Asymptotic Giant Branch stars

Falk Herwig

Los Alamos National Laboratory

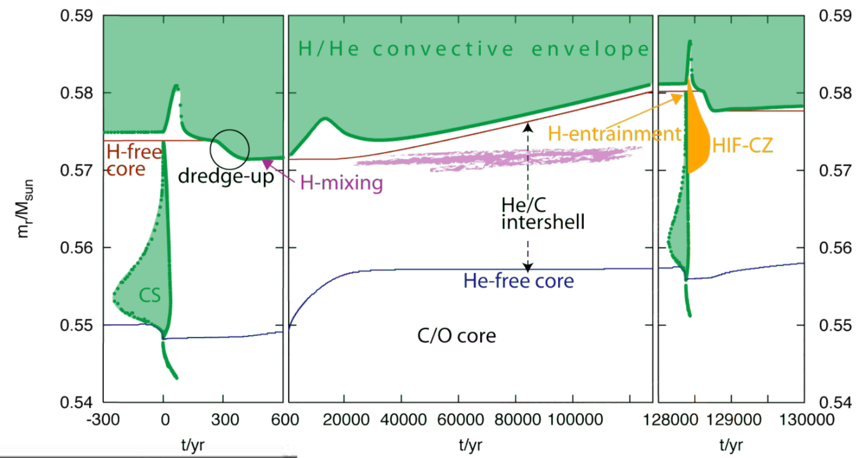
Theoretical Astrophysics Group

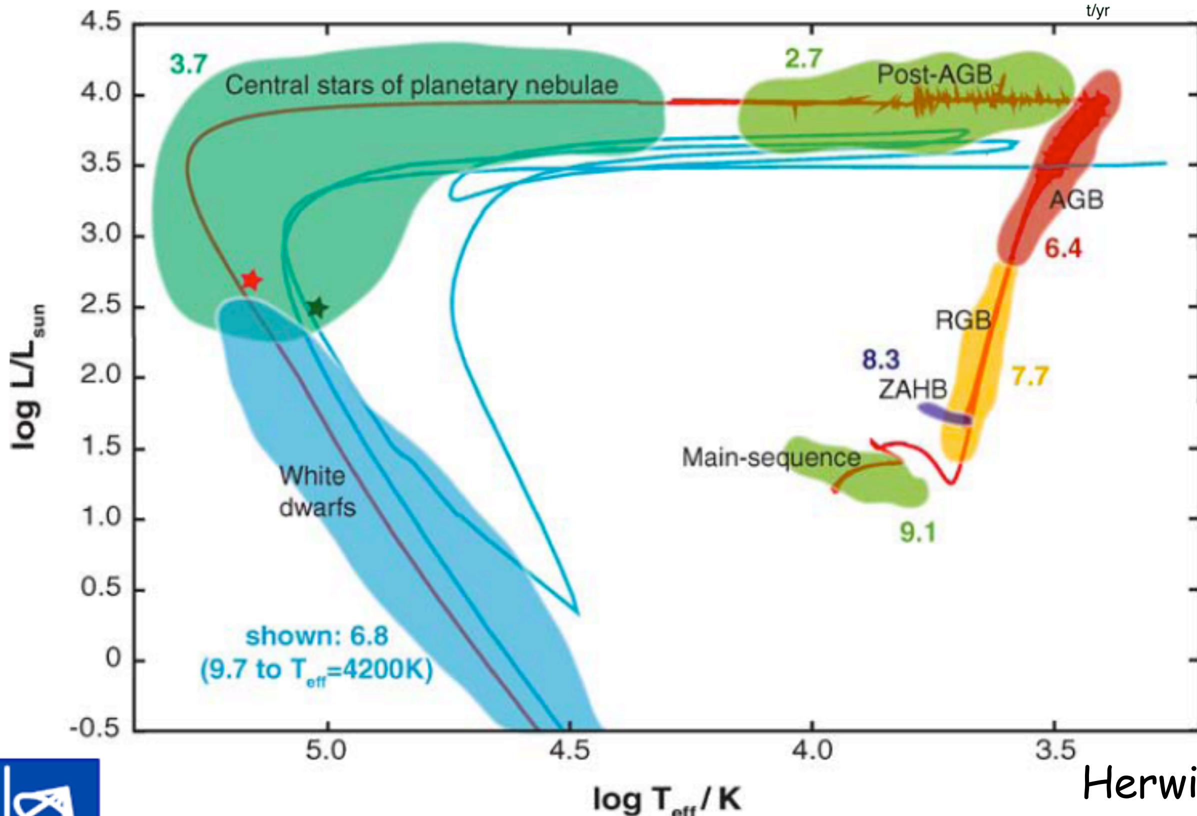
LA Neutron Science Center

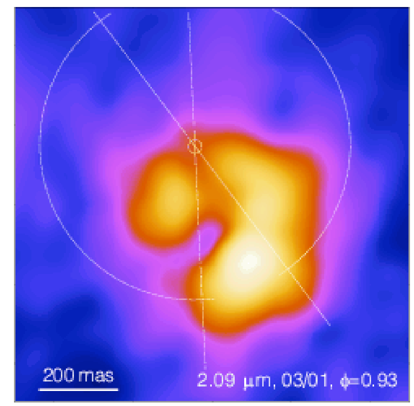
Introduction:

NGC 6826
(Balick etal)

AGB evolution







IRC 10+216, Speckle image,
Menchikov etal 2002

Herwig 2005, ARAA.

JINA focus AGB stars: Why do we care?

- AGB stars account for ~75% of the stellar material re-ejeted into the ISM
    - Large fraction (~40%) of C, primary producer of N
    - Half of all trans-iron elements are made by the s-process in AGB stars
    - At very low metallicity in the early Universe: large primary production of many light n-heavy species (like ^{23}Na, $^{24/25}$Mg)
- AGB (including s-process) yields for near-field cosmology applications (e.g. Venn etal. 204, Fenner etal. 2006) to study cosmological formation history of our galaxy and it's dwarf spheroidal satellites
- Test bed for physics of mixing and nucleosynthesis: plenty observables of intrinsic nuclear production
- Supernova progenitors: WD for SNIa, super AGB for ONe core-collapse

AGB star research at JINA

Astro physics simulation:

- 1D stellar evolution
- 2D and 3D stellar hyrodynamics
- Nuclear network calculations

Nuclear physics:

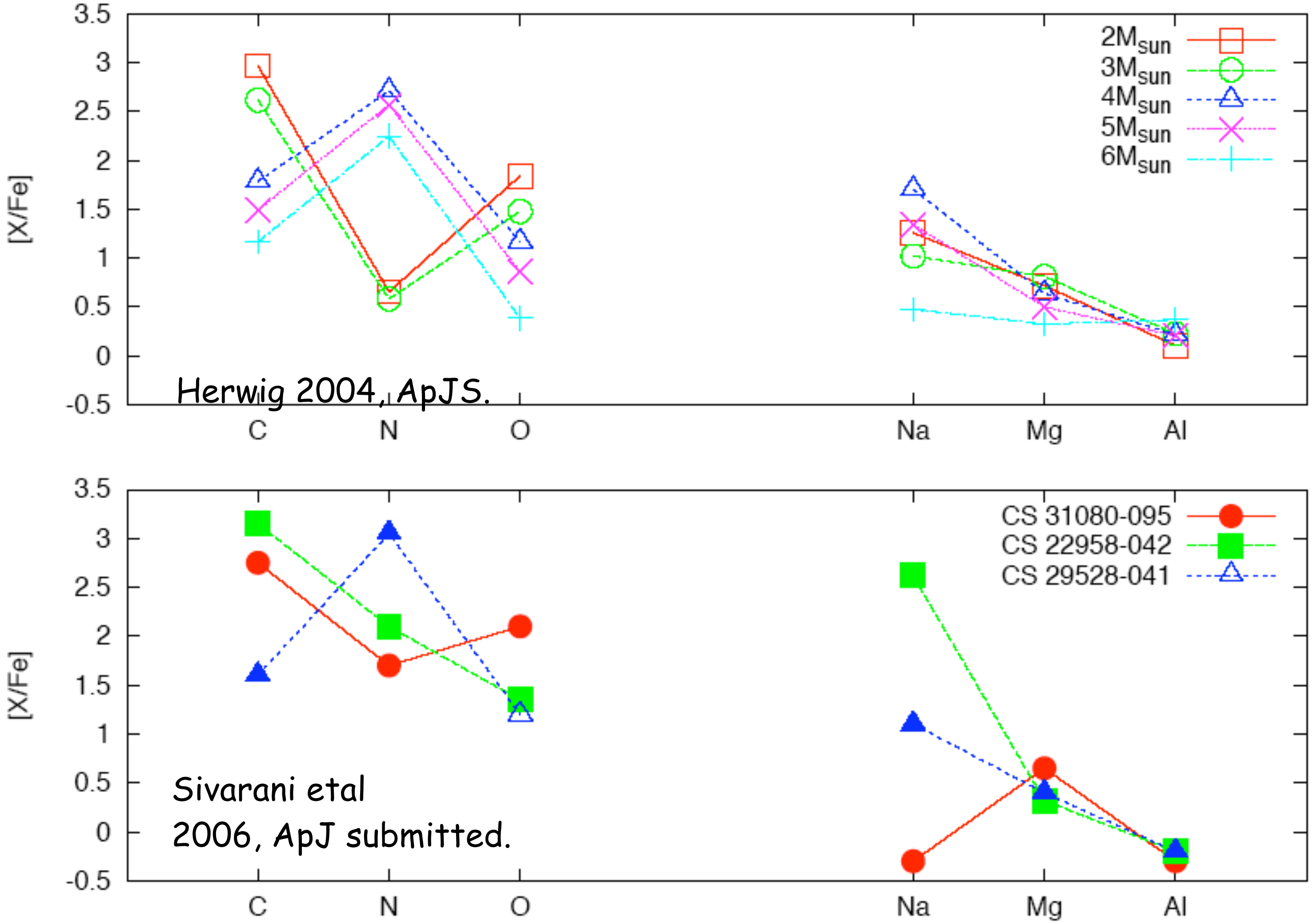
- Nuclear physics experiments
  - Charged particle: e.g. ^{22}Ne
  - n-capture X-section: Sm-Eu-Gd
  - Weak interactions
- Nuclear theory and rate evaluation

Astrophysics Observables:

- Stellar spectroscopy, surveys
- Pre-solar grains

A JINA Observation - Astrophysics Project:

The AGB signature in C-rich extremely metal-poor (binary) stars



[Fe/H]

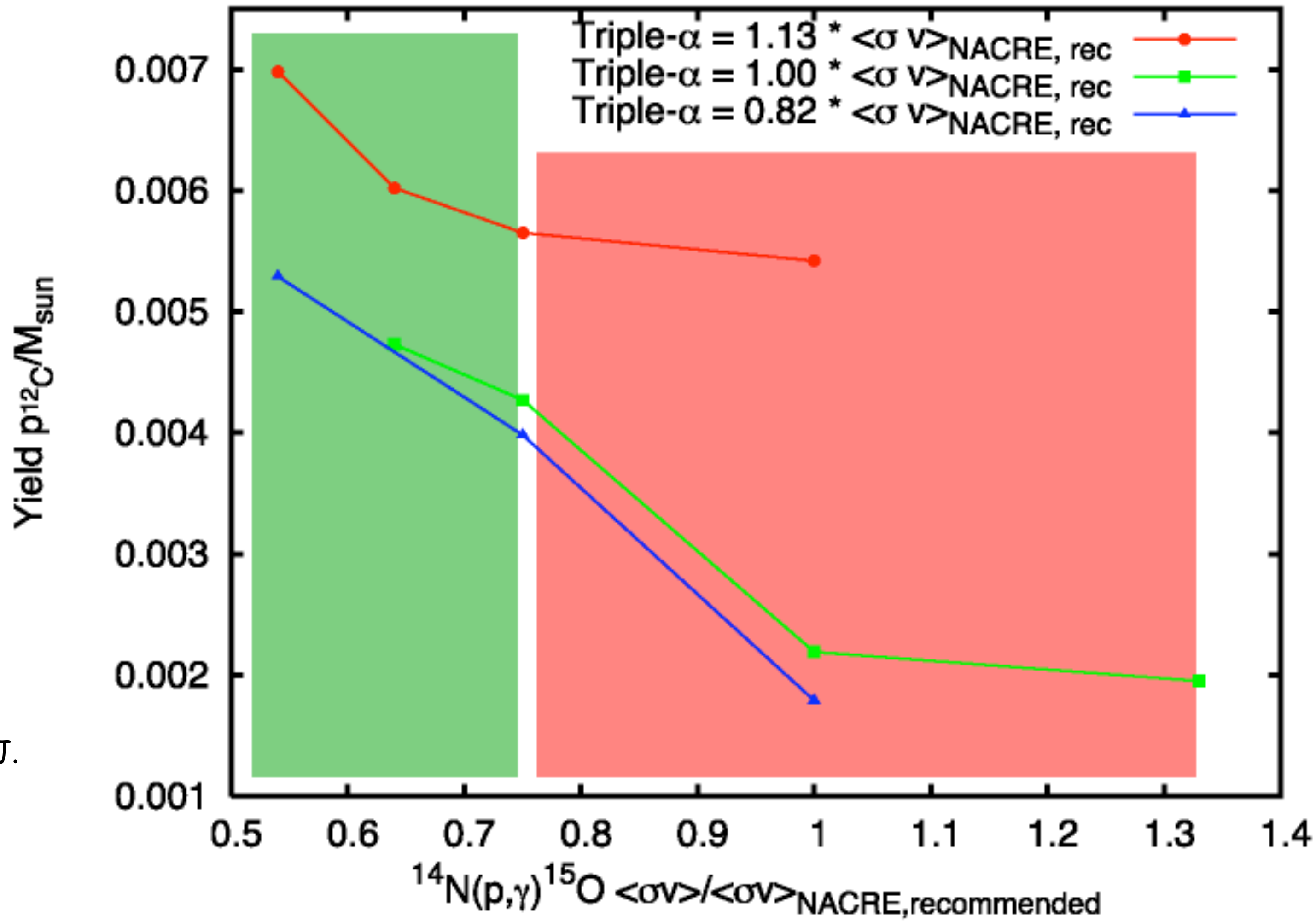
Models:
-2.3

-2.85
-2.85
-3.3

A JINA Astrophysics - Nuclear Theory/Evaluation project:

Dredge-up mixing in AGB stars and nuclear reaction rates

Total C yield as a function of nuclear reaction rate = what one $2M_\odot$ star of $0.5\ Z_\odot$ ejects into the ISM.

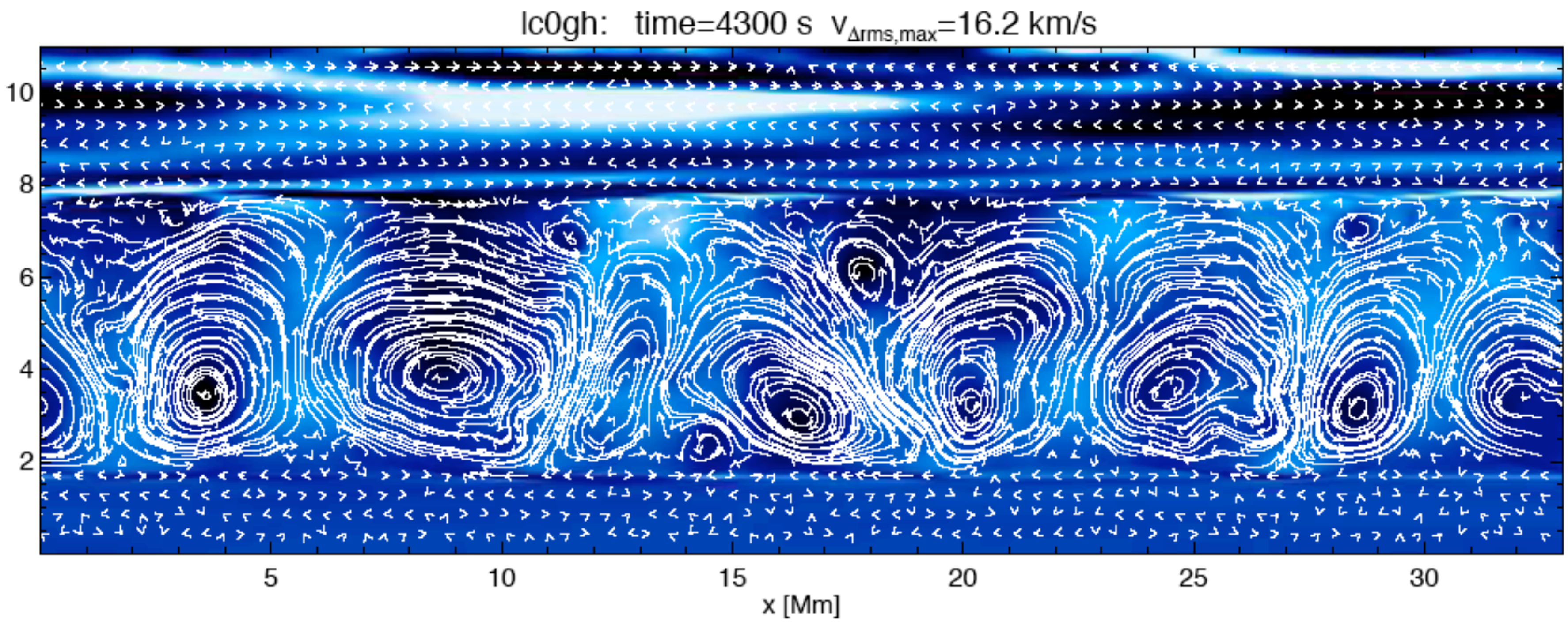


Herwig etal 2006, PRC

Herwig & Austin 2004, ApJ.

JINA Computational Astrophysics - Nuclear Experiment project:

s-Process, Hydrodynamics and Mixing of He-shell Flash Convection

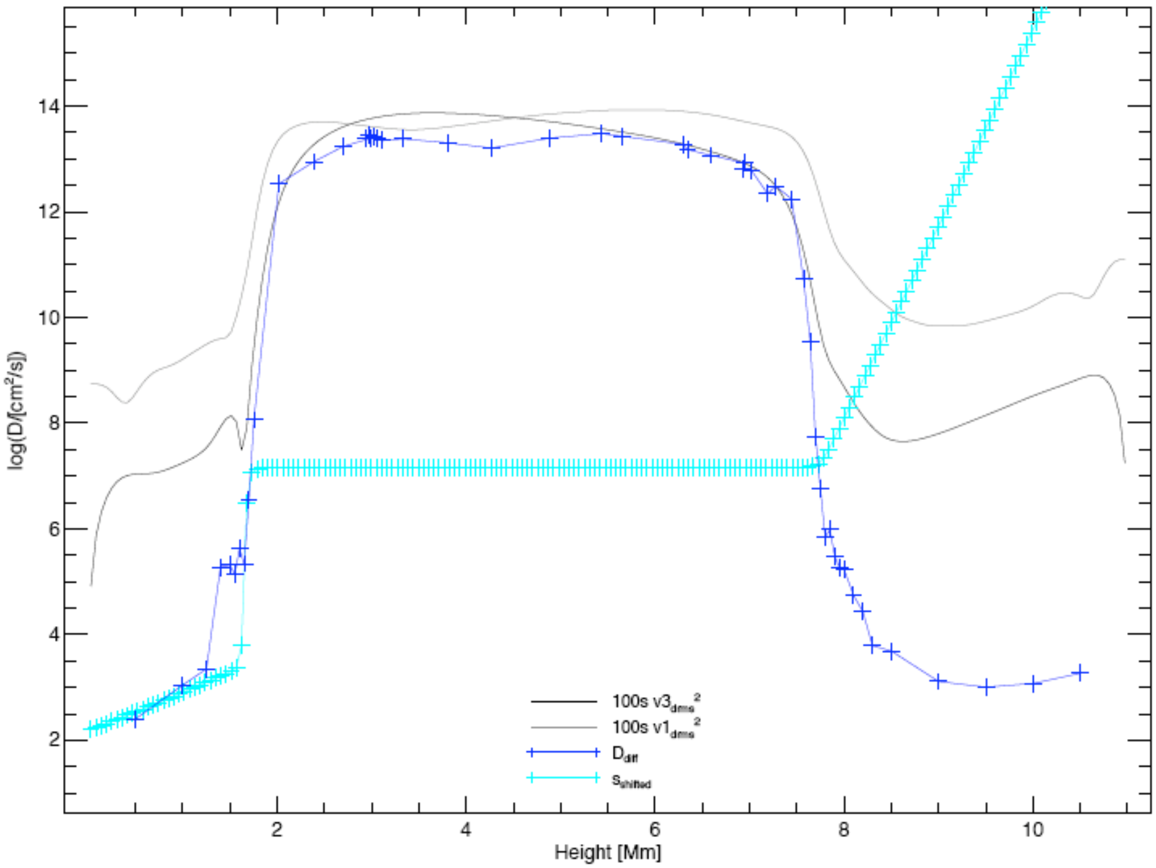


2D, 1200x400,
Herwig etal 2006, ApJ.

On this slide is a convection movie
Showing the entropy fluctuations
in the life presentation.

JINA Computational Astrophysics - Nuclear Experiment project:

s-Process, Hydrodynamics and Mixing of He-shell Flash Convection

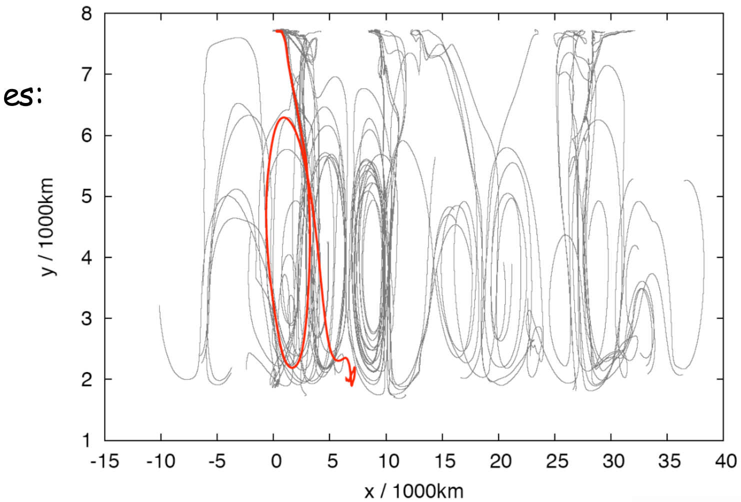


- Determine convective overshoot mixing for stellar interior nuclear burning zones
- Validate through astrophysical abundance observables:
    - through bare pre-WD cores (Werner & Herwig 2006, PASP review)
    - Sm-Eu-Gd s-process project

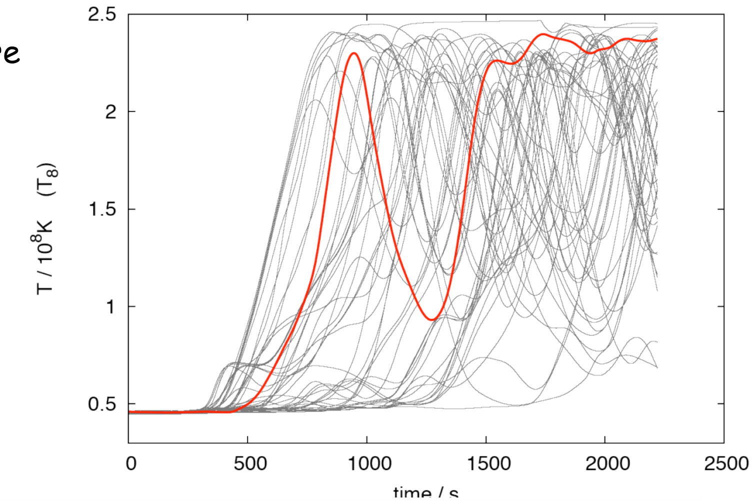
Blue solid: diffusion coefficient reflecting hydrodynamic mixing, black: vertical and horizontal rms-velocities, light blue: entropy (scaled), the plateau indicates the convectively unstable region (Freytag & Herwig, 2006, in prep).

JINA Computational Astrophysics - Nuclear Experiment project:
s-process in hydrodynamic convection simulations

Eularian trajectories:

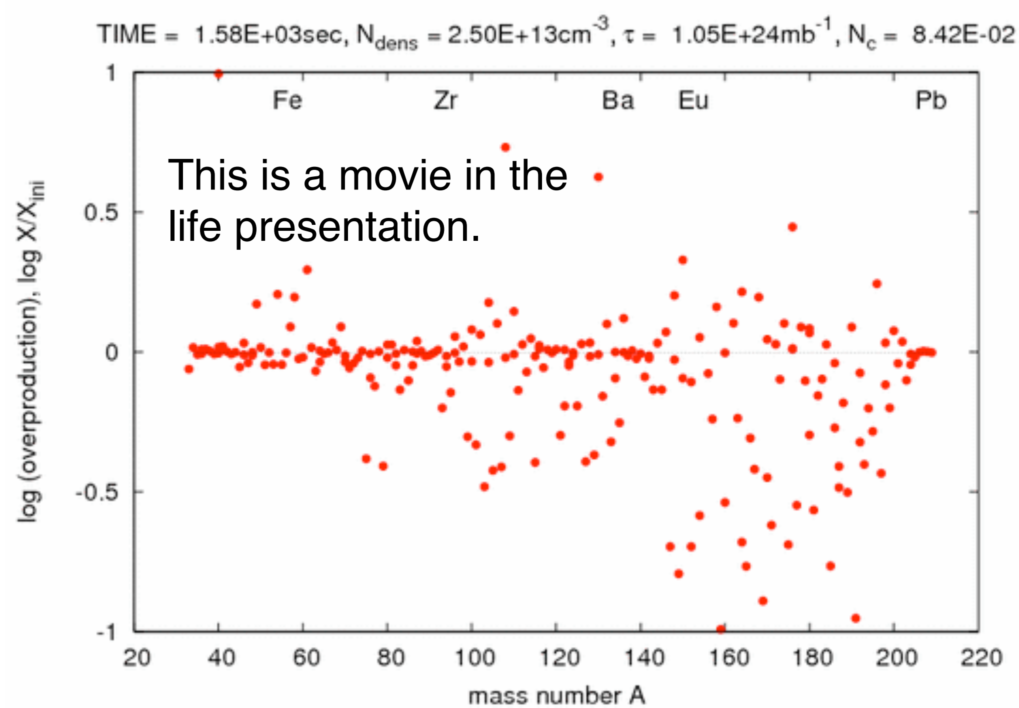


Temperature evolutions:



High-temperature s-process nucleosynthesis in the He-shell flash convection zone along trajectories from hydrdoynamics simulation, involves:

- Updated s-process network with T-dependent weak interactions and n-capture cross sections (JINA student Pignatari)
- New n-cross sections for unstable species (Reifarth@LANSCE, former JINA student Courture, now LANL post-doc)

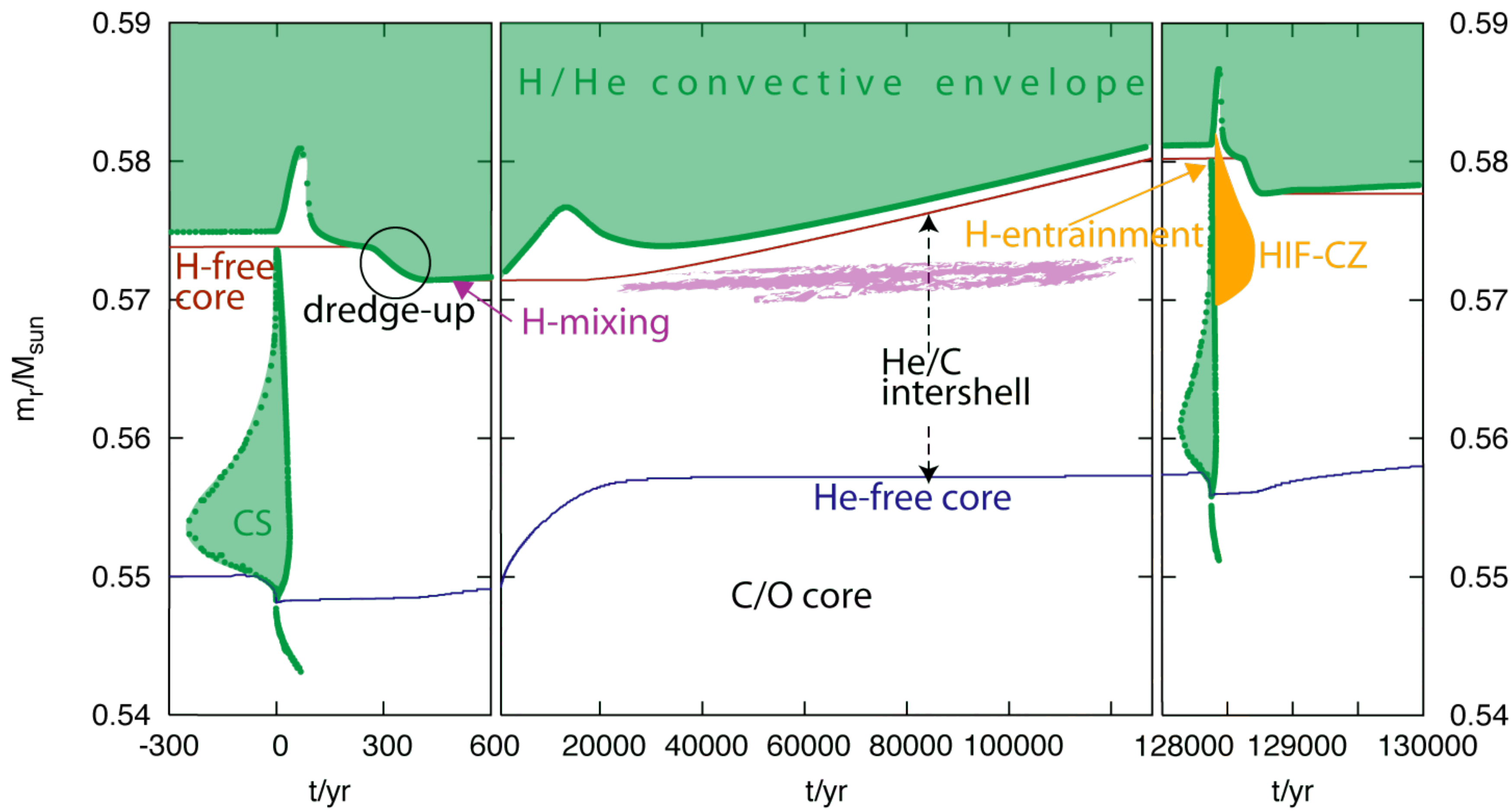


Final Remarks

- JINA promotes connecting to and leveraging related projects elsewhere: Aspects of the stellar burn and mix hydrodynamics work are done as part of ASC code V&V. Through adding some resources JINA enables dual use for nuclear astrophysics program.
- JINA provides a platform to coordinate complementary capabilities: larger and more integrated problems can be attacked, e.g. coordinate n-cross section measurements and modeling at LANL, with charged particle measurements, stellar observations and pre-solar grain laboratory analysis at ND/MSU/Argonne (the "Sm-Eu-Gd project").

BACKUP SLIDES:

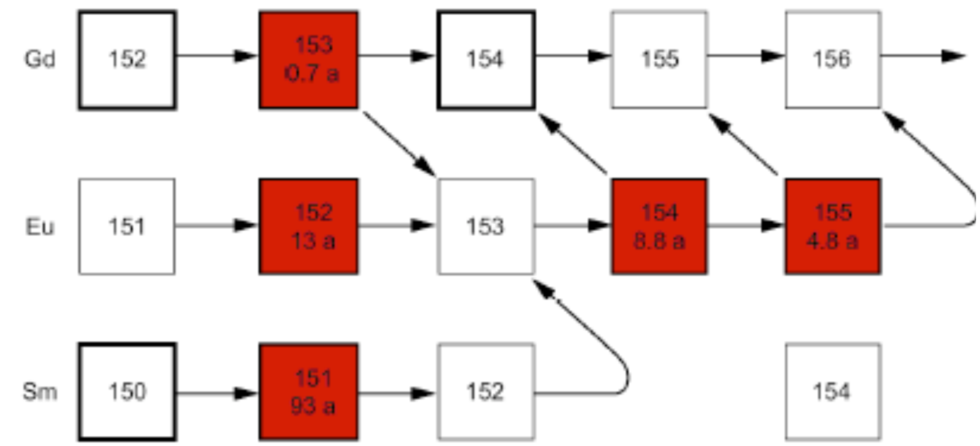
He-shell flashes in AGB stars
(with non-standard burning and mixing at extremely low metallicity)

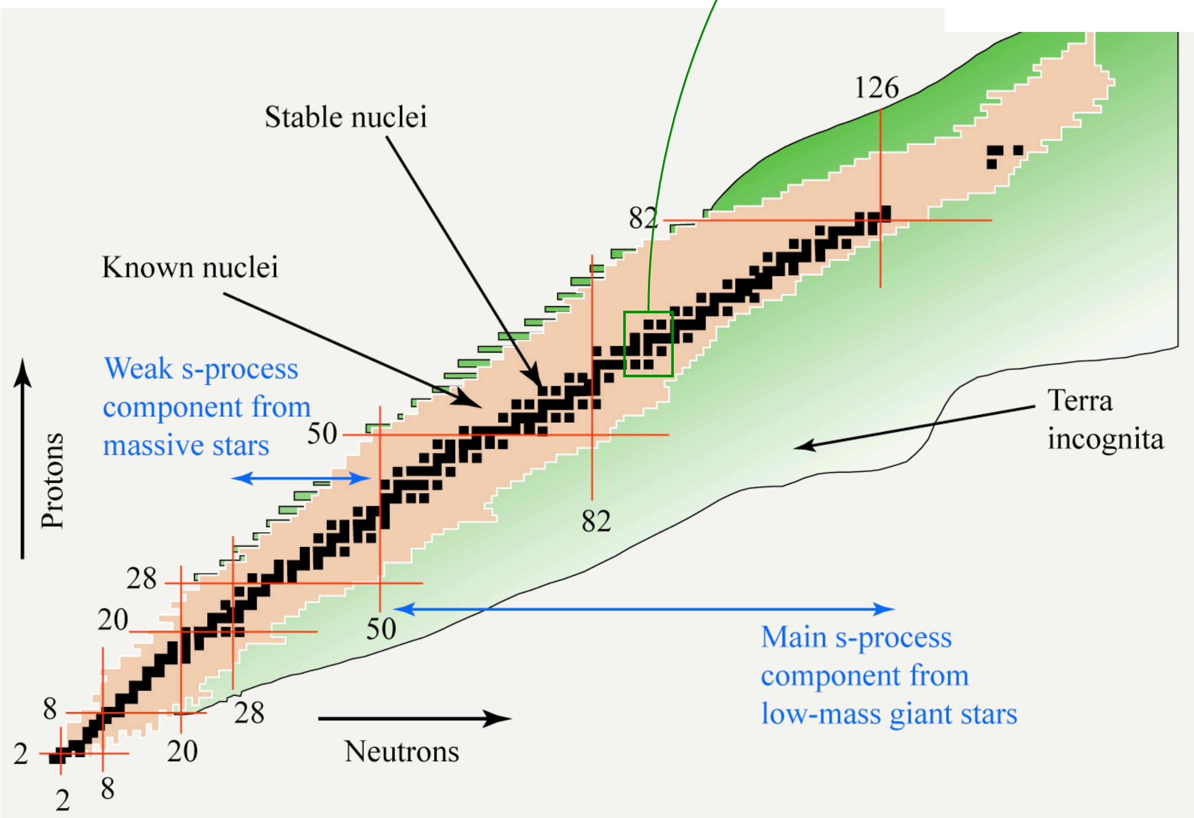


Adopted from Herwig, 2005, ARAA, 43.

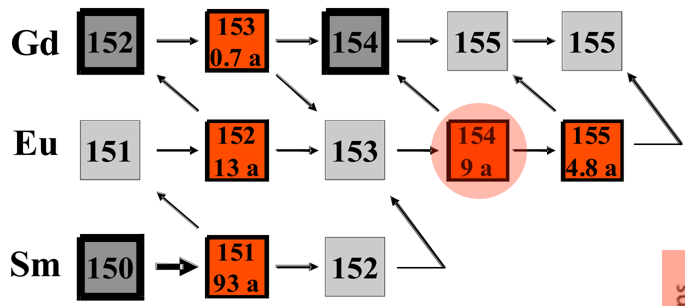
Nuclear Astrophysics: The *s* process branchings

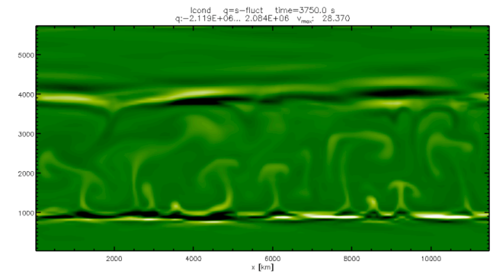
Competition of β-decay and neutron capture depends on n-density and/or temperature, which in turn depends on stellar model and mixing properties.

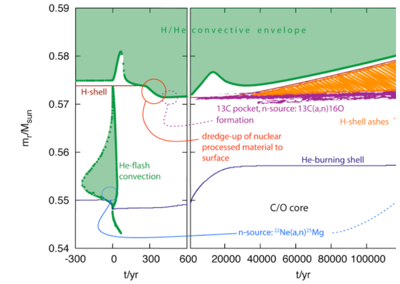




A specific example: branchpoint ^{154}Eu





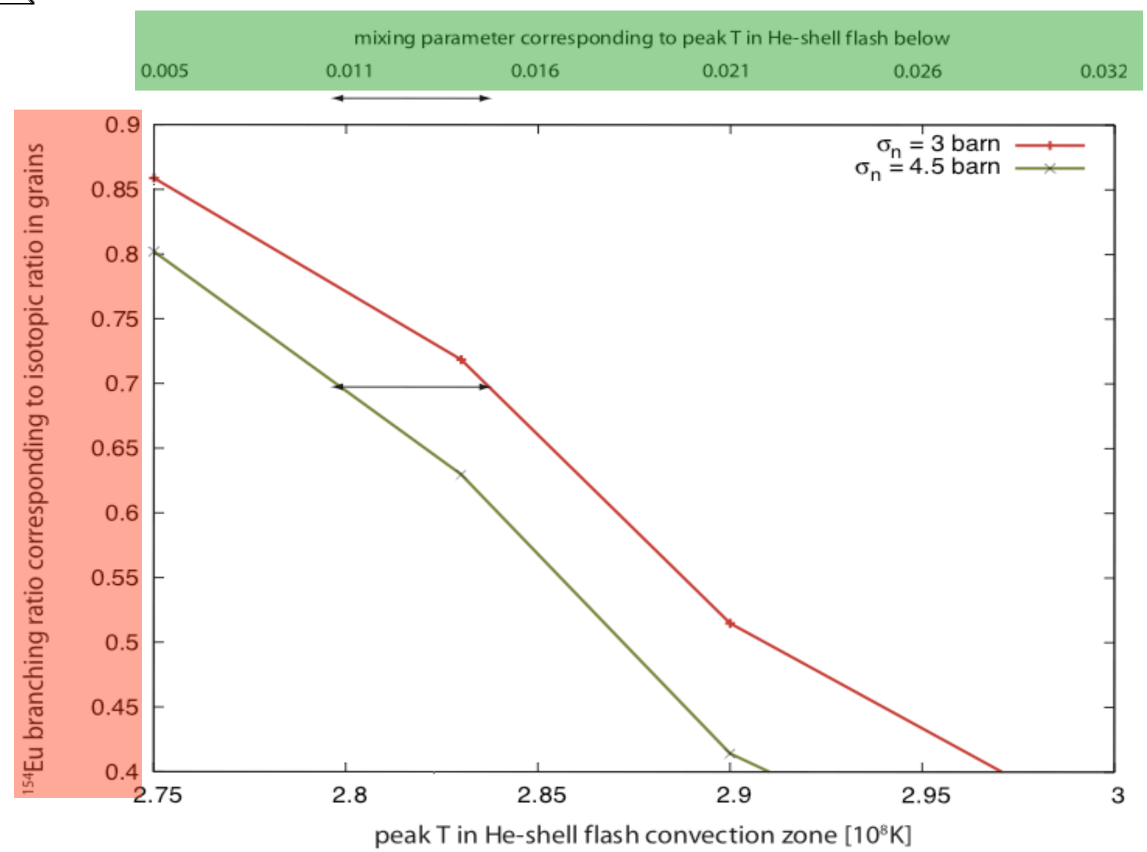


Branching ratio: $f = \lambda_\beta / (\lambda_\beta + \lambda_n)$

β-decay rate: $\lambda_\beta = (\ln 2) / t_{1/2}$

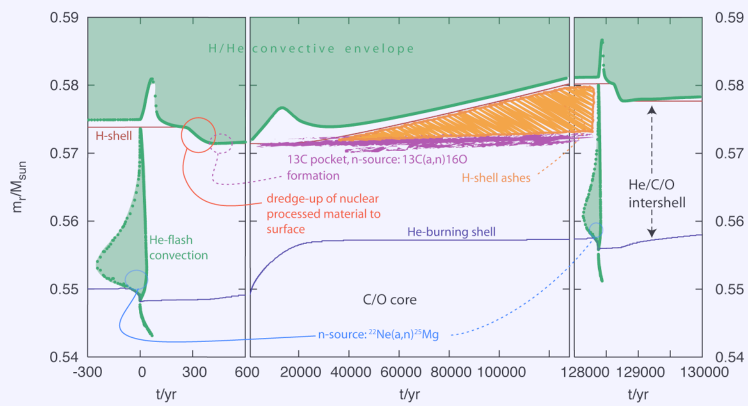
n-capture rate: $\lambda_n = \sigma_n v_T N_n$

$f(^{154}Eu) \sim {}^{154}Gd/{}^{152}Gd$

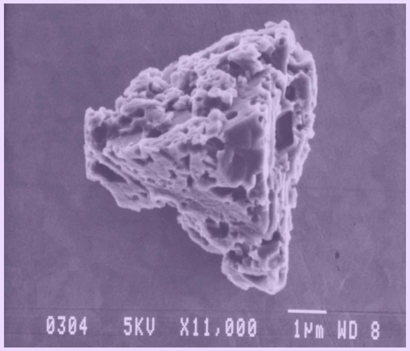


Sm-Eu-Gd: a collaborative multi-physics, multi-institutional project

Astrophysics modeling: Provide theory and simulation to link from nuclear experiment to astrophysical observables -> improve predictive power of models (LANL/T-6).

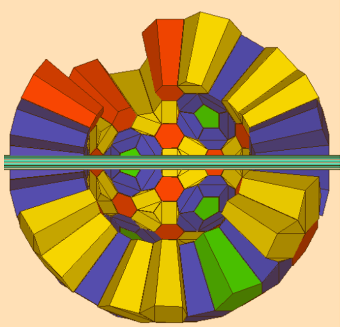


Pre-solar grains: First *individual grain* isotopic measurements for multiple elements - Sm-Eu-Gd - with new experimental technology (CHARISMA) at Argonne National Lab, collaboration request letter received.

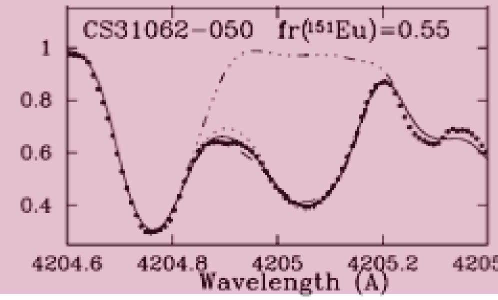


Nuclear Physics Experiments with DANCE:

- (n,γ) measurements of radioactive samples with 4π BaF_2 array, that can not be performed anywhere else
- First complete experimental data coverage for an entire branching region
- LANL/LANSCE, T-16



Observations: Systematic campaign Eu hyper-fine line splitting to determine Eu isotopic ratios in extremely metal poor stars, sample will be obtained in part from SEGUE/SDSS-II candidates (JINA/MSU).



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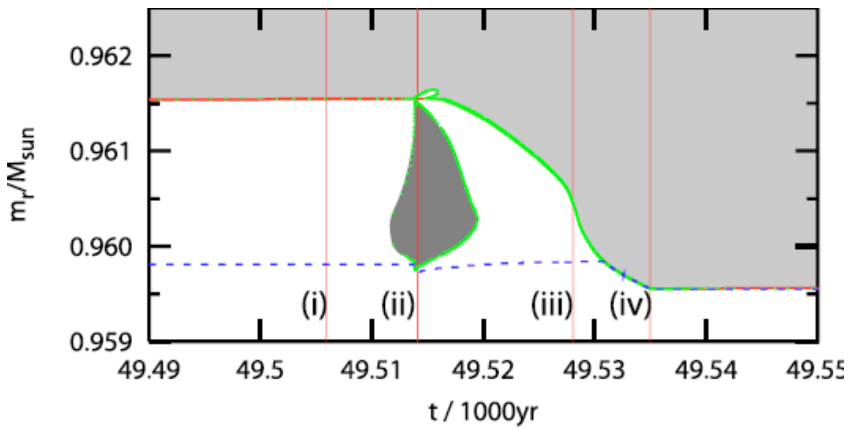
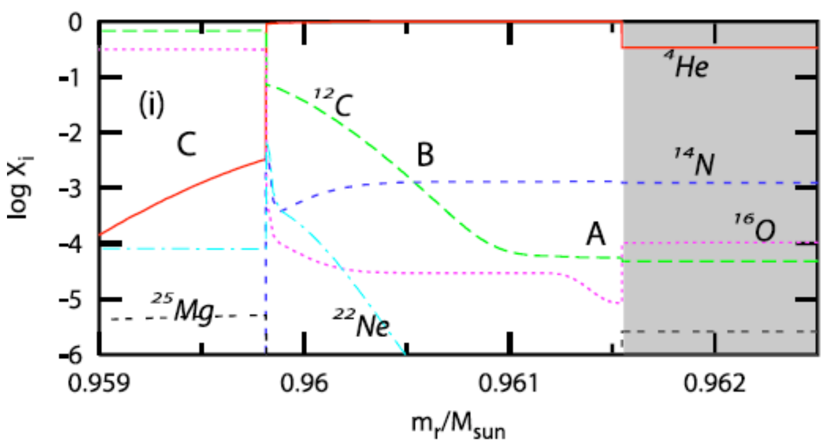
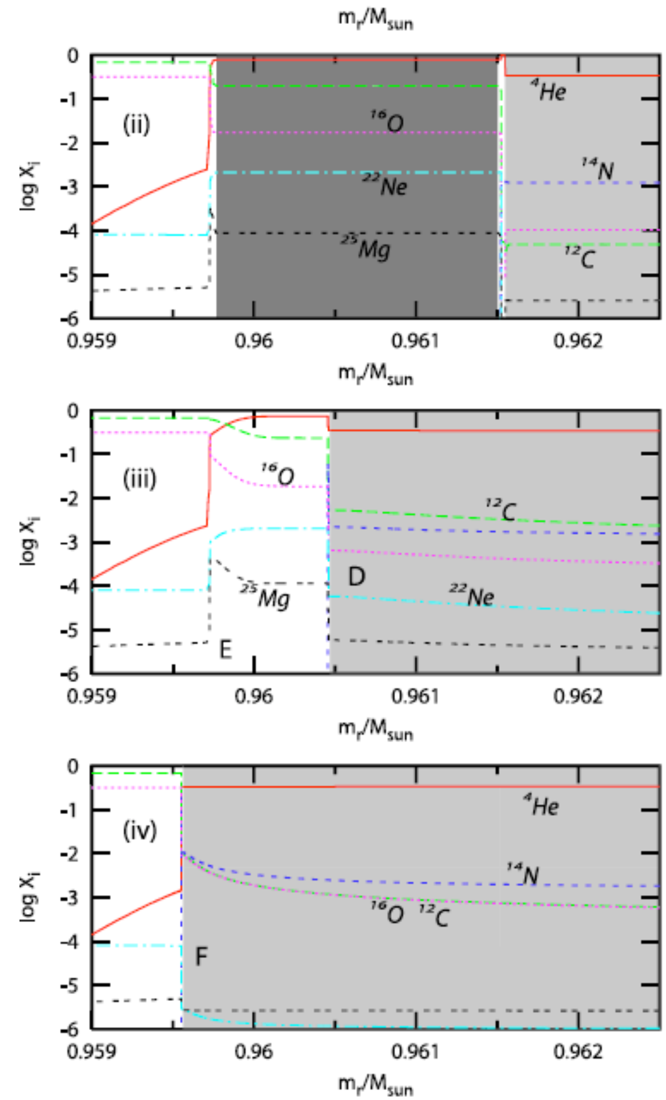
Abundance evolution through a He-shell flash

$M_{ZAMS} = 5M_{\odot}, Z = 10^{-4}$

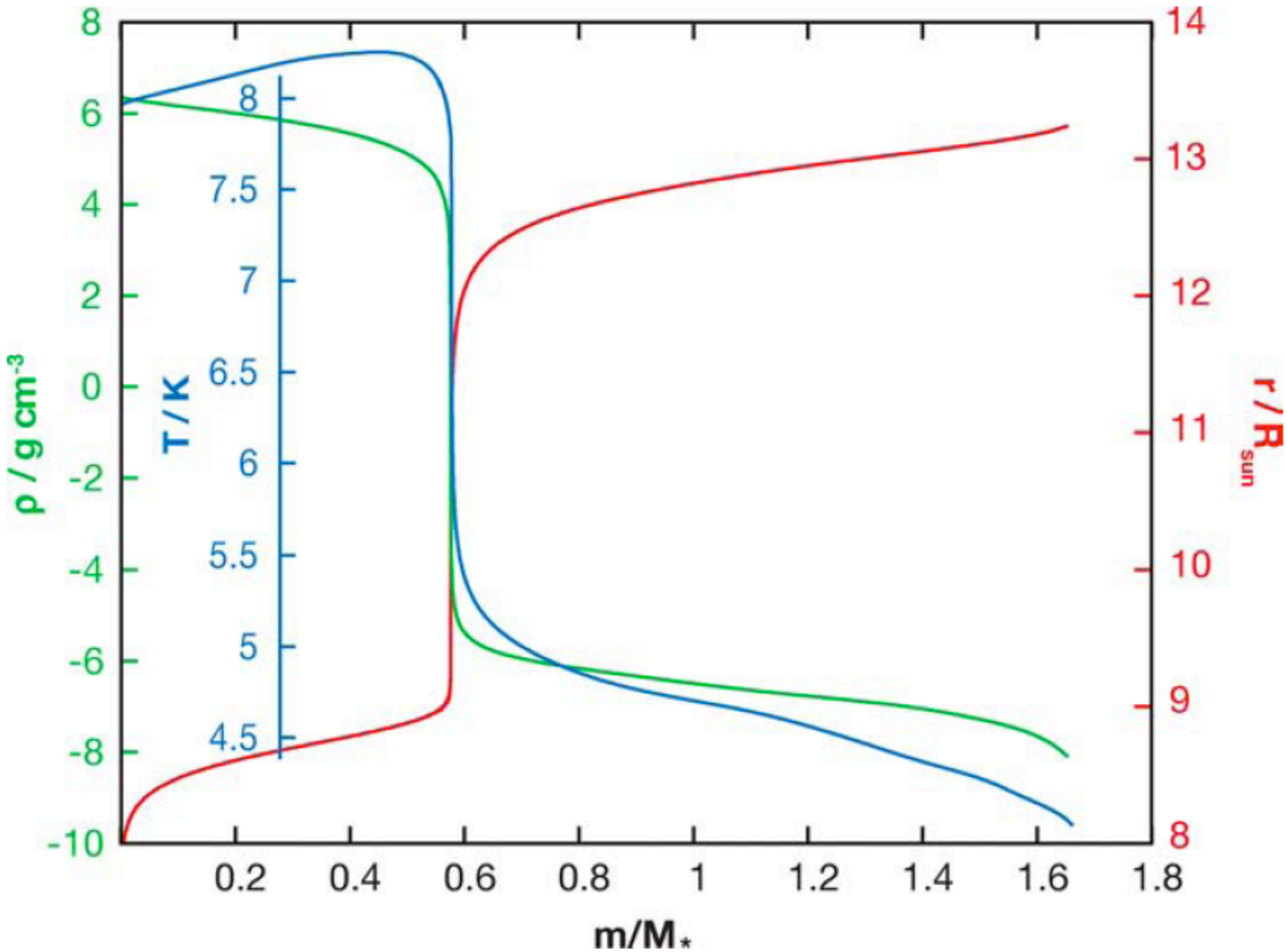




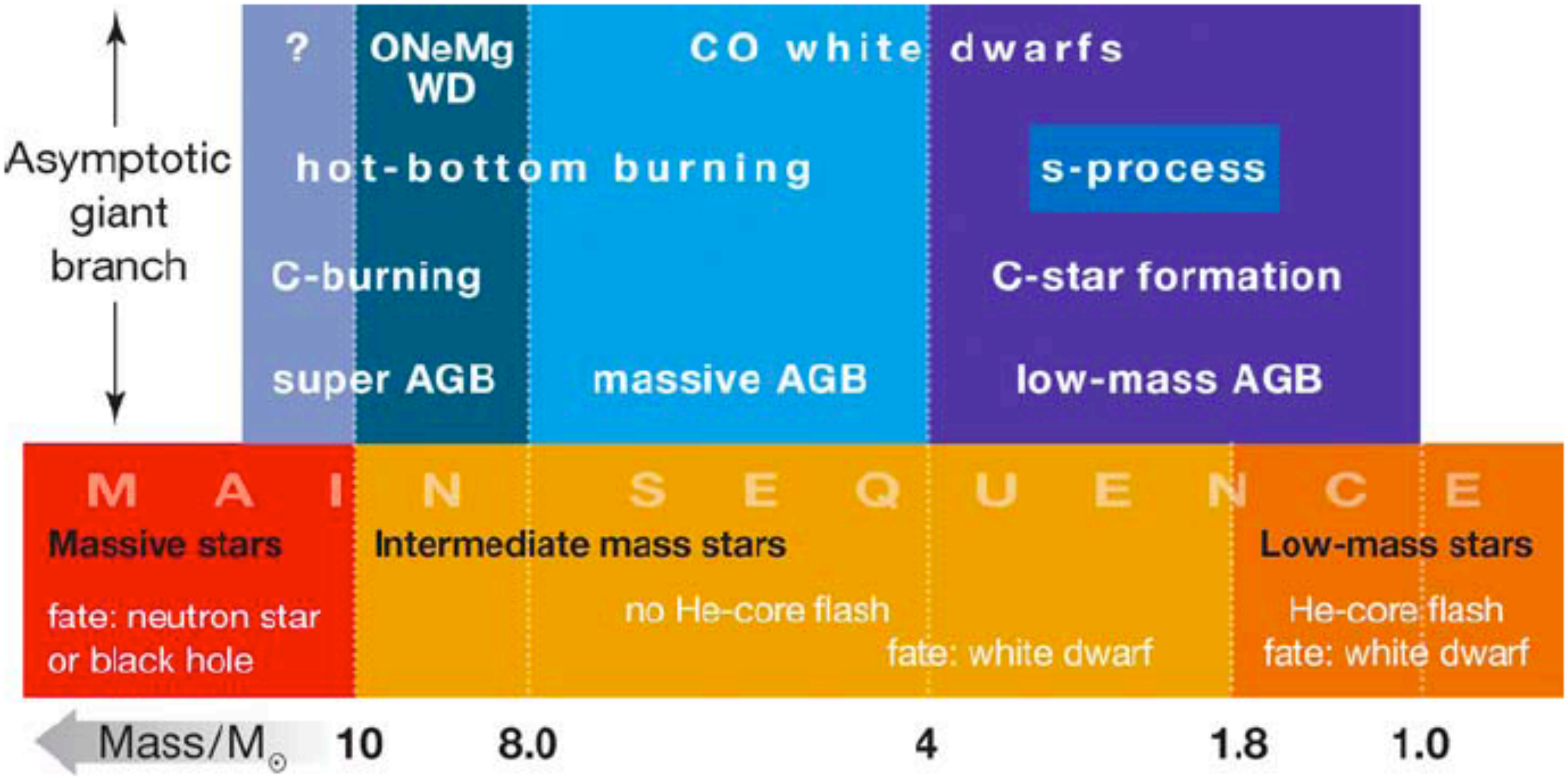


Herwig, 2004a,b, ApJ(S)

Structure of AGB stars



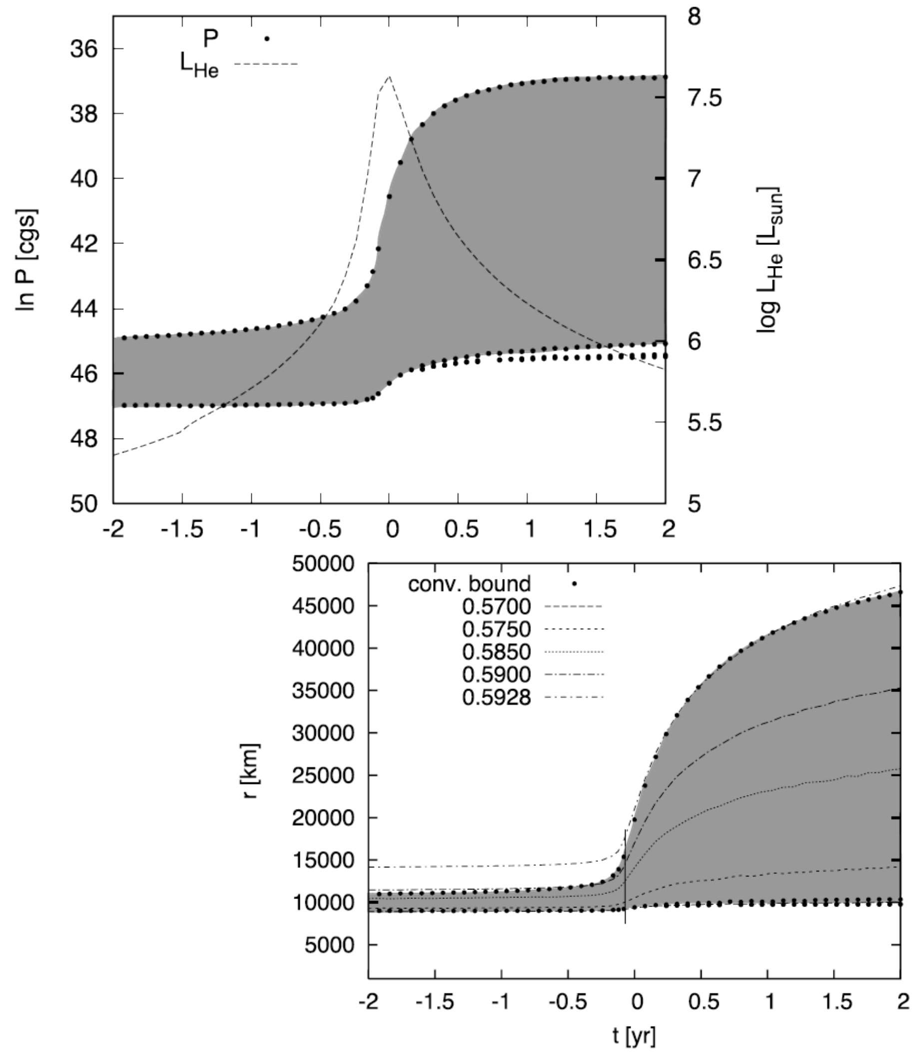
Initial mass and evolution fate



Hydrodynamics of He-shell flash convection

Collaborators: Bernd Freytag, Robert Hueckstaedt, Frank Timmes

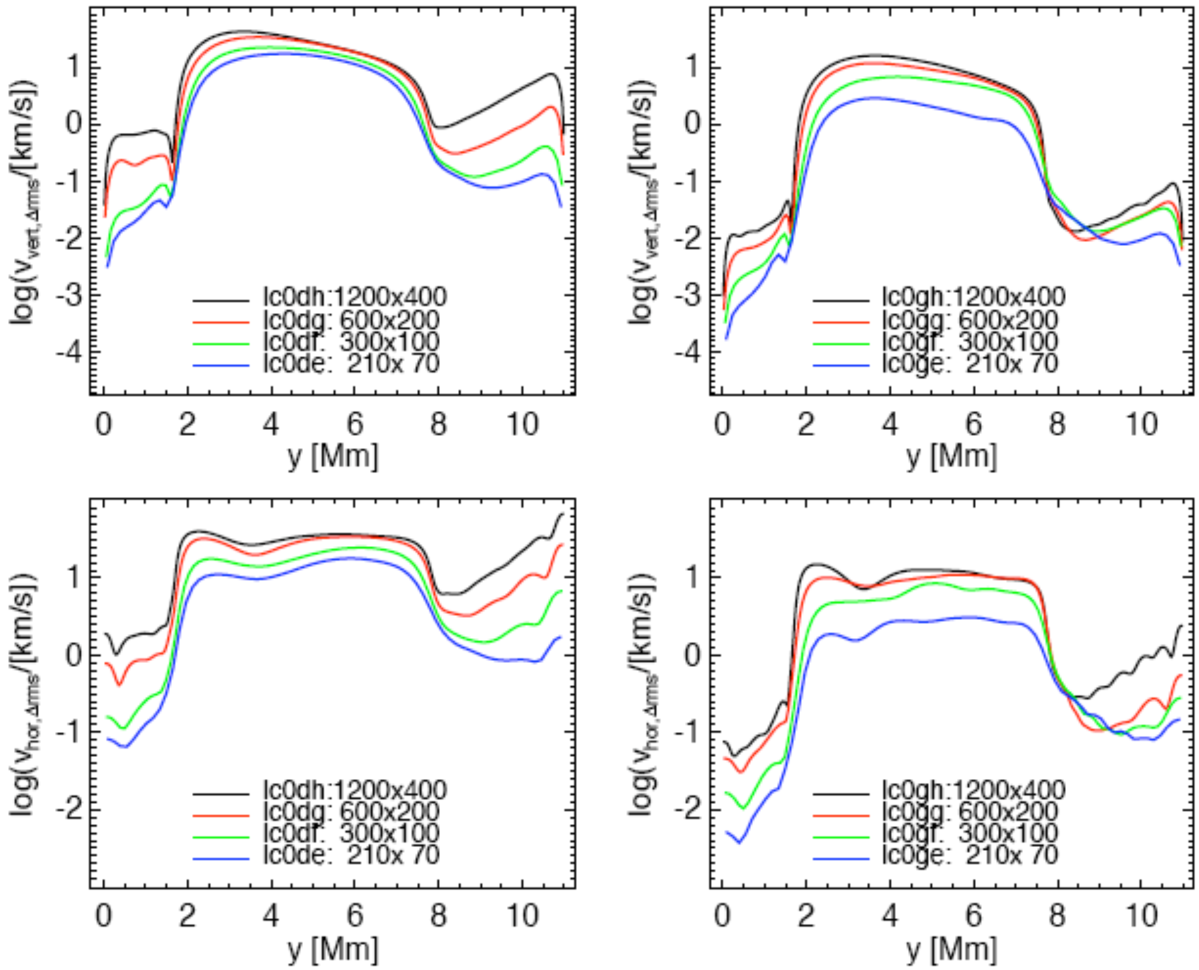
- 2D and 3D hydrodynamics simulations of a short duration (~20ksec) of He-shell flash convection at a time just before the peak of He-flash
- Explicit, Eulerian, compressible grid code RAGE
- Initial conditions: piecewise polytropic stratification with gravity that closely resembles the actual conditions in a specific $2M_{\odot}$, Z=0.01 thermal pulse model



Convergence

vertical v

horizontal v



Driving x 30

x1