The origin of magnetic fields in hot stars

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Magnetism in single hot stars

- 7% of single massive (OB) stars are magnetic
- 5-10% of intermediate-mass AB stars are magnetic

The magnetic fields of single OBA stars are simple, mainly oblique dipoles, with $B_p \sim 100$ to 10000 G.

What is the origin of these magnetic fields?
Core dynamo fields?

A dynamo can generate a field in the convective core.

→ the time needed for the field to be visible at the surface is longer than the lifetime of the star.

(Charbonneau & MacGregor, 2001, Brun et al. 2005)
Dynamo fields in the radiative envelope?

It is not possible to excite/maintain a dynamo in the radiative envelope (Zahn, Brun & Mathis 2007).

Dynamo implies a correlation between rotation and field: not observed.
Dynamo in sub-surface convection zone

→ a dynamo in the sub-surface convection zone can develop

→ these fields are 10 to 100 times weaker than the observed ones

→ They would produce small scale field structures

(Cantiello & Braithwaite 2011)
Fossil fields

- stable analytical mixed configuration of fossil fields predict simple dipole
- simulations of fossil fields reproduce these configurations

These configurations are the ones observed on the main sequence (MiMeS)
They are also observed on the PMS (Alecian et al. 2013)

→ The magnetic field of massive stars is of fossil origin!
Fossil fields

(Extra ?) tilt of the dipole ?

Dipole

Relaxation to dipole

Seed fossil field enhanced by dynamo
Interaction between a core dynamo and a fossil field

ASH 3D simulations: interaction of dynamo in core and fossil field in envelope

Modifications:
- strengthen the core field
- makes rotation of the envelope more rigid
- changes the orientation of the fossil field

(Featherstone et al. 2009)
Impact of rotation on a fossil field

Theoretical calculations show that

- rotation does not affect the magnetic configuration (Emeriau & Mathis 2014)
- rapid rotation hinders stability of the fossil fields (Emeriau et al. 2015)

→ This would explain why magnetic fields have not been directly detected in classical Be stars so far
→ However, two rapidly rotating magnetic B stars exist: HR5907 and HR7355

When stability is not reached, the star can still host an ultra-weak (small-scale?) field (Aurière et al. 2007, Lignières et al. 2014, Braithwaite & Cantiello 2013) → see talk by A. Blazere
BinaMlcs: Binity and Magnetic Interactions in various classes of Stars

→ exploit binarity to yield new constraints on the physical processes in hot and cool magnetic stars
→ 2 large programs: ESPaDOnS@CFHT and Narval@TBL
→ role of magnetism during stellar formation, magnetospheric star-star (and star-planet) interactions, impact of tidal flows on fossil and dynamo fields, impact of magnetism on mass and angular momentum transfer

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Alecian et al. in prep.
Statistical results on magnetism in hot binaries

7 confirmed OBA SB2 systems with a magnetic component → magnetic hot binaries exist

Statistical study: 201 hot (O to F5) SB2 binary targets observed (402 stars) → we should have detected 28-40 magnetic stars (if 7-10% as single stars) → 1 detection of a magnetic F4+F5 system, 0 detection in 200 systems → magnetism is less present (~1%) in hot binaries than in single hot stars

Related to star formation? → no fragmentation of dense core when the medium is magnetic (Commerçon et al. 2011)
Conclusions

- The field of hot stars are simple (oblique dipole), strong and stable → the fields are of fossil origin

- Rapid rotation makes it more difficult for fossil fields to reach stability → explains the lack of fields in classical Be stars?

- ~7% of single OBA stars are magnetic, but only ~1% of binary hot stars are magnetic
  → There are much less magnetic hot binaries than magnetic single hot stars
  → This is probably related to stellar formation and provides constraints on formation theory and simulations