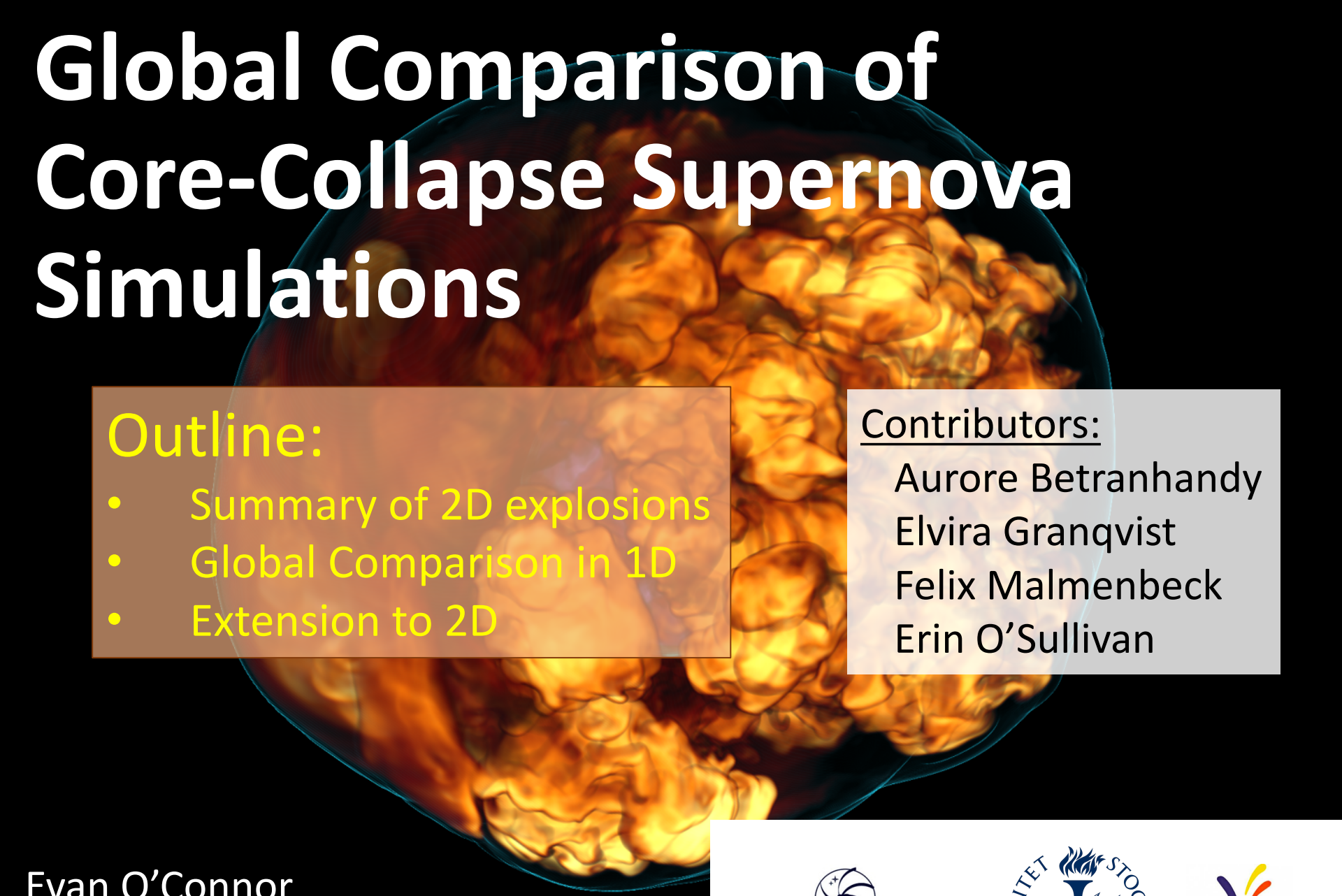
Global Comparison of Core-Collapse Supernova Simulations



Outline:

- Summary of 2D explosions
- Global Comparison in 1D
- Extension to 2D

Contributors:

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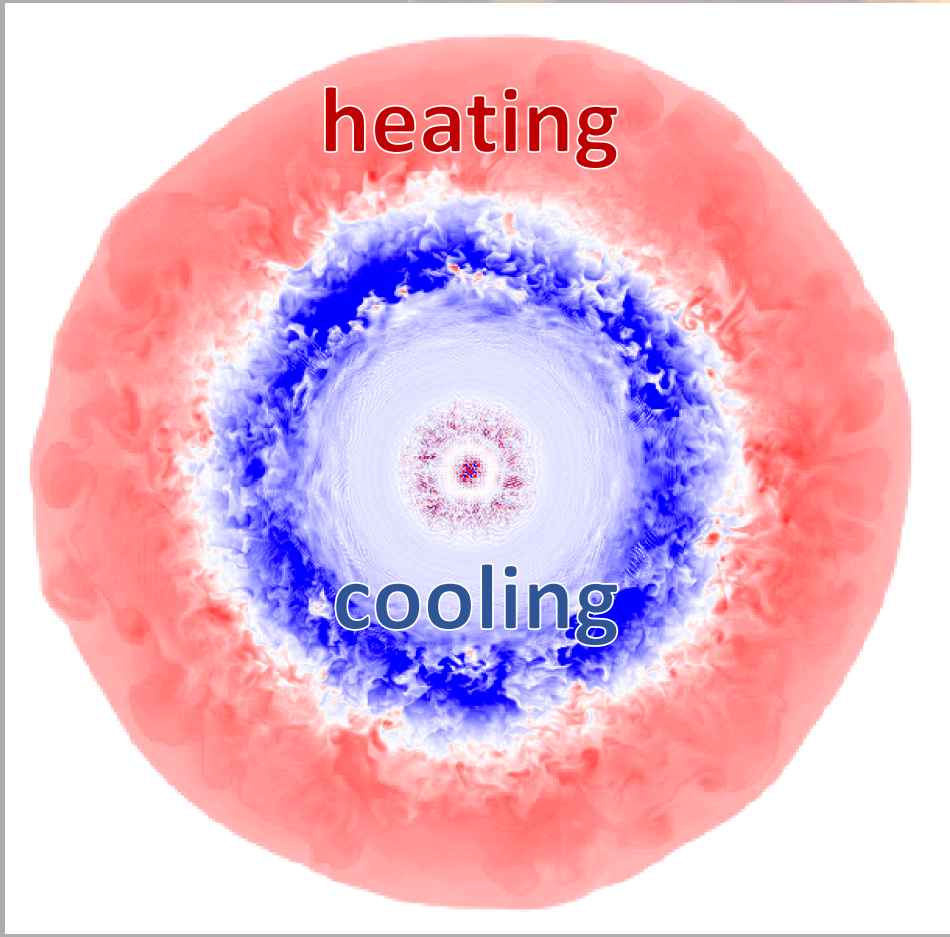
The Core-Collapse Supernova Problem



- The naive `prompt` mechanism fails
- The prevailing mechanism is the **turbulence-aided neutrino mechanism**
  - Neutrinos from core heat outer layers
  - Drives convection
  - Turbulence pressure support aids heating and drive explosion
- Very successful in 2D*, many successful explosions
- Success in 3D too: fewer simulations

The Core-Collapse Supernova Problem

Understanding the transition from an imploding iron core to an exploding star has been a persistent and difficult problem in astrophysics.

Requires:

3D - (Magneto)hydrodynamics

General Relativity

Movie

Nuclear Reactions

Progenitors

Nuclear Equation of State

Neutrino Transport & Interactions

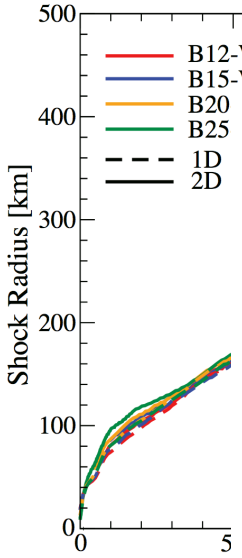
Computational Physics

EO & Couch (2018b)

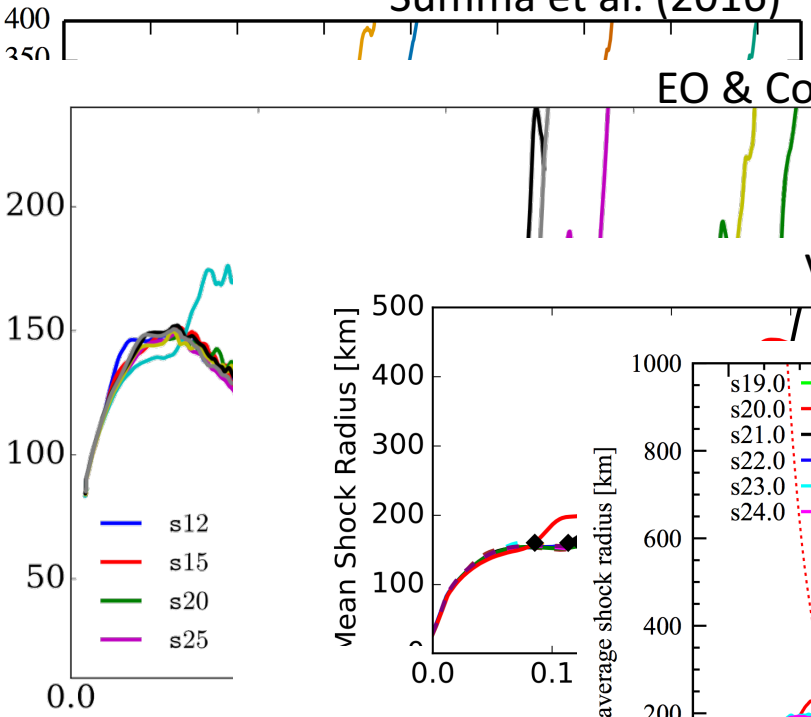
Explosion Successes in multiD – 2D

Woosley & Heger (2007) progenitors

Bruenn et al. (2013)

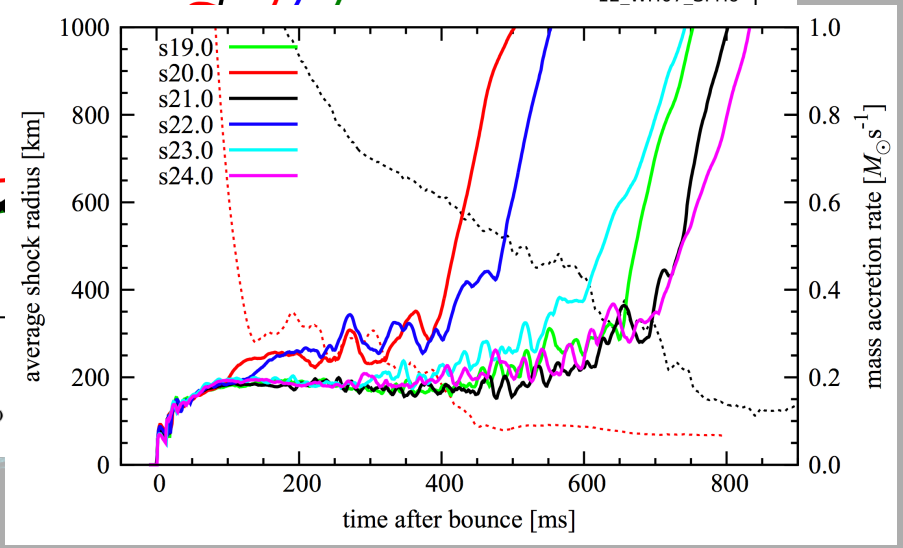


Summa et al. (2016)



EO & Couch (2018a)

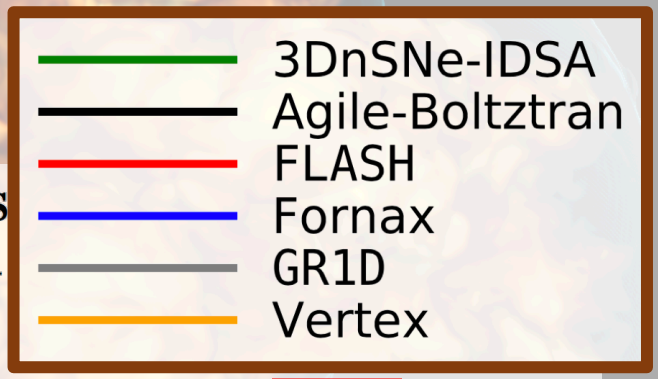
Vartanyan et al. (2018) (EOS)



Nakamura et al. (2015) (prog..)

Global effort towards agreement

- Want to demonstrate the community's ability to simulate SN
- Comparison of 6 core-collapse supernova codes
- *Very carefully* control input physics and initial conditions to ensure fair comparison



Global Comparison of Core-Collaps
Simulations in Spherical Symmetry

Evan O'Connor[1], Robert Bollig[2,3], Adam Burrows[4], Sean Couch[5,6,7,8], Tobias Fischer[9], Hans-Thomas Janka[2], Kei Kotake[10], Eric Lentz[11], Matthias Liebendörfer[12], O. E. Bronson Messer[13,11], Anthony Mezzacappa[11], Tomoya Takiwaki[14], David Vartanyan[4]

Journal of Physics: G 45 10 2018

Details of Input Physics

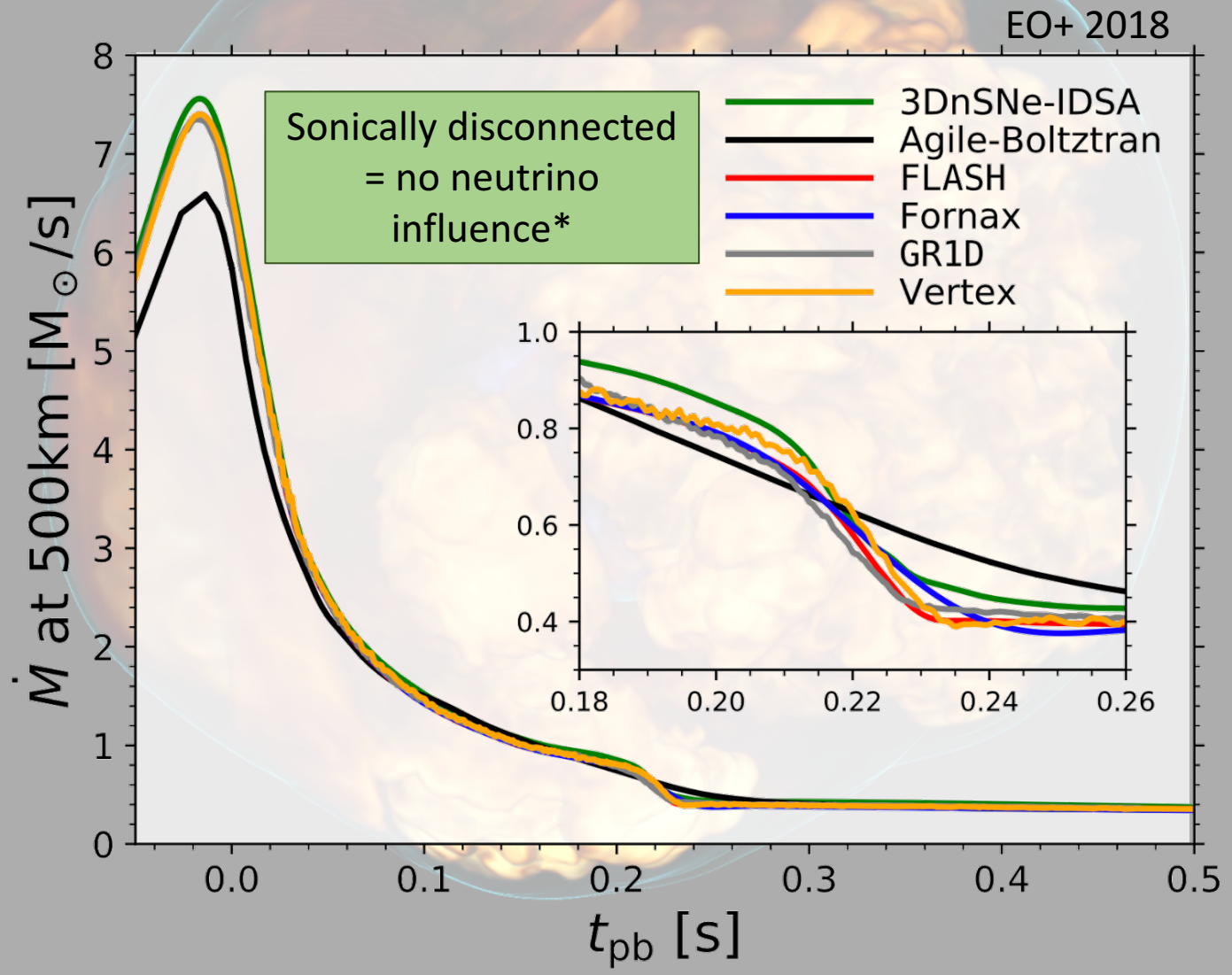
Non-Neutrino Physics

- **20 Msun** progenitor from Woosley & Heger (2007) [sollo03/s20/s20#presn]
- Map Density, Y_e, Temperature (not pressure, entropy or energy)
- Outer edge of domain: 10^9 cm
- **SFHo** Equation of State, **no low density treatment**
- Full or effective GR (case A)
- 1D

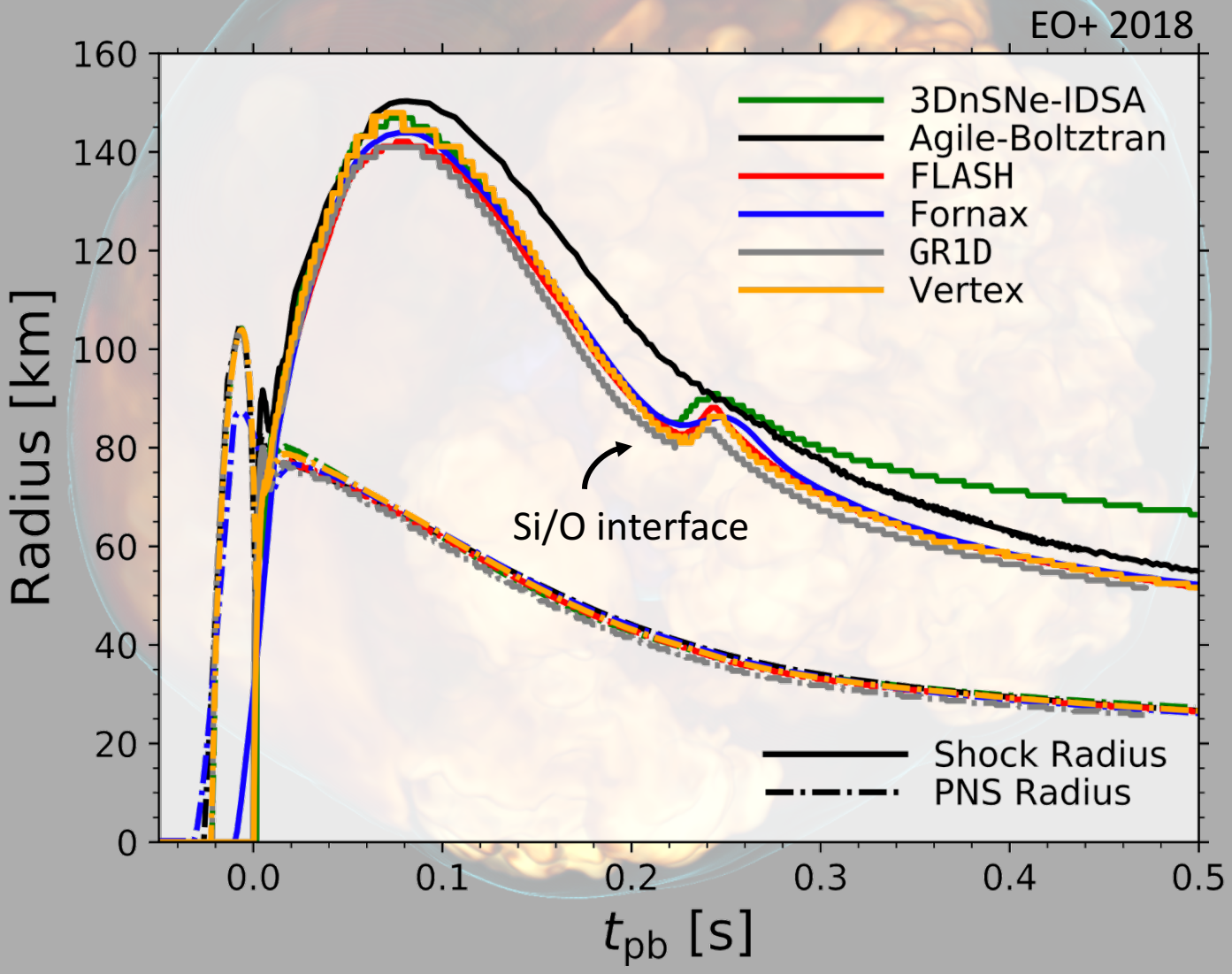
Neutrino Physics

- Essentially **Bruenn (1985)** rates
- +weak magnetism
- +ion-ion correlations and form factor for ν-A scattering
- neutron-proton rest mass different (no mean field shifts)
- e^+e^- and NN Brems for pair processes
- 3 species, ν_e anti-ν_e, $\nu_x = \{\nu_\mu, \nu_\tau,$ anti-ν_μ, anti-$\nu_\tau\}$
- Ignore light species in EOS

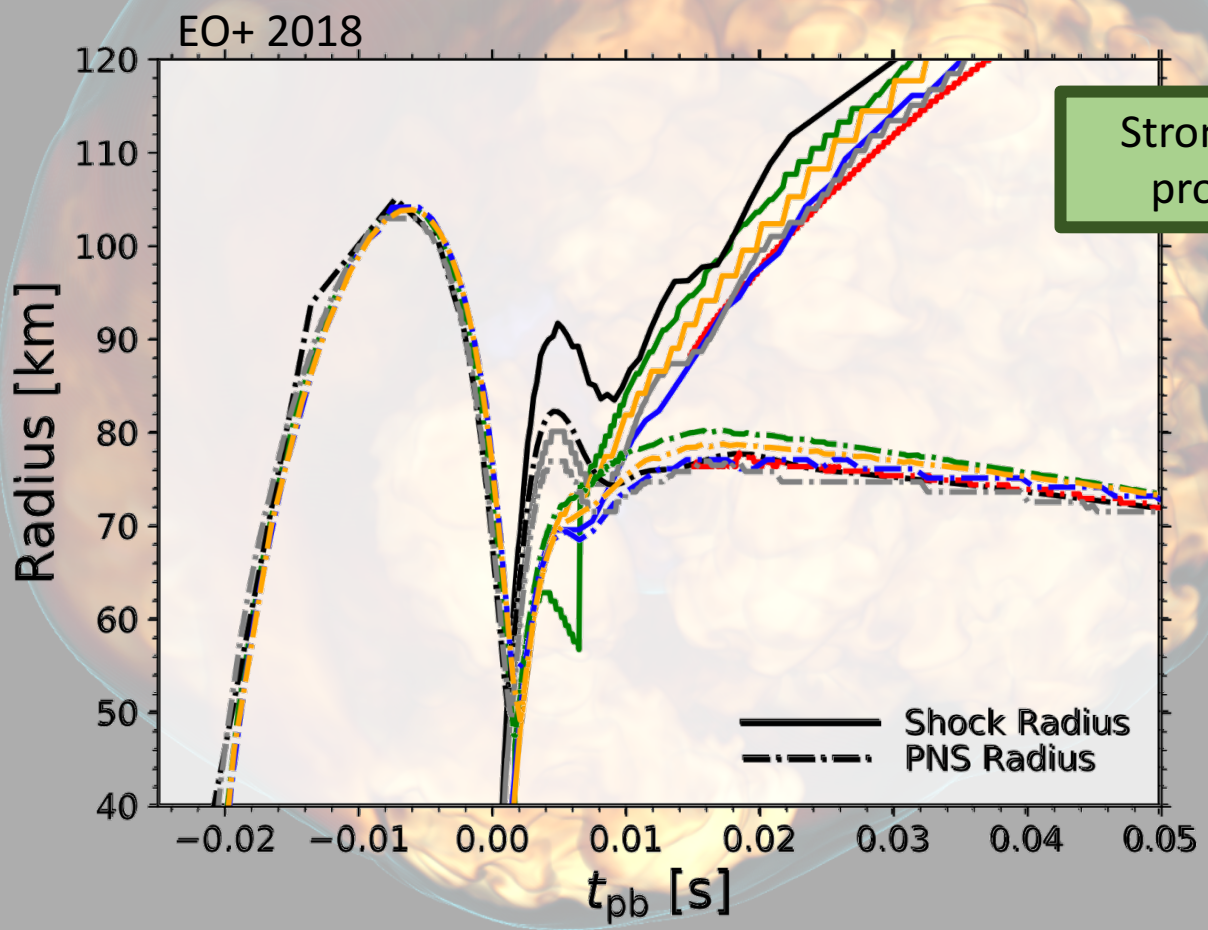
Comparing the Gravity & Hydro



Excellent Shock Radius Agreement



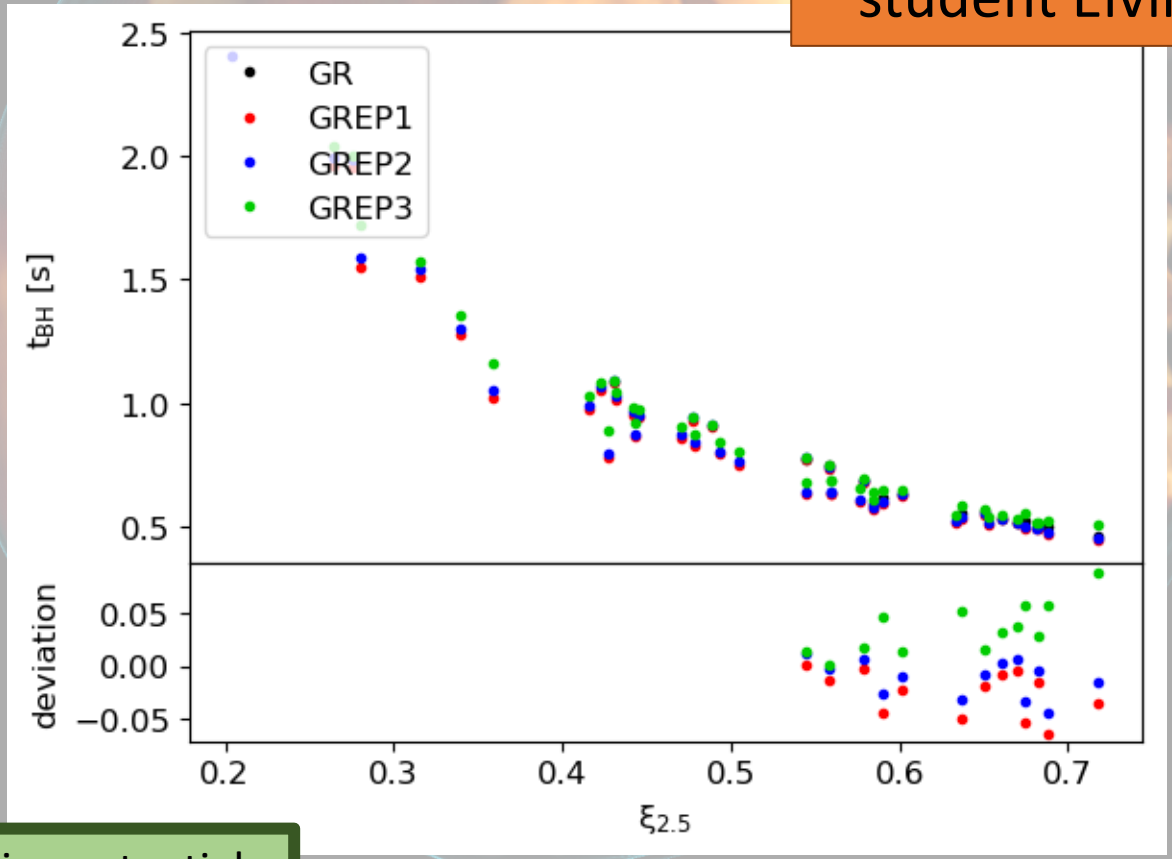
Aside: Probing GR effects



Stronger initial Shock propagation in GR

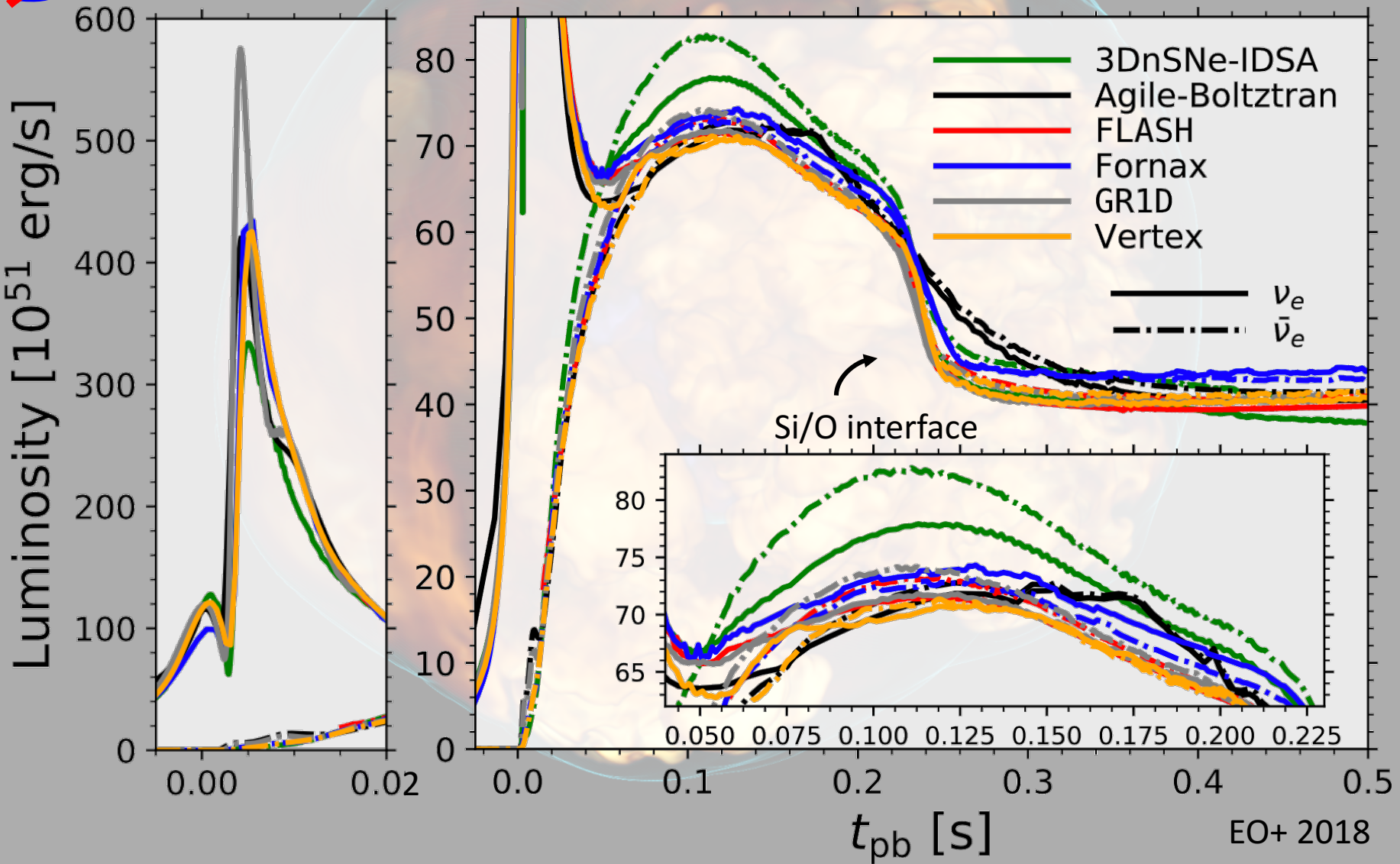
Aside: Probing GR effects

Work by Stockholm University Bachelor student Elvira Granqvist



With effective potential, black hole formation time within 5%

Neutrino Transport Comparison



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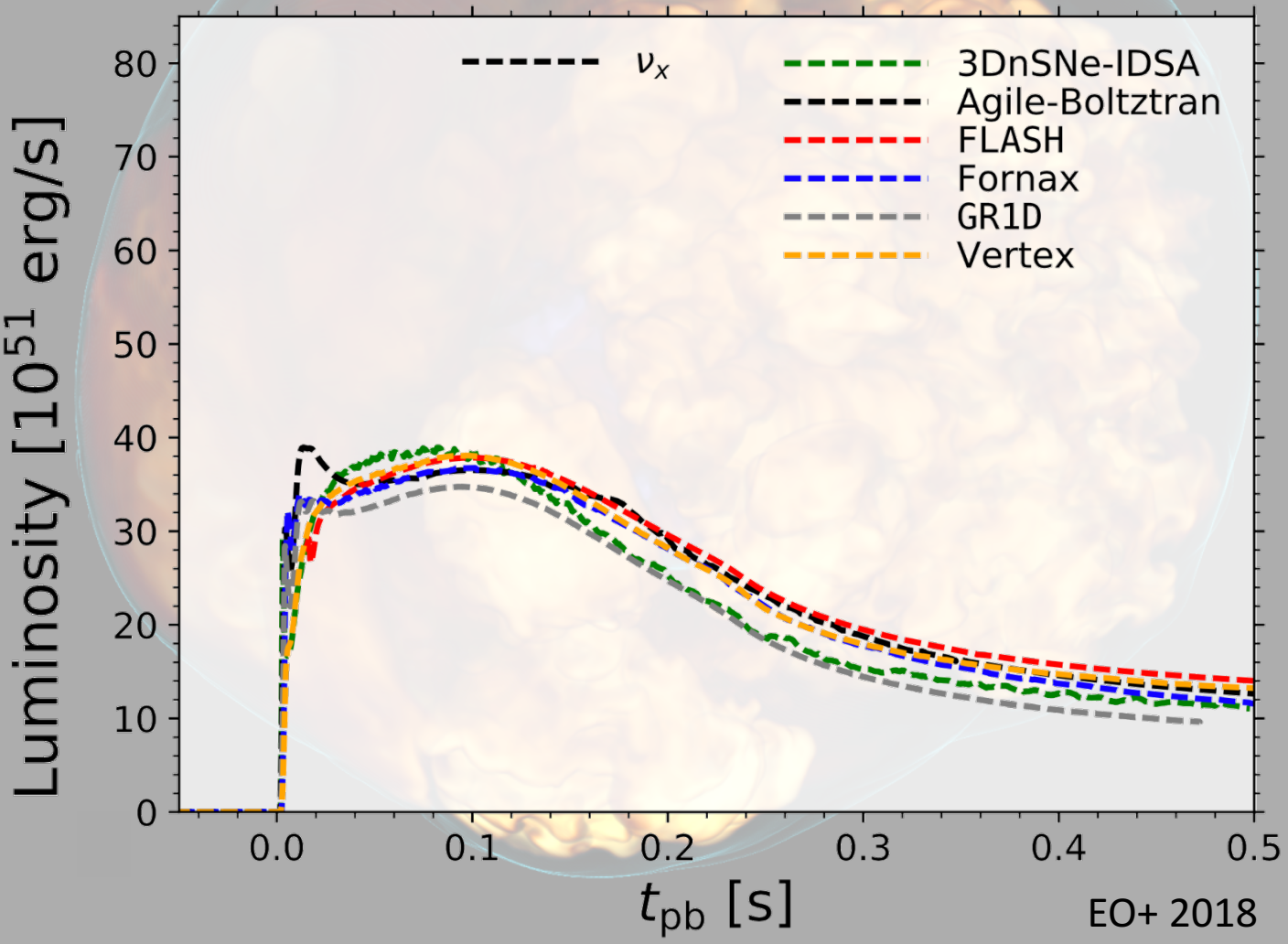
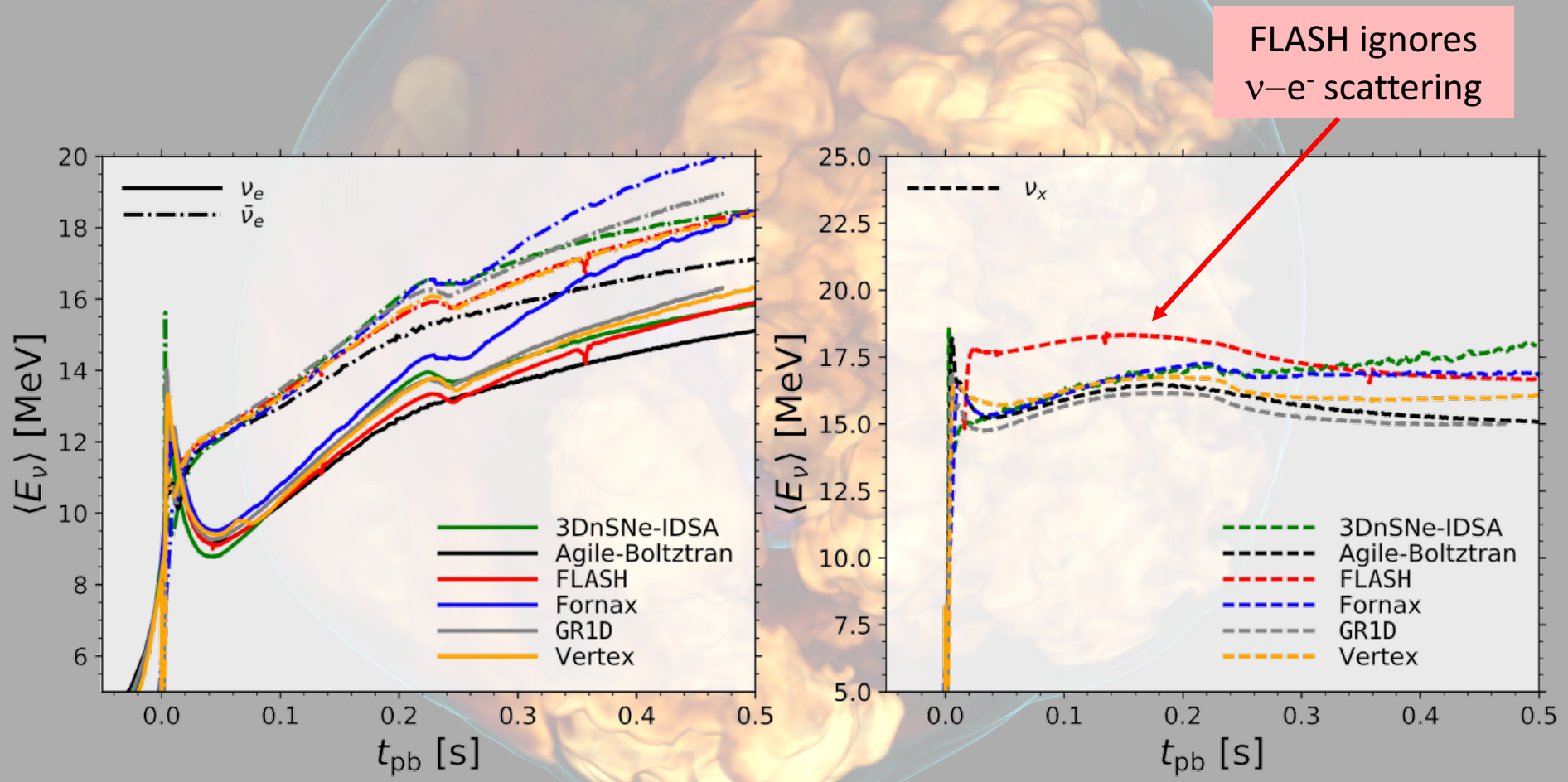
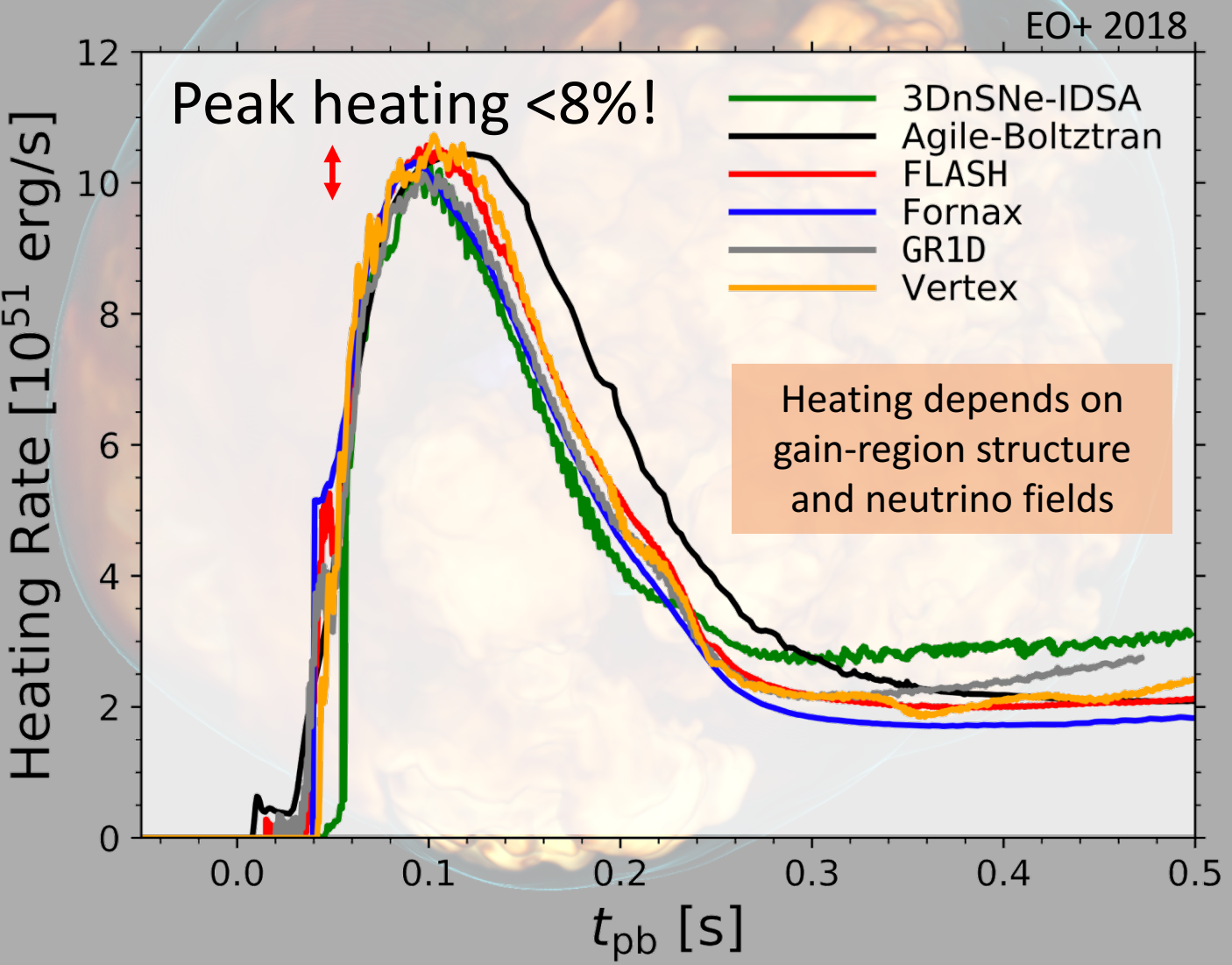


Neutrino Spectra start off well



Neutrino heating is critical



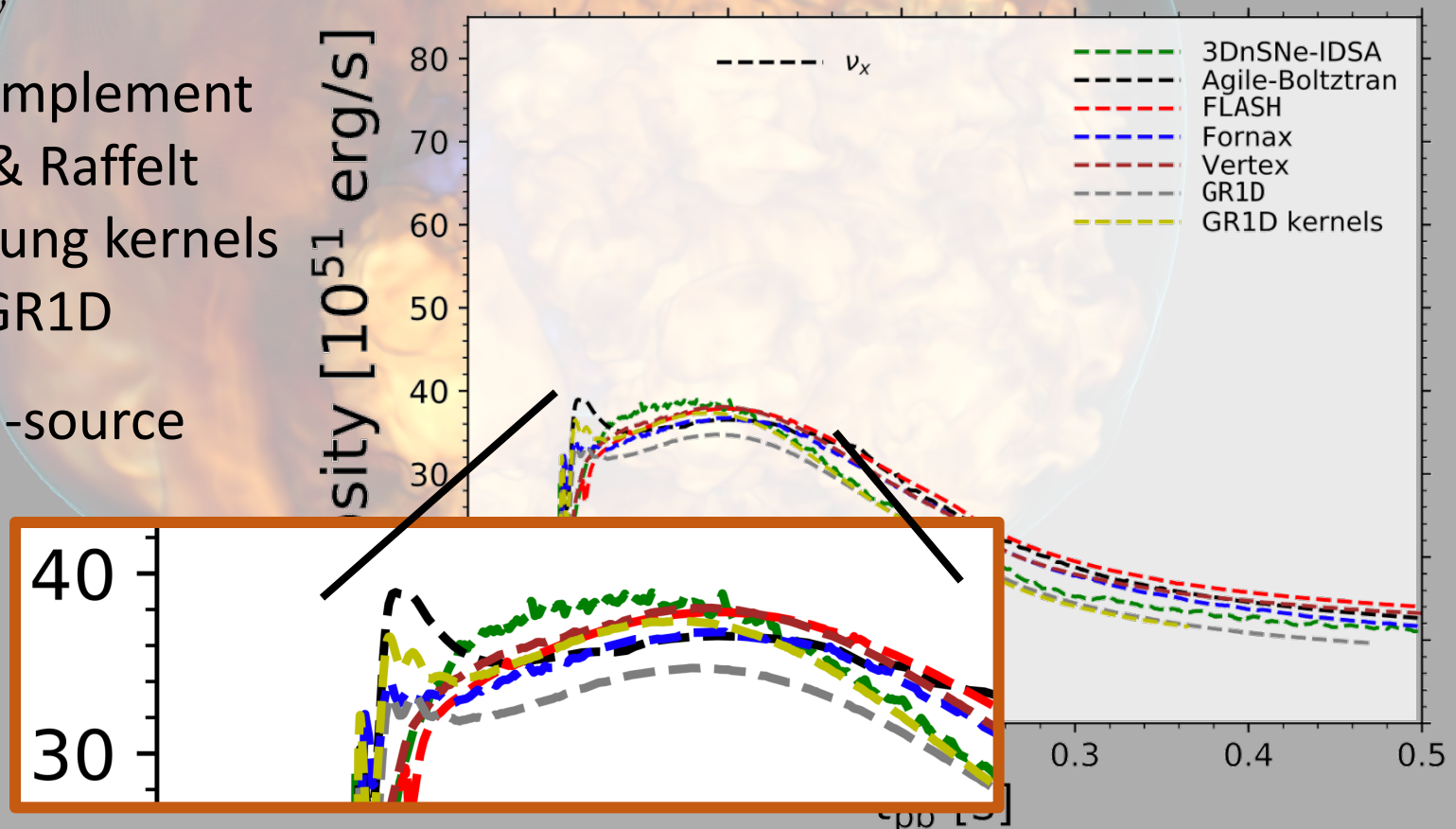
Test bed for future advances

Work led by Stockholm University PhD student Aurore Betranhandy

For Nucleon-Nucleon Bremsstrahlung GR1D & FLASH use *effective emissivity* η_ν^{eff} and κ_ν^{eff}

Aurore has implement Hannested & Raffelt Bremsstrahlung kernels in NuLib & GR1D

will be open-source



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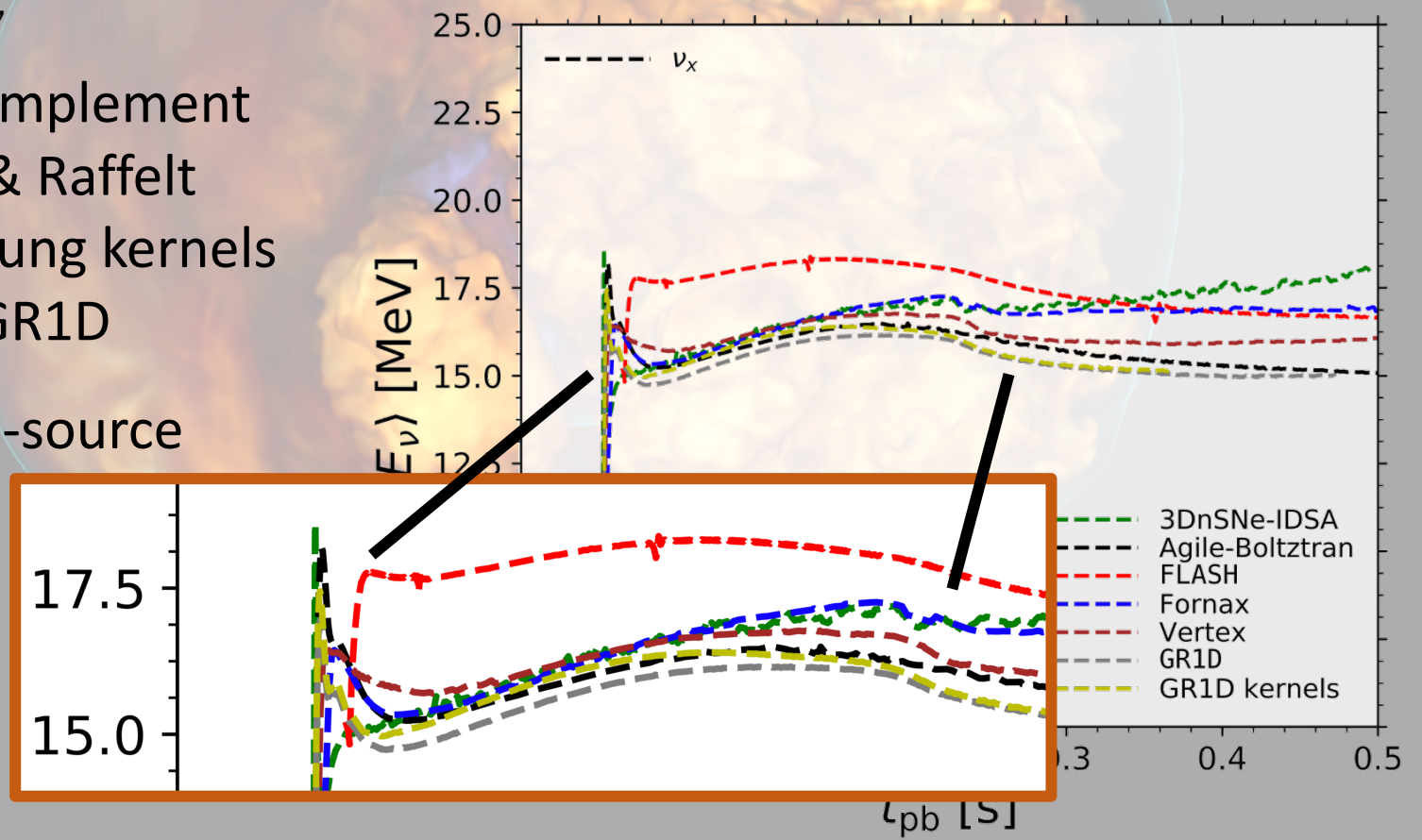

Test bed for future advances

Nucleon-nucleon Bremsstrahlung implementation in NuLib

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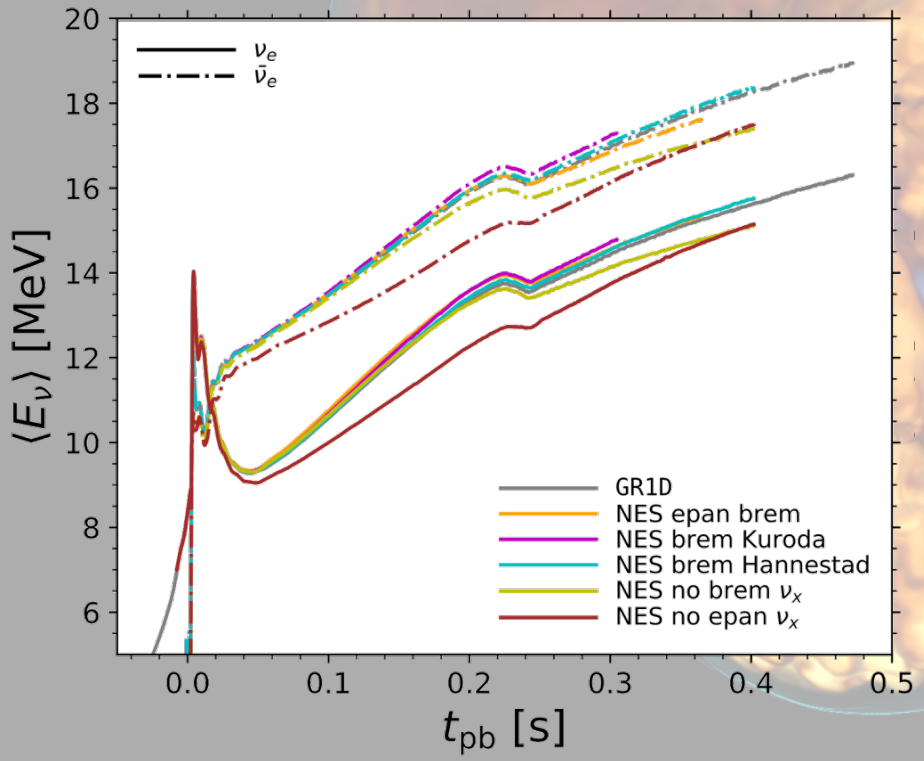
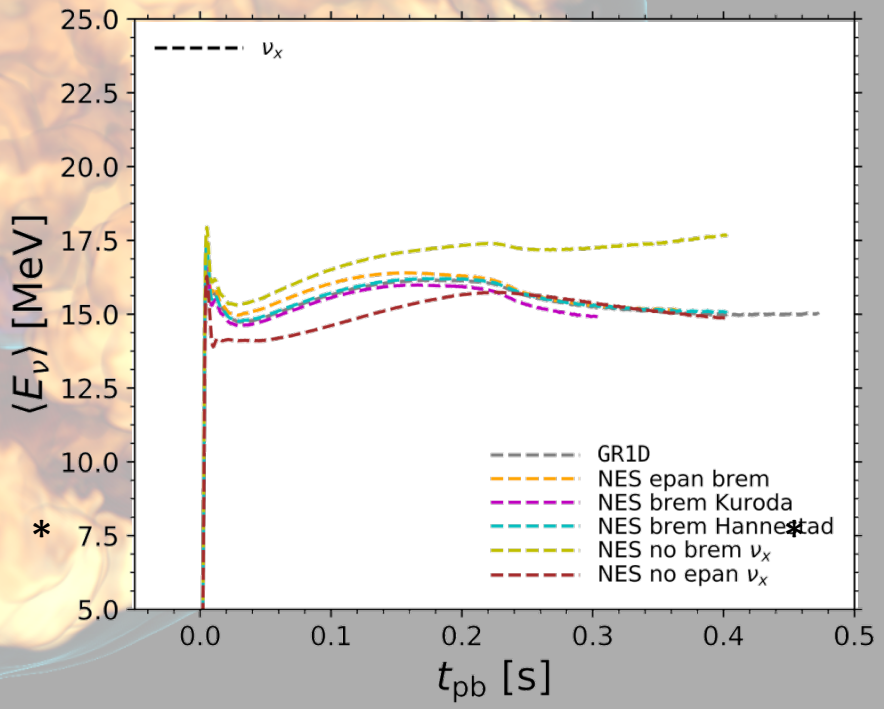


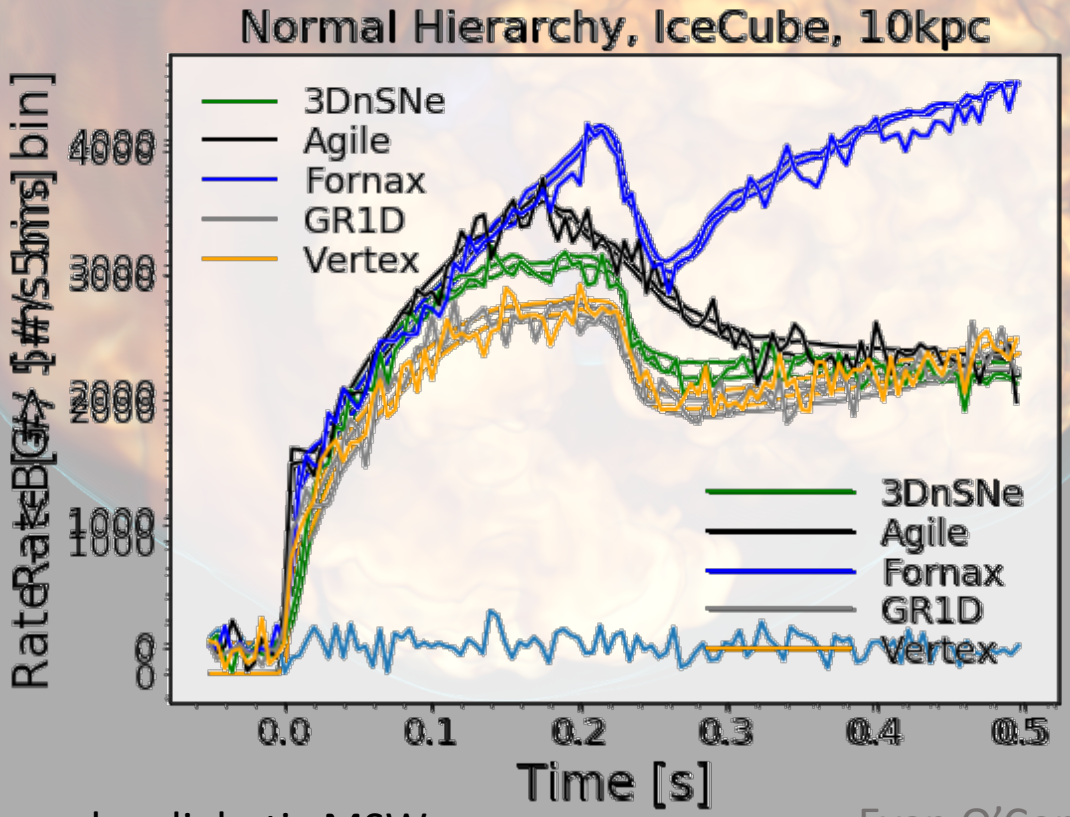


Testing systematic errors

Work by Stockholm University Master's student Felix Malmenbeck and Erin O'Sullivan

Felix implemented detailed IceCube detector into SNOwGLoBES

- Energy-dependent effective volume
- Noise, efficiency, deadtime, …



*Normal Hierarchy: only adiabatic MSW

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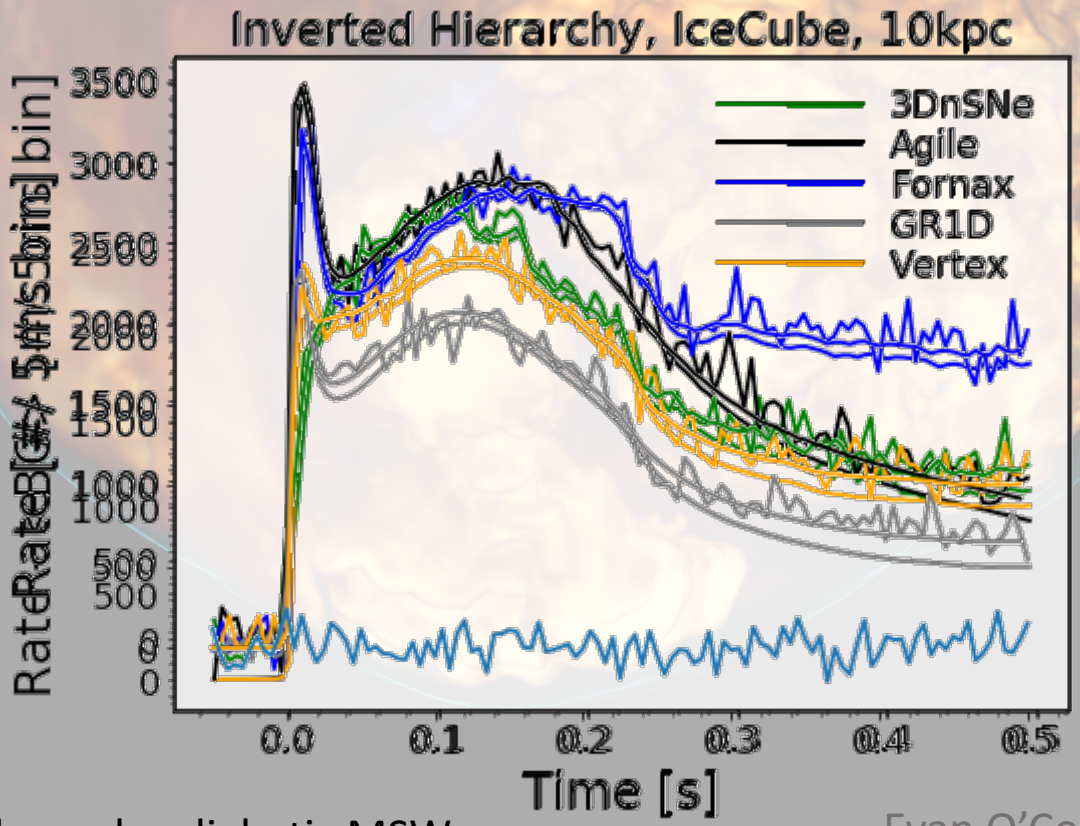
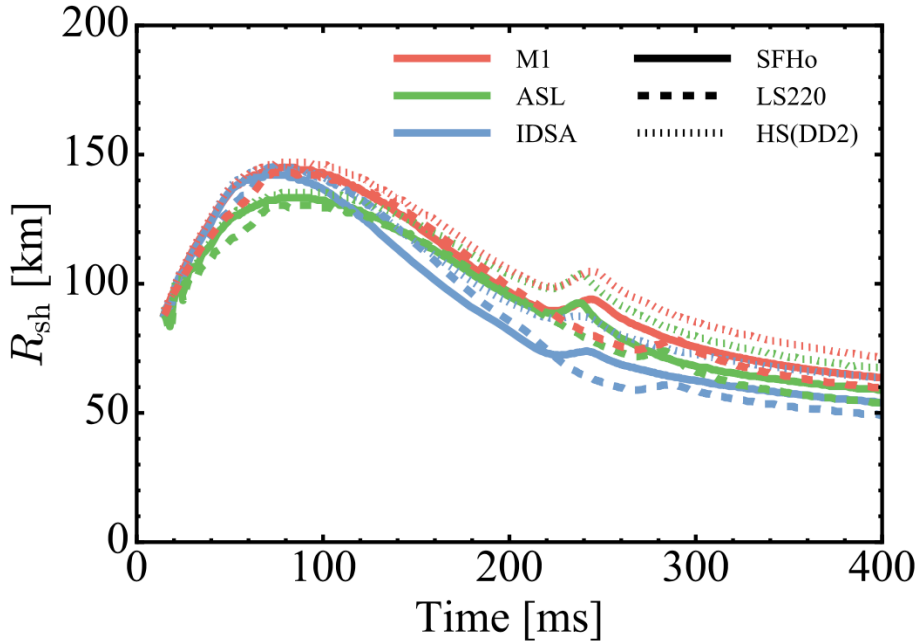


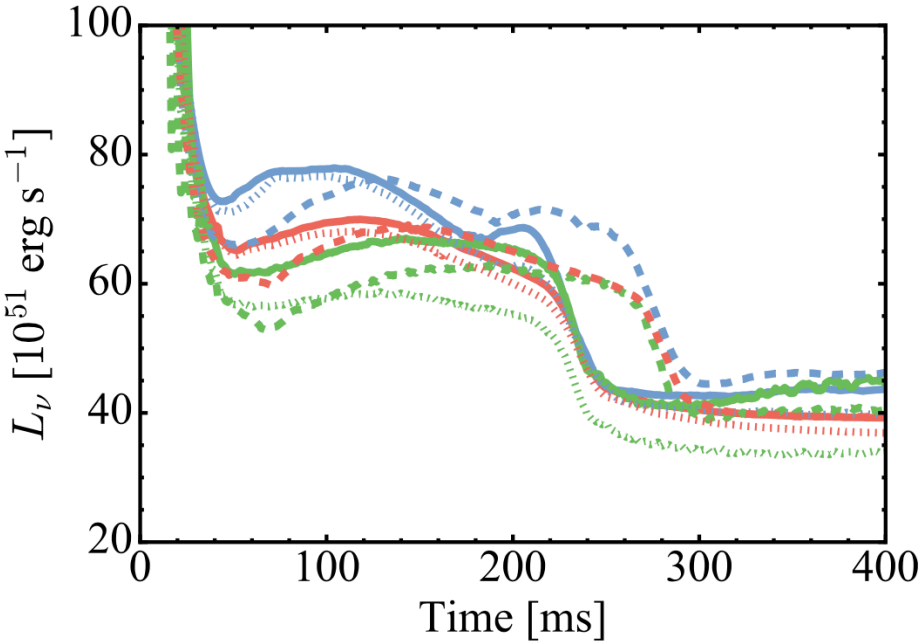
*Inverted Hierarchy: only adiabatic MSW

2D extension

- Keep hydrodynamics fixed – all use FLASH with same grid setup
- Vary neutrino physics to see potential impact of approximations

Pan et al. (2019)





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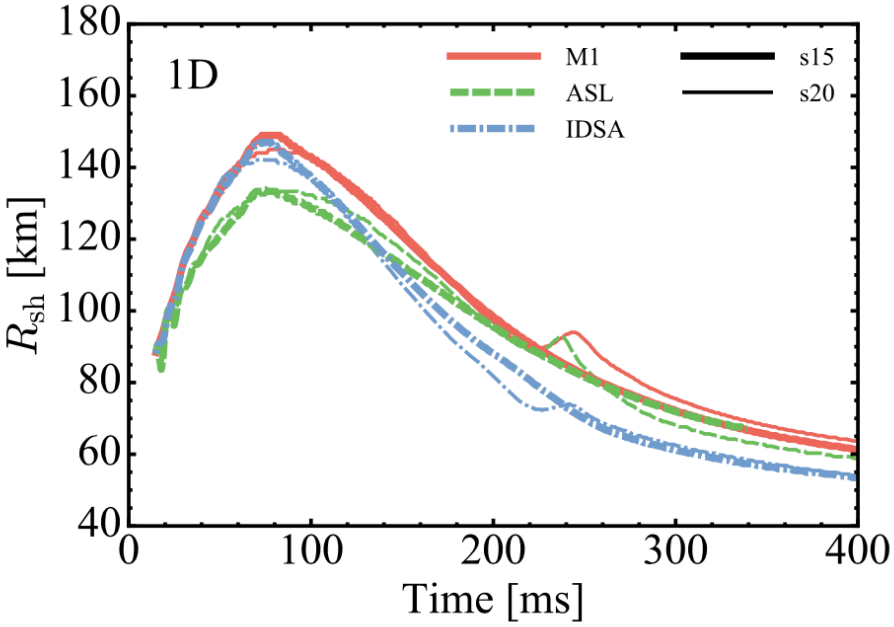

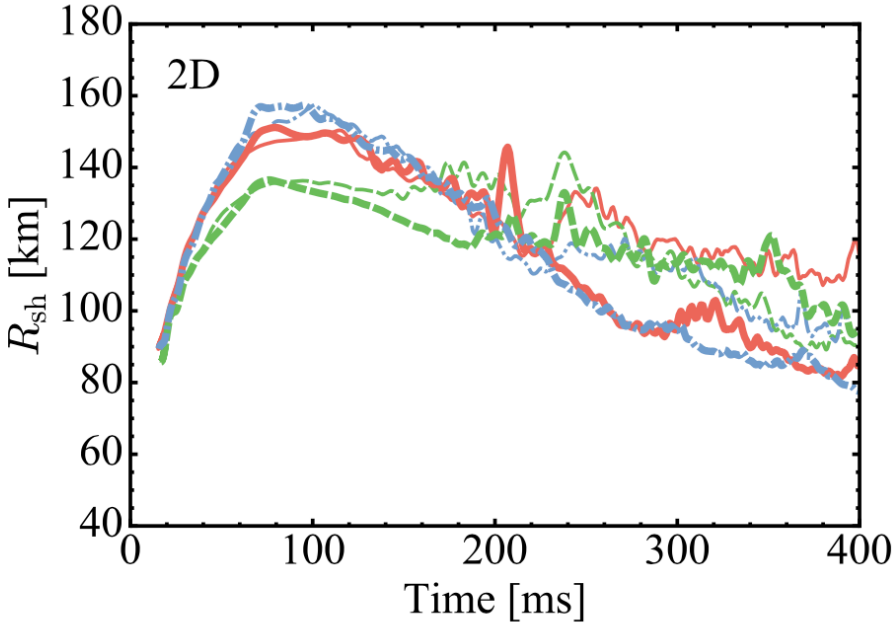

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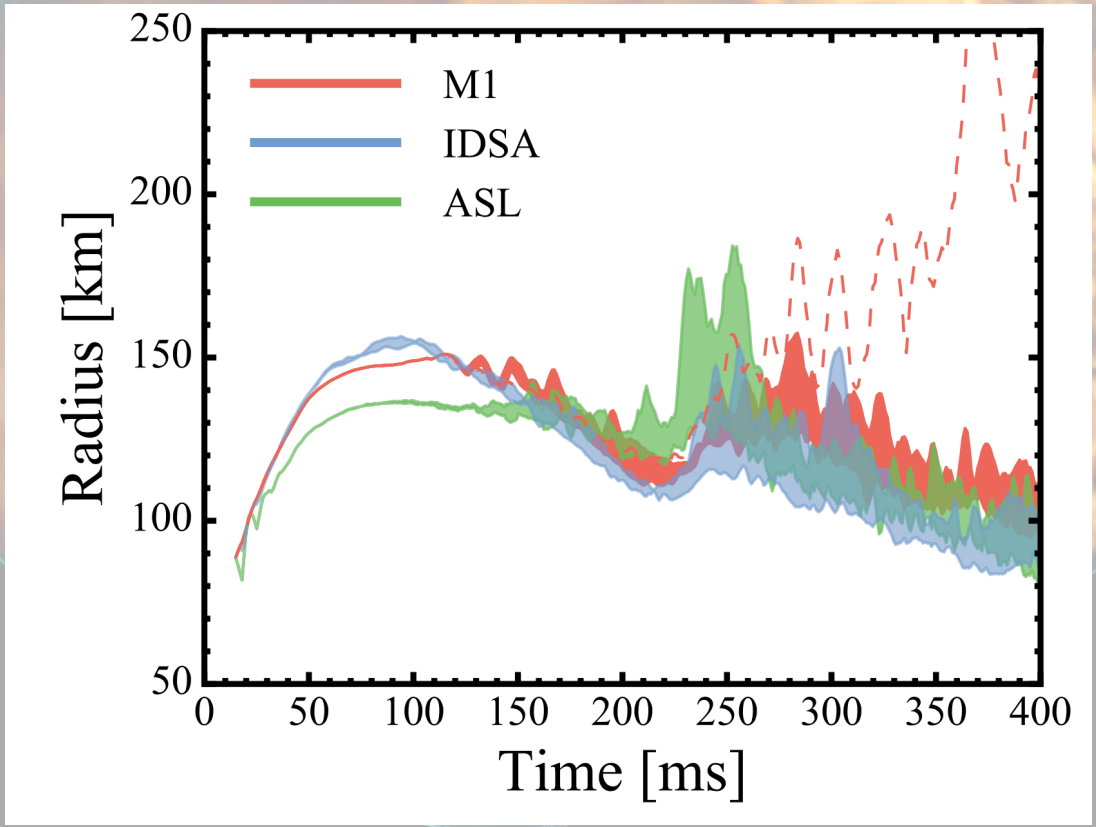
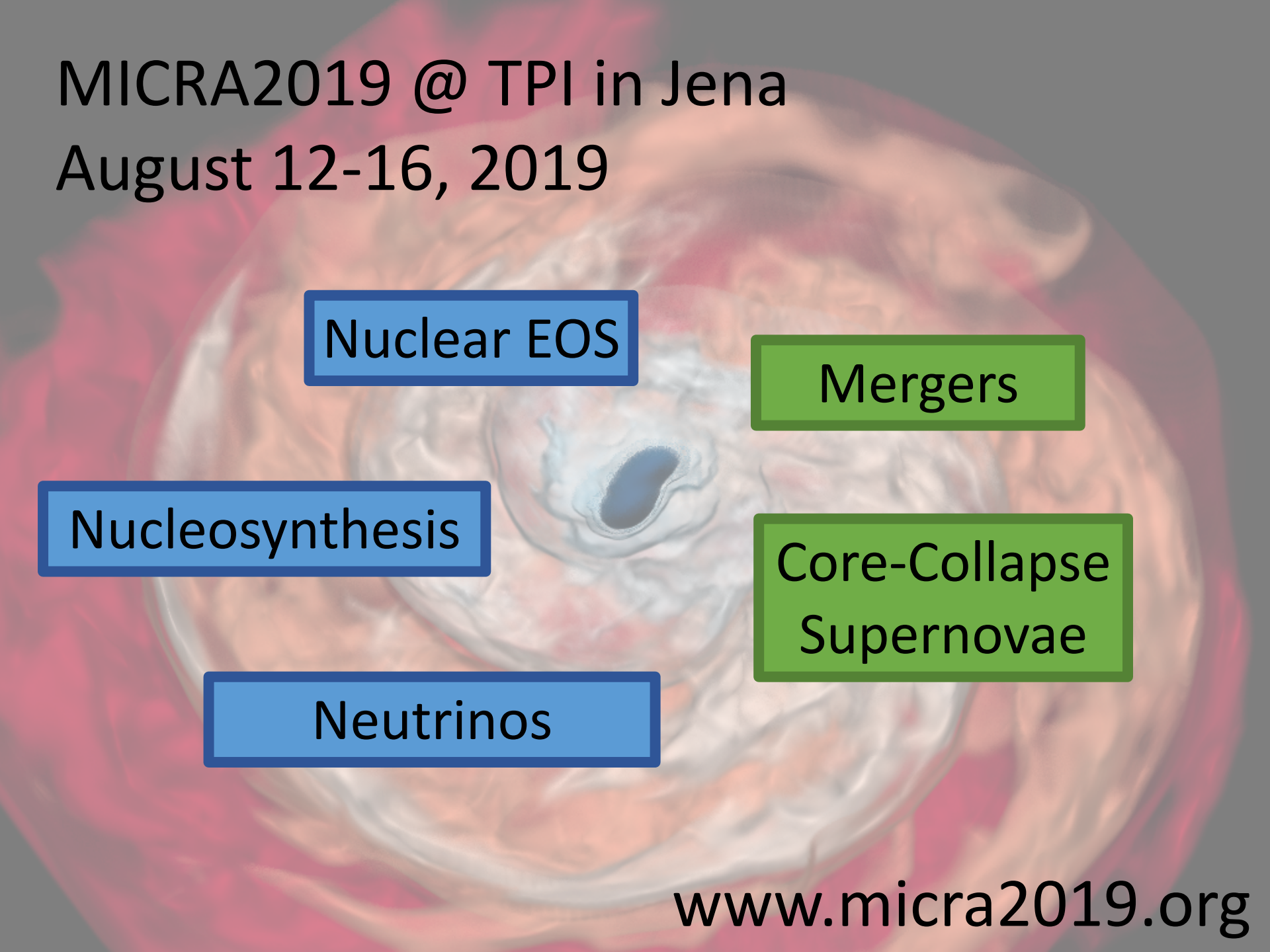


Pan et al. (2019)

MICRA2019 @ TPI in Jena
August 12-16, 2019



www.micra2019.org

Summary

- 1D global comparison raises confidence (we hope) in the community's ability to simulate SN. This is just the start of a hopefully strong effort.
- Data sets gives great test bed for new interactions, GR, systematic tests, and extension to multiD.