IAC-16.C C.2.2.1,x35876

67th International Astronautical Congress

Guadalajara 26-30 September 2016

Paolo Santini Memorial Lecture:

"Half a century of Space Adventure at Centre Spatial of Liège"

Author: Prof. Pierre ROCHUS, CSL (Centre Spatial de Liège), Belgium, prochus@ulg.ac.be

Motivations for space activities started in 1958: it was then a small laboratory of Institute of Astrophysics of Liege (IAL). In 1962, under the name of IAL-Space, it began real space activities observing the auroras in ultraviolet by sending around twenty sounding rockets, launched mostly from the base of Kiruna (Sweden). IAL-Space was finally recognized in 1975 as a coordinated test installation of the European Space Agency. It moved to Sart Tilman in 1984 to reach more spacious buildings. Subsequently IAL-Space got the status Research Center in 1988, it became a PRODEX Institute and changed its name to CSL in 1992. Lately it has further expanded with the commissioning of a new test facilities like FOCAL 3, FOCAL XXL, enabling to perform tests in the infrared range. Centre spatial de Liège is now a research Centre dedicated to space instrumentation including environmental test facilities and high level laboratories. It works for the European Space Agency (ESA), for the space industry and for regional industries. From the beginning of its more than 50 years long history, CSL develops, assembles, calibrates and/or tests observation instruments and relevant sub-systems capable to operate in a harsh environment, in order to serve the demands of the space science. Space Systems Program focuses its effort to incorporate CSL into the teams dedicated for definition, design, integration and/or ground and in flight calibration of scientific payload missions, mainly under the final authority of the most prestigious Space Agencies (ESA, NASA, JAXA, CNES, BELSPO, …). Today, more than 15 complex pieces of CSL technology have been launched in space, all of them operating nominally. Some of the most significant instruments made by CSL are: S2 / S68 telescope on TD1/ESRO, Halley Multicolor Camera (HMC/GIOTTO), FOC (HST), EIT solar telescope (SOHO), HI (STEREO), SWAP (PROBA 2), optical monitors with OM (Newton), OMC (INTEGRAL) and various contributions on PACS (Herschel), MIRI (JWST), UVS (JUNO) and COROT. In 2011, this strong heritage allows CSL to be awarded with the Extreme UV Imager (EUI) PIship of Solar Orbiter (ESA M1 science mission). For the Future, CSL is involved in the L1 JUICE, L2 ATHENA, M1 Solar Orbiter, M2 EUCLID, M3 PLATO, S1 CHEOPS, S2 SMILE ESA missions as well as the SPP, ICON NASA Missions. CSL is an Academic Member of IAF since 1988. The presentation will concentrate on the development of Space Instruments during this half a century of Space Adventure, focusing on Solar Physics and Space Weather Instruments.

1. INTRODUCTION

It is an honor for me to present the 6th Paolo Santini Memorial Lecture corresponding to the 10th anniversary of his death. In 2006, ten year ago, Professor Paolo Santini was supposed to give the Breakwell Lecture choosen by the Astrodynamics Committee. for the IAC 2006 Congress in Valencia. Unfortunately a deadly disease attacked him and shortly took him to death the 5th of May 2006.

Professor Paolo Santini was Professor at University of Rome "La Sapienza". He was the co-founder of the IAF Materials and Structures Committee and one of the outstanding personalities within IAF and the IAA for almost 40 years. He was a man of great scientific knowledge, talents, prestige and great cultural influence, a perpetual source of power and ideas within international aero-space community (IAF, AGARD, ICAS).

The Materials & Structures Committee of the IAF was proud to have established the Paolo Santini Memorial Lecture starting from 2011. Paolo Santini performed during almost 50 years in the aerospace field. His researches spanned many arguments, encompassing: flexible space structures, optimization, stability analysis, thermal analysis, smart structure, Orbital problems, heat conduction and its related thermo-elastic problems in the space structures, the study of the stability in flexible orbiting structures, the problem of the sloshing in satellites , the acoustics of the launchers to the study

of the multibody systems and the active control of the vibrations through the use of the so-called smart structures etc. just to mention the ones more related to the space field. This presentation will mainly be an historical ([1] [2] 3): the half century of Space challenges at Centre Spatial de Liège. During the presentation, whenever possible as long as time allows it, technologies close to Professor P. Santini and to this session will shortly be mentioned: Stable Structure, thermo elastic deformations and its verification (4 ..11), Additive layer manufacturing for Space Subsystems (11….17), Design and qualification of Space Instruments Space (18…28), thermal control with PCM (29…31), MEMS based magnetometers (32…34), thermal radiation transfer modelization (35…36), astrodynamics and orbit determination (37), contamination (38…40), structure dynamics of flexible structures (41…44), solar panels with concentrators(45), aeronautic subsystems (46)

In the early 1960's, two European institutions were created for developing space research. The ESRO (European Space Research Organization) was charged of the building of scientific satellites; the Eldo (European Launcher Development Organization) would develop the necessary rockets. In order to discuss financial, management and priorities, from 1966 to 1975, the European space conference (ESC) conveyed regularly the European ministers in charge of the space research. Belgium participated to the European space effort since the beginning and was actively involved within intergovernmental negotiations. Théo Lefèvre and Charles Hanin, ministers in charge of scientific research, were particularly active as chairman of ESC. Théo Lefèvre fighted on several frontlines to save space Europe; he was convinced of the necessity to ensure the European control of launchers. With France and Germany, Belgium was until the end member of the Eldo. Starting in 1969, Théo Lefèvre negotiated with the United States, an European participation to the ambitious American post-Apollo program. But it was under Charles Hanin presidency, thanks to his intuition and his tenacity, that, during the ESC summit of 31 July 1973, an agreement was reached on three points: 1) the merge of Eldo and Esro in one European space agency (the future Esa); 2) the new program Ariane; 3) the building of the orbital laboratory Spacelab as the European participation to the American post-Apollo program.([1])

2. Early days of the team and development of CSL in short

Space Activities at the University of Liège started earlier in the framework initiated by the work of the International Geophysical Year (IGY, 1957-1958) and was the reason of the launch of the first artificial satellite, into an East-West rivalry atmosphere which provoked widespread interest in space activities and the actuation of major financial resources.

Europe has quickly positioned itself as the third global partner by creating COPERS (Provisional Commission for Studies and Space Research) then ESRO (European Space Research Organization) and finally the ESA (European Space Agency). These organizations were created from the efforts of the scientific community. Professor **Pol Swings** at the University of Liège was one of the founders and long remained active at European level. He proposed the first two European experiments (S1 and S2) to be embarked on the first three axes stabilized satellite TD1. The other protagonist of the Belgian Space Research was his student Marcel Nicolet, Secretary General of the IGY and founder in 1965 of the Institute for Space Aeronomy, the I.A.S.B. The grant of spatial vectors was ensured at European level through the financial contributions of member states, which was relatively easy to obtain given the positive atmosphere enjoyed by the Space Research internationally. ([1] [2])

Belgian Grants were modest but sufficient to financially support national experiences; they were eventually taken over by the Scientific Policy Programming Services.

Closely with COPERS later with ESRO, the Institute of Astrophysics was able to initiate in 1964 a series of sounding rockets flight the first in Sardinia, then in 1966 the first sounding rocket launch from Kiruna (Esrange).

In 1967, the S2 proposal from Professor A. Monfils was selected by ESRO for TD1. The Belgian/UK Ultraviolet Sky Survey Telescope (S2/68) in the ESRO TD1 satellite carried out a controlled scan of the entire sky. In collaboration with a group from the University College of London, CSL was responsible for the design, development and calibration of the main spectrophotometric Ultraviolet telescope, S2/S68, of that satellite.

This important contribution allowed 'strengthening the role and status of the team of André Monfils.

Paradoxically this major success closed the first golden age of the team. The team lost in fact after that time, its main supports at the University and at the region but the IAL Space Team remained strongly unified in these difficult conditions, which could counterbalance an academic environment less favorable. With limited funding's, the team could nevertheless contribute to the development of the Photon Detector Assembly (PDA) of the Faint Object

Camera (FOC) of the Hubble Space Telescope and of the Halley Multicolour Camera (HMC).
The FOC was designed to take imaging observations of astrophysical sources from the near ultraviolet to the near infrared (1150 to 6500 Angstroms). The instrument was removed from HST during Servicing Mission 3B in March, 2002
The HMC was the imaging system on the Giotto spacecraft and was the only remote sensing instrument on board which could look at the nucleus of comet Halley. The FOC was one of the 4 original axial instruments aboard the Hubble Space Telescope (HST).
To keep the entire team in activity, the team leader André Monfils accepted to participate to less academic activities like calibration tests of the METEOSAT radiometer making use of the testing facilities developed for S2/TD1. This decision was the wright decision because this led IAL Space the possibility to become an Coordinated Test Facility and later test the different versions of METEOSAT radiometers. The Coordinated Test Facility of IAL Space was obtained with the support of Belgian SPPS (Les Services belges de la Politique et de la Programmation Scientifique; Gilberte Dehoux at that time) and the European Space Agency (Georges Pieter Van Reeth); IAL Space acquired for 5 years, renewed several times, the status of "Coordinated Facility Space Agency European ". Through this status, IAL Space received a high-performance hardware, and was given responsibility for many important projects.
The long period of competition for subsidies and for recognition as autonomous group was at that time forgotten and gave way to an atmosphere of cooperation beneficial to both spatial theoretical astrophysics, and finally at the University of Liège.
At the retirement of Professor A. Monfils in 1990, the Space team included then forty-eight members. Later in 1991, for clarity purpose, and at the request of the University, we changed the "IAL Space" acronym into "Centre Spatial de Liège", which is working since then under the direct responsibility of the Board of 'University. (Figure 1).

Figure 1: Change of name in 1992

This name recalls the Toulouse Space Centre, and refers to the name of the Astrophysics Institute of Paris, which had been suggested at the time by P Swings.

The projects come from diverse backgrounds, including always the European Space Agency. They now cover almost the entire spectrum of electromagnetic radiation.
CSL acquired cruising speed and the number of employees has exceeded one hundred.
The story of CSL can be simplified in different periods corresponding to small changes in activities and orientations
Period 1 (1960-1975): Space Instruments and the research associated to the in house developed instruments
Period 2 (1975 -1988): ESA Coordinated Test Facility associated with assembly, alignment, calibration, space qualification of Remote Sensing Instruments for ESA Science or Earth Observation Directorates, coming from ESA or European Industry. During that period, the funding for in house Space Instruments and associated research were drastically reduced.
Period 3 (1988 à 1999): With the creation of PRODEX in 1986 and the adoption in Belgium in 1991, funding became available on a more regular basis for the development of Remote Sensing Instruments up to launch (without the associated research which became funded to other Institutes associated to CSL), in addition to the ESA Coordinated Test Facility; CSL got an Institute Agreement in the frame of PRODEX. The first instruments developed under PRODEX are outlined in Figure 2.

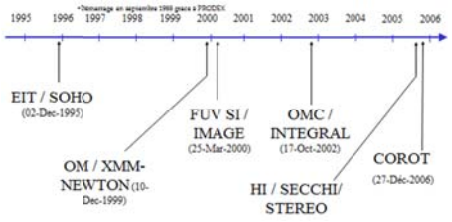


Figure 2: Space Instruments developments between 1988 and 2005

Period 4 (1999-2005): In addition to the already existing activities, the University of Liège and the Walloon region push CSL to develop new products and create around 10 Spin-offs in the domains of Optical Metrology, Earth Observation image analysis, LASER technologies and others. CSL was at the origin of the creation in 1999 of Wallonia Space Logistics (WSL) an incubator which is focused on technologic start-up firms whose technologies are most of the time the result of spatial R&D projects. The incubator's mission is to support young entrepreneurs coming mainly from Walloon universities in creating their company, to help to get

it going and to accompany the project during its first years of growth so as to contribute to increase the number of high tech firms in Wallonia.

Period 5 (2005 - now) : While CSL is still performing tests for ESA and Industry , this is no more coordinated as an ESA Coordinated Test Facility since 2005 but due to the specific tasks realized by CSL and the expertise of CSL in Optical metrology (ISO, NEWTON, Tiger team on Herschel Telescope, PLANCK optical testing, …) and in Straylight Testing and Simulation (COROT and CHEOPS baffle, STEREO HI, SO HI, SPP WSPR, PROBA V), CSL becomes a **Center of Excellence in Optics.**

From that period, the Space Instrumentation development is no more limited to PRODEX and the Science Directorate but to **Industrial Contracts for Earth Observation Instruments and subsystems**. (See Figure 3).

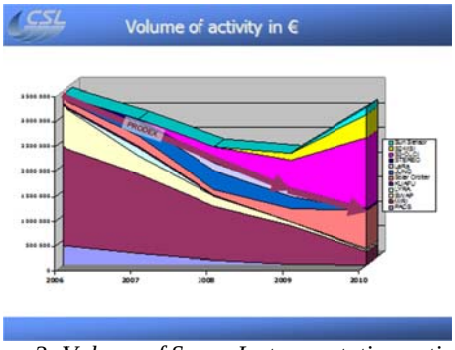


Figure 3: Volume of Space Instrumentation activities for PRODEX under the arrow compared to the volume of Space Instrumentation under Industrial contracts.

New technical Research activities are also starting financed by the Wallonia's Marshall Plan and by the European Community H2020. In an effort to boost the competitiveness of the Walloon Region in sectors where it already had potential, the Walloon government adopted the Marshall Plan in September 2005. This plan is encouraging collaboration in Research between Industries and Research Centers and Universities.

The presentation will concentrate on the development of Space Instruments and their qualification during this half a century of Space Adventure, focusing on Solar Physics and Space Weather Instruments.

CSL Space Technologies [4] will be very shortly presented.

3. Scientific instrumentation at CSL

CSL participates in the development of several remote sensing instruments developed mainly for ESA, NASA, CNES and BELSPO see Figure 4

Participation to ESA and NASA Science Missions

Mission	Launch	H/W	Tests	Mission	Launch	H/W	Tests
HST (NASA)	1990	X	X	GAIA	2013	-	X
SOHO	1995	X	-	LISA-Pathfinder	2014	-	-
CASSINI-H. (NASA)	1997	-	-	ASTRO-H(JAXA)	2014	-	-
XMM	1999	X	X	BEPI-COLOMBO	2015	-	X
IMAGE(NASA)	2000	X		MICROSCOPE(CNES)	2016	-	-
CLUSTER	2000	-	-	SOL ORBITER (M1)	2017	X	-
INTEGRAL	2002	X	-	CHEOPS(S1)	2017	X	?
MARS-EXPR.	2003	-	-	JWST (NASA)	2018	X	X
ROSETTA	2004	-	(X)	Solar Probe+ (NASA)	2018	X	-
VENUS-EXPR.	2005	-	-	EUCLID(M2)	2020	X	X
HINODE(JAXA)	2006	-	-	JUICE(L1)	2022	X	?
COROT (CNES)	2006	X	X	SPICA (JAXA)	2022	X	?
STEREO(NASA)	2006	X	-	PLATO.. (M3)	2024	?	?
HERSCHEL	2009	X	X	L2 ATHENA/L3 GW		(Call for ideas)	
PLANCK	2009	-	X	??? (M4) Ariel, Thor, Xipe		(Call in 2014)	
PROBA-2	2009	X	-	(S2) SMILE		(Call in 2015)	
JUNO (NASA)	2011	X	-	PROBA-3 ICON NASA		X	

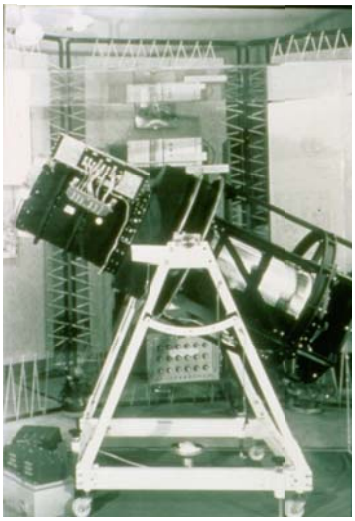
Figure 4: Participation to Science Missions

In 1960 started the design, realization, calibration and testing of instruments for sounding rockets under COPERS support which will become ESRO in 1962 (operational only in 1964).

The spectrometer R81 was launched on the 20th of November 1966 on a CENTAURE sounding rocket. The team performed 11 CENTAUR flights between February 1967 and november 1971

Centaure Sounding Rocket of ESRO

In 1967 the S2 proposal from Professor A. Monfils was selected by ESRO for TD1. The Belgian/UK Ultraviolet Sky Survey Telescope (S2/68) in the ESRO TD1 satellite carried out a controlled scan of the entire sky. It measured the absolute ultraviolet flux distribution between 2740A and 1350A of point sources down to 10th visual magnitude for unreddened early B stars.



The Belgian/UK Ultraviolet Sky Survey Telescope (S2/68) in the ESRO TD1 satellite

S2/S68 in space conditions in the space simulator , FOCAL 2 of IAL Space

TD-1A satellite

The TD1 Catalog of Stellar Ultraviolet Fluxes represents results from the sky-scan experiment on the TD1 satellite of the European Space Research Organization (ESRO), now part of ESA. It lists the absolute fluxes, in four passbands, for 31,215 stars
TD-1A, or Thor-Delta 1A, was a European astrophysical research satellite which was launched in 1972. Operated by the European Space Research Organisation, TD-1A made astronomical surveys primarily in the ultraviolet, but also using x-ray and gamma ray detectors

The S2 / S68 tests last several months but even after the validation of experience, FOCAL 2 remains not idle. At the end of the campaign, the facility is used to conduct new calibration tests on various space instruments including a Swedish instrument to embark on a satellite Interkosmos (USSR).

Through these campaigns, capabilities and expertise of the scientific and technical team of Professor Monfils begin to be recognized at European level and IAL Space is approached in 1974 by the French company " Engins Matra ". Engins Matra is, at this time, in charge of developing a key radiometer of "Meteosat". This instrument, a radiometer, is the heart and brain of the satellite. It must be calibrated under vacuum.

The technological challenges are extraordinary. The operating conditions of the radiometer in geostationary orbit impose to cool the infrared detectors to - 190 ° C in a particularly demanding thermal environment. FOCAL 2 must be equipped with a cold screen cooled to temperatures close to absolute zero. This is only possible by using liquid helium (4 K) and this application will mark the start of an important collaboration between the Monfils Group with the Laboratory of Low Temperatures led by Professor Roger Blanpain at the University of Liège.

Radiometer of "Meteosat".

From left to right: Claude Jamar, Roger Blanpain, André Monfils and Antonio Cucchiaro

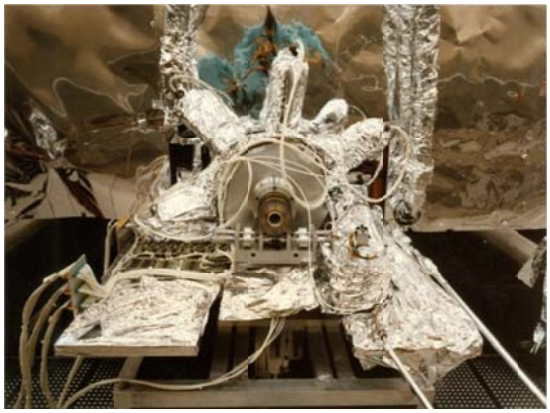
With the visibility provided by the Meteosat program, IAL Space sign new contracts with British Aerospace and Matra. The team is selected to participate in the certification of the Faint Object Camera (FOC), one of the first instruments of the mission "Hubble Space Telescope", the famous giant NASA space observatory.

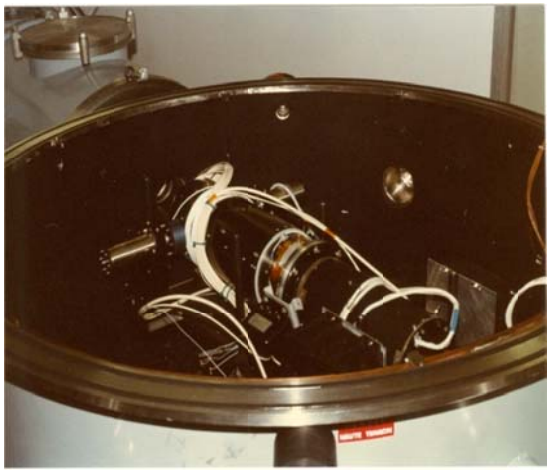
FOC is a very high resolution camera for the study of extremely distant and faint objects . IAL Space is responsible for certifying and calibrating its sensors (Photon Detector Assembly - PDA) as well as to participate in a consortium conducting thermal testing of the complete instrument at ESTEC (Test Centre of the European Space Agency Noordwijk in the Netherlands).

The Faint Object Camera (FOC), one of the first instruments of the "Hubble Space Telescope"

This project offers a unique opportunity to IAL Space to develop its test facilities park. In order to calibrate the "PDA", FOCAL 2 is not suitable because it is not equipped to perform measurements in the far ultraviolet (120nm - 650nm). IAL Space then order a new vertical axis vacuum chamber of 1.5m in diameter and 0.7m in height, coupled with a monochromator. This tank is used to go at least 10^{-5} mB of internal pressure and reproduce controlled thermal environments between + 120 °C and -190 °C. Commissioned in 1978, it was named "Focal 1.5" by analogy with its bigger sister "FOCAL 2".

"Focal 1.5" tank coupled with a monochromator.



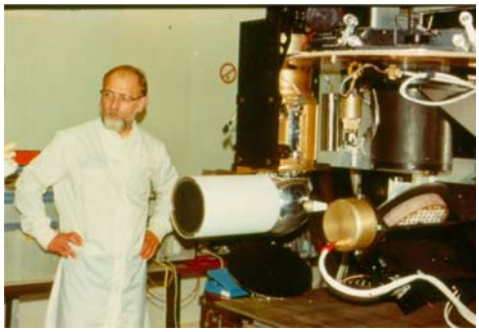


PDA under tests

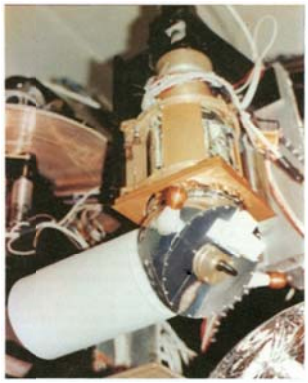
With these investments, IAL Space gets a new recognition of the European Space Agency being distinguished as a leading location in Europe for certification and calibration of instruments combining optics and electronics in space environment.

This recognition will have an immediate effect. IAL Space is integrated in a consortium of European research institutes who proposed an instrument to the space probe "Giotto".

Giotto is an extraordinary ESA mission. Its ambition a little crazy to go to the Halley's Comet which is coming back in the vicinity of the earth after 76 years of loop in the solar system. To achieve these objectives, the probe carried a payload consisting of not less than 10 scientific experiments designed and conducted by various European and American scientific institutions. Among these we have mass spectrometers, various plasma analyzers, a magnetometer and a camera in several colors.

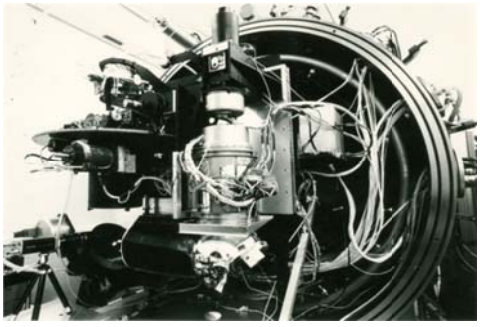


Dr Uwe Keller, HMC PI and HMC



HMC

The instrument was remarkable but still not easy to certify. This task was devoted to IAL Space. Given the severe constraints of the encounter, it was necessary to design and implement an optomechanical system with 7 degrees of freedom, computer driven, allowing not only to perform an optical diagnostic and calibration of experience, but also define the dynamic capabilities of the shooting in the acquisition and pursuit of the comet.

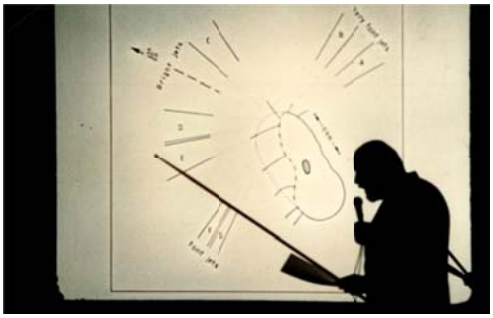


Calibration of HMC at CSL

GIOTTO was launched in 1985, photographed the nucleus of Halley's Comet in 1986. The the spacecraft Giotto, passed a few hundred kilometers

away from the well-known comet of HALLEY in 1986. The mission was very successful and many people will certainly recall the live shows with the beautiful and dramatic images of the discovery of the nucleus of a comet, seen for the first time by the mankind.

First images of Halley Comet



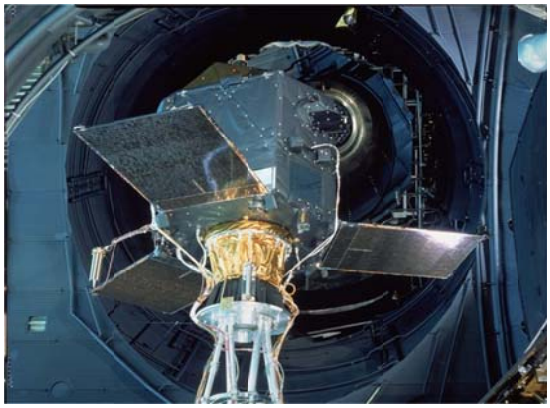
Dr Uwe Keller, Principal Investigator for Giotto's Halley Multicolour Camera, describes a projection of findings from the comet encounter, at ESOC in March 1986.

Dr Uwe Keller, Principal Investigator for Giotto's HMC, at CSL in June 2016 (30 years after GIOTTO results).

GIOTTO satellite assembling

First image of the nucleus of Halley's comet

While IAL Space engineers and technicians simulate Halley's comet, the European Space Agency is launching new science projects. Among these is an ambitious survey project of stars in our galaxy. This project, initiated in 1980, named after the Greek astronomer who compiled one of the first star catalogs "Hipparcos" (for HIgh Precision Parallax Collecting Satellite).



"Hipparcos" (for HIgh Precision Parallax Collecting Satellite).

The realization of the satellite and its equipment is attributed to Aeritalia and Engins Matra. Almost naturally, Engins Matra turns to IAL Space to achieve the vacuum testing of the double field of view telescope the satellite payload. Teams of IAL Space are enthusiastic but soon realize that there is a huge difficulty.

A new vacuum chamber larger than FOCAL 2 is necessary and adequate room is needed to install it. But there is no way to extend the Institute of Astrophysics building in Cointe.

During the year 1983, the decision was taken to construct a new building for IAL Space. Largely funded by the Walloon Ministry of Technology and supported by the European Space Agency, a building of 3640 m² will be erected in the Science Park of Sart-Tilman where the technological spin-offs of university begin to settle.

The new facilities were inaugurated in November 1984. For IAL Space, it is a new era which begins. In his opening address, Professor Monfils will hammer: "IAL Space is a university department managed like a private company."

The building is designed around a large clean room of 480 m² of floor area and 10 meters high. Equipped with a bridge of 5 tons, it will house the new space simulator "FOCAL 5", a cylindrical steel monster 5 meter diameter and 7 meters long, made also by the Ateliers de la Meuse.

New CSL building in 1984

480 m² and 10 meters high clean room. Equipped with a bridge of 5 tons, it will house the new space simulator "FOCAL 5".

The new facility is quickly requested. While Giotto's validation campaign continues at Cointe, two models of the Hipparcos instrument are tested and calibrated under vacuum in this new facility between 1985 and 1987 using optical calibration means (OGSE Optical Ground Support Equipment) specially designed and assembled at CSL

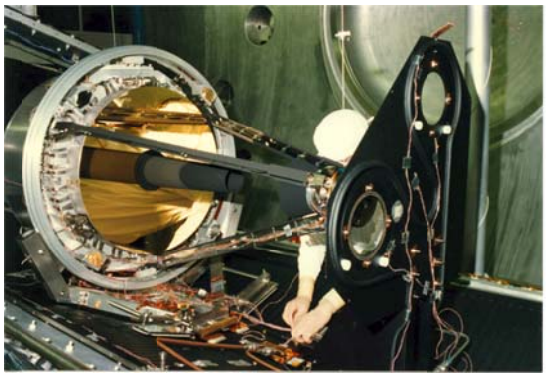
Hipparcos instrument in FOCAL 5

ISO satellite is an ESA scientific mission which will make observations of the cold universe and interstellar dust in the infrared spectrum. To operate at these wavelengths (between 2.5 and 200 microns), the focal plane of the instrument must be cooled to a temperature of about 4K (-269 ° C). In the late 80s, there are only few laboratories in Europe able to prepare and conduct such tests. IAL Space is part of this exclusive circle.

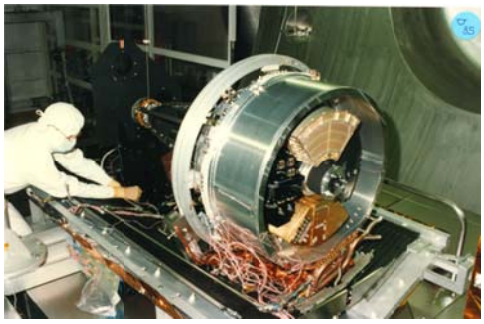
ISO (Infrared Space Observatory)

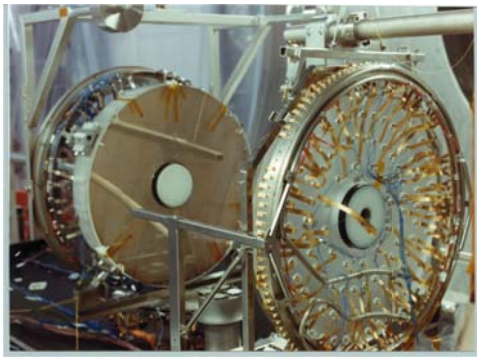
On this occasion, IAL Space implements creative ways including a double-wall thermal enclosure disposed in the simulation chamber Focal 5 and fed with nitrogen and liquid helium. This chamber also allows the sight of the focal plane by a interferometric collimator measuring the optical quality of the instrument.

The helium consumption needed for these tests requires the acquisition of the first liquefier of IAL Space, the Koch 1630, still operational today, capable of producing liquid helium at -296 ° C (4 ° K) from pure gaseous helium.



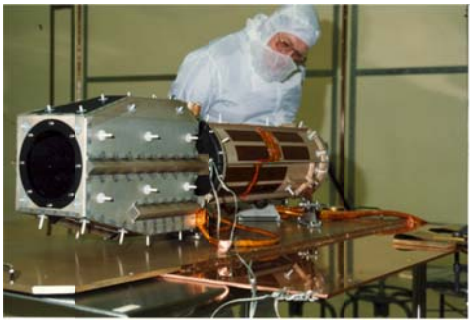
ISO under metrological tests at IAL Space





Cooling system

In 1988, CSL is been prime contractor for the instrument "Extreme Ultraviolet Imaging Telescope" EIT launched on the satellite NASA / ESA SOHO (SOlar and Héliocentric Observatory) in 1995; it photographed the solar corona. Pierre ROCHUS is the Project Manager of a Consortium of 3 Countries and 7 laboratories. EIT will be the first Instrument funded under PRODEX.



Extreme Ultraviolet Imaging Telescope

.

CSL has also contributed actively to the following projects:

- XMM / Newton through the development of 'Optical Monitor "
- INTEGRAL by the optics and mechanics of "Optical Monitor Camera"
- IMAGE (NASA's medium explorer) through the implementation of the optomechanical an imaging spectrometer in ultraviolet.

Active in the field of instrumentation from the '70s, CSL participates in the development of various instruments, for example most recently:

- PACS, which is currently flying aboard the satellite Herschel ESA;
- a heliospheric imager for NASA's mission SECCHI / STEREO;
- several parts of the French satellite COROT;
- several important elements of the MIRI instrument for the James Web Space Telescope;
- the whole telescope SWAP for observing the sun from minisatellite PROBA2.

4. Testing activities at CSL

Parallel to these activities related to the development of scientific instruments, the Space Center of Liege is now one of four testing facilities of the European Space Agency (ESA) and specializes in the performance evaluation of satellite payloads, under observation as well as astrophysics geophysics. Optical vacuum tables, in the halls of high level of cleanliness, can describe the behavior of instruments submitted to a restored space environment. Tests can be performed from temperatures of -270 °C to +120 °C with interferometric stability. The vacuum chambers with optical benches range from 1 m³ to 200 m³ in volume. Many space experiments have been tested at CSL, up from METEOSAT to Planck satellite, through the instruments of Hipparcos and XMM / Newton, GAIA, TROPOMI, PROBA V , …

The facilities allow CSL and implement environmental testing in a space environment but also on mechanical testing machine for vibration required to certify the equipment during launches. These vibration tests can be performed in cryogenic conditions, which is required for infrared mission

equipment's which are cooled before launch (Herschel).

The CSL has equipment to measure the state of molecular and particulate cleanliness.

5. Center of excellence in optics

As Center of excellence in optics, the CSL has adopted advanced equipment and specialized in various technological activities for terrestrial and space applications. For example:

- surfaces polished by ion beam;
- surface structures with microscopic irregularities controlled by ion beam;
- deposition of thin films and optical coatings;
- microfabrication technology (networks, integrated optics, ...);
- developments in the field of photovoltaics, including the development of concentrators for solar panels for space and terrestrial applications;
- development of sensors for monitoring the integrity (health monitoring).

6. ACKNOWLEDGMENT

The author wish to thank BELSPO for their continuous support in Space Instrumentation activities..

7. LIST OF ABBREVIATIONS

ATHENA	Advanced Telescope for High-ENergy Astrophysics

BELSPO	Belgian Science Policy Office
CHEOPS	CHaracterising ExOPlanets Satellite
COPERS	Commission Préparatoire Européenne de Recherche Spatiale
COROT	COnvection ROtation and planetary Transits
CSL	Centre Spatial de Liège
EIT	Extreme UV Imaging Telescope
ELDO	European Launch Development Organisation
EPCSR	European Preparatory Commission for Space Research
ESRO	European Space Research Organization
EUCLID	named after the ancient Greek mathematician Euclid of Alexandria, the "Father of Geometry"), is a space mission currently under development by the European Space Agency (ESA). The objective of Euclid is to better understand dark energy and dark matter by accurately measuring the acceleration of the universe.
EUI	Extreme UV Imager
FOC	Faint Object Camera
FOCAL 2	Facilité d' Optique et de Calibration a Liège de 2 mètres
GEERS	Groupe d'Etudes Europeen pour la Collaboration dans le domaine des Recherches Spatiales
Herschel	The European Space Agency's Herschel Space Observatory (formerly called Far Infrared and Sub-millimetre Telescope or FIRST)
HI	Heliospheric Imager
HMC	Halley Multicolour Camera
HST	Hubble Space Telescope
IAL	Institute of Astrophysics of Liège
IAL Space	Institut d'Astrophysique de Liège Space
IGY	International Geophysics Year
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
ISO	Infrared Space Observatory
JAXA	Japan Aerospace Exploration Agency
JUICE	JUpiter ICy moons Explorer
JUNO	JUpiter Near-polar Orbiter
JWST	James Webb Space Telescope
MIRI	Mid-Infrared Instrument
OGSE	Optical Ground Support Equipment
OM	Optical Monitor
OMC	Optical Monitor Camera
PACS	The Photoconductor Array Camera and Spectrometer
PDA	Photon Detector Assembly
PLATO	PLAnetary Transits and Oscillations of stars
PROBA	Project for Onboard Autonomy' microsatellites
PROBA-V.	Proba-V is the fourth satellite in the European Space Agency's PROBA series; the V standing for Vegetation.
PRODEX	PROgramme de Développement d'Expériences scientifiques
SMILE	Solar Wind Magnetosphere Ionosphere Link Explorer
SO	Solar Orbiter
SOHO	SOlar & Heliospheric Observatory
SPP	Solar Probe Plus
SPPS	Services belges de la Politique et de la Programmation Scientifique
STEREO	Solar TErrestrial RElations Observatory
SWAP	Sun Watcher using APS detectors and image processing
TD-1A,	Thor-Delta 1A,
UVS	UV Spectrometer
WISPR	Wide-Field Imager for Solar Probe Plus
WSL	Wallonia Space Logistics

8. REFERENCES

[1] LAUREYS (D.), "La Contribution de la Belgique à l'aventure spatiale européenne. Des origines à 1973", *BEAUCHESNE*

[2] HOCHER (A). ESRO, "L'Europe Spatiale", UPI*1974*.

[3] CUCCHIARO (A.), "FOCAL 50 ans d'exploration au Centre Spatial de Liège", *Presse Universitaire de Liège*.

[4] ROOSE (S.), Stockman (Y.), Rochus (P.), Kuhn (T), Lang (M), Baier (H.), Langlois (S.), Casarosa (G.), Optical methods for non-contact measurements of

membranes Acta Astronautica 11/2009;

[5] Stockman, Y., Thizy, C., Lemaire, P., Georges, M., Mazy, E., Mazzoli, A., Houbrechts, Y., Rochus, P., Roose, S., Doyle, D., & Ulbrich, G. (2004). Development of optical ground verification method for mum to sub-mm reflectors. 5th International Conference on Space Optics, Proceedings of the 5th International Conference on Space Optics (ICSO) (pp. 721-7). Noordwijk, Netherlands: ESA Publications Division.

[6] Stockman, Y., Houbrechts, Y., Nazé, Y., Rochus, P., Tock, J. P., & Gondoin, P. (1999). PSF modeling of the XMM flight mirror modules. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series (pp. 265-275).

[7] Thizy, C., Vandenrijt, J.-F., Georges, M., Stockman, Y., Rochus, P., Queeckers, P., Dubois, F., Defise, J.-M., & Doyle, D. (2010).Development of digital holography in the long wave infrared range for assessment of space reflectors. Proceedings of ICSO2010 - International Conference on Space Optics. Noordwijk, Netherlands: European Space Agency.

[8] Rossi, L., Zhukova, M., Jacques, L., Halain, J.-P., Hellin, M.-L., Jamotton, P., Renotte, E., Rochus, P., Liébecq, S., & Mazzoli, A. (2014, June 18). Solar simulation test up to 13 solar constants for the thermal balance of the Solar Orbiter EUI instrument. Proceedings of SPIE.

[9] Jacques, L., Halain, J.-P., Rossi, L., Hellin, M.-L., Jamotton, P., Liébecq, S., Mazzoli, A., Renotte, E., & Rochus, P. (2015, March 26). Thermal Balance Test of Solar Orbiter EUI Instrument Structural and Thermal Model with 13 Solar Constants. Paper presented at Spacecraft Thermal Control Workshop, El Segundo, United States.

[10] Jacques, L., Halain, J.-P., Rossi, L., Thibert, T., Hellin, M.-L., Jamotton, P., Mazy, E., Renotte, E., Fleury-Frenette, K., & Rochus, P. (2011, October 07). Ultrathin EUV Filters Testing and Characterization under High Flux (13 SC) for Solar Orbiter EUI Instrument. Paper pnresented at 62nd International Astronautical Congress, Cape Town, South Africa.

[11] Steinmetz, F., Lengowski, M., Winter, D., Salvador, L., Röser, H.-P., & Rochus, P. (2013). Validation of the Structural-Thermal Model of the Small Earth Observation Satellite Flying Laptop. Selected Proceedings of the 9th IAA International Symposium on Small Satellites for Earth Observation.

[12] Rochus, P., Plesseria, J.-Y., van Elsen, M., Kruth, J.-P., Carrus, R., & Dormal, T. (2007). New applications of rapid prototyping and rapid manufacturing (RP/RM) technologies for space instrumentation. Acta Astronautica, 61, 352-359.

[13] Rochus, P. (2015, August 22). "Additive Layer Manufacturing for Space Instrumentation and subsystems". Paper presented at Keynote lecture at Future Flight Vehicle Innovation Competition, X'ian, Chine.

[14] Rochus, P. (2014, October 29). "Advanced Manufacturing Methods for Systems of Nanospacecrafts". Paper presented at AEROTECH V 29-30th October 2014, Kuala Lumpur, Kuala Lumpur, Malaisie.

[15] Rochus, P., Plesseria, J.-Y., Corbelli, A., Masse, C., Rigo, O., Pambaguian, & Bonvoisin, B. (2014, April 04). ADVANCED MANUFACTURING METHODS FOR SYSTEMS OF MICROSYSTEM NANOSPACECRAFT – STATUS OF THE PROJECT. Paper presented at ", European Conference on Spacecraft Structures, Materials and Environmental Testing, Brauwnschweig, Allemagne.

[16] Nutal, N., Rochus, P., Collette, J.-P., Crahay, J., Larnicol, M., Jochem, H., Magnien, J., Masse, C., Rigo, O., Vanhumbeeck, J.- F., & Pambaguian, L. (2015). SURFACE ENGINEERING FOR PARTS MADE BY ADDITIVE MANUFACTURING. 66th InternationalAstronautical Congress.

[17] Rochus, P., Plesseria, J.-Y., Corbelli, A., Pambaguian, L., Masse, C., Rigo, O., & Bonvoisin, B. (2014, October 03). New applications of Advanced Manufacturing Methods for space instrumentation and Systems of Nanospacecraft. Paper presented at 65th International Astronautical Congress, Toronto, Canada. Copyright ©2014 by the International Astronautical Federation, Toronto, Canada.

[18] Rochus, P., & Defise, J.-M. (1995). Design and qualification of the Extreme-UV Imaging Telescope (EIT). IAF IAC 1995

[19] Seaton, D., Berghmans, D., Nicula, B., Halain, J.-P., De Groof, A., Thibert, T., Bloomfield,

S., Raftery, C., Gallagher, P., Auchère, F., Defise, J.-M., D'Huys, E., Lecat, J.-H., Mazy, E., Rochus, P., Rossi, L., Schühle, U., Slemzin, V., Yalim, S., & Zender,J. (2013). The SWAP EUV Imaging Telescope Part I: Instrument Overview and Pre-Flight Testing. Solar Physics, 286.

[20] Halain, J.-P., Rochus, P., Defise, J.-M., Mazy, E., & Mazzoli, A. (2011, July). Straylight-Rejection Performance of the STEREO HI Instruments. Solar Physics.

[21] Mas-Hesse, J. M., Gimenez, A., Culhane, J. L., Jamar, C., McBreen, B., Torra, J., Hudec, R., Fabregat, J., Meurs, E., Swings, J.-P., Alcacera, M. A., Balado, A., Beiztegui, R., Belenguer, T., Bradley, L., Caballero, M. D., Cabo, P., Defise, J.-M., Diaz, E.,Domingo, A., Figueras, F., Figueroa, I., Hanlon, L., Hroch, F., Hudcova, V., Garcia, T., Jordan, B., Jordi, C., Kretschmar, P., Laviada, C., March, M., Martin, E., Mazy, E., Menendez, M., Mi, J. M., de Miguel, E., Munoz, T., Nolan, K., Olmedo, R., Plesseria, J.-Y., Polcar, J., Reina, M., Renotte, E., Rochus, P., Sanchez, A., San Martin, J. C., Smith, A., Soldan, J., Thomas, P., Timon, V., & Walton, D. (2003). OMC: An Optical Monitoring Camera for INTEGRAL - Instrument description and performance. Astronomy and Astrophysics, 411(1), 261-L268.

[22] Mende, S. B., Heetderks, H., Frey, H. U., Lampton, M., Geller, S. P., Habraken, S., Renotte, E., Jamar, C., Rochus, P., Spann, J., Fuselier, S. A., Gérard, J.-C., Gladstone, R., Murphree, S., & Cogger, L. (2000). Far ultraviolet imaging from the IMAGEspacecraft. 1. System design. Space Science Reviews, 91, 243-270.

[23] Delaboudinière, J.-P., Artzner, G. E., Brunaud, J., Gabriel, A. H., Hochedez, J. F., Millier, F., Song, X. Y., Au, B., Dere, K. P.,Howard, R. A., Kreplin, R., Michels, D. J., Moses, J. D., Defise, J.-M., Jamar, C., Rochus, P., Chauvineau, J. P., Marioge, J. P., Catura, R. C., Lemen, J. R., Shing, L., Stern, R. A., Gurman, J. B., Neupert, W. M., Maucherat, A., Cugnon, P., van Dessel, E. L., & Clette, F. (1995). EIT: Extreme-Ultraviolet Imaging Telescope for the SOHO Mission. Solar Physics, 162, 291-312.

[24] Howard, R. A., Moses, J. D., Vourlidas, A., Newmark, J. S., Socker, D. G., Plunkett, S. P., Korendyke, C. M., Cook, J. W., Hurley, A., Davila, J. M., Thompson, W. T., St Cyr, O. C., Mentzell, E., Mehalick, K., Lemen, J. R., Wuelser, J. P., Duncan, D. W., Tarbell, T. D., Wolfson, C. J., Moore, A., Harrison, R. A., Waltham, N. R., Lang, J., Davister, C., Eyles, C. J., Mapson-Menard, H., Simnett, G. M., Halain, J.-P., Defise, J.-M., Mazy, E., Rochus, P., Mercier, R., Ravet, M. F., Delmotte, F., Auchere, F., Delaboudiniere, J. P., Bothmer, V., Deutsch, W., Wang, D., Richel, N., Cooper, S., Stephens, V., Maahs, G., Baugh, R., McMullin, D., & Carter, T. (2008). Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI). Space Science Reviews, 136, 67-115.

[25] Habraken, S., Renotte, E., & Rochus, P. (2000). 54. The IMAGE Mission (NASA): design, test and results from the Far UV Spectrographic Imaging. Space Science.

[26] Halain, J.-P., Rochus, P., Renotte, E., Defise, J.-M., Rossi, L., & Jacques, L. (2010). The technical challenges of the Solar-Orbiter EUI instrument. Proceedings - Society of Photo-Optical Instrumentation Engineers, 7732(26).

[27] Mazzoli, A., Landini, F., Vivès, S., Lamy, P., Halain, J.-P., & Rochus, P. (2010). Stray light analysis and optimization of the ASPIICS/PROBA-3 Formation Flying solar coronagraph. SPIE, Space Telescopes and Instrumentation 2010 : Optical, Infrared and Millimeter Wave (San Diego, 27 juin-2 juillet).

[28] Plesseria, J.-Y., Mazy, E., Defise, J.-M., Rochus, P., Lemmens, E., & Vrancken, D. (2003). Optical and mechanical design of a straylight rejection baffle for CoRoT. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series (pp. 167-176).

[29] Collette, J.-P., Rochus, P., Peyrou-Lauga, R., Pin, O., Nutal, N., & Crahay, J. (2012). Prototyping of a Phase Change Material Heat Storage Device. Proceedings of the 63rd International Astronautical Congress 1-5 Octobre 2012.

[30] Faraji, M., Najam, M., El Alami, M., Bouhssine, Z., Berroug, F., Lakhal, E. K., El Omari, M., & Rochus, P. (2012). Numerical Analysis of the Passive Heating of Building integrated Phase Change Materials. ECCOMAS Special Interest Conference Numerical Heat Transfer 2012.

[31] Collette, J., Rochus, P., Peyrou-Lauga, R., Ramusat, G., Pin, O., Nutal, N., & Crahay, J. (2013, September). Advanced Thermal Control of Launcher Equipment Bay using Phase Change Material. Paper

presented at IAC 2013, Beijing, Chine.

[32] Rochus, V., Jansen, R., Tilmans, H. A. C., Rottenberg, X., Chen, C., Ranvier, S., Lamy, H., & Rochus, P. (2012). Poly-SiGe-based MEMS Xylophone Bar Magnetometer. IEEE SENSORS 2012.

[33] Rochus, V., Lamy, H., Niyonzima, I., & Rochus, P. (2009). A Xylophone Bar Magnetometer for micro/pico satellites. Materials and Structures Symposium (C2.8): Specialised Technologies, including Nanotechnology

[34] Lamy, H., Niyonzima, I., Rochus, P., & Rochus, V. (2010). A Xylophone Bar Magnetometer for micro/pico satellites. Acta Astronautica, 67(7-8), 793-809.

[35] Vueghs, P., & Rochus, P. (2009). Adjoint Equations and Error Measure in Radiative Heat Transfer with Diffuse Reflection.Proceedings of the ASME 2009 Heat Transfer Summer Conference HT2009.

[36] Vueghs, P., Rochus, P., de Koning, H.-P., & Pin, O. (2009). Use of the "Radiosity Importance Concept" in the Error Estimation in Radiative Heat Transfer Design of Spacecraft. 1st INTERNATIONAL CONFERENCE OF SPACE TECHNOLOGY - ICST 2009.

[37] Halain, J.-P., Welter, T., Francken, P., Krier, G., Wauthier, P., & Rochus, P. (1998). Performance of Least Squares and Kalman Filter Algorithms for Orbit Determination Using Single- and Multi-Station Tracking of Geostationary Satellites (AAS 98-368). Spaceflight Dynamics 1998, Volume 100 Part 1, Advances in Astronautical Sciences (pp. 835).

[38] Kokkinos, D., Gailly, P., Georges, M., Tzeremes, G., Rochus, P., & Fleury-Frenette, K. (in press). Real-time measurement of temperature variation during nanosecond pulsed laser induced contamination deposition. Applied Optics.

[39] Kokkinos, D., Rochus, P., & Fleury-Frenette, K. (2014, September 11). Recent results on LIC and implementation of new measurements techniques. Paper presented at First International Workshop on Space-based Lidar Remote Sensing Techniques and Emerging Technologies.

[40] Orban, A., & Rochus, P. (1997). 26. Assessment of Cleanliness requirements for space optical instruments; Proc. of the Third International Symposium on Environmental Testing for Space Programmes, ESTEC, 24-27-6-97, SP-408, August 1997.

[41] Dewalque, F., Rochus, P., & Bruls, O. (2015). Importance of structural damping in the dynamic analysis of compliant deployable structures. Acta Astronautica, 111, 323-333.

[42] Rochus, P., Defise, J.-M., Plesseria, J.-Y., Hault, F., Janssen, G., & Kaldeich-Schürmann, B. (1999). SM98-146/413 Effective Modal Parameters to Evaluate Structural Stresses. Spacecraft Structures, Materials and Mechanical Testing (pp. 437).

[43] Dewalque, F., Rochus, P., & Bruls, O. (2014). Importance of structural damping in the dynamic analysis of compliant deployable structures. Proceedings of the 65th International Astronautical Congress (IAC).

[44] Jonckheere, S., Bergen, B., Halain, J.-P., Rochus, P., Desmet, W., & Vandepitte, D. (2011, May). Filter failure analysis for the SWAP instrument on-board of PROBA2. COMPDYN.

[45] Habraken, S., Defise, J.M.,Collette, J.P. , Rochus P., D'Odemont, J.A., Hogge, M., Solar Arrays and Concentrators , 51st IAC, Rio de Janeiro, Brazil 2000

[46] Rochus, P. (1984). Lubrification Unit for Turbofan CFM56 2. Determination of the Mechanical Properties of the Shear Groove in the rotary Shaft by the Stress Gradient Method. Bulletin Technique du Bureau Veritas, 113-120.