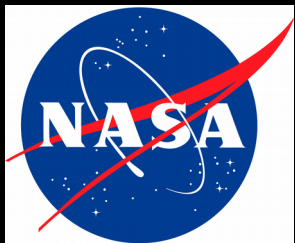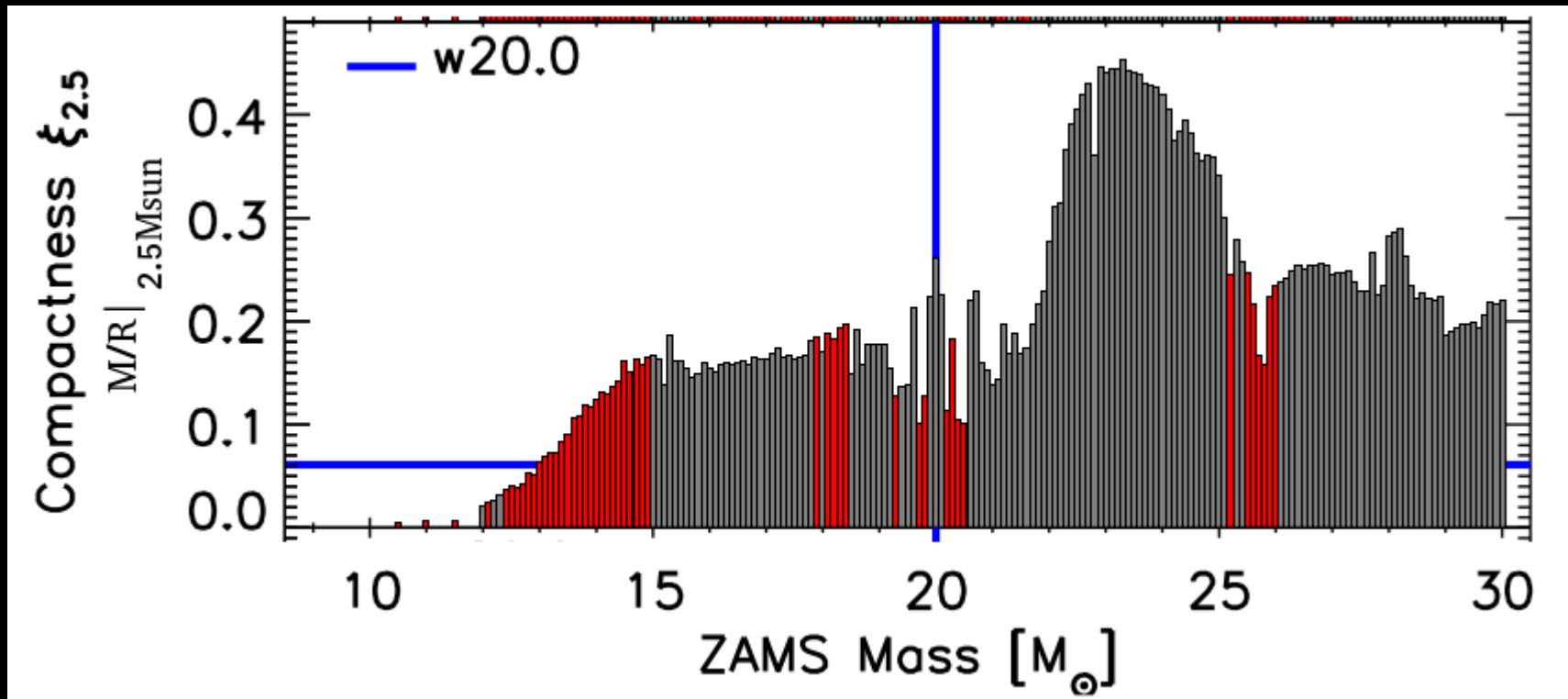# Variations in pre-SN models

Farmer, R; Fields, F; Petermann, I; Dessart, L; Cantiello, M; Paxton, B; Timmes, F

(Soon)

What do pre-SN stars look like?
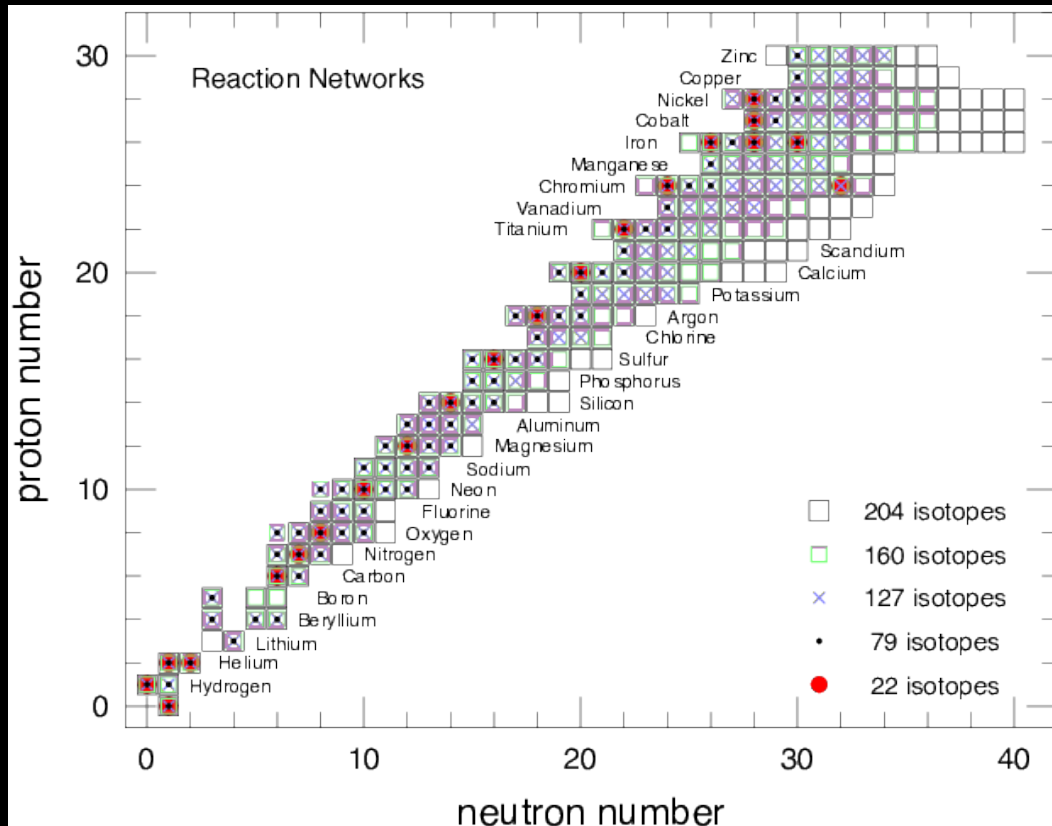

(Ertl et al 2016)

What drives the variation in the final state?

Can we put an error bar on the models?

Ugliano et al 2012
Sukhbold et al 2014, 2016
Ertl et al 2016
Petermann et al 2017

Adams Talk
Dolence Talk
Janka Talk
Patnaude Talk

Ensemble of models

(Farmer et al 2016 http://goo.gl/kdKYnS)

Evolve stars from pre-MS to core-collapse with MESA
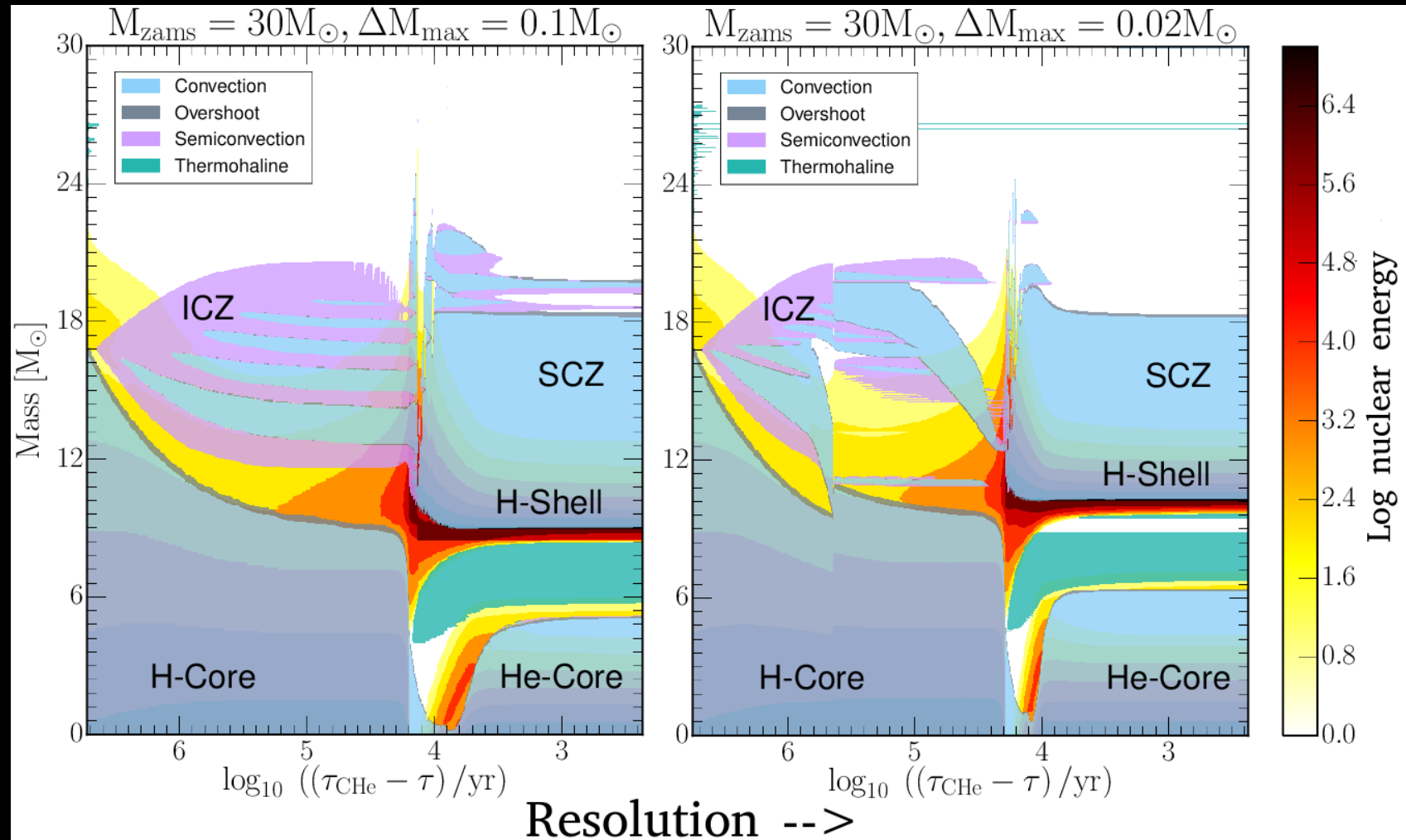
15, 20, 25, 30 Msun models

5 Spatial resolution

5 Nuclear networks
– Fully coupled

With/out mass loss

What affects how the star burns each major fuel source?
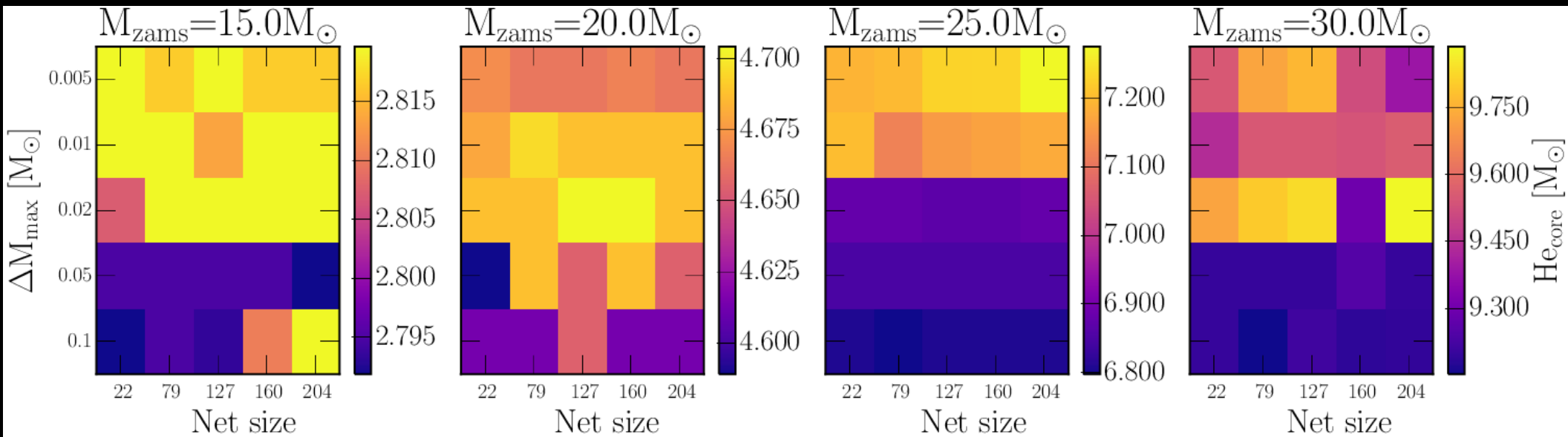
Evolution on the MS

Increasing resolution acted like a stronger semiconvective mixing

Can inject fresh fuel into the core when ICZ merges with the H-core

Non-linear behaviour in MS lifetime with respect to resolution
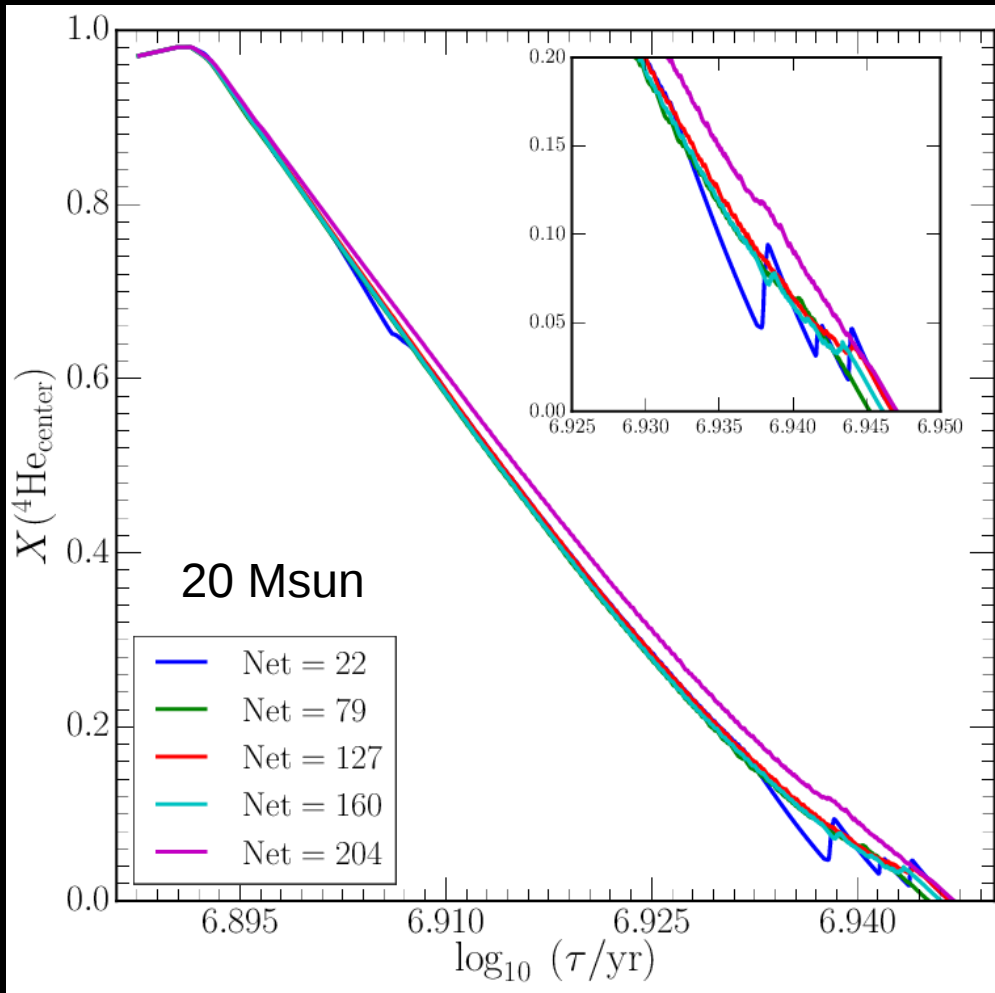
Evolution on the MS

Bifurcation in behaviour of the He core mass/age/total mass lost

15/20 Msun models is the injection of fuel into the H-shell

25/30 Msun models is the injection of fuel into the H-core

Degeneracy between resolution and strength of semiconvection

Langer et al 1985 Ding et al 2014

Evolution during CHe

Core breathing pulses

Uncertainty in the treatment of the convective boundary during CHe (Constantino et al. 2016)

Blue loops in HR diagram?

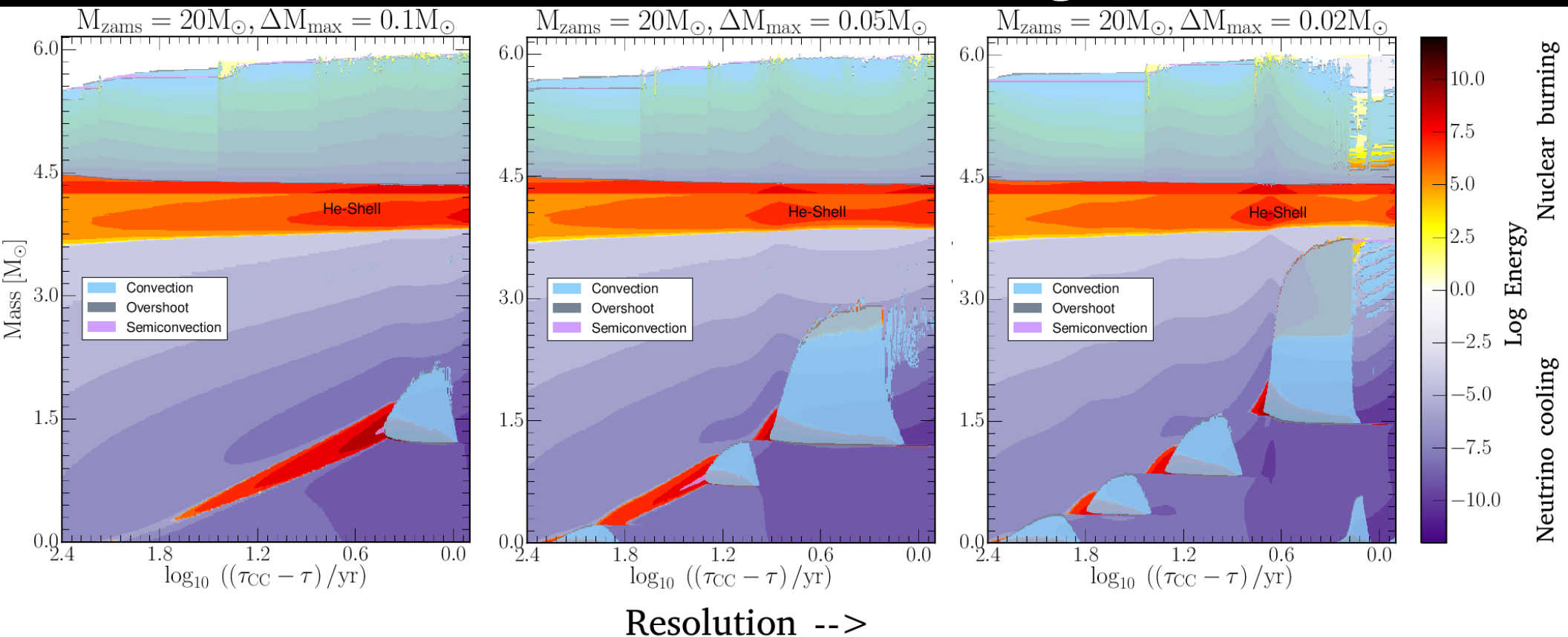Leads to larger fraction of O in the C/O core

– Change carbon burning

Better model of convection/semi boundary needed?

Castelani et al 1985   Straniero et al 2003
Caputo et al 1989   Constantino et al 2016
Boothroyd et al 1993
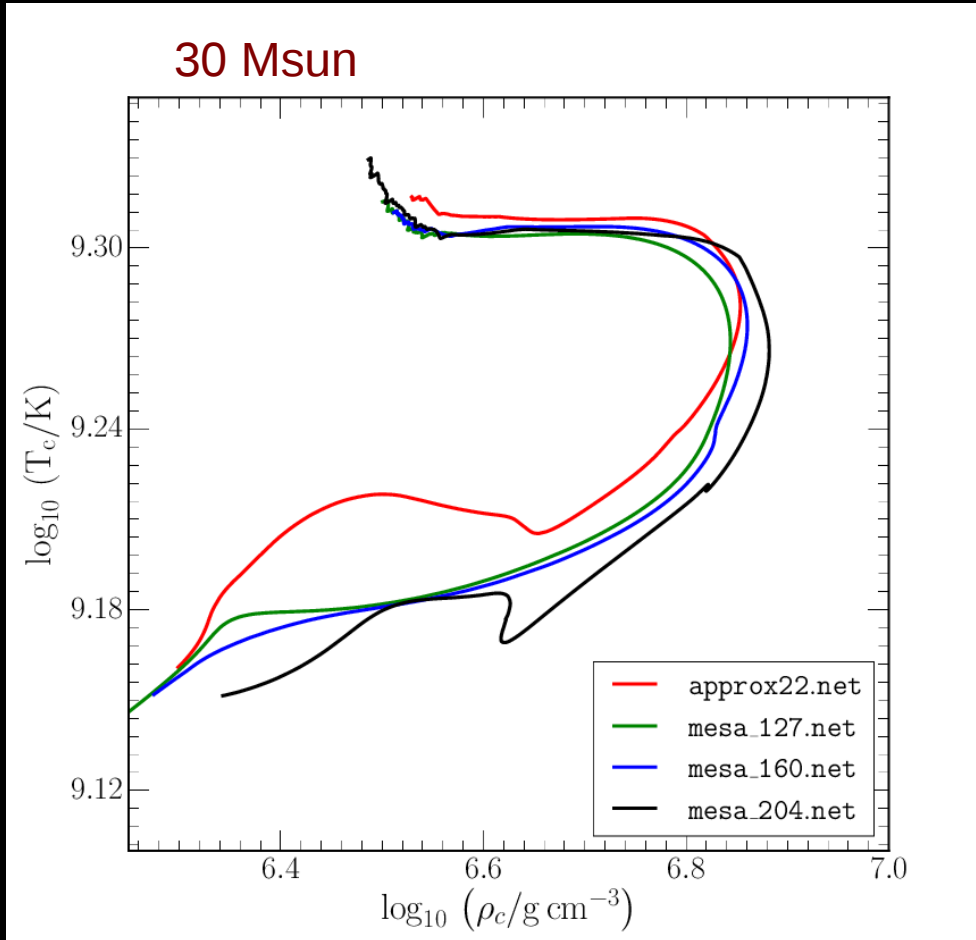
Carbon burning

Stellar core is now dominated by neutrino cooling

Transition between radiative carbon burning and convective burning at 20Msun

Sets the stage for the final compactness, based on ability to ignite shells later

Farmer et al 2015 Cristini et al 2016

Neon burning

30 Msun

As net increases behaviour of neon ignition changes

Core density increases with increasing net size

Increased neutrino cooling from thermal neutrino cooling
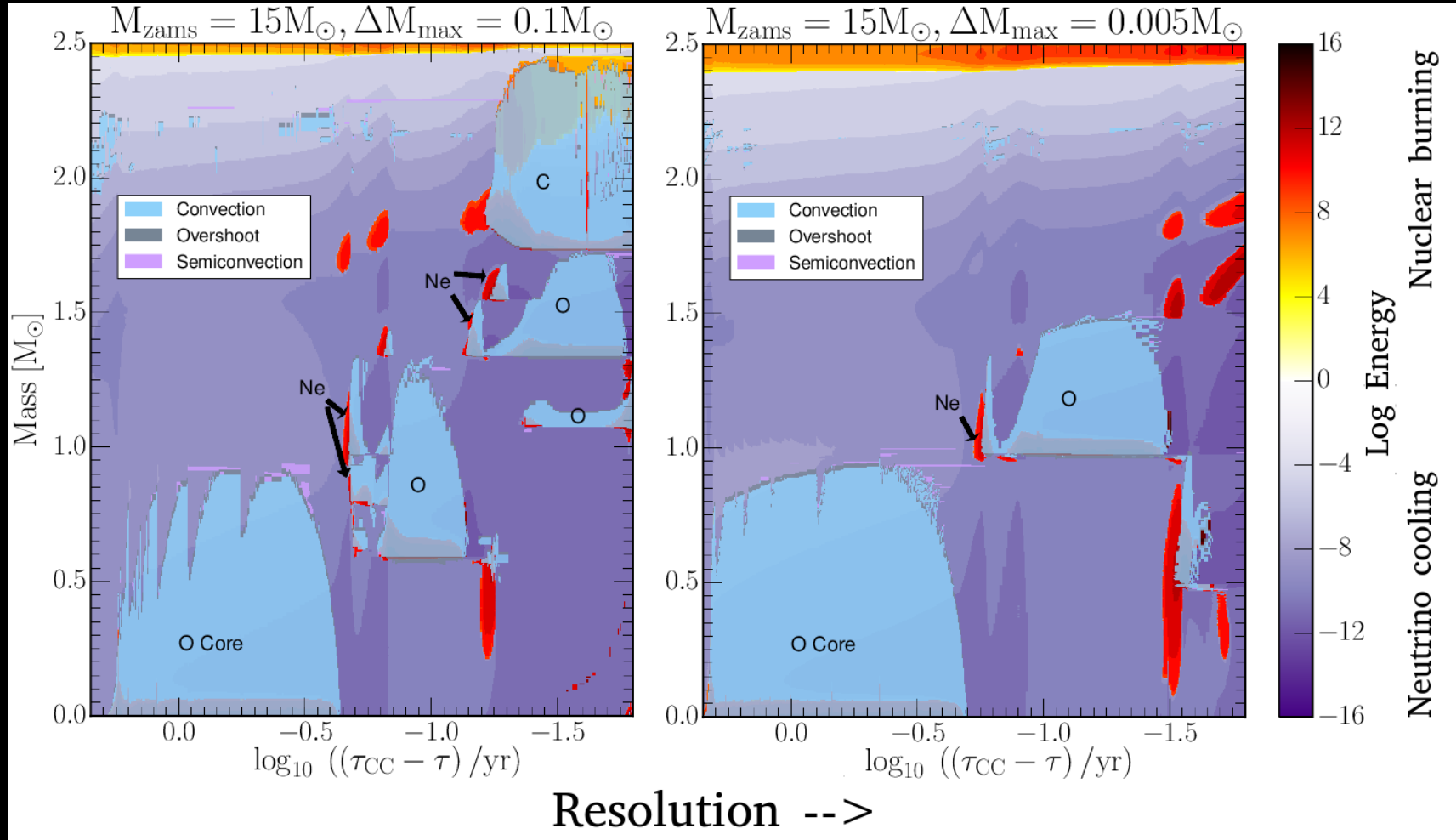
Neon ignition delayed

Becomes more vigorous when it does ignite

Behaviour transitions from:
- Igniting at the center
- Off center weak radiative flash
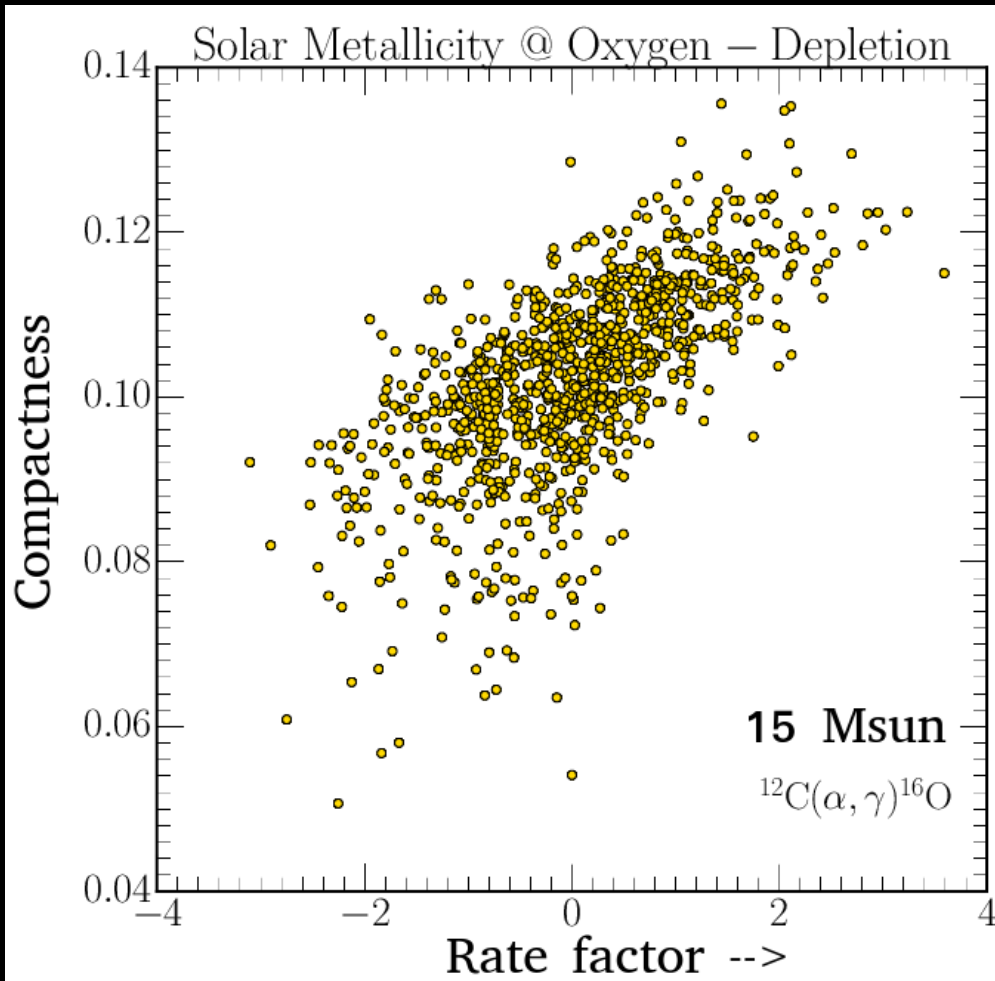- Off center convection flashes

Oxygen burning

Behaviour can be non-linear due to step like nature of igniting a shell

Choice of isotopes/reactions becoming important

Chatzopoulos et al 2016 Müller 2016 Jones et al 2017

Reaction rates

Solar Metallicity @ Oxygen − Depletion

15 Msun

$^{12}C(\alpha, \gamma)^{16}O$

(Fields et al 2017)

What about the rates themselves?

For each rate Monto carlo sample from known measurement uncertainties, from STARLIB

Evolve model up to oxygen depletion
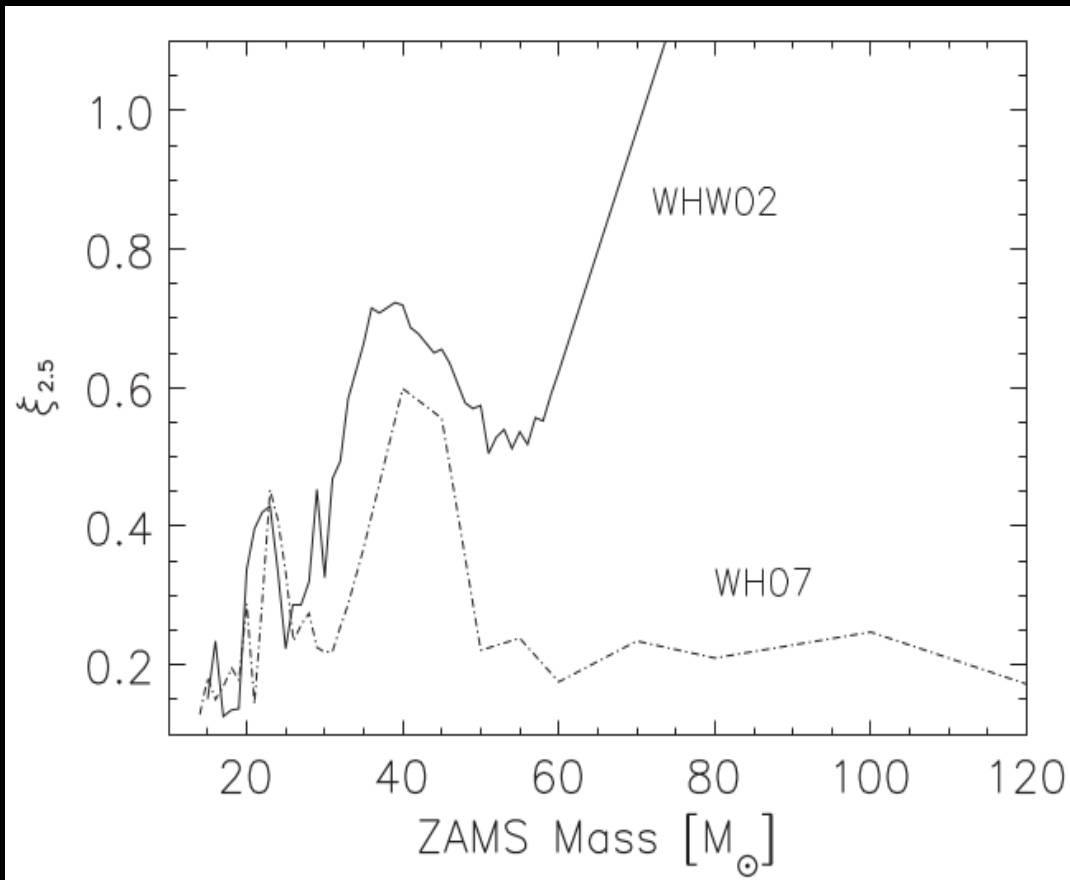
Trend shows effect of 12C → 16O

Scatter shows the effect of other rates

~20% variation in compactness

Rauscher et al 2016
Nishimura et al 2017

Metallicity (Well Mass loss)
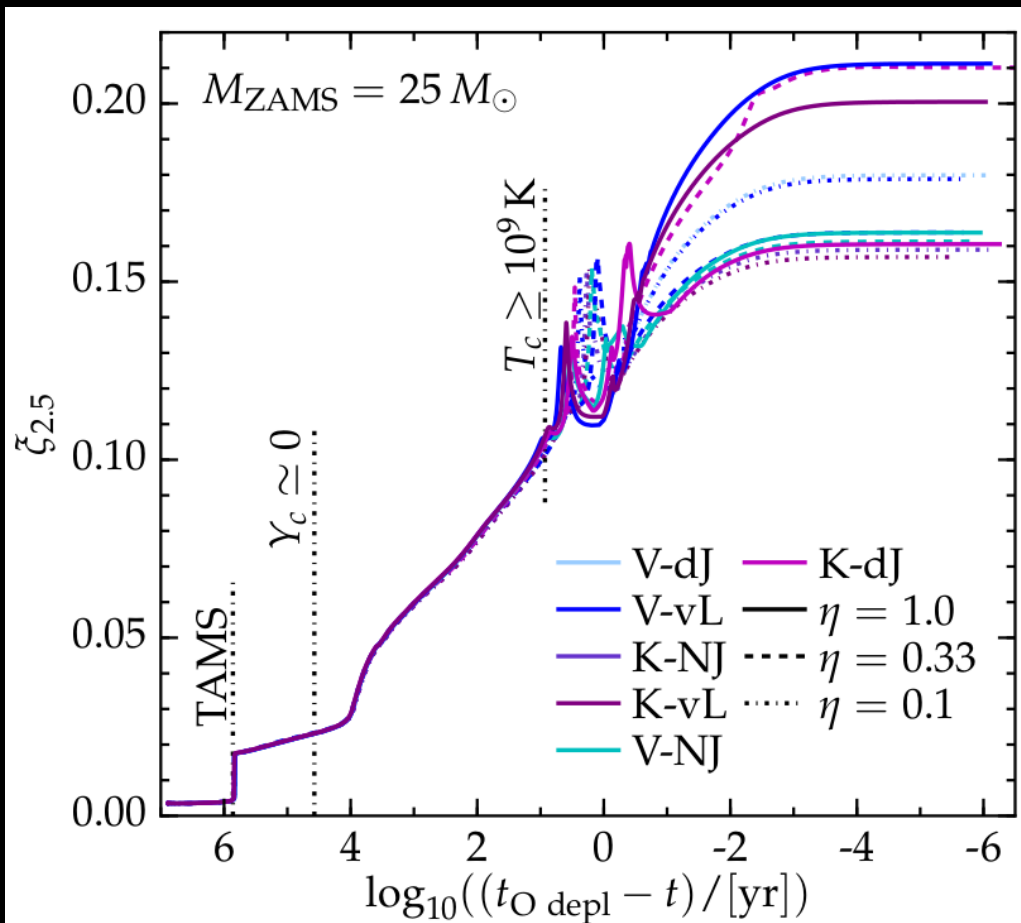

(Sukhbold et al 2014)

Very low Z vs Solar Z

Big differences due to mass loss (~0 for low Z) during Che

Changes the lifetimes

- – Winds (Owocki Talk)
- – Episodic (Quataert, Margutti Talk)
- – Binarity (Vanbeveren Talk)

Mass loss (Winds)

(Renzo et al this week?)

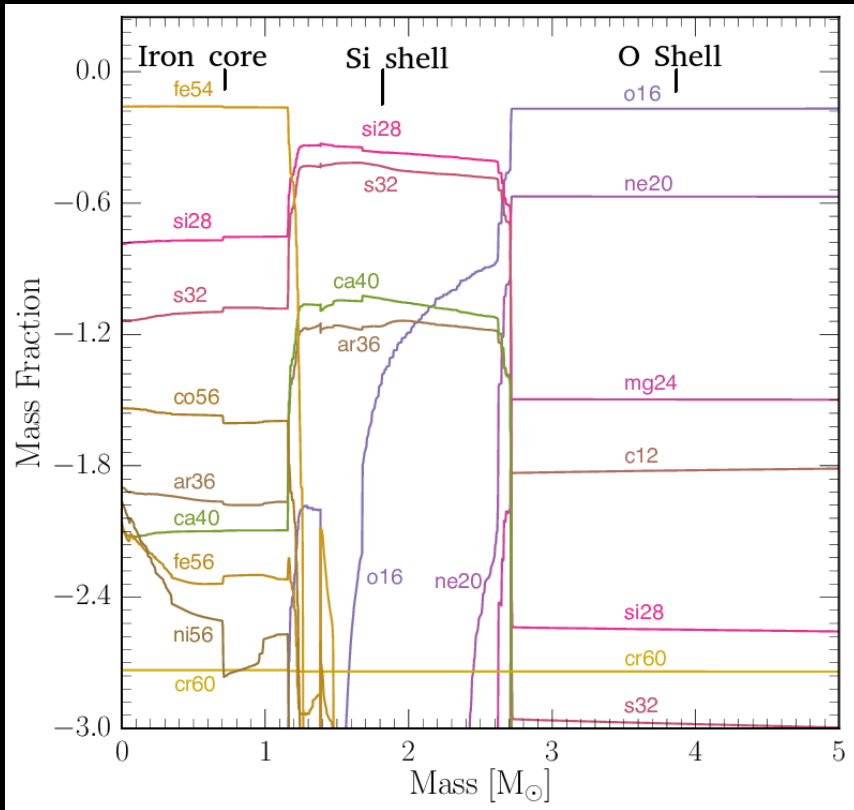Evolve MESA models with various combinations of mass loss prescriptions and strengths

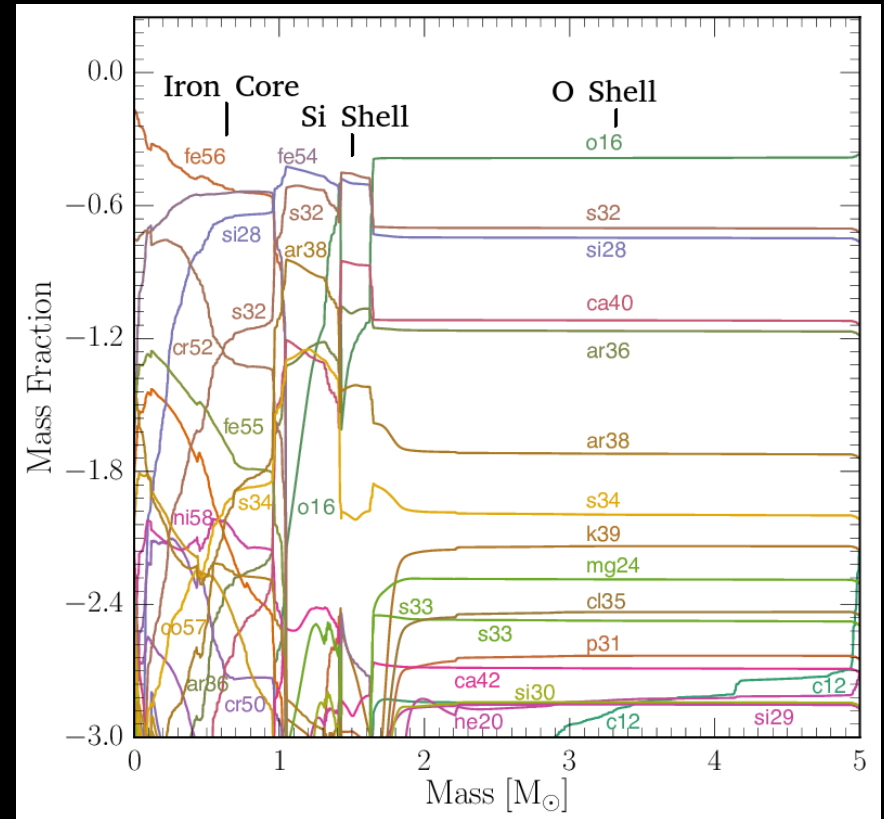Tracks are the same till Ne burning

Mass loss turned off at T>10^9K

"Seed" differences in the models grow larger afterwards as shells begin to ignite

Core Si burning

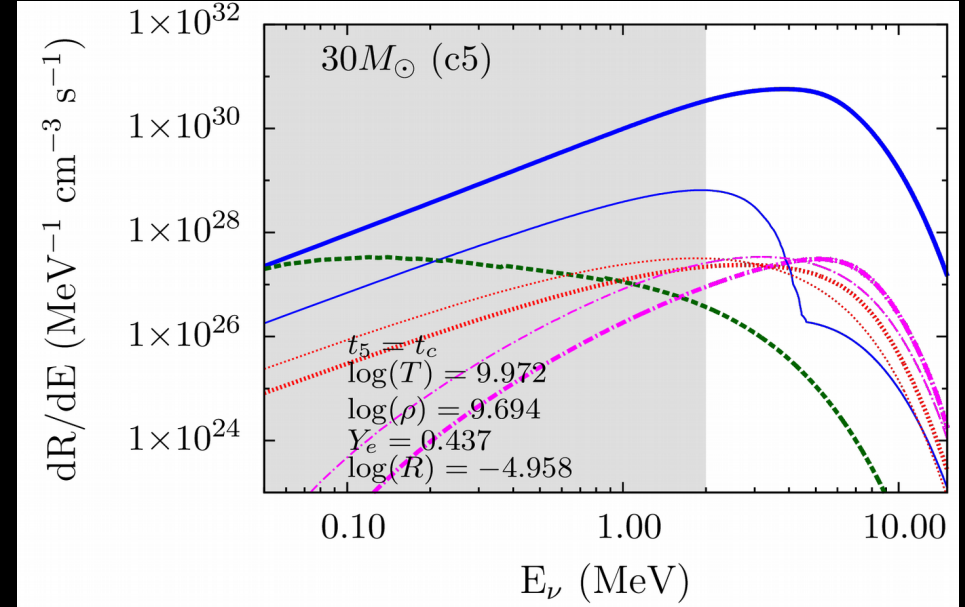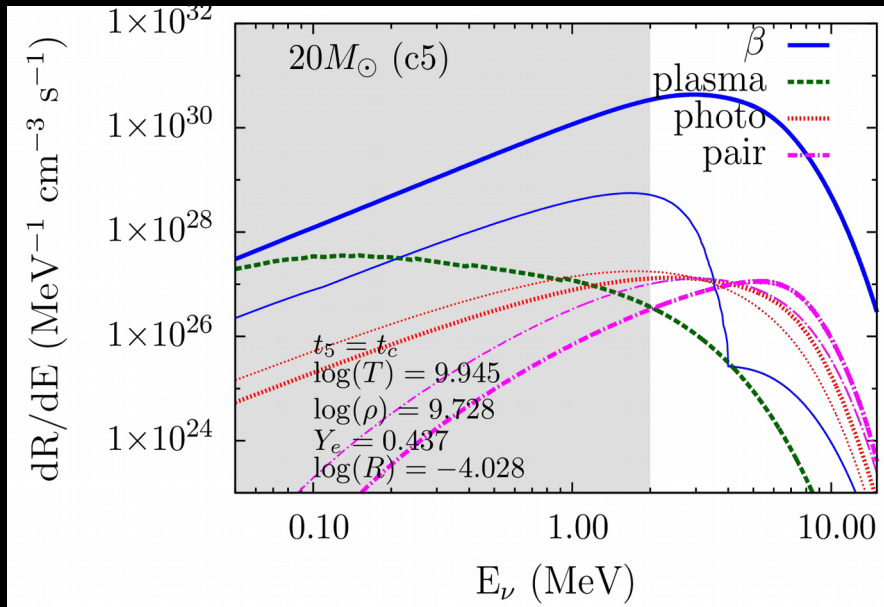25 Msun 22 isotopes

25Msun 204 isotopes

Number and size of shells varies with net

Factor 2 in Si burning time

What would this to do to the SN/observables?

Can we probe the core at CC?

(Patton et al 2016)

Neutrinos detectable within ~hrs before CC within ~Kpc

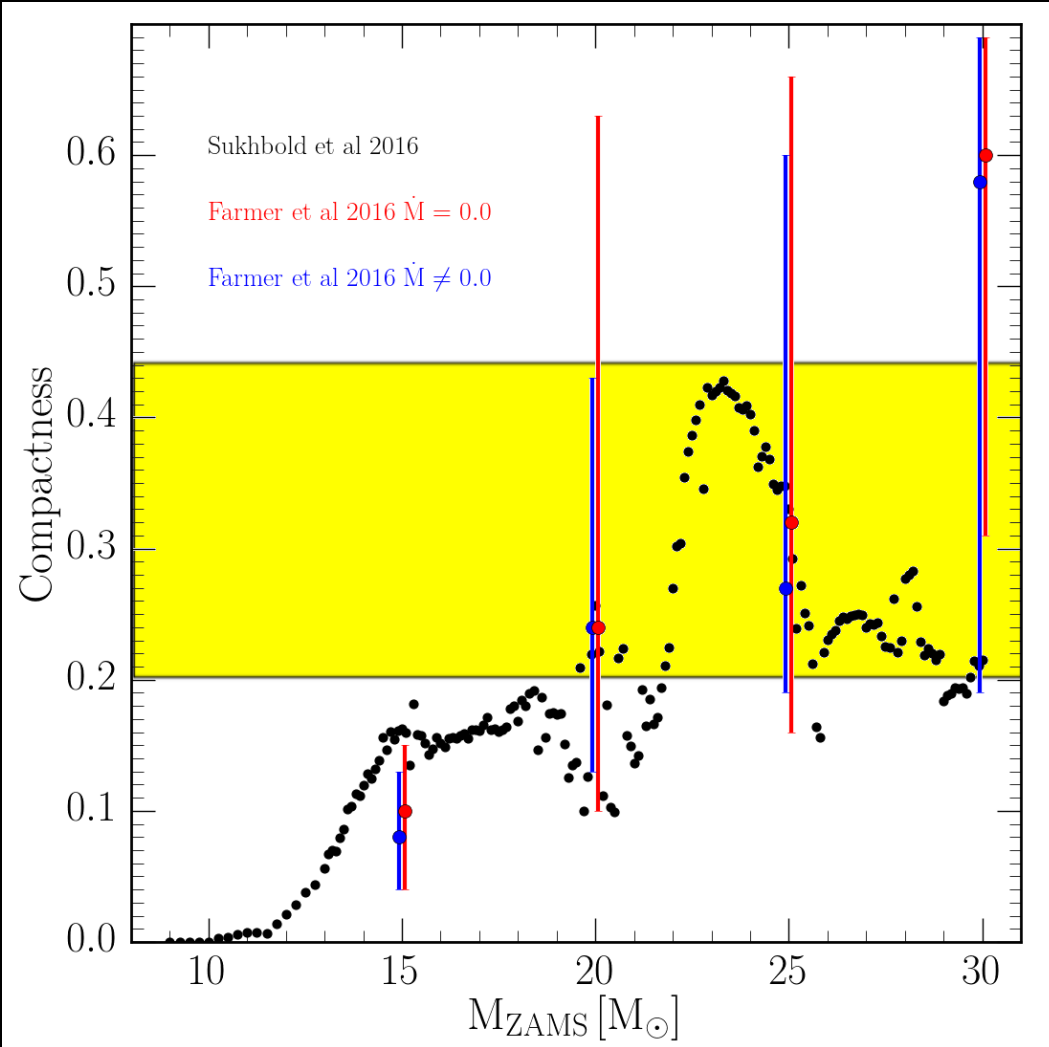Predominately from Beta decays (at CC)

Factor 2 neutrino counts between 15-30 Msun models

Behaviour is non-linear with initial mass

Yoshida et al 2016
Misch et al 2016

Final state

Range of final states possible

Uncertainty in final state increases as initial mass increases

Final mass, Ye, Fe core mass ~10%

Only considering resolution, network size and mass loss

~20% from rates, ~20% mass loss on/off

Impact on SN?

Ugliano et al 2012
Sukhbold et al 2014, 2016
Ertl et al 2016
Petermann et al 2017

Summary

- Final state is non-linear, based on a complex history of how each fuel source burns

- Uncertainties propagate from the MS to CC

- How do these variations effect the resulting SN?

- What about other parameters? Rotation, convection, overshoot, other mass loss(es)

  – Correlations between uncertainties?