Challenges in the understanding of the evolution of massive stars

Anahí Granada, Instituto de Astrofísica La Plata (IALP)

In replacement of **Georges Meynet, Geneva University**

Massive Stars & Supernovae, San Carlos de Bariloche, November 6th 2018

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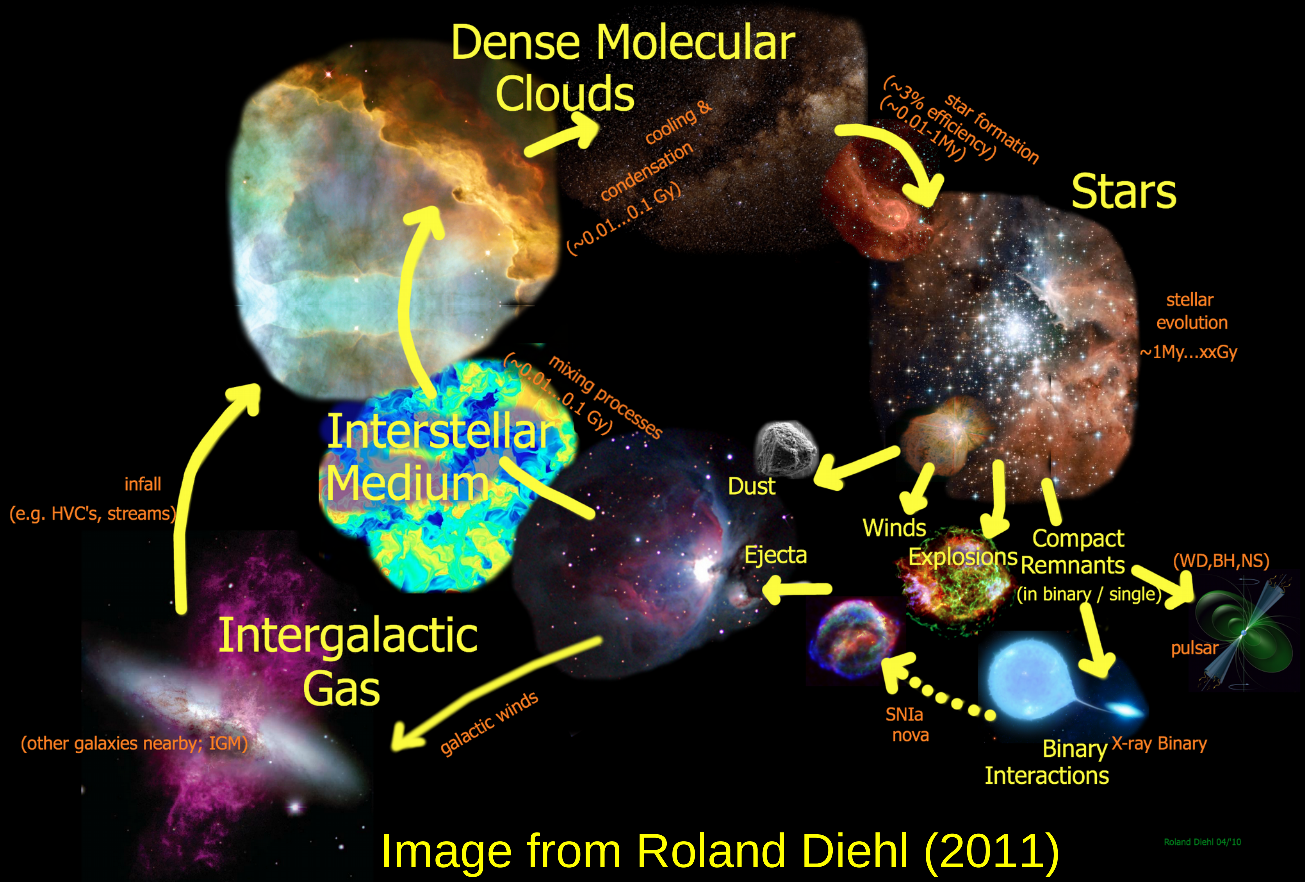


Image from Roland Diehl (2011)

THE CHALLENGES

CONVECTION → **physics of the boundaries of the convective zones?**
→ **how to go beyond the mixing length theory?**

MASS LOSS → **impact of pulsation, dust?**
→ **origin/frequency/conditions for outbursts?**

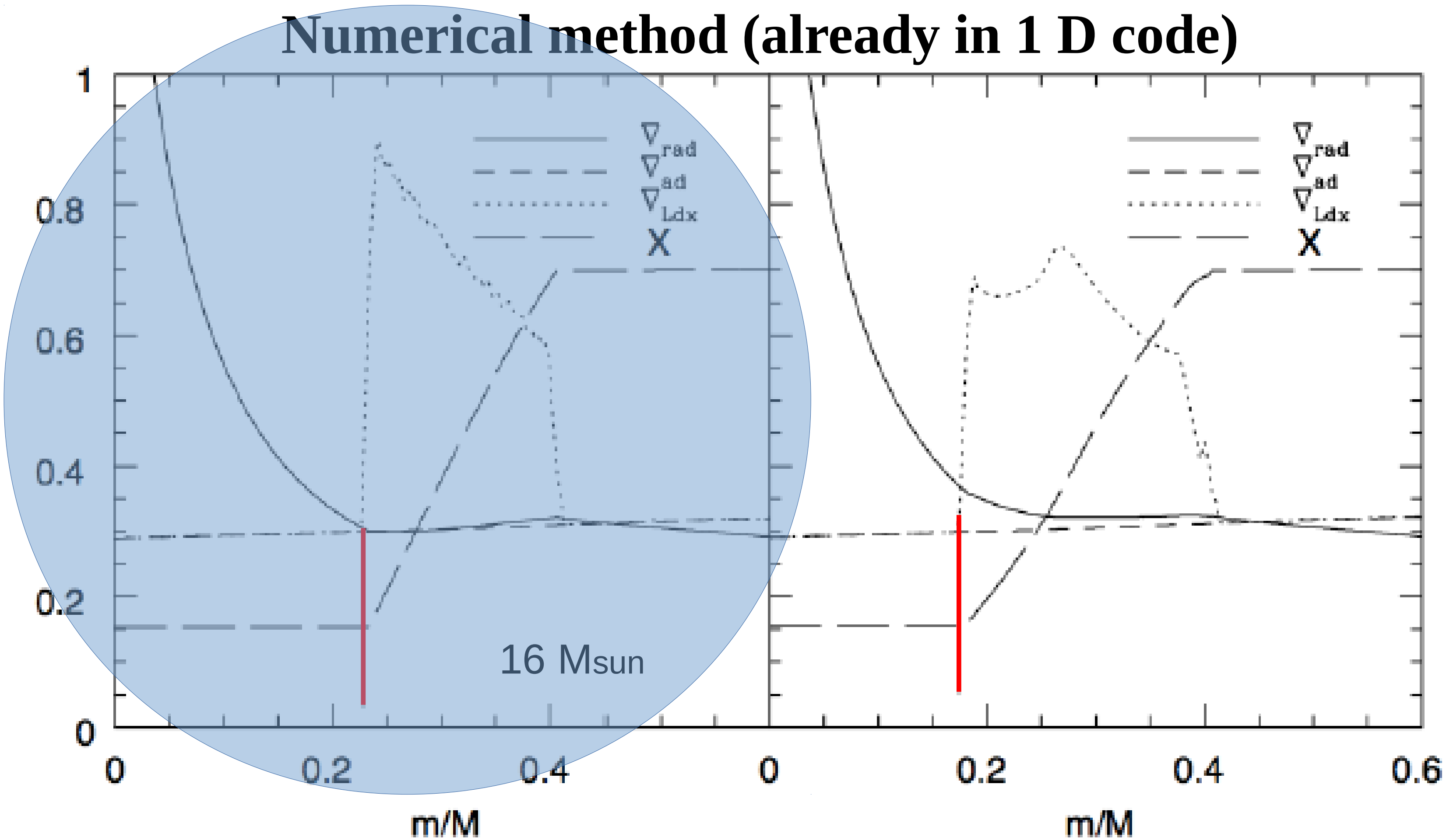
ROTATION → **transport processes?**
→ **origin of fast rotators?**

MAGNETIC FIELDS → **impact of wind magnetic braking?**
→ **impact on the core rotation at the pre-SN stage?**

MULTIPLICITY → **Is mass transfer/CE phase the sole significant effects?**
→ **How to handle with the numerous parameters?**

CONVECTION

Numerical method (already in 1 D code)



Gabriel, Noels, Montalbàn, Miglio 2014, A&A 596, A63

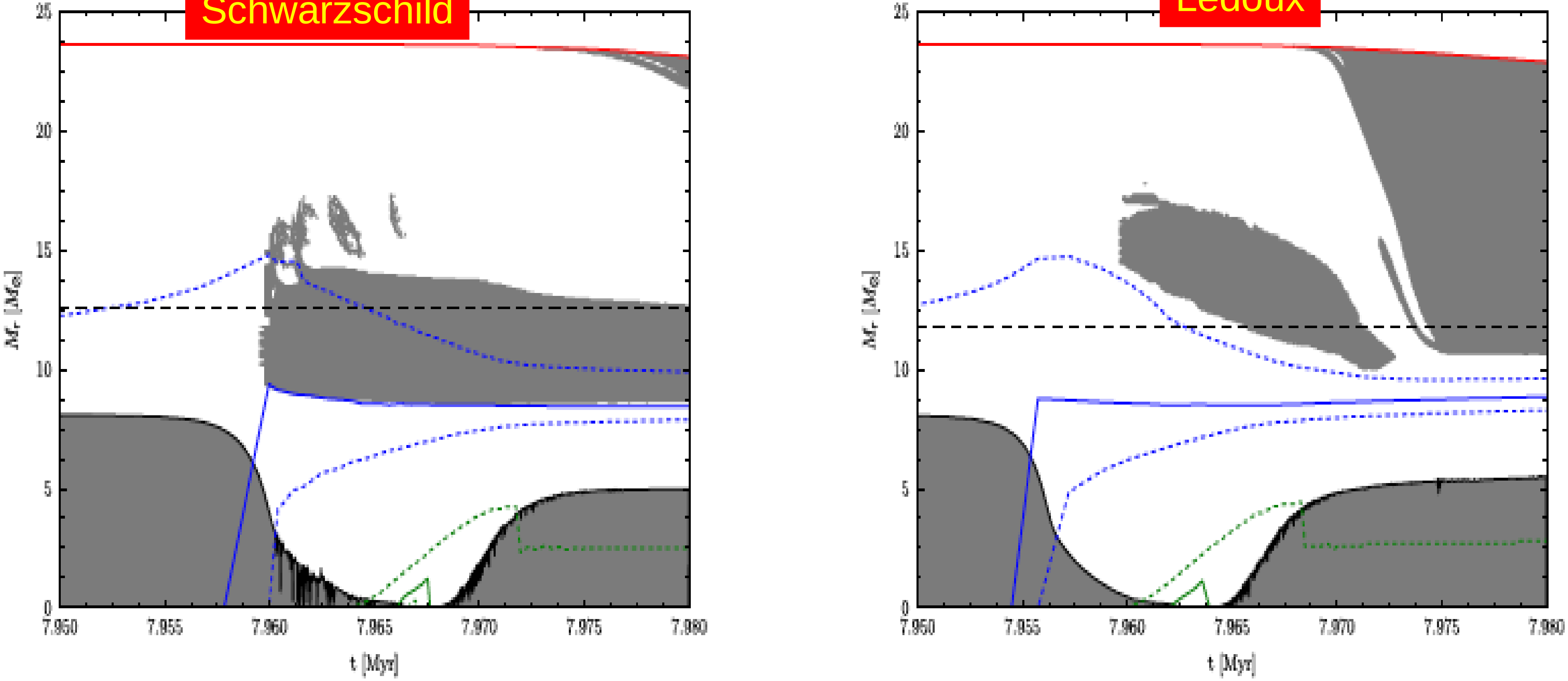
Position of the convective boundaries--> interp/extrapolation from within the convective region.

CONVECTION

25 Msun (second crossing BSG)

Schwarzschild

Ledoux



Georgy, Saio, GM, 2014, MNRAS, 439, L6

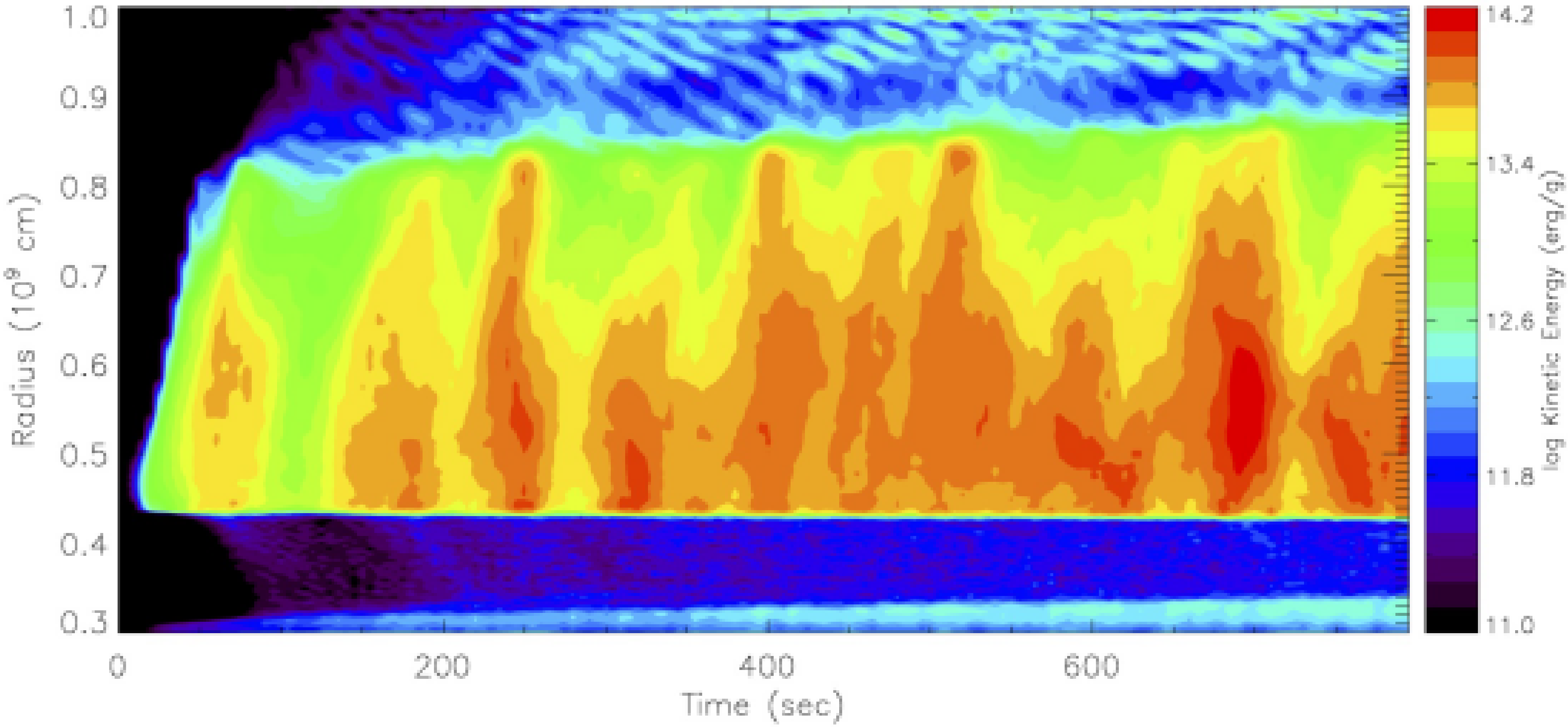
Surface abundances

model/star	N/C	N/O	X_{He}
"Schwarzschild" (model)	57.86	4.17	0.635
"Ledoux" (model)	6.97	1.61	0.458

CONVECTION

'Extrapolating the weather to determine the climate.'

Arnett & Meakin 2016,
Reports on Progress in Physics, Volume 79, Issue 10, article id. 102901



Arnett & Meakin 2007
See also Cristini et al. 2016

MASS LOSS : wind or outbursts

Impact on evolution

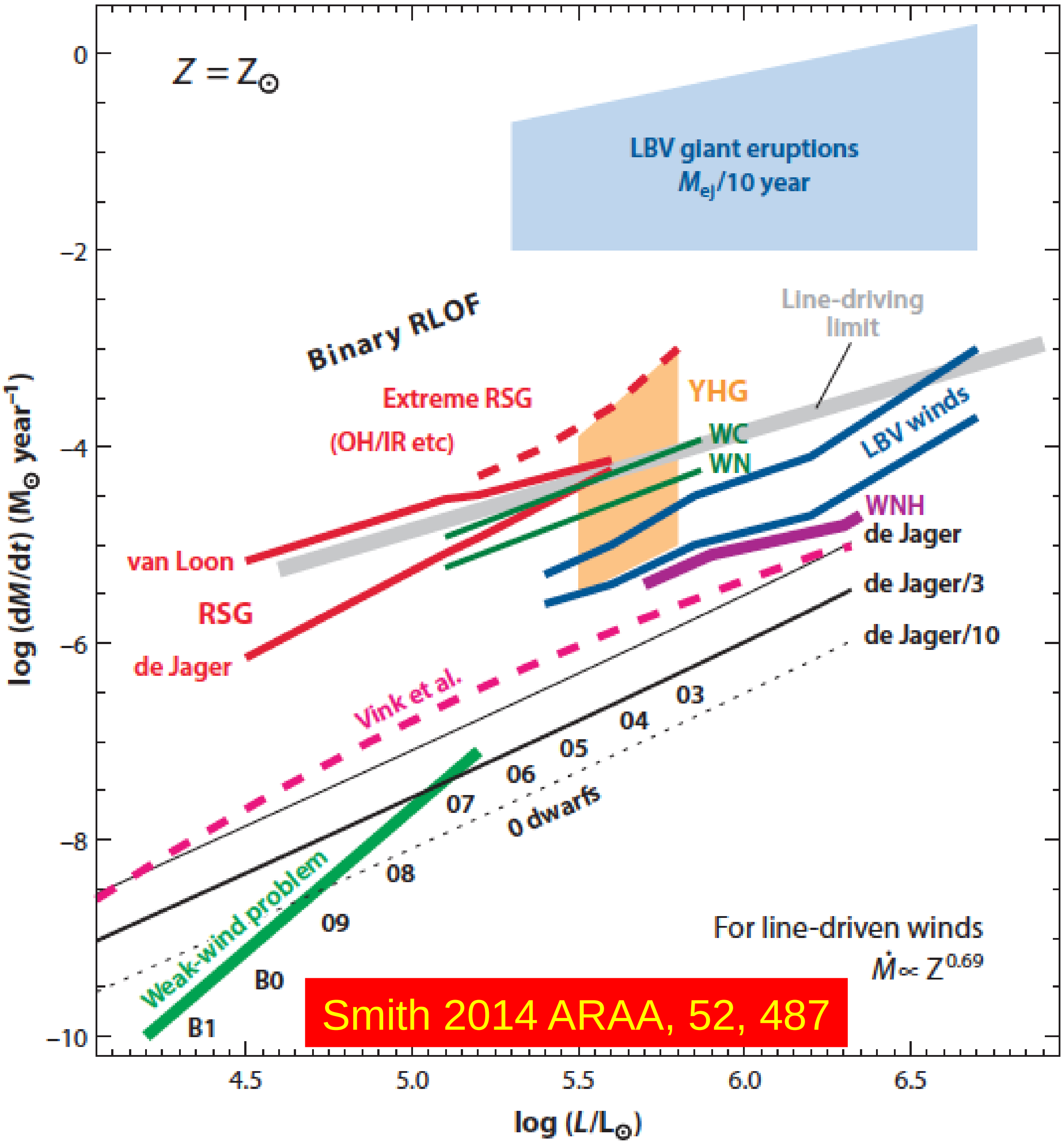
→

$\Delta M = dM/dt \, \Delta t$

Continuous processes

or

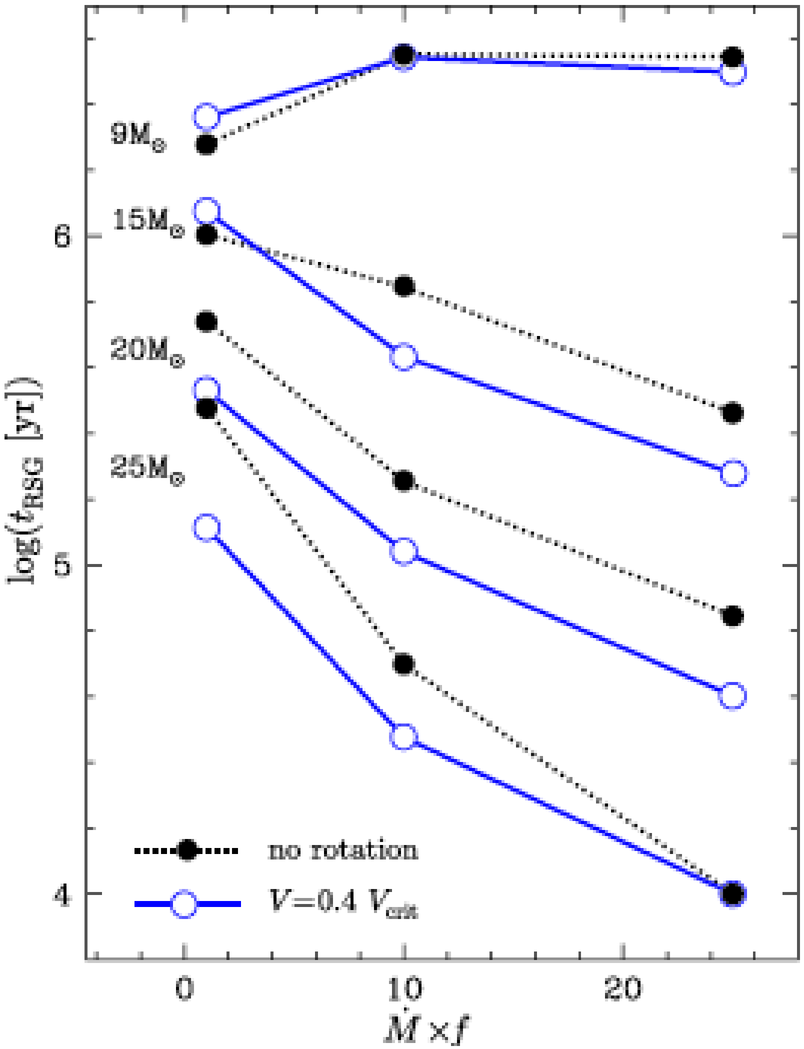
outbursts

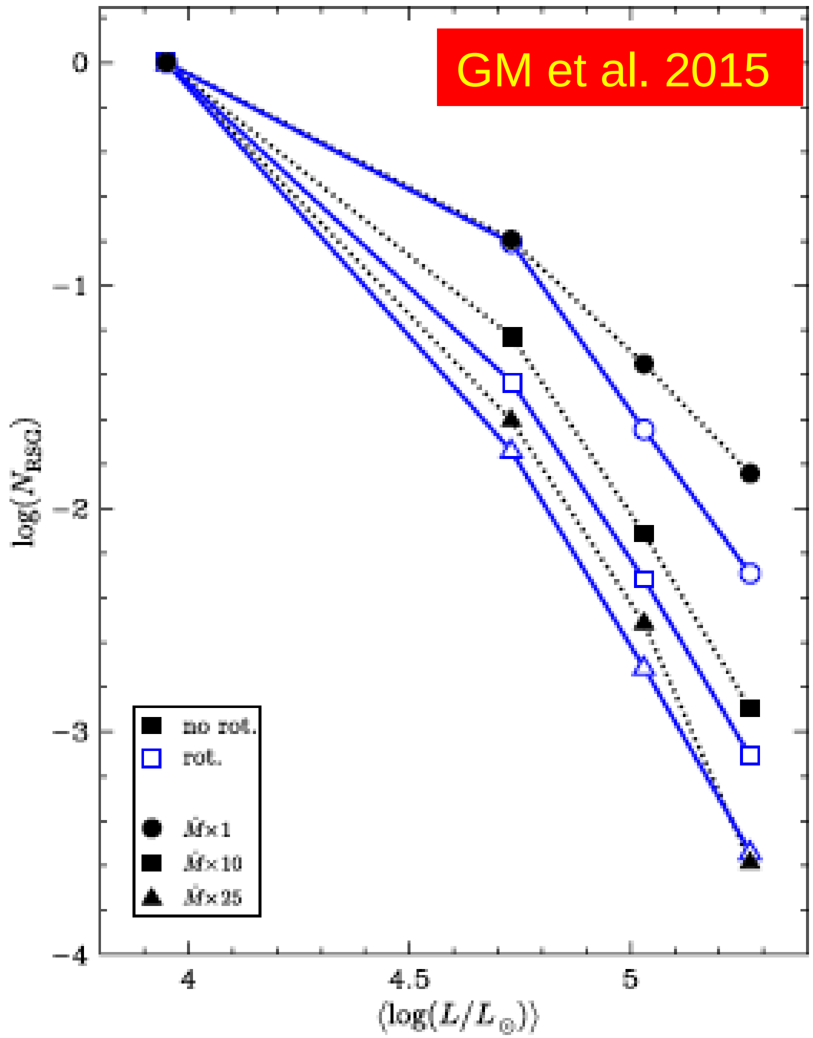


Smith 2014 ARAA, 52, 487

MASS LOSSES

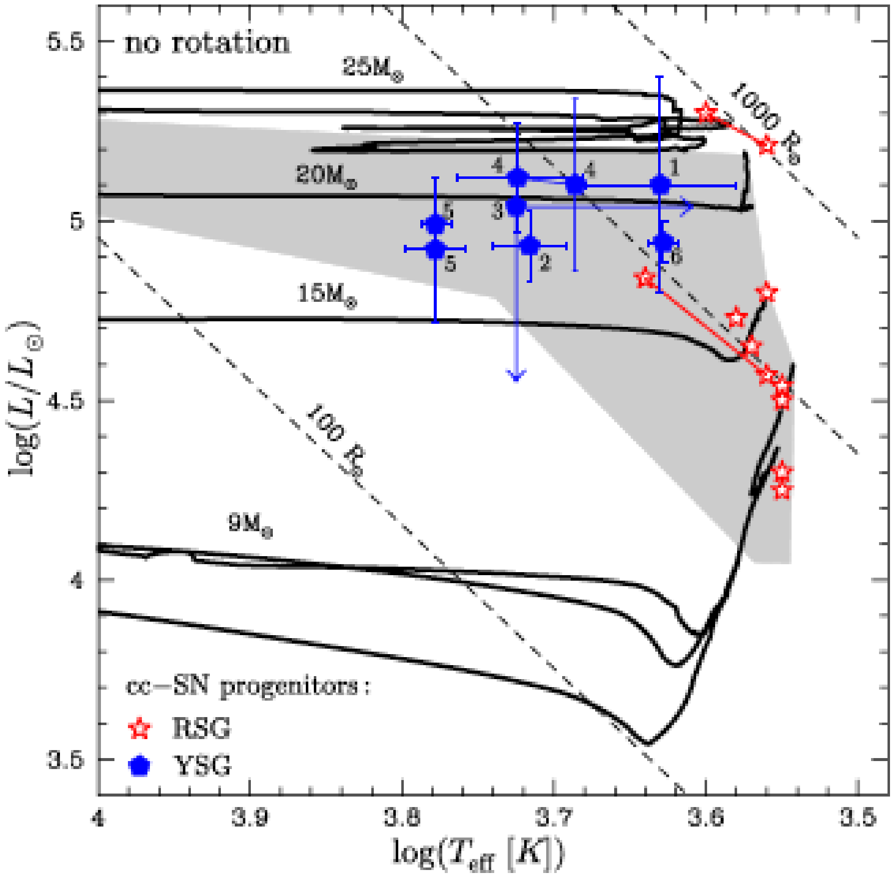
The luminosity function of RSG depends on the mass losses during the RSG phase

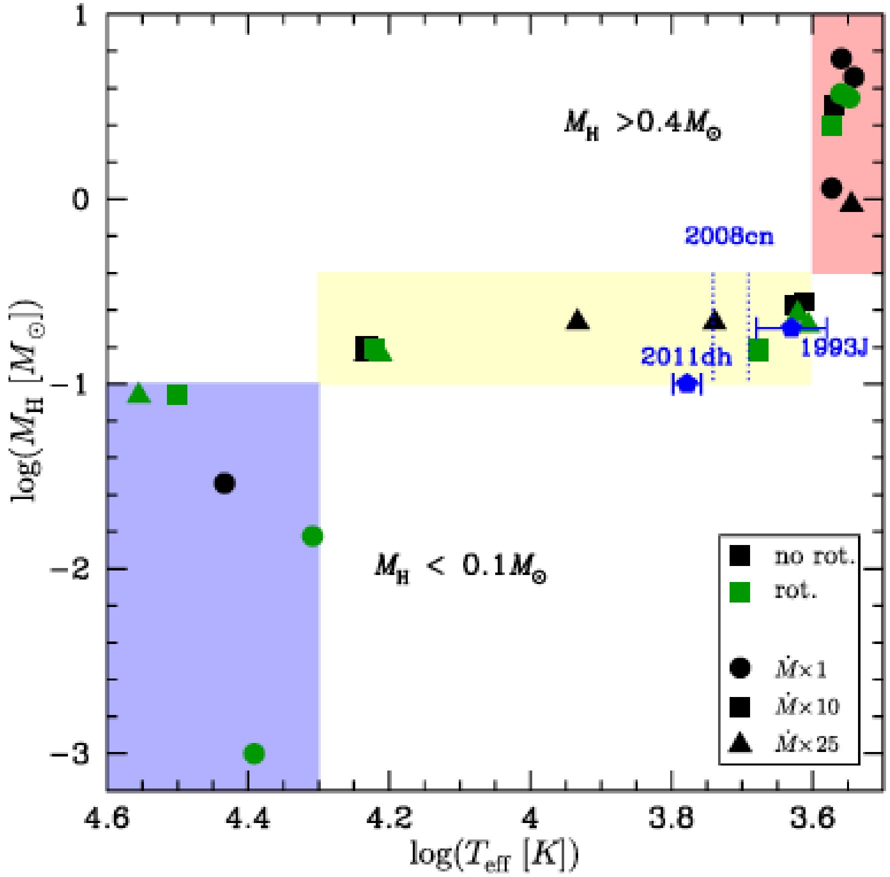




MASS LOSSES

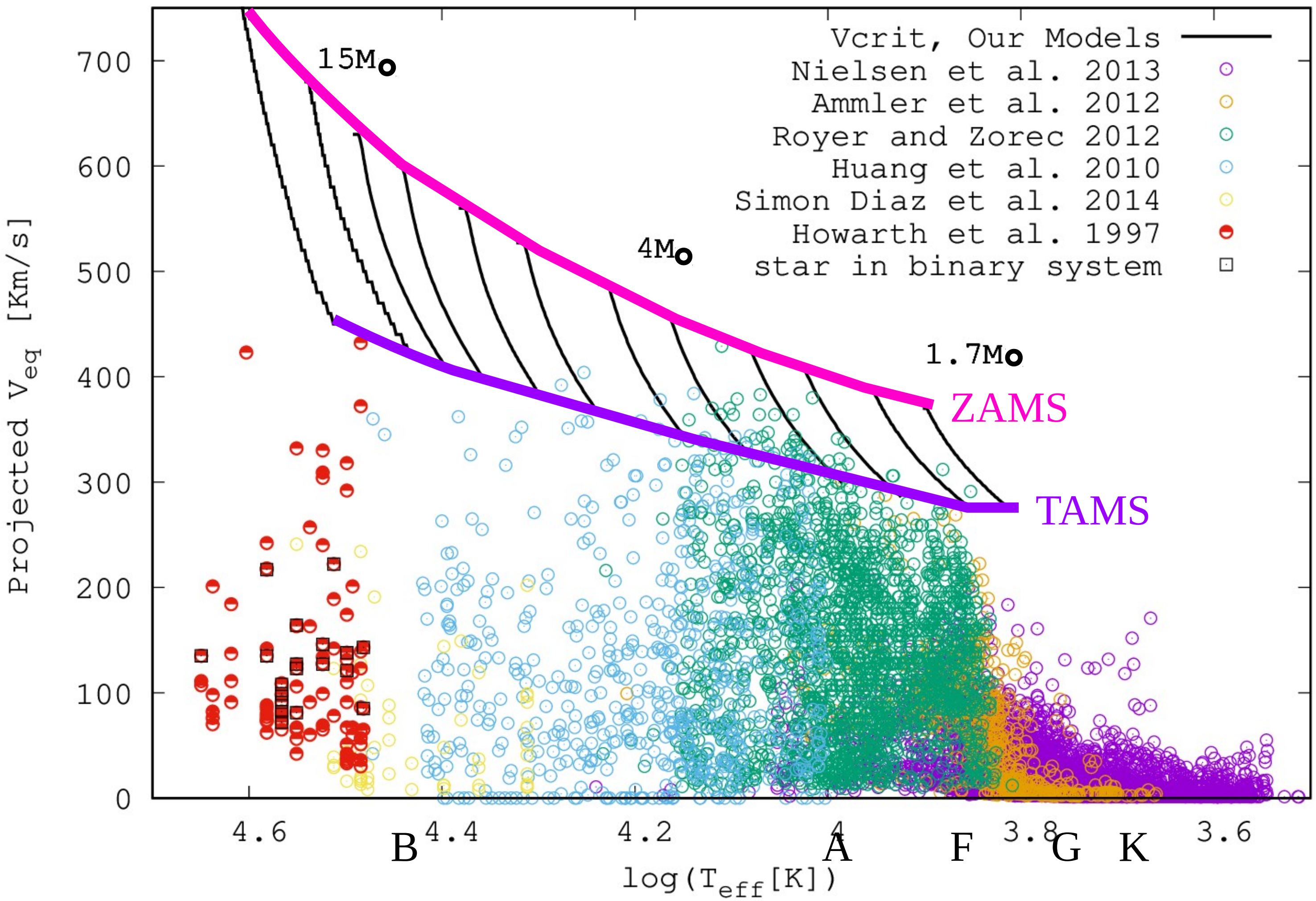
Impact on the CCSN progenitors





Georgy 2012, A&A 538, L8; GM et al. 2015, 575, A60

ROTATION



Rotation of LC V stars reflects the different mechanisms governing the formation and evolution of stars

TRANSPORT PROCESSES INDUCED BY ROTATION

What is needed : -An energy reservoir

-A process which extracts energy from this reservoir for producing a movement

Two types of energy reservoir

1) Excess energy in differential rotation

2) Energy of rotation

Gradient of Ω needed

Ω needed

The process is viscosity

The process is meridional circulation

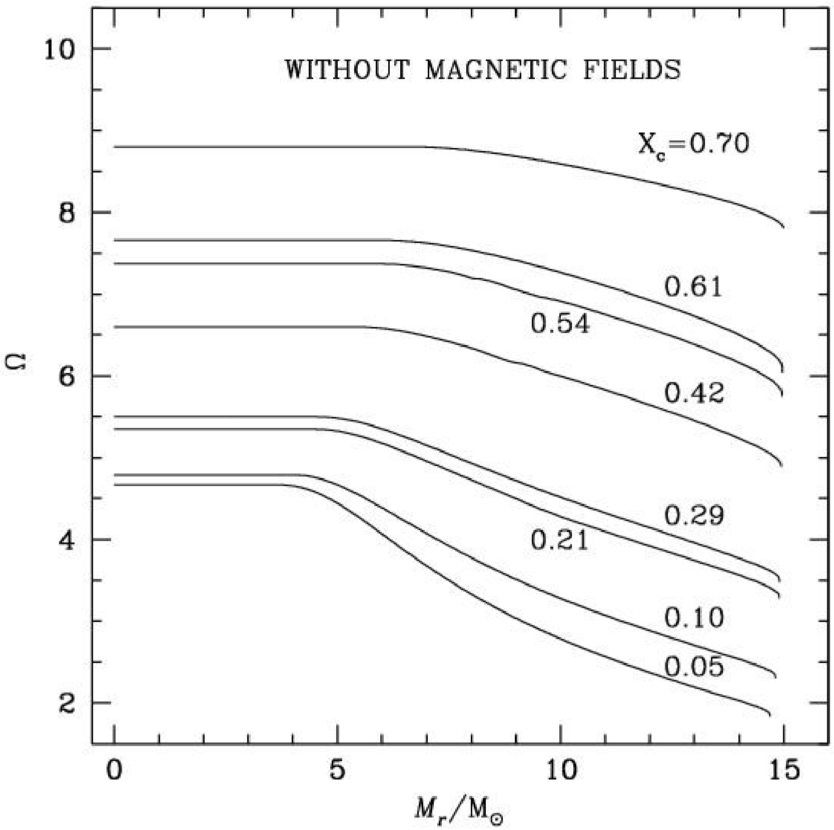
WITHOUT INTERNAL MAGNETIC FIELD	WITH INTERNAL MAGNETIC FIELD
Weak coupling	**Strong coupling**
Zahn 1992	Spruit 1999, 2002 But Zahn et al. 2007
Differential rotation Mixing of the elements due to shear Efficiency of mixing ≈ $d\Omega/dr$	**Solid body rotation** Mixing of the elements due to meridional circulation Efficiency of mixing ≈ Ω

CONSEQUENCES FOR THE EVOLUTION OF THE ANGULAR MOMENTUM

THE TWO FAMILIES OF ROTATING STELLAR EVOLUTION MODELS

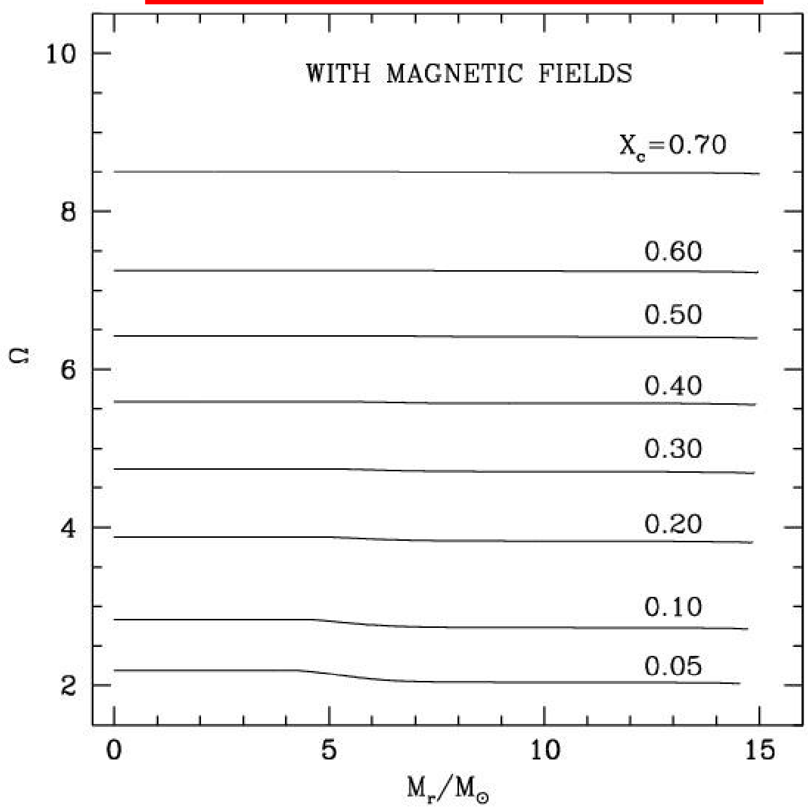
MODELS WITHOUT INTERNAL MAGNETIC FIELDS

MIXING IS SHEAR DRIVEN



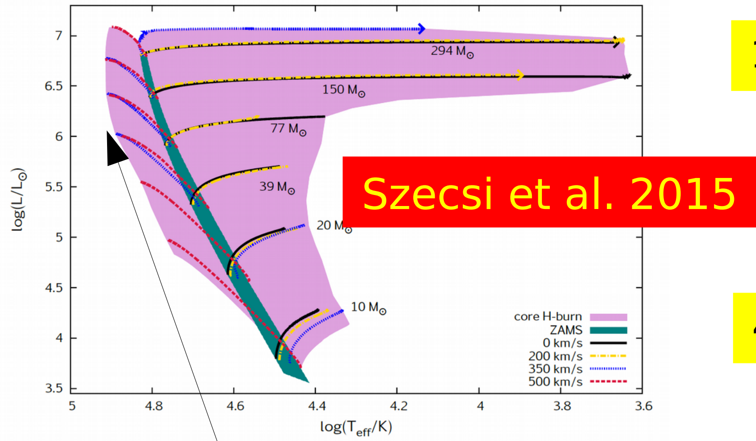
MODELS WITH INTERNAL MAGNETIC FIELDS

MIXING IS DRIVEN BY MERIDIONAL CURRENTS



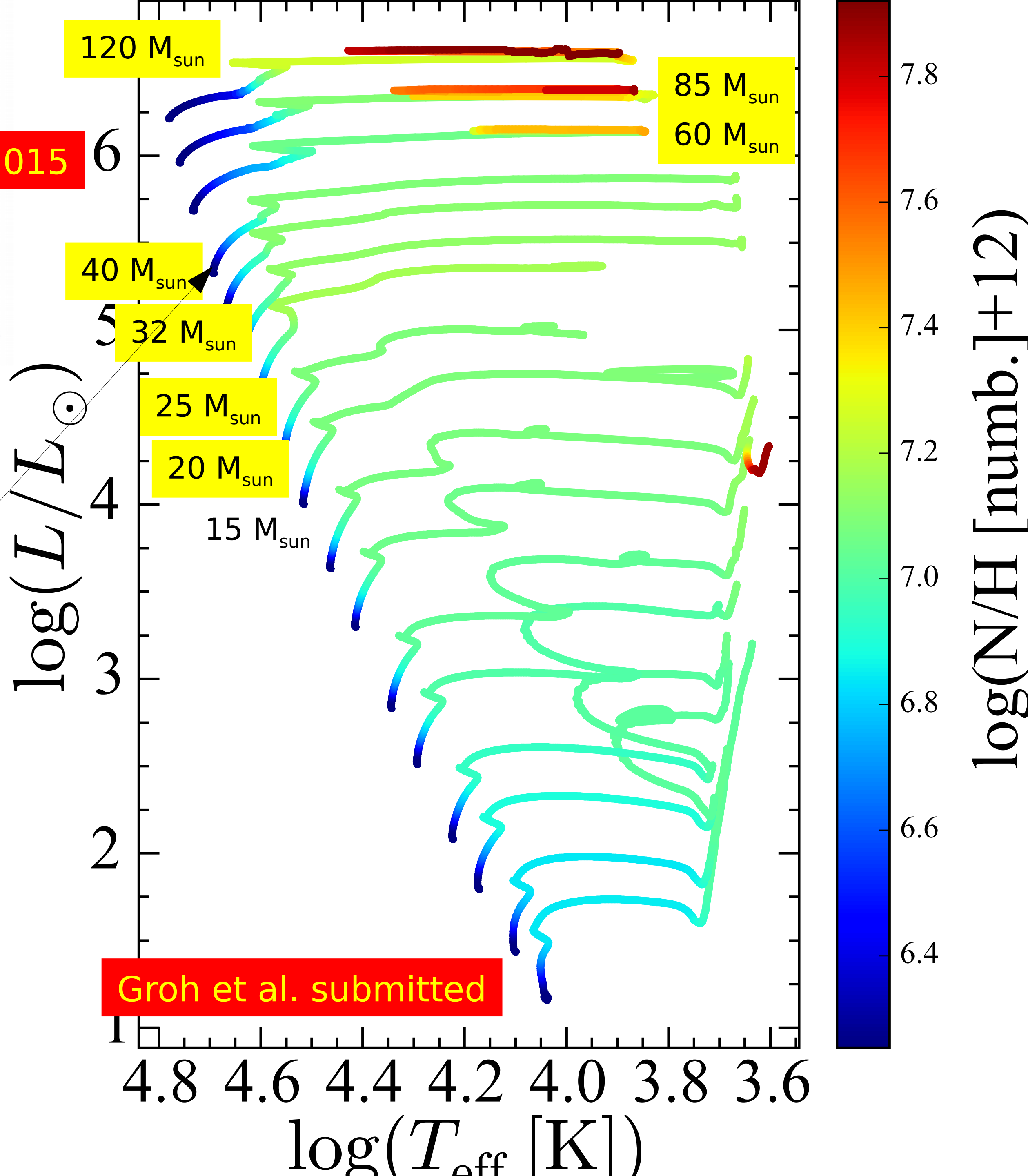
Maeder & Meynet 2005

Mixing efficiency increases
with rotation, initial masses, decreasing metallicity in both cases

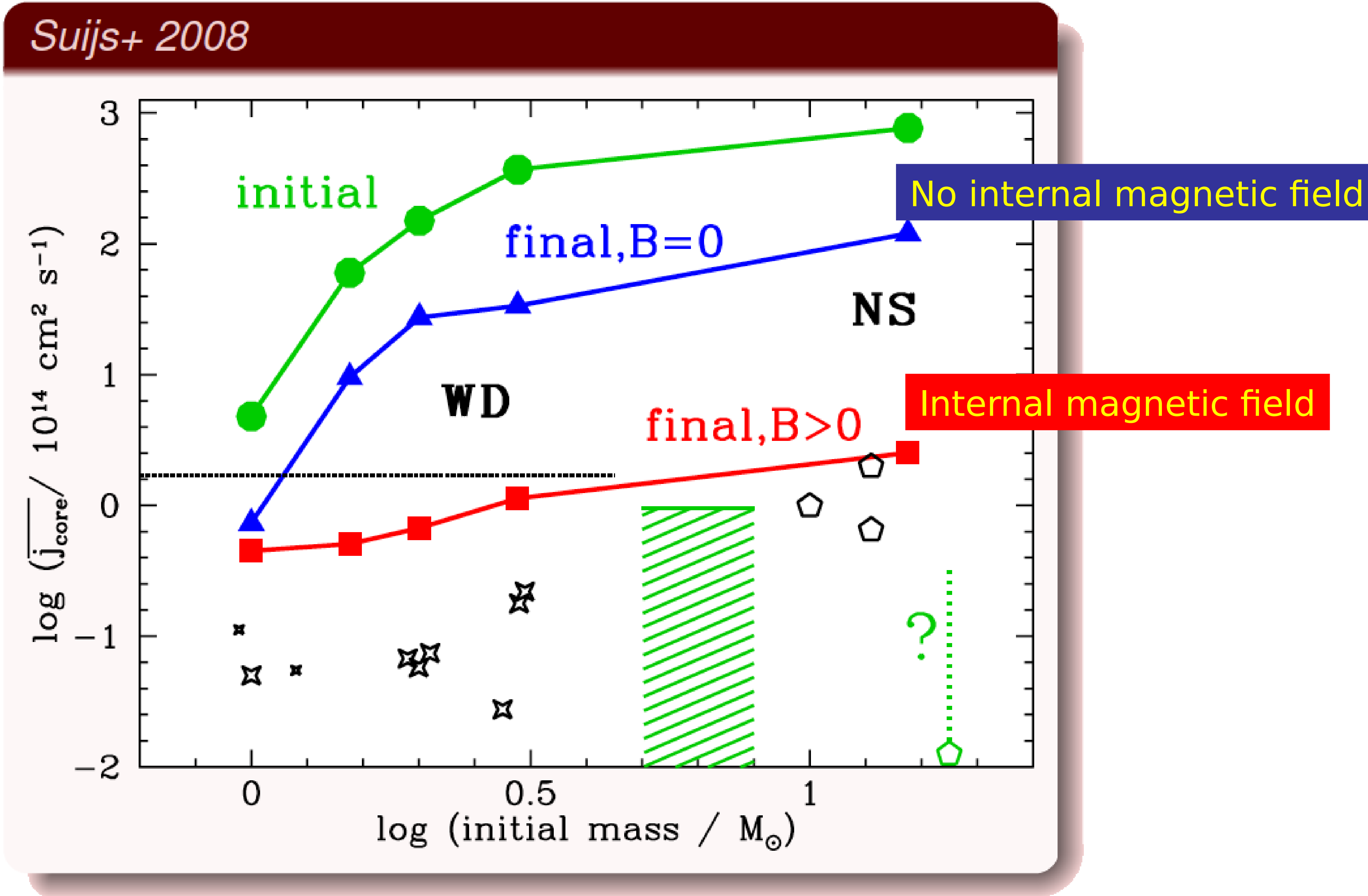


M_{ini} [M_{sun}]	V_{ini} km s^{-1}
150	350
77	350
39	350

M_{ini} [M_{sun}]	V_{ini} km s^{-1}
120	463
85	469
60	435
40	393
32	366
25	343
20	314



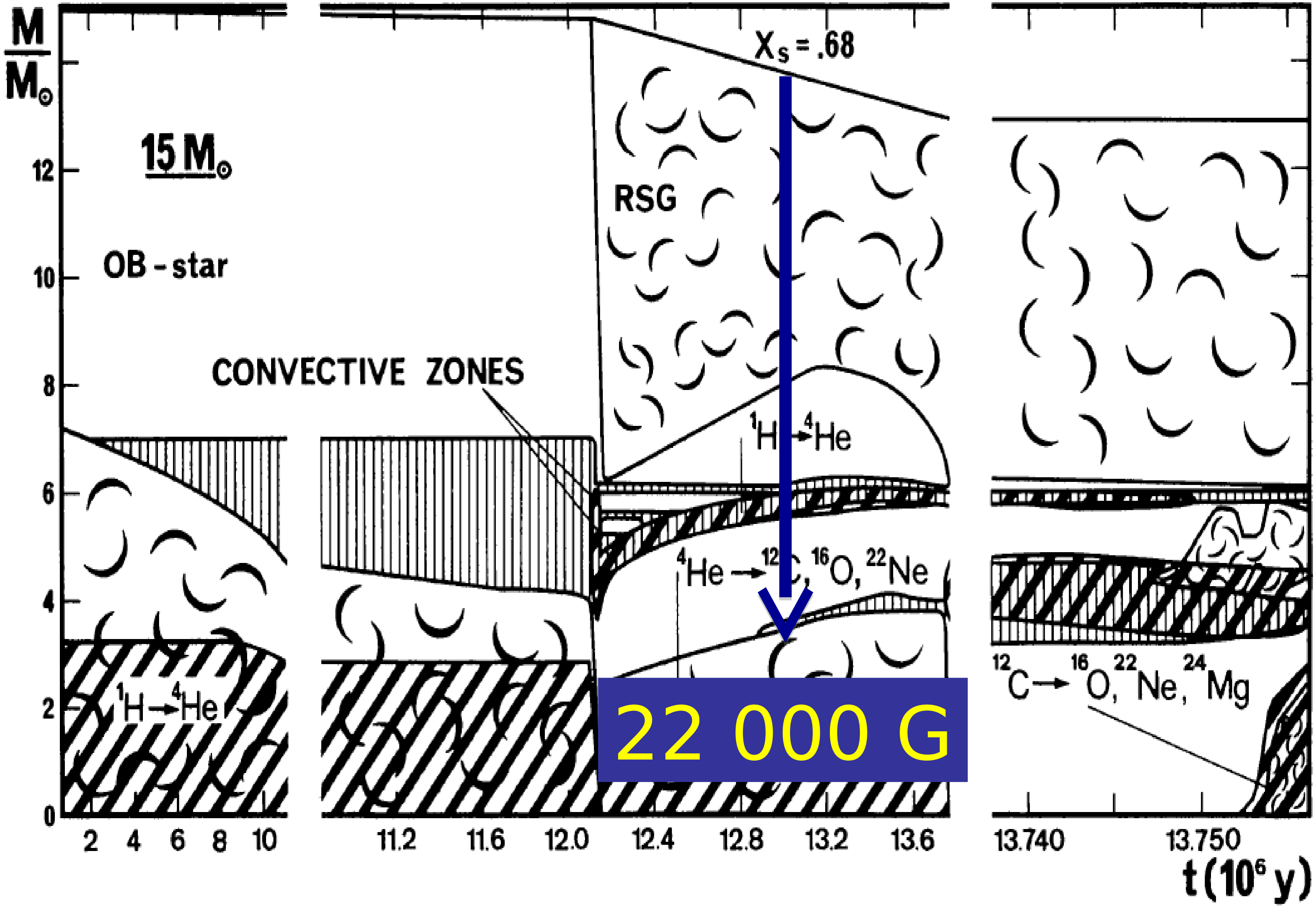
Angular momentum in the remnant



Magnetic coupling between the core and the intermediate radiative zone ?

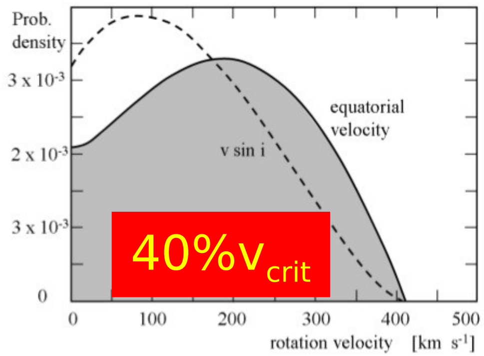
Maeder and Meynet (2014)

If Pulsar 10^{12} G for a density of $10^{14.6}$ g cm^{-3}, flux conservation→B_c~22 000 G in core at mid He-burning phase



A few Challenges in massive star evolution

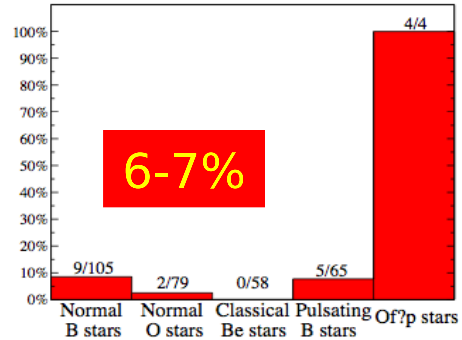
ROTATION



40%v_{crit}

Huang et al. 2010

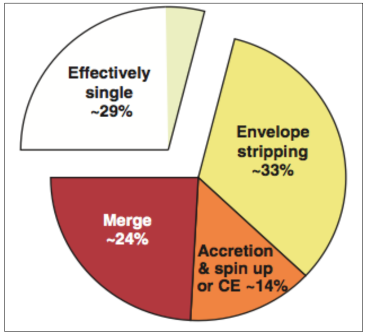
MAGNETIC FIELD



6-7%

MIMES Survey (Wade et al.)

MULTIPLICITY



50-70%

Sana et al. 2012

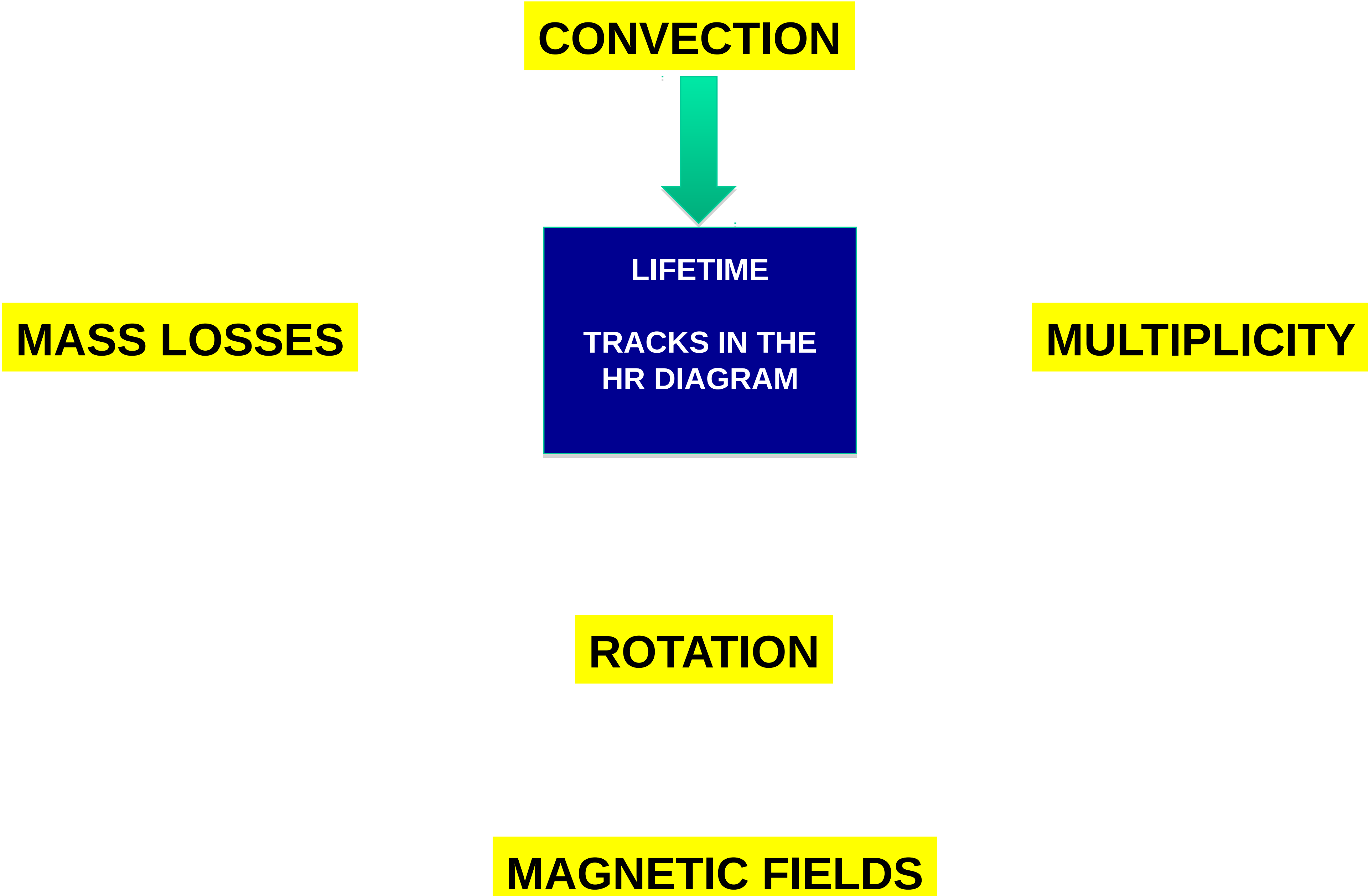
What is the origin of these distributions

How do these distributions vary with metallicity?

How do these distributions vary with the environment? (e.g. stellar density)

What are the impacts on the interior?

THESE PROCESSES ARE INTERCONNECTED



THESE PROCESSES ARE INTERCONNECTED

CONVECTION

LIFETIME

TRACKS IN THE HR DIAGRAM

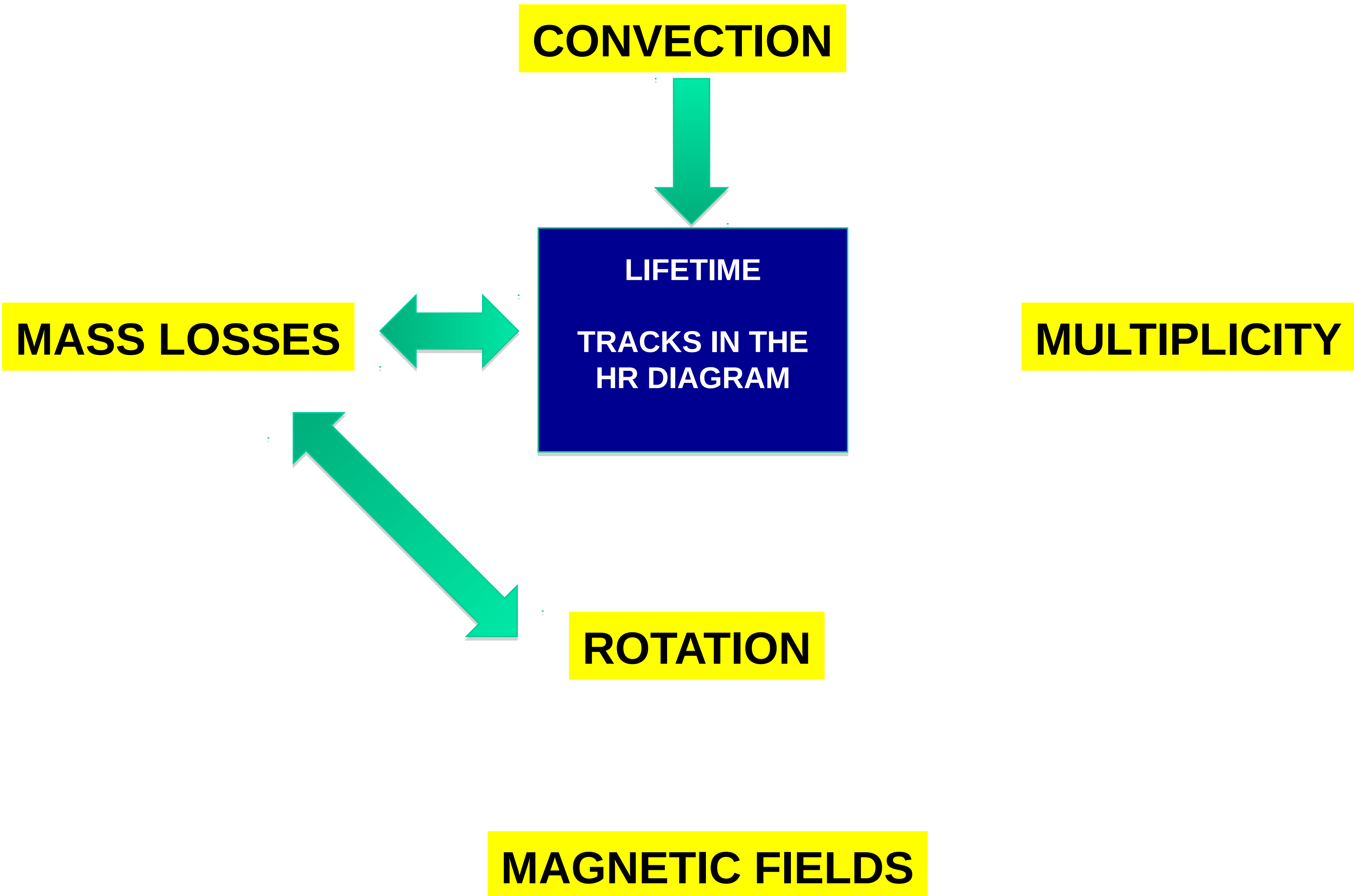
MASS LOSSES

MULTIPLICITY

ROTATION

MAGNETIC FIELDS

THESE PROCESSES ARE INTERCONNECTED



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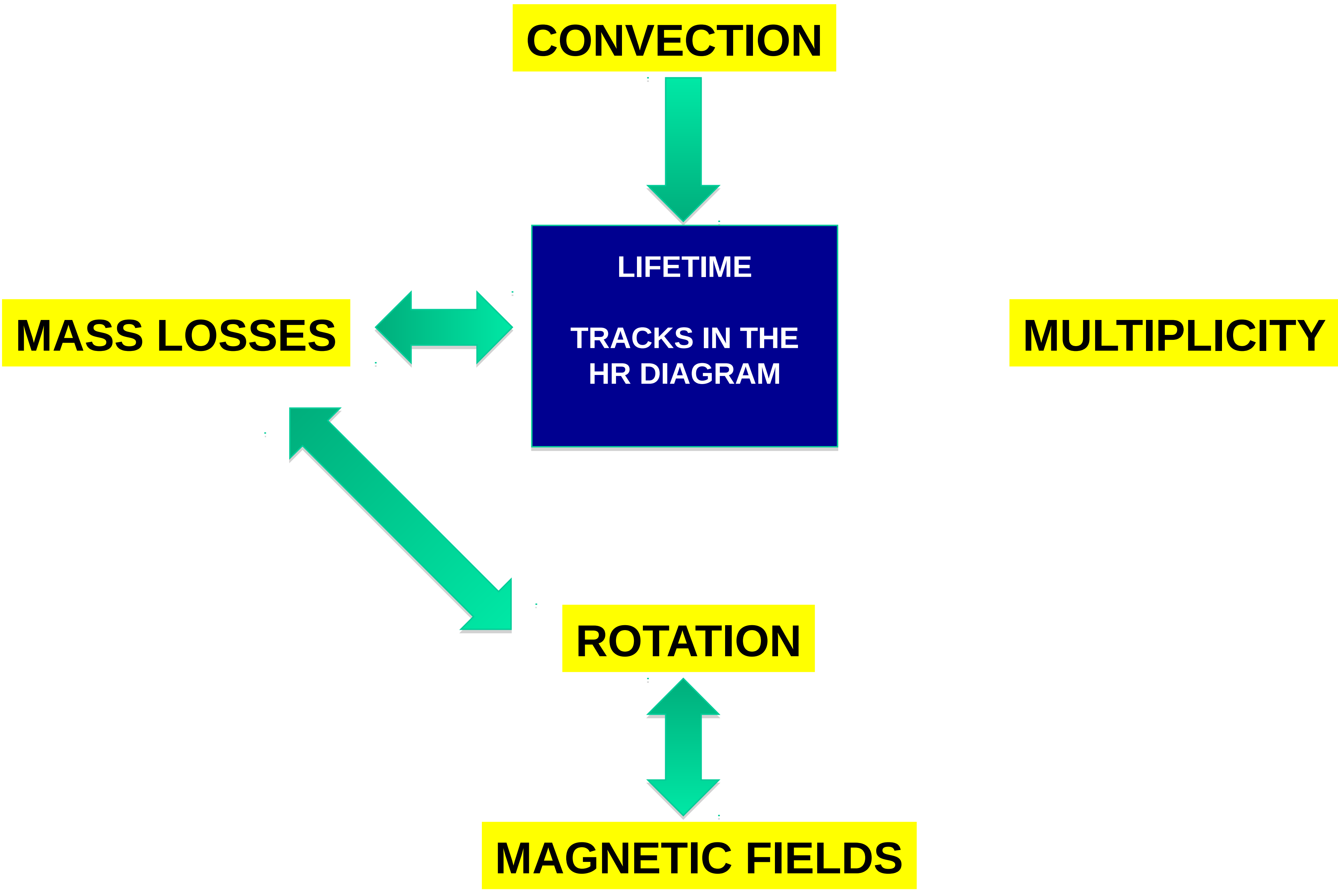

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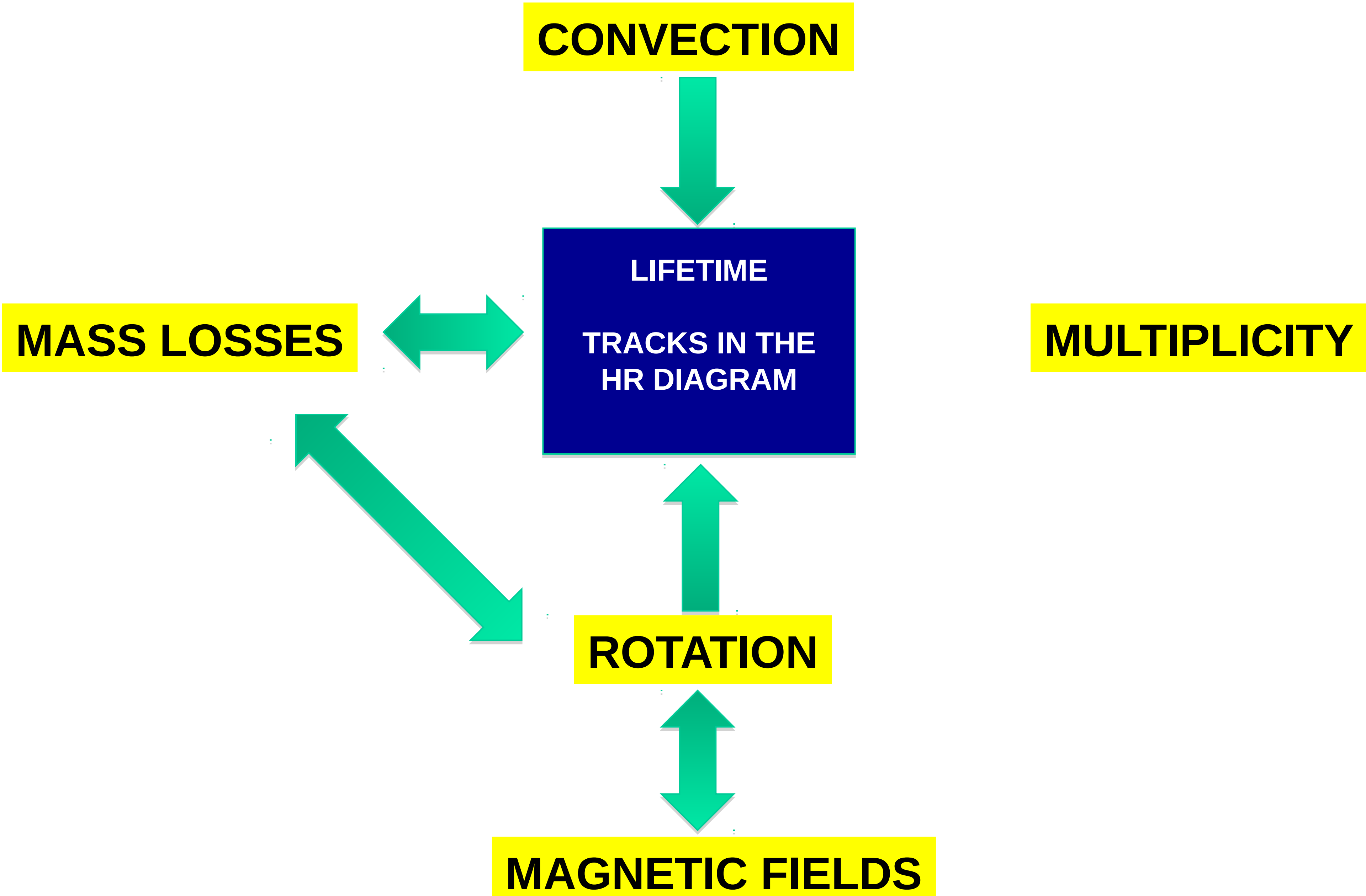

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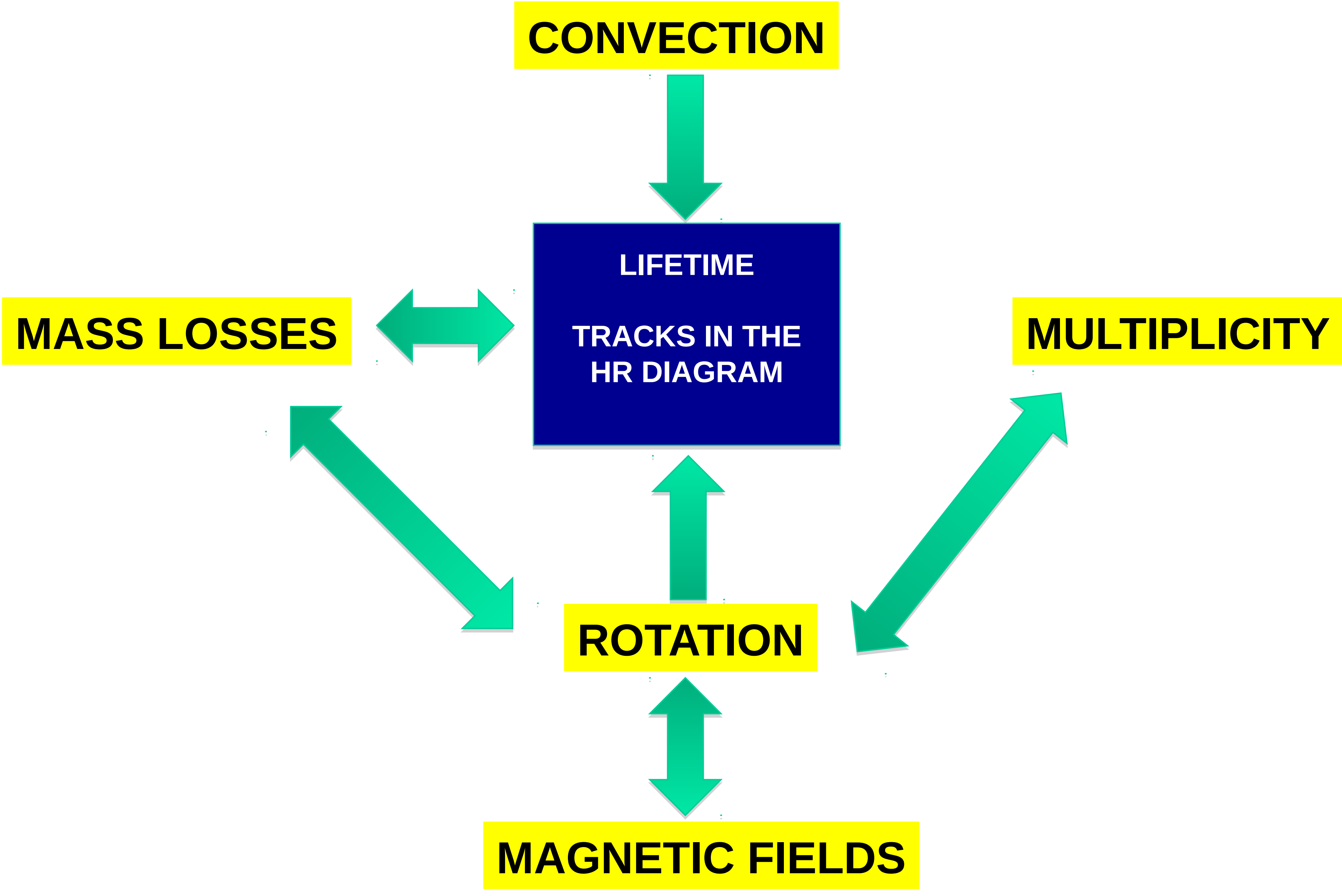

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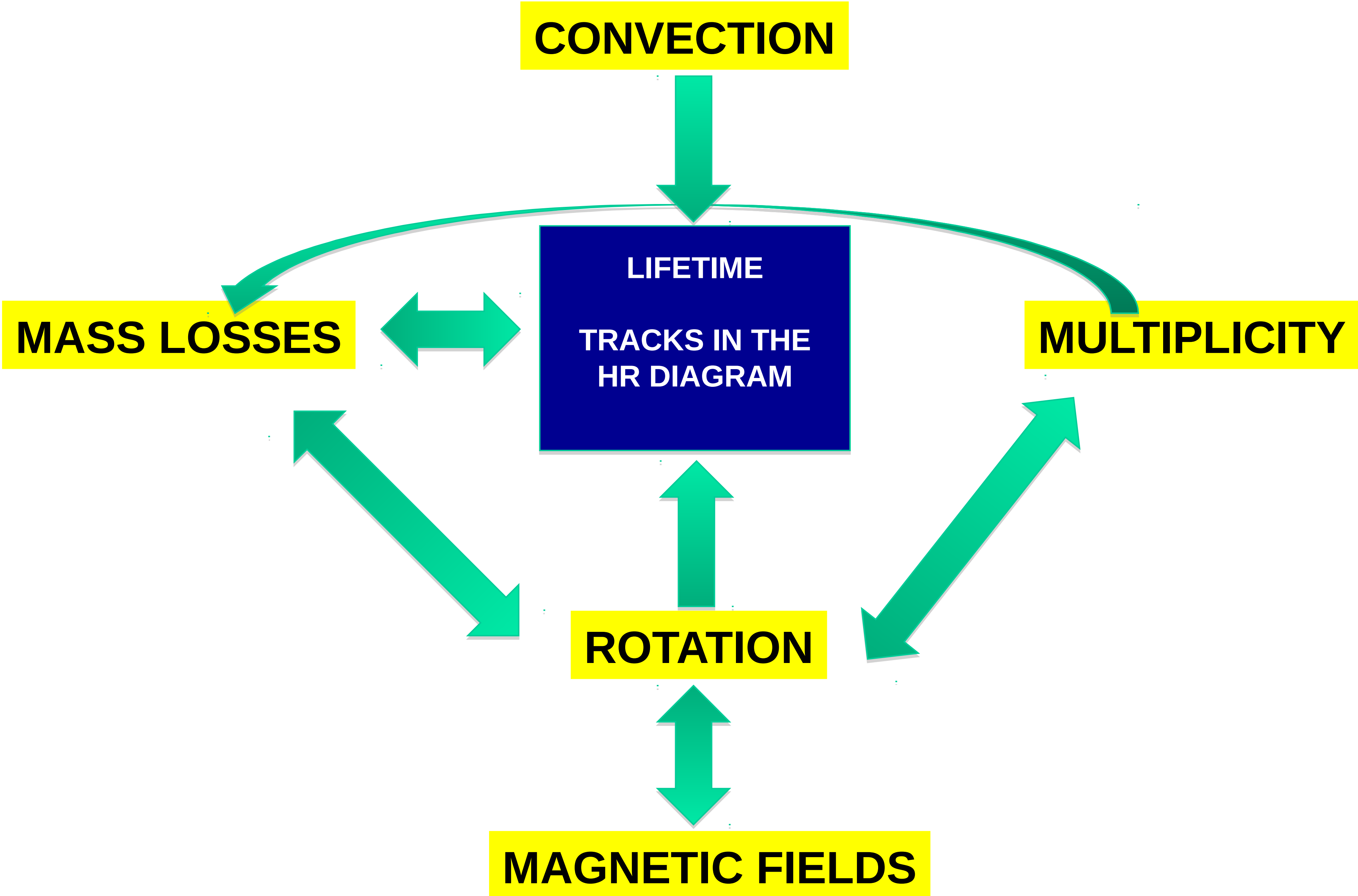

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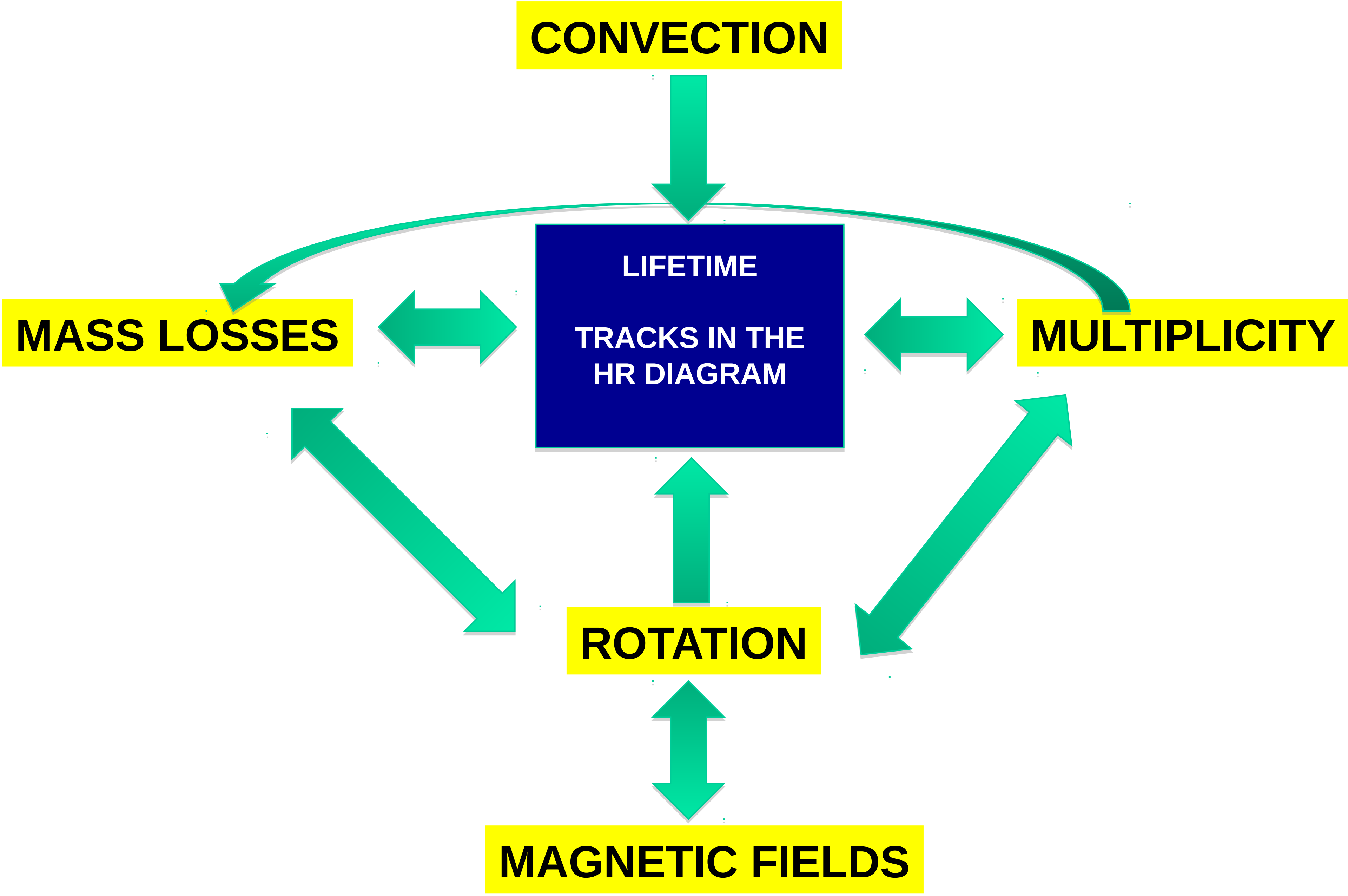

THESE PROCESSES ARE KEYS FOR STARS AND SUPERNOVAE

Lifetime	CONVECTION	CCSN progenitors
Stellar Populations	MASS LOSSES	Supernova type
Surface abundances	ROTATION	SN explosion
Surface velocities	MAGNETIC FIELDS	Light curve
Nucleosynthesis	MULTIPLICITY	Remnant

IMPACT OF CHEMICAL COMPOSITION