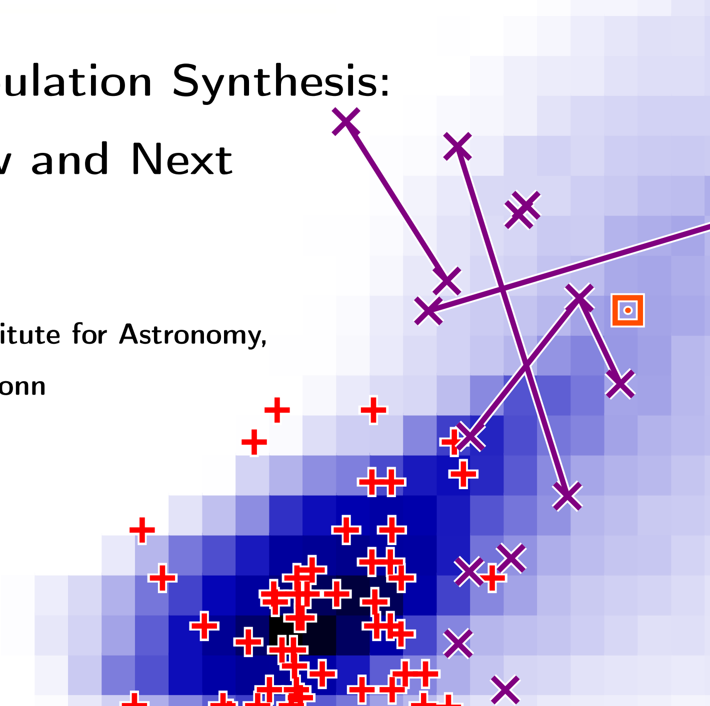
# Binary Population Synthesis: Now and Next



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1. Why population synthesis?

   ***QUANTITATIVE, STATISTICAL***

   See Selma's talk for examples.

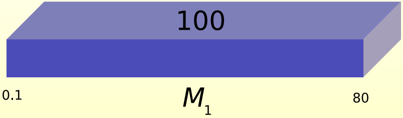
2. Why not use a detailed stellar code to solve everything?

3. What do we have now? ***binary_c/nucsyn***

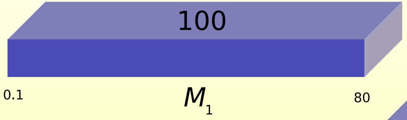
4. What do we need in the (near) future?

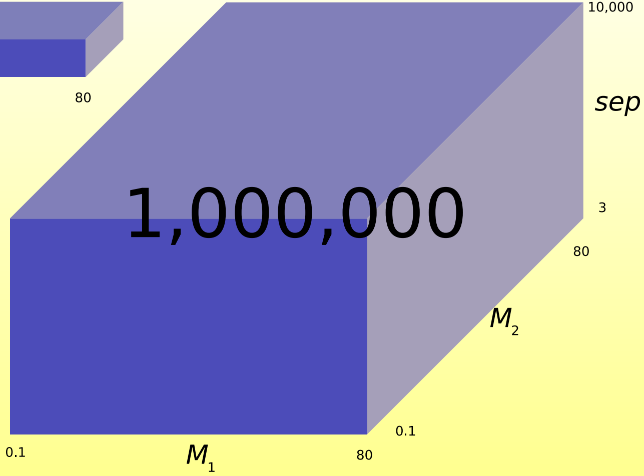
5. What are we doing about it?

# Why not use a detailed code?

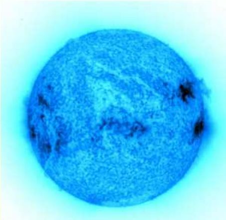
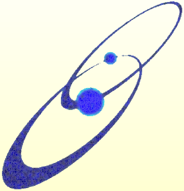


# Why not use a detailed code?



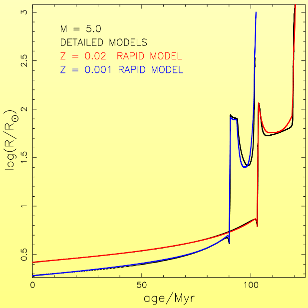



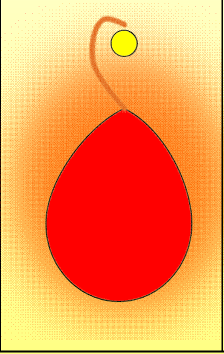
# Parameter Spaces

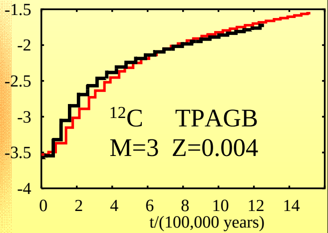
| |  $M$, $Z$, $v_{\mathrm{rot}}$ |  $M_1$, $M_2$, $Z$, $v_{\mathrm{rot}}$ $a/P$, $e$, $J_{\mathrm{orb}}$ |
|---|---|---|
| Mixing | $\sigma_{\mathrm{conv}}, \sigma_{\mathrm{thermoh}}, \sigma_{\mathrm{rot}}$ | $\sigma_{\mathrm{conv}}, \sigma_{\mathrm{thermoh}}, \sigma_{\mathrm{rot}}, \sigma_{\mathrm{tides}}$ |
| Nucleo | $\langle \sigma v \rangle$ | $\langle \sigma v \rangle$ |
| ΔMass | $\dot{M}_{\mathrm{wind}}, v_{\mathrm{kick}}$ | $\dot{M}_{\mathrm{wind}}, \dot{M}_{\mathrm{tides}}, v_{\mathrm{kick}}$ $\dot{M}_{\mathrm{RLOF}}, \alpha_{\mathrm{CE}}, \lambda_{\mathrm{CE}}$ $\dot{M}_{\mathrm{wind-acc}}$ |
| $B$ & Δangmom | $B$, $(\sigma_B)$, $\dot{J}_{\mathrm{wind}}, \dot{J}_{\mathrm{B}}$ | $B$, $(\sigma_B)$, $\dot{J}_{\mathrm{wind}}, \dot{J}_{\mathrm{B}}$, $\dot{J}_{\mathrm{tides}}$ , $\dot{J}_{\mathrm{RLOF}}, \dot{J}_{\mathrm{wind-acc}}$ |
| | +selection effects | +selection effects |

# Binary_c/nucsyn code

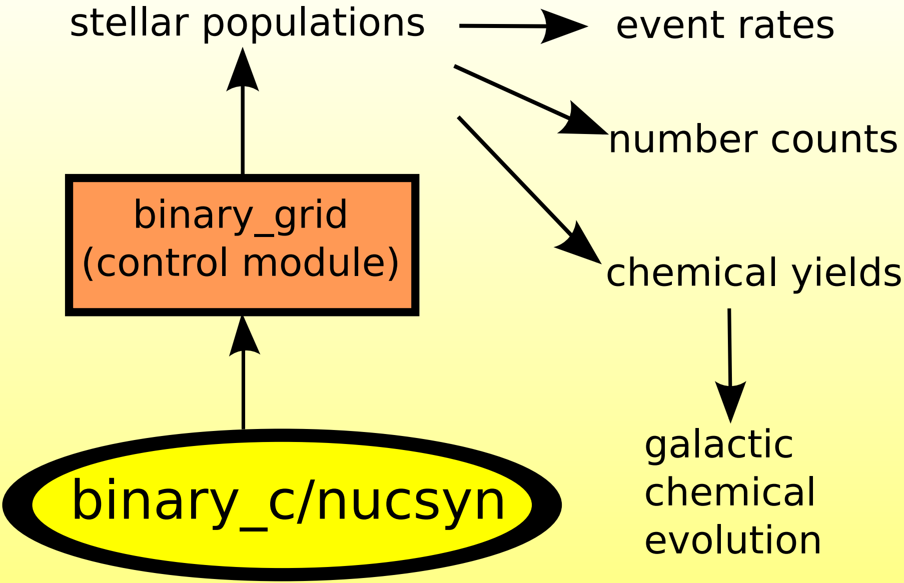
| stellar evolution | binary algorithm | nucleosynthesis |
|---|---|---|
| Fit $L, R, M_c$ as $f(M, Z)$<br>Mass loss | Wind acc<br>RLOF<br>Tides | Dredge ups<br>HBB<br>Massive stripping<br>Supernovae<br>Thermohaline |



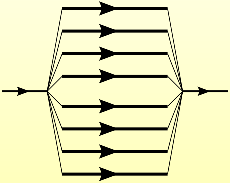


**framework: stellar grid**



# Recent updates: RLOF, grid, documentation

- Physics: Improved "Adaptive RLOF", interesting results:
  See Selma's talk
- Software: Updates to improve grid:
  Parallel threads
  More efficient grid algorithm



- Documentation:
  ***binary_c/nucsyn*** already documented
  ***binary_grid*** now fully documented
  ***Essential!***
- Code Setup (soon)
  Subversion
  Mailing lists
  Growing user base

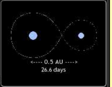
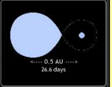
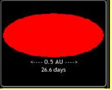
SUBVERSION

# Online resources

http://www.astro.uni-bonn.de/~izzard/binary_c.html

## binary_c/nucsyn results

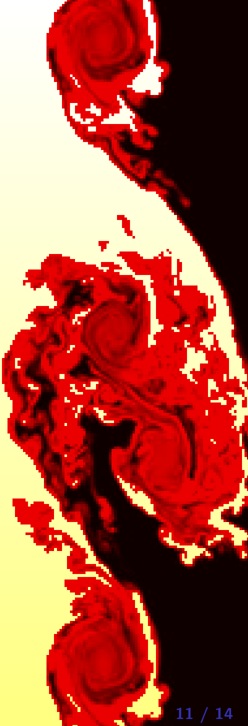
A frontend to the binary_c/nucsyn code

| Evolution Time (MYr) | Star 1 mass ($M_\odot$) | Star 2 mass ($M_\odot$) | Star 1 type | Star 2 type | Separation ($R_\odot$) | Period | Eccentricity | Star 1 R/ROL | Star 2 R/ROL | What's happening? | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0000 | 14.000 | 6.000 | Main Sequence | Main Sequence | 100.000 | 25.92 | 0.00 | 0.106 | 0.095 | In the beginning there was a star... | $^{1}H$ 7.00e-01 7.00e-01<br>$^{4}He$ 2.80e-01 2.80e-01<br>$^{12}C$ 3.19e-03 3.19e-03<br>$^{14}N$ 1.16e-03 1.16e-03<br>$^{16}O$ 1.01e-02 1.01e-02<br>$^{56}Fe$ 1.23e-03 1.23e-03<br>Ba 1.64e-08 1.64e-08 |  |
| 14.0936 | 13.718 | 6.002 | Hertzsprung Gap | Main Sequence | 101.340 | 26.63 | 0.00 | 0.256 | 0.103 | Stellar Type Change | $^{1}H$ 7.00e-01 7.00e-01<br>$^{4}He$ 2.80e-01 2.80e-01<br>$^{12}C$ 3.19e-03 3.19e-03<br>$^{14}N$ 1.16e-03 1.16e-03<br>$^{16}O$ 1.01e-02 1.01e-02<br>$^{56}Fe$ 1.23e-03 1.23e-03<br>Ba 1.64e-08 1.64e-08 |  |
| 14.1165 | 13.715 | 6.003 | Hertzsprung Gap | Main Sequence | 101.384 | 26.64 | 0.00 | 1.000 | 0.103 | Begin Roche Lobe Overflow | $^{1}H$ 7.00e-01 7.00e-01<br>$^{4}He$ 2.80e-01 2.80e-01<br>$^{12}C$ 3.19e-03 3.19e-03<br>$^{14}N$ 1.16e-03 1.16e-03<br>$^{16}O$ 1.01e-02 1.01e-02<br>$^{56}Fe$ 1.23e-03 1.23e-03<br>Ba 1.64e-08 1.64e-08 |  |
| 14.1165 | 13.715 | 6.003 | Hertzsprung Gap | Main Sequence | 101.384 | 26.64 | 0.00 | 1.000 | 0.103 | Common Envelope Evolution in | $^{1}H$ 7.00e-01 7.00e-01<br>$^{4}He$ 2.80e-01 2.80e-01<br>$^{12}C$ 3.19e-03 3.19e-03<br>$^{14}N$ 1.16e-03 1.16e-03<br>$^{16}O$ 1.01e-02 1.01e-02<br>$^{56}Fe$ 1.23e-03 1.23e-03<br>Ba 1.64e-08 1.64e-08 |  |

# Limitations

Fitting formula approach:

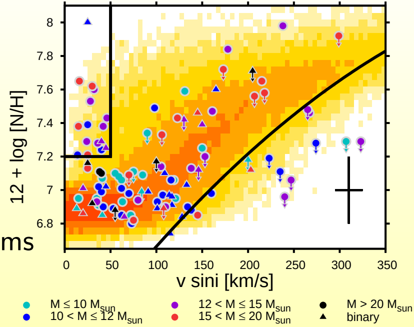
- STABLE and FAST ... but limited.
- Only have fits to $M$ and $Z$.
- $0.1 \leq M \lesssim 50\,\mathrm{M}_\odot$, $10^{-4} \leq Z \leq 0.03$
- No (reliable) chemistry *in massive stars*
- Cannot explore many ***big*** uncertainties e.g.
    - Mixing: $\sigma_{\mathrm{rot}}$, $\sigma_{\mathrm{thermo}}$ etc.
    - Nucleosynthesis and mixing
    - $B$ field production, destruction
    - Angular momentum distribution
- New observations drive modelling efforts



# Scientific rationale:

## *Do we need a new code?*

If we want to




1. Reproduce "Hunter" plots
2. Constrain strength of mixing mechanisms
3. Model { chemistry / mixing / angular momentum } in *populations* of massive binaries
4. Extend to problems beyond main-sequence O/B-type stars (LBV, WR, NSs, BHs, X-ray binaries, GRBs etc. etc....)

Then ***YES*** we do.

...lots of helper software already exists.

(And not limited to *massive* binaries)

# Technical Challenges

Can it be done? ... Must stay FAST but must do MORE.

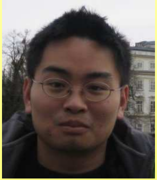
## *binary_c runtime* $\sim 0.1\,\mathrm{s}$


Speed up:

- cluster/multi-core machines
- GPUs?
- Better algorithm:
  - Separate mixing and stellar evolution

Slow down:

- Model conv/thermohaline/rotational mixing *shell by shell*
- Stellar evolution tables: large data sets
  - Computer science problem?
- Time & smart people to develop algorithms:
  - First step: **Herbert Lau** arrives 2011 →
  - Bonn group has detailed (binary) models



# Conclude


- We have a tool, ***binary_c/nucsyn***, to make progress ***now***
- http://www.astro.uni-bonn.de/~izzard/binary_c.html
- ***binary_c/nucsyn*** has a finite shelf life
- We need to start planning for the future
- I have already been doing this...
- ... but what do you think should be included?
- ... are you interested in helping?