

# Neutrino Fast Flavor Oscillations in Neutron Star Merger Disks

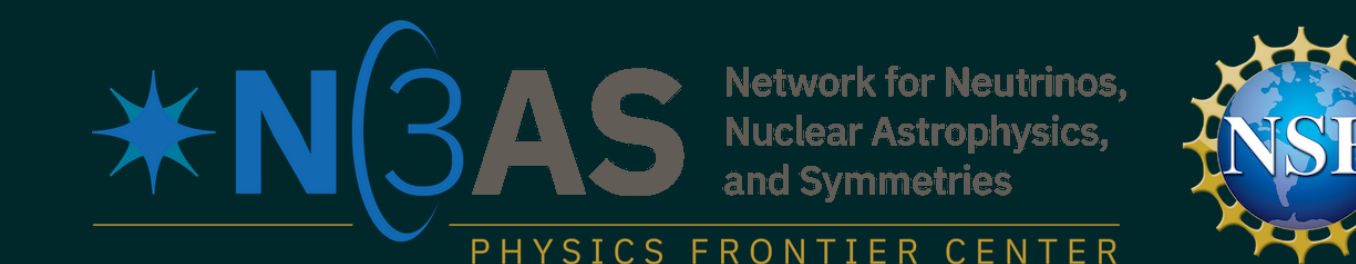
Kelsey Lund <sup>1,2,†</sup>

with P. Mukhopadhyay <sup>1</sup>, G.C. McLaughlin <sup>3</sup>, J.M. Miller <sup>4</sup>

<sup>1</sup> UC Berkeley <sup>2</sup> Institute for Nuclear Theory, Seattle, WA, USA <sup>3</sup> Department of Physics, North Carolina State University, Raleigh, NC, USA <sup>4</sup> Los Alamos National Laboratory, Los Alamos, NM, USA <sup>†</sup> N3AS Fellow



klund@berkeley.edu  
kelslund.github.io



## Context

Neutron star mergers are a preferred site for the synthesis of heavy elements via the rapid neutron capture (*r*-) process.

The black hole-accretion disk system that remains after the merger can provide the necessary conditions for *r*-process nucleosynthesis.

Neutrinos play an important role in setting the conditions in the merger ejecta by setting the ratio of neutrons to protons ( $Y_e$ ):



## Combining MC Neutrino Transport & FFCs

Fast flavor instabilities occur when there is a *crossing* in the angular distributions of neutrinos and antineutrinos. Fast flavor instabilities drive fast flavor conversions (FFCs)



We incorporate FFCs into a classical 3D-GRMHD disk simulation with Monte Carlo neutrino transport by implementing a prescription<sup>[3]</sup> to modify the neutrino field given an ELN-XLN crossing using the *crossing indicator function*:

$$G_\nu = (f_{\nu_e} - f_{\bar{\nu}_e}) - \frac{1}{2}(f_{\nu_x} - f_{\bar{\nu}_x}) = 0$$

## Magnetohydrodynamics → Nucleosynthesis

nubhlight<sup>[1]</sup>: 3D General relativistic Radiation magnetohydrodynamics (GRMHD) simulation for black hole + accretion disk systems

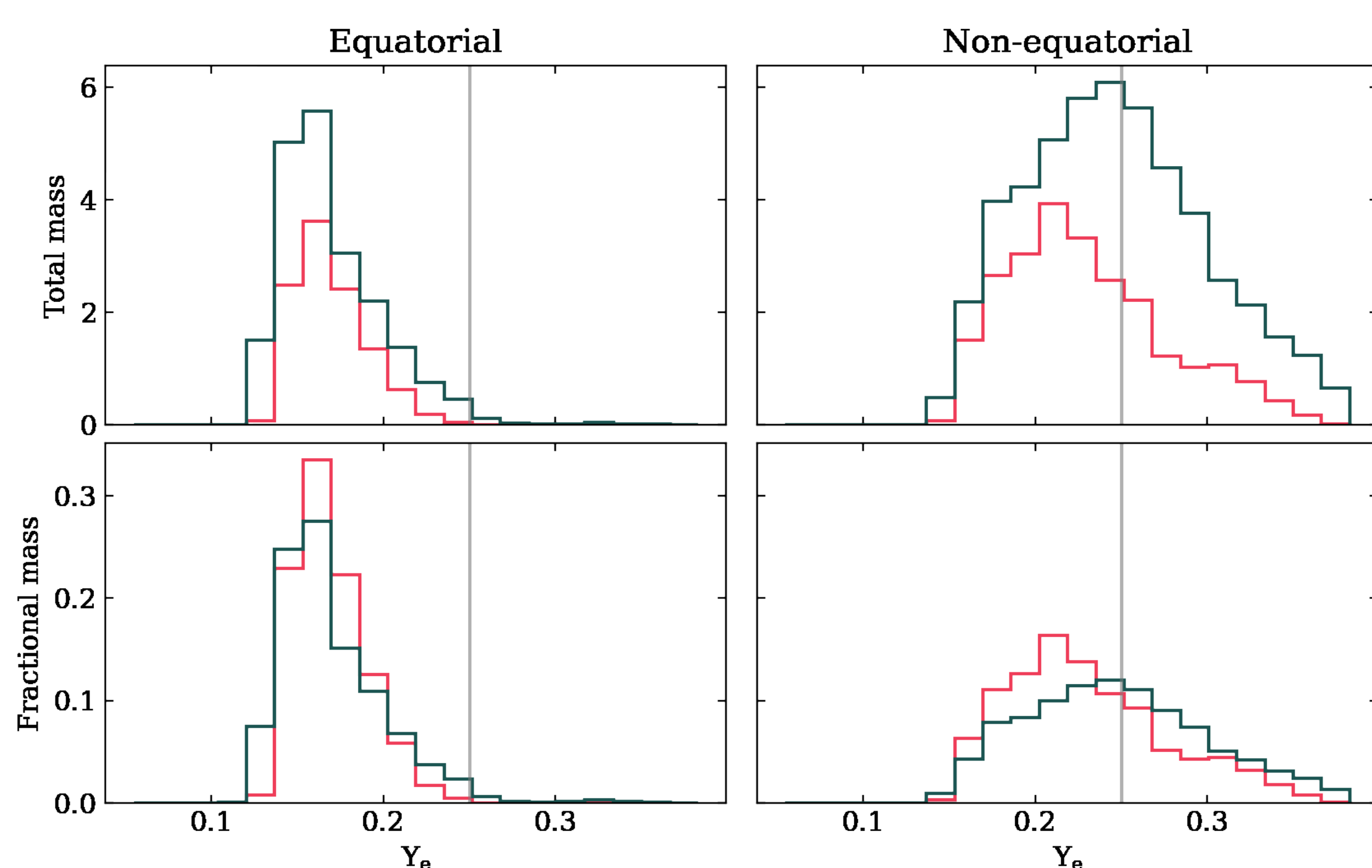
disk mass	black hole mass	initial $Y_e$
0.12 $M_\odot$	2.58 $M_\odot$	0.1

Nucleosynthesis using PRISM<sup>[2]</sup> via nubhlight tracer particles

## Ejecta Properties

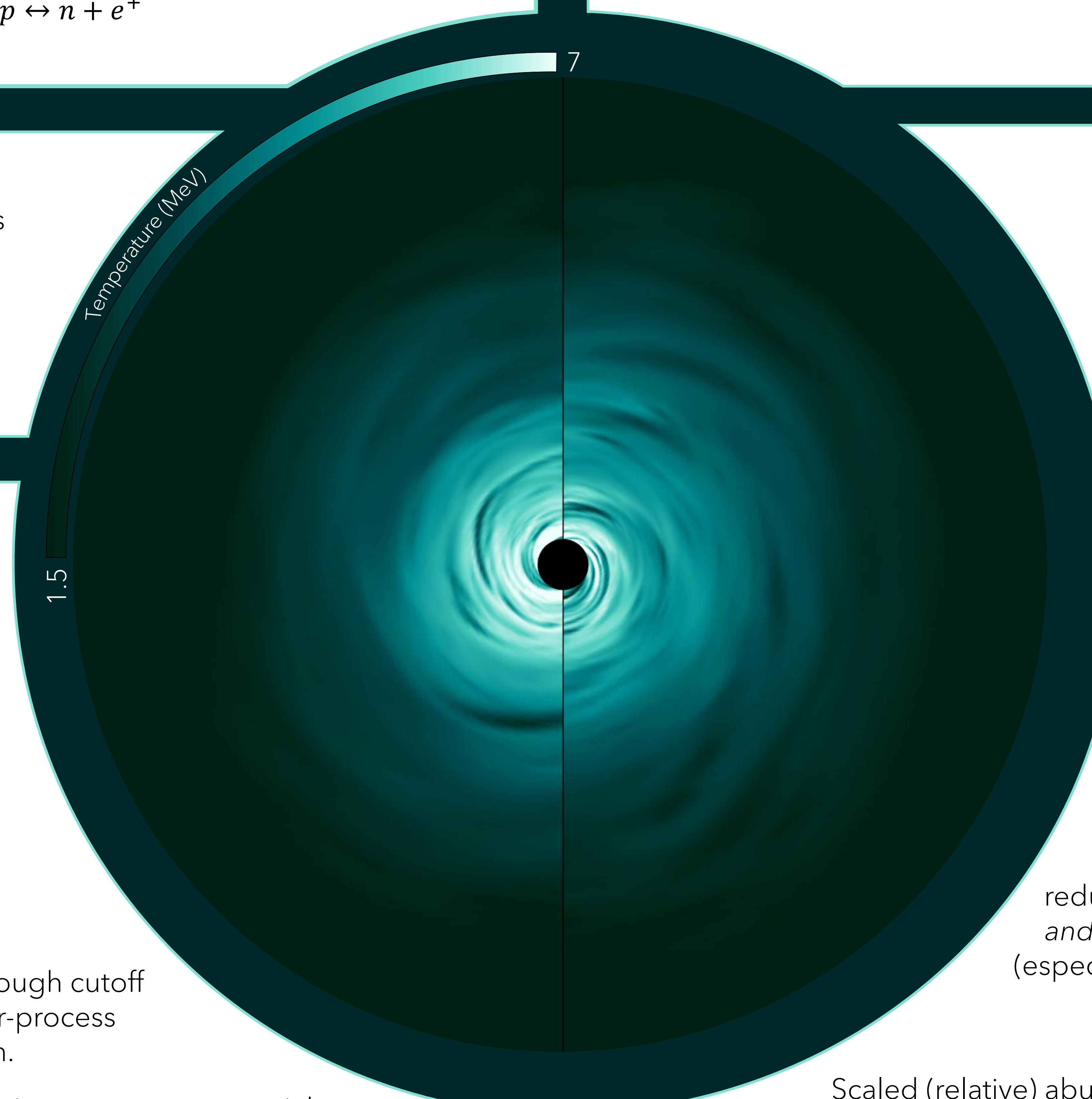
Oscillations more effectively cool the disk, weaken thermal wind component of the ejecta. This leads to decreased total mass ejected:

without oscillations:	with oscillations:
$M_{ej} = 2.2 \cdot 10^{-3} M_\odot$	$M_{ej} = 1.1 \cdot 10^{-3} M_\odot$



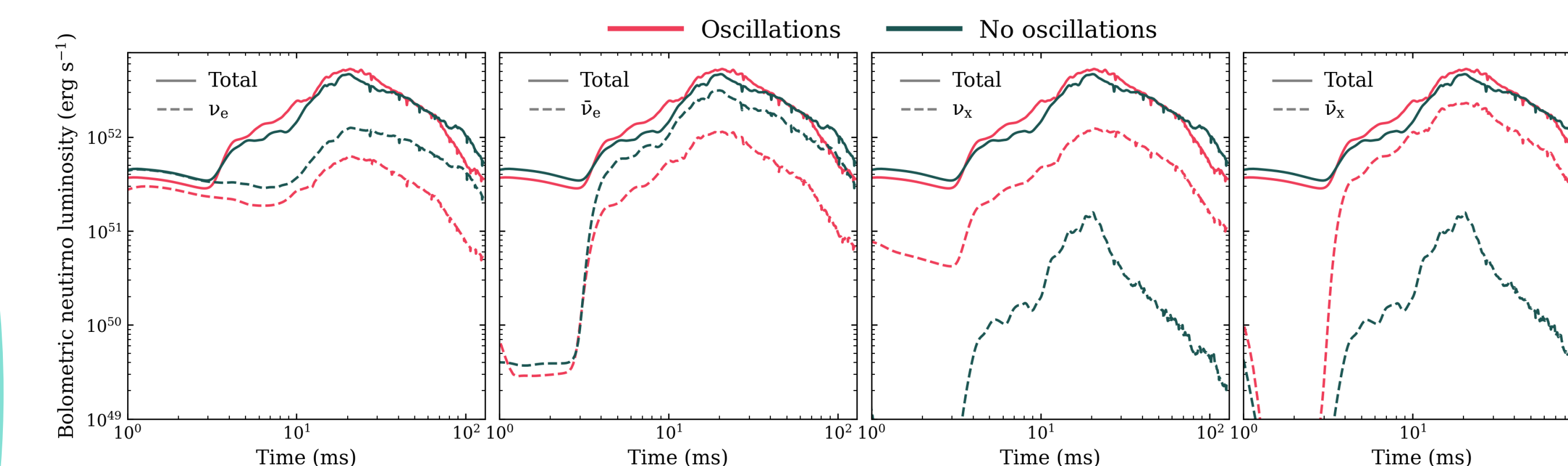
$Y_e = 0.25$ : rough cutoff for robust *r*-process production.

FFCs result in more non-equatorial material with lower  $Y_e$ : better conditions for robust *r*-process



## Neutrino Luminosity

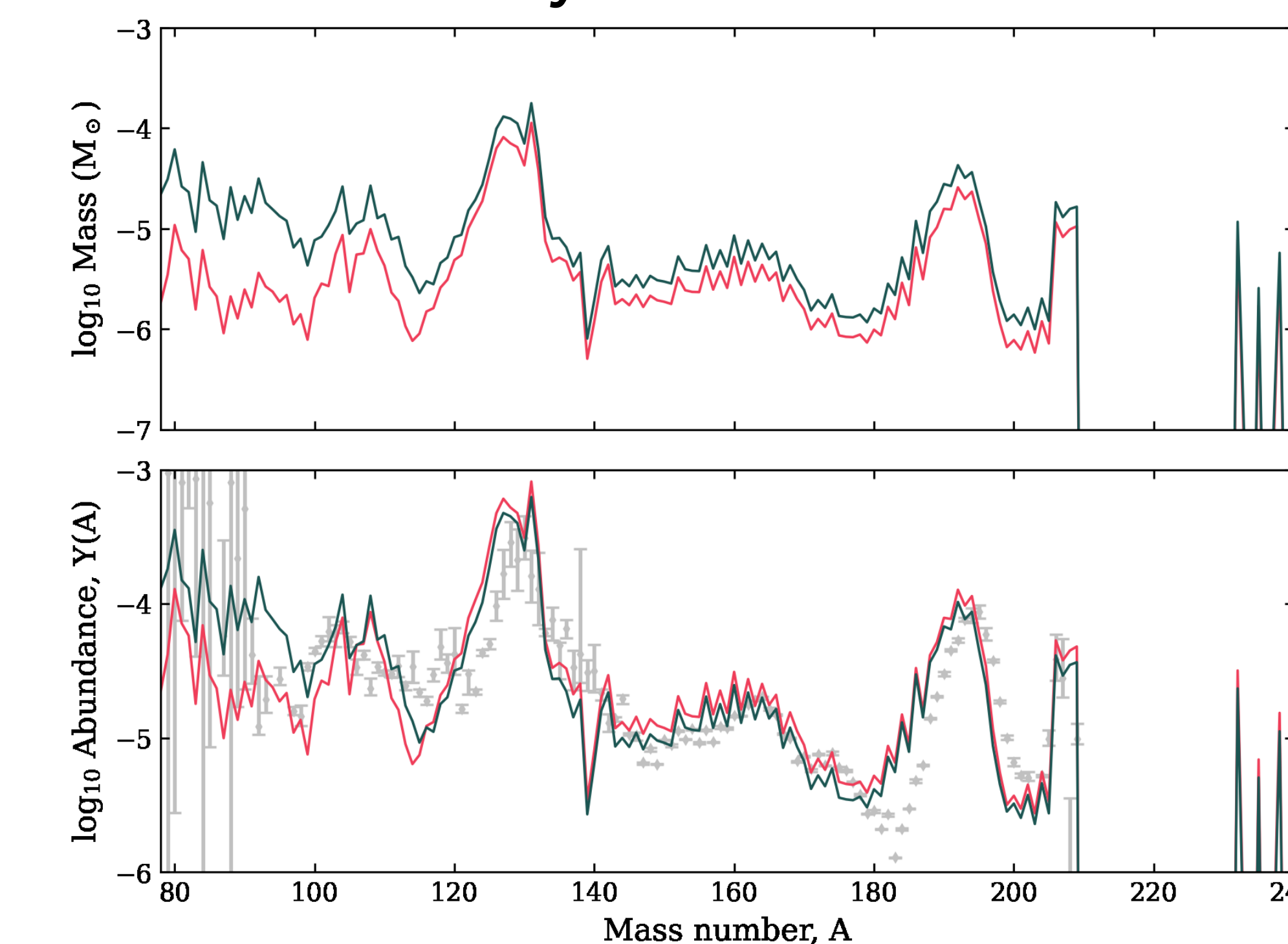
FFCs enhance heavy flavor neutrino luminosity, decrease electron flavor neutrino luminosity. More energy is lost when oscillations are included - decreased temperatures (see center figure), weakened thermal wind



Total abundances (in  $M_\odot$ ) show FFCs reduce total ejecta mass and total *r*-process mass (especially weak *r*-process)

Scaled (relative) abundances show effect of more neutron-rich ejecta caused by FFCs: main *r*-process is relatively enhanced by FFCs

## Nucleosynthesis: Abundances



## Concluding Observations

- The post-neutron star merger disk system remains a promising site for the production of a full *r*-process pattern.
- Neutrinos and their transport are key ingredients for our understanding of heavy element nucleosynthesis.
- FFCs can *decrease* ejecta mass but *increase* the fraction of main *r*-process material produced in the ejecta.

Center figure: comparison of temperature in the disk, measured at 25ms postmerger, comparing simulation without oscillations (left) and with oscillations (right)