Frequency of planets in multiple systems

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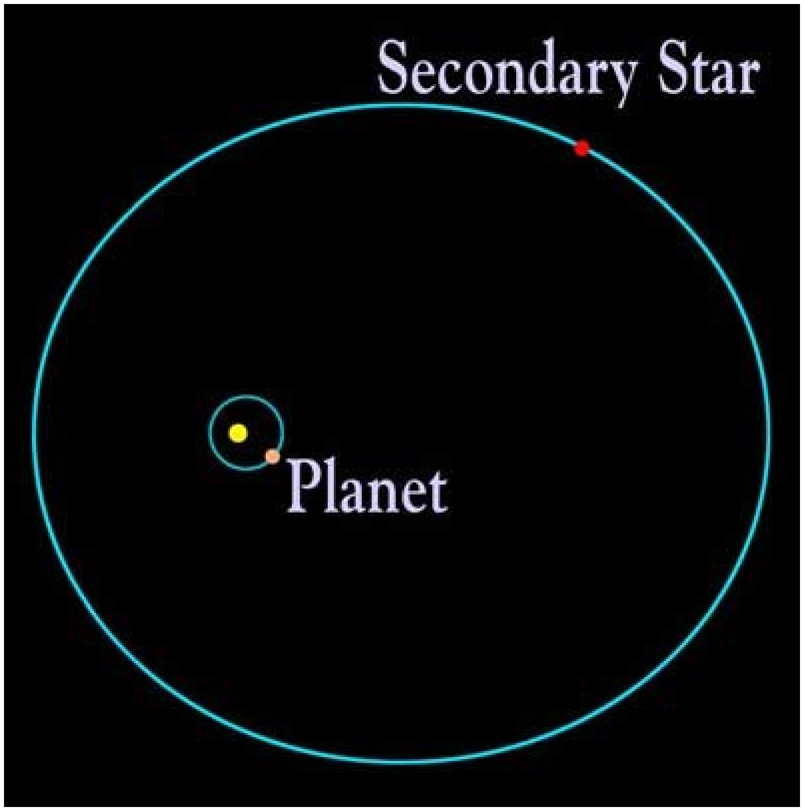
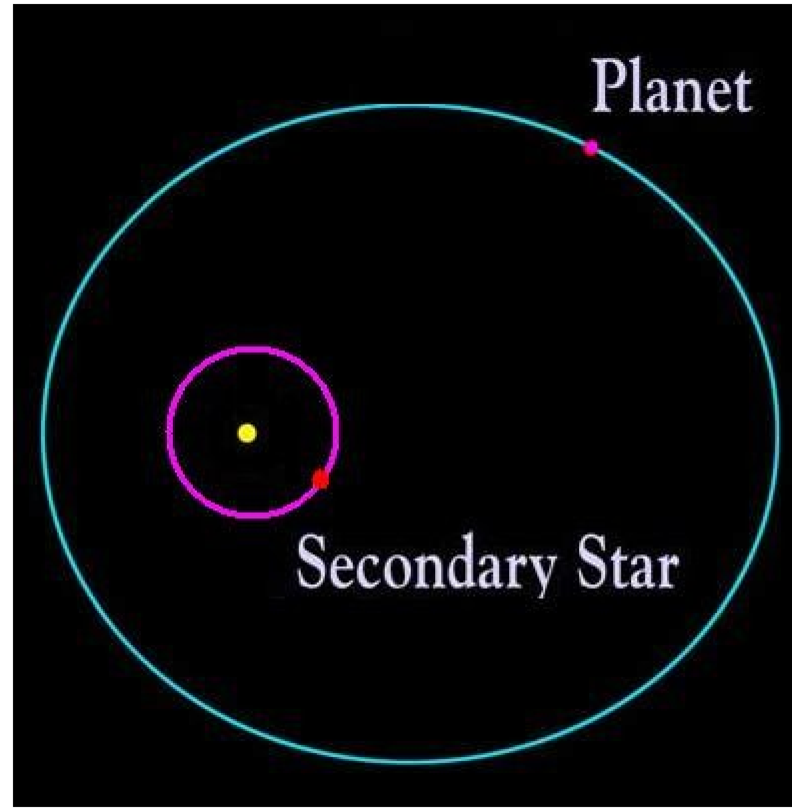
Outline:

- Introduction
- Searching for an unbiased sample
- Completeness and selection effects
- Frequency VS separation
- The case of close binaries
- Discussion and conclusions

What are we searching for?



P-Type orbit



S-Type Orbit

<u>N.B. All the planets discovered up to now are in P-type configuration</u>

Frequency of planets in binaries: why does it matters?

More than an half of the stars in our galaxy are in binary or multiple systems, so the contribute of those systems can't be neglected if we want to know something about the planetary population in our galaxy

The differences between planets in singles and multiple systems would shed light on the effects of the presence of the companion star on the planet formation mechanisms, in particular in the case of very close binaries.

Despite the frequency, and in particular its dependencies on the binary separation, is a key information in this context, only preliminary estimates are available in literature!!

Binary stars: an undesirable guest?!?

Most of the RV planet search surveys have biases against the binaries. Usually they esclude:

- The binaries with $\rho < 2''$
- The spectroscopic binaries

The first dedicated surveys started in 2000, and the samples contains only few hundred stars.

The Uniform Detectability sample

We searched for binaries in the Uniform Detectability (UD) sample by Fischer & Valenti (2005)

This sample is made of 850 stars selected from the target lists of Lick, Keck and AAT planet search surveys, having at least 10 observation available, spanning 4 years.

The stars added after the planet discovery by other groups are excluded.

Only the planets with K > 30 Km/s and with period less than 4 years are considered.

The UD binaries sub-sample - I

Selection criteria:

We searched for known or claimed companions of the UD stars, checking available sources listing stellar companions.

Inclusions:
- Stars with RV or astrometric trends, even without other indications of binariety
- Stars with brown dwarfs companions

Exclusions:
- Stars with non-confirmed companions
- Stars with CCDM companions with inconsistent proper motion

The UD binaries sub-sample - II

Properties of the UD binaries

Table 8. Properties of binaries found in the UD sample: projected separation (arcsec), eccentricity and semi major-axis (when available), masses of the object and the companion, and critical semimajor axis for dynamical stability of planets (Holman & Wiegert 1999). For systems for which only the projected separation was available (empty spaces in eccentricity column) the semi major axis was derived from the projected separation using the relation a(AU)=1.31ρ(arcsec)d(pc) (see Fischer et al. 2002; Duquennoy & Mayor 1991). The asterisk in the last column marks systems discussed individually in Appendix A. The mass flag indicates the source for the companion mass: **a:** M_{comp} from VF06; **b:** M_{comp} from Reid & Gizis (1997); Delfosse et al. (2000); **c:** M_{comp} from individual papers (see Reference below).

HD	ρ (arcsec)	ecc	a (AU)	a_{crit} (AU)	M_{obj} ($M_\odot$)	M_{com} ($M_\odot$)	Mass Flag	Remarks
531 A	5.30		482.30	76.37	1.64	1.66	a	S
531 B	5.30	[illegible]	[illegible]	[illegible]	1.66	1.64	a	S
3074	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.99	b	S
3651	[illegible]	[illegible]	[illegible]	[illegible]	0.89	0.06	b	S (*)
3770					1.25			S, RV
3795					1.94			S, RV, $\Delta\mu$
3821	8.45	[illegible]	284.51	51.50	1.00	0.63	b	S
4614	12.49	0.49	72.00	10.30	0.99	0.51	b	S
4747		0.64	6.70	0.79	0.82	0.04	c	S, SB
6734					1.08			S, $\Delta\mu$
6872 A	14.60		1442.48	271.29	1.91	1.03	b	S

A(AU)= 1.31 * ρ(arc sec) * d(pc)

0.31

Remarks: P: Stars with planets as in FV05; **S:** Stars without planets as in FV05; **SB:** Spectroscopic Binaries; **RV:** Stars with RV linear trends (see Nidever et al. 2002); **$\Delta\mu$:** Stars with discrepant proper motion in Hipparcos and Thyco II (see Makarov & Kaplan 2005); **G:** Stars with accelerating proper motions in Hipparcos. (see Makarov & Kaplan 2005).

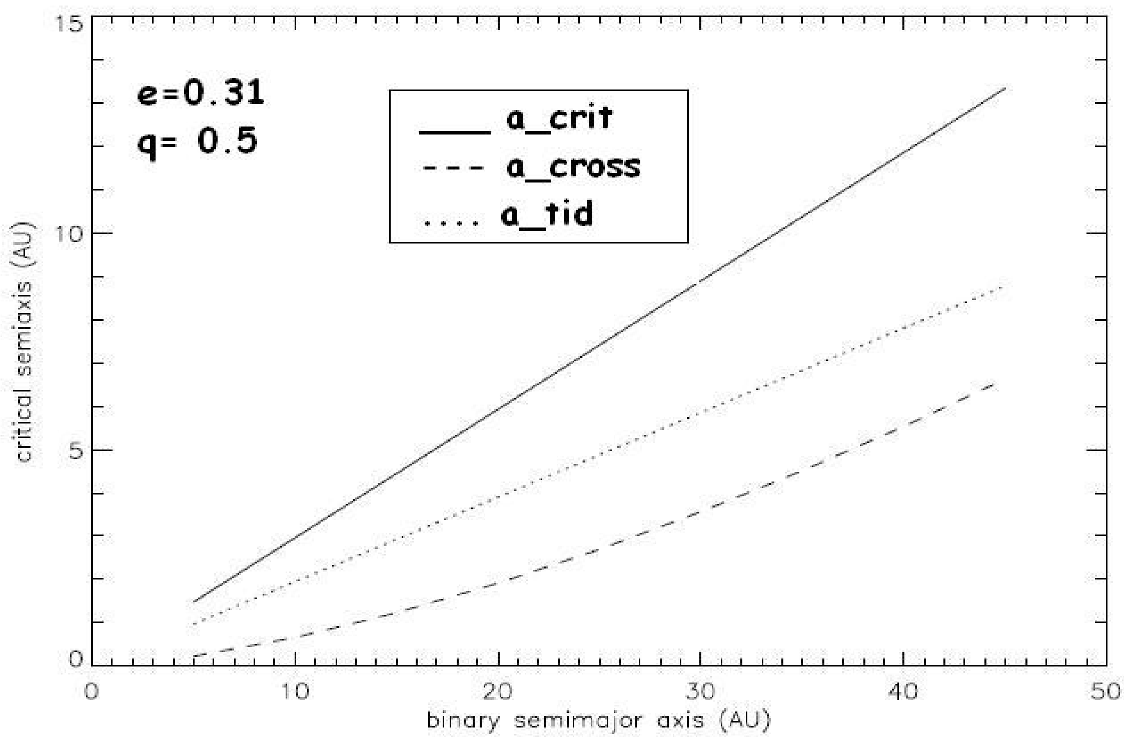
Notes

- Stars with both components in the UD sample are listed twice
- Only the closest companions are listed
- In case of hierarchical triple systems, we consider the influence of the closest pair as a single companion
- If the star is a spectroscopic binary, we report the minimum companion mass

Interval

The critical semi-major axis for dynamical stability

$$a_{crit} = \left(0.464 - 0.380\mu - 0.631e_{bin} + 0.586\mu e_{bin} + 0.150e_{bin}^2 - 0.198\mu e_{bin}^2\right) a_{bin}$$



- It represent the maximum value of the semimajor axis for a stable orbit around the planet host (see Holman & Wiegert 1999).
- It is larger than the limit of the region in which the encounter velocities of planetesimals is small enough to allow the accretion of kilometer-size planetesimals (see Thébault et al. 2006).
- The radius of tidal truncation (see Pichardo et al. 2005 and Pfhal & Mutherspaugh 2006) is intermediate between these two values.5

A global estimate of the frequency

Stars	Planets	Frequency	
202	15	7.4 ± 2.4	
647	34	5.3 ± 1.1	

An upper limit on the sample incompleteness.

Following the approach of Dunquennoy & Major (1991), we can guess that ~ 57% of the stars in the UD sample should be binaries: 296 lost binaries.
If all those stars haven't planets, the frequency values turn to:
3.9 ± 0,94 for the UD binaries and 9.31 ± 0,69 for the UD singles.

The planet frequency in binaries should not be lower than one third of that orbiting single stars.

A more precise evaluation of the number of missing binaries:

In the estimate of the number of the missing binaries we must take into account that known spectroscopic binaries and systems with ρ < 2" were excluded from the original sample.

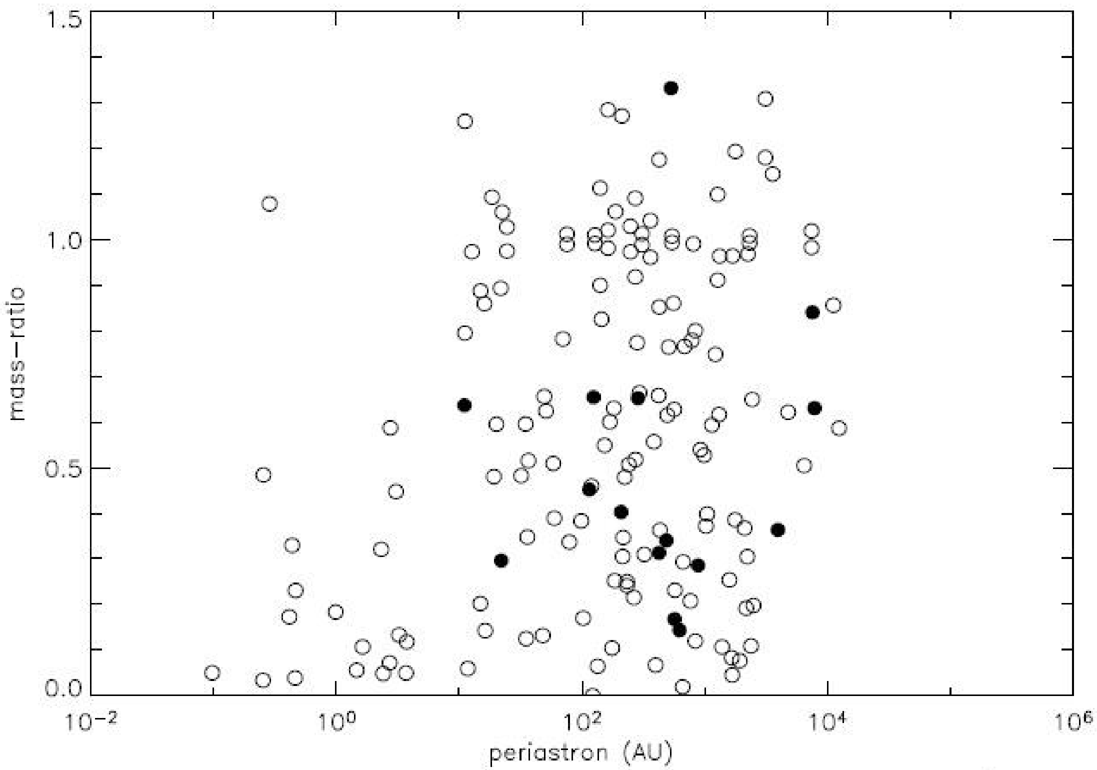
~ 45,7% of the DM91 binaries would have ρ < 2" for the distance distribution of the UD sample and should be excluded a priori!

So the number of missed binaries decreases to 202.
If we exclude the spectroscopic binaries, the stars with brown dwarf companion and the systems with wide companions orbiting close pair with ρ < 2", 120 UD binaries are left, so only 95 binaries are lost.

The new values of the planet frequency are then:
6.75 % for the UD binaries and 5.4 % for the singles.

Results – II/a

Frequency VS periastron values

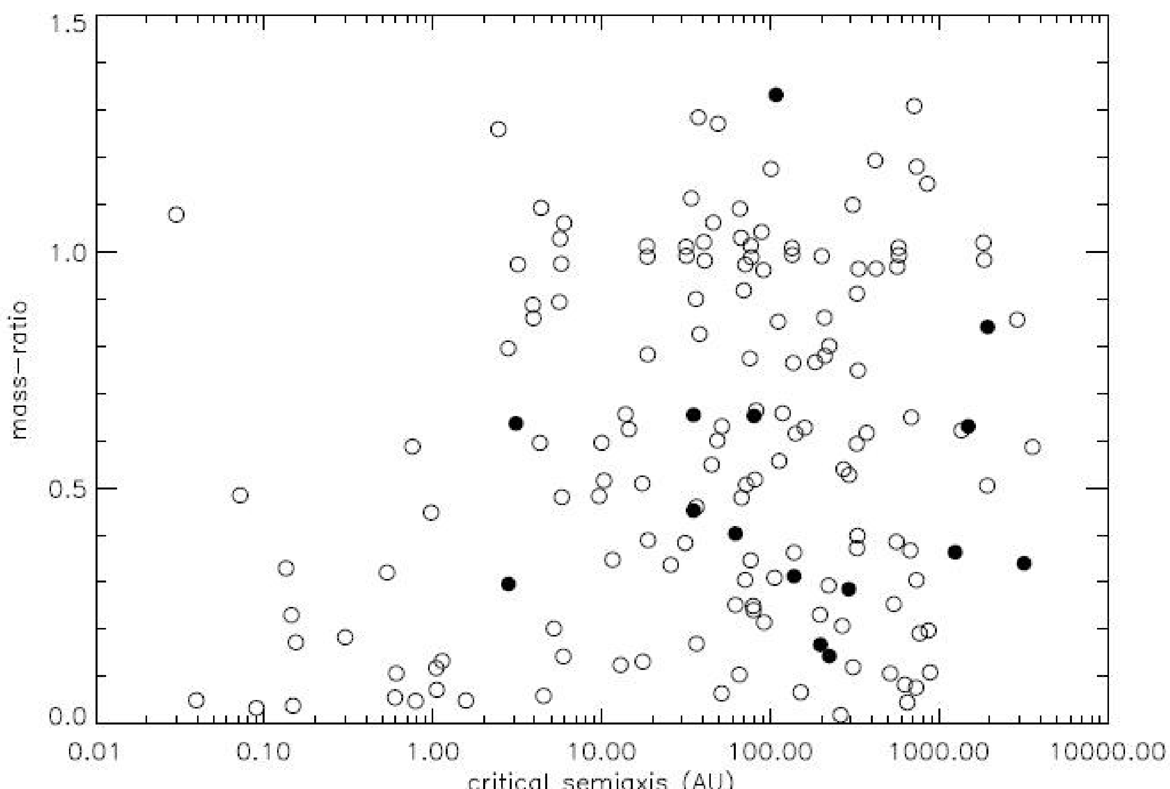


Periastron	N_{star}	$N_{planets}$	$\frac{N_{planets}}{N_{stars}}$
< 50 AU	81	2	0.025±0.020
50 - 200 AU	28	2	0.071±0.064
200 - 500 AU	30	3	0.100±0.076
500 - 1000 AU	23	4	0.174±0.123
> 1000 AU	39	4	0.103±0.068

Table 2. Frequency of planets in binaries with different values of periastron.

Results – II/b

Frequency VS critical semiaxis

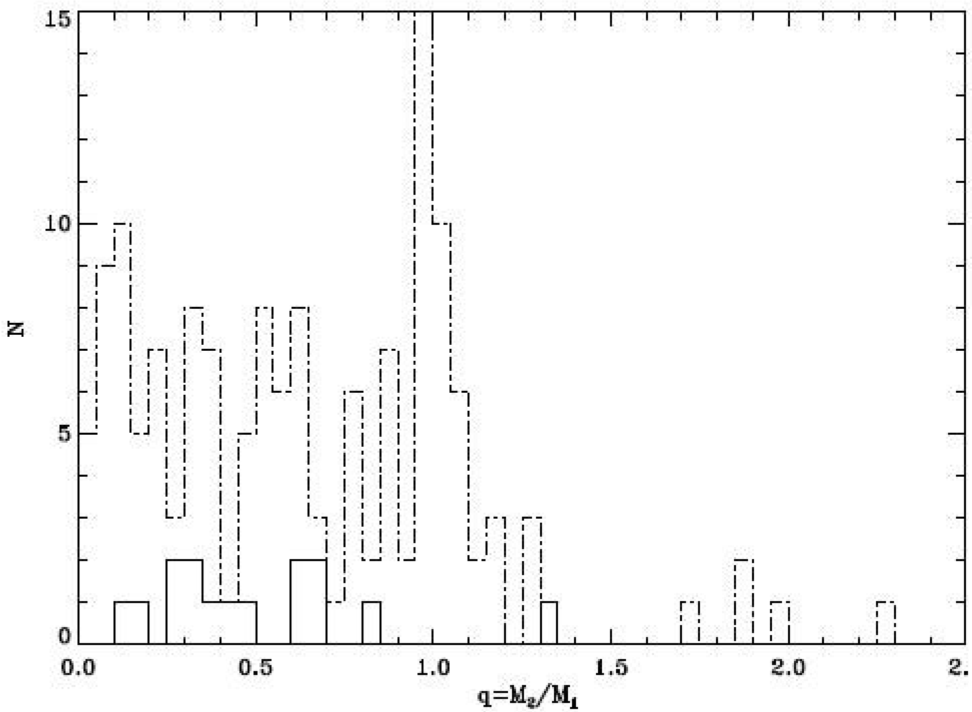


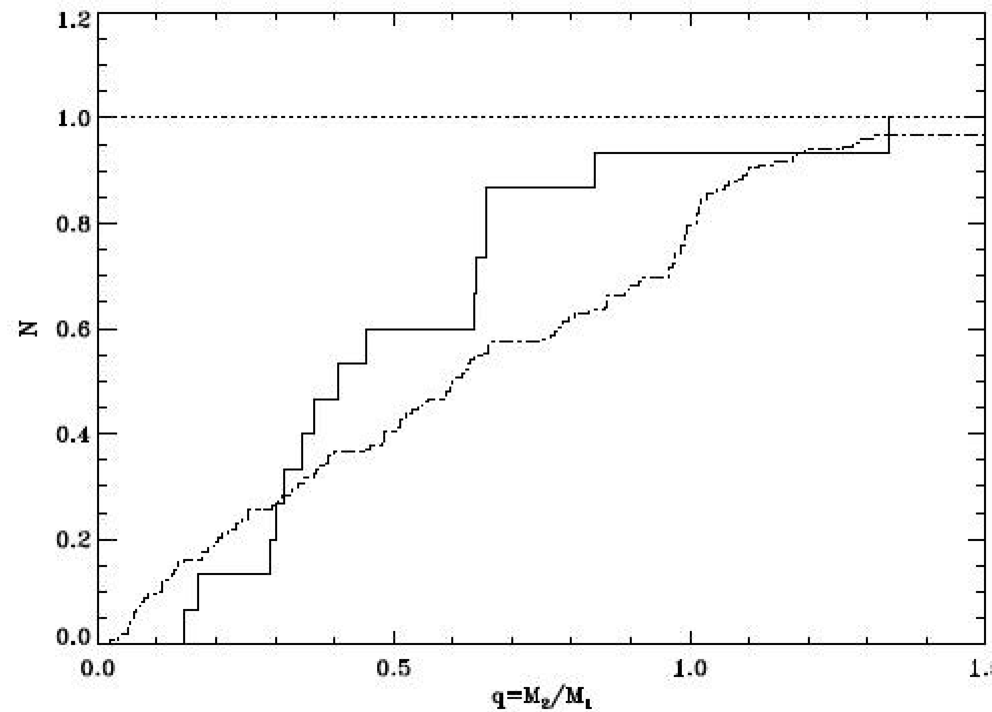
a_{crit}	N_{star}	$N_{planets}$	$\frac{N_{planets}}{N_{stars}}$
< 20 AU	89	2	0.022±0.018
20 - 50 AU	18	2	0.111±0.105
50 - 100 AU	24	2	0.083±0.076
100 - 250 AU	26	4	0.154±0.107
> 250 AU	45	5	0.111±0.066

Table 1. Frequency of planets in binaries with different values of a_{crit}.

Results – IV

Dependence on mass-ratio





Completeness of binary hosts VS non planet hosts

Planet hosts are systematically searched for companions after planet detection. The completeness of binariety of planet hosts is larger and the result is an higher frequency of planets in binaries.

a_{crit}	N_{star}	$N_{planets}$	$\frac{N_{planets}}{N_{stars}}$
< 20 AU	89	2	0.022±0.018
20 - 50 AU	18	2	0.111±0.105
50 - 100 AU	22	2	0.091±0.083
100 - 250 AU	23	2	0.087±0.079
> 250 AU	43	3	0.070±0.051
UD Singles sub-sample	654	38	0.058±0.011
Entire UD binary sub-sample	195	11	0.056±0.021

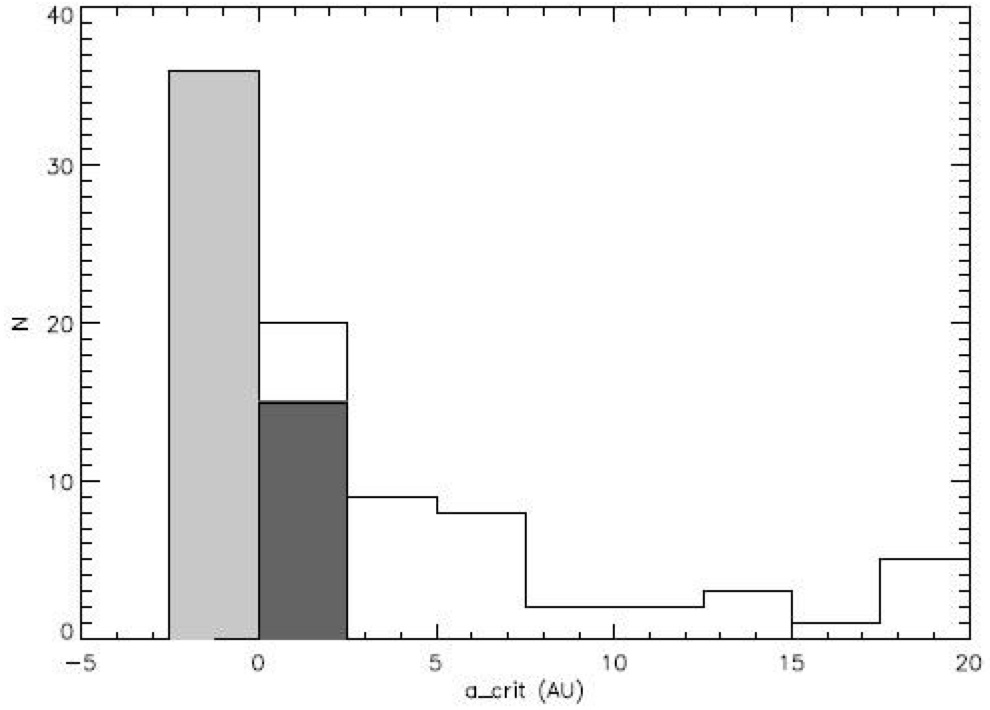
Table 3. Frequency of planets in binaries with different values of a_{crit}, without considering as binaries the planet-host whose companions were discovered thnaks to dedicated follow-up after planet detection.

Dependence on separation

The completeness of binariety probably depends on separation:

- At small separation the completeness is guaranteed by the inclusions of stars with RV or astrometric trends
- Wide binaries are easily detected and then included in CCDM and WDS
- The intermediate bin is probably the most incomplete one, because those companions requires dedicated high-resolution imaging, and does not cause relevant RV or astrometric signatures.

Effects on incomplete informations on orbits and masses of the companions



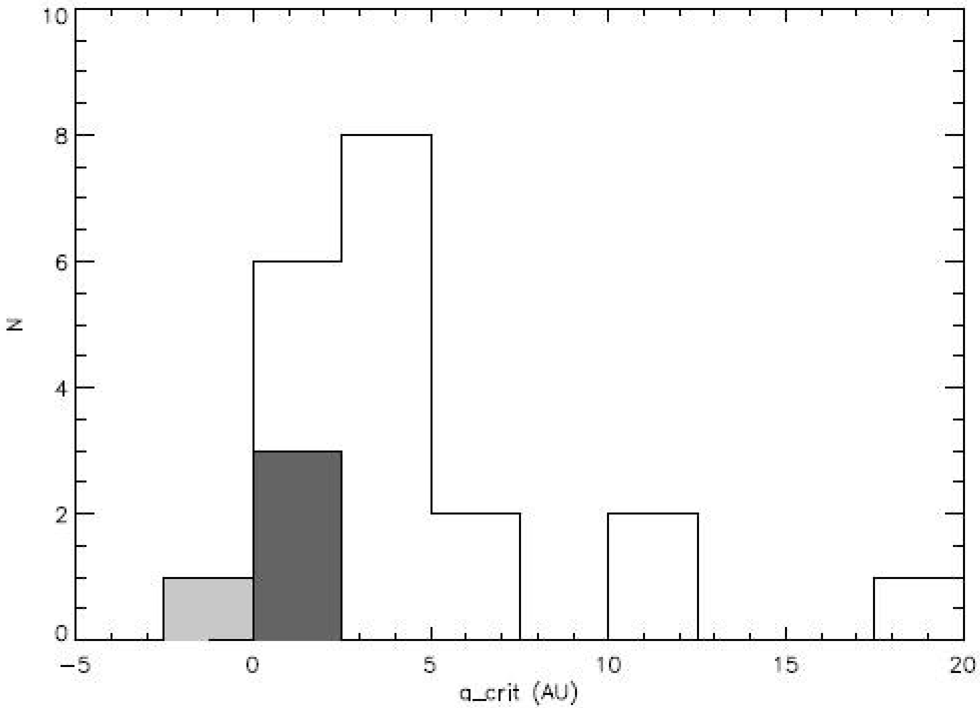
The determination of a_crit requires the availability of full binary orbit and an estimate of the companion mass.

We haven't those informations for the stars included on the basis of dynamical signatures!!

The value of the semimajor axis inferred from the projected separation could not fit the real one.

The volume limited sample

Our final sample is not so unbiased as we hope for!!!



We select a volume-limited sample with a radius of 18 pc.
As expected, it is more complete because the 2" limit corresponds to a smaller physical separation (36 AU).

a_{crit}	N_{star}	$N_{planets}$	$\frac{N_{planets}}{N_{stars}}$
< 20 AU	21	2	0.095±0.088
> 20 AU	23	2	0.087±0.079
VLUD Singles sub-sample	85	8	0.094±0.043
Entire VLUD binary sub-sample	44	4	0.091±0.059

Table 4. Frequency of planets in binaries with different values of a_{crit} for the volume-limited sample.

The case of close binaries - I

Clues on the planet formation

- Close binaries seems to have different mass distribution (see Desidera and Barbieri 2007)
- We found indication of a lower frequency

A low frequency (~ 0.1% see Pfahl & Muterspaugh 2006) would be compatible with dynamical interactions that cause the formation of the binary after planet formation.

We tested the probability to obtain the observed number of close binaries with planets for different values of frequency.

Frequency	Probability full sample	Probability VLUD sample
0.1%	0.3%	0.02%
1%	14.6%	1.4%
5%	14.1%	17.8%
10%	0.79%	28.5%

Table 7. Probability to observe 2 binaries with planets in a sample of 81 (resp. 19) binaries in the UD (resp. VLUD) sample with periastron < 50 AU, for different planet frequencies.

The case of close binaries - II

The run of planet frequency in close binaries

There is a possible paucity of planets in binaries with a_crit ~ 10-30 AU
But we found 5 planets in systems with a_crit < 10 AU and 4 planets in stars with a_crit ~ 30-50 AU!!

The frequency distribution seems to be bimodal, with a secondary maximum at a_crit ~ 3-5 AU and this could be an indication of different formation mechanisms

BUT: actually we haven't enough informations to confirm or reject these hypothesis!!

Conclusions

- ✔ The frequency of planets in single or binary stars are fairly similar
- ✔ Even taking into account the incompleteness in the binary detection, we estimate that the frequency of planets in binaries could not be more than a factor of 3 lower than in single stars
- ✔ A wide companion seems to play a marginal rule on the formation and evolution of giant planets
- ✔ Planets can form in close binaries, possibly with a different mechanism and their frequency seems to be lower than in the wider systems.