

Keeping a Pulse on CCSNe with Gravitational Waves

Mike Pajkos

Michigan State University

Sean Couch, KuoChuan Pan, Evan O'Connor



Tools at Our Disposal

- Light—macrophysics (explosion energy & elemental abundances)
- Neutrinos—microphysics (flavor oscillations)
- Gravitational waves (GWs) new lens → Verify old questions in new ways & answer new ones too



Attacking the Problem from Both Ends



Outline

- Science
 - Connecting GWs to physicals
- Software
 - GR Hydro
 - Upgrading to FLASH5



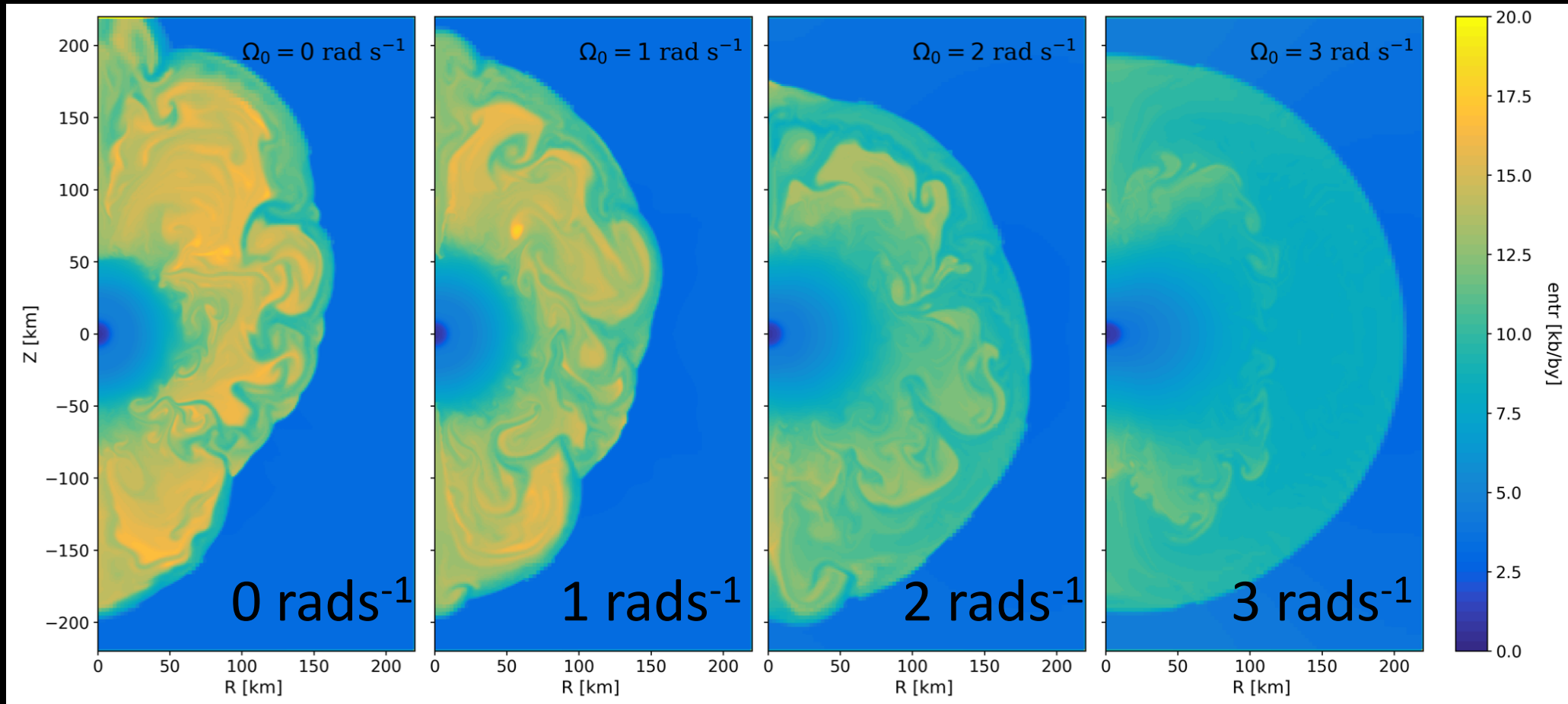
Standing CCSN Questions Answered with GWs

- Effect of Rotation?
- Activity behind the shock? (Andresen+ 18)
- Properties of the compact object? (Sotani+ 17)



Visualizing Weakened Convection

Axis of Rotation →



Equator →

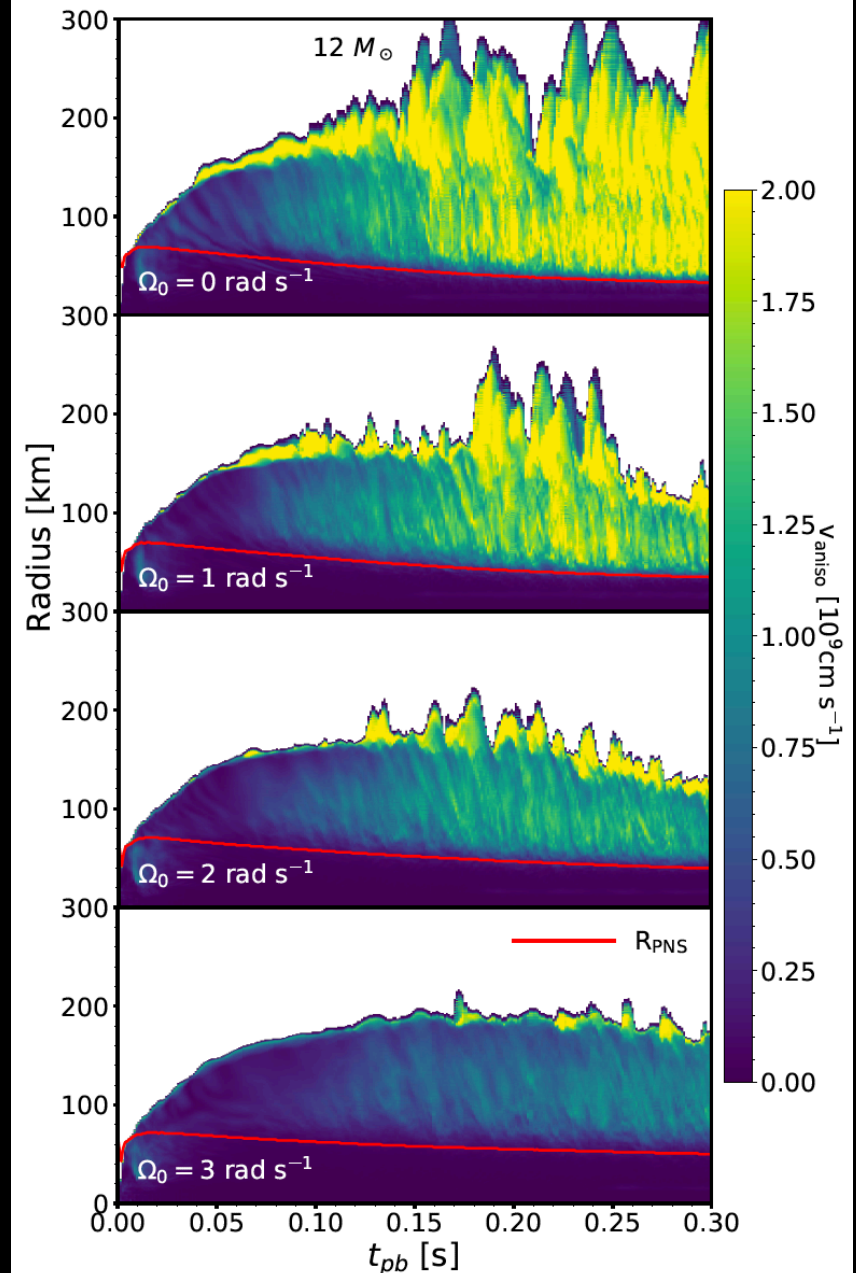


Visualizing Weakened Convection

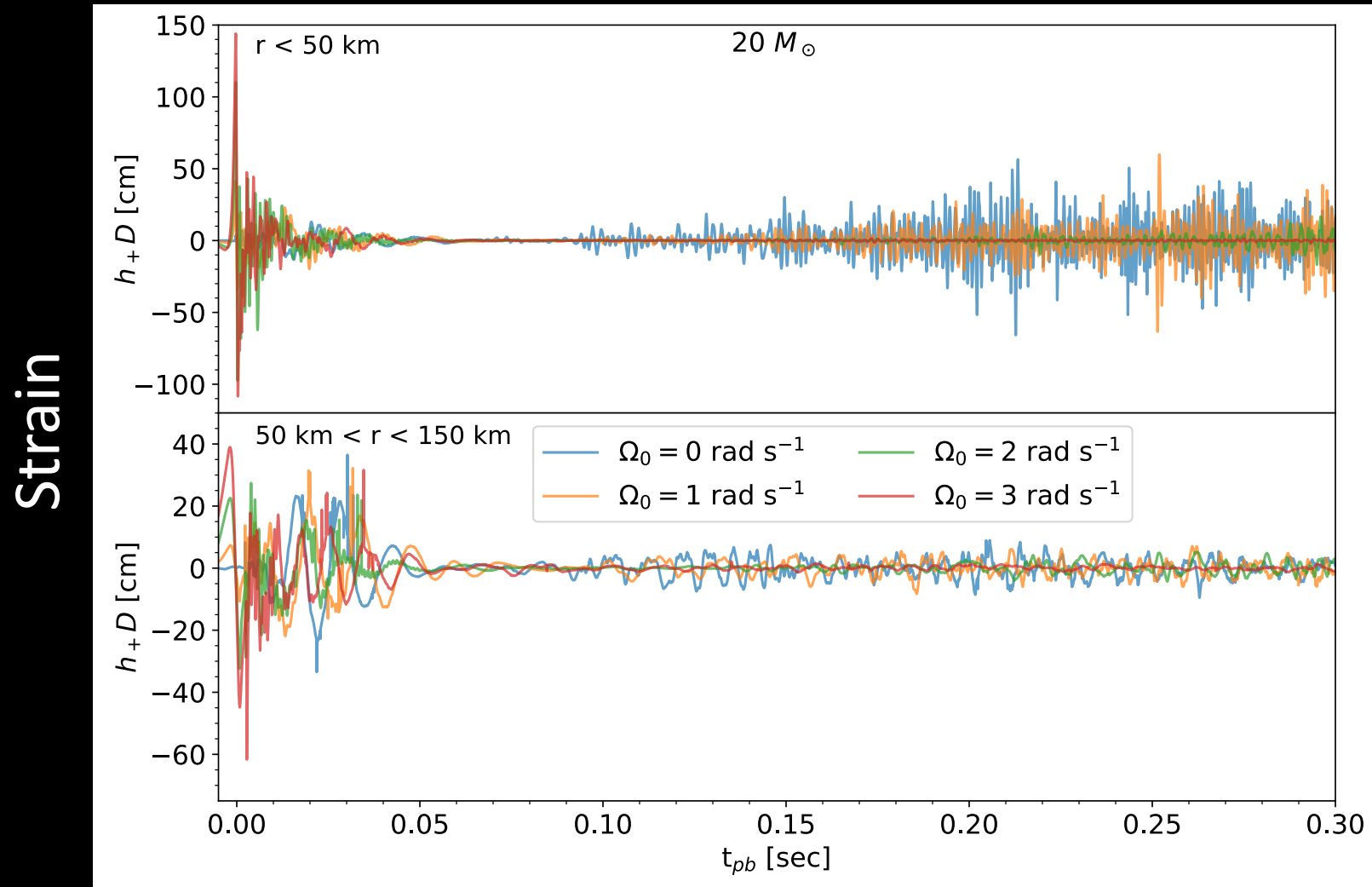
- Tested with $12 M_{\odot}$ progenitor (Sukhbold+ 16)
- Increasing rotation rate weakens convection

Pajkos+ 2019, ApJ, 878, 13

Radius



Impact on the GW Signal

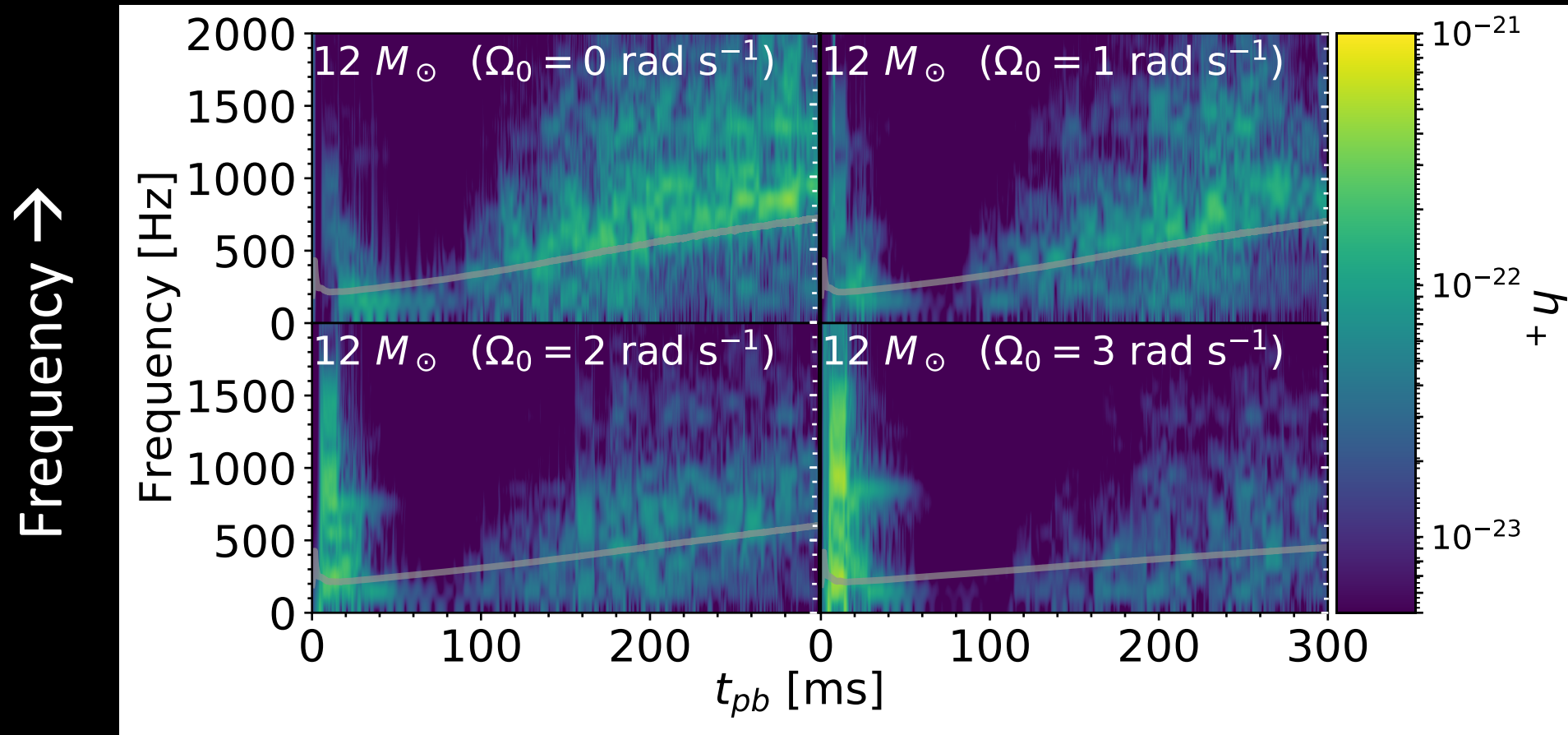


Time \rightarrow

Pajkos+ 19



Tracking Protoneutron Star (PNS) Evolution 2D



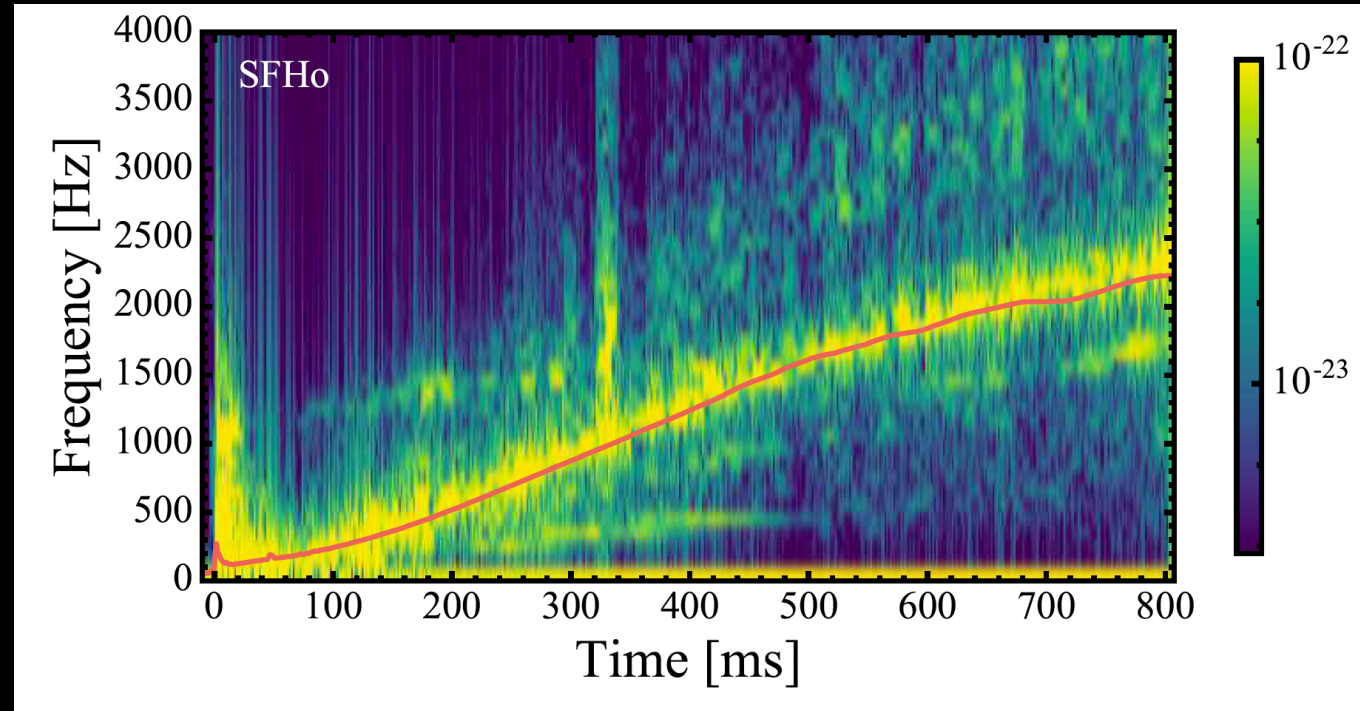
Pajkos+ 19



Tracking Protoneutron Star (PNS) Evolution 3D

- Surface gravity
- Surface temperature (neutrinos & EOS)
- Compactness (Muller+ 2013)

Frequency →



Time →

Pan+ 2018



Spiral Modes in 3D

- Low T/W instability (Andresen+ 2018)
- Solberg-Hoiland stability criterion still applies
- Observationally, can we distinguish these instabilities?



Attacking the Problem from Both Ends



Need for Computational Improvement

- Model fidelity (GR Hydro)
- Keeping up with hardware
 - Portability
 - Locality

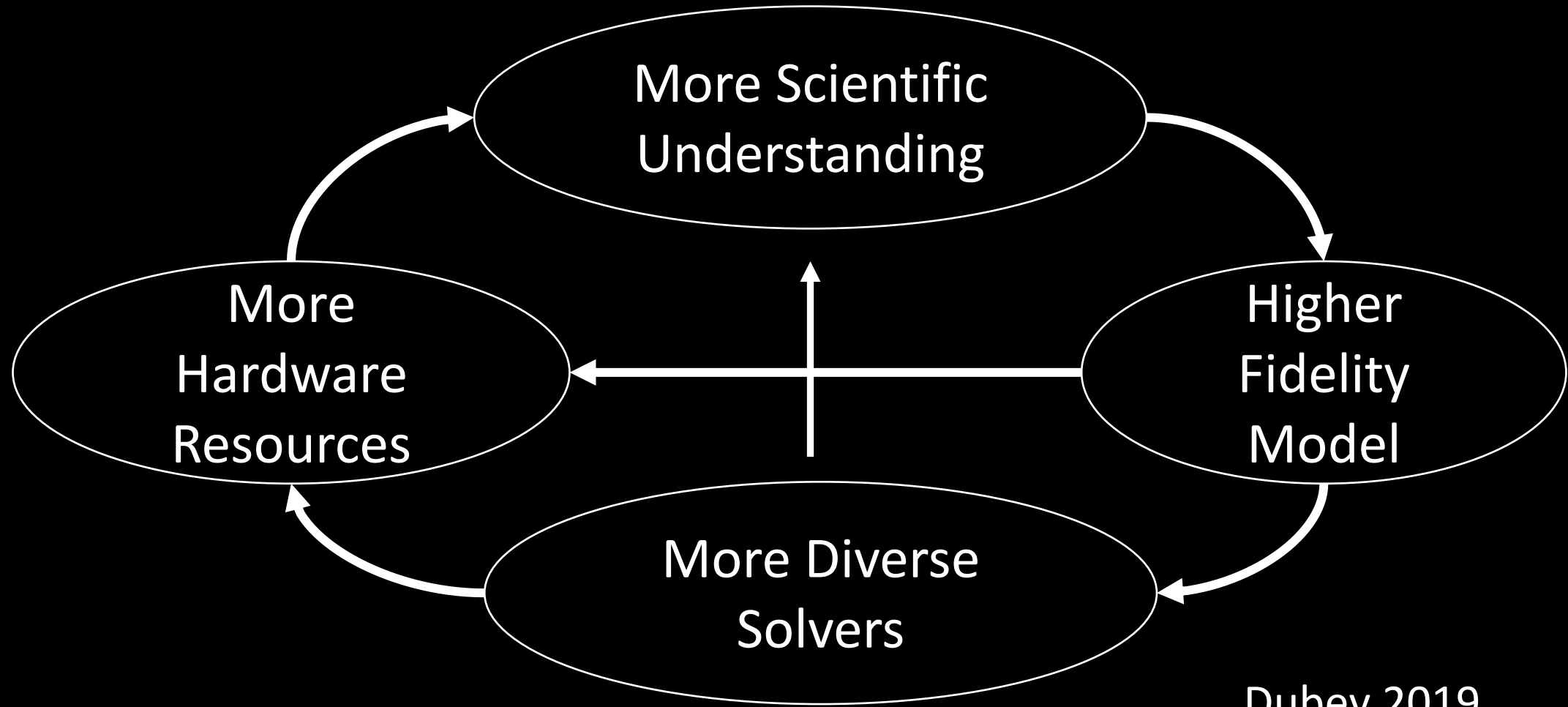


Importance of GR Hydrodynamics

- PNS compactness \uparrow (Kuroda+ 2012)
 - Mean neutrino energy \uparrow
- GW peak frequencies \uparrow (Muller+ 2013)
- Need GR Hydrodynamics to properly translate GWs to physical information
- Update FLASH with Valencia formulation (eg. Mosta+ 2013)



Transcending Performance



Dubey 2019



Transcending Performance

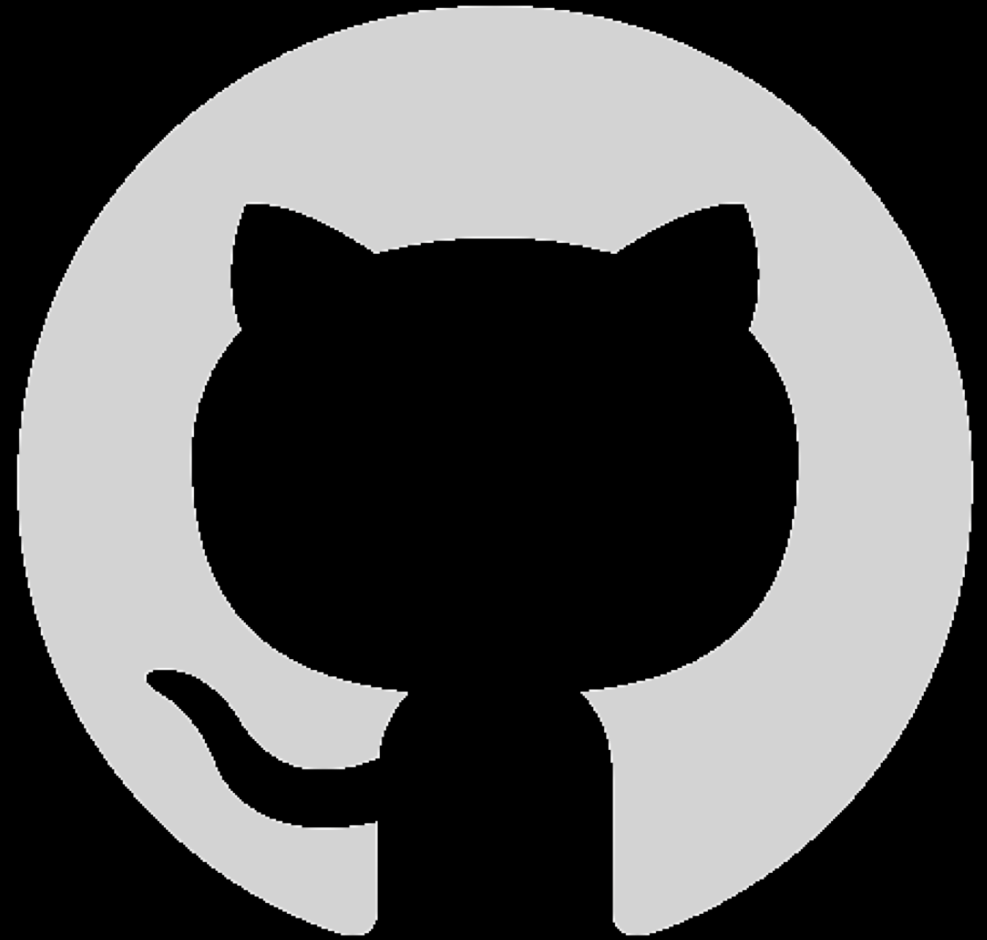
- Extensibility- well defined structure/modules
- Portability- easily transitions between machines
- Performance- locality & scalability
- Maintainability- clean code & testing
- *We need these factors to ensure the longevity of our science*



Argonne

FLASH5 Overview

- Open-source
- ECP-Astro/FLASH5



Github



Summary

- GWs allow us to extract observables and constrain EOS
- Our understanding of CCSNe depends on proper treatments of relativistic effects
- Anticipating future hardware architectures acts as insurance for future projects

