“Astrophysics in the LOFAR era”

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Innovative SETI by the KLT

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What is SETI ?

- SETI is the Search for Extraterrestrial Intelligence.
- SETI began in 1960 with "Project Ozma" conducted by Frank Drake.
- No ET signal was found so far, but we only explored distances < 100 pc.
- The simplest form of SETI is to look for an alien CARRIER on a very narrow band (< 1 Hz)

5 Complexity Levels for SETI

- Level 1: **Piggyback SETI at 1.420 GHz by FFT.**
- Level 2: **Wideband SETI by KLT (LOFAR ?).**
- Level 3: **Targeted Searches (on HabCat stars).**
- Level 4: **Leakage Searches (by SKA << ~ 5 pc).**
- Level 5: **Entanglement & Encrypted SETI (?).**

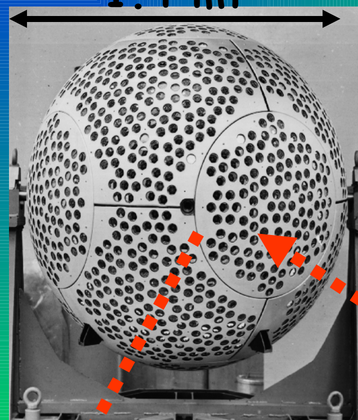
SETI at Medicina (Italy)

- The signal processing for SETI at Medicina is performed by an analyzer (Serendip IV**) with a resolution of 0.6 Hz.**
- This spectrometer works with 24 million channels and a 15 MHz input bandwidth centered around the hydrogen line at 1.420 GHz, as traditional in SETI since 1960.
- New post-processing algorithms have been successfully tested: the **Hough transform** for the Doppler effect recognition (i.e. to cope for **drifting signals**) and
- The **Karhunen-Loève Transform (KLT)** to filter very weak signals out of any **colored background noise**.

From SETI to ASTEROIDAL RADAR at Medicina.

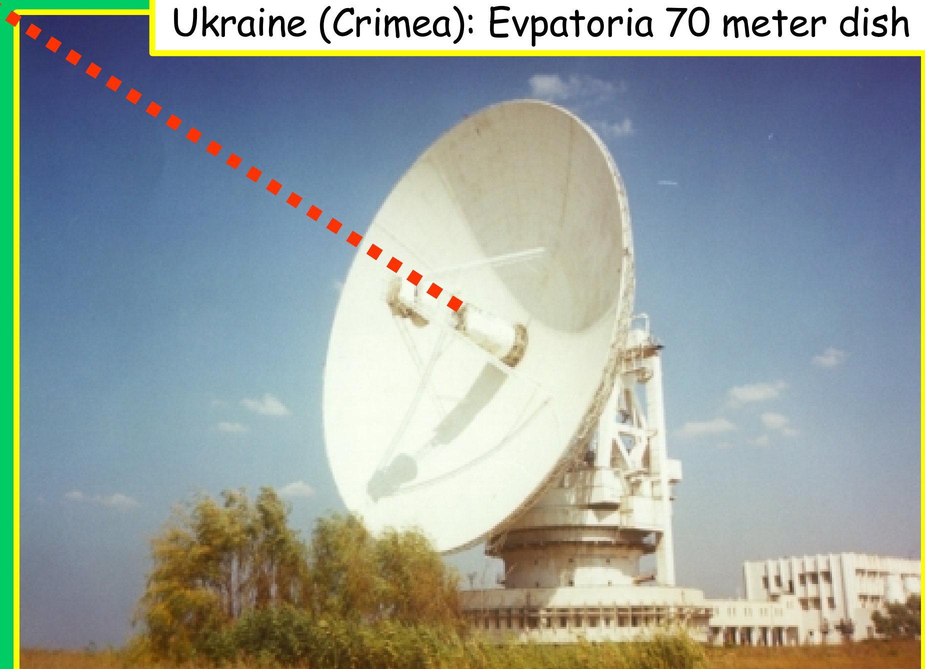
The SETI facilities at Medicina were first used in 2001 to Detect Space Debris and TEST the Asteroidal RADAR.

1.4 mt



Etalon 1, launched in 1989 (Laser ranging), orbiting at 19.000 Km

Ukraine (Crimea): Evpatoria 70 meter dish



Medicina:
32 meter dish

S IVBW=15 MHz
Nch=24 M

Di Martino, Montebugnoli et Al. 2004 paper

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Results of the first Italian planetary radar experiment

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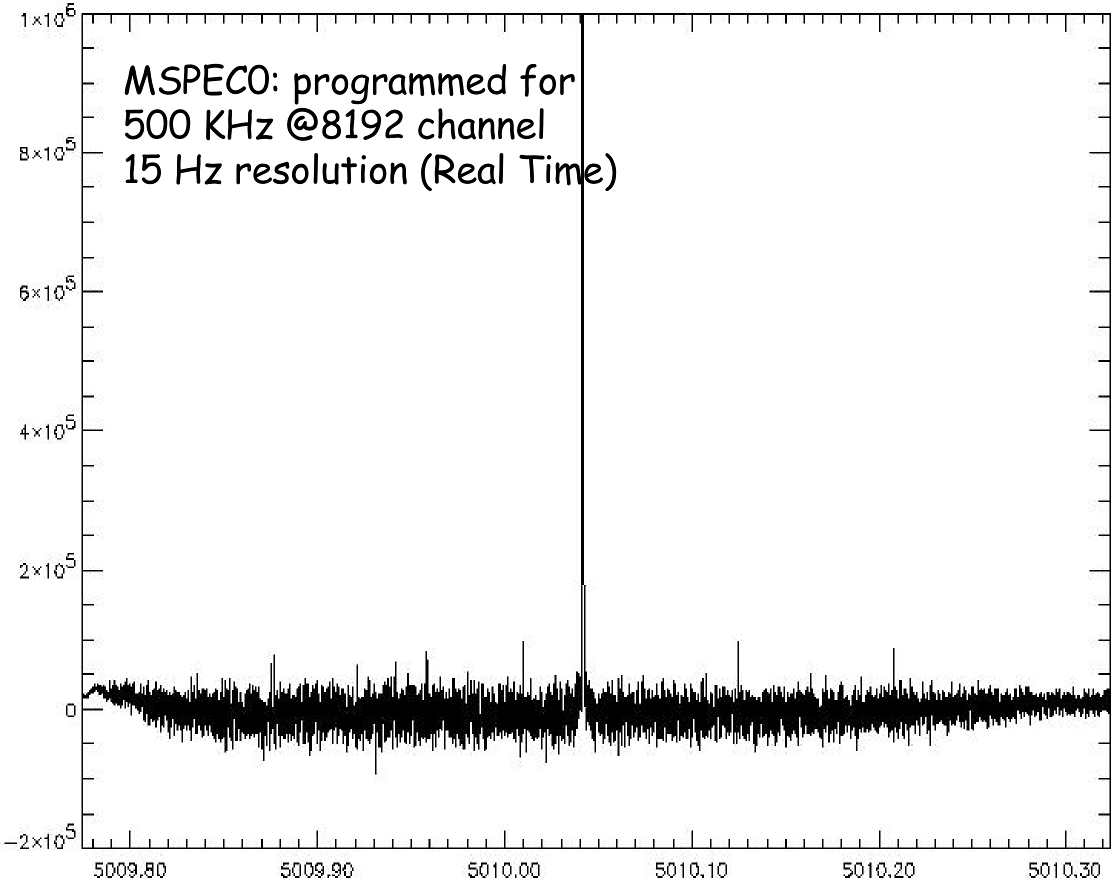
SETI back-end used for debris detection: …so good that IT WENT OFF SCALE!!!



The minimal radar cross section σ_{min}, which could be detectable with this Evpatoria → Medicina system in GEO orbit can be estimated with

$$\sigma_{min} = 4\pi\, r_1^2\, r_2^2\, \lambda^2 k T s (S/N)_{min} / P_t S_t S_r t$$

let $r_1 = r_2 = 36.000$ $S_t = 2500\ m^2$ $S_r = 500\ m^2$ $\lambda = 6\ cm$ $P_t = 150\ KW$ $(S/N)_{min} = 10$ $t = 10\ sec$

$\sigma_{min} \approx 2\ cm$

2007 paper on KLT+SETI for asteroid & space debris RADAR

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ACTA ASTRONAUTICA

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Academy transactions note

Advantages of Karhunen–Loève transform over fast Fourier transform for planetary radar and space debris detection

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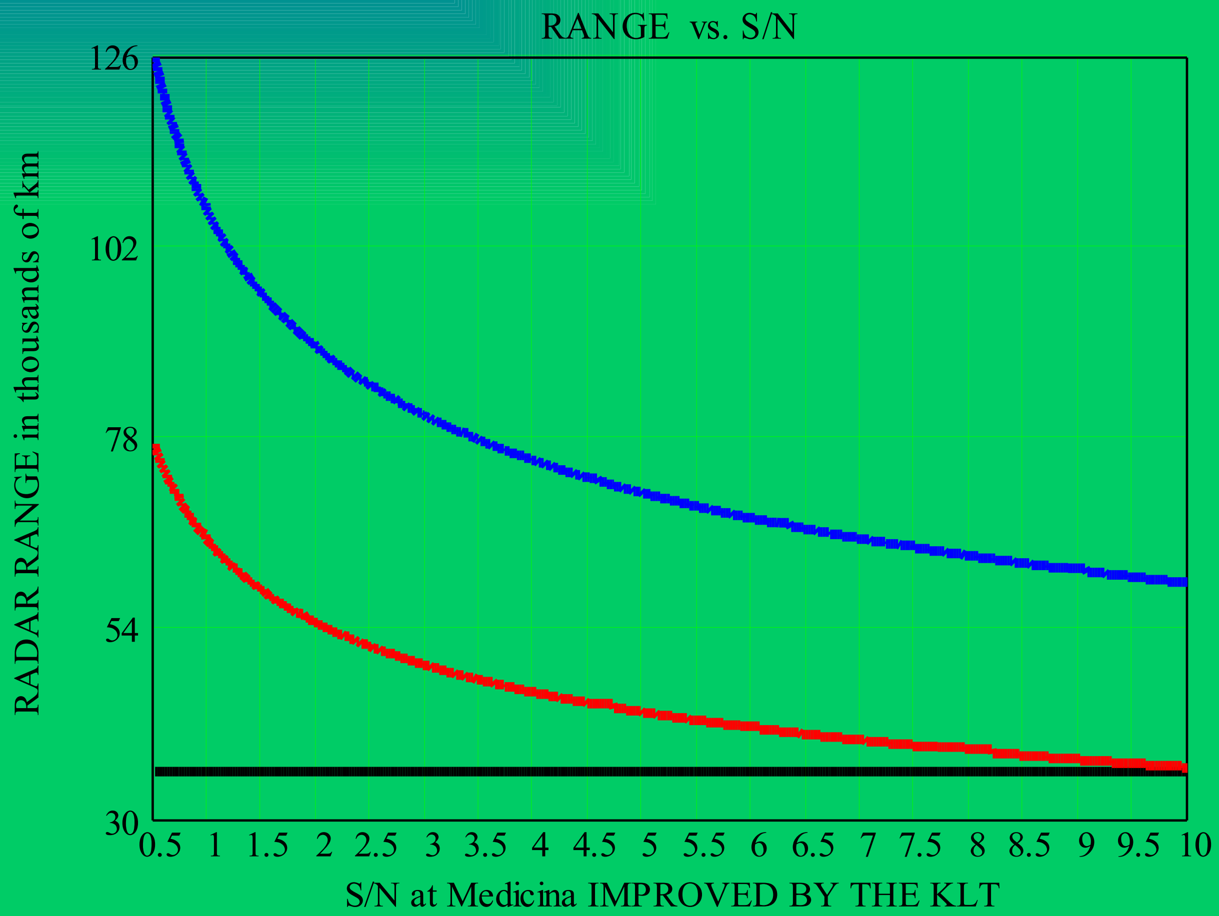
Abstract

The present article describes that the range of any radiotelescope (and radar in general) may be increased by virtue of software, if one replaces the fast Fourier transform by the Karhunen–Loève transform. The range increases with the inverse of the fourth root of the signal-to-noise ratio when this ratio decreases. Thus, the range on any radiotelescope (and radar) may be increased without changing the hardware at all, but by changing the software only. This improvement in the range of the radiotelescope is currently implemented at the 32-m antenna located at Medicina, near Bologna, in Italy, for both SETI and general radioastronomy.

Radar RANGE vs. S/N

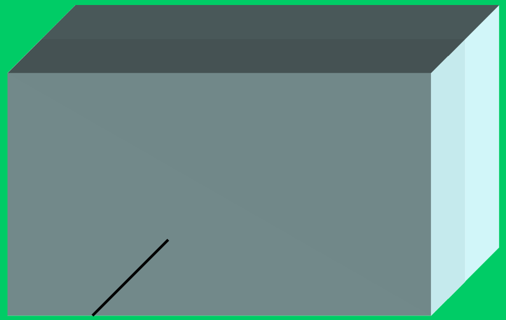
$$\text{Radar\_RANGE} \propto \frac{1}{\sqrt{\sqrt{S/N}}} = \frac{1}{\sqrt[4]{S/N}}$$



What is the KLT ?

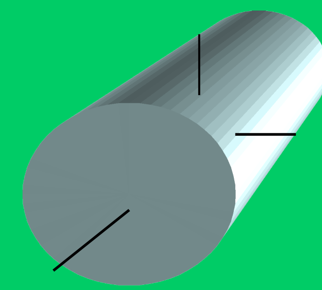
- Example (a Newtonian analogy): consider a solid object, like a BOOK, described by its INERTIA MATRIX.

- Then there exist only one special reference frame where the Inertia Matrix is DIAGONAL. This is the reference frame spanned by the EIGENVECTORS of the Inertia matrix.



$$I' = \begin{pmatrix} I'_{xx} & 0 & 0 \\ 0 & I'_{yy} & 0 \\ 0 & 0 & I'_{zz} \end{pmatrix}$$

"Newtonian Analogy" to the KLT



If two of the body dimensions are small then the corresponding moments of inertia are very small too.

$$I = \begin{pmatrix} I_{xx} & 0 & 0 \\ 0 & \approx 0 & 0 \\ 0 & 0 & \approx 0 \end{pmatrix}$$

Thus, they are almost ZEROS in the INERTIA MATRIX.

And only the FIRST EIGENVALUE in the Inertia Matrix is non-zero.

This is called DOMINANT eigenvalue.

KLT mathematics

- If $X(t)$ is a stochastic process (= input to the radio telescope) it can be expanded into an infinite series

$$X(t) = \sum_{n=1}^{\infty} Z_n \, \phi_n(t) \qquad 0 \leq t \leq T$$

- then
  - $\phi_n(t)$ are orthonormalized time functions:

$$\int_0^T \phi_m(t) \, \phi_n(t) \, dt = \delta_{mn}$$

Z_n are random variables, not changing in time, with the property

$$\langle Z_m \, Z_n \rangle = \lambda_n \, \delta_{mn}$$

- In conclusion, the KLT separates the radiotelescope input (= noise + signal(s)) into ***UNCORRELATED*** components.

KLT mathematics

$$\int_0^T \langle X(t_1)\, X(t_2) \rangle\, \phi_n(t_1)\, dt_1 = \lambda_n\, \phi_n(t_2)$$

- Integral equation yielding both the Karhunen-Loève's eigenfunctions $\phi_n(t)$ and corresponding eigenvalues λ_n .
- The kernel of this integral equation is the autocorrelation.
- This is the best basis in the Hilbert space describing the (signal+noise). The KLT adapts itself to the shape of the radiotelescope input (signal+noise) by adopting, as a reference frame, the one spanned by the eigenfunctions of the autocorrelation. And this is turns out to be just a LINEAR transformation of coordinates in the Hilbert space. Thus, it is an easily INVERTIBLE TRANSFORMATION.

KLT filtering

- There is no degeneracy (i.e. each eigenvalue corresponds to just one eigenfuction only).

- The eigenvalues turn out to be the variances of the random variables Z_n, that is $\sigma^2_{Z_n} = \lambda_n = \langle Z_n^2 \rangle > 0.$

- Since $\langle Z_n \rangle = 0$ we can SORT in descending order of magnitude the eigenvalues and the corresponding eigenfunctions. Then, if we decide to consider only the first few eigenfunctions as the "bulk" of the signal, and to apply the inverse KLT, that's what KLT filtering is: we just declare the taken-off part as "noise"!

- The Galileo mission by NASA-JPL used the KLT…

KLT vs. FFT

	KLT	FT	
↑	Works well for both wide and narrow band signals	Rigorously true for narrow band signals only	↓
↑	Works for both stationary and non-stationary input stochastic processes	Works OK for stationary input stochastic processes only	↓
↑	Is defined for any finite time interval	Is plagued by the “windowing” problems	↓
↓	Needs high computational burden: no “fast” KLT	Fast algorithm FFT	↑

Future SETI by the SKA

Table 1
Detectability of Terrestrial Analog Signals by the SKA

Signal	Power (W)	Range (pc)	Number of Stars
Detection Threshold = 10^{-28} W m^{-2}			
	2	0	
	1	1	
	33	310	
	500	3×10^7	
	5000	6×10^9	
Detection Threshold = 10^{-29} W m^{-2}			
TV	3×10^5	6	4
1 MW signals	10^6	3	11
Airport Radars	10^8	100	500
Ionospheric Radars	2×10^{11}	1500	6×10^8
Arecibo Radar	2×10^{13}	15,000	6×10^{10}

Power levels are in terms of the equivalent effective isotropically radiated power (EIRP).

Table taken from the 2004 paper "The Cradle of Life", by Joe Lazio, Jill Tarter and David James Wilner,

New Astronomy Reviews, Vol. 48 (2004), p. 985.

Conclusions

- SETI, the Search for ExtraTerrestrial Intelligence, has so far been investigated since 1960 only **<u>modestly</u>** by the international astronomical community. NASA was FORBIDDEN to do SETI by the US Congress in 1993. Some countries are doing "poor" SETI today: USA, Australia, Argentina, Italy, Japan, France...
- This may be due to FEARS by the politicians that a contact with ETs would shake the beliefs of Humanity too much...
- The International Academy of Astronautics (Jill Tarter et Al.) issued SETI PROTOCOLS for "ethical behavior" in a Contact.
- **Lofar &SKA will enable much more refined SETI searches.**
- **<u>It's high time to EXPAND THE SETI SEARCHES</u>**

Thanks !