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Could We Search for Primitive Life on Extrasolar Planets in the Near Future? The DARWIN Project

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We revisit the idea of R. Bracewell and R. Angel *et al.*, that exoplanets around nearby stars could be detected in the IR (6–17 μm) and their spectra analyzed, searching for CO_2, H_2O, O_3, CH_4, and NH_3 spectral features. The presence, or absence, of CO_2 would be the indication of a deep similarity, or difference, with the atmospheres of telluric planets in the Solar System. That of H_2O would indicate a habitable planet and O_3 would reveal a large photosynthetic activity, indicating the presence of life based on carbon chemistry. As do these authors, we suggest an IR nulling interferometer pointing to the star and working as a coronograph. Our main contribution is to propose an observatory made of four to five 1-m class telescopes observing from 4–5 AU to avoid the solar zodiacal light (ZL) background at 10 μm instead of four 8-m telescopes observing from the vicinity of Earth. This allows the mission to be feasible in the *near future*. The discovery of ozone on an extrasolar planet would be a major scientific event. The concept, named DARWIN, is under consideration by the European Space Agency for its Horizon 2000 Plus program.

1. INTRODUCTION

The search for life in the universe will be a central theme in the scientific activity of the 21st century. For many millennia, humans have tried to understand how we and our world came to be. A related question is "the prevalence of planetary systems throughout the Universe (. . .) and the likelihood that other planets have given birth to life, even advanced and intelligent forms of lives (see Epicurus, 300 B.C.). We live in a *remarkable time*, when human beings (. . .) have attained the possibility of finding the *first real answers* to some of these most meaningful questions" (TOPS report, Burke, 1992).

As financial resources are scarce, it is important to distinguish which are the key steps. Until mid-1995, an opinion was developing stating that our solar system might be exceptional as far as the presence of Jupiter is concerned. It was based on the lack of discovery of giant planets ($M_{pl} \sin i > 1$–$3\ M_{Jupiter}$, where i is the angle between the exosystem plane and the sky) by Walker *et al.* (1995) in a limited star sample (21 stars) and the difficulty for present theoretical models to form Jupiter-mass objects. The situation was radically changed by fall 1995 when M. Mayor and D. Queloz (1995) announced the discovery of a Jupiter-mass companion to 51 Peg. This announcement was followed by the confirmation of the first discovery and that of two somewhat larger companions to 47 UMa and 70 Vir a few months later by G. Marcy and R. Butler (1996).[1]

[1] *Note added in proof.* The discovery of several other planets with ($M \sin(i)/M_{Jupiter}$) around MS stars has been announced since our manuscript was accepted. Up to July 1996: 55 Cnc A (0.8), τ Boo A (3.9), HD 114762 (10), upsilon And (0.6) (G. W. Marcy and R. P. Butler, private communication); Lal 21185 (0.9) (G. Gatewood, private communication).

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These discoveries were made from larger star samples. They point to the existence of giant gaseous planets and a large diversity among planetary systems.

The high precision velocimetry technique used has just begun its surveys and, combined with other techniques (differential astrometry, microlensing ...), it is likely to show evidence of other giant exo-planets in the next 10 years. The next breakthroughs would be (i) the search for habitable telluric planets and, in case of actual discoveries, (ii) the search for indices of primitive life on them. These two steps are essential because the mere detection of Jupiter-like planets would not really answer our basic question. The following concept is one of the very few possibilities we have of addressing these two questions in the *near future*.

2. HOW TO EVIDENCE LIFE BY REMOTE SENSING?

2.1. The O_2 Criterion

Evidencing the presence of life on an exoplanet by remote sensing is a formidable challenge. In a very interesting paper, T. Owen (1980) has shown that, if based on chemistry, life is likely to rely on organic chemistry and require the presence of liquid water. As the raw material in the primitive atmospheres of terrestrial planets is expected to be fully oxidized carbon (CO_2), a massive development of life would imply some reduction of CO_2 by photosynthesis and the corresponding release of free O_2. As the latter gas is highly reactive with reducing planetary rocks, the author has concluded that the massive presence (1–1000 mbar) of O_2 would be a strong indication of (primitive) life.

An alternative source of free O_2 is the UV photolysis of H_2O. However, the latter process is likely to occur only in planets with temperatures higher than that of Earth, e.g., Venus, and this temperature could be derived from the distance of the planet to its star and an estimate of its atmospheric greenhouse effect.[2]

2.2. The O_3 Criterion

O_2 has spectral signatures in the visible, e.g., at 760 nm, but such a search would face the huge ratio of the star to planet fluxes (5×10^9). R. Bracewell (1978) and R. Angel *et al.* (1986) have pointed out the advantage of searching in the mid IR, where this ratio is improved by almost three orders of magnitude. The latter authors have shown that the 6–17 μm region is very informative as it contains spectral features of H_2O (< 8 μm), O_3 (9.6 μm), and CO_2 (15 μm). Several authors (J. Kasting *et al.,* 1985; A. Léger *et al.,* 1993 and refs. therein) have shown that O_3 is an attractive tracer of O_2 because it has a logarithmic dependence upon the O_2 concentration: even a small amount of the latter (e.g., 1 mbar) would give rise to a significant O_3 band at 9.6 μm, much easier to detect than the corresponding O_2 bands.

The instrument proposed by R. Angel *et al.* (1986) as well as other authors (Watson *et al.,* 1991; Diner *et al.* 1991) was an apodized coronographic telescope with a diameter of order 16 m. In further papers, R. Angel (1989) and Shao (1989) have proposed to block the star light with a nulling interferometer using 8-m class telescopes. The reason for having such large telescopes was to overcome the strong ZL background at 1 AU. Unfortunately, this feature postponed the projects to the far future when such large telescope assemblies could be launched.

3. THE DARWIN PROPOSAL

The aim of this paper is to show that a similar goal can be achieved with smaller telescopes provided the interferometer is carefully designed and sent to 4–5 AU where the 10-μm ZL emission is much weaker (Bracewell and McPhie 1979). Our concept, called DARWIN, is similar to R. Angel's (1989) but for its dimensions. It has 4 to 5 IR telescopes of the 1-m class, regularly located on a 30–50 m diameter circle (Fig. 1).

3.1. Condition for Angular Separation between the Planet and Its Star

The Stefan law and the inverse square law imply that a planet is at about 300 K if its distance d to its star, with luminosity L, satisfies $(d/1\text{AU}) = (L/L_0)^{1/2}$, where L_0 is the solar luminosity. At a distance D, its maximum angular separation θ from the star results from the parsec definition: $\theta = (d/1\ \text{AU})/(D/1\ \text{pc})$ as. The criterion for a good angular separation between a planet and its star is obtained from the interferometer transmission map, i.e., the map of its transmission as a function of the coordinates of a source in the sky referred to the interferometer axes (Figs. 2a and 3a). For the five telescope configuration (Fig. 3), we consider that a planet is fairly well separated from its star if $X \geq 1.0$ because the transmission goes up to 90% of the local maximum during the interferometer rotation. The requirement on θ that results is $\theta = \lambda/2r$, where $2r$ is the interferometer diameter and λ the IR wavelength. For $\lambda = 10$ μm, $2r = 50$ m, it is 41 mas. The maximum stellar distance that allows such an angular separation is

$$D_{\text{sep}} < 24.4\, \overline{L}^{1/2}\, 2\overline{r}\, \overline{\lambda}^{-1} \quad (\text{pc}), \tag{1}$$

where reduced quantities are $\overline{L} = L/L_0$, $2\overline{r} = 2r/50$ m, $\overline{\lambda} = \lambda/10$ μm.

[2] *Note added in proof.* Such a large abiotic production of O_2 would require a H_2O photolysis followed by H escape during a runout greenhouse effect event on the planet. It would use up the water present at its surface. T. Owen has recently pointed out that the *simultaneous* discovery of O_2 and H_2O would be a criterion for the existence of primitive life (comment at the NASA workshop "Blue Dot Planet," Moffett Field, June 27–28, 1996).

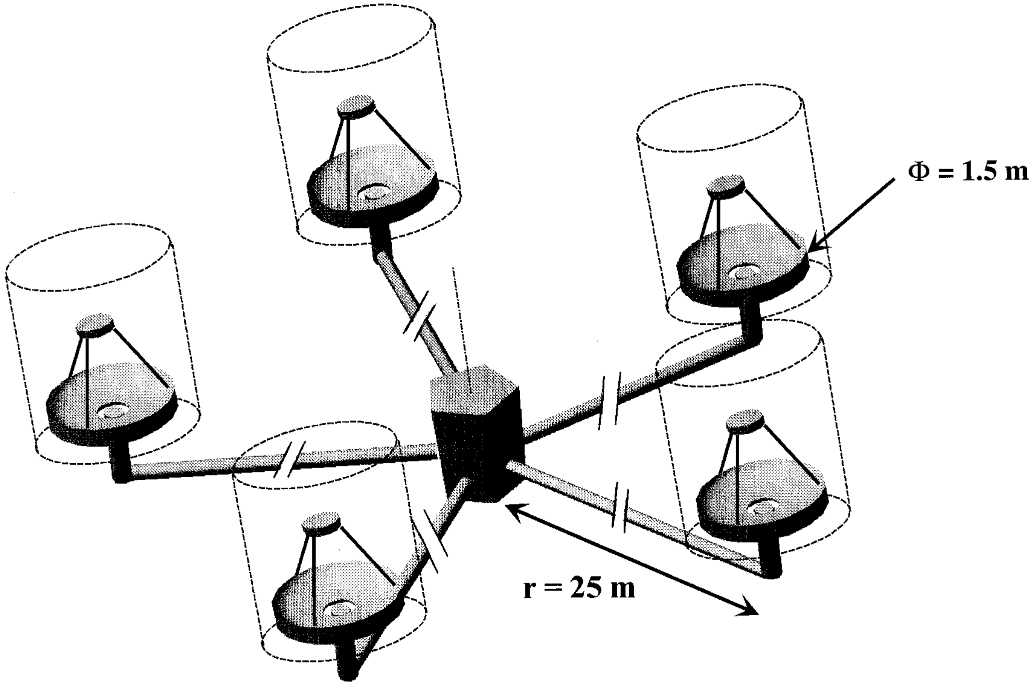

FIG. 1. Scheme of DARWIN in a five-telescope design.

3.2. The Planetary Flux

We assume a total efficiency of 15% for the detectors and the optics, including the beam recombining device (see Section 3.5). When the transmission of the five-telescope interferometer is at one of its first maxima (transmission = 70%, Fig. 3a), the number of photo-electrons generated by a planet per spectral element is

$$N_{\text{pl}} = 6.3 \times 10^2\ \overline{D}^{-2}\ \overline{\Phi_5}^2\ \overline{\text{Res}}^{-1}\ \overline{R_{\text{pl}}}^2\ \bar{t} \quad \text{(ph-el)}, \quad (2)$$

where $\overline{D} = \text{D}/10$ pc; Φ_5 is the telescope diameter, $\overline{\Phi_5} = \Phi_5/1.5$ m; Res $\equiv \lambda/\Delta\lambda$ is the spectrometer resolution, $\overline{\text{Res}} = \text{Res}/20$; R_{pl} and R_{E} are the planet and Earth radii respectively, $\overline{R_{\text{pl}}} = R_{\text{pl}}/R_{\text{E}}$ and $\bar{t} = \text{t}/1\text{h}$.

N_{pl} is a small number indeed and it must be extracted from noise and spurious signals, e.g., starlight leaks, $N_{\text{st leaks}}$. If ρ is the interferometer rejection factor and $\overline{fL}$ is the ratio of the stellar to the solar flux at 10 μm, one reads

$$N_{\text{st leaks}} = 5.6 \times 10^4 \overline{\rho}^{-1}\ \overline{fL}\ \overline{D}^{-2}\ \overline{\text{Res}}^{-1}\ \overline{\Phi_5}^2\ \bar{t} \quad \text{(ph-el)}, \quad (3)$$

where $\bar{\rho} = \rho/10^5$.

Clearly, a high and stable ρ is needed. Its limiting factors are (i) optics defects, (ii) imperfect optical path difference (OPD) cancellation, (iii) imperfect guiding of the individual telescopes, and (iv) finite star diameter. We think that the value of 10^5 is accessible because the three first points can be kept individually less than 0.5×10^5: (i) corresponds to a mirror quality of only $\lambda_v/5$ if optical filtering is applied at the output of each individual telescope (Ollivier *et al.,* in preparation); (ii) can be achieved if one monitors the delay lines responsible for the global pointing of the interferometer in the visible, where the stellar flux is quite strong, and obtains 20 times better accuracy at $\lambda \approx 10$ μm—quantitatively it corresponds to a $\lambda_v/140$ control of the OPD; (iii) requires guiding an individual telescope with a standard deviation of 600 μas or 1/140 Airy disk diameter in the visible, which should be possible by fine tuning with a small active mirror; finally, point (iv) is solved by using a four- or five-telescope interferometer whose transmission has a deep null in the center and varies as θ^{-4}, where θ is the angular separation between the source and the system axis (Angel, 1989). Quantitatively, an interferometer made of five telescopes located on a 50-m-diameter circle has a transmission smaller than 10^{-6} for a centered disk source with an angular radius of 0.73 mas at the most demanding (shortest) wavelength, 6 μm. Note that the radius of the Sun seen at 10 pc, a typical distance at which G stars will be observed (Table I in Section 3.7), is 0.45 mas.

3.3. The Solar Zodiacal Light Problem

In the vicinity of Earth, the Solar ZL, in 75% of the sky, has a surface brightness less than or equal to λI_λ (10 μm) = 7.5×10^{-6} Wm^{-2}sr^{-1} (Boulanger and Pérault, 1988). If S is the individual telescope area and Ω its observing solid angle, the ZL photon flux is proportional to $S\Omega$. To

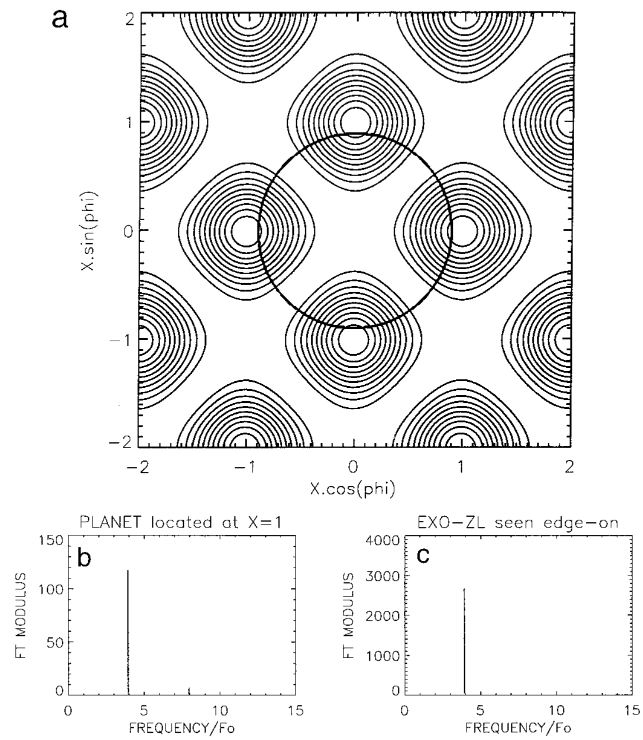

FIG. 2. (a) Transmission map of a four-telescope interferometer as a function of X cos φ and X sin φ where $X = 2r\theta/\lambda$, r is the radius of the interferometer circle where the telescopes are located, θ is the angle, in the sky plane, between the source and the interferometer pointing direction, φ is the source azimuthal angle counted from the direction of an interferometer arm, and λ is the observation wavelength. Transmission starts from zero in the center of the map, is very flat (αX^4), and goes up to 1.0 at the top of the hills. Isotransmission curves are drawn with 0.1 steps. When the interferometer is rotating, while pointing to the star, a planet describes a circle with radius X in the transmission plane. In the present example, $X = 0.9$. The mean value of the transmission over the whole map is 25%. The Fourier analysis, with respect to φ, of a planetary signal with $X = 1$, and that of an exozodiacal disk similar to the solar disk, seen edge-on, are reported in (b) and (c) respectively. The strong zero-frequency peak due to nonmodulated spurious signals has been withdrawn. The distinction between the two Fourier spectra is not obvious and would require observations at different positions of the planet on its orbit, and therefore values of X.

reduce the background, this quantity has to be minimized. Its lower limit is imposed by diffraction: $S\Omega \approx 3.7\lambda^2$. The corresponding diameter FOV, at 10 μm, is 3.4 as for 1.5 m telescopes. For a mean transmission of the interferometer map of 20% (Fig. 3a), the number of photoelectrons generated by the ZL must be $N_{ZL} = 4 \times 10^6\ \overline{\mathrm{Res}}^{-1}$ ph-el hr^{-1}, which would give *prohibitive photon noise*. This is why R. Angel (1989) proposed larger telescope diameters: N_{pl} increases as Φ_5^2 whereas N_{ZL} is independent of the telescope size. An alternative solution is to use 1-m class telescopes and go further away from the Sun so that the zodiacal dust is cooler and its mid-IR emission is much weaker around 10 μm. In order to have N_{ZL} significantly smaller than $N_{\mathrm{st\ leaks}}$, the ZL, at 10 μm, has to be decreased by a factor of about 200, for nominal values of D, Φ_5, and R_{pl}. This is possible, according to recent ZL models (Reach *et al.,* 1995), if we go to 4–5 AU. Then, at 10 μm,

$$N_{ZL} = 2.0 \times 10^4\ \overline{\mathrm{Res}}^{-1}\ \bar{t} \quad \text{(ph-el)}. \tag{4}$$

3.4. Thermal, Detector, and Cirrus Sources of Noise

Lowering the thermal emission of the optics and detector noise to a level similar to N_{ZL} or lower is possible if the telescope temperature is $\leq$30 K, the detector dark current 2 e^- sec^{-1}, and the readout noise 13 e^-. One gets

$$N_{\mathrm{thermal}}(\lambda < 15\ \mu\mathrm{m}) < 50\ \overline{\mathrm{Res}}^{-1}\ \bar{t} \quad \text{(ph-el)},$$

which is negligible,

and for 2 detectors per spectral element, 60 readouts per interferometer turn in order to study both telluric and more distant planets, and one rotation per 2 hr, the total detector noise is equivalent to the photon noise of a current:

$$N_{\mathrm{det}} = 2.4 \times 10^4\ \bar{t} \quad \text{(el)}. \tag{5}$$

The valuable studies by the EDISON team (Thronson *et al.,* 1993) have shown that the former objective is accessible at 4 AU by passive cooling. Good detectors' (BIB's?) characteristics should meet the detector specifications in the near future provided they are (actively) cooled to $\leq$4 K.

The Cirrus emission (Boulanger and Pérault, 1988) gives a mean flux of

$$N_{\mathrm{Cirrus}} = 1.2 \times 10^4\ \overline{\mathrm{Res}}^{-1}\ \bar{t} \quad \text{(ph-el)}. \tag{6}$$

This background cannot be avoided and its value indicates the limit of further useful decreases of the preceeding sources of noise.

To separate the planetary signal from the stable, but stronger, spurious signals, we propose to use the Bracewell (1978) concept of slowly rotating the interferometer ($f_0 \approx$ 0.5 turn hr^{-1}) while continuously pointing to the star. The planet signal is then periodic whereas spurious signals are not modulated (Fig. 2b and 3b).

3.5. *Exo-zodiacal Light*

There is a important exception to the above statement: the *exo-ZL* signal, i.e., that coming from the emission of zodiacal dust in the external star system. For a system similar to the Solar System, the Zodiacal cloud is 400 times brighter than the Earth at 10 μm. When such a flux goes through the interferometer transmission map, with an Earthlike planet at $X = 0.9$ (Figs. 2a and 3a) and the exo-ZL correspondingly located in the map, it gives a photon electron flux 55 times stronger than $N_{\rm pl}$:

$$N_{\text{exo-ZL}} = 3.4 \times 10^4\, \overline{D}^{-2}\, \overline{\text{Res}}^{-1}\, \overline{\Phi_5}^2\, \bar{t} \quad \text{(ph-el).} \qquad (7)$$

When the exo-system is observed face on, it does not give a modulated signal, but this is no longer true when the angle i between the normal to the exoecliptic plane and the line of sight increases (Figs. 2c and 3c). Regarding the capability to distinguish between the exo-ZL and planet signals, a *non-centrally symmetric* interferometric pupil has a major advantage: it mainly modulates the planet signal at nf_0 (where n is the order of symmetry of the pupil function), while the symmetric emission of the exozodiacal light is modulated at $2nf_0$. We have studied the possibility of generalizing the rules leading to a deep central null (Mennesson *et al.,* in preparation), starting from Angel's cross configuration: they can indeed be generalized assuming that the telescopes are regularly spaced on a circle. If the phases of each beam are properly tuned, the sum of the complex amplitudes cancels for an on-axis source. Any even configuration, starting with $n = 4$ (precisely Angel's cross), will preserve the deep central null and feature a θ^{-4} dependency of the off-axis intensity. But this is also true for odd configurations, from $n = 5$. In the $n = 3$ case, one can achieve a central null but unfortunately the transmission close to the axis varies as θ^{-2}. Therefore, we consider in the following an interferometer with five telescopes (Fig. 1) which modulates the planetary signal at 5 f_0 whereas the exozodiacal light is modulated at 10 f_0 and higher harmonics (Fig. 3b and 3c). For instance, even with an exo-ZL *100 times stronger* than the Solar ZL, we find that one-third of the stellar systems of Table I could still be studied. The transmission map of the five-telescope nulling interferometer is not dense; i.e., even when the interferometer rotates, a planet in a random position will

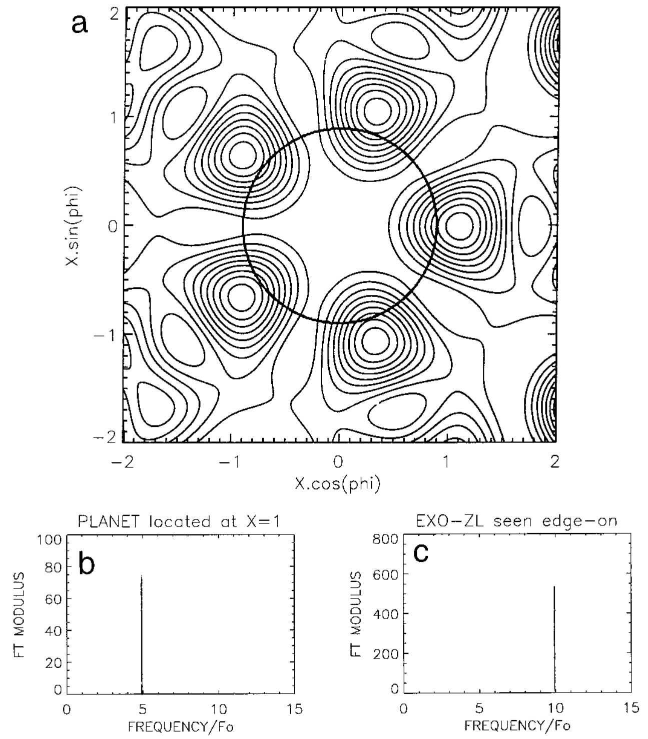

FIG. 3. Same as Fig. 2 for a five-telescope interferometer with 0.07 contour steps. The mean value of the transmission over the whole map is 20%. The Fourier spectra are quite different for a planet (b) and a exozodiacal disk (c), because the transmission map has no central symmetry. On the other hand, the maximum transmission at the first hilltops goes up to 0.70 only. This configuration would be preferred to the four-telescope one if most exo-ZL appear to be brighter than the solar ZL.

not necessary cross regions of the map where the transmission is high, e.g., a planet at $X = 1.9$ in Fig. 3a. For a given planet, to efficiently measure its whole 6–17 μm spectrum, the interferometer dimensions should be uniformly changed by a factor of 1.5. However, other solutions, such as setting the telescopes on an ellipse, that would not require changing the interferometer dimensions are currently under consideration (Mennesson *et al.,* in preparation). This "movable" version would have advantages, especially if the interferometer had an *imaging mode*, but it makes the concept less reliable. On the other hand, a 4 or 3 telescope interferometer, in a diamond shape or a linear array (Angel, 1989 and Angel *et al.,* in preparation) has a dense transmission map and can accommodate fixed dimensions but it is less efficient in separating planetary from exo-ZL signals (Figs. 2b and 2c).

Also, the beam-combiner is more difficult to design for an odd number of beams. We have proposed (Mennesson *et al.,* in preparation) a set-up derived from an imaging combiner for eight beams: it has the advantage of being conceptually simple and of using only 50/50 beamsplitters, but its efficiency is rather low, only 62% for peak transmission. More efficient designs are under study but they will require abandonment of these simple concepts. In all cases, the beam combiner must be achromatic and polarization independent. These constraints probably cannot be fulfilled throughout the total bandpass of the system; it is hence likely that the beams will have to be split in polarization as well as into several bandpasses prior to recombination.

The observations by ISO and SIRTIF should permit a better modelling of dust around MS stars and estimate of the importance of exo-ZL at 10 μm around nearby stars. They should influence the choice between the different configurations.

3.6. *Mission Strategy*

Considering an 8-yr mission with 4 yr of integration time, we can use the first integration year to detect telluric exoplanets and the next 3 ones to spectroscopically analyze the interesting candidates, if any, in the 6–17 μm range. By numerical simulation, we have shown that a SNR of 20 when the planet is at an interferometer transmission maximum leads to an actual signal to noise ratio of $\mathrm{SNR}_{\mathrm{actual}} = 10$ for the planet's main Fourier peaks when the interferometer is rotated, which is acceptable for detecting $\approx$50% deep spectral bands. To allow the detection of the planetary signal, the additional spurious fluxes (N_i) have to be stable. However, they introduce a photon noise with a standard deviation equal to the square root of the mean signal, so that $\mathrm{SNR} = N_{\mathrm{pl}}/(\Sigma_i N_i)^{1/2}$. Getting a sufficient SNR implies a minimum value of the fluxes and therefore a maximum distance of the stellar system, D_{SNR}. At 10 μm, D is the solution of:

$$\begin{aligned}&[6.3\times 10^2\,\overline{D}^{-2}\,\overline{\Phi_5}^{\,2}\,\overline{R_{\mathrm{pl}}}^{2}\,\overline{\mathrm{Res}}^{-1}\,\bar{t}\,]^2\\ &\quad = 400(\mathrm{SNR}/20)^2\,[(5.6\times 10^4\,\bar{\rho}^{-1}\,\overline{fL}\,\overline{D}^{-2}\,\overline{\Phi_5}^{2} + 3.2\times 10^4\\ &\qquad + 3.4\times 10^4\,z\,\overline{D}^{-2}\,\overline{\Phi_5}^{2})\,\overline{\mathrm{Res}}^{-1}\,\bar{t} + 2.4\times 10^4\,\bar{t}\,], \qquad (8)\end{aligned}$$

when the exo-ZL is z times the Solar ZL.

3.7. *Number of Stellar Systems That Can Be Studied*

Considering the most restrictive condition between relations (1) and (8) for the maximum stellar distance and the

TABLE I
According to the Stellar Spectral Class, Number of Stellar Systems That Can Be Investigated with a 5 × 1.5 m Telescopic Array Located on a 2r = 50 m Circle, for Planetary Detection,[a] Spectroscopy of CO_2,[b] and Spectroscopy of O_3[c]

sp. class	D_{sep} (pc)	D_{SNR} detect. (pc)	mv limit	Nb detect. (single star)	D_{SNR} CO_2 spectr. (pc)	t_{integ} (h)	Nb CO_2 spectr. (s. st.)	D_{SNR} O_3 spectr. (pc)	t_{integ} (h)	Nb O_3 spectr. (s. st.)
F0-4	51.0	<u>18.6</u>	4.3	6	<u>12.9</u>	200	2	<u>9.5</u>	800	1
F5-9	33.5	<u>19.7</u>	5.3	18	<u>14.1</u>	200	6	<u>10.7</u>	800	3
G0-4	24.3	<u>20.3</u>	6.2	31	<u>14.7</u>	200	12	<u>11.4</u>	800	5
G5-9	<u>18.8</u>	20.6	6.8	36	<u>15.1</u>	200	18	<u>11.7</u>	800	9
K0-4	<u>12.9</u>	20.8	7.0	16	15.3	117	15	<u>12.0</u>	800	12
K5-9	<u>8.1</u>	21.0	7.5	5	15.6	28	5	12.3	240	5
M0-4	<u>4.4</u>	21.3	8.1	5	15.9	5.0	5	12.7	42	5
	Accessible			117			64			40
	to be actually observed			117			44			22

[a] Res = 2, $t_{\mathrm{integr.}} \leq 30$ hr, total integration time = 1 yr, $z = 1$ with three observations of the same system at different dates. Maximum distances are D_{sep}, allowing for the angular separation of a 300 K planet from its star, and D_{SNR} for its detection with $\mathrm{SNR}_{\mathrm{actual}} = 5$, or SNR = 10 in Eq. (8). For each spectral class, the limiting distance is underlined.

[b] Res = 6, $\mathrm{SNR}_{\mathrm{actual}} = 12.5$, $t_{\mathrm{integr.}} \leq 200$ hr or 8.3 days, total integration time limited to 1 yr.

[c] Res = 20, $\mathrm{SNR}_{\mathrm{actual}} = 20$, $t_{\mathrm{integr.}} \leq 800$ hr or 33 days, total integration time limited to 2 yr.

star density in the solar neighbourhood (Scalo, 1986), Table I gives the number of systems where terrestrial planets can be studied, using a five 1.5-m telescope interferometer and considering that multiple stars cannot be worked out. In about 100 stellar systems planets can be searched for during one integration year and observed several times, typically three, in order to determine the planetary motions. Most of these are *late F, G and early K stars,* which is quite convenient as these are considered as the best candidates to have *habitable* planets (Kasting *et al.,* 1993).

During the next three integration years, longer observations ($t_{\text{integration}} \leq 800$ h) at higher spectral resolution (Res = 20) could be performed typically on 44 stellar systems selected among the previous ones. During such long integration times, an Earthlike planet will move typically by 30° in its orbit. This will have been determined by the characterization of the planetary motion during the first year of observation and the spectroscopic observations will be positioned to take it into account.

The first objective would be to search for CO_2 at 15 μm. The presence or absence of this gas would indicate a deep similarity to or difference from the atmospheres of telluric planets in the Solar System because all of the latter contain this gas. That of H_2O, at $\lambda < 8$ μm, would indicate a habitable planet and the simultaneous presence of H_2O and O_3 (9.6 μm) would reveal important photosynthetic activity, indicating the presence of carbon-chemistry-based life, which would be *a major discovery*.

The presence of CH_4 and NH_3 and possibly (hydro-) chlorofluorocarbon species could also be searched for in this extremely informative part of the electromagnetic spectrum through the 7.65, 10.5, and 10–11 μm bands, respectively. A higher spectral resolution (Res $\approx$ 150) would probably be required for nonambiguous detections if the species are minor components, as in the Earth atmosphere. However, it opens quite attractive possibilities for Jovian planets, and for terrestrial planets in next generation missions.

4. CONCLUSION

The mission proposed leads to the study of a star sample of about 100 objects using an interferometer with 1.5 m telescopes, which does not appear to be out of our near future building capabilities. It addresses one of the *most fundamental problems* that science can deal with. In addition, the mission would have important purely astronomical by-products such as the possibility to study the central parts of young stellar disks, circumstellar envelopes, narrow line regions of AGN, and QSO's.

Challenging technological problems have to be solved, e.g., our capability to build a very high rejection, achromatic, nulling interferometer and large, deployable, and possibly variable size structures in space. However, none seems out of reach of our next decade technology. The European Space Agency is currently considering such a compelling mission in its Horizon 2000 Plus program.

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