Title: Cosmic Tides

Date: Jan 29, 2013 11:00 AM

URL: http://www.pirsa.org/13010114

Abstract: We apply CMB lensing techniques to large scale structure and solve for the 3-D cosmic tidal field. We use small scale filamentary structures to solve for the large scale tidal shear and gravitational potential.

By comparing this to the redshift space density field, one can measure the gravitational growth factor on large scales without cosmic variance. This potentially enables accurate measurements of neutrino masses and reconstruction of radial modes lost in 21 cm intensity mapping, which are essential for CMB and other cross correlations. We relate the tidal fields to the squeezed limit bispectrum, and present initial results from simulations and data from the SDSS.

Beating Cosmic Variance with Cosmic Tides

Ue-Li Pen, Ravi Sheth, Xuelei Chen, Zhigang Li

CITA, ICTP, NAOC

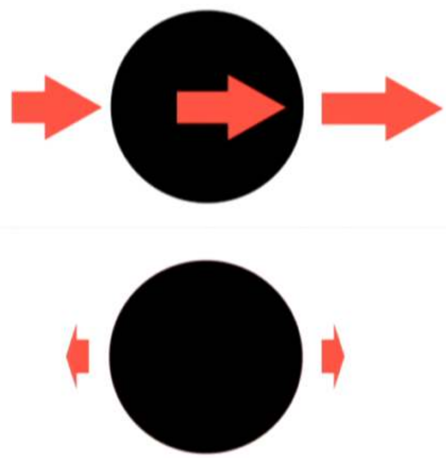
arxiv:1202.5804

January 29, 2013

Overview

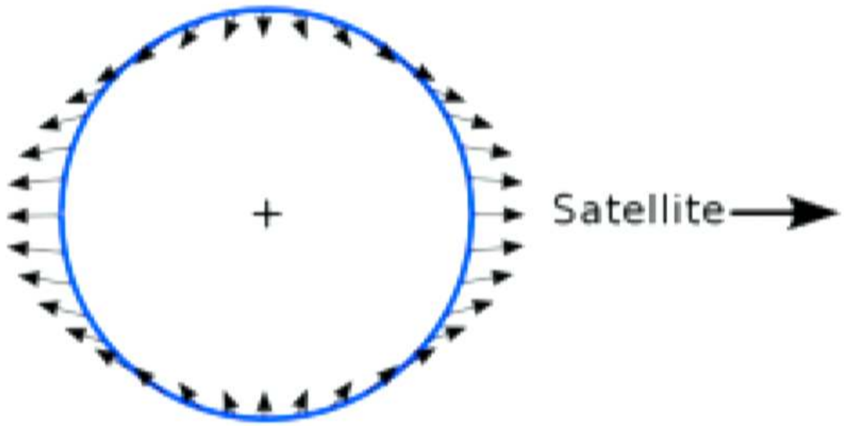
- What is a tide?
- Tides and large scale structure
- Overcoming cosmic variance
- Neutrinos and more

Tides



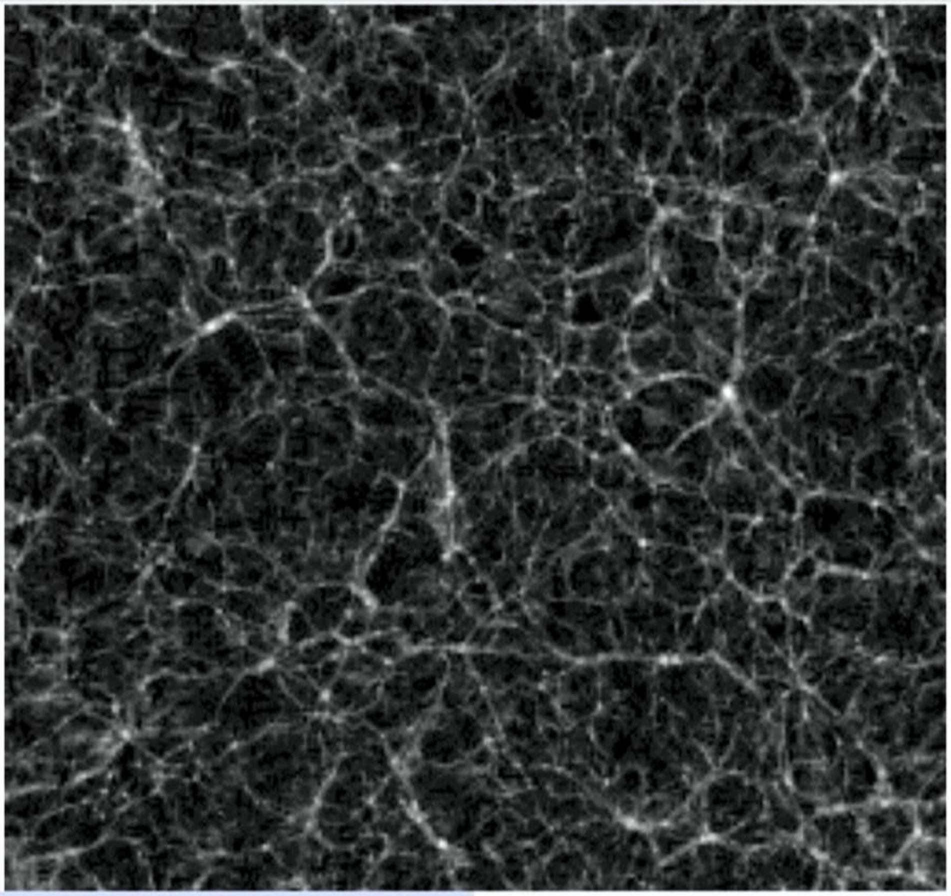
Graphic of tidal forces; the gravity field is generated by a body to the right. The top picture shows the gravitational forces; the bottom shows their residual once the field of the sphere is subtracted; this is the tidal force. (From Wikipedia)

Tides on Earth



The Moon's gravity differential field at the surface of the Earth is known as the Tide Generating Force. This is the primary mechanism driving tidal action, explaining two tidal equipotential bulges, and accounting for two high tides per day. In this figure, the Moon is either on the right side or on the left side of the Earth (at center). (truncated from Wikipedia)

Cosmic Tides



Gravity reconstruction

- analogous to CMB lensing, 21cm lensing of LSS
- large scale tidal fields aligns smaller scale structures
- use alignment of small filaments to measure large scale tidal field
- perfectly understood for Gaussian fields (Challinor, Lewis, etc)
- optimal quadratic estimators for non-Gaussian fields (Lu and Pen 2008)
- Simple framework for understanding information saturation (White, Meiksen, Rimes, Hamilton)
- equivalent to squeezed bispectrum quadrupole (Creminelli et al 2011)

Heuristic kernel: CMB Lensing

Gradient of the density field convolved by a Gaussian window.

$$W = \exp\left(\frac{-r^2}{2\sigma^2}\right) \quad (1)$$

then we obtain a windowed gradient density field

$$\bar{\delta} = \int W\delta. \quad (2)$$

Take log to Gaussianize: $\delta_g = \log(1 + \bar{\delta})$
The tidal shear field is the quadratic outer product

$$T_{ij} = (\partial_i \delta_g)(\partial_j \delta_g). \quad (3)$$

The density field is derived from a convolution:

$$\langle\delta\rangle(x) = \int T_{ij}(x')K_{ij}(x - x')d^3x' \quad (4)$$

Heuristic kernel: CMB Lensing

Gradient of the density field convolved by a Gaussian window.

$$W = \exp\left(\frac{-r^2}{2\sigma^2}\right) \quad (1)$$

then we obtain a windowed gradient density field

$$\bar{\delta} = \int W\delta. \quad (2)$$

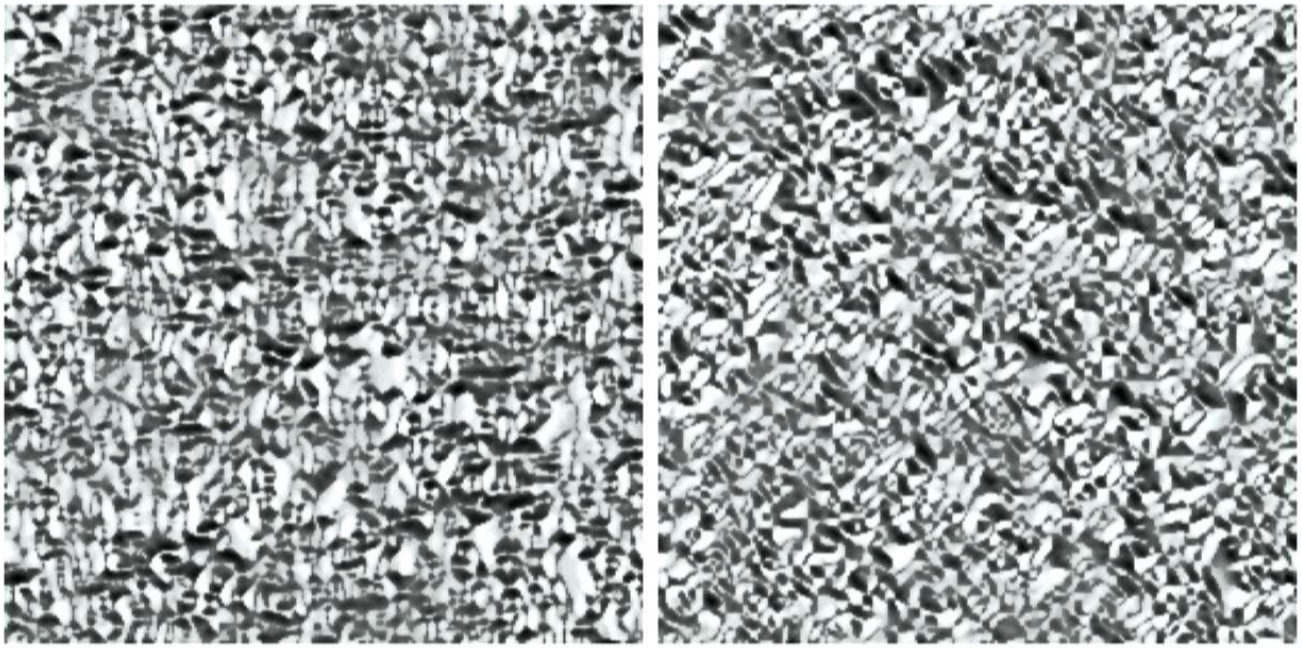
Take log to Gaussianize: $\delta_g = \log(1+\bar{\delta})$
The tidal shear field is the quadratic outer product

$$T_{ij} = (\partial_i \delta_g)(\partial_j \delta_g). \quad (3)$$

The density field is derived from a convolution:

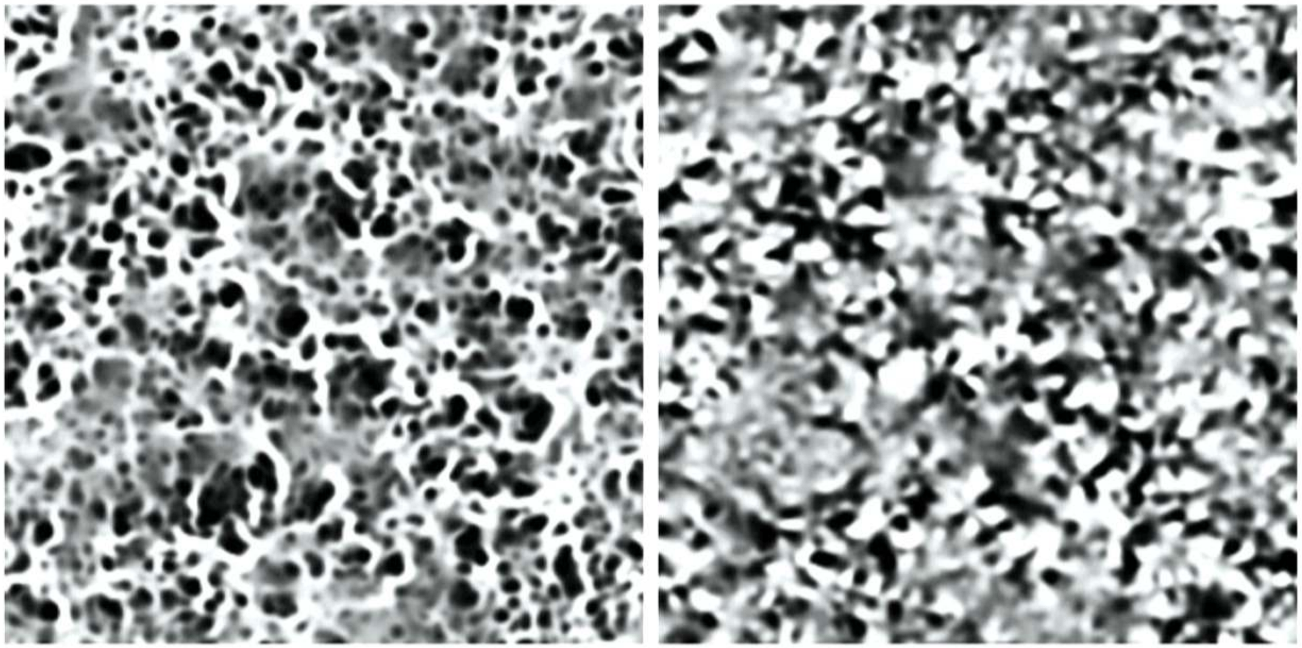
$$\langle\delta\rangle(x) = \int T_{ij}(x')K_{ij}(x-x')d^3x' \quad (4)$$

Tidal Shear



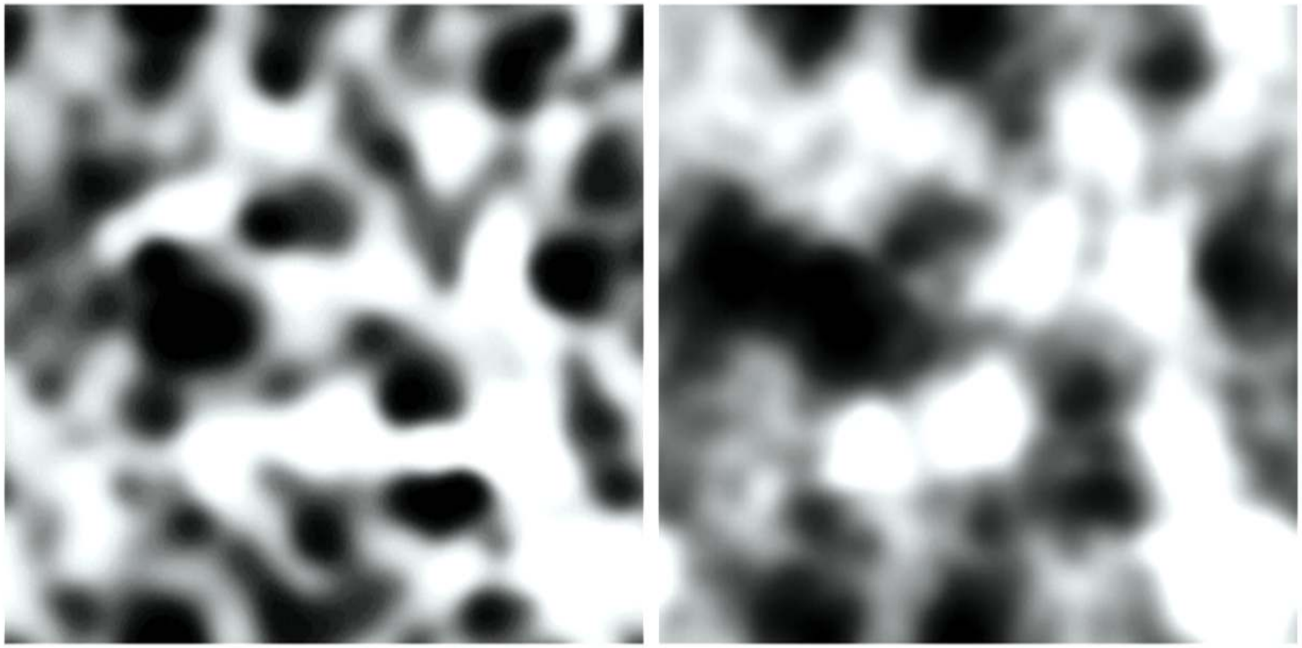
$\gamma_1 = T_{xx} - T_{yy}, \ \gamma_2 = 2T_{xy}$

Tidal Convergence Reconstruction



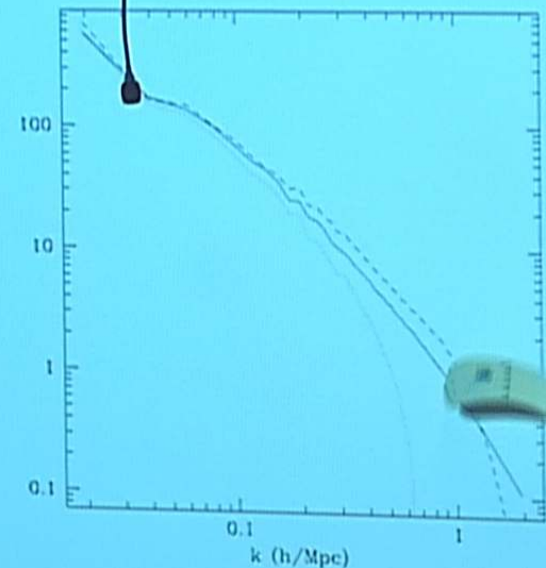
$\kappa = \nabla^{-2}(\gamma_{1,xx} - \gamma_{1,yy} + 2\gamma_{2,xy})$, $\kappa_b = \nabla^{-2}(\gamma_{2,xx} - \gamma_{2,yy} - 2\gamma_{1,xy})$

Smoothed field comparison

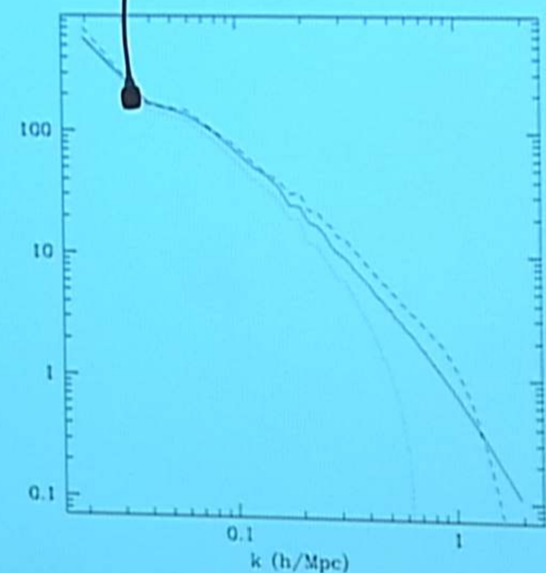


Density: reconstructed (left), original (right)

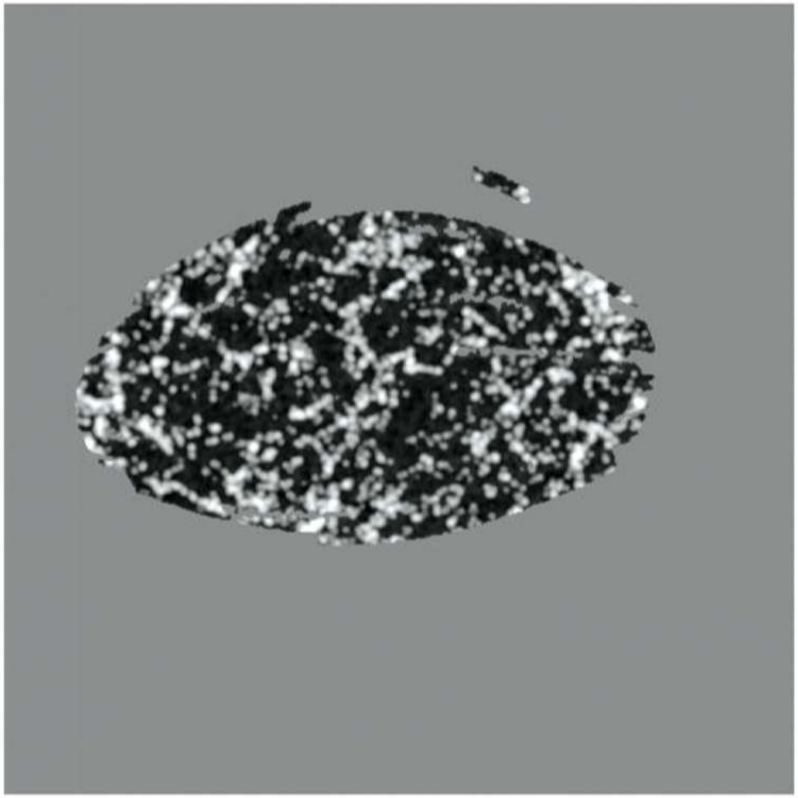
Power Spectrum



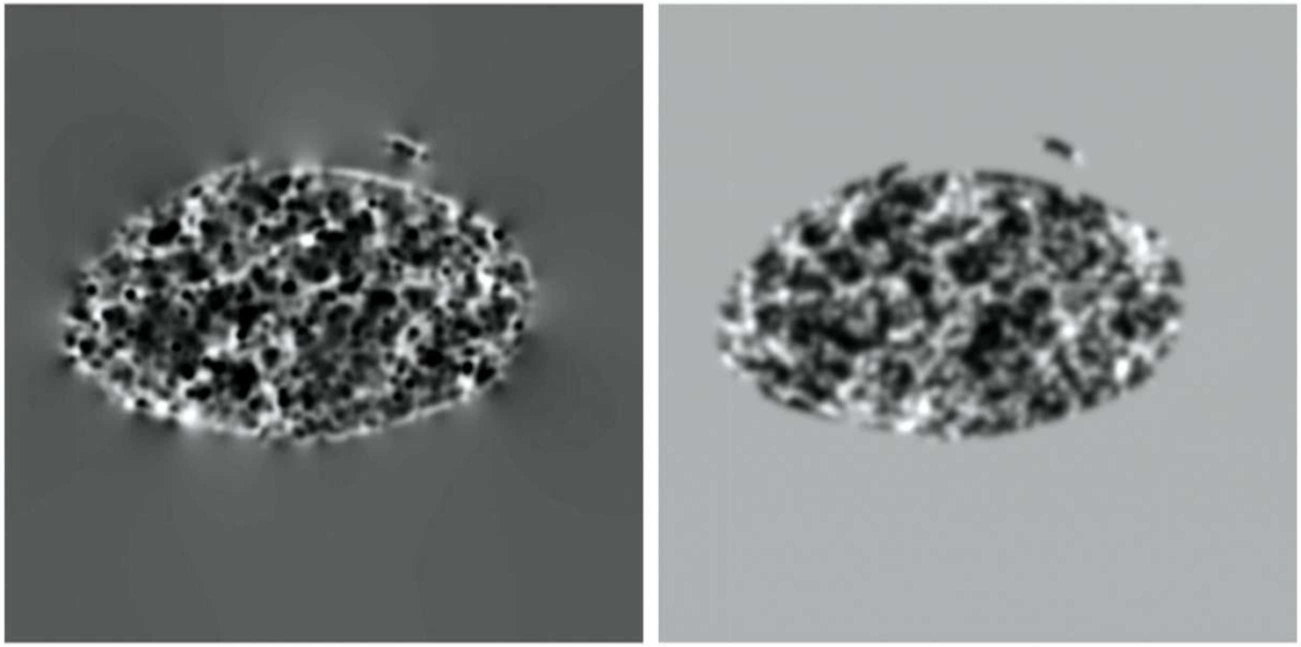
Power Spectrum



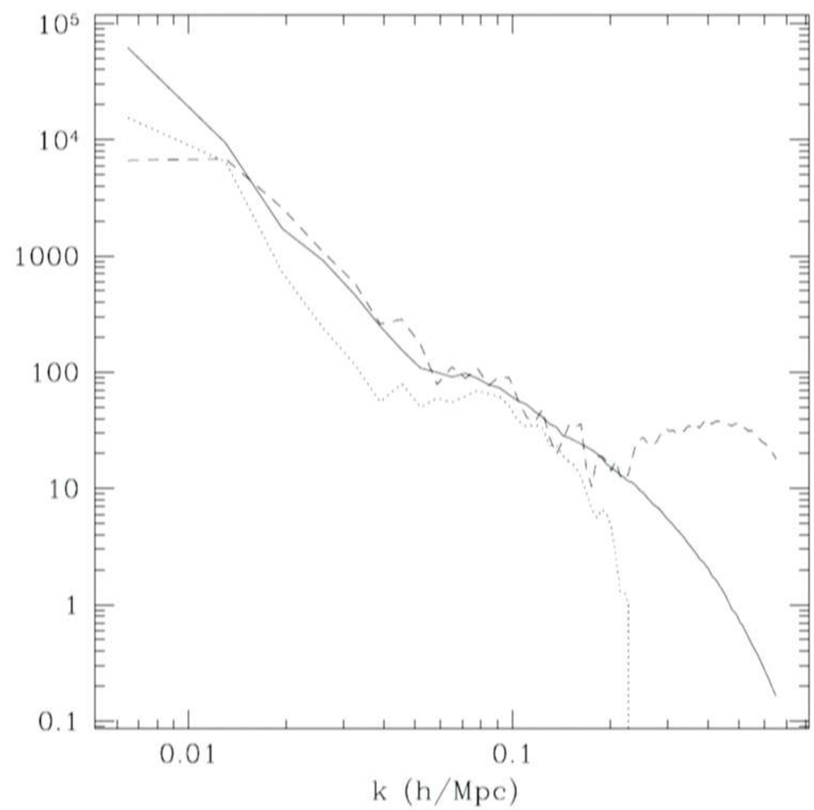
Real Data: SDSS



Cosmic Convergence



Cosmic Power



Cosmic Power dilemma

- Power spectrum theoretically cleanest at low k
- statistics best at high k
- Cosmic variance limit?

Overcoming Cosmic Variance?

- measure something better than $1/\sqrt{N}$
- c.f. Mcdonald and Seljak (2009)
- Goal is to measure transfer function
- could be measured better than $P(k)$ if both density and velocity are measured on the same mode
- RSD measure different modes
- Cosmic tides vs redshift space measure growth factor on same modes!
- can use large wavelength linear modes.

What the future may bring

- Use full SDSS catalog: 10x more galaxies
- other surveys: 6dF, 2dF, wiggleZ, etc
- Future surveys: BOSS, CHIME, etc
- Measure scale and time evolution of transfer function: neutrino masses, modified gravity?
- change observing strategies? Smaller volumes, closer by, all-sky, deeper?

Conclusions

- Cosmic Tides: a new window on gravity
- well developed non-Gausian theory
- Initial confirmation in simulated and real data
- Potentially measure low k power spectrum better than cosmic variance
- Applications: tests of modified gravity, neutrino masses, dark energy

Heuristic kernel: CMB Lensing

Gradient of the density field convolved by a Gaussian window.

$$W = \exp\left(\frac{-r^2}{2\sigma^2}\right) \tag{1}$$

then we obtain a windowed gradient density field

$$\bar{\delta} = \int W\delta. \tag{2}$$

Take log to Gaussianize: $\delta_g = \log(1 + \bar{\delta})$
The tidal shear field is the quadratic outer product

$$T_{ij} = (\partial_i \delta_g)(\partial_j \delta_g). \tag{3}$$

The density field is derived from a convolution:

$$\langle\delta\rangle(x) = \int T_{ij}(x')K_{ij}(x - x')d^3x' \tag{4}$$

Heuristic kernel: CMB Lensing

Gradient of the density field convolved by a Gaussian window.

$$W = \exp\left(\frac{-r^2}{2\sigma^2}\right) \tag{1}$$

then we obtain a windowed gradient density field

$$\bar{\delta} = \int W\delta. \tag{2}$$

Take log to Gaussianize: $\delta_g = \log(1 + \bar{\delta})$
The tidal shear field is the quadratic outer product

$$T_{ij} = (\partial_i \delta_g)(\partial_j \delta_g). \tag{3}$$

The density field is derived from a convolution:

$$\langle\delta\rangle(x) = \int T_{ij}(x')K_{ij}(x - x')d^3x' \tag{4}$$