From brown dwarf companions to planetary companions of brown dwarfs:

Results using high-precision astrometry

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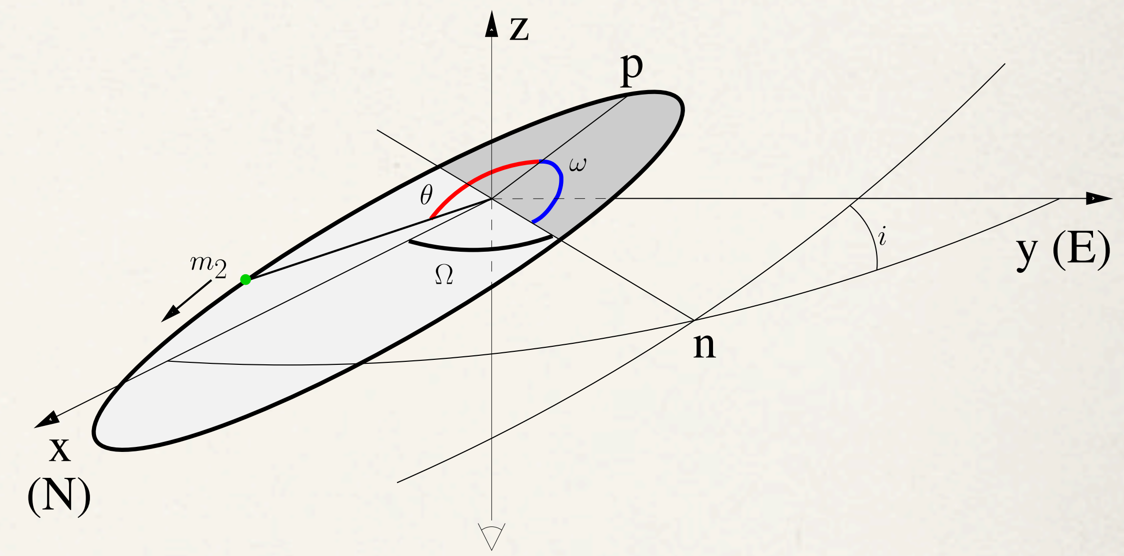
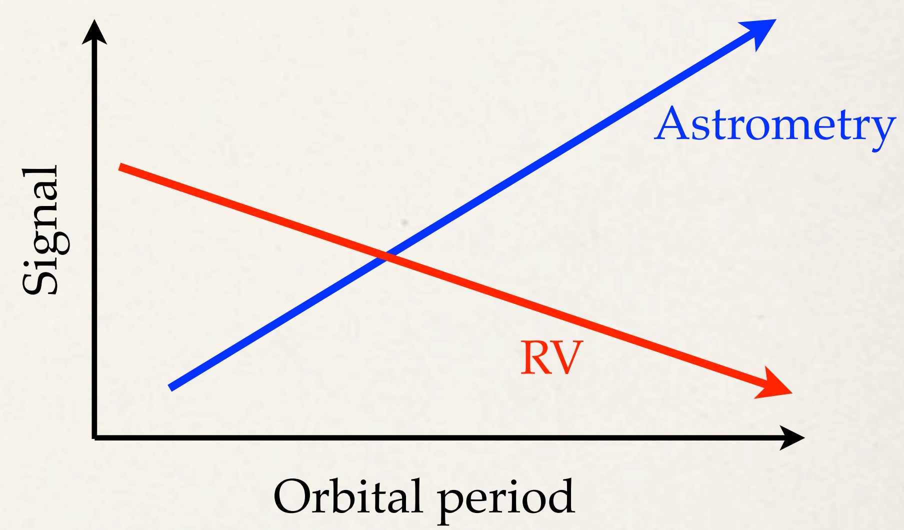
studying planets with astrometry

yields complete system information, since sensitive to all orbital parameters



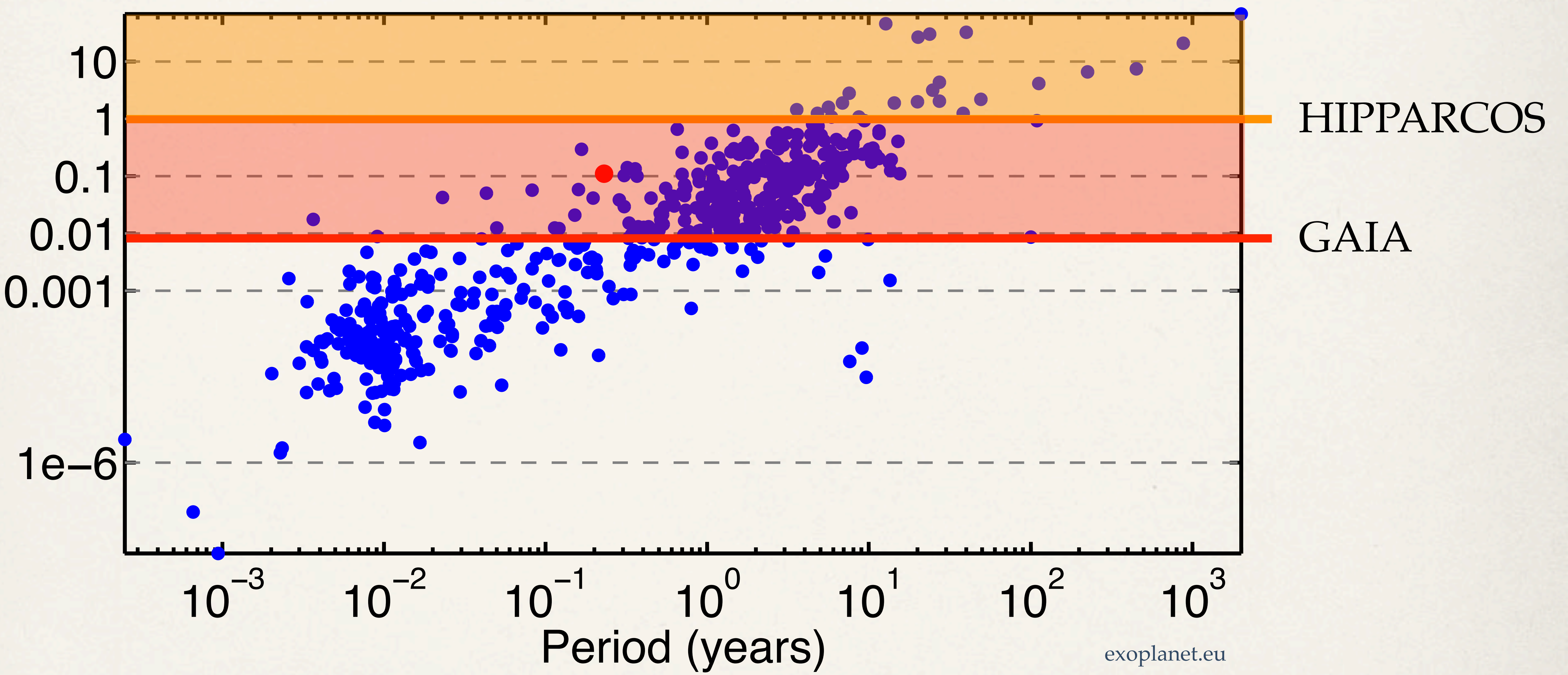
sensitivity increases with orbital period



2D complement to 1D radial velocities
($M_2 \sin i \rightarrow M_2$)

at high-precision, astrometry opens up a new detection space

studying planets with astrometry



outline

1. HIPPARCOS astrometry of candidate brown dwarf companions

D. Ségransan, D. Queloz, C. Lovis, M. Marmier + Geneva planet group, N. Santos (Porto), S. Zucker (Tel Aviv)

2. Search for planetary-mass companions of M- and L-dwarfs

P. Lazorenko (Kiev), E. Martín (Madrid), D. Ségransan, D. Queloz, S. Udry, M. Mayor (Geneva)

3. Astrometric planet search with the PRIMA interferometric facility

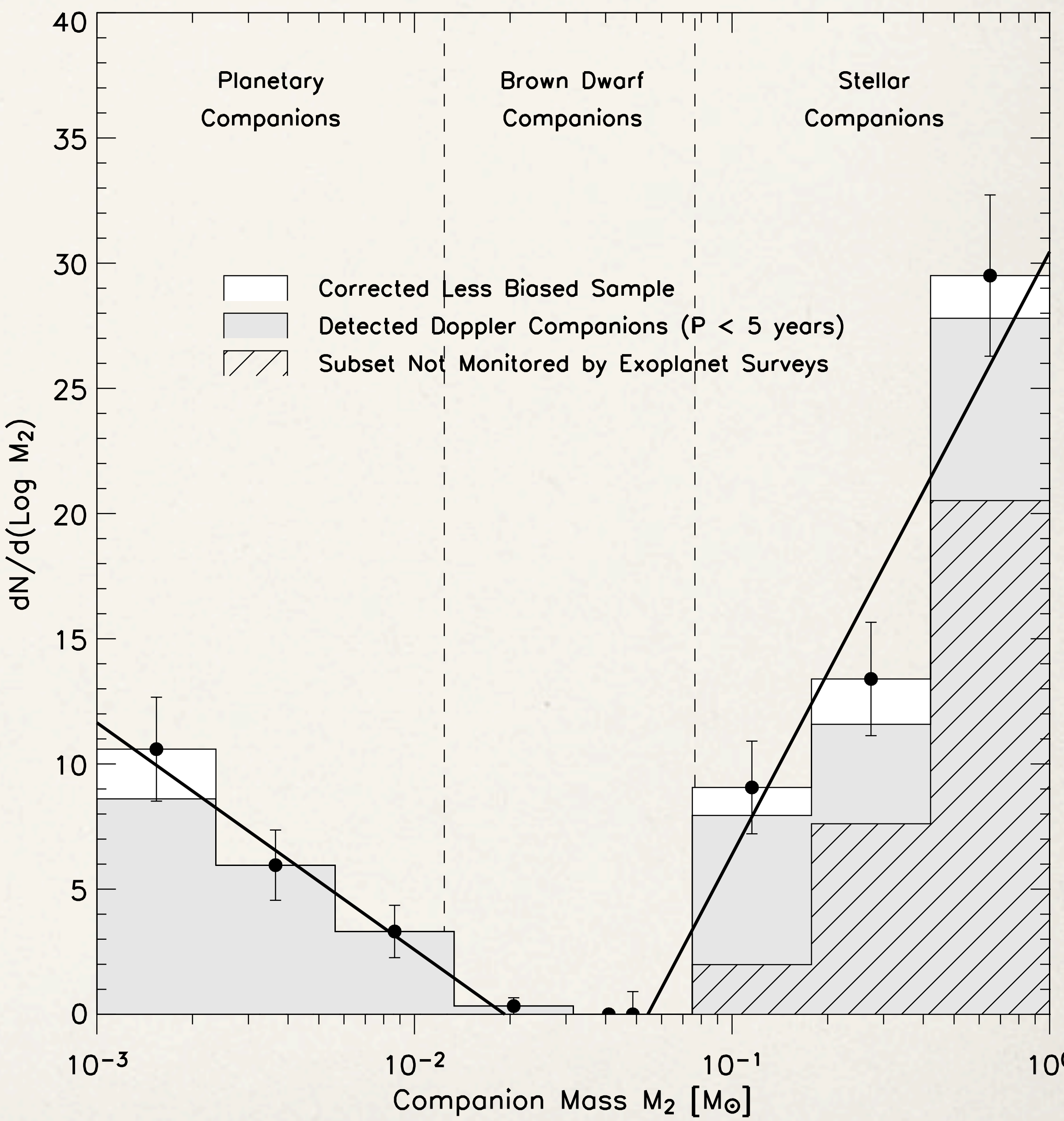
ESPRI consortium, ESO

close BD companions to Sun-like stars

- RV studies show that close ($<$ 10 AU) brown-dwarf companions to Sun-like stars are rare compared to planets and stars

- few (~40) objects with M_2 sini =13-80 M_J

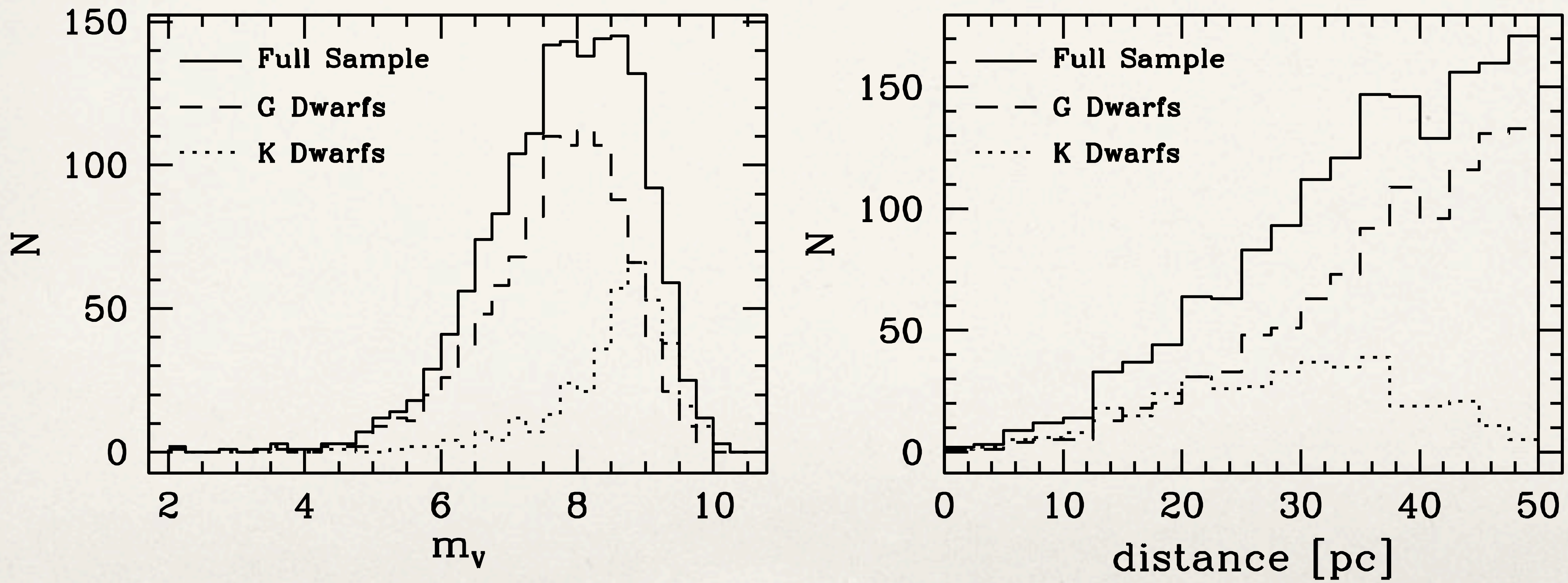
- What are the properties of the BD companion population?



Grether & Lineweaver 2006

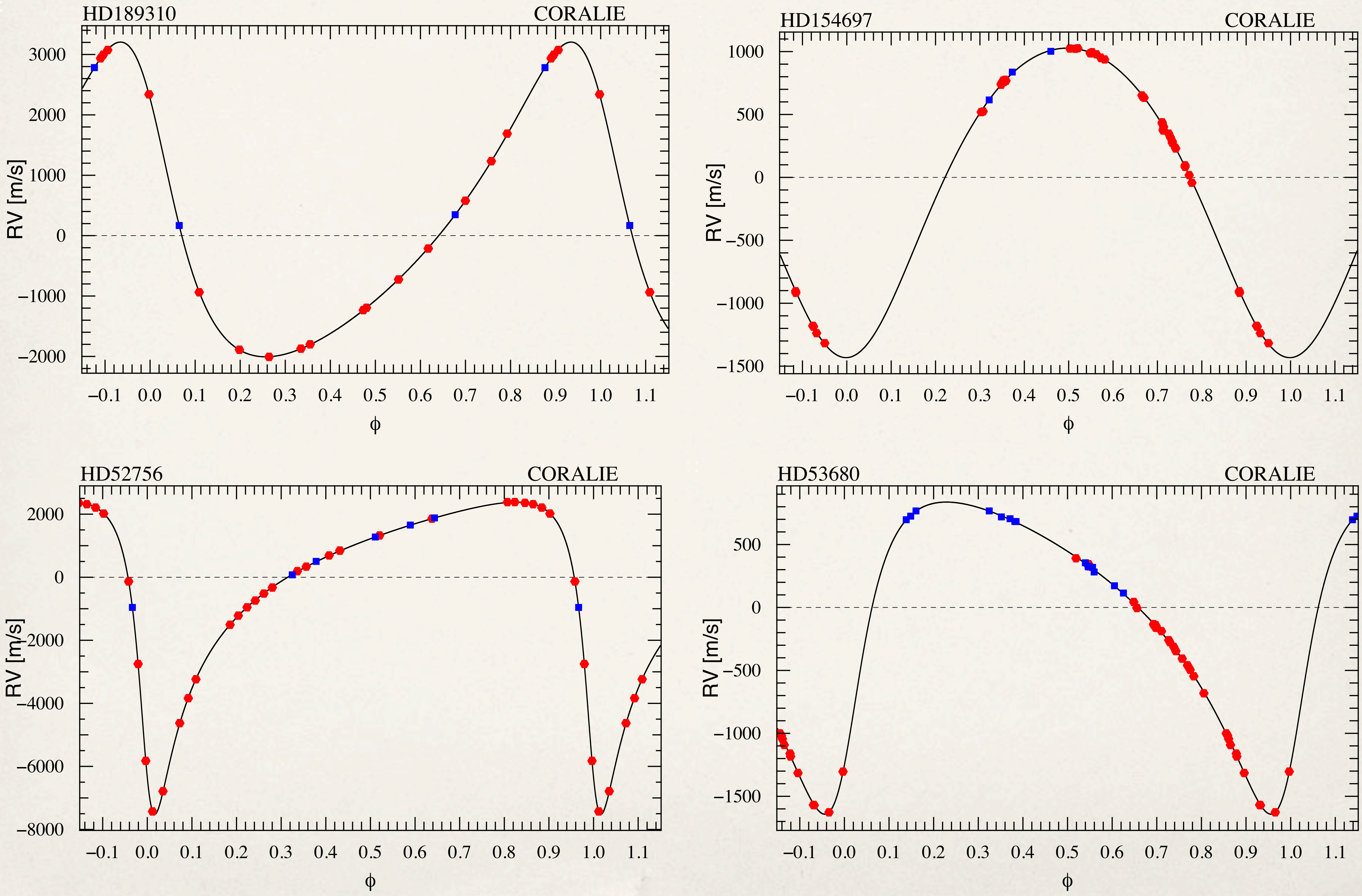
CORALIE radial-velocity survey

- CORALIE is an R~60000 optical spectrograph on the 1.2 m Swiss Telescope (La Silla)
- surveying 1647 southern G- and K-dwarfs since 1998
- epoch accuracy of 5-7 m/s lead to the discovery of more than 50 planets (e.g. Ségransan et al. 2010)
- in this sample, we identified the companions with M_2 sini = 13-80 M_J



Udry et al. 2000

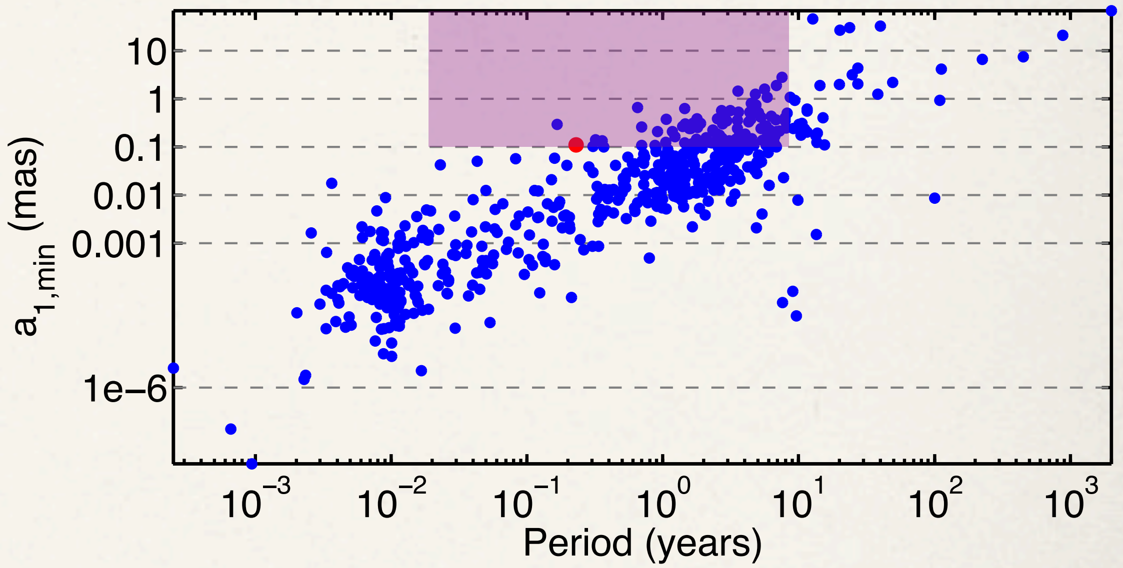
candidate brown-dwarf companions



from minimum to real masses

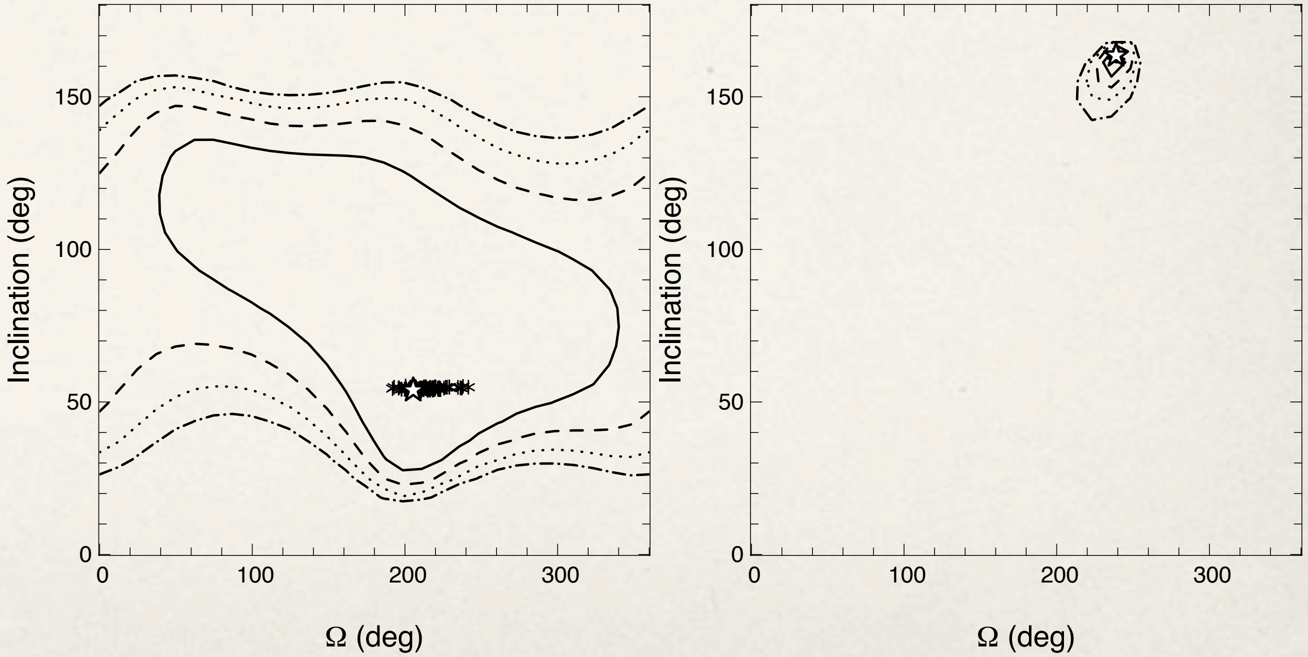
- HIPPARCOS astrometry satellite (1989-1993)
- new reduction of raw data by van Leeuwen (2007), per-epoch precision ~1-7 mas
- RV constrains 5 orbital parameters (P,T_0,e,ω,K_1), use astrometry to find the two remaining ones (i,**Ω**)

(Mazeh et al. 1999, Halbwachs et al. 2000, Zucker & Mazeh 2001)



Assessing the quality of the fitted orbit:

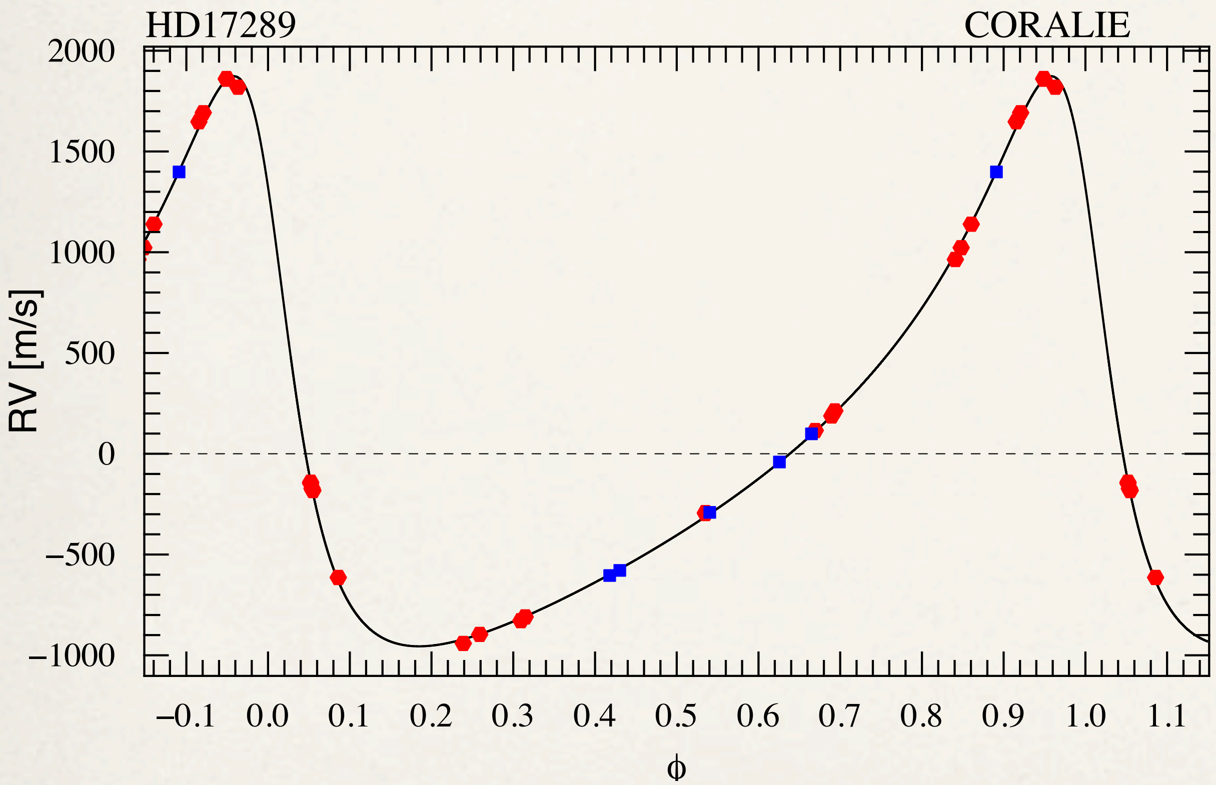
- confidence contours in i-**Ω**-space
- statistical significance from simulated pseudo-orbits

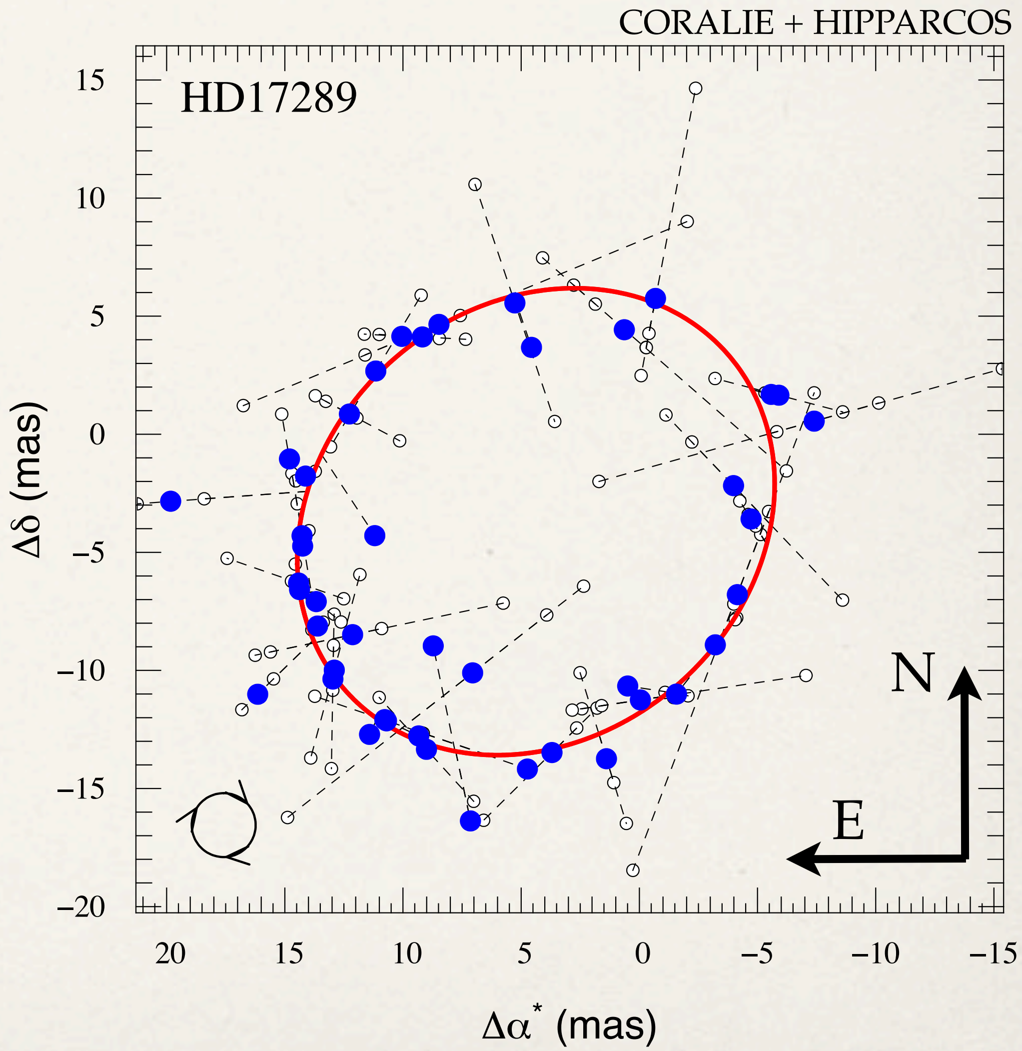


detected astrometric orbit

$M_2 \sin i = 49 \pm 2\ M_{Jup}$

$i = 173.2 \pm 0.5$ deg
$\rightarrow M_2 = 0.52 \pm 0.05\ M_{\odot}$





the frequency of close BD companions

- in total 20 candidate BD companions were identified in the uniform+complete CORALIE survey of 1647 stars, i.e. the candidate frequency is 1.2 ± 0.3 %

- **10 companions are in fact M-dwarfs**

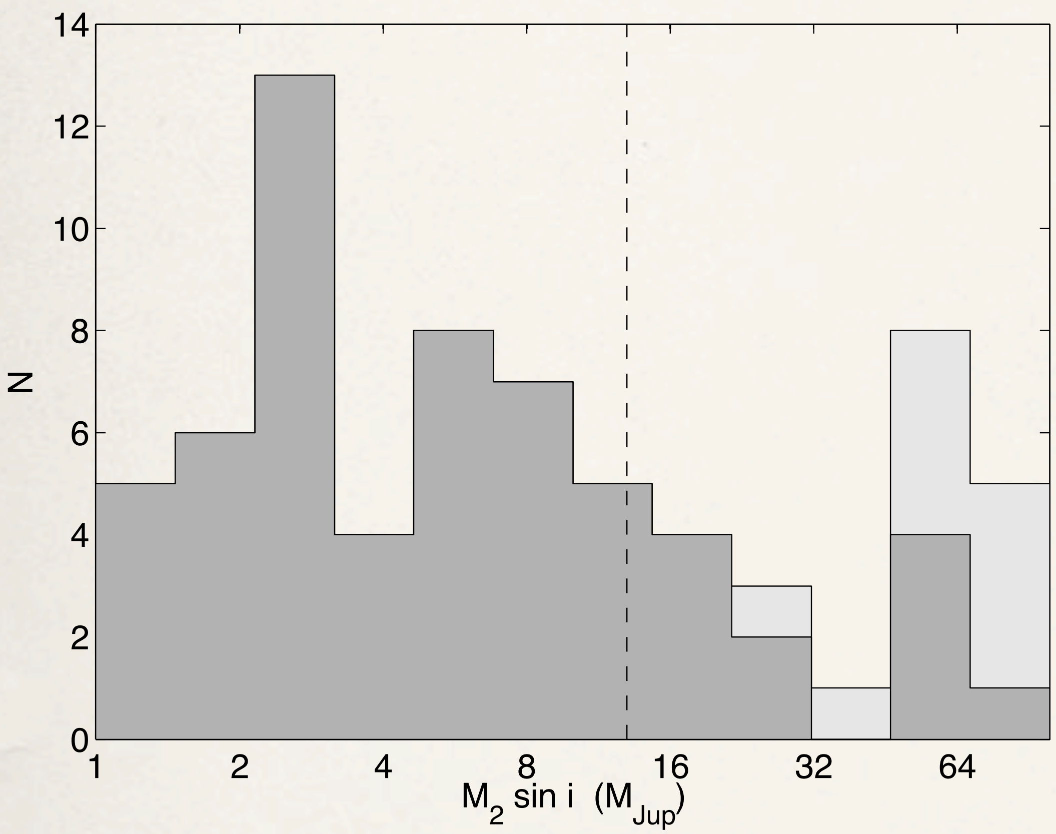
$\Rightarrow$ (Less than) 0.6 ± 0.2 % of Sun-like stars have a brown dwarf companion within 10 AU.

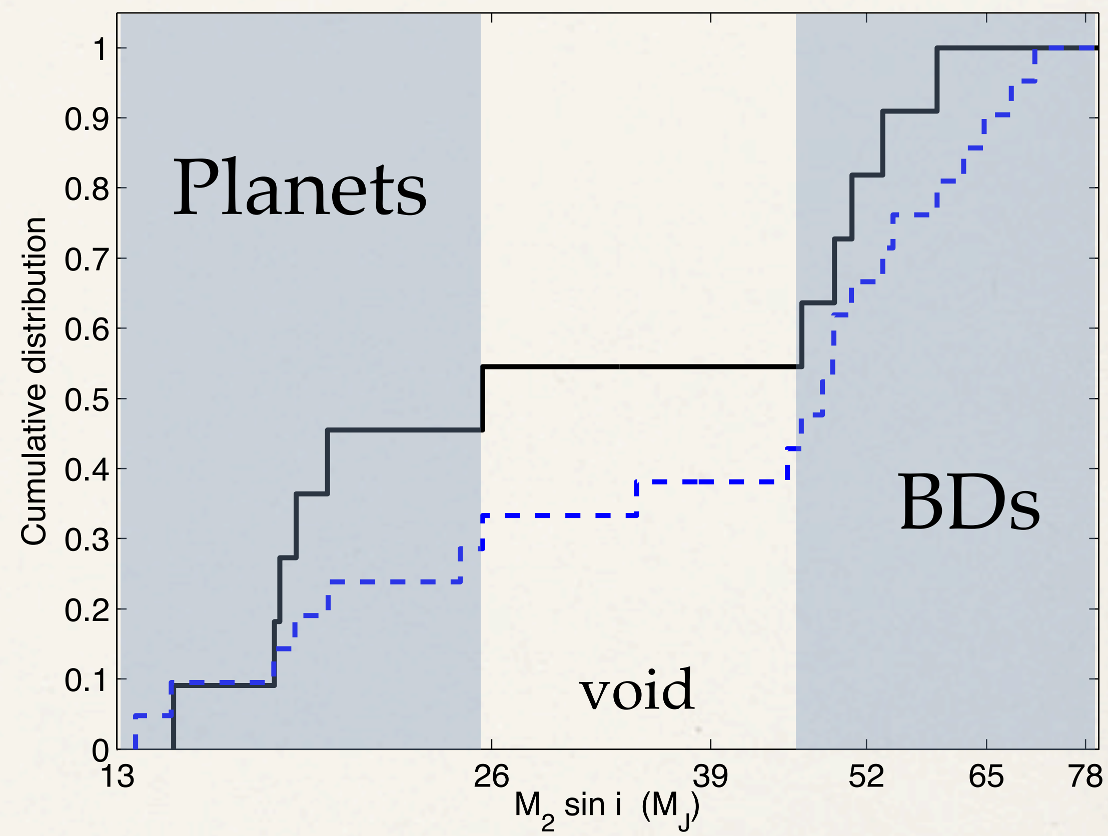
Sahlmann et al., 2011, A&A, 525

sorting planets from BD companions

(orbiting Sun-like stars within 10 AU)

CORALIE companions with M_2 sini < 80 M_J





Sahlmann et al., 2011, A&A, 525

Sahlmann et al., 2011, IAUS 276

- mass distribution shows a lack of objects between 25-45 M_J
- a possible dividing line between massive planets and brown-dwarf companions
- low frequency of BD companions and an upper planet-mass limit at ~30 M_J are expected in the core-accretion scenario

(Mordasini et al., 2009)

2. Search for planetary-mass companions of M- and L-dwarfs

P. Lazorenko (Kiev), E. Martín (Madrid), D. Ségransan, D. Queloz, S. Udry, M. Mayor (Geneva)

precision astrometry with FORS/VLT

Principles

Lazorenko & Lazorenko 2004, Lazorenko 2006

large telescope to average out atmospheric image motion

large number of reference stars within the FOV

exquisite camera/telescope: small systematic errors and high temporal stability

detailed modelling of PSF distortions and atmospheric image motion

Performance

Lazorenko et al. 2007, 2009, 2011

FORS in imaging mode 4′ x 4‘ (FORS2 optical camera on 8 m telescope VLT-UT1)

Demonstrated astrometric precision of ~0.05 mas with FORS1/2 on time scales of days-years

the planet around VB 10

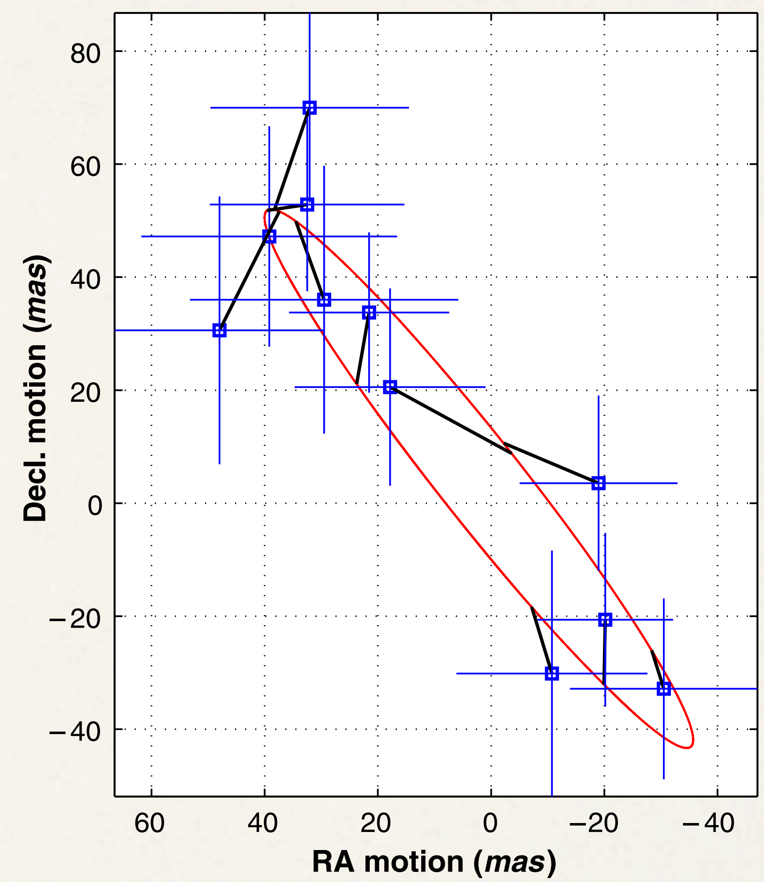
ultracool dwarf (M8) at 6 pc

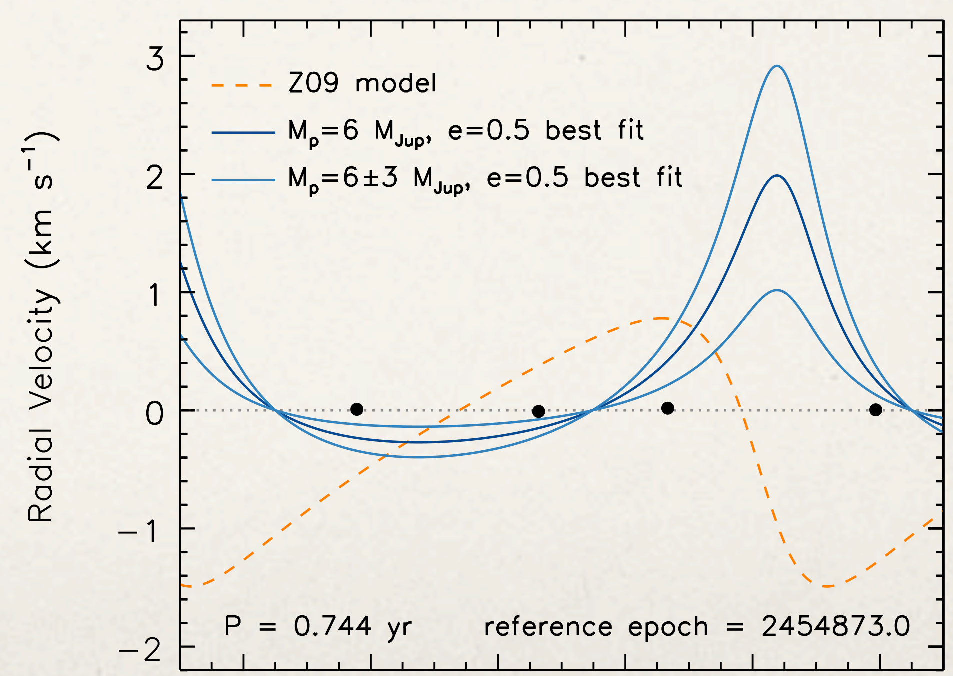
planetary-mass companion announced by Pravdo & Shaklan (2009): $P = 271$ d, $M_2 = 6.4\ M_J$

proposal for follow-up with FORS submitted

refuted by Bean et al. (2010) with infrared RV

(Anglada-Escudé et al., 2010; Rodler et al., 2011)





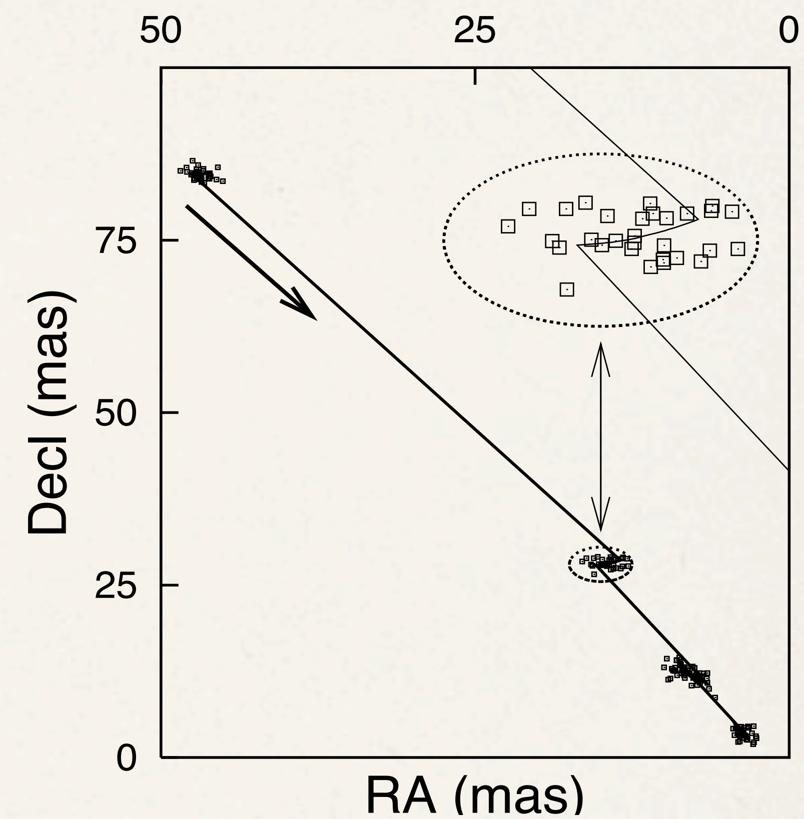
FORS2 observations of VB10

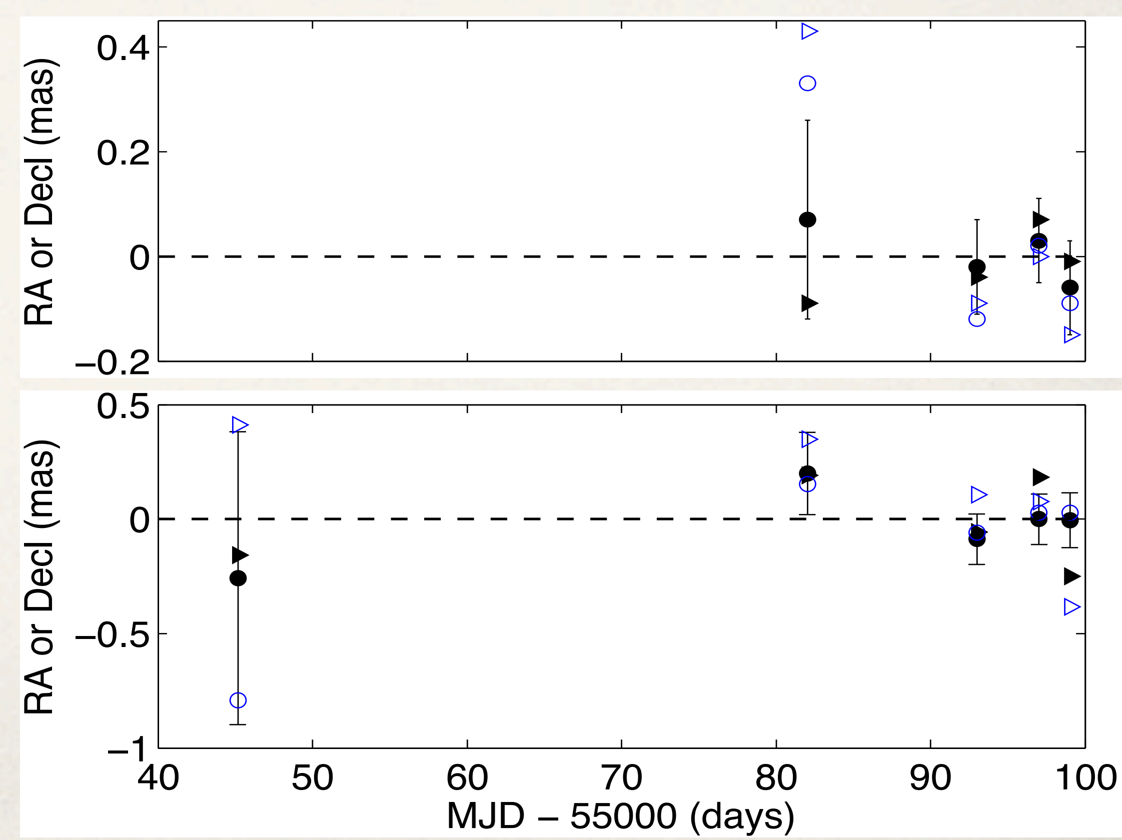
four epochs over 17 days with mean nominal precision of 0.09 mas

parallax and proper motion from 9 years of Palomar-STEPS data

Monte-Carlo resampling while considering all uncertainties allowed us to reject the planet with FAP of $5\ e^{-4}$

Lazorenko et al., 2011, A&A, 527





Search for planets around L-dwarfs

Planets are found around many stellar types, but none has been confirmed around a brown dwarf (mass ratio > 10:1, within 10 AU).

Are the conditions for planet formation met around brown dwarfs?

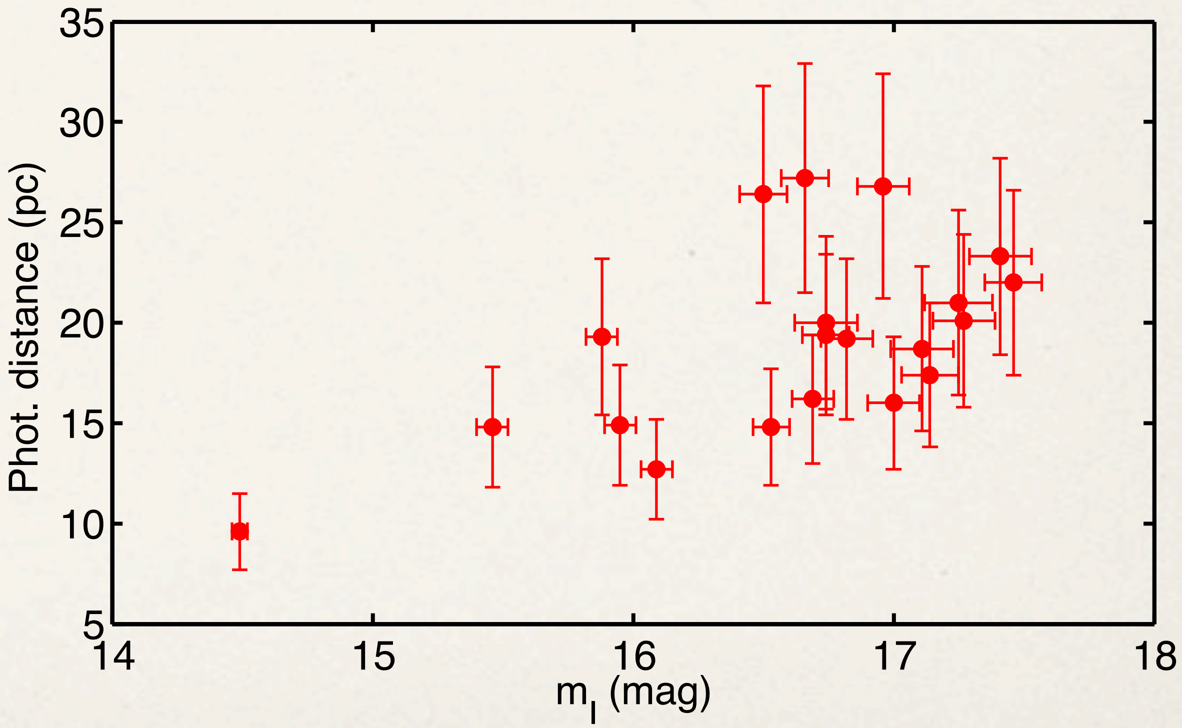
the survey

20 late-M and early-L dwarfs close to the galactic plane within 30 pc (Phan-Bao et al., 2008)

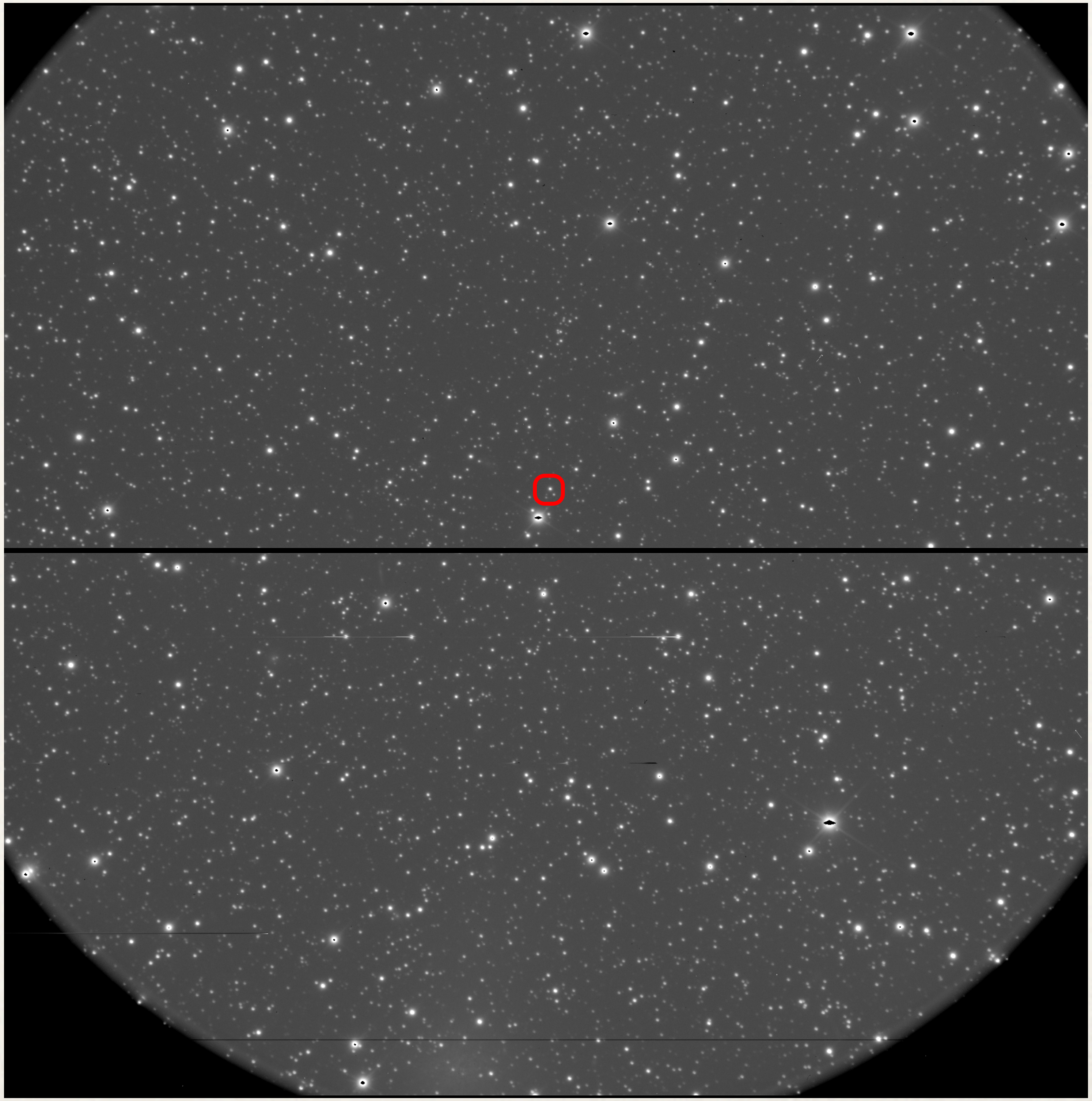
2-year programme to obtain 10 epochs on each target with a precision of 0.1 mas

15 nights of FORS2 granted in P86-P89

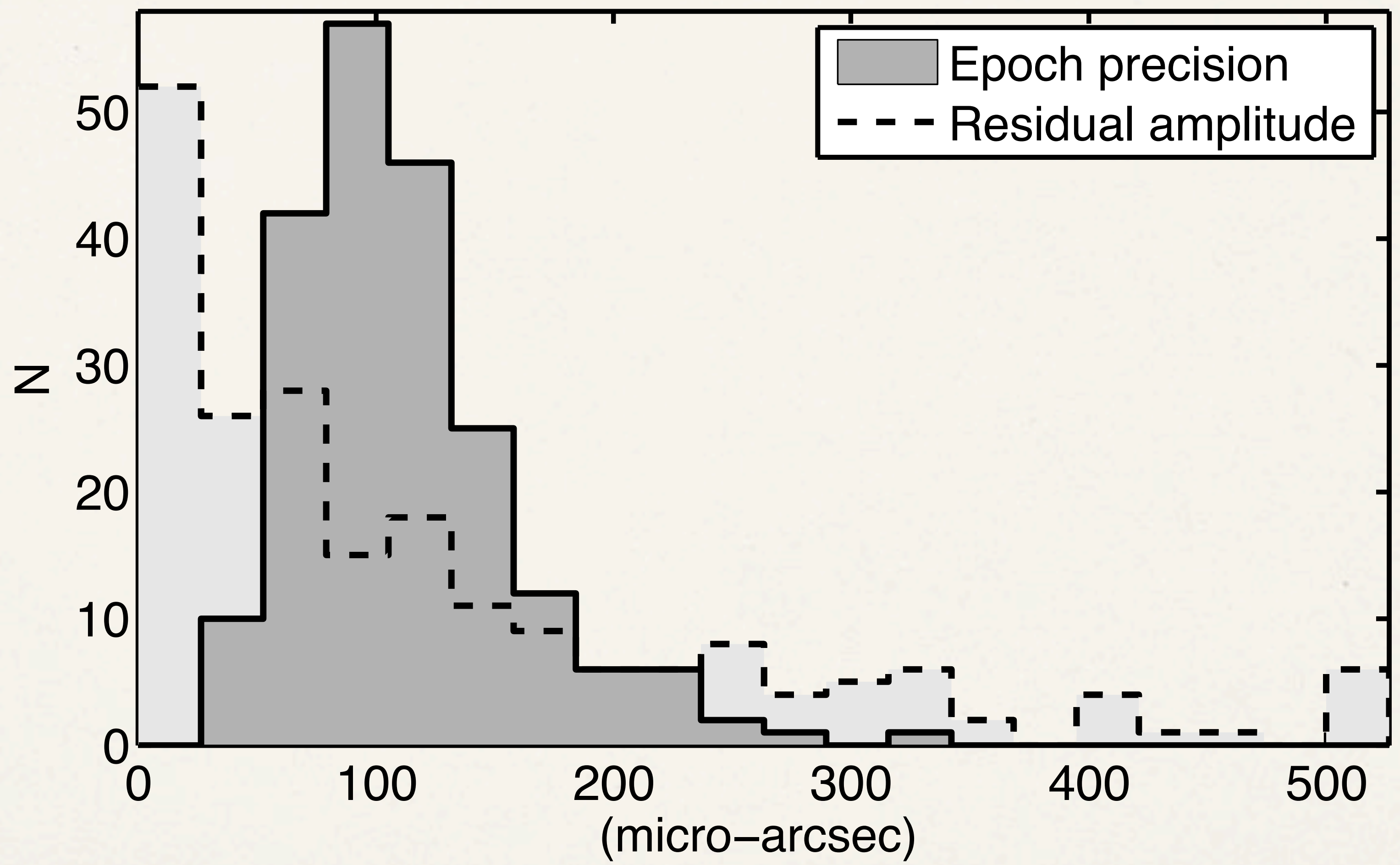
At that level of precision, the survey is sensitive to companions with mass ratios from 1:1 to ~1:200 and periods of 50 - 500 days



sample FORS image



preliminary results: precision



summary of L dwarf astrometry

we routinely obtain epoch precisions of 0.1 mas ($\approx$1/1000 pix)

7 months of data still pending. Data reduction and analysis is ongoing

typical parallax precision: ~0.1 - 0.4 %

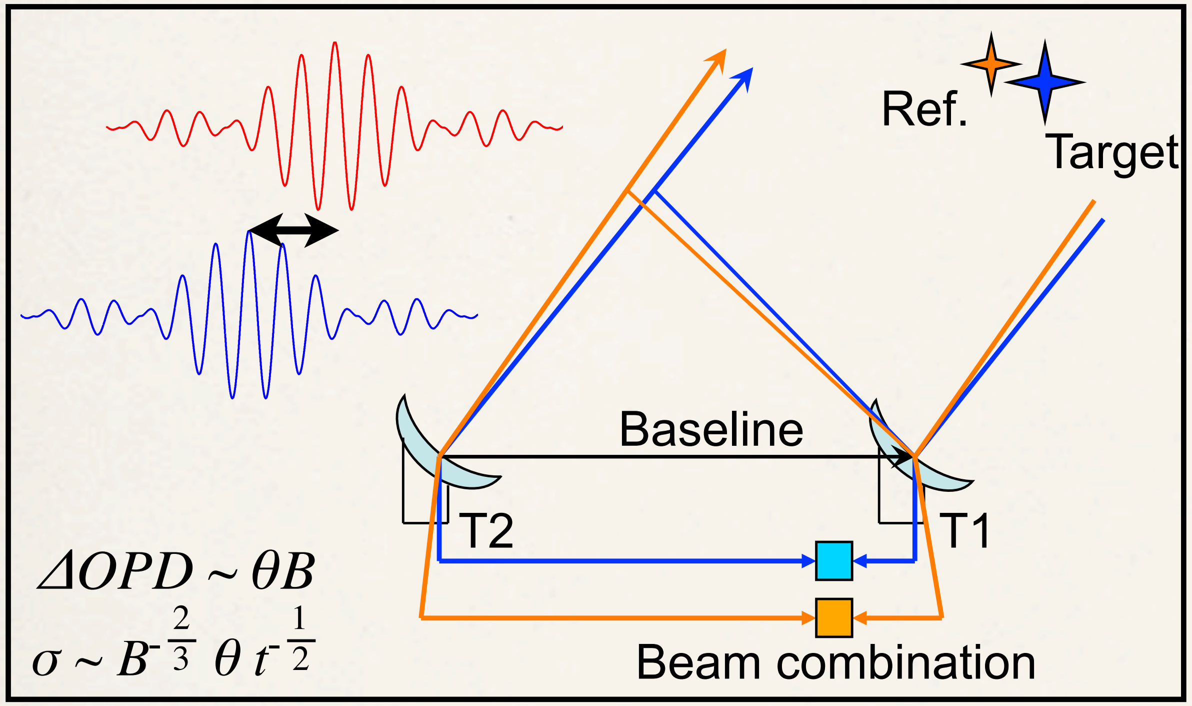
preliminary detection limits already indicate sensitivity to jupiter mass planets (mass ratio ~1:50) within 0.04-0.5 AU

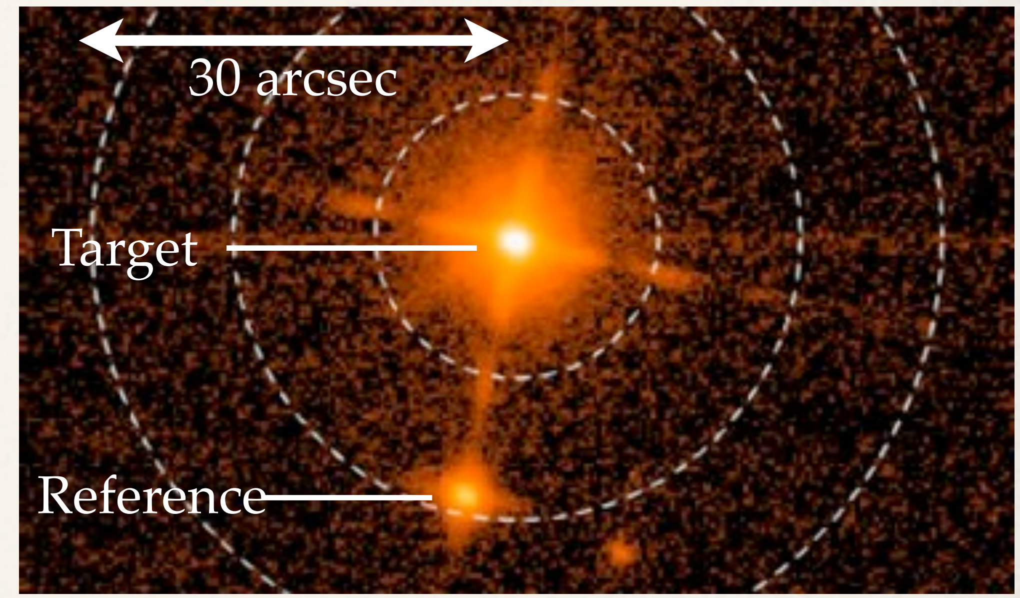
bridging the gap between radial velocity (<0.05 AU, e.g. Blake et al., 2010) and imaging (> ~1 AU, e.g. Stumpf et al., 2010) surveys

3. Astrometric planet search with the PRIMA interferometric facility

ESPRI consortium, ESO

high-precision astrometry with an interferometer





K-band image of an ESPRI target.

single-reference relative astrometry within a narrow field

interference fringe separation in delay space is proportional to angular separation

atmospheric limit:
0.01 mas for 30 min integration and a 100 m baseline (Shao & Colavita, 1992)

Exoplanet search with PRIMA

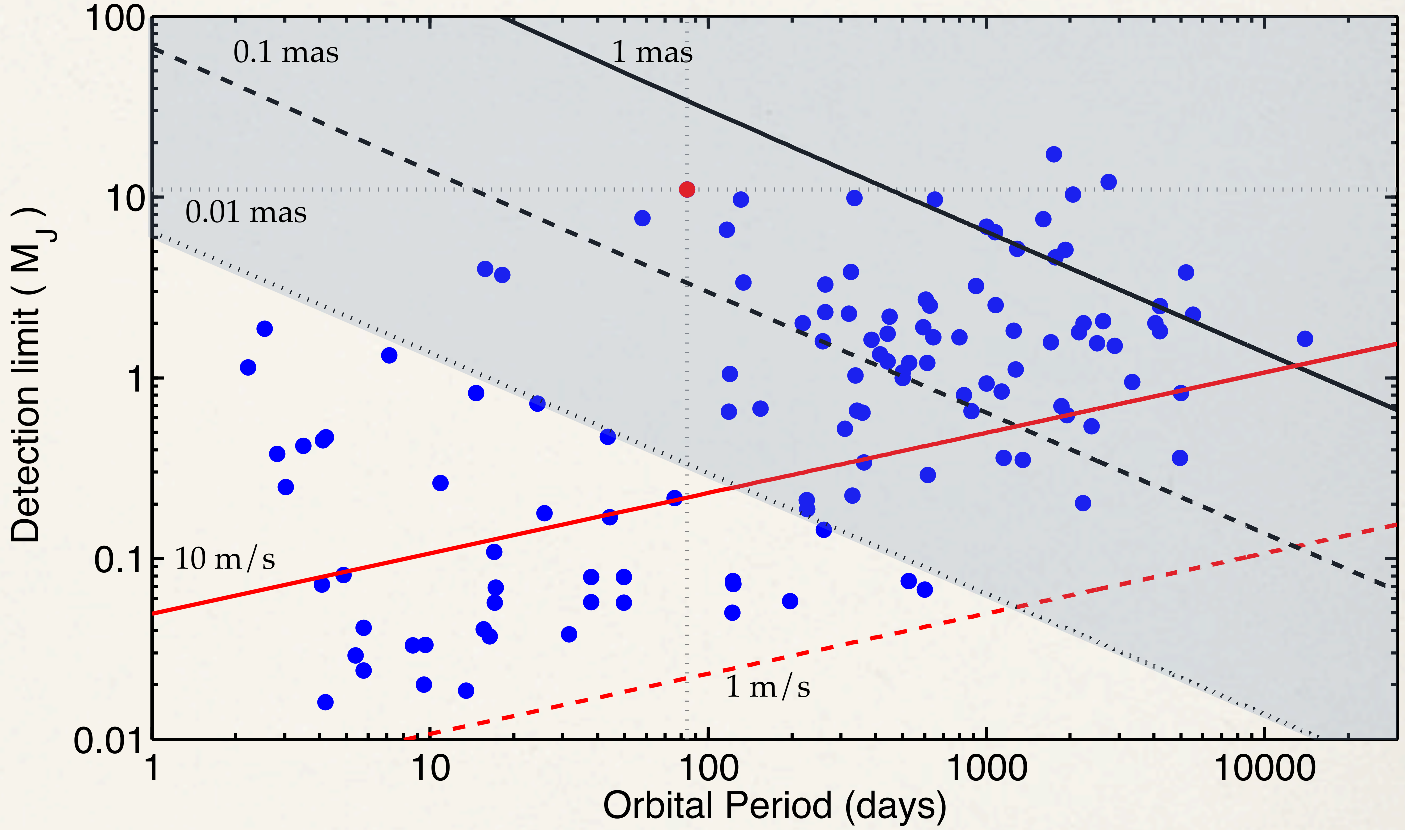
PRIMA is the dual-feed facility of VLTI

Consortium of MPIA, LSW (Heidelberg), Obs. Geneva

contributing differential delay lines + astrometric preparation and data reduction software

three target groups: hosts of RV planets, young stars, nearby main-sequence stars (~100 in total)

precision requirement 0.01 - 0.1 mas



Launhardt et al., 2008, SPIE

Delplancke et al., 2006, SPIE
van Belle et al., 2008, Messenger
Pepe et al., 2008, SPIE
Sahlmann et al., 2009, A&A

commissioning results

design goal of 0.01 mas sets accuracy constraints at ~10^{-6} on observables:
5 nm on optical path lengths and 100 μm on baseline

1st light in January 2011 and
3 commissioning runs

Facility is operational

Accuracy goal not yet met due
to large systematic errors
(baseline knowledge).

The measurement precision is good
and 0.03 mas were achieved
(requirement is met within a factor 2).

Error sources are being identified and eliminated. Work in progress ...

Conclusions

1. Only 0.6 ± 0.2 % of Sun-like stars have a brown dwarf companion within 10 AU.

2. An empirical dividing line between massive planets and brown-dwarf companions close to Sun-like stars is at 25-45 M_J.

3. Astrometry at 0.1 mas level over a year's timespan is realised with FORS/VLT.
This makes the detection of planets around close-by brown dwarfs possible and yields their parallaxes at ~0.2 % precision.

4. An astrometric planet search programme using PRIMA/VLTI will begin soon.

High-precision astrometry is a powerful tool to measure the properties of exoplanet populations.

The necessary improvement in accuracy from Hipparcos (1 mas) to 0.1 mas is possible today, but requires specialised techniques and instruments.

The results shown here are pioneering the GAIA mission, which will go several steps further.

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