

Nuclear Physics I: Nuclear Astrophysics

PHYS 8801

Alexander Heger¹

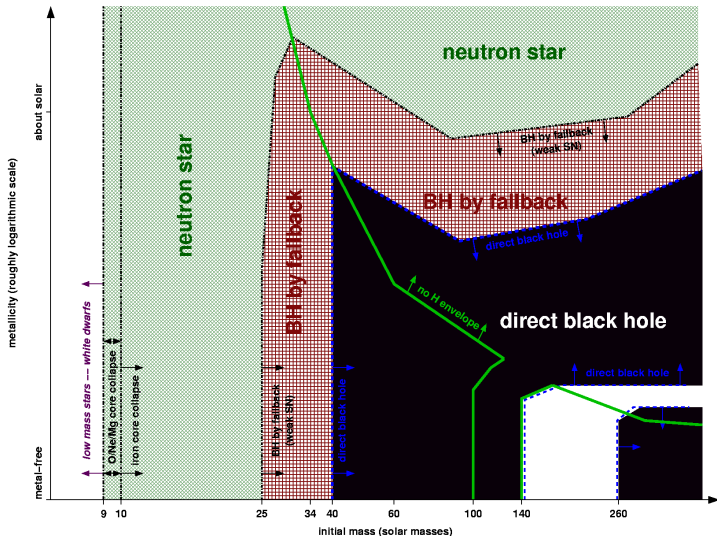
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School of Physics and Astronomy
University of Minnesota

Nuclear Physics I: Nuclear Astrophysics, Spring 2012

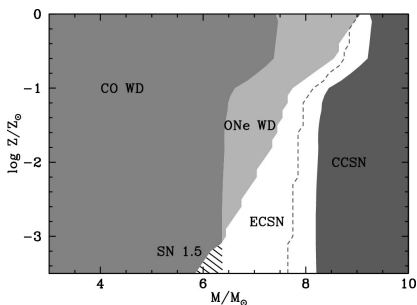
Agenda

- 1 Remnants as a Function of Mass and Metallicity
- 2 Regimes of Stellar Evolution
- 3 Low-Mass and Intermediate-Mass Stars
 - Evolution of a $8 M_{\odot}$ Star
 - Evolution of a $4 M_{\odot}$ Star
- 4 Planetary Nebula

Remnants - Mass and Metallicity



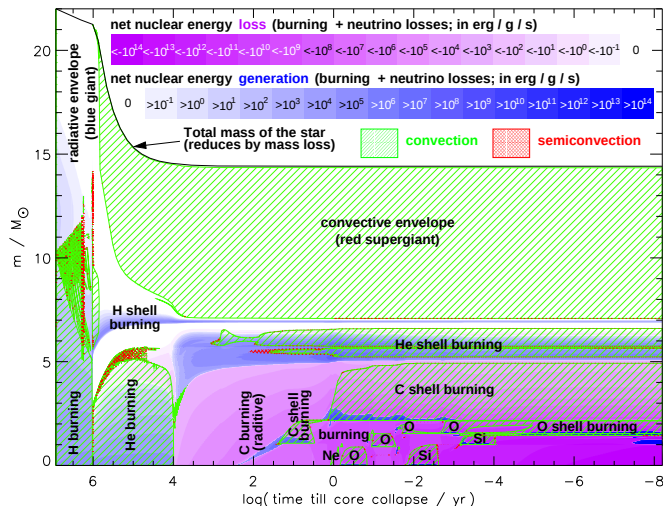
Fates of Intermediate and Massive Stars



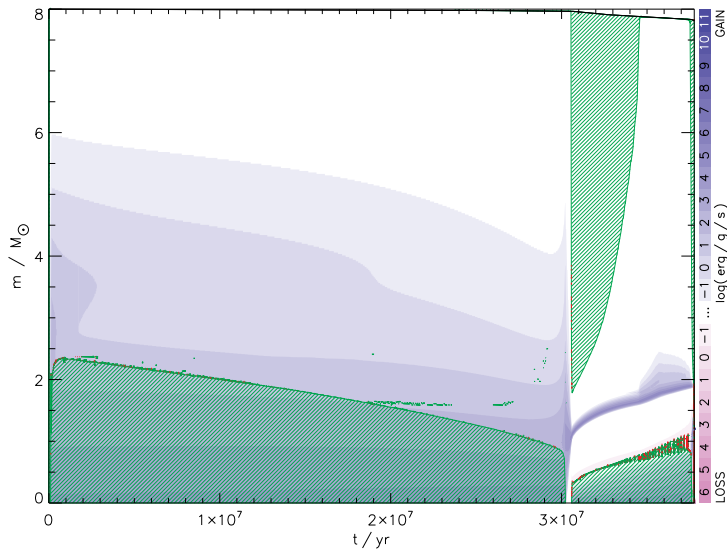
NOTE

- exact mass ranges depend on uncertainties in stellar physics (mixing, mass loss, nuclear cross sections, etc.)
- they also depend on metallicity and on initial rotation rate of star

Burning Phases in the Stellar Interior

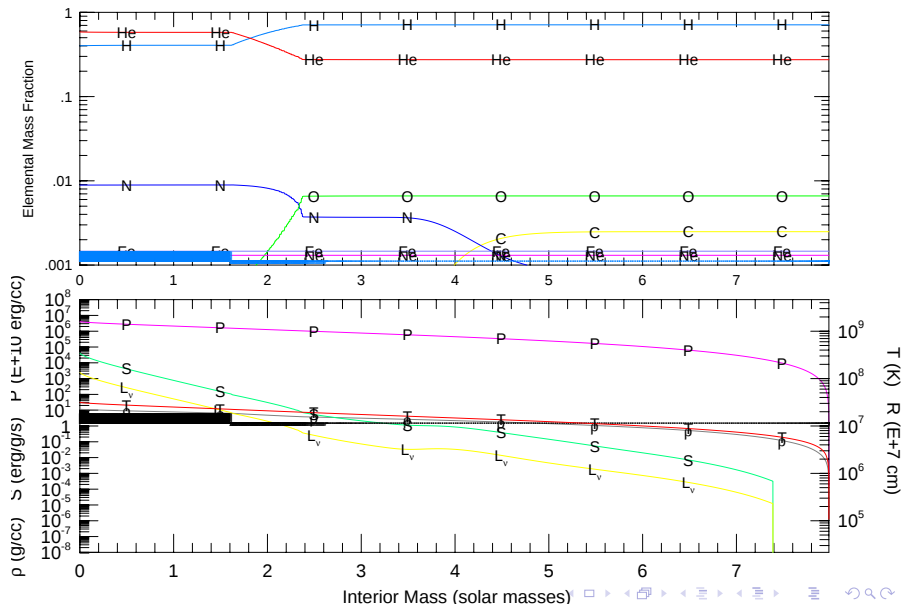


Kippenhahn Diagram, $8 M_{\odot}$ Star

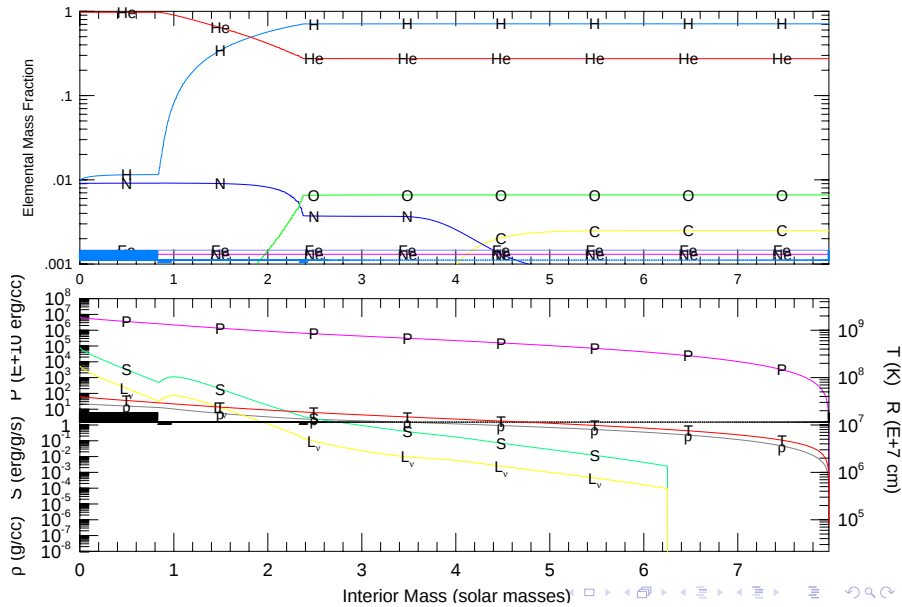




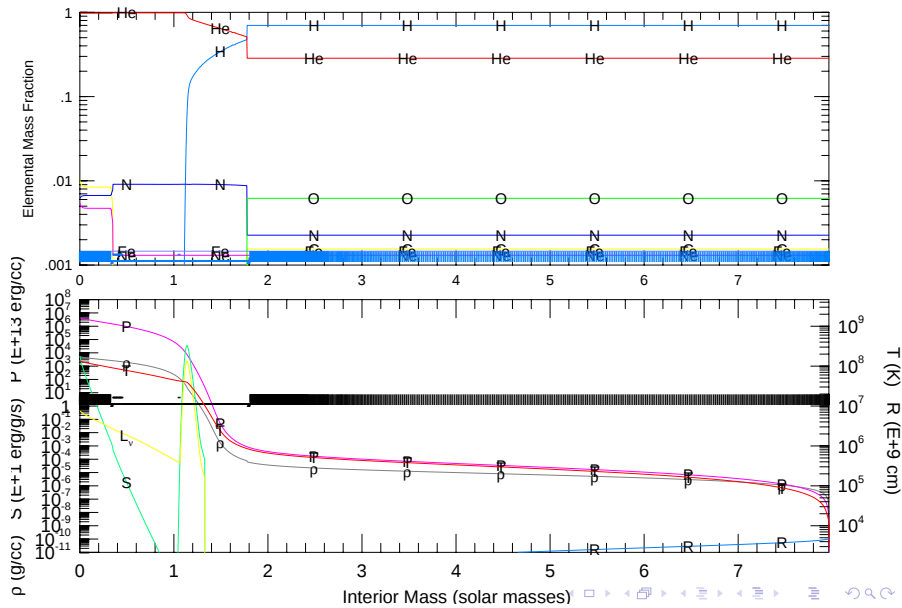
8 M_☉ Star, Middle of Hydrogen Burning



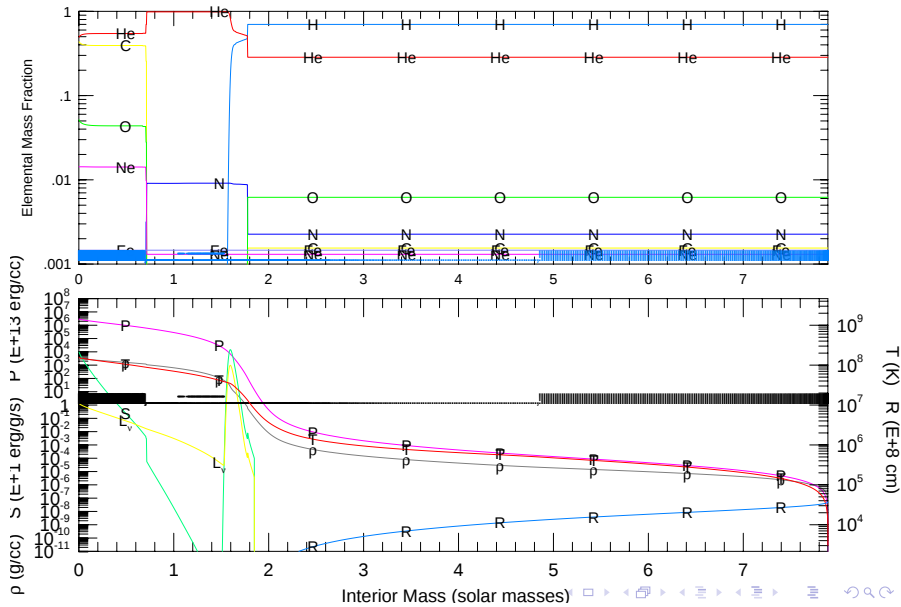
8 M_☉ Star, End of Hydrogen Burning



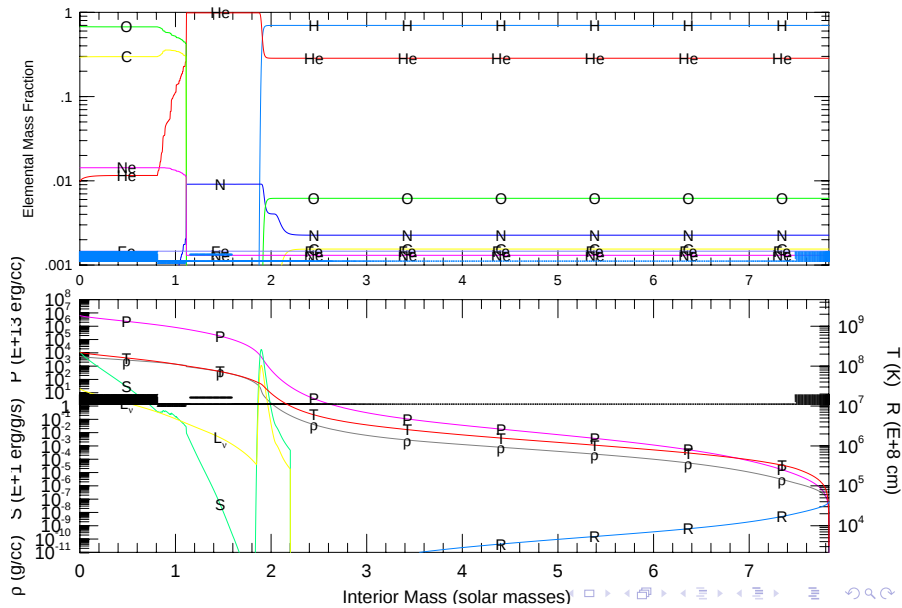
8 M_☉ Star, Beginning of Helium Burning



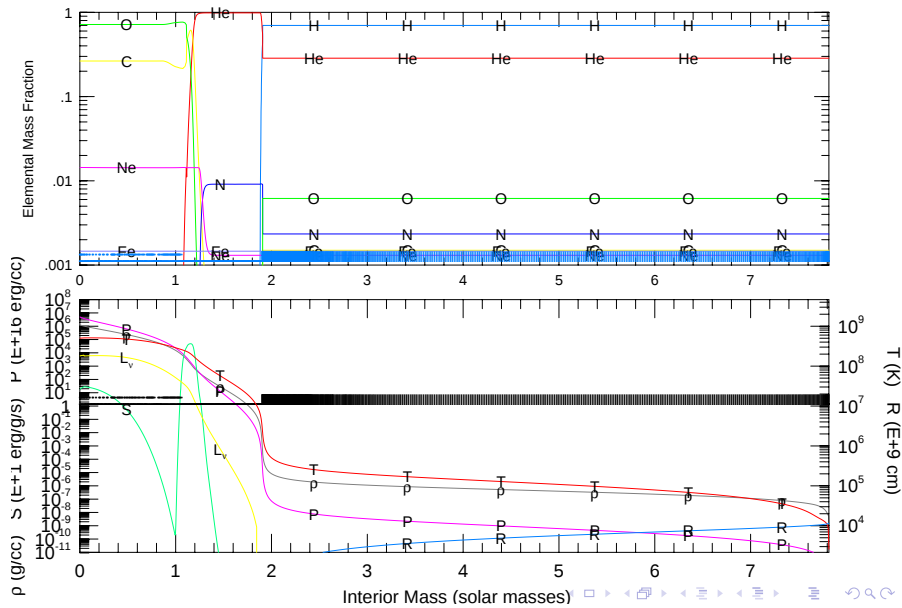
8 M_☉ Star, Middle of Helium Burning



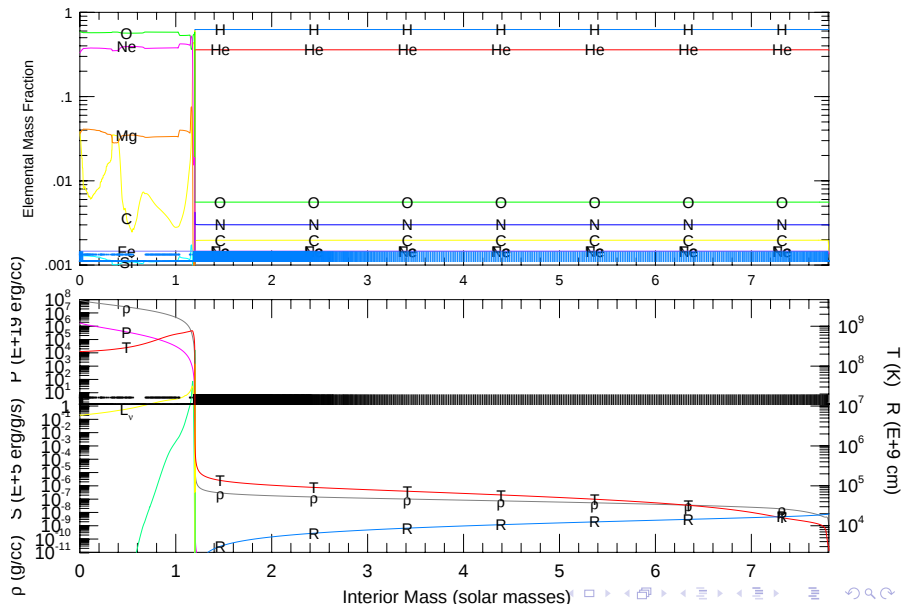
8 M_☉ Star, End of Helium Burning



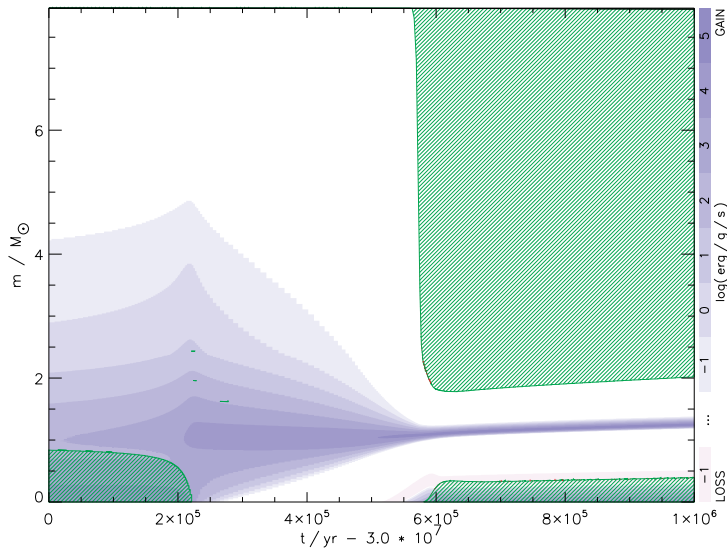
8 M_☉ Star, $T_c = 5 \times 10^8$ K



8 M_☉ Star, Last Model Computed



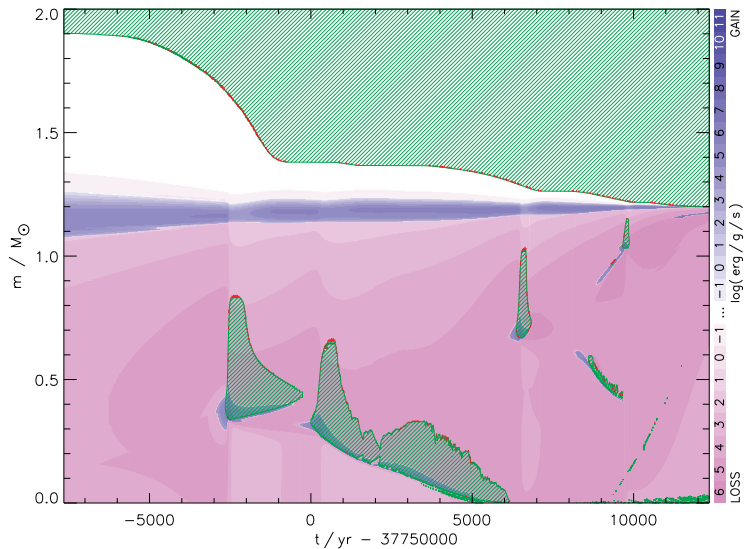
Kippenhahn Diagram, $8 M_{\odot}$ Star, He Ignition



Low-Mass and Intermediate-Mass Stars Planetary N



Kippenhahn Diagram, 8 M_☉ Star, Off-Center C Ignition

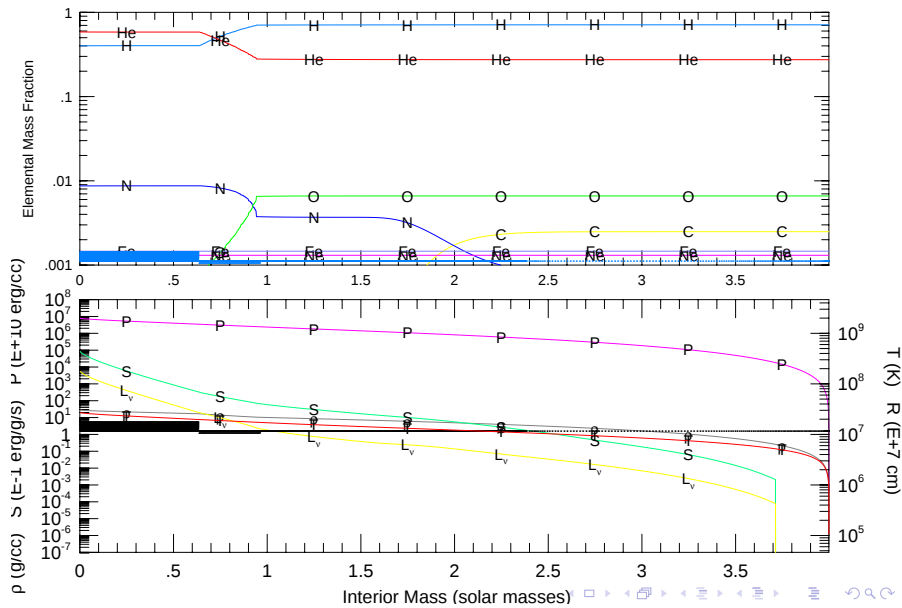


Evolution of a 4 M_⊙ Star

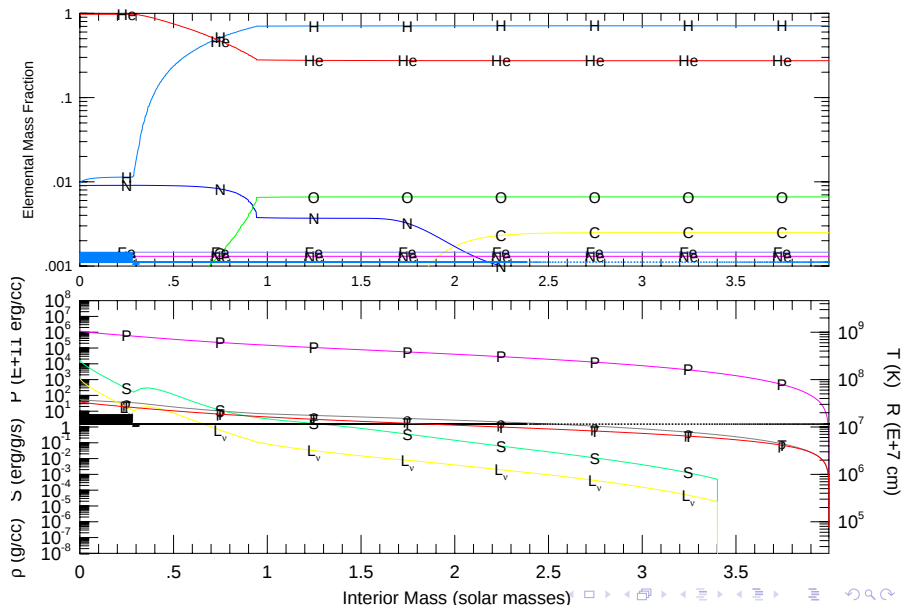
Low-Mass and Intermediate-Mass Stars Planetary N



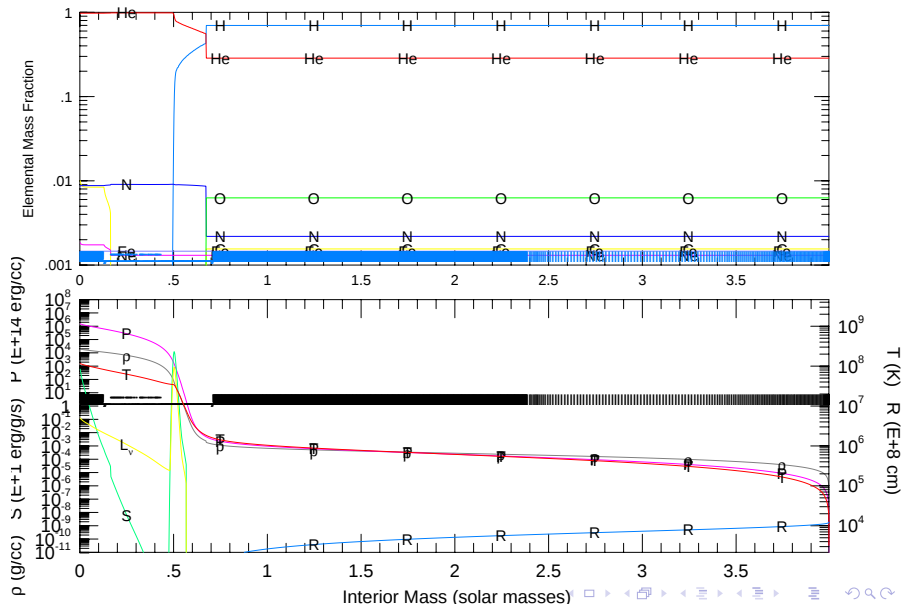
4 M_⊙ Star, Middle of Hydrogen Burning



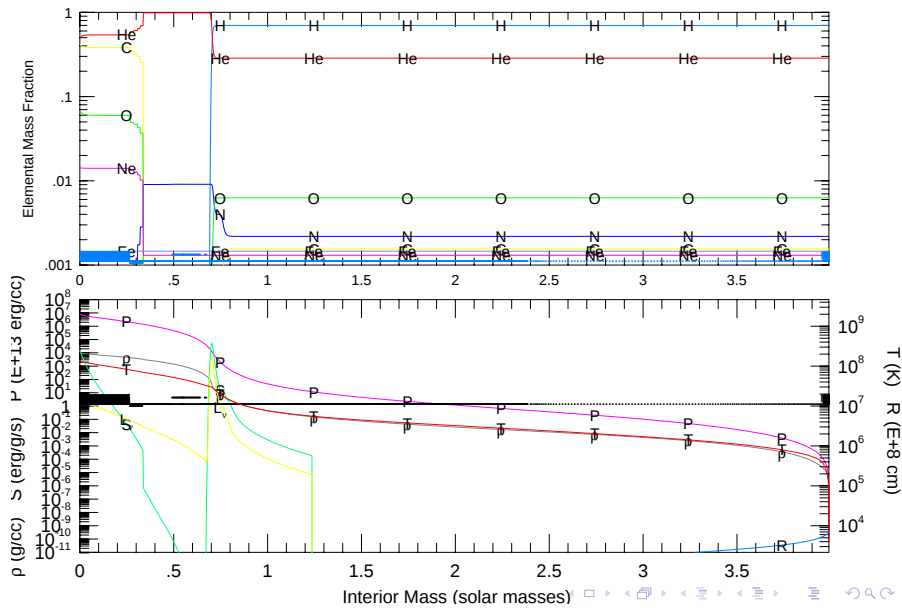
4 M_☉ Star, End of Hydrogen Burning



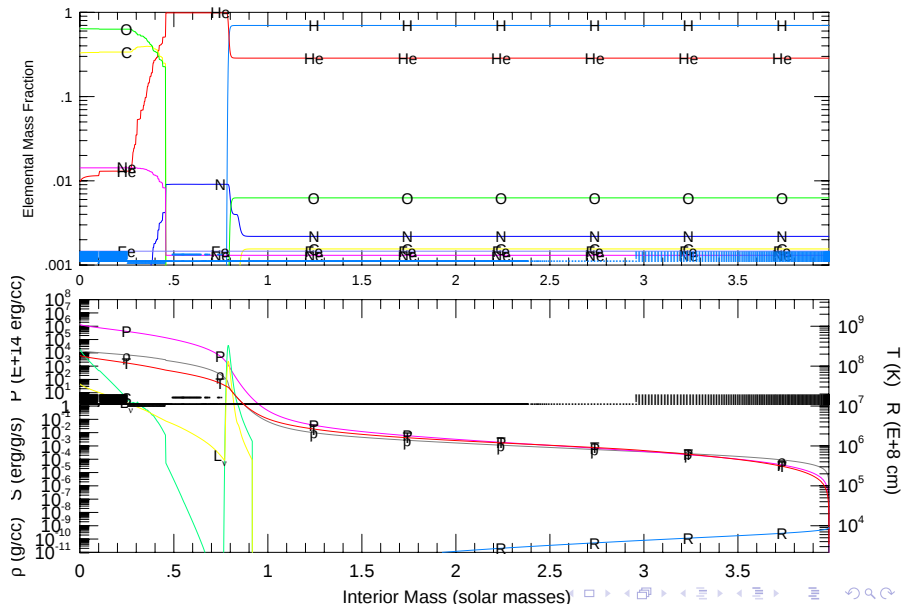
4 M_⊙ Star, Beginning of Helium Burning



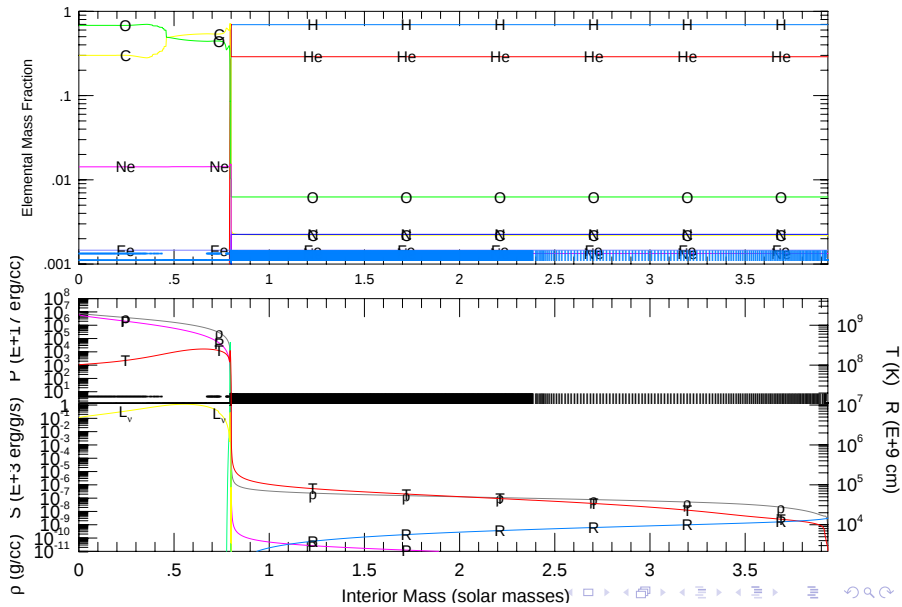
4 M_☉ Star, Middle of Helium Burning



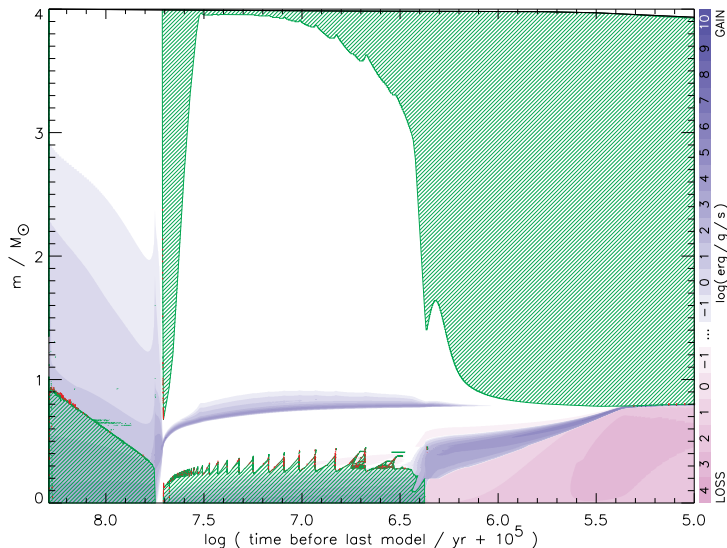
4 M_☉ Star, End of Helium Burning



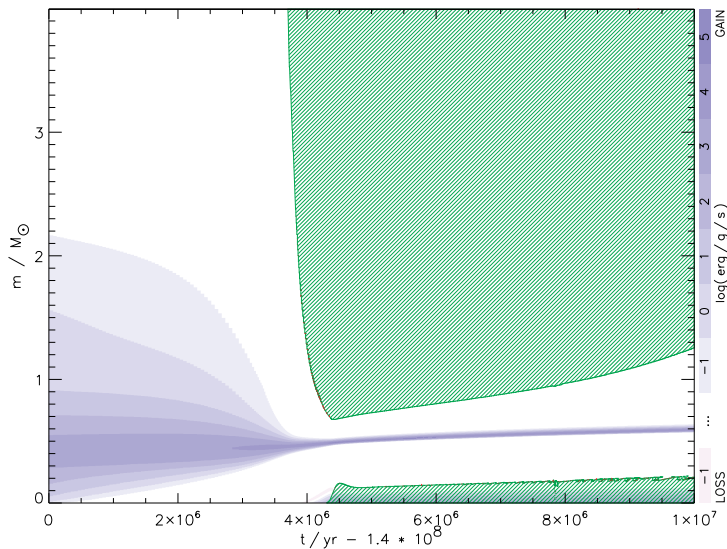
4 M_⊙ Star, Last Model Computed



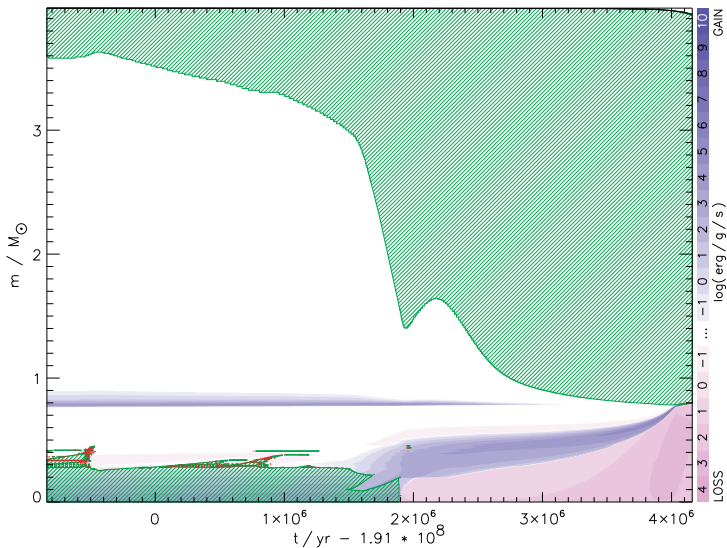
Kippenhahn Diagram, $4 M_{\odot}$ Star



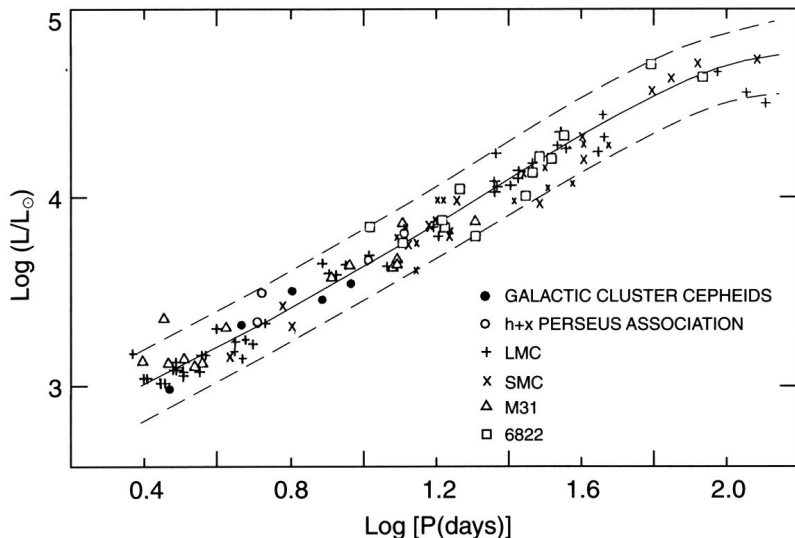
Kippenhahn Diagram, $4 M_{\odot}$ Star, He Ignition



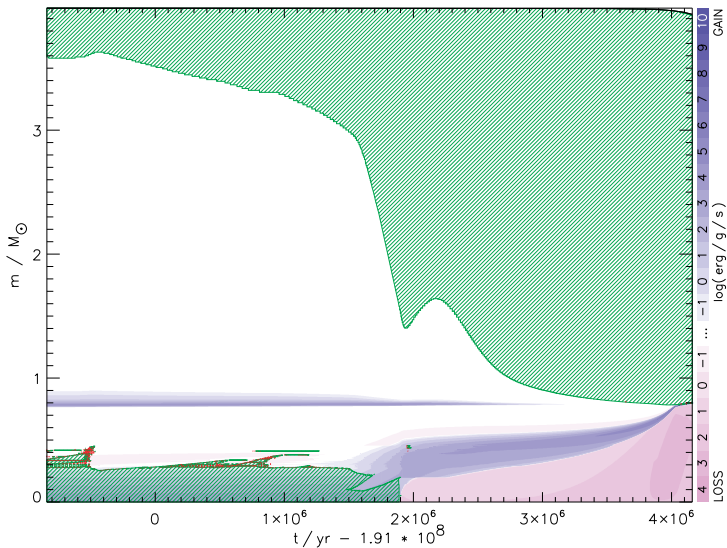
Kippenhahn Diagram, $4 M_{\odot}$ Star, He Depletion



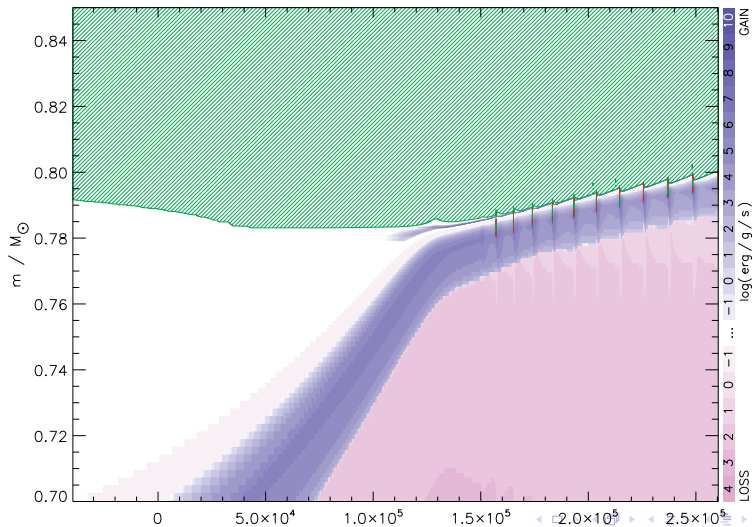
Period-Luminosity Relation for Cepheids



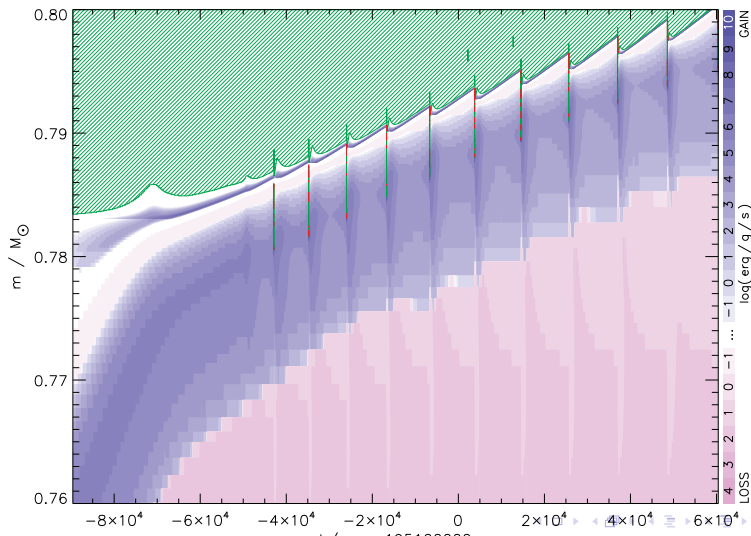
Kippenhahn Diagram, $4 M_{\odot}$ Star, He Depletion



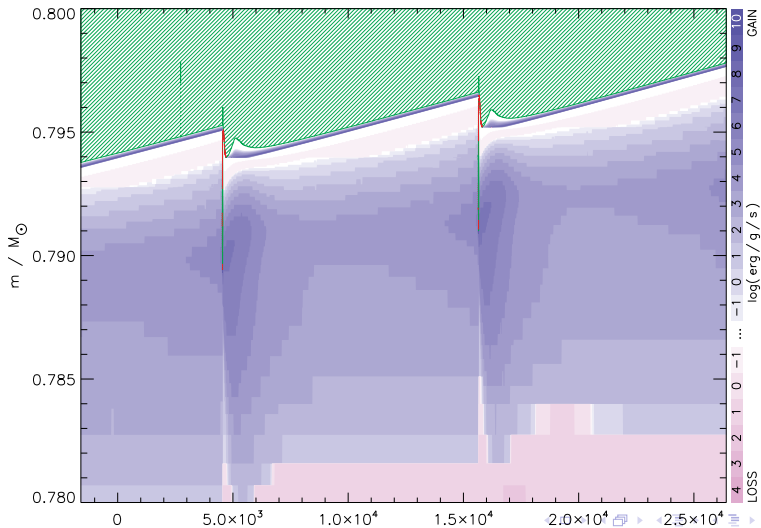
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



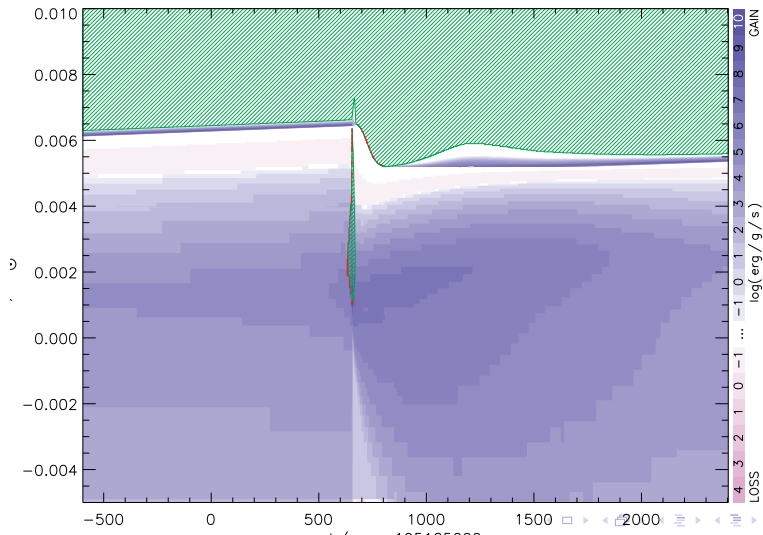
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



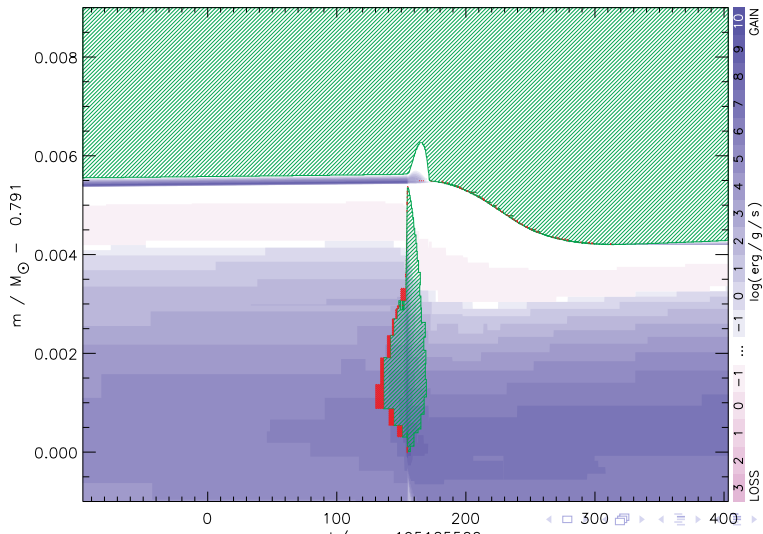
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



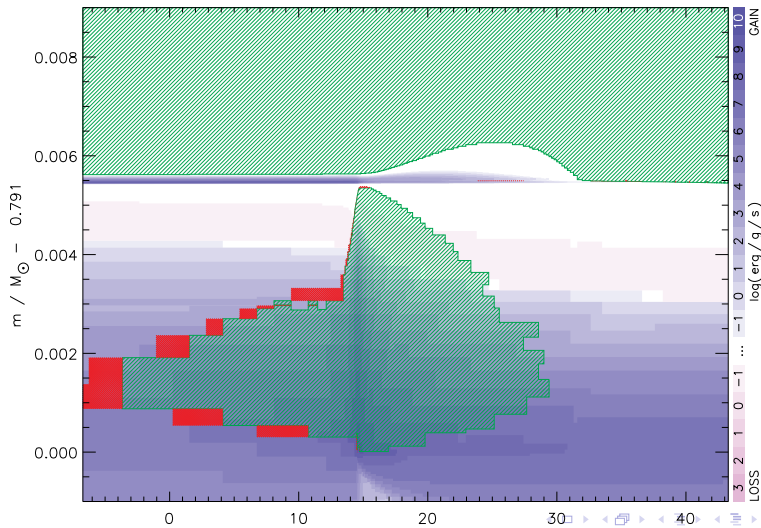
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



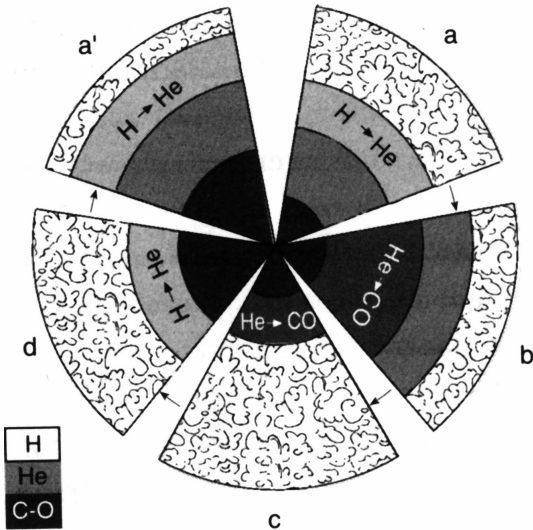
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



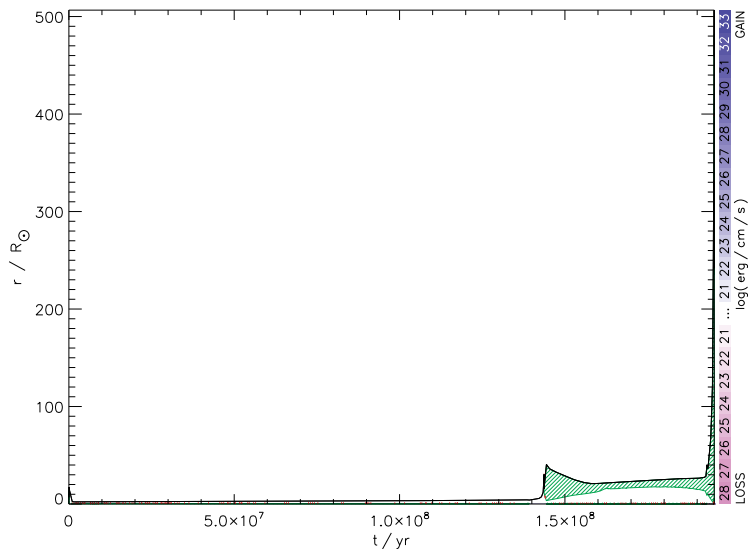
Kippenhahn Diagram, $4 M_{\odot}$ Star, Post-Core He burning



Change of Structure During AGB Cycle



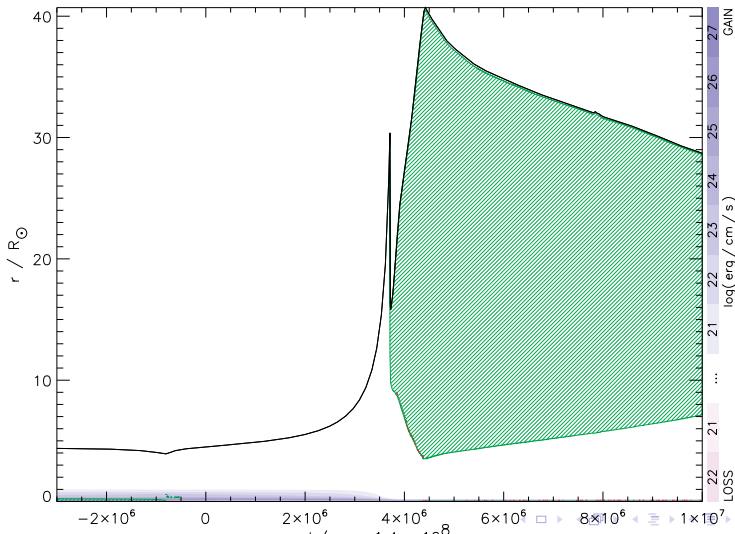
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



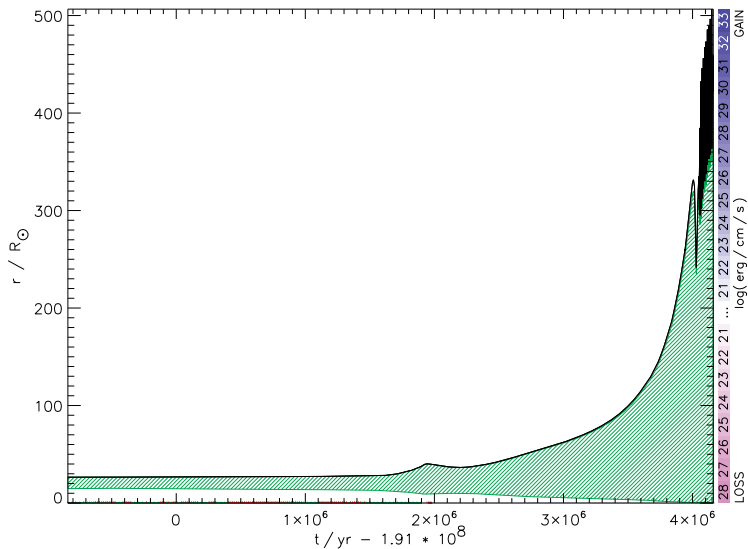
Kippenhahn-Radius Diagram, 4 M_⊙ Star



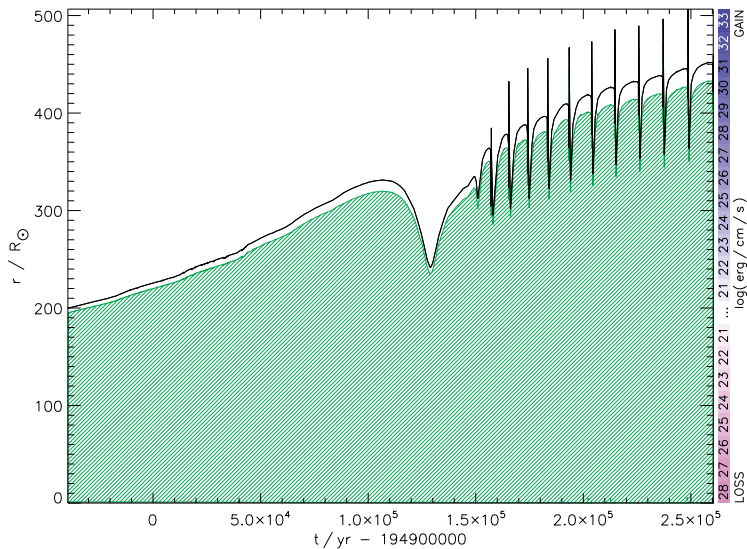
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Helium Ignition



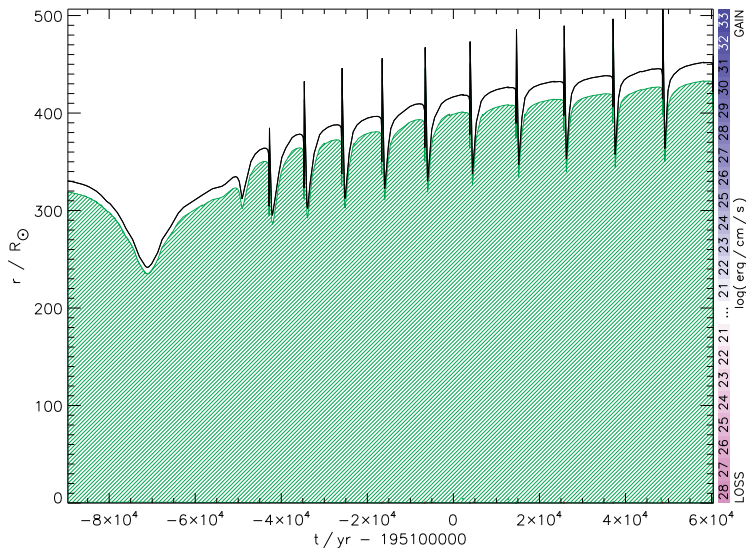
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, He Depletion



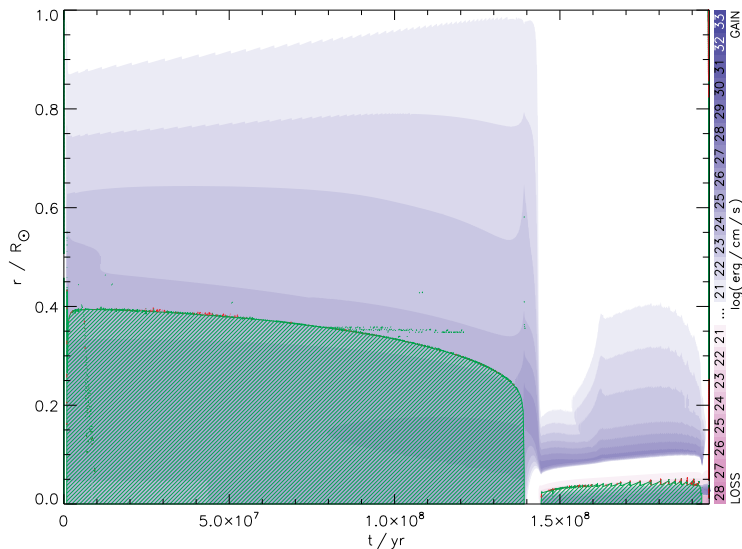
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



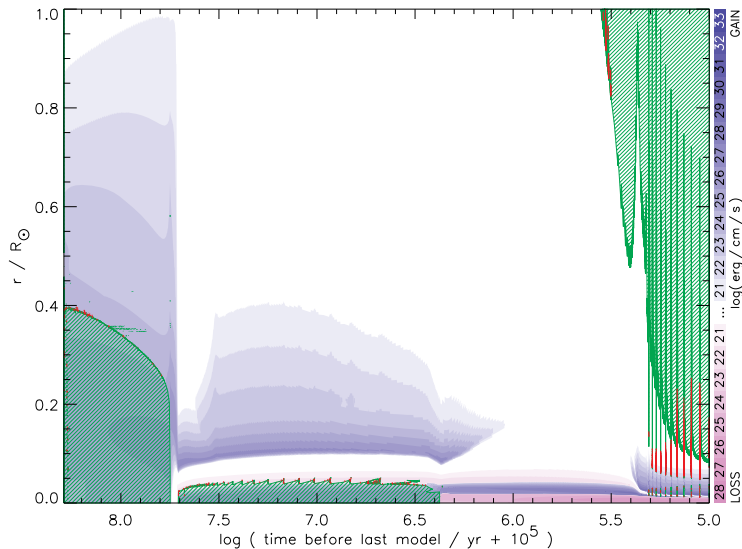
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



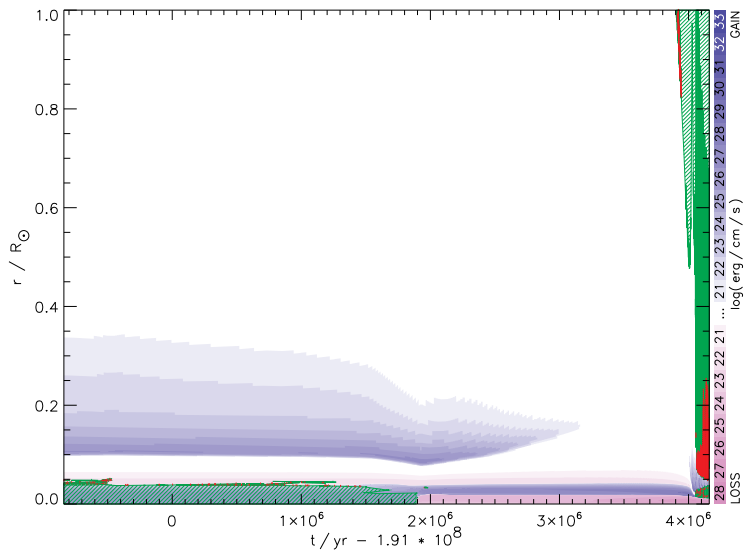
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



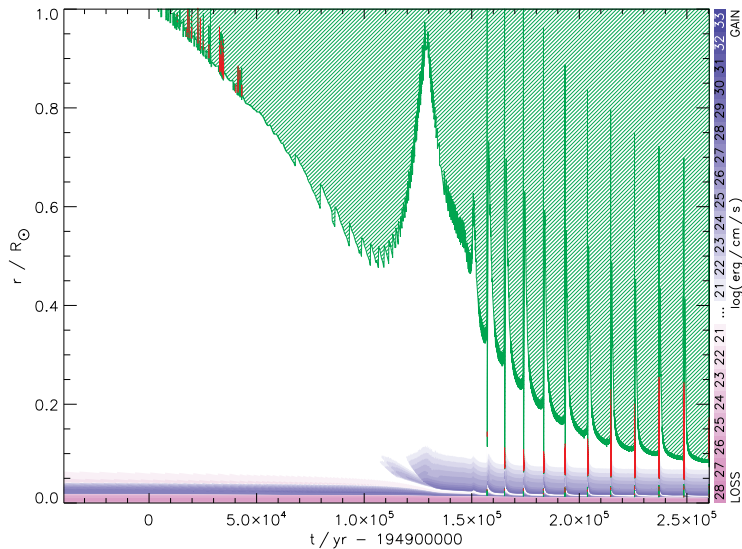
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



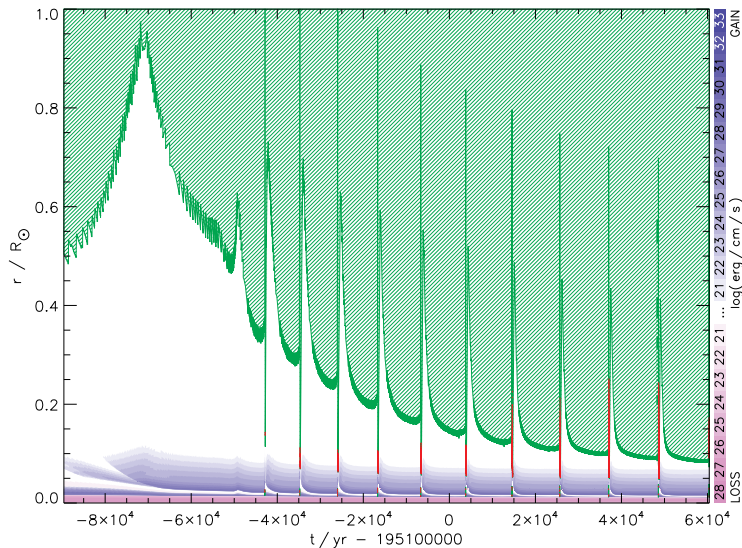
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, He Depletion



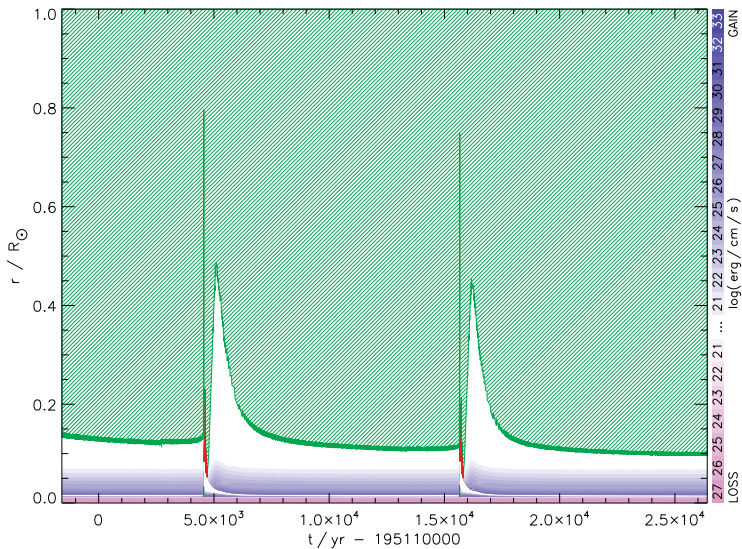
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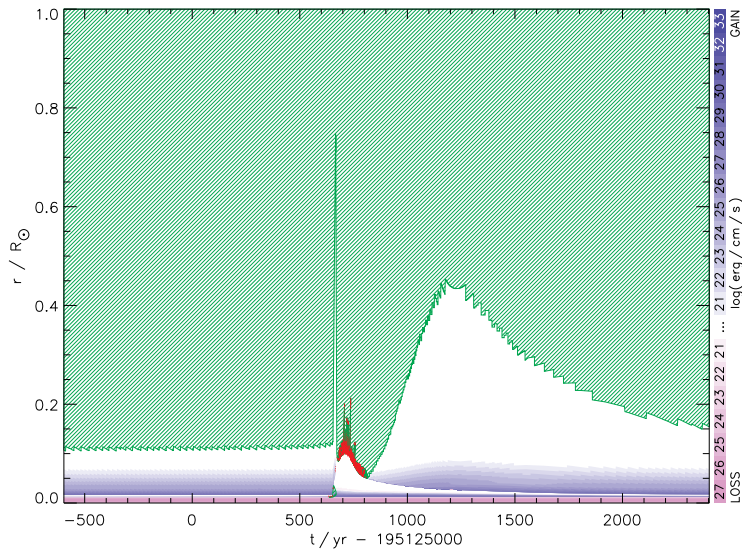
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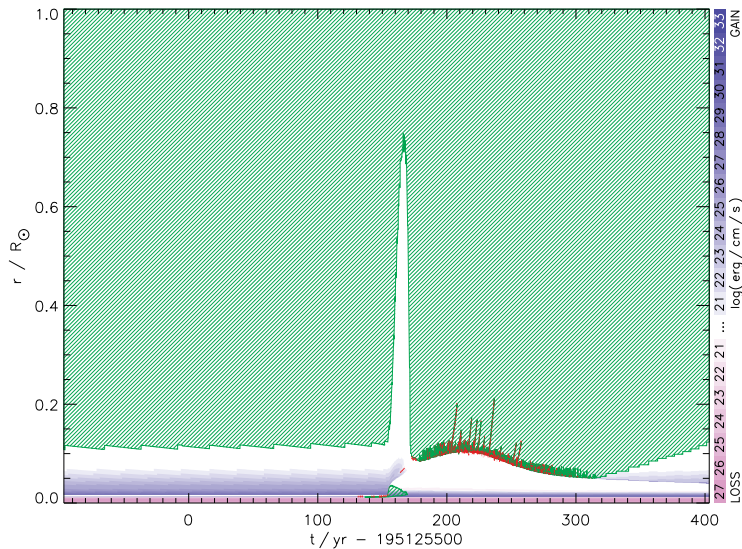
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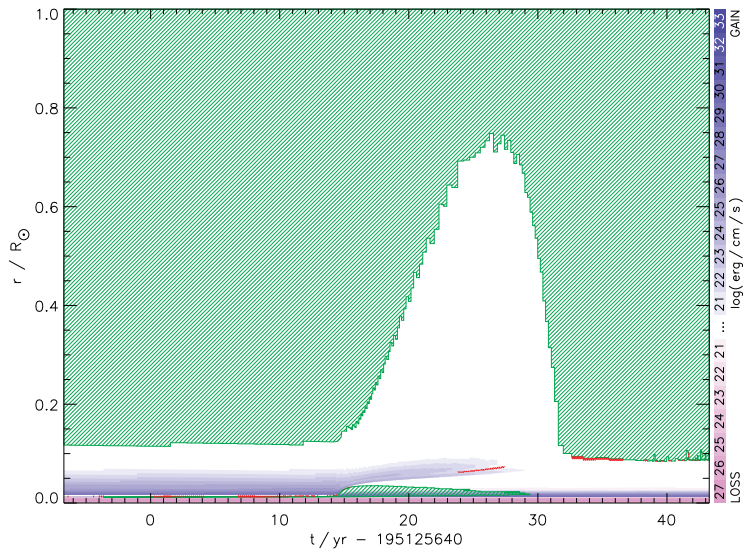
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



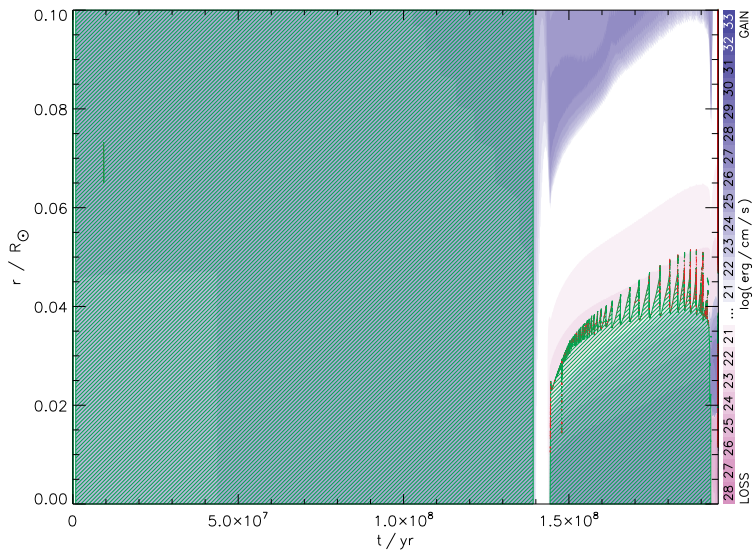
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



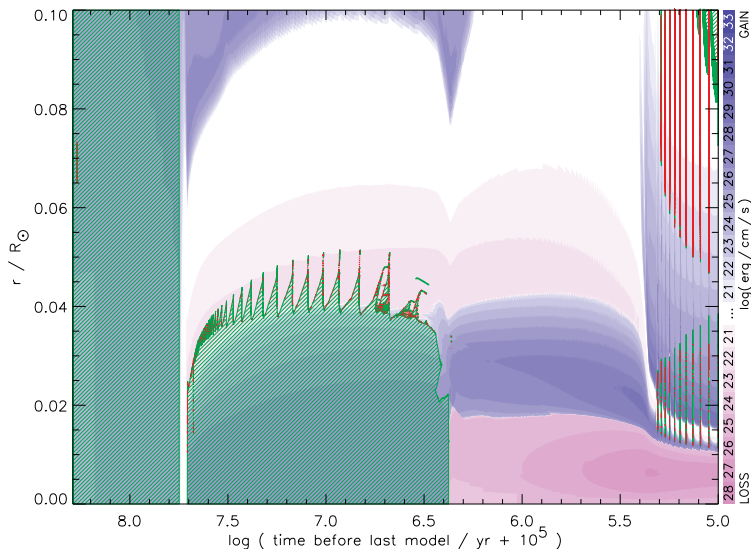
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



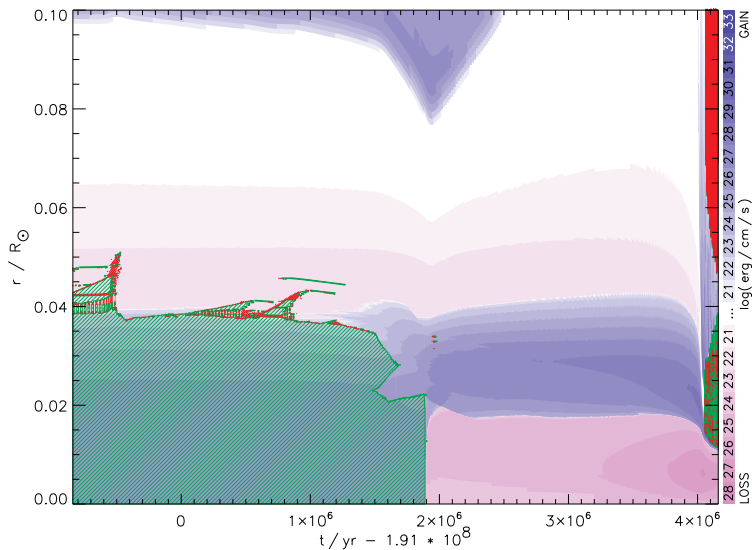
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



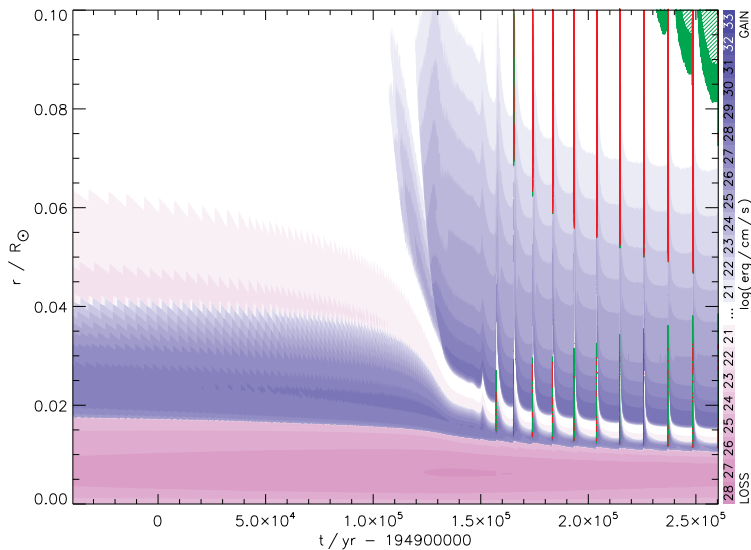
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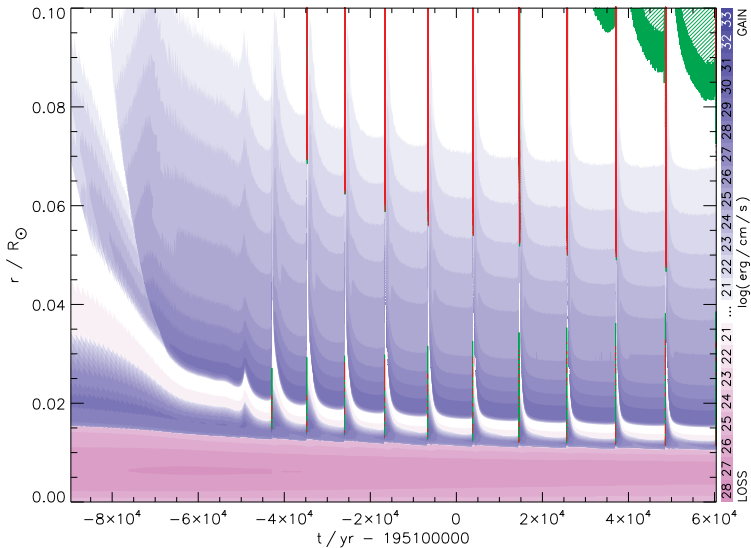
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, He Depletion



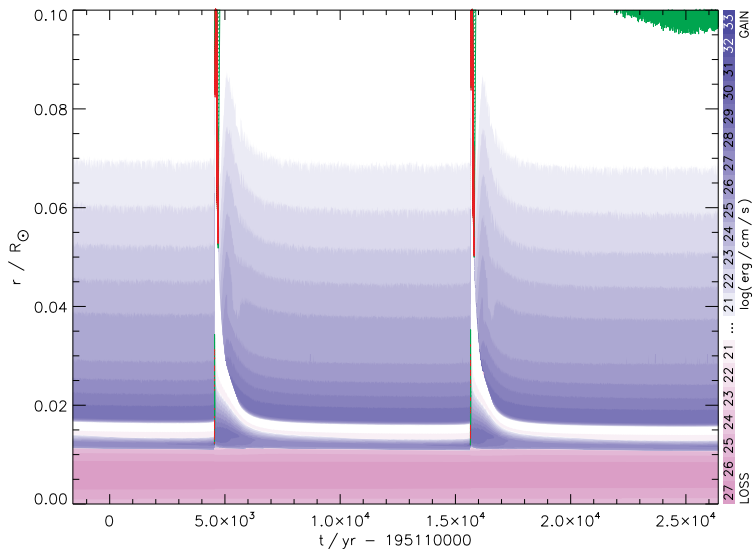
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



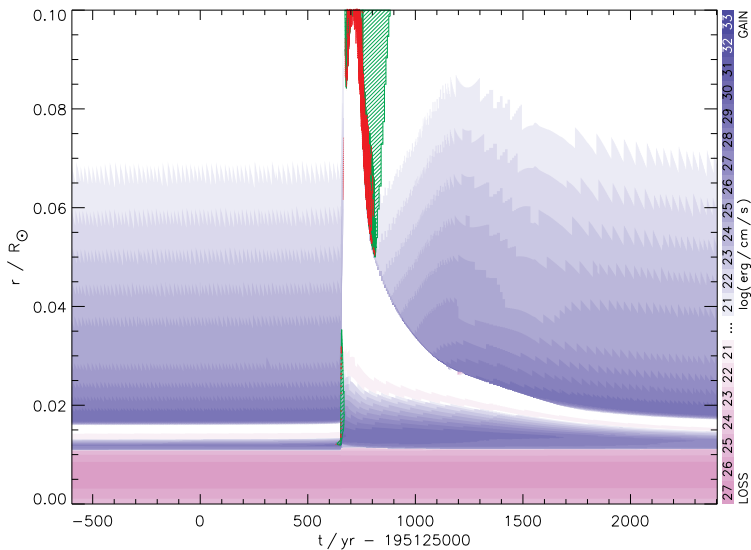
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, Start of AGB



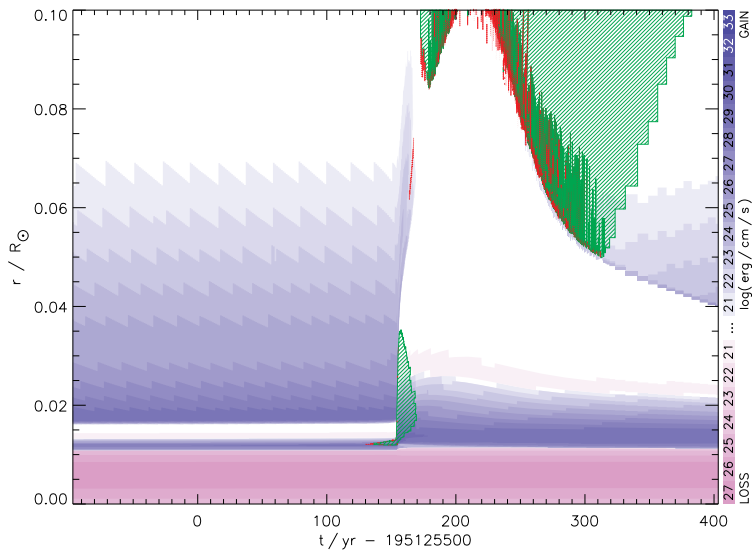
Kippenhahn-Radius Diagram, 4 M_⊙ Star, AGB Phase



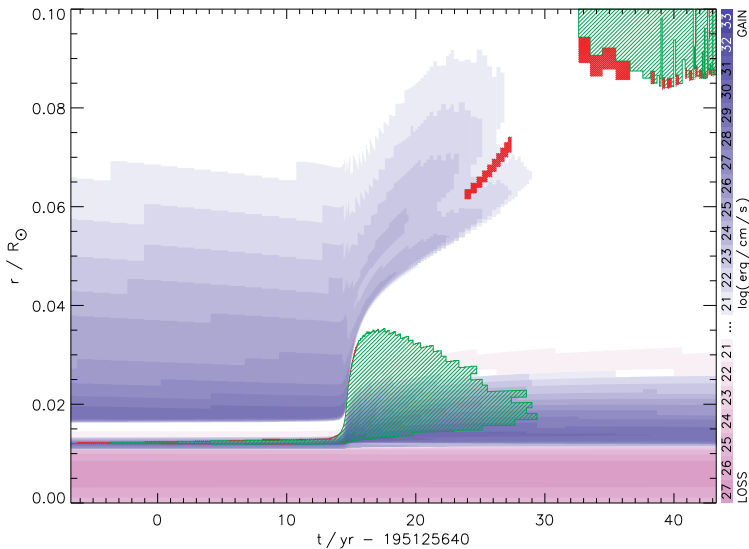
Kippenhahn-Radius Diagram, 4 M_⊙ Star, AGB Phase



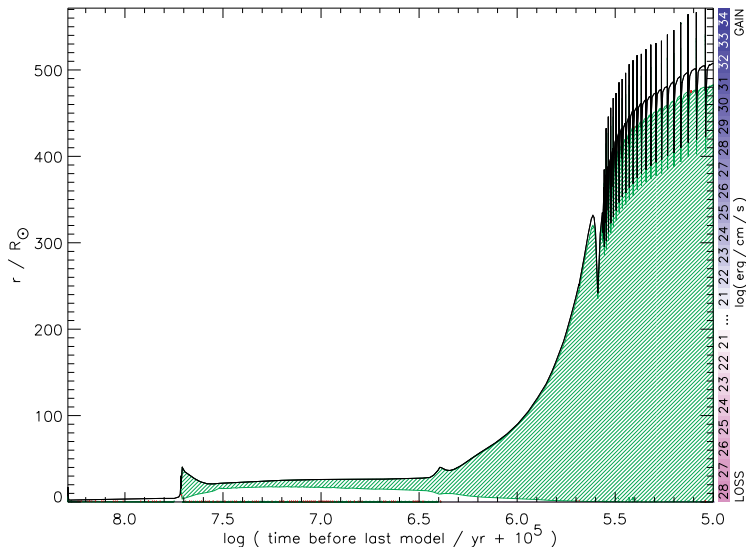
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star, AGB Phase



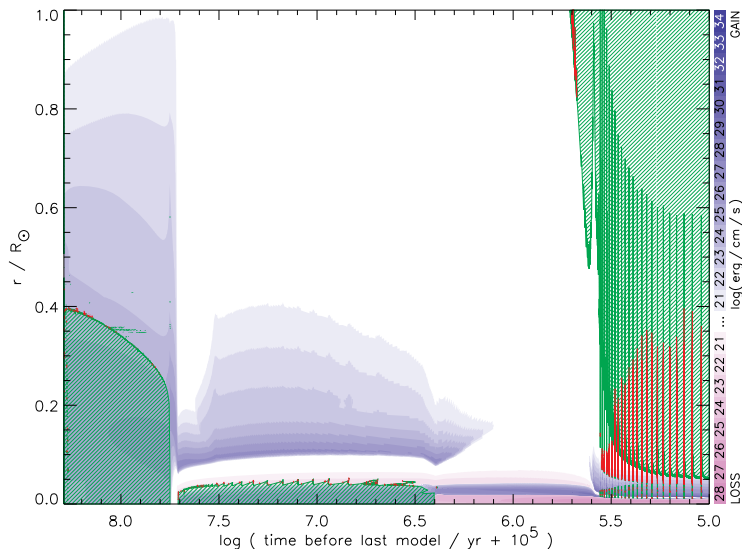
Kippenhahn-Radius Diagram, 4 $M_{\odot}$ Star, Start of AGB



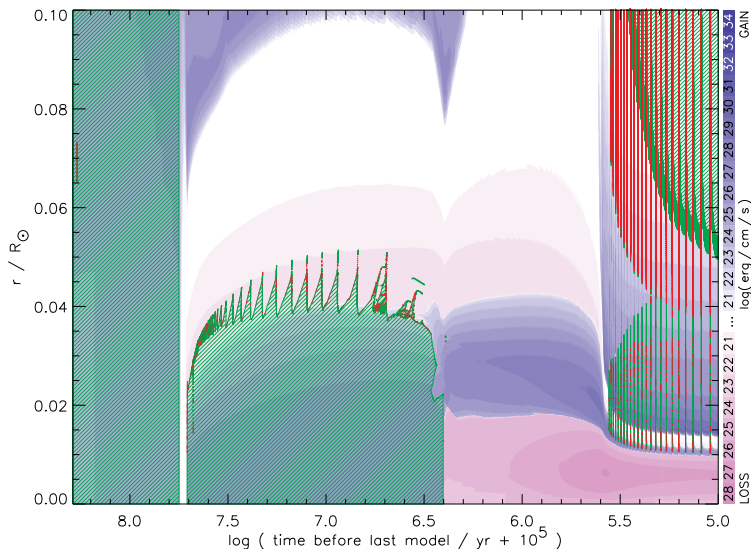
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



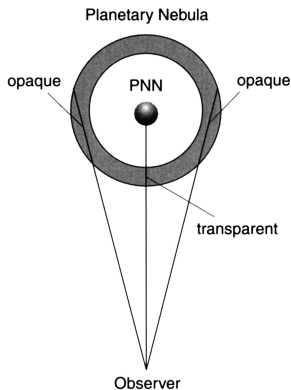
Kippenhahn-Radius Diagram, $4 M_{\odot}$ Star



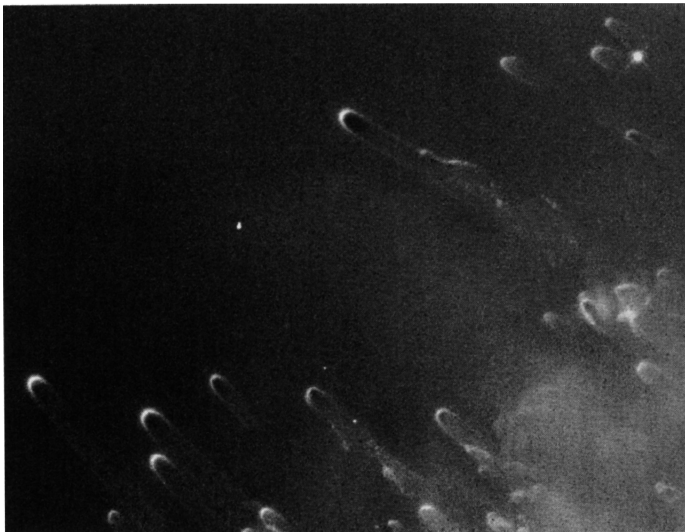
Rare Spherical Planetary Nebula Abell 39



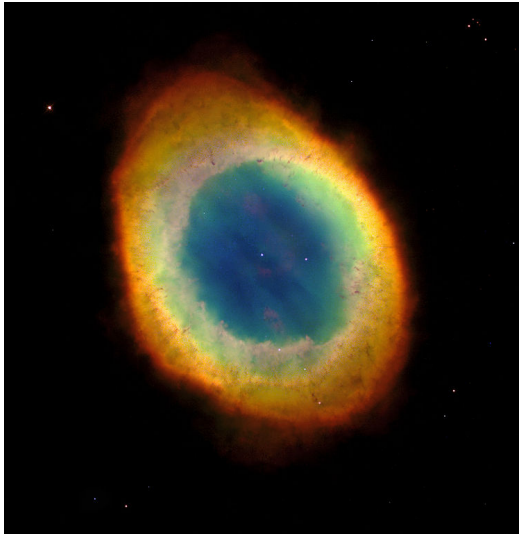
Planetary Nebula Ring



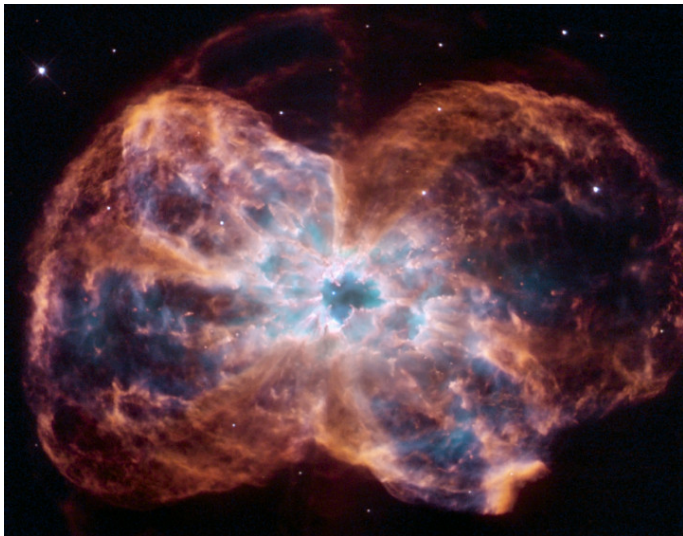
Helix Nebula Details



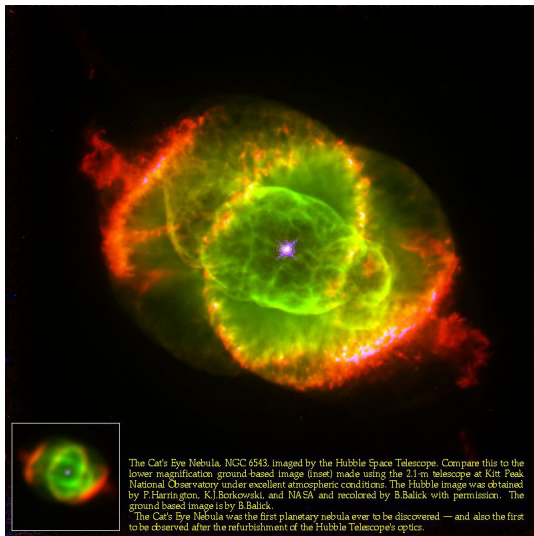
M57 The Ring Nebula



Planetary Nebula NGC 2440



NGC 6543 - "Cat's Eye"



M2-9

