Binary Star Nucleosynthesis

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Nucleosynthesis Mechanisms

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  - Evolved stars
- C-burning: $\mathrm{C} + \mathrm{C} \rightarrow \mathrm{O} + \ldots$
  - Massive stars, Ia Supernovae
- O, Ne, Mg, Si burning $\rightarrow \mathrm{Fe}$
  - Massive stars (core collapse SN)
- r and s-process: neutron capture (Co-Pb, U, Th etc.)
  - Supernovae (and neutron stars?)
  - AGB stars (and massive stars?)
  - Other sites? (Very) Open question

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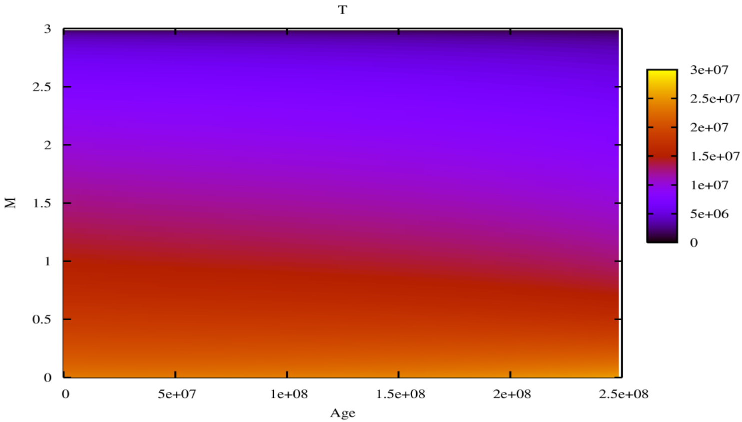
Single Star Evolution

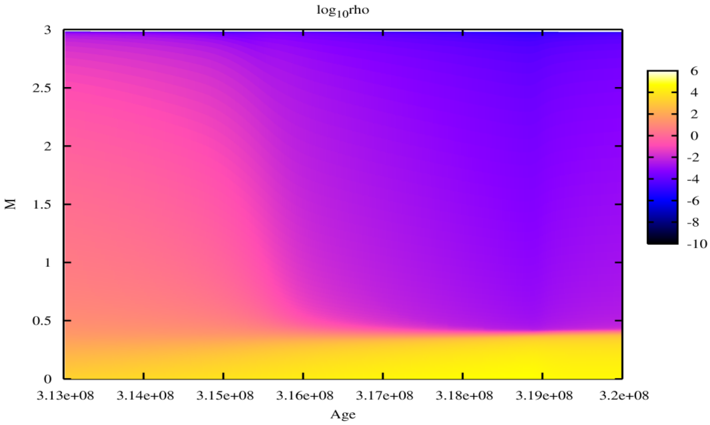
- 99+% Thermostatic H-burning (Main Sequence)



Plots made with *Window to the Stars* - see later!

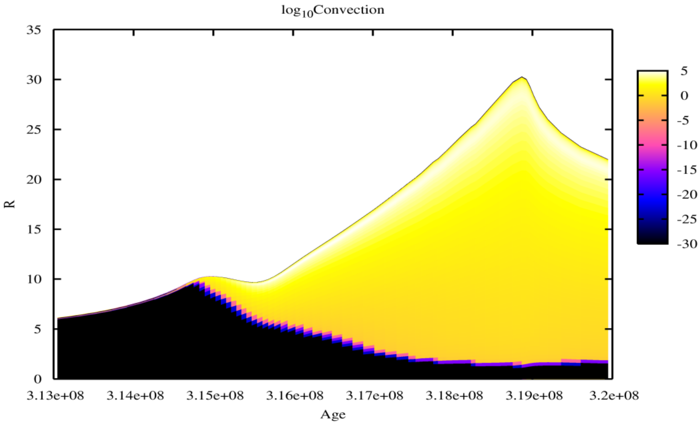
Single Star Evolution

- 99+% Thermostatic H-burning (Main Sequence)
- Core fuel used up: core compression



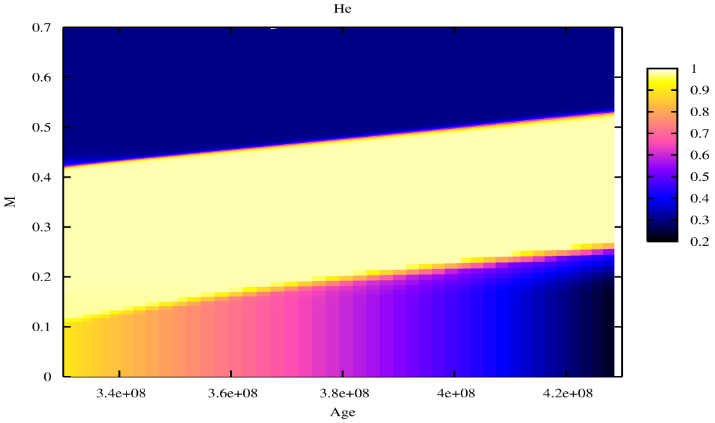
Single Star Evolution

- 99+% Thermostatic H-burning (Main Sequence)
- Shell burning: hot shell, convective envelope → giant



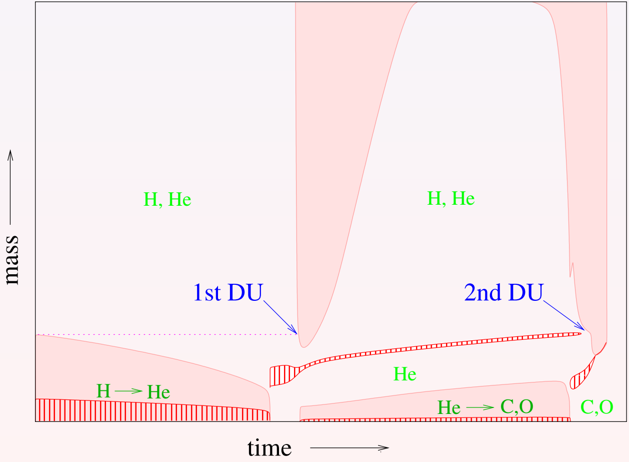
Single Star Evolution

- 99+% Thermostatic H-burning (Main Sequence)
- Burning moves to next fuel ($H \rightarrow He$, $He \rightarrow C$ etc.)



Dredge-Up

- Convection zone reaches into burnt material≡"Dredge Up"



Dredge-Up

- Convection zone reaches into burnt material≡"Dredge Up"
  - 1st: GB
  - 2nd: Early AGB
  - 3rd: Thermally Pulsing AGB (Pols, here, recently!)
- All decrease surface hydrogen
- All increase surface helium
- Other isotopes may increase or decrease

Stellar Death

- Mass loss occurs (mainly) in giant phases
- $M \lesssim 5 - 12\,\mathrm{M}_\odot$: mass loss in second giant phase (AGB) terminates evolution
- $M \gtrsim 5 - 12\,\mathrm{M}_\odot$: core burns to iron, collapse, explodes: supernova
- In all cases:
  Most of the (processed) stellar material is ejected back into the interstellar medium
- Nucleosynthesis begins again with the next generation of stars (Galactic Chemical Evolution. . .)

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Binary Star Evolution

A marriage made in heaven. . . ?

or

A prelude to divorce!

- Many stars ($> 50\%$) are binaries
- Companions increase the chance of **mass-loss** if the stars are close
- Also **mass gain**
- The situation is complex, depends delicately on initial conditions e.g. masses, composition, orbital parameters and many physical processes
- First, focus on mass loss mechanisms, then mass gain. . .

Binary mass loss

- Stellar Wind: Same as single stars but perhaps "Companion Reinforced Attrition Process" (Tout & Eggleton 1988)
- Roche-lobe overflow (Roche 1847?) : radius $>$ Roche-lobe size
- Prevents the giant phases of evolution by stripping the star of its envelope fuel
- Especially important: removes AGB phase of evolution and associated C/N/s-process production (yields fall)

RLOF

Stable

- RLOF → mass loss → star shrinks (τ_{nuc})
- Lose mass to ISM, or accrete on companion

Unstable

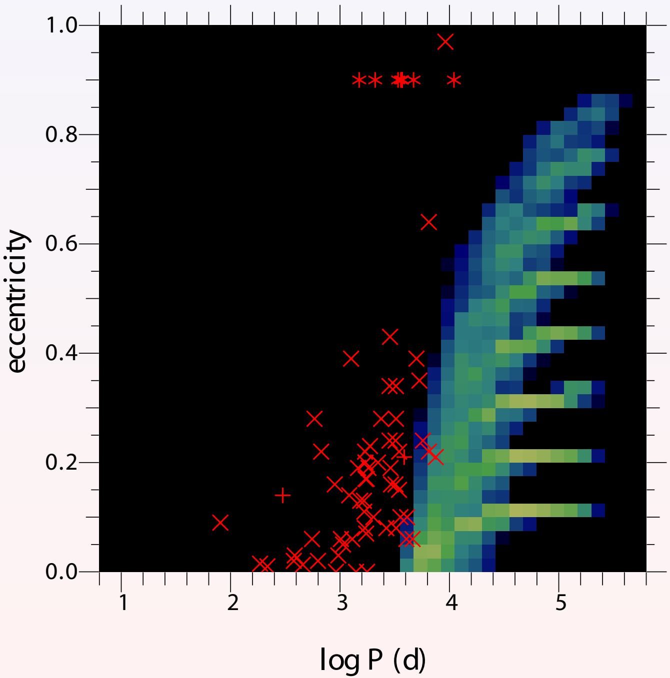
- RLOF → mass loss → star expands (τ_{dyn})
- Common envelope evolution: cores spiral in

Common Envelope Movie

- Leads to either core merger (source of new TPAGB stars?)
- Or close binary if energy sufficient to eject envelope
- Very uncertain process (ask Gijs. . .) → SNIa progenitors?

Mass gain: strange stars

- Accretion from wind, RLOF stream or both
- Mixes processed matter into companion envelope
- Leads to strange stars:
  - Carbon enhanced: CH stars, extrinsic C-stars (C dwarfs)
  - s-process enhanced: Barium stars, S-stars (maybe Tc), Pb-stars . . .
  - Low metallicity: CEMPs, $^{14}\mathrm{N}$, s-, r- and α-enhancements
  - $^{26}\mathrm{Al}$ production in massive stars?
- A challenge to us model the correct proportions and properties of these stars
- Tells us a lot about binary processes e.g. Ba-stars eccentricity problem



1.0
0.8
0.6
0.4
0.2
0.0
eccentricity
1
2
3
4
5
log P (d)

Mass gain: mix, bang!

Often a companion leads to an explosive relationship:

- If the accreting star is a CO or ONe white dwarf, accreting matter can form a hydrogen layer which explodes in a nova (^{13}C, ^{15}N and ^{17}O)
- A CO WD can accrete until $M > M_{\mathrm{Ch}}$ and explode as a SNIa (Fe, Ca, Si, O)
- An ONeWD can accrete until $M > M_{\mathrm{Ch}}$ and form a NS in an "accretion induced collapse" (r-process?)

Other important binary processes:

- NS mergers, X-ray binaries, Symbiotics etc.

Population Synthesis

- A model of a large number (e.g. 10^6) of stars to give a statistical analysis of a stellar population
- e.g. stellar number counts, SN rates, nova rate, integrated spectra etc.
- Population *Nucleosynthesis* :
  - Chemical yields (related to GCE)
  - Stars exotic surface abundances
- Useful for chemical evolution, counts of strage star types etc.
- Remember:
  - Single stars M_1, Z
  - Binaries $M_{1,2}$, Z, P, e

Rob's Rapid Nucleosynthesis Code

Stellar Evolution

- Rapid single/binary stellar evolution code of Hurley et al 2002
- Based on models calculated with Eggleton ev. code
- Very fast, models popsyn and Globular Clusters

Nucleosynthesis

- Low/int. mass based on Karakas et al 2002 detailed models (Izzard et al 2004)
- Massive (WR) stars Dray et al 2004 models
- SN, nova yields (WW95, CL04, JH98 etc.)
- Binary processes: wind accretion, RLOF, common envelope, mergers etc.

Runtime: 0.1s per system→about $10^6\,\mathrm{stars/day}$

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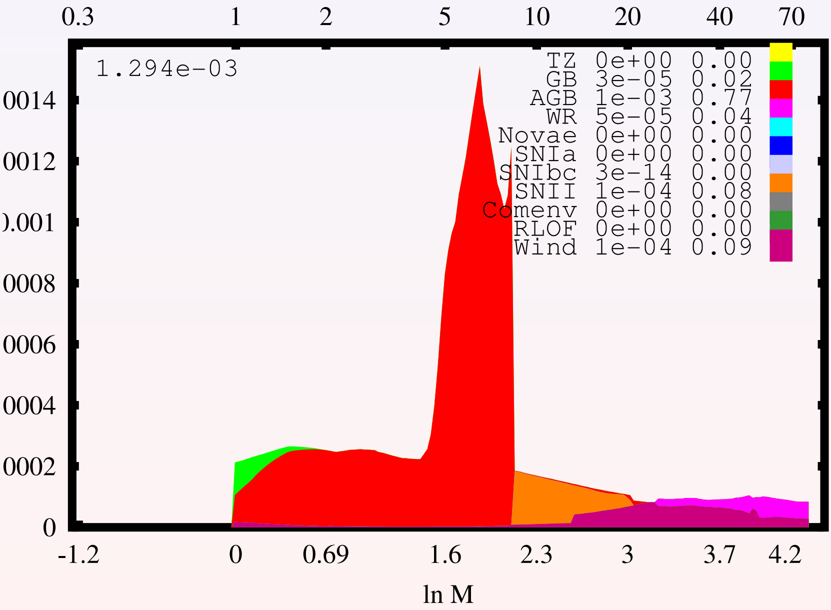
Chemical Yields

- Definition: Mass of isotope thrown into space by a population of stars
- Definition in a binary: the same
- Use

$$\frac{\text{mass ejected by stellar population}}{\text{mass into stellar population}}$$

as a much fairer number: there is more mass in binaries

Results: Single vs Binary stars ^{14}N



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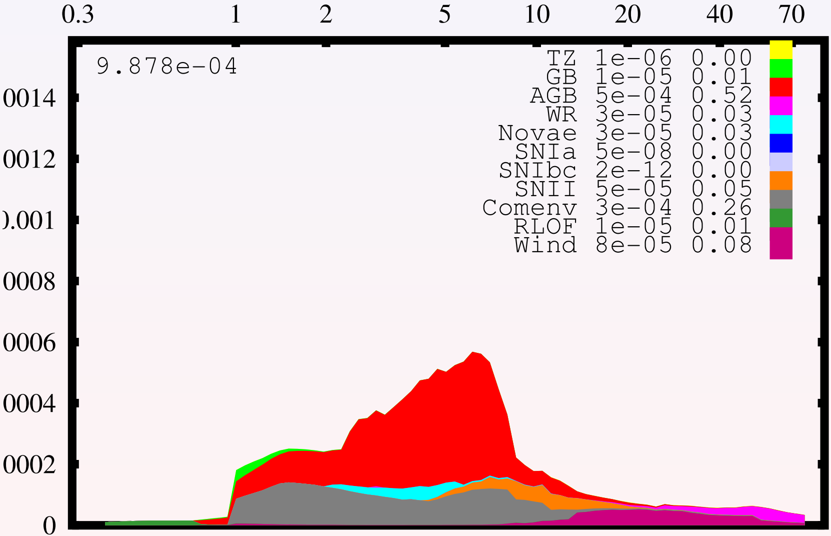


Results: Single vs Binary stars

^{12}C	$+33\%$	^{22}Ne	-21%
^{13}C	$+35\%$	^{23}Na	-21%
^{14}N	-24%	^{24}Mg	$+15\%$
^{15}N	$+73\%$	^{25}Mg	-15%
^{16}O	$+14\%$	^{26}Mg	-10%
^{17}O	$+6\%$	^{56}Fe	$+144\%$
^{20}Ne	$+0.6\%$	^{65}Cu	-12%
^{21}Ne	-4%	Ba	-19%

Results to be updated soon with the newest models.

Currently in Utrecht…

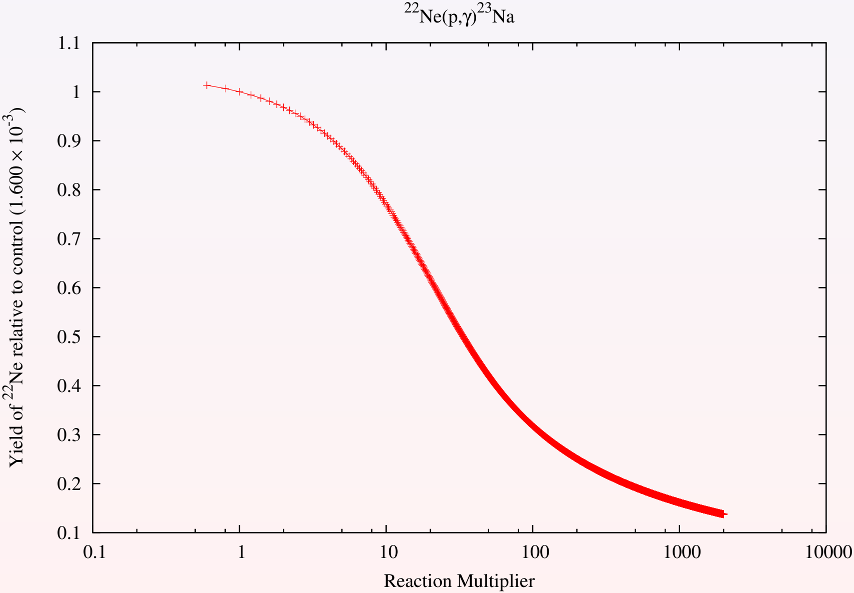
1. Improve the code
2. Reaction rates
3. Super-TPAGB stars
4. CEMPs
5. *s*-process
6. Interfaces: WWW and *TWIN*
7. Futurology

Current work: improving the code

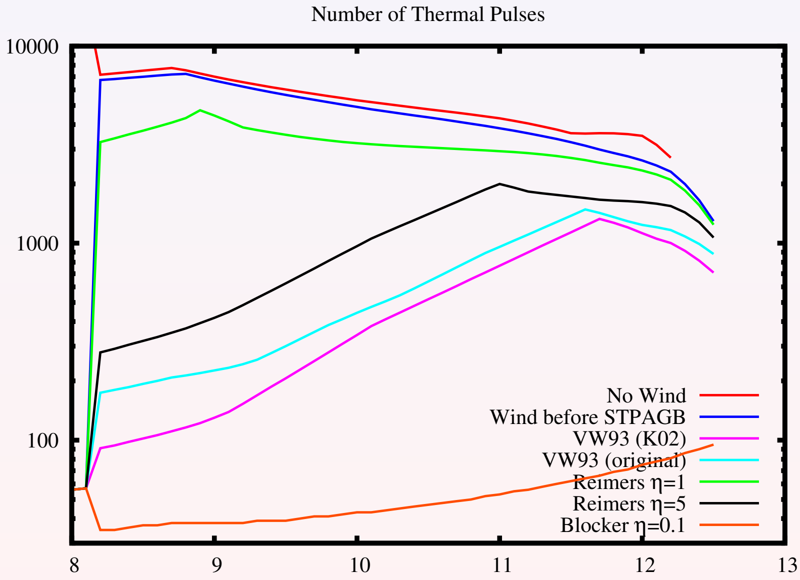
Recent updates to our code:

- Latest SN yields (CL2004, also pop III yields)
- Improved s-process data (Torino group, 400 isotopes!)
- Beowulf cluster code
- Radioactive decays of most species
- Nuclear network enhancements (NeNa, MgAl)
- Better treatment of accretion and thermohaline mixing
- Direct coupling to GCE code, variable Z, SFR, inflows, outflows etc.
- Super-AGB stars
- Overshooting AGB stars (Axel Bonačić)
- Build and run on iPod

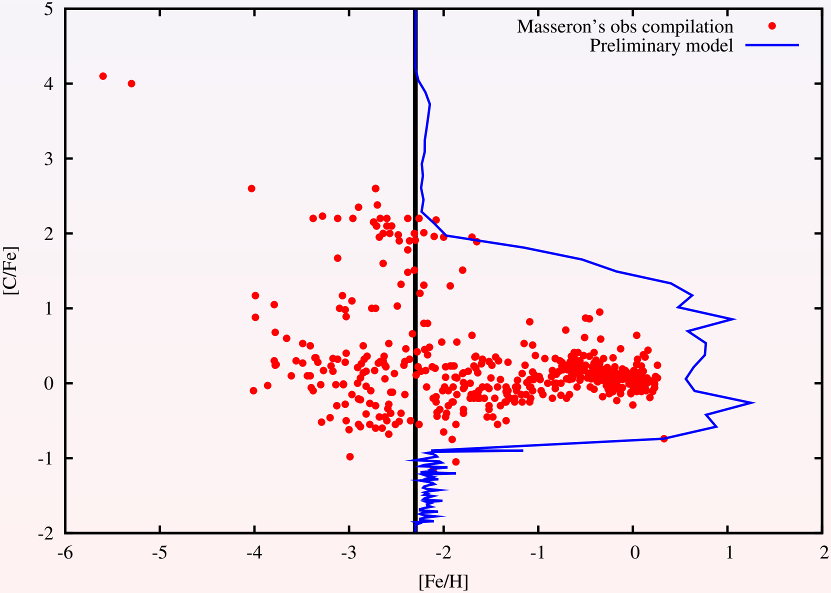
Current work: reaction rates (with Maria Lugaro)



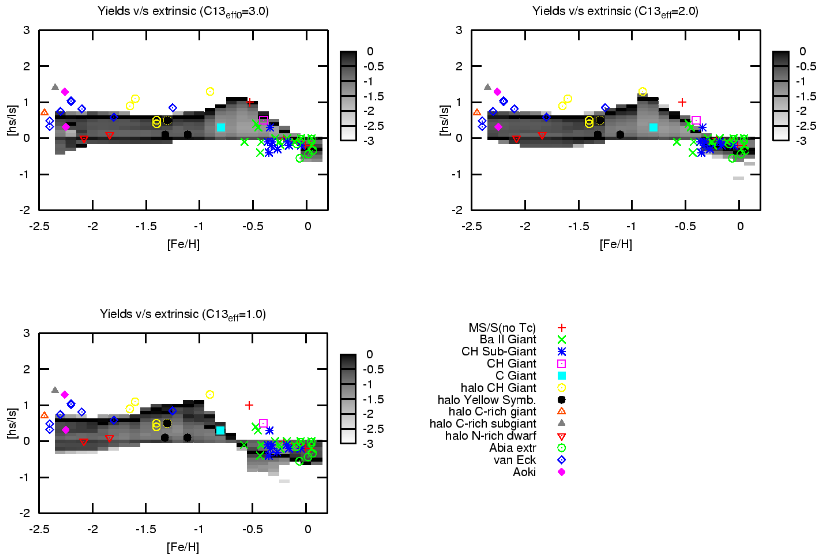
Current work: STPAGBs (with Arend-Jan Poelarends)



Current work: CEMPs (with Onno Pols)



Current work: *s*-process (with Axel Bonačić)



Current work: interfaces: WWW

See *www.ciqua.org*

Stellardb

- Online stellar abundance database
- Advanced presentation and data-mining tools
- User login, submit your own data! (please)
- See Ödman & Izzard (2004)

Binary nucleosynthesis

- Evolve binaries on the web
- Gives evolutionary history: period, Roche lobe image etc.
- Calculates nucleosynthetic yields for most isotopes

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Current work: interfaces: *TWIN*

Modernising the code

- Work with Evert Glebbeek to improve the *TWIN* code
- e.g. low-Z evolution, detailed binary evolution

Window To The Stars

- From unreadable lists of numbers to...
- A Perl/GTK2 front end!
- Evolve stars
- Analyse results
- HR & Kippenhahn diagrams: paper-standard figures

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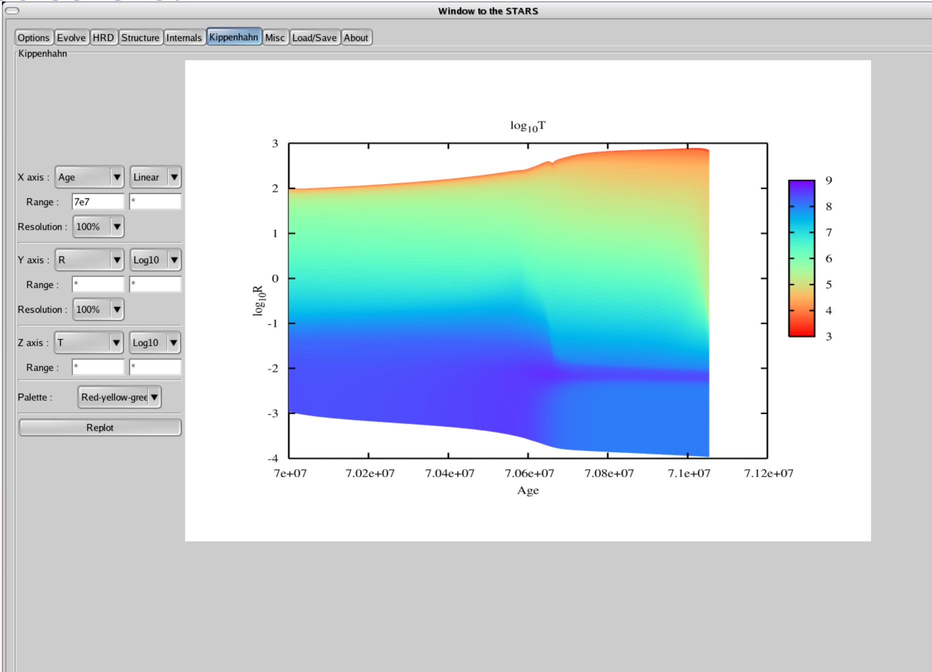
Screenshot



Window to the STARS
Options
Evolve
HRD
Structure
Internals
Kippenhahn
Misc
Load/Save
About
Kippenhahn
X axis :
Age
Linear
Range :
7e7
*
Resolution :
100%
Y axis :
R
Log10
Range :
*
*
Resolution :
100%
Z axis :
T
Log10
Range :
*
*
Palette :
Red-yellow-gree
Replot
log10T
log10R
Age
7e+07
7.02e+07
7.04e+07
7.06e+07
7.08e+07
7.1e+07
7.12e+07
3
2
1
0
-1
-2
-3
-4
9
8
7
6
5
4
3

Future plans

- Population synthesis of CEMPs, esp. N problem
- Improve GCE model, esp. for local group dwarfs
- Cosmological number counts (whose idea was this?)
- Reaction rate uncertainties at $Z = 10^{-4}$ (GC connection): NIC
- Improve STPAGB star models
- More work with the TWIN code ("proper" binary models)

Future plans

- Dinner