A white paper:
Exploring the nearest habitable exoplanets

Jean-Loup Bertaux, August 4st, 2019

in response to the : **Call for White Papers in the Voyage 2050 long-term plan in the ESA Science Programme**

Figure 1. A picture of the night side of the Earth showing a typical technosignature: the lights from the cities, growing from year to year, and showing traces of mercury and sodium emission lines. It reveals the presence of a (modestly) advanced civilization on Earth. Detecting technosignatures on other habitable planets is the ultimate goal of this proposal, with the detection of bio-signatures as an intermediate step.

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Preambule

At age 77, I have no pretention to take the lead of any future project. The present white paper reflects a number of ideas that came to my mind since about ten years, about the search for extra-terrestrial intelligence, with the search for life on habitable exoplanets as an intermediate step with large telescopes in space. I am sure that a large number of scientists do share some of the ideas and opinions exposed in this white paper. The scientific community working on exoplanets has developed in an extraordinary fashion since the discovery of 51 Pegasi b revealed in October 1995 (Mayor and Queloz, 1995), faster and larger than any other astronomic community.

One purpose of the present white paper is to advocate the conjunction of the ESA Science Programme and the ESA Human Spaceflight and Robotic Exploration Programmes (in short in the following : Exploration programme) for this endeavour, in a scheme similar to the one put in place to set up the ESA Exomars programme, with the already very successful Exomars 1 (also called TGO, Trace Gas Orbiter). A scheme which does include co-operation with other space agencies (here, Roscosmos), but should include NASA for the exploration of habitable exoplanets.

Of course, when the word “exploring” is used in the title, this does not at all imply that we need to go there for an in-situ exploration. The word “exploring” is more related to the Exploration programme of ESA, and to the systematic character of research which is developed here. Up to now, the search of exoplanets has been done in areas of parameters that would give the highest return in the shortest time (for example, monitoring many stars at the same time like Corot and Kepler missions to detect transiting exoplanets). Here, we advocate for a systematic search of habitable exoplanets around the nearest stars from our sun, by order of increasing distance from our sun. This is because the nearest habitable exoplanets are easiest to characterize in terms of bio-signatures and technosignatures.

1. Are we alone in the Universe?

There are 200 billions stars in our Galaxy. Giordano Bruno was the first man to understand that stars were objects alike our Sun, and declared boldly at the end of 16th century:
“There are also numberless earths circling around their suns, no worse and no less than this globe of ours”, in “De l'Infinito, Universo, e Mondi,1584”.
Arthur C. Clarke (physicist and author of 2001: A Space Odyssey) wrote: "The idea that we are the only intelligent creatures in a cosmos of a hundred billion galaxies is so preposterous that there are very few astronomers today who would take it seriously. It is safest to assume therefore, that they are out there and to consider the manner in which this may impinge upon human society."
But before 1995, we had absolutely no proof of the existence of any planet around any star (except our Sun). Then the first exoplanet (around another star) was found in 1995, followed by many others, several thousands at present (August 2019). With

this revolution of exoplanets, the concept of extra-terrestrial intelligence escaped the realm of science fiction to fall in the realm of Science for short.

Therefore, the question is no longer: ”Are we alone in the universe?” but rather: ”Where is the nearest star hosting a planet with an advanced civilization, and how far is it from our Sun?”
An obvious New Frontier for humanity is to locate our nearest neighbours technically advanced. Indeed, there is a growing public query that must be answered: ”Are we alone in the Universe?” and European countries must participate to the efforts needed to answer this question from the tax-payer, through the ESA Scientific and Exploration programs.

The existence of an advanced civilization (say, as advanced as us or more) requires three items:
1. existence of exoplanets in the habitable zone of their host star
2. emergence of life
3. emergence of intelligence and technology (not like ants or termits)

As soon as he understood that stars are alike our Sun, Giordano Bruno used the “principle of mediocrity” to declare “There are also numberless earths circling around their suns, no worse and no less than this globe of ours”.
This principle of mediocrity means that our Earth has nothing special in the Universe: we are “mediocre, in the middle”.
Clearly we now know that point 1 above is true, since we found numerous planets in the HZ (129? according to The Habitable Zone Gallery, http://www.hzgallery.org/). This is justifying a posteriori the use of the principle of mediocrity.
But we must recognize that we know ***nothing*** about the probability of point 2 and point 3. Finding traces of life on Mars would help very much for an estimate of probability of point 2. But another way is to search for bio-signatures on habitable exoplanets, and even technosignatures. ESA must take part of this great endeavour.

2. NASA approach on Exoplanets Exploration.
Because its content reflects many of my own convictions, we reproduce below a text describing the NASA’s philosophy on this matter, found at:
https://science.nasa.gov/astrophysics/programs/ExEP

« NASA's Exoplanet Exploration Program is leading humankind on a voyage of unprecedented scope and ambition, promising insight into two of our most timeless questions: Where did we come from? Are we alone?
The primary goal of the program is to discover and characterize planetary systems and Earth-like planets around nearby stars. The missions are designed to build on each other's success, each providing an essential step forward toward the goal of discovering habitable planets and evidence of life beyond.
The first phase of exploration entails building an understanding of how many and what kinds of planetary systems nature has provided. Much of this work has been done with ground telescopes around the world, pushing the limits of their ability to detect smaller planets through Earth's turbulent atmosphere. The Kepler mission, in the stillness of space, is probing deeper into the galaxy to detect smaller and more Earth-like planets around other stars. Future NASA and international missions, as well as larger and more sensitive ground observatories, will extend this exoplanetary

census much farther in the coming years. At the same time, important investigations will tell us about the environments around stars with exoplanets, such as dust and debris in disks that could make further measurements of the planets more difficult.
Ultimately, the goal is to see whether there are exoplanets that show signs of possible life that we know how to interpret. The evidence will be primarily in the form of detailed spectroscopic studies of the atmospheres of extrasolar planets. For a planet to host life, our expectations are that the planet would require liquid water on the surface. We do not assume that the planet would necessarily resemble Earth itself. It would lie in an orbit that is neither too close nor too far from its star, so that liquid water could exist over geological timescales, and its atmosphere would contain the right balance of gases that could support life. Moreover, the atmosphere of the planet would be altered by the presence of life, such that only the existence of living organisms could account for the unusually high levels of gases in its atmosphere. (It's not that scientists reject any possibility of other life forms than what we know, but we do not yet know what other life forms could exist or how to look for them.)
The volume of space that would be explored would be limited to the closest stars. In this context "nearby" is understood to be stars that lie within approximately 20 parsecs (60 light-years) from our Sun. This is roughly the distance we can explore using technologies available in the next decade.
The ultimate stakeholder in the adventure of exoplanet exploration is the public who underwrites it. NASA's Exoplanet Exploration Program is especially interested in making materials and information available so that all can appreciate and understand the new scientific discoveries and the challenges ahead, and to engage and inspire students to take interest in technical and scientific matters. »

As we know it, life requires liquid water. A planet must be at a suitable distance of its host star, not too far (water would be ice) and not too near (water would be hot vapour). The limits define the so-called Habitable zone, HZ. Therefore the search for life and technology advanced civilizations must concentrate on exoplanets in the Habitable Zone of their host star, and ESA should concentrate efforts on this type of exoplanets.

3. The probability of habitable planet.

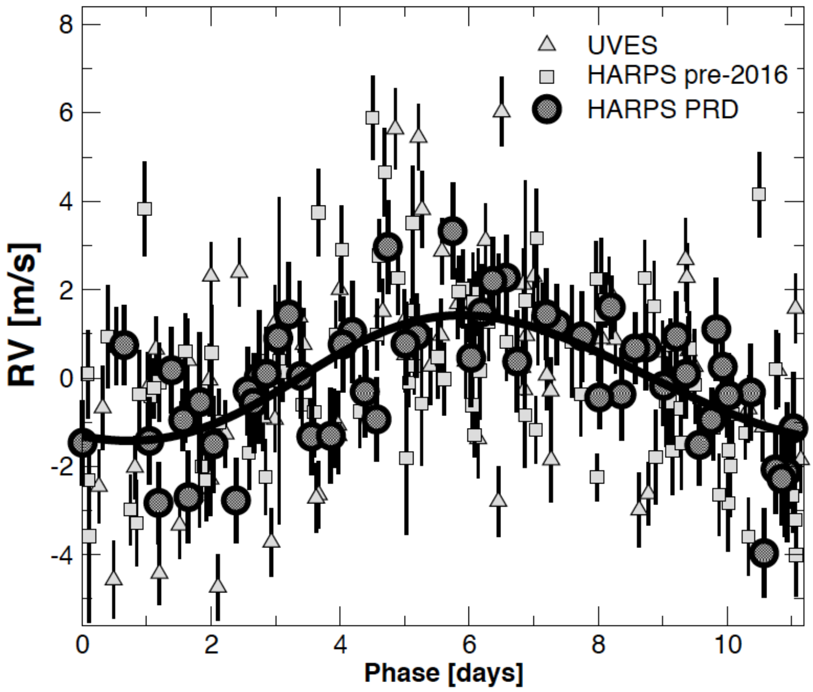
3.1 The case of Proxima Centauri b.

Classically, the probability of existence of a habitable planet (therefore, in the HZ of its host star) around one given star is noted η_{Earth}. The value of this probability η_{Earth} has been estimated by various authors, with a wide range of values. Multiplying η_{Earth} by the 200 billions stars of our galaxy gives the number of exoplanets where life could have emerged in our galaxy alone.

It was a fantastic discovery (Anglada-Escudé et al., 2016) that a potentially habitable exoplanet of the Earth type is revolving around the star Proxima Centauri, so called because it is the star closest to our sun. From a statistical point of view, it gives an estimate of η_{Earth}, because this star was selected at random. Indeed, in its race around the galactic center, the sun must have been close to many stars. The one that is currently closest to us therefore occupies this relative position completely by chance. However, this randomly selected star has an earth-like planet in the habitable zone of its star: not too far away because the water (if present) would be in the form of ice, as on Mars, nor too close because it would be steam, as on Venus. At the habitable distance, water is liquid, a necessary condition for the appearance of life as we know it. This shows that the probability of the existence of a planet around any terrestrial type star in the habitable zone is very high, confirming what could be derived or extrapolated from statistics on the approximately 3,000 exoplanets currently listed.

For example, if η_{Earth} = 10%, there was only a 1 in 10 chance that there would be one around that star Proxima Centauri. And there is one! So, the fact that there is one is all the more unlikely as η_{Earth} is small. Therefore, a likely estimate of η_{Earth} is around 0.5. Even if it were 0.1, when we multiply by the fraction η_{Earth} the 200 billion stars in our galaxy, we find ourselves with 20 billion exoplanets potentially habitable in our galaxy alone!

This discovery also demonstrates the full potential of the ground based radial velocity method (used here to discover Proxima Centauri b) to systematically explore the galactic vicinity of the sun. The observations were conducted from 2000 to 2016, and the star's reflex motion velocity was 1.4 m/s (figure 2). This long duration is good for detection of a periodic signal, which phase is conserved for a very long time. Therefore, a reflex motion can be detected even if it is much smaller than the accuracy of each individual RV (radial velocity) measurement, or "jitter noise" from the star. This would be the case for an Earth orbiting a solar type star (0.09 m/s).



: 2: **All datasets folded to the 11.2 days signal**. Radial velocity measurements phase folded

Figure 2. All Radial Velocity measurements of star Proxima Centauri collected by HARPS and UVES spectrometers (from Anglada-Escudé et al., 2016)

3.2. A ground-based program that could be helped by ESA.

It is my contention that future sophisticated observatories capable of characterizing the atmospheres to find bio-signatures (signs of life), and search for intelligent life, must not spend their precious time in trying to find the existence of an exoplanet around a star. It would be much more efficient to target them towards stars where the presence of a planet is already known, as well as the distance of the planet to the star and its period and phase. Therefore, a new observation strategy will have to be put in place, validated by the example of Proxima Centauri.
Priority should be given to observing the stars closest to the sun, for example the few hundred that are less than 30 light years away, each night, over several years, to make the most exhaustive inventory possible. It is not necessary to use giant telescopes. Medium-sized telescopes (2 to 3m) can be used, provided they are equipped with ultra-stabilized spectrometers such as the ESO HARPS spectrometer used for Proxima Centauri b. Several years, because it is necessary to detect a weak, but periodic signal, whose period and phase are preserved for years, which makes it possible to eliminate many other interfering signals.

A rough estimate of the cost of one set –up is about 15 M€. This is based on the cost of “off-the shelf” 2m automated telescopes, and the estimate of HARPS-like spectrometers building. The operation cost is about 10% per year of the hardware cost. An ensemble of about 30 set-ups could monitor systematically the 3,000 stars nearest to the sun.

All set-ups could be independently run by Universities at observatories already existing, or new observatories. One requisite would be that the set of stars to be observed should be coordinated between them, to avoid duplicates or triplicates. Also, both North Hemisphere and South hemisphere should be covered. NASA is already financing exoplanets set-ups, and ESA could do the same thing, in co-ordination with ESO.

4. Search for signs of life in exoplanets (bio-signatures).

The subject of what bio-signatures to search for has been discussed many times extensively, and will not be reviewed here again. We may refer to a presentation by Rauer and Greenfell (2016), and papers from Meadows et al. (2017), Schwieterman et al. 2017, and many others. Tinetti et al. (2017) reviewed the capabilities of the ESA ARIEL mission dedicated to warm and hot transiting planets.
Detection of water vapor in the atmosphere: combined with the temperature, it would indicate the presence of liquid water, a prerequisite for life (as we know it). On Earth, dioxygen O_2 and ozone O_3 are directly the result of life and should be searched for. However, O_2 might be a “false positive”, resulting from photo-dissociation of CO_2. The presence of methane CH_4 together with O_2 would however indicate a situation of chemical disequilibrium indicative of life. The absence of O_2 might also be a “false negative”: there was life on Earth’s oceans 2.5 billion years ago, in spite of the absence of O_2 in the atmosphere. On the ground, chlorophyll has a distinct spectral

reflectance signature (the red edge) that should also be searched for (Sagan et al., 1993). Below we discuss briefly some options concerning the observational techniques associated to the search of bio-signatures.

4.1. Large telescopes: on ground or in space?

There are several projects of large telescopes on the ground (i.e, the ESO 42 m, the 30 meter telescope in Hawaii). However, atmospheric turbulence is an obstacle to make very precise measurements from the ground. For instance, in the field of discovery of transiting planets, only large planets (about Jupiter size and more) could be discovered from the ground, while space project Corot and Kepler could detect planets of Earth' size and slightly below (Petigura et al., 2013). Therefore, it is very likely that only telescopes in space will be able to characterize atmospheres of EPHZ (exoplanets in the habitable zone).

4.2.Transiting versus non-transiting planets

At present there is a lot of emphasis on transiting planets. Their atmosphere may be characterized by the absorption that they produce in the host star's light. As a pioneer of the method of stellar occultation for measuring the atmospheres of Venus, Mars and the Earth (SPICAV on Venus Express, SPICAM on Mars Express, GOMOS on ENVISAT for ozone monitoring), I cannot despise this method which takes advantage of the high stellar flux. However, a transit of an exoplanet requires a special geometry, which limits the number of star/exoplanets which can be characterized with this method. The alternate method is to measure the thermal infrared emission of the planet, and the star light scattered by the ground and clouds of the planet.

Because non-transiting planets are much more numerous than transiting planets, they are statistically much nearer the Sun, and therefore easier to observe and to characterize, to detect bio-signatures and techno-signatures. They must be observed, in the spirit of exhaustive search of EPZH with increasing distance to the sun.

It is easy to show that the probability of transit for an exoplanet is $\sin \alpha = R^*/D$, where α is the angle subtended by the stellar radius R^* from the distance D of the exoplanet to its host star. It can be shown (Bertaux 2014a) that that, on average, a transiting exoplanet is at a distance from the sun larger than a non-transiting one by a ***gain factor*** F_g:

$$F_g = (\sin \alpha)^{-1/3} \quad (1)$$

A non-transiting planet is brighter than its transiting counterpart by a factor Fg^2.The host star also is brighter by the same factor, and the signal/noise ratio is larger by the factor F_g (assuming the noise is the random fluctuation of the star signal). A telescope with a diameter larger by a factor F_g is needed to get the same S/N ratio for a transiting planet for the same exposure time.

Mass, luminosity and radius R^* of a main sequence star are linked to its spectral type quantified by its effective temperature T_{eff}. The distance of the HZ depends also of

T_{eff}. The equilibrium temperature T_p of a planet of albedo A without green-house effect at distance D form the host star can be computed easily and it comes:

$$T_p = T_{eff} (R^*/2D)^{1/2}(1\text{-}A)^{1/4} \qquad (2)$$

The value of sin α = R*/D can be derived simply from equation (2):

$$\sin \alpha = R^*/D = 2 (T_p/T_{eff})^2(1\text{-}A)^{-1/2} \qquad (3)$$

The gain factor defined in equation (1), $F_g= (\sin \alpha)^{-1/3}$ can therefore be expressed as:

$$F_g=2^{-1/3} (T_p/T_{eff})^{-2/3}(1\text{-}A)^{1/6} \qquad (4)$$

From this expression we see that the gain factor F_g is weakly dependent on the albedo A, and dependent on the stellar type (T_{eff}) and the equilibrium temperature of the planet $T_{p.}$

We now consider the special case of planets in the habitable zone (Bertaux 2014a). This requires a certain range of equilibrium temperature T_p. Counting on some atmospheric green house to increase the surface temperature above 273 K to get liquid water, the boundaries of the habitable zone are usually considered for T_p as 195 and 285 K, while the Earth is at T_p= 258 K (equilibrium with no atmosphere and no green house effect).

On Figure 3 is plotted the gain factor F_g defined in (4) as a function of the star's effective temperature T_{eff} for various planet equilibrium temperatures T_p= 195, 258, and 285 K (Selsis et al. 2007). We have also plotted the gain factor for the middle of the habitable zone for 100 stars of the Cantrell et al. (2013) sample within 10 pc from Sun. For this sample the gain factor varies with T_{eff} from 3.2 to 9, with a middle value of 6 (corresponding to solar type stars). We may summarize these findings by stating that transiting exoplanets in the habitable zone of nearby stars are in average at a distance 3.2 to 9 times further out from the sun than non-transiting exoplanets, the gain factor depending on the stellar type. It shows the whole interest of non-transiting planets, not only for the flux consideration, but also for the angular separation between the host star and the planet: the larger, the easier it is to discriminate the light from the planet from the one from the host star.

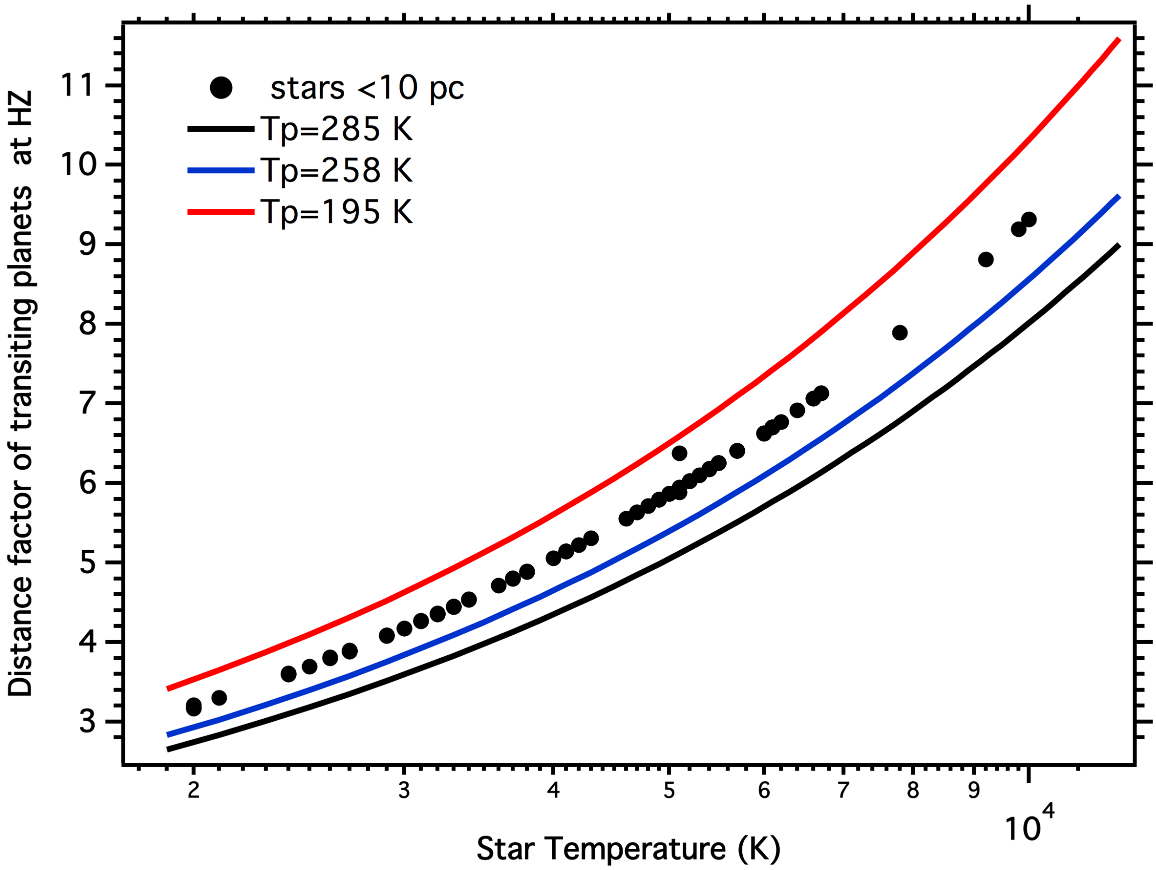


Figure 3. Gain Factor as a function of star effective temperature T_{eff}, for various values of the equilibrium temperature T_p of the planet: 285 K and 195 K determine the inner and the outer boundaries of the habitable zone, and the blue curve for 258 K is representative of the case of the Earth (without greenhouse effect). The black dots were computed for a sample of 100 nearby stars (distance to Sun <10 pc) taken from Cantrell et al. (2013), and the middle of the habitable zone. The outlier is one component of a double star, GJ702 B.

4.3. Internal or external occulter.

For the observation of non-transiting planets, an occulter is likely necessary, to reduce drastically the contaminating light of the star. In such a case, some part of the exoplanet orbit might be lost by the masking, but not its entirety. The use of an occulter allows to reduce the contaminating signal of the star, while letting the direct signal of the planet (either scattered star signal of thermal IR emission). The occulter may be internal to the observing telescope, or the occulter may be external.

4.3.1. External occulter

The US astronomer Webster Cash has proposed (Cash, 2006) a system in which an external occulter with a special “flower” shape” is used to mask the central star as viewed by a telescope in space. In order to let an exoplanet to be seen from the main telescope, the occulter must be placed at distances of typically 50 thousands of km from the telescope. One potential problem of the external occulter is that it will be itself in full sun (except if placed in the shadow cone of the Earth, a case not considered here), and could be itself a strong source of stray light for the observing telescope. Cash mentioned JWST as a possible observing telescope. The simultaneous presence of JWST and GAIA around the Lagrange point L2 should open the opportunity to learn more on the concept of external occulters. The ESA GAIA spacecraft, with its large sunshade (circular, 10 m diameter), could serve as an external occulter for JWST, to be observed from different shade-viewing angles, and with different star backgrounds: heavily star populated, or at high galactic latitude.

The use of an external occulter is a typical case where pointing from one star to another is a rather lengthy process, requiring the change of position of the occulter w.r.t. the telescope. Clearly one better know in advance the existence of an EPHZ around the next target star, for instance as a result of the RV ground-based program.

4.3.2. Internal occulter

There are a number of different types of internal occulters. Here we would like to mention a new type of internal occulter developed at IKI (Moscow) by the team of Sacha Tavrov (Frolov et al. 2016), based on achromatic interference between the main field of view and a rotated field of view. A proof-of-concept is already working in the laboratory, but the development for space use would certainly benefit from the interest of the european exoplanet community.

5. Large telescopes in space for bio-signatures: the role of astronauts.

After the pioneering work of Spitzer and Hubble Space Telescope (HST) on exoplanets, we all anxiously wait for the launch of James Webb Space Telescope (JWST) delayed to 2021. However, JWST (6.5 m diameter telescope) will have limited capabilities, and should be considered only as a precursor to larger telescopes in space that must be thought of right now. NASA is considering HabEx and LUVOIR as possible future space telescopes “that will explore how to search for signs of habitability and life on exoplanets.” The ATLAST (Advanced Technology Large-Aperture Space Telescope) project from NASA is based on a diameter of 8-16 meter, to be launched in a single shot with new heavy launchers from NASA (see details in Wikipedia). Placed at L2 Lagrange point, it has the interesting capability to be serviceable by astronauts.
Indeed, astronauts have played a vital role in the deployment and maintenance of the HST, with in-orbit replacement of major focal instruments and spacecraft sub-systems. They have also demonstrated their capability into the construction of the International Space Station (ISS). We argue that large space telescopes could be similarly constructed by assembling in space segmented mirrors to reach diameters larger than 10 m. From the ESA point of view, this endeavour could be a part of the Moon Village concept, which encompasses also L2 Lagrange point.

6. The search for technosignatures

While SETI programs (Search for Extra-Terrestrial Intelligence) consisted of attempts to detect radio (or optical) signals emitted on purpose by ETI, there is now a recent change of paradigm in this field. We are talking of the detection of ***unintentional*** signs of an advance civilization: technosignatures. By analogy with Earth’s case, potential technosignatures are: lights at night of growing towns (figure 1), with possibly sodium and mercury spectral signatures. In the radio domain, 50- 60 Hz and harmonics, low frequency submarine emissions, leakage of trans-horizons radars, etcetera.

NASA organized a workshop in 2018 on this subject :
https://www.hou.usra.edu/meetings/technosignatures2018/
We quote:
"It's been a quarter-century since Congress cut off NASA funding for the search for extraterrestrial intelligence, or SETI, but now the space agency is revisiting the topic under another name: technosignatures".

"I'm excited to announce that NASA is taking the 1st steps to explore ways to search for life advanced enough to create technosignatures: signs or signals, which if observed, would let us infer the existence of technological life elsewhere in the universe," Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate, said in a tweet today.

In this potentially immensely important field (see Arthur Clarke quotation), ESA must not lag way behind NASA. The acquisition of disk-resolved images of nearby habitable exoplanets may required huge (1-10 km) telescopes to be operated in space. One concept is the" diluted pupil" of Antoine Labeyrie: a large ensemble of free-flying telescopes covering some square kilometers, with recombination at a place within the shadow of the Earth (L2, for example). This could be deployed in the 2040-2080 time frame.
Hera also, the role of astronauts should be of crucial importance. Another possibility to be considered would be a huge radio-telescope on the Moon, opposite to the sub-Earth point to be protected from terrestrial radio interferences.

7. Additional comments:

7.1 The sphere of knowledge of the existence of technical humanity.

Earth's bio-signatures have existed for 2 billion years (oxygen), 0.5 billion (ozone). Therefore the whole Galaxy (size 10^5 light years) knows that there is life on Earth, for a very long time: we cannot hide it.

The terrestrial techno-signatures (i.e., figure 1) exist since only ≈ 100 years, so we are known in a small sphere of 100 light years containing a few thousand stars. This sphere of "knowledge of the existence of technical humanity" increases at the speed of light, encompassing more and more stars each year. Therefore, if there is an advanced civilization in this sphere of knowledge, they know our existence. They just need to be slightly more advanced than us by a few decades, since we will have this detection capability within a few decades. Since "they" can spot us, we need to be able to spot them. Communication is another matter, not discussed here. We must act quickly!

7.2. Technosignatures versus bio-signatures.

At first glance it seems much more difficult to record a technosignature than a bio-signature. However, a bio-signature will always be subject to interpretation, and certainty in this matter might be difficult to reach. On the contrary, a technosignature will be probably much less controversial than a bio-signature. This is at least one reason to focus already now on the detection of technosignatures.

7.3 Space telescopes dedicated to known habitable exoplanets.

The exploration of the solar system was done with dedicated missions to each planet, with adequate instrumentation: we knew the existence of our solar system planets, sufficiently well to design a space mission taylored to the explored planet.

Similarly, the (exhaustive) knowledge of exo-planets in the vicinity of the Earth will allow to define better the future space telescopes to study them (distance to sun, and distance to host star dictate the angular size of coronagraph to mask the host star). It is obviously much more demanding to study an exoplanet at 3 pc than at 10 pc or 30 pc. Therefore, it is important to get an exhaustive inventory form RV ground based monitoring of all stars nearest to our sun. Proxima Centauri b is at 1.3 pc.

8.Conclusions and proposals to ESA Science Directorate

The search for life in the universe, and intelligent life, is an obvious New Frontier for humanity. Europe should participate to the efforts to reach this new frontier. To go towards this goal, below are listed a few proposals to the Science Directorate. I am convinced that these proposals could reach a large consensus among the european scientific community working on habitable exoplanets.

General:
1**-** coordinate this area of research with the Human Spaceflight and Robotic Exploration Programmes of ESA for the implementation of large telescopes in space.
2- coordinate with NASA and possibly other space agencies (Roscosmos)
3- implement inside the Science Directorate a new Scientific group dedicated to exoplanets, similar to SSWG and AWG.

Specific :
4- investigate the possibility to observe GAIA with JWST to better characterize external occulters. It would probably require to phase the halo orbit around L2 of JWST, in such a way that the two spacecraft would come close enough: say, less than 20,000 km. I have made a computation showing that Herschel and Planck were never closer than 150,000 km from each other, probably on purpose? ESOC should study this matter more accurately than what I have done.
5- investigate (with ESO ?) the possibility to implement a network of RV set-ups to make a systematic survey of Habitable planets around the nearest stars. Such networks do exist already for Earth observations (TCCON, NDACC, …).
6. R and D on internal occulters, including the Tavrov's variant.
7. propose to NASA to participate to the next future NASA space telescopes now under studies. ESA already participates to HST and JWST and could participate to these future space telescopes dedicated to the search of bio-signatures.
8. investigate the role of astronauts in the building of very large telescopes in space, and investigate where the best place would be (on the Moon, in orbit around the Moon, or at L2 point, likely with RTG to be in the shadow of the Earth).

9.Short biography of the proposer: According to ADS (new system), I am today (August 4, 2019) an author or co-author of 531 refereed publications, totaling 19,887 citations with H-index of 71. This performance may be the privilege of age rather than a sign of excellence, but may be not.

My scientific work has been mainly about atmospheres of the Earth, Venus and Mars, comets, solar wind, the interstellar/interplanetary medium, and I consider myself as a planetologist. I worked in exo-planets only since 1993, when I helped Pierre Connes to develop his concept of Absolute Astronomical Accelerometer, dedicated to the discovery of exoplanets. Indeed, Pierre Connes had shown (1985) that the best way to detect an exoplanet was the indirect method of Radial Velocity, with a cross-dispersed spectrometer under vacuum for better stabilization. With the PhD students of Pierre Connes, François Bouchy and Jérôme Schmitt, we developed the AAA at Observatoire de Haute Provence (OHP, France). It worked well finally, reached the nominal 1 m/s precision on short term, but the accuracy went down to 10 m/s on longer periods. I suspect that this is due to the fact that we did not correct the stellar spectrum in real time form the telluric absorptions that may contaminate the RV algorithm. In parallel, Mayor and Queloz (1995) discovered the first exoplanet around a solar-type star also at OHP. Around 2000, I joined the HARPS consortium under the direction of Michel Mayor, participated to the design and funding of HARPS, and performed a 10 nights campaign of observations at La Silla Observatory (ESO) in Chile.

More recently, with Rosine Lallement form Observatoire de Paris, we developed an on-line web-service, TAPAS (http://cds-espri.ipsl.fr/tapas/), allowing to compute the spectrum of Telluric absorption for any observation, taking into account the meteorological fields of the atmosphere (Bertaux et al., 2014b). I was invited to a workshop in February 2019 in New-York dedicated to only one subject: the correction of telluric absorption of high spectral resolution star spectra collected for the detection of exoplanets with the RV method. There were 35 people attending this workshop on this very narrow subject, showing that the RV method is expanding fast. In 2018 I was invited to write one chapter of the Handbook of exoplanets (Springer) dedicated to the possible detection of relief on exoplanets (Bertaux, 2018).

"The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand."

- Carl Sagan

References

Anglada-Escudé, G. *et al.* , A terrestrial planet candidate in a temperate orbit around Proxima Centauri, *Nature* http://dx.doi.org/10.1038/nature19106

Bertaux, J.L., 2014a : EPSC Abstracts
Vol. 9, EPSC2014-864, 2014
European Planetary Science Congress 2014

Bertaux, J. L., Lallement, R., Ferron, S., Boonne, C., Bodichon, R., TAPAS, a web-based service of atmospheric transmission computation for astronomy, 2014b 2014A&A...564A..46B , http://cds-espri.ipsl.fr/tapas/

Bertaux, J.L., Solid Exoplanet Surfaces and Relief, Handbook of Exoplanets, H. J. Deeg, J. A. Belmonte (eds.) (2018), https://doi.org/10.1007/978-3-319-55333-7_162

Cash,W., Nature, vol.442, p.51-53, 2006

Cantrell, Justin R., Todd J. Henry, and Russel J. White, The Solar Neighborhood Xxix: The Habitable Real Estate Of Our Nearest Stellar Neighbors, The Astronomical Journal, 146:99 (20pp), 2013

Connes, P., Absolute Astronomical Accelerometry, Ap&SS, 110, 211-255 (1985)

Frolov, P. et al., "Achromatic interfero-coronagraph with variable rotational shear: reducing of star leakage effect, white light nulling with lab prototype," *J. Astron. Telesc. Instrum. Syst.* **2**(1), 011002 (2016) [doi:10.1117/1.JATIS.2.1.011002].

Mayor, M., & Queloz, D. ,1995, Nature, 378, 355

Meadows, Victoria S., Reflections on O_2 as a Biosignature in Exoplanetary Atmospheres 2017AsBio..17.1022M (2017)

Petigura, E.A., Howard, A.W., Marcy, G.W., 2013. Prevalence of Earth-size planets orbiting Sun-like stars. Proc Natl Acad Sci U S A., 110(48), 19273-19278. doi:10.1073/pnas.1319909110.

Rauer and Greenfell (2016) (https://nai.nasa.gov/calendar/workshop-without-walls-exoplanet-biosignatures/#archive)

Sagan C, Thompson WR, Carlson R, Gurnett D, Hord C (1993) A search for Life on Earth from the Galileo spacecraft. Nature 365:715

Selsis, F., Kasting, J. F., Levrard, B., et al. 2007, A&A, 476, 1373

Schwieterman et al. 2017 Identifying Planetary Biosignature Impostors: Spectral Features of CO and O4 Resulting from Abiotic O2/O3 Production, 2016ApJ...821L..34S

Tavrov, A. et al., "Common-path achromatic rotational-shearing coronagraph," *Opt. Lett.* **36**(11), 1972-1974 (2011) [doi:10.1364/OL.36.001972].

Tinetti, Giovanna et al., A chemical survey of exoplanets with ARIEL, Experimental Astronomy, Volume 46, Issue 1, pp.135-209 (2018)

Back-cover page listing the proposers: This white-paper reflects my personal views. I am (Jean-Loup Bertaux) the only proposer, but I think that the ideas therein are shared by a vast scientific community.