Effective Field Theory in Cosmology

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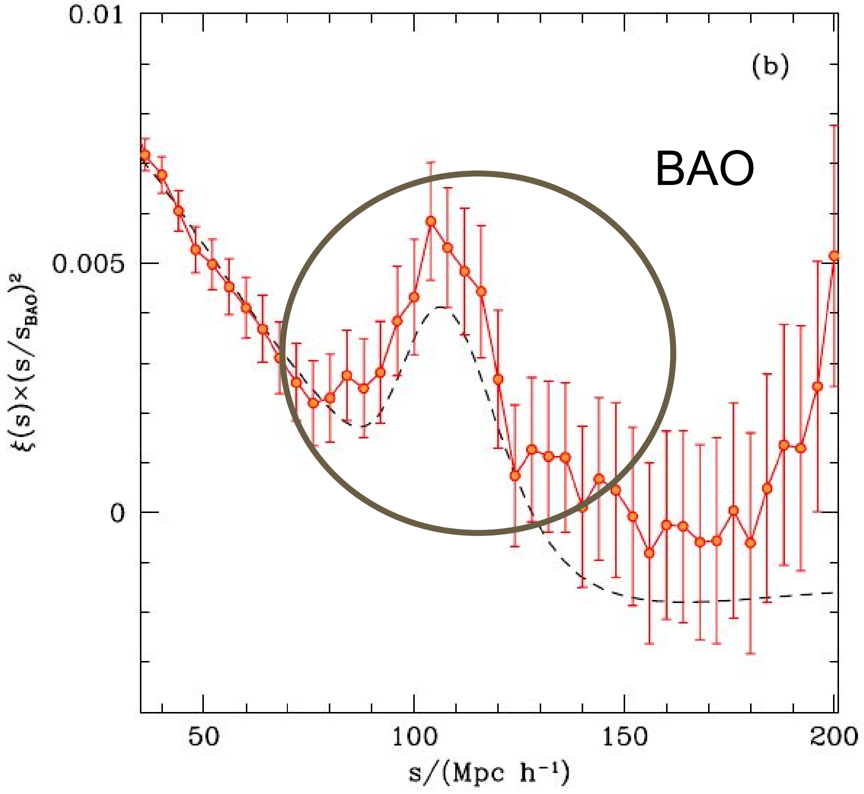
Presentation Summary

- Motivation
- Fluid Equations
- Standard Perturbation Theory (SPT)
- Problems with Standard Perturbation Theory (SPT)
- EFT + Results
- Perspectives

Motivation

SDSS - BOSS

1203.6616

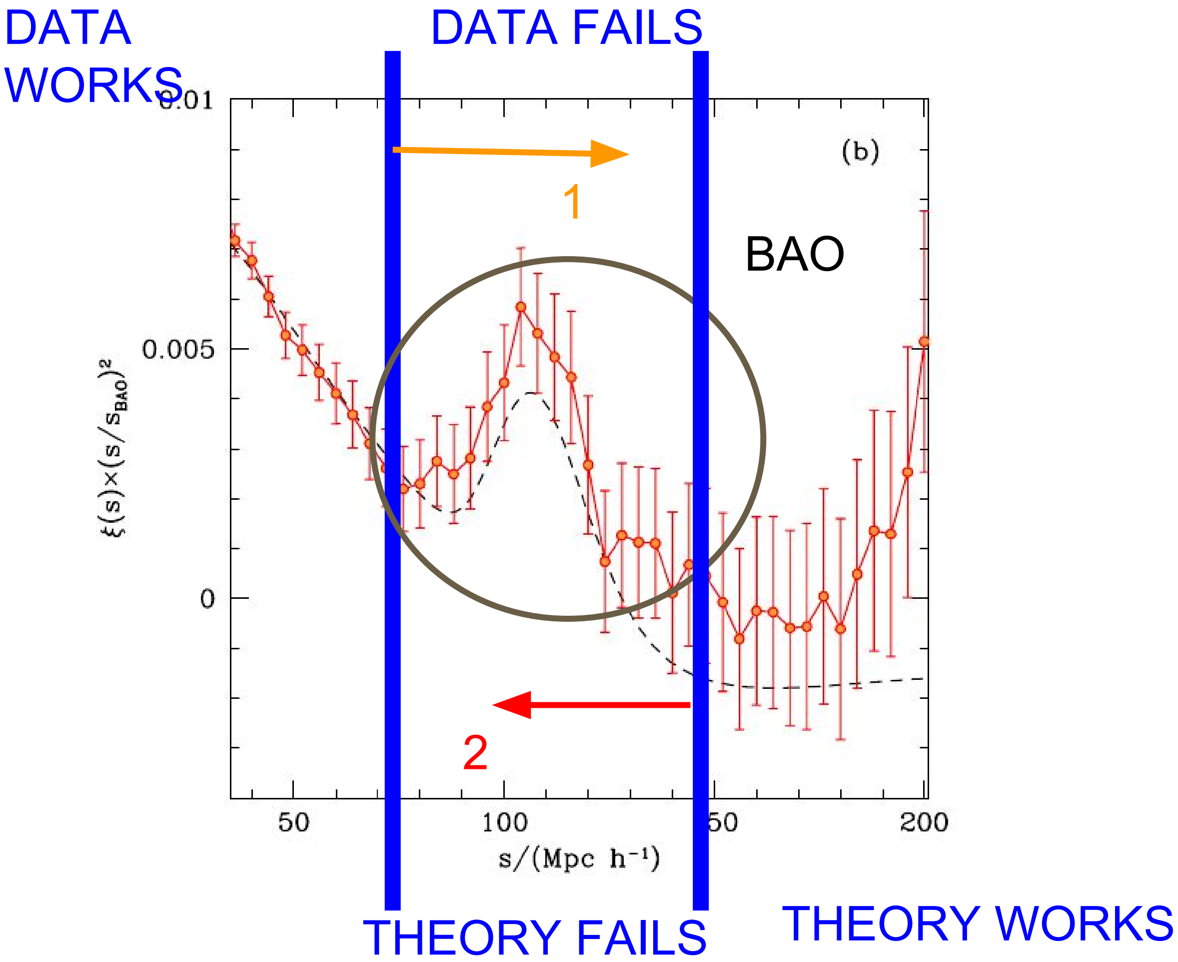


Motivation

HOW TO IMPROVE COSMOLOGICAL CONSTRAINTS?

1)IMPROVE DATA

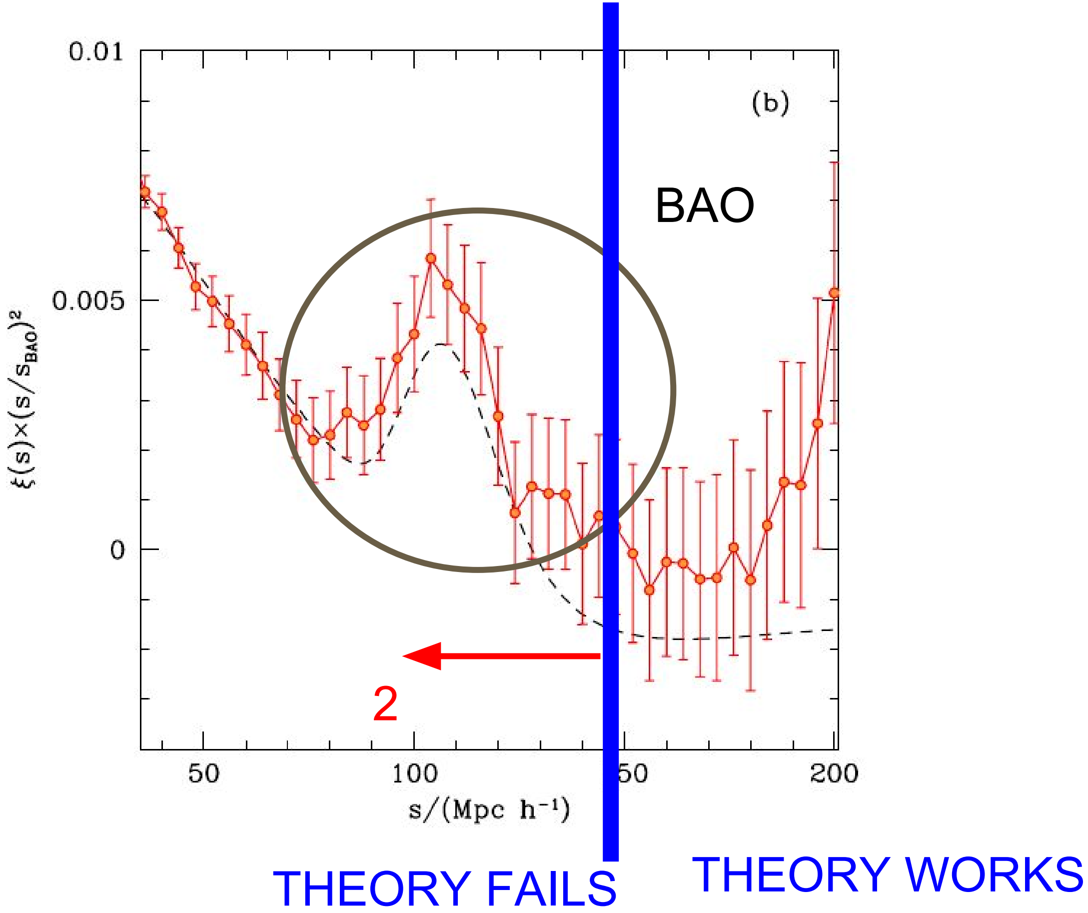
2)IMPROVE THEORY



Motivation

THIS WORK:

2)IMPROVE THEORY



Fluid Equations

Bernardeau et al., 2002. ArXiv: 011255

Fluid Equations

Mass Conservation

$$\frac{\partial \delta(\mathbf{x},\tau)}{\partial \tau} + \nabla \cdot \{[1+\delta(\mathbf{x},\tau)]\, \mathbf{u}(\mathbf{x},\tau)\} = 0,$$

Euler

$$\frac{\partial \mathbf{u}(\mathbf{x},\tau)}{\partial \tau} + \mathcal{H}(\tau)\ \mathbf{u}(\mathbf{x},\tau) + \mathbf{u}(\mathbf{x},\tau) \cdot \nabla \mathbf{u}(\mathbf{x},\tau) = -\nabla \Phi(\mathbf{x},\tau) - \frac{1}{\rho} \nabla_j \left(\rho\, \sigma_{ij}\right),$$

Poisson

$$\nabla^2 \Phi(\mathbf{x},\tau) = \frac{3}{2} \Omega_m(\tau)\ \mathcal{H}^2(\tau)\ \delta(\mathbf{x},\tau).$$

Perfect Fluid Discussion

No shear/viscosity

$$\sigma_{ij} \approx 0$$

Euler

$$\frac{\partial \mathbf{u}(\mathbf{x},\tau)}{\partial \tau} + \mathcal{H}(\tau)\ \mathbf{u}(\mathbf{x},\tau) + \mathbf{u}(\mathbf{x},\tau)\cdot\nabla\mathbf{u}(\mathbf{x},\tau) =$$

$$-\nabla\Phi(\mathbf{x},\tau) - \frac{1}{\rho}\nabla\cdot(\rho\,\sigma_{ij})\ ,$$

Break down in small scales (and in larger scales with time evolution)

EFT should consider these contributions!!!

Linear Solution

Linear Solution

Mass Conservation

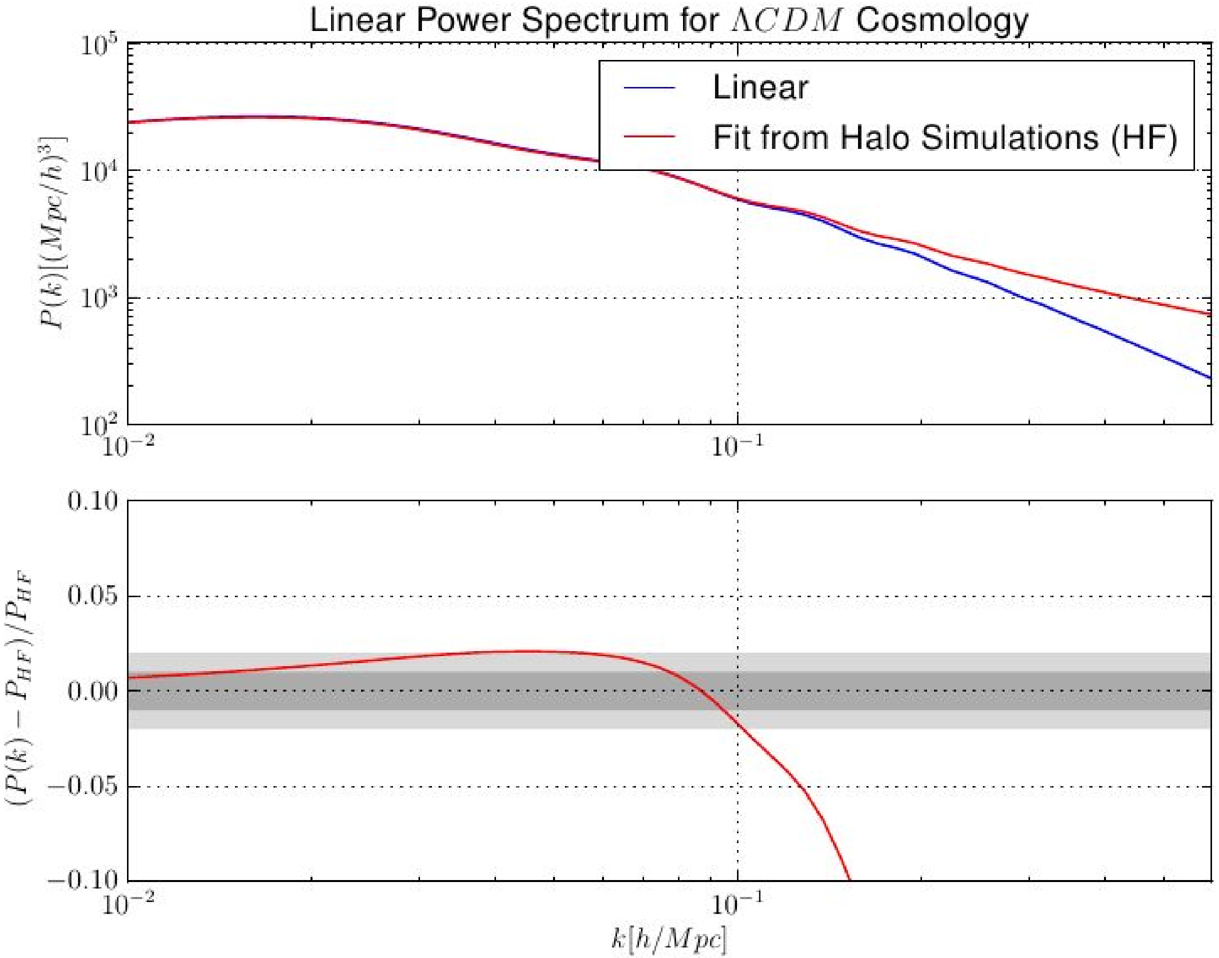
$$\frac{\partial \delta(\mathbf{x},\tau)}{\partial \tau} + \nabla \cdot \{[1+\delta(\mathbf{x},\tau)]\,\mathbf{u}(\mathbf{x},\tau)\} = 0,$$

Euler

$$\frac{\partial \mathbf{u}(\mathbf{x},\tau)}{\partial \tau} + \mathcal{H}(\tau)\;\mathbf{u}(\mathbf{x},\tau) + \mathbf{u}(\mathbf{x},\tau)\cdot\nabla\mathbf{u}(\mathbf{x},\tau) = -\nabla\Phi(\mathbf{x},\tau) - \frac{1}{\rho}\nabla_j\left(\rho\,\sigma_{ij}\right),$$

Poisson

$$\nabla^2\Phi(\mathbf{x},\tau) = \frac{3}{2}\Omega_m(\tau)\;\mathcal{H}^2(\tau)\;\delta(\mathbf{x},\tau).$$



Linear Power Spectrum for ΛCDM Cosmology
Linear
Fit from Halo Simulations (HF)
$P(k)[(Mpc/h)^3]$
10^5
10^4
10^3
10^2
10^{-2}
10^{-1}
$(P(k) - P_{HF})/P_{HF}$
0.10
0.05
0.00
−0.05
−0.10
10^{-2}
10^{-1}
$k[h/Mpc]$

Non-Linear Solution

Non-Linear Solution

Just a FT of main equations: $\theta(\mathbf{x}, \tau) \equiv \nabla \cdot \mathbf{u}(\mathbf{x}, \tau)$

$$\frac{\partial \tilde{\delta}(\mathbf{k}, \tau)}{\partial \tau} + \tilde{\theta}(\mathbf{k}, \tau) = -\int \mathrm{d}^3\mathbf{k}_1 \mathrm{d}^3\mathbf{k}_2 \delta_D(\mathbf{k} - \mathbf{k}_{12}) \alpha(\mathbf{k}_1, \mathbf{k}_2) \tilde{\theta}(\mathbf{k}_1, \tau) \tilde{\delta}(\mathbf{k}_2, \tau)$$

$$\frac{\partial \tilde{\theta}(\mathbf{k}, \tau)}{\partial \tau} + \mathcal{H}(\tau)\, \tilde{\theta}(\mathbf{k}, \tau) + \frac{3}{2} \Omega_m \mathcal{H}^2(\tau) \tilde{\delta}(\mathbf{k}, \tau) = -\int \mathrm{d}^3\mathbf{k}_1 \mathrm{d}^3\mathbf{k}_2 \delta_D(\mathbf{k} - \mathbf{k}_{12})\, \beta(\mathbf{k}_1, \mathbf{k}_2) \tilde{\theta}(\mathbf{k}_1, \tau) \tilde{\theta}(\mathbf{k}_2, \tau)$$

HIGHLY NONLINEAR EQUATION NO EXACT SOLUTION

Perturbation Theory (SPT)

$$\hat{\delta}(\boldsymbol{k}, \tau) = \sum_{n=1}^{\infty} a^n(\tau)\delta_n(\boldsymbol{k}) , \quad \hat{\theta}(\boldsymbol{k}, \tau) = \sum_{n=1}^{\infty} \dot{a}(\tau)a^{n-1}(\tau)\theta_n(\boldsymbol{k})$$

PERTURBATION THEORY!!!

Perturbation Theory

$$\hat{\delta}(\boldsymbol{k},\ \tau) = \sum_{n=1}^{\infty} a^n(\tau)\delta_n(\boldsymbol{k})\ , \quad \hat{\theta}(\boldsymbol{k},\ \tau) = \sum_{n=1}^{\infty} \dot{a}(\tau)a^{n-1}(\tau)\theta_n(\boldsymbol{k})$$

PERTURBATION THEORY!!!

$$\frac{\partial\tilde{\delta}(\mathbf{k},\tau)}{\partial\tau} + \tilde{\theta}(\mathbf{k},\tau) = -\int \mathrm{d}^3\mathbf{k}_1\mathrm{d}^3\mathbf{k}_2\delta_D(\mathbf{k}-\mathbf{k}_{12})\alpha(\mathbf{k}_1,\mathbf{k}_2)\tilde{\theta}(\mathbf{k}_1,\tau)\tilde{\delta}(\mathbf{k}_2,\tau)$$

$$\frac{\partial\tilde{\theta}(\mathbf{k},\tau)}{\partial\tau} + \mathcal{H}(\tau)\ \tilde{\theta}(\mathbf{k},\tau) + \frac{3}{2}\Omega_m\mathcal{H}^2(\tau)\tilde{\delta}(\mathbf{k},\tau) = -\int \mathrm{d}^3\mathbf{k}_1\mathrm{d}^3\mathbf{k}_2\delta_D(\mathbf{k}-\mathbf{k}_{12})\,\beta(\mathbf{k}_1,\mathbf{k}_2)\tilde{\theta}(\mathbf{k}_1,\tau)\tilde{\theta}(\mathbf{k}_2,\tau)$$

Perturbation Theory (SPT) to Diagrams

Perturbation Theory (SPT) to Diagrams

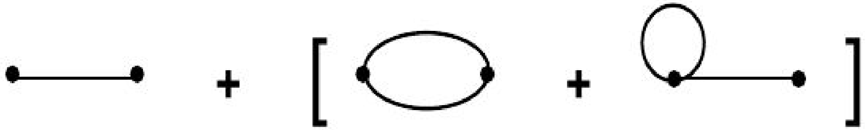
$$\langle\delta\delta\rangle = \underbrace{\langle\delta_1\delta_1\rangle}_{\text{tree-level}} + \underbrace{2\langle\delta_1\delta_3\rangle + \langle\delta_2\delta_2\rangle}_{\text{1-loop}}$$

$$+ \underbrace{2\langle\delta_1\delta_5\rangle + 2\langle\delta_2\delta_4\rangle + \langle\delta_3\delta_3\rangle}_{\text{2-loop}} + \underbrace{\mathcal{O}(\delta_1^8)}_{\text{higher loops}}$$

Perturbation Theory (SPT) to Diagrams

1-LOOP

LEVEL:

$\langle\delta(1)\delta(2)\rangle_c =$ 

$$P_{22}(k,\tau) \equiv 2\int [F_2^{(s)}(\mathbf{k}-\mathbf{q},\mathbf{q})]^2 P_L(|\mathbf{k}-\mathbf{q}|,\tau) P_L(q,\tau)\mathrm{d}^3\mathbf{q},$$

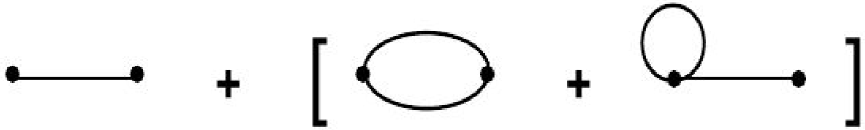
$$P_{13}(k,\tau) \equiv 6\int F_3^{(s)}(\mathbf{k},\mathbf{q},-\mathbf{q}) P_L(k,\tau) P_L(q,\tau)\mathrm{d}^3\mathbf{q}.$$

Perturbation Theory (SPT) Problems

Perturbation Theory (SPT) Problems

1-LOOP LEVEL:

$<\delta(1)\delta(2)>_c =$



INTEGRAND DOES'T CONVERGE
INSERTING A CUTOFF SCALE (non-physical)

$$P_{22}(k,\tau) \equiv 2 \int [F_2^{(s)}(\mathbf{k}-\mathbf{q},\mathbf{q})]^2 P_L(|\mathbf{k}-\mathbf{q}|,\tau) P_L(q,\tau) \mathrm{d}^3\mathbf{q},$$

$$P_{13}(k,\tau) \equiv 6 \int F_3^{(s)}(\mathbf{k},\mathbf{q},-\mathbf{q}) P_L(k,\tau) P_L(q,\tau) \mathrm{d}^3\mathbf{q}.$$

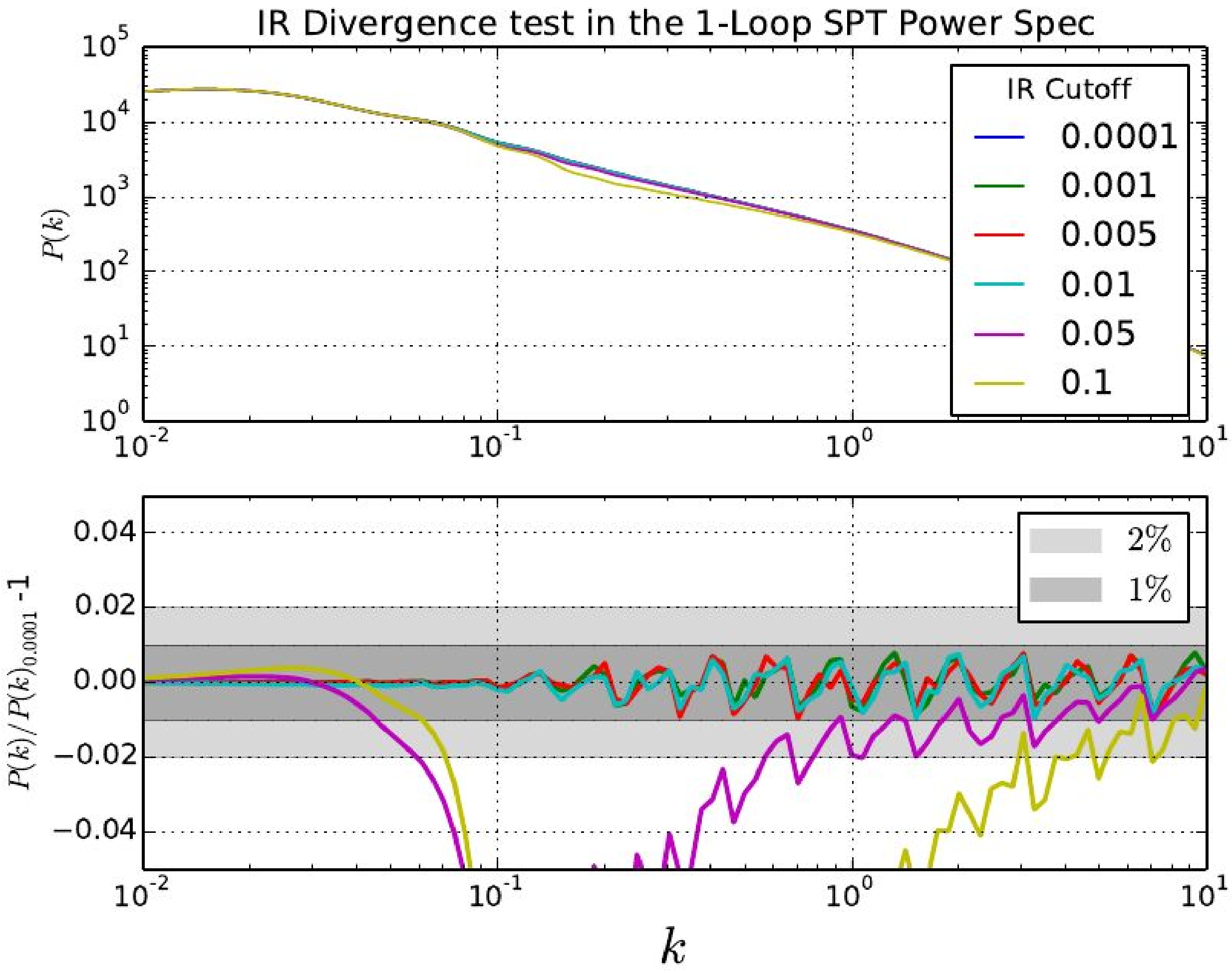
COULD HAVE IR OR UV DIVERGENCES

No IR Divergence

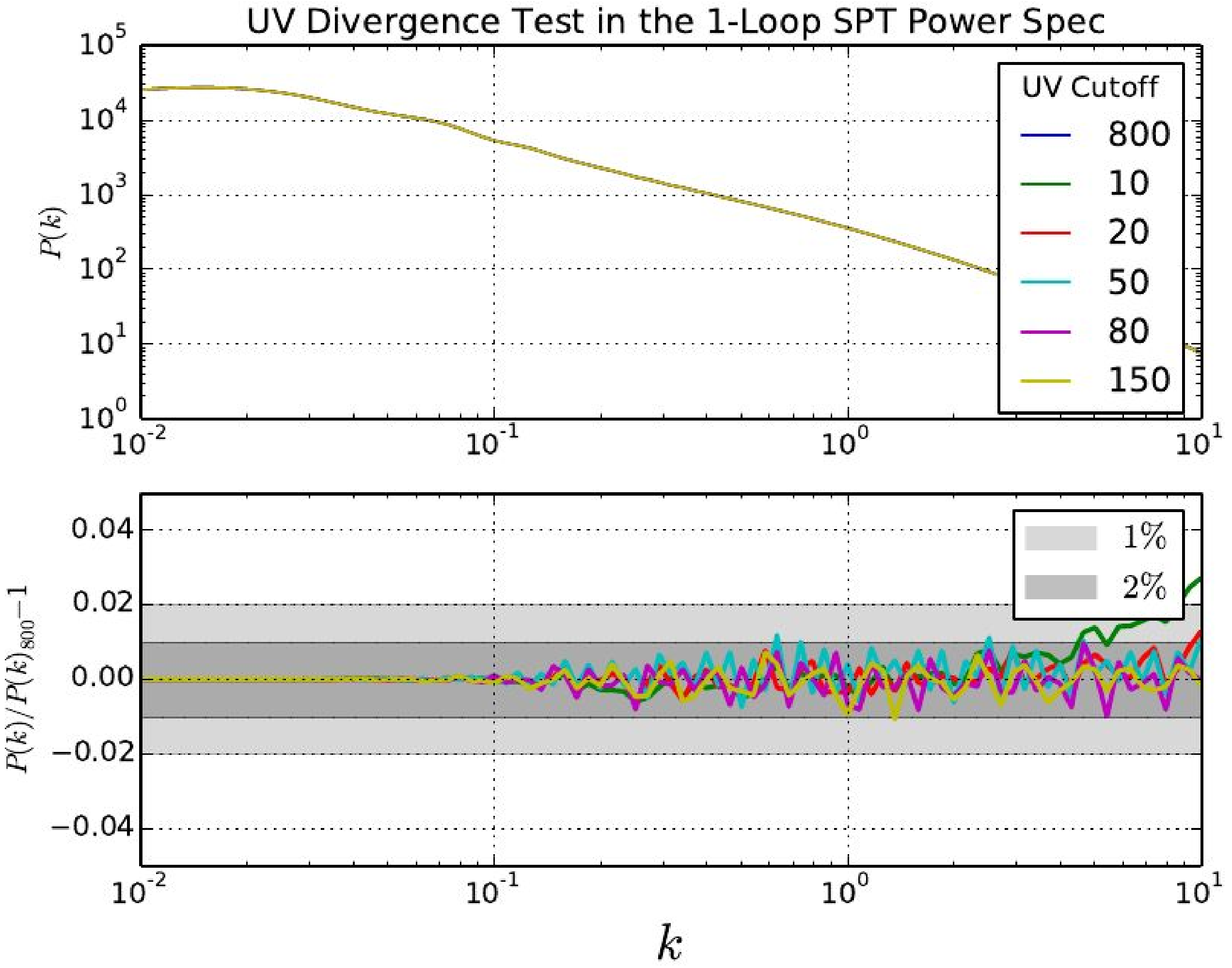
More about

IR in

1404.5954



Still UV Divs.



Effective Field Theory

Carrasco et al, 2012. ArXiv: 1206.2926

Effective Field Theory

- Effective Theory: Description of physics at a scale of interest. It's description embraces all meaningful d.o.f. at this scale.

→ Assuming our ignorance!

- Include a length scale in theory. Cutoff the unknown at Λ^{-1}
- Include stress tensor in Euler $[\tau^{ij}]_\Lambda$
- Sound Speed characterizing imperfect fluid deviations. Measure it from N-Body simulation.

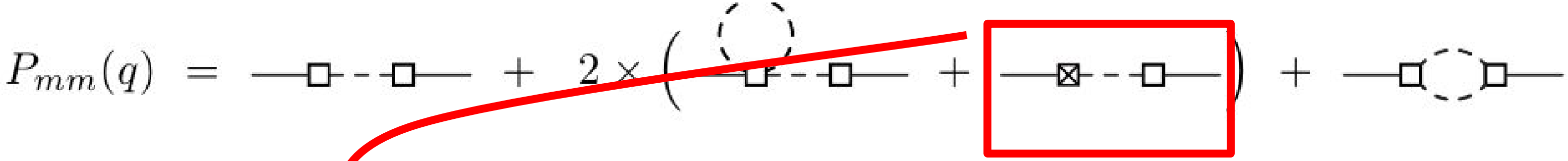
{Counterterms}

- Theory should be independent of Λ. Counterterm cancel out this dependence.

Effective Field Theory

Filter Convolution: $\Upsilon_\star(\mathbf{x}) = \int d\mathbf{x}' W_\Lambda(\mathbf{x}-\mathbf{x}')\Upsilon(\mathbf{x}') \quad W_\Lambda(\mathbf{x}) = \left(\frac{\Lambda}{\sqrt{2\pi}}\right)^3 \exp\left[-\frac{1}{2}\Lambda^2 x^2\right]$

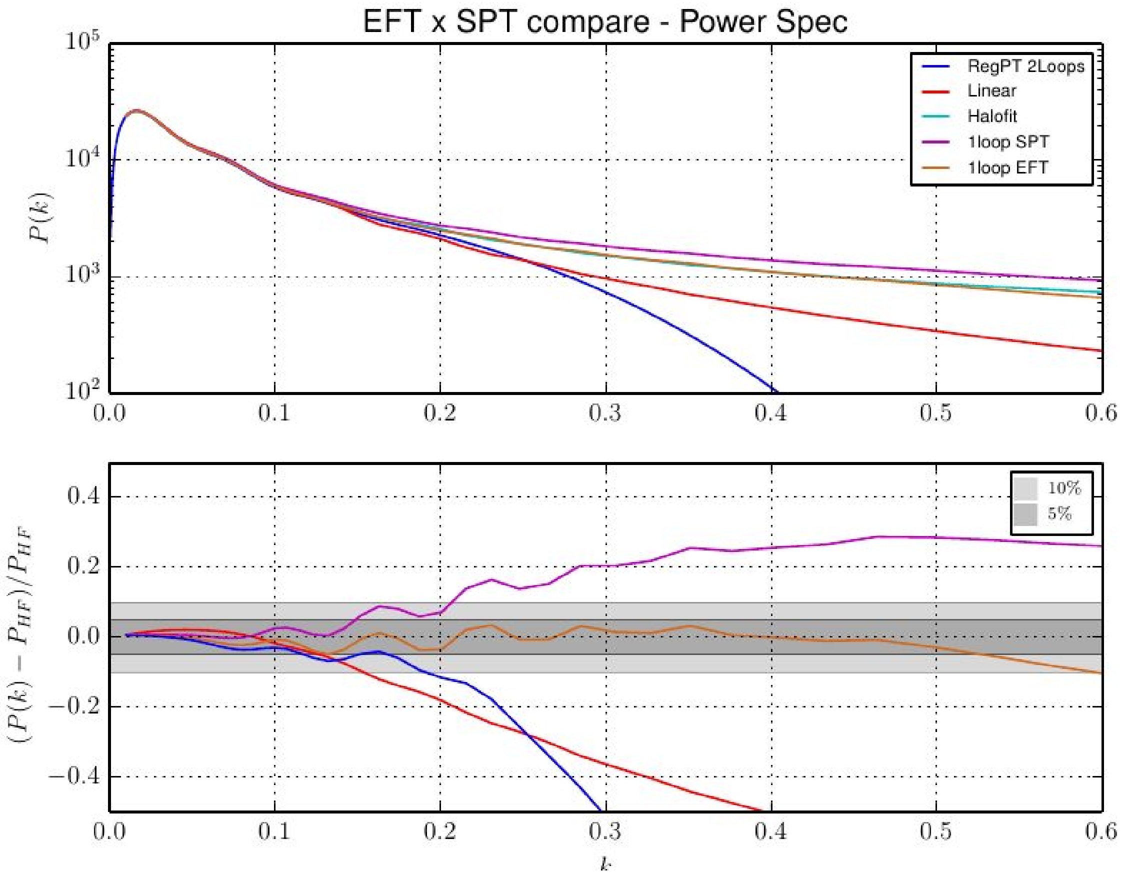
New eq $\frac{\partial \mathbf{u}_\star(\mathbf{x},\tau)}{\partial \tau} + \mathfrak{H}(\tau)\mathbf{u}_\star(\mathbf{x},\tau) + \mathbf{u}_\star(\mathbf{x},\tau).\nabla\mathbf{u}_\star(\mathbf{x},\tau) = -\frac{1}{\rho}\nabla_j(\tau^{ij})_\star$



Counterterm: $2(2\pi)c^2_{s(2)}(z)\frac{k^2}{{k_{\rm NL}}^2}P_{11}(k)$

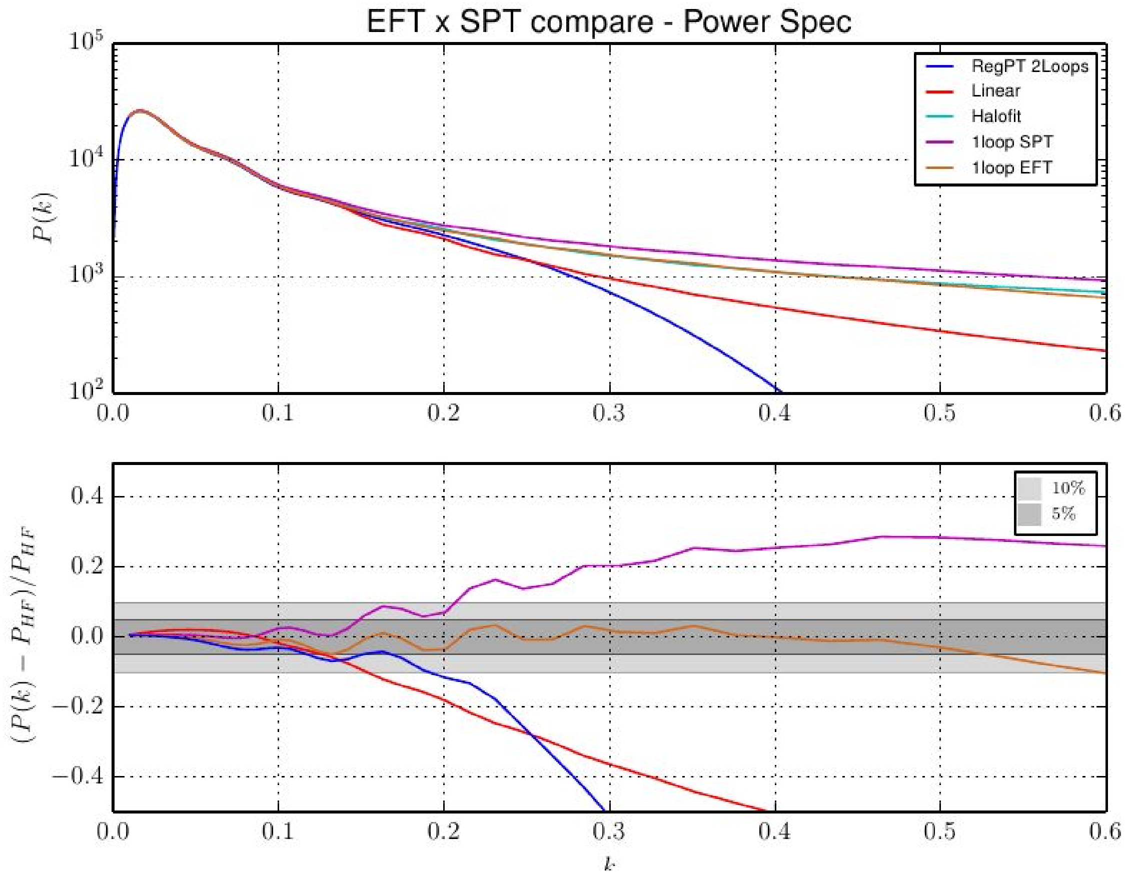
Sound Speed

EFT Results



EFT x SPT compare - Power Spec
RegPT 2Loops
Linear
Halofit
1loop SPT
1loop EFT
$P(k)$
10^5
10^4
10^3
10^2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
10%
5%
$(P(k) - P_{HF})/P_{HF}$
0.4
0.2
0.0
−0.2
−0.4
k

EFT Results



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$(P(k) - P_{HF})/P_{HF}$
0.4
0.2
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−0.2
−0.4
k

Future Plans

- More Loops EFT
- EFT and Bias
- Lagrangian Space EFT (BAO better reproduction)
- Modified Gravity EFT
- Inflation predictions with 3-point function

Acknowledgments

Marcos Lima

Rafael Porto

The Organizers

References

F. Bernardeau, S. Colombi, E. Gaztanaga, and R. Scoccimarro. Large scale structure of the universe and cosmological perturbation theory. *Phys. Rept.*, 367:1–248, 2002.

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