Non-linear flows for the neutrino masses

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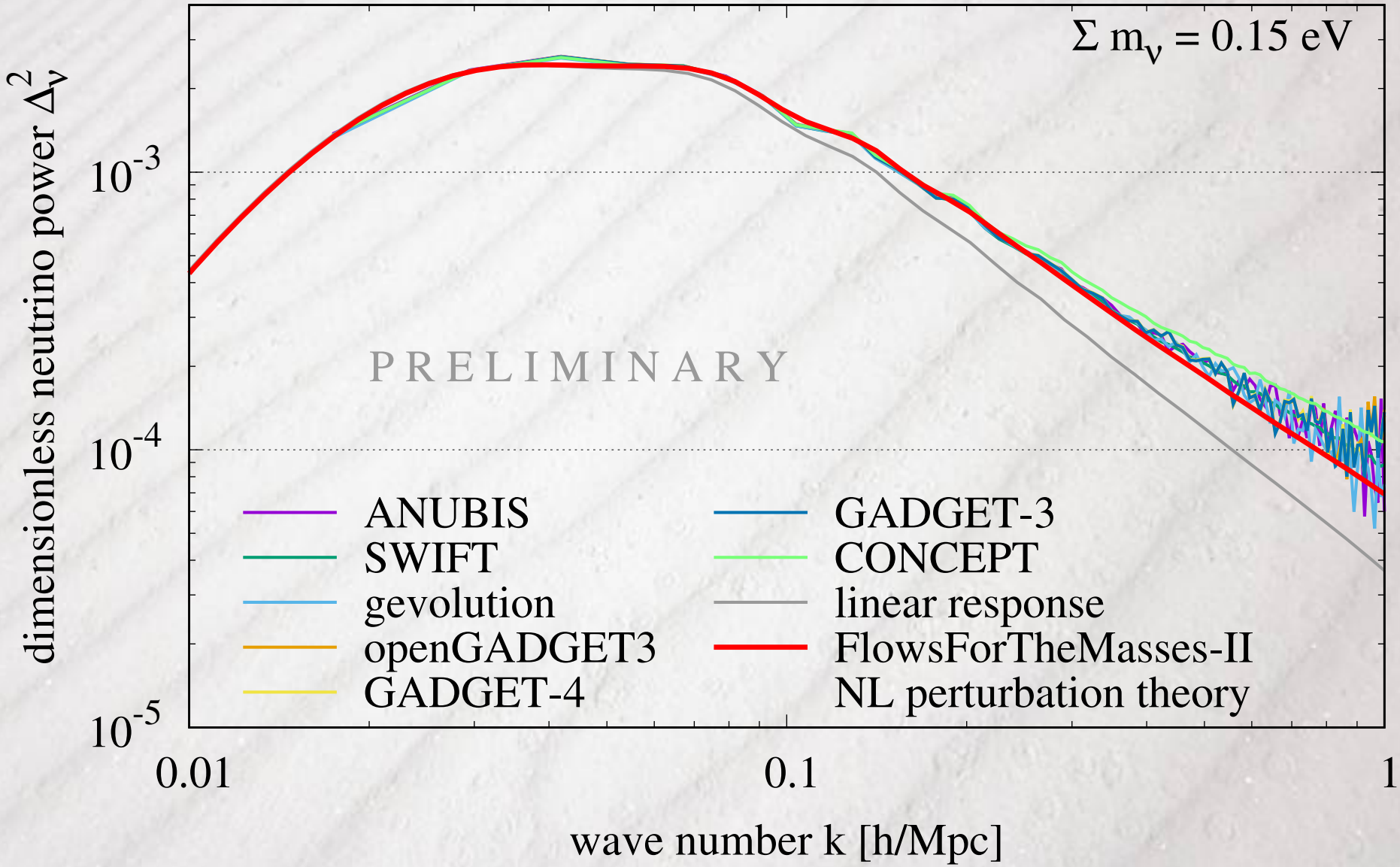
Begin at the ending: First non-linear perturbative Δ^2_ν

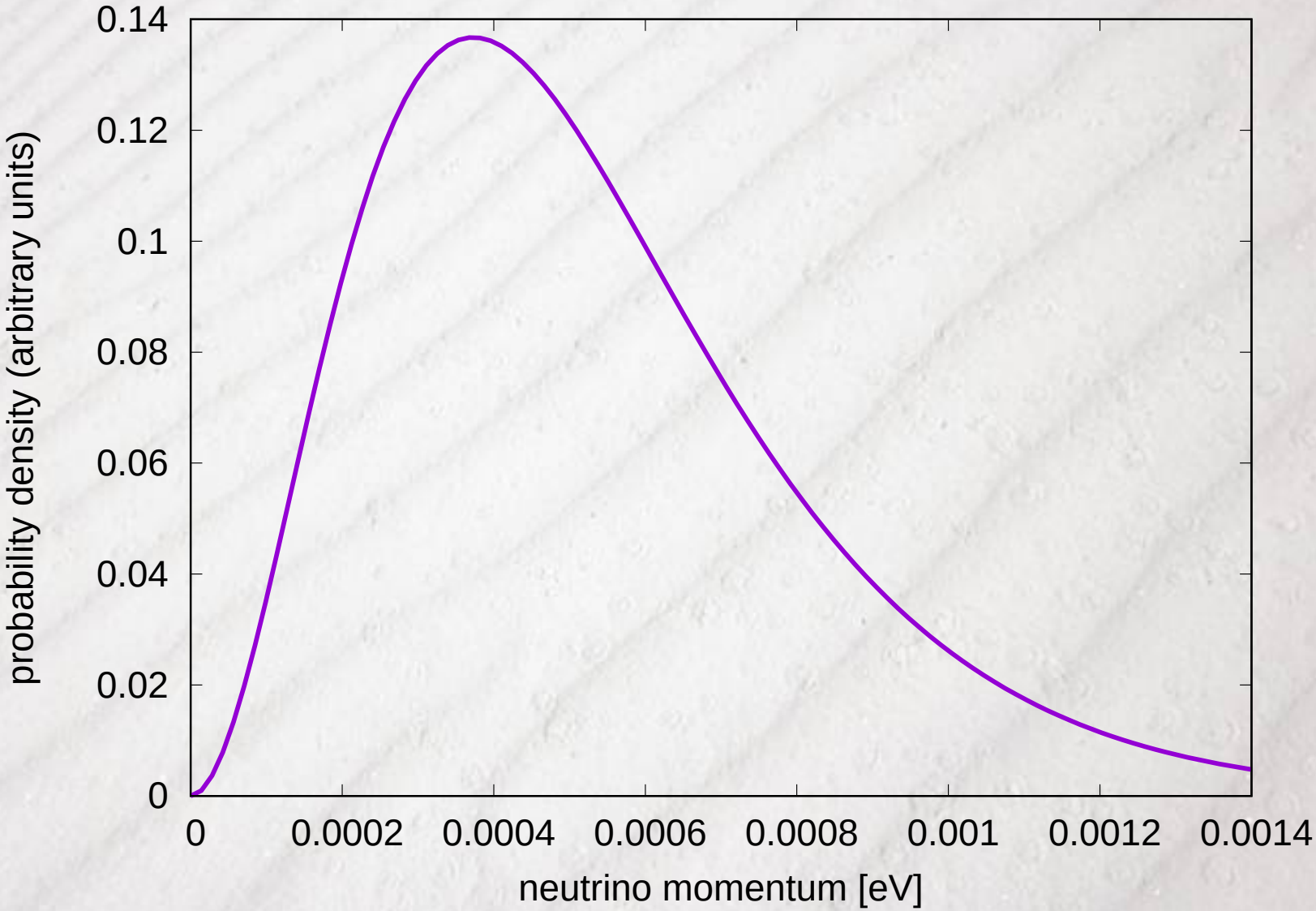
N-body: Euclid, 2211.12457. Nonlin.PT: Chen, AU, Wong, 2210.16020.



What's so difficult about neutrinos?

Neutrinos have a Fermi-Dirac momentum distribution.

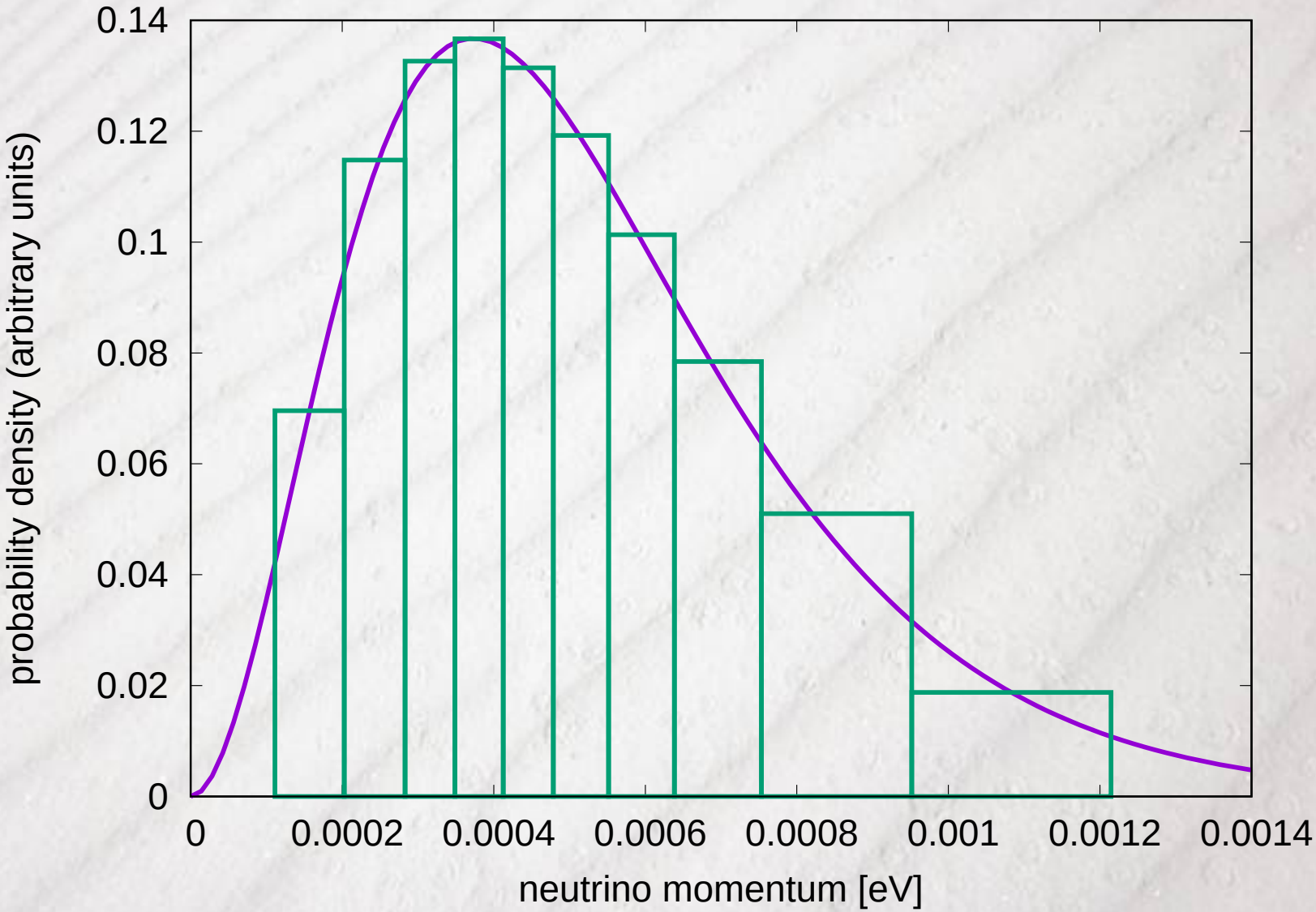
They do not obey the continuity and Euler fluid equations.



Discretize the Fermi-Dirac distribution

Idea: bin distribution into flows, each of which obeys fluid eqs.

Dupuy and Bernardeau, JCAP **1401**:*030(2014)*



Steps to a non-linear perturbation theory

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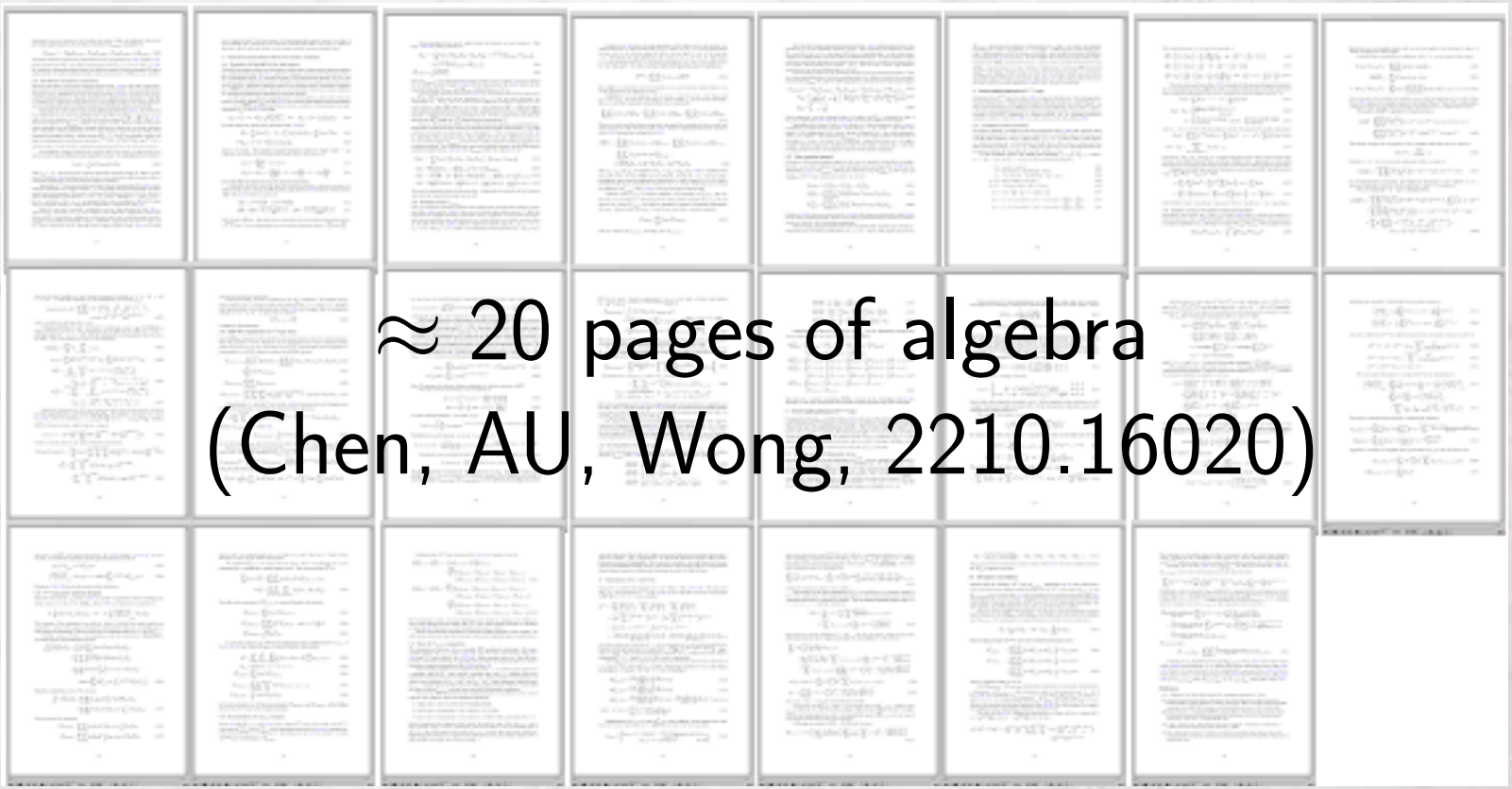

≈ 20 pages of algebra
(Chen, AU, Wong, 2210.16020)

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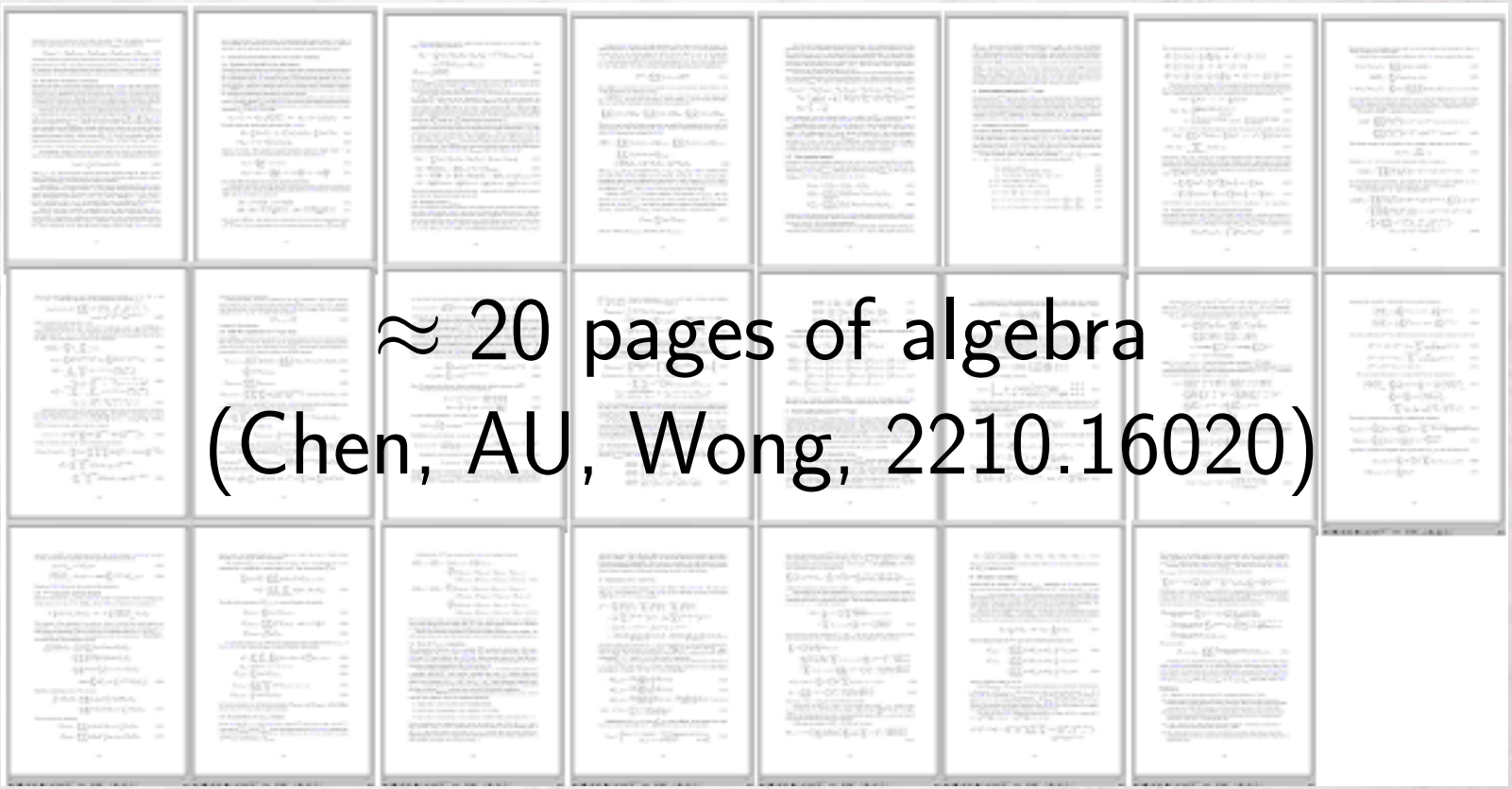
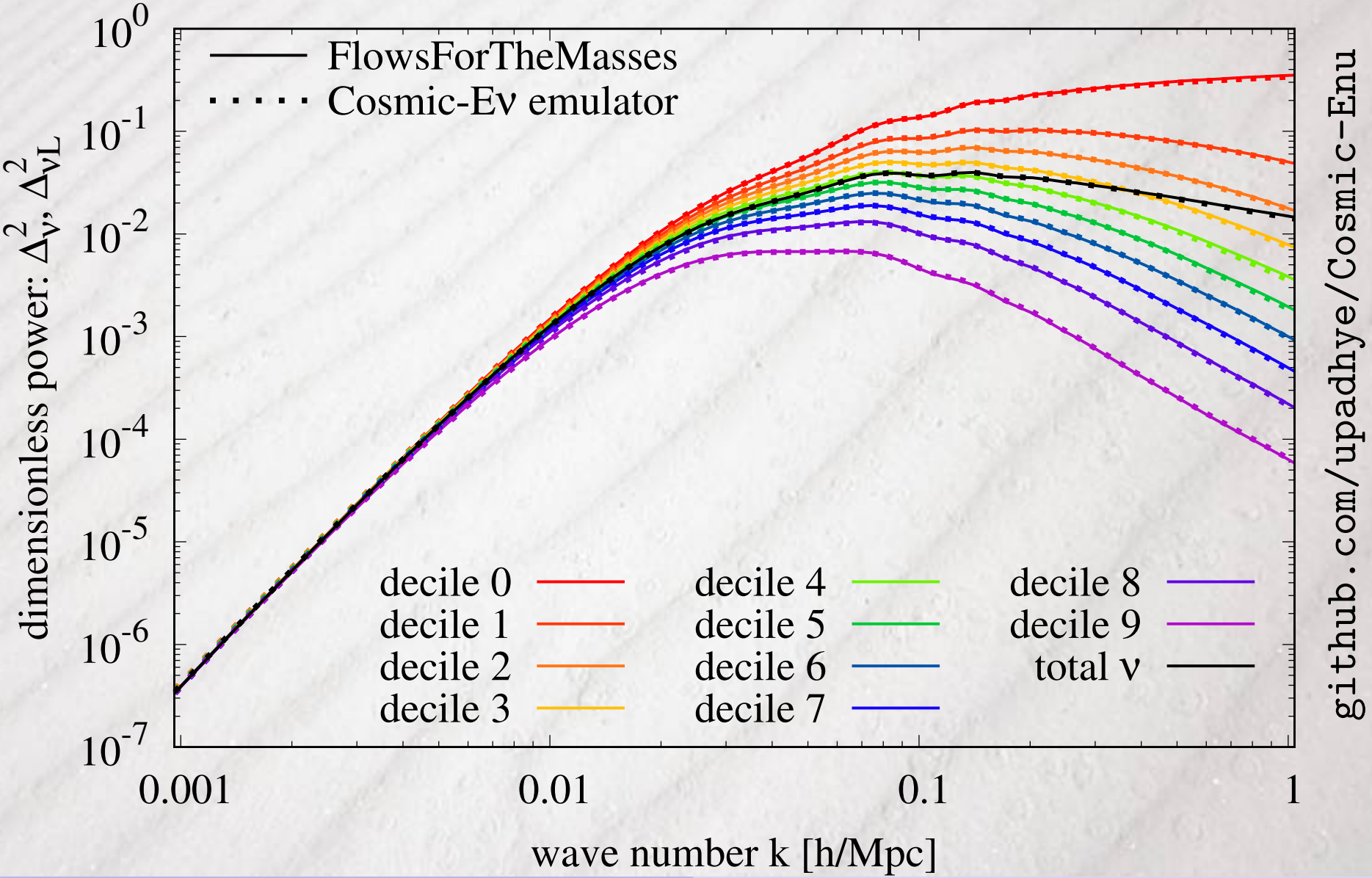


Result: 400-fold reduction in computational cost from > 1 yr to ≈ 1 day for reasonable accuracy: `github.com/upadhye/FlowsForTheMasses`

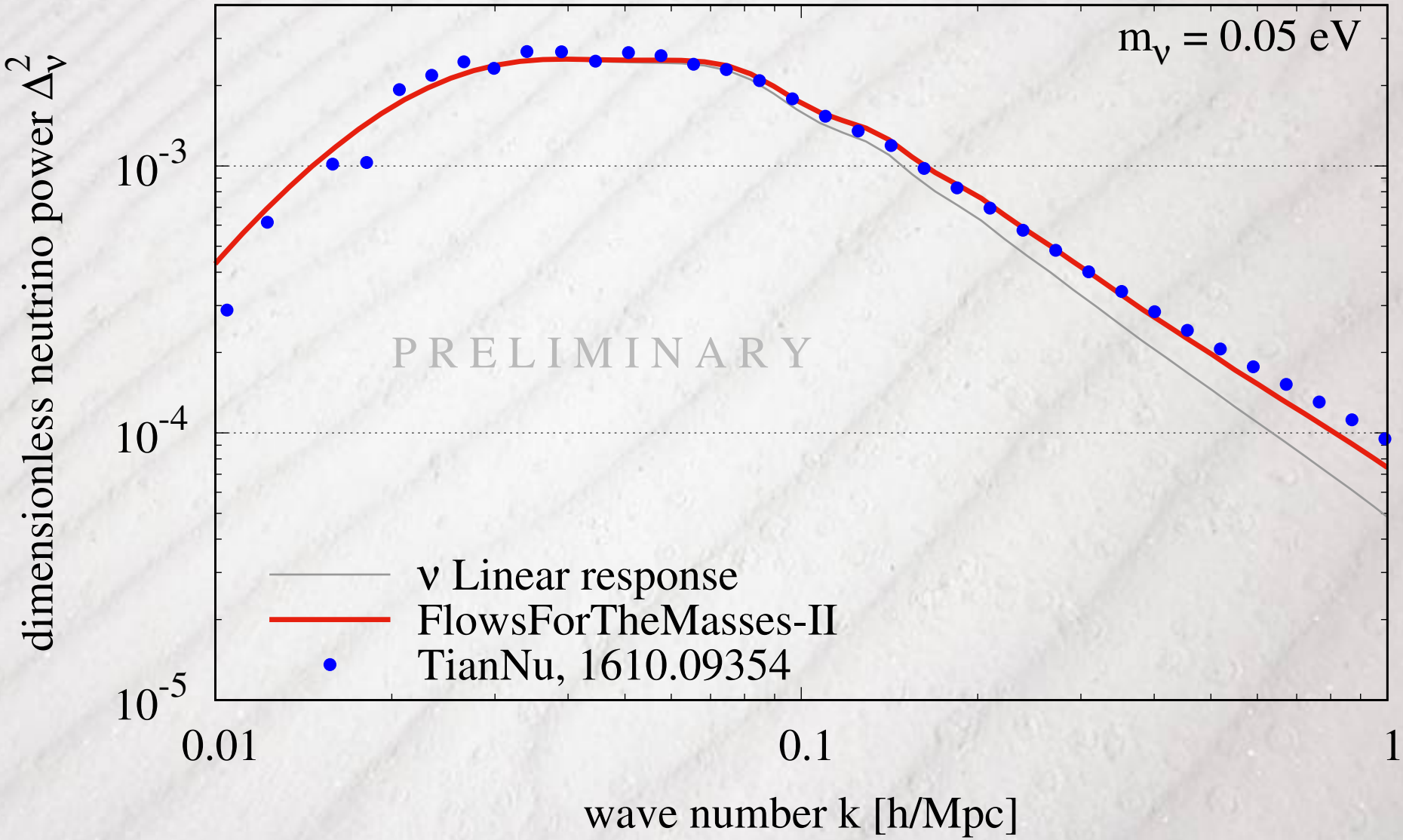
Power spectrum emulator: Cosmic-Eν

$w_0 = -1.11$, $w_a = 1.1$, $\Omega_{\nu,0}h^2 = 0.00716$ (AU++, 2311.11240)



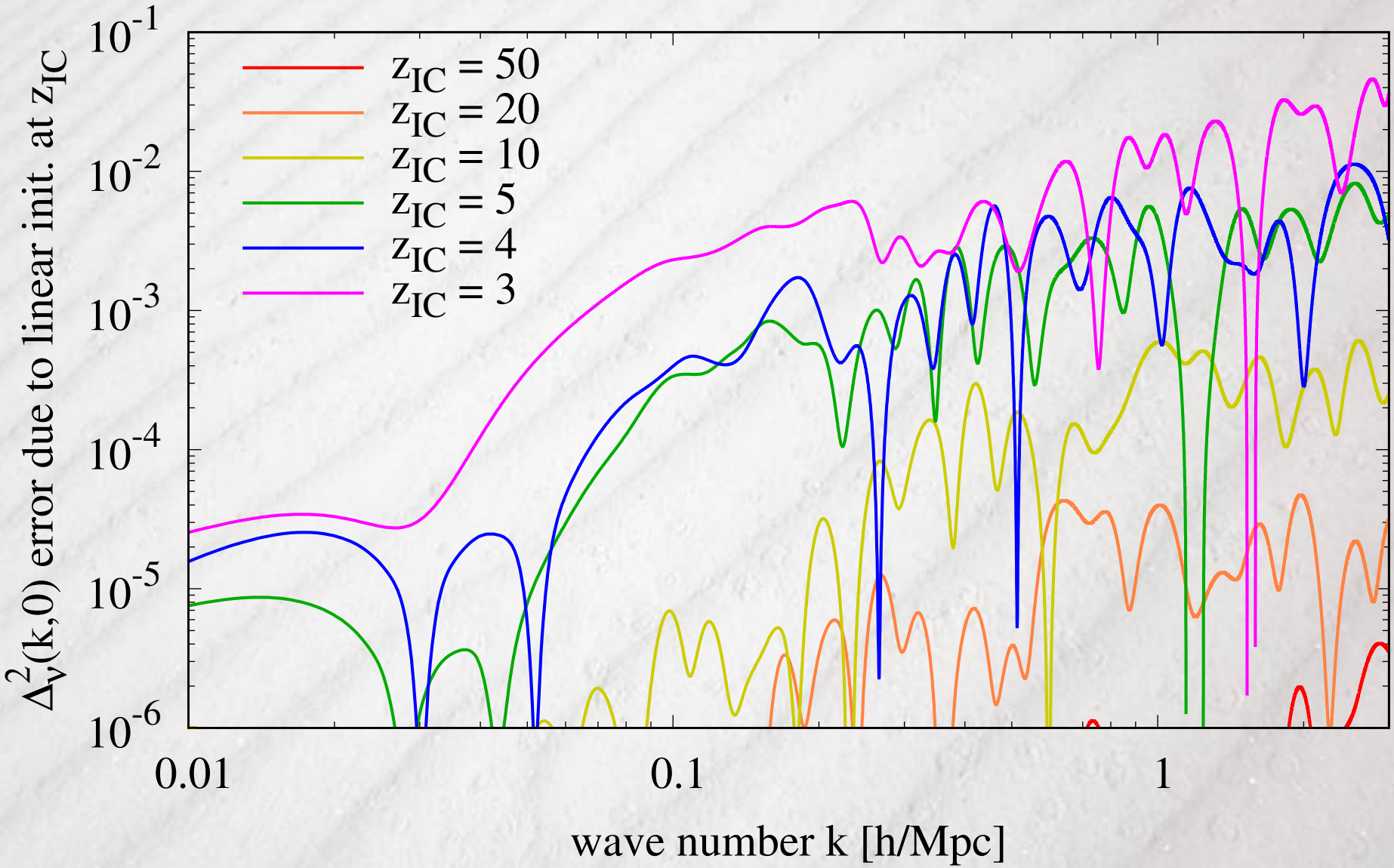
More efficient momentum binning

TianNu: Inman++ 1610.09354. Nonlin.PT: Chen, AU, Wong, 2210.16020.



Initial conditions for N-body simulations

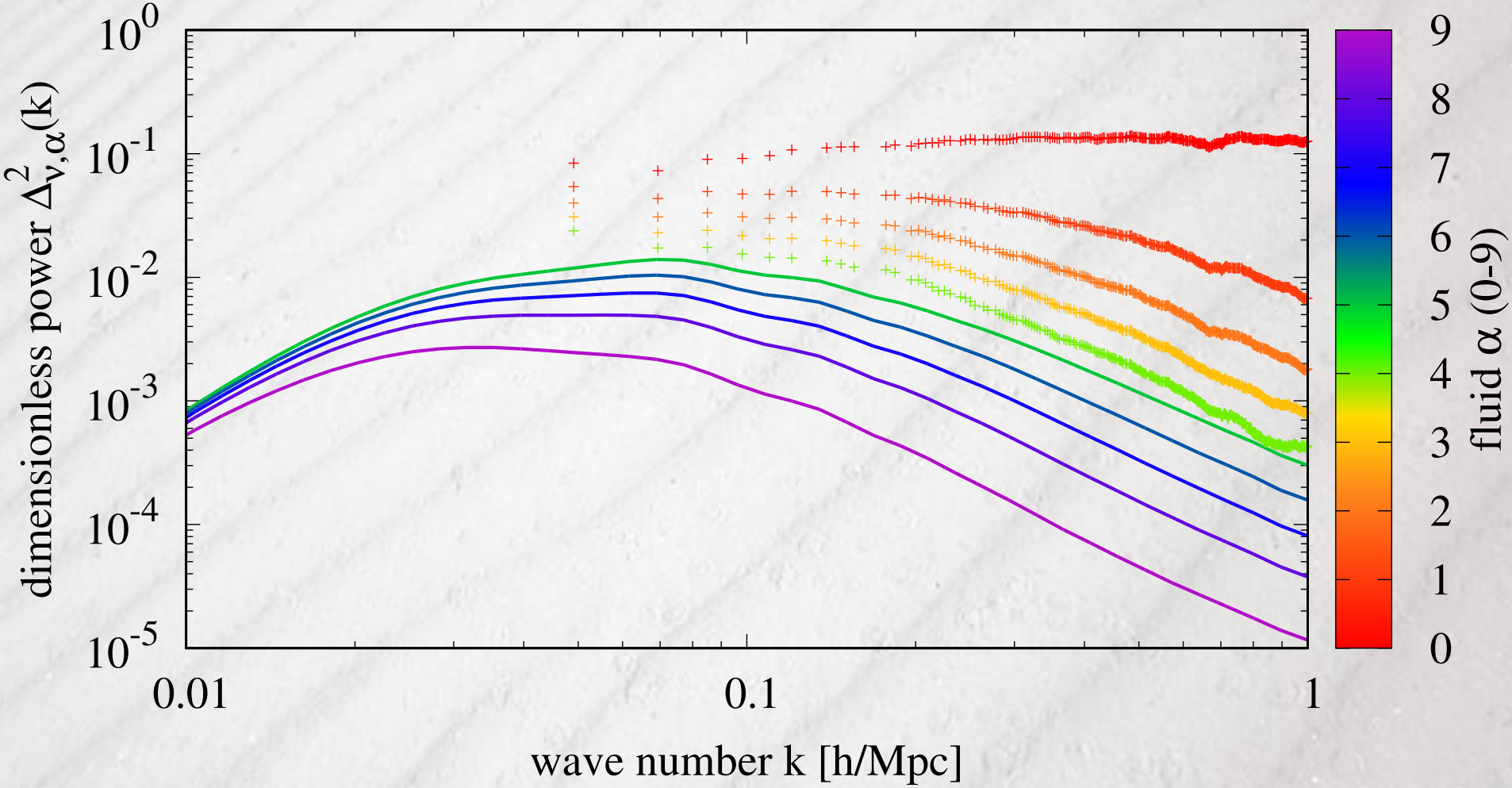
How wrong are we if we initialize $m_\nu = 0.05$ eV using linear theory at $z_{\rm IC}$?



Non-linear hybrid N-body simulation

Longer-term goal: Non-linear verion of linear hybrid N-body simulation:

Chen, Mosbech, AU, Wong 2210.16012



Use particles for initially-slow ν, `FlowsForTheMasses` for initially-fast ν

Summary

1. Developed the first non-linear perturbative $\Delta^2_\nu(k)$:
   Chen, AU, Wong, JCAP **05**:*46(2023)[2210.16020]*
   `github.com/upadhye/FlowsForTheMasses`
2. Emulated `FlowsForTheMasses`: *AU++, 2311.11240*
   `github.com/upadhye/Cosmic-Enu`
3. Steady improvements to momentum binning, numerical stability (in prep.)
4. Future work:
   - Non-linear neutrino initial conditions for N-body simulations
   - Non-linear hybrid simulation with fast ν evolved with PT
   - Extensions to other hot dark matter: axions, etc.