Medium-term perspectives for space interferometry

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Outline

- *Point 1*: What did the current Exoplanets science changed for space interferometry ?

- *Point 2*: What could be a space interferometer within the L2/L3 missions framework ? What is the current maturity level ?

- *Point 3*: What are the synergies with other GA topics and with other mission concepts ?

SI science objectives

- A key driver for SI has been to exploit the high angular resolution feature to:

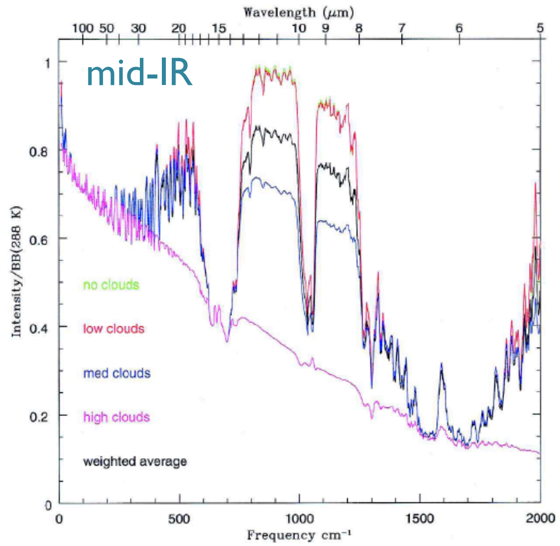
- Characterize spectroscopically habitable planets and/or planetary systems properties → search for bio-signatures and their relation to exo-life

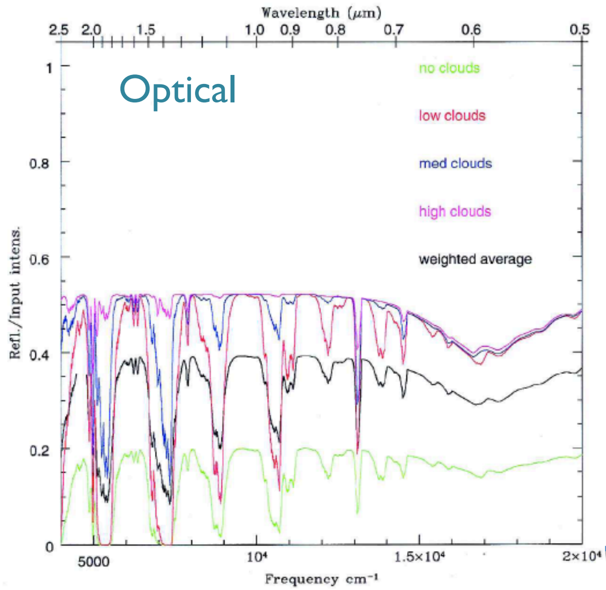
- Produce high resolution spectro-imaging data for General Astrophysics science *(star formation and evolution, AGNs and blackholes, formation and evolution of galaxies)*

SI science objectives

- In the general context of exoplanetology, the goal of an infrared interferometric mission is :

- ➢ Exploit high angular resolution feature to access the HZ of Solar type stars up to a distance of ~20 pc
- ➢ Measure the abundance of molecular features in the infrared (CO_2, O_3, H_2O…) in H-rich or H-poor atmosphere
- ➢ Take advantage of the reduced star/planet contrast in the mid-IR





Des Marais et al. (2002)

The Darwin 2007 proposal

- The Darwin 2007 proposal considered the following:

  - 4x2m telescopes (+ 1hub) in free-flying configuration
  - No prior detections of nearby terrestrial exoplanets → half of the 5-year mission lifetime for detection followed by low-resolution spectroscopy
  - No estimate for η_{earth}, back then assumed to be $\eta_{earth}=1$
  - The abundance of super-Earths (~2-10 M_{earth}, ~1.5-2.5 R_{earth}) was not yet assessed

Diameter	1m	2m
Screened	**76**	**218**
# F	5	14
# G	15	53
# K	20	74
# M	36	77
CO_2, O_3	**17**	**49**
# F	1	2
# G	4	8
# K	3	12
# M	9	27
H_2O	**14**	**24**
# F	0	1
# G	2	4
# K	1	5
# M	11	14

(1) Spectroscopy phase of 2.5 year.
(2) Values for $R_p=1.R_E$. Increases for $R_p>1.0R_E$

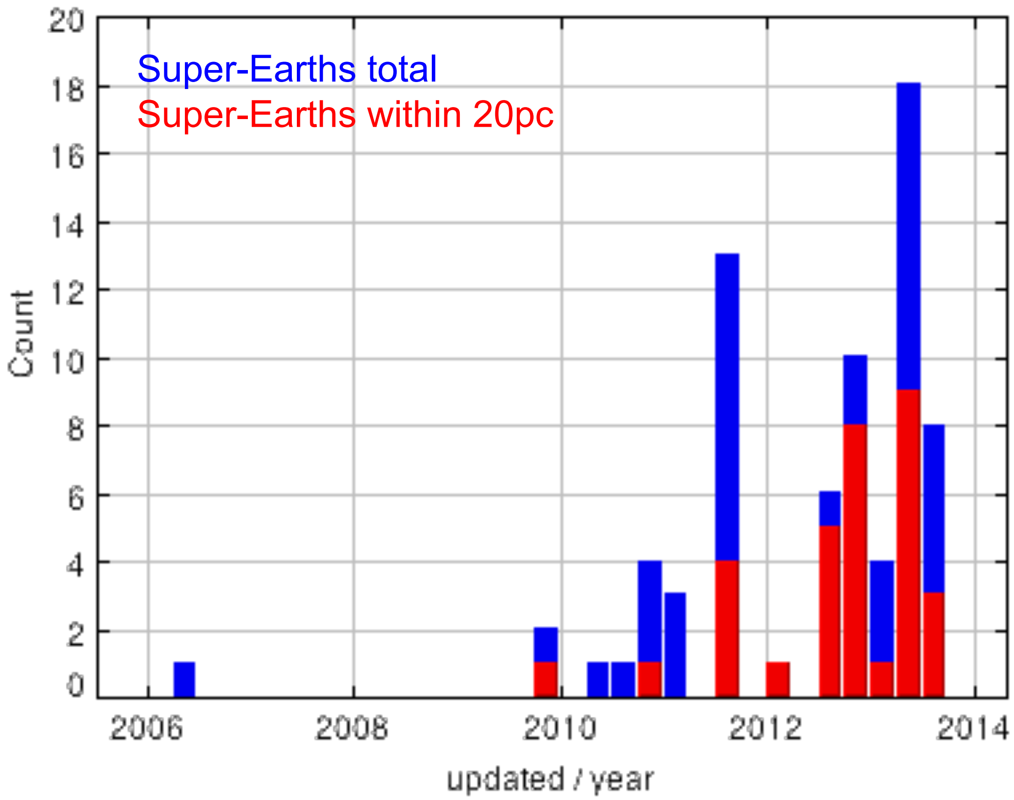
Landscape since 2007

- RV surveys, Kepler and Corot missions revealed a large population of Super-Earths, potential candidates for supporting life.

- Trend towards an increase of small-mass planets in the mass distribution

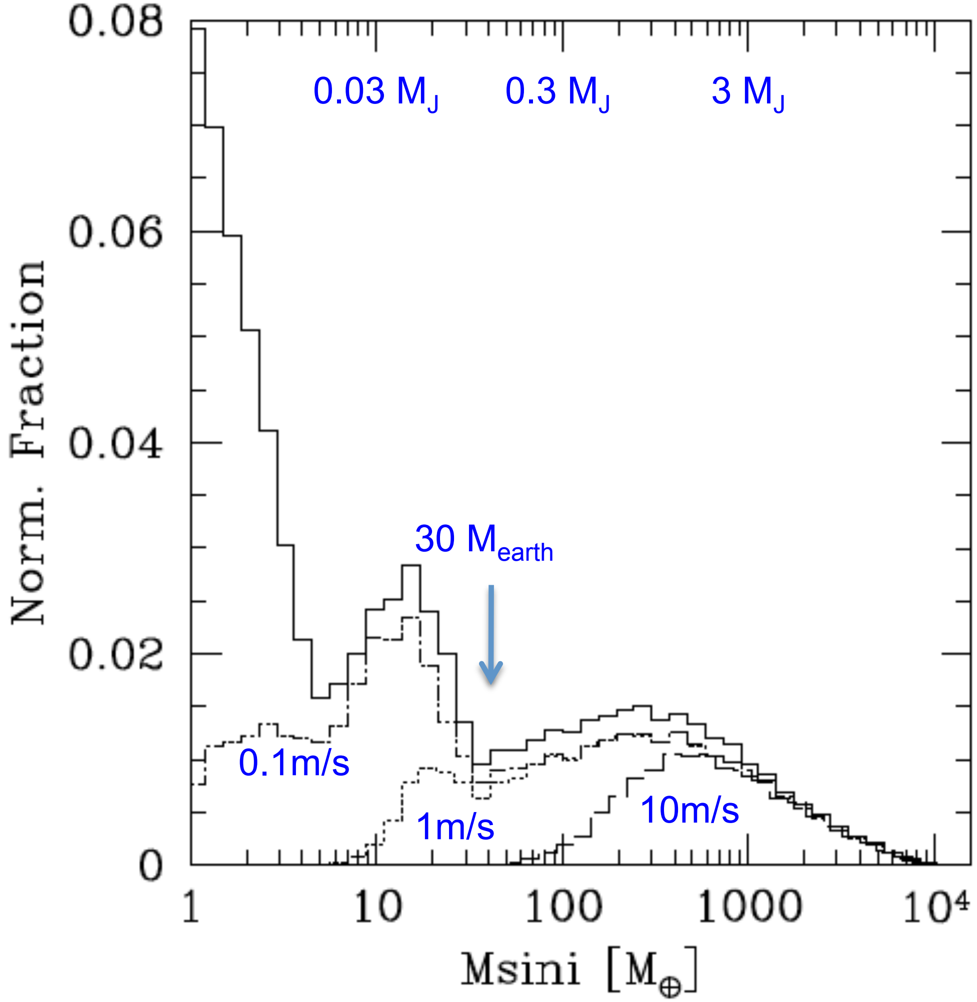
  (e.g. Fressin et al. 2013, ApJ 766, 81 for Kepler;

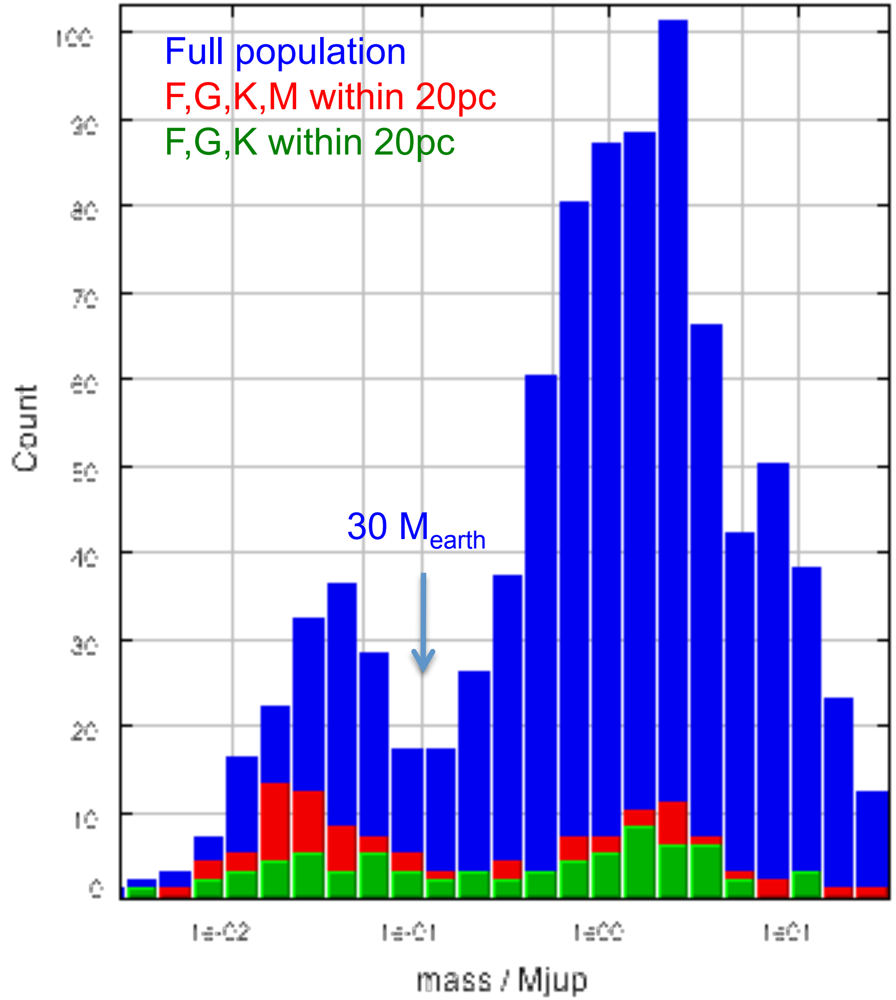
  Mayor et al. 2011, arXiv: 1109.2497 for CORALIE+HARPS);



Landscape since 2007

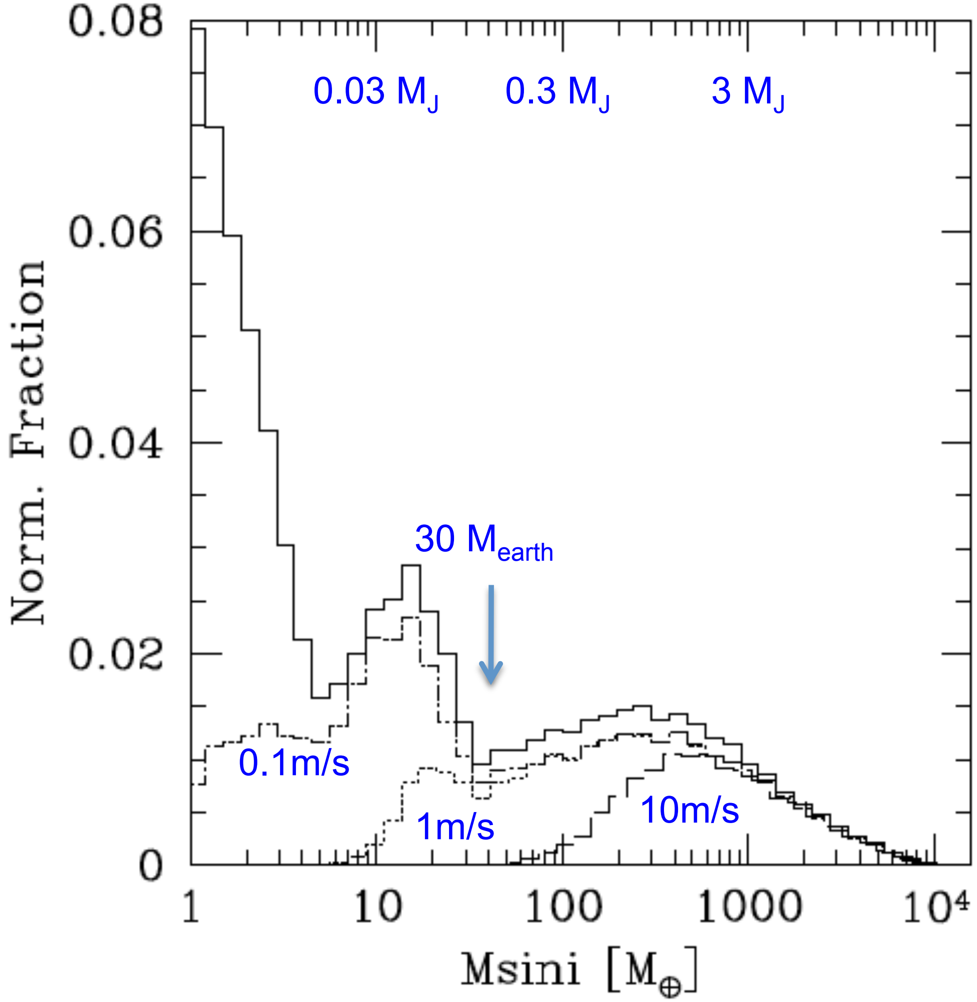
Mordasini et al. (2009)

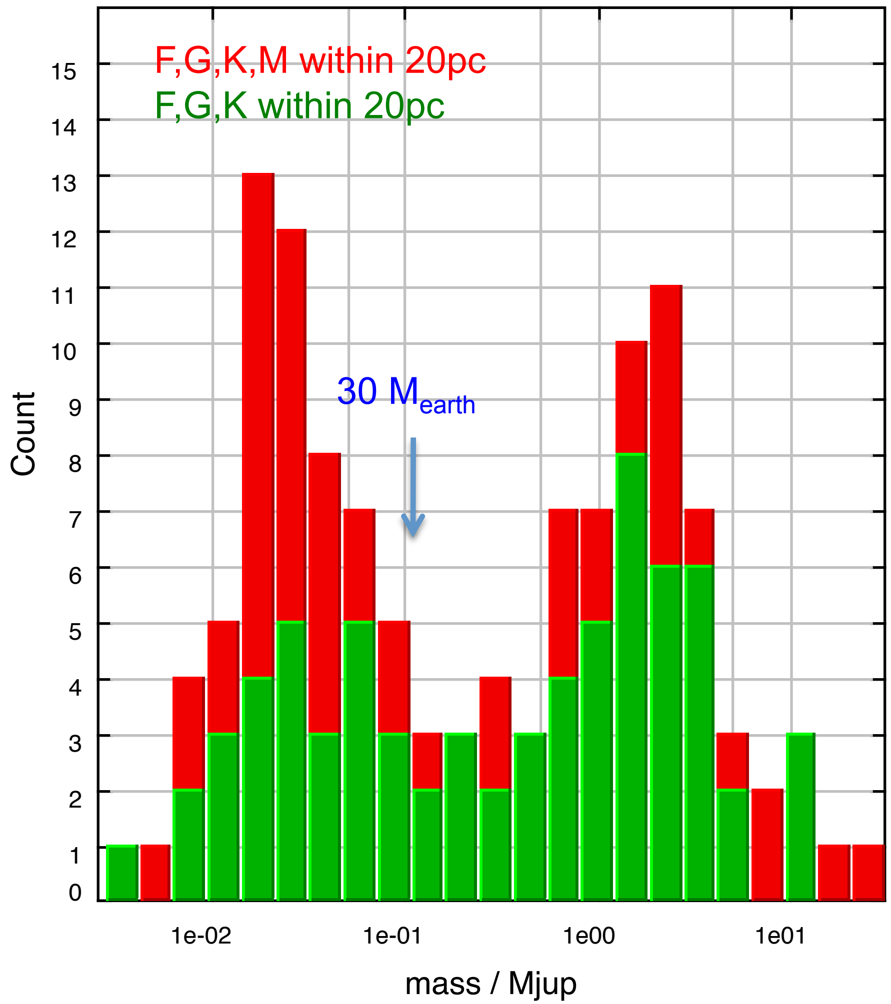




Landscape since 2007

Mordasini et al. (2009)





Occurrence Earths and Super-Earths

- Kepler points out the high frequency of low-mass planets around FGK
- No direct correlation between the stellar mass and planet properties (for FGK)

Average Number of Planets Per Star for Different Period Ranges (in Percent)

Class	Period Range (days)										
	0.8–2.0	0.8–3.4	0.8–5.9	0.8–10	0.8–17	0.8–29	0.8–50	0.8–85	0.8–145	0.8–245	0.8–418
Giants	0.015	0.082	0.25	0.43	0.70	0.93	1.29	2.00	3.24	4.19	5.24
Large Neptunes	0.004	0.010	0.12	0.21	0.50	0.82	1.31	1.97	2.41	2.94	3.18
Small Neptunes	0.035	0.22	0.95	2.88	6.55	11.8	18.3	23.5	27.8	30.9	...
Super-Earths	0.17	0.91	2.40	5.30	9.60	14.1	19.4	23.0	29.6	...	...
Earths	0.18	0.79	2.51	5.21	7.91	10.8	14.9	18.4	...	...	...
Total											

Fressin et al. (2013)

Occurrence Earths and Super-Earths

	FGK	M stars
Earths	$0.23^{+0.16}_{-0.10}$ (1)	
	0.15 ± 0.03 (2)	$0.51^{+0.06}_{-0.05}$ (3)
Super Earths	$0.12^{+0.04}_{-0.03}$ (1)	$0.52^{+0.5}_{-0.16}$ (4)
	0.19 ± 0.02 (2)	

(1) Howard et al. (2010), RV

(2) Fressin et al. (2013), transits

(3) Dressing et al. (2013), transist

(4) Bonfils et al. (2013), RV

- Occurrence of small planets around M stars seems to be higher than around FGK stars

Habitable Zone

- The assumption of η_{earth}=1 is too simplistic
- It is a difficult number to constraint due to the incompleteness of the Kepler survey
- Difficult to differentiate M and FGK in terms of η_{earth}

	FGK	FGKM	M dwarfs
Traub (2012, ApJ 745, 20)[1]	$0.34^{+0.14}_{-0.14}$ (P < 42d)		
Kopparapu (2013, ApJ 767, L8)[2]			$0.48^{+0.12}_{-0.24}$ (P < 50d)
Gaidos (2013, ApJ 770, 90)[3]		$0.46^{+0.09}_{-0.07}$	
Bonfils (2013, A&A 549, A109)[4]			$0.41^{+0.54}_{-0.13}$
Dressing (2013, ApJ 767, 95)[5]			$0.15^{+0.13}_{-0.06}$ (P < 50d)

(1) R_p=0.5-2R_E / (2) R_p=0.5-1.4R_E / (3) R_p=0.8-2R_E / (4) Msin(i)=1-10M_E / (5) R_p=0.5-1.4R_E

Mid-talk message

Kepler's compares frequencies for all class of planets (Giants down to Earths), although biased towards short periods

→ Trend for a high-frequency of low-mass planets (Earth/SuperEarths) around F,G,K,M stars

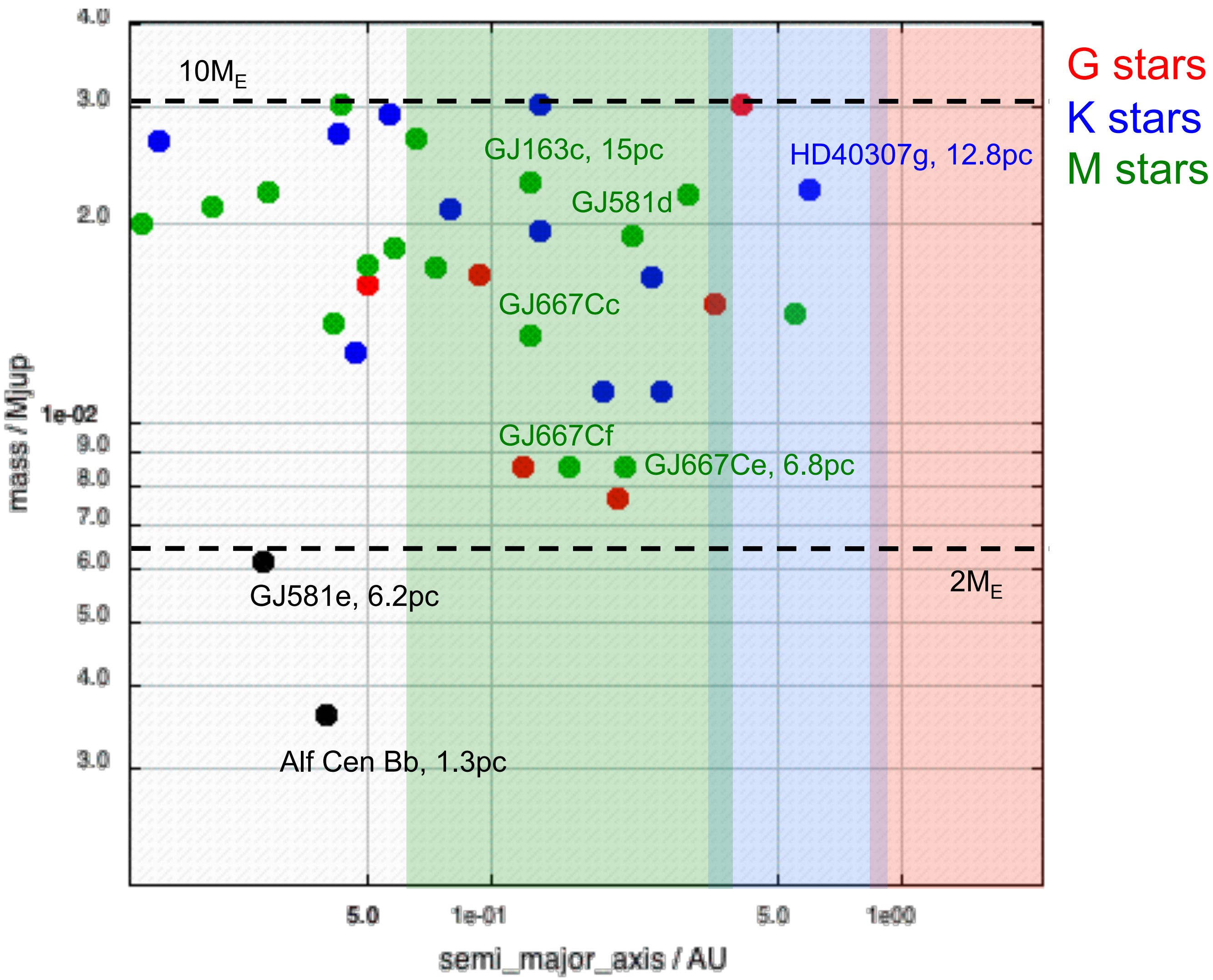
Mid-talk message

- For the population of Earths/SuperEarths in the HZ, more realistic estimate for η_{earth} can now be considered.
  - η_{earth}~20%-30% for FGK stars, but significant incompleteness (lower values are possible)
    - We still need to detect such planets down to $1M_{earth}$ the solar neighborhood (RV surveys may be limited by high stellar activity)

Mid-talk message

- For the population of Earths/SuperEarths in the HZ, more realistic estimate for η_{earth} can now be considered.
  - More secure η_{earth}~40%-50% for M stars makes them good candidates for habitability searches.
    - Present and future search for Earths in the HZ down to $1 M_E$ (e.g. CARMENES, ESPRESSO)
    - Transiting Super-Earths in the HZ may be characterized by EChO
    - However, conditions for habitability for M dwarfs (tidal lock, flares, high-level of UV and X-ray…) are debated

Snapshot view within 20pc

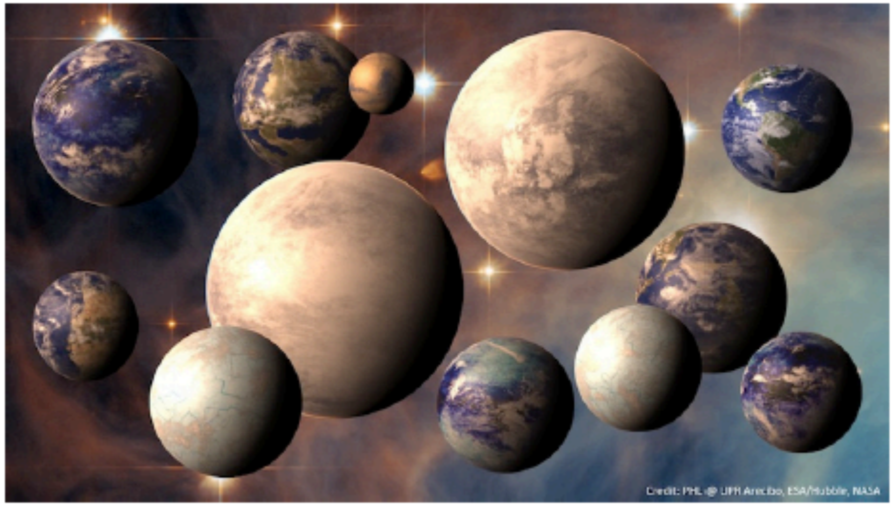


L2/L3 Cosmic Vision Call

- Define the science themes associated to the next ESA large missions, L2 (launch in 2028) and L3 (launch in 2034)
- One proposal submitted by the Exoplanet community, with focus on spectroscopic characterization and habitability quest

Exploring Habitable Worlds beyond our Solar System

White paper submitted in response to ESA's call for science themes for the L2/L3 missions of its Cosmic Vision program



Coordinator / spokesperson: Andreas Quirrenbach

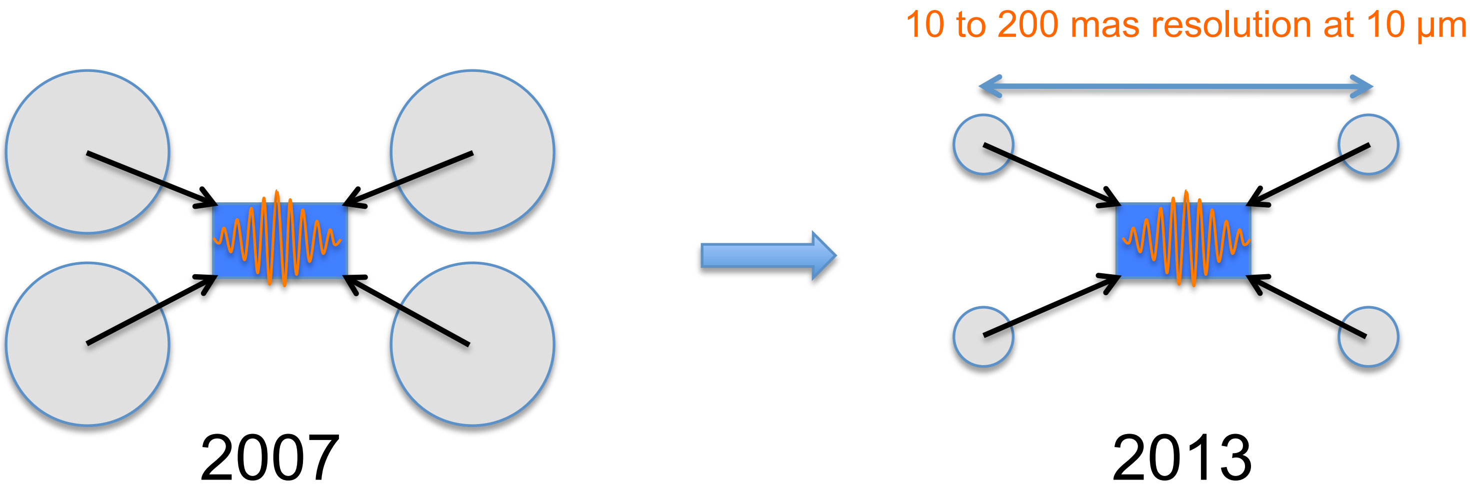
- Characterize known nearby exoplanets
- "*Habitability and ultimately E.-T. life in the wider context of comparative planetology*"
- Aiming at the L3 slot (2034)
- Basically two strawman concepts:

- 2.5m telescope in the visible+corono
- 4x0.75m free-flying interferometer in the mid-IR

Space interferometry at OHP conference

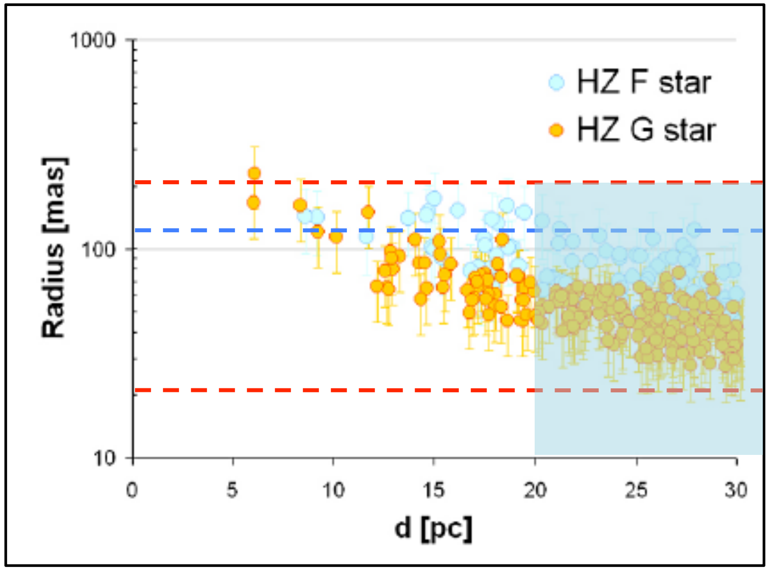
- Major change with respect to DARWIN 2007

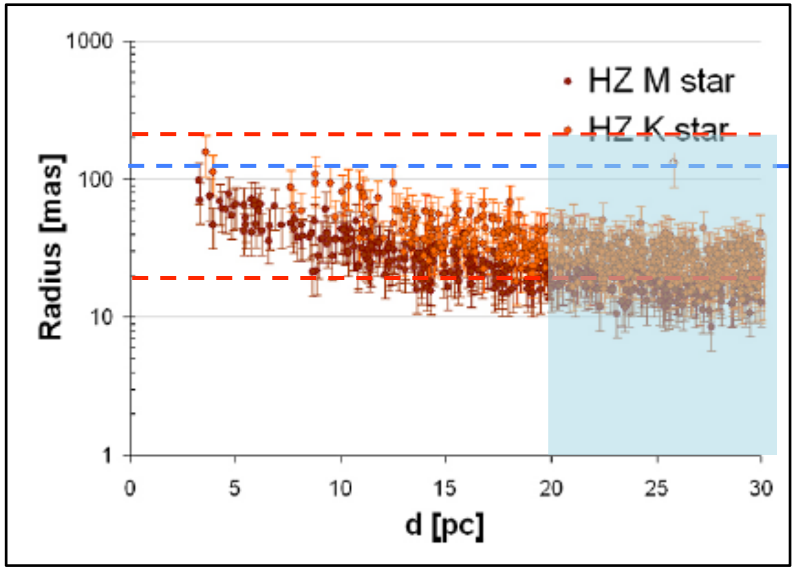
  2m → 0.75m telescopes



- Cost goes ∝ D^3, hence cost/size substantially reduced

Accessing the HZ





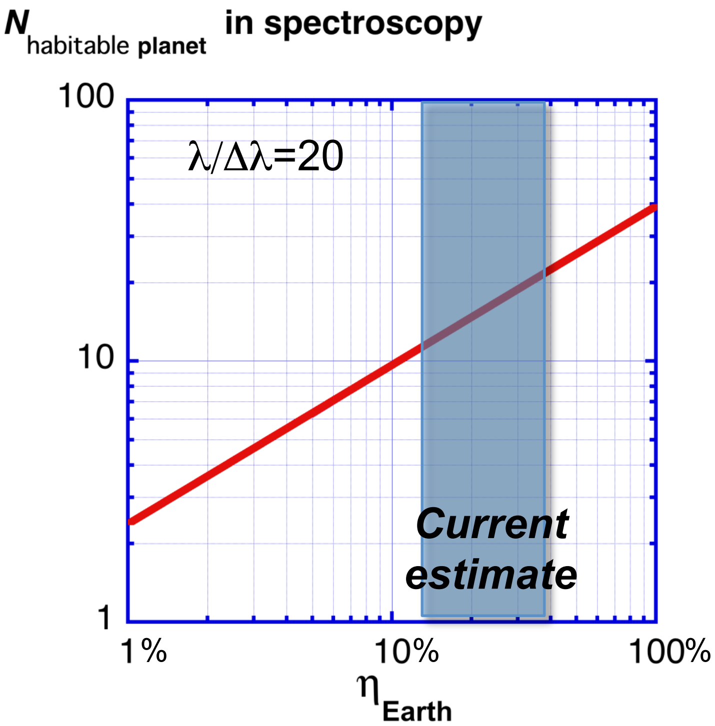
Kaltenegger et al. (2013)

---- Coronograph detection limit for D=2.5m, λ=700nm (O_2 line), IWA=2λ/D

---- Interferometer detection limits for B=5-50m, λ=10μm

Impact of the value of η_{earth}

- The value of η_{earth} will strongly impact the maximum distance for spectral characterization, and thus the total number of doable targets



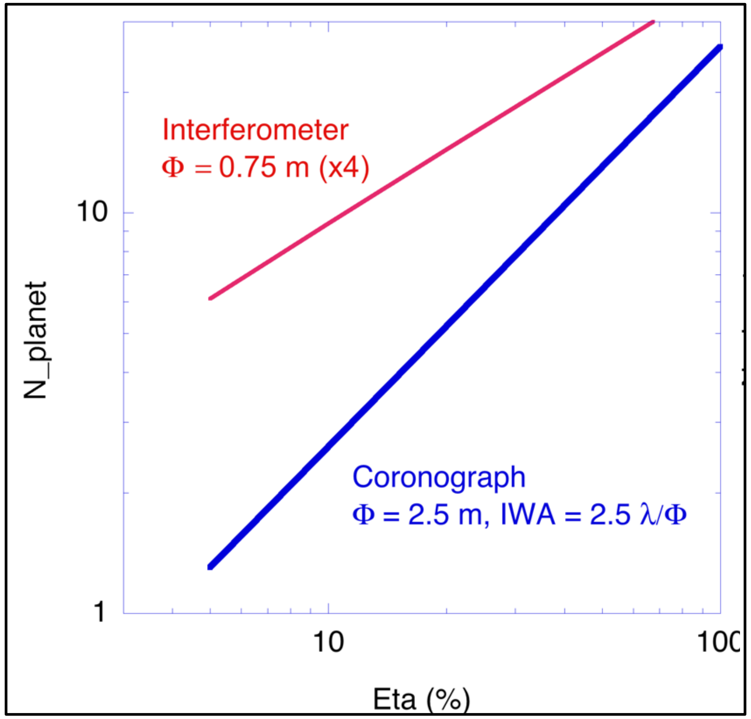
A. Leger (priv. comm.)

– *Super-earths* considered with R_p = 1.5 R_{Earth}
– Prior detection
– 5-year baseline for spectroscopy (instead of 3)
– 4x0.75m mirrors
– R=20 for O_3

A 4x0.75-m can characterize ~10 (η_{earth}=10%) to ~25 (η_{earth}=50%) 1.5R_E planets within 20pc, in 5 years, with R=20

Interferometry vs Coronography

- The value of η_{earth} will strongly impact the maximum distance for spectral characterization, and thus the total number of doable targets



A. Leger (priv. comm.)

Technology readiness

- Except for the technology of Formation Flying, technology development studies for space interferometer in Europe have been paused after ~2009
- In the US, those efforts have been pursued further (PDT bench)

Critical Technology	Readiness level	Comment
Broadband Starlight Suppression	TRL4	suppression of 10^{-8} (10mu,BW=10%)(1)
mid-IR spatial filtering	TRL4	TRL5 after cryotesting
Adaptive Nulling	TRL4	nulling at $8x10^{-6}$ (10mu,BW=10%)(1)
Optical Delay Lines	TRL6	TNO demonstrator
Cryocoolers	TRL6	
Thermal shield	TRL6	
Detectors	TRL6	
Precision FF	TRL8/9 with PRISMA and PROBA-3	

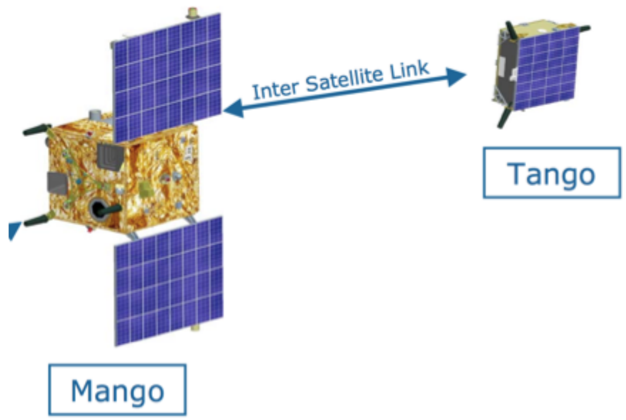
Adapted from Liseau (2010). (1) Martin et al. (2010, 2012)

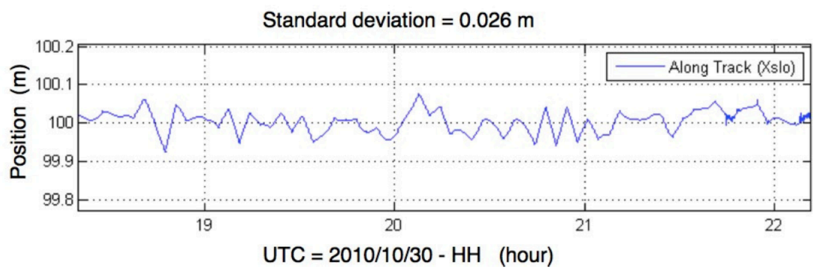
FORMATION FLYING

The PRISMA experiment (Swedish Corp., CNES, DLR)

- Orbits range for 10m to few km
- Small (150 kg) and microsatellite (40 kg)
- Tests to maintain stable relative positioning
    - Accuracy of few cm has been achieved
    - Limited by the RF sensors and ISL
- **Demonstration of the "Optical Arm" building block**

  → No higher complexity in terms of procedure from 1 to 4 O.A.





Next step: ESA's PROBA 3 project (launch 2017)

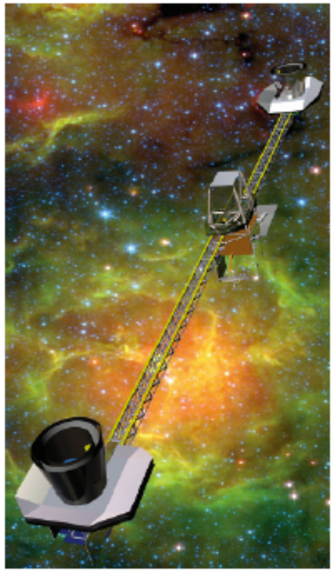
- Goal is to develop laser-based sensors to maintain ~100 μm positioning accuracy

Space interferometry beyond exoplanets

- Infrared space Interferometry is not limited to exoplanets characterization.
- Already in 2007, an imaging channel has been defined
  - Requires aperture synthesis by rotation of the array (but might be a difficult task in terms of FF operation)
  - From 2007 estimates, we derive 0.25μJy, 0.7μJy, 1.3μJy and 2.1μJy point-source sensitivityin 1h and 5σ.
  - Large program for General Astrophysics
- Other missions have considered the interferometric approach in space within the L2/L3 call, like e.g.
  - FIRIT and ESPRIT for the Far-IR range (SP M. Sauvage)
  - The Planetary Science Infrared Observatory (SP L. Fletcher)

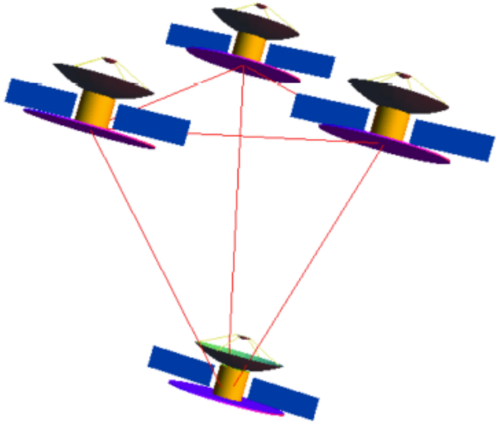
Space interferometry beyond exoplanets

from FIRIT L2/L3 proposal



FIRIT, a direct detection imaging interferometer

- 25 – 400 μm, Michelson-type interferometer
- Extendable baseline up to 36m
- Two 1-m telescopes movables on boom for aperture synthesis, optics cooled at T<5K



From ESPRIT L2/L3 proposal

ESPRIT, a heterodyne interferometer for the FIR

- 4x3.5-m dishes in free-flying configuration
- Baselines >50m
- Lower constraints on temperature: passive cooling of the dishes is OK

Take-home message (1)

- Super-Earths appear to be frequent. Models suggest they may possess atmospheres suitable for habitability quest. Since they are larger than Earths they are easier to detect/characterize
- If S-Earths are frequent, Earth-mass ones might be even more (Howard et al. 2010). However, they need to be detected in the solar neighborhood in particular around G,K stars
- Infrared stellar interferometry is ideally equipped to probe the HZ within 20pc. Hence, even in case of low η_{earth}, the number of accessible targets remains acceptably high
- A 4x0.75-m ISI is within the L-class budget (i.e. <1B€).It could characterize ~10 (η_{earth}=10%) to ~25 (η_{earth}=50%) 1.5R_E planets within 20pc, in 5 years, with R=20

Take-home message (2)

- Key technology like Formation-Flying has made a significant step forward since 2009 with PRISMA. PROBA-3 mission will improve on the positioning accuracy
- Other mission concepts are based on the infrared interferometric approach. Many required technology developments are in common to those missions (OPD, Cryogeny, FF). Next-to-come EC Program Horizon2020 should offer funding opportunities in this field (http://ec.europa.eu/enterprise/policies/space/research/, Madrid Workshop)
- Outcome of L2/L3 selection process should be known by November 2013. The Exoplanets theme is an excellent one, but competition is very strong. If selected, only a joint effort can face the challenge