Signatures of Cosmic String Wakes in N Body Simulations

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McGill University

August 31 - 2017

Content

Current Section

Introduction

T. Kibble, J. Phys. A 9, 1387 (1976); A. Vilenkin and E.P.S. Shellard, Cosmic Strings and other Topological Defects (Cambridge Univ. Press, Cambridge, 1994); T. W. B. Kibble, Phase Transitions In The Early Universe, Acta Phys. Polon. B 13, 723 (1982).

- Cosmic strings are linear topological defects in QFT
- Cosmic strings exist as solutions for models that go beyond the Standard Model of Particle Physics
- One analogy from condensed matter physics is line defects in crystals
- A second analogy is a vortex line in superfluid or superconductor
- Cosmic strings are one dimensional regions of trapped energy with important gravitational affects for cosmology

Introduction

T. Kibble, J. Phys. A 9, 1387 (1976); A. Vilenkin and E.P.S. Shellard, Cosmic Strings and other Topological Defects (Cambridge Univ. Press, Cambridge, 1994); T. W. B. Kibble, Phase Transitions In The Early Universe, Acta Phys. Polon. B 13, 723 (1982); Brandenberger, Robert H. , Topological defects and structure formation (1994)

- If a model of nature admits cosmic string solutions, they will necessarily form in the early universe
- In this case, cosmic strings will persist to the present time as a scaling network

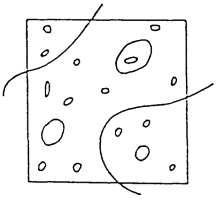


Figure 1: scaling solution for the cosmic string network at an arbitrary time

Introduction

Dvorkin, Hu and Wyman, 2011; A. Vilenkin and E.P.S. Shellard, Cosmic Strings and other Topological Defects (Cambridge Univ. Press, Cambridge, 1994);

- The cosmic string tension μ is given by $G\mu \approx (\eta/m_{pl})^2$, where η is the energy scale at which they form
- The best robust constraint is $G\mu \approx 1.5 \times 10^{-7}$

Introduction

R.B., A-C. Davis and M. Hindmarsh, 1991; X.Zhang and R.B. (1999); R.B., Y. Cai, W. Xue and X. Zhang (2009); Bramberger, Brandenberger, Jreidini, Quintin 2015

- Observing cosmic strings can give information about particle physics models
- Constraining μ will rule out classes of particle physics models
- Cosmic strings could produce interesting results for cosmology: baryogenesis, primordial magnetic fields, the origin of supermassive black holes

Introduction

- LSS provides an alternative arena for probing cosmic strings

Current Section

Wake formation

- Conical space: deficit angle $\alpha = 8\pi G\mu$
- Introduces velocity perturbations $\delta v = 4\pi\gamma_s v_s G\mu$

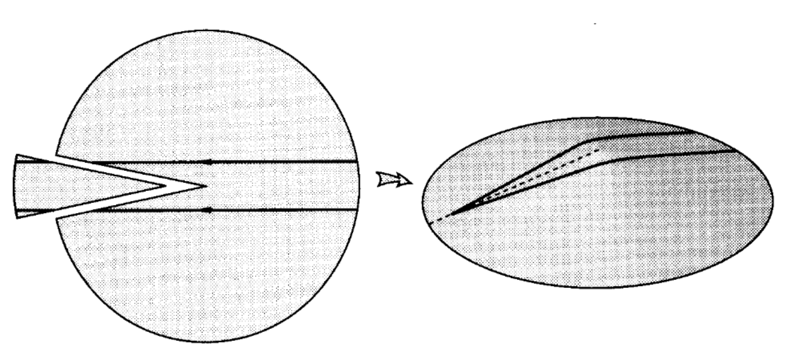


Figure 2: Effect on the LSS (Vilenkin 1994)

Wake formation

A. Stebbins, S. Veeraraghavan, Rm H. Brandenberger, J. Silk e N. Turok, Cosmic String Wakes, Astrophys. J. 233, 1 (1987); A. Vilenkin and E.P.S. Shellard, Cosmic Strings and other Topological Defects (Cambridge Univ. Press, Cambridge, 1994)

- The deficit angle create a wedge-like structure called wake

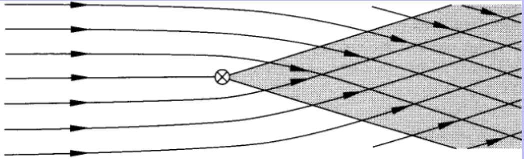


Figure 3: Effect on the LSS (Vilenkin 1994)

- The wake has the following dimensions

$$V \approx t_i \times t_i v_s \gamma_s \times 4\pi G\mu t_i v_s \gamma_s$$

Wake evolution

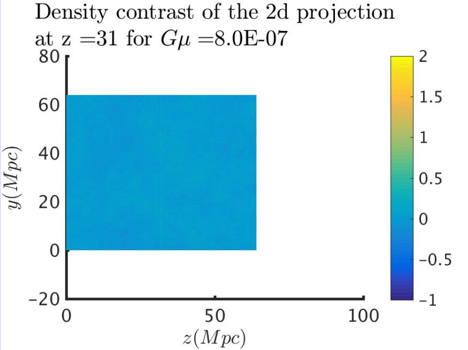
A. Stebbins, S. Veeraraghavan, Rm H. Brandenberger, J. Silk e N. Turok, Cosmic String Wakes, Astrophys. J. 233, 1 (1987); A. Vilenkin and E.P.S. Shellard, Cosmic Strings and other Topological Defects (Cambridge Univ. Press, Cambridge, 1994)

- The wake produces a non linear density fluctuation at arbitrarily early times
- The wake accrete matter and grows in thickness proportionally to the scale factor

Current Section

Studying wake disruption

- LCDM fluctuations grows in 3 dimensions while the wake only grows in 1 dimension
- One way to study the local wake disruption is to consider a small box with the wake thickness dimension



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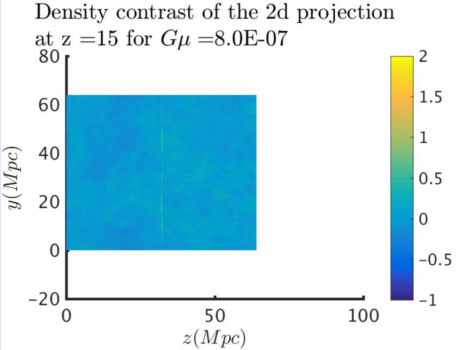

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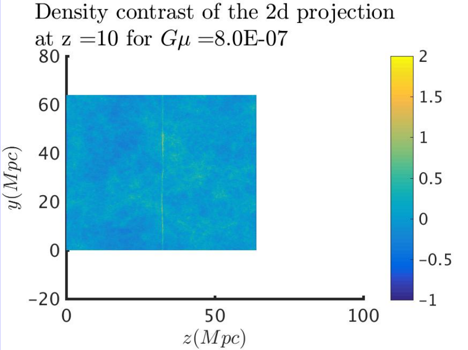

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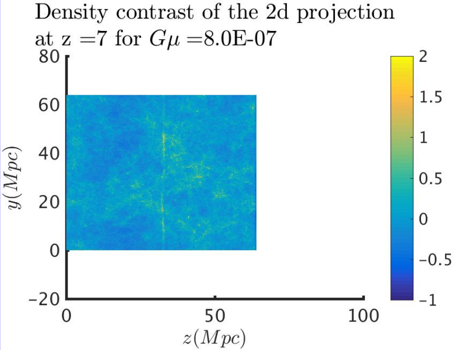

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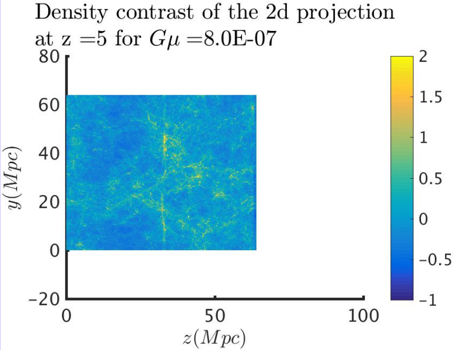

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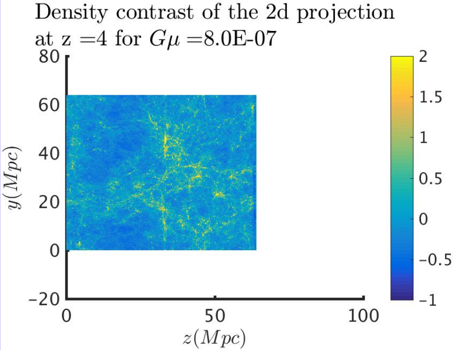

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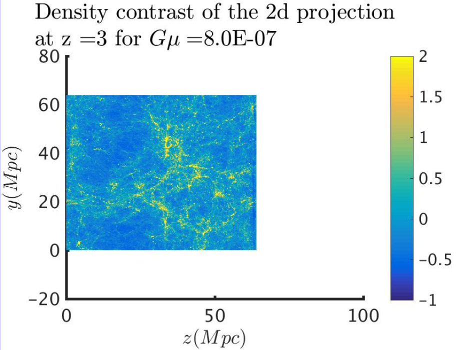

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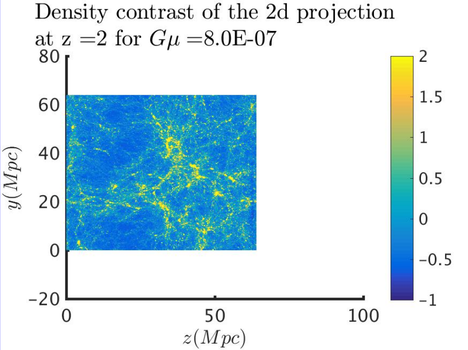

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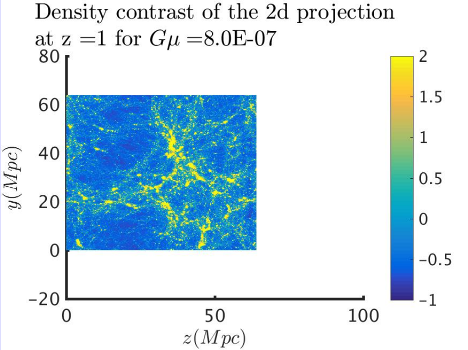

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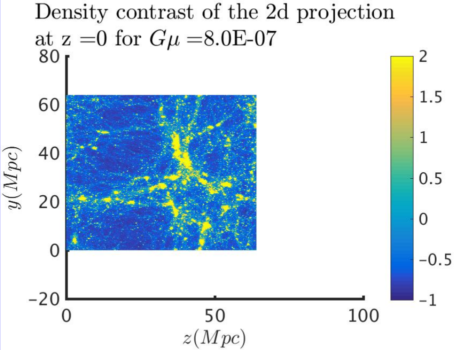

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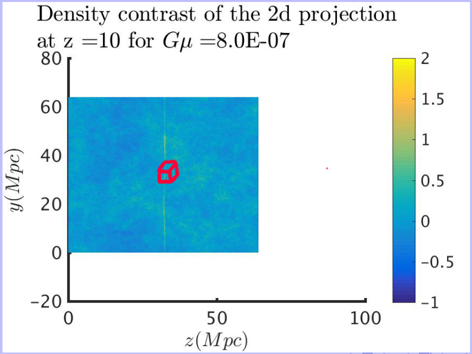


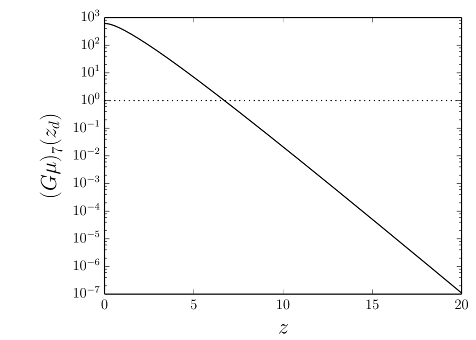
Local Delta condition

Brandenberger, Hernández and DC, arXiv 1508.02317

- If the variance Δ^2 of the density contrast is approximately one, then the wake is locally disrupted:

$$\Delta^2(\psi_3(z), z) \approx 1$$

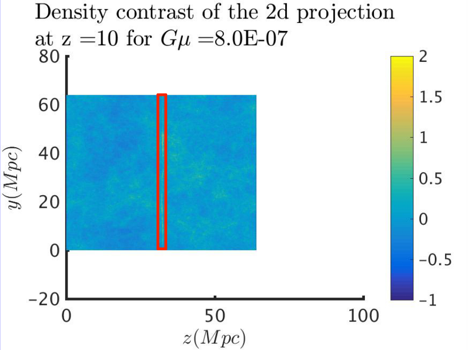
- The tension of cosmic string wake that will be locally disrupted at a given redshift is showed below



Global sigma condition

Brandenberger, Hernández and DC, arXiv 1508.02317

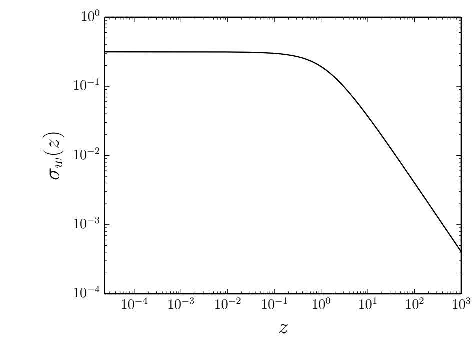
- The previous criteria missed the global volume of the wake, so a natural extension would be to consider a box with the dimensions of the whole wake.



Global sigma condition

Brandenberger, Hernández and DC, arXiv 1508.02317

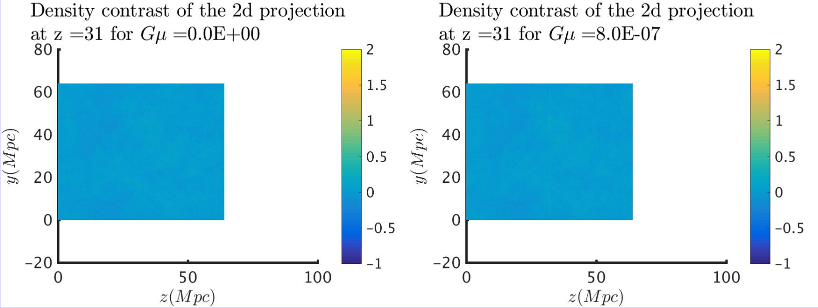
- The resulting standard deviation in the wake region is :



Current Section

Setup of the simulation

- CUBEP3M N-body simulation code
- Initial conditions of the particle distribution were modified



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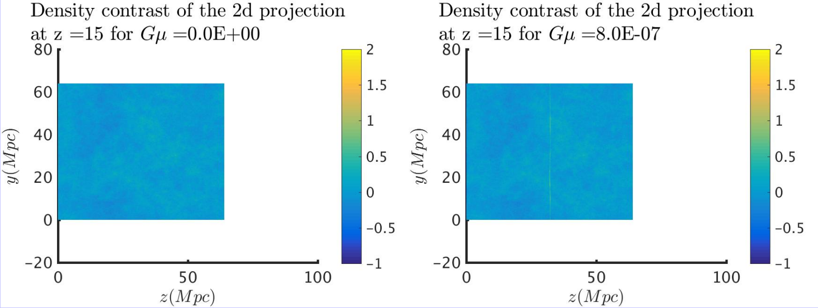

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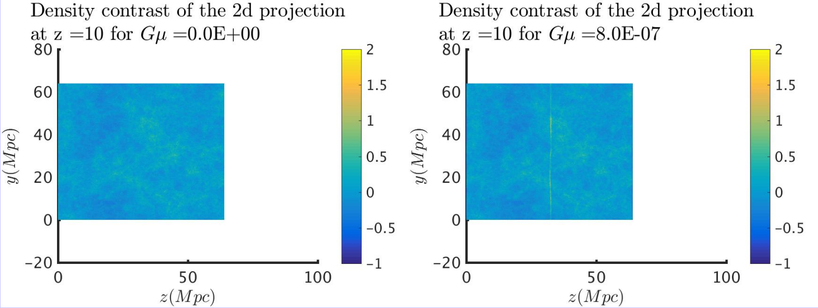

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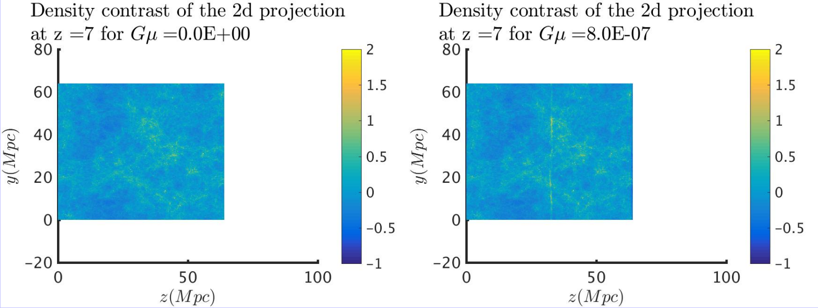

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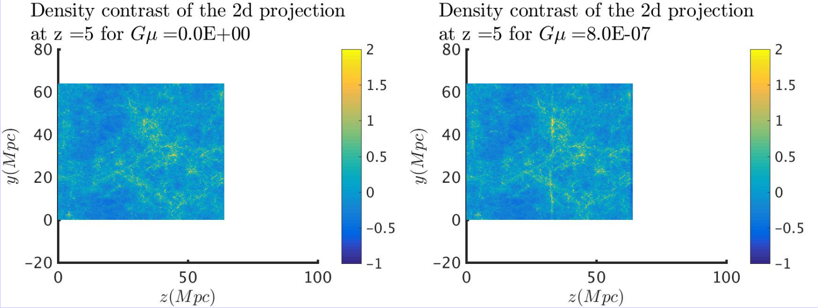

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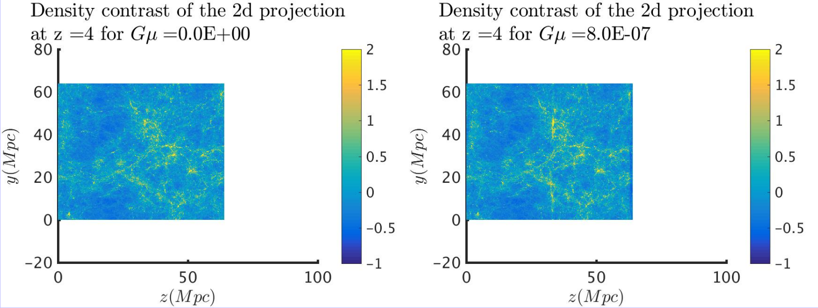

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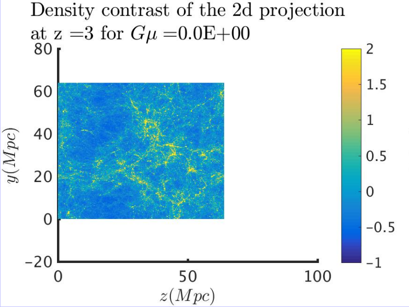

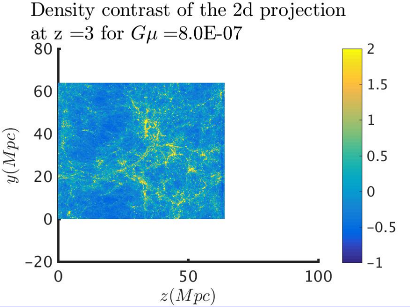

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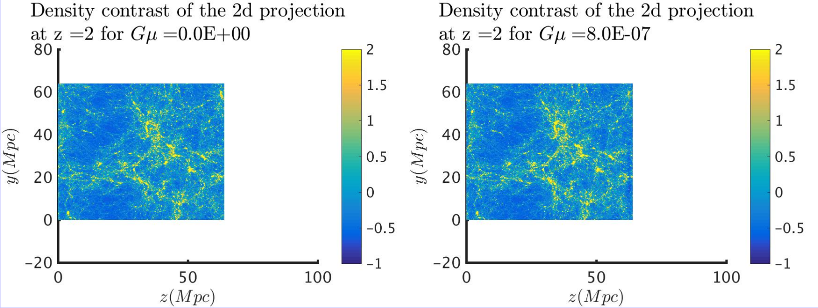

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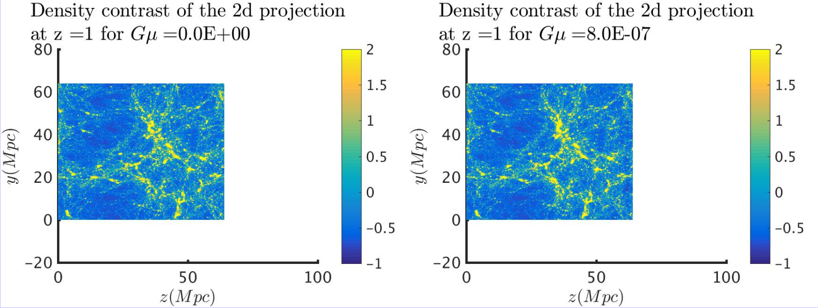

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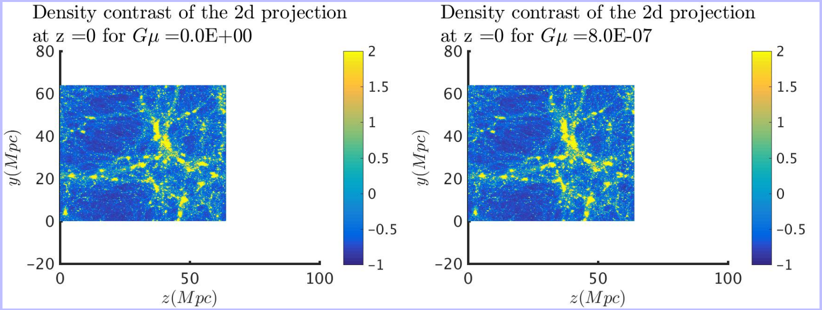

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

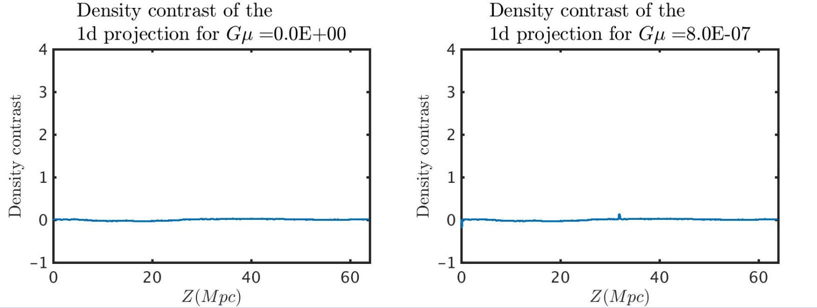

Figure 4: $z = 31$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

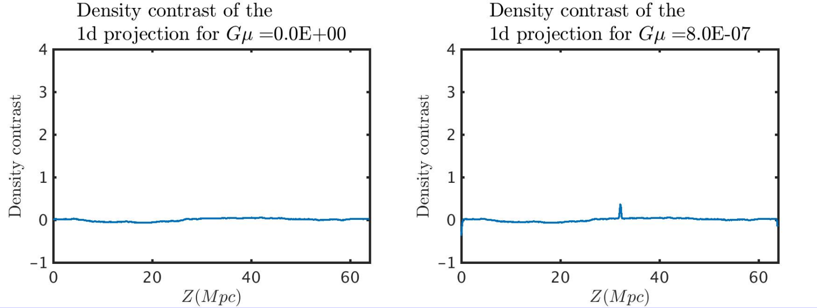

Figure 4: $z = 15$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

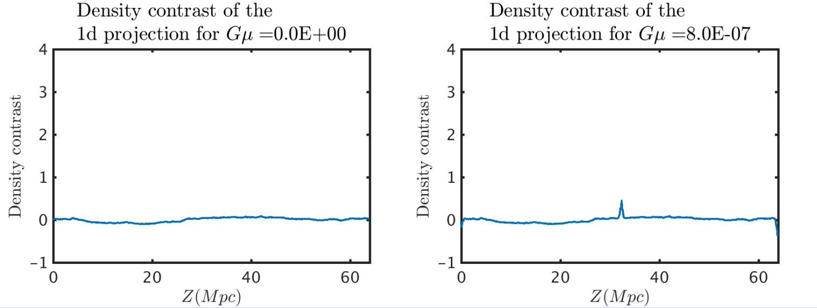

Figure 4: $z = 10$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

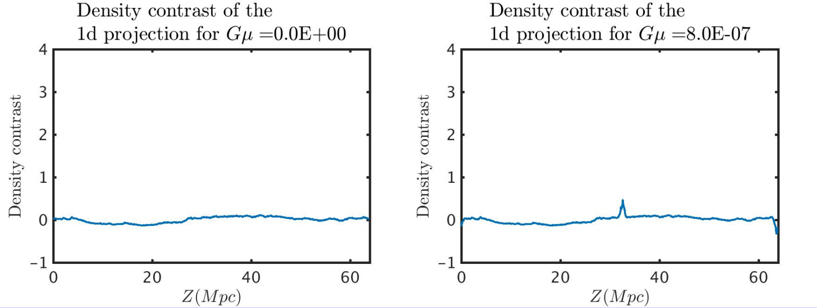

Figure 4: $z = 7$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

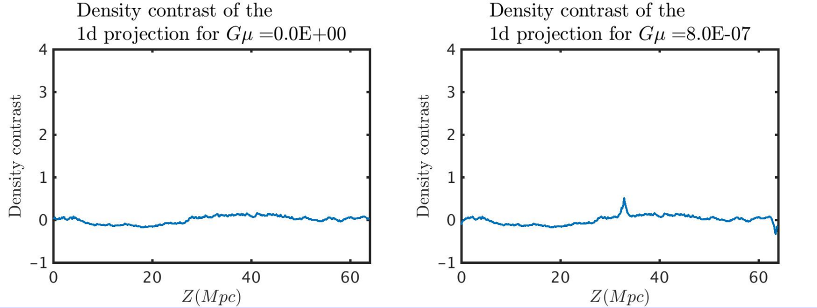

Figure 4: $z = 5$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

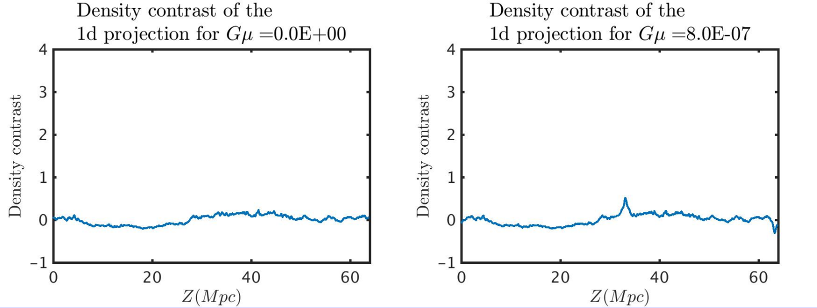

Figure 4: $z = 4$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

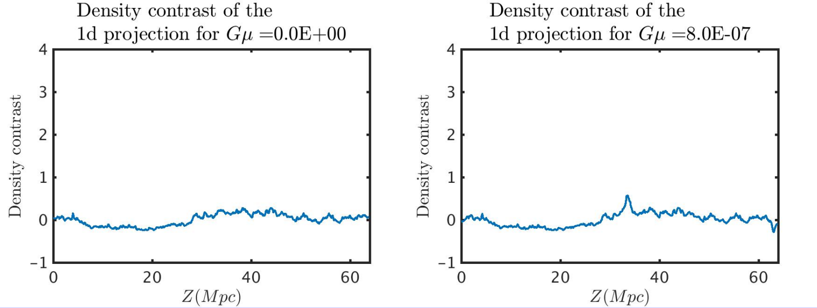

Figure 4: $z = 3$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

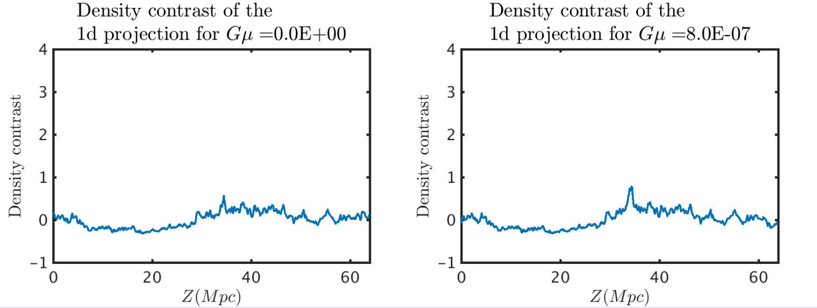

Figure 4: $z = 2$

Global wake overdensity

- Computation of the density inside slices
- One dimensional projection result

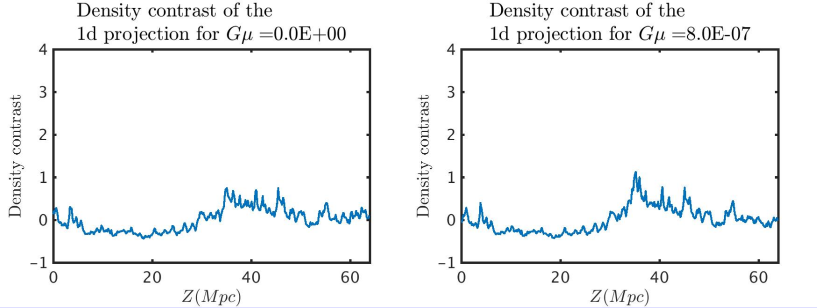

Figure 4: $z = 1$

Global wake overdensity

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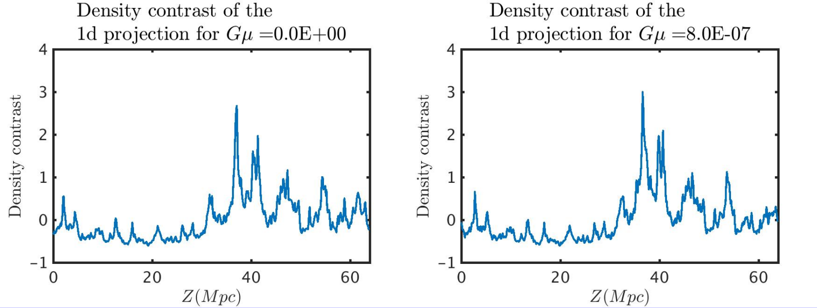

Figure 4: $z = 0$

Dropping the wake orientation prior

- The previous analysis is repeated for many different orientations
- If the wake signal is clear on the one dimensional projections it will correspond to the peak of the density contrast

Spherical maps

- A spherical map is generated in which each point on the sphere corresponds to a pair of angles and the color corresponds to the peak of the density of the associated 1D projection:

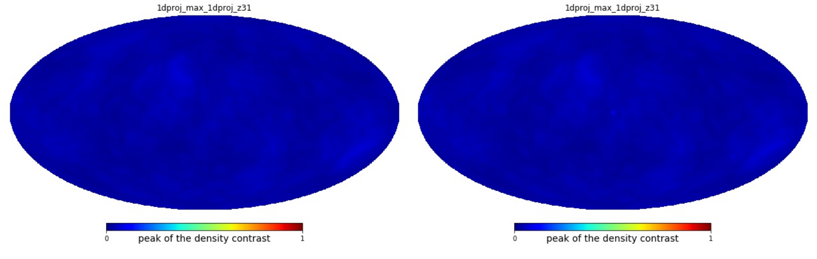

Figure 5: with no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 31$

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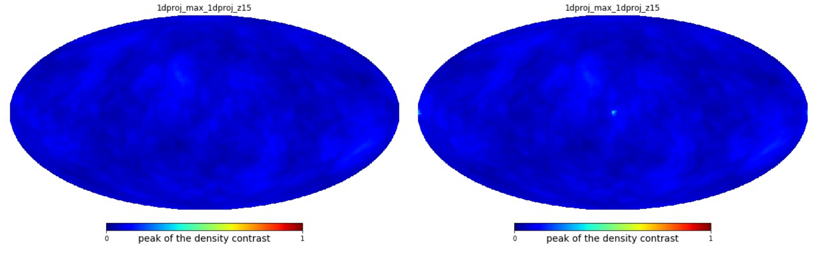

Figure 5: with no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 15$

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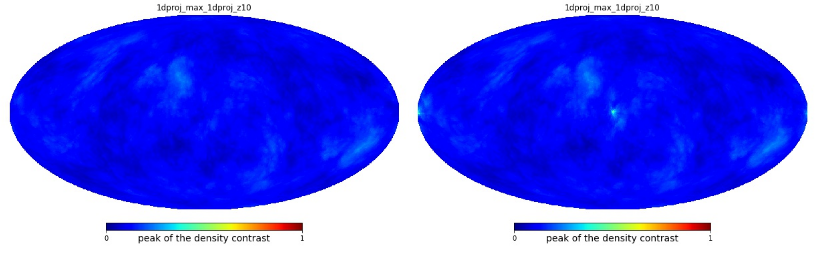

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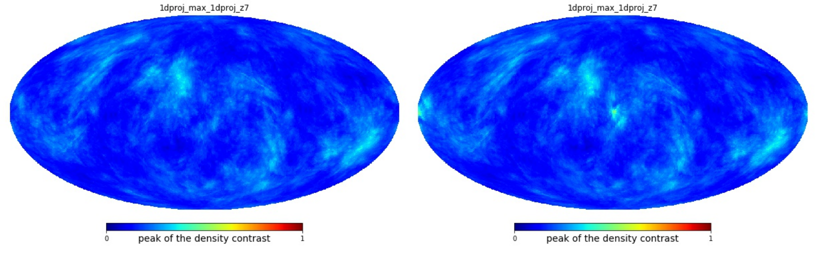

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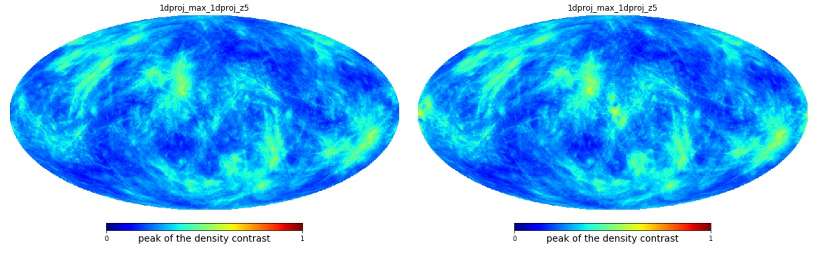

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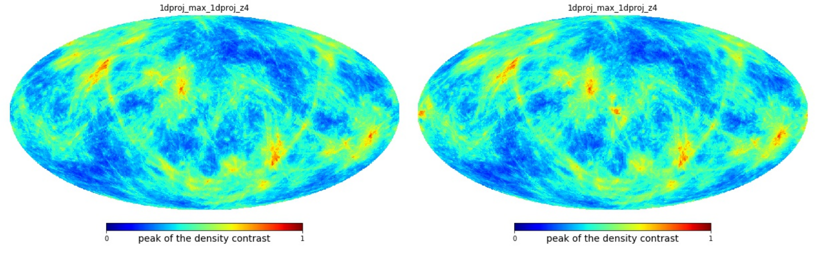

Figure 5: with no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 4$

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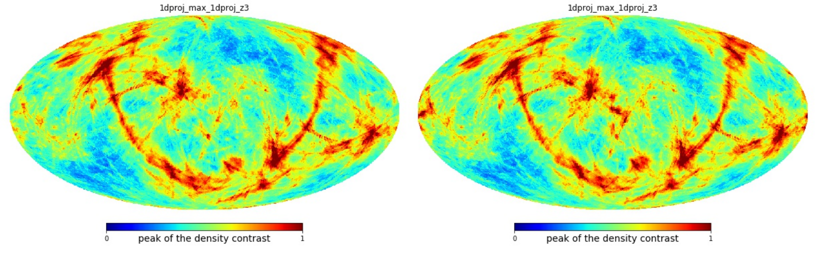

Figure 5: with no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 3$

Beyond peak detection

- Large scale density fluctuations can contaminate the wake characterization if it is based only in peaks :

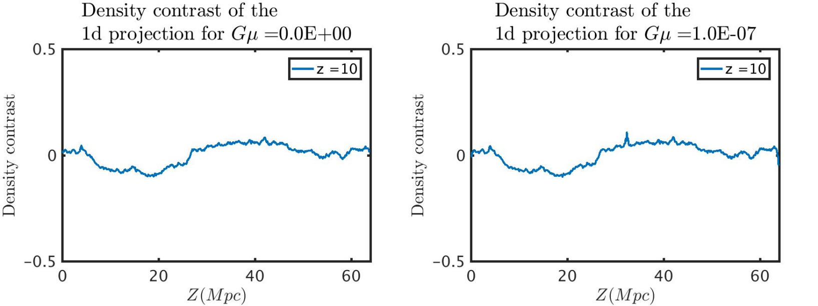

Figure 6: $z = 10$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

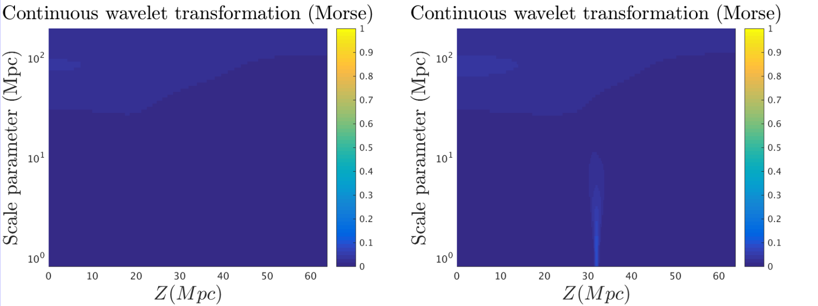

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 31$

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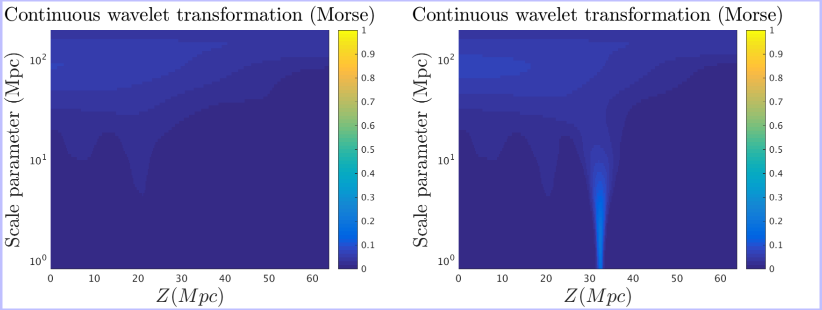

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- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

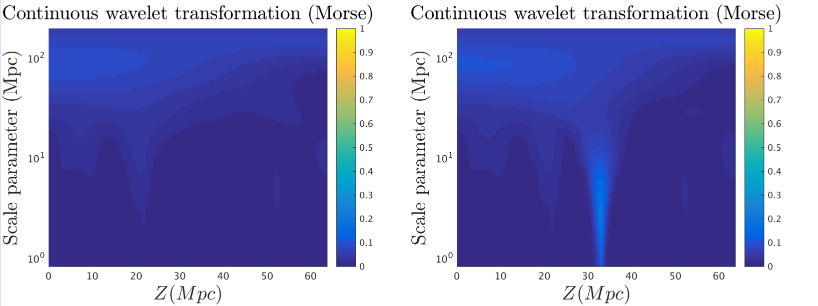

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 10$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

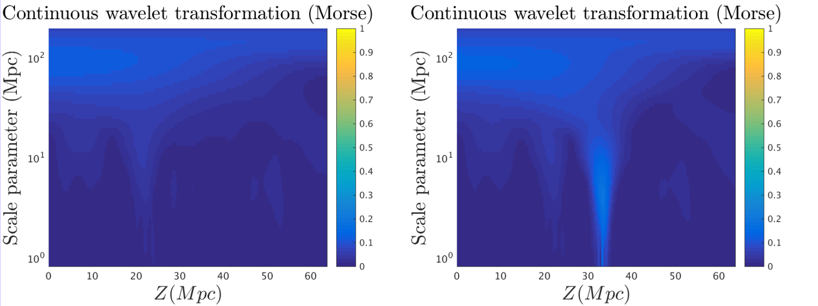

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 7$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

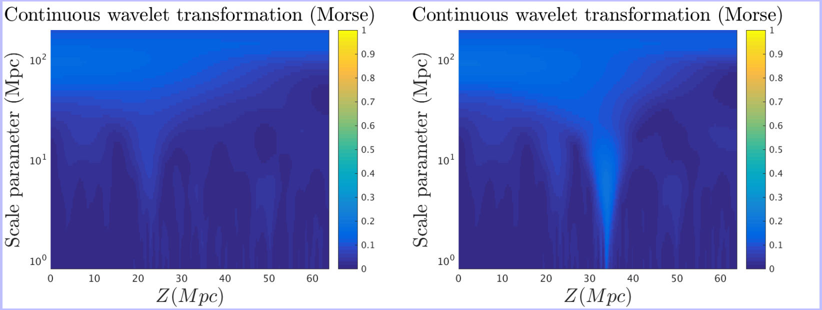

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 5$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

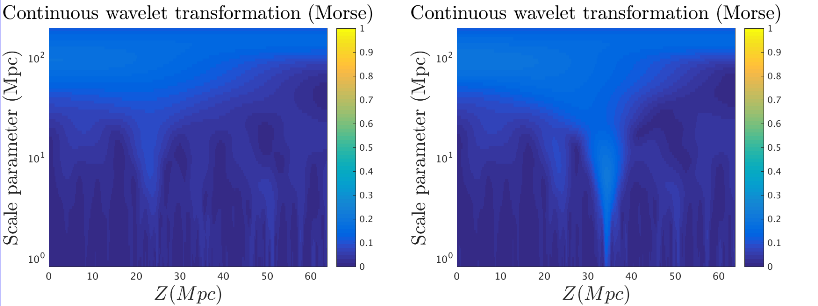

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 4$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

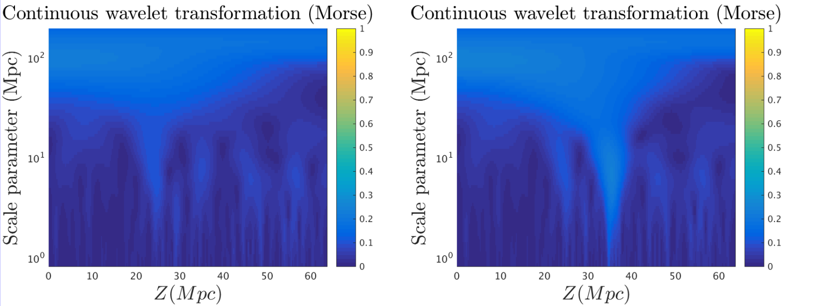

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 3$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

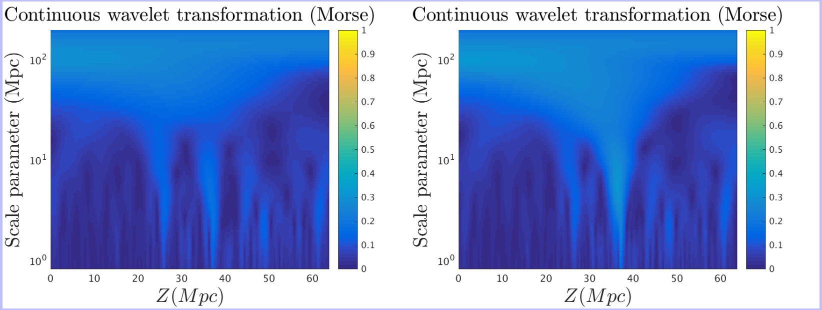

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 2$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

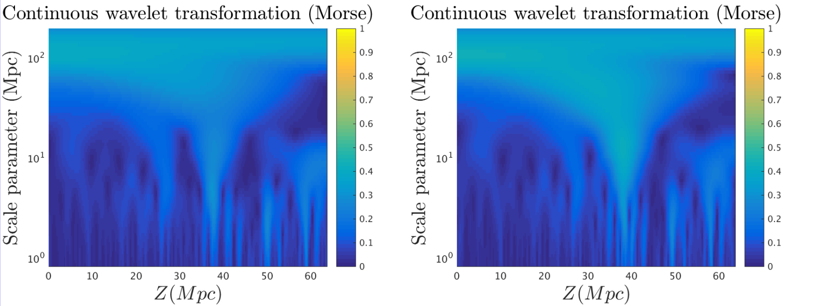

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 1$

Beyond peak detection

- A good way to focus only on the relevant scale of interest is to analyze the data using the wavelet multiresolution decomposition
- This technique provides the localized features on different scales.

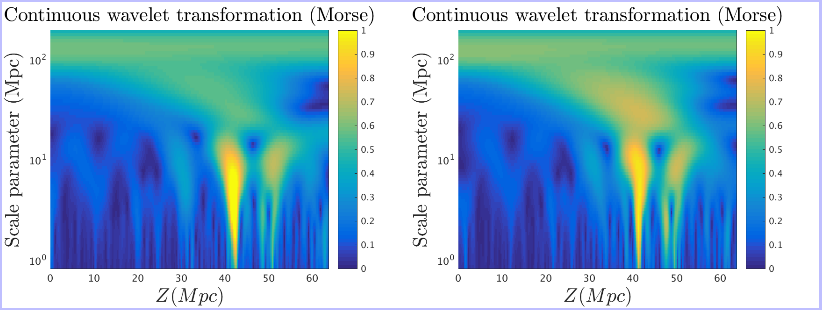

Figure 7: no wake (left) and with a wake $G\mu = 8 \times 10^{-7}$ (right), $z = 0$

Current Section

Summary

- Wakes of cosmic string can lead to distinguishable signals on the large scale structure
- Peak analysis on the dark matter product of N-Body simulations can locate $G\mu = 8 \times 10^{-7}$ wakes down to $z = 5$ and $G\mu = 1 \times 10^{-7}$ wakes down to $z = 10$
- Wavelet analysis of the dark matter product of N-Body simulations have the potential to locate $G\mu = 8 \times 10^{-7}$ wakes down to $z = 2$ and $G\mu = 1 \times 10^{-7}$ wakes down to $z = 5$

Future work

- Explore statistical methods: apply wavelet analysis to many orientations; 3D ridglets; AI techniques
- Connect with observations: populate halos with galaxies, analyze 21cm and optical experiments;
- Consider the network of wakes
- Study non-straight wakes

Thank you