Bilan Binarité/Multiplicité

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E. Moraux, I. Joncour, J.-B. Le Bouquin

N. Nardetto, …

Caveat

- PNPS proposals : 3
- Biblio ADS binary/multiple/tidal with 1st author affiliated to a French institute
- 2015 - 2018
- Only studies concerning mainly the PNPS

  $\Rightarrow$Excluded compact and high-energy objects (more PNHE and PNGRAM)

Outline

I. Studies of binary/multiple systems
   - Basic properties
   - Formation
   - Evolution
   - 2/3/N-body interactions

II. Binary interaction, a tool for stellar/planetary physics
   - Fundamental parameters
   - Distances
   - Environment
   - Binary+planet

III. Perspectives and Conclusions

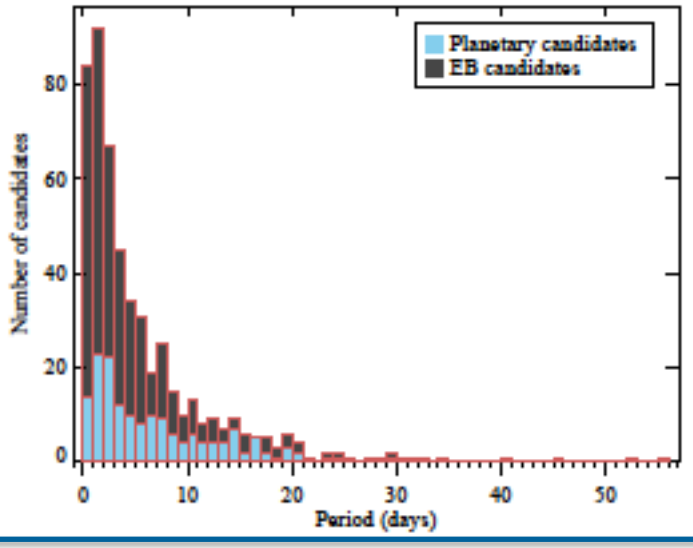
Studies of binary/multiple systems

Basic properties

EBs candidates with K2

Barros+2016

- K2 campaign 1 -> 6
- Optimised data reduction
- Light-curve extraction, K_P<15 mag
- Everything public



Wide binaries

Halbwachs+2017

=> Présentation Halbwachs

- RV measurements of CPM stars with CORAVEL
- Sample of 116 WBs, F5 -> M0
- Distribution of separations from 100 to 30000 au

  ⇒log-normal distribution

  ⇒Constrain formation processes

Catalogue of eclipsing binaries from Dome C with the ASTEP400 program

Chapellier+2016

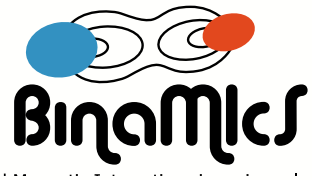
- 40cm robotic telescope, 1°x1° FOV
- 310000 stars observed in 2010-2012, 11.5 < *R* < 17.5 mag
- 673 EBs, 1166 V*
- Catalog: period, depth, semi-amplitude, light-curves

SPIRou Input Catalogue: global properties of 400 M dwarfs

Fouqué+2018

- ESPaDOnS observations
- Fundamental properties of 440 M6-M0 dwarfs
- 57 SB + additional VB

Binarity and Magnetic Interaction in Various Classes of Stars



- Bmag properties of ~230 close SB2
  - ~210 hot (F5-O3) systems, V < 8 mag
  - 5 additional hot magnetic
  - ~15 cool systems
- ESPaDOnS + Narval LP, PI HARPSpol prog.
- Snapshot of hot systems => Bmag det.
  - Incidence < 2% (compared to 10% in isolated ABO)
- Monitoring of Bmag targets
  - Work in progress

Alecian+2015, Alecian+ in prep.

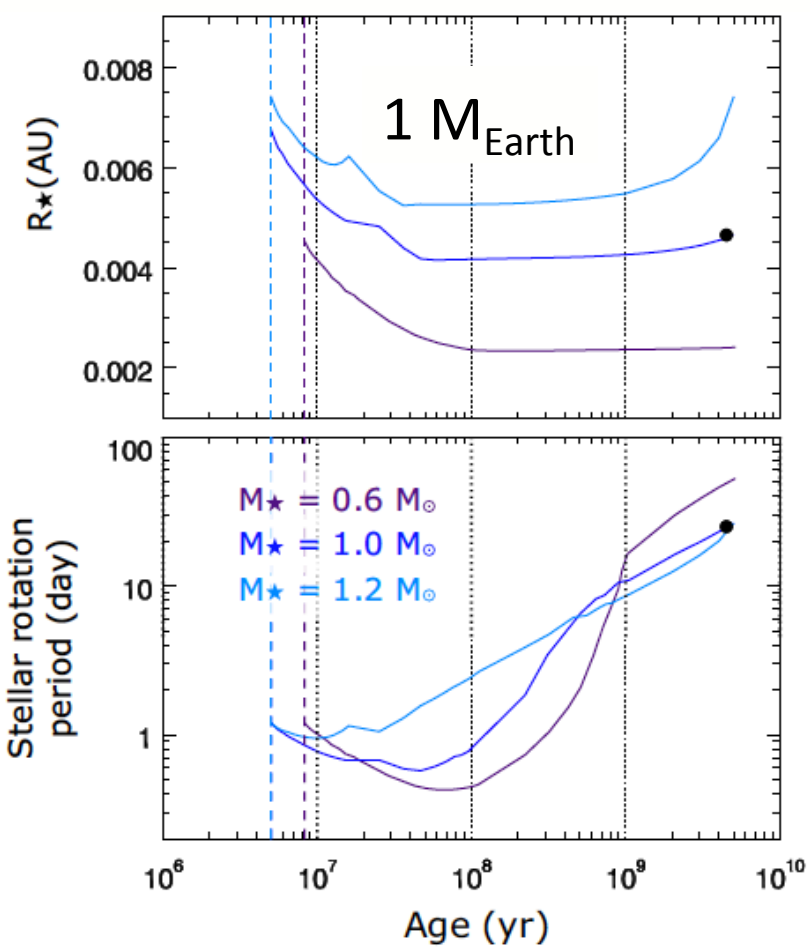
Studies of binary/multiple systems

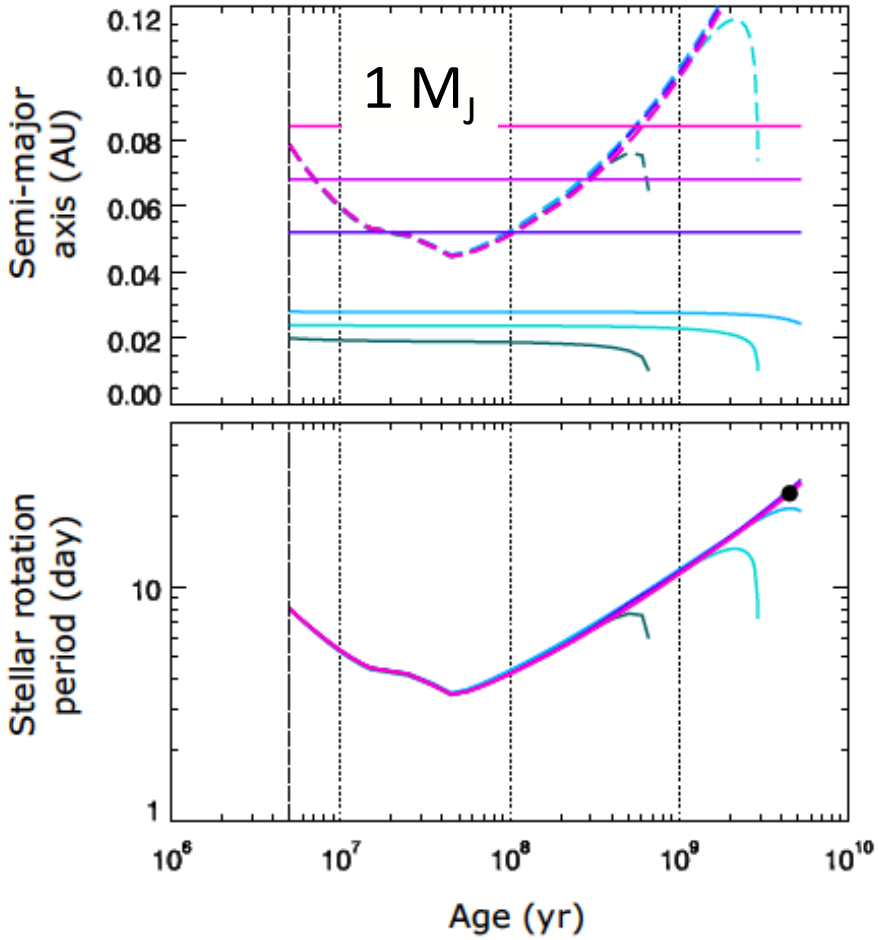
Tidal and magnetic interaction

(Close companions)

Dynamical tides and convective interiors

Effect of an orbital companion on the stellar rotation evolution including stellar winds





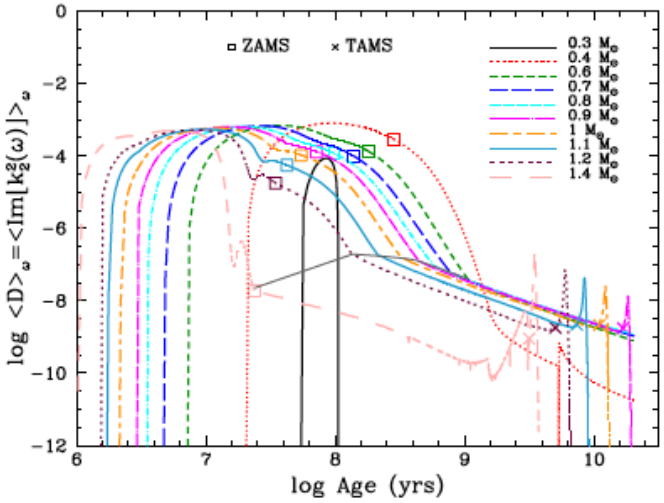
Mathis+2015, 2016, Auclair-Desrotour+2016, Guenel+2016, Bolmont+2016, Gallet+2017

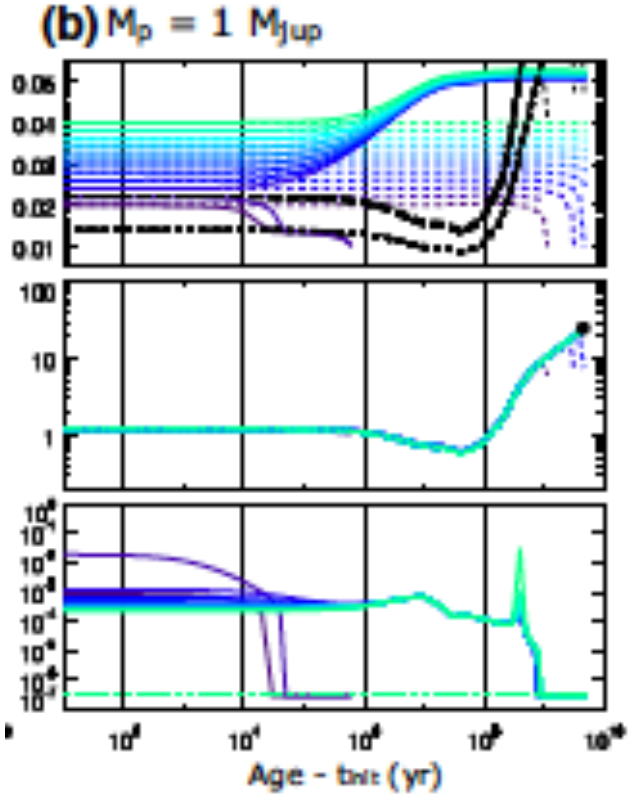
+ S. Mathis talk

Tidal dissipation on PMS

- Dissipation largest during PMS

Bolmont+2016





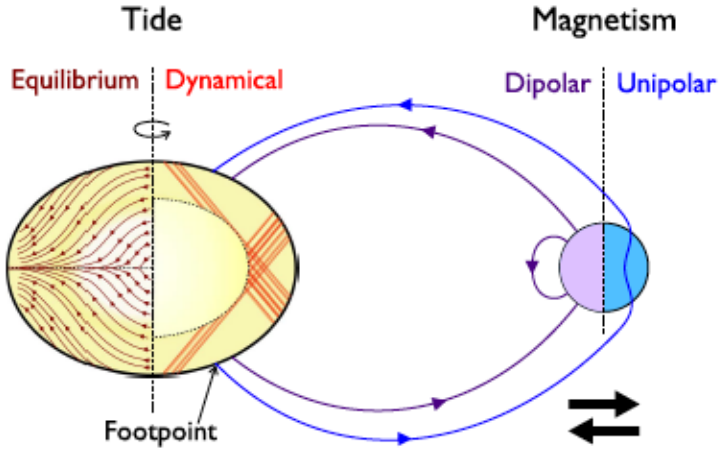
- Planet evolution: inside or outside migration
- Star+Planet+Disk: Star-Disk dominate in PMS

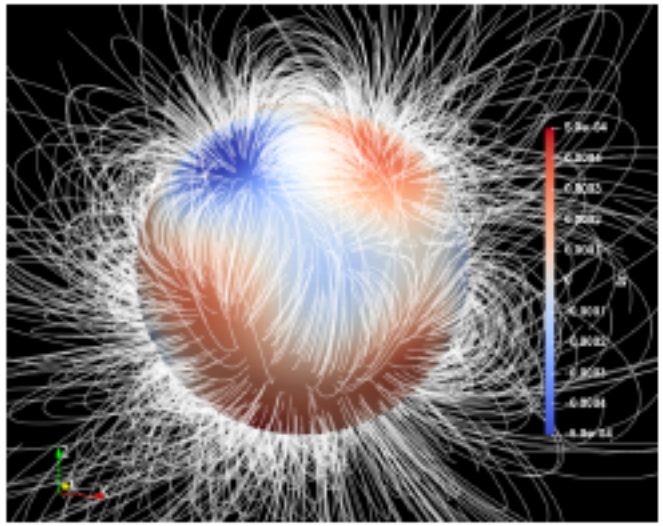
Bouvier+2015

Tidal + Magnetic interaction

- Tidal and magnetic torques are non-negligible for planet migration

Strugarek+2017





- Elliptical tidal instability can dissipate or amplify Bfield in radiative interiors
- Dissipation of Bfield in massive close binaries ?

Vidal+2017

D. Cébron présentation

Vidal+ in prep.

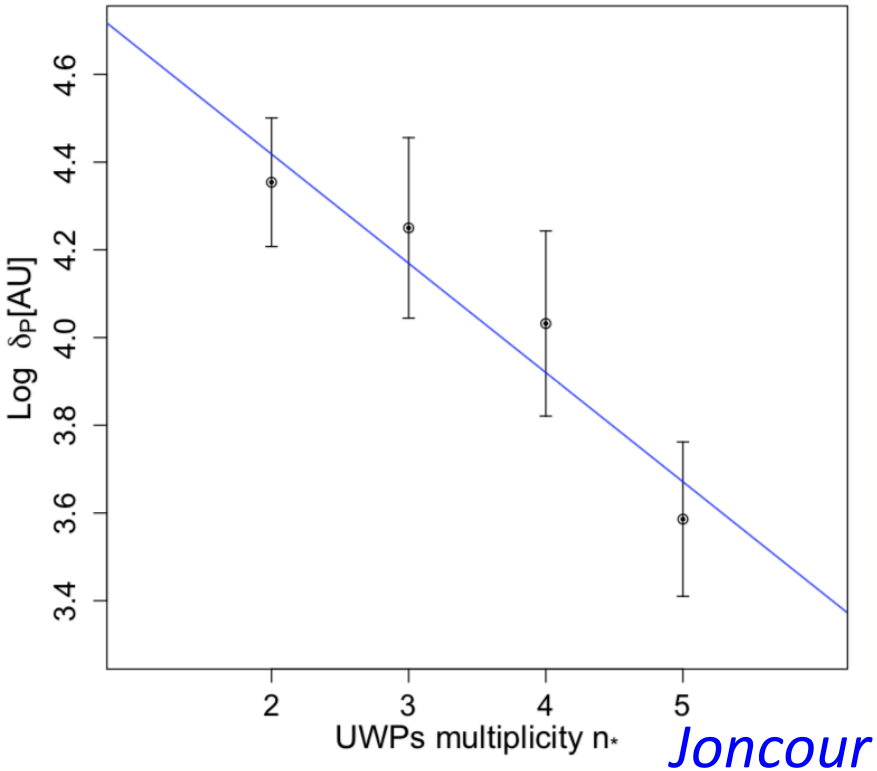
Studies of binary/multiple systems

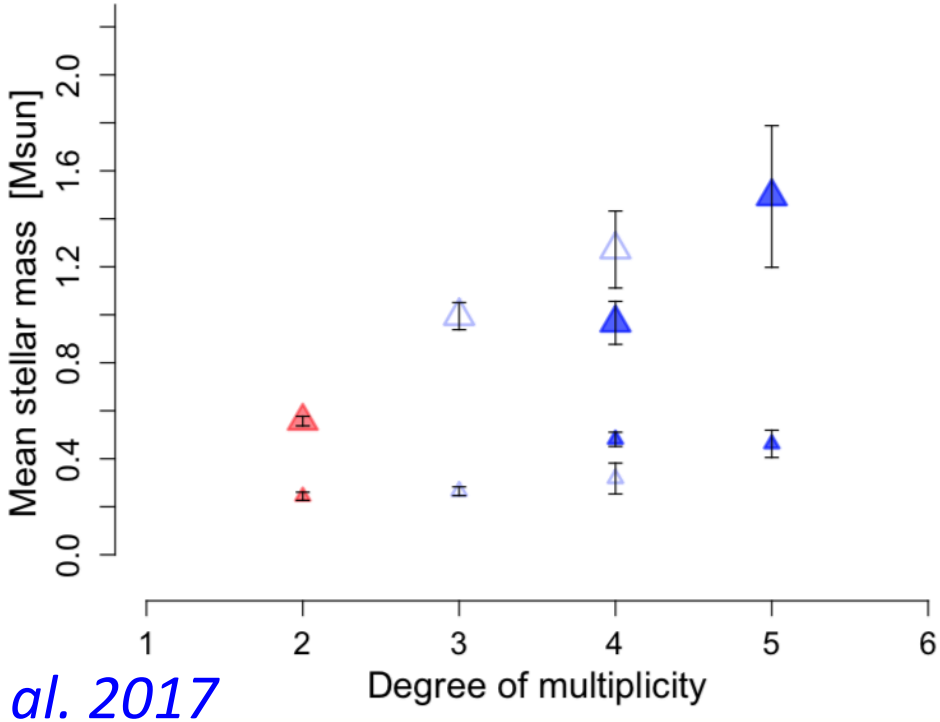
Formation

Towards understanding the fragmentation process

- Discovery of a large population of ultra-wide pairs (5-60 kAU) in Taurus
- Degree of multiplicity increases when the separation decreases and the primary mass increases

→ Constraints on the fragmentation processes

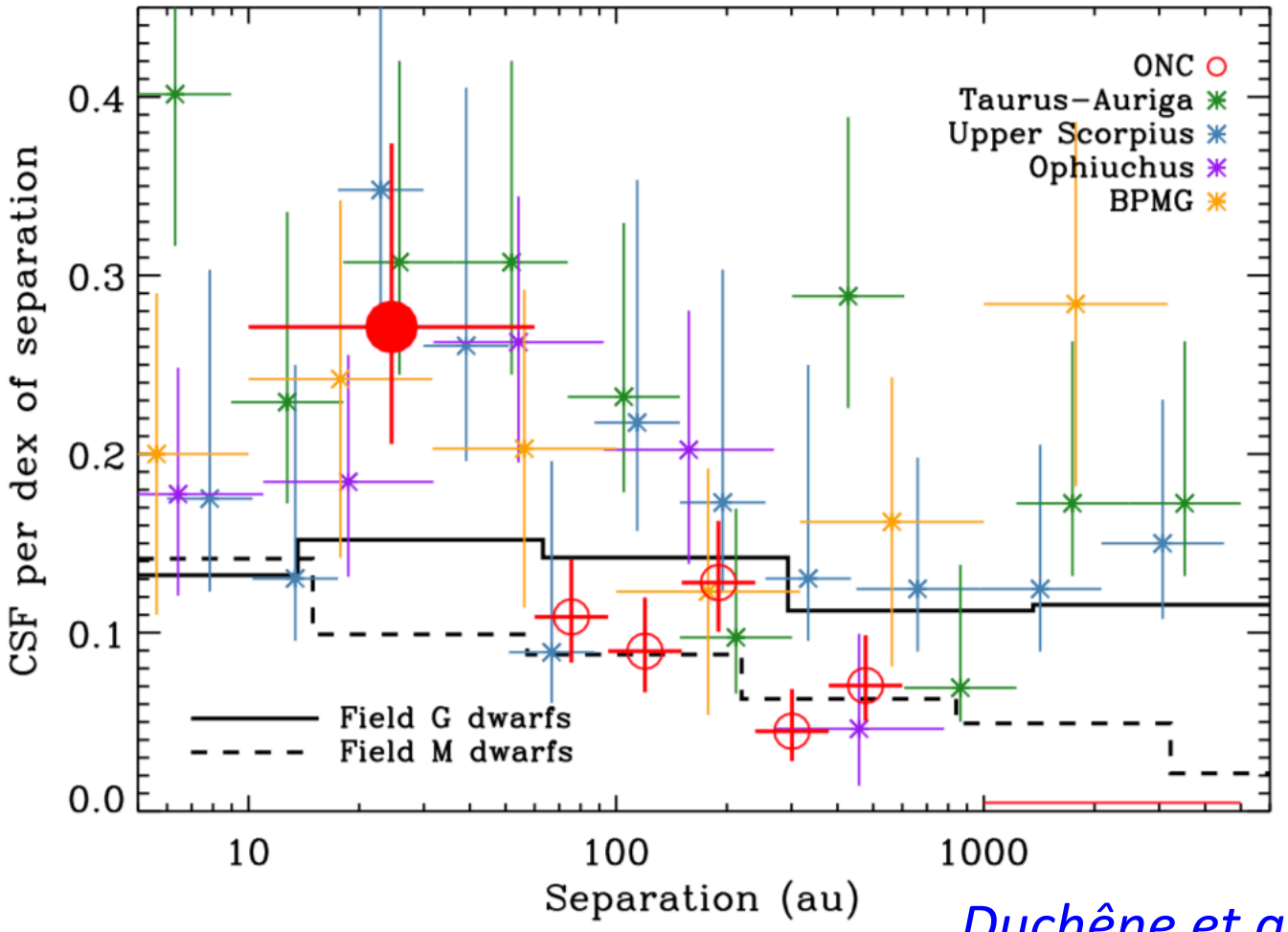




Joncour et al. 2017

Are the initial multiplicity properties universal ?

Separation distribution for multiple systems observed in the field and nearby SFRs



Duchêne et al. submitted

Formation / Fragmentation

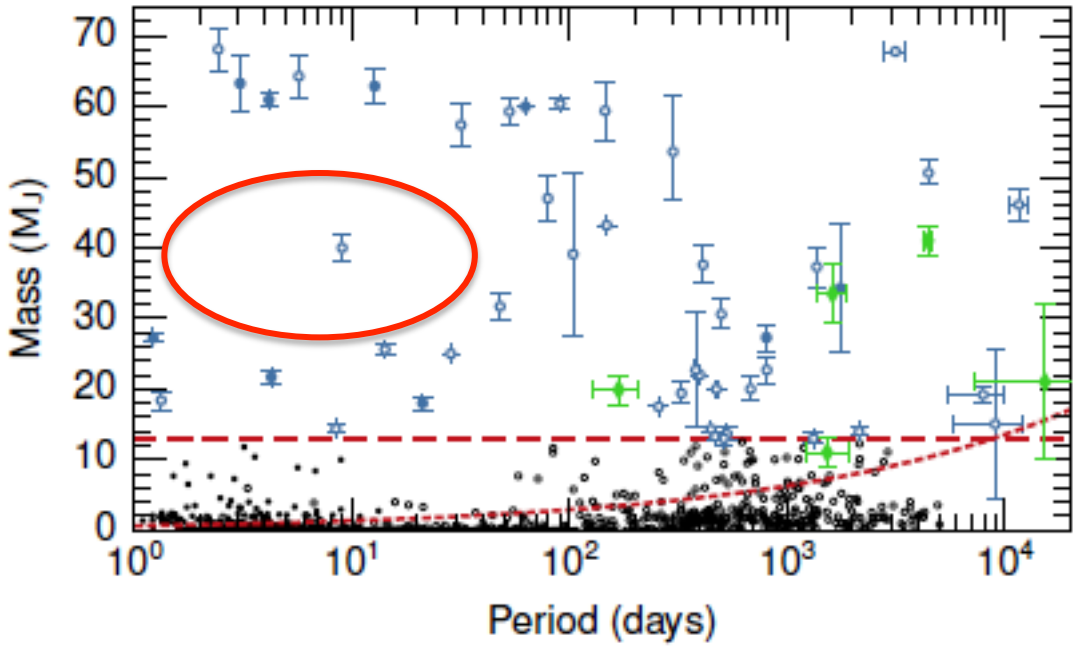
- Fragmentation ? When ? Where ?
- Models:
  - Work of Hennebelle
  - Work of Commerçon
- Constraining the CMF and IMF
  - Work of Motte et al.

B. Commerçon presentation
P. Hennebelle presentation
F. Motte presentation

The brown dwarf desert around stars

- Microlensing companion detection
- Combining with other kind of detection (RV, imaging, transit)

- Desert:
  - Porb < 30 d
  - 30 < M < 60 M_J
- Star-like formation ?
  Disk instability?
  Tidal interaction ?



Ranc+2015

Studies of binary/multiple systems

Evolution

- Collisional gravitational N -body models

  ⇒Dissolution rate evolution of wide binaries

  ⇒Formation of very tight (a ~0.01 au) binaries

  ⇒Multiplicity fraction of wide binaries increases with the mass of the primary

  Dorval+2017

- Paucity of brown dwarfs companions around FGKM-type stars compared to exoplanets

  ⇒Characteristic timescales of brown dwarf engulfement

  ⇒Porb < 10 d => tidal effect important around GK

  Damiani+2016

Binary interaction as a tool for stellar physics

Constraining fundamental stellar parameters

- SOPHIE+GAIA => Constraining mass to 1% accuracy

Halbwachs+2014,2016, Kiefer+2017
=> J.-L. Halbwachs presentation

- Properties and abundances of massive SB2

⇒dynamical mass < prediction from stellar tracks of single stars

⇒ tides do not affect abundances

⇒mass transfer + removal of external layers affect the observed abundances

Martins+2017

- Roche tomography of dwarf novae SS Cyg

  ⇒the best determination parameter of the Roche filling star in case of non-eclipse, i.e. when *i* is unknown

  Hill+2017

- Interferometric observations of O-type binaries
  - RV => unrealistic masses
  - GAIA +interferometry => masses independantly of radial velocities with an accuracy of 5 to 15%.

  Le Bouquin+2017

- SMA on an Herbig star + low-mass young companion

  ⇒disagreement of ages, confirming previous studies in young clusters.

  Lacour+2016

- GJ65 AB in NACO, PIONIER, UVES

  ⇒Constrain R, M, [Fe/H], the mass-radius relation

  ⇒R larger by 14%

  ⇒Inflation of the stars by the inhibition of convection by intense magnetic fields due to their fast rotation ?

  Kervella+2016

Binary interaction as a tool for stellar physics

Constraining magnetic fields origin

- Roche tomography of a CV star
  - Spots coverage and position observed over 8 years to constrain the dynamo action in such systems.

Hill+2016

- BinaMIcS
  - Fossil fields less frequent in close binaries than isolated stars
  - Memory of IC of formation ?

Alecian+ in prep.

Binary interaction as a tool for stellar physics

Constraining distances

Les binaires à éclipses comme indicateurs de distances dans l'univers

credit: press release ESO

LETTER

doi:10.1038/nature11878

An eclipsing-binary distance to the Large Magellanic Cloud accurate to two per cent

G. Pietrzyński[1,2], D. Graczyk[1], W. Gieren[1], I. B. Thompson[3], B. Pilecki[1,2], A. Udalski[2], I. Soszyński[2], S. Kozłowski[2], P. Konorski[2], K. Suchomska[2], G. Bono[4,5], P. G. Prada Moroni[6,7], S. Villanova[1], N. Nardetto[8], F. Bresolin[9], R. P. Kudritzki[9], J. Storm[10], A. Gallenne[1], R. Smolec[11], D. Minniti[12,13], M. Kubiak[2], M. K. Szymański[2], R. Poleski[2,14], Ł. Wyrzykowski[2], K. Ulaczyk[2], P. Pietrukowicz[2], M. Górski[2] & P. Karczmarek[2]

Nature, 2013, 495, 76

8 années d'observations photométriques et spectroscopiques de 8 binaires à éclipses dans le LMC => R1, R2 en km

$d \sim R/\theta$

www.eso.org

Relation brillance de surface couleur (SBCR) => θ1, θ2 en mas

Distance au LMC avec 2.2% de précision:
49.97 +/- 0.18 (stat.) +/- 1.1 (syst.) kpc

Budget d'incertitudes: amplitudes des vitesses K1, K2 (0.5%), rayons stellaires (0.5%), inclinaison (0.2%), rougissement (0.8%), metallicité (0.3%), photométrie (0.5%) et SBCR (2%).
SBCR = di Benedetto 05

- Correcting the impact of rotation on the SBCR of early-type using interferometry to improve the distance determination with EB.

Challouf+2015, 2017

- Cepheids

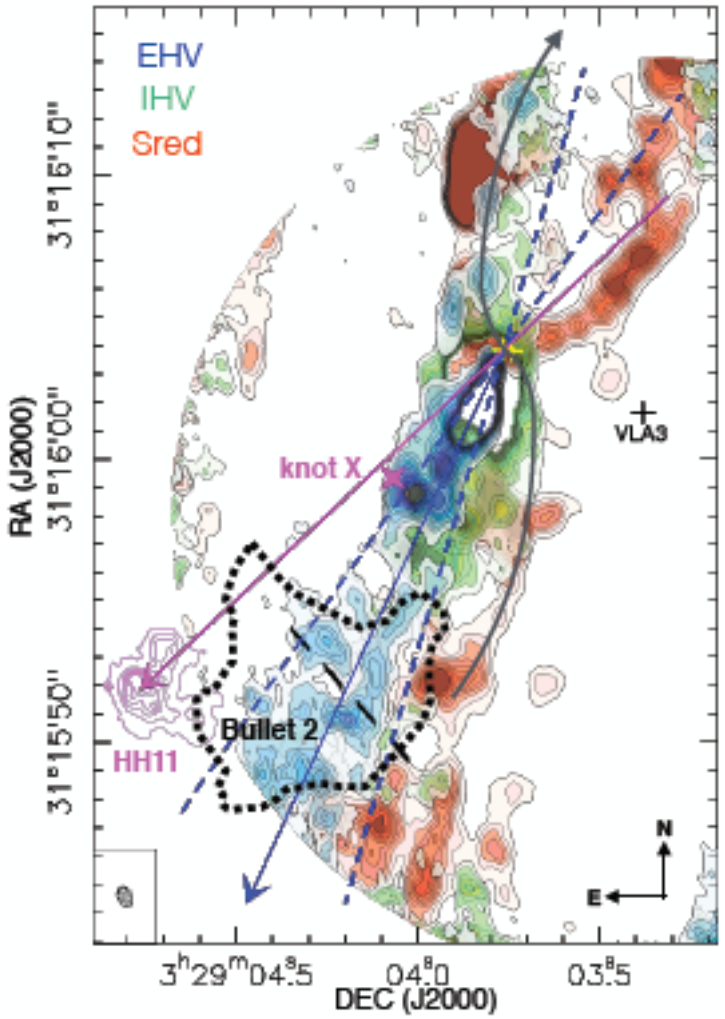
Nardetto+

Binary interaction as a tool for stellar physics

Constraining environment features of young and evolved stars

- An eccentric companion of a protostar trigger multiple coplanar jets separated by several tens of UA
- PBI obs (Programme CALYPSO)

Lefevre+2017



- Aperture masking of an Herbig star + low-mass young companion

  ⇒Disagreement of ages

  ⇒Companion can be responsible of misalignement of the inner disk with the outer disk, but not of the truncation of the outer disk.

Lacour+2016

- Measurements of magnetic fields in the particle-accelerating collinding-winds binaries (PACWB) to constrain the origin of their synchrotron emission.

  $\Rightarrow$No detection with some limits as low as 200 G.

Neiner+2015

Binary + Planet

- Calculation binary+planets => planet formation => binary evolution

  Andrade Ines +2018

- The role of binarity on shaping planetary systems confirmed with SPHERE observation of planet host stars. Dynamical interaction of a binary star with a planet

  Moutou+2017

- Secular dynamics of hierarchical three-body systems to understand the (no) co-planarité of planets orbiting binary systems

  Correia+2016

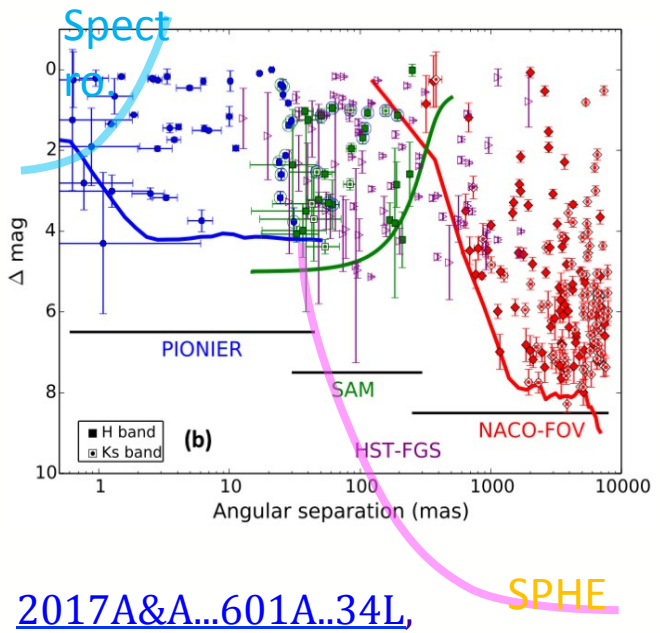
- Impact of orbital resonances on asteroids motion in a binary + giant planet system

  Bancelin+2015, 2016

Perspectives

Main results : Multiplicity of Massive Stars

- Multi-technique large program to unveil the unbiased properties of multiplicity
  - *100%* of young O-stars are close multiple, favors disk fragmentation through gravitational instability.
  - Most of them will interact with their companion. Link to Gravitation Wave progenitors ?
- Direct measurement of stellar mass to calibrate models
  - All direct measures so-far are *less massive* than expected from spectro-photometry + models
  - Mostly benchmark on ~10 objects.
  - Limited by systematics on the Radial Velocity due to stellar wind. VLTI+GAIA should be free from those.
- Detailed study of peculiar systems
  - Magnetic pairs, massive encounter, wind-wind collision…



2017A&A...601A..34L, 2014AJ....148..114M, 2014A&A...568A..94N, 2013A&A...553A.131S , 2017A&A...600L....5H, 2017MNRAS.464.3561M, 2015A&A...579A..68G, 2014A&A...565L....2D, 2014A&A...561A.101L, 2012MNRAS.423.2711D…

Ramping-up and Prospective :

- Binaries as calibration probes
  - Precise masses and distances from SB2+OLBI validate the systematics of Hipparcos and Gaia at <1% (Kiefer, Halbwachs)
  - Ultra-precise astrometry of binary can reveal the wobble from planets (Monnier)

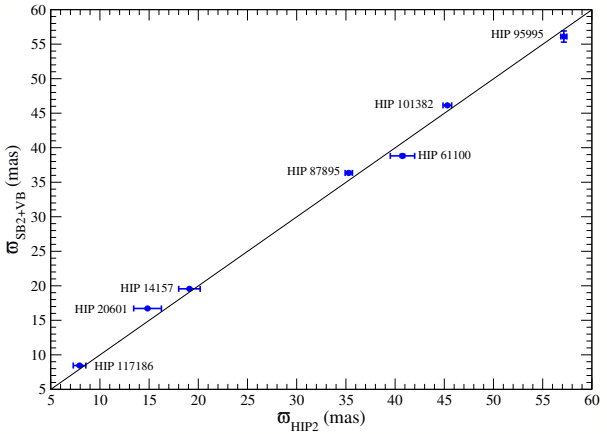


Fig. 5. Comparison of the corrected Hipparcos 2 parallaxes with the SB2+VB solutions.

- Binarity/multiplicity is (re)becoming the workhorse of Long Baseline Interferometry since few years, because the technique has access to more spectral types and larger samples than ever.
- VLTI increased sensitivity from H=6 to H=8 was a *breakthrough* (e.g sample of O-type stars increased from few to 120).
- Next step is to exploit the 330m baseline of CHARA (2x VLTI) with the same level of sensitivity and efficiency.

Origine et Formation

- E. Moraux : « Origine et évolution des amas stellaires jeunes », 2015 – 2017, 3.5 k€ 2015, pas de demandes en 2016 ni en 2017
- T. Bohm: « Caractérisation de l'interaction forte dans la binaire jeune SB2 PMS HD 104237 – rôle du champ magnétique stellaire », 2015-2016, 1.5 k € en 2015, 3 k€ 2016
- B. Commerçon : « Formation d'étoiles : des coeurs denses prestellaires aux Protoétoiles », 2015 – 2018, avec un impact à la fois global sur l'origine de la fonction initiale de masse des étoiles, et local sur le mécanisme de formation des étoiles binaires, Comment sont déterminées les propriétés de multiplicité des étoiles ? 3.5 k€ 2015, 5 k€ 2016, 6 k€ en 2017, 9.5 k€ en 2018
- S. Guilloteau : « Formation des systèmes planétaires : Structure et dynamique, des disques protoplanétaires », analyse de systèmes binaires, découverte de systèmes multiples, 4k€ 2015, 5 k€ 2016, 6 k€ en 2017, 5 k€ en 2018
- F. Motte : « L'origine de la masse des étoiles dans notre Galaxie telle que vue par ALMA et le JWST », 2018 – 2020, WP1 - relation CMF/IMF, multiplicité des cœurs, CMF avec multiplicité, sous-fragmentation, 5 k€ en 2018

MS phases

- JB Le Bouquin : « La binarité des étoiles massives à Haute Résolution Angulaire », 2017 – 2019, 4.5 k€ en 2017, 3 k€ en 2018
- Binamics, 5 k€ 2015, 4.5 k€ 2016,
- C. Neiner : « The BRITE spectropolarimetric project », 12 eclipsing binaries observed, 2015 – 2017, 3k€ 2015, 3 k€ 2016, 2.2 k€ en 2017
- Manquent :
  - Binarité + GAIA : Arenou + Halbwachs
  - Effets de marée : S. Mathis …
  - F. Martins : « properties of six short-period massive binaries: A study of the effects of binarity on surface chemical abundances » A&A 607, 82
  - C. Hill : « Magnetic activity of interacting binaries » IAUS 328, 54
  - P. Auclair-Desrotour : « Tidal interactions in rotating multiple stars and their impact on their evolution », IAUS 307, 208
  - E. Di Folco : « GG Tauri: the fifth element », A&A 565, 2

Stades Evolués

- JC Bouret : « Evolution and Fate of Fast-Rotating Massive Stars at Low metallicity », 2013 – 2017, 2k€ 2015, pas de demande en 2016 ni en 2017
- JC Bouret : « Before the Burst: The properties of Rapidly Rotating, Massive Supergiants », 2017-2018, binary scenario for Rapidly rotating, evolved massive stars are thought to be the progenitors of long gamma-ray bursts (LGRBs). 3k€ en 2017, 2.5 k€ en 2018
- P. Stee : « Modélisation des étoiles chaudes massives et exploitation des mesures à haute résolution angulaire des instruments VLTI/AMBER et CHARA/VEGA », 2014 - 2016, l'influence de la binarité dans les étoiles Be sera également étudiée, 4 k€ 2015, 5 k€ 2016
- A. Meilland : « Etudes HRA des étoiles chaudes massives: Préparation des programmes scientifiques et exploitation de la nouvelle génération d'instruments VLTI & CHARA », 2017, 6.5 k€ en 2017, pas de demande en 2018
- N. Nardetto: « Céphéides par interférométrie : distance et physique stellaire », un des sous-projets : enveloppe circumstellaire et binarité, 2013 – 2016, 5.5 k€ 2015, pas de demande en 2016 ni en 2017
- S. Charpinet : « Astérosismologie des étoiles compactes évoluées », 2012 – 2017, quelques cibles étudiées sont dans des binaires, 3.5 k€ 2015, 4 k€ 2016, 2.5 k€ en 2017
- P. Tisserand : « Quel est le produit de fusion de 2 naines blanches de masse intermédiaire », 2015 – 2019, 4 k€ 2015, 4 k€ 2016, pas de demande en 2017
- S. Blondin : « Constraining the Progenitors and Explosion Mechanisms of Type Ia Supernovae », 2016 – 2019, 2 scenarios : WD+WD merger, WD+accretion from an evolved star, 3.5 k€ 2016, 3 k€ en 2017

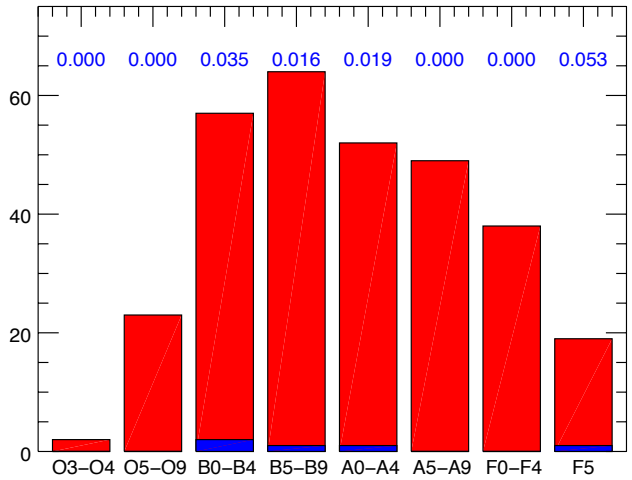
Ecoles/Conférences

- E. Moraux : « ECOLE EVRY SCHATZMAN 2015 « Les amas d'étoiles : jalons de la physique stellaire et de l'évolution galactique », 2015
- E. Lagadec : « Conférence : « The Physics of Evolved Stars II : the impact of binarity », 2017
- A. Marcowith : « Symposium IAUS 331 : SN 1987A, 30 Years Later », aide conférence, une session sur la binarité des progéniteurs
- E. Josselin : « Le diagramme HR en radio : physique stellaire aux grandes longueurs d'ondes (Ecole Evry Schatzman 2016) », 2016, Cours 2 : Activité, binarité et magnétisme vus en radio.
- T. Lanz : « The physics of evolved stars: a conference dedicated to the memory of Olivier Chesneau », 2015
- P. Lesaffre : « Conférence 'Blowing in the Wind' », Session 7: Duplicity and winds

Perspectives

Conclusion

Hot sample



Cool sample

- Work in progress