Design Reference Mission

The Design Reference Mission (DRM) is a set of observing programs which together provide a tool to assist with tradeoff decisions in the design of the E-ELT (examples of observing proposals)

=> technical requirements for the E-ELT
=> requirements in term of instrumental need

Detection of Earth twins in HZ of solar-type stars with VR's

=> Need for a high-resolution, ultra-stable spectrograph with precise wavelength calibration: CODEX
=> No special requirements on AO system

REM: CODEX also useful for other planet sciences (characterisation):

- detection of reflected light -> real mass (sin*i*), albedo
- transmission spectroscopy: detection of chemical species in the atmosphere

DRM approach

1. Scientific goal
   - express precise scientific question
   - outline strategy to get the answer
   - induced instrumental requirements
2. Definition of required target sample
   - properties of the targets
   - # of available targets
3. Definition of optimal observing strategy
   - # of needed observations
   - time span of the observations
   - optimal instrumental mode
4. Estimation of the required telescope time
   - per target
   - for the complete sample

(1) Exoplanet: the scientific questions

The continuation of indirect exoplanet detections (RV search) and characterisation with ELT's will lead to unique results in at least three main aspects of exoplanetary science:

1) Discovery of Earth-like planets
(i.e. Earth-mass planets in the Habitable Zone of solar-type stars)

2) Determination of planetary parameters (radius, density) for Earth-mass planets detected by transit searches (CoRoT, Kepler, PLATO).

3) from Jupiter-mass down to Neptune-mass planets around fainter stars (e.g. clusters)

WARNING: If the stellar noise limit (not known yet) is not below the 10 cm/s level, the main improvement from ESPRESSO to CODEX (for RV measurements) resides "only" in the gain in photon noise.

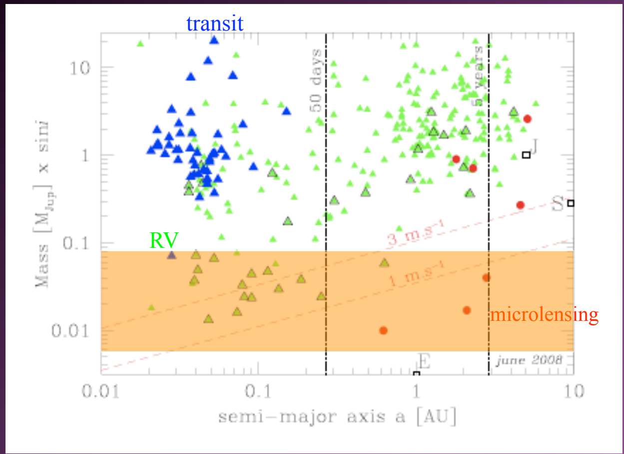
REM: PLATO: bright stars with 8 < V < 11
V=11, Texp=15 min => 10 cm/s with the E-ELT (scaled from HARPS)
(=> importance of the S/N effect)
ETC (0.5 arcsec fiber) => 5 cm/s => optimistic

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}

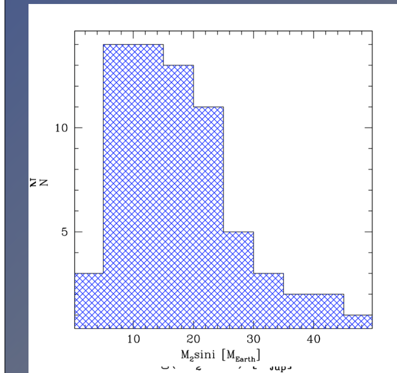
Observations: small mass planets everywhere?



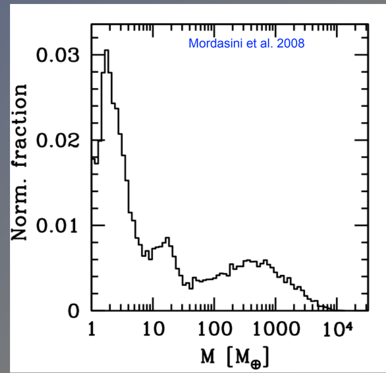
HARPS: An emerging population of super-Earths

1) Mass distribution

Observations



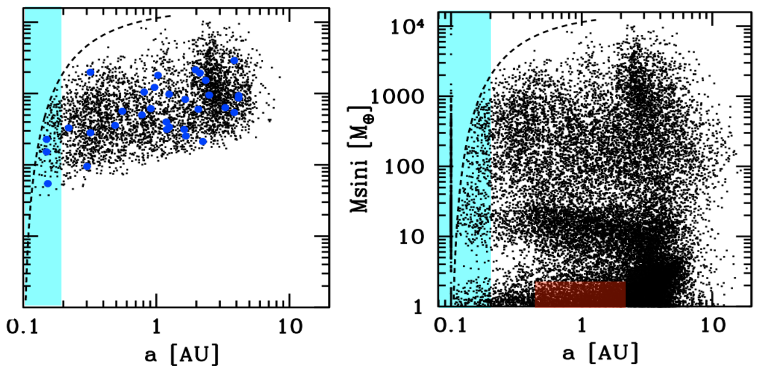
Theory



Monte-Carlo Simulations of planet formation via core accretion

10 m/s

all



Prediction: Many very small mass, solid planets

Many Earths

- Mordasini, Benz, Alibert (2004-2008)
- Ida & Lin (2004-2008)

DRM approach

1. Scientific goal
   - express precise scientific question
   - outline strategy to get the answer
   - induced instrumental requirements
2. Definition of required target sample
   - properties of the targets: main limitations
   - # of available targets
3. Definition of optimal observing strategy
   - # of needed observations
   - time span of the observations
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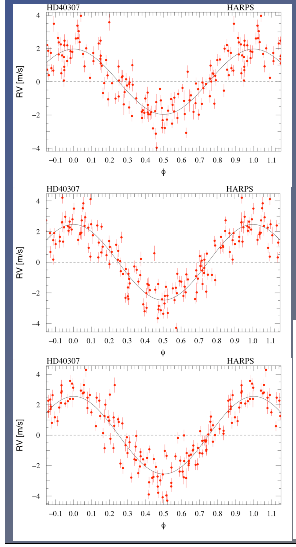
An emerging population of Hot Neptunes and Super-Earths

Mayor et al. A&A in press



P_1 = 4.31 days
e_1 = 0.02
m_1 sini = 4.3 $M_\oplus$

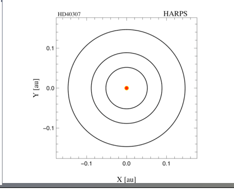
P_2 = 9.62 days
e_2 = 0.03
m_2 sini = 6.9 $M_\oplus$

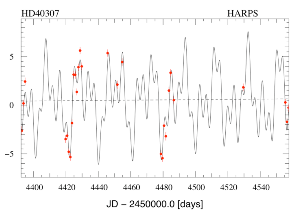
P_3 = 20.5 days
e_3 = 0.04
m_3 sini = 9.7 $M_\oplus$

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

O-C = 0.85 m/s
135 observations

+drift = 0.5 m/s/y

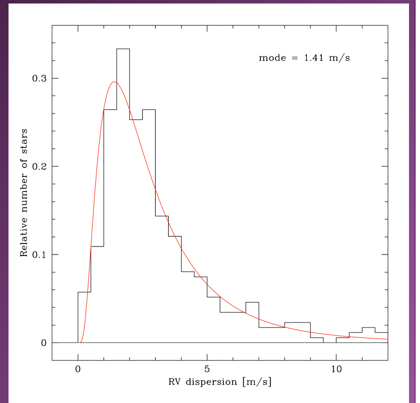




Encouraging results....

At the present limit of the radial-velocity technique

- HARPS high-precision programme: ~400 FGK low-activity dwarfs
- Typical observed dispersion: ~1.5 m s^{-1}
- Résiduals around published orbits: < 1.0 ms^{-1}

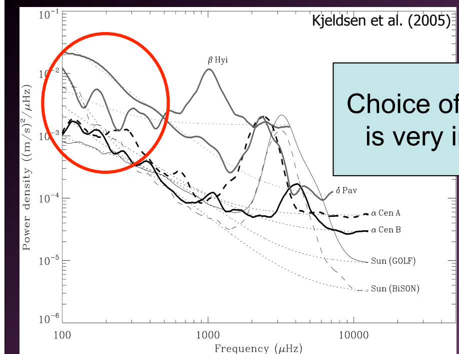


Main cause of variability ?

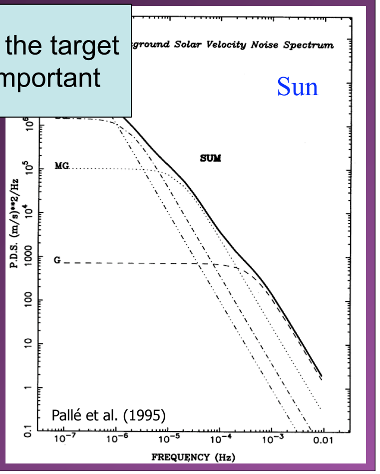
- **Instrumental ?**
- **Stellar (pulsations, granulation, spot…) ?**
- **Population of small planets ?**

Granulation?

- Granulation (τ ~ 6 min)
- Mesogranulation (τ ~ 3h)
- Supergranulation (τ ~ 1 day)
- Active regions (τ ~ 10 days)



Choice of the target is very important



- Other sources of noise at lower frequencies
- Simulations

Stellar activity (preliminary approach)

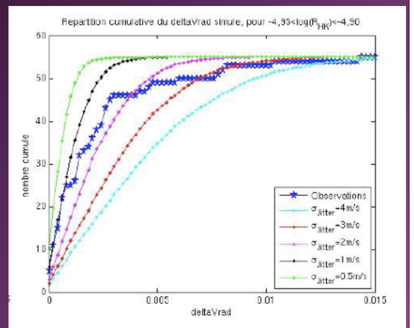
HARPS high-precision sample

Activity indicator: log(R'$_{HK}$)

Model (simulations):
- hyp: statistical effect (gaussian) of typical value (sigma)
- use of actual times of the observations

Effect estimate:
- Compare cumulative function of RV dispersion of models and observations

Warning: all effects still included



==> Lowest activity stars well represented by activity level <= 1 m/s

10-15% of G0-K8 dwarf stars with log(R'$_{HK}$)<-4.9

Need quiet stars
-> lowest activity level?
Enough measurements to statistically beat the jitter

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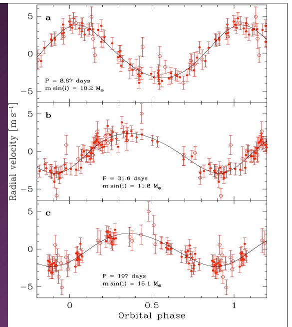
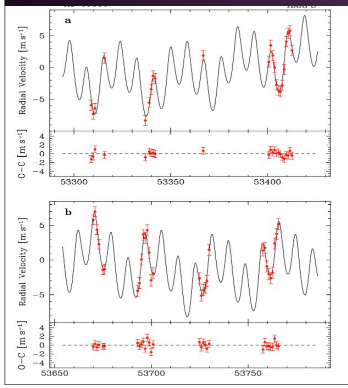
HD 69830: A trio of Neptunes

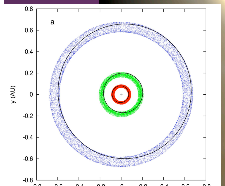
P1 = 8.67 days   a = 0.078 AU   M sini = 10.2 M_{Earth}
P2 = 31.6 days   a = 0.186 AU   M sini = 11.8 M_{Earth}
P3 = 197 days   a = 0.63 AU   M sini = 18.1 M_{Earth}

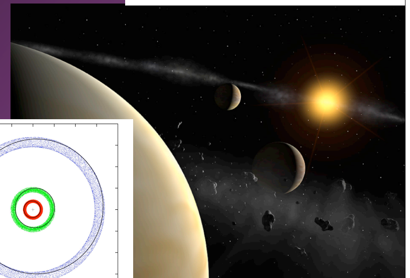
O-C = 0.65 m/s

HARPS@3.6-m telescope, ESO La Silla







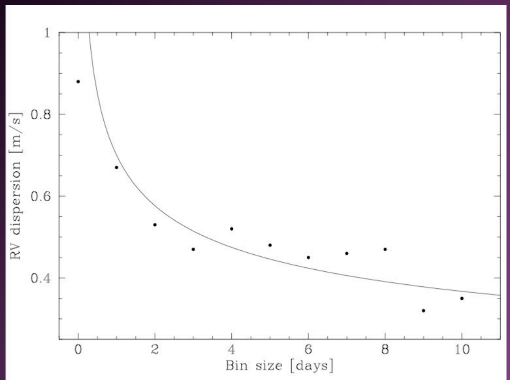


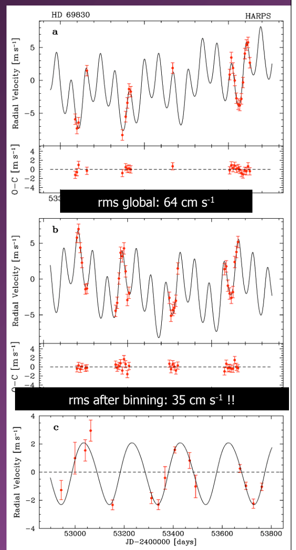
Lovis et al., Nature 2006

HD 69830   >>>>>   0.35 m/s

- On 4 seasons …

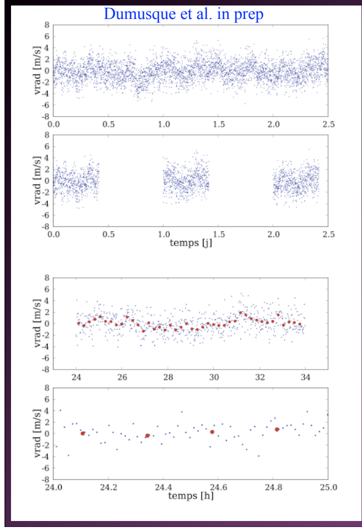
  residuals to the orbital fit
  - Residuals as function of the binning on …. days





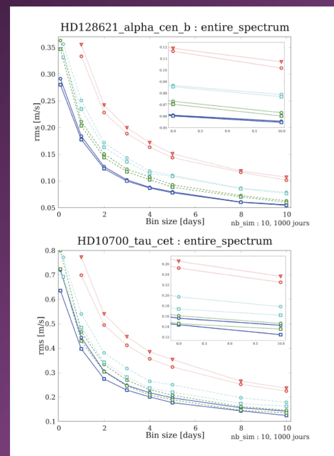
Simulations

- real asteroseismology observations
-> noise model   => synthetic observations



strategy
-> RV rms

Beat the stellar limitations with
- good targe selection
- clever observational strategy

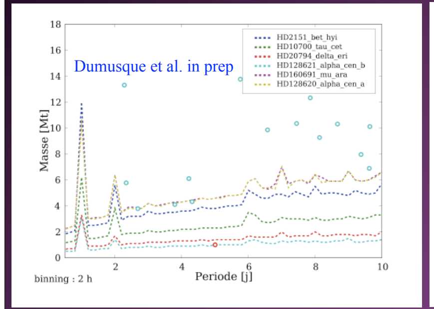


-> detection limits in the mass-period diagram

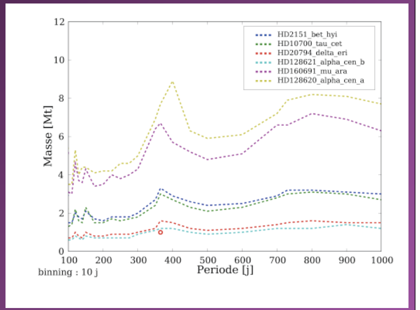
Beat the stellar limitations with
- good targe selection
- clever observational strategy

- Averaging => no period effect!
- Work in progress to introduce activity effect in a better way

Earth at P=5d



Earth at 1 AU => feasible



DRM case for the detection of terrestrial planets in the habitable zone of solar-type stars

1. Target sample
   - non binary, non active stars from existing planet-search surveys (e.g. HARPS)
   - ~ 10% of solar-type stars (from log(R'_HK) measurements)
     => probably only the most quiet part of them
     => at least several 10's (100's) in each hemisphere with V<9.5 (<5 cm/s in 15 min)

2. Observing strategy (see simulation results in science case)
   - 12-15 min on target per measurement
     => to average stellar oscillations and to be at the ~5 cm/s of photon noise
   - 3-4 measures per night (over 3 hours) to average granulation
   - observe the star over several +/- consecutive nights to average activity effects
     Possible strategy: 5 nights over 10 days per month (TBC)
   - follow the star as much as possible along the year: 8 months

3. Required telescope time estimate (scaled from HARPS)
   - per target: 160 measurements of 12-15 min + 5 min overheads (TBC) = 50 h/yr
   - follow the star over 2 years (for confirmation) -> TBC, important for statistics
   - complete sample: 20 stars (statistics OK from HARPS results) => 2000 h
   - programme spread over 5 years => 200h = 20 nights per periods

4. => Large programme

Other possible DRM cases

- Preliminary remark: scaling of precision with photon noise
  - 2 mag fainter (V<=11.5) => 6 times more flux => Texp~1.5h (at 5 cm/s)
  - 20-30 cm/s in 15 min for a V=14 star
- Transit candidates follow-up
  - P and phase known => less observations for same mass limit
  - we do not chose the targets => stellar noise is main limitation
  - simulations to be done
- Reflected light
  - Need S/N>10,000 for reflected light (TBC)
    => > 75 min for a V=6.5 star
    => > ~20 h for a V=9.5 star
- Transmission spectroscopy
  - To be studied