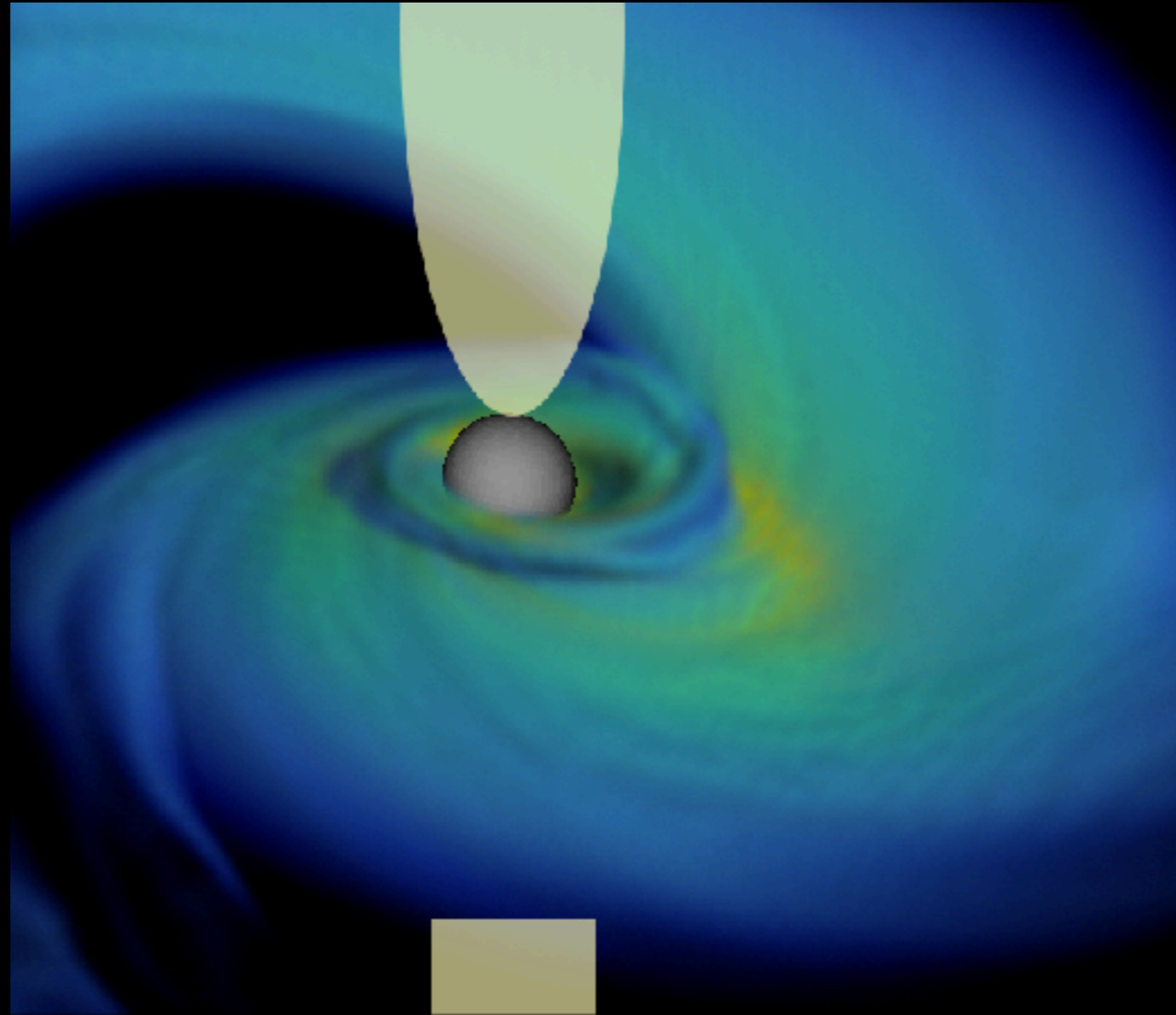


Numerical simulations of neutron star mergers



Francois Foucart
University of New Hampshire

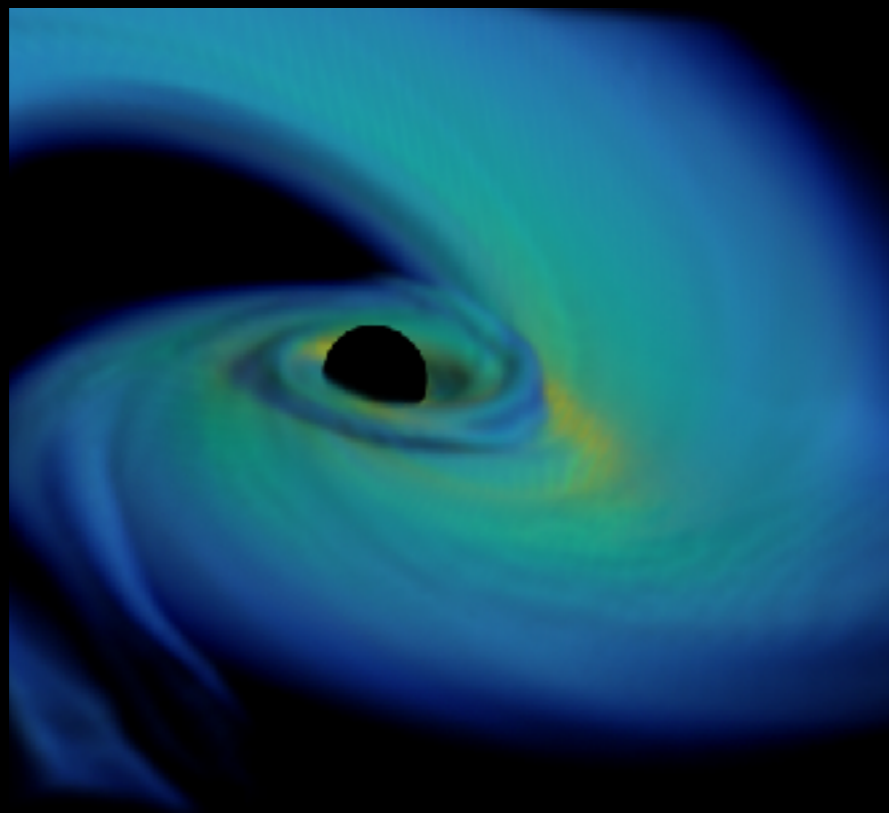
CIPANP18
June 1st 2018

Physics of NS mergers

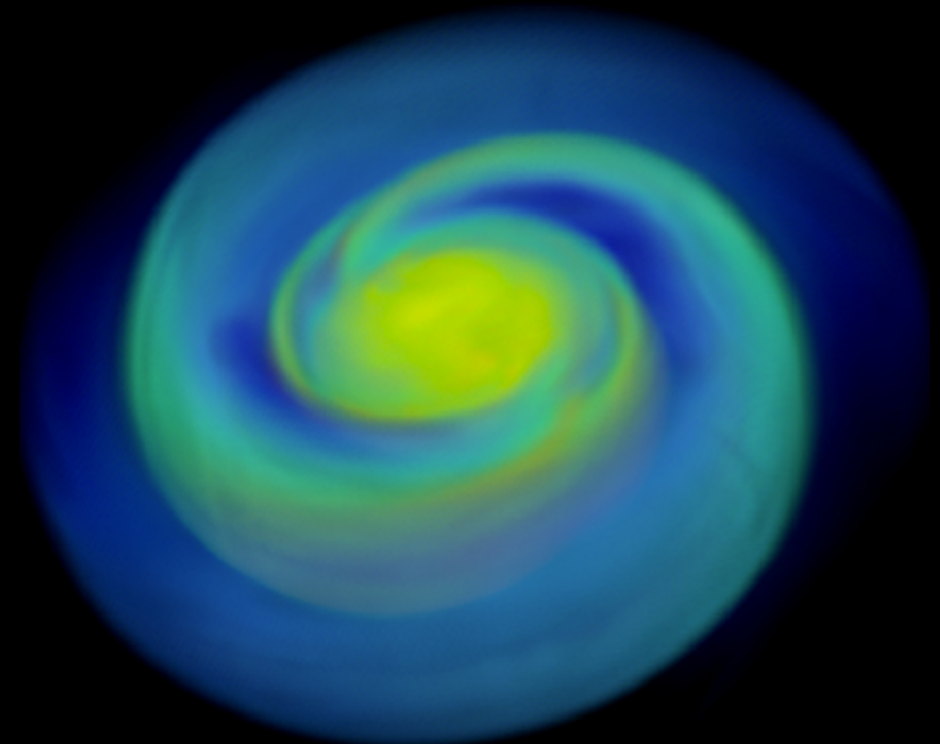
(1) Inspiral/Merger:

- Need General relativity + Tides in neutron stars (Equation of state)
- Most important phase to model GWs!

Black Hole-Neutron Star



Neutron Star-Neutron Star

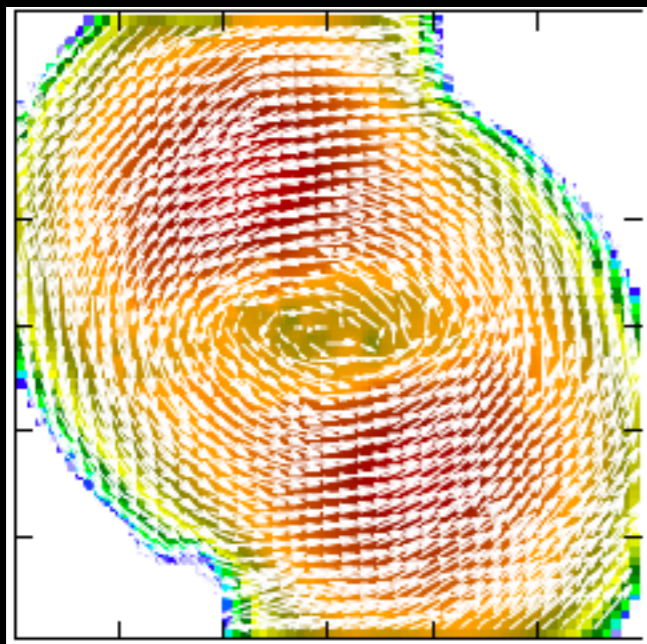


Physics of NS mergers

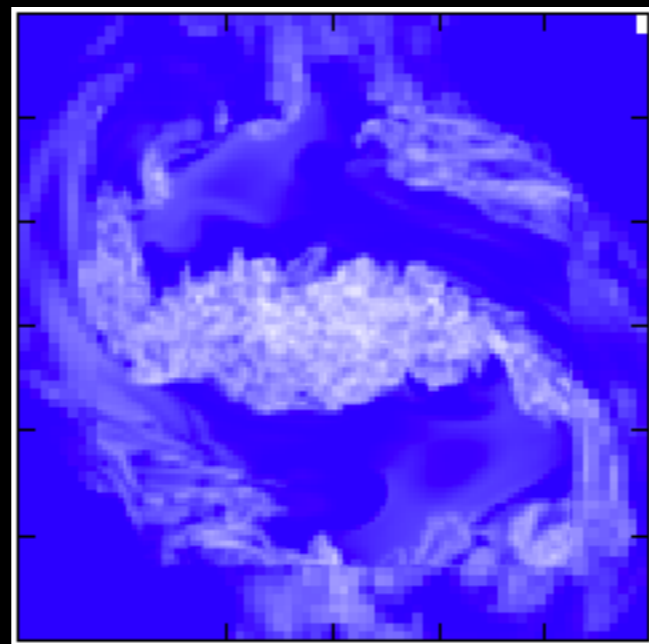
(2) Post-merger magnetic fields :

- Grow from small-scale instabilities (MRI, shear)
- Transport angular momentum, drive outflows/jets, heat remnant

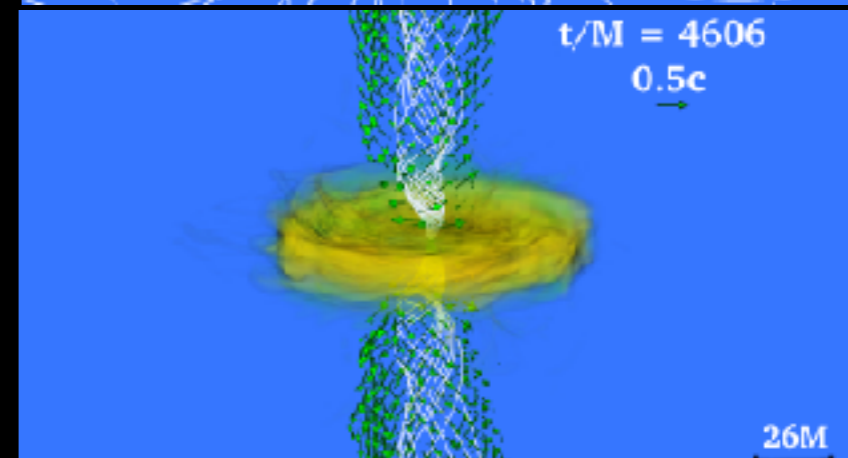
Density/Velocity



Magnetic field Amplitude



Kiuchi et al. 2015

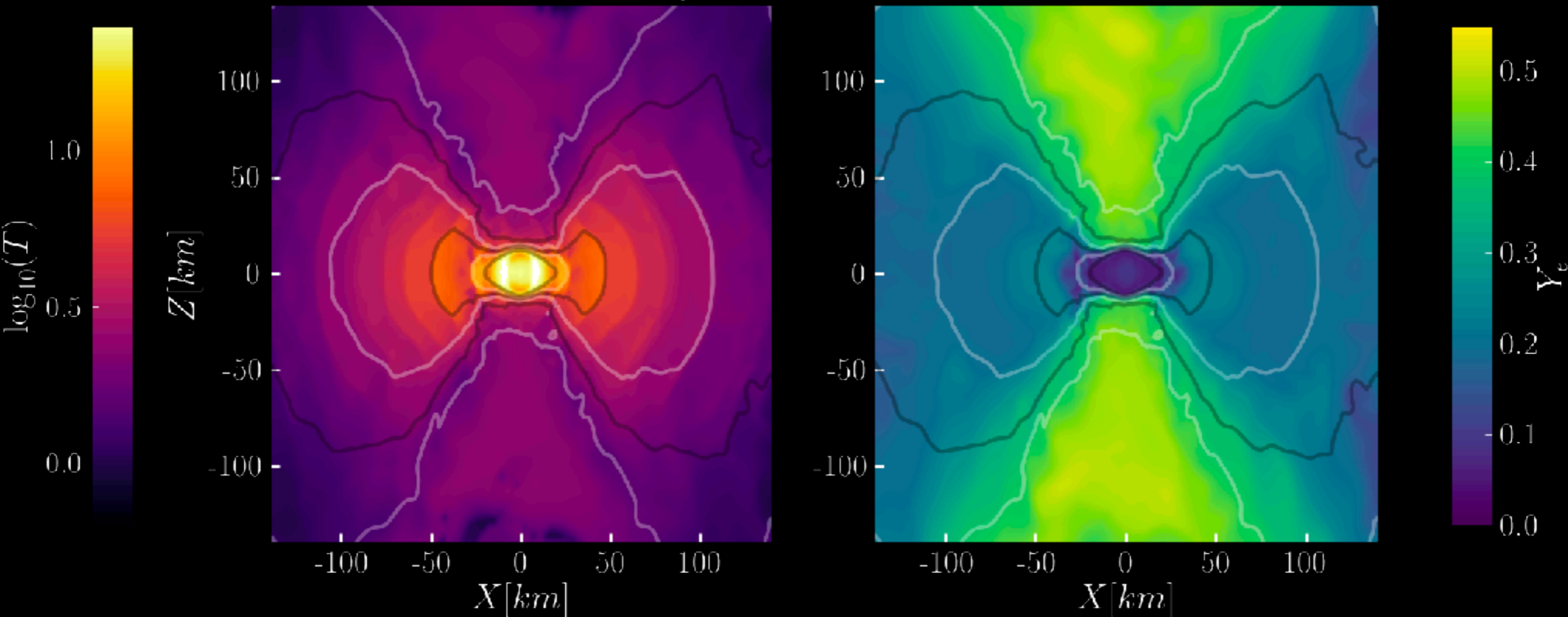


Ruiz et al. 2016

Physics of NS mergers

Neutrinos

(Image: Foucart et al, in prep)



(1) Neutrinos cool the remnant disk

(2) Neutrinos drive polar outflows

(3) Neutrino absorption / Antineutrino emission increase Y_e of outflows

(4) Pair annihilation deposits energy in polar regions

Status of simulations

General Relativity

Evolution and GW
production well under
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Magnetic Fields

Resolving growth of B-field remains beyond our computational capabilities.

Sims rely on sub-grid models, or artificially imposed large-scale field structure

Waveform modeling

- Objective: unbiased estimates of tidal parameters in GW observations, possibly with $\sim 10\%$ accuracy in aLIGO
- Multiple groups nominally capable of sufficient (?) waveform accuracy [THC, SACRA, SpEC, BAM]

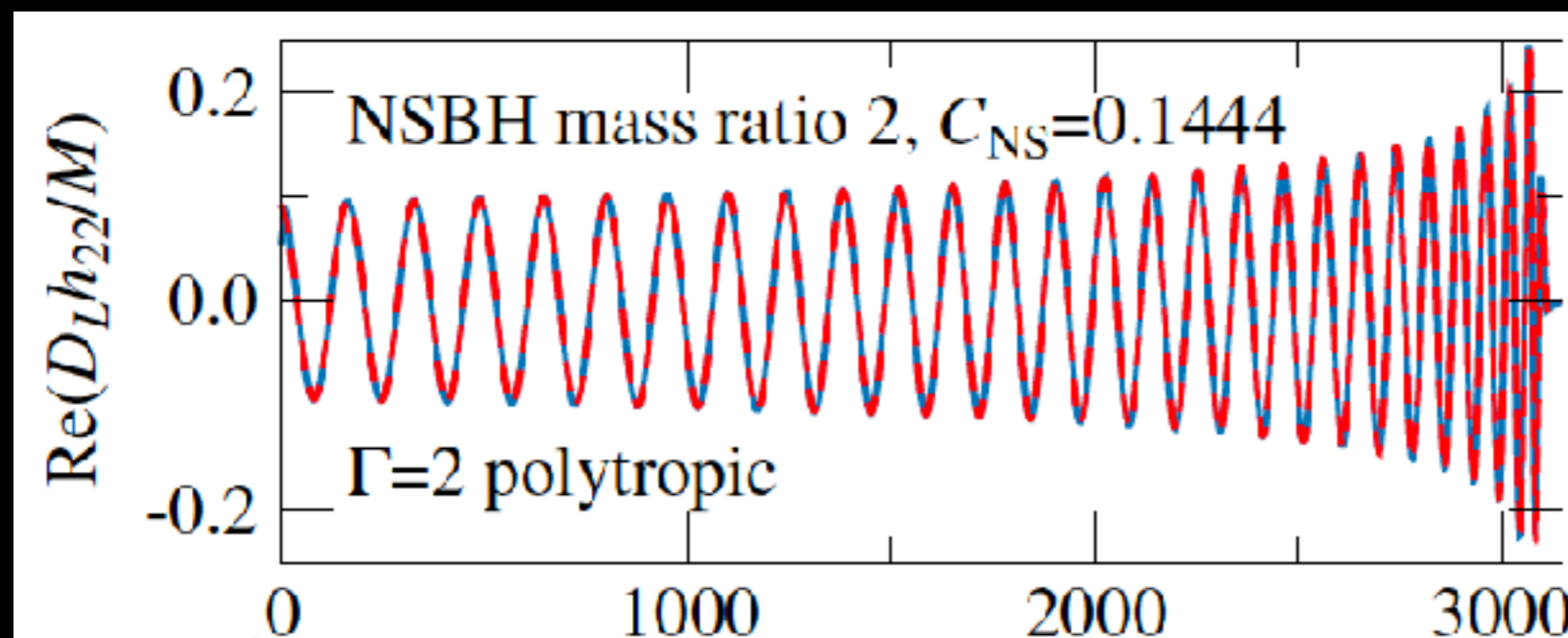


Image:
Hinderer et al. 2016

- ToDo list for NR and analytical modelers (in progress):
 - Parameter space coverage, EoS model dependency
 - Code comparisons
 - GW model testing using latest NR results, **impact of hybridization**

Outflow modeling

NSNS \rightarrow NS

NSNS \rightarrow BH

BHNS

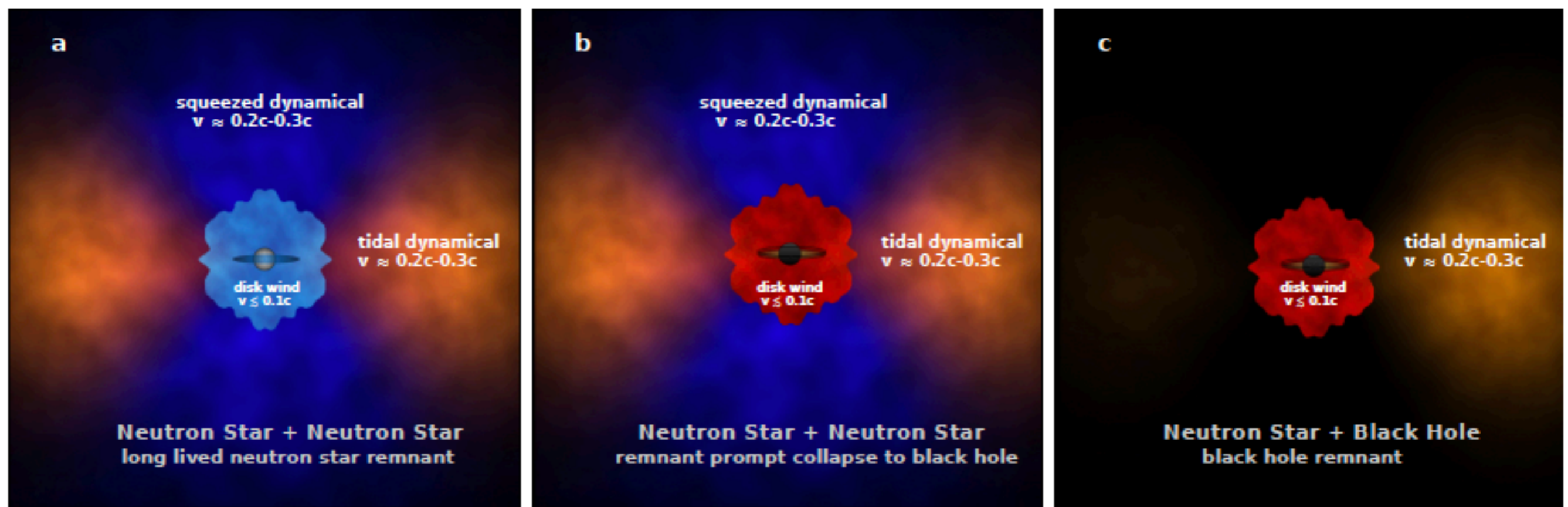


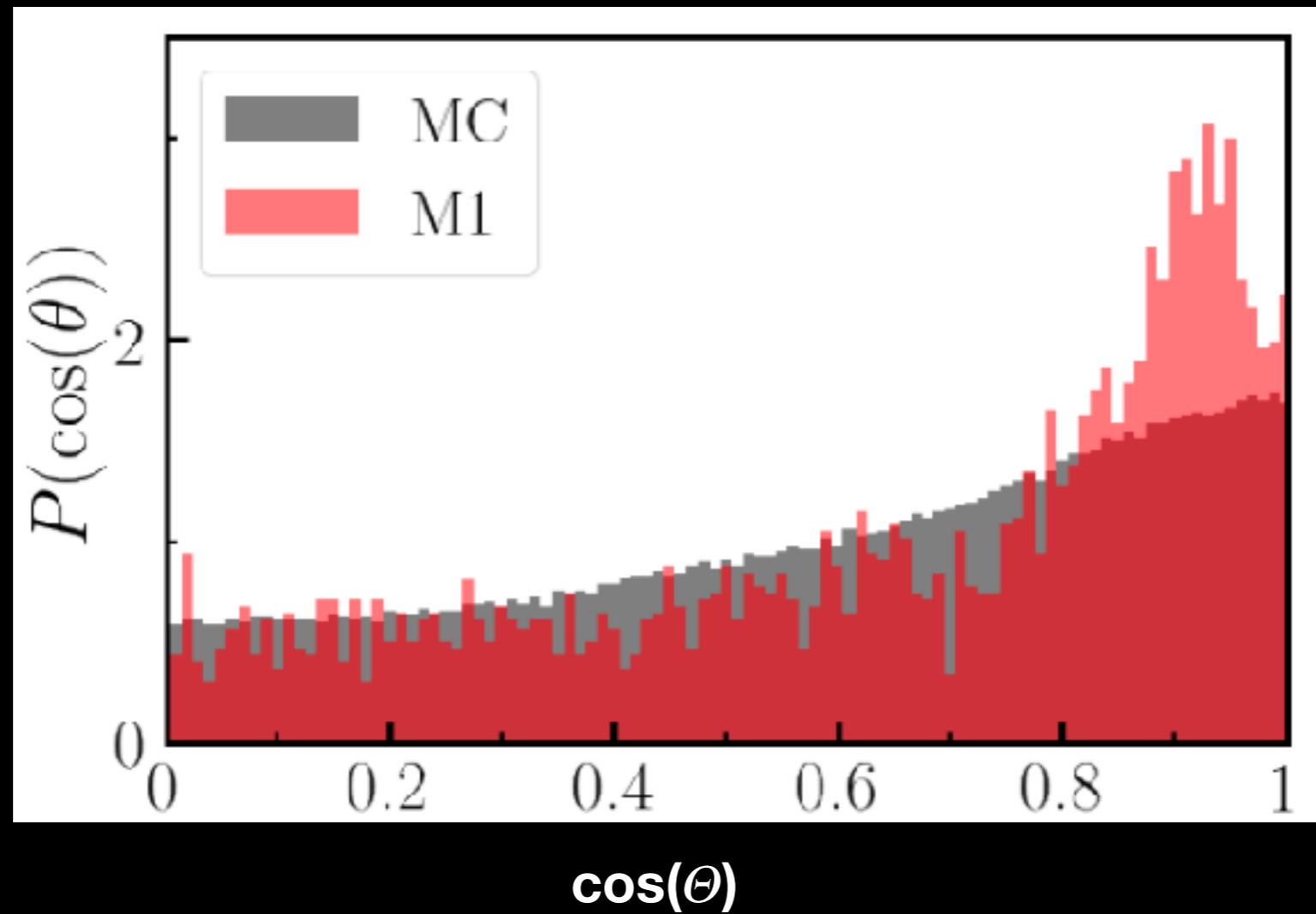
Image: Kasen et al 2017

Objectives:

Go from kilonova \rightarrow outflow properties \rightarrow binary properties!
Understand r-process nucleosynthesis

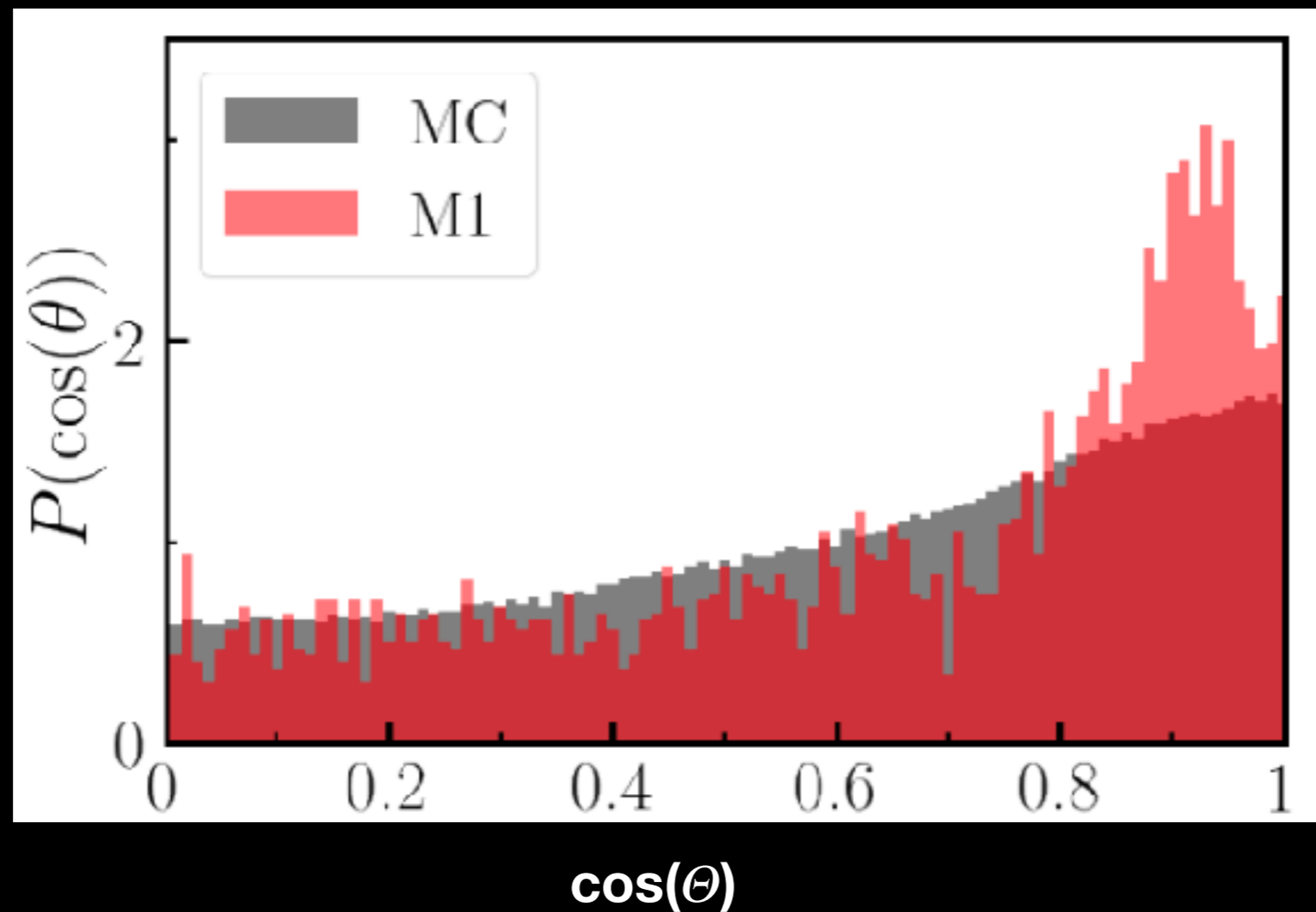
Outflow modeling

Foucart et al., in prep : Impact of inaccurate M1 closure



Outflow modeling

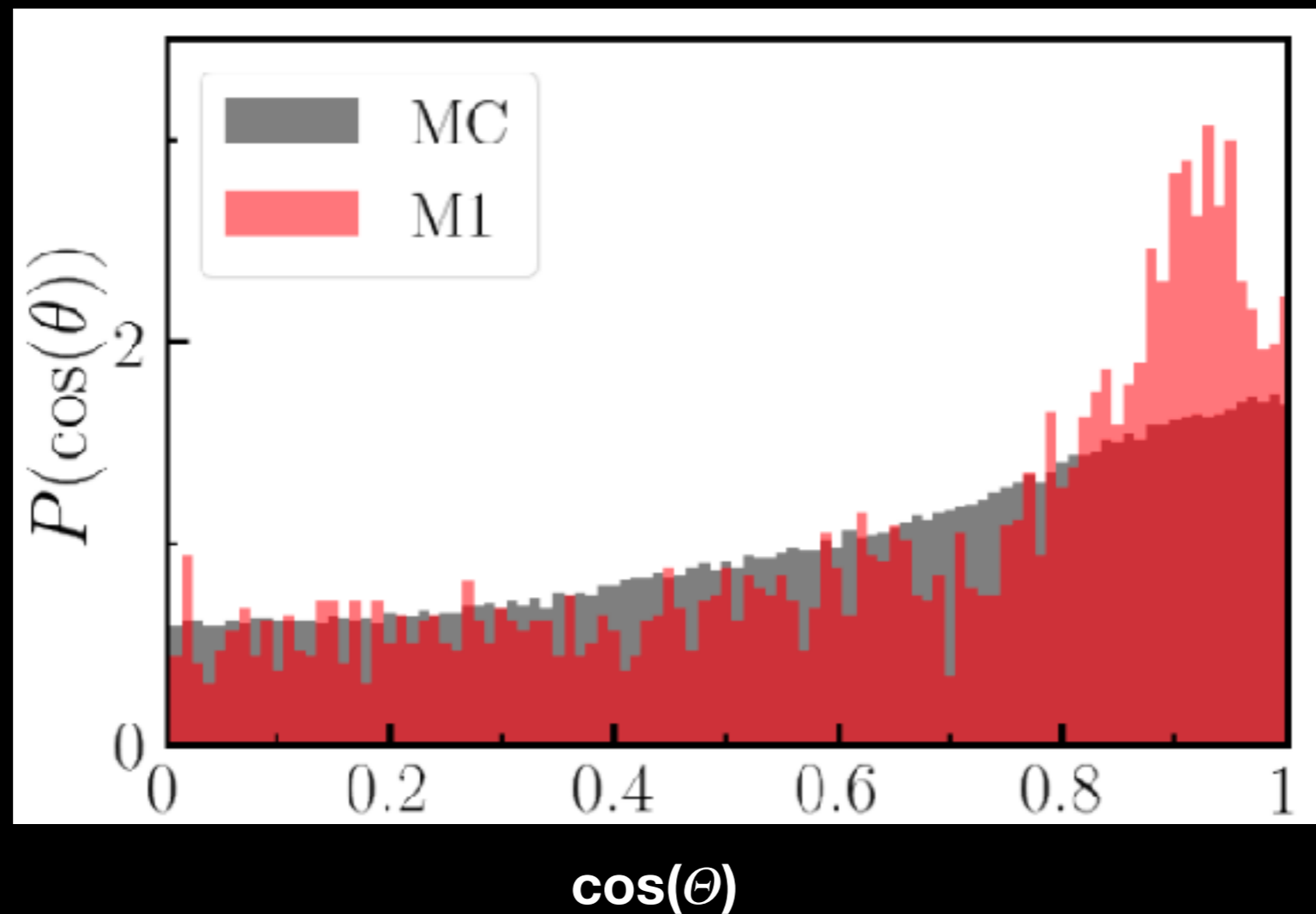
Foucart et al., in prep : Impact of inaccurate MI closure



Foucart et al. 2017:
Inaccurate neutrino **energy**
estimates ->
Errors in composition

Outflow modeling

Foucart et al., in prep : Impact of inaccurate M1 closure

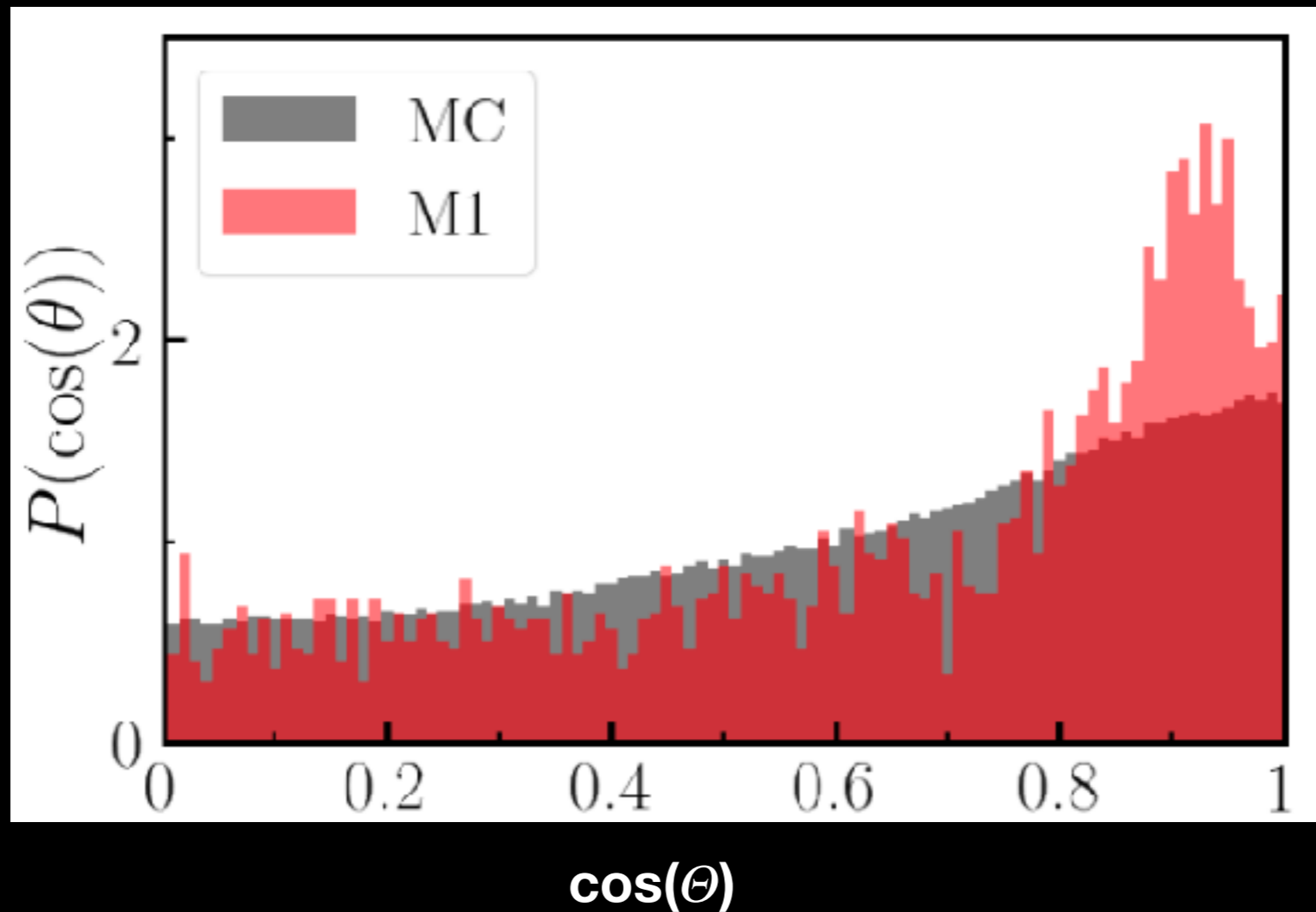


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Mass of outflows depends
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Fernandez, Just, Siegel:
Do not forget disk outflows!!
20%-40% of remnant disk will be
unbound

Conclusions

- Rapid progress in physical realism of simulations
 - Current limits: small scale instabilities, neutrino transport, long evolutions
- Waveform modeling is staying ahead of aLIGO accuracy
- Outflow/nucleosynthesis predictions remain qualitative
- Important questions not discussed here:
 - How to power short gamma-ray bursts?
 - Do jet/wind interactions impact kilonovae?