R & D

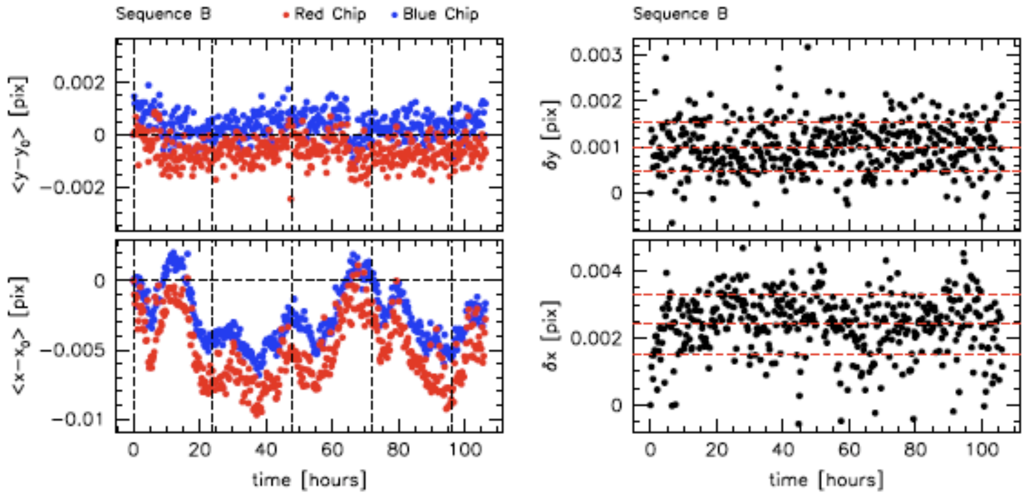
Telescope Guiding:
Tests on FRD and Scrambling on different type of fibres
made at ESO (G. Avila)

Wavelength Calibration:
Development of LFC Calibration System
in collaboration with MPQ (Steinmetz)

Detector Stability:
Analysis and modeling of HARPS tests and
Development of super stable cryostat (FP7)
Ad-Hoc Test Campaign and development

Detector and Cryostat

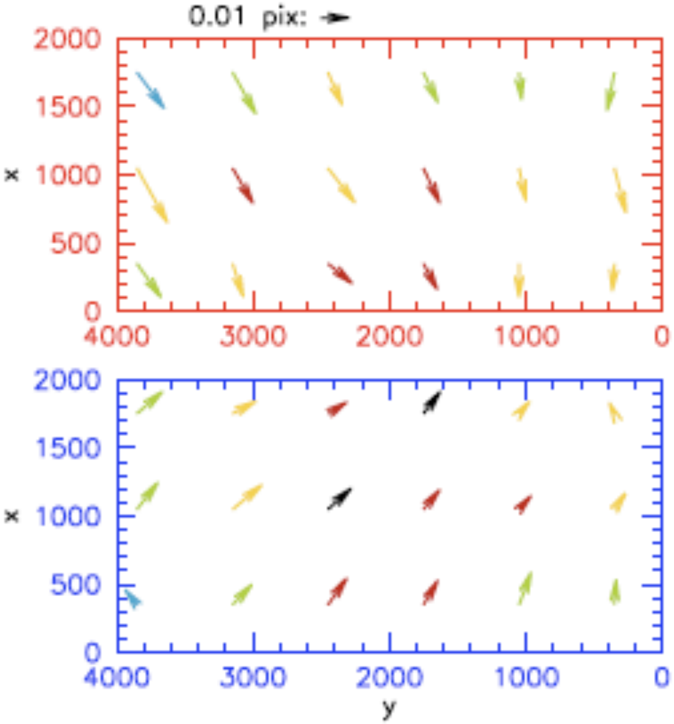
Controlled tests were performed for 4 days with HARPS:
Acquisition of Th-A exposures with 2 fibres plus Controlled Variations of CCD temperature
(M. Guilleuszik et al. , in preparation)

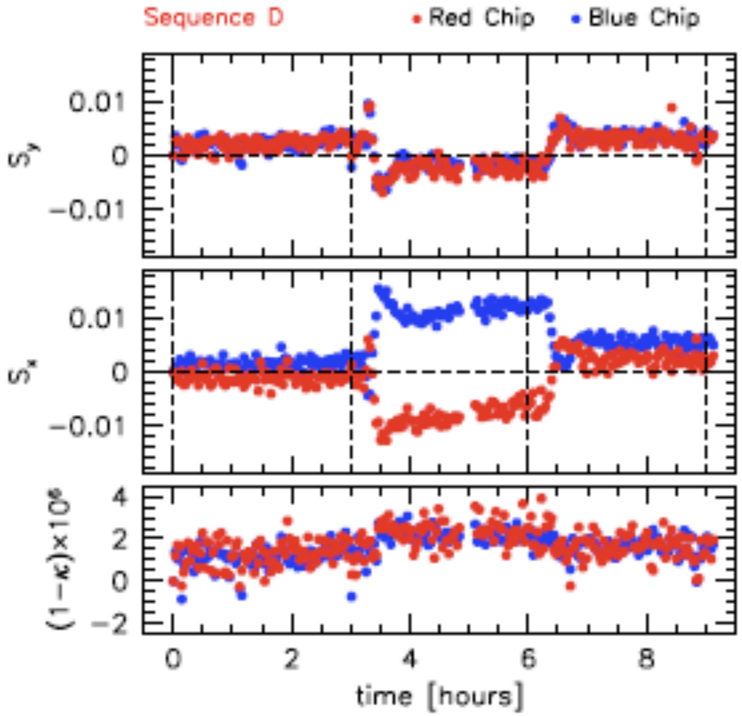


CCDs: Super stable cryostat under study 1 mK stability

Contacts started with CCD manufacturers on possible large formats (9x9cm). Not negative answers but limitations might be present when considering all the aspects

Detector Stability & Expansion





Differential movements of the Th-A lines in the detector: ~0.01/2 pixel/K (right)
Left: the detector expands around the attachments of the mosaic to the support
After modeling, a new cryostat/system will be designed. Differential movements
Within ~150 pixels one order of magnitude less ~10^{-6} pixel/mK

ESPRESSO and CODEX the next generation of RV planet hunters at ESO

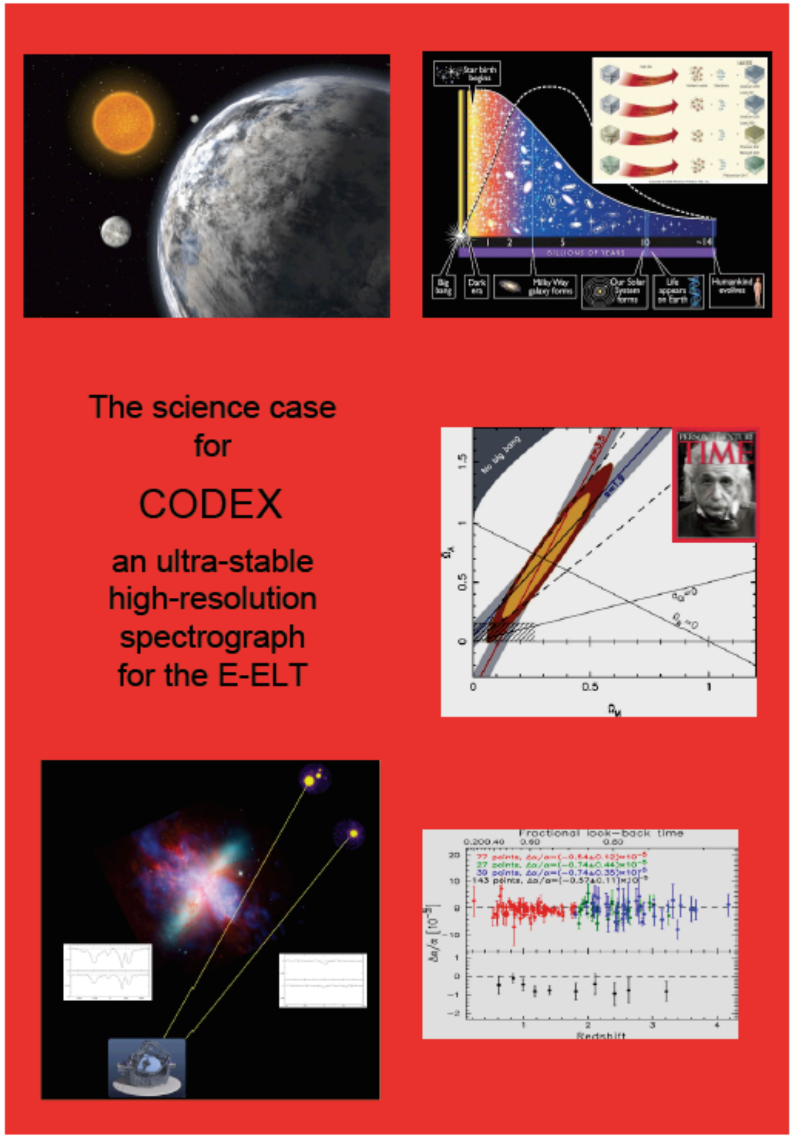
Luca Pasquini, ESO

ESO,
Geneve Observatory
Instituto de Astrofisica de Canarias
INAF-Trieste and Brera
Institute of Astronomy Cambridge
University of Lisboa and Porto

CODEX Science Main Cases

1. Dynamical measurement Universal expansion (C2)
2. *Extrasolar Twin Earths (S3)*
3. Variability of Physical Constants (C3)
4. Metallicity of the low density IGM (C7)
5. Nucleochronometry

PRECISION SPECTROSCOPY REQUIRES MANY PHOTONS AT HIGH R: VERY LARGE TELESCOPE APERTURES !!



The *HARPS* heritage

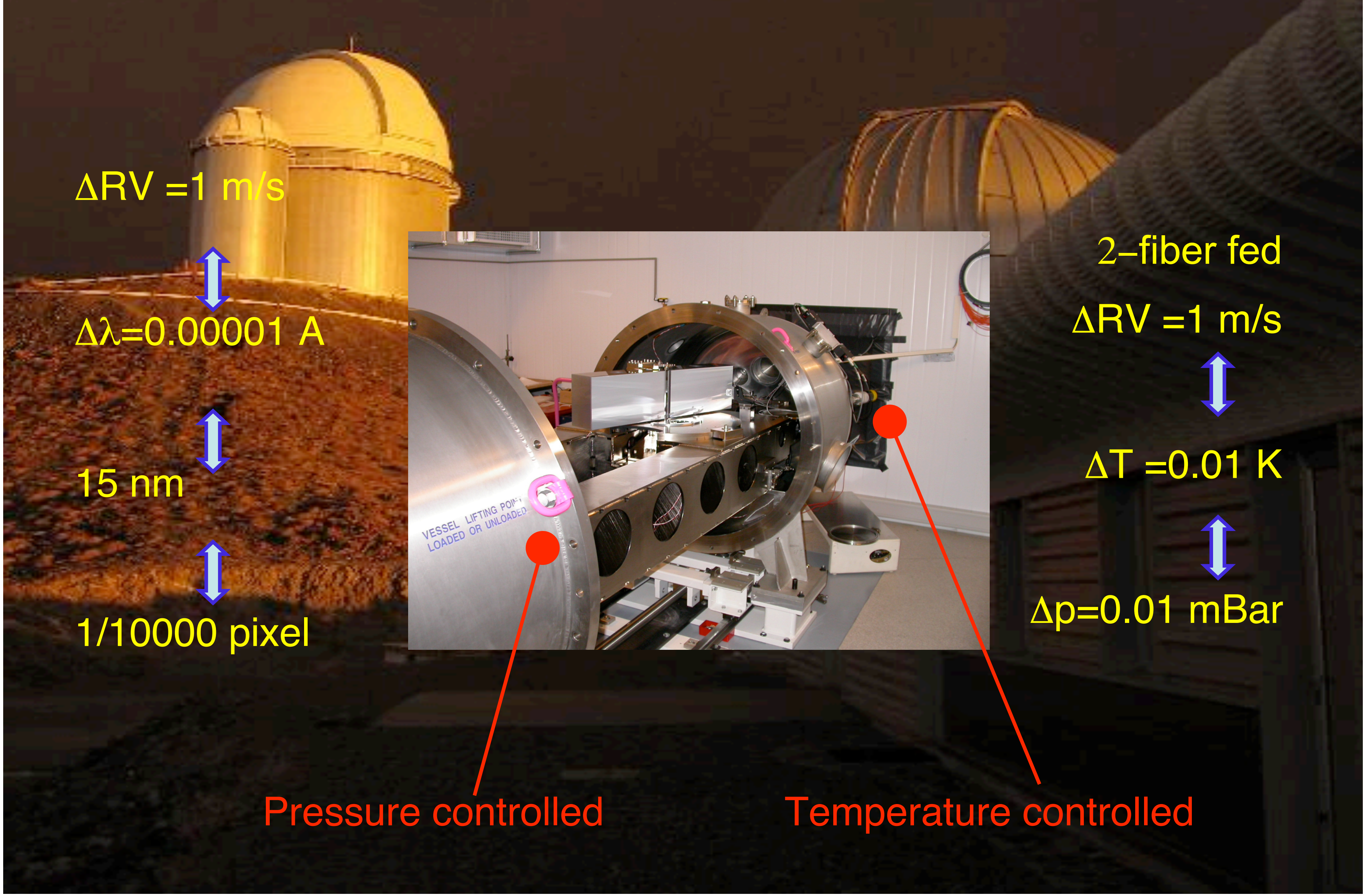
The ***HARPS*** spectrograph (Mayor et al. 2003) is
the planet hunter operating for 6 years at the ESO 3.6m telescope

The ***HARPS*** heritage is twofold

Scientific

Technological

HARPS: stability at 1 m/s

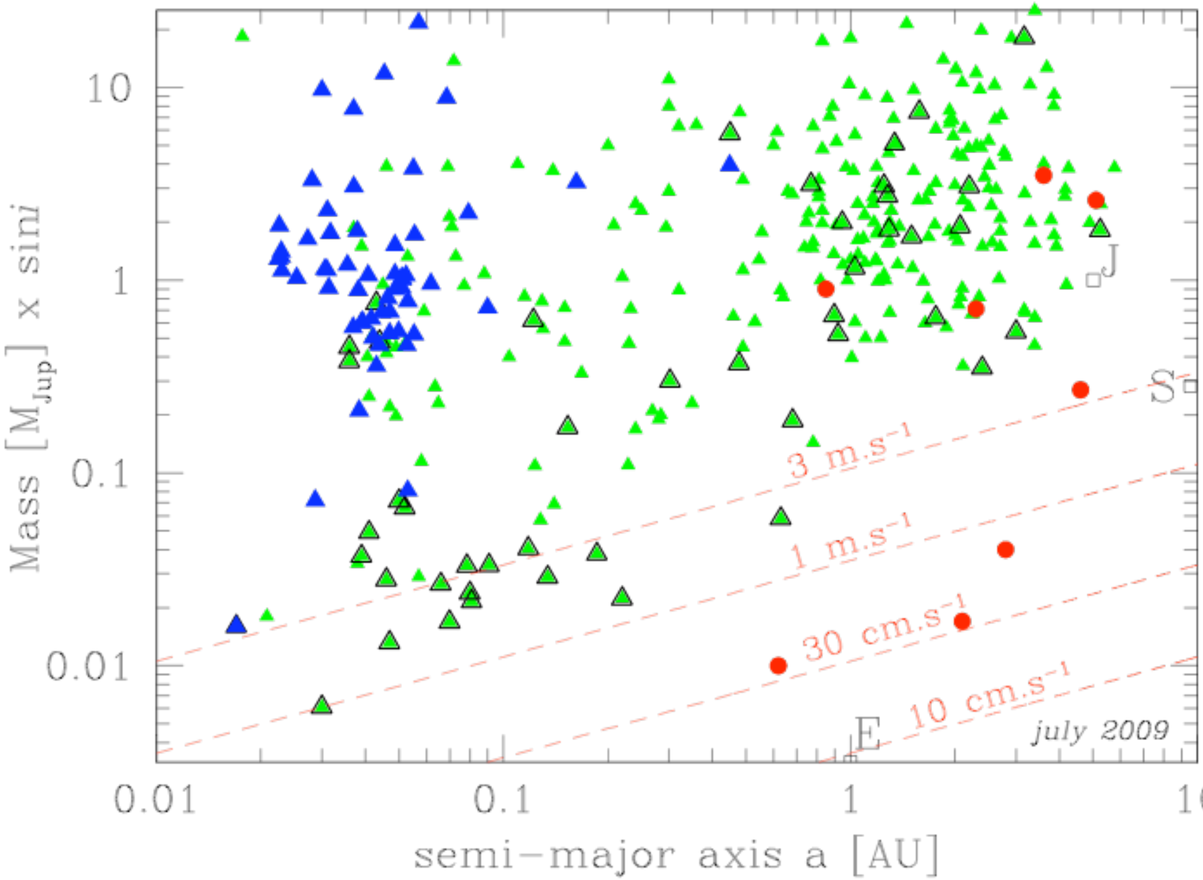


HARPS Scientific Heritage

" Aiming at 1 m/s^{-1} is useless (and you will never succeed) "
(anonymous, 1998 - 2003)

16/20 Neptune mass planets have been discovered by HARPS in 5 yrs of operations

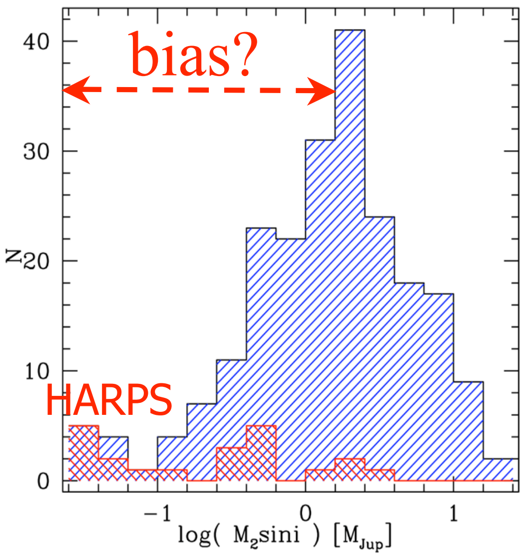
(Bouchy et al. 2009 A&A 496, 527)

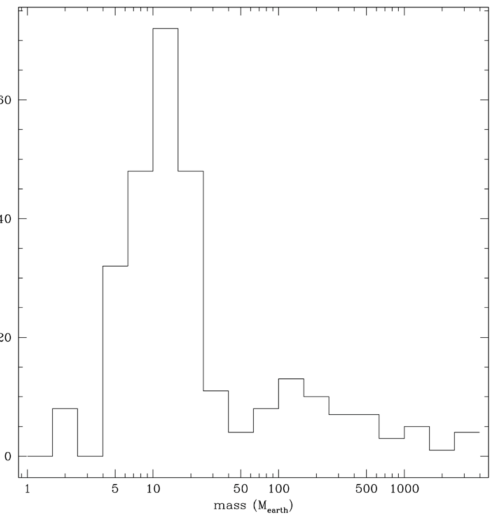


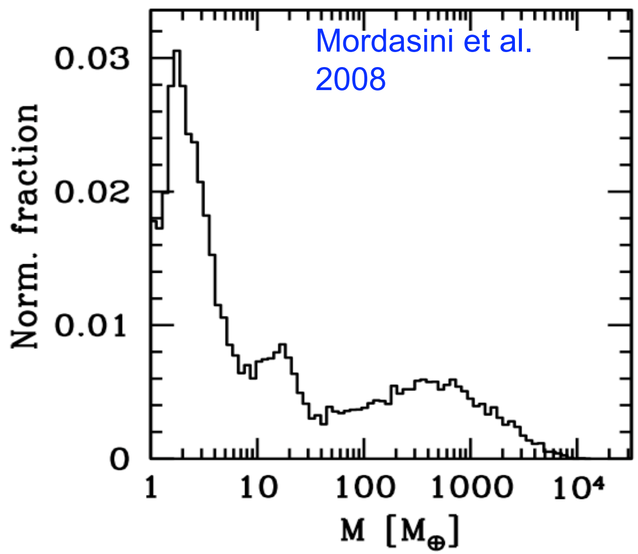
A population of low mass planets

From the HARPS high precision survey: Newly discovered low mass planet population indicates a quite common (up to 30%) frequency of low mass planets around solar stars (Lovis et al. 2009)

Are we at the edge of discovering the predicted large population of terrestrial planets ?





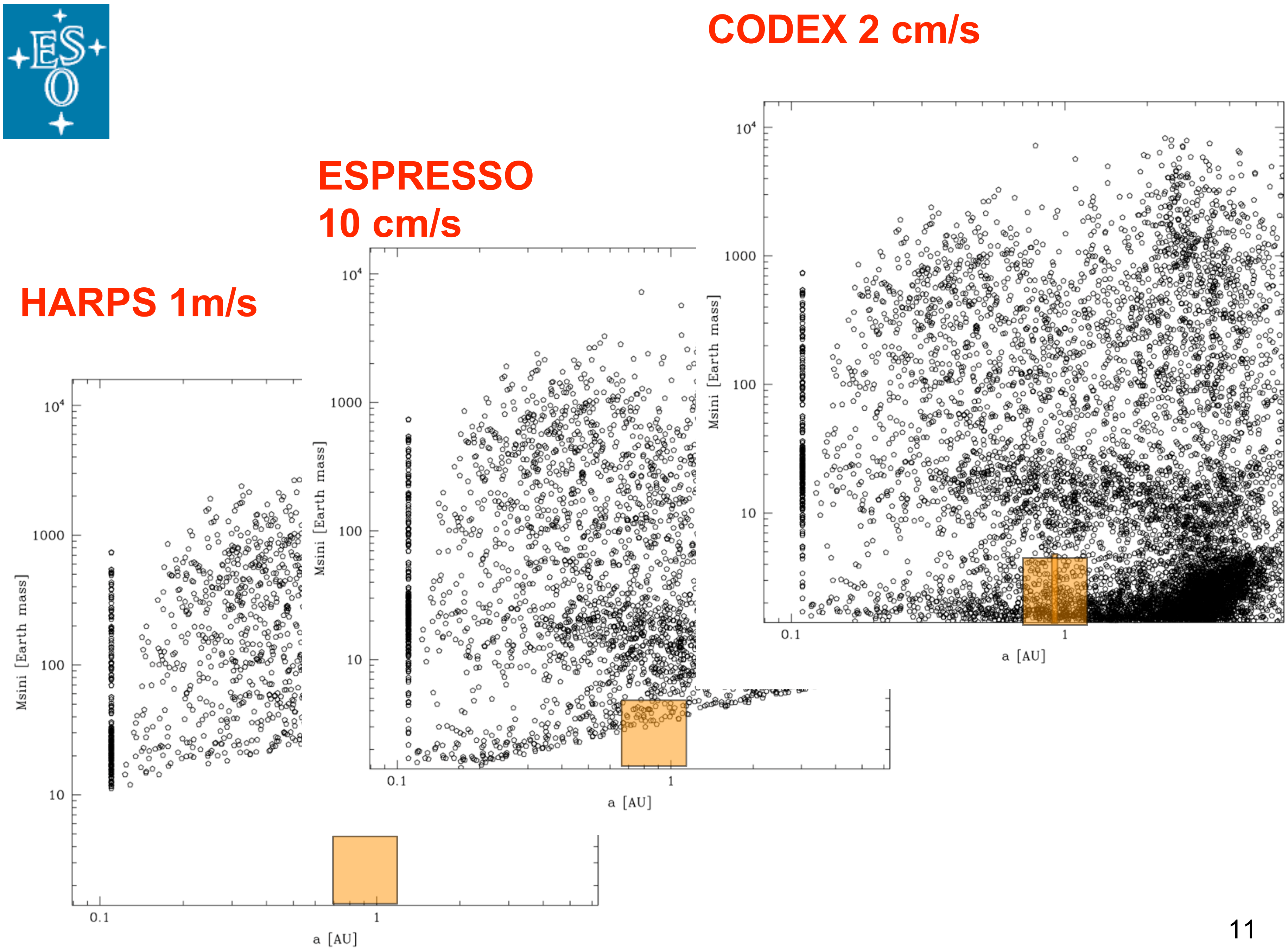


P<100d sample for giant planets = 8 * sample for super-Earths

Planet Detectability with radial velocities

$$k_1 = \frac{28.4\,\mathrm{m\,s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}}\right)^{-2/3} \left(\frac{P}{1\,\mathrm{yr}}\right)^{-1/3}$$

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_{\oplus}$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}


CODEX 2 cm/s
ESPRESSO
10 cm/s
HARPS 1m/s
Msini [Earth mass]
a [AU]
10⁴
1000
100
10
0.1
1

Summary of Requirements

	Espresso	CODEX
Telescope	VLT (8m)	E-ELT (42m)
Scope	Rocky Planets	Earth-Like
Sky Aperture	1 arcsec	0.80 arcsec
R	150000	150000
λ Coverage	350-730 nm	380-680 nm
λ Precision	5 m/sec	1 m/sec
RV Stability	< 10 cm/sec	< 2 cm/sec
	4-VLT mode (D=16m) with RV=1m/sec	

ESPRESSO & CODEX

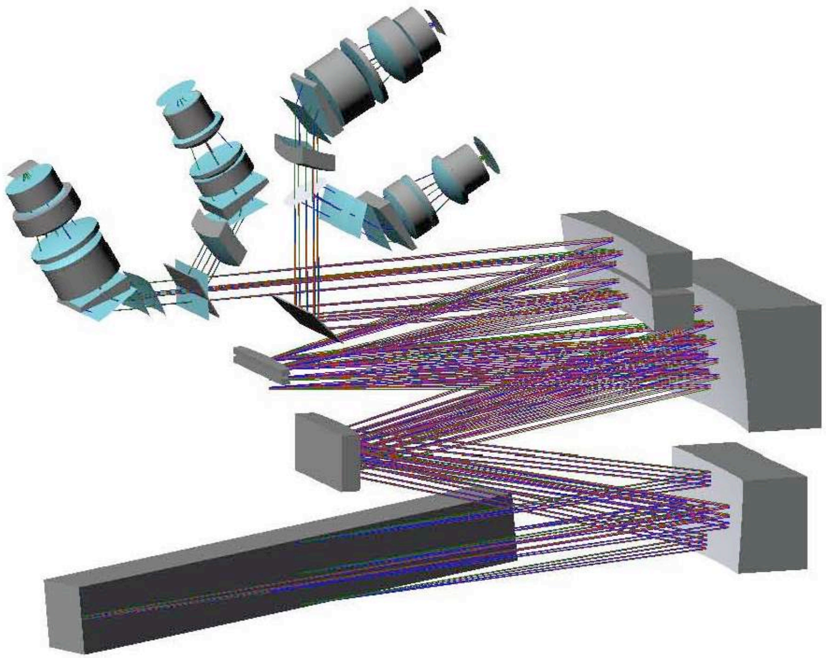
In addition to its own scientific merits **ESPRESSO is the precursor of CODEX**

Similar technical solutions will be adopted

Some critical items will be first used with ESPRESSO

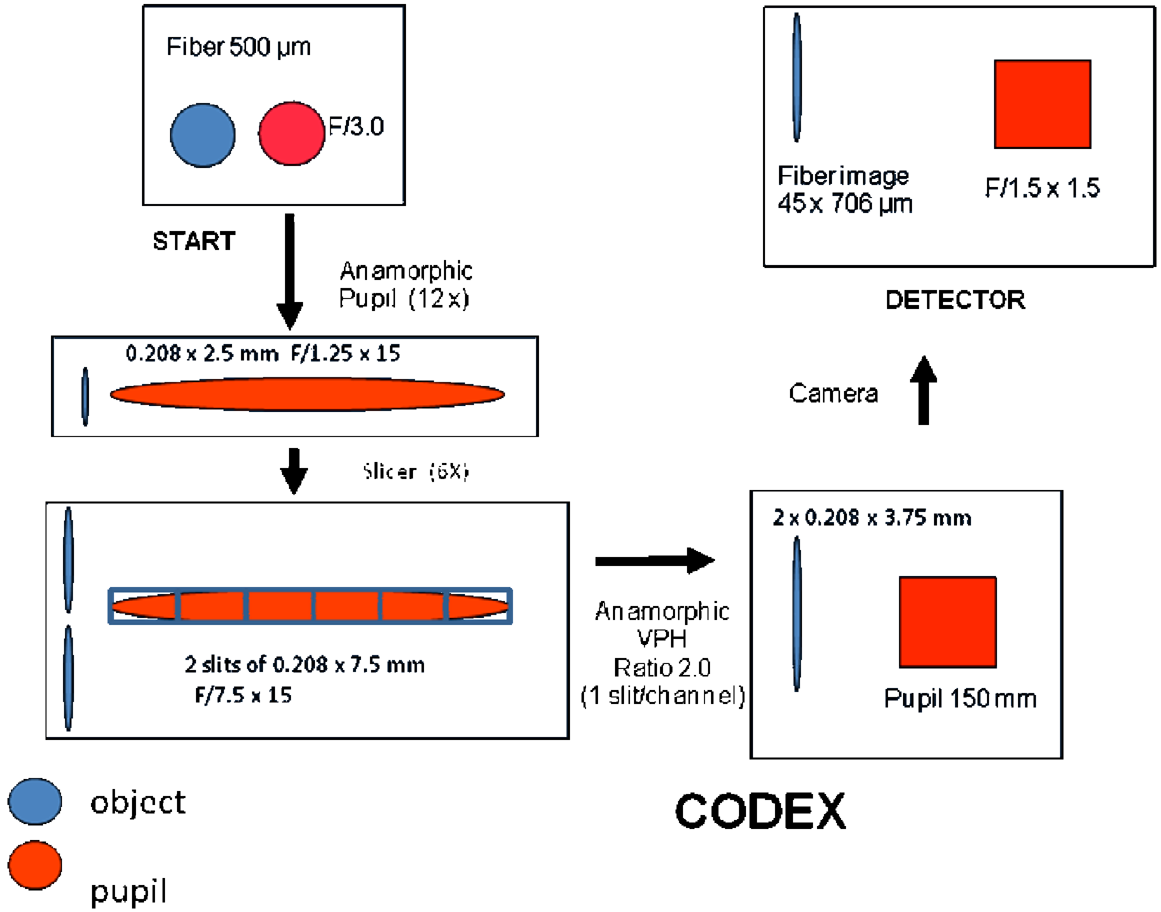
Gain in knowledge with operations: experience shows that optimal results require operations and data analysis to the extreme performance
a RV shift of 2 cm/sec ~ $4*10^{-5}$ pixel, or 6 angstroms in the focal plane

Optical Design



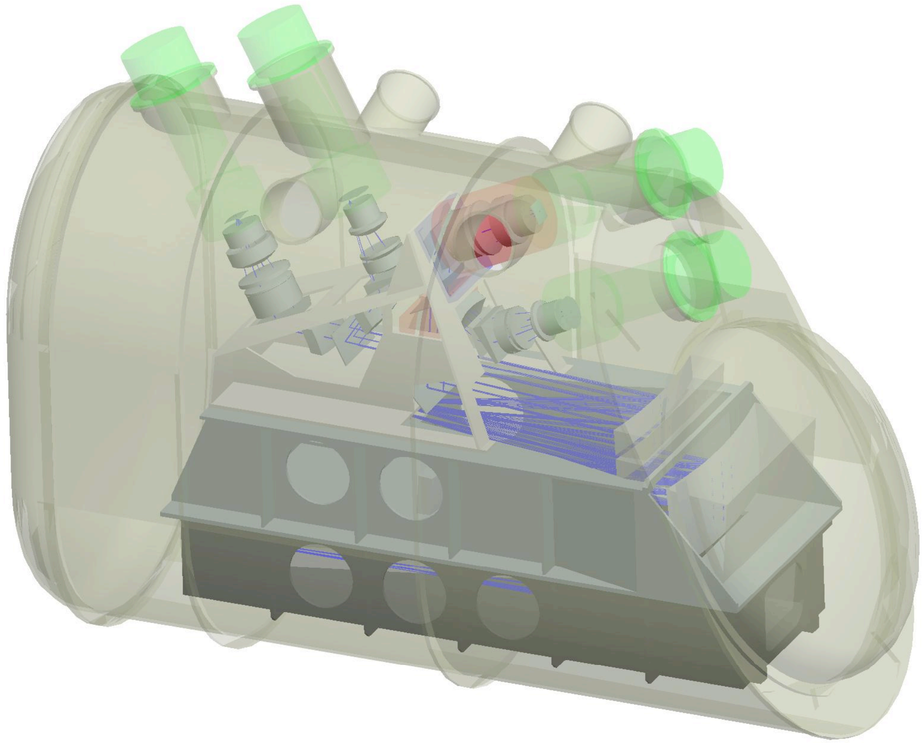
Anamorphism (12X) plus Pupil Slicer (8X) → 1 echelle (1.6x0.2m)
Dychroic → 4 Spectra (2 Red + 2 Blue)
Slanted VPHG compress each of the spectra to 45x706 microns on CCD
Object + sky (or sim cal) recorded simultaneously

Pupil and Image evolution



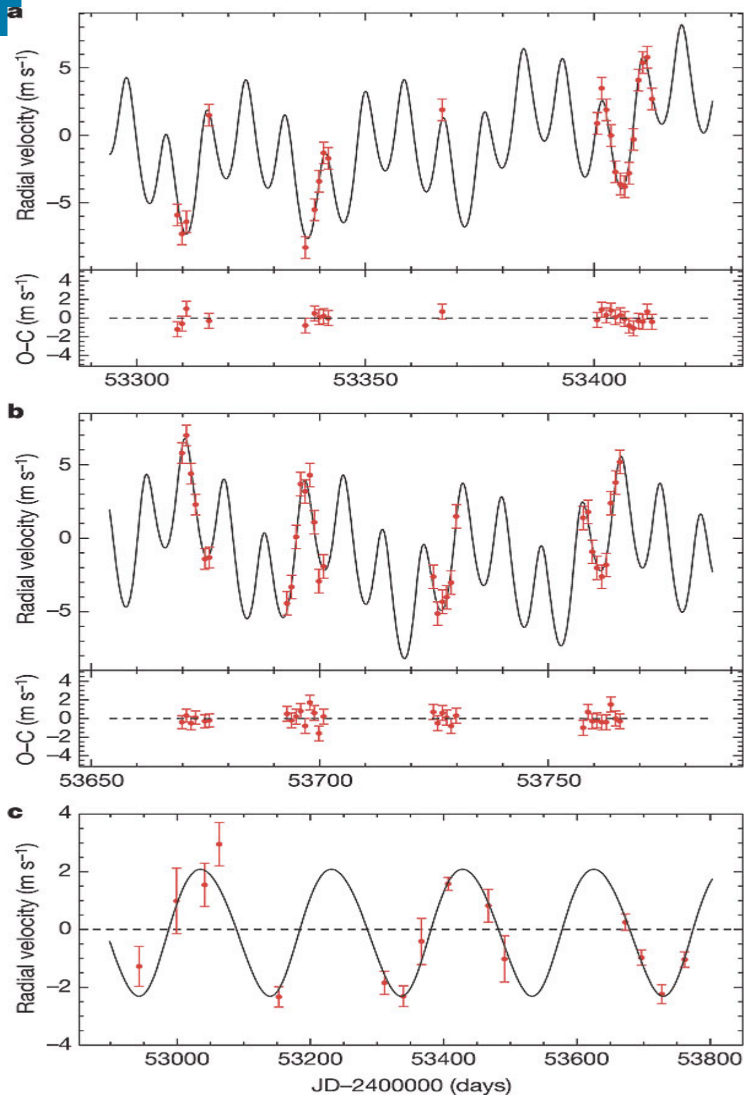
Two spectra (obj + sim cal or sky) recorded simultaneously in each camera (2 blue and 2 red cameras)

Mechanical Concept



CODEX Approximative Dimensions vacuum vessel:
3000x2400x4200 (mm) [height x width x length] , 3 Optical Benches

The HARPS Precision



3 Neptunes

(Lovis et al. 2006, Nature 441, 305)

σ(O-C) ~ 64 cm s^{-1} for the last (500 Days) group of highest precision observations.

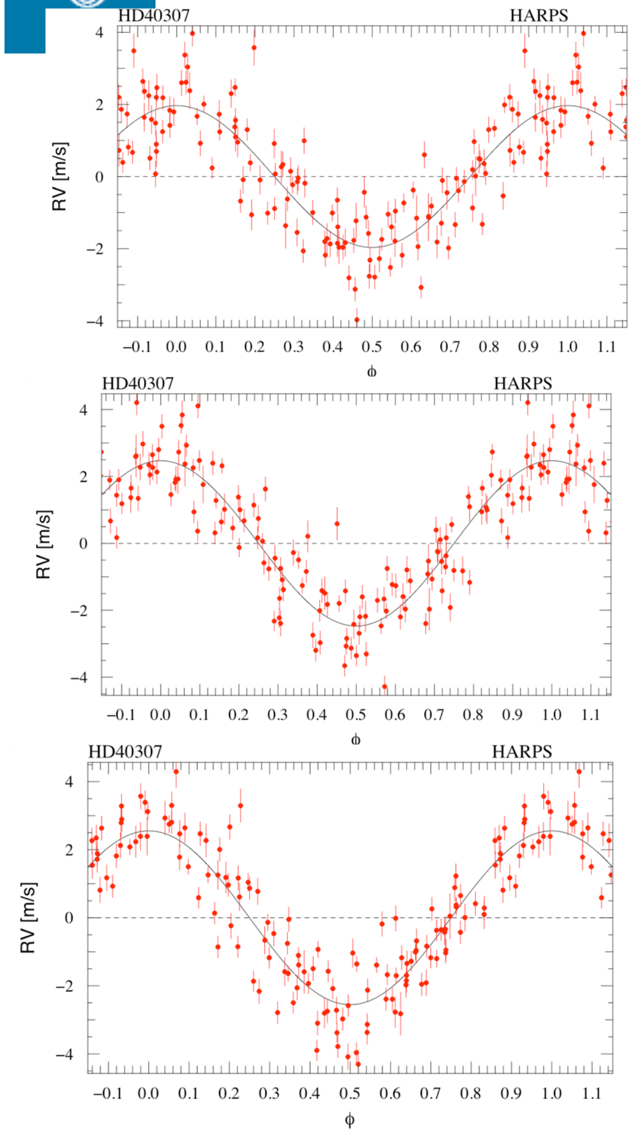
This includes:

Photon Noise

Stellar Noise

'Instrument' Noise

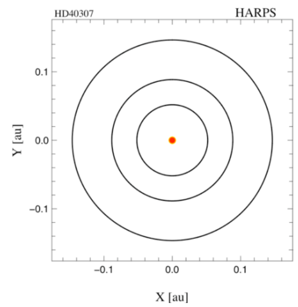
More examples…



m_1 sini = 4.3 $M_\oplus$

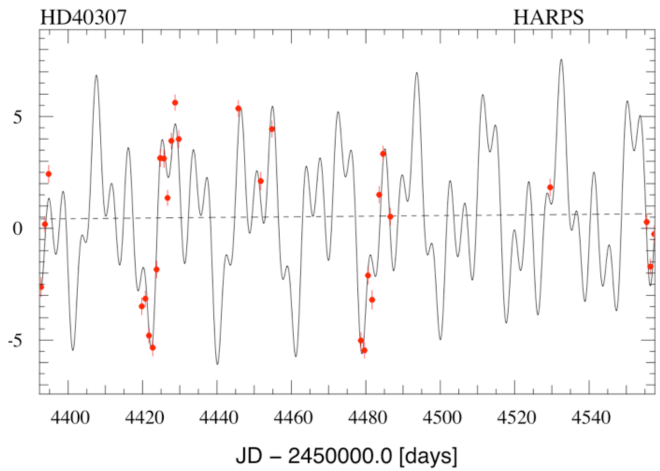
P_2 = 9.62 days
e_2 = 0.03
m_2 sini = 6.9 $M_\oplus$

P_3 = 20.5 days
e_3 = 0.04
m_3 sini = 9.7 $M_\oplus$



HD 40307
K2 V
Dist 12.8 pc
[Fe/H] = -0.31

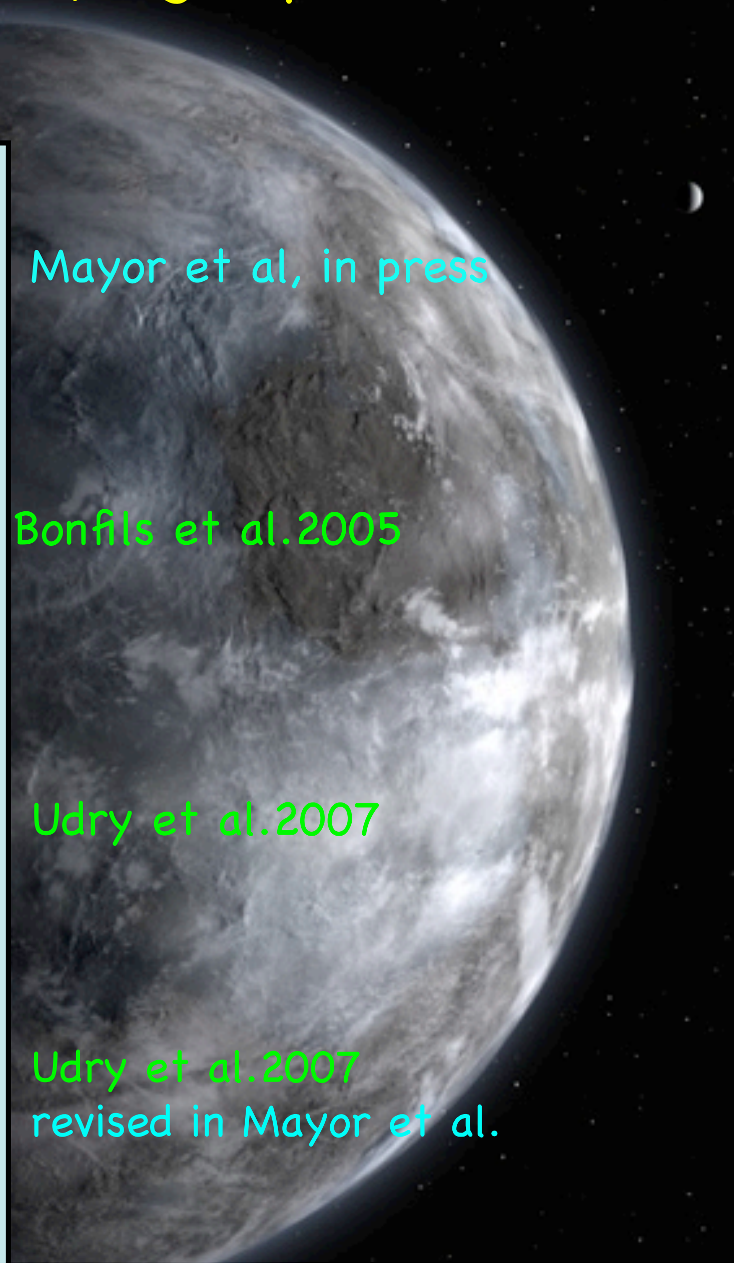
O-C = 0.85 m/s

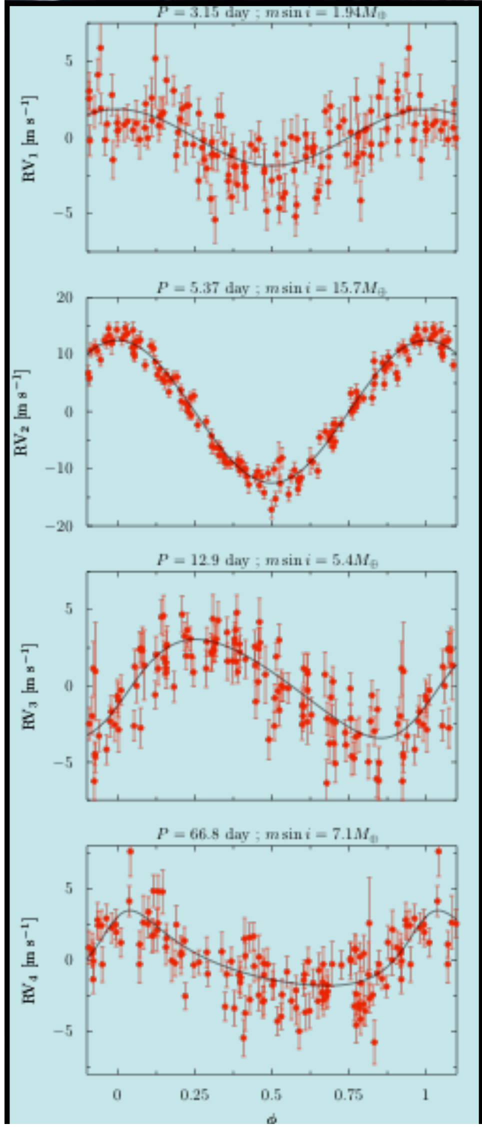


Mayor et al. A&A 493, 639 (2009)

Two super-Earth (5-7 M_{Earth}) in a 4-planet system + a very light planet of 1.94 M_{Earth}

Gl 581,
M3V star





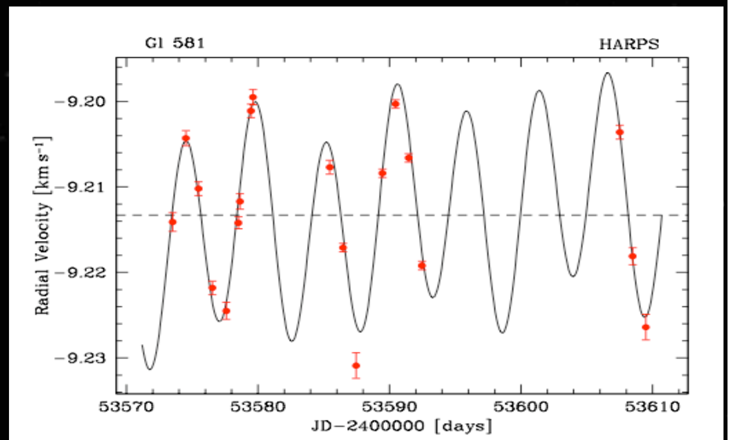
Mayor et al, in press

Bonfils et al.2005

Udry et al.2007

Udry et al.2007
revised in Mayor et al.

P1=3.15d M1=1.94M_{Earth}
P2=5.37d M2=15.7M_{Earth}
P3=12.9 d M3=5.4M_{Earth}
P4= 66.8 d M4= 7.1 M_{Earth}

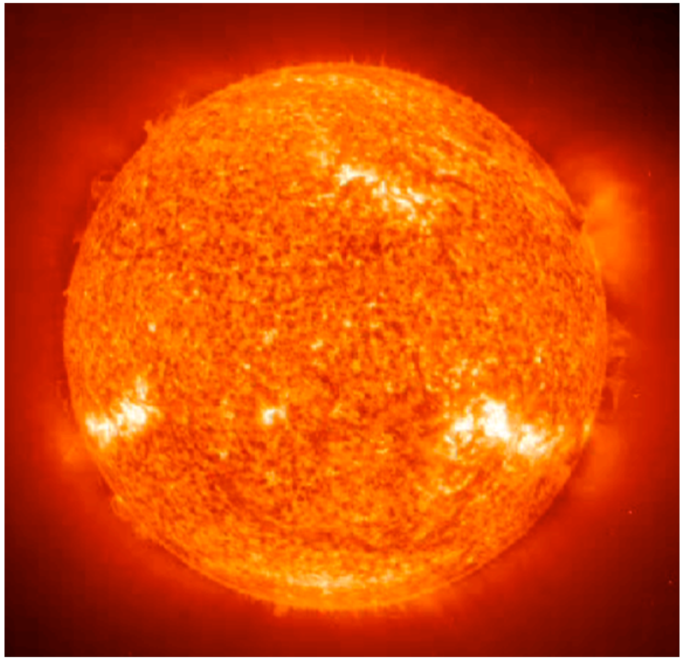


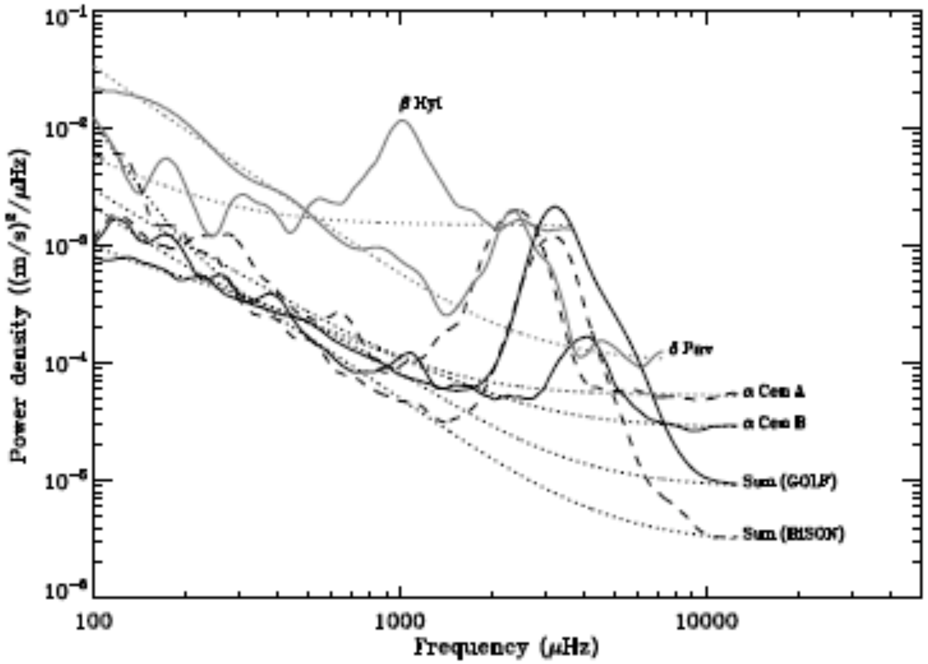
Sources of “Noise”

- **Photon Noise. Rule of thumb: S/N ratio of 5000/pixel for 2 cms^{-1} at R=150000… <u>V~9 at ELT (42 m) in 20 Minutes</u>**
- Intrinsic to the stars
- Instrumental / Observational

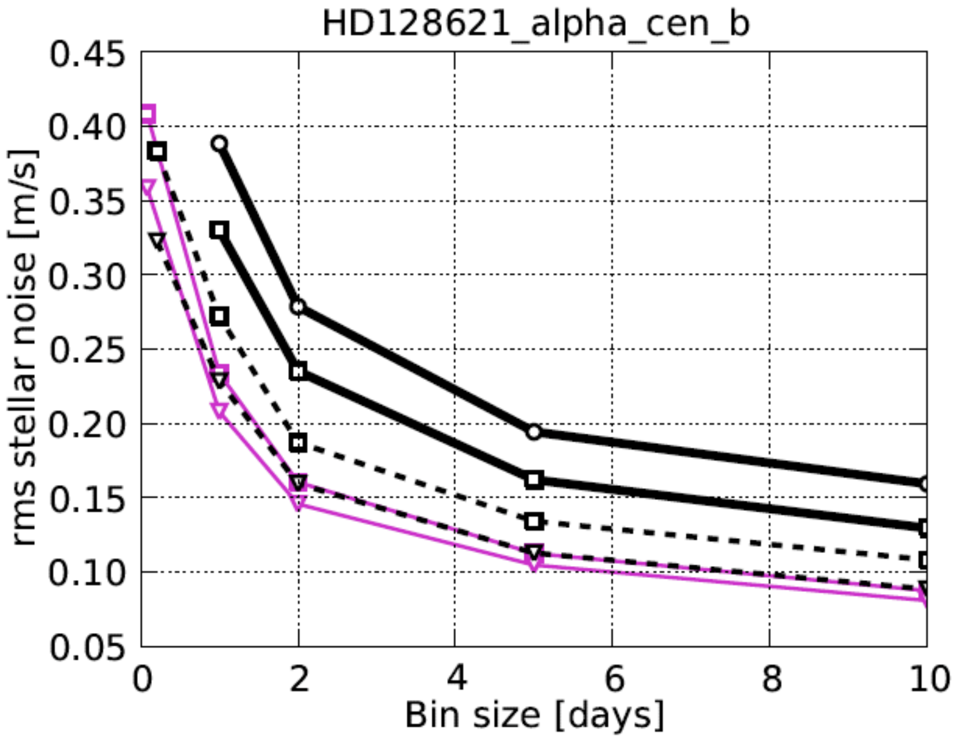
Intrinsic Stellar RV Variability

What is ‘noise’ for RV measurements, is signal for others: Stellar Oscillations, Granulation, Magnetic activity … (see Tinney, Boisse’)





Stellar "Noise"



Stellar Activity Noise

'Oscillations' Noise :

Bin the data

α Cen B simulations based on HARPS measurements (Udry 2009)

HARPS Instrument Noise

HARPS uses a simultaneous reference calibration:

Telescope Guiding ~ 30 cm s^{-1}

Wavelength Reference Stability: Wavelength Calibration

Th-A lamps ~ 30 cm s^{-1}

The above are the two dominant factors

Opto-mechanics Instabilities :

Detector instability (TBD)

Wavelength Reference Precision (TBD)

Plans for precision spectroscopy

HARPS : Guiding system upgrade (ongoing) and LFC as soon
as available (TB approved) : Goal ~ 30 cm/sec
Hopefully in 2011

ESPRESSO at VLT: 10 cm/sec JUST APPROVED (2015)

CODEX @ E-ELT: 2 cm/sec (first generation, TBD if first light)

TBD: CRIRES upgrade: machine for un-surpassed RV in IR:
AO + monomode fibre + LFC