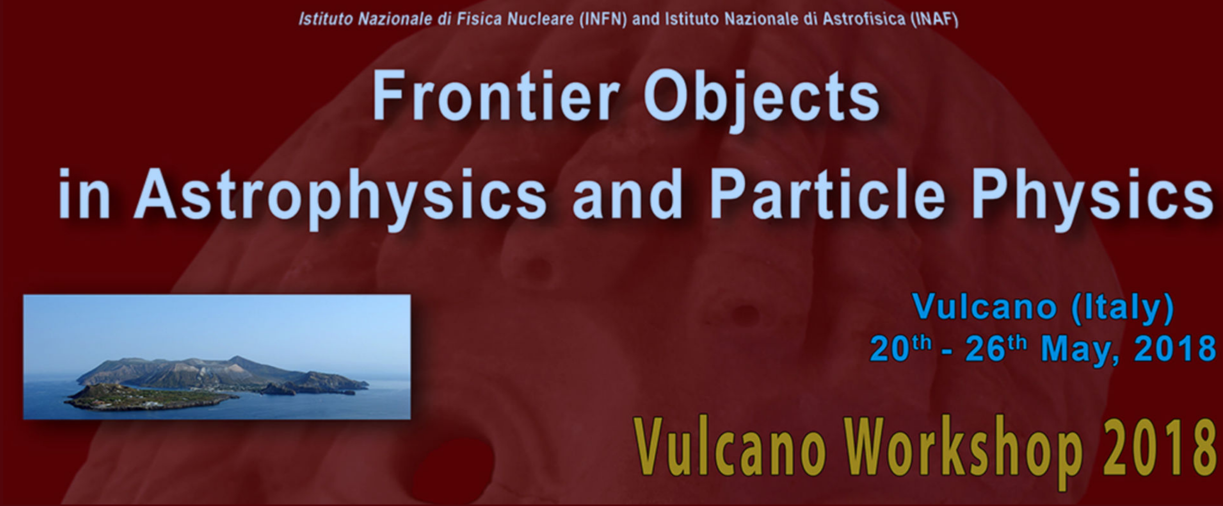
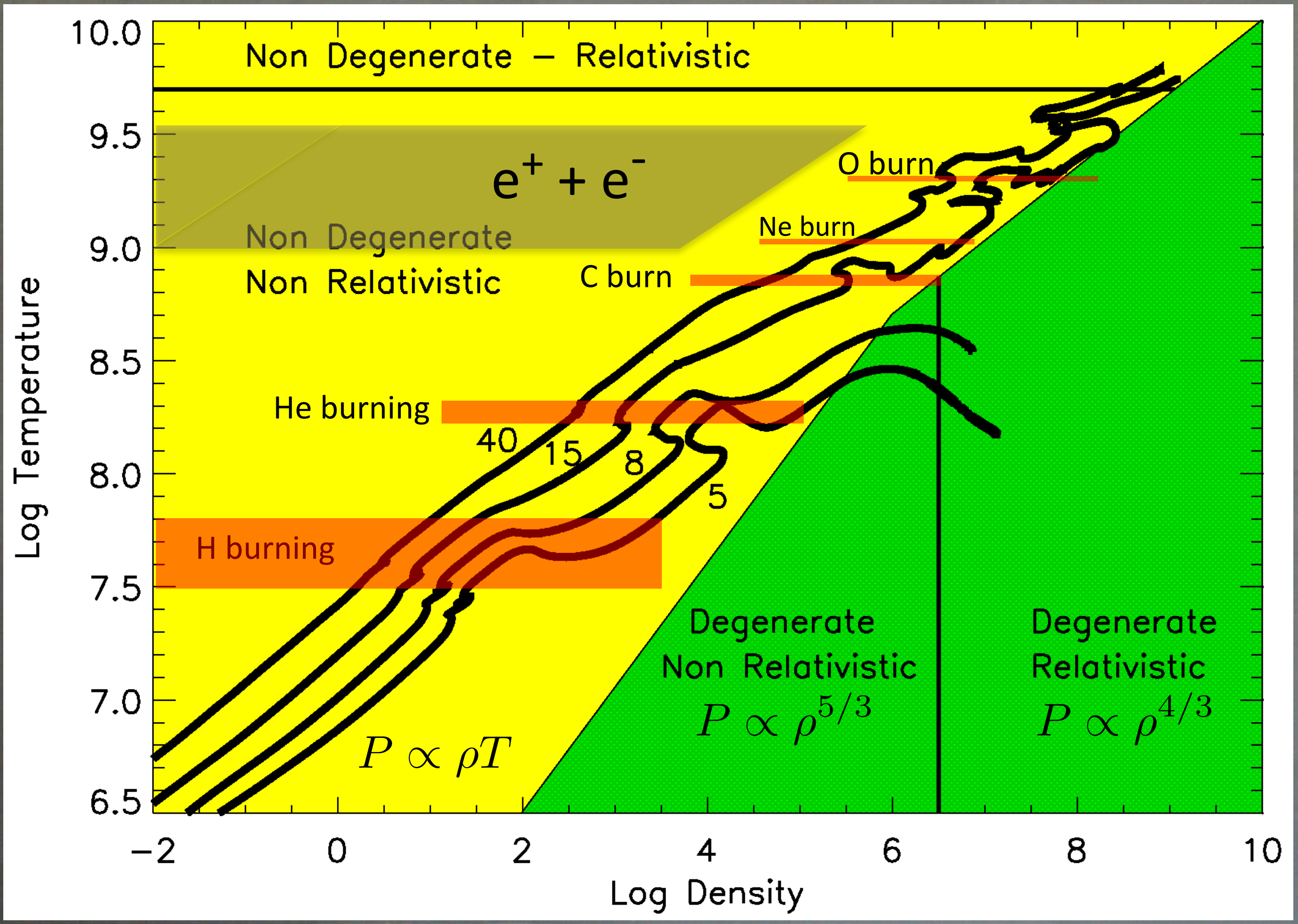
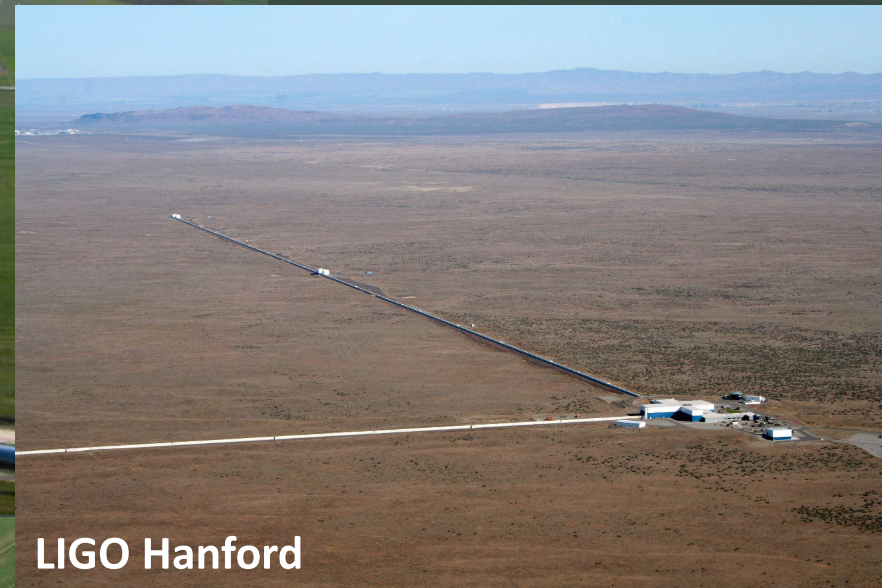


The initial mass - remnant mass relation as a function of the initial mass, metallicity and rotation velocity.

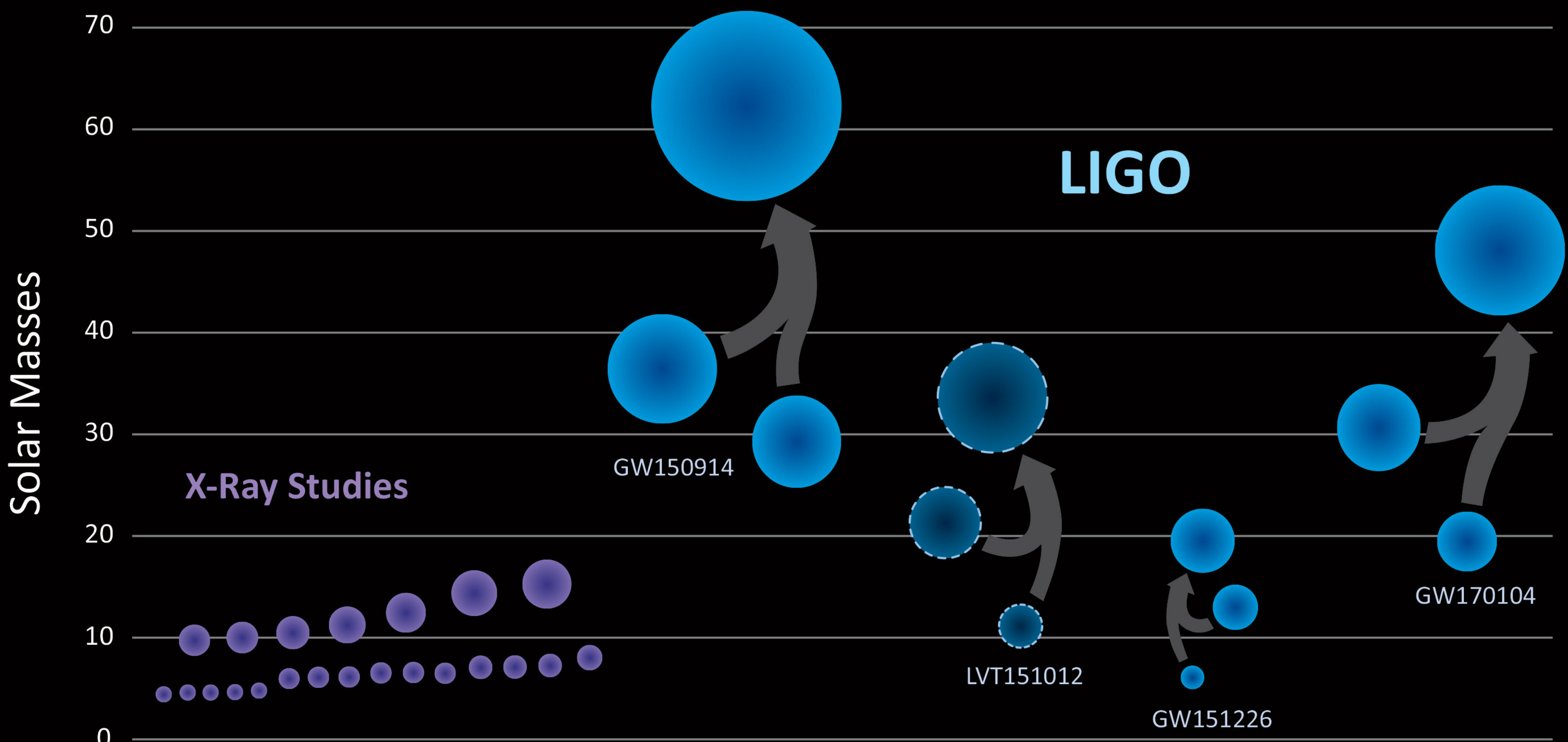
Alessandro Chieffi
INAF – Istituto di Astrofisica e Planetologia Spaziali Italy
Centre for Stellar and Planetary Astrophysics Monash University – Australia
Institut d'Astronomie et Astrophysique - ULB – Bruxelles
alessandro.chieffi@inaf.it

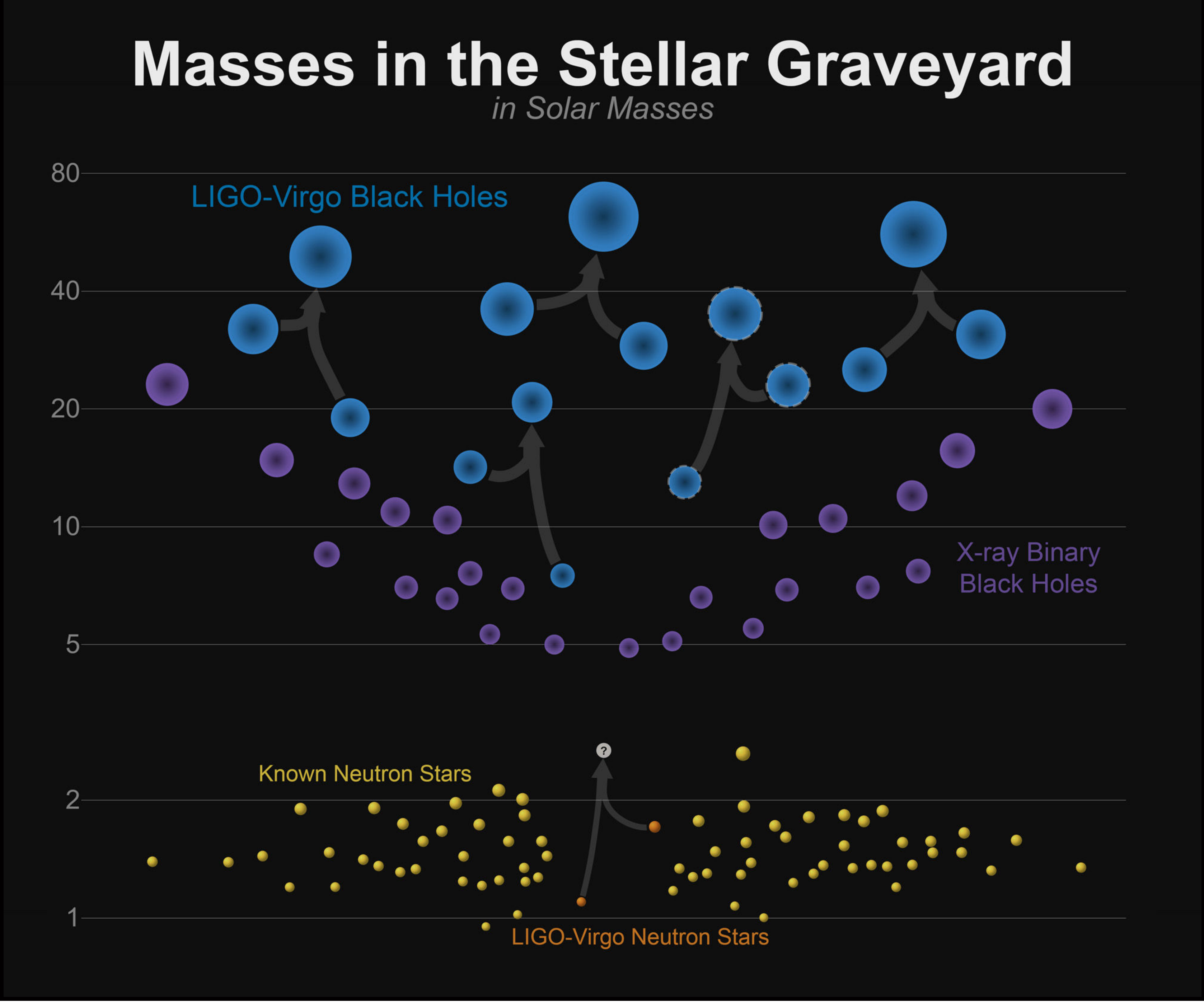

Non Degenerate – Relativistic
$e^+ + e^-$
Non Degenerate
Non Relativistic
O burn
Ne burn
C burn
He burning
H burning
40
15
8
5
$P \propto \rho T$
Degenerate
Non Relativistic
$P \propto \rho^{5/3}$
Degenerate
Relativistic
$P \propto \rho^{4/3}$
Log Temperature
Log Density
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
−2
0
2
4
6
8
10

LIGO – VIRGO : Laser Interferometer Gravitational Observatories



Black Holes of Known Mass




Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
X-ray Binary
Black Holes
Known Neutron Stars
?
LIGO-Virgo Neutron Stars

The Astrophysical Journal, 821:38 (45pp), 2016 April 10 doi:10.3847/0004-637X/821/1/38

CORE-COLLAPSE SUPERNOVAE FROM 9 TO 120 SOLAR MASSES BASED ON NEUTRINO-POWERED EXPLOSIONS

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The Astrophysical Journal, 818:124 (23pp), 2016 February 20 doi:10.3847/0004-637X/818/2/124

A TWO-PARAMETER CRITERION FOR CLASSIFYING THE EXPLODABILITY OF MASSIVE STARS BY THE NEUTRINO-DRIVEN MECHANISM

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Spherically symmetric, first-principles simulations do not yield explosions by the neutrino-driven mechanism except for low-mass progenitors with oxygen–neon–magnesium cores (Kitaura et al. 2006; Janka et al. 2008) or small iron cores (Melson et al. 2015). These stars are characterized by an

Binding energy

Mass-Radius relation
Density profile

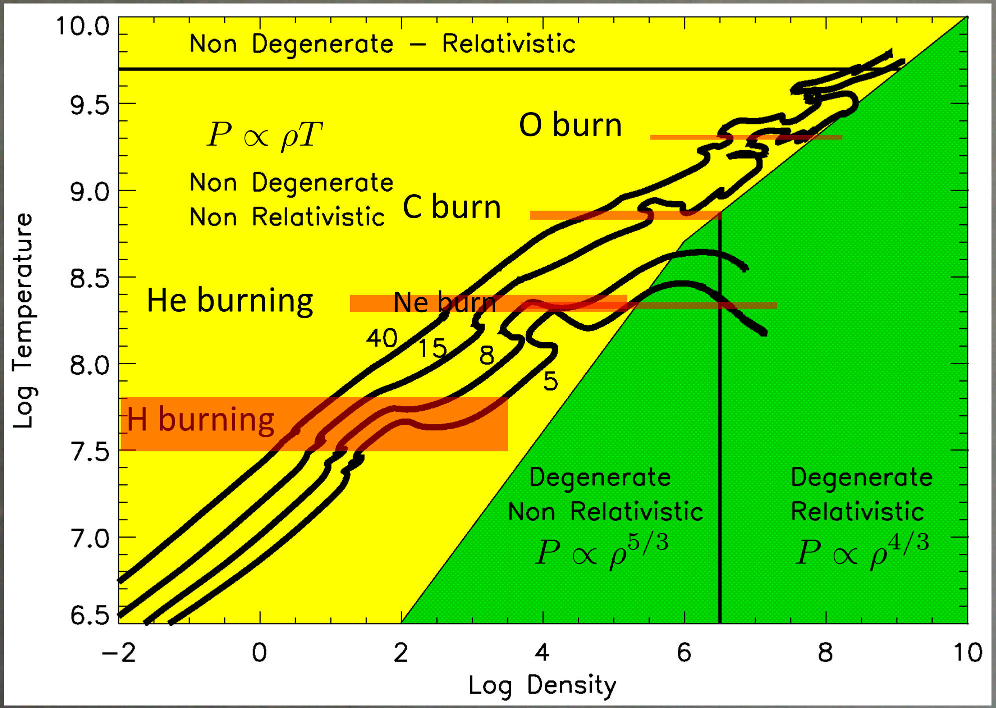
Binding energy

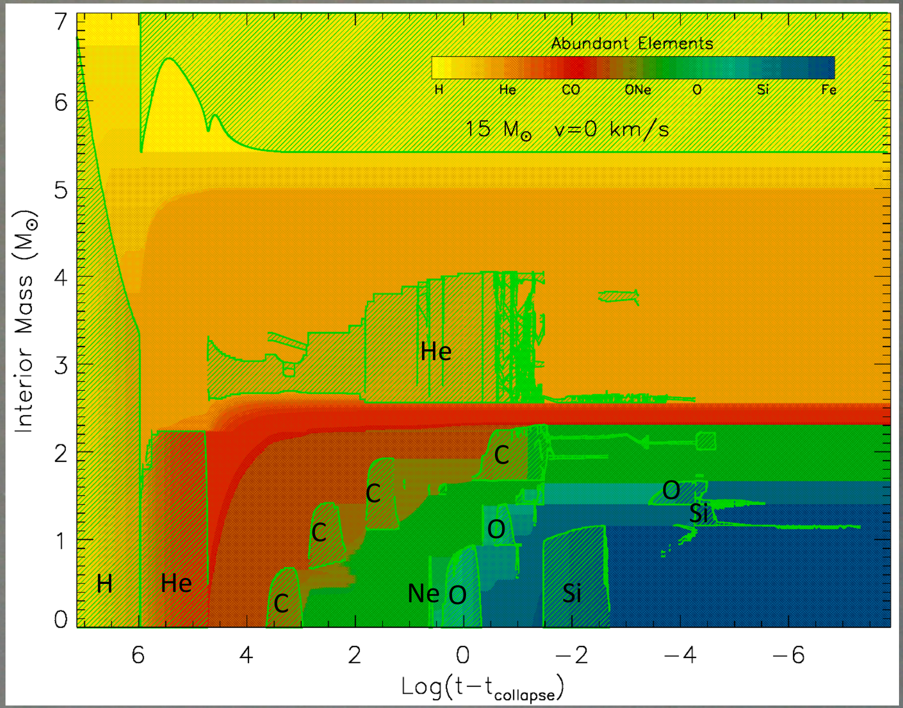
Mass-Radius relation
Density profile

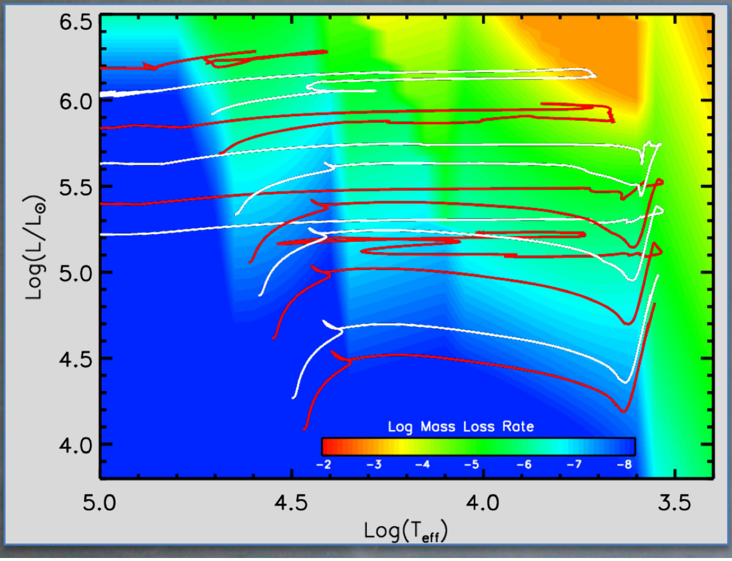
Shock wave

Fraction of the gravitational energy released by the collapse of the Fe core

The hydrostatic evolutionary history of a massive star



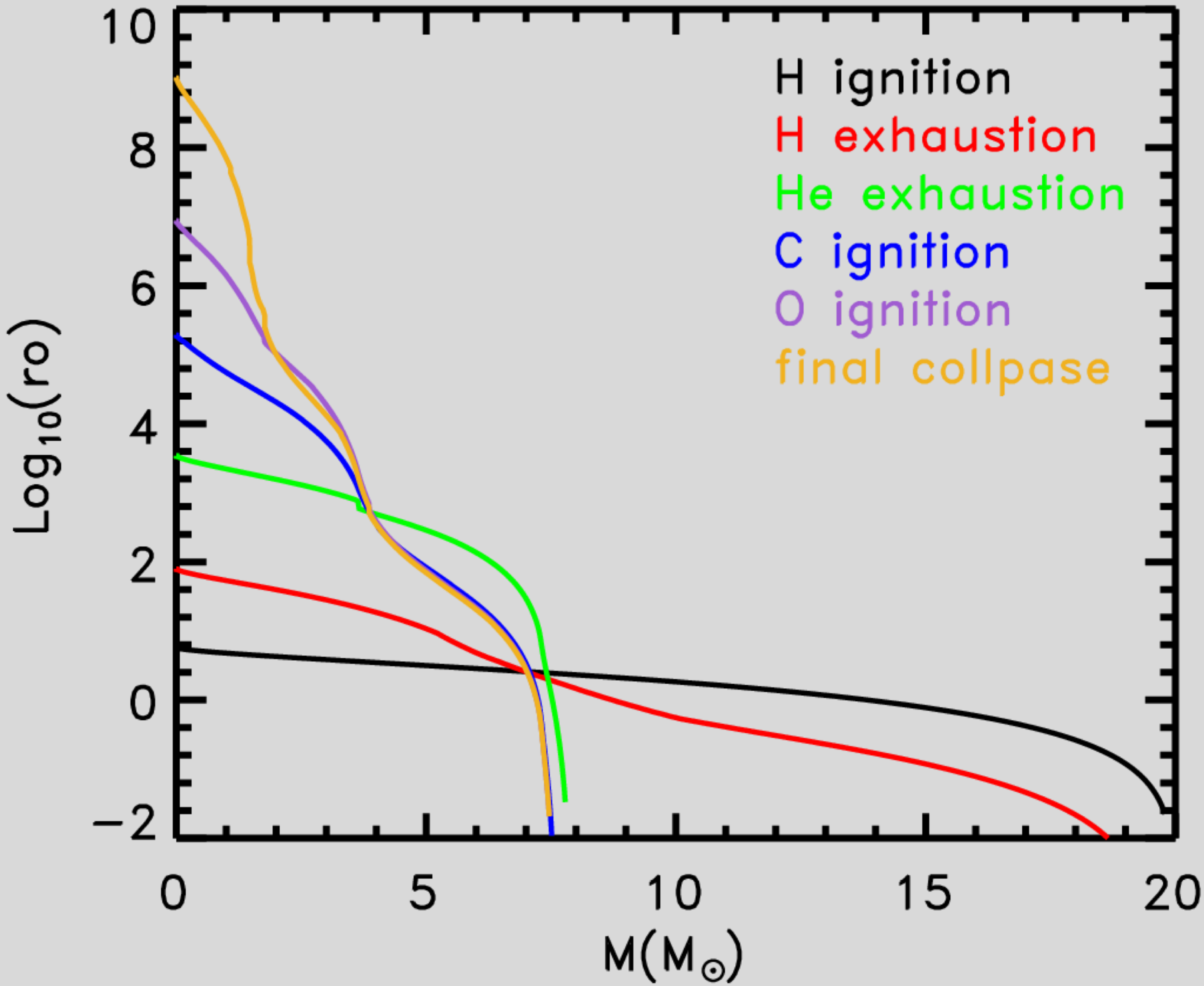




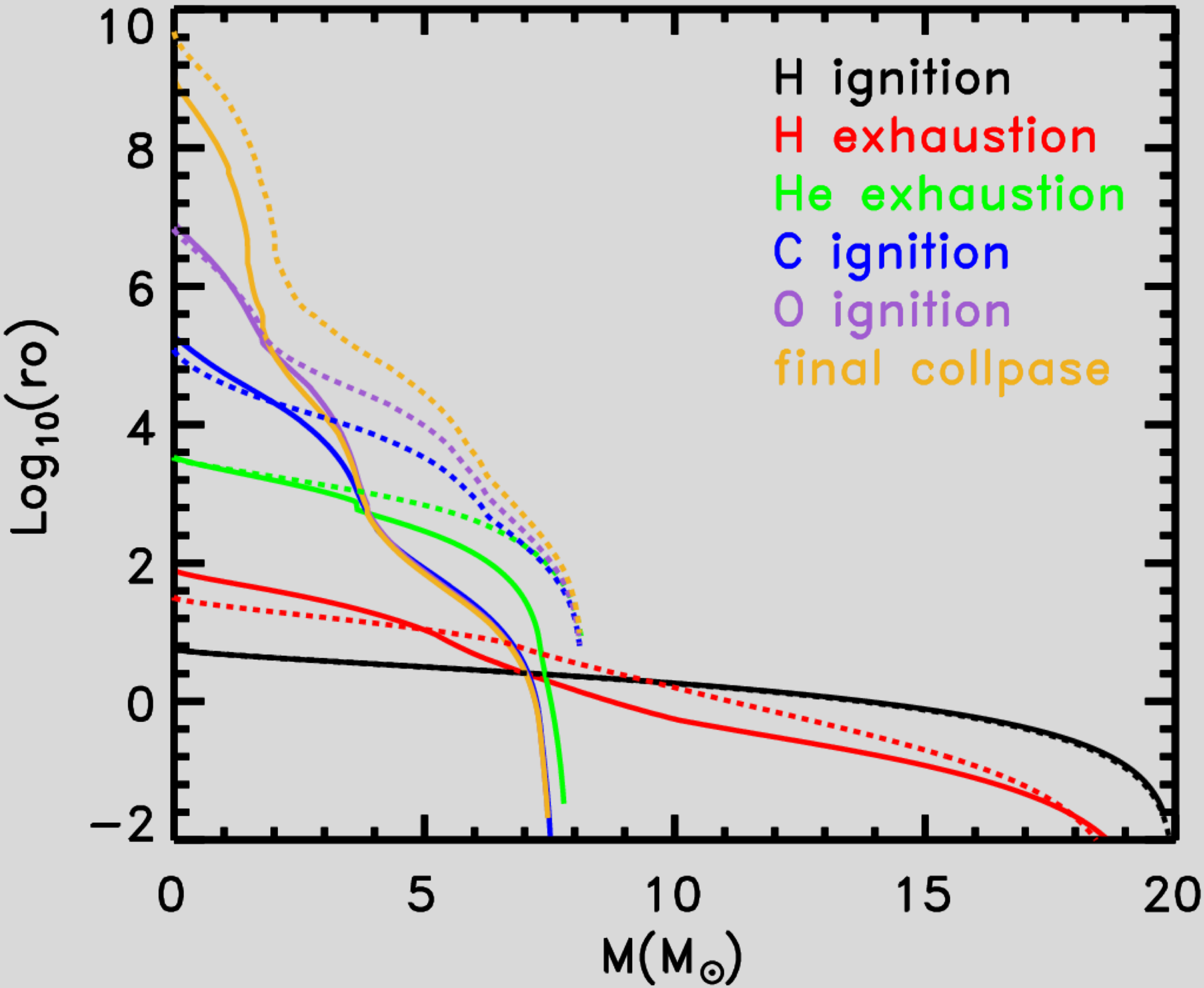
The hydrostatic evolutionary history of a massive star

To get reliable remnant masses we NEED accurate:

Mass-Radius relation
Density profile
Degree of compactness



H ignition
H exhaustion
He exhaustion
C ignition
O ignition
final collpase
Log10(ro)
M(M⊙)
10
8
6
4
2
0
−2
0
5
10
15
20

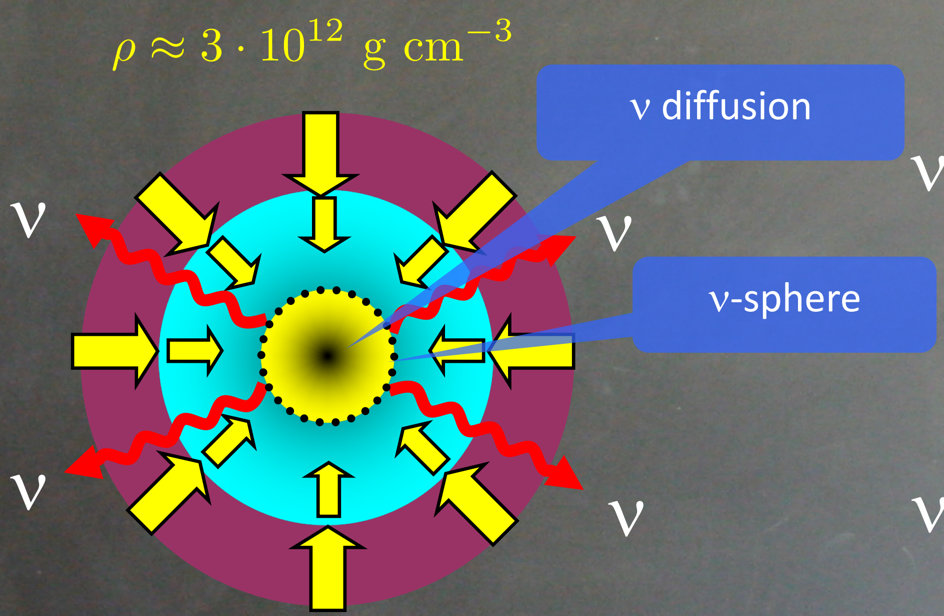

H ignition
H exhaustion
He exhaustion
C ignition
O ignition
final collpase
Log10(ro)
M(M⊙)
10
8
6
4
2
0
−2
0
5
10
15
20

CORE COLLAPSE SUPERNOVAE: ENERGETICS

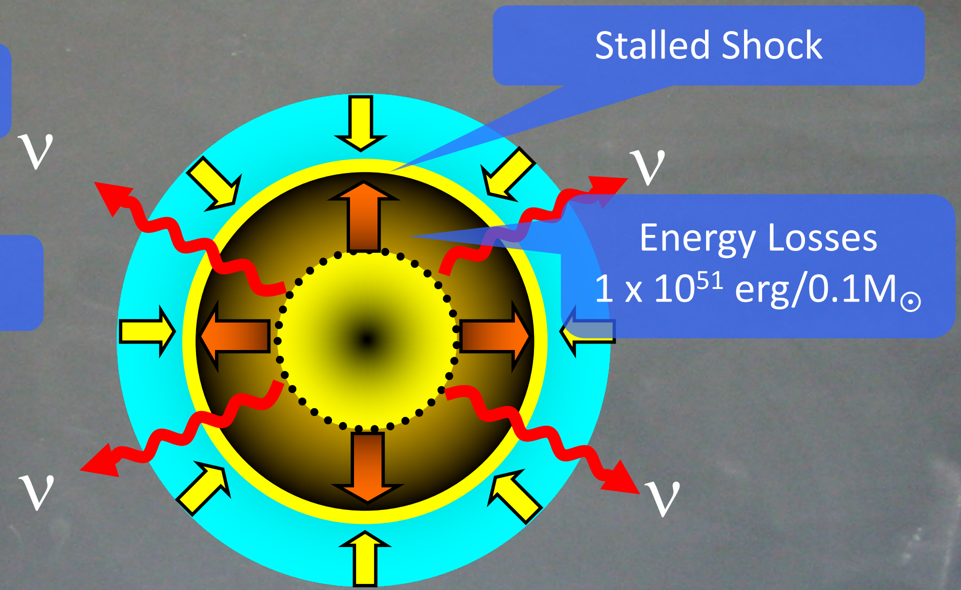
Combining all the energy required to explain the SN display with all the energy lossess we get

$$\Delta E_{available} \approx \Delta E_{grav} - \Delta E_{loss} \approx 10^{53}\ \mathrm{erg}$$

There is plenty of energy to drive a succesful explosion!

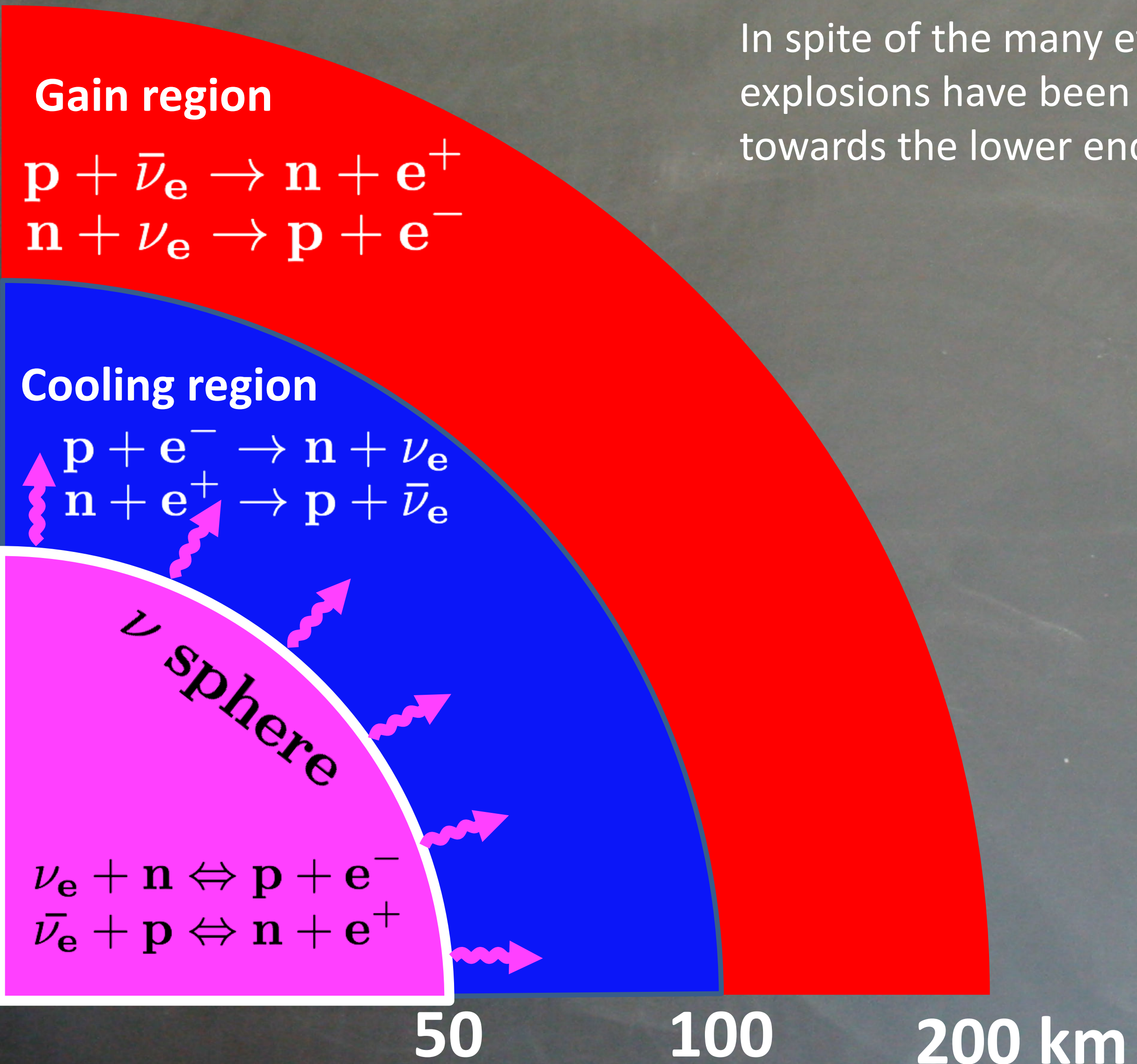


Neutrino Trapping



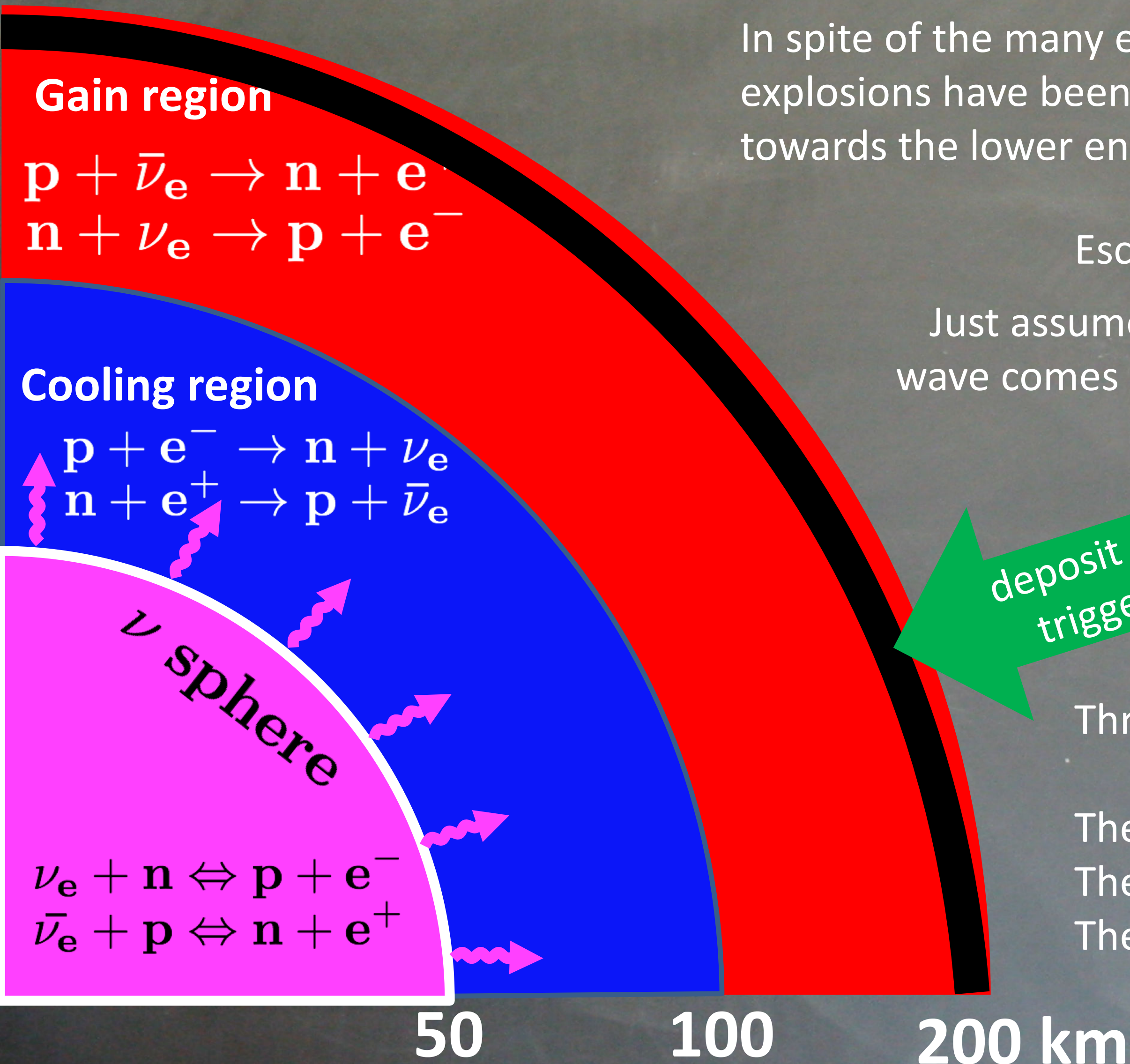
“Prompt”shocks eventually stall!

CORE COLLAPSE SUPERNOVAE: EXPLOSION



In spite of the many efforts, just a few successful explosions have been obtained up to now, but only towards the lower end of the massive stars: 9-10 $M_\odot$.

CORE COLLAPSE SUPERNOVAE: EXPLOSION



In spite of the many efforts, just a few successful explosions have been obtained up to now, but only towards the lower end of the massive stars: 9-10 $M_\odot$.

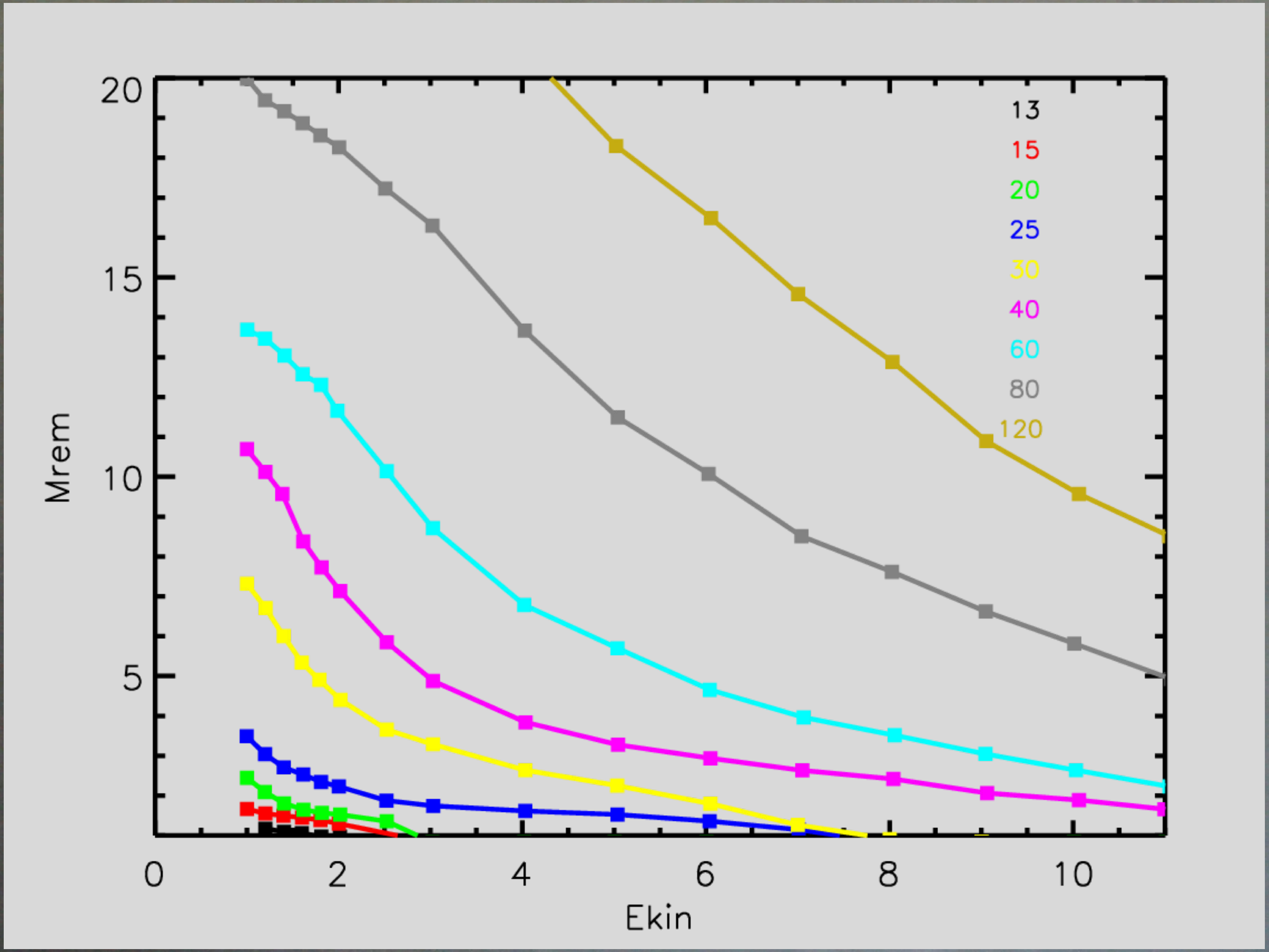
Escamotage:

Just assume that the shock wave comes out of the Fe core

deposit ***by hand*** energy to trigger the shock wave

Three different techniques adopted:

The piston (Woosley +)
The thermal bomb (Nomoto +)
The kinetic bomb (Limongi & Chieffi)


20
15
10
5
0
2
4
6
8
10
Mrem
Ekin
13
15
20
25
30
40
60
80
120

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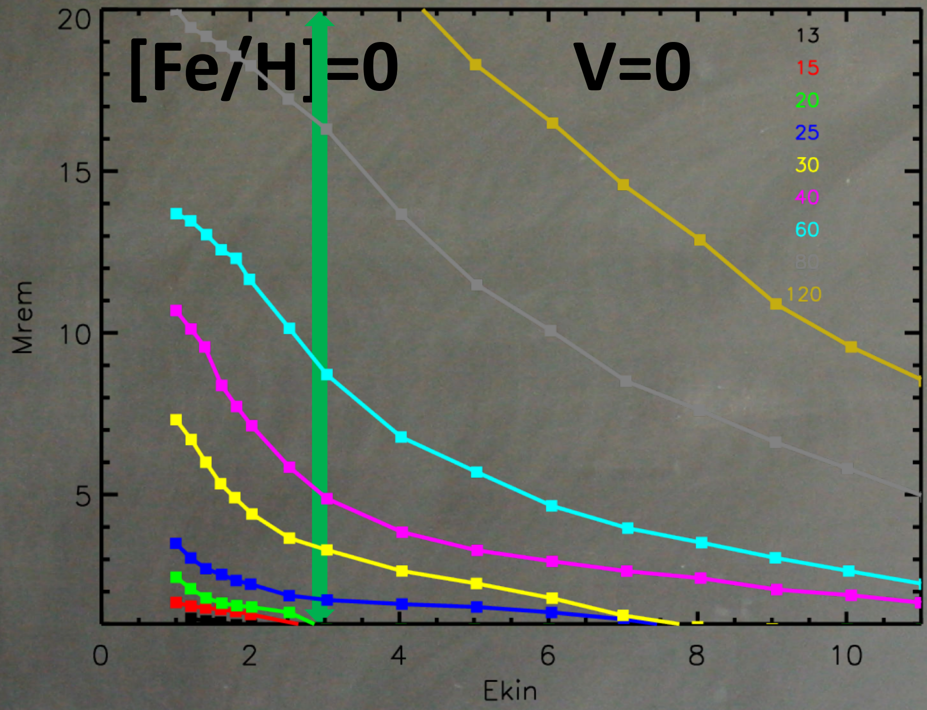
The calibration aims at producing the explosion energy and ejected ^{56}Ni mass of SN 1987A compatible with observations, for which the best values are $E_{\mathrm{exp}} = (1.50 \pm 0.12) \times 10^{51}$ erg (Utrobin 2005), $E_{\mathrm{exp}} \sim 1.3 \times 10^{51}$ erg (Utrobin & Chugai 2011), and $M_{\mathrm{Ni}} = 0.0723$–$0.0772\,M_{\odot}$ (Utrobin et al. 2014), but numbers reported by other authors cover a considerable range (see Handy et al. 2014 for a compilation). The explosion energy that we accept for an SN 1987A model in the calibration process is guided by the ejected ^{56}Ni mass (which fully accounts for short-time and long-time fallback) and a ratio of E_{exp} to ejecta mass in the ballpark of estimates based on light-curve analyses (see Table 1 for our values).

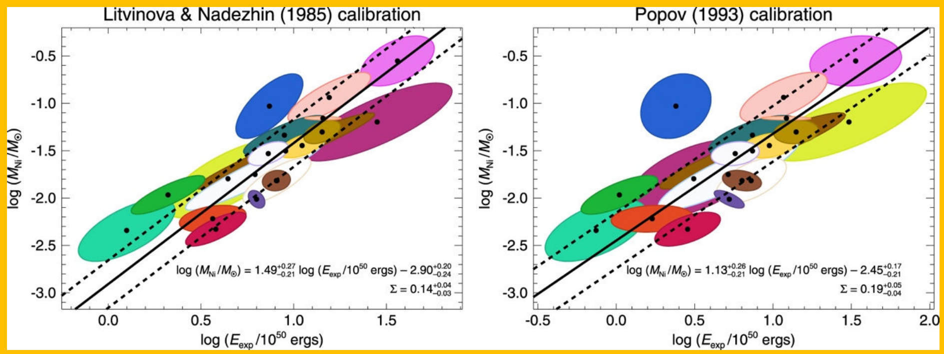
Because of the "gentle" acceleration of the SN shock by the neutrino-driven mechanism (also in 3D simulations; see Utrobin et al. 2014), it is difficult to produce this amount of ejected ^{56}Ni just by shock-induced explosive burning. $M_{^{56}\mathrm{Ni}}$ in



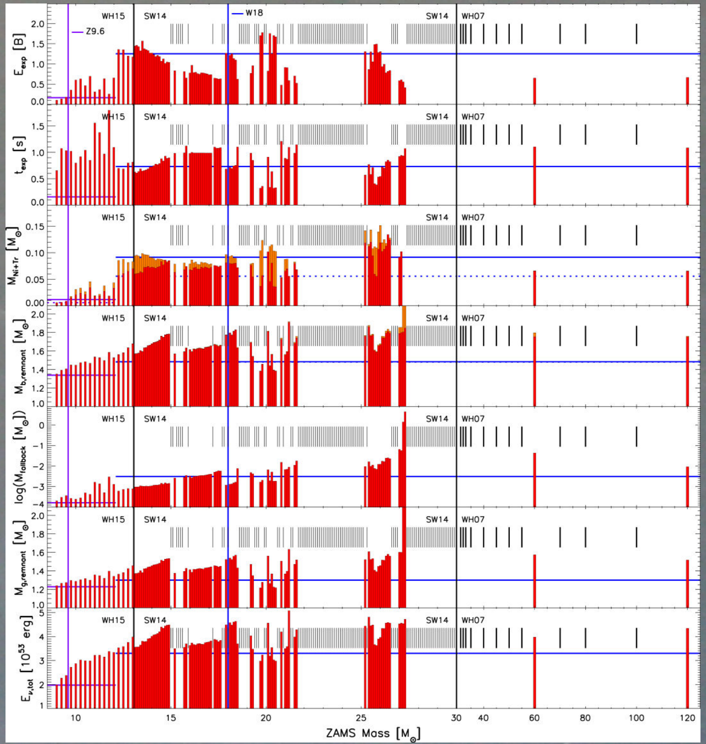
Compactness parameter ξ
(O' Connor & Ott 2011, ApJ 730,70)

$$\xi_i = \frac{M_i(M_\odot)}{R_i(10^3\ km)}$$

Best value ➔ i=2.5 $M_\odot$



2015 Pejcha & Prieto ApJ 806,225



Sukhbold+ (2016) ApJ 821, 38

Our *current* recommended scenario is:

$$13 \leq M(M_{\odot}) \leq 25$$

Mixing and fall back as suggested by Umeda & Nomoto (2002):

Inner border fixed by requiring [Ni/Fe]=0.2

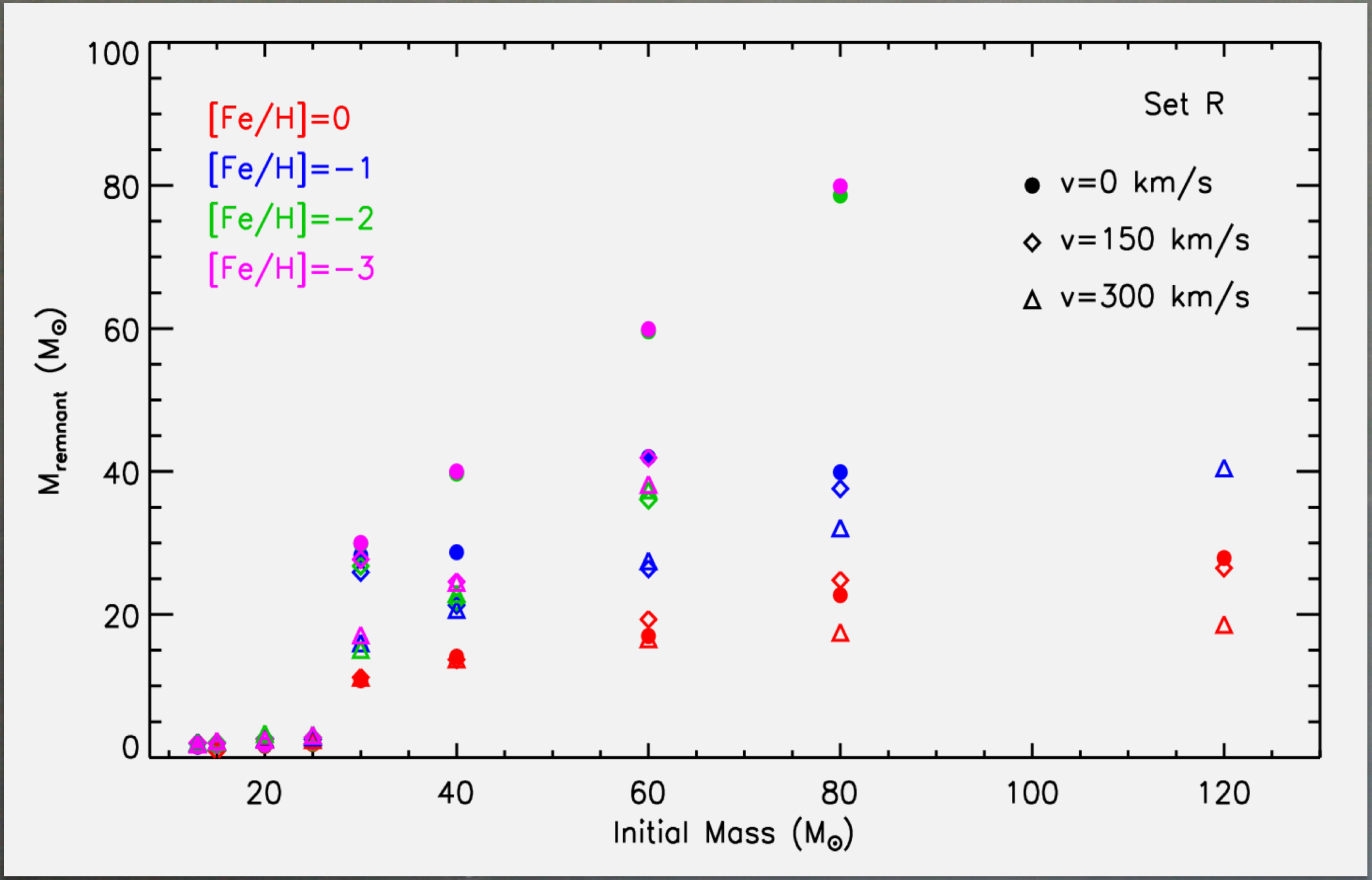
Outer border fixed at the base of the Oxygen burning shell

Mass of the remnant fixed by requiring the ejection of 0.07 $M_{\odot}$ of ^{56}Ni

$$25 < M(M_{\odot}) \leq 120$$

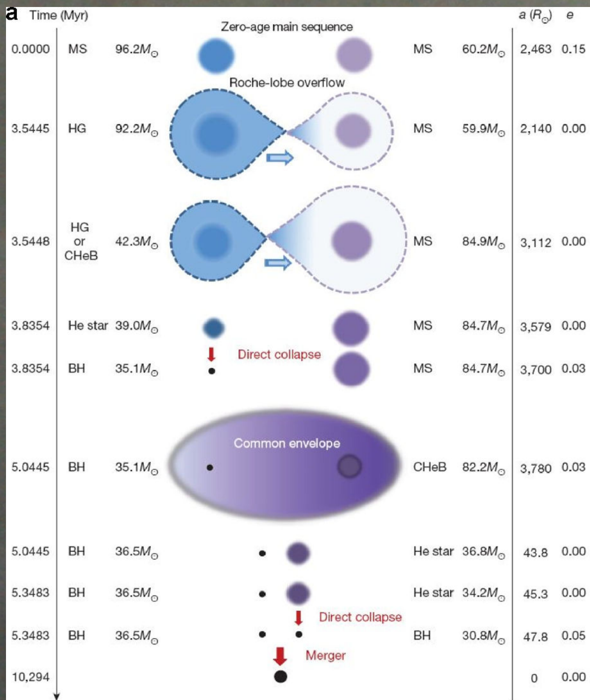
Mass of the remnant equal to the current mass at the core bounce

Initial mass – remnant mass relation

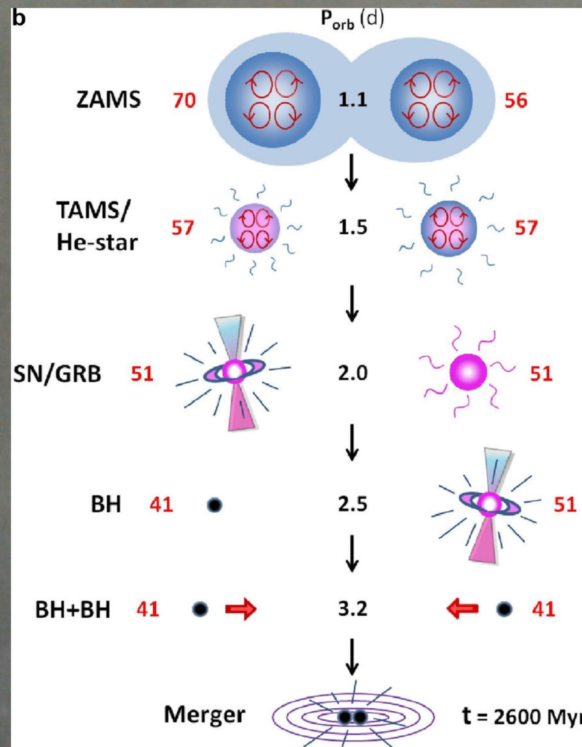


Scenarii proposed to explain GW150914

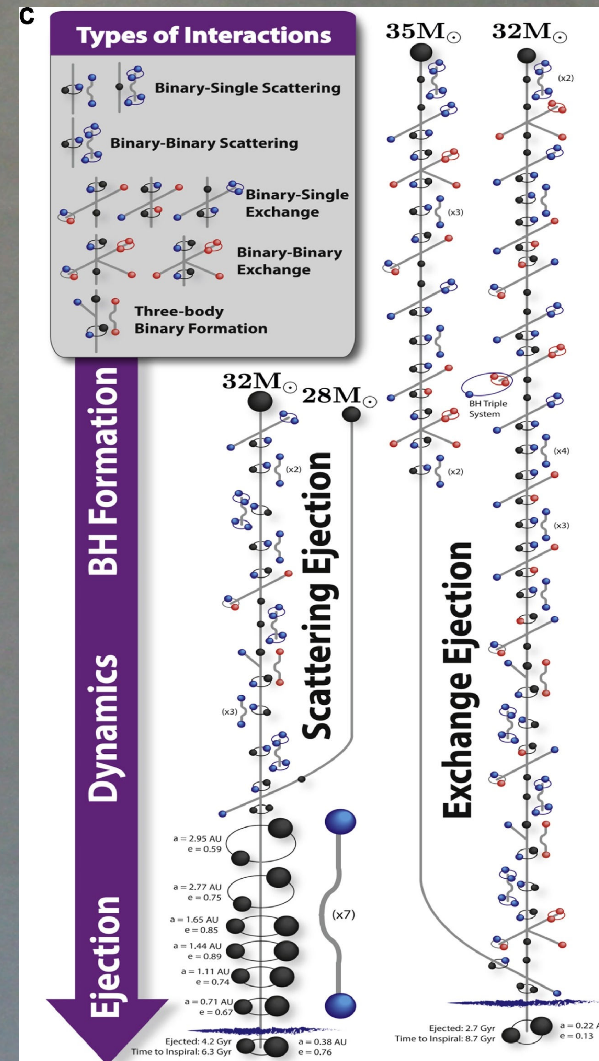
Classical binary evolution



Over-contact binary evolution



Dynamical formation of a BBH



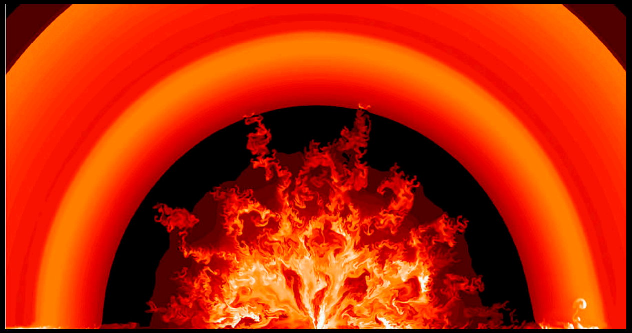
Courtesy Mirabel (2017) NAR 78,1

Conclusions

Be very, very careful when you read (or listen) about the Remnant mass – Initial mass relation

…

You risk entering a fairy world



KEEP CALM AND STAY TUNED