The BinaMIcS project
Massive magnetic binary stars

E. Alecian

Collaborators: C. Neiner, P. Kervalla,
J.-B. Le Bouquin, S. Mathis, G. Wade,
A. Tkachenko, C. Folsom, J. Morin, G. Hussain,
S. Gregory, A. ud-Doula, J. Grunhut, D. Cébron
and the BinaMIcS collaboration

BinaMIcS

Binarity and Magnectic Interaction in various classes of stars

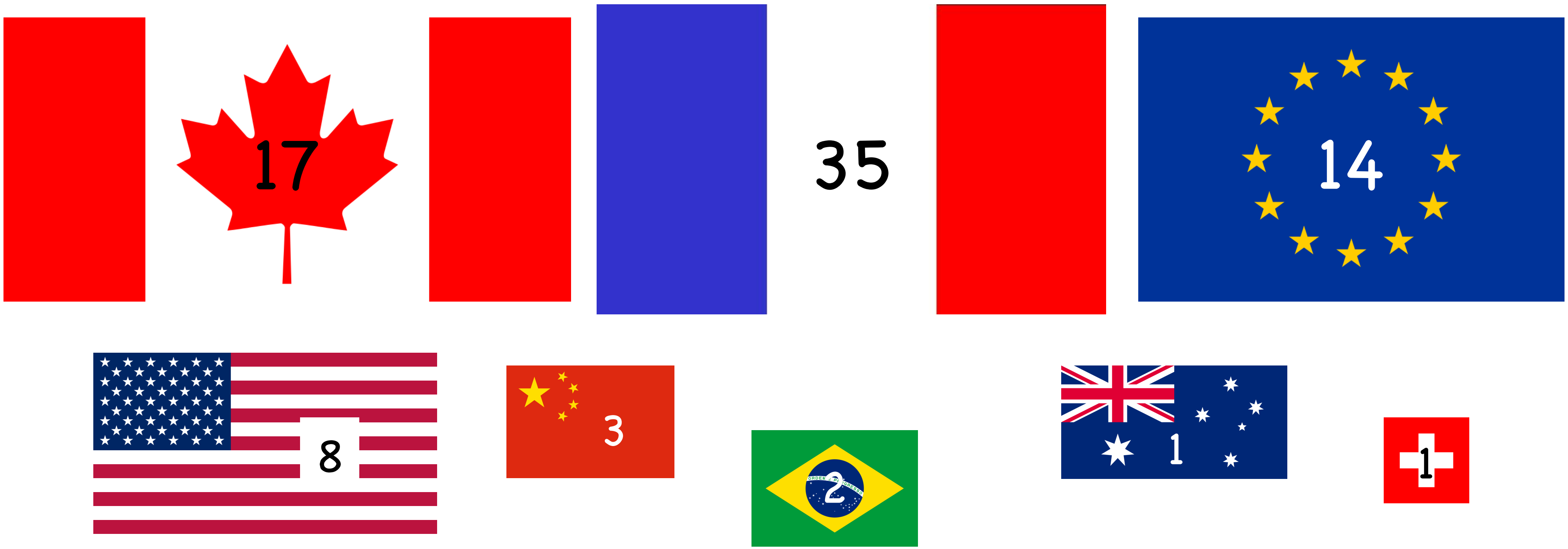
- Aim: use the binarity to bring constraints on the physical processes of a magnetic star

Why Binarity and Stellar Magnetism ?

- Direct measurement of fundamental parameters

- Laboratory of novel physical processes through Star-Star interactions:
  - tidal deformation
  - mutual heating
  - wind-wind collisions
  - magnetospheric coupling
  - pulsation excitation

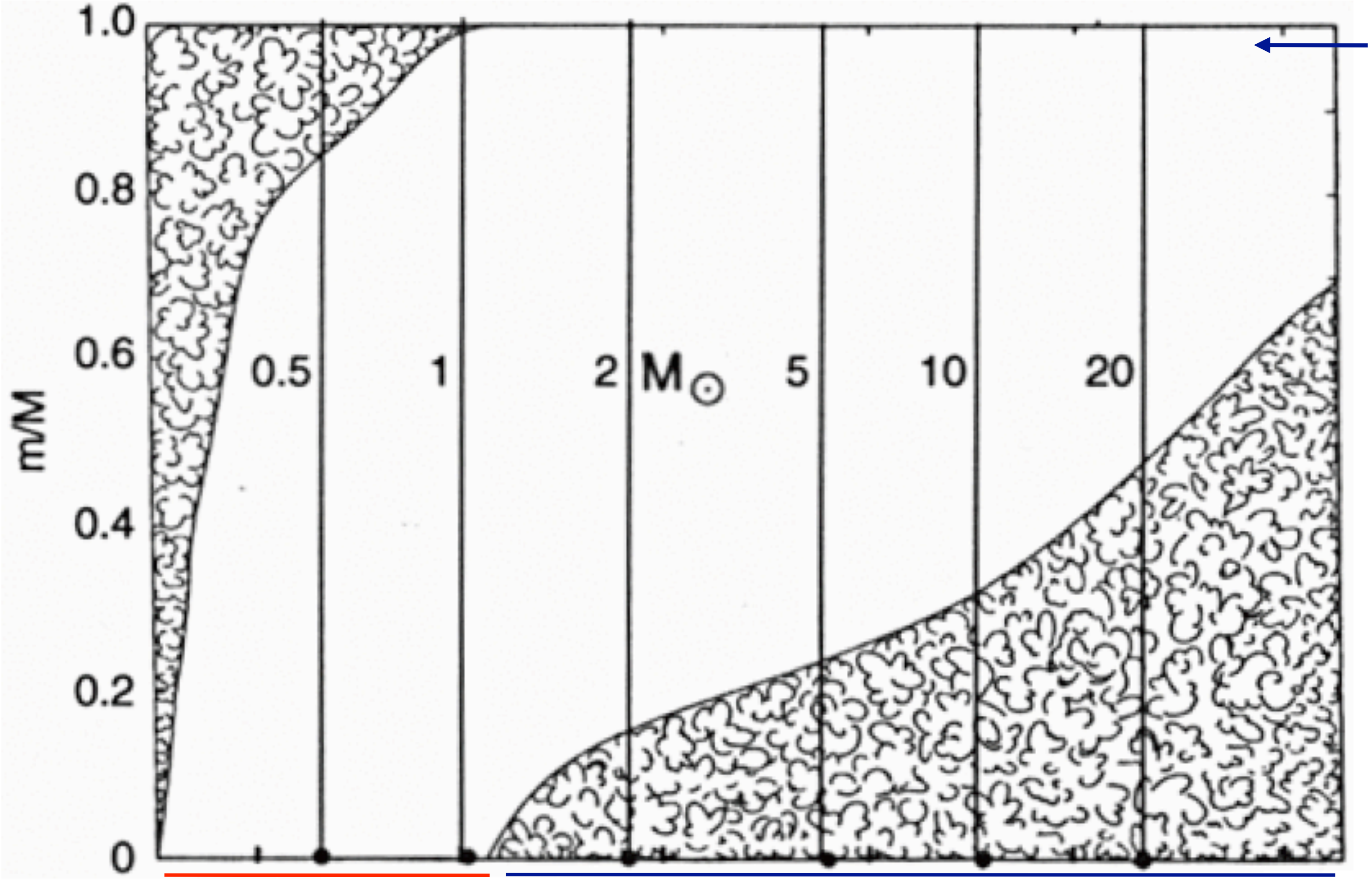
The BinaMIcS collaboration



- PI: E. Alecian
- ~80 scientists
  gathering observers, modellers, theoreticians, specialised in stellar magnetic fields at all mass, and/or binarity
- ~40 institutes, 13 countries

Problematics

Stellar magnetism



Subsurface convection

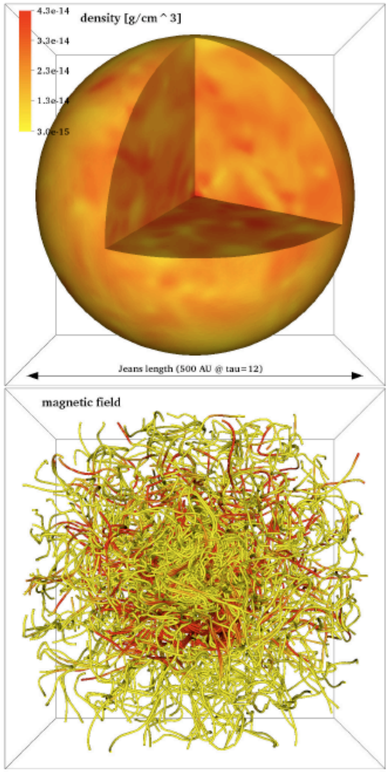
Cool stars:
C.E.: Dynamo field
(correlations with M, age, Ω)
R.C.: Fossil field

Hot stars:
C.C.: Dynamo field
R.E.: Fossil field
(not correlated)

Kippenhahn & Weigert 1997

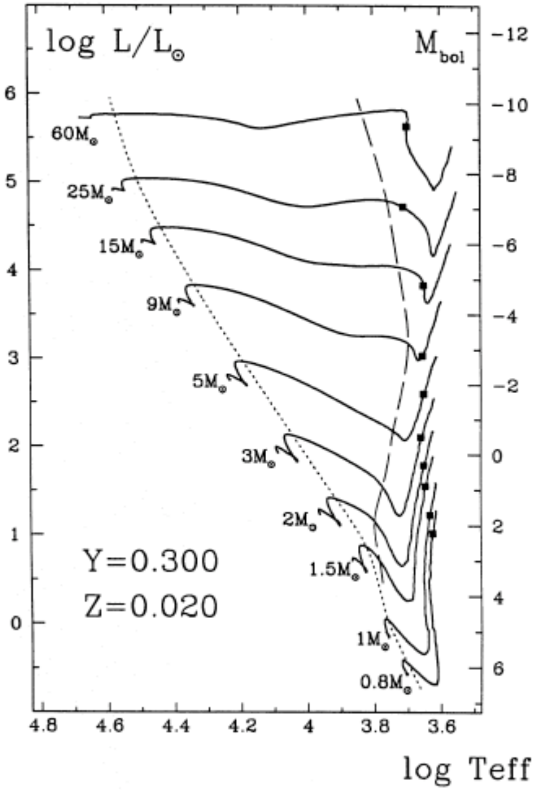
Fossil fields in intermediate-mass & massive stars

Interstellar medium



Federrath et al. 2011

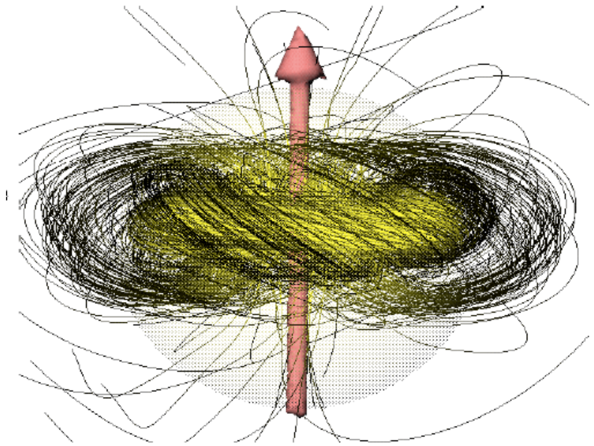
PMS



Bernasconi & Maeder 1996

Stable zone relaxation

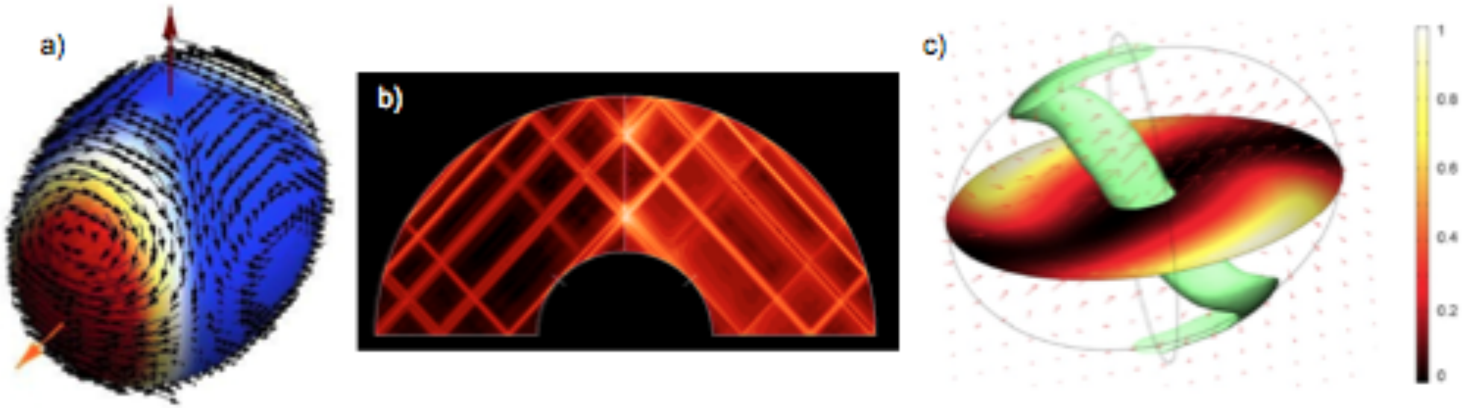
Braithwaite & Nordlund 2006;
Duez & Mathis 2010
Emeriau & Mathis 2014



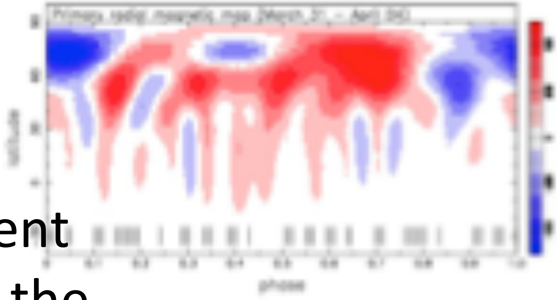
Single stars: 7%
Alecian et al. 2013
Wade et al. 2014

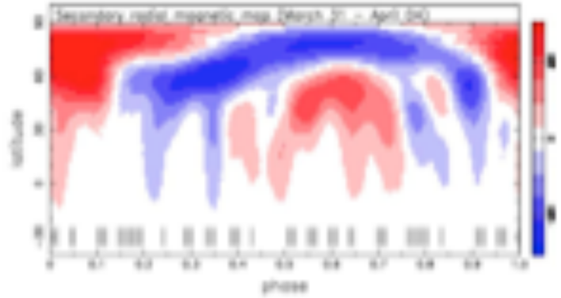
How do tidally-induced internal flows impact fossil or dynamo fields ?

- An initially eccentric system with non-synchronised, non-aligned components => asymptotic state where, orbit is circular, components are synchronised and spins are aligned
  - due to transfert of the kinetic energy of tidal flows to heat
- During this process 3 type of velocity fields are generated:
  - equilibrium tide (3D large scale flow, Rémus et al. 2012)
  - dynamical tide (helical oscillation, Ogilvie & Lin 2007)
  - spin-over flow (instability of gravito-inertial waves, Cébron 2011)



How do magnetospheric Star-Star interactions modify stellar activity ?

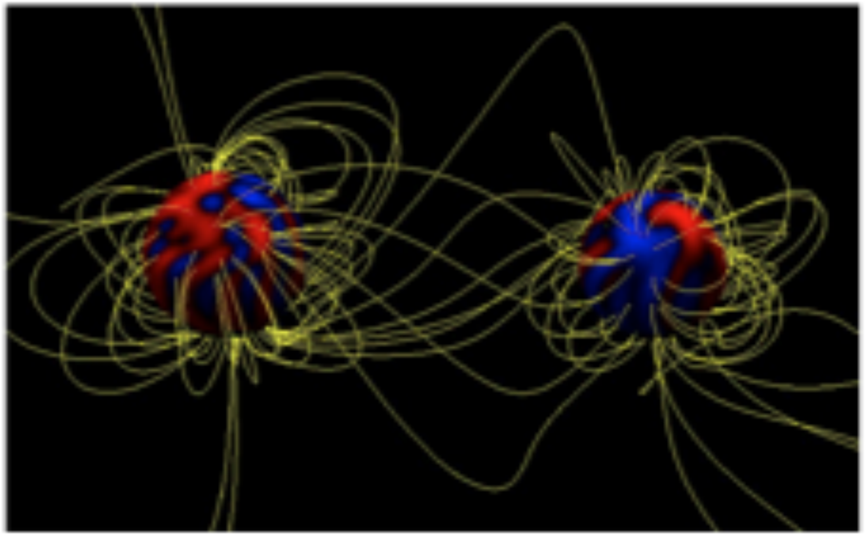




- Close component

⇒ interacting magnetosphere

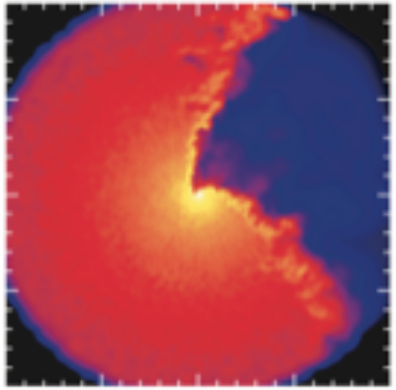
⇒ reconnection as one of the component pass through the magnetosphere of the secondary:
  - e.g. Star-Planet Interaction (Shkolnik 2008)
  - e.g. V774 Tau A: cyclical variability of flaring (Torres et al. 2012)
- 3D magnetospheric model :
  - Enhanced magnetic activity
  - Model the coronal emission
  - Location of open field lines



HD 155555 Dunstone et al. (2008)
Dunstone & Holwarth, priv. comm.

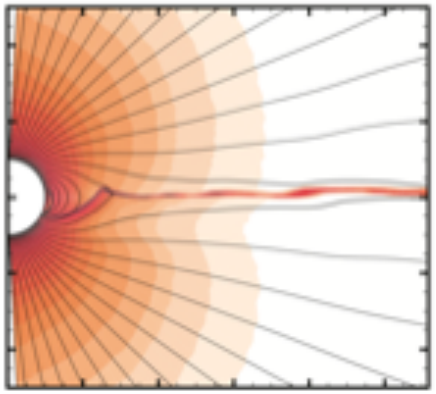
What is the magnetic impact on outflows and mass transfers ?

Colliding stellar wind (Russell 2011)



- Winds are present in low and high mass stars
- These winds carry away angular momentum
- These winds can be at the origin of mass transfer
- Magnetic fields can play a role in the mass transfer
- e.g. W-UMa stars, RS CVn, Algol ...:
  magnetic cycles are proposed to be at the origin of the orbital period modulation (Applegate 1992)

⟹ Constraints on magnetic fields are crucial to better understand these phenomena



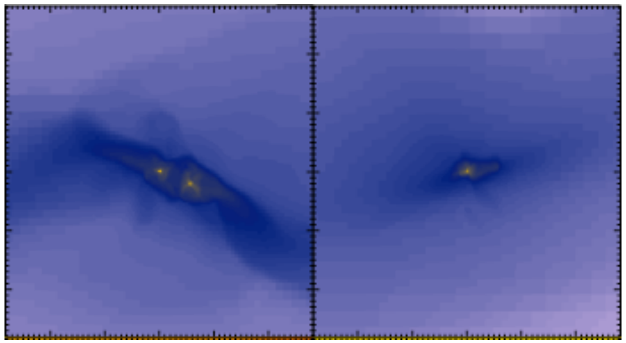
Magnetic wind (ud-Doula & Owocki 2002)

What is the impact of magnetic fields during stellar formation, and vice-versa ?

- Magnetic fields in massive stars is of fossil origin
- But:
  - Magnetic fields observed only in < 10% of intermediate- and high-mass stars *(e.g. MiMeS project)*
  - Magnetic fields detected only in one component of SB2s

- Star formation modelling with magnetic field
  => reduce fragmentation => reduce binarity

Commerçon, Hennebelle et al.



Commerçon et al. (2011)

Observing strategy and resources

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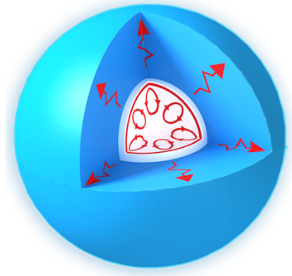
Spectropolarimetric Observing Strategy: the hot components



- Close SB2 systems:
  - P < 20 d, V < 8 mag
- The hot-SC (Survey Component):
  - ~200 close systems selected in SB2 catalogues (Taylor 2003, Pourbaix et al. 2009, Sana et al.), of OBA types
  - includes >20 eclipsing binaries
  - aim: statistical properties + new magnetic discoveries
- The hot-TC (Targeted Component):
  - 6 OBA SB2 containing supposedly a magnetic star
  - aim: confirmation then follow-up to model the magnetosphere and magnetic fields and to compare with single star magnetosphere and fields

Spectropolarimetric Observing Strategy: the cool TC component

- 11 dwarfs, 4 RS CVn (+ 1-3 cool-PMS)
  - various eccentricities (from 0.00 to 0.34), masses (from 0.16 to 2.5 $M_{\odot}$), and orbital periods (from 1.88 to 18.78 d)
  - includes 2 eclipsing binaries
  - all show signs of activity

- Aims:
  - obtain magnetic maps of both components
  - study the variations over the orbit for the most eccentric systems
  - compare the magnetic properties with single stars
  - explore magnetic activity under the most extreme conditions (W UMa systems)

Observational resources

- An ESPaDOnS large program (PIs: E. Alecian, G. Wade):
  - 604 h allocated over 8 semesters (2013A-2016B)
- A Narval large program (PI: C. Neiner):
  - 150 h allocated over 4 semesters (2013A-2014B)

- Additional observing programs
  - PIONIER interferometric observations (P.: J.-B. Le Bouquin)
  - CHANDRA X-rays observations (PI: C. Argiroffi)
  - Photometric observations (PI: A.-E. Essayed)

Preliminary results of the hot components

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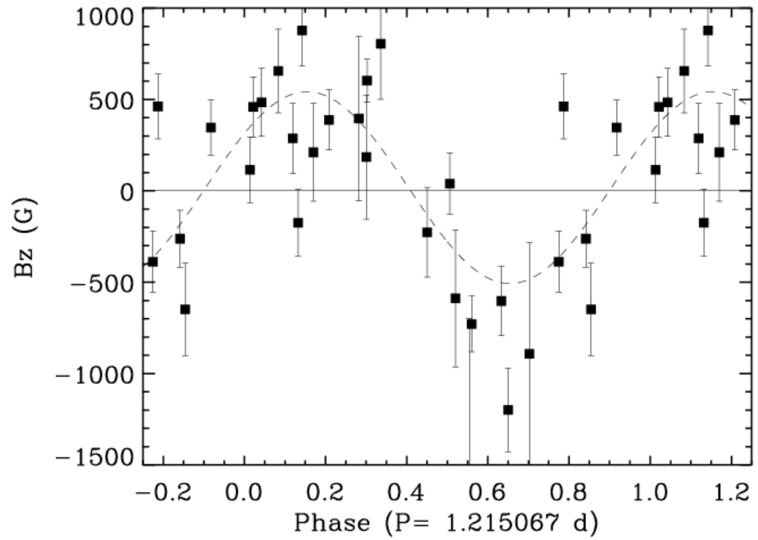
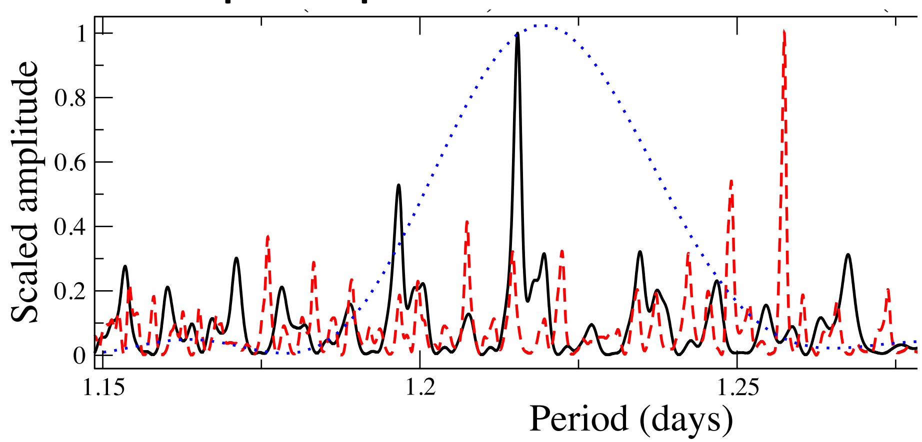
Plaskett: MiMeS + BinaMIcS

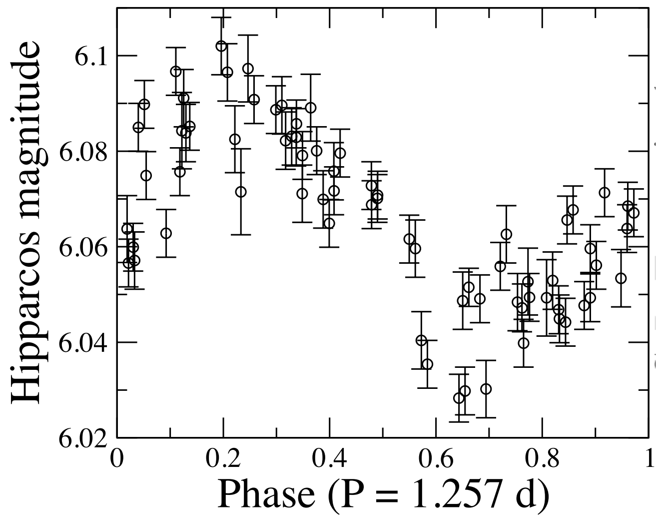
- Plaskett = O8III/I+O7.5V/III SB2
- M1+M2 ~ 120 Msun
- P: non-magnetic N-rich, C-poor
- S: magnetic, N-poor, He-rich
- Variable X-ray emitter
- Porb = 14.4 d
- Bp = 2 - 3 kG, i = 40-70°, β ~ 80°
- HIP: P ~ 1.25 d, Corot + ESPaDOnS: P ~ 1.21 d

  => Spin-up

Grunhut et al.



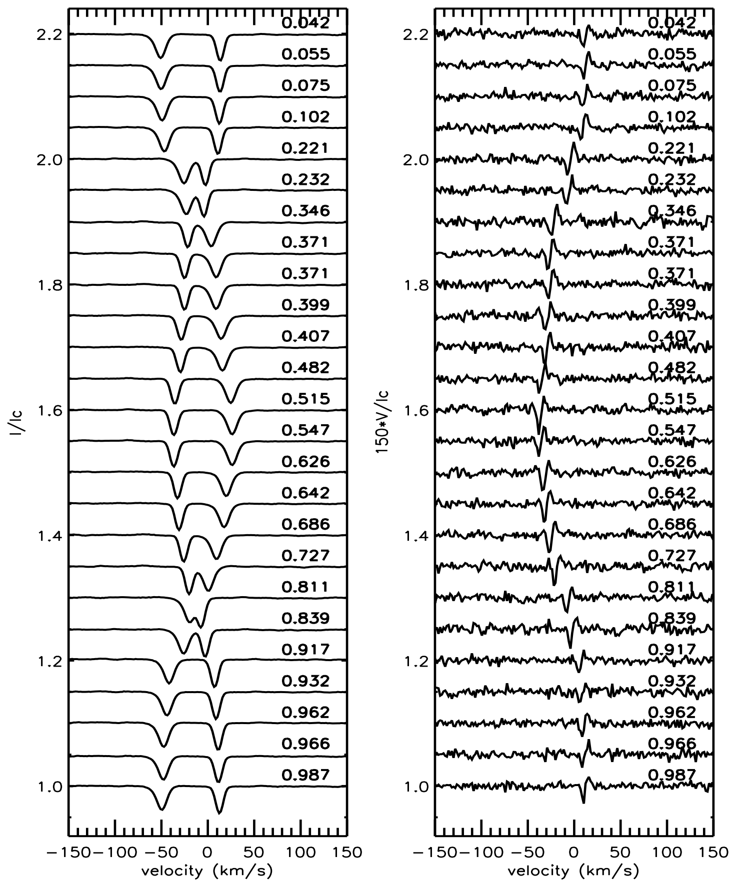




Monitoring of HD 5550

- 25 obs. over 2 months
- Orbital solution
  - => confirm results of Carrier et al. (2002)
- Spectral disentangling
  - (FDBinary, Ilijic et al. 2004)
  - => Pb with abundances anomalies
- Fit of the combined spectrum
  - (ZEEMAN/LMA, Folsom et al. 2013)
  - P: Teff=11500 K S: Teff=7500-8000 K
  - P: log(g) = 4.5 S: log(g) = 3.5-4.5
  - P: Ap S: Am
  - LP/LS ~ 8

- Next steps:
  - Re-do the spectral disentangling
  - Magnetic mapping

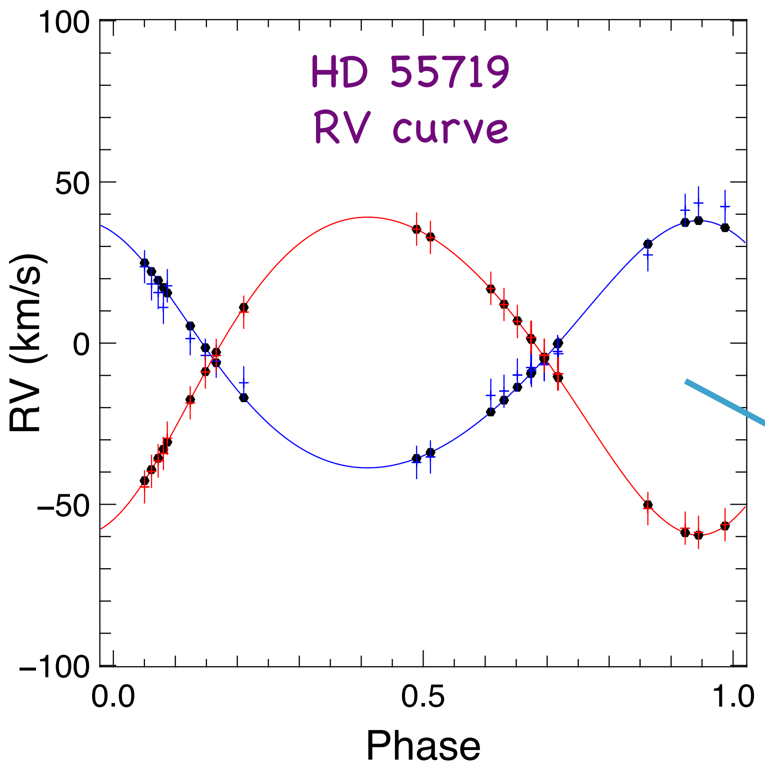


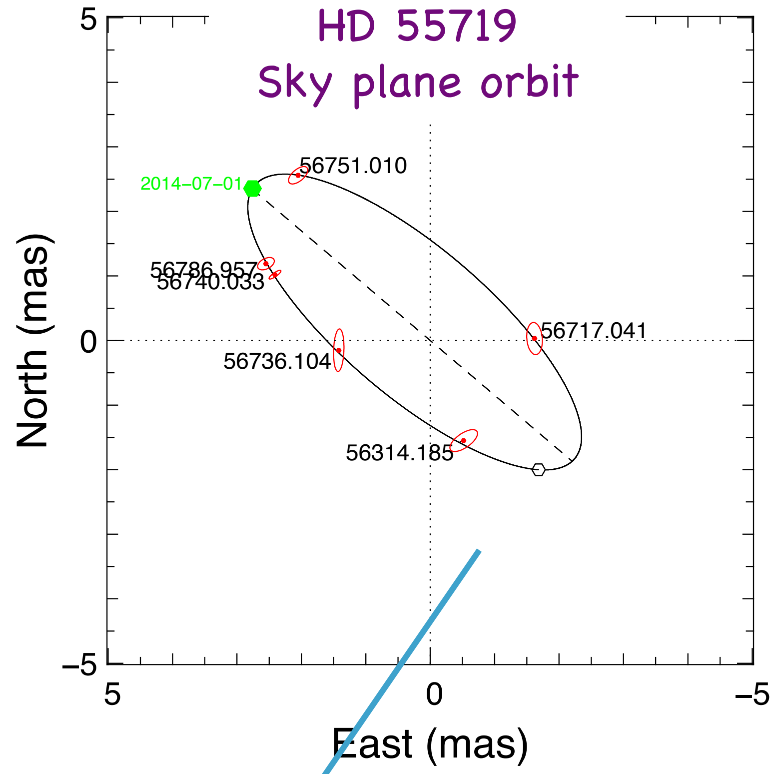
Tkachenko, Alecian, Folsom, Neiner, Landstreet, Sikora, Wade et al.

Analysis in progress

PIONIER/VLTI Observations

- PIONIER/VLTI (ESO): interferometry with 4 telescopes (H band)
- follow-up of the hot-TCs
- Spectro +Interfero => 3D orbit of the binary
- => constrained quantities: i, FS/FP, age





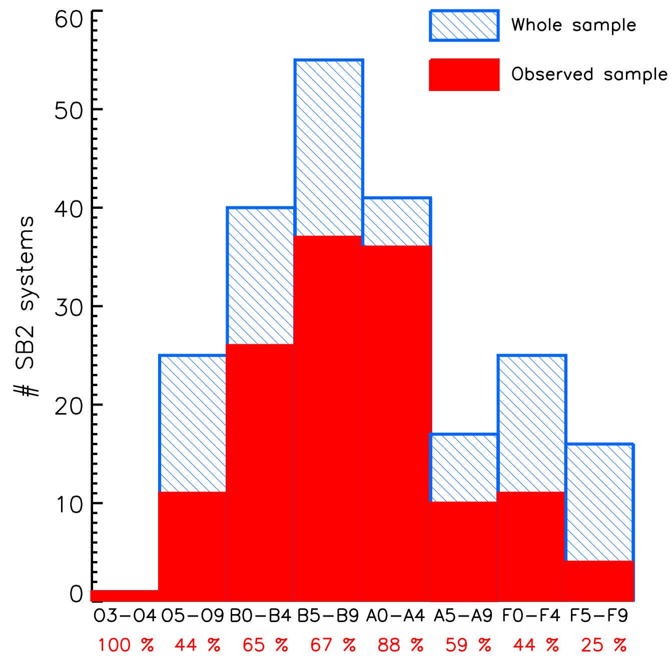
i = 110°
FS/FP = 0.85
full orbit
masses

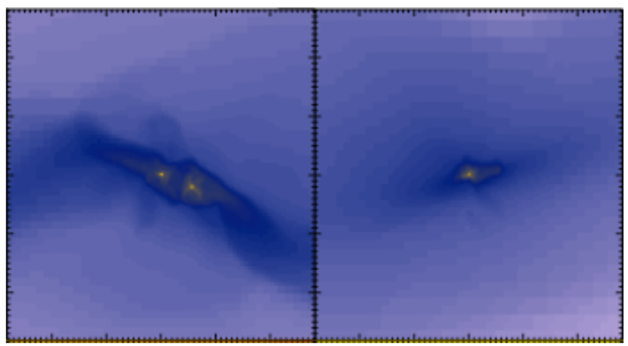
Le Bouquin, Alecian, et al.

Preliminary survey results

- Original sample:
  - 200 SB2 systems, P_{orb} < 20 d, V < 8 (V < 6 for Narval)
  - Detection limit ~ 50 G
- Today:
  - ~250 obs. of 190 OBA SB2 systems (50 systems with Narval)
  - 1 magnetic detection : F4V + F5V
  - 18 to 38 fossil fields were expected

⇒ memory of early star formation ? *(see e.g. the work of B. Commerçon, P. Hennebelle et al.)*





Commerçon et al. (2011)

Follow-up and Perspectives

- Fossil field problematic
  - Analyse the survey as a function of SpT, mass, orbital parameters
  - Acquire additional observations to improve statistics
  - Extend the survey towards larger separations (up to 100 d)
- Tidal, star-star, magnetospheric problematics
  - Magnetic maps of the TC targets, and compare with single stars
  - Magnetic maps at periastron and apostron for eccentric objects
  - Try and detect additional magnetic systems
  - Model the unique system Plaskett
- Facilities:
  - ESPaDOnS, Narval
  - PIONIER, GRAVITY, CHARA => orbital parameter space
  - CHANDRA => magnetic vs coronal activities

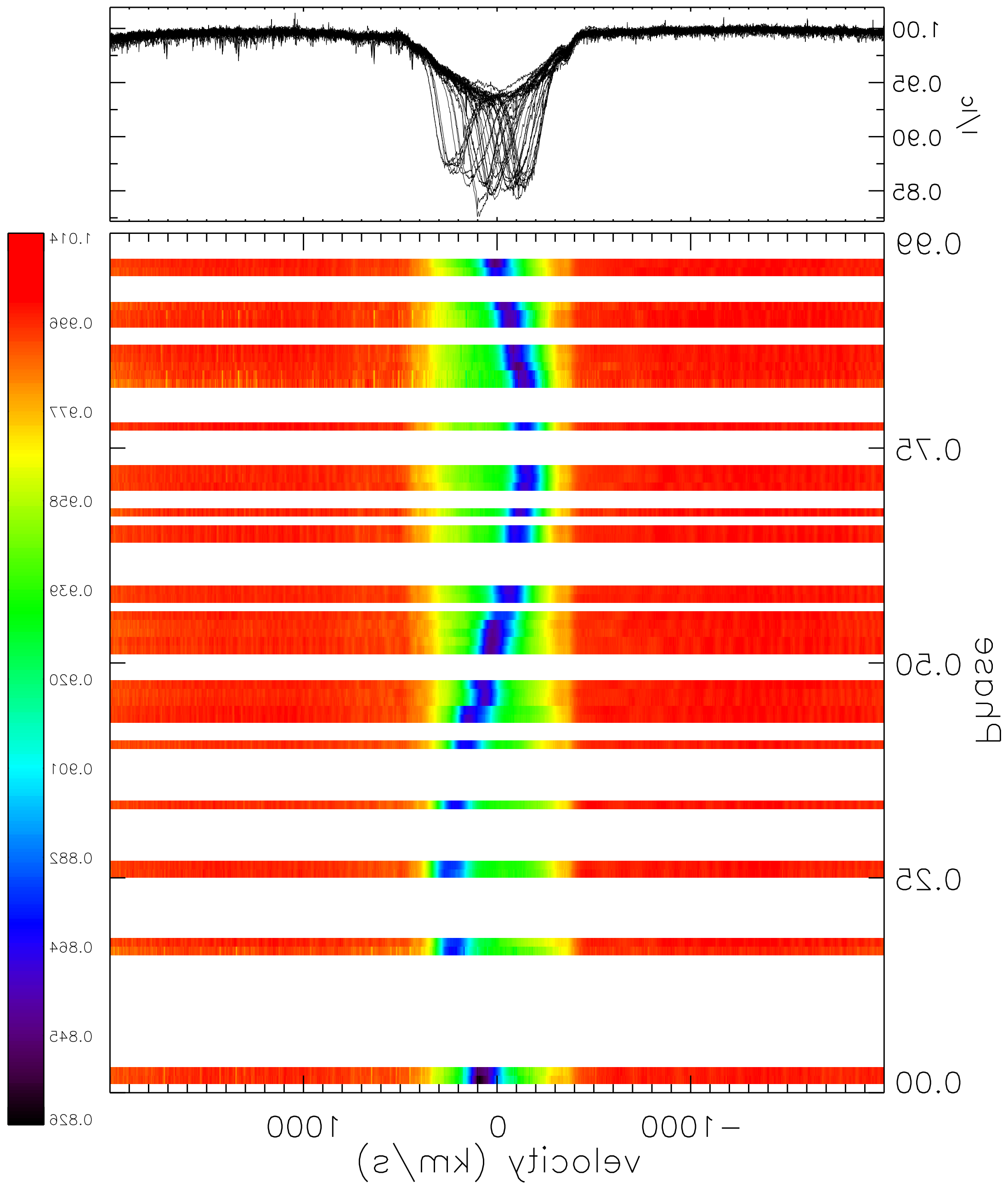
Thank you for the support of AFE!

BinaMIcS

Plaskett: a binary system ?

- Clear RV of the narrow component
- Lack RV of the broad component
- Both O8-O7 stars
- => Physical binary ?

- Work in progress



Grunhut et al.