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Introduction to the SETI program, criticalities and future strategies

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Abstract. In this paper, we will analyze the evolution of the SETI (Search for Extra-Terrestrial Intelligence) program whose aim is to look for artificial radio signals from advanced civilizations in the space with the radiotelescopes (there is also SETI program in the optical band but here we consider only the search in the radio band). We will investigate the intrinsic criticalities and difficulties of the program considering anyway that it has a low probability of success: we don't know where to point the large antennas, the tuning frequency, what to search for, at which moment to observe, what sensitivity is required to receive an ET signal. It is extremely difficult to exactly set the just mentioned parameters and correctly answer all the questions. In the future, SETI observational activities will have to be based on the synergy between different groups with competences in mathematics, Physic and engineers introducing new research paradigms and related algorithms. The SETI program represents a challenge to the limit of the impossible for both our current technologies and knowledge! We search for an unknown analog or digital signal buried in an ocean of man-made radio interferences, self-generated noise and natural noise from the radio sources that populate the universe.

Key words. SETI – Radio Communication – Exoplanets – Data processing

1. Introduction.

The formal birth of the SETI program was just after the launch of the Russian Sputnik, the first artificial satellite in the world. In 1959, Giuseppe Cocconi and Philip Morrison suggested using the microwaves in the region of the Hydrogen line emission at 21 cm, to look for radio communications from other inhabited worlds or to communicate between different planetary systems (Cocconi 1959), as described in an article on the prestigious US magazine "Nature".

Radio searches for extraterrestrial signals officially began in 1960, when Frank Drake (who wrote the Drake Equation) was based at the Greenbank (NRAO, West Virginia). Drake used the 85-foot Tatel radio telescope in his Project Ozma (named after the queen figure in the Wizard of Oz), which examined signals coming from two nearby stars, Tau Ceti and Epsilon Eridani. Looking at the hydrogen frequency (1,420 MHz), Drake searched for both repeated sequences of uniformly patterned pulses, and sequences of prime numbers; the detection of either of these would indicate the presence of an extraterrestrial civilization, but with no success (Drake 1961). On the other hand, he exploited the technology of that time using noisy receiver and a very poor data processing (analog domain). Since late 1970 NASA started to be interested in the program, which became a reality in late the 80ies. The first SETI observations started in 1992 in the 500th anniversary of the discovery of the new world by "Christopher Columbus". Unfortunately, in late 1993 the American Congress definitively canceled the SETI program, probably for lack of funds or due to other unknown reasons (Garber 1999). SETI activities were taken over by the new SETI Institute, based in Mountain View (California) today fully operative with funds coming from donations from individuals, industries of the Silicon Valley or other. The University of Berkeley also participates in the SETI program with a group of researchers. Serendip II- V. (Backus 1992; Serendip 1988; Werthimer 1995; Cas 2016) were a revolutionary spectrometer able to operate in parallel at the ongoing observation without interfere with the observer. At the Medicina dish antenna a Serendip IV system acquired data from 1998 till 2008 in the frame of the SETI-Italia program as reported in Tab. 1.

It is very likely that in our galaxy exists a large number of extrasolar planets, similar to the earth, hosting advanced civilizations. These could able to communicate through electromagnetic signals in certain segments of the spectrum. The possible bands of frequencies that ET could exploit for the communications, especially towards its spacecraft traveling in the galaxy, are those to which his atmosphere turns out to be transparent. From our observation point, the frequency windows open toward/from the universe are the radio and the optical one. The current SETI research in Italy is mainly conducted in the radio window and until today has been based on the hypothesis that if an extraterrestrial civilization wants to notify us of its presence, it probably irradiates a monochromatic signal (radio carrier) toward the outer space:

1. it is not strongly affected by interstellar/interplanetary dispersion and scattering.
2. searching for monochromatic signals is computationally efficient with a Fast Fourier transform (complexity scales as $N_s \log(N_s)$) where N_s is the number of signal samples.
3. simple to interpret: a narrowband beacon carries only one bit of information, but it is enough to tell us that an alien civilization somewhere exists.
4. is very efficient from an energetic point of view because all the available energy is concentrated in the radio carrier.
5. it is easily distinguishable from natural radio emission.

In a near future, optical SETI (OSETI) programs could start in some national optical observatories still operating but not completely overscheduled. In this case, we would look for very short laser pulses of the order of a nanosecond. These two types of signals (radio carrier and laser pulses) have the advantage of being easily distinguishable from those of natural origin. Due to the Earth atmosphere transparency at the radio and optical bands, they can easily reach the ground based observatories. If the transmission is not intentional and the radio waves arriving from space represent the residue of electromagnetic activities of ET (communications, spacecraft control etc..), the problem becomes really difficult. Even if the antenna is pointed in the right direction, tuned on the exact frequency, with the appropriate sensitivity and observing at the right time but the received signal is totally unknown, it is very difficult to use the right detector. For this reason it is unlikely to notice a possible hidden information in an ocean of noise. In fact, the demodulator on board of the receiver must be compatible with the modulation of the transmitted signal, otherwise the information is lost. It is likely that ET has long been disseminating unknown radio signals in space, which almost certainly risk being never detected by our modern radio systems.

With the current radio telescopes, we search for sinusoids (monochromatic signals) shifting linearly in frequency (Doppler effect) due to variation of the radial component correlated to the relative Earth-Exoplanet motion. In this approach, the search for a monochromatic radio signal is done with a high-resolution FFT (Fast Fourier Transform) performed by very powerful low cost computers that are available today on the market. However, in the future,

Table 1. SETI-Italia activities at the Medicina (Bologna) 32 m dish antenna.

Institution	Station	Program name	Back-End	Periods	Funds
CNR/INAF	Medicina	SETI ITALIA	Serendip IV	1998-2008	CNR/INAF
INAF/ASI	Medicina	ITASEL	Spectra-1	2005-2013	INAF/ASI

it will be necessary to change the searching algorithms to considerably increase the probability of success of the program. Maybe we are looking for an alien signal that does not actually exist (see the above mentioned CW signal searched till today), or there are indeed alien radio signals wandering in space that we are unable to reveal with our current technology. We could be unable to detect because we do not know what we have really to search for. It is a truly complex scenario!

2. Main difficulties of the program.

The SETI Program assumes being possible to establish a radio communication link, as schematically shown in Fig. 1, between an exoplanet and the planet Earth.

To increase the power (P_{out}) at the receiver output connector, it is clear that the effects of the impressive attenuation due to the FSPL (Free Space Path Loss) have to be strongly reduced. FSPL is defined as the loss incurred by a radio signal as it travels in a straight line through a vacuum space with no absorption or reflection of energy from nearby objects (It is why distant headlights are more faint than close ones). Signal detection becomes extremely complicated if it is time-varying with some type of unknown modulation. The SETI search space is characterized by many parameters and it is a very hard task to set them with the right value in order to increase the program success possibilities. A list is reported in Tab. 2 with some hypothesis on how to facilitate the demand reported in the first column:

In the case the alien transmissions are not intentional and then not specifically aimed at our planet, it means that these are residues from their own radio communication activities. At this point, the problem to extract it from the background noise becomes extremely complicated because we don't know anything about the morphology of such a signal (almost surely digitally modulated).

Every single row of the above reported table, is here commented:

2.1. Antenna Pointing.

It is easy to point the antenna to already cataloged exoplanets, or single sources as well, because their positions on the sky are known (targeted mode). In the case the source position is unknown, we have to systematically scan all the sky in order to search for it (sky survey mode). In this case a very high number of possible antenna displacements is required. In practice, such a number depends on both the operating frequency and the antenna size that determine the size of its FoV (Field of View). Anyway, this remains one of the most complex parameters to be defined. Beyond our assumptions, it is unlikely that ET will intentionally point his antenna towards the earth by sending a radio signal and, at the same time, it is unlikely that just by chance we orientate one of our antennas to his direction.

Considering that a space radio link is composed by two antennas of the SRT class (64 m), as an exercise, it can be computed by how many telescope position is composed the celestial dome. The following formula (1) gives the number of beams:

$$N_{beam} = \frac{4}{\left[\tan(28.6 D_{\lambda}^{-1})\right]^2} \tag{1}$$

Considering a working frequency of 1420 MHz, the number of antenna beams needed to cover all the visible sky is 1.510^6. This means

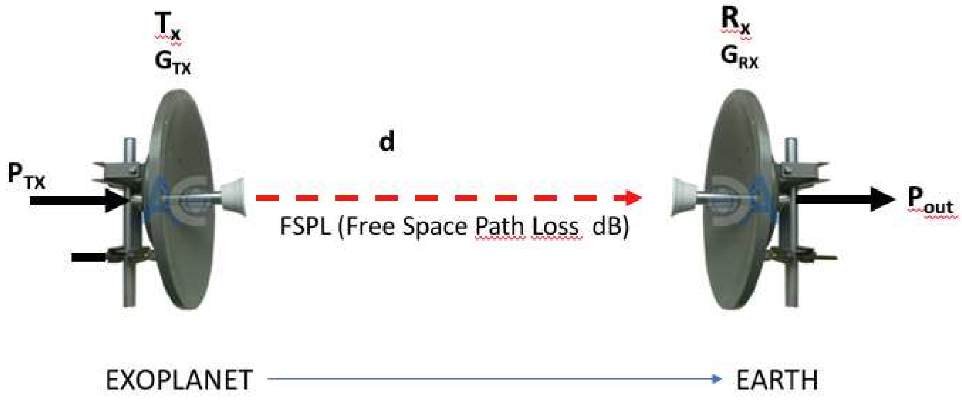

Fig. 1. Basic radio link block diagram for the SETI Program.

Table 2. Simplification hypothesis for some of the search parameters.

Search Parameters:	**Hypothesis**
In which direction the antenna has to be pointed?	*The antenna can be pointed to a certain set of exoplanets similar to the earth (targeted observations).*
At which frequency the radio telescope has to be tuned?	*The more suitable frequency band is from 1 GHz to 10 GHz where the galactic noise contribute is very low: the preferred band is that one of the emission of neutral hydrogen (1420 MHz), or more generally the band of the so-called water hole spanning from the neutral Hydrogen (1420 MHz) to the OH at 1720 MHz).*
What signal do we look for? Analog? Digital? Modulated? In this case how is modulated?	*The radio signal searched today, as a proof of the ET presence, is a CW radio signal probably intentionally sent by ET.*
What is sensitivity with which do we have to observe?	*Observing with the largest available antennas probably the "sensitivity" requirement is met.*
Are we in the right time window of the "electromagnetic visibility" of that alien civilization?	*Regarding the time window of the alien "electromagnetic visibility", nothing can be hypothesized. . . .*

that if ET already points its antenna toward us, randomly moving our dish we have one chance in 1.510^6 to point it in the right direction!! If ET doesn't know anything about us, the probability that it points our planet with its 64 m antenna considered in this example, is the same of 1.510^6. Then the probability that ET points his antenna in our direction while we point our one in his direction is represented by 1 part in 2.2510^{12}. Just for a practical example to evaluate such probabilities, we assume F=1420 MHz and some different configurations of ET transmitter and Earth base receiver composed by FAST (500 m), ARECIBO (300 m), SRT (64 m) and MEDICINA (32 m) antennas as reported in Tab. 3.

Table 3. Chance of success with different configurations.

ET antenna (m)	TX Gain (dB)	Num. of Beam (TX)	RX Earth antenna (m)	RX antenna Gain (dB)	Num. of Beam (RX)	UNINTENTIONAL ET doesn't take (care of the Earth.) One chance in:	INTENTIONAL ET is pointing Earth. One chance in:
64	57	$1.5 \cdot 10^6$	32	51	$3.7 \cdot 10^5$	$5.6 \cdot 10^{11}$	$3.7 \cdot 10^5$
64	57	$1.5 \cdot 10^6$	64	57	$1.5 \cdot 10^6$	$2.2 \cdot 10^{12}$	$1.5 \cdot 10^6$
4300	71	$3.2 \cdot 10^7$	64	57	$1.5 \cdot 10^6$	$4.8 \cdot 10^{13}$	$1.5 \cdot 10^6$
500	75	$9.0 \cdot 10^7$	300	71	$3.2 \cdot 10^7$	$29 \cdot 10^{14}$	$3.2 \cdot 10^7$
500	75	$9.0 \cdot 10^7$	500	75	$9.0 \cdot 10^7$	$481 \cdot 10^{14}$	$9.0 \cdot 10^7$

2.2. Frequency at which the radiotelescope has to be tuned.

In the book "Communication with Extra Terrestrial Intelligence (CETI)" edited in the 70s, Barnard M. Oliver, basing on the article by Cocconi and Morrison appeared in Nature in 1959, proposed the use of the lower part of microwaves (1-10 GHz) as the most suitable segment of the electromagnetic spectrum for the search for extraterrestrial radio signals (Fig.2) for the following reasons:

- Galactic noise (synchrotron radiation) at a minimum.
- Thermal noise (isotropic background noise) at a minimum.
- Quantum noise (spontaneous emission or shot noise) at low level.
- Star noise at low level.

In particular, within this "Silent Valley", the search for signals is limited to a segment that lies between the emission of the neutral hydrogen H (1420 MHz) and that one of the OH (1720 MHz) referred as the waterhole. In the case ET wanted to be noticed (a questionable supposition that meets, however, the favorable opinion of many SETI researchers) could transmit a signal within a band included in such a waterhole.

The name given to this particular band of frequencies would like to remember the waterhole in the desert, around which the animals gather to quench their thirst. If in the universe exist several civilizations, they would probably meet from an electromagnetic point of view, each other around the frequencies related to the waterhole to get noticed through their radio emission!

In the 0.9-10 GHz frequency segment there are 9.1 10^9 1Hz wide channels. This means that the chance to detect a CW signal in this band is one in 9.1 10^9.

2.3. What signal are we searching for.

Which type of radio signals could we expect from an extraterrestrial technologically advanced civilization? This is a core question for the SETI program and it is extremely difficult to answer because we do not know anything about their technology, their way of being and how (or if) they communicate through radio waves or with other unknown mode. In the case we wanted to reveal our presence to the aliens, we would send out to space a monochromatic signal, then we suppose that even ET could behave in this way. Such a type of signal is considered to be very efficient because all the available energy is concentrated on the radio carrier but it doesn't carry information since no modulation is present. Anyway, if detected, it should be considered absolutely a valuable detection because makes us aware that someone must have generated and sent it into the space! Anyway, it is realistic to think that it is unlikely (not impossible) that some extraterrestrial civilization wants to indicate its presence to us. It could be instead more likely to receive alien radio signals coming from their normal planetary radio activities (if any). In this case, what kind of signal could we receive? Analog? Digital? Modulated in which way? This is another extremely complicated question which is difficult to answer. The type of modulation must be absolutely known because the receiver needs to be equipped with a demodulator compatible with the modulation mode used at the trans-

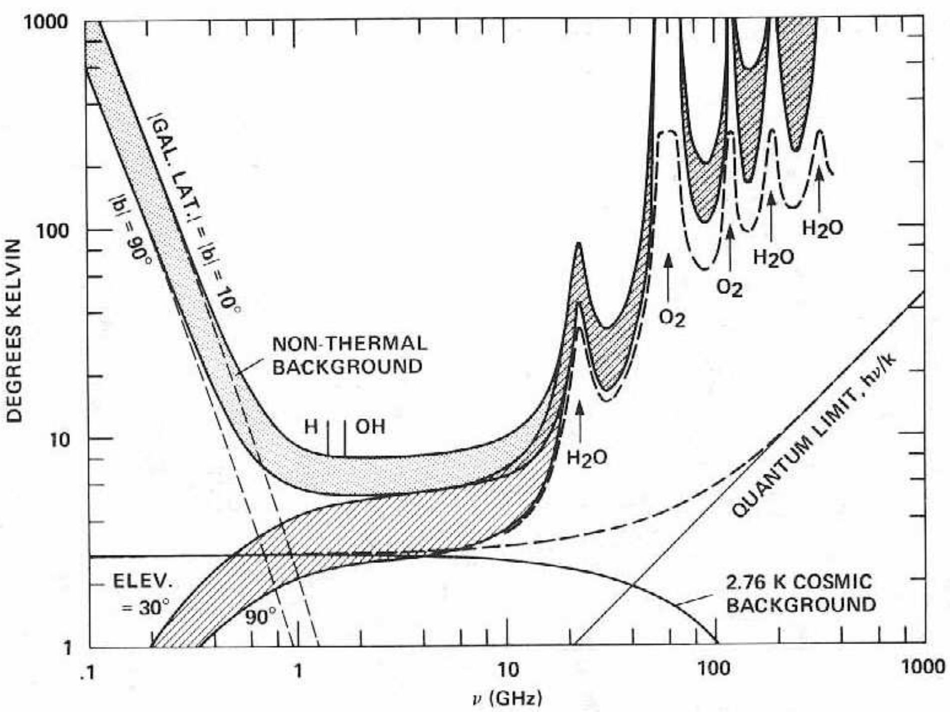

Fig. 2. Microwave window.

mitter stage, otherwise, the information could be completely lost.

In Fig. 3 is shown a very simple schematic block diagram of a radio communication link where it is clear that if the transmitter, for instance, is PSK modulated (Phase Shift Keying is a digital modulation process), the receiver must be equipped with a detector suitable for the PSK and this occurs for any type of modulation. This is a great challenge because if we a priori don't know the modulation mode we cannot apply for the correct demodulation algorithm. And it is even more complicated if we deal with an absolutely unknown alien modulation mode. For many decades, on our planet we transmitted analog signals (radio, TV, etc.) then, with the advancement of technology, we have moved to the digital techniques (satellites, military, TV, DAB, etc.). A similar evolution could be thought for the alien civilization radio transmissions as well. The digital field, in fact, offers many advantages as to concentrate most of the energy in the information. If the modulation mode is not known, the digital signals received increasingly resemble the noise making them even more undetectable! The post-processing phase is one of the most critical stage of the SETI "chain".

Worthy of note is the Spread Spectrum mode, which is considered to be the most suitable modulation mode for interstellar radio communications, being insensitive to radio interference in the environment in which the receiver operates.

In Fig. 4 are reported the different types of both analog and digital basic modulations used by modern terrestrial technology. Fig. 5 shows, in a more detail, only the various types of digital modulation used today. Since any kind of analysis and signals detection must be carried out with suitable algorithms and procedures,

we report in Tab. 4 the main processing algorithms (ITU-R 2011). To date, the main goal of the modulation techniques is to compress as

Table 4. Main analysis tools for different operational mode.

Parameter to be measured	Analysis tool	Modulation type	Radio Environment
Presence of a radio communication signal	Cross-Correlation of Q-I signal or of instantaneous AI with reference signal	Any modulation type but especially for known TDMA, CDMA and DSSS signal	Any
	Spectral power density	Any modulation type	Medium and high SNR
	Auto-correlation and cyclic auto-correlation	OFDM, SC-FDMA, SC-FDE	Any
	Spectrum correlation analysis	Unknown DSSS and weak signals	Any
PRF or burst length	Amplitude time signal analysis	OOK, Radar, IFF, other bursted signals	Medium and high SNR
Carrier frequency and subcarrier frequency	Spectral power density	Any modulation type	Medium and high SNR
	Instantaneous frequency F_i istogram	FSK	Medium and high SNR
	Instantaneous frequency F_i average	FSK	Medium and high SNR
	Spectrum of I-Q signal raised to power $N(=)$ M(MPSK), 4(QAM) or $\frac{1}{4}$ for CPM)	PSK, QAM, CPM	Positive SNR
	Spectrum correlation analysis	Any linear modulation and especially ASK, BPSK, QPSK	Any
	The spectrum of signal module raised to power 2 or 4 with severe filtering	Pi/2DBPSK, Pi/4DQPSK, SQPSK	Positive SNR Any
Emission bandwidth and channelization	Spectral power density compared with mask or limit line function	Any modulation type	Medium and high SNR
Frequency distance between subcarriers (Shift for FSK)	Spectral power density. Harmonic search and/or harmonic markers	FSK, OFDM, COFDM	Medium and high SNR
	Spectral power densiti. Harmonic search and/or harmonic markers		Medium and high SNR

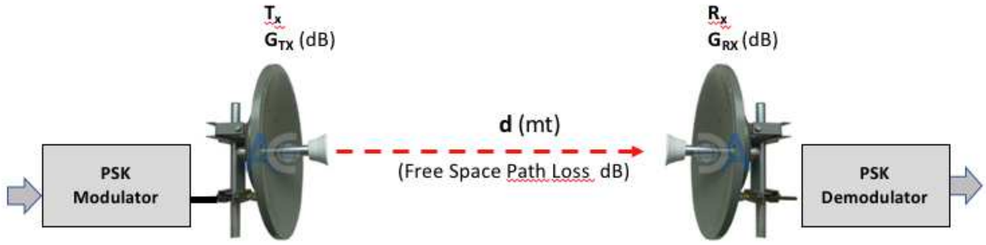

Fig. 3. Example of a radio link (for example with a PSK modulation) architecture. The demodulation method at the receiver side has to be strictly related to the Tx modulation.

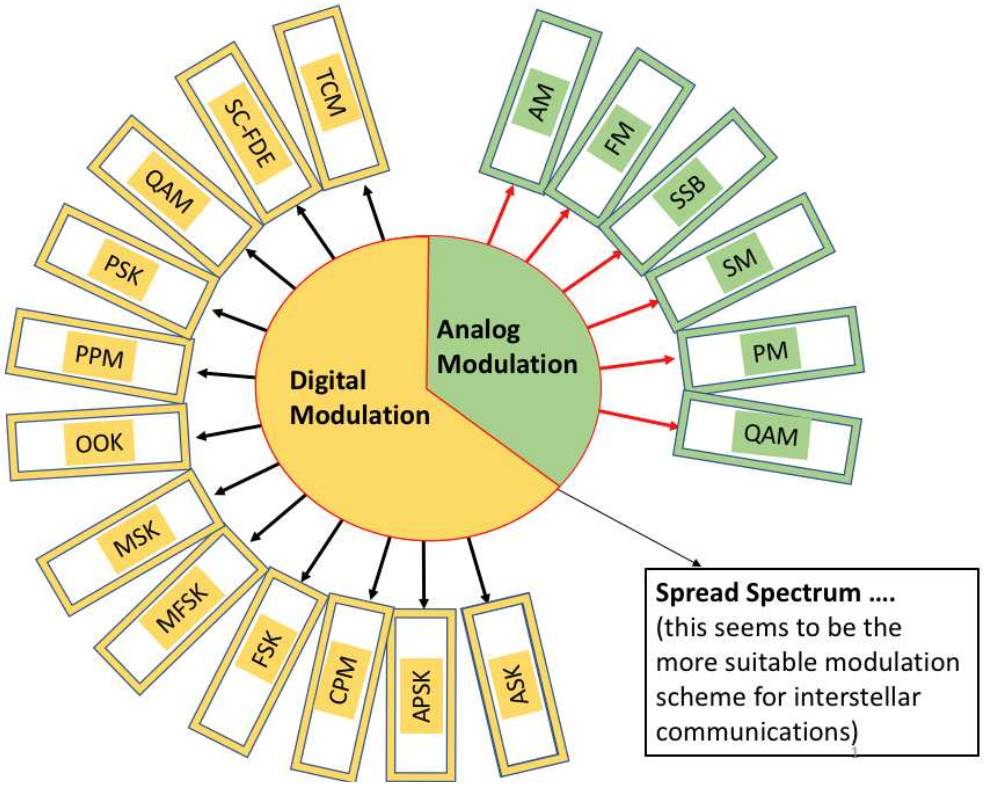

Fig. 4. A simple list of both analog and digital modulation.

much data as possible into the least amount of spectrum. We could speculate that ET, looking for the maximum efficiency, can transmit a CW signal in the analog domain and something similar to the OFDM (Orthogonal Frequency Division Multiplexing) in the digital domain as shown in Tab. (5) where the spectral efficiency for a set of known modulation methods is reported (Frenzel 2012).

The digitally modulated signals occupy a certain bandwidth, as reported in Tab. 6 for a reduced set of different types of common digi-

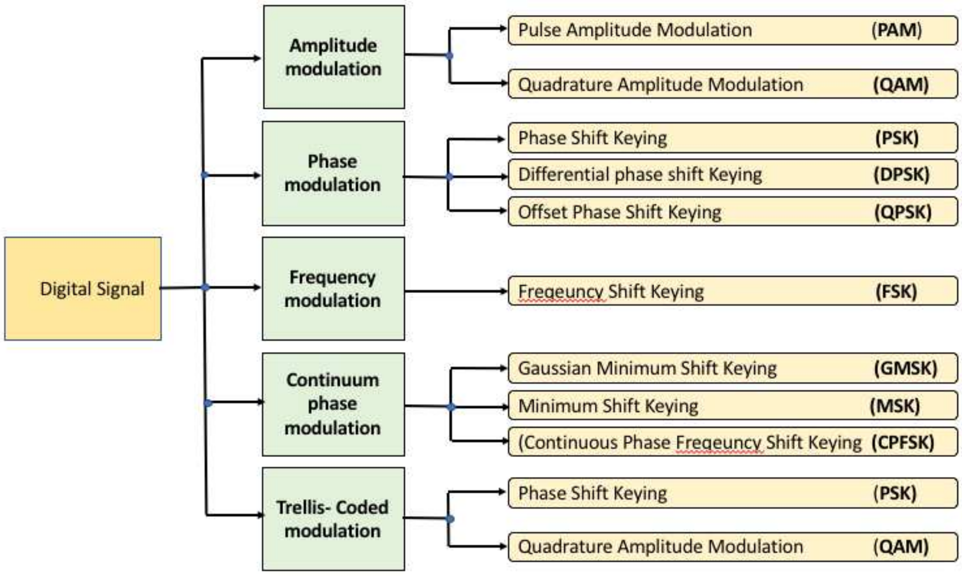

Fig. 5. A more detailed list of the digital modulation mode used to date.

Table 5. Spectral efficiency for the more common modulation methods.

Type of modulation	Spectral Efficiency (bit/s/Hz)
FSK	<1 (related with the modulation index)
GMSK	< 1.35
BPSK	1
QPSK	2
8PSK	3
16QAM	4
64QAM	6
OFDM	>10 (depends on the type of modulation and the number of carrier

tal signals. It is clear that it is difficult to detect and extract information from a digital communication buried into the noise implementing a sole spectrum analysis. This type of digital signal could be transmitted by the aliens toward their spacecraft wandering in the space

Different types of modulation correspond to different bandwidths allowing a certain data transmission velocity. This is expressed by the Shannon Hartley equation that relates the maximum capacity C of a given communication channels with a certain noise and bandwidth. Such a capacity is given by:

$$C = B_w \log_2\left(1 + \frac{S}{N}\right) \qquad \textit{bit/sec} \qquad (2)$$

where

- B_w is the bandwidth
- S/N is the signal to noise ratio

Considering, for example, a *ZigBee* type signal (B_w = 5 MHz) and S/N ratio of 10, the capac-

Table 6. Band occupation for a set of modern digital signals.

Type of signals	Channel bandwidth
GSM	200 KHz
CDMA (IS-95)	1.25 MHz
CDMA2000	1.25 MHz (Channel bonding@1xEx-DO Rev.B;C)
3GPP WCDMA	5 MHz
3GPP TD-CDMA	5 MHz
3GPP LTE	1.4, 3.5, 10, 15, 20 MHz
WIMAX IEEE 802.16xxx	3.5, 5, 7, 8.75, 10, 20 MHz
TETRA	25, 50, 100, 150 KHz
WLAN & WIFI	20, 22 MHz
DECT	1.728 MHz
ZigBee	5 MHz
ATSC	6 MHz
DVB-H	5, 6, 7, 8 MHz
T-DBM	1.536 MHz
OFDM	1.25 to 20 MHz @128 to 2048 sub-carriers

ity of the channel is C = 17 Mbit/sec. This parameter is important in the case the signal has to be demodulated. The study of algorithms for the computation of the entropy (or the agnostic entropy) of a very noisy information, could play an important role in the design of new procedures for searching for information buried in a noisy band. We recall that Shannon helps to model virtually all the systems that store, process or transmit information in digital form, from compact disks to computers, from faxes to probes for deep space investigation! At the moment is not foreseen to find out the meaning of a code of an alien message. When this will be required in the future, surely the difficulties will increase in an unpredictable way!

2.4. What sensitivity do we need.

Having exactly set the antenna pointing direction, the frequency, the type of signal, the demodulation algorithm etc it is necessary to have the right sensitivity to receive the signal! Since we don't know the minimum requested value, we have to perform the observations at the maximum available sensitivity. This is obtained through large radio telescopes and in the future by means of the large array. The sensitivity is the result of many factors that characterize the radio link. Here following we deal with main aspects of a hearth-exoplanet link in order to compute the P_{out} at the receiving antenna terminal. To do this, we need to evaluate the link budget taking into account all the gains and losses (including the FSPL -Free Space Path Losses-) being present in such a link. It takes the form of the equation below:

$$R_x \textit{ power (dBm)} = T_x \textit{ power (dBm)} + \sum \textit{Gains (dB)} - \sum \textit{Losses (dB)} \quad (3)$$

It is mainly a matter of accounting for all the different losses and gains between the transmitter and the receiver, in other words:

- transmitter power
- antenna gains (receiver and transmitter)
- antenna feeder, cables, connector (receiver and transmitter) and FSPL losses

Considering a given transmitted power level P_{TX}, the above reported parameters and the Pout are here estimated in a practical example: an Earth-Trappist-1 (40 Ly) and Earth-Kepler-452 (1400 Ly) link assuming f=1.42 GHz, a 300 m T_x and a 64 m R_x dishes antennas (65% efficiency).

Recalling the base block diagram of Fig. 1, we compute the antenna gains.

2.4.1. TX and RX antenna gains

The formula is reported in (4).

$$G(dB) = 10\log\left(\frac{\eta 4\pi A_{coll}}{\lambda^2}\right) \quad (4)$$

where

- η is the antenna efficiency
- A_{coll} is the collecting area
- λ is the wavelength

The T_x and R_x antenna gains are reported in Tab. 7.

2.4.2. Losses and FSPL

This term is represented by the sum of all the losses due to cables, connectors and other, including the FSPL (Free Space Path Loss). As mentioned above, the distances are such as to introduce an incredible attenuation of the signal strength in its path from the exoplanet to the Earth. Here following it is reported as the distance d (m) and the frequency f (Hz) are parts of the FSPL formula (5):

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + \\ +20\log_{10}(\frac{4\pi}{c})(dB) \quad (5)$$

The Free Space Losses results for the above considered practical example, are in Tab. 8:

At this point, recalling the formula (3), we are able to calculate the signal power P_{out} at the receiver antenna output connector with the formula (6), assuming two levels of the transmitter power (1MW and 100 MW) for each exoplanet (Fig. 6):

$$P_{out} = P_{TX} + G_{TX} - L_{TX} - FSPL - L_{misc} - \\ -L_{RX} + G_{RX}(dBm) \quad (6)$$

where

- P_{out} is the receiver antenna output - P_{TX} is the transmitted power (dBm) - G_{TX} is the transmitter antenna gain (dB) - L_{TX} is the transmitter losses (coax, connectors...) (dB) - FSPL is the Free SPace Path Losses (dB) - L_{misc} is the miscellaneous losses (fading margin, body loss, polarization mismatch and other losses) (dB) - L_{RX} is the receiver losses (coax, connectors) (dB) - G_{RX} is the receiver antenna gain (dB)

The results are reported in Tab. 9.

The very huge path loss makes radio links very difficult to establish over long distances, unless extremely low noise receivers, very powerful ET transmitters and very large T_x and R_x antennas are available.

We are now able the compute the maximum Operative Range. To evaluate it we refer to the Fig. 6 applying the Kraus formula (7). Providing here measurements in meters and watts, the range is expressed in light years.

$$Range_{Ly} = 10^{-16}\sqrt{\frac{P_T A_{effTX} A_{effRX}}{(S/N)kT_{sys}\lambda^2\Delta f}} \quad (7)$$

where

- Range (Ly)
- P_T is the transmitted power (W)
- A_{effXX} is the transmitter and receiver antenna effective area (m^2)
- k is the Boltzman's constant (J/K)
- T_{sys} is the system temperature (K)
- Δf is the frequency resolution (Hz)
- λ is the wavelength (m)
- (S/N) is the Signal to Noise ratio

As an example, in the Tab. 10 the ranges with different antennas (Medicina and SRT), different frequencies (1.42 GHz and 8.5 GHz) and transmitter power of 100 MW, are reported for a 1 Hz signal.

The distances obtained, however, are small in comparison to the extension of the whole galaxy (100,000 light years radius).

2.5. Electromagnetic visibility interval.

Table 7. The gain for different diameter dish antennas.

Antenna	Diameter (m)	Frequency (GHz)	Efficiency %	Gain (dB)
T_x	300	1.42	65	**71**
R_x	64	1.42	65	**57**

Table 8. List of the Free Space Losses in the case of Trappist-1 and Kepler planets.

Planet	Distance (km)	Frequency (GHz)	Free Space Loss (dB)
Trappist-1 40 Ly	3.8E14	1.42	**387**
Kepler-452 1400 Ly	1.3E16	1.42	**418**

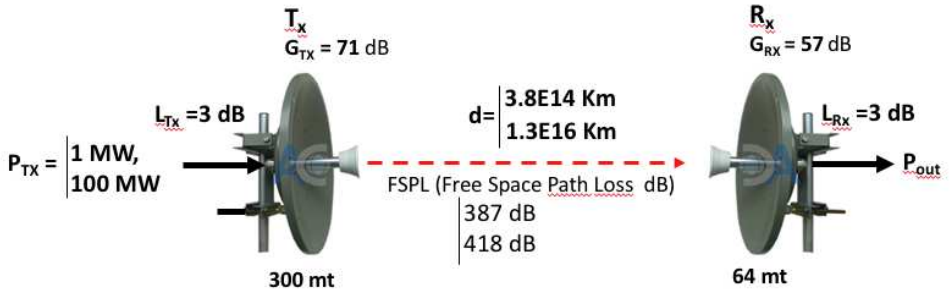

Fig. 6. Radio link for the discussed example.

A civilization characterized by an appropriate technology, in its evolution is visible, from an electromagnetic point of view, from the outer space for a certain time or, at least, this happened during our evolution! One of the first human appeared on earth about 4 million years ago (*Australopitecus afarensis*). It is expected that our planet will be completely cabled with optical fibers by the year 2150. In this way, the radio visibility of the earth from space will drastically decrease! Only radio transmissions for communication with spacecraft will remain active (Fig. 7). The period in which the humankind has intensively emitted radio waves will be about 200 years. Then a technologically advanced alien civilization would have seen the earth bright, from a radio point of view, only for 1 / 20.000 of its evolution time, therefore a very narrow time slot.

3. Some remarks.

After the analysis of the parameters that have to be correctly set in order to be successful with the program, it comes out that it is very difficult

Table 9. P_{out} in the TX (300 m) and RX (64 m) configuration.

Planet	Frequency (GHz)	TX power (MW)	Free Space Loss (dB)	P_{out} RX connector (dBm)
Trappist-1 40 Ly	1.42	1	387	-183
Trappist-1 40 Ly	1.42	100	387	-163
Kepler-452 1400 Ly	1.42	1	418	-214
Kepler-452 1400 Ly	1.42	100	418	-194

Table 10. Different range for a 300 m alien dish TX antenna with different radiotelescopes (Medicina and SRT), operating at 1.4 GHz with a 100MW transmission power.

Rx antenna on Earth (m)	Alien Tx antenna (m)	Frequency (GHz)	Power (MW)	T_{sys} (K)	Chan (Hz)	Range (Ly)
Par. 32 m Medicina	300	1.42	100.0	60	1	476
Par. 32 m Medicina	300	8.5	100.0	40	1	3496
64 m (SRT)	300	1.42	100.0	60	1	954
64 m (SRT)	300	8.5	100.0	120	1	4036

Fig. 7. The planet will be probably completely cabled with optical fibers by the year 2150, then no more radio activities except to/from spacecrafts.

to set them in the right way. The "radio silence" we have had until now maybe means that the observation parameters have been not correctly set and not because they don't exist. It could be possible also that the alien civilization doesn't use radio techniques for local communications or to make themselves noticed and/or establish interstellar communications.

Just to give a practical idea about the chances to correctly point the antenna, we consider to operate with the SRT antenna as a receiver and a similar antenna as a transmitter. In a complete sky survey, it comes out one chance in $3 \cdot 10^{10}$ to point our antenna in their direction. So, a lot of work is requested in the future to increase such a very small probability, maybe changing the searching paradigm or the searching instrumentation. In the next step of SETI the new Square Kilometre Array (`www.skatelescope.org`), with its wide Field of View pixeled by thousands of beams at a sensitivity never reached before, will be exploited. The observation modes still now are Sky Survey and/or Targetted. In both cases the radio transmissions from ET are expected to be either intentional or not, in the analog domain or in the digital one. It is fundamental to know the domain of the signals because the detection algorithms are completely different from one case to the other. In the analog domain searches will continue for intentional monochromatic signals by means of high-frequency resolution FFT working in parallel with possible Wavelets, Duffing Oscillators (optimal for non-linear environment) and Stochastic Resonance algorithms. In the case of an unknown modulated signals, the proposed transform is the KLT (Karhunen Loewe Transform) (Maccone 2012) even if it seems to be affected by a poor detection sensitivity. Anyway, various works to increase it have already been done with excellent results (Schilliró 2008; Maccone 2010). To date, there is no KLT algorithms operating on-line with the observations at the national radio telescopes (Medicina, Noto, Cagliari).

In the case of alien signals in the digital domain, the detection process becomes even more complicated. The final match for the identification of an extraterrestrial radio signal will be played, most likely, in the digital domain. The algorithm for extracting an unknown digital signal confused into the noise, will be one of the most difficult challenges ever faced in digital signals processing!

4. Future strategies.

The Medicina, Noto and SRT antennas, schematically reported in Fig. 8, are interconnected via a very wide band optical fibers. This network could be considered a national long baseline interferometer system, as a concept of a new generation high performances SETI radiotelescope. Such a configuration could offer the cancellation of the local interferences, for every single antenna, during the real time correlation process. In addition, it could be an extremely suitable radio interferometer for a high gain and high spatial resolution SETI candidate signals confirmation.

It should represent the first large array in Europe performing so accurate SETI activities.

The future of the SETI program will be based on the introduction of new research paradigms involving the use of Signal Processing strategies completely different from those used to date (Tab. 11). As already mentioned, the greatest effort must be devoted to the detection of digital signals modulated in an unknown way. Probably an accurate analysis of entropy could give us indications on the presence or not of a signal buried in the noise, even if a high sensitivity is not expected from this method. Given the enormous amount of data acquired and analyzed, a way could probably be to discard the noise online and store the remaining data. This aim could be achieved by introducing the "Dyspoissonism", a mode to estimate the randomness of a signal (Russell 2017). From this point on, an extremely new and very vast research scenario opens up. Maybe in the future, we will face the problem to decode the received signal. At present, this is not planned because an answer is not foreseen. Answering means understand the message, deciding who should transmit, at what title, what to transmit, how to transmit, on behalf of whom to transmit, who will pay the large expenses for the transmission and then, not less important, the enormous power needed to cover the immeasurable distances, the radio waves flight time, etc. ...

5. Conclusion.

Due to the huge difficulties to set the right observation parameters, SETI is an extremely complex program in which the probability of success is presently very low. Its added value is for the possible technological and data processing (algorithms) feed back that could be useful for other scientific programs.

In the future, parallel to the search for monochromatic signals underway today, a joint multidisciplinary approach will be needed among the various SETI activities around the world. The goal is to develop both new technologies and design new algorithms to make the observations more effective than those conducted until today, in the frame of new research paradigms. Care has to be taken for the methods based on entropy (Shannon) and similar

Fig. 8. The national radiotelescopes linked via a wide band optical fiber.

Table 11. Summary of the SETI past and future post processing.

	Past	Today	Future
Algorithms	FFT	FFT /KLT/Wavelets	- Stochastic resonance - Duffing Oscillator - Agnentropy - New algorithms for digital signal detection.
Processor	DSP	FPGA, Multicore CPU	FPGA, Multicore CPU, GPU, Array of GPU

methods, within a desirable future (radio / optical) SETI program funded by INAF.

Up to now, no intelligent radio signals have been received in the course of the SETI activities but just man-made radio interferences! Continuing to investigate is a must because maybe up to now we have searched in the wrong mode, in the wrong position, at the wrong time, at the wrong frequency, with not sufficient sensitivity and a not suitable signal demodulation. We have to continue the search because as the English astronomer Martin Reese stated, *"the absence of the evidence is not the evidence of the absence"*. Most likely, life in the Milky Way is a common event but, due to the incommensurable distances among the planets, probably every civilization spends its own existence completely isolated and suspended somewhere into the galaxy as. . . .. if it was really alone!

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