The *Darwin* space mission

A White Paper for
ESA's Exo-Planet Roadmap Advisory Team, July 2008

Abstract

The search for biological activity on Earth-like planets around nearby stars remains one of the central challenges in the field of exoplanet research. This is made more compelling following the recent detection of Super-Earths and the first spectroscopic characterization of the atmospheres of giant planets at IR wavelengths. In the coming decade, ground-based Radial Velocity searches and space-based astrometry programs can lead to the identification of Earth-like planets in the Habitable Zone around a well-selected sample of nearby stars. Formation-flying interferometers such as *Darwin* and TPF-I will be able to measure the mid-IR spectra of the atmospheres of these Earth-like planets, providing key markers for *comparative planetology* as well as indicators for *biological activity* through the measurement of key planetary parameters (T_{pl}, albedo, R_{pl}) and estimates of the abundances of H_2O, CH_4, CO_2 and O_3 in their atmospheres. Apart from the molecular fingerprints for life on other planets, this wavelength range provides a favorable planet/star contrast ratio and the possibility to adapt the mission to the size of the target list.

Space-based nulling interferometry provides the required angular resolution and starlight suppression. Independent studies both in Europe and the United States have now converged on a common Emma-X-array architecture. Nulling breadboards and formation-flying experiments have shown that the required technology is now emerging. This WP proposes the continuation of the technology development to support a higher fidelity definition of an interferometry mission, further detailing its performance and cost. *The risk of a long break in the technology effort,* ongoing since 1995, is emphasized.

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Cooperation

The *Darwin*-TPF-I projects have been developed in close cooperation between ESA and NASA. It is highly desirable that this cooperation continues and that a single international mission be built, including participation of other countries such as Japan.

1. What is unique in obtaining the thermal IR spectroscopy of a Habitable Planet?

Thermal IR spectroscopy allows the determination of important planetary parameters as its effective temperature, albedo, radius… and the presence/absence of many key gases in its atmosphere. This information will be valuable for Comparative Planetology answering questions as: "have all large planets in the Habitable Zone (HZ) carbon dioxide in their atmosphere?" It will also, for the first time, allow to address the question of the existence of life outside the Solar System in a scientific way. Thereafter, we consider this second issue.

1.1 What do we want to know to search for bio-indicators?

In a famous paper, Sagan et al. (Sagan 1993) analyzed a spectrum of the Earth taken by the Galileo probe, searching for signatures of life. They concluded that the large amount of O_2 and the simultaneous presence of CH_4 traces are strongly suggestive of biology. Searching for signs of life on potentially very different planets, means that we need to gather as much context information as possible in order to understand how the observed atmosphere works, especially temperature and planetary radius.

A Habitable Planet

The HZ is defined as the region around a star within which starlight is sufficiently intense to maintain liquid water at the surface of the planet, without initiating runaway greenhouse conditions vaporizing the whole water reservoir and, as a second effect, inducing the photodissociation of water vapor and the loss of hydrogen to space (see Kasting 1993 for a detailed discussion).

Liquid water can be present further away from the star than the HZ, in the interior of planets or satellites, as possibly in Europa, and host a form of life that does not rely on the stellar light. However, this life could not develop to a large extend because its metabolisms would rely on very limited sources of energy compared to stellar light.

The presence of H_2O in the atmosphere of an exoplanet and an estimate of its surface temperature would be a strong indication that liquid water is present on its surface and that the planet is habitable.

Biomarkers

Our present search for signs of life is restricted to extraterrestrial life forms that share fundamental characteristics with life on Earth, in that it requires liquid water as a solvent and has a carbon based chemistry (Des Marais et al., 2000, Astrobiol. 2, 153). It can be shown that this limitation is probably not that severe, the carbon-water "solution" being a main avenue in the possible forms of life (T. Owen, 1978).

Biomarkers (or biosignatures) are used here to mean detectable molecular species, or set of species, whose presence at significant abundance strongly suggests a biological origin. This is, for instance, the case for the pair CH_4 + O_2. *Bio-indicators* are indicative of biological processes but can also be produced abiotically in significant quantities.

Oxygen in high abundance is a promising bio-indicator. A detectable concentration of O_2 and/or O_3 and of a reduced gas like CH_4 can be considered as a signature of biological activity. The spectrum of the earth has exhibited a strong infrared signature of ozone for more than 2 billion years. The depth of the saturated O_3 band is determined by the temperature difference between the surface-clouds continuum and the ozone layer. CH_4 is not readily identified using low-resolution spectroscopy for present-day Earth, but the methane feature at 7.66 µm in the IR is easily detectable at higher abundances, e.g., 100× abundance (Kaltenegger 2007)), provided that the spectrum contains the whole band and a sufficient SNR. N_2O is produced in abundance by life but only in trace amounts by natural processes. Nearly all of Earth's N_2O is produced by the activities of anaerobic denitrifying bacteria. N_2O would be hard to detect in the Earth's atmosphere with low resolution, as its abundance is low at the surface (0.3 ppmv) but it could be present at higher concentration in other inhabited planets.

There are other molecules that could act as excellent biosignatures, in fact techno-signatures, e.g. the manufactured chloro-fluorocarbons (CCl_2F_2 and CCl_3F) in our current atmosphere in the thermal infrared waveband. Their detection at present abundance on Earth would require mean resolution spectroscopy (Res. ~ 200).

The combined presence of O_3, CO_2 and H_2O band within the context of Earth physical parameters indicates the presence of life. This is because, knowing the size of the planet and its surface temperature, there is no photo-physical-chemical model of its atmosphere that can produce these gases without an important oxygenic photosynthesis activity (Fig.2). It can be shown that such photosynthesis has to have a biological origin.

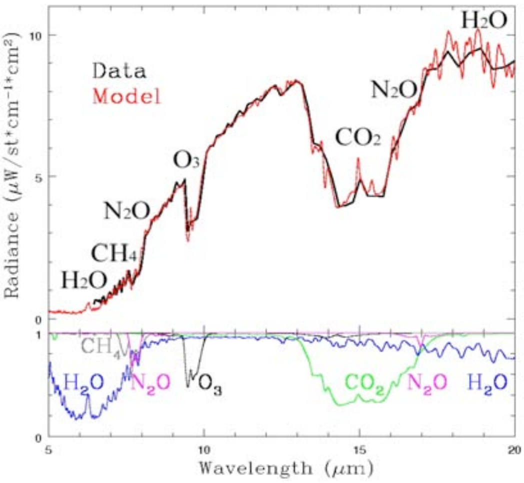

Figure 1: Spectrum of the Earth in the thermal IR (Christensen et al., J. Geoph Res. 102, 875, 1997)

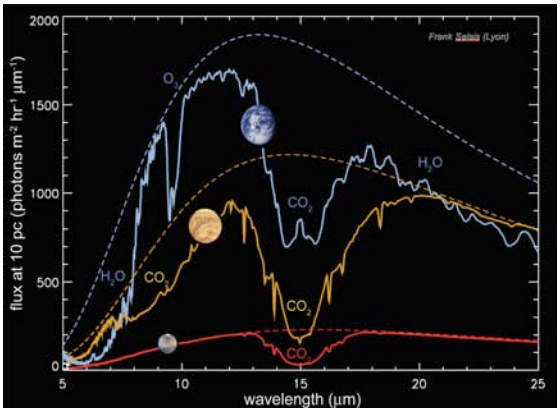

Figure 2: The thermal IR spectra of Earth, Venus and Mars. Only Earth has the triple signature of O_3, CO_2 and H_2O that indicate a biological activity (Selsis, 2007)

The need for physical parameters

The search for signs of life implies that one needs to gather as much information as possible in order to understand how the observed atmosphere physically and chemically works (see e.g. Kaltenegger & Selsis, 2007). The knowledge of the temperature and planetary radius is crucial for the general understanding of the physical and chemical processes occurring on the planet (tectonics, hydrogen loss to space). One can calculate the stellar energy of the parent star that is received at the planet's measured orbital distance. This gives only very little information on the surface temperature of the planet, which also depends on its albedo and the efficiency of the greenhouse effect.

1.2 What can thermal IR photometry and spectroscopy provide?

The presence / absence of an atmosphere from orbital flux variations

The orbital flux variation in the IR, measured in the detection phases, can provide some important information. The thermal light curve (i.e., the integrated infrared emission measured at different positions on the orbit) exhibits variations due to the phase (whether the observer sees mainly the dayside or the night side) and to the season (if the planet has a nonzero obliquity, Fig.3). Important phase-related variations are due to a high day/night temperature contrast and imply a tenuous, or no, *atmosphere* and the absence of a *stable liquid ocean*. Therefore, habitable planets can be distinguished from airless or Mars-like planets by the amplitude of the observed variations (Selsis 2003, ESA-SP539; Gaidos et al. 2004, New Astr. 10, 67). Note that also Venus-like atmosphere would exhibit extremely lowamplitudes and can only be distinguished by spectroscopy from habitable planets.

Temperature and radius of the planet

With a low-resolution spectrum of the thermal emission, the mean brightness temperature and the radius of the planet can be obtained, in first approximation, by fitting the envelope of the thermal emission by a Planck function. The ability to estimate the ground temperature relies on the existence and identification of spectral windows probing down to the planetary ground. For an earth-like planet there are some atmospheric windows that can be used in most of the cases, especially between 8 and 11 µm. However, this window would become opaque at high H_2O partial pressure (e.g., the inner part of the HZ where a lot of water is vaporized) and at high CO_2 pressure (e.g., Venus or the very young Earth). A much better estimate of the radius and of the temperature can be obtained by comparing the spectrum, including its features, with *a grid of synthetic spectra* (Paillet, 2007, PhD thesis, ENS Lyon; Kaltenegger & Selsis, in preparation).

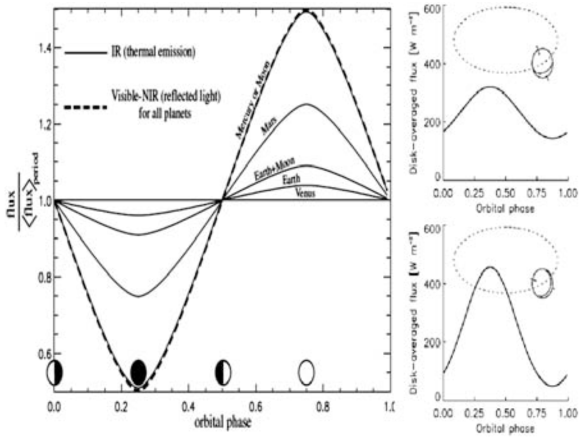

Figure 3: orbital fluxes in the IR

Identification of key atmospheric gases

The key atmospheric gases that we want to identify have a clear spectral signature (ro-vibrational modes) except for the homopolar molecule O_2 (Fig.1). The latter has a good marker, O_3, which can indicate the presence of molecular oxygen, even in small amounts.

With arbitrarily high signal-to-noise and spatial and spectral resolution, it is relatively straightforward to remotely ascertain that Earth is a habitable planet, replete with oceans, a greenhouse atmosphere, global geochemical cycles, and life. The interpretation of observations of other planets with limited signal-to-noise ratio (SNR) and spectral resolution, as well as absolutely no spatial resolution, as envisioned for the first generation missions will be far more challenging.

The following step-by-step approach can be taken to set the system in context. After detection, we will focus on main properties of the planetary system, its orbital elements as well as the presence of an atmosphere using the light curve of the planet and/or a crude estimate of the planetary nature using very low-resolution information (three or four channels). Then higher resolution spectra will be used to identify the compounds of the planetary atmosphere and to establish the temperature and radius of the observed exoplanet. In that context, we can then test if we have an abiotic explanation of all compounds seen in the atmosphere of such a planet. If we do not, we can work with the exciting biotic hypothesis.

The range of characteristics of planets is likely to exceed our experience with the planets and satellites in our Solar System. Earth-like planets orbiting stars of different spectral type might evolve differently (Segura, 2005, Astrobiol 5, 706). Models of such planets need to consider the changing atmospheric structure, as well as the interior structure of the planet. One crucial factor in interpreting planetary spectra is the point in the evolution of the atmosphere when its biomarkers become detectable (Kaltenegger et al., 2007, ApJ. 658, 598). Those spectra will be used as part of a big grid to characterize any exoplanets found.

In conclusion, thermal IR provides an ensemble of key physical and chemical information that will be valuable to enter the fascinating domain of exobiology outside the Solar System

2. How to obtain the thermal IR spectrum of a Telluric Planet?

2.1 The need for a Direct Detection

Measuring the thermal IR spectrum of a telluric planet in the Habitable Zone (HZ) of its star requires a direct detection of its photons in the 7 – 18 μm domain (goal 6 – 20 μm). Several major difficulties are met: (i) the small angular separation between the star and the planet, (ii) the star/planet flux contrast, (iii) the presence of different backgrounds.

2.2 Three major problems and their possible solutions

Angular resolution

In order to disentangle the faint emission of an Earth-like planet from the overwhelming flux of its host star, the planetary system needs to be spatially resolved. The angular size of the HZ around the nearest (easiest) stars ranges between 10 and 100 mas. In the thermal IR, this would require an instrument of 100 m, or larger, if a target list of few hundred objects is aimed for (10 m, or larger, in the visible-near IR). The only solution to overcome such a constraint is to rely on diluted apertures i.e., interferometers. This solution has ***a major advantage*** if the collectors are carried by free-flying spacecrafts***, it can adapt its baseline to the star/planet angular separation***. Typical suitable baselines are 10 to 200 m.

Star/planet contrast

For a sun-earth system, the contrast varies from ρ = 4 10^7 to 1.3 10^6 at 7 and 18 μm, respectively (Fig.4). A possible solution to deal with this huge contrast is the use of the interferometer in a nulling mode, as proposed as early as 1978 by Bracewell (Nature, 274, 780).

However, the stellar disk having a finite value, nulling factors, $nl \equiv 1/\rho$, smaller than 10^{-5} if technically feasible, would be of no use. Differential measurements, with and without the planetary signal, are mandatory to obtain the planetary photons. This requires a very high stability of the stellar flux leaks.

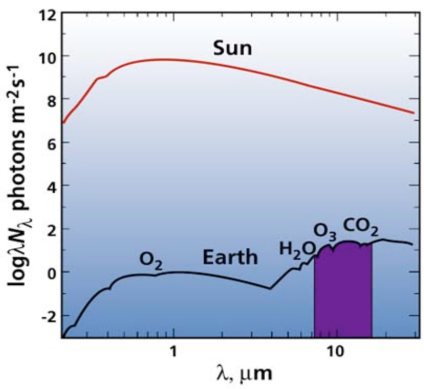

Figure 4: The Sun and Earth fluxes as seen from 10 pc

To obtain the relevant data at 7 μm, one can show that in addition to a mean value <*nl*> = 10^{-5}, the nulling function must be very stable on long integration times, σ_{nl}(few days) = 3 10^{-9}, or that the null fluctuations must be calibrated with such an accuracy.

Background sources contributions

In addition to the stellar and planetary signals, the telescopes will receive background signals from the solar Zodiacal Light (ZL), the exo-ZL, and the thermal emission of the optics. Their shot noises are unavoidable and their mean values must be very stable to be subtracted by proper modulations. The latter should be possible, taking advantage of the centro-symmetry, in first approximation, of these backgrounds around the star, as opposed to planets.

2.3 Interferometer configurations

During the period 1995 – 2006, in Europe and in the US numerous interferometer configurations were considered in order to cope with (i) the finite size of the stellar discs, (ii) possible confusion with exozodiacal light and (iii) subsystem drifts. This has independently led both teams to the concept of phase chopping, and remarkably, these approaches have finally converged in 2006 to a common design, the X-array in the Emma configuration (Fig.5).

The idea of the X-array interferometer was proposed in the US (O. Lay & S. Dubovitsky, 2004, SPIE 5491, 874) and the Emma arrangement of the spacecrafts was proposed in Europe (A. Karlsson, 2004; Thales Alenia Space, 2007).

This configuration provides high spatial resolution to distinguish multiple planets and starlight suppression tailored to each target object. Most importantly, it eliminates all deployable structures and simplifies the optics, thus reducing the overall cost.

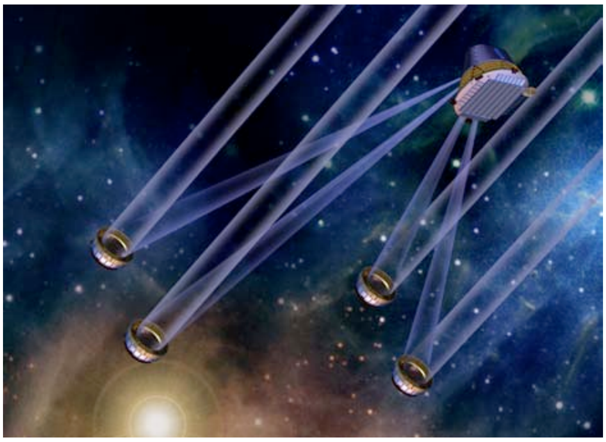

Figure 5: An artist view of the X-array in Emma configuration (not to scale)

3. Studies and technical pre-requirements

3.1 Thermal IR spectroscopy, a likely avenue for the future

As explained above, the direct detection planet light in the thermal IR is the most promising path to characterizing the spectra
of Earth-like exoplanets. The advantages of this approach are:

- It provides key information about the planet that is not available by other techniques (Sect.1);

- The observatory design can be adapted (baseline length and collecting area) to the size of the target stars, thus increasing the number of planets that can be characterized, an important feature for the long term development of the field.

3.2 Why *Darwin* has not been selected by ESA for its first round of Cosmic Vision program?

Darwin was certainly the proposal best suited to the 1st theme of the Cosmic Vision: "What are the conditions for planet formation and the emergence of life?" However, it was not selected in 2007, because the reviewers felt that its technology was yet not fully mature. A road map to further advance the technological readiness of the mission is described below.

3.3 The need to qualify key technology elements

The studies by ESTEC have identified different necessary subsystems:

- Optical Delay Lines. This point is probably close to be achieved thanks to the prototype built by TNO and presently available at ESTEC (Fig.6);
- Achromatic Phase Shifters for the nulling interferometers;

- Single Mode Fibres, or Integrated Optics devices that work in the (6 – 20 μm) range and can relax the extreme quality of the optical surfaces that would be required otherwise;
- Laboratory simulators that can mimic to a high degree of fidelity the flight environment conditions in terms of the different perturbations that the nulling instrument will have to deal with;
- Servo-systems that use different types of modulations and can cope with the sources of noise and drifts.

3.4 The need for a laboratory demonstrator of the nulling instrument

When the different sub-systems are satisfying, it will be necessary to assemble them in test beds that demonstrate the capability to reach the required performances, e.g. σ_{nl}(few days) = 3 10^{-9} rms, and detect a simulated planetary contrast with the proper contrast.

The NASA Planet Detection Test bed is being built in that direction (Fig.7), but it is not sure that it will be funded for a long enough duration so that it can reach its goal. Anyway, it is short by an order of magnitude when compared to the astronomical requirements (Fig.7). A similar demonstrator, with the full performances needed should be built in Europe, with a step-by-step approach.

3.5 The example of the SIM demonstrator

A very instructive case is that of the SIM project. The technological requirements for the mission are extreme, e.g. metrology of the optical delay line of the science interferometer requires an accuracy of 10 pm, a tenth of a typical atomic distance 1 Å = 100 pm, which is notsurprising when it is noted that the typical angle to be measured is 0.30 μas[1] To check whether these requirements were achievable, a major technical effort has been done during 10 years at JPL, which reached a clear positive answer in 2005. For instance an accuracy of 3 pm was demonstrated for length metrology. As a result, space agencies know that if they decide to build this mission, it is technically feasible.

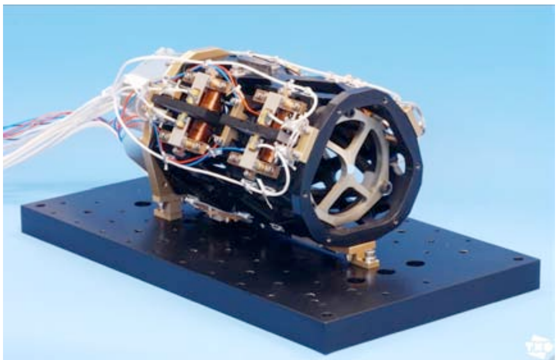

Figure 6: Optical Delay Line built by TNO for ESA. The stator and mobile parts can be seen. Levitation and displacement drive are magnetic.

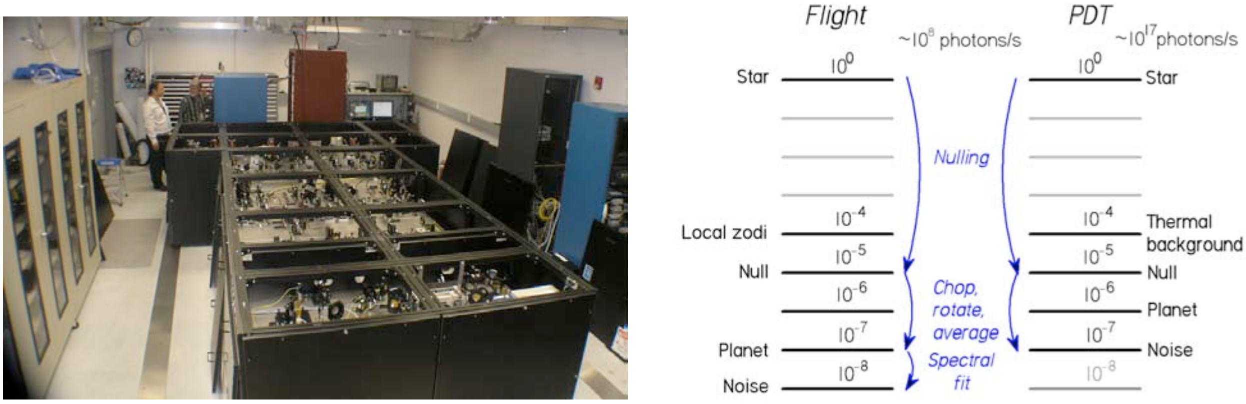

Figure 7: The Planet Detection Test bed (PDT) at JPL in progress and the compared performances of what is needed in flight and what is foreseen for the test bed. The aim of the PDT is to simulate the detection of a planet in the presence of the starlight with a nulling interferometer that is very similar to what is considered in flight (nulling, phase modulation…)

3.6 Consequences of a possible long break in ESA technology effort

ESA has supported a significant technological effort on interferometry since 1995. Several tens of TRPs have been issued by ESTEC on different key points identified by its engineers. With the non-selection of *Darwin* in 2007 the management decided to freeze this effort and wait for the recommendations by the EPR-AT. This attitude makes sense because if the task force were to propose a road map that excludes spectroscopy in the thermal IR, the corresponding effort would be useless. However, if this is not the case, and if this spectral domain is considered as essential to obtain the scientific information needed, a danger must be pointed out: ***if there is a long break in the support of the technology needed for nulling interferometry, there is a serious risk of loosing the know-how that has been progressively built during that period. Industrial and academic teams will be dissolved and their experience diluted and eventually lost. This has indeed already begun with system teams, only very reduced teams are still involved in technological developments with shrinking in-house funding which could be suppressed in the absence of a clear signal from the Agency. This could eventually be a large waste of money invested by ESA.***

4. Science and technology precursors to mitigate risks

In addition to laboratory test beds demonstrating that the performances needed for the space instrument are within our reach, the following precursors appear to be useful to mitigate risks for the large spectroscopic mission.

4.1 Scientific information needed to properly design the instrument

The different contributions to the IR flux that reaches the telescopes are shown in Fig.8. It appears that in addition to the stellar leaks, the solar Zodiacal Light (ZL), the thermal emission of the optical parts and the exo-ZL are background contributions whose intensities are significantly larger than the planetary signal. Although their mean signal can be subtracted, they will contribute significantly to the total noise.

Presently, the intensity of the two first contributions can be estimated, but there is a serious unknown regarding the exo-ZL around possible target stars. Data exist the circumstellar discs but they were obtained at long wavelengths, e.g. 100 μm corresponding to the emission of cold dust. We do not currently know the amount of warm dust emitting in the 6 – 20 μm range, except in the case of our own Solar System. Whether for the majority of main sequence stars their ZL is inferior or superior to ~20 times the Solar one will have a major consequence on the instrument design because the corresponding noise will be weaker or dominant with regard to the other background contributions. Different instruments can be considered to obtain this information:

4.1.1 *Ground based nulling interferometers*

This was the idea of the ESA-ESO GENIE study. However it concluded that the VLTI was not appropriated for that goal (too long bases and too many mirrors in the optical trains).

- The **Keck-I** has proven to be limited to high level of exo ZL, ≥ 100 times the solar level, named "zodi".
- The **LBTI** project is better adapted (optimal baseline, minimum number of mirrors to limit their total emission). An expected sensitivity of *15 zodis* is foreseen in 2011. If this goal were reached, this instrument would provide the basic information we need.
- The ***Aladdin*** proposal, a nulling interferometer at Dome C, is a by-product of the GENIE study. If the perturbations due to the very first tens of meters of the atmosphere can be avoided, Antarctica could be an ideal site for astronomy in general and

especially for IR astronomy. In case the LBTI does not meet its expectations, *Aladdin* could be a very attractive alternative.

4.1.2 *Space instruments*

- (Cold) **Spitzer** has no relevant spatial resolution. It deduces the zodiacal dust emission from the difference between its measurement and the expectation of the stellar emission in the thermal IR. The uncertainties on stellar emission and on photometric calibration limit these estimates to very strong exo-ZL levels (~ 1000 zodis).
- **JWST** will have a better sensitivity but will suffer the same limitations as Spitzer, except for a few cases where its coronograph on the MIRI instrument can be used. At 10 μm, the diffraction-limited instrument can observe at working angles larger than 300 mas.

  This corresponds to the HZ (T ~ 300 K) of the very few K & G stars closer than 3 pc, e.g. α Cent A & B, τ Cet and ε Eri, much too small a sample.

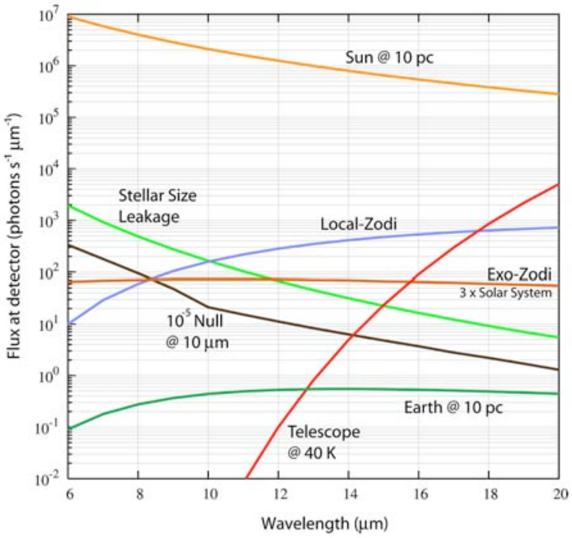

Figure 8: The different fluxes reaching the collectors of Darwin/TPF-I

- **FKSI** and ***Pegase***. These space nulling interferometer proposals would be much more appropriated. In a recent study, Defrère et al. (2008, A&A accepted) have estimated their sensitivities. FKSI is a Bracewell interferometer on a 12.5 m boom, which can detect exo-ZL down to *1 zodi*. *Pegase* is also a Bracewell but with free flying collectors and an adjustable baseline (40 – 500 m). Its sensitivity is ~ 10 zodis but could be improved if shorter base lengths (20 m) were possible.

4.2 Free-Flying precursor missions

The demonstration of this needed technology is on rather good tracks, the more as it seems to be a necessary technique for many future space missions. The Autonomous Transfer Vehicle (**ATV**) for the International Space Station by ESA flew in April 2008. The **Prima** mission, Swedish led, is scheduled for June 2009. **Proba-3** (ESA) is foreseen for 2012, although presently it is not fully funded. Simbol-X is under study at CNES and ASI with a possible launch in 2014 (Fig.9).

4.3 Interferometry performed from space

No space mission is presently decided that will demonstrate the capability of performing interferometry in space. Interesting proposals are:

- SIM-Lite would make extremely accurate astrometric measurements using interferometry but not in a nulling mode (see Sect.5);
- FKSI would perform nulling interferometry from a rigid boom;

Pegase would do the same but in conditions closer to what is considered for the nulling interferometer spectrometer, since all its spacecrafts would be free flyers.

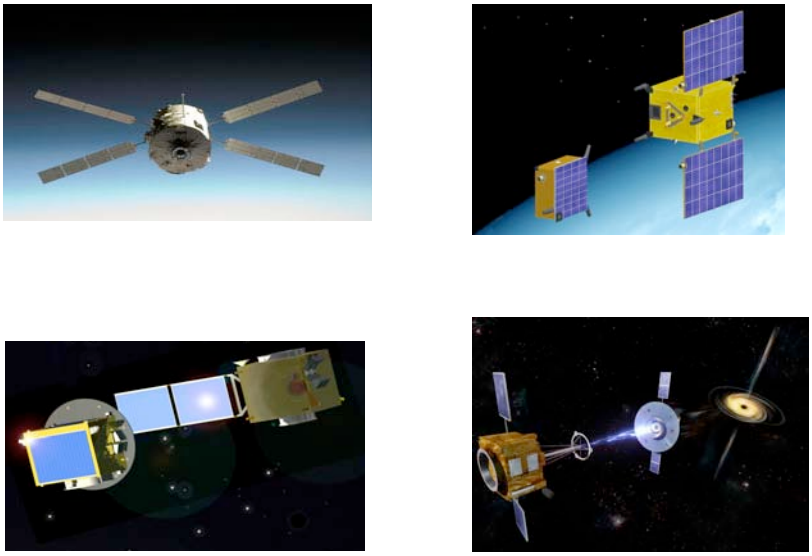

Figure 9: Different examples of Free Flying space-crafts or projects: Autonomous Transfer Vehicle (ATV), ESA April 2008; Prisma, Swedish Space Corporation 2009; Proba-3, ESA, 2012; Simbol-X, CNES ASI 2014.

5. Search for proper targets

Since 2004, about 20 exoplanets were discovered with masses only a few times the mass of the Earth. Present results, most coming from the HARPS programs, suggest that the already published discoveries only represent the tip of the iceberg. A recent census of planetary candidates among stars of the HARPS "high precision" sub-program has revealed about 45 possible low-mass planets (m *sin*i < 30 M_Earth). Statistically, this would mean that at least 30% of solar-like stars do possess such close-in ice giants and super-Earths. But a much larger number may be expected since current radial-velocity surveys are only detecting the shorter orbital period planets (period <~ 50 days). This is confirmed by discoveries of similar objects at larger separations (a few AUs) using the microlensing technique, and is also in agreement with the predictions of Monte Carlo simulations of planet formation.

A possible Road Map aiming at performing the spectroscopy of potentially habitable planets, either in the thermal IR (interferometer) or in the visible (coronograph), could be as follows.

5.1 Determining the statistical abundance of telluric planets in the HZ of stars

This is the goal of the ***Kepler*** mission (launch Feb. 2009). It should study 100,000 stars, searching for planetary transits of objects with radius as small as 1 R_{Earth}, at 1 AU of G stars i.e., actual analogues of the Earth. Due to the geometrical requirement for a planet to transit in front of a star, the corresponding probability is low (0.5%). ***Therefore, the discovery list of Kepler, as well as that from any transit survey, cannot provide a significant fraction of the target list for the spectroscopic mission*** because the latter stars must be chosen among the nearby objects. However, it will provide *a key number, η_{Earth},* the fraction of stars that has an Earth-like planet in its HZ. The recent discovery by Radial Velocity (RV) technique of hot Super-Earths (Mayor et al. 2008, Astro-ph) gives us a hint that η_{Earth} is quite high, but statistics on actual earth analogues is mandatory.

The **PLATO** proposal would do a similar job on brighter stars, ***but 8 years later*** (2017).

5.2 Determining actual planetary targets for spectroscopy

A priori two techniques could detect potentially habitable planets around nearby stars, if the proper instrument can be built *and* if there are no astrophysical limitations: RV and astrometry.

- *Radial Velocity (RV).* The velocity imprinted by 1 M_{Earth} planet at 1 AU of a G star is 0.09 m/s. The present accuracy of the best RV instrument, HARPS, is improving continuously, and is presently ~ 1 m/s rms *for very quiet stars*. However, it seems that there are astrophysical limitations to going much further for stars with average activity: stellar spots produce a noise of ~ 1 m/s rms (see specific White Paper: "Identifying nearby Earth-size planets…"). It must be noted that nearby stars are a given sample and measurements restricted to very quiet objects can produce only a limited subset of this sample.

- *Astrometry*. The situation looks better for astrometry. The same stellar spots produce a noise on the photometric position of a G star at 10 pc of ~ 0.25 μas rms, whereas the signal imprinted by a 1 M_{Earth} planet at 1 AU of the same star is 0.30 μas. After a reasonable integration time, ~ 1 yr, a S/N ratio of 5 can be obtained if a perfect instrument can be built (see the above quoted WP). The recently proposed SIM-Lite instrument has the capabilities of doing so (see SIM-Lite WP) and could detect Earth analogues around about 60 nearby stars and characterize their orbits. If Super-Earths exist in the HZ of stars, e.g. planets with M_{pl} = 3 M_{Earth} (R_{pl} = 1.35 R_{Earth}), it could detect them around much more stars.

As a result, it seems possible to establish a list of potentially habitable planets, in the mid-term future (~ 2020). A large spectroscopic mission without the risk that this mission finds no suitable planet could then investigate them. In addition, the knowledge that such targets exist around stars that can be seen in the night sky with naked eyes would give a significant impulse to our whole discipline and put the question of funding a large spectroscopic mission in the thermal IR in a much more favorable context, in the space agencies and in the large Public.

6. Conclusion

A mission dedicated to the detection and spectral characterization of Earth-like exoplanets will provide information for a range of science interests including: planet and star formation theories, comparative planetology, atmospheric chemistry and astrobiology. Such a mission will provide out first chance to observe planets similar to the Earth, to characterize and classify them according to their properties and conditions, and to draw conclusions regarding the governing transformation processes both of biogenic and non-biogenic nature.

The thermal IR wavelength range can provide unique information and therefore will be a central part of this study for the mid-term and long-term future. Space-based nulling interferometry provides the required angular resolution and starlight suppression.

Independent studies both in Europe and the United States have converged on a common architecture: the Emma-X-array. Nulling breadboards and formation-flying experiments have shown that the required technology is emerging. The authors of this White Paper think that ***it is essential for ESA to restart rapidly its technical effort in this domain*** in order to keep the advantage of the studies already performed and the corresponding know-how. Too long a break will lead to industrial and academic teams being dissolved and their experience being diluted and eventually lost. It would be a pity because the IR approach has a great future. Europe so far has been a pioneer in that domain and should make the best possible use of the legacy of its preceding efforts.