ESF LESC-PESC Exploratory Workshop:
Observation, Characterization and Evolution of Habitable Exoplanets and Their Host Stars
Bairisch Kölldorf, 29th November - 1st December 2009

ESF Exploratory Workshop Status Report on: Observation, characterization and evolution of habitable exoplanets and their host stars

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1. INTRODUCTION

The *European Science Foundation* (ESF) is an association of 80 member organizations devoted to scientific research in 30 European countries. The Mission of ESF is to provide a common platform for its Member Organizations in order to advance and connect European research centres and to explore new directions for research at the highest scientific level. Through its activities, the ESF serves the needs of the European research community in a global context. The main objectives of ESF for the years 2006-2010 as defined by its current strategic plan are to promote science strategy and science synergy, paving the way for initiatives across disciplinary and geographic boundaries in the *European Research Area* (ERA).

Each year, ESF supports approximately 50 so-called Exploratory Workshops across all scientific domains. The Exploratory Workshops scheme is one of the key instruments of their Science Strategy pillar. The focus of the scheme is on workshops aiming to explore an emerging and/or innovative field of research or research infrastructure of interdisciplinary character. It is expected that an ESF sponsored workshop will conclude with plans for specific follow-up research activities and/or collaborative actions or other specific outputs either within the frame of ESF (e.g. prepare the ground to develop a Forward Look, a Research Networking Programme or a EUROCORES proposal; publication of a policy briefing, etc.) or for submission to the EU 7th Framework Programme or to other European or international funding organizations.

During the year 2009 the International Year of Astronomy was celebrated. One of the most important and interesting problems in modern astrophysics is the discovery of exoplanets, and the characterisation of these discoveries has evolved dramatically since the first detection of such an object more than a decade ago. Now more than 400 exoplanets are known and the near future observing facilities become extremely powerful. After the recent discoveries of small exoplanets like CoRoT-7b with $1.65R_{\mathrm{Earth}}$ by the CNES-led European CoRoT-space observatory and the discovery by the ground based $\mathrm{M}_{\mathrm{Earth}}$-project in the USA of the $2.68R_{\mathrm{Earth}}$ size planet GJ1214b, one can expect that potentially habitable rocky exoplanets will be discovered during the not so distant future. Because exoplanet research becomes more and more important an ESF sponsored Exploratory Workshop was held in the village of Bairisch Kölldorf, Austria, 29th November – 1st December 2009 (see Fig. 1).

The workshop addressed four main aspects: One objective focused on the discussion of the present status related to exoplanet roadmap exercises, existing and future mission concepts, including space and ground-based projects. The second objective was related to the characterisation of the host stars of potential terrestrial exoplanets. Because it is from fundamental importance – *related to habitability and atmosphere evolution* - to observe and analyze the activity, radiation and plasma environment and the ages of exoplanetary host stars various methods for obtaining observational evidence of the radiation environment, Coronal Mass Ejections (CMEs) and stellar winds as well as the stellar age were addressed. The third objective was a survey of exoplanet or host star characterisation relevant research carried out at present, in non-

EU Eastern European countries especially the Ukraine and the Russian Federation. A special issue for the peer reviewed Russian journal Solar System Research (SSR), which can be seen as an equivalent of Planet. Space Sci. (PSS) and which is available to the international science community in English (published by Springer) and in Russian, inside the Russian Federation and Ukraine based on some workshop topics is planned during 2010, so that exoplanet science activities become more known to researchers in these countries.

Finally one main objective of the workshop was related to discussions on plans to establish a coordinated effort, which bring together different research groups in Europe and other countries so that ground-based and space-based observations of exoplanets and their host stars can be coordinated in the best way. This report summarizes the main points of the two day workshop.

Fig. 1: The workshop participants in front of the ESF-workshop location in Hotel Legenstein, in Bairisch Kölldorf, Austria. From left 3th row: Alessandro Sozzetti, Alexander Tavrov, Ignasi Ribas, Enric Palle, Rene Liseau, Nicola Sarda, Martin Leitzinger, Siegfried Eggl, Ansgar Reiners, Eike Günther, Dmitry Bisikalo, Rudolf Dvorak, Jean Schneider; From left 2th row: Leonid Ksanfomality, Ivanka K. Stateva, Elke Lohinger, Jean-Mathias Grießmeier, Kristina Kyslyakova, Helmut Lammer, Adrian Belu, Mats Holmström, Valery I. Shematovich, Mathieu Barthelemy; From left 1th row: Mariangela Bonavita, Manuel Güdel, Joseph Seckbach, Yuri N. Kulikov, Arnold Hanslmeier.

In Sect. 2 we discuss the present exoplanet roadmap procedures and their status carried out by the European Space Agency (ESA) and the exoplanet community connected to the so called Blue Dots team. In Sect. 3 existing, planned and future space-based projects relevant for the characterization of exoplanets are discussed. Sect. 4 covers ground-based projects. In Sect. 5 we address the importance of the exoplanet host star – target star – characterization, related to exoplanet research. Sect. 6 addresses UV-astronomy and its relevance to exoplanet science. In Sect. 7 we point out that theoretical modeling is very important in the present stage for helping to design proper instruments and the interpretation of data which can characterize exoplanet atmospheres and the environment of their host stars. Finally we discuss the possibilities how a coordinated and well organized exoplanet research community could be established.

2. ROADMAPS FOR SPACE MISSIONS DESIGNED FOR THE DETECTION AND CHARACTERISATION OF HABITABLE EXOPLANETS

We are in an era where the field of *exoplanetology* evolves very rapidly in three aspects: new scientific results, new scientific ideas, new technological idea and development. This makes the science-political situation evolving permanently. It is therefore difficult to make a definitive roadmap; here we describe the situation as it is in early 2010. On the US side, the Decadal Survey Astro2010 is currently working on US plans. The outcome is foreseen for late 2010. On the European side, in September 2004 the European Space Agency ESA organized its Cosmic Vision 2015-2025 workshop, at UNESCO in Paris, France which brought together scientists from all over Europe where they could present and outline what they thought should be the major issues of space exploration during 2015 – 2025, focusing on four major themes such as:

I. What are the conditions for planet formation and the emergence of life?
    - From gas and dust to stars and planets;
    - From exoplanets to biomarkers;
    - Life and habitability in the Solar System;

II. How does the Solar system work?
III. What are the Fundamental Physical Laws of the Universe?
IV. How did the Universe originate and what is it made of?

This exercise showed that Europe is richer than ever in ideas for what should be done in space science in the coming years. ESAs Cosmic Vision 2015-2025 programme aims at furthering Europe’s achievements in space science and is based on a massive response by the scientific community to ESA’s call for themes, issued in April 2004.

The exoplanet community finally submitted one comprehensive proposal for the L class (~ 650 M€) domain:

- Darwin;

Three proposals for the M-class (~ 470 M€) domain:

- SEE-COAST: Super-Earth Explorer – Coronagraphic Off Axis Space Telescope

- PEGASE: a space interferometer to study stellar environments and low mass objects;
- PLATO: PLAnetary Transits and Oscillations of stars;

and the M-class mission

- Euclid: Dark energy with its capability to search for exoplanets by microlensing;

As well as one mission of opportunity class (~ 150 M€) domain:

- SPICA – A joint JAXA-ESA mission to discover the origins of planets and galaxies.

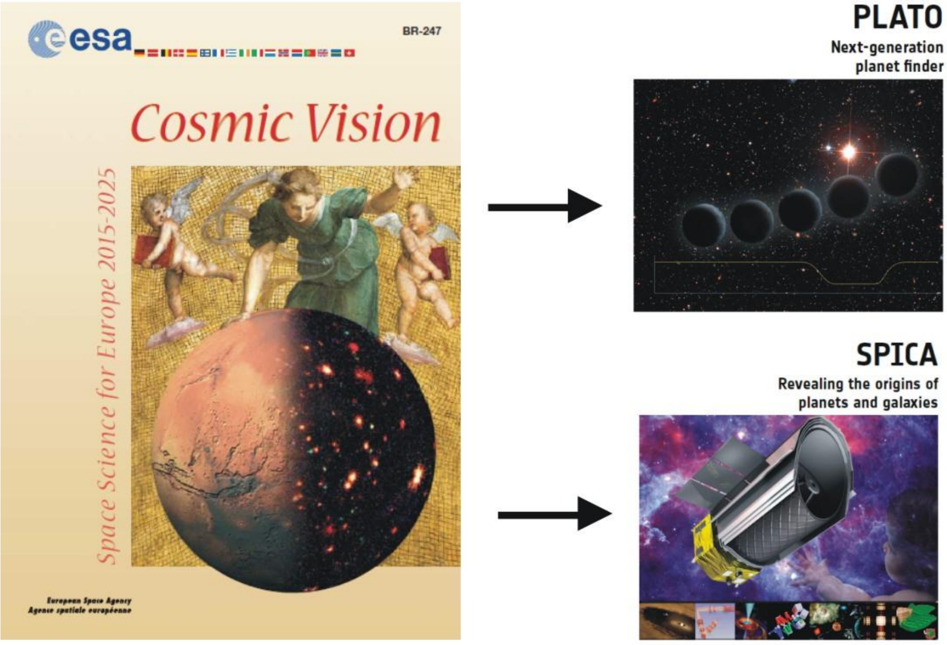
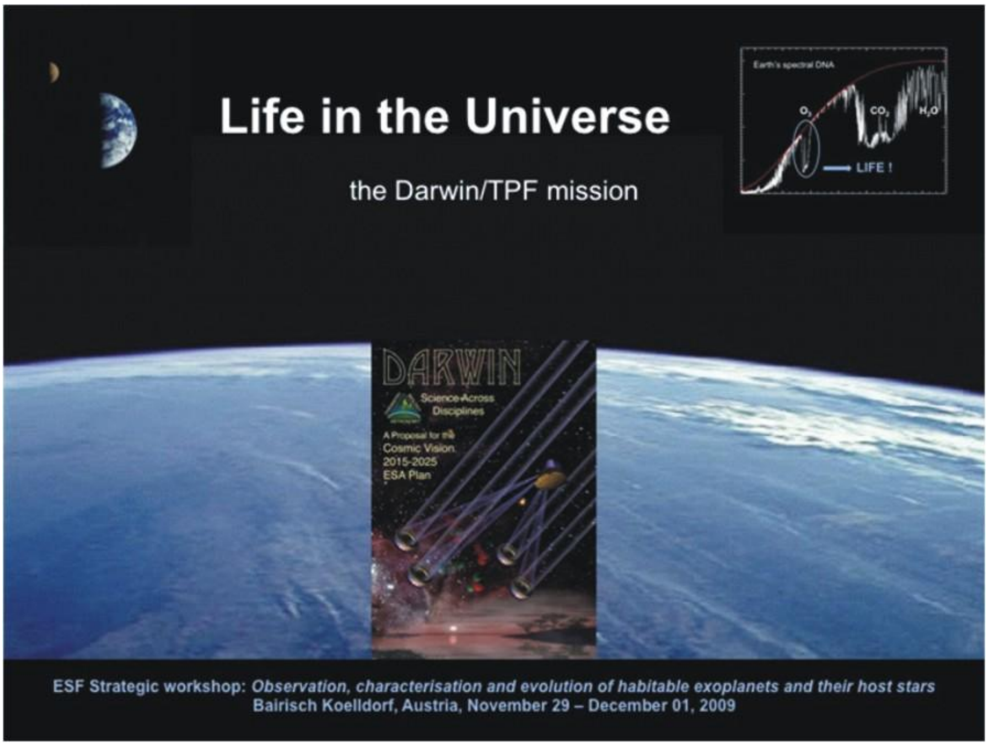


Fig. 2: Finally three exoplanet science related space missions originated from the Cosmic Vision 2015-2025 programme are still be studied by ESA, the M-class next-generation planet finder PLATO, Euclid, mainly devoted to dark energy but with the search for exoplanets by microlensing as a by-product and the mission of opportunity class contribution to the Japanese SPICA telescope.

Finally after advises and stepwise evaluations of the ESA advisory bodies such as the Astronomy Working Group (AGW) one M-class exoplanet mission, namely PLATO and the low cost mission of opportunity contribution to the Japanease SPICA telescope were selected 2007 and will be further studied in competition with other M-class missions for a possible launch date around 2017. One should also mention that the Dark Energy-Cosmology mission Euclid which is also studied within the Cosmic Vision programme has a so-called Extra Euclid Survey Science Programme (EESSP) where a microlensing survey could be planned during the extensions of the Euclid mission. A 3-month extension of the Euclid mission would be sufficient to undertake a unique microlensing survey of the Galactic Bulge, reaching detection limits which would include planets similar to those in our solar system with masses larger than Mercury.

As mentioned above the Darwin mission failed to be selected to be studied further within the Cosmic Vision programme under the frame of L-class missions. The primary aim of the proposed mission Darwin is to search for signs of Life on extrasolar planets and their moons. Since the mid-nineties, we know that planets abound in the Universe and we can expect Life to do so as well. The suggested technical solution to accomplish the scientific goals of Darwin is an adaptable nulling interferometer, operating at mid-infrared wavelengths in both photometric imaging and spectroscopic mode, and with a total collecting area comparable to that of the James Webb Space Telecope (JWST). The Darwin team had been closely collaborating by NASA supported team in the USA within ESAs Terrestrial Science Advisory Team TE-Sat. In fact, the to ESA proposed Darwin concept had been jointly developed. The American twin of Darwin is named TPF-I (Terrestial Planet Finder-Interferometer).



Life in the Universe

the Darwin/TPF mission

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Fig.3: Illustration of the Darwin/TPF mission concept and proposal. For the time being, one can look forward to the likely recommendation of an astrometry mission SIM-L by the US National Academies Decadal Survey. If the highly-ranked SIM-L mission will also be selected by NASA for implementation, ESA/Europe could engage itself as a partner. Astrometric data, complementing radial velocity results, would constitute a true milestone on the road of Darwin/TPF-I-type exoplanet atmospehr characterisation missions. Precise planetary positions would then already be known and such mission could focus on the spectroscopic search for life on the discovered rocky exoplanets.

With the Darwin proposal, 51 scientists responded to the Call for L-missions within ESAs Cosmic Vision 2015-2025 programme. The fact that the proposal was accompanied by signatures of 650 supporting scientists from 20 countries underscores the widespread interest in this highly interdisciplinary endeavor. It is also very well known that there is an enormous interest among the public, which could provide ESA an excellent opportunity to make it wider known to the European taxpayers and their politicians.

What regards the Cosmic Vision 2015-2025 proposal, it had seen a decade of preparatory research and had undergone considerable maturation, both technologically and scientifically. For instance, under the tutorship of ESA, a full scale industrial study had been carried out by Alcatel. An international conference was held in Stockholm in 1999 in which Alcatel was actively participating in the science sessions, but also as a financial sponsor.

Therefore, it came to many European scientists as a surprise, that Darwin was not selected for further study within the Cosmic Visison 2015-2025 programme. The underlying details for this non-selection seem not publicly available. However, from contacts with members of the ESA advisory bodies AWG, SSWG, SSAC and SPC it became clear that the main reason was a supposed insufficient Technology Readiness Level (to go forward in the selection process requires TRL equal to or higher than five). Little technology studies related to Darwin has been performed by ESA since 2007, while in the USA some of the technological research continued related to the TPF-projects. By mid-2009, US research had resulted in TRL6 for most critical technologies. Exceptions were:

- cryogenically controlled nulling interferometry;

and

- high precision formation flying of multiple spacecraft;

At the ESF-Workshop it was discussed if ESA could lead the cryo-breadboard research related to Darwin/TPF-I-type missions, perhaps in collaboration with national laboratories. The Sweden-led international two-spacecraft mission PRISMA, designed to test multiple formation flight, has its planned launch in February 2010. In addition, ESA is itself planning a mission of similar scope, viz. Proba-3, for launch in 2013. The successful completion of such tests could enable a Darwin/TPF-type project to enter the Definition Phase (TRL5: Phase B) and/or the Implementation Phase (TRL 5-6: Phase C/D). However, until now, after the first Cosmic Vision mission selection no L-class exoplanet mission is for seen by ESA before 2020 or even 2025.

In December 2006 the NSF-NASA-DOE Astronomy and Astrophysics Advisory Committee (AAAC) established an ExoPlanet Task Force (ExoPTF) as a subcommittee to advise the NSF and NASA on the future of the ground-based and space-based search for and study of exoplanets, exoplanetary systems, Earth-like exoplanets and habitable environments around other stars. The ExoPTF was asked to recommend a 15-year strategy to detect and characterize exoplanets and planetary systems, and their formation and evolution, including specifically the identification of nearby candidate Earth-like planets and study of their habitability. The involved scientists developed a strategy which is intended to address three main fundamental questions, ranked in a priority order, within three 5 year long periods, over 15 years:

I. What are the physical characteristics of planets in the habitable zones around a bright, nearby stars?

II. What is the architecture of planetary systems?

III. When, how and in what environments are planets formed?

Finally in May 2008, the established US-roadmap recommends the following strategy for the detection and characterization of Earth-size exoplanets. For Earth-size and mass exoplanets discovered around host stars which are much less massive and cooler than our Sun (mainly M-dwarfs), the existing ground-based techniques including radial velocity and transit searches, and space-based facilities such as Spitzer and the developed JWST, should be adequate for detecting and studying objects close to the mass and size of the Earth.

In parallel to the M-star strategy they concluded that the detection of such planets around the hotter and brighter F, G, and K stars, some which are very close in properties to our Sun is assessed with the CoRoT and Kepler space observatories, but new space missions are required for detection and study of specific Earth-mass and Earth-sized objects. They concluded that these projects should include the development of a space-based astrometric mission, narrowly-focussed to identify specific nearby stars with Earth-mass planets, followed by the direct detection and characterization via a space-based coronagraph/occulter or interferometric mission (e.g. TPF-C, TPF-I, etc.). Ground- and space-based microlensing programs pursued in parallel would provide complementary information and science.

Finally the ExoPTF recommended that the observation of dust around nearby potential target stars should be undertaken early, so that one can determine whether typical systems are clean enough to make direct detection feasible. Besides the search and charactization strategies for Earth-type exoplanets, the US-Task Force addressed recommended programs in ground-based observations of larger exoplanets, planet-forming disks, and theoretical and laboratory studies crucial to interpreting and understanding the outcome of the planet search and characterization observations.

On the other side of the Atlantic, the European Space Agency (ESA) has initiated during 2008 an expert advisory team of advising ESA on the best scientific and technological roadmap to address questions related to the characterization of terrestrial exoplanets up to the possible detection of biomarkers and the preparation of an exoplanet roadmap in order to fulfill scientific goals of the ESA Cosmic Vision

2015-2025 scientific plan with respect to exoplanets and especially terrestrial bodies orbiting stars other than our Sun.

Shortly after the Exoplanet Roadmap Advisory Team (EPRAT) was formed, an open Call for White Papers for the European science community was issued. During August 2008 and 2010 the EPRAT team evaluates the papers and suggestions by the scientists and takes them into account in the preparation of the final report which will be released to the scientific community in summer 2010. Before the report will be published, EPRAT plans an open workshop in ESTEC, The Netherlands were the roadmap will be discussed between participating scientist and the EPRAT team. Feedbacks will be included in the final report which is expected to include a survey of existing and planned facilities, both ground- and space-based; and the scientific goals likely to be achieved with these facilities as well as the identification of future facilities, mission concepts and relevant technologies which are needed to achieve the scientific goals.

As discussed above after ESAs call for Cosmic Vision L and M class missions three exoplanet related missions, namely PLATO, Euclid and SPICA will be further studied for a possible launch around 2017, but both projects have to compete with other M-class missions such as Euclid (see microlensing capability of rocky exoplanets during possible mission extension) and Solar Orbiter.

Besides the two mission studies mentioned above ESAs EPRAT team follows the discoveries by CoRoT, Kepler and various ground-based projects such as HARPS or the M_{Earth}-project and evaluates the affectivity of near future ground based projects such as the:

- E-ELT (42 m telescope), other 30 m class (2 US) facilities and associated instrumentation (e.g. EPICS);
  - Time frame: now – 2020.
  - Results: Indirect detection of terrestrial exoplanets, and direct detection/spectra of hot gas giants.
- Ground transit surveys/ micro-lensing surveys;
- Second generation instruments;
  - E.g. PRIMA (VLTI), SPHERE (VLT), Espresso.
  - Super HARPS (WHT), 0.1 m/s radial velocity (RV).

In space:

- Herschel;
  - Time frame: now – 2011.
  - Results: Direct detection of zodiacal and Kuiper-Edgeworth disks in Sun like systems out to 20 pc (key program).

The obtained White Papers could describe scientific studies, ongoing technological developments, measurements with existing facilities, new instruments, new facilities or space mission concepts needed for technological developments, considerations from theoretical modeling, or any other recommendations or information that can support the EPR-AT in its work. The current evaluation of these papers, suggestions include for instance:

- An European participation in the US planned astrometry space mission SIM-Lite;
    - 0.6 μarcsec allow detection of 1 M_{Earth} mass around 60-70 nearby stars.
- A comparison between astrometry, spectroscopy and RV measurements for finding targets for later studies;
    - Astrometry deemed one order of magnitude better than RV/photometry.
- ALADDIN: A ground based L-band nulling interferometry in antarctica;
    - Detecting zodiacial dust around solar type stars.
- Exo-zodi characterisation from space;
    - FKSI and/or PEGASE.
- Ground-based high precision RV spectroscopy in IR;
    - High stability, 1m/s, dedicated to M-type dwarf strs with a few Earth masses.
- Automated microlensing surveys, from ground and space;
    - Ground-based networks leading to space-based implementations.
- Darwin: Characterization of exoplanet atmospheres without searching the planets vs. the classical study which contained search and characterization;
- EPICS: imager for the E-ELT;
    - Detection of Neptune/super-Earth’s within 10 pc.
- External Occulters in space;
- Small (1-2m) Coronographs in space;
    - SEE COAST: direct detection of super-Earth’s.
- The THESIS space project;
    - 1.4 m telescope in L2 feeding 2 MIR spectrometers.
    - Spectroscopic characterisation of Earth-like planets orbiting M-type dwarf stars.
- Exoplanet capabilities of the SPICA telescope + coronograph;
- Fresnel Imager in space
    - Variety of occulter
- Methods and technology status from EADS;
    - ”ESA has focussed on nulling interferometry in recent years. An industrial trade between interferometry, coronography and occulters can not be made on insight but require testbeds….”
- Atmospheric modelling theory;
    - Biomarkers as a function of atmospher evolution time.

The activity of ESAs EPRAT is intended to be finished during summer 2010 and the final roadmap will be presented to ESA, the ESA advisory bodies and the scientific community.

Besides the exoplanet roadmap exercises of the big space agencies like NASA in the US and ESA in Europe, the exoplanet science community which supported also the Darwin mission and especially its scientific goals, established the so-called Blue Dots team, which is organized around a core of coordinating groups of experts in several planetary characterization, themes which cover:

- Exoplanet targets and their environments;
- Formation and evolution of planetary systems;
- Habitability criteria;
- Observations of exoplanetary atmospheres;

and as well as relevant detection techniques:

- Single aperture imaging;
- Multiple aperture imaging;
- Microlensing;
- Radial velocities;
- Astrometry;
- Transits;
- Modeling habitable planets.

One of the Blue Dots team main concerns is related to Public outreach and education, the stepwise building of a well organized and structured European exoplanet community, European networking and funding search, acting as an interface with the industry and observers / contact points for international collaboration. In first steps scientists involved to the Blue Dots team are also connected to the EU funded Europlanet project within the Na2 working groups *Exoplanets and other planetary systems* (WG5) and *Magnetic worlds, the Sun-planet connection* (WG4).

During September 14 – 18, 2009, the Blue Dots team an international scientific conference in Barcelona, Spain with the main aim dedicated to the characterization of exoplanet atmospheres with the goal of detecting signs of biological activity. The aim of this conference was to help to integrate the prospective efforts in Europe, the USA and other countries to build a community around this theme, and bring together several pathways towards its final goal. During the *Pathways to Habitable Planets* conference, four main steps were defined in order to fulfill the future objective of finding and characterizing habitable planets, these four steps can be considered as the following roadmap milestones:

Carry out a statistical analysis of the frequency of exoplanets in our Galaxy, and especially those planets that are terrestrial in nature. This analysis includes elaborating a star survey; determining the stellar types that harbor planetary *systems; exploring their structure, variety, and size distribution; and finding the frequency of terrestrial planets within the habitable zone. For this type of study, current technology is being employed, such as the space missions CoRoT and Kepler (transits) and the ground instrument HARPS (radial velocities). In the future, other space missions that study transits (PLATO, TESS) and gravitational lensing should be carried out to attain a global vision of the exoplanets in our Galaxy.*

Carry out one or more missions (possibly through collaboration between space agencies) of transit observations in order to characterize hot terrestrial exoplanets. The James Webb Space Telescope (JWST, launch date in 2014), a joint mission between NASA and ESA, may be able to contribute to this objective. However a dedicated mission with an optimized design is needed to cover the wide spectral range needed, including the visible. Ground-based observations obtained with 10-m class telescopes (VLT) and the future giant 40-m class telescopes (E-ELT) could provide important contributions to the characterization of transits some of giant and Neptune-size exoplanets.

Launch a mission capable of characterizing habitable terrestrial exoplanets in search for biomarkers, as a joint collaboration between space agencies. To determine the technological approach of this flagship mission it is necessary to mature and assess concepts, including precursor missions, related to coronography, interferometry and external occulters. In addition, the experience gained from upcoming missions like SPICA (JAXA/ESA) and JWST (NASA/ESA) will be essential.

I. Statistical study of planets with size $< 2\ R_{Earth}$ and related mass $< 10\ M_{Earth}$

II. Select the best targets suitable for spectroscopic follow-up

III. Carry out spectroscopic characterization

Fig. 4: Illustration of the 3 steps necessary to detect and characterize habitable Earth-like exoplanets, including bio-markers.

From the evaluation of the various exoplanet roadmap exercises as carried out by NASA (ExoPTF), ESA (EPRAT) and BDT one finds that the previous strategy as proposed within the original Darwin/TPF-I concepts changed from mission concepts which were designed to search, find and characterize Earth-like rocky exoplanets.

It seems that a consensus crystallizes within the exoplanet community, which can be summarized in the three steps illustrated also in Fig. 4. These steps can be summarized in:

I. A statistical study of planetary objects in order to get information about their abundance, an identification of potential target and finally an analysis of these targets.

II. Spectral analysis of Earth-like planets is mandatory, particularly to identify bio-signatures.

III. Direct characterization of exoplanets should be done by spectroscopy, both in the visible and in the infrared spectral range.

The way leading to the direct detection and characterization of exoplanets is then paved by several questions, either concerning the pre-required science or the associated observational strategy. The Blue Dot team works, like the ExoPTF in the USA and the EPRAT in Europe on a report, which will also be released during the first half of 2010 to the science community and decision makers. An important aspect is international cooperation. Given the budgetary limitations in anycountries, it is essential to coverage toward space missions in cooperation. ESA, JAXA and NASA cannot in the coming decade build a large mission by their own.

3. EXISTING, PLANNED, AND FUTURE SPACE PROJECTS RELEVANT FOR EXOPLANET CHARACTERISATION

At present (January 2010) there are two space observatories, namely CoRoT (CNES-led European) and Kepler (NASA) in orbit, which search exoplanets with the transit method. Transits of Earth-size exoplanets produce a small change in the host star`s brightness of about $1/10^4$ lasting for 2 - 16 hours. This change must be absolutely periodic if it is caused by a planet and if possible at least three times confirmed. In addition, all transits produced by the same planet must be of the same change in brightness and last the same amount of time, thus providing a highly repeatable signal and robust detection method. The size of the planet is found from the depth of the transit and the size of the star.

3.1 The CoRoT and Kepler space observatories

The CoRoT (Convection, Rotation and planetary Transits) space observatory is led by the French space agency CNES, in a cooperation with ESA, Austria, Brazil, Belgium, Germany and Spain. Initially the goal of the CoRoT mission was the observation and study of variable stars via asteroseismology. After the discovery of the first hot Jupiter in the mid 90ies – the search for exoplanets was included in the mission program (Schneider and Chevreton). CoRoT was successfully launched on December 27 from Baikonour, and the first observations started during February 2007. Besides the discovery of several exosolar gas giants (e.g., see special issue Astron. Astrophys., Vol. 506, 1, Oct. IV, 2009: The CoRoT space mission: early results; Dvorak et al. 2010), CoRoT detected the first transiting *rocky* super-Earth-type planet with a size of about 1.68 R_{Earth} (Léger et al. 2009). The life-time of the mission was scheduled for 3 years of observations and recently the extension for another three years was approved.

The CoRoT satellite has a length of about 4 m, a diameter of about 2 m and weights about 630 kg. The accuracy of the pointing is 0.5 arcsec with a capacity of the telemetry of 1.5 Gbit/day. Three systems are operating on the satellite. *CoRoTel* is an afocal telescope with 2 parabolic mirrors and aperture of 0.27 m and a cylindric baffle with a length of 2 m. *CoRoTcam* is a wide field camera consisting of a dioptric objective of 6 lenses where the focal unit is equipped with 4 frame-transfer-CCD 2048x4096. Two of the four CCDs are for the exoplanet program and two are for the seismology program. Finally *CoRoTcase* is hosting the electronics and the software managing the aperture photometry processing. A total number of 12000 stars and magnitudes between 11 and 16 are observed in the exoplanet mode. CoRoT polar orbit of the satellite allows observing 150 days, the long run, and between 20 and 30 days the short run, both in the direction of the center respectively anticenter of the galaxy.

Fig. 5: Left, the CoRoT space observatory at the top of a Soyuz rocket on the launch path of the Baikonour Cosmodrome, short before the launch (insert) and right an illustration of the satellite in orbit.

Radial velocity measurements to confirm planet candidates are usually performed with the 3.6 m HARPS spectrograph in La Silla, the 1.93 m SOPHIE spectrograph in the Observatoire de Haute Provence, the CORALIE spectrograph in La Silla, the Coud´e echelle spectrograph from the 2 m telescope in Tautenburg (TLS), Germany and the UVES and FLAMES spectrographs in Chile, as well as spectrographs at McDonald observatory.

The discovery of CoRoT-7b, the first small rocky exoplanet with measured radius and mass, and therefore with a known density, has opened up a new era, in which the CoRoT extended mission and Kepler are now playing a major role. While CoRoT has demonstrated that exoplanets can be observed via transits from space, due to the mission design CoRoT cannot discover Earth-size exoplanets within the habitable zones of their host stars. This is a task where NASAs Kepler satellite will take over.

The scientific objective of the Kepler satellite which was launched successfully launched on March 6, 2009 is to explore the structure and diversity of planetary systems. The Kepler space observatory surveys a large sample of stars with the following main scientific goals:

- Determination of the percentage of terrestrial and larger planets there are in or near the habitable zone of a wide variety of stars;
- Determination of the distribution of sizes and shapes of the orbits of these exoplanets;
- Estimate how many planets there are in multiple-star systems;
- Determine the variety of orbit sizes and planet reflectivity, sizes, masses and densities of short-period giant exoplanets;
- Identify additional planets of each discovered planetary system by using other techniques;

and

- Determine the properties of those stars that harbor planetary systems.

Kepler is a 0.95 m diameter telescope which has a very large field of view of about 105 square degrees. The fields of view of most telescopes are less than one square degree. Kepler needs this large a field in order to observe continuously andsimultaneously monitor the brightnesses of more than 100 000 stars during the nominal mission life time of about 3.5 years.

The design of the entire system is such that the combined differential photometric precision over a 6.5 hour integration is less than 20 ppm (one-sigma) for a 12th magnitude solar-like star including an assumed stellar variability of 10 ppm. This is a conservative, worse-case assumption of a grazing transit. A central transit of the Earth crossing the Sun lasts 13 hours. And about 75% of the stars older than 1 Gyr are less variable than the Sun on the time scale of a transit.

The science case of the Kepler fits like that of CoRoT into the discussed exoplanet roadmap steps and supports also the objectives of the future ExoPTF-recommended NASA Space Interferometry Mission (SIM-Lite) and the Terrestrial Planet Finder (TPF-C/I) projects. Although these future missions will not re-observe the Kepler discoveries, the CoRoT/Kepler results can be used for the identification of common stellar characteristics of host stars for future planet searches, for the definition of the volume of space needed for the search. Based form the mission design, planet formation models and discovered exoplanets, the Kepler team estimated that the mission may discover about 50 planets with the size of the Earth, about 185 exoplanets where most of them have sizes of about 1.3 R_{Earth} and more than 600 exoplanets with sizes around 2.2 R_{Earth}. Kepler's first discoveries of 4 exoplanets in the hot Jupiter/Saturn domain, and one hot Neptune was announced at the American Astronomical Society in Washington DC, on January 4, this year.

However, both telescopes, CoRoT and Kepler target rather faint stars, up to mV=15 and beyond. Their ground-based follow-up, in particular in radial velocity monitoring, is made difficult by this relative faintness. As a consequence, ground-based confirmation and mass measurements are restricted to the largest of the CoRoT and Kepler planets, which impacts definitely the scientific return of these two missions. In case Kepler will discover Earth-size planets within the habitable zones of Sun-type stars the mass determination will be very difficult.

3.2 PLATO: The next generation exoplanet transit mission

As mentioned before, PLATO is proposed as a next generation exoplanet transit mission with the main focus to detect and by including follow-up programs to characterize exoplanets and their host stars in the solar neighborhood. The main differences between CoRoT/Kepler and PLATO will be its strong focus on bright stellar targets, typically with mV ≤ 11, including a large number of very bright and nearby stars, with mV ≤ 8.
Because of this PLATO would fit into the pre-characterization aim of rocky exoplanets close enough to the Solar System. If this is possible future missions could spectroscopically study the atmospheres of the discovered planets. The prime science goals of PLATO are:

- The detection of exoplanets of all kinds reaching down to small, terrestrial planets in the habitable zone;
- The study of the host stars (age, activity, etc.);
- The pre-characterization of the discovered exoplanetary systems, planets + host stars;
- The identification of suitable targets for future, more detailed characterization, including a spectroscopic search for biomarkers in nearby habitable exoplanets.

During ESAs assessment study three concepts for the PLATO-telescope have been studied. In the first concept, the chosen solution has 12 reflective telescopes with a field-of-view of about 1800 deg^2, and a total collecting area for each observed star of 0.15 m^2, while the second concept uses 54 refractive telescopes with a field-of-view of 625 deg^2, and a total collecting area for each observed star of 0.29 m^2. The third concept proposes a different arrangement with 42 refractive telescopes. PLATO is planned to be launched by a Soyuz 2-1b launcher around 2017, which will inject the spacecraft in a direct transfer orbit and transfer the telescope to the second Lagrange point.

These goals will be reached by ultra-high precision, long (few years), uninterrupted photometric monitoring in the visible band of very large samples of (pre-selected) bright stars.

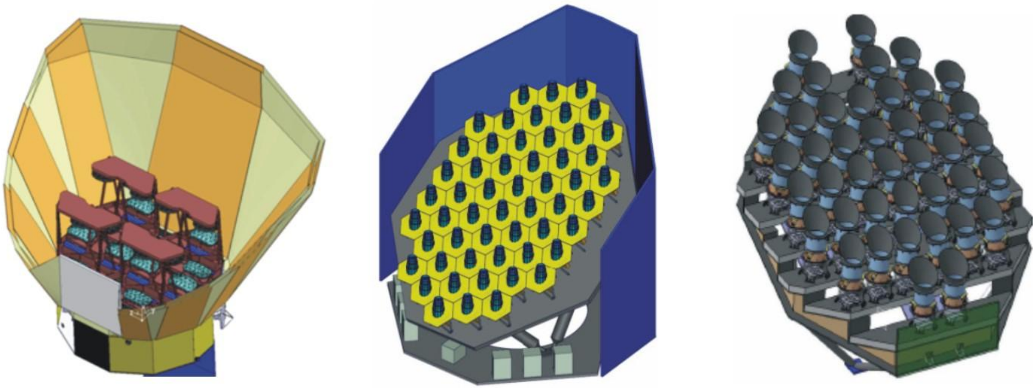


Fig. 6: Illustration of the three studied PLATO-telescope concepts. Right (first concept) 4 groups of 3 telescopes (brown) mounted on an angled optical bench. The deployable sunshield is shown in yellow/orange. Middle (second concept) 54 telescopes mounted on the tilted base plate. The sun shield is shown in blue. FEE boxes are visible at the bottom. Each telescope has a hexagonal radiator attached to the barrel segment which is shown in yellow. Right (third concept) telescopes mounted in groups on a staircase shaped optical bench (courtesy of the PLATO team).

The obtained space-based data will be complemented by ground-based follow-up observations, in particular very precise radial velocity monitoring, which will be used to confirm the planetary nature of the detected events and to measure the planet masses. Planetary rings and large moons around exo-Jupiter`s or exo-Saturn`s can also be detected by their modification on the shape and duration of the transit light-curve. For example, for a Saturn-analogue at 1 AU from the parent star, the ingress and egress take one hour for the planet and two hours for the ring. In addition, the planet ingress (egress) starts (ends) steeper for the planet than for the ring. Finally, the projected inclination of the ring with respect to the planet's orbital plane and the ring optical depth can be derived from the transit shape, which provides valuable information for the formation and evolution studies of the system.

Several host stars of discovered exoplanets will be amongst the brightest. Therefore, they will be the natural targets for atmospheric studies, either through:

- transmission spectroscopy,

or

- reflection spectroscopic studies.

The second program of PLATO focuses on asteroseismology and stellar evolution. It is planed that the instrument will perform a detailed seismic analysis of the planet host stars, allowing a precise determination of their radii, masses and ages, from which the radii, masses and ages of the exoplanets will be derived. This will provide a complete characterization of the exoplanetary systems, including their evolutionary status. The obtained results will add to the knowledge of planets related to the age of their host star, activity, etc. If one obtains atmospheric knowledge by follow-up observations one can study the role of the host star (age) activity to particular atmosphere species during the evolution of the planet in time.

To fulfill the whole program the mission relies on an extensive ground-based follow up programme which is illustrated in Fig. 7. PLATO discoveries should be complementary with ESO`s 42 m E-ELT telescope. Phase-A studies of the likely first generation suite of instruments are currently underway. This includes the Exo-Planet Imaging Camera and Spectrograph (EPICS), which will be optimized for visible and near-IR photometric, spectroscopic and polarimetric observations. Interesting discovered exoplanets will be considered as prime targets by E-ELT follow-up characterization observations and for other future space projects/program dedicated to the search for bio-markers.

Asteroseismic data from PLATO will be used to measure the stellar masses and ages, to confirm and improve the star’s radius already known from the Gaia mission, which will be discussed in the following Sect., as well as to study the internal structure and internal angular momentum of planet host stars.

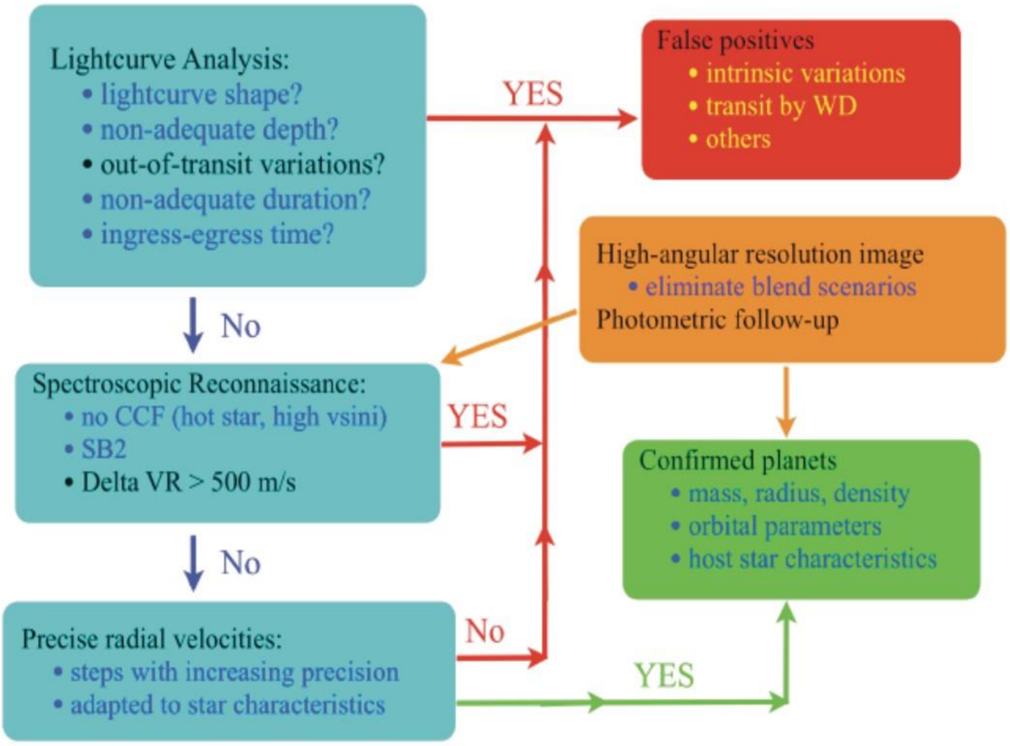


Fig. 7: Schematic illustration of planned follow-up activities for PLATO targets (courtesy of the PLATO team).

1.3 Gaia

The ESA Gaia all-sky survey space mission, due to launch in Spring 2012, will monitor astrometrically, during its 5-yr nominal mission lifetime, all point sources (stars, asteroids, quasars, extragalactic supernovae, etc.) in the visual magnitude range 6-20 mag, a huge database encompassing ~ 10^9 objects. Using the continuous scanning principle first adopted for Hipparcos, Gaia will determine the five basic astrometric parameters (two positional coordinates α and δ, two proper motion components μα and μδ, and the parallax ϖ) for all objects, with end-of-mission precision between 6 μas (at V=6 mag) and 200 μas (at V=20 mag).

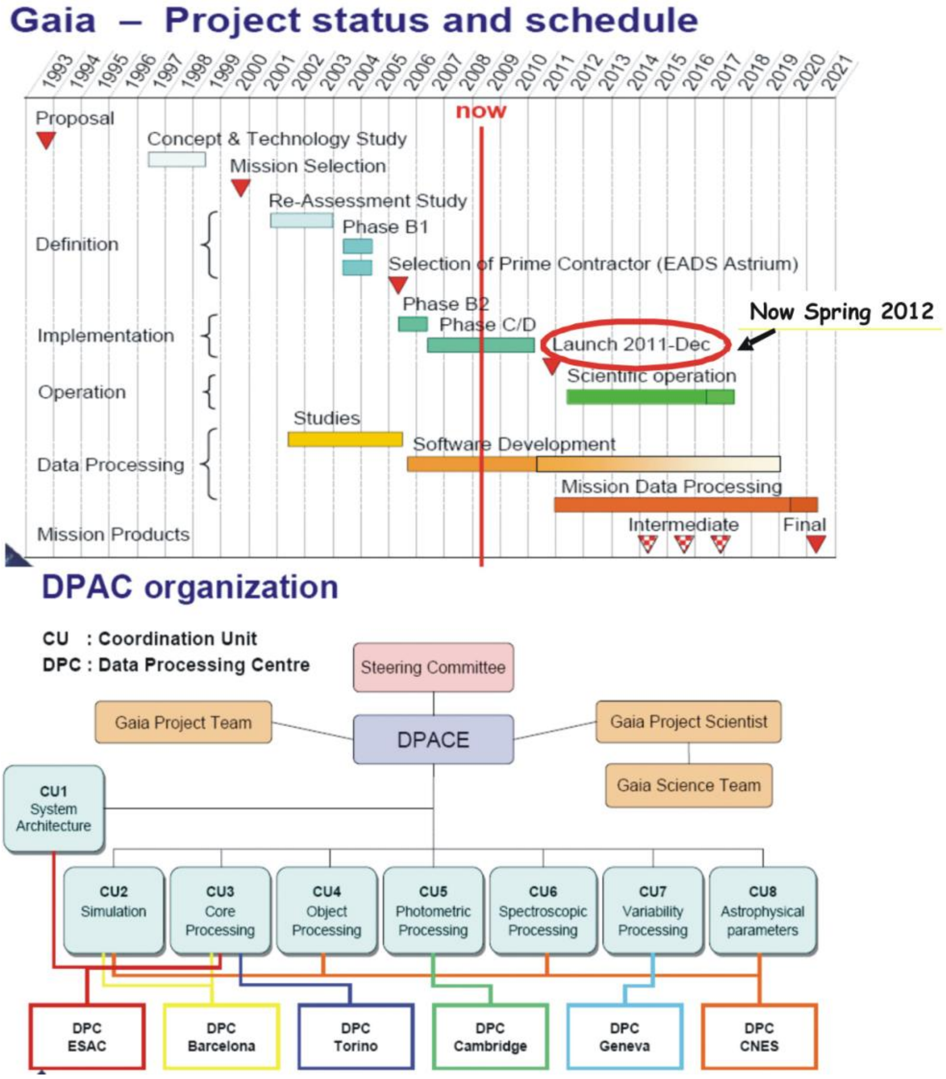


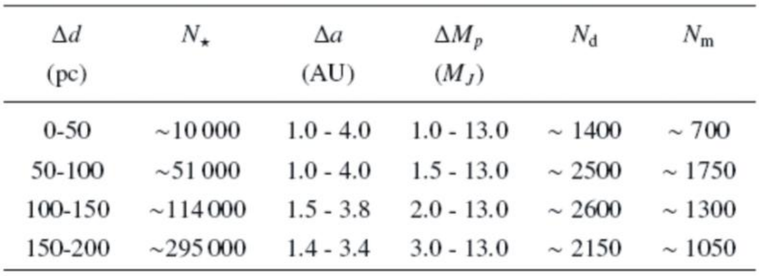
Fig. 8: Above illustration of the Gaia history and current project status, with actual launch foreseen in spring 2012. Below a chart of the Gaia Data Processing and Analysis Consortium (DPAC), in charge of the scientific processing of the Gaia data and production of the final Gaia catalogue, expected to be released by the team sometime during 2020.

Gaia astrometry, complemented by on-board spectrophotometry and (partial) radial velocity information, will have the precision necessary to quantify the early formation, and subsequent dynamical, chemical and star formation evolution of the Milky Way Galaxy. The broad range of crucial issues in astrophysics that can be addressed by the wealth of the Gaia data is summarized by e.g., Perryman et al. (2001).

One of the relevant areas in which the Gaia observations will have great impact is the astrophysics of planetary systems (e.g., Casertano et al. 2008), in particular when seen as a complement to other techniques for planet detection and characterization (e.g., Sozzetti 2009). The problem of the correct determination of the astrometric orbits of planetary systems using Gaia data (highly non-linear orbital fitting procedures, with a large number of model parameters) will present many difficulties. For example, it will be necessary to assess the relative robustness and reliability of different procedures for orbital fits, together with a detailed understanding of the statistical properties of the uncertainties associated with the model parameters.

For multiple systems, a trade-off will have to be found between accuracy in the determination of the mutual inclination angles between pairs of planetary orbits, single-measurement precision and redundancy in the number of observations with respect to the number of estimated model parameters. It will constitute a challenge to correctly identify signals with amplitude close to the measurement uncertainties, particularly in the presence of larger signals induced by other companions and/or sources of astrophysical noise of comparable magnitude. Finally, in cases of multiple-component systems where dynamical interactions are important (a situation experienced already by radial-velocity surveys), fully dynamical (Newtonian) fits involving an n-body code might have to be used to properly model the Gaia astrometric data and to ensure the short- and long-term stability of the solution (Sozzetti 2005).

Table 1: Estimated exoplanet discoveries for stars with $V<13$ during the Gaia survey as function of stellar distance Δd, number of stars N_*, semimajor axis Δa, planetary mass ΔM_p in Jovian masses (e.g., Casertano et al. 2008).



Δd (pc)	$N_\star$	Δa (AU)	ΔM_p (M_J)	N_d	N_m
0-50	~10 000	1.0 - 4.0	1.0 - 13.0	~ 1400	~ 700
50-100	~51 000	1.0 - 4.0	1.5 - 13.0	~ 2500	~ 1750
100-150	~114 000	1.5 - 3.8	2.0 - 13.0	~ 2600	~ 1300
150-200	~295 000	1.4 - 3.4	3.0 - 13.0	~ 2150	~ 1050

All the above issues could have a significant impact on Gaia`s capability to detect and characterize planetary systems. For these reasons, within the pipeline of Coordination Unit 4 (object processing) of the Gaia Data Processing and Analysis Consortium

(DPAC), in charge of the scientific processing of the Gaia data and production of the final Gaia catalogue to be released sometime in 2020, a Development Unit (DU) has been specifically devoted to the modelling of the astrometric signals produced by planetary systems. The DU is composed of several tasks, which implement multiple robust procedures for (single and multiple) astrometric orbit fitting (such as Markov Chain Monte Carlo and genetic algorithms) and the determination of the degree of dynamical stability of multiple-component systems.

Using Galaxy models, our current knowledge of exoplanet frequencies, and Gaia`s estimated precision (~10µas) on bright targets ($V < 13$), Casertano et al. (2008) have shown how Gaia`s main strength will be its ability to measure astrometrically actual masses and orbital parameters for possibly thousands of giant planets, and to determine the degree of co-planarity in possibly hundreds of multiple-planet systems. Its useful horizon for planet detection (encompassing ~ 3×10^5 stars) extends as far as the nearest star-forming regions (e.g., Taurus at d ~ 140 pc) for systems with massive giant planets ($M_\mathrm{p} \geq 2\text{-}3\ M_\mathrm{J}$) on $1 < a < 4$ AU orbits around solar-type hosts, and out to d ~ 30 pc for Saturn-mass planets with similar orbital semi-major axes around late-type stars.

In summary, Gaia holds promise for crucial contributions to many aspects of planetary systems astrophysics, in combination with present-day and future extrasolar planet search programs. For example, the Gaia data, over the next decade, will allow us to:

- Significantly refine of our understanding of the statistical properties of extrasolar planets;
- Carry out crucial tests of theoretical models of gas giant planet formation and migration;
- Achieve key improvements in our comprehension of important aspects of the formation and dynamical evolution of multiple-planet systems;
- Provide important contributions to the understanding of direct detections of giant extrasolar planets;
- Collect essential supplementary information for the optimization of the target lists of future observatories aiming at the direct detection and spectroscopic characterization of terrestrial, habitable planets in the vicinity of the Sun;

and

- Will enhance our knowledge on potential exoplanet host star parameters, which is important for asteroseismic studies yielding the age of the star for instance.

3.4 Relevant projects in orbit, development or study: SPITZER/HST, JWST, TESS, SPICA, SIM-Lite

The SPITZER and Hubble Space Telescope (HST) detected recently atmospheric species in the hydrogen-rich atmospheres of a few transiting hot gas giants with a resolution of about 5. The telescopes can be used for transit spectroscopy by taking a photometric measurement of the exoplanet and its host star during the transit and later another measurement when the star is occulting the exoplanet. By subtracting first signal from the second, the remained signal from the planet can be analyzed. Because the signal obtained from the exoplanet is very faint compared to that of its host star, such observations demand a very high photometric stability over the observing time. Theoretical models indicate that transit spectroscopy may be possible for super-Earth`s if they orbit around stars which are cooler and therefore fainter than our Sun.

The HST follower, James Webb Space Telescope (JWST), currently constructed by ESA/NASA and launched in 2014 is a large infrared telescope with a 6.5-meter primary mirror. Originally planned for observations related to star and planet formation, one of its key scientific objectives will be the characterization of exoplanets. This capability was recently recognized after the recent observations by SPITZER and HST. The JWST has three instruments which are relevant for exoplanet characterization. The NIRCAM covers wavelengths between 2-5 μm, the TFI 2-5 μm and MIRI 5-28 μm. By using the transit spectroscopy method as described above, JWST will make also a contribution to the detection of atmospheric species in exoplanet atmospheres. There are model simulations and plans to investigate the possibility that, if transiting super-Earth`s orbit nearby red cool, faint dwarf stars, atmospheric spectra, including bio-markers may be obtained.

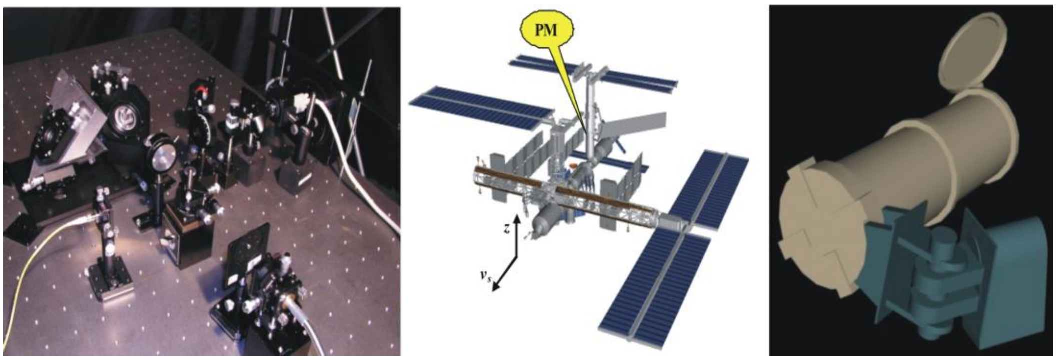


Fig. 9: Left laboratory test bed of the three-dimensional common path interferometer for achromatic nulling, which is planned to be tested on a 0.7 m telescope (right) which will be installed at the Russian ISS segment around 2015.

Besides the ESA-studied European transit mission PLATO, a Transiting Exoplanet Survey Satellite (TESS) is planned by scientists at MIT, the Harvard-Smithsonian Center for Astrophysics, and NASA-Ames. The TESS satellite would use a set of six wide-angle cameras with large, high-resolution electronic CCDs so that an all-sky survey of transiting planets around the closest and brightest stars could be carried out. The scientists involved in the study of the TESS project expect that the capabilities of this space observatory are such that it could discover hundreds of rocky exoplanets from Earth-size to super-Earth-sizes. Further TESS may detect giant exolanets at large orbital radii with a photometric precision comparable to that of CoRoT with periods up to several tens of days around bright stars. TESS would have the capability to do an all-sky survey to study bright nearby potential exoplanet hosts. In combination with JWST the detected exoplanets could then be a very good candidate for spectroscopic follow-up.

The Russian Space Research Institute (IKI) currently investigates in the laboratory a small three-dimensional common path interferometer for achromatic nulling related to problems of stellar coronography (Tavrov 2008). In Bracewell’s method, a long-baseline interferometer increases the resolution by using two telescopes. in this interferometer, the light from the background on-axis source (star) has a phase shift by π radians and interferes with a phase difference of π.

At the same time, the light from the off-axis source (planet) interferes with another phase difference, so that the off- axis source is attenuated only slightly and has a signal level sufficient for photodetection. The suppression of the on-axis source (star) allows the observation of the off-axis source (exoplanet). The theoretical parameters agree with their laboratory experiment, in which the demonstrated achromatic nulling of the on-axis signal with a nulling contrast of 10^{-3} in a visible spectral range 300 nm in width.

In astronomical observations, exosolar planets have a total brightness that is lower than the brightness of a star by 6 – 10 orders of magnitude, depending on the wavelength range, respectively, from the IR to the visible. The theory is developed for the dependence of the nulling contrast due to partial spatial coherence caused by the finite size of an extended source. It shows that the method of nulling interferometry in the existing implementation could be applied in the IR, where the required nulling contrast is 10^{-6} (Tavrov 2008). The method is planned to be tested on a 0.7 m telescope which will be brought to the Russian segment of the ISS around 2015. Besides various scientific goals the ISS T-600 telescope the three-dimensional common path interferometer for achromatic nulling will be tested related to trial methods of coronagraphic observation of exoplanets and other low contrast targets.

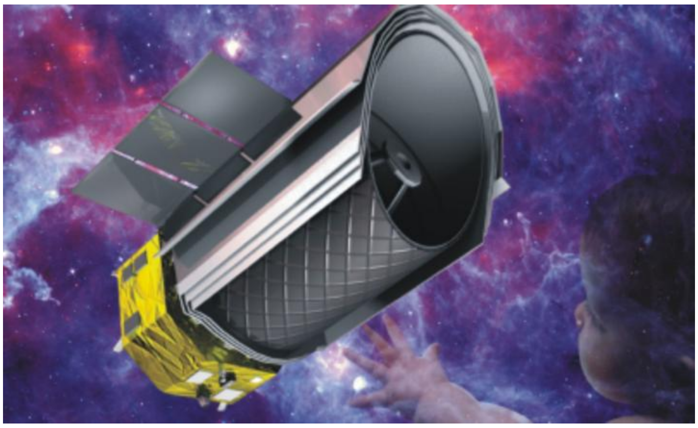


Fig. 10: Illustration of the JAXA/ESA SPICA telescope which may be launched around 2015-2017.

The SPICA (SPace Infrared telescope for Cosmology and Astrophysics) space observatory is a proposed Japanese JAXA mission with a large 3 m class infrared telescope where ESA would contribute within Cosmic Vision 2010-2025 by a mission of opportunity to the telescope assembly, a ground station, and the science operations. The European part of the mission is the SAFARI instrument.

Besides astrophysical and cosmological science questions (formation studies on the evolution of galaxies) SPICA also addresses solar system and exoplanet science relates issues related to:

- Formation and evolution of planetary systems (dust and gas of planetary nebulae, protoplanetary discs, etc.);
- Study of the ice-line in other star systems;
- Detailed characterization of Kuiper Belt Objects in the solar system and exosolar systems;
- Atmosphere characterization by the before mentioned transit spectroscopy of known exoplanets in MIR (H_2O, CH_4, NH_3, CO_2, etc.).

The SAFARI-instrument, which is to be built by a consortium of European institutes, with Canadian and Japanese participation, is an imaging Fourier Transform Spectrometer designed to provide continuous coverage in photometry and spectroscopy from 34 to 210 μm, with a field of view of 2′× 2′ and spectral resolution modes $R = 2000$ (at 100 μm), $R \sim$ few hundred and $20 < R < 50$. Four detector technologies are undergoing development to meet these requirements, where several of these detector technologies have already demonstrated that they should be capable of delivering the required sensitivity for SAFARI and all are undergoing a development program aimed at proving their compatibility with the SPICA system - the final detector selection will be made by mid 2010.

Data obtained by SPICA has several solar system science connections for instance related to the chemistry of protoplanetary discs, which is the major reservoir of key species with prebiotical relevance, such as oxygen, ammonia (NH_3), methane (CH_4) or water (H_2O) to be found later in exoplanets, asteroids and comets. Within SPICA's capabilities is the study of the ice-lines in early planetary systems which will enhance our understanding how the water is delivered to the Earth, maybe early Mars, early Venus and terrestrial exoplanets within habitable zones. Information of dust and mineralogy in planetary nebulae will be obtained via MIR/FIR mapping. SAFARI will study Kuiper Belt analogues of other planetary systems out to 150 pc, during the epoch at > 10 Myr when the transition form protoplanetary to debris discs occurs. If SPICA is approved the satellite will be launched after 2015 with JAXA's H-IIB from the Tanegashima Space Centre and is planned as a nominal three year mission with a goal of 5 years orbiting at L2.

SIM-Lite is a NASA space-based differential astrometry project that could be launched around 2015-2020. It consists of a white light interferometer with a small aperture that could measure astrometric signatures of less than 0.6 micro arcseconds at nearby stars. This would allow seeing the deflection in the plane of the sky caused by any accompanying Earth-mass planets for about the 60 - 80 nearest solar-type stars.

3.5 Beyond 2020

By evaluating the present space projects and planned project until 2020, by assuming no rise in budgets on can see that the characterization of exoplanet, including rocky Earth-like exoplanets is a complicated task, which is dependent of various small to medium class space observatories which have to compete with other non-exoplanet related space missions. However, it is unlikely that there will be a space mission before 2020 for direct characterization of exoplanet atmospheres.

As mentioned before, the Euclid mission which is dedicated to map the geometry of the dark Universe was ranked scientifically high and is studied further within the Cosmic Vision 2010 – 2015 projects. It is planned that the science return of Euclid can be further enhanced through an extension of the Euclid mission after 2020 which can undertake additional surveys and use microlensing for the detection of low mass exoplanets. This microlensing signal originates from a temporary magnification of a galactic bulge source star by the gravitational potential of an intervening lens star passing near the line of sight, with a parameter ≤ the Einstein ring radius. A planet which orbits the lens star generates a caustic structure in the source plane. The source star transiting or passing next to one of these caustics will have an altered magnification compared to a single lens, showing a brief flash or a dip in the observed light curve.

The duration of such planet lensing anomalies scales with the square root of its mass, lasting typically one hour for Mars-mass, a few hours for Earth-mass, and up to 2-3 days for Jupiter-mass planets. The Euclid science team plans a 3-month extension of the nominal mission period for undertaking a unique microlensing survey of the Galactic Bulge, so that exoplanets with masses > Mercury can be detected. Euclid has high angular resolutions which will together with the uninterrupted visibility and NIR sensitivity, be ideal for such imaging capabilities. They will provide detections of microlensing events using as sources G and K stars for rocky exoplanets down to 0.1-1 M_{Earth} from orbits of 0.5 AU. It is expected that such a space-based microlensing survey is a good way to enhance our understanding of the nature of planetary systems and their host stars, which is required to understand planet formation and habitability.

Besides the microlensing capability of an extended Euclid mission exoplanet projects related to spectroscopically characterization are studied. The Super Earth Explorer Coronagraphic Off-Axis Space Telescope (SEE-COAST or SEE) was proposed during ESAs Cosmic Vision 2010-2025 programme as a M-class project but was not selected by ESAs AWG for further studies such as the exoplanet transit mission PLATO. SEE-COAST or such a type of mission could be aimed for direct detection and characterizing exoplanets from the super-Earth (~5 Earth masses) to gas giant regime. Such missions would be dedicated to investigate and study star systems known to have exoplanets. Given the rapid advances in the methods employed to find exoplanets which can be characterized by a SEE-COAST-type mission, mainly by ground based RV and astrometric measurements several interesting target planets should be observable.

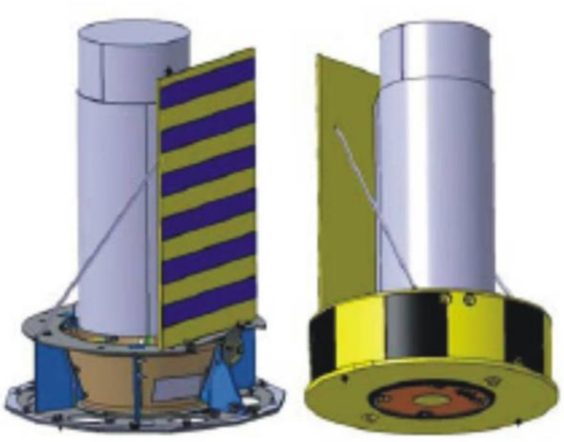


Fig. 11: Illustration of the SEE-COAST space observatory, which is designed for direct characterization of exoplanet atmospheres. One may expect that the first generation of such type of missions may be developed after 2020.

SEE-COAST as shown in Fig. 11 consists of a space telescope, a coronagraph to suppress the starlight and a spectropolarimeter to take full advantage of the information embedded in the light that is reflected by the exoplanet. The photons from the exoplanets will be submitted to an extensive analysis which should give as much information as possible about the investigated targets:

- spatial information from the imager;
- near-infrared spectral fluxes from the Integral Field Spectrograph;
- visible spectral fluxes and polarization from the high-precision polarimeter.

All that can be learnt from the faint exoplanet signal will be acquired to an unprecedented level of high-contrast imaging spectro-polarimeter. One may expect that a SEE-COAST-type mission may belong to the first generation of direct characterization missions for exoplanets.

This first generation is expected to be in the 1.5 – 2 m coronagraph class which could study atmospheres of giant exoplanets, Neptune-class and even super-Earth atmospheres (e.g., Schneider et al. 2009). After 2020 These missions may be followed by a generation of an interferometer (Cockel et al. 2009, Lawson et al. 2009), an external occulter (Glassman et al 2009), a large 8-m class coronagraph (visible), a

Fresnel Interferometric Imager (Koechlin et al 2009) or a 20 m segmented coronagraph which would resample a super-JWST for the NIR (Lillie et al. 2001).

The characterization of exoplanet atmospheres with these 2020+ space observatories will be focused on spectroscopy and polarimetric approaches. Additionally to the detection of atmospheric gases, the polarimetric approach could also be used for the study of clouds, surface, rings, etc. (Stam 2008).

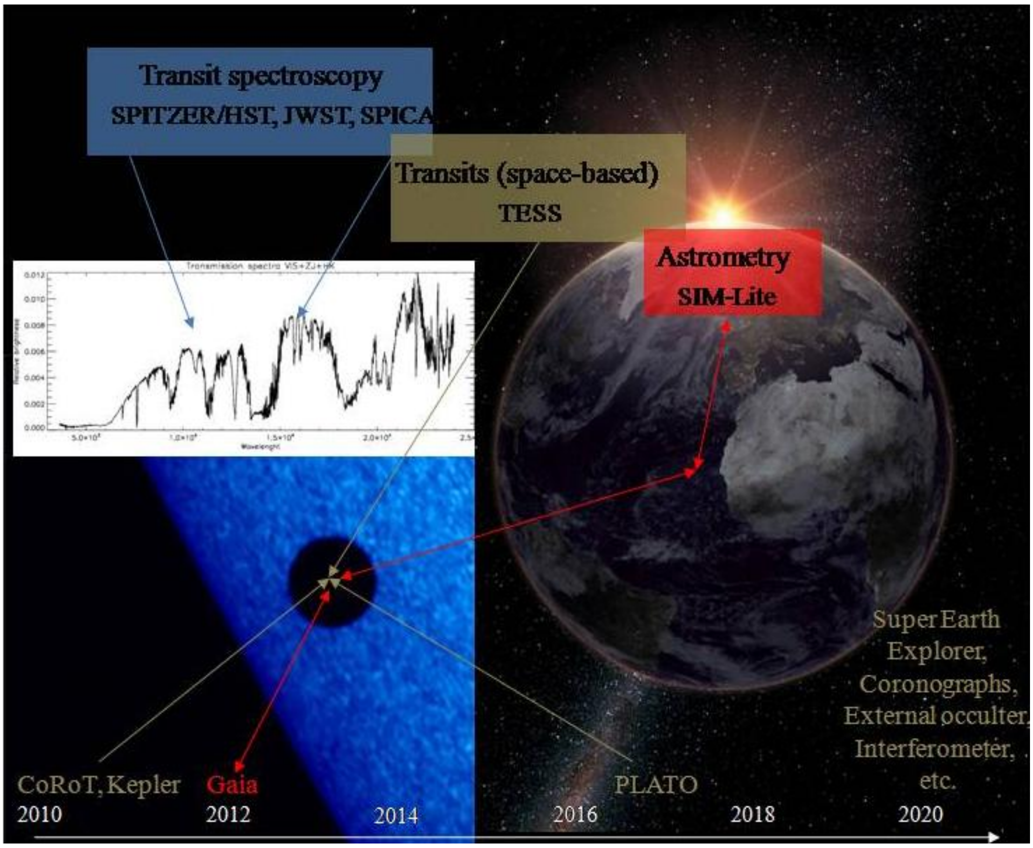


Fig. 12: Illustration of orbiting developed and planned S- and M-class exoplanet-related space missions between 2010 – 2020. One can see that during the next ten years the characterization of exoplanet atmospheres will be a complex and time consuming interplay between transits, astrometry and transit spectroscopy. The current budgets available to the space agencies do not allow a technologically feasible direct atmosphere characterization space mission. It seems that direct characterization space missions will not be developed before 2020-2025.

3.6 SEARCH a future space mission concept?

The study of a future space mission concept with the name SEARCH originated during the FFG-ESA-ESO-ISSI-Austrospace sponsored Summer School in Alpbach, Austria between July 21 – 30, 2009, whose theme was *Exoplanets: Discovering and Characterizing Earth Type Planets*, and further developed during a Post-Alpbach workshop by an international team of young European scientists and former Summer School participants at the Space Research Institute of the Austrian Academy of

Science in Graz, Austria the week before the ESF Exploratory workshop was held. The SEARCH mission concept is intended to study the diversity of terrestrial exoplanets by using spectro-polarimetry.

Since the host star`s light scattered from an exoplanet is going to be polarized to a certain degree, depending on surface and atmospheric features, polarimetric measurements contain valuable information on these characteristics not accessible by other methods. Examples are cloud coverage, cloud particle size and shape, ocean coverage, atmospheric pressure among others. Also the change in the degree of polarization over one orbital period contains valuable information on the orbital inclination, which is not accessible by radio velocity measurements. By combining this method with a spectral measurement, it should be possible to characterize the atmospheric composition and to detect molecules like H_2O, O_2, O_3, NH_3 and CH_4.

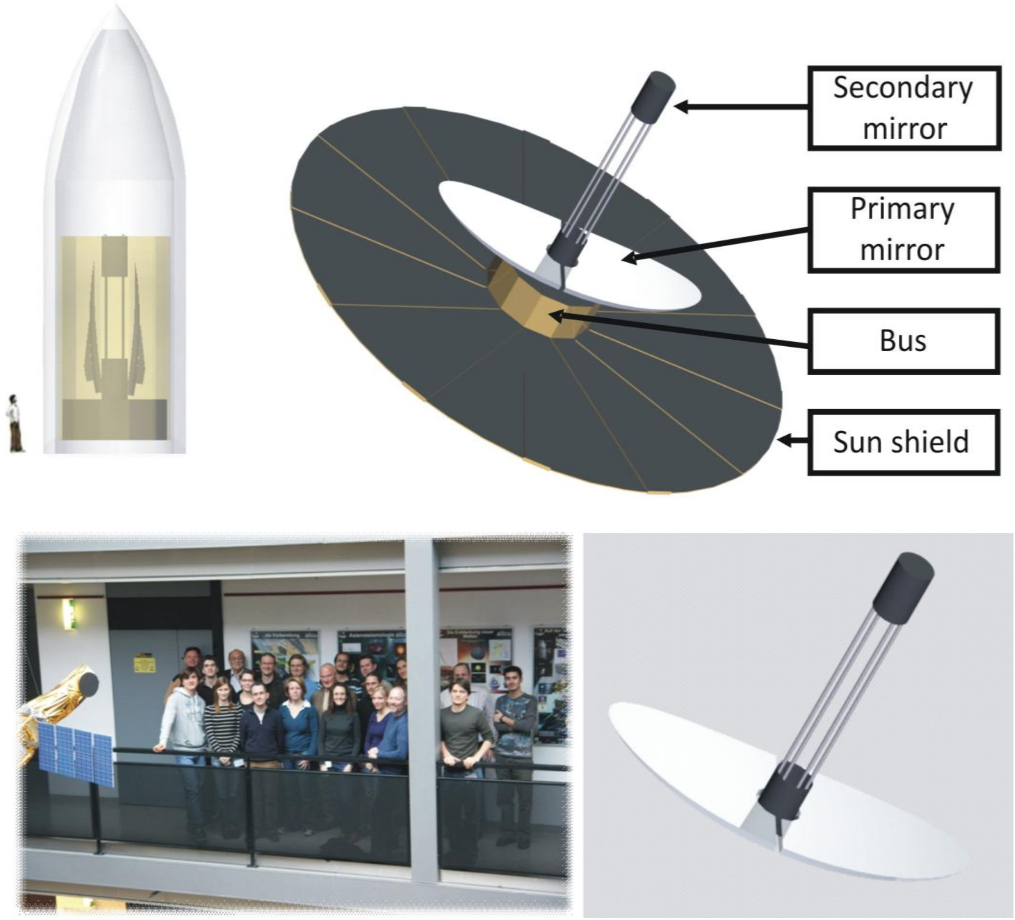


Fig. 13: Illustration of the SEARCH concept with its folded 9 m × 3.7 m mirror which fit well into an Ariane 5 rocket. Bottom left the SEARCH team at the Space Research Institute (IWF) of the Austrian Academy of Sciences during the Post Alpbach workshop (Nov. 24 – 29, 2009), where they developed this mission concept.

In order to achieve these ambitious goals two main obstacles have to be overcome, being the high contrast ratio between the exoplanet and its host star and the need to spatially resolve these two with the spacecraft's telescope. To meet those two requirements, new design concepts have been developed an analyzed.

The proposed mirror is an f/1 parabolic mirror with elliptical rim the size of 9m × 3.7 m in a Cassegrain layout. It is cut in half and folded towards the secondary mirror to fit into Ariane 5 as illustrated in Fig. 11. Thus, with the SEARCH-concept problems regarding the symmetric distribution of weight at launch can be overcome. Also the on axes-configuration significantly decreases the polarization losses introduced by the system. This design allows for an angular resolution high enough to resolve planets as close to its host star as 0.5 AU in a distance of 10 pc and as close as 1.4 AU in a distance of 30 pc, being able to actually characterize Earth-type exoplanets in a significant target sample. Given the possibility to overcome technical problems in the manufacturing of such large mirrors, it is thinkable to launch a 20 m × 3.7 m mirror within an Ariane 5 rocket. The mirrors surface smoothness is crucial to the quality of the optical system. Since it is not possible to meet the required smoothness over the whole area of the mirrors, active optics has been introduced correcting the wave front aberrations due to deviations on the mirror surface.

Regarding contrast ratio, it has been shown, that polarimetry itself can reduce the contrast ratio between host star and planet by 5 orders of magnitude, because of the host star's light being almost completely unpolarized. For the mission discussed, a half-wave-achromatic four quadrant phase mask can be chosen as both, a coronograph and a polarimeter. In addition to that, the use of an integral field spectrograph is proposed for separation of light from the star and the planet as well as the reduction of speckle noise. It is clear that there are further technological developments to be made before a mission concept like SEARCH can be realized. Nevertheless, since nearly all of those are key developments for other planned or already scheduled space missions, the SEARCH concept may be able to use these developments to achieve the ambitious goal of characterizing Earth-like planets beyond 2020.

2. PRESENT AND FUTURE GROUND BASED EXOPLANET PROJECTS

Besides the before mentioned space-based exoplanet projects there exist many ground-based exoplanet programs dedicated to radial velocity (RV) surveys/observations, transit searches, etc. where we can only mention a few of them. From the more than 400 exoplanets, more than about 80 % were detected by the RV-method, mostly of them are gas giants, about a dozen are hot Neptune`s and a handful of super-Earth’s. From this fact one can see that the ground-based exoplanet programs are important for example for the determination of the constraints on the exoplanet mass function, and orbit distribution.

The most prominent present day RV-telescopes are Coralie, Sophie, HARPS, HIRES, Lick, and AAPS. These instruments are capable of long term precision studies with RVs of < 1 m s^{-1}, allowing the detection of Neptune’s and super-Earth’s on short orbital periods and gas giants on long periods up to 10 years. Around 2014, NAHUL and GTC, SPIROU and CFHT should improve the exoplanet detection limit to about 1 m s^{-1} around cool M-type dwarf stars.

Several instruments are being planned for large telescopes currently in operation. Specifically, the next generation of ultra high precision RV-instruments can on a dedicated 8 m telescope, take the precision currently available on telescopes like the ESO 3.6 m + HARPS combination (0.5-1 m s^{-1}) and may improve it by a factor of 10. The main problem is the activity of the target stars which demand more or less continuous coverage of the whole phase of the orbital revolution of a planetary candidate and, in the case of low mass exoplanets like super-Earth`s, many periods. However, specially developed telescopes and instruments will carry the present day RV-studies into a new domain of low exoplanet masses.

The ESPRESSO and VLT may detect Earth-mass exoplanets within the habitable zone of low mass M and K stars with a velocity of about 10 cm s^{-1}. Future ground-based RV programs such as CODEX and the ELT may reach the detection of Earth-mass exoplanets within the habitable zones over spectral types M, K, G and F around 2020.

Fig. 14: Size comparison of the VLT (middle) and the future E-ELT (left) with the pyramids of Giza.

If space observatories like TESS or PLATO which are dedicated to detect such low mass exoplanets close to our solar system are approved, the ground based RV-follow up with these instruments will deliver the masses of the discovered transiting rocky exoplanets with a high accuracy.

Besides the RV-method, projects liked the recently started M_{Earth} project in the USA, which is a photometric ground-based survey of about 2000 nearest M-dwarfs are also established. The M_{Earth} project with an accuracy of $< 5 \times 10^{-3}$ mag, is optimized for to search for transiting super-Earth's in the habitable zone of close M-dwarfs. The project consist of a suite of eight amateur-sized telescopes with 40 cm diameter mirrors, each with a sensitive CCD light detector that measures the near-infrared brightness in wavelength range between 700 – 900 nm of a star. In case the brightness dims for about 60 minutes and repeats its dimming periodically over days and weeks, an exoplanet candidate is discovered, which can be confirmed after the mass determination via a RV follow-up. The M_{Earth} project discovered recently a sub-Uranus /super-Earth-type planet with the size of about 2.7 Earth-radii with an orbital period of 1.6 days around the small, faint star GJ 1214 (Charbonneau et al. 2009). In Europe the WTS/UKIRT survey will target a large sample of low-mass stars, searching for transiting rocky planets with periods of a few days.

Another European project related to the detection of exoplanets around very low mass stars uses the precision of measurements in the near infrared which is compared to optical wavelength from different instruments (ESO VLT/UVES, Keck/HIRES) (Reiners and Basri 2010; Reiners et al. 2010). It shows that for early -M stars only no advantage is existent. From ~M4 type stars on, the near Infrared gains in precision towards cooler types. Optical together with near Infrared high precision spectroscopy will provide a powerful tool for the search for exoplanets orbiting very low mass stars.

Fig. 15: The Russian Terskol telescope in the northern Caucasus mountains is planned to test the characterization of known mon-transiting exoplanets by a polarimetric method.

In the Russian Federation a project called Terskol of exoplanet observations is planned for the 2010-2014 period, with a new 2 m telescope. Within this project known non-transiting exoplanets will be observed by means of the polarimetric method, looking for their tangential transits, and using the experimental and theoretical models for inferring more data from these objects (Ksanfomality 2007).

The polarimetric search method has been tested experimentally for this purpose; the necessary astronomical observations and their processing have been performed. The results obtained allow one to assert with caution that the suggested method yields positive results and can be of use both in searching and characterizing exoplanets and refining their masses. The high correlation between the polarization variations and the revolution period of an exoplanet for which no transits are known (51 Peg) suggests that the angle between the orbital plane of the planet and the observer's direction is small ($\sin i \approx 1$). This allows refining the exoplanet mass, since the parameter $M\sin i$ turns into M if the effect is actually related to a tangential transit of the exoplanet's comet-like tail.

Single aperture imaging is another technique where instruments with or without coronagraphs related to direct detection surveys on the VLT, Gemini, Keck, and HST are planned. Future planet finder instruments on 8-m class telescopes on the VLT and Gemini S./Subaru, such as SPHERE, GPI, HiCIAO are planned to be in operation in the near future (2010-2011). The main observations with these instruments are dedicated for spectral characterization of self luminous exosolar gas giants. In the visible, the SPHERE instrument is capable to detect irradiated gas giants with $R > 1R_{\mathrm{Jup}}$, at about 1AU around nearby bright stars.

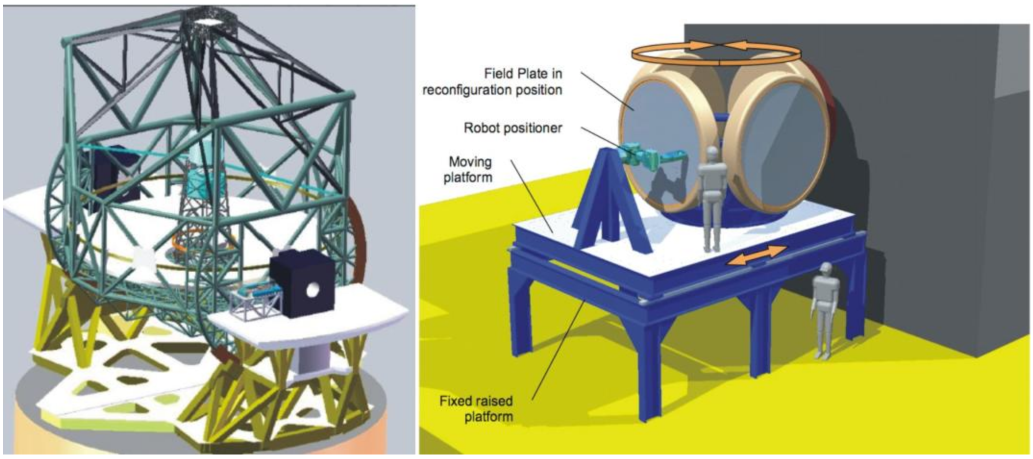


Fig. 16: Illustration of the baseline design of the Exoplanet Imaging Camera and Spectrograph (EPICS) on the left and OPTIMOS-EVE on the right (ESO).

Ground-based astrometry projects on large telescopes like with FORS2 instrument on the VLT can reach typically 100 μarcs over a few years necessary to detect exosolar gas giants around late M-type stars and Neptune-mass objects at brown dwarfs. One can expect that future astrometric facilities are based on the use of adaptive optics and imaging cameras at large ground-based telescopes.

Several ground-based surveys related to micro-lensing observation are currently ongoing and have been successful in the detection of the first super-Earth's in orbits of very distant stars. The micro-lensing method appears to have significant capability as the technology evolves.

Several large facilities are being planned for the near future. Based on adaptive optics and segmented telescopes, examples are the Thirty Meter Telescope (TMT), with an 30 m effective aperture, in the USA and in Europe the 42 m European Extremely Large Telescope (E-ELT). Operating from wavelengths ranging from UV to IR, science addressed by these large instruments include besides star- and planet formation, cosmological and extra-galactic research also the observation of exoplanets. There are currently four E-ELT instruments for the characterization of exoplanets under study:

> CODEX: RV-measure with an accuracy of 2 cm s^{-1}. This accuracy would allow detecting exoplanets with the mass of the Earth at 1 AU, orbiting a Sun-like G-type star → Rocky exoplanets detectable on inactive stars;

and

> EPICS (Exoplanet Imaging Camera and Spectrograph): Direct planet imager; this instrument is a imager and spectrograph with extreme adaptive optics → A transiting 10 M_{Earth} planet around K and M-stars brighter than about V=10 mag detected with PLATO would also be detectable with EPICS. With regard to young, forming exoplanets, it will be possible to study the early evolution which will lead to a better understanding of the initial mass function of such objects.

Besides CODEX and EPICS two other instruments, namely SIMPLE and OPTIMOS-EVE are also studied for the E-ELT. SIMPLE will have the capability to observe atmospheres of exoplanets in the wavelength range of 0.8 - 2.5 μm and OPTIMOS-EVE will be dedicated for RV-surveys of extragalatic exoplanets in the optical and IR channels.

3. CHARACTERISATION OF TARGET STARS AND EXOPLANET ENVIRONMENTS

Our knowledge regarding the discovered exoplanets is directly related by our knowledge of the parent star. The stellar X-ray and EUV (XUV) radiation and the stellar plasma outflow constitute a permanent forcing of the upper atmosphere of the exposed exoplanets and therefore can affect the atmospheric evolution and even habitability. The main effect of these forcing factors is to ionize heat, chemically modify, expand and slowly erode the upper atmosphere throughout the lifetime of an exoplanet.

The host star and its related activity can influence the ability to detect and measure exoplanet parameters. This can result in systematic errors:

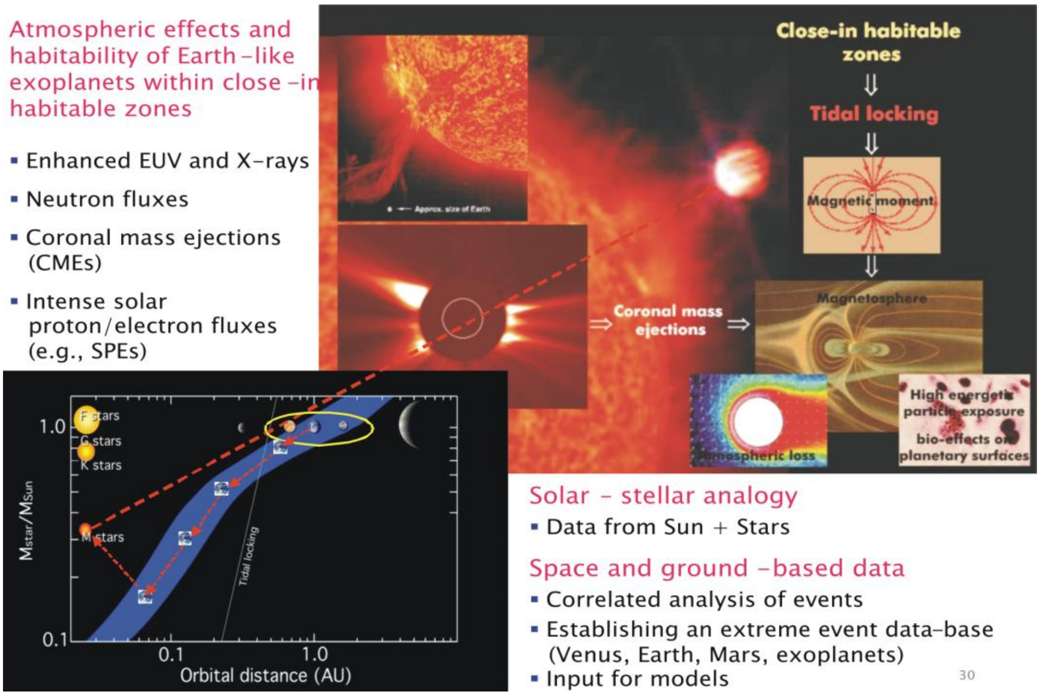
- In indirect methods, all we see is the starlight (activity, binarity/rotation);
- In direct methods, there can be challenges to detectability (zodiacal light, binarity);

- Calculated planetary properties (mass, radius) are relative to those of the star (in a linear manner).

By ultimately determining the intrinsic properties of exoplanets, their host star is the overwhelmingly larger source of energy. The stellar radiations and plasma environment (winds and CMEs) critically affect the composition, thermal properties, atmosphere evolution and even the mere existence of a planetary atmosphere, or its water inventory.

The physical and fundamental properties for target stars are, the stars mass, radius, chemical composition and age. These properties can be determined by the following methods:

- Calibrations (from binaries, clusters, etc);
- Stellar evolution models;
- Asteroseismology;
- Age: kinematics, asteroseismology, activity, chemical abundances (Li, Be), theoretical models.



Atmospheric effects and habitability of Earth-like exoplanets within close-in habitable zones

- Enhanced EUV and X-rays
- Neutron fluxes
- Coronal mass ejections (CMEs)
- Intense solar proton/electron fluxes (e.g., SPEs)

Solar - stellar analogy

- Data from Sun + Stars

Space and ground-based data

- Correlated analysis of events
- Establishing an extreme event data-base (Venus, Earth, Mars, exoplanets)
- Input for models

Fig. 17: Illustration of terrestrial exoplanets which are orbiting inside their habitable zones, related to different orbit locations based on the luminosities of their host stars. One can expect that the atmospheres of Earth-like exoplanets within close-in habitable zones are stronger affected by the host star's radiation and plasma outflow compared to the Earth orbiting a GV star (Sun) at 1 AU.

The radiative properties of the targets can be studied if one obtains a detailed spectral energy distribution from X-rays to IR, and radio. Other important stellar parameters are related to the time variability of the stellar emissions. Such processes can vary from:

- Minutes to hours: microvariability, flares, mass ejections;
- Days: spot modulations, spot evolution;
- Years: spot cycles;
- Centuries: Maunder-like minima;

to:

- billions of years: rotational spin down.

Short-term variations up to years can be studied by establishing time-series with photometry. For longer timescales observations of stellar proxies or stars of the same spectral class with different ages are the best options.

5.1 Stellar radiation environment as function of age

In general, the boundaries of the habitable zone shown in Fig. 17 change throughout the star’s lifetime as the stellar luminosity and activity evolve.

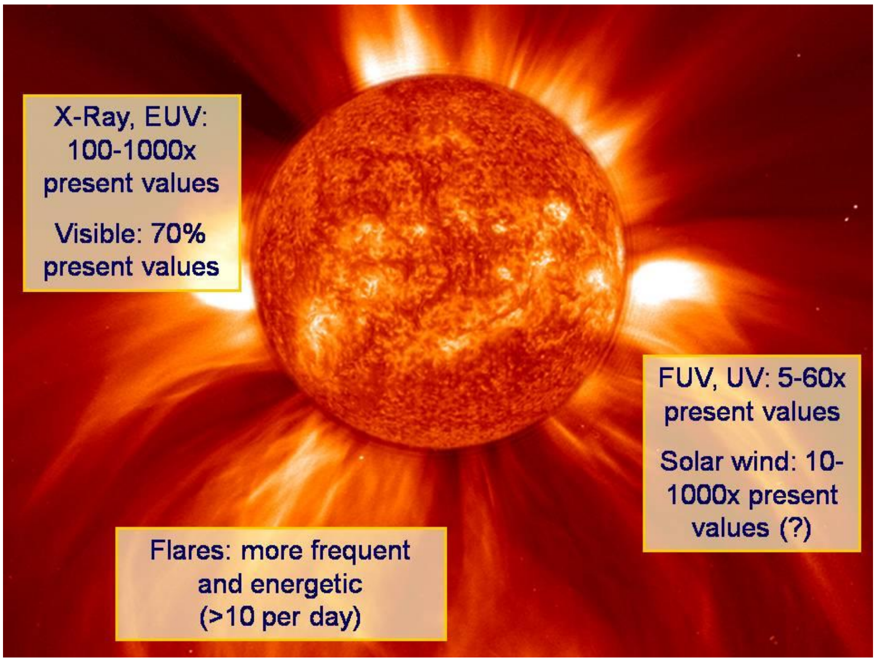


Fig. 18: Multi-wavelength X-ray and EUV (XUV) observations by the ASCA, ROSAT, EUVE, FUSE and IUE satellites of solar proxies with different ages indicate that the young Sun (stars) was very active in the short wavelength range.

Because the evolution is different for different star-types, and furthermore depends on their age and the location of the habitable zone around the host star one can expect that the atmospheric evolution of Earth-like exoplanets is strongly coupled with the evolution of the host star. This fact makes the type and the age of exoplanet host stars very important.

From that point of view the PLATO mission concept is an interesting one, because the resulting high quality light curves will be used for measuring the characteristics, and on the other hand to provide a seismic analysis of the host stars of the detected planets, from which precise measurements of their radii, masses, and ages will be derived.

Activity in late-type stars (i.e., spectral types G, K, M) has been the subject of intense studies for many years by various satellites such as: ASCA, ROSAT, EUVE, FUSE and IUE. The most important physical phenomena of stellar activity include modulations of the stellar photospheric light due to stellar spots, intermittent and energetic flares, coronal mass ejections (CMEs), stellar cosmic rays, enhanced coronal X-rays, and enhanced chromospheric UV emission. For solar-type stars this has been studied with high accuracy within the *Sun in Time* project, where a sample of single nearby G0–V main sequence stars with known rotation periods and well-determined physical properties, luminosities and ages which cover 100 Myr – 8.5 Gyr has been analyzed. From these data one can conclude that the solar integrated flux between 0.1 – 120 nm was higher by a factor of 6, 3.5 Gyr ago than compared to the present state and up to 100 times more intense than that of today Sun. Also, during the

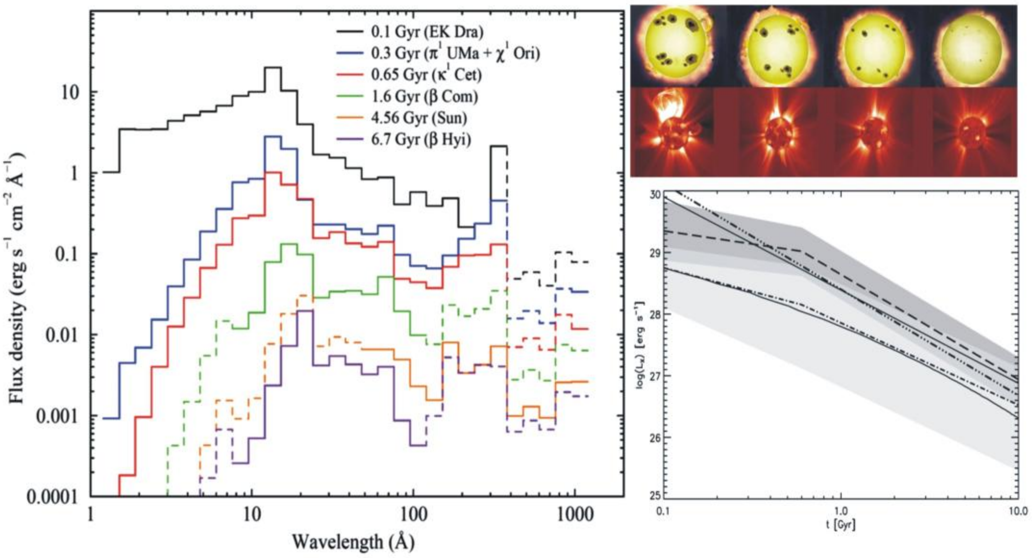


Fig. 19: Left, flux density as function of wavelength for the solar proxies with different ages which are studied within the Sun in Time project (Ribas et al. 2005). Right panel, the dashed line gives the median SXR-ray luminosity of G stars, the dark shaded area the 1σ equivalent of the luminosity distributions (Penz et al. 2008). The dash-dotted line and the light shaded area show the same for M dwarfs (Penz and Micela 2008). The solid lines display (from top to bottom) the scaling law from Ribas et al. (2005) for solar analogs in the range 0.1-10 nm, and the scaling from Guinan and Engle (2009) for a sample of M dwarfs, respectively The dash-dot-dotted line displays the scaling law for G stars from Scalo et al. (2007).

first 100 Myr after the Sun arrived at the zero-age main-sequence (ZAMS) (Ribas et al. 2005). This activity–age relation indicates that lower mass stars spend more time in this highly active but saturated phase before beginning their activity decay. In particular, solar-type stars stay at saturated emission levels until they age to ~100 Myr, and then their X-ray, SXR luminosities rapidly decrease as a function of age following a power law relationship (Ribas et al. 2005).

But low mass M-dwarfs, on the other hand, have saturated emission periods up to 0.5–1 Gyr and possibly longer for late-type M stars (Scalo et al. 2007). After that the luminosity decreases in a way similar to solar-type stars. Therefore, one may expect that the atmospheres and their evolution will be stronger – longer - affected at lower mass stars compared to more massive solar like G-type stars of F-type stars.

5.2 Stellar mass loss and plasma outflow

Stellar winds and CME plasma outflows have also important implications for the stellar and exoplanetary environments. The outflowing stellar plasma can lead to non-thermal losses of planetary atmospheres exposed to it, especially non- or weakly magnetized ones. As one can see from Fig. 17, due to tidal locking and slow rotation the magnetic dynamos of rocky exoplanets within orbits of lower mass stars may be weaker compared to fast rotating planets like the Earth. Additionally close-in exoplanets are exposed by dense plasma flows close to their host stars.

The present Sun has an integrated mass-loss rate of about 2×10^{-14} M_{Sun} yr^{-1} (Wang 1998). This is about 2-3 orders of magnitude lower than directly detectable rates with current instruments. Winds from non-solar-like objects, such as cool red giants, supergiants or young T Tauri stars, are so dense that they produce observable spectral features (P Cygni profiles) or continuum excesses at IR and radio wavelength ranges. However, non-detection of radio emission can at least place upper limits on the winds of solar-like stars (e.g., Gaidos et al. 2000).

During the last years several indirect methods for studying tenous stellar winds of Sun-like stars have been evaluated. The method which yielded the largest number of mass loss estimates so far was the search for astrospheric absorption in the region where the stellar wind meets the local interstellar medium and neutral hydrogen is formed via charge exchange. This gives rise to an absorbtion of the blue side of the stellar Lyman-α line. The amount of absorption is proportional to the stellar wind ram pressure and therefore yields estimates of the mass loss rate (Wood et al. 2002; 2005). By applying this method with the Hubble STIS spectrograph the mass loss rates of about a dozen solar-like stars and cooler stars have been derived. Depending on the age of the observed star, the mass loss rates are in the order of < 0.2 – 100 times the present solar rate.

Wargelin and Drake (2001; 2002) suggested the observation of X-ray charge exchange emission which is created by interaction of the stellar wind plasma with the interstellar medium. Up to now this method only yielded upper limits to the mass-loss rate due to lack of spatial and spectral resolution of current instruments. When application of this method will be feasible with future instruments, also the wind`s velocity, composition and geometry could be constrained.

A different approach was undertaken by Debes (2006) who analyzed pre-cataclysmic binary systems composed of an M dwarf and a white dwarf with atmospheric metal lines. Assuming that the observed metal lines are produced by accreting material from the M dwarfs' plasma outflow, the mass loss can be estimated. This resulted in mass loss estimates of 0.005 - 0.3 solar values for three close binaries, but several orders of magnitude higher for than solar rates for the wide systems, which are inconsistent with the evolution of such systems.

A magnetized stellar wind model taking into account the influence of the magnetic field on wind acceleration for fast rotating stars has been developed recently by Holzwarth and Jardine (2007). Fast rotating stars should have higher terminal wind velocities which should yield lower mass loss rates for a given wind ram pressure compared to slow rotators. From their considerations the maximum mass loss rate caused by ordinary stellar wind (not CMEs, etc.) expected for solar-type stars should not exceed about ten times the solar rate.

However, one needs clearly more observations in the future with HST, WSO-UV or IXO, etc. Although stellar wind observations are difficult to obtain, but if we don't understand how the stellar plasma outflow evolves with the age of the star after its arrival at the ZAMS one will never fully understand its role in the evolution of planetary atmospheres and even habitability.

5.3 Radio observations of active stars

High energy solar/stellar activity can be divided in two phenomena, outbreaks of radiation (flares) and high velocity mass expulsions (CMEs). Both are known and well studied on the Sun, although the question of the mechanism together with the correlation of both is still debated. However, flares or the short wavelength radiation environment (X-ray, EUV) of a star and CMEs, may have severe consequences when interacting with atmospheres of habitable exoplanets orbiting their host stars at close distances. This is the case for M-stars, where the habitable zone is at around 0.1AU. A strong stellar XUV-environment together with the Roche-Lobe effect can lead to a total mass loss scenario of the exoplanets hydrogen atmosphere (e.g., Lammer et al. 2009). On the other side, CMEs, high velocity clouds consisting of high energetic particles, may lead to the erosion of the planet's atmosphere (Khodachenko et al. 2007).

As discussed above the evolution of the stellar XUV environment can be approximated by star clusters and associations of different age. Concerning stellar CMEs, the situation is a bit more complicated, since there is no direct detection method for this phenomenon, in contrast to stellar flares, which can easily be detected in lightcurves. There are only a few attempts for the detection of stellar mass expulsions. Maybe one of the most interesting is a spectral transient emission feature detected in the blue wing of the Balmer line H_γ with a Doppler shift of 5800 km s^{-1} on the active and young M-dwarf AD Leonis (Houdebine et al. 1990).

There are also other wavelength ranges which include phenomena which are known signatures of CMEs on the Sun. An analysis of tens of solar CMEs and temporal correlated decameter type II bursts indicates, that every solar decameter type II burst of this study is correlated with a CME, but not every CME is correlated with a decametric type II burst. We are using this context to search for stellar analogues of these decametric type II bursts on active late-type main-sequence stars, especially on M-stars, due to the before mentioned effect on exoplanetary atmospheres.

Due to this analysis a project was initiated to observe such decametric type II bursts on active M dwarfs with the present time World's largest decameter array, the UTR-2 (Ukrainian T-shaped Radiotelescope 2nd modification) shown in Fig. 20 and hosted by the Institute of Radio Astronomy in Kharkov of the Ukrainian Academy of Sciences. The huge effective area of the UTR-2 is more than 150 000 m² large and ensures a sensitivity of about 1 Jy or less depending on the observing conditions. The instrument has a multi-beam capability of five simultaneously operating beams. Further a selection of five digital back-ends is available from 1024 up to 16384 frequency channels. All of them perform FFT (Fast Fourier Transformation) in realtime.

Fig. 20: The World's largest decameter array operated by the Institute of Radio Astronomy in Kharkov of the Ukrainian Academy of Sciences is used also for the search of radio signals originated in exoplanet magnetospheres and decametric type II bursts which are related to stellar CMEs.

First results were obtained during an observational campaign which took place in February of 2007 at the UTR-2. The target for this campaign, AD Leo, was selected due to its young age of about 200 Myr, a $\log L_x$ value of 28.8, the close distance of 4.7

pc, and of course suitable coordinates. Two digital back-ends were installed on beam 3 and 5 (beam 3 is pointing at the target and beam 5 is pointing one degree apart for the investigation of the background). The integration time was set to 100 ms in a bandwidth of 18-30 MHz.

During more than 60 hours of ADLeo observations at the UTR-2, many structures could be detected in the dynamic spectra. After careful analysis only a handful shows a high probability of being of stellar origin, according to their only appearance in spectra of beam 3 and further only appearance in the main lobe of the antenna pattern. So far structures which show a slow frequency drift (type II) could not be detected, instead structures with a high frequency drift (1-2MHz s^{-1}) similar to solar decameter type III bursts were detected.

For this kind of observation coordinated optical photometry provided by the observatory in Tatranska Lomnica hosted by the Slovakian Academy of Sciences were provided. Due to a bad weather situation during the UTR-2 observation campaign, there was only one night possible. The light-curve obtained by this night shows a distinct variation with a steep incline and a longer decaying tail. This indicates that a flare started around 2 a.m. UT, but the corresponding dynamic radio spectra didn`t show any convincing variation.

A possible interpretation of the non-detection of stellar analogues of solar decameter type II bursts might arise from the difference of M- and G-stars atmospheres (temperature and spatial scales) and due to the difference of convective layers. Therefore observations at the GMRT (Giant Meterwave Radia Telescope) in India of the National Centre for Radio Astrophysics of the TATA Institute of Fundamental Research are currently proposed again to observe AD Leonis. Also planned are further observations at the UTR-2 but this time of young and active G- and K-type stars.

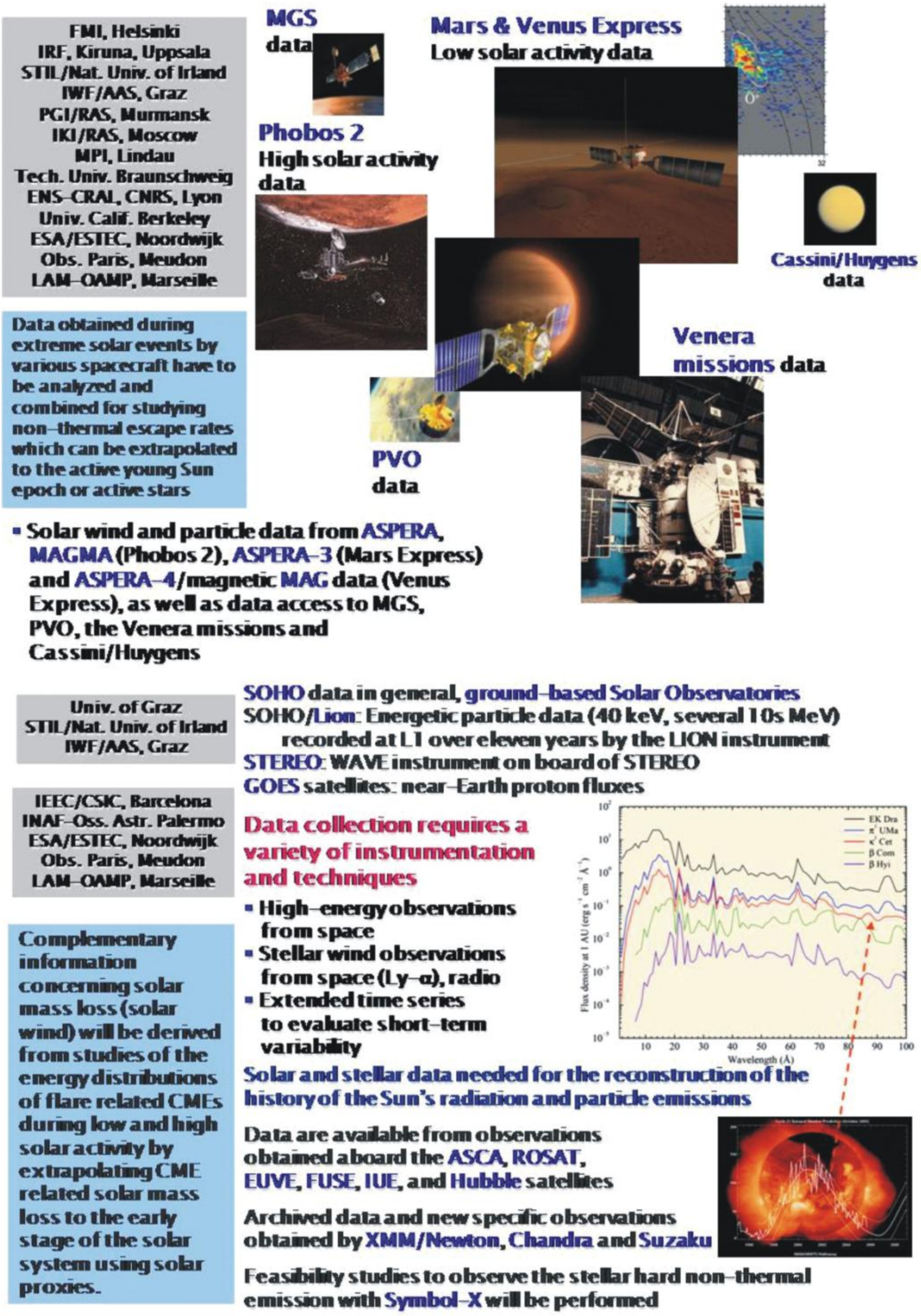
5.4 Using Venus, Earth and Mars as exoplanet proxies when they experiencing extreme solar events

Exoplanet science has a strong link to solar system science where many important data and expertise have been collected during the past decades. By establishing a coordinated study of the behaviour of the upper atmospheres, ionospheres, magnetospheric environments and thermal and non-thermal atmospheric loss processes of Venus, Earth, and Mars during *extreme solar events* important knowledge could be established related to exoplanet atmospheres orbiting within extreme steller environments.

Such studies can also serve as a proxy for the influence of the active young Sun (G-star) with implications for the evolution of planetary atmospheres (solar system and exoplanets), water inventories and habitability. Extreme events involve enhanced solar EUV and X-ray radiation, neutron fluxes, coronal mass ejections (CMEs) and related intense solar proton/electron fluxes (e.g., SPEs), auroral phenomena, magnetic storms, etc. Responses of planetary atmospheres include: thermospheric and ionospheric density variations, changes in atmospheric composition including ozone depletion leading to changes in heating/cooling, temperature and wind perturbations, photochemistry, collisional excitation, deactivation and cooling due to IR-, optical and UV-emissions, magnetospheric compression, enhancement of secondary particles, etc. Studies of the evolution of the spectral irradiances (X-ray, EUV, UV) of solar-type stars of different ages will be used as a proxy for reconstructing the history of the Sun's radiation output. Complementary information concerning solar mass loss (solar wind) will be derived from studies of the energy distributions of flare related CMEs during low and high solar activity by estimating CME related solar mass loss to the early stage of the solar system using solar proxies.

There are many space-based data available to the European exoplanet community. Energetic particle data (40 keV, several 10s MeV) recorded at L1 over eleven years by the LION instrument on SOHO, data which will be obtained by the WAVE instrument on board of STERO, particle, near-Earth proton fluxes can be used from GOES satellites, magnetic field and electromagnetic data from the Phobos 2 mission to Mars and its Moons, plasma data from ASPERA-3 (Mars Express / MEX) and ASPERA-4/magnetic MAG data (Venus Express / VEX), CLUSTER and Double Star, ENA data from MEX, VEX, and NUADU (Double Star). There are many atmospheric data available for CO_2 rich atmospheres beginning with the Venera missions, MEX, VEX, and other missions. Density and temperature changes in the Earth's thermosphere during extreme solar events could be analyzed by using low perigee satellite data (e.g., CHAMP, GOCE). Short/medium duration ionospheric disturbances can be monitored by GPS and GLONASS transmissions revealing large variations in the northern hemisphere total electron content (TEC). Europe's GOMOS/Envisat instruments provide observations of both short-term (days) and long-term (months) atmospheric effects caused by extreme solar events such as SPEs. GOMOS which was developed at the FMI measures e.g. ozone, NO_2, and NO_3 in the stratosphere and mesosphere. Data obtained by the Millimetre-wave Airborne Receivers for Spectroscopic CHaracterisation in Atmospheric Limb Sounding (MARSCHALS) project will be utilized to analyze the chemistry and composition in the Earth's thermosphere. Solar and stellar data needed for the reconstruction of the history of G-star (solar) radiation and particle emissions are available as discussed before from observations obtained aboard the SOHO, STEREO, ASCA, ROSAT, EUVE, FUSE, and IUE a satellites . New specific observations will be obtained by XMM/Newton, Chandra and Suzaku. Feasibility studies to observe the stellar hard non-thermal emission with Symbol-X will be performed.

Especially studies which set the Earth in context with Earth-like exoplanets under extreme stellar conditions could also use ground-based observations, which may include radio tomographic monitoring of the TEC (Total Electron Content). This can allow reconstruct the 2-D structure of the terrestrial ionosphere/thermosphere during extreme solar events. Parameters of the ionosphere can be determined by using the EISCAT radar network and magnetometer chain in northern Europe.



FMI, Helsinki
IRF, Kiruna, Uppsala
STIL/Nat. Univ. of Irland
IWF/AAS, Graz
PGI/RAS, Murmansk
IKI/RAS, Moscow
MPI, Lindau
Tech. Univ. Braunschweig
ENS–CRAL, CNRS, Lyon
Univ. Calif. Berkeley
ESA/ESTEC, Noordwijk
Obs. Paris, Meudon
LAM–OAMP, Marseille

MGS
data

Mars & Venus Express
Low solar activity data

Phobos 2
High solar activity data

Cassini/Huygens
data

Data obtained during extreme solar events by various spacecraft have to be analyzed and combined for studying non–thermal escape rates which can be extrapolated to the active young Sun epoch or active stars

Venera
missions data

PVO
data

- Solar wind and particle data from ASPERA, MAGMA (Phobos 2), ASPERA–3 (Mars Express) and ASPERA–4/magnetic MAG data (Venus Express), as well as data access to MGS, PVO, the Venera missions and Cassini/Huygens

Univ. of Graz
STIL/Nat. Univ. of Irland
IWF/AAS, Graz

SOHO data in general, ground–based Solar Observatories
SOHO/Lion: Energetic particle data (40 keV, several 10s MeV) recorded at L1 over eleven years by the LION instrument
STEREO: WAVE instrument on board of STEREO
GOES satellites: near–Earth proton fluxes

IEEC/CSIC, Barcelona
INAF–Oss. Astr. Palermo
ESA/ESTEC, Noordwijk
Obs. Paris, Meudon
LAM–OAMP, Marseille

Data collection requires a variety of instrumentation and techniques

- High–energy observations from space
- Stellar wind observations from space (Ly–α), radio
- Extended time series to evaluate short–term variability

Complementary information concerning solar mass loss (solar wind) will be derived from studies of the energy distributions of flare related CMEs during low and high solar activity by extrapolating CME related solar mass loss to the early stage of the solar system using solar proxies.

Solar and stellar data needed for the reconstruction of the history of the Sun's radiation and particle emissions

Data are available from observations obtained aboard the ASCA, ROSAT, EUVE, FUSE, IUE, and Hubble satellites

Archived data and new specific observations obtained by XMM/Newton, Chandra and Suzaku

Feasibility studies to observe the stellar hard non–thermal emission with Symbol–X will be performed

Fig. 21: Summary of available data obtained by solar system and solar science missions/projects which could be evaluated and used for exoplanet research by using solar system planets exposed by extreme solar events as proxies for exoplanet twins which orbit under extreme stellar environments around their host stars.

There are also many theoretical codes available for the analysis and study of exoplanet-proxy events at Venus, Earth and Mars. Test-particle/Monte Carlo, MHD, hybrid, diffusive-photochemical, thermal balance, and global circulation models are available for: investigating ionized and neutral atmospheres, solar wind/planetary interactions, and particle energy deposition in the upper atmospheres. The 1-D Sodankylä Ion and Neutral Chemistry Model will be used to study the ionospheric-atmosphere interaction processes, caused by e.g. proton/electron precipitation or solar X-ray flares, which lead to changes in atmospheric composition.

5.5 Search for exoplanetary radiosignals

In the solar system, all strongly magnetized planets are known to be intense non-thermal radio emitters. For exoplanets, an analogous radio emission is expected, which, in some cases at least, is expected to be much more intense than that of the solar system planets. The study of exoplanetary radio emission has recently become an active field of research, with both a considerable number of theoretical studies and various observation campaigns. One of the reasons for this interest is the fact that the discovery of exoplanetary radio emission would yield information which is complementary to that which can be obtained using the currently established methods.

Among other, radio emission would convey information on the planetary rotation (which would allow to check current ideas on tidal locking), the strength of the stellar wind and stellar CMEs, and the existence and intensity of a planetary magnetic field. The latter factors are important ingredients for studies of planetary habitability. Using known planetary characteristics (mass, radius, age, orbit, distance, etc) Grießmeier et al. (2007) estimated the maximum emission frequency and the radio flux for all exoplanets known as of 13.1.2007. Fig. 22 gives a brief update, including all exoplanets that were discovered since.

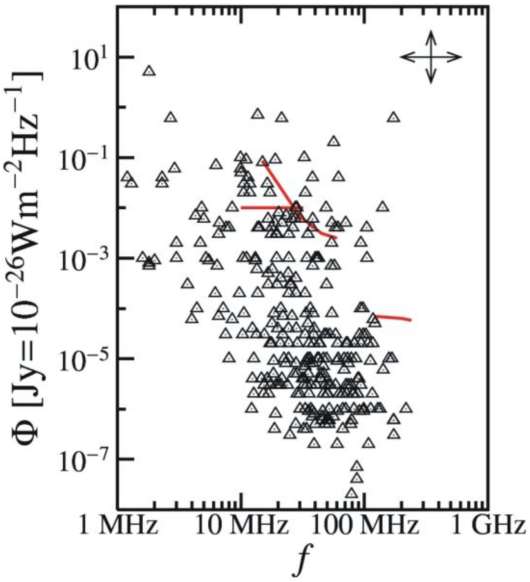


Fig. 22: Estimated the maximum emission frequency and the radio flux for all exoplanets currently known (updated from Grießmeier et al. 2007).

The results are visualized in Fig. 22. For each exoplanet individually, the expected maximum emission frequency and the estimated maximum radio flux (maximum of the three models: magnetic energy model, CME model, kinetic energy model) is given. The predicted planetary radio emission is denoted by open triangles (two for *potentially locked* exoplanets, otherwise one per exoplanet). The typical uncertainties (a factor of 2−3 for the maximum emission frequency, and approx. one order of magnitude for the flux) are indicated by the arrows in the upper right corner. Due to the relatively faint signal, large antenna arrays are required. For this reason, this kind of observation can only be performed by ground-based radio-telescopes as the UTR-2 shown in Fig. 20 or LOFAR (Low Frequency Array). As the terrestrial ionosphere is reflective for low frequencies, frequencies below 10 MHz are not observable from the ground, which gives the lower limit for the frequency range of interest. Fig. 22 shows that the upper limit of that frequency range appears to be around ~200 MHz.

The expected sensitivity of new and future detectors (for 1 h integration and 4 MHz bandwidth, or any equivalent combination) is shown for comparison. Horizontal red line at 10 mJy: upgraded UTR-2, sloped red lines: low band and high band of LOFAR. The instruments' sensitivities are defined by the radio sky background. For a given instrument, a planet is observable if it is located either above the instrument's symbol or above and to its right.

Up to ~30 exoplanets should be observable using either of these instruments. It can also be seen that the maximum emission frequency of a considerable number of exoplanets lie below the ionospheric cut-off frequency 10 MHz, making ground-based observation of these planets impossible. The figure also shows that the relatively high frequencies of the planned LOFAR high band are probably not very well suited for the search for exoplanetary radio emission. These instruments could, however, be used to search for radio-emission generated by unipolar interaction between exoplanets and strongly magnetized stars.

6. UV OBSERVATONS OF PLANETARY AND STELLAR ENVIRONMENTS

6.1 UV emissions of exoplanets

In the solar system taken as reference, one may consider three main types of atmospheric compositions.

- The first one concerns the giant gaseous planets with atmospheres mainly composed of atomic and molecular hydrogen and around 10 % of helium and a layer of hydrocarbons;
- The second one concerns Mars and Venus with mainly CO_2 and its dissociation products CO and O;
- The third one corresponds to the Earth and Titan with a mixture of heavy molecules (mainly N_2, O_2 and O at high altitudes in the first case, N_2 and CH_4 in the second).

Another point of importance influencing the atmospheric emissions is the presence of a magnetic field. In the solar system, Venus constitutes an exception since there is no clue of any magnetic field in its history. All the other planets have or had an intrinsic magnetic field. This is also the case of some of the biggest satellites.

The main emissions of the giant planets are the H-Lyman-α line at 121.6 nm as shown in Fig. 23 and the H_2 Lyman and Werner systems between 80nm and 170nm.

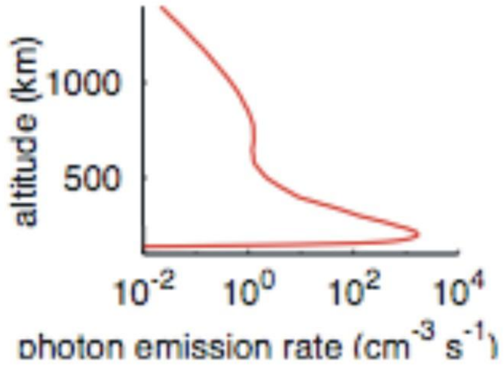


Fig. 23: Lyman-α photon emission rate in the Jovian atmosphere (from Ménager et al. accepted in Astron. Astrophys. 2010).

In the auroral oval the Lyman α emission reaches around 100 kR i.e. 8.10^9 ph.$cm^{-2}s^{-1}sr^{-1}$. The total H_2 emission reaches between 1-2 MR. Although not in the UV range, it is important to mention the H_3^+ emissions in the IR at 2 and 4μm and are the only ones observable from the ground.

These emissions bring information on the type of atmosphere. A recent sensitivity study on the Jovian case shows that the Lyman-α emission is strongly sensitive to the atmospheric model (see also Ménager et al. 2009). It is also linked to the particles precipitations. For example the Lyman α Jovian line is sensitive to electrons up to 10 keV (Ménager et al. 2009). The Jovian auroras are mainly controlled by plasma produced in the magnetosphere. To reach 100 kR, the total amount of energy coming from precipitating electrons is 11 erg $cm^{-2}s^{-1}$. This is 275 times higher than the flux due to the solar wind at Jupiter orbit.

As a primary approach and in lack of data, it is reasonable to consider that hydrogen-rich exoplanets, especially hot Jupiter’s have atmospheric compositions similar to the one of Jupiter itself. Yelle (2004) produces an atmospheric model considering a hot hydrogen corona. We used this model to calculate the Lyman-α emission of such planets. In the case of HD209458b, the modeled dayglow reaches 200 MR and is almost constant on the disk. Calculation at the limb gives 30 MR at 150,000 km of the planet’s 1 bar level. For the emissions due to electrons precipitation it reaches 20 MR with 100 eV electrons when scaling the stellar electrons flux on the Earth case, which means 1 erg $cm^{-2}s^{-1}$ at 1AU. Considering Jovian conditions the flux is 275 times higher. This calculation considered a planet without magnetic field.

220 MR corresponds to around 1/100 of the solar Lyman-α emission and considering the emitting surfaces the total emission of the planet represents around 1/1000 of the total emission of the star on the disk. At Earth, the flux is in that case around 10^{-7} ph cm^{-2} s^{-1}. For HD189733b this means 1.2×10^{-6} ph.$cm^{-2}s^{-1}$. If the hypothesis is a Jovian-like electron flux, the electronic contribution will thus increase by 275 and the total planetary emission will increase by a factor of 25 which means approximately 2×10^{-6} and 3×10^{-5} ph cm^{-2} s^{-1} for HD209458b and HD189733b respectively or 1/40 of the emission of the parent stars.

Of course several other emissions can be expected if the composition is similar to Mars, Venus or Earth atmospheres. For Martian or Venusian type atmospheres, the main emissions in the UV are the Cameron band between 170 and 300 nm and the CO_2^+ emissions at 288.3 and 289.6 nm. The day glow of these lines represents 17 kR and 7 kR. For both Venus- and Earth-type atmospheres, the oxygen green and red lines (557 nm and 630 nm) are very intense. For example, the Venus green line has an intensity of 70 kR on the dayside. It is also important to mention the Nitrogen bands in the UV (Vegard Kaplan especially) and the O 130 nm line, which is optically thick but can nevertheless be used to deduce atmosphere compositions.

The atmospheric UV emissions are therefore fundamental tools to characterize exoplanetary atmospheres. The modelling effort is under way and already produces several important results. The main difficulty is that these emissions will be very difficult to observe with the current facilities (i.e. Hubble STIS). However the first objects to observe are identified: HD189733b for the Lyman-α line is the best transiting candidate at the beginning of 2010. If we consider planets that are not in transit, closer planets could be considered as target for detecting UV emissions, like Gliese 876 and 581 at distances between 5-10 pc. Of course the first line to consider is Lyman-α but for smaller planets CO, O or N_2 emissions have to be considered as well. In this frame, a strong need for a new UV space telescope appears.

6.2 ENAs used for exoplanet and host star environment characterization

As discussed before, hydrogen-rich gas giants or exoplanets with expanded hydrogen thermospheres can be detected in the Lyman-α line at 121.567 nm, as neutral hydrogen atoms absorb Lyman-α photons. This is visible as a dip in the light-curve of the transit signal. The presence of an extended hydrogen cloud around a planet can be explained by several scenarios, depending on the composition of the atmosphere. Stellar wind produces additional absorption features, making it possible to distinguish between hydrodynamic, hot atom and stellar-wind induced mass loss and additionally observing stellar wind conditions at the location of extrasolar planets.

For instance the hot Jupiter HD209458b is an exoplanet found to transit the disk of its parent star. Observations have shown a broad absorption signature about the Lyman α stellar line during a transit, suggesting the presence of a thick cloud of atomic hydrogen around the HD 209458b (Vidal-Madjar et al. 2003).

Holmström et al. (2008) and Eckenbäck et al. (2010) studied the production of energetic neutral atoms (ENAs), which are produced as a result of the interaction between the stellar wind protons and the exosphere (see Fig. 22). ENA-clouds were discovered around every planet in the solar system, where spacecraft have been flown including the Earth.

By choosing expected values for the stellar wind and modeled exosphere, the spatial and velocity distributions of ENAs give an absorption which is in good agreement with the observations.

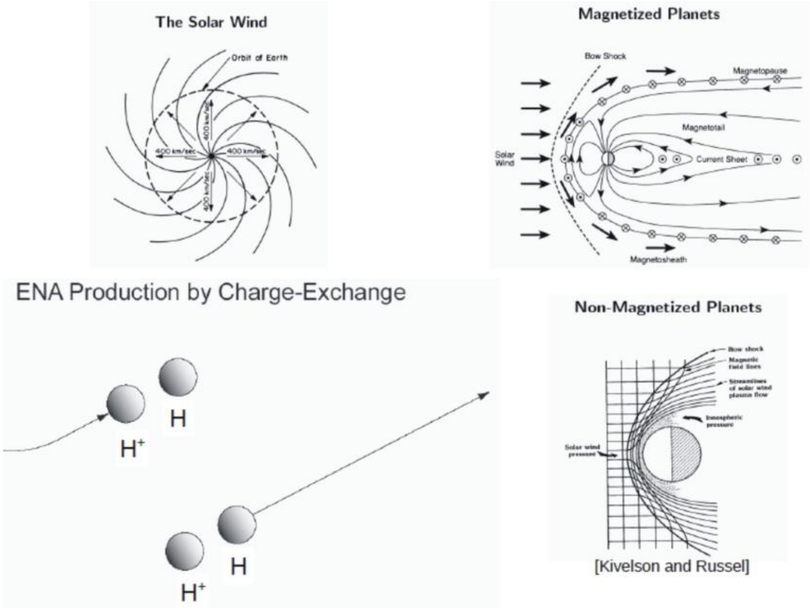


Fig. 24: Solar/stellar wind induced ENA generation around planetary bodies.

From the best fit of the modeled data with the observation one obtains knowledge of the planetary obstacle, i.e. the magnetopause stand-off distance (related magnetic dynamo, magnetosphere) – the location where the incoming stellar plasma flow dynamic ram pressure if balance by the magnetic pressure. For the particular exoplanet a stand-off distance $\geq 4\ R_{\mathrm{pl}}$ would fit the data at its best. If one compares the obstacle stand-off distance with existing exomagnetospheric models the best fit would agree with 0.4 times the value of the Jovian magnetic moment.

These Lyman-α observations compared with thermospheric modeling, including hydrodynamic expansion and out-flow models, photochemical produced hot planetary hydrogen atoms and stellar wind plasma interaction modeling can be a useful diagnostic for:

- Exomagentospheric modeling;

- For obtaining a better understanding of the thermospheric-exospheric structure of hydrogen-rich exoplanets;

and

- For inferring stellar wind plasma properties around the exoplanets location.

However, the currently available data are not sufficient to put good limits on planetary magnetic moments but this could become feasible after the launch of new UV observatories like the WSO-UV around 2012.

The observation of ENA clouds around hydrogen-rich Earth-like exoplanets, or super-Earth's like the recently discovered H_2O-hydrogen-rich GJ1214b in the UV-range would provide a unique opportunity to study the interaction of stellar activity and planetary atmospheres of low mass exoplanets close to their host stars.

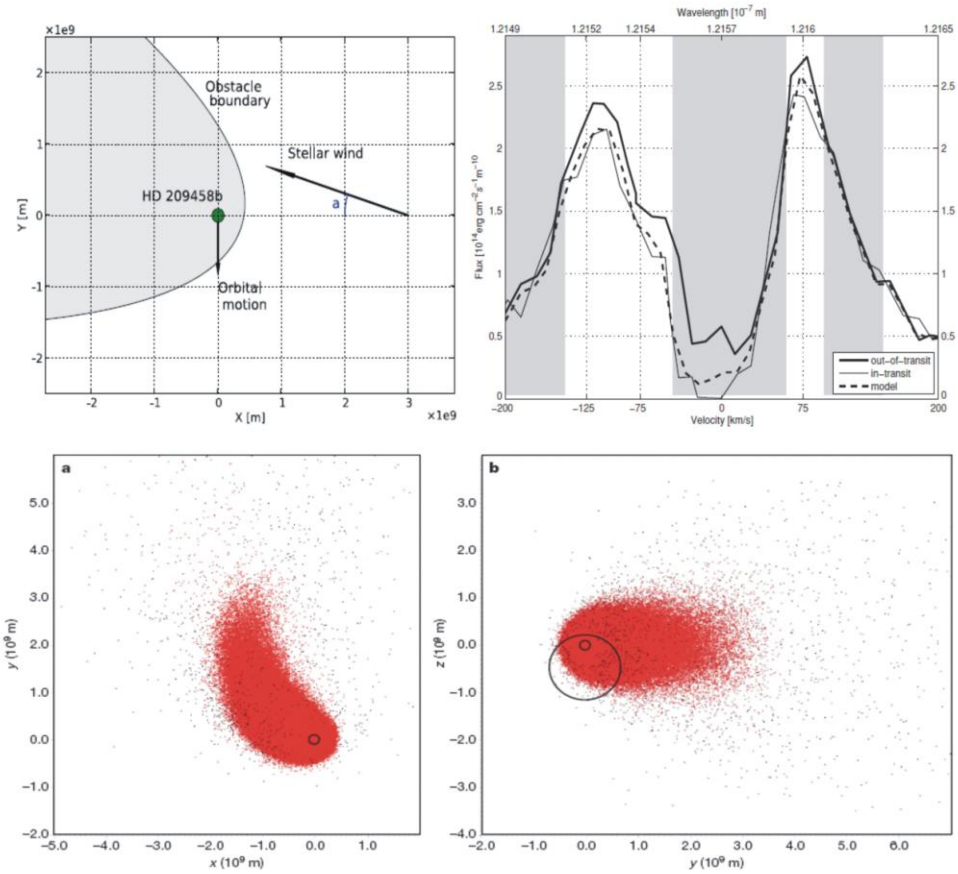


Fig. 25: Top left: Illustration of near-planet geometry and the ENA production region. This work only considers ENAs produced outside of the obstacle boundary which could be a magnetopause in case HD209458b. Top right: Obtained attenuation spectrum and comparison with observations (Eckenbäck et al. 2010). Bottom: a) shown from above, perpendicular to the planet's orbital plane; b), as seen from Earth, along the direction of the x-axis. Each point corresponds to a hydrogen meta particle. The small circles show the planet size at mid-transit. The large circle in b) shows the star's position.

During the Summer School *Exoplanets: Discovering and Characterizing Earth Type Planets* which was held in Alpbach, Austria during July 21 – 30, a group of young scientists and students brought up the ideas to observe extended hydrogen exospheres with an UV telescope in Lymann-α, similar as described above for hot Jupiter's. For ENAs to be produced in the atmosphere of rocky exoplanets there has to be a substantial amount of hydrogen extending outward a planet's magnetopause where interaction with stellar wind particles can take place. The process of photolysis dissociates hydrogen-bearing molecules like H_2O und CH_4 in the upper layers of the atmosphere, creating free hydrogen atoms which lead to the formation of extended hydrogen exospheres. There are several stages in planetary evolution, during which a planet may host such an extended hydrogen exosphere.

Ocean planets are being widely discussed, with the discovery of several super-Earth`s, but we currently have very little knowledge about the formation and early stages of planetary evolution. A super-Earth (~10 M_{Earth}) with the same relative composition as Earth is very likely to be a water-rich world. Numerical simulations by have suggested that the majority of terrestrial-type planets form with a water content of several Earth oceans (e.g., Lammer et al. 2008; 2009 and references therein). If one assumes the terrestrial planets in the solar system to be typical, then there has to be a mechanism leading to the loss of a substantial fraction of the primordial water reservoir. Evaporation of these oceans, caused by a greenhouse effect and/or the brightening of the host star, could create a hydrogen corona of several planetary radii (e.g., Watson et al. 1981).

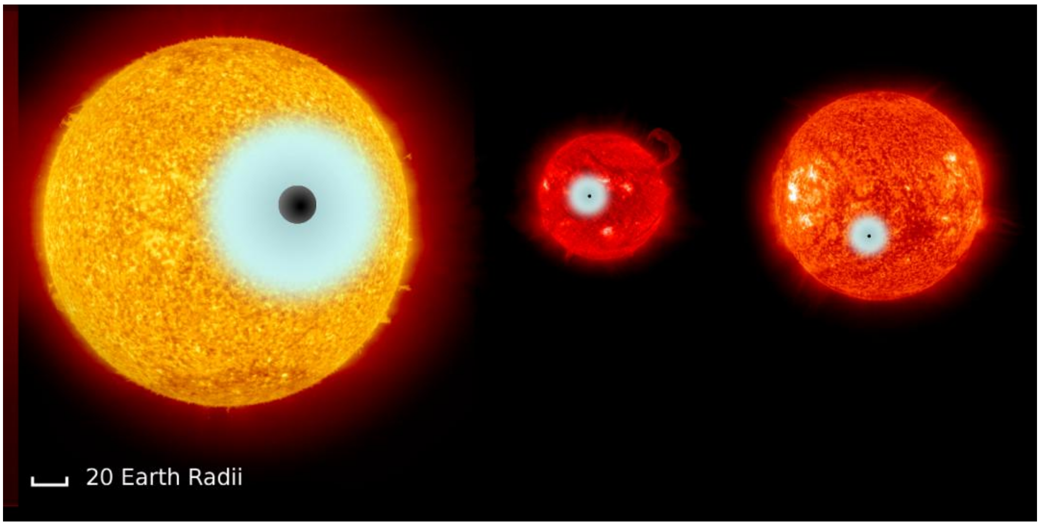


Fig. 26: This illustration shows the size relation of exoplanets with extended hydrogen coronae around G-type stars and M-dwarfs, respectively (all radii to scale). On the left there is a Jupiter-like exoplanet with the size of of $1R_{Jup}$ with an extended hydrogen thermosphere of 4.3 R_{Jup} orbiting a Sun-type star, on the right an Earth-analogue with an atmosphere extending up to 10 R_{Earth} around an M-star (0.35 R_{Sun} and $0.55R_{Sun}$, respectively). In the observation of HD209458b the hydrogen thermosphere-exosphere resulted in a dip in the light curve of 15%. It is reasonable to assume that Lyman-α intensity can be similar for the M-star. Hence as a rough estimate, the occultation of the $0.35R_{Sun}$ M-dwarf by an Earth-size exoplanet would show a dip of about 6%, and 2.5% for the $0.55R_{Sun}$ M-dwarf. (Pictures of the stars are adapted from NASA).

Another possibility are carbon-rich exoplanets with a CH_4/NH_3-rich atmosphere. Planets forming beyond the snow line are expected to accrete large fractions of volatiles like water, methane and ammonia. Such a planet would have a much larger radius than a rocky planet with a low amount of volatiles, making its detection easier. If we take into account the possibility that these kinds of super-Titans could migrate closer to their host star, they would exhibit a dense $HO_2/CH_4/NH_3$ atmosphere. A high rate of volcanic outgassing of H_2O-vapor on an exoplanet, exceeding the escape rate would also allow a hydrogen-rich thermosphere to build up, creating conditions favourable to the formation of the building blocks of life (e.g., Lammer et al. 2008; 2009 and references therein). On a planet with several Earth masses and the same bulk composition the period of high volcanic activity could be even longer, since the amount of radioactive elements in the core of the planet would be higher.

Even some forms of life can alter a planet`s atmosphere significantly. On Earth, about 3.5 Gyr ago, CH_4 producing bacteria started consuming carbon dioxide and producing methane. Methane levels were rising up to 1000 times the present level (e.g., Kaltenegger et al. 2007). Methane in such abundances will most likely diffuse into the upper layers of the atmosphere, and be photo-dissociated, producing hydrogen atoms.

To conclude, the detection and investigation of extended hydrogen atmospheres around exoplanets of all type provides very promising insights into the interaction of the host star’s plasma environment and with the planet itself, as well as it sheds light into the evolutionary stage of these exoplanets and their atmospheres. M-dwarfs are especially suited for this type of research, as they represent the majority of stars in our neighbourhood, and exhibit strong stellar activity, including in the Lyman- α range for very long time scales. The star-to-planet radius ratio is also more favourable towards terrestrial-type planets with extended hydrogen coronae around M-stars, making them ideal targets for investigating the interaction between stellar wind and planetary atmospheres in the future.

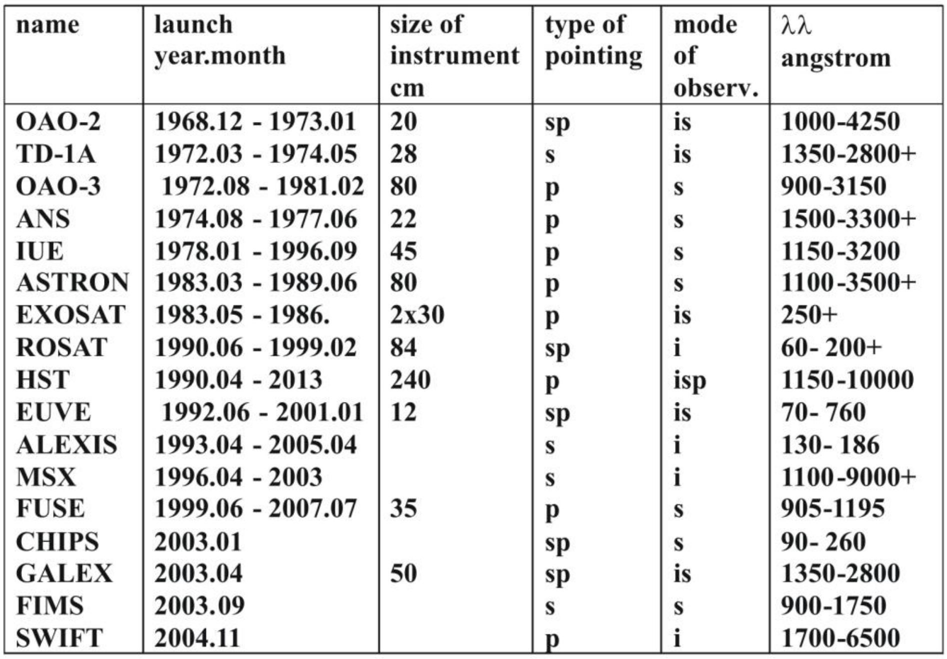
6.3 WSO-UV: Future UV observations beyond Hubble

Table 2 summarizes all the UV projects. One can see that the HST is at present time the only UV space observatory in operation. For observing and studying the scientific tasks addressed before new missions are needed. There are 3 projects in the UV pipeline:

- TAUVEX: 3 years, imaging in the 140 – 320 nm region with a 3 × 20 cm telescope;
- ASTROSAT: launch 2010, 5 years of sky imaging in the 100 – 300 nm region with 2 × 40 cm telescope (including a X-ray study);
- WSO-UV: launch 2012, > 7 years of spectroscopy and imaging in the 100 – 320 nm region with a 1.70 m telescope.

Beyond 2012 the following projects are planned. Lyra-B which may be launched around 2012 has a nominal project time of 3 to 5 years and carries out 10-band photometry (4 of them are in UV) in the 185 – 1050 nm range with a 0.5 m telescope. Other UV missions or projects like the SUVO are planned not before 2020+, UV and Opt imaging and spectroscopy with 8 m telescope.

Table 2: Summary of all UV projects carried out until now. The HST will stop its operations around 2013.



name	launch year.month	size of instrument cm	type of pointing	mode of observ.	λλ angstrom
OAO-2	1968.12 - 1973.01	20	sp	is	1000-4250
TD-1A	1972.03 - 1974.05	28	s	is	1350-2800+
OAO-3	1972.08 - 1981.02	80	p	s	900-3150
ANS	1974.08 - 1977.06	22	p	s	1500-3300+
IUE	1978.01 - 1996.09	45	p	s	1150-3200
ASTRON	1983.03 - 1989.06	80	p	s	1100-3500+
EXOSAT	1983.05 - 1986.	2x30	p	is	250+
ROSAT	1990.06 - 1999.02	84	sp	i	60- 200+
HST	1990.04 - 2013	240	p	isp	1150-10000
EUVE	1992.06 - 2001.01	12	sp	is	70- 760
ALEXIS	1993.04 - 2005.04		s	i	130- 186
MSX	1996.04 - 2003		s	i	1100-9000+
FUSE	1999.06 - 2007.07	35	p	s	905-1195
CHIPS	2003.01		sp	s	90- 260
GALEX	2003.04	50	sp	is	1350-2800
FIMS	2003.09		s	s	900-1750
SWIFT	2004.11		p	i	1700-6500

From the near future UV projects the Russia-led WSO-UV space telescope is the best suited for the observations of hydrogen-clouds around exoplanets after HST stops its operation in 2013. The WSO-UV is grown out the needs of the Astronomical community to have access to the Ultraviolet (UV) range of the spectrum. The WSO-UV project consists at present of partners from Russia, Spain, Germany, China, Ukraine, and Khazakhstan. It is an international space observatory for observation in UV spectral range (> 100 - 350 nm) and it includes a telescope with primary mirror of 170 cm and scientific instruments – imaging field cameras and 3 spectrometers (resolving power ranges from 2000 to 55000).

The WSO-UV illustrated in Fig. 25 incorporate a primary mirror of 1.7 m diameter which is half of the collecting area of HST), but taking advantage of the modern technology for astronomical instrumentation, and of a high altitude, high observational efficiency orbit, WSO-UV will provide UV-optical astronomical data quantitatively and qualitatively comparable to the exceptional data base collected by HST.

The science tasks of the WSO-UV space observatory will be related to the study of thermal and chemical evolution of the Universe, including the search for dark baryonic matter, supernovae. Besides these astrophysical themes the WSO-UV will be a powerful tool for stellar physics, the study of accretion discs, stellar wind detection related to stellar activity, and finally the study of the outer layers of exoplanetary atmospheres. The study with the WSO-UV of transiting exoplanets will provide most of the information related to stellar-planet interaction discussed in the previous section.

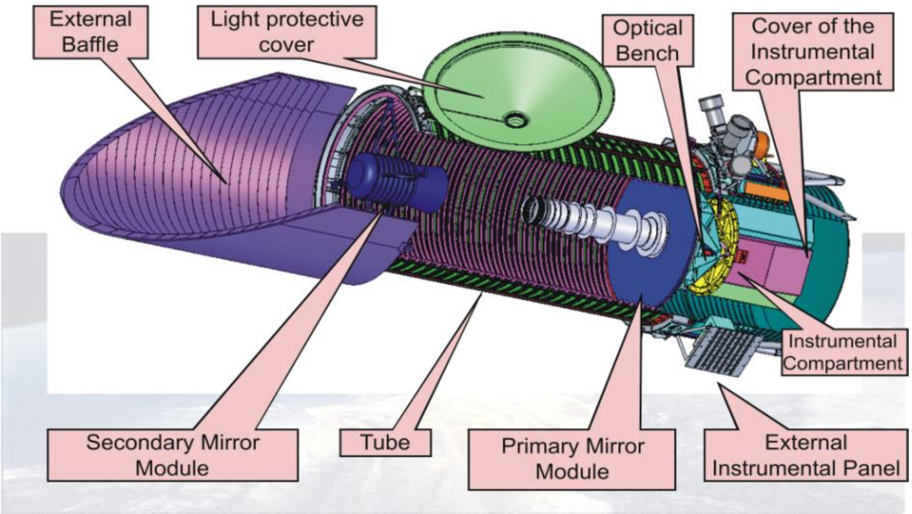


Fig. 27: Illustration of the Russian WSO-UV telescope. The observatory includes a single 1.7 m aperature telescope capable of high resolution spectroscopy, long slit, low resolution spectroscopy, and deep UV and optical imaging. The Russian Federal Space Agency ROSCOSMOS has confirmed its readiness to lead the WSO-UV project so that the project was included in the Federal Space Program of the Russian Federation and is planned to be launched around 2012 (http://wso.inasan.ru/).

7. THEORY AND MODELLNG EFFORTS

In combination with the various exoplanet search techniques, observation strategies, and exoplanet and host star characterization efforts comprehensive modeling strategies in the following fields have to be carried out (see also Figs. 28; 29; 30):

- Orbital dynamics and dynamic habitability
  (e.g., *www.univie.ac.at/adg/exostab/*)
- Modeling of spectra;
- Photochemical and climatological (cloud) studies;
- Biomarker studies;
- Hydrodynamic flow modeling of highly irradiated thermospheres;
- Atmospheric expansion studies;
- Hot particle and planetary coronae modeling;
- MHD and hybrid code application to exoplanet exospheres;
- Stellar-plasma-magnetosphere-upper atmosphere-ionosphere coupling;
- ENA cloud diagnostics;
- Geodynamic modeling;
- Planetary formation modeling;
- Habitability models.

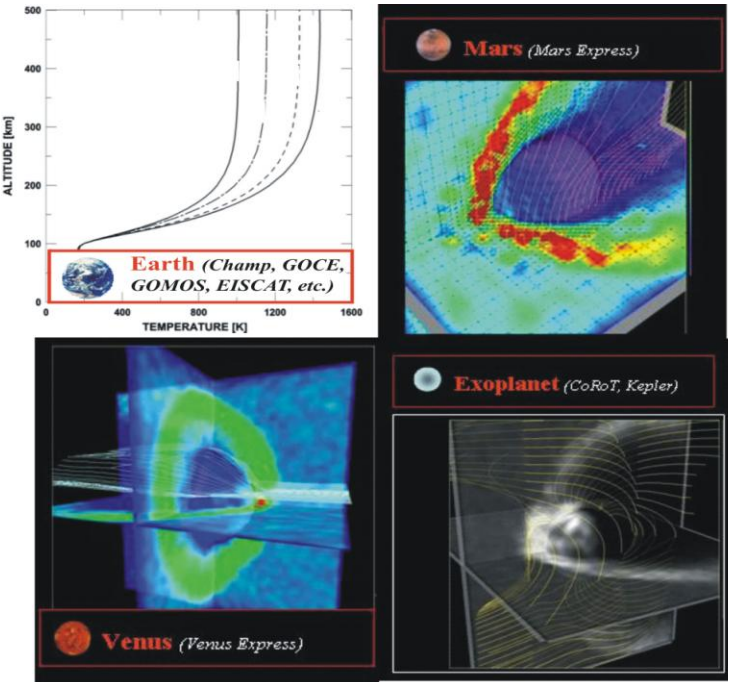


Fig. 28: Illustration of applications of Monte Carlo test-particle, magnetohydrodynamic, hybrid, and diffusive photo-chemical thermal balance models developed for solar system planets which should be applied to Earth-size exoplanets.

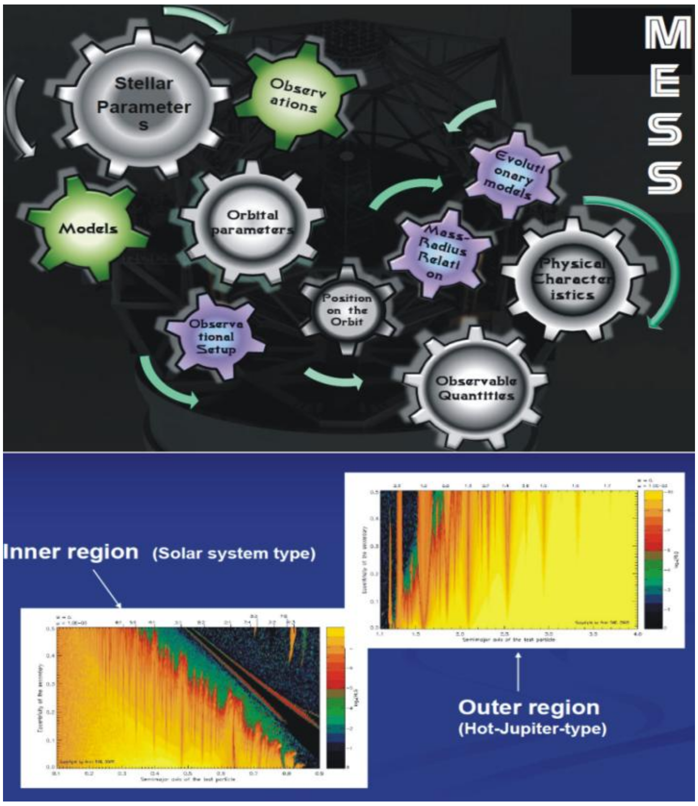


Fig. 29: Illustration of the Multi-purpose, Exoplanet Simulation System (MESS) which is currently developed for precursor studies of the E-ELT show the complexity of exoplanet modelling. Below simulations investigating dynamic habitability with ExoStab which is appropriate for single-star single-planet system and can study the: stability of an additional planet, the stability of the habitable zone (HZ) and the stability of an additional planet with respect to the HZ.

One can expect that only a well coordinated and strategically organized exoplanet community will successfully solve the 4 fundamental questions regarding our place in the Universe which were addressed in ESAs Cosmic Vision 2010 – 2015 program.

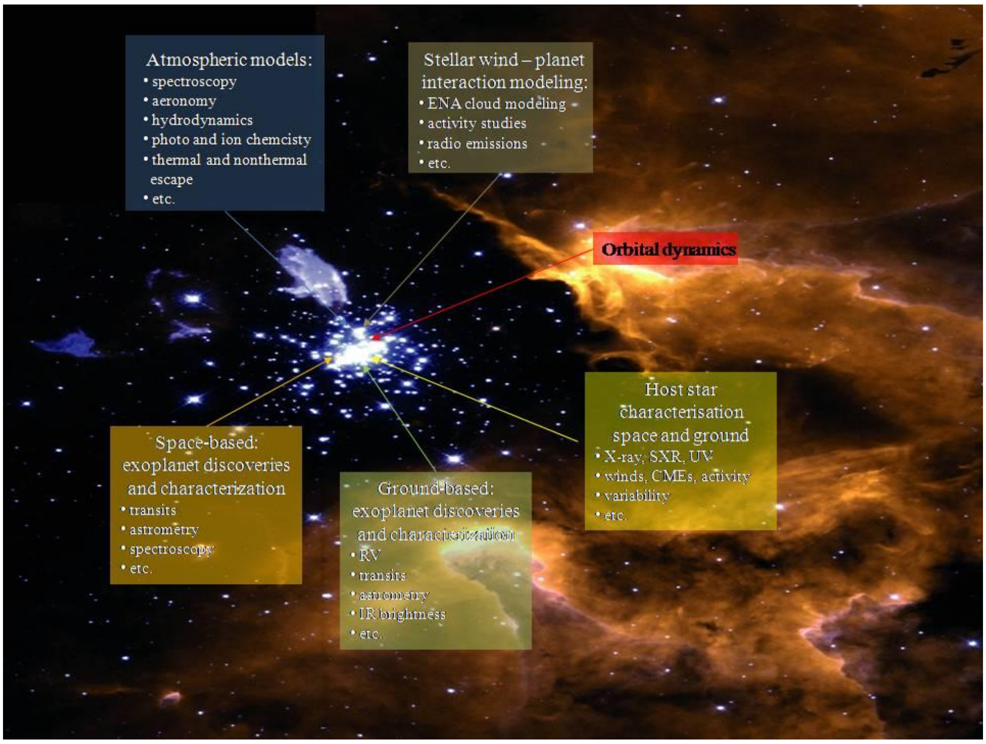


Fig. 30: Only a well coordinated effort consisting of space- and ground-based observations, combined with various modelling efforts will solve the fundamental questions regarding mankind's role and destiny in the Universe.

8. ESTABLISHING A COORDINATED EUROPEAN EXOPLANET COMMUNITY

At the present, European scientists do an excellent job in the field of exoplanet discoveries and research. Many scientific studies are carried out all over Europe by institutes, research groups and single researchers. In the next step, exoplanet research in Europe needs to be more seen within the scientific community and the public. Teams such as the Blue Dots Team worked hard on that task during the past years. We think that the ESF together with existing exoplanet related science teams like existing ISSI teams, or networking research projects such as the German-based Helmholtz Alliance project *Planetary Evolution and Life* and working groups within the EU funded Europlanet project (especially Na1 and Na2) can be very useful supporters to build up a well coordinated and structured exoplanet research infrastructure and community in Europe.

As a next step beyond ESF funded Exploratory Workshops or ESF Research Conferences we would recommend that interested researchers (astronomers, planetary scientists and solar/stellar physicists) try to establish an exoplanet related ESF

Research Networking Programme or an ESF EUROCORES network, which will allow researchers from various European countries and even from outside Europe on collaborative research projects. Such a Network could be used for expanding into an EU exoplanet project for their FP8 calls in the future.

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APPENDIX

ESA EPRAT
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Blue Dots Team
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http://www.europlanet-ri.eu/networking
http://www.europlanet-ri.eu/contacts

Europlanet: Observation Infrastructure Networking
Helmut O. Rucker, Steve Miller
http://europlanet-na1.oeaw.ac.at/

Europlanet: Science Networking
Ari-Matti Harri; Karoly Szego
https://europlanet-scinet.fi/

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9. FINAL PROGRAMME

Sunday 29 November 2009

morning	*Arrival*
from 12.00	*check-in and registration starts at reception of the hotel*
14.00-14.10	**Welcome by Convenor** **A. Hanslmeier,** Graz
14.10-14.30	**Presentation of the European Science Foundation (ESF)** **I. Stateva**, ESF Standing Committee for Physical and Engineering Sciences (PESC)
14.30-15.40	**Session: Roadmaps for the detection and characterization of habitable exoplanets**
14.30-14.50	**The target habitats** **A. Hanslmeier**, Graz and **Helmut Lammer**, Graz
14.50-15.10	**The ESA exoplanet roadmap: Exo-planet roadmap advisory team (EPRAT)** **R. Dvorak,** Vienna
15.10-15.30	**The Blue Dots exoplanet search and characterization strategy** **V. Coude du Foresto,** Meudon
15.30-15.40	**Discussion**
15.40-16.00	*Coffee / Tea Break*
16.00-17.50	**Session: Existing and near future space projects (missions) relevant for exoplanet (system) characterization**
16.00-16.20	**Darwin in the context of the ESA Cosmic Vision 2015-2025 Programme** **R. Liseau,** Onsala
16.20-16.50	**From CoRoT (in orbit), Kepler to PLATO and radial velocity measurements** **E. Günther,** Tenerfife
16.50-17.10	**Exoplanets within Cosmic Vision besides PLATO-SPICA&Euclid** **E. Palle,** London
17.10-17.30	**GAIA (exoplanet programme –astrometry)** **A. Sozzetti,** Torino
17.30-17.50	**JWST & future NASA ongoing project studies** **A. Belu,** Bordeaux
17.50-18.00	**Discussion**
20.00	*Social event: wine degustation*

Monday 30 November 2009

09.00-10.30	**Morning Session: Ground based projects (telescopes)**
09.00-09.20	**E-ELT: spectro-imaging and polarimetry** **M. Bonavita,** Padova
09.20-09.40	**The Terskol project and exoplanet programmes in Russia** **L.V. Ksanfomality,** Moscow

09.40-10.00	**Search for exoplanet radiosignals (Karkov, LOFAR, etc.)** **J.M. Grießmeier,** Dwingeloo
10.00-10.20	**Radio observation of active stars** **M. Leitzinger,** Graz
10.20-10.30	**Discussion**
10.30-11.00	*Coffee / Tea Break*
11.00-12.10	**Session: A roadmap for the host (target) star classification; evolution of the stellar radiation and plasma environment**
11.00-11.20	**CoRot-7b: detection, observation and characterization** **E. Günther,** Tautenburg
11.20-11.40	**Target stars for exoplanet missions** **I. Ribas,** Bellaterra
11.40-12.00	**Stellar winds and plasma outflow, activity (X, EUV) relation with age** **M. Güdel,** Zürich
12.00-12.10	**Discussion**
13.00-14.30	*Lunch*
14.30-16.20	**Session: UV observations of exoplanets – stellar environment & upper atmosphere structure**
14.30-14.50	**UV emissions of exoplanets** **M. Barthelemy,** Grenoble
14.50-15.10	**Characterizing stellar winds via exoplanet-ENA-cloud observations** **M. Holmström,** Kiruna
15.10-15.30	**Hydrogen-rich extended thermospheres (hot Jupiters &Earth like planets)** **Y. Kulikov,** Murmansk
15.30-15.50	**Hot hydrogen coronae around hot Jupiters** **V. Shematovich,** Moscow
15.50-16.10	**Discussion**
16.10-16.30	*Coffee / Tea Break*
16.30-17.20	**Session: Orbital dynamics, exoplanet observations and modeling**
16.30-16.50	**Orbits in 1:1 resonance** **R. Dvorak,** Vienna
16.50-17.10	**ExoStab** **E. Lohinger,** Vienna
17.10-17.20	**Discussion**
20.00	*Dinner*

Tuesday 1st December 2009

09.00-13.00	**Session: Planned projects and projects under preparation**
09.00-09.20	**World-wide medium class projects for characterization of super Earths** **J. Schneider,** Meudon
09.20-09.40	**WSO-UV** **D. Bisikalo,** Moscow
09.40-10.00	**Coronograph on the ISS** **A. Tavrov,** Moscow

10.00-10.20	**Detecting planets around low-mass stars** **A. Reiners,** Göttingen
10.20-10.40	**Characterizing exoplanetary atmospheres via reflected ligh** **S. Eggl, Vienna**
10.40-10.50	**Discussion**
10.50-11.10	*Coffee / Tea Break*
11.10-11.25	**Doctorate school in Hamburg and Göttingen on extrasolar planets and their host stars** **A. Reiners,** Göttingen
11.25-13.00	**discussion on follow-up activities / networking / collaboration**
13.15	Lunch
Afternoon	*End of Workshop and departure*

10. List of Participants

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Gender:

Male: 22 Female: 2

Countries of Origin

Austria	5	France	4
Germany	2	Israel	1
Italy	2	Netherlands	1
Russia	5	Spain	1
Sweden	2	Switzerland	1