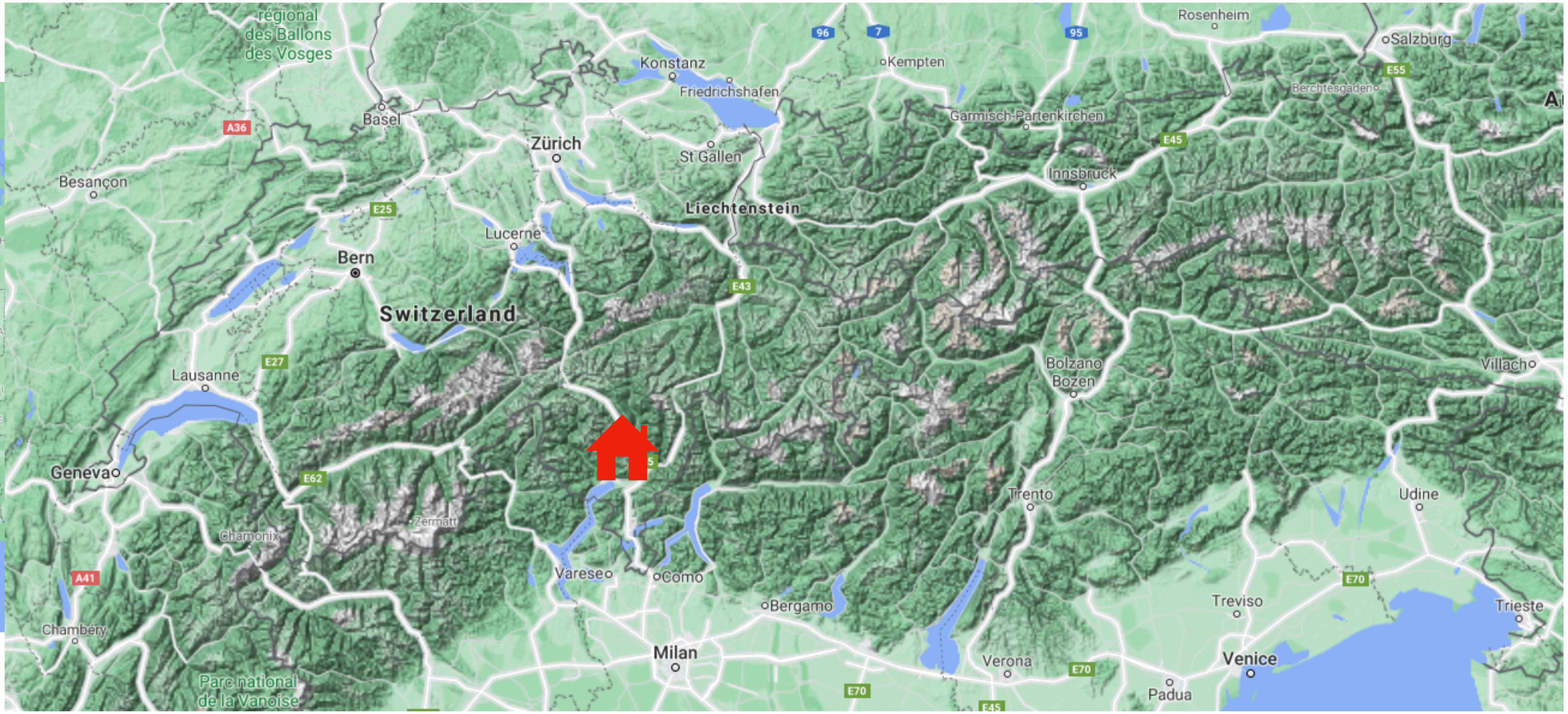
CERN Theory Group Retreat 2022

Enea Di Dio



CERN Theory Group Retreat 2022

Enea Di Dio

2005-2010

CERN Theory Group Retreat 2022

Enea Di Dio

2010-2014

CERN Theory Group Retreat 2022

Enea Di Dio

2014-2017

CERN Theory Group Retreat 2022

Enea Di Dio

2017-2019

CERN Theory Group Retreat 2022

Enea Di Dio

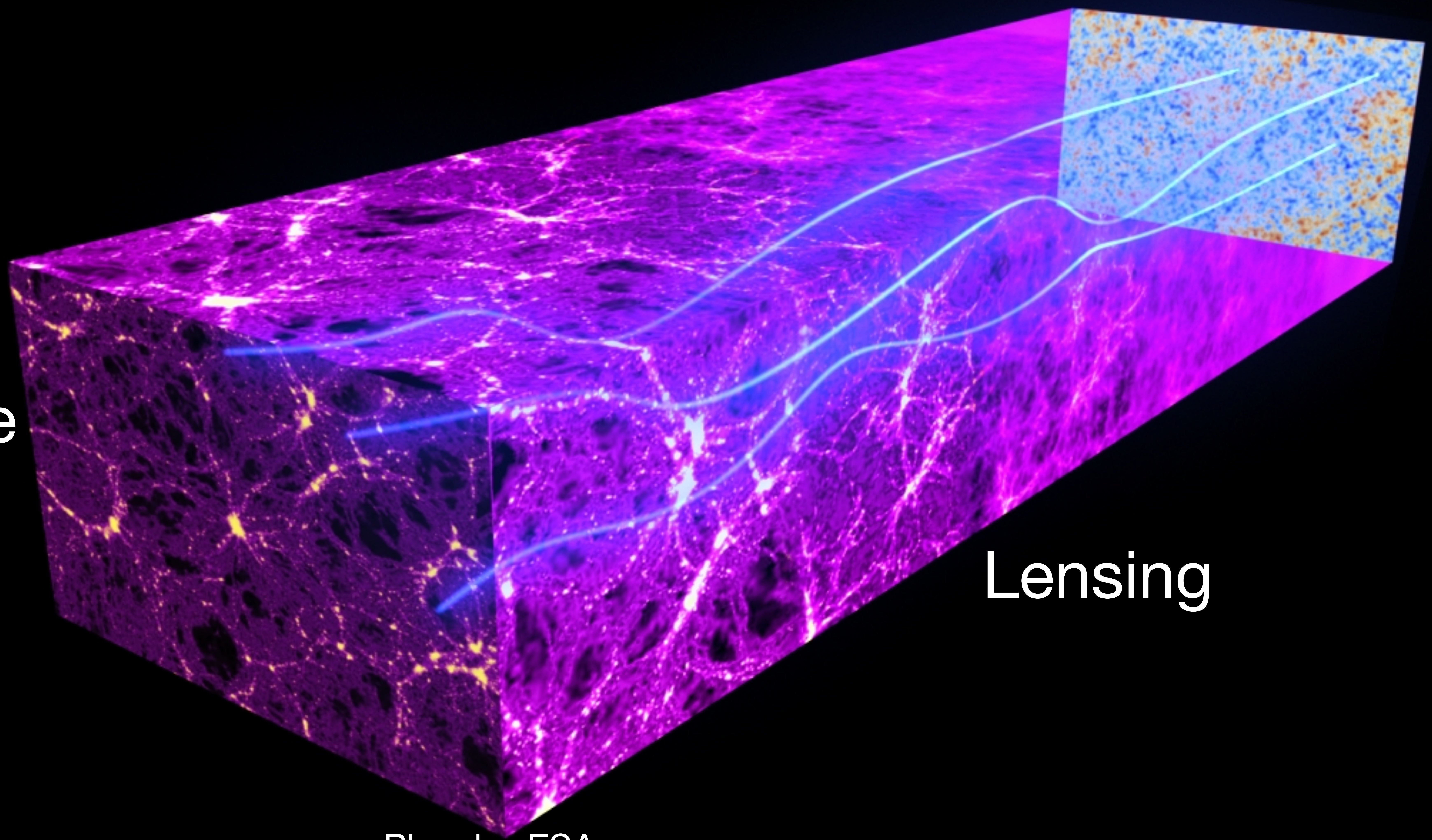
2019-2020

CERN Theory Group Retreat 2022

Enea Di Dio

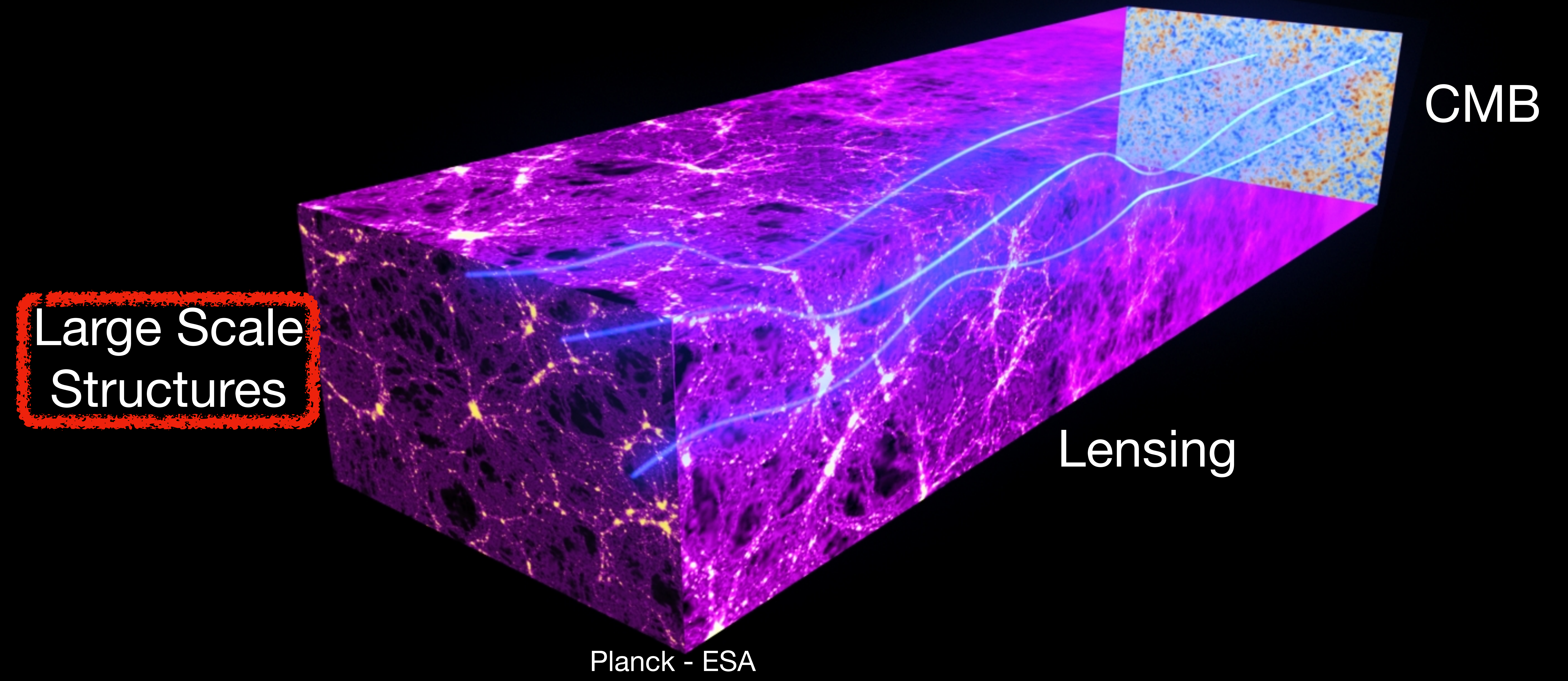
from 2020

My research interests

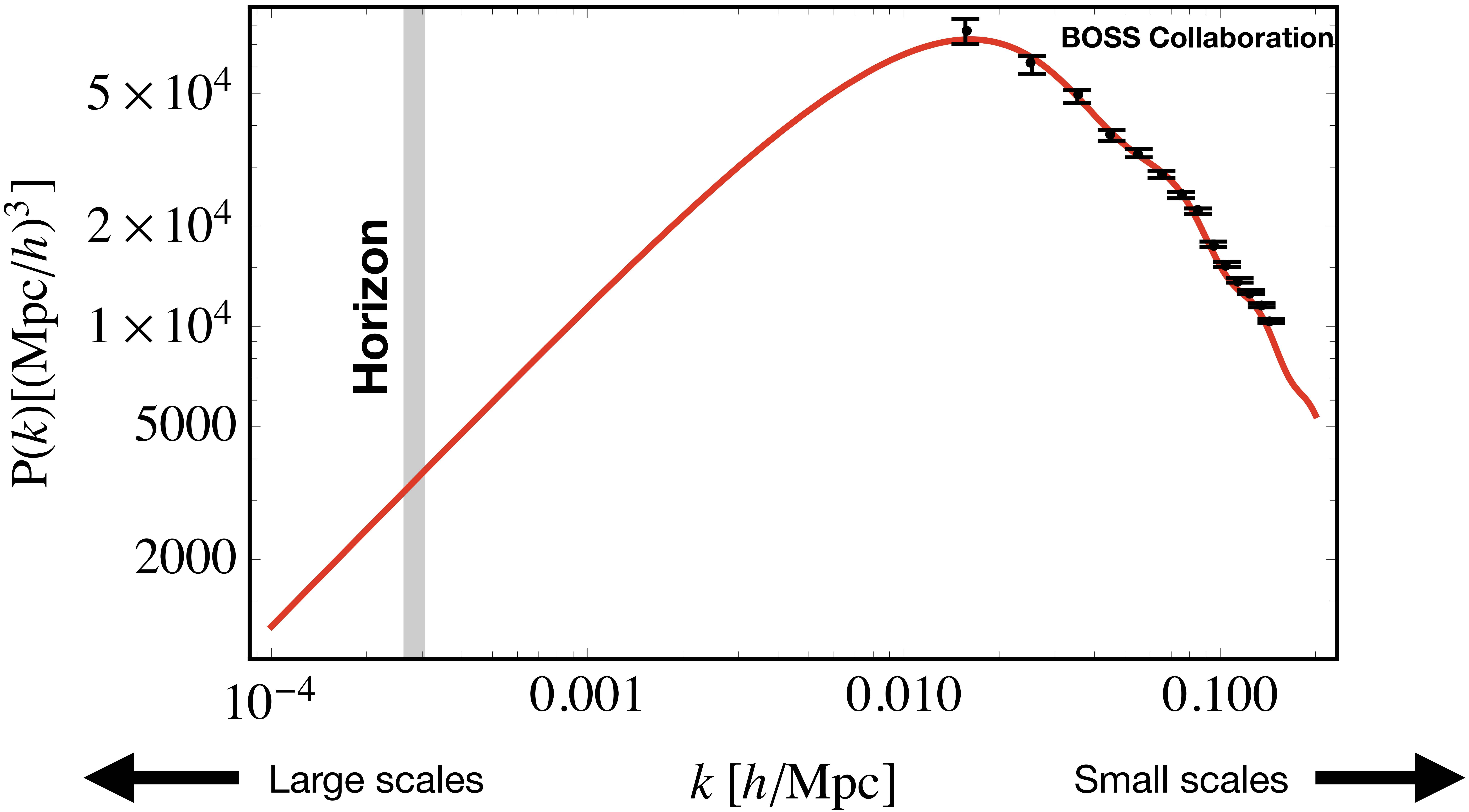


Planck - ESA

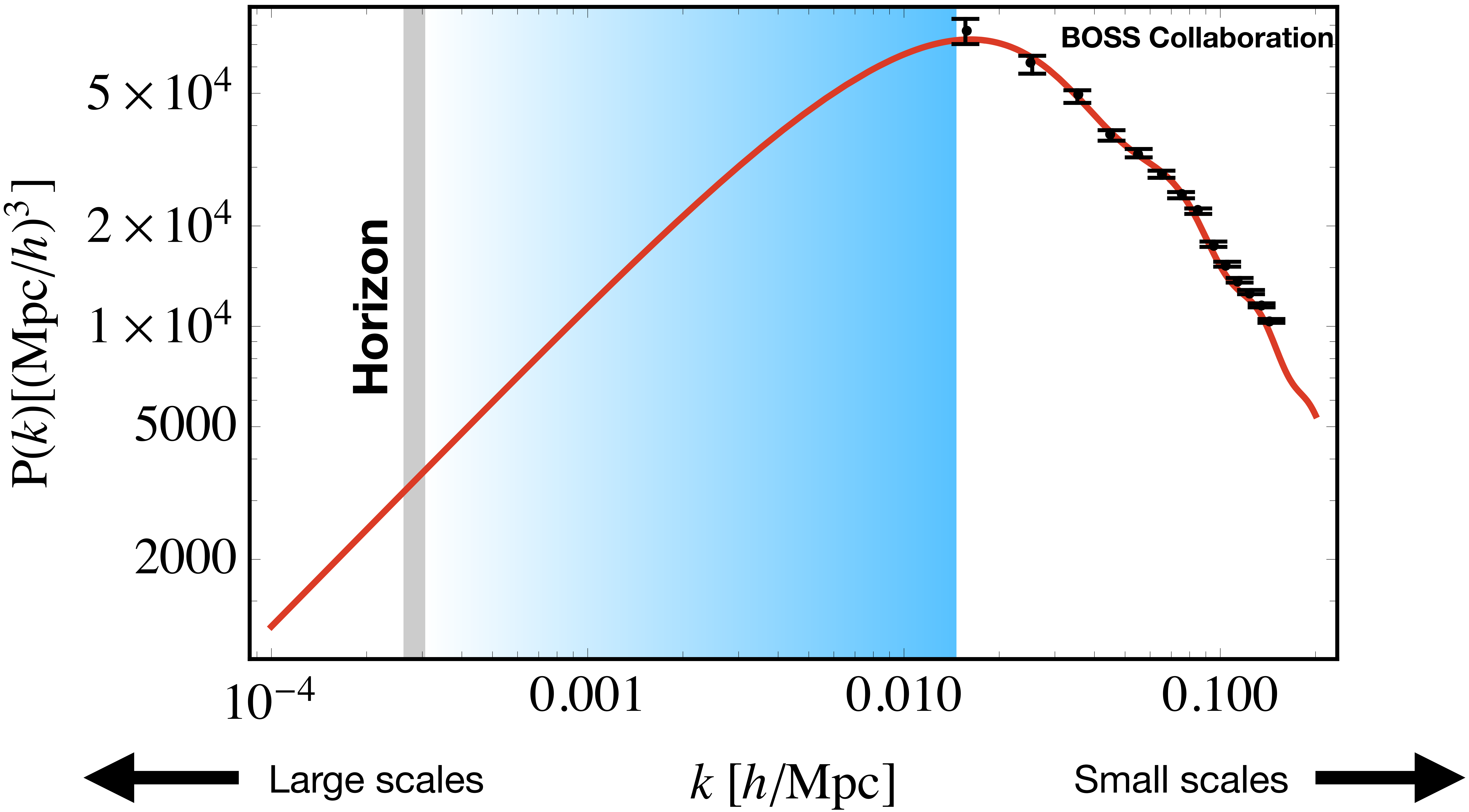
My research interests



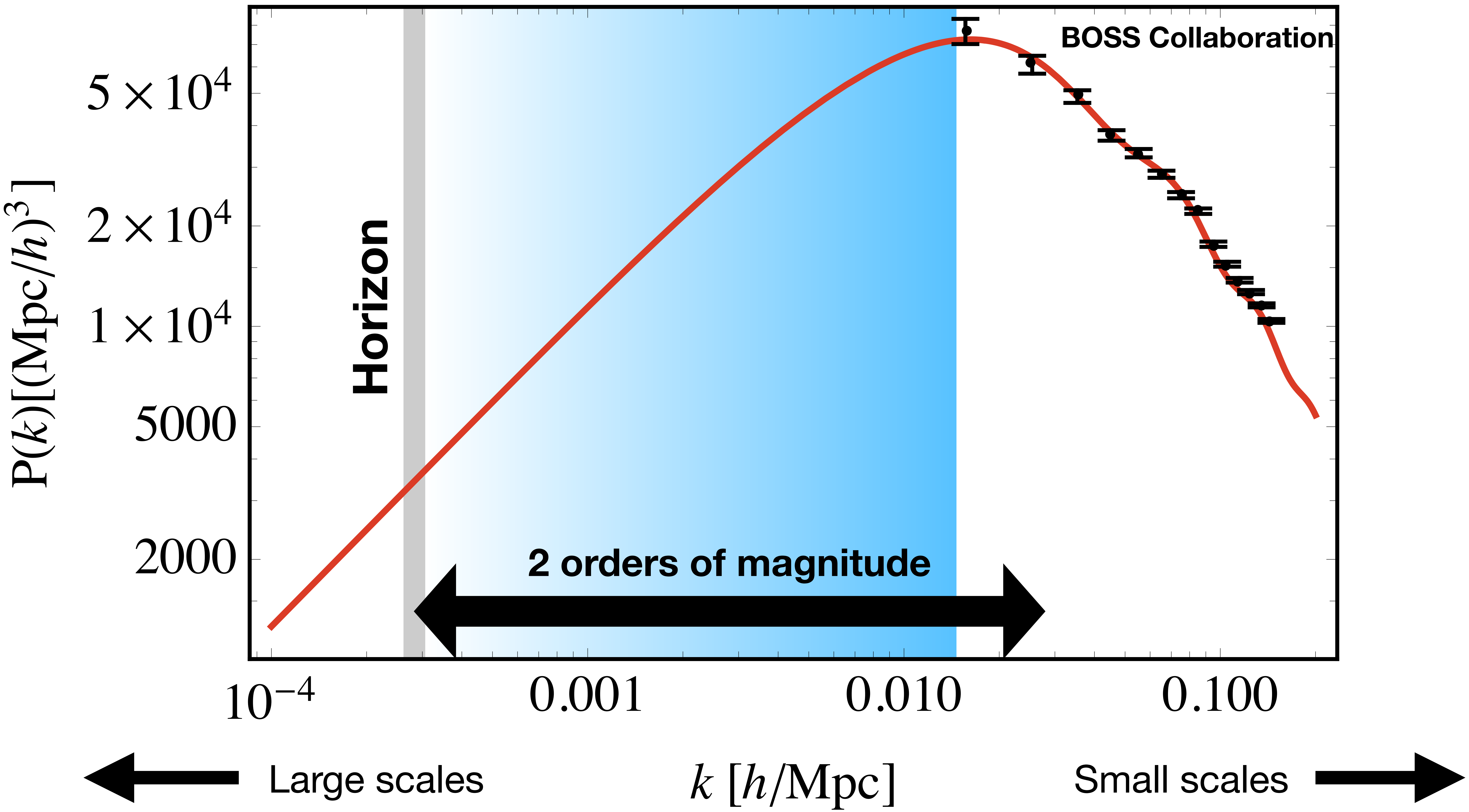
Upcoming Galaxy Surveys



Upcoming Galaxy Surveys



Upcoming Galaxy Surveys



Galaxy Surveys

Observation

$$\Delta\left(\mathbf{n}, z\right) = \frac{N\left(\mathbf{n}, z\right) - \langle N \rangle(z)}{\langle N \rangle(z)}$$

Theory

Galaxy Surveys

Observation

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M$$

Theory

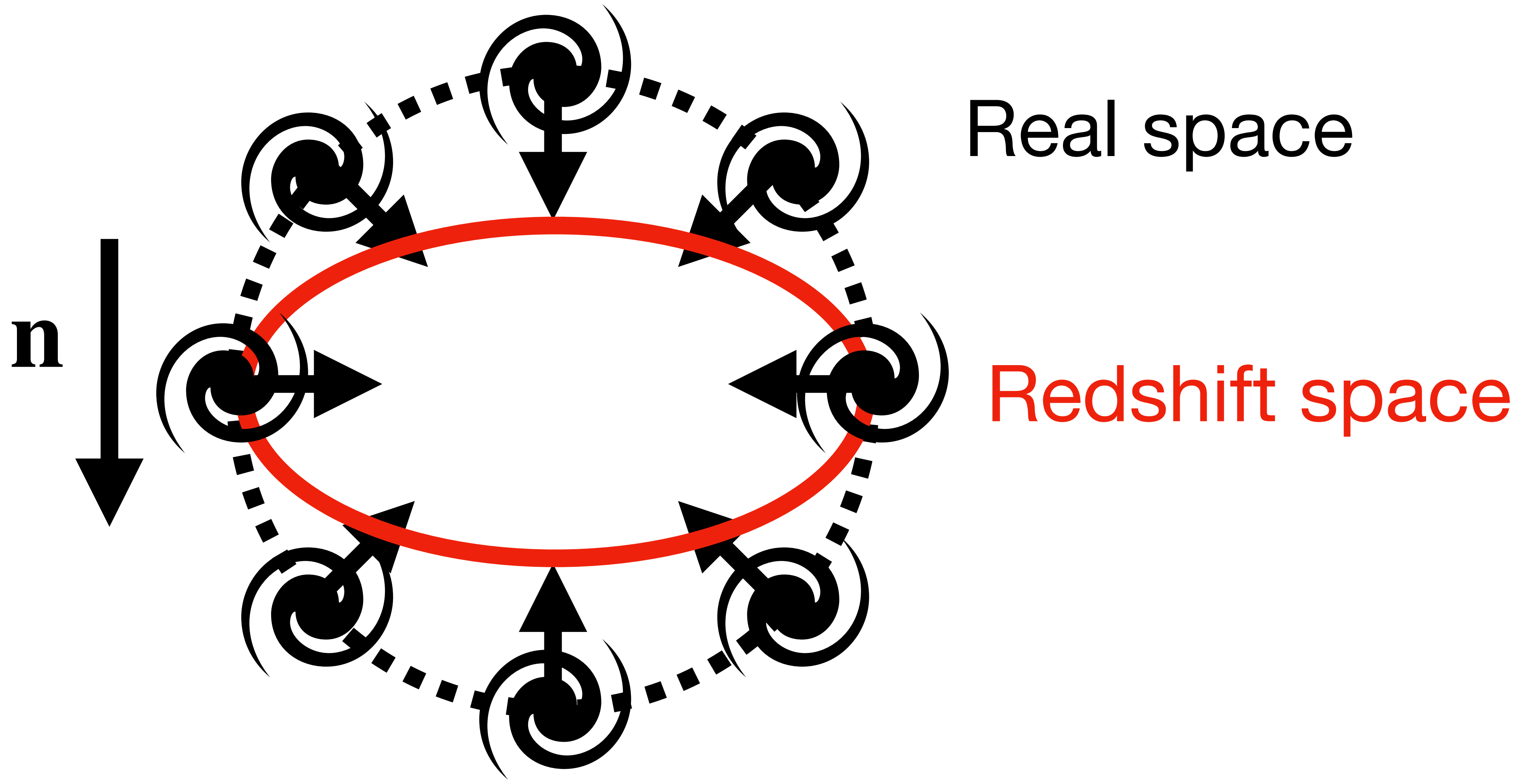
Galaxy Surveys

Observation

Theory

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathcal{H}^{-1} \partial_r \mathbf{v}_{\parallel}$$

Redshift perturbation $z = \bar{z} + \delta z \simeq \bar{z} - (1 + \bar{z})\, \mathbf{n} \cdot \mathbf{v}$

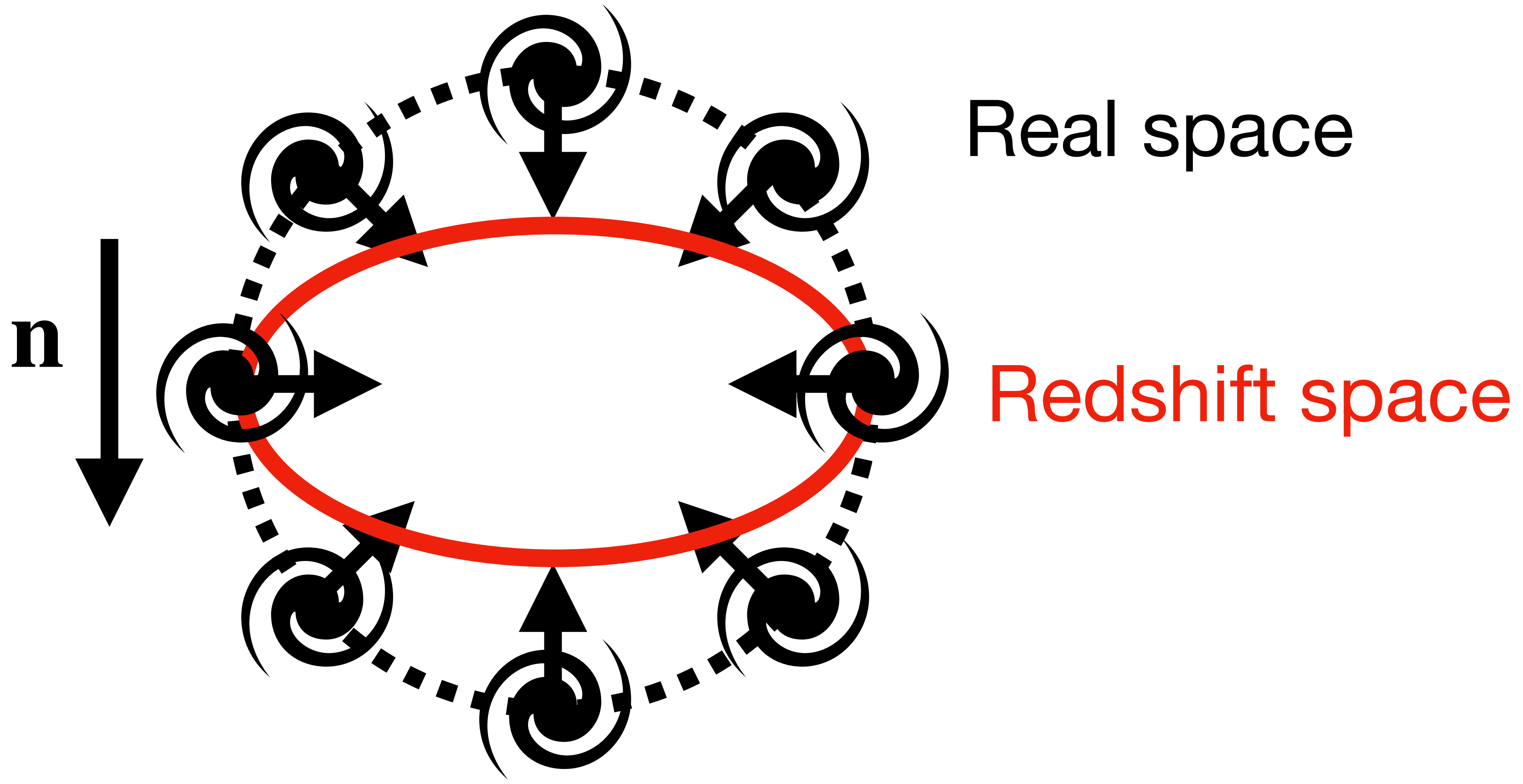


Galaxy Surveys

Observation / Theory

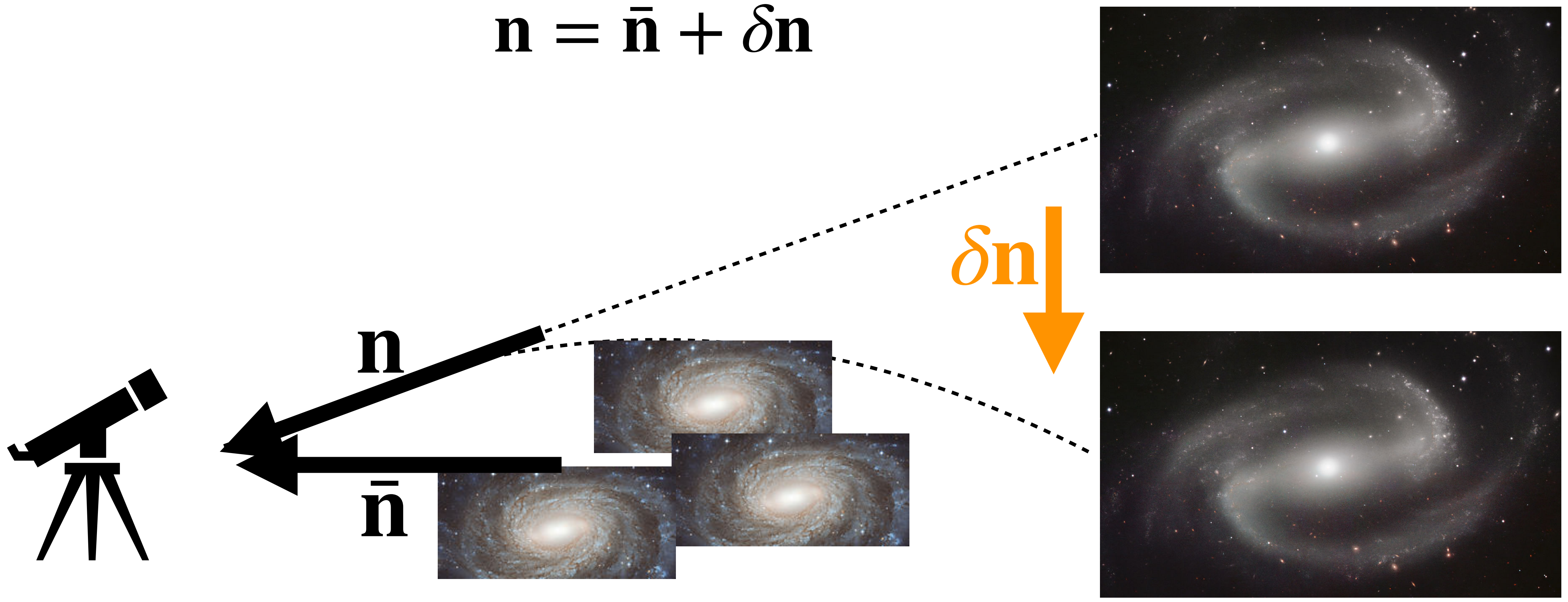
$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathscr{H}^{-1}\partial_r \mathbf{v}_{\parallel} - 2\kappa$$

Redshift perturbation $z = \bar{z} + \delta z \simeq \bar{z} - (1+\bar{z})\,\mathbf{n}\cdot\mathbf{v}$



Deflection angle

$\mathbf{n} = \bar{\mathbf{n}} + \delta\mathbf{n}$

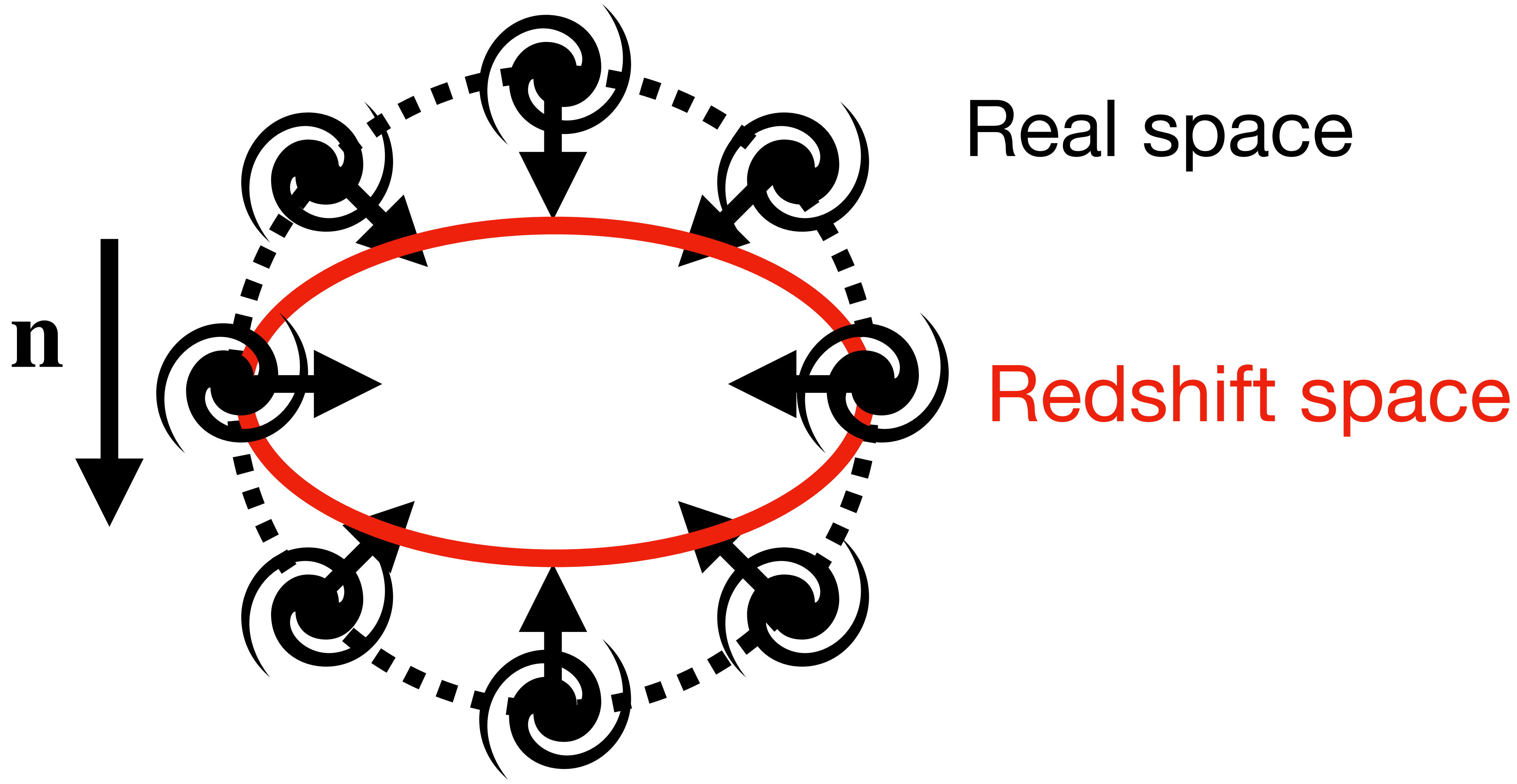


Galaxy Surveys

Observation | Theory

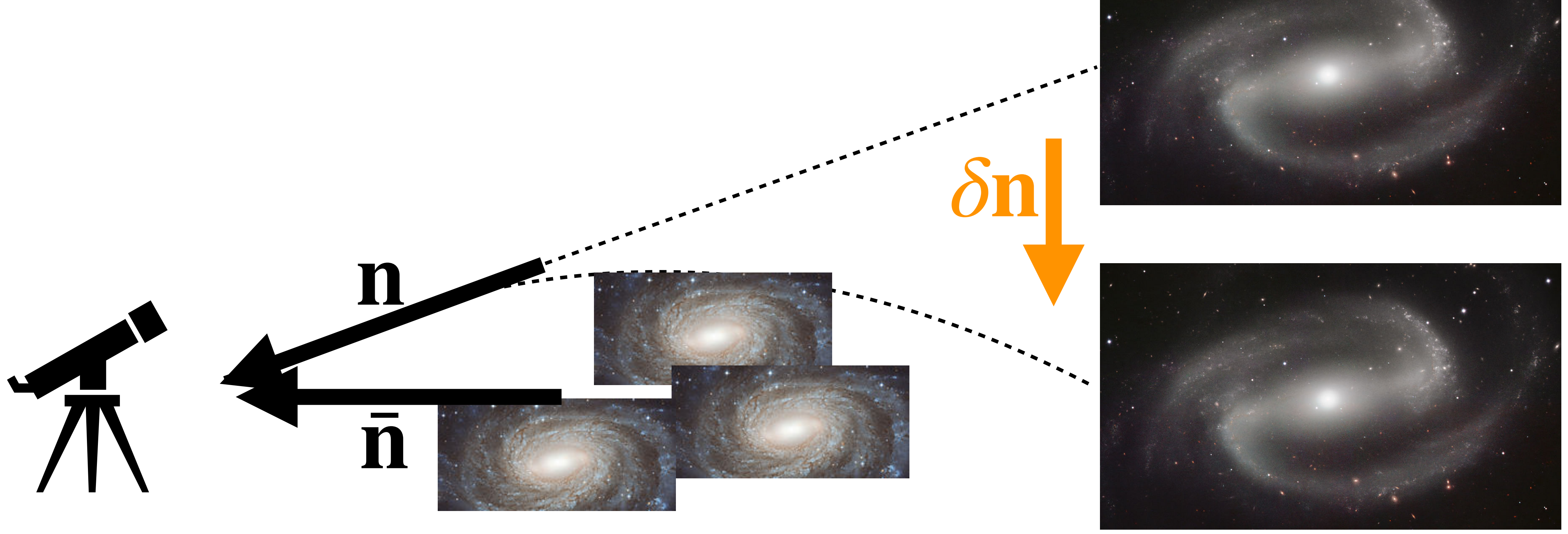
$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathscr{H}^{-1}\partial_r \mathbf{v}_{\parallel} - 2\kappa + \mathcal{O}(\mathbf{v}_{\parallel}) + \mathcal{O}(\Phi)$$

Redshift perturbation $z = \bar{z} + \delta z \simeq \bar{z} - (1 + \bar{z})\,\mathbf{n} \cdot \mathbf{v}$



Deflection angle

$\mathbf{n} = \bar{\mathbf{n}} + \delta\mathbf{n}$



Galaxy Surveys

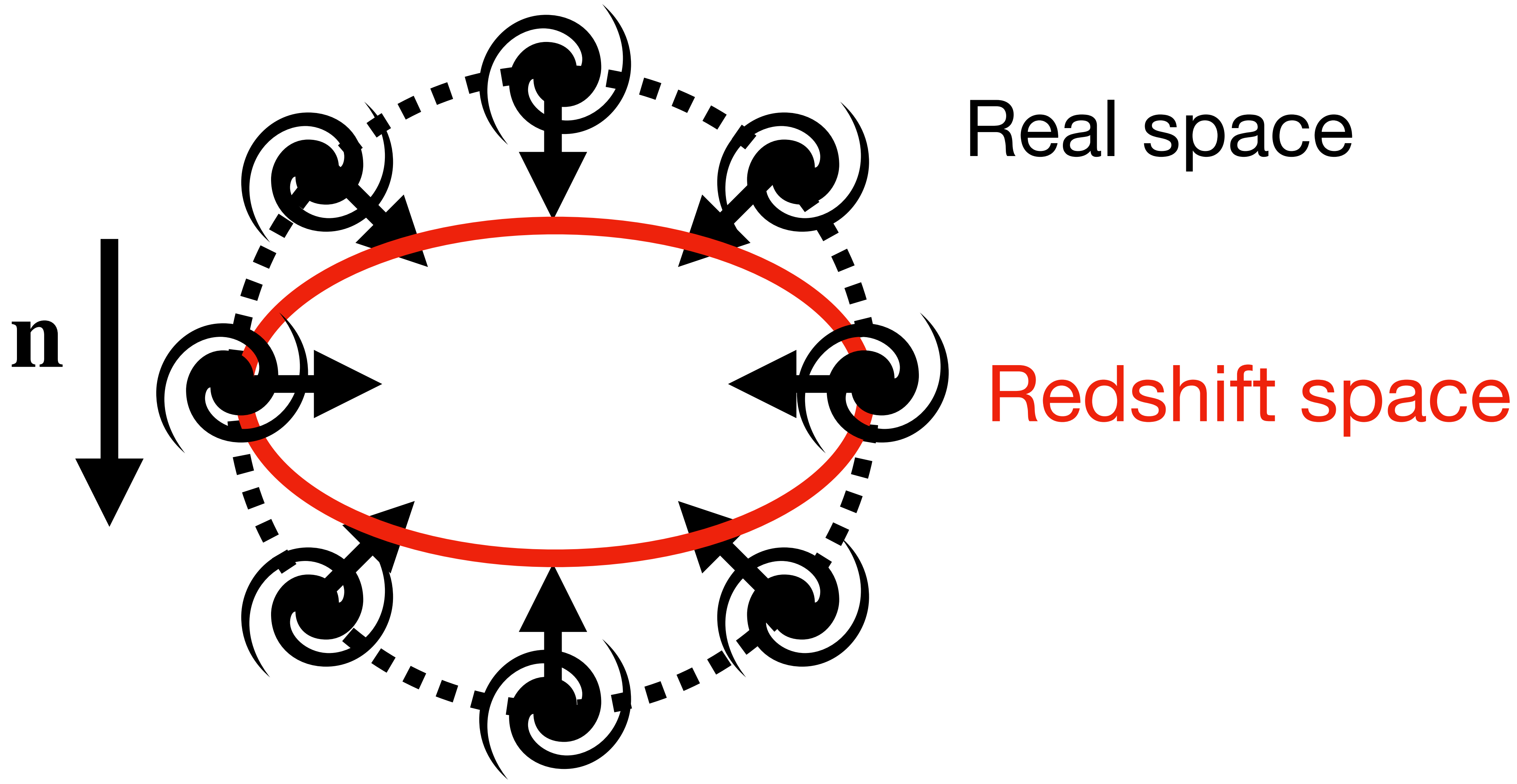
Observation

Theory

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N\rangle(z)}{\langle N\rangle(z)} = b_1\delta_M + \mathcal{H}^{-1}\partial_r \mathbf{v}_\parallel - 2\kappa + \mathcal{O}(\mathbf{v}_\parallel) + \mathcal{O}(\Phi)$$

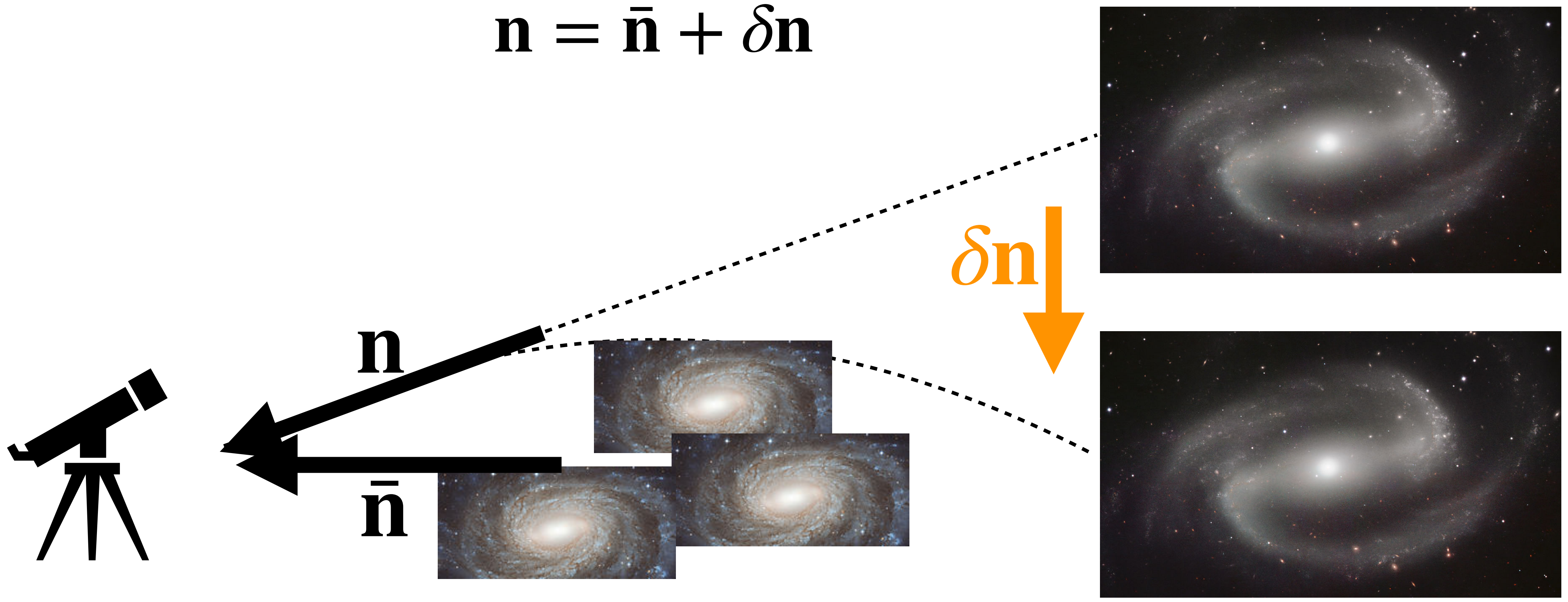
Newtonian

Redshift perturbation $z = \bar{z} + \delta z \simeq \bar{z} - (1+\bar{z})\,\mathbf{n}\cdot\mathbf{v}$



Deflection angle

$\mathbf{n} = \bar{\mathbf{n}} + \delta\mathbf{n}$



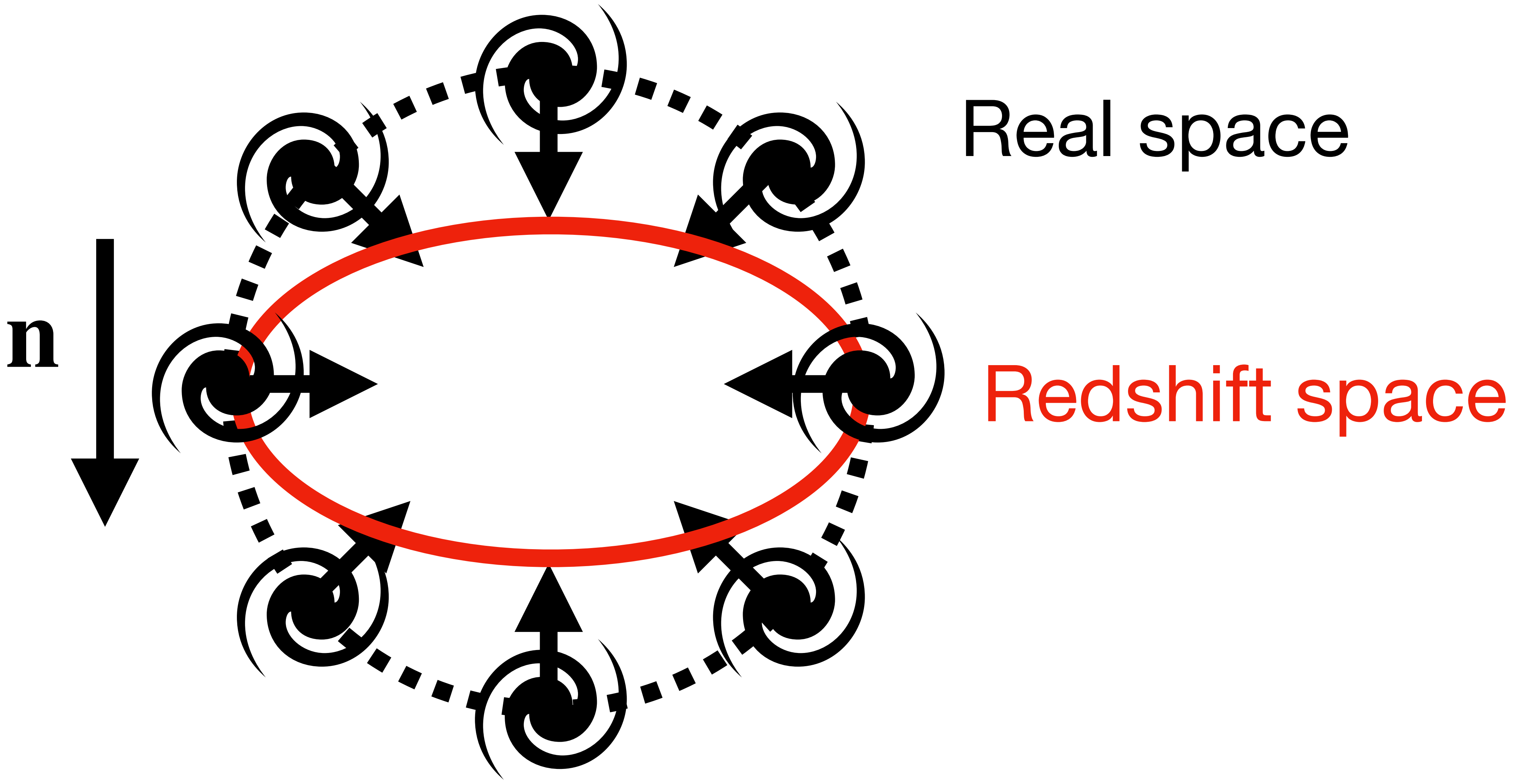
Galaxy Surveys

Observation | Theory

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathscr{H}^{-1}\partial_r \mathbf{v}_\parallel - 2\kappa + \mathcal{O}(\mathbf{v}_\parallel) + \mathcal{O}(\Phi)$$

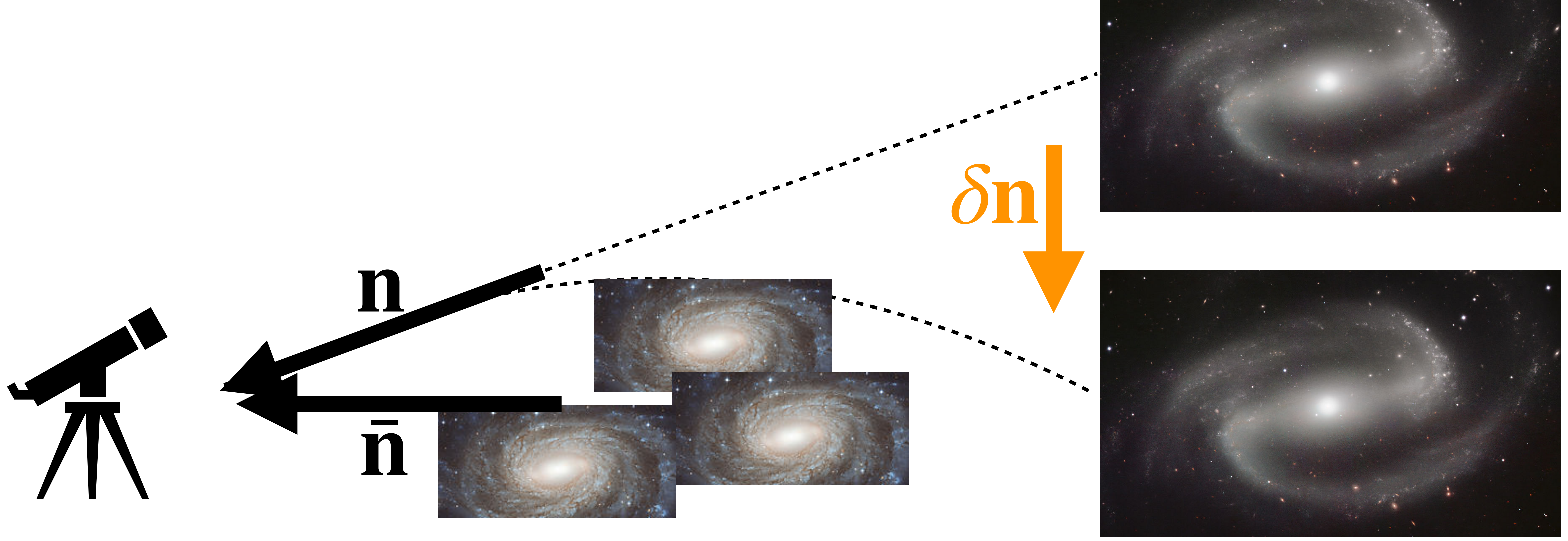
Newtonian | **Relativistic**

Redshift perturbation $z = \bar{z} + \delta z \simeq \bar{z} - (1+\bar{z})\,\mathbf{n}\cdot\mathbf{v}$



Deflection angle

$\mathbf{n} = \bar{\mathbf{n}} + \delta\mathbf{n}$



Galaxy Surveys

$$
\begin{aligned}
\Delta\left(\mathbf{n}, z\right) = \; & bD_m + \mathcal{H}^{-1}\partial_r v_{||} \\
& + \frac{5s_b - 2}{2}\int_0^r dr' \frac{r - r'}{rr'}\Delta_\Omega\left(\Psi + \Phi\right) \\
& + \mathcal{R}\left(v_{||} - v_{||_o}\right) - \left(2 - 5s_b\right)v_{||_o} \\
& + \Bigg\{ \left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + \left(\mathcal{R} + 1\right)\Psi - \mathcal{R}\Psi_o + \left(5s_b - 2\right)\Phi + \dot{\Phi}\mathcal{H}^{-1} \\
& \qquad + \left(f_{\rm evo} - 3\right)\mathcal{H}V \Bigg\} \\
& + \frac{2 - 5s_b}{r}\int_t^{t_o}\left(\Psi + \Phi\right)dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right)dt' \,.
\end{aligned}
$$

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

$$\begin{aligned}\Delta(\mathbf{n}, z) = & \; bD_m + \mathcal{H}^{-1}\partial_r v_{||} \\ & + \frac{5s_b - 2}{2}\int_0^r dr' \frac{r - r'}{rr'}\Delta_\Omega(\Psi + \Phi) \\ & + \mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o} \\ & + \left\{\left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R} + 1)\,\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\,\Phi + \dot{\Phi}\mathcal{H}^{-1} \right. \\ & \qquad \left. + (f_{\text{evo}} - 3)\,\mathcal{H}V \right\} \\ & + \frac{2 - 5s_b}{r}\int_t^{t_o}(\Psi + \Phi)\, dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right) dt' \,.\end{aligned}$$

Newtonian

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

$$\Delta(\mathbf{n}, z) = bD_m + \mathcal{H}^{-1}\partial_r v_{||}$$

Newtonian

$$+\frac{5s_b - 2}{2}\int_0^r dr' \frac{r - r'}{rr'}\Delta_\Omega(\Psi + \Phi)$$
$$+\mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o}$$
$$+\left\{\left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R} + 1)\,\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\,\Phi + \dot{\Phi}\mathcal{H}^{-1} + (f_{\rm evo} - 3)\,\mathcal{H}V\right\}$$
$$+\frac{2 - 5s_b}{r}\int_t^{t_o}(\Psi + \Phi)\, dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right) dt' \, .$$

Relativistic

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

$$\Delta(\mathbf{n}, z) = bD_m + \mathcal{H}^{-1}\partial_r v_{||}$$

Lensing

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

$$+\mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o}$$

$$+\left\{\left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R} + 1)\,\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\,\Phi + \dot{\Phi}\mathcal{H}^{-1}\right.$$

$$\left. + (f_{\text{evo}} - 3)\,\mathcal{H}V\right\}$$

$$+\frac{2 - 5s_b}{r}\int_t^{t_o}(\Psi + \Phi)\, dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right) dt' \, .$$

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

$$\Delta(\mathbf{n}, z) = bD_m + \mathcal{H}^{-1}\partial_r v_{||}$$
$$+\frac{5s_b - 2}{2}\int_0^r dr' \frac{r - r'}{rr'}\Delta_\Omega(\Psi + \Phi)$$

Velocity

$$+\mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o}$$
$$+\left\{\left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R} + 1)\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\Phi + \dot{\Phi}\mathcal{H}^{-1}\right.$$
$$\left. + (f_{\mathrm{evo}} - 3)\mathcal{H}V\right\}$$
$$+\frac{2 - 5s_b}{r}\int_t^{t_o}(\Psi + \Phi)\, dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right) dt' \,.$$

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

$$
\begin{aligned}
\Delta(\mathbf{n}, z) = {} & bD_m + \mathcal{H}^{-1}\partial_r v_{||} \\
& + \frac{5s_b - 2}{2} \int_0^r dr' \frac{r - r'}{rr'} \Delta_\Omega (\Psi + \Phi) \\
& + \mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o} \\
& + \Bigg\{ \left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right) \mathcal{H}_0 V_o + (\mathcal{R} + 1)\,\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\,\Phi + \dot{\Phi}\mathcal{H}^{-1} \\
& \qquad + (f_{\mathrm{evo}} - 3)\,\mathcal{H}V \Bigg\} \\
& + \frac{2 - 5s_b}{r} \int_t^{t_o} (\Psi + \Phi)\, dt' + \mathcal{R} \int_t^{t_o} \left(\dot{\Psi} + \dot{\Phi}\right) dt' \,.
\end{aligned}
$$

Gravitational potential

Yoo, Challinor & Lewis, Bonvin & Durrer

Galaxy Surveys

Observation

Theory

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathcal{H}^{-1} \partial_r \mathbf{v}_{\parallel} - 2\kappa + \mathcal{O}(\mathbf{v}_{\parallel}) + \mathcal{O}(\Phi)$$

Lensing

$$\int_0^r dr' \frac{r - r'}{rr'} \Delta_\Omega \Phi \sim \int_0^r dr' \frac{r - r'}{r} r' H_0^2 \delta_{M,0} \sim (rH_0)^2 \delta_M$$

deep galaxy surveys

Velocity

$$v_{\parallel} \sim \mu \frac{H}{k} \delta_M$$

non-zero dipole

Gravitational Potential

$$\Phi \sim \left(\frac{H}{k}\right)^2 \delta_M$$

search of primordial non-gaussianity

The IR behaviour

$$\begin{aligned}\Delta(\mathbf{n}, z) = {} & bD_m + \mathcal{H}^{-1}\partial_r v_{||} \\ & + \frac{5s_b - 2}{2}\int_0^r dr' \frac{r - r'}{rr'}\Delta_\Omega(\Psi + \Phi) \\ & + \mathcal{R}\left(v_{||} - v_{||_o}\right) - (2 - 5s_b)\, v_{||_o} \\ & + \Bigg\{\left(\mathcal{R} - \frac{2 - 5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R} + 1)\,\Psi - \mathcal{R}\Psi_o + (5s_b - 2)\,\Phi + \dot{\Phi}\mathcal{H}^{-1} \\ & \quad + (f_{\text{evo}} - 3)\,\mathcal{H}V\Bigg\} \\ & + \frac{2 - 5s_b}{r}\int_t^{t_o}(\Psi + \Phi)\, dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi} + \dot{\Phi}\right) dt'\,.\end{aligned}$$

Gravitational potential

$$\xi \supset \langle\Phi\Phi\rangle \sim \int \frac{dq}{2\pi^2} q^2 P(q)\, \frac{j_0(qs)}{(qs)^4}$$

IR divergence

The IR behaviour

$$\begin{aligned}\Delta(\mathbf{n},z) &= bD_m + \mathcal{H}^{-1}\partial_r v_{||} \\ &+ \frac{5s_b-2}{2}\int_0^r dr'\frac{r-r'}{rr'}\Delta_\Omega(\Psi+\Phi) \\ &+ \mathcal{R}\left(v_{||}-v_{||o}\right) - (2-5s_b)\,v_{||o} \\ &+ \Bigg\{\left(\mathcal{R}-\frac{2-5s_b}{\mathcal{H}_0 r}\right)\mathcal{H}_0 V_o + (\mathcal{R}+1)\Psi - \mathcal{R}\Psi_o + (5s_b-2)\Phi + \dot{\Phi}\mathcal{H}^{-1} \\ &\quad + (f_{\rm evo}-3)\mathcal{H}V\Bigg\} \\ &+ \frac{2-5s_b}{r}\int_t^{t_o}(\Psi+\Phi)\,dt' + \mathcal{R}\int_t^{t_o}\left(\dot{\Psi}+\dot{\Phi}\right)dt'\,.\end{aligned}$$

Gravitational potential

IR safe — IR divergence

$$\xi \supset \langle\Phi\Phi\rangle \sim \int\frac{dq}{2\pi^2}q^2P(q)\,\frac{j_0(qs)-1}{(qs)^4} + \int\frac{dq}{2\pi^2}q^2P(q)\,\frac{1}{(qs)^4} = \left[\int\frac{dq}{2\pi^2}q^2P(q)\,\frac{j_0(qs)-1}{(qs)^4}\right] + \sigma_\Phi^2$$

By including all the terms we can show that

$$\sum_{\mathcal{O}\mathcal{O}'}(\sigma^2)^{\rm div}_{\mathcal{O}\mathcal{O}'} = 0$$

Grimm, Scaccabarozzi, Yoo, Biern Castorina & ED

The theoretical predictions are independent from the gravitational potential in the IR limit

Galaxy Surveys

Observation | **Theory**

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathscr{H}^{-1} \partial_r \mathbf{v}_{\parallel} - 2\kappa + \mathcal{O}(\mathbf{v}_{\parallel}) + \mathcal{O}(\Phi)$$

Lensing $\int_0^r dr' \frac{r - r'}{rr'} \Delta_\Omega \Phi \sim \int_0^r dr' \frac{r - r'}{r} r' H_0^2 \delta_{M,0} \sim (rH_0)^2 \delta_M$ **deep galaxy surveys**

Velocity $v_{\parallel} \sim \mu \frac{H}{k} \delta_M$ **non-zero dipole**

Gravitational Potential $\Phi \sim \left(\frac{H}{k}\right)^2 \delta_M$ **search of primordial non-gaussianity**

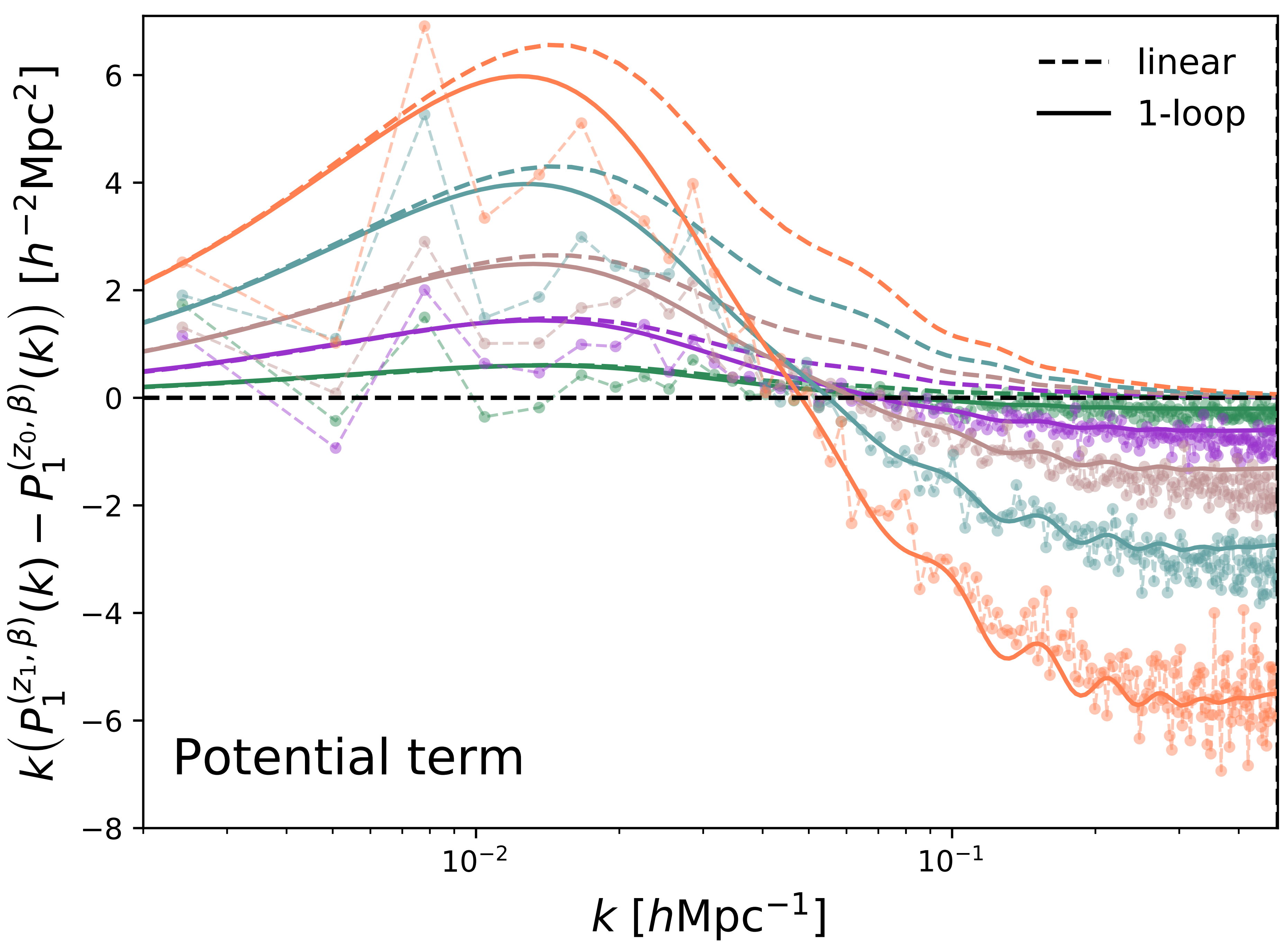
Dipole of the power spectrum at one loop

$$\Delta_{\rm gal}(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N\rangle(z)}{\langle N\rangle(z)}$$

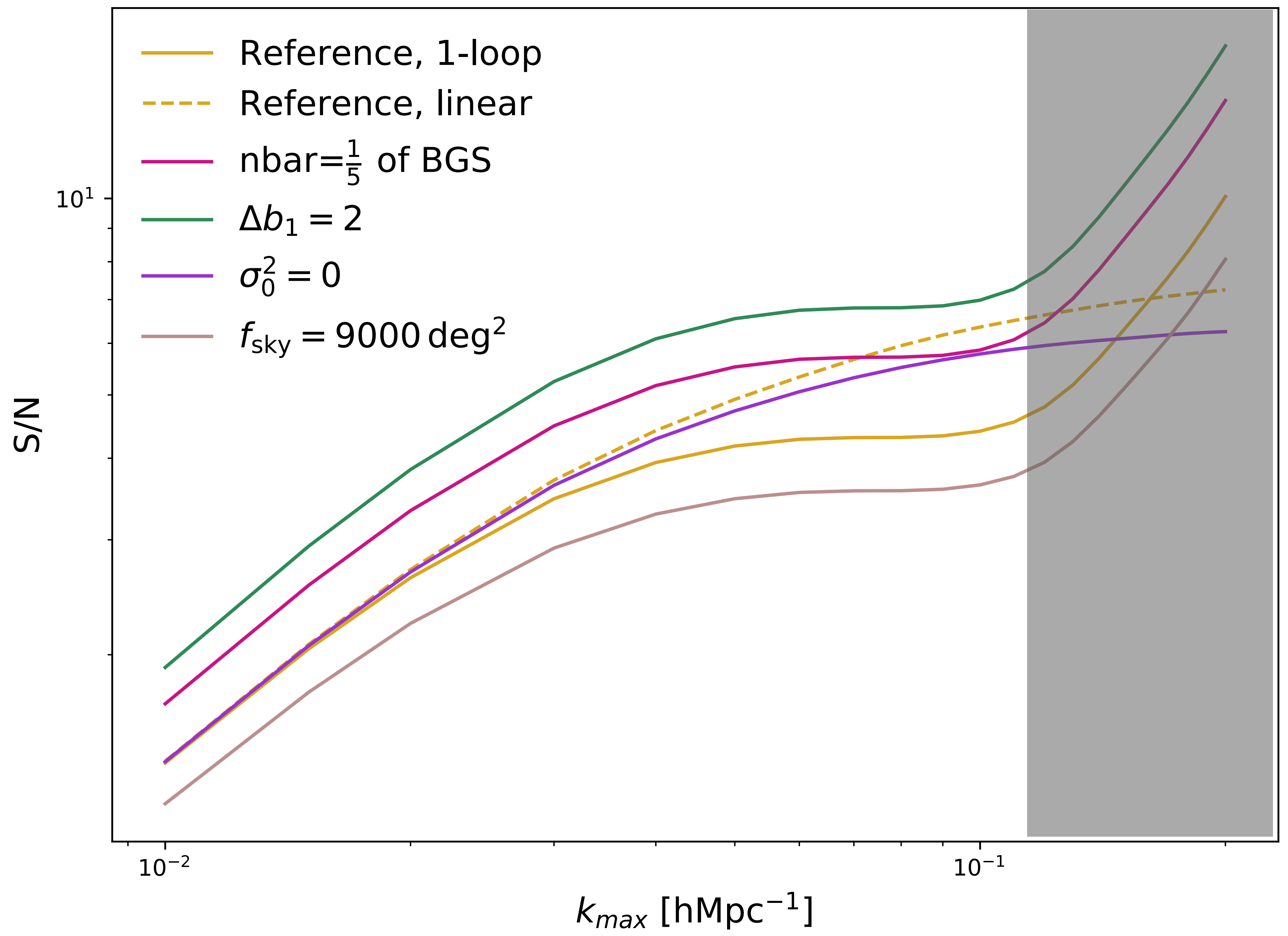
At 3rd order in perturbation theory

ED & Seljak, ED & Beutler

Comparison with relativistic N-body sims



DESI Forecast



Beutler & ED

Galaxy Surveys

Observation | **Theory**

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathcal{H}^{-1} \partial_r \mathbf{v}_\parallel - 2\kappa + \mathcal{O}(\mathbf{v}_\parallel) + \mathcal{O}(\Phi)$$

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GaPSE
(Galaxy Power Spectrum Estimator)

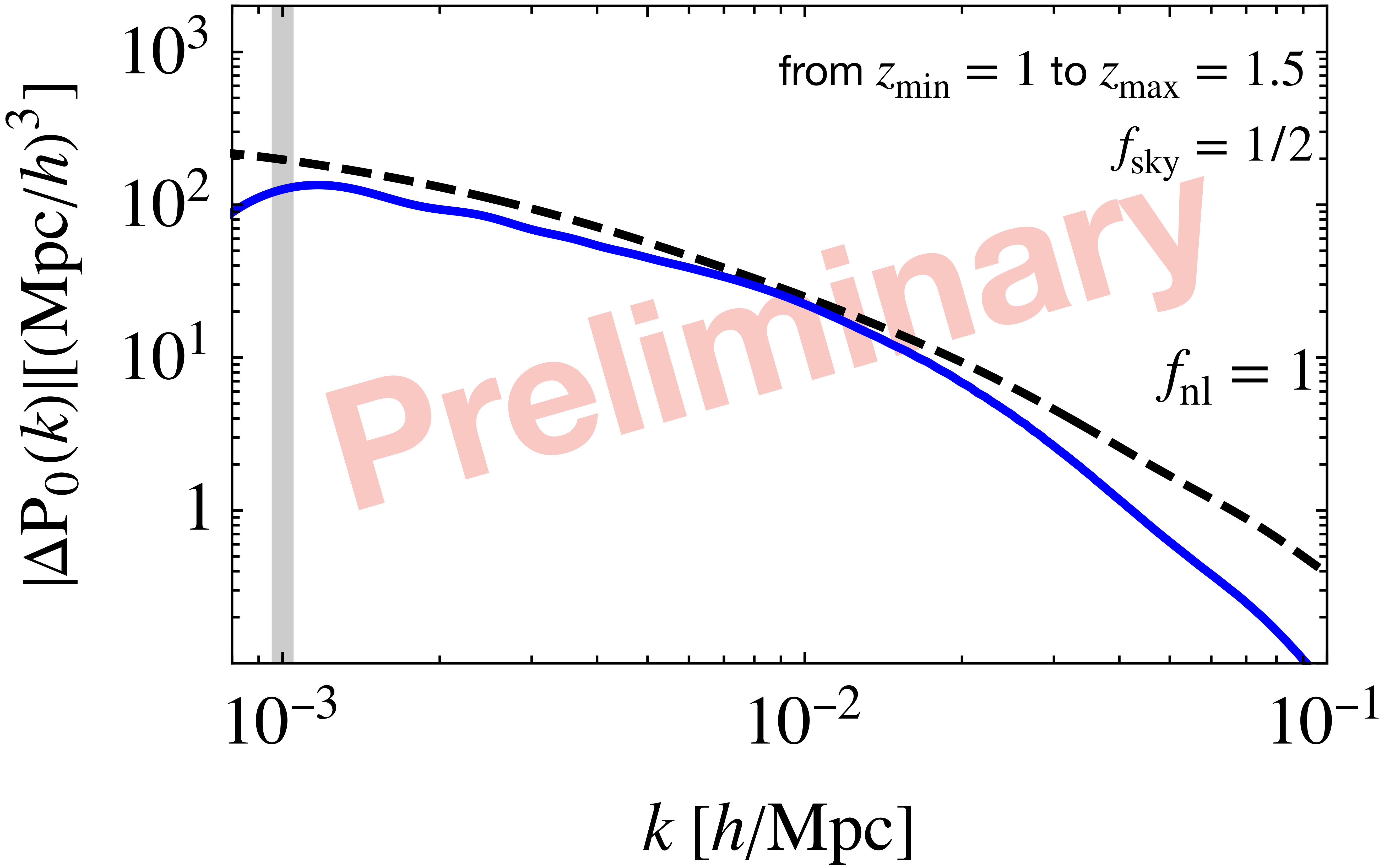
Foglieni, Pantiri, Castorina, ED
[in preparation]

soon publicly available

Fast and accurate numerical code to compute $\langle \hat{P}_L(k) \rangle$ for galaxy number counts and luminosity distance including:

✓ all relativistic effects
✓ window function
✓ wide-angle effects
✓ primordial local non-gaussianity (scale-dependent bias)

all these effects are relevant at the largest scales



Data analysis
- in full-sky
- with magnification
- without relativistic effects

Galaxy Surveys

Observation

Theory

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Lensing

$$\int_0^r dr' \frac{r - r'}{rr'} \Delta_\Omega \Phi \sim \int_0^r dr' \frac{r - r'}{r} r' H_0^2 \delta_{M,0} \sim (rH_0)^2 \delta_M$$

deep galaxy surveys

Velocity

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search of primordial non-gaussianity

Galaxy Surveys

Observation **Theory**

$$\Delta(\mathbf{n}, z) = \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)} = b_1 \delta_M + \mathscr{H}^{-1} \partial_r \mathbf{v}_\parallel - 2\kappa + \mathcal{O}(\mathbf{v}_\parallel) + \mathcal{O}(\Phi)$$

Lensing $\int_0^r dr' \frac{r - r'}{rr'} \Delta_\Omega \Phi \sim \int_0^r dr' \frac{r - r'}{r} r' H_0^2 \delta_{M,0} \sim (rH_0)^2 \delta_M$ **deep galaxy surveys**

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Galaxy Surveys

Observation | **Theory**

$$\Delta(\mathbf{n},z) = \frac{N(\mathbf{n},z) - \langle N\rangle(z)}{\langle N\rangle(z)} = b_1\delta_M + \mathscr{H}^{-1}\partial_r \mathbf{v}_\parallel - 2\kappa + \mathcal{O}(\mathbf{v}_\parallel) + \mathcal{O}(\Phi)$$

Lensing

$$\int_0^r dr' \frac{r-r'}{rr'}\Delta_\Omega\Phi \sim \int_0^r dr' \frac{r-r'}{r} r' H_0^2 \delta_{M,0} \sim (rH_0)^2\,\delta_M$$

deep galaxy surveys

Velocity

$$v_\parallel \sim \mu \frac{H}{k}\delta_M$$

non-zero dipole

Gravitational Potential

$$\Phi \sim \left(\frac{H}{k}\right)^2 \delta_M$$

$$f_{\rm nl}^{\rm eff} \sim 1$$

search of primordial non-gaussianity

Thank you