MULTI-MESSENGER SIGNALS FROM THE LANDSCAPE OF CORE-COLLAPSE SUPERNOVAE

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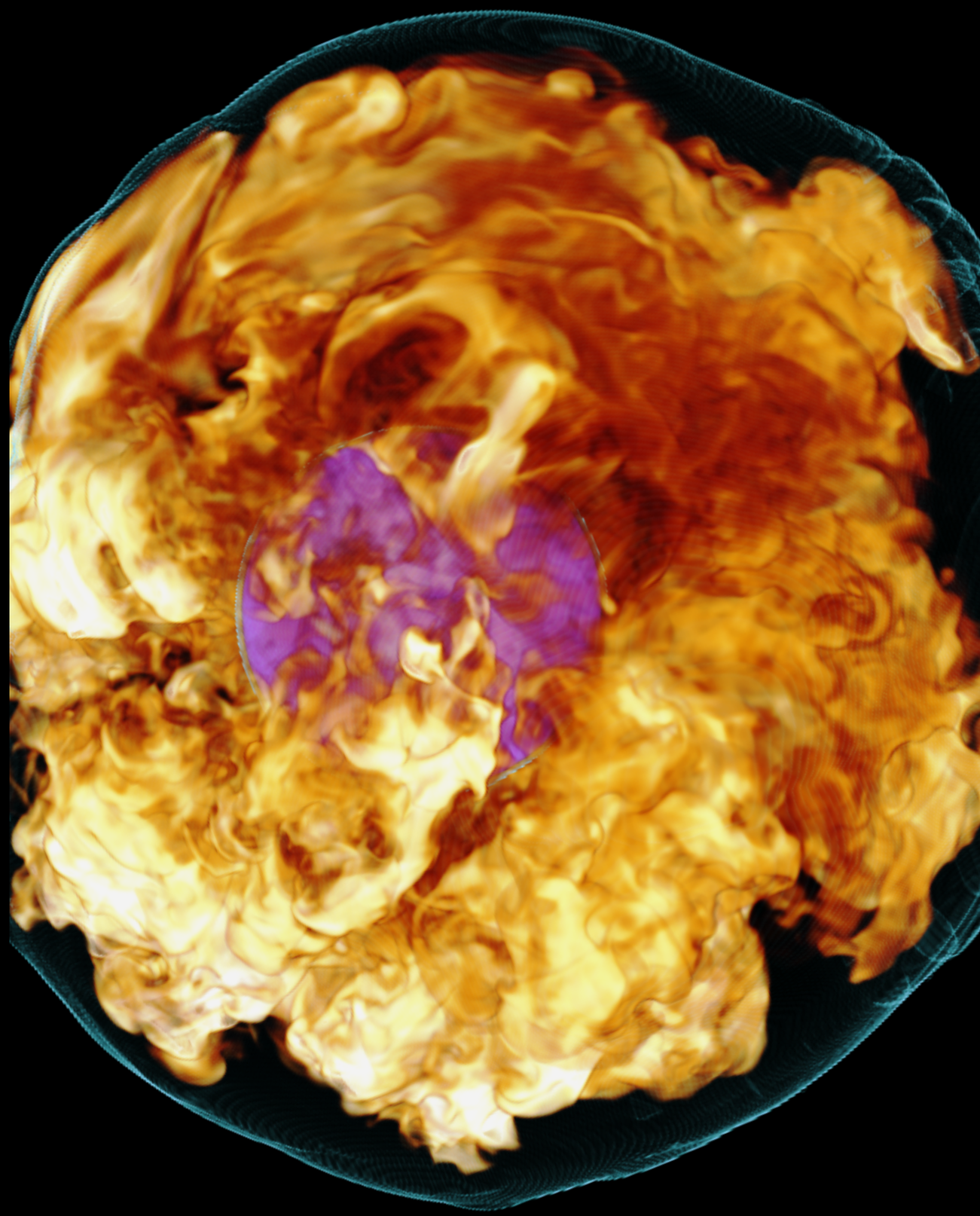
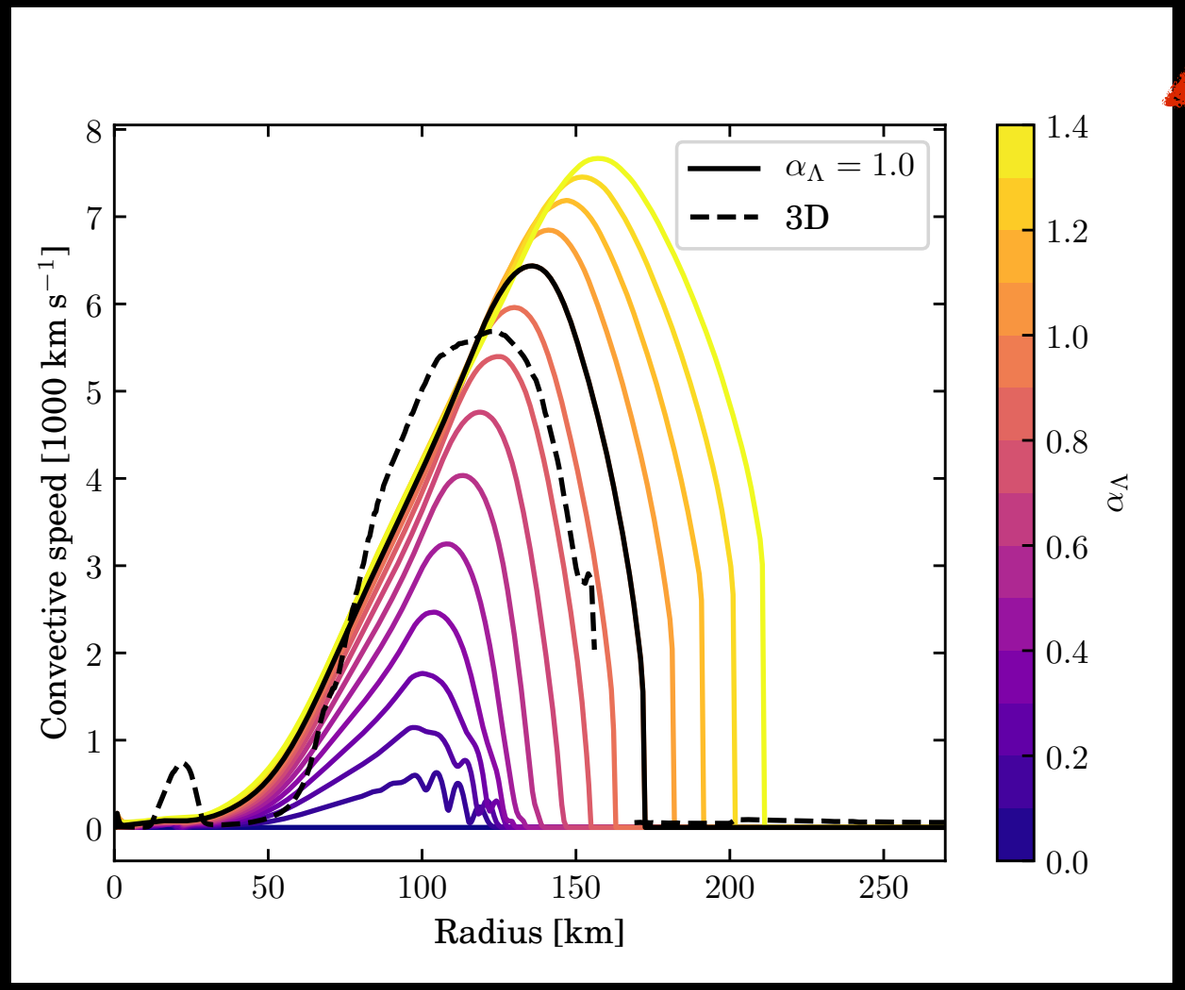
THE PROBLEM

- 3D CCSN simulations take months of supercomputer time
- Still need 1D models for…
  - Population studies, nuclear EOS, nucleosynthesis, neutrino physics, etc
- But we need to do better!



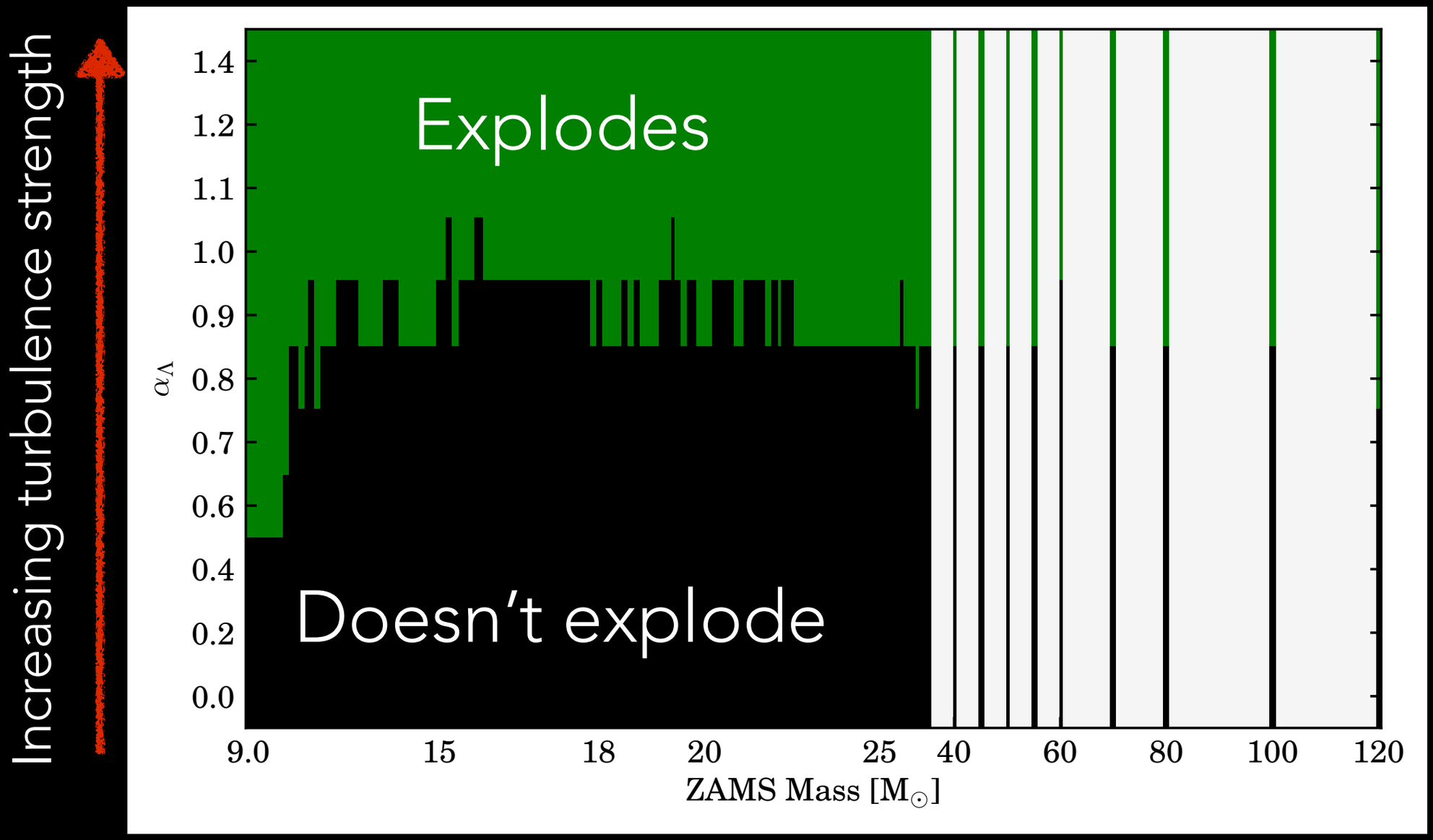
SUPERNOVA TURBULENCE IN REDUCED-DIMENSIONALITY (STIR) MODEL

- Reproduce physical explosion mechanism (turbulence and convection) in spherical symmetry
- Better replicate local thermodynamics
- Provide predictions of explodability, nucleosynthesis, neutrino spectra & luminosities, remnant mass distributions, etc, etc



Couch, Warren, & O'Connor (2019)
arXiv:1902.01340

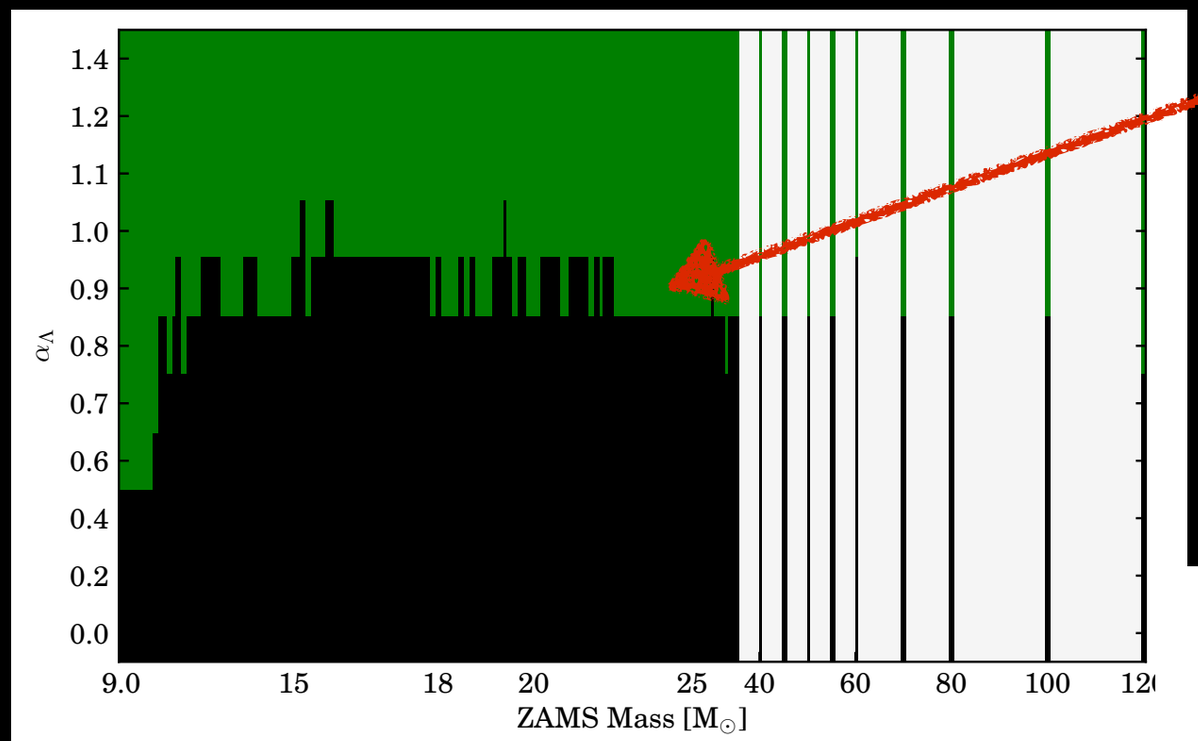
LANDSCAPE OF PROGENITORS:
EXPLODABILITY



138 progenitors (9-120 $M_\odot$) from Sukhbold et al (2016)

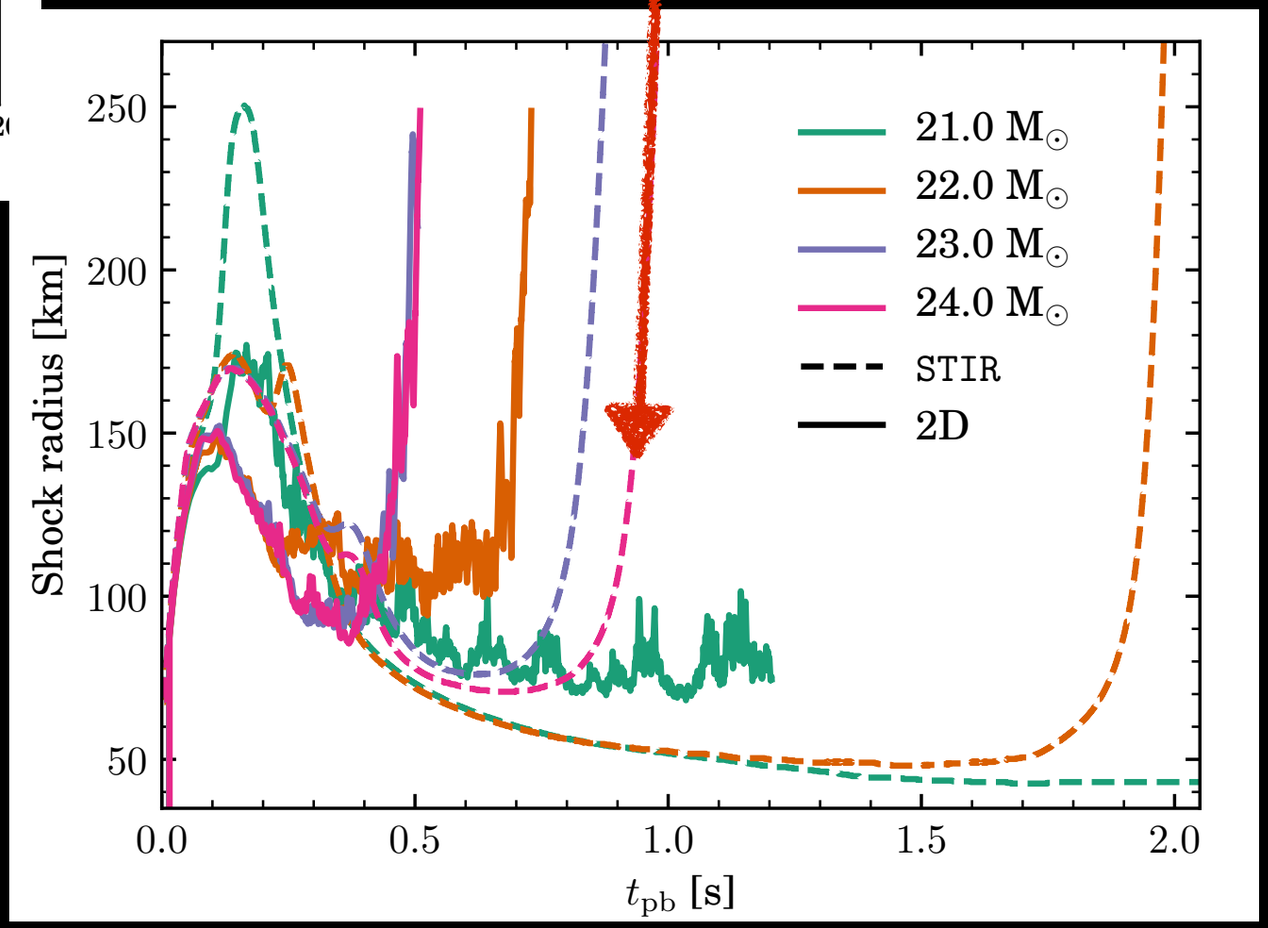
Couch, Warren, & O'Connor (2019)

LANDSCAPE OF PROGENITORS:
EXPLODABILITY

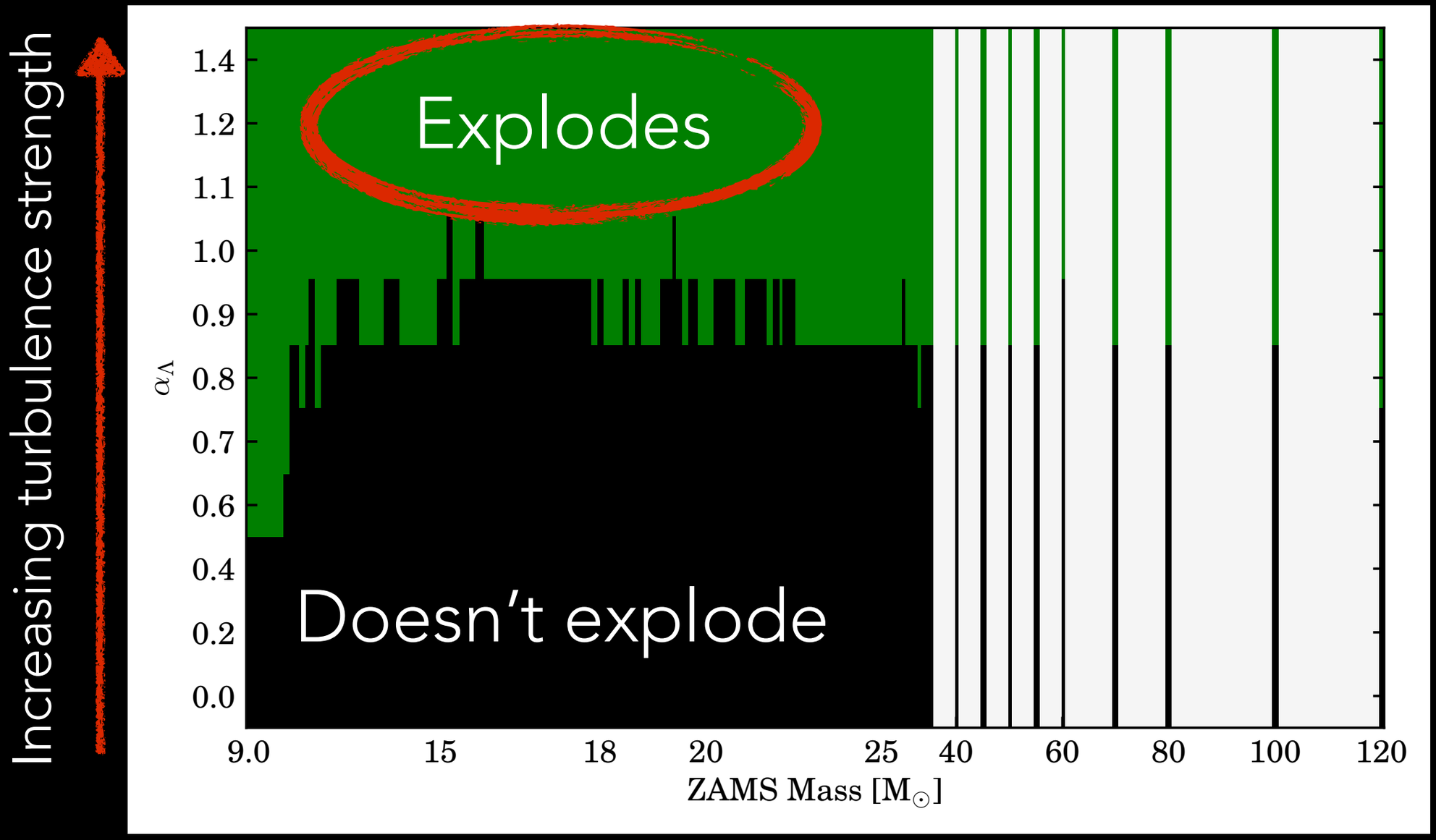


Couch, Warren, & O'Connor (2019)

20-25 $M_\odot$
explodes in 2D
(see O'Connor & Couch (2018))



LANDSCAPE OF PROGENITORS:
EXPLODABILITY



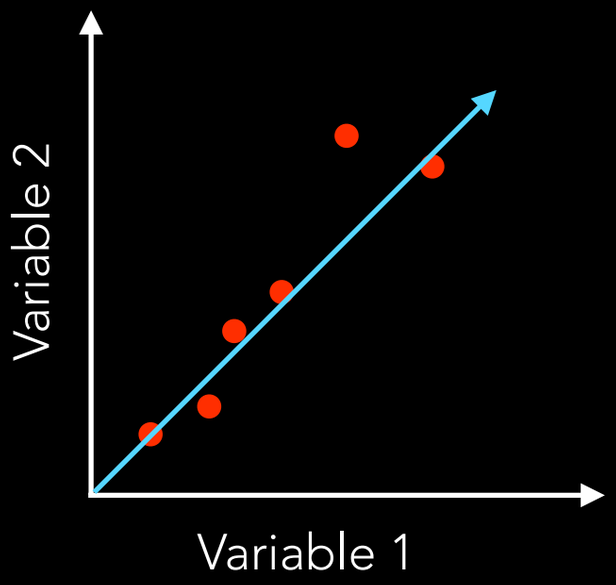
138 progenitors (9-120 $M_\odot$) from Sukhbold et al (2016)

Couch, Warren, & O'Connor (2019)

A BRIEF INTERLUDE ON CORRELATIONS

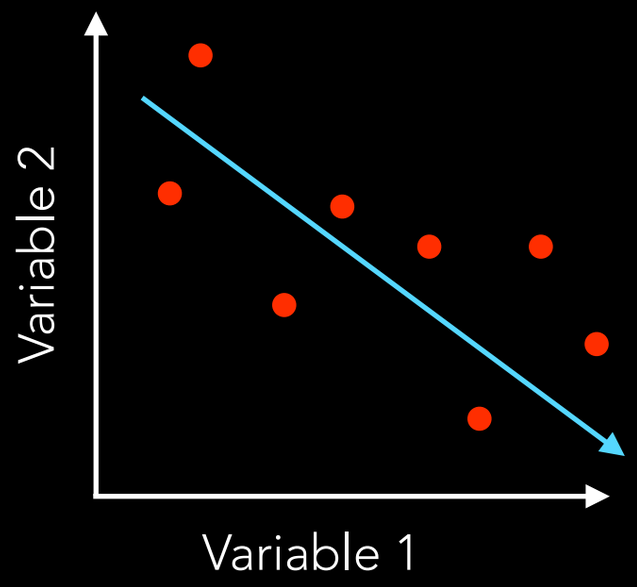
Pearson r value:

- Varies between -1 and 1
- Value tells you about *strength* of correlation
- Sign tells you about *relationship* between variables



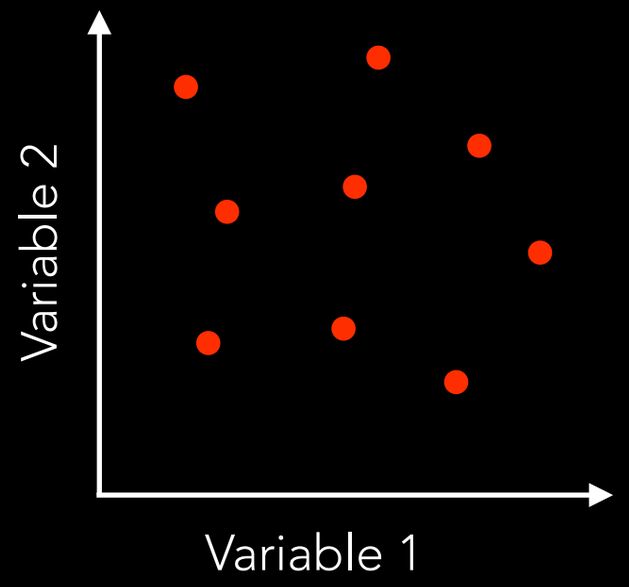
Strong, positive correlation

$r > 0.7$



Weak, negative correlation

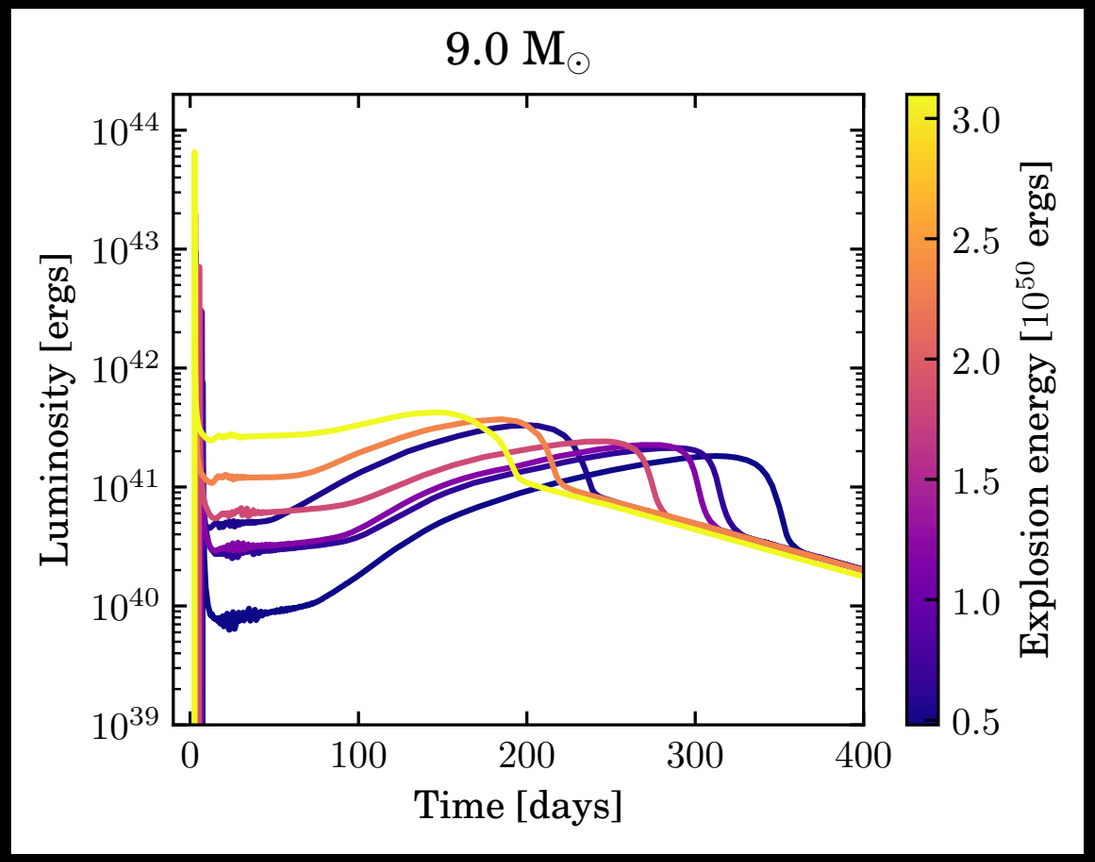
$0 > r > -0.3$



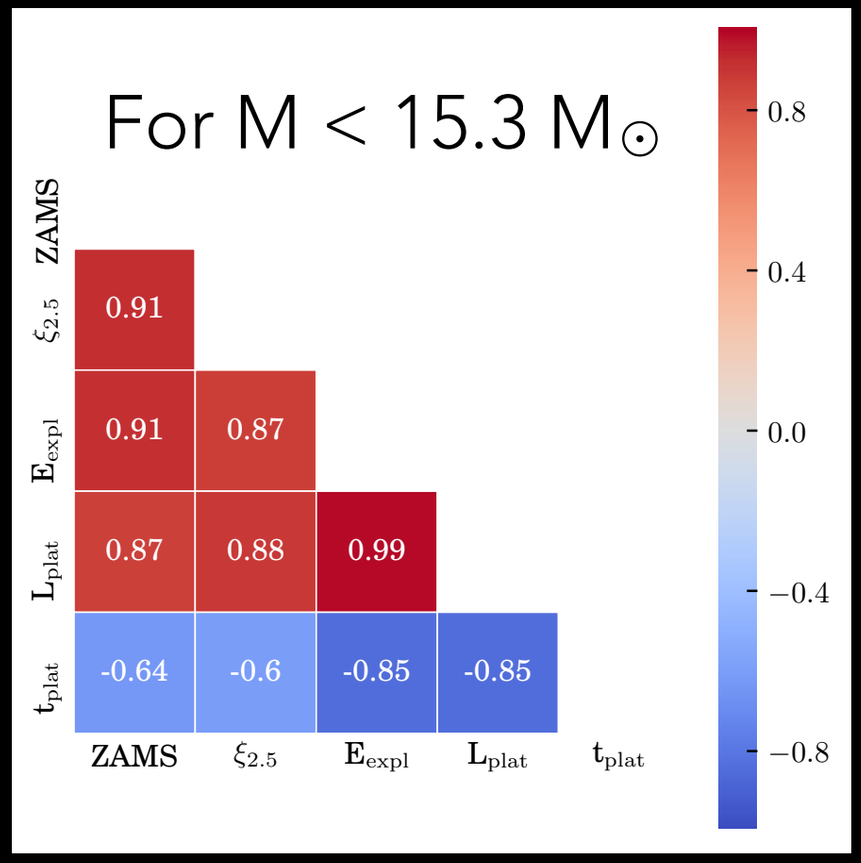
No correlation

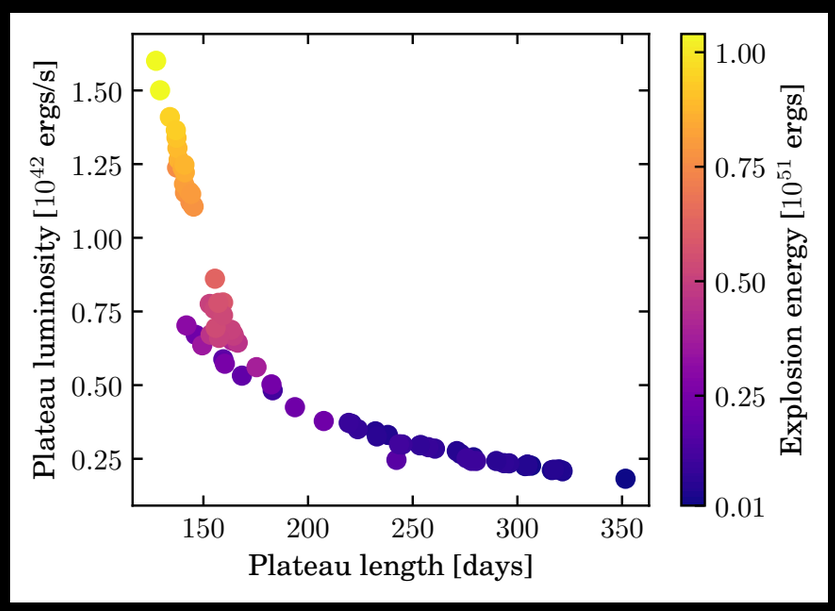
$r \sim 0$

MULTI-MESSENGER SIGNALS:
LIGHT CURVE



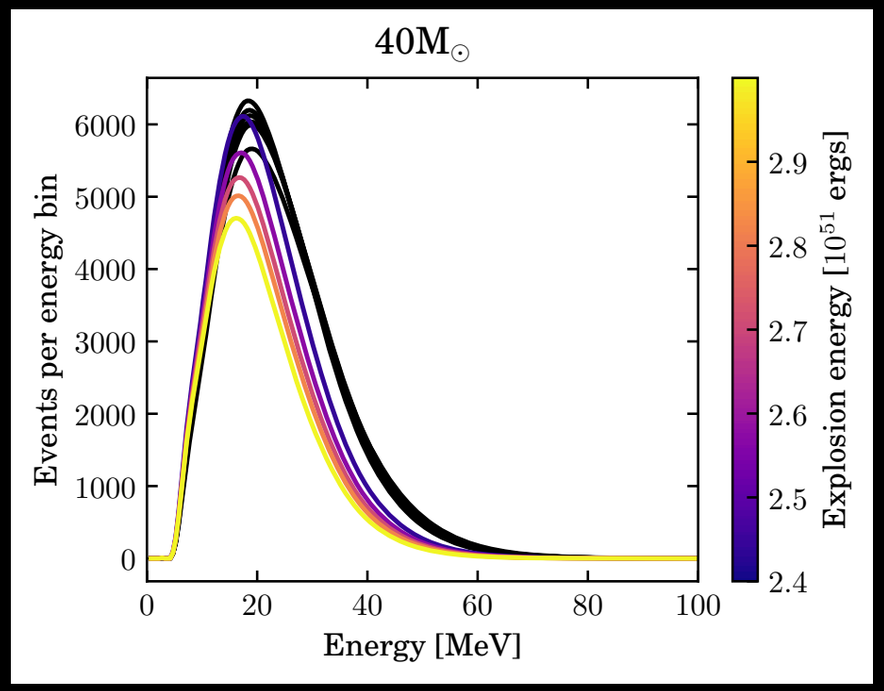
Warren, Couch, & O'Connor (in prep)

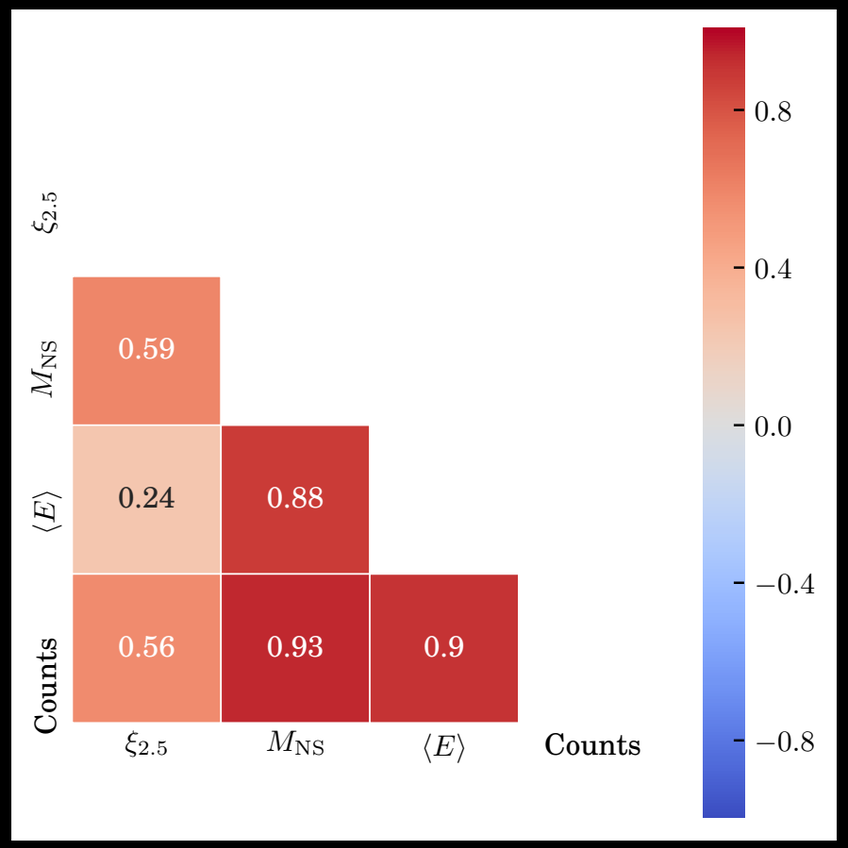




Modeled light curves with SNEC code

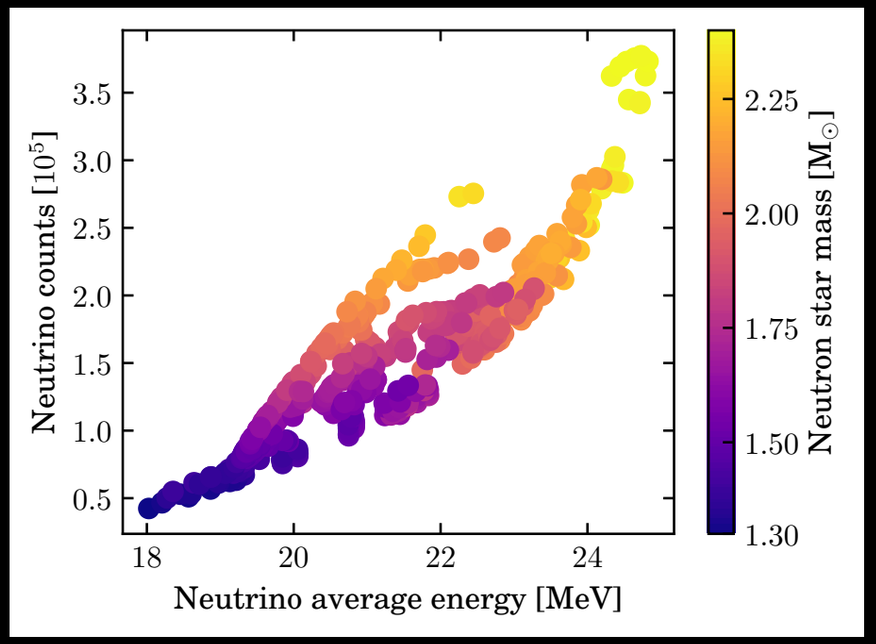
MULTI-MESSENGER SIGNALS:
NEUTRINOS



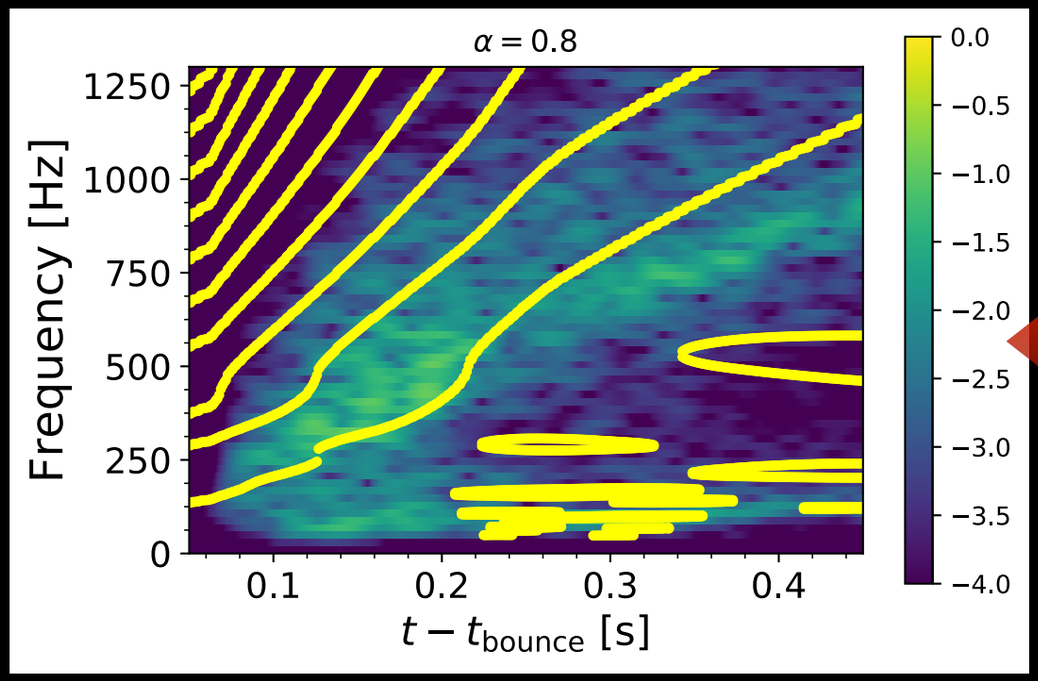


Warren, Couch, & O'Connor (in prep)

Modeled neutrino counts with SNOwGLoBES



MULTI-MESSENGER SIGNALS:
GRAVITATIONAL WAVES



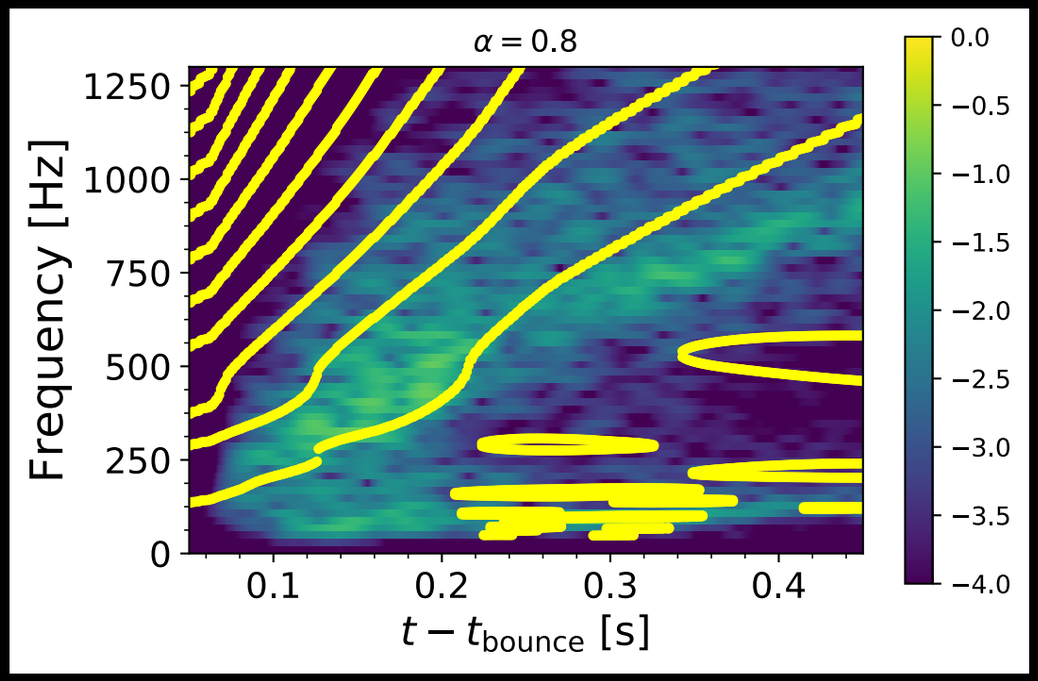
Warren, Couch, & O'Connor (in prep)

Pick out dominant GW frequency by comparison to 3D

Modeled GW emission using eigenfrequencies of PNS (Morozova et al (2018)

MULTI-MESSENGER SIGNALS:

GRAVITATIONAL WAVES



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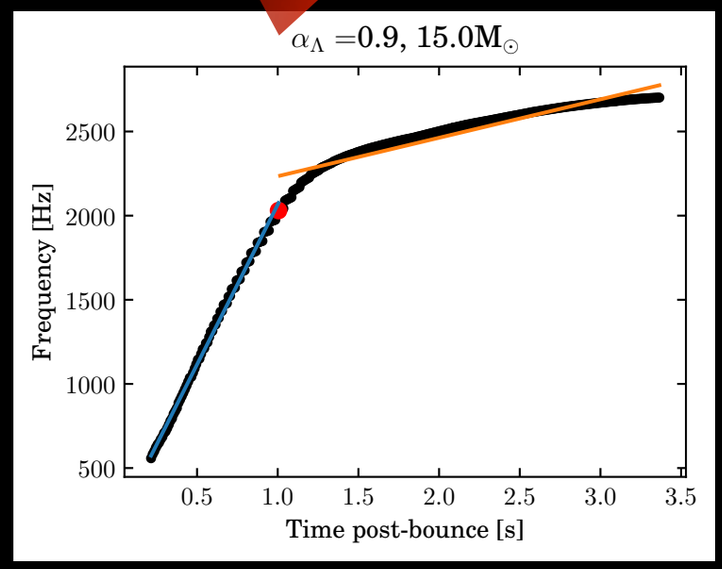
Parameterize GW evolution

Modeled GW emission using eigenfrequencies of PNS (Morozova et al (2018)



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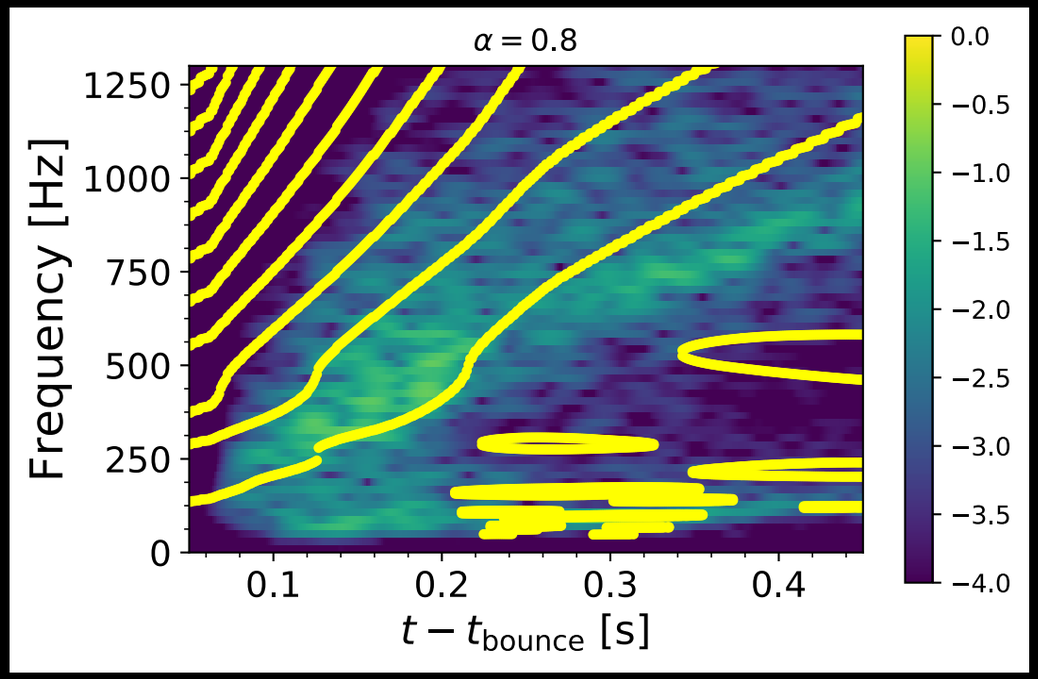

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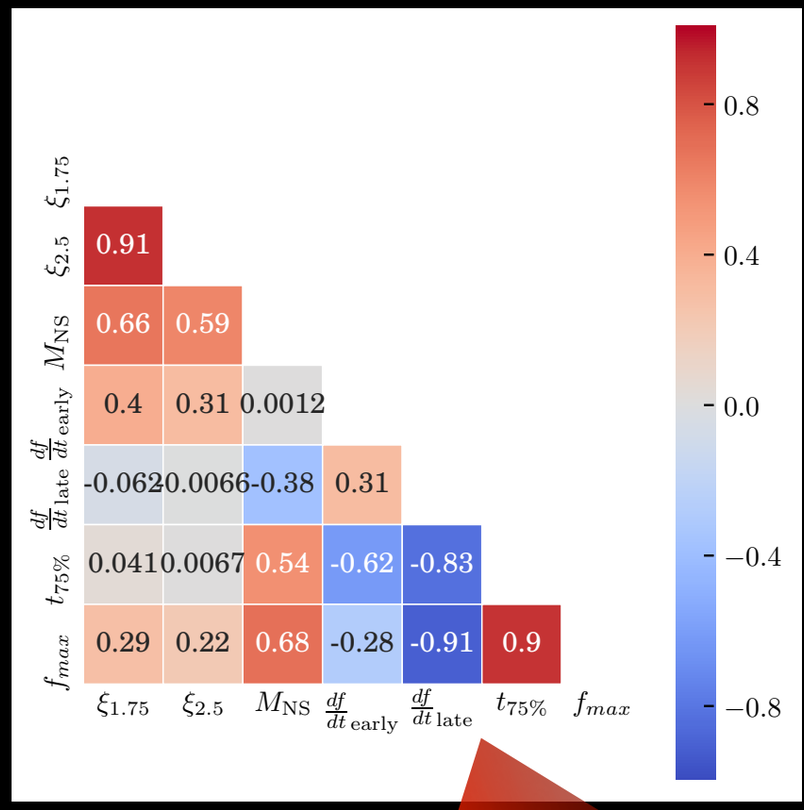
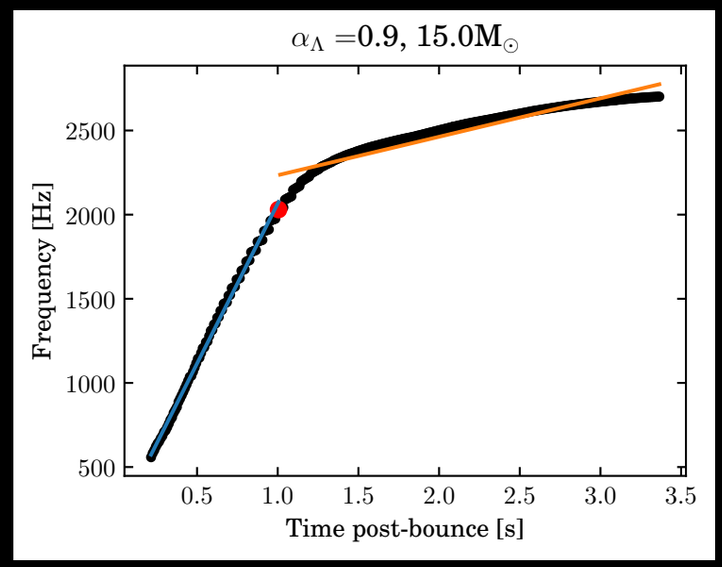
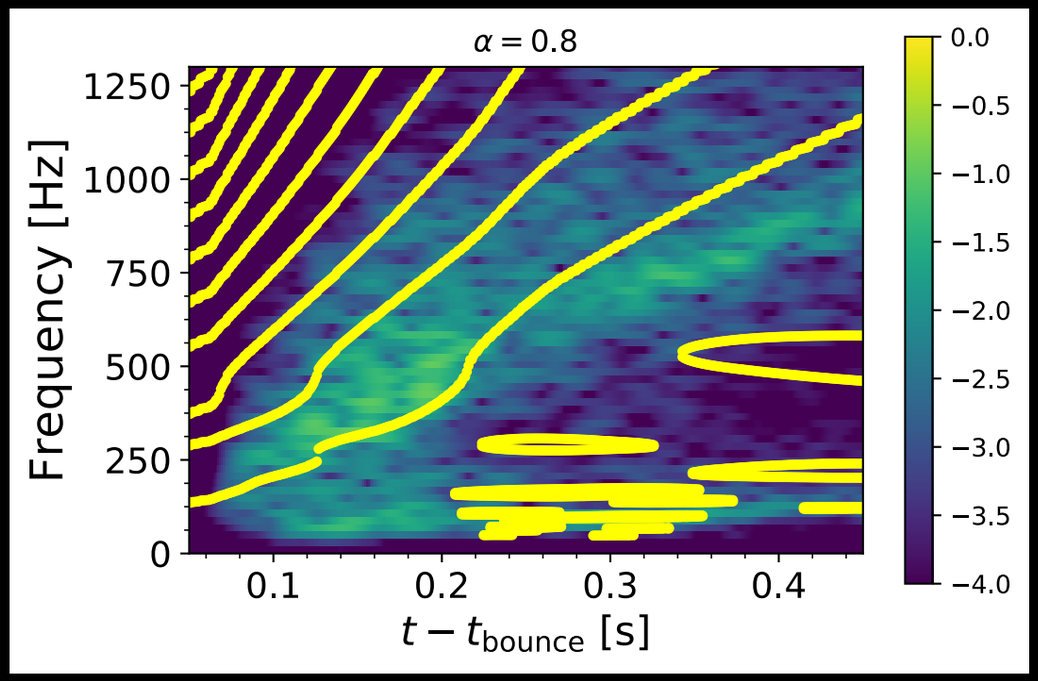


Modeled GW emission using eigenfrequencies of PNS (Morozova et al (2018)



Explore correlations

MULTI-MESSENGER SIGNALS:
GRAVITATIONAL WAVES



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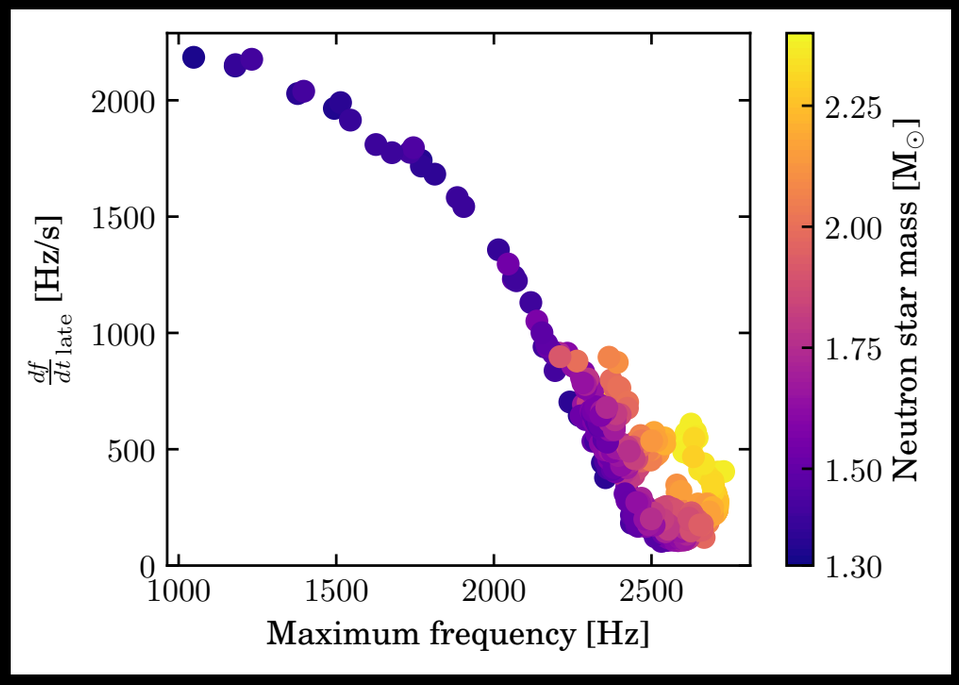

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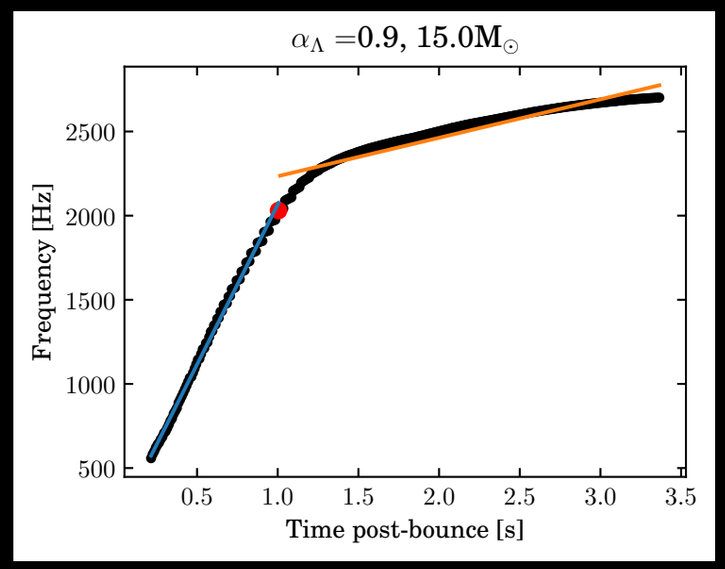
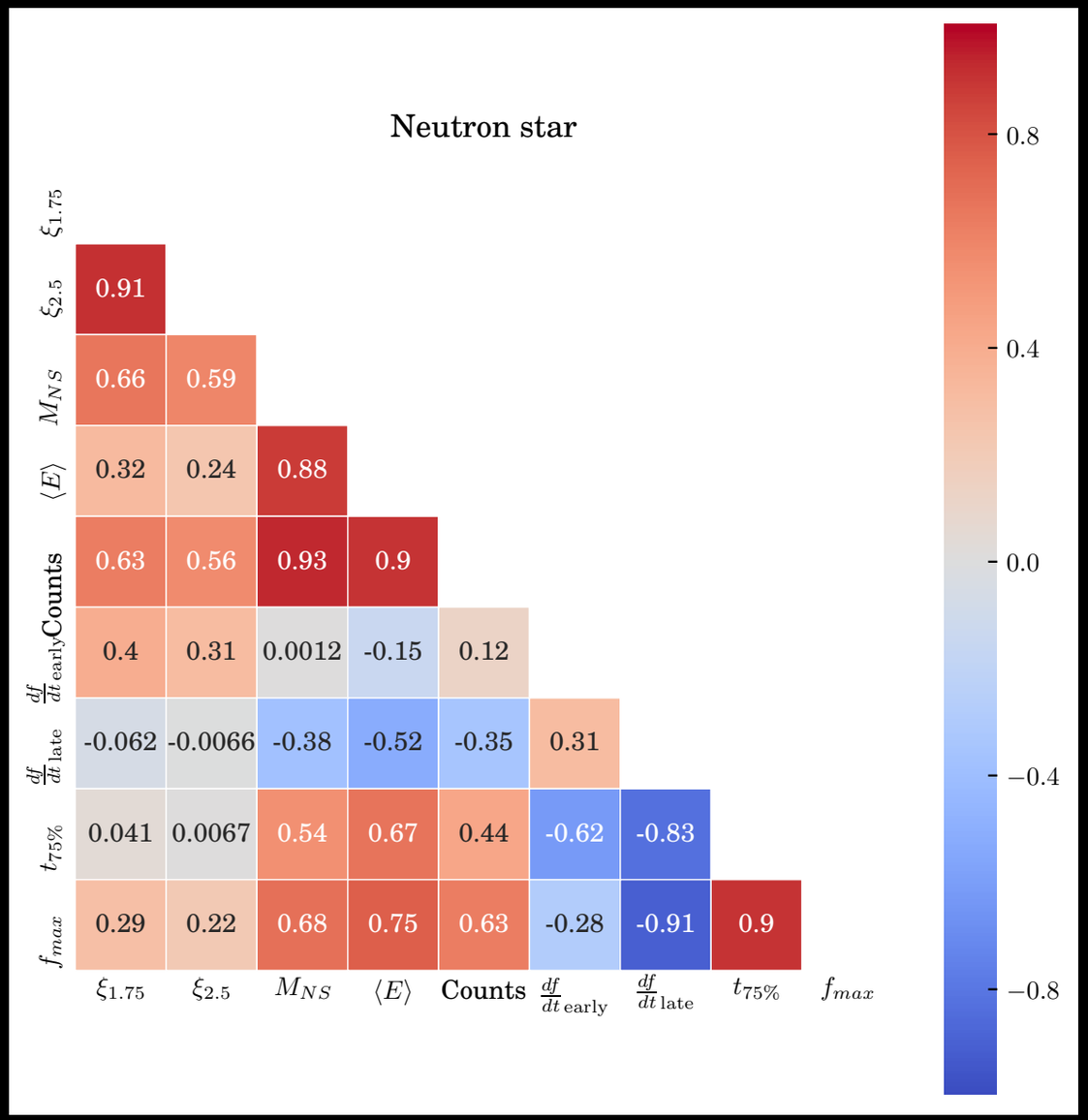
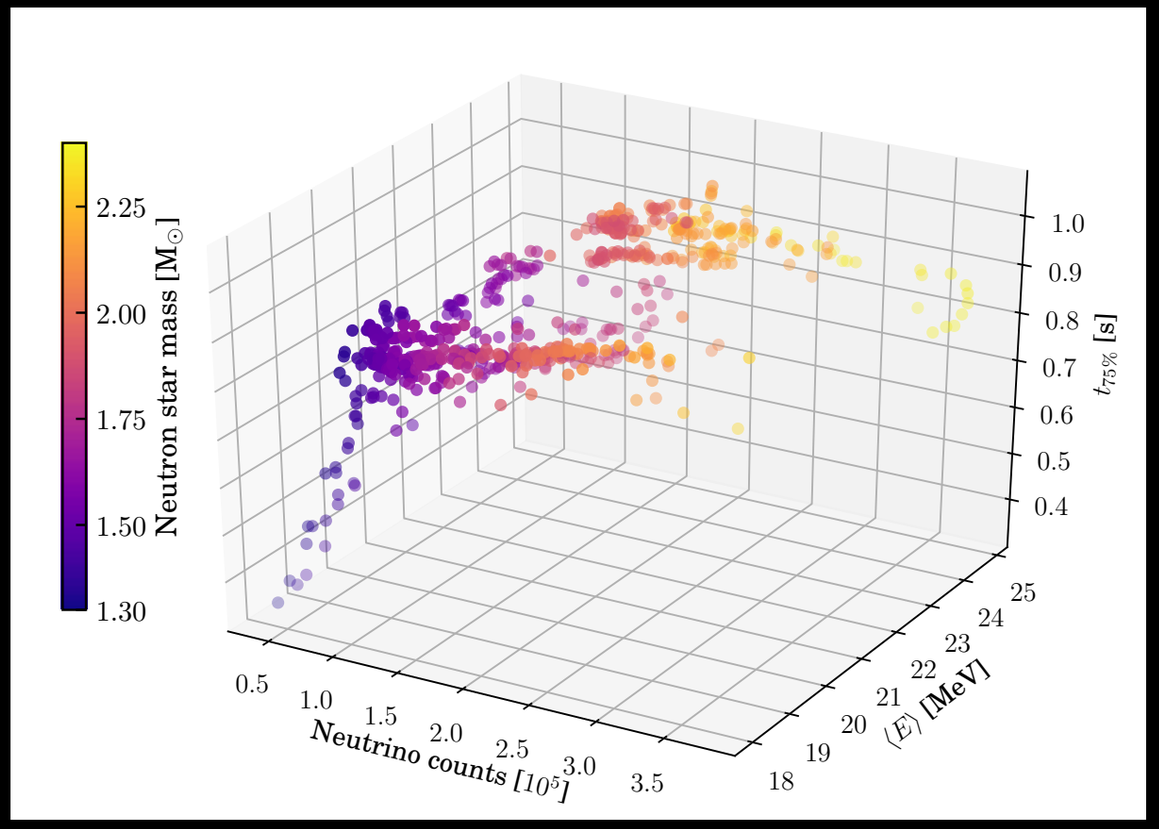


Find new way to determine NS mass

MULTI-MESSENGER SIGNALS:
COMBINED ANALYSIS





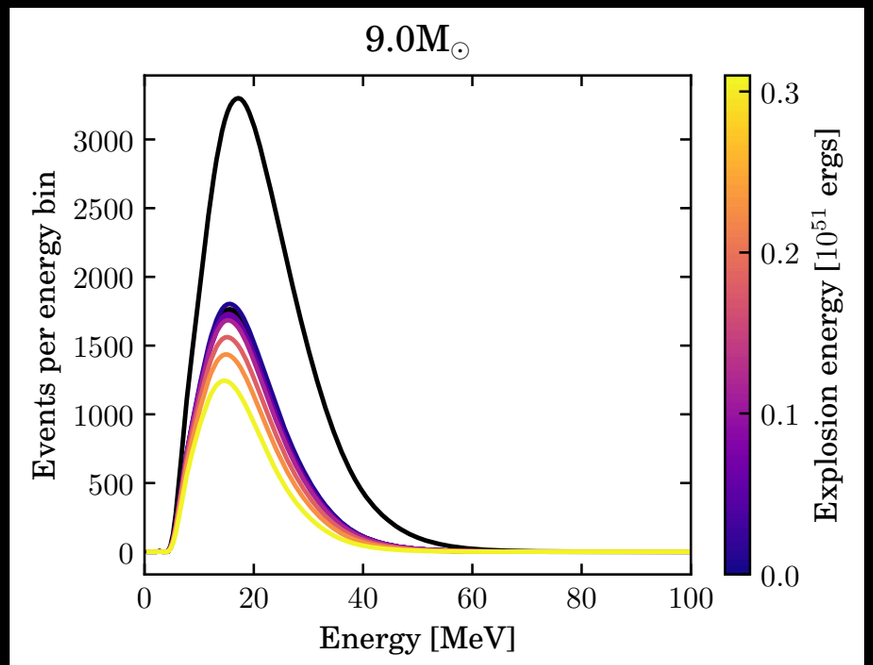
Warren, Couch, & O'Connor (in prep)

WHAT'S NEXT?

- Have predictions for large range of CCSN (9-120 $M_{\odot}$):
  - Neutrino signals
  - Gravitational wave signals
  - Light curves
  - Remnant object mass distributions
- We are also investigating (Ask me later!):
  - Failed explosions
  - Effects of neutrino flavor mixing
  - Sensitivity to nuclear EOS
- Still to do:
  - Sensitivities to metallicity, rotation, magnetic fields, binarity, etc
  - Nucleosynthesis and implication for GCE

THANK YOU!

MULTI-MESSENGER SIGNALS:
NEUTRINOS



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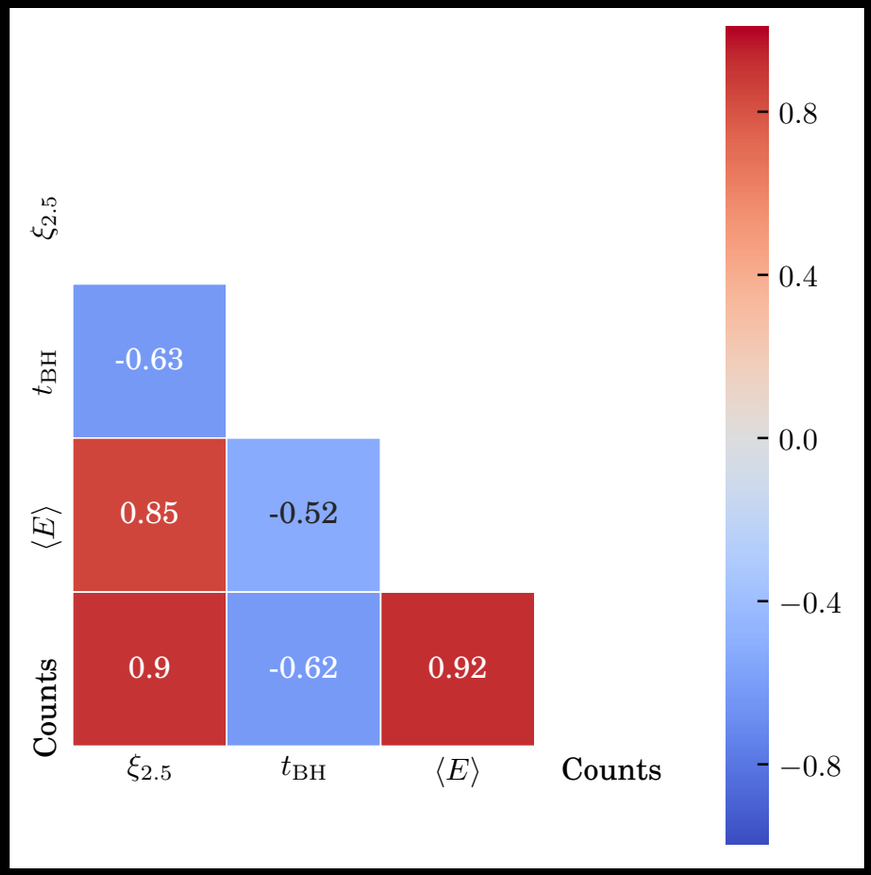

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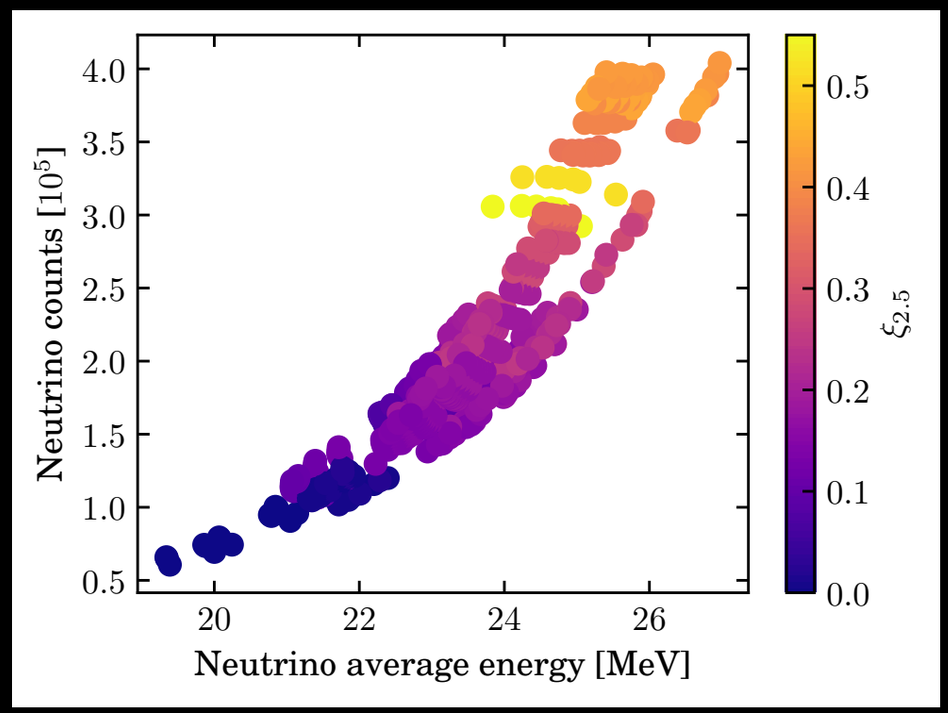

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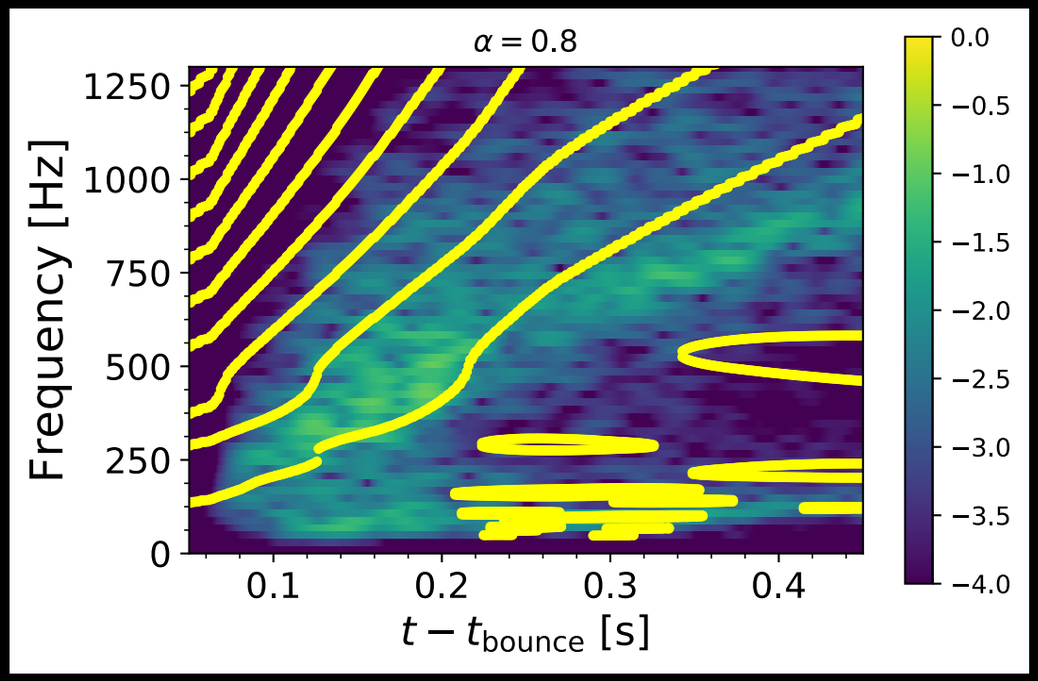
GRAVITATIONAL WAVES



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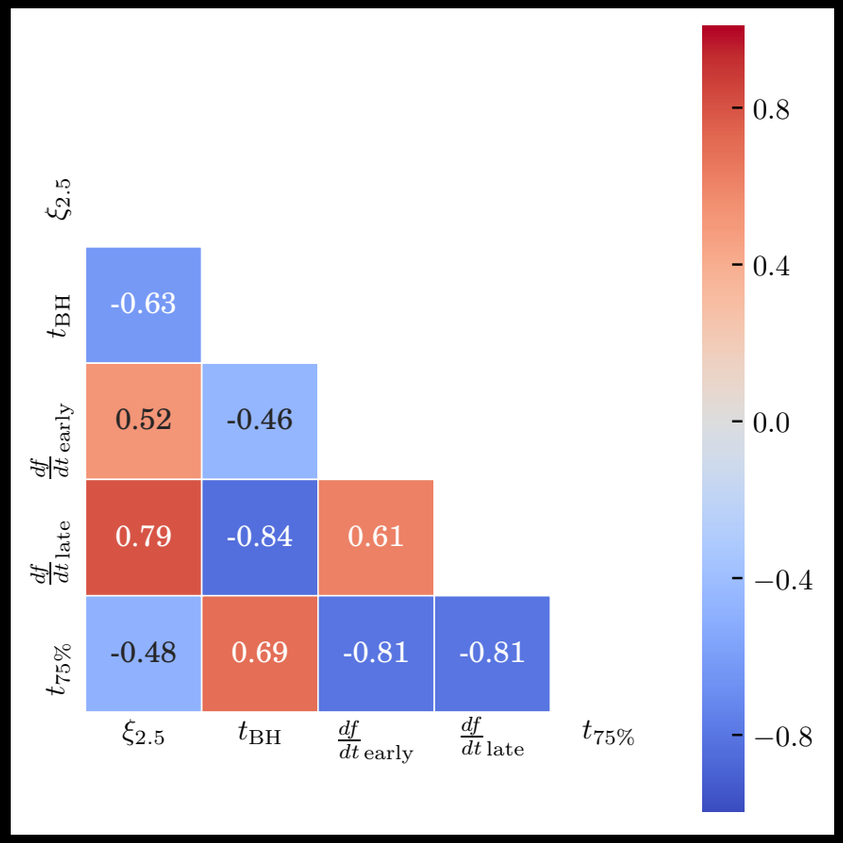
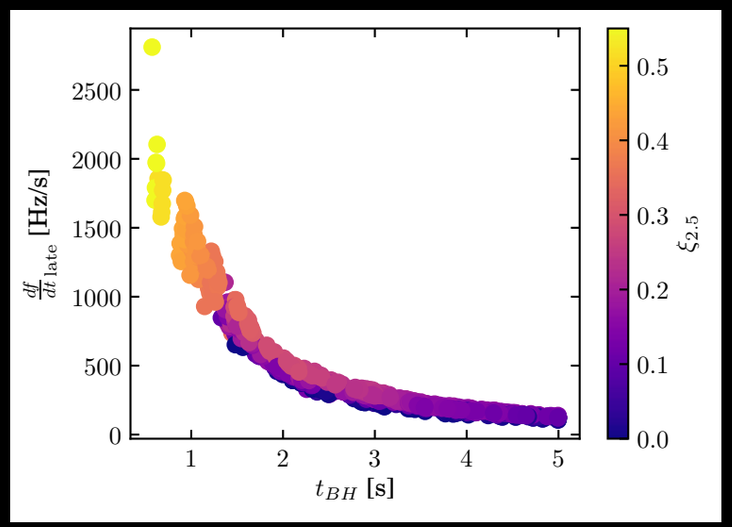
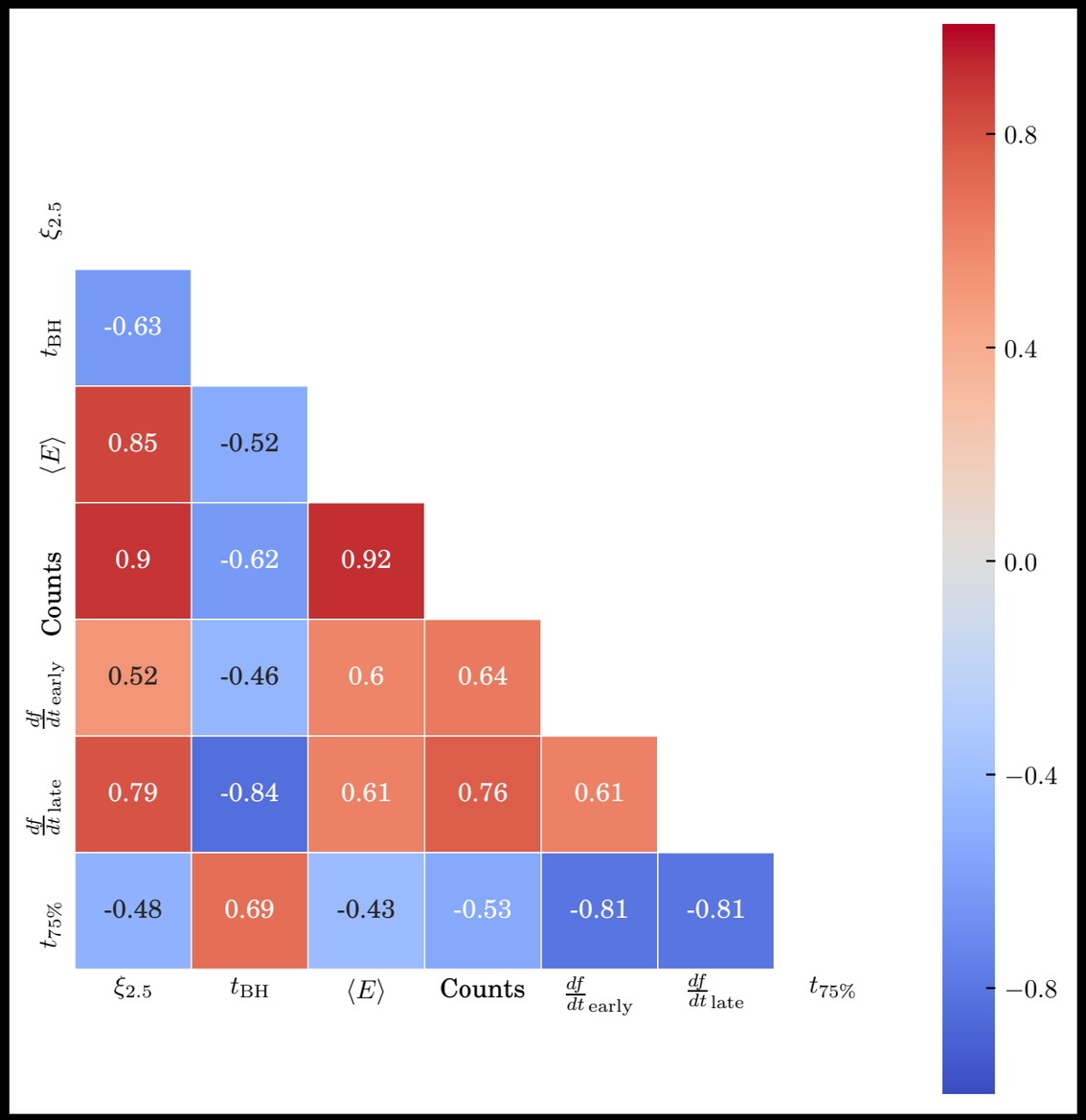
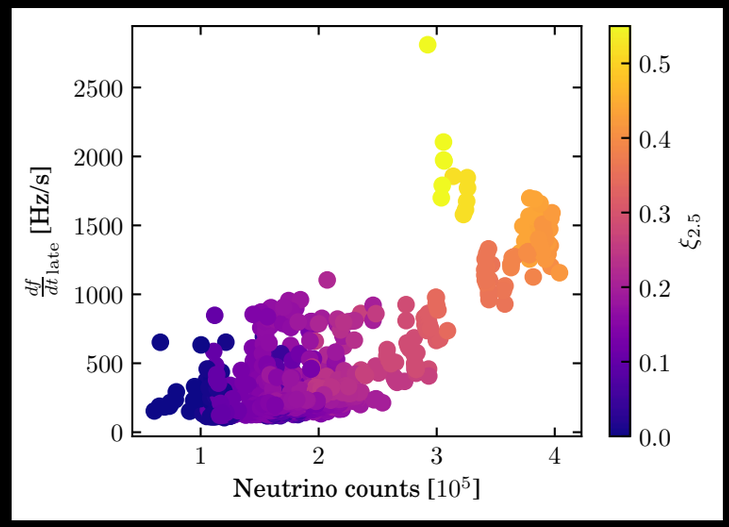


Modeled GW emission as described in Morozova et al (2018)



MULTI-MESSENGER SIGNALS:
COMBINED ANALYSIS

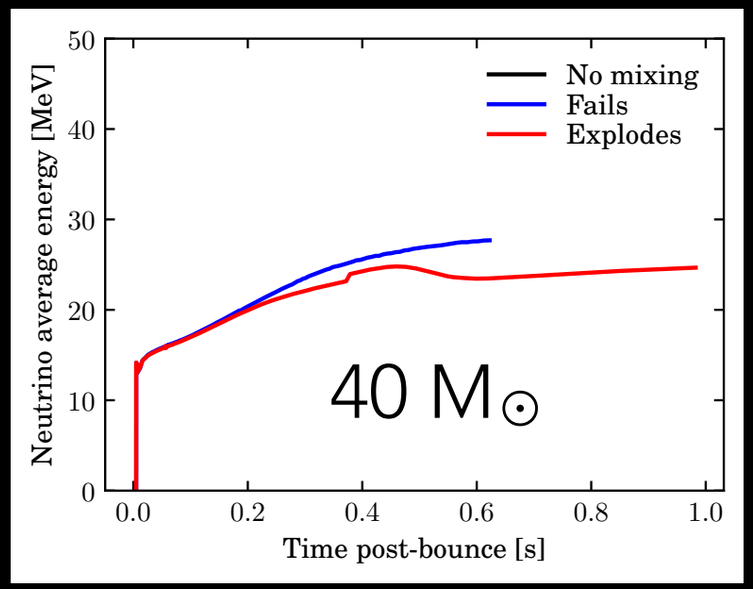




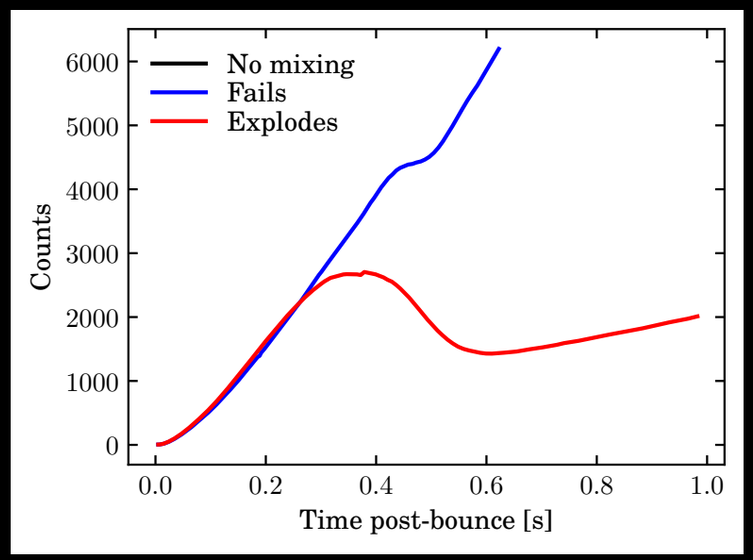
Warren, Couch, & O'Connor (in prep)

FURTHER COMPLICATIONS:

NEUTRINO FLAVOR MIXING



Often try to use neutrino emission to distinguish between progenitors, EOS, etc…

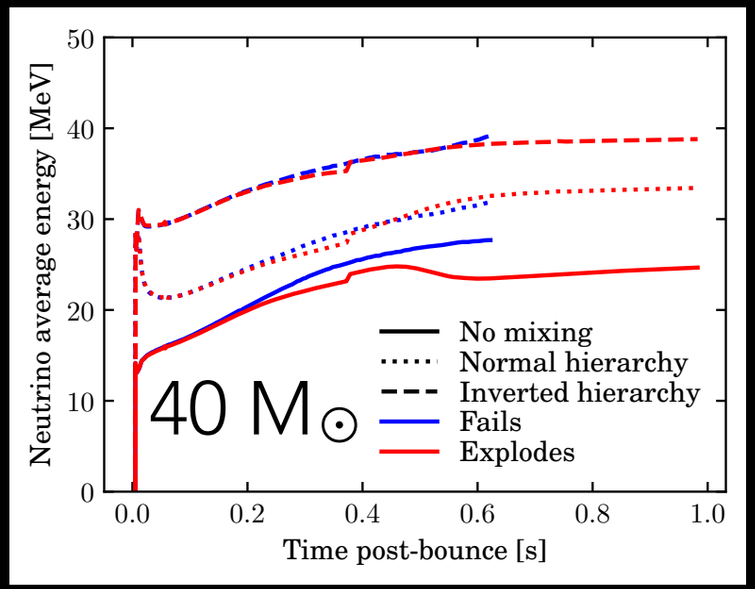


But CCSN models do not currently include neutrino flavor mixing.

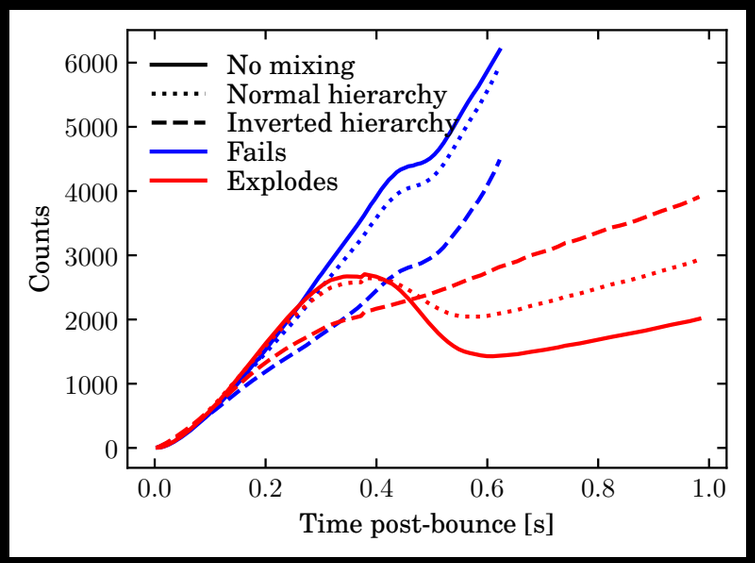
Warren, Couch & O'Connor (in prep)

FURTHER COMPLICATIONS:

NEUTRINO FLAVOR MIXING



However, we still have another window: gravitational waves



Can break the degeneracy with correlated neutrino & gravitational wave signals

**Considering *only* MSW mixing in stellar envelope

Warren, Couch & O'Connor (in prep)

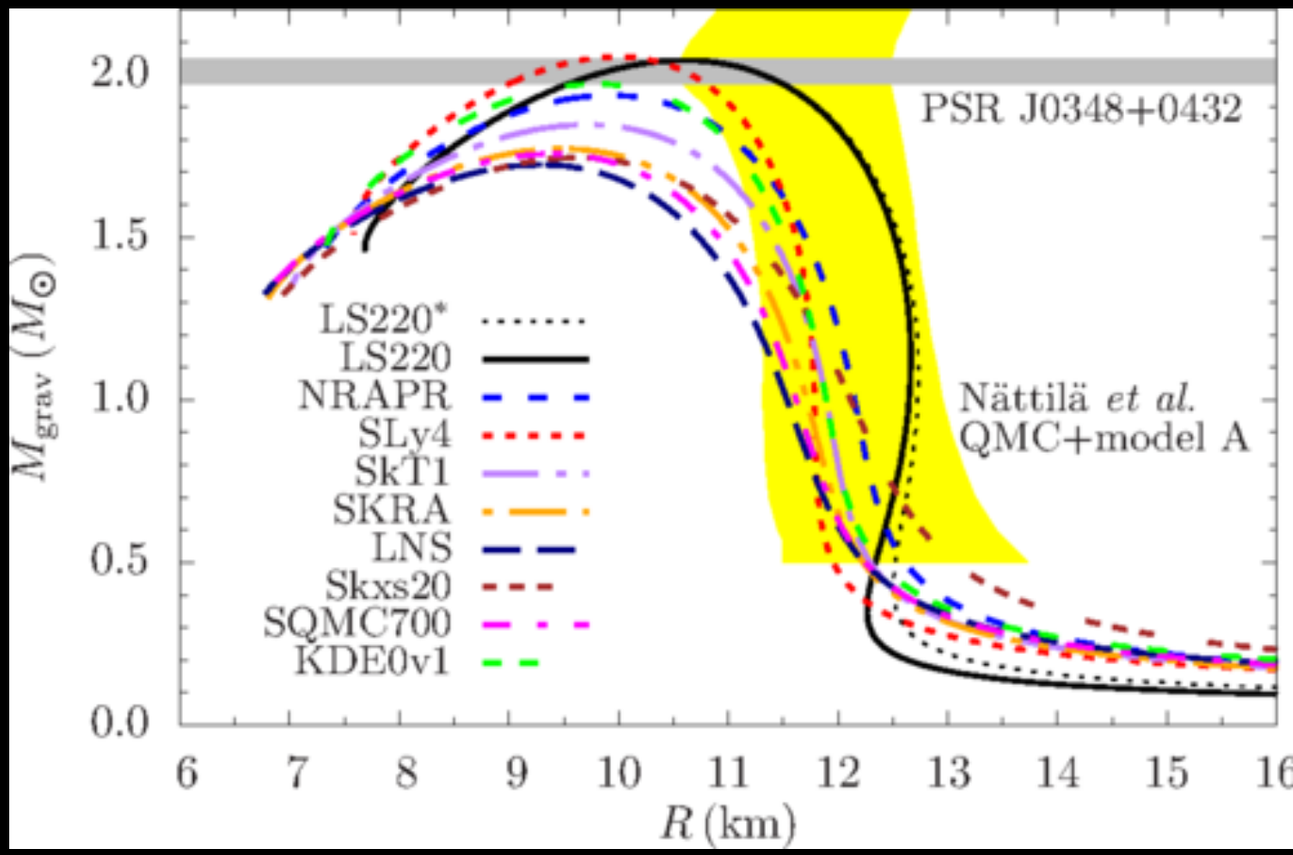
What can we learn from multi-messenger signals?

EOS SENSITIVITIES

Brandon Barker

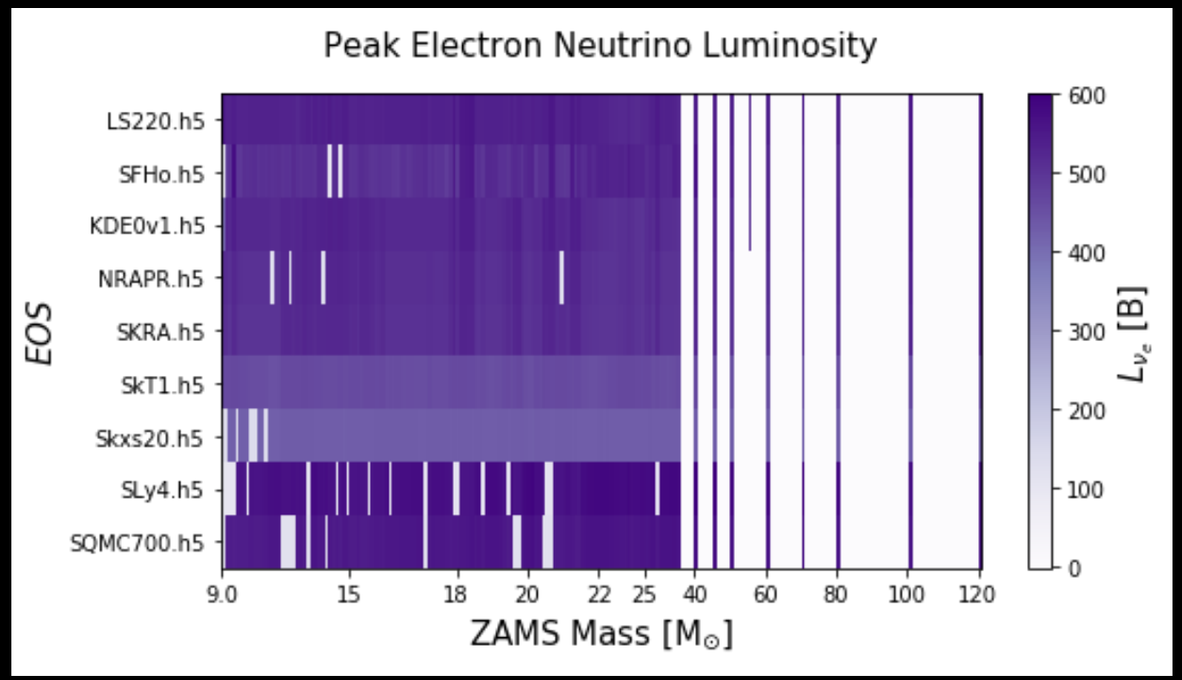
Theo Cooper

- Want to explore sensitivity of CCSNe to uncertainties in the nuclear EOS
- Several parameters are constrained by experiment and "characterize" EOS
  - Saturation density n_0
  - Incompressibility K_0
  - Symmetry energy J

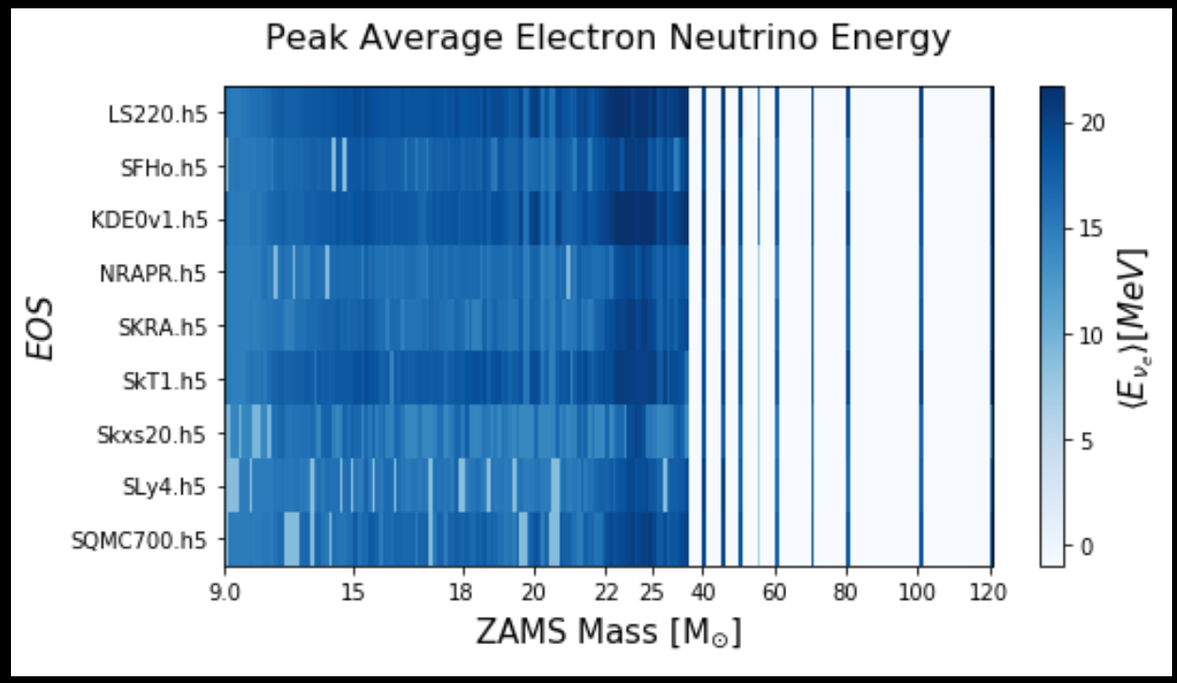


Schneider et al (2017)

EOS SENSITIVITIES



Using “best fit” convection parameters from 3D fitting

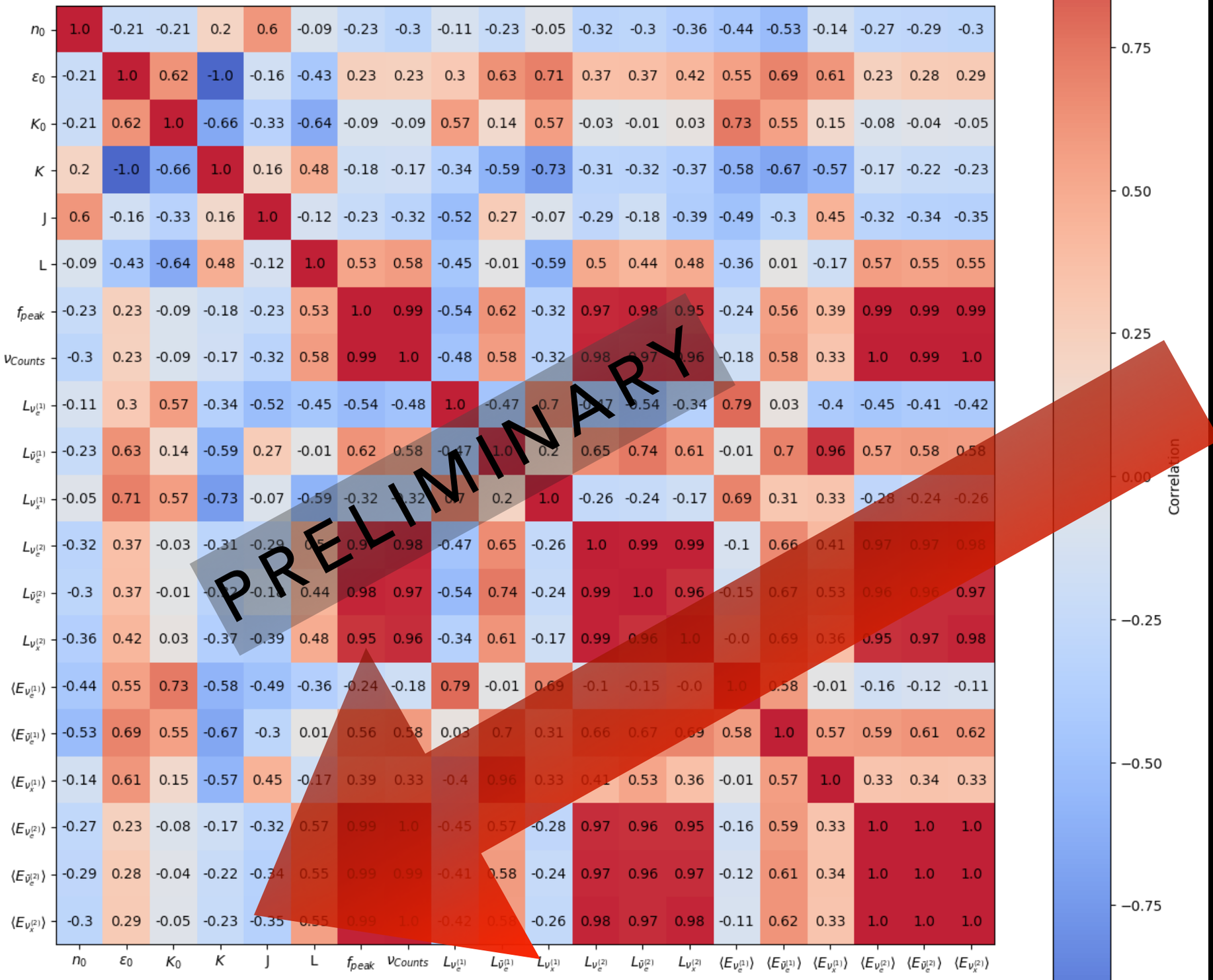


DFT EOSs from Schneider et al (2017)

Warren, Barker, Cooper, et al (in prep)

What can we learn from multi-messenger signals?

EOS SENSITIVITIES



Include nuclear physics parameters *directly* in our correlation calculations

Warren, Barker, Cooper, et al (in prep)