The initial mass – remnant mass relation for core-collapse supernovae

XIII ET Symposium

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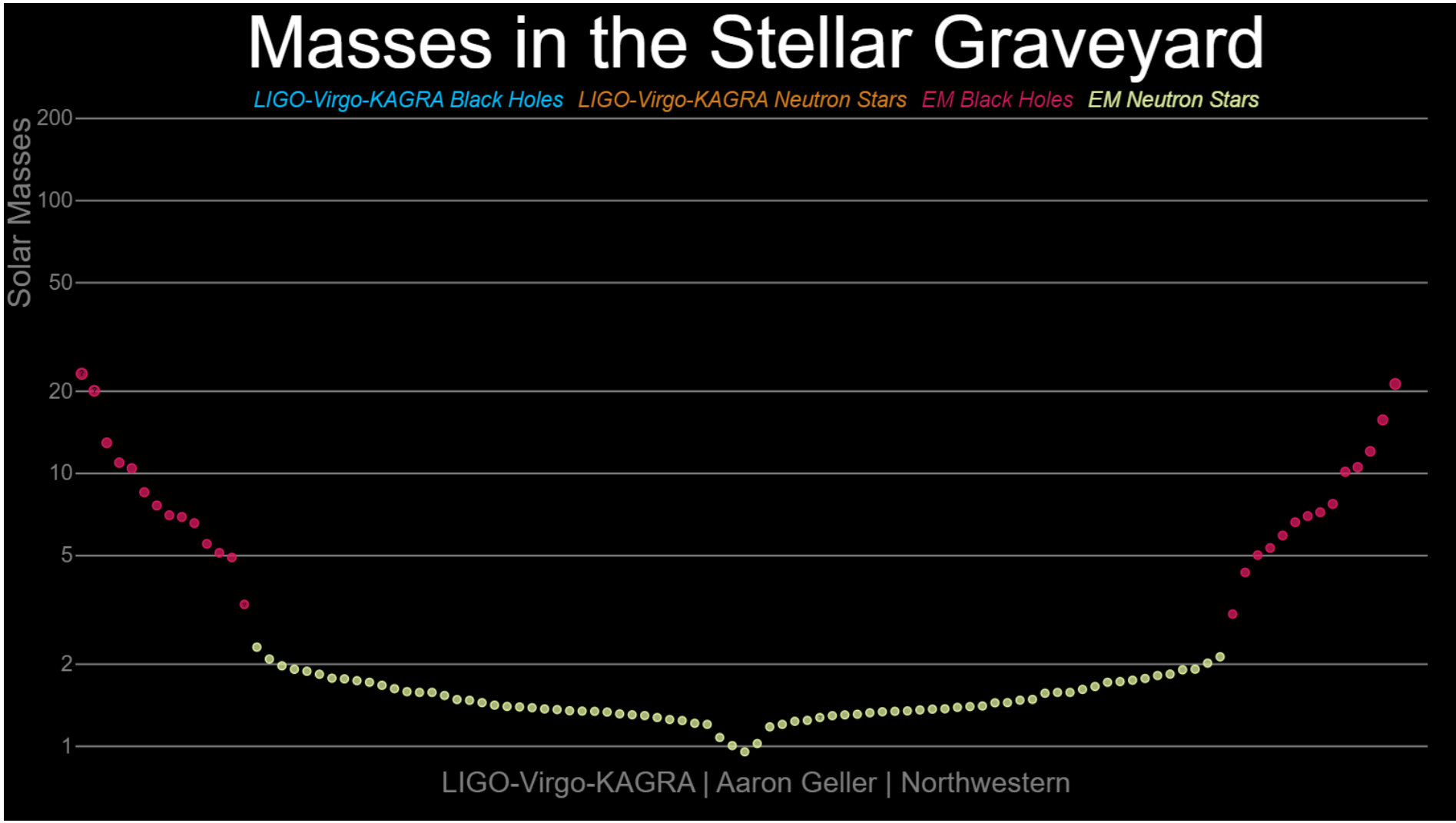
SISSA

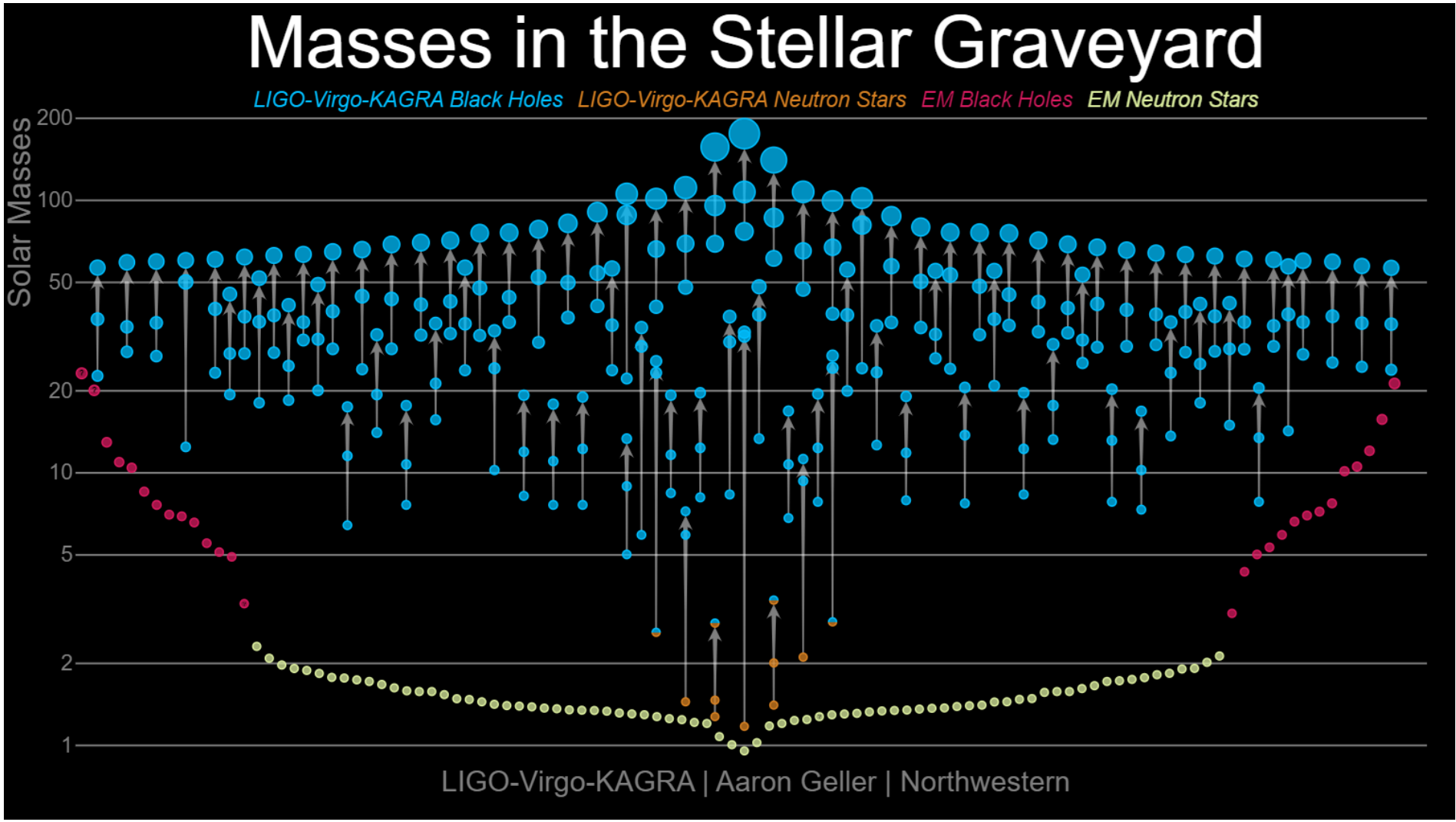
Before GWs

- Stellar BH **upper limit** $\sim 25 M_{\odot}$
- BH detected in **X-Ray Binaries**



After O3

- Discovered a **new population** of stellar BHs that can form BH-BH binaries
- The **heaviest BH** has mass $86M_{\odot}$

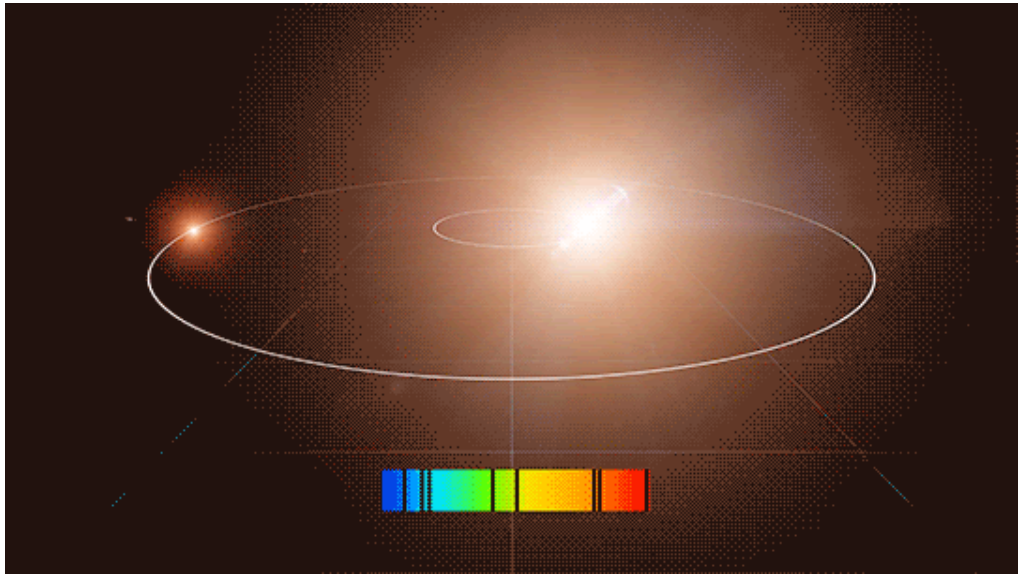


How such massive objects can form?

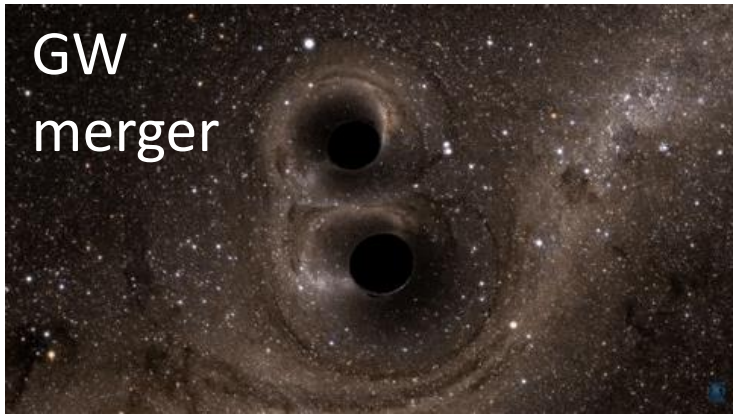
Ingredients for BHB merger

Dynamical evolution of Stellar System

Evolution of Stellar Binaries



Final Fate of Massive Stars



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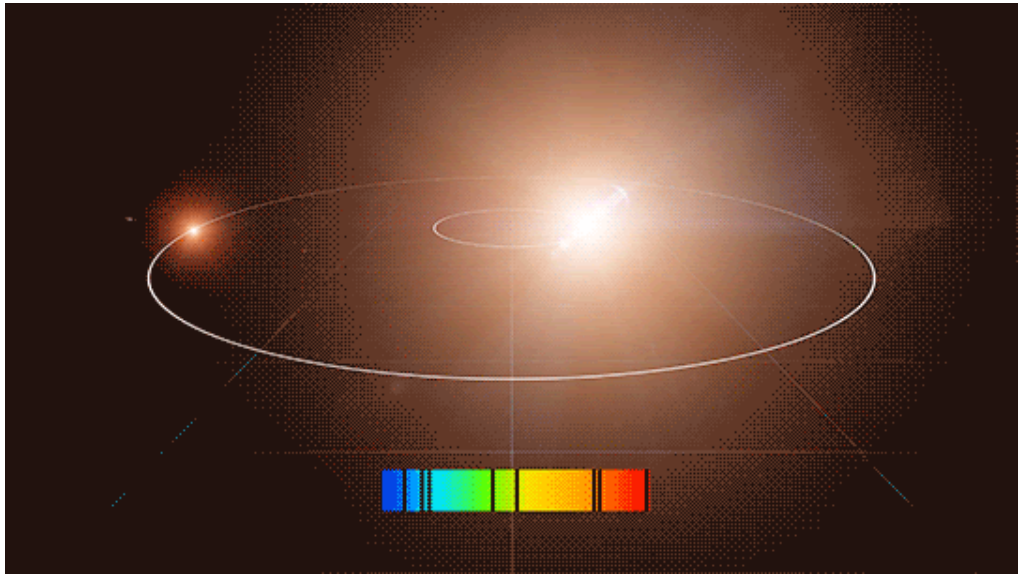


My research's Topic

Final Fate of Massive Stars

Our tools:

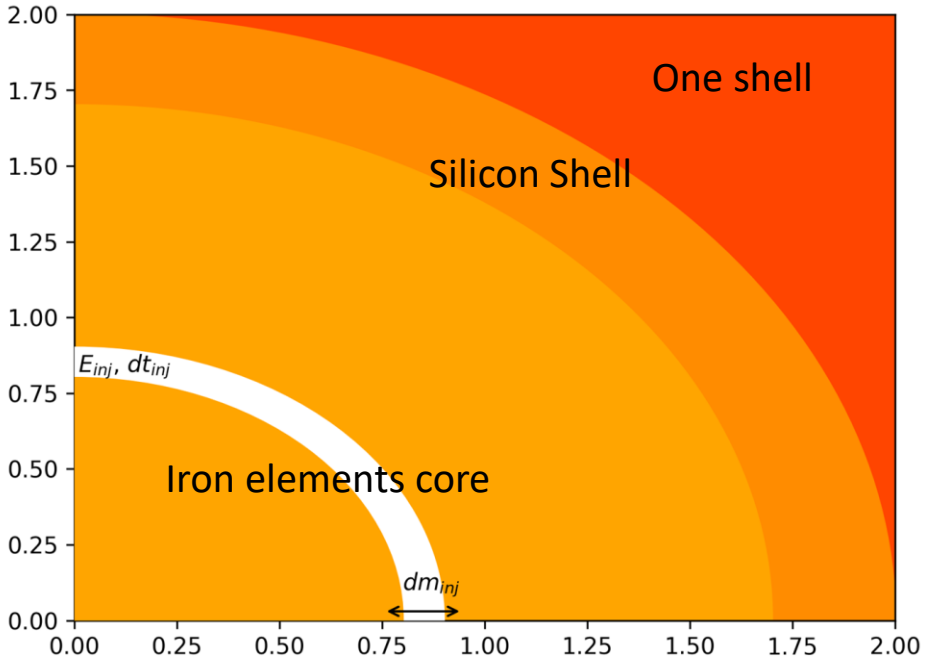
- **FRANEC** stellar evolution code (Chieffi & Limongi 2013, Limongi & Chieffi 2018)
- **HYPERION** hydrodynamical code (Limongi & Chieffi 2020)

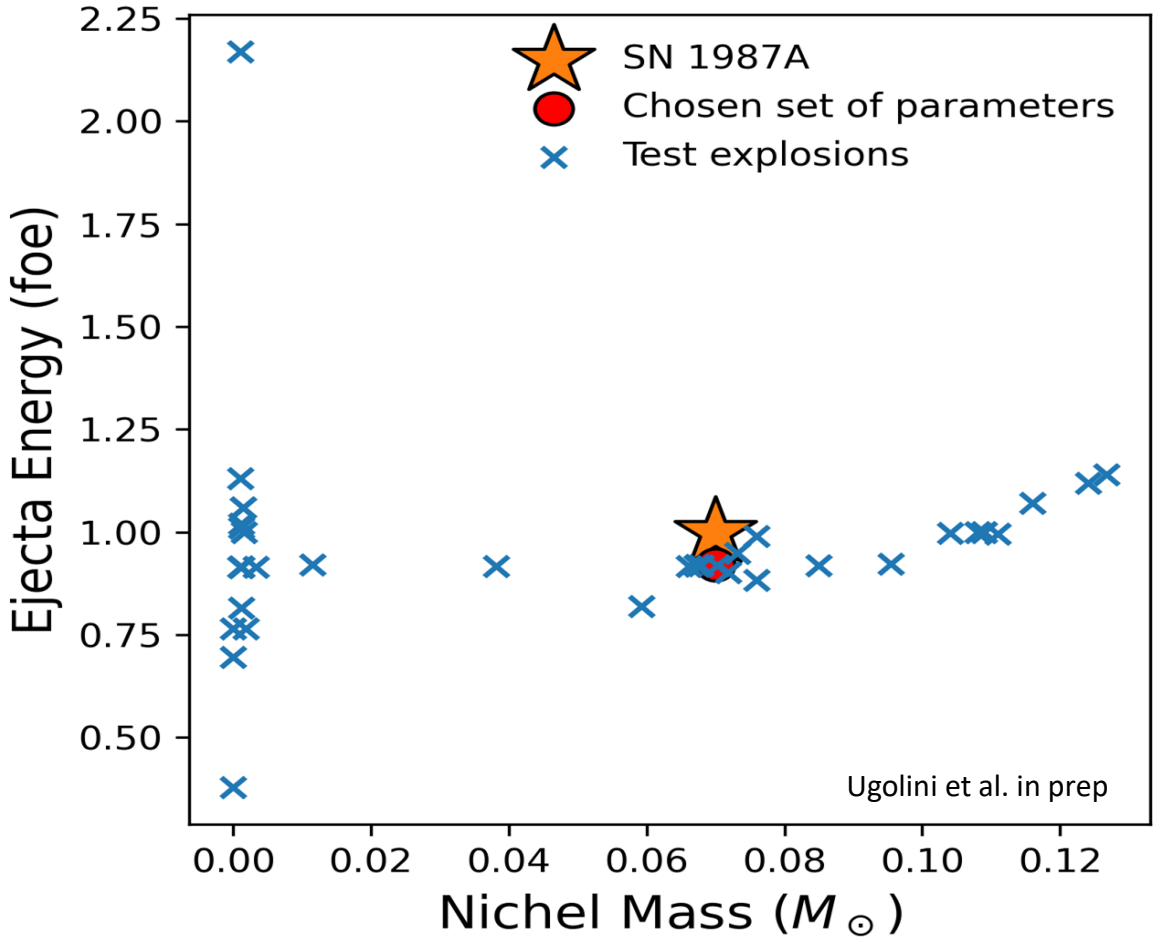
We performed a self-consistent and homogeneous study of stellar progenitors and their supernova explosions

Calibration of supernova explosions

The **free parameters** of the HYPERION code are:

- E_{inj}, the injected **thermal energy;**
- dm_{inj}, the **mass interval** where the energy is injected;
- dt_{inj}, the **time needed** to inject the energy



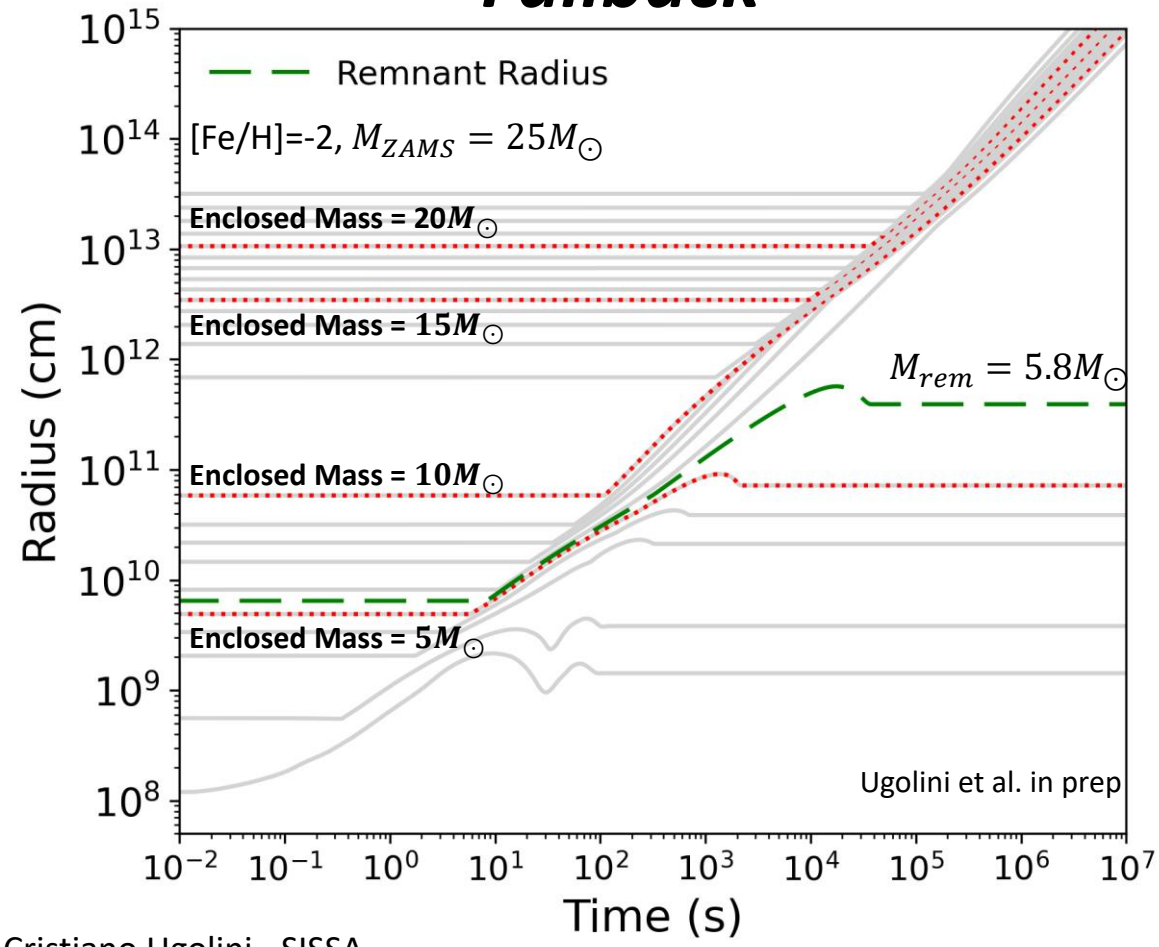


We **calibrate** the free parameters of HYPERION **to match the observed properties of SN1987A**

How we determine the remnant mass?

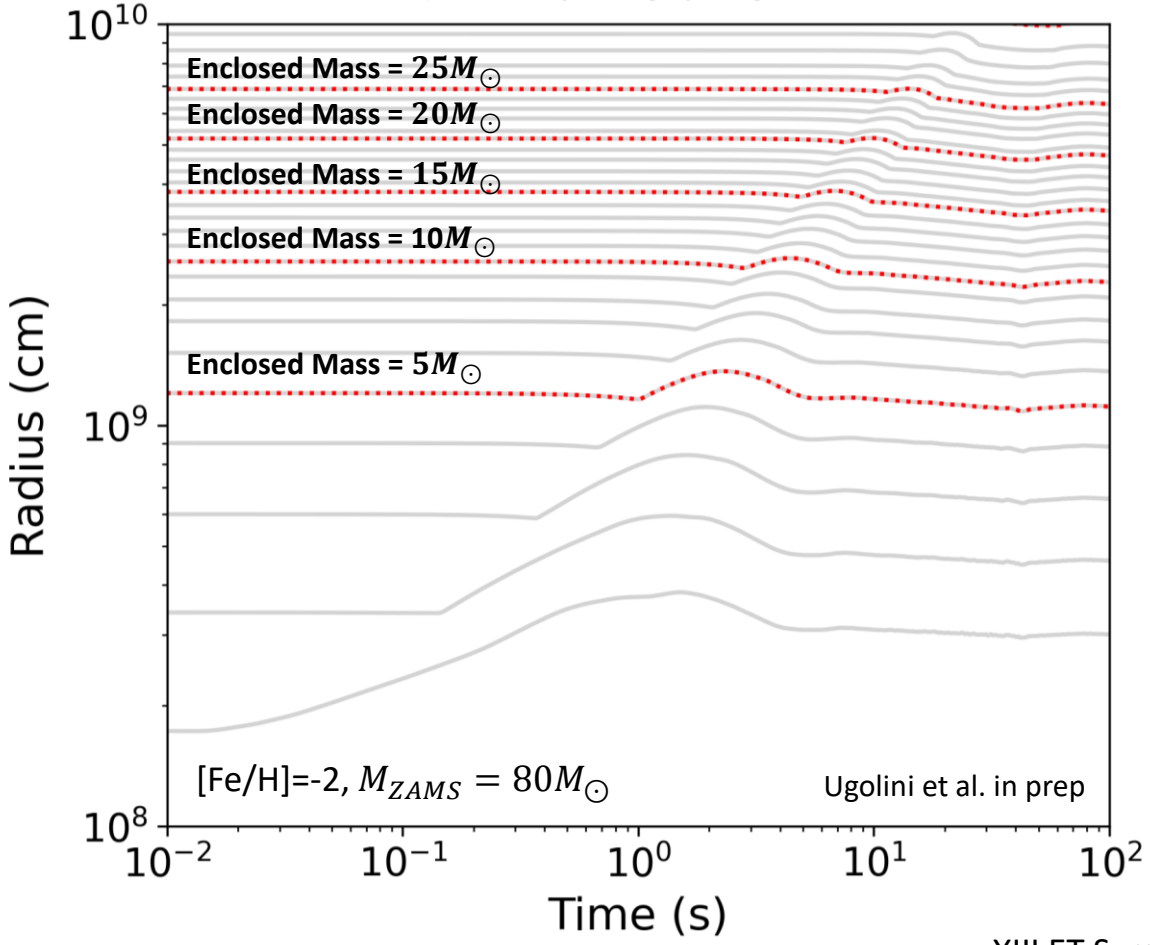
Successful SN explosion:
The most internal region do not reach the **escape velocity**

→ ***Fallback***



Failed SN explosion:
The shock **exhausts its energy** as it moves through the star

→ ***Failed-SN***



Non-rotating stellar progenitors

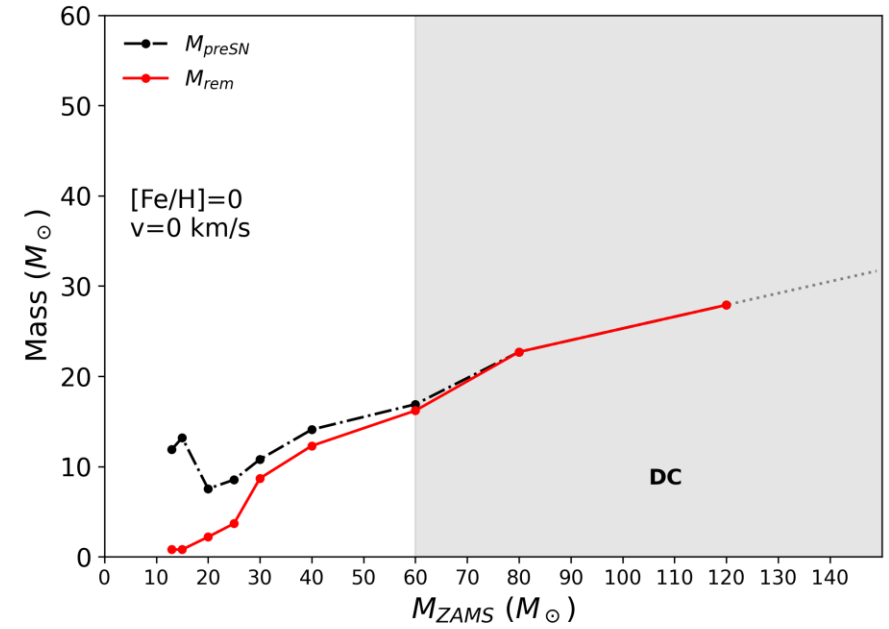
Metallicity **strongly affects** the final BH mass

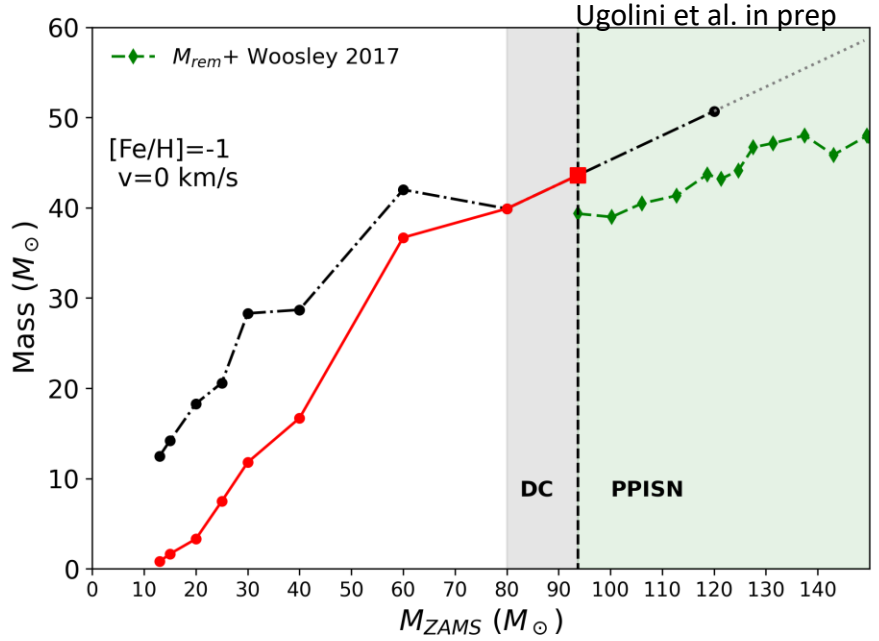
Our code **cannot follow** the evolution of stars unstable against pair-production

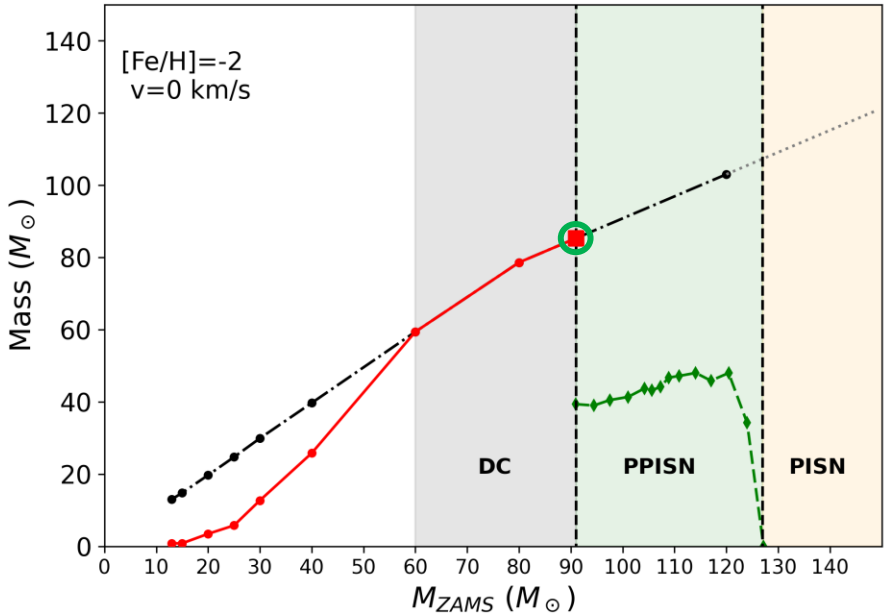
$M_{CO} = 35M_{\odot}$, criterion for the onset of **pulsational pair-instability supernovae** (Heger et al. 2002)

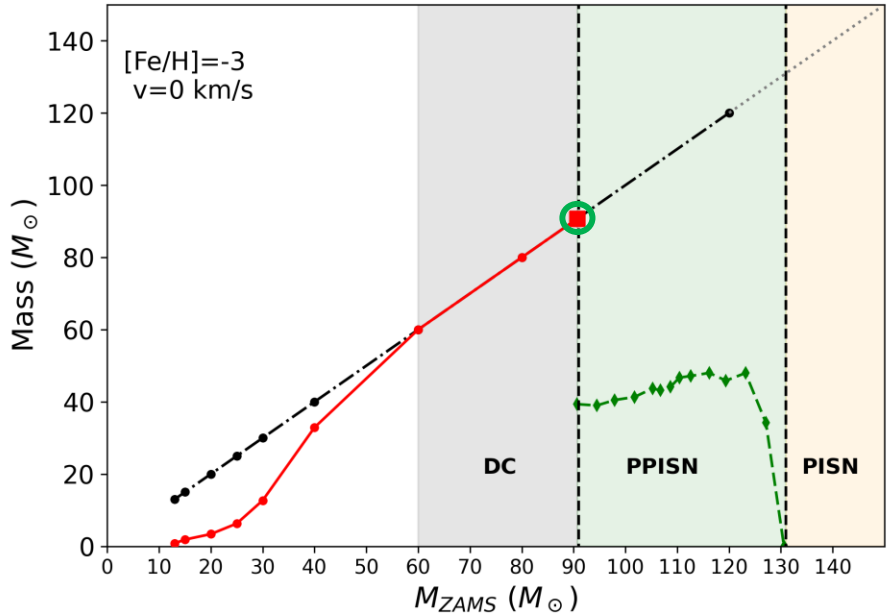
We use the results of Woosley et al. 2017 for the remnant masses

Ugolini et al. in prep







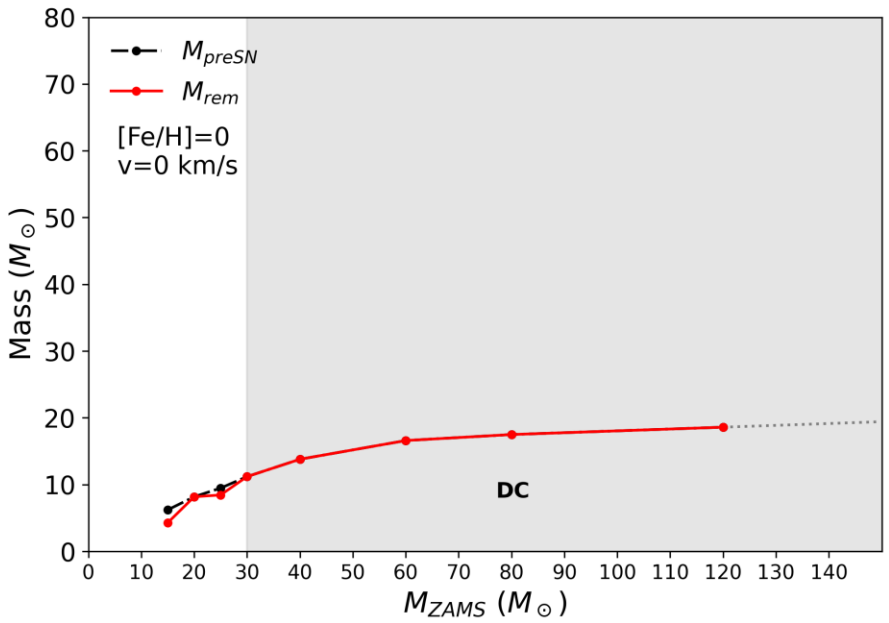


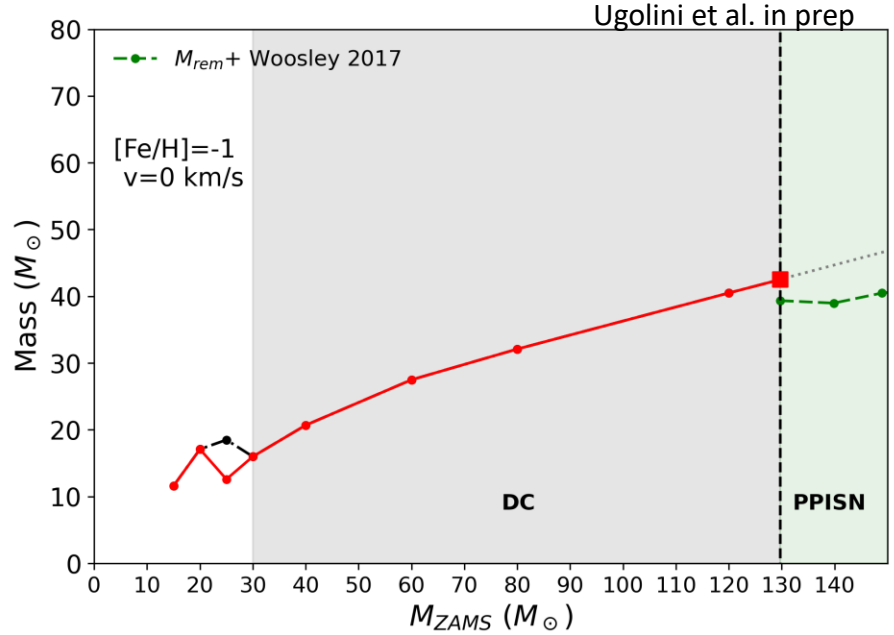
Rotating stellar progenitors

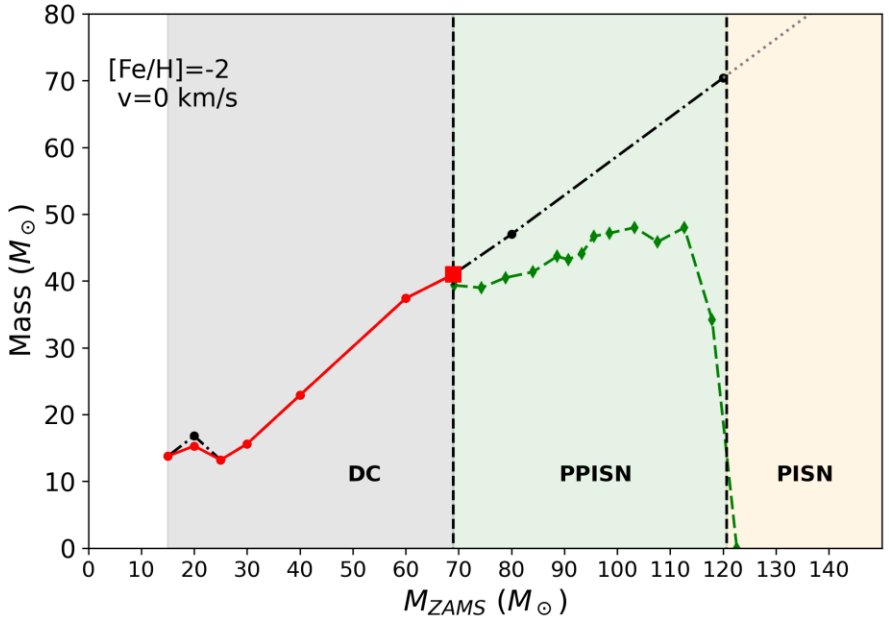
Rotation strongly **enhances mass loss** and **chemical mixing**

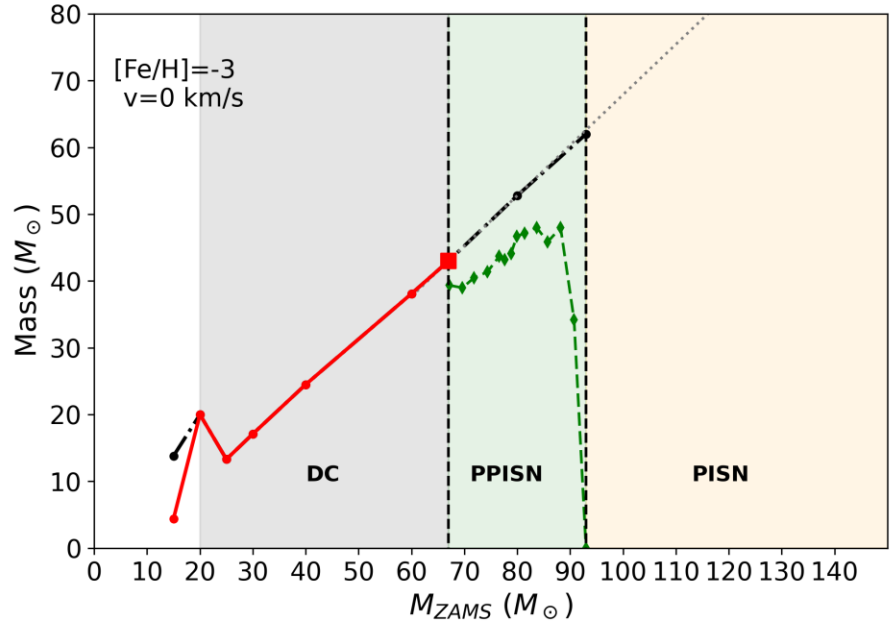
Pulsational pair-instability supernovae occur for **lighter stars** with respect to the non-rotating case

Ugolini et al. in prep



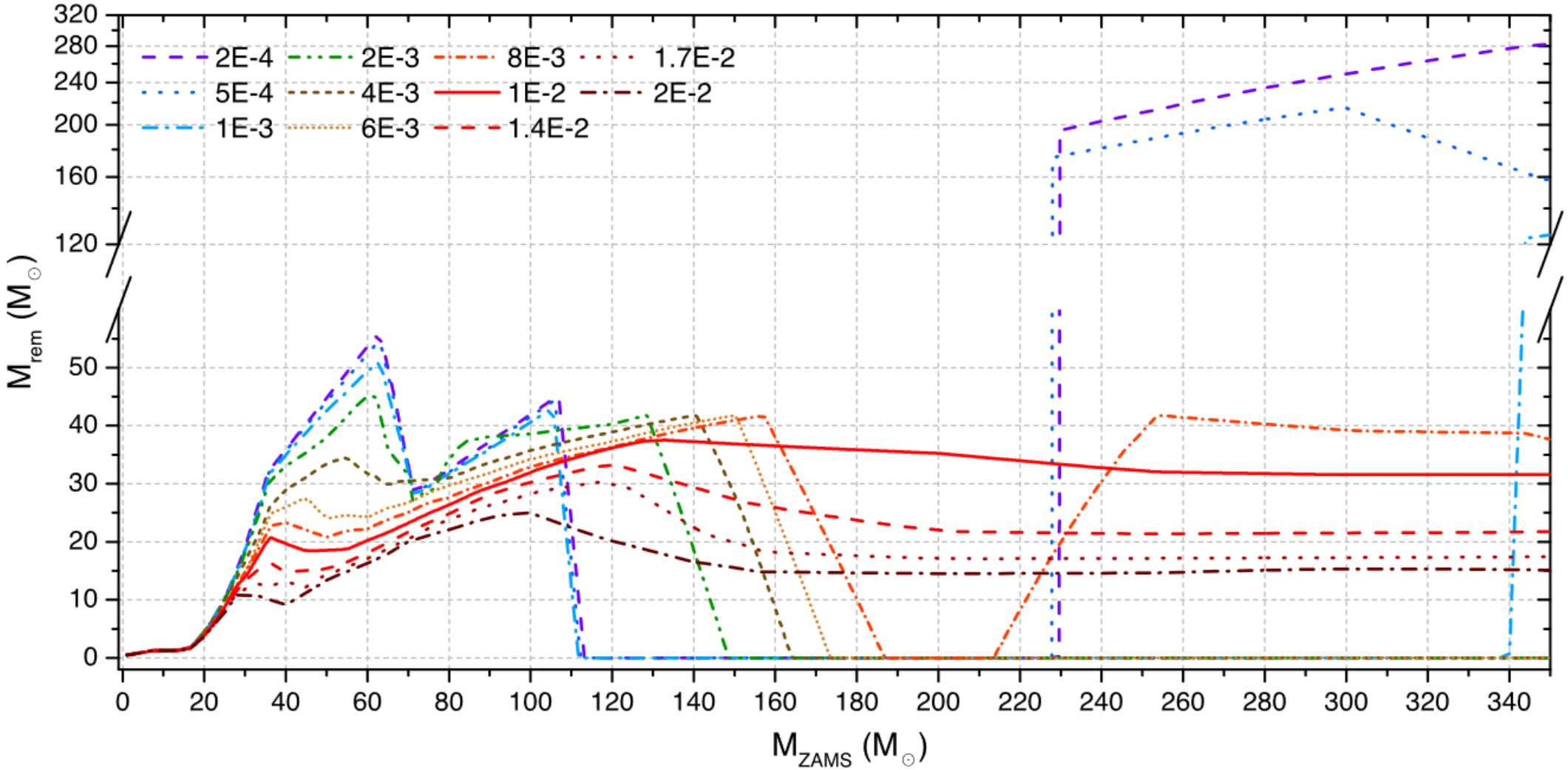






Implications of our results: the upper mass gap

Spera & Mapelli 2017



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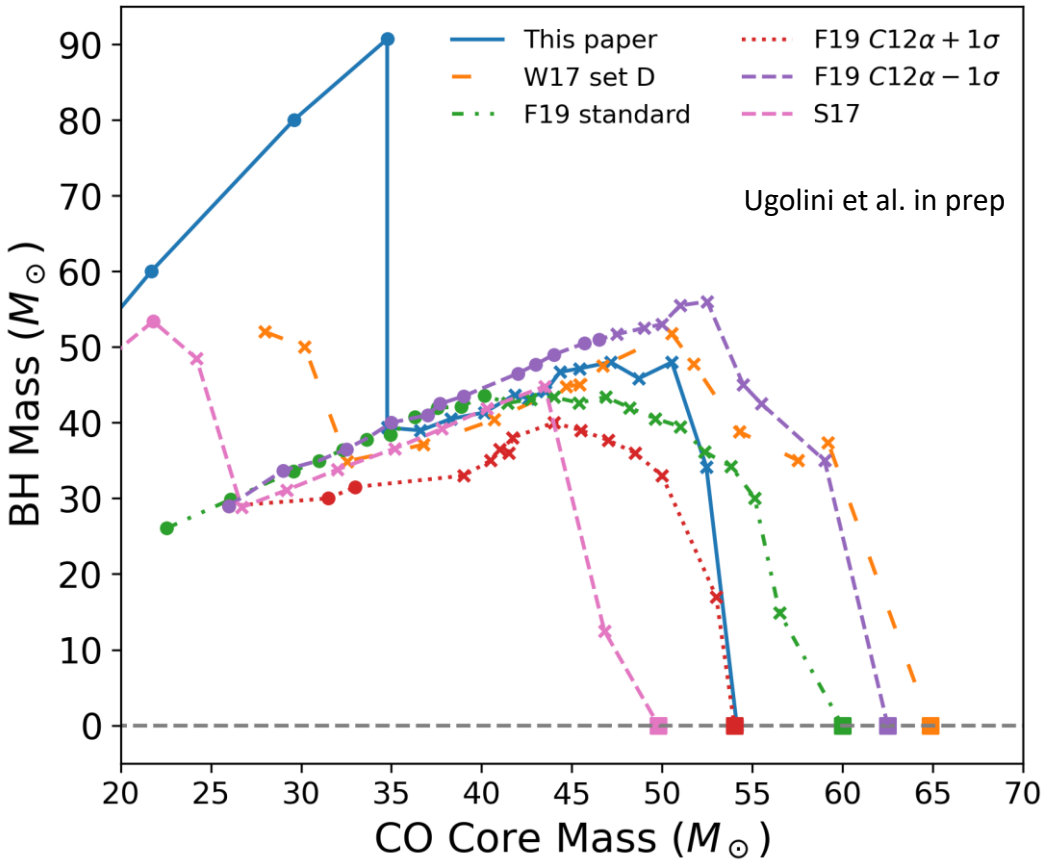
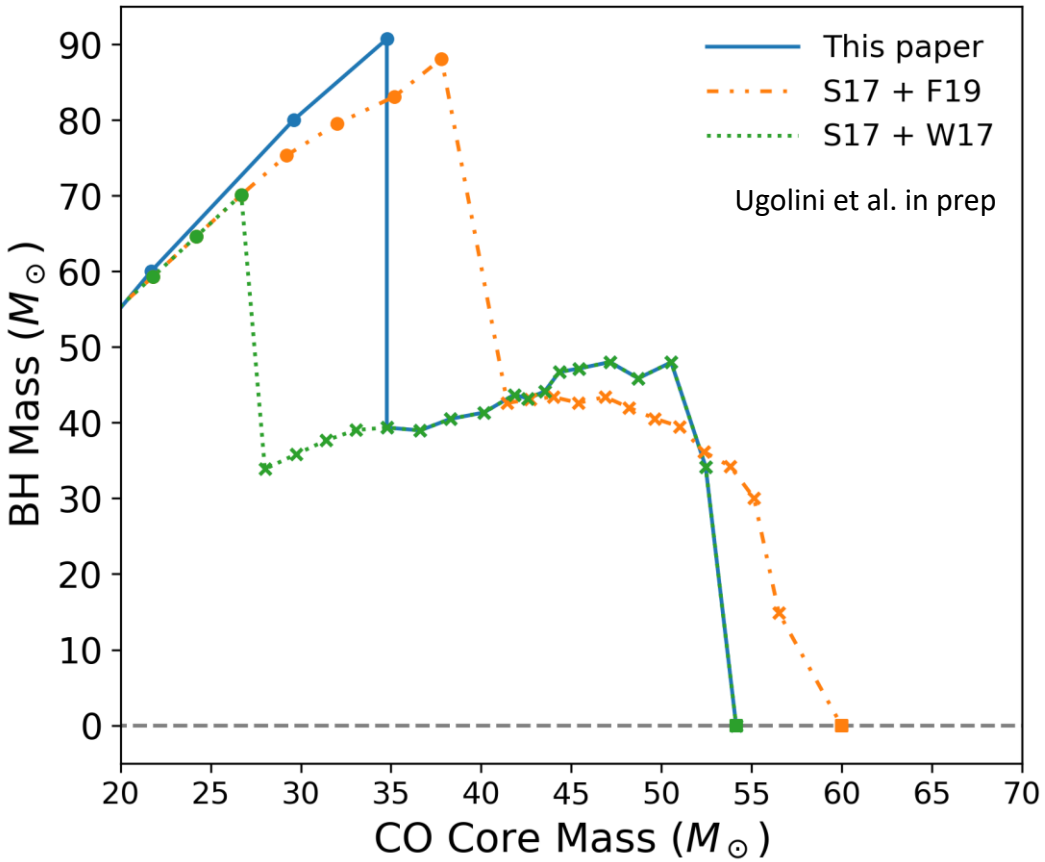




Varying the **criterion** for the onset of PPISNe has a **crucial impact** on the **heaviest BH** that form from the evolution of **single stars**

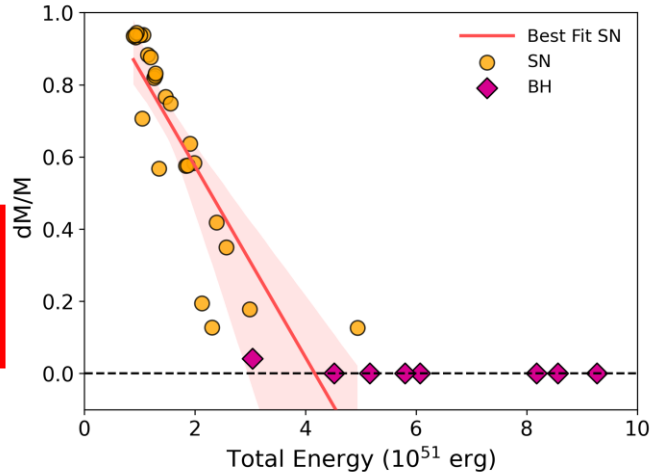
Fitting Formulas

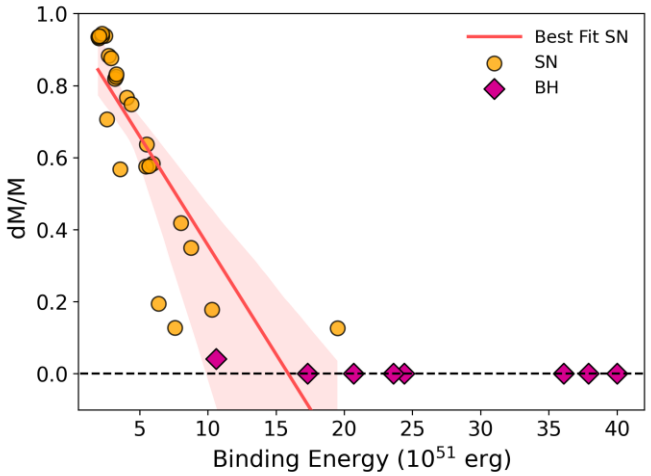
We search for **any linear relation** between the properties of the star at the pre-SN stage and its remnant mass.

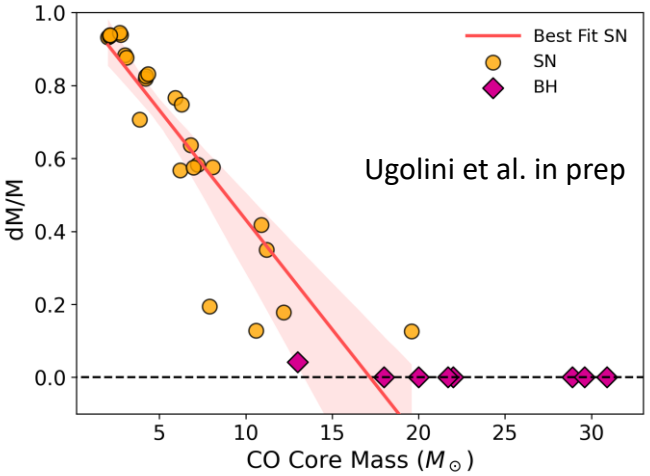
$$dM/M = \frac{M_{preSN} - M_{rem}}{M_{preSN}}$$

For the **non-rotating progenitors** we find:

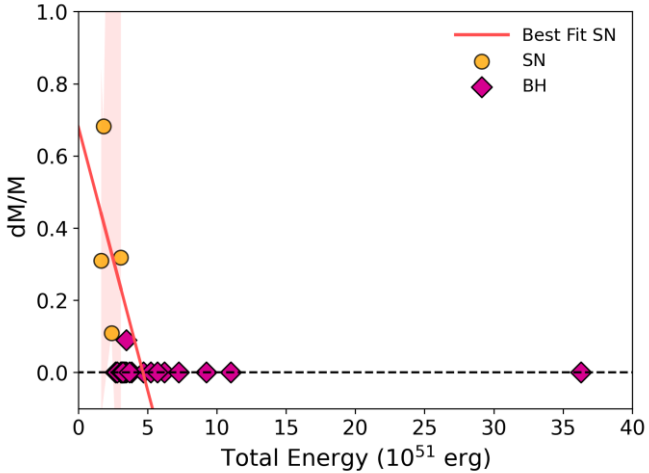
$$dM/M = \begin{cases} mx + b, & x \leq x_{DC} \\ 0, & x > x_{DC} \end{cases}$$

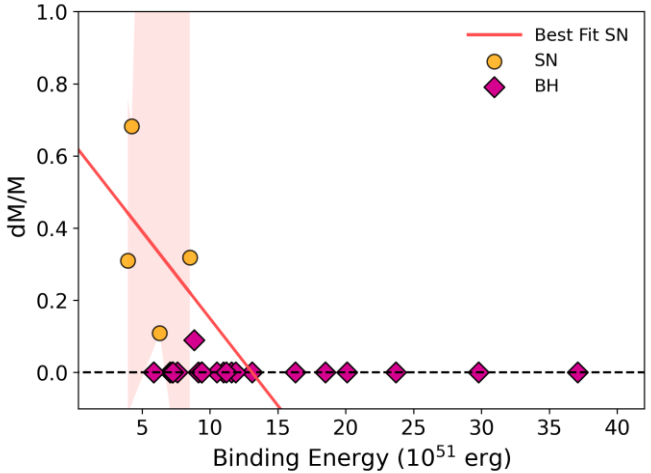


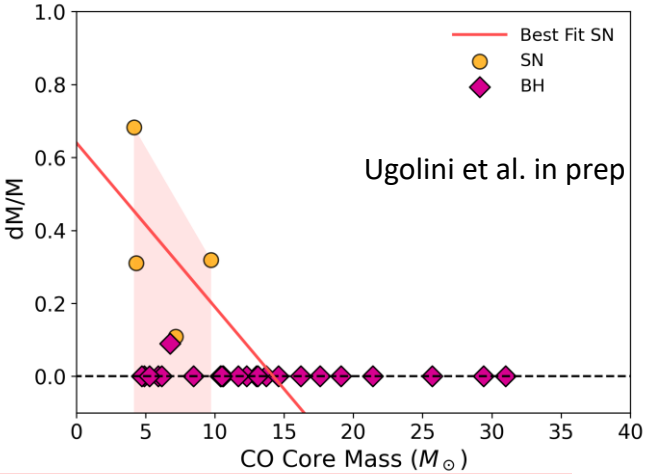




For the **rotating** progenitors, **we do not** find any **linear relation in place**







Linear fits cannot capture the complexity of the physics behind the SN explosion mechanism

Summary and conclusion

- Homogeneous study of the **evolution** and **explosion** of massive stars
- BH mass spectrum and implications on the **position** of the upper mass gap
- Linear fits **cannot capture** the complexity of the physics behind the SN explosion mechanism

Thank you for your attention

Please feel free to contact me anytime if you have idea on the topic:
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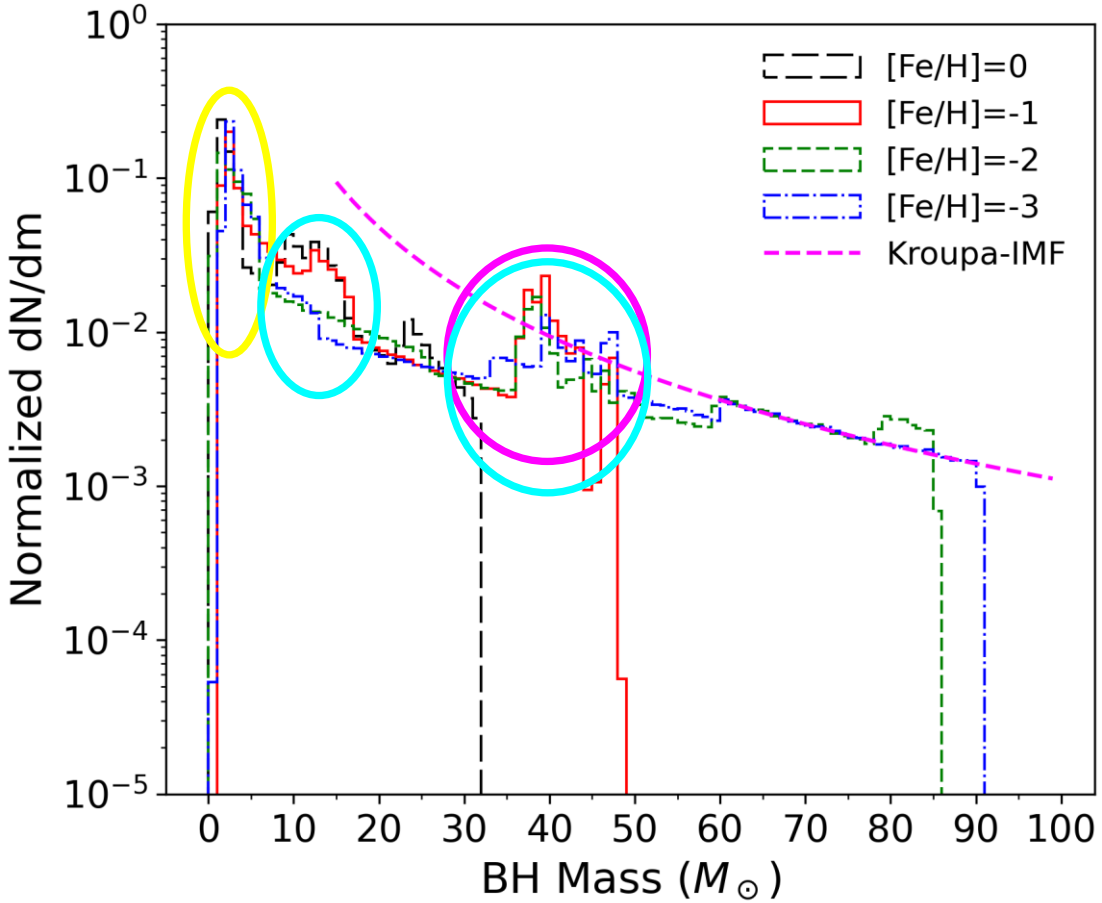
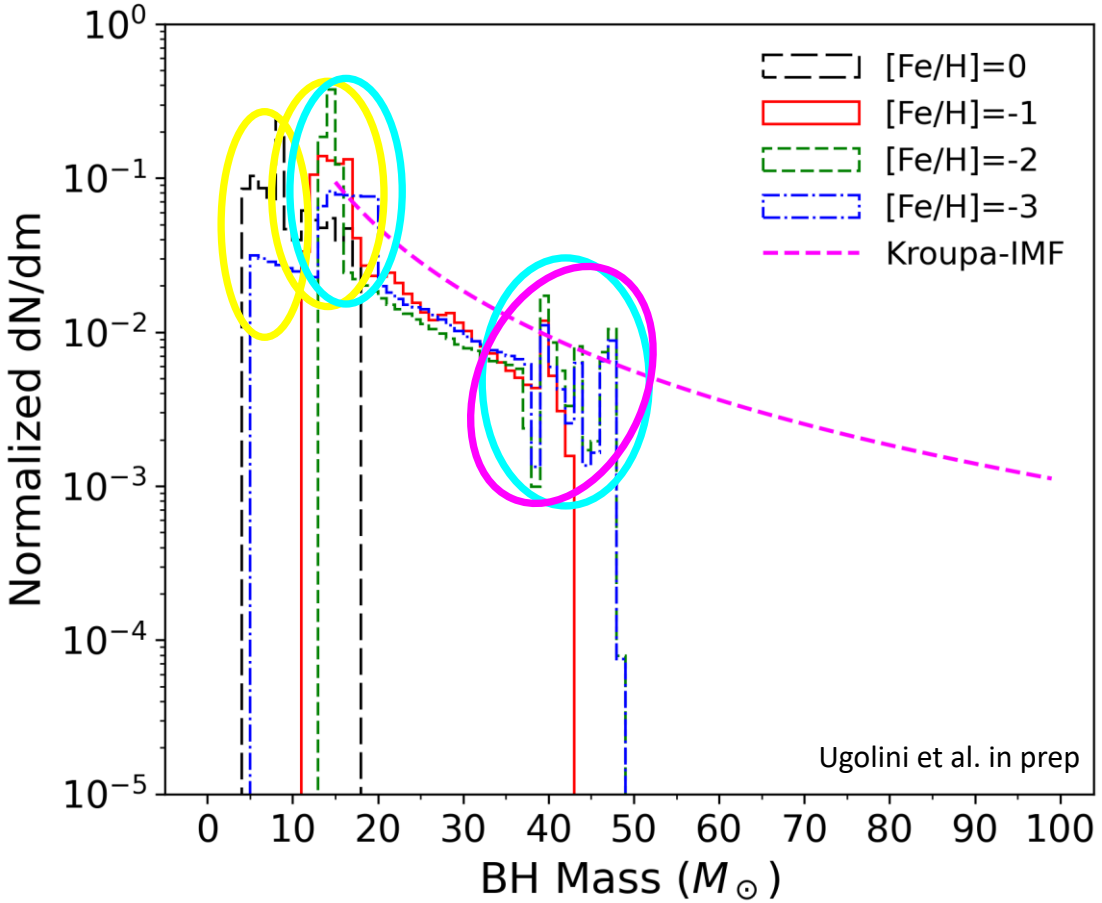
BH Mass Spectrum

We apply our results to a populations of **10^6 stars**, with $M_{ZAMS} \propto m^{-2.35}$ (Kroupa IMF)

We find **several peaks** in the **BH distribution**, which are features of the:

- IMF
- SN details
- PPI prescriptions





The **feature emerging** from the **BH mass spectrum** are **degenerate**

Not easy to detach from each other!!!