Executive Summary

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Optical Compressive Sensing (CS) Technologies for Space Applications

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1 Scope of the document

This document summarizes the findings of the project Optical Compressive Sensing (CS) Technologies for Space Applications (CS4Space).

2 Introduction

The project aims at designing an optical instrument based on Compressive Sensing (CS) for a space applications.

Conventional sampling or compression methodologies follow Shannon-Nyquist theorem stating that if a signal frequency band or spectrum is limited to a frequency B [Hz], the signal is completely determined by a sample-rate larger than 2xB samples per second.

Compressive Sensing (CS) provides a fundamentally new approach to data acquisition or signal sampling. CS theory predicts that signal or images can be accurately recovered from fewer measurements than those usually considered necessary as long as two fundamental principles are fulfilled: sparsity and incoherence.

A signal is sparse when it can be represented in a domain (integral transform) with a limited number of non-zero coefficients.

The signal or image is sampled by taking a given number of measurements that are linear combinations of the signal/image. The linear combinations (combined in a so-called sampling or measurement matrix) are incoherent in the integral transform domain.

3 Project execution

The first objective is to identify space applications and technologies having the potential for the development of optical systems based on compressive sensing techniques.

The second objective is the use of technologies and algorithms to develop new type of optical instruments using compressive sensing for space.

To assess in practice the level of achievement of the objectives, 2 requirements were defined by the agency in the statement of work:

1. At least 5% improvement on each one of the following parameters:
   compression ratio, processing time and PSNR
2. At least 40% reduction of system's mass, power and volume

The project was organized in five stages:

1. Review of all sort of optical instruments designed for Earth observation and Space science and exploration covering a wide electromagnetic spectrum from X-ray to FIR. In parallel, CS elements such as algorithms and hardware for CS were also reviewed.
2. Down selection of the many instruments to only a few on the basis of a FOM quantifying their potential for an implementation with compressive sensing.
3. Selection of 2 instruments for the preliminary design according to a performance model.
4. Detailed design of the one with the best potential.
5. Rehearsal of the project execution and roadmaps definition to build an EBB and an EM based on the detailed design.

3.1 Optical instruments review

After a review of several tens of instruments, the instruments with the best potential were limited to 9. 5 for Earth Observation (EO) and 4 for Science and Space Exploration (SSE). The table below provides the main features, the spectral bands, the reason the instrument has some potential for a CS implementation and the name of the instrument.

	Main features	Spectral band	Push for CS	Representative instrument
EO 1	Pushbroom Hyperspectral imager (2D detectors) Diffractive element High spatial/spectral resolution	VIS-NIR	Large data set	OLI or WorldView-3
EO2	Pushbroom Multispectral imager Diffractive element High spatial/spectral resolution	SWIR-MWIR-LWIR	Low spatial resolution of existing detector, Large data set	SLSTR
EO3	Scanner-less camera Large CCD Programmable color filter Geostationary High spatial resolution	VIS-NIR	Large data set	FCI
EO4	High-sensitive low noise detector Geostationary High spatial resolution	LWIR-TIR	Low spatial resolution of existing detector	FCI/SEVERI
EO5	Whiskbroom FTIR spectrometer Moderate spatial resolution	SWIR-MWIR-LWIR	Low spatial resolution of existing detector, Faster measurement of the spectrum	MIPAS, IKFS-2
SSE 1	Framing camera Multi-spectral	VIS	Higher resolution, reduction in data volume	IMP
SSE 2	2D imaging spectrometer	IR	Reduction in data volume	CRISM/VIRTIS
SSE 3	Fourier transform spectrometer	IR	Reduction in data volume	PFS
SSE 4	Counting system	EUV or neutron spectroscopy	Improved spatial resolution	FREND

Table 1: Preselection of the optical instruments with the best potential for an implementation with CS

For the list of 9 instruments, 2 instruments were selected for the preliminary design according to output of a Figure-Of-Merit (FOM) set to quantify the potential of these instruments.

In practice there are several issues with the parameters considered in these FOMs. Several FOM have been evaluated until identifying one that can provide meaningful output with the practical limitations met. Practical limitations stand for example in the fact that the original image without compression is necessary to assess SNR or PSNR but it is never available for an existing instrument. Also, literature about existing instruments never or rarely provides the details about the power consumption of the building-blocks contributing to the image acquisition, storage, compression and transmission. Etc. Hence, it is useless to define a FOM using these figures.

We finally ended with a FOM with three coefficients. Each of them quantifying a key figure to compare standard and CS instruments.

$$\mathrm{FOM}_3 = \mathrm{A} \cdot \left(\frac{1}{\frac{\Delta \mathrm{m}}{\mathrm{m}} + \frac{\Delta \mathrm{V}}{\mathrm{V}} + \frac{\Delta \mathrm{E}}{\mathrm{E}}} \right) + \mathrm{B} \cdot \left(\frac{\mathrm{AfterCompressionBit}_{\mathrm{pixel\ (PAN)}}}{\mathrm{NBit}_{\mathrm{pixel}}(\mathrm{PAN}) \cdot 0.25} + \frac{1}{\mathrm{MaxSpectralBand}} \sum_{1}^{\mathrm{MaxSpectralBand}} \frac{\mathrm{AfterCompressionBit}_{\mathrm{pixel}}}{\mathrm{Nbit}_{\mathrm{pixel}} \cdot 0.25 \cdot 0.25} \right) + \mathrm{C}$$

$$\cdot \left(\frac{\mathrm{Nb\ of\ Colon} \cdot \mathrm{Nb\ of\ Row\ (PAN)}}{\mathrm{Raw\ image\ size\ (PAN)}} + \frac{1}{\mathrm{MaxSpectralBand}} \sum_{1}^{\mathrm{MaxSpectralBand}} \frac{\mathrm{Nb\ of\ Colon} \cdot \mathrm{Nb\ of\ Row}}{\mathrm{Raw\ image\ size}} \right.$$

The first term of this FOM is related to physical figures. The second is related to the efficiency of the compression and proportional to processing resources needed respectively for the standard compression and for CS. The last one is proportional to the size of the reconstructed image and the size of the raw image. The A, B and C factors allow giving a weight more or less important to the respective term in the equation.

Δm: mass difference between implementation without and with CS. This is the mass of the eventual additional CS hardware.

M: mass of the instrument without CS.

ΔV: volume difference between implementation without and with CS. This is the volume of the eventual additional CS hardware.

V: volume of the instrument without CS.

ΔE: power consumption difference between implementation without and with CS. This is the power consumption of the eventual additional CS hardware.

E: power consumption of the instrument without CS.

ΔR: compression factor with CS and with standard compression (the instruments have always spatial compression.

Δm: mass difference between implementation without and with CS. This is the mass of the eventual additional CS hardware.

Nb of colon x Nb of row: size of the uncompressed or reconstructed image

MaxSpectralBand: number of spectral bands

$\mathrm{Nbit}_{\mathrm{pixel}}$: number of bits per pixel

$\mathrm{AfterCompressionBit}_{\mathrm{pixel}}$: number of bits per pixel after standard compression

Raw Image: size of the image provided by the detector within a CS architecture

With this FOM, we obtained the following results for the various pre-selected instruments:

Instrument	FOM
EO1: Worldview3	A x 2.7+ B x 7.3 + C x 17.8
EO2: SLSTR	A x 0.919 + B x 20 + C x 2
EO3: FCI (VIS-NIR)	A x 5.38 + B x 20 + C x 9.2
EO4: FCI (IR)	A x 10.8 + B x 20 + C x 3.2
EO5: MIPAS	A x 5.2 + B x 20 + C x 2
SSE1: IMP	A x 0.12 + B x 15.3 + C x 31
SSE2: CRISM	A x 0.49 + B x 2.86 + C x 18.9
SSE3: PFS	A x 0.532 + B x 10 + C x 2
SSE4: FREND	A x 0.09 + B x 8 + C x 2

Table 2: FOM of the pre-selected instruments.

In agreement with the Agency, FCI and MIPAS were selected for the preliminary design.

3.2 CS state-of-the-art

CS has an algorithmic and a hardware dimensions

CS can be considered as an acquisition and reconstruction method. The sampling or acquisition consists of a small number of linear random combinations of the signal/image of interest, where each of these measurements is recorded randomly to ensure their incoherence with the integral transform domain. The reconstruction is performed by a nonlinear procedure, i.e. an optimization algorithm.

CS can be used for a given applications as long as some precepts are verified or taken into account. There are:

1) The existence of an orthonormal basis (or frame or transform domain) where the signal/image of interest can be sparsely represented. In this domain, the signal can be represented with a limited number of coefficients.
2) The sampling process consist in a serie of the measurements which are a linear combinations of the signal/image.
3) Incoherence between the rows of the measurement matrix representing the linear combinations and columns of the sparsity basis (frame) must be guaranteed. In other words, the linear combinations must be incoherent (noise like) in the transform/basis domain.
4) The last step, the Reconstruction of the signal/image is complex and processing resources consuming.

There are several practical consequences related to the CS precepts.

The assessment of the existence of an appropriate transform domain requires to have the possibility to evaluate different domains with the expected signal/image. Hence, a set of reference signals/images is necessary for to verify this precept.

A practical solution must be found to generate linear combinations of the signal/image. Practically, the best solution is to use Spatial Light Modulator (SLM). The use of such element drives the optical design of the instrument.

With this solution it is simple to introduce incoherence or randomness in the sampling process. This is used in the most popular CS system concept: the Single Pixel Camera where a single pixel detector is used in association with SLM.

In this project we have extended this concept by considering matrix detectors. Indeed matrix detectors are often used often in standard instrument. There are less and less spectral bands for which matrix detectors are not available.

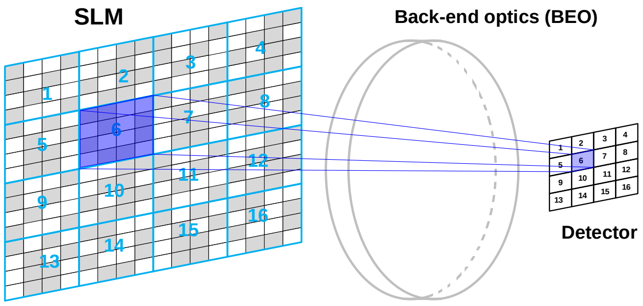

Figure 1: "extended" single-pixel camera concept where 16 micro-mirrors' reflection onto each pixel of the detector

With the “extended” single-pixel camera concept, it is possible to define the number of micro-mirrors reflecting the signal onto the detectors depending on the number and size of the detectors.

The necessity to make a given number of measurements introduces a constraint on the time allocation for one measurement which depends on several parameters such as: the detector sensitivity, the albedo of the target, etc.

The last step of CS is the reconstruction or decompression of the signal/image. This process is computing resources hungry. It is hardly compatible with on-board processing units. Perhaps, with new generation of qualified embedded processing units, this drawback will be less important. As a consequence, for now, we have considered that space applications where the decompression can take place where large amount of computing power is available have a larger potential for CS than the ones where the reconstruction must take place on-board.

When comparing CS with traditional compressions, we observe that CS does not automatically provide the best compression rate.

	Compression rate	Compression complexity (time + memory)	Decompression complexity (time + memory)
Lossless compression	bad (~50%)	high	high
Lossy compression	very good (~1% to ~10%)	high+	high+
Compressed sensing	average (~25%)[1]	**Non existent**	High++

Table 3: Comparison of lossy, lossless and CS compression

However, the main advantage of CS is that the compression step takes place in the acquisition process. This saves on-board resources as for example raw signal or image does have to be stored on-board before compression.

The advantages of CS are:

- **Compression speed** as CS merges acquisition and compression in a single step and the sampling process consists in simple linear projections.
- **Universality,** sensing is independent of the reconstruction algorithm. In case of improvement of reconstruction algorithms, image quality is enhanced.
- **Low power consumption at the sensor/encoder as CS m**oves the complexity to the decoder/reconstruction side. Resource consumption is limited on encoder side.
- **Natural measurements encryption as the s**ignal/image can only be decoded if the sensing matrix is known.
- **Robust to data packet loss (transmission)** as it is not required to have all the measurements to recover the data.

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[1] The compression rate of CS depends of 3 parameters, 1) the sparsity of the data in some representation, 2) the property of the sensing matrix, 3) the reconstruction algorithm. In some application, the compression rate can be as low as 3% [Golbabaee, M., Arberet, S., & Vandergheynst, P. (2013). Compressive source separation: Theory and methods for hyperspectral imaging. Image Processing, IEEE Transactions on, 22(12), 5096-5110].

3.3 Design of a CS instrument

On the basis of the results of the FOM and in agreement with the Agency, FCI and MIPAS were considered to have the best potential for a CS implementation. After the preliminary design phase it appeared that FCI is the highest potential. In general, multi-spectral imagers has a high potential for CS. Their potential is even higher if large matrix detectors are not available for some spectral bands.

To quantify in more details the potential of both instruments, a performance model has been developed. This performance model contains the receipt to evaluate the potential of a given instrument to implemented via CS.

From hardware perspective, the first step is to find the optimal position of the SLM and then to update or design the optical system (fore-optics and back-end optics). The telescope of FCI has 4 mirrors. The last one (M4) is a small dimension mirror oriented at 45°. This mirror is placed just before the back-end optics (BEO) that split spectrally the signal and adapt the signal to the features of the detectors used for the different spectral bands.

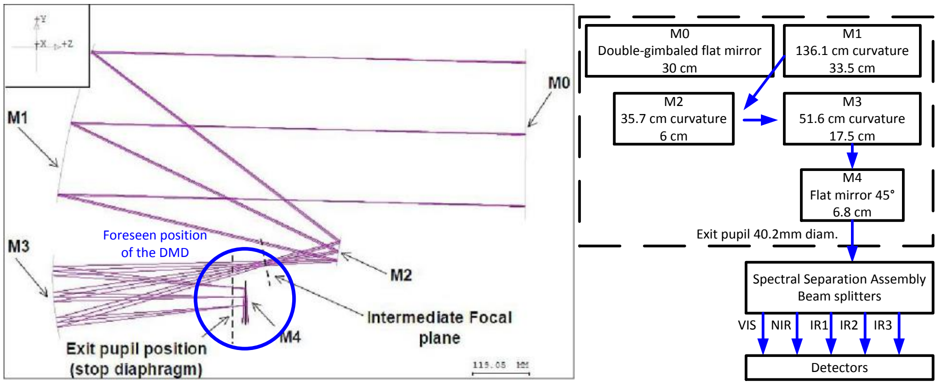


Figure 2: FCI

The position of M4 is perfect to place the SLM. The beam is focused on a limited plan and it is just before the BEO and the detectors. At this position, the signal projected on the different detectors can spatially coded with the SLM.

Once the position is defined the optical elements must be adapted to the features of the SLM. The SLM is a matrix of micro-mirrors. Each mirror can be actively controlled to be turned at +/- 17° according to the optical axis. This makes a reflection angle of +/- 34°.

During the project, we had the objective to be in position to compare in practice the CS implementation with an existing instrument. This imposes to introduce as less as possible modifications on common sub-systems found in both systems. This is a very costly approach for an EBB. For example, FCI optics and detectors are state-of-the-art parts that are unique. To use reproduction of them in an EBB is too costly.

For this reason we explored alternatives such as: using spare parts of an existing instruments (CaSSIS in the table above) or simply use off-the-shelf parts for common sub-systems. This is developed furthermore in the next section.

While in the project we made a design based on FCI and CaSSIS, we provide here only the FCI based designed.

The complete instrument has the following blocks:

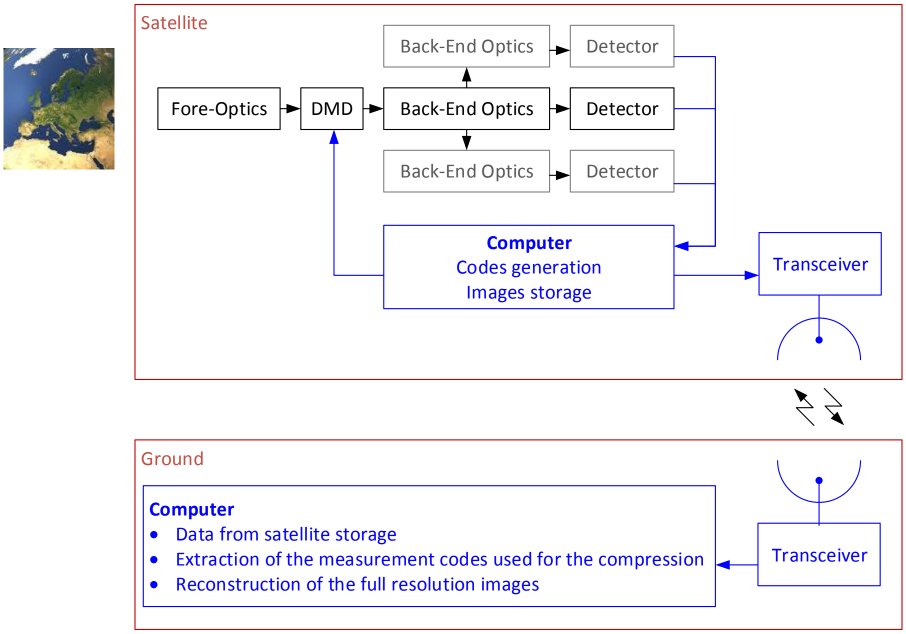


Figure 3: CS instrument building-blocks

We had to make a reverse engineering of the FCI telescope as the related IP is property of Kayer-Threde resp. OHB and consequently not all information is available for a direct reproduction.

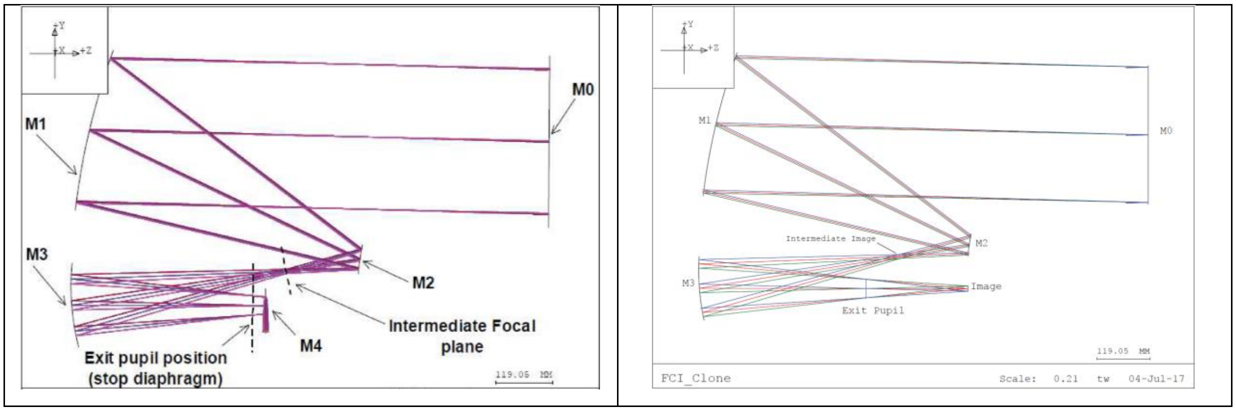


Figure 4: original and modified FCI fore-optics.

The resulting performance of the optics iare summarized in the figure below. The Wave Front Error results < 23 nm rms. The following figure shows the WFE versus the field of view. The wavelength used in the plot is 1000 nm, thus the units of the WFE are µm.

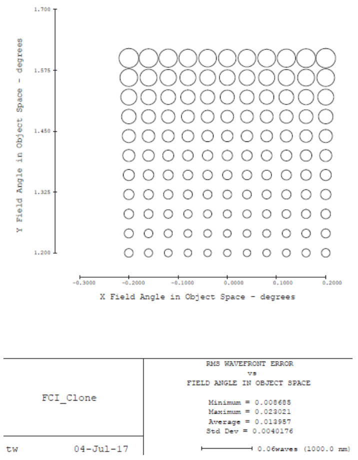


Figure 5: Optical Performance: Wave Front Error versus Field of View

The SLM or DMD features considered for the design are the following. There are the characteristics of an off-the-shelf Texas Instrument product: the DLP9000.

Item	Value	Comment
Array size [pixels]	2560 x 1600	-
Micromirror pitch [µm]	7.56	-
Resulting size [mm x mm]	19.3636 x 12.096	
Tilt angle	+/- 12° relative to flat state	Optical deflection is then +/- 24°

Table 4: SLM features

On the basis of the SLM (DMD) features, the BEO can be designed. It consists of a relay optics, which has the DMD as its object position and images that onto detectors (quoted here below as CCD). The BEO configuration is:

For the design, there exists a general problem of clearance between the incoming to and the outgoing beam from the SLM. Because the beam envelope is converging towards the SLM and diverging away from the SLM, an increase of distance does not quickly solve the problem.

In addition, the detectors plane has to be tilted because according to the deflection angle of the SLM. This leads to use the Scheimpflug principle for the design.

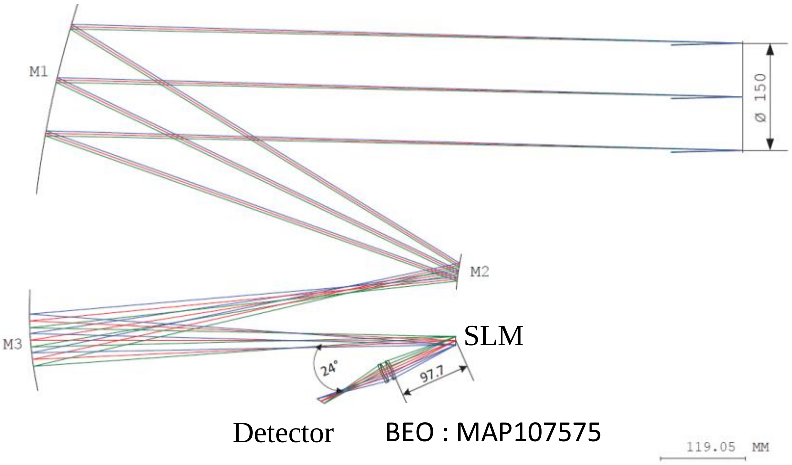


Figure 6: Breadboard design considering FCI telescope and off-the-shelf Thorlabs MAP107575 BEO

With this design the clearance problem is addressed and the resulting vignetting limited. Because of the deflection angle of the SLM and the plane of the detectors the magnification changes with the working distance which is different on the upper and lower part of the SLM and detectors. This is the unavoidable penalty of the Schmeimplfug configuration that has to be limited as much as possible. This is shown below by a footprint of 5×5 points of field angles in the plane of the detector.

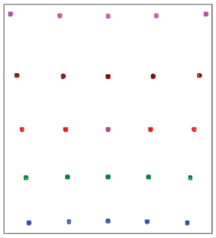


Figure 7: image projection on the detector

From algorithmic perspective, to assess the CS precepts, we started to analyze images similar to the ones provided by FCI with the objective of determining of transform domain in which they have a limited of non-zero coefficients. For this purpose we used SEVIRI images, the predecessor of FCI that readily available.

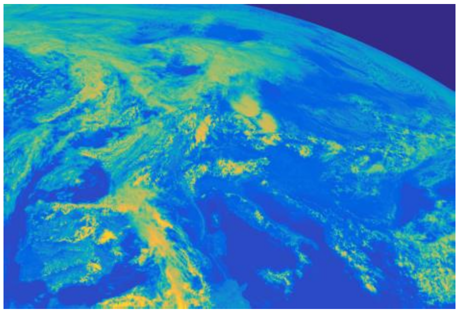


Figure 8: SEVIRI image in the VIS 0.6 channel

Since the evaluation images contain diffuse structures as well as defined edges, orthogonal wavelets (OW) from Daubechies family and Sparsity Average (SA=3 OW) are good candidate for the transform domain. The reconstruction quality metric is the signal to noise (SNR).

With this choice for the transform domain, the low rank assumption (sparsity) or the rank estimation (or the number of necessary coefficients for a given transform domain) has to be assessed. We performed a singular value decomposition (SVD) of the SEVIRI images. The figure below shows the SVD of the example data cube. It can be observed that despite not being strictly low rank (large amount of nonzero coefficients but most of them are negligable), the data cube can be well approximated by a low rank representation with a limited number of coefficient of 3 to 5. Taking these values, we can estimate that the number of measurements needed to recover the entire data cube is **m_t ~ 8%-17% of $n_1 n_2$** (n_1 is the spatial dimension and n_2 is the spectral dimension). If we don't exploit inter-channel correlations, the number of theoretical measurements needed is m_t ~ 32%-36% of $n_1 n_2$.

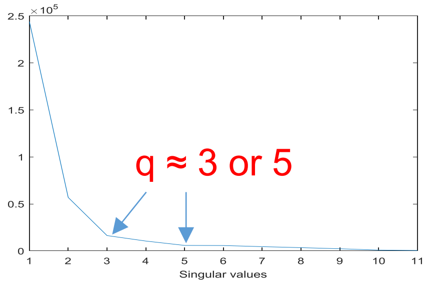


Figure 9: Singular Value Decomposition of the data cube

After the sparsity model identification, the measurement matrix or operator must be determined.

To ensure an incoherent sampling process, each block of matrix is a realization of a binary random matrix whose entries are Bernoulli distributed random variable with p=1/2. This kind of matrix allows to have an equal number of ones and zeros (or always half of the SLM mirrors pointing to the detectors). It maximizes the intensity of the signal on the detectors for a CS system.

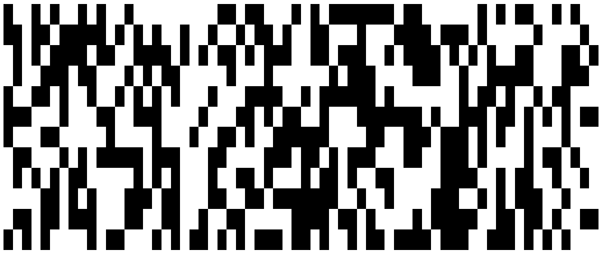


Figure 10: Example of one realization of a random sensing matrixfor 12 measurements (rows) with Bernoulli 0.5

For the measurement matrix we considered a scenario 1 where the same measurement matrix is used for the spectral channel and a scenario 3 where a different measurement matrix is used for each spectral channel.

Both scenario where assessed with OW and SA.

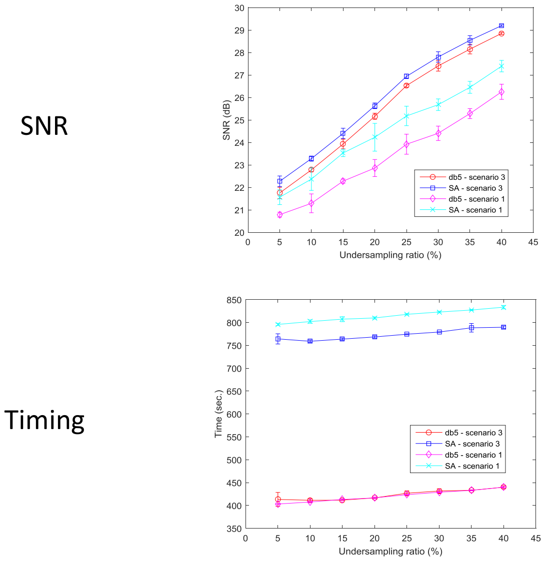


Figure 11: evaluation of the measurement matrix for OW and SA transform domains

In term of the SNR, the scenario 3: a different measurement matrix for each spectral channel, provides the best results. When considering the shortest computation (reconstruction) time, scenario 3 with OW transform domain is the best trade-off.

The last step of a CS system after the transform domain and the measurement matrix choice, is the reconstruction algorithm. After detailing the implementation of 2 different algorithms, only the primal-dual with forward backward iterations algorithm (PD-FB) requiring less computing time was implemented.

The reconstructions were performed using a MATLAB implementation of the algorithm (without parallelization) run in an i7 processor with four cores at 3.6GHz with 64Gb of RAM. Notice that the reconstruction times vary from 400 sec to 850 sec, i.e. from around 7 minutes to around 15 minutes with a non-optimized implementation of the algorithm.

3.4 Development roadmap

3.4.1 EBB roadmap

Even when considering using spare parts of an existing instrument for the breadboard, the cost remains high. Hence, for the EBB we prefer to consider an off-the-shelf fore-optics.

The EBB roadmap is made on the basis of the development status of breadboard critical building-blocks (SLM, SLM driver, CS elements, opto-mechanics, system management) see Figure 3. We consider also a limited number of spatial channels limited to bands for which cryogenic cooling is not mandatory.

For the EBB, the goal is to focus on challenges only related to CS and not on ones that would also be present for a standard instrument. For this reason, all the optical parts are off-the-shelf.

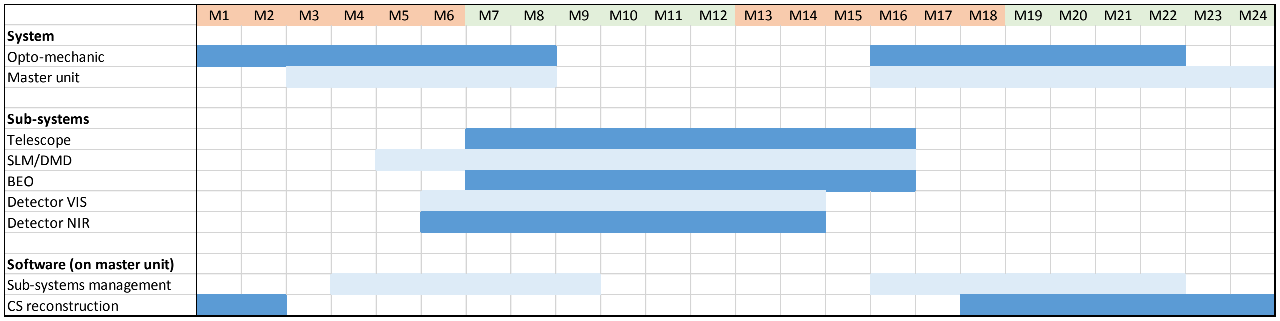
The EBB is a breadboard allowing to focus the efforts on the key parts of a CS optical instrument and limit as much as possible the cost of parts that are common to CS and standard instruments. Its concept permits to compare in practice an optical instrument that is set either to work as a standard or as a CS instrument.

The instrument can be run without compression if the SLM micro-mirrors are all oriented in the same direction. This allows the practical comparison of a standard and CS instrument.

The critical building-block of the EBB:

- SLM: off-the-shelf (TI product)
- SLM driver: off-the-shelf (TI evaluation board)
- Fore-optics and BEO: off-the-shelf
- CS elements: taken from this project
- System management: partly off-the-shelf

With these considerations for these building-blocks, we propose the following planning and cost for the EBB:



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24
System																								
Opto-mechanic	■	■	■	■	■	■	■	■								■	■	■	■	■	■	■		
Master unit			░	░	░	░	░	░								░	░	░	░	░	░	░	░	░
Sub-systems																								
Telescope							■	■	■	■	■	■	■	■	■	■								
SLM/DMD					░	░	░	░	░	░	░	░	░	░	░	░								
BEO							■	■	■	■	■	■	■	■	■	■								
Detector VIS						░	░	░	░	░	░	░	░	░										
Detector NIR						■	■	■	■	■	■	■	■	■										
Software (on master unit)																								
Sub-systems management				░	░	░	░	░	░							░	░	░	░	░	░	░		
CS reconstruction	■	■																■	■	■	■	■	■	■

Table 5: EBB development schedule

3.4.2 EM roadmap

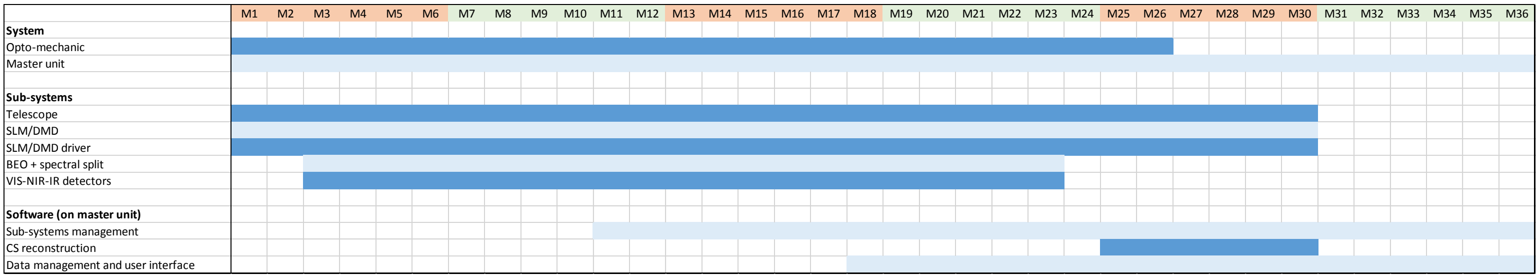
For the EM, the cost to push forward building-blocks requiring further development to achieve TRL5 has to be considered in addition to other cost.

The EM build over the results of the EBB and address in particular the sub-systems that require a strong effort to bring them on a clear roadmap leading to the qualification.

For the EM, the building-blocks that require to be developed further are:

- An European SLM.
- A SLM driver to be developed on purpose.
- A master unit that embeds all functionalities described in Figure 3.
- The fore-optics is a reproduction of an existing instrument.

With these considerations for these building-blocks, we propose the following planning and cost for the EM:



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
System																																				
Opto-mechanic	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
Master unit	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Sub-systems																																				
Telescope	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
SLM/DMD	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░						
SLM/DMD driver	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
BEO + spectral split			░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░													
VIS-NIR-IR detectors			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■													
Software (on master unit)																																				
Sub-systems management											░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
CS reconstruction																									■	■	■	■	■	■						
Data management and user interface																		░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░

Table 6: EM development schedule

4 Findings

There is a large literature on CS but in comparison, there are few papers describing the real implementation of a CS instrument. The project shows the receipt to build a CS instrument. It shows the path and the conditions to build a CS optical instrument that can compete in term of performances and functionalities set with traditional instruments.

The findings of the activity are numerous and the following ones represent the most important:

1. The most interesting CS architectural principle for the implementation is the so-called single pixel camera architecture extended to architecture using 2D matrix detectors,
2. This principle involves the use of a light modulator that is the main driver of the instrument's optical design,
3. The essential CS algorithmic elements which are the sparsity model, the measurement operator and the solver are well identified,
4. The conditions to favor a CS implementation are: an application taking place close to Earth or on a platform with a large transceiver bandwidth such as the compressed measurements can be send to Earth to be reconstructed with the appropriated computing resources. The most interesting instrument type is a multi-spectral imager.
5. There is no mass and volume saving with a CS based instrument when compared to a standard one as these figures are impacted mostly be the fore-optics,
6. There are important advantages of CS implementation when considering the compression ratio, the capture time, the processing time and the power consumption. It is noticeable that with an extreme compression ratio of 5%, the images are still of excellent quality.
7. The compression computing time for the CS is zero as the compression is integrated in the way of capturing the dataset.
8. The improvement on the power consumption is hardly quantifiable. In first look, it is worse for a CS instrument as an additional building-block (DMD module) is added in comparison with a standard instrument. However, when the saving in mass-memory and transmission bandwidth is considered, the additional power consumption of the DMD module is compensated and results in an overall power consumption lower than for a standard instrument.
9. The performance model delivered provides a receipt to evaluate the potential of a given instrument.

In practice, the main challenge for the adoption of CS in this domain is to convince applications people that limiting the information captured during the measurements does not impact (or impact with a predictable degree) the data quality. This is probably more acceptable in the case of the frame considered for the project: EO and long history of instruments with a knowledge of the images expected. This is probably less acceptable in cases where images can contain unexpected content (e.g. Cassini mission).

While a large majority of the studies in relation with CS is paper work and only a few describe implementations, we show here a competitive implementation of an optical instrument with CS. We show what the critical aspects of the implementation are and we are in position to quantify the advantages of such an architecture.