Testing the Laws of Gravity with CFHTLenS and WiggleZ

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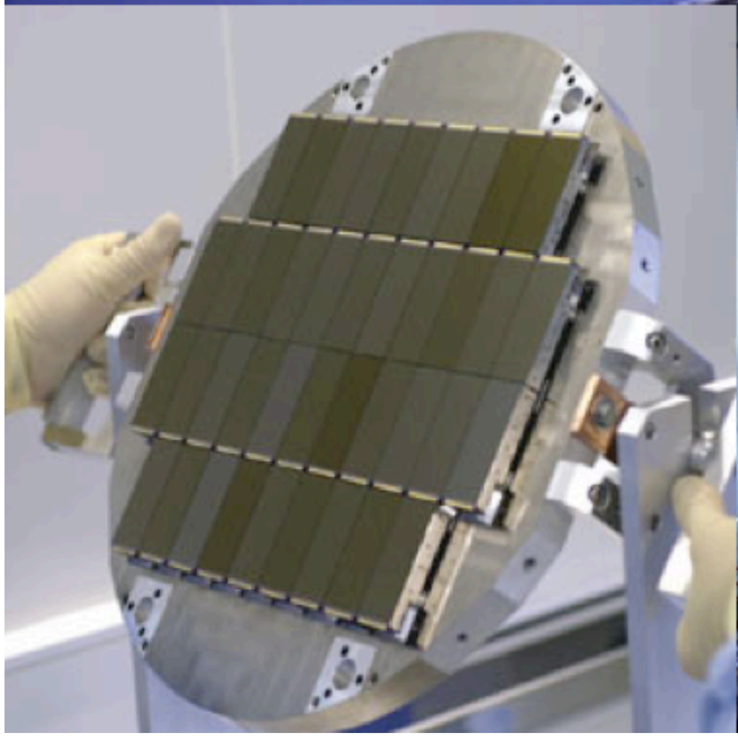
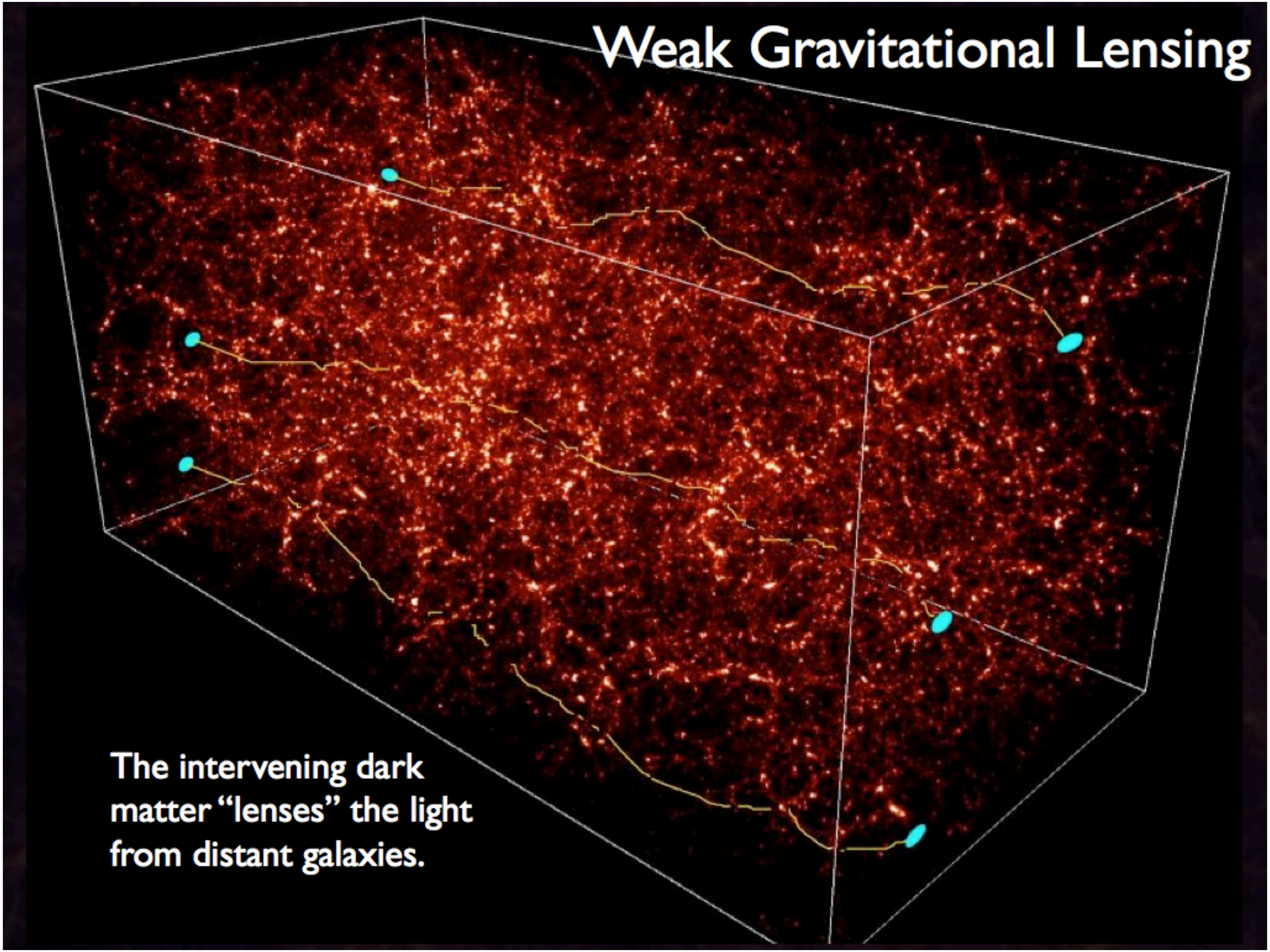
+ CFHTLenS Collaboration + WiggleZ Collaboration

CFHTLenS

- The state-of-the-art cosmological survey with 155 sq degrees, ugriz to i<24.7 (7σ extended source)
- Uses 5 yrs of data from the Deep, Wide and Pre-survey components of the CFHT Legacy Survey



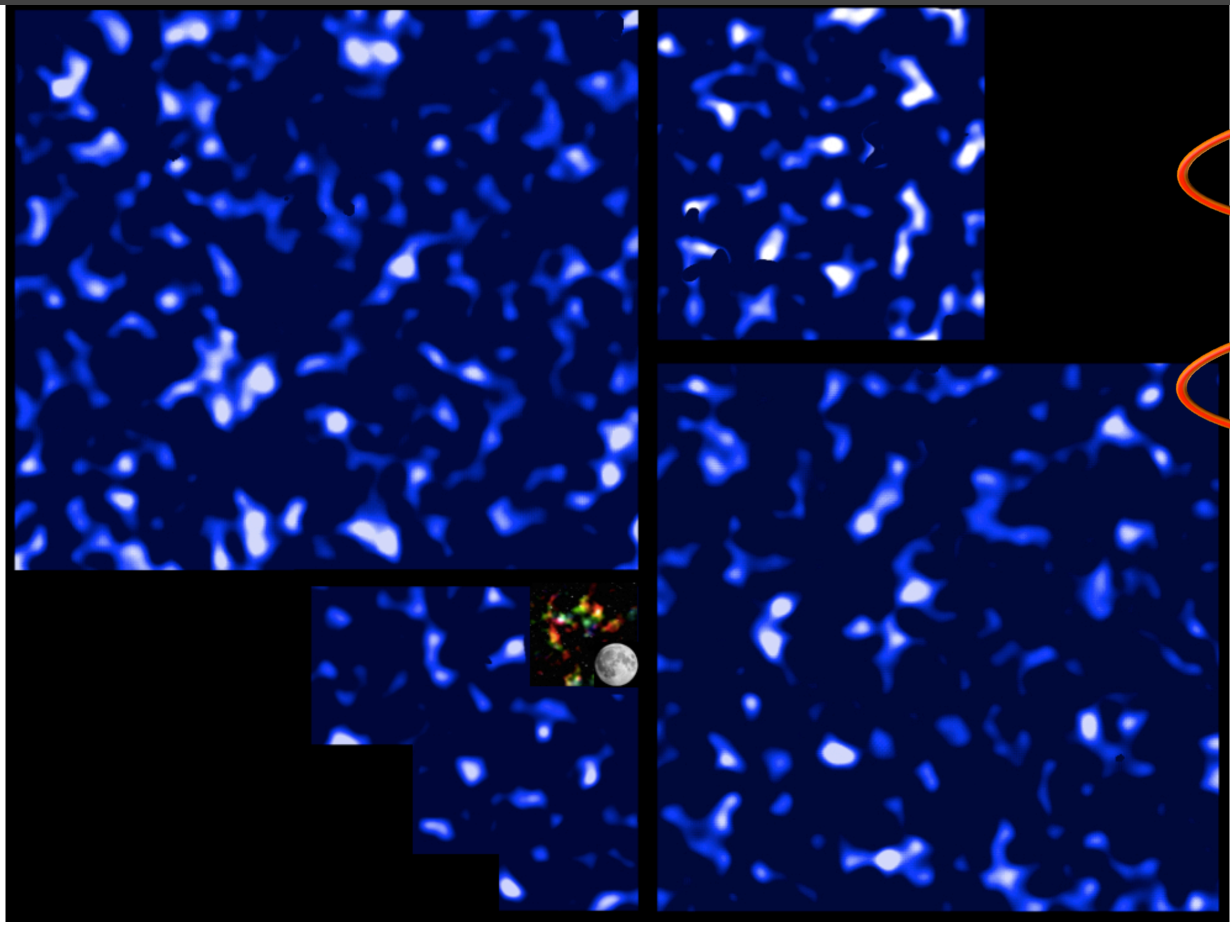

Weak Gravitational Lensing
The intervening dark matter "lenses" the light from distant galaxies.

CFHTLenS Survey Statistics

- **High resolution**: 17 gals per sq arcmin
- **Deep imaging:** $z_m = 0.75$
- **Accurate redshifts:** $\sigma_z = 0.04(1+z)$ with 4% outliers
- **Accurate shear:** calibration corrections

  $\langle m \rangle = -0.007$ $\langle c \rangle = 0.001$
- **Robust to systematic errors:** 80% of the data used

Mass Map



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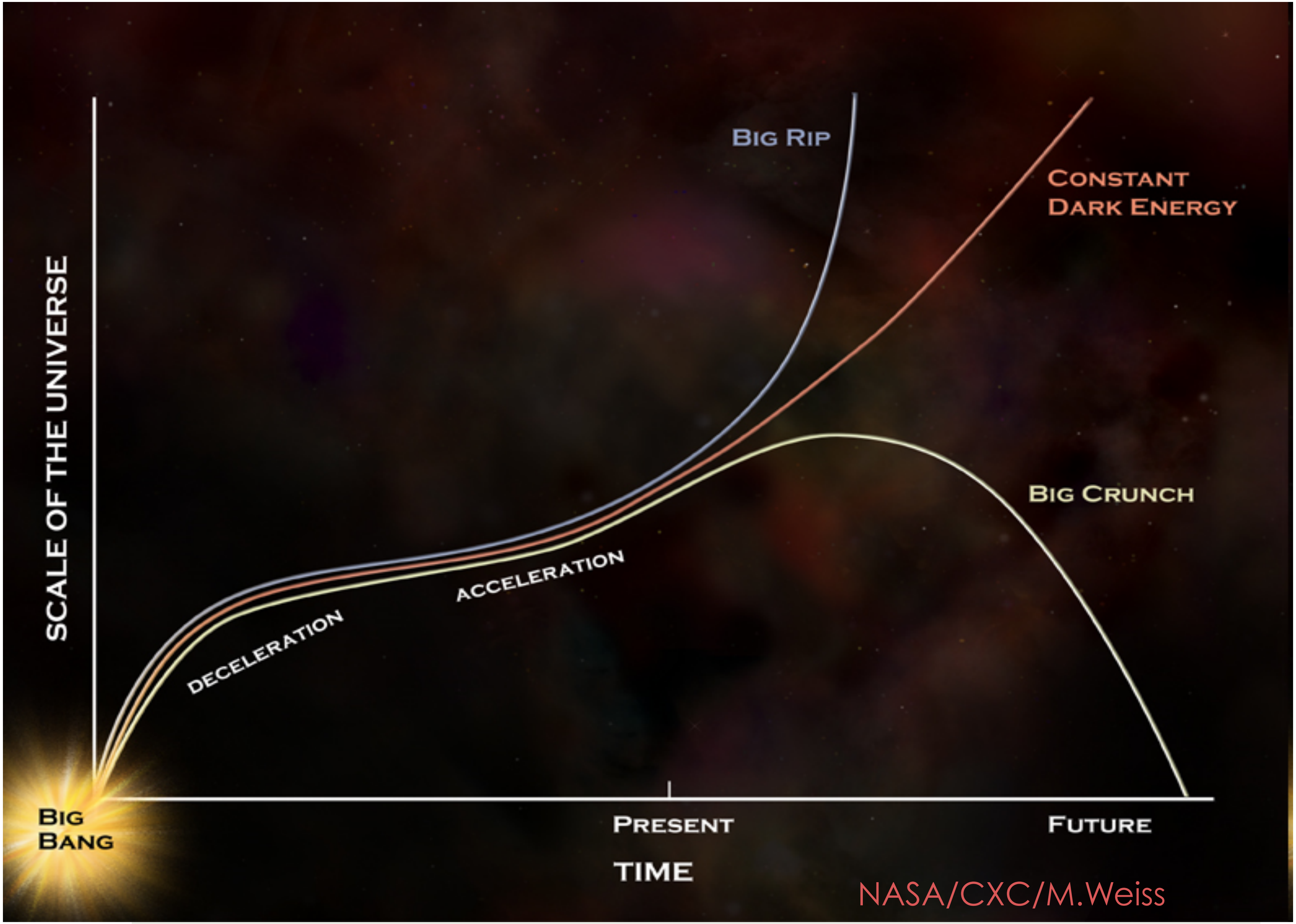
Van Waerbeke, Heymans, CFHTLens collaboration

Modified Gravity or Dark Matter?

- Dark Matter

Modified Gravity or Dark Energy?



Big Rip
Constant
Dark Energy
Big Crunch
Scale of the Universe
Deceleration
Acceleration
Big
Bang
Present
Future
Time
NASA/CXC/M.Weiss

Modified Gravity or Dark Energy?

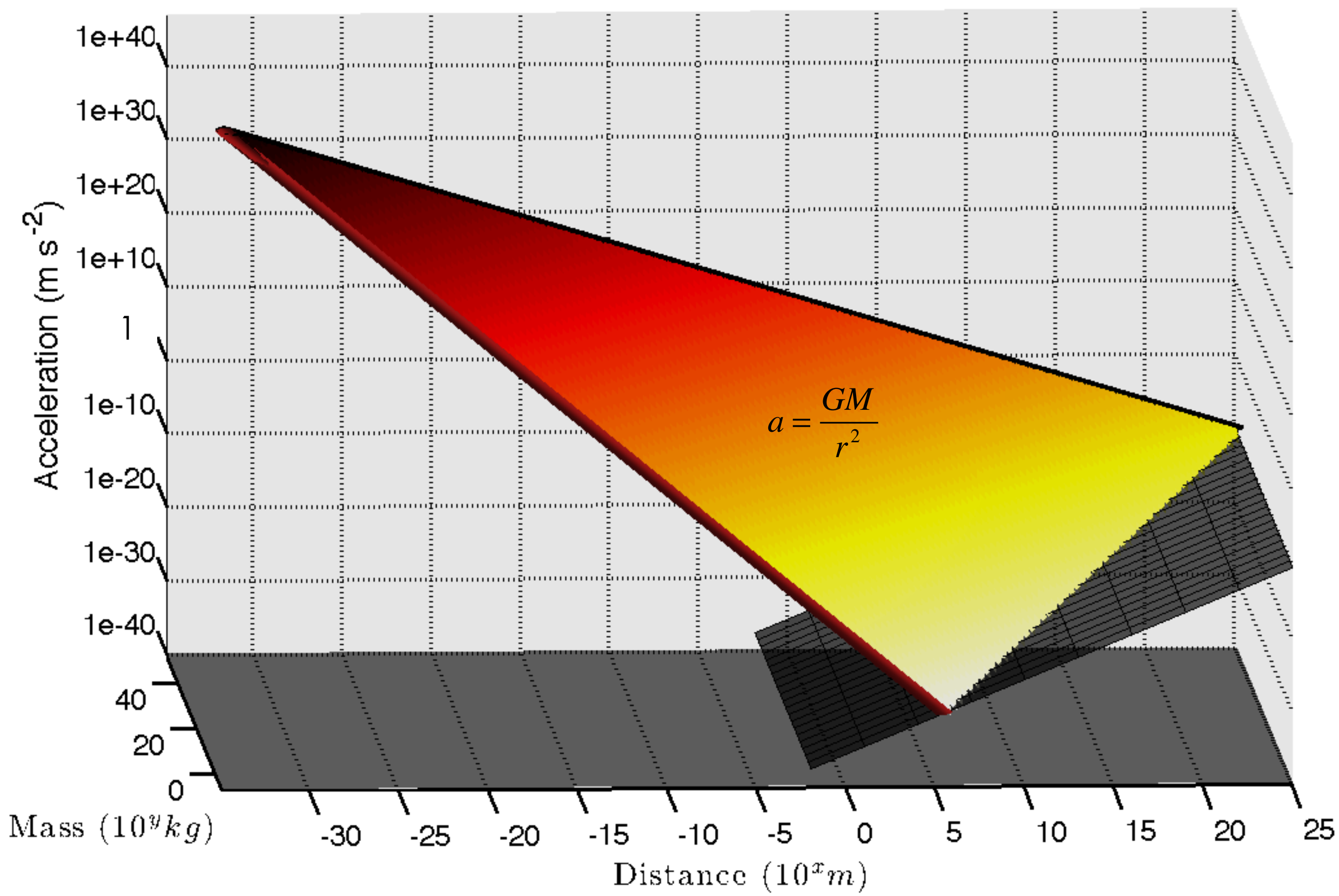
EITHER

- The bulk of the Universe violates the strong energy condition

OR

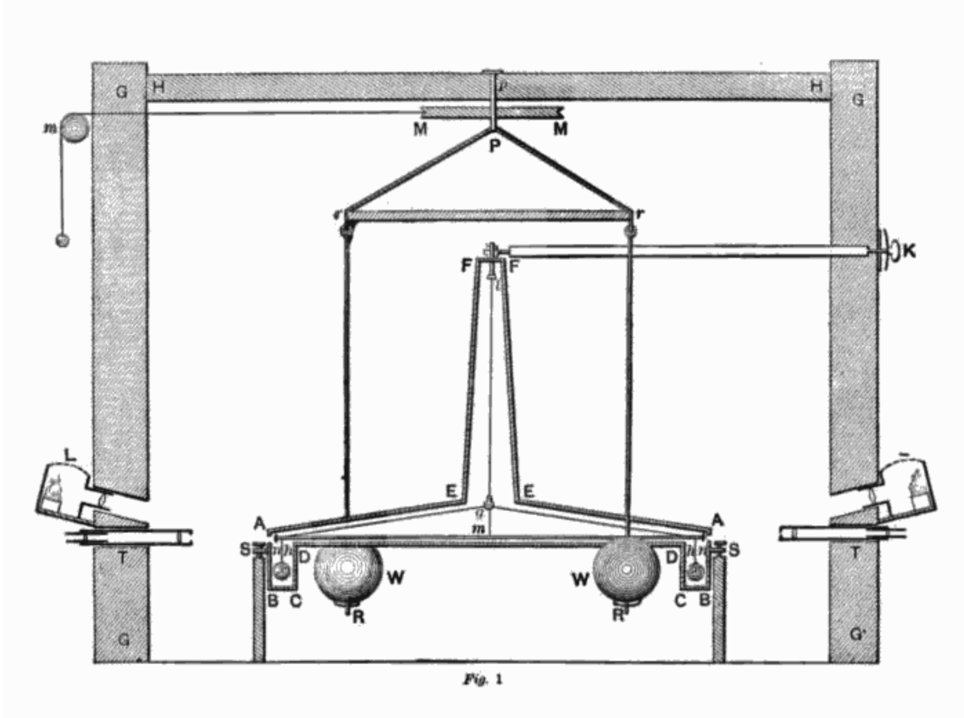
- Our theory of gravity is wrong

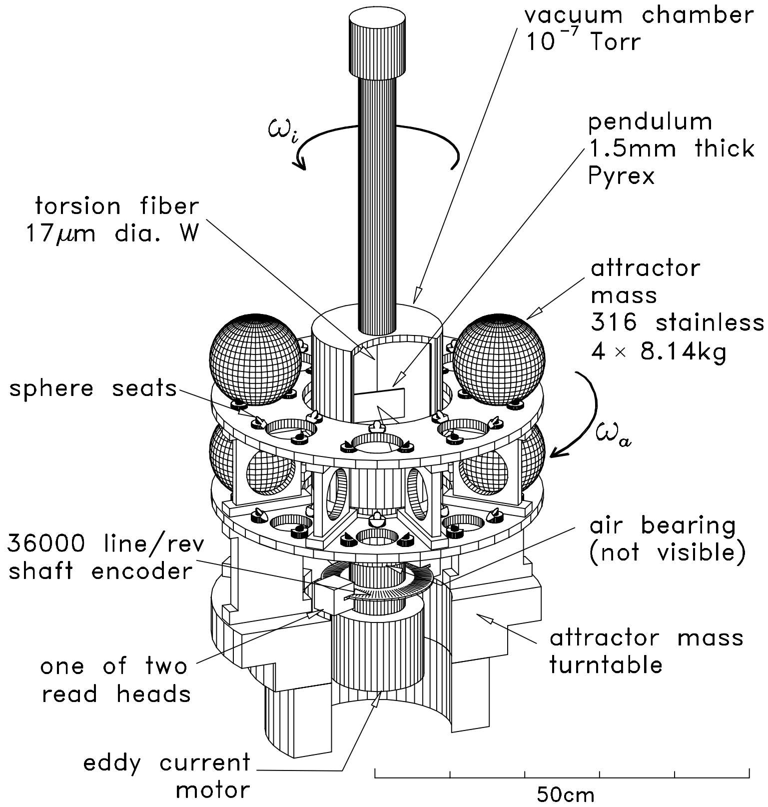
Boundaries of Classical Gravity



Local Tests of Gravity

- Torsion Balance

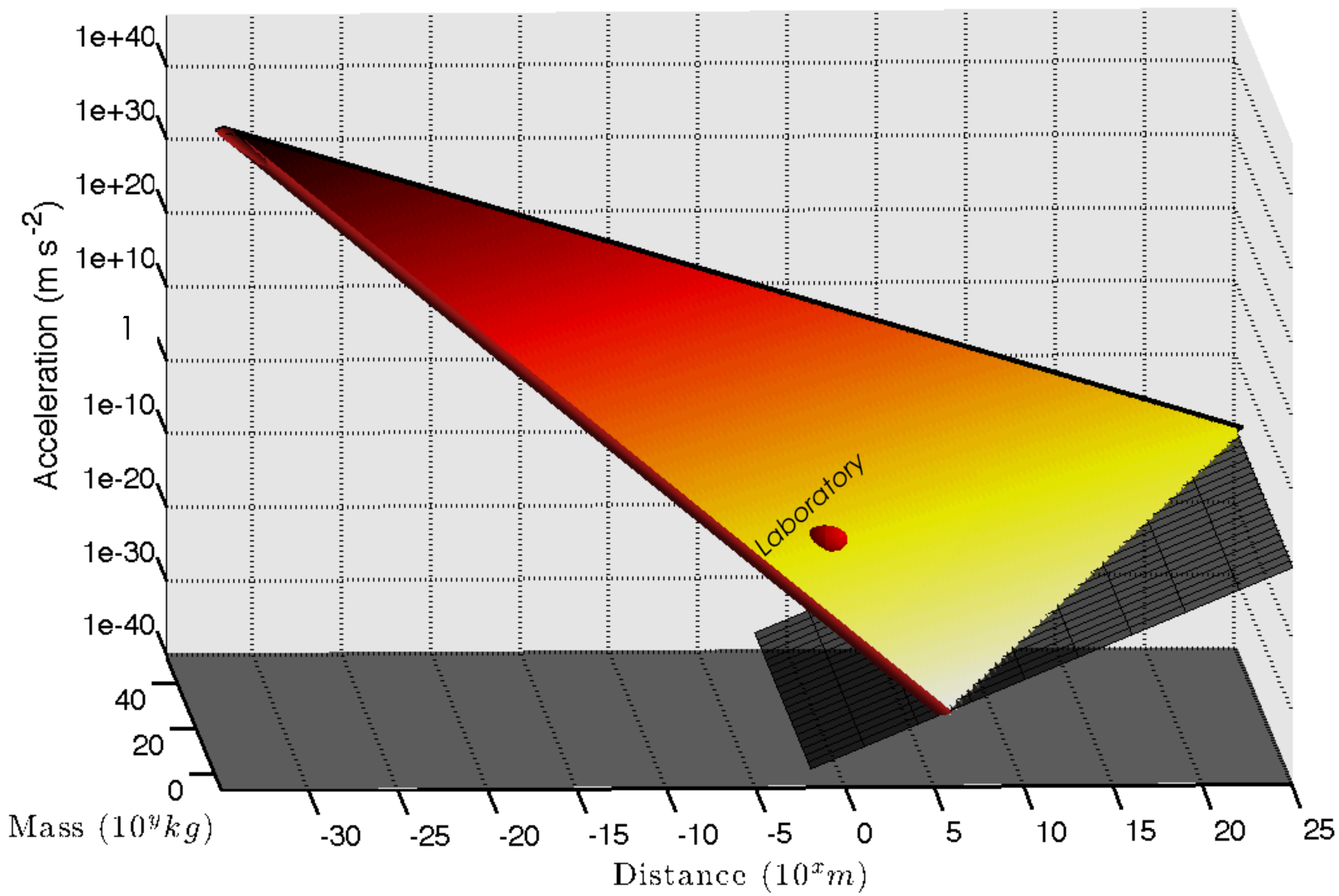




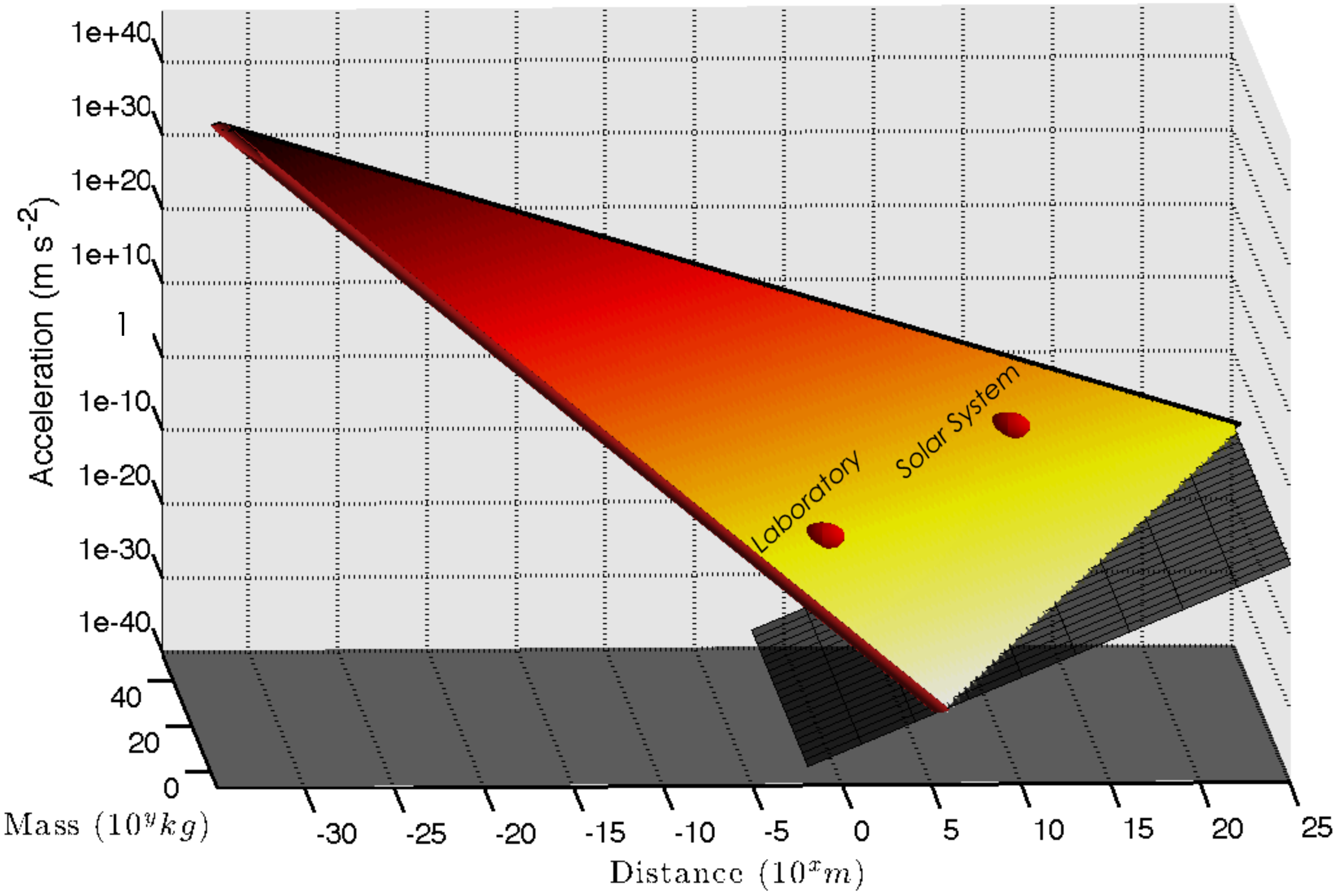
G=6.674

Gundlach & Merkowitz, 2000

Boundaries of Classical Gravity



Boundaries of Classical Gravity

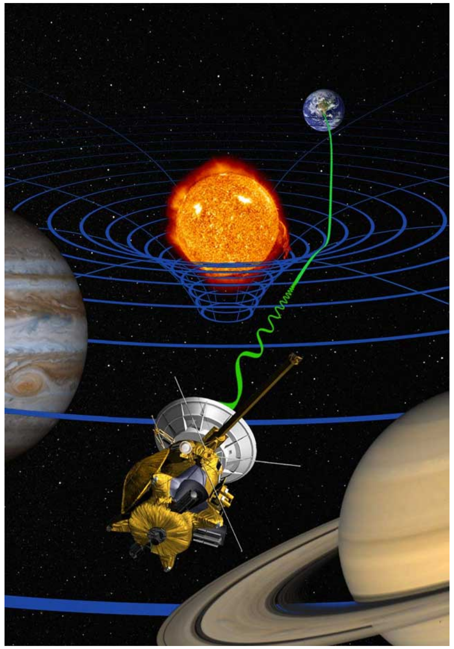


Solar System Tests

- Cassini Timing

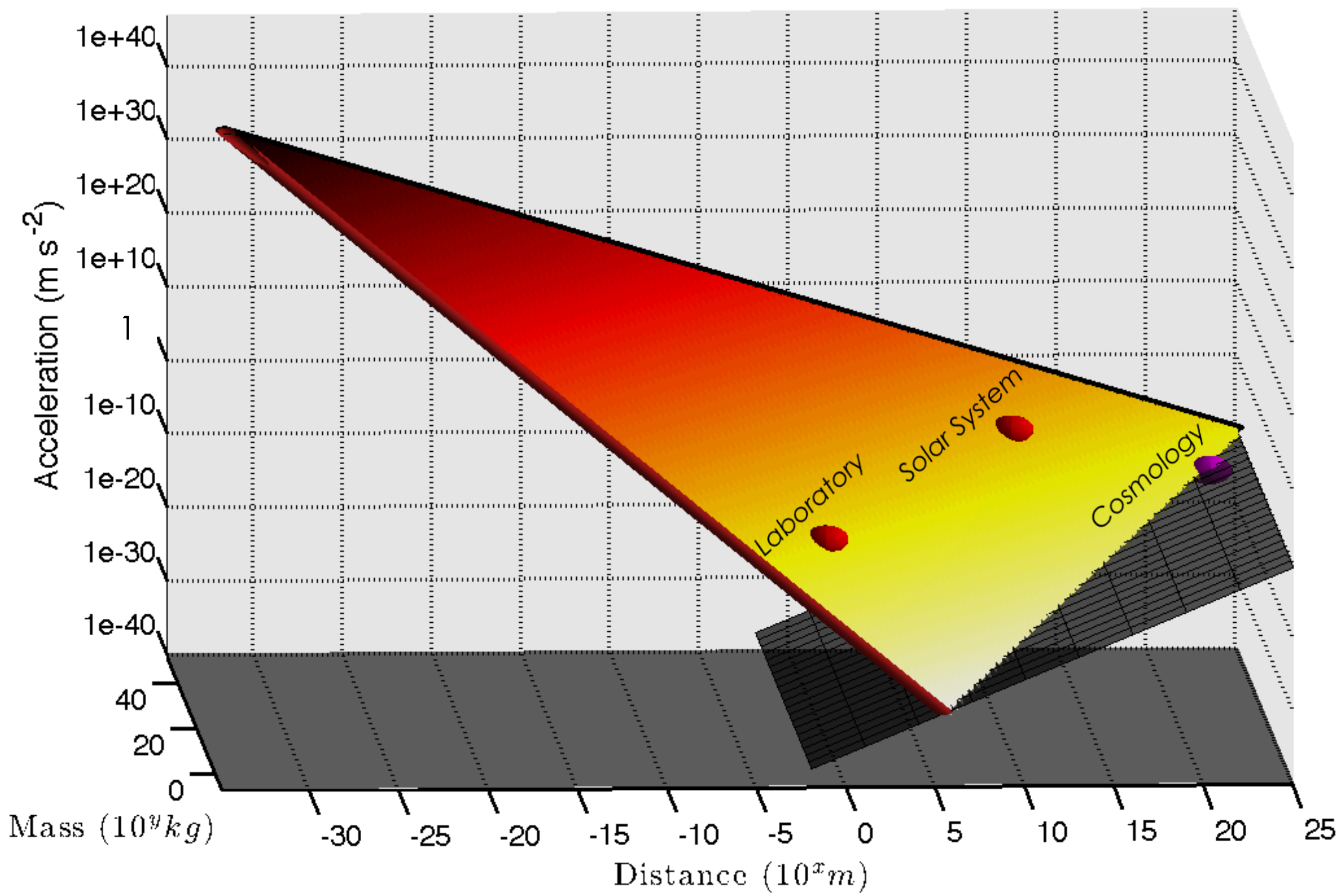
$$\gamma - 1 = (2.1 \pm 2.3) \times 10^{-5}$$

Bertotti et al. (2003)



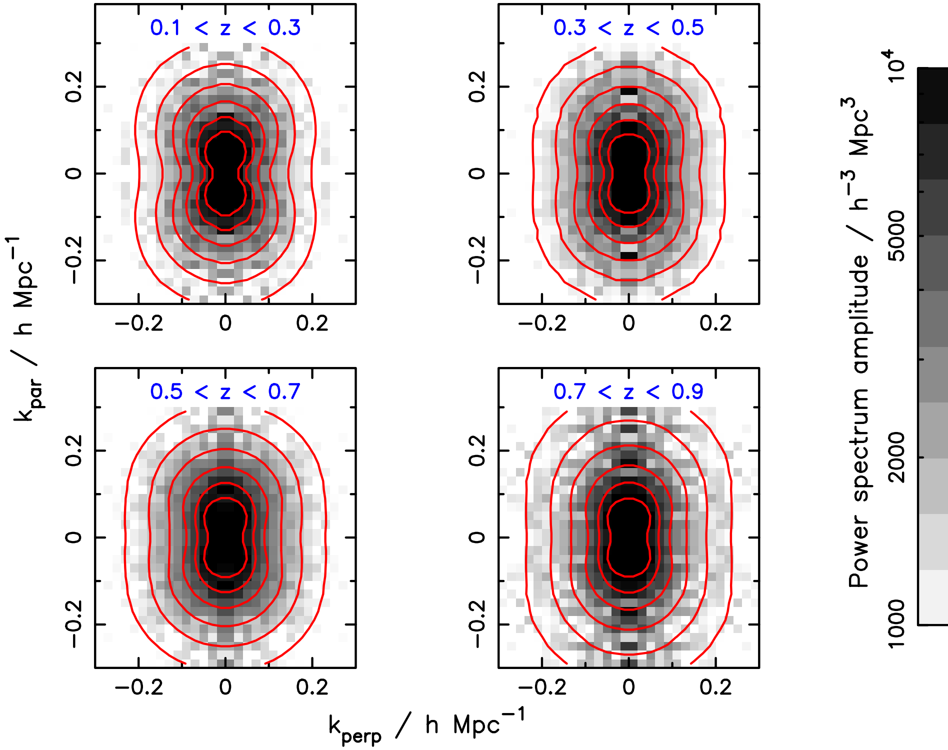
NASA

Boundaries of Classical Gravity



Data

- CFHTLenS Cosmic Shear
  - Two redshift bins; $1 < \theta < 100$ arcmin
- WiggleZ Redshift Space Distortions (Blake et al. 2011)
- Auxiliary Data
  - WMAP7 (l >100)
  - $H_0 = 73.8 \pm 2.4$ km s^{-1} Mpc^{-1} (Riess et al. 2011)
- Utilise CosmoPMC, MGCAMB, WMAP Likelihood, CosmoloGUI



Blake et al 2011

Cosmological Observables

$$ds^2 = -(1+2\varphi)dt^2 + (1-2\phi)a^2 d\vec{x}^2$$

- Predictions
  - Newtonian Gravity $\qquad \phi = 0$
  - General Relativity $\qquad \dfrac{\phi}{\varphi} = 1$
  - f(R) models $\qquad \dfrac{1}{2} < \dfrac{\phi}{\varphi} < 1$

Alternative Theories of Gravity

- f(R)
- TeVeS
- Hořava-Lifschitz
- DGP
- Braneworld
- Bimetric Theories
- …
- For a review see Clifton et al (2011)

Parameterisation

$$ds^2 = -(1+2\varphi)dt^2 + (1-2\phi)a^2 d\vec{x}^2$$

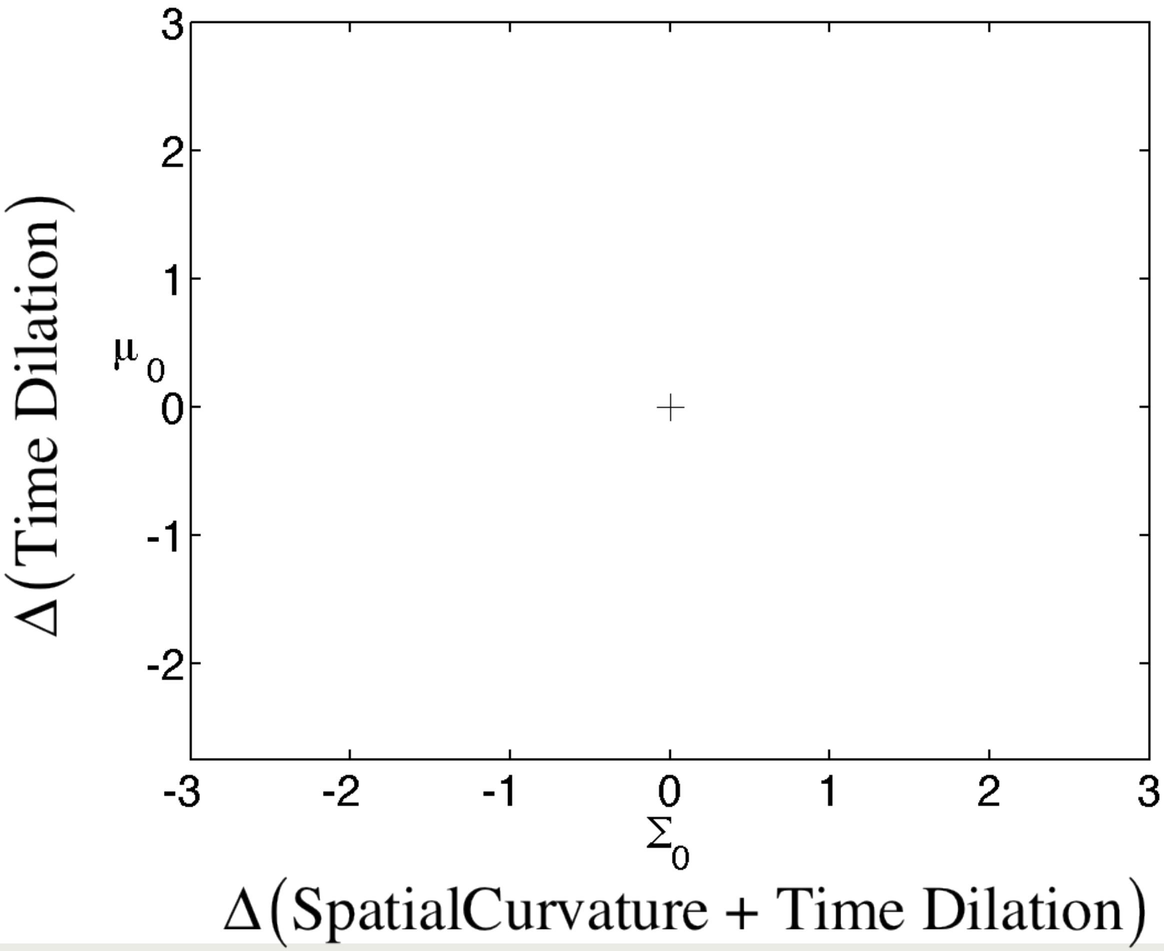
- Gravitational potential as experienced by galaxies:

$$\nabla^2\varphi = 4\pi G a^2 \bar{\rho}\delta\left[1+\mu\right] \qquad \mu(a) \propto \Omega_\Lambda(a)$$

- Gravitational potential as experienced by photons:

$$\nabla^2(\varphi+\phi) = 8\pi G a^2 \bar{\rho}\delta\left[1+\Sigma\right] \qquad \Sigma(a) \propto \Omega_\Lambda(a)$$

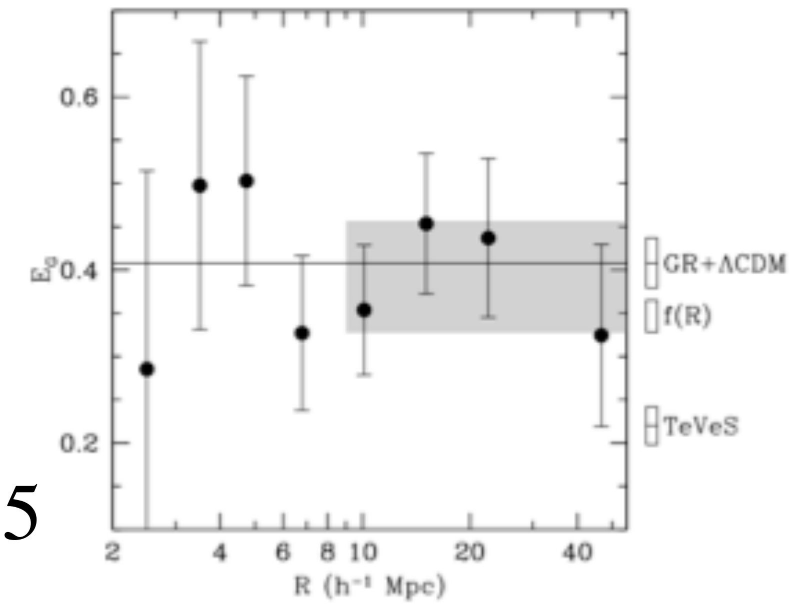
Parameterisation



Previous Constraints

$$E_G(z) \simeq \frac{\Omega_m}{f(z)}$$

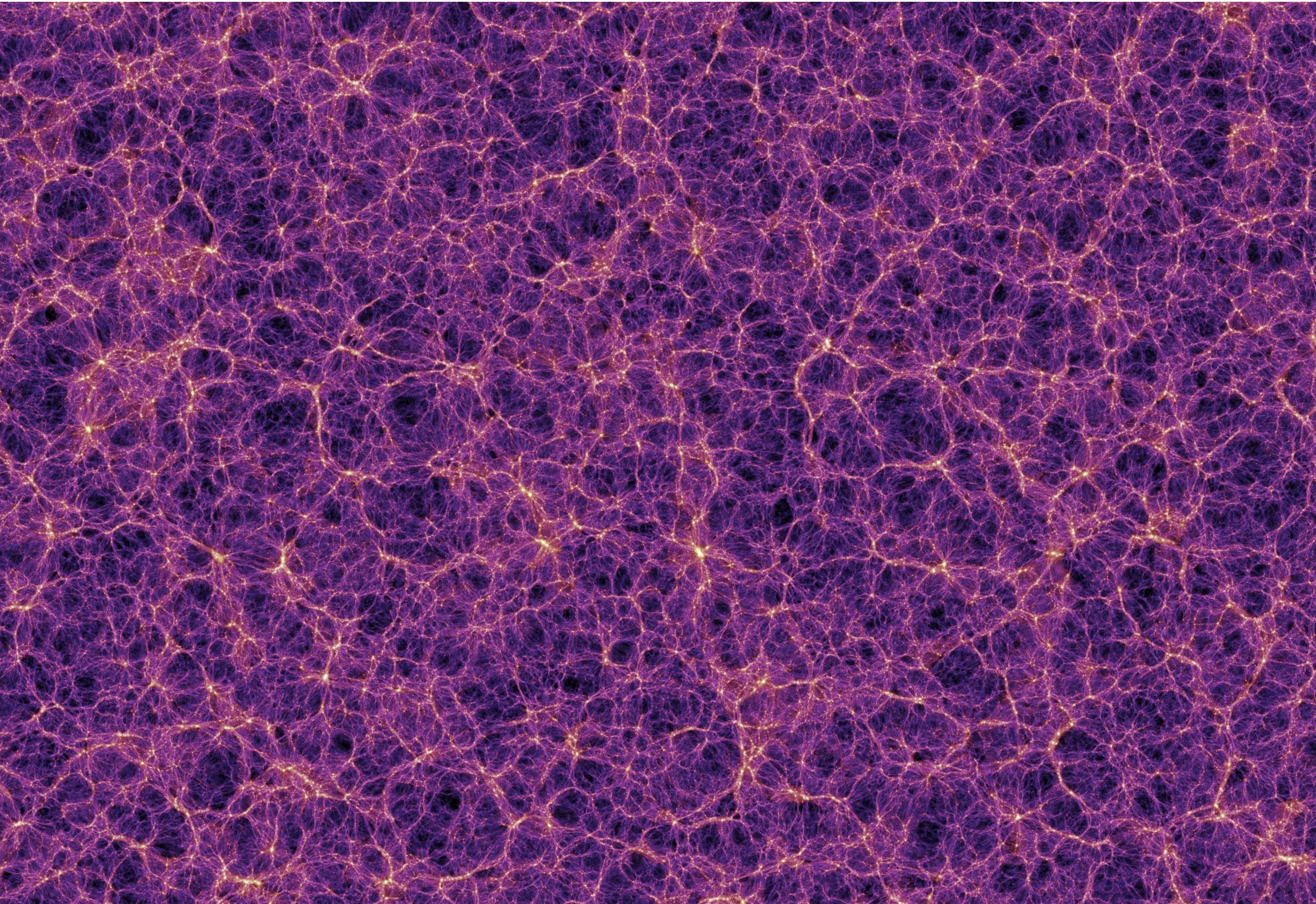
$$E_G(z = 0.32) = 0.392 \pm 0.065$$



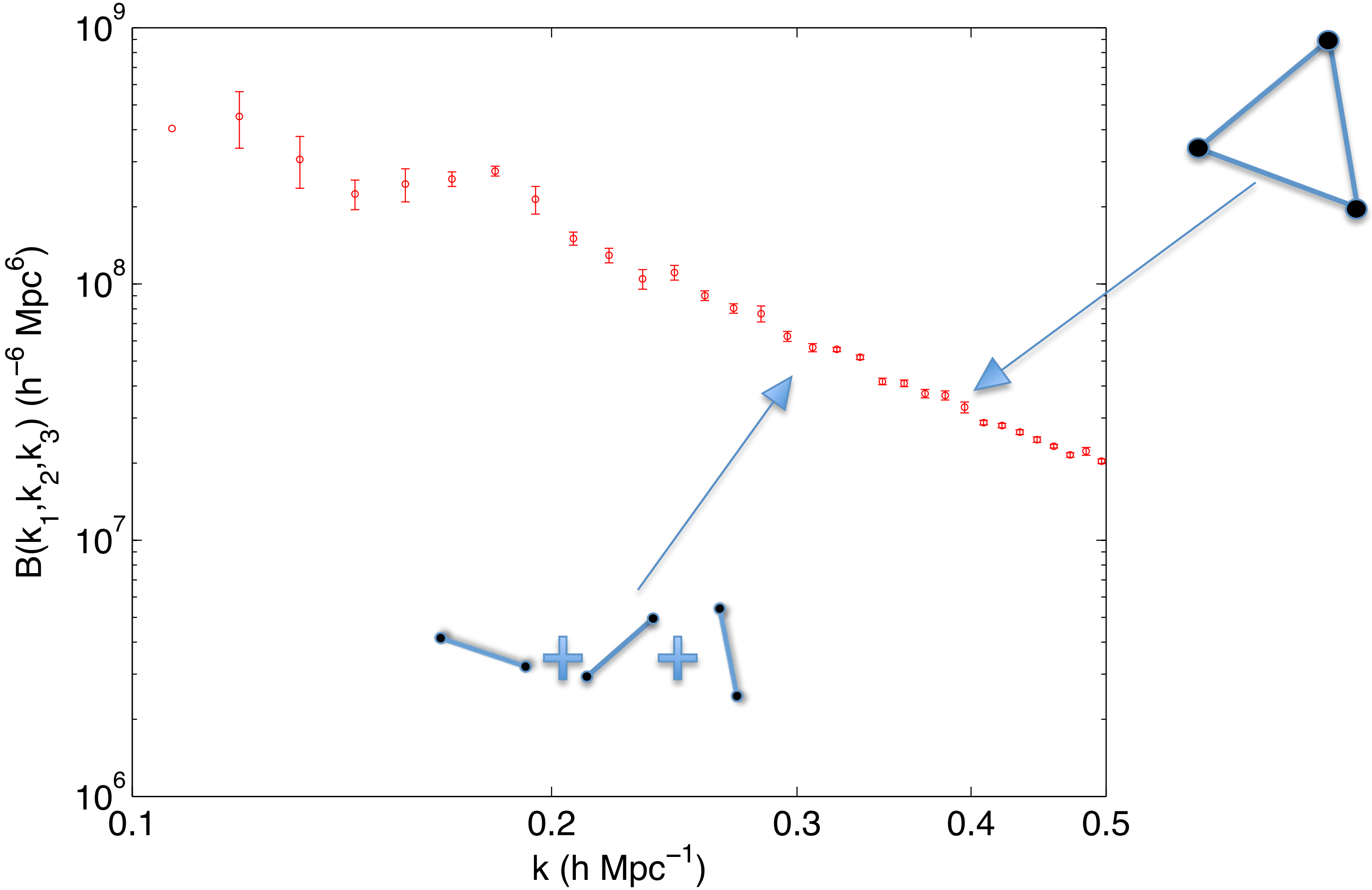
Reyes et al 2010

Clipping the Cosmos:
The Bias and Bispectrum of Large Scale Structure

F Simpson, J B James, A F Heavens,
C Heymans, PRL 107:271301 (2011)

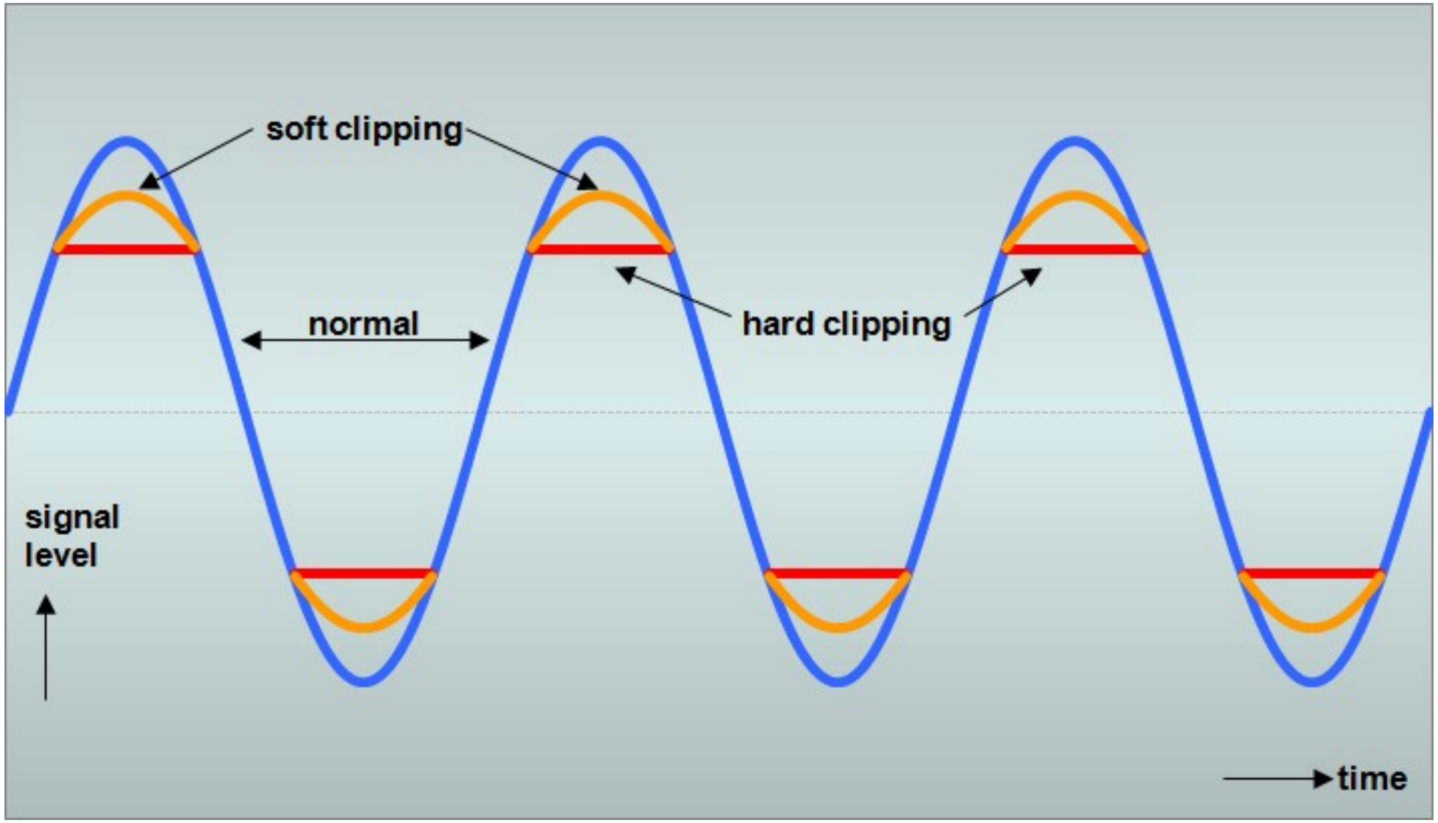


Dark Matter Bispectrum

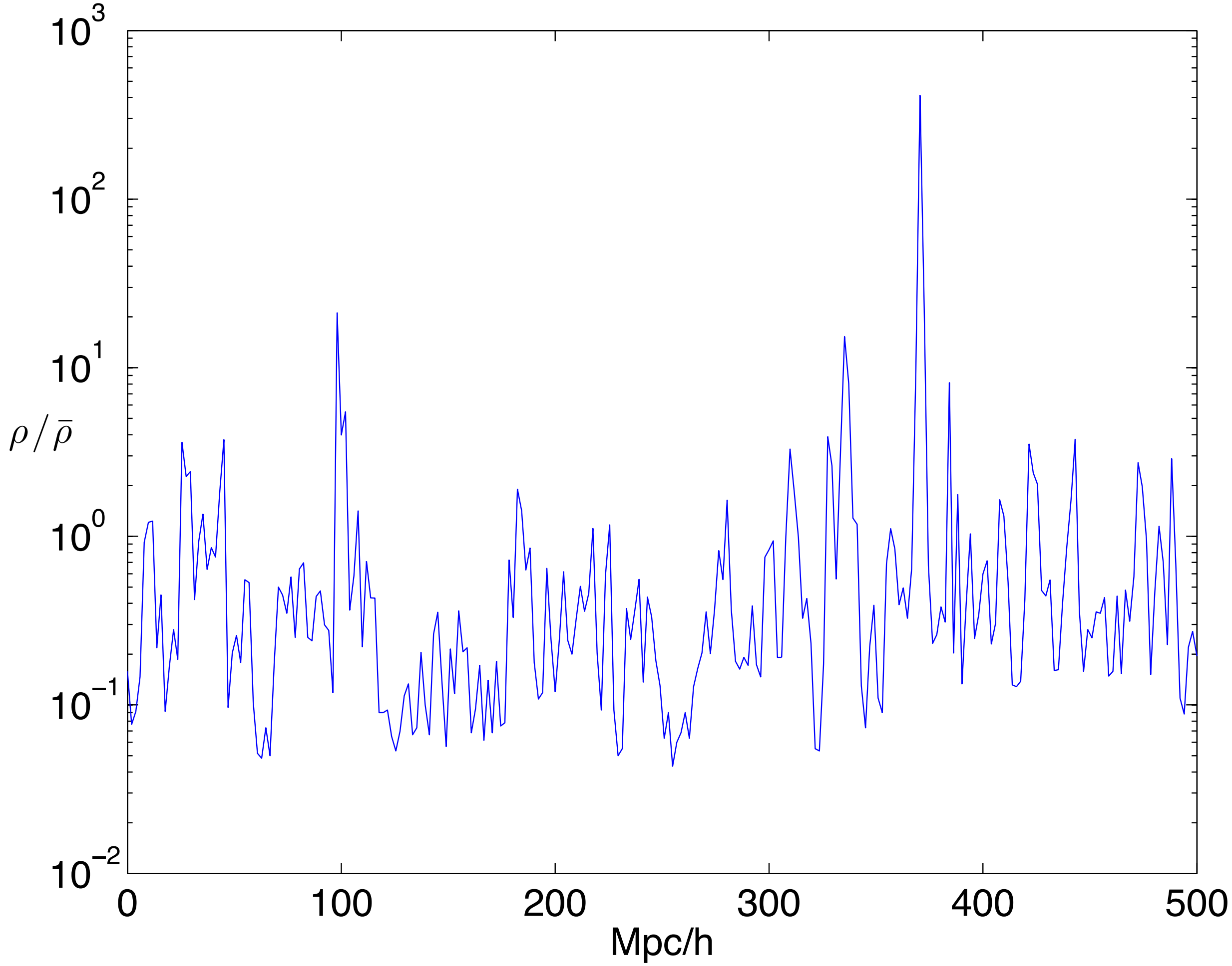


$$B(k_1 k_2 k_3) = \langle \delta(k_1)\delta(k_2)\delta(k_3) \rangle$$

Clipping



Clipping the Density Field



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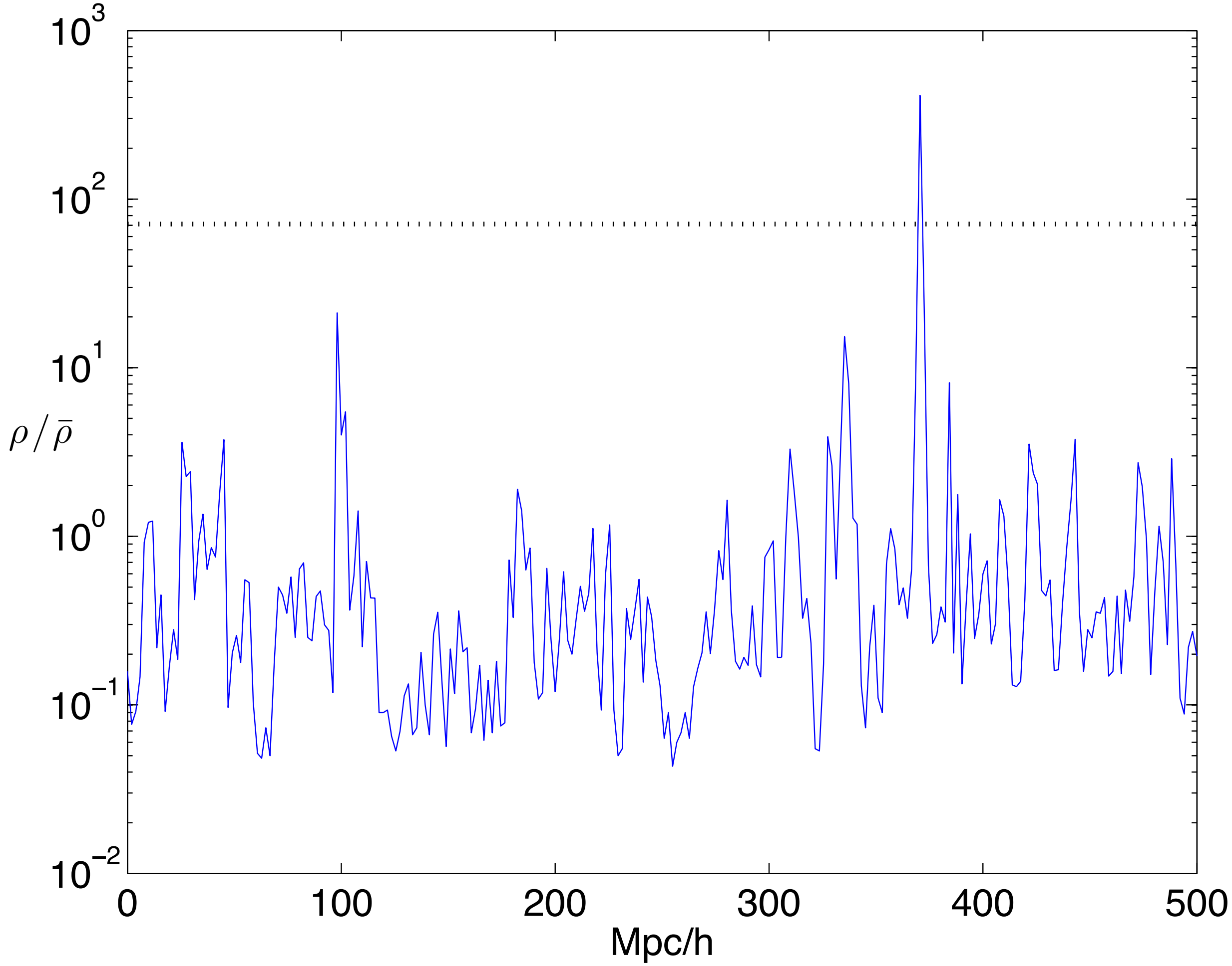
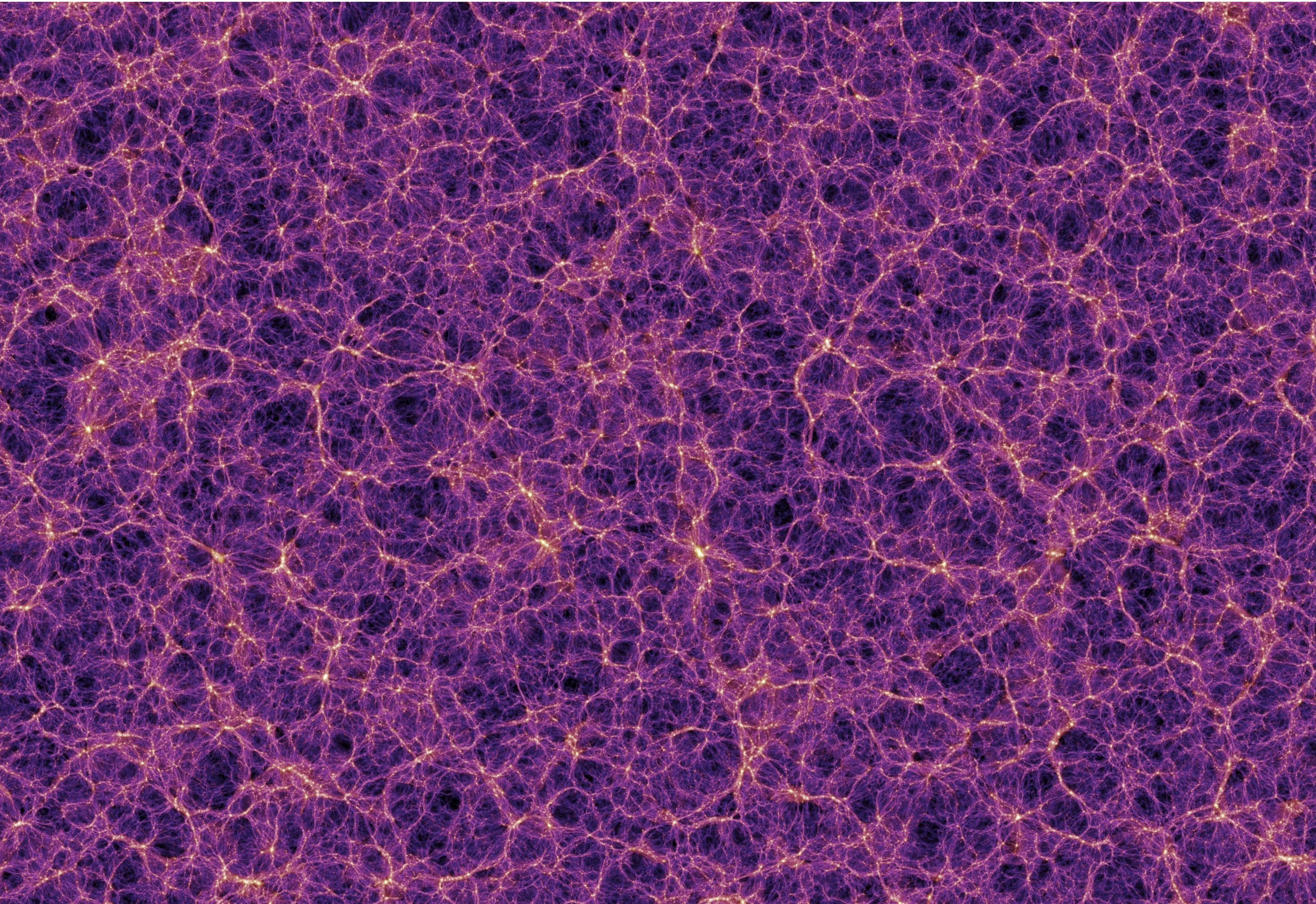
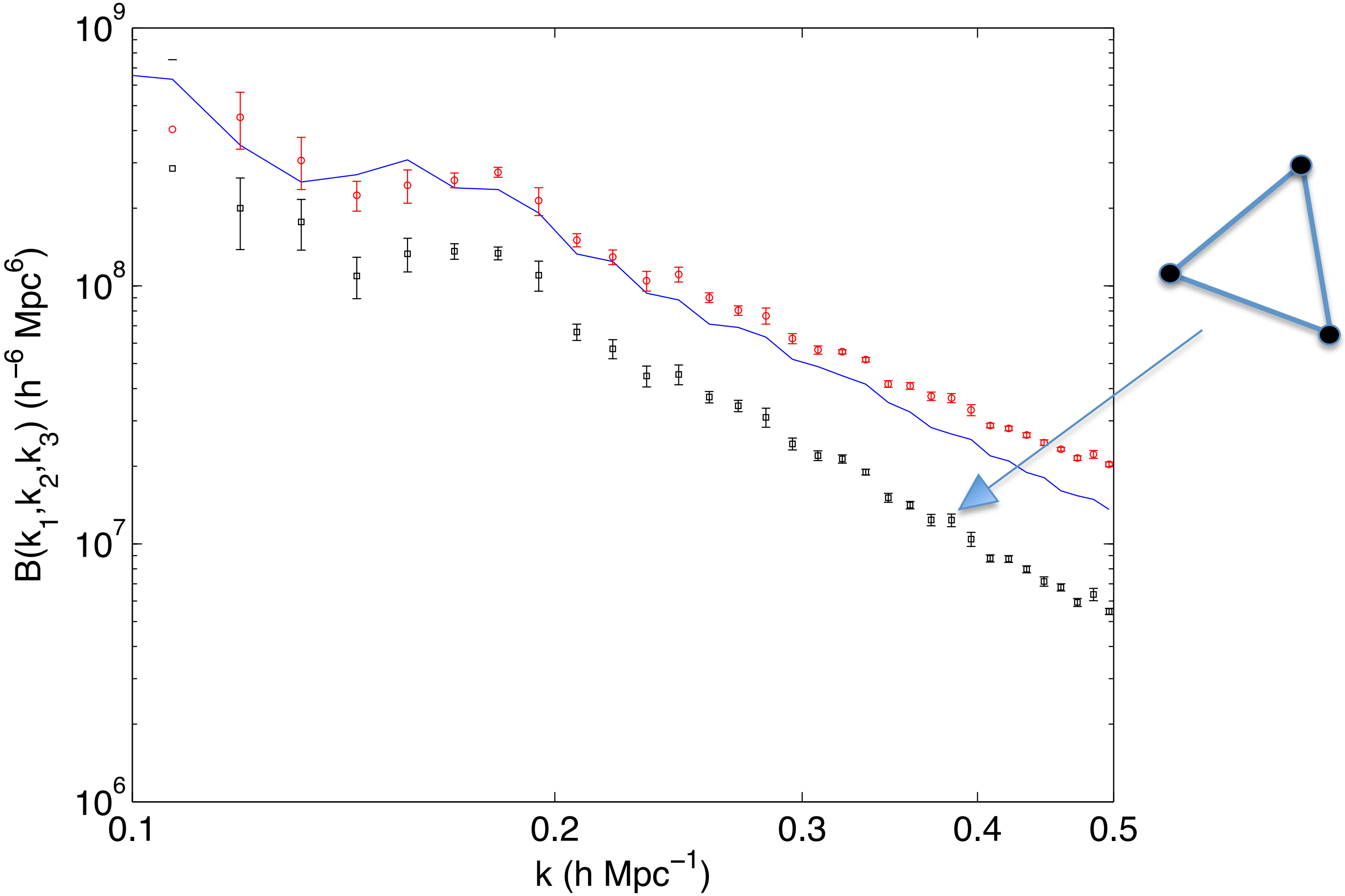


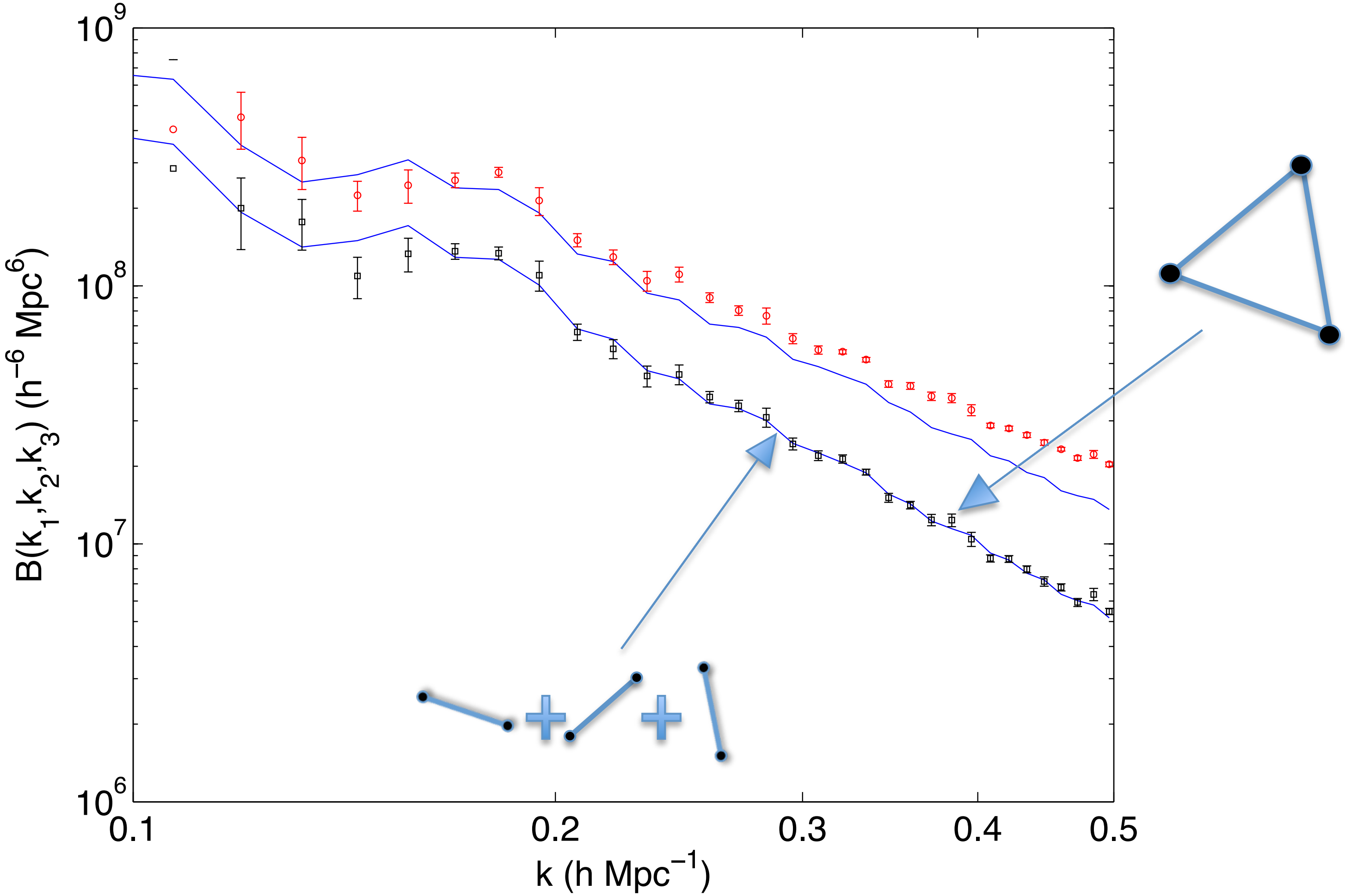


Clipped Bispectrum



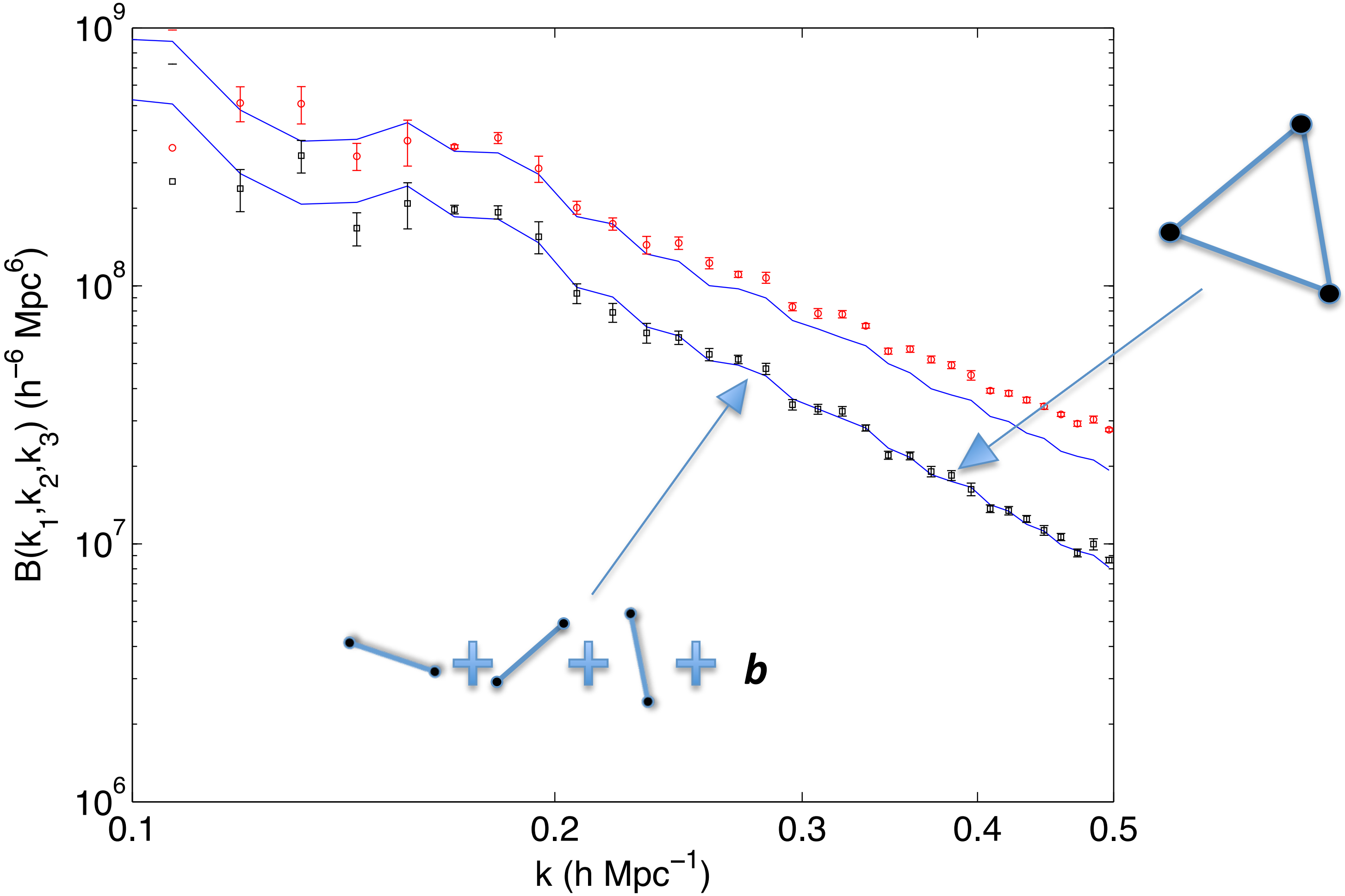
FS, James, Heavens, Heymans 2011

Clipped Bispectrum



FS, James, Heavens, Heymans 2011

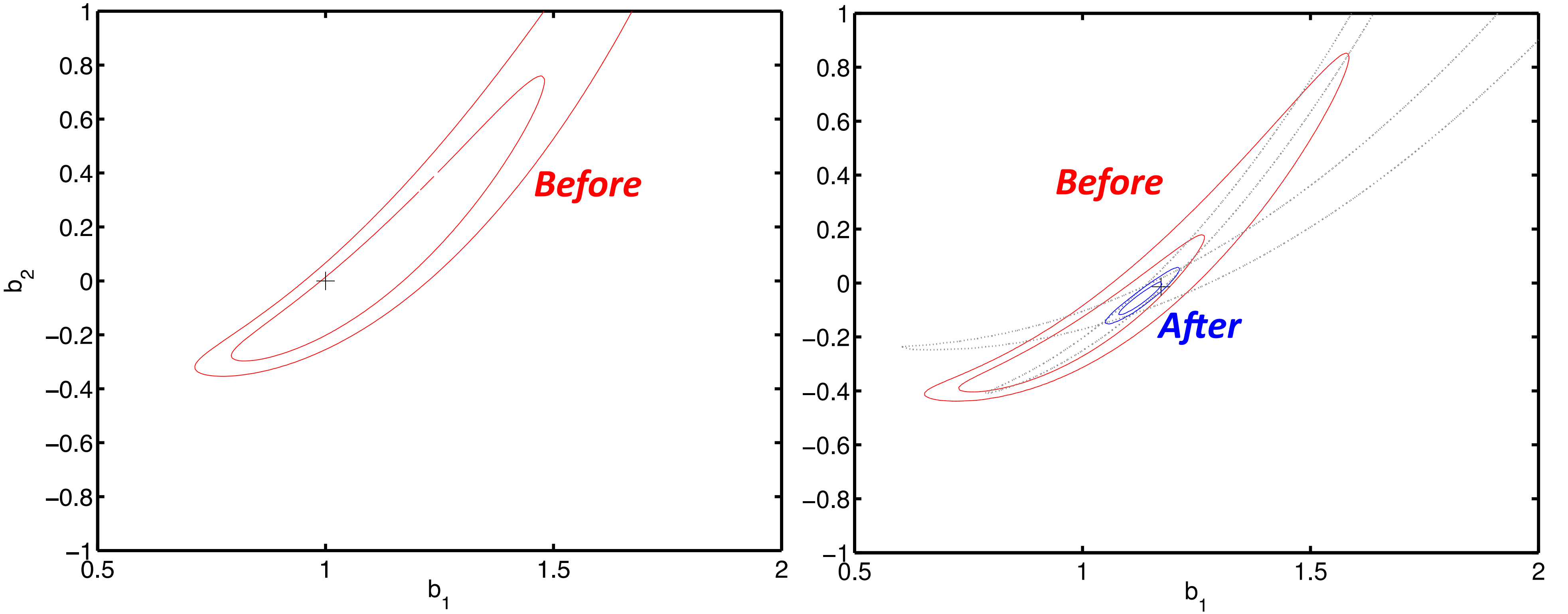
Now with galaxies…



FS, James, Heavens, Heymans 2011

Bias Measurements

$$\delta_g = b_1\delta + \frac{b_2}{2}\delta^2$$

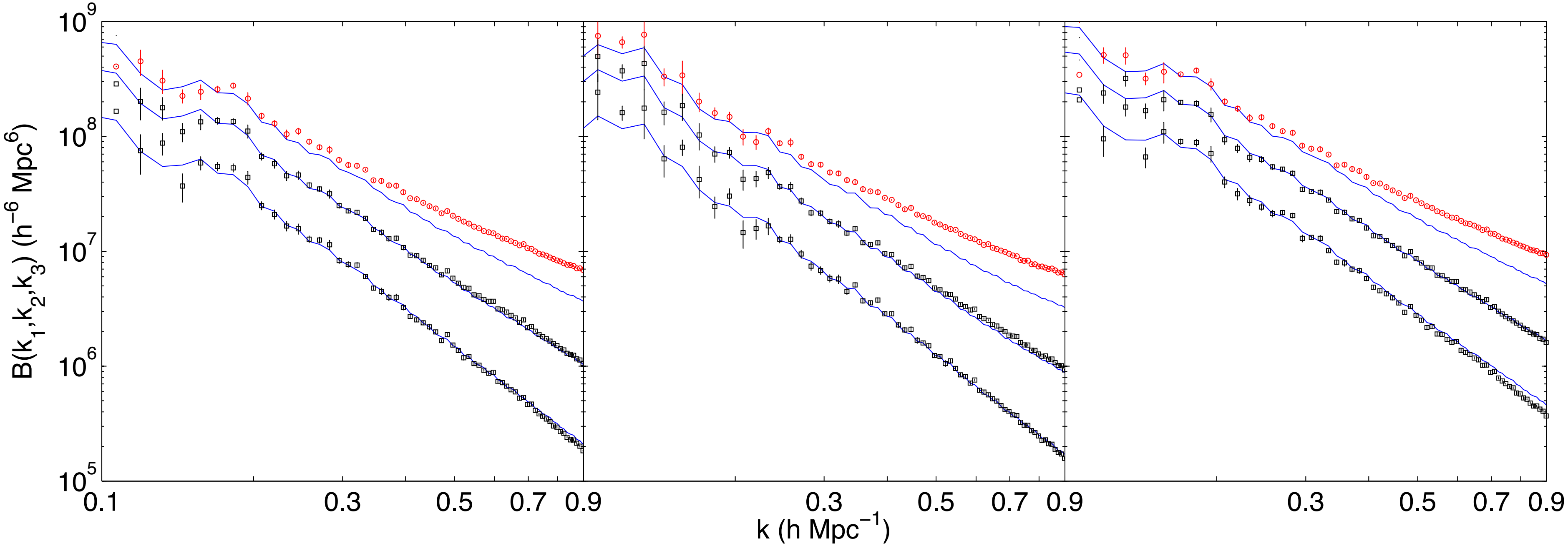


Dark Matter

Galaxies

FS, James, Heavens, Heymans 2011

How far?



Dark Matter
(3:2:1)

Dark Matter
(2:1:1)

Galaxies
(3:2:1)

FS, James, Heavens, Heymans 2011

Potential Applications

- P(k) parameters
  - b, σ_8, n_s
- Primordial Non-Gaussianity
  - f_{NL}
- Redshift Space Distortions
  - $f(z)$
- Neutrino Mass
  - m_ν

Summary

- Extend applicability of perturbation theory applied to bispectrum from k~0.1 to k>0.7
- Number of triangles scales as k^6
- Determination of bias to sub-percent precision