51 Pegasi b … already 30 years.

Michel Mayor
University of Geneva

The change of paradigme in the middle of 20th century

Struve,Otto 1952, The Observatory 72: 199

Observatory (1952) 72,199

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

By Otto Struve

With the completion of the great radial-velocity programmes of the major observatories, the impression seems to have gained ground that the measurement of Doppler displacements in stellar spectra is less important at the present time than it was prior to the completion of R. E. Wilson's new radial-velocity catalogue.

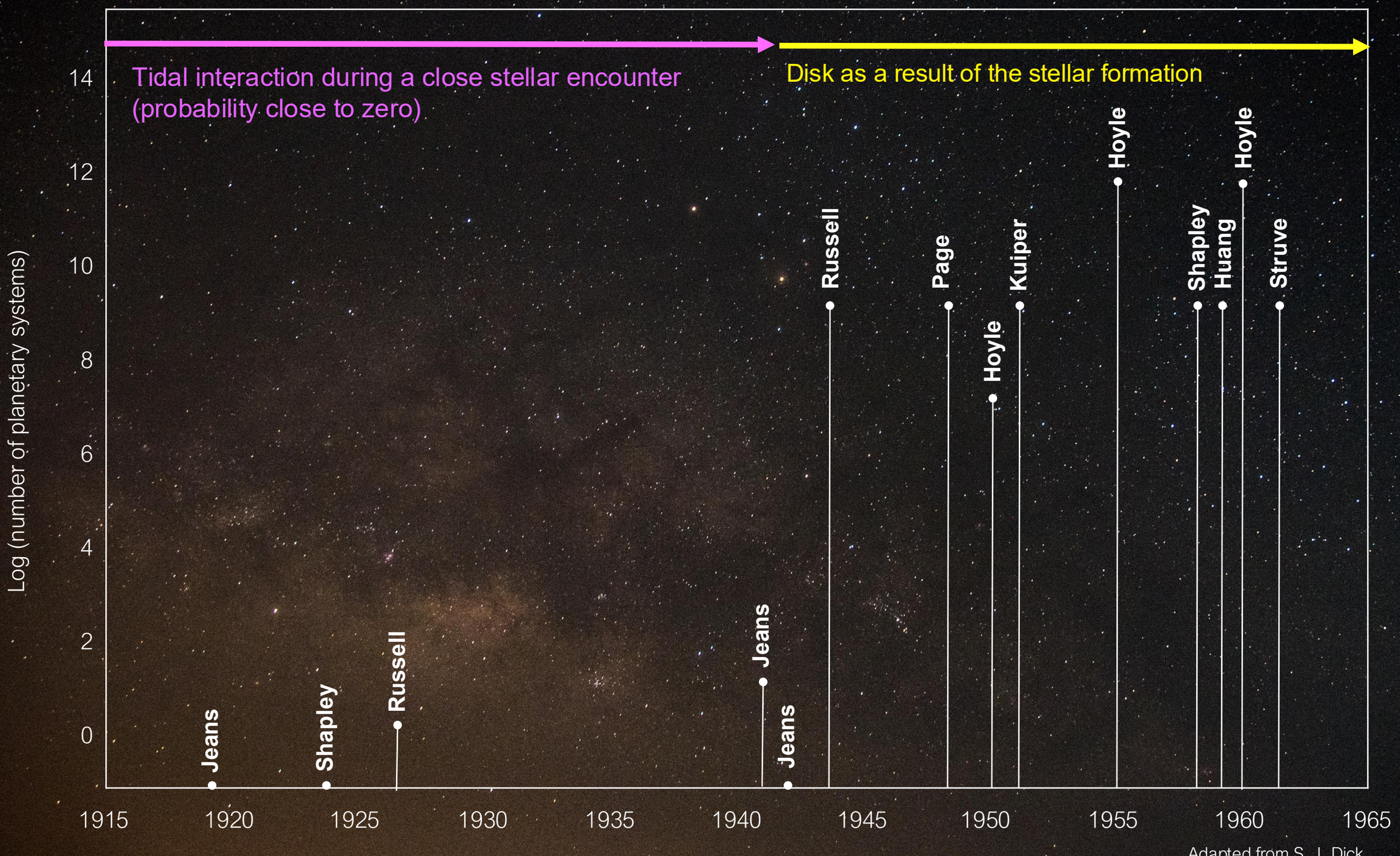
I believe that this impression is incorrect, and I should like to support my contention by presenting a proposal for the solution of a characteristic astrophysical problem.

One of the burning questions of astronomy deals with the frequency of planet-like bodies in the galaxy which belong to stars other than the Sun. K. A. Strand's[1] discovery of a planet-like companion in the system of 61 Cygni, which was recently confirmed by A. N. Deitch[2] at Poulkovo, and similar results announced for other stars by P. Van de Kamp[3] and D. Reuyl and E. Holmberg[4] have stimulated interest in this problem. I have suggested elsewhere that the absence of rapid axial rotation in all normal solar-type stars (the only rapidly-rotating G and K stars are either W Ursae Majoris binaries or T Tauri nebular variables,[5] or they possess peculiar spectra[6]) suggests that these stars have somehow converted their angular momentum of axial rotation into angular momentum of orbital motions of planets. Hence, there may be many objects of planet-like character in the galaxy.

But how should we proceed to detect them? The method of direct photography used by Strand is, of course, excellent for nearby binary systems, but it is quite limited in scope. There seems to be at present no way to discover objects of the mass and size of Jupiter; nor is there much hope that we could discover objects ten times as large in mass as Jupiter, if they are at distances of one or more astronomical units from their parent stars.

Estimated number of planetary systems

in the Milky Way



Adapted from S. J. Dick

Stellar radial velocities as a tool to search for planetary companions

(Belorizky, D. 1938, L'Astronomie 52:359)

Struve, O. 1952, Proposal for a project of high-precision radial velocity work, Observatory 72:199

Eighties and nineties : Stellar precision velocity techniques : a lot of ideas and interest for RV planet searches.

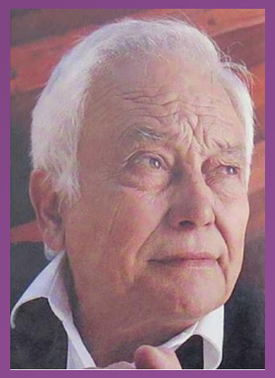
1973: R.Griffin	*Telluric lines*		
1979 : B.Campbell & G.W. Walker	*HF cell*	*15m/s*	
1982: M.Smith	*Telluric lines*		
1981: D.Hall & K.Hinkle	*N_2H cell + FTS*		
1985: P.Connes	*FP tunable,stellar accelerometer*		
1985: W.Cochran & B.Young	*FP reflection*		
1985: R.McMillan & al.	*Stellar accelerometer*		
1991: G.Marcy & P.Butler	*Iodine cell*	*15m/s*	
1993: A.Baranne,D.Queloz,M.Mayor	*Echelle,fibers,cross-correl.*	*13m/s*	*ELODIE*
1996: G.Marcy & P.Butler	*SW improvment , I-cell*	*3m/s*	
2003: M.Mayor,F.Pepe,D.Queloz +	*vacuum,fibers,thermal control*	*1 m/s*	*HARPS*

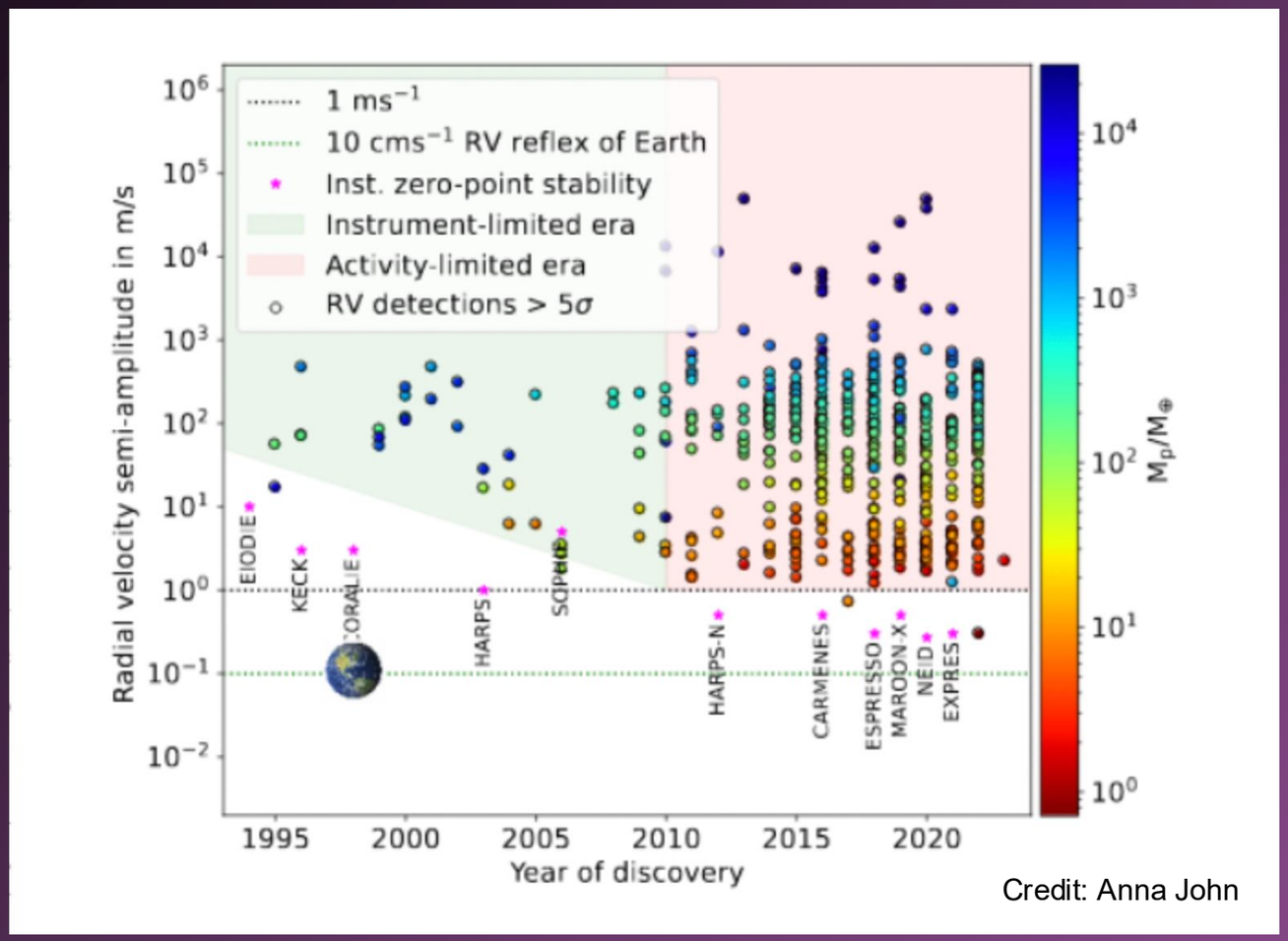
First steps of the cross-correlation spectroscopy

Fellgett, P., 1955, “A proposal for a radial velocity photometer,” Opt. Acta 2, 9-15.

Griffin, R. F., 1967, “A photoelectric radial-velocity spectrometer,” Astrophys. J. 148, 465–476.

Baranne, A., Mayor, M. Poncet J.L. 1979, «A new tool for radial velocity measurements » Vistas Astr. 23,279- 316





Credit: Anna John

All the spectrographs with instrumental precision better than 1m/s are using diverse cross-correlation spectroscopy approaches

From CORAVEL to ELODIE at OHP (300 to 15 m/s)

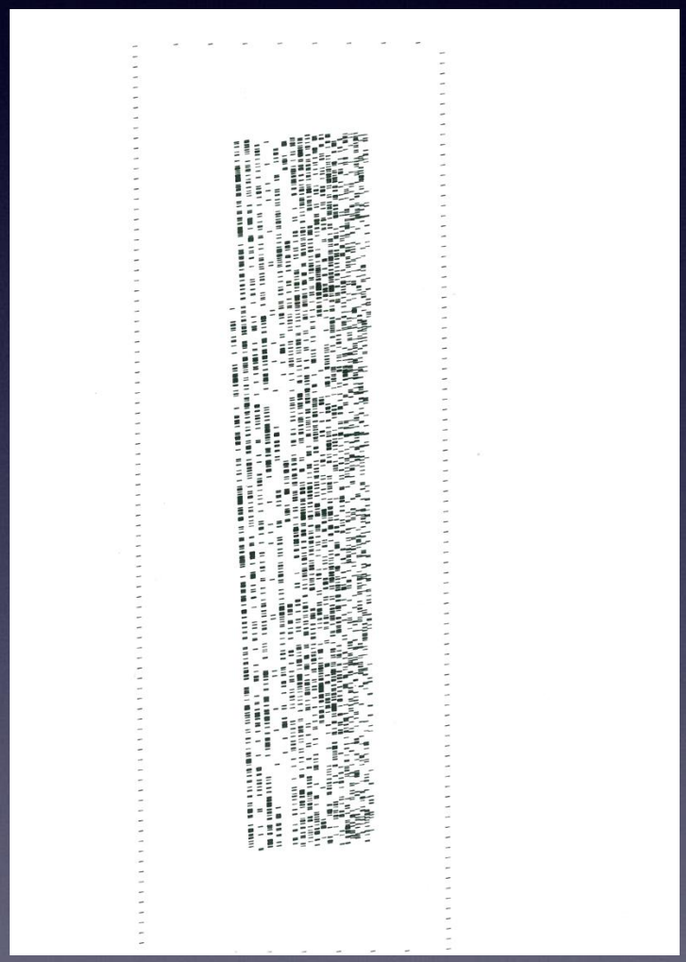
CORAVEL and the OHP 1m telescope

1977- 1994

Efficacity gain of 4000 by comparison with the photographique plate technique

But a precision limited to 300m/s
???

Physical cross-correlation > fix template



Baranne,A., Mayor,M., Poncet,J.L. 1977 CR Acad.Sc.Paris,Ser.B 285:117
Baranne,A., Mayor,M., Poncet,J.L. 1979, Vistas in Astronomy 23:279

A search for Jupiter-mass companions to nearby stars.

Show affiliations

Walker, Gordon A. H. ; Walker, Andrew R. ; Irwin, Alan W. ; Larson, Ana M. ; Yang, Stephenson L. S. ; Richardson, Derek C.

We have carefully monitored the radial velocities of 21 bright, solar-type stars for 12 years, None has shown any reflex motion due to a substellar companion to an upper limit of between 1 and 3 Jupiter masses (X sin i) for orbital periods less than 15 years, We can also rule out companions of more than 3 to 10 Jupiter masses (X sin i) at much longer periods based on long-term trends in the radial velocities, limits imposed by astrometry and zones of orbital stability in wide binaries. When our negative result is combined with other searches, one can say that, so far, no planets of the order of a Jupiter-mass or greater (ge;0.001 M ⊙) have been detected in short-period, circular orbits around some 45 nearby, solar-type stars. This absence presents an interesting challenge to theories of planet formation.

Publication: Icarus, Volume 116, Issue 2, p. 359-375.

Pub Date: August 1995

DOI: 10.1006/icar.1995.1130

Bibcode: 1995Icar..116..359W

Keywords: Planetary Companions: Nearby Stars; Planetary Companions: Detection

Proximity of Jupiter-Like Planets to Low-Mass Stars

Show affiliations

Boss, Alan P.

The sensitivities of astrometric and radial velocity searches for extrasolar planets are strongly dependent on planetary masses and orbits. Because most nearby stars are less massive than the sun, the first detection is likely to be of a Jupiter-mass planet orbiting a low-mass star, with a possible theoretical expectation being that Jupiter-like planets will be found much closer [inside the Earth-sun separation of 1 astronomical unit (AU)] to these low-luminosity stars than Jupiter is to the sun (5.2 AU). However, radiative hydrodynamic models of protoplanetary disks around low-mass stars (of 0.1 to 1 solar mass) show that Jupiter-like planets should form at distances (approximately 4 to 5 AU) that are only weakly dependent on the stellar mass.

Publication: Science, Volume 267, Issue 5196, pp. 360-362

Pub Date: January 1995

DOI: 10.1126/science.267.5196.360

Bibcode: 1995Sci...267..360B

ELODIE spectrograph on the 193 cm at the Haute-Provence Observatory

ELODIE: A spectrograph for accurate radial velocity measurements

A. Baranne[1], D. Queloz[2], M. Mayor[2], G. Adrianzyk[3], G. Knispel[3], D. Kohler[3], D. Lacroix[3], J.-P. Meunier[3], G. Rimbaud[3] and A. Vin[3]

Astron. Astrophys. Suppl. Ser. **119,** 373-390 (1996)

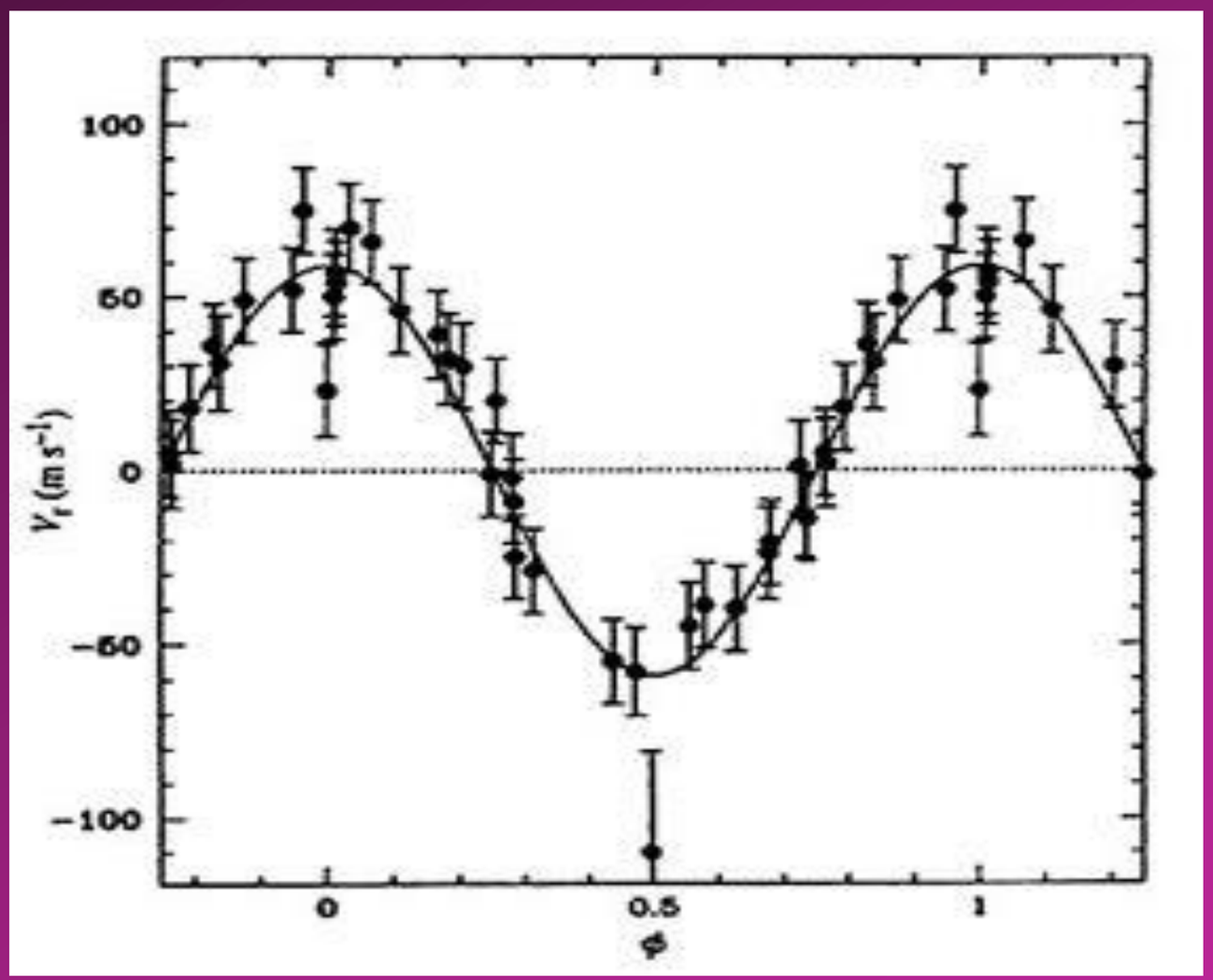
Discovery of a first planet (51 Pegasi b) hosted by a star similar to our Sun

$M_{pl} = 0.5\ M_{Jup}$

(Mayor & Queloz , Nature 1995)

P = 4.2 days .... 1/1000 of theoretical predictions !!!!!

a = 0.04 UA



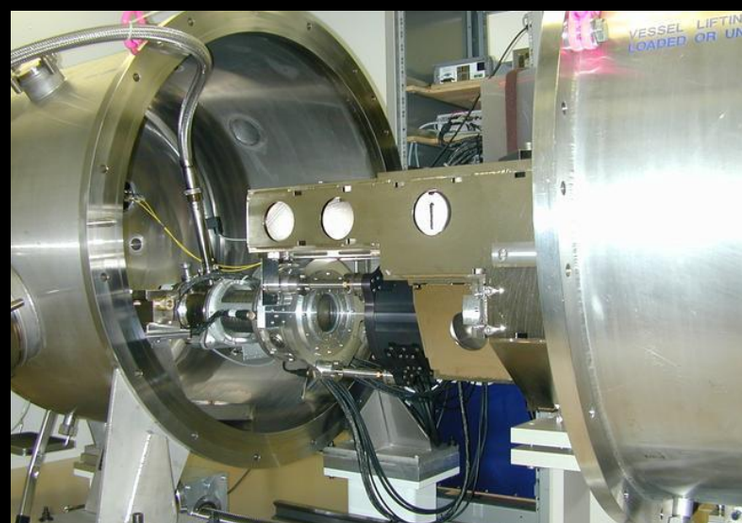
Goldreich & Tremaine 1980
Papaloizou & Lin 1986
Lin, Bodenheimer & Richardson 1996

Today : more than 6000 exoplanets have been discovered and characterized.

HARPS (1 m/s) : The southern sky and the discovery of Super-earths and mini-Neptunes.

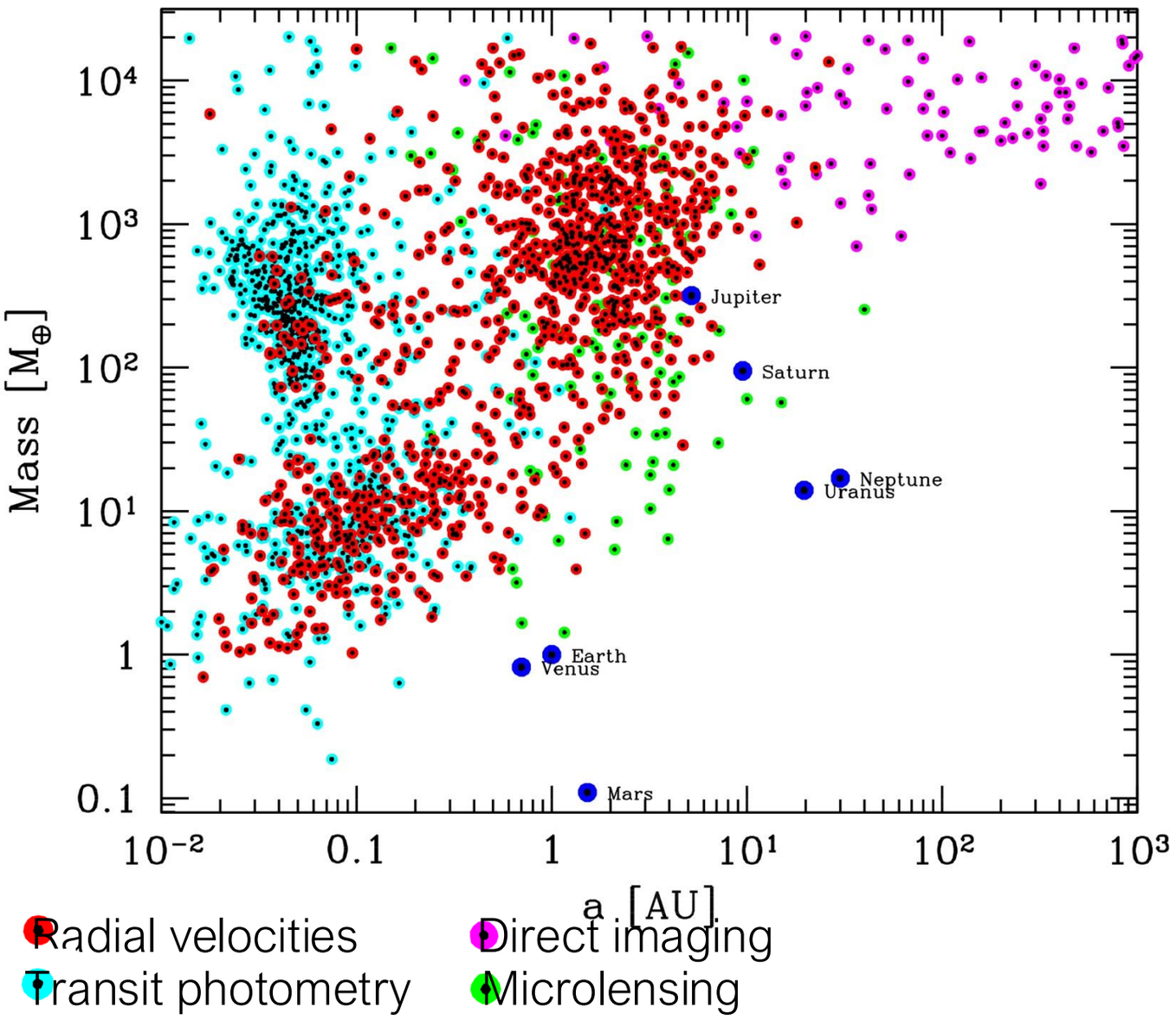
HARPS: A spectrograph to search for exoplanets.

Mayor,Pepe,Queloz et al 2003



The diversity of planetary systems

…30 years of observations



SURVEY HARPS :

500 nights of the 3.60 m telescope !
at ESO La Silla

An amazing diversity

Discovery of the numerous Super-Earth subpopulation 1 -10 Earth-Mass

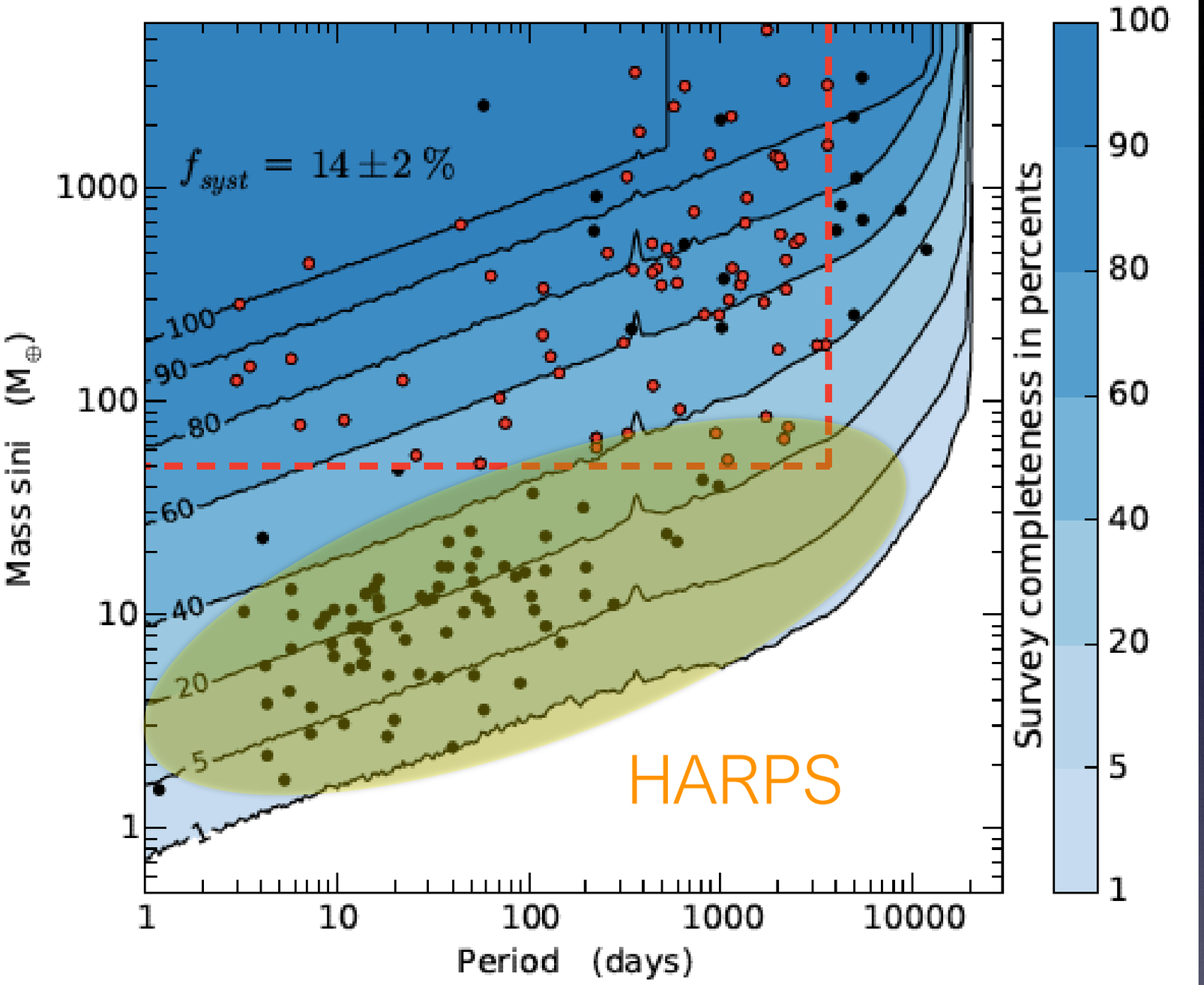


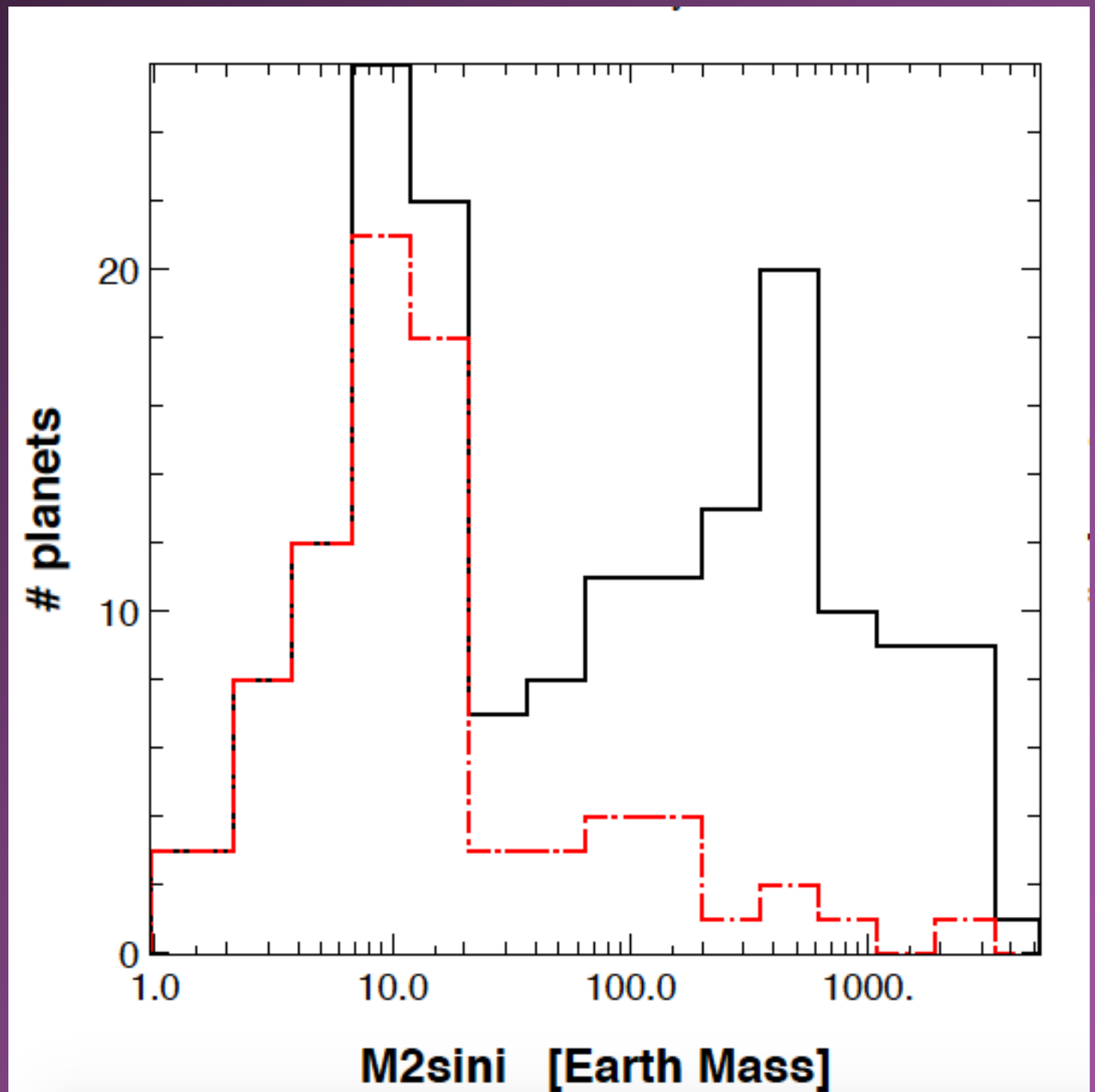
Fig. 5. Plot of the 169 planets of the considered HARPS+CORALIE sample in the $m_2 \sin i - \log P$ plane. The superimposed curves indicate the completeness of the survey. These detection probabilities are valid for the whole sample of 822 stars. After correcting for the detection bias, the fraction of stars with at least one planet more massive than 50 $M_\oplus$ and with a period smaller than 10 years is estimated to be 14 ± 2 %. The red points represent the planets which

The HARPS survey at la Silla continuing since 2003

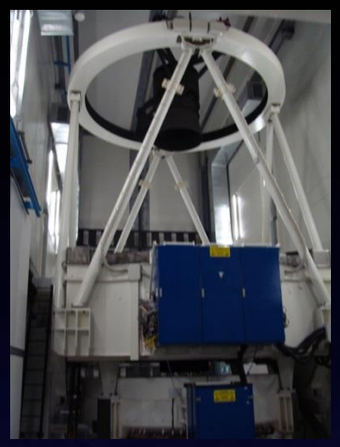
*** % of planetary systems as function of mass, period, metallicity of the host star, …

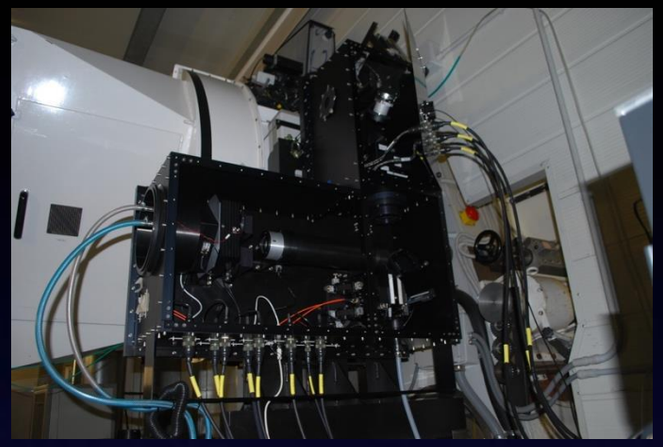
In red : Period < 100 days ……. Huge excess of planets in the domain of Super-Earths and Neptune-mass planets.

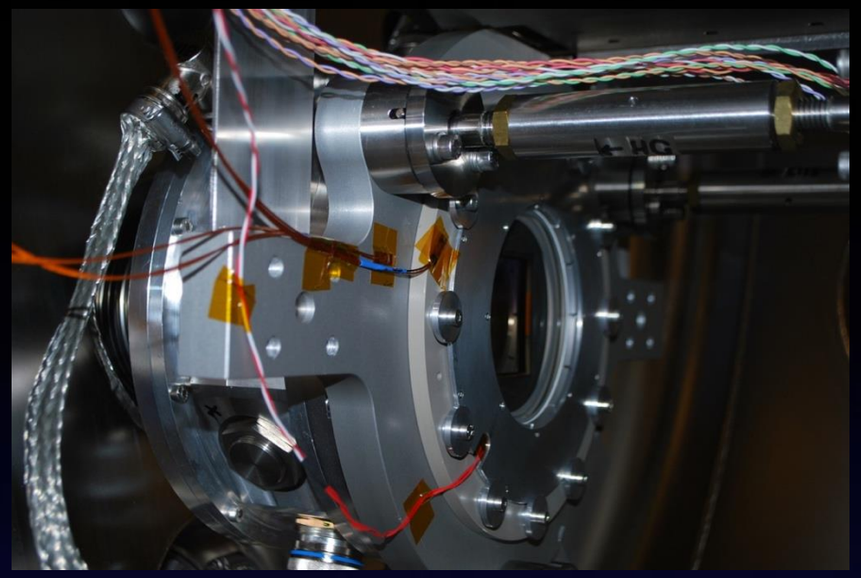
In black : Combined sample CORALIE ,volume and precision limited with HARPS sample higher precision ….. the « giant planet population is over represented »

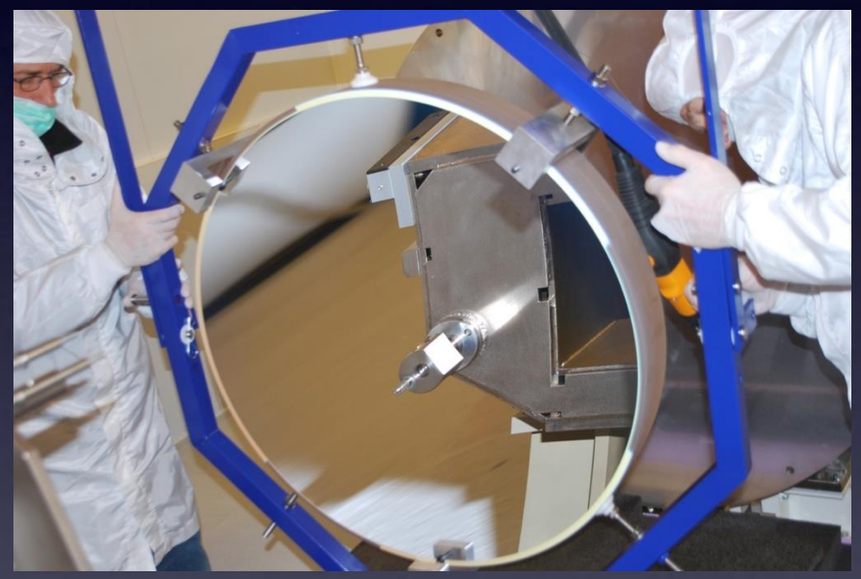


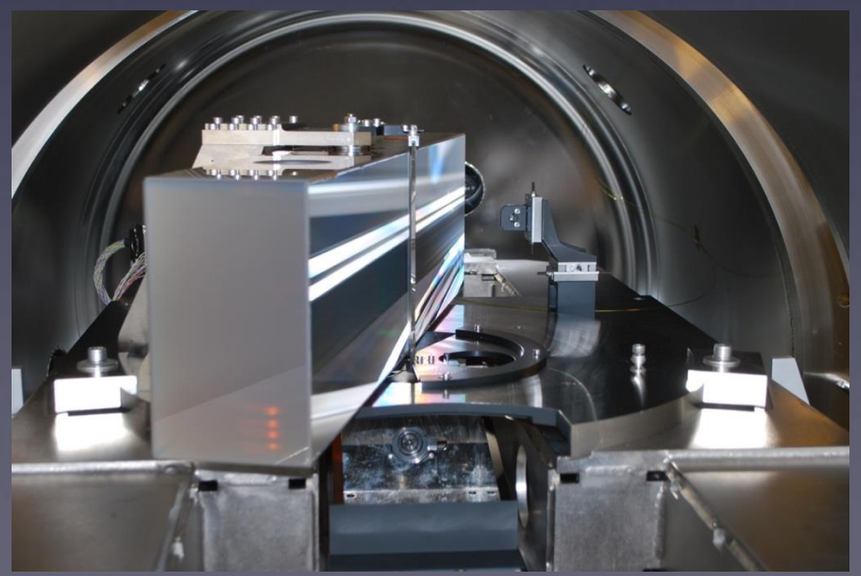
HARPS-N @ Galileo telescope at La Palma Observatory











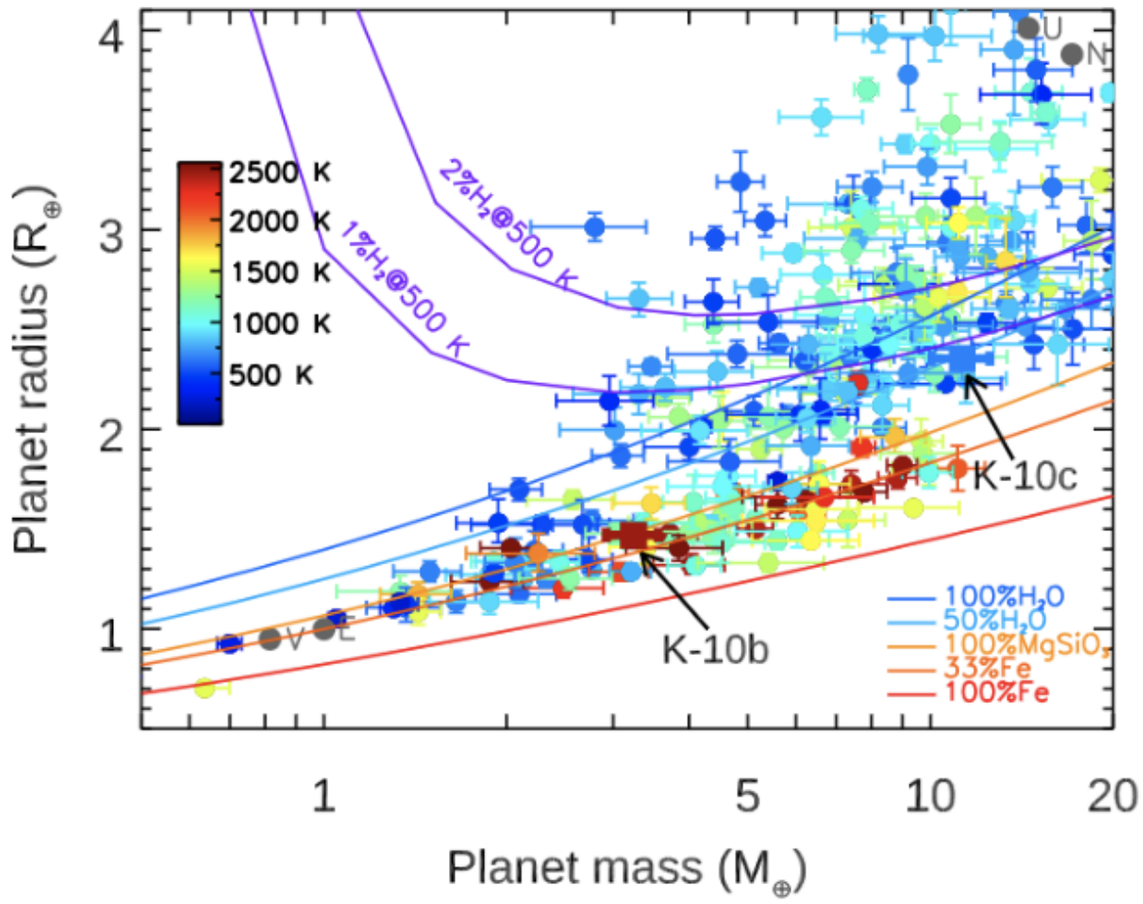


Fig. 10. Mass-radius diagram of small ($R_p \leq 4\ R_\oplus$) planets with mass and radius determinations better than 4σ and 10σ, respectively, color-coded by planet equilibrium temperatures. The different solid curves, from top to bottom, correspond to planet compositions of 100% iron, 33% iron core and 67% silicate mantle (Earth-like composition), 100% silicates, 50% rocky interior and 50% water, 100% water, rocky interiors and 1% or 2% hydrogen-dominated atmospheres (Zeng & Sasselov 2013). The gray dark circles indicate Venus (V), the Earth (E), Uranus (U), and Neptune (N). Kepler-10 b and c are indicated squares.

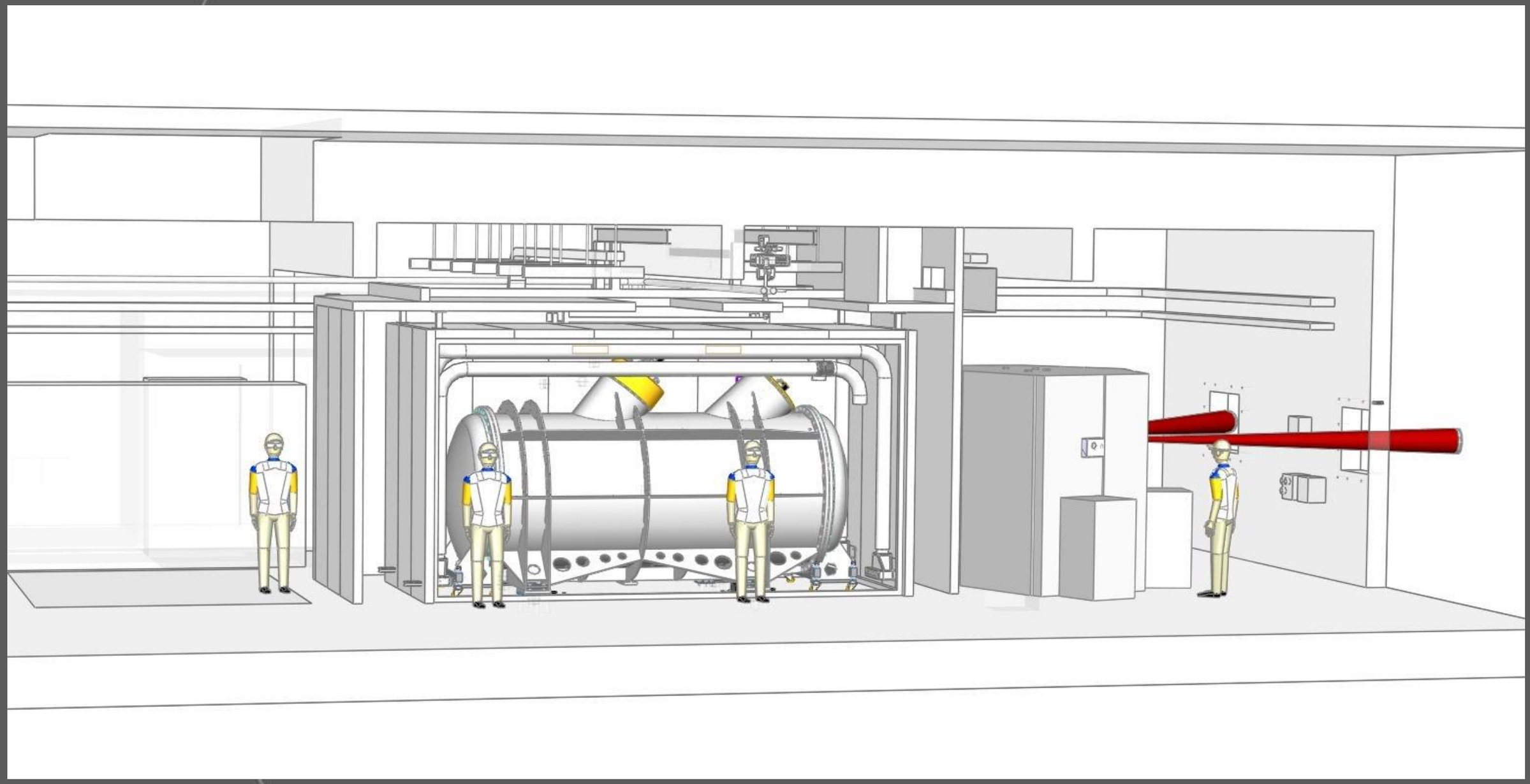
Consortium

- Institutes of four countries
  - Portugal: Univ. of Porto (N. Santos), Univ. Lisbon
  - Italy: INAF Trieste (S. Cristiani), INAF Brera
  - Spain: IAC (R. Rebolo Lopez)
  - Switzerland: Univ. Geneva (Lead, F. Pepe), Univ. Bern

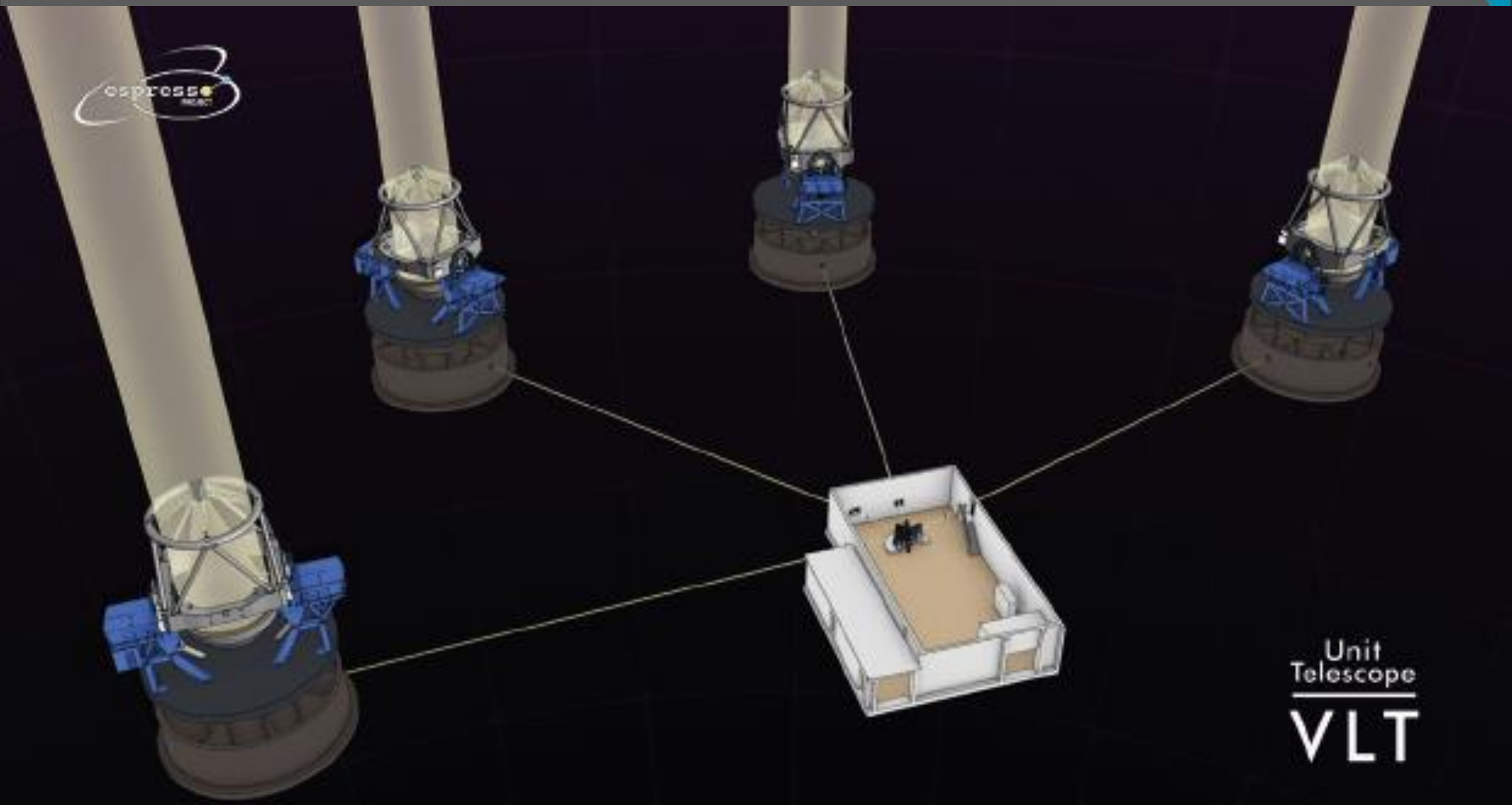
- Associated Partner
  - ESO (L.Pasquini), Garching and Paranal

A spectrograph on a 16 m telescope,I. Pepe,F.et al. 2021 , A&A 645:96-122

A stabilized environment



Combined Coudé Lab



Increasing the precision

Radial velocity via cross-correlation spectroscopy:
A path to the detection of Earth-type planets

SPECTRO	year	precision	Telescope	
CORAVEL	1977	300 m/s	1 m	OHP
ELODIE	1994	13 m/s	1.9 m	OHP
CORALIE	1998	6 m/s	1 m	ESO Chile
HARPS	2003	1 m/s	3.6 m	ESO Chile
HARPS-N	2013	1 m/s	3.5 m	IAC La Palma
ESPRESSO	2018	0.1 m/s	8.2 m (x4)	ESO Chile

An increase of the sensibility by a factor 3000 during the last 40 years

Thank you