Dear Editor,

We thank the three referees for their careful and constructive reviews of our paper. We have modified our manuscript according to their reports, details are given below. We have also changed some sentences to make our points clear.

Regards,
Hong-Ming Zhu, Ue-Li Pen, Xuelei Chen and Derek Inman

Re: LZ13895
Probing neutrino hierarchy and chirality via wakes
by Hong-Ming Zhu, Ue-Li Pen, Xuelei Chen, et al.

Dear Mr. Zhu,

The above manuscript has been reviewed by our referees. While we cannot make a definite commitment, we will probably accept your paper for publication, provided you make changes that we judge to be in accordance with the appended comments (or other satisfactory responses are given).

With your resubmittal, please include a summary of changes made and a brief response to all recommendations and criticisms.

Yours sincerely,

Stanley G. Brown
Consulting Editor
Physical Review Letters
Email: prl@aps.org
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IMPORTANT: Editorial "Review Changes"
http://journals.aps.org/prl/edannounce/PhysRevLett.111.180001

Second Report of Referee A -- LZ13895/Zhu

The authors have corrected the calculations as required, showing small
changes in the final results. They say also to have checked their back
of the envelope estimates against fully numerical integration,
obtaining a signal only 15% smaller than what stated in the paper.

There are still some missing points in the text, as the value of the
galaxy-bias adopted for the different surveys, the fact that all the
galaxies are located at a fixed redshift (which is not a good
approximation for very large surveys as LSST and Euclid), etc...

Since, at least for left-handed neutrinos, the authors find a signal
orders of magnitude larger than future 21cm sensitivities, I do not
think more precise calculations would alter the main conclusions of
the manuscript. However, the authors should add a few words about the
galaxy bias adopted in the paper, and provide some explanation for
their choice to locate all the galaxies at a fixed redshift, instead
of using the correct galaxy distribution of Euclid and LSST.

Reply: As we only need the direction of the relative velocity to calculate the dipole, the value of the bias is irrelevant. We add one comment below Eq.3 to explain this. We did the calculation as suggested by the referee, using the correct galaxy distribution of LSST and Euclid. We find the signal is larger than our previous estimate since surveys like LSST contain many galaxies at higher redshifts, where the lensing effect is more prominent. We replot fig.3 and fig.4 according to this, and change the lensing weight to the one with the galaxy distribution.

Given the provided checks, and the quite original idea, I suggest
publication in PRL, once the authors have made the small additions
mentioned above.

Report of Referee B -- LZ13895/Zhu

The paper proposes a new way of measuring the neutrino mass, using a
distortion of the weak lensing shear field by neutrino wakes around
halos. However, the effect is extremely small, and would always be
smaller than the effect of the neutrino mass on the power spectrum.
The euclid+LSST constraints (already futuristic) only constrain the
mass to a level already ruled out by current galaxy clustering
surveys. Given this, the paper in my view clearly fails the notability

requirement for PRL and thus should not be accepted as a Letter.

Reply: The effect of the neutrino mass on the power spectrum is degenerate with the galaxy bias, which is poorly known due to complicated baryon physics. So we try to propose some different ways to constrain neutrino masses, which suffer less from the unknown baryon effects.

I also share the concerns of the previous referee that the calculations, essentially order of magnitude estimates, presented here are still overly simplistic and overly generous, and reject it also for that reason.

Overall I feel that when the below points are addressed, it will be clear that the effect is far too small to ever observe, in which case to be accepted the paper should be resubmitted to PRD making this conclusion clear in the abstract. I may be wrong about this, but I would ask the authors to perform the calculation with some care. Effects this small are easily swamped.

Specifically:

1. N-body simulations run by Inman et al. 2015 found that the nonlinear effect is substantially smaller than the linear theory effect assumed here. Part of this is due to the assumption of a static halo mass to estimate the effect of neutrino wakes. You should use the more correct non-linear effect, especially since you are the same authors on both papers.

Reply: Indeed, we did see that the expected relative velocity is smaller in simulation than in linear theory. Nonetheless, using a slightly smaller value of the velocity changes how the mass is resolved not the qualitative picture presented here. We also note that we expect non-linearities in the density (halo) fields to be larger than in the velocity field so we prefer to be consistent in our use of linear theory.

2. It is not clear to me that your assertion that nothing else creates the dipole moment due to neutrino wakes is true. For example, it seems to me AGN jets could easily induce a local dipole. As the neutrino wake effect is very small, even a small effect of AGN can swamp the neutrino wake signal.

Reply: In order for a baryonic effect (such as AGN) to mimic the signal presented here it would need to be asymmetric (e.g. differing jets for the AGN) and systematically aligned with the relative velocity field. Since we have no reason to expect such alignment, any asymmetries will add noise to the signal but not mimic it.

3. In the simple mode-counting arguments employed to estimate observability, particularly for the 21 cm experiment, the error on kappa is dominated by the large number of small-scale modes. However, the neutrino wake effect occurs only on large scales, and goes to zero for $k > 1$, so only these modes should be counted when estimating errors. This would greatly diminish the power of the 21 cm experiment at least.

Reply: We use 21cm observations as sources instead of lenses. The relative motion at low redshift produces dipoles around halos, which we try to measure with distortions of high redshift sources by these dipole mass distributions. No matter how small the source is, it will always be affected by the lenses.

4. The 21 cm experiment as described in the given reference is futuristic to the point of total infeasibility. It is also only vaguely sketched, and I do not feel you have done enough work to demonstrate its potential to measure neutrino wakes. For example, the calculation done in the paper is for large halos at z=0.3. If you wish to include 21 cm constraints, you should perform a calculation of the neutrino wake effect for the smaller and higher redshift halos which are measured by a dark ages 21 cm experiment.

Reply: With higher redshift sources, more lenses at low redshift will contribute to the signal. While contributions from high redshift is smaller and down weighted by the lensing kernel, the total signal will still a little stronger than the current estimate. This will not change the main conclusion of this paper.

5. Finally, as a small point, rather than using non-standard terms such as ‘quasi-degenerate’ in the abstract, it would be better to frame the paper as quantitative potential constraints on physical variables, like the neutrino mass, or the mass splitting.

Reply:

We should make this change. Perhaps change to sum of neutrino masses > x meV?

Report of Referee C -- LZ13895/Zhu

This paper discusses an interesting, original idea on a potential probe to the neutrino sector of the dark matter, by comparing the mass density field that is inferred from the large-scale distribution of galaxies and from weak gravitational lensing, and focusing on the phenomenon of the wake produced by dark matter halos on the distribution of neutrinos.

In my opinion the paper should be accepted for publication in Physical Review Letters. This new idea can clearly give rise to new developments in the field of large-scale structure. Even though the idea has not been exhaustively checked with numerical simulations, and the effect is very small and difficult to detect with currently planned surveys, I think this is not a reason to prefer publication in Phys. Rev. D. The letters should precisely highlight new ideas that may potentially introduce new elements of discussion in their research field. The authors have reasonably answered the comments of the previous referees.

I would also like to give the following comment to the authors: it is assumed in the paper that the non-linear effect that depends on the presence of neutrinos with a certain velocity dispersion as a dark matter component is described as wakes that can be modeled as if they were created by halos of fixed mass M. This is not clear to me, actually the wakes are produced by the entire large-scale structure, not just halos, and the halos in any case do not have fixed mass but they are continuously growing. In the end, the thing that is important is that one uses the galaxy distribution to predict a large-scale velocity field, and from this, to predict a difference between the density field of cold dark matter and that of neutrinos, as a function of the neutrino velocity dispersion. Weak lensing is then used to test if the neutrino component is there, and to measure its contribution to the density. The question is to what extent one can measure the small difference due to neutrinos. It is not clear if this difference is adequately modeled by considering the abundance of halos of mass M; perhaps the real overall effect might be larger than this simple halo model predicts. This can only be studied in a much more complete work, but I think the authors may consider saying something about this.

Reply: The relative motion between CDM and neutrinos will also produce an observable effect in the entire large-scale structure, which is the cross correlation dipole between CDM and neutrinos. This has been studied in our previous paper. We add one comment in the second paragraph following the citation of our previous paper. A detailed study about the accumulation of neutrinos around a growing halo with a bulk velocity can be accomplished similarly as in M. LoVerde & M. Zaldarriaga, PRD 89, 063502, which gives an complete description of the clustering of neutrinos in the cosmological background. We add something about this in the last paragraph in section ”Neutrino wakes and lensing signal”.