Massive neutrinos and scale-dependent galaxy bias

Sunny Vagnozzi

Newton-Kavli Fellow @ KICC, University of Cambridge

sunny.vagnozzi@ast.cam.ac.uk   www.sunnyvagnozzi.com

sunnyvagnozzi   @SunnyVagnozzi

Cosmology from Home, 24 August - 4 September 2020

Neutrino-induced scale-dependent bias (NISDB)

SV, T. Brinckmann, *et al.*, *JCAP* **1809** (2018) 001 [arXiv:1807.04672]

Should we worry about the scale-dependent galaxy bias induced by massive neutrinos?

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Bias due to neutrinos must not uncorrect'd go

Sunny Vagnozzi,[a,b] Thejs Brinckmann,[c] Maria Archidiacono,[c] Katherine Freese,[a,b,d] Martina Gerbino,[a] Julien Lesgourgues[c] and Tim Sprenger[c]

[a]The Oskar Klein Centre for Cosmoparticle Physics,
Department of Physics, Stockholm University,
SE-106 91 Stockholm, Sweden

[b]The Nordic Institute for Theoretical Physics (NORDITA),
Roslagstullsbacken 23, SE-106 91 Stockholm, Sweden

[c]Institute for Theoretical Particle Physics and Cosmology (TTK), RWTH Aachen University,
Otto-Blumenthal Straße, D-52056 Aachen, Germany

[d]Leinweber Center for Theoretical Physics, Department of Physics, University of Michigan,
Ann Arbor, MI 48109, U.S.A.

E-mail: sunny.vagnozzi@fysik.su.se, brinckmann@physik.rwth-aachen.de, archidiacono@physik.rwth-aachen.de, ktfreese@umich.edu, martina.gerbino@fysik.su.se, lesgourg@physik.rwth-aachen.de, tsprenger@physik.rwth-aachen.de

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JCAP09(2018)001

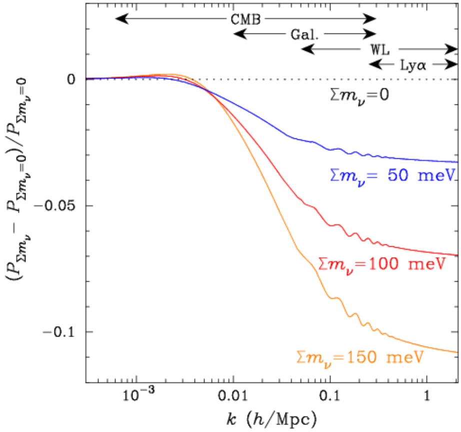
Why care about massive neutrinos and scale-dependent galaxy bias?

Why care about all this?

Why care about massive neutrinos and scale-dependent galaxy bias?

- Because neutrino masses are the only direct evidence for BSM physics
- Because cosmology *should* measure the total neutrino mass soon...
- ...and galaxy clustering is a powerful probe in this sense...
- ...but galaxy bias (and modelling systematics thereof) is an important nuisance towards a robust modelling of galaxy clustering data!

Neutrinos and their impact on the LSS



Credits: Abazajian et al., Astropart.Phys. 63 (2015) 66

Two important effects:

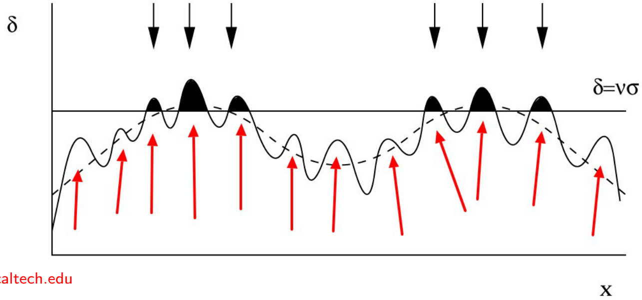
- Small-scale matter power spectrum suppression: size of effect $\approx 8 f_\nu$
- Reduction in the rate at which perturbations grow: size of effect $\approx 3/5 f_\nu$

One **fictitious effect** (this talk):

- Large-scale scale-dependence of galaxy bias: size of effect $\approx f_\nu$

(Large-scale) galaxy bias

Galaxy formation is a **threshold process**



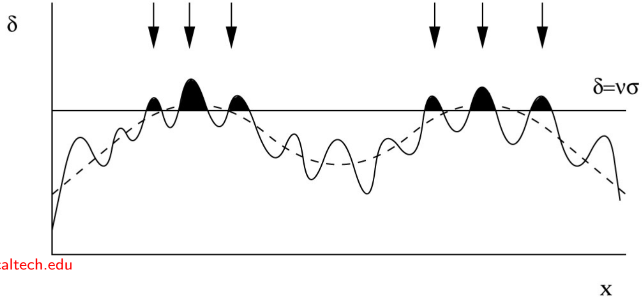
Credits: ned.ipac.caltech.edu

Peaks which collapse to galaxies more clustered than the underlying matter distribution Kaiser, ApJL 284 (1984) L9 ; Bardeen et al., ApJ 304 (1986) 15; Mo & White, MNRAS 282 (1996) 347

Heuristically: galaxy bias tells you how hard it is (how high is the threshold) to form the tracer in question on a certain scale

(Large-scale) galaxy bias

We measure a scaled version of the matter power spectrum:



Credits: ned.ipac.caltech.edu

$$P_g(k) = b^2(k) P_m(k)$$

$P_m(k)$: what we want to measure (neutrino mass signature is here)
$P_g(k)$: what we measure
$b^2(k)$: what makes life hard; $b(k) \xrightarrow[k \to 0]{}$ **constant** on large scales

(Large-scale) galaxy bias

What does this expression mean?

$$P_g(k) = b_m^2(k) P_m(k)$$

Heuristically: tracer g (galaxies) forms from field m (matter)

Does this picture make sense in the presence of massive neutrinos?

Large-scale galaxy bias with massive neutrinos

On the scales relevant for galaxy formation neutrinos free-stream and suppress structure formation

$$P_g(k) = b^2_{cb}(k) P_{cb}(k)$$

Tracer g (galaxies) forms from field cb (cold dark matter+baryons), **NOT** from field m=cb+ν

$\rightarrow$ b_{cb} is a more meaningful/physical definition of galaxy bias in the presence of massive neutrinos

Neutrino-induced scale-dependent bias (NISDB)

The "bad" definition of bias b_m features a spurious scale-dependence on large scales, which depends on M_ν:

$$P_g(k) = b_m^2(k, M_\nu) P_m(k)\,, \quad b_m(k, M_\nu) \xrightarrow[k\to 0]{} \cancel{\mathrm{const}}$$

The "good" definition of bias b_{cb} is approximately constant on large scales and does not depend on M_ν (it is *universal*): Castorina *et al.*, JCAP 1402 (2014) 049

$$P_g(k) = b_{cb}^2(k) P_{cb}(k)\,, \quad b_{cb}^2(k) \xrightarrow[k\to 0]{} \mathrm{const}$$

Linear RSD formula modified as expected: Villaescusa-Navarro et al., ApJ 861 (2018) 53

$$P_g(k) = (b_{cb} + f_{cb}(k, M_\nu)\mu^2)^2 P_{cb}(k)$$

An inconsistency in the literature?

Inconsistency in the literature: using b_m but treating it as b_{cb}

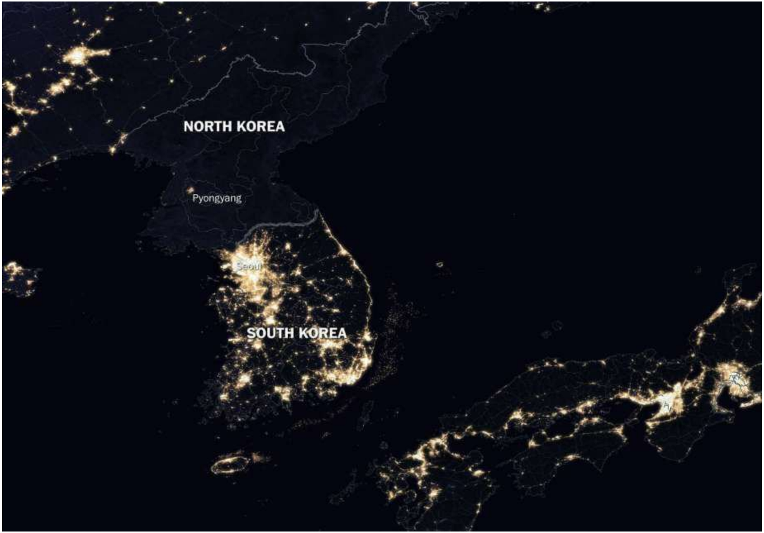
In other words: defining the bias with respect to the total matter field but treating it as if it were a constant on large scales

Is this inconsistency a problem for current and future galaxy clustering analyses?

Getting the bias model wrong: a simple analogy

Credits: ISS

Getting the bias model wrong: a simple analogy



Credits: ISS

Does this inconsistency affect galaxy clustering analyses?

Not with current data, but it will be a problem in the future!

Fisher matrix analysis

Biases from neutrino bias: to worry or not to worry?

Alvise Raccanelli, Licia Verde, Francisco Villaescusa-Navarro

Monthly Notices of the Royal Astronomical Society, Volume 483, Issue 1, February 2019, Pages 734–743, https://doi.org/10.1093/mnras/sty2162

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ABSTRACT

The relation between the halo field and the matter fluctuations (halo bias), in the presence of massive neutrinos, depends on the total neutrino mass; massive neutrinos introduce an additional scale dependence of the bias that is usually neglected in cosmological analyses. We investigate the magnitude of the systematic effect on interesting cosmological parameters induced by neglecting this scale dependence, finding that while it is not a problem for current surveys, it is non-negligible for future, denser or deeper ones depending on the neutrino mass, the maximum scale used for the analyses, and the details of the nuisance parameters considered. However, there is a simple recipe to account for the bulk of the effect as to make it fully negligible, which we illustrate and advocate should be included in analysis of forthcoming large-scale structure surveys.

Raccanelli *et al.*, MNRAS 483 (2019) 734

Full MCMC analysis

Bias due to neutrinos must not uncorrect'd go

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Abstract

It is a well known fact that galaxies are biased tracers of the distribution of matter in the Universe. The galaxy bias is usually factored as a function of redshift and scale, and approximated as being scale-independent on large, linear scales. In cosmologies with massive neutrinos, the galaxy bias defined with respect to the total matter field (cold dark matter, baryons, and non-relativistic neutrinos) also depends on the sum of the neutrino masses M_ν, and becomes scale-dependent even on large scales. This effect has been usually neglected given the sensitivity of current surveys. However, it becomes a severe systematic for future surveys aiming to provide the first detection of non-zero M_ν. The effect can be corrected for by defining the bias with respect to the density field of cold dark matter and baryons, rather than the total matter field. In this work, we provide a simple prescription for correctly mitigating the neutrino-induced scale-dependent bias effect in a practical way. We clarify a number of subtleties regarding how to properly implement this correction in the presence of redshift-space distortions and non-linear evolution of perturbations. We perform a Markov Chain Monte Carlo analysis on simulated galaxy clustering data that match the expected sensitivity of the *Euclid* survey. We find that the neutrino-induced scale-dependent bias can lead to important shifts in both the inferred mean value of M_ν, as well as its uncertainty, and provide an analytical explanation for the magnitude of the shifts. We show how these shifts propagate to the inferred values of other cosmological parameters correlated with M_ν, such as the cold dark matter

Abstract

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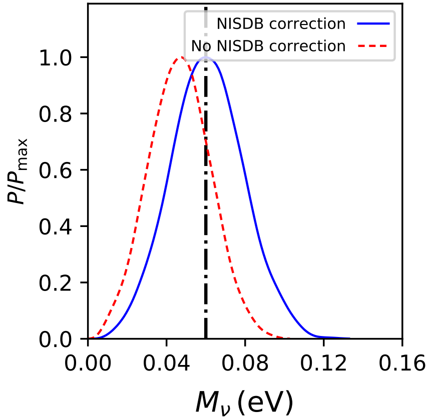
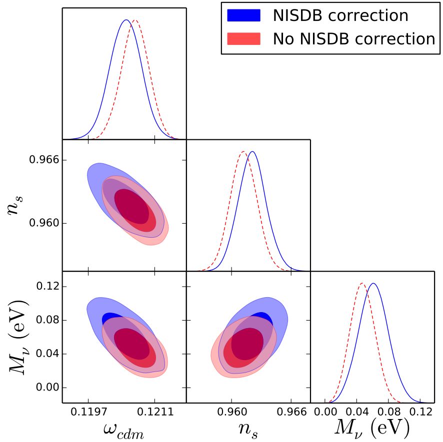
SV *et al.*, JCAP 1809 (2018) 001

Neutrino-induced scale-dependent bias (NISDB)

Forecast for Euclid (`montepython` likelihood `euclid_pk`)



SV *et al.*, JCAP 1809 (2018) 001



SV *et al.*, JCAP 1809 (2018) 001

Neutrino-induced scale-dependent bias (NISDB)

Shifts in recovered central value *and* uncertainties of M_ν and cosmological parameters correlated with M_ν...

...i.e. not only inferring *wrong* parameters, but also thinking you are more sensitive than you actually are!

Shifts in M_ν and σ_{M_ν} are a factor of $\approx 3/4$:

$$\Delta P_m/P_m \approx -8f_\nu \,, \quad \Delta P_{cb}/P_{cb} \approx -6f_\nu$$

Neutrino-induced scale-dependent bias

Bad news: if you don't correct for the NISDB, you mess up not only M_ν but also other parameters (*e.g.* σ_8 and n_s)

Good news: our patch to `CLASS` is now public with `v2.7` $\rightarrow$ use it!

Version history

The developement of CLASS benefits from various essential contributors credited below. In absence of specific credits, developements are written by the main CLASS authors, Julien Lesgourgues and Thomas Tram.

In case you are interested in downloading an old version, go to the class_public page. There is a horizontal bar with *commits, branches, releases, contributors*. Click releases and you'll get `zip` or `tar.gz` archives of all previous versions.

v2.7 (10.09.2018)

- includes a new graphical interface showing the evolution of linear perturbations in real space, useful for pedagogical purposes. To run it on a browser, read instructions in `RealSpaceInterface/README` (credits: Max Beutelspacher, Georgios Samaras)
- when running with `ncdm` (non cold dark matter) while asking for the matter power spectrum `mPk`, you will automatically get both the total non-relativistic matter spectrum *Pm(k,z)* and the baryons-plus-cdm-only (`cb`) spectrum *Pcb(k,z)*. The latter is useful e.g. for computing the power spectrum of galaxies, which traces `bc` instead of total matter (see e.g. 1311.0866, 1807.04672). From the `classy` wrapper you get the `cb` quantities through several new functions like `pk_cb()`,

Conclusions

- In the presence of massive neutrinos the meaningful definition of bias is with respect to the CDM+baryons field, *not* the total matter field
- An inconsistent galaxy bias treatment can bias [1] future galaxy clustering analyses...
- ...leading to incorrect inference of cosmological parameters (e.g. M_ν, ω_c, n_s,...) and spurious increase in sensitivity

Find out more on JCAP **1809** (2018) 001 [`arXiv:1807.04672`]

[1] No pun intended