THE MASS RATIO DISTRIBUTION OF SPECTROSCOPIC BINARY STARS

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THE IMPORTANCE OF *f(q)*

- M_A and M_B and the mass ratio q=M_B/M_A distributions

- Binary formation mechanisms? e.g. random pairing, *f(q)* constant, *q* depends on M_A?
  - we already know that multiplicity is function of M_A
  - and possibly *f(q)* also

- Evolution of binary systems? e.g. twins population?

- Comparison between populations or families of stars
  e.g. PRGs and normal G-K giants;
  long and small periods

Spectroscopic Binaries

$$f(M) = \frac{(M_B \sin i)^3}{(M_A + M_B)^2} = \frac{K_A^3 P}{2\pi G}(1-e^2)^{3/2}$$

For exoplanet:

$$f(M) \approx \frac{M_B^3 \sin^3 i}{M_A^2} \qquad (\text{since } M_B << M_A).$$

M_A known → one can obtain $M_B \sin i$

As we can assume i is randomly distributed, if M_A is known, one could thus use the distribution of

$$Y = f(m)/M_A = q^3/(1+q)^2 \sin i$$

to determine the distribution of $f(q)$

THE WRONG WAY

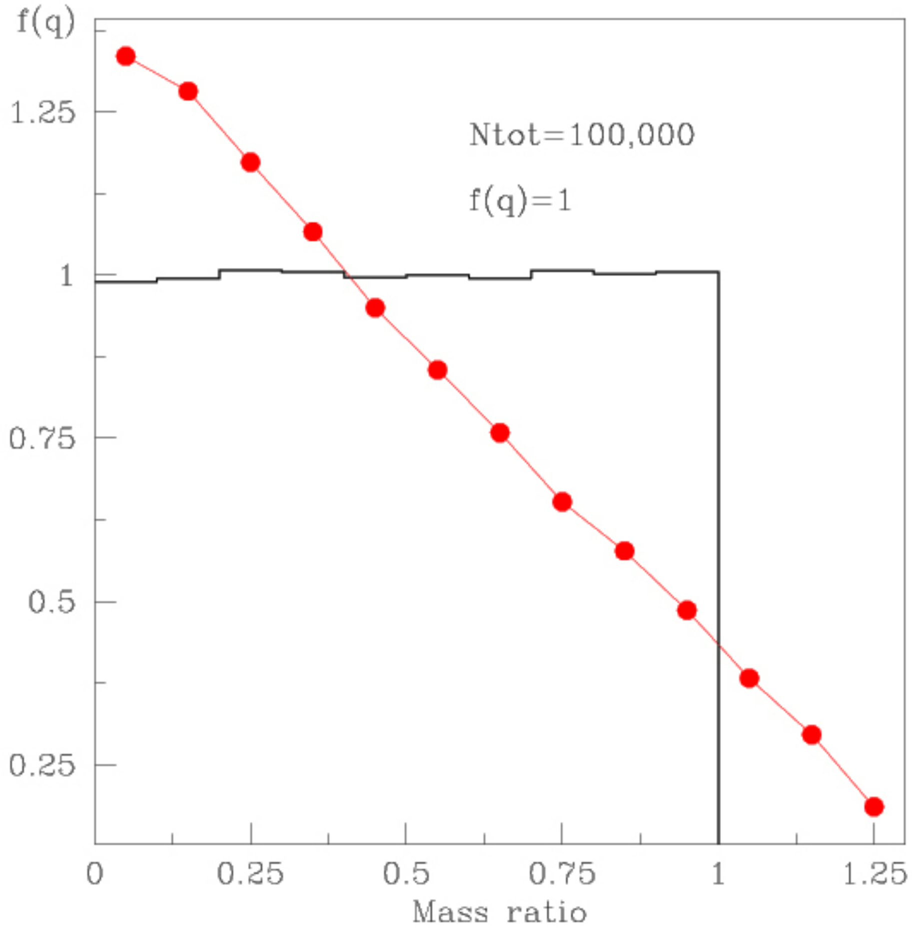
- *"There is always an easy solution to every human problem – neat, plausible, and wrong."*

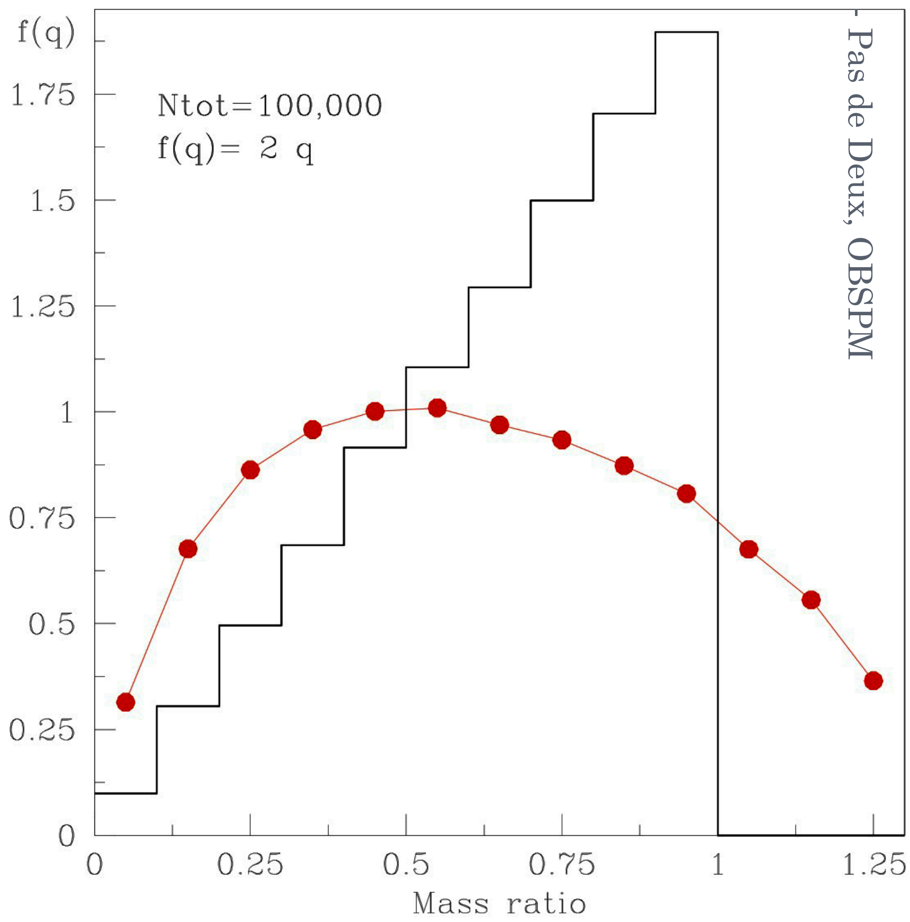
  H.L. Mencken, 1917

- Simplest way: replace $sin^3\,i$ by $\langle sin^3\,i \rangle$

  e.g. Aitken 35; Trimble 90; Trimble 09

ASSUMING MEAN $sin^3\ i$ DOES NOT WORK!





Halbwachs 87; Mazeh & Goldberg 92; Boffin+ 92

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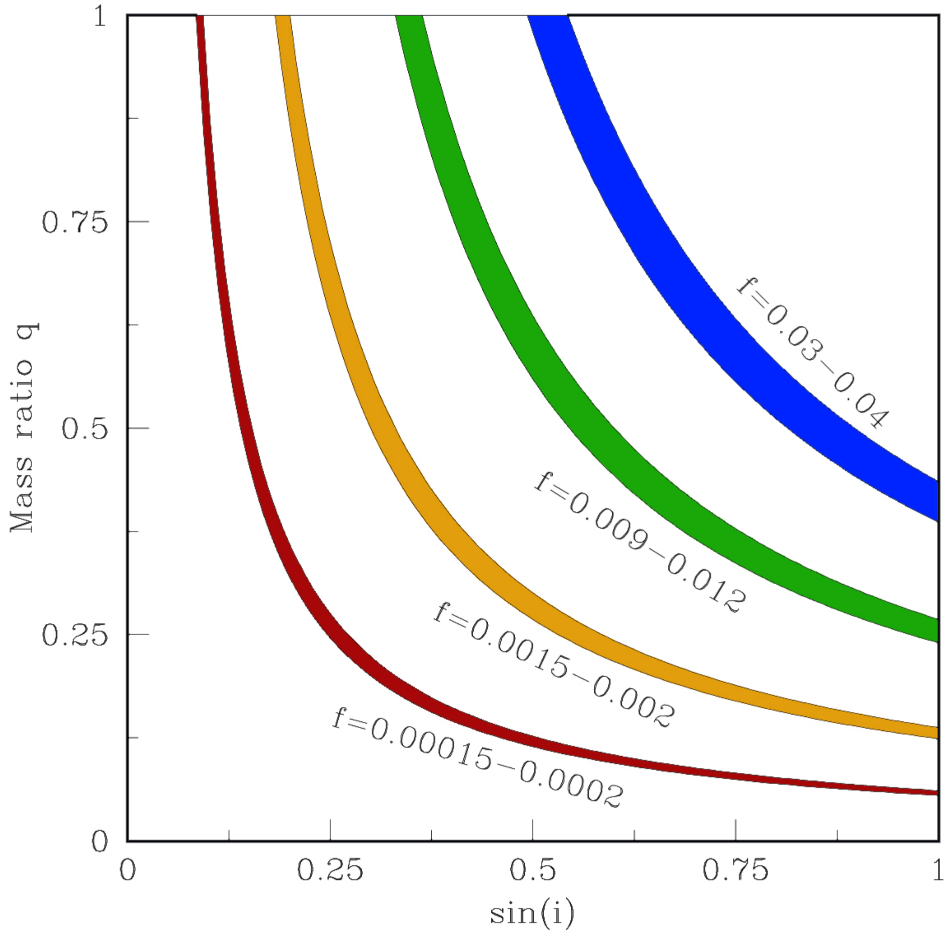


e.g. Mazeh & Goldberg 92

Errors arise because for a given *f(m)*, *i* and *q* are not independent anymore and so the mean cannot be the same as when the full range of *i* is allowed

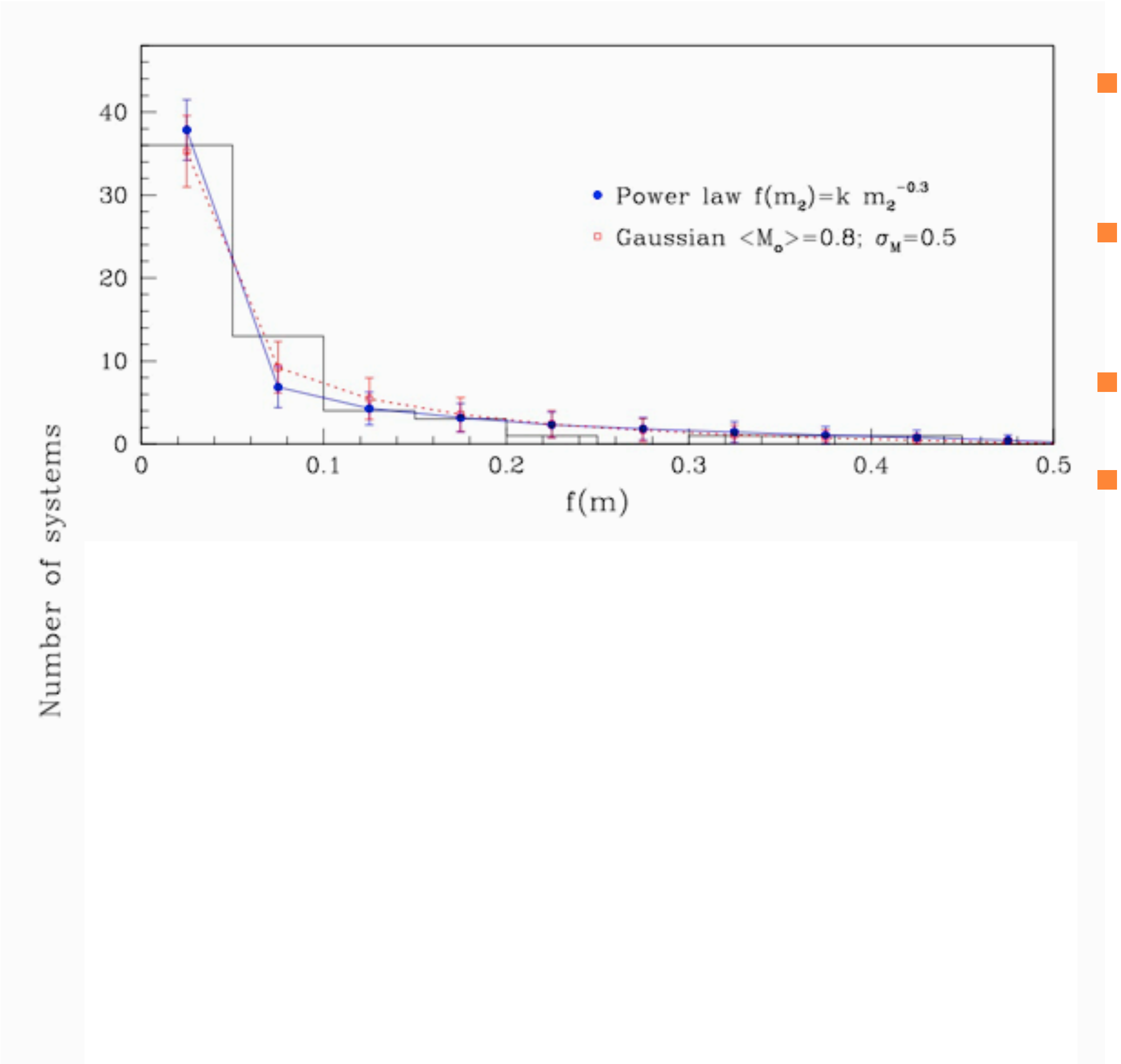
Similar for exoplanets: *a posteriori* distribution of *sin i* is dependent on M_B distribution (see also Ho & Turner 11)

Error is also due to the shape of $f(sin^3\ i)$, cf. Halbwachs 87

Functional form fitting

- Instead, one could assume a *f(q)* and then compute the *f(Y)* and compare to observed one – using a minimisation method

  (Jaschek & Ferrer 72; Halbwachs 87; see also Tabachnik & Tremaine 02 for exoplanets)
- Disadvantage: need to assume functional form and is thus very limited
- Advantage: not tempted to see spurious peaks
- Important (although obvious) remark: one should not compare to distribution of *f(m)* but distribution of *log f(m)*, cf. wide dynamic range

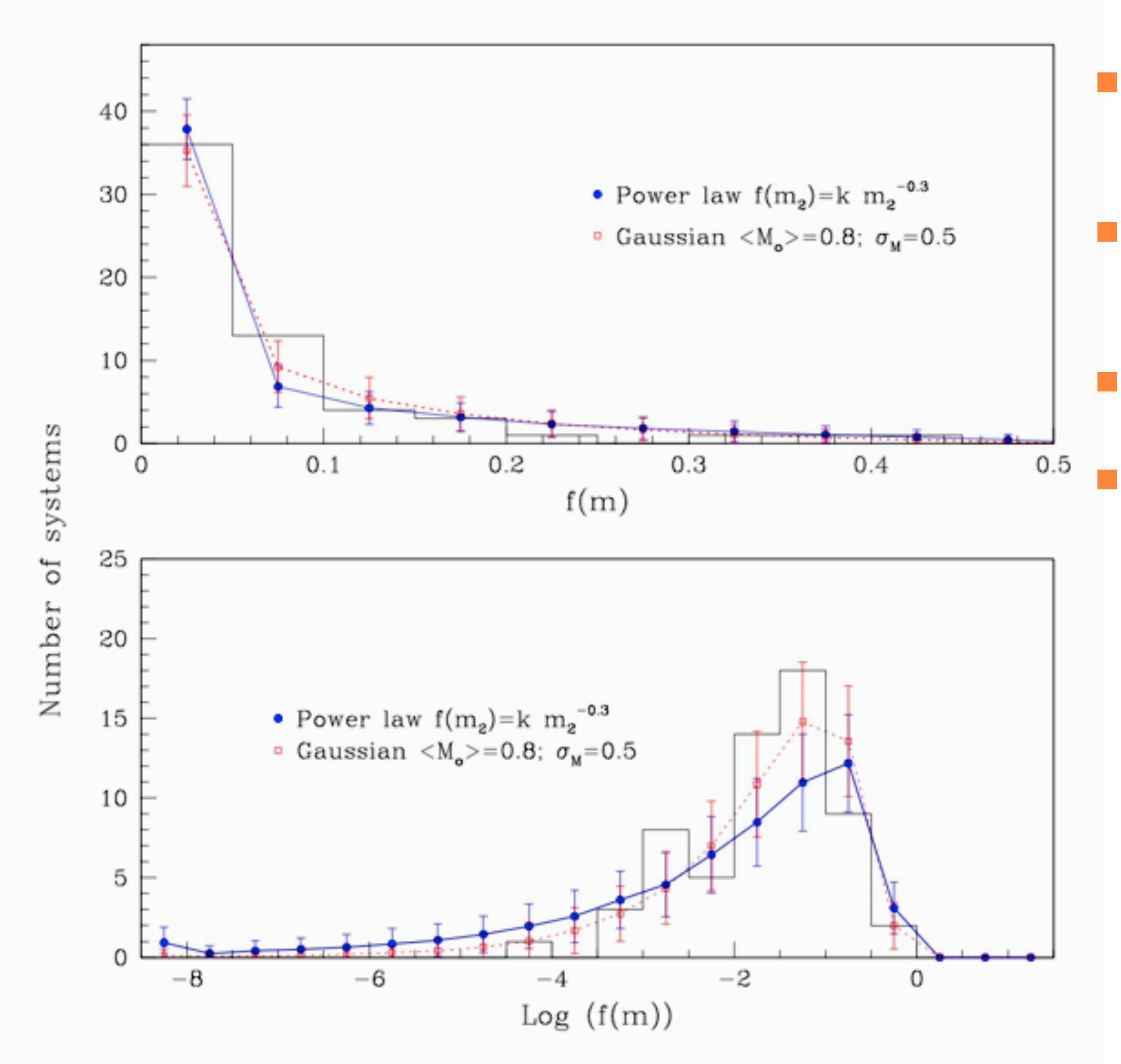


Carquillat & Prieur 07

- 60 orbits (for 53 Am systems)
- Fit distribution of mass function
- M_1=2 $M_\odot$
- Assume functional forms: gaussian and power law

INCORRECT!

(as seen when compare to *log f(m)*)



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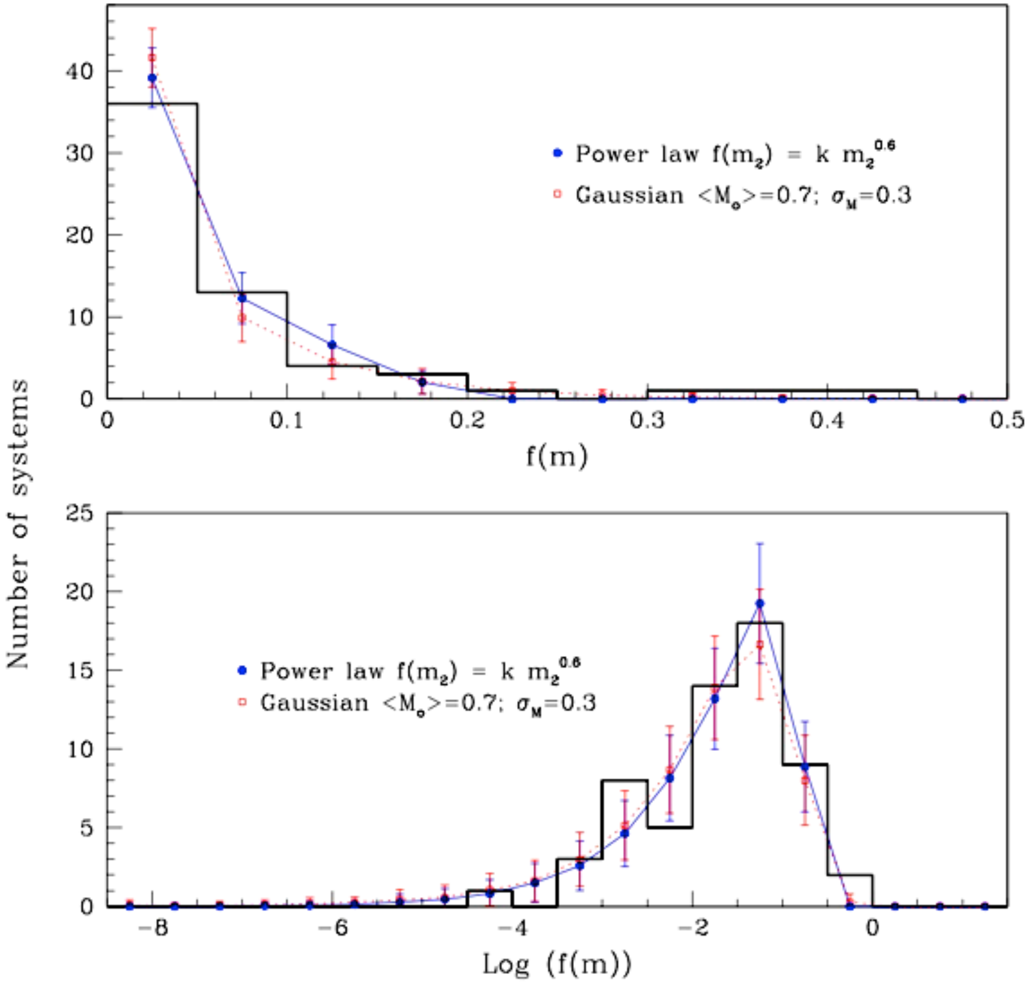
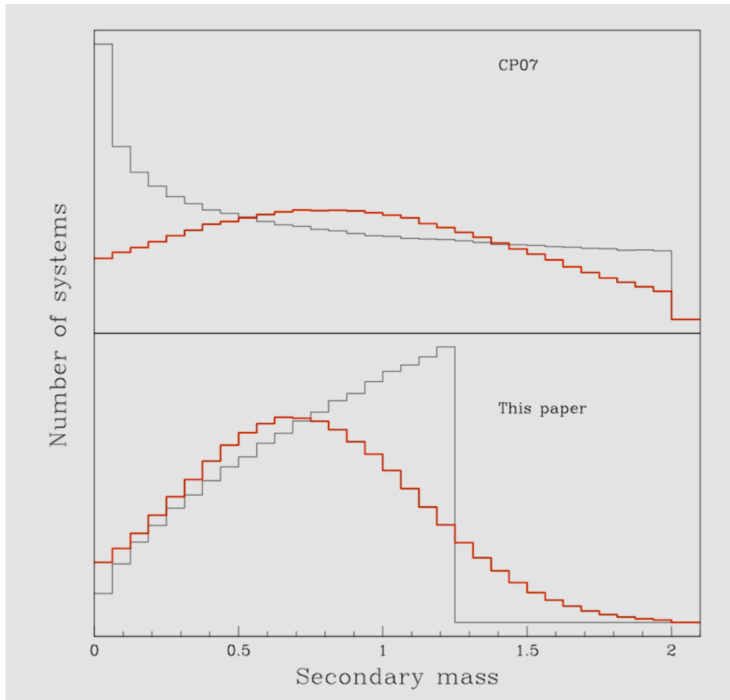
Carquillat & Prieur 07

REVISITING CP07



Boffin 10

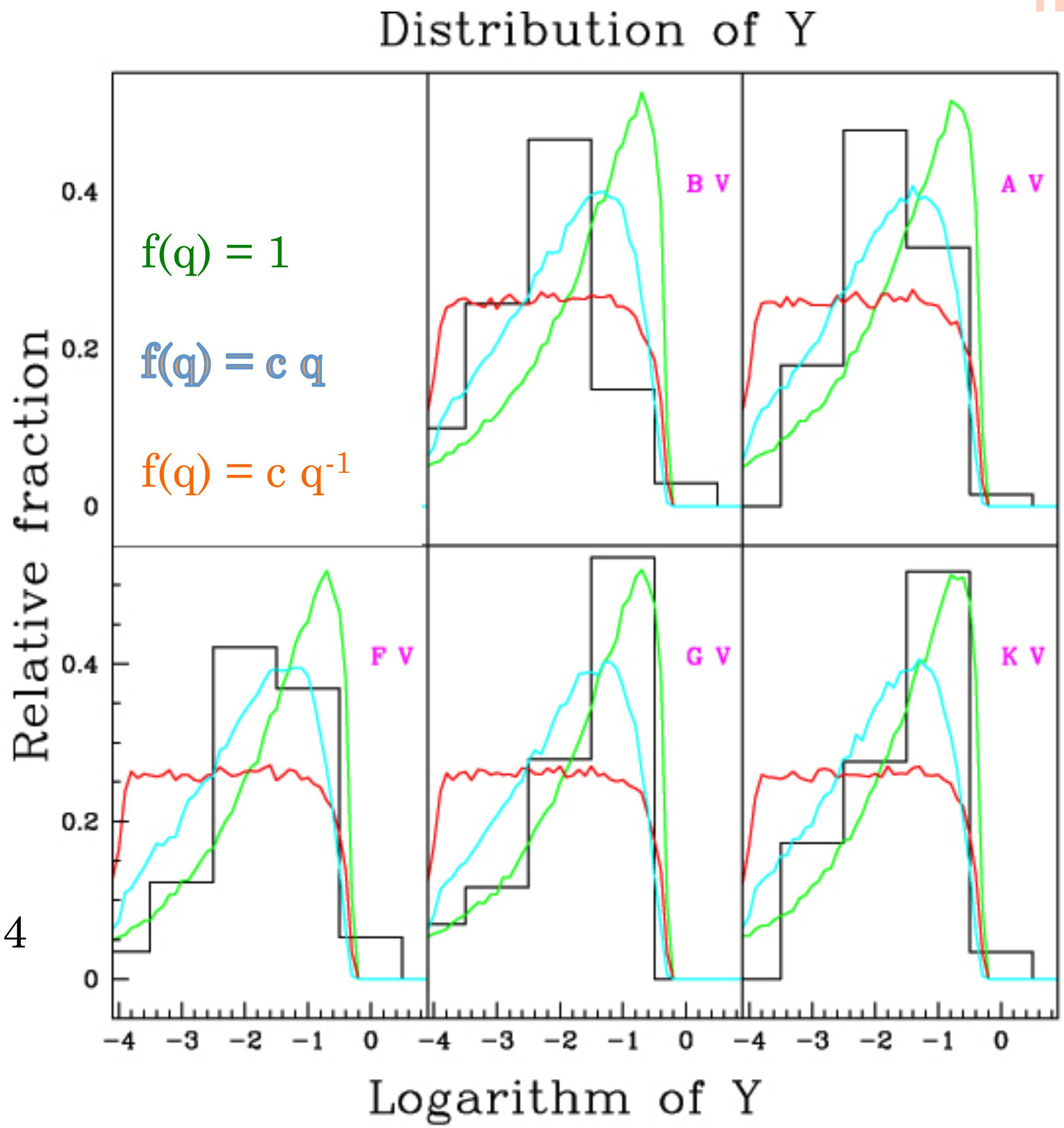
- Fit the *log f(m)* distribution
- Power law with positive index!
- Need to limit to $M_2 < 1.25\ M_\odot$
- Gaussian is narrower



S_B^9 DATABASE

Spectral Type	Number of systems	<q>
B V	101	0.3789
A V	67	0.4686
F V	57	0.6164
G V	43	0.5673
K V	29	0.6105

Pourbaix, Jancart & Boffin 04



INVERSION METHOD

From Q=q^3 / (1 + q)^2, we have $f(m) = M_A\, Q^3 \sin^3 i$

Thus Y(Q) = $Q \sin i$ is available from observations. The distribution $\psi(Q)$ we are looking for is thus given by

$$\Phi(Y) = \int_0^\infty \Psi(Q)\, \Pi(Y|Q)\, \mathrm{d}Q.$$

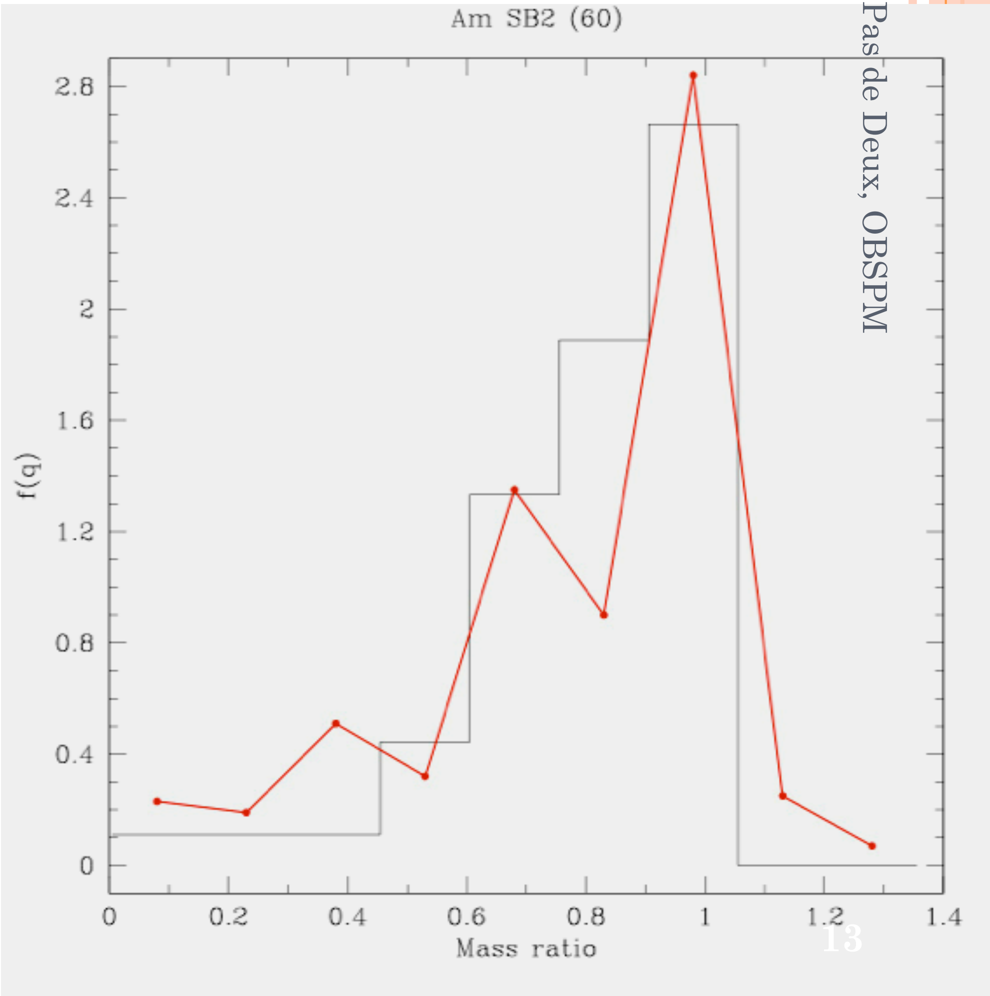
As $f(i) = \sin i$, this reduces to an Abel equation.

One can thus solve it, either by numerically computing it (need smoothing) or using the Lucy-Richardson inversion algorithm

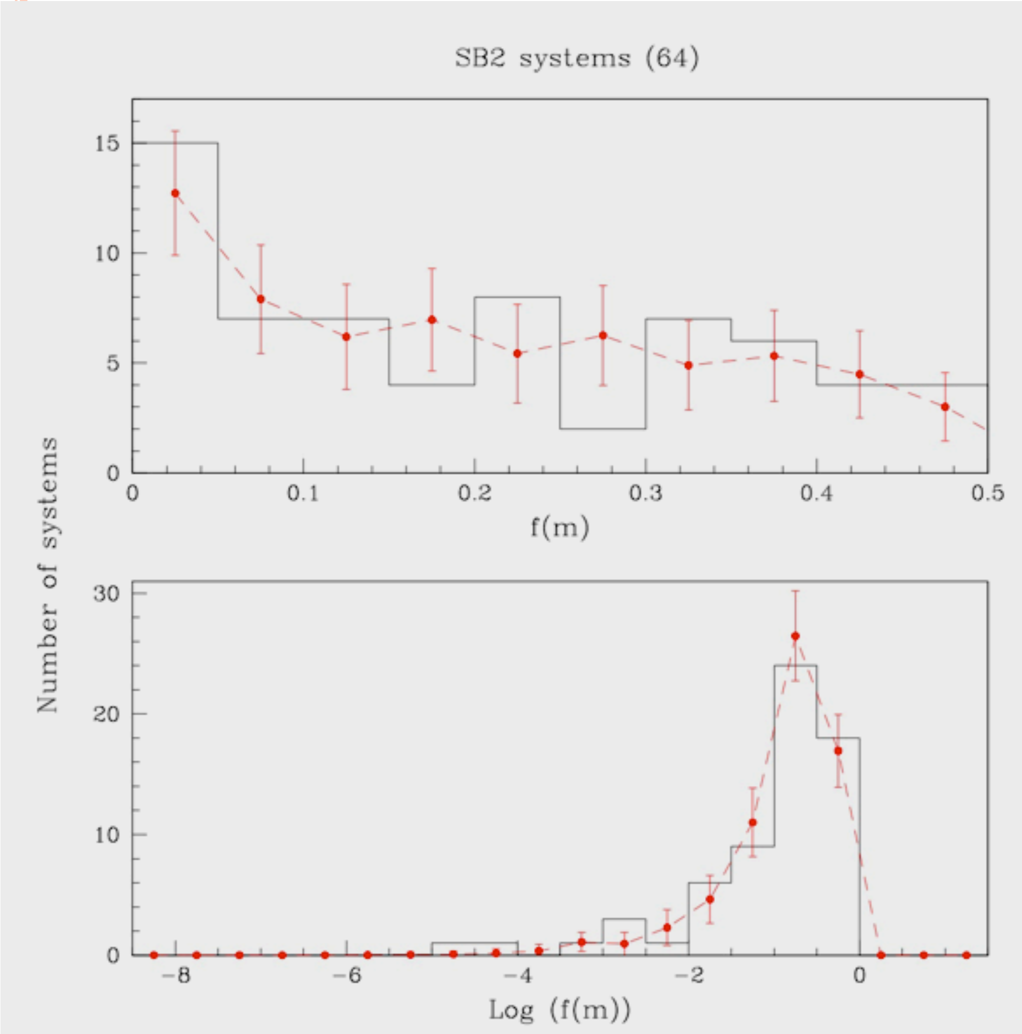
Boffin+ 92, 93, Cerf & Boffin 94, Mazeh & Goldberg 92

Back to Am stars: Extending the sample

- Literature search → created a new catalogue to have more orbits
- 162 orbits of Am stars : 98 SB1 and 64 SB2
- For SB2, we directly have q
- I apply Richardson-Lucy inversion method – check with SB2



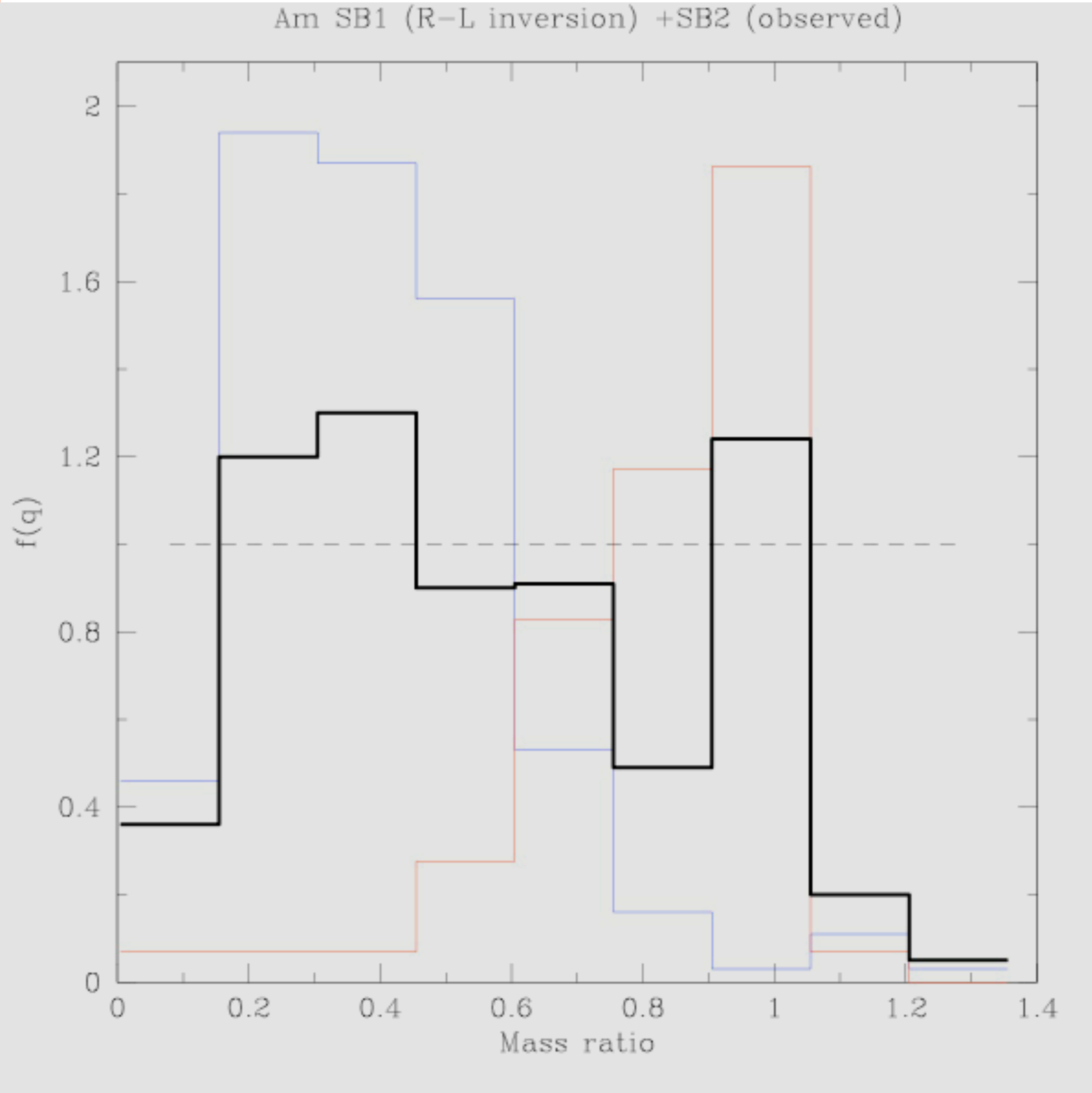
EXTENDED AM STAR SAMPLE



- With SB2, I can also check the methodology, i.e.
  - random *i*
  - M_1 constant (=2 $M_\odot$)
  - fitting log f(m)
- works!

→ can apply to the whole sample of SB1

MASS RATIO DISTRIBUTION



- SB1 : R-L method
- SB2 : direct
- Or SB1 + SB2 : R-L method

→ compatible

- Final *f(q)* will depend on ratio between SB1 and SB2
- Observational biases difficult to assess!

OBSERVATIONAL BIASES

- Magnitude selection (Öpik effect)
- Detection limit K_D, where $K < K_D$ are not found
  - Typically $K_D > 3\text{-}4\ s_{RV}$
- Orbits too long cannot be obtained (no solution but also K too small)

- One need to be aware of these and, if sure we understand them, correct them, or be sure we do not need to care about them.

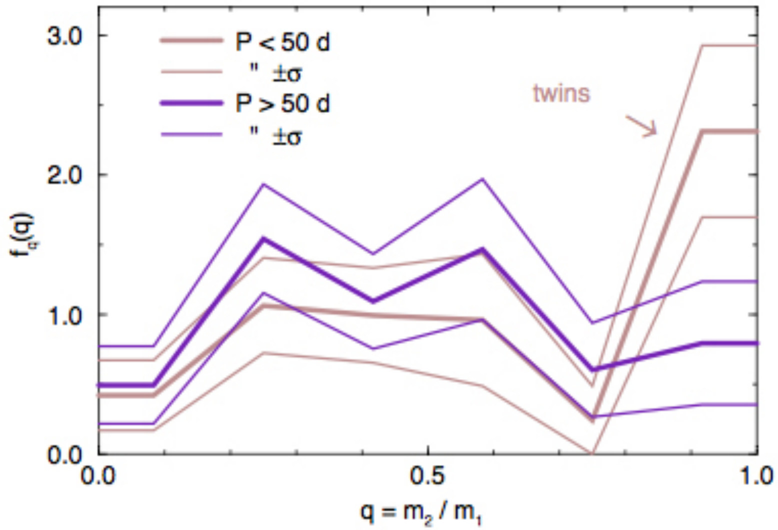
THE SOLAR-LIKE SAMPLE – NEARBY AND IN CLUSTERS

f(q) for binaries with P< 10 y

For G-K-M primaries, 2 modes:

- *0,1 < q < 0,7 ,*

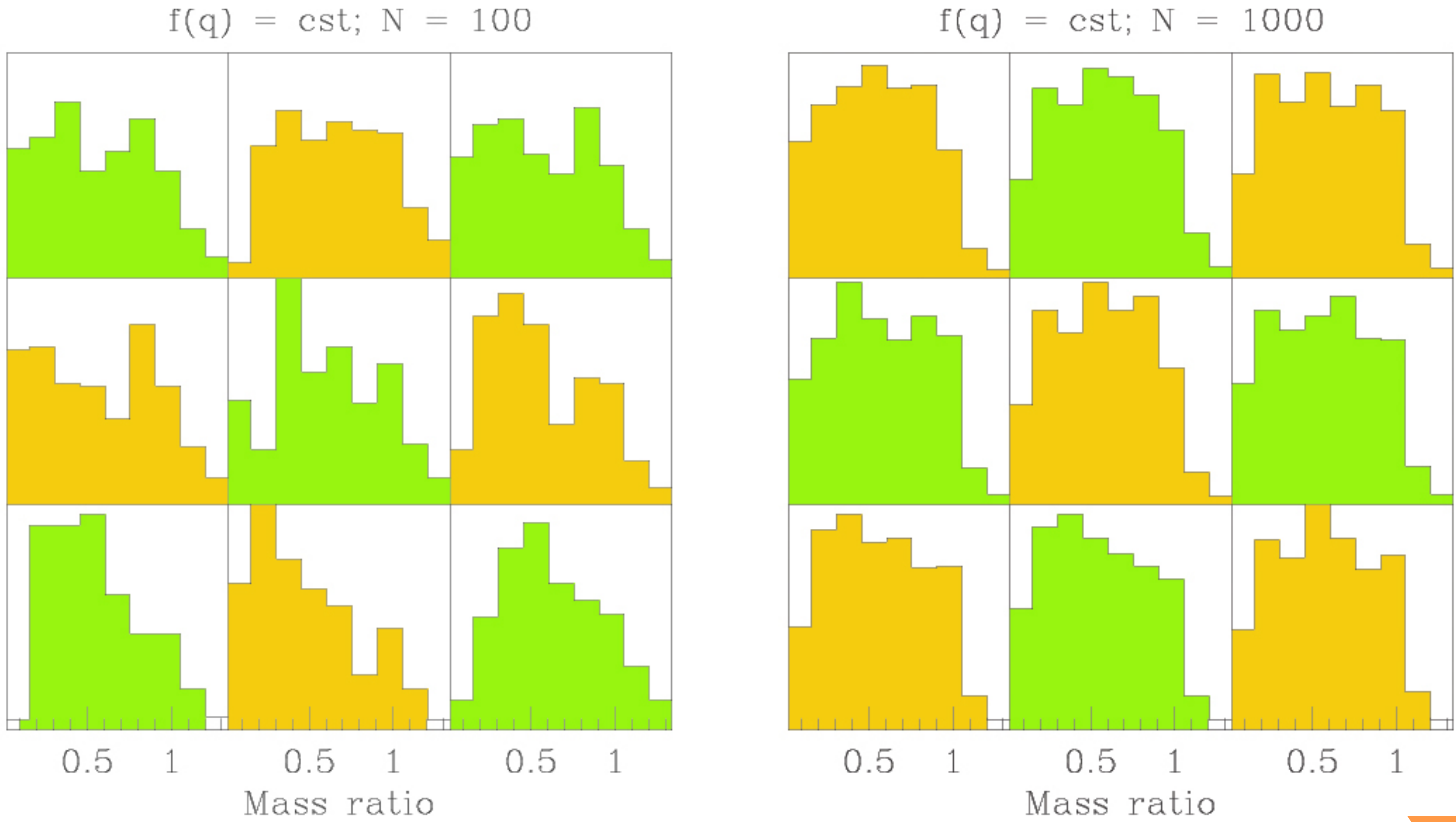
With a "brown dwarf desert" (q<0,1) vanishing for P> 2-3 years



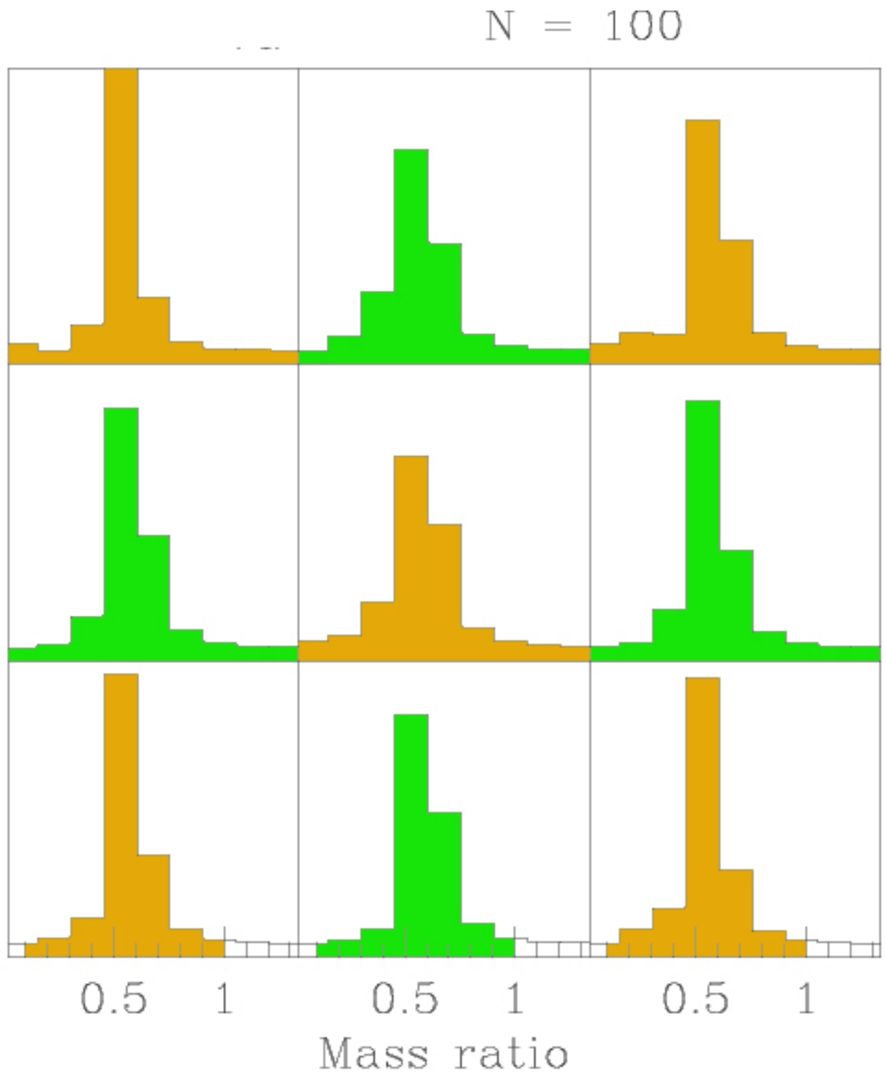
Halbwachs+ 03

- *q > 0.8, with a peak around q=1 ("twins"). Vanishing when P increasing.*

EFFECT OF SAMPLE SIZE (*f(q)* UNIFORM)

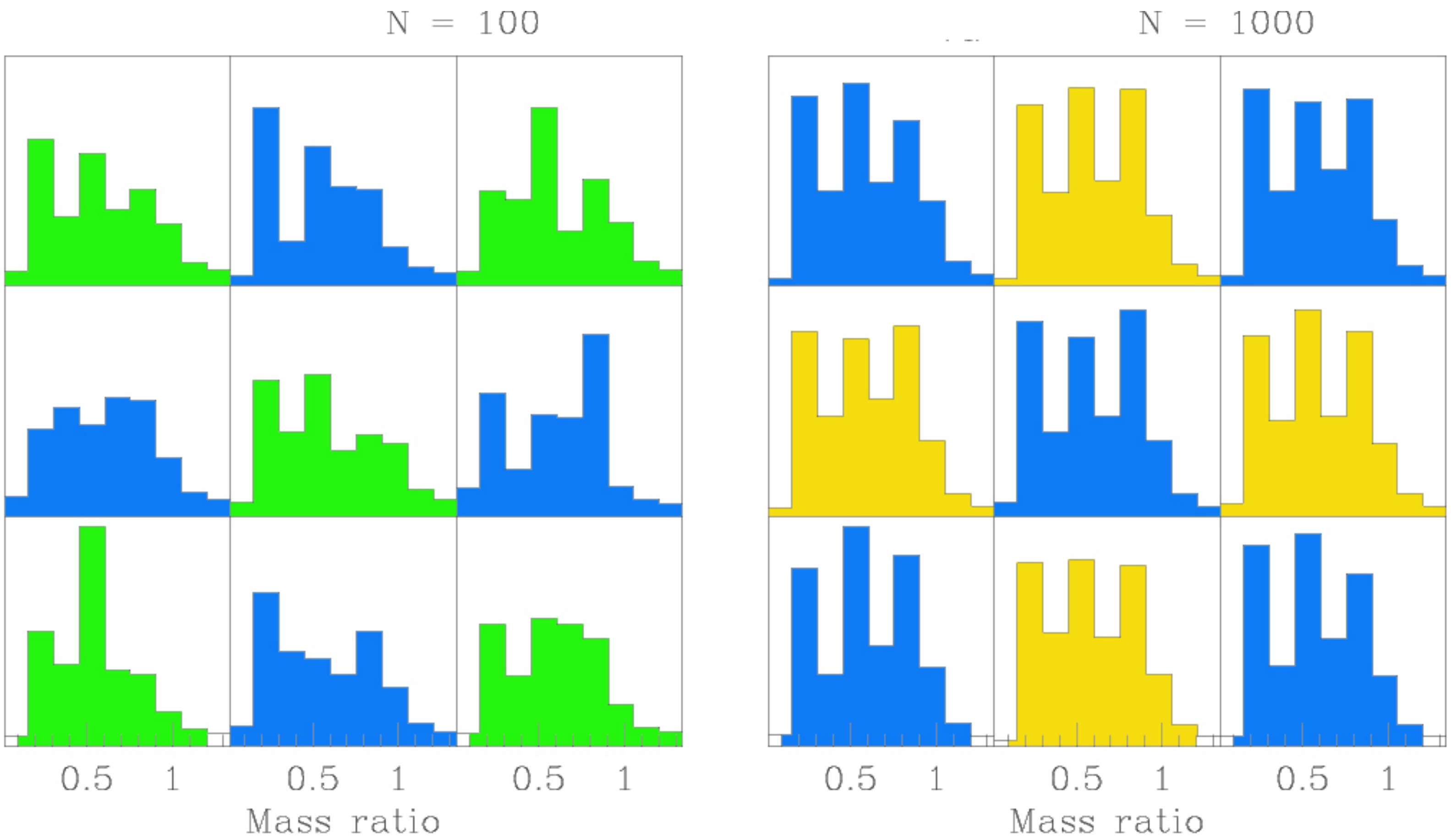


Single peak seems more robust



10 October 2011 - Pas de Deux, OBSPM

3 PEAKS



See also Brown 11, for application to exoplanets

A CATALOGUE OF 213 G-K GIANTS

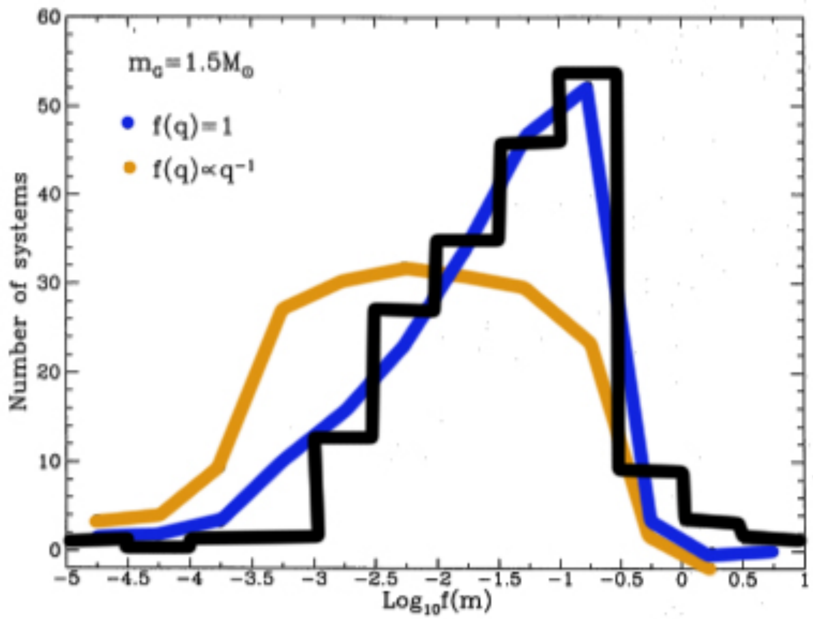
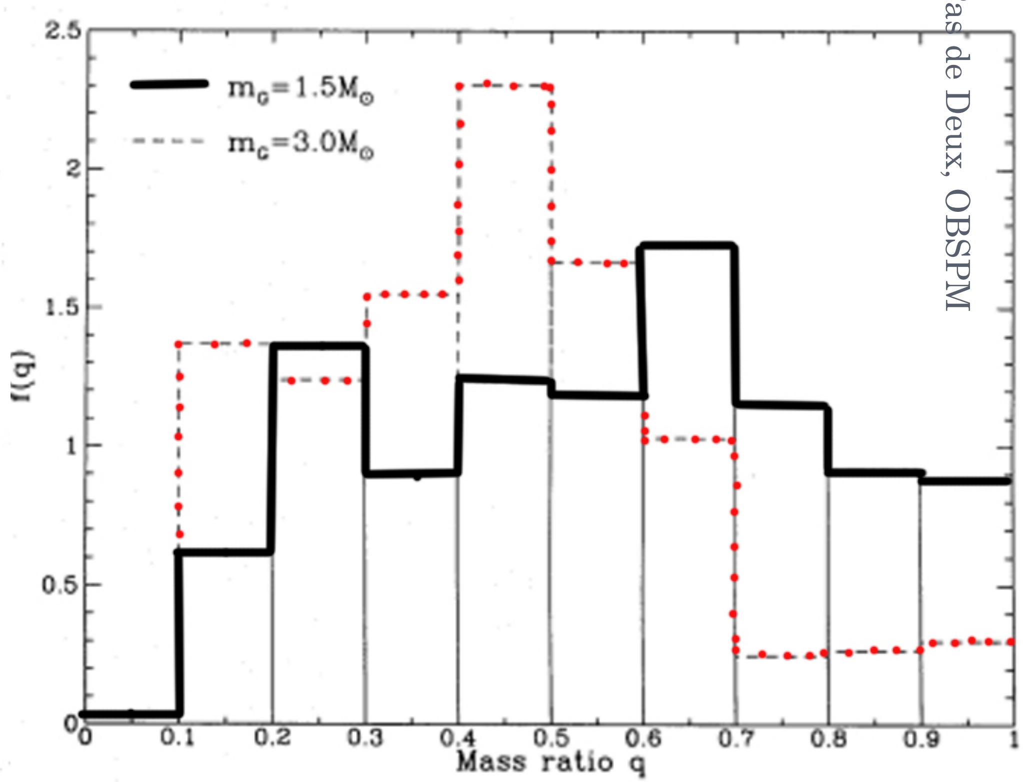


Fig. 10. Distribution of log $f(m)$ computed by the Monte Carlo technique using a giant mass $m_G = 1.5\,M_\odot$ and $f(q) = 1$ (●) or $f(q) \propto q^{-1}$ (■), compared to the observed one (solid line)



Boffin, Cerf & Paulus 93

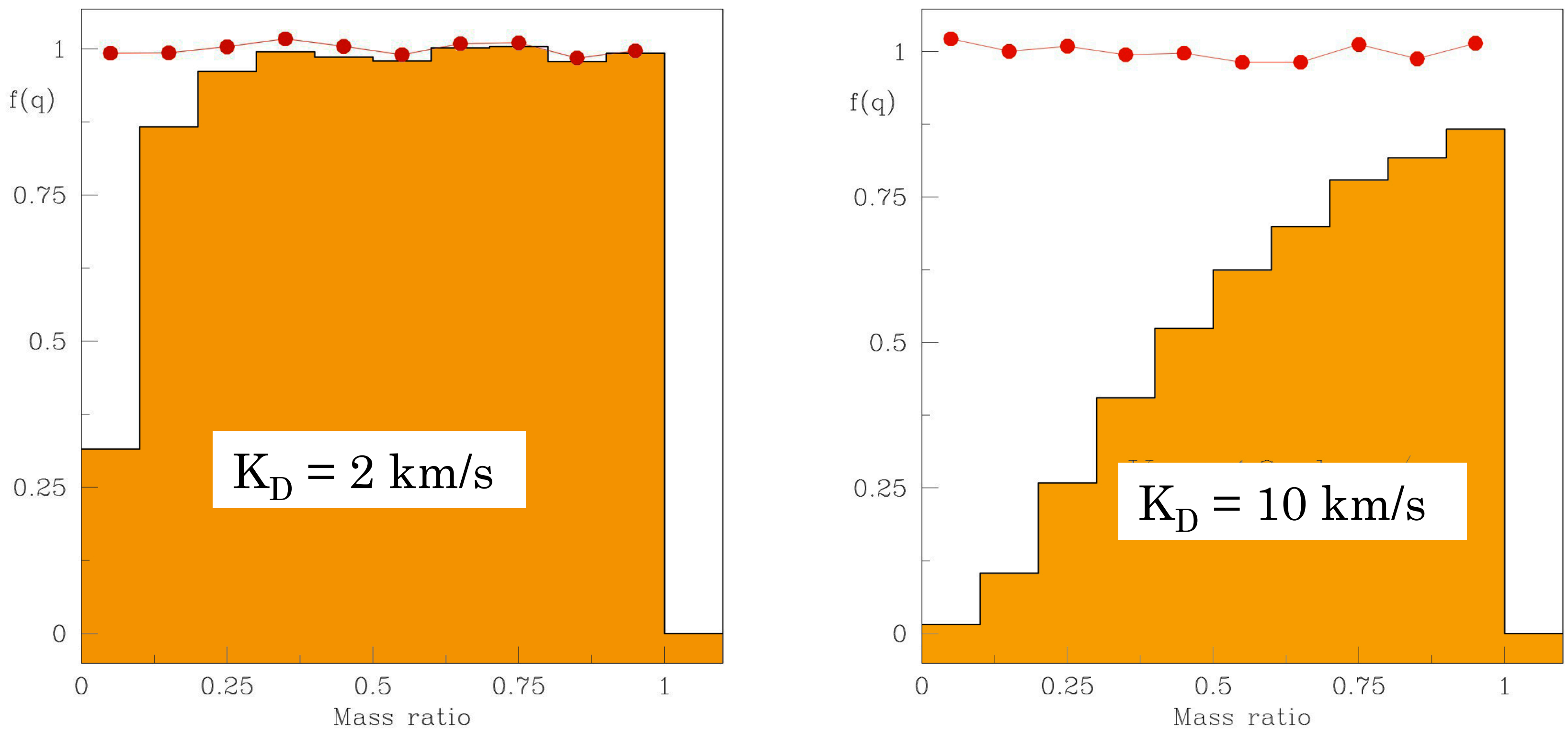
WHAT ABOUT GAIA?

- GAIA will provide us with a flurry of new SBs
- Observe for 5 years
- ˜10^6 orbits could be derived, finally making it possible to have huge samples for statistical analysis
- The survey will be homogeneous, so the bias should be quantifiable
- Simplest: look only at eclipsing binaries (*i~90*)
- But why limit ourselves?

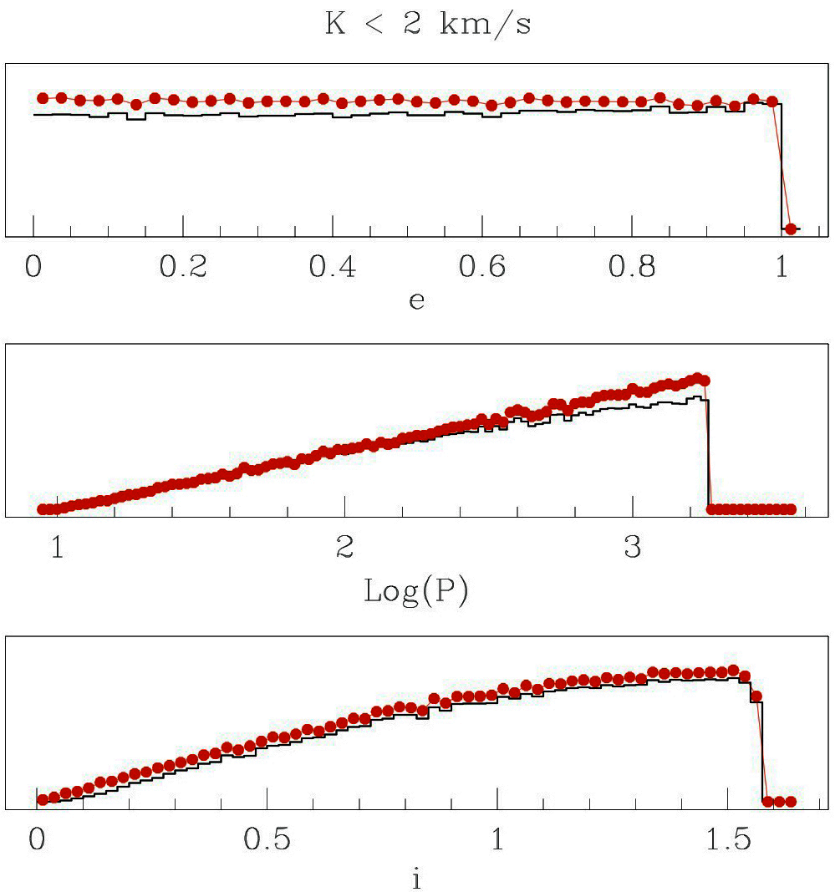
GAIA (II)

- Problem:
  - RV accuracy degrades quickly with G and with spectral type
  - s_{RV} ~ a few km/s for relatively bright G-K star (single measurement)
  - s_{RV} ~ 10–20 km/s for A-F stars (single measurement)

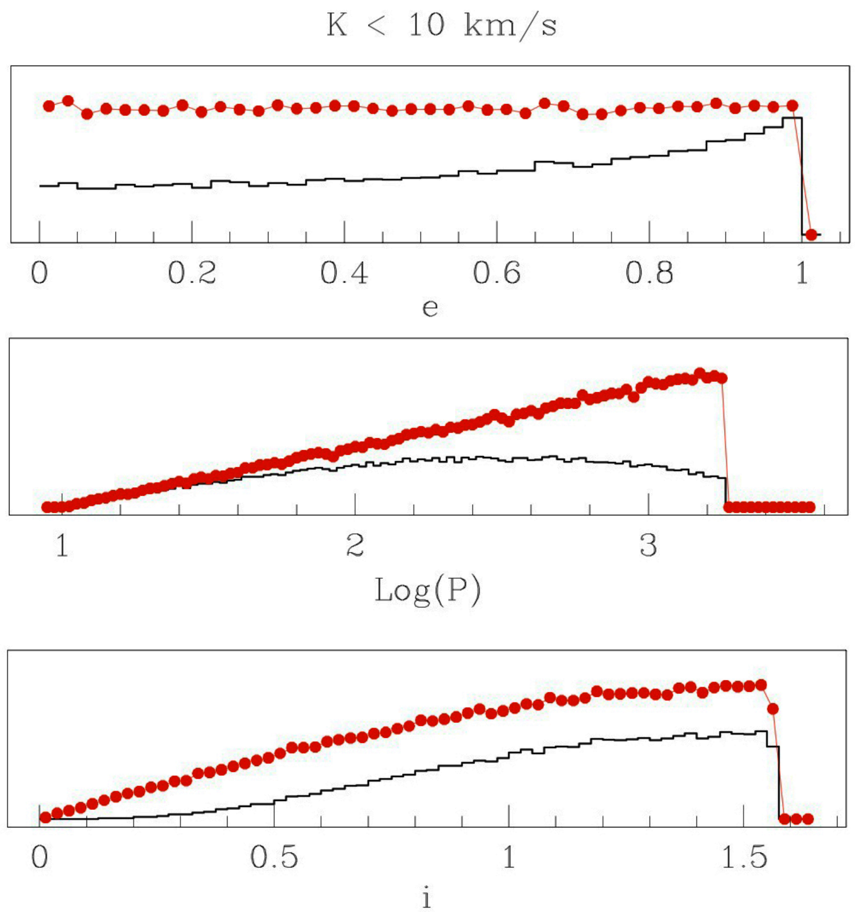
EFFECT OF K ON DERIVED f(q)



EFFECT OF K



K < 2 km/s
0
0.2
0.4
0.6
0.8
1
e
1
2
3
Log(P)
0
0.5
1
1.5
i



K < 10 km/s
0
0.2
0.4
0.6
0.8
1
e
1
2
3
Log(P)
0
0.5
1
1.5
i

CONCLUSION

- *f(q)* important
- There are some ways to retrieve it by statistical methods
- But be aware of the limitations and the rules of the game

- GAIA will revolutionise this – even though it will also be limited in the binaries it can sample