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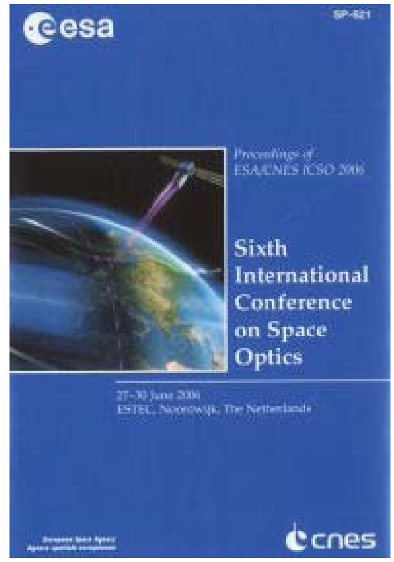

Declic: design, integration and testing of a multi configurable instrument using optical diagnostics to study directional solidification and critical fluids

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DECLIC: DESIGN, INTEGRATION AND TESTING OF A MULTI CONFIGURABLE INSTRUMENT USING OPTICAL DIAGNOSTICS TO STUDY DIRECTIONAL SOLIDIFICATION AND CRITICAL FLUIDS

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ABSTRACT

DECLIC, a Facility dedicated to the study of transparent media under microgravity, will be used in an ISS EXPRESS Rack. This paper focuses on the EXL which contains two optical boxes disposed on two opposite sides of the cavity where the Inserts to be studied shall be locked. At the moment, three types of inserts are planned to be accommodated in the EXL. Various optical diagnostics are available by configuring the EXL (sources, sensors, mechanisms). After the presentation of the EXL design, this article deals with some manufacturing and testing aspects, such as the use of COTS (cameras). Specific OGSE have been developed in order to simulate the optical interfaces and the propagation of beams in the inserts. Three models of the EXL have been integrated and fully tested, including the Flight Model. The sequence of tests, the performances measured, and then some images of the experiments performed with the inserts will be presented.

1. INTRODUCTION

DECLIC (Dispositif pour l'Etude de la Croissance et des Liquides Critiques) is a joint CNES/NASA research program to be implemented in the International Space Station (ISS). It is dedicated to the study of various physical phenomena under microgravity environment, by means of optical observation of transparent materials
- Fluids near the critical point
- Directional solidification of model alloys

More generally, thanks to its modular architecture consisting of scientific inserts placed inside the facility, many types of science can be done taking advantage of the resources of DECLIC.

The DECLIC instrument comes in the form of two similar lockers, one ELectronic Locker (ELL) and one EXperimental Locker (EXL), accommodated in an EXPRESS rack inside the ISS (Fig 1.). The EXPRESS rack provides power, communication link, air and water loops for thermal control.

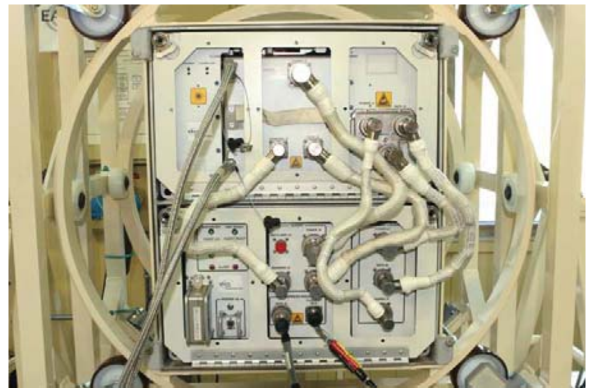

Photo courtesy of EADS SPACE Transportation

Fig. 1. DECLIC instrument, front view.

The EXL includes a cavity wherein various Inserts can be placed and locked very accurately by the crew members of the ISS. EXL and Inserts optics constitute together the complete Optical Sub System. (Fig.1.)

EADS-SODERN (F- 94 Limeil Brévannes) is responsible of the EXL and of the optics of the Inserts. The prime contractor for DECLIC is EADS-SPACE Transportation (EADS-ST) (F- 33 Saint Médard en Jalles). Three models have been manufactured. EM (Engineering Model) and LM (Laboratory Model are used by CNES and Scientists. Completion of system tests of EXL-FM (Flight Model) with ELL and Inserts by EADS-ST is scheduled for end of 2006.

This paper presents the optical diagnostics and the design of EXL. Then, the specific optical tools developed for AIT will be described, and the performances obtained during tests and the first experiments with the inserts will be reported.

2. OPTICAL DIAGNOSTICS AND MAIN REQUIREMENTS

The optical diagnostics used with the inserts dedicated to Critical Fluids study (ALI up to 65°C and 70 bars and HTI up to 455°C and 500 bars) and with Insert

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dedicated to Directional Solidification (DSI) are the followings:

Diagnostic	ALI	HTI	DSI
Wide Field Imagery	HR + HS	HR + HS	HR
Wide Field Imagery with grid	HR	HR	
Narrow Field Imagery	HR + HS	HR + HS	HR
Wide Field Transverse Imagery			HR
Wide Field Interferometry	HR + HS		HR
Transmission measurement	X	X	
Low Angle Scattering	X	X	
Perpendicular Scattering	X	X	

In this table the notation HR means that the diagnostic is required with a high resolution of at least 1000 x 1000 pixel, and the notation HS means that the diagnostic is required with a high speed, that is close to 1000 image/s.
So, 14 different diagnostics are needed. To make these diagnostics available, the optical architecture has to be configurable according the chosen diagnostic.

Since the EXL shall be installed inside a SSL, it is required to use damping foam all around the EXL, and thus, the external dimensions of the EXL are imposed: width 440 mm (Y axis); height 241 mm (Z axis); depth 504 mm (X axis, perpendicular to the front panel). In this volume, a cavity is dedicated to receive the inserts whose external dimensions are 200 x 200 x 450 mm, this last value being along X axis.

3. DESIGN OF THE EXL

The EXL is designed:
- to be mounted in a SSL,
- to lock each insert in the accurate position, by the way of ergonomic mechanisms,
- to share avionics air cooling loop with the insert when this latter makes use of it,
- to exchange dissipated power with the avionics air loop,
- to provide and to configure lighting beam for each diagnostic, by means of mechanisms,
- to adapt field of view size and focusing plane of the object planes in the insert, using specific optics and mechanisms,
- to provide cameras and optical sensors used by optical diagnostics,
- to provide 3D accelerometer measurement
- to interface all electrical signals, commands and power supply with the ELL,
- to be compliant with ISS safety requirements.

The diagram (Fig.2.) shows the organization of the EXL.
EXL is composed of a central structure, made of Titanium, on which all other sub assemblies are mounted, like on two optical benches. This structure gives mechanical and thermal stability. Inside the internal volume created by the plates are located the mechanisms used to lock the insert, and the fans to blow the air to the cooling loop. (See Fig.2.). One plate supports the elements of the Optical Emitter Box (OEB), such as laser, optical systems designed to adapt the beams, and the air loop. The plate on the opposite side supports the groups of the Optical Receiver Box (ORB), like focusing lenses or cameras sensors, and the last part of the air loop. This plate constitutes also the mechanical reference for insert positioning.
After closing OEB and ORB with their covers, EXL will be surrounded by soft foam and placed in a Single Stowage Locker. A Cavity Closure Tool (CCT) with transparent windows shall be placed between EXL and the door of the SSL during launch.

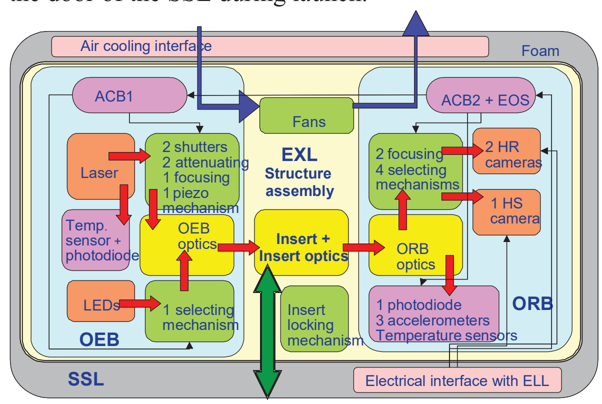

Fig.2. EXL Principles

The light sources, in OEB, are of two types. The laser (633 nm) is dedicated to diagnostics using interferometry, light scattering and transmittance measurements. Six LED's (670 nm) are used for imagery. This light may exit from OEB by 4 optical ports. On three of them, laser beams are collimated with diameter (0.3 or 12 mm) and optical power selected by mechanisms. A defocusing mechanism and a two axes piezo actuator adapt the reference beam of a Mac Zendher interferometer, going directly to the ORB from the fourth port of the OEB (Fig.3.).

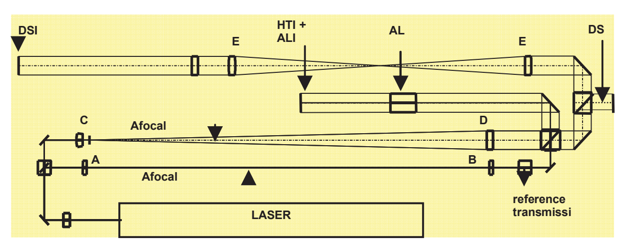

Fig.3. Laser beams in the OEB (in 2D)

A selecting mechanism drives the light of the LED, associated to a given diagnostic (HR or HS camera, wide or small FOV, i.e. WF/SF, imagery with a grid), in such a way that the beam is blended by a dichroic

surface with the laser beams. All these optical axes are parallel to Y axis, and their coordinates along X are -220, -80, 0, +220 mm. this last axis is out of the Z=0 plane.
Except the reference photodiode of the laser beam, located in the OEB, and the photodiodes for perpendicular light scattering that are mounted in the critical fluids inserts, all the optical sensors are installed in the ORB. The light arrives in ORB through 5 optical ports, with axes parallel to Y axis. Along X axis, their coordinates are -80, 0, +65, +220 mm.

Thanks to beamsplitters and motorized selecting mechanisms in the ORB, the beams can be addressed on 3 cameras and on a photodiode. Others mechanisms are used to focus the images (through the volume of the sample to be studied), to select a magnification (WF and NF) for the FOV, and also to insert a grid in the beam in order to measure gradient index in the fluids. An example of one optical configuration (HTI-WF with an image on HR1 camera) is shown on Fig. 4. Many parts of these optics are used for other diagnostics, as indicated on this figure.

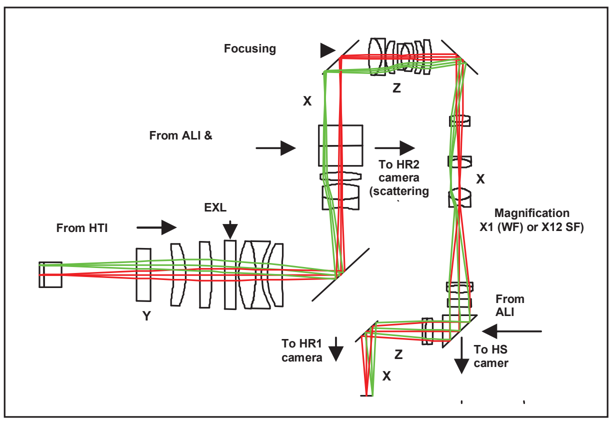

Fig.4. Optical layout of ORB HTI-WF-HR1

The optical system is rather complex and very dense. In the EXL, 172 optical components are used. In inserts, their number varies from 9, for the HTI to 33 for DSI. Optical paths in the EXL are configured by 13 mechanisms.

4. MANUFACTURING AND INTEGRATION

COTS - The development of the EXL required using some COTS (Commercial Off The Shelf). The ability for the main optronics parts (cameras and laser) to comply with the environmental conditions for launch and use in the ISS were critical points of this development. The upgrade of the HeNe laser concerned mainly the power supply and was quite simple. The chosen cameras sustained mechanical environment after upgrade, as well as vacuum, but the adaptation of the cameras to thermal environment induced by their use in a closed box, without air convection aboard the ISS, and with a worst case of an avionics air cooling loop close to 29°C, was challenging. Very fine thermal models have been developed; they have been tuned by tests on the first models of the EXL. Finally, after this upgrade, each camera has been accepted after a successful burn-in test equivalent to the worst thermal conditions.

SPECIFIC TEST EQUIPMENT AND TOOLS - An important requirement for the integration of EXL is to keep the same performances with any insert mounted in any model of EXL. The Ground models EM (Engineering Model) and LM (Laboratory Model) will be used by the scientists to develop and to validate the insert that will be installed further in the FM (Flight Model) aboard the ISS. EADS-SODERN has developed, manufactured and tested two specific tools to adjust and verify the angular alignment and the centring of the optical beams as well as the optical power and the level of signal received on the cameras.

ISE, shown on Fig.5, is the tool dedicated to the beams exiting the OEB.

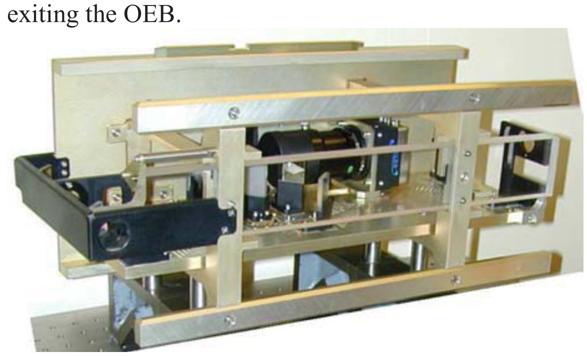

Fig.5. View of the ISE tool.

Mechanical interfaces are identical to those of a real insert, i.e. a reference plane with 3 positioning pins on its surface facing the ORB support plate. ISE is designed such that alignment, with an accuracy better than 0.25 mrad, and centring (tolerances are around 50 µm) may be achieved simultaneously. The key component is a reference optical plate, with a flatness of 2 fringes over 480 mm and 0.15 mrad parallelism with the mechanical reference plane. All the collimated beams reflected inside the ISE, can be observed with a telescope at the same time. The transmitted part of these beams is imaged on the camera installed in the ISE; this camera is focused on 4 optical reticles accurately mounted on the ISE structure in the theoretical position of the centre of each beam. When replacing this camera by a calibrated photodiode, the ISE allows measuring the optical power.

ISR (Fig.6.) is the second tool. Using the beams coming from OEB, after adjustment using the ISE, this tool simulates the optical paths of the 3 inserts DSI, HTI and ALI. An optical bench is accurately located in the EXL with respect to the mechanical interfaces, identical to those of ISE. The optics, identical to Inserts optics, are mounted on the optical bench with restricted tolerances. ISR is designed to be used in two configurations. In the first one, corresponding to the adjustment of ORB, repositionable reticules are fixed on the bench. The second configuration is obtained by removing the above reticules; they are replaced by optical targets (resolution target, diffusers, and calibrated prisms). Four such targets, placed in the object focal planes of the optical ports of ORB, are mounted on a three axes mechanism that is used to select the appropriate target, to move the patterns in the FOV and to focus them in the planes to be analyzed (for example, -10 to + 30 mm for DSI axial imagery).

Fig.6. View of the ISR tool.

Moreover, an EGSE simulates the ELL interfaces, and enables the image acquisition.

EXL INTEGRATION – The integration of the EXL was split in three main phases.

- Assembly of the structure, including the two mechanisms to lock the inserts, and of the air cooling loop blown by two fans.
- Integration of OEB equipments, using ISE, by setting the OEB optical bench horizontal.
- The EXL is turned round so that ORB optics are placed horizontally upwards (Fig.7.). The 25 opto –mechanical subsystems, already assembled and tested, are integrated on the optical bench, using ISR for optical adjustments.

After finalization of electrical harnesses, OEB and ORB are closed by covers.

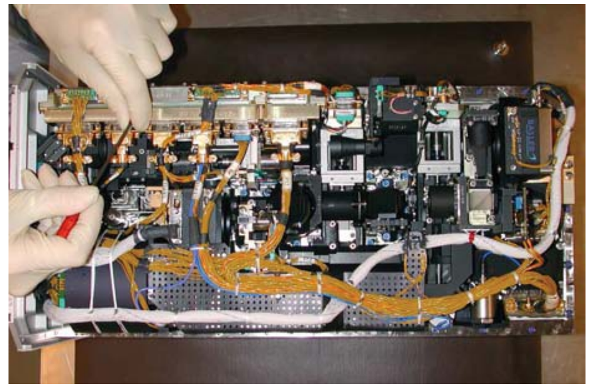

Fig.7. ORB-FM Last stage of integration

5. TESTS AND PERFORMANCES

The test sequence applied to the EXL includes several optical and functional tests performed before and after the tests that could potentially affect the optical performances. For the FM, this test sequence has been the following:
EXL optical and functional test (initial reference)
EXL low and high pressure tests
EXL functional tests after installation in SSL
EXL physical properties measurements
EXL optical and functional test before acoustic test
EXL acoustic test
EXL optical and functional test after acoustic test
EXL optical and functional test at high environment and cooling air temperature
EXL optical and functional test
EXL thermal storage
EXL optical and functional test
EXL vibration tests
EXL optical and functional test (final reference)
EXL electrical tests
EXL physical properties measurements
EXL functional tests (final)

This paper can't list all the results of the tests. Only the main optical performances are indicated.

- Parallelism of optical axes (laser beams) coming from OEB with Y axis < 0.7 mrad
- Centring of laser beam coming from OEB vs. theoretical position in the insert < 0.25 mm
- Divergence of Ø12 mm laser beams < 0.3 mrad
- Uniformity of Ø12 mm laser beams > 0.55
- Optical power of laser beams emitted by OEB : from 30 μW to 300 μW,
- Tilt of laser beam by activating the piezo actuator (2 axes) > 4 mrad,
- Uniformity of Ø 12 mm LED's beams > 0.7
- Image FOV on cameras for Ø 12 mm object plane in the inserts: 1012 ± 12 pixels
- Centring of images on cameras > 9 pixels,

- Optical resolution in the object plane of inserts (measurement method: USAF 1951 resolution target)
  - ALI / HTI WF : < 12 µm
  - ALI / HTI SF : < 3 µm
  - ALI interferometry : < 24 µm
  - DSI axial imagery : < 7 µm
  - Low Angle Scattering : < 1.8 mrad in a FOV of 26°

Then, after integration at system level in the DECLIC system, EXL has been tested by EADS-ST with real inserts. Some results obtained with EXL-FM are presented herebelow.

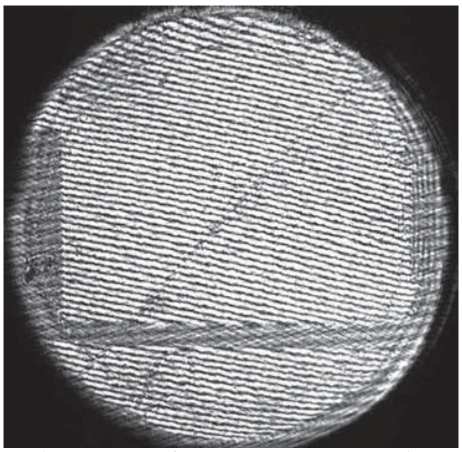

Photo courtesy of EADS SPACE Transportation

Fig.8. ALI Interferometry cell (CO_2 cell) HR camera. The meniscus separating vapour and liquid phases is clearly visible.

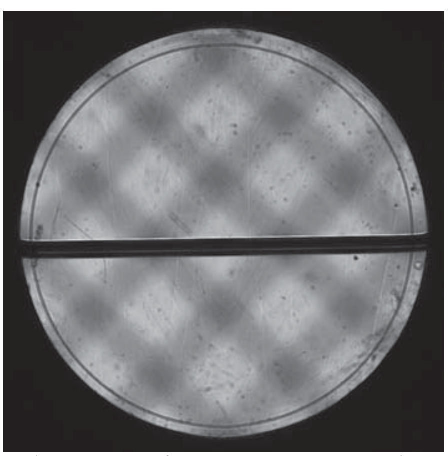

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Fig.9. ALI SF_6, direct observation cell, WFOV with grid

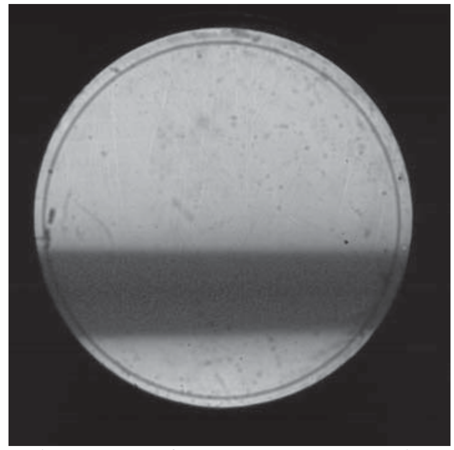

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Fig.10. ALI SF_6, direct observation cell, , close to the critical point. The meniscus becomes very wide.

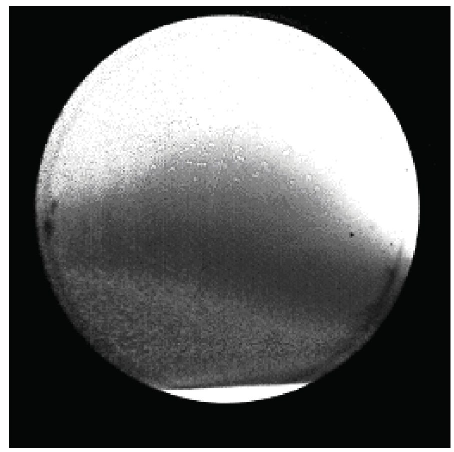

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Fig.11. ALI SF_6 direct observation cell, at the critical point. Both phases are nearly completely mixed

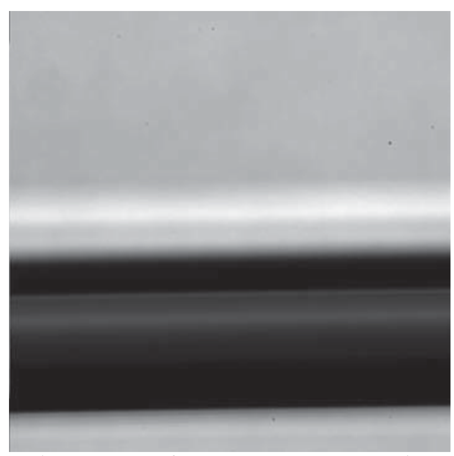

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Fig.12. Meniscus, ALI, narrow field observation, HS camera

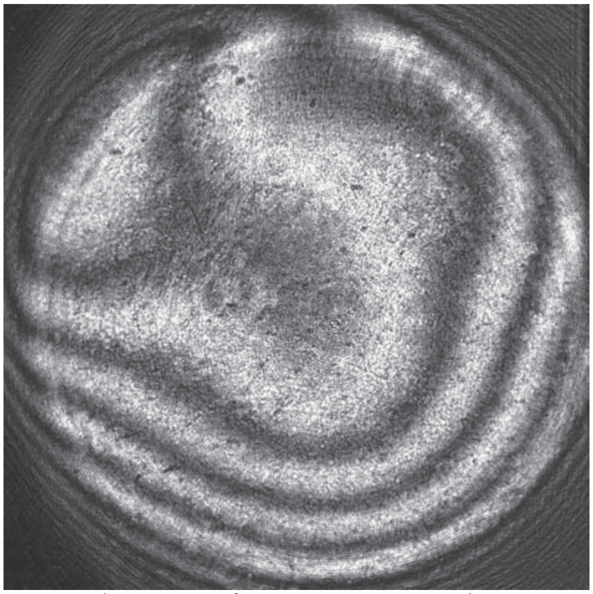

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Fig.13. DSI interferometry

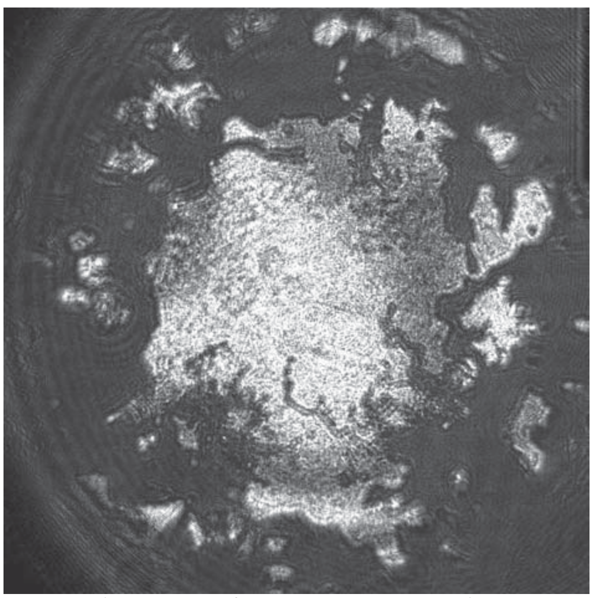

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Fig.14. DSI direct observation of the solidification front

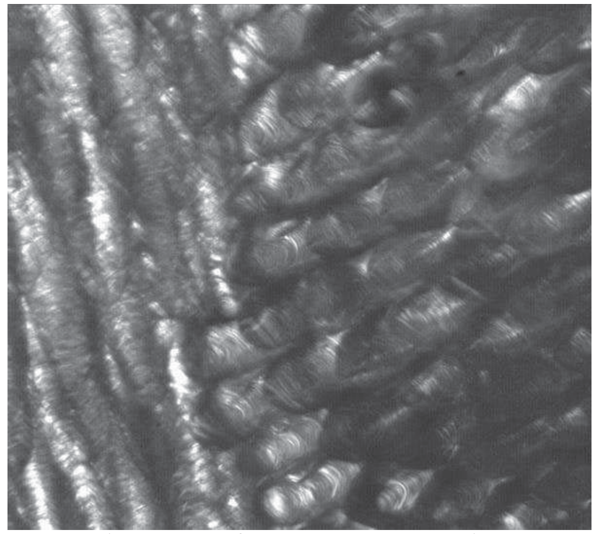

Photo courtesy of EADS SPACE Transportation

Fig.15. DSI axial narrow field observation: formation of dendrites in succinonitrile during solidification

6. CONCLUSION

DECLIC facility includes in the EXL (Experiment Locker) a versatile optical system. Even if the internal optics of OEB and ORB seems rather complex due to the desired compactness, and to the mechanisms used to configure the different diagnostics, the optical interface with the inserts is rather simple. The 3 inserts developed simultaneously with the instrument including the EXL will use 14 optical diagnostics, but other combinations can easily be adapted with new inserts. The performances of these diagnostics have been demonstrated; and the FM will be ready for a launch to the ISS in 2007.