2021

Maximum Black Hole mass across Cosmic Time

by

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IA-FORTH Journal Club discussion by

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2021

Outline

01 LIGO: What have we observed so far?

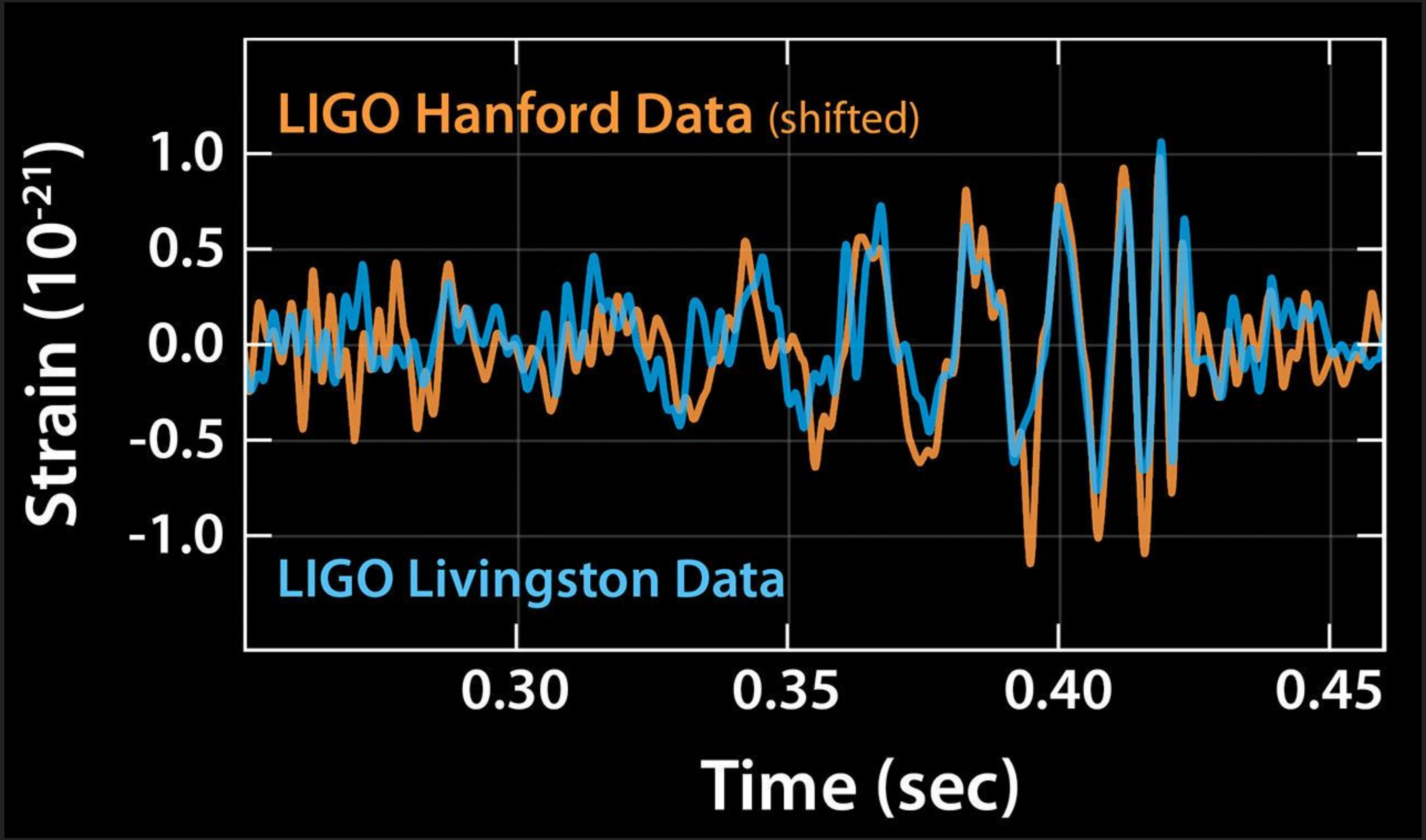
02 How are BH binaries formed?

03 A new way to make massive BHs in very massive stars

04 Summary & Conclusions

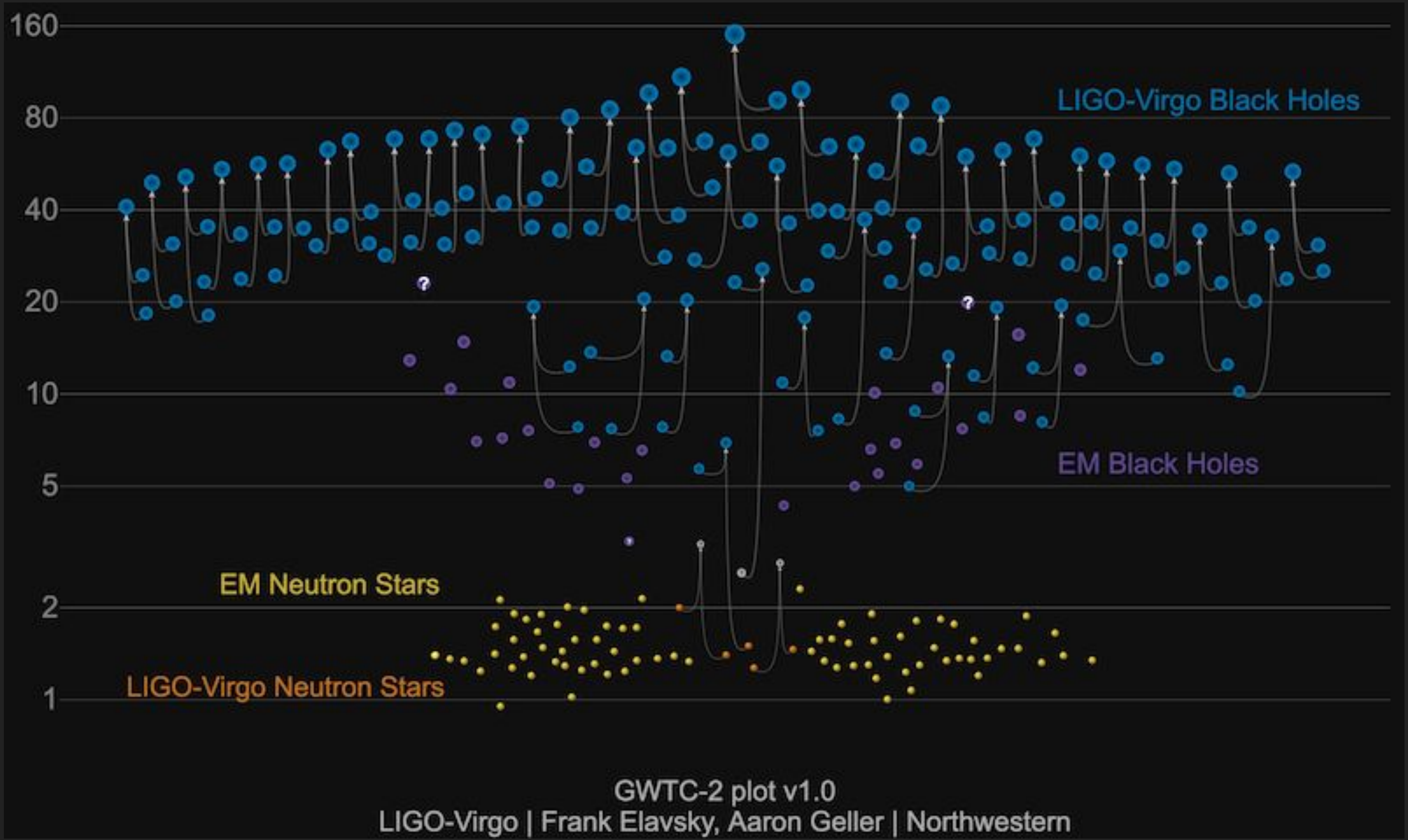
LIGO: what have we observed so far?

The dawn of GW astronomy



LIGO Scientific Collaboration and Virgo Collaboration, 2016

Observed BHs so far...



How are BH binaries formed?

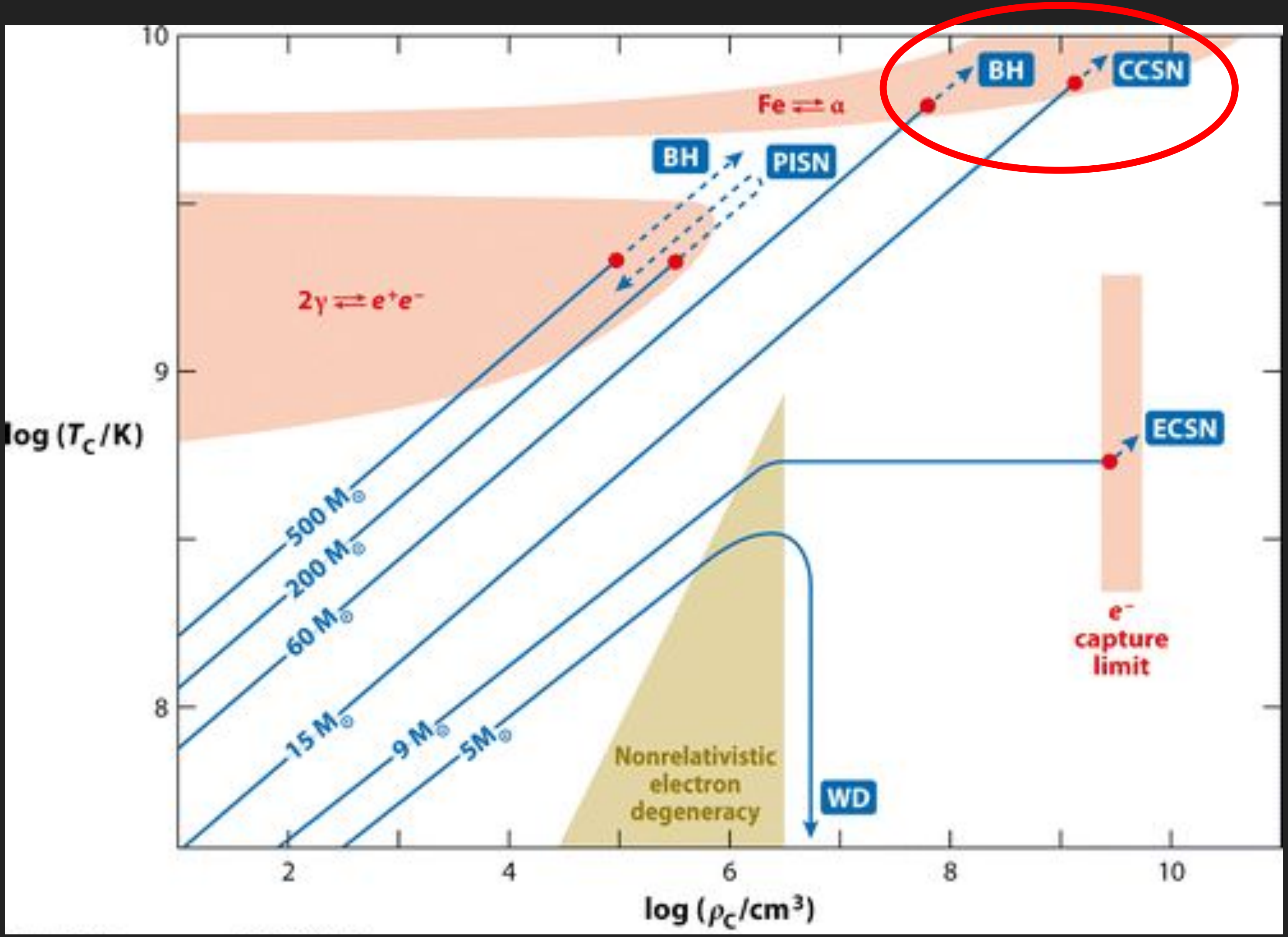
How is one BH formed?

When massive nebulae become unstable, they collapse and *a star is born*

Massive stars evolve ~90% close to the main sequence, burning hydrogen

When they run out of hydrogen, they become cold and large, and burn heavier elements

How is one BH formed?



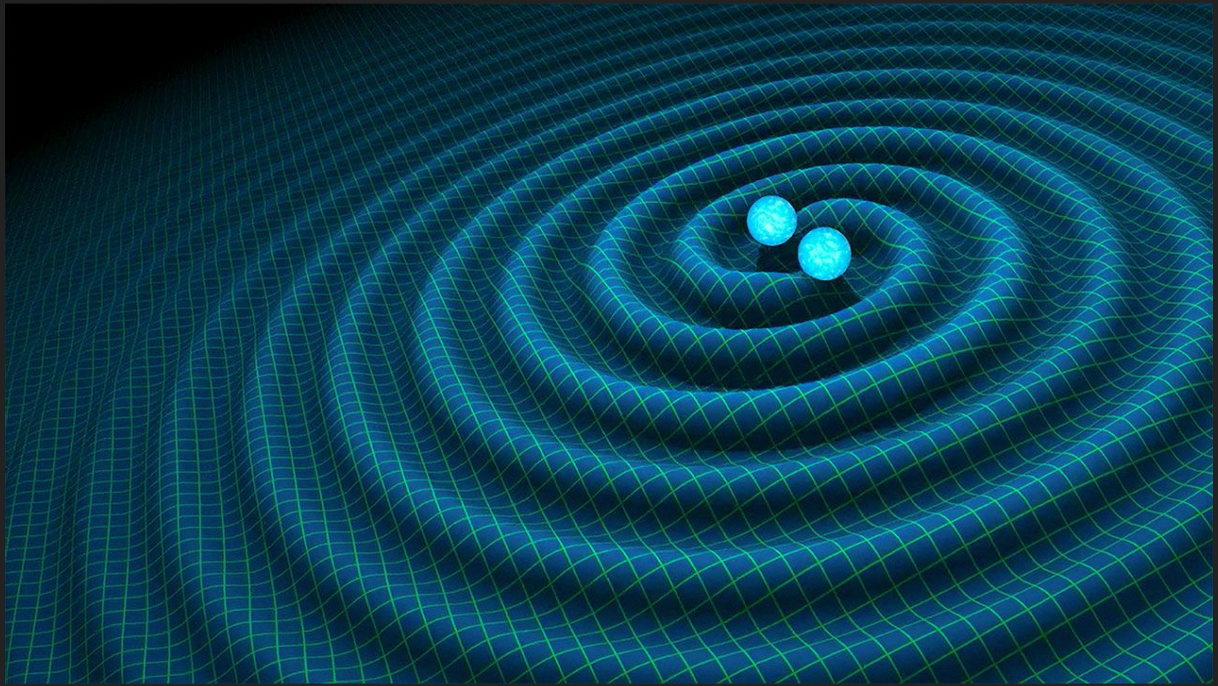
Langer 2012

Other things to consider about BH binary progenitors...

To get a binary BH system to **merge within a Hubble time**, you need to form two BHs close together

Massive stars that make black holes are complicated to study because they have **stellar winds**, which regulate the distribution of BH masses

Our understanding of **mixing processes** can alter their evolution



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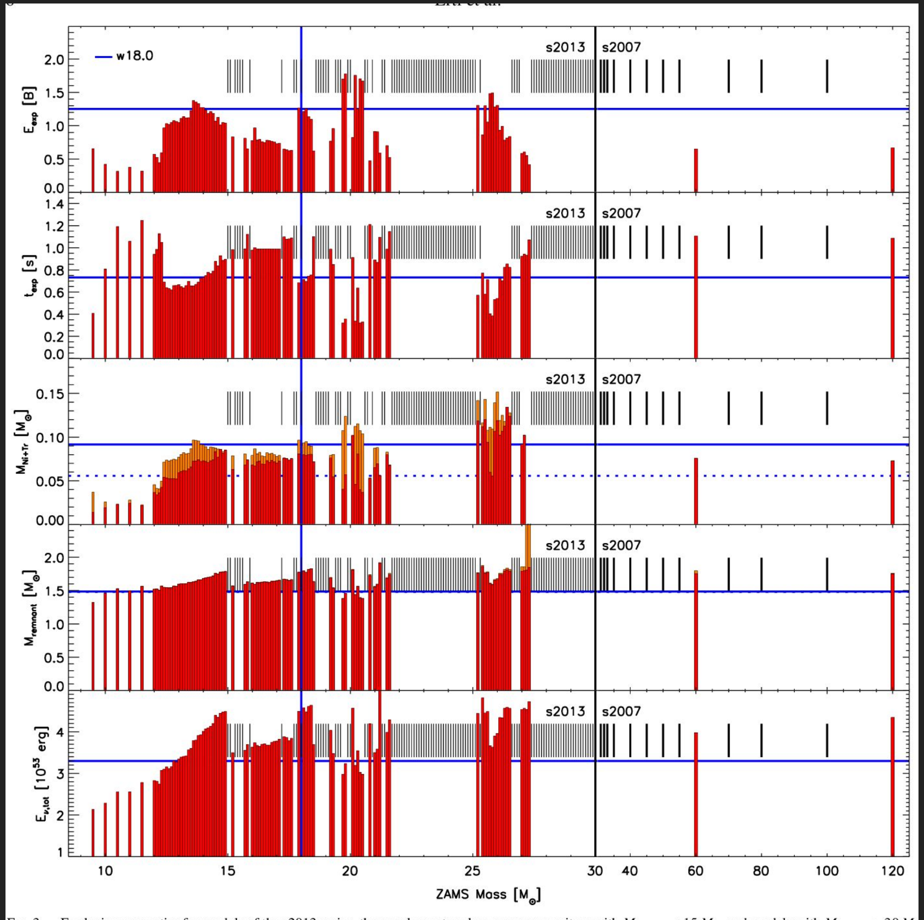
What can we expect the distribution of mergers to look like??

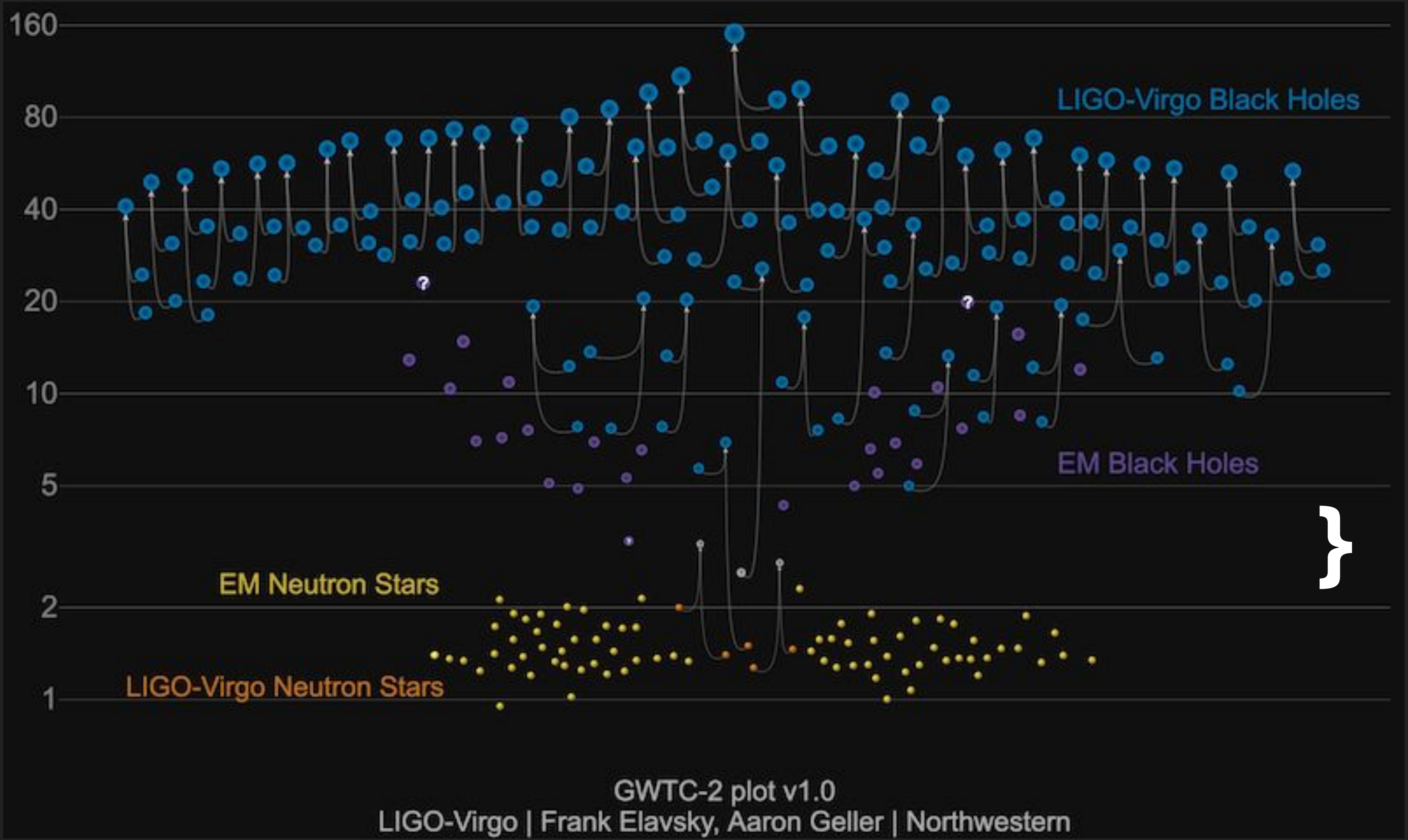
Massive stars also make supernovae

The lowest mass BH formed by massive stars should correspond to the transition between systems that form NS+SNe, and those that collapse into BHs



Ertl et al. 2016

Lower mass gap



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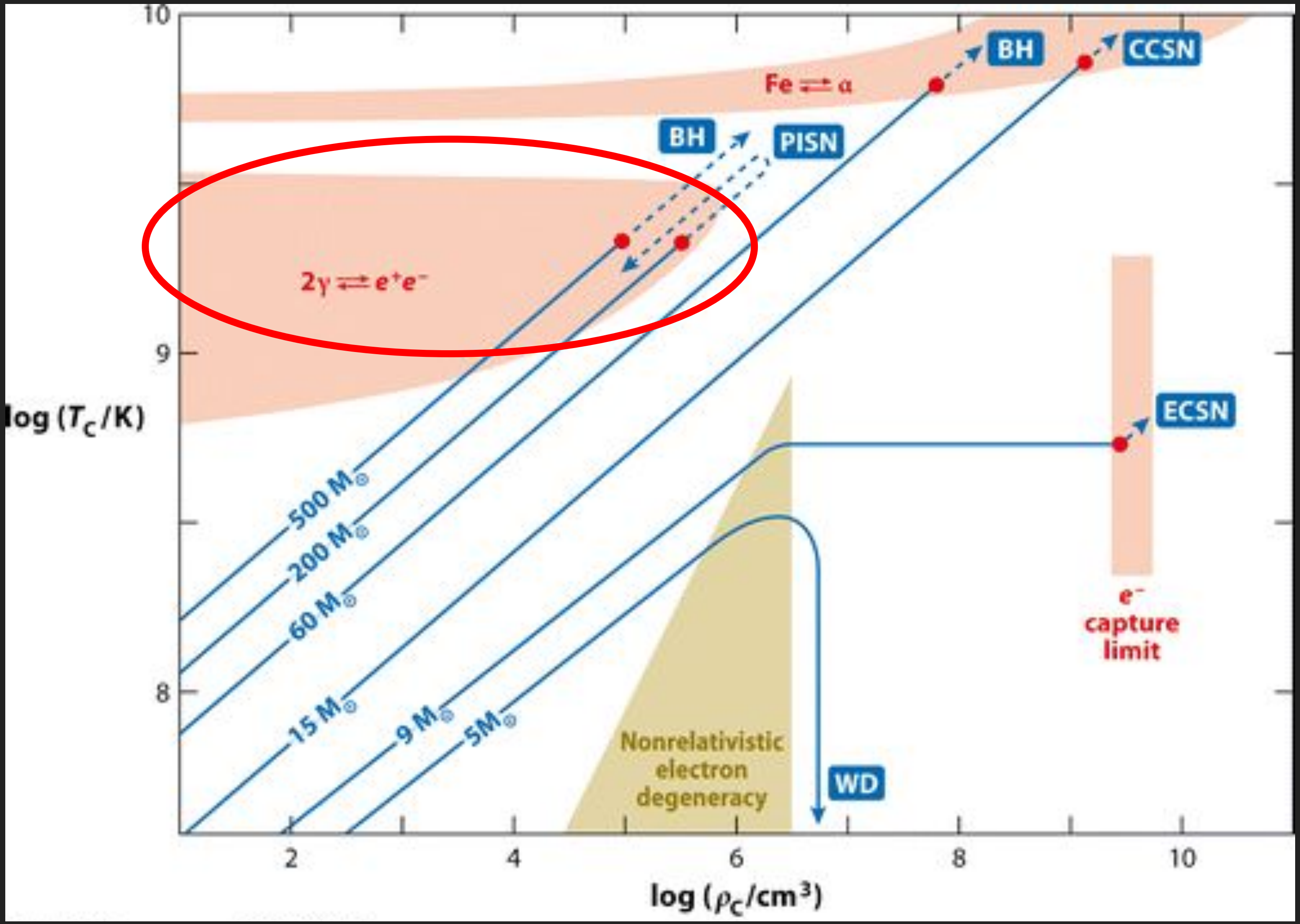
How is one BH formed?

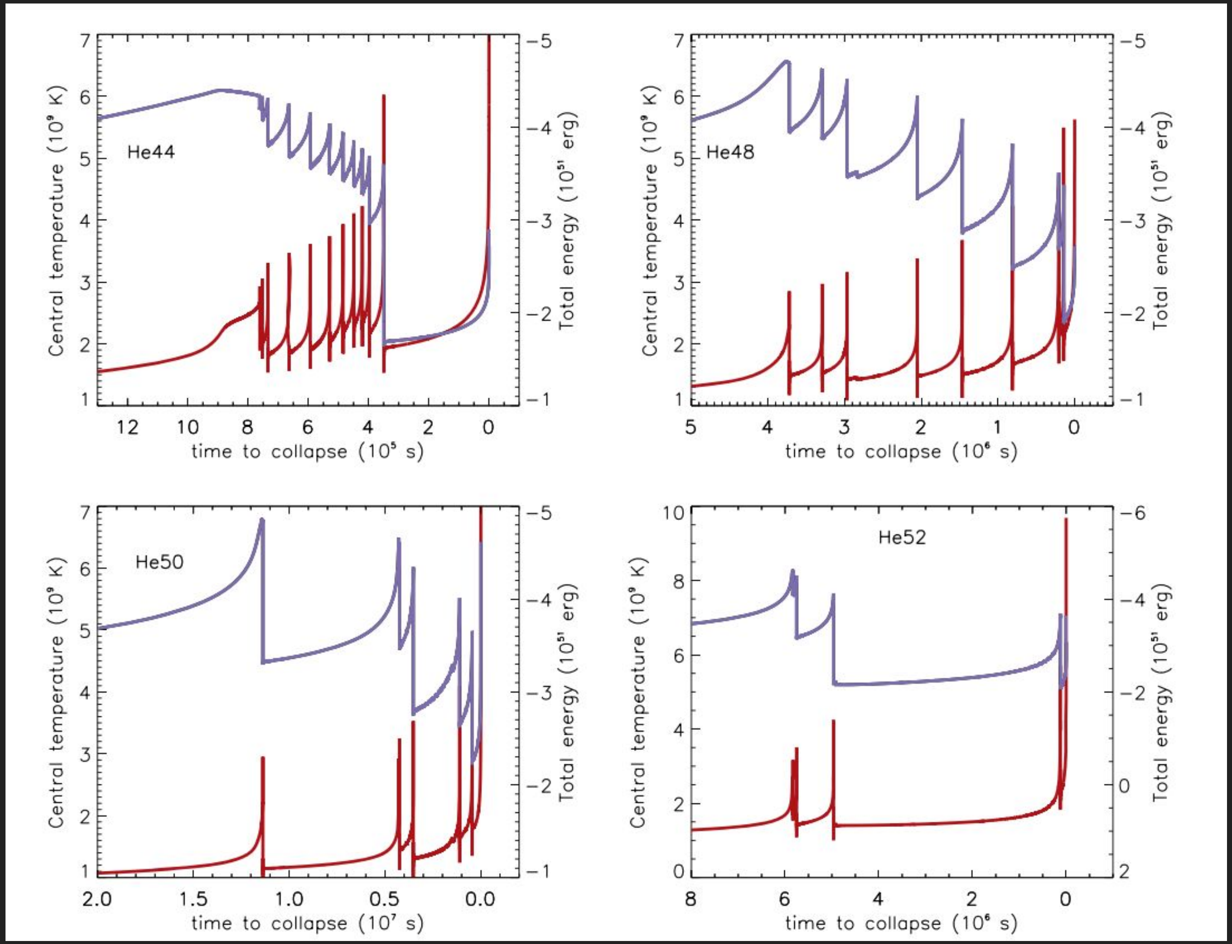


Langer 2012

What can we expect the distribution of mergers to look like??

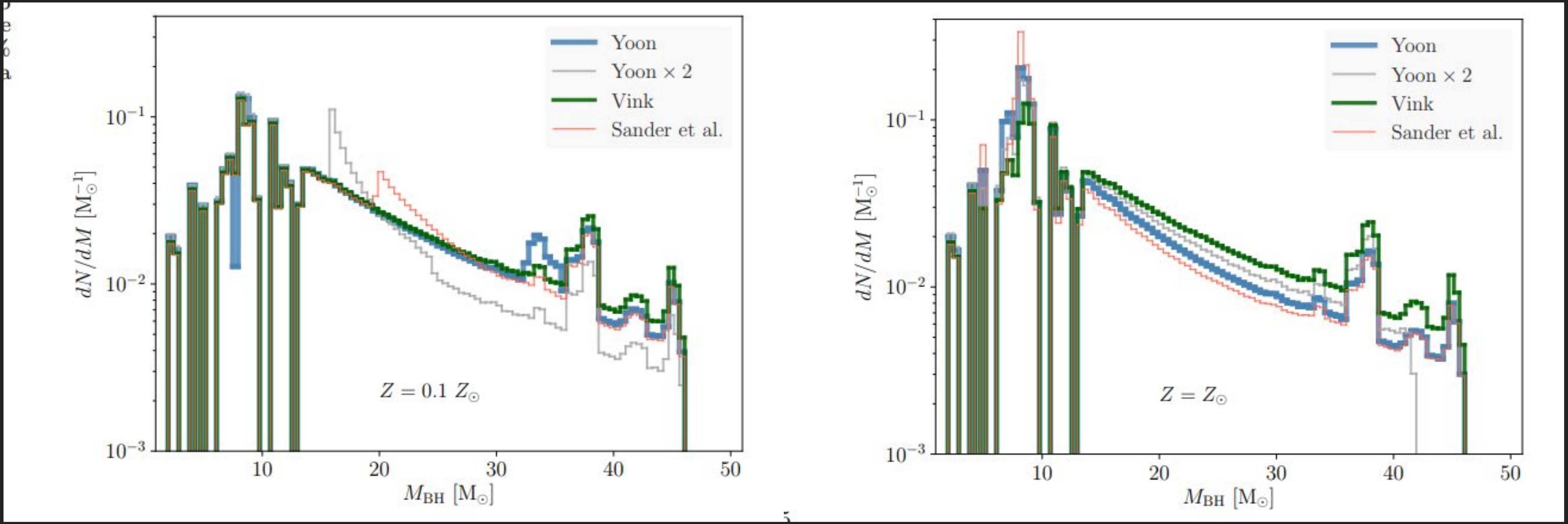
Very massive stars experience pair instability in their cores. This leads to a runaway thermonuclear process that leads to an explosion that leaves behind no remnants.

Stars close to this limit experience pulsations caused by this instability, which limits the maximum BH mass.



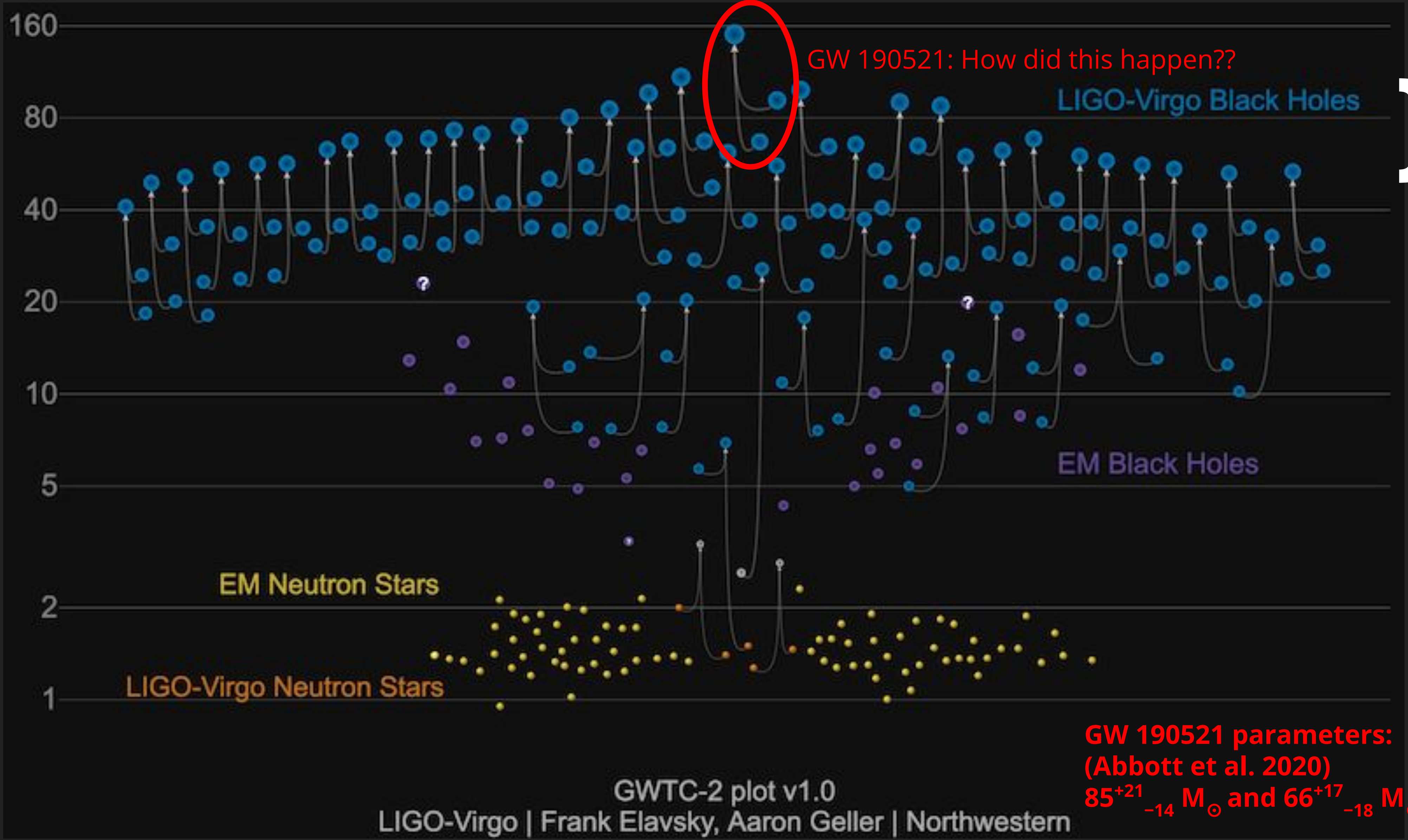
Woosley 2017

What can we expect the distribution of mergers to look like??



Woosley et al. 2020

Higher **mass gap**



GW 190521 parameters:
(Abbott et al. 2020)
85^{+21}_{-14} $M_\odot$ and 66^{+17}_{-18} $M_\odot$

A new way to make massive BHs in very massive stars

Key points

- Previous studies assume that VMSs lose their hydrogen envelopes during their evolution in **binary interactions** or during an **LBV phase**, which may not happen at low Z

- Mixing parameters are uncertain. If VMSs have **low overshooting**, they will evolve to have relatively **small cores**

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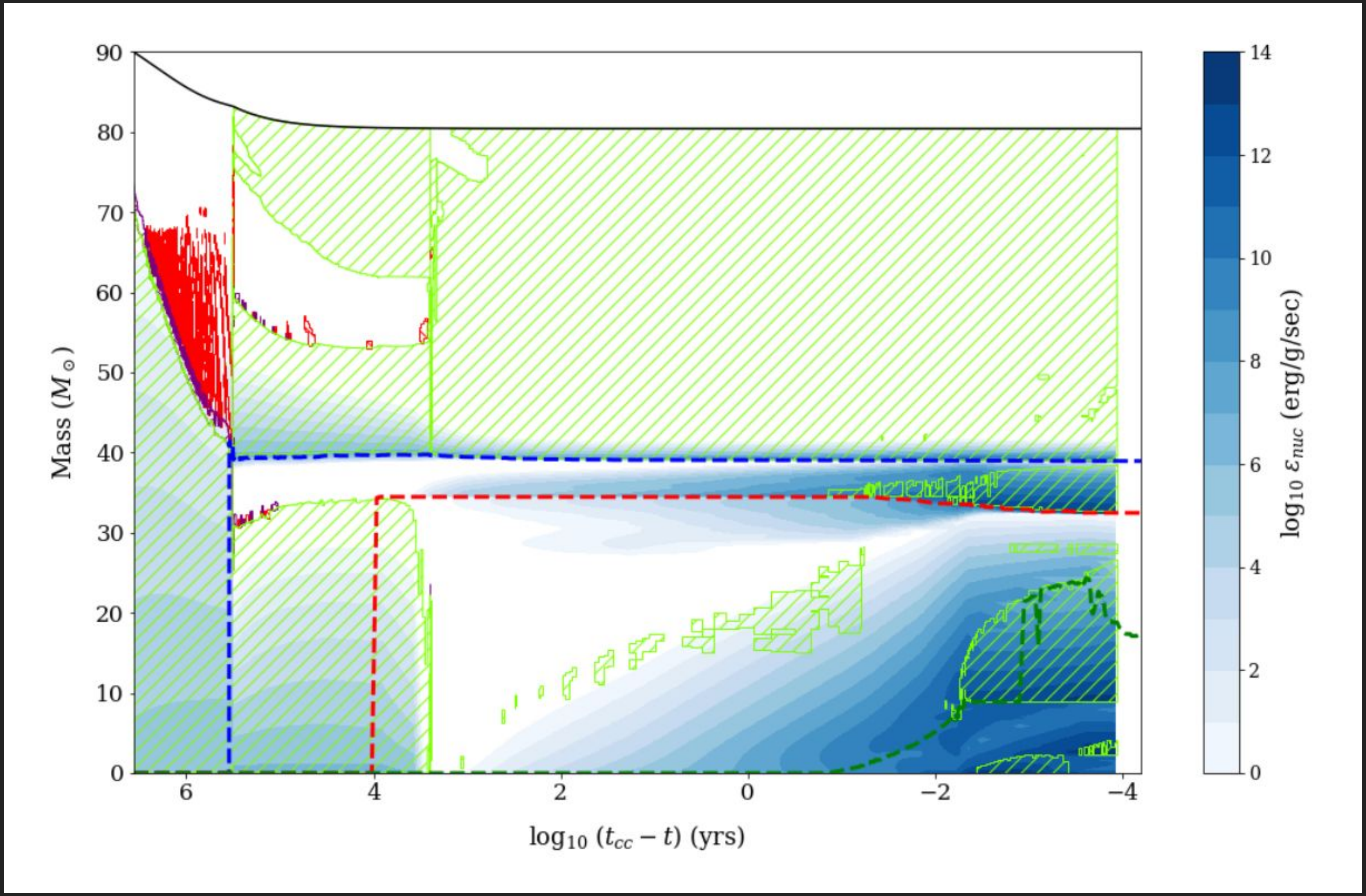
$f_{OV} = 0.01$

$Z = 0.1\ Z_{\odot}$

MLT++

Physically motivated reduction of stellar winds

Results

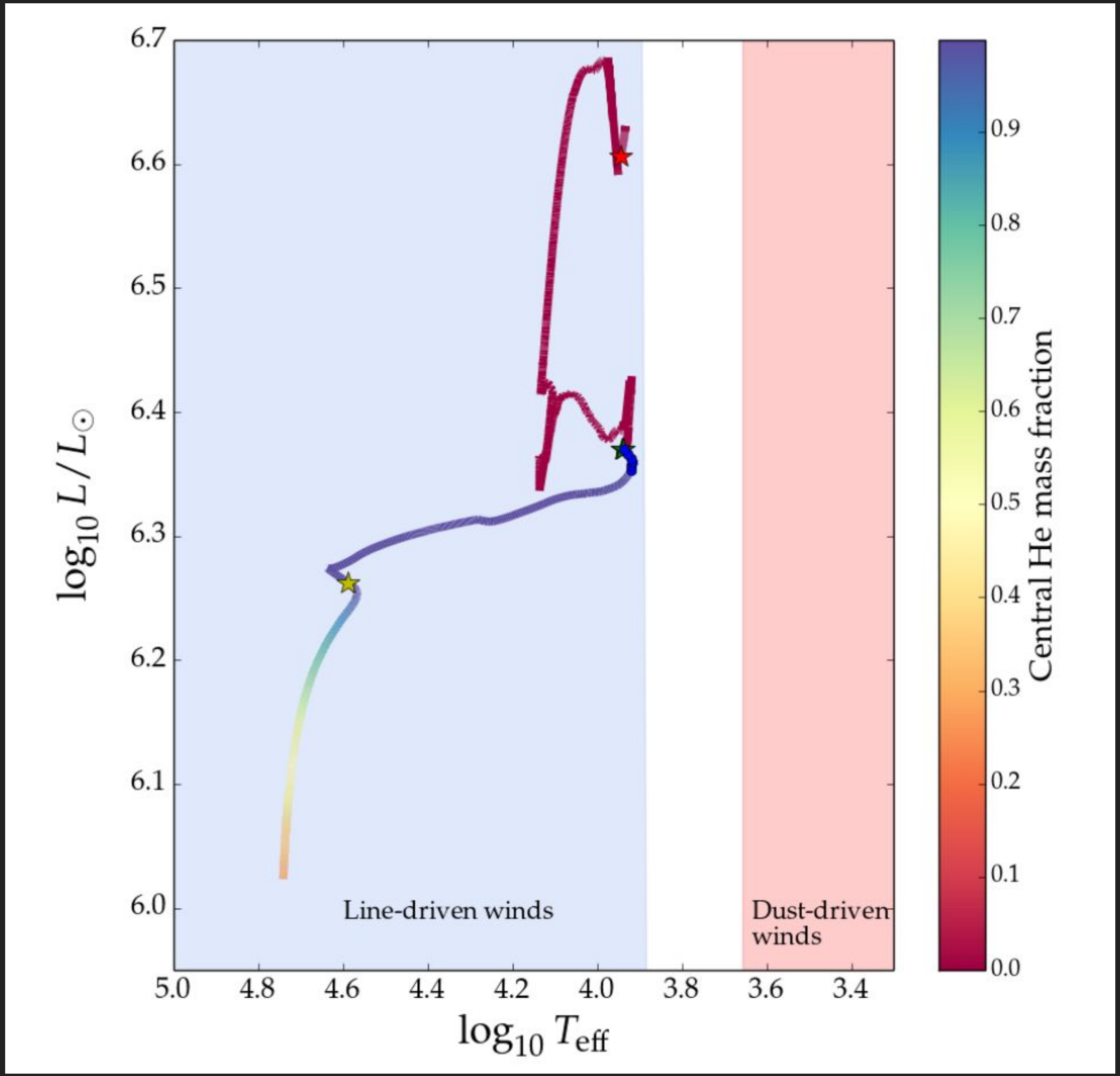


M_{CO} = 32.7 $M_\odot$

M_{env} = 42.9 $M_\odot$

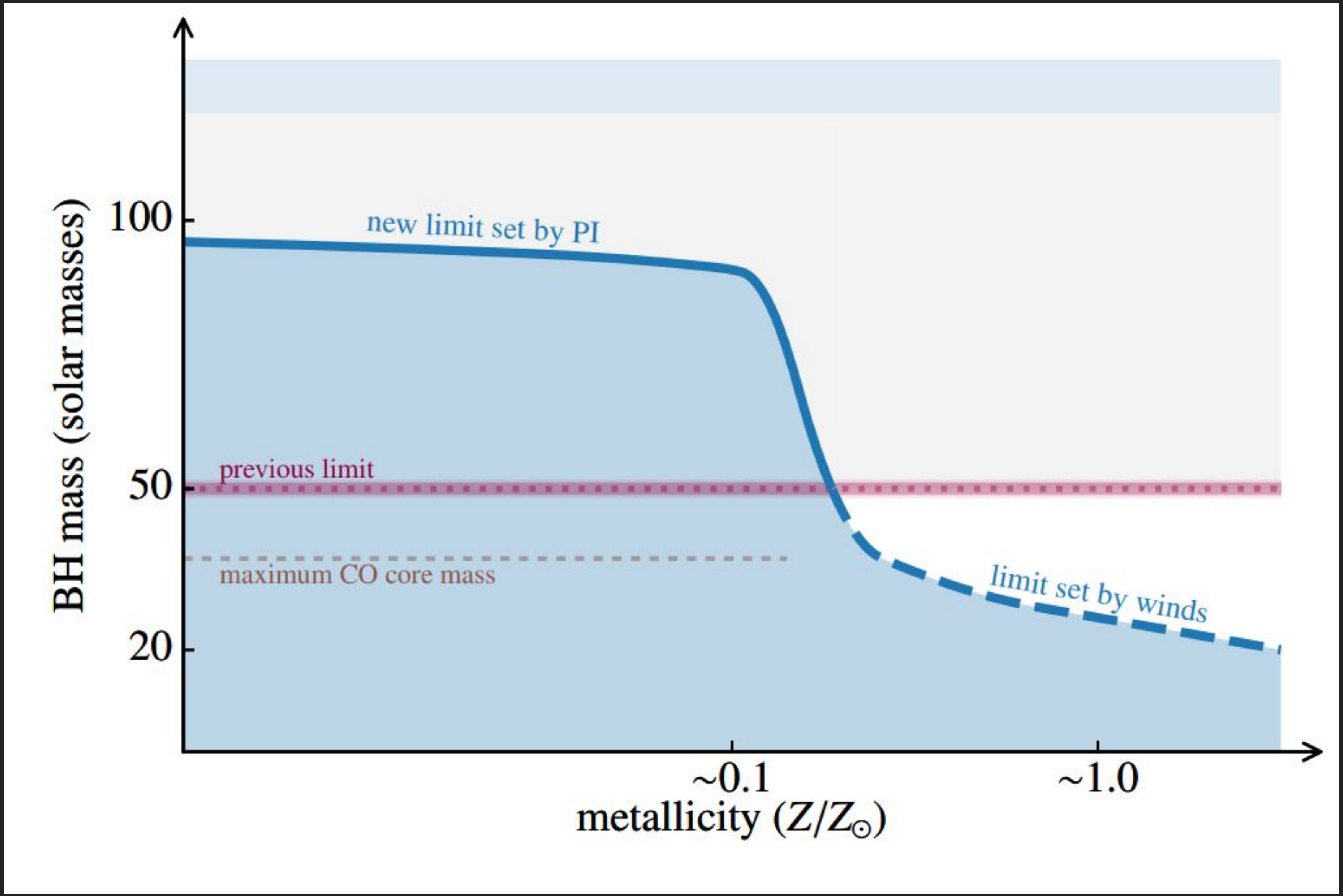
M_{fin} = 80 $M_\odot$

Results



Low mass loss and overshooting allow the star to avoid the RSG region, where mass loss is stronger

Results



BH mass (solar masses)
100
50
20
new limit set by PI
previous limit
maximum CO core mass
limit set by winds
~0.1
~1.0
metallicity (Z/Z⊙)

Caveats

- The numerical treatment of mixing and energy transport is uncertain
- The actual mass loss rates for VMSs at low Z is very uncertain
- It is not trivial to assume that the final stellar mass is equal to the BH mass
- The role of binarity is omitted
- There are other channels to produce such events with the assumptions of previous works (e.g. triple stellar systems, dynamical mergers in dense stellar systems)

Summary & conclusions

Summary & conclusions

- The authors find that the **upper mass limit for BH masses** coming from VMSs depends on mass loss and mixing, and can be increased up to **around 90** $\mathbf{M_\odot}$

- Their channel relies on stars at low Z that have **small cores** and **massive envelopes**, and evolve as **blue supergiants**

- Could potentially have large implications on how we interpret GW observations, but more theoretical work is required