TRACING THE ORIGIN OF ELEMENTS

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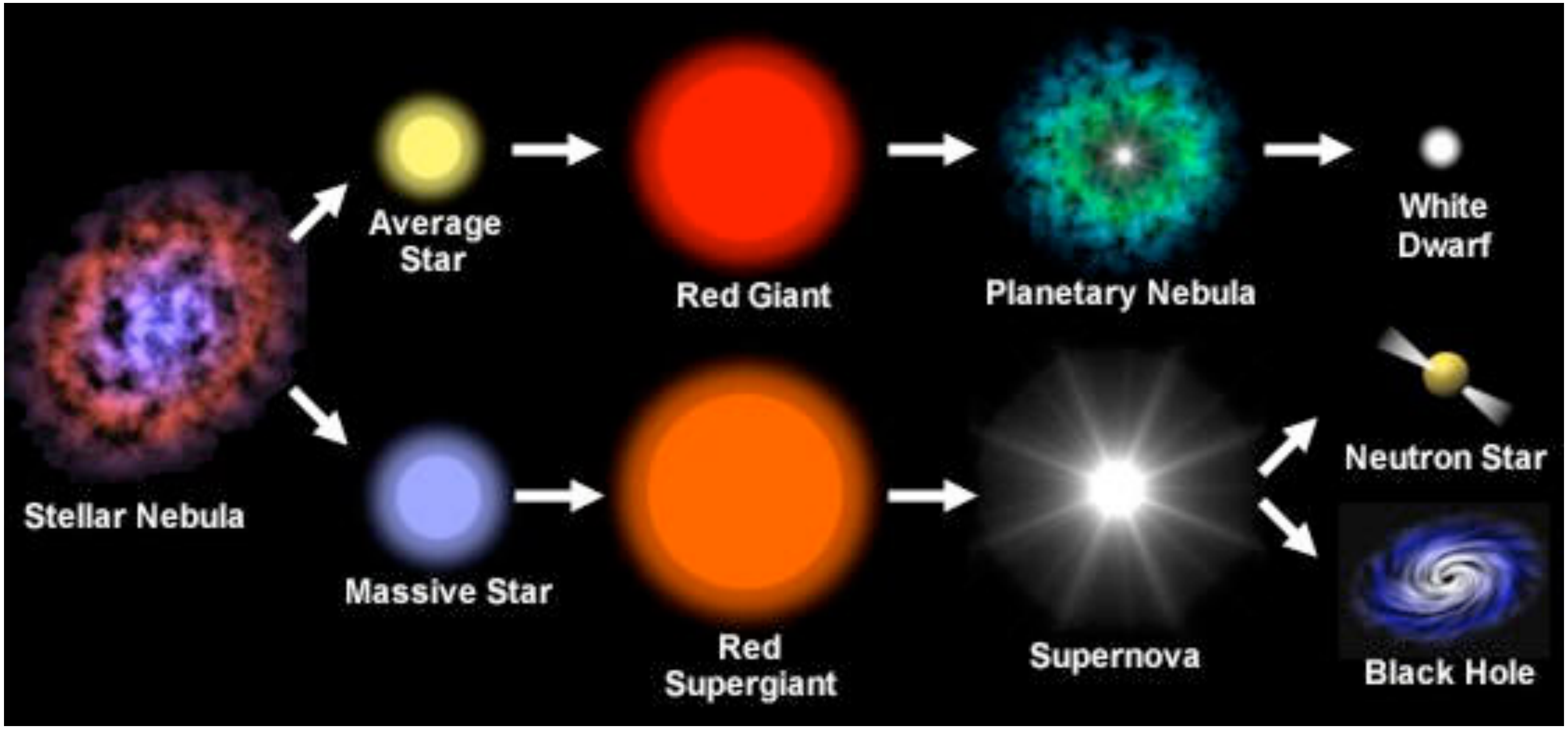
Stellar group seminar
11/01/17

OUTLINE

- Stellar physics modeling from $1M_\odot$ to $25M_\odot$ and Z=0.02 to Z=0.0001
- Application of yields in chemical evolution
- Nucleosynthesis in convective O-C shell merger
- Intermediate neutron-capture (i) process in 3D

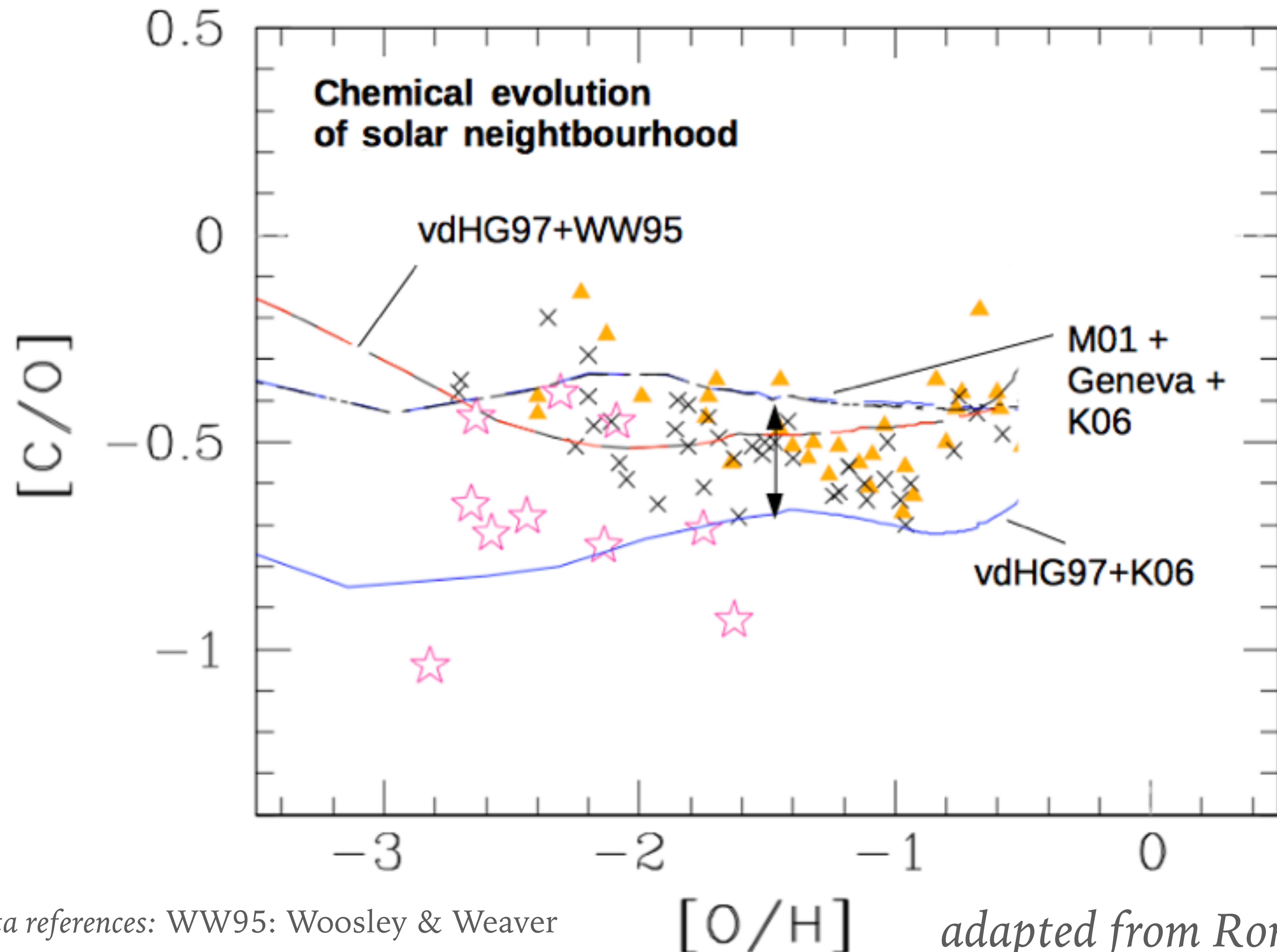
CHALLENGES OF YIELD MODELING

- The elements are made in both low-mass and massive stars, and yields are typically provided by different groups for each of these
- Consequence: Variation in nuclear physics and model assumptions
- Often only incomplete set of species available



http://www.seasky.org

IMPACT ON CHEMICAL EVOLUTION



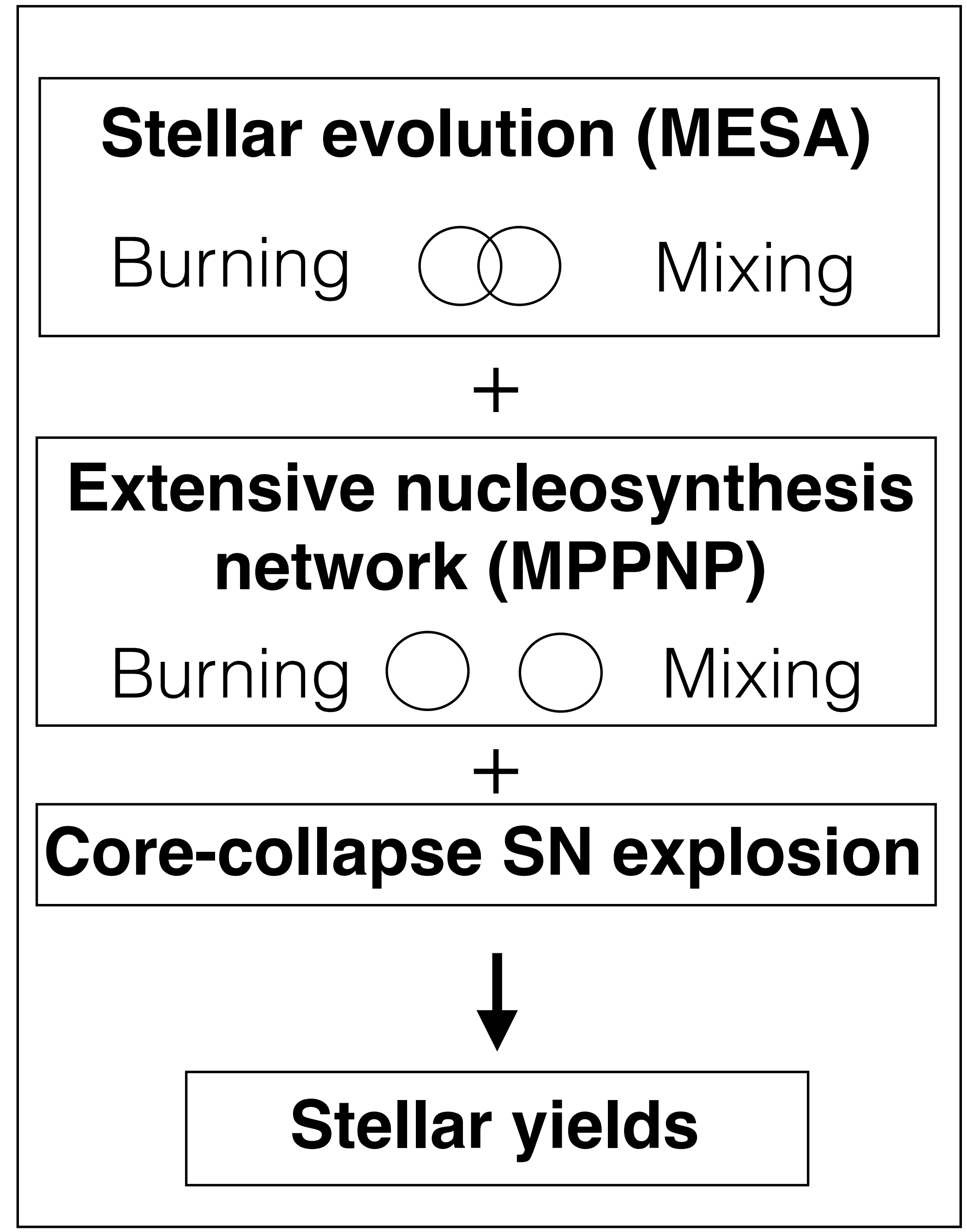
Yield data references: WW95: Woosley & Weaver 95, VdHg97: Van den Hoek & Groenewegen 96, M01: Marigo 01, K06: Kobayashi+06, Geneva group (e.g. Meynet 02, Hirschi 07),

adapted from Romano+10

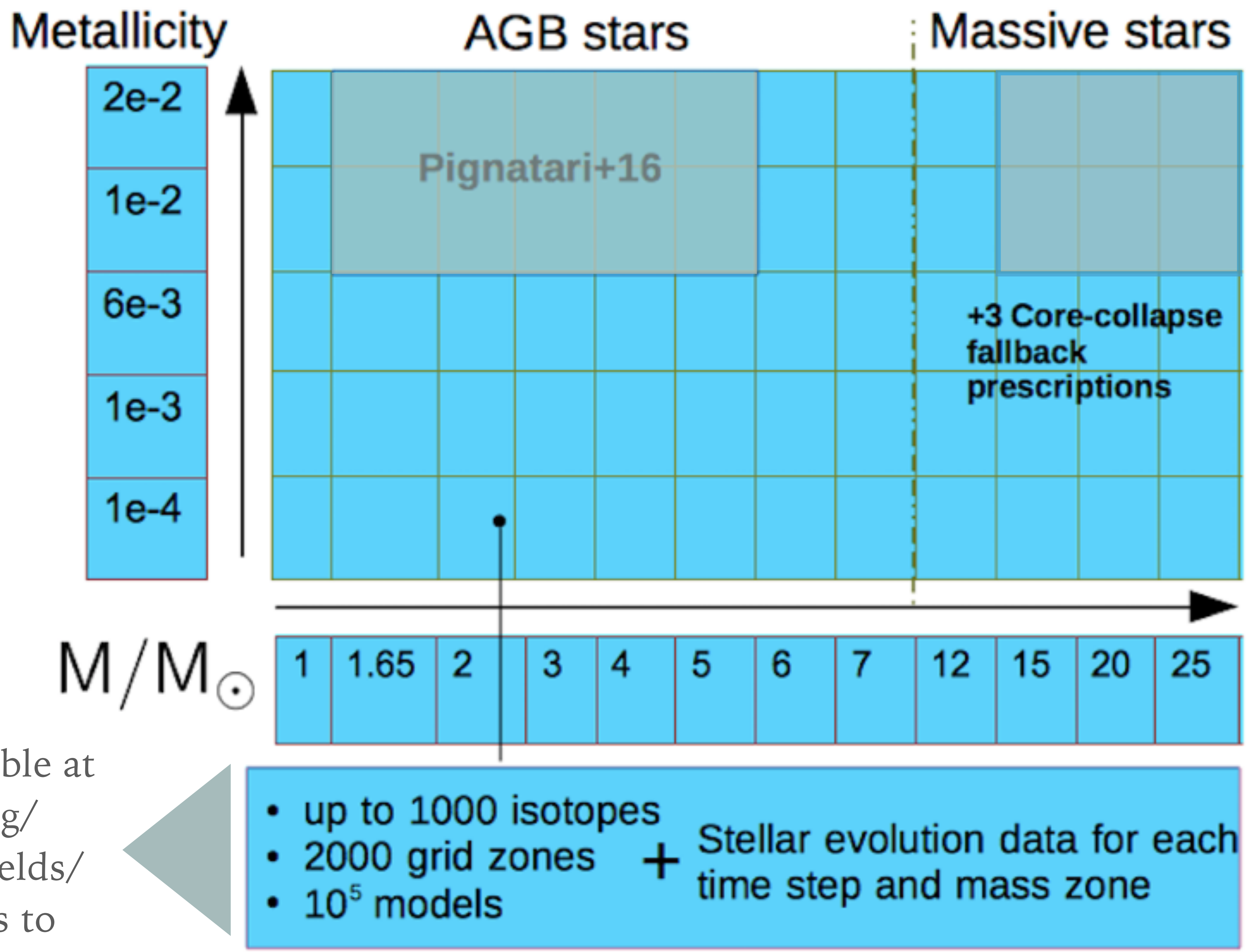
Milky Way data references: Akerman+04, Spite +05, Fabbian+09

NUGRID APPROACH

- AGB + massive star modeling
- Stable elements + isotopes up to Bi
- Same rate input in stellar simulation and post-processing
- Semi-analytic core-collapse SN model
- No rotation, magnetic fields



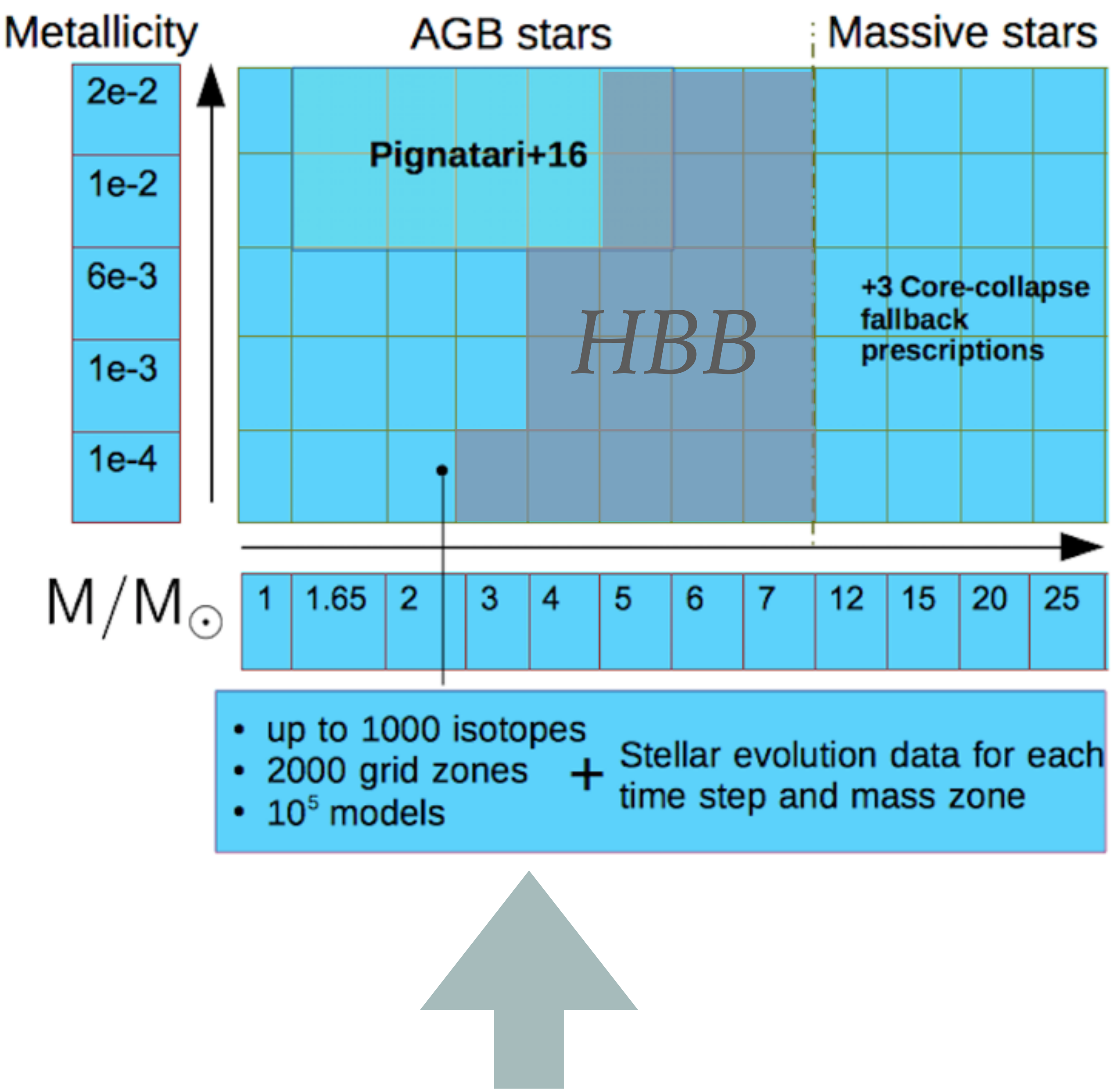
NUGRID YIELDS



Reference data available at http://nugridstars.org/data-and-software/yields/set-1 w/ python tools to analyze and explore.

C. Ritter, F. Herwig, S. Jones, M. Pignatari, C. Fryer, R. Hirschi 2017, in prep.

FEATURES OF STELLAR MODELS



Web exploration of NuGrid datasets

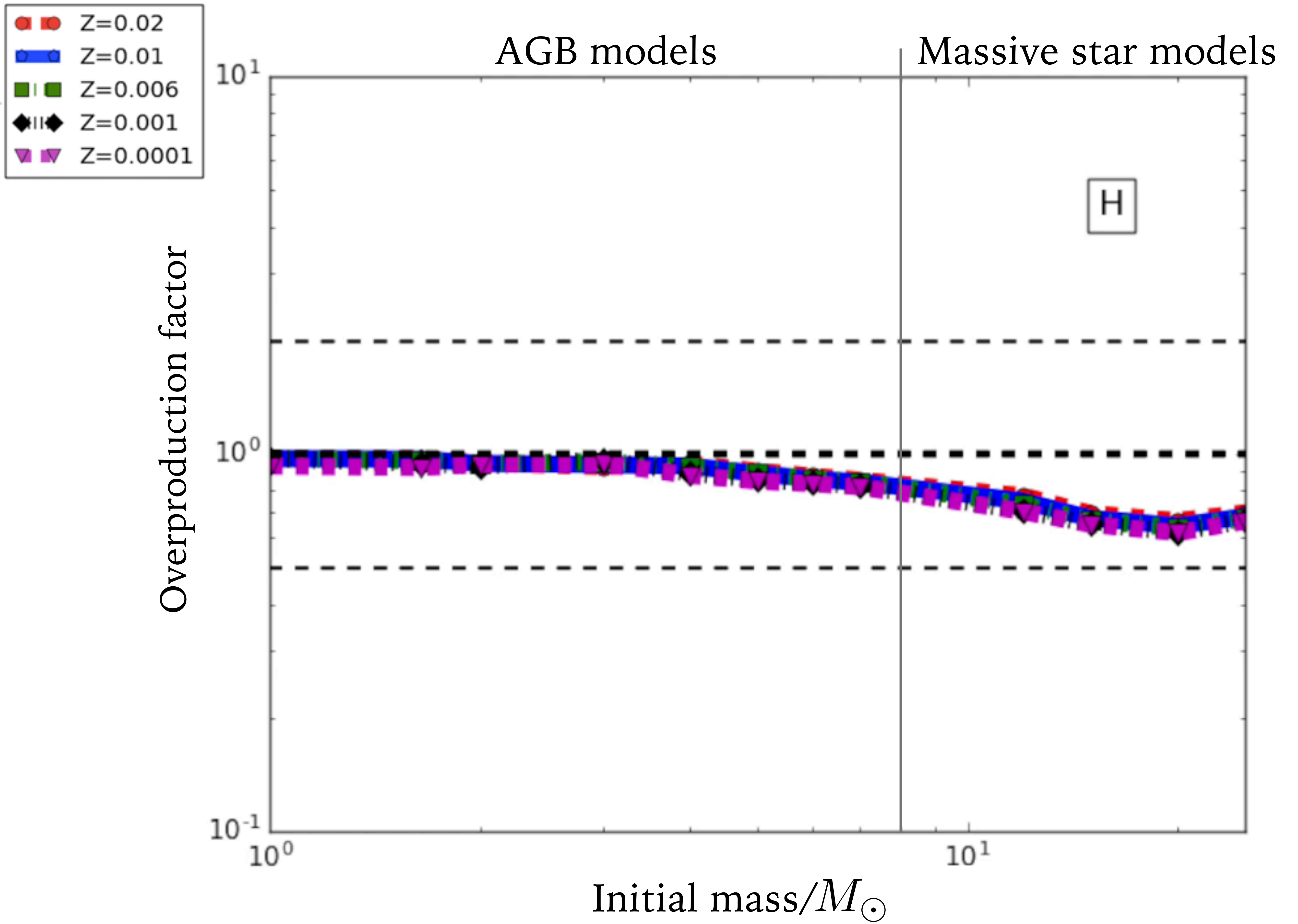
- Convective boundary mixing in all AGB models
- Hot dredge-up in massive and super-AGB stars
- H ingestion potential i-process site (Jones+16)
- Mass-and metallicity dependent fallback of SN models (Fryer+12)
- Shell merger
- Nested network approach to model Hot-bottom-burning species & heavy elements

NESTED NETWORK PREDICTIONS

Yields of stellar models of $5M_\odot$ at Z=0.0001

specie	This work	Herwig 04	Karakas 10	Cristallo+15
C-12	6.948E-04	4.587E-04	2.787E-03	1.274E-02
C-13	9.086E-05	4.372E-05	4.059E-04	1.856E-04
N-14	4.691E-03	1.680E-03	2.405E-02	3.405E-04
O-16	1.824E-04	3.008E-04	6.094E-04	9.350E-04
Sr-88	8.969E-10			2.238E-08
Zr-90	1.520E-10			4.399E-09
Ba-136	2.236E-11			1.029E-09
Pb-208	1.465E-10			1.284E-08
C-12/C-13	7.65	10.49	6.87	68.64
C-12/O-16	3.81	1.52	4.5	13.63

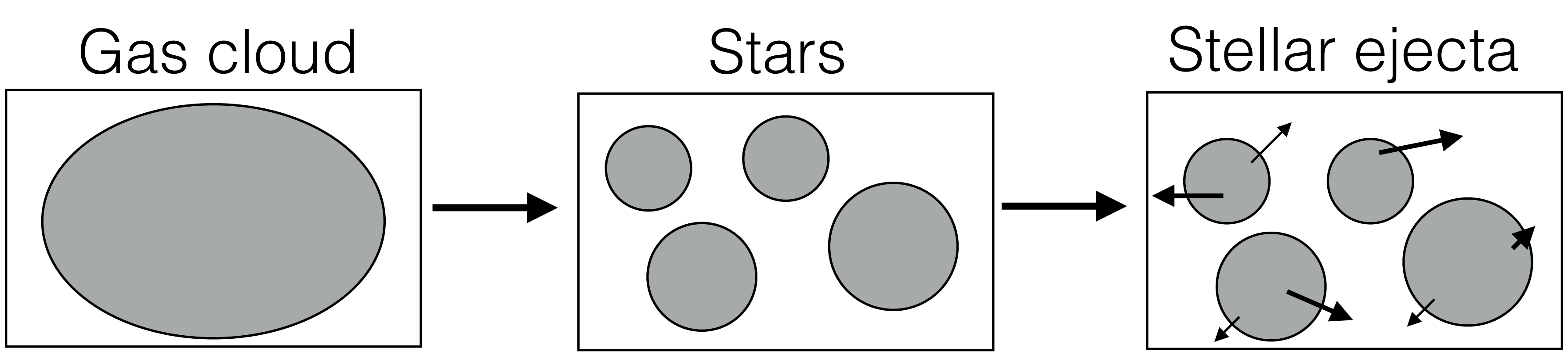
Simultaneous prediction of HBB & heavy elements in AGB stars.



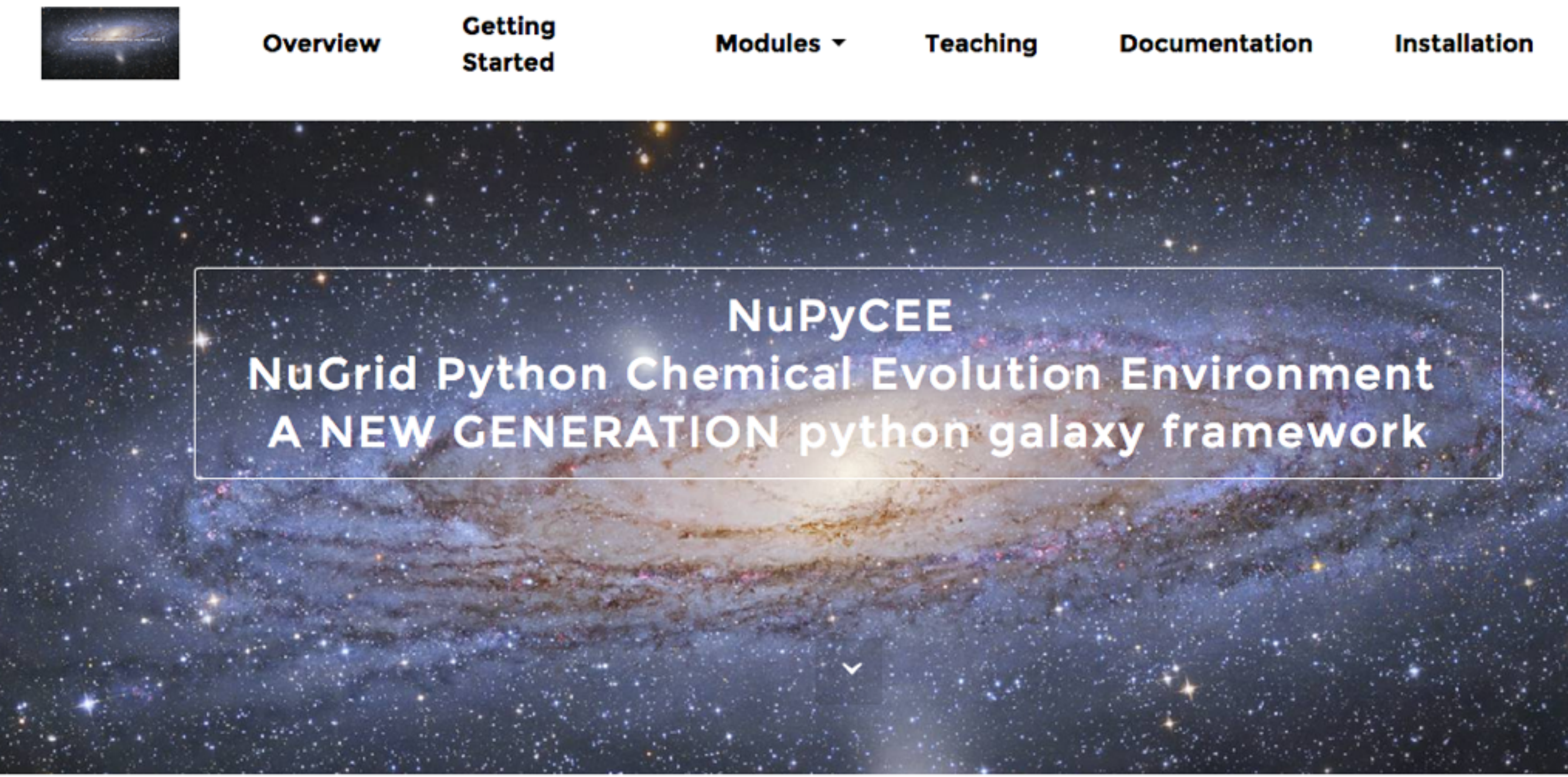
Z=0.02
Z=0.01
Z=0.006
Z=0.001
Z=0.0001
AGB models
Massive star models
H
Overproduction factor
Initial mass/$M_\odot$
10^1
10^0
10^{-1}
10^0
10^1

APPLICATION OF YIELDS IN CHEMICAL EVOLUTION

- How to deliver (NuGrid) yields in 3D hydrodynamic simulations and semi-analytic models of galaxy formation?
- Application of The Stellar Yields for Galactic Modeling Applications (SYGMA) module
- SYGMA folds yields and other stellar parameter into simple stellar populations



C. Ritter, B. Côté, F. Herwig, J. F. Navarro, C. Fryer, L. Siemens 2017, in prep.



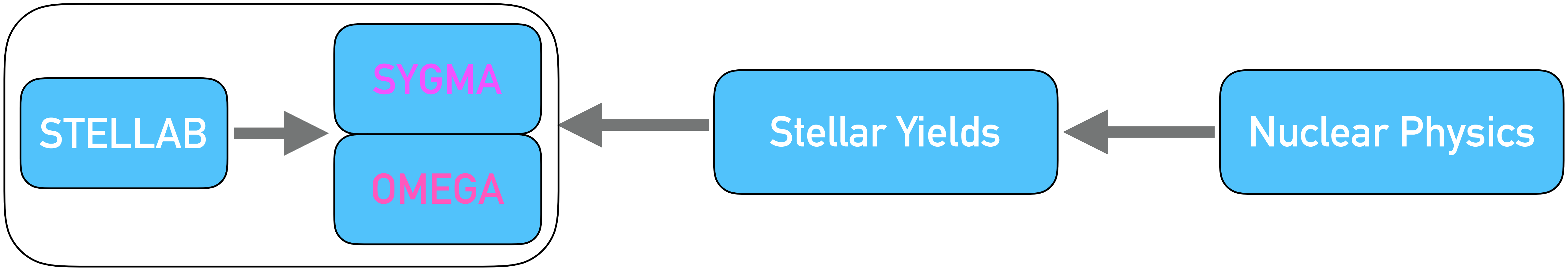
NUGRID

University of Victoria

JINA-CEE

http://nugrid.github.io/NuPyCEE

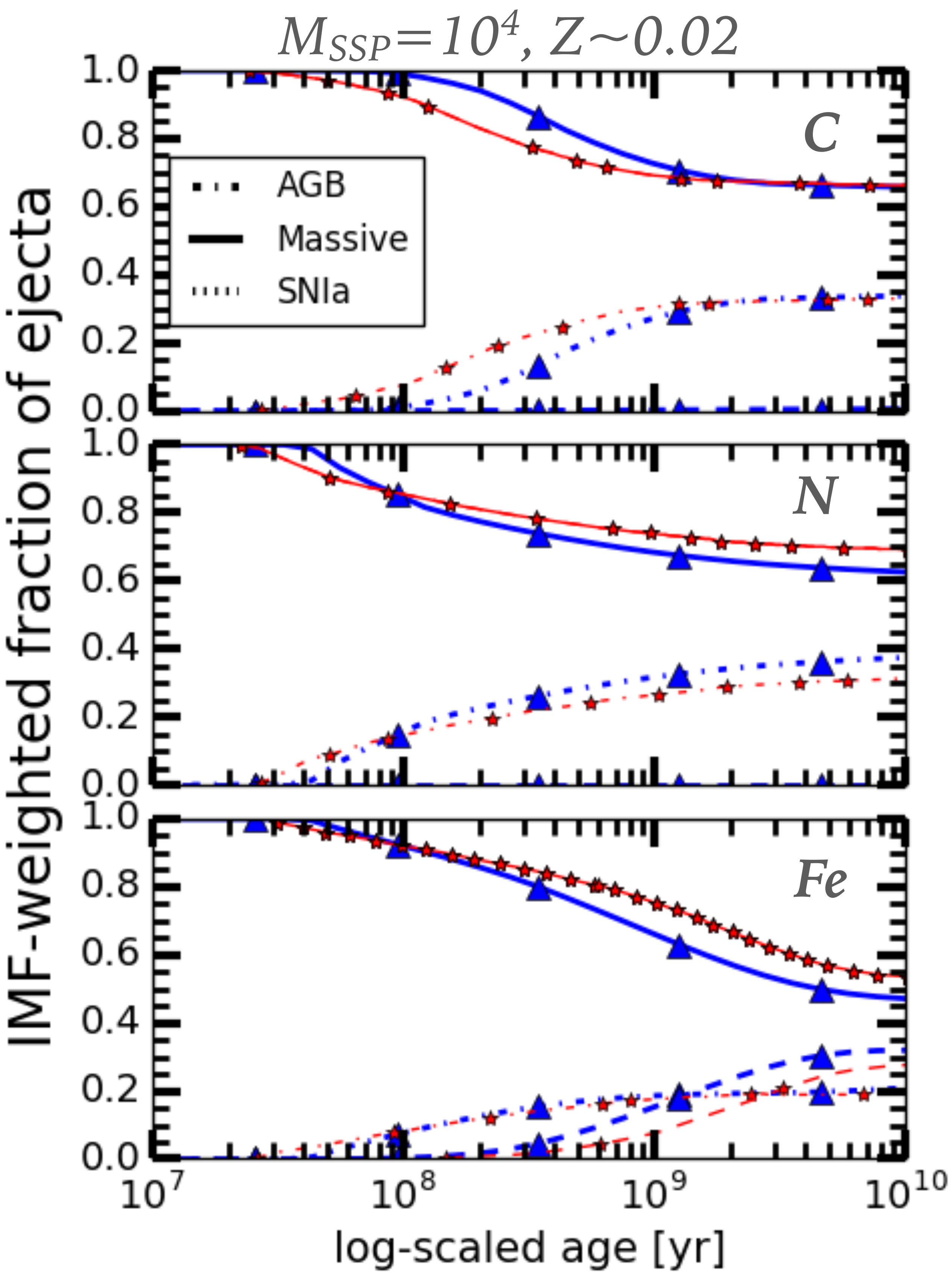
NUGRIDS PYTHON CHEMICAL EVOLUTION FRAMEWORK



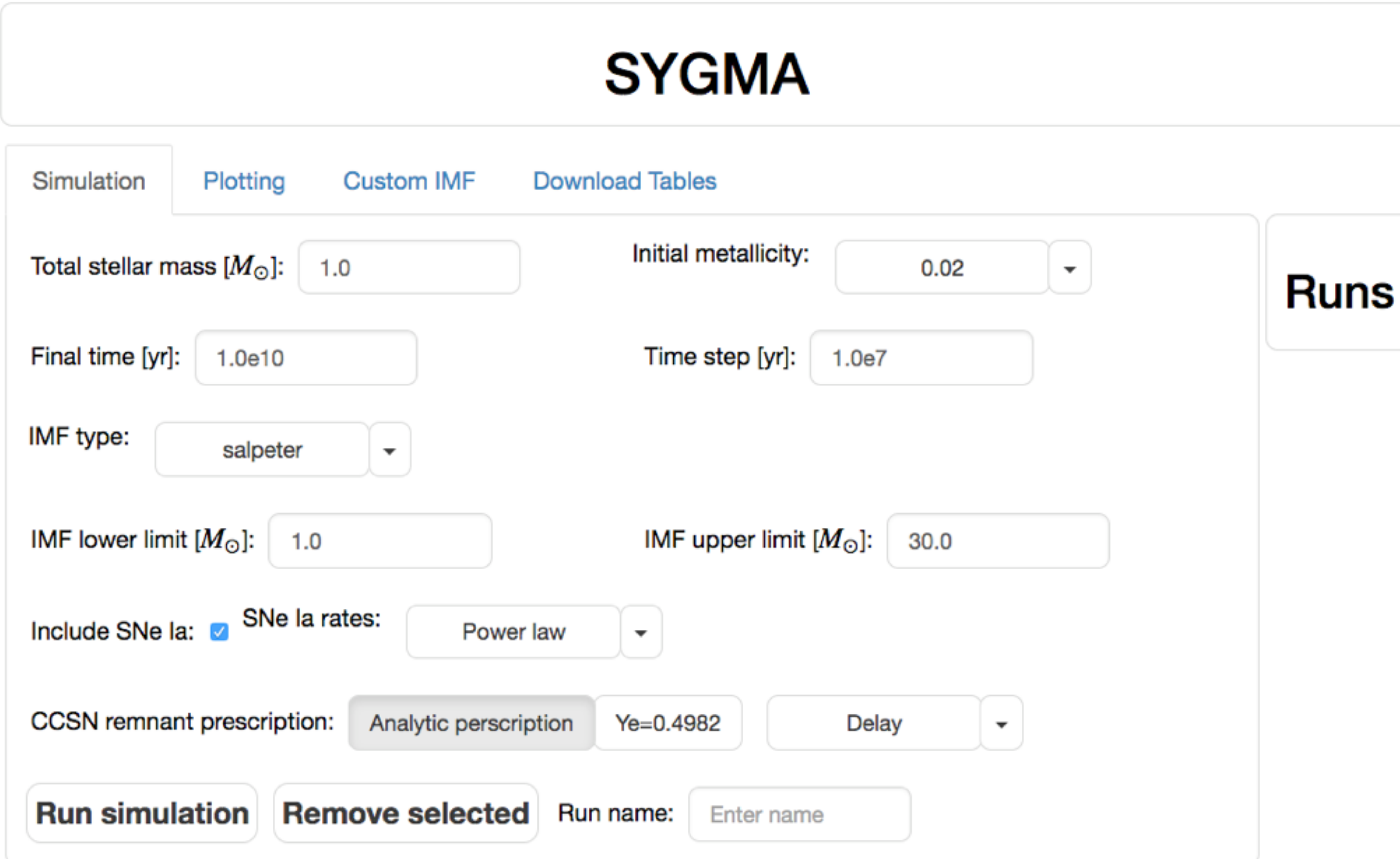
Applications of 1-zone galaxy model OMEGA

- Uncertainty of chemical evolution parameter (Côté, Ritter et al. 2016a)
- Impact of mass and metallicity range of yields on chemical evolution (Côté et al. 2016b)
- Impact of inflow and outflow models on chemical evolution of Sculptor (Côté et al. 2016c)
- Constraining neutron star mergers and r-process sites (Côté et al. 2016d)
- Impact of O-C shell merger on chemical evolution (Ritter et al. 2017, in prep.)
- Project: Sensitivity study of reaction rates with NuGrid yield grid

FEATURES OF SYGMA



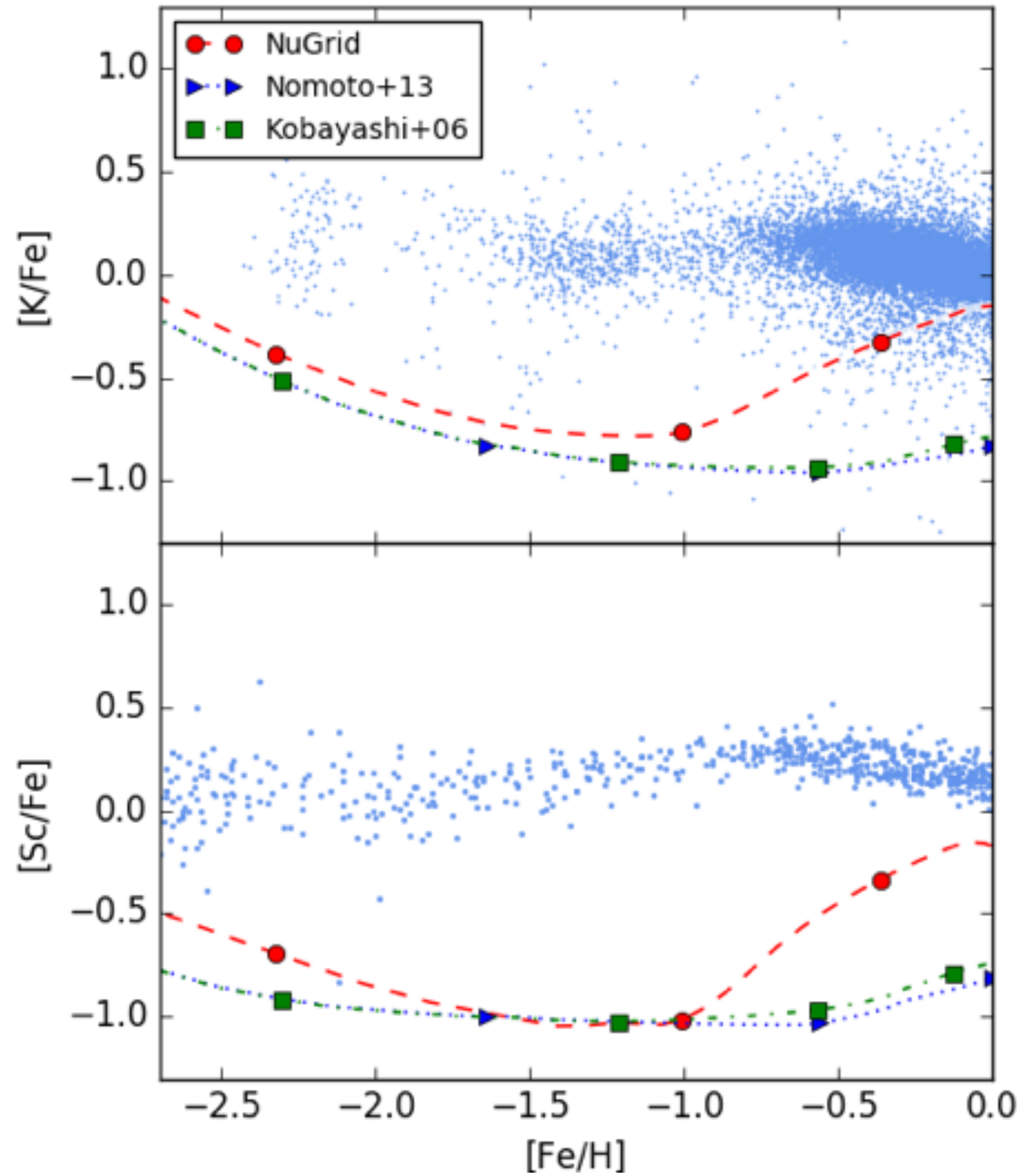
- Comparison with Wiersma+09: Differences despite same yield input
- Exotic sources: r process material from CCSN & neutron-star merger
- Extensive yield library
- Trace stellar parameter such as total kinetic energy, energy bands
- Web interface for simulation, analysis and download



http://nugrid.github.io/NuPyCEE

THE ORIGIN OF K AND SC

- Underproduction of K and Sc in Milky Way models compared to disk and halo stars
- Several production mechanism have been considered for Sc: vp process (Froehlich+06), jet-induced SN explosions (Tominaga 09)

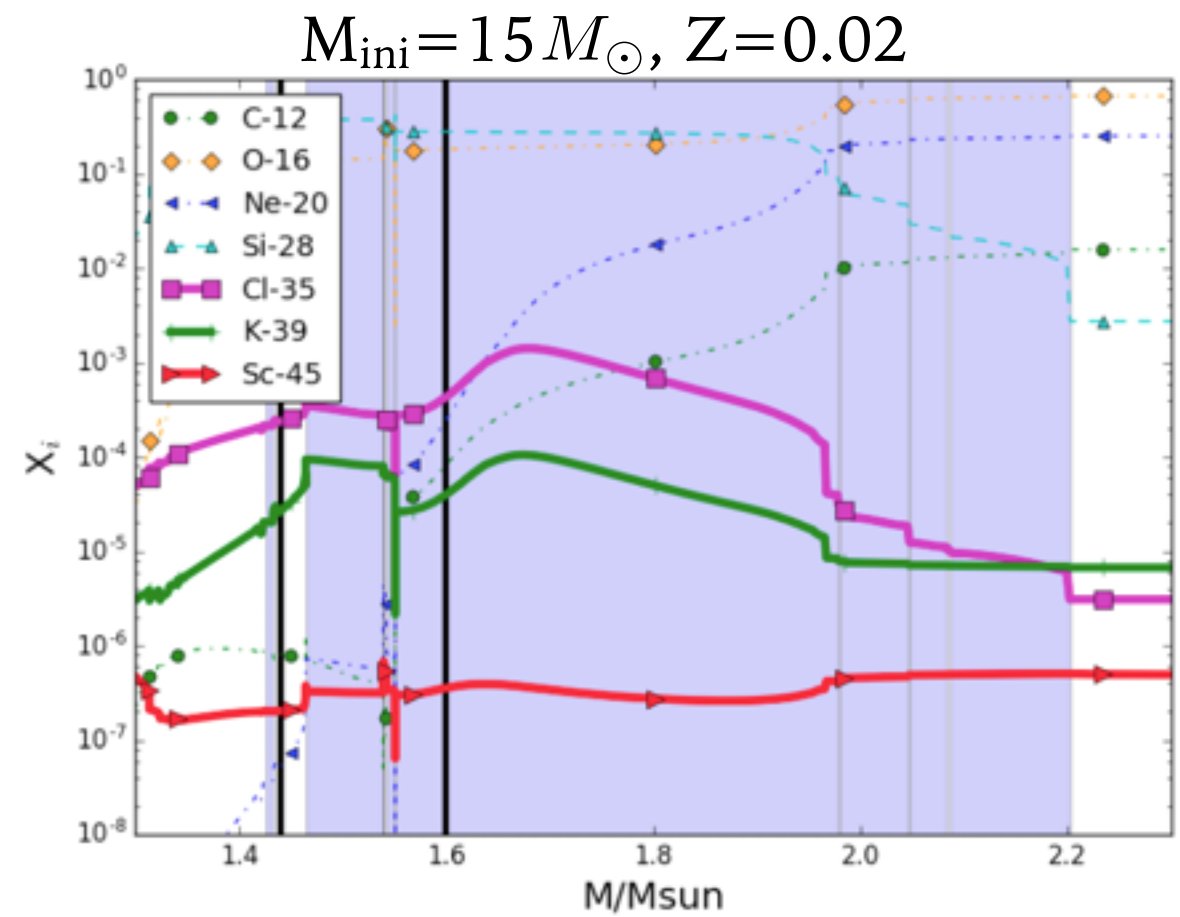


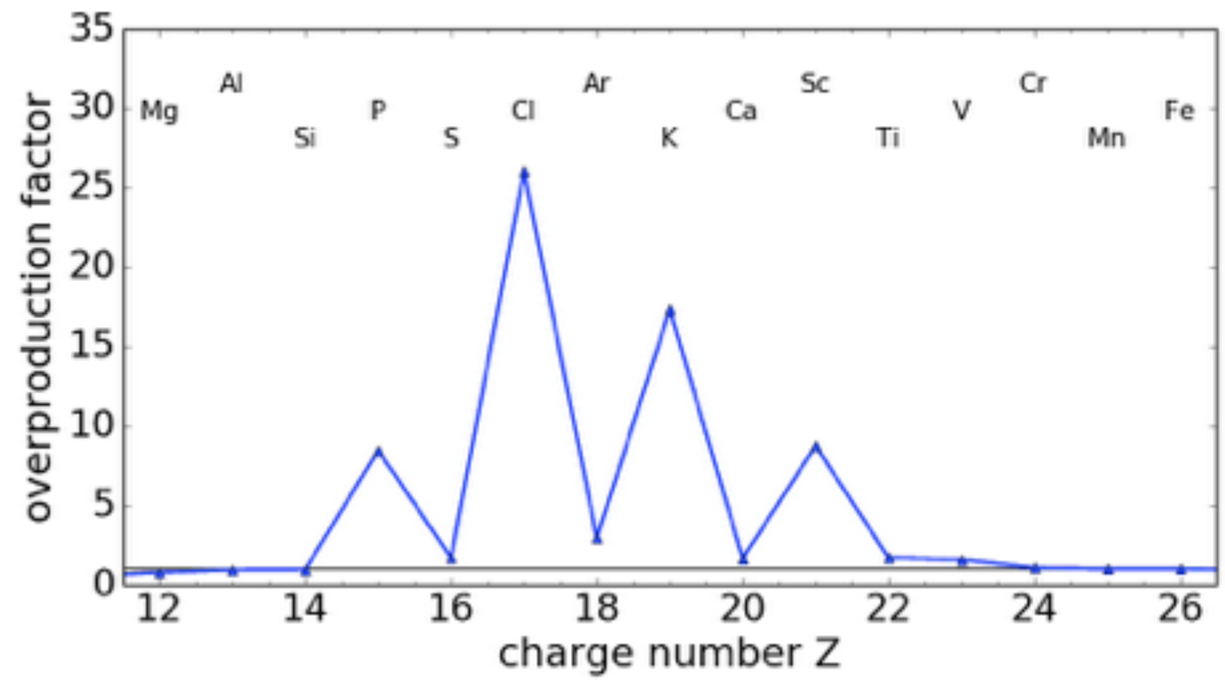
Milky Way data references: APOGEE R13, Battistini+15, Roederer+14, Ishigaki+12/13

NUCLEOSYNTHESIS IN CONVECTIVE O-C SHELL MERGER

- Effective production of Cl, K and Sc in 1D stellar models of NuGrid
- Preliminary GCE tests show that a 50% merger rate in pre-SN models could reproduce the observed abundance of K and Sc
- *Reactive-convective nucleosynthesis* during shell merger require 3D hydrodynamic simulations

C. Ritter, R. Andrassy, B. Côté, F. Herwig, P. Woodward, P. Pignatari, S. Jones 2017, in prep.

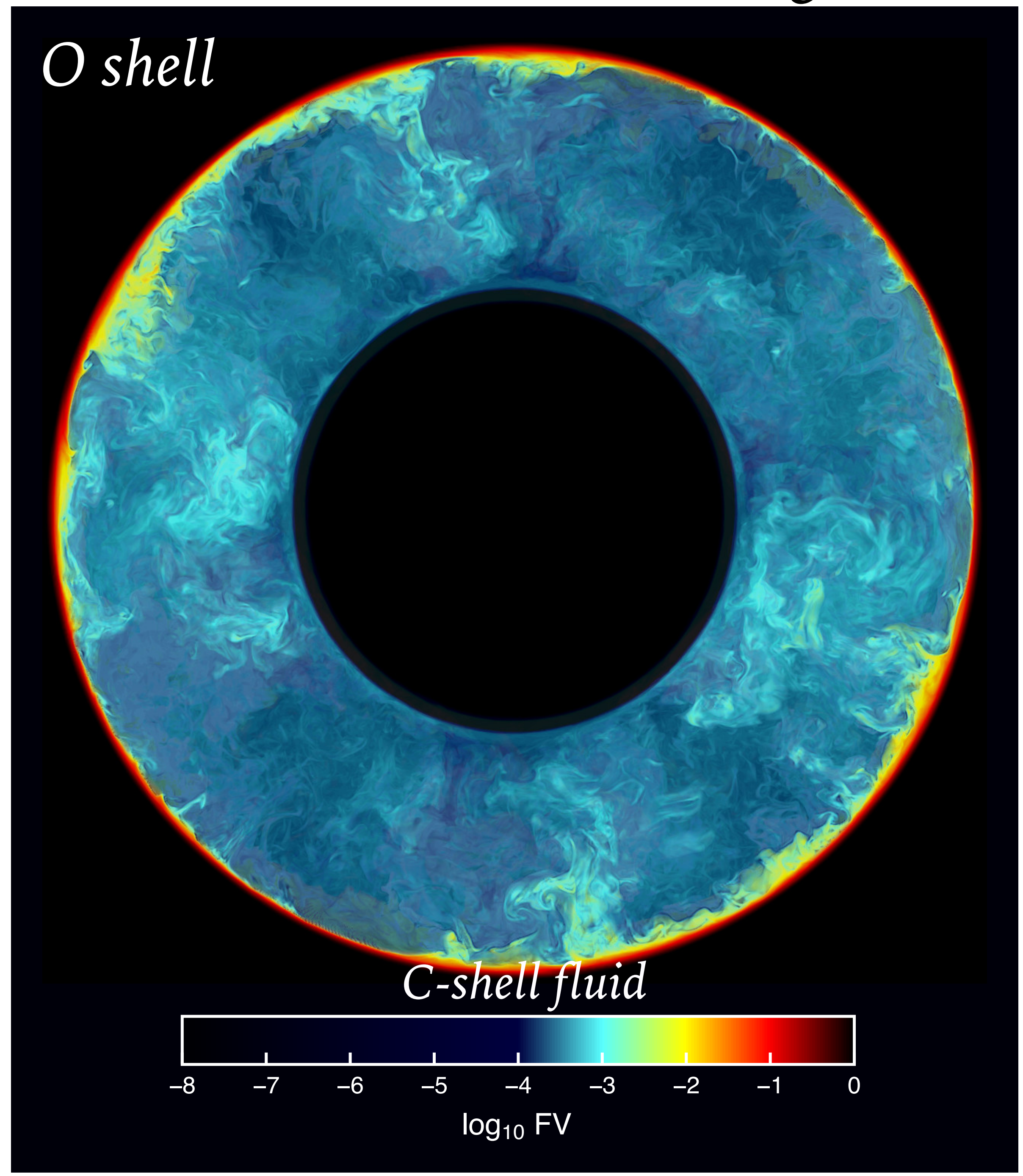




3D HYDRODYNAMIC SIMULATIONS OF THE O SHELL

- C-shell fluid entrainment motivated by Jones+16
- Features: 4π star-in-box simulation in 768^3 grid resolution with PPMstar code (Woodward+15) of stellar model with $M_{ini}=25M_\odot$ at Z=0.02
- Derive diffusion coefficient for 1D setup from spherically-averaged steady-state solution
- Comprehensive nucleosynthesis in 1D with strongly increased entrainment rates confirms large production of odd-Z nuclei

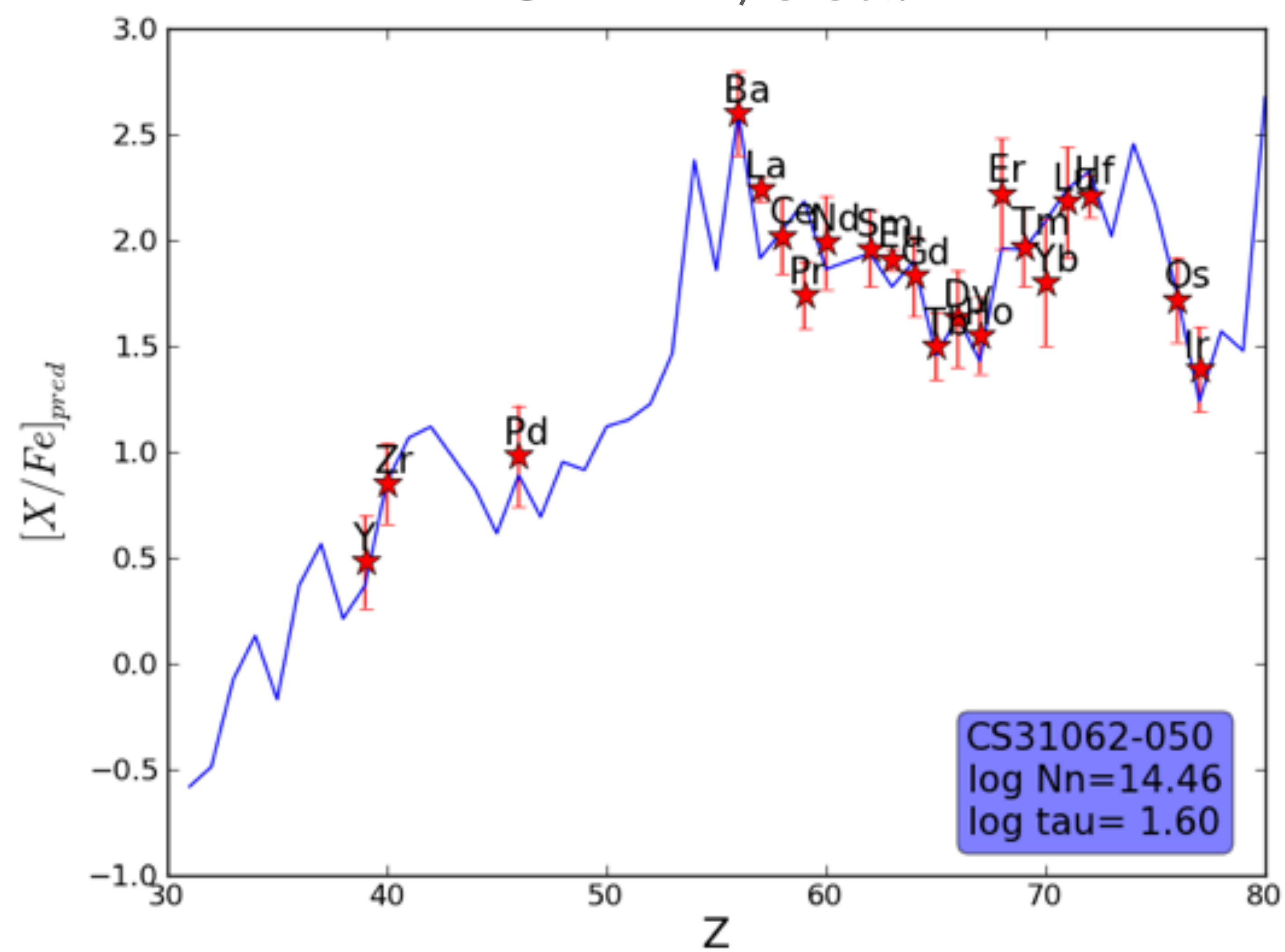
After 148min of C-fluid ingestion



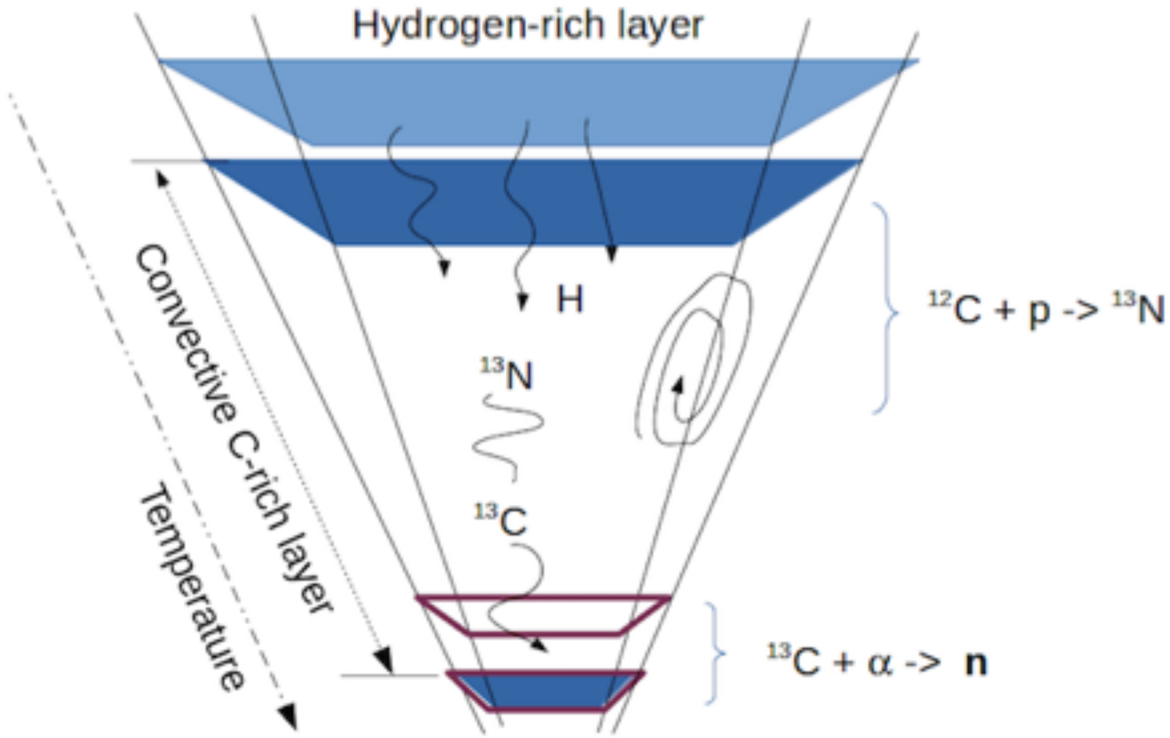
OBSERVATIONAL HINTS OF THE I PROCESS

- i-process 1-zone model in good agreement with observed heavy-element signature of CEMP-r/s stars (Dardelet+15)
- Open cluster stars (Mishenina+15), metal-poor halo star (Roederer+16)
- Low-Z post-AGB stars in small and large Megallanic cloud (Lugaro+15), post-AGB star Sakurai's object (Herwig+11)
- Pre-solar grains (Jadhav+13, Fujya+13)

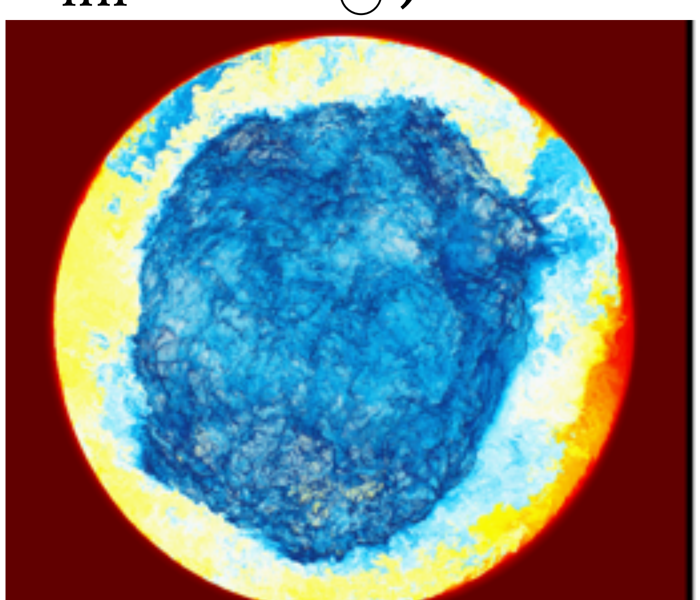
CEMP-r/s star



CHALLENGE OF I PROCESS MODELING



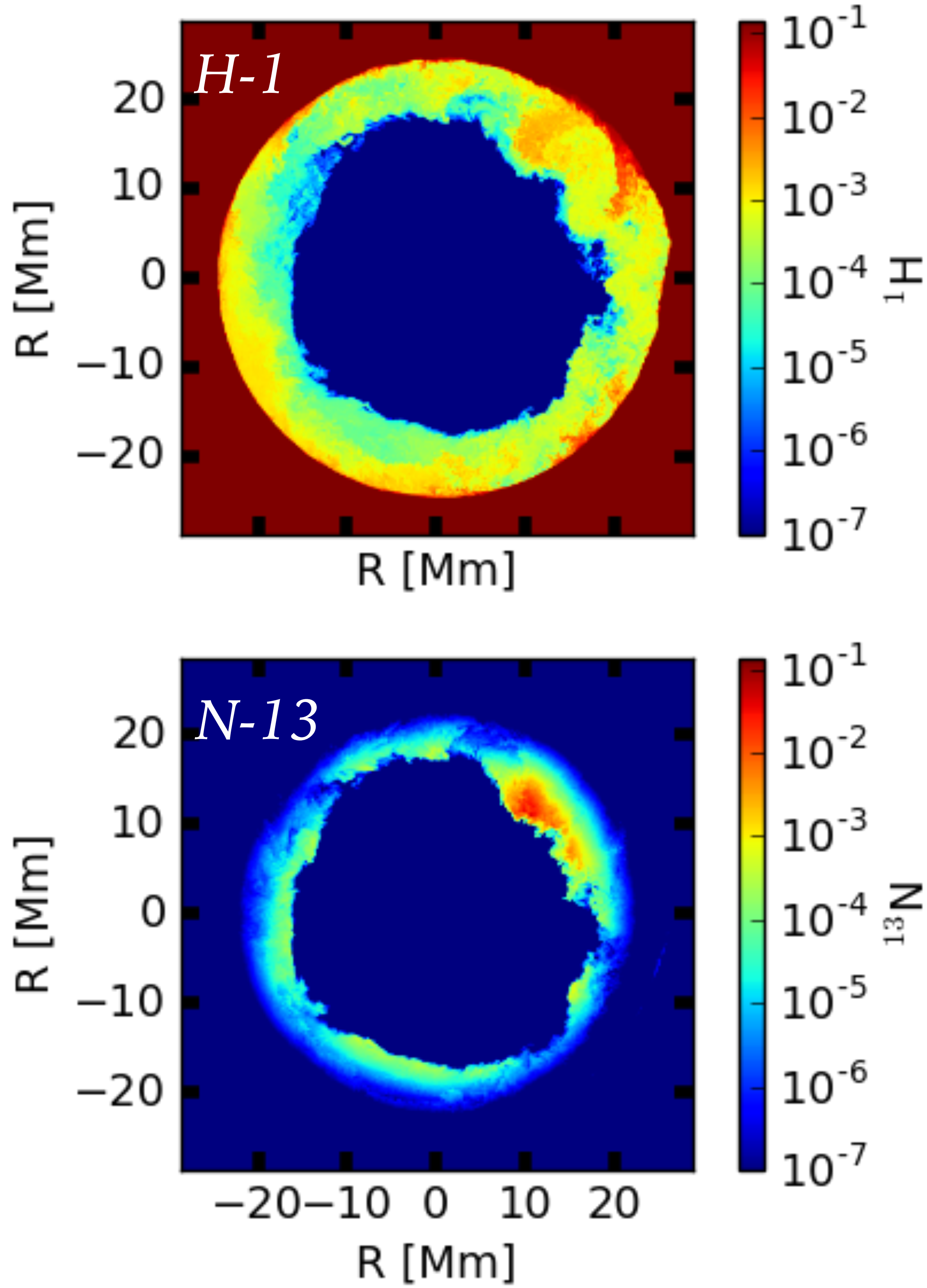
$M_{ini} = 2\,M_\odot$, $Z = 10^{-5}$



Woodward, in prep.

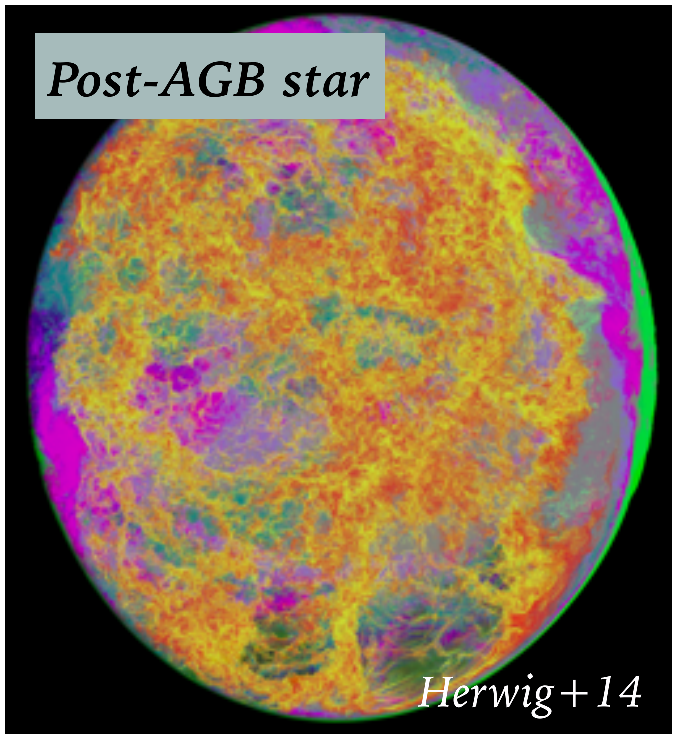
- He-core and shell flashes (e.g. Iwamoto+04, Campbell+10), VLTPs (Herwig+11), SAGB stars (Jones+16), accreting WDs (Denissenkov+16)
- *Reactive-convective regimes* require modeling with 3D hydrodynamical simulations (Herwig+11/14)
- Large networks for heavy element predictions in 3D hydro simulations are currently not feasible

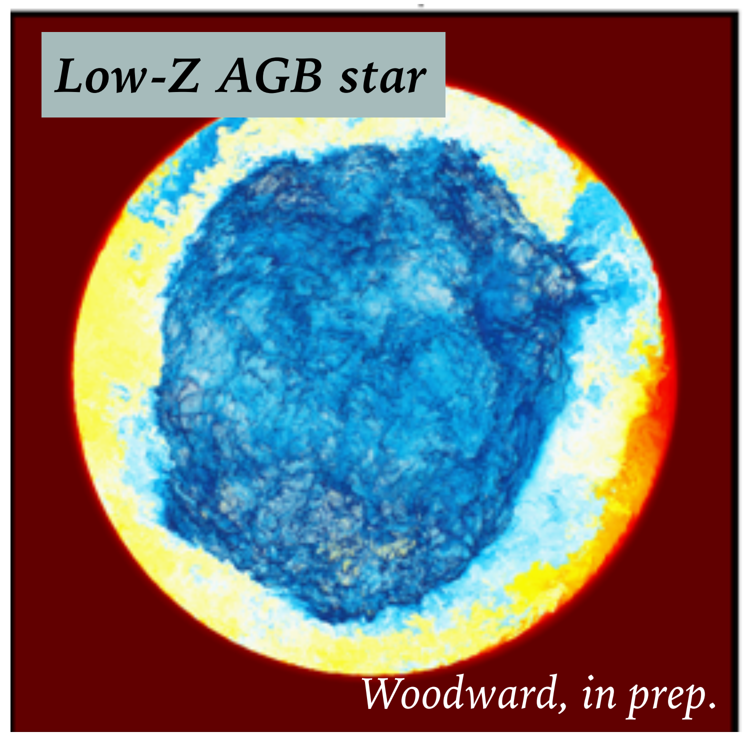
TOWARD I PROCESS PREDICTIONS IN 3D

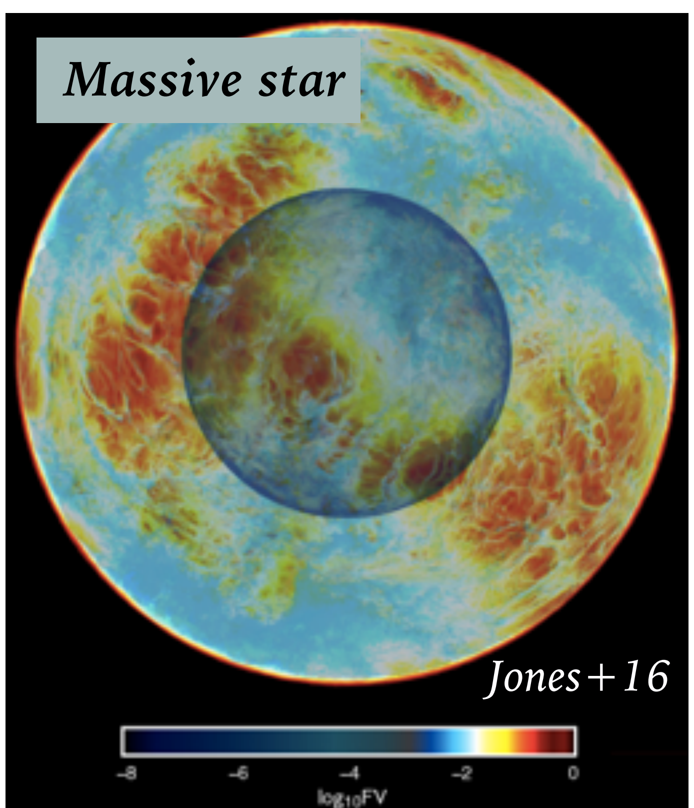


- Advective post-processing of hydro data
- Reduced grid and larger time steps due to sub-sonic flows leads to substantially lower cost
- Co-processing in PPMstar framework: Advantage of scaling capability and advection routines
- **Project:** Predict heavy elements produced in low-Z AGB stars in collaboration with Paul Woodward

LONG-TERM SCIENCE GOALS







- Insights into nucleosynthesis of reactive-convective mixing events in 3D of AGB stars, post-AGB stars and massive stars
- Comparison with abundance signatures of single stars and abundances of populations through chemical evolution