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Title:	Understanding Core-Collapse Supernovae
Author(s):	Fryer, Christopher Lee
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Understanding Core-Collapse Supernovae

Chris Fryer

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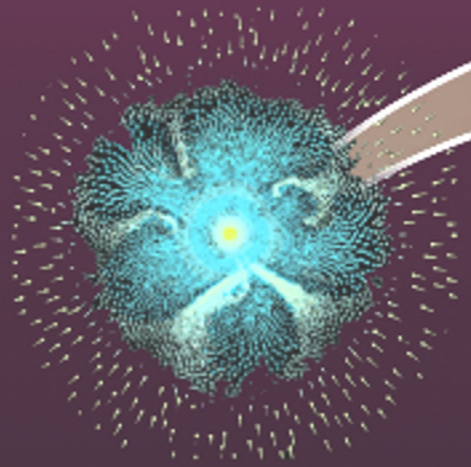
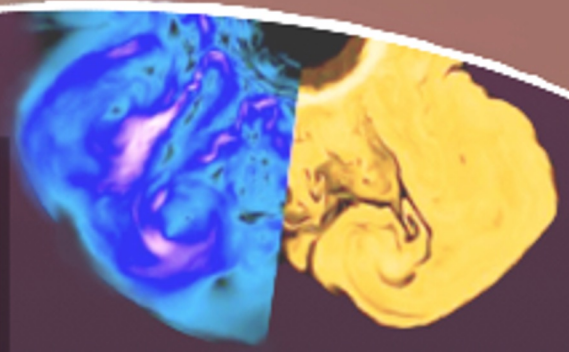




CCSN Phase
Followups / studies
- Diagnostics
  Observables

WHAT WE NEED TO KNOW:
- ✓ Condensed matter
- ✓ Neutrino physics
- ✓ General Relativity
- ✓ Magnetohydrodynamic
- ✓ Plasma Turbulence
- ✓ Nuclear physics
- ✓ Cosmic-ray acceleration
- ✓ Radiation transport
- ✓ Chemistry of Galactic dust

Phase I – Core collapse

Radio followup (pulsars)
X-ray followup (binaries)
Multimessenger detections

- Prompt emission
  Gravitational waves
  MeV Neutrinos
- Compact remnants
  Mass and spin (through GW, radio and X-ray observations)

Phase II – Propagation of the blastwave through the star

EM followup for stellar abundance patterns
Dust study (in lab and with SN observations)

- Shock breakout
  UVOIR and X-ray light curves, spectra
- Nucleosynthetic yields
  Galactic dust composition
  Galactic chemical evolution

Phase III –Propagation of the blastwave through the circumstellar medium

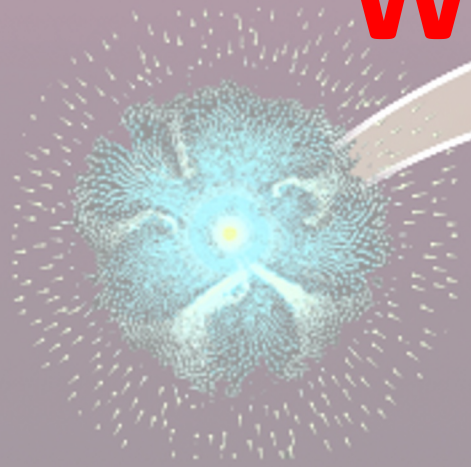
Broad band followup (Radio – gamma-ray)

- Temporal evolution of emitted radiation
  Light curves and spectra
- Supernova remnant
  Light curves, spectra (lines)
  Imaging of morphology (asymmetric explosions)
  Polarimetry (magnetic fields structure)

Understanding Core-Collapse Supernovae

With Cosmic Explorer

Chris Fryer



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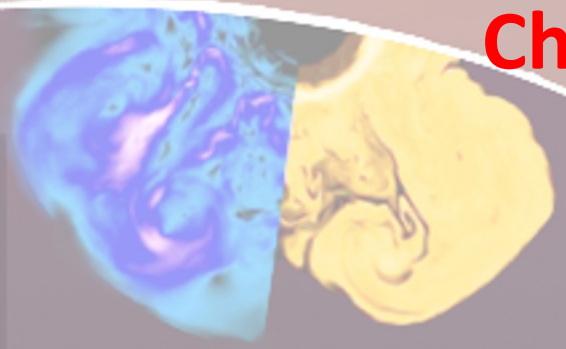

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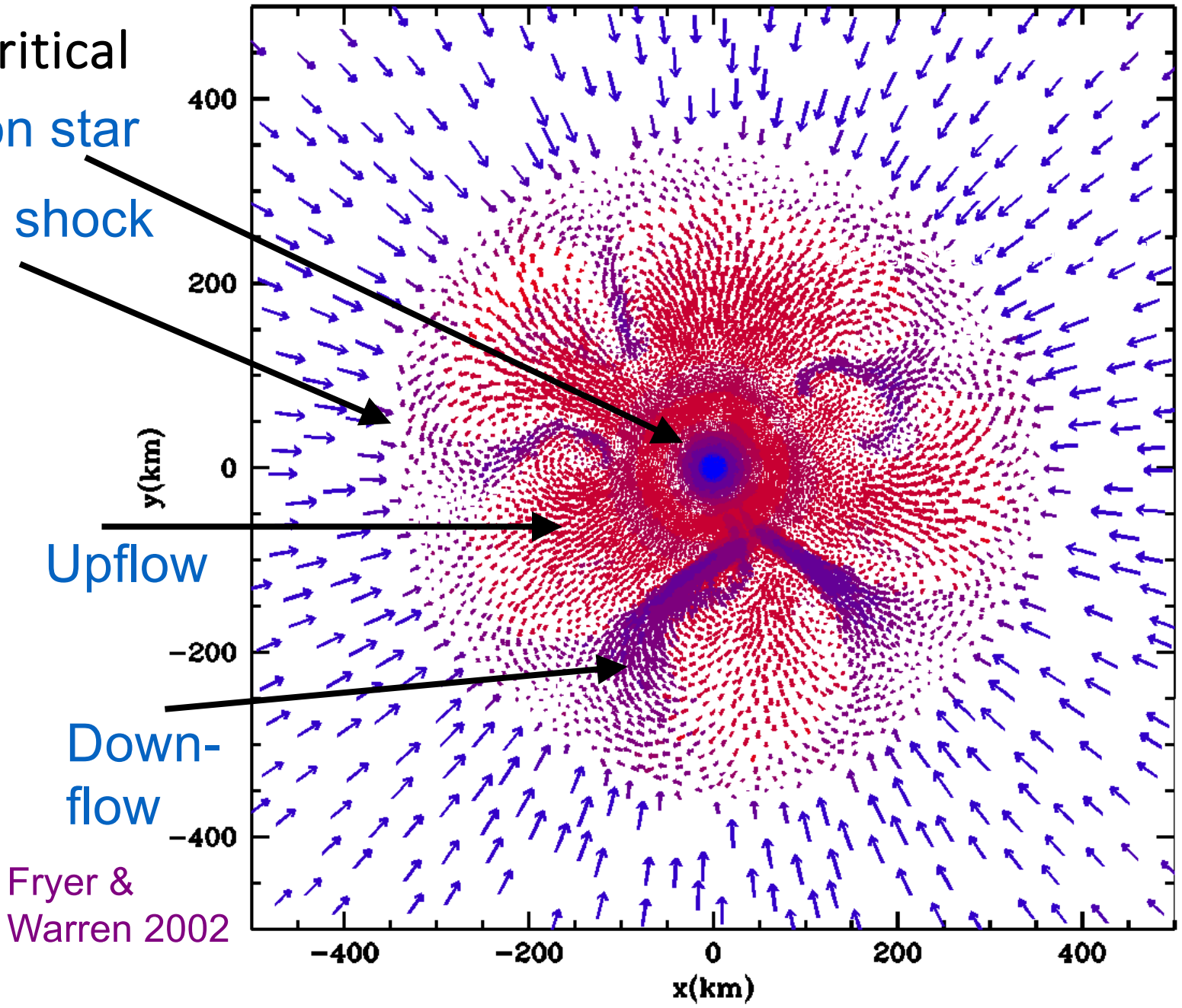
The Herant et al. 1994 solution: Convection Critical



Fryer & Warren 2002

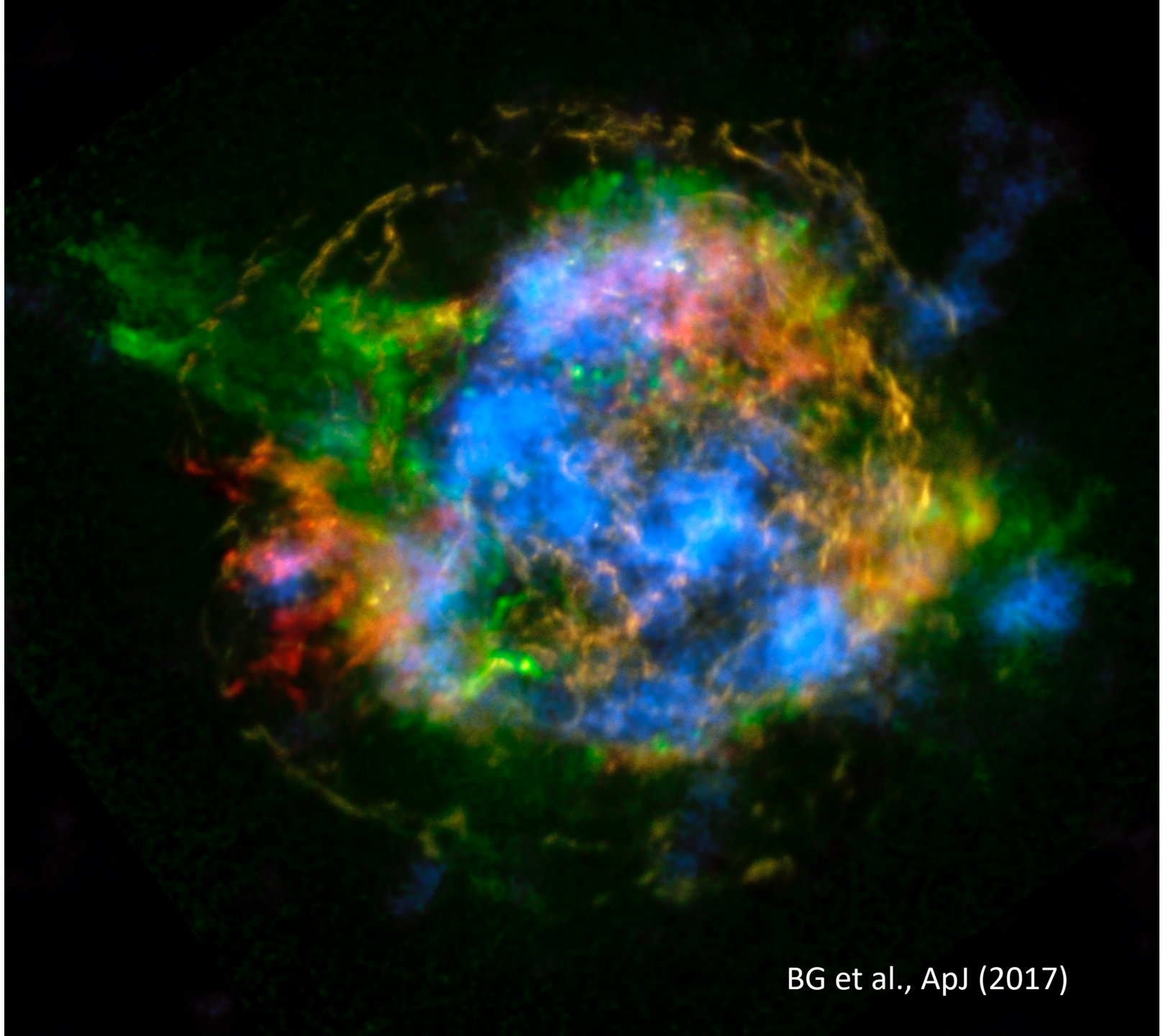
- Convective model current paradigm behind normal core-collapse supernovae: explains energies, progenitor masses, remnants?
- But a lot of questions remain:
- what is the nature of convection?
- what are the progenitors (masses, red vs. blue)?
- how prevalent are alternate explosion mechanisms?

NuSTAR

Most of the evidence of asymmetric explosions was indirect:

1) Lines in gamma-rays, IR
2) NS kicks
3) Remnants
4) ….

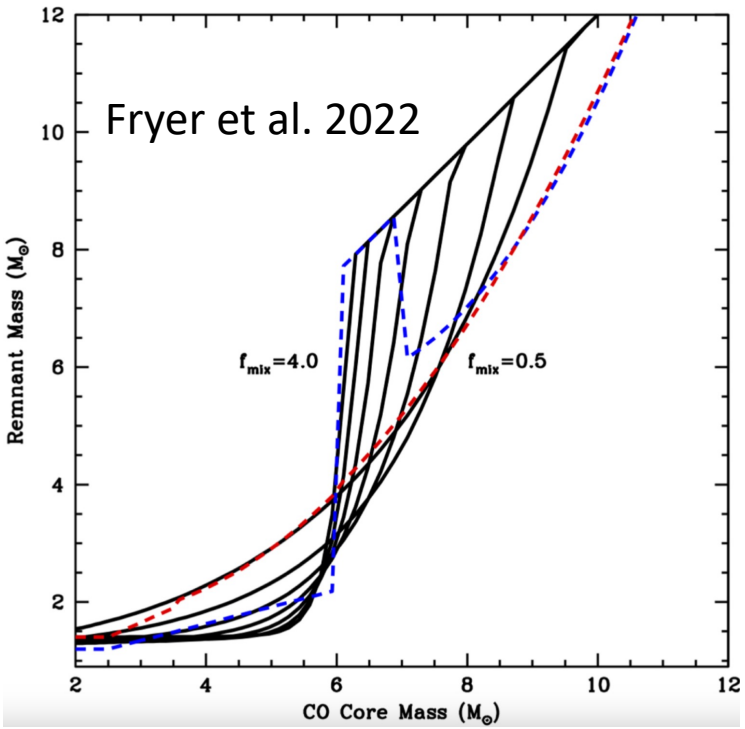
This all changed with NuSTAR observations of Cas A.



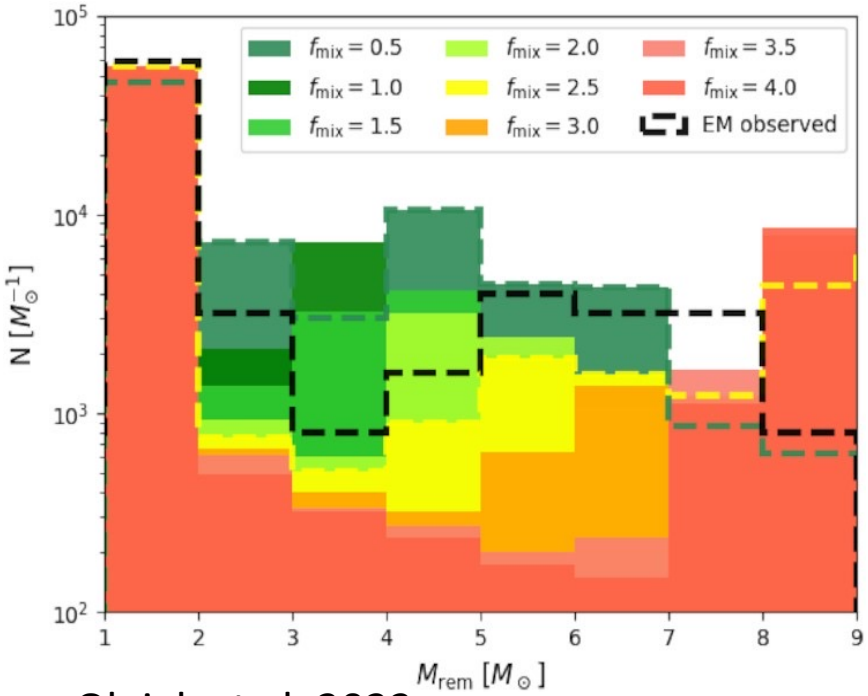
BG et al., ApJ (2017)

Example: Remnant Mass Distributions

Coupling Stellar Models (also constrained by SN ejecta remnants, …), Supernova Engine and Explosion calculations with physical understanding.

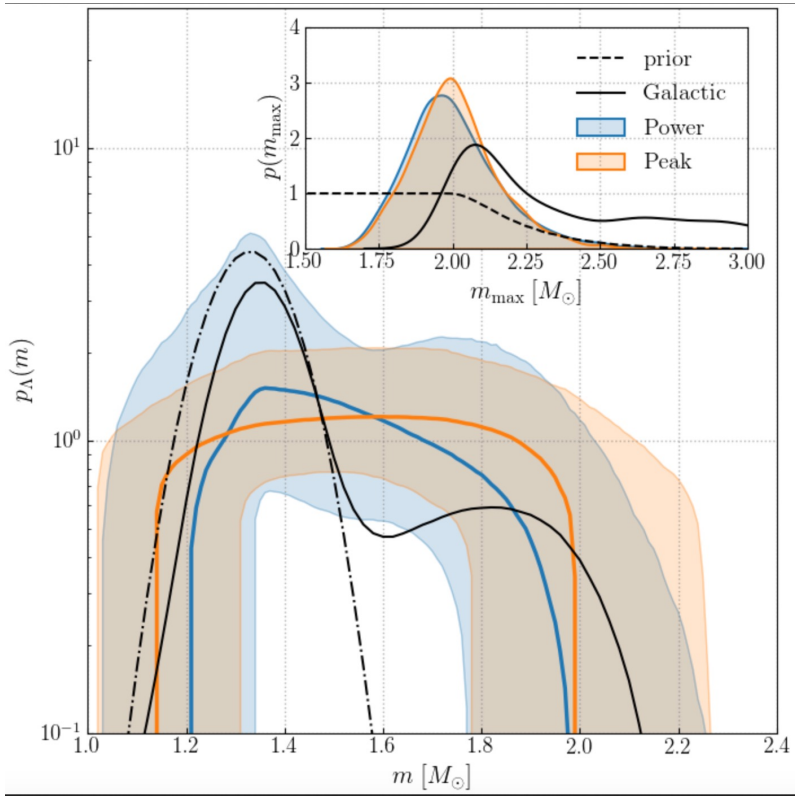


Folding our knowledge of stellar evolution and supernovae with a knowledge of Binary Stars (e.g. stellar observations), physics of binary interactions (e.g. Luminous Red Novae, …).



Olejak et al. 2022

Comparison to data requires understanding data systematics, analysis uncertainties, …



LIGO collaboration et al. 2021

The Future with Cosmic Explorer

How well we constrain the data depends on our understanding of the details.

- With its potential to significantly expand the database of compact remnant masses, CE has the potential to characterize the mass distribution of merging compact remnant systems. Are there predictions for how accurately it will measure the individual mass components?
- Coupled with population synthesis models, we can constrain compact remnant formation which can then be tied to the details of the convective engine. We need to fully understand the binary physics, especially for tight binaries, we are missing crucial physics – see Becerra et al. (2023).
- We also need to probe the SN engine physics to characterize better the dependence of remnant masses on the properties of the convection. This requires more than running simulations (it is impossible to resolve this engine). We have to understand the physics.