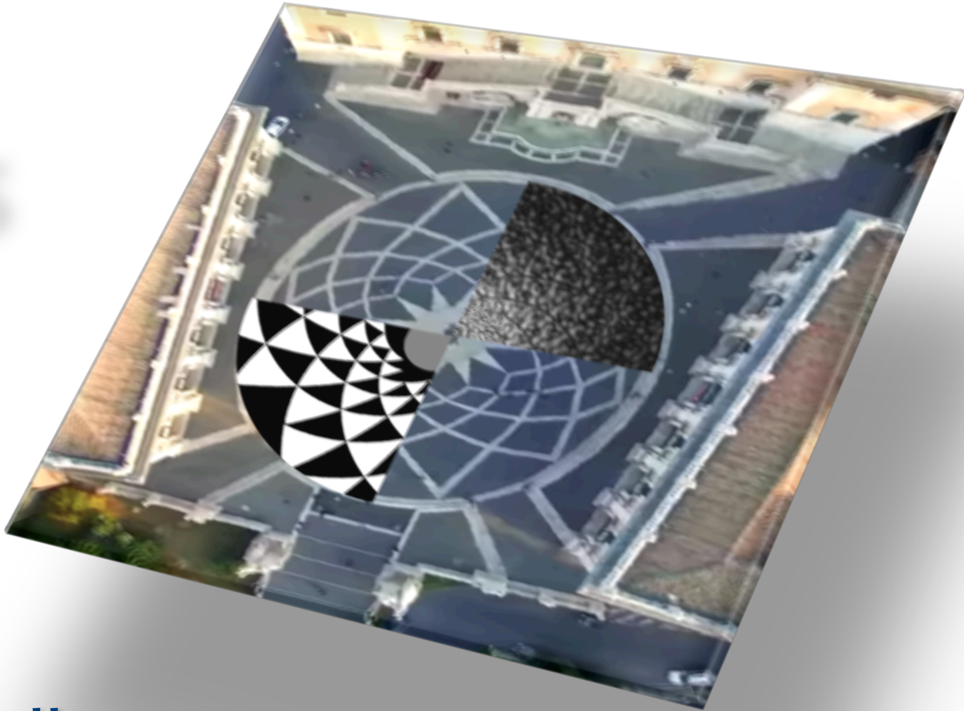
FINDING EARTH TWINS WITHIN 10PC

ROME, 19-10 NOVEMBER 2018

Exoplanets in Italy



@exoplanetsit

Isabella Pagano

INAF - Catania Astrophysical Observatory

BREAKTHROUGH INITIATIVES

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FRONTIERA

Where in Italy

What

NOW ⟷ **FUTURE**

Harps-N

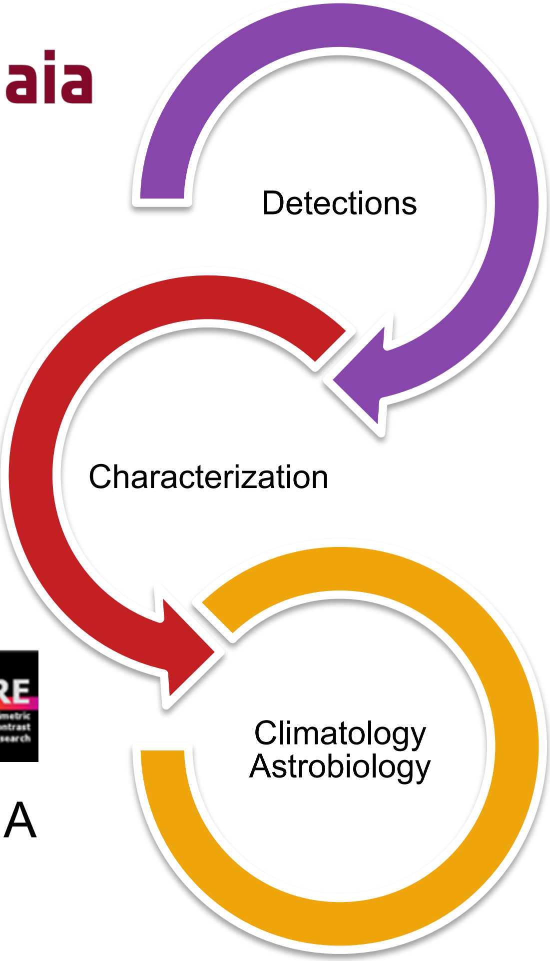
GIARPS

APACHE

EXORAP

espresso

gaia



ALMA
VLA

cheops

plato

ARIEL

ELT (e.g, HIRES)
SKA

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High-res spectroscopy programs

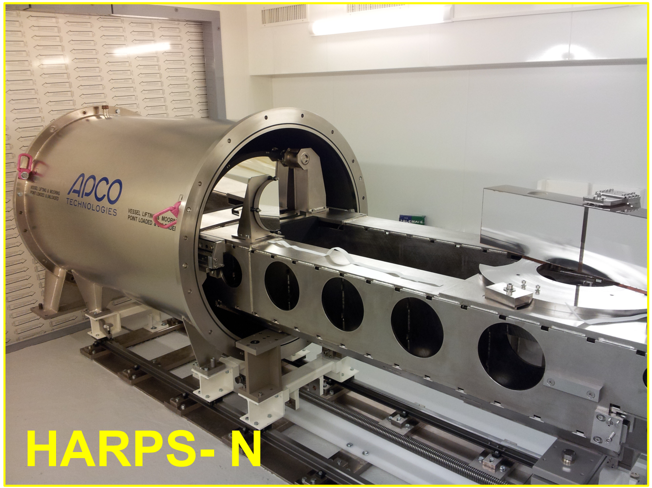
- **GAPS** (HARPS-N and GIARPS @TNG)
  - The diversity of architectures of planetary systems **Done**
    - HARPS-N 380 nights – 2012-2017
  - The origin of the exoplanetary diversity
    - GIARPS (HARPS-N & GIANO)

28 nights – 2017-2018
34 nights x 10 semesters – since March 2018

- **HARPS-N GTO**
  - Follow up of Kepler & Tess targets
  - Search for low mass planets.

40 nights x semester

Telescopio Nazionale Galileo
Canarian Islands



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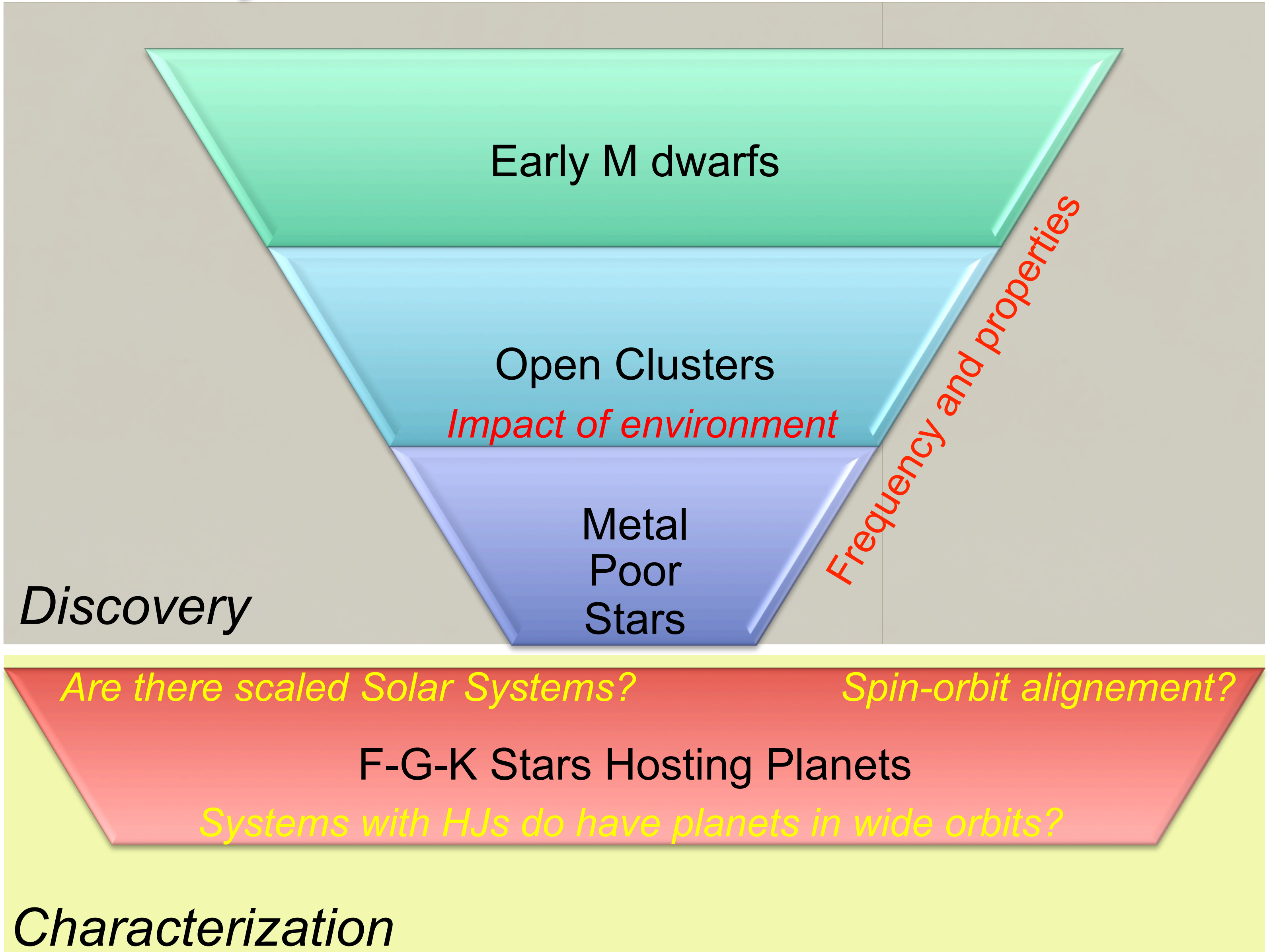
GAPS

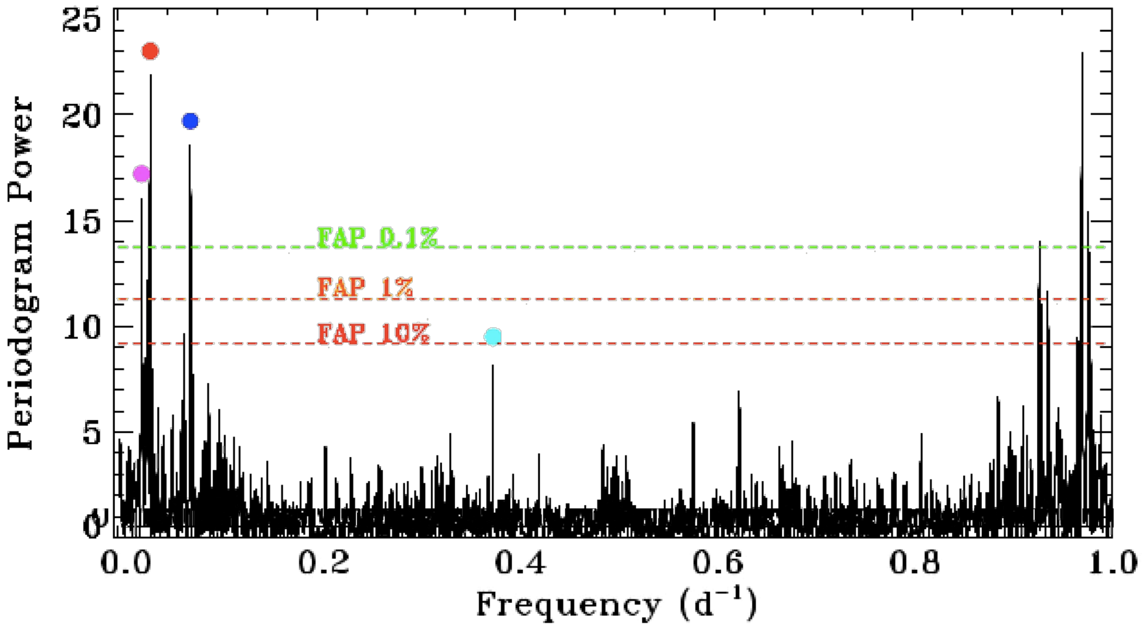
Global Architecture of Planetary Systems

- Started in 2012, it involves about 70 Italian astronomers and 20 foreign collaborators
- It gathers experts in:
  - High-resolution spectroscopy,
  - Stellar activity and pulsations,
  - Crowded stellar environments,
  - Planetary systems formation,
  - Planetary dynamics,
  - Data handling.

Early GAPS Science themes



M dwarfs survey: Super Earths system around an dM



GJ 3998 b & c

Affer et al. 2016

Msini ~ 2.5 M_{Earth}
P = 2.6 d
e = 0
K = 1.8 m/s

Msini ~ 6 M_{Earth}
P = 13.7d
e = 0.06
K = 2.7 m/s

- P = 30.7 d: rotational period of the star
- P = 42.5 d: modulation of the stellar variability due to differential rotation
- P = 2.6 d: orbital period of GJ 3998b
- P = 13.7 d: orbital period of GJ 3998c

GAPS

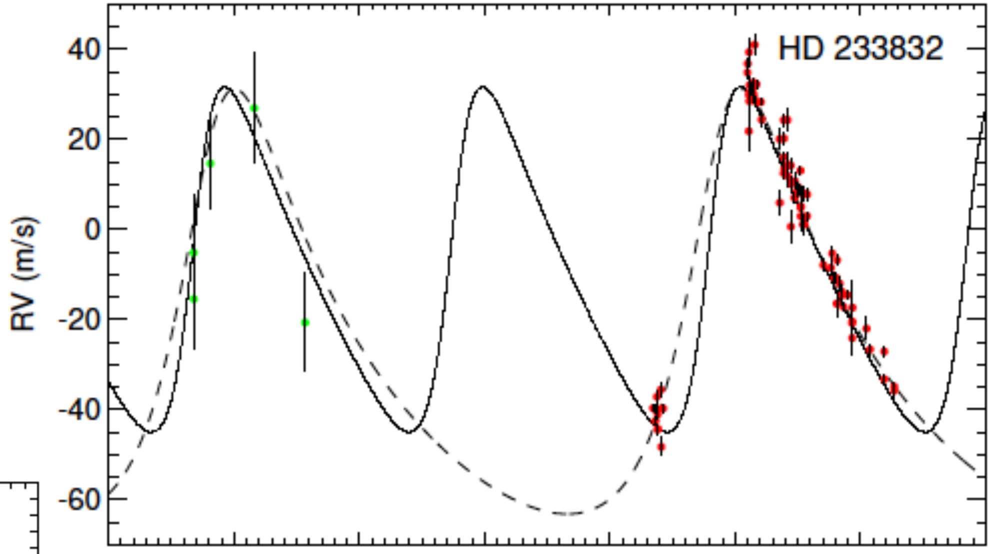
Metal-poor stars survey: Long period giant planets

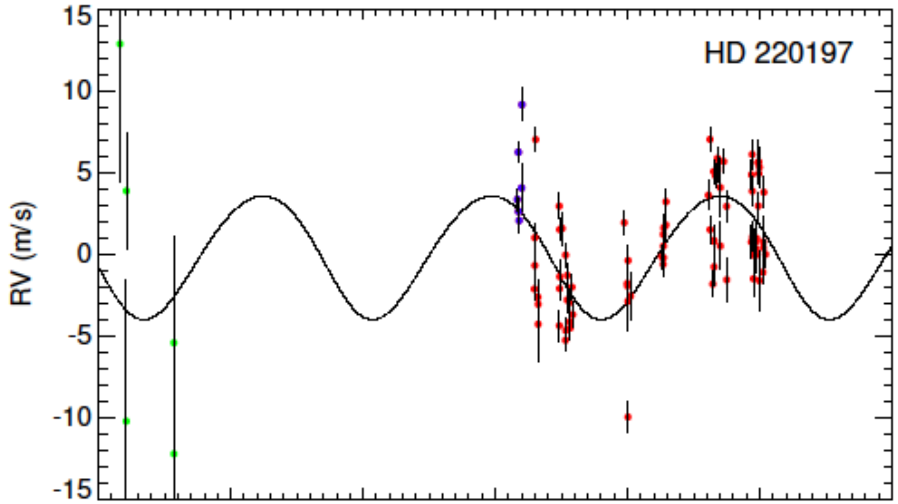
Two Long-Period Giant Planets

- Both in the high-[Fe/H] tail of the sample;

-0.1 ≤ [Fe / H]≤ -0.5 dex

- Combined HIRES/HARPS-N solution;





System	HD 220197 b	HD 233832 b
Period	1728 d	2058 d 4047 d
Msini	0.20 M_J	1.78 M_J 4.438 M_J
Mstar	0.91 M_{sun}	0.71 M_{sun}
[Fe/H]	-55	-0.66

Barbato et al, 2018

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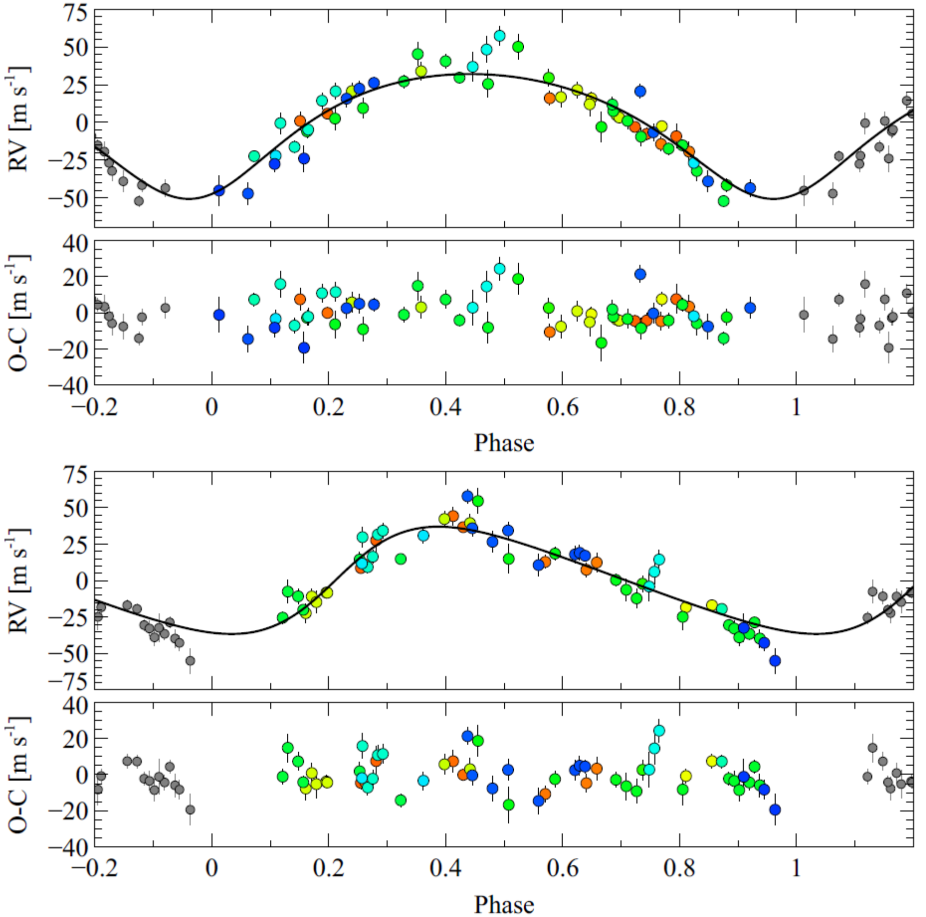
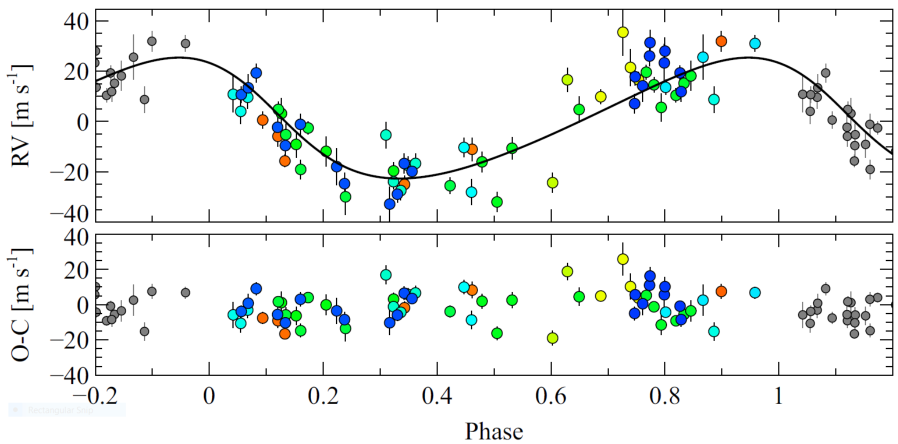
GAPS Open Clusters:

Two new planetary systems in Praesepe





	OC 107b	OC 116b	OC 116c
P	78.3 d	42.0 d	113.9d
Mass	0.47 M_J	0.64 M_J	0.78 M_J
e	<0.24	<0.28	<0.30
Prot	9.1	9.4	

- Detections made possible by modeling of stellar activity

Malavolta et al., 2016, A&A 558A..118M

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ISTITUTO NAZIONALE DI ASTROFISICA INAF

GAPS Early GAPS main results

- ✓ Moderately frequent super-Earth planets at small separation around early M dwarfs. **Often multiple systems.**
- ✓ **Lack of hot Neptunes and Super-Earths** around metal-poor stars, frequency of **warm neptunes** similar to solar-type stars
- ✓ Evidence for impact of metallicity on orbital migration?
- ✓ **No paucity of planets** in open clusters
- ✓ Possible **signatures of dynamical interactions** in the architectures
- ✓ **Negative impact** of the presence of outer giant planets on inner low-mass planets
- ✓ Decisive **role of tides in shaping the properties of close-in planets** revealed by eccentricity +spin-orbit determination
- ✓ Erratic nature of SPI, role of planet eccentricity?

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GAPS

The origin of the exoplanetary diversity

INAF ISTITUTO NAZIONALE DI ASTROFISICA

- GAPS main result ➔ astonishing diversity in the architectures of planetary systems.
- **What is the origin of this diversity?**
  - Investigation of architecture and properties at different ages give clues on formation mechanisms and migration paths
- **GAPS Evolution (since 2018)**
  - Exploring planets in young systems
  - Studying the composition of planets atmospheres

GIARPS

HARPS-N R=120000; 380-690 nm
GIANO R=50000; 950-2500 nm

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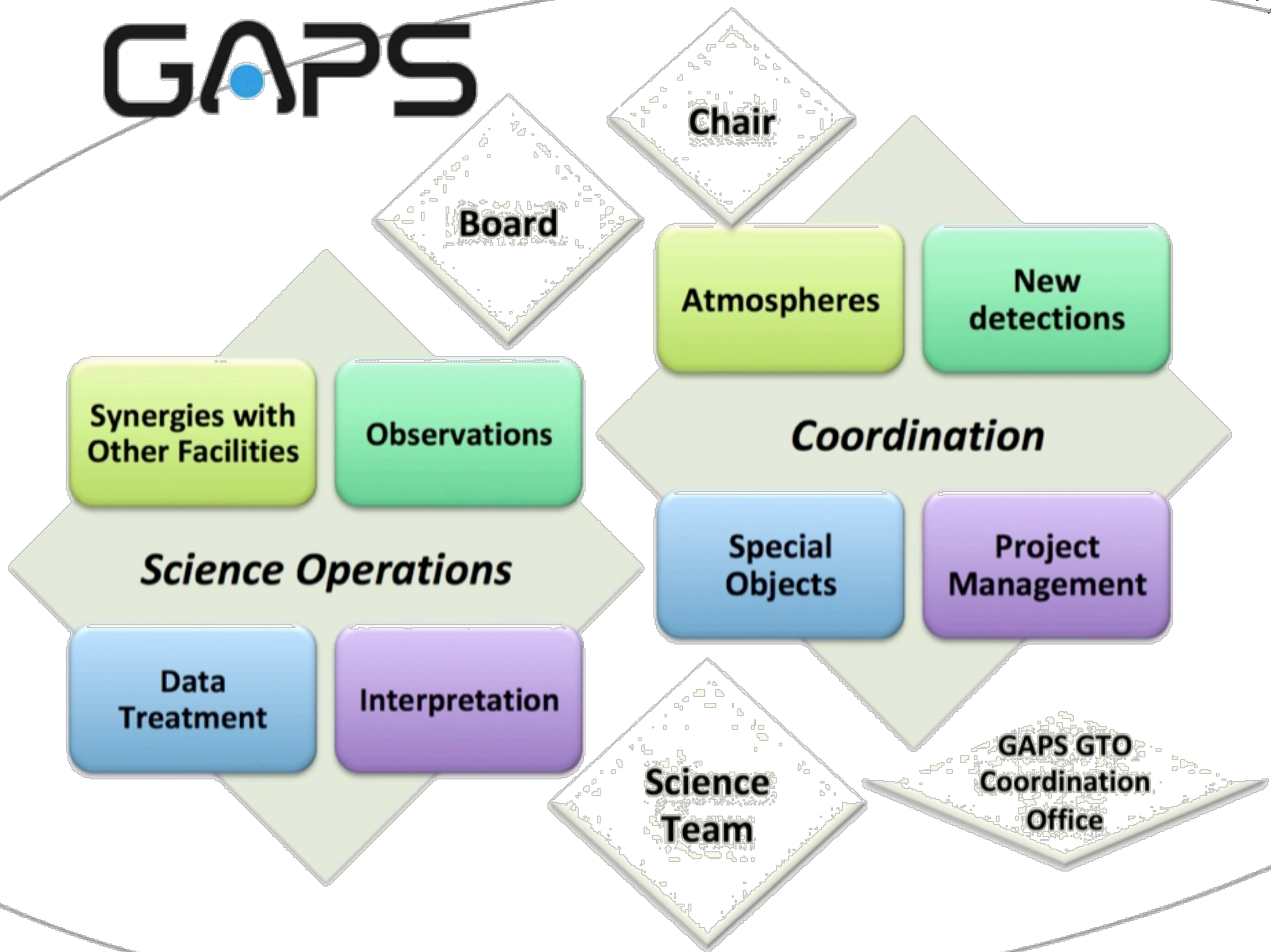
GAPS


Chair
Board
Atmospheres
New detections
Coordination
Special Objects
Project Management
Synergies with Other Facilities
Observations
Science Operations
Data Treatment
Interpretation
Science Team
GAPS GTO Coordination Office

GAPS:
The growing of a community

- Investment on young people ➔ post-docs
- Targeted PhD fellowships:

  ~ 20 PhD students
- Thematic and curricular courses activated in the universities also with the collaboration of INAF researchers

GAPS: Strategies and growing of competences

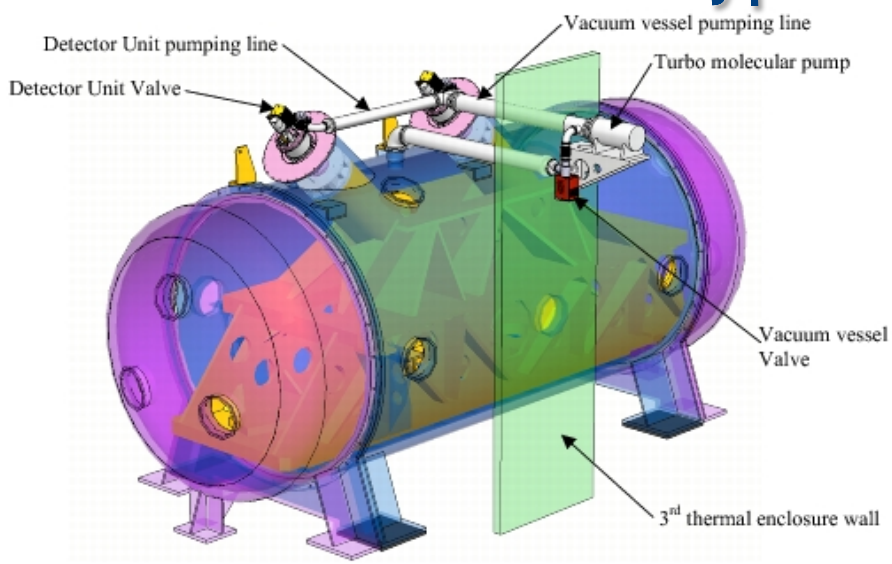
- Development of strategies to optimize the use of telescope time
- Simulations, time scale, frequency of observations, time sharing with other programs:
  - Tailoring the observing strategy and long term planning are key to success of a detection program.
  - Need of dense sampling and large number of measurements when activity modeling is needed (>100 in many cases)
  - Joint scheduling with HARPS-N GTO implemented since AOT34 for better monitoring of the hottest targets
- Integration with INAF e-infrastructures:
  - Interfacing with archives and workflow management system (IA2 archive and YABI) for "flexible" data reprocessing (parameters, masks, new indicators, etc.)
- Importance of support observations (e.g., photometry)

GAPS:
Development of original tools

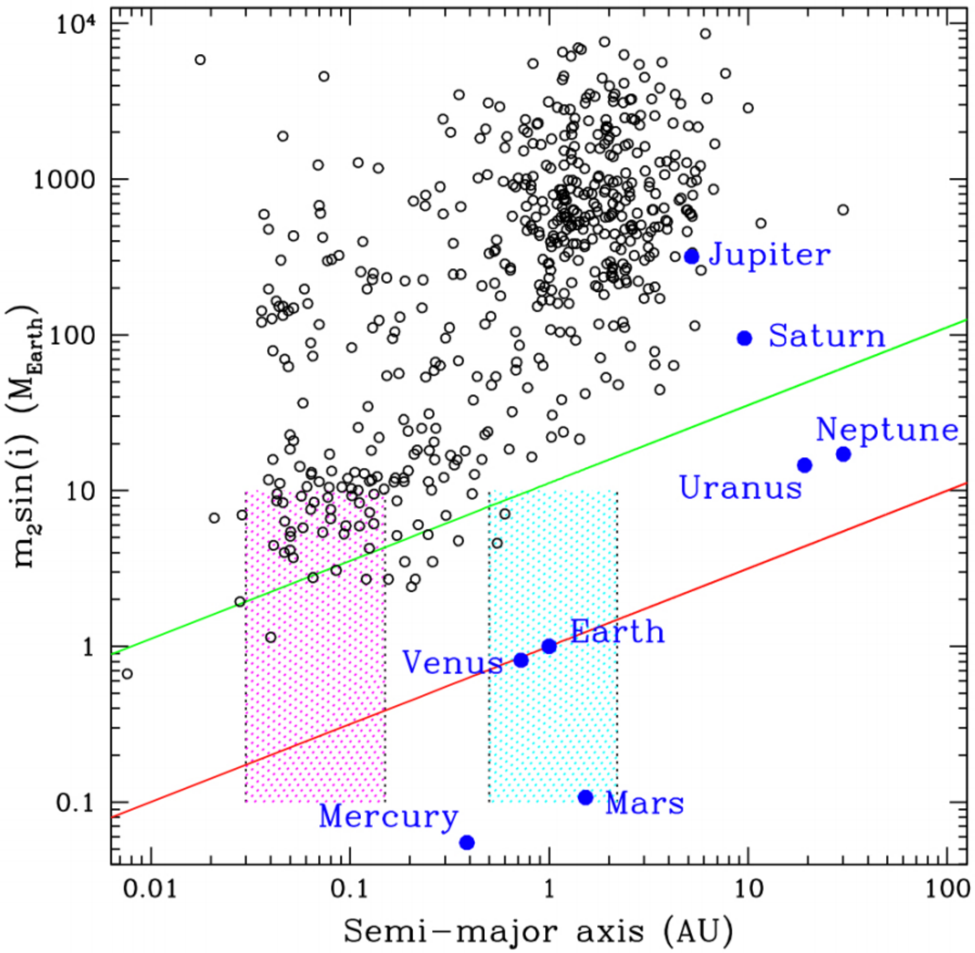
- Ad hoc masks (impossible with HARPS-S);
- Detection of Keplerian signals in the presence of activity:
  - Gaussian process and RV challenge: applying the traditional expertise of our community on stellar activity to planet detection;
- Modeling of the R-M effect;
- Joint spectroscopic and photometric solutions;
- Development of activity indicators based on row profiles;
- Statistical methods for assessing detectability.

ESPRESSO@VLT

- A fiber-fed, cross-dispersed, high resolution echelle spectrograph (R=120,000)
- **Few well selected targets**
- Few cm/sec → rocky planets around solar type stars



ESPRESSO@VLT



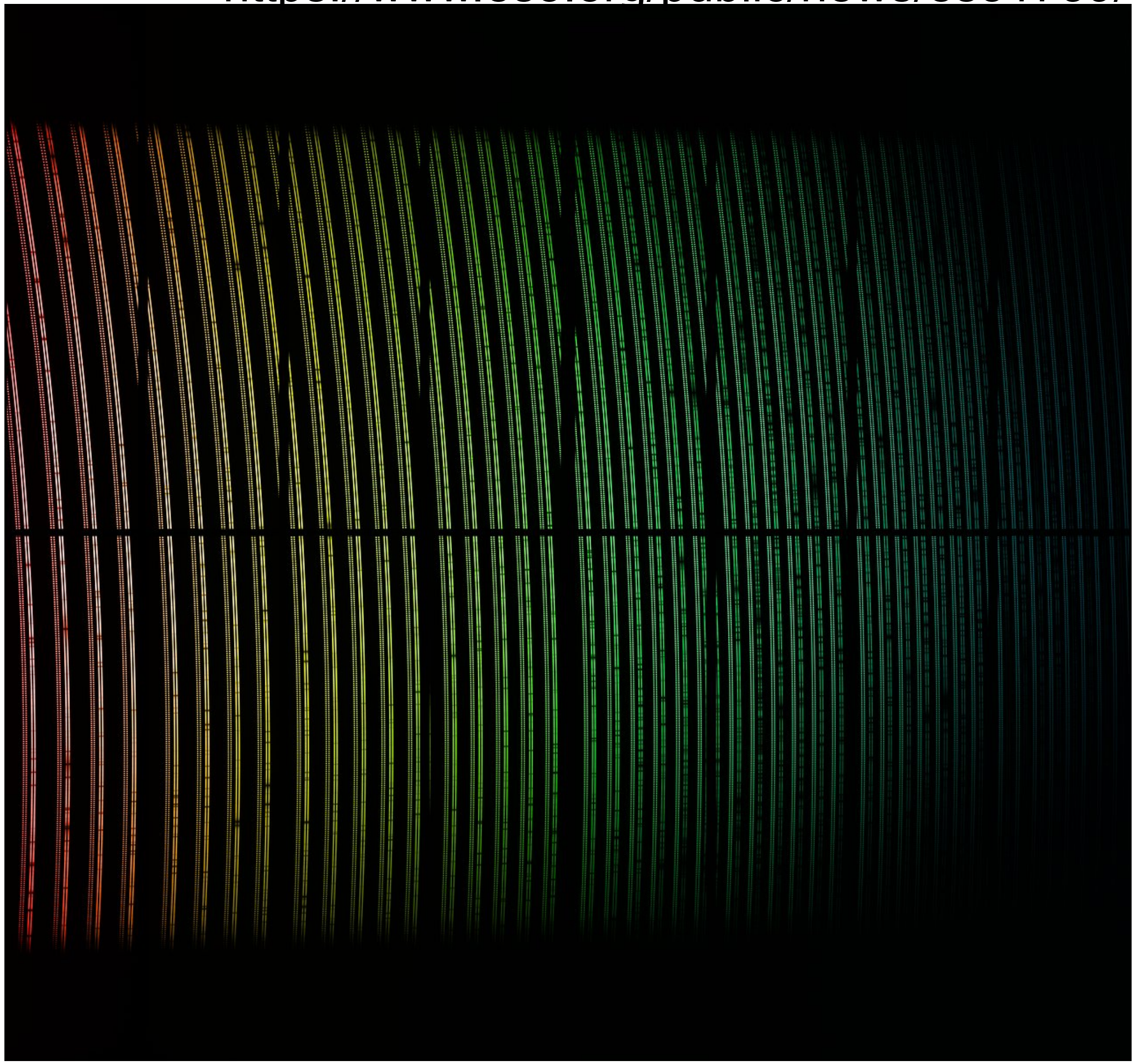
- Red line: 10 cm/s curve for planets orbiting a 0.8 M$_\odot$ star (ESPRESSO limit)
- Green line: 1m/s curve for planets orbiting a 1 M$_\odot$ star
- Blue and pink areas: habitable zones of stars of 0.8-1.2 M$_\odot$, and 0.2-0.3M$_\odot$, respectively.

Pepe et al. 2014

Espresso first light

https://www.eso.org/public/news/eso1739/

Dec 2017



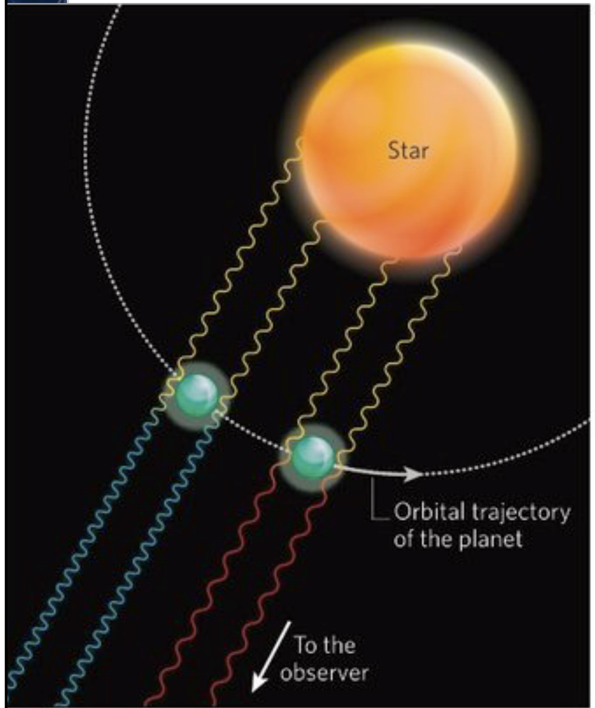
HIRES@ELT

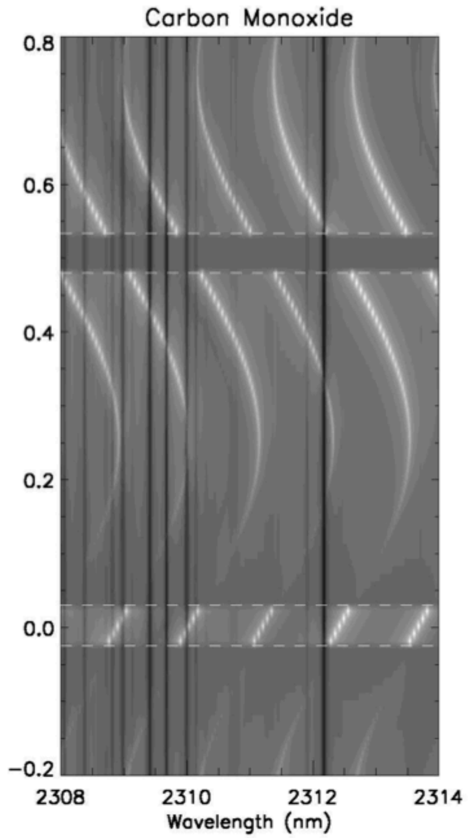
2nd generation ELT instrument

Italian PI

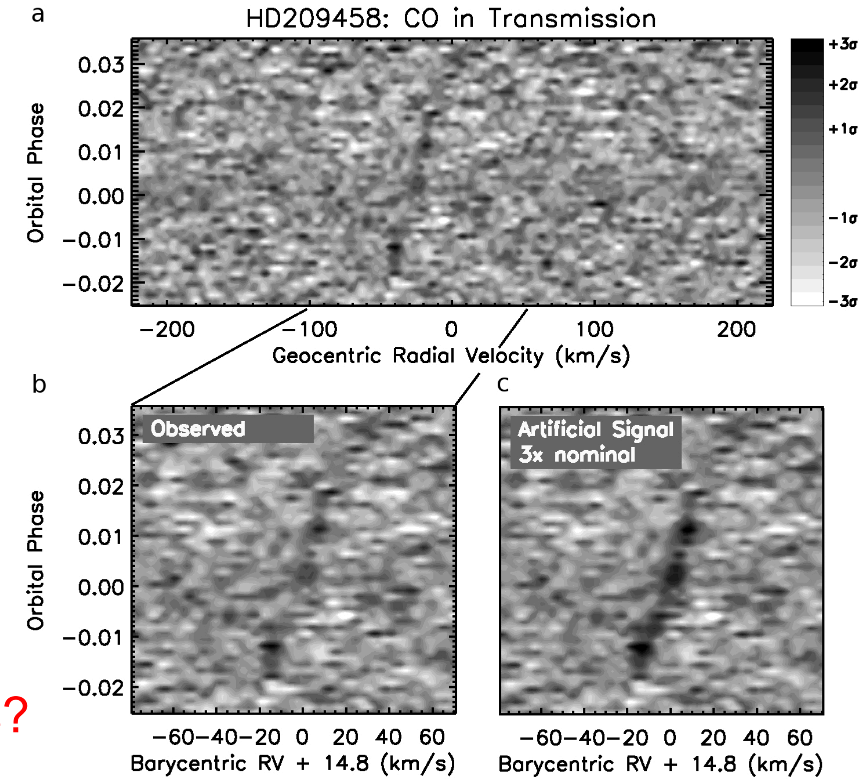
- **High-Dispersion Spectroscopy** (R≥100,000) & **Large effective area**
  - Molecular Bands are resolved in tens of individual lines
  - Strong Doppler effects due to orbital motion of the planet (up to >150 km/sec)
  - Moving planet lines can be distinguished from stationary telluric & stellar lines

Observing Strategy: *already tested*





CO in transmission
HD 209458 b
CRIRES@VLT
Snellen et al. Nature 2010



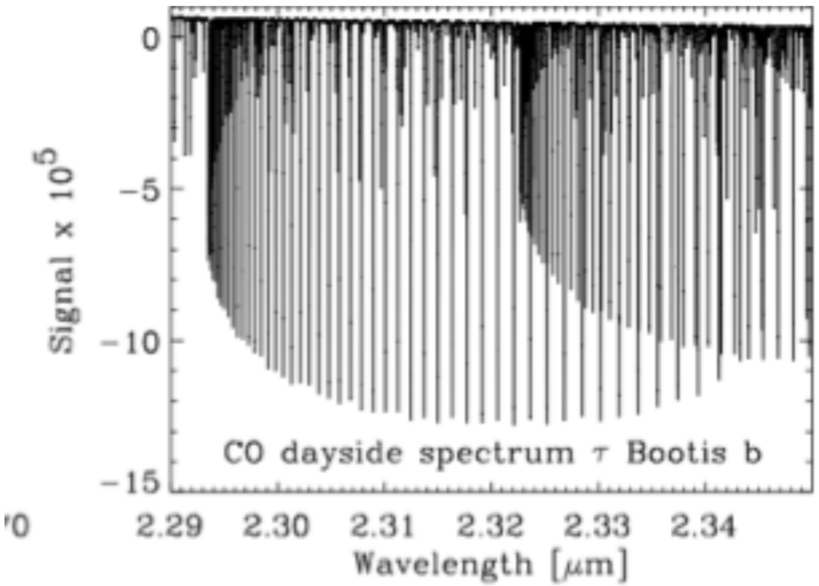
- Reveals planet orbital velocity
- Solves for masses of both planet and star (model independent)
- Evidence for blueshift - high altitude winds?
  - marginal 2σ suggestion

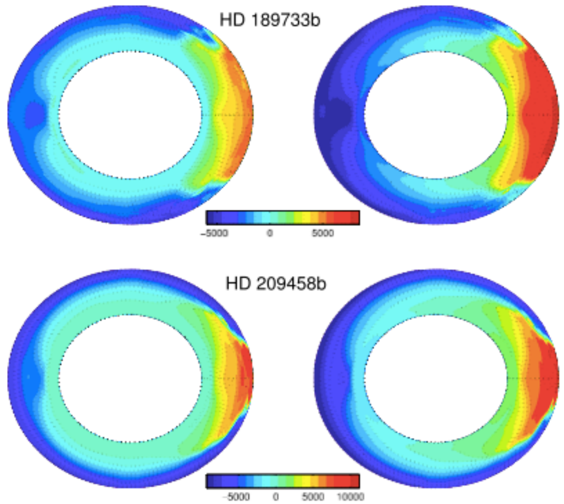
GIARPS!!

HIRES@E-ELT

ELT: 39 m Large Area!

- Orbital inclinations and masses of >100 non-transiting planets
- Detection of the individual lines (instead of cross-correlation)
- T/P profile; unambigous detections of inversion layers
- Line broadening: planet rotation and circulation
- Molecular spectra (CO,CO_2,H_2O,CH_4) as function of orbital phase → photochemistry, T/P vs. longitude
- Evolution of planetary atmospheres





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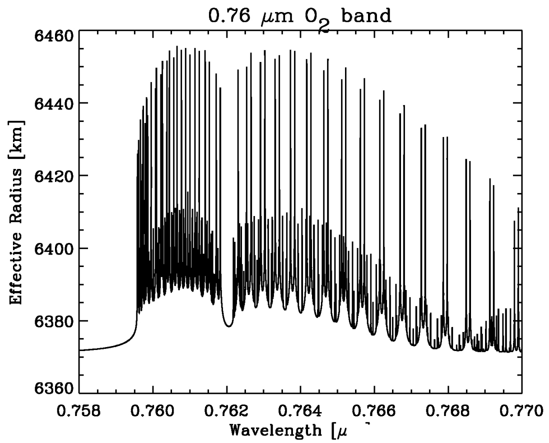
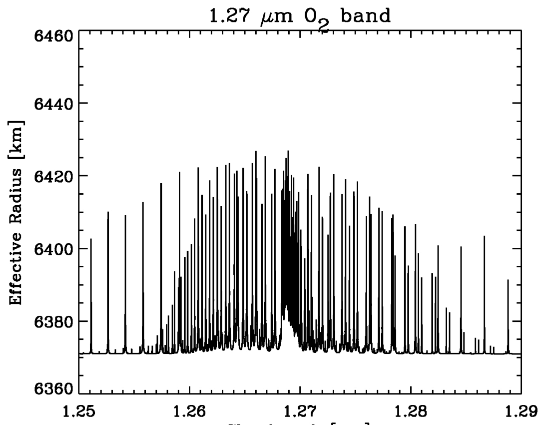
HIRES@E-ELT

- The most ambitious HIRES Science Case:
- Characterizing twin-Earths
  - O_2 in transmission is possible





Snellen et al. 2013

Stellar type	R_* [R_{sun}]	M_* [M_{sun}]	a_{HZ} [au]	Prob [%]	P_{HZ} [days]	Dur. [hrs]	I (η_e=1) [mag]	Line Contrast	SNR σ
G0-G5	1.00	1.00	1.000	0.47	365.3	13	4.4 - 6.1	2×10^{-6}	1.1-2.5
M0-M2	0.49	0.49	0.203	1.12	47.7	4.1	7.3 - 9.1	8×10^{-6}	0.7-1.5
M4-M6	0.19	0.19	0.058	1.52	11.8	1.4	10.0-11.8	5×10^{-5}	0.7-1.7

Ground based roadmap

RV
Inner planets

HARPSN	GIARPS	Espresso	HIRES
1 m/s Quiet stars	1 m/s Active stars + Atmospheres	10 cm/s Earth like planets also in solar type stars	Atmospheres

Imaging
Outer planets
Disks
Young systems

SPHERE	SHARK
Southern Sky	Northern Sky Contemporary VIS-NIR

Cf. Ragazzoni & Pedichini talks

Exoplanets from Space

- **CHEOPS** *ready: launch 2019*
- **PLATO** *preparation ongoing; launch 2026*
- **Ariel** *preparation ongoing; launch 2028*

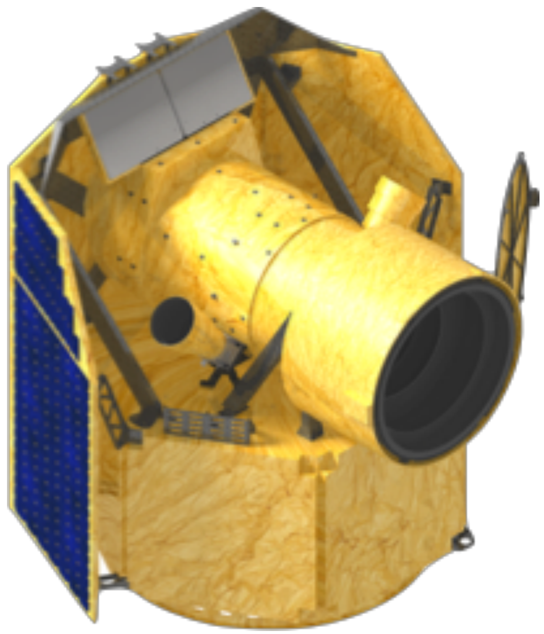
cheops

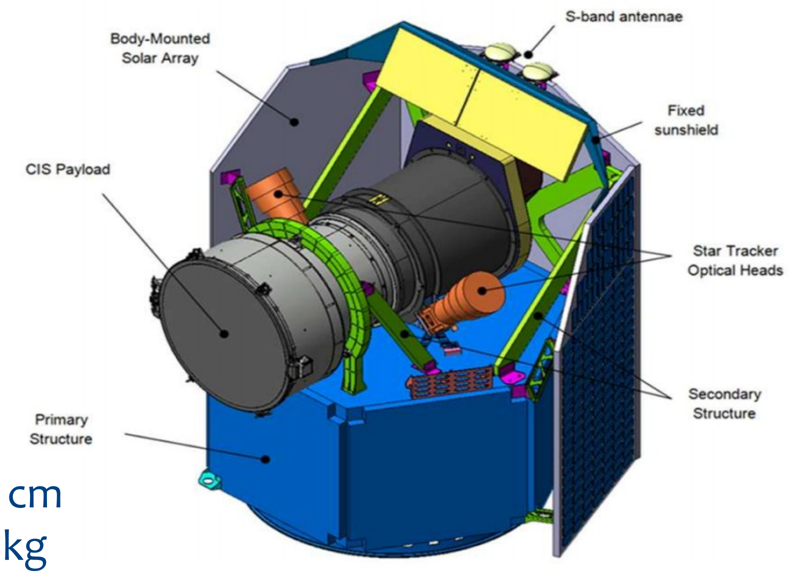
plato

CHEOPS

cheops

- S class mission (S1)
- Budget envelope < 150 M€ (≤ 50 M€ from ESA)
- Launch: end of 2018 => fast development (TRL 5 when selected)
- Operation: 3.5 (+1.5) yrs - shared launch





Mirror diameter: 33 cm
Payload Weight: 60 kg
Total weight: 250 Kg

CHEOPS main science goals

- Perform 1st-step characterisation of super-earths & neptunes
  by measuring accurate radii & bulk densities for such planets orbiting bright stars

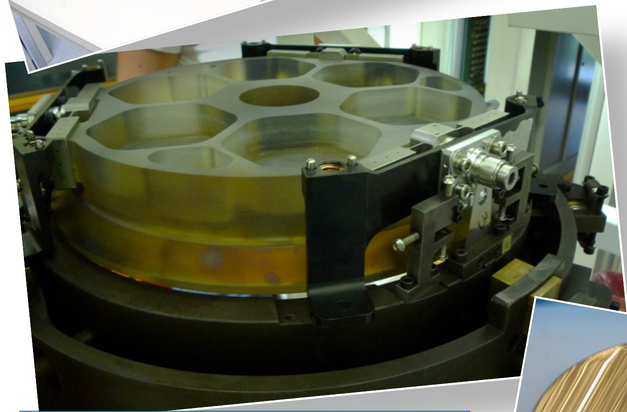
- Provide golden targets for future atmospheric characterisation
  by finding the planets most amenable to deep atmospheric studies

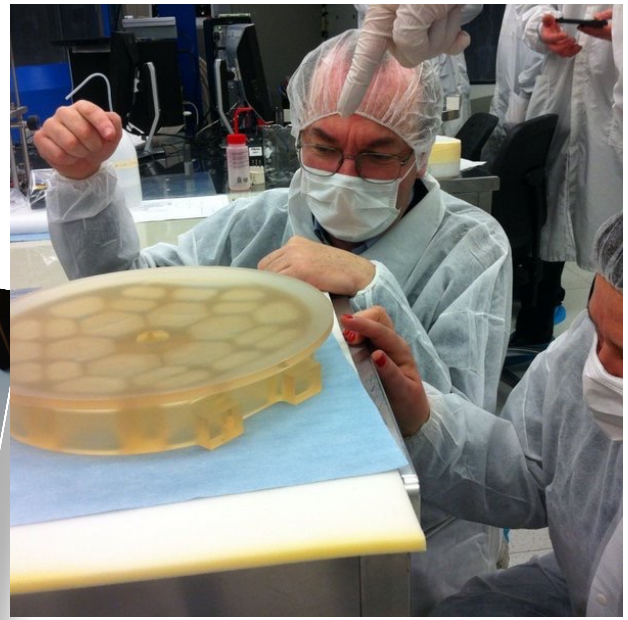
How it works

- ✓ High-precision photometry
  - ✓ Achieve a photometric precision similar to *Kepler*
- ✓ Observing brighter stars anywhere in the sky

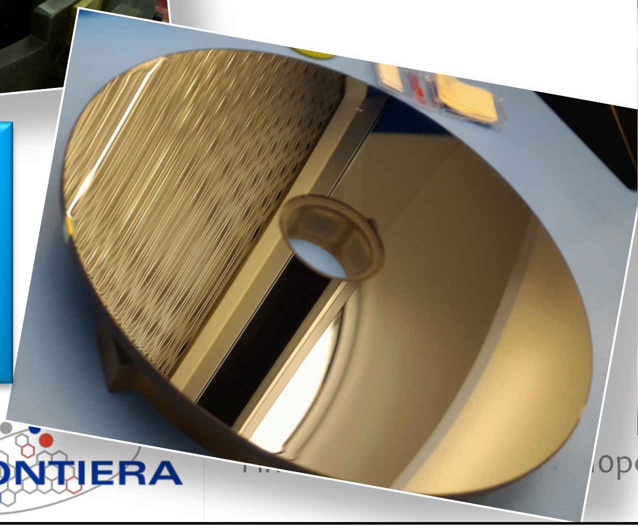
Optics made in Italy

- INAF
  - Oss. Astronomico Padova
  - Oss. Astrofisico di Catania
- ASI
  - SELEX ES/Leonardo
    - Thalenia Alenia Space
    - Medialario
  - SSDC: Mirror Science Data Archive



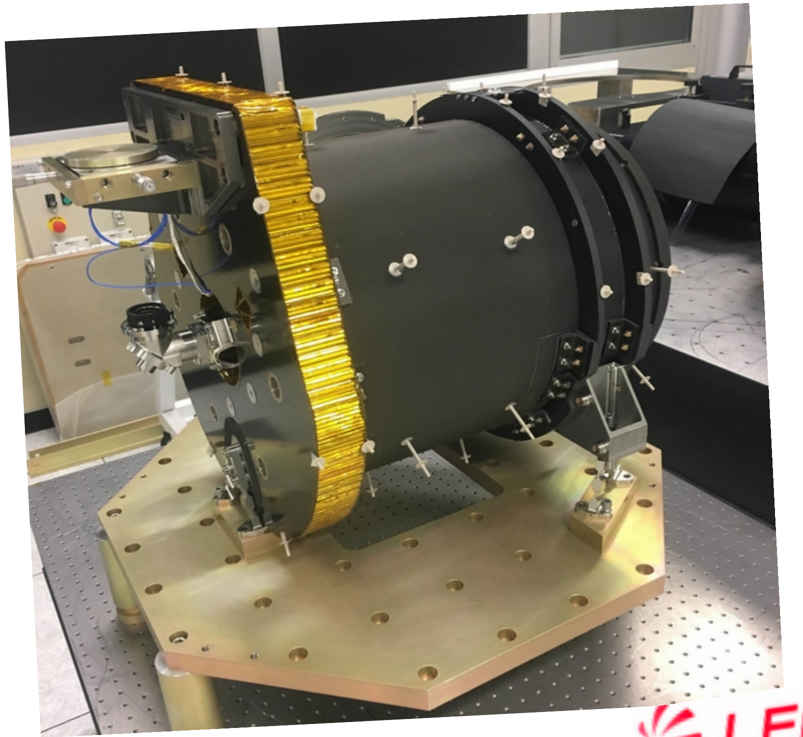


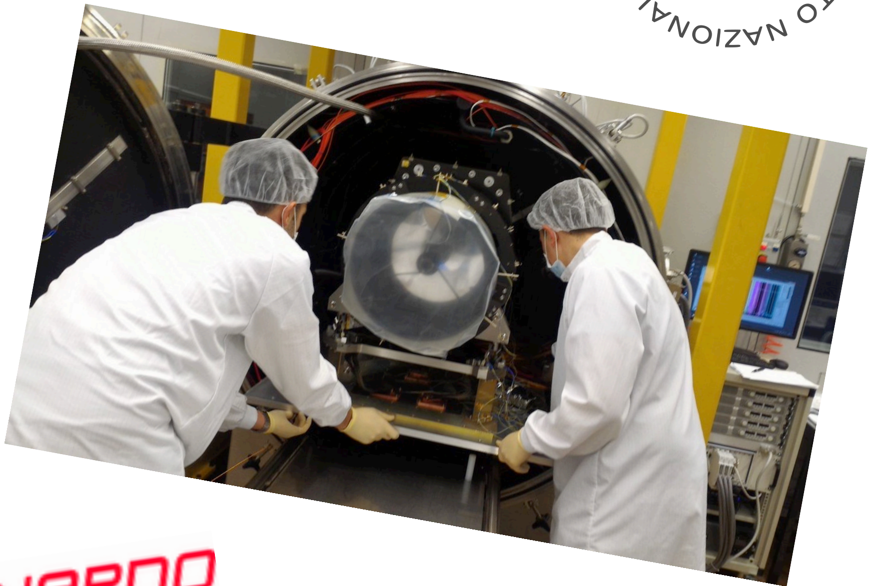
Italy responsible for the optics and the telescope integration



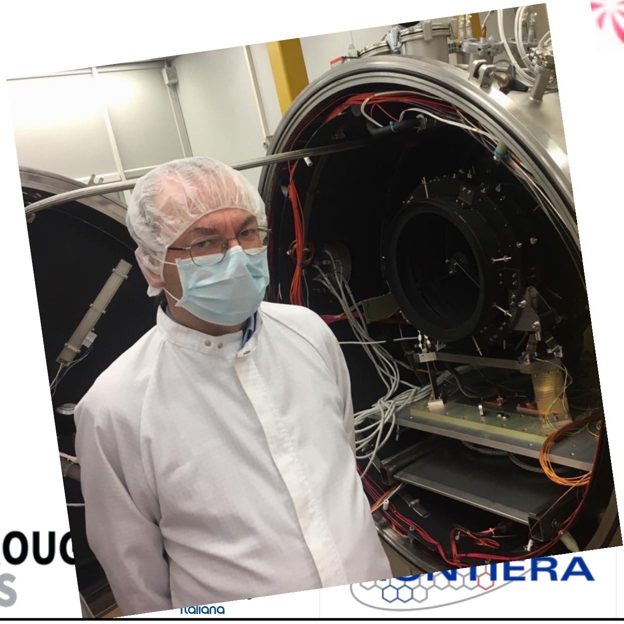
Flight Model

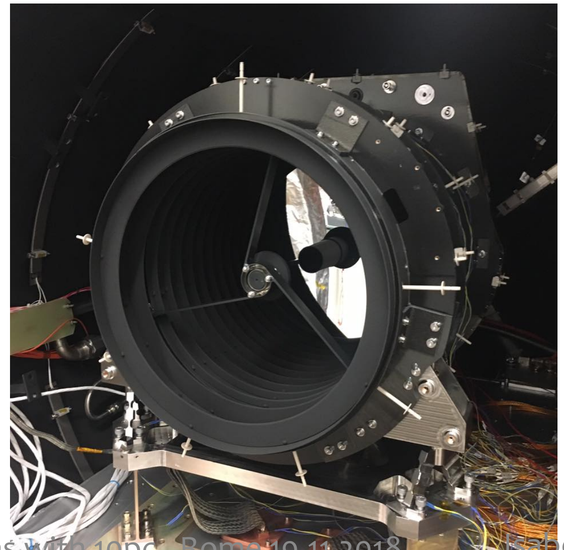
delivered 3 Jun 2016





LEONARDO
AIRBORNE & SPACE SYSTEMS





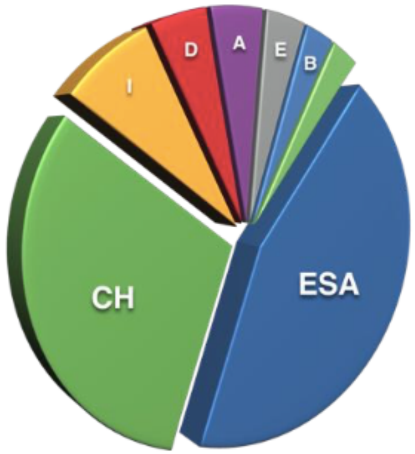
UNIVERSITÄT BERN

BREAKTHROUG
INITIATIVES

CHEOPS Status

- Satellite ready
- Payload ready end 2017
- Integration Satellite-Payload done
- Final tests ongoing
- Ready for launch Jan 2019
- Launch with Soyuz Fregat shared with Cosmo-Skymed from Kourou.
- Launch window: 15 Oct – 14 Nov 2019

Budget



- Total costs: ~105 M€
- ESA share: 50 M€

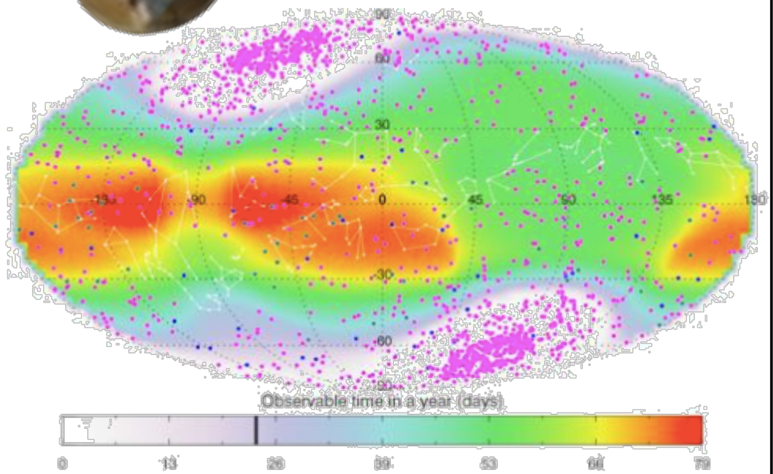
CHEOPS GTO program

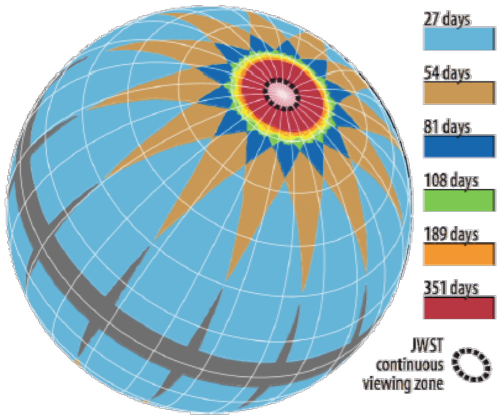
- Search for exoplanet transits in known planetary systems that have been discovered by other techniques, in particular radial velocity.
- Improve the determination of the mass-radius relationship for exoplanets in the low-mass range (sub-Saturn), and to relate it to planet formation and evolution models
- Detect new planets around stars already known to host a planetary system, detect Trojan, look for planets on A stars, search for rings and exo-moons around transiting planets, detect dust inhomogeneity transiting stars with edge-on debris disks (Beta Pic transit...)
- Measure the geometric albedos (secondary eclipses) and visible phase curves of hot Jupiters
- Precise analysis of the transit curve to determine the shape, Love number, or tidal factors of the systems, and search for possible exo-moons or rings as well.
- Characterize stars properties relevant to the measurements of exoplanets.

TESS synergies with CHEOPS

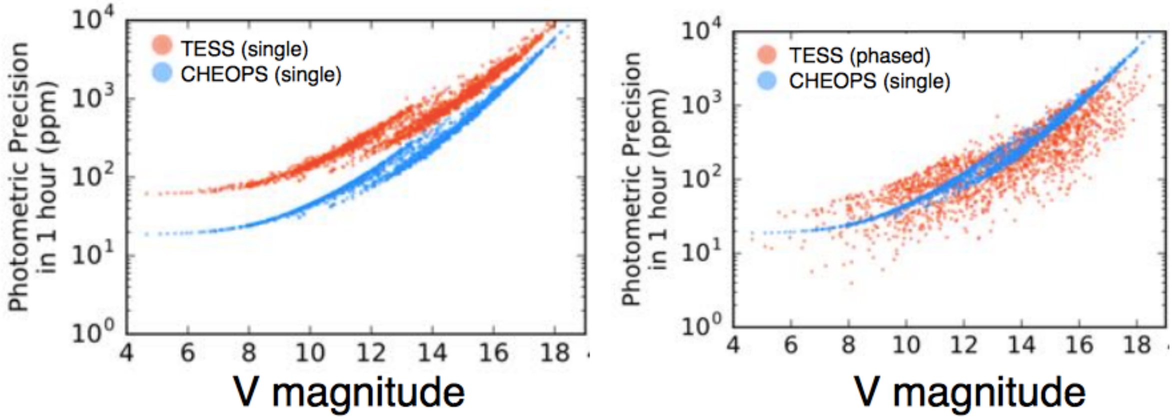
CHEOPS and TESS Team have explored possible synergies

- Validate long-period candidates (only 2 good TESS transits for $P > 9$ days)
- CHEOPS will get precise radii & densities for most interesting planets.





I. Ribas & Z. Berta-Thompson



Open time for guest observers

- 20% of CHEOPS time will be open time for guest observers
  - 6100+ hours
  - 25% of it will be DDT time
- Open time can be time-critical and non-time critical
  - for overall efficiency, non-time critical observations are welcome
- ESA will be organising the call and the selection (~ 6 months before launch)
- The consortium target list published prior to the call will be protected .

CHEOPS flexibility

- CHEOPS mission operation is conceived in order to adjust the program to accommodate new and interesting objects. E.g.:
  - CHEOPS can follow-up any new targets identified by TESS requiring more data,
  - Include in its schedule any new interesting targets whose characterization could be interesting to plan follow up spectroscopic measurements.
- The CHEOPS input catalogue can be optimized almost in real time (weekly basis)

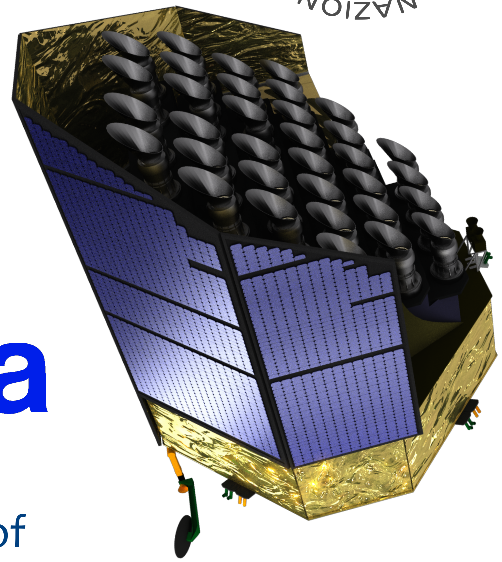
@cheops_it

PLATO

PLAnetary Transits & Oscillations of Stars

– M class mission (M3)
– Budget envelope ~ 650 M€ (≤ 500 M€ from ESA)
– Launch: 2026 – Launcher Soyuz Fregat from Kourou
– Operation: 4.25 yr (+2) yrs

[*satellite built with consumable for 8 yr*]



Key Science Goals:

✓ Detection of terrestrial exoplanets in the habitable zone of solar-type stars and characterization of their bulk properties needed to determine their habitability.

✓ Understanding of the formation, the architecture, and the evolution (ages) of planetary systems by means of a full inventory of the physical properties of thousands of rocky, icy, and gaseous giant planets.

TOP Key Objective:

- Up to a dozen of planets with Earth mass and Period > 80 d

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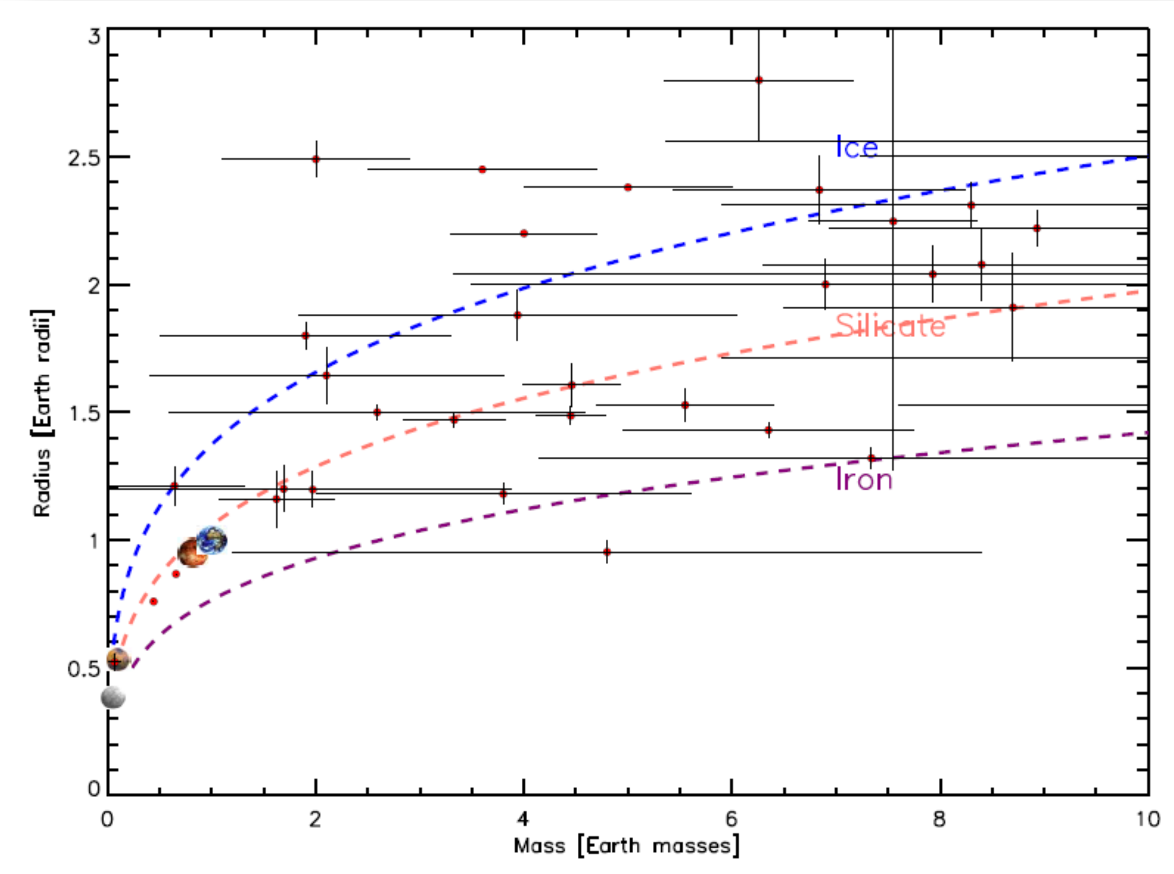
Diversity of super-Earths



- ✓ Masses vary by a factor of ~4 (with large errors)
- ✓ Radii vary by a factor of ~3

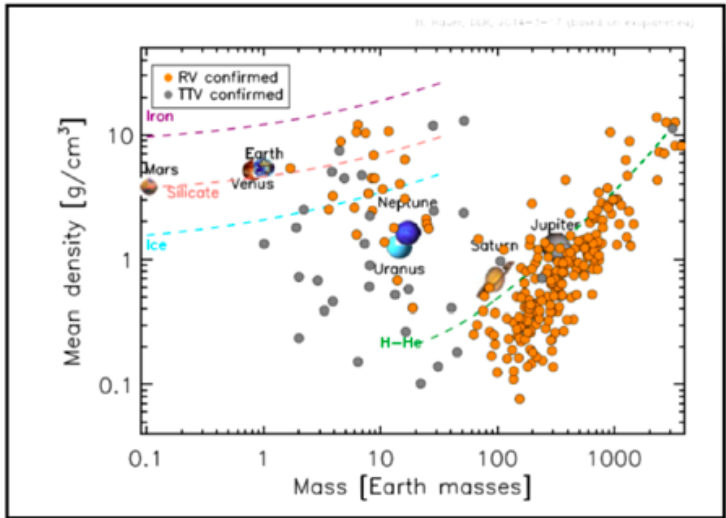
🡐 $M \leq 10\ M_E$

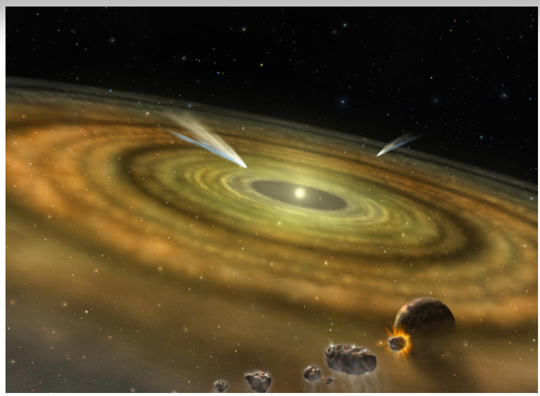
→ **Accurate masses & radii are required to separate terrestrial from mini-gas planets**

A biased view

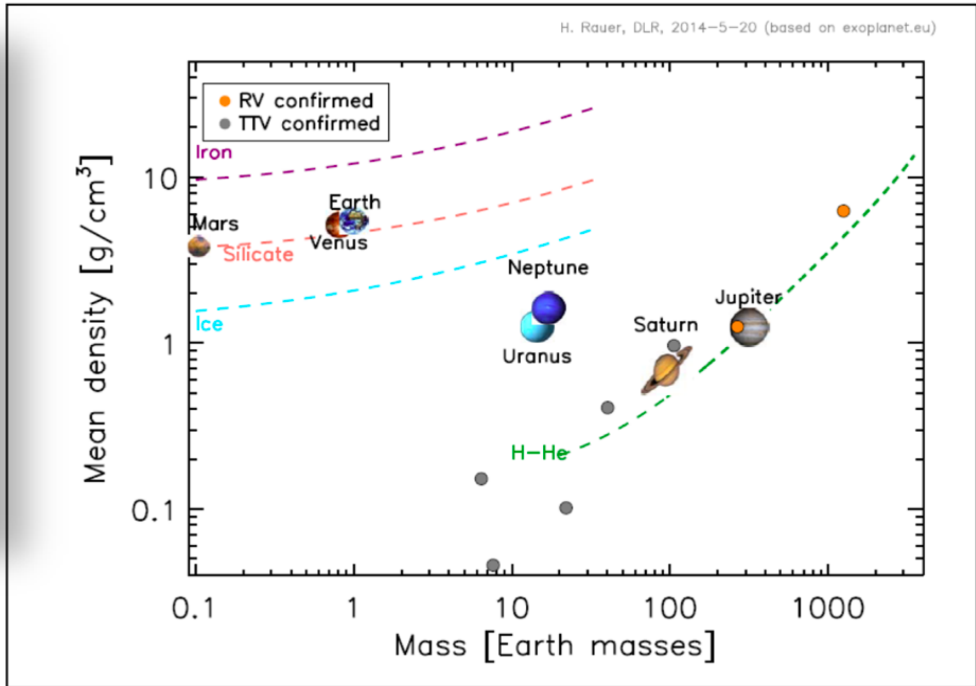
Our knowledge on planet nature is limited to close-in planets so far.

All planets

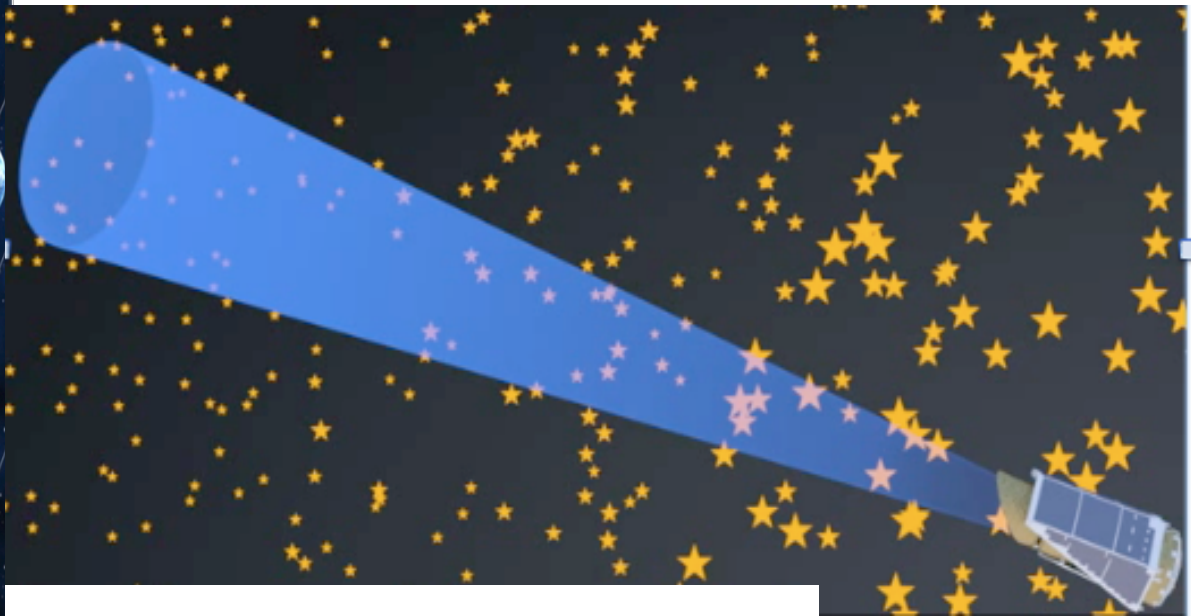




Planets with P>80 days

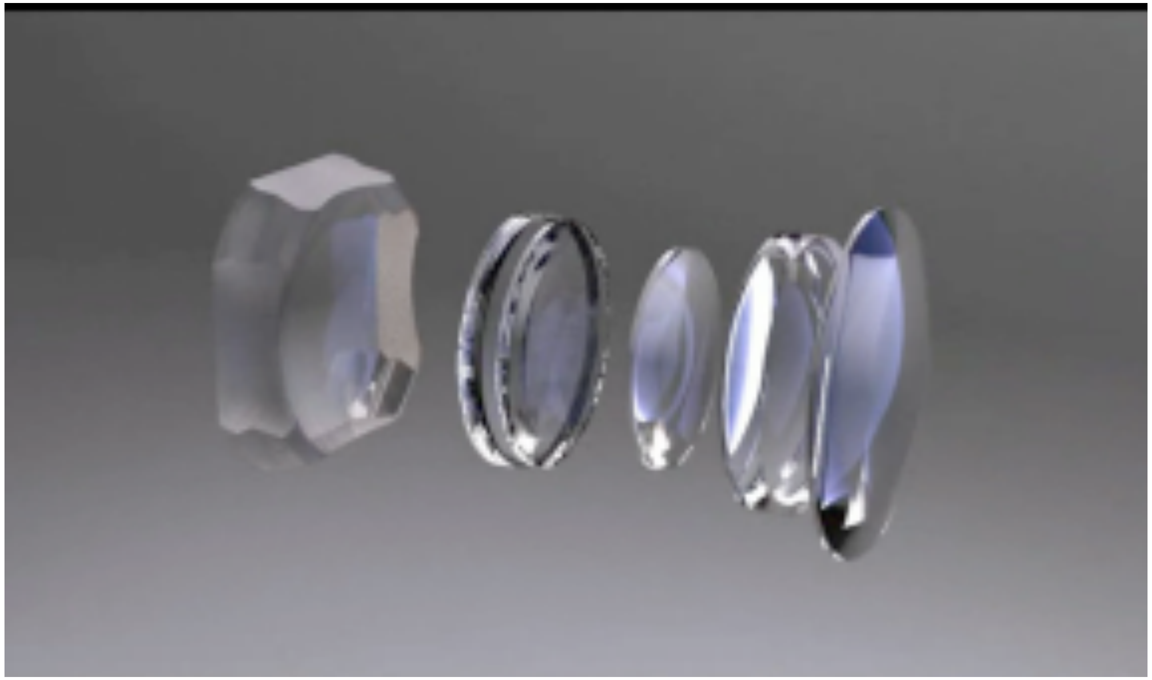


Large FoV concept



Searching for transits of
Bright Stars →
→ large FoV!

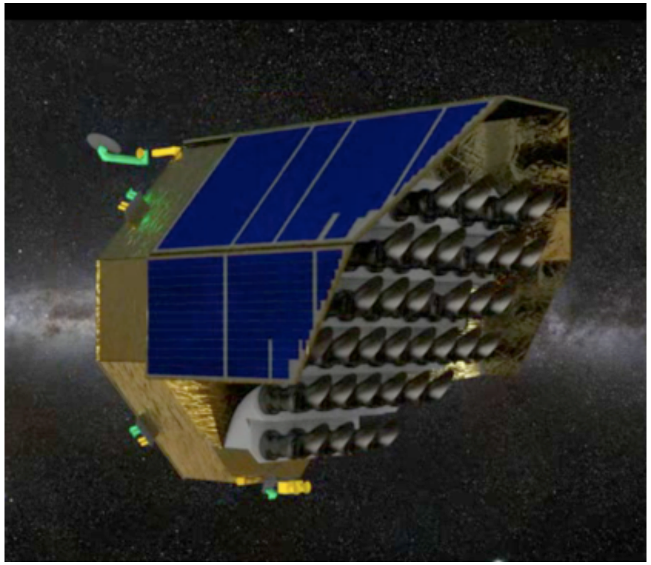
Telescope Concept



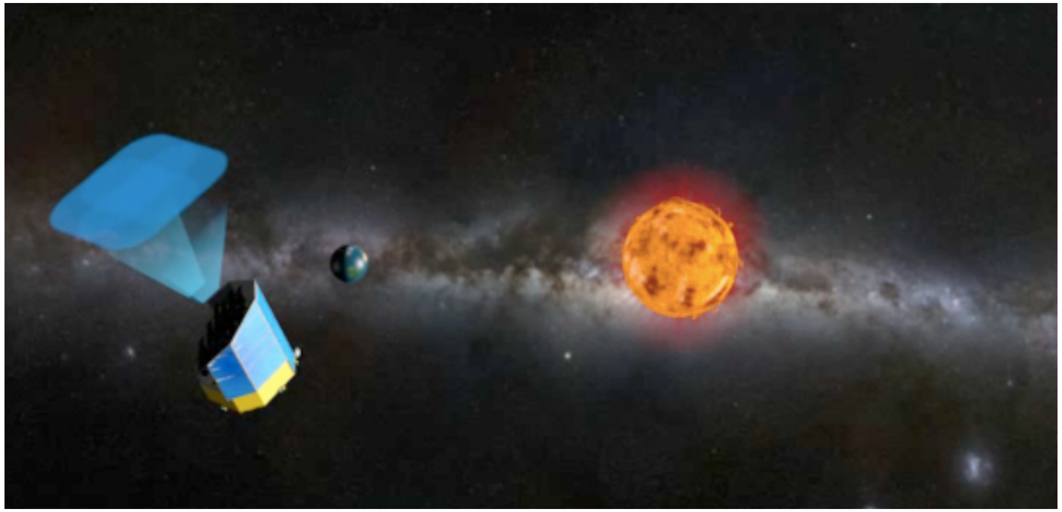
- ✓ fully dioptric, 6 lenses
- ✓ pupil 120 mm
- ✓ dynamical range: $4 \leq m_V \leq 16$
- ✓ Spectral range = 500 – 1050 nm

Single Telescope FoV ~1200 sqdeg
Equivalent to a circle of ~38.7 deg diameter

Multi-telescope concept & Mission profile



Very wide field + large collecting area:
multi-instrument concept



Overlapping FoV
~2250 sqdeg
Ø ~53 deg

Collecting area of a 1.12 m

- 4 years nominal science operation (*satellite consumables for 8 yr)*
- 2 long pointings + step-and-stare phase

PLATO measurements

-

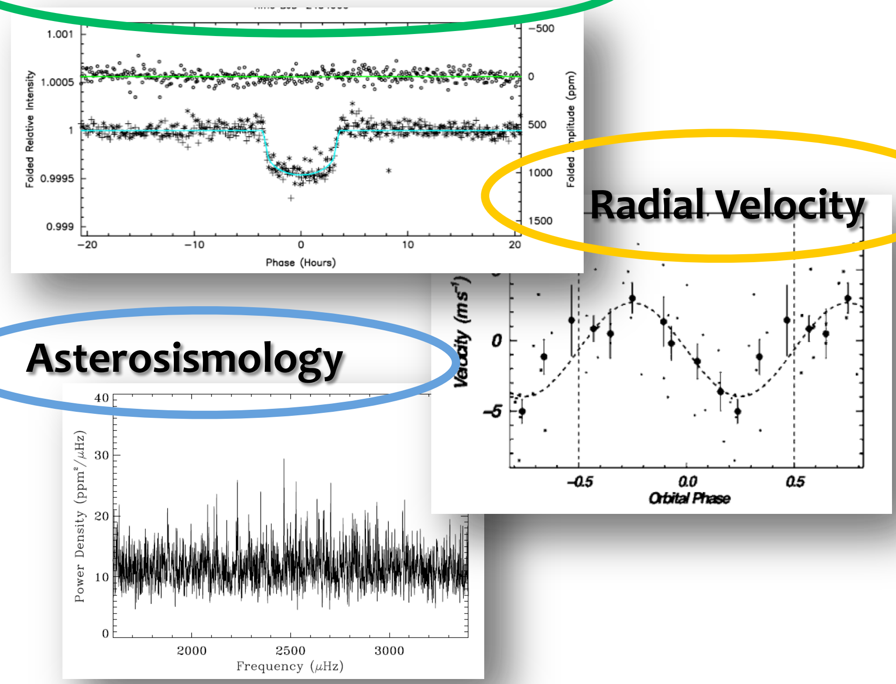
- radius ~3%
- mass ~10%
- age~10%

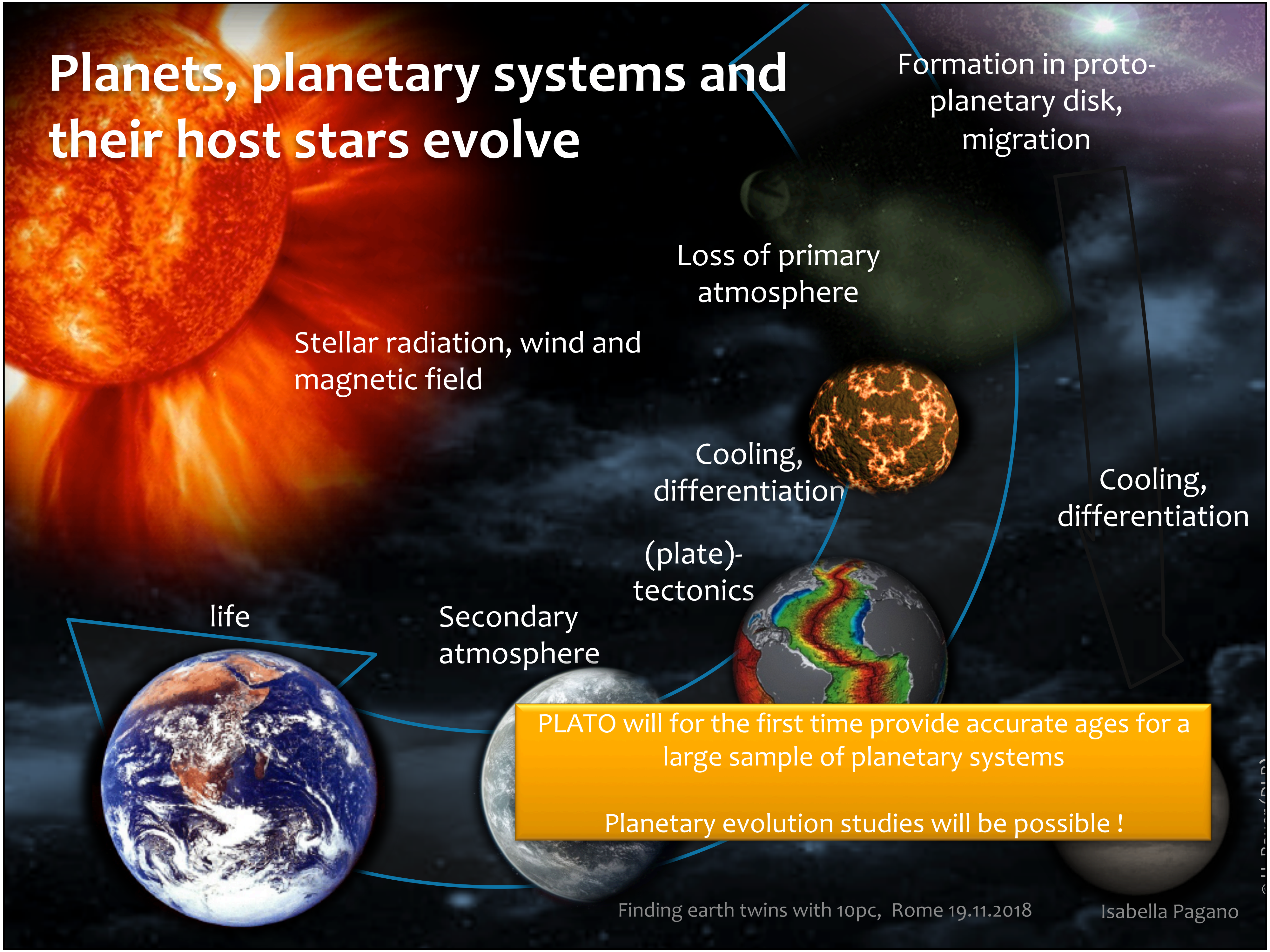
Techniques

Transits

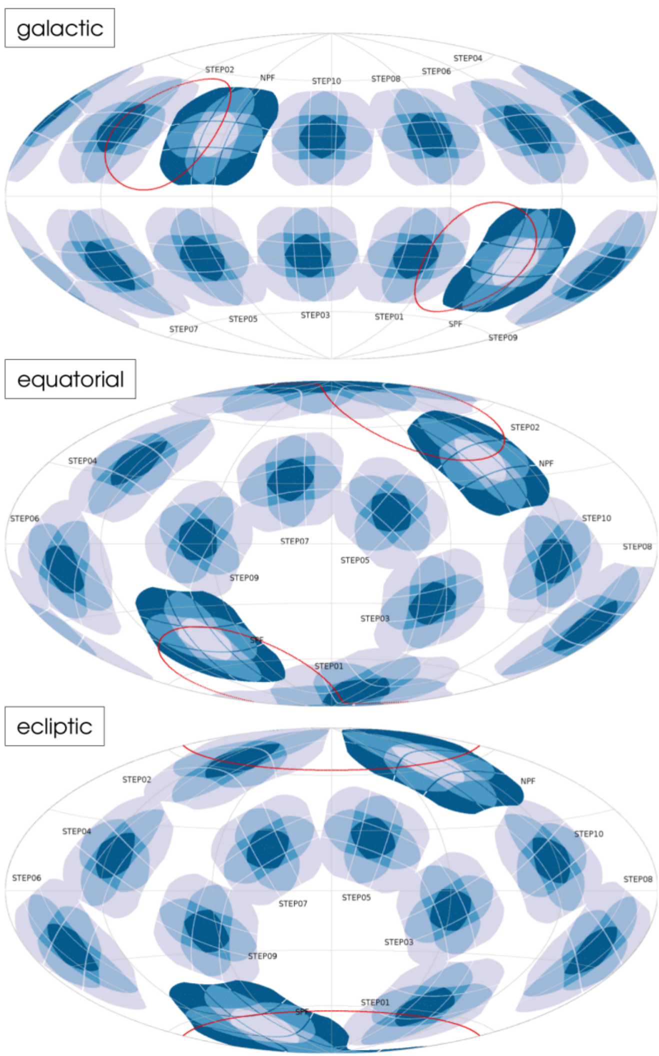
Radial Velocity

Asterosismology




Planets, planetary systems and their host stars evolve
Formation in proto-planetary disk, migration
Loss of primary atmosphere
Stellar radiation, wind and magnetic field
Cooling, differentiation
Cooling, differentiation
(plate)-tectonics
life
Secondary atmosphere
PLATO will for the first time provide accurate ages for a large sample of planetary systems
Planetary evolution studies will be possible !
Finding earth twins with 10pc, Rome 19.11.2018
Isabella Pagano

PLATO fields



- Final Coverage:
  2π sr ~ half of the sky
- The LD fields cover N/S emispheres
- Order of execution of LDs and S&S will be finalised in a coming phase.

PLATO in Italy

- ✓ **INAF**
  - OA Catania (Science, Payload)
  - OA Padova (Science, Payload)
  - OA Brera (Science, Payload)
  - IAPS-Roma (Science, Payload)
  - FGG (Payload)
  - OA Palermo (Science)
  - OA Torino (Science)
  - OA Capodimonte (Science)
  - OA Roma (+Teramo) (Science)
  - OA Arcetri (Science)
- ✓ **Padua University, Physics & Astronomy Dep.** (Science)
- ✓ **ASI-SSDC** (PDC, Science)

About 70 scientists/engineers active in PLATO in Italian research institutes!

About 120 scientists interested to exoplanets field in Italy!

Main Italian contribution

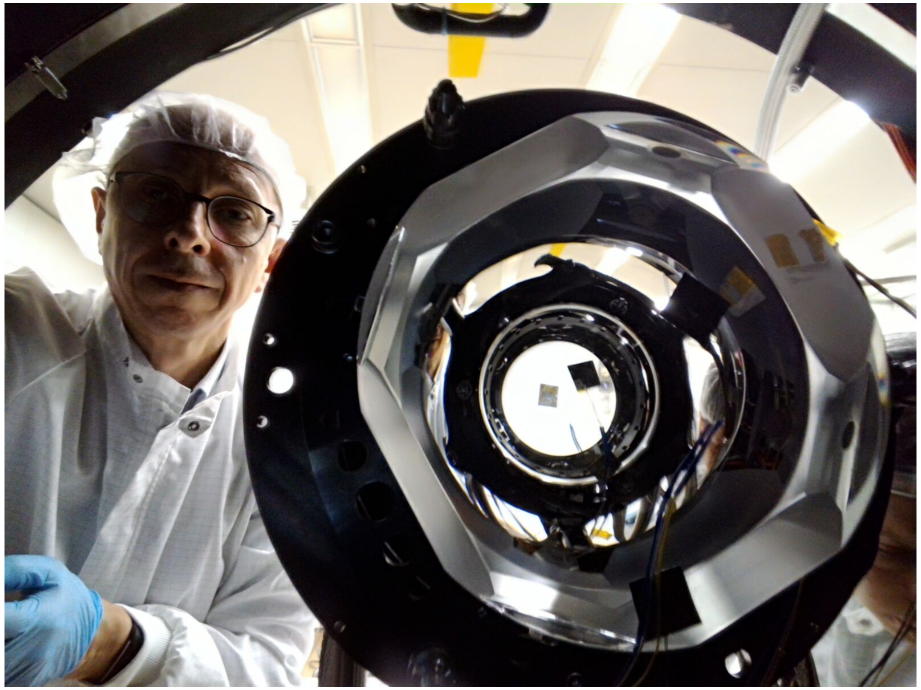
- 26 Telescopes
- Instrument Control Unit
- Imput Catalogue

- **Italian Scientific Responsible:** I. Pagano
- **Members of the PLATO Science Working Team:** G. Piotto, R. Ragazzoni
- **Members of the PMC Board:** I. Pagano, G. Piotto

https://platomission.com

@platomissioncon

ISTITUTO NAZIONALE DI ASTROFISICA
INAF
NATIONAL INSTITUTE FOR ASTROPHYSICS

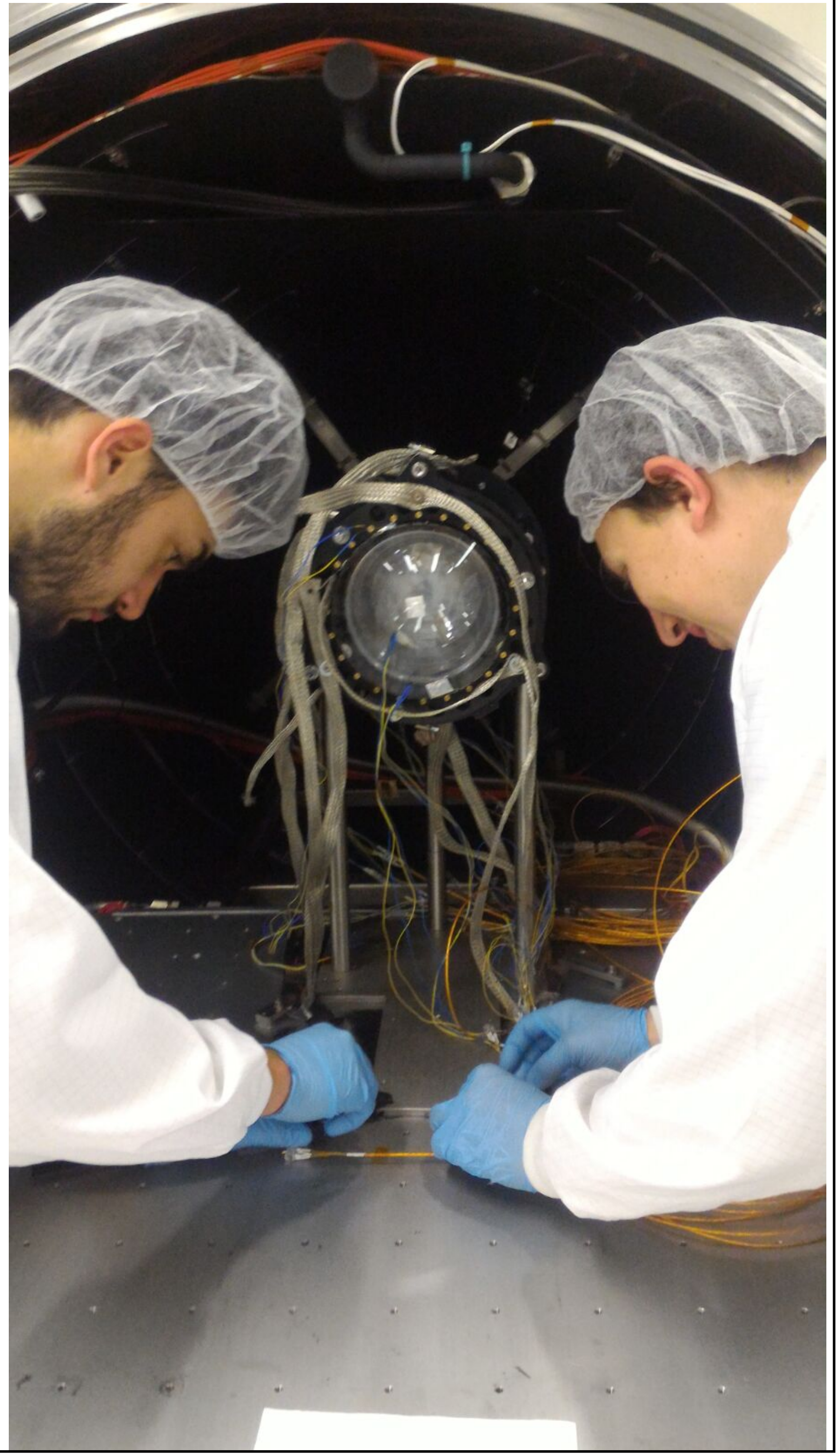


LEONARDO
AIRBORNE & SPACE SYSTEMS

BREAKTHROUGH
INITIATIVES

agenzia spaziale italiana

FRONTIERA



ARIEL

Enabling planetary science across light-years

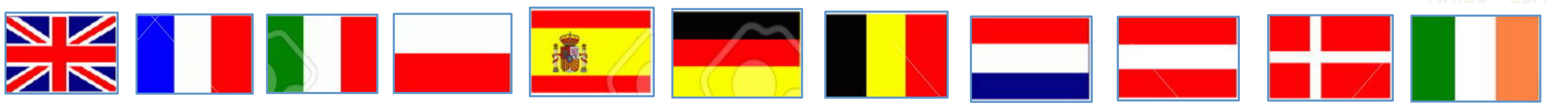
- M4 ESA mission (selection Oct/Nov 2017)
- 1-m telescope, spectroscopy from VIS to IR - Simultaneous coverage 0.5-7.8 micron (R =1 to 300)
- Payload consortium: 11 ESA countries
- Atmospheres of ~1000 exoplanets (rocky + gaseous), mainly transits and eclipse

Individual planet

Chemical composition
Atmospheric circulation + cloud pattern
Equilibrium or non-equilibrium chemistry?
Impact with stellar environment
Coupling interior-atmosphere
Impact of stellar environment & system history

Large population of diverse planets

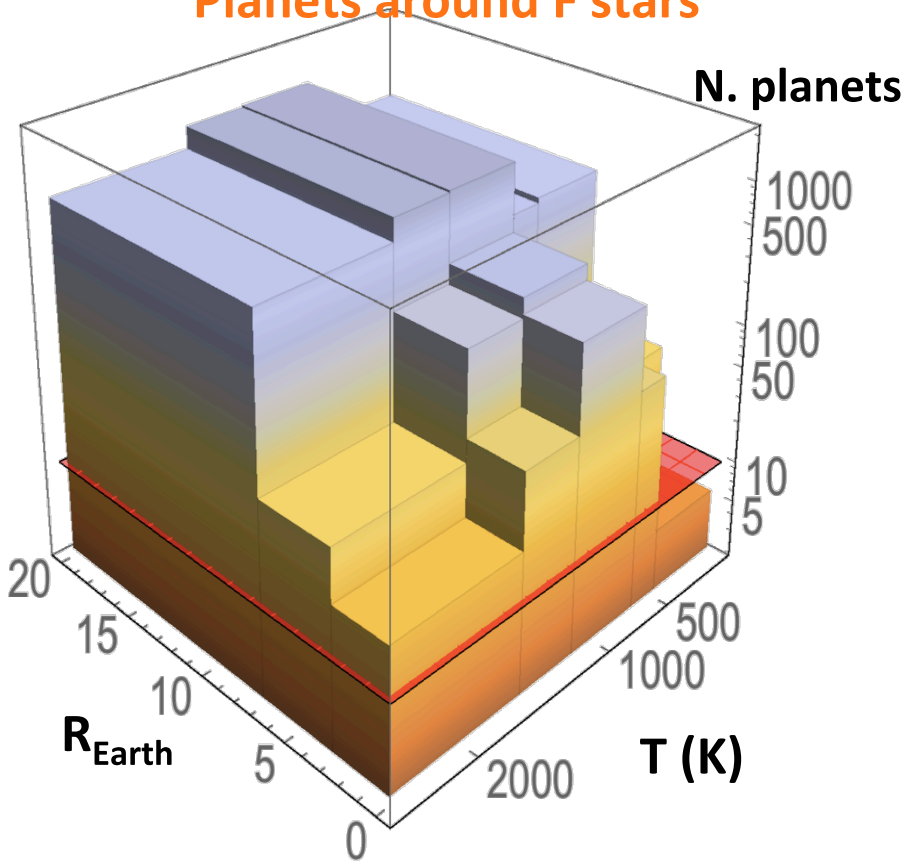
Chemical diversity
Correlation clouds–temperature-stellar-type
How fast atmospheres change through time?
Correlation elemental composition planet provenance
Coupling atmosphere-interior through time
Transition between terrestrial planets and sub-Neptunes



Large population of warm/hot planets

SELECTED OUT OF 10,000 PLANETS OPTIMAL FOR CHEMICAL OBSERVATIONS

Planets around F stars



Parameter space to be sounded:

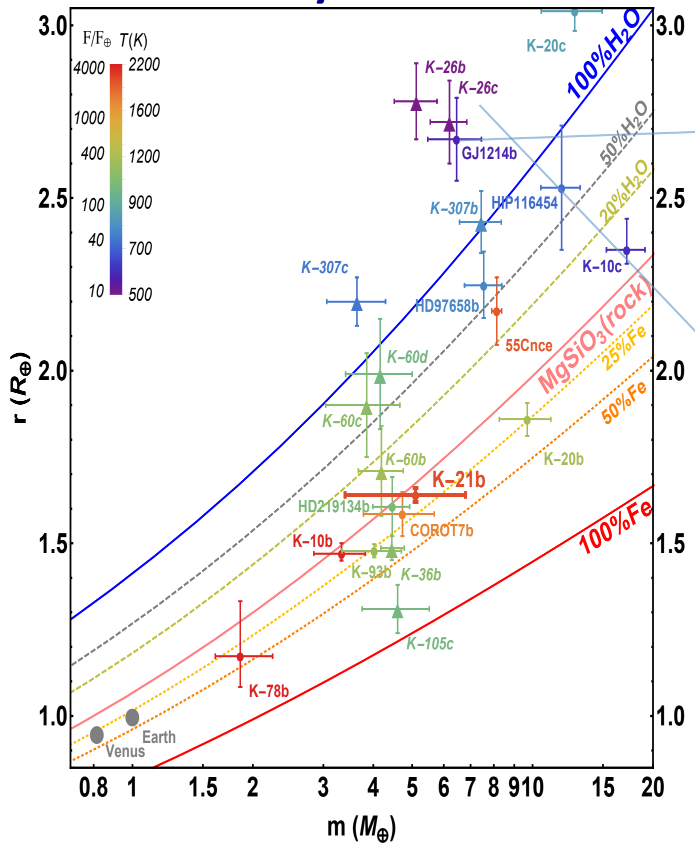
- Planet size,
- Temperature,
- Density;
- Stellar type,
- Metallicity

The sample should have ~ 1000 planets

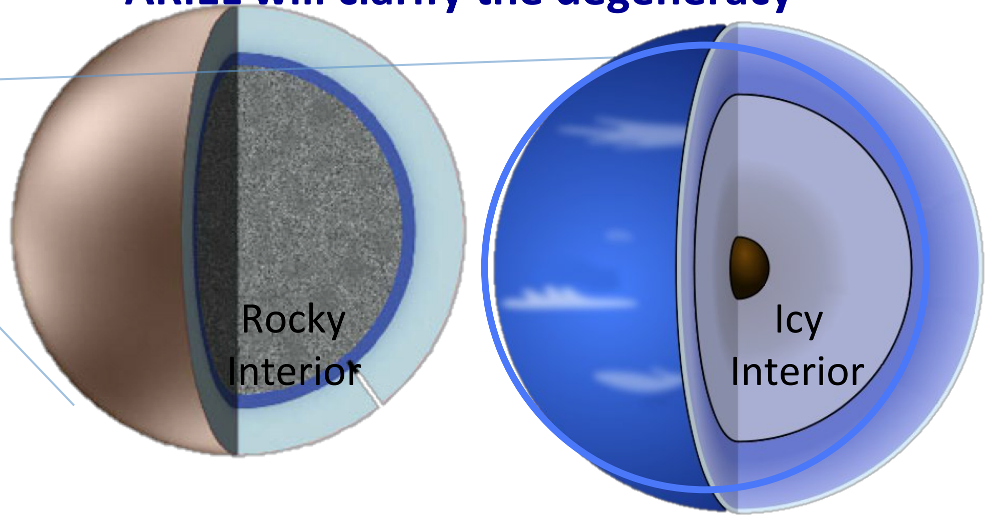
Chemical diversity

ARIEL WILL CLARIFY CORRELATION WITH THE DENSITY

Density observations



Atmospheric composition through ARIEL will clarify the degeneracy



H/He Atmosphere

Water vapour Atmosphere

Same mean density – Different atmospheric signatures

PAYLOAD CONTRIBUTION

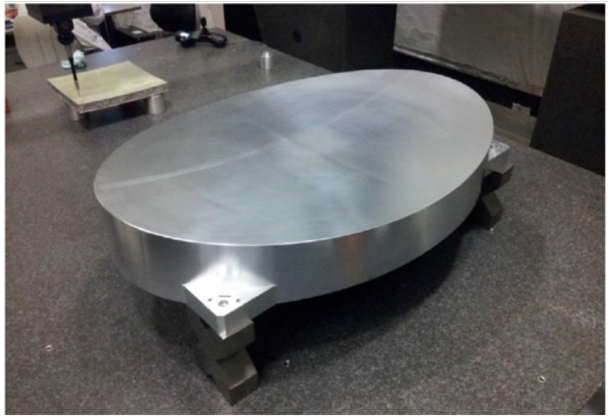
- System
- Telescope
- Electronics

Telescope

Responsibility of the optics

Design and realization of the primary (1-min aluminum) mirror – New technology – Needs for a pathfinder

Realization of the telecopes structure



Science activities

Contribution to several WGs

- Stellar Variability (obs & th)
- Target list Selection
- Atmospheric chemistry (gaseous planets)
- Atmospheric chemistry (super-Earths)
- Laboratory simulations of planetary atmospheres
- Cloud Modelling
- Spectral Retrieval Simulations
- Data Analysis Techniques
- Planet formation
- Preparatory follow-up observations from the ground
- Synergy with Plato/Cheops/TESS/Gaia/ELT
- Upper atmosphere/escape processes
- ...

@exoplanetsit