Massive neutrinos and scale-dependent galaxy bias

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Neutrino-induced scale-dependent bias (NISDB)

Journal of Cosmology and Astroparticle Physics

SISSA

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]

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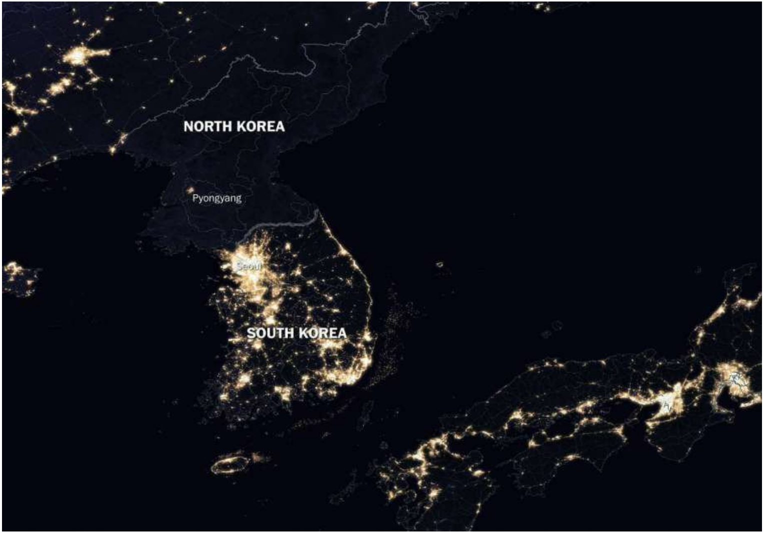
It is a well known fact that galaxies are biased tracers of the distribution of matter in the Universe. The galaxy bias is usually factored as a function of redshift and scale, and approximated as being scale-independent on large, linear scales. In cosmologies with massive neutrinos, the galaxy bias 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

Neutrinos and galaxy bias: a simple analogy

Credits: ISS

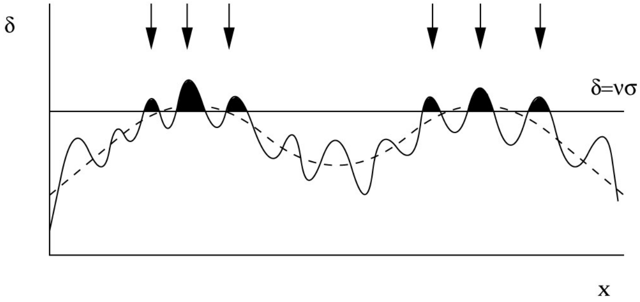
Neutrinos and galaxy bias: a simple analogy



Credits: ISS

(Large-scale) galaxy bias

Galaxy formation is a **threshold process**

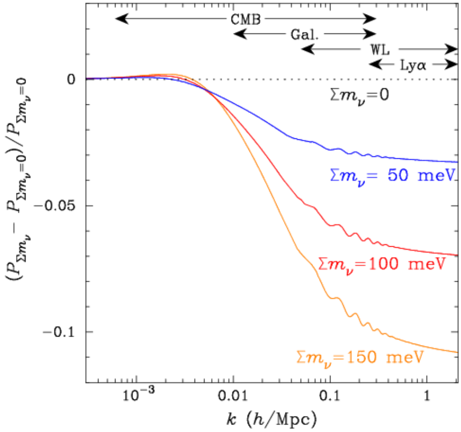


Credits: ned.ipac.caltech.edu

The peaks which first collapse to form galaxies will be more clustered than the underlying mass distribution Kaiser, ApJL 284 (1984) L9 ; Bardeen et al., ApJ 304 (1986) 15; Mo & White, MNRAS 282 (1996) 347

Bias tends to a **constant** value on large scales

Neutrinos and their impact on the LSS



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

Two important effects of massive neutrinos:

- Small-scale suppression of the matter power spectrum. Size of effect $\approx 8f_\nu$ ($10f_\nu$ in the non-linear regime)
- Reduction in the rate at which perturbations grow. Size of effect $\approx 3/5f_\nu$

One more **fictitious effect**:

- Scale-dependence in galaxy bias on large scales. Size of effect $\approx f_\nu$

Neutrino-induced scale-dependent bias (NISDB)

On large scales:

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

$P_m(k)$: what we want to measure
$P_g(k)$: what we measure
b: bias (generally scale-dependent)

But when neutrinos are present... Castorina *et al.*, JCAP 1402 (2014) 049

$$P_g(k) = b_m^2(k, M_\nu) P_m(k)$$

Physical reason: halo formation to leading order only responds to the CDM+b field (galaxies form at peaks of the CDM+b density field)

Neutrino-induced scale-dependent bias (NISDB)

More meaningful definition of bias with respect to CDM+baryons **only**:

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

$b_{cb}(k)$ is approximately k-independent on linear scales, whereas b_m is not

Castorina *et al.*, JCAP 1402 (2014) 049

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

Redshift-space distortions

Linear RSD formula modified just as you expect:

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

Villaescusa-Navarro et al., ApJ 861 (2018) 53

Treatment of non-linearities a bit trickier

See SV et al., JCAP 1809 (2018) 001 for more discussions

Does this inconsistency affect $P(k)$ analyses?

Not at the moment, but it will!

Fisher matrix analysis

ACCEPTED MANUSCRIPT

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

Alvise Raccanelli, Licia Verde, Francisco Villaescusa-Navarro

Monthly Notices of the Royal Astronomical Society, sty2162,
https://doi.org/10.1093/mnras/sty2162
Published: 09 August 2018

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 which 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.

Issue Section: Article

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

Full MCMC analysis

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Abstract

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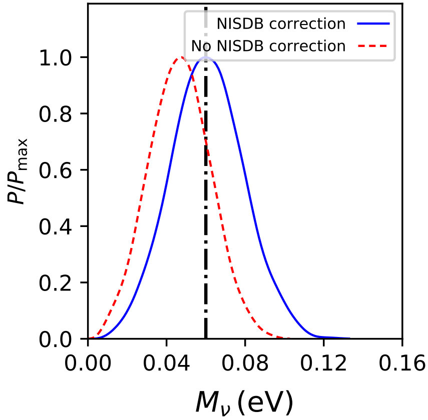
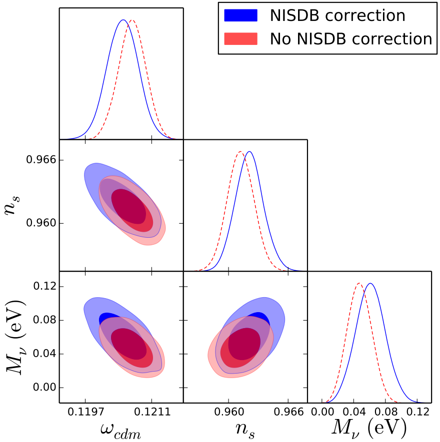
SV *et al.*, JCAP 1809 (2018) 001

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 it...

...i.e. inferring *wrong* parameters and thinking you are more sensitive than you actually are!

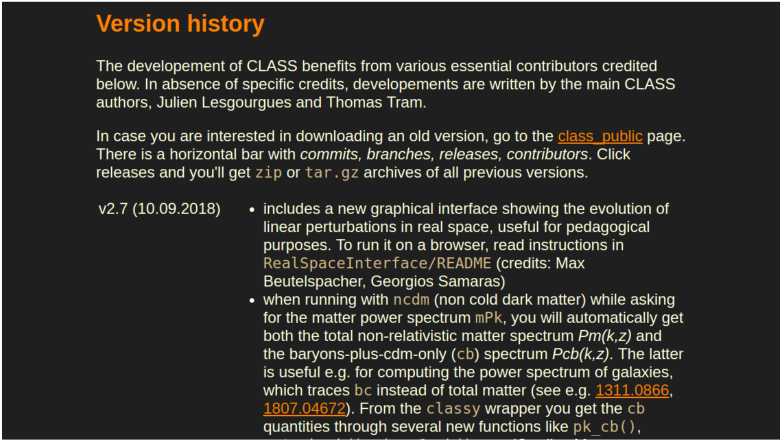
Shifts in M_ν and σ_{M_ν} are a factor of $\approx 3/4$:

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

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()`,

...the end of the story?

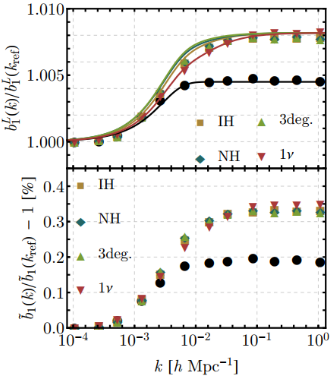
- Actually $b_{cb}(k)$ still depends on M_ν and is scale-dependent on large scales...

  LoVerde PRD 90 (2014) 083530, PRD 93 (2016) 103526; Muñoz & Dvorkin, PRD 98 (2018) 043503

- ...as halo formation cares *mostly* about the CDM+baryons field...
- ...but also about the history of perturbation growths:

$$b(k) \propto \frac{d\delta_{\rm crit}}{d\delta_{L,\rm coll}(k)}$$

- Effect recently seen convincingly in simulations Chiang, LoVerde, Villaescusa-Navarro, PRL 122 (2019) 041302



Muñoz & Dvorkin, PRD 98 (2018) 043503

Conclusions

- In cosmologies with massive neutrinos the meaningful definition of bias is with respect to the cold dark matter plus baryons field, *not* the total matter field
- An inconsistent bias treatment can bias [1] future galaxy clustering analyses...
- ...leading to incorrect inference of cosmological parameters (e.g. M_ν, ω_c, n_s,...)

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

[1] No pun intended