Implications of the primordial power asymmetry for inflation

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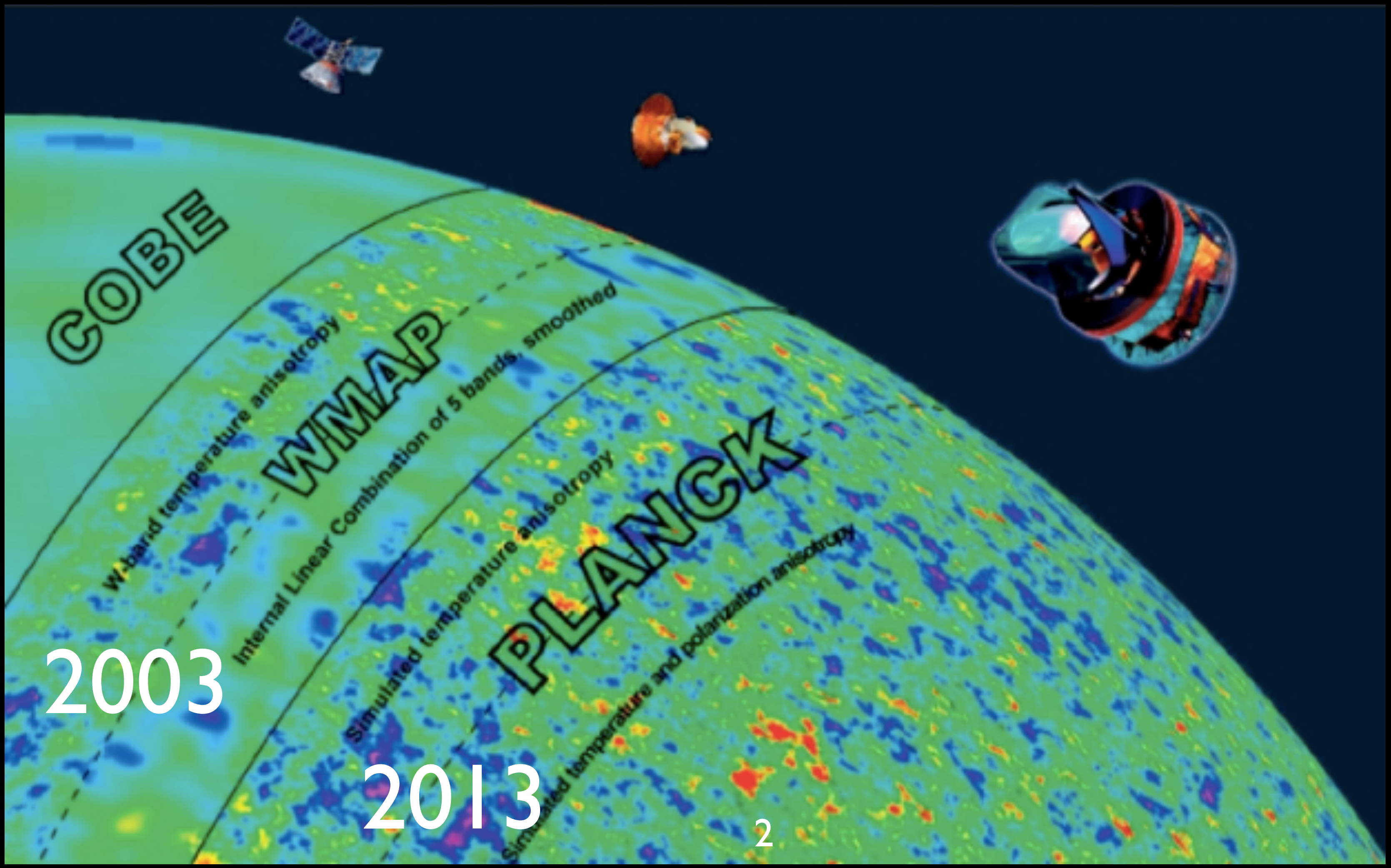
CB, Regan, Seery, Tarrant arXiv:1511.03129

Texas Symposium, Geneva: 14th December 2015

How much have we learnt from the precision era?

- Planck: 25 times better sensitivity and 3 times better resolution than WMAP, the previous best experiment

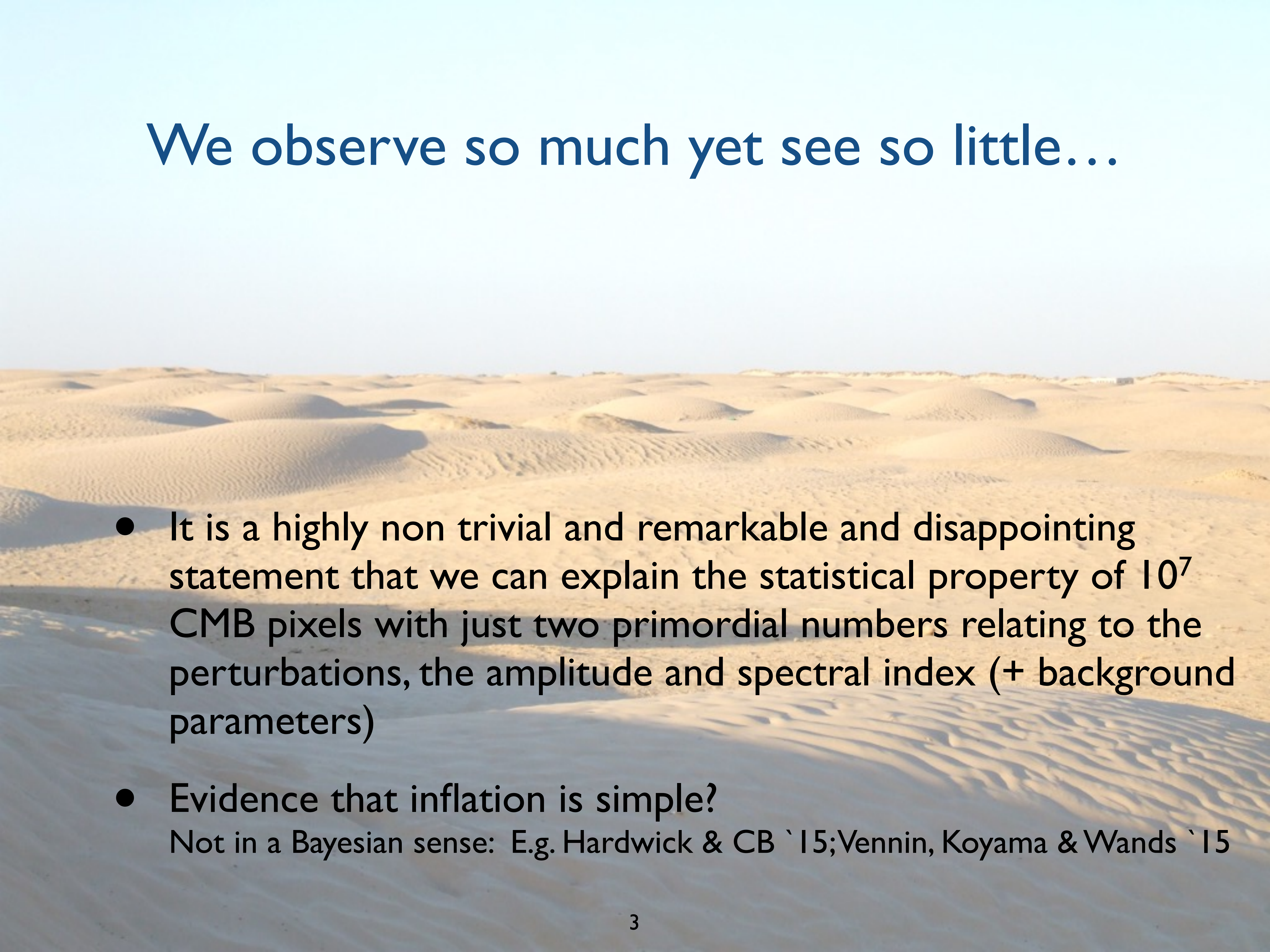


1992

2003

2013

We observe so much yet see so little…



- It is a highly non trivial and remarkable and disappointing statement that we can explain the statistical property of 10^7 CMB pixels with just two primordial numbers relating to the perturbations, the amplitude and spectral index (+ background parameters)

- Evidence that inflation is simple?
  Not in a Bayesian sense: E.g. Hardwick & CB `15; Vennin, Koyama & Wands `15

Anomalies

None of the anomalies are significant enough to rule out the simplest models, several are ~ 3 sigma. They include the lack of power on large scales, the cold spot, various alignments and the power asymmetry

However, anomalies might provide clues for where to finally find a deviation from the simplest models

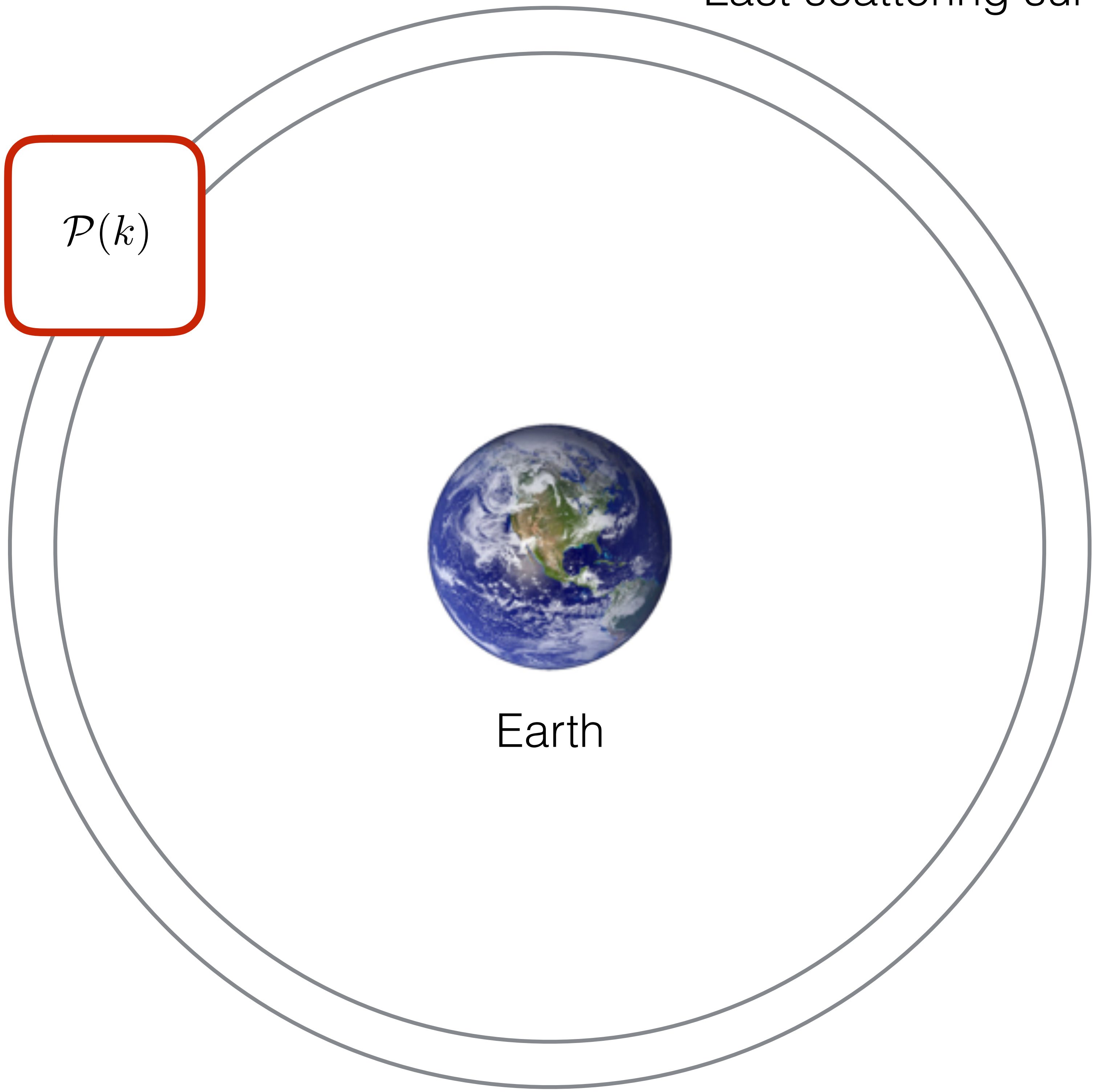
With large data sets, we are bound to find some anomalies. Quantifying the "look elsewhere" effect is difficult and controversial

In particular, anomalies involving large scales are here to stay, they were already observed by WMAP and are cosmic variance limited (other than polarisation)

Schwarz et al review 2015

modes in the box
contribute to $\delta T/T$

Last scattering surface



$\mathcal{P}(k)$

Earth

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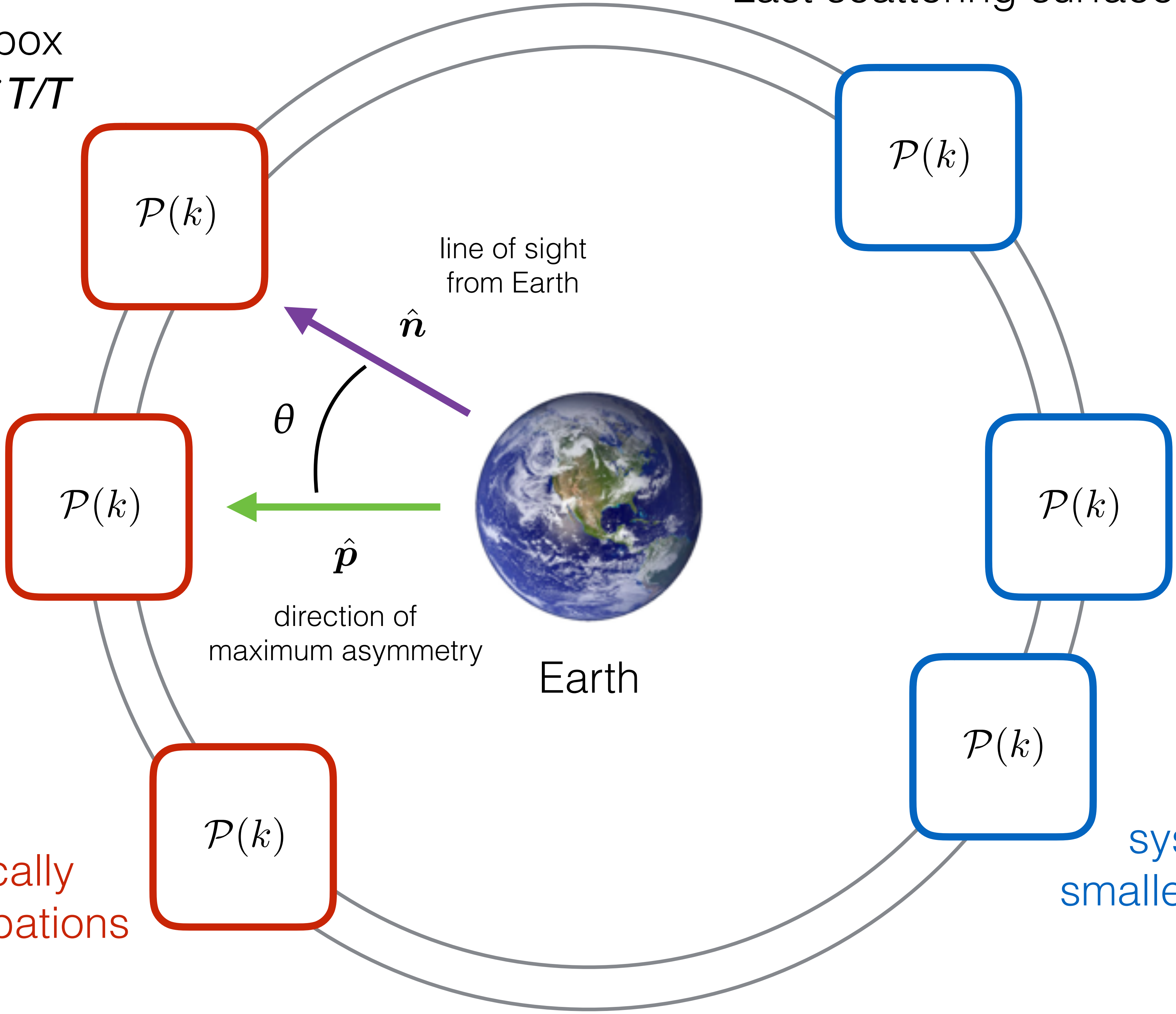
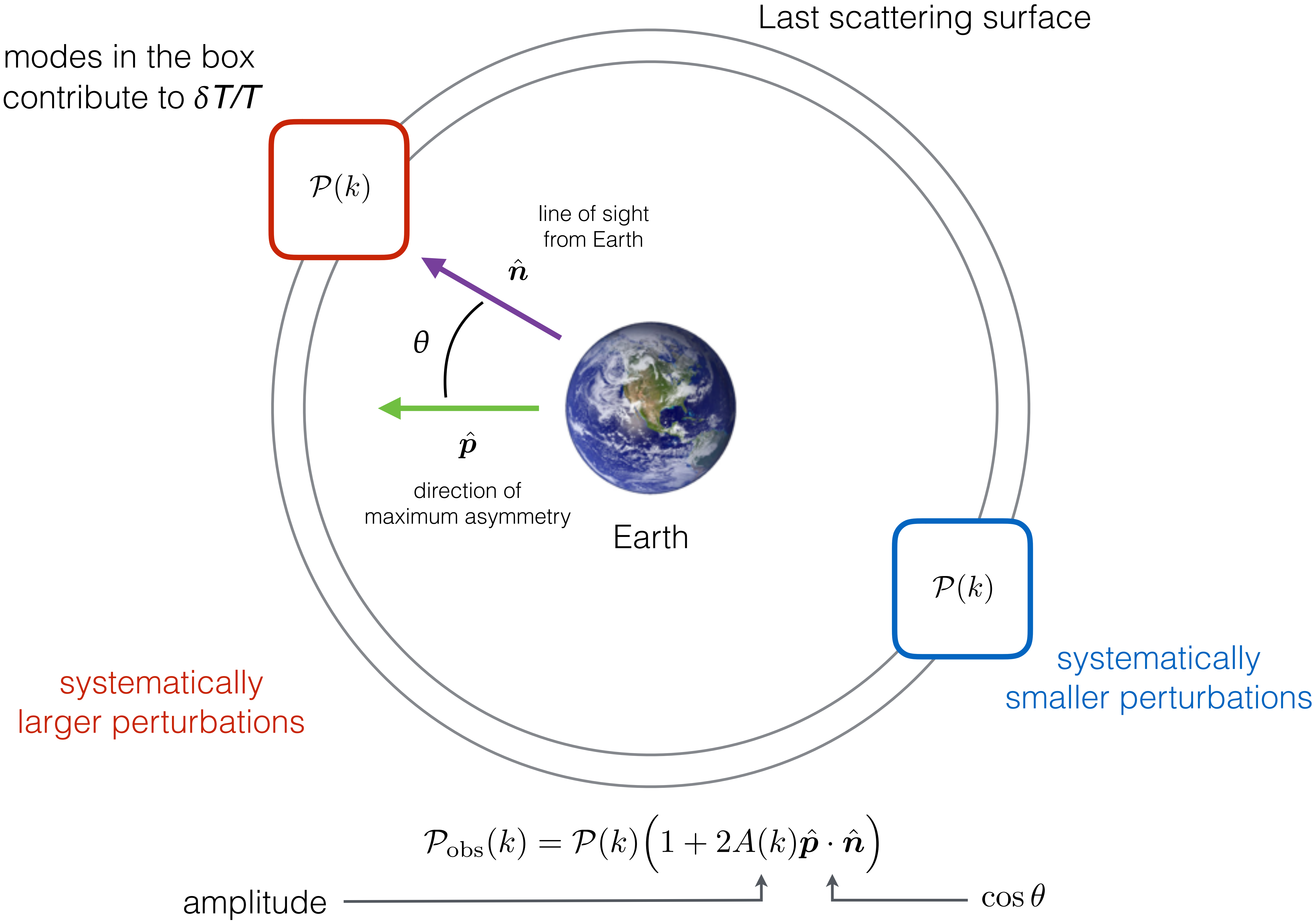


systematically
larger perturbations

systematically
smaller perturbations

$$\mathcal{P}_{\rm obs}(k) = \mathcal{P}(k)\Big(1 + 2\underbrace{A(k)}_{\text{amplitude}}\underbrace{\hat{\boldsymbol{p}}\cdot\hat{\boldsymbol{n}}}_{\cos\theta}\Big)$$



Last scattering surface

modes in the box
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$\mathcal{P}(k)$

line of sight
from Earth

$\hat{\boldsymbol{n}}$

θ

$\hat{\boldsymbol{p}}$

direction of
maximum asymmetry

Earth

$\mathcal{P}(k)$

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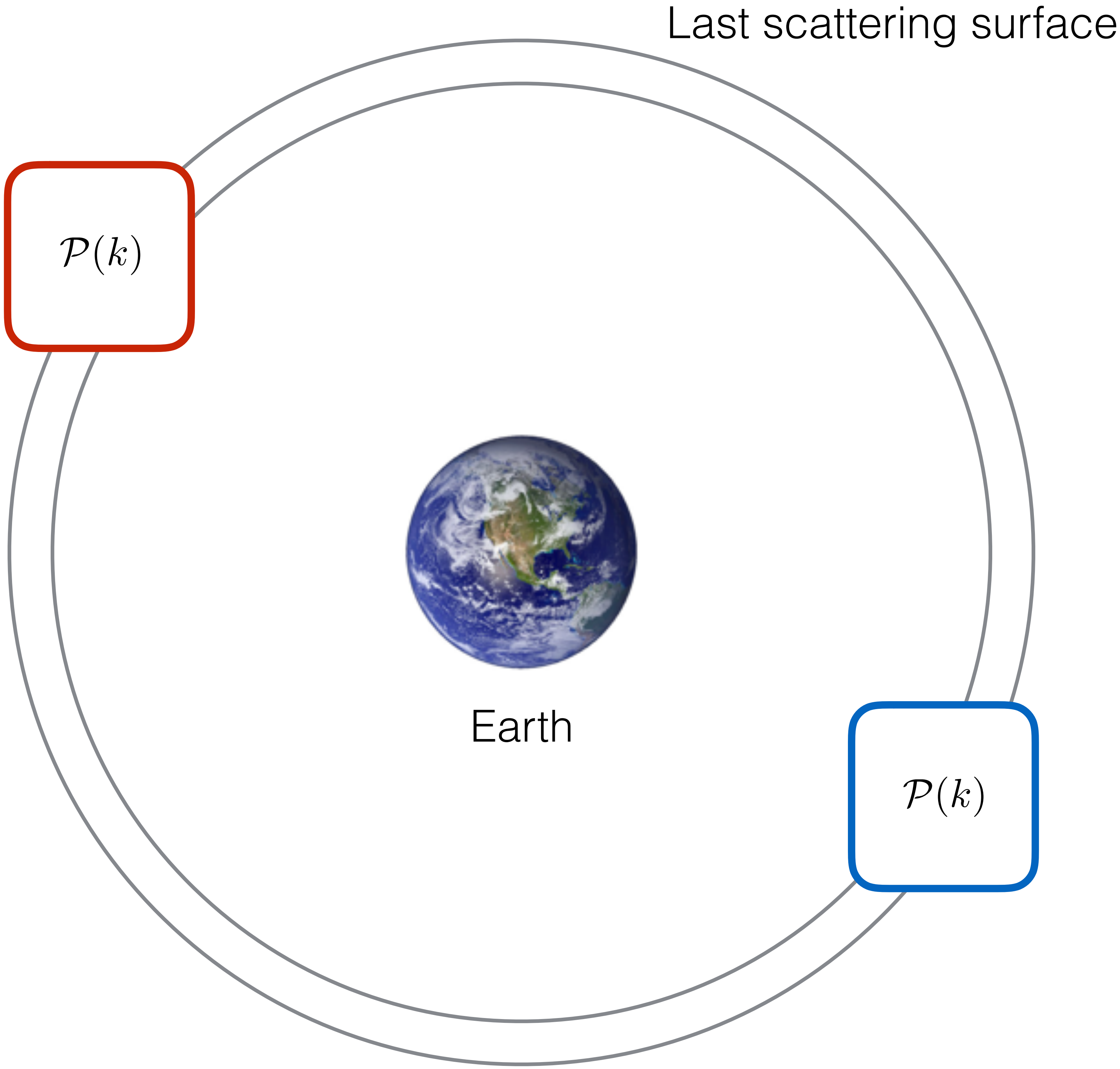
amplitude

$\cos\theta$



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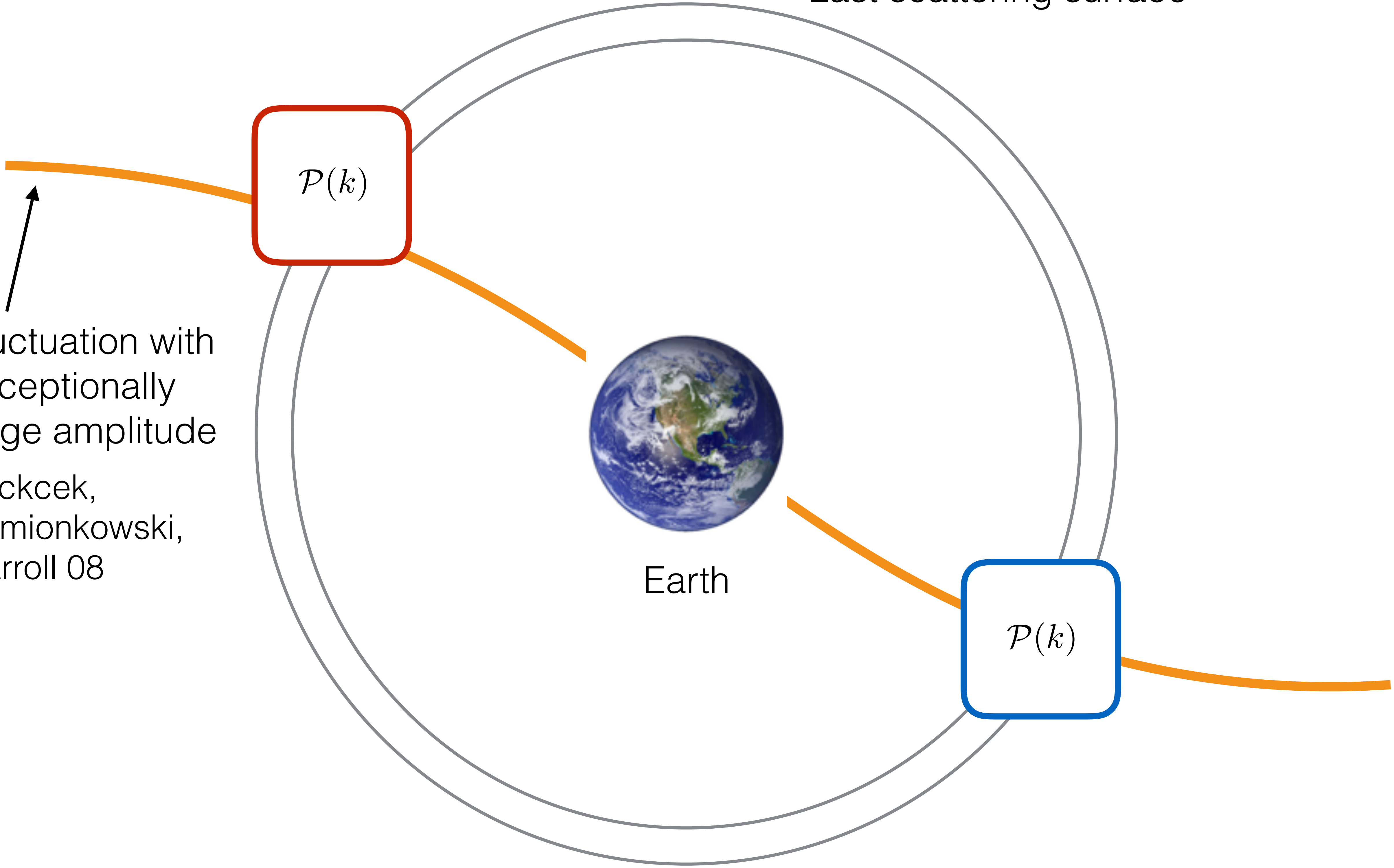
Our Hubble volume is embedded within some larger volume



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Fluctuation with exceptionally large amplitude

Erickcek, Kamionkowski, Carroll 08

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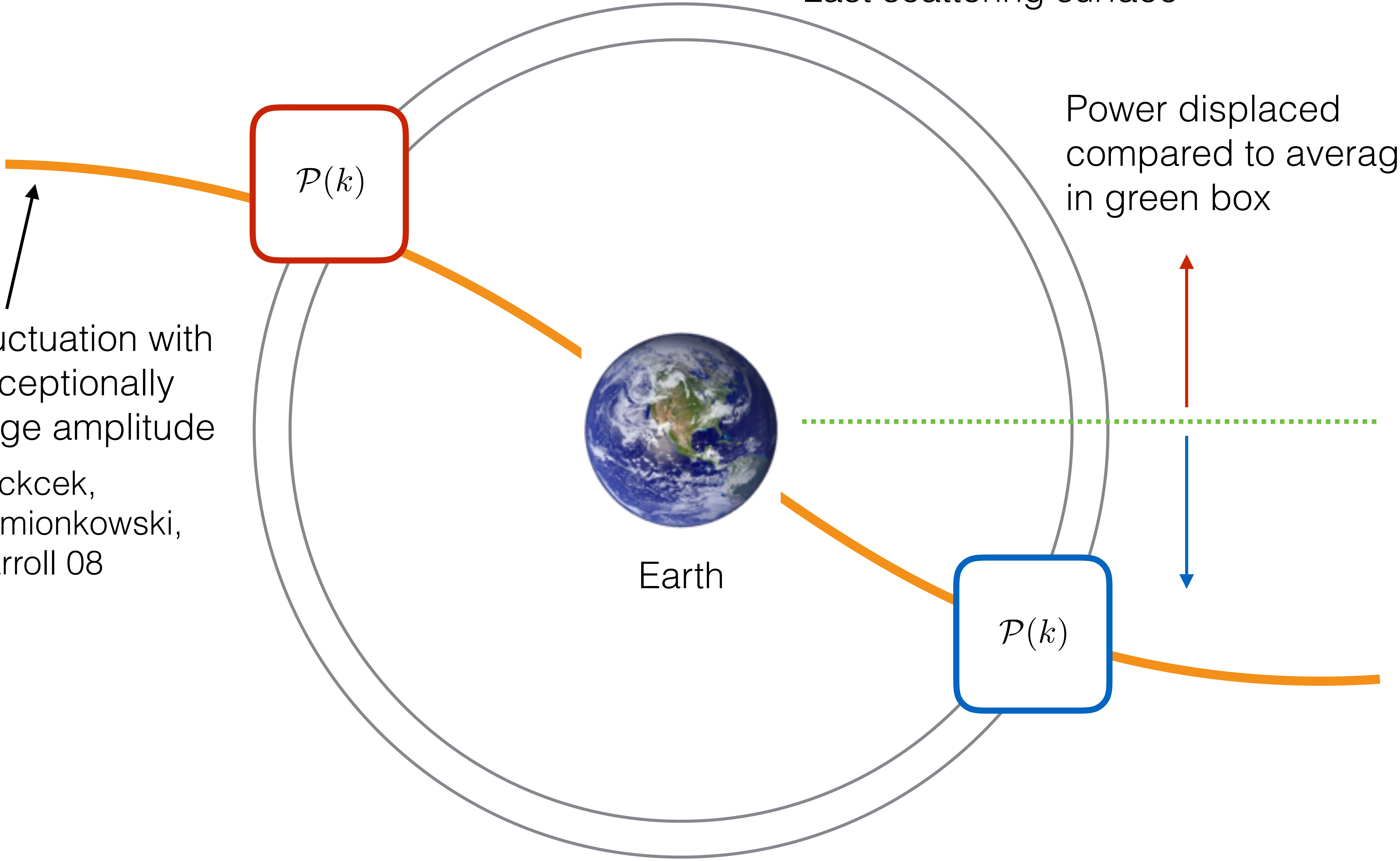

Last scattering surface

Power displaced compared to average in green box

Fluctuation with exceptionally large amplitude

Erickcek, Kamionkowski, Carroll 08

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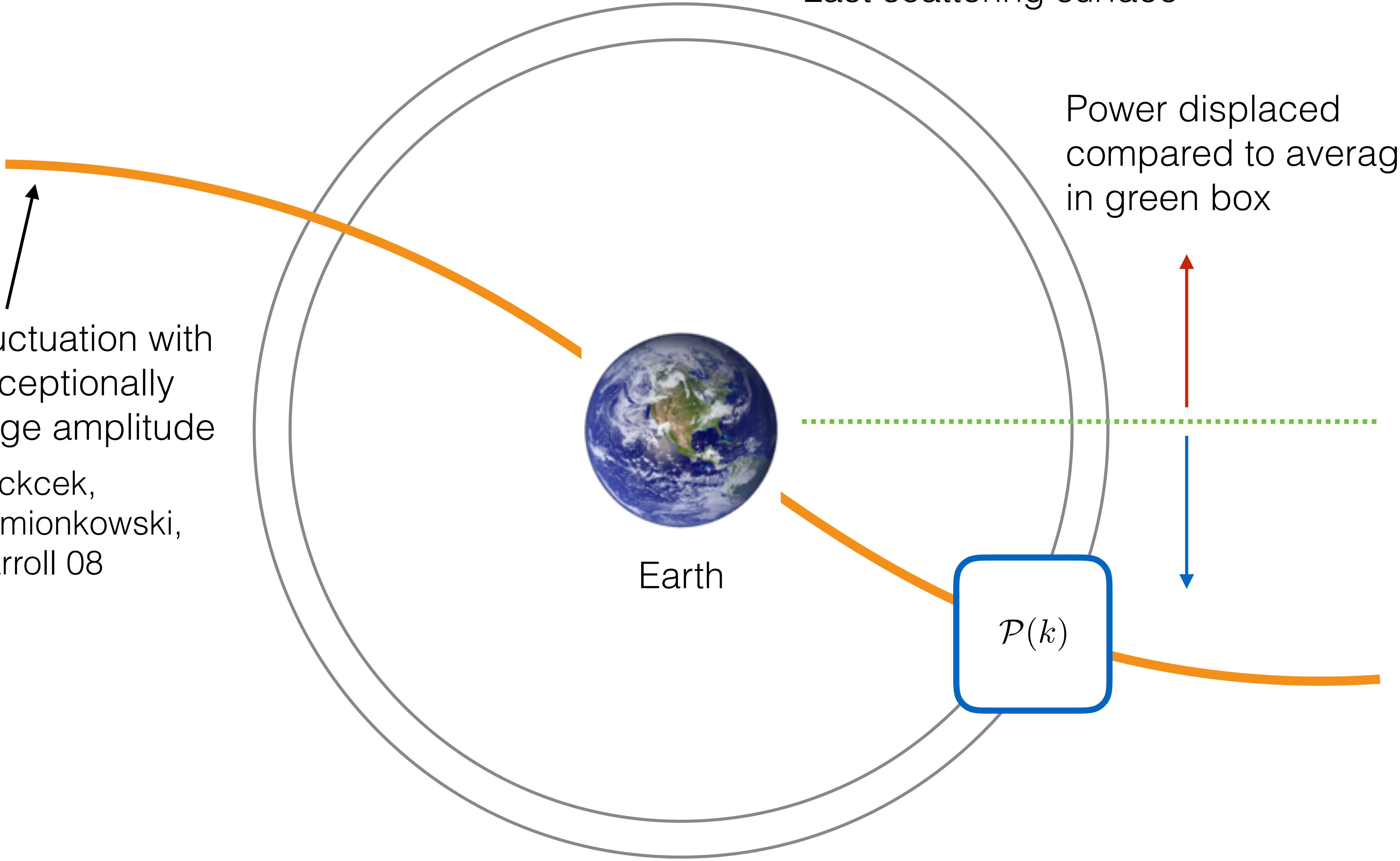

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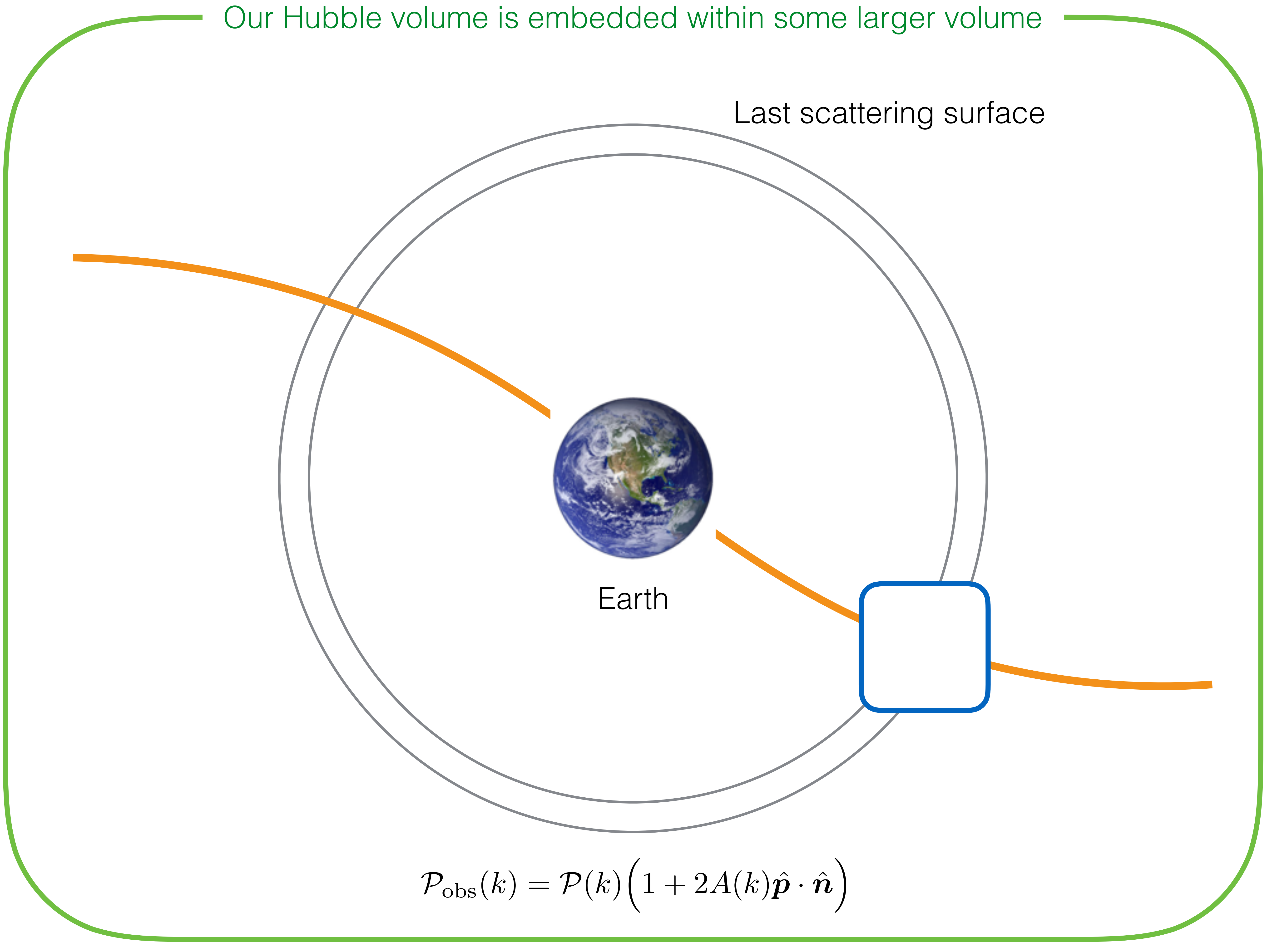

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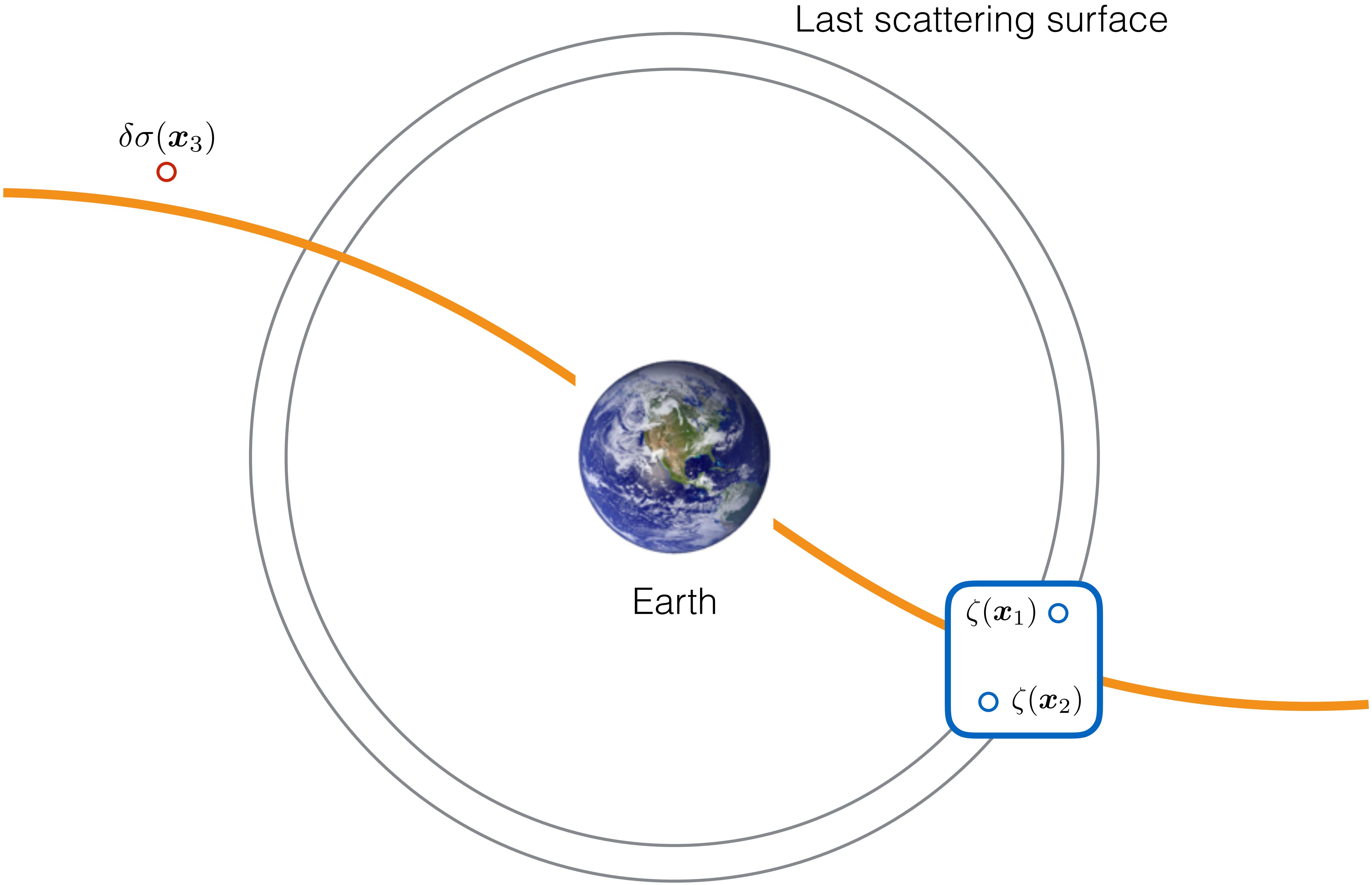


Last scattering surface

$\delta\sigma(\boldsymbol{x}_3)$

Earth

$\zeta(\boldsymbol{x}_1)$

$\zeta(\boldsymbol{x}_2)$

$$\mathcal{P}_{\rm obs}(k) = \mathcal{P}(k)\Big(1 + 2A(k)\hat{\boldsymbol{p}}\cdot\hat{\boldsymbol{n}}\Big)$$

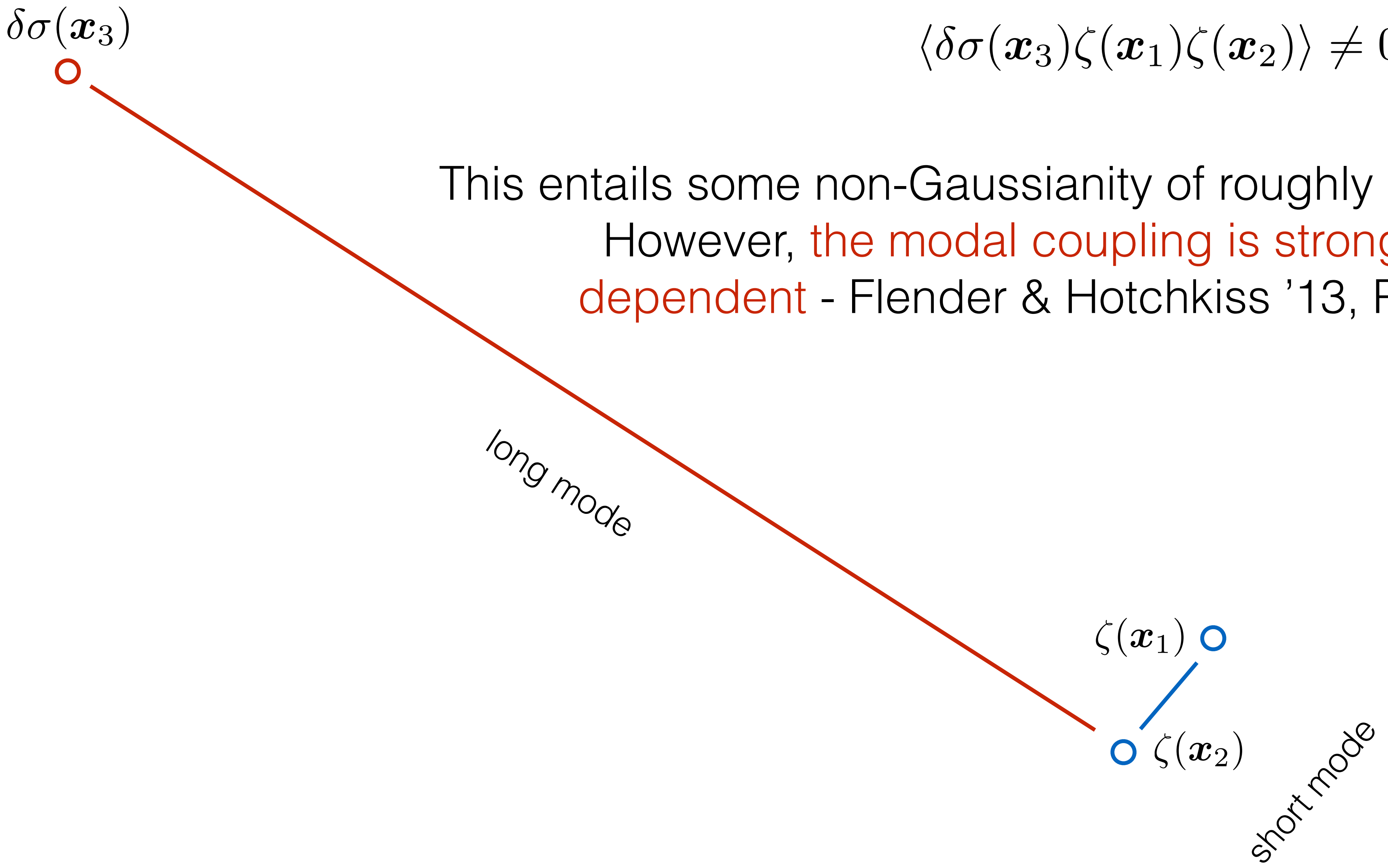

$\delta\sigma(\boldsymbol{x}_3)$
$\zeta(\boldsymbol{x}_1)$
$\zeta(\boldsymbol{x}_2)$

The small-scale fluctuation responds to the long wavelength mode only if

$$\langle \delta\sigma(\boldsymbol{x}_3)\zeta(\boldsymbol{x}_1)\zeta(\boldsymbol{x}_2)\rangle \neq 0$$

This entails some non-Gaussianity of roughly local type

However, the modal coupling is strongly scale dependent - Flender & Hotchkiss ’13, Planck ‘15



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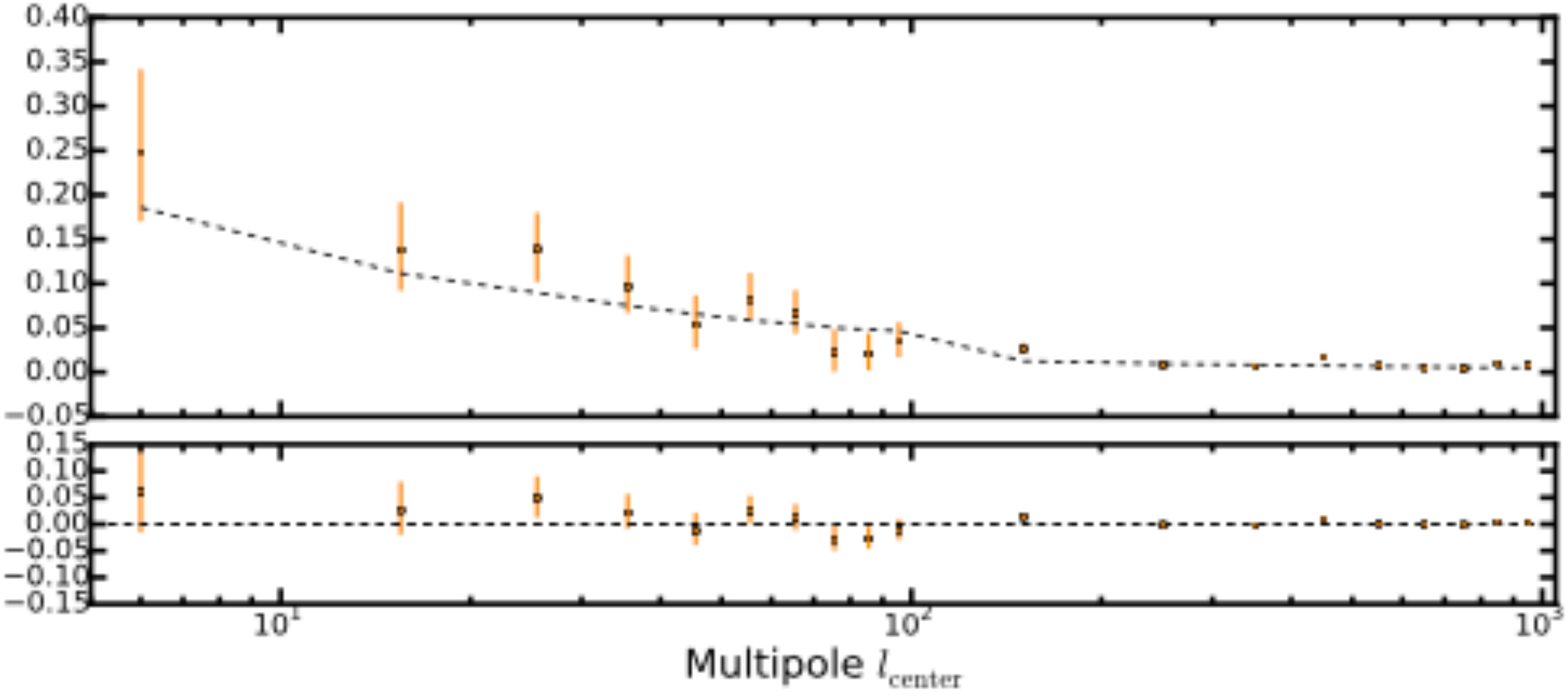
fit by power-law

$$A(k) \sim k^{-0.5}$$



Aiola et al. 15

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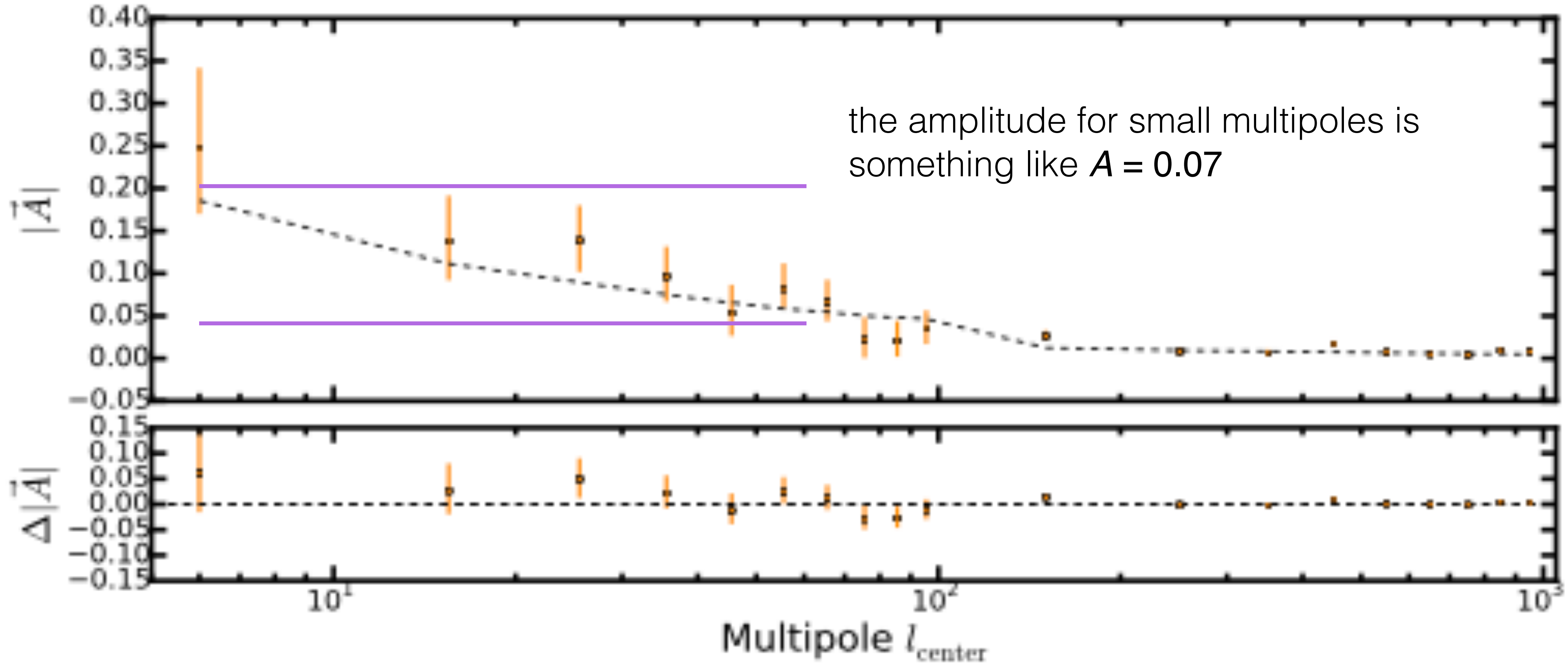
must scale like

$k^{-0.5}$

doesn't depend on ***k***



the amplitude for small multipoles is something like $A = 0.07$

Aiola et al. 15

Power spectrum asymmetry

- To explain it, we need a very large amplitude horizon scale perturbation
- Impossible with an adiabatic mode: Erickcek, Kamionkowski & Carroll ’08
- This super horizon perturbation requires a large amplitude isocurvature perturbation (which single-field inflation cannot generate) - if “real” it is a signature of multiple fields
- The asymmetry needs a scale dependence ten times larger than that observed for the power spectrum, much larger than in usual slow-roll calculations
- Normally the scale dependence of f_{NL} is calculated for equilateral configurations
- Instead we should calculate the scale dependence due to changing the short-wavelength mode while keeping the long wavelength fixed

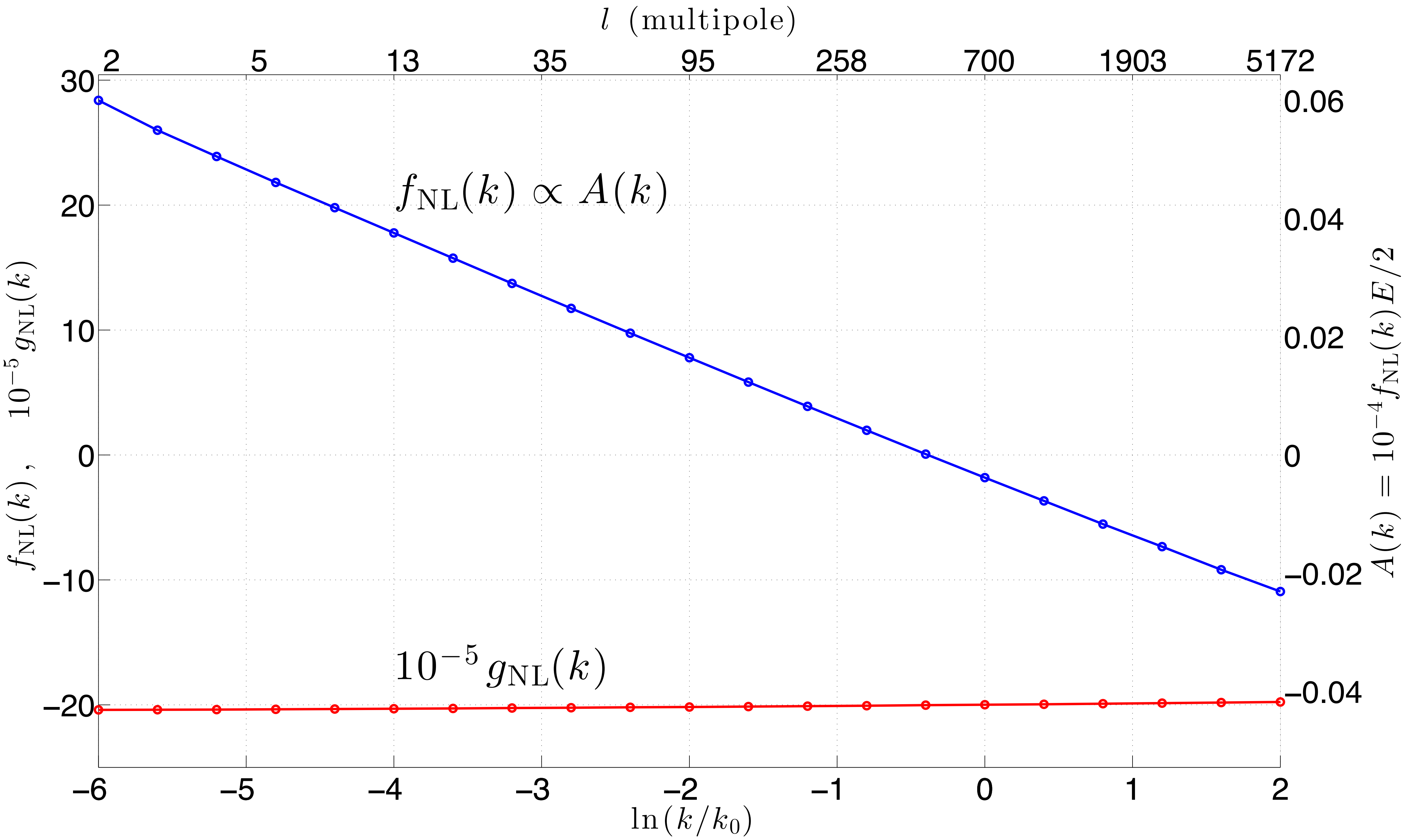
Model building attempt: Take 1

- Consider the simplest case in which in any one field generates all of the perturbations
- To preserved the quasi scale invariance of the power spectrum, the only possible source of a strong scaling is a large self-interaction
- The log scale dependence for equilateral configurations is (Byrnes et al. `10)

$$n_{f_{NL}} \sim \frac{\sqrt{r_T}}{f_{NL}} \frac{V'''}{3H^2}$$

- However for large scale dependences, we need to include the higher-order terms, which resum to give a log instead of power law scale dependence
- Even worse, we find a large and scale invariant g_{NL}~10^5 and a huge quadrupolar modulation of the power spectrum, these latter two problems were not spotted before despite many papers performing similar model building

This is as good as it gets



Byrnes and Tarrant `15

$$P_\zeta = P_{\rm iso}\left(1 + 2A\hat{\mathbf{n}}.\hat{\mathbf{p}} + B\left(\hat{\mathbf{n}}.\hat{\mathbf{p}}\right)^2\right)$$

Too large $g_{\rm NL}$ and scale invariant B~14, 3 orders-of-magnitude too large
Problem arises due to strong scale-dependence, ignore “solutions” which ignore this

Model building attempt: Take II

- Give ourselves the additional freedom/complication of more than one field generating the perturbations
- The scale-invariant and Gaussian inflaton perturbations can generate the power spectrum
- Strongly scale-dependent non-Gaussianity can be generated by a strong scaling of the non-Gaussian field in this case, without any self interaction
- This solves the problems of large g_{NL} and B - are we done?
- Instead we need a large eta parameter $\eta_{\sigma\sigma} \sim -0.25 \qquad n_A \simeq 2\eta_\sigma = -0.5$
- However, this makes the non-Gaussian field roll quickly, it either dominates over the inflaton which kills f_{NL}, or we have to start with such a tiny initial value that the field is in a quantum diffusion dominated regime and scale dependence goes away - eta cannot be a constant
- Byrnes, Regan, Seery & Tarrant '15 (see also Kenton & Mulryne `15)

The horrors of model building

The simplest working potential we found

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$$V = V_0\left(1 - \frac{1}{2}\frac{m_\phi^2\phi^2}{M_\mathrm{P}^4}\right)\left(1 + \frac{1}{2}\frac{\sigma^2}{M_\mathrm{P}^2}\left[\frac{m_1^2 - m_2^2}{2M_\mathrm{P}^2}\tanh\frac{\sigma - \sigma_\mathrm{c}}{\sigma_\mathrm{step}} - \frac{m_1^2 + m_2^2}{2M_\mathrm{P}^2}\right] \right.$$
$$\left. - \frac{1}{2}\frac{\sigma_\mathrm{c}^2}{M_\mathrm{P}^2}\frac{m_1^2 - m_2^2}{2M_\mathrm{P}^2}\left[1 + \tanh\frac{\sigma - \sigma_\mathrm{c}}{\sigma_\mathrm{step}}\right]\right).$$

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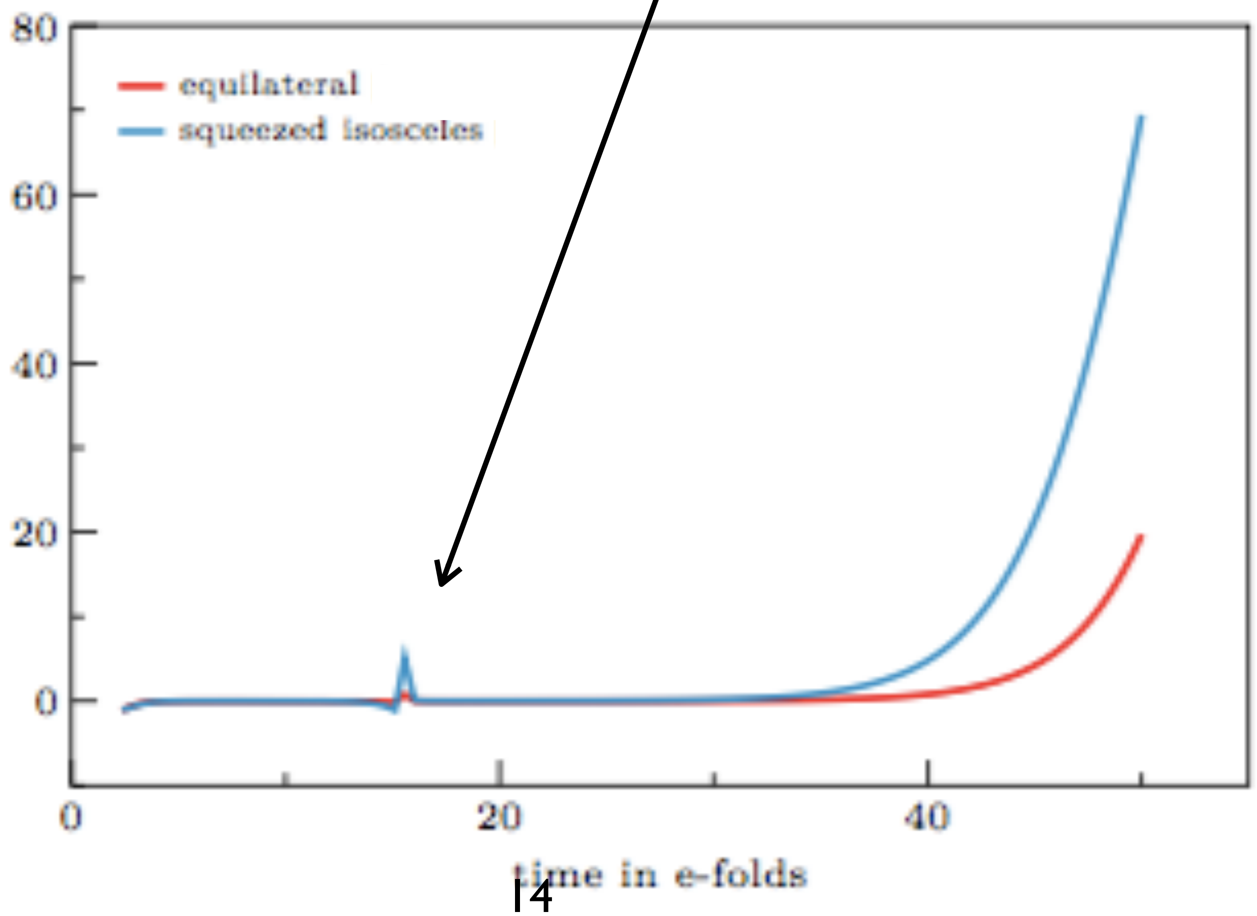
only works for special parameter values and finely tuned initial conditions

The growth of f_{NL} with time for equilateral and squeezed configurations.
For the local template, there would be no difference



The (power law) scaling in the squeezed limit achieves the correct scaling of the asymmetry

- Previous papers discussed the problem of $f_{NL}>100$, but without specifying the scale dependence and using the (scale invariant) local template

$$\frac{|a_{20}|}{5\times 10^{-6}}\frac{|f_{NL}|}{10}\simeq 10\left(\frac{A}{0.07}\right)^2$$

- Lyth `14, Kanno et al. `14, Kobayashi, Cortes & Liddle `15, etc
- Despite having large f_{NL} on large scales, the Planck response to the bispectrum from our model is $f_{NL}\sim 1$ (for all standard templates)
- In order to get the correct amplitude, we need to tune the amplitude of the super-horizon mode in sigma to be about 10-100 times larger than is typical (however, see Adhikari, Shandera & Erickcek '15)
- This is the case with every explanation of this type, but without new physics this is a >10 sigma fluctuation to explain a 3 sigma statistical anomaly!
- We have also checked that the low-l multipoles are not too large

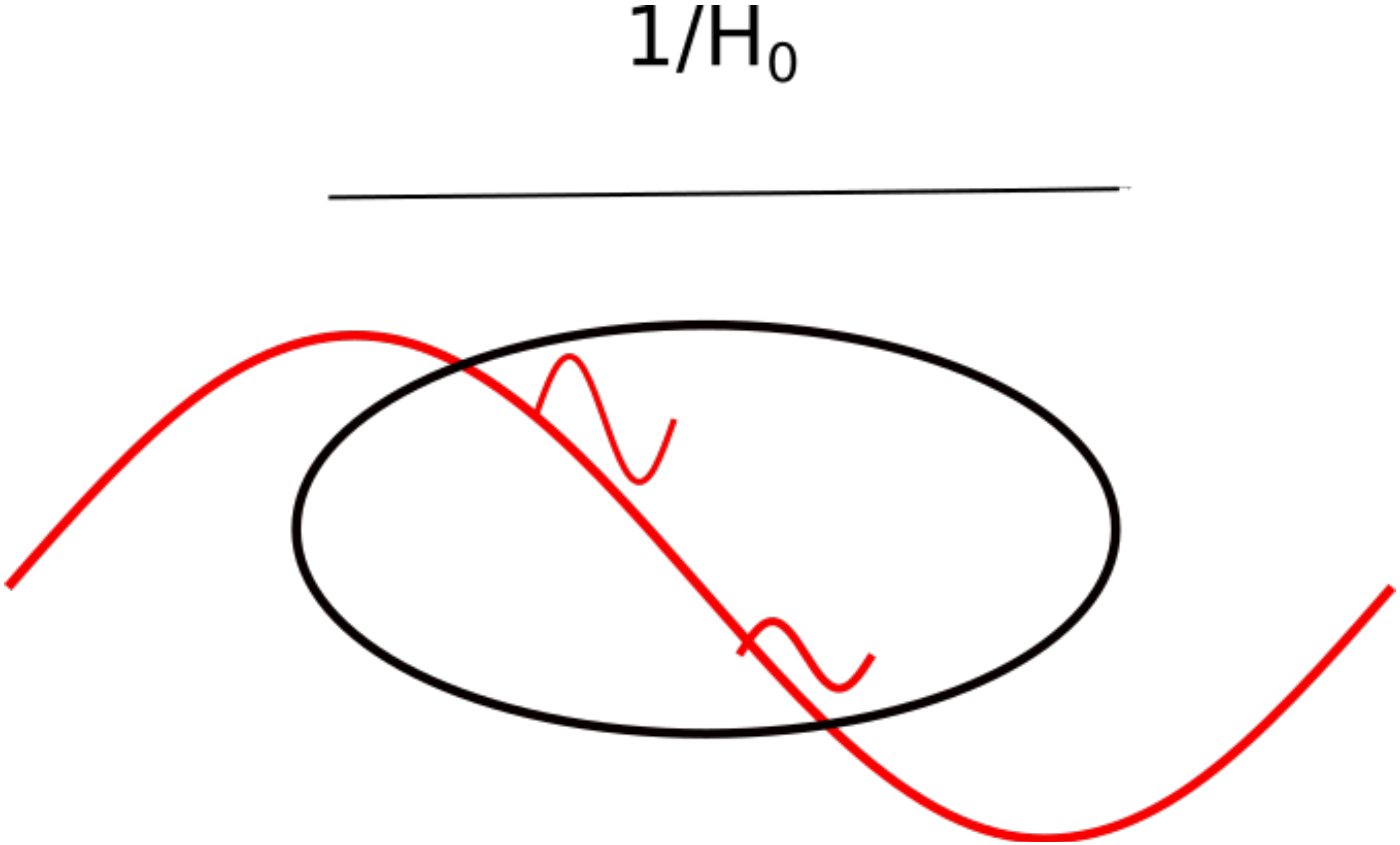
Anomaly/Asymmetry lessons

- Theorists are creative, any a posteriori detection is probably hard to explain with a sensible model
- Once a model has been built to explain something strange, one must be careful to check if it predicts other strange things.
  Normally it will! Ideally this would explain a different anomaly, but often rules out the model
- Typical tunings required include the very large amplitude super-horizon wavelength mode, the hard work which goes into building the strong scale dependence and the initial conditions of the fields. Remember the significance of the anomaly you wanted to explain

Conclusions

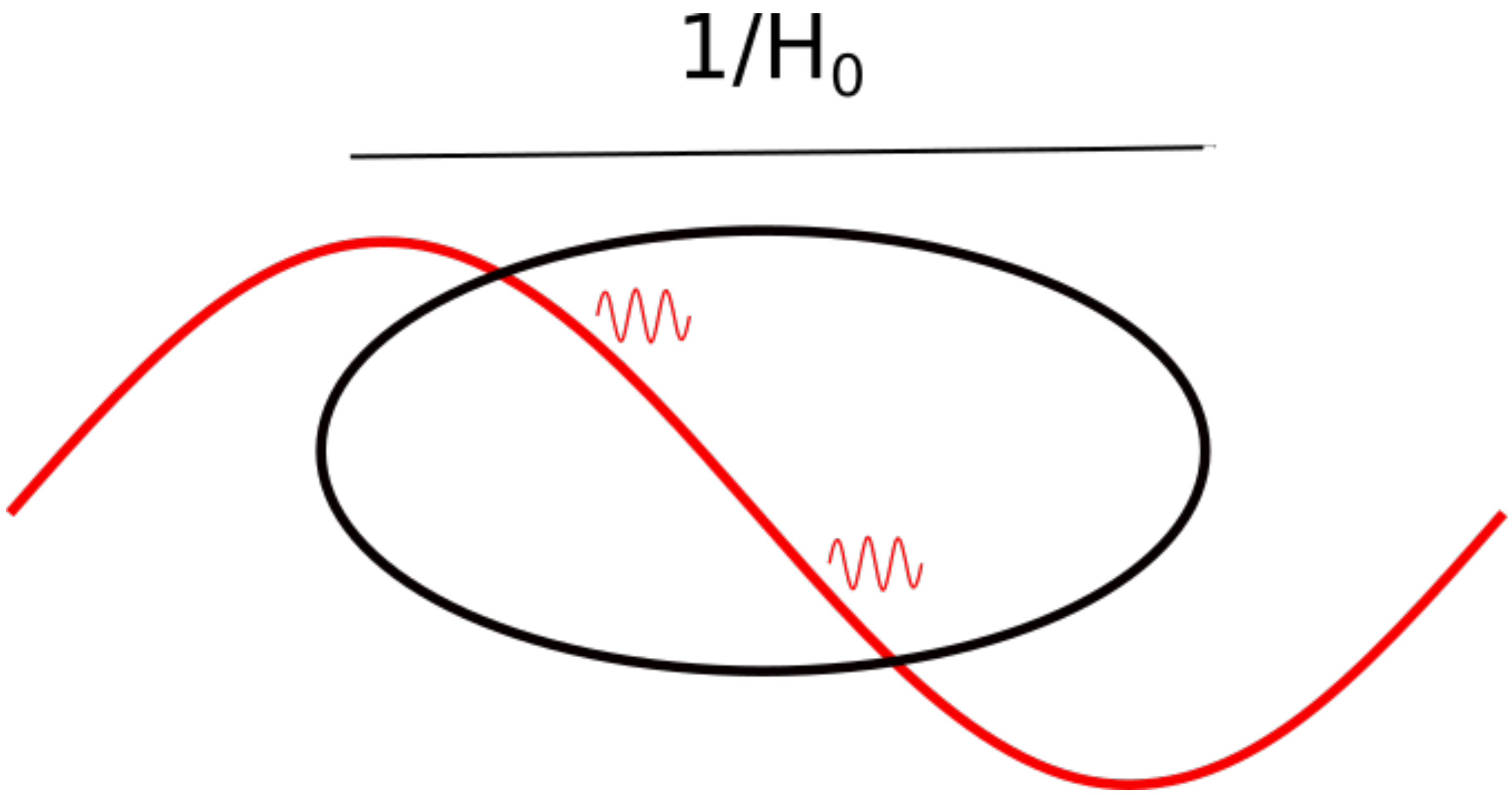
- The latest Planck constraints remain broadly consistent with the simplest single field models of inflation, but absence of evidence is not evidence of absence
- Anomalies could be the first clue to new physics
- We have calculated in detail how the asymmetry depends on strongly-scale dependent non-Gaussianity, which bispectral shapes and scalings matter, and shown our complicated bispectrum does not conflict with Planck non-Gaussianity constraints
- A successful model must have the correct scaling and amplitude to explain a 10% effect, but not generate additional signatures which are ruled out. This is difficult. Beware of incomplete calculations
- When you have succeeded, compare the model to the significance of the asymmetry you wished to explain

Long-short wavelength coupling



The superhorizon mode modulates the amplitude of the shorter wavelength modes (l<100)

Smells like local non-Gaussianity



But with a twist, the short wavelength modes do not feel a coupling

Strongly scale-dependent “local” non-Gaussianity

What is the required shape and scale dependence of the bispectrum?

How does this relate to the response of the power spectrum to the long wavelength mode?

What are the observational constraints?

Can we build a theoretical model?