The Effects of Rotation in Starburst99 Models

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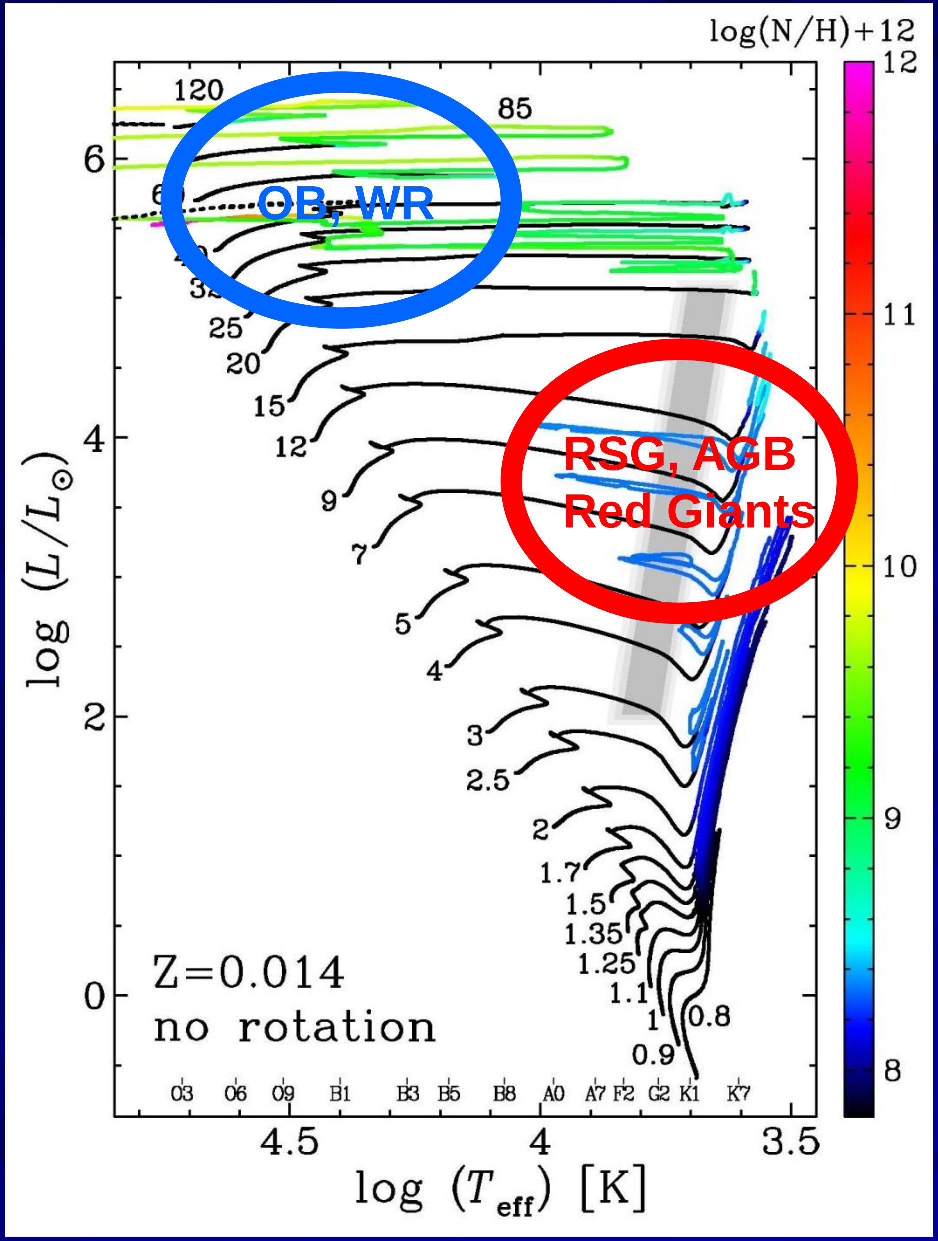
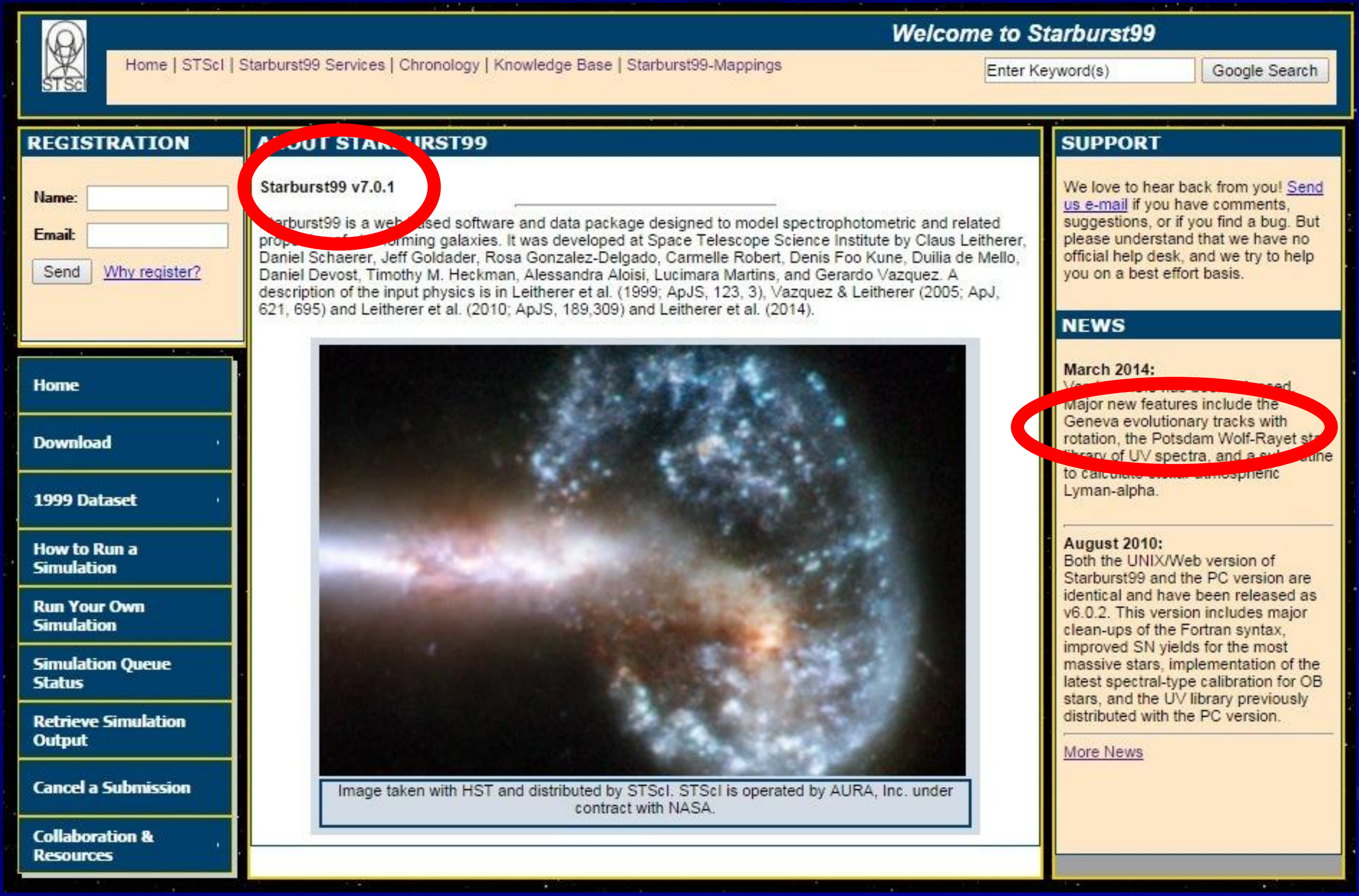


- HRD from Ekström et al. (2012)
- Hot, massive vs. cool, less massive stars
- Hot: all stages of evolution matter
- Cool: late stages of evolution matter
- Hot: atmospheres relatively well understood
- Cool: atmospheres are quite uncertain
- Stellar structure and evolution of massive stars is a major challenge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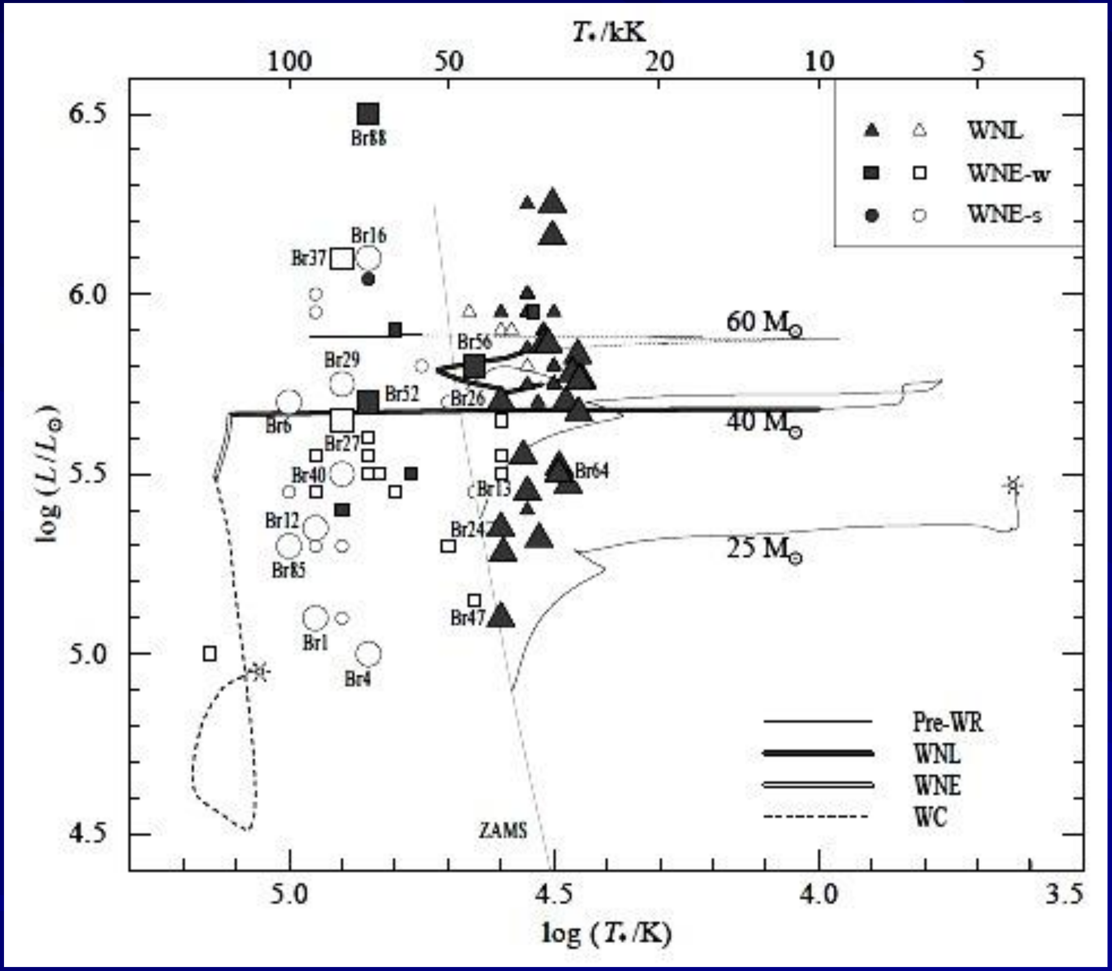
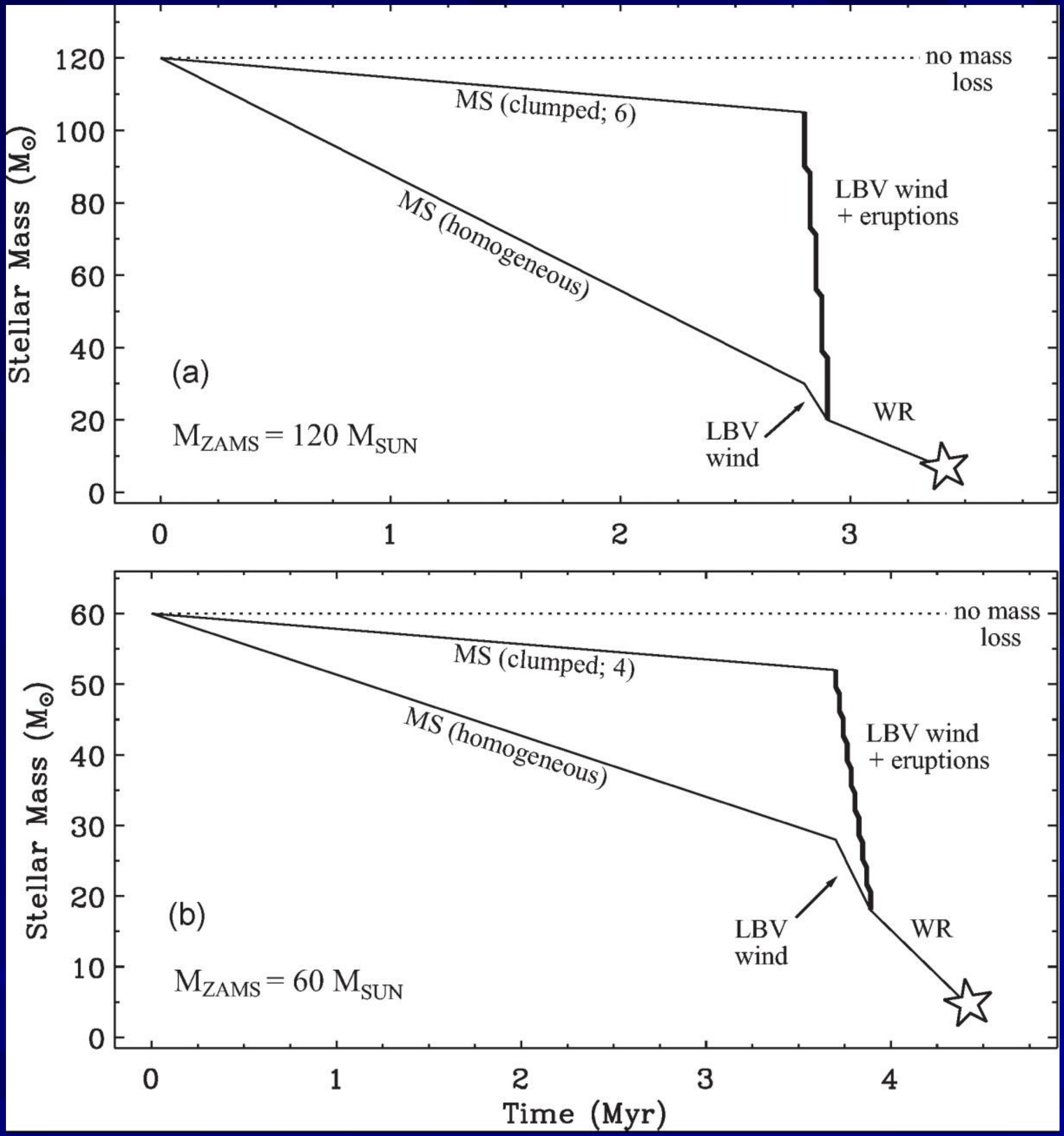
Starburst99 v7.0.1
Daniel Schaerer, Jeff Goldader, Rosa Gonzalez-Delgado, Carmelle Robert, Denis Foo Kune, Duilia de Mello, Daniel Devost, Timothy M. Heckman, Alessandra Aloisi, Lucimara Martins, and Gerardo Vazquez. A description of the input physics is in Leitherer et al. (1999; ApJS, 123, 3), Vazquez & Leitherer (2005; ApJ, 621, 695) and Leitherer et al. (2010; ApJS, 189,309) and Leitherer et al. (2014).
Image taken with HST and distributed by STScI. STScI is operated by AURA, Inc. under contract with NASA.
SUPPORT
We love to hear back from you! Send us e-mail if you have comments, suggestions, or if you find a bug. But please understand that we have no official help desk, and we try to help you on a best effort basis.
NEWS
March 2014:
Major new features include the Geneva evolutionary tracks with rotation, the Potsdam Wolf-Rayet
Lyman-alpha.
August 2010:
Both the UNIX/Web version of Starburst99 and the PC version are identical and have been released as v6.0.2. This version includes major clean-ups of the Fortran syntax, improved SN yields for the most massive stars, implementation of the latest spectral-type calibration for OB stars, and the UV library previously distributed with the PC version.
More News

- Why do we need a new generation of evolution models?
- What is different in the models?
- How do they compare with data?

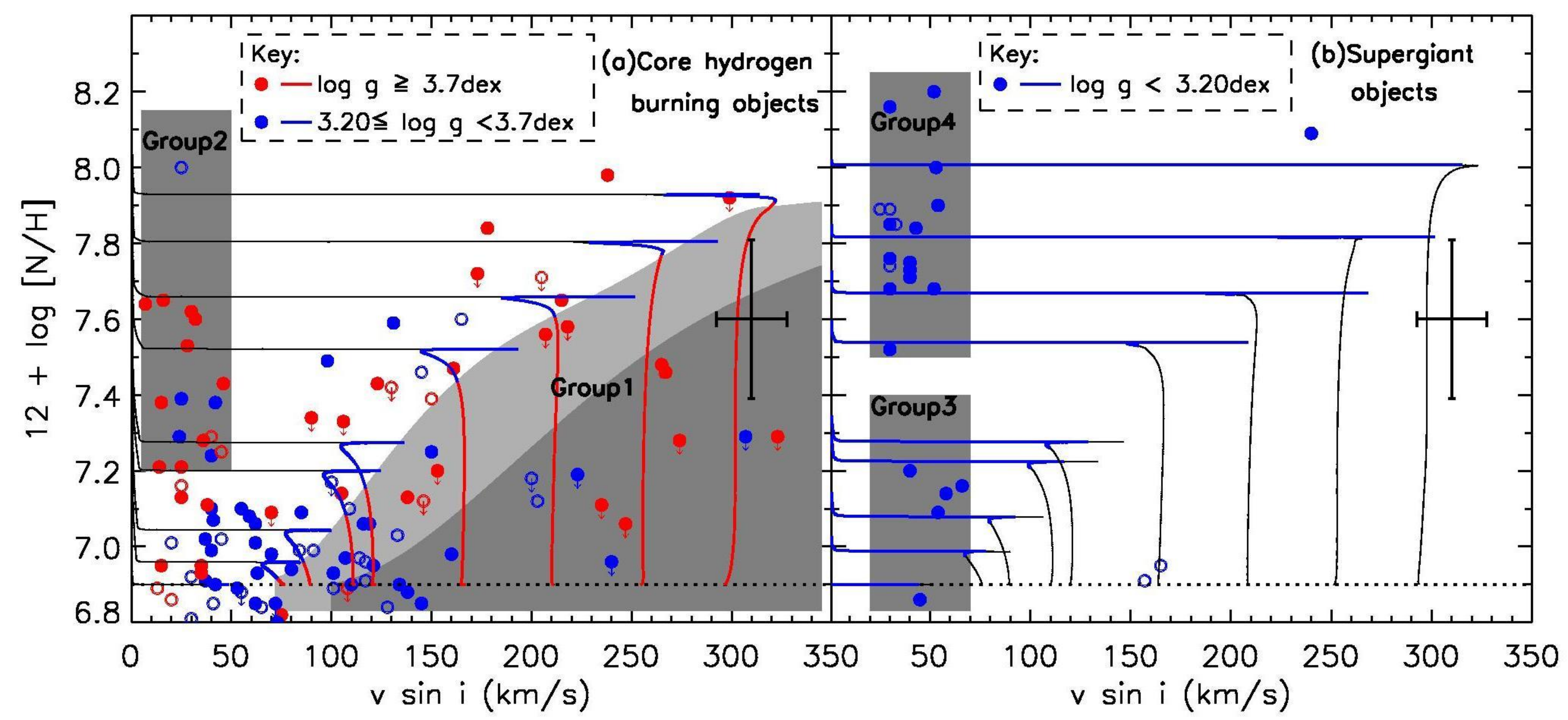


- HRD from Hamann & Koesterke (2000)
- Conti scenario (Conti 1976): WR stars are low-mass, enriched descendants of O stars
- O stars have strong stellar winds
- $dM/dt \approx 10^{-5}\ M_\odot yr^{-1}$; t = 5 Myr → lose 50 $M_\odot$
- Expose He, N, C-rich core
- O star → WR star

…. the golden (gilded) age of massive-star research

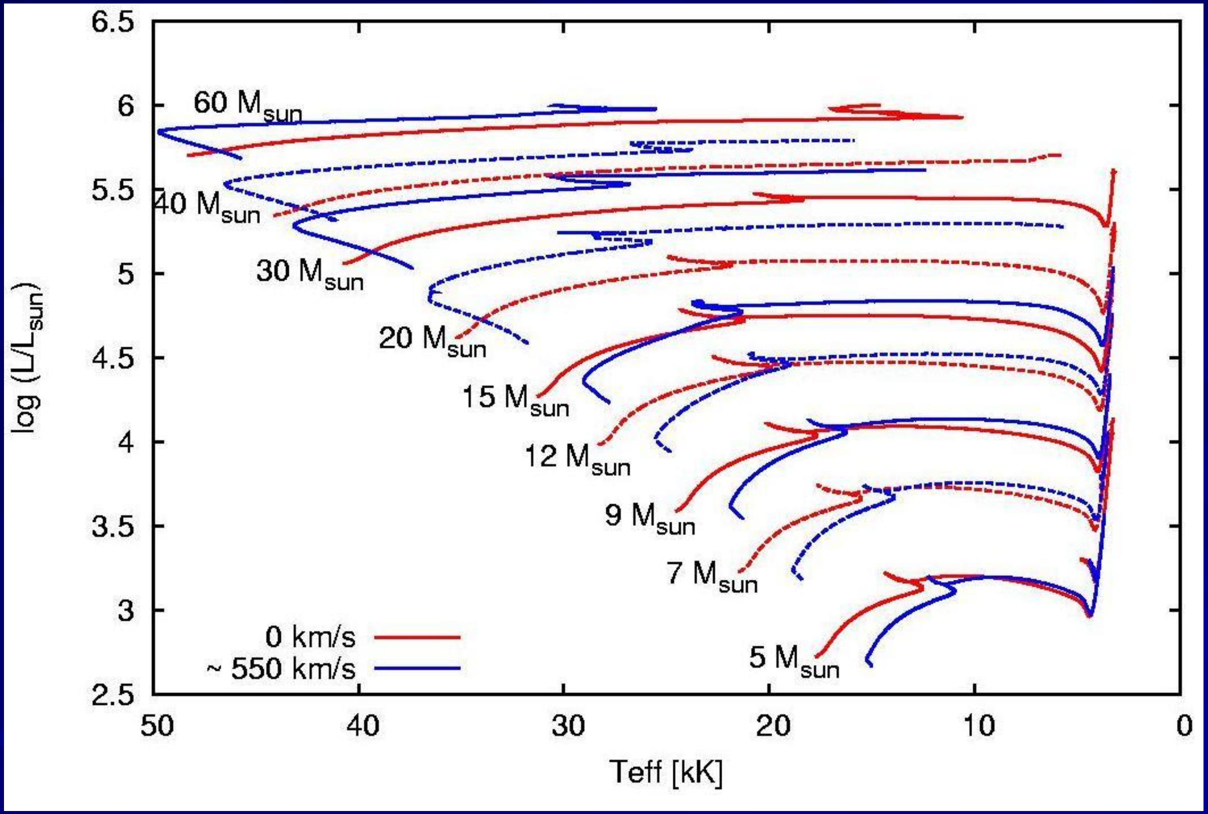


- Smith (2009)
- Stellar winds of hot stars are highly inhomogeneous
- Mass-loss rates of OB stars are overestimated by factors of 5!
- How do OB stars lose their mass?



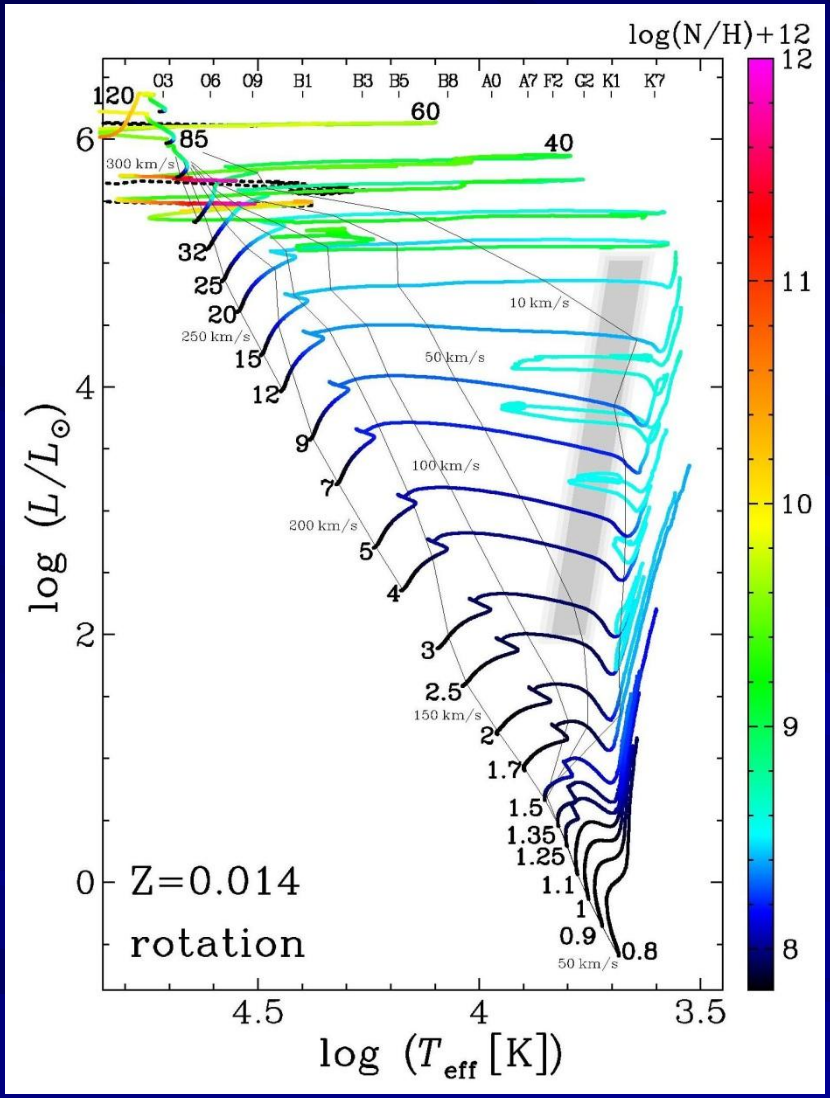
- Hunter et al. (2009): N/H and v sin i in LMC B stars
- Significant N enrichment on the main sequence
- Rotation must be important

Brott et al. (2011): evolutionary models with rotation

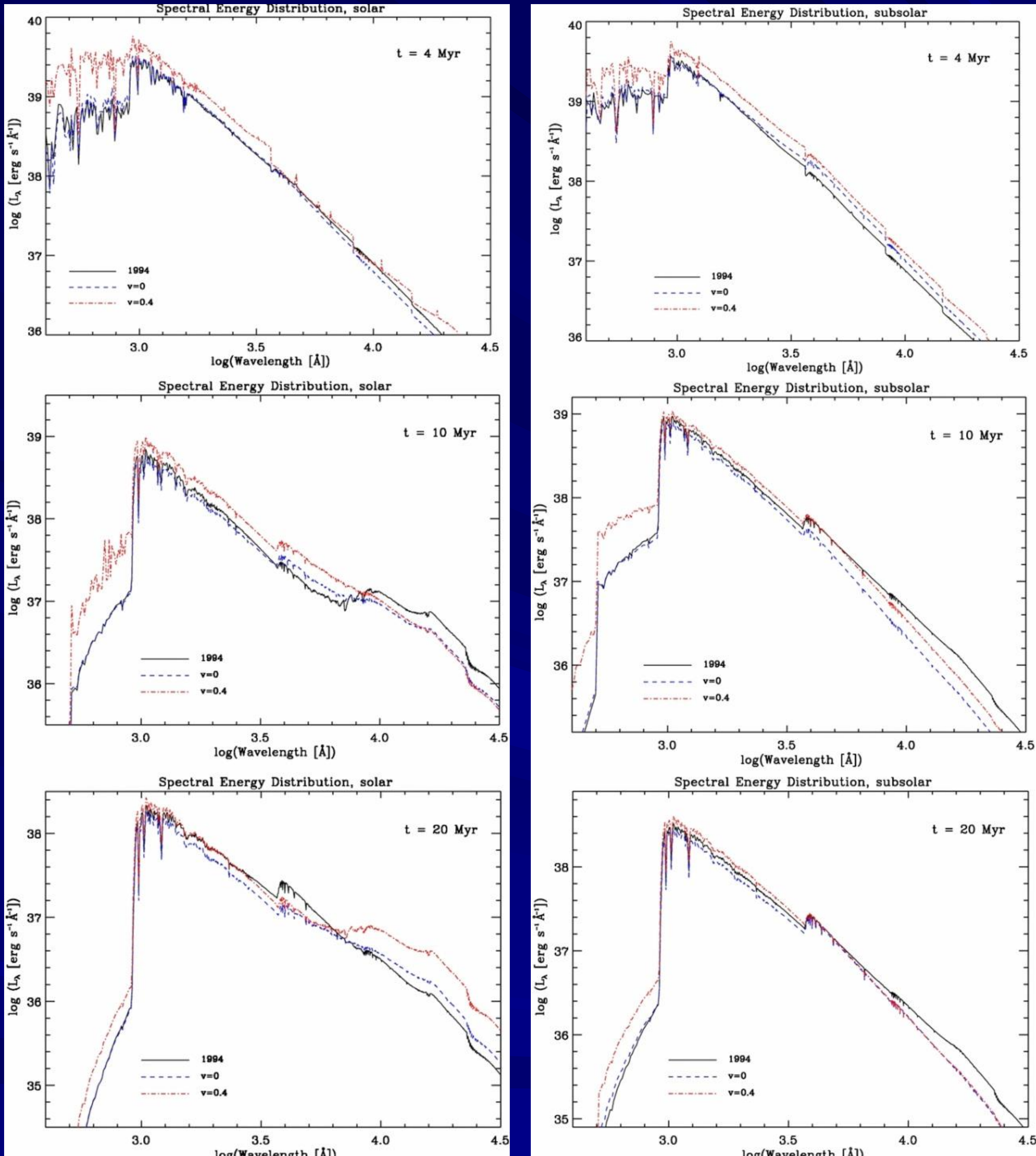


1. M < 2 $M_\odot$: rotation negligible because of magnetic braking
2. 2 $M_\odot$ < M < 15 $M_\odot$: T_{eff} decrease caused by centrifugal forces
3. M > 15 $M_\odot$: larger convective core with higher T_{eff} and L

Ekström et al. (2012): full set of evolution models with rotation

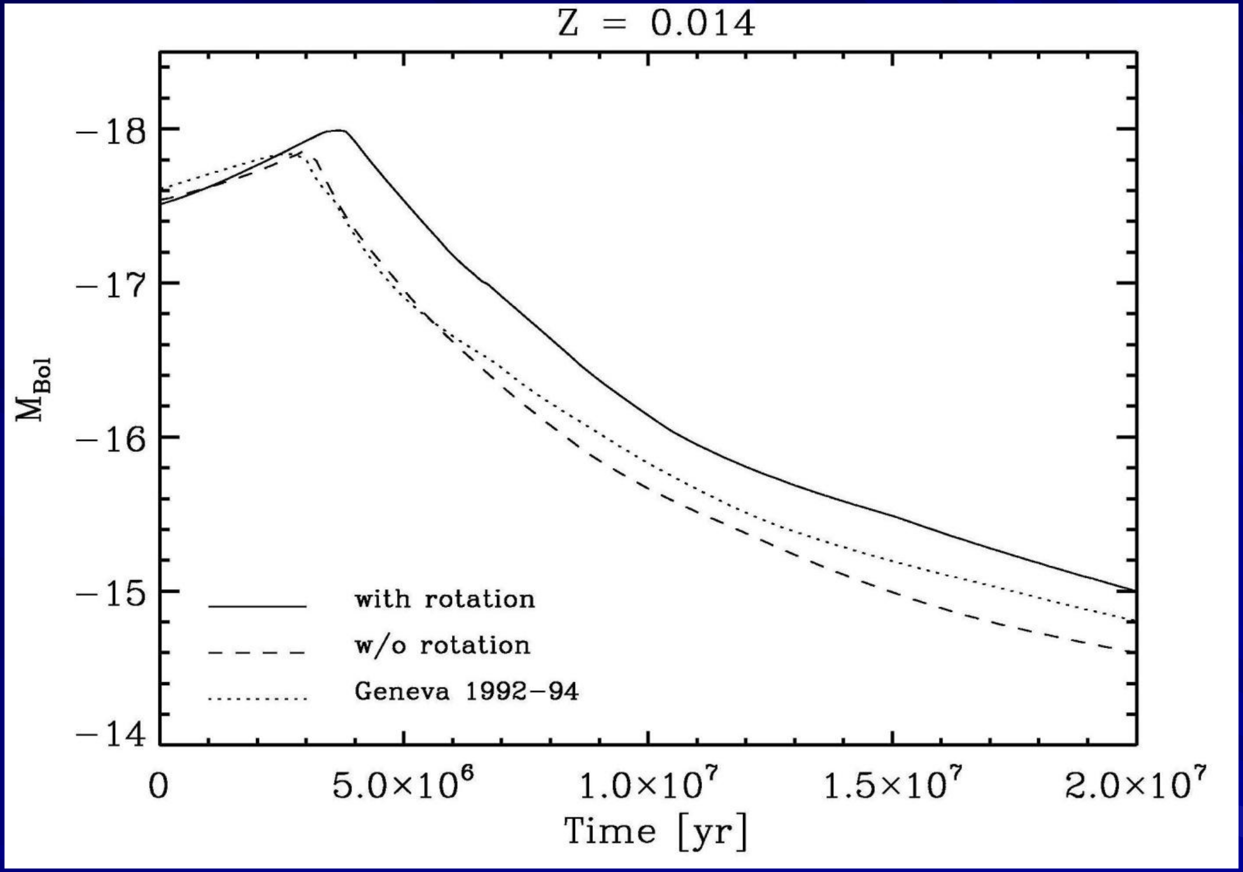


- $0.8\ M_\odot < M < 120\ M_\odot$
- $Z = Z_\odot$
- $v_{rot} = 0.4\ v_{breakup}$ on ZAMS
- Calibrated extensively via local stars and star clusters
- Implemented in Starburst99 v7.0 (Leitherer et al. 2014)



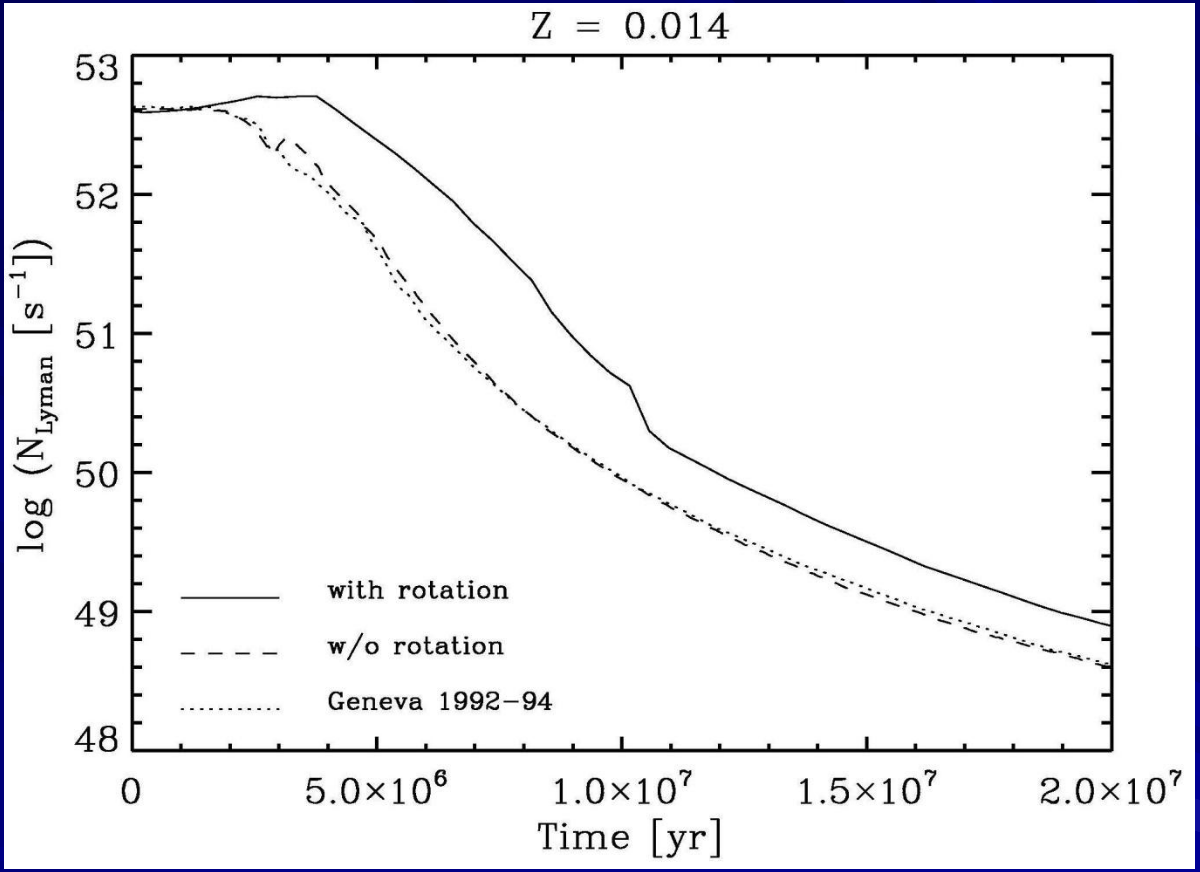
- Leitherer et al. (2014)
- UV to near-IR SED of standard SSP
- *Z* = $Z_\odot$ and 1/7th $Z_\odot$

M_{Bol} vs. time (SSP, 10^6 $M_\odot$, $Z_\odot$, Kroupa IMF)



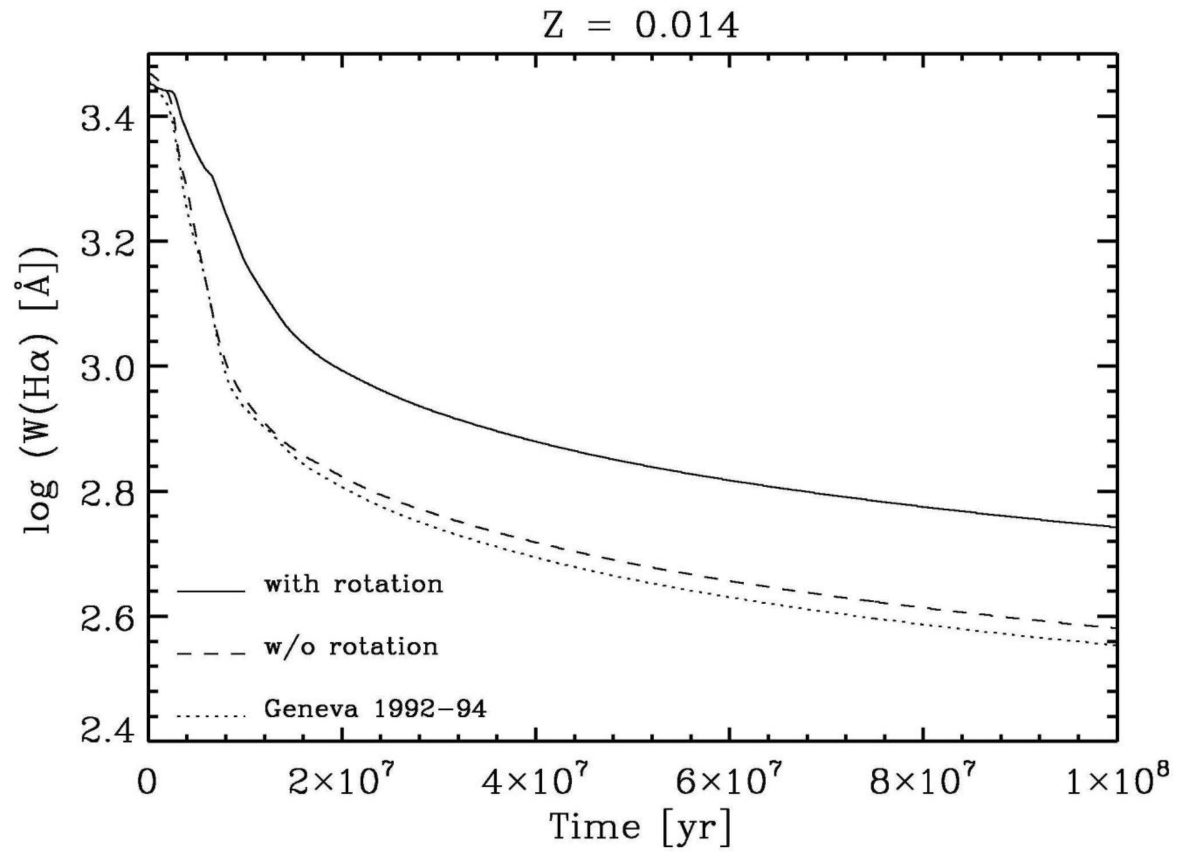
- Models with rotation are more luminous by ~0.4 mag because of the higher L/M and T_{eff} of individual stars

Lyman photons vs. time (SSP, 10^6 $M_\odot$, $Z_\odot$, Kroupa IMF)



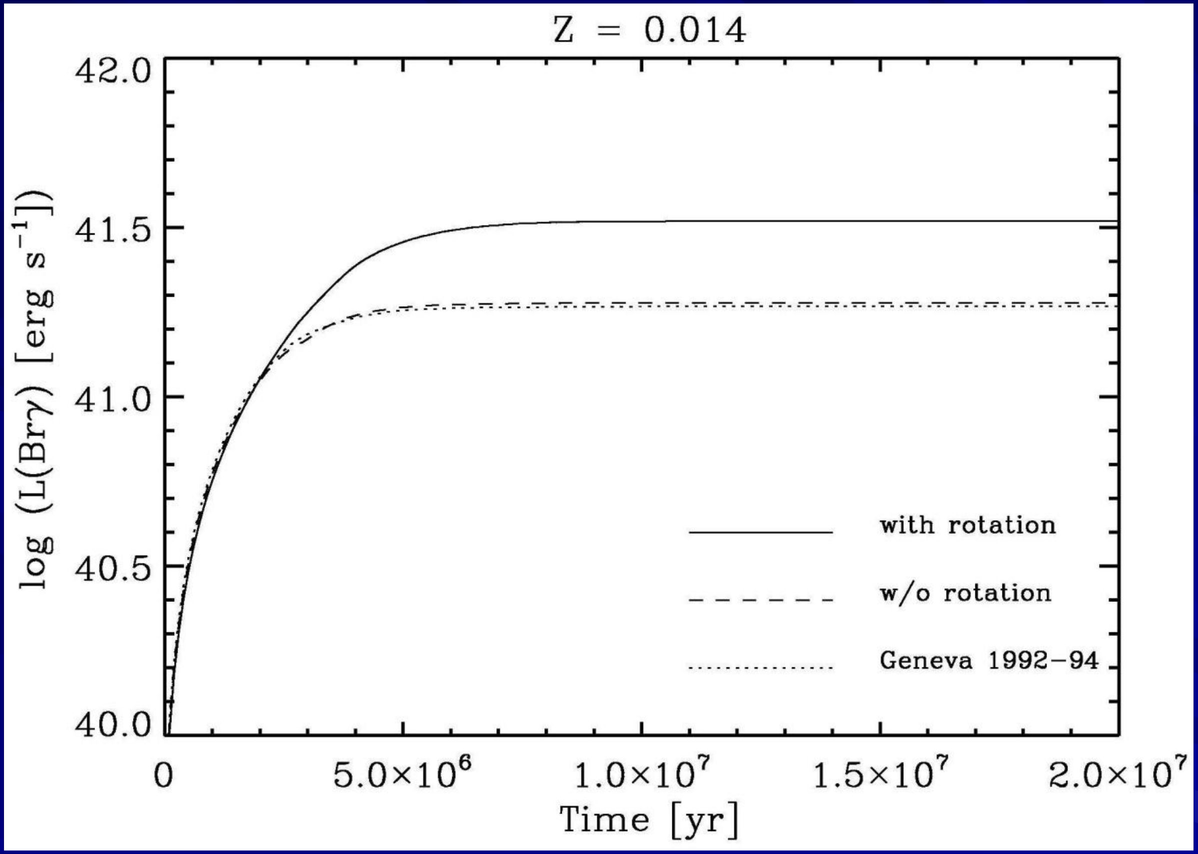
- The number ionizing photons increases by a factor of ~4 when hot, massive stars are present

Hα equivalent width vs. time (continuous SF, $Z_\odot$, Kroupa IMF)



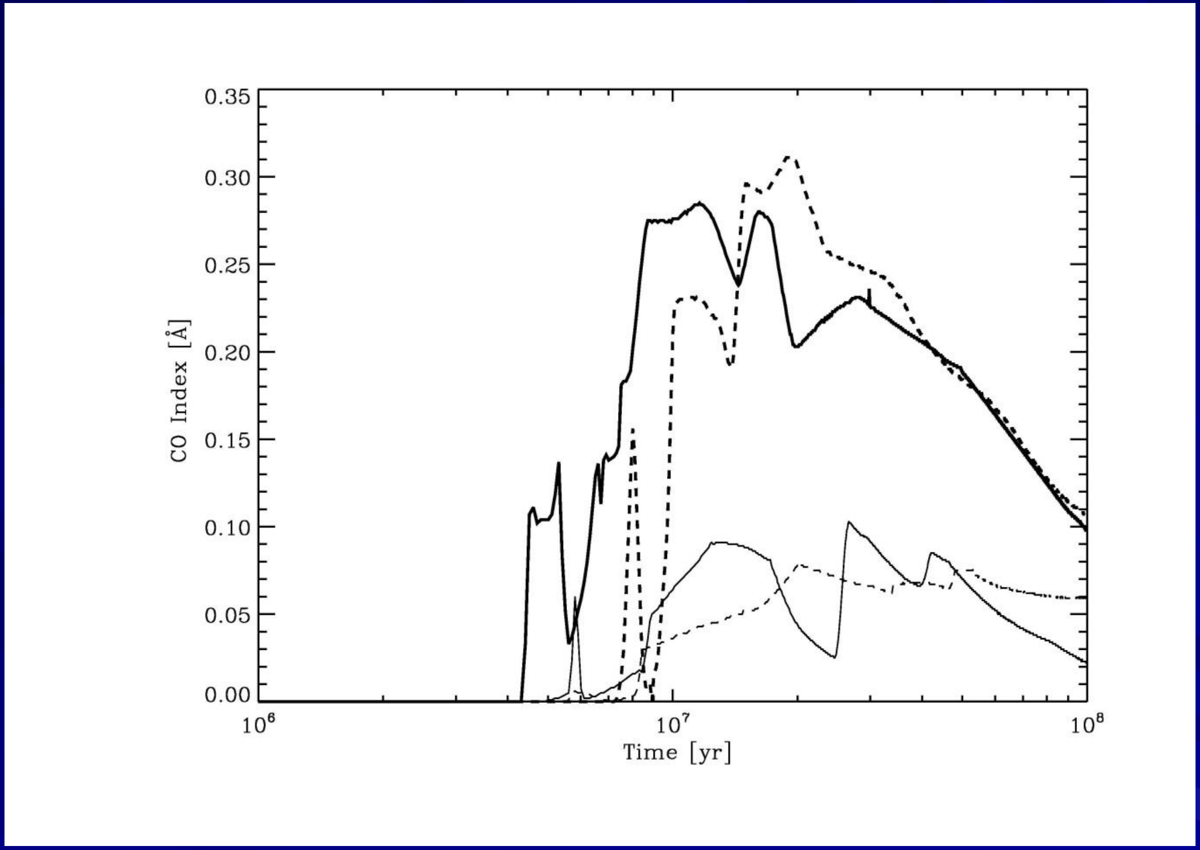
- W(Hα) increases by ~0.2 dex. If used as an IMF indicator in late-type galaxies, the new models change the IMF exponent from, e.g, 2.3 to 2.6

Brγ luminosity vs. time (SFR = 100 $M_\odot$ yr^{-1}, $Z_\odot$, Kroupa IMF)



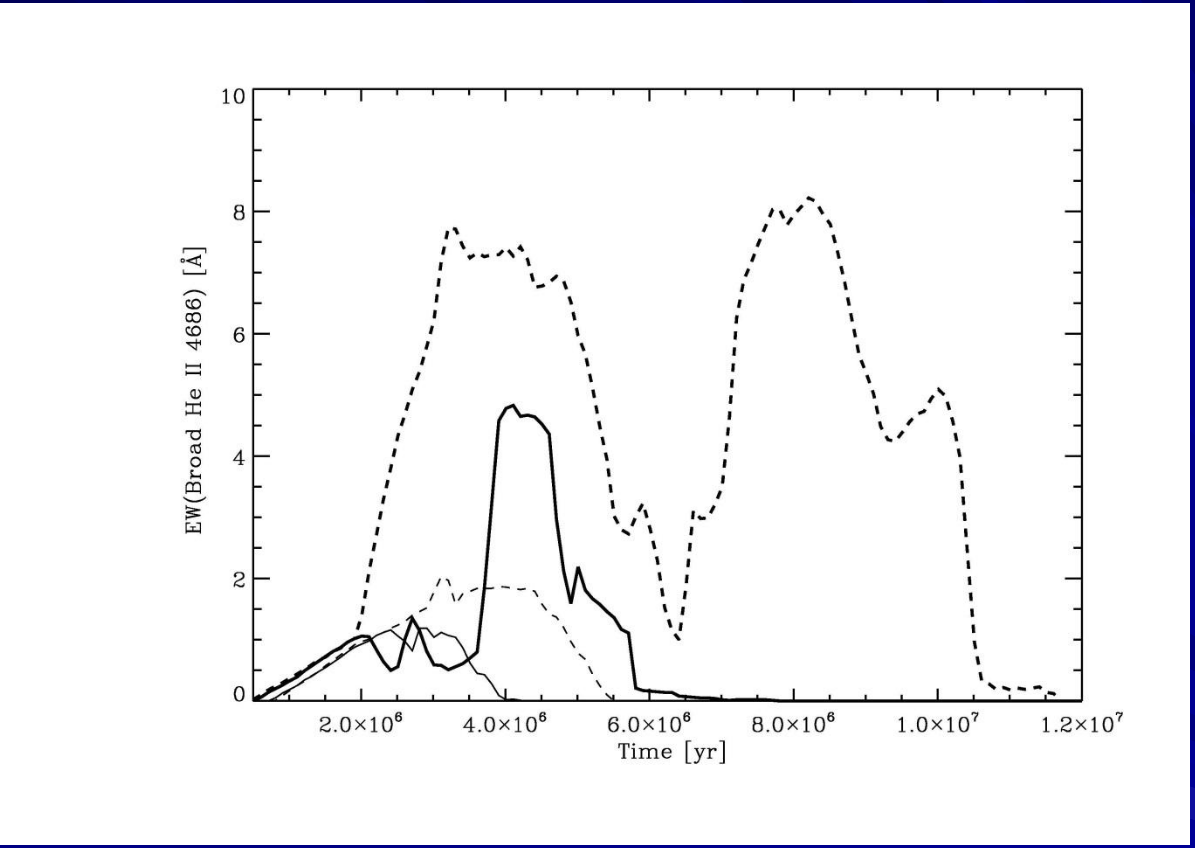
- Applied to IR-luminous galaxies: models with rotation lead to, e.g., SFR = 100 $M_\odot$ yr^{-1}, whereas models without give SFR = 175 $M_\odot$ yr^{-1}.

CO index vs. time (SSP, 10^6 $M_\odot$, Kroupa IMF)



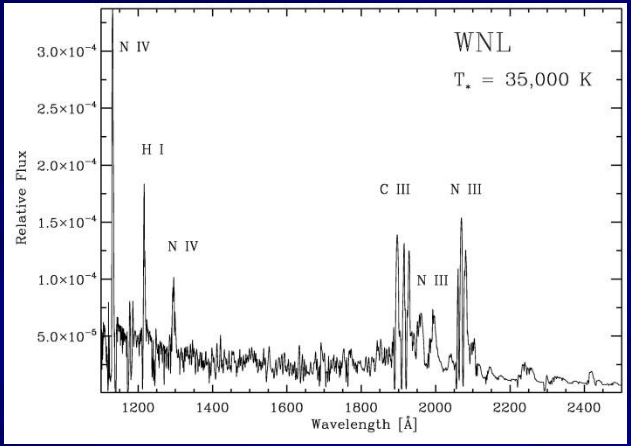
- Thick solid: $Z_\odot$, no rotation; thick dashed: $Z_\odot$, rotation
- Thin solid: 1/7 $Z_\odot$, no rotation; thin dashed: 1/7 $Z_\odot$, rotation

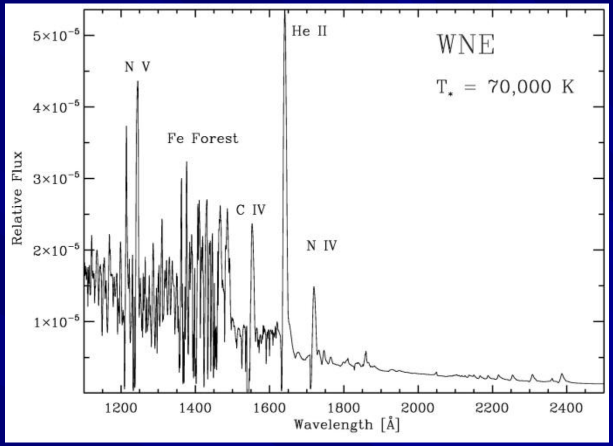
EW(4686) vs. time (SSP, 10^6 $M_\odot$, Kroupa IMF)

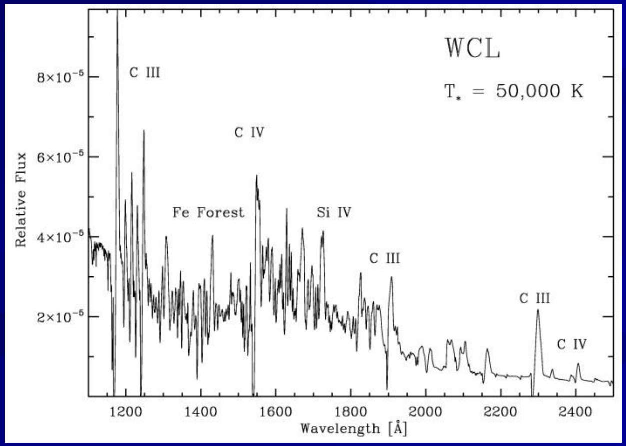


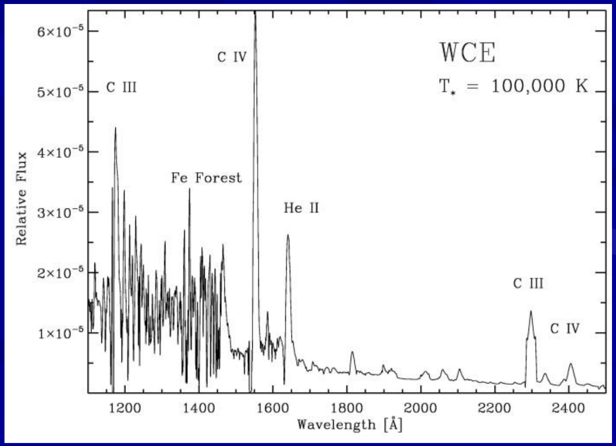
- Thick solid: $Z_\odot$, no rotation; thick dashed: $Z_\odot$, rotation
- Thin solid: 1/7 $Z_\odot$, no rotation; thin dashed: 1/7 $Z_\odot$, rotation

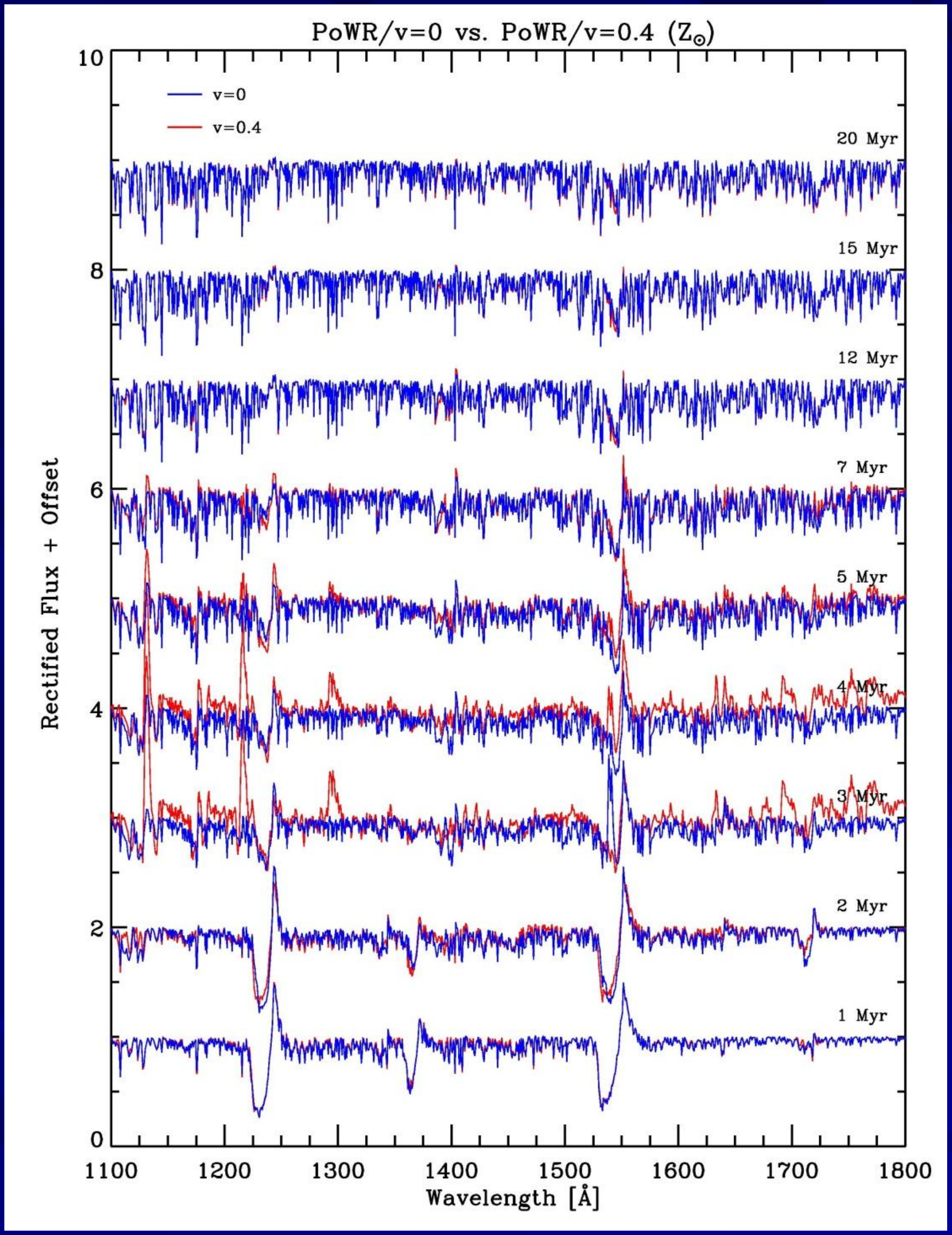
Implemented W-R library in Starburst99 using PoWR models available at http://www.astro.physik.uni-potsdam.de/~wrh/PoWR/powrgrid1.html









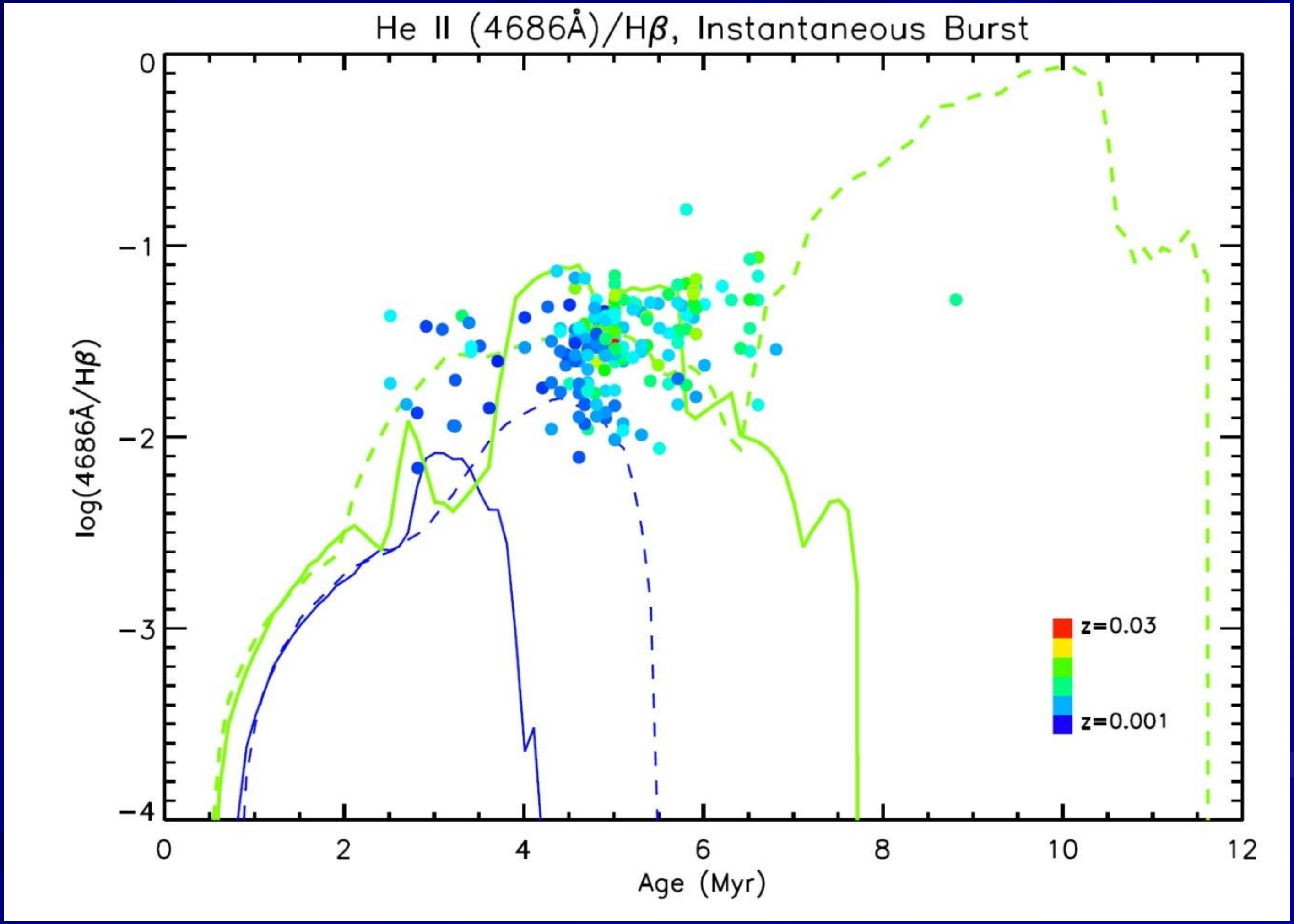


- UV spectrum of evolving SSP at different epochs
- Blue: no rotation
- Red: with rotation
- WR stars show several detectable features in addition to He II λ1640

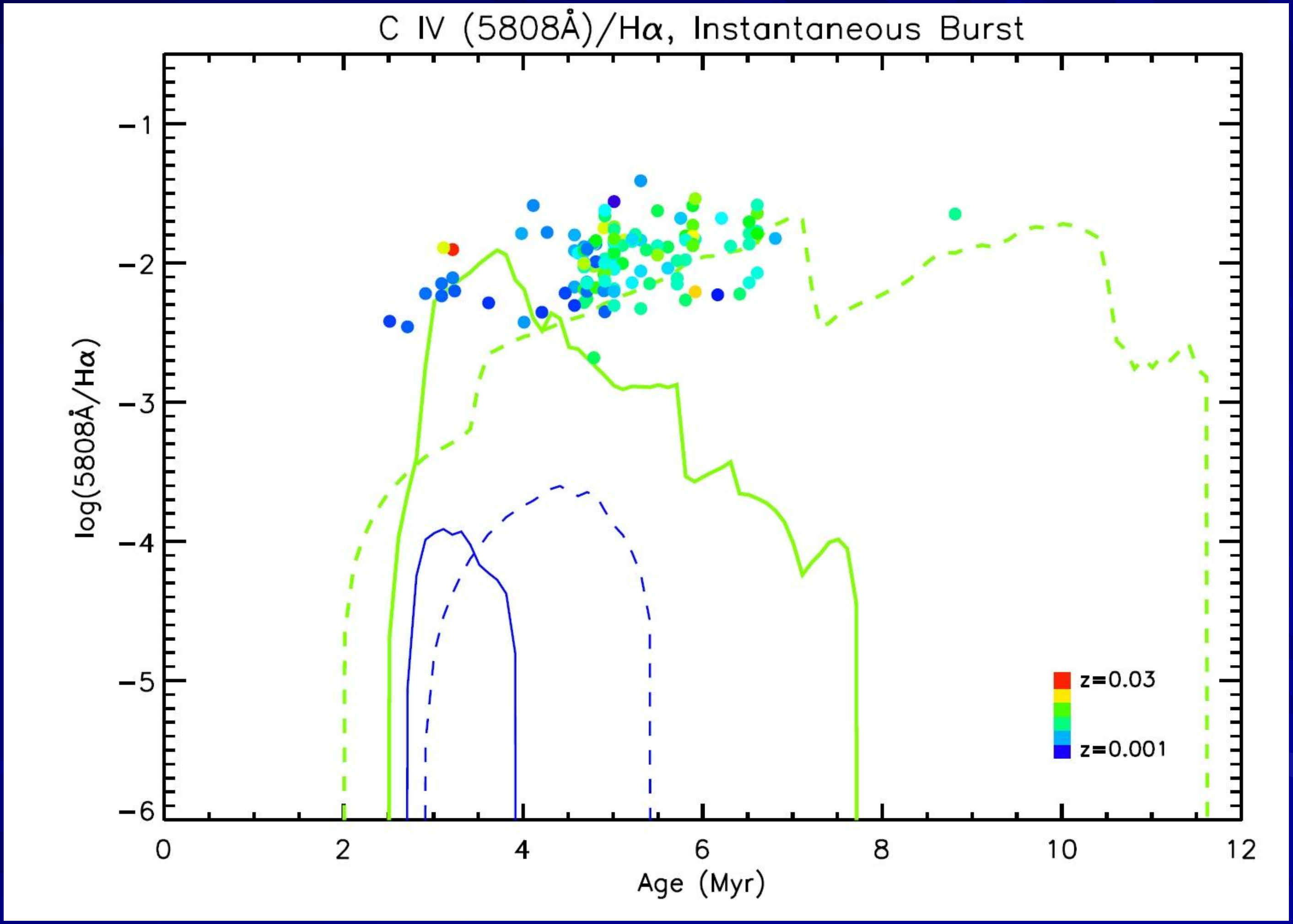
Comparison with SDSS DR7

- Geneva tracks were calibrated via stellar data in the Local Group (e.g., WR/O/RSG); affected by small-number statistics (e.g., 12 WR stars in SMC)
- Here: use integrated galaxy data from SDSS DR7
- Identify all WR galaxies via He II 4686 (Agienko et al. (2013)
- 2.2 Mpc < *D* < 650 Mpc
- 7.2 < log O/H +12 < 8.7 (T_e and *R23*)
- ~280 galaxies

He II λ4686 SDSS vs. models



C IV λ5808 SDSS vs. models



- Solar chemical composition: both rotating and non-rotating models agree with WN population
- Solar chemical composition: SDSS data favor rotating models for WC stars
- Subsolar composition: both rotating and non-rotating models grossly underpredict WR stars
- Subsolar models predict many hot stars but they are not chemically enriched → no WR stars

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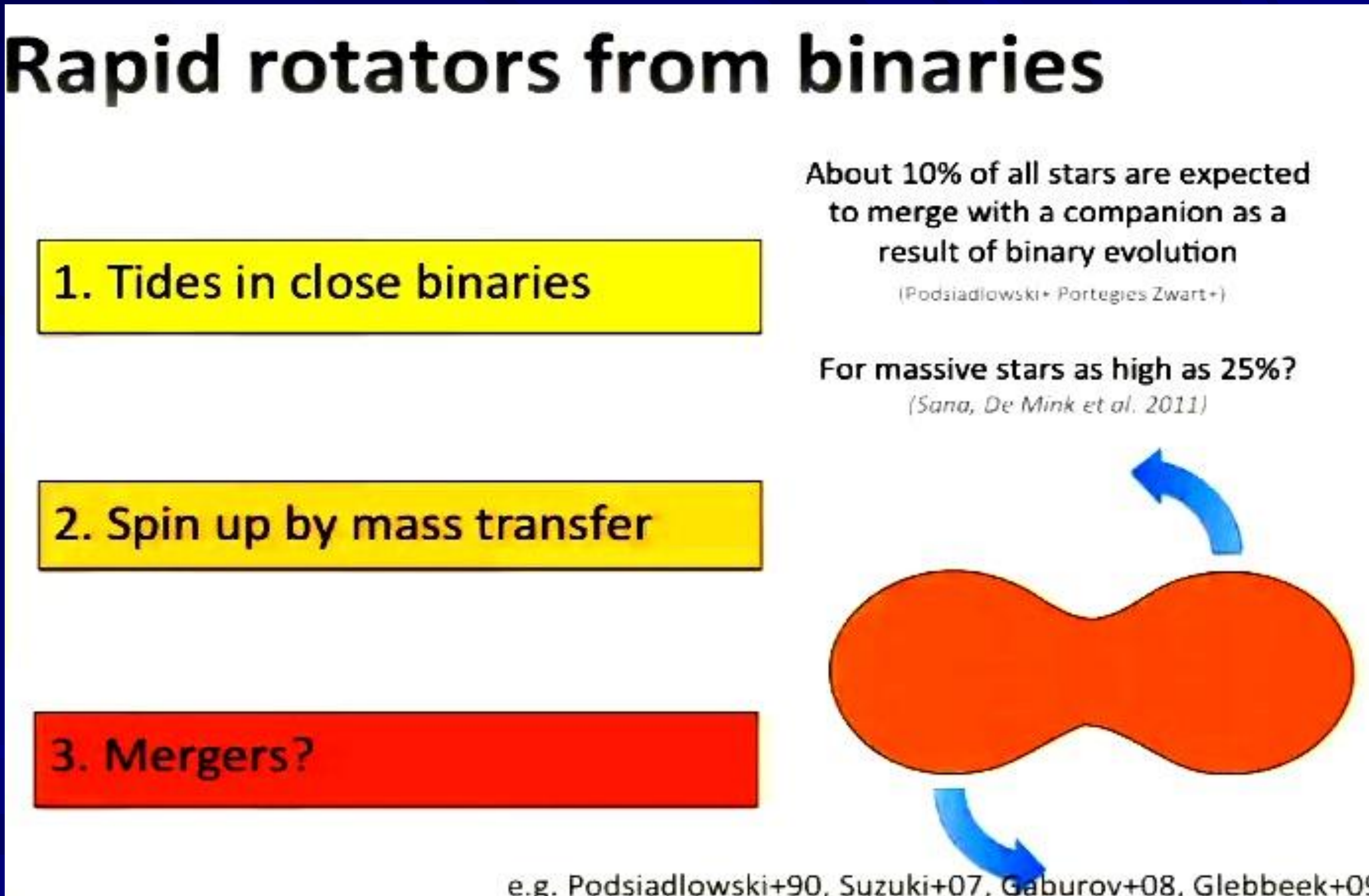
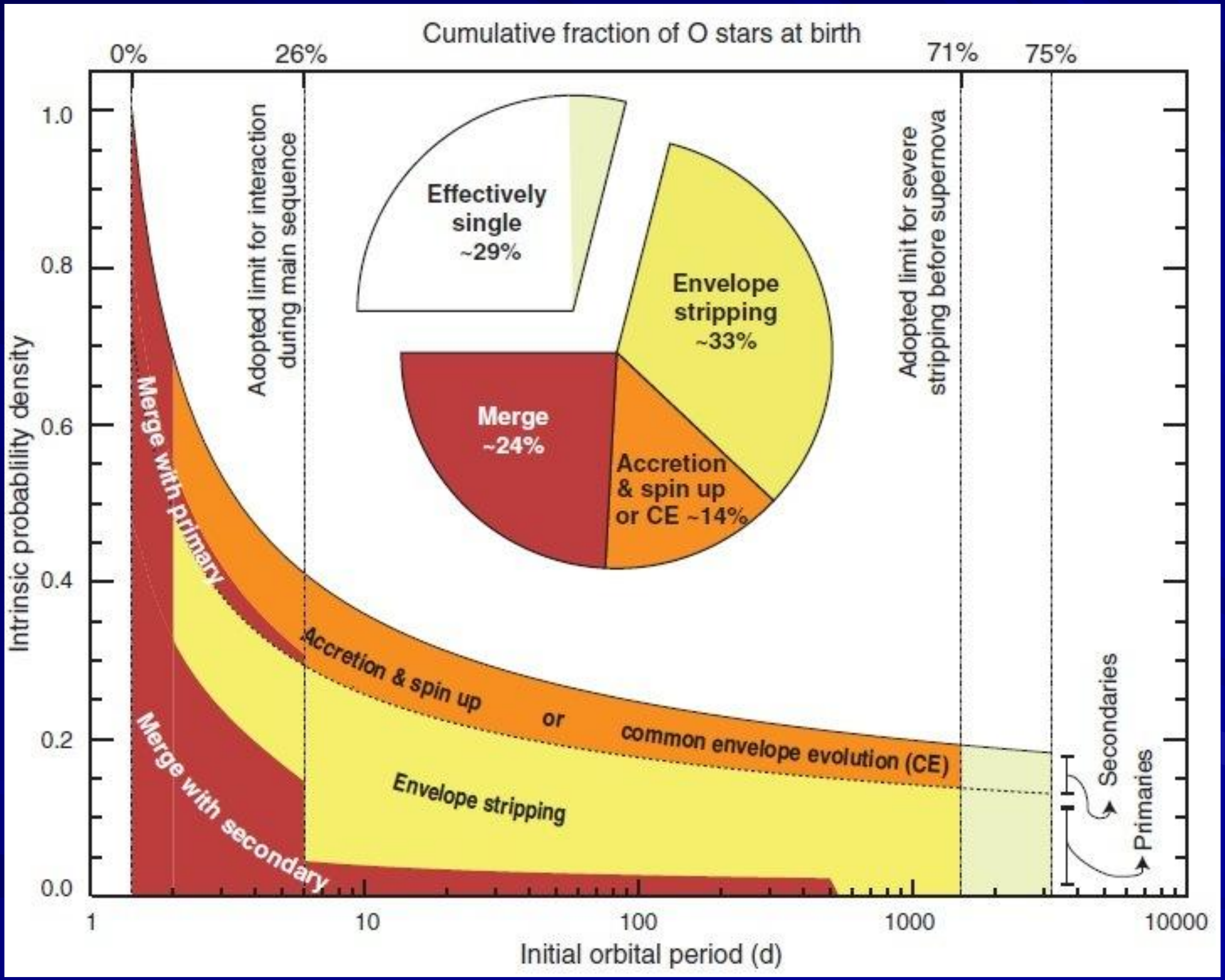
- Subsolar composition: both rotating and non-rotating models grossly underpredict WR stars
- Subsolar models predict many hot stars but they are not chemically enriched $\rightarrow$ no WR stars
- Hint: all 12 WR stars in the SMC are binaries….

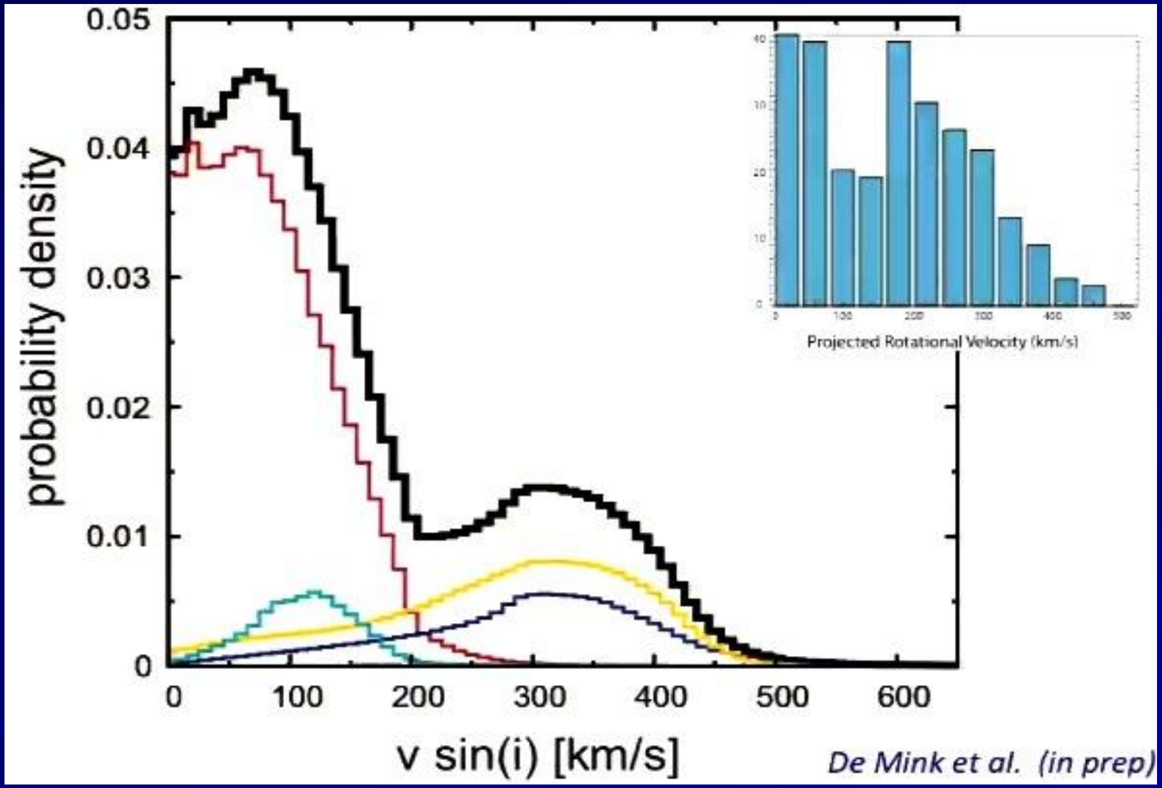
de Mink (2012)


Rapid rotators from binaries
1. Tides in close binaries
2. Spin up by mass transfer
3. Mergers?
About 10% of all stars are expected to merge with a companion as a result of binary evolution
(Podsiadlowski+ Portegies Zwart+)
For massive stars as high as 25%?
(Sana, De Mink et al. 2011)
e.g. Podsiadlowski+90, Suzuki+07, Gaburov+08, Glebbeek+09

Sana et al. (2012):
evolutionary channels of massive close binaries

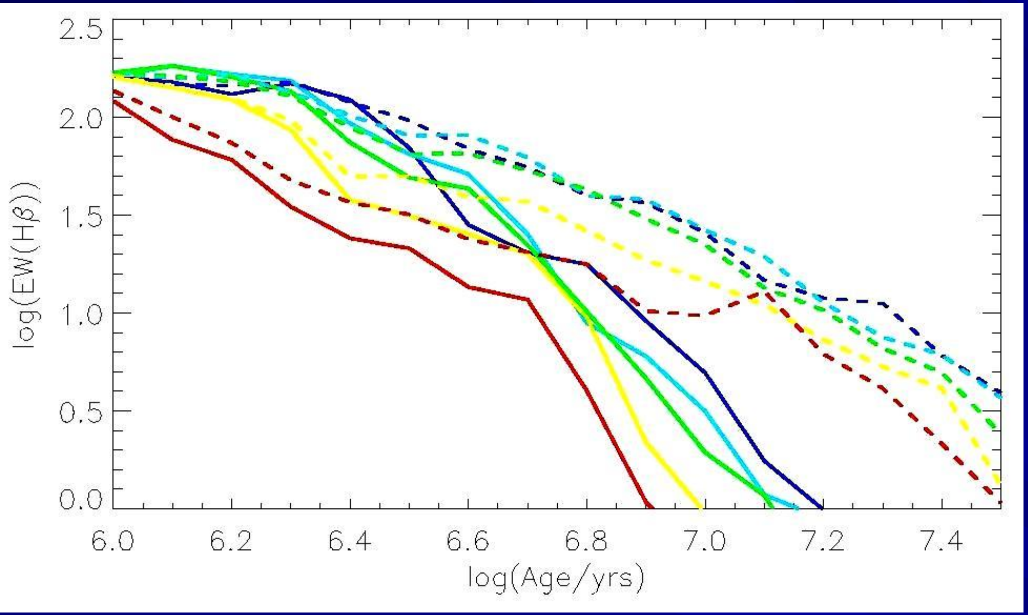


de Mink (2012): simulated rotation velocity distribution



- Magenta: single
- Cyan: interacting
- Yellow: spin-up
- Blue: merger

Eldridge & Stanway (2009): rejuvenation effect in SSP



- Evolution of Hβ equivalent width with time in SF galaxy
- Solid: single stars with different Z; dashed: binaries with different Z
- Hot, ionizing population appears after ~10 Myr
- Relevance: age spread of star formation? LINERs?

Take-Away Points

- Stellar evolution is a major uncertainty in modeling populations of massive stars
- The latest generation of evolution models is drastically different from the previous one
- Stellar mass loss, rotation and binarity all affect evolution and are difficult to distinguish empirically
- The uncertainties increase with decreasing wavelength and can reach a factor of several in the Lyman continuum