STELLAR ROTATION and EVOLUTION

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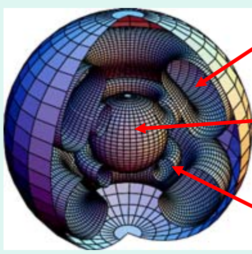
- 22/09/09 Lect 1: Rotation and stellar structure
- 22/09/09 Lect 2: Rotation and stellar winds
- 24/09/09 Lect 3: Rotation and stellar evolution

ROTATION AND STELLAR EVOLUTION

Literature

- Hirschi et al, A&A 425, 649, 2004
- Hunter et al. A&A 496, 841, 2009
- Lamers & Cassinelli, Introduction to Stellar Winds, Cambridge, 1999
- Maeder & Meynet, The evolution of rotating stars, ARAA, 38, 113, 2000
- Maeder & Meynet 2005, IAU Symp 2005
- Martyayan et al. (preprint), 2009

Different types of instbilities in a fast rotating massive MS star



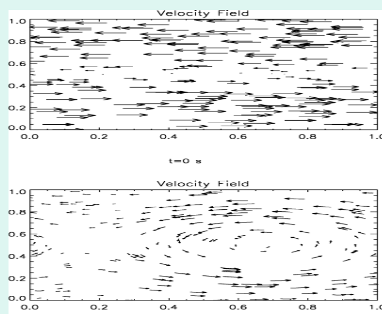
Meridional circulation

H-fusion core: convective

Shear instability: between core and meridional circulation

All these motions help to transport nuclear products from the core to the surface and to redistribute angular momentum!

CIRCULATION BY SHEAR INSTABILITY



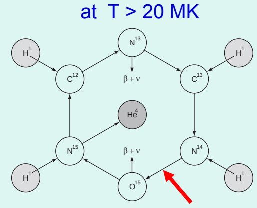
Brueggen & Hillebrandt 2001

CHANGES IN THE SURFACE ABUNDANCES:

- EVIDENCE FOR EFFICIENT MIXING
- TEST FOR THE ROTATIONAL MIXING THEORY

Expected changes in surface composition due to mixing

The CNO-cycle for H-He fusion at T > 20 MK



Slowest step (~10^5 yrs)!!

So there is a pile-up of N^{14} at the expense of C^{12}

When the cycle is in equilibrium all reactions occur at the same rate (nr per gram per sec).

τ_j = lifetime of ion j ($1/\tau$ = reaction/ion.s)

N_j = nr of ions j (per gram)

In equilibrium:

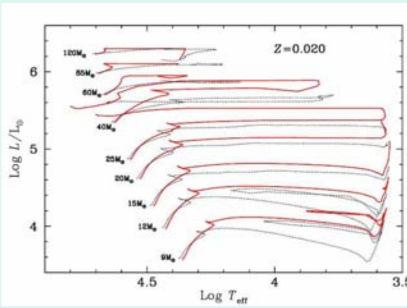
R = $N_j \times 1/\tau_j$ = constant

So : $N_j \sim \tau_j$

Equilibrium shift according to $1/\tau_j$

N^{14}/C^{12} changes from initially 0.1 to 50 !! in CNO-equilibrium

Evolution without and with rotation

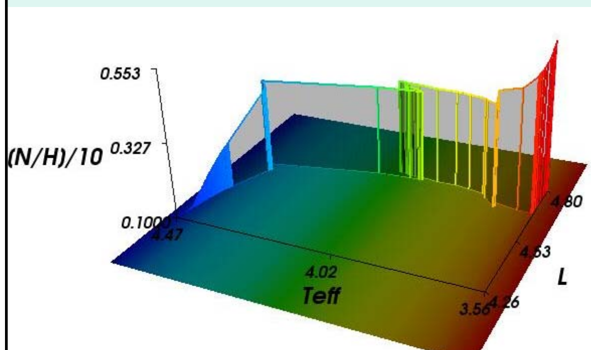


Dotted = no rotation

Red = with rotation

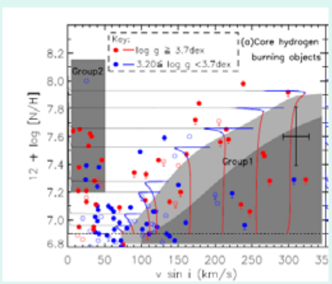
(300 km/s)

Meynet and Maeder 2003



cf also Heger & Langer 1998

Observed N-enhancement in OB stars



Main-sequence B-stars in LMC

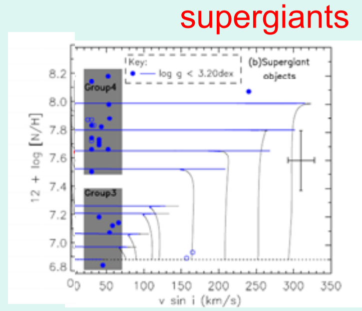
predicted tracks = 13 Msun star different v

Initial N/H

Tracks = predicted rotation + mixing of M= 13 Msun
Vertical = main sequence
Horizontal = expansion after MS

I.Hunter et al, 2009

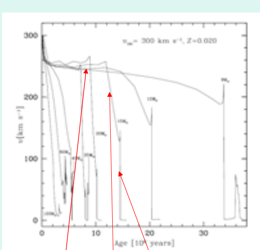
N –enhancement in LMC supergiants

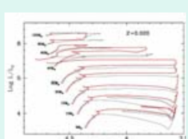


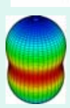
predicted tracks = 19 Msun star different v

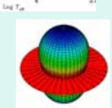
I.Hunter et al, 2009

The evolution of rotation









MS

Expansion after MS

Bi-stability disk

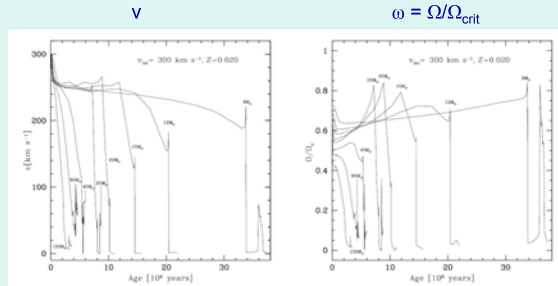
polar massloss on MS

bi-stability disk

Meynet & Maeder 2003

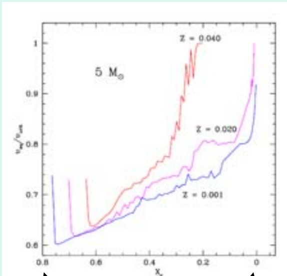
THE EVOLUTION OF ROTATION

v $\qquad$ $\omega = \Omega/\Omega_{crit}$



Starting at v=300 km/s it just does NOT reach critical rotation

The effect of metallicity



H-content at core

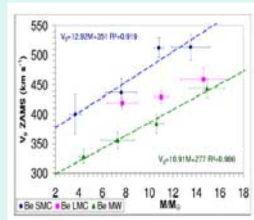
ZAMS

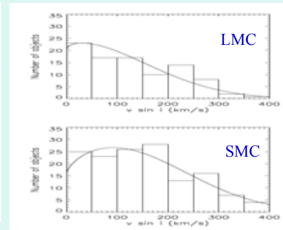
TAMS

5 Msun star starting at v/v_{crit} = 0.65

metal poor stars are less likely to reach critical rotation IF they start with same v/v_{crit}

Rotation of stars depends on their metallicity !





Martayan et al 2007

LMC: <v sin i>=100 km/s, width=150 km/s

SMC: <v sin i> =175 km/s, width=150 km/s

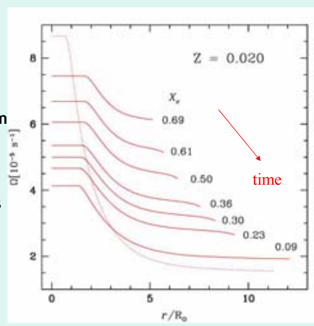
Hunter et al. 2008

Evolution of Ω(r) during the Main Sequence in case of spherical mass loss

1. Core is convective, so it behaves as solid rotator

2. Transport of angular momentum from convective core outwards

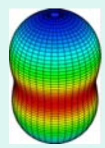
3. Removal of angular momentum at the surface by the stellar winds

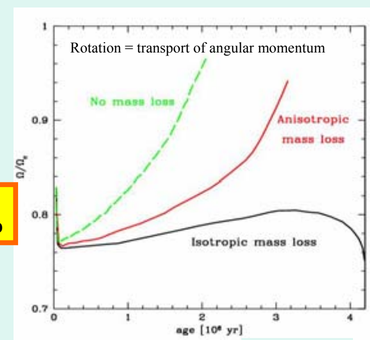


20 M_{sol}, V_{ini}= 300 km s^{-1}

The effect of rotation plus mass loss on Ω/Ω_{crit}

40 Mo with <v> = 440 km/s

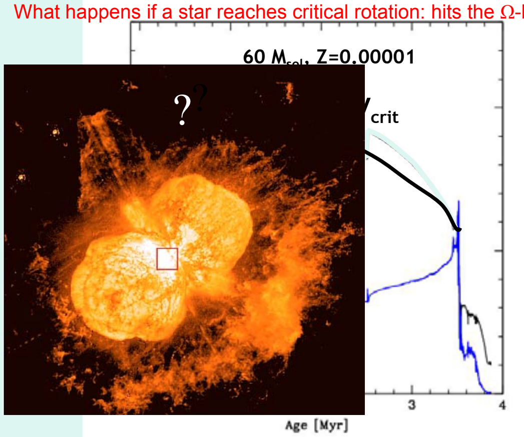




Anisotropic mass loss favours break-up

Maeder, 2002

What happens if a star reaches critical rotation: hits the Ω-limit ?

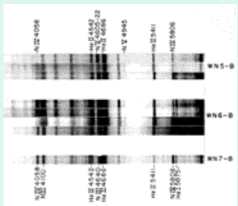


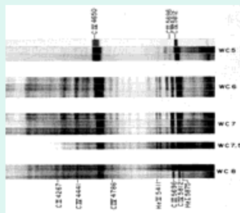
WOLF-RAYET STARS

A CRUCIAL TEST FOR STELLAR EVOLUTION THEORY

Very easy to observe up to large extragalactic distances

WN and WC stars

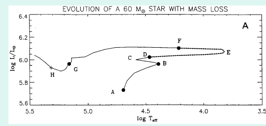


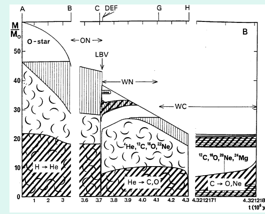


WN = N-rich
He-rich
H-poor
= products of advanced CNO cycle

WC = C-rich
He-rich
no H
= products of He-fusion

WR stars : stripping of stars





Ratio of O-stars/WR stars depends crucially on mass loss history !

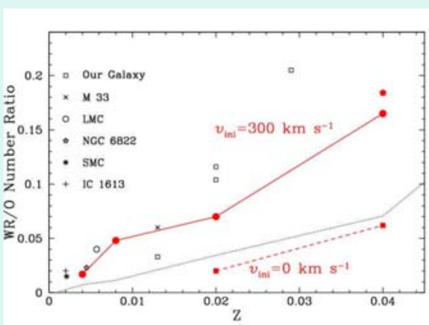
Low mass loss:
1. only most massive stars are stripped to WR-phase:
WR/O = small

2. Stars explode as Red SG:
H-rich SN (type II)

High mass loss:
1. many massive stars are stripped to WR-phase:
WR/O = high

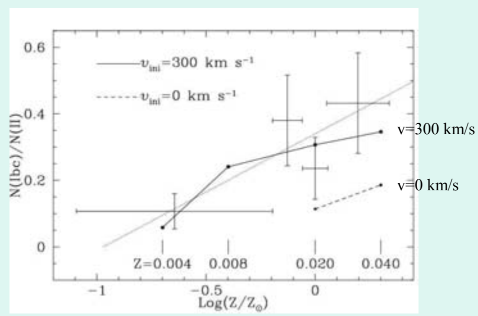
2. Stars explode as WR-stars
H-poor SN (type I)

The WR/O star ratio : observed versus predicted



Meynet & Maeder 2005

A similar test of stripping: SN I (no-H) / SN II (H)



Observed points from Prantzos and Boissier (2003)

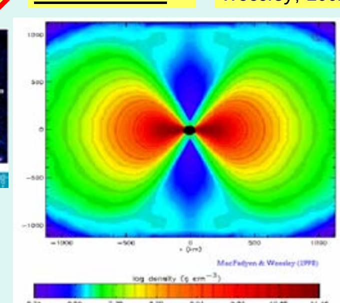
Meynet & Maeder 2005

Gamma Ray Bursters

associated with SN Ic:
no H and little or no He
↓
progenitors are WO stars
= rare stars with
products of C - burning

Relation SN - GRB ⇒ **COLLAPSAR:** Woosley, 2002

Hjorth et al. 2003



Precursor: Rotating WO star ? Is there enough rotation ?
1 % of all WR would be enough.

Conditions to form GRB

1. You have to peel of the star just enough to have the correct surface composition (He-poor and C+O rich):
   Solar metallicity stars have too high mass loss rates
   So they must be low metallicity stars

2. But low metallicity stars have too little mass loss to peel–off the stars to get WR- stars:
   So only in a very narrow metallicity range? Unlikely!!

3. Possible solution:
   Low metallicity stars (Z ~ 0.004 or so)
   with rotation-enhanced mass loss and mixing ?

CONCLUSIONS

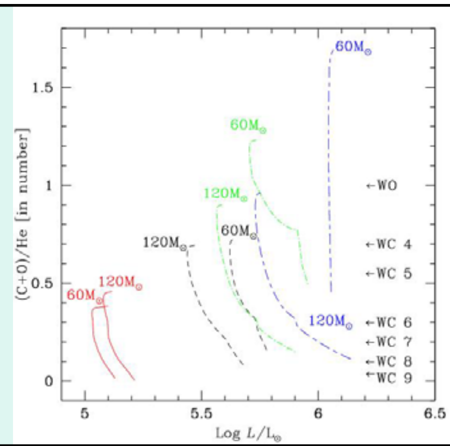
1. Rotation and transport of angular momentum affects stellar evolution in two ways:
   a. evolution of the rotation
   b. mixing of nuclear products

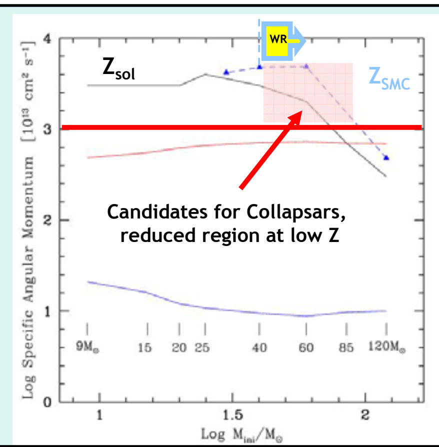
2. Star in low metallicity galaxies rotate faster than at high metallicity. This has important consequences for the first generation of stars

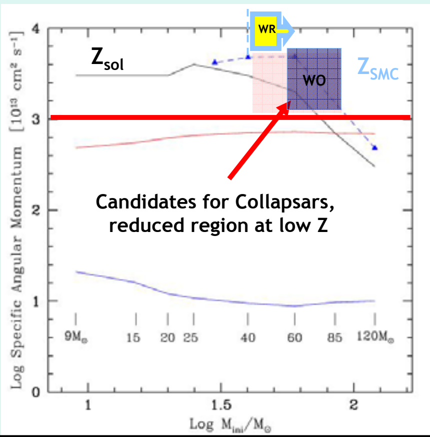
3. Rotation results in enhanced polar mass loss.
   - this will lead to an increase of $\omega=\Omega/\Omega_{crit}$ on the main sequence.
   - this might explain the eruptions in Luminous Blue Variables (?)

4. Rotational mixing can explain (at least qualitatively)
   - the appearance of nuclear products on the surface of massive star
   - the ratio of WR/O stars and ratio of SNIbc/SNII

5. Rotation and transport of angular momentum in low metalicity stars might help to explain the occurrence of GRBs (?)







At Z=0.004

~1% of the Core collapse supernovae are of type Ic