

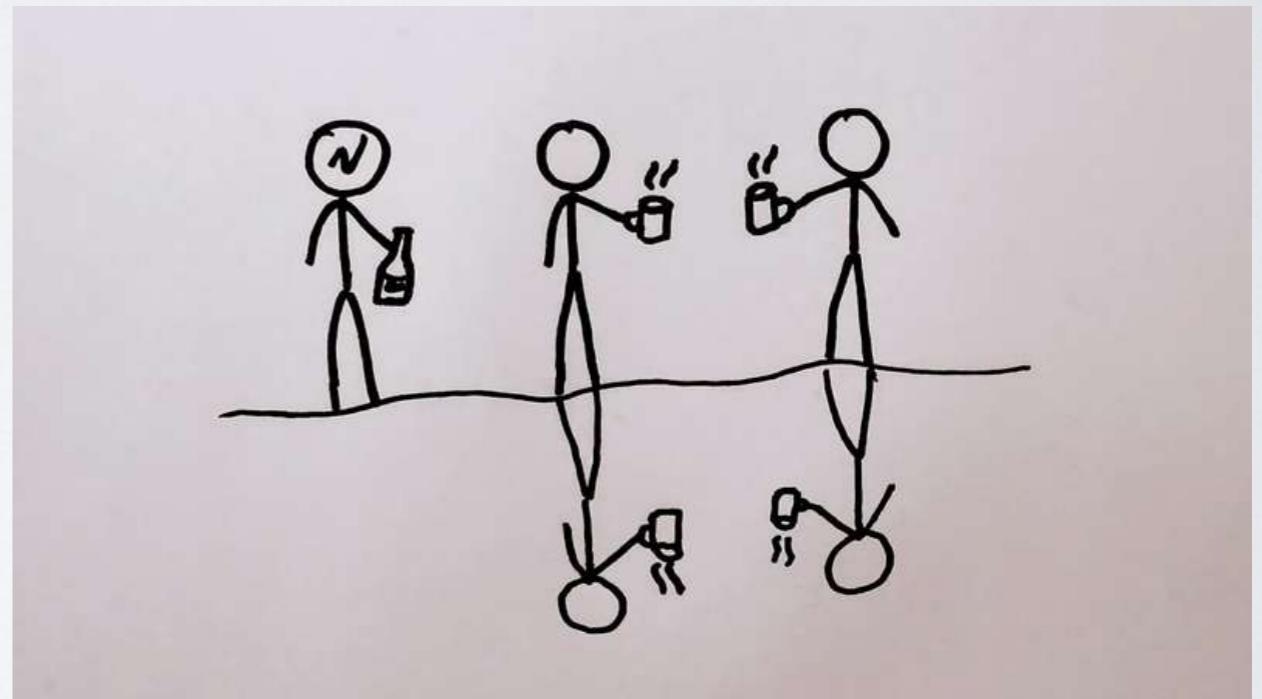
# NEUTRINO LIFETIME CONSTRAINT FROM MAJORON DECAY

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# NEUTRINOS

- Standard Model fermion
- 3 lepton flavours
- Interacts weakly
- No right-handed partner
- Mass:TBD\*



# NEUTRINO MASS

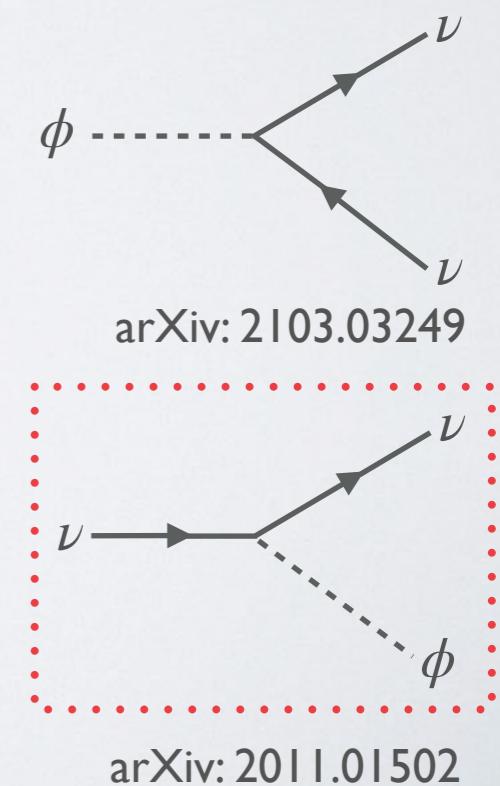
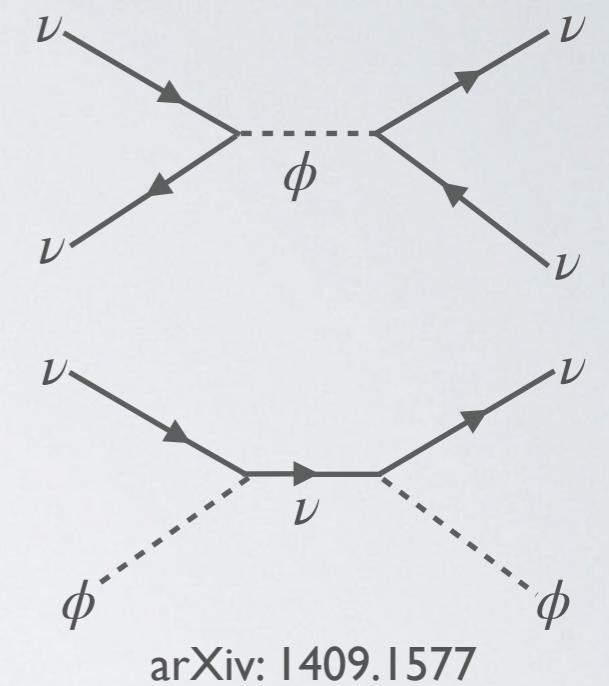
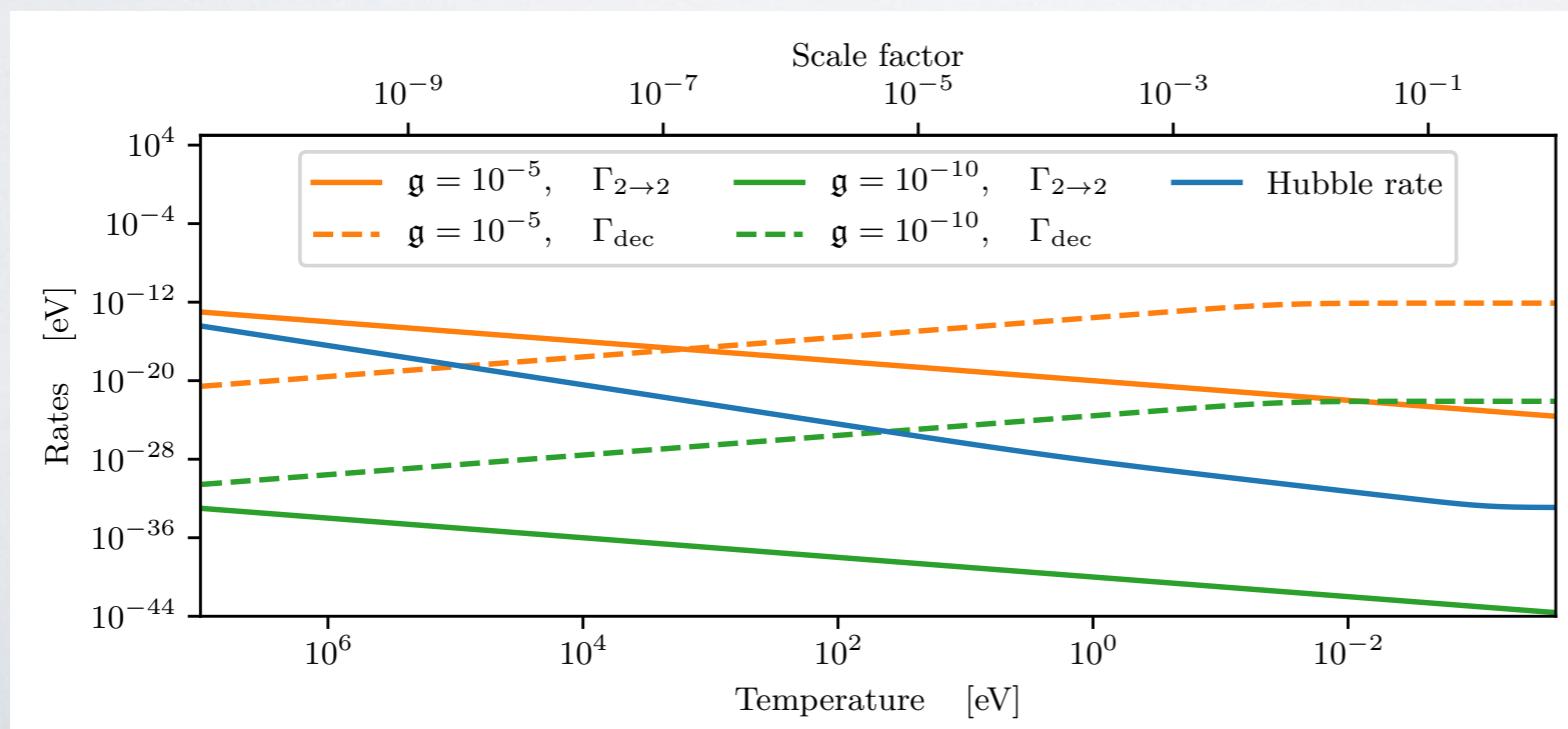
- Non-trivial mass generation for neutrinos.
- Lots of good ideas on the market, e.g. Seesaw models.
- *Key point for us:* Majorana mass terms lead to a new Goldstone boson coupled to neutrinos.

# NEUTRINO-MAJORON INTERACTIONS

- Interaction term of the form

$$\mathcal{L}_{\text{int}} = g_{ij} \bar{\nu}_i \nu_j \phi$$

- $\phi$  could be heavier or lighter than the neutrinos.
- Coupling between neutrino mass states  $i$  and  $j$ .



# NEUTRINO DECAY: TWO REGIMES

- *Relativistic mother particle*: early recoupling; inverse decay process active.

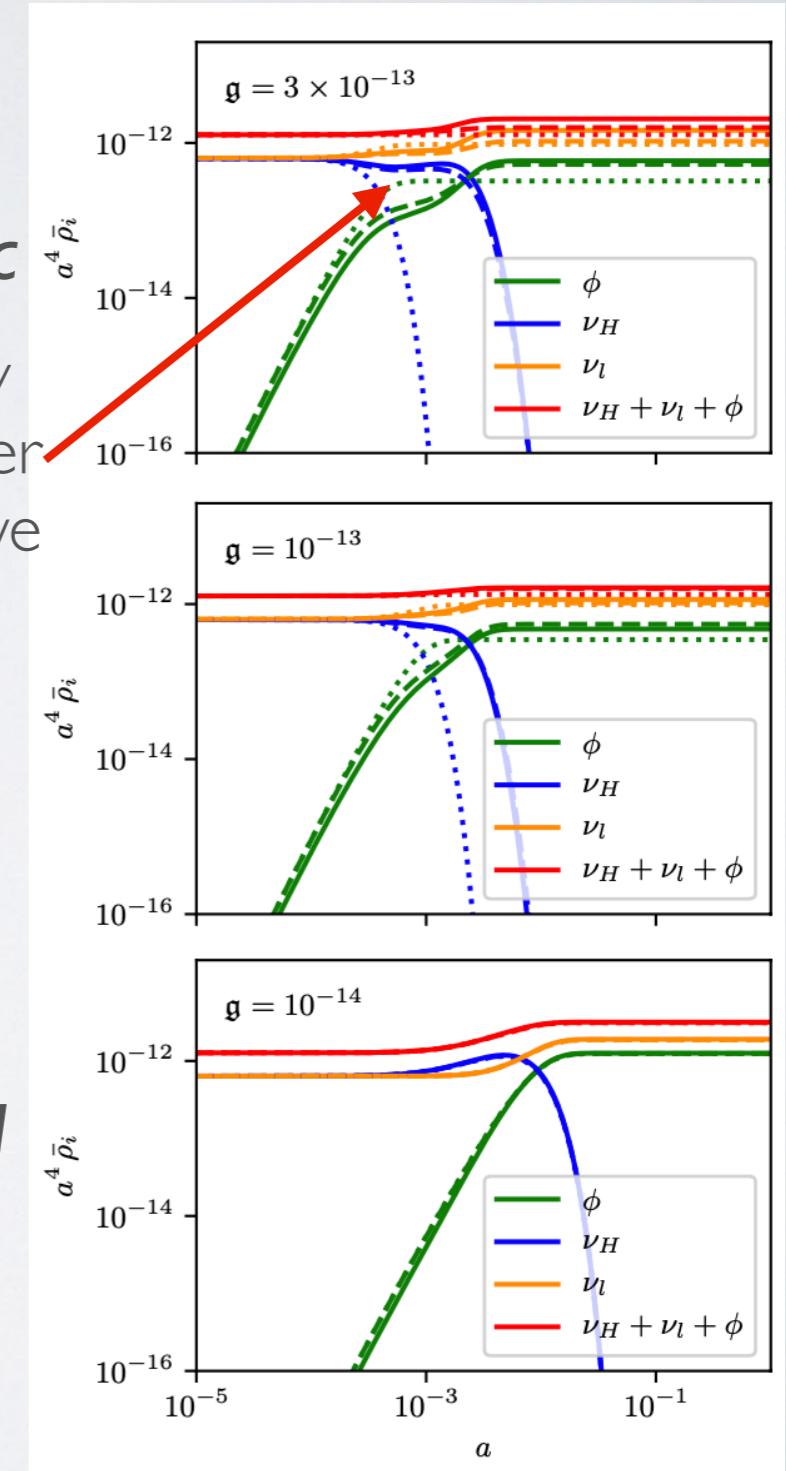
*The focus of this talk.*

- *Non-relativistic mother particle*: late recoupling; inverse decay kinematically suppressed.

- *Assumption*: massless daughters.

## Relativistic

Inverse decay  
keeping mother  
population alive



# COSMOLOGICAL IMPLICATIONS: RELATIVISTIC DECAY

- CMB is sensitive to the free streaming behaviour of neutrinos.
- Free streaming is lost while inverse decay is active.
- CMB has a preference on the decay timing/strength.
- Lower bound on neutrino lifetime. (Hannestad & Raffelt,  
Archidiacono & Hannestad, Escudero & Fairbairn)

# RELATIVISTIC DECAY MODELLING

- Transport rate:  $\Gamma_T = \Gamma_{\text{dec}}^0 \left( \frac{m_{\nu H}}{E_{\nu H}} \right)^3$ 
  - 1x time dilation
  - 2x relativistic beaming
- Free streaming switches off when  $\Gamma_T(z^*) \simeq H(z^*)$
- Damping term in Boltzmann hierarchy,  $\frac{\partial F_\ell}{\partial \tau} = \dots - a \Gamma_T F_\ell$
- $\tau_0 \gtrsim 1.24 \times 10^9 \text{ s} (m_{\nu H}/50 \text{ meV})^3$  (95 % C.L.) (Archidiancono & Hannestad 2017)

# OUR WORK: FULL BOLTZMANN APPROACH

- Full collision terms included in the Boltzmann eqn.
- Solve for the EoM of the total  $\nu\phi$  fluid anisotropic stress,  $a^4\Pi_{\nu\phi}$ .
- Assumptions: massless daughters; thermal BG distribution; separable ansatz:  $F_\ell(k, q) \simeq -\frac{1}{4} \frac{d\bar{f}}{d \ln q} \mathcal{F}_\ell(k)$  ; common perturbations  $\mathcal{F}_\ell$  across all species.

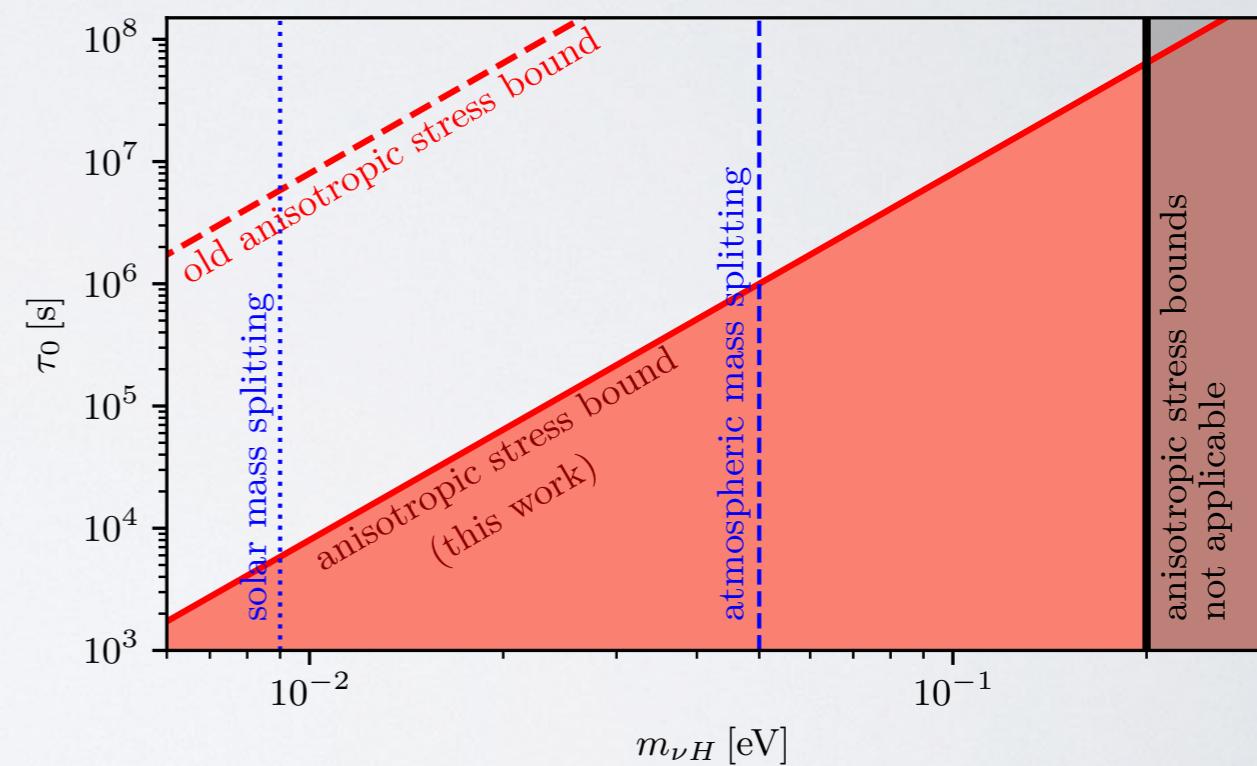
# RESULT

- The leading order rate is in fact *not* the transport rate.

$$\left( \frac{d(a^4\Pi_{\nu\phi})}{d\tau} \right)_C \sim -a\Gamma_{\text{dec}}^0 \left( \frac{m_{\nu H}}{E_{\nu H}} \right)^5 (a^4\Pi_{\nu\phi})$$

- The neutrino lifetime constraint is relaxed to

$$\tau_0 \simeq (4 \times 10^5 \rightarrow 4 \times 10^6) \text{ s} \left( \frac{m_{\nu H}}{50 \text{ meV}} \right)^5$$



# SUMMARY

- Neutrino-majoron decay is a prediction of certain neutrino mass models.
- The decay lifetime can be constrained by cosmology through neutrino free streaming.
- The full Boltzmann treatment yields a different dampening rate to the neutrino anisotropic stress.
- The lifetime constraint can be relaxed by  $\sim 3$  orders of magnitude to  $\tau_0 \simeq (4 \times 10^5 \rightarrow 4 \times 10^6) \text{ s} \left( \frac{m_{\nu H}}{50 \text{ meV}} \right)^5$ .

# REAL NEUTRINO MASS HIERARCHY

- If the daughter mass is not assumed to be zero, the suppression to the dampening rate is even larger.
- $$\left( \frac{d(a^4\Pi_{\nu\phi})}{d\tau} \right)_C \sim \left( -1 + \frac{m_{\nu l}^4}{m_{\nu H}^4} + 4 \frac{m_{\nu l}^2}{m_{\nu H}^2} \ln \frac{m_{\nu H}}{m_{\nu l}} \right) a \Gamma_{\text{dec}}^0 \left( \frac{m_{\nu H}}{E_{\nu H}} \right)^5 (a^4\Pi_{\nu\phi})$$