Close binaries in hierarchical systems

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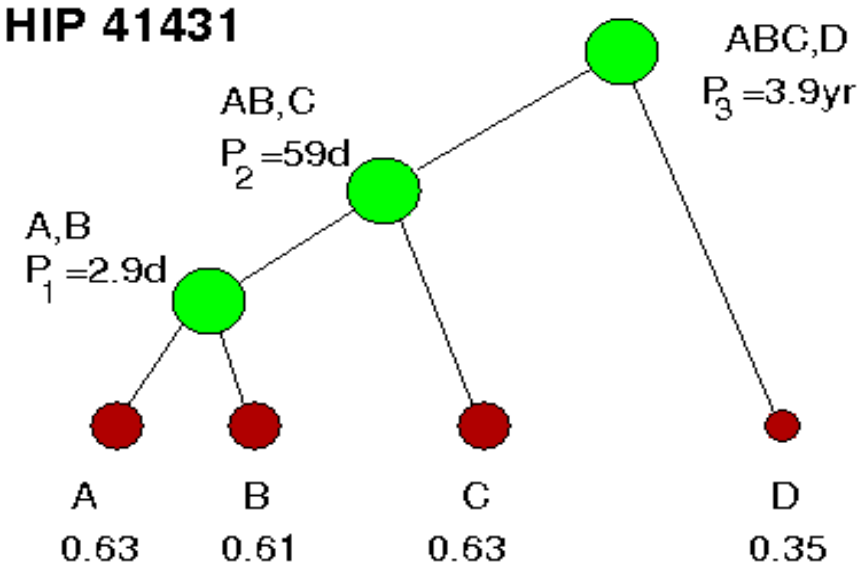
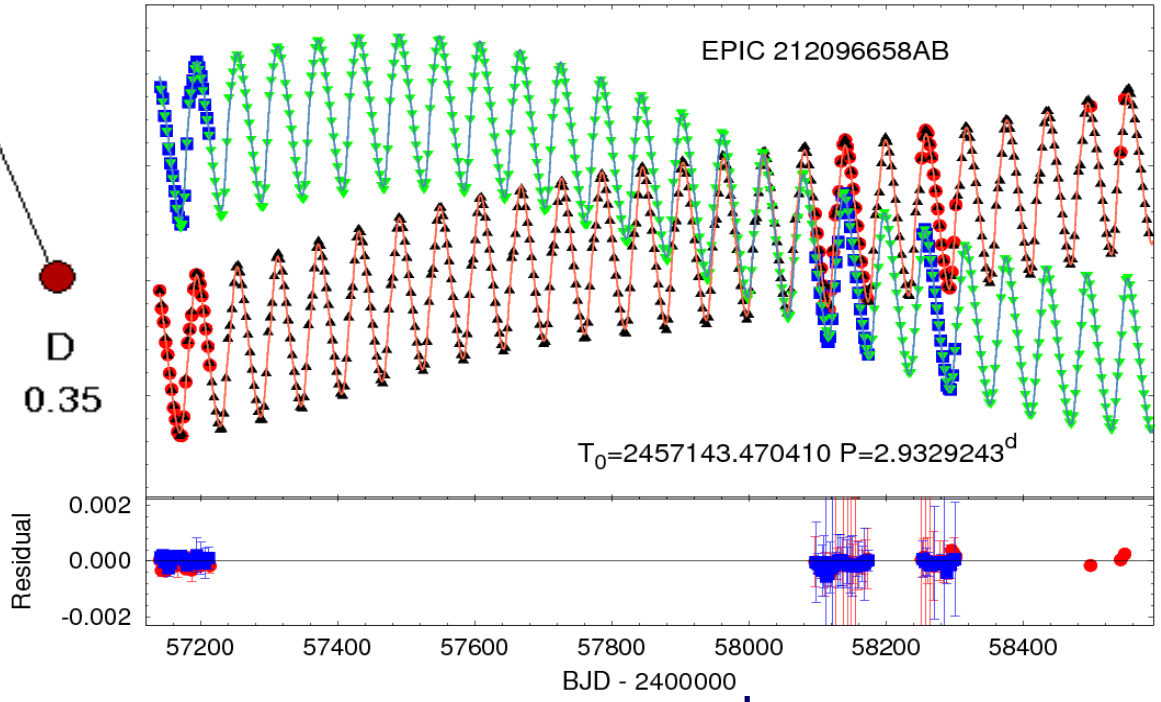
CTIO





Questions

- Are **all** close binaries - inner systems in hierarchies?
- If they are related to hierarchies, why?
- Dynamical origin (Kozai-Lidov cycles)?
- Migration during accretion
- Strange subsystems in hierarchies

Definition of close binaries: P<10d

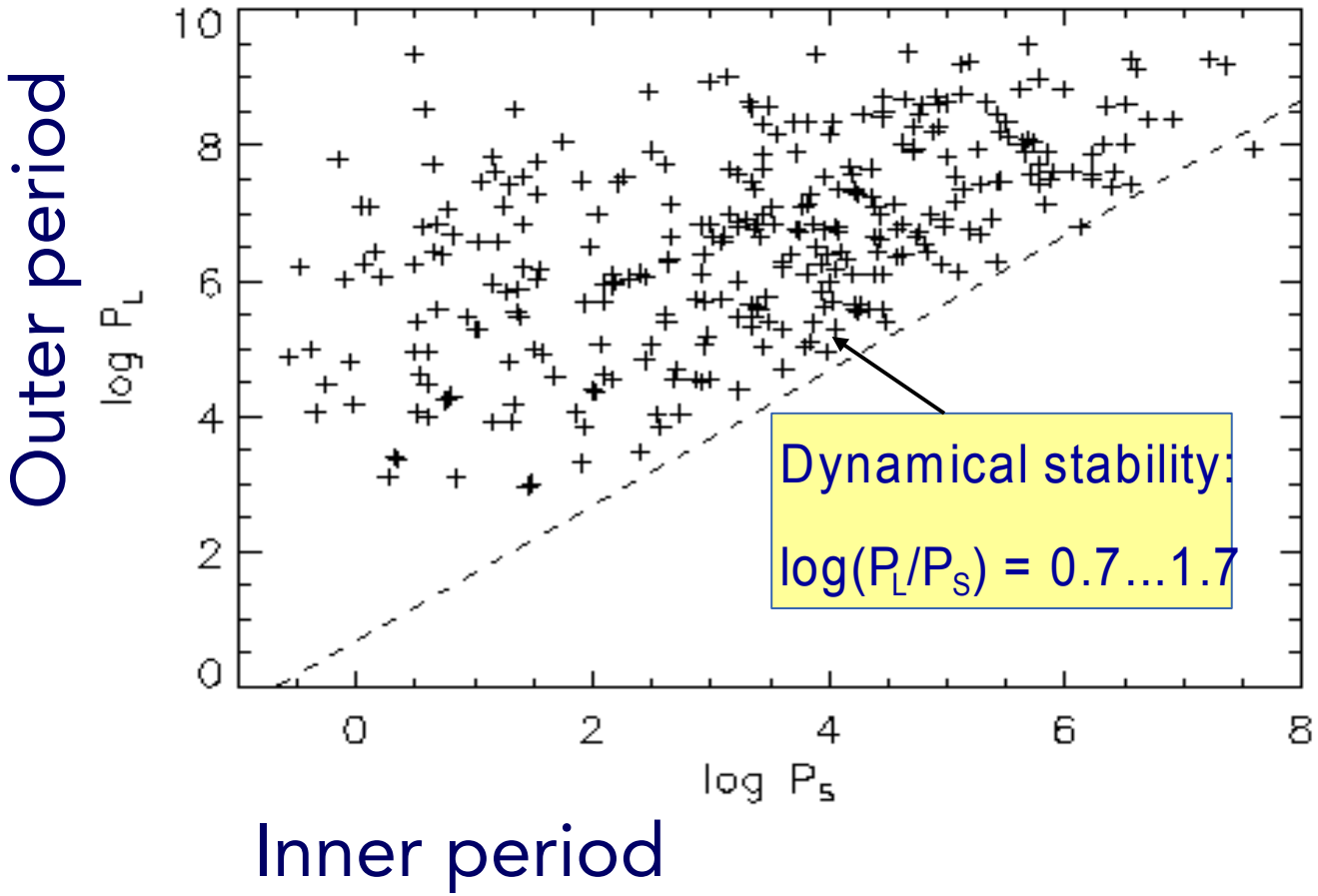
Bonus:
Upper Scorpius

Relation between close binaries and triples

- Suspected for a long time (A.Batten, S.Rucinsky,...)
- Explains close-binary formation by Kozai cycles with tidal friction (KCTF) – Kiseleva & Eggleton, 1998
- Statistics proves that CBs are related to hierarchies
- Yet, close pairs without tertiary companions do exist!

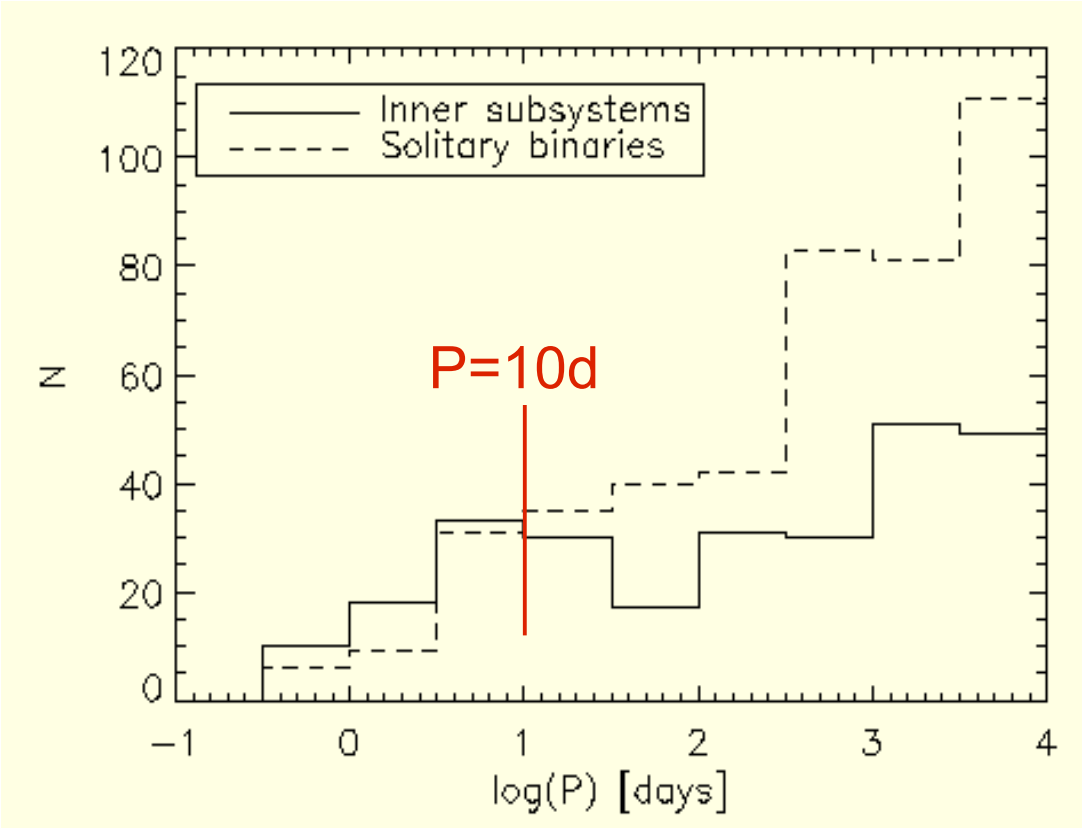
Period ratios in triple systems
(FG-stars within 67pc, volume-limited)

~500 triples within 67pc



Similar P_{in}, P_{out} distributions:
Can select inner and outer pairs independently?

Close binaries like to be in triples



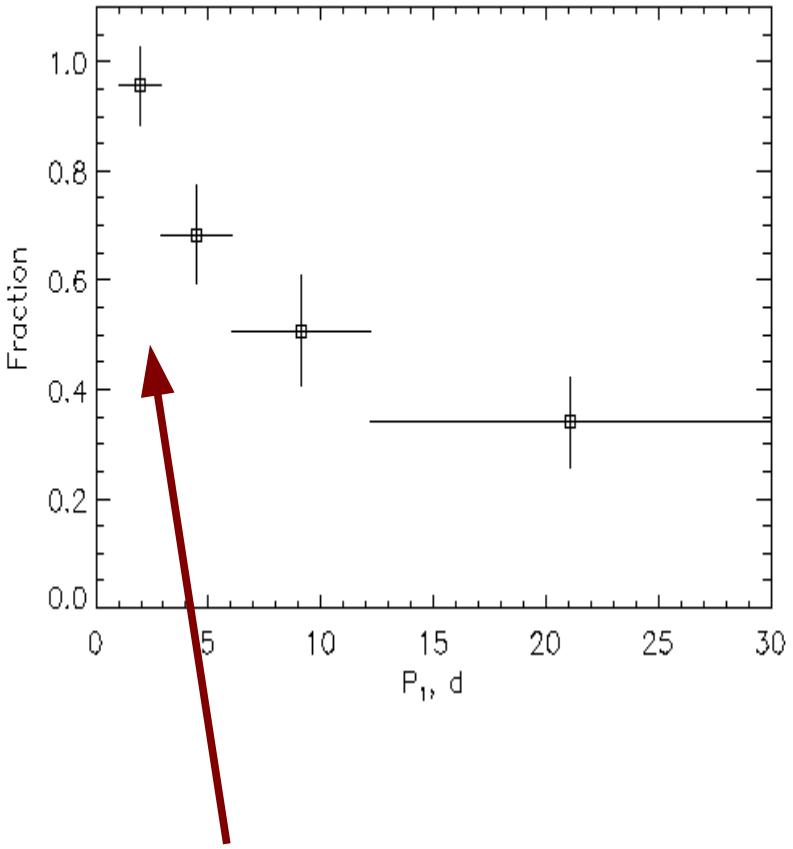
What fraction of solar-type binaries with P<10d are inner subsystems in triples?
Model: 35%
Reality: 57% 63/(63+47)

$P<10^4$d: 279 inner,
439 solitary

Independent-multiplicity model fails for P<10d

Solar-type stars within 67pc (updated)

Tertiary companions to close binaries



- Frequency depends on P_{in}
- P>10d exist without triples

Many tertiaries are very wide!?

2006, A&A, 450, 681
NACO + 2MASS

CB fraction is proportional to multiplicity

Fraction of P=2...6d

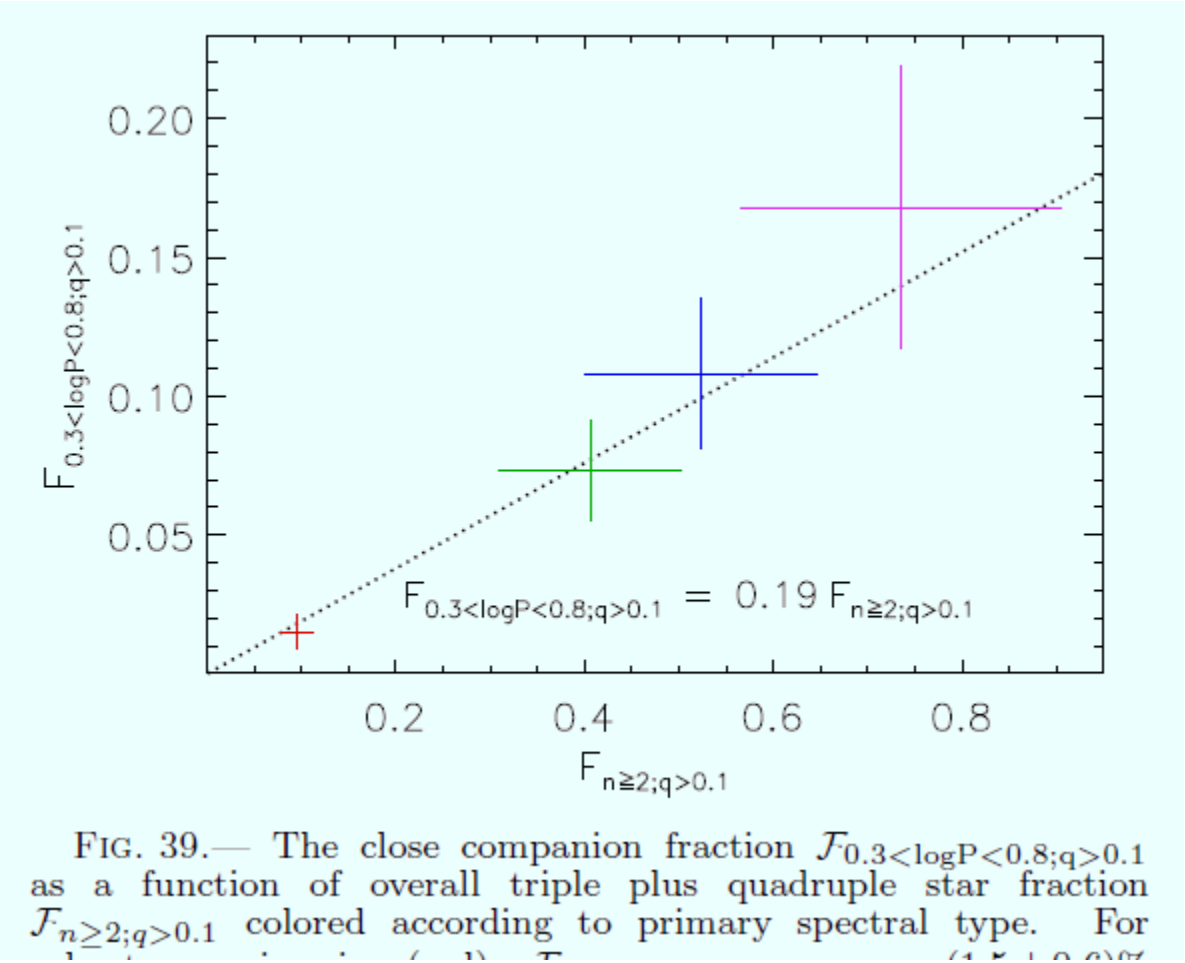


FIG. 39.— The close companion fraction $\mathcal{F}_{0.3<\log P<0.8;q>0.1}$ as a function of overall triple plus quadruple star fraction $\mathcal{F}_{n\geq 2;q>0.1}$ colored according to primary spectral type. For

One triple
out of 5 hosts a
close binary

Moe & Di Stefano
2017 ApJS, 230, 15

KCTF: Kozai-Lidov cycles with tidal friction

- Mis-aligned triple (i >39°) with K-L cycles
- Inner eccentricity grows, tidal interaction
- Result: P_{in}<10d, circular orbit, mis-aligned
- Various modifications to basic KCTF

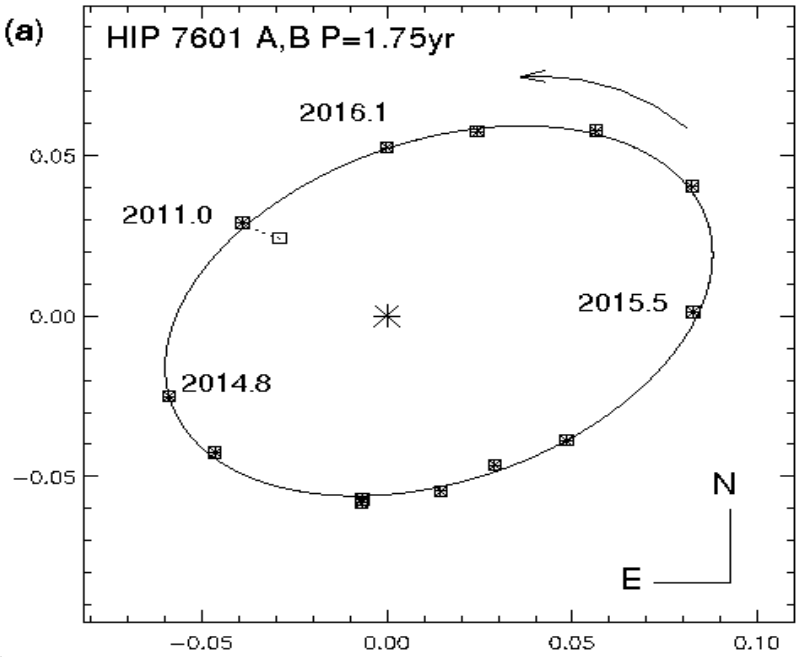
Fabrycky & Tremaine (2007): preference of P~10d, i ~39°

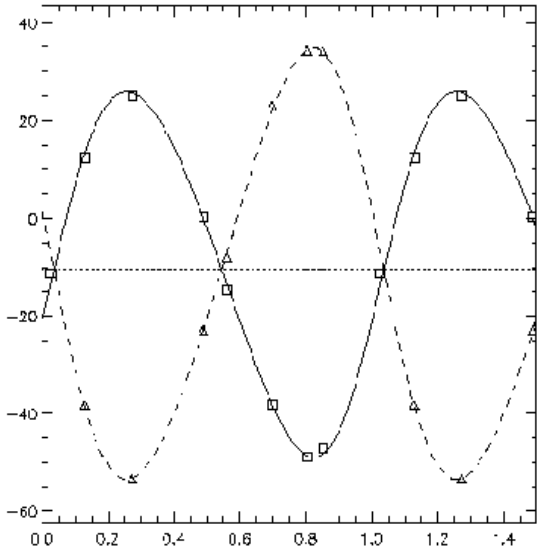
Moe & Kratter (2018 ApJ 854, 44): works at PMS, not frequent enough.

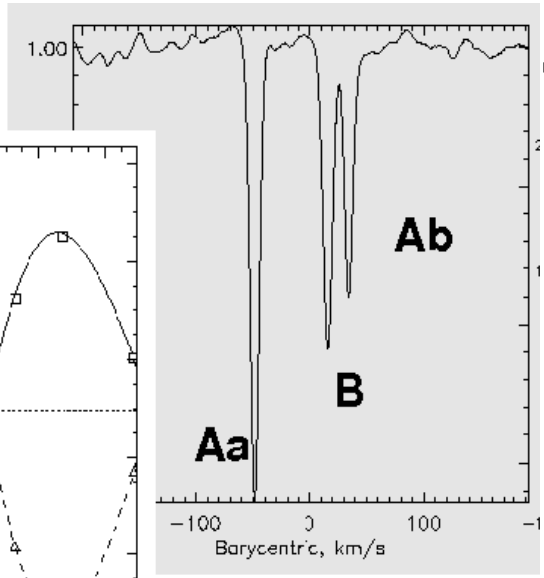
To test, we need a large sample of hierarchies with inner orbits

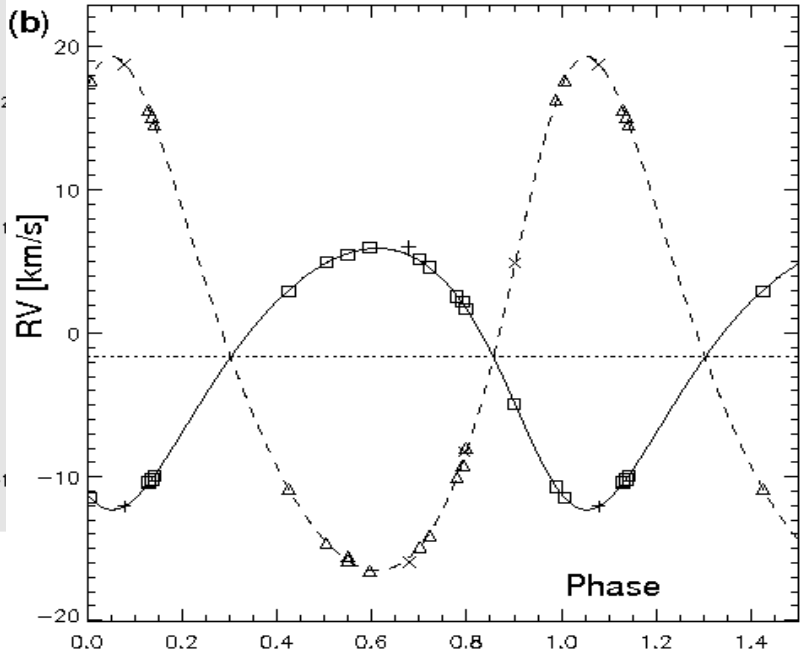
CHIRON survey of multiples

HIP 7601: 1.75yr + 19.4 days,
at 27pc. Masses to 3%, lithium



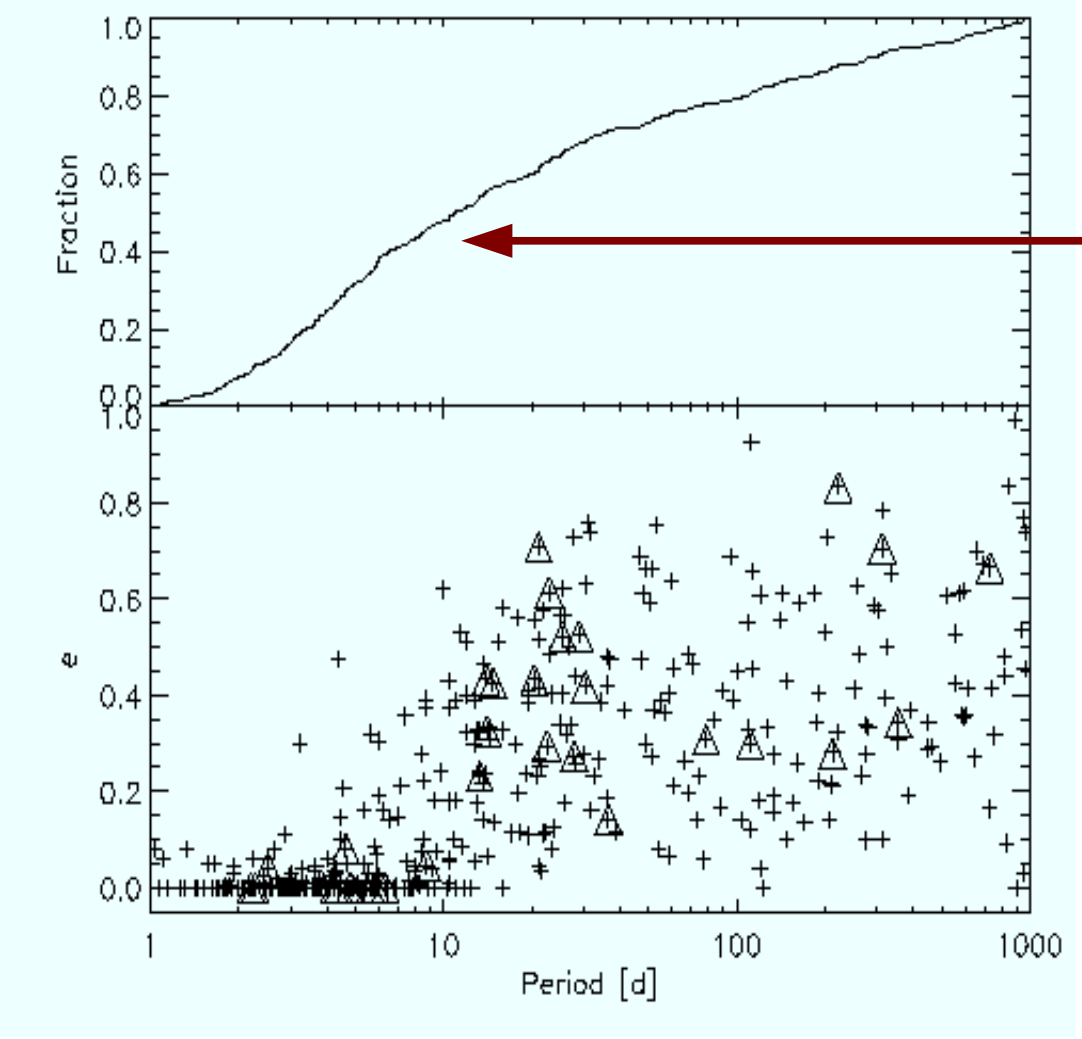






2016, AJ, 152,11

CHIRON, paper VI (in prep.)



No details
at P_{in} ~10d !

Period-eccentricity of inner subsystems (MSC)

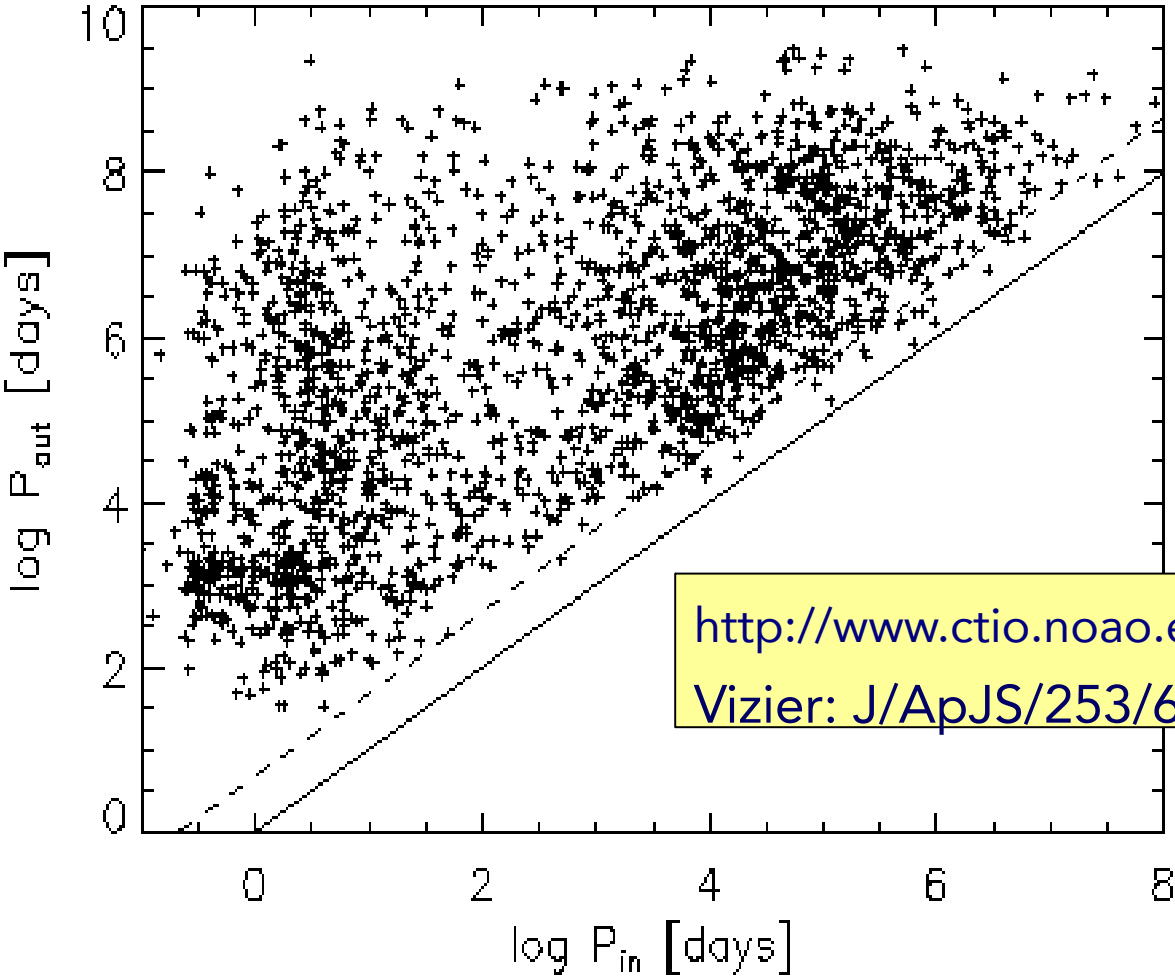
N=511 (35: CHIRON)
Mass <1.5 solar

Borkovits et al. (2016): tight triples with EBs are mostly co-planar

Tokovinin & Smekhov 2002: peak at P~7d?

The Multiple Star Catalog (MSC)

~2200 hierarchies. Mostly a few solar mass, within 300pc



Last update:
July 2019

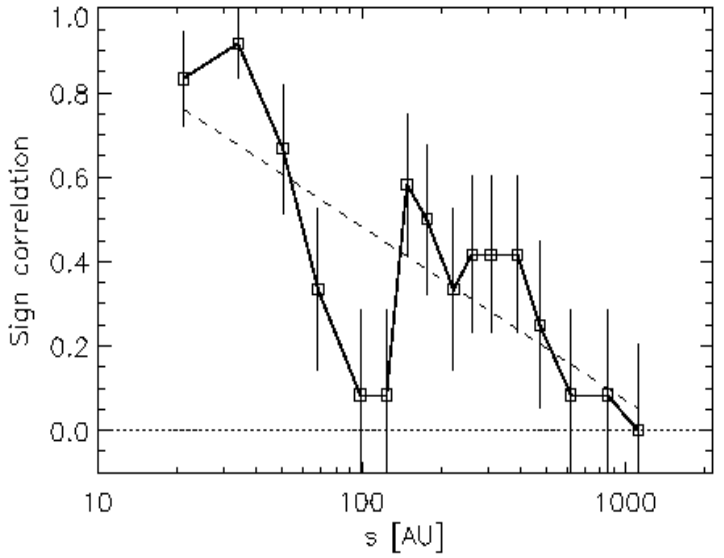
Biased!

http://www.ctio.noao.edu/~atokovin/stars
Vizier: J/ApJS/253/6

Are triples co-planar?

- Generally, not. Misaligned orbits → KCTF!
- Strong alignment for a_{out}<50 AU. Average inclination i~30°.
- No alignment for a_{out}>1000 AU.

Aligned triples: less eccentric inner orbits



2017, ApJ, 844, 103

Borkovits+ 2016 MNRAS, 455, 4136: close triples are aligned

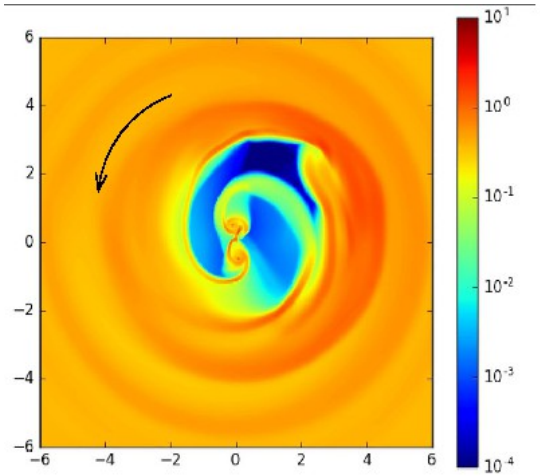
Not enough misaligned triples for KCTF

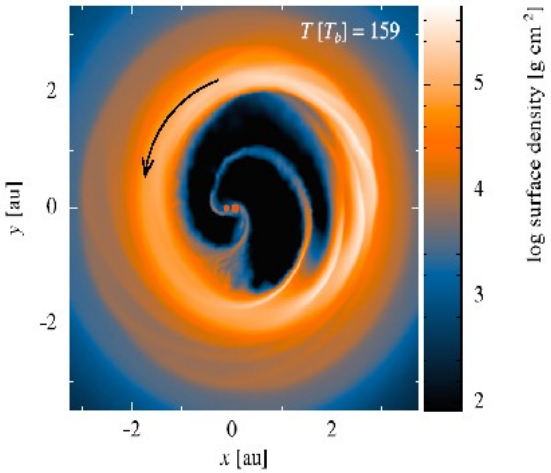
Less alignment in massive triples?

Most close binaries formed by migration

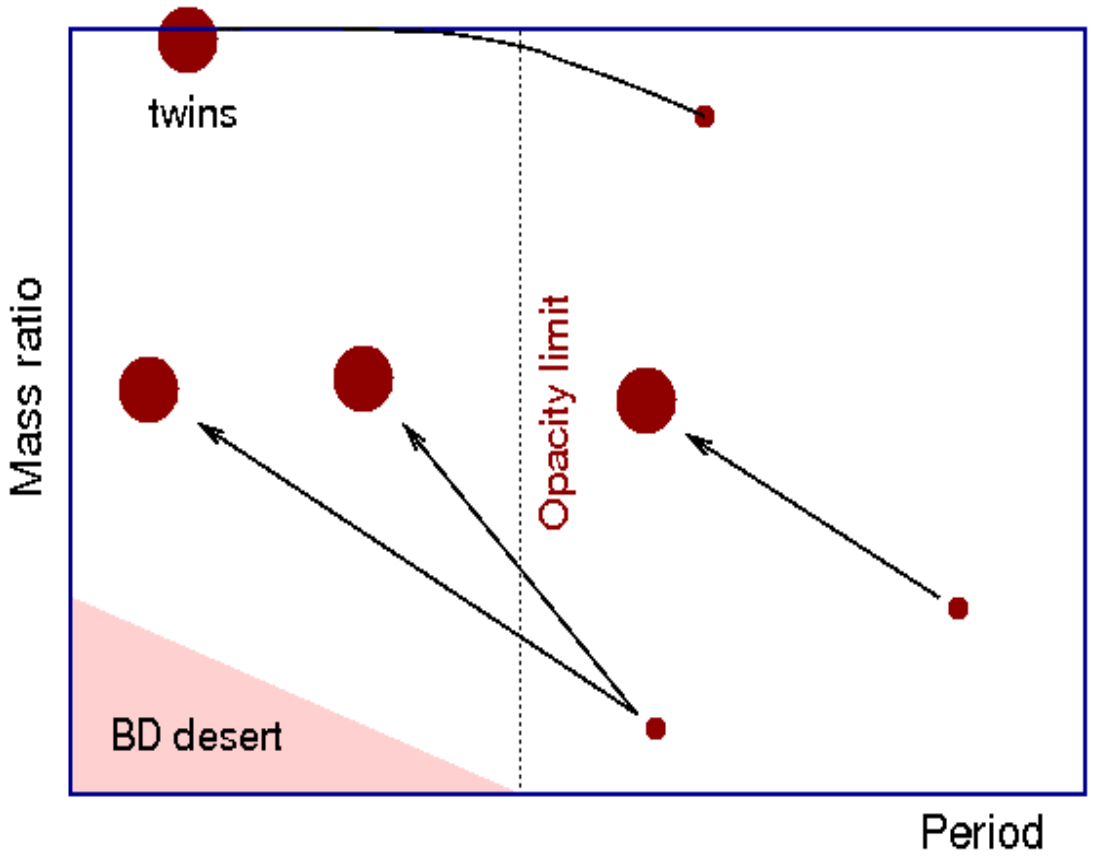
- Companions form at a>10au by disk fragmentation, at larger distances - by core fragmentation
- Stellar (and binary) masses grow by accretion
- Accretion onto a binary shrinks its orbit

$$da/a = -\eta\,(dm_2/m_2), \quad \eta = 1...4$$





Accretion-driven migration



$$da/a = -\eta\, dm_2/m_2$$

$$dm_2 = f_2(q)\, dm,$$

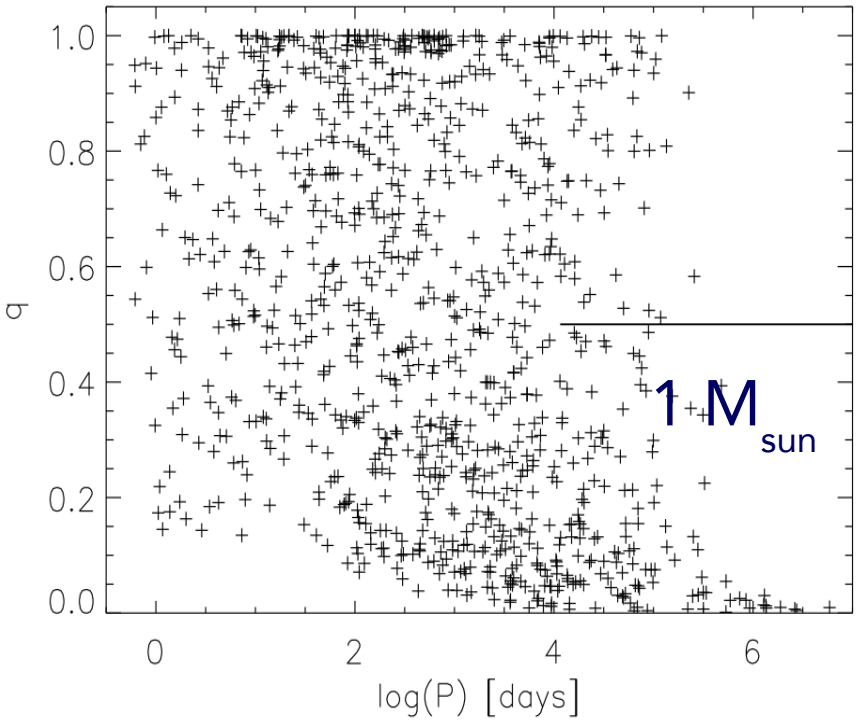
$$f_2 \geq 0.5$$

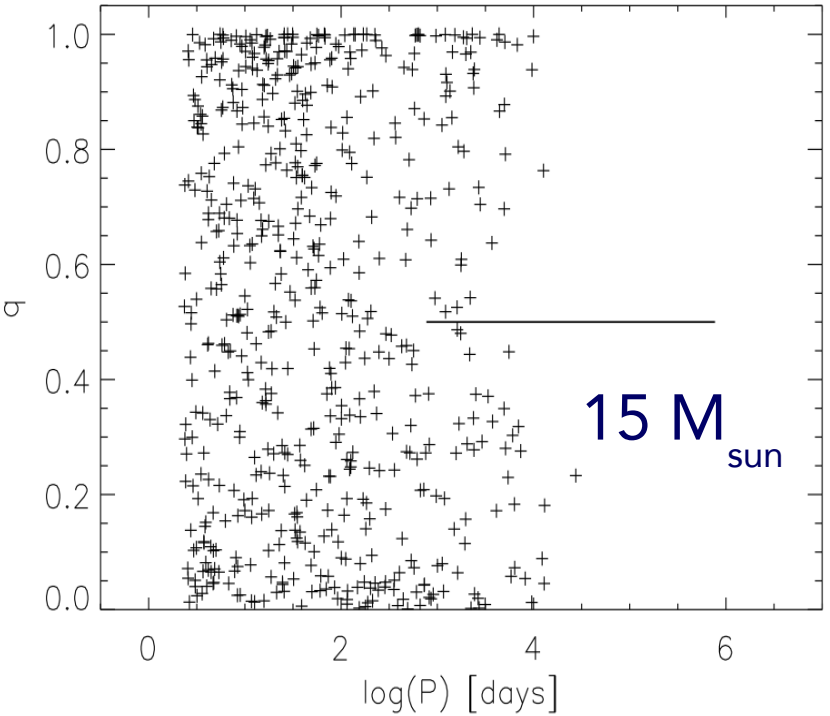
1. Pulsed accretion
2. Companion forms at random time

Need a “prescription”: P,q evolution

Black-hole binaries: similar theory

Toy model of binary migration

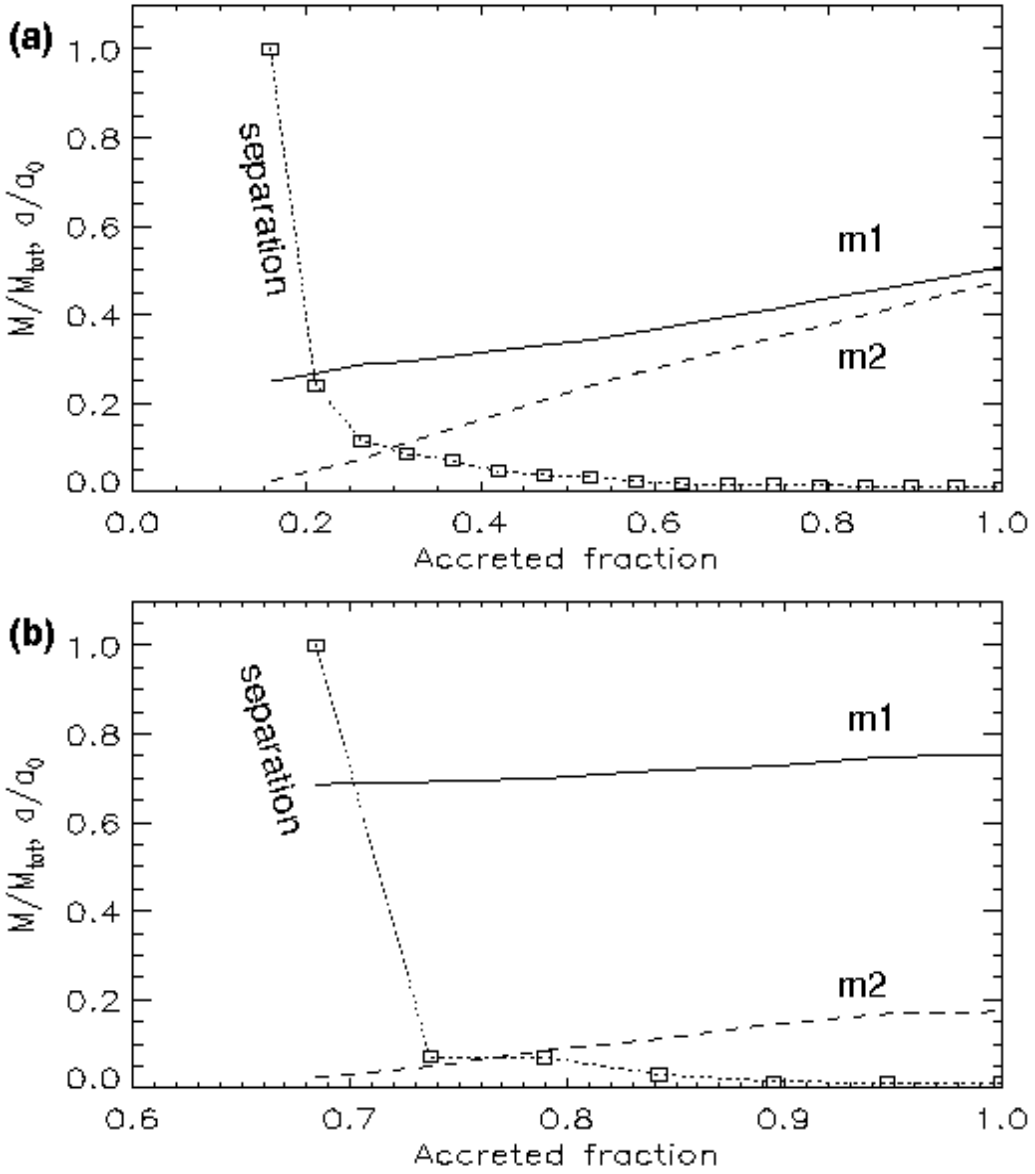


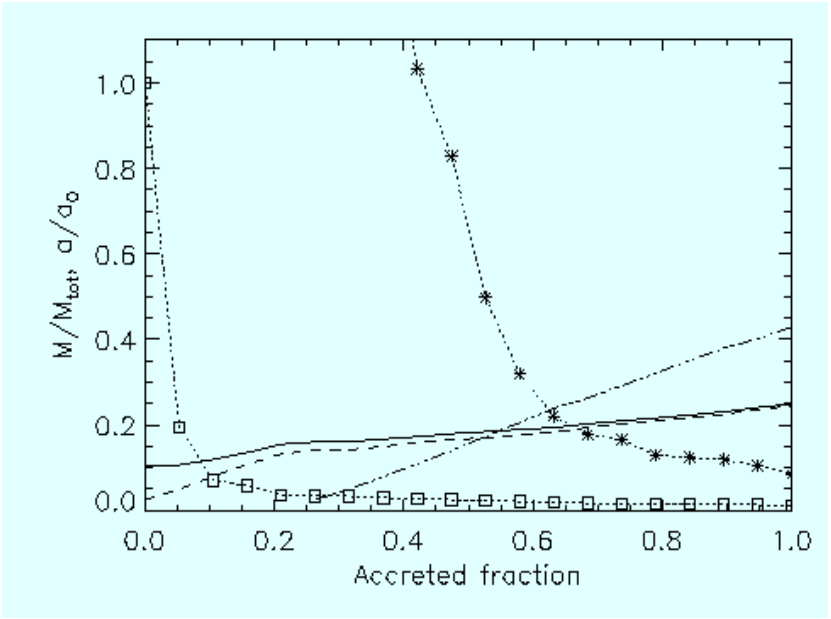


Explains BD desert and twins (q>0.95)

In collaboration with Maxwell Moe

Examples of binary evolution

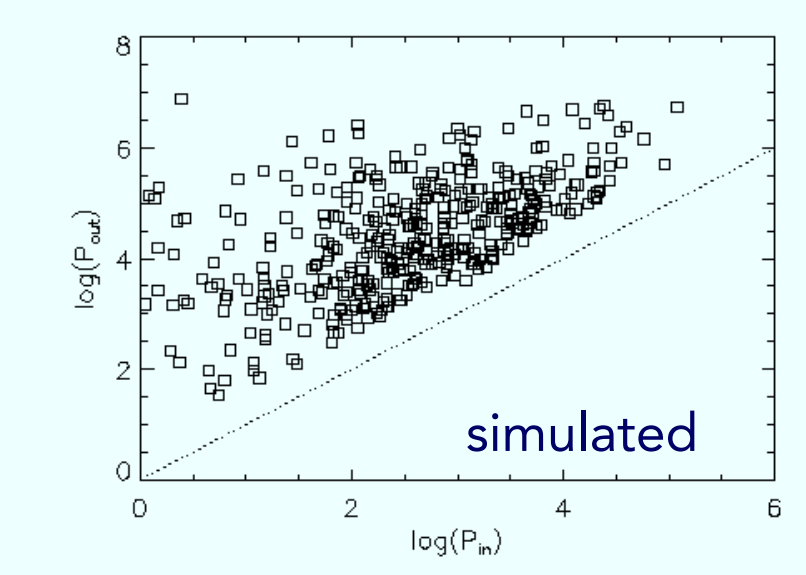


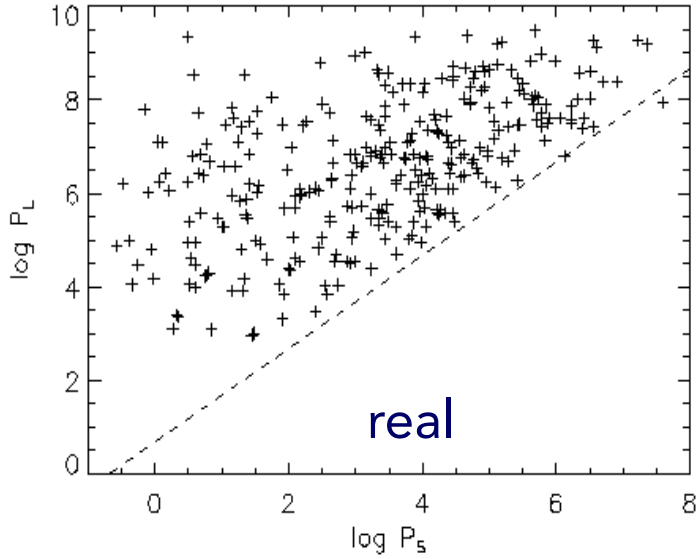


Triple system

Why many CBs are triple?

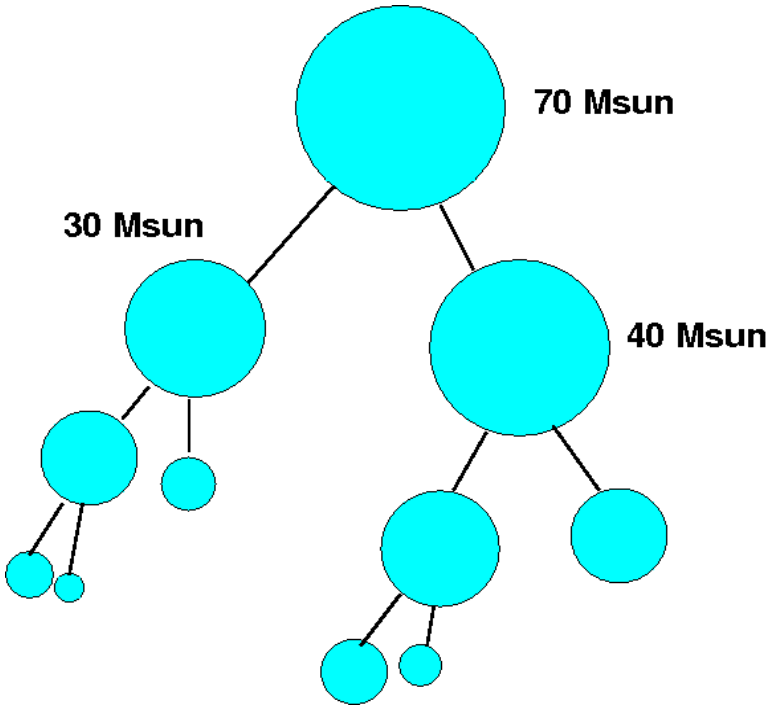
- Close binary = strong migration = large accretion
- Large accretion = more companions = more triples = more massive stars





Very massive stars formed by merging?

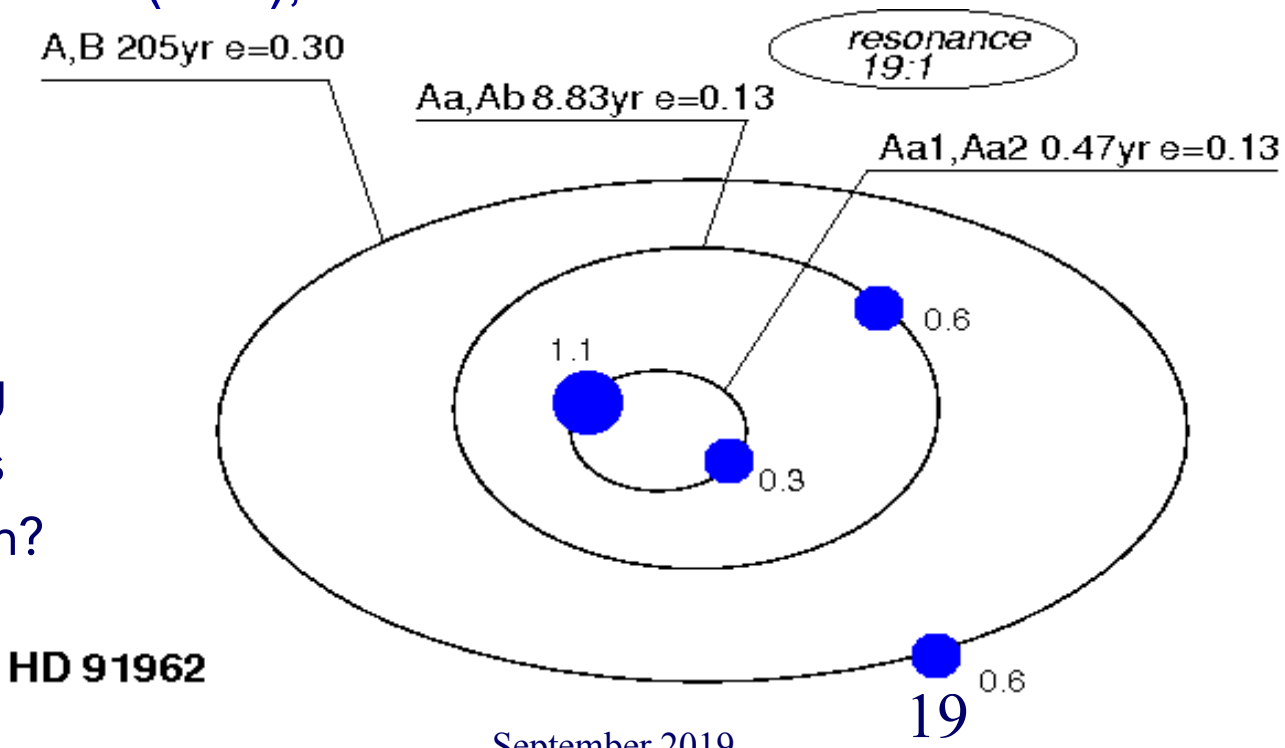
- Nuclear evolution of a 100-M_{sun} star is shorter than the mass assembly time, unless a huge accretion rate is assumed.
- Merging of lower-mass binaries delays the evolution and helps mass assembly. Strong accretion is still needed to cause merging.
- Many massive stars are close binaries that just failed to merge!



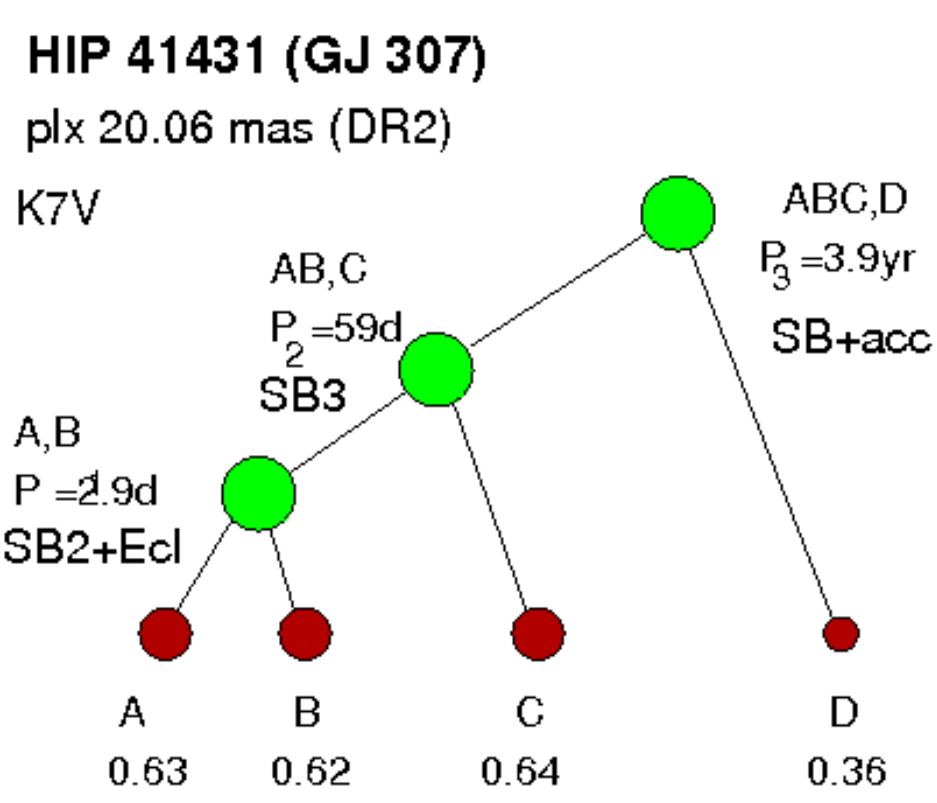
"Planetary" hierarchies: products of migration

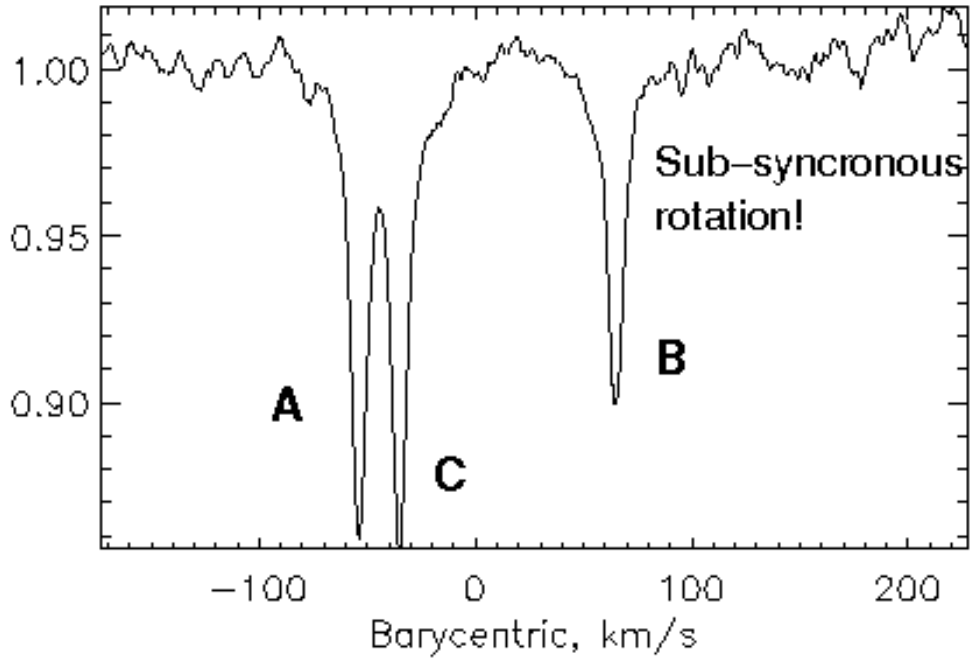
- Resemble solar system
- Co-planar to within 30°, mildly eccentric orbits
- Moderate period ratios (~20), resonances?

Companions formed too soon, preventing growth of inner pairs and further migration?



HIP 41431 (Borkovits et al., 2019, MNRAS, 487, 4631)





Strong dynamical interaction between orbits
All nearly co–planar!

Tight “planetary” quadruple

HIP 41431 (continued)

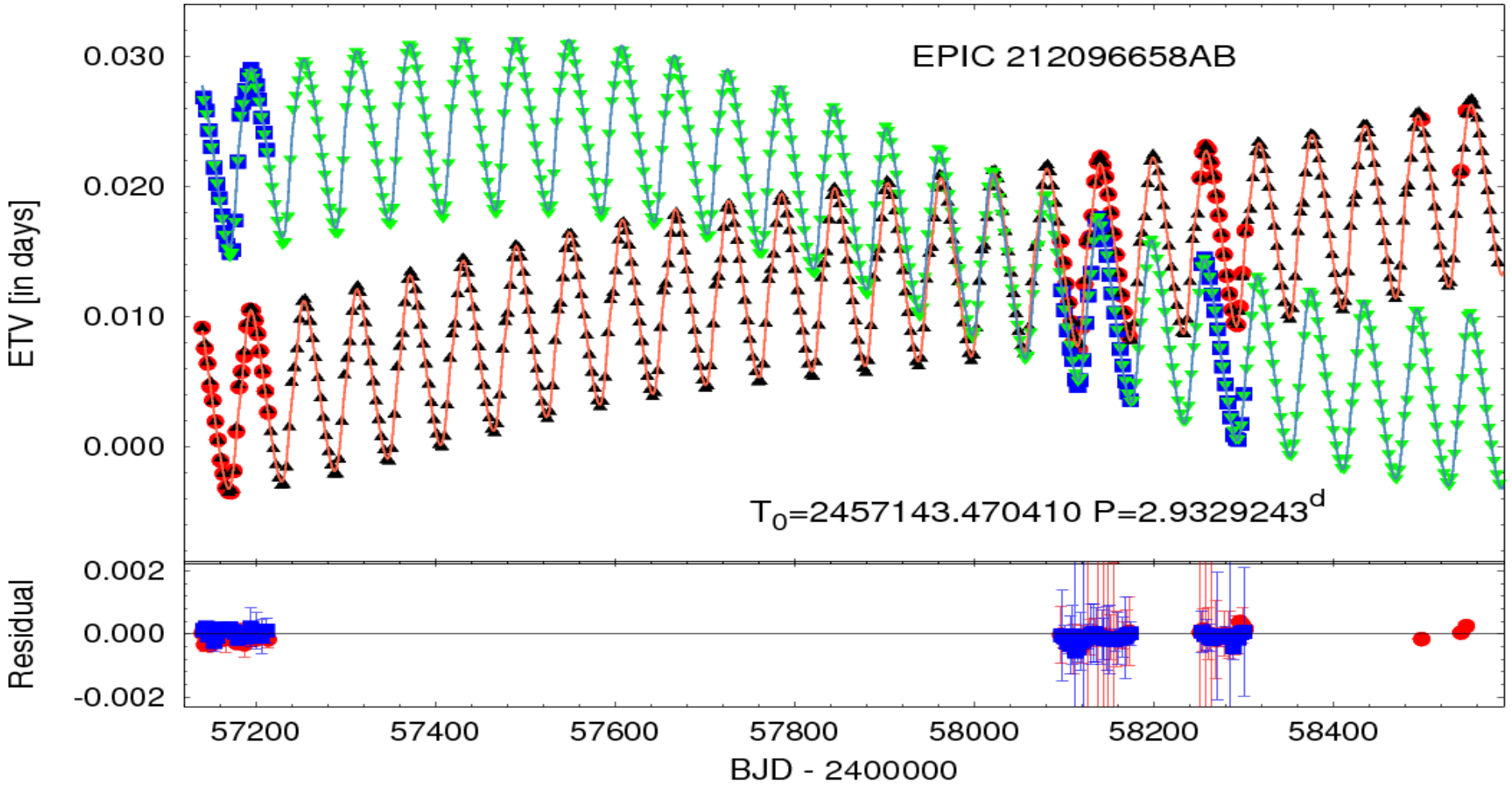
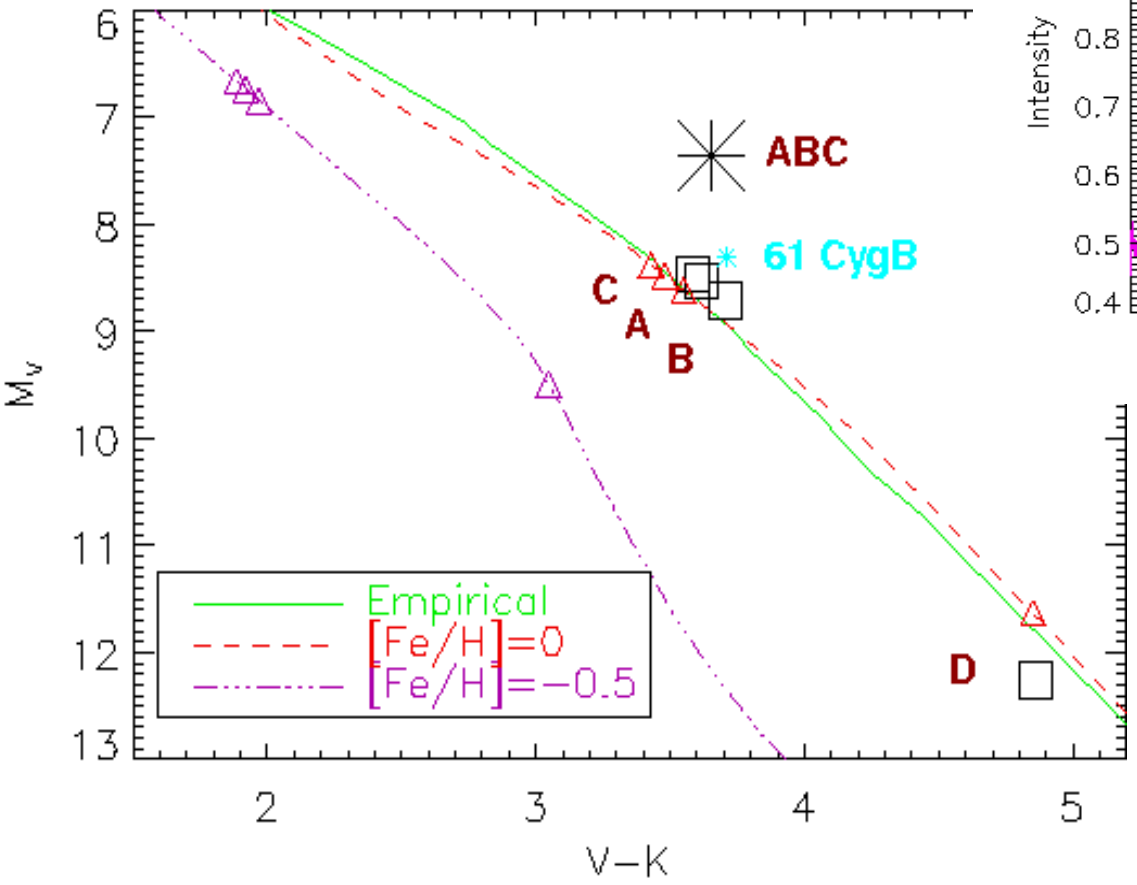
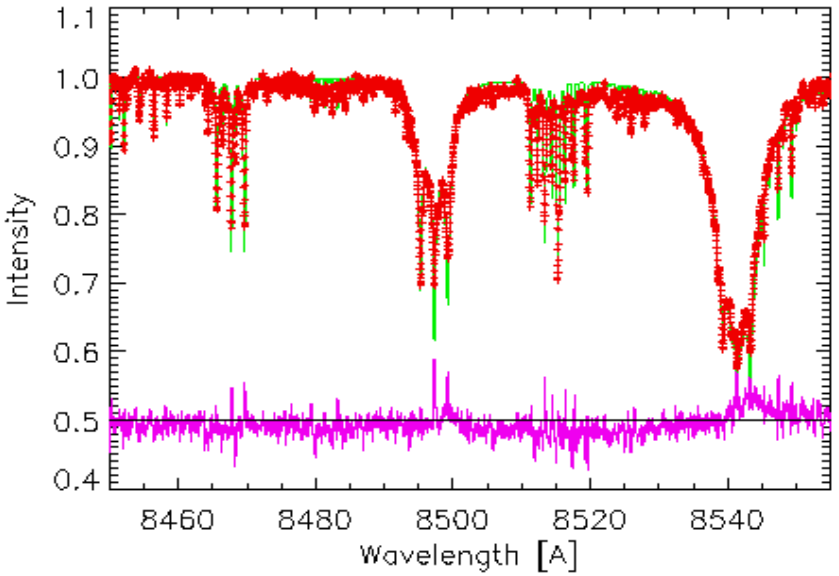


Photo-dynamical model: fit eclipses and RVs, accounting for dynamics

HIP 41431 on the CMD

Anchor stellar models

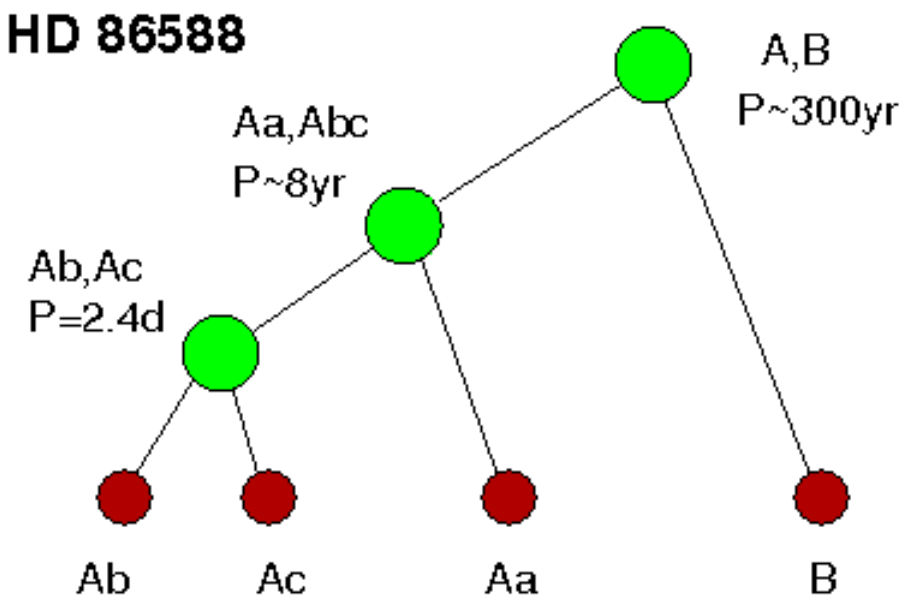


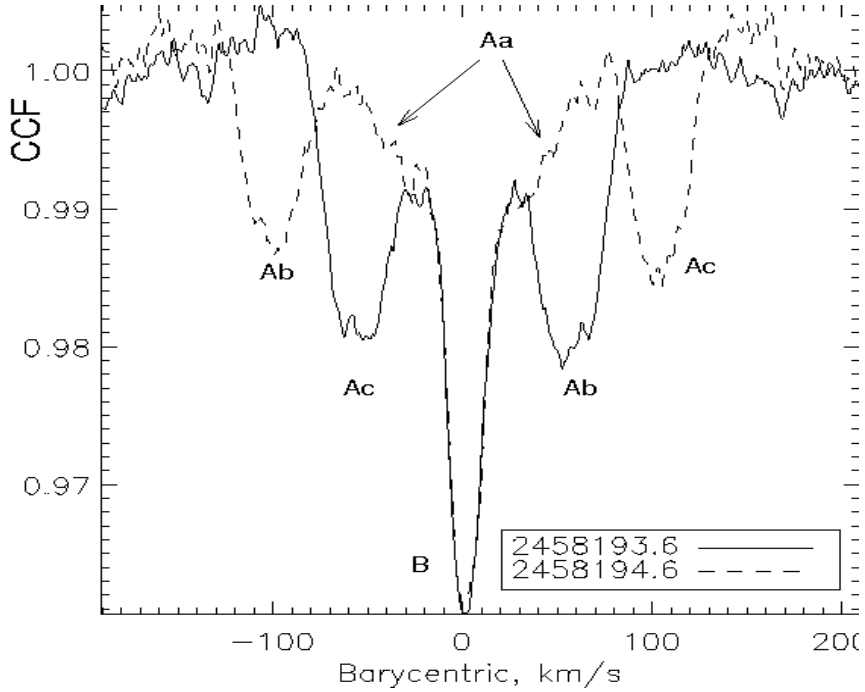


VLT/UVES spectrum
Teff=4000K, [Fe/H]= -0.5

Young and eccentric

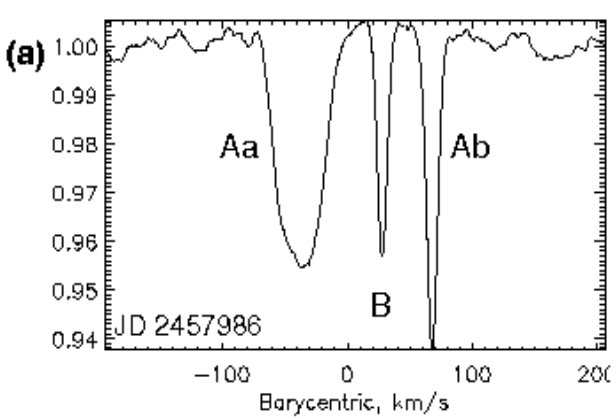
HD 86588: juvenile quadruple age (25...150Myr). Inner binary: P=2.4day, e=0.09? Tidal age ~1Myr ?!

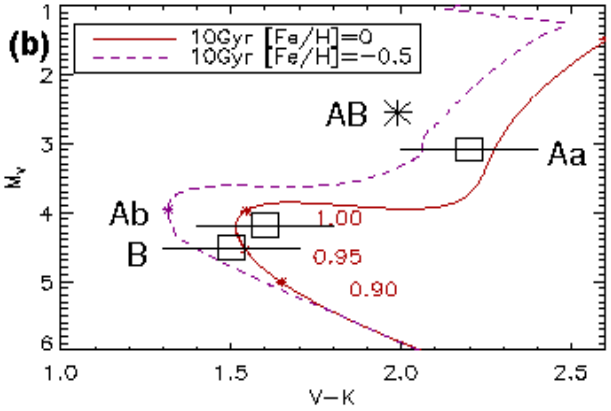


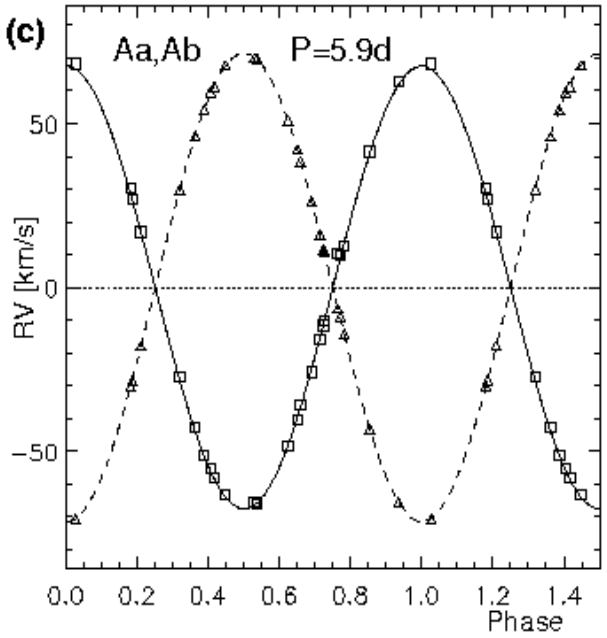


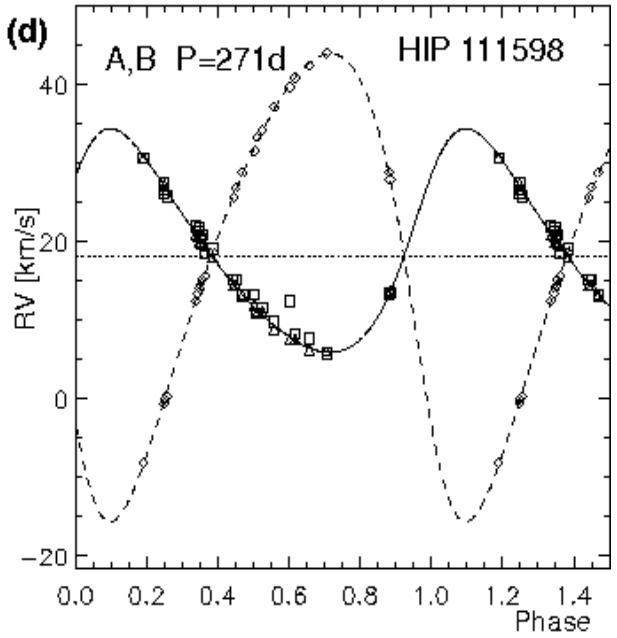
2018, AJ, 156, 120

HIP 111598: old & enigmatic









Comp	Vsin i
Aa	28
Ab	4 ??!
B	2

$V_{sync}=8.6\ (R_*/R_{sun})$

Aa is chromospheically active (spots, X-ray)

q=0.95

q=0.47

Challenges of inner binaries

- Axial rotation (sub-synchronous in HIP 41431, different in HIP 111598)
- Eccentric orbits with P<10d
- "Algol paradox": i~90°!
- Mean motion resonances?
- 2+2 quadruples

Dynamical chaos? A. Hamers+ (2015 MNRAS, 449, 422):
3+1 quadruple system with comparable K-L time scales.
A. Correia+ (2016 CeMDA, 126, 189): spin-orbit interaction.

What next?

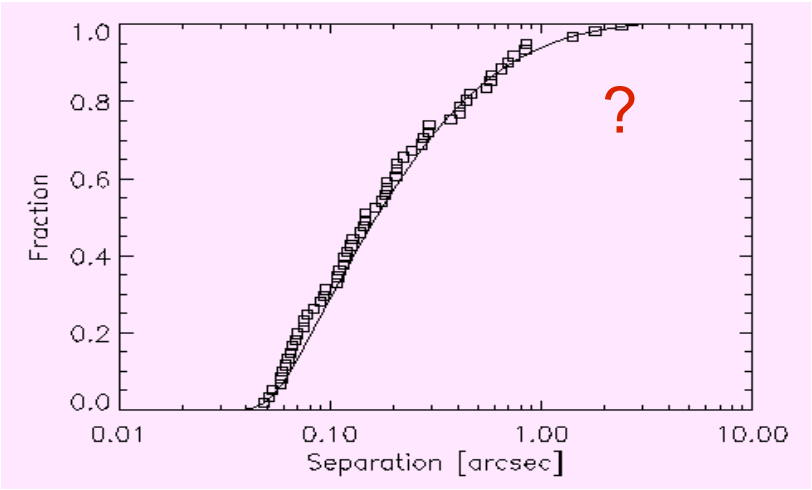
- Larger samples (Gaia, APOGEE, ?)
- PMS close binaries: statistics?
- 2+2 quadruples
- Theoretical modeling of migration
- Dynamical challenges
- Predictive population synthesis

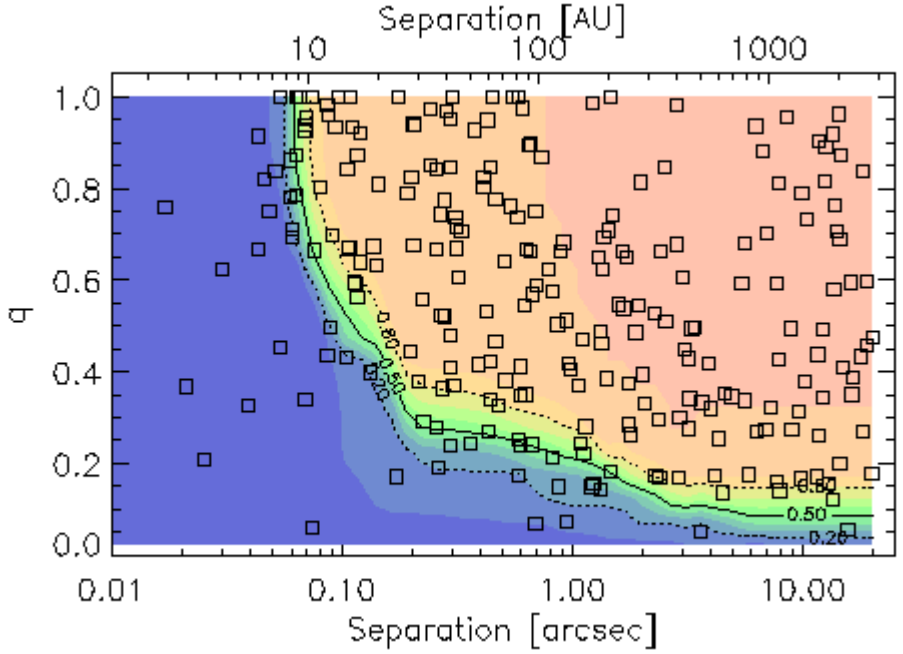
Summary

- Close binaries “like” to be within hierarchies, but can live without.
- Kozai-Lidov cycles with tidal friction are not the dominant formation mode of close binaries, but migration is.
- Relation between close binaries and hierarchies is not casual.
- There are unexplained facts and challenges.

Binaries in Upper Scorpius

OB association, age ~8Myr, sample N=614 (<M3V)





Double-periodic Kepler
2018 AJ, 156, 138

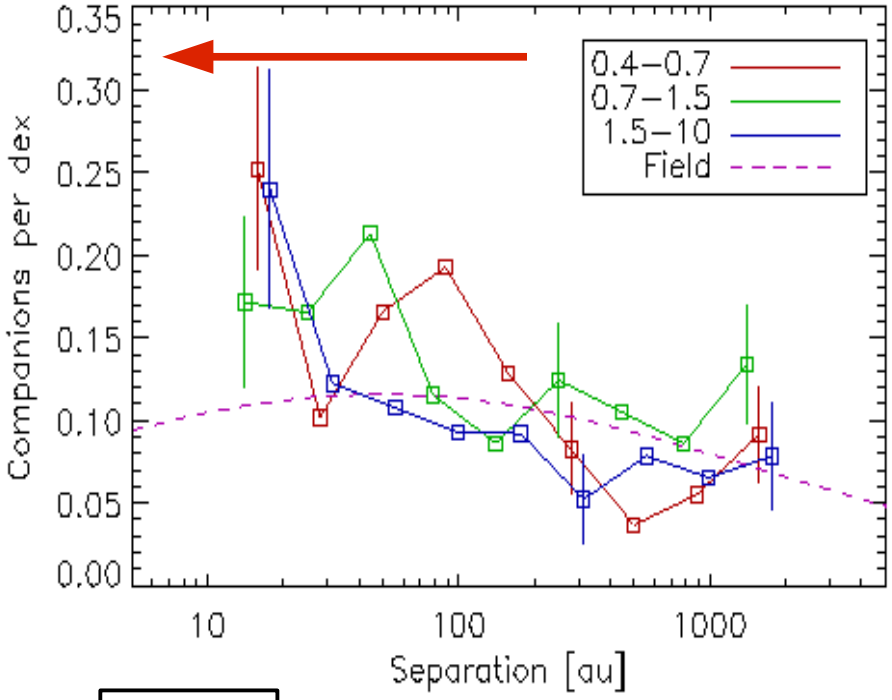
No binaries >100 AU?

All ~250 binaries in USco

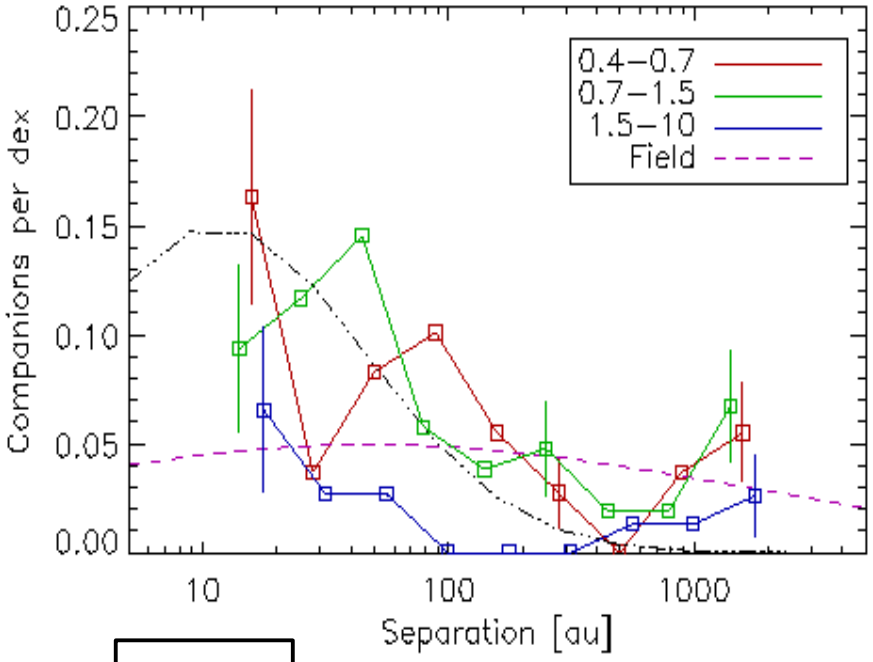
N=129, 70 resolved, 16 known

Upper Scorpius ≠ field!

Taurus



q>0.3



q>0.7

There is no such thing as “universal binary population”

Thank you!